PANTHEON

Community-Based Smart City Digital Twin Platform for Optimised DRM operations and Enhanced Community Disaster Resilience

D2.4

SCIENTIFIC AND TECHNICAL CAPACITIES REPORT

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TASK ABSTRACT

Task 2.4 studies the state of the art in scientific and technical capabilities that have been developed in Europe and worldwide to support the planning, the preparedness and the prediction phases in the disaster management cycle.

[1] **Please indicate the type of the deliverable using one of the following codes**:
R = Document, report
DEM = Demonstrator, pilot, prototype, plan designs
DEC = Websites, patents filing, press & media actions, videos
DATA = data sets, microdata
DMP = Data Management Plan
ETHICS: Deliverables related to ethics issues.
OTHER: Software, technical diagram, algorithms, models, etc.

[2] **Please indicate the dissemination level using one of the following codes**:
PU = Public
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Table of Contents

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

Abbreviation	Definition
AI	Artificial Intelligence
AOGCM	Atmosphere-Ocean General Circulation Models
API	Application Program Interphases
CAMS	Copernicus Atmosphere Monitoring Service
CAP	Common Alerting Protocol
CDI	Combined Drought Indicator
CIP	Critical Infrastructure Protection
CISA	Cybersecurity and Infrastructure Security Agency
CIWIN	Critical Infrastructure Warning Information Network
CoBRA	Community Based Resilience Analysis
C3S	Copernicus Climate Change Service
DIAS	Data and Information Access Services
DRR	Disaster Risk Reduction
DSS	Decision Support System
EC	European Commission
ECMWF	European Centre for Medium-Range Weather Forecasts
ECPP	European Civil Protection Pool
EFAS	European Flood Awareness Systems
EDO	European Drought Observatory
EEWS	Earthquake Early Warning Systems
EFDRR	European Forum for Disaster Risk Reduction
EFFIS	European Forest Fire Information System
EPCIP	European Programme for Critical Infrastrucutre Protection
ERCC	Emergency Response Coordination Centre
ERNCIP	European Reference Network for Critical Infrastructure Protection
ESA	European Space Agency
ESM	Earth System Models
ETWS	European Tsunami Warning System
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
EWM	Early Warning and Monitoring
EWS	Early Warning System
FWI	Fire Weather Index
GCM	Global Circulation Model
GDACS	Global Disaster Alert and Coordination System
GDO	Global Drought Observatory
GFS	Global Forecast System
GloFAS	Global Flood Awareness Systems
GNSS	Global Navigation Satellite System
GIS	Georgraphic Information System

IoE	Internet of Everything
IoT	Internet of Things
JRC	Joint Research Center
LiDAR	Light Detection and Ranging
LITE	Lidar In-Space Technology Experiment
LoRaWAN	Long Range Wide Area Network
ML	Machine Learning
MRF	Medium Range Forecast
NCEP	National Centers for Environmental Prediction
NIPP	National Infrastructure Protection Plan
NWP	Numerical Weather Prediction
OCHA	Office for the Coordination of Humanitarian Affairs
OSOCC	On-site operations coordination centre
PNT	Positioning, Navigation and Timing
QDM	Quantile Delta Mapping
RCDE	Radiative-Convective-Dynamical Equilibrium
RI	Risk Identification
RP	Risk Priorisation
SAR	Synthetic Aperture Radar
SCF	Smart City Framework
SDM	Statistical Downscaling Model
SRSP	Shock Responsive Social Protection
TAS	Tsunami Alerting Software
UAV	Unmanned Aerial Vehicle
UNISDR	United Nations Office for Disaster Risk Reduction
VOSOCC	Virtual On-site operations coordination centre
WEA	Wireless Emergency Alters
WMS	Web Map Service Interface

EXECUTIVE SUMMARY

During the last 50 years, a huge number of scientific and technical capabilities have been developed to support the mitigation of the impact of disasters (natural and man-made). Most of these capabilities have been developed for the short term forecast of the hazards and for the support of the response. Much less capabilities have been developed for the planning, preparedness and long-term prediction phases as national, regional and local factors have to be taken into account, which limits the interest of generic tools.

The document presents the existing capabilities that are widely accessible and/or known in the domains of:

- Environment modelling,
- Meteorological scientific tools,
- Collaboration tools,
- Smart cities systems applications.

Environment modelling can be used in any phase. It is especially very useful when combined with event simulations to determine the likely impacts of the hazards. The scientific models can predict events at more or less long terms depending on the type of hazards/events. For the strategic planning, the scientific models can give indications on the location and magnitude, but they are not precise enough to precise where, when and how the event will happen. At shorter term (emergency planning), the precision is much better and enables a more accurate management of the operation. The collaborative tools are extremely useful not only to prepare the plans (anticipate) by integrating all the expertise of the agencies involved in disaster management but also to share the most relevant information. Finally, the smart cities applications and similar initiatives enable to integrate the citizen in the cycle to enhance alarms, alerts, and field data.

1 INTRODUCTION

The objective of this deliverable is to give an overview of the technical and scientific capabilities that exist in the domain of disaster management support. It gives PANTHEON the state of the art in the domain, even if these capabilities are not always integrated in operational systems. The focus of PANTHEON is the planning phase (strategic planning well before the event occurs and emergency planning when the event will occur at short term and the precise location and magnitude are known or at least are better defined).

The deliverable is a part of the big picture provided by the outcomes of Work Package 2 that gives the state of the art in all the domains of Disaster management (initiatives, frameworks, capabilities) with a special focus on Greece and France that are the countries where PANTHEON system will be tested according to scenarios chosen by the end-users and stakeholders.

The deliverable is structured according to the following sections:

2. Global frameworks and plans for infrastructure protection and civil safety and security

3. Mapping of relevant scientific knowledge

4. Data sharing capabilities

5. Existing early warning system

6. Tools and models for critical infrastructure protection and civil security

After the description of the existing capabilities, the deliverable (section 7) gives an overall assessment for the PANTHEON use cases in Greece and in France to have the best possible idea of the legacy systems.

Finally, a conclusion (section 8) gives the essential outcomes of the study.

2 GLOBAL FRAMEWORKS AND PLANS FOR INFRASTRUCTURE PROTECTION AND CIVIL SAFETY AND SECURITY

The most relevant global framework in Disaster Risk Reduction (DDR) is the Sendai Framework, approved by United Nations in Japan [1]. As mentioned in PANTHEON deliverable D2.1 [2] this framework aims at aggregating all the activities related with DDR in the time horizon from 2015 to 2030.

With a major effort given to climate change risk reduction and resilience strengthening, the mayor innovative element is the involvement of local communities in the decision-making process and in organising the response actions.

The Sendai[3] framework also proposes the enhancement of the international cooperation and the deployment of multi-hazard warning systems, accessible to citizens. It also makes emphasis in the post-disaster phases, expanding preparedness not only in the response phase, but also in the recovery, rehabilitation and reconstruction phases.

Three types of hazards are listed: the hydro-meteorological, the geophysical and the technological, being the first two named as natural hazards. The hydro-meteorological hazards are expected to grow as the climate change keeps rising temperatures and will affect to specific places where resilience needs to be enforced.

The Sendai framework is supported by the Paris Agreement [3], the legally binding international treaty on climate change. It was adopted by 196 Parties at the UN Climate Change Conference (COP21) in Paris, France, on 12 December 2015 and entered into force on 4 November 2016. Objective is to limit global temperature rise to 1.5 degrees Celsius.

In Europe, the priorities in DRR were discussed in the 7th European Civil Protection[4] with separate debates for prevention, preparedness and response in different days. All three had a first presentation on the impact of climate change and the expectation of growing extreme weather conditions. The citizens involvement was also a common factor to all three debates, increasing the awareness and knowledge as part of the prevention, and disseminating success stories in preparedness.

All humanitarian actors in EU are joined in European Union Civil Protection Mechanism (UCPM). In particular we found the European Civil Protection and Humanitarian Aid Operations (DG ECHO), the International Partnerships (DG INTPA), and the Neighbourhood Policy and Enlargement (DG NEAR).

Moreover, the UCPM Knowledge Network[5] is the European main framework on Disaster Risk Reduction (DDR) and aims to strengthen the mechanism in preventing, preparing for and responding to disasters by improving the coordination at all levels, integrating a combination of skills and expertise and deploying a regional cooperation model.

For the UCPM Knowledge Network it is very important to use and share data and science to understand better the risk and learn to better prevent them. Within these, a report [4] proposes the creation and sharing of:

- databases

[3] https://www.undrr.org/publication/sendai-framework-disaster-risk-reduction-2015-2030
[4] https://civil-protection-humanitarian-aid.ec.europa.eu/partnerships/civil-protection-partners/7th-european-civil-protection-forum_en
[5] https://civil-protection-knowledge-network.europa.eu

- scientific papers and knowledge
- proved solutions and good practices
- cross-disciplinary learning, and
- advances in the studies about the complexity of risk, especially in multi-hazard situations.

In the preparedness tasks, the report proposes the use of new technologies and the application of digitalisation. Within the UCPM Knowledge Network the training of responders in Civil Protection Mechanism is proposed to improve through the expansion of the use of the following tools and methodologies:

- immersive technologies, such as virtual reality and augmented or mixed reality,
- learn through gaming, and
- simulation of risk scenarios in complete safety.

Moreover, for the response phase, more new emerging technologies are proposed. Adding them also in the training requirements is a must to have responders, volunteers, and citizens with the sufficient capabilities to use them in the moment of emergency response. The tools listed in the report[1] are:

- sensors deployed on field
- unmanned vehicles, either ground or aerial, that can be deployed to allow the access to dangerous and/or inaccessible zones
- satellite-based communications and data provision (e.g. GOVSTACOM, EGNSS, Galileo or Copernicus)
- artificial intelligence (AI) tools, which can help to predict the evolution of a hazard and provide new ways for action.

The addition of such tools has great opportunities but is not empty of risks due to limited operational experience in some of them, the additional complexity introduced in the already complex situation of a hazard or in case of an ineffective integration of the new technologies into the existing methods and tools.

A special mention is given to the inclusion of disabled and vulnerable citizens in the emergencies. While it is considered that the population in this situation is as today of a 15%, in case of disaster and additional 15% could be also become disable. Planning the actions to fulfil the desired response needs to be carefully done.

The Emergency Response Coordination Centre (ERCC) includes funding to provide humanitarian assistance to respond to crises that could not be foreseen in DG ECHO's humanitarian implementation plans. It is known as the Emergency Toolbox[6] and most of its tools can be used for disaster preparedness as well as for response, such as:

- The small-scale tool, to assist a limited number of people (< 100,000) affected by a natural hazard or human-induced disaster. This includes the deployment of preparedness activities.
- The Epidemics Tool, to prevent and respond to epidemic outbreaks.
- The International Federation of Red Cross and Red Crescent Societies Disaster Relief Emergency Fund and Forecast-based Action, to provide National Red Cross and Red Crescent Societies with funds for early action or for response.

The EU Civil Protection Mechanism was activated 114 times in 2021[7]. Most relevant hazards of that year were:

- the COVID-19,

[6] https://civil-protection-humanitarian-aid.ec.europa.eu/emergency-toolbox_en
[7] https://www.consilium.europa.eu/en/infographics/civil-protection/

- the floods in Belgium,
- the forest fires in the Mediterranean, in the Western Balkans and in Austria,
- the repatriations from Afghanistan,
- the earthquake and a hurricane in Haiti, and
- the war in Ukraine.

It is important to highlight the fraction of actuations of the UCPM outside of the EU. The international activity of the EU, the European Civil Protection Pool (ECPP), is composed by the EU members and 8 participating states that commitment their national resources under the same mandate.

Also, a priority for preparedness is given by this activity, including a list of tools and resources for each priority:

- Early Warning Systems (EWS), an integrated system to predict, monitor and communicate hazards to individuals, governments, businesses and communities to take timely actions to reduce disaster risks. Examples are:
    - Global Disaster Alert and Coordination System, available at www.gdacs.org
    - Climate and Early Warning Systems, available at www.crews-initiative.org
    - Integrated Food Security Phase Classification, available at www.ipcinfo.org
    - Community Basel Surveillance, available at www.cbsrc.org
- Anticipatory Action, a set of pre-agreed early action protocols that define responsibilities, funds and actions, as essential steps for preparedness. Examples are:
    - German Red Cross Anticipation Hub, available at www.forecast-based-financing.org/anticipation-hub
- Logistics, as the way to improve the local and national level organisation of the first responders and reducing the need for international mobilisation when possible. Examples are:
    - Logistics Cluster, available at www.logcluster.org
- Strengthening of Capacity of first responders to have the right skills, the appropriate tools and the institutional support to implement a timely and effective response. Examples are:
    - Oxfam Novib, available at www.oxfamnovib.nl
    - CoBRA, the Community Based Resilience Analysis tool and methodology, available at www.undp.org
- Shock Responsive Social Protection (SRSP), a system to embed DDR in the political mandate and all its strategies and activities. Includes instruments to tackle the challenges of social exclusion, poverty and vulnerability in general. Examples are:
    - NEXUS, available at www.socialprotection.org
- Cash preparedness, to be able to transfer funds to offer beneficiaries dignity, choice and flexibility. Examples are:
    - CaLP joint donor humanitarian cash transfers, available at www.calpnetwork.org
- Institutional policy and legislative frameworks, these are frameworks that ensure that institutional and legal barriers will not hamper response capacity. Examples are:
    - Check list on Law and DRR, available at www.disasterlaw.ifrc.org.
- Data and information management and technology, as a key player in the risk assessment and essential for providing information about risks to which a population or a geographical area are exposed. Examples are:
    - Harvard Humanitarian Initiative, available at www.hhi.harvard.edu

- Contingency planning and business continuity, a set of well-developed contingency plans to help ensure the relevant decisions and provisions related to resources, roles and responsibilities are taken in advance, agreed and well understood by all relevant actors. Examples are:
    - Contingency planning Guide by Red Cross, available at www.ifrc.org
    - Business continuity help desk, available at www.preparecenter.org
- Urban preparedness, to mitigate the accelerated growth of cities and the lack of convenient planning that affect the informal settlement patterns, the limited access to land and house and the lack of security of tenure. Examples are:
    - URBANET debates, available at www.urbanet.info
    - UN Habitat, available at www.urbanresiliencehub.org
    - ICLEI, local governments for sustainability, available at resilientcities2019.iclei.org
    - ISET Network, a framework for Urban Climate Resilience, available at www.i-s-e-t.org
    - City resilience index by ARUP, available at www.arup.com
- Climate and environmental interventions, to reduce the risk of disaster due to the degradation of ecosystems by addressing the environmental concerns as part of the preparedness planning. Examples are:
    - Green recovery and reconstruction toolkit, available at www.worldwildlife.org
    - Environmental emergency centre, available at www.climatecentre.org
    - World Bank climate change portal, available at climateknowledgeportal.worldbank.org
- Preparedness in conflict and violent situations, actions that must include the intensity of the conflict, the possible population displacements, the community self-protection strategies, the access for humanitarian interventions and the neutrality of the actions. Examples are:
    - Global public policy institute agenda, available at www.gppi.net
    - FAO resources, available at www.fao.org/emergencies
- Preparedness for drought, produced by an increase in the opportunity for preparedness and early action to avoid seasonal and irregular drought conditions. Examples are:
    - FAO drought preparedness, available at www.fao.org
    - Start network, available at www.startnetwrok.org.
- Preparedness for protection, to provide material need of assistance such as food, water, shelter and medical. Examples are:
    - Professional standards for protection, available at www.icrc.org
    - Sphere handbook, available at spherestandards.org
- Preparedness for displacement, to support displaced people and avoid them been subject to vulnerability. Examples are:
    - Platform for disaster displacement, available at disasterdisplacement.org
    - Environmental migration portal and Transhumance tracking tool, available at environmentalmigration.iom.int/data-and-resources
    - Global compact on refugees, available at globalcompactrefugees.org

3 MAPPING OF RELEVANT SCIENTIFIC KNOWLEDGE

3.1 SPACE-BASED EARTH OBSERVATION

Remote sensing is defined as the acquisition of information of some element that is not in contact with the observer. The main remote sensing tool to observe the earth are satellites and unmanned aerial vehicles (UAVs).

Satellites are space vehicles containing sensors and communication links. Different sensors being used in earth observation are listed in section 3.1.1. With these sensors, satellites can capture different information relevant to emergency management, and with the communications capability all this sensed data can be downloaded to ground to process it and to generate a list of applications and services which will be listed in section 3.1.2. Special emphasis in both sections will be given to Copernicus, the earth observation program of the European Union.

Satellites can be used also for space observation, but the ones used for earth observation can be either geostationary or orbiting across the globe. Geostationary satellites always observe the same part of the earth (as in example the three satellites from the EUMETSAT, the European Organisation for the Exploitation of Meteorological Satellites). Geostationary satellites have a low resolution (in the order of kilometres) since they might stay at high altitude. Orbiting satellites typically orbit at lower altitudes and thus can obtain higher resolutions (from metres to centimetres). Therefore, orbiting satellites need to be continuously controlled and have a temporal cadence. For these reasons, satellites with the same type of sensors are launched in pairs or more, to get temporal continuity in the sensing.

Ground stations across the world are deployed together with the satellite launching to control and correct the satellite orbits, and to download the large volume of data collected from smart sensors. Only Copernicus (*the European eyes on sky*), is generating 16 terabytes of data per day.

The Copernicus programme was approved by the European Commission in 1998 (former name CMES) with the objective to support research in earth science, environment, and climate change. First deployment started in 2008 and full operative service was reached in 2014. Copernicus is funded and managed by the EU State Members and the ESA (European Space Agency). Up to six Sentinel missions have been launched, each with different types of sensors: Sentinel 1 with radar, Sentinel 2 with visual cameras, Sentinel 3 with meteorological sensors, Sentinel 4 with multispectral, Sentinel 5 with atmospheric sensors, and Sentinel 6 with altimeter. In addition to its satellites, Copernicus also receives information from other satellite constellations and from a network of in-situ sensors.

3.1.1 TYPES OF SPACE-BASED EARTH OBSERVATION TECHNOLOGIES

Sensors on board satellites or other vehicles such as aircraft, UAV, ground robbers or under-water vehicles have different physical characteristics that allow them to obtain diverse perceptions from an object or body. Follows a synthetic review of the major sensor technologies found in satellites such as the Sentinel ones.

3.1.1.1 Synthetic Aperture Radar (SAR)

Radars are active sensors that generate the energy source needed to obtain in return the characteristics of a sensed body. In the case of synthetic aperture radar (SAR) the sensor holds an additional software component that permits the recreation of a full map of data from individual units of information. The software component allows to build smaller and cheaper sensors with similar throughput than classical radars. Especially the small size is very convenient for satellite and other aerial vehicles.

The Sentinel-1 mission represented a completely new approach to earth observation mission with the operational needs for SAR data program. Figure 1 shows the *C-SAR* instrument mounted on the Sentinel 1 satellite, the active phased array antenna providing fast scanning in elevation to the SAR.

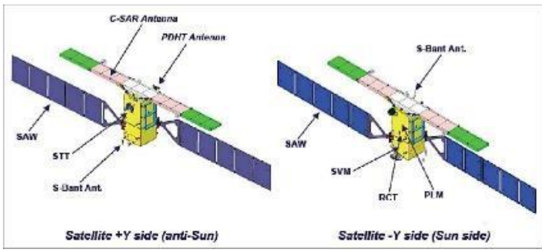

Figure 1 Sentinel 1 with SAR sensor.

3.1.1.2 Light Detection and Ranging (LiDAR)

LiDAR is yet another radar technology in which the energy source consists of a laser ray. In comparison with sound-based radars the improvements are much higher speed and less dispersion and noise. LiDAR returns a cloud of points that represent a surface shape with a very high density. In satellites the LiDAR are mainly used to obtain the terrain elevation map, also known as digital elevation model and obstacles characteristics (e.g. buildings and hights).

LiDAR on board a satellite was issued by NASA during its LITE (Lidar In-Space Technology Experiment) 9-days mission to measure the atmosphere with laser precision. To our knowledge none of the Sentinel satellites has a LiDAR on board, so multiple works present how to combine LiDAR data obtained by an aircraft or a UAV, with the Sentinel data to generate downstream services to Copernicus.

3.1.1.3 Global Navigation Satellite System (GNSS)

Although the Global Navigation Satellite System (GNSS) is rather a technology for positioning, navigation and timing (PNT) than an earth observation technique. It is composed by several satellites that provide geographical positioning to receivers located on the earth surface. The satellites follow known orbits and must actuate jointly as constellations, providing atomic time broadcast messages that are received by the ground receiver. The receiver has information on the ephemerides, this is, the accurate position of the satellites at each moment, and by computing the different time of arrival of the signal of at least 4 satellites it can calculate its own position. A fifth satellite will also allow the computation of the altitude of the receiver. The more satellites are in view the better the accuracy of the receiver position calculation.

The European GNSS is named Galileo, with 30 satellites orbiting at medium altitudes. Most receivers today can joint data from Galileo and other GNSS from other countries such as GPS (USA), GLONASS (Russia) and BeiDou (China).

3.1.1.4 Geographic Information Systems (GIS)

A geographic information system (GIS) is a software technology designed to process geographical data. GIS includes visualization tools to visualise geographical data in form of a map, projection algorithms to transform

3-dimension data into a 2-dimension map and a number of functionalities aimed at adding value to the geographical data being processed.

The leading GIS provider is ESRI, an American and multinational geographic information system software company, that commercialises ArcGIS products and has a 40% of the world market share. But open-free software platforms have been developed on volunteer basis and under EU funding. For instance, DIVA-GIS is the open GIS software proposed by the European Environment Agency. QGIS, PostGIS or GRASS are other well-known open source platforms.

Join efforts under the umbrella of the Open Geospatial Consortium (OGC) have produced the OpenGIS standard Web Map Service Interface (WMS) that allows a common programming interface to retrieve maps and other geographical data from a web portal using the HTTP standard protocol. GIS data format standardization in Europe is promoted since 1990 by the JRC under the INSPIRE program. ESRI technology features modules OGS and for INSPIRE modules.

3.1.2 APPLICATIONS OF SPACE-BASED OBSERVATION TECHNOLOGIES IN SMART CITIES

Copernicus offers open data, free of payment and majorly full access (limited in case of emergency data and restricted for security data). The same applies for the USA LANDSAT system. Data is stored, corrected and processed and can be retrieved by end users in raw mode but generally using the Copernicus services. For most of the services registration is needed.

Copernicus services are available to provide geospatial data, processed information and maps for:

- Land
- Sea
- Emergency
- Atmosphere
- Border security
- Climate change

Services are reachable through Copernicus web portals, through application program interphases (API) and through DIAS (Data and Information Access Services), which include access to data and cloud processing services. Downstream services, derived from the above, are also available provided by national governments, associations, non-governmental organization or private companies. Different terms may apply to these other services. The US LANDSAT system also has its procedures.

3.1.2.1 Urban planning and management

Copernicus Land services support applications in a variety of domains such as forest management, water management, agriculture and food security, and so on, being particularly suitable for urban planning.

The planning and management of urban areas is a key component of the European sustainable development policy. Today more than a quarter of the European extension is covered by urban land. Local and regional authorities have significant responsibilities in the field of urban planning and they shall face important challenges that have large impact on citizens' quality of life. Urban planning challenges are the growing need of mobility, the management of tons of waste, the use and promotion of renewables energies, and much more. Copernicus services are available to all to face these challenges. Land services include data on land use, land cover classification, urban growth maps, urban green areas, population density, urban heat islands, imperviousness of urban soil, etc.

Copernicus Land services are organized in 3 classes depending on the scope of the data: global, Pan-European and Local, being Local Land service known as Urban Atlas the most appropriate for urban planning. It includes a new Dashboard that helps users to understand the full potential of the tool. The Urban Atlas has a 10 m resolution and uses years 2006, 2012 and 2018 as reference years to calculate and show urban changes.

An example of the use of Copernicus Land services in urban planning is given in a report [5]. The report shows how a German start-up company used Copernicus Land services to build an application used to inform building companies on progress of a constructions work. With the application clients were able to save up to three hours per day, saving thousands of euros and achieving more accurately their construction deadlines.

An example of the Copernicus Land services can be seen in Figure 2, which shows the differences from 2012 to 2018 of the buildings constructed in Paris.

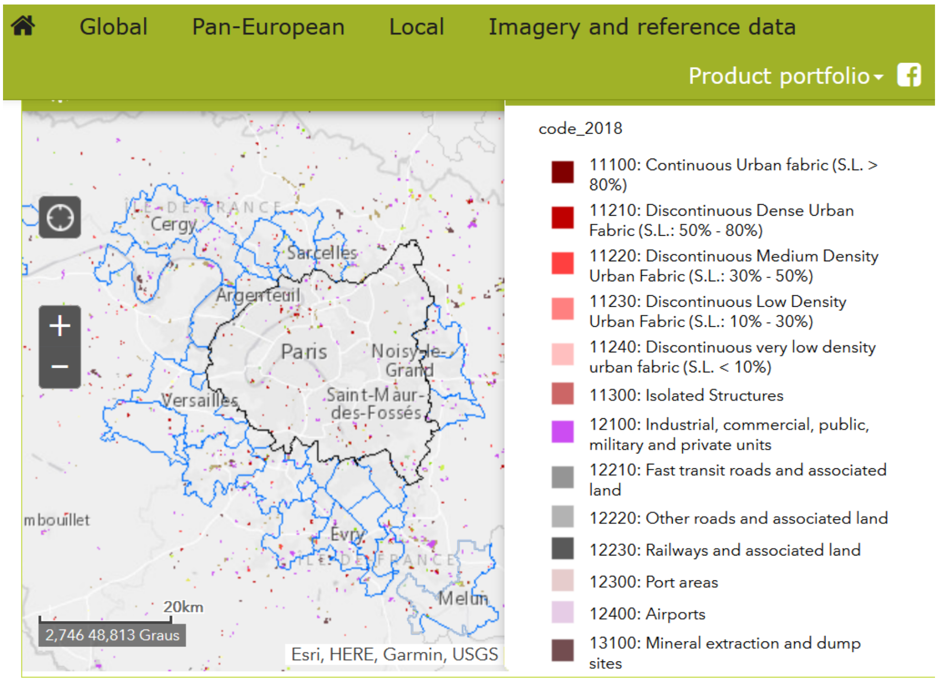

Figure 2 Copernicus Land Services example.

3.1.2.2 Environmental monitoring and management

Copernicus Atmosphere and Copernicus Climate Change services are available for the monitoring of the environment and its responsible management.

The Copernicus Atmosphere Monitoring Service (CAMSa) provides continuous data and information on the atmospheric composition, describing the current situation in near-real-time, forecasting the situation expected up to 4 days ahead, and analysing data to provide scientific assessment of the atmospheric health. CAMS focuses on five areas: atmospheric composition for air quality assessment, ozone layer for ultra-violet radiation knowledge, greenhouse and reactive gases emissions, solar radiation for health, agriculture and renewable energy purposes, and climate forcing in support of the Paris Agreement.

