Project of Strategic Interest NEXTDATA

WP2.5

D2.5.A – Preliminary version of the archive and access portals to global and regional simulations for NextData, with spatial resolution from about 70 to 120 km for the global simulations and between about 4 and 50 km for regional simulations, for the reference periods 1950-2005 (historical) and 2006-2050 (projections) under RCP 4.5 and RCP 8.5 emission scenarios.

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This deliverable provides a description of the preliminary version of the NextData archive and access portal to global and regional simulations made available by the contributing partners. In the following a description of the models used and simulations performed by each partner is provided.

1. **CMCC** (Contributions by: T. Lovato, S. Fiore, A. Sanna, E. Bucchignani and S. Gualdi)

1.1. Global climate simulations performed with the CMCC-CM climate model at T159 (120 km) spatial resolution (CMIP5)

1.1.1. Model description

The CMCC-CM model (Scoccimarro et al. 2011) is a coupled atmosphere–ocean general circulation model which has been implemented and developed starting from the Scale Interaction Experiment SINTEX-G (SXG) model (Gualdi et al. 2008; Bellucci et al. 2008) and from the CMCC Carbon Cycle Model (Fogli et al. 2009; Vichi et al. 2011).
In CMCC-CM, the ocean component is the global ocean model OPA 8.2 (Madec et al. 1998), in its ORCA2 global configuration. The horizontal resolution is 2°x2° with a meridional refinement near the equator, approaching a minimum 0.5° grid spacing. The model has 31 vertical levels, 10 of which lie within the upper 100 m. ORCA2 also includes the Louvain-La-Neuve (LIM) model for the dynamics and thermodynamics of sea ice (Fichefet and Morales-Maqueda 1999). Ocean physics includes a free-surface parameterization (Roullet and Madec 2000) and the Gent and McWilliams (1990) scheme for isopycnal mixing. For more details about the ocean model and its performance, readers are referred to Madec et al. (1998).
The atmospheric model component is ECHAM5 (Roeckner et al. 2003) with a T159 horizontal resolution, corresponding to a Gaussian grid of about 0.75°x 0.75°. This configuration has 31 hybrid sigma-pressure levels in the vertical and top at 10 hPa. The parameterization of convection is based on the mass flux concept (Tiedtke 1989), modified following Nordeng (1994). Moist processes are treated using a mass conserving algorithm for the transport (Lin and Rood 1996) of the different water species and potential chemical tracers. The transport is resolved on the Gaussian grid. A more detailed description of the ECHAM model performance can be found in Roeckner et al. (2006).
The communication between the atmospheric model and the ocean models is carried out with the Ocean Atmosphere Sea Ice Soil version 3 (OASIS3) coupler (Valcke 2006). Every 160 min (coupling frequency), heat, mass, and momentum fluxes are computed and provided to the ocean model by the atmospheric model. Sea surface temperature (SST) and velocities are provided to the atmospheric model by both ocean models. The global ocean model also provides sea ice cover and thickness to the atmospheric model. The relatively high coupling frequency adopted allows an improved representation of the interaction processes occurring at the air–sea interface. No flux corrections are applied to the coupled model.

1.1.2. Simulation description

The CMCC-CM climate model has been implemented to perform a wide range of the CMIP5 climate simulations and scenario projections. In particular, following the CMIP5 protocol, a simulation of the pre-industrial period, with natural only forcing, a simulation of the historical period (1850-2005), with reconstructed historical anthropogenic forcing and solar variability, and two scenarios climate change projections (2006-2100) under the representative concentration pathways (RCPs) for anthropogenic emissions RCP 4.5 and RCP 8.5 [Moss et al., 2010], have been performed.

The model characteristics and the performed experiments are summarised in Table 1.1.1

Table 1.1.1: Summary of the CMCC global model used in NextData and its main characteristics

Model	**Components and resolutions**	**CMIP5 Experiments/Forcing Scenario**	**Period**	**CMOR Archive size**
CMCC-CM	Atmosphere ECHAM5 T159 (1.125°) 31 vertical levels. Ocean OPA-ORCA8.2, 2°x2°, 30 vertical levels.	Pre-industrial	300 yrs in pre-industrial (1850) conditions	~ 2.5 TB
		Historical CMIP5	1850-2005	~ 1 TB
		RCP 4.5	2006-2100	~ 1 TB
		RCP 8.5	2006-2100	~ 1 TB

1.1.3. Data access

The data can be downloaded from the CMCC NextData THREDDS service at the following address:

http://nextdata.cmcc.it:8080/thredds/CMIP5

Available data

The following table, Table 1.1.2 summarizes the available variables and time frequencies, units and number of levels at which they are available:

Table 1.1.2: Summary of the available model variables

CMOR name	**Long name**	**Unit**	**Monthly**	**Daily**	**6hr**	**3hr**
prc	Convective precipitation	[Kg m-2 s-1]	1	1		1
pr	Total precipitation	[Kg m-2 s-1]	1	1		1
evspsbl	Evaporation	[Kg m-2 s-1]	1			
hfss	Surface sensible heat flux	[W m-2]	1	1		1
hfls	Surface latent heat flux	[W m-2]	1	1		1
rsds	Surface SW Radiation Downward	[W m-2]	1	1		1
rlds	Surface LW Radiation Downward	[W m-2]	1	1		1
rsus	Upwelling SW at SFC	[W m-2]	1	1		1
rlus	Upwelling LW at SFC	[W m-2]	1	1		1
rlut	Outgoing LW Radiation	[W m-2]	1	1		1
ps	Surface Pressure	[Pa]	1			1
psl	Mean sea level pressure	[Pa]	1	1	1	
tas	Air temperature at 2m	[K]	1	1		1
ts	Surface temperature	[K]	1	1		
huss	Surface specific humidity	[kg kg-1]	1	1		1
hurs	Surface relative humidity	%	1			
tasmin	Minimum Temperature at	[K]	1	1		

	2m					
tasmax	Maximum Temperature at 2m	[K]	1	1		
clwvi	Total column liquid water	[kg m-2]	1			
prw	Total column water vapour	[kg m-2]	1			
clt	Total cloud cover	[0-1]	1	1		1
zg	Geopotential Height	[m]	16	7		
ta	Temperature	[K]	16	7	3	
ua	U component of wind	[m s-1]	16	7	3	
va	V component of wind	[m s-1]	16	7	3	
hus	Specific humidity	[kg kg-1]	16	7		
uas	U wind speed at 10m	[m s-1]	1			1
vas	V wind speed at 10m	[m s-1]	1			1
sfcWind	Wind speed at 10m	[m s-1]	1	1		
prsn	Snowfall	[Kg m-2 s-1]	1	1		1
mrros	Runoff	[Kg m-2 s-1]	1			
mrso	Soil water	[kg m-2]	1			
thetao	Sea water potential temperature	[K]	30			
so	Sea water salinity	1e-3 (i.e., ppt)	30			
uo	Eastward sea water velocity	m s-1	30			
vo	Northward sea water velocity	m s-1	30			
wo	Upward sea water velocity	m s-1	30			

3D data (zg, ta, ua, va, hus) are available for the following pressure levels:

- Monthly: 1000, 925, 850, 700, 600, 500, 400, 300, 250, 200, 150, 100, 70, 50, 30, 20 hPa
- Daily: 1000, 850, 700, 500, 250, 100 and 50 hPa
- 6hr: 850, 500, 250

1.1.4. References

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1.2. Regional Climate Simulations performed with the Ocean-Atmosphere Coupled Model COSMOMED for the Mediterranean region

1.2.1. Model Description

The regional coupled ocean-atmosphere climate model COSMOMED is based on the COSMO-CLM limited area model (Rockel et al. 2008) as atmospheric component, and NEMO-MFS, a regional configuration of Nucleus for European Modelling of the Ocean (NEMO; Madec 2008) implemented at very high resolution in the Mediterranean basin, as oceanic component.

