## **MED-CORDEX** initiative for Mediterranean Climate studies.

PM. Ruti, S Somot, C Dubois, S Calmanti, B Ahrens, A Alias, R Aznar, J Bartholy, S Bastin, K Béranger, J Brauch, JC Calvet, A Carillo, B Decharme, A Dell'Aquila, V Djurdjevic, P Drobinski, A Elizalde-Arellano, M Gaertner, P Galán del Sastre, C Gallardo, F Giorgi, S Gualdi, A Bellucci, A Harzallah, M Herrmann, D Jacob, S Khodayar, S Krichak, C Lebeaupin, B L'Heveder, L Li, G Liguori, P Lionello, B Onol, B Rajkovic, G Sannino, F Sevault.

#### Author Information:

P M Ruti, S Calmanti, A Carillo, A Dell'Aquila, G Sannino – ENEA-UTMEA, Energy and Environmental Modeling, Rome, Italy; S Somot, C Dubois, A Alias, JC Calvet, B Decharme and F Sevault – CNRM, Toulouse, France; B Ahrehs, J Brauch – Un of Frankfurt, Germany; R Aznar – Puerto de lo Estados, Spain; J Bartholy – Eotvos Lorand University, Hungry; S Bastin K Beranger, P Dobrinski, C Lebeaupin and B L'Heveder – IPLS, Palaiseau Cedex, France; V Djurdjevic, B Rajkovic – Institute of Meteorology, University of Belgrade, Serbia; A Elizalde-Arellano and D Jacob – MPI, Hamburg, Germany; M Gaertner, C Gallardo – UCLM, Toledo, Spain; P Galán, UPM, Spain; F Giorgi – ICTP, Trieste, Italy; S Gualdi and A Bellucci – CMCC, Bologna, Italy; A Harzallah – Institut National des Sciences et Technologies de la Mer, Salammbo, Tunisia; M Herrmann – LEGOS, Toulouse, France; S Krichak – Dept. of Geophysics and Planetary Sci., Tel Aviv University, Israel; S Khodayar – Karlsruhe Institute of Technology, Karlsruhe, Germany; L Li – IPSL, Jussieu, Paris; G Liguori – University of Alcalà, Spain; P Lionello, Università di Lecce, Italy; B Onol, Meteorological Engineering Department, Instanbul, Turkey.

Corresponding author: Paolo M Ruti, ENEA, Environment and Climate Change, Roma, Italy E-mail: <u>paolo.ruti@enea.it</u>,

Since early' 90s, many research projects analyzed and focused on downscaling of global climate simulations over the Euro-Mediterranean region. Euro-Mediterranean region is considered as particularly vulnerable to climate variability and change, in particular because of the sensitivity of its environment to changes in the water cycle. The areas surrounding the Mediterranean basin have quite a unique character that results both from their complex morphology and socio-economic conditions. The region features an enclosed sea, which is connected to the Atlantic ocean only by the Strait of Gibraltar, is surrounded by very urbanized littorals and a complex topography from which numerous rivers feed the Mediterranean sea. This results in complex interactions and feedbacks involving ocean-atmosphere-land processes, which play a prominent role in climate and, in turn, heavily impact on human activities.

Based on previous and existing initiatives and taking advantage of new fully coupled Regional Climate System Models (RCSMs), developed for the CIRCE-EU project, the Mediterranean climate research community has proposed the MED-CORDEX initiative. MED-CORDEX is a coordinated contribution to CORDEX that is supported by HyMeX and MedCLIVAR international programs. *MED-CORDEX (www.medcordex.eu) is a unique framework within CORDEX, where research community will make use of both regional atmospheric, land* 

surface, river and oceanic climate models and coupled regional climate system models for increasing the reliability of past and future regional climate information and understanding the processes that are responsible for the Mediterranean climate variability and trends. MED-CORDEX will contribute to develop a regional earth system (see Figure 1).

