Project of Strategic Interest NEXTDATA

Deliverable 2.5.2:
Report on the “scientific questions”

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Contents

1. Introduction

The major objective of WP2.5 is the collection of climate data produced — both within the NextData project and within other national and international projects — with model simulations or analyses and provided to the scientific communities and to the users (stakeholders and decision makers) communities to investigate processes and phenomena or to perform impact assessments.

Beside the technical activities related to the data collection, their production, organization and harmonization and their accessibility via data server, the partners involved in the WP were also engaged in the identification of specific scientific problems whose resolution (or, at least, improved understanding) might benefit from the availability of the data.

In particular, the partners have been involved in the definition of a set of "scientific questions", meant to illustrate, as an example, the potential of the data produced within the WP to address scientific problems particularly relevant for the region of interest of the project, i.e. high mountain areas and the Mediterranean region.

The definition of the "scientific questions" has been the results of a series of three meetings between the WP partners, where the main problems concerning the climate variability and its characterization in the regions of interest for NextData were discussed. In the course of these meetings the following set of general scientific problems have been identified:

- *Downscaling of climate simulations for the Alpine region*: the investigation of the climate variability and change and their impacts in regions with complex orography, such as, for example, the Alpine area, requires the availability of high-quality data, with resolution much higher than the one offered by the climate models commonly used to perform the simulations. Generally, this problem is tackled by performing a downscaling of the low-resolution climate simulations. The downscaling can be carried out adopting different approaches and techniques, such as, for instance, the dynamical downscaling performed with limited area, high-resolution models; the statistical downscaling, based on the empirical identification of statistical links between large-scale and small-scale parameters; the stochastic downscaling, which exploits the observed spatiotemporal structure of the fields to be downscaled to construct ensembles of stochastic fields used to reproduce realistic statistical properties at small scales, conserving the large-scale features. All these different techniques present pros and cons and it is of great scientific interest a full comprehension and characterization of their respective advantages and disadvantages in areas of complex physiography and orography, such as the Alpine region. In WP2.5, a series of studies will be conducted, where the results obtained from the dynamical, statistical and stochastic downscaling methodologies will be compared and analysed.
- *Climate variability of the Mediterranean region with particular focus on the long (multi-annual and decadal) time-scales*: the Mediterranean area has been identified as one of the most responsive areas to climate change (Giorgi, 2006). Therefore, improving the understanding of climate variability in this region, especially its low-frequency component, is very important for a better knowledge of the mechanism underpinning the climate change signal and its possible impacts in the area. To this aim, it is necessary to make available long time series of climate data suitable for the detection and characterization of the main modes of variability. High-quality observations for the Mediterranean region are relatively scarce and, above all, sparse and limited in time. These limitations, however, can, at least in part, be overcome by the use of numerical models, adequate to reproduce the small-scale features and the complex physiography of the basin, including the air-sea interaction. The low-frequency climate variability of the Mediterranean area, thus, will be explored by means of long simulations (multi-secular) performed with high-resolution, coupled atmosphere-ocean models able to reproduce the small-scale features and processes that characterize the climate of the region (e.g., Gualdi et al 2013).
- *Simulation and reproduction of the main climatic features of regions with complex orography, such as Hindu-Kush-Karakorum–Himalaya, Andes, Alps*: numerical simulations of the processes underpinning the climate variability in regions with complex orographic features are of great importance both from the scientific point of view and for the impacts they have on a number of social and economical

sectors. Therefore, an improvement of the understanding of these processes and their representation in numerical models deserves and requires special attention and additional efforts. To this aim, specifically designed and coordinated numerical experiments could be conducted in order to enhance our comprehension of the processes governing, for example, the variability of the hydrological cycle in high-mountain areas or the role of orography in determining the main features of the atmospheric circulation (wind) in the area.

The discussion of these general scientific problems conducted among the WP2.5 partners did set the framework for the definition of a set of scientific questions considered of importance and relevance for the NextData goals. Furthermore, the high-level of challenge set by the scientific problems raised requires the production of high-quality data generated with coordinated numerical experiments, specifically designed and performed within the project. The design, implementation and performance of these coordinated simulations are crosscutting activities between WP2.5 and WP2.6, that will be conducted in the following phases of the project.

In the following of this document, the main scientific questions and the numerical experiments required to address them are briefly discussed and illustrated.