The Copernicus Climate Change Service (C3S) provides scientific-based information about the past, present and future climate in Europe and the rest of the World in support to the adaptation and mitigation policies of the European Union. C3S users include scientists, consultants, planners, policy makers, media and any citizen eager at searching for objective data. The tools offered permit the assessment of climate change impacts on biodiversity, the sustainable water management of urban supplies or the dispatching of alerts about air-pollution, solar storms effects or smoke dispersion.

Examples of data available through the CAMS and C3S services are given in Figure 3 and

Figure 4.

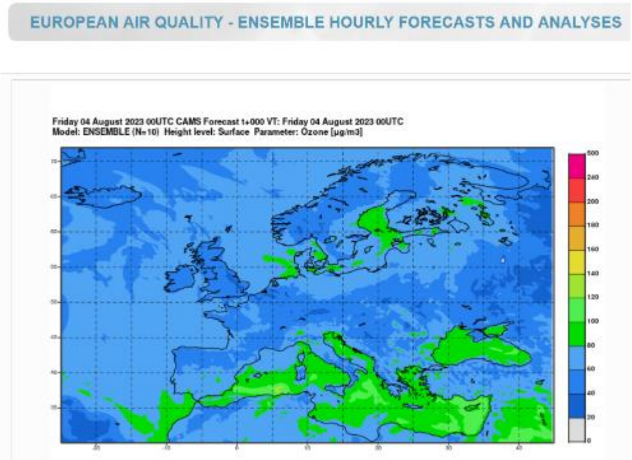

Figure 3 CAMS real-time map example on air quality

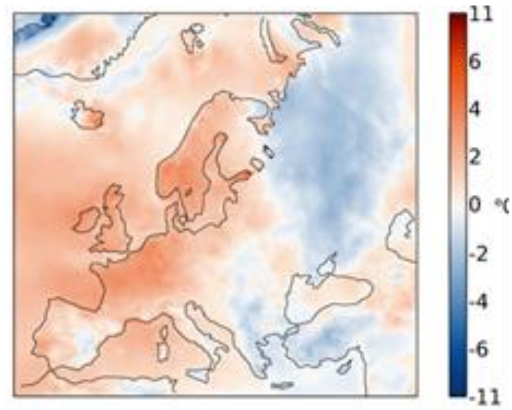

Figure 4. C3S Surface air temperature anomaly for June 2023

3.1.2.3 Disaster management and emergency response

Copernicus provides a list of services and datasets related to emergency management and known as Copernicus EMS. They can be classified in mapping services and early warning and monitoring. The mapping services are full open. Two types of maps are available: rapid maps for early response, and risk & recovery maps for the rest of the phases. See in Figure 5 and Figure 6 examples of these mapping services.

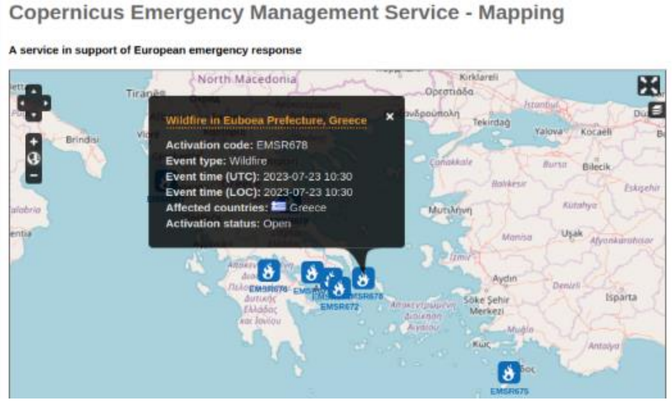

Figure 5. Example of Rapid Mapping

Figure 6. Example of Risk & Recovery Mapping

The Copernicus Early Warning and Monitoring (EWM) services offers critical geospatial information at European and global level to managers and first responders. Through continuous observations Copernicus EWM can monitor and to forecasts floods, droughts and forest fires.

Floods related services

There are two services related to floods: the European Flood Awareness Systems (EFAS) and the Global Flood Awareness Systems (GloFAS). While the **EFAS** is the Pan-European probabilistic early warning system for flood risk and hazard focused mainly in the preparedness phase, the **GloFAS** aim is to support international organizations in decision making and particularly in large trans-national river basins.

EFAS products are a set of maps and graphs that highlight possible future flood risk from the EFAS forecast simulations. Figure 7 shows the process used to obtain the forecast, based mainly in the fusion of hydrological and meteorological data.

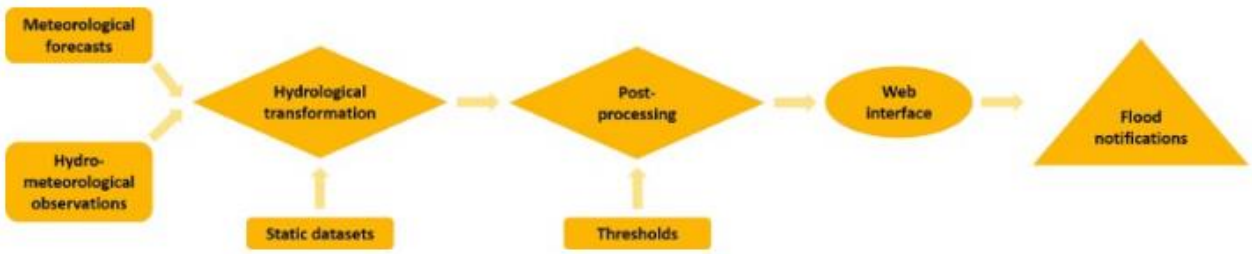

Figure 7. EFAS hydrological forecasting chain; European Centre for Medium-Range Weather Forecasts

Lead-time of different products are up to 4 hours (ERICHA radar-based local flash floods), 5 days (ERIC flash flood), 10 days (medium-range floods and flood impact) and 8 weeks (SEAS - seasonal hydrological outlooks). An example of ERICHA is visible in

Figure 8. EFAS real-time forecast and products (including notifications) are only available to EFAS partners and EFAS third parties. This is why the figure shows no relevant data. Under approval, research project partners can be granted access with no-redistribution limitation. In addition, EFAS forecasts and products are freely available to all after 30 day.

The global flood service, GloFAS, is freely accessible to all registered users and provides forecasting and monitoring of floods across the world. GloFAS products have lower spatial and temporal resolution, with product looking at up to 30 days (GloFAS Medium-range forecasts) and 16 weeks (GloFAS Seasonal forecasts). Also, the GloFAS Rapid Risk Assessment (RRA) is available to those who want to assess flood impact on population, infrastructure (health, education, airport facilities) and land cover. Finally, GloFAS Global Flood Monitoring (GFM) is a near real-time global flood monitoring providing 11 different flood-related map views such as flood extension, water extension, obtention of reference water mask, uncertainty values, affected population, affected land cover, etc. An example of GloFAS is shown in Figure 9.

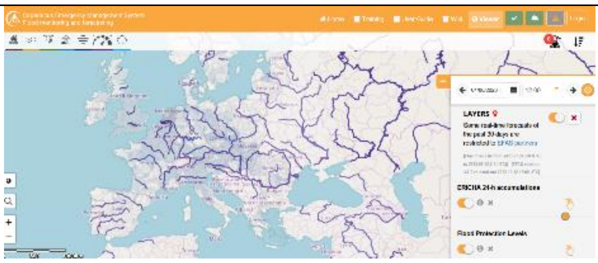

Figure 8. EFAS (limited view)

Figure 9. GloFAS

Fires related services

All services related with wildfires are aggregated under the European Forest Fire Information System (EFFIS, JRC). EFFIS holds information about active fire. It can visualise them in maps and overlay it with additional information on human settlements, protected areas, landcover and soil fuel types. EFFIS generates the fire risk forecast for different time span and different indexes. In addition, for active fires and forecast, EFFIS can obtain burnt areas, fire severity maps and vegetation regeneration, information useful for the recovery phase and for insurance assessment. In addition, the EFFIS has a module to calculate the emissions and forecast smoke dispersion.

Figure 10 and Figure 11 show two of the available views in EFFIS, the current situation viewer and the wildfire risk viewer respectively. In addition to these maps, the EFFIS portal has the current statistics portal, a news feed about fires, a data request from and long-term fire weather forecast.

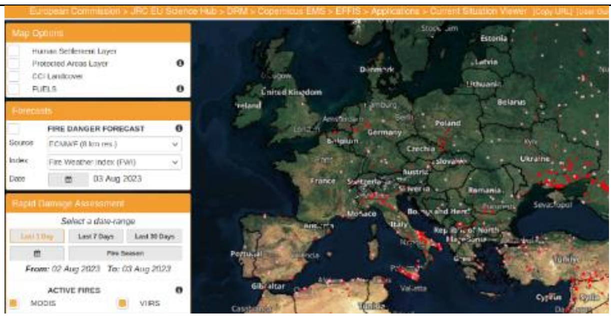

Figure 10. EFFIS monitoring of active fires

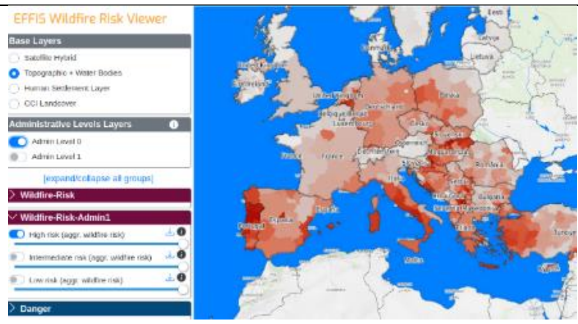

Figure 11. EFFIS risk of fires

Drought related services

Two similar services with different geographical scope are available through the Drought Observatory for Europe (EDO) and Global Drought Observatory (GDO). Both provide maps for drought monitoring that rely on the analysis of a set of components of the hydrological cycle (precipitation, evaporation, soil moisture, reservoir levels, river flow, groundwater levels, etc.) and land cover (vegetation stress, fuel). Figure 12 and

Figure 13 show both views and reports and forecast for the next 3 months are published.

EDO and GDO differ in the drought indicator used. EDO calculates the Combined Drought Indicator (CDI) based on the larger number of inputs available for Europe, in special trough in-situ sensors, and GDO uses the Risk of Drought Impact for Agriculture (RDrI-Agri) indicating the probability of having impacts from a drought, with particular focus on vegetation. Regional products are also accessible through DO portals.

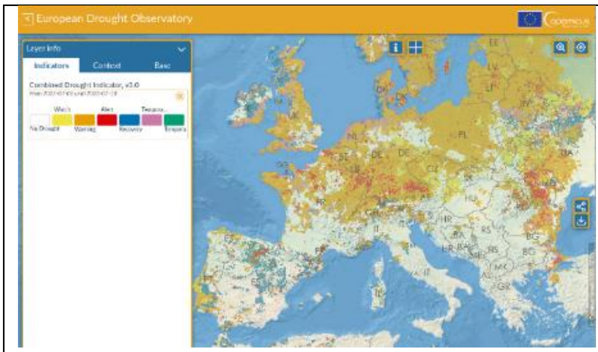

Figure 12. EDO

Figure 13. GDO

3.2 AERIAL & IN-SITU OBSERVATION AND MODELLING

3.2.1 TYPES OF AERIAL & IN-SITU OBSERVATION AND MODELING TECHNOLOGIES

3.2.1.1 UAV-based observation technologies and geospatial models

Climate, natural and security crises tend to expand, both in magnitude and complexity, and their impacts on the infrastructure and communities become, over time, more and more out of control. In this context, the use of airborne means as Earth observation tools was very quickly identified as essential to improve the understanding and management of crises, and as an essential tool making it possible to anticipate the appearance and the development of these crises, and therefore identify the best ways to respond to them or to limit their effects.

Given the large number of means and tools, whether at the level of aerial platforms (aircraft, helicopters, unmanned devices, balloons, etc.) or onboard payloads (RGB, infrared, /LiDAR, various sensors, etc.), the difficulty consists, however, in identifying the most relevant solutions with respect to the need, which depends on the period considered in relation to the unfolding of the events themselves.

The following section proposes a time breakdown of the implementation of a crisis management tools and, considering the advantages and disadvantages of each airborne data collection solution, considers the deployment of each of them according to the phases identified.

Phases to be considered for Crisis Management & Planification

In the framework of Crisis Management and Situational Awareness, the acquisition, processing, and use of data, whether of airborne origin or not, are divided into two main requirements: near-real time (this concept corresponds to a few tenths of a second to around twenty minutes depending on operational needs) to delayed delivery that can range from a few hours to a few days or weeks. The choice and quantification of this deadline will depend on the mission to be fulfilled, whether it is tactical purpose with a strong operational connotation aiming to meet an immediate and effective need, or strategic purpose aiming to meet an objective dedicated to planning, preparation of resources and training of rescue teams and stakeholders involved in the management of the future crisis.

Figure 14 illustrates these different phases, the two axes related to data delivery times being represented in blue and green.

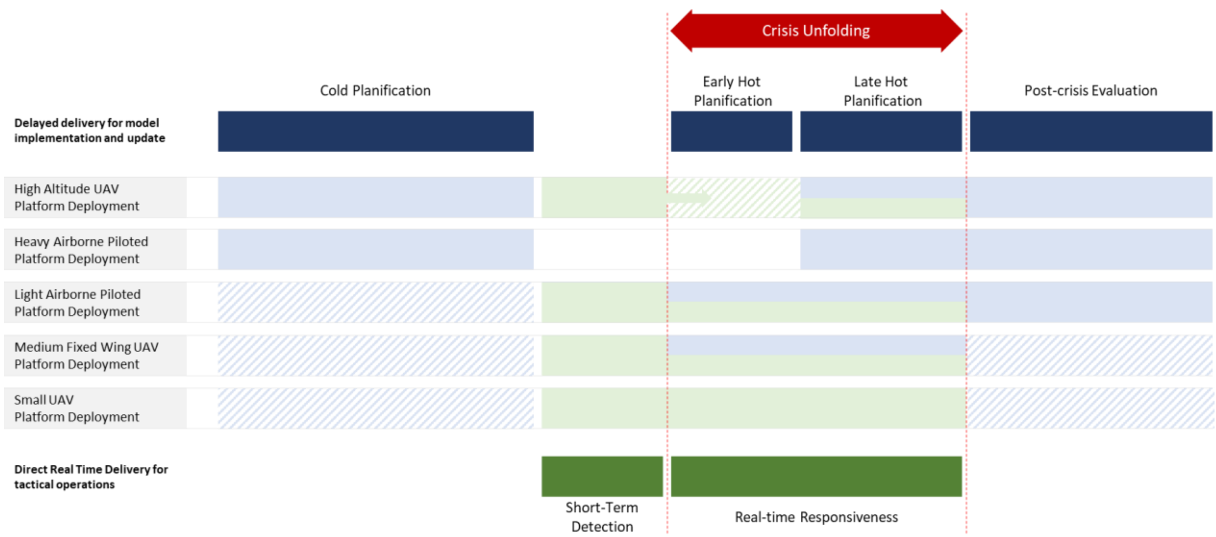

Figure 14: Sequencing of phases associated with crisis management processes.

These phases are broken down as follows:

- **Cold planning:** well in advance of the outbreak of a crisis, the objective is to collect accurate data over large areas as the nature and the location of the crisis are not known, but with a low requirement on operational flexibility and delivery lead-time.

  Main constraints: high level of data quality (resolution, level of detail, homogeneity, etc.) characterized by large surfaces to be covered and a significative requirement on high frequency of data refreshing which result in very large volumes of data to be managed and processed, and by the need to engage heavy aerial means for data collection and processing. Intermediate and light aerial means may possibly be used for very specific mapping missions (for example, precise mapping of all or part of a small city).

- **Short-term detection:** in the context of an imminent outbreak of a crisis, resources are deployed to detect specific events and monitor the evolution of the situation. The quality of the data is not a strong requirement, but their availability within short deadlines reinforces the interest and the added value of the mission. In most cases, the mission will therefore be part of a process aimed at supporting the teams on the ground to anticipate, trigger evacuation procedures and deploy emergency devices as quickly as possible and in the most relevant places.

  Main constraints: great operational flexibility to be able to deploy in areas of interest shortly after their identification, and ability to deliver information in very short lead-time (from real time to a few tens of minutes) that reduces data volumes as they quickly become obsolete, so medium and light aerial means are often more affordable and more relevant for these missions.

- **Early re-planning:** immediately after the outbreak of a crisis, the need is to quickly assess its intensity, locate the most critical areas, identify people in distress, assess the needs in terms of emergency devices to be deployed and update the information collected during the cold planning phase (for example, reconstruct the state of the communication networks, etc.). This approach is part of the deployment of the first involvement of rescue teams, which aims to hinder the progression of the crisis and to assist people to protect them from its direct effects.

  Main constraints: great operational flexibility to be able to deploy to areas of interest shortly after their identification, and ability to deliver high-level information in very short time frames (from real time to a few tens of minutes). The addition of augmented reality to help understand the situation and support decision support mechanisms can further reduce the processing times for this data, and the mechanisms for integrating data into existing models. must be automated with the same objective. Medium and light devices will be preferred, preferably with strong mission backend capabilities based on Augmented Reality and Artificial Intelligence.

- **Real-time support to rescue operations:** the objective is to provide information to ground rescue teams to help them better understand the situation and anticipate its evolution. It is also a question of helping these teams to direct their efforts according to specific objectives to be fulfilled (For example, saving people or buildings, etc.) or to put in place measures to protect themselves from effects of the crisis.

  Main constraints: these missions involve extremely high reactivity and flexibility and aims to deliver very high-level information (possibly improved using Augmented Reality and Artificial Intelligence) in very short times (maximum a few seconds) with a low level of quality. They will be more easily carried out using medium or light aerial means guaranteeing more flexibility but having powerful mission backend capabilities based on Augmented Reality and Artificial Intelligence.

- **Lately re-planning:** in a further step after early re-planning, the need consists in re-mapping the impacted zones in order to identify the effective consequences for specific infrastructures (state of the roads, damage to the power supply or telecommunication systems, status of critical buildings…) and with respect to aspects related to the community (State of distress of the populations, route taken by the refugees, grouping of people). This approach is part of the deployment of the second involvement of rescue teams aiming to restore the functioning of the infrastructures and to assist victims to enable them to survive in a degraded environment.

Main constraints: As it is a question of refreshing the models built during the cold planning phase, a high level of data quality (resolution, level of detail, homogeneity, etc.) can be requested with a characteristic of surfaces to be covered potentially significantly lower since the area of the crisis is known. The volumes of data to be managed and processed are therefore significantly reduced, but the information processed must be made available within reasonably short deadlines (a few hours to a few days). These parameters qualify all the aerial means depending on details characterizing the mission.

- **Post-crisis assessment:** the objective is to establish the state of degradation, essentially with the objective to plan reconstruction activities, within the framework of the constitution of insurance files or with the objective of refreshing the prediction models and planning tools to improve efficiency and added value.

  Main constraints: high level of data quality (resolution, level of detail, homogeneity, etc.) characterized by medium-sized areas to be covered leading to significant volumes of data to be managed and processed, but without strong requirements on delivery times. All aerial means can be deployed depending on the surface to be covered and the type of mission to be carried out, but heavy means will probably be preferred.

Specific Issue for Airborne Deployment during Crisis Period

One of the difficulties in deploying aerial assets in a crisis zone concerns the management of airspace during the crisis. These ones are usually reserved for the emergency services themselves, whether, for example, the medical helicopters deployed to carry away the injured people or the water bombers having to fight against large fires. This results in a partial or total closure of airspace, and therefore a limitation of other activities.

This point can be critical as it prevents the deployment of Earth Observation support resources and can, if not properly managed, lead to over-accidents which aggravate the crisis.

Although this subject is specific to the crisis period itself and can therefore be considered outside the scope of PANTHEON project, which focuses on the cold planning phase, taking this constraint into account during the planning process and training of crisis management processes must be fully integrated upstream to allow stakeholders to be able to manage deployment of specific airborne means.

Types of Available Airborne Capability

- **Small UAV Platforms:** UAVs are unmanned aerial devices weighing a few kilograms, characterized by a fixed wing or rotary wing configuration (see Figure 15), which can be equipped with RGB or IR cameras (Especially NIR and SWIR for night vision) that can be integrated on fixed or gimbal-type mounts, and various sensors such as, for example, LiDAR. They are particularly agile and versatile, making them ideal for collecting geospatial data in hard-to-reach or dangerous areas during a crisis, but payload capabilities are limited due to the low masses that can be carried. Their low autonomy dedicates them to proximity missions implying that the operator is close to the area of operation, which limits them to extremely precise and punctual missions.

Obtaining flight authorizations can be a problem, which can be reduced if the flight is carried out within a limited perimeter under the direct supervision of the pilot and if the authorities recognize the flight as being in the public interest.

Figure 15: View of a DJI drone equipped for RGB sensor.

- **Drone Fixed Wing Platforms:** This category of UAV includes larger fixed-wing aircraft (see Figure 16) weighing a few tens of kilograms and characterized by very long-distance range capabilities (up to 400 km) for very long durations (up to at 8h). Their relatively small size (around 4m wingspan) does not classify them as MALE (Medium Altitude Long Endurance drones), which are heavier machines with additional operational capabilities, but more expensive and complex to implement and not covered in this study.

  These intermediate UAVs generally have RGB or IR cameras (NIR and SWIR for night vision or MWIR for hot spot detection) that can be integrated on fixed or gimbal-type mounts, and various sensors such as, for example, LIDAR. Their autonomy and the long range dedicate them for missions of re-mapping of disaster areas or for front line reconnaissance (as part of rapid hot planning).

  Obtaining flight authorizations can be a problem, especially since this type of air vector is supposed to be operated at a great distance from the ground station and outside the direct control of the pilot. The authorities can, however, facilitate procedures that recognize the theft as being in the public interest.

Figure 16: View of the Boreal drone from M3 Systems.

- **Light Piloted Aircrafts:** This type of platform consists of single-engine aircraft of the ULM or CS-VLA types (less than 450kg, see Figure 17) equipped with RGB or IR cameras (NIR and SWIR for night vision or MWIR for the detection of hot spots) that can be integrated into fixed or gimbal-type mounts, and various sensors such as, for example, LIDAR. The specificity is the possibility of taking off with a crew reduced to a single pilot while guaranteeing a certain flexibility and reactivity because no specific authorization is required, as long as the pilot respects the regulatory limitations possibly put in place on the area to be overflown.

  This type of air vector is also particularly useful for missions requiring high responsiveness and coverage of large areas, particularly in the context of the rapid hot planning phase.

Figure 17: View of a SONACA 200, a version of which was later transformed into a light Earth Observation platform.

- **Heavy Piloted Aircrafts:** These devices are heavier, often twin-engine, and based on platforms ranging, for example, from the CESSNA 404/406 (see Figure 18) to the CESSNA 208 CARAVAN specifically modified and equipped, up to the original DIAMOND DA42 more suitable for aerial reconnaissance and earth observation. These machines are heavier and more complex to implement than the previous ones, often requiring crews of two to four people (at least a pilot and a mission manager who supervises the payloads) and which requires more flight preparation. The deployment lead-time is usually a few days which, in combination with the fact that the payloads are heavier and more efficient, reserves its aircraft for pre-crisis and post-crisis missions, with a possibility for the second cold replanning when the crisis spread over a long period.

  Various types of payloads can be installed but mostly focused on RGB, IR and LIDAR, but they are technologically more advanced and achieve much higher levels of data quality and allow larger volumes to be achieved due to higher flight altitudes.

Figure 18: View of a maritime surveillance CESSNA 406.

- **High Altitude Unmanned Platforms:** These platforms are still at development stage, the only concept being already operational being the AIRBUS ZEPHYR (see Figure 19). This type of aerial vector, supposed to fly at altitude between 16km and 22km for several weeks, operating by using solar panels and batteries, is seen as a complement to satellite solutions. Its main advantage is the possibility of being deployed and being able to stay on the area of interest, thus offering the possibility of generating and providing data and information in real time and continuously for a very long period.

  Associated with high-performance payloads and given a relatively reasonable altitude compared to the satellites, the level of quality of the data generated could be appreciable, the latter being however characterized by a significant geographical coverage. All these characteristics qualify these aerial vectors for all missions spread out along the crisis management process, whether for the massive capture of data aimed at preparing the planning models or for the missions or more tactical missions aiming to support rescue teams in real time.

  The type of payload that can be onboard will focus on RGB and IR, with a preference for SAR-type radars to pass through cloud layers and guarantee day and night operations in all weather conditions.

Figure 19: View of the stratospheric drone ZEPHYR from ADS.

Summary of Pros & Cons

The table in Figure 20 summarizes the comparisons that can be drawn between the different aerial platforms.

	Small UAV	Medium UAV	Light A/C	Heavy A/C	HAPS
Maturity	High (but reglementation	High (but reglementation	Medium (as quite new)	High	Under development
Reactivity	Medium (1 or 2 days)	Medium (1 or 2 days)	High (4h)	Low (Few days or 1 week)	Low if not already on the AoI
Flexibility	High	High	High	Medium	
Operational Complexity	Medium	Medium	Simple	Quite complex due to flight organization	Very complex
Range	Few dozen of meters	Few hundreds of kilometers	Few hundreds of kilometers	Few hundreds of kilometers	Infinite
Endurance	1h	8h	4h	8h	Infinite
Limitation	Reglementation	Reglementation	No	No	Unknown
Type of sensors	RGB, IR, LIDAR with low performances	RGB, IR, LIDAR with low performances	RGB, IR, LIDAR with medium performance	RGB, IR, LIDAR or other with high performances	RGB, IR, LIDAR or other with medium
Data Quality	Very high	High	Medium/high	High	Medium
Geographic corverage	Very low	Low	Medium	High	Very high
Real-time delivery	Yes (more dedicated)	Yes, possible	Yes, possible	No, not main mission	Yes, possible

Figure 20: Pros & cons of various airborne solutions deployed in the context of crisis management.

Real Examples of Airborne Mean Deployments

The following sections give some practical examples of crisis management around the world using airborne means. This list is not exhaustive, but it gives an overview of the possibilities offered by these types of solution.

- **3D Simulation to anticipate Centennial Flooding in Paris:** In January 2018, the Paris region in France was affected by major flooding. To anticipate the development of floods and better prepare all stakeholders for incoming emergency interventions, the authorities used drones to monitor the situation.

  The drones were deployed to fly over the flooded areas and the banks of the Seine (see Figure 21), providing real-time aerial imagery to the rescue teams. These images made possible to obtain an overview of the extent of the floods, to identify the most affected areas and to follow the progress of water in the urbanized areas. The authorities were therefore able to better anticipate crisis evolution and take preventive measures to protect populations and infrastructure against flooding effects.

