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A look to the HyMeX program

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Abstract

The international HyMeX (Hydrological Mediterranean Experiment) program aims to improve our understanding of the water cycle in the Mediterranean, using a multidisciplinary and multiscale approach and with emphasis on extreme events. This program will improve our understanding and our predictive ability of hydrometeorological hazards including their evolution within the next century. One of the most important results of the program will be its observational campaigns, which will greatly improve the data available, leading to significant scientific results. The interest of the program for the Spanish research groups is described, as the active participation of some of them in the design and execution of the observational activities. At the same time, due to its location, Spain is key to the program, being a good observation platform. HyMeX will enrich the work of the Spanish research groups, it will improve the predictive ability of the weather services, will help us to have a better understanding of the impacts of hydrometeorological extremes on our society and will lead to better strategies for adapting to climate change.

Key words: Mediterranean, hydrological cycle, extremes, climate change, observation

1 Introduction

The Mediterranean is a geographically unique place (Woodward, 2009): it is relatively small, almost closed, with a semi-arid climate, surrounded by continents with strong relief, with densely urbanized coastal areas, and crossed by numerous rivers. Consequently, it presents unusual weather patterns (Jansà, 1966) that make the interactions between ocean, atmosphere, and continental surfaces multiple and especially determinant in the region.

Intense rain, hail, floods and high winds are common in the region (Jansà, 1997; Llasat, 2009). Forest fires, heat waves and summer droughts are also significant. Their frequency and intensity might possibly worsen in the future due to the climate change (Giorgi, 2006). An increase in temperature is expected, together with a decrease in the average precipitation in summer and an increase in variability (Giorgi and Lionello, 2008). In relation to water resources, we should add an increase in demand for a resource that may decrease and become more variable (Iglesias et al., 2006, 2009) to the climate change.

Knowledge about the future evolution of Mediterranean weather is still limited, and there are significant gaps in trends and variability at local and regional scales. To improve this knowledge, it is essential to study the interactions of the ocean-atmosphere-continental surface system and its associated feedback processes as a whole.

Moreover, the ability to forecast high-impact phenomena is still insufficient. It is necessary to improve our understanding of the fine-scale processes and their nonlinear interaction with other larger scale processes. This must be done in a multidisciplinary way to improve our knowledge of the environments that affect processes and their evolution and to improve the surveillance and prediction systems in a more comprehensive manner. In addition, knowledge of these phenomena is important for the evaluation of their effects on the environment and ecosystems, both terrestrial and marine.

Generally, this type of multidisciplinary study needs to be addressed in the context of large-scale projects, which often consist of framework programs supported by international agencies such as the World Meteorological Organization (WMO) or UNESCO. Examples of this type of program would be FRIEND (Flow Regimes from International Experimental and Network Data), where the Mediterranean pole was initially treated within the AMHY project (Alpine and Mediterranean Hydrology) and currently in MedFriend; GEWEX (Global Energy and Water Cycle Experiment), part of the WCRP (World Climate Research project), and finally MEDEX (Mediterranean Experiment), which was predominantly a meteorological project (http://medex.aemet.uib.es) that contributed scientifically and in the building of the Mediterranean meteorological community network,, leaving a valuable legacy for later projects such as HyMeX.

The article reviews the objectives of the HyMeX project and its different subject areas, specified in working groups. Then, we continue reviewing the implementation strategy, placing particular emphasis on the observation phase that took place in autumn 2012 in the Western Mediterranean. Finally, we present a specific example of activity on the subject dealt with by working group 2, which aims at hydrologically modeling the Ebro basin to apply it to future scenarios. A brief summary and conclusions close the paper.

2 Scientific objectives

The scientific challenges mentioned above have led research groups from all around the world to organize themselves in the international HyMeX (Hydrological Cycle in the Mediterranean Experiment) research program, the objectives of which are (Ducrocq et al., 2010):

- To improve the quantification and understanding of the water cycle in the Mediterranean, emphasizing intense events. This is done through observation and modeling of the coupled Mediterranean system, examining its variability at different scales and its characteristics over a decade, in the current context of strong global change.
- To assess the vulnerability of society and the economic system to extreme events and their adaptation capacity, paying special attention to the impact of floods and droughts. The ecological and environmental aspects are also considered in this objective.

Multidisciplinary research will be done in the framework of the program which, together with the database to be created, will be used to improve observing, modeling and prediction systems, for scales ranging from hours to decades. Ultimately, it will allow solid adaptation measures to be defined to meet the challenges posed by the global changes expected for forthcoming decades in the Mediterranean region.

3 Research topics

The research activity derived from the objectives described above is structured into five main sections, as detailed below, following Ducrocq et al. (2010). These blocks coincide with the working groups around which the HyMeX scientific planning is organized. However, it must be said that the working groups do not have limited areas: different issues can be linked to each other given the cross-sectional characteristics of the project.