Since early' 90s, many research projects analyzed and focused on downscaling of global climate simulations over the Euro-Mediterranean region (RACCS, Machenauer et al., 1998; MERCURE, Machenauer et al., 1996; STARDEX, Goodess, 2003; PRUDENCE, Christensen et al., 2007; ENSEMBLES, Van der Linden P and Mitchell JFB 2009). Euro-Mediterranean is considered as particularly vulnerable to climate variability and change, specifically concerning water cycle and natural ecosystems (Rosenzweig, 2007; Plan Bleu, 2009). In the 21st century the Mediterranean is expected to be one of the most prominent and vulnerable climate change "hot spots" (Giorgi, 2006).

Several international initiatives have produced important detailed climate information, impact and adaptation studies for the Mediterranean region Mediterranean, and are effectively contributing to the regional climate research for the incoming years. MedCORDEX action is based mainly, but not only, on three main initiatives:

- an international framework called the Coordinated Regional climate Downscaling Experiment (CORDEX, Giorgi et al., 2009) aimed at improving coordination of international efforts in regional climate downscaling research (<u>http://wcrp.ipsl.jussieu.fr/RCD\_CORDEX.html</u> and http://cordex.dmi.dk/);
- HyMeX (Hydrological cycle in the Mediterranean Experiment, http://www.hymex.org/) experimental program aims at improving our understanding of the water cycle in the Mediterranean with emphasis on intense events and social-economic impacts, based on monitoring and modeling the Mediterranean atmosphere-land-ocean coupled system. Med-CORDEX will make use of HyMeX field campaign (Figure1) to improve physical scheme of regional climate components (ocean, atmosphere, river, landsurface).
- MedCLIVAR (Mediterranean CLImate Variability), a network program endorsed by CLIVAR and supported by the ESF (European Science Foundation), which addresses the description of the climate of the Mediterranean region on multiple time scales (from paleoclimate to climate projections and involving the multiple components of the climate system).

# Scientific specificity of Mediterranean downscaling.

To date most regional climate models (RCMs) have been essentially composed by an atmospheric component coupled to a land surface scheme and driven over ocean areas by prescribed sea surface temperature (SST). Although such a RCM can be sufficient for many applications, there are cases in which the fine scale feedbacks associated with air–sea interactions can substantially influence the spatial and temporal structure of regional climates. The Mediterranean basin is characterized by extremely complex coastlines and topographical features, such as the Alpine, Apennine, Pyrenees and Balkan mountain chains, the Italian and Hellenic peninsulas and middle-to-large islands (Balearic, Sicily, Sardinia, Corsica, Crete and Cyprus). From the atmospheric point of view this morphological complexity leads to the formation of intense weather phenomena. A typical example of such phenomena is the Mistral

