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Translate Data Into Meaning:

integration of meteorology and geomatics to generate meaningful information for decision makers

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1. Introduction

The main objective of this thesis is to provide guidance on how to identify and characterize the needs for meaningful and usable information among various users of meteorology, including members of the public, emergency managers, other government decision makers, and private-sector entities, both direct users and intermediaries. To do so, it is first necessary to analyse which data, tools and information are available, secondly to understand how users and especially users who have to take decisions based on weather variability interpret and use the weather information (Heimann, 1993, Abrahamson et al., 2008, Cristofori et al. 2014) and finally to find solutions to adapt the weather information to specific end-users requirements (Bartzokas et al., 2010; Gracia et al. 2014).

A variety of actors at all scales and acting in different domains such as emergency management (Braman, et al. 2010, tourism (Lohmann and Kaim, 1999), agriculture (FAO and WFP, 2010; Haile, 2005), sports and leisure (Lobozewicz, 1981, Pezzoli et al, 2010; Pezzoli et al. 2012) and commercial activities, are becoming more aware of the challenges and opportunities that meteorological data analysis poses for their operational goals.

The increasing availability of meteorological data (observational records, radar and satellite, numerical weather prediction models) during the last decades coupled with a rapid improvement in technology led to the widespread dissemination of the weather information to a variety of users on a regular basis (Bhatt et al., 2010). The content of the disseminated weather information varies according to the issuing organization, the type of assessment performed and the form of dissemination used. Particularly through the internet and mobile application all users, despite their varied background, can access to big amount of data with a high potential to gather essential input that can significantly help their decisions. Some examples can include the development of early warning systems for disaster risk reduction, the availability of climatological analysis for climate change resilience and adaptation, the monitoring and forecasting of precipitation anomalies for food and water security as well as the development of very detailed weather analysis for high level sport performance and health or the daily weather bulletins disseminated to the public by regional and national weather services. In addition the improvement of forecast skills in recent years have contributed to the increased interest of users in receiving weather inputs and in using them as a base information for their decisions (Bröcker & Smith, 2007; Joslyn & LeClerc, 2012).

At the same time, providers of weather or climate information are learning that simply creating and disseminating information without context does not necessarily serve the requirements of specific users (Dilling and Berggren, 2014). One of the main issues is related to the scientific approach of weather analysis and to the representation of results, which are hardly understandable for non-technical users and therefore not easily usable to make decisions . As a result, there are several researches aiming at finding new ways of supporting decision making by supplying easy to use information. Many of these researches suggest that much more consultation with stakeholders is necessary in order to effectively serve their needs and provide usable information (Dilling and Lemos 2011; Cash et al. 2006; Lemos and Morehouse 2005). While this is undoubtedly true, there is also in many cases an existing wealth of experience understanding needs of stakeholders that could be assessed before additional interaction is warranted. For instance users do not need data or hardly accessible scientific analysis results; users need an information able to immediately address key messages in a way that can help on the one hand to better contextualize main issues and on the other hand to set priorities and alternative strategies.

Geographical Information Systems (GIS), provide essential spatial analysis capabilities for the identification of problems, gathering information relevant to that problem, develop alternative solutions, decide which solution best solves the problem implement that solution (Hedia and Goze, 2005).

Moreover map stimulates visual reasoning and decision-making of users by activating brain functions along visual processing paths. The map as a system of conventional cartographic signs, triggers complex visual impulses in the brain. This visual information processing evokes the selection of relevant visual features, supports higher cognitive processes (e.g. knowledge formation, hypothesis generation, judgement) and introduces relevant physical actions, (e.g. eye movements) (Swienty 2008). Since the respective user of cartographic representations is in the focus of interest of map making and map use, contributions to the further development of the conceptions of cartography as seen from the user's side are of interest.

Therefore within this research, a methodology for the integration of meteorological data and GIS capabilities is investigated and applied to three different end users having similarities and differences. Scientific analysis methodologies, results and cartographic products are adapted to specific requirements, experience and perceptions of the three different users.

2. Science, Environment and Decision Making

This paragraph aims at presenting main issues, challenges and opportunities of the use of decision support tools for helping people to better understand the complex interactions existing between the environment and the human activities. Firstly the basis of decision making are described, secondly some of the main actors interested in the analysis of the environmental variations and changes are presented, thirdly the main environmental factors affecting human activities and life are analysed and finally a brief description of decision systems tools is outlined.

2.1 Bases of decision making

Decision making is the study of identifying and choosing alternatives based on the values and preferences of the decision maker. Making a decision implies that there are alternative choices to be considered, and in such a case we want not only to identify as many of these alternatives as possible but to choose the one that has the highest probability of success or effectiveness and best fits with our goals, desires, lifestyle, values, and so on (Harris, 2012). Within the decision making process the first priority is to define who are the decision makers and the stakeholders involved in the decisions, since an early identification of these actors reduces the possible disagreement about problem definition, requirements, goals and criteria (Baker et al. 2001). According to Baker et al. (2001) a general decision-making process can be divided into eight main steps:

- STEP 1 Define the problem
- STEP 2 Determine the requirements that the solution to the problem must meet
- STEP 3 Establish goals that solving the problem should accomplish
- STEP 4 Identify alternatives that will solve the problem
- STEP 5 Develop evaluation criteria based on the goals
- STEP 6 Select a decision-making tool
- STEP 7 Apply the tool to select a preferred alternative
- STEP 8 Check the answer to make sure it solves the problem

Therefore after having defined the different users of the scientific analysis that has to be performed it is essential to accurately assess the users' needs. The users' needs assessment should be performed by building relationship with them to understand the operational context, the perception, the temporal and the spatial scale of actions and decisions. This phase is essential in order to define the key environmental variables that might affect the decision process, to choose the more appropriate methodologies for the data analysis and finally to implement tools and services that can facilitate the identification of main issues, alternatives and solutions within the specific context.

2.2 Users of the environmental information

The interaction between weather, climate and the natural environment results in a complex system that has significant impacts on a variety of fields including human and animal health, food security, water resources management, land use planning, leisure sport and tourism. Therefore users of the information derived from the analysis of this complex systems are characterized by different background, experience and needs. Decision support tools have to help decision-makers in making quantitative and qualitative analysis of the interactions between weather, climate, the environment assessing also the impacts on the society and the ecosystems.

Depending on the specific context in which decision makers work the developed tools have to be set differently considering different environmental variables, different visualization of the information and different analysis.

One of the most common application of decision support tools is related to practitioners operating in the field of disaster risk reduction. These users need mainly information and tools able to address several issues including:

1. assessment of location, type, frequency or probability of the hazard
2. integration of vulnerability and exposure with the hazard
3. assessment of the potential impact of hazard on population, properties and infrastructures
4. monitoring of an ongoing disaster
5. determination of different risk levels to identify acceptable levels of risk
6. assessment of risk reduction measures

The tools for risk identification may include local, regional, national or global assessment to provide an information targeted to specific needs. For example, institution working at a global scale would need to derive an immediate overview of nations or regions most at risk. On the other hand a regional institution might need to go into a more detailed analysis of infrastructures or population most at risk.

In the fields of human health, water and food security the assessment of weather and climate data is essential as well as the integration of these data with socio-economic and geographical aspects. Within a context of climate variability and change, the challenges related to an accurate assessment of environment and human relationships is crucial. Climate and weather sensitive analysis should include environmental but also economic, ecologic and social aspects providing the possibility of performing complex multi-sectoral and multidisciplinary analysis and translating results in easy to understand messages that highlight opportunities, challenges, alternatives and solutions. Also in this case the choice of the spatial and temporal scale more suitable for the requirements of the specific analysis is essential.

Environmental information plays a crucial role also in high level sport performance, especially in outdoor activities. During the past decade several research have been investigating the effects of environmental conditions on sport performance and more generally on human health. Results of accurate and adapted analysis allow not only to set the best winning strategy during a race but also to select the best technology and materials or to plan the more appropriate training. However the operational use of decision support tools that integrate climatological and weather parameters in the sport performance analysis are still at an early stage. This is mainly related to the uncertainty and complexity of environmental analysis results. Therefore a significant effort in simplifying the information by accurately assessing the priorities and perception of this specific kind of users is considered crucial to enhance the confidence in the reliability and usability of science-technology as a decision support tool.

2.3 Key environmental factors

There is a multitude of environmental factors that can have an impact on human activities, life and the environment and therefore significantly affecting our decisions. The interactions between people and the environment may involve different perceptions depending on the temporal scale (a single moment, the past, the future, the near real-time), the spatial scale (local, regional, global), the systems involved in the interaction (human, social, economic, ecologic, biophysical). Therefore is hard to define a specific set of key environmental variables that have to be taken into account while developing a decision support analysis or tools.

Variables including temperature, rainfall, sea level, river discharge are some of the most common factors that provide an estimation of hazard to be used into risk and resilience support strategies.

Also factors like the state of the vegetation, the availability of surface and ground water or the humidity of the soil and the land use are essential to address water resource management and food security issues. To address ecological issues it is essential to consider additional factors such as the state of the atmosphere, the emissions, potential changes in life style and productions, etc. Considering human health many systems take into account both weather or climate data and consideration about diseases occurrence, availability and quality of health resources, age or gender. Despite this multitude of factors that may contribute and interact, it should be noted that the weather and the climatological parameters play a crucial role in the relationship between people and the environment. It is therefore fundamental on the one hand to rely on accurate and reliable data and on the other hand to effectively integrate weather and climatological analysis with the additional factors that can help in assessing impacts.

2.4 Decision Support systems

The realization of a Decision Support Systems (DSS) is located in the whole evolution of the methods and tools of the geographical information science. There is no formal method of production of DSS (Prévil et al. 2004). A real DSS should not come down to an integrator of models in which the understanding of the decision-making problem is neglected. The DSS must not be treated as a tool of simply overlaying of features of territorial data and even less as an interface press-buttons to excite a set of algorithms in more or less sophisticated simulation software. The DSS has to answer fundamentally to territorial decision-making problems. Numerous so-called integrated systems neglect simply the underlying decision-making problem and do not often constitute anything more than a platform where the only effort of integration applies to the format of the data in a way that the user does not have to go through too much trouble to make one interface compatible with the other (Cesur et al., 2004; Andreu et al., 1998; Dieulin and Boyer, 2003). The application of the DSS comes along with technological, organizational and important social implications involved its application. The DSS should cover the following operational specificities a) socio-constructivist and contextualist aspects of learning, b) multicriteria approaches to decision theory, and c) methodologies concerning the science of geographical information. DSS in Emergency Management can be treated as a way of learning (key environmental issues) and a territorial long-term realization, aiming at giving to decision-makers and stakeholders of the management, a complex system, based on the management of the territorial information (Longley et al., 2005). The method of implementation of an DSS is not intended to replace the political debate or the human decision. The end aims at first at taking into account the limited rationality by the territorial decision (Rosenhead, 2001), to inform the steps of a decisional territorial process (Carver et al., 1998) and to organize the actions of the decision-making (Heywood et al., 2006). The application of a DSS requires a patient and rigorous work which has to start with the construction of the decision-making stakes followed by an effort to structure the objects of territorial processes. In the case of a territorial problem, the geomatics tools and modelling can help in putting together the main facts, actions, flows or phases of activities of the territorial processes (Heywood and Carver, 1994; Hill et al., 2005). The objective of appropriation by the stakeholders of the territorial decision must be always present in all the steps (Prévil et al., 2004).

3. Meteorological Data and Products

A big amount of meteorological data is currently available and the amount of available data is expected to increase in the following years.

Super computers along with big meteorological datasets can allow a variety of actors to receive essential information for different purposes that span from the monitoring of real-time meteorological conditions to the forecasting of expected weather conditions within the following days or to the analysis of the climatology covering longer time periods like months or years.

Meteorological and climatological data are disseminated mainly through the internet or through public and private data bases depending on the organization in charge of the measurement and the dissemination.

There are several kinds of data such as ground based stations measurements, moving stations observation data, radio soundings, remote sensing data, numerical weather prediction models reanalysis and forecasts.

Key issues related to the availability of such a big amount of data are mainly related to:

- the spatial distribution of data
- the temporal scale coverage
- the accuracy and reliability of data
- the suitability of data to the requirements of specific operations

This chapter presents an overview of the recent methodology for the monitoring and forecasting of environmental variability, the acquisition of data and the validation of measurements, the issuing of weather predictions including narrative weather bulletins or web based Early Warning Systems and finally some key concepts related to the accuracy, reliability and probability of occurrence.

3.1 Monitoring and Forecasting

The distinction between monitoring and forecasting relates to the Weather forecasting is the attempt by meteorologists to predict the state of the atmosphere at some future time and the weather conditions that may be expected. On the other hand the monitoring relates to the real-time situation or to the analysis of past data in order to derive a variety of analysis such as trends, anomalies, extremes.

The forecasting in normally performed using Numerical Weather Prediction (NWP) Models. NWP is focused on taking current observations of weather and processing these data with computer models to forecast the future state of weather. Knowing the current state of the weather is just as important as the numerical computer models processing the data. A growing number of entirely private companies compete to sell weather forecasts to a wide range of end users. Although a few of these companies are able to some extent to run their own proprietary numerical models, most of them need access to basic numerical model outputs from national weather agencies. For example, operational forecast products from the American Global Forecasting System (GFS) can be acquired free of charge from the US National Centers for Environmental Predictions (NCEP). Private companies can also buy products from the Met Office (forecasts and observations) under conditions laid down by ECOMET, the interest consortium of the national meteorological services of the European Economic Area (http://www.meteo.oma.be/ECOMET/).

On the other hand Earth Observation (EO) or satellite remote sensing offers unique capabilities to perform a monitoring of the current state of the environment. Its simultaneous area wide and transboundary coverage provides a uniform spatial information layer to correlate or extrapolate isolated field data. It thus can be a cost efficient and objective mapping and monitoring instrument. There is one main issue related to both NWP and to EO data: they are not a stand-alone tools but require ground truthing and needs to be integrated and assimilated by means of geographical information systems, data modelling and decision support systems with other available information and data like well information or geological maps.

In the following sub-paragraphs the most common NWP models and RS data for the forecasting and monitoring of weather parameters applied to decision making are illustrated.

3.1.1 Mesoscale models

A mesoscale model is a numerical weather prediction model with sufficiently high horizontal and vertical resolution to forecast mesoscale weather phenomena. These phenomena are often forced by topography or coastlines, or are related to convection and they are essential in tactical situation where real-time observations need to manage with visibility, turbulence, sensible weather or sea states. Physical laws of motion and conservation of energy govern the evolution of the atmosphere. These laws can be expressed by a series of complex mathematical equations that make up the core of numerical weather prediction systems. Each variable in the model represents a different aspect of the weather (wind, pressure, etc.). Through the model we can guess the evolution of the system starting from some initial values. Unfortunately at this point we can find one of the most critical issues: the boundary conditions. They refer to the initialization meteorological conditions, represented mathematically, at the edges of the area of the model run. Calculated model fields must be consistent with these boundary conditions.

It turns out that most mesoscale models rely on comparatively coarse resolution global or regional models with substantially larger grid spacing to provide them their initial and boundary conditions (Figure 3.1). Of course, a global model with the same resolution and physics as a mesoscale model is superior to a version covering a limited domain because there are no boundary condition problems. Moreover a composite global model built from many mesoscale models is not computationally practical for short-term forecasts at the present time. For now, most mesoscale models can only be as good as the information fed into them from the larger scale model output.

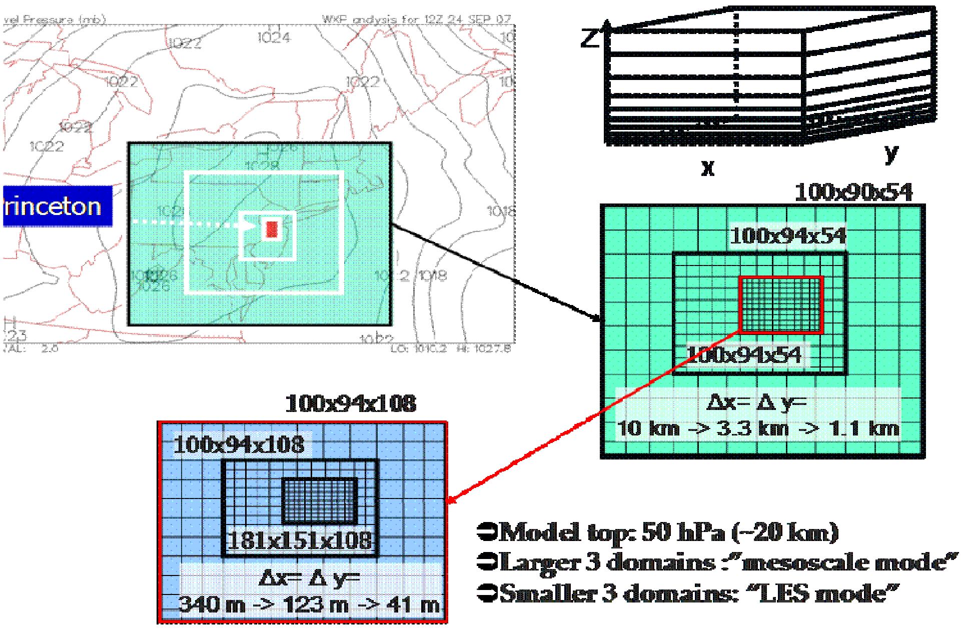


Figure 3.1 Initialization of a mesoscale model with a global model (source http://efm.princeton.edu/)

Mesoscale models are run at varying horizontal resolutions with grid spacing typically less than 30 km. As a result of their relatively fine resolution, these models are usually run over a limited area. Combining many of them, each one characterized by its initialization values and conditions, we can get a global weather overview covering regions where environmental conditions change rapidly too without losing precision. Mesoscale models cannot resolve features and/or processes that occur within the context of a single grid box. Local flows, swirls, or obstacles are not taken into account in a single cell space. Friction is larger near tall trees and buildings than it is over open areas. We cannot realistically expect weather models to resolve features at this scale, no matter how high the resolution. As a result, they must account for the total effect of these obstacles and surfaces on the ow with a single number that represents friction within the grid box. The method of accounting for such effects, without directly calculating them, is modelling the effects of a process (emulation) rather than modelling the process itself (www.meted.ucar.edu).

Many known processes are not taken in account too: soil moisture and evaporation, air convection, sun radiations reflection.

3.1.2 The Global Forecast System (GFS)

The Global Forecast System (GFS) is a weather forecast model produced by the National Centers for Environmental Prediction (NCEP). Dozens of atmospheric and land-soil variables are available through this dataset, from temperatures, winds, and precipitation to soil moisture and atmospheric ozone concentration. The mathematical model is run four times a day, and produces forecasts for up to 16 days in advance, but with decreased spatial resolution after 10 days. The forecast skill generally decreases with time (as with any numerical weather prediction model) and for longer term forecasts, only the larger scales retain significant accuracy. It is one of the predominant synoptic scale medium-range models in general use. The entire globe is covered by the GFS at a base horizontal resolution of 18 miles (28 kilometers) between grid points, which is used by the operational forecasters who predict weather out to 16 days in the future. Horizontal resolution drops to 44 miles (70 kilometers) between grid point for forecasts between one week and two weeks. The GFS model is a coupled model, composed of four separate models (an atmosphere model, an ocean model, a land/soil model, and a sea ice model), which work together to provide an accurate picture of weather conditions. Changes are regularly made to the GFS mode to improve its performance and forecast accuracy.

NOAA-GFS data are available at http://nomads.ncdc.noaa.gov/data/gfs4/ having a 0.5 resolution and a 6h temporal resolution at global scale (Figure 3.2). The dataset is stored as a GRIB2, format that contains one or more data records, arranged as a sequential bit stream. Each record begins with a header, followed by packed binary data. Data can be downloaded as vector as a raster. Raster normally allow more flexibility to be overlaid with geographic reference layers allowing users to make different kind of analysis

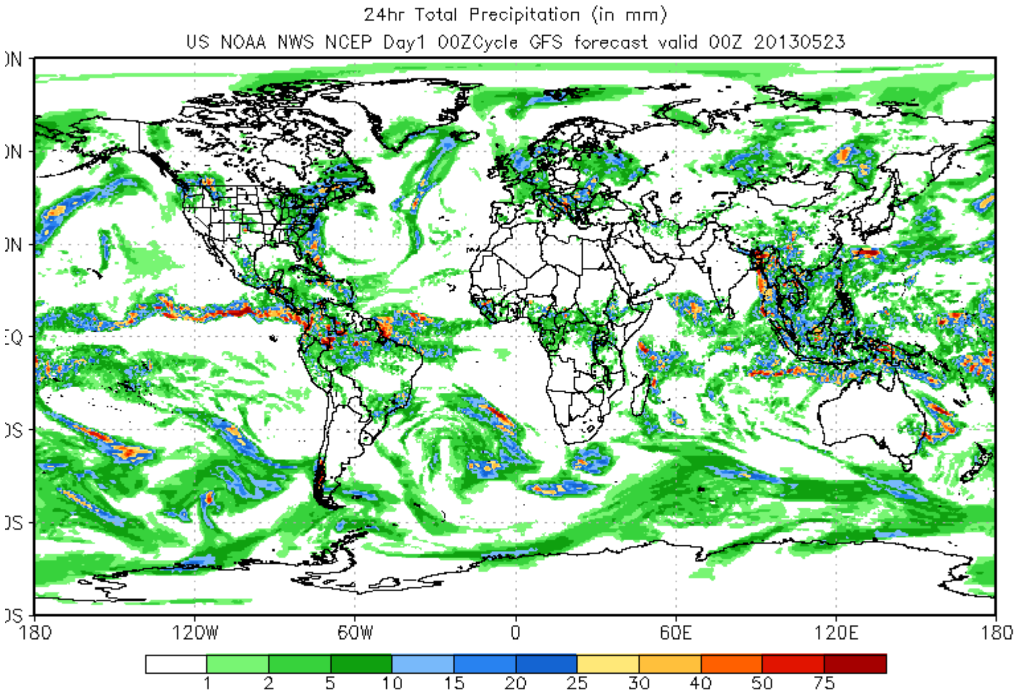


Figure 3.2: The cumulated GFS raster (source catalog.data.gov)

3.1.3 The Tropical Rainfall Measuring Mission (TRMM)

The Tropical Rainfall Measuring Mission (TRMM) is a joint mission between NASA and the Japan Aerospace Exploration Agency (JAXA) to study rainfall for weather and climate research (Huffman et al., 2010). The term refers to the satellite name the mission used to collect data once launched on November 27, 1997 from the Tanegashima Space Center in Japan. Prior to TRMM, the distribution of rainfall worldwide was known to only a 50% degree of uncertainty and the global distribution of vertical precipitation was far less well determined. As of July 2014, fuel to maintain orbital altitude was insufficient and NASA ceased station-keeping manoeuvres for TRMM, allowing the spacecraft's orbit to slowly decay.

TRMM was a compound of different instruments: a precipitation radar, a microwave imager, a scanner for visible and infra-red radiations and a clouds and earth radiant energy sensor. All this tools combined managed to produce a continuous data stream for over 17 years allowing scientists and developers from all over the world to use them in many domains and applications.

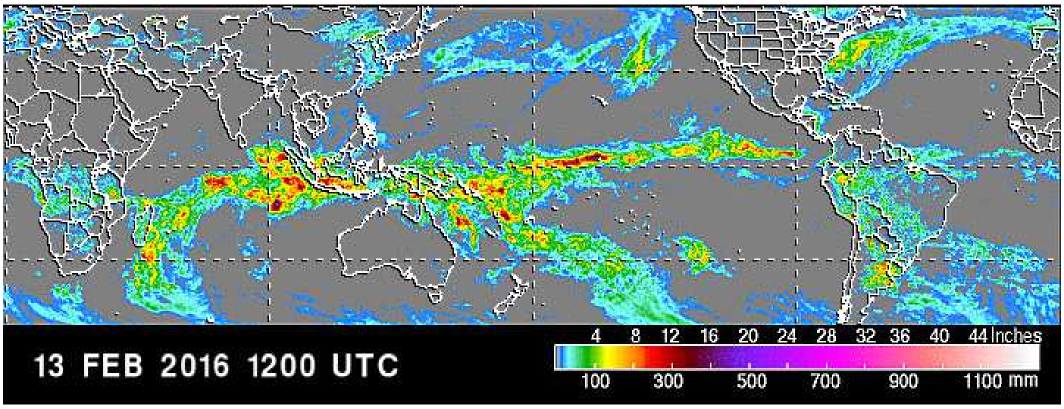


Figure3.3 accumulated precipitation from TRMM (source trmm.gsfc.nasa.gov/)

TRMM precipitation data are available in 0.25°spatial resolution, 3h temporal resolution, covering the latitude band 50°N-50°S (Figure 3.3). They are exposed as a binary file using FTP protocol at: ftp://trmmopen.gsfc.nasa.gov/pub/merged/mergeIRMicro.

3.1.4 LandScan

LandScan is a dataset furnished under license by the Geographic Information Science & Technology group. They are an Oak Ridge National Laboratory pioneer in the development, implementation, and application of systems for geographic information since 1969. The raster they release is the _nest resolution global population distribution data available. The LandScan algorithm, an R&D 100 Award Winner, uses spatial data and imagery analysis technologies and a multi-variable dasymetric modeling approach to disaggregate census counts within an administrative boundary. Since no single population distribution model can account for the differences in spatial data availability, quality, scale, and accuracy as well as the differences in cultural settlement practices, LandScan population distribution models are tailored to match the data conditions and geographical nature of each individual country and region.

The data is distributed in both an ESRI grid format and an ESRI binary raster format. The dataset has 20,880 rows and 43,200 columns covering North 84 degrees to South 90 degrees and West 180 degrees to East 180 degrees. Data values The values of the cells are integer population counts representing an average, or ambient, population distribution. An ambient population integrates diurnal movements and collective travel habits into a single measure. Since natural or manmade emergencies may occur at any time of the day, the goal of the LandScan model is to develop a population distribution surface in totality, not just the locations of where people sleep. Because of this ambient nature, care should be taken with direct comparisons of LandScan data with other population distribution surfaces.

3.2 Data acquisition and validation

The volume and diversity of environmental data is increasing exponentially, placing great demand on the infrastructure to measure, transport, manage, and store this data, and requiring ever-greater computational power for simulations that use it. This creates new opportunities for specialized services, developed with researchers in public and private institutions. Data are mainly acquired using different kind of sensors placed on a variety of support and places.

Some examples of open source meteorological data sets include precipitation data, temperature data, air quality and can store both real-time and historical data in order to fit different needs going from climatological analysis to the now-casting.

One of the most complete and suitable dataset is the Global Historical Climatology Network (GHCN), an integrated database of climate summaries from land surface stations across the globe that have been subjected to a common suite of quality assurance reviews (Figure 3.4). The data are obtained from more than 20 sources. Some data are more than 175 years old while others are less than an hour old. Data can be accessed through ftp or directly online.

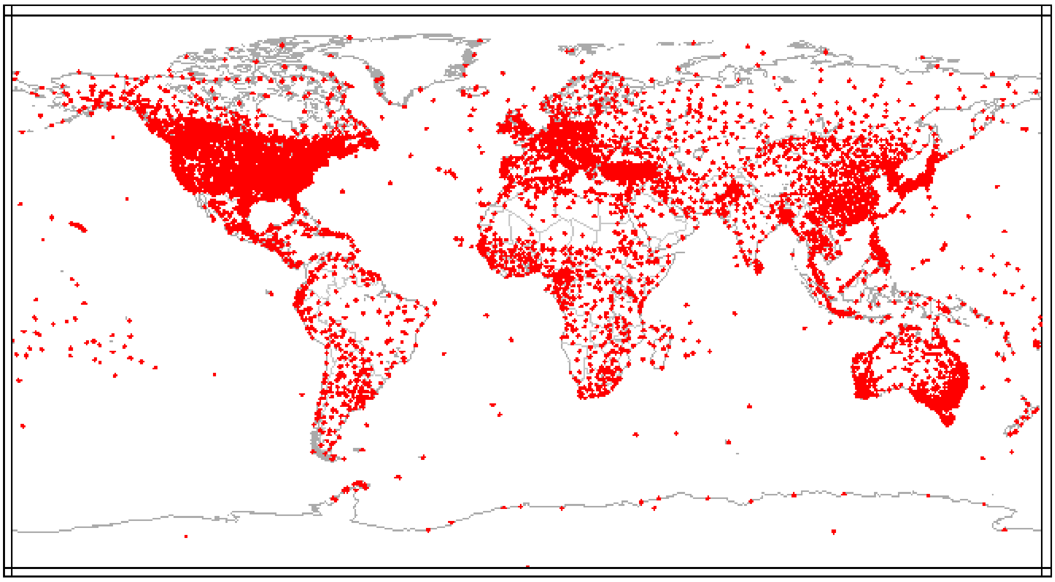


Figure 3.4 Map of land stations in the Global Historical Climatology Network where air temperature (NOAA National Climate Data Center)

In January 2016, Air Quality real-time information is made available by more than 70 countries, thanks to the huge effort from each countries EPAs (Environmental Protection Agencies) Austria. There are currently more than 20,000 known air quality monitoring stations in the world, out of which more than 8,200 are published on the aqicn.org project (Figure 3.5). In order to keep a high level on consistency, only stations with particulate matter (PM2.5/PM10) readings are published. The AQI standard for every single published station is based on the US EPA Instant-Cast standard.

Figure 3.5 World Air Quality monitoring overage (http://aqicn.org/sources/)

The open data situation is definitely improving, more and more countries are freeing their climate data. The USA, Canada and Australia have a long traditions. Germany, The Netherlands, Finland, Sweden, Norway, Slovenia, Brazil and Israel have just freed their data. China and Russia are pretty good with sharing data. Switzerland has concrete plans to free their data.
That there are large differences between countries and this is illustrated by Figure 3.6 showing the data availability for daily mean temperature data in the ECA&D database, a dataset that is used to study changes in severe weather. The green dots are data where you can download and work with the station data, the red dots are data that ECA&D are only allowed to use internally to make maps. In the number of stations available you can clearly see many national boundaries; that is not just the number of real stations, but to a large part national policies on data sharing.

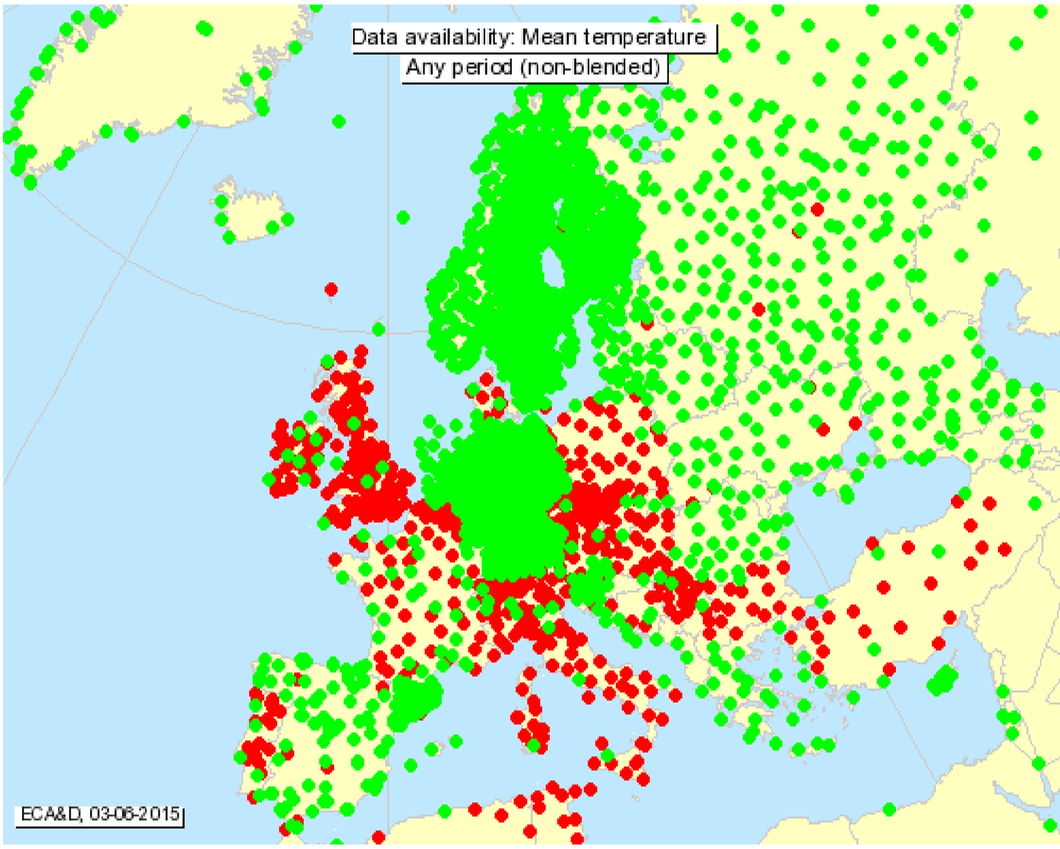


Figure 3.6 Mean Temperature data availability in Europe (http://variable-variability.blogspot.it/2015/06/congress-WMO-free-climate-data.html)

Sharing data, making them homogeneous and validate them are three of the main outcomes highlighted by the 17th WMO congress which fostered the adoption of the Global Framework on Climate Services (GFCS) 17th session of the World Meteorological Congress Geneva, Switzerland, 25 May – 12 June 2015.

Increased efficiency of existing weather systems will more than ever require reliable data. Reliable data play a key role in the analysis, monitor, and forecast of weather system behaviours as bad quality data may result in an erroneous decision scheme. These data are provided in a large part by the measuring system, in which a sensor is an important element. The sensor measures a physical quantity and converts it into a signal that can be read by an observer or by an instrument. The measuring system then converts the sensor signals to values aiming to represent certain "real" physical quantity. These values, known as raw data, needs to be validated before other use in order to assure the reliability of results from data application. Generally raw data may include errors such as noise, drift, outliers, malfunctions, etc. In addition to the possible measurement deviations related to the sensor performance itself, the errors can occur due to various reasons, e.g., the sensor installation problem and the measurement assumption violation. The data validation is an essential step to improve data reliability. Data validation is a subject associated to various domains and is mainly made using statistic methodologies (Sun et al. 2011, Bertrand et al. 2013, Holt, 2004). The errors are mainly detected and corrected by comparing one station to its neighbours. The closer the neighbours are, the more accurate we can assess the real climatic changes. This is especially important when it comes to changes in severe and extreme weather, where the removal of non-climatic changes is very challenging.

3.3 The weather bulletin

One of the most common tools used for the dissemination and communication of weather information is the weather bulletin. The weather bulletin can be produced either automatically or wrote up by a forecaster.

The main tasks of a weather forecaster are to analyse the complex information derived from meteorological models, weather stations and further technological tools, to interpret them based on his specific know-how or experience and to translate them into a final information that can meet the understanding and expectations of the final users.