2. The Scientific Questions

2.1. What are the advantages and disadvantages of the different downscaling techniques commonly used to produce high quality data for impact studies in areas with a complex orography? (CMCC, CNR-ISAC)

The detection of regional climate change is a challenging issue for researchers, since the impacts of climate change will mostly be felt at local scale. The local analysis, in particular, is a necessary tool in areas with complex topography, which strongly force and influence regional and local climate. Global climate models (GCM) are generally unsuitable to simulate the climatic features of these regions, since they are characterized by resolutions generally around or coarser than 100 km, which is too poor for impact studies in areas, where many important phenomena occur at spatial scales generally smaller than a few tens of km.

Downscaling the low-resolution climate simulations is the main and more commonly used approach to produce suitable data for both impact studies and for the investigation of the small-scale phenomena that characterize the local climate variability and climate change signals. In particular, the downscaling is applied for areas with complex orography, such as for example the Alpine region, where the GCMs often fail in reproducing also the basic features of the climate seasonal variability (e.g., Bucchignani et al. 2012).

Different techniques have been developed to downscale information from GCMs to regional scales. These can be categorized into three main approaches: "Dynamical downscaling" uses regional climate models (RCMs) to simulate finer-scale physical processes consistent with the large-scale weather evolution prescribed from a GCM (Giorgi et al., 2001); "Statistical downscaling" adopts statistical relationships between the regional climate and carefully selected large-scale parameters (von Storch et al., 1993). These relationships are empirical (i.e., calibrated from observations) and they are applied using the predictor fields from GCMs in order to construct scenarios. "Stochastic downscaling" exploits the observed spatiotemporal structure of the fields to be downscaled to construct ensembles of stochastic fields used to reproduce realistic statistical properties at small scales, conserving the large-scale features (Wilks, 1999).

There are a number of application related criteria that contribute to an appropriate choice of downscaling method in a particular context (Wilby et al., 2004). However, there are assumptions involved in all of the techniques, which are difficult to verify a priori and contribute to the uncertainty of results. Therefore, it is of great interest to explore what are the advantages and disadvantages of the different downscaling techniques, including the assessment of the associated uncertainties, by comparing different downscaling models from both approaches, applied to the Alpine area.

Several previous studies have compared dynamical and statistical downscaling methods (e.g., Kidson and Thompson, 1998; Wilby et al., 2000; Hay and Clark, 2003; Wood et al., 2004, Schmidli et al. 2007). Here, however, we will to include into the analysis also the results from the stochastic downscaling technique and we will consider much higher target resolutions (about 10 km) than those used in the previous studies. This will provide information on the respective weakness and strength of the different approaches when very-high resolution data are required for mountain ares.

The usage of a Regional Climate Model (RCM) with a horizontal resolution of about 15 km for an area like the Alpine region can be a useful tool for the description of the climate variability on local scale (from 50 to 200 km2). In particular, the investigation of the evolution of precipitation over small-size areas such as Alpine river catchments, characterized by short response times to intense precipitation events, might benefit from the use of high resolution RCM. The knowledge of possible trends for the precipitation can help the decision makers to prepare mitigation and adaptation strategies. In fact, intense rains can cause floods, but also landslides phenomena (such as mudflow). The high degree of interest devoted by the scientific and social community for these applications is due to the expected increase of natural hazards due to climate change.

2.2. *What is the low-frequency component of the climate variability that characterizes the Mediterranean area? (ENEA, CMCC)*

The characteristics of natural multi-decadal climate variability in the Mediterranean and the ability of global models to capture such regional anomalies remain to be fully explored. Focusing on the major drivers of Mediterranean climate variations at multidecadal time scale and beyond, precipitation variations are significantly affected by the variability of the North Atlantic Oscillation NAO via modifications in sea level pressure and associated circulation anomalies while the Atlantic Multidecadal Oscillation (AMO) significantly contribute to decadal climate anomalies in temperature (Mariotti and Dell'Aquila 2011). Starting from these general considerations, in these task we will analyze the capability of multi-secular global simulations (INGV coupled T31-ORCA2) in reconstructing the climate variability over the Mediterranean region, with particular attention devoted to the representation of large scale modes (i.e. NAO, AMO) that can critically affect the climate over Mediterranean region. The drivers of climate at multi-secular time scale are mostly orbital, solar, volcanic, changes in land use/land cover and some variation in greenhouse gas levels (PMIP project, Schmidt et al 2011). We will take advantage of the new multi secular PLASIM simulations performed by CNR-ISAC in order to asses which PMIP forcing can better reproduce the variability of Mediterranean region. The main goal of this task is a feasibility study for forthcoming multi-secular regional simulations over Mediterranean region, taking advantage of pre-existing global simulations and of a new global EC-EARTH simulation planned by CNR-ISAC. In particular the issues of reliability of Boundary Conditions (BC) outside the Mediterranean region and Initial Conditions (IC) will be addressed.

