10.8 HYMEX, AN EXPERIMENTAL PROGRAM DEDICATED TO THE HYDROLOGICAL CYCLE IN THE MEDITERRANEAN

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1 SCIENTIFIC MOTIVATION

The Mediterranean basin has quite a unique character that results both from physiographic conditions and historical and societal developments. The region features a nearly enclosed sea surrounded by very urbanized littorals and mountains from which numerous rivers originate (Fig. 1). This results in a lot of interactions and feedbacks between ocean-atmosphere-land processes that play a predominant role on climate and on high-impact weather. The Mediterranean area concentrates indeed the major natural risks related to water cycle which include heavy precipitation and flash-flooding during the fall season, severe cyclogeneses associated with strong winds and large swell during winter, and heat waves and droughts accompanied by forest fires during summer. The capability to predict such high-impact events remains weak for many reasons, including the limited availability of experimental data and the consequent limited understanding of the underlying fine scale and large scale physical processes and their non-linear interactions.

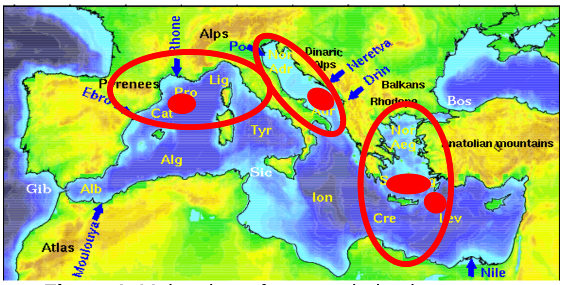

Figure 1. Major sites of strong winds, dense water formation over the Mediterranean basin (red ellipses).

Water resource is a critical issue for a large part of the Mediterranean basin. Freshwater is rare and unevenly distributed in time and space with few short duration heavy precipitation and long drought periods. Moreover, this happens in a situation of increasing water demands and climate change. Mediterranean regions have been indeed identified as one of the two main "hot-spots" of the predicted climate change, confirming that climate is especially responsive to global change in Mediterranean (Giorgi, 2006). A large decrease in mean annual precipitation and increase in precipitation variability during the dry (warm) season are expected as well as a significant generalized warming. There are still however large uncertainties on the future evolution of the Mediterranean climate. Progress is needed in the monitoring and modelling of the Mediterranean coupled climate system (atmosphere-land-ocean) in order to better quantify the on-going changes and to better predict their future evolution which should help policy makers apply mitigation and adaptation strategies.

These societal and science issues motivate the HyMeX (HYdrological cycle in the Mediterranean Experiment, http://www.hymex.org/) program which is an experimental program aiming at a better quantification and understanding of the water cycle in the Mediterranean - with emphases on intense events.

2 HYMEX SCIENCE OBJECTIVES

HyMeX is an international project which aims at

- improving our understanding of the water cycle, with emphases on extreme events by means of monitoring and modelling the Mediterranean coupled system (atmosphere-land-ocean), its variability (from the event scale, to the seasonal and interannual scales) and characteristics over one decade in the context of global change,
- evaluating societal and economical vulnerability and adaptation capacity to extreme meteorological and climate events.

In particular, HyMeX aims at addressing key issues related to (1) the water budget of the Mediterranean basin, (2) the continental hydrological cycle and related water resources, (3) heavy precipitation and flash-flooding and (4) intense air-sea exchanges produced by severe regional winds and cyclogeneses. HyMeX aims also at monitoring vulnerability factors and adaptation strategies developed by different Mediterranean societies to accommodate the impacts of climate change and intense events. A schematic of the main scientific topics of the HyMeX project is shown in Fig. 2 and a comprehensive description of the HyMeX underlying science is provided in the project white-book (Béranger et al., 2008; see http://www.hymex.org).

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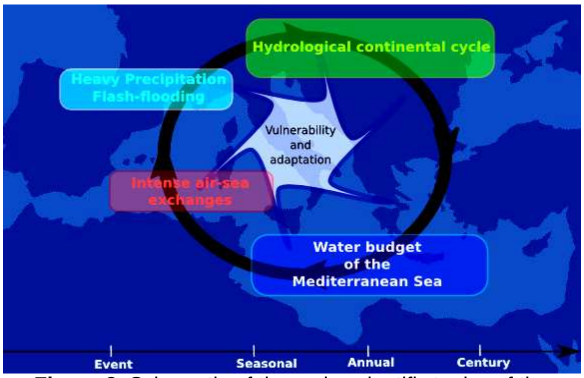

Figure 2. Schematic of the main scientific topics of the HyMeX project.