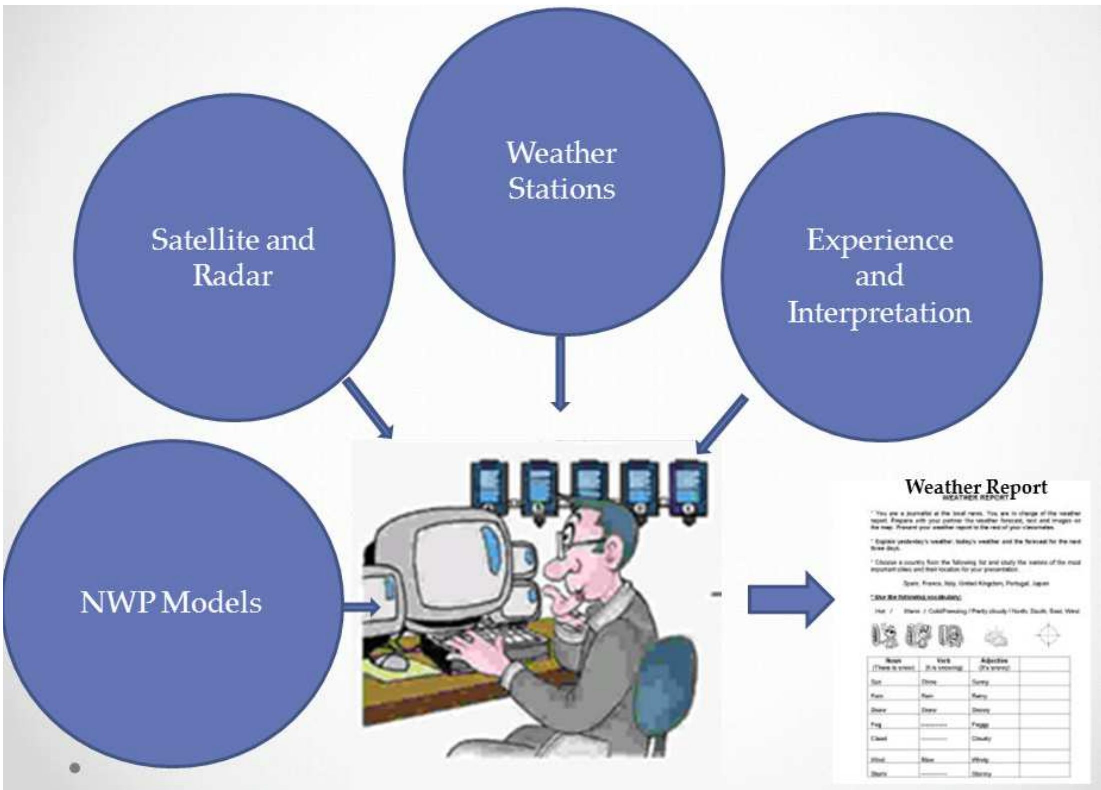


Figure 3.7 The Weather Bulletin

There is a vast literature analysing the quality of a weather bulletin (Wright and Flood, 1973; Jolliffe and Jolliffe, 1997 and on the perceived usefulness (Önkal and Bolger 2003; Fischhoff, 1994, Yates et al., 1996). Crucial to assess the skill of a weather forecast are the understandability and effectiveness of the disseminated information. Understandability and effectiveness might significantly change if we refer to a quantitative or to a qualitative forecast. On the one hand a quantitative forecast would mainly present the information using data that have to be interpreted and translated into a specific meaning by the users often leading to misunderstanding or misinterpretation, depending on user's perception or experience. On the other hand decisions can be significantly helped by qualitative forecasts that contains the interpretation of a professional forecaster by means of short phrases that helps in detailing the predicted situation including information about probability of uncertainties.

Depending on the specific user an effective weather bulletin should address in an immediate and easy to understand manner the key information highlighting also the uncertainties and quantifying impacts or consequences of the predicted environmental conditions on the specific activities that the user have to manage.

Two different weather bulletins issued for two users having different needs are shown in Annexe 1. The first bulletin has been developed during a service provided to the WFP's Emergency Preparedness and Response Branch who has mainly needs for prioritizing actions in case of emergencies at a global scale. The second one is an example of daily weather report issued for the Austrian Sailing Federation Olympic Team. Olympic sailing requirements are to know significant key factors on wind and current evolution at a very local scale.

3.4 Early Warning Systems (EWS)

One of the five main areas of gaps and challenges identified in the Hyogo Framework for Action 2005-2015 were: "Risk identification, assessment, monitoring and early warning" (UNISDR, 2005) Likewise, one of the five priorities for action was "Identify, assess and monitor disaster risks and enhance early warning" (UNISDR, 2005). Early warning systems have been defined as: "The provision of timely and effective information, through identifying institutions, that allow individuals exposed to a hazard to take action to avoid or reduce their risk and prepare for effective response" (Glantz, 2003). Early warning systems are divided into many disciplines including environmental, planning and disaster related sciences to psychological behaviour involved in issuing and interpreting early warnings. These parts, which themselves, are autonomous research areas, can be combined together to form early warning. Two main components of early warning are hazard and risk. These are the processes which take place before the warning is issued. On the other hand the final steps include issuing the reaction to the warning and reaction to the warning. These final steps includes setting up reliable and redundant communication methods to ensure the early warning signal reaches all who it was intended for, development of evacuation routes and assignments of shelters. The information issued by an EWS can be used by planners, relevant government organizations, humanitarian practitioners and an additional variety of actors to have an early indication of risk.

The Joint Research Centre (JRC) is the European Commission's in-house science service which employs scientists from all the Europe to carry out research in order to provide independent scientific advice and support to EU policy. The JRC in recent years has built The Science Hub, a platform for information and exchange about all scientific activities carried out by all institutes across Europe. It aims to gradually integrate and aggregate all of the European Commission's science related activities, tools, laboratories, facilities, databases and networks. Part of the work in flood early warning systems has been completed with the Integrated Flood Map (Figure 3.8), a WebGIS application which ties together many different dataset and applications from many sources all around the Europe. It mixes observations with forecasts, it has rainfall datasets and flood datasets, it has datasets at widely different scales. Each of this layers brings to the application his dataset in order to deliver to users a precise and verified point of view allowing him to not chase different sites and focus on his intents.

Figure 3.8 The Integrated Flood Map application

Noteworthy is the NASA MODIS Global Flood Mapping, a tool which is already studying the flooding events once they outbreak. Using satellite optical systems like microwave remote sensing, an alternative to optical flood monitoring less influenced by clouds, they manage to provide continuous flood maps.

4. Geospatial Information Technologies

4.1 Benefits

According to ESRI GIS Dictionary (http://support.esri.com) Geospatial Technologies are those "technological approaches, such as GIS, photogrammetry, and remote sensing, for acquiring and manipulating geographic data". Those technologies indeed allow to collect, process and manage data characterized by a spatial component which is described by geographic coordinates, referred into a specific coordinate system, along with other attributes.

In particular, Geographic Information Systems (GIS), Global Positioning Systems (GPS) and Satellite Remote Sensing (RS), offer a valuable help for the assessment of environmental issues for the following reasons. Firstly, GIS provide a flexible environment to store, analyse, manage and map spatial information integrating other typologies of georeferenced data provided as result of multidisciplinary analysis (Ashure et al, 1998; NRC, 2002). Secondly, RS provides timely and reliable information of the dynamics of the Earth's surface and atmosphere which thus can be continuously monitored (Donoghue, 2002; Melesse et al., 2007; Mather et al., 2009). Thirdly, GPS technologies enable technical and non-technical users to accurately track the position of relevant environmental and geographic features. In addition, the possibility to quickly integrate and visualize various information coming from different sources into one system, allows to quickly produce immediately understandable cartographic products that can address a variety of climate change related issues such as potential impacts on land use, health care, transportation or households (Ferrandino, 2014; Duncan et al., 2014). For instance, raster weather data can be integrated with many vector datasets in an common reference system, allowing, on one hand, to perform statistical and spatial analysis and, one the other hand, to overlay wheatear information with other geographic data.

Moreover, the widespread diffusion and development of geospatial information technologies allow to effectively reduce costs, both in term of time and economic resources, required for carrying out in-situ spatial surveys (Cay et al., 2004; Shamsi, 2005). These technologies indeed permit to access a big amount of information characterized by a large spatial and temporal coverage and, at the same time, they provide the possibility to easily update the data for monitoring activities (Ashur 1998; NRC, 2002). As matter of facts, geospatial information technologies offer a broad assortment of innovative solutions in many different sectors and activities such as: Disaster Risk Management (DRM) (Altan et al., 2013; Miyazaki et al., 2015;

Tomaszewski, 2014), environmental sustainability (Melesse et al., 2007; Chigbu et al., 2013) and climate change analysis (Donoghue, 2002; Sundaresan et al., 2015).

Moreover managing weather data as raster data brings many benefits especially to Web-GIS software developers including:

The data structure is simple to visit (occasionally may be linked to an attribute heap)

The raster format is very well supported by statistical and spatial analysis tools

Continuous surfaces can be easily represented by a uniform distribution of geometries

Many dataset can be easy overlaid in an efficient way

4.2 Available Open-Source data

Over the last decades, several open-source projects, based on the provision of web portals containing geo-referenced data, have been developed. "Collaborative Mapping" is particularly advantageous because in those countries where the national cartography services are missing, incomplete or not-updated, because it is able to provide geospatial information continuously updated.

As a consequence, a fundamental source of geospatial information derives from open-source platforms or imagery archives. For instance:

- OpenStreetMap (OSM, https://www.openstreetmap.org): it is a wide used open platform where a large number of users (more than 2 million of registered user in 2015) may generate geospatial reference data from different sources (e.g. uploading GPS tracks, mapping from aerial and satellite imageries, etc.).
- Wikimapia (http://wikimapia.org/): it is an open-content collaborative map, where anyone can create geospatial data. According to its website, it aims "to describe the whole world by compiling as much useful information about all geographical objects as possible, organize it and provide free access to our data for public domain".
- GeoNames (http://www.geonames.org/): it is an open-source geographical database containing over 10 million of geographical names and over 9 million of features. All the features contained in the database follow the same categorization standard based on nine feature classes and further subcategorized classes.

- GeoNode (http://geonode.org/): is a geospatial platform for the management and publication of geospatial data. With GeoNode, users may create data and visualize maps.
- Landsat (http://landsat.usgs.gov//about_project_descriptions.php): it is a satellite mission which "represents the world's longest continuously acquired collection of space-based moderate-resolution land remote sensing data". Several open-source tools allow to freely download a vast selection of satellite imageries acquired since the beginning of the 1970's.

Therefore a profitable preliminary collection campaign, of open-source geospatial data, might be conducted in order to retrieve essential data such as:

- Basemap cartography, to held a map depicting background reference information
- Reference datasets (such as administrative boundaries, road networks, water resources, settlements, land-use and land-cover data, etc.) to make spatial relationships between different types of data.
- Satellite imageries, to perform environmental monitoring and meteorological analysis: several satellite mission provide imageries free-to-use such as Tropical Rainfall Measuring Mission (TRMM) and Global Precipitation Measurement (GPM), used to produce the accumulated precipitation, or Landsat missions, used to extract further geospatial information or to detect land-cover changes.

4.3 Acquisition of geospatial data

Once open-source archives have been harvested but some reference data are still missing, geospatial information technologies allow to retrieve additional data performing specific automatic, semi-automatic or manual procedures. Some of the most common methodologies, used to acquire both reference and thematic information, are the following:

- Supervised and un-supervised classifications: sensing satellite imageries, these methodologies allow to produce thematic classifications of the territory in a specific number of classes according to the value of reflectance of each pixels.
- Photo-interpretation: it is the activity of observing and examining air photos and satellite imageries, in order to identify Earth's environment objects. Using editing application, included in the basic tool suites of GIS programs, it is possible to manually extract reference and thematic georeferenced information.

- Change-detection: this technique allows to gather information about changes in the attributes of specific raster or vector data over a defined time period. Typical practical applications of change-detection procedures regard the urban and territorial land-cover and land-use monitoring.

4.4 Geographic Information system organization strategy

Considering the manifold nature and source of data treated, in the realization of a GIS or a Spatial Data Infrastructure (SDI), particular attention has to be devoted in the designing the structure of the database accommodating meanwhile also the specific end-user's requirements.

Common used data standards establish key rules in order to standardize the format and the meaning of data allowing to share, exchange and better understand the data produced. As stated in the United States Geological Survey (USGS) agency website "standards provide data integrity, accuracy and consistency, clarify ambiguous meanings, minimize redundant data" (http://www.usgs.gov/datamanagement/plan/datastandards.php). Therefore an adequate spatial data architecture facilitates the interoperability of the information with others GIS projects and allow to make the data usable also for other users.

An important preliminary activity in the realization of a GIS is therefore the organization of the database starting from the definition of a set of common general attribute fields, such as:

- "Lat" and "Long": the geographic coordinates of latitude and longitude that specify the precise location of the feature censed or extracted.
- "Date": date when the feature has been censed or extracted.
- "Name": name of the feature censed or extracted.
- "Admin 1", "Admin 2", "Admin 3": respectively the primary administrative division of a country, the administrative subdivision of a first-order and second-order in which the feature is contained.

A practical example of further standard specifications is furnished in the glossary produced by GeoNames (http://www.geonames.org/export/codes.html).

Successively, a set of specific attributes able to describe the specific needs of the project and the perception of users is fundamental in order to realize a customized GIS.

5. Case studies

Within this research the following three main users have been identified:

- Humanitarian practitioners acting at global scale,
- A regional Civil Protection
- A national sailing team

The first category is represented in particular by the World Food Program Emergency Preparedness and Response Branch (WFP OMEP) . The OMEP provides strategic support to ensure that WFP is as ready as possible, that its response both internally and with partners is coherent and that decision-makers have the best information available. Therefore, one of the crucial OMEP decision-makers need is to clearly visualize WFP's operating environment, using the best technology and systems to obtain accurate digital and paper maps and other products, clearly presenting raw information and analysis in an easily understandable form. Also targeted geospatial analyses obtained using high-resolution satellite data and weather forecasts have the potential to show the immediate impact of a disaster such as extreme precipitation, flood or drought on the ground and the number of people most acutely affected.

Analysis disseminated to the OMEP should primarily delivered at global scale, since the main interest is to quantify potential impacts and therefore to prioritize actions within the potential most affected countries.

The second user is represented by a regional Civil Protection and in particular by the Civil Protection of Catalonia. Civil Protection is the national body that deals with the prediction, prevention and management of exceptional events. In agreement with regional and local governments, it has a guiding role in the development of projects and activities for the prevention, forecast and monitoring of risks. Moreover, it coordinates the response to natural disasters, catastrophes or other events that, due to their intensity and extent, should be faced with extraordinary interventions. Therefore warning messages hes to be delivered with the aim of helping the Civil Protection in the prevention and the emergency phases leading to the implementation of Emergency Plans at regional, provincial and municipal level.

The third users has been chosen in a completely different field of action: the Olympic Sailing. Similarly to humanitarian practitioner and to Civil Protection users, also high level sailors must take their final decisions in a very short time and based on strategical analysis that are driven by an integration of meteorological variables and geographic references.

5.1 A global Early Warning System for the monitoring and forecasting of extreme precipitation

The following paragraphs illustrate the work conducted for the upgrade of the Extreme Rainfall Detection System (ERDS) and its adaptation to specific requirement of the World Food Programme (WFP), the food aid branch of the United Nations, using an integration of monitoring and forecasting data together with GIS capabilities. Firstly the Web-GIS platform is described with particular attention to the visualization of rainfall data and extreme precipitation warnings. Secondly results of the application of ERDS capabilities to two different case studies are presented.

5.1.1 The Web-GIS platform

The Extreme Rainfall Detection System (www.erds.ithacaweb.org) has been initially developed by ITHACA (Information Technology for Humanitarian Assistance, Cooperation and Action) under a special request made by the WFP, in order to increase efficacy in approaching emergency preparedness related to flood events. This was conceived as a completely automated system running at river basin scale having a global coverage by using 3B42 and 3B42RT satellite rainfall data, products of the Tropical Rainfall Measuring Mission (TRMM) Multisatellite Precipitation Analysis (TMPA). The 3 hourly real-time 3B42RT data with some statistical adjustments are used to detect critical rainfall events and to create alerts in near real-time.

The following four main issues have been identified in the preliminary phase of this research:

the inadequacy of TRMM resolution to work at a basin scale

- the very high false alarm rate
- the lack of forecasting capabilities
- the hardly accessible final information

Therefore it has been proposed to develop a semi-automated methodology relying on the use of a WebGIS application in order to provide meaningful and usable exceptional near-real time rainfall alerts to WFP and to other assistance humanitarian organizations who need easy to access information about flood hazard worldwide (Terzo et al. 2012). On the other hand the ERDS Near-Real System time has been upgraded by adding forecasting capabilities for extreme precipitation events with up to seven days lead-time.

The first step of the updated methodology is the calculation of the accumulated precipitation in order to produce both near-real time and forecast quasi-global rainfall raster maps for different time frames (i.e. 24h, 48h, etc.).

The near-real time rainfall data processing uses the TRMM3B42RT dataset. TRMM precipitation data are available in 0.25° spatial resolution, 3h temporal resolution, covering the latitude band 50°N-50°S.

The forecast rainfall data processing uses the NOAA model having a 0.5° resolution and a 6h temporal resolution at global scale. Firstly TRMM 3h and GFS 6h rainfall datasets are processed in order to calculate daily accumulated precipitation matrices. Secondly daily precipitation matrices are summed for the calculation of near-real time and forecasted accumulated precipitation for different periods of time and up to 7 days lead-time. Finally accumulated precipitation matrices are transformed into raster maps and displayed through the ERDS WebGIS application (Figure 5.1).

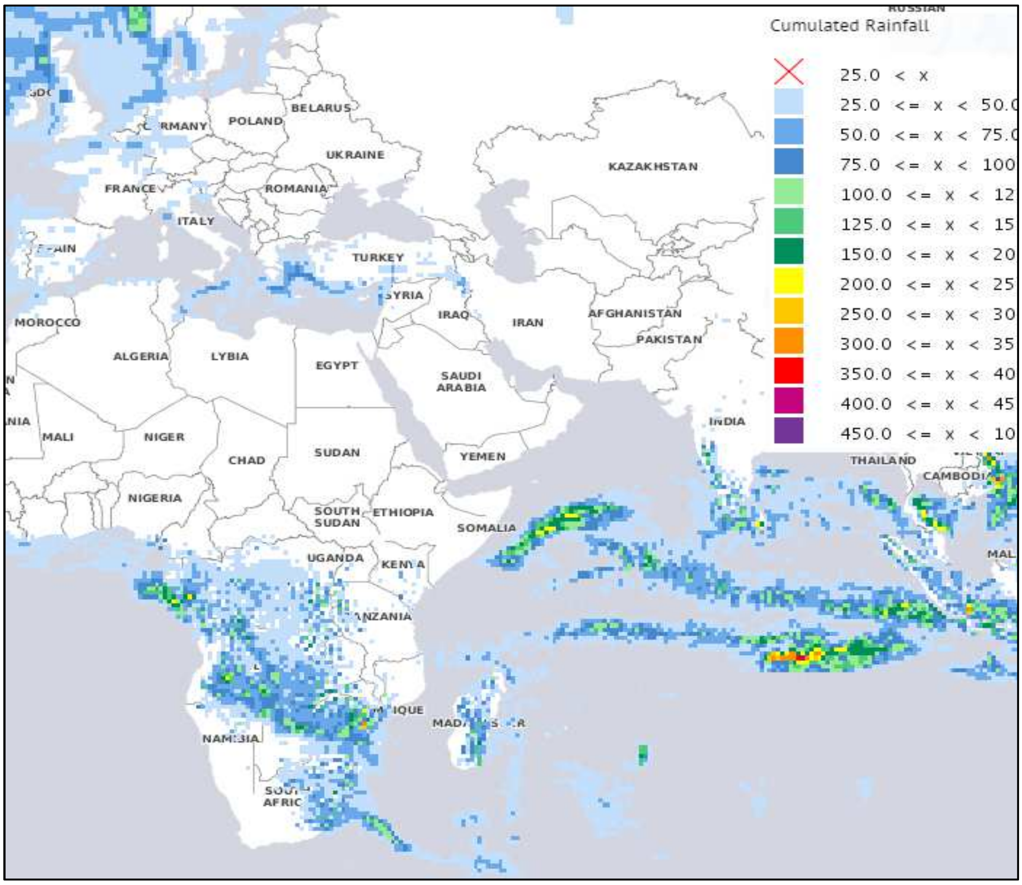


Figure 5.1 ERDS Web-GIS application, overview of 144h accumulated precipitation from GFS

This allows the generation of a particularly flexible information suitable for users interested in assessing both short-term heavy rainfall events and medium term persistent rainfall events (up to 14 days considering the aggregation of near-real time and forecasted precipitation data).

The second step of the methodology is devoted to the calculation of extreme rainfall alerts. This is made by applying rainfall thresholds to the accumulated precipitation values calculated before. Thresholds are defined as the amount of precipitation for a given duration over a specific climatological area. When thresholds are exceeded, three alerts levels (low, medium and severe) are produced. An accurate calculation of temporal and spatial distribution of climatological precipitation extremes is a key component in the generation of reliable heavy rainfall alerts (Fowler and Kilsby, 2003; Ramesh and Teegavarapu, 2012). On the other hand Meteorological information and warnings have traditionally been based on fixed thresholds for one parameter, often with a fixed time scale, e.g. precipitation rate over 24 hours. This traditional approach, currently adopted by a number of national and regional Civil Protection meteorological services, makes evaluation of the quality of forecasts easy and homogenous for a given area with climatic homogenous conditions.

Therefore two methods for the calculation of extreme rainfall alerts are applied in ERDS. The first one considers daily precipitations exceeding 80mm, 120mm and 150 mm as fixed thresholds for the three levels of alert (low medium and severe) and multiplies them by three coefficients (0.65, 0.8, 1) depending on the climatological classification derived by the new digital Köppen-Geiger world map on climate classification for the second half of the 20th century (Kottek et al., 2006). The map of the climatological coefficients that are used at global scale is presented in Figure 5.2.

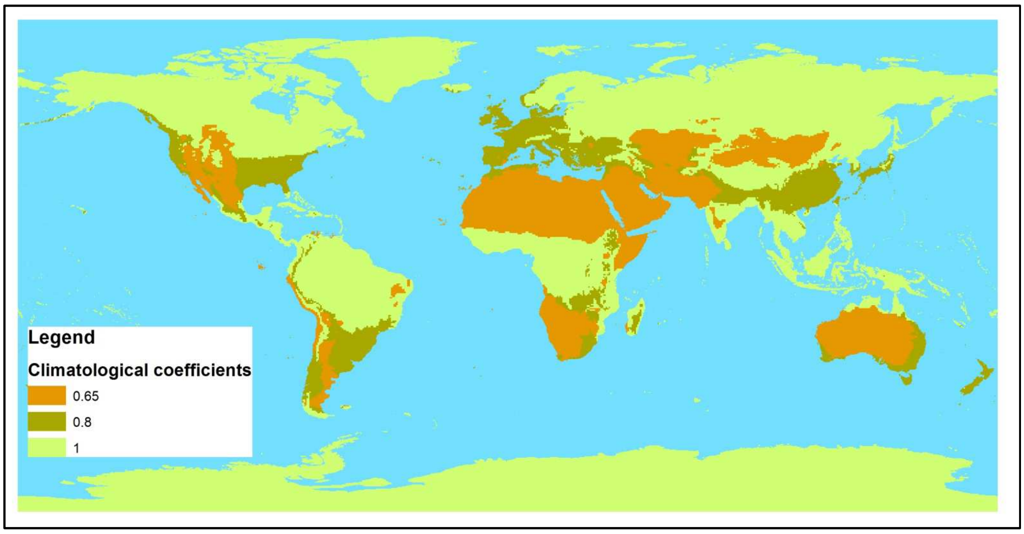


Figure 5.2 - Climatological coefficients for the calculation of fixed rainfall thresholds.

The second methods uses the climatological analysis of the TRMM-TMPA historical data set which covers the period from 1998 to the delayed present (Huffman et al., 2007). For instance the three level of alerts are issued when the daily precipitation rate exceeds the 95th, 98th and 99th percentiles.

Warnings are disseminated through the ERDS WebGIS platform as raster maps displaying alerts at pixel resolution (Figure 5.3).

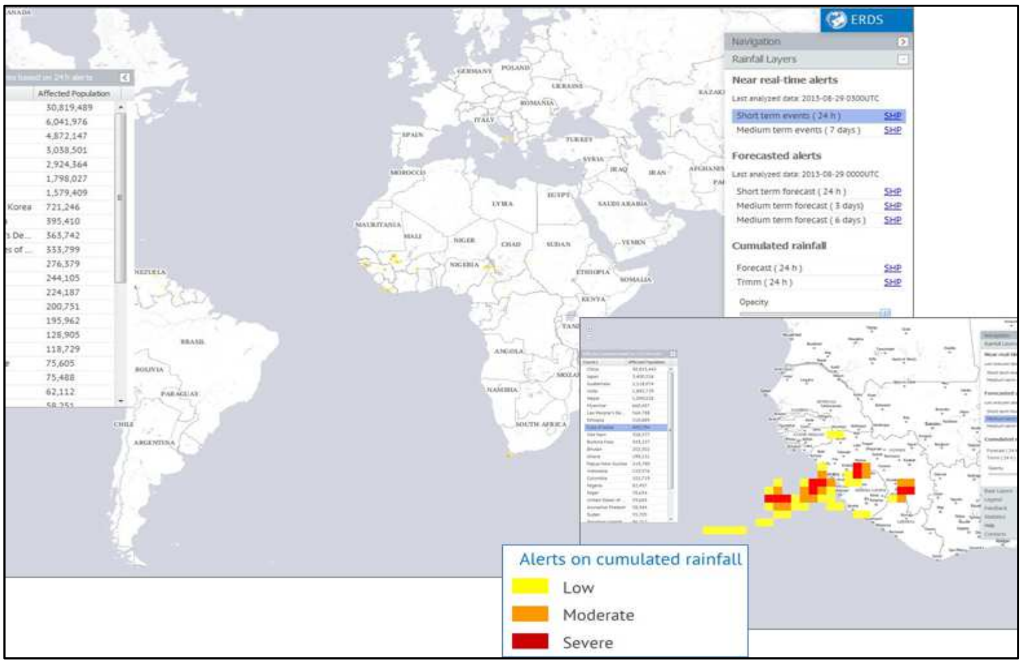


Figure 5.3 Example of ERDS warning map

As it was previously stated the resolution of TRMM and GFSS data is not suitable for generating alerts with the level of accuracy required for a local scale risk assessment. Moreover alerts displayed at pixel resolution might be not meaningful for users who are not familiar with scientific information.

Therefore the third step of the automated methodology, consists in the integration of rainfall alerts with vulnerability data sets such as base map data, demographic data, etc. This allows to geographically contextualize the event and to produce value added information, such as an assessment of the damage grade of affected critical infrastructures, transport systems, affected population, aid and reconstruction logistics, etc.

Globally consistent datasets are generally available, even as public domain: those data has the advantage to allow the production of consistent output results, and therefore can be considered as a primary resource in case of services intended to provide a wider and seamless overview of specific phenomena. Locally, more accurate and updated datasets may be available: but their accessibility is not granted, both for technical and licensing issues. Other than the advantage to produce more accurate value added analysis, the adoption of local and authoritative datasets has a positive consequence that post-event analysis and maps would more easily integrated in the end users operational framework.

For the scope of the analysis described in this paper, the adoption of globally consistent reference datasets to estimate vulnerability was therefore considered the best option. In details, the following data sources were used to derive vulnerability layers:

- Vector Map (VMAP) Level 0 is a vector-based collection of GIS data with global coverage (nominal scale 1/1.000.000) and entirely in the public domain. VMAP0 was used to derive major watercourses and administrative boundaries in Mozambique;
- LandScan ™ is a global population distribution dataset at approximately 1 km resolution, representing ambient population (average over 24 hours);
- GeoNames is a geographical database that covers all countries and contains over eight million placenames that are available for download free of charge.

To facilitate users who need to have a global overview of main issues related to real-time, past and predicted extreme rainfall, the web application has been provided with an Alert page that gives a list of alerted countries ordered by the potentially most affected, in terms of population, to the least affected. Information is provided for three different time frames: 24h, 72h and 144h.

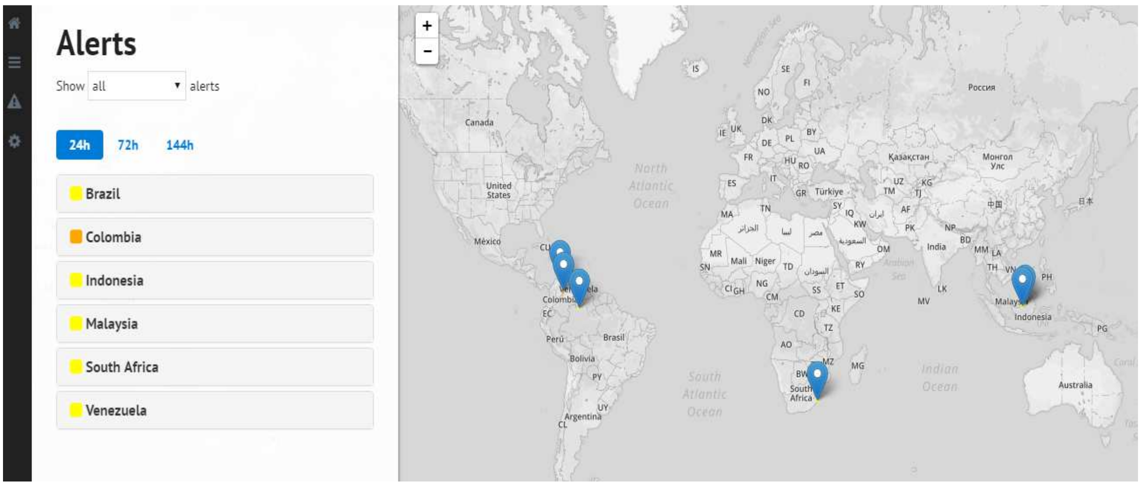


Figure 5.4 ERDS forecast alerts page

The platform allows, by clicking on one alerted country, to open a window showing the calculation of the maximum precipitation estimate derived from the GFS model and the potentially affected population (Figure 5.5). Also a box containing a graphic showing the 24h precipitation amount, the accumulated precipitation over the whole period and the rainfall alert thresholds is shown. This graphic is particularly useful to immediately identify for which time frame a specific threshold is exceeded and to give an indication about the nature of the extreme rainfall: short lived extreme precipitation or persistent rainfall.

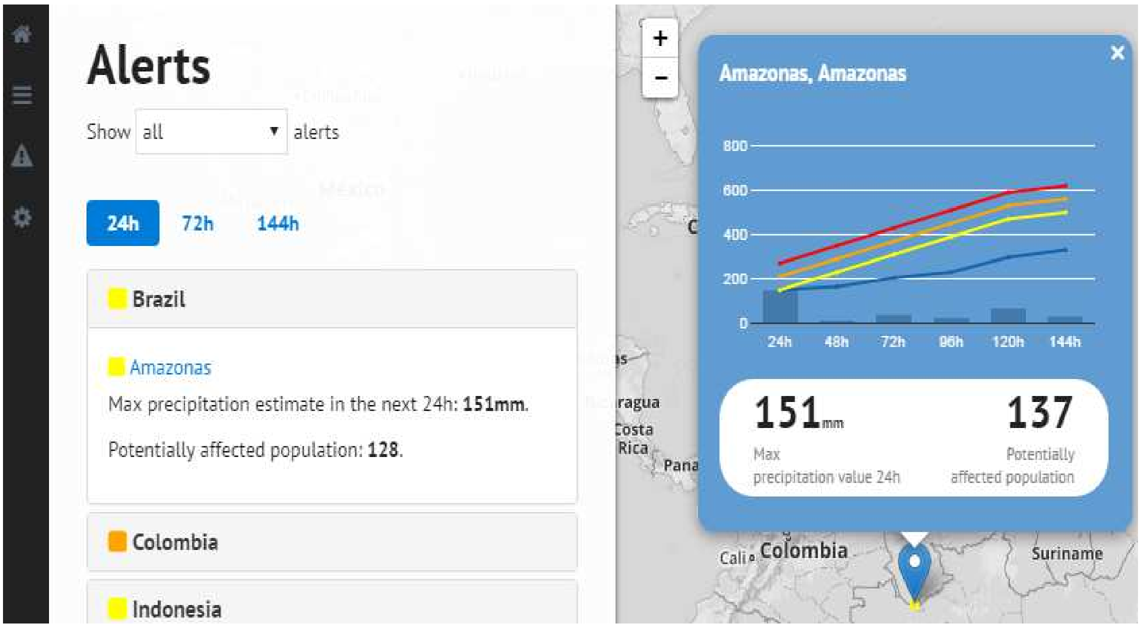


Figure 5.5 ERDS zoom over an alerted country and accumulated precipitations graphic

The alert forecast districts translate pixel alerts into a visual overview of potential affected districts (Figures 5.6 and Fig 5.7) at a global scale. The colour of each affected district is associated to the maximum value of alerted pixels included in each district. On the other hand, if another criteria is considered more suitable for the analysis that has to be performed, it is possible to adapt the analysis by using the average of pixel alerts, or the minimum value, etc.

Figure 5.6 ERDS alert forecast districts 72h overview

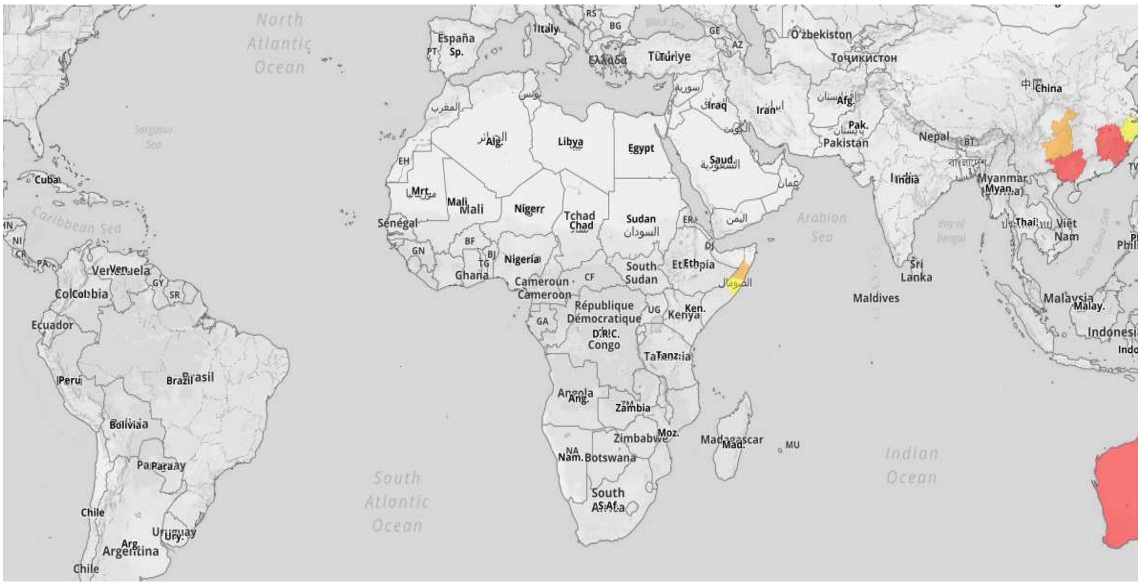


Figure 5.7 ERDS alert near real-time districts 72h overview

By comparing the view at global scale with a view over a specific area of interest it is immediately understandable how alerts at district level are derived from the gridded accumulated precipitation and which kind of different information is delivered by the two visualizations at pixel or at district scale. An example over Somalia considering the accumulated precipitation derived from TRMM on 06052016 at 10.00UTC, is shown in figures 5.8 and 5.9.