This kind of regional high resolution simulation with all relevant natural driving factors of Mediterranean climate can help us in analyzing the spatial coherence of Mediterranean climate change signal against natural variability (Paeth and Mannig 2012).

2.3. *What is the role of model spatial resolution in simulating the effects of the Andes on the regional atmospheric circulation and represent its interaction with the large-scale variability (e.g., ENSO)?* (ENEA, CMCC)

Southern Hemisphere (SH) is generally characterized by absence of mountain chains, the only relevant exception are the Andes that, extending north of the equator to around 50S, can highly impact the SH climate variability at different temporal and spatial scales.

El Nino-Southern Oscillation (ENSO) and other planetary scale phenomena (meridional shift of ITCZ, trade winds, …) impact the Andean climate differently along its length. The presence of a such steep orography along the Pacific coasts can modulate the remote effect of ENSO and produce, inducing topographic convection, contrasting climate conditions along the two flanks (arid conditions on the western flank of chain and moist conditions to the east in the subtropics; the pattern is reversed in midlatitudes) (Garreaud 2009) .

In this task we will analyze the numerical climate simulations from CMIP5 initiative (global simulations) and possibly from CORDEX experiment (regional runs) in order to assess the systematic error experienced over the Andean region by climate models, their capability in reproducing the ocean-atmosphere coupled modes of variability, and the role of spatial resolution in reproducing the interaction of the zonal mean flow with orography in climate simulations. The analysis will be carried out at different spatial and temporal scales:

1) Long term mean and interannual variability: Representation of circulation patterns and major precipitation features over the Andean region in available climate simulations.

2) Large scale variability : The presence of Andes can modulate the propagation of wave-like disturbances over southern oceans (e.g. Pacific South American patterns, Renwick and Revell 1999, Robertson and Mechoso 2003). At the same time the mountain chain can impact to the remote effects of ENSO over Atlantic via interaction of atmospheric flow with orography.

3) Baroclinic scale: The presence of Andes cordillera can lock and distort the structure and the main characteristic of baroclinic systems (e.g., Berbery and Vera, 1996; Seluchi et al., 1998, 2006; Dell'Aquila et al 2007).

4) Mesoscale systems: The deep orographic convection and local effects such as windstorms can be evaluated and analyzed in very high resolution simulations able to resolve mesoscale phenomena, even if a lack of in-situ observations make a comparison and validation not so straightforward.

The final objective of this task is the ideal design for high resolution forthcoming regional simulations able to correctly reproduce interaction of flow with complex orography.

2.4. *What is the role of low-frequency natural variability in modulating the long-term trend observed and projected for the hydrologic cycle in the Alpine region? (CMCC)*

The Alpine region is characterized by a potentially vigorous hydrological cycle driven by intense precipitation amount of orographic nature. However, low winter temperatures, even at low and medium elevations, are responsible for the large proportion of solid to liquid precipitation, which delays the winter runoff and river discharge till spring, when the snow melts.

The Alps are subject to important changes in precipitation and temperature because of the increase of radiative forcings due to the changes greenhouse gases and aerosols concentrations. Snow might indeed disappear at low to medium elevations by the end of the 21th century due to the anthropogenic global warming (Beniston 2012). The related hydrological issue has been extensively studies in the context of the main regional climate models (RCMs) intercomparison experiments (PRUDENCE, ENSEMBLES, Christensen et al. 2007, Déqué et al. 2007, Zampieri et al., 2012). In fact, regional climate change information in the presence of complex topography and land-sea distribution as the Alpine region can be improved by high resolution downscaling of the General Circulation Models (GCM) data (Giorgi and Mearns, 1999). Previous results might be complemented in NextData by analyzing the more recent RCMs runs as, for instance, those of the CORDEX project and other already existing in-house runs. This study will be conducted by computing the long-term statistically significant changes in precipitation, snowfall, evapotraspiration, runoff and, where available, snow cover, soil moisture and river discharge, between the present climate simulations (1951-2000 or later) and the future scenarios run (RCP85 and RCP45, 1951-2100). The relatively long-periods (50 years with respect to the more common 30 years) are chosen here in order to isolate the effects of the changes in radiative forcings from the natural low-frequency variability acting on the decadal scale.