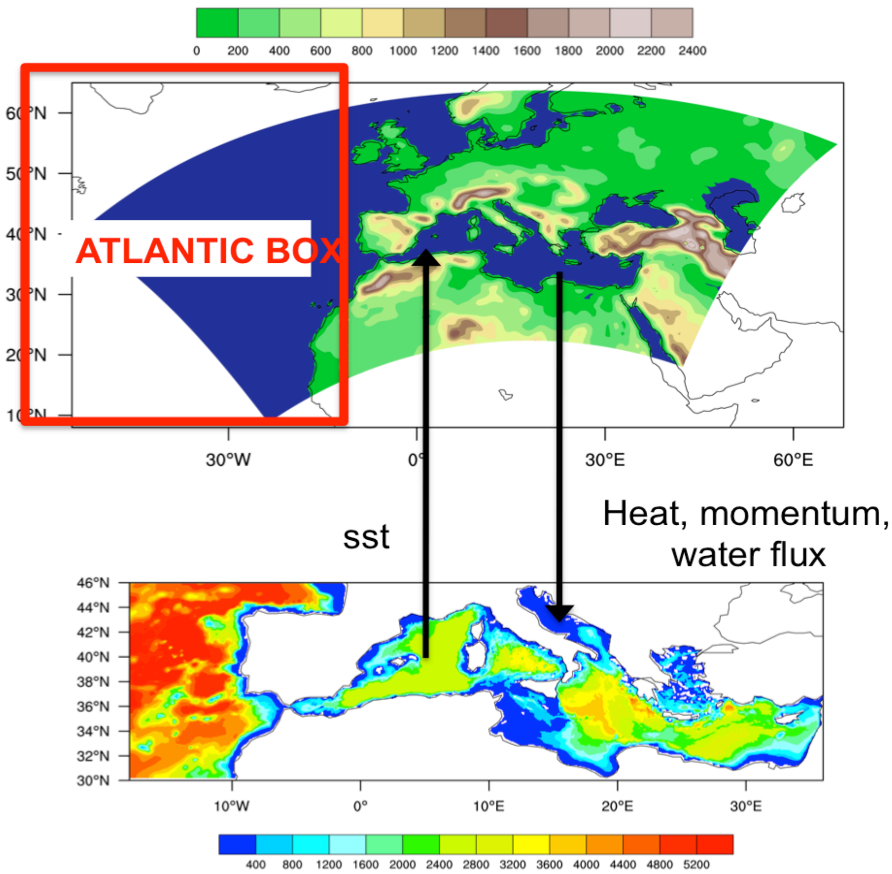

*Fig. 1.2.1**:** Domains of the atmospheric model (with topography) and of the ocean model (with bathymetry).*

COSMO-CLM is the climate version of the COSMO model (Steppeler et al. 2003), the operational non-hydrostatic mesoscale weather forecast model developed at the German Weather Service (DWD). Successively, the model has been modified by the CLM-Community, in order to develop also climatic applications. The updates of its dynamical and physical packages allow its application in cloud resolving scales (Doms and Forstner 2004). It can be used with a spatial resolution between 1 and 50 km. For more details on the formulation of the model and on the parameterization settings, the reader is addressed to (Holton 2004; Kessler 1969; Tiedtke 1989).

In the present version of the coupled AORCM, the atmospheric component COSMO-CLM is implemented with a spatial resolution of about 0.44° (about 44 km) and 40 vertical levels.

The spatial domain covers the Mediterranean region, including an Atlantic box, ranging from 54W–67E and 8.75N–63.75N (Figure 1.2.1). The choice of the domain is justified by the need to cover the Mediterranean basin region, including an area over the eastern part of the Atlantic Ocean (Atlantic box), which is necessary to the coupling with the Mediterranean Sea model.

The parameterization of atmospheric aerosols is the one of Tegen et al. (1997): a seasonal cycle for the different aerosol species is introduced. The convective parameterization employs convective scheme used in the ECMWF Integrated Forecast System (IFS) cycle 33r1 (Bechtold, 2008). The seasonal cycle of sea surface albedo is introduced, using the values from Cogley (1979). Further details on the simulation can be found in the attached documentation file.

The ocean component, NEMO-MFS, is an eddy-permitting marine model able to realistically represent the dynamical processes that characterize the Mediterranean Sea (Oddo et al. 2009). In the present configuration of the coupled AORCM, NEMO-MFS has a 1/16° (about 6.7 km) horizontal resolution and 71 levels along the vertical.

More information about the performances of NEMO-MFS in reproducing the main features of the Mediterranean Sea dynamics can be found in Oddo et al. (2009). Gualdi et al. (2013a), Gualdi et al. (2013b) and Dubois (2012), on the other hand, provide an extended discussion of the capability of NEMO-MFS to reproduce the observed features of the air-sea surface fluxes, when coupled to an atmospheric model.

The communication between the atmospheric model and the ocean models is carried out with the Ocean Atmosphere Sea Ice Soil version 3 (OASIS3) coupler (Valcke 2013). Every 120 min (coupling frequency), heat, mass, and momentum fluxes are computed and provided to the ocean model by the atmospheric model.

In the coupling, heat (radiative and turbulent fluxes), mass (evaporation, precipitation, and runoff), and momentum fluxes are provided to the ocean model by the atmospheric model. At the same time, the atmosphere receives the Mediterranean SST from the ocean model. It is worth noticing that the high-resolution information produced by NEMO-MFS is partly deteriorated in the coupling procedure, by averaging the SST over the coupling frequency time and by interpolating the field to the coarse atmospheric model.

On the other hand, Dubois et al. (2012), examining the performances of CIRCE models in terms of surface heat and water budgets over Mediterranean Sea, showed that the presence of an underlying marine model, which realistically simulates the small-scale spatial structures over the Mediterranean, is still beneficial in terms of the air–sea interactions.

1.2.2. Simulation description

The regional climate model COSMOMED has been used to perform the CORE Med-CORDEX simulations as described in the Med-CORDEX phase 1 protocol (Ruti et al. 2016). More specifically, the framework for the Med-CORDEX CORE simulations follow the CORDEX frame over the Mediterranean domain (MED-44) and the following experiments have been conducted:

- Atmosphere-Land only
- 50 km over the MED-44 CORDEX domain
- Evaluation run (ERA-Interim driven runs, 1989-2008 minimum)
- Historical runs (1981-2005 minimum, 1950-2005 advised)

Scenario runs (RCP8.5, RCP4.5, 2011-2040 or 2041-2070 minimum, 2006-2100 advised).

The model characteristics and the performed experiments are summarised in Table 1.2.1

Table 1.1.1: Summary of the CMCC regional model used in NextData and its main characteristics

Model	**Components and resolutions**	**Med-CORDEX Core phase 1 Experiments**	**Period**	**Archive size**
COSMOMED	Atmosphere COSMOCLM-44 (0.44°) 31 vertical levels. Ocean NEMO-MFS, 1/16°x1/16°, 71 vertical levels.	Historical with ERA-Interim boundary conditions	1979-2010	~ 0.3 TB
		Control run with boundary conditions from CMCC-CM historical integration.	1950-2005	~ 0.5 TB
		RCP 4.5 run with boundary conditions from CMCC-CM	2006-2100	~ 1 TB
		RCP 8.5 run with boundary conditions from CMCC-CM	2006-2100	~ 1 TB

1.2.3. Data access

The data can be downloaded from the CMCC NextData THREDDS service at the following address:

http://nextdata.cmcc.it:8080/thredds/cosmomed

Available data

The following table, Table 1.2.2, summarizes the available variables, units, frequencies and number of levels:

Table 1.2.2: Summary of the available model variables

Variable name	**Longname**	**Unit**	**Daily**	**6hr**	**3hr**
wbt_13c	wet bulb temperature	[K]			1
T_2M	2m temperature	[K]			1
TOT_PREC	total precipitation amount	[Kg m-2 s-1]			1
PS	surface pressure	[W m-2]			1
PMS	mean sea level pressure	[W m-2]			1
QV_2M	2m specific humidity	[kg kg-1]			1
U_10M	U-component of 10m wind	[m s-1]			1
V_10M	V-component of 10m wind	[m s-1]			1
CLCT	total cloud cover	[Fract.]			1
DURSUN	duration of sunshine	[sec]			1
ALHFL_S	averaged surface latent heat	[W m-2]			1

	flux				
ASHFL_S	averaged surface sensible heat flux	[W m-2]			1
ASWDIFU_S	averaged diffuse upwnward sw radiation at the surface	[W m-2]			1
ALWU_S	averaged upward lw radiation at the surface	[W m-2]			1
ASOD_T	averaged solar downward radiation at top	[W m-2]			1
ASWDIR_S	averaged direct downward sw radiation at the surface	[W m-2]			1
RAIN_CON	convective rainfall	[Kg m-2 s-1]			1
ASWDIFD_S	averaged diffuse downward sw radiation at the surface	[W m-2]			1
ALWD_S	averaged downward low radiation at the surface	[W m-2]			1
PRS_CON	mass flux density of convective snowfall	[Kg m-2 s-1]			1
SNOW_CON	convective snowfall	[Kg m-2 s-1]			1
ALB_RAD	surface albedo	[Fract.]			1
FI	geopotential	[m]		4	
QV	specific humidity	[kg kg-1]		4	
T	temperature	[K]		4	
U	U-component of wind	[m s-1]		4	
V	V-component of wind	[m s-1]		4	
RELHUM	relative humidity	%		4	
AEVAP	surface evaporation	[Kg m-2 s-1]		1	
RUNOFF_G	subsurface runoff	[Kg m-2 s-1]		1	
RUNOFF_S	surface runoff	[Kg m-2 s-1]		1	
W_SO_ICE	soil frozen water content	[Kg m-2]		1	
W_SO	soil water content	[Kg m-2]		1	
SNOW_MELT	snow melt	[Kg m-2 s-1]		1	
W_SNOW	surface snow amount	[Kg m-2]		1	
ASOD_T	averaged solar downward radiation at top	[W m-2]		1	
ASOB_T	averaged TOA net downward shortwave radiation	[W m-2]		1	
ATHB_S	averaged surface net downward longwave radiation	[W m-2]		1	
ASOB_S	averaged surface net downward shortwave radiation	[W m-2]		1	
ATHB_T	averaged TOA outgoing longwave radiation	[W m-2]		1	
AUMFL_S	averaged eastward stress	[Pa]		1	