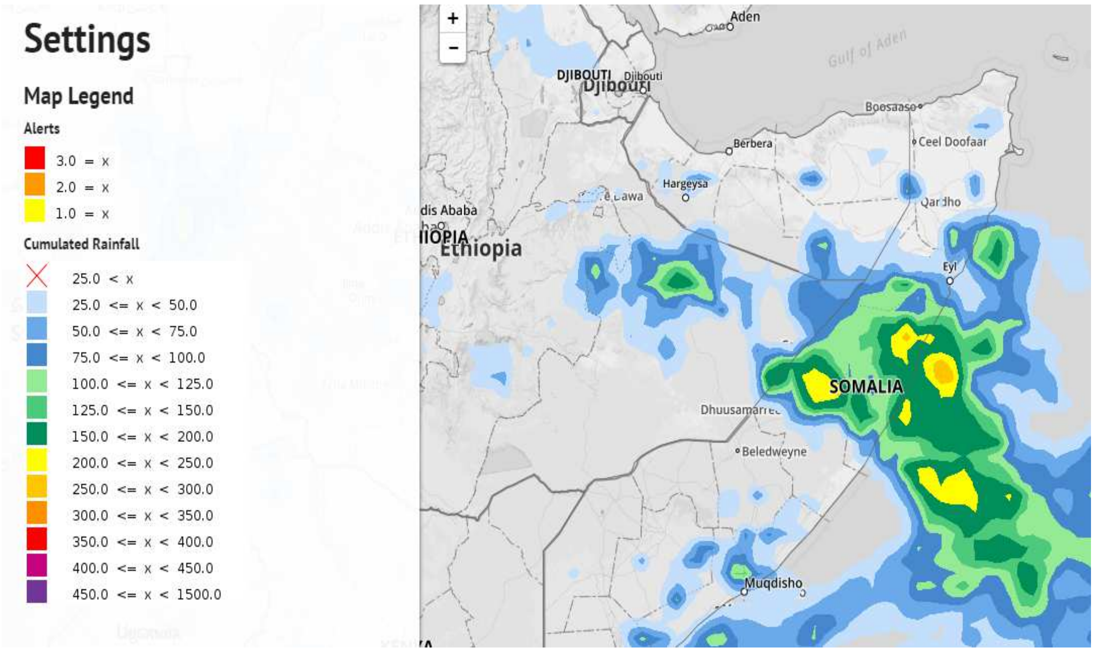


Figure 5.8 Accumulated precipitation near real-time 72h (zoom over Somalia 08/05/2016)

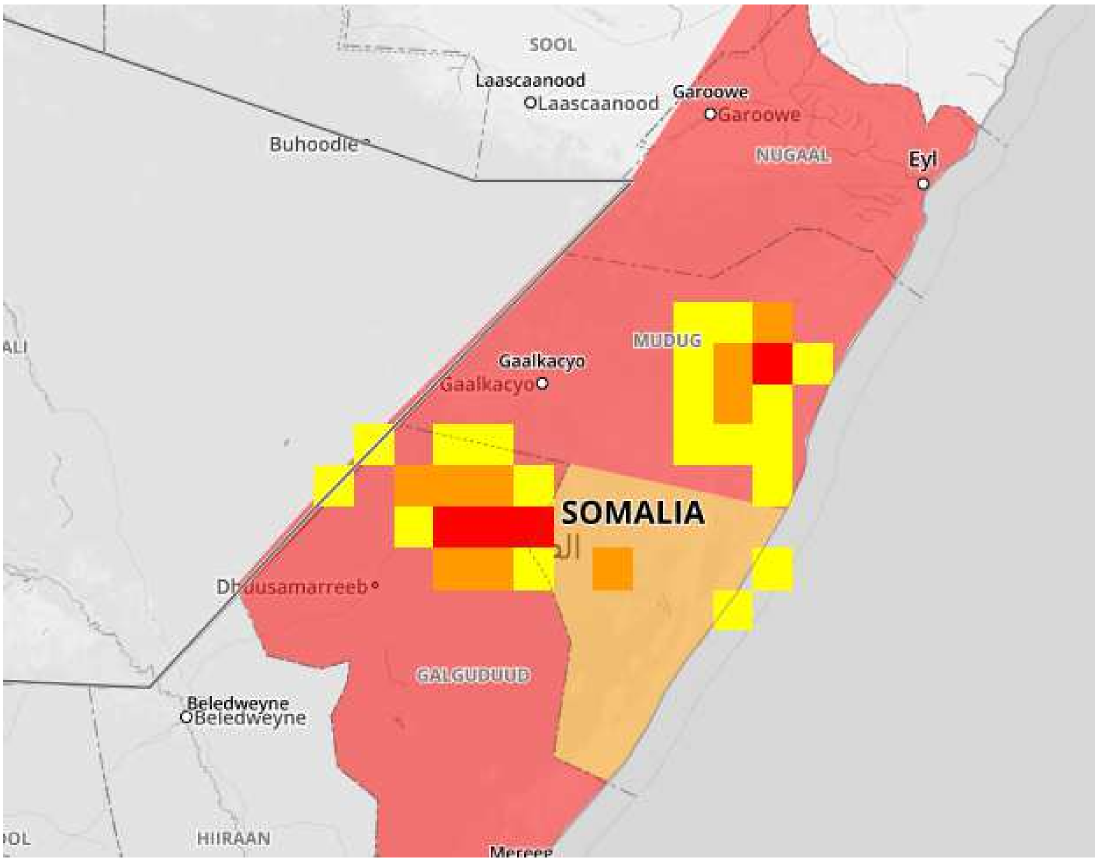
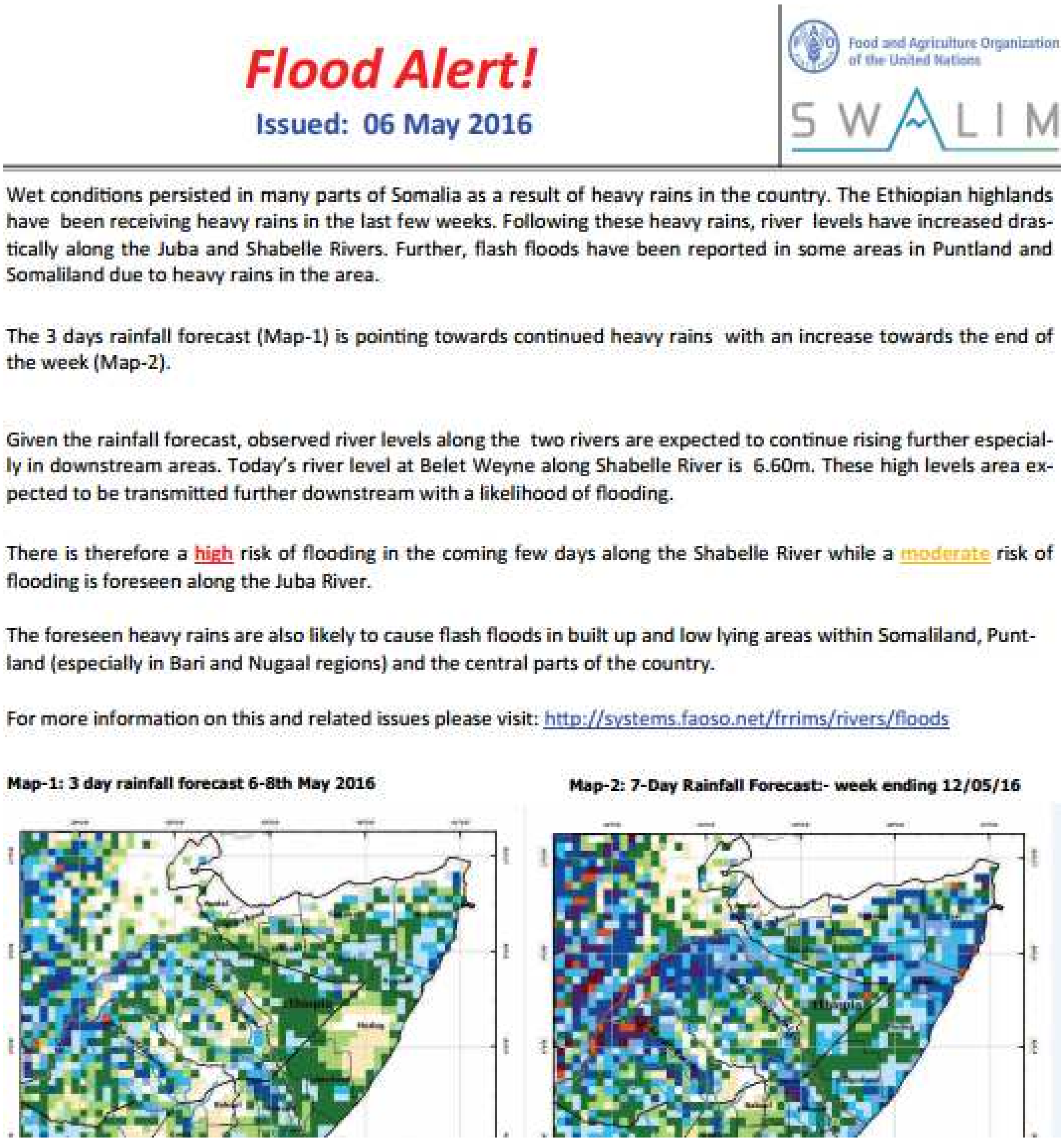


Figure 5.9 alert near real-time at pixel scale superposed to alert districts 48h

(zoom over Somalia 08/05/2016)

ERDS issued a red alert over Galguud, northern Mudug and Nugal districts and an amber alert over southern Mudug for the period 06-08052016 based on the calculation made using TRMM data.

The SWALIM flood alert bulletin (Figure 5.10) was issued from FAO on 6th of May with a high probability of extreme rainfall over Somalia. Alerts at district level visualized by ERDS allow users to immediately focus on potentially affected administrative areas being particularly understandable for non-scientific users who has to prioritize actions based on geographical and social parameters.



Flood Alert!

Issued: 06 May 2016

Food and Agriculture Organization of the United Nations

SWALIM

Wet conditions persisted in many parts of Somalia as a result of heavy rains in the country. The Ethiopian highlands have been receiving heavy rains in the last few weeks. Following these heavy rains, river levels have increased drastically along the Juba and Shabelle Rivers. Further, flash floods have been reported in some areas in Puntland and Somaliland due to heavy rains in the area.

The 3 days rainfall forecast (Map-1) is pointing towards continued heavy rains with an increase towards the end of the week (Map-2).

Given the rainfall forecast, observed river levels along the two rivers are expected to continue rising further especially in downstream areas. Today's river level at Belet Weyne along Shabelle River is 6.60m. These high levels area expected to be transmitted further downstream with a likelihood of flooding.

There is therefore a high risk of flooding in the coming few days along the Shabelle River while a moderate risk of flooding is foreseen along the Juba River.

The foreseen heavy rains are also likely to cause flash floods in built up and low lying areas within Somaliland, Puntland (especially in Bari and Nugaal regions) and the central parts of the country.

For more information on this and related issues please visit: http://systems.faoso.net/frrims/rivers/floods

Map-1: 3 day rainfall forecast 6-8th May 2016

Map-2: 7-Day Rainfall Forecast:- week ending 12/05/16

Fig 5.10 Sketch from the SWALIM flood alert bulletin of 06/05/2016

(http://www.faoswalim.org/resources/site_files/Flood%20Alert%20-06052015.pdf)

5.1.2 Extreme Rainfall hazard assessment: application to Mozambique case study

The main results presented below are obtained from the analysis of the heavy rainfall event that affected southern Mozambique during the second week of January 2013 (Cristofori et al. 2015). This event was officially classified as a disaster meeting the EM-DAT criteria (http://www.cred.be), on 21th January 2013. For instance a GLobal IDEntifier number (GLIDE), which is a globally common Unique ID code for disasters proposed by the Asian Disaster Reduction Centre (UNISDR, 2004), was issued for the Mozambique January 2013 event. The assigned code was FL-2013-000008-MOZ, composed by two letters to identify the disaster type (e.g. FL - Flood), the year of the disaster, a six-digit sequential disaster number and the three-letter ISO code for country of occurrence. Glide Number news reported that on 12 January the Mozambique already authorities declared an Orange Alert due to heavy rains that affected central and southern Mozambique since early January 2013. On 21 January the population had already suffered loss and damages and small-scale flooding resulted in nine deaths and affected a total of 18,699 people throughout the country. 1,889 houses were destroyed, 985 damaged and 679 inundated.

The situation as of January 21st was assessed using the 1 week accumulated rainfall from TRMM. Figure 5.4 shows on the left hand side the extreme rainfall alerts derived from the comparison between accumulated rainfall and the fixed thresholds. Medium to severe extreme rainfall warnings were issued for the upstream areas of the Limpopo river basin (red and orange dotted alerts) based on the past 7 days accumulated rainfall over these areas.

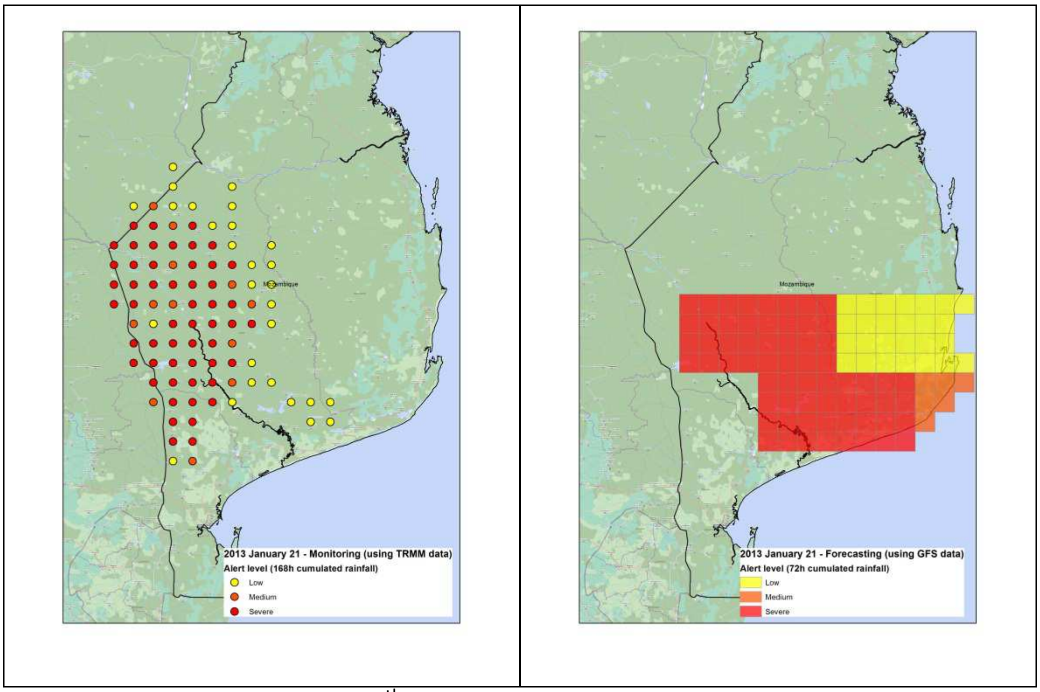


Figure 5.4 Situations as of January, 21th. a) On the left: alerts about accumulated rainfall over the past 7 days; b) on the right: alerts about accumulated forecasted rainfall for the next 3 days.

Figure 5.4 presents as well, on the right hand side, alerts derived comparing the GFS 72h accumulated rainfall with the fixed thresholds. Examination of this map shows that ERDS forecasted, for the following three days, heavy rainfall moving from the upstream area of Limpopo river towards the downstream areas. This resulted in an extended area of severe level alerts over south-western Mozambique.

In order to assess the effect of persistent rainfall over the same areas, alerts obtained from TRMM rainfall and alerts obtained from GFS rainfall were superimposed. New alerts were calculated based on the 1week accumulated rainfall estimates, until the 21st of January, and on the forecasted rainfall until the 23rd of January. Results from this calculation are presented in Figure 5.5.

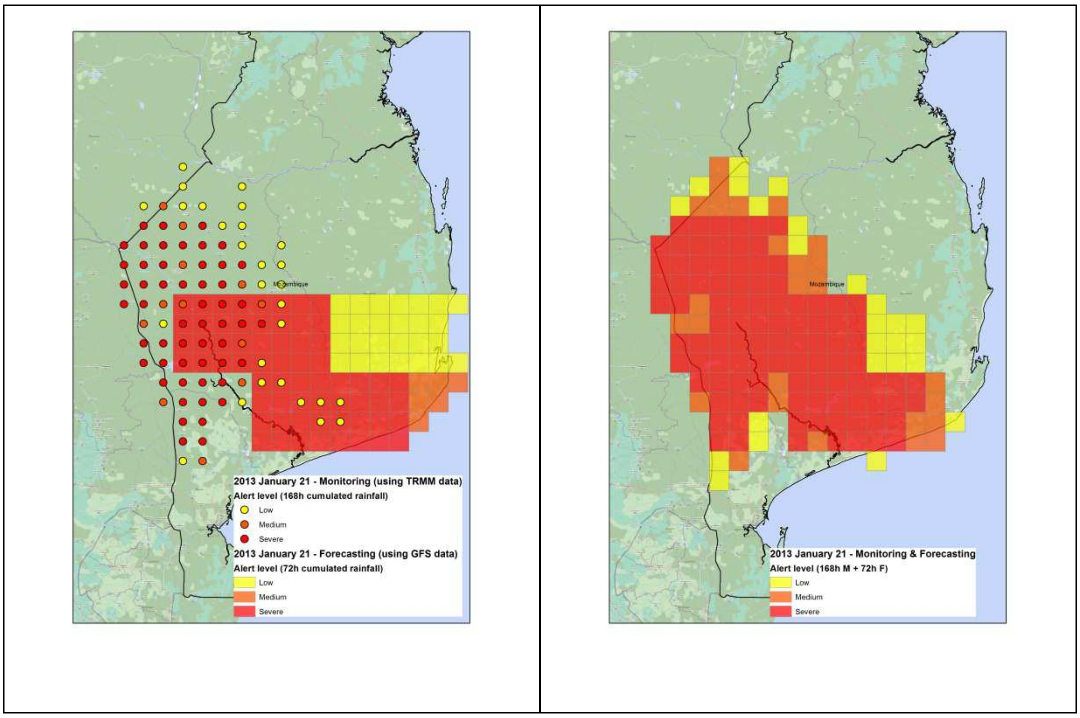


Figure 5.5 – a) On the left: integration of the two different alerts, about monitoring and forecasting data; b) on the right: results of the integration.

From the analysis of this map it is evident that ERDS highlighted an extended area of severe alerts over southern Mozambique for the period 15th to 23rd of January. Since the severe alerts are spread on a very wide portion of territory, the results obtained are not easily usable by humanitarian practitioner who have to prioritize actions and areas of intervention. Therefore rainfall alerts maps were integrated with geographical reference data in order to identify the areas at highest risk.

The first analysis was made based on the idea that areas located in the proximity of major rivers have an higher risk of flooding. Therefore an intersection of the rainfall alerts produced by the assimilation of monitoring and forecasting data with the main watercourses layer was performed. From the larger area of alerts identified before, only the areas at major risk of flooding were selected considering as criteria the proximity to the Limpopo River (Figure 5.6).

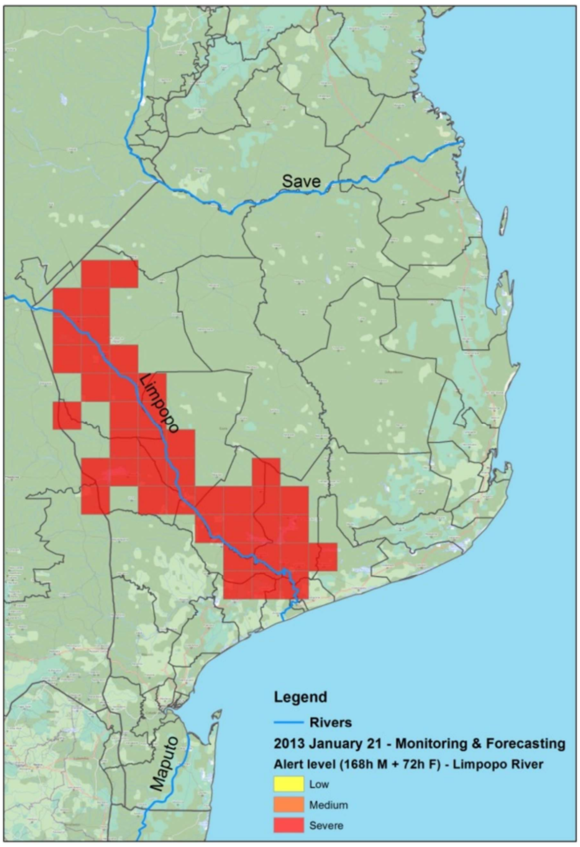


Figure 5.6 – Selection of areas at major risk of flooding, obtained through the intersection of rainfall alerts and the main watercourses layer.

A further important element to be considered is the population distribution, in order to make an assessment of the vulnerability in flood-prone areas. Using the LandScan layer, alerts pixel calculated before were coloured considering as criteria the number of inhabitants living in each pixel. Moreover tanks to the intersection with the GeoNames layers, the main cities located along the Limpopo river were superposed to the map. This allowed an immediate cross-reference between heavy rainfall information and land-marks.

The final map is presented in Figure5.7 and highlights the higher risk areas as the ones where the most important cities are located and hence were a larger number of inhabitants is living. These areas are located along the Limpopo river and in particular downstream its course (pink-violet pixels).

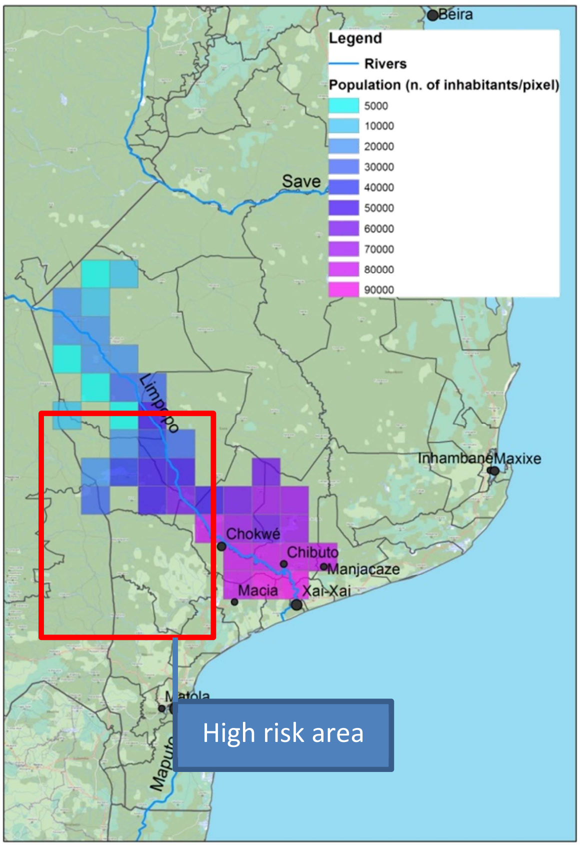


Figure 5.7 Integration of extreme precipitation alerts with LandScan and GeoNames layers.

As a final step, after having identified the main risk area, a flood-extent scenario was associated to the rainfall alert map. This is particularly useful for risk managers, in order to have an information about the distribution of the past flood events effect and consequently to provide an assessment of the more probable floodable areas in case of an extreme rainfall event over the area identified in the map. In this example the flood scenario has been produced processing the historical datasets of MODIS data (Figure 5.8) (Ajmar et al., 2010; Ajmar et al., 2012).

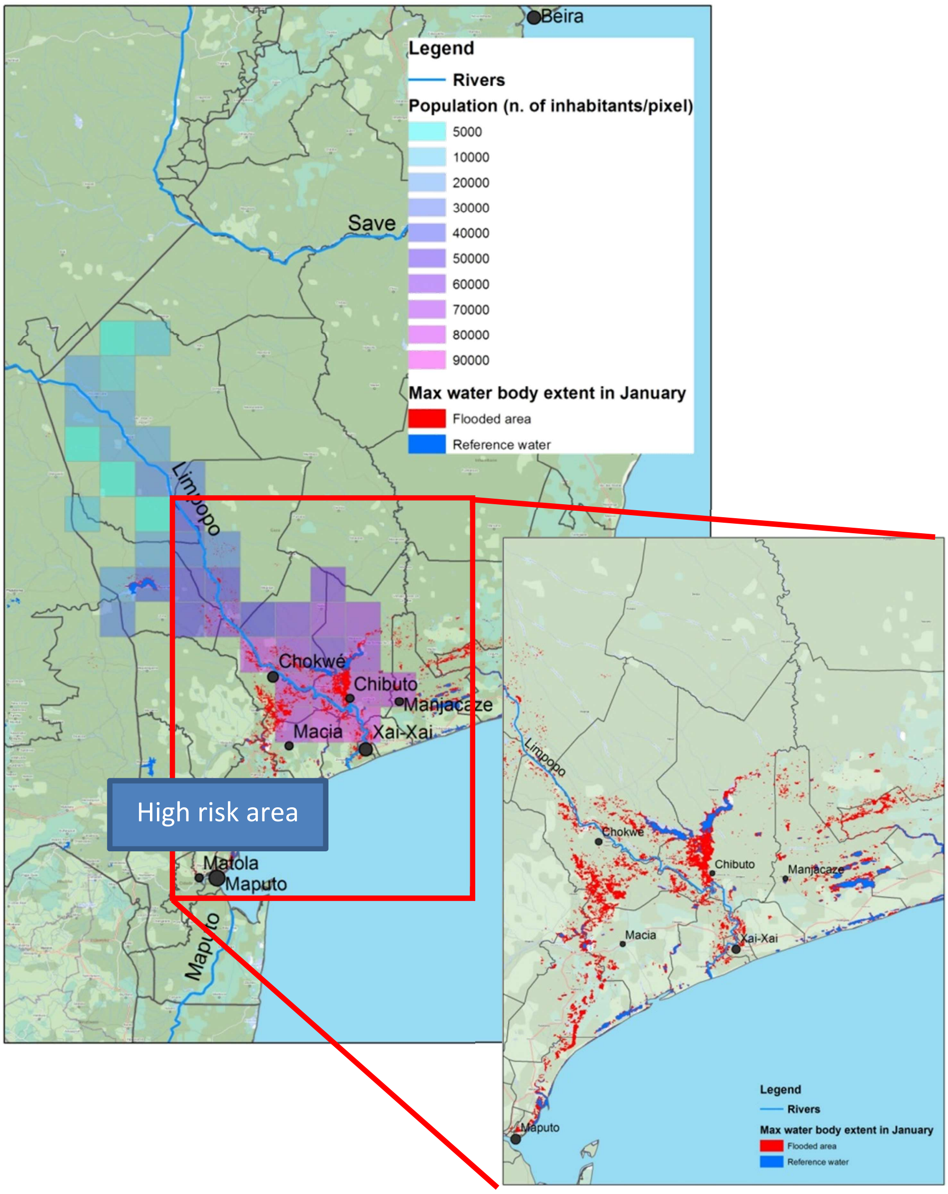


Figure 5.8 High risk flood scenario, produced processing the historical datasets of MODIS data.

The map produced by the United Nation Office for the Coordination of Humanitarian Affairs (OCHA) related to the Mozambique Provinces affected from 12 to 31 January 2013 (Figure 5.9), shows that, considering the southern Mozambique, the most affected area was the Gaza province. This is in fairly close agreement with the alert map obtained by the combination of TRMM and GFS rainfall alerts (Fig. 5.8).

Moreover in the report issued on 29th January 2013 by Reliefweb it was stated that 'Multiple villages including the city of Chokwe are completely inundated by flood waters along the river. However flood waters appear to be receding in this area as they move south of Chokwe. Flood waters have reached as far as Xai Xai south of Chokwe city. East of the Limpopo River additional villages are inundated as flood waters progress south east from the river. Large sections of road and railroad are also affected.'

This analysis strongly confirms that the most affected areas, within the Gaza province, were the ones around Chokwe and the east side of the Limpopo river as highlighted in Figure 5.9.

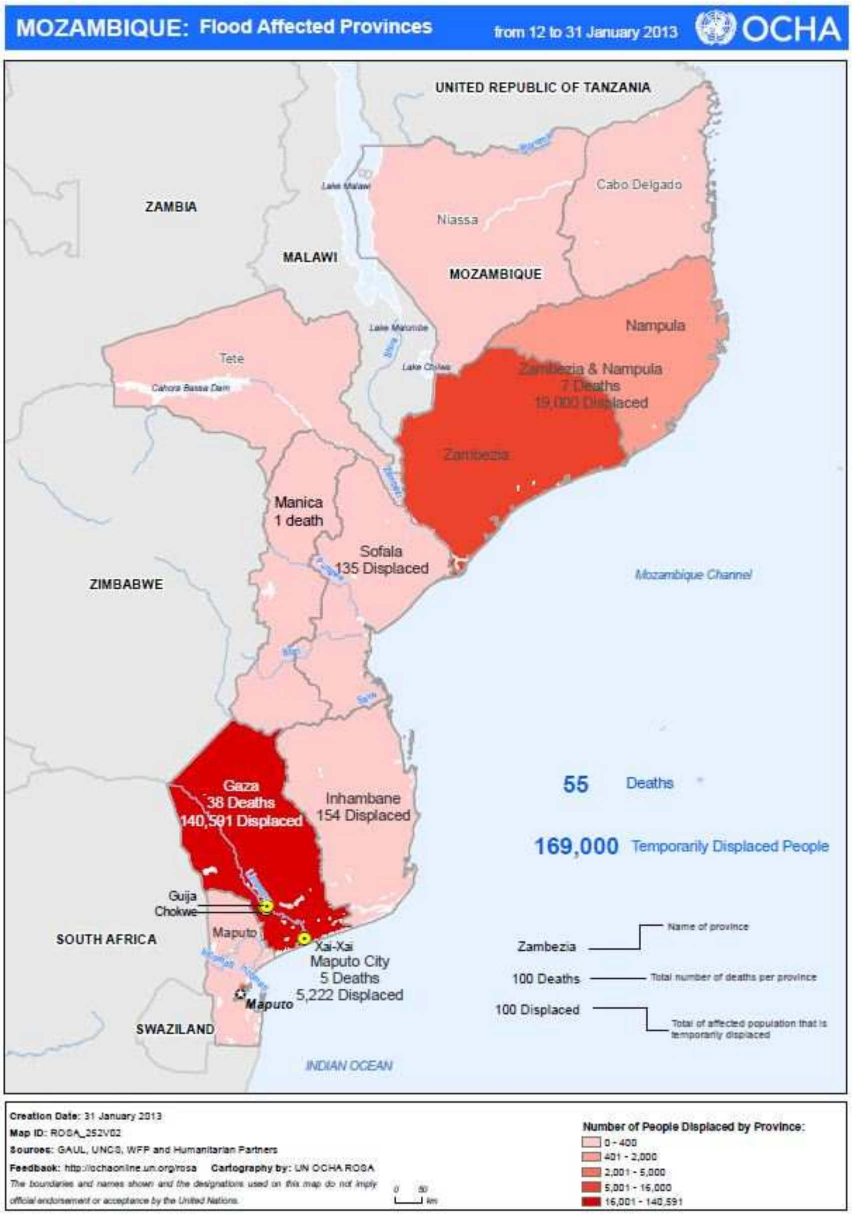


Figure 5.9 Map produced by OCHA, highlighting the Mozambique Flood Affected Provinces from 12 to 31 January 2013.

5.1.3 Flood risk assessment methodology: application to Malawi

The risk assessment methodology outlined in this sub paragraph (Cristofori et al., 2015) relies on the use of the Malawi Spatial Data Platform (MASDAP) developed in the framework of the Shire River Basin Management Program (SRBMP), a program carried out by the Government of Malawi together with the World Bank. MASDAP is a web platform, developed on top of the GeoNode application, that provides the users with a series of functionalities such as uploading and downloading geospatial data, sharing data, creating and printing web maps into a typical GIS environment. In order to enable local government personnel to integrate different kind of EO data for the dissemination of flood risk information through a GeoNode application, a training session on the 'Use of satellite data and weather prediction model rainfall data for vulnerability assessment' was held in Blantyre (Malawi) in December 2014. The main goal of the training was to illustrate a step by step workflow for the download and processing of satellite derived precipitation estimates, the calculation of extreme precipitation alerts, the integration of alerts with geospatial reference data and the publication of final warnings into the MASDAP platform. This methodology leads to the production of added-value maps for extreme precipitation and flood risk assessment, particularly useful in case of lack of high-resolution hazard data.

The main steps of the presented workflow are listed below:

1. Hazard assessment
2. Publication of the hazard information
3. Exposure Assessment
4. Integration of Hazard and Exposure
5. Publication of final risk warnings

The first step of the hazards assessment is the calculation of the accumulated precipitation for several time frames (i.e. 6h, 24h, 48h, 1 week, etc.), in order to have different hazard information related to short-term heavy rainfall events or to persistent rainfall over the same area. Accumulation of precipitation can be performed into a GIS environment, the output being a raster containing the sum of the 3h satellite precipitation estimates, over the chosen period. The second step of the hazard assessment is the generation of the extreme precipitation alerts which are calculated based on extreme rainfall thresholds defined at a national or at a regional scale. Alerts are issued when the near-real time accumulated rainfall exceeds the defined thresholds. Extreme rainfall thresholds for Malawi have been derived processing the after-real-time TRMM data-set, covering the period from 1998 to the delayed present and considering values of accumulated precipitation, over each time frame, exceeding the 95th percentile. For instance three alert level have been used:

1. Alert 1 – Low Warning Level (97th percentile)
2. Alert 2 – Medium Warning Level (98th percentile)
3. Alert 3 – High Warning Level (99th percentile)

The hazard layers can be then published into MASDAP, containing either the accumulated precipitation values or the extreme rainfall alerts. It should be noticed that accuracy of the produced warnings is strongly related to the resolution of the used data, which is often too coarse to produce a valuable hazard information for a local scale assessment. Moreover an information displayed as gridded precipitation or as pixel level alerts, can be particularly difficult to understand by non-scientific users.

Therefore in order to reference the hazard to the area of interest, different base layers can be chosen and overlaid to the hazard layers. Moreover, depending on the specific end-user needs, several analyses can be made by taking into account further layers of exposed assets such as water resources, settlements, land use/land cover and population density. These analyses are based on geospatial intersection between the event layer and the mentioned exposure layers.

As a result several maps showing the final risk information can be produced and published on the MASDAP web platform, leading to a meaningful and immediate visualization of areas and assets at the highest risk. Additionally a summary table containing the classification of at-risk cities or population and the related accumulated precipitation values or warning level can be rapidly produced.

An example of maps produced during the training is presented in the results section.

Results obtained during the training are illustrated below. The analysis is applied to the extreme rainfall event that occurred over central Malawi in January 2013.

Figure 5.10 shows the comparison between the 72h accumulated precipitation, calculated between 05/01/2013 at 00.00UTC and 08/01/2013 at 00.00UTC, and the extreme precipitation alerts derived using the defined extreme rainfall thresholds.

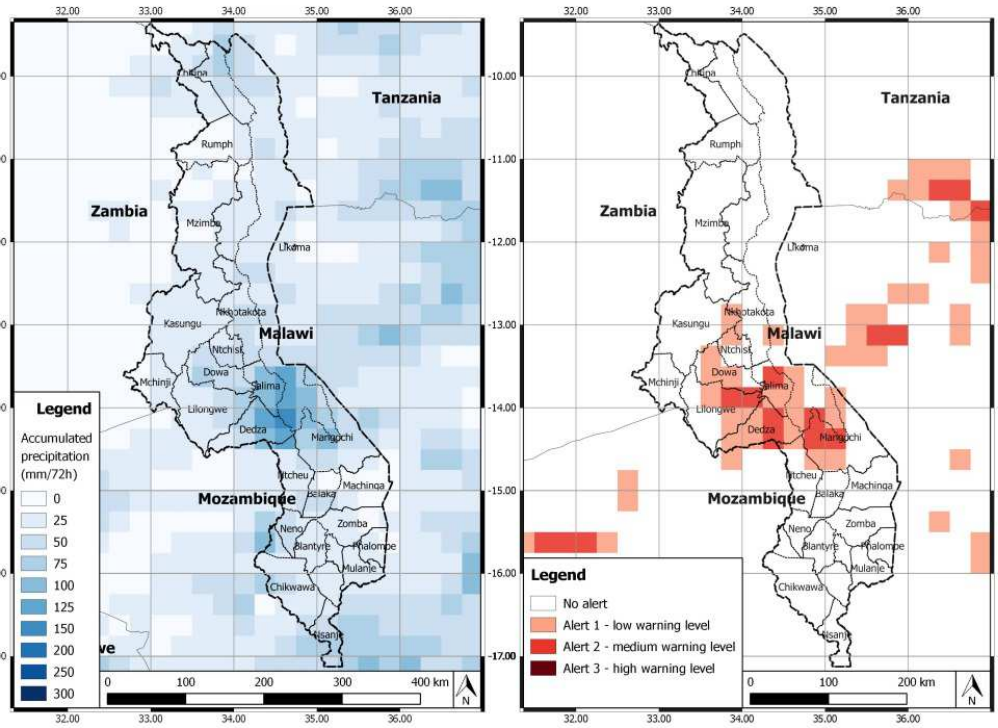


Figure 5.10 72h TRMM-3B42RT accumulated precipitation and Extreme Precipitation Alerts (05-07 January 2013)

The accumulated precipitation map, on the left hand side of the figure, shows an area of high precipitation over central Malawi, which produces low to medium warning level alerts displayed on the right hand side. While produced maps proved to deliver a valuable information to scientific users, such as Meteorology and Hydrology departments personnel, gridded alerts were not meaningful for the Survey Department personnel, who is used to work with geo-data in order to prioritize actions at national or local level.

Therefore trainees were asked to derive alerts for administrative levels. This procedure was performed by downloading the Administrative Census layer from MASDAP and by making a 'grid statistic for polygons', using the Administrative Census layer as the input polygons and the extreme precipitation alerts layer as the input grid. Several criteria were tested, such as the 'maximum precipitation alert per district' or the 'mean precipitation alert per district', leading to different levels of hazard quantification. Figure 5.11 shows results obtained applying the 'maximum alert per district' criteria. The produced map was able to address a more immediate geographical visualization of potentially affected areas. Moreover, from the analysis of the attribute table related to the derived map (Table 5.1), it was evident that users could quickly access to essential information related to alerted administrative levels, such as the name of administrative level, the population density, or the census district number.