Figure 21: View of the banks of the Seine filmed by a drone during the 2018 floods.

The data collected by the drones then made possible to generate 3D models of the city, and to incorporate the effects of a centennial flooding event by identifying the levels that can be reached by the water. Figure 22 represents general views and the impact on neighbourhoods in the city.

Figure 22: Overview of flooded Paris provided by 3D models.

This type of tool can allow, for example, to identify the general impact on critical infrastructures such as regional electrical distribution network or, more specifically, the effects of rising water levels on more specific buildings. Figure 23 illustrates these two applications for the case of a possible centennial flooding in Paris.

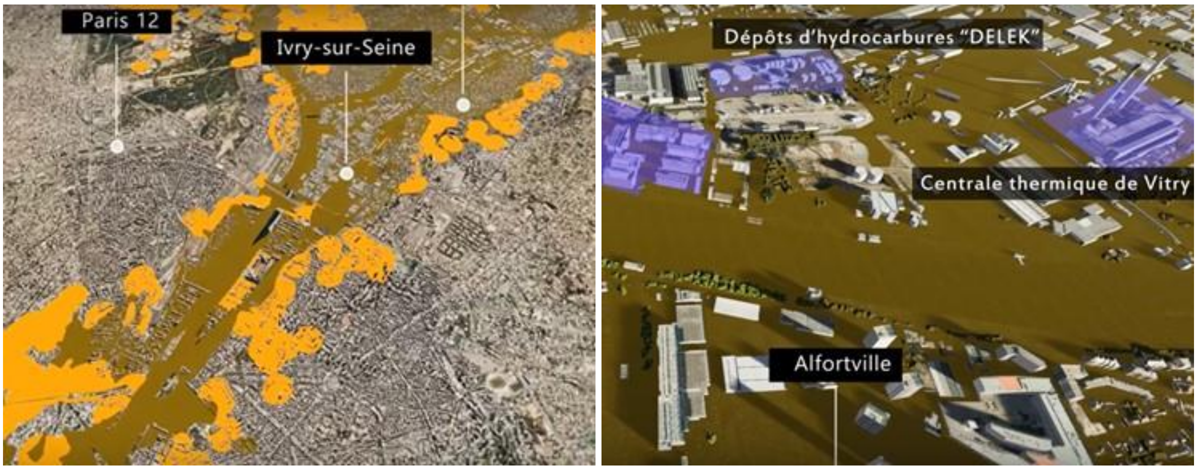

Figure 23: Impact of a hundred-year flood on the electricity network of the Paris Region and on certain more specific critical buildings.

This type of functionality must allow to correlate the geographical effects of the simulated crisis with a mapping of all infrastructures, the objective being to establish a priority list. Figure 24 shows this approach aimed at screening infrastructures according to criteria established elsewhere.

Figure 24: Screening of infrastructures according to their criticality for the community and their exposure to the crisis effect

Finally, this type of model can help to better understand the local and general effects of the crisis on people themselves, on human communities, on infrastructures and in terms of operational constraints for the rescue teams. Figure 25 illustrates a particular application where the height of the water in a neighbourhood makes it possible to better identify the impacted floors (and therefore define fallback zones for the victims) and, combined with charts quantifying the difficulties encountered by individuals moving on foot or having to manoeuvre a boat in a flooded area characterized by a certain level of flows, can help the authorities to dispatch rescue and equipment in an adequate manner. All these illustrations are coming from several websites[8,9].

Figure 25: Visualization of the situation at ground level.

- **Major Flood Prevention in UK:** in 2014, the UK faced a series of winter storms which caused major floodings in parts of the country. With the objective to better prepare authorities and all stakeholders to future potential flooding and improve rescue planification, the UK's Environment Agency has deployed Earth Observation aerial means to map high-risk hotspots.

  The planes were equipped with high-resolution cameras and LiDAR sensors to fly over high-risk regions, including coastal areas and around river subject to potential overflowing. The data collected was used to create accurate topographic maps and elevation models which were used to identify areas most vulnerable to potential flooding.

  This early aerial mapping allowed authorities to plan rescue team interventions and target high-risk areas. Additionally, aerial data helped identify critical infrastructure, such as hospitals, schools, and evacuation centres, that could be affected by flooding. This type of map is also used to raise public awareness of areas at risk, making people aware of the risks incurred and, through the preventive actions that this may have generated, involving them in the crisis management process.

  Thanks to this early deployment of aircraft for aerial mapping, the United Kingdom was able to develop topographic maps of regions at risk, identify the most sensitive areas and improve its flood preparedness and strengthen disaster relief planning to deal more effectively with future extreme weather events. This

8 https://www.ouest-france.fr/meteo/inondation/video-3d-et-drone-la-seine-en-crue-comme-vous-ne-l-avez-jamais-vue-5527796

9 https://rennes.maville.com/actu/actudet_-video-3d-et-drone.-la-seine-en-crue-comme-vous-ne-l-avez-jamais-vue_54135-3369193_actu.Htm

example demonstrates how airborne assets can be used proactively to improve the resilience of communities to potential crises. Additional information is provided in several websites [10,11].

Prevention related to Major Fires in California: crisis situations other than major floods can also be supported by modelling through the acquisition of airborne data and the resulting numerical modelling. For example, the present case covers a global and increasingly recurrent problem characterized by the development of forest fires reaching the size of a region (few square kilometres).

California regularly faces destructive wildfires, especially during periods of drought and wildfire-friendly weather. To anticipate crisis management and strengthen forest fire prevention, Californian authorities regularly use airborne means to map high-risk areas.

Planes equipped with RGB and IR cameras and LiDAR fly over sensitive forest areas, including areas where the risk of fire is high due to dense vegetation and the presence of inhabited infrastructure. These flights make it possible to detect areas with an increased risk of fire and to identify areas requiring preventive management, such as the reduction of dry vegetation (Pruning, controlled burning) and the creation of firebreaks.

This type of activity essentially results in maps giving different types of information that can influence the occurrence or spread of fires. Figure 26 represents, for example, topographic or local vegetation maps, two parameters necessary to understand the risks associated with forest fires.

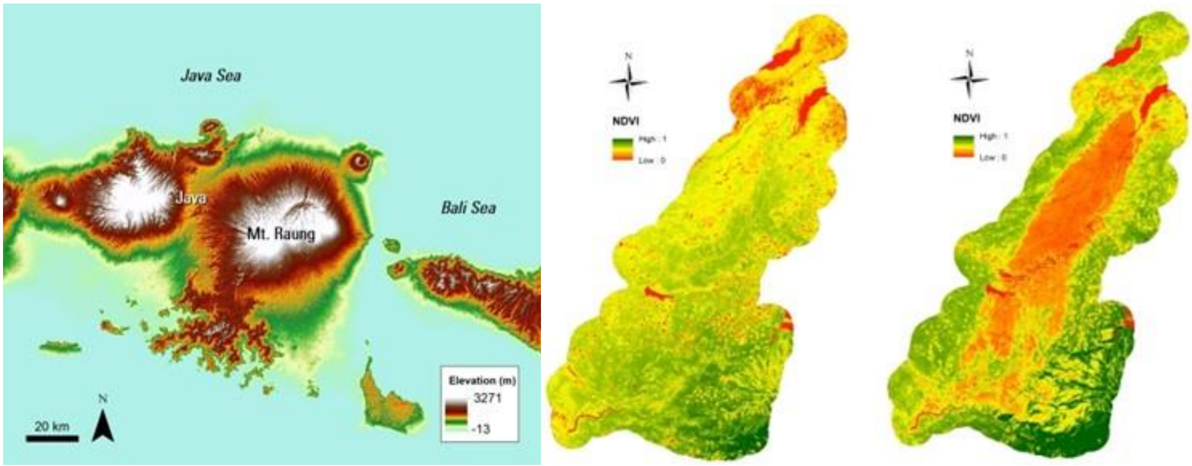

Figure 26: Topographic and vegetation condition maps used in forest fire prevention.

Other information, just as already critical but more complex to use, can be collected using airborne means and mapped onto maps. Figure 27 illustrates, for example, the mapping of soil moisture content and surface temperature. This information exploited and correlated in numerical models often using artificial intelligence, and possibly combined with forecast or instantaneous weather models, can establish a level of risk according to the geographical position.

[10] https://environmentagency.blog.gov.uk/2014/08/04/high-flyers-tales-from-the-aerial-survey-team/
[11] https://www.gov.uk/government/news/environment-agency-uncovers-landscape-with-laser-mapping.

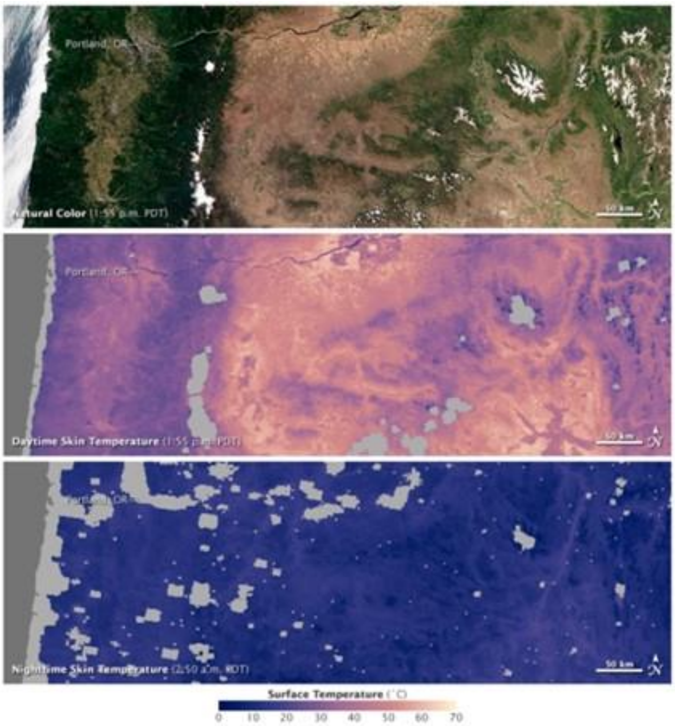

Figure 27: Ground temperature maps (Recorded via satellite or airborne systems).

The information given above comes from the NASA site[12] describing all the tools developed in the framework for fighting forest fires.

3.2.1.2 Ground-based sensing and communication technologies (IoT) and prediction models

Smart cities are heavily reliant on modern monitoring systems and technologies, and Internet of Things (IoT) is a prominent one among them. Based on a multitude of sensors (and occasionally, actuators), IoT is capable of wirelessly or wired transmitting data from the observational area/point to the monitoring and control centre. Some of the applications of IoT in smart cities include:

- Environmental and microclimate monitoring (including air pollution)
- Public transportation and traffic management
- Infrastructure monitoring
- Water management
- Buildings
- Waste management
- Healthcare
- Parking

[12] https://www.earthdata.nasa.gov/learn/pathfinders/wildfires-data-pathfinder/find-data#pre-fire

- Lighting
- Disaster management

Accordingly, relative sensors may include:

- Weather parameters sensors (temperature, air humidity, etc.)
- Motion detection sensors (radars, lidars, etc.)
- Optical sensors (cameras)
- Proximity sensors
- Smoke, dust and other chemical (e.g. particulate matter, $PM_{2.5}$) sensors
- Gas sensors
- IR (infrared) sensors
- Accelerometers
- Tank level probes

IoT communications include both wired and wireless technologies, accompanied with corresponding standards and protocols. These technologies (i.e. physical/data link layer protocols) define the type of network used and its basic specifications, and can be summarized as [6]:

Wired:

- **Ethernet (IEEE 802.3):** One of the most common Local Area Network (LAN) technologies. It is a low-cost technology, using a twisted pair of cables for the implementation of the physical connection between devices. Its range is usually up to 100m and the data rate can reach 400Gbps. Most common usages include smart home and smart office applications.
- **HomePlug PG:** Power line communication technology, using the existing electrical wiring building infrastructure to connect devices. It also uses Ethernet cables. Range is up to 300m and operating frequencies span from 24-500kHz. The data rate can be between 4-200Mbps. Common applications include smart homes and offices, smart grid applications and electric vehicles.
- **HomePNA:** Applied in home networks by reusing telephone and coaxial cables. The range can be up to 300m and the operating frequencies between 12-44MHz. The data rate can reach 320Mbps, while usual applications include smart homes and offices.
- **HomeGrid/G.hn:** A technology that uses the existing power line infrastructure, coaxial cables, telephone lines and plastic optical fibers. Operating frequencies vary depending on the physical medium used and are 100MHz for power lines and 200MHz for phone lines and coaxial cables. Range can reach up to 100m, while data rates can be up to 1Gbps for power lines and 1.7Gbps for phone lines and coaxial cables.
- **MoCA:** Multimedia over Coax Alliance, uses coaxial cables and can offer high reliability, security and data rate. The range is up to 90m and the operating frequencies span from 500-1650MHz. The data rate is up to 10Gbps, and the applications include smart homes, buildings, hospitals, hotels and schools.

Wireless:

- **NB-IoT:** (Narrowband IoT), a Low Power Wide Area Network (LPWAN) technology, specifically designed for IoT applications. Optimized for exchanging small amounts of data over a large number of devices in a secure and reliable manner. Frequency bands usually span from 700-2200MHz, and the range can reach up to 10km in rural areas and 1km for urban ones. Data rate can be up to ~20Kbps for the uplink connection and ~200Kbps for the downlink. Scalability (i.e. number of devices used) can reach up to many thousands. Applications include smart cities, industrial IoT, smart buildings, smart agriculture and others, where generally long range, low power and not very high data rates are required.

- **LoRaWAN:** An LPWAN technology, using frequency bands from 868-928MHz in most areas around the world. Range can be up to 20km for rural areas and 2-5km for urban ones. Data rates can vary, spanning from 50-300Kbps. Similarly, to NB-IoT, applications span from smart cities to smart agriculture and industrial IoT.
- **Bluetooth:** (BLE, Bluetooth Low Energy), a short range wireless technology, mostly employed in Personal Area Networks (PANs). Designed to transmit small amounts of data with low energy consuming. The operating frequency band is at 2.4GHz and the range is typically at around 70m (spanning from 50-150m). Data rates are usually around 1Mbps. Most popular applications are smart homes, smart wearables, smart health and retail industry.
- **ZigBee:** (IEEE802.15.4), a medium range technology for low power and cost-efficient wireless networks with low power consumption, usually employed in smart home applications. Frequency bands are 868MHz for the EU and 2.4GHz for the rest of the world. Range varies from 10-100m, while data rates can be up to 20Kbps for the 868MHz band and 250Kbps for the 2.4GHz band. Popular uses are applications that demand medium range with close by deployed nodes, such as home automation.
- **Z-Wave:** Technology developed for low power home automation applications. Operating frequency is at 868MHz, while the range is up to 100m. Data rates can be as high as 100Kbps. Applications are like ZigBee.
- **WiFi:** (Wireless Fidelity), a widely used technology (IEEE802.11) that interconnects objects ad-hoc or directly to the internet. The most recent version (WiFi 6 or 802.11ax), operates both at 2.4GHz and 5GHz with a low power consumption, while maximum range is at 100m. Data rate can be as high as ~9.6Gbps. Usual applications include smart home and smart retail.
- **SigFox:** Another LPWAN technology developed for low power and low data rate transmission. Operating frequencies are at 868MHz for Europe and at 902-928MHz for the rest of the world. Data rates are extremely low, at 100bps, whereas range can be up to 30-50km for rural areas, and up to 10km for urban ones. Applications are similar to the NB-IoT case.
- **NB-Fi:** (Narrowband fidelity), an LPWAN technology developed for bidirectional communication between machines. It employs the unique characteristic of using artificial intelligence, to improve system performance and suppress interference. Operating frequency bands are at 868MHz and 915MHz. Data rates are also low, at 100bps and range can reach 50km for rural areas and 16km for urban ones. Applications are similar to the NB-IoT and SigFox cases.
- **Cellular (3G/4G/5G):** Wireless cellular technologies utilize various frequency bands (900MHz, 1.8GHz, sub-6GHz 5G, 25-29GHz) and include different data rates (up to 36Gbps for 5G). Ranges can vary also, from a few kilometres to a few hundred meters (in 5G micro-cells).
- **LiFi:** (Light Fidelity), a technology using visible light communications. Operating frequencies span from near infrared (~430THz) to near ultraviolet (~770THz). Range is relatively small and usually smaller than 10m, depending on the light intensity. Data rates span from 100Gbps to 1Tbps. Applications include smart cities, healthcare and underwater operations.
- **RFID:** (Radio Frequency Identification), a technology developed to store and remotely retrieve small volumes of data, by using RFID tags and an RFID reader. Operating frequency bands include 13.56MHz and 860-956MHz, while active tags typically use the 433MHz, the 2.45GHz and 5.6GHz

bands. Depending on the operating frequency, ranges vary from 1m to 100m. Similarly, data rates can be as low as a few hundreds of Kbps (e.g. 100-500), to as high as a few Gbps (e.g. ~1.5). Applications are usually limited to retail, and asset and inventory tracking.

- **DASH7:** An extension of RFID with a LoRaWAN architecture. It operates in the 433MHz, 868MHz and 915MHz frequency bands. Data rates are 9.6Kbps, 55.6Kbps and 166.7Kbps. Range is inversely proportional to the data rates, spanning from 0-5km. It is also used in smart city, smart building, smart agriculture and industrial IoT applications.

The above technologies utilize a variety of application layer protocols, which set the standards for the processes of identification and interaction between the network entities (devices, nodes, etc.). The application layer protocols include[13]:

- **MQTT:** (Message Queueing Telemetry Transport), a lightweight protocol specifically developed for IoT and M2M (Machine-to-Machine) applications with limited bandwidth. It employs a publish/subscribe architecture, where entities can either publish (i.e. transmit) or subscribe (i.e. receive).
- **HTTP:** (HyperText Transfer Protocol), the most widely used internet protocol, which makes easier the interconnection of the IoT devices to the web. It is well supported by the standard IoT cloud services, such as Amazon's AWS IoT and Microsoft's Azure IoT.
- **WebSocket:** A bidirectional protocol developed to quickly transmit large amount of data in web applications. It creates an initial connection between the client and the server, making the subsequent messages having small overhead. It is best suited for IoT applications with low latency and frequent communication requirements, since it enables devices (clients) and servers to simultaneously transmit and receive data in real-time.
- **AMQP:** (Advanced Message Queuing Protocol), an open source protocol, not specifically designed for IoT applications. It supports more routing options than MQTT, but also comes with increased complexity.
- **CoAP:** (Constrained Application Protocol), developed for low power and lossy networks. It is usually combined with UDP (User Datagram Protocol), increasing its efficiency and making it extremely suitable for IoT applications with strict battery conservation requirements.
- **XMPP:** (Extensible Messaging and Presence Protocol), an open protocol built on XML (Extensible Markup Language), designed for instant messaging applications. It offers good handling of structured data, and due to its open source nature, it provides high accessibility.
- **DDS:** (Data Distribution Service), a real-time and interoperable protocol developed for reliable transmission and distributed processing application requirements. Data are being exchanged directly between peers, instead of being transmitted to a central hub. It uses a publish/subscribe mechanism.
- **SMS/SMPP:** (Short Message Peer-to-Peer Protocol), a protocol allowing devices to transmit and receive text messages by using cellular infrastructure connections.
- **USSD:** (Unstructured Supplementary Service Data), a messaging protocol used in GSM-based cellular networks. It is used to retrieve text data (e.g. location, temperature, etc.) without the need for a data connection. It is becoming obsolete, due to its dependence on the older 2G/3G systems.

[13] https://www.emnify.com/iot-glossary/guide-iot-protocols

Of key importance are also the network and transport layers protocols, such as[14]:

- **IP:** (Internet Protocol), the basic network protocol, offering the access to the Internet. It provides an IP address to the network entities, allowing thus other network entities to send them data packets, even if they do not belong to the same network.
- **TCP:** (Transmission Control Protocol), a transport protocol that defines the rules and parameters for data exchange between software applications. It prioritizes accuracy rather than speed and can send resent request in the case of lost data.
- **UDP:** (User Datagram Protocol), a transport protocol that prioritized speed over reliability by utilizing a connectionless procedure for data transmission. It offers low latency, making it suitable for time-sensitive IoT applications and cases, such as video streaming, Voice over Internet Protocol, and others.

Regardless of the specific technologies and protocols used, IoT-based monitoring, in cooperation with big data analytics and/or high performance computing techniques, can offer major advantages in the prediction of natural and man-made disasters, and thus, critically support disaster management, prevention, preparedness and mitigation actions. A detailed review on the use of IoT for disaster management can be found in [7].

Several natural disasters, especially those stemming from local or wide area weather and climatic conditions (such as floods, wildfires or even landslides), can be predicted and prevented by using IoT-based environmental/weather conditions monitoring, which can also be enhanced by other means of observation, such as aerial and space-based. The monitoring data are utilised for producing timely and precise local weather forecasts, which will critically support the local authorities and decision makers in taking preventive measures and actions against the possible catastrophic results of a smart city affecting disaster.

The smart city weather forecasting can constitute a part of a disaster early warning system, which is an architecture designed for hazard monitoring, forecasting, risk assessment, preparedness, and other disaster management related activities [8]. A comprehensive review of such systems can also be found in [8].

Current developments on weather forecasting are trying to exploit the benefits of advanced processing capabilities of (AI), especially for the implementation of accurate forecasting models. Further developments could include the assimilation of the data coming from the different sources (in-situ, aerial and space-based), along with the full utilization of Machine Learning (ML) algorithms and techniques for optimising prediction accuracy and minimizing the prediction timeframe.

In general, the locally deployed, IoT weather stations can provide valuable information on the site-specific weather conditions, increasing drastically the accuracy of the global or wide area weather forecasting models. This is achieved by feeding the global forecasting models with the IoT-based data, supporting thus the space- and radar-based forecasts. Furthermore, global weather forecasting models can be downscaled to local scale and use the IoT data as a single source of input.

A review of IoT-based weather monitoring and forecasting methods can be found in [9]. Moreover, focusing on smart city flood management, [10] provides a thorough review on existing literature, trends and applications.

[14] https://www.emnify.com/iot-glossary/guide-iot-protocols

On the other hand, IoT-based road traffic monitoring, prediction and signal control can be significant, especially in cases of evacuations and/or emergency departures from disaster affected areas. A variety of methods and models have been developed, including AI techniques, and can be found in [11].

Regarding earthquakes, there have been a few applications, where IoT sensor data are combined with AI/ML techniques for the more effective prediction of an upcoming event [12].

Lastly, with respect to terrorist attacks, which constitute a major man-made inflicted disaster, an IoT-based prediction architecture/model is presented in the literature [7].

In the framework of the PANTHEON project, IoT technologies will be used for the monitoring of the local city microclimate and/or infrastructure conditions, offering thus valuable information to the process of disaster management. In general, applications may include:

- Local weather/microclimate monitoring and prediction of extreme weather events (heavy rainfalls, floods, etc.)
- Fires
- Infrastructure predictive maintenance and fault monitoring/detection, etc.
- Power/electricity/gas network monitoring and predictive maintenance

Specifically, PANTHEON will utilise IoT-based weather (or micro-climate) stations, equipped with a set of sensors suitable to measure a variety of environmental parameters, such as:

- Air temperature and relative humidity
- Solar radiation
- Wind vector
- Precipitation

These stations are proprietary developed, low-cost and fully customizable with respect to the needed sensors. They exploit modern wireless technologies, such as NB-IoT or 4G/5G mobile networks, to transmit the gathered data to a cloud platform for further management, analysis and processing. The data, when analysed and processed, will be inputted to the simulation module of the Digital Twin, to provide a virtual double of the environmental conditions in the area of interest, which will assist in the process of predicting possible disasters and make decisions to prevent and mitigate their impacts.

3.2.1.3 Digital Twin based Smart City models

In an era marked by rapid urbanization and increasing demands for sustainable development, the emergence of smart city initiatives has gained significant momentum. At the forefront of this urban transformation lies the integration of digital twin technologies, which hold the potential to revolutionize urban planning, resource management, and citizen engagement. The concept of smart city digital twin technologies has impact on shaping the cities of tomorrow.

Urban Simulation Smart city digital twin technologies create virtual replicas of physical cities, combining real-time data and advanced modelling techniques to offer a holistic and dynamic representation of urban environments. By mimicking the behaviour of cities, these digital twins allow decision-makers to gain invaluable insights, test scenarios, and devise data-driven strategies to enhance urban efficiency and sustainability.

Enhanced Urban Planning and Design Digital twins enable urban planners and designers to simulate and visualize the impact of various interventions before implementation. By integrating data from multiple sources, such as IoT sensors, satellite imagery, and social media feeds, digital twins can provide a comprehensive understanding of urban systems. Planners can assess the effects of proposed infrastructure projects, optimize land use, and identify potential bottlenecks, thereby facilitating informed decision-making and reducing costly and time-consuming trial and error processes.

By analysing real-time data on energy consumption, waste management, water usage, and transportation patterns, cities can identify areas for improvement and implement targeted interventions. For instance, real-time simulations can help optimize traffic flow, reduce energy consumption in buildings, or predict waste generation patterns, leading to better resource allocation and reduced environmental impact.

By visualizing data and making it accessible to the public, citizens can actively participate in the decision-making process and provide valuable feedback. Digital twins can empower communities by enabling them to explore alternative scenarios, propose changes, and witness the potential impact of their suggestions. This participatory approach fosters a sense of ownership and collective responsibility, ultimately leading to more inclusive and citizen-centric urban development.

Ensuring data privacy, security, and interoperability remains crucial. Cities must establish robust governance frameworks, data sharing protocols, and cybersecurity measures to protect sensitive information. Additionally, addressing the digital divide and ensuring equitable access to technology becomes paramount to prevent exclusion and promote equal opportunities for all citizens.

Smart city digital twin technologies hold immense potential in transforming urban landscapes by optimizing planning, resource management, and citizen engagement. By leveraging real-time data and advanced modelling techniques, cities can unlock unprecedented levels of efficiency, sustainability, and liveability. However, careful consideration of challenges such as data privacy and equity is vital to ensure that the benefits of these technologies are accessible to all. As cities embrace the opportunities presented by smart city digital twin technologies, they move closer to realizing their visions of a smarter, more connected, and sustainable future.