3.1 Water balance of the Mediterranean

The water balance of the Mediterranean Sea (Mariotti et al., 2002) (E-P-R, evaporation minus precipitation minus river runoff) is negative. This imbalance is offset by a double flow in the Strait of Gibraltar. The study of water balance is key, because it governs two basic points of the Mediterranean system, which can be affected in the long term by (1) the rate of formation of dense water and its temperature and salinity, which strongly affect thermohaline circulation, biogeochemical cycles, fishing and water quality, and (2) the density and salinity of the water flow going in depth to Gibraltar, which influences the characteristics of the Atlantic Ocean at middle depth.

The atmosphere and the Mediterranean Sea are mutually affected. For example, locally, the sea provides moisture and energy to the precipitating events and, in large part, determines the atmospheric instability at low levels. At a regional level, the Mediterranean is a major source of moisture for the surrounding regions. The effect of the contribution of continental water to the sea (through rivers and from groundwater) is also an important factor in Mediterranean hydric dynamics.

So far, the Mediterranean water balance has never been studied as a whole; on the contrary, it has been studied separately for each of the compartments of the system (atmosphere, ocean and inland watersheds) and the results are not consistent. HyMeX aims to reconcile balance estimates using observations and models and also wants to better understand how each compartment affects the others, from intense convective systems (at a local scale) to the climate (at a regional scale). To do so, it is necessary to increase the observations in key points of the Mediterranean, in order to better fit the models used to estimate each of the components of the balance.

3.2 Continental hydrological cycle

In the Mediterranean area, hydrological processes on the continental surface are highly variable in space and time, due to the high variability of precipitation, the complicated topography, the spatial distribution of geological features and the land use. Due to the characteristics of the Mediterranean basin, evaporation plays a very important role, but it is little known. For example, many improvements still need to be made to understand the role of vegetation, which is essential in evapotranspiration. In recent years there have been many advances in distributed models based on SVAT-type models (soil-vegetation-atmosphere transfer) (Noilhan and Planton, 1989; Noilhan and Mahfouf, 1996; Boone et al., 1999), with vegetation models (Calvet et al., 1998; Gibelin et al., 2006) and their combination, but the gaps in knowledge of these processes are still important.

In terms of geology, the Mediterranean is surrounded by many karst regions that strongly affect the dynamics of groundwater. These karst systems are highly nonlinear and there is very limited knowledge of their geometry, therefore the calculation of the water balance becomes difficult and speculative. Their role in freshwater input to the sea is also unknown. The integration of these structures in the models is complicated. In general, the characteristics of the region hinder the elaboration of the regional hydrological models needed to study the water cycle on this scale (Habets et al., 2008; Quintana-Seguí et al., 2009). Other processes that must also be taken into account are snow, urban development, and the behavior of soil moisture, a variable that we should be highly familiar with to be able to initialize hydrological and meteorological models properly, the measurement of which recently started to be possible from satellite (Kerr et al., 2010).

In the current context of strong climate change, it is essential that the continental water balance is well known, in order to foresee its evolution and to design adaptation strategies that are effective. This cannot be done in isolation and must be done taking into account the other compartments of the system (atmosphere and ocean).

3.3 Intense precipitation events and flooding

Heavy rainfall and flash floods are common in the Mediterranean basin. They generally occur in late summer and autumn (mainly in the western part), when the sea is relatively warm, favoring strong latent instability and high evaporation, in markedly southern atmospheric situations usually associated with synoptic and mesoscale depressions that favor and organize the advection of warm, humid air at low levels on the continent, as well as the release of latent instability and upward forcing. The Mediterranean orography also plays a very important role in these factors (Jansà et al., 1996; Llasat, 2009). Also, the small basins enclosed by steep slopes that are typical of the region facilitate heavy rainfall becoming torrential flooding, or can even lead to extensive flooding in basins, if the situation is stationary and the process is re-fed.

The study of these intense and abundant rainfalls events is not easy, as there are a variety of nonlinear mechanisms that come into play, making our predictive ability relatively limited at present. There is a shortage of observations on the sea and on the microphysical and dynamic processes taking place within the convective systems. Nevertheless, the high-resolution nonhydrostatic research models are achieving quite a realistic simulation of these intense precipitation systems (i.e. Chancibault et al., 2006). However, the difficulties are still significant, such as the initialization of the systems and the parameterization of the microphysics of the processes.

Once the intense precipitating phenomenon has happened, it is difficult to simulate the effects properly in the form of quick flooding due to the lack of well-instrumented basins where all relevant processes can be observed and the difficulty of the transferability of hydrological models from one basin to another due to the strong spatial heterogeneity of the geophysical features.

Finally, climate change may affect the operation of all these systems, changing their frequency and intensity, making it important to understand how they are related to the Mediterranean coupled system.

3.4 Intense interactions between sea and atmosphere

The interactions between the sea and the atmosphere are especially intense in some key spots of the Mediterranean Sea, affecting the functioning of both the ocean and the atmosphere. The strong winds dramatically intensify the interactions, favoring the formation of dense water and deep ocean convection (Marshall and Schott, 1999). Although we are familiar with the basic ingredients for the formation of these strong regional winds, many questions related to the details of the mechanisms present and their time variability are still to be answered.