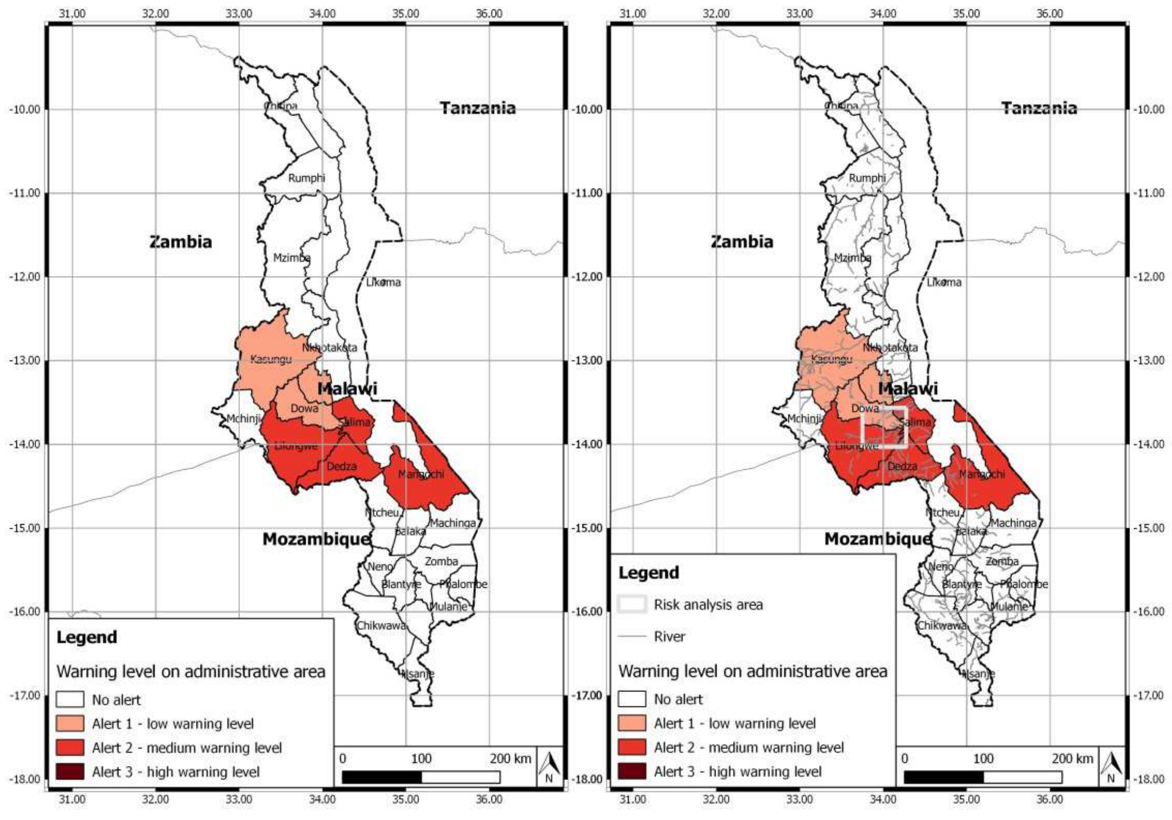


Figure 5.11 Administrative level extreme precipitation alerts and visualization of the 'risk analysis area'

Admin. Level	Alert Level	Census district number	Total population per admin. level	Population density per admin. level
Kasungu	1	7	707862	88
Ntchisi	1	9	249914	145
Dowa	1	10	641895	210
Salima	2	11	371938	173
Lilongwe	2	12	1325010	228
Dedza	2	14	671137	179
Mangochi	2	16	885355	132

Table 5.1 - Attribute table of alerted Administrative Levels

In order to obtain a finer flood risk assessment, trainees were asked to perform an additional analysis considering the exposure of populated places to potential flooding. This analysis was performed over a specific area of interest: the Risk Analysis Area shown in Figure 5.12.

Firstly the River Network layer and the Populated Places layer were downloaded from MASDAP and uploaded into the work environment. Secondly each village (Populated Place) was associated to the alert level of the gridded alert layer calculated previously. Result of this procedure is shown in the middle part of Figure 5.12, and highlights villages coloured with the corresponding level of alert.

Thirdly it was decided to use, as exposure criteria, the proximity to the main river network. Therefore a new layer was created considering a 1km buffer around each river, and the alert levels of villages included within the buffer areas were increased by one. Bottom part of Figure 5.11 shows the final risk map produced during the training session.

This final map allows an immediate and intuitive visualization of most at risk areas. Moreover, as mentioned in the case of administrative level alerts, the data summarized in the attribute table represent a key data-set for the calculation of essential information such as the amount of population or the number of households for each alerted village.

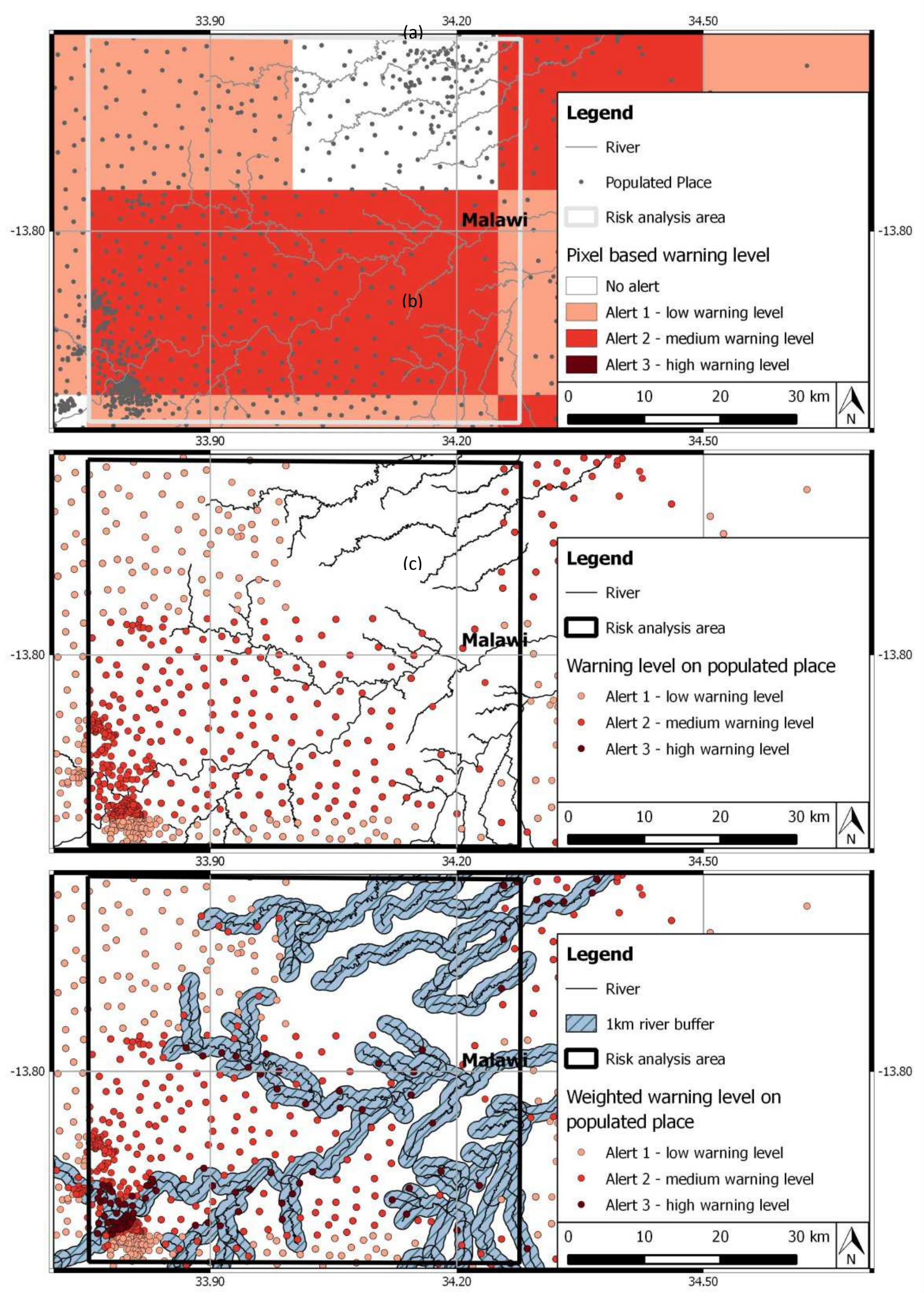


Figure 5.12 Flood risk assessment maps, resulting from the analysis performed over the 'risk analysis area'

As a final step the produced information was uploaded into MASDAP platform and shared with different stakeholders in an easy-to-use and common environment. The web platform functionalities allow either the publication of the final map previously produced into an external GIS environment, or the upload of the different layers generated following the proposed workflow. In this second case the final map can be then composed into MASDAP, eventually overlaying additional reference data-set available in the platform. An example of the final visualization into MASDAP is shown in Figure5.13.

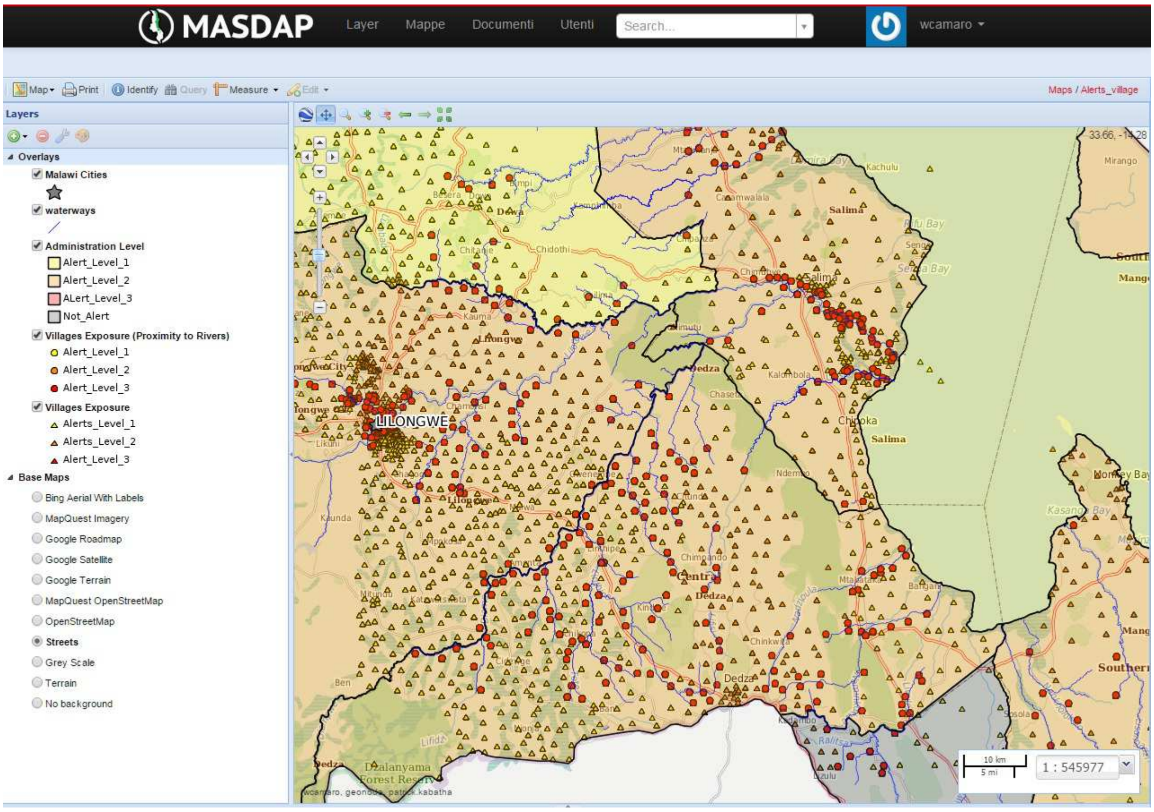


Figure 5.13 Alerts representation using MASDAP platform and considering accumulated precipitation alerts and villages exposure

Maps produced for the assessment of the January 2015 flood event in Malawi are shown in Annex IV. These maps include also the assessment of exposure to identify specific assets most at risk (Cristofori et. al., 2016).

5.2 A regional Early Warning System for coastal hazards

In the framework of the iCoast Project (www.icoast.eu) Ithaca has been involved in two tasks related to the development of coastal state indicators and of risk scenario definitions. These activities have been focused in finding the most relevant indicators addressing end-users with understandable information about potential impacts of coastal hazard and in implementing a visualization system that enable the integration of multiple alerts in order to produce both numerical and visual representation of alerts.

5.2.1 Coastal State Indicators

Coastal State Indicators (CSIs) are key parameters providing end-users with an essential information about coastal hazards and related impacts in order to enhance the prediction, the monitoring and the mitigation of coastal risks.

To select an effective set of coastal state indicators it is essential to identify relevant metrics that provide an assessment of environmental conditions that may have an impact on the coastal areas.

CSI have to be:

- measurable - to quantify the magnitude of each parameter
- predictable - in order to provide Early Warning Information
- comparable - to compare the predicted or the current state of the indicators with a preferred situation
- informational - providing users with an immediate and easy to understand information about coastal risk and possibly about coastal impacts

Therefore within iCoast, CSI are chosen as a set of key parameters that can be derived from the meteorological and the hydrodynamic modules, and that can be aggregated, weighted and compared with reference thresholds, in order to produce alert messages that can be tailored to different end-users needs. This last point is particularly relevant within iCoast, since the ambition of the CSI module is to suggest a methodology able to target different users by considering the interaction of a specific sub-set of coastal indicators.

The interaction of scientist, public authorities, coastal managers and the public is a key component of any effective alert system. On the one hand scientists can produce a considerable amount of data for the prediction and the monitoring of the state of the coastal environment in front of a storm. Moreover in the last decades the rapid development of new technologies favored the increase of the temporal and spatial resolution of both Numerical Weather Prediction models and of radar or in-situ monitoring techniques. On the other hand the final information provided by scientist is often too complex and hardly accessible for the end-users, especially considering that prediction models have to deal with uncertainty and that decision makers need immediate and easy to understand information in order to prioritize actions (Van Koningsveld et al., 2005 and Ojeda-Martínez et al., 2009). Although a wide literature exists in the field of the applicability and effectiveness of risk indicators in coastal areas, as described in the next paragraph, their operational application into the coastal alert systems deployed by Mediterranean countries is not widespread yet.

Therefore the proposed coastal indicators module is aimed at using both physical variables currently used into official coastal alert systems and more complex parameters used by scientists for the storm impact assessment on the coastline, combining them into a Geographic Information System environment, in order to produce final alerts that can meet requirements of a variety of users.

5.2.2 Coastal State Indicators Selection

The aim of the CSI module is to generate early warnings providing a timely information about potential risk faced by the population, by the infrastructures and more generally by the environment located within the coastal areas. As stated in the introduction, CSIs are mainly derived from variables provided by the meteorological and the hydrodynamic modules.

A first set of Coastal State Indicators is represented by a sub-set of seven physical variables used as trigger for meteorological and flood warnings from the majority of the operational National and Regional warning systems of the Mediterranean.

This sub-set composed by both hydrodynamic and meteorological data, includes:

1. *Significant Wave Height*
2. *Wave Direction*
3. *Wave Peak Period*
4. *Mean Water Level*
5. *Wind Speed*
6. *Wind Direction*
7. *24h accumulated Precipitation*

In particular the Significant Wave Height, the Peak period and the Mean Water Level correspond to the ‘peak morphodynamic oriented’ coastal-storm indicators reported into the Driver Characterization Report (Action C2, iCOAST project). All the above mentioned variables are primarily used as a feed into the Alert Matrix (see Paragraph 3). On the other hand they are able to provide a first easy to understand indication about the extreme sea state and the potentially hazardous meteorological conditions that might be generated by a storm.

Generally warnings for coastal waters are issued whenever strong winds or high waves are expected. These kind of warnings provide a particularly easy-to-understand and effective information for the users of coastal areas such as recreational users, owners of temporary properties located near the shore and more generally for the public, in order to be aware about the most appropriate action to take when dangerous conditions are imminent or expected.

On the other hand a variety of users could benefit from the iCoast projects output, as described in more detail in paragraph 4, and in particular decision makers. Decision makers need to know if a storm will have significant impacts on population, properties and infrastructures and their decisions relate to whether to issue a warning or not, the level of the warning to be issued, the action that has to be taken. For instance one of the main targets of the iCoast project are urban beaches and coastal defence infrastructures where most of the casualties and damages have been reported in the last two decades (Gracia et al., 2014).

Therefore, according to the outcomes of the review of existing CSIs, it is essential to take into account further parameters able to describe the physical processes that drive coastal damages. The focus is made particularly on the assessment of main coastal damages reported in the Report Inventory (Action C1, iCOAST project): flooding, erosion/accumulation, destruction. Therefore the following four parameters, so called 'storm integrated' coastal-storm indicators into the Driver Characterization Report, are chosen as additional CSIs:

Total Energy (TE) $= \sum_{i=1}^{i=N} H_i^2 \cdot (t_{i+1} - t_i)$

Total Energy Flux (TEF) $= \sum_{i=1}^{i=N} H_i^2 \cdot T_{P_i} \cdot (t_{i+1} - t_i)$

Run Up Parametrization (RU1) $= \sum_{i=1}^{i=N} H_i^{0.5} \cdot T_{P_i} \cdot (t_{i+1} - t_i)$

Run Up Stockdon (RU2) $= 1.10 \cdot (H_0 L_0)^{0.5} \cdot \left(0.35\beta_f + \frac{(0.563\beta_f^2 + 0.004)^{0.5}}{2}\right)$

5.2.3 Coastal State Indicators Visualization

The implemented methodology foresees the comparison of the selected coastal state indicators values against 3-level thresholds. Different parameters require a different algorithm of comparison: the parameters Hs, WaD, Tp generate alerts only in case the corresponding threshold level is exceeded for 6 consecutive hours; the parameters TE, TEF, RU1 instead, being calculated as cumulative sums, generate alerts even if they exceed the thresholds for a single time step; finally the RU2 and the Sea Level parameters, given that are parameters valid instantaneously, generate alerts the first time they exceed the thresholds. In particular the RU2 parameter is calculated only in deep water condition (see equation).

The comparison of parameters against thresholds generates alert arrays with 2 dimensions: one is the beach target dimension (spatial), the other is the time dimension. In particular the time dimension has the same time step as the original input variables, which is one hour.

In order to summarize the results and make them more user-friendly, the alert array is then downsampled in the time dimension, by taking into account only the maximum alert value per day, for each beach target.

Finally all the alerts obtained for each parameter are collected together in a single daily matrix (to observe an example of alert matrix, see Table 5.2). In order to be easily and instantly comprehensible for all the different users, for each beach targets, CSIs alert values are expressed using a "traffic light" representation: a situation of calm (green colour), a situation of caution (yellow colour), a situation of moderate alert (orange colour) a situation of alert (red colour). Besides the CSIs alert values, other meaningful columns have been also added in the matrix table:

- the typology of beach targets that might differ among "barrier beach", "enclosed beach", "groynes", "open beach", "port" and "revetments";
- the reference date for which the alerts are forecasted;
- storm begin, storm end and storm duration which indicate respectively the hour when Hs starts to be greater than 2m, the hour when Hs reverts under 2m and the time span during which Hs has been remained over 2m.

Furthermore, the daily CSI alerts collected in the matrix table might also be represented in a map regarding the entire Catalan coastline (see Figure 5.14).

Beach target Name	Beach type	date	WiS	WiD	Pcp	Hs	WaD	Tp	MWL	TE	TEF	RU1	RU2	Storm begin	Storm end	Storm duration
BADALONA BEACH	OPEN BEACH	26/12/2008	0	0	0	2	2	2	0	2	2	2	2	2008-12-26 13:00:00	2008-12-27 19:00:00	30
BARCELONA BEACH	ENCLOSED BEACH AND GROYNES	26/12/2008	0	0	0	2	2	2	0	2	2	2	2	2008-12-26 13:00:00	2008-12-27 22:00:00	33
CABRERA DE MAR BEACH	REVETMENTS	26/12/2008	0	0	0	2	2	3	0	3	2	2	1	2008-12-26 13:00:00	2008-12-27 20:00:00	31
CAMBRILS PORT	PORT	26/12/2008	0	0	0	1	3	1	0	1	1	0	0	2008-12-26 18:00:00	2008-12-27 15:00:00	21
FORUM PORT	PORT	26/12/2008	0	0	0	2	3	2	0	2	2	2	1	2008-12-26 13:00:00	2008-12-28 11:00:00	46
GAVA BEACH	OPEN BEACH	26/12/2008	0	0	0	2	3	3	0	2	2	1	2	2008-12-26 14:00:00	2008-12-28 16:00:00	50
GINGOLERS GROYNES	GROYNES	26/12/2008	0	0	0	0	1	3	0	0	0	0	0	-	-	-
L'ESCALA BEACH	OPEN BEACH	26/12/2008	0	3	0	3	3	3	0	3	3	2	2	2008-12-26 10:00:00	2008-12-28 17:00:00	55
LLANÇA PORT	PORT	26/12/2008	0	3	0	3	2	3	0	3	3	2	2	2008-12-26 10:00:00	2008-12-28 00:00:00	38
LLORET DE MAR BEACH	POCKET BEACH	26/12/2008	0	0	0	3	2	2	0	3	3	2	1	2008-12-26 11:00:00	2008-12-28 13:00:00	50
MARQUESA BEACH	OPEN BEACH	26/12/2008	0	3	0	1	1	1	0	1	1	0	0	2008-12-26 18:00:00	2008-12-27 18:00:00	24
MATARO PORT	PORT	26/12/2008	0	0	0	2	2	2	0	3	2	2	2	2008-12-26 12:00:00	2008-12-27 21:00:00	33
OLIMPIC PORT	PORT	26/12/2008	0	0	0	2	3	2	0	2	2	2	2	2008-12-26 13:00:00	2008-12-28 12:00:00	47
PALS BEACH	OPEN BEACH	26/12/2008	0	3	0	2	3	2	0	3	3	2	2	2008-12-26 09:00:00	2008-12-28 19:00:00	58
PREMIA DE MAR PORT	PORT	26/12/2008	0	0	0	2	2	2	0	2	2	2	2	2008-12-26 13:00:00	2008-12-27 20:00:00	31
RIERA RIUDOMS GROIN	GROYNES	26/12/2008	0	0	0	1	3	0	0	1	1	0	0	2008-12-26 17:00:00	2008-12-27 15:00:00	22
RIFA-PILANS BEACH	OPEN BEACH	26/12/2008	0	0	0	1	2	1	0	1	1	0	0	2008-12-26 17:00:00	2008-12-27 15:00:00	22
SANT SEBASTIA BEACH	ENCLOSED BEACH	26/12/2008	0	1	0	2	3	2	0	2	2	2	2	2008-12-26 13:00:00	2008-12-28 10:00:00	45
SITGES BEACH	ENCLOSED BEACH AND GROYNES	26/12/2008	0	0	0	2	2	3	0	2	2	1	2	2008-12-26 15:00:00	2008-12-28 11:00:00	44
SOUTHERN MATARO BEACH	REVETMENTS	26/12/2008	0	0	0	2	2	2	0	3	2	2	2	2008-12-26 13:00:00	2008-12-28 01:00:00	36
TORDERA RIVER DELTA	OPEN BEACH	26/12/2008	0	2	0	3	3	2	0	3	3	2	1	2008-12-26 11:00:00	2008-12-28 14:00:00	51
TOSSA DE MAR BEACH	POCKET BEACH	26/12/2008	0	2	0	3	3	2	0	3	3	2	2	2008-12-26 11:00:00	2008-12-28 16:00:00	53
TRABUCADOR BAR	BARRIER BEACH	26/12/2008	0	0	0	1	3	3	0	1	1	0	0	2008-12-26 18:00:00	2008-12-27 19:00:00	25

Table5.2 Example of alert matrix (forecast WRF 3km issued on 26/12/2008 for the 26/12/2008).

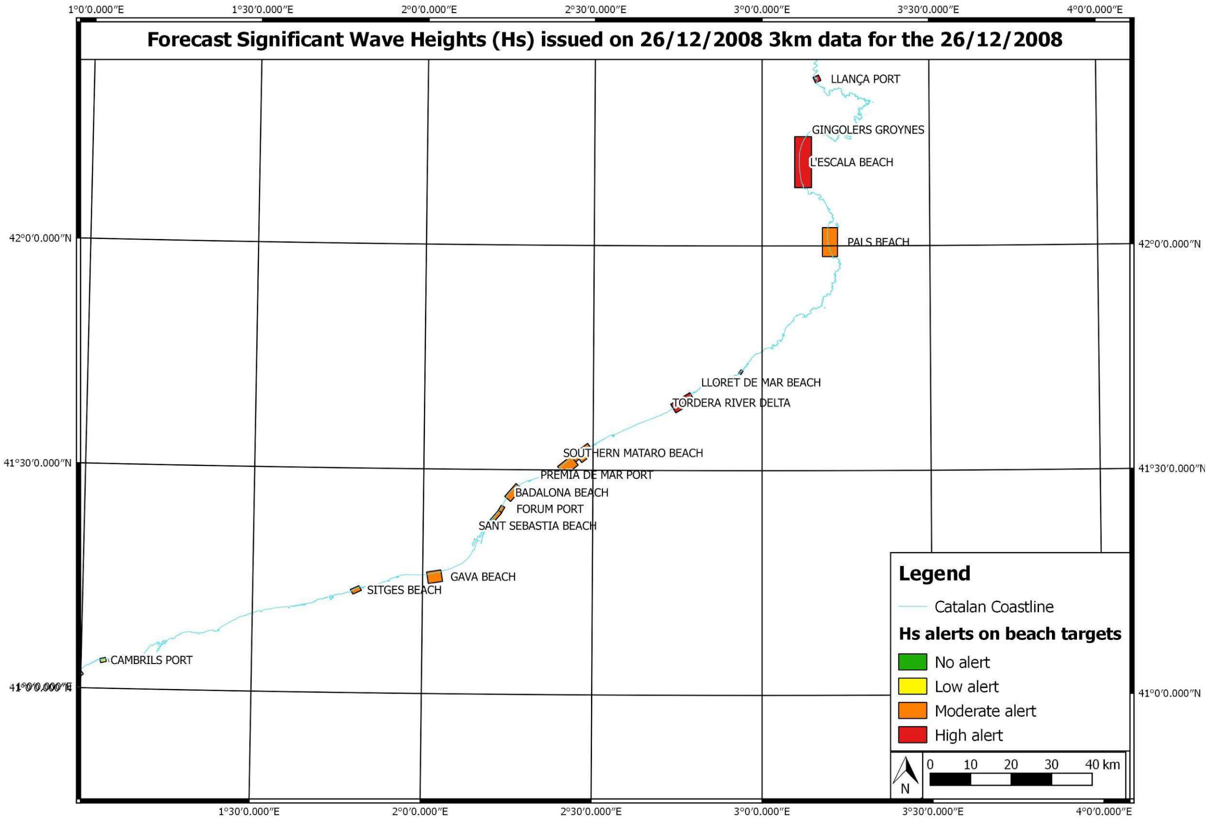


Figure 5.14 Example of alerts estimated for the Catalan beach targets regarding the Hs CSI (forecast WRF 3km issued on 26/12/2008 for the 26/12/2008).

5.2.4 Identification of end-users and generation of warning messages

Since the Catalan coast, similarly to almost all the Mediterranean coast, is interested by a multitude of human activities and is availed by several different typologies of users, the CSI module is conceived as a tool able to address alerts to this variety of users who need to receive different warnings in order to take specific decisions based on their needs.

Context-aware alert messaging is a key issue in order to implement an effective EWS indeed, as stated by Meissen et al. (2008), “even existing national EWS in developed countries – which mainly use broadcast dissemination – are often ineffective when it comes to targeted warnings for specific areas or user groups”. Nowadays, it is generally acknowledged that communities are not homogenous and hence their different vulnerable groups might need different warnings (Thrush et al., 2005; Shaw et al., 2005; Tapsell et al., 2005). The type of area or the socio-economic composition of the population are also important factors that should be considered in the communication phase of the EWS (Balmforth et al., 2006; Twigger-Ross, 2005).

In order to deliver more efficient warning messages, the iCoast innovative approach aims to improve general warning messages by adapting them to the profile and to the specific characteristics of the different end-users.

Firstly, five different categories of users have been identified :

1. iCoast group: it represents the scientific community characterized by a high level of knowledge and expertise regarding extreme natural events, hydrological, meteorological and morpho-dynamic modelling.
2. Civil protection: it is the public agency, at national and/or local level, designated to the prediction, prevention and management of exceptional events; it is the authority in charge to protect the sake of life, the properties, the settlements and the environment from damages and dangers caused by natural catastrophes.
3. Coastal managers and maritime spatial planners: they are the professionals working in the public institutions and in the public authorities in charge of the management of the coastal areas. They plan the long-term development of the coastal communities protecting the natural environmental and predisposing mitigation actions in order to make the local community more resilient to natural events.
4. Inhabitants: they are all the citizens who live or own goods, real estates or economy activities in the coastal areas.
5. Occasional users: differently from the previous category, they do not live or own any properties but they frequent the coastal areas for leisure and entertainment reasons (i.e. tourism and sport).

Secondly, among the set of CSIs (see paragraph 2.3), according to the characteristics of each category of end-users, the most relevant indicators have been selected in order to generate the alerts. The goal is to select the sub-set of indicators able to deliver a message about potential damages and actions that have to be taken focusing on different end-users requirements.

Thirdly, customized warning messages associated with preventive mitigation actions have to be identified for each type of user (see Table 5.3).

1. iCoast group: one of the principal iCoast challenges is to provide an appropriate and efficient use of numeric prediction models. Therefore an alert message has to be addressed to the iCoast modelling group when a beach target is expected to receive a damaging storm, in order to timely plan a higher resolution modelling over this area. As

better explained in a previous iCoast deliverable (see Deliverable - Action F1; May 2015), the architecture of the project has been designed at two complementary levels. Firstly, a partial set of meteorological and hydrological models run once a day to provide a first level of CSIs. These indicators are used to decide whether or not to activate a second level of execution. In this case, a full chain of hydrologic and morphologic models is run to provide refined information only respectively at local domains and at beach targets where the first level of alarm has been raised (i.e. the area most at risk). A wise and proper exploitation of the second set of more accurate models, which are run only when they are actually necessary, guarantees to save a considerable amount of computational efforts and economic resources.

2. Civil protection: alerts produced will be specifically targeted to the civil protection agency. These warnings are supposed to be related to the likelihood of occurrence of significant impacts on population, properties or infrastructures. Consequently to this warning message, the authority in charge might decide whether to disseminate or not the alert to the population and whether to undertake or not quick defense measures.
3. Coastal managers and maritime spatial planners: this type of user, who have to plan mitigation and resilience initiatives, is alerted whenever the iCoast module results produce an alert related to likelihood of flooding, erosion, accumulation or destruction.
4. Inhabitants: similarly to the warning message spread to the civil protection end-user, also a warning message concerning the situation of danger to life, risk of damages to goods or properties should be addressed to inhabitants of the coastal area. During a catastrophic event, an appropriate communication should thus secure goods and save several lives making the inhabitants informed about the on-going threat.
5. Occasional users: end-users who frequent the coastal areas for leisure and entertainment reasons should instead be informed on the risk regarding the activities located in the coastline (i.e. the activities placed along the beaches or near the beaches) in order to take an appropriate decision whether to visit or not the coastal area at risk.

Finally a ‘mitigative actions’ message is associated to each ‘warning message’, as summarized in Table 5.3. The proposed methodology allows to quickly generate alerts addressed to each end-user just by selecting each specific end-user category, since the sub-set of indicators which contribute to the generation of the each warning message can be automatic.

Moreover it might help in facilitating and in making more flexible the communication phase, eventually selecting a more effective communication channel (e.g., e-mail, SMS, MMS, voice, signal systems, etc.) in relation to each end-users group characteristics.

Users	**Most relevant CSI**	**Warning messages**	**Mitigative actions**
iCoast group	*Total Energy* *Total Energy Flux* *Run Up Parametrization* *Run Up Stockdon*	risk of damaging storm	run/do not run higher resolution models
Civil Protection	*Significant Wave Height* *Wave Direction* *Wave Peak Period* *Mean Water Level* *Wind Speed* *Wind Direction* *Precipitation* *Total Energy* *Total Energy Flux* *Run Up Parametrization* *Run Up Stockdons*	risk of significant impacts on population, properties or infrastructures	disseminate or do not disseminate alert and plan quick defense measures
Coastal Defense and Planning Managers	*Total Energy* *Total Energy Flux* *Run Up Parametrization* *Run Up Stockdon*	risk of flooding, erosion or destruction	plan mitigation/resilience measures
Inhabitants	*Significant Wave Height* *Wave Direction* *Wave Peak Period*	danger to life, risk of damages to goods and properties	move/don’t move, protect

	Mean Water Level *Wind Speed* *Wind Direction* *Precipitation*		
Occasional users	*Significant Wave Height* *Wave Peak Period* *Wind Speed* *Wind Direction* *Precipitation*	risk for beach/near-beach activities	go/don’t go

Table 5.3 End-users of the Catalan coast, indicators considered for the generation of tailored warning messages and associated mitigative actions.

5.3 A decision support project for enhancing high level sport strategies

In Olympic sailing, individual competitors or teams of athletes sail various classes of sailboats in timed trials over a single course. The contest requires them to navigate upwind, downwind and everything in between. Their final time depends on numerous factors, including the boat design, the skill of the sailors, course difficulty and ocean currents. Perhaps the most important factor, though, is how well the athletes can harness the wind that fills their sails.

Because wind constantly changes speed and direction, athletes and coaches hope to have the best information at the start of a run.

Moreover in some specific areas also the tidal current plays a crucial role in the definition of the best strategy before the start. Tidal current can definitely be a very big advantage for sailors if they are able firstly to identify patterns, secondly to develop a high level of confidence in the predictability of these patterns and finally if they are able to recognize key signs, such as ‘slack current’ lines, by their own on the water.

That’s why the Austrian Sailing Federation implemented a science-technology and science communication project to study and communicate to sailors and coaches the most important current and features of the Rio 2016 Olympic Sailing venue.

5.3.1 Weather Project ‘Towards Rio 2016’: the operational research project

This sub-paragraph reports the operational research project conducted in September 2013 to identify challenges, opportunities, needs and gaps for the development of a weather project aimed at studying the current and weather patterns for the Guanabara Bay (Rio de Janeiro) and to address key information to sailors and coaches in an immediate, understandable and usable way.

The main points of the Weather Project ‘Towards Rio 2016’ are:

- Historical and real-time wind data availability
- Historical and real-time current data availability
- Atmospheric model availability
- Tidal current model availability
- Realization and validation of wind call-book
- Realization and validation of tidal current call-book
- Building-up of an effective communication protocol between meteorologist and coaches/athletes
- Learning how to read and use the call-books
- Learning how to use and interpret measurements at sea

Course area for Rio 2013 Olympic Games will be located in four different positions, two inside the Guanabara Bay and two outside the bay, affected by very different wind and current conditions depending on the specific topography and bathymetry of the areas (Figure 5.15).

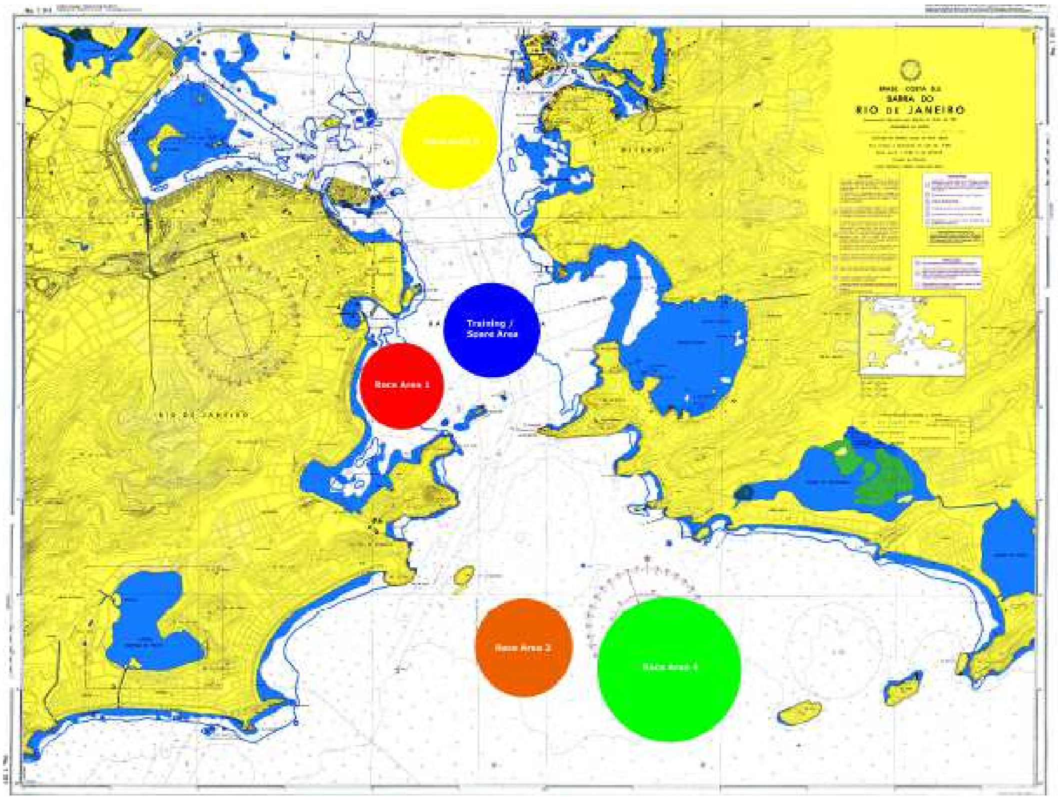


Figure 5.15 Rio 2016 Olympic Racing Areas

The use of a weather model using a 1km and 3km grid resolution and a current model using a 30m resolution is essential to have a first understanding of wind and current systems in the different Olympic racing areas (Figure 5.16).