In fact, the climate of the Alps is also influenced by other factors such as, for instance, the North Atlantic Oscillation in winter (Beniston 2012), and the Atlantic Multidecadal Oscillation, especially on the western and southern flanks in spring and summer, respectively (Sutton and Hodson 2005). These teleconnections are responsible for the low-frequency variability of climate and are believed to be determinant for the recent rapid temperature trend observed over the Alps that cannot be explained by changes of radiative forcings alone. Therefore, the understanding of these factors might be of great importance for the adaptation policies to the short-term climate variability and changes.

We propose to conduct a preliminary analysis of the existing GCMs results, and especially the AMIP experiments with prescribed Sea Surface Temperature (SST) in order to assess the ability of the GCMs to reproduce the observed atmospheric patterns that are responsible for the major impacts on the climate variability and changes over the Alps. This study can be extended to decadal climate predictions (see Bellucci et al., 2012 for a global analysis) in order to assess the skill of the initialized model simulation and the reliability of the forecasted climate of the next decades over the Alps. The outcomes of this analysis will be used as a framework to select (or construct) the boundary conditions for the additional RCMs simulations, providing suitable data for impact studies.

Dynamical downscaling experiments will be conducted with the regional climate model developed by the Consortium for Small-scale Modeling (COSMO-CLM. Rockel et al., 2008). COSMO-CLM is a non-hydrostatic limited-area atmospheric prediction model designed for climate simulation. The COSMO-Model is based on the primitive hydro-thermodynamical equations describing compressible non-hydrostatic flow in a moist atmosphere without any scale approximations. Therefore, it is suitable for high-resolution simulations over the Alps. In fact, due to the complex orography of the region, the hydrostatic approximation (i.e. neglecting the vertical acceleration of the flow) cannot be applied.

Based on previous experience with this model (Bucchignani et al., 2011), and in order to develop a comparable ensemble of results, we will be perform simulations at resolutions of 14 and 8 km in the so called "Greater Alpine Region" covering the area included in the 2E to 20E longitudinal range and in the 40N to 52N latitudinal range.

Differently from previous experiments, lateral boundary conditions will be selected from the GCM-AMIP runs covering the period 1850 to 2005. This set of simulation will be compared with observed data and will assess the ability of the model chain to study the impact of low-frequency climate variability on the hydrology of the Alps.

The downscaling runs with the boundary conditions derived from the decadal simulations will last 20 years and be conducted for two periods. A first period, starting in 1985 and covering the last transition from the cold to the warm phase of the AMO, will be used to validate the downscaled decadal predictions with respect to the downscaled AMIP runs. The second period will start in 2005, and will provide the high-resolution climate data in order to assess the possible changes of hydrological cycle over the Alps in the near future.

2.5. How can we improve models of severe hydro-meteorological events in areas with complex topography?

Predicting weather and climate and its impacts on the environment, including hazards such as floods, droughts and landslides, continues to be one of the main challenges of the 21st century with significant societal and economic implications.

Changes in precipitation extremes, from droughts to intense precipitation events can have an enormous impact in terms of hydrogeological risk, availability of water resources, human health, food security and ecosystem conservation (IPCC AR4 report 2007). The challenge is represented by the improvement of current climate forecasting chains to include the modeling of severe hydro-meteorological events at a regional scale (Shukla et al. 2009). Simulations of future climate in different emission scenarios, currently being produced in the framework of the fifth climate model intercomparison project (CMIP5), are typically obtained using hydrostatic models and available only at quite coarse spatial resolutions which do not allow an accurate representation of intense precipitation events such as hurricanes, Mediterranean storms or precipitation over complex orography.

Over non-homogeneus terrain, several factors influence precipitation: wind speed and wind direction variability, orographic barriers, elevation, local orographic slopes, and exposure with respect to prevailing winds are all potentially significant effects. As a result, the presence of mountains modifies mesoscale precipitation patterns and rainfall intensity, especially in the case of atmospheric disturbances associated with short and intense meteorological events (Smith 2006).

Regions, where significant impacts of climate change are expected and where precipitation modeling is particularly challenging due to the formation of intense and complex meteorological structures and to rich and complex orography, are the Hindu-Kush-Karakoram – Himalaya range (HKKH), the Mediterranean and the Alps. The HKKH is a region which is exceptionally exposed to future impacts of climate change, also due to the presence of numerous glaciers which feed rivers and sustain water resources for almost a billion people (Akhtar et al. 2008, Hewitt 2005). The Mediterranean and the Alps area represents another 'hot-spot' of climate change, with rich orography and exposed to the influx of cyclonic activity from the Atlantic (Giorgi 2006, Giorgi and Lionello 2008). Historic data show recent changes in the frequency and intensity of precipitation events, with a shift towards a hotter and dryer climate characterized by episodes of increasingly intense precipitation. The assessment of similar changes in future climate scenarios is paramount to evaluate impacts on the delicate Mediterranean and Alpine ecosystems and on a region characterized by an already great exposure to hydrogeological risks.