wind, which blows through the Rhone valley into the Gulf of Lions and across to Corsica and Sardinia through the Strait of Bonifacio (Chronis et al., 2010). Another example is the Bora wind, which blows in a north-easterly direction across a series of topographical channels into the North Adriatic Sea. Several coastal locations of the Central (e.g. the Gulf of Genoa) and Eastern (e.g. Cyprus island) Mediterranean are also centers of topographically-induced intense cyclogenesis (e.g. Buzzi and Tibaldi 1978; Alpert et al. 1995). Such events dramatically influence the Mediterranean ocean circulation (Herrmann and Somot, 2008). The Mediterranean Sea is a semi-enclosed and evaporative basin in which a wide range of oceanic processes and interactions of regional interest occur. It is connected to the Atlantic Ocean by the shallow Strait of Gibraltar and is composed of two basins of similar size, i.e. the Western and the Eastern Mediterranean Seas, separated by the shallow Strait of Sicily. To the northeast it is also connected to the Black Sea through the Bosphorus channel. In the Strait of Gibraltar, at the surface, the comparatively fresher and warmer Atlantic water flows into the Mediterranean Sea to compensate for the negative mass balance inside the basin (where evaporation prevails on precipitation) and to replace cooler and saltier Mediterranean water flowing out at depth into the Atlantic. The role of the Mediterranean outflow on the Atlantic circulation has been also debated in recent papers (Rahmstorf, 1998; Artale et al., 2006). Deep Mediterranean water is produced at different locations by intense air-sea interactions: in the Gulf of Lions (western Mediterranean), the Southern Adriatic, the northeast Levantine basin and the Aegean Sea in the eastern Mediterranean (see MEDOC group, 1970; Roether et al. 1996). The basin's circulation is characterized by the presence of sub-basin gyres, intense mesoscale variability and a strong seasonal signal. Interannual variability is also observed and most of it is directly related to interannual variability of atmospheric forcings (Josey 2003; Mertens and Schott 1998; Herrmann et al., 2010; Josey et al., 2011). Such physical processes have two critical characteristics: first, they derive from strong air-sea coupling and, second, they occur at fine spatial scales. In order to explicitly resolve the twoway interactions at the atmosphere-ocean interface in the Mediterranean region, coupled ocean-atmosphere models have been developed (Somot et al., 2008, Artale et al., 2009; Dell'Aquila et al., 2011) showing their added-value compared to atmosphere-only RCM.

## Air-sea Interaction.

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 Mediterranean thermohaline circulation. Although the scheme of the thermohaline circulation is reasonably well investigated, little is known about its variability as well as its contribution to the climate of the region at inter-annual and decadal scales. The feedback of the Mediterranean Sea basin on the atmosphere through the terms of the water budget is of paramount importance in order to evaluate the impact on human activities in the context of global warming, and in particular to assess the impact of an increase of the ocean heat content on high-impact weather frequency and intensity, and on sea level rise issue.

Mediterranean air-sea interaction is characterized by several processes on different time scales. Atmospheric high frequency variability (cyclones passage, cyclogenesis, low level jets

etc) forces upper ocean response on short time scale (Herrmann and Somot, 2008). Atmospheric teleconnection or planetary waves long term variance (for instance NAO) will influence the air-sea fluxes (Josey et al., 2011) and then the upper ocean heat and water budget (2003 heat wave and relative Mediterranean warming is a good example), while long term ocean water mass formation and variability can influence the atmospheric water input (the relevance of this process has been highlighted for surrounding areas such as Sahel, see Fontaine et al., 2010).

Here we propose two examples of how present Regional Climate Models reproduce surface parameters related to air-sea interaction processes. Figure 2 shows observed and modeled sea surface salinity (SSS) inter-annual time-series. All models used in the analysis are fully coupled regional climate system models including at least the ocean, atmosphere and land-surface components. Some of the models also include the river feedbacks (MPI, ENEA, CNRM) that is of a primary importance for the SSS variability. In addition MPI RCSM explicitly resolves the Black Sea and the Bosphorus Strait. CNRM RCSM includes monthly-varying Atlantic ocean boundary conditions. Gridded data from two ECMWF reanalysis products (ERA40, 1960-2001 and ERA-Interim, 1989-2008) are used as atmosphere lateral boundary conditions for the simulations. As follows from figure 2, the initialization and the spin-up phase seem to play a relevant role in determining the evolution of the system, although intra-model spread is comparable to the two observational data sets differences. It is noteworthy that all the models capture the salinity minimum during late nineties.

The success in the simulation of the Mediterranean SST with the RCMs was among the factors for supporting the development of Regional Climate System Models over the Mediterranean basin. It appears obvious that Mediterranean SSTs and related oceanatmosphere feedbacks influence the evolution of mesoscale cyclones (Lionello et al., 2003) and Mediterranean Hurricanes (Gaertner et al., 2007). Moreover, the eastern basin SSTs significantly impact on African Monsoon variability and strength (Fontaine et al., 2009).