AVMFL_S	averaged northward stress	[Pa]		1	
T_S	soil surface temperature	[K]		1	
HPBL	Height of boundary layer	[m]		1	
CLCH	high cloud cover	[Fract.]		1	
CLCM	medium cloud cover	[Fract.]		1	
CLCL	low cloud cover	[Fract.]		1	
TMAX_2M	2m maximum temperature	[K]		1	
TMIN_2M	2m minimum temperature	[K]		1	
VMAX_10M	maximum 10m wind speed	[m s-1]		1	
TQV	total rain water content vertically integrated	[Kg m-2]		1	
TQC	vertical integrated cloud water	[Kg m-2]		1	
TQS	total snow content vertically integrated	[Kg m-2]		1	
H_SNOW	thickness of snow	[m]		1	
SOSSTSST	Sea Surface temperature	[K]	1		
SOSALINE	Sea Surface Salinity	[K]	1		
SOSSHEIG	Sea Surface Height	[m]	1		
SOWAFLUP	Net Upward Water Flux	[Kg m-2 s-1]	1		
SOWAFLCD	concentration/dilution water flux	[Kg m-2 s-1]	1		
SOSALFLX	Surface Salt Flux	[Kg m-2 s-1]	1		
SOHFLDO	Shortwave Radiation	[W m-2]	1		
SOMIXHGT	Turbocline Depth	[m]	1		
SOMXL010	Mixed Layer Depth 0.01	[m]	1		
SOICECOV	Ice fraction	[Fract.]	1		
SOWINDSP	wind speed at 10m	[m s-1]	1		
SOHEFLDP	Surface Heat Flux: Damping	[W m-2]	1		
SOSAFLDP	Surface salt flux: damping	[Kg m-2 s-1]	1		
VOZOCTRX	Zonal Current	[m s-1]	30		
SOZOTAUX	Wind Stress along i-axis	[Pa]	30		
VOMECRTY	Meridional Current	[m s-1]	30		
SOMETAUY	Wind Stress along j-axis	[Pa]	30		
VOTEMPER	Temperature	[K]	30		
VOSALINE	Salinity	[Psu]	30		

1.2.4. References

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1.3. Regional Climate Simulations performed with the atmospheric stand alone model COSMO-CLM implemented over the Mediterranean region and over the Alpine region.

1.3.1. *Model Description*

The model used to perform these simulations is the atmospheric limited area model COSMO-CLM described in Sections 1.2.1, but in stand alone configuration, i.e. not coupled with an ocean model but forced with prescribed sea-surface temperature where required. The model has been implemented over two different domains: the whole Mediterranean and the Alpine region.

1.3.2. Simulation description

Alpine domain: this dataset has been obtained with a simulation performed implementing the model over the Alpine region domain defined as: 3-17°E; 43-48°N centred on the Alpine space, adopting a spatial resolution of 0.0715° (about 8 km), and considering the period 1979-2011. Initial and boundary conditions were provided by ECMWF ERA-Interim Reanalysis, with a horizontal resolution of about 80 km.
The following variables have been provided, at daily resolution: two-meter temperature (average, maximum and minimum), total precipitation, over the period 1980-2011.
Mediterranean domain: this dataset has been obtained with a simulation conducted over the domain -13-40°E; 29-50°N, and with a spatial resolution of 0.125° (about 14 km), for the period 1971-2100 considering the IPCC A1B scenario. Initial and boundary conditions are provided by the global model CMCC-MED, at horizontal resolution of 0.75° (about 85 km).
The following variables have been provided, at daily resolution: two-meter temperature (maximum and minimum), total precipitation, over the period 1971-2100.

1.3.3. Data access

The data can be downloaded from the CMCC NextData THREDDS service at the following address:

http://nextdata.cmcc.it:8080/thredds/COSMO-CLM_4.8

1.3.4. References

Montesarchio M, Zollo A, Bucchignani E, Mercogliano P, Castellari S. 2014. Performance evaluation of high-resolution regional climate simulations in the Alpine space and analysis of extreme events, Journal of Geophysical Research: Atmospheres 119: 3222–3237. doi: 10.1002/2013JD021105.

1.4. MEDSEA dataset description for NextData

1.4.1. Model and Simulation Description

The dataset of physical variables for the Mediterranean Sea was produced in the framework of the MedSeA project (EU Grant Agreement 265103, http://medsea-project.eu), herein referred as MedSea dataset. In particular, these data cover a 50 year long period, namely from 2000 to 2050, and represent the near-future changes of the system under the RCP8.5 IPCC scenario.
The MedSea dataset includes daily mean i) three-dimensional fields of seawater potential temperature, salinity, and velocities, and ii) two-dimensional fields of mixed layer depth, surface heat and water fluxes, sea surface height, precipitation, river runoffs, wind speed, and solar radiation.
The ocean general circulation model used to generate this projection is NEMO (v3.4, Madec, 2008) and it was implemented with the parameterizations and numerical schemes thoroughly described in Oddo et al. (2009), therein referred as MFS_V2.2 configuration. Overall, the model grid has a regular horizontal resolution of 1/16 of degree (which corresponds to about 6.5 km) and a vertical z-coordinate discretization in 72 levels, with spacing ranging from 3 meters in surface layers to 350 meters in the bottom ones. Boundary conditions come from the atmosphere-ocean global circulation model CMCC-CM (Scoccimarro et al., 2011) and account for 6-hourly atmospheric fields, daily fresh water discharges (rivers and Black Sea exchange), and monthly fields of temperature, salinity, and velocities prescribed at the open lateral boundaries (see details in Lovato et al., 2013).
Importantly, the information about the possible climate change signals that might affect the Italian seas in the coming future has been used as a contribution to the Italian National Plan for Climate

Change Adaptation and to investigate the threats posed by marine heat waves to low motility organisms (Galli et al., 2017).

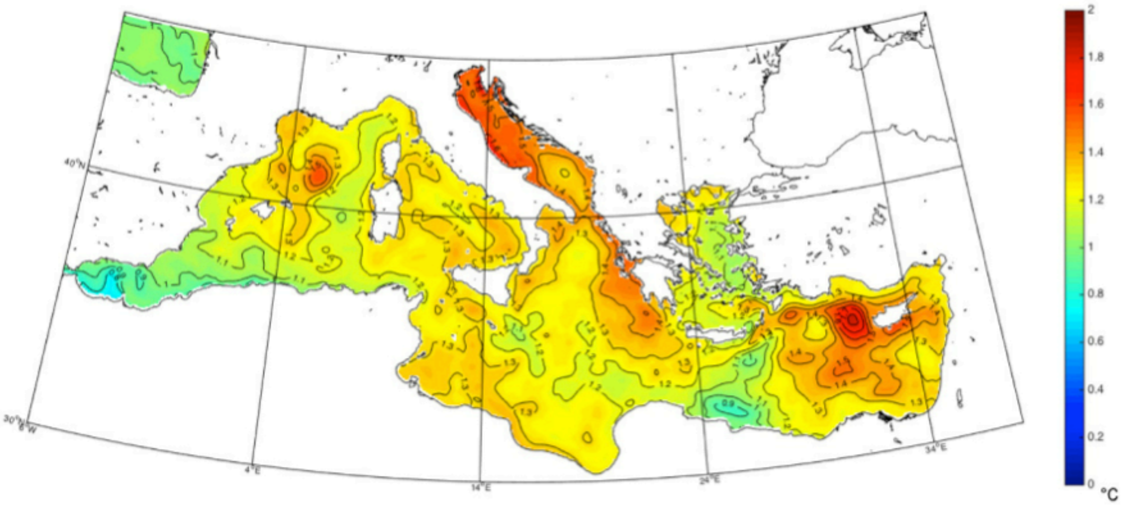

Figure 1.4.1: Spatial distribution of sea surface temperature differences (°C) between the mean values of 2041-2050 and 2000-2009 time windows, as obtained form the MEDSEA dataset.