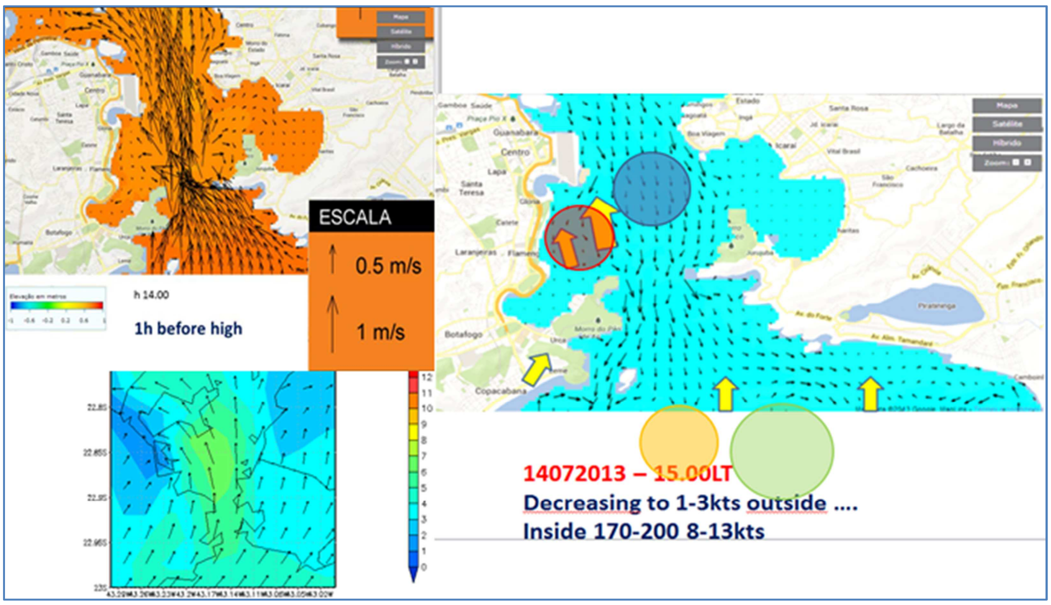


Figure 5.16 Rio 2016 Example of current and wind models used during the 2013 training campaign (http://numa.lamce.coppe.ufrj.br/home/home.php)

The use of the wind measurement systems on motorboats is fundamental to have a faster and more accurate understanding of the wind system at sea (Figure 5.17).

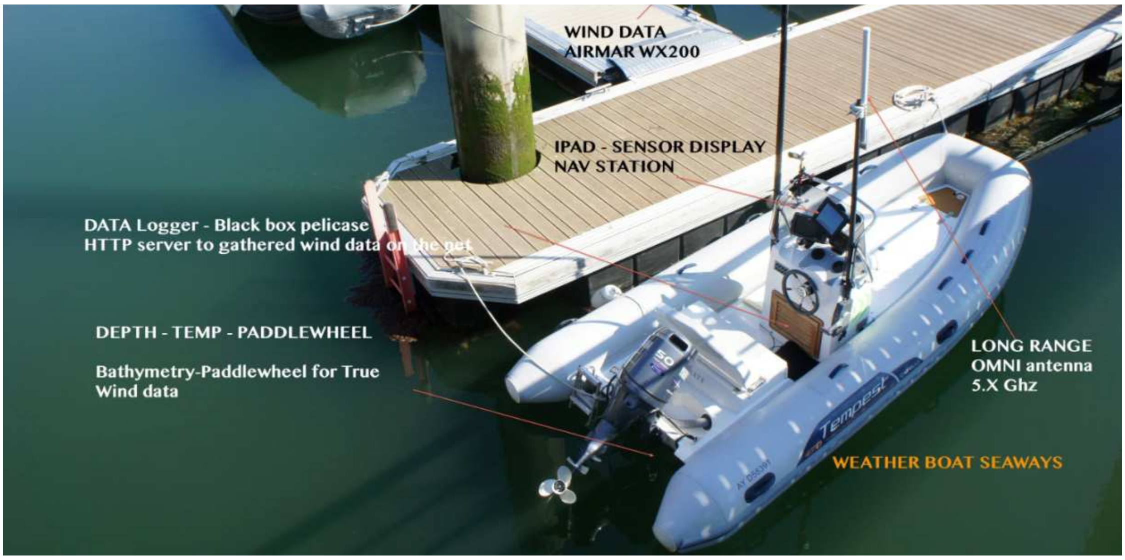


Figure 5.17 Weather boat instruments

The possibility of recording atmospheric parameters during training/races is essential both for the reanalysis of the forecasted wind pattern and for building a data-base for the statistical analysis that is used for the realization of the call-book, the bigger the data-bases the more reliable the statistical analysis (Figure 5.18).

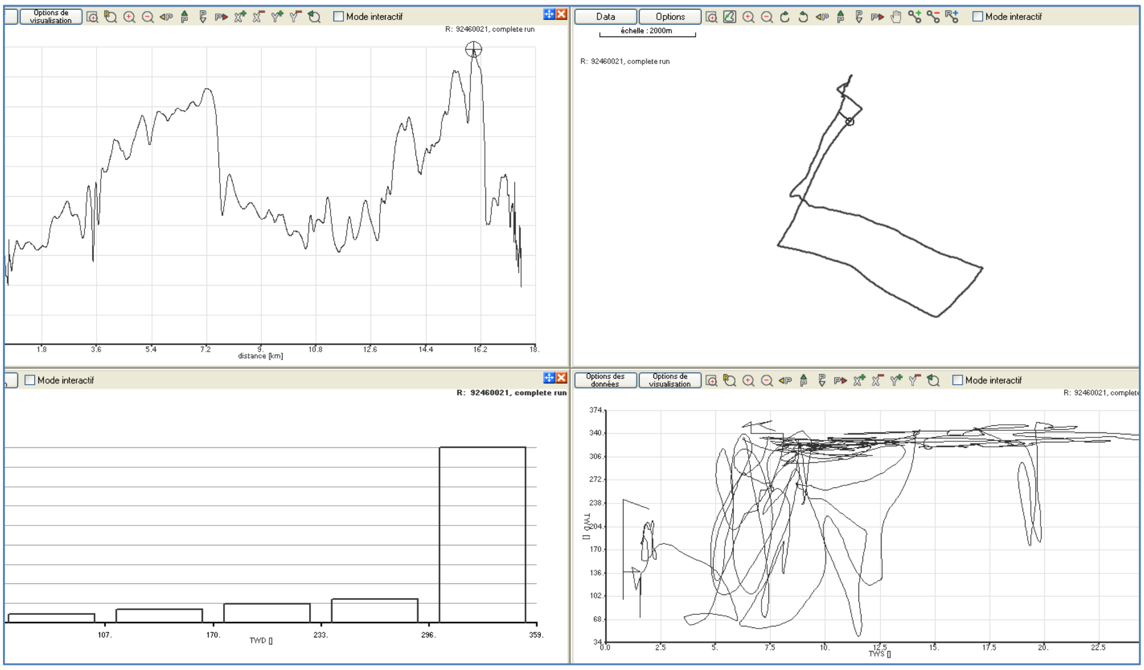


Figure 5.18 Example of wind data analysis platform

During the operational research project the key findings included the following points.

Wind:

- wind patterns are strongly influenced by topography, air density, sea temperature and dynamic of water flow
- wind can be classified into repeatable systems if a complete data base of combined weather models and measured atmospheric parameters will be built during following years
- accurate and reliable measured data at sea are essential for calibrating the wind model and for the realization of the wind call-book
- the possibility of correlating wind data at sea with wind data on-land can give a strong added value in order to classify wind-patterns into a more efficient data-base that can be used also during Olympic Games (when data at sea are not allowed)
- data analysis software and methodology will be the key-fact for having a reliable and useful wind call-book

Current:

- tides are strongly influencing the sea current
- the bathymetry of the bay is characterized by abrupt changes that strongly influence the tidal current flow
- an higher resolution bathymetry would allow the run of a higher resolution tidal stream model with an increased accuracy of the current call-book
- data analysis software and methodology is a the key-fact for having a reliable and useful wind call-book

Therefore it has been identified that the 'Towards Rio 2016 Project' should have included the following activities:

1. Coordination
2. Modeling
3. Measurement
4. Forecast
5. Analysis
6. Validation
7. Visualization
8. Call-Books
9. Seminars – Trainings

Below some considerations sent to the Austrian Sailing Federation as a report after the Operational Research project are presented.

The coordination phase is essential to have an effective management of the whole weather project. Different scientific areas (modeling, measurement, forecasting, data analysis, data visualization) should be combined together and difficult scientific parameters should be analyzed. Results should be translated into meaningful and easy-to-use information for coaches/athletes.

For every area the best strategy has to be investigated and some synergies within institutions or companies that play a key role in every specific field have to be found in order to achieve the best balance between cost and added benefits.

Finally the validation and training phases have to be organized in a critical way in terms of timing, location, parameters, results.

The modelling activity was conducted in a very early stage with the collaboration of the Federal University of Rio the Janeiro is investigated. The added value given by their free open-source current model University during the two training weeks has been:

- the 3km wind model maps
- the 30m tidal current maps

This is just a very first step towards a real collaboration which should be based on:

- the availability of raw data from models,
- the possibility of calibrating models with data coming from our measurement platforms,
- an exchange of competencies and know-how over the Guanabara Bay wind-current coupled system

Moreover the availability of an higher resolution bathymetry for the Bay should allow the run of an higher resolution tidal current model with all the above mentioned benefits.

The Measurement phase was conducted in collaboration with Seaways (www.seaways.fr).

Measurements should be done both during trainings, races and during a separate measurement campaign (2013-2014).

In situ forecasts consists in daily bulletin, weather briefing, updates, weather-coaching session on the water, training session with measurement instruments, daily downloading of wind and current data, reanalysis of the forecasts, debriefing with coaches and athletes, daily updating of call-books. The results obtained during the two weeks training in Rio are quite encouraging. Two main weather patterns (SE and SW sea breeze) have been recognized, studied and explained to coaches and athletes both in-land and at sea. Daily weather briefings and reanalysis of previous day have *increased the effectiveness of the weather coaching sessions. Also daily current maps have been produced using the 30m resolution model adapted to each race area.*

Being in-situ during training sessions gives the possibility not only to recognize the main wind systems but also to help coaches and athletes to understand visible signs on the sea (clouds, visibility, channels). This is fundamental from one side for the weather coaches in order to study the area in a more accurate way and on the other side for coaches and athletes in order to be independent during the Olympic Games.

It is well demonstrated that forecasts sent from a remote location are not as useful as forecasts done in-situ because briefings, debriefings, trainings on sea and accurate reanalysis of data are missing and hence there is no real added value to the realization of the call book.

The analysis of wind and current data will be done:

- after every measurement campaign
- during every training session
- after every training session in order to feed-up the data base

Moreover data available from our remote dissemination platform (see phase 3) will be analyzed in particular during months of July, August and September in order to find-out repeatable and significant patterns for the Olympic period.

The software and methodology for the analysis of atmospheric and current parameters will be done in strong collaboration with Seaways and with the provider of wind and current models (Federal University of Rio) in order to strengthen the collaboration within different scientific areas and to obtain more reliable and accurate results.

A validation of wind and current models, measured data, measurement systems, wind call-book, current call-book will be done:

- after every measurement campaign
- after every training session

This will include a collaborative phase with Seaways and the provider of wind and current models as well.

Call-book drafting is a strategic activity which should be done with a constant and strong collaboration between the weather coach, the coaches and the athletes. Every daily information coming from every phase mentioned above will be stored in a data-base and translated into a final product that will be used by coaches during the Olympic Games.

A very first draft of both wind and current call-books will be ready by December 2013, than a first update of these products will be ready for July 2014 in order to test it during the 2014 test-event. The call-books will be updated and improved constantly after every training, racing, measurement campaign in Rio.

5.3.2 Project implementation

The report presented in this sub-paragraph details the main activities that were been planned at the end of the Operational Research Project and were seen as fundamental to develop an appropriate decision support tool that identifies wind and current features for the Olympic venue.

Activiti 1 - Wind data collection

In order to conduct an appropriate wind data collection campaign four motorboats have been equipped with the following sensors:

- a 4.50 m high, with a damper on the bottom part and shrouds to maintain the mast
- AIRMAR sensor for the compass, gps
- LCJ sensor for the wind (ultrasonic measurement)
- wind data logger (data recorder, data multiplexer)
- display tools to vizualize in realtime data on the boat : Furuno screen , Ipad , smartphone (drifter)
- CAN network for the data transmission between each systems

Accuracy of visualized data in real-time on the rib is very good when ‘heading’ and ‘boat-speed’ are constant or their variation is gradual.

It has been observed that with sudden and big variations of ‘heading’ and ‘boat-speed’, the system needs about 30sec-1min time to record accurate data. Although this is not a crucial problem for the real-time use of the wind measurement system, the accuracy of the final data analysis will be affected by errors, therefore work has to be focused on the filtering of recorded data.

Data currently are recorded through the data-logger without applying any specific correction to raw data coming from the sensors. A software to convert .nmea logged data into a.csv file has been developed.

The filtering methodology for the improvement of accuracy of raw data will be studied and a software will be developed during June 2015, in order to have a first draft software to test in Rio by July 2015. The improved software will be delivered at the end of July 2015 Rio campaign.

Further assessment on the accuracy of recorded and filtered wind data, and further improvements on the software, if needed, will be performed in September 2015. It is necessary to do this refinement in September because we have to assess how the wind system will perform with the typical ‘August wind’, which is more unstable and lighter than in May or July.

Data can be recorded from each rib and downloaded daily in order to be stored locally.

Using the analysis software, data are transformed into a .csv file where daily parameters are organized as shown in Figure 5.19.

```
DATE;HOUR_LT;LAT;LON;W_TWD_MAG;TWS;W_TWD_TRUE;BOATS;HEADING_MAG;P
RESSURE;TEMP;HUMIDITY
04042015;143828;-22.914896666666667;-
43.098758333333336;174.0;7.48;152.0;0.0;309.0;30.0;31.0;64.2
04042015;143830;-22.91489;-
43.09876;174.0;7.48;152.0;0.0;309.0;30.0;31.0;64.4
04042015;143832;-22.914886666666668;-
43.098758333333336;174.0;7.48;152.0;0.0;309.0;30.0;31.0;64.4
04042015;143834;-22.914884999999998;-
43.0987633333333;182.0;10.19;160.0;0.0;308.0;30.0;31.0;64.3
04042015;143836;-22.914881666666666;-
43.09876666666667;184.0;10.25;162.0;0.1;310.0;30.0;31.0;64.0
04042015;143838;-22.914883333333332;-
43.098773333333334;186.0;10.19;164.0;0.0;312.0;30.0;31.0;64.0
04042015;143840;-22.914888333333334;-
43.09878;184.0;10.19;162.0;0.0;310.0;30.0;31.0;64.0
04042015;143842;-22.91489;-
43.09878166666667;186.0;10.19;164.0;0.0;312.0;30.0;31.0;64.0
04042015;143844;-22.914896666666667;-
```

Figure 5.19 Wind data software post-processing result

A procedure to upload the .csv file into an open-source Geographic Information System analysis software has been developed. This procedure allows the visualization of georeferenced wind vectors and their classification according to specified parameter chosen by the end-user (TWD, TWS, date, etc. An example of daily wind data visualization and analysis platform is shown in Figures 5.20 and 5.21.

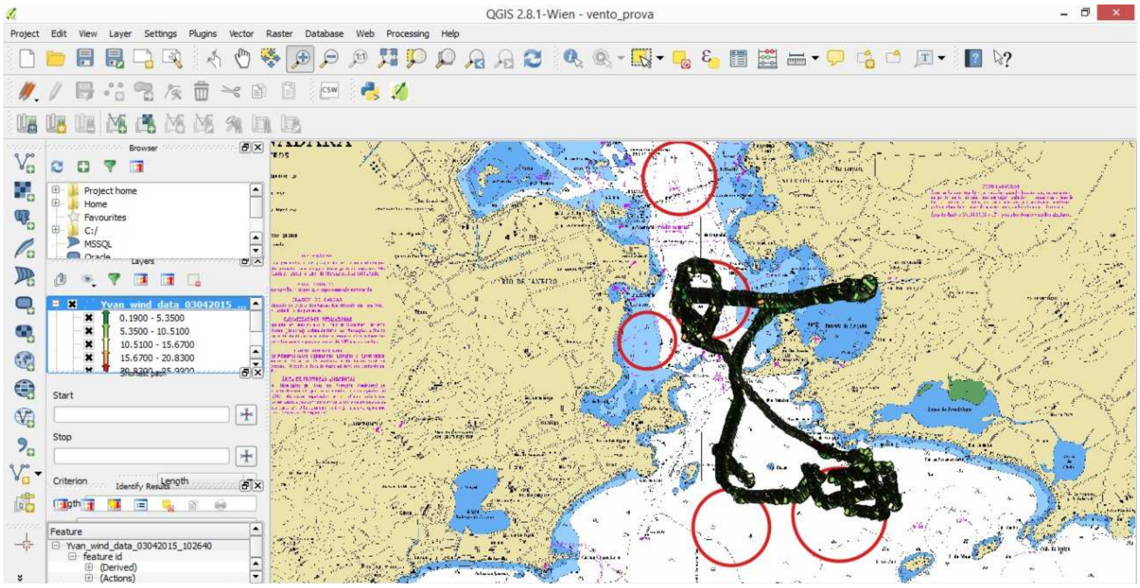


Fig. 5.20 Wind measurements track visualization in QGIS

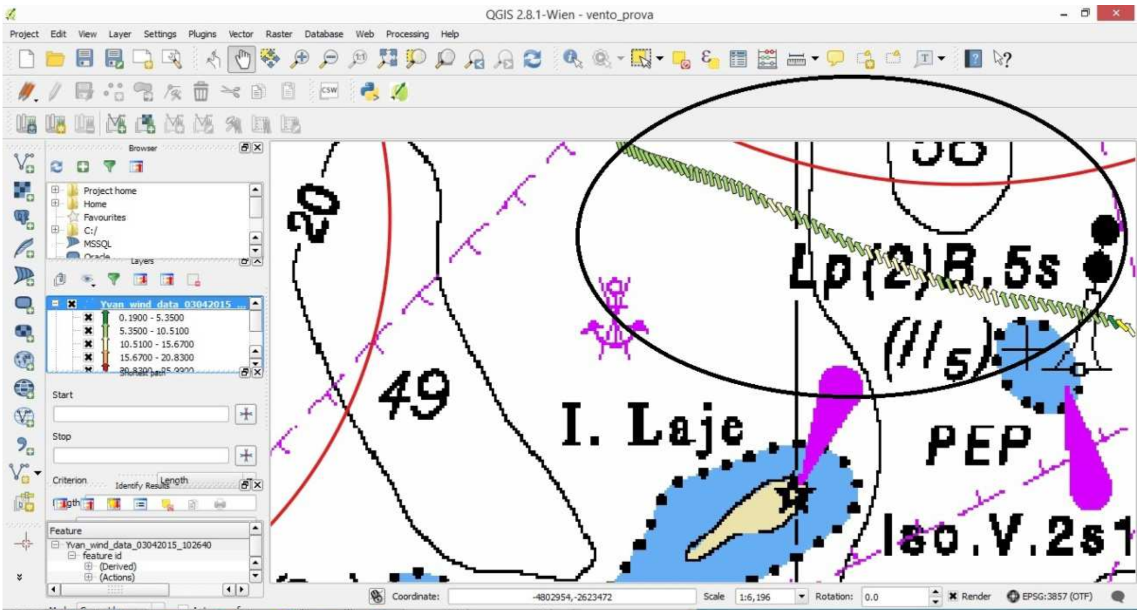


Figure 5.21 Selection of 'recorded track' and visualization of wind measurements for the selected track in QGIS

Selected tracks can be also visualized in a table (Figure 5.22). that can be used for performing numerical analysis on the data and to visualize time series of wind for specific days.

lat lon	date	hhmmss	W_TWD_MAG	TWS	W_TWD_TRUE
POINT(-43.14044499999999971 -22.93171999999999855)	3042015	155732	173	10.93	151
POINT(-43.1405533333333664 -22.9316299999999984)	3042015	155734	166	11.81	144
POINT(-43.14069666666666336 -22.93155666666666548)	3042015	155736	155	12.8	133
POINT(-43.14085500000000195 -22.93150166666666578)	3042015	155738	167	5.14	145
POINT(-43.14101833333333502 -22.93146000000000129)	3042015	155740	177	7.5	155
POINT(-43.14117666666666651 -22.93141666666666723)	3042015	155742	168	6.36	146
POINT(-43.14132666666666438 -22.93138333333333279)	3042015	155744	177	10.21	155
POINT(-43.14146666666666619 -22.93134999999999835)	3042015	155746	183	9.86	161
POINT(-43.14161166666666958 -22.93131166666666587)	3042015	155748	179	10.13	157
POINT(-43.14177000000000106 -22.93128499999999903)	3042015	155750	176	10.39	154
POINT(-43.14193166666666457 -22.93125166666666814)	3042015	155752	170	9.14	148
POINT(-43.1420966666666672 -22.9312183333333337)	3042015	155754	171	8.64	149
POINT(-43.14226666666666432 -22.93119000000000085)	3042015	155756	178	9.3	156
POINT(-43.14243666666666854 -22.93117166666666762)	3042015	155758	174	9.66	152
POINT(-43.14260666666666566 -22.9311550000000004)	3042015	155800	180	8.09	158
POINT(-43.14277833333333234 -22.93113166666666558)	3042015	155802	180	8.96	158
POINT(-43.14294499999999744 -22.93109666666666513)	3042015	155804	186	11.3	164
POINT(-43.14311166666666963 -22.93105833333333266)	3042015	155806	182	12.13	160
POINT(-43.14327000000000112 -22.93101333333333258)	3042015	155808	174	11.32	152
POINT(-43.1434283333333326 -22.9309733333333341)	3042015	155810	172	11.49	150
POINT(-43.14358833333333365 -22.93093500000000162)	3042015	155812	180	11.19	158
POINT(-43.14375499999999874 -22.9308966666666656)	3042015	155814	180	9.79	158
POINT(-43.14391666666666936 -22.93085333333333153)	3042015	155816	179	9.85	157
POINT(-43.14407500000000084 -22.93080166666666742)	3042015	155818	176	10.6	154
POINT(-43.14424000000000348 -22.93074500000000171)	3042015	155820	176	10.9	154
POINT(-43.14439333333333337 -22.93068500000000043)	3042015	155822	180	10.64	158
POINT(-43.14454333333333125 -22.93062499999999915)	3042015	155824	176	11.59	154
POINT(-43.14470166666666984 -22.93056333333333185)	3042015	155826	180	11.41	158
POINT(-43.1448566666666693 -22.93049500000000052)	3042015	155828	180	11.48	158
POINT(-43.14501833333333281 -22.93042833333333164)	3042015	155830	182	11.72	160

Figure 5.22 Selection of 'recorded track' and visualization of wind measurements table for the selected track

Activity 2- Recorded wind data analysis

Recorded data are stored daily into a data-base during trainings and racing days. Data can be visualized through a GIS software, for coaches and athletes. An in-depth analysis of wind data is also performed after each training session and results will be represented into the call-book.

Activity 3- Wind call book

A draft of the call-book based on daily weather predictions, past years' experience, daily briefing-debriefings, wind data analysis, classification of weather patterns will be delivered before July 2015 training session. Further improvements will be performed after following training sessions or races.

Activity 4- Current measurement campaign

Four current drifters have been delivered to Austrian Sailing Federation. The calibration test phase is finished. Accuracy of data is very high. Drifters have been used operationally for data collection from 27/03/2015 to 06/04/2015. Data have been stored into a database, daily.

Measurement have been focused on the period H-3 to H+3 (considering H as High Water time) and for the Pao de Acucar and Escola Naval racing areas. One day has been consecrated to the offshore racing area measurement (Copacabana race course), in order to set up a methodology for the offshore areas.

Activity 5 - Current analysis software design

A software for the visualization in real time of surface current measurements on an Android Smart-Phone has been developed. Restitution of data from the software is very user-friendly and allows an immediate visualization of current direction and speed, as well as an indication of the accuracy of measurements conditions (Figure 5.23).

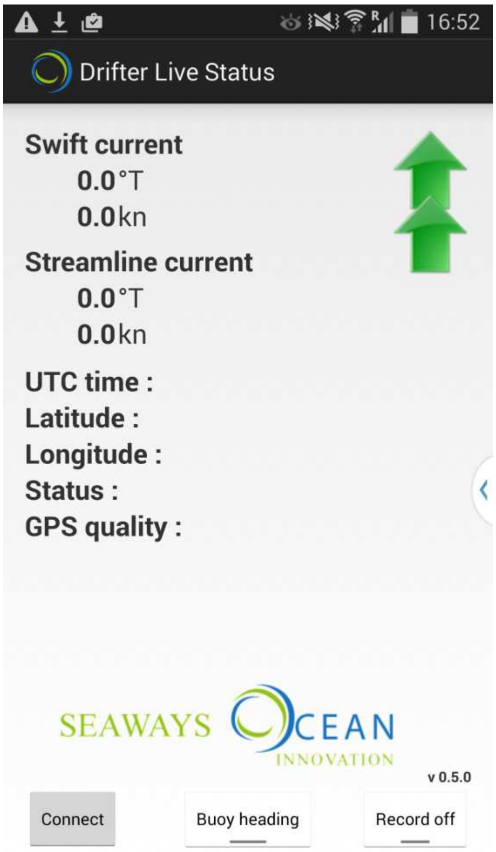


Figure 5.23 Current data software application (www.seaways.fr)

The software is capable as well of recording data into .kml and .csv format for the post-processing and visualization of data. Format is compatible with the recorded wind data as shown in figure 5.24.

```
survey_2015_03_29.txt - Blocco note
File  Modifica  Formato  Visualizza  ?
date      time       lat      lon       dir        speed    tide
29/03/2015      95606   -22.91523743    -43.13442993    218.3   0.4     H
29/03/2015      100017  -22.91306686    -43.13635254    116     0.3     H
29/03/2015      100328  -22.9144516     -43.13671112    95.2    0.1     H
29/03/2015      100612  -22.9152317     -43.13642883    232     0.3     H
29/03/2015      100907  -22.91543961    -43.1379776     120.5   0.2     H
29/03/2015      101301  -22.91727448    -43.14017868    157.3   0.4     H
29/03/2015      101752  -22.91759491    -43.13883972    152.2   0.3     H
29/03/2015      102233  -22.91596413    -43.14180374    138.4   0.4     H
29/03/2015      102331  -22.91603851    -43.14174271    141     0.4     H
29/03/2015      102740  -22.91591835    -43.14548111    134.3   0.4     H+1
29/03/2015      102824  -22.91596222    -43.14545059    139.7   0.3     H+1
29/03/2015      102911  -22.9160099     -43.14540863    140.1   0.3     H+1
29/03/2015      103252  -22.91565704    -43.14971542    125.5   0.3     H+1
29/03/2015      103554  -22.91619301    -43.15086746    135.9   0.4     H+1
29/03/2015      103918  -22.91635132    -43.15408325    155.3   0.5     H+1
29/03/2015      104001  -22.91644859    -43.15405655    162.3   0.5     H+1
29/03/2015      104310  -22.9174099     -43.15610504    169.6   0.4     H+1
29/03/2015      104718  -22.9180603     -43.15830994    298.5   0.5     H+1
29/03/2015      105138  -22.9194622     -43.16174698    24.7    0.1     H+1
29/03/2015      105904  -22.92209625    -43.16012573    4.8     0.2     H+1
29/03/2015      110318  -22.92234612    -43.15782928    25.9    0.1     H+1
29/03/2015      110641  -22.92243195    -43.15621948    26.7    0.2     H+1
29/03/2015      111059  -22.92248154    -43.15496445    344.2   0.2     H+1
29/03/2015      111623  -22.92218399    -43.15092468    138.6   0.4     H+1
29/03/2015      112128  -22.92236137    -43.14879227    109.7   0.8     H+2
29/03/2015      112319  -22.92248726    -43.14866638    124.8   0.4     H+2
29/03/2015      112802  -22.92261887    -43.14653015    115.2   0.3     H+2
29/03/2015      113544  -22.92109489    -43.13752747    109.2   0.1     H+2
29/03/2015      114200  -22.91355515    -43.14293289    180     0.3     H+2
29/03/2015      114301  -22.91363144    -43.14293289    180     0.3     H+2
29/03/2015      114616  -22.91562843    -43.14229202    170.5   0.2     H+2
29/03/2015      115017  -22.9186554     -43.14163971    180     0.6     H+2
29/03/2015      115026  -22.91866875    -43.14163589    171.3   0.4     H+2
```

Figure 5.24 .txt file of current data software post-processing result

Activity 6 - Current data analysis

A procedure to upload the .csv file into an open-source Geographic Information System analysis software has been developed. This procedure allows the visualization of georeferenced current vectors and their classification according to specified parameter chosen by the end-user (current speed, current dir., tidal height time, etc…).

An example of daily current data visualization and analysis platform is shown below:

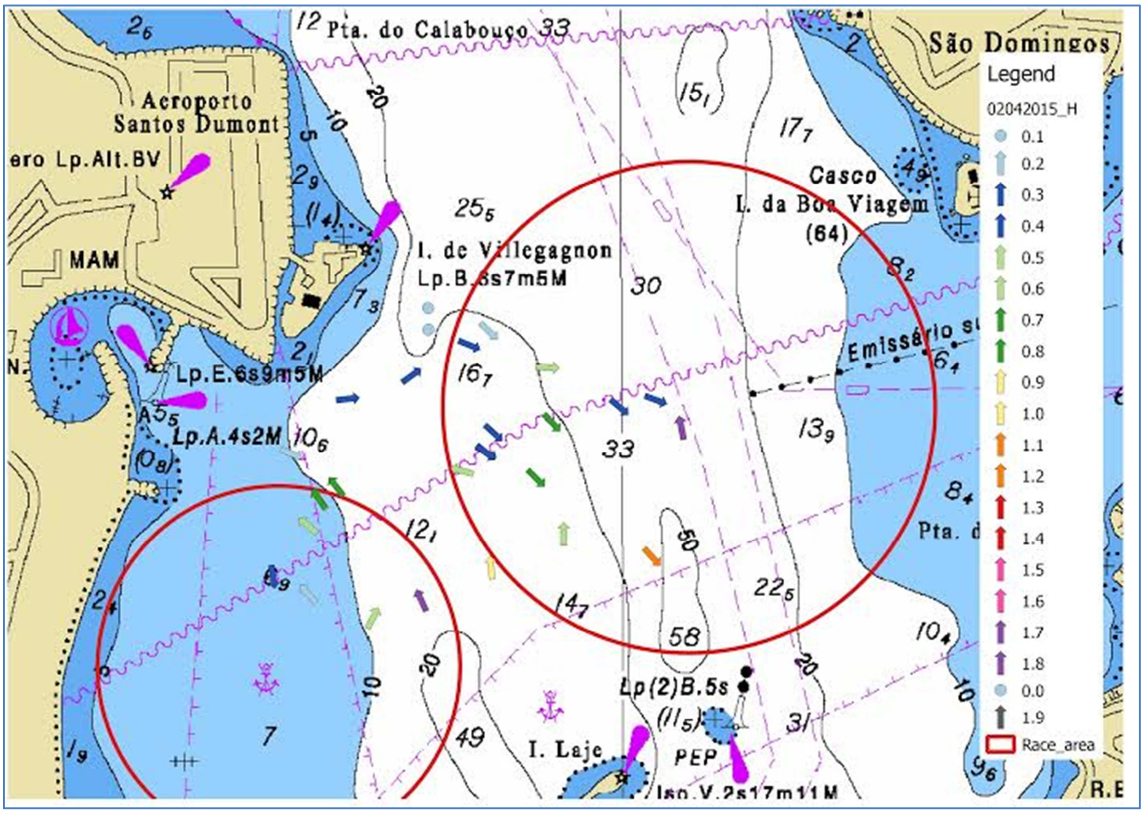


Figure 5.25 – current data visualization platform - example at High Water of 02/04/2015

The whole procedure, from the record of data at sea, to the download of data and their visualization (Figure 2.25) is ready to be performed daily in a fast and very intuitive way.

However an in-depth analysis of current patterns has to be made and a correlation between tidal flow, visual current lines (Figure 5.26), tidal level, wind and pressure conditions has to be constantly performed in order to have the final representation of current patterns into the call-book.

Figure 5.26 Tidal current convergence line - example at High Water of 02/04/2015

The mapping has been performed using the GIS software showed above. The main focus of this activity is to find the most effective representation of the current data analysis results in order to be easily understood and used by coaches and sailors. A very first study of the representation strategy has already been performed. Further improvements will be assessed and performed after each measurement campaign.

Activity 7 - Current call book

A draft of the call-book based on the analysis and representation of recorded data during measurement campaigns has been developed on the basis of performed analysis. The call-book is constantly updated when further measurements are available. Particular attention is devoted to the final representation of scenarios, including multi-parameter analysis that allow the integration of current and wind patterns to get the key information needed to set the best strategies.

Some examples of daily maps produced for the visualization of current measurements performed using the drifter and their overlay to the hydrodynamic model of current are shown into Annex V.

6. Conclusions and further developments

The main aim of this study is to analyse the potential for integrating weather and climate information with geomatics to produce meaningful and understandable information for decisions makers that have to deal with environmental factors. The interactions between the environment, people, human activities, infrastructures and ecosystems can be analysed through complex systems or models. These analysis require a significant amount of data that have firstly to be chosen, then to be analysed and finally to be integrated in order to produce different scenarios or results that give a specific information about possibilities, challenges, alternatives, risks and possible actions.

The main issues related to the use of environmental data include:

- the availability of data
- the reliability of data
- the property of data
- the adaptability of data to the context

Therefore a significant effort has to be done in choosing the best available data with a particular attention to the context in which decision makers are operating. For instance some operators would need to make analysis at global scale while others might be interested in a very local scale. In addition also the temporal scale plays a crucial role in choosing the more suitable data and analysis tools. The monitoring of near real-time events, the now-casting of events with a very short lead-time, the analysis of climatological trends or the study of past and future scenarios require very specific and adapted approaches.

It is therefore fundamental to start with an in-depth analysis of the requirements of targeted users. Define the problem, determine the requirements that the solution to the problem must meet, establish goals that solving the problem should accomplish, identify alternatives that will solve the problem and develop evaluation criteria based on the goals, are fundamental steps that have to be done to select a decision-making tool that is understandable and usable by technical and non-technical people.

Within this research three different users have been chosen, having different needs, operating in different contexts and having different backgrounds. For each user a different decision making tool have been developed by integrating meteorological and climatological analysis results, numerical modelling, remote sensing techniques and geographic information systems.

The main advantage of using this integrated approach is on the one hand the possibility of studying very complex systems in a highly accurate way thanks to high level technological tools and scientific approach and on the other hand to be able to translate complex results into easy to understand visual maps that help the identification of issues, priorities and winning strategies. The integration of meteorology and geomatics represents a particular effective solution to develop flexible decision support tools that can immediately address environmental information to variety of users, since they provide generalizable and standardisable procedures and technology, particularly effective to conduct multi-disciplinary analyses. Therefore, despite the specific environmental data used and the specific requirements of the project, one can adopt the same methodology presented in this study to effectively meet the goals of the decision making protocols and to add value to existing capacity especially in data-poor regions.