Strong winds can cause destratification of the mixed layer formed during the summer, followed by oceanic convection in specific points and/or the formation of dense water. However, these processes also depend on other factors such as the Tirreni current (Grignon et al., 2010). Strong winds are also responsible for rapid changes between ocean-atmosphere fluxes. After the winter, when the sea becomes stratified again, the dense water formed spreads, contributing to the thermohaline circulation. This process is highly variable from one year to another. Note that we do not know enough about the hierarchy of processes and the complexity of the interactions due to the lack of appropriate observations.

3.5 Social vulnerability and resilience

The population in the Mediterranean region is increasing, especially in coastal areas. Many of these areas are characterized by a high risk of flooding, as there is both a high likelihood of heavy rains and the presence of torrential basins. Despite the preventive measures taken, usually with fairly large hydraulic infrastructures, it is a risk that increases mainly because of increased vulnerability, including exposure (Neppel et al., 2003; Llasat et al., 2008). Something similar occurs with drought.

The study of human impact is not simple, since it can influence the vulnerability and the danger, generating responses that are difficult to model. Human impact should not only be considered from the point of view of increased

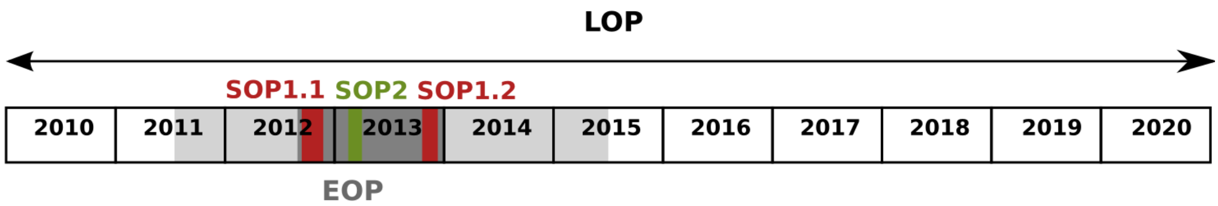

Figure 1. Observation periods in the northwestern Mediterranean (Source, HyMeX).

vulnerability, it should also be studied as a factor that contributes to the very risk. In the context of climate change, the population confronts environmental changes at different scales, from extreme events at a small scale (torrential storms and flooding) to longer-term changes, such as an increase in the frequency of droughts.

To reduce economic and human losses, research should be done in different areas. On the one hand, we need to have a better understanding of the physics and the process of predicting events as well as preventive measures. On the other hand, we must study all the factors that can influence the impact, such as the behavior of people against risks, the cost of life and insurance, the characteristics of buildings and exposed structures, etc. In this field, the more typical approach is to build databases that contain information about the physical characteristics of the events and data on damage (i.e. Barnolas and Llasat, 2007; Guzzetti and Tonelli, 2004; Llasat et al., 2009). The analysis of high-impact events can help to identify the factors that increase the risk. For this purpose, we also work with proxy indicators, such as petitions received by meteorological services (Amaro et al., 2010). Recent studies show that many human casualties are due to dangerous behavior rather than passive vulnerability (i.e. Ruin et al., 2008).

Finally, the concept of ecosystem services (ES) is used to connect humans with their environment. The ES and their vulnerability depend heavily on the state of the (agro)ecosystem and its bidirectional interactions with water and climate. Although ES can be measured in the same way all across the Mediterranean, the dependence of ES on human beings depends on local factors. Droughts can have a strong impact on the ES. Thus, the analysis of the effects of different factors prevailing in the state of ecosystems can generate new information on desertification in the Mediterranean.

4 Implementation strategy

According to the basic documents of HyMeX (www.hymex.org), the program strategy is defined on two main areas: observation and modeling.

4.1 Observation

The general observation strategy consists of three levels (Figure 1):

- A long-term observation period (LOP). This should last 10 years and began in 2010. It should serve to gather comments on the entire coupled system in order to analyze the seasonal and interannual variability of the water cycle and to estimate the water balance. The LOP implies an intensification of the current operational observations and covers the entire Mediterranean. In the case of any high-impact events that may occur, there will be dedicated studies and post-event research.
- Enhanced observation periods (EOP). These are devoted to the study of the water balance and processes. The EOP should last 4 years, from mid 2011 to mid 2015, and includes special observation periods. The EOP is based on the intensification of the operative observation systems in some target areas (TA) for high impact events.
- Special observation periods (SOP). These last a few months, between 2012 and 2013. Their objective is to collect detailed data on TA to study key processes. In this case, besides the available observation systems during the EOP, there will be some dedicated fixed, mobile and air resources.

Three target areas have been defined: the north-western Mediterranean, the Adriatic and the south-eastern Mediterranean (Figure 2).

This article focuses on the north-western Mediterranean. This area contains all the hydrometeorological phenomena that are of interest to HyMeX: heavy rainfall, dense water formation under the influence of strong winds and the cyclogenesis in the Gulf of Lion. The region also includes the Rhone and Ebro rivers, which are major Mediterranean rivers, and many small basins that respond to heavy downpour with flooding.

It is planned to collect data and/or install instruments in key areas of our territory, using the following strategy:

- Hydrometeorological areas: Valencian Country, Catalonia, Cévennes-Vivarais, Liguria-Tuscany, Lazio and the NE of Italy. The state of the project in these areas is variable. Pilot zones are also to be created in these areas for the implementation of hydrological models distributed at a regional scale. The Ebro is one example. Within these areas there may be super-zones, which have a scale of 1 to 10 km^2 and will be used to study small-scale processes.