1.4.2. Data access

The data can be downloaded from the CMCC NextData THREDDS service at the following address:

http://nextdata.cmcc.it:8080/thredds/MedSea_2000-2050_RCP8.5

1.4.3. References

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1.5. The CMCC Nextdata Thredds Data Server

The CMCC Thredds Data Server (TDS) implemented for the needs of the Nextdata project is hosted at the CMCC SuperComputing Centre on a virtual machine specifically installed and configured to meet the special needs of the project.
In particular, the virtual machine has the following features:

- vCPU: 4 cores Intel(R) Xeon(R) CPU E5-2640 0 @ 2.50GHz
- OS: CentOS 6.4
- RAM: 4 GB
- Core Software: Apache Tomcat 7.0.41 and TDS 4.3.17
- Firewall configured to give access only on port 22 (ssh), 80 (http standard) and 8080 (tomcat standard);

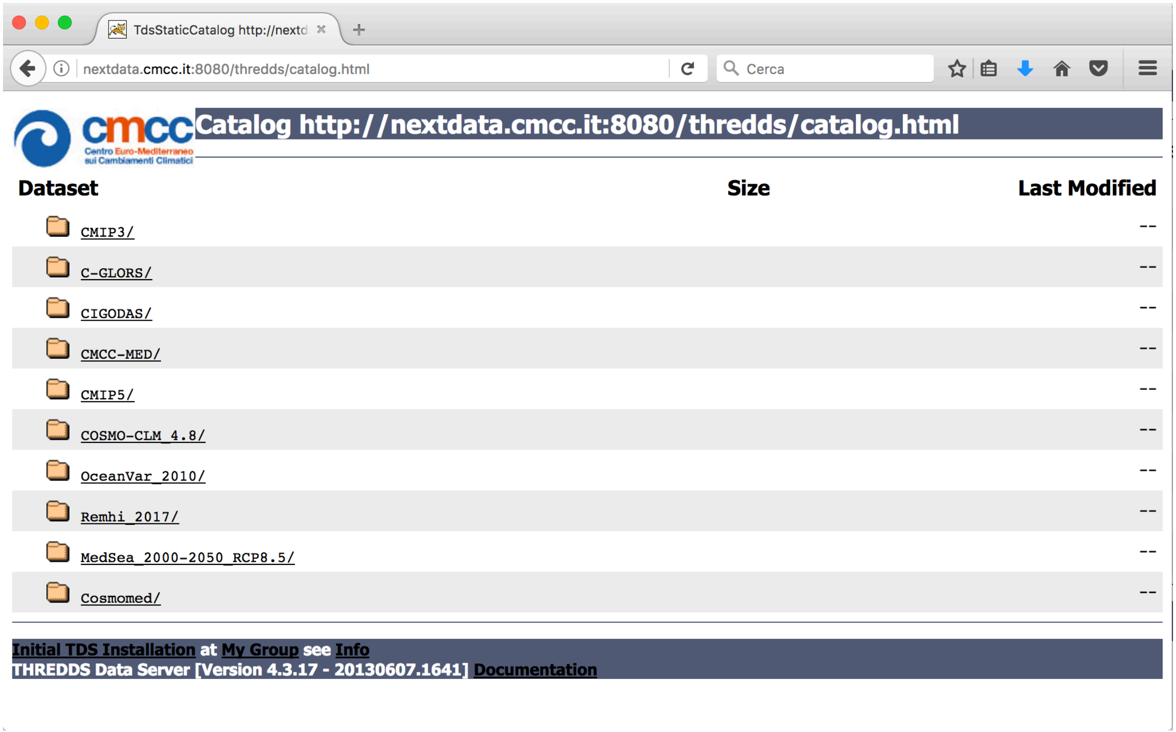

Figure 1.4.2: Spatial distribution of sea surface temperature differences (°C) between the mean values of 2041-2050 and 2000-2009 time windows, as obtained form the MEDSEA dataset.

This virtual machine is connected to a storage system with about 200TB of capacity that stores all the datasets that CMCC is providing for the NextData project.
The service is available at the following URL: http://nextdata.cmcc.it:8080/thredds (see Figure 1.4.2).

The Thredds Data Server (TDS) offers the following data access services:

- OPeNDAP;
- HTTP;
- WCS;
- WMS;
- NetcdfSubset.

as it is shown in the following example (Fig. 1.4.3):

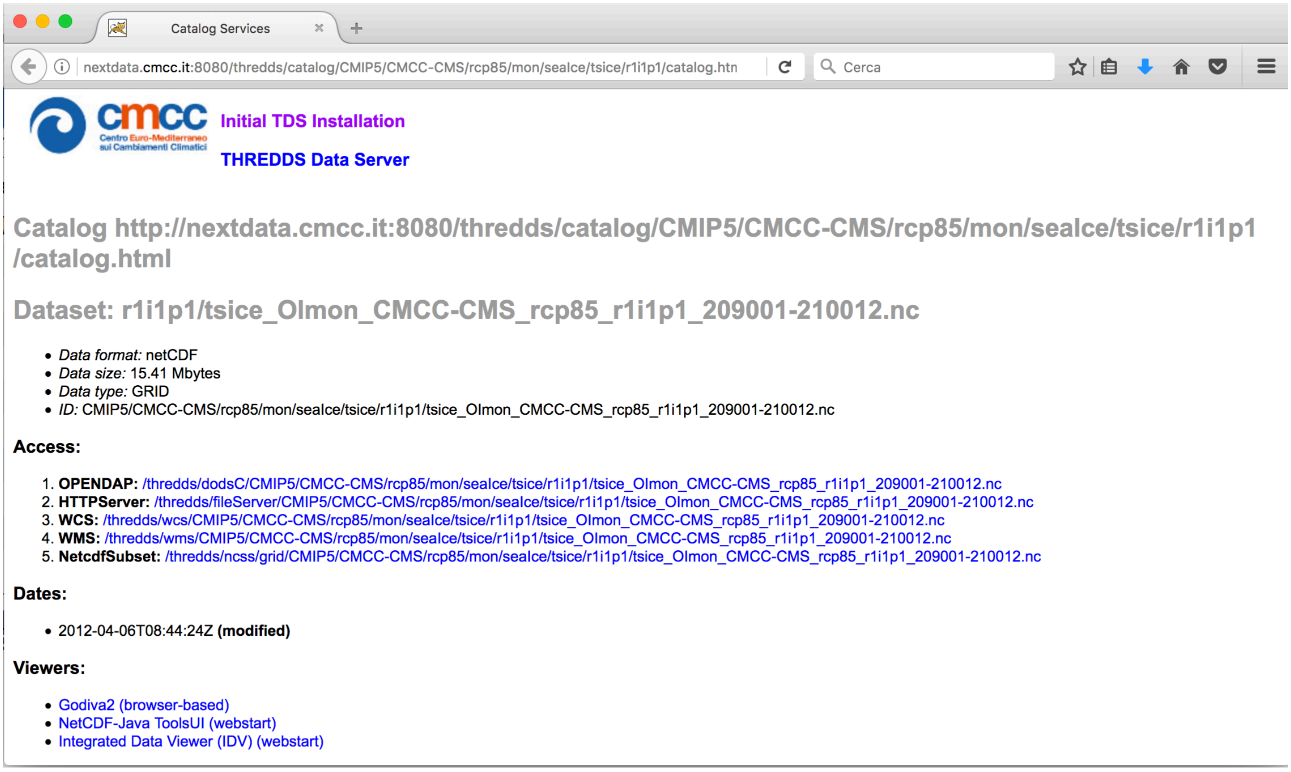

Figure 1.4.3: Data access services of the NextData Thredds Data Server (TDS)

Moreover, on the same virtual machine the LAS (Live Access Server) service is hosted. The LAS is a web service designed to provide flexible access to geo-referenced scientific data. At this moment, in order to test this new service a couple of datasets only produced by CMCC are available.
The reference URL is http://nextdata.cmcc.it:8080/las.
Examples are shown in Fig. 1.5.1 (how to display a variable) and Fig. 1.5.2 (how to geo-reference the variable through the "Google Earth" option).