The RCSMs are more reliable than GCMs in simulating the SST small scale spatial features (Figure 3). Especially in winter, the RCSMs are able to better reproduce the SST pattern despite the fact that different GCM drivers have been used as boundary conditions for these regional simulations. This result implies for example that RCSMs may be used for reconstructing pre-satellite SSTs or to forecast 21<sup>st</sup> century scenario SST evolution. However, a finer ocean model resolution (from state-of-the-art eddy permitting ocean models to eddy resolving) is likely to further improve winter SSTs variability.

Applying fully coupled Regional Climate System Models in combination with stand-alone models and with assimilation systems to improve our understanding of the Mediterranean Climate and to produce reliable climate information for climate change impact studies appears timely. In the following we describe a suggested coordinated initiative which is in line with the CORDEX and HyMEX international initiatives.

## MED-CORDEX plan.

Two main phases have been envisaged within the MED-CORDEX (www.medcordex.eu) action: performing state-of-the-art coupled runs feeding the next IPCC report (AR5) by the end of 2011; developing new experiments to test the capability of climate models to reproduce observations, improve the simulation of the single components of the climate systems and

their interactions, based on the HyMeX field campaign and other new contributions (dedicated process studies).

Following CORDEX guidelines, MED-CORDEX will promote present climate (ERAInterim period 1989-2008) and scenario simulations (RCP8.5 and RCP4.5, 1950-2100) with a minimum resolution of 50 km. However, some specific actions of MED-CORDEX would be: 1. production of an ensemble of simulations with coupled Regional Climate System Models (RCSM), i.e with fully interactive Atmosphere-Land surface-River-Ocean components,

covering the whole Mediterranean basin at high resolution; 2. development of stand-alone simulations for all the components targeting very-high resolutions (10 km for the atmosphere, land-surface and river runoff and 2 km for the ocean);

3. extending the ERA-Interim CORDEX runs to present in order to use the most recent validation data available and the HyMeX field campaign results;

4 development of common strategies for ocean model initialization for decadal-to-scenario simulations;

One of the key feature of MED-CORDEX is to create a close collaboration with observational and satellite communities (Hymex, Med-CLIVAR) in order to improve model components, and to increase the link with the impact communities. The new modeling products and climatic data-base will be of paramount importance for new Mediterranean initiatives concerning Climate Services.

Figure1. a) Maximum model integration area for coupled systems. The Target Areas of the Hymex field campaign (dashed areas), include hydrometeorological sites and ocean sites, where dense water formation and ocean convection take place. The Hymex field campaign will allow model validation and physical schemes improvement. b) Sketch of the Mediterranean climate system, considering all the components: atmosphere, ocean, river and land, vegetation, chemistry, bio-chemistry and the link with the Atlantic Ocean (Gibraltar). Med-CORDEX is a unique framework where regional atmospheric, land-surface, river and oceanic modeling components will be coupled in a regional earth system.

Figure2. Surface Salinity time series averaged over the Mediterranean from regional and global models, and from analysis data. Grey shaded lines represent two observational datasets based on gridded ocean analysis of in-situ observations: the MEDATLAS-II products (Rixen et al. 2005) and the MetOffice EN3 products (Ingleby and Huddleston, 2007). The colored lines show 6 simulations performed with 5 coupled ocean-atmosphere regional climate models (CNRM, ENEA, MPI, LMD, MORCE-MED) driven by ECMWF atmosphere reanalyses (ERA40 or ERA-Interim). ENEA, MPI and CNRM models have an interactive river routine scheme coupled with the ocean component. MPI has an explicit Black Sea representation whereas it is parameterized for the other models. CNRM model has a monthly-varying Atlantic ocean lateral boundary condition for S and T. All models except for MORCE-MED performed a multi-decadal spin-up before the first year of the run.