Contribution from NextData

The NextData archive will include case studies of results from non-hydrostatic high resolution simulations in high-altitude areas, where the complex orography will impose the development of specific modelling solutions. In particular we will perform high-resolution regional dynamical downscaling of climate scenarios produced by a global climate model, using a state-of-the-art convective model.

The goal of these simulations is to characterize the precipitation climatology and potential hydrologic impacts in these areas at very high spatial resolution (up to about 4 Km, corresponding to the "cloud-

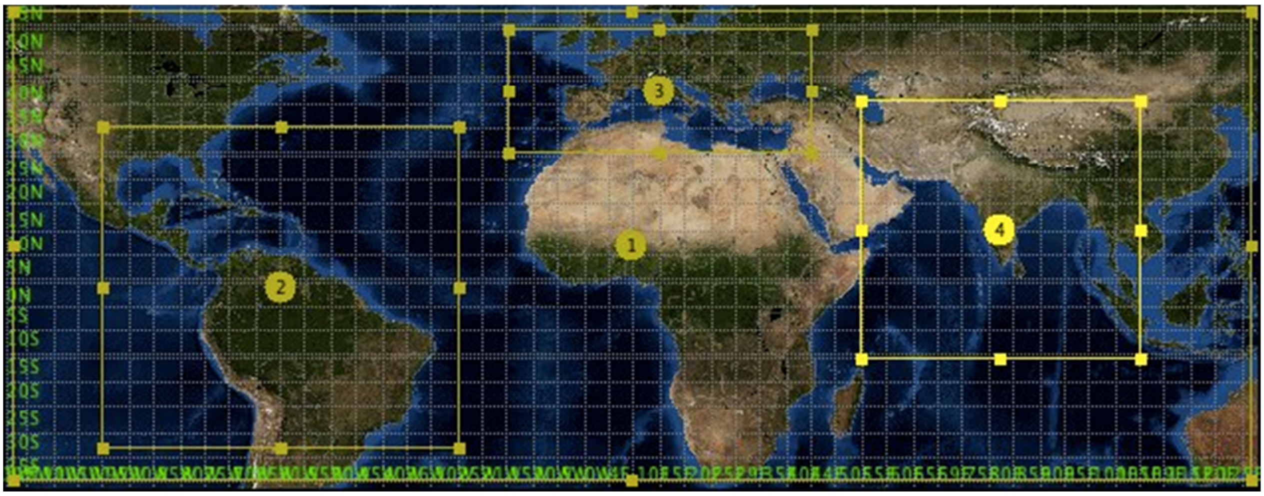

Figure 1. representation of the large scale domain over which dynamical downscaling with the WRF model is being tested. The second-level boxes represent focus areas over which further downscaling with the same model will be explored.

permitting" range, representing a leading-edge limit for climate change research), for future time-slices such as the period 2041-2050

To this end, RCP 4.5 and RCP 8.5 emission scenarios produced with the EC-Earth climate model will be downscaled using the WRF atmospheric model. Specifically, we will characterize changes in the amplitude of the probability distribution of precipitation intensities, of the length of dry periods and of the duration of precipitation events. We will assess changes in the amplitude probability distribution of precipitation intensities, of the length of dry periods and of the duration of precipitation events. The data produced will be extremely useful also for following climate impact studies in the focus areas, providing a high resolution climatology for a full set of atmospheric variables, projected for 5 years-long time-slices in the 21st century, in standard CMIP5 RCP 4.5 and RCP 8.5 scenarios.

The convection-permitting atmospheric model used to this purpose is the Weather Research and Forecasting model (WRF) with its hydrologic extensions package (WRF-Hydro), a state-of–the-art mesoscale numerical atmospheric circulation model, with a long development history for massively parallel computation applications. WRF has been widely used for hydro-meteorological research applications (e.g. Parodi and Emanuel 2009, Parodi and Tanelli 2010, Parodi, Foufoula-Georgiou and Emanuel 2011). For a comprehensive description of this model, we refer to Skamarock et al. (2005). Different microphysical schemes are available in the model. These have been found to lead to significant differences in terms of the spatial distribution of precipitation and of the vertical distribution of hydrometeors [Gilmore et al., 2004; Liu and Moncrieff , 2007]