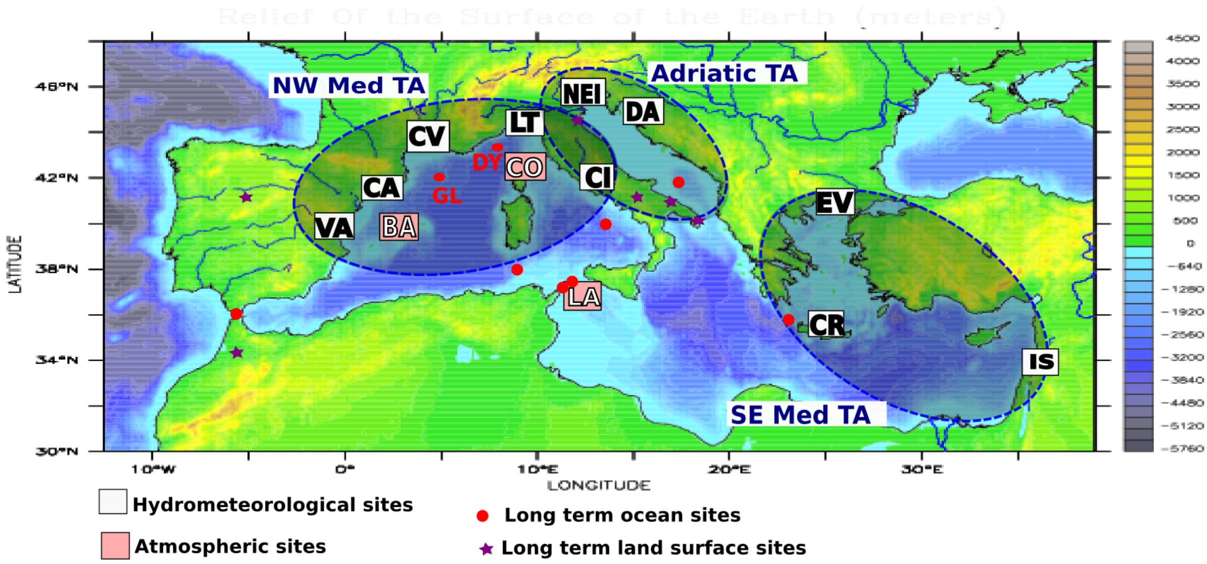

Figure 2. Priority study areas (Ducrocq et al., 2010).

- Two well located atmospheric areas to observe the flow that feeds the coastal precipitating systems. These areas are the Balearic Islands and Corsica.
- The Gulf of Lion is an area for oceanographic study with two super-areas equipped with buoys and anchors. This area will be used to monitor the formation of dense water.

4.2 Modeling

The modeling strategy is closely associated with the observation strategy, because the models must be used to improve the observation strategy and the observations must be used to improve the models. In the previous sections, we have already mentioned the main shortcomings of the current simulation systems: improvement of the simulation of the coupled Mediterranean system (including air, sea and continental surface), improvement of the meso-scale simulation systems both in the atmosphere and the ocean, improvement of the hydrological models to better simulate sudden floods, etc. This strategy includes the following topics:

- Development and improvement of coupled models (AORCM) for a better description and understanding of the Mediterranean water cycle and its variability and trend. Development of a range of regional climate projections.
- Improvement of the deterministic prediction systems of high impact convective events.
- Design of ensemble modeling systems dedicated to the study of the predictability of heavy rainfall and severe cyclogenesis. Quantification and evaluation of the different sources of uncertainty for the prediction of severe events at different scales. Coupling of forecasting systems for sets with hydrological models, to make probabilistic predictions of the hydrologic response and to study the predictability of flash floods.
- Hydrological Simulation of the whole Mediterranean basin with data assimilation. Simulation of pilot basins, such as the Ebro, at a regional scale, and simulation of processes in small basins. Improvement of the understanding of the hydrologic response and the state of soil moisture before and during intense events, to improve the initialization and the representation of the processes in hydrological models.
- Modeling of new processes and improvement of the relevant parameterizations for the different compartments of the Earth system. Development of data assimilation techniques.
- Development of high-resolution coupled ocean-atmosphere models for the western Mediterranean.
- Assimilation of atmospheric, oceanic and hydrologic data.

Therefore, with this broad range of actions to improve the models, we aim to improve our ability to simulate different aspects of the Mediterranean system, thus improving our understanding and our predictive ability, using all possible synergies between the ocean, atmosphere and continental surfaces.

5 Organization

The HyMeX White Paper (Drobinski and Ducrocq, 2008) was the first step before writing the International Science Plan (Ducrocq et al., 2010). The implementation of the project is included in the International Implementation Plan, which is not a unique, closed document. The scientific plan is organized into the five major scientific issues mentioned

Table 1. Extraordinary means for SOP1 in Spain, beside planes, extraordinary use of operative means.