3.2.2 APPLICATIONS OF AERIAL & IN-SITU OBSERVATION AND MODELLING TECHNOLOGIES IN SMART CITIES

Urban Planning and Design: Aerial and in-situ observation technologies provide high-resolution data on the existing urban environment, including land use patterns, infrastructure networks, and population distribution. The capabilities of various sensors reach far beyond the obvious benefits available at platforms like Google Earth. They provide reflective responses all along the electromagnetic spectrum which enables detection of objects or patterns of the earth's surface and their condition. The sensors cover many spatio-temporal dimensions, with a flexible repetition rate and in various scales ranging from spatially detailed analysis on single buildings or building block level to global studies on continental scale. This data can be utilized to create accurate 3D models and simulations, assisting urban planners and designers in visualizing potential scenarios, optimizing urban layouts, and assessing the impact of proposed interventions. Remote sensing has the capabilities of transforming and improving many parts of urban governance. The outlined design for remote sensing information hubs, a better mainstreaming into policy frameworks and procedures and into initiatives in the (economically) least developed world would ensure a better, more ecologically founded urban. Monitoring urban growth and its environmental impacts is a widespread objective in the reviewed literature corpus, showing the real potential of remote sensing in monitoring and steering one of the largest socio-economic and environmental changes in human history. Due to regular image acquisitions, remote sensing is especially valuable to track temporal changes, thus potentially creating a neutral information source for assessing and balancing policies planning [13].

- **Infrastructure Management**: Aerial observation technologies such as drones and satellite imagery are effective in monitoring and inspecting critical infrastructure, including bridges, roads, and utility networks. Based on the data from the aerial survey (point data and aerial photos), with the help of structure condition plans and information about the bridge object from the client, 3D models for the structure visualization are created. The visualizations comprise a) the creation of a photorealistic model from the aerial survey data and b) the creation of a 3D approximation model of the bridge as a BIM model. By capturing real-time data, these technologies enable early detection of maintenance needs, asset deterioration, or potential risks, facilitating proactive maintenance and ensuring the efficient operation of urban infrastructure. Because of the exposure to natural and/or human hazards and diverse loading conditions, transport infrastructures are subjected to physical damages up to levels that may determine disruption of networks if effective maintenance is not performed. To minimise the impacts of deterioration processes and loss of performance, stakeholders expect nowadays that risk and resilience assessment is performed almost in real-time with an accuracy level sufficiently high to estimate potential losses and to define suitable actions to maximise resilience. Computer vision techniques, in conjunction with acquisition through remote cameras and UAVs, offer promising non-contact solutions to civil infrastructure condition assessment. The goal of such a system is to convert the image or video data automatically and robustly into actionable information. Unsupervised learning techniques further reduce the need for labelled data by identifying the underlying probabilistic structure in the observed data. For exemplification, Chloride as a cause of damage on concrete structures can be determined on the surface by means of remote sensing methods. First experiments with Graz University of Technology show a spectral imaging of chloride in the range of approx. 1450 nm – like the spectral range of the moisture content. An imaging and measurement by mean of multispectral sensors is thus possible [14,15].
- **Environmental Monitoring**: Aerial and in-situ observation technologies are invaluable in monitoring and managing environmental parameters within smart cities. They can measure air quality, noise levels, temperature, humidity, and other environmental factors, providing real-time data for assessing the impact of pollution, optimizing energy consumption, and implementing sustainable urban practices. One of the significant advantages of remote sensing is the possibility of accessing an extensive open database that contains information from decades ago. UAVs have appeared as a relevant subtopic in remote sensing and environmental monitoring papers in the last three years. The inclusion of multispectral or hyperspectral cameras in the drones will allow better environmental monitoring. Like the inclusion of multispectral cameras, the inclusion of other capabilities such as light detection and ranging (LiDAR) or radar sensing systems might be included in UAVs in the next few years. The advances in autonomous vehicles will soon impact the autonomous flying of UAVs. Including this artificial intelligence will enhance the monitoring capabilities of these devices [16].
- **Disaster Management:** Aerial observation technologies, coupled with in-situ sensors and modelling, play a critical role in disaster management and emergency response. They enable rapid assessment of disaster-affected areas, identification of potential hazards, and monitoring of evacuation routes. Real-time data collected from these technologies' aids in coordinating emergency services, allocating resources, and minimizing the impact of disasters on urban areas. The aerial photograph will help the stakeholder as decision maker to know the first response step that they will take. In the case of natural occurring events, lake landslides, the evacuation process can be started in less than 30 minutes after the landslide occurrence, yet the whole basic imagery of the area can be available as soon as 2 hours and 45 minutes after the landslide occurrence. The aerial photograph is effective enough for landslide first response to make the time become efficient and to reduce the other

possibility of further landslides induce by evacuation process. Studies revealed that both experts and non-experts are equally successful in solving the task of crisis management using images or derived topographic products, like maps [17,18].

- **Transportation and Mobility**: Aerial and in-situ observation technologies provide valuable insights into traffic patterns, pedestrian flows, and transportation infrastructure. This data can be used to optimize traffic management, improve public transportation routes, and enhance pedestrian safety. Modelling techniques based on this data facilitate the development of intelligent transportation systems, dynamic traffic management, and efficient urban mobility solutions. Activity Based Transport Demand models have tried to reconstruct people behaviour and choices as a function of the opportunities and services available but due, mostly, to lack of data and calculus complexity they have never evolved toward a more holistic approach. To understand the phenomenon, instead, an overall assessment should be conducted, which analyses how, simultaneously, the different factors can affect modal choice. Additionally, mobile mapping and effective geospatial data processing algorithms are needed in order to acquire an accurate description of the considered area and to extract the required information e.g. to automatically determine both the characteristics and conditions of the infrastructures for all users; to be able to measure cyclability, walkability and safety of each path; and to define the buildings characteristics to correlate them with the commercial activities and the residential characteristics of the census data. To accomplish such a task, interdisciplinary competences are required. Therefore, on the one hand, multidisciplinary studies, and research to acquire higher volumes of information are required in order to define and assess innovative transport models. On the other hand, to efficiently handle huge amount of data (i.e., Big Data) innovative techniques to store and analyse information are needed. The Internet of Things (IoT)/Internet of Everything (IoE) paradigm [19] is exploited to ingest, store, process, and manipulate Big Data. In the context of urban mobility for Smart Cities, a huge amount of information is collected, including static data, such as the road graph, 3D infrastructure representations, transport offers of public and sharing services, census data, and dynamic data, as for example information about traffic, weather conditions, presence counting etc. Such information can be directly produced by people or “things”, as for example IoT sensors, Open Data, readings from personal devices, social media, etc., or obtained indirectly from 3D mapping activities, or social, geographical, and urbanistic studies. Mobility in urban spaces is continuously transforming and adapting to daily challenges, as can be seen with the global shift towards smart city planning. This shift towards encouraging citizens to utilise multi-mobility modes in their daily commute has led to a reduction in road congestion. However, despite the benefits, there is still a huge dependence on private vehicles. The aim is not to prohibit the use of private vehicles but to create an efficient public transportation system which would lead to citizens not using private vehicle. Leveraging data from citizens to guide were and how to develop has been gaining attention over the past recent years as researchers and practitioners are now able to mine data from social media platforms. IoT has assisted transportation planners to track mobility patterns in the city in real-time, predict future transportation congestion trends, monitor traffic flow within the city [20]. Therefore, as the internet is now entangled in to the citizen’s lives as citizens carry their smart phones everywhere, this presents new possibilities for city planning, as mobility information can be collected at real-time and future trends can be predicted [21,22].
- **Energy Efficiency**: Urban areas, which gather more than half of the world’s population [23], have a steadily increasing share in global energy consumption, and all indications are that this trend will not change. At the same time, cities are centres of innovation, engines of development and economic growth, and provide the necessary services to their residents. Energy consumption in urban areas results directly from their function, the way buildings are used, and the increasing time we spend in them. Aerial and in-situ observation technologies support the monitoring and optimization of energy usage within smart cities. They enable the collection of data on energy consumption patterns in buildings, street lighting, and other urban systems, facilitating energy efficiency initiatives and the

implementation of demand-response strategies. Modelling techniques based on this data assist in identifying energy-saving opportunities and optimizing the integration of renewable energy sources into the urban energy grid. Improving in the energy efficiency of urban buildings and maximizing the savings and the resulting benefits require information support from city decision-makers, planners, and designers. The selection of the appropriate analytical methods will allow them to make optimal design and location decisions. Therefore, the development of an innovative decision support system using multi-criteria analysis and Geographic Information Systems (decision support system + Geographic Information Systems = DGIS) for planning urban development was logical development. On the other hand. In the race towards carbon neutrality, the building sector has fallen behind and bears the potential to endanger the progress made across other industries. With several billion operational buildings around the globe, working towards a carbon-neutral building sector requires solutions which enable stakeholders to accurately identify and retrofit subpar buildings at scale. To accelerate the identification of promising retrofit targets, new methods are being experimented which can estimate a building’s energy efficiency using purely remotely sensed data such as street view and aerial imagery, OSM-derived footprint areas, and satellite-borne land surface temperature (LST) measurements. End-to-end deep learning architecture is used for predicting building energy efficiency from LST data, street view, and aerial imagery [24,25].

In conclusion, aerial and in-situ observation and modelling technologies offer a wide range of applications in smart cities. From urban planning and infrastructure management to environmental monitoring and citizen engagement, these technologies provide valuable data and insights to enable more efficient, sustainable, and liveable urban environments. By leveraging the power of these advanced techniques, cities can optimize resource allocation, improve services, and create a more inclusive and participatory urban ecosystem.

3.3 CLIMATE MODELLING AND FORECASTING

Climate modelling and forecasting technologies are an integral part of the DRM operations for the PANTHEON project. In this section, the types of climate and weather prediction models and their potential applications in smart cities are briefly introduced.

3.3.1 TYPES OF CLIMATE MODELLING AND FORECASTING MODELS

Climate modelling and forecasting involves the use of mathematical and computational models to simulate the Earth's climate system and understand its behaviour under different conditions. There are various methods and approaches used in climate modelling and weather predictions, which are broadly categorized below.

3.3.1.1 Energy Balance Models (EBMs)

These models simplify Earth's climate system by considering the balance between incoming solar radiation and outgoing thermal radiation. EBMs are useful for understanding global temperature changes due to changes in radiative forcing. Zero-dimensional EBMs, introduced by researchers like Budyko [26] and Sellers [27], provide globally averaged values without explicit spatial dimensions [28]. Their fundamental equation captures changes in heat storage, equating absorbed solar radiation with emitted terrestrial radiation. The equation involves factors such as effective heat capacity, surface temperature, planetary albedo, and Total Solar Irradiance (TSI) [28].

The simplicity of EBMs lies in their ability to encapsulate essential climate processes within a compact framework. The models often consider albedo (reflectivity) changes due to ice and snow cover, as well as emissivity (radiative properties) variations with temperature. While some models linearize equations for convenience, others incorporate additional dimensions such as latitude to study spatial variations. For instance, a one-dimensional EBM can include latitude bands to analyse temperature changes across different regions [28].

Box models share similarities with EBMs, representing different areas or components as averages within distinct compartments. These models capture interactions between compartments through parameterizations based on the characteristics of each box. Compartmental exchanges simulate transfers between atmospheric layers, land/ocean surfaces, deep oceans, and even carbon cycle components [28]. This approach enhances the ability to study specific processes and feedbacks within the climate system. References from the literature emphasize the contributions of various researchers to the field of energy balance modelling. Renowned researchers such as Budyko, Sellers, Berger, Ghil, Milankovitch have contributed to understanding the atmospheric dynamics, climatic responses, and insolation effects [29, 30].

3.3.1.2 Box Models

Box models simplify complex systems into compartments or "boxes" to gain insights into specific environmental processes. They are often used to study chemical reactions and the movement of substances within the atmosphere or oceans [31]. These models, also known as zero-dimensional (0D) models (ZDMs), focus on specific components of the Earth's climate and provide insights into their behaviour and interactions. In recent years, the field of climate modelling has witnessed substantial progress, including the integration of Box Models within more comprehensive frameworks, harnessing the power of modern computational resources.

In contemporary climate modelling, Box Models are often employed as components within larger Earth System Models (ESMs) that encompass a broader range of environmental factors. Within this context, Box Models contribute by representing specific processes in detail while collaborating with other components to create a more holistic representation of the Earth's climate.

A notable example of the integration of Box Models can be seen in the use of ML techniques in weather and climate modelling, as highlighted in a recent study on ML's applications in numerical weather and climate modelling [32]. ML offers new avenues for enhancing the accuracy and efficiency of climate models. ML algorithms can be utilized for tasks such as solving equations, emulating parametrization schemes, and even predicting climate patterns. The evolution of ML in climate modelling underscores the field's adaptability and its incorporation of contemporary computational advancements.

3.3.1.3 Radiative-Convective Models (RCMs)

These models build upon the basic energy balance concept by including vertical layers of the atmosphere and account for radiative processes as well as convective heat transfer within the atmosphere. Their aim is to capture the balance between radiative cooling and convective heat release within the Earth’s atmosphere. An important aspect of RCMs is their focus on the radiative-convective equilibrium, where the radiative cooling at the top of the atmosphere is balanced by the latent heat release from convective processes.

Recent research has advanced the field of RCMs, delving into various aspects of atmospheric dynamics and energy transport. For instance, studies have explored the application of RCMs in understanding convective equilibrium across different scales. The concept of Radiative-Convective-Dynamical Equilibrium (RCDE) has been introduced, integrating fixed vertical motion into the equilibrium study [33]. This approach enhances the understanding of atmospheric dynamics and reveals insights into vertical velocity, temperature, humidity, and circulation patterns.

Another study comparing CMIP6 historical climate simulations and future projected warming to an empirical model of global climate highlighted the significance of feedback mechanisms, heat content, and radiative forcing in determining temperature trends and climate sensitivity. Additionally, this study underlined the importance of understanding greenhouse gas concentrations and solar irradiance as inputs for these models [34].

Moreover, RCMs have been employed to study the influence of clouds on climate and energy budgets. Clouds play a significant role in modulating the Earth's radiative balance and affect temperature and precipitation patterns. Recent developments include the incorporation of self-consistent patchy clouds in RCMs, enabling a more accurate representation of cloud-climate interactions on terrestrial planets, including exoplanets [35]. This advancement showcases the versatility of RCMs in studying a wide range of planetary conditions and their impact on energy distribution. References from the literature highlight the breadth of recent research in the field of RCMs. These references encompass studies on statistical water vapor absorption models, entropy production in climate modelling, atmospheric cooling rates, and the impact of clouds on climate dynamics [33, 35, 36]. The application of RCMs spans from Earth's atmospheric dynamics to exoplanet climate modelling, showcasing the relevance of these models in understanding a wide range of climatic phenomena.

3.3.1.4 Earth System Models of Intermediate Complexity (EMICs)

These models bridge the gap between simple climate models and complex Atmosphere-Ocean General Circulation Models (AOGCMs). EMICs offer a valuable tool for understanding climate dynamics, exploring long-term climate changes, and projecting future scenarios. These models incorporate various components and processes, simulating interactions between the atmosphere, ocean, land, biosphere, and ice, allowing scientists to examine climate behaviour over millennial timescales. EMICs are defined by their intermediate level of detail, making them more complex than simple climate models while being less computationally intensive than AOGCMs. This intermediate complexity allows EMICs to capture important feedbacks and processes, such as ice sheets, vegetation dynamics, and carbon cycles. They are comparable to AOGCMs geographically and are detailed in various research works. For instance, in the IPCC's Fourth Assessment Report, different EMICs are listed, including BERN2.5CC and C-GOLDSTEIN, which represent diverse Earth system components and interactions [37].

One of the significant advantages of EMICs is their ability to simulate various interactions within the climate system, such as the North Atlantic Meridional Overturning Circulation (MOC). EMICs have been evaluated by comparing their outputs to observational data, AOGCMs, and historical records, confirming their credibility in reproducing temperature, precipitation patterns, and other climate variables. Notably, EMICs' response to doubled CO_2 concentrations closely matches that of AOGCMs, further validating their performance [38]. EMICs have been employed to study a range of climate phenomena, including historical land cover changes. For example, deforestation's impact on global temperature has been explored using EMICs. Studies have shown that deforestation led to a decrease in global temperature due to increased albedo, with this cooling partially offsetting CO_2-driven warming in the 19th century [38].

While EMICs offer valuable insights, they do come with limitations. Their intermediate complexity might not fully capture small-scale processes, and uncertainties exist in their projections. To enhance their utility and accuracy, EMICs have been coupled with other models, such as JUMP-LCM, which combines elements of simple and complex models. Additionally, emulators provide a rapid estimation of climate complexity [38].

3.3.1.5 Global Circulation Models (GCMs)

GCMs are numerical models that simulate the interactions of the atmosphere, oceans, land surface, and ice cover and use 3D grids to calculate factors such as wind, heat, radiation, humidity, and hydrology. They are utilized to explore climate phenomena, study long-term climate trends, and assess the potential effects of human activities on the environment by considering factors such as solar radiation, greenhouse gas concentrations, ocean currents, and thus providing insights into complex climate dynamics.

GCMs exhibit challenges and limitations. An important challenge of GCMs is their spatial and temporal resolution [39]. Due to computational limitations, GCMs tend to use relatively coarse grids, which limits their ability to capture fine-scale regional climate variations, which are important when assessing local impacts of climate change, such as changes in precipitation patterns or extreme weather events.

Recent research has focused on improving GCMs by addressing their limitations and uncertainties. Proposed enhancements include increasing model resolution, incorporating machine learning techniques, and refining calibration methods. The concept of "digital twins" and reduced-complexity models has gained attention as potential approaches to refine climate projections and understand complex climate systems [39]. Furthermore, GCMs are critical tools in predicting climate change impacts in specific regions. A study conducted in the transboundary Koshi river basin in China and Nepal illustrates the importance of selecting suitable GCMs for assessing climate change in a specific area [40]. The study combined multiple methods to select representative GCMs for the region, considering factors such as historical performance and envelope-based approaches. The findings highlighted the variability of GCM outputs due to complex topography and emphasized the need for downscaling techniques to refine climate data for accurate model selection and impact assessment.

3.3.1.5.1 Atmospheric General Circulation Models (AGCMs)

These models are special types of GCMs that simulate the behaviour of the atmosphere alone, often using prescribed sea surface temperatures as inputs. AGCMs operate on a grid system, dividing the atmosphere into three-dimensional grid cells. For each grid cell, equations that describe atmospheric motion, energy balance, and heat transfer are solved. These models consider fundamental physical principles, such as conservation of mass, momentum, and energy, as well as radiative transfer equations [41]. One of the primary goals of AGCMs is to simulate the general circulation of the atmosphere, which involves large-scale atmospheric motions driven by the Earth’s rotation, solar heating, and energy exchanges between different regions. These models can replicate atmospheric features like jet streams, trade winds, and monsoons, allowing scientists to study how changes in these patterns might affect global climate and weather [41].

Contemporary research has focused on improving the accuracy and representation of AGCMs. These efforts include refining parameterizations of processes that occur on scales smaller than the model grid, such as cloud formation and precipitation. For example, researchers have explored superparameterization, where cloud processes are represented by more detailed models embedded within the larger AGCM [42].

Furthermore, the integration of Earth System Models (ESMs) has extended the capabilities of AGCMs. ESMs incorporate interactions between the atmosphere, oceans, land surface, and biosphere, creating a more comprehensive representation of the Earth's climate system. This enables researchers to study feedback loops and interactions between different components of the climate system.

3.3.1.5.2 Coupled Atmosphere-Ocean General Circulation Models (AOGCMs)

Coupled AOGCMs are special types of GCMs that integrate atmospheric and oceanic models. These models emerged in the mid-1980s and combine atmospheric general circulation models (AGCMs) with ocean general circulation models (OGCMs), creating a holistic representation of the Earth's climate system [43]. While AGCMs focus on atmospheric processes and circulation, OGCMs simulate oceanic dynamics, including currents, heat transport, and ocean-atmosphere interactions.

AOGCMs offer numerous advantages in climate modelling. They account for the intricate feedback mechanisms between the atmosphere and oceans, which are crucial for accurate climate projections. These models help scientists investigate phenomena such as El Niño, La Niña, and the Atlantic Meridional Overturning Circulation (AMOC), providing insights into regional climate patterns and extreme events. Additionally, AOGCMs are widely used in Intergovernmental Panel on Climate Change (IPCC) assessment reports to project future climate scenarios [44].

Despite their benefits, AOGCMs have limitations. Computational constraints and model simplifications can introduce biases and uncertainties into simulations. The spatial resolution of AOGCMs might not capture fine-scale regional variations, which are essential for understanding local climate impacts. To address this, researchers have developed techniques such as regional climate models (RCMs) and empirical/statistical methods to enhance the resolution of AOGCM projections at smaller scales.

Recent research has aimed to improve the accuracy of AOGCMs by enhancing model components and parameterizations. Studies have explored the representation of sea ice dynamics, ocean-atmosphere coupling, land ice-ocean interactions, glacial melt, and icebergs [45]. Advances in numerical methods, like unstructured meshes and adaptive vertical discretization, have allowed models to better capture complex oceanic processes. Efforts are being made to evaluate and validate AOGCMs by comparing their simulations with observational data [1]. This helps identify model strengths and weaknesses, refine parameterizations, and enhance the overall reliability of projections. As technology and computational power continue to advance, AOGCMs are expected to improve in complexity and resolution. Their integration with Earth System Models (ESMs), which include interactions with land, biosphere, and cryosphere components, will enable a more comprehensive understanding of the Earth's climate system [43].

3.3.1.6 Earth System Models (ESMs)

ESMs are an extension of GCMs that include additional components, such as the biosphere, cryosphere, and lithosphere. ESMs are utilized to simulate a variety of Earth system’s phenomena, including climate variability, ocean circulation patterns, temperature changes and sea level rise. They provide insights on how different factors, such as greenhouse gas emissions, solar radiation, and volcanic activity, influence the Earth's climate over various timescales.

Recent advancements in ESMs have been driven by collaborative efforts. The Coupled Model Inter-comparison Project (CMIP) plays a significant role in evaluating and improving ESMs. Projects like ESMValTool[15] aim to validate and assess the performance of ESMs using various metrics and data sources [46]. Such tools facilitate model comparison, identification of strengths and weaknesses, and enhancement of model development. ESMs incorporate a wide range of components and processes such as biogeochemical cycles, including carbon and sulphur cycles, that influence climate responses, feedbacks, and human impacts [47]. Recent studies have highlighted the importance of incorporating microbial processes into ESMs to

[15] https://esmvaltool.org

improve predictions of global ocean ecosystems [47]. Clouds, with their impact on radiation and temperature regulation, are another critical aspect that ESMs aim to represent accurately [47].

Advancements in Earth system modelling have been achieved through improvements in model components, parameterizations, and resolutions. High-resolution models provide finer details of Earth processes, enabling better representation of regional climate variations and local-scale phenomena [47]. Integrated models participate in CMIP efforts to project future climate changes and assess their impacts [48].

3.3.1.7 Climate Model Ensembles

Ensembles involve running multiple simulations using climate models, each with slightly different initial conditions or model parameters, to capture the range of possible outcomes and uncertainties associated with future climate.

One important application of climate model ensembles is in assessing tropical cyclone (TC) activity and its future implications. For instance, a study by researchers in Australia [49] utilized large climate model ensembles to address the challenge posed by limited historical data for assessing changes in TC behaviour along the Australian east coast. By analysing these ensembles, the study successfully identified observed TC trends and projected an increase in TC activity. This heightened activity was linked to higher risks of extreme winds, heavy precipitation, and flooding. Particularly, regions like the southern Southwest Pacific basin face escalating threats from damaging TC winds and intense rainfall, underscoring the growing risk of TC-induced damage and water ingress due to wind-driven rain.

Another overview article [50] discusses the diverse applications of large ensemble climate model simulations. These applications span across topics such as regional precipitation shifts, volcanic impacts on the stratosphere, variability in the North Atlantic Oscillation and extreme events influenced by atmospheric circulation. These studies not only enhance our comprehension of climate complexities but also improve the assessment of model performance and potential impacts.

3.2.1.8 Regional Climate Models (RCMs)

Regional Climate Models (RCMs) bridge the gap between global climate simulations and local impacts. These models offer a finer spatial resolution compared to global climate models (GCMs), enabling scientists to study the intricacies of climate variability, assess regional climate change, and develop localized adaptation strategies.

One study conducted in Florida, USA, exemplifies the role of RCMs in capturing climatic indices and evaluating their performance [51]. The evaluation compared multiple RCMs driven by GCMs to reproduce precipitation and temperature-based climatic indices. The results showed varying levels of skill in replicating indices, with certain RCMs, such as EC-EARTH.HIRHAM5 and MPI-ESM-LR.CRCM5-UQAM, performing relatively well. The mean ensemble of RCMs displayed notable accuracy in temperature-based indices.

Europe's regional climate scenarios, developed by the RC/CLM Community, highlight the importance of RCMs in understanding present and future climate patterns[16]. These scenarios involve fine-resolution transient simulations that span from 1960 to 2050 under IPCC scenarios A1b and A2. RCMs excel in capturing spatial climate variations by considering factors such as topography, lakes, and land-sea differences. To enhance accuracy, RCMs are integrated with other models, including hydrological, ocean, sea-ice, and ecosystem models. The Cosmo-CLM model, a high-resolution weather/climate model, is a prominent example used in

[16] https://climate-adapt.eea.europa.eu/en/metadata/portals/regional-climate-model-climate-scenarios-for-europe

this effort. This integration helps to refine climate understanding and adaptation strategies, bridging the gap between global climate trends and local impacts.

3.3.1.8 Statistical Downscaling Models (SDMs)

These models are valuable tools in climate modelling that facilitate the translation of large-scale climate information from global climate models (GCMs) to smaller scales, allowing for a more detailed and localized understanding of climate patterns and their impacts. SDMs bridge the gap between coarse-resolution GCM outputs and finer-scale regional or local climate variations.

One approach that highlights the application of SDMs is the use of trend-preserving Quantile Delta Mapping (QDM) and Quantile-Preserving Localized-Analog Downscaling (QPLAD) methods [52]. These methods enhance the output of climate models for impacts research by downscaling global model outputs from CMIP6 experiments. The resulting dataset, named Global Downscaled Projections for Climate Impacts Research (GDPCIR), preserves extreme events while providing a 0.25° horizontal-resolution product. This enables researchers to better understand and assess the potential impacts of future climate changes on a more localized scale.

A study that compares SDMs and regional climate models (RCMs) across Europe underscores the benefits of SDMs for localized climate information [53]. The comparison involved a machine learning-based SDM evaluated against multiple RCMs for various climatic variables. The SDM outperformed RCMs in many metrics, with bias correction enhancing their alignment. The study recommends considering SDMs alongside RCMs due to their computational efficiency and data availability, especially for regional information provision. The research suggests further investigations into long-term trends and the sensitivity of SDMs to global climate models.

3.3.1.9 Numerical Weather Prediction (NWP) Models

Numerical weather prediction (NWP) uses mathematical models of the atmosphere and oceans to predict the weather based on current weather conditions. NWP models focus on meso-scale storm processes within a 15 to 20-km grid. These models offer forecasts at grid points, requiring spatiotemporal interpolation for specific points of interest. Key principles for successful NWP forecasts include atmospheric motion, data assimilation, postprocessing, probabilistic predictions, validation, and parameterization testing. The most prominent NWP models are described below.