2.1 The water budget of the Mediterranean basin

The Mediterranean sea is characterized by a negative water budget (excess evaporation over freshwater input) balanced by a two-layer exchange at the Strait of Gibraltar composed of a warm and fresh upper water inflow from the Atlantic superimposed to a cooler and saltier Mediterranean outflow. Light and fresh Atlantic water is transformed into denser waters through interactions with the atmosphere that renew the Mediterranean waters at intermediate and deep levels, and generate the thermohaline circulation. Although the scheme of this thermohaline circulation is reasonably well drawn, little is known about its variability at seasonal and inter-annual scales. The feedbacks of the Mediterranean Sea basin on the atmosphere through the terms of the water budget need also to be further investigated. In addition, the budget of the Mediterranean Sea has to be examined in the context of the global warming (e.g. Somot et al., 2007), and in particular by highlighting the impact of an increase of the ocean heat thermal content on high-impact weather frequency and intensity.

2.2 The continental hydrological cycle and related water resources

The rainfall climatology of the Mediterranean region is characterized by dry summers frequently associated with very long drought periods, followed by fall and winter precipitation that are mostly very intense. This results in high daily/seasonal variability in aquifer recharge, river discharge, soil water content and vegetation characteristics, for which the interaction with the atmosphere is not well known. This includes for example the impact of the large extension forest fires associated with drought during summer on the evapotranspiration component of the hydrological cycle. The role of the surface states (land use/land cover) and of the soils on the modulation of the rainfall needs also to be better understood (Anquetin et al., 2006). Hydrological and hydrogeological transfer functions are also characteristic of the Mediterranean basin, notably because of the specificities of the peri-mediterranean karstic and sedimentary aquifers. Progress in their understanding is of primary importance for the development of integrated management of the hydrosystems, and its adaptation to anthropogenic pressure and the climate change.

2.3 Heavy precipitation and flash-flooding

During the fall season, the Mediterranean region is prone to heavy precipitation and devastating flash-flooding and floods. Daily precipitation above 200 mm are not rare during this season, reaching in some cases values as exceptional as 700 mm recorded in September 2002 during the Gard (France) catastrophe. Large amounts of precipitation can accumulate over several day-long periods when frontal disturbances are slowed down and strengthened by the orography (e.g. Massif Central and the Alps), but also, huge rainfall totals can be recorded in less than a day when a mesoscale convective system stays over the same area for several hours. Whereas large scale environment propitious to heavy precipitation is relatively well known (e.g. Nuissier et al., 2008), progress has to be made on the understanding of the mechanisms that govern the precise location of the anchoring region of the system as well as of those that produce in some cases uncommon amount of precipitation. The contrasted topography, the complexity of the continental surfaces in terms of geology and land use, the difficulty to characterize the initial moisture state of the watersheds make the hydrological impact of such extreme rainfall events very difficult to assess and predict.

2.4 Intense air-sea exchanges

The Mediterranean Sea is characterized by several key-spots of intense air-sea exchanges associated with very strong winds, which are caused by the orographic response to the large scale forcing (e.g. Mistral, Bora, Sirocco, Tramontana; e.g. Salameh et al., 2009), deep cyclogenesis (e.g. Genoa cyclogenesis; e.g. Trigo et al., 1999; Campins et al., 2006) and high/low pressure patterns. These successive intense air-sea exchange events and the associated sea surface cooling affect considerably the heat and water budget of the Mediterranean Sea with formation of dense water and deep ocean convection during winter and early spring (Fig. 1). Ecosystems functioning are strongly related to this complex dynamics which need to be better understood (Johannessen et al., 2006). Hydrological and dynamical characteristics as well as inter-annual variability of the dense water and deep ocean convection formation have thus to be better documented in order to stress the respective roles of the atmospheric forcing and oceanic processes. How much these modifications of the ocean mixed layer in their turn influence the atmospheric boundary layer is not also well known.