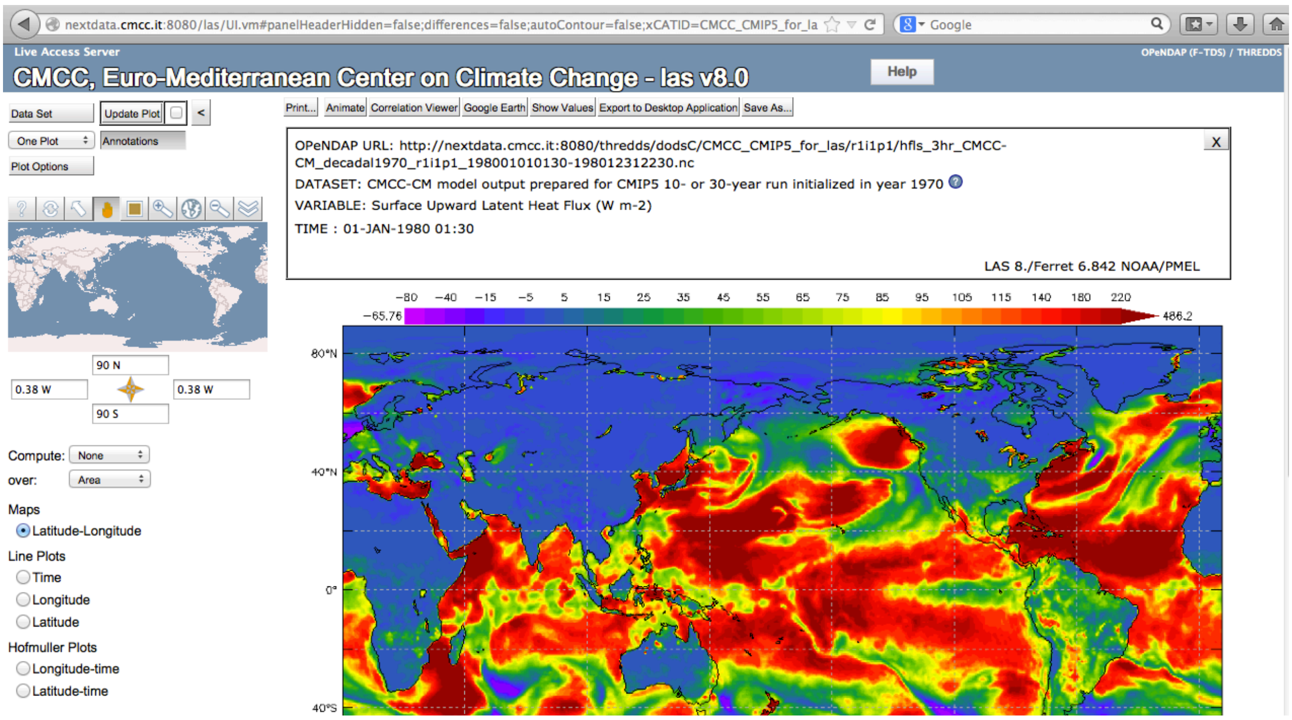

Figure 1.5.1: Tool for displaying a variable

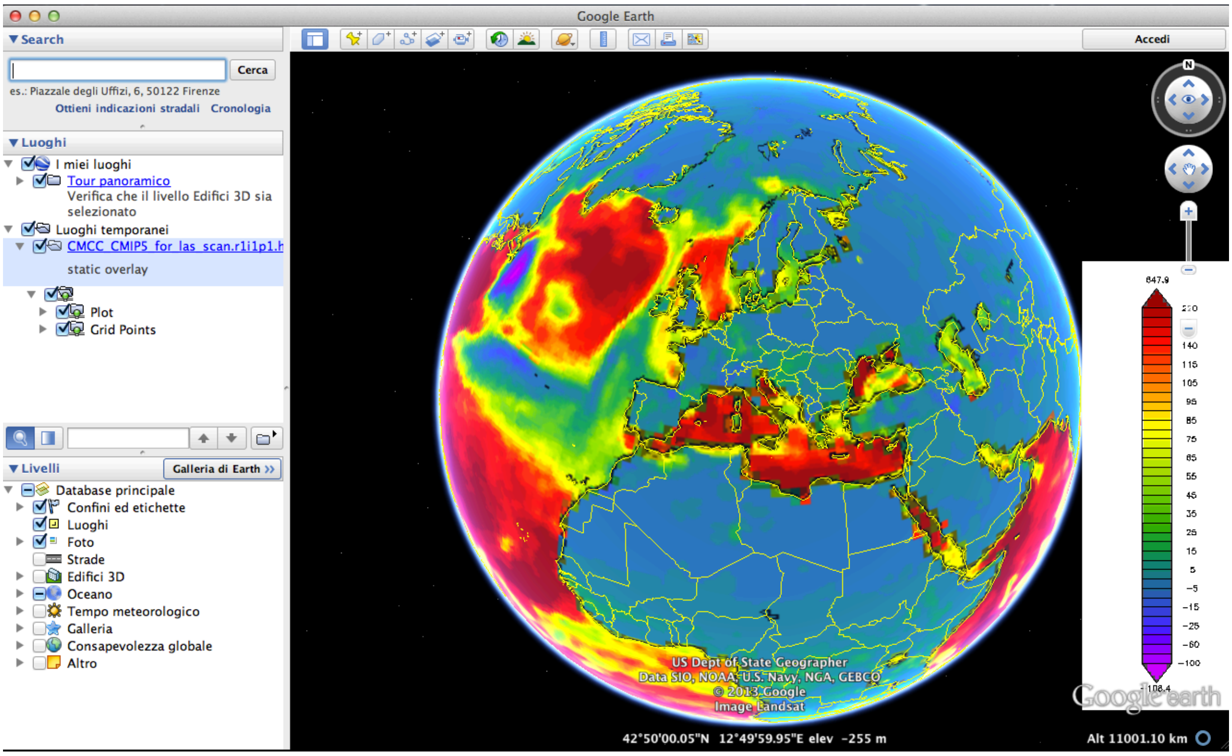

Figure 1.5.2: Tool for geo-referencing a variable through Google Earth

2. **ISAC-CNR** (Contribution by: Jost von Hardenberg, Paolo Davini)

2.1. Climate simulations with the global model EC-Earth at T159 (120 km) resolution (CMIP5)

2.1.1. *Model description*

EC-Earth is a state-of-the-art Earth System Model, based on the concept of seamless prediction [Hazeleger et al., 2012] developed in the framework of the European Consortium EC-Earth, which includes more than 20 research institutions, universities and other public parties from ten different countries. The core of the EC-Earth model is a fully coupled atmosphere-ocean-sea ice model system joining the Integrated Forecast System of the European Centre for Medium-Range Weather Forecasts and the ocean model Nucleus for European Modelling of the Ocean (NEMO) [Madec, 2008]. It also includes the land surface modulus H-Tessel [Dutra et al., 2010] and the sea-ice model LIM-2 [Fichefet and Morales-Maqueda, 1997]. The standard EC-Earth v2.3 configuration was run at T159 horizontal spectral resolution (corresponding to about 1.125 grid resolution) with 62 vertical levels, for the atmosphere, and an irregular grid with about 1 degree resolution and 42 vertical levels for the ocean.

The model consists of two separate codes running in MPMD mode, the ocean model NEMO and the atmospheric model IFS. IFS is a parallel spectral atmospheric model developed at ECMWF, highly optimized, tested, and used for operational production of forecasts at high resolution. NEMO is based on the OPA physical ocean model based on finite differences with MPI communication. The coupler OASIS3 (Valcke 2006) synchronizes the two submodels and manages the exchange and interpolation of physical coupling fields. Communications between the models and the OASIS3 coupler is enabled by a set of library routines based on the MPI library. All models are written in C and FORTRAN.

2.1.2. *Simulation description*

We used the EC-Earth model v2.3 to simulate climate in the period 1850– 2005, using reconstructed historical anthropogenic forcing and solar variability (according to the CMIP5 protocols), and to create scenarios runs for the period 2006– 2100, based on the representative concentration pathways (RCPs) for anthropogenic emissions RCP 2.6, RCP 4.5 and RCP 8.5 [Moss et al., 2010]. RCP 4.5 [Thomson et al., 2011] is a scenario that stabilizes anthropogenic radiative forcing at $4.5 Wm^{-2}$ (compared to preindustrial) in the year 2100. The more extreme RCP 8.5 scenario [Riahi et al., 2011] assumes no effective climate change policies and a continuation of high energy demand and high greenhouse gas emissions, leading to $8.5\ Wm^{-2}$ of anthropogenic radiative forcing in 2100. RCP 2.6 [van Vuuren et al., 2007] is a low emission scenario in which anthropogenic forcing starts decreasing around the mid-2040s. The historical run was started from an initial pre-industrial spinup of the model performed by the EC-Earth consortium. All RCP scenario runs continued the historical run starting in 2006.