Further improvements might require a stronger collaboration with economists and social scientists to perform a more in depth assessment of end-users requirements, through interviews or focus groups and to perform a cost-benefit analysis of taking a specific decision based on the decision support tools output. Also the integration of higher resolution numerical weather prediction or geographical data would lead to a more accurate representation of scenarios.

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Annexes

Annex I - Weather bulletins issued for the UN-WFP

Weather inputs 14/10/2014

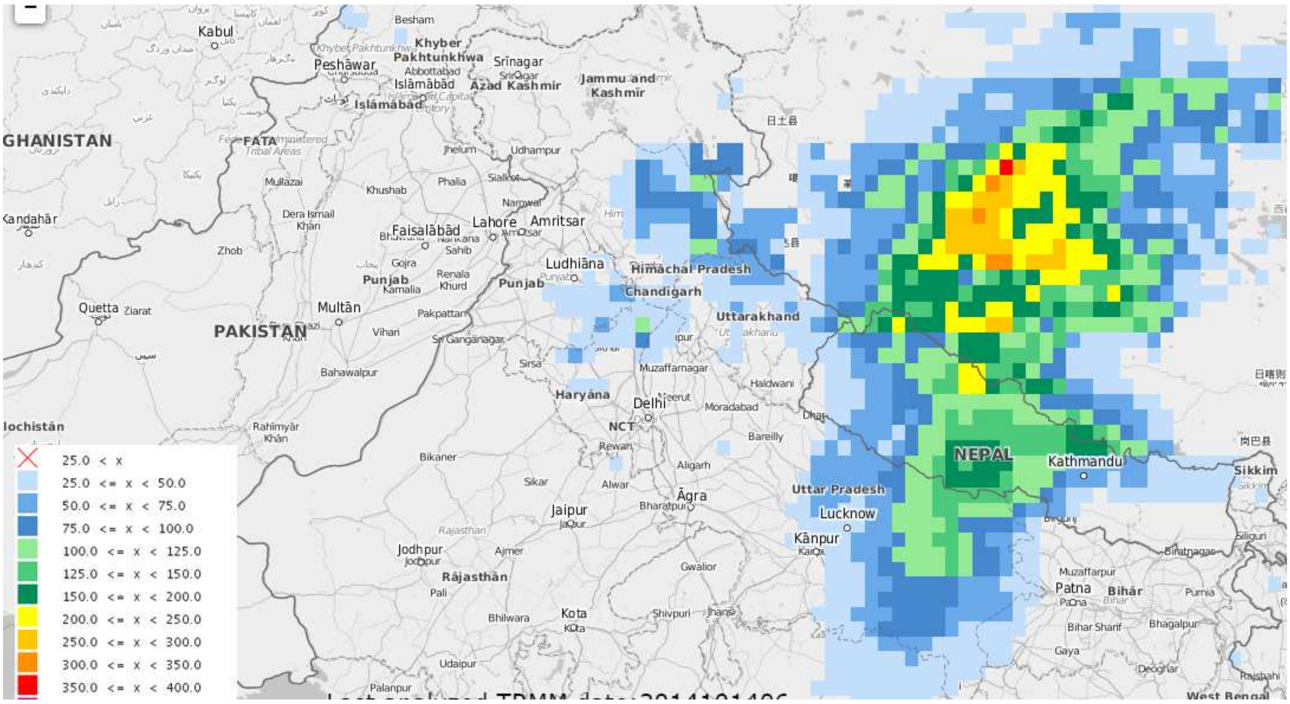
Level of confidence: *AVERAGE up to 72h forecast, LOW for more than 72h forecast*

ASIA

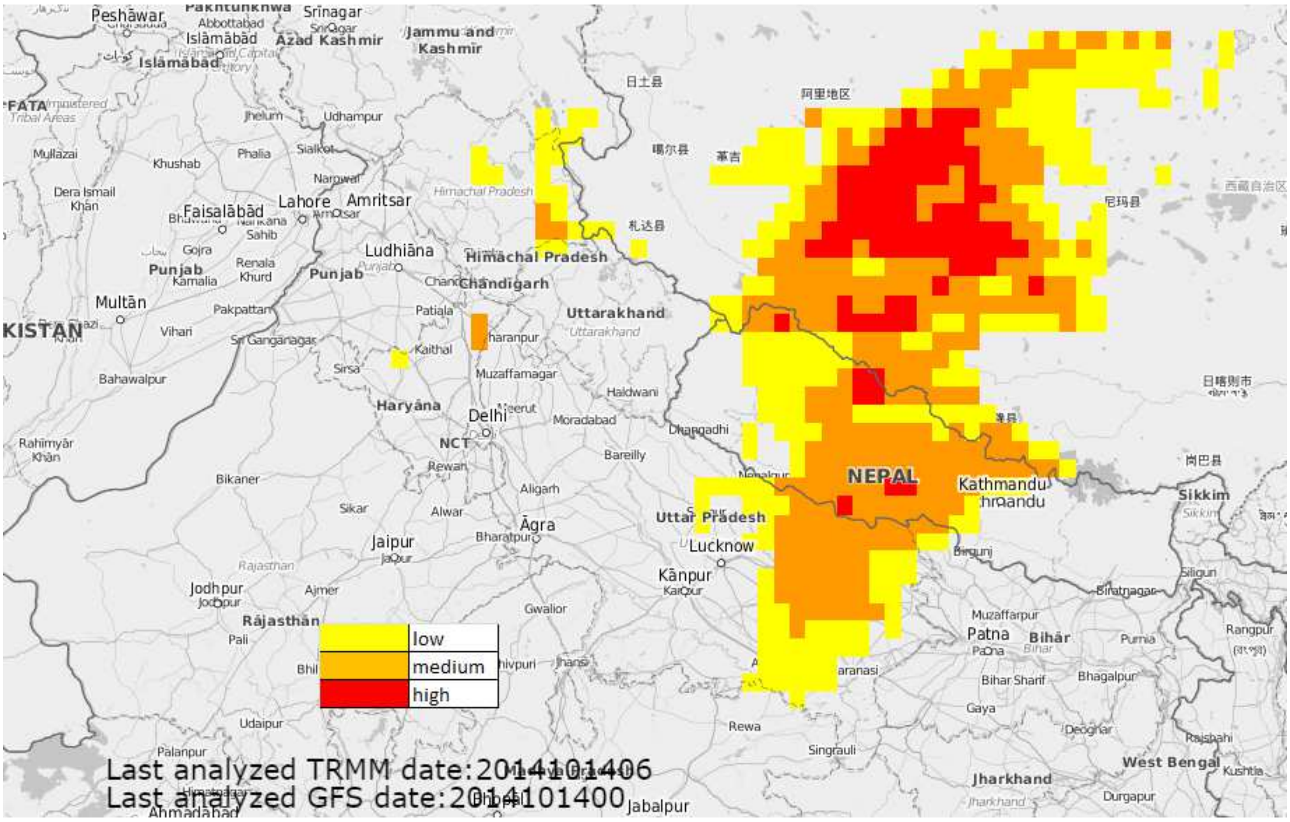
INDIA, NEPAL – TROPICAL CYCLONE HUDHUD

Precipitations:

Above 150mm/24h occurred over eastern Uttar Pradesh and central-western Nepal over the past 24h. Above 250mm/24h, locally up to 350mm/24h occurred over western Tibet.



Monitoring from TRMM data: accumulated precipitation over past 24h (www.ithacaweb.org)



Monitoring from TRMM data: ALERTS on accumulated precipitation over past 24h (www.ithacaweb.org)

Precipitation Forecast: *heavy to locally very heavy precipitations (locally above 120mm/24h) may still occur over western-central Nepal, over the next 24h.*

Impact: *medium risk of localized flooding-landslides over western-central Nepal and western Tibet during next 24h.*

PHILIPPINES

Precipitations:

Increasing precipitation over central-northern Philippines (especially central-southern Luzon) by Wednesday 15/10/2104 and through Friday 17/10/2014.

Impact:

Low risk of minor flooding/landslides.

AFRICA

SIERRA LEONE-LIBERIA- COTE D'IVOIRE

Precipitations:

Locally moderate precipitations (40-50mm/24h) occurred over coastal Sierra Leone, coastal Liberia, and north-eastern Cote d'Ivoire during the past 24h.

Locally moderate precipitations may still occur over Sierra Leone, Liberia, and Cote d'Ivoire through Thursday 16/10.

Impact:

Low risk of localized flooding over Sierra Leone and Liberia due to locally moderate showers, especially over coastal areas.

NIGERIA, CAMEROON

Precipitations:

Locally moderate showers (up to 60mm/24h) over south-eastern Nigeria and western Cameroon by through Thursday 16/10.

Impact:

Low risk of minor flooding over south-eastern Nigeria and west south-western Cameroon through Thursday 16/10.

SOUTH AMERICA

ANTIGUA and BARBUDA, REPUBLICA DOMINICANA, CUBA, BERMUDA

Precipitations:

Hurricane GONZALO is currently affecting Antigua and Barbuda Islands with rainfall above 150mm/24h. GONZALO will track north-westwards during the next 24h and then northwards.

Locally heavy precipitations may affect eastern Republica Dominicana during the next 24h.

Locally heavy precipitations may affect Bermuda by Friday 17/10.

Impact:

Low risk of significant flooding.

COSTA RICA, PANAMA, GUATEMALA, HONDURAS, NICARAGUA, SOUTHERN MEXICO

Precipitations:

An area of Low pressure is located south of Guatemala and may be become a Tropical Cyclone in the next 48h.

Increasing chance of heavy showers over Guatemala, El Salvador, south-western Honduras, southern Nicaragua, Costa Rica, western Panama and south-western Mexico (Guerrero, Oaxaca, Chiapas, Tabasco, Campeche, Yucatan) through the end of the week.

Impact:

Medium risk of minor localized flooding/landslides over Costa Rica, Guatemala, southern Nicaragua through the end of the week.

Medium risk of localized flooding over coastal Guerrero, Oaxaca by Saturday 18/10.

COLOMBIA

Precipitations:

Heavy precipitation (above100mm/24h) occurred over north-western coast of Colombia (Chocò, Valle del Cauca, Cauca). Moderate to locally heavy showers may still occur over these areas through Friday 17/10.

Impact:

Medium risk of minor localized flooding/landslides over Chocò, Valle del Cauca, Cauca.

The second one is an example of a weather bulletin conceived for an Olympic Sailing Federation user (specificare finalità dell'utente, decisioni da prendere, unsertainties…etc…)

Annex II - Weather bulletins issued for the Austrian Sailing Federation

Date: *Apr/22 /2014*

Time: *07:30 AM*

Event: *World Cup Hyeres*

Synopsis: *low pressure over Baleares. Easterly gradient over this area.*

Gradient Wind:

TIME	*11h (09UTC)*	*13h (11UTC)*	*16h (14UTC)*	*19h (17UTC)*
TWD,TWS (1000m)	*105 11 kts*	*105 11 kts*	*115 9 kts*	*090 4 kts*
TWD,TWS (10m)	*085 11 kts*	*100 12 kts*	*105 10 kts*	*100 6 kts*

WARNINGS: *--*

Air Mass: *cold, humid, unstable*

Sky: *partly cloudy with nice sunny spells, chance of isolated rain showers (especially over land)*

Max. Temp. over land: *18ºC* ***SST:*** *14ºC*

Sea state: *0.5-0.8m*

First scenario – easterly gradient, thermally enhanced

TIME	*TWD AVG*	*TWD RANGE*	*TWS AVG*	*TWS RANGE*
1000	*080*	*070-090*	*9*	*7-11*
1100	*090*	*080-100*	*9*	*7-11*
1200	*095*	*085-105*	*12*	*9-15*
1300	*100*	*090-110*	*13*	*10-16*
1400	*100*	*090-110*	*14*	*11-18*
1500	*100*	*090-110*	*14*	*11-18*
1600	*110*	*100-120*	*12*	*10-14*

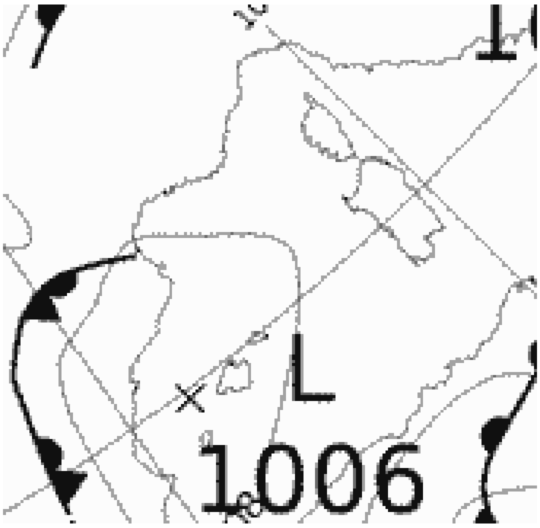
1700	*120*	*110-130*	*10*	*8-12*
1800	*120*	*110-130*	*8*	*6-10*

Key Facts

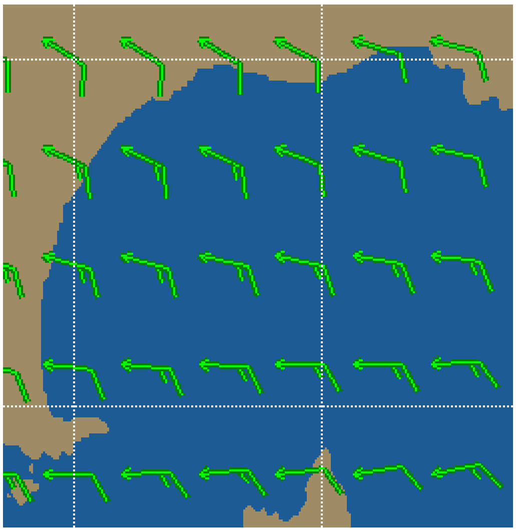
1. ***Confidence level*** *– Model consistency: AVERAGE*
2. ***Weather pattern/summary****: moderate easterly with thermal enhancement.*
3. ***Trend:*** *weak north-easterly in the morning, veering fast towards about 090 and increasing during central hours, due to thermal heating. The wind should be easing in the end, with a possible right trend towards 120-130 (however this trend is not reliable).*
4. ***Geographical features****: left bend prevailing in the well-established easterly breeze (most probable with a 110 breeze, less probable with a 090 breeze).*
5. ***Reference values:*** *max left 070; max right 120*
6. ***Other scenario:*** *in case of lighter gradient wind (let's say 5-6kts at about 10 h), the thermal heating could drive the wind towards about 130-140 8-12 kts during central hours, easing in the end.*
7. ***Clouds:*** *in our main scenario there will be some medium-high clouds moving fast from E to W in the beginning and some Cu/Cb building over land during central hours, but probably moving towards W. Clear sky and STEADY small Cu over land can be a sign for the 'other scenario', however the most important sign for the 'other scenario' is the light wind speed at about 10.00LT.*
8. ***TWS range****:*
   8-20kts

Outlook:

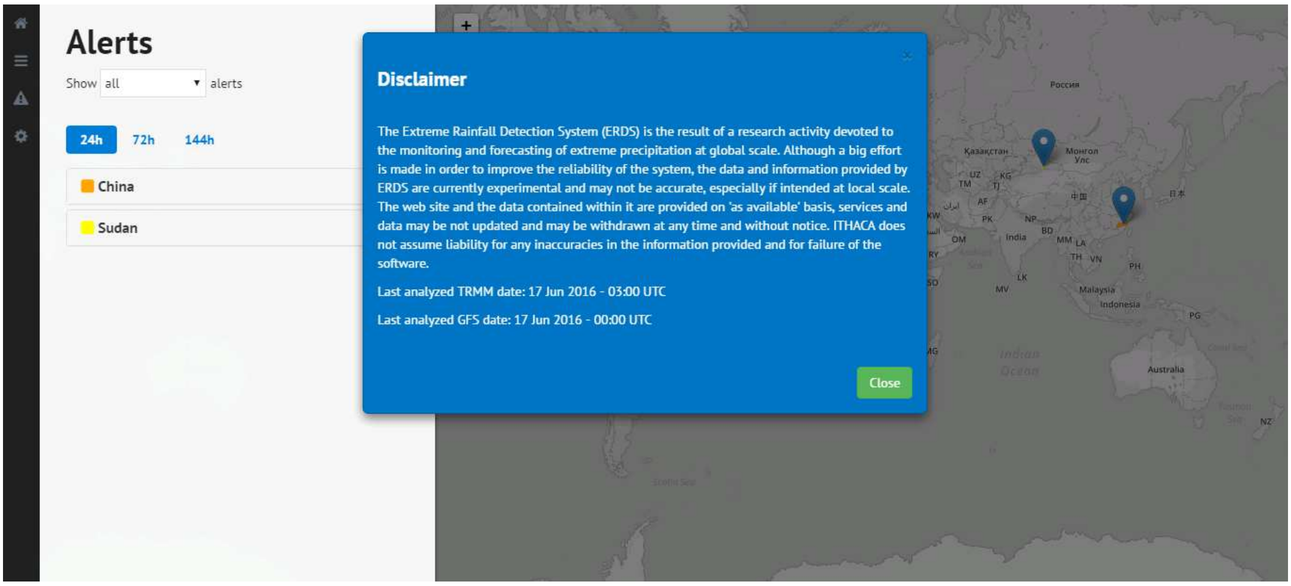
DAY	***WINDS AND WEATHER***
D+1 *Wed 23*	*Sunny* *W-SW 7-15kts increasing to 15-20kts in the afternoon*
D+2 *Thu 24*	*Sunny becoming cloudy* *W-SW 5-10kts increasing to 10-15kts in the afternoon*
D+3 *Fri25*	*Mostly cloudy with chance of rain* *W 8-16kts*

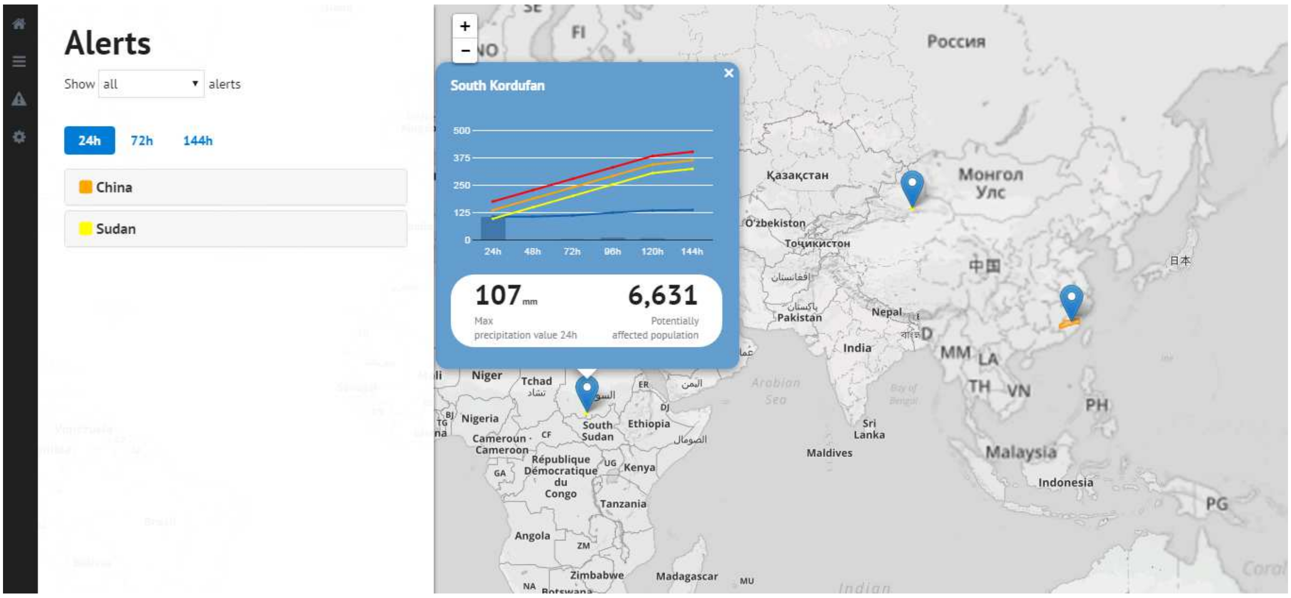


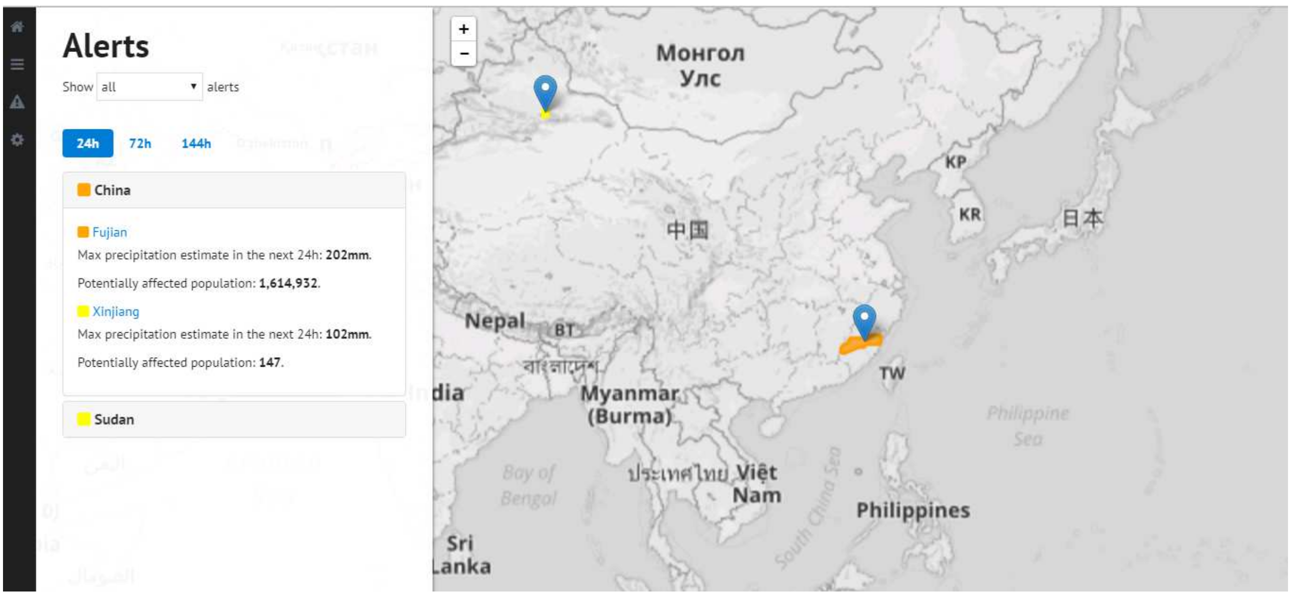
Analysis 02.00LT (00.00UTC)

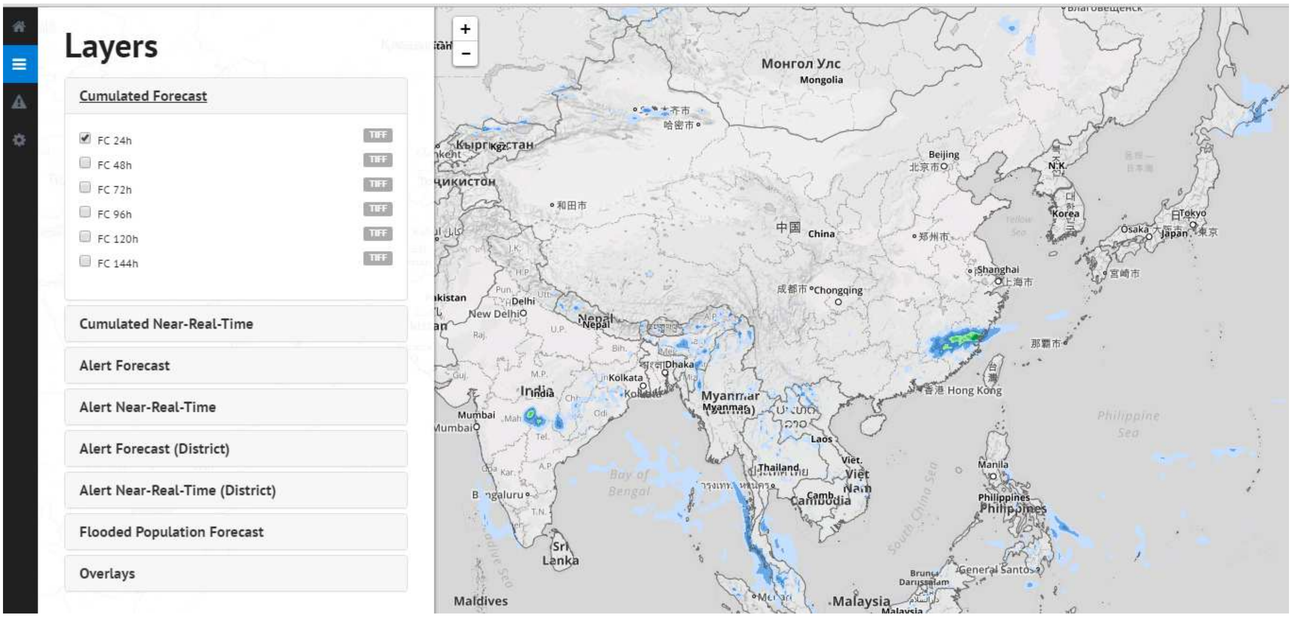
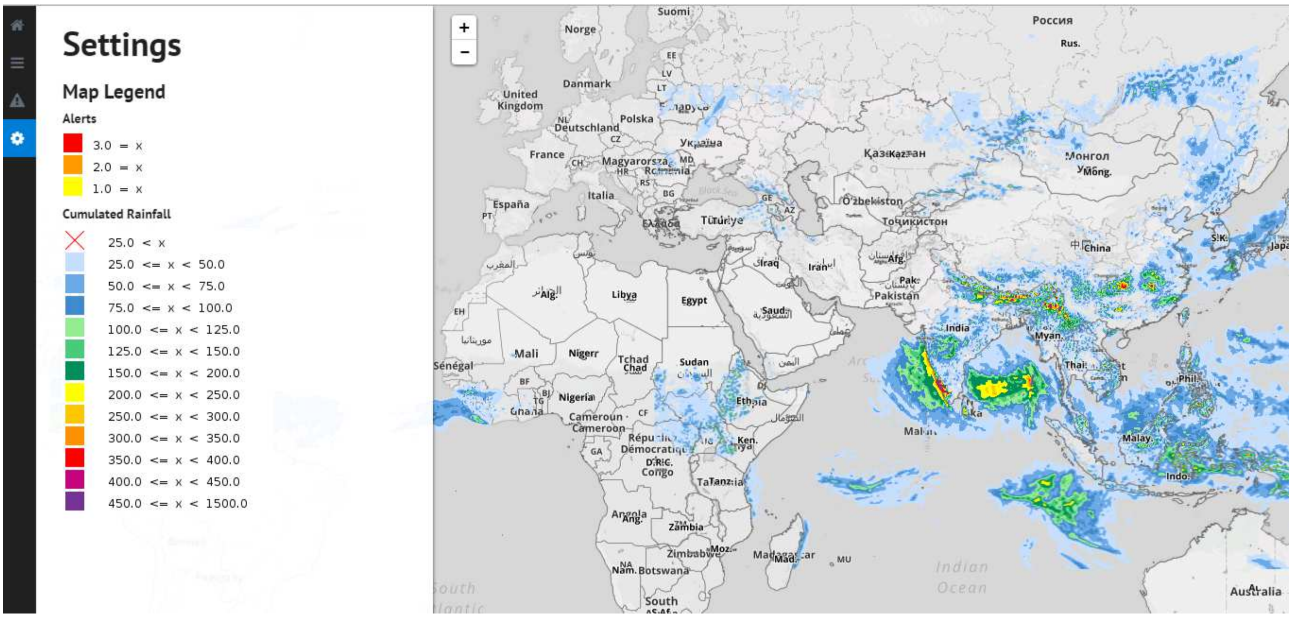

Forecast at 13.00LT (11.00UTC)

Annex III – ERDS web-GIS platform








Layers
Cumulated Forecast
FC 24h
FC 48h
FC 72h
FC 96h
FC 120h
FC 144h
Cumulated Near-Real-Time
Alert Forecast
Alert Near-Real-Time
Alert Forecast (District)
Alert Near-Real-Time (District)
Flooded Population Forecast
Overlays
Монгол Улс
Mongolia
Beijing
China
Shanghai
Hong Kong
Nepal
India
Mumbai
Kolkata
Myanmar
Thailand
Laos
Cambodia
Philippines
Manila
Sri Lanka
Malaysia
Maldives
Korea
Japan
Tokyo
Osaka
Bay of Bengal
Philippine Sea

Settings
Map Legend
Alerts
3.0 = x
2.0 = x
1.0 = x
Cumulated Rainfall
25.0 < x
25.0 <= x < 50.0
50.0 <= x < 75.0
75.0 <= x < 100.0
100.0 <= x < 125.0
125.0 <= x < 150.0
150.0 <= x < 200.0
200.0 <= x < 250.0
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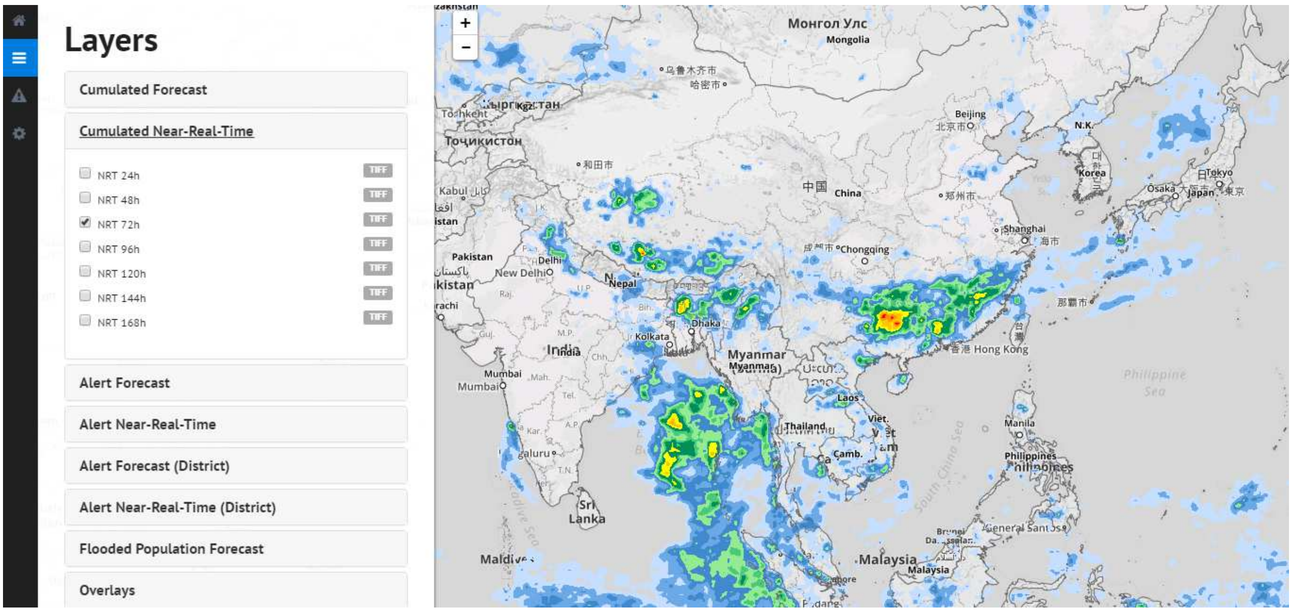
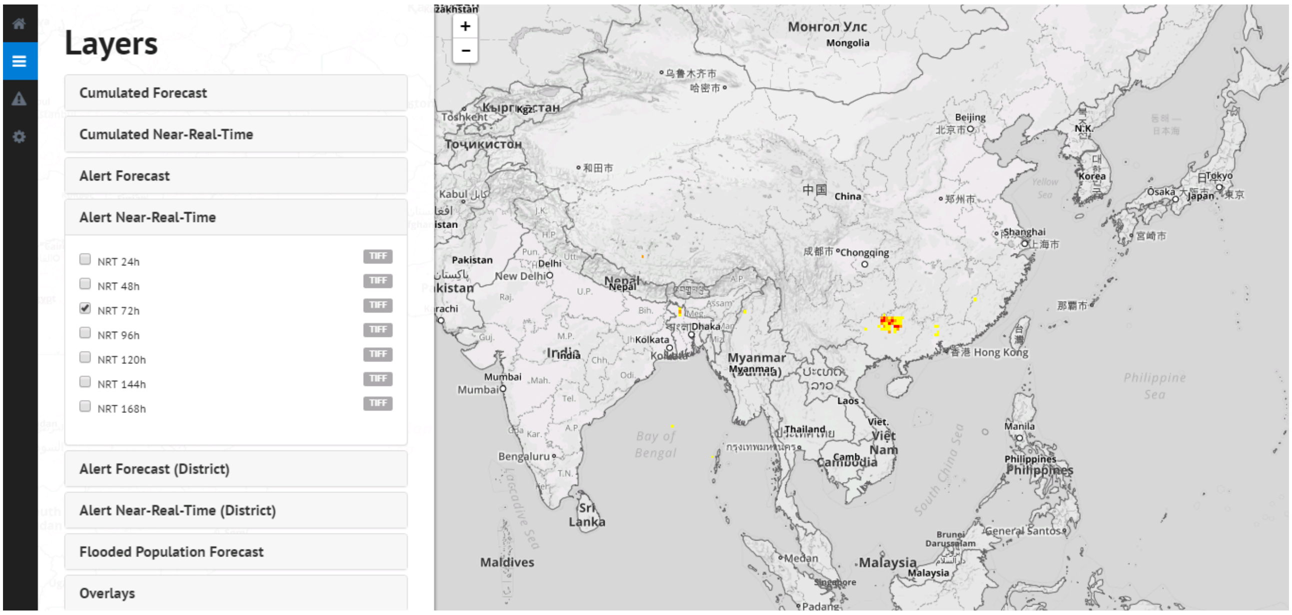
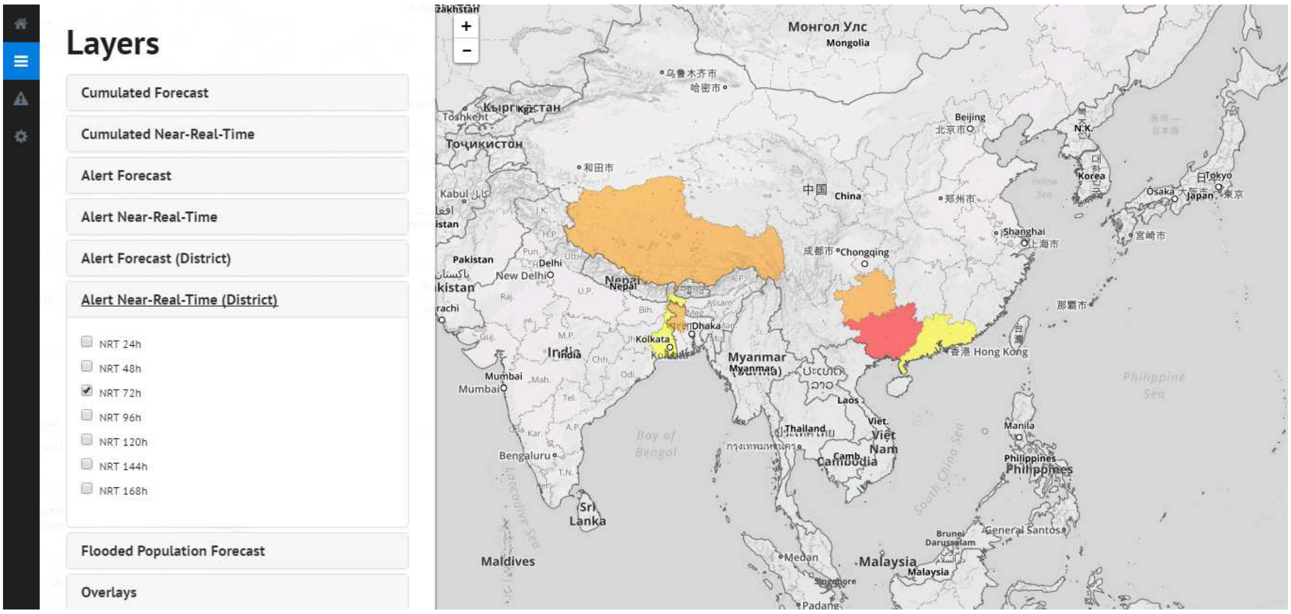
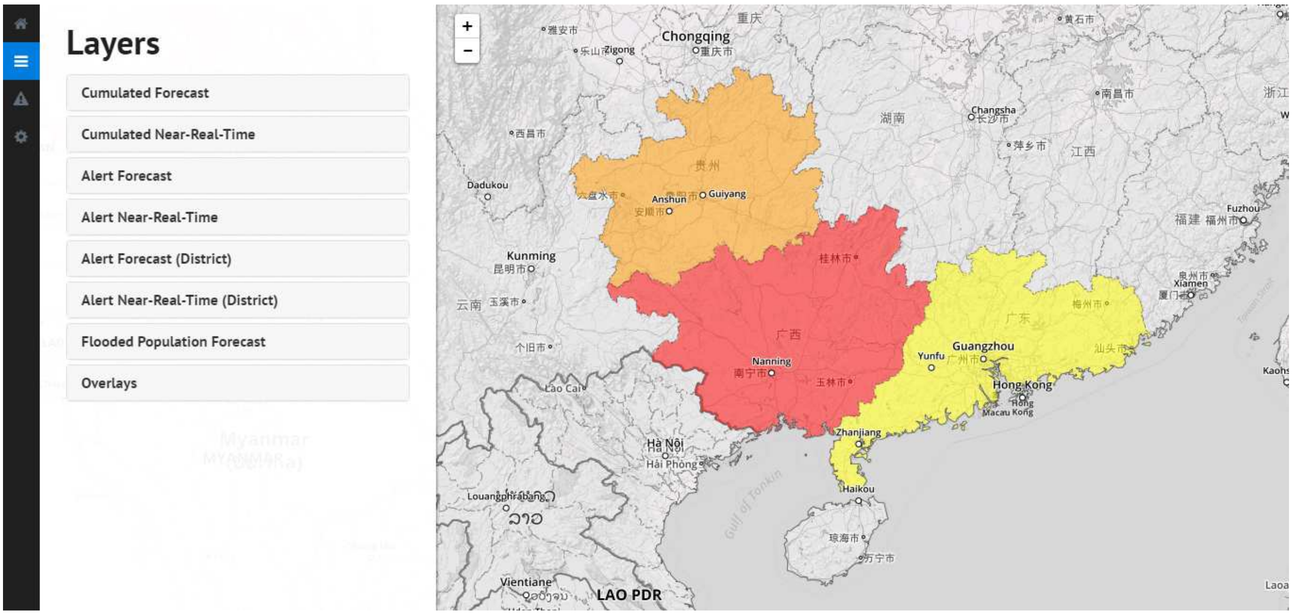
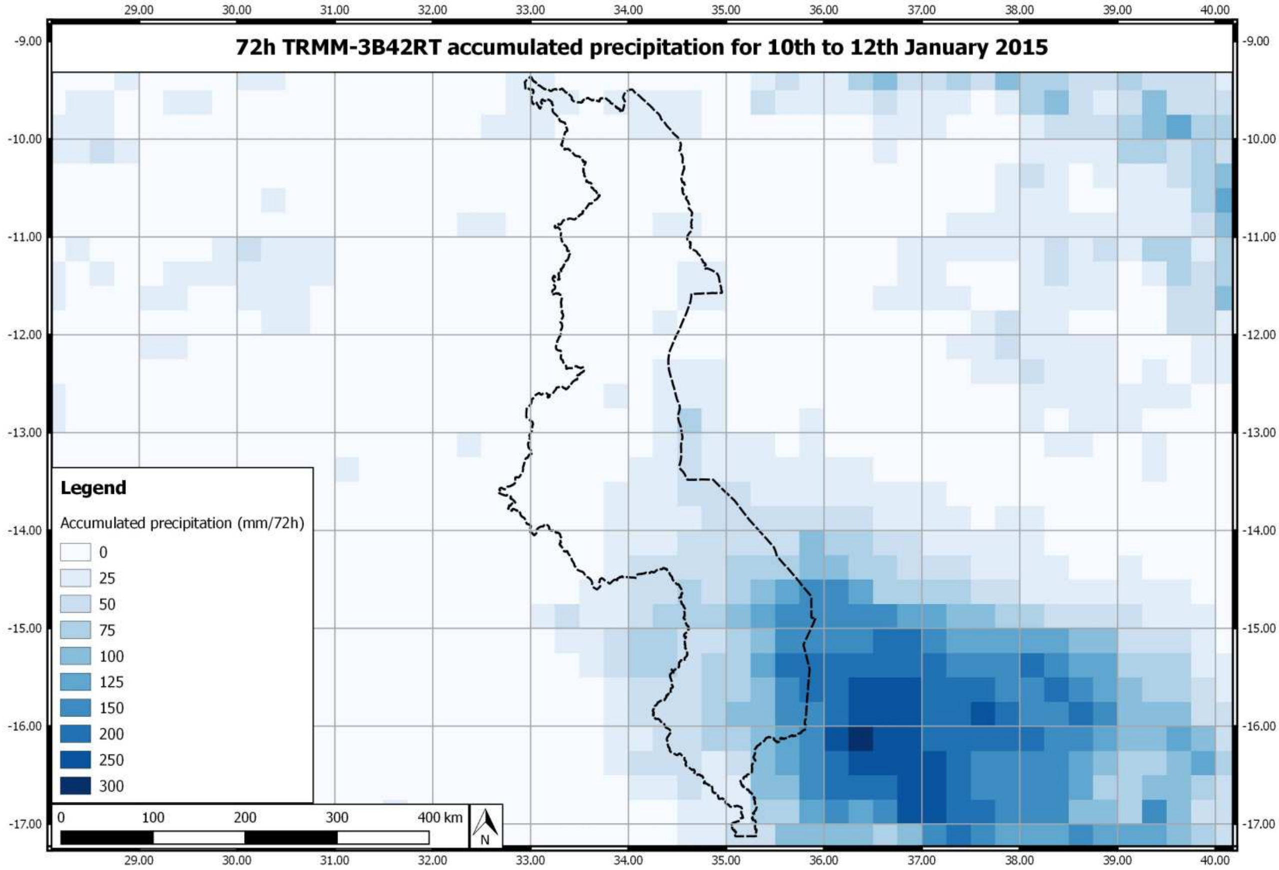
India
Egypt
Libya
Sudan
Mali
Niger
Tchad
Nigeria
Cameroun
Angola
Zambia
Botswana
Indian Ocean
Australia