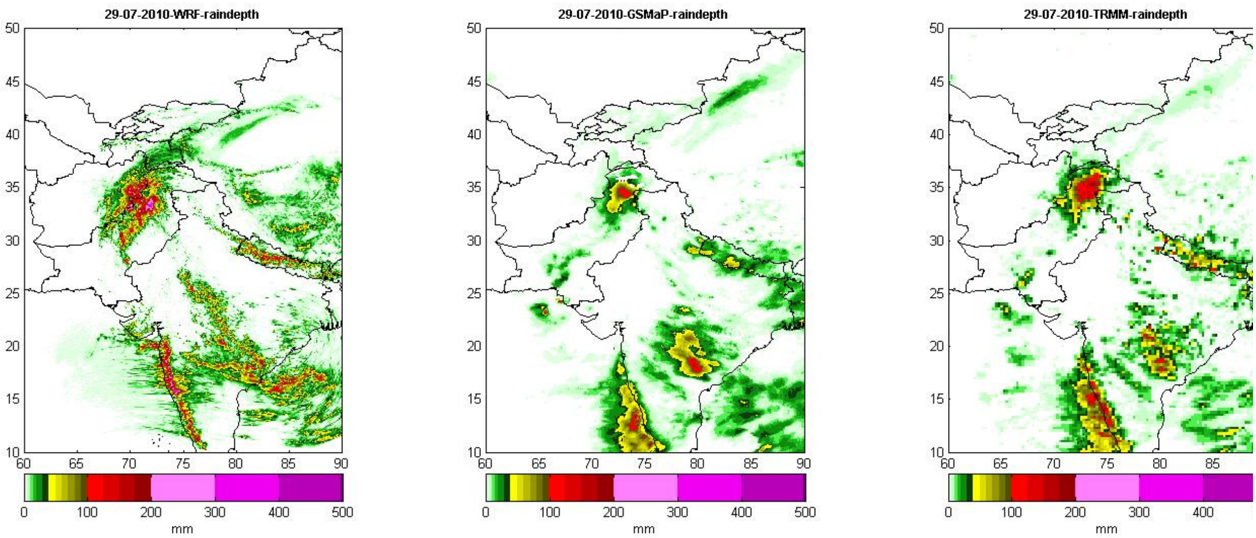

Figure 2. Example of average daily precipitation simulated with WRF, compared with GSMaP and TRMM observations, on the 29th of July 2010.

Global scale climate scenarios to be used as boundary conditions for the high-resolution convective model will be provided by already existing runs of the EC-Earth global coupled climate model. EC-Earth represents a state-of-the-art, high-resolution earth-system model, developed by a large consortium of european research institutions and researchers. The model contains advanced, robust and validated components for the atmosphere (the ECMWF IFS cycle 31r1 model), the ocean (NEMO version 2; Madec 2008), sea ice (LIM2; Fichefet and Morales Maqueda 1997) and land processes (H-Tessel; Balsamo et al. 2009). EC-Earth has been validated and applied in a series of recent publications (Hazeleger 2000 and 2011; Johnston 2011; Sterl 2011; Wouters 2011) and is participating in the current CMIP5 comparison. The historic and RCP 4.5 and RCP 8.5 scenario simulations needed as boundary conditions for this project have already been performed by CNR-ISAC and will be included in the NextData archive.

A first simulation with the WRF model is being produced for the historical period on a large domain extending from 110°W to 120°E and from -30°S to 60°N at about 22 km resolution. The climatology of this simulation will be compared with available large scale climatologies from reanalysis products and from the EC-Earth global model, allowing to verify if the application of this model over such a large domain produces a realistic climatology. The domain includes the dynamical domains of the Atlantic Stormtrack, and of the Indian Monsoon. An illustration of such a domain, with possible focus areas on which further dynamical downscaling will be performed is illustrated in figure 1.

In a following phase second-level, convection-permitting resolution nested domains will resolve the Western European and Mediterranean area and the Indian continent plus the Tibetan plateau at higher resolution (up to 3.5 Km cases will be explored). If the climatology produced by WRF over the large domain described above will prove to be realistic, it will be possible to use a two-way nested solution. In alternative, high-resolution runs will be performed with the model over the focus areas, with boundary conditions directly form EC-Earth and using domains compatible with those defined in the CORDEX project.