3.3.1.9.1 European Centre for Medium-Range Weather Forecasts (ECMWF) NWP model

The European Centre for Medium-Range Weather Forecasts (ECMWF) employs advanced Numerical Weather Prediction (NWP) models to provide accurate and timely weather forecasts. In recent years, ECMWF's NWP model has undergone significant enhancements. One upgrade in 2019 integrated weakly coupled ocean-atmosphere data assimilation, contributing to improved forecasts [54].

Contemporary scientific references highlight the application of deep learning to enhance short-term prediction accuracy. A hybrid NWP-ML model was proposed to refine ECMWF forecasts, achieving better temperature and precipitation predictions up to 3-day lead times. This approach addresses limitations in traditional NWP models, offering improved accuracy and potential cost savings [55].

Additionally, ECMWF's NWP model contributes to meteorological education through the OpenIFS model and state-of-the-art training techniques. References cover various aspects of weather prediction, atmospheric behaviour, and climate anomalies. These educational resources facilitate enhanced understanding and practical applications in the field [56].

Furthermore, ECMWF provides historical weather forecast datasets that play a pivotal role in energy forecasting. The NWP forecast dataset contributes to predictions in solar energy production, wind forecasts, load predictions, and distribution outage forecasts. An article emphasizes the importance of ECMWF's high-resolution ensemble prediction system (HRES) model and its applications in the energy sector [57].

ECMWF's advancements also extend to coupled data assimilation (DA), involving atmosphere, land, ocean, and sea ice components. Coupled DA enhances initial conditions by exchanging information across different components, contributing to more accurate forecasts. The center's focus on ocean-atmosphere coupling, interface observations, and sustainable practices underscores its commitment to improving forecasting accuracy and supporting reanalysis [58].

3.3.1.9.2 ICOsahedral Non-hydrostatic (ICON) NWP model

The ICON model is designed to address a wide range of atmospheric phenomena, including weather forecasting, climate studies, and atmospheric research. It employs an innovative grid structure based on triangular elements, which allows for efficient simulations and accurate representation of complex atmospheric processes.

Recent scientific references shed light on various aspects of the ICON NWP model. A sensitivity study conducted on the ICON-LAM model over Italy evaluates its parameterization schemes, performance, and biases. Recommendations for improving turbulence schemes and parameterizations are discussed, highlighting the model's ability to simulate temperature accurately while addressing precipitation biases [59].

A comprehensive overview of the ICON modeling framework reveals its application in simulating Europe's climate, regional weather patterns, and greenhouse gas fluxes. The ICON model's versatility and accuracy are showcased through multiple variants such as ICON-CLM and ICON-ART, contributing to improved climate indices, precipitation patterns, and simulation efficiency [60].

The German Meteorological Service (DWD) operates and utilizes the ICON model extensively for both global and regional numerical weather prediction[17]. ICON's capabilities range from global forecasts to fine-scale regional predictions, catering to various applications including hazardous weather forecasting.

Additionally, advancements in the ICON model extend to the upper atmosphere, as highlighted in a study introducing the upper-atmosphere extension of the ICON general circulation model. This research covers a wide array of topics such as numerical model testing, atmospheric dynamics, and radiative transfer models, demonstrating ICON's capability to simulate a broad range of atmospheric phenomena [61].

3.3.1.9.3 Global Forecast System NWP model

The Global Forecast System (GFS) is a prominent Numerical Weather Prediction (NWP) model developed by the National Centers for Environmental Prediction (NCEP) within the National Oceanic and Atmospheric Administration (NOAA) in USA. Originally split into GFS Aviation (AVN) and GFS Medium Range Forecast (MRF)

[17] https://www.dwd.de/EN/ourservices/nwp_forecast_data/nwp_forecast_data.html

models before January 2003, the GFS has undergone changes in terms of grids, domains, run frequencies, and output frequencies over the years[18].

The GFS model's applications extend beyond meteorology, as evident in a study evaluating NCEP GFS-based rainfall forecasts over the Nagavali and Vamsadhara basins in India. NWP models such as GFS offer quantitative forecasts using techniques like satellite data and radar information. However, these forecasts require validation due to the inherent variability. The evaluation of the GFS T574 model's forecasting skill in this study highlights its significance in providing accurate forecasts for regions prone to monsoon rainfall and cyclones [62].

3.3.2 APPLICATIONS OF CLIMATE MODELLING AND FORECASTING TECHNOLOGIES IN SMART CITIES

Climate modelling and forecasting technologies have become integral components of smart city initiatives, enabling cities to better understand, adapt to, and mitigate the impacts of climate change. A non-exhaustive list of applications is presented below:

- Climate-Smart Governance and Planning: Climate modelling and forecasting technologies help cities anticipate extreme weather events, sea-level rise, and other climate-related challenges. This information aids urban planners in designing resilient infrastructure, such as flood defences, drainage systems, and evacuation routes. For instance, cities can use predictive models to identify areas prone to flooding and implement adaptive strategies to reduce risks [63].
- Energy Efficiency and Environmental Sustainability: Smart cities integrate climate data to optimize energy consumption and reduce greenhouse gas emissions. Advanced sensors and data analytics enable real-time monitoring of energy usage in buildings, transportation, and other sectors. By analysing climate patterns and energy consumption, cities can implement demand-response programs, energy-efficient lighting systems, and renewable energy sources [64].
- Public Health and Resilience: Climate modelling aids in understanding the health risks associated with changing climate conditions. By analysing climate data alongside health records, cities can predict and respond to disease outbreaks, heatwaves, and air quality issues. Early warnings and targeted interventions can enhance public health and reduce vulnerabilities [65].
- Urban Mobility and Transportation: Climate forecasts influence transportation planning by anticipating weather-related disruptions and optimizing traffic flow. Real-time data from sensors and IoT devices enable dynamic route planning, efficient public transportation systems, and shared mobility services. This leads to reduced congestion, lower emissions, and enhanced mobility [63].
- Emergency Response and Disaster Management: Climate models provide critical information for disaster preparedness and response. Cities can simulate the impacts of various climate-related disasters and develop response strategies. Real-time data feeds from IoT sensors and social media platforms enable rapid assessment and allocation of resources during emergencies [65].
- Citizen Engagement and Awareness: Climate forecasting technologies empower citizens with real-time climate information. Smart city platforms can deliver weather forecasts, air quality updates, and safety alerts directly to residents' devices. This promotes awareness, community engagement, and collective actions to address climate challenges [66].
- Data-Driven Decision-Making: Climate modelling and forecasting technologies provide data-driven insights for informed decision-making. Cities can use this information to allocate resources

[18] https://www.ncei.noaa.gov/products/weather-climate-models/global-forecast

effectively, develop long-term sustainability plans, and track progress towards climate-related goals [64].

Incorporating climate modeling and forecasting technologies into smart city frameworks enables cities to become more resilient, sustainable, and adaptive to the challenges posed by climate change. By integrating these technologies with other smart city components, such as IoT, AI, and big data analytics, cities can enhance their overall quality of life and contribute to a more sustainable future.

4 DATA SHARING & PROCESSING IN SMART CITIES

Smart cities are those that leverage information and communications technology to manage a city's assets and processes efficiently and provide connectivity and mobility to an ever-growing urban population.

Smart cities are transforming urban landscapes by integrating technology and data to improve the quality of life for residents. These cities leverage the power of the IoT and other advanced technologies to gather vast amounts of data from various sources. This data includes information from sensors, devices, infrastructure, and even citizens themselves, generating a wealth of valuable insights that can drive informed decision-making and enhance urban services.

However, the true potential of smart cities lies not only in the collection of data but also in the effective sharing and utilization of this information. Data sharing forms the backbone of smart cities, enabling various stakeholders to collaborate and derive actionable intelligence from the collected data. It involves the secure and responsible exchange of data among city authorities, businesses, research institutions, and citizens, fostering a holistic approach to urban development and governance.

The benefits of data sharing in smart cities are far-reaching. It enables city planners and administrators to make data-driven decisions, leading to optimized resource allocation, improved service delivery, and enhanced sustainability. By pooling and sharing data, cities can identify patterns, trends, and correlations that can inform policymaking, urban planning, and infrastructure development.

Moreover, data sharing fosters innovation and economic growth within smart cities. By providing access to relevant data sets, governments and city authorities encourage start-ups, entrepreneurs, and researchers to develop innovative solutions to urban challenges. This collaboration creates an ecosystem that nurtures entrepreneurship, accelerates technological advancements, and attracts investment, further fuelling economic development.

However, the successful implementation of data sharing in smart cities requires careful consideration of various factors. Privacy and security concerns are paramount, as the collection and sharing of sensitive data can potentially compromise individual privacy rights. Ensuring data anonymization, encryption, and implementing robust cybersecurity measures is essential to build trust among stakeholders and safeguard personal information.

In addition, data governance frameworks and policies need to be established to regulate data sharing practices. Clear guidelines must be defined regarding data ownership, access rights, and usage restrictions to ensure ethical and responsible data handling. Open data initiatives and standards can also play a crucial role in facilitating interoperability and enabling seamless data exchange between different systems and stakeholders.

Furthermore, citizen engagement and empowerment are vital components of data sharing in smart cities. By involving citizens in the data-sharing process, cities can foster a sense of ownership and encourage active participation. Citizens can contribute data voluntarily, provide feedback, and gain access to valuable information, enabling them to make informed decisions and actively contribute to urban development.

4.1 TYPES OF DATA SHARING TECHNOLOGIES AND TOOLS

Data sharing in smart cities, involves the collaboration and exchange of information among various components, including software and hardware, to enable seamless connectivity and data analysis. Sensors and IoT devices form the foundation of data collection in smart cities. These devices are embedded in various urban infrastructure and public spaces, such as traffic signals, streetlights, waste management systems, and environmental monitoring stations. They collect real-time data on parameters like traffic flow, energy consumption, air quality, and waste levels. The data collected by these devices serves as the primary input for data sharing [67].

4.1.1 APPLICATION PROGRAMMING INTERFACES (APIS)

Communication Networks: To transmit data from sensors and IoT devices to the central data repositories, communication networks play a crucial role. These networks can include wired and wireless connections, such as cellular networks, Wi-Fi, and LoRaWAN (Long Range Wide Area Network). These networks ensure that the collected data is efficiently transmitted to the central data storage for further processing and analysis.

Application programming interfaces (APIs) are a vital component of smart city development. Typically used by software engineers to easily interact with different components, resources and data repositories, APIs also provide researchers and officials the information they need to elevate city life. This trend in municipalities adopting an API-based approach broadly follows a larger trend in software development. For example, developers use APIs to build apps that track the time of arrival of public transportation, which makes moving around a city in a bus, subway, or ferry more predictable. Apps that use APIs can help residents make non-emergency complaints (such as downed trees, overflowing trash cans and graffiti) to municipalities and track the progress of the solution. APIs are even helping tourists identify must-see places of interest and lead them to seek off-the-beaten-path experiences for a more enjoyable visit.

4.1.2 DATA WAREHOUSES

Data Storage and Management: Smart cities require robust data storage and management systems to handle the vast amount of data generated by sensors and IoT devices. Cloud-based platforms are often utilized to store and manage this data. Cloud storage offers scalability, accessibility, and reliability, allowing stakeholders to securely store and access data from anywhere at any time. Additionally, data management systems help in organizing, categorizing, and indexing the data for efficient retrieval and analysis.

4.1.3 CLOUD COMPUTING SERVICES

Data Integration and Analytics: Data sharing involves integrating data from different sources and domains to gain comprehensive insights. This integration is facilitated by software platforms that combine and normalize the collected data. Advanced analytics tools and algorithms are then applied to extract meaningful patterns, trends, and correlations from the integrated data. These analytics processes enable decision-makers to make data-driven decisions, identify potential issues, and optimize resource allocation in various areas, including transportation, energy, and public services.

4.1.4 DATA VISUALIZATION

Data Visualization and Reporting: To communicate the analysed data effectively, data visualization tools are used. These tools transform complex data sets into visual representations such as charts, graphs, and maps. Data visualization allows stakeholders to understand and interpret the information quickly, facilitating informed decision-making. Furthermore, comprehensive reports can be generated using the analysed data, providing a clear overview of key findings and insights. GIS websites are often used to evaluate the development of smart cities. The application of webGIS in an urban setting has many functions. One of the main functions of the application of webGIS when viewed in terms of government, is related to spatial planning. WebGIS can also be used by governments to distribute information to the public. If viewed from the perspective of use by the community, webGIS will help the community in finding the location of urban infrastructure. Through the use of this application, planners or designers can balance the amount of density in the area with the provision of necessary facilities in a very short time [68].

In smart cities, ensuring secure and controlled access to data is crucial. Access control mechanisms and authentication protocols are implemented to safeguard sensitive information and prevent unauthorized access. Encryption techniques are often used to protect data during transmission and storage. Additionally, privacy regulations and policies are enforced to ensure the responsible handling of personal data and protect the privacy rights of citizens.

Overall, the combination of sensors, IoT devices, communication networks, data storage systems, analytics tools, and security measures form a comprehensive ecosystem for data sharing in smart cities. These components work together to enable seamless connectivity, efficient data collection, integration, analysis, visualization, and secure sharing of valuable insights, leading to improved urban planning, resource allocation, and citizen engagement [69].

4.2 APPLICATIONS OF DATA SHARING TECHNOLOGIES AND TOOLS IN SMART CITIES

4.2.1 "FIWARE - A FRAMEWORK FOR SUCCESS"

What makes the FIWARE approach unique and powerful is the curated framework of Open-Source software platform components which can be assembled and, together with third-party components, used to build entire platforms that support a faster, easier and cheaper development of Smart Solutions. With FIWARE, Public Administrations have the chance to implement Smart City platform strategies that avoid vendor lock-ins and facilitate collaborations towards the development of a sustainable market [70].

Open Standards allow for cross-domain and cross-border interoperability and replicability of solutions. Providers of these solutions can develop once and deploy in multiple cities when they adopt de-facto standards. This way, open standards contribute to the development of a market with appealing incentives, from financial to social benefits, helping a truly innovative ecosystem emerge.

Open Source is a powerful weapon for driving the definition of standards following a "driven-by-implementation" and agile approach. Thanks to Open Source-based technology smaller companies can build business cases for customers who find it challenging to buy a product/service from a large corporation. Large players, on the other hand, can secure their position working at the edge of innovation. From a business perspective, Open Source is relevant due to its power of commoditizing elements in the technology stack, ultimately impacting positively those companies whose core business is not selling general-purpose platform software but adjacent components / products / services.

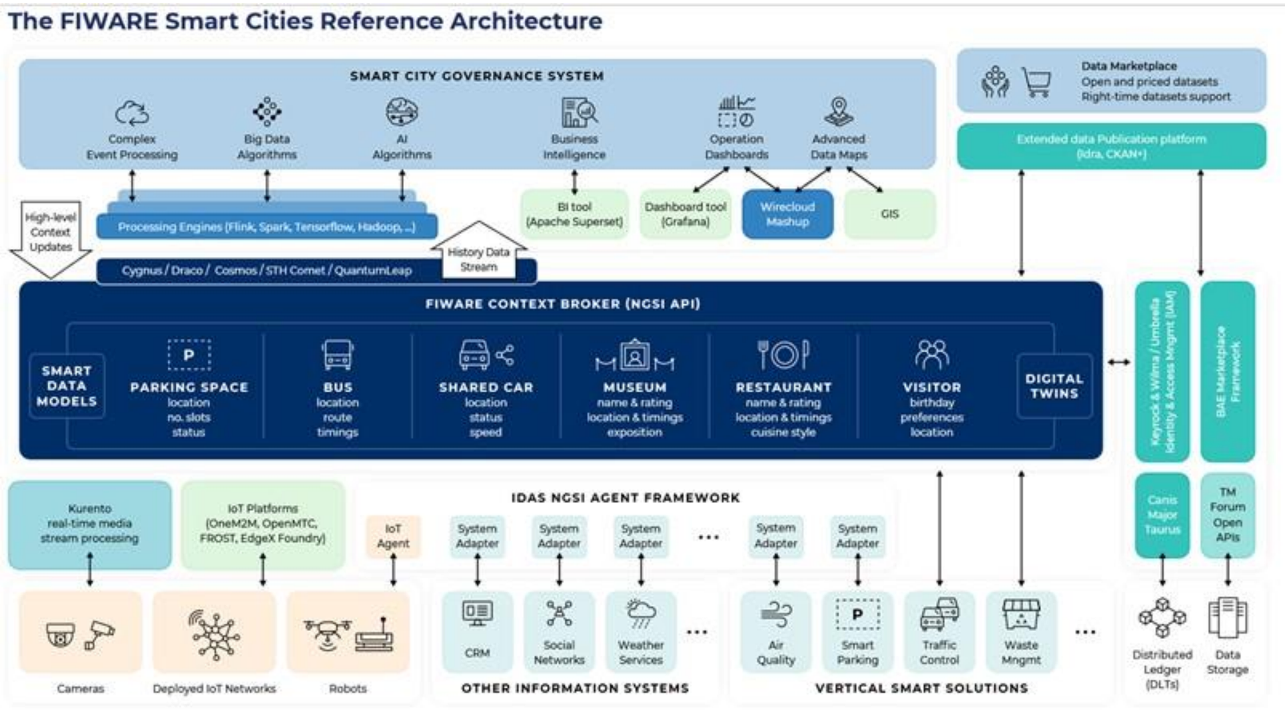

Figure 28: Visualisation of FIREWARE Smart Cities Reference Architecture.

4.2.2 SMART CITY FRAMEWORK -CITY PULSE

Smart City Framework (SCF), a high-level architecture of a platform that describes the scope of the innovations expected from the CityPulse project and the way they are integrated together in a coherent conceptual system. SCF serve as a reference model and architecture (ARM) to be used by smart city stakeholders, project partners and any other interested parties when engaged in technical discussions about smart cities services based on real-time information streams. The Smart City Framework is expected to be an initial architecture to set the main concepts, common language, and the boundaries for smart city project. The framework offers an overall report upon the architecture in different views, functional, interface and information, security and privacy view and thus explains respectively what the framework does, how components interact with each other, the generation and flow of information, and the necessary mechanisms to address security and privacy concerns about city and citizen relevant data [71].

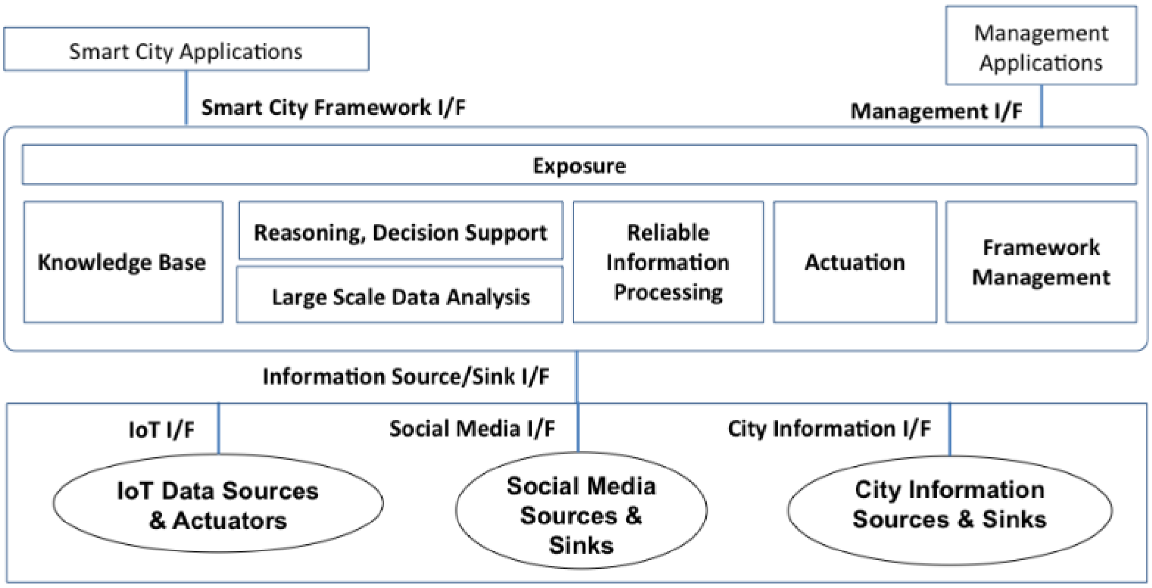

Figure 29: High-level view of Smart City Framework.

4.2.3 CITYSDK

CitySDK, is a service development kit for cities and developers that aims to harmonize APIs across cities. The CitySDK SOA architecture is typically structured on SQL DB. The project makes transformations on each dataset to obtain and manage uniform data. There are no semantic relationships among the data collected from data providers; only some of the links between an event and the Point of Interest to which it refers are established. The work on interoperability is limited at the API level, and in the drafting of guidelines and standards for the data providers and the API users.

4.2.4 WEB GIS – ESRI SOLUTIONS ARCGIS URBAN

ArcGIS Urban is an immersive 3D experience designed to improve urban planning and decision-making. Quickly visualise projects in your local context and leverage location intelligence to drive better decisions. Be more proactive and less reactive in your planning process. Simplify project collaboration across internal agencies and public stakeholders.

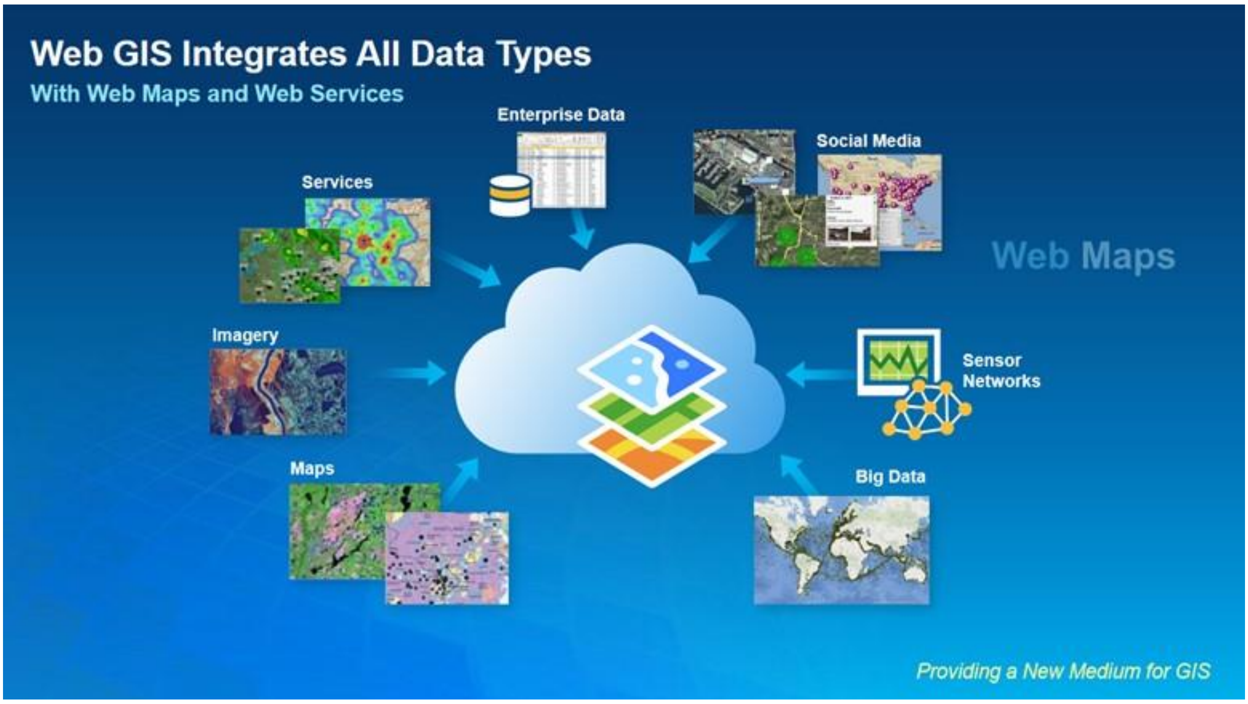

Figure 30: Overview Web GIS Web Maps and Web Services.

5 EARLY WARNING SYSTEMS FOR RISK IDENTIFICATION IN SMART CITIES

Early Warning Systems (EWS) are pivotal in smart cities for risk identification, providing valuable time to act to minimize damage. They leverage a wide range of technologies, including Internet of Things (IoT) sensors, data analytics, and AI algorithms, to monitor, detect, and predict potential threats, ensuring proactive management of urban risks. Early Warning Systems such as CAP, WEA, EFAS, EEW, and ETWS are essential tools in the arsenal of critical infrastructure protection and civil security. They provide the foundation for rapid, effective responses to disasters, safeguarding lives, and minimizing damage to essential assets. Integrating these systems into smart cities aligns with the EU HORIZON project objectives of enhancing disaster resilience and public safety.

The objective is to significantly improve the accessibility and provision of multi-hazard early warning systems and disaster risk information and assessments to the public by the year 2030. In 2015, the European Commission (EC) unveiled its Action Plan on the Sendai Framework, targeting the execution of measures and actions that would fulfil the four key priorities and seven goals of the Sendai Framework by its Member States. Furthermore, in 2017, the European Forum for Disaster Risk Reduction (E.F.D.R.R.) disclosed the results of a Forum session that took place in Istanbul, Turkey. These results encompassed 17 outcomes, some of which included incorporating vulnerable groups in local and national Disaster Risk Reduction (DRR) strategies, improving the resilience of communities, affirming the Union's dedication to accomplishing the Sendai Framework's objectives, prioritizing the protection of national heritage sites in national strategies, and designing people-centred multi-hazard early warning systems [72].

5.1 TYPES OF EARLY WARNING SYSTEMS AND EARLY WARNING TOOLS

In the face of natural disasters such as floods, earthquakes, or wildfires, Early Warning Systems (EWS) can provide timely alerts to residents and relevant authorities. They use sensor data and predictive modeling to determine the likelihood of an imminent disaster, allowing for evacuations or other precautionary measures to be undertaken. A non-exhaustive list is presented below.

5.1.1 COMMON ALERTING PROTOCOL (CAP)

The Common Alerting Protocol (CAP)[19] is an internationally recognized standard for exchanging emergency alerts and public warnings. CAP ensures the interoperability of various alerting systems, facilitating the timely dissemination of critical information during emergencies. It supports multiple types of alerts, including weather warnings, civil emergencies, and more, making it a versatile tool for comprehensive early warning.

5.1.2 WIRELESS EMERGENCY ALERTS (WEA)

Wireless Emergency Alerts (WEA)[20] are short emergency messages sent by authorized government alerting authorities through mobile carriers. These alerts reach mobile devices in a specific geographic area, notifying

[19] https://www.oasis-open.org/standards#capv1.2

[20] https://www.fcc.gov/consumers/guides/wireless-emergency-alerts-wea

users about imminent threats like severe weather conditions, AMBER alerts, or presidential alerts. WEA is a valuable tool for reaching the public quickly, especially in situations where immediate action is required.