Layers
Cumulated Forecast
Cumulated Near-Real-Time
NRT 24h
NRT 48h
NRT 72h
NRT 96h
NRT 120h
NRT 144h
NRT 168h
Alert Forecast
Alert Near-Real-Time
Alert Forecast (District)
Alert Near-Real-Time (District)
Flooded Population Forecast
Overlays
Монгол Улс
Mongolia
Beijing
China
Shanghai
Hong Kong
Pakistan
New Delhi
Nepal
India
Mumbai
Kolkata
Dhaka
Myanmar
Thailand
Laos
Philippines
Manila
Sri Lanka
Malaysia
Korea
Japan
Philippine Sea

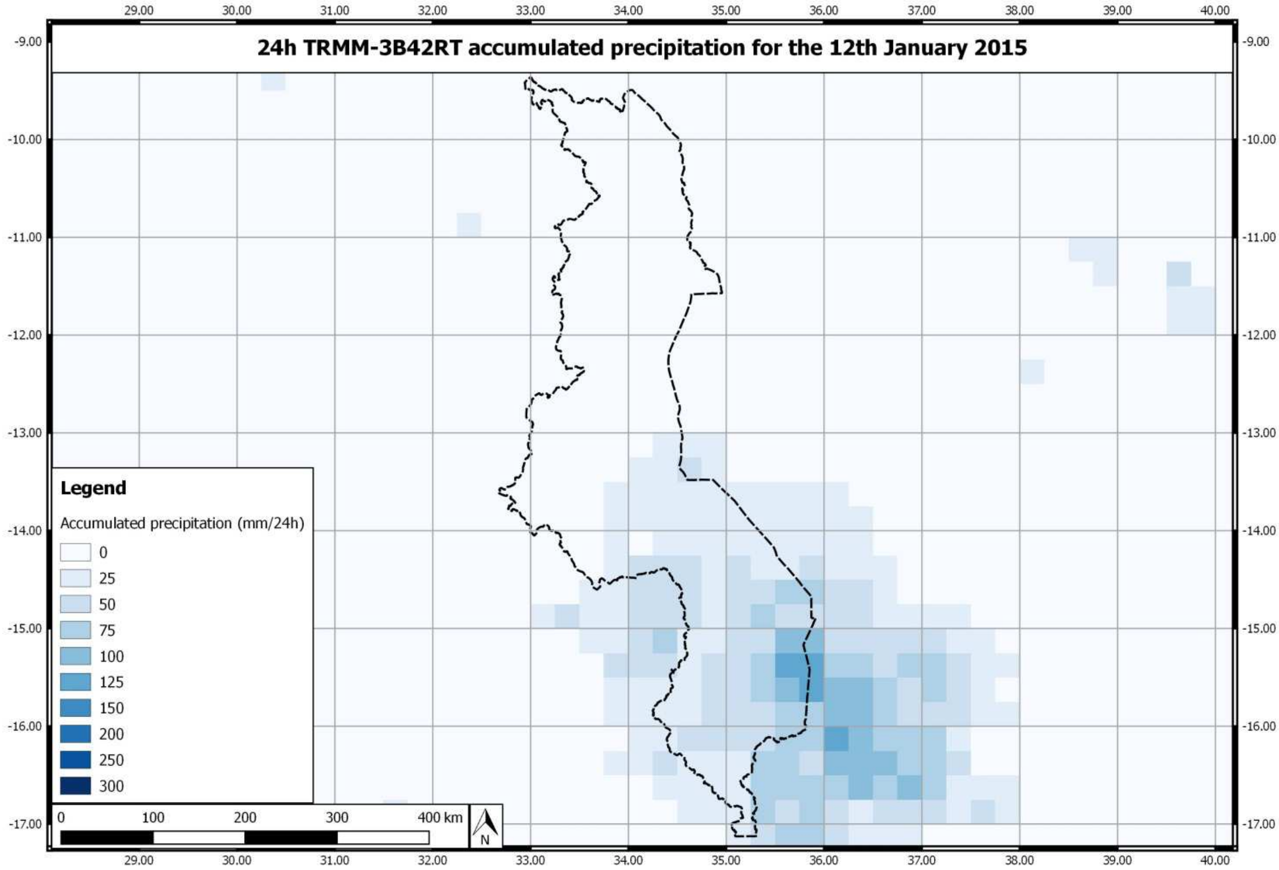

Layers
Cumulated Forecast
Cumulated Near-Real-Time
Alert Forecast
Alert Near-Real-Time
NRT 24h
NRT 48h
NRT 72h
NRT 96h
NRT 120h
NRT 144h
NRT 168h
TIFF
Alert Forecast (District)
Alert Near-Real-Time (District)
Flooded Population Forecast
Overlays
Mongolia
China
India
Pakistan
Nepal
Myanmar
Thailand
Cambodia
Malaysia
Philippines
Sri Lanka
Maldives
Bay of Bengal
Philippine Sea
South China Sea

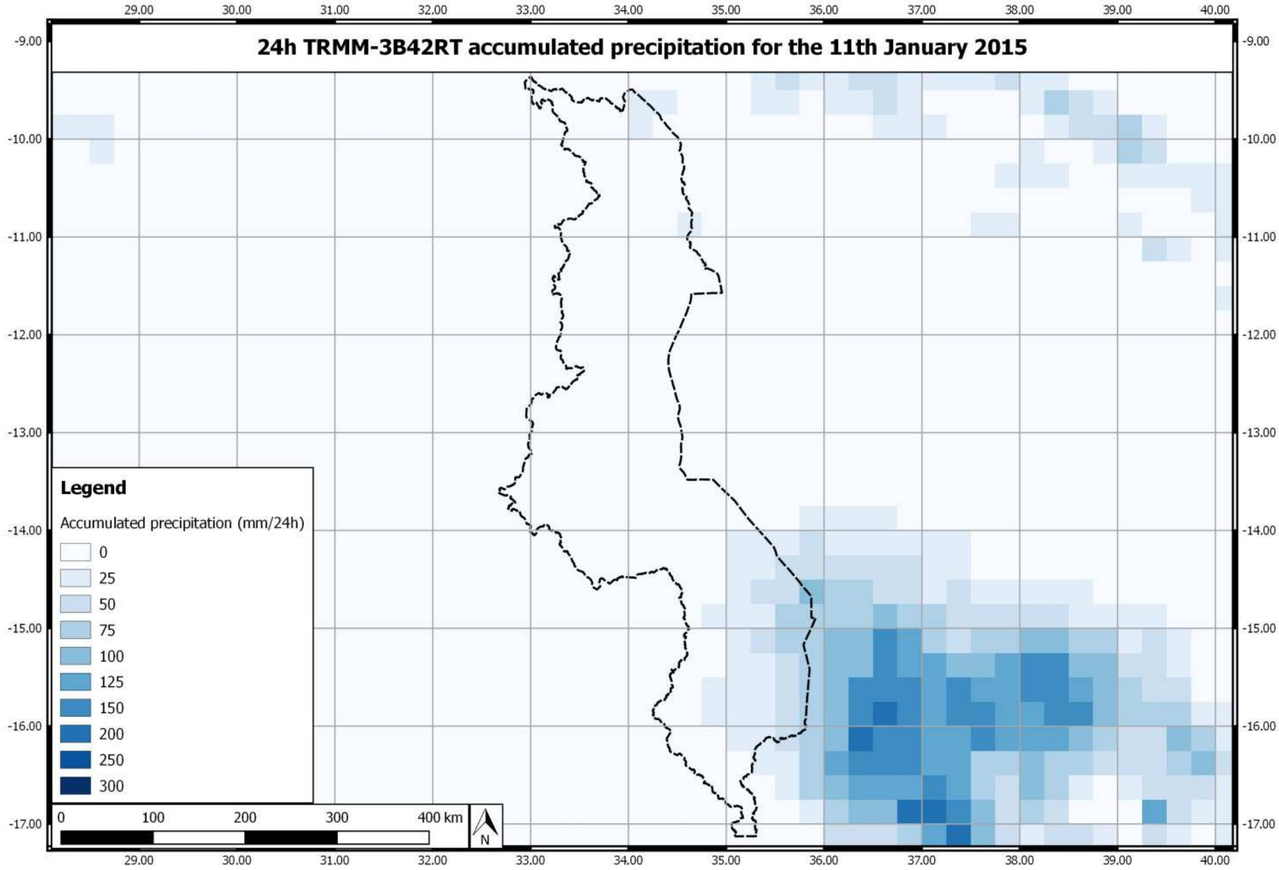

Layers
Cumulated Forecast
Cumulated Near-Real-Time
Alert Forecast
Alert Near-Real-Time
Alert Forecast (District)
Alert Near-Real-Time (District)
NRT 24h
NRT 48h
NRT 72h
NRT 96h
NRT 120h
NRT 144h
NRT 168h
Flooded Population Forecast
Overlays
Mongolia
China
India
Pakistan
Nepal
Myanmar
Thailand
Cambodia
Malaysia
Philippines
Sri Lanka
Maldives
Bay of Bengal
Philippine Sea
South China Sea

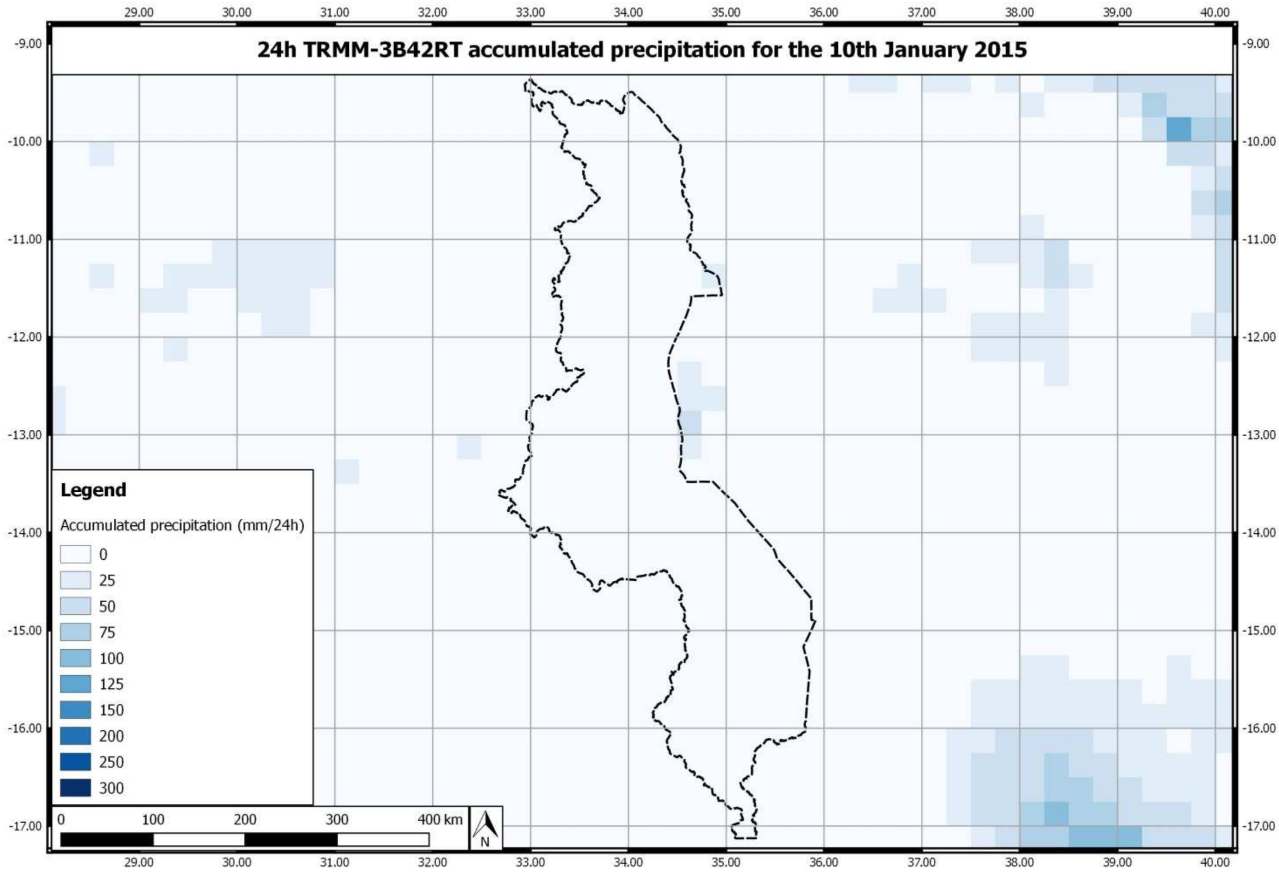

Layers
Cumulated Forecast
Cumulated Near-Real-Time
Alert Forecast
Alert Near-Real-Time
Alert Forecast (District)
Alert Near-Real-Time (District)
Flooded Population Forecast
Overlays
Chongqing
Guiyang
Kunming
Nanning
Guangzhou
Hong Kong
Zhanjiang
Haikou
Changsha
Vientiane
LAO PDR

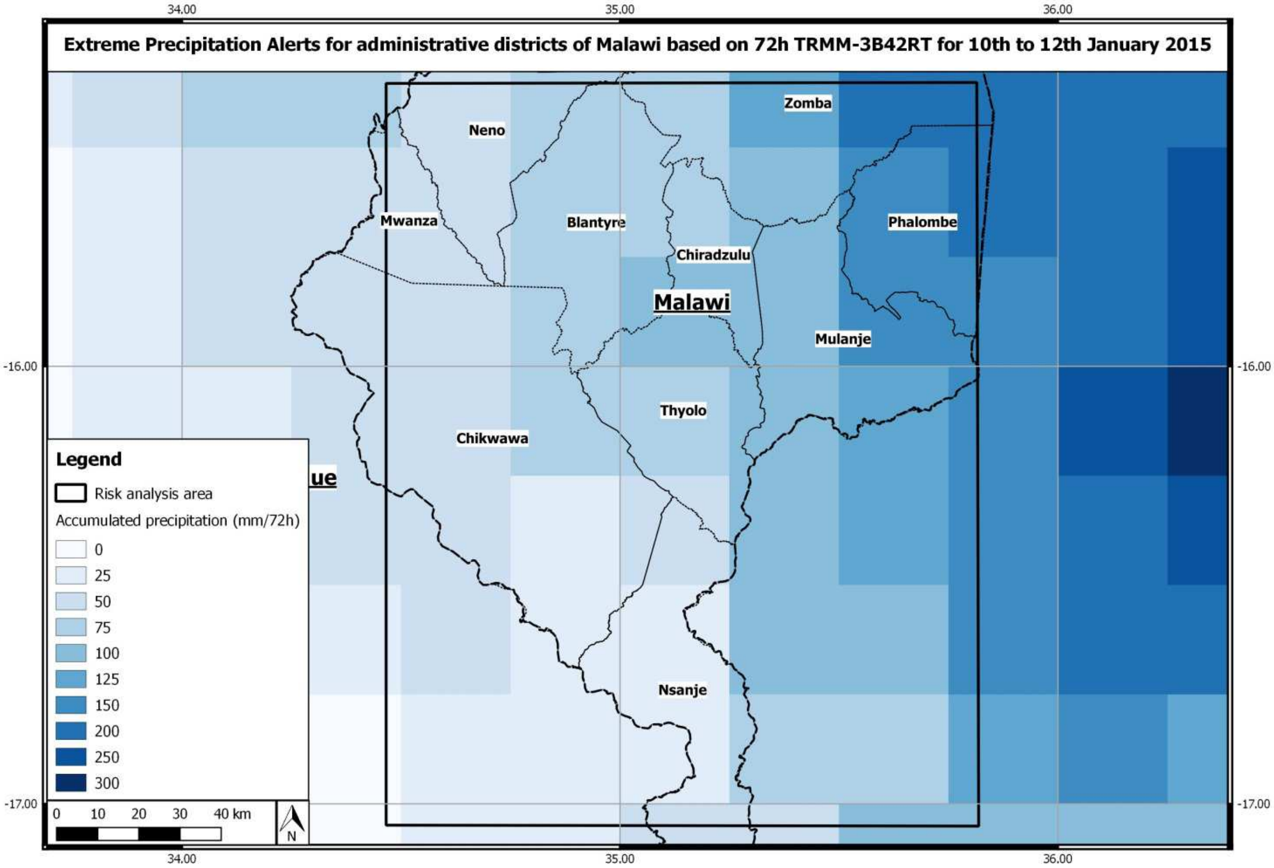
Annex IV – Malawi January 2015 flood event – Vulnerability Maps

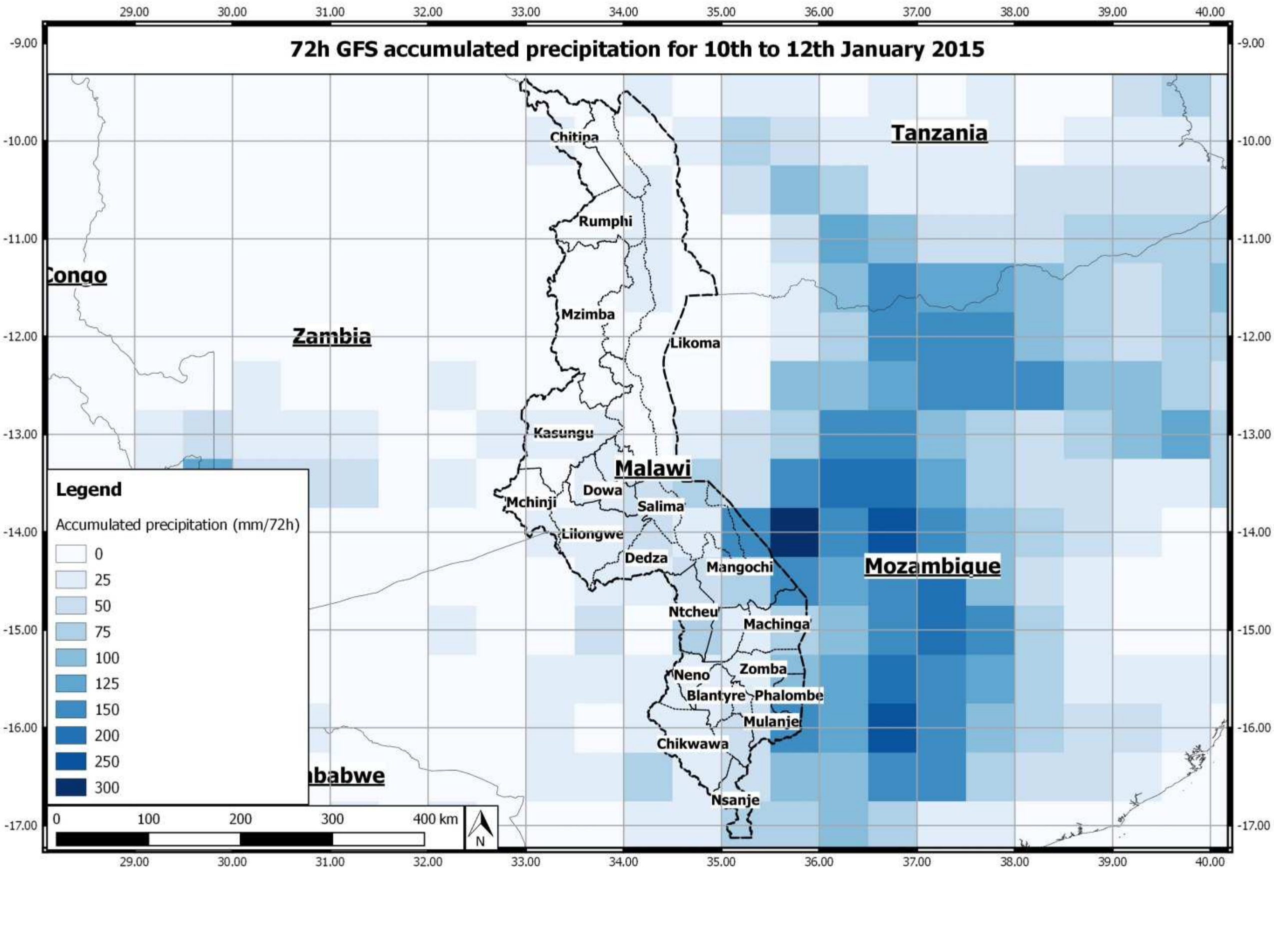


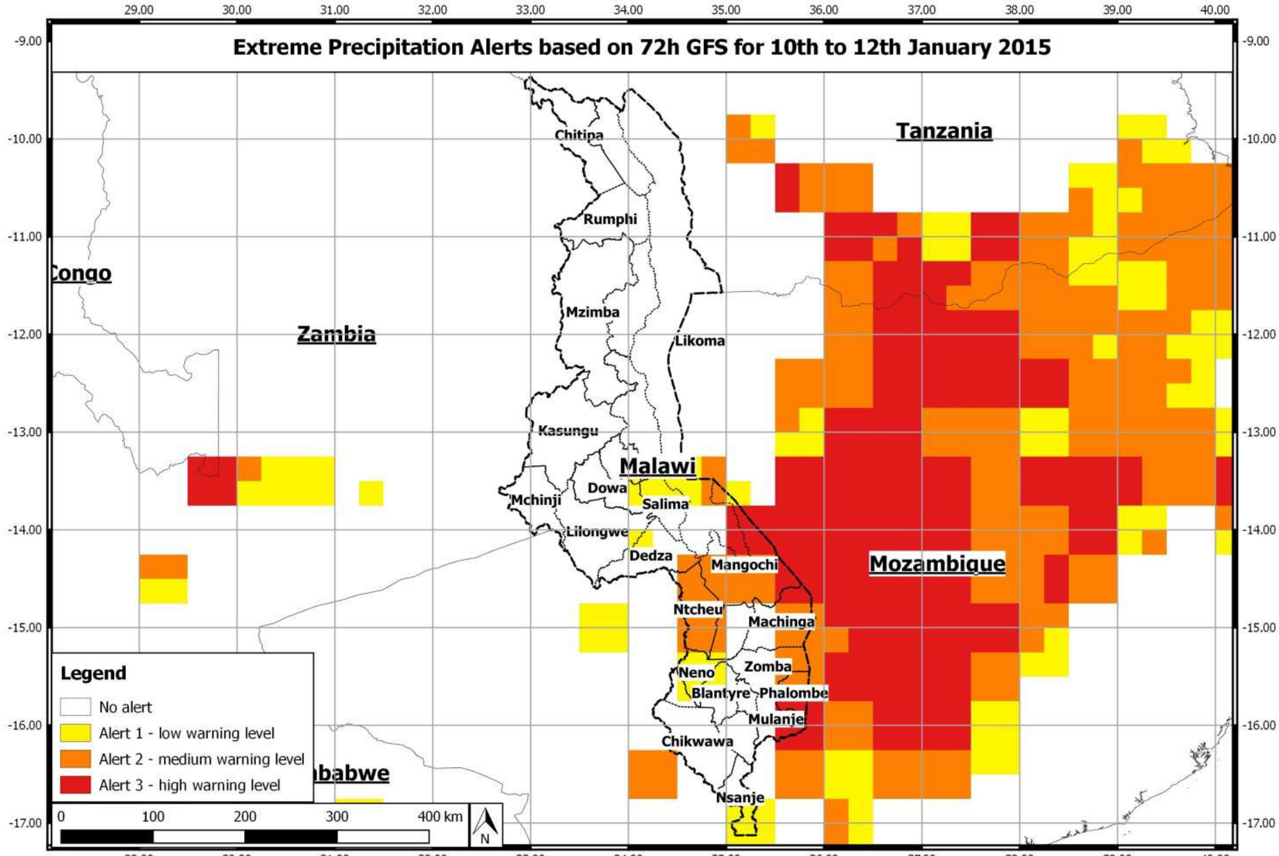


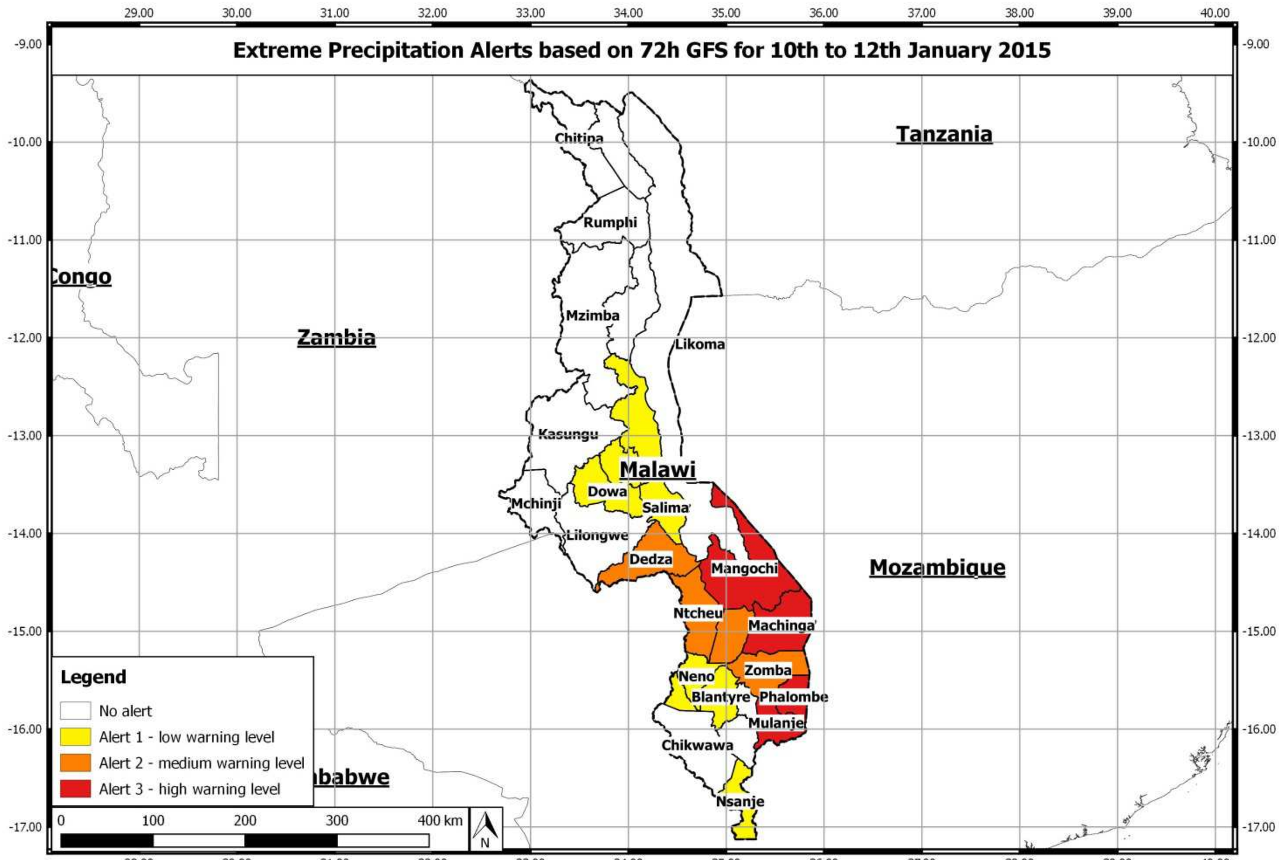

24h TRMM-3B42RT accumulated precipitation for the 11th January 2015
Legend
Accumulated precipitation (mm/24h)
0
25
50
75
100
125
150
200
250
300
0 100 200 300 400 km
N
29.00 30.00 31.00 32.00 33.00 34.00 35.00 36.00 37.00 38.00 39.00 40.00
-9.00 -10.00 -11.00 -12.00 -13.00 -14.00 -15.00 -16.00 -17.00

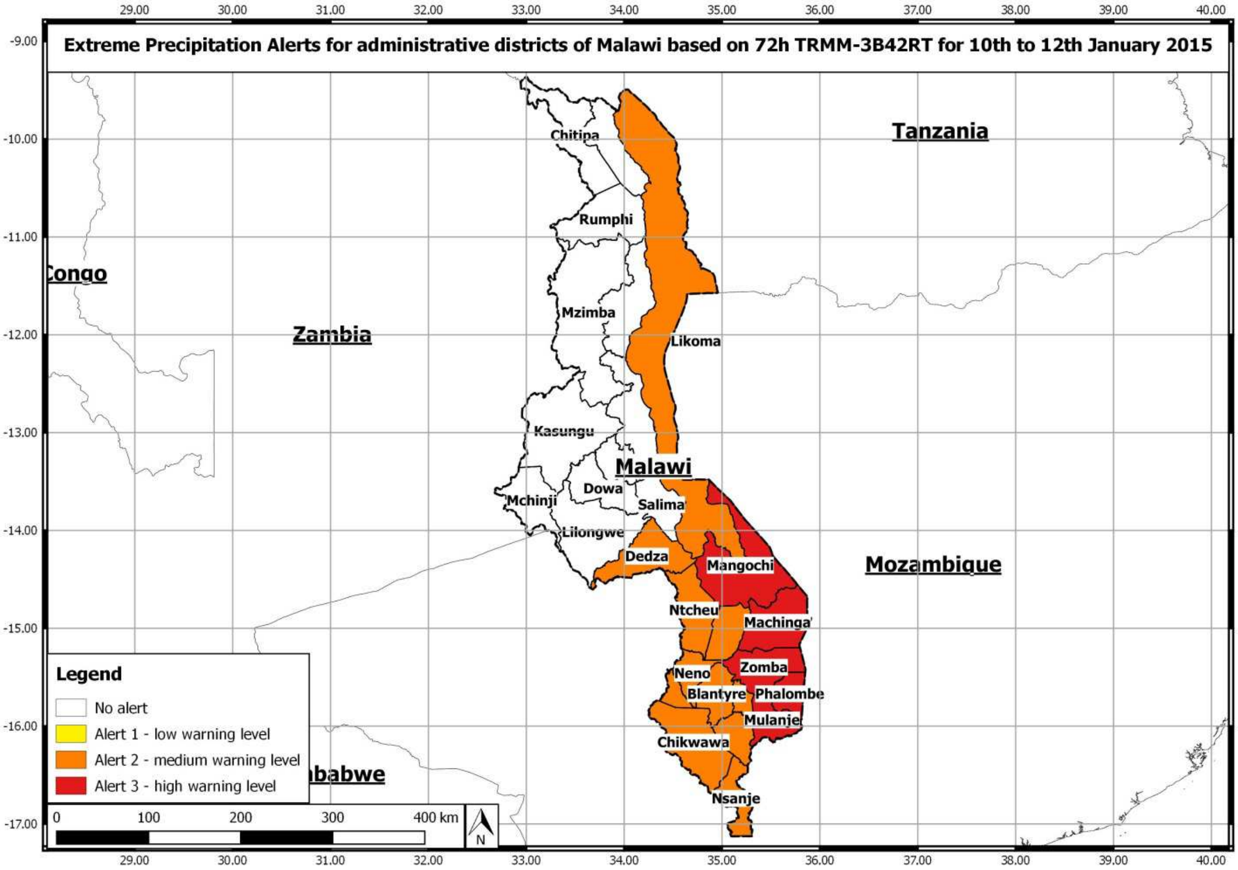

24h TRMM-3B42RT accumulated precipitation for the 10th January 2015
Legend
Accumulated precipitation (mm/24h)
0
25
50
75
100
125
150
200
250
300
0 100 200 300 400 km
N
29.00 30.00 31.00 32.00 33.00 34.00 35.00 36.00 37.00 38.00 39.00 40.00
-9.00 -10.00 -11.00 -12.00 -13.00 -14.00 -15.00 -16.00 -17.00