As a preliminary step to this study, a first case study has been performed simulating a specific, high-intensity rainfall events in the Pakistan-HKK area. In particular the simulation reproduces the atmospheric conditions which produced the 2010 Pakistan floods which began in late July, producing heavy monsoon rains in the Khyber Pakhtunkhwa, Sindh, Punjab and Balochistan regions of Pakistan and affecting the Indus River basin. Approximately one-fifth of Pakistan's total land area was underwater, with a death toll of about 2000 people. This event has been simulated with the WRF model (version 3.3.) in cloud-permitting mode (d01 14 km and d02 3.5 km): different convective closures and microphysics parameterization have been tested. A deeper understanding of the processes responsible for this event has been gained through comparison with rainfall depth observations, radiosounding data and geostationary/polar satellite images (see fig. 2 for an example). In particular the analysis of different microphysical options and convective closures has allowed to plan and implement the longer and more challenging experiments to be performed with WRF described above.

3. References

Akhtar, M., Ahmad, N., Booij, M. J. (2008). Journal of Hydrology, 355, 148–163. doi:10.1016/j.jhydrol.2008.03.015.

Balsamo G, P Viterbo, A Beljaars, B van den Hurk, M Hirschi, AK Betts and K Scipal (2008). ECMWF Tech. Memo. 563.

Bellucci, A., S. Gualdi, S. Masina, A. Storto, E. Scoccimarro, C. Cagnazzo, P. Fogli, E. Manzini, A. Navarra (2012) Decadal climate predictions with a coupled OAGCM initialized with oceanic reanalyses, Climate Dynamics, doi: 10.1007/s00382-012-1468-z.

Beniston, M. (2012) Is snow in the Alps receding or disappearing?, Wiley Interdisciplinary Reviews: Climate Change, Volume 3, Issue 4, pages 349–358, July/August 2012

Berbery, E. H. and Vera, C. S.: Characteristics of the Southern Hemisphere winter storm track with filtered and unfiltered data, J. Atmos. Sci., 53, 468–481, 1996.

Bucchignani E., A. Sanna, S. Gualdi, S. Castellari, P. Schiano (2011). Simulation of the climate of the XX century in the Alpine space, Natural Hazards, 2011, doi: 10.1007/s11069-011-9883-8.

Christensen J.H., T.R. Carter, M. Rummukainen, G. Amanatis (2007). Prediction of regional scenarios and uncertainties for defining European climate change risk and effects: the PRUDENCE project Climatic Change (2007), p. 81

Déqué M., D.P. Rowell, D. Lüthi, F. Giorgi, J.H. Christensen, B. Rockel, D. Jacob, E. Kjellström, M. de Castro, B. van den Hurk (2007). An intercomparison of regional climate simulations for Europe: assessing uncertainties in model projections, Climatic Change http://dx.doi.org/10.1007/s10584-006-9228-

Dell'Aquila, A., P. M. Ruti, S. Calmanti, and V. Lucarini (2007), Southern Hemisphere midlatitude atmospheric variability of the NCEP-NCAR and ECMWF reanalyses, J. Geophys. Res., 112, D08106, doi:10.1029/2006JD007376

Emanuel, K., (2008), Bull. Amer. Meteor. Soc., 89, ES10-ES20.

Fichefet T and MA Morales Maqueda (1997). J Geophys Res 102:12609– 12646.

Hazeleger, W. and co-authors (2010). Bull Amer Meteor Soc 91: 1357–1363.

Hazeleger W., X. Wang,, C. Severijns, S. Ştefănescu, R. Bintanja, A. Sterl, K. Wyser, T. Semmler, S. Yang, B. van den Hurk, T. van Noije, E. van der Linden, K. van der Wiel (2012). Clim. Dyn., 2012, 39, 2611-2629.

Hewitt, K., (2005). Mountain Research and Development 25, 332–340.

IPCC, (2007). The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Johnston M.S., and co-authors (2011). Climate Dynamics, 1—19.

Krol, M., Houweling, S., Bregman, B., van den Broek, M., Segers, A., van Velthoven, P., Peters, W., Dentener, F., and Bergamaschi, P (2005). Atmos. Chem. Phys., 5, 417- 432, 2005.

Liu, C. and M. W. Moncrieff (2007). Mon. Weather Rev., 135, 2854–2868, 2007.

Madec G (2008). NEMO ocean engine. Note du Pole de modélisation, Institut Pierre- Simon Laplace (IPSL), France, No 27 ISSN No 1288-1619

Garreaud RD (2009). The Andes climate and weather Adv. Geosci., 22, 3–11, 2009

Gilmore, M. S., J. M. Straka, and E. N. Rasmussen (2004). Mon. Weather Rev., 132, 1897–1916.

Giorgi and Mearns (1999). Introduction to special section: regional climate modeling revisited Journal of Geophysical Research, 104, pp. 6335–6352.

Giorgi, F., (2006). Geophysical Research Letters 33, L08707. doi:10.1029/2006GL025734.