5.1.3 GDACS - GLOBAL DISASTER ALERT AND COORDINATION SYSTEM

The Global Disaster Alert and Coordination System[21] provides alerts and estimates impacts of earthquakes, tsunamis, tropical cyclones, floods, volcanos, and droughts worldwide. The map of disaster shows alerts during the past 4 days. The map is produced by EC-JRC. The blurred events in the list below are the past events before last 4 days.

- For drought alerts, all the events listed in the homepage are ongoing events. In bold: i) new events; ii) events where a significant worsening has been detected (+ 0.5 GDACS score or increase in the Alert Level); iii) events where new information products are available (Global Drought Observatory Report).
- For Forest Fires alerts, the events are all the ongoing events of class Orange or Red plus the Green alerts with burned area exceeding 10k ha and population within 5 km exceeding 10k.

5.1.4 REVERSE 112

"Reverse 112" or "Public Warning System" is a communication procedure that enables authorities to send alerts to citizens in case of emergencies. The system is called "reverse" because, unlike traditional emergency calls where citizens contact authorities (like dialling 112 in Europe), this system involves authorities reaching out to citizens.

Technologically, “Reverse 112” integrates different communication mediums to make sure the message reaches a maximum number of people.

Structure and Operation:

1. Central Alerting System: The Reverse 112 process starts at a central alerting system managed by local, regional, or national authorities. This system is typically software-based and allows for the input of emergency messages, the selection of the geographic area to be alerted, and the transmission of alerts through multiple channels.
2. Multi-channel Communication: Reverse 112 uses a multi-channel approach to reach its audience. Channels often include:
    - Cell Broadcast: Like SMS, but with a much broader reach and the ability to target a specific area, regardless of whether recipients are subscribers or roaming users. It is not affected by network congestion.
    - SMS: Direct text messages to all mobile phones within the designated area.
    - Email: If email addresses are available and registered with the system.
    - Social Media: Utilizing popular platforms like Twitter, Facebook, etc.
    - Apps: Some regions may have specific emergency alert apps.

[21] https://www.gdacs.org

- TV and Radio Broadcasts: Public and private broadcasters can disseminate alerts.
- Landline Calls: Automated voice calls can be sent to landlines.

3. Geo-targeting: ”Reverse 112” can send alerts to people within a specific geographic area. This is often achieved using cell broadcast technology, which sends messages to all cell phones connected to certain cell towers or using geolocation data for more specific targeting in other channels like SMS or push notifications.

Reverse 112 is a crucial tool within an EWS as it allows rapid, widespread communication of impending threats. It can be used to alert the public about various emergencies, including natural disasters (floods, fires, earthquakes, severe weather), public health emergencies (pandemics, chemical spills), security threats (terrorist attacks), and more.

In addition to simply alerting the public about these threats, Reverse 112 can provide critical information about how to respond, such as evacuation orders, shelter-in-place instructions, or guidance on where to find further information. This can significantly enhance the effectiveness of a city's response to emergencies, reduce panic, and ultimately save lives and property.

In summary, Reverse 112 as an EWS is a proactive communication system that uses multiple channels and technologies to alert the public about potential emergencies, enhancing the resilience and safety of smart cities.

5.1.5 THE OSOCC PLATFORM

The OSOCC[22] is a real-time online coordination tool/platform used by disaster response professionals, that facilitates the exchange of information among different actors and stakeholders as early as possible in the case of emergency. An OSOCC brings together the OCHA (United Nations Office for the Coordination of Humanitarian Affairs), national disaster management authorities, teams from UNDAC and USAR, as well as other responders so that they all can share and exchange information in the initial phase of response to major natural disasters. The OSOCC is both a methodology and a physical location for the coordination of on-site emergency response. It is supported and promoted by the UN Office for the Coordination of Humanitarian Affairs (OCHA) and is used as a tool to support the governments in countries that are affected by disasters. The use of the OSOCC is not restricted to governments but can also be utilised by international and regional response organizations when responding to emergencies, i.e., by coordinating the assistance to affected populations [73].

A special component of the OSOCC system is the Virtual OSOCC (VOSOCC), a real-time online coordination platform that allows rapid information exchange early in an emergency. It is part of the Global Disaster Alert and Coordination System (GDACS), a cooperative framework supported by OCHA Geneva. “Specific features of the VOSOCC allow first responders to exchange information such as baseline country information (including relevant socio-economic and demographic information), entry points and other logistical aspects, relief team status, assessment information, cluster activities, civil-military coordination arrangements, environmental risks and security“ [73]. Additionally, the VOSOCC also supports the coordination of trainings, the sharing of information and the discussion of projects.

[22] https://www.insarag.org/guidance-notes/manuals/v-osocc

5.1.6 COPERNICUS EMERGENCY MANAGEMENT SERVICES (CEMS)

The Copernicus Emergency Management Service (CEMS)[23] is a European initiative that aims to provide timely and accurate geospatial information and services to support emergency management and response activities. It is part of the Copernicus programme, which is the EU Earth observation and monitoring programme. CEMS uses satellite imagery and other geospatial data to monitor and assess various types of emergencies, including natural disasters, such as floods, wildfires, and earthquakes, as well as man-made disasters like industrial accidents and oil spills. The service provides information to help authorities and emergency responders make informed decisions and take appropriate actions in emergency situations.

CEMS operates early warning systems for specific types of hazards, such as floods and wildfires. These systems use data from various sources, including satellites, weather models, and ground-based sensors, to detect and forecast potential emergencies and provide alerts to authorities. It provides a suite of tools and services, including GIS-based early warning systems for Early Warning. These systems integrate satellite and earth observation data to monitor various hazards, such as floods, wildfires, and earthquakes, and deliver early warnings to authorities and the public. Some major tools for disaster management and resilience from CEMS are listed below.

5.1.6.1 European Flood Awareness System

The European Flood Awareness System (EFAS)[24] and Global Flood Awareness System[25] develop an overview of ongoing and possible future flooding up to 10 days into the future to support preparatory measures for flood events, particularly in large transnational river basins. The aim of EFAS is to support preparatory measures before major flood events strike, particularly in the large trans-national river basins and throughout Europe in general. EFAS is a collaborative effort within the European Commission that provides early flood warnings for various European regions. It uses hydrological models, meteorological data, and remote sensing to predict river and coastal floods. This tool assists local authorities in taking proactive measures to mitigate flood risks, protect critical infrastructure, and evacuate residents if necessary.

5.1.6.2 European Forest Fire Information System and Global Wildfire Information System

The European Forest Fire Information System[26] and Global Wildfire Information System[27] forecast dangerous weather conditions up to 10 days ahead and provide near-real-time information on active fires and burnt areas. These systems analyse the severity and risk that each forest fire poses for the local population and the environment. This allows informed decisions on the deployment of the rescEU[28] firefighting capacity. EFFIS supports the services in charge of the protection of forests against fires in the EU and neighbour countries and provides the European Commission services and the European Parliament with updated and reliable information on wildland fires in Europe. Since 1998, EFFIS is supported by a network of experts from the countries in what is called the Expert Group on Forest Fires, which is registered under the Secretariat General of the European Commission. Currently, this group consists of experts from 43 countries in European, Middle

[23] https://emergency.copernicus.eu
[24] https://www.efas.eu
[25] https://www.globalfloods.eu
[26] https://effis.jrc.ec.europa.eu
[27] https://gwis.jrc.ec.europa.eu
[28] https://civil-protection-humanitarian-aid.ec.europa.eu/what/civil-protection/resceu_en

East and North African countries. In 20 15, EFFIS became one of the components of the Emergency Management Services in the EU Copernicus program.

5.1.6.3 European and Global Drought Observatories

The European and Global Drought Observatories[29] give information on potential and ongoing droughts, including meteorological indicators, soil moisture anomalies, vegetation stress and river low flows. The EDO pages contain drought-relevant information such as maps of indicators derived from different data sources (e.g., precipitation measurements, satellite measurements, modelled soil moisture content). Different tools, like Compare Layers, allow for displaying and analysing the information and drought reports give an overview of the situation in case of imminent droughts.

5.1.6.4 European Tsunami Early Warning System (ETWS)

The European Tsunami Early Warning System (ETWS)[30] is designed to detect and issue warnings for tsunamis in the Mediterranean and North-East Atlantic regions. It relies on a network of seismometers and tidal gauges to detect underwater seismic activity and monitor sea levels. ETWS ensures that coastal communities and critical infrastructure are prepared for potential tsunamis, reducing the impact of these devastating events.

5.1.7 FLOOD EARLY WARNING SYSTEMS (FEWS)

Flood Early Warning Systems (FEWS) designed specifically to predict and provide alerts for floods. These systems are crucial in areas prone to flooding, where timely warnings can save lives and minimize damage. They work by monitoring key data that can indicate an increased risk of flooding, then issuing alerts when certain thresholds are reached.

Below are some components and characteristics of a typical flood EWS:

1. Data Collection: A variety of data is collected and monitored to predict floods. This can include rainfall data, river levels, soil moisture content, and weather forecasts. The data is usually collected through a network of sensors and weather stations, often supplemented by satellite and radar observations.
2. Data Analysis: Advanced algorithms, often incorporating AI and machine learning, are used to analyse the collected data and predict flooding. This can include estimating when and where floods will occur, how severe they are likely to be, and how long they are expected to last.
3. Risk Assessment: Once a potential flood is identified, the system assesses the risk based on factors such as population density in the potential flood zone, the time of day (which can affect whether people are awake and able to respond to warnings), and the presence of key infrastructure that might be affected.
4. Warning Issuance: If a significant flood risk is identified, the system issues warnings. These can be disseminated through various channels, such as text messages, social media, emergency broadcasts on TV and radio, sirens, or dedicated mobile apps. The warning will typically include information about the expected severity of the flood, the areas likely to be affected, and recommended actions for those in the area.

[29] https://edo.jrc.ec.europa.eu/edov2/php/index.php?id=1000
[30] https://ec.europa.eu/newsroom/horizon2020/items/18775

5. Emergency Response Coordination: In addition to issuing warnings to the public, the flood EWS can also alert emergency services and local authorities, enabling them to respond more effectively. This can include activating flood defences, planning evacuations, and coordinating rescue efforts.

5.1.8 EARTHQUAKE EARLY WARNING SYSTEMS (EEWS)

Early Warning Systems for earthquakes (EEWS) are specifically designed to detect seismic activity and issue alerts to areas that might be affected by an impending earthquake. These systems work on the principle of detecting the initial seismic waves, known as P-waves, which travel faster than the more destructive S-waves and surface waves. By detecting the P-waves, the EWS can provide some advance warning before the more damaging shaking arrives.

Earthquake Early Warning (EEW)[31] systems detect seismic activity and issue alerts seconds to minutes before the arrival of strong shaking waves. While specific EEW systems may vary by region, they typically consist of a network of seismic sensors, data processing centres, and alert distribution mechanisms. These systems provide valuable time for individuals to take cover, critical infrastructure to shut down safely, and emergency services to prepare for the aftermath of an earthquake.

Key components and features of earthquake Early Warning Systems include:

1. **Seismic Sensors**: Networks of seismic sensors are deployed in earthquake-prone regions to detect ground motion. These sensors measure the vibrations caused by seismic waves, and their data is transmitted in real-time to a central processing system.
2. **Data Processing and Analysis**: The seismic data collected from the sensors is analysed in real-time to determine the characteristics of the earthquake. This includes estimating the earthquake's magnitude, location, and the expected intensity of shaking at different locations.
3. **Warning Generation**: If the system detects an earthquake with the potential to cause significant shaking in certain areas, it generates warning messages. These messages typically contain information about the earthquake's location, magnitude, and expected arrival time of the more damaging shaking at specific locations.
4. **Alert Dissemination**: The warning messages are disseminated to various channels to reach the affected population and critical infrastructure. Common communication channels include mobile apps, emergency alert systems on mobile phones, social media, sirens, and emergency broadcast systems.
5. **Response Actions**: Along with alerting the public, earthquake EWS also trigger automated actions in critical infrastructure systems. For example, it can initiate automated shutdown procedures in transportation systems, gas pipelines, power plants, and other sensitive infrastructure to minimize potential damage.
6. **Regional and International Collaboration**: In some cases, earthquake EWS operates on a regional or international level. This allows countries or regions to share seismic data and coordinate warning efforts for large earthquakes that might affect multiple areas.

[31] https://earthquake.usgs.gov/earthquakes/shakealert

It's important to note that while earthquake EWS can provide valuable seconds to minutes of warning, they do not predict earthquakes. They can only provide alerts based on the detection of initial seismic waves, which occur before the damaging shaking reaches a particular location. These few seconds of warning can be crucial for people to take protective actions, such as dropping, covering, and holding on, finding safe places, or evacuating from hazardous areas.

5.1.9 WILDFIRE EARLY WARNING SYSTEMS

Early Warning Systems for wildfires are especially important in regions prone to wildfires, where they can provide valuable time for both emergency responders to prepare and for residents to evacuate if necessary. A special example is the evacuation of 19.000 people in Rhodes Island, Greece during the summer 2023 wildfires.

A wildfire EWS works through several key steps:

1. **Data Collection**: Various types of data are collected and monitored to help predict and detect wildfires. This data may include weather conditions (such as temperature, humidity, wind speed, and lightning activity), vegetation dryness, and satellite imagery. Some systems also use ground sensors or aerial drones for real-time surveillance.
2. **Data Analysis and Risk Assessment**: Advanced algorithms, which can incorporate AI and machine learning, analyse the collected data to assess wildfire risk. These algorithms may consider factors such as the current dryness of vegetation, the weather forecast, and the geographical layout of the land. If a wildfire starts, these systems can track its progress and predict its direction and speed of spread.
3. **Warning Issuance**: If the system detects a high risk of a wildfire or if a wildfire has already started, it can issue warnings. These warnings are typically disseminated through various channels, including emergency alert systems, social media, mobile apps, TV and radio broadcasts, and direct messages or calls to residents in the affected areas.
4. **Emergency Response Coordination:** Along with issuing warnings to the public, the EWS can also alert emergency responders, such as local fire departments, forestry services, and other relevant agencies. This can allow these agencies to respond more quickly and effectively, whether that involves fighting the fire, preparing for evacuation, or other emergency measures.

However, it's important to note that while EWS can provide warnings when conditions are ripe for wildfires or when wildfires have started, predicting exactly when and where a wildfire will ignite is still a challenge due to the myriad variables involved, such as human activity or lightning strikes. Therefore, the key goal of these systems is to monitor conditions, provide early warnings when possible, and support efficient and effective responses when wildfires do occur.

5.1.10 FIRE WEATHER INDEX (FWI) SYSTEMS

FWI[32] systems integrate weather data, satellite imagery, and historical fire behaviour to predict wildfire risks and behaviour. They provide real-time information to aid in wildfire management and evacuation planning.

[32] https://www.nwcg.gov/publications/pms437/cffdrs/fire-weather-index-system

Analogous in concept to the National Fire Danger Rating System (NFDRS), the FWI system depends solely on weather readings. Resulting fuel moisture codes and fire behaviour indices are based on a single standard fuel type that can be described as a generalized pine forest, most nearly jack pine and lodgepole pine.

The Fire Weather Index System calls for weather observations to be collected from a standard observation site and time. Location standards can be found in the, Weather Guide for the Canadian Forest Fire Danger Rating System. The system calls for observations to be taken at solar noon when the sun is at its peak directly overhead.

5.1.11 TSUNAMI ALERTING SOFTWARE (TAS)

TAS[33] is an open-source software tool for EWS Integration that aids in the integration of data from various sensors and sources for tsunami early warning systems. It facilitates real-time data processing and dissemination, enabling faster response to tsunami threats. TasALERT and TasRECOVERY provides a centralised online platform helping you to know what to do before, during and after an emergency event.

During an emergency TasALERT is Tasmania's primary source of clear and consistent emergency warnings and information from emergency services and other government agencies, with a real-time map display and easy-to-use, high performing interface.

After the emergency response period, TasRECOVERY will connect you with all the support, advice and services you need. TasALERT also provides access to emergency preparedness information, assisting you to Get Ready for an emergency event.

TasALERT and TasRECOVERY is administered by The Department of Premier and Cabinet and is the Tasmanian Government's official and primary source of emergency warnings, information, and Recovery information.

5.1.12 NASA MODIS

These satellites use infrared and thermal imaging to detect wildfires and provide near-real-time alerts to authorities. Data from these satellites can be integrated into wildfire management systems. MODIS[34] (or Moderate Resolution Imaging Spectroradiometer) is a key instrument aboard the Terra (originally known as EOS AM-1) and Aqua (originally known as EOS PM-1) satellites. Terra's orbit around the Earth is timed so that it passes from north to south across the equator in the morning, while Aqua passes south to north over the equator in the afternoon. Terra MODIS and Aqua MODIS are viewing the entire Earth's surface every 1 to 2 days, acquiring data in 36 spectral bands, or groups of wavelengths (see MODIS Technical Specifications). These data will improve our understanding of global dynamics and processes occurring on the land, in the oceans, and in the lower atmosphere. MODIS is playing a vital role in the development of validated, global, interactive Earth system models able to predict global change accurately enough to assist policy makers in making sound decisions concerning the protection of our environment.

5.1.13 EUROPEAN SPACE AGENCY'S SENTINEL-2

Like MODIS, ESA Sentilnel-2[35] satellites use infrared and thermal imaging to detect wildfires and provide near-real-time alerts to authorities.

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[33] https://alert.tas.gov.au/get-ready/tsunami
[34] https://modis.gsfc.nasa.gov
[35] https://sentinel.esa.int/web/sentinel/missions/sentinel-2

The Copernicus SENTINEL-2 mission comprises a constellation of two polar-orbiting satellites placed in the same sun-synchronous orbit, phased at 180° to each other. It aims at monitoring variability in land surface conditions, and its wide swath width (290 km) and high revisit time (10 days at the equator with one satellite, and 5 days with 2 satellites under cloud-free conditions which results in 2-3 days at mid-latitudes) will support monitoring of Earth's surface changes.

5.1.14 TOOLS FOR CYBERSECURITY EARLY WARNING

5.1.14.1 Claroty

Claroty[36] offers advanced ICS cybersecurity solutions designed to protect critical infrastructure from cyberattacks. It provides real-time threat detection and vulnerability assessment for industrial networks.

5.1.14.2 ThreatConnect

ThreatConnect[37] is a platform that aggregates and analyses cyber threat intelligence data. It helps critical infrastructure operators identify and respond to cyber threats in real-time.

5.1.14.3 Splunk Security Information and Event Management (SIEM) System

Splunk's[38] Security Information and Event Management SIEM system provides real-time monitoring and analysis of security events across critical infrastructure networks. It enables rapid threat detection and response.

5.1.14.4 Cyberbit SOC 3D

SOC 3D[39] automates incident detection and response processes. It accelerates cyber incident resolution, crucial for minimizing downtime in critical infrastructures.

5.2 APPLICATIONS OF EARLY WARNING SYSTEMS IN SMART CITIES

Early Warning Systems (EWS) have a wide range of applications in smart cities, across various sectors. These systems play a crucial role in enhancing the resilience of cities by providing real-time alerts for potential risks and crises. Here are some of the key applications:

- **Climate Change and Disaster Management**: EWS are used to monitor weather patterns and geophysical data to predict natural disasters such as **floods**, **earthquakes**, hurricanes, **wildfires** and tsunamis. These systems help in early evacuation and efficient deployment of emergency resources, reducing the impact of such disasters.
- **Public Health Monitoring**: EWS can monitor and analyse health data to detect potential outbreaks of diseases, allowing for early interventions. This can also be used to manage public health crises such as pandemics or outbreaks of foodborne illnesses.
- **Terrorist attacks:** EWS can be used to help detect and prevent terrorist attacks, although it's important to note that this is a complex and challenging task given the unpredictable nature of such threats. An EWS for terrorism primarily focuses on detecting patterns, anomalies, or indicators that

[36] https://claroty.com
[37] https://threatconnect.com/threat-intelligence-platform
[38] https://www.splunk.com/en_us/products/enterprise-security.html
[39] https://www.cyberbit.com

suggest a potential terrorist activity. These systems often rely on a combination of intelligence gathering, data analysis, and machine learning algorithms to identify potential threats.

- **Traffic and Transportation Management**: EWS can analyse traffic data in real-time, allowing authorities to predict and manage traffic congestion. They can also detect potentially dangerous road conditions, such as icy roads, and alert drivers in advance.
- **Infrastructure Management:** By continuously monitoring the structural health of buildings, bridges, and other infrastructure, EWS can detect early signs of potential failures or damage. This can prevent accidents and allow for efficient maintenance planning.
- **Air and Water Quality Monitoring**: EWS are used to monitor environmental conditions, alerting authorities to issues such as poor air quality, high noise levels, or water pollution. This can help in proactive management of environmental health risks.
- **Energy Management**: EWS in smart grids can predict energy demand and supply, alerting to potential energy shortages or system failures. This can help in efficient energy management and prevent blackouts.
- **Cybersecurity**: In an increasingly connected world, EWS can monitor network data to detect potential cybersecurity threats, allowing for proactive measures to protect the city's digital infrastructure.
- **Public Safety and Security**: EWS can analyse data from security cameras, social media, and other sources to detect potential security threats. This can help prevent crimes and manage public safety incidents.
- **Economic and Financial Risk Management**: EWS can analyse economic data to predict potential economic downturns, financial crises, or other risks, helping the city to manage its economy proactively.

By integrating EWS into city management, smart cities can not only respond to crises more effectively, but they can also take preventive measures to mitigate risks, enhance resilience, and ensure the safety and well-being of their citizens.

6 TOOLS AND MODELS FOR CRITICAL INFRASTRUCTURE PROTECTION AND CIVIL SECURITY

Ensuring the security and resilience of critical infrastructure is paramount for the well-being of society and the functioning of smart cities. In alignment with EU HORIZON project goals, this section explores essential tools and models designed to enhance critical infrastructure protection and civil security while addressing the integration of technologies for effective disaster management.

6.1 PREDICTIVE ANALYTICS

In this Section, we delve into the world of Predictive Analytics—a transformative field that empowers decision-makers with the ability to foresee and plan for a wide array of potential scenarios. Predictive analytics leverages historical and real-time data, advanced algorithms, and modeling techniques to paint a clearer picture of the future.

This proactive approach to risk management is invaluable in the realm of critical infrastructure and civil security. In an era where smart cities thrive on the fusion of technology and urban living, the protection of critical infrastructure and the assurance of civil security have become more complex and multifaceted than ever before. PANTHEON acknowledges the imperative to anticipate, prepare for, and respond to the evolving threats that smart cities and critical infrastructure face.

In the spirit of EU HORIZON's commitment to pioneering research and actionable insights, this section will not only introduce the concept of Predictive Analytics but also provide practical methodologies and real-world tools that align with EU HORIZON project guidelines and objectives. Together, we embark on a journey of anticipation, equipping ourselves with the knowledge and tools to safeguard our smart cities and critical infrastructure from the uncertainties of an ever-changing world.

6.1.1 DISASTER SIMULATION MODELS

Disaster Simulation Models are powerful tools for predicting and assessing the impact of disasters on critical infrastructure and smart cities. These models use various techniques, such as agent-based modeling and Monte Carlo simulations, to simulate disaster scenarios, enabling better preparedness and informed decision-making.

The tools below and their software applications, including DisasterAWARE, HAZUS, AnyLogic, SWIFT, and Simio, provide valuable capabilities for simulating disasters, assessing vulnerabilities, and enhancing the resilience of critical infrastructure and smart cities. Depending on the specific requirements of EU HORIZON projects, these tools can be utilized or customized to create comprehensive disaster simulation models.

6.1.1.1 DisasterAWARE

DisasterAWARE[40], developed by Pacific Disaster Center, is a comprehensive disaster simulation and decision support tool. It integrates real-time data, modeling, and analytics to provide situational awareness during disasters. It covers various hazards, including earthquakes, tsunamis, floods, and wildfires, making it suitable for a wide range of scenarios.

[40] https://www.disasteraware.com

6.1.1.2 HAZUS

HAZUS[41] is a software application developed by FEMA (Federal Emergency Management Agency) in the United States. It is used for assessing and mitigating the impact of natural disasters, including earthquakes, floods, hurricanes, and tsunamis. HAZUS incorporates Geographic Information System (GIS) data to estimate physical, economic, and social impacts of disasters.

6.1.1.3 AnyLogic

AnyLogic[42] is a powerful simulation software that supports agent-based modeling, system dynamics, and discrete event simulation. While not tailored specifically for disaster simulations, it provides a versatile platform to develop custom disaster models. It has been used in various research projects to simulate disaster scenarios and evaluate resilience strategies.

6.1.1.4 SWIFT (Simulation Weather Forecasting Tools)

SWIFT[43] is an open-source software tool developed by the European Space Agency (ESA) for simulating extreme weather events and their impact on infrastructure and society. It combines weather data with models to simulate the effects of weather-related disasters, helping to assess vulnerabilities and improve resilience.

6.1.1.5 Simio

Simio[44] is a simulation software that allows users to create detailed models of complex systems, including disaster scenarios. It is widely used in academia and industry to simulate a variety of situations, from supply chain logistics to emergency response planning. Simio can be applied to develop custom disaster simulation models tailored to specific critical infrastructure needs.

6.1.1.6 FlamMap6 (Fire Area Simulator)

FlamMap6 (previous ARSITE)[45] is a software tool used by fire management agencies to simulate the spread of wildfires based on various factors like weather, terrain, and fuel conditions. It aids in planning containment strategies. FlamMap is a fire analysis desktop application that runs in a 64-bit Windows Operating System environment. It can simulate potential fire behaviour characteristics (spread rate, flame length, fireline intensity, etc.), fire growth and spread and conditional burn probabilities under constant environmental conditions (weather and fuel moisture). With the inclusion of FARSITE it can now compute wildfire growth and behaviour for longer time periods under heterogeneous conditions of terrain, fuels, fuel moistures and weather.)

The FlamMap fire mapping and analysis system can describe potential fire behaviour for constant environmental conditions (weather and fuel moisture). Fire behaviour is calculated for each pixel within the landscape file independently. Potential fire behaviour calculations include surface fire spread, flame length, crown fire activity type, crown fire initiation, and crown fire spread. Dead fuel moisture and conditioning of dead fuels in each pixel based on slope, shading, elevation, aspect, and weather. With the inclusion of

[41] https://www.fema.gov/flood-maps/products-tools/hazus
[42] https://www.anylogic.com
[43] http://swift.irap.omp.eu
[44] https://www.simio.com
[45] https://www.firelab.org/project/farsite

FARSITE, FlamMap can now compute wildfire growth and behaviour with detailed sequences of weather conditions.