Means	Place	Institution	State	Observations
Balloon launch base at a constant level (boundary layer)	Minorca	CNES (Centre National d'Etudes Spatiales)	FRA	Extraordinary means. P, T, U and wind observations in a journey of some hundred km at low level
Water vapor and aerosol lidar	Minorca	LSCE (Laboratoire des Sciences du Climat et l'Environnement)	FRA	Extraordinary means. Continuous observation of aerosol and water vapor profiles
Radiosounding	A Coruña Madrid Múrcia Mallorca Tenerife	AEMET (Agencia Estatal de Meteorología)	ESP	Ordinary means but with extraordinary implementation of radiosounding for DTS (see text) or out of the DTS
Radiosounding	Barcelona	SMC (Servei Meteorològic de Catalunya)	ESP	Ordinary means but with extraordinary implementation of radiosounding for DTS (see text) or out of the DTS
Surface automatic stations network	More than 400 locations	AEMET	ESP	Extraordinary diffusion in real time
Surface automatic stations network	Catalonia	SMC	ESP	Hourly extraordinary diffusion of 180 stations with rain, 169 with humidity and temperature and 17 with wind
Electric shock network	Catalonia	SMC	ESP	Extraordinary dissemination in real time
Marine gliders	Mediterranean Sea	SOCIB (Coastal observation system of the Balearic Islands)	ESP	Measurement of temperature, conductivity, pressure, fluorescence and dissolved oxygen in the water

above. The implementation plan has been done based on the task teams and team support that work on the observation and modeling platforms and on cross tasks. The consistency of the project is overseen by the International Scientific Steering Committee chaired by P. Drobinski. There is also an International Executive Committee for Implementation and Science Coordination and a project office. HyMeX is highly internationalized, and national executive committees have been established in different countries. Since 2007, international workshops have been organized annually by HyMeX. The program has been endorsed by the WMO, WWRP-THORPEX, WCRP-GEWEX and Med-CORDEX, a fact that puts it in a good place in the international context.

Spain is one of the largest contributors to HyMeX activities and also a beneficiary of the scientific results derived from them. The east coast of the Iberian Peninsula and the Balearic Islands are well located and have a wide variety of interesting watersheds. Many of the subjects addressed by the program are, in fact, the research lines of the Spanish groups, and the observations currently done by the different meteorological services and hydrographic confederations are very useful for the project. Recently, about 25 groups of Spanish meteorological services, universities and research institutes have explicitly shown their commitment to the program and are coordinated in order to promote concerted actions of a scientific nature. HyMeX.es (http://hymex.uib.es) establishes a framework that facilitates the exchange and transfer of knowledge and execution plans between groups and provides a single organized conversational partner.

Regarding the SOP, with all the extraordinary deployment of resources and the extraordinary securing of observation, it is expected to achieve very detailed descriptions of a variety of weather situations of interest, especially with regard to heavy rainfall in all areas of the northwestern Mediterranean, particularly those that affect Spain, for a better understanding of these situations. These detailed descriptions will be of great interest to validate mesoscale forecasting models under development. The mesoscale models validated in specific cases will be used for diagnostic studies of the situations of interest. The campaign is yet another op-

Table 2. Planes overflying Spanish airspace (areas of the Balearic Islands, Catalonia and Valencian Country).

Plane	Adscription	Flight characteristics	Observations
ATR42	SAFIRE (Service des Avions Français Instrumentés pour la Recherche en Environnement), France	4 hours of autonomy 100 m s^{-1} cruise velocity 5 km cruising altitude	P, T, U, wind Lidar Leandre (PBL, WV) Turbulent flows
Falcon F20	SAFIRE, France	3 hr 30 m of autonomy 200 m s^{-1} cruise velocity 10 km cruising altitude	P, T, U, wind Radar clouds RASTA Cloud microphysics Dropsondes

portunity to make impact studies in predicting extraordinary observations, such as radiosoundings, in order to advance in the optimization of observation resources, especially in high impact situations.

6 Special Observation Period 1

The first Special Program (SOP-1) observation campaign started in the autumn of 2012. The focus is placed on the Western Mediterranean and the intense rainfall that is characteristic of the region. It is expected to get a sample of about 13 days with "heavy" rain (more than 100 mm day^{-1}) and about 31 days with "significant" rain (more than 60 mm day^{-1}).

The means deployed include instrumented research aircraft (Tables 1 and 2) to conduct monitoring and observation missions of the precursor conditions of flash flooding episodes in southern France and the Iberian Peninsula Mediterranean facade, as well as *in situ* research missions on the convective systems already formed. Three of the foreseen flight plans that take place in Catalonia, Valencian Country and the Balearic Islands can be highlighted. Free balloons, at a constant height, are also used to investigate the feeding current of the convective systems. The releasing base is on the Balearic Islands, close to Maó (Minorca), which may be the source or place of passage of feeding currents of convective systems in France, Catalonia, Corsica, Liguria and Tuscany.