The following table, Table 2.1.1 summarizes the available experiments performed with EC-Earth.

Table 2.1.1: Summary of the EC-Earth model used in NextData and its main characteristics

Model	**Components and resolutions**	**Experiment/Forcing**	**Period**	**CMOR Archive size**
EC-Earth 2.3	Atmosphere IFS T159 (1.125°) 62 vertical	Historical CMIP5	1850-2005	1.5 TB

	levels Ocean NEMO-ORCA1, 1°x1°, 46 vertical levels	RCP 2.6	2006-2100	1 TB
		RCP 4.5	2006-2100	1 TB
		RCP 8.5	2006-2100	1 TB

2.1.3. *References*

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- Thomson, A. M., et al. (2011), RCP4.5: a pathway for stabilization of radiative forcing by 2100, Clim. Chang., doi:10.1007/s10584-011-0151-4.
- Van Vuuren DP, Den Elzen MGJ, Lucas PL, Eickhout B, Strengers BJ, Van Ruijven B, Wonink S, Van Houdt R (2007) Stabilizing greenhouse gas concentrations at low levels: an assessment of reduction strategies and costs. Clim Chang 81:119–159

2.1.4. Data access

The data can be downloaded from the CINECA THREDDS service at the following address:

http://nextdataproject.hpc.cineca.it/thredds/catalog/NextData/EC-Earth/catalog.html

The directory structure is as follows (following CMIP5 CMOR format):

http://nextdataproject.hpc.cineca.it/thredds/catalog/NextData/EC-Earth/CMIP5/<EXP>/<FREQ>/<DOMAIN>/<VAR>/r8i1p1/catalog.html

Where EXP=experiment, FREQ=[3hr,6hr,day,mon], DOMAIN=[land,atmos], VAR=variable.

An interactive atlas of these simulations, including spatial maps of selected variables and timeseries is available at http://www.to.isac.cnr.it/ecearth

An interactive tool for data extraction and subsetting from this archive is available on the NextDATA portal at http://www.nextdataproject.it/?q=content/ec-earth-cmip5-data-extraction .

Available data

The following table, Table 2.1.2 summarizes the available variables, frequencies, units and number of levels:

Table 2.1.2: Summary of the available EC-Earth model variables

CMOR name	**Longname**	**Unit**	**Monthly**	**Daily**	**6hr**	**3hr**
prc	Convective precipitation	[Kg m-2 s-1]	1	1		1
pr	Total precipitation	[Kg m-2 s-1]	1	1		1
evspsbl	Evaporation	[Kg m-2 s-1]	1			
hfss	Surface sensible heat flux	[W m-2]	1	1		1
hfls	Surface latent heat flux	[W m-2]	1	1		1
rsds	Surface SW Radiation Downward	[W m-2]	1	1		1
rlds	Surface LW Radiation Downward	[W m-2]	1	1		1
rsus	Upwelling SW at SFC	[W m-2]	1	1		1
rlus	Upwelling LW at SFC	[W m-2]	1	1		1
rlut	Outgoing LW Radiation	[W m-2]	1	1		1
ps	Surface Pressure	[Pa]	1			1
psl	Mean sea level pressure	[Pa]	1	1	1	
tas	Air temperature at 2m	[K]	1	1		1
ts	Surface temperature	[K]	1	1		
huss	Surface specific humidity	[kg kg-1]	1	1		1
hurs	Surface relative humidity	%	1			
tasmin	Minimum Temperature at 2m	[K]	1	1		
tasmax	Maximum Temperature at 2m	[K]	1	1		
clwvi	Total column liquid water	[kg m-2]	1			
prw	Total column water vapour	[kg m-2]	1			
clt	Total cloud cover	[0-1]	1	1		1
zg	Geopotential Height	[m]	16	7		
ta	Temperature	[K]	16	7	3	
ua	U component of wind	[m s-1]	16	7	3	
va	V component of wind	[m s-1]	16	7	3	
hus	Specific humidity	[kg kg-1]	16	7		
uas	U wind speed at 10m	[m s-1]	1			1
vas	V wind speed at 10m	[m s-1]	1			1
sfcWind	Wind speed at 10m	[m s-1]	1	1		
prsn	Snowfall	[Kg m-2 s-1]	1	1		1
mrros	Runoff	[Kg m-2 s-1]	1			
mrso	Soil water	[kg m-2]	1			

3D data (zg, ta, ua, va, hus) are available for the following pressure levels:

- Monthly: 1000, 925, 850, 700, 600, 500, 400, 300, 250, 200, 150, 100, 70, 50, 30, 20 hPa
- Daily: 1000, 850, 700, 500, 250, 100 and 50 hPa
- 6hr: 850, 500, 250

2.1.5. *Publications*

1. Palazzi, E., Filippi, L., & von Hardenberg, J. (2016). Insights into elevation-dependent warming in the Tibetan Plateau-Himalayas from CMIP5 model simulations. *Climate Dynamics*. https://doi.org/10.1007/s00382-016-3316-z
2. Terzago, S., von Hardenberg, J., Palazzi, E., & Provenzale, A. (2014). Snowpack Changes in the Hindu Kush–Karakoram–Himalaya from CMIP5 Global Climate Models. *Journal of Hydrometeorology*, *15*(6), 2293–2313
3. Filippi, L., Palazzi, E., von Hardenberg, J., & Provenzale, A. (2014). Multidecadal Variations in the Relationship between the NAO and Winter Precipitation in the Hindu Kush–Karakoram. *Journal of Climate*, *27*(20), 7890–7902. https://doi.org/10.1175/JCLI-D-14-00286.1
4. Palazzi, E., von Hardenberg, J., & Provenzale, A. (2013). Precipitation in the Hindu-Kush Karakoram Himalaya: Observations and future scenarios. *Journal of Geophysical Research: Atmospheres*, *118*(1), 85–100. https://doi.org/10.1029/2012JD018697

2.2. CLIMATE-SPHINX Global climate simulations at resolutions from T1279 (16 km) to T159 (120 km)

Climate modelling is currently one of the most computationally challenging problems in science and yet also one of the most urgent problems for the future of society. It is well known that a typical climate model (with a resolution of ~120-km in the atmosphere and ~100-km in the ocean) is unable to represent many important climate features, in particular the Euro-Atlantic weather regimes.

Recent studies have been shown that climate models at much higher resolutions (~16km) simulate these patterns more realistically. Whilst few would doubt the desirability of being able to integrate climate models at such a high resolution, there are numerous other areas of climate model development which compete for the given computing resources: for example, the need to incorporate additional Earth System complexity. Instead of explicitly resolving small scale processes by increasing the resolution of climate models, a computationally cheaper alternative is to use stochastic parameterization schemes.

The main motivation for including stochastic approaches in climate models is related with the observed upscale propagation of errors, whereby errors at very small scales (only resolved in high horizontal resolution models) can grow and ultimately contaminate the accuracy of larger scales in a finite time. A stochastic scheme includes a statistical representation of the small scales, so is able to represent this process. There is mounting evidence that stochastic parameterizations prove beneficial for climate simulations. These results highlight the importance of small-scale processes on large-scale climate variability, and indicate that although simulating variability at small scales is a necessity, it may not be necessary to represent the small-scales accurately, or even explicitly, in order to improve the simulation of large-scale climate. The experiments described in this section (performed using computing resources provided by the Climate SPHINX PRACE project) aim to investigate the sensitivity of climate simulations to model resolution and stochastic parameterisations, and to determine if very high resolution is truly necessary to facilitate the simulation of the main features of climate variability.

The EC-Earth Earth-System model was used to explore the impact of Stochastic Physics and of resolution in long climate integrations as a function both of model resolution (from 120km to 16km for the atmosphere) and in coupled and uncoupled configurations. By comparing high and low resolutions integrations we estimated the impact of the increased resolution on climate simulation. By comparing experiments with and without the implementation of stochastic physics we estimated the impact of stochastic physics. By comparing experiments with stochastic physics with experiments carried out without stochastic physics, but at higher resolutions, we assessed to what extent the stochastic representation of the sub-grid processes can compare with the explicit representation of them. This investigation project has provided a significant progress towards reliable climate predictions, exploring the respective role of numerical resolution and stochastic parameterisations in improving climate simulation quality.