6.1.2 TOOLS BASED ON AI AND MACHINE LEARNING

AI techniques can be used for the three main themes of communication, modelling and detecting. AI or Artificial Intelligence mimics human intelligence and processes by computer systems procedures. As Andrew Harper, Special Advisor on Climate Action of the United Nations High Commissioner for Refugees (UNHCR), commended, AI has the potential to speed up our understanding of natural hazards, analysing large volumes of data (and images) from different sources and improve proactive rather than reactive actions for disaster risk reduction (DRR)[46].

6.1.2.1 AI for modelling: forecasting, and projecting

We are quite familiar with the use of predictive models in weather forecasts. However, AI can help scientists with multiple natural hazards prediction as well. It is a helpful compound and scalable flood prediction instrument, as demonstrated by Feyera Hirpa, a Senior Data Scientist of One Concern Inc., who tested his predicting models during the 2019 flood in Chikuma River in Japan after Typhoon Hagibis[47]. The observed inundation model obtained a good match of the actual flood, validating AI's power for flood prediction. In fact, models might fit the training dataset perfectly well, but there are no guarantees that it will do equally well in real-life scenarios. Promising prediction applications are also seen in wildfire vulnerable areas, noted Helen Li, Senior AI Researcher at the China Academy of Information and Communication Technology (CAICT). However, real-time forecasting is still a struggle for computer-based modellers.

Another challenging example relates to "forecasting the onset, size, duration and hazard of [volcanic] eruptions by integrating observation with quantitative models of magma dynamics", said Corentin Caudron, Research Officer, Research Institute for Development (IRD). However, earthquakes and tremors characteristics can help better understand the manifestation of eruptions and their evolution. All thanks to machine learning (ML), which helped manage and extrapolate vast volcanic-seismic data to achieve high accuracy in forecasting and prediction. To complicate things, every volcano behaves slightly differently from one another, and machine learning has shown to provide a promising volcano-independent forecasting approach. It seems that AI helps accelerate data acquisition and analysis, considering the spectrum of heterogeneity owned by each natural hazard and situation.

6.1.2.2 AI for data monitoring and hazard detection

Andrea Toreti, Senior Scientist/Scientific Officer at the European Commission's Joint Research Centre (JRC) in Italy, showed how artificial intelligence (AI) can help monitor weather-related risks to food security. He introduced the 'Climate Service', a system designed to support informed decisions able to reduce risks and disasters related risks to agriculture with the support of climate variability models. The Climate Service is a tool to detect extreme events, such as droughts, in the agricultural sector, in relation to crop productivity, for example. He strongly believes that technology must be computationally scalable and sustainable to have an impact.

Finally, Nicolas Longépé, Earth Observation Data Scientist, Phi-lab Explore Office, European Space Agency (ESA/ESRIN), highlights the limitations of AI while emphasizing its ability to detect 'near real time' situations

[46] https://blogs.egu.eu/divisions/nh/2021/06/28/artificial-intelligence-for-disaster-management-thats-how-we-stand
[47] https://blogs.egu.eu/divisions/nh/2019/12/16/a-coffee-with-mr-fujitsuka-typhoon-hagibis-and-the-recovery-process

because of the associated unpredictability of the models. The detection of tropical cyclones is one of the core research objectives of the European Space Agency using a visual pattern analyst on atmosphere clouds and satellite images. The Agency also focuses on the detection of wildfires using hyperspectral data. One of the technologies used now is "AI at the edge" or "AI@edge", where AI is deployed directly on the spacecraft, making it more secure, versatile, highly responsive and requiring low data exchange with the user. There are new opportunities for AI in Space and related technologies that can also have an actual application in disaster risk detection, analysis and then reduction.

6.1.2.3 Limitations – Future work on AI tools

We understand that smart and timely decisions are needed to avert, mitigate, and manage all kinds of risks. In this respect, the use of AI in the decision-making process has shown tremendous promises. Despite those promises, the key challenges are:

- to actively involve stakeholders in all phases of the project, building trustful cooperation.
- to transfer usable, useful information to key actors to efficiently communicate the risk and its uncertainty.
- to create hybrid models that would include classic statistics with human behaviours.
- to enhance the accessibility and transparency of data and methods.

6.1.2.4 AI for communication

According to the Coordinator of Global Risk Analysis and Reporting Section, United Nations Office for Disaster Risk Reduction (UNISDR), Adam Fysh, communication in DRR means posing the right questions on who creates the risks and who suffers the consequences of risk. For this reason, stakeholders' involvement is crucial to strengthen the understanding and the response to multiple risks, but only if the key informants are included rather than convinced, and a two-way communication based on trust is built.

One perfect example was suggested by Ioannis Andredakis, a Senior Analyst on Disaster of the Directorate for Civil Protection and Humanitarian Operations of the European Commission. He recalled a couple of years back of a wildfire in Athens in Greece that killed 110 people. The biggest problems raised were two. The first was understanding the level of risk in terms of the number of people involved, how the fire was evolving, in which direction, and how fast. And the second was how to effectively roll out an emergency evacuation plan avoiding fear-related behaviours that would have exposed more people than those already involved. "*With AI, the situation would have been understood rapidly and communicated efficiently, possibly reducing the number of people involved*", he concluded.

Recent experiences with natural hazards show that we still confront challenges regarding the accuracy, reliability and modality of information being communicated and individuals' ability to elicit the appropriate response and accept its uncertainty. "*The risk of being wrong*" is still a big challenge, and recent advanced technology may host more uncertainty that is yet to be considered. However, technology is still an ally in disaster risk analysis and an essential instrument for scientists, industries, and policymakers involved in DRR. AI is a fast-analysis instrument that has not seen its full application in the aftermath of disasters yet. For example, it has not been used to classify the damages (humans still do it), Andredakis reminds. So, AI's deployment is at the utmost priority to enhance the understanding of all phases of disasters, and this can be done by accelerating the development of algorithms that are reliable for our safety.

6.1.2.5 AI for data: monitoring and detecting

One of the challenges regarding extreme weather changes is connected to food insecurity around the world. Food security is also jeopardised by the presence or overabundance of locusts, especially in West Africa, where the crop damage has been estimated to be $2.5 billion in 2003-2005 only. These data are alarming, said Hadia Samil, Researcher at the MILA Quebec Artificial Intelligence Institute. AI can be used to detect in 'real time' the attacks of locusts and predict their movements to some extent by analysing remote sensing images.

6.2 RISK ANALYSIS AND MITIGATION FOR CRITICAL INFASTRUCTURE PROTECTION

Critical infrastructure, encompassing systems vital for the functioning of society, faces an ever-evolving array of threats in today's interconnected world. Ensuring its resilience against various hazards, whether natural or man-made, is of paramount importance. Critical Infrastructure Protection (CIP) is the comprehensive approach adopted to secure these vital systems. The exploration of adverse incidents in critical infrastructures and their interdependencies has garnered significant interest within the industry as well as with the research community. Investigating these failures and their potential cascading effects through interdependencies and assessing the associated risks can be computationally demanding; however, the results can significantly bolster risk assessments and present innovative pathways for risk mitigation in critical infrastructures, smart cities and industrial or in-city environments.

6.2.1 MODELING RISK FOR CRITICAL INFRASTRUCTURE PROTECTION

Inside the National Infrastructure Protection Plan (NIPP)[48], a systematic classification of tools, frameworks, and methodologies is established based on their intended purposes. This categorization primarily focuses on the stage or stages within the risk management framework that these resources support. Following NIPP's security objectives, relevant tools and models should be presented based on specific categories, and namely *(i) Risk Identification (RI), (ii) Risk Impact Assessment (RIA), and (iii) Risk Prioritization (RP) or else Mitigation Planning for decision support (MP)*.

We endeavour to identify and categorize various existing tools and frameworks, thereby establishing a shared foundation for identifying threats and conducting risk assessments. This examination encompasses both conceptual and qualitative studies on infrastructure interdependencies, as well as modeling and simulation techniques. The comparative framework is based on two primary dimensions: the intended purpose of each tool and its technical modeling approach. The following list provides a concise overview of pivotal tools, shedding light on their unique features and capabilities. By harnessing the power of these methodologies and tools, critical infrastructure stakeholders can bolster their preparedness and resilience, ensuring the continued functioning of systems that underpin modern society.

Critical infrastructure modeling encompasses various techniques to develop protective tools. Famous research by Ouyang [75] classifies these methodologies into five main categories:

1. **Empirical Approaches**: Analyse interdependencies using historical data and expert knowledge, enabling risk analysis and mitigation.
2. **System Dynamics Approaches**: Manage complex systems with feedback loops, analysing the connections between infrastructure components.

[48] https://www.cisa.gov/topics/critical-infrastructure-security-and-resilience/national-infrastructure-protection-plan-and-resources

3. **Agent-Based Approaches**: Model infrastructure as agents with rules governing their interactions, simulating complex behaviours.
4. **Network-Based Approaches**: Represent infrastructure as networks, providing insights into topology and performance under hazards.
5. **Other Approaches**: Include economic theory, cellular automata, mathematical equations, and real-time simulations.

Table 1 below shows the civil sectors where each infrastructure can reside or provide services, according to CISA[49] and the corresponding EU EPCIP[50].

Table 1: Critical infrastructure sectors and their abbreviation prefixes.

Sector	Prefix	Sector	Prefix
Chemical	CH	Financial Services	FS
Commercial Facilities	CF	Food and Agriculture	FA
Communications	C	Government Facilities	GF
Critical Manufacturing	CM	Healthcare and Public Health	HPH
Dams	D	Information Technology	IT
Defense Industrial Base	DIB	Nuclear Reactor Materials/Waste	NRMW
Emergency Services	ES	Transportation Systems	TS
Energy	E	Water/Wastewater Systems	W

6.2.2 TOOLS FOR CRITICAL INFRASTRUCTURE ASSESSMENT AND MITIGATION

According to the Cybersecurity and Infrastructure Security Agency (CISA)[51], CIP involves identifying and prioritizing critical assets, assessing vulnerabilities, and implementing strategies to mitigate risks. This protection framework, developed under the National Infrastructure Protection Plan (NIPP)[52], provides a blueprint for enhancing the security and resilience of critical infrastructure in the United States.

In this context, a diverse set of methodologies and advanced tools have emerged to address the multifaceted challenges of critical infrastructure protection. These tools traverse the entire spectrum of risk analysis, spanning identification, assessment, prioritization, and mitigation of vulnerabilities. For instance, methodologies such as RAET, IRRIIS, EURACOM, and BIRR, along with sophisticated tools like NSRAM, collectively contribute to enhancing critical infrastructure security. Notably, CIP/DSS and CIPDSS-DM, developed under the NIPP, stand as comprehensive risk assessment methodologies capable of addressing the unique challenges posed by critical infrastructure. IIM employs system dynamics and probabilistic

[49] https://www.cisa.gov/topics/critical-infrastructure-security-and-resilience/critical-infrastructure-sectors
[50] https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2006:0786:FIN:EN:PDF
[51] https://www.cisa.gov/critical-infrastructure-protection
[52] https://www.cisa.gov/national-infrastructure-protection-plan

simulations to offer insights into risk management. These tools play an indispensable role in the pursuit of robust and adaptive strategies to safeguard critical infrastructure.

1. **RISK ANALYSIS AND EVALUATION TOOLKIT (RAET)**[53]: RAET is an integrative platform which facilitates the complete workflow for cyber-physical risk assessment, i.e., it helps water companies to identify, analyse, evaluate threat scenarios and explore appropriate mitigation options which can manage these threats effectively. RAET binds into a seamless workflow a series of interdisciplinary approaches to synthesize actionable intelligence and support informed decision making. It is comprised of state-of-art tools for fault tree analysis, threat scenario formulation, cyber-physical simulation engines (including hydraulics and quality simulators) that assess the impact of cyber-physical attacks on any water distribution network, results evaluation, and visualization applications, along with cyber-physical risks and assorted mitigation measures database.
2. **IRRIS**[54]: The EU Integrated Project IRRIIS - Integrated Risk Reduction of Information- based Infrastructure Systems - aimed at protecting public life, economy and society depend to a very large extend on the proper functioning of critical infrastructure (CIs) like energy supply or telecommunication. IRRIIS Middleware Improved Technology - a collection of software components, which facilitates IT- based communication between different forms of infrastructure and different infrastructure providers -, and SimCIP (Simulation for Critical Infrastructure Protection), a simulation environment for controlled experimentation with a special focus on CIs interdependencies.
3. **EURACOM**[55]: EURACOM is a methodology and tool used for risk analysis in critical infrastructure protection. It covers all five stages of risk analysis.
4. **BIRR**[56]: BIRR is a methodology or tool employed in critical infrastructure protection for risk analysis, addressing all five stages of risk analysis. U.S. Argonne National Laboratory launched in (2010) the Resilience Index (R.I.) and Better Infrastructure Risk and Resilience (BIRR) methodology for assessing infrastructure risk and resilience to various hazards.
5. **NSRAM (Network Simulation Risk Analysis Model)**[57]: NSRAM stands for Network Security Risk Assessment Modeling. It is a toolset developed by the James Madison University CIPP research team to enable the assessment of network security risks. NSRAM is a complex network modeling and simulation tool used for risk analysis in critical infrastructure protection. It specializes in three sectors.
6. **CIP/DSS (Critical Infrastructure Protection Decision Support System)** [76]: CIP/DSS is a comprehensive risk assessment methodology designed for application across all sectors. It employs system dynamics with continuous time-step simulation. The Critical Infrastructure Protection Decision Support System (CIP/DSS) simulates the dynamics of individual infrastructures and couples separate infrastructures to each other according to their interdependencies. For example, repairing damage to the electric power grid in a city requires transportation to failure sites and delivery of parts, fuel for repair vehicles, telecommunications for problem diagnosis and coordination of repairs, and the availability of labor. The repair itself involves diagnosis, ordering parts, dispatching crews, and performing work. The electric power grid responds to the initial damage and to the completion of repairs with changes in its operating characteristics. Dynamic processes like these are represented

[53] https://uwmh.eu/products/85-raet-the-risk-analysis-and-evaluation-toolkit.html
[54] https://coss.ethz.ch/research/pastprojects/irriis.html
[55] https://cordis.europa.eu/project/id/225579/reporting
[56] https://www.anl.gov/article/better-infrastructure-risk-and-resilience
[57]https://ec.europa.eu/research/participants/documents/downloadPublic?appId=PPGMS&documentIds=080166e5c4bccdd7

in the CIP/DSS infrastructure sector simulations by differential equations, discrete events, and codified rules of operation. Many of these variables are output metrics estimating the human health, economic, or environmental effects of disturbances to the infrastructures.

7. **CIPDSS-DM (Critical Infrastructure Protection Decision Support System - Decision Making)**[58]: CIPDSS-DM is a tool intended to assist analysts and policymakers in evaluating and selecting optimal risk mitigation strategies. It complements CIP/DSS.
8. **CIDA (Critical Infrastructure Dependency Analysis Tool**) [77]: CIDA is a hybrid tool that integrates empirical and network-based approaches, employing growth models and fuzzy logic to consider the effects of dependencies. It covers the last three risk management stages.
9. **Athena** [78]: Athena is a tool primarily designed for risk impact assessment (RIA) and can be used to model different risk events in various sectors.
10. **CARVER+**[59]: CARVER+ is an innovative risk and vulnerability assessment software system which brings your security assessments to life using the CIA's CARVER Target Analysis and Vulnerability Assessment Methodology. CARVER+ is effective at analysing assets in multiple critical infrastructure components for risk identification (RI) and risk prioritization (RP) by using rating matrices to generate hazard maps.
11. **IEISS (Integrated Energy Infrastructure Simulation System**)[60]: IEISS is suitable for risk mitigation planning (RMP) in energy, water, wastewater, nuclear reactor materials, and waste sectors. It simulates dynamic behaviour, including the effects of system interdependencies.
12. **IIM (Infrastructure Impact Model**)[61]: IIM is a continuous input-output model that employs analytical models to determine the impacts of attacks on infrastructures and their cascading effects across interconnected infrastructures. It is used in the energy, water, and wastewater sectors.

Table 2 below maps the aforementioned tools and the relevant sector that they cover [79].

Table 2: Tools and relevant sectors.

Tool Name	Description	Sector
RISK ANALYSIS AND EVALUATION TOOLKIT (RAET)	An integrative platform for cyber-physical risk assessment in water companies, featuring fault tree analysis, threat scenario formulation, simulation engines, results evaluation, and visualization applications.	W
IRRIS	IRRIIS Middleware and SimCIP, an EU Integrated Project aimed at protecting critical infrastructure through IT-based communication and simulation experimentation.	All
EURACOM	A methodology and tool for risk analysis in critical infrastructure protection, covering all five stages of risk analysis.	All
BIRR	A methodology for risk analysis in critical infrastructure protection, addressing all five stages of risk analysis, launched by U.S. Argonne National Laboratory.	All

[58] https://www.osti.gov/biblio/946040
[59] https://www.carverplus.com
[60] https://inldigitallibrary.inl.gov/sti/3489532.pdf
[61] https://inldigitallibrary.inl.gov/sti/3489532.pdf

NSRAM (Network Simulation Risk Analysis Model)	A complex network modeling and simulation tool specialized in risk analysis in critical infrastructure protection, focusing on three sectors.	E, IT, C
CIP/DSS (Critical Infrastructure Protection Decision Support System)	A comprehensive risk assessment methodology employing system dynamics and simulating the dynamics of individual infrastructures and their interdependencies.	All
CIPDSS-DM (Critical Infrastructure Protection Decision Support System - Decision Making)	A tool intended to assist analysts and policymakers in evaluating and selecting optimal risk mitigation strategies, complementing CIP/DSS.	All
CIDA	A hybrid tool integrating empirical and network-based approaches, employing growth models and fuzzy logic to consider the effects of dependencies in the last three risk management stages.	All
Athena	Primarily designed for risk impact assessment (RIA) and modeling different risk events in various sectors.	C, CF, CM, DIB, E, FS, IT, NRMW, WWS, TS
CARVER+	An innovative risk and vulnerability assessment software system using the CARVER Target Analysis and Vulnerability Assessment Methodology to analyse critical infrastructure components for risk identification and prioritization.	HPH
IEISS (Integrated Energy Infrastructure Simulation System)	Suitable for risk mitigation planning (RMP) in various sectors, simulating dynamic behaviour and system interdependencies.	E, TS, WWS
IIM (Infrastructure Impact Model)	A continuous input-output model employing analytical models to determine the impacts of attacks on infrastructures and their cascading effects in the energy, water, and wastewater sectors.	F, E, C, IT, TS, FS

A smaller fraction of tools (5%) extends their coverage to over four risk analysis stages and more than ten sectors. Most of these encompass broad methodologies or originate from the United States, such as CIP/DSS, CIPDSS-DM, CBRSim (Fort Future), and CIMSuite [80].

1. CIP/DSS and CIPDSS-DM: Developed under the National Infrastructure Protection Plan, these tools employ system dynamics and continuous time-step simulation for comprehensive risk assessment across all sectors. CIPDSS-DM aids analysts and policymakers in selecting optimal risk mitigation strategies, synergizing effectively with CIP/DSS.
2. CIDA and Athena: These tools can illustrate cascading effects across all sectors and infrastructure relationships. CIMSuite, employing system dynamics and probabilistic simulations, addresses four risk management stages (RI, RIA, RMP, EE). CIDA, a hybrid tool, integrates empirical and network-based approaches to cover the last three risk management stages (RP, RMP, EE). Athena focuses on risk impact assessment (RIA) and offers versatile modeling capabilities across various sectors. CIDA is the only publicly available tool among these options.

3. CARVER-2: Effective in risk identification (RI) and risk prioritization (RP), these tools analyse critical infrastructure components based on the severity of failure impacts. CARVER-2 utilizes rating matrices and hazard maps to maintain network asset inventories.
4. IEISS and IIM: Suited for risk mitigation planning (RMP) in various sectors, including energy, water, wastewater, and nuclear reactors, these tools simulate dynamic behaviour and system interdependencies. IIM, employing continuous simulation, has broader sector coverage compared to IEISS. IEISS utilizes a multi-agent system with Monte Carlo simulation as a supplementary technique, while IIM employs rating matrices and network theory with continuous time-step simulation.

6.2.3 EUROPEAN PROGRAMME FOR CRITICAL INFRASTRUCTURE PROTECTION (EPCIP)

The European Programme for Critical Infrastructure Protection (EPCIP)[62] is a pivotal initiative within the European Union dedicated to enhancing the security and resilience of critical infrastructure. EPCIP outlines a comprehensive framework that promotes cooperation between EU member states and relevant stakeholders. It emphasizes the importance of risk assessment, cross-sector collaboration, and the development of protective measures.

The general objective of EPCIP is to improve the protection of critical infrastructure in the European Union (EU). This will be achieved by implementing the European legislation set out in this communication. The legislative framework for the EPCIP consists of the following:

- a procedure for identifying and designating European critical infrastructure and a common approach to assessing the need to improve the protection of such infrastructure. This will be implemented by means of a directive.
- measures designed to facilitate the implementation of EPCIP, including an EPCIP action plan, the Critical Infrastructure Warning Information Network (CIWIN), the setting up of Critical Infrastructure Protection (CIP) expert groups at EU level, CIP information sharing processes, and the identification and analysis of interdependencies.
- support for EU countries regarding National Critical Infrastructures (NCIs) that may optionally be used by a particular EU country, and contingency planning.
- an external dimension.
- accompanying financial measures, and in particular the Specific EU Programme on "Prevention, Preparedness and Consequence Management of Terrorism and other Security Related Risks" for the period 2007-13, which will provide funding opportunities for CIP related measures.

The ECPIP action plan has three main work streams:

1. the first relates to the strategic aspects of EPCIP and the development of measures horizontally applicable to all CIP work.
2. the second concerns the protection of European critical infrastructures and aims to reduce their vulnerability.
3. the third is a national framework to assist EU countries in the protection of their NCIs.

The action plan is an ongoing process and regular reviews will be carried out.

[62] https://eur-lex.europa.eu/EN/legal-content/summary/european-programme-for-critical-infrastructure-protection.html

6.2.4 CRITICAL INFRASTRUCTURE WARNING INFORMATION NETWORK (CIWIN)

A warning network (the Critical Infrastructure Warning Information Network or CIWIN)[63] has been set up by a specific Commission proposal for the purposes of exchanging best practices and providing an optional platform for the exchange of rapid alerts linked to the Commission's ARGUS system. The CIWIN network has been developed as a Commission owned protected public internet-based information and communication system, offering recognised members of the EU's CIP community the opportunity to exchange and discuss CIP-related information, studies and/or good practices across all EU Member States and in all relevant sectors of economic activity. The CIWIN portal, following its prototype and pilot phases, has been up and running since mid-January 2013.

Where specific expertise is needed, the Commission may set up CIP expert groups at EU level to address clearly defined issues. Depending on the sector of critical infrastructure, the functions of experts may include:

- assistance in identifying vulnerabilities, interdependencies, and sectoral best practices.
- development of measures to reduce vulnerabilities and of performance metrics.
- formulation of case studies.

6.2.5 EUROPEAN REFERENCE NETWORK FOR CRITICAL INFRASTRUCTURE PROTECTION (ERNCIP)

The European Reference Network for Critical Infrastructure Protection (ERNCIP)[64] is a collaborative network established by the European Commission to facilitate research, development, and innovation in the field of critical infrastructure protection. ERNCIP serves as a platform for knowledge exchange and the development of best practices.

IPSC, under the mandate of the DG Home, in the context of the European Programme for Critical Infrastructure Protection (EPCIP), and with the agreement of Member States, set up the ERNCIP project in 2009. The preparatory phase was successfully completed in November 2010 and the project started its implementation phase in 2011. ERNCIP aims at providing a framework within which experimental facilities and laboratories will share knowledge and expertise to harmonize test protocols throughout Europe, leading to better protection of critical infrastructures against all types of threats and hazards.

Their mission is to foster the emergence of innovative, qualified, efficient, and competitive security solutions, through the networking of European experimental capabilities. ERNCIP is a direct response to the lack of harmonised EU-wide testing or certification for CIP products and services, which is a barrier to future development and market acceptance of security solutions.

ERNCIP plays a pivotal role in advancing the capabilities and preparedness of smart cities and critical infrastructure by promoting research, testing, and the validation of security solutions. It focuses on various critical infrastructure sectors, including energy, transportation, and telecommunications, and encourages the integration of cutting-edge technologies for enhanced security and resilience.

[63] https://home-affairs.ec.europa.eu/networks/critical-infrastructure-warning-information-network-ciwin_en
[64] https://erncip-project.jrc.ec.europa.eu/european-reference-network-critical-infrastructure-protection

7 OVERALL ASSESSMENT PER PANTHEON USE CASES (ALL)

In this chapter, an overall assessment of the under-study regions for the PANTHEON use cases is taking place. In the first section we reference relevant EU projects that share similar characteristics or outcomes to PANTHEON. In the second section, we describe the per-region assessments that will aid in understanding the existing technological landscape and the relevant tools to use for the PANTHEON platform.

7.1 RELEVANT EU PROJECTS

TEMA[65] – Trusted Extremely Precise Mapping and Prediction for Emergency Management. Consortium 20 participants from the EU Funding Program Horizon Europe - Global Challenges and European Industrial Competitiveness - Digital, Industry and Space Duration 48 months Start date 1 December 2022.

SAFERS[66] – Structured Approaches for Forest fire Emergencies in Resilient Societies. Consortium 14 participants from the EU and the United Kingdom. Funding Program H2020 Societal Challenges - Climate action, Environment, Resource Efficiency and Raw Materials. Duration 36 months. Start date 1 October 2020.

INGENIOUS[67] – The First Responders (FR) of the Future: A Next Generation Integrated Toolkit (NGIT) for Collaborative Response, increasing protection and augmenting operational capacity. Consortium 24 participants from the EU, Norway, South Korea, Switzerland and the United Kingdom. Funding Program H2020 Secure societies - Protecting freedom and security of Europe and its citizens. Duration 48 months. Start date 1 September 2019.

SHELTER[68] – Sustainable Historic Environments hoListic reconstruction through Technological Enhancement and community-based Resilience. Consortium 25 participants from the EU, Turkey and the United Kingdom Funding Program H2020 Societal Challenges - Climate action, Environment, Resource Efficiency and Raw Materials Duration. 48 months. Start date 1 June 2019.

FASTER[69] – First responder Advanced technologies for Safe and efficienT Emergency Response (FASTER, 2019) Consortium 27 participants from the EU and Japan. Funding Programme H2020 RIA - Research and Innovation action. Duration 36 months Start date 1 May 2019.