The campaign plans include the deployment of mobile radar with fast sweeping capacity. The involvement of institutions such as Météo France, the ERSL of the Ecole Polytechnique Fédérale de Lausanne (Switzerland), NOAA/National Severe Storms Laboratory (USA) and the University of Delft (Netherlands), providing mobile radar, proves the interest of the international scientific community in the campaign. The data collected will allow an analysis of the evolution of the fine structure of precipitating systems. The results should allow us to make more accurate predictions by improving their representation in models.

The campaign is complemented by innovative measures in the three-dimensional field of lightning, the size and energy distribution of hydrometeors or the measurement of heat flows with latest generation instruments such as scintillation counters. We should also mention the role of the "opportunity ships", which take direct measurements and launch radioprobes according to their position and the scientific interests of the campaign. A water vapor and aerosols lidar has been installed on Minorca, near Ciutadella. In addition to the atmospheric observations, some maritime measuring instruments have joined the campaign, such as gliders from the SOCIB, the operational oceanography center based in Majorca.

The operating radiosounding networks with DT (data targeting) philosophy are also used; this consists of making extraordinary soundings, out of standard hours at stations located in areas particularly sensitive to the prediction, based on the weather situation (Jansà et al., 2011). As in the DTS campaign of MEDEX, EUMETNET/EUCOS, the monitoring program of the European network of meteorological services finances and provides technical support for this part of the HyMex SOP-1 campaign. The application of the DT philosophy is done using a DTS (Data Targeting System) tool, jointly developed by the ECMWF and the UK Met Office. Fifty weather stations were selected within the DTS. In Spain, five stations of the AEMET network (A Coruña, Madrid, Murcia, Majorca and Tenerife) and a station of the Meteorological Service of Catalonia (Barcelona) have been included. Besides all this, the regular data from networks operating in different countries are used for SOP-1, including data that are not usually disseminated internationally, both to decide which additional observations are needed, as well as to improve the meteorological models. Original data from the radars operating in Catalonia and from the electric shocks network are also sent. The complete list of means is given in Table 1.

As for the air means, two planes were deployed in the area (Table 2). ATR42 flights are intended to document the feeding flow of convective system, especially in the formation phase, but also once they are formed. The climate knowledge of the feeding areas was useful to establish the flight pattern models that were coordinated between Spain and France, in our case, and between France and Italy, in the case of flights within Italian airspace. The flights of the sec-

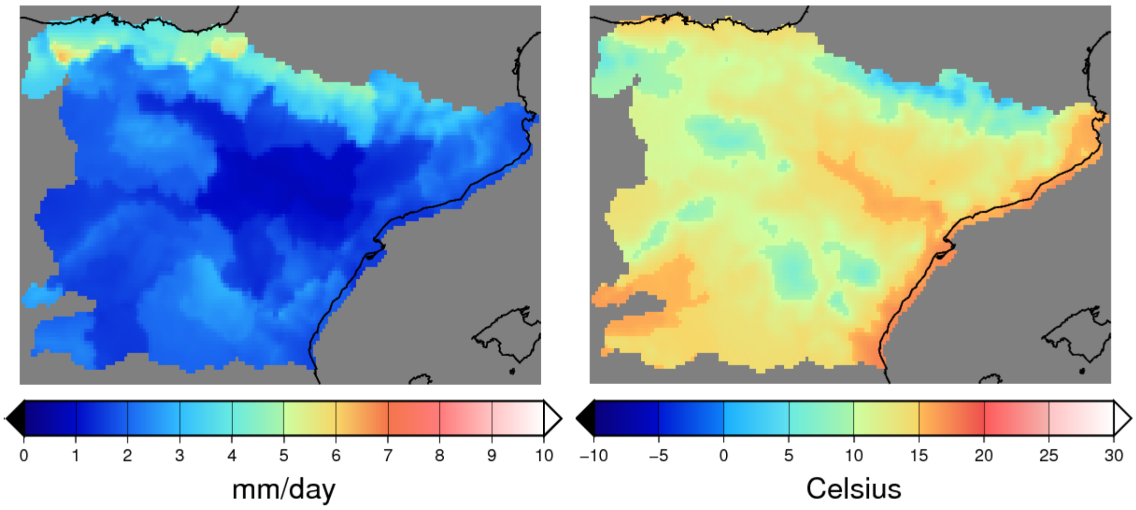

Figure 3. Average precipitation (left) and temperature (right) for the hydrological year 2009/2010 in the Northeast of the Iberian Peninsula reproduced by the SAFRAN atmospheric analysis system.

ond aircraft, the F20, are intended to document *in situ* the convective systems formed and their environment.

All these means are coordinated from the Operations Centre (HOC) based at Montpellier, which will be the focal point of other secondary centers located in Palma, Corsica and Toulouse. The center will be continuously in operation, with Meteo France predictors which have, in addition to routine operational forecasts, high-resolution experimental predictions. Based on the diagnosis of the situation and the available predictions, HOC is responsible for issuing early warnings and alerts to the community, and making decisions on the activation of the so-called Intensive Observation Periods (IOPs). During these periods all instruments must be activated in order to achieve a comprehensive monitoring of the status of scientific interest identified. Flight operations are also coordinated from this center. The Secondary Center of Palma, in daily contact with the HOC, pays special attention to the meteorological problems that affect or may affect Catalonia, Valencian Country and the Balearic Islands to advise the HOC on prediction and to give recommendations regarding the declaration of IOPs, warning and early warning and on the definition and implementation of some operations, especially aeronautical operations in Spanish airspace or nearby. The Secondary Center is installed at the headquarters of the AEMET Delegation in the Balearic Islands, but it is open to interested researchers or institutions.