Figure3 Taylor diagram of SST patterns over the Mediterranean from regional and global models. Capital letters represent low resolution global models, small letters are high-resolution regional models or global models with a refinement over the Mediterranean Sea (see legend). Colors correspond to the seasons: DJF (black); MAM (green); JJA (red); SON (blue). In a Taylor diagram the spatial correlation of given pattern with a selected reference is represented by the angle with the horizontal and the corresponding unbiased RMSE is represented by the distance from the point (1,0). The distance from the origin represents the standard deviation of the selected pattern normalized to the standard deviation of the reference. The reference seasonal SST are extracted from the high-resolution satellite-based climatology prepared by Marullo et al. (2007), updated to cover the period 1985-2010. Note that no direct observational input is used to drive the model SSTs inside the Mediterranean, which are then a pure result of the model climatic state.

#### References

Alpert, P, Stein U, Tsidulko M (1995) Role of sea fluxes and topography in eastern Mediterranean cyclogenesis. In: The global atmosphere and ocean system, vol 3, pp 55–79

Artale V, S Calmanti, PM Rizzoli, G Pisacane, V Rupolo, M Tsimplis 2006, The Atlantic and Mediterranean Sea as connected systems. *Developments in Earth and Environmental Sciences*, *Volume 4*, 2006, *Pages 283-323* 

Artale et al., (2009): An Atmosphere-Ocean Regional Climate Model for the Mediterranean area: Assessment of a Present Climate Simulation. Climate Dynamics DOI 10.1007/s00382-009-0691-8

Ben Rais Lasram F., Guilhaumon F., Albouy C., Somot S., Thuiller W., Mouillot, D. (2010) The Mediterranean Sea as a "cul-de-sac" for endemic fishes facing climate change, *Global Change Biology*, doi: 10.1111/j.1365-2486.2010.02224.x

Buzzi A, Tibaldi S (1978) Cyclogenesis in the lee of the Alps: a case study. Quart J Roy Meteor Soc 104:271 287

Christensen, J.H., B. Machenhauer, R.G. Jones, C. Schar, P.M. Ruti, M. Castro and G. Visconti, 1997: ``Validation of present-day regional climate simulations over Europe: LAM simulations with observed boundary conditions". Climate Dynamics, 13, pp 489-506, 10.1007/s003820050178.

Christensen, J.H., Carter, T.R., Rummukainen, M. and Amanatidis, G., Evaluating the performance and utility of regional climate models: the PRUDENCE project, Climatic Change, vol. 81, 1–6, 2007.

Chronis, T., Papadopoulos, V., and Nikolopoulos, E.: QuickSCAT observations of extreme wind events over the Mediterranean and Black Seas during 2000–2008, Int. J. Clim., doi:10.1002/joc.2213, 2010.

Dell'Aquila A, S Calmanti, PM Ruti, MV Struglia, G Pisacane, C Adriana, G Sannino, 2011Impacts of seasonal cycle fluctuations over the Euro-Mediterranean area using a Regional Earth System model. Accepted on Climate Research.

Fontaine B., P. Roucou, S. Sivarajan, Sébastien Gervois, Fabrice Chauvin, Maria Belen Rodriguez de Fonseca, Paolo Ruti, Serge Janicot, 2010: Impacts of Warm and Cold situations in the Mediterranean Basins on the West African monsoon: observed connection patterns (1979-2006) and climate simulations. Climate Dynamics, 35, 95-114..

Gaertner, M. A., D. Jacob, V. Gil, M. Domínguez, E. Padorno, E. Sánchez, and M. Castro (2007), Tropical cyclones over the Mediterranean Sea in climate change simulations, *Geophys. Res. Lett.*, 34, L14711, doi:10.1029/2007GL029977.

Giorgi, F., 2006. Climate change hot-spots. Geophys. Res. Lett., 33:L08707,

doi:10.1029/2006GL025734

Giorgi F, C Jones, GR Asrar :., 2009 Addressing climate information needs at the regional level: the CORDEX framework. WMO Bulletin 58 (3) - July 2009

Goodess, The EGGS, Issue No. 6, 10 December 2003.