2.2.1. Model description

The climate model used for these simulations is EC-Earth version 3.1, a significantly updated version compared to the version described in the previous section. Version 3 of EC-Earth includes several important updates in the components, including IFS 36r4, NEMO version 3 and an improved sea-ice scheme LIM3. EC-Earth version 3.1, released in April 2014, is the result of over 18 months of testing and tuning of the model by the consortium, with significant contributions from ISAC-CNR which coordinated the tuning working group.

The model includes the SPPT and SKEB stochastic schemes (Palmer et al. 2009), which were used for half of the experiments. The model was significantly improved by tuning. In particular tuning aimed at providing a realistic radiative budget (net longwave, shortwave, sensible and latent heat fluxes at the surface and at top of the atmosphere + cloud forcing), by tuning convective and microphysical parameterizations in the model. Additionally the non-orographic gravity wave drag parameterization was tuned by modifying the meridional momentum flux amplitude profile. With this change the model can represent a realistic Quasi-Biennal Oscillation at all the resolutions explored in the experiments. For the SPPT stochastic scheme a global mass and energy fix was developed and implemented by ISAC in order to guarantee conservation of humidity and energy.

2.2.2. Experiment description

The experiments were performed in the framework of the CLIMATE SPHINX PRACE project, which provided the needed supercomputing resources (20 Mio core hours on the SuperMUC machine at LRZ, Germany)

Three types of experiments were performed: present-day AMIP (PDA), future scenario AMIP (FSA) and past-to-future coupled (PFC). PDA and FSA are atmosphere-only simulations: 20 ensemble members are run at T159 (~ 125 km), 20 at T255 (~ 80 km), 12 at T511 (~ 40 km), 6 at T799 (~ 25 km) and 2 at T1279 (~ 16 km) for both PDA and FSA experiments. For each resolution, half of the ensemble members have the stochastic physics parameterisations activated. All simulations have the same vertical grid with 91 levels (L91): these are hybrid levels with the last full level at 0.01 hPa. The atmosphere-only experiments extend for 30 consecutive years, from 1979 to 2008 for PDA, while FSA experiments are run from 2039 to 2068. PFC simulations are run with IFS at the T255L91 configuration, coupled with NEMO using the ORCA1 grid (a tripolar grid with resolution of 1° longitudinally and refinement to 1/3° at the Equator) with 46 vertical levels. The upper model level is at ca. 3m and 10 levels are in the upper 100 m. Six ensemble members are run, three with the stochastic parameterisation active and three control members without stochastic parameterisation, from 1850 to 2100.

The initial conditions (ICs) in both the PDA and FSA experiments are taken from the ECMWF ERA-Interim Reanalysis for January 1st, 1979. For PFC simulations, two 320-year spin-ups were

carried out in coupled mode to equilibrate the ocean to the atmospheric forcing. Having spun-up, three oceanic states – from spin-up year 300, 310 and 320 – were coupled with three different atmospheric ICs; these were run in coupled mode for a further 10 years with fixed greenhouse gas (GHG) forcing for the year 1850.
Anthropogenic forcings (GHGs, stratospheric ozone and volcanic aerosol concentrations) were set according to the CMIP5 protocol. The SST/sea-ice forcing for historical forcing was obtained from the recently developed HadISST2.1.1 dataset (a pentad based dataset, with 0.25x0.25 res. for SSTs and 1x1 res. for sea ice concentration).
SSTs for future simulation were built using the high resolution spatial and temporal variability from the HadISST 2.1.1 and the mean change and trends from ensemble mean EC-Earth simulation (v 2.3) for CMIP5 described in the first section, in the RCP 8.5 scenario. Projected sea-ice cover was also provided by a CMIP5 EC-Earth RCP8.5 projection (choosing a most representative member from the full EC-Earth consortium ensemble by comparison with observed sea-ice in the historical period).
The experiments performed, the size of the ensembles and other technical details are summarized in the following table, Table 2.2.1:

Table 2.2.1. Experiments performed in the framework of the Climate-SPHINX project

Truncation	Resolution	No. of members	Time step	Backscatter ratio	Conv. adj. time	Mom. launch
T159	125.2 km	10 + 10	3600 s	0.032	2.6	0.00375
T255	78.3 km	10 + 10	2700 s	0.040	2.0	0.00375
T511	39.1 km	6 + 6	900 s	0.085	1.5	0.00375
T799	25.0 km	3 + 3	720 s	0.095	1.3	0.00368
T1279	15.7 km	1 + 1	600 s	0.095	1.2	0.00334
T255C	78.3 km	3 + 3	2700 s	0.040	2.0	0.00375

More details on the experimental setup can be found in Davini et al. (2017).

2.2.3. References

Palmer, T., Buizza, R., Doblas-Reyes, F., Jung, T., Leutbecher, M., Shutts, G., Steinheimer, M., and Weisheimer, A.: Stochastic parametrization and model uncertainty, European Centre for Medium-Range Weather Forecasts, 2009.

2.2.4. Data access

The data are available from the NextDATA THREDDS server at CINECA at the following address:

https://nextdataproject.hpc.cineca.it/thredds/sphinx.html

The directory structure is as follows:

https://nextdataproject.hpc.cineca.it/thredds/catalog/SPHINX/<EXP>/post/Post_<YEAR>/ifs/<FREQ>/catalog.html

Where EXP=experiment, YEAR=year, FREQ=[3hr,6hr,day,mon,smon].

All experiments have 4 letters:

- The first letter is the resolution: C=coarse=T159L91; L=low=T255L91; M=medium=T511L91; H=high=T799L91; U=ultra=T1279L91

- The second letter is the type of experiment: A=atmospheric-only present day; F=atmospheric-only future scenario; C=coupled scenario
- The third letter is stochastic physics yes/no: B=baseline, no stochastic physics; S=stochastic physics active
- The fourth letter is the ensemble member number. Numbers range from 0 to 9 for coarse and low resolution, 0-5 for medium resolution, 2-4 for high resolution. Ultra resolution experiments are named uab3/ufb3 and uab2/ufb2. For coupled experiments the run identifier are 0-2. There is a special ensemble member "m" which represents the ensemble mean of all ensemble members.

Timeseries plots of all experiments are available: http://sansone.to.isac.cnr.it/ecearth/diag/SPHINX/

2.2.5 Available data

These experiments (Climate SPHINX) produced more than 1 Petabytes of raw data during production, and finally about 140 Tb of post-processed data which have been stored in the archive.
An automatic post-processing procedure, aimed at extracting monthly (MON), daily (DAY), 6 hours (6HRS) data for different subsets of variables was implemented. More than 50 fields have been stored at monthly frequency.
For daily and 6hours data 3D fields have been degraded to T255 due to archive size limitation. Additional output at 3 hours frequency has been stored for the Euro-cordex region (3HRS_CDX) and a sub-domain including India, Tibet and Pakistan (3HRS_ITP). Total precipitation has been saved also over the global grid at full resolution with 3 hours frequency (3HRS). Finally, synoptic monthly means have been stored (SMON).
A few non-linear variables (e.g. humidity) have been computed from 3-hour output and then averaged at the required frequency in order to not lose information. Data are stored in netcdf4 Zip format (Hdf5 compression).
An indicative list of the variables available on the THREDDS server at the given frequency can be found in the following table (Table 2.2.2).