The autumn 2012 campaign is a great opportunity that will place all data collected during the campaign through the HyMeX Database at the service of research groups. This way, the Hymex Database will become the cornerstone in atmospheric research in the Mediterranean region during the next decade.

7 Example of the water balance study in the Ebro Basin

There are several scientific projects taking place in Spain as part of HyMeX (see Appendix). These projects include a variety of issues, such as climate simulation, teleconnections related to the Mediterranean, decadal prediction, climate downscaling, data assimilation, the improvement of meteorological observation with remote instruments, the prediction of extreme events, including floods, droughts and their social and economic impacts, the hydrology of the Mediterranean basins, the influence of vegetation and its changes, the simulation of the dynamics of the Mediterranean Sea, dense water formation, improvement of the ocean observation, the Gibraltar flow, etc.

Is presented below, as an example, an ongoing project which began as part of the HyMex orbit.

The Ebro Basin is the second largest river basin in the western Mediterranean and plays a fundamental role in the management of water resources in the Iberian Peninsula. Its features are typically Mediterranean: (1) it is strongly heterogeneous, there is a large spatial and temporal variability of precipitation, evapotranspiration and soil moisture, (2) it is strongly influenced by humans (López-Moreno et al., 2011), (3) it might be adversely affected by climate change (Altava-Ortiz et al., 2011; Quiroga et al., 2011), (4) its contributions of water and nutrients to the Mediterranean are relevant for many coastal and oceanographic processes (Ludwig et al., 2010), and (5) it suffers intense precipitation events in its eastern part (Llasat et al., 2005).

Currently, the Ebro Observatory (URL - CSIC), in collaboration with AEMET, Météo-France and the University of Barcelona, is working on the implementation of a distributed hydrological model that should cover the Ebro basin and all Catalonia (Quintana-Seguí et al., 2011b). The project has several purposes. Firstly, by implementing a system of meteorological analysis (Quintana-Seguí et al., 2008; Figure 3) and a land surface model (Noilhan and Mahfouf, 1996), we want to study the water balance in the basin at a resolution of 5 km. This should allow a better understanding of the balance terms and the role of soil moisture, a variable that is critical to the initialization of hydrological and meteorological models. In addition, we are working on methods of statistical downscaling (Turco et al., 2011), which should allow the forcing of the surface model with high quality future scenarios in order to study the future evolution of the water balance of the basin in the context of climate change. This will be very useful for the future study of water resources in the basin, but also to better understand the future evolution of the hydrometeorological extremes affecting the area (Quintana-Seguí et al., 2011a).

8 Conclusions

HyMeX is a very ambitious program that aims to address the Mediterranean hydrological cycle from all the points of view and scales that are needed to understand its operational details. The program should be able to improve the quantity and quality of the available data, thus improving the modeling tools needed to understand the processes involved. The scientific results of HyMeX should improve our ability to predict the most important hydrometeorological hazards in the Mediterranean, including heavy rainfall and subsequent floods. This improvement in the knowledge of the coupled system will improve our understanding of the Mediterranean climate system and the production of more reliable and stronger climate scenarios. Spain is a key to the program, due to its geographical location and the scientific interests of the Spanish researchers. The research groups and weather services in Spain will be able to provide a wealth of data and knowledge to the project and, at the same time, will receive the benefits. The linking to HyMeX.es, the participation in the Annual International Workshops and the involvement in research activities planned within the HyMeX program, such as the SOP I in the autumn of 2012, are an opportunity to continue the internationalization of the Spanish research groups and to influence the international research agenda on scientific issues that have important consequences for our society.

HyMeX has become the integral study framework of international reference for the water cycle in the Mediterranean. The research teams in Spain must not miss the opportunity to become a part of them and actively participate in this program to grow and vindicate our work nationally and internationally. This is why HyMeX is open to the integration of new groups and perspectives concerning its activities.