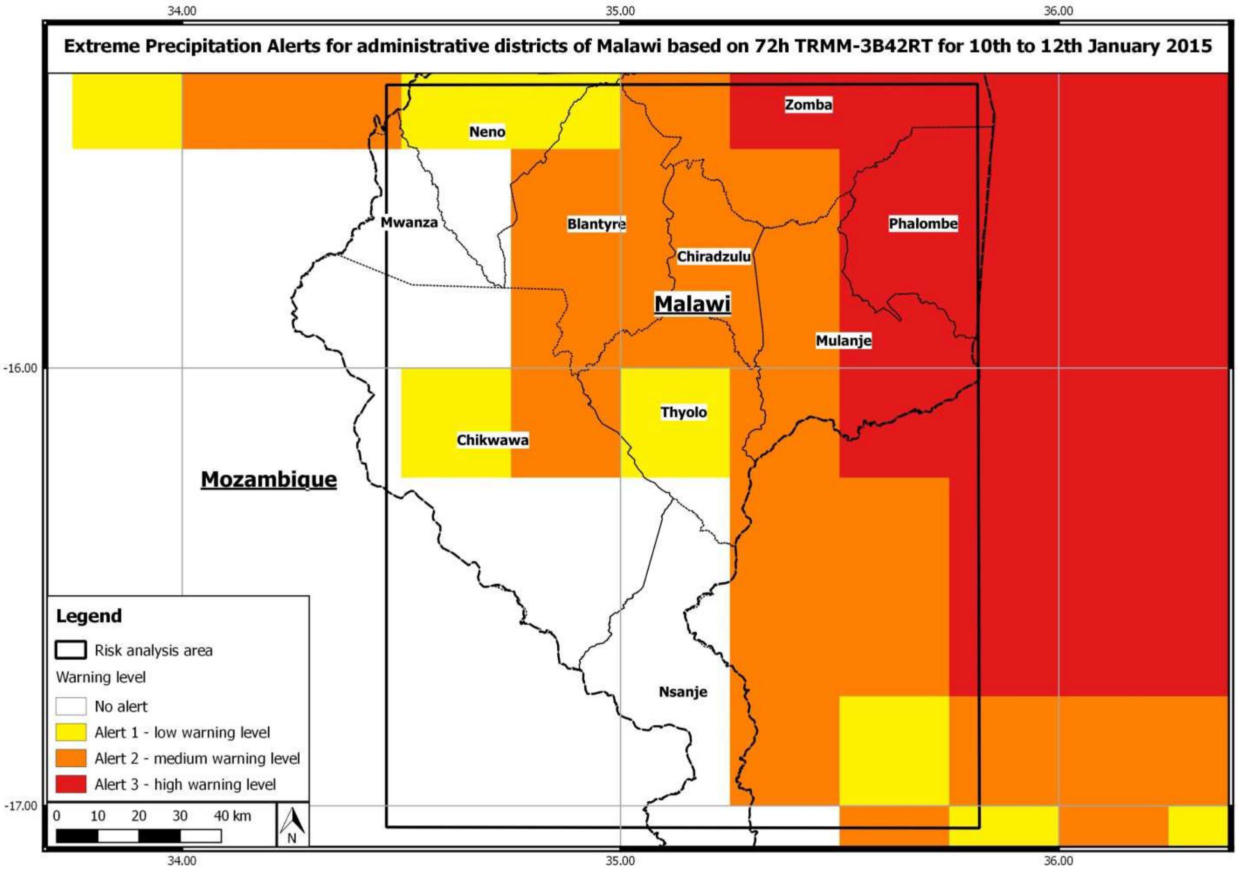

Extreme Precipitation Alerts for administrative districts of Malawi based on 72h TRMM-3B42RT for 10th to 12th January 2015
Zomba
Neno
Mwanza
Blantyre
Phalombe
Chiradzulu
Malawi
Mulanje
Thyolo
Chikwawa
Nsanje
Legend
Risk analysis area
Accumulated precipitation (mm/72h)
0
25
50
75
100
125
150
200
250
300
0 10 20 30 40 km
N
34.00
35.00
36.00
-16.00
-17.00

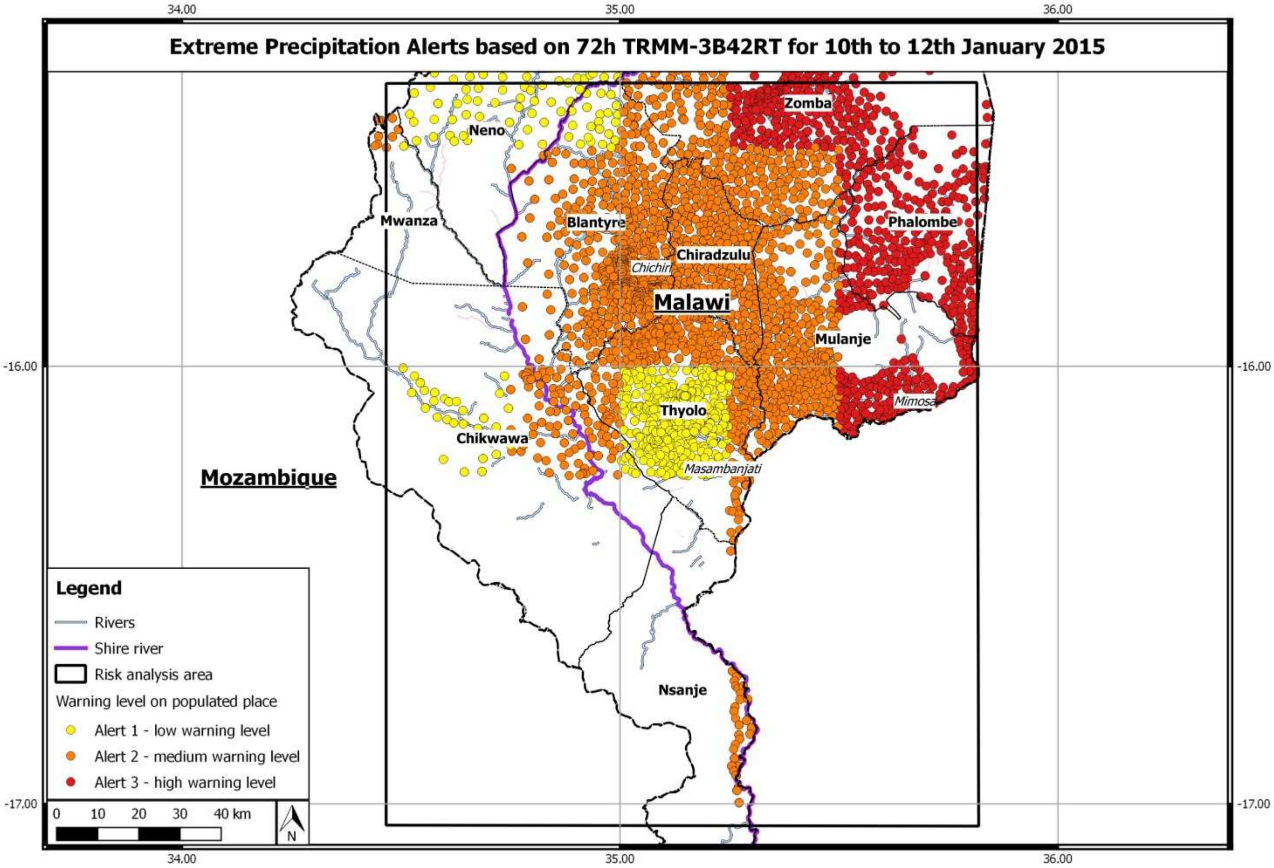

72h GFS accumulated precipitation for 10th to 12th January 2015
Tanzania
Chitipa
Rumphi
Mzimba
Likoma
Zambia
Kasungu
Malawi
Dowa
Mchinji
Salima
Lilongwe
Dedza
Mangochi
Mozambique
Ntcheu
Machinga
Neno
Zomba
Blantyre
Phalombe
Mulanje
Chikwawa
Nsanje
Legend
Accumulated precipitation (mm/72h)
0
25
50
75
100
125
150
200
250
300
0 100 200 300 400 km
N
29.00
30.00
31.00
32.00
33.00
34.00
35.00
36.00
37.00
38.00
39.00
40.00
-9.00
-10.00
-11.00
-12.00
-13.00
-14.00
-15.00
-16.00
-17.00

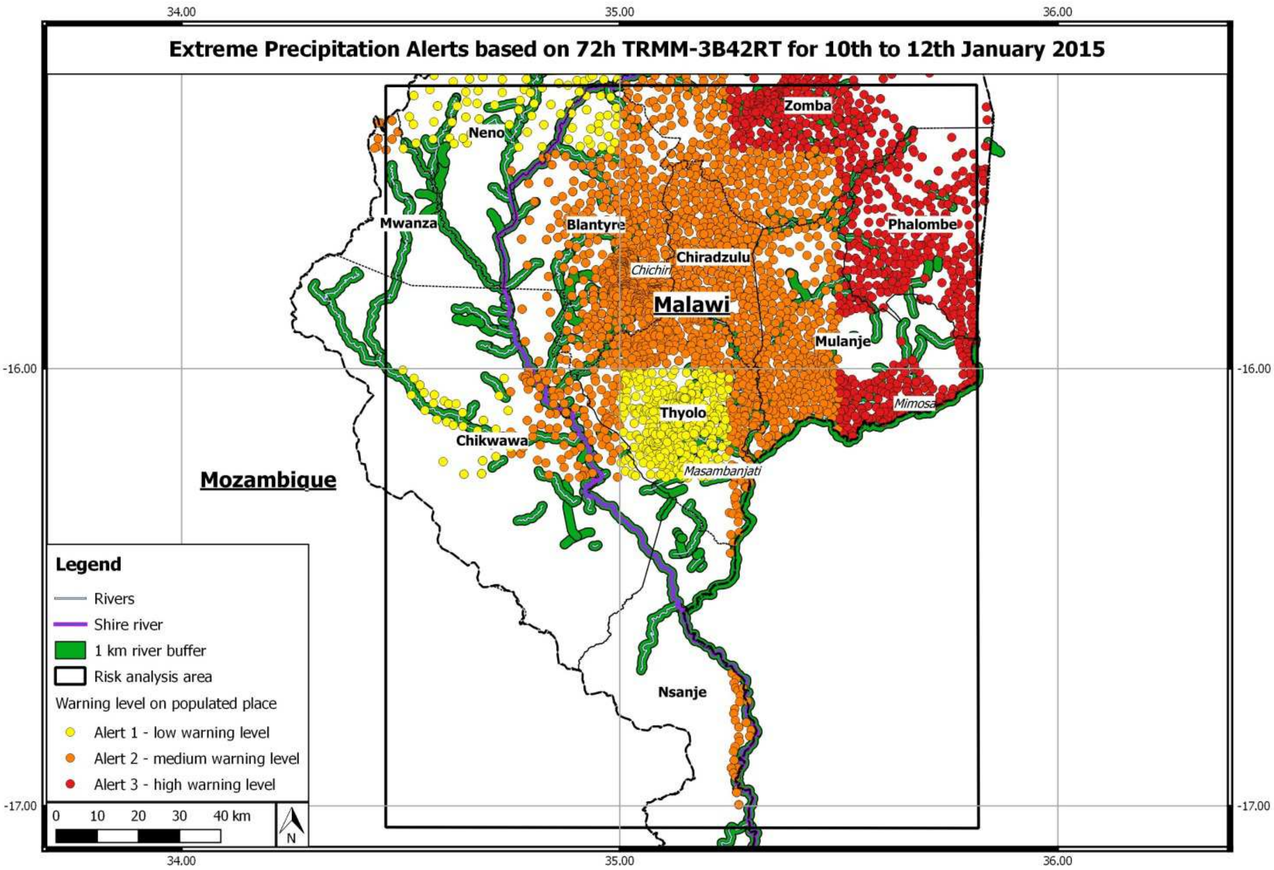

Extreme Precipitation Alerts based on 72h GFS for 10th to 12th January 2015
Tanzania
Congo
Zambia
Malawi
Mozambique
Chitipa
Rumphi
Mzimba
Likoma
Kasungu
Dowa
Mchinji
Salima
Lilongwe
Dedza
Mangochi
Ntcheu
Machinga
Neno
Zomba
Blantyre
Phalombe
Mulanje
Chikwawa
Nsanje
Legend
No alert
Alert 1 - low warning level
Alert 2 - medium warning level
Alert 3 - high warning level
0 100 200 300 400 km
N

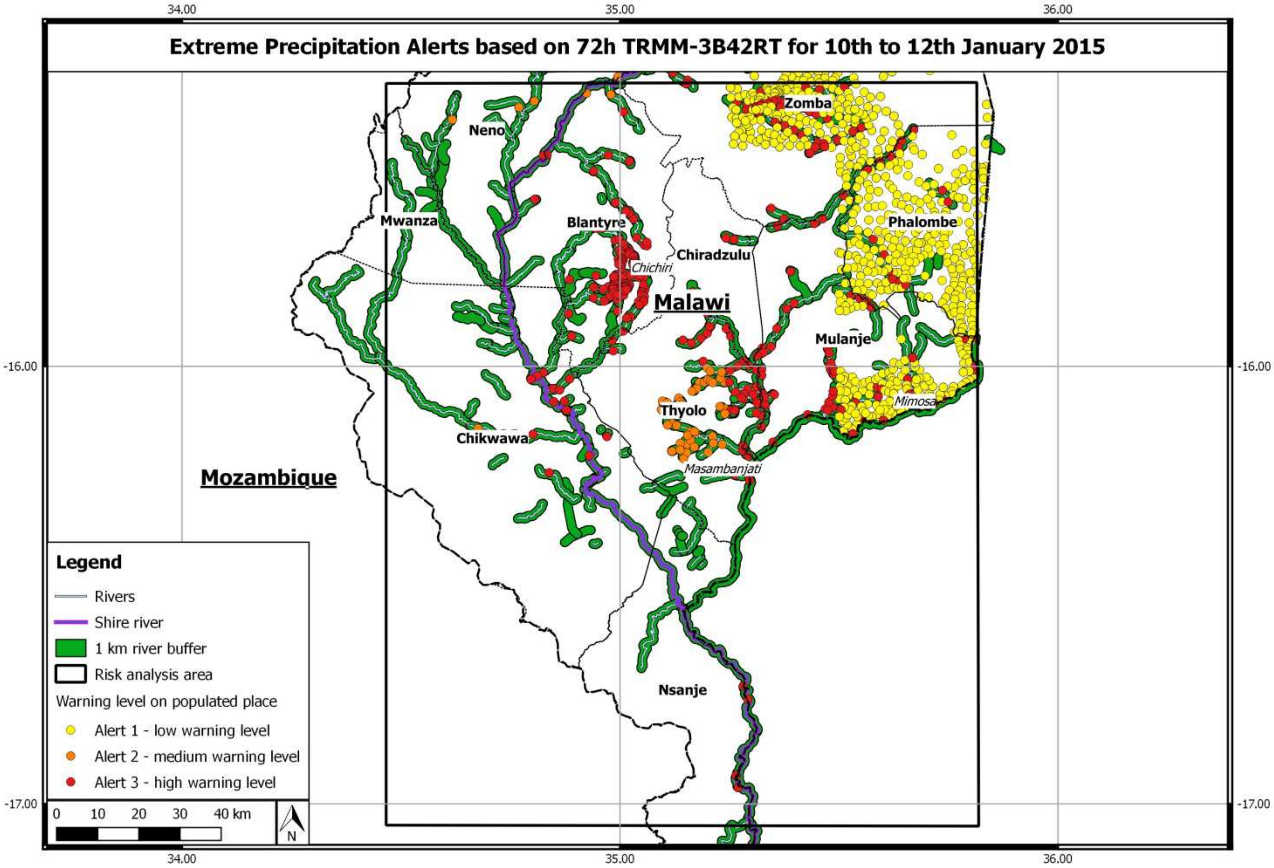

Extreme Precipitation Alerts based on 72h GFS for 10th to 12th January 2015
Tanzania
Congo
Zambia
Malawi
Mozambique
Chitipa
Rumphi
Mzimba
Likoma
Kasungu
Dowa
Mchinji
Salima
Lilongwe
Dedza
Mangochi
Ntcheu
Machinga
Neno
Zomba
Blantyre
Phalombe
Mulanje
Chikwawa
Nsanje
Legend
No alert
Alert 1 - low warning level
Alert 2 - medium warning level
Alert 3 - high warning level
0 100 200 300 400 km
N

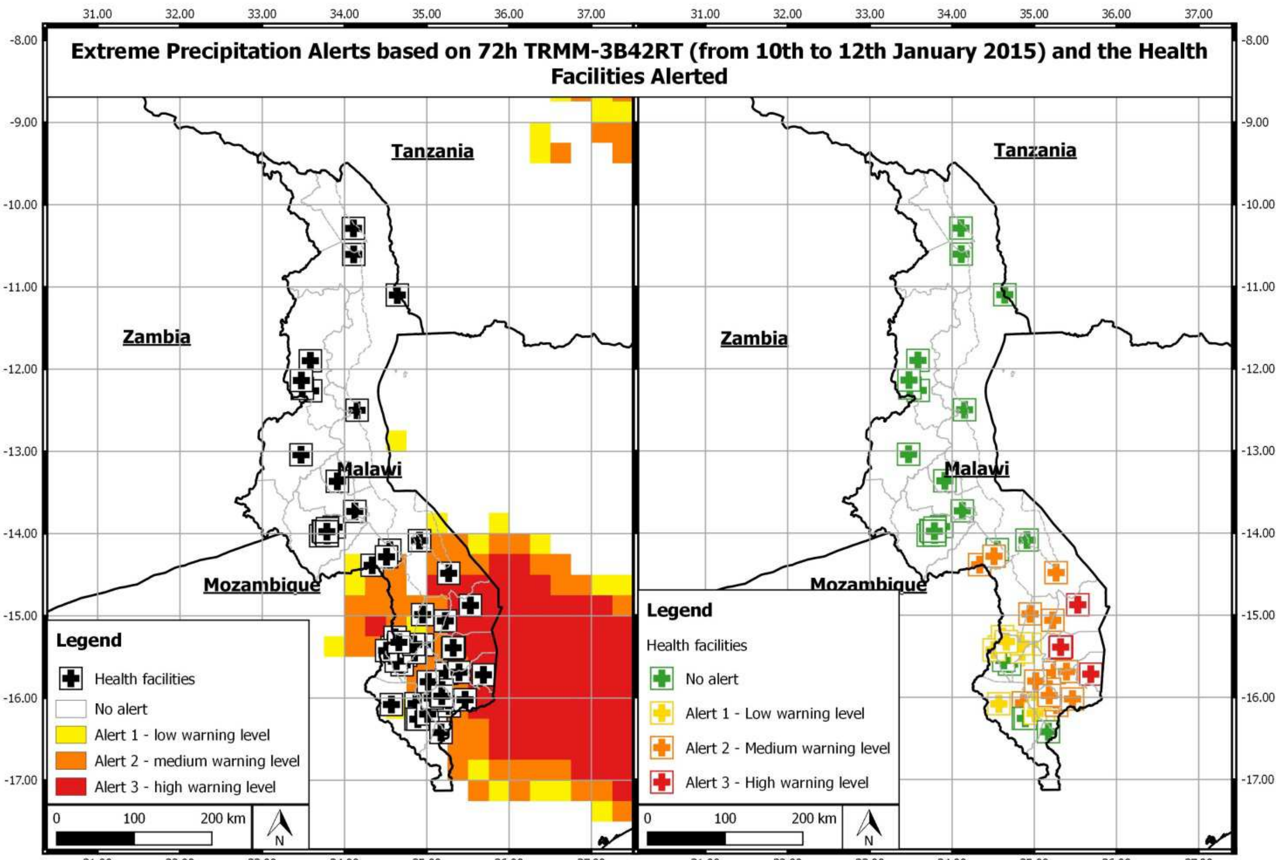

Extreme Precipitation Alerts for administrative districts of Malawi based on 72h TRMM-3B42RT for 10th to 12th January 2015
Tanzania
Zambia
Malawi
Mozambique
Chitipa
Rumphi
Mzimba
Likoma
Kasungu
Dowa
Mchinji
Salima
Lilongwe
Dedza
Mangochi
Ntcheu
Machinga
Neno
Zomba
Blantyre
Phalombe
Mulanje
Chikwawa
Nsanje
Legend
No alert
Alert 1 - low warning level
Alert 2 - medium warning level
Alert 3 - high warning level
0 100 200 300 400 km

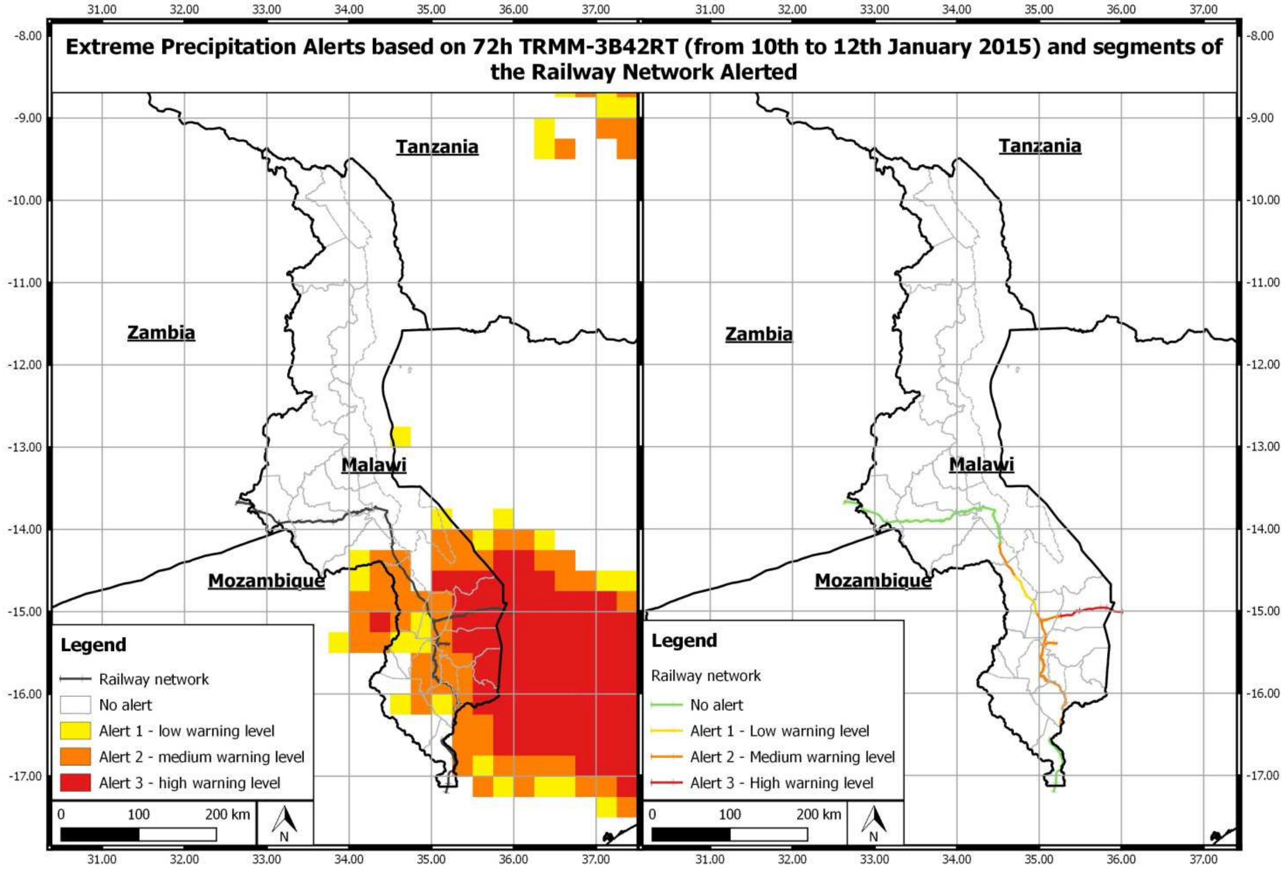

Extreme Precipitation Alerts for administrative districts of Malawi based on 72h TRMM-3B42RT for 10th to 12th January 2015
Zomba
Neno
Mwanza
Blantyre
Chiradzulu
Phalombe
Malawi
Mulanje
Thyolo
Chikwawa
Mozambique
Nsanje
Legend
Risk analysis area
Warning level
No alert
Alert 1 - low warning level
Alert 2 - medium warning level
Alert 3 - high warning level
0 10 20 30 40 km

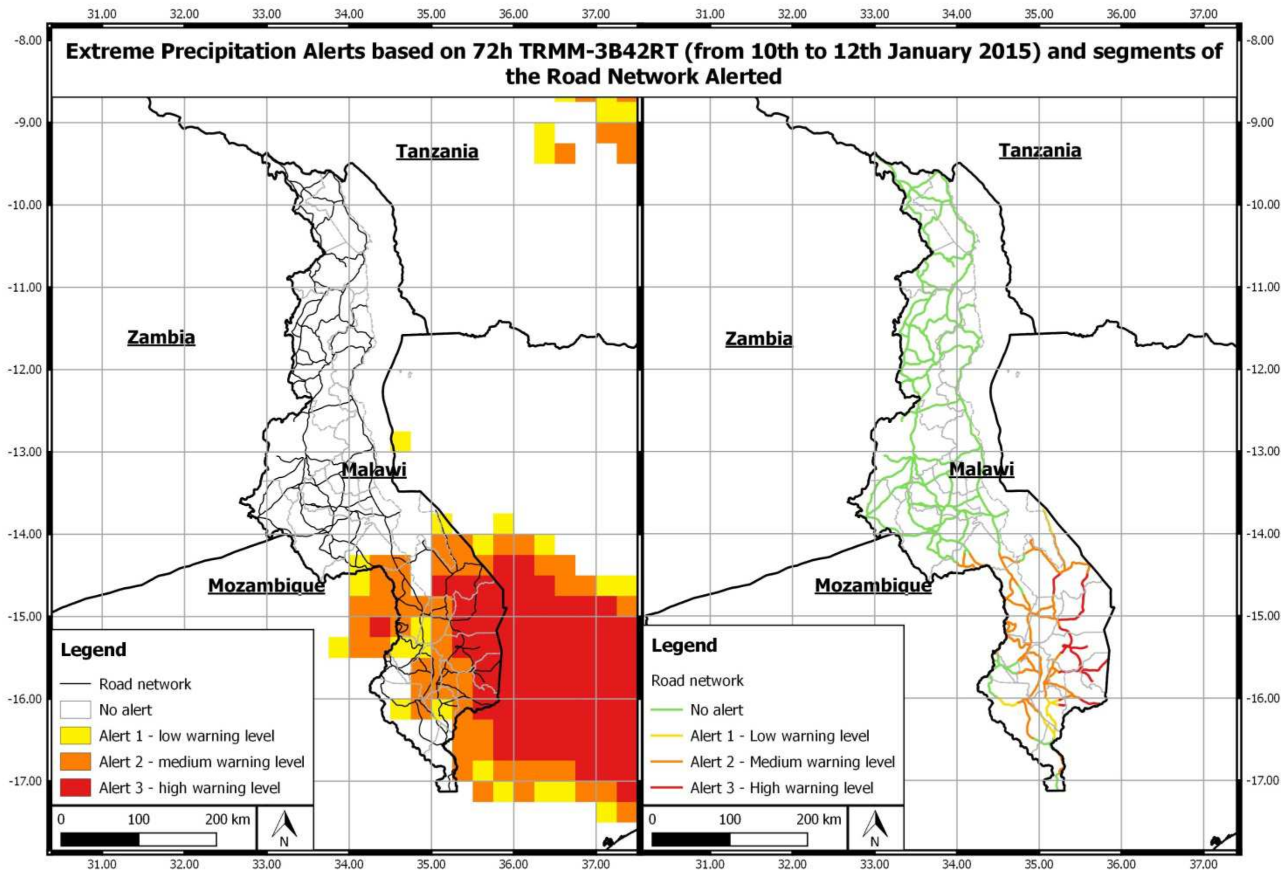

Extreme Precipitation Alerts based on 72h TRMM-3B42RT for 10th to 12th January 2015
34.00
35.00
36.00
-16.00
-17.00
Zomba
Neno
Mwanza
Blantyre
Phalombe
Chiradzulu
Chichiri
Malawi
Mulanje
Thyolo
Mimosa
Chikwawa
Masambanjati
Mozambique
Nsanje
Legend
Rivers
Shire river
Risk analysis area
Warning level on populated place
Alert 1 - low warning level
Alert 2 - medium warning level
Alert 3 - high warning level
0 10 20 30 40 km
N

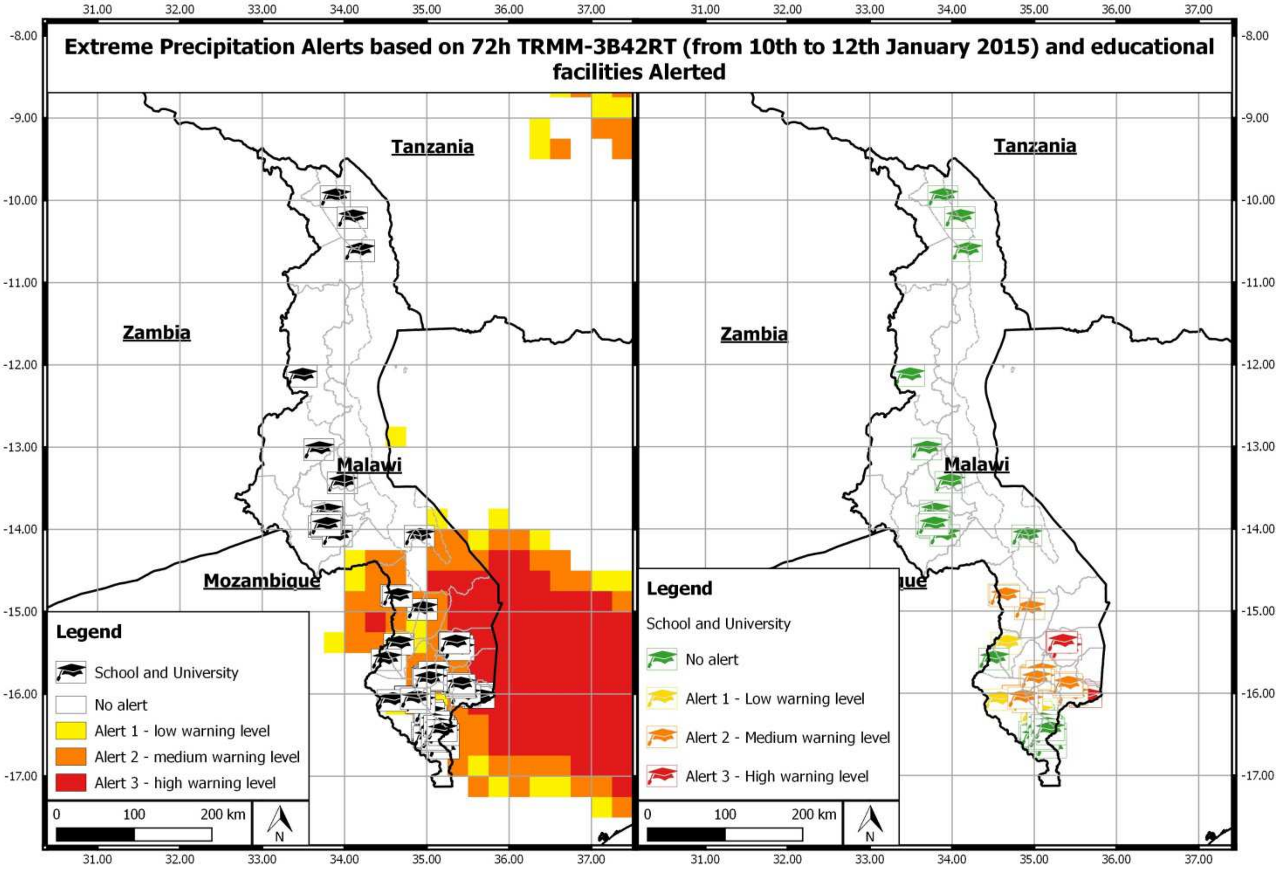

Extreme Precipitation Alerts based on 72h TRMM-3B42RT for 10th to 12th January 2015
34.00
35.00
36.00
-16.00
-17.00
Zomba
Neno
Mwanza
Blantyre
Phalombe
Chiradzulu
Chichiri
Malawi
Mulanje
Thyolo
Mimosa
Chikwawa
Masambanjati
Mozambique
Nsanje
Legend
Rivers
Shire river
1 km river buffer
Risk analysis area
Warning level on populated place
Alert 1 - low warning level
Alert 2 - medium warning level
Alert 3 - high warning level
0 10 20 30 40 km
N


Extreme Precipitation Alerts based on 72h TRMM-3B42RT for 10th to 12th January 2015
Zomba
Neno
Mwanza
Blantyre
Phalombe
Chiradzulu
Chichiri
Malawi
Mulanje
Thyolo
Mimosa
Chikwawa
Masambanjati
Mozambique
Nsanje
Legend
Rivers
Shire river
1 km river buffer
Risk analysis area
Warning level on populated place
Alert 1 - low warning level
Alert 2 - medium warning level
Alert 3 - high warning level
0 10 20 30 40 km
N
34.00
35.00
36.00
-16.00
-17.00


Extreme Precipitation Alerts based on 72h TRMM-3B42RT (from 10th to 12th January 2015) and the Health Facilities Alerted
Tanzania
Zambia
Malawi
Mozambique
Legend
Health facilities
No alert
Alert 1 - low warning level
Alert 2 - medium warning level
Alert 3 - high warning level
No alert
Alert 1 - Low warning level
Alert 2 - Medium warning level
Alert 3 - High warning level
0 100 200 km
N
31.00
32.00
33.00
34.00
35.00
36.00
37.00
-8.00
-9.00
-10.00
-11.00
-12.00
-13.00
-14.00
-15.00
-16.00
-17.00


Extreme Precipitation Alerts based on 72h TRMM-3B42RT (from 10th to 12th January 2015) and segments of the Railway Network Alerted
Tanzania
Zambia
Malawi
Mozambique
Legend
Railway network
No alert
Alert 1 - low warning level
Alert 2 - medium warning level
Alert 3 - high warning level
0
100
200 km
N
Legend
Railway network
No alert
Alert 1 - Low warning level
Alert 2 - Medium warning level
Alert 3 - High warning level


Extreme Precipitation Alerts based on 72h TRMM-3B42RT (from 10th to 12th January 2015) and segments of the Road Network Alerted
Tanzania
Zambia
Malawi
Mozambique
Legend
Road network
No alert
Alert 1 - low warning level
Alert 2 - medium warning level
Alert 3 - high warning level
0
100
200 km
N
Legend
Road network
No alert
Alert 1 - Low warning level
Alert 2 - Medium warning level
Alert 3 - High warning level


Extreme Precipitation Alerts based on 72h TRMM-3B42RT (from 10th to 12th January 2015) and educational facilities Alerted
Tanzania
Zambia
Malawi
Mozambique
Legend
School and University
No alert
Alert 1 - low warning level
Alert 2 - medium warning level
Alert 3 - high warning level
0 100 200 km
N
Tanzania
Zambia
Malawi
Legend
School and University
No alert
Alert 1 - Low warning level
Alert 2 - Medium warning level
Alert 3 - High warning level
0 100 200 km
N

Annex V – Example of current maps for the validation of the hydrodynamic model