FLOOD-serv[70] – Public FLOOD Emergency and Awareness SERVice. Consortium 12 participants from the EU. Funding Programme H2020 Societal Challenges - Europe In A Changing World - Inclusive, Innovative And Reflective Societies. Duration 36 months. Start date 1 August 2016.

iREACT[71] – Improving Resilience to Emergencies through Advanced Cyber Technologies. Consortium 20 participants from the EU, Norway and the United Kingdom. Funding Program H2020 Secure societies - Protecting freedom and security of Europe and its citizens. Duration 36 months. Start date 1 June 2016.

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[65] https://tema-project.eu/ DOI 10.3030/101093003
[66] https://safers-project.eu/ DOI 10.3030/869353
[67] https://ingenious-first-responders.eu/ DOI 10.3030/833435
[68] https://shelter-project.com/ DOI 10.3030/821282
[69] https://www.faster-project.eu
[70] https://www.floodserv-project.eu/ DOI 10.3030/693599
[71] http://project.i-react.eu (link currently not working)

ANYWHERE[72] – EnhANcing emergencY management and response to extreme WeatHER and climate Events. Consortium 35 participants from the EU, Norway, Switzerland and the United Kingdom. Funding Programme H2020 Secure societies - Protecting freedom and security of Europe and its citizens. Duration 42 months. Start date 1 June 2016.

SAFEDAM[73] - Advanced technologies in the prevention of flood hazards. Consortium 5 consortium members. Funding Programme Poland: National Centre for Research and Development; Defense and Security Programme. Duration 53 months. Start date December 2015.

DRIVER+[74] – DRiving InnoVation in crisis management for European Resilience. Consortium 42 participants from the EU, Norway and Israel. Funding Programme FP7-SECURITY. Duration 72 months. Start date 1 May 2014.

C2IMPRESS[75] - C2IMPRESS is an ongoing Horizon Europe Project, with the aim to increase citizen awareness on multi-hazard risks. The project aims to develop a people-centric instead of the traditional hazard-centric approach and envisages to develop several innovative and holistic tools. Such tools include resilience frameworks encompassing methodologies and guidelines for the enhancement of resilience of citizens and authorities, dynamic models for the accurate prediction of future extreme phenomena, early warning systems, which use and assess big data for the better monitoring and understanding of multi-hazards, and a multi-actor decision support platform for novel and more efficient Disaster Risk Reduction and Climate Change Adaptations strategies.

INDIGO[76] – Innovative Training & Decision Support for Emergency operations. Consortium 8 participants from the EU. Funding Programme FP7-SECURITY - Specific Programme "Cooperation": Security. Duration 36 months. Start date 1 May 2010.

AIDERS[77] - Real-time Artificial Intelligence for DEcision support via RPAS data analyticS[78]. **Grant agreement no:** UCPM-2019-PP-AG/873240. **Duration:** 1 January 2020 – 31 December 2021. **Research area:** Currently, the majority of first responders seeking to introduce Remotely Piloted Aircraft System (RPAS) units into their operations are quickly stumbled upon the deluge of collected data and reside merely on snapshots to inform incident commanders of the situation in the field. The AIDERS project aims at developing application-specific algorithms and novel mapping platform that will harness the large volume of data that first responders are now able to collect through heterogeneous sensors (including visual, thermal and multispectral cameras, LIDAR, CBRN sensors, etc.) on-board RPAS units, and converting that data into actionable decisions for improved emergency response. To address this challenge, the AIDERS project will capitalize on:

1. The long-lasting collaboration of the first responder and technical partners in the consortium to identify which information needs to be extracted from the collected data,
2. Design online machine learning algorithms to process and analyse the received data in real-time in order to build knowledge maps, and

[72] http://anywhere-h2020.eu
[73] https://www.safedam.gik.pw.edu.pl/safedam_eng
[74] https://cordis.europa.eu/project/id/607798
[75] https://www.c2impress.com
[76] http://indigo.diginext.fr
[77] https://civil-protection-humanitarian-aid.ec.europa.eu/funding-evaluations/financing-civil-protection/prevention-and-preparedness-projects-civil-protection/overview-past-track-i-and-track-ii-projects/real-time-artificial-intelligence-decision-support-rpas-data-analytics-aiders_en
[78] https://www2.kios.ucy.ac.cy/aiders

3. Implement novel visualizations that higher-command can use to take intelligent decisions.

The second objective is to deploy the developed AI toolkit in small and large real-life exercises to investigate its potential benefits and capabilities to effectively support the missions of first responders. By the end of the project, the intention is to deliver a stable version of the developed software, made available as an open-source software (OSS) toolkit that can be easily downloaded and installed by first responders. The third objective is to share the knowledge gained in developing the AI toolkit and the experience gained in using it during exercises in: a) courses of the UCPM Training Program (including the Assessment Mission Course), b) workshops conducted in each country of the participating end-user partners of the consortium, and c) conferences and journal publications made by the technical partners of the consortium.

7.2 ASSESSMENT FOR GREECE

According to various reports and assessments issued by both the Greek Ministry of Climate Change[79] and international organisations[80], the top hazards assessed for Greece are the following:

- Extreme weather events: Greece is expected to experience extreme weather events such as heat waves and droughts due to climate change. These events can have moderate to severe impacts on life and health in the country.
- Landslides: Landslide activity in Greece has been increasingly high over the last decade due to urbanization and development in landslide-prone areas, continued deforestation, and extreme meteorological events. Landslides have moderate to severe impacts on the country.
- Floods: Flood hazard and risk mapping have already been conducted in Greece as a result of the EU Floods Directive. However, there are little provisions for comprehensively mapping other hazards and consequent risks.
- Forest fires: Greece is prone to forest fires, which can have severe impacts on the country. The understanding of climate change projections for forest fires is limited at national and subnational levels, and further studies should be developed to be used for disaster risk management.

7.2.1 FOREST FIRES

Forest fires are a significant hazard in Greece, with the country experiencing an average of 1,500 wildfires per year, which burn an average of 20,000 hectares of forest land. The frequency and severity of forest fires in Greece have been increasing in recent years, with the 2018 wildfire in the Attica region being one of the deadliest in the country's history, claiming the lives of 102 people. Fuel management is a critical tool for preventing forest fires and facilitating the work of firefighters. Fuel treatment, such as mechanical removal, grazing, or prescribed burning, is a major component of fuel management. Fuel management programs, fuel and fire breaks, and forest management measures can mitigate the risk and make effective and efficient the control of wildfires. The Greek government has implemented several measures to reduce the risk of forest fires, including the establishment of a national forest fire prevention and management system, which includes the development of a national forest fire risk map and the creation of a national forest fire database.

However, the understanding of climate change projections for forest fires is limited at national and subnational levels, and further studies should be developed to be used for disaster risk management. Climate change is expected to increase the frequency and severity of forest fires in Greece, with projections indicating

[79] https://epiteliki.civilprotection.gov.gr/sites/default/files/PDF/%CE%95%CE%9A%CE%98%CE%95%CE%A3%CE%97%20%CE%91%CE%93%CE%93/en_drm_plan.pdf
[80] https://climateknowledgeportal.worldbank.org/country/greece

that the number of days with high fire danger will increase by 20-30% by the end of the century. The increase in temperature and the decrease in precipitation, combined with the accumulation of fuel due to land abandonment and the expansion of urban areas, are expected to exacerbate the risk of forest fires in Greece.

In addition to fuel management, other adaptation measures can help reduce the risk of forest fires in Greece. Improved land planning and development, building material and design, forest fire risk awareness and sensitization campaigns, and informed wildfire evacuation plans can all contribute to reducing the impact of forest fires. A theoretical analysis of warning systems and public preparedness programs in Greece found a benefit-cost ratio of nearly 40:1 for investing in awareness raising along with fuel management near homes, due to the reduced impact on casualties.

In conclusion, forest fires are a significant hazard in Greece, and the country needs to implement a comprehensive approach to reduce the risk of forest fires. This approach should include fuel management, climate change adaptation measures, and public awareness campaigns. Further research is also needed to better understand the impact of climate change on forest fires in Greece and to develop effective disaster risk management strategies.

Reports state that the Greek government should also prioritize the development of early warning systems and emergency response plans to ensure that wildfires are detected and contained as quickly as possible. One of the challenges in managing forest fires in Greece is the lack of resources and personnel. The country has a limited number of firefighters and firefighting equipment, which can make it difficult to respond to large-scale wildfires. Based on the report[81], the government should invest in increasing the number of firefighters and equipment, as well as in training programs to ensure that firefighters have the necessary skills to respond to wildfires effectively. Another challenge is the lack of coordination between different agencies and stakeholders involved in forest fire management. The government should establish a clear framework for coordination and collaboration between different agencies, including the fire service, forestry service, civil protection service, and local authorities. This framework should include clear roles and responsibilities, as well as mechanisms for sharing information and resources. Finally, it is essential to involve local communities in forest fire management. Local communities can play a critical role in preventing and responding to wildfires, as they are often the first to detect and report fires. The government should work with local communities to develop community-based fire prevention and management programs, including training programs and awareness campaigns. In summary, forest fires are a significant hazard in Greece, and the country needs to implement a comprehensive approach to reduce the risk of forest fires. This approach should include fuel management, climate change adaptation measures, public awareness campaigns, early warning systems, emergency response plans, increased resources and personnel, coordination and collaboration between different agencies, and community-based fire prevention and management programs. By taking a holistic approach to forest fire management, Greece can reduce the impact of wildfires and protect its citizens and natural resources.

7.2.2 EXTREME WEATHER EVENTS

Greece experiences a range of high-impact weather events, including floods, lightning activity, hail, snow/frost, windstorms, and tornados. During the period 2000–2020, there was an increasing trend in the number of weather-related events with socioeconomic impacts. Flash floods were the most hazardous weather-related phenomenon, and despite recent advances and technologies for risk mitigation, flash flood

[81] https://epiteliki.civilprotection.gov.gr/sites/default/files/PDF/%CE%95%CE%9A%CE%98%CE%95%CE%A3%CE%97%20%CE%91%CE%93%CE%93/en_drm_plan.pdf

events with adverse effects have increased during the past two decades. Flash floods were the most hazardous weather-related phenomenon, and despite recent advances and technologies for risk mitigation, flash flood events with adverse effects have increased during the past two decades. Climate change is expected to increase the frequency and severity of extreme weather events in Greece. A study commissioned by the Greek government found that the number of people facing water stress will grow by 3.5 million to nearly 9 million—about 80% of the total population—in a 3°C warming scenario. For all southern European countries, including Greece, mitigation alone is not enough to avoid the adverse impacts of climate change, and adaptation strategies will be needed. Floods are a significant hazard in Greece, with the country experiencing frequent and intense heavy and extreme precipitation events. Available literature shows a clear trend for more frequent and more intense heavy and extreme precipitation events in the future, along with higher flooding risk. The literature review also identified a future increase in the intensification of heavy and extreme precipitation events in the city of Athens; the percentage of precipitation amount due to extreme precipitation for the 2051–2100 period is projected to be almost double the reference period value. Lightning activity is another significant hazard in Greece, with the country experiencing an average of 1.5 million lightning strikes per year. Lightning strikes can cause wildfires, power outages, and damage to infrastructure. Hail is also a significant hazard in Greece, with the country experiencing frequent and severe hailstorms, particularly in the northern regions. Windstorms and tornados are less frequent but still pose a significant risk in Greece. The Attica region is particularly vulnerable to high-impact weather events because the region has faced extensive deforestation and urbanization over the years. The most highly vulnerable areas (regional units) are located near the coastal zone, and as such, they tend to be more densely populated and thus more vulnerable to weather-related phenomena.

7.2.3 LANDSLIDES

Landslides are a significant hazard in Greece, with high occurrence rates in certain areas of the country, such as Western Greece, along the Pindos Mountain range, and in Evia, Magnesia, Pieria (Katerini), Crete, Samos, and Ikaria. Landslides can cause significant damage to infrastructure, property, and human life, as evidenced by the case of Palaio Mikro Chorion, which was destroyed due to debris falls and flows in 1963 and caused the deaths of 13 people. In recent years, the occurrence of landslides in Greece has been increasingly high due to urbanization and development in landslide-prone areas, continued deforestation, and extreme meteorological events, resulting in a significant increase in total economic losses. The National Strategy for Climate Change Adaptation, published by the Ministry of Environment and Energy in 2016, identifies landslides as one of the major climate change effects in Greece, occurring as a cascading event following an earthquake or an extreme weather event (heavy rainfall). The level of understanding of landslide risk in Greece is relatively high, with several studies having been conducted to assess landslide susceptibility and hazard zonation. Koukis et al. (2005) [81] developed a landslide hazard zonation map for Greece, which identified areas of high, moderate, and low susceptibility to landslides based on geological, geomorphological, and hydrological factors. Sakkas et al. (2016) used a weighted linear combination approach to model landslide susceptibility in Greece, validated with spatial and statistical analysis. According to the National Risk Assessment, landslides are identified as a high-risk hazard, with a high likelihood of occurrence and a high potential impact on human life and infrastructure. The report also highlights that the occurrence of landslides is expected to increase due to climate change, with more frequent and intense rainfall events leading to increased soil saturation and instability.

In addition to the National Risk Assessment, several other studies have been conducted to assess the impact of climate change on landslide risk in Greece. For example, a study by Kotroni et al. (2017) [82] used a regional climate model to project changes in precipitation patterns in Greece, finding that the frequency and intensity of extreme precipitation events are expected to increase in the future, leading to an increase in landslide risk [83]. Another study by Papadopoulos et al. (2018) [84] used a combination of climate and landslide models to assess the impact of climate change on landslide risk in the Peloponnese region of Greece, finding that the number of landslides is expected to increase by up to 50% by the end of the century [85]. The impact of landslides on the Greek economy is significant. According to the Bank of Greece, the total economic losses due to landslides in Greece between 2000 and 2010 amounted to approximately €1.5 billion.

In addition to direct economic losses, landslides can also have indirect impacts on the economy, such as disruptions to transportation networks and damage to critical infrastructure, including water supply systems and power grid. To mitigate the impact of landslides in Greece, several measures have been proposed. These include the development of early warning systems, the implementation of land-use planning and zoning regulations, and the use of engineering measures such as slope stabilization and drainage system. The National Disaster Risk Management Plan also includes measures to reduce landslide risk, such as the identification of high-risk areas and the development of emergency response plans.

In conclusion, landslides are a significant hazard in Greece, with high occurrence rates in certain areas of the country. The impact of climate change is expected to increase the frequency and intensity of landslides in the future, leading to significant economic losses and impacts on infrastructure and human life. To mitigate the impact of landslides, a range of measures have been proposed, including early warning systems, land-use planning and zoning regulations, and engineering measures such as slope stabilization and drainage systems.

7.2.4 FLOODS

Greece has a long history of devastating floods that have caused significant damage to infrastructure, property, and human life. The National Risk Assessment identifies river floods as the most significant flood hazard in Greece, with a high likelihood of occurrence and a high potential impact on human life and infrastructure.

According to the European Environment Agency, Greece is one of the countries in Europe most affected by river floods, with an average of 1.5 flood events per year between 1980 and 2010 [86]. The cost of river floods in Greece is also significant, with the World Bank estimating that the average annual losses for residential properties from current (2020) river flooding at the highest administrative division level for EU Member States is €1.2 billion.

The level of understanding of flood risk in Greece is relatively high, with several studies having been conducted to assess flood susceptibility and hazard zonation [87]. The EU Floods Directive, implemented in Greece in 2007, requires the development of flood hazard and risk maps for all river basins and coastal areas. As a result, flood hazard and risk mapping have already been conducted in Greece, with the development of flood hazard maps for 33 river basins and flood risk maps for 14 river basins. Regarding climate change projections, extreme weather events such as heavy rainfall and flash floods are expected to increase in frequency and intensity in Greece, leading to an increase in flood risk. The National Strategy for Climate Change Adaptation identifies river floods as one of the major climate change effects in Greece, with an increase in the frequency and intensity of extreme precipitation events leading to increased river discharge and flood risk.

To mitigate the impact of floods in Greece, several measures have been proposed. These include the development of early warning systems, the implementation of land-use planning and zoning regulations, and the use of engineering measures such as the construction of flood protection structures and the restoration of natural floodplains. The National Disaster Risk Management Plan also includes measures to reduce flood risk, such as the identification of high-risk areas and the development of emergency response plans.

Multiple reports signify floods as a significant hazard in Greece, with a long history of devastating floods that have caused significant damage to infrastructure, property, and human life. The level of understanding of flood risk in Greece is relatively high, with flood hazard and risk mapping having already been conducted in the country. The impact of climate change is expected to increase the frequency and intensity of floods in the future, leading to significant economic losses and impacts on infrastructure and human life. To mitigate the impact of floods, a range of measures have been proposed, including early warning systems, land-use planning and zoning regulations, and engineering measures such as the construction of flood protection structures and the restoration of natural floodplains. In addition to these measures, there are also efforts to improve flood risk management in Greece through international cooperation. For example, the European Union's Civil Protection Mechanism provides support to Member States in the event of natural disasters, including floods[82]. Greece has also participated in several international projects aimed at improving flood risk management, such as the FloodProBE project, which developed a framework for assessing the effectiveness of flood protection measures[83]. Also, Flood Observatory[84]and FloodHub[85] are two web tools that can be used to extract information concerning historical data for floods in Greece.

Overall, while floods are a significant hazard in Greece, the country has made significant progress in understanding and managing flood risk. However, with the impact of climate change expected to increase flood risk in the future, continued efforts will be needed to mitigate the impact of floods and protect infrastructure and human life.

7.2.5 WORLD BANK - ASSESSMENT OF HEATWAVES IN GREECE

A study from the World Bank's Climate Change Knowledge portal[86] presents the compounded risk categorization of temperature-based heat and population for the country. It showcases an assessment of the impacts of climate change on Greece, focusing on the risks posed by heatwaves. By analysing historical and projected climate data, as well as socio-economic factors such as population density and poverty, this study aims to provide a comprehensive overview of the challenges faced by Greece and the adaptation measures that can be taken to address them.

Greece is a country that is particularly vulnerable to the impacts of heatwaves due to its location in the Mediterranean region and its high population density in urban areas. The assessment of heatwaves in Greece is based on historical and projected climate data, which indicates that the frequency, intensity, and duration of heatwaves are expected to increase in the coming years. The compound risk categorization of temperature-based heat and population for Greece shows that the seasonality of highest heat risks may expand later in the century, particularly for higher emission pathways. The heatplot for hot day categorization for Greece, based on SSP5-8.5 and the 50th percentile, shows that the risk factor categorization is expected to increase over time. The socio-economic backdrop against which one needs to later assess heat risks is explored in Section II: Population and Poverty Dynamics. This section highlights the importance of understanding the social and economic factors that contribute to vulnerability to heatwaves, such as poverty, age, and health status. To address the risks posed by heatwaves in Greece, it is important to implement

[82] European Commission. 2021. "Civil Protection Mechanism".
[83] FloodProBE project. 2017. "FloodProBE: Flood Risk Management in the Black Sea Basin."
[84] http://floodsobservatory.blogspot.com/http://floodsobservatory.blogspot.com
[85] https://enigma.space.noa.gr/index.php/web-services/floodhub
[86] https://climateknowledgeportal.worldbank.org/country/greece

adaptation measures that focus on reducing exposure and vulnerability. These measures may include improving urban planning and design to reduce the urban heat island effect, increasing access to cooling centres and public spaces, and improving public health systems to better respond to heat-related illnesses. Overall, the assessment of heatwaves in Greece highlights the urgent need for action to address the risks posed by climate change. By implementing effective adaptation measures, it is possible to reduce the impacts of heatwaves and protect the health and well-being of the population.

The impacts of climate change on Greece are expected to be significant, particularly in relation to heatwaves. Historical and projected climate data indicate that the frequency, intensity, and duration of heatwaves are expected to increase in the coming years, which will have a range of impacts on human health, infrastructure, and natural ecosystems. In addition to heatwaves, Greece is also vulnerable to other climate-related hazards such as droughts, floods, and wildfires. These impacts are likely to be exacerbated by socio-economic factors such as population density, poverty, and urbanization. However, by implementing effective adaptation measures, it is possible to reduce the impacts of climate change and protect the health and well-being of the population. Certain sectors and regions of Greece that are particularly vulnerable to the effects of climate change. For example, urban areas with high population density are at greater risk of heatwaves due to the urban heat island effect, which can exacerbate the impacts of extreme heat. Coastal regions are also vulnerable to sea-level rise and storm surges, which can lead to flooding and erosion. In addition, certain sectors such as agriculture and tourism are likely to be impacted by changes in temperature and precipitation patterns.

7.2.6 ΑΤΛΑΣ - NATURAL RISK INFORMATION AND MANAGEMENT PLATFORM

The ATLAS[87]web application aims to gather all geospatial information and knowledge to bridge the knowledge gap regarding the impacts of past events and the management of potential future events in the Attica Region. In this context, the application, by incorporating relevant data and information on prevention, preparedness, natural disaster occurrence, and the management of emergency needs arising from them, will assist in supporting disaster risk management actions at the regional or local level. It will also serve to inform the local population and visitors to the Attica Region.

The application encompasses knowledge and information generated within the framework of the project, including information related to four specific risks: earthquakes, wildfires, floods, and extreme weather phenomena. The application provides all the necessary tools and functions which, in combination with the relevant information, make it a significant tool for the Attica Region in achieving the aforementioned goals. It is open and freely accessible from any device and is continuously updated in terms of its data and functionalities.

7.2.7 COPERNICUS ASSESSMENT - USE CASE PILOT AREA OF ATTICA REGION

In the realm of critical infrastructure protection and civil security, timely and accurate information is paramount to mitigate the impact of disasters. On the afternoon of 17 July 2023, an ongoing wildfire ignited in eastern Attica, Greece, necessitating immediate response efforts. To support the assessment of the wildfire's extent and the damage it had caused, Copernicus EMS Rapid Mapping was activated. This chapter presents a comprehensive overview of the activation, the data sources and analysis employed, and the subsequent response efforts.

[87] https://pafsaniasportal.geol.uoa.gr/portal/apps/sites/#/project_frontpage/pages/atlasplatform

7.2.7.1 Activation Overview

The activation of Copernicus EMS Rapid Mapping was prompted by the wildfire incident in eastern Attica. The event, characterized by its rapid spread through low vegetation, posed a significant threat to the region. Activation aimed to provide initial rough estimation products that would aid in assessing the wildfire's scope and impact, thus enabling informed decision-making by authorities and response teams. Further details on this activation, including service conditions and specific information on the event, can be accessed via the provided QR code or the following link: EMSR672 Activation Details.

7.2.7.2 1Data Sources and Analysis

To facilitate an accurate assessment, a combination of pre-event and post-event satellite imagery was employed. The pre-event image utilized was sourced from ESRI World Imagery, acquired on 14 April 2022, with a resolution of 0.6 meters.

The post-event image, derived from Pléiades-1A/B, was acquired on 19 July 2023 at 09:44 UTC, with a resolution of 2.0 meters. These images were utilized as background references for analysis.

Figure West Attica EMS map product. Further estimates have been made using Sentinel-2 satellite images and uploaded on Sentinel hub Playground[88].

7.2.7.3 Base Vector Layers

A robust set of base vector layers, including OpenStreetMap, Wikimapia.org, GeoNames 2015, Corine Land Cover (CLC) 2018, EuroBoundaryMap 2017, Inset maps from JRC 2013 and GISCO 2010, Natural Earth 2012, CCM River DB, and GeoNames 2015, were integrated into the analysis. These vector layers provided essential geographic context for the assessment.

7.2.7.4 Population Data and Digital Elevation Model

Population data was sourced from the GHS Population Grid © European Commission, 2022. A Digital Elevation Model (DEM) derived from COP-DEM-EEA-10-R product © DLR e.V. (2014-2018) and © Airbus Defence and Space GmbH (2020) was utilized for terrain analysis. Both datasets were essential in understanding the potential impact of the wildfire on populated areas and the local topography.

A thematic layer, crucial for assessing the wildfire's impact, was derived from the post-event satellite image using visual interpretation techniques. This layer provided critical insights into the extent of the wildfire-affected areas and the severity of damage.

7.2.7.5 Response and Further Analysis

In addition to the initial rough estimation products provided by Copernicus EMS Rapid Mapping, further analysis and estimates were conducted using Sentinel-2 satellite images. These supplementary estimates were uploaded and made accessible through the Sentinel Hub Playground, offering an enhanced understanding of the wildfire's evolution and impact.

The activation of Copernicus EMS Rapid Mapping in response to the wildfire in eastern Attica, Greece, exemplifies the critical role of advanced geospatial technologies and data analysis in disaster management. By leveraging a diverse range of data sources and analysis techniques, responders and decision-makers were equipped with vital information to assess and respond to the wildfire effectively. This chapter underscores

[88] https://apps.sentinel-hub.com/sentinel-playground

the importance of timely and accurate information in protecting critical infrastructure and ensuring civil security in smart cities[89].

7.3 ASSESSMENT FOR FRANCE

The situation in France is very similar to the one in Greek. A lot of projects deal with environment modelling and use scientific models to play simulated crises.

The pilots selected for France (Paris) are:

- Terrorist attack,
- Centennial flood.

For terrorist attacks, a high focus has to be put on the vulnerability of critical infrastructure and on the access to essential locations and facilities (location of the events, hospitals, etc.). The geography per se is in general less crucial. The main characteristic of this type of crises is that location, dates and mode of action is hardly predictable with the requested precision to plan the reaction in detail.

For the centennial flood, a lot of work has already been done. PANTHEON will put the emphasis on the digital twins.

[89] https://emergency.copernicus.eu/EMSR672

8 CONCLUSIONS

The PANTHEON project focuses on the cold planning period, the aim being to feed digital models, whether in 2D or 3D, which models will then be used to perform the risk assessment, to refine the procedures for deploying rescue means and the preventive training of these teams in charge of these operations.

In this context, heavy airborne means, or even stratospheric platforms, have the advantage of being able to cover huge geographic surfaces such as, for example, a complete region or a large city of several hundred thousand people, with delivery of high-quality data. They will therefore be deployed, for example, to scan wooded areas or map the aquifer basins of rivers likely to overflow.

Conversely, small drones will be used to scan small areas ranging from 1 hectare to an area covering a small town (several thousand people). The main objective will be to build 3D visualization models by photogrammetry or 2.5D extrusion. In the same framework, small aircrafts will be used to scan and map slightly larger areas such as, for example, a complete river valley or a medium-sized city (several tens of thousands of people).

Regarding more specific needs, particularly in terms of exotic payloads other than RGB, LIDAR or IR sensors, the use of drones will be favoured because of their ability to approach the areas to be analysed and their flexibility, this requirement often being required by the relevant payloads (Analysis of air pollutants, temperature sensors, etc.).

From the environment modelling, PANTHEON will develop the societal models to study the vulnerability of the cities as regards the chosen scenarios, which mean getting the data on the critical infrastructures (transport, energy, water and of course all centres and facilities that will be used in the response phase.

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