2.5 Vulnerability factors and adaptation strategy

The Mediterranean region is characterized by an increasing demography, leading to urban sprawl especially on coastal areas. In a context of climate change, this population is confronted with challenging environmental changes, such as short-time extreme events (heavy precipitation, flash-flood, heat wave, etc) and long-term modifications (change in access to water resources, drought,…) (e.g. Iglesias and Moneo, 2005). HyMeX aims at monitoring vulnerability factors and adaptation strategies developed by different Mediterranean societies to accommodate the impacts of climate change and intense events.

3 HIGHLIGHT ON MESOSCALE PROCESSES

The complex topography of the Mediterranean basin plays a crucial role in steering air flow and the Mediterranean Sea acts as a moisture and heat reservoir, so that energetic mesoscale features are present in the atmospheric circulation which can evolve to high-impact weather systems. The contribution of the coupled processes to the life-cycle of these extreme events is a central aspect of HyMeX. Indeed, there is a crucial need to validate sensitivity numerical experiments that have for instance shown the effect of strong offshore windstorms as well as onshore low-level jets that frequently accompanies heavy rainfall events on the thermal exchanges that occur between the ocean mixed layer and the atmospheric boundary layer (Fig. 3) (Lebeaupin Brossier et al., 2008; Lebeaupin

Brossier and Drobinski, 2009) and on the continental hydrological response (Manus et al., 2009).

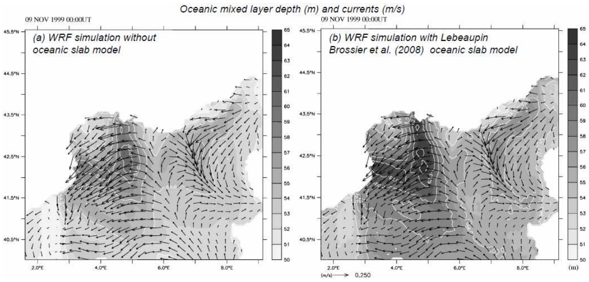

Figure 3: Oceanic mixed layer depth and current in the Gulf of Lions during the 9 Nov. 1999 mistral event as predicted by a WRF simulation without oceanic slab model (a) and with Lebeaupin Brossier et al. (2008) slab model. From Lebeaupin Brossier and Drobinski (2009).

A good representation of the mesoscale processes involved in high impact weather events is also essential to investigate the contribution of these events to the long-term water cycle over the sea and over land, especially in the context of global change. Their simulation is mandatory in regional climate modelling (e.g. Salameh et al., 2009; Hermann and Somot, 2008; Lionello and Giorgi, 2007; Lionello et al., 2007).

4 HYMEX OBSERVATION STRATEGY

The general observation strategy is based on a three-level nested observation scheme (Fig. 4):

4.1. A Long-term Observation Period (LOP)

The LOP will last about 10 years to gather and provide additional observations of the whole coupled system in order to analyze the seasonal-to-interannual variability of the water cycle and to estimate the water budget. It is proposed that the LOP consists in enhancing the current operational observing systems and existing long-term observatories in hydrology, oceanography and meteorology, not excluding the setup of new networks. There is a general agreement that the LOP will have to cover the whole Mediterranean basin, developing and maintaining the acquisition of the long-term time series required to study its seasonal and interannual variability.

4.2. Enhanced Observation Periods (EOP)

The EOP will be set-up for both budget and process studies. EOP is envisaged lasting for at least 4 years, embracing the SOP periods. However EOP may cover only part of the year, *i.e.* activities may be restricted for some aspects to specific periods (e.g. autumns for heavy precipitation, extending to winter for severe cyclogenesis and strong winds). EOP is mainly based on enhancement of existing research observatories and operational observation networks.

4.3. Special observation periods (SOP)

The SOP will last several months and will aim at providing detailed and specific observations to study key processes of the water cycle in specific Mediterranean regions. In addition to the EOP observation framework, dedicated ground-based, shipborne, ballon-borne and airborne means will be deployed during the SOPs in key regions.