Giorgi, F., Lionello, P., (2008). Global and Planetary Change 63 (2–3), 90–104.

Gualdi S., S. Somot, L, Li, V. Artale, M. Adani, A. Bellucci, A. Braun, S. Calmanti, A. Carillo, A. Dell'Aquila, M. Déqué, C. Dubois, A. Elizalde, A. Harzallah, D. Jacob, B. L'Hévéder, W. May, P. Oddo, P. Ruti, A. Sanna, G. Sannino, E. Scoccimarro, F. Sevault, A. Navarra (2012). Bull. Amer. Meteo. Soc., in press. DOI: 10.1175/BAMS-D-11-00136.1.

Mariotti A, Dell'Aquila A (2011). Decadal climate variability in the Mediterranean region: roles of large-scale forcings and regional processes. Clim Dyn 38:1129–1145

Paeth, H and Manning B (2012). On the added value of regional climate modeling in climate change assessment Clim Dyn DOI 10.1007/s00382-012-1517-7.

Parodi, A., and K. Emanuel, (2009), J. Atmos. Sci., 66, 3449–3463. doi: http://dx.doi.org/10.1175/2009JAS3103.1

Parodi, A. and S. Tanelli (2010), Journal of Geophysical Research-Atmospheres, 115, D00J14, 18 PP., doi:10.1029/2009JD013302

Parodi, A., E. Foufoula-Georgiu, and K. Emanuel (2011), Journal of Geophysical Research-Atmospheres, 116, D14119, 12 pp.,doi:10.1029/2010JD015124

Renwick, J. A., and M. J. Revell (1999). Blocking over the South Pacific and Rossby wave propagation, Mon. Weather Rev., 127, 2234–2247.

Robertson, A. W., and C. R. Mechoso (2003) Circulation regimes and low frequency oscillations in the South Pacific sector, Mon. Weather Rev., 131, 1566– 1576.

Rockel B, Will A, Hense A (2008). The regional climate model COSMO-CLM (CCLM). Meteorol Zeitschrift, 17(4):347–348.

Seluchi, M., Serafini, Y., and Le Treut, H. (1998). The impact of the Andes on transient atmospheric systems: A comparison between observations and GCM results, Mon. Weather Rev., 126, 895–912.

Seluchi, M., Garreaud, R., Norte, F., and Saulo, A. (2006). Influence of the Subtropical Andes on Baroclinic Disturbances: A Cold Front Case Study. Mon. Weather Rev., 134(11), 3317–3335.

Schmidli, J., C. M. Goodess, C. Frei, M. R. Haylock, Y. Hundecha, J. Ribalaygua, and T. Schmith (2007). Statistical and dynamical downscaling of precipitation: An evaluation and comparison of scenarios for the European AlpsJ. Geophys. Res., 112, D04105, doi:10.1029/2005JD007026, 2007.

Schmidt, G. A., Jungclaus, J. H., Ammann, C. M., Bard, E., Braconnot, P., Crowley, T. J., Delaygue, G., Joos, F., Krivova, N. A., Muscheler, R., Otto-Bliesner, B. L., Pongratz, J., Shindell, D. T., Solanki, S. K., Steinhilber, F., and Vieira, L. E. A. (2011). Climate forcing reconstructions for use in PMIP simulations of the last millennium (v1.0), Geosci. Model Dev., 4, 33-45, doi:10.5194/gmd-4-33-2011.

Shukla, J., R. Hagedorn, B. Hoskins, J. Kinter, J. Marotzke, M. Miller, T. N. Palmer, and J. Slingo, (2009). Bull. Amer. Meteor. Soc., 90, 175–178.

Skamarock, W. C., J. B. Klemp, J. Dudhia, D. O. Gill, D. M. Barker, W. Wang, and J. G. Powers (2005), A description of the Advanced Research WRF version 2. NCAR Tech. Note NCAR/TN-468+STR, 88 pp.

Sterl A., and co-authors (2011). Climate Dynamics, 1—19.

Wouters, B., Drijfhout, D., Hazeleger, W., Climate Dynamics, 1—19 (2011)

Sutton, R. T., and D. L. R. Hodson (2005) Atlantic Ocean forcing of North America and European summer climate. Science, 309, 115–118.

Wilks, D. S. (1999). Multisite downscaling of daily precipitation with a stochastic weather generator, Clim. Res., 11, 125– 136.

Zampieri M, F.Giorgi, P. Lionello, G. Nikulin (2012). Regional Climate change in the Northern Adriatic Phys. Chem. Earth 40-41:32-46, DOI: 10.1016/j.pce.2010.02.003.