Herrmann, M. and Somot, S.: Relevance of ERA40 dynamical downscaling for modeling deep convection in the Mediterranean Sea, Geophys. Res. Lett., 35, L04607, doi:10.1029/2007GL032442, 2008.

Herrmann M., Sevault F., Beuvier J., Somot S. (2010) What induced the exceptional 2005 convection event in the Northwestern Mediterranean basin ? Answers from a modeling study. *JGR-O* (in press), doi:10.1029/2010JC006162

Ingleby, B., and M. Huddleston, 2007: Quality control of ocean temperature and salinity profiles - historical and real-time data. Journal of Marine Systems, 65, 158-175 10.1016/j.jmarsys.2005.11.019

Josey S (2003) Changes in the heat and freshwater forcing of the eastern Mediterranean and their influence on deep water formation. J Geophys Research 108 (C7)

Josey, S. A., S. Somot, and M. Tsimplis (2011), Impacts of atmospheric modes of variability on Mediterranean Sea surface heat exchange, J. Geophys. Res., 116, C02032, doi:10.1029/2010JC006685.

Lionello, P. et al. (2006) Cyclones in the Mediterranean region: climatology and effects on the environment, pp. 324—372. Chapter 6 of Mediterranean Climate Variability Ed P Lionello P Malanotte-Rizzoli, R Boscolo, 2009. Elsevier, Amsterdam, ISBN 978-0-444-52170-5

Machenhauer B, Wildelband M, Botzet M, Jones RG, D´qu´M. 1996. Validation of presentday regional climate simulations over Europe: Nested LAM and variable resolution global model simulations with observed or mixed-layer ocean boundary conditions. Max-Planck Institute Report 191. Max-Planck-Institut f`r Meteorologie: Hamburg, Germany.

Machenhauer B, Windelband M, Botzet M, Christensen JH, Déqué M, Jones J, Ruti PM, Visconti G (1998) Validation and analysis of regional present-day climate and climate change simulations over Europe. MPI Report No 275, MPI, Hamburg, Germany, 87 pp

Marullo, S., B. Buongiorno Nardelli , M. Guarracino, and R. Santoleri, 2007: Observing the Mediterranean Sea from space: 21 years of Pathfinder-AVHRR sea surface temperatures (1985 to 2005): re-analysis and validation. Ocean Sci., 3, 299–310

MEDOC Group (1970) Observations of formation of deep-water in the Mediterranean Sea. Nature 227:1037-1040

Mertens C and Schott F (1998) Interannual variability of deep-water formation in the Northwestern Mediterranean. J Phys Oceanogr 28:1410-1424

Rahmstorf, S: Influence of Mediterranean Outflow on Climate. Eos, Volume 79, Number 24, June 16, 1998

Roether W, Manca B, Klein B, Bregant D, Georgopoulos D, Beitzel W, Kovacevic V, Luchetta A (1996) Recent changes in Eastern Mediterranean Deep Waters. Science 271:333-334

Rosenzweig, C., G. Casassa, D.J. Karoly, A. Imeson, C. Liu, A. Menzel, S. Rawlins, T.L. Root, B. Seguin, P. Tryjanowski, 2007: Assessment of observed changes and responses in natural and managed systems. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,

Somot S., Sevault F., Déqué M., Crépon M. (2008) 21st century climate change scenario for the Mediterranean using a coupled Atmosphere-Ocean Regional Climate Model. *Global and Planetary Change*, 63(2-3), pp. 112-126, doi:10.1016/j.gloplacha.2007.10.003

Plan Bleu, 2009: STATE OF THE ENVIRONMENT AND DEVELOPMENT IN THE MEDITERRANEAN, ISBN : 978-92-807-3061-6 Job Number: DEP/1232/GR

Van der Linden P, Mitchell JFB (eds). 2009. ENSEMBLES: Climate change and ist impacts: Summary of research and results from the ENSEMBLES project. Met Office Hadley Centre, Exter.