Appendix A Specific objectives of each of the participant groups at HyMeX.es

- *Climate Forecasting Unit (CFU). Catalan Institute of Climate Sciences (IC3)*: Decadal climate prediction. Research into the interannual variability of rainfall and temperature.
- *Group of Physical Oceanography, Dept. of Ecology and Marine Resources IMEDEA (Universitat de les Illes Balears - CSIC)*: Characterization and understanding of the hydrological cycle in the Mediterranean from a better knowledge of the variability of the sea level. Use of the observations of the sea level for the validation of circulation models. Mass water balance of the Mediterranean.
- *Meteorology Group. Department of Physics. Universitat de les Illes Balears*: Extreme weather phenomena and their processes. Characterization of MEDICANES and determination of their frequency and intensity in the 21st century. Error sources in the mechanisms of hydrometeorological prediction. Improvement of prediction through directed observation.
- *Research group on climatology, hydrology, risk and land. Department of Earth Sciences. Universitat de les Illes Balears*: Historical evolution of flood risks. Creation of a database of historical droughts and floods. Study of the economic and social impact of extreme events using GIS in Majorca. Development of post-event surveys in cases of sudden flood.
- *EOLO Group. Universidad del País Vasco*: Analysis of water vapor transport in the Ebro basin. Determination of 3D fields for wind and humidity vertical profiles by means of wind profilers.
- *Ebro Observatory (Universitat Ramon Llull - CSIC)*: Simulation of the continental hydrological cycle of the Mediterranean basin through a distributed physical model. Analysis of atmospheric variables near the surface. Impacts of climate change on the Mediterranean basins. Statistical disaggregation.
- *Water Resources Research Group. Universidad de Salamanca*: Analysis of the change in the soil use and hydrologic processes involved. Climate variability of water resources. Soil-water-plant process in environments with limited water. Remote sensing applied to hydrology.
- *TROPA Research Group. Department of Geophysics and Meteorology. Universidad Complutense de Madrid*: Study of remote influences in the Mediterranean. Study of the influence of the Mediterranean on global climate. Modes of atmospheric interannual variability in the Mediterranean. Natural decadal modulation. Influence of global warming.
- *MOMAC Group. Universidad de Castilla-La Mancha*: Assessment of the impact of pairing in the Mediterranean water balance modeling and analysis of the risk of developing tropical cyclones in the Mediterranean

during the 21st century. Improvement of the understanding of climate change in the Mediterranean region through simulating situations. Analysis of the exchanges between the Black Sea - Aegean Sea and their effects on the Mediterranean. Analysis of the influence of river runoff on the water balance of the Mediterranean.

- *Spanish Meteorological Agency (AEMET)*: Ocean-atmosphere modeling including factors of the hydrological cycle. Evaluation and simulation of the conditions of the continental hydrological cycle. Climate variability observed and projected and century trends. Better understanding and prediction of heavy rainfall. Better understanding and prediction of strong winds, cyclones and cyclogenesis in the Mediterranean.
- *Meteorological Service of Catalonia (SMC)*: Data assimilation in numerical weather prediction models (NWP). Improvement of the quantitative estimation of rainfall from radar data. Nowcasting. Improvement of the monitoring of weather situations by combining data from multiple remote sensors. Analysis of extreme weather phenomena. Climate projections for the twenty-first century using the method of scale dynamic disaggregation.
- *Institute of Earth Sciences Jaume Almera*: Dynamics of vegetation at a regional and continental scale. Analysis of the teleconnections of sea surface temperature, the continental indicators of vegetation and climate change indexes in the Mediterranean and Africa.
- *GAMA Group. Department of Astronomy and Meteorology. Universitat de Barcelona*: Disaggregation of climate scenarios. Study of the effect of projected climate change on water resources. Analysis of extreme weather events, especially floods and droughts. Study of the social impact, vulnerability and adaptation to climate change and of the damage trends caused by floods and droughts.
- *Sea Sciences Institute/Marine Technology Unit. Mediterranean Centre of Marine and Environmental Research. CSIC and Meteoestartit*: Study of the dense water formation processes. Study of the evolution of the temperature of the upper layer of the sea and the air-ocean exchange. Study of the evolution of temperature and salinity in the ocean depths. Improvement of the sea surface salinity data collection from the SMOS satellite observations. Delivery of reticular maps of soil moisture and ocean salinity from SMOS measurements. Improvement of sea-atmosphere relation (heat, mass and momentum) in the oceanic models using data assimilation methods.
- *Laser, Molecular Spectroscopy and Quantum Chemistry Group. Department of Physical Chemistry. Universidad de Murcia*: Determination of seasonal and annual variations of atmospheric humidity in Murcia. Evaluation of the effect of Saharan dust on air humidity and rainfall.
- *Environmental Physics Laboratory (Ephyslab). Universidade de Vigo. Unit Partnered with the Pyrenean Institute of Ecology (CSIC)*: Humidity transportation from Lagrangian approaches. Diagnosis and physical analysis of extreme weather events. Diagnosis and physical mechanisms of drought.
- *Dynamics and Climate Impact Unit (CDIU). Catalan Institute of Climate Sciences (IC3)*: Understanding the impact of the Mediterranean SST on regional atmospheric circulation. Improvement of the seasonal forecasting skills in the Euro-Mediterranean region. Development of a reliable metasystem of seasonal prediction of the climate in the Mediterranean region.
- *Research Group on Water, Land and Sustainability. Universitat Autònoma de Barcelona*: Study of social and land vulnerability to floods and droughts. Development of vulnerability maps that integrate physical and social information. Estimation of absolute and relative economic costs of floods and droughts. Development of water consumption patterns for different types of urban and touristic settlements.
- *Group of Physical Oceanography of Malaga (GOFIMA). Universidad de Málaga*: Registration of the variability of the Mediterranean outflow and the properties of water near the seafloor in a wide range of time scales, from tide seasons to interannual. Improvement of the outflow estimates. Tracking of the propagation of signals occurring in the Mediterranean at a basin scale towards the open sea. The formation of deep water in the western Mediterranean would be of special interest as an index of climate conditions in the western basin.

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