Table 2.2.2: Summary of the available SPHINX variables

IFS name	CMOR name	Longname	Unit	mon	day	6hrs	3hrs	3hrs_cdx	3hrs_hkk	smon
lsp	**----**	Large-scale precipitation	[Kg m-2 s-X]							
cp	**prc**	Convective precipitation	[Kg m-2 s-X]	X	X			X	X	X
cp+lsp	**pr**	Total precipitation	[Kg m-2 s-X]	X	X		X	X	X	X
e	**evspsbl**	Evaporation	[Kg m-2 s-X]	X	X			X	X	X
tisr	**rsdt**	Top incoming SW radiation	[W m-2]	X						X
tisr-tsr	**rsut**	Top outgoing SW at top	[W m-2]	X						X
sshf	**hfss**	Surface sensible heat flux	[W m-2]	X	X			X	X	X
slhf	**hfls**	Surface latent heat flux	[W m-2]	X	X			X	X	X
ssrd	**rsds**	Surface Downward SW Radiation	[W m-2]	X	X			X	X	X
strd	**rlds**	Surface Downward LW Radiation	[W m-2]	X	X			X	X	X
ssrd-ssr	**rsus**	Surface upward SW radiation	[W m-2]	X	X					X
strd-str	**rlus**	Surface upward LW radiation	[W m-2]	X	X					X
ttr	**rlut**	Top outgoing LW radiation	[W m-2]	X	X					X
tsrc	**----**	Top Net SW Radiation, Clear Sky	[W m-2]	X						X
ttrc	**----**	Top Net LW Radiation, Clear Sky	[W m-2]	X						X
ssrc	**----**	Surface Net SW Radiation, Clear Sk	[W m-2]	X						X
strc	**----**	Surface Net LW Radiation, Clear Sk	[W m-2]	X						X
lnsp	**ps**	Surface Pressure	[Pa]	X	X					
msl	**psl**	Mean sea level pressure	[Pa]	X	X	X				
2t	**tas**	Air temperature at 2m	[K]	X	X	X		X	X	X
skt	**ts**	Surface temperature	[K]	X	X			X	X	X
2t+2d+lnsp	**huss**	Surface specific humidity	[kg kg-X]	X	X			X	X	X
2t+2d	**hurs**	Surface relative humidity	%	X	X			X	X	X
mn2t	**tasmin**	Minimum Temperature at 2m	[K]	X	X					
mx2t	**tasmax**	Maximum Temperature at 2m	[K]	X	X					
z	**zg/9.8X**	Geopotential Height	[m]	**17**	**11**	**8**				
t	**ta**	Temperature	[K]	**17**	**11**	**8**				
u	**ua**	U component of wind	[m s-X]	**17**	**11**	**8**				
v	**va**	V component of wind	[m s-X]	**17**	**11**	**8**				
q	**hus**	Specific humidity	[kg kg-X]	**17**	**11**	**8**				
ewss	**tauu**	East-West surface stress	[Pa]	X						
nsss	**tauv**	North-South surface stress	[Pa]	X						
10u	**uas**	U wind speed at X0m	[m s-X]	X	X	X		X	X	
10v	**uas**	V wind speed at X0m	[m s-X]	X	X	X		X	X	
10si	**sfcWind**	Wind speed at X0m	[m s-X]	X						
sd/rsn	**snd**	Snow depth	[m]	X	X					
sd	**snw**	Snow water equivalent	[Kg m-2]	X	X					
sf	**prsn**	Snowfall	[Kg m-2 s-X]	X	X			X	X	
ro	**mrros**	Runoff	[Kg m-2 s-X]	X				X	X	
svwl1-4	**mrso**	Soil water	[kg m-2]	X	X			X	X	
svwl1	**mrsos**	Soil water in the upper layer	[kg m-2]	X	X			X	X	
pt	----	Potential temperature	[K]	**2**	**2**					
pv	----	Potential vorticity	[K m2 Kg-X s-X]	X	X					
fal	---	Forecasted Albedo	[0-1]	X						

IFS name	CMOR name	Longname	Unit	mon	day	6hrs	3hrs	3hrs_cdx	3hrs_hkk	smon
stl1	**tsl1**	Soil temperature level X	[K]	X	X					
ci	**sic**	Sea ice concentration	[0-1]	X	X					
tciw+tclw	**clwvi**	Total column condensed water path	[kg m-2]	X						
tciw	**clivi**	Total column ice water	[kg m-2]	X						
tcwv	**prw**	Total column water vapour	[kg m-2]	X						X
tcw	----	Total column water	[kg m-2]		X					X
tcc	**clt**	Total cloud cover	[0-X]	X	X					X
lcc	---	Low cloud cover	[0-X]	X						X
mcc	---	Medium cloud cover	[0-X]	X						X
hcc	---	High cloud cover	[0-X]	X						X

6hrs vertical levels: 925,850,700,500,600,400,250,100 hPa
Daily Vertical levels: 1000,925,850,700,600,500,400,250,100,50,10 hPa
Monthly vertical levels: 1000,925,850,700,600,500,400,300,250,200,150,100,70,50,30,20,10 hPa

The atmospheric-only present day (Historical CMIP5 scenario) period ranges from 1979 up to 2008.
Atmospheric-only future scenario runs (RCP8.5 CMIP5 scenario) ranges from 2039 up to 2068.
Coupled scenario runs range from 1850 up to 2100 (Historical up to 2005, then RCP 8.5).
Boundary conditions are stored only for the present-day AMIP experiments. Each experiments has a "bc" folder in the post-processing of the first year of the experiments (1979) that contains the boundary conditions. Orography, land sea mask, type of vegetation and high and low vegetation percentage cover have been saved. These are stored in both GRIB format on the original Gaussian reduced grid or in netcdf format on the regular Gaussian grid. Boundary conditions for future and coupled experiments are the same as the correspondent present-day simulation. For example, orography for a T511 future simulations (i.e. mf??) can be downloaded browsing for year 1979 of mab0 experiments.
We decided to not store the SST field. Instead, we use tsl1, the first layer of the soil temperature. In IFS, the soil temperature over is saved over both the land (a real soil temperature) an over the sea, where represents the SSTs. Therefore, SST can be obtained thus downloading the tsl1 field, which is available at daily and monthly frequency.
Resolution-dependent details for all experiments are summarized in the following table 2.2.3 (T255C is the coupled experiment):

Table 2.2.3. Resolution-dependent details of the Climate-SPHINX experiment

Truncation	No. of cores	Wall time (per year)	Leg length	Output data (per year)	Post-proc data (per year)
T159	224	52 min	1 year	26 GB	9.7 GB
T255	588	1 h 12 min	1 year	64 GB	24 GB
T511	840	6 h 10 min	6 months	249 GB	35 GB
T799	1120	14 h	2 months	605 GB	57 GB
T1279	1540	30 h	1 month	1.6 TB	111 GB
T255C	588	1 h 35 min	1 year	38 GB	30 GB

2.2.5. *Publications*

- Watson, P. A. G., Berner, J., Corti, S., Davini, P., von Hardenberg, J., Sanchez, C., Weisheimer, A., & Palmer, T. N. (2017). The impact of stochastic physics on tropical rainfall variability in global climate models on daily to weekly timescales. *Journal of Geophysical Research: Atmospheres*. https://doi.org/10.1002/2016JD026386

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2.3. Regional climate simulations for Europe (12 km and 4 km resolution)

An improved generation of regional climate models (RCM) has been recently developed and applied in the framework of the CORDEX (COordinated Regional climate Downscaling Experiment; Giorgi et al. 2009) initiative, with the aim to produce regional climate change projections world-wide for input into impact and adaptation studies, considering multiple forcing GCMs from the CMIP5 archive. Recent results for the European branch of the CORDEX initiative (Kotlarski et al. 2014) confirm, with simulations on grid-resolutions up to about 12 km (0.11 degree), the ability of RCMs to capture the basic features of the European climate for the period 1989-2008, but also show non-negligible deficiencies of the simulations concerning selected metrics, certain regions and seasons: for example seasonally and regionally averaged temperature biases are mostly smaller than 1.5 °C, while precipitation biases are in the ±40% range.
Recent literature (Rasmussen et al. 2011) has shown that a reduction of the overestimate in precipitation over orography can be achieved avoiding convective parameterizations and resolving convection explicitly at high enough spatial resolutions. Starting from these findings, in the project which created the data in this archive, we moved one step further, performing very high-resolution regional dynamical downscaling of historical climate scenarios produced by the ERA-Interim reanalysis and of climate change scenarios produced by a global climate model (the EC-Earth model), using the state-of-the-art non-hydrostatic Weather Research and Forecasting (WRF) regional climate model. To the best knowledge of the authors, we performed for the first time long climate simulations over the European domain at a very fine cloud-permitting resolution of about 4 km (0.037°) with explicitly resolved convection and a sharp representation of orography.

2.3.1. Model description

We used the Advanced Research version of WRF (ARW), version 3.4.1, which is a non-hydrostatic, compressible, and scalar-conserving state-of-the-art atmospheric model (Skamarock et al. 2005). Recent applications of the WRF Model as a nested RCM for dynamical downscaling can be found in Lo et al. (2008) and Bukovsky and Karoly (2009). The area of study used for model integration is the European domain defined in CORDEX (Jacob et al. 2013). This represents an area defined in an equidistant latitude–longitude projection with rotated North Pole, extending approximately in the range 27°–72°N latitude and 22°W–45°E longitude. For the high-resolution run, we use a two-way nested strategy. This allowed us to avoid abrupt changes in the resolution between the forcing dataset (ERA-Interim; 0.75°) and the numerical mode.

2.