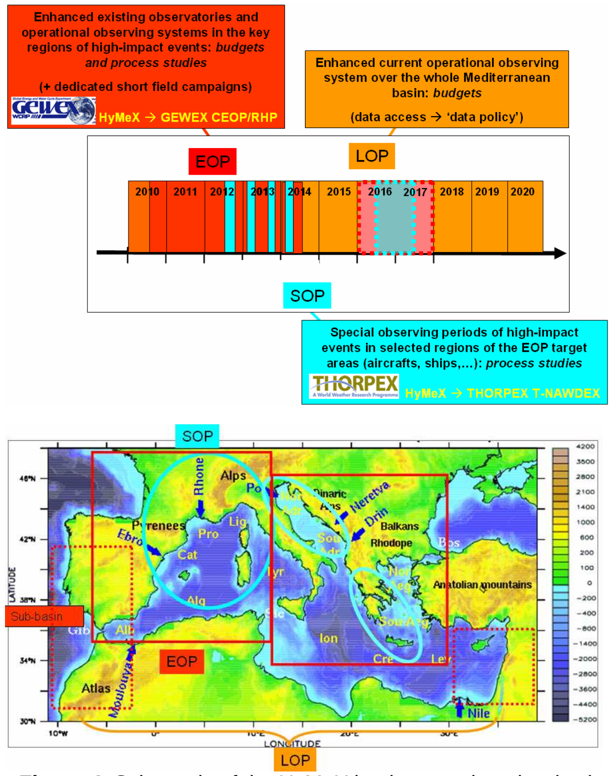

Figure 4: Schematic of the HyMeX implementation plan (top) and location of the SOP, EOP and LOP target area (bottom).

Outcomes of the multi-disciplinary research conducted in HyMeX should be beneficial to the improvement of

- observational and modelling systems of ocean, atmosphere and land,
- the prediction capabilities of high-impact events,
- the accurate simulation of the long-term water-cycle,
- the definition of adaptation measures, especially in the context of global change.

5 HYMEX MODELLING STRATEGY

The modelling strategy associated with the observation strategy includes among others:

- The development of regional coupled systems (ocean-atmosphere, atmosphere-land, ocean-land-atmosphere) to reduce uncertainties of the future regional projections. Validation of these systems includes measuring their skill in accurately simulating the Mediterranean water budget by using the HyMeX multidisciplinary databases.
- The development and improvement of high-resolution deterministic or ensemble modelling systems to improve the prediction capabilities of extreme events. Some of these systems will run in real-time during the SOPs to serve as guide for the deployment of dedicated instrumentation. Figure 5 illustrates one of these systems currently developed for real-time application during the HyMeX SOPs. The AROME-WMED model is a version of the AROME NWP system running its own 3-hourly rapid update assimilation cycle at 2.5 km over the western Mediterranean. Such high-resolution large domain allows to include the major mountain ranges of the western Mediterranean region (Atlas, Pyrenees, Alps, Massif Central, etc) and to describe their influence on the atmospheric circulation.
- The development of new process modelling, parameterization development, novel data assimilation systems for the different Earth compartments. For example, improvement of air-

sea flux parameterizations or development of data assimilation in cloud and precipitation systems are major objectives of HyMeX, and part of the observation strategy is designed to serve these objectives.

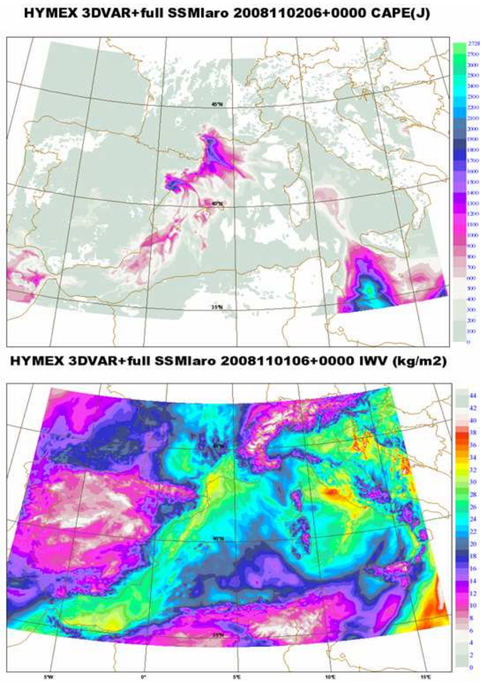

Figure 5: CAPE (J/kg, top) and Integrated Water Vapour (mm, bottom) from the the 2.5-km AROME –WMED analysis for an heavy precipitation event over Northwestern Mediterranean. (Duffiurg et al., 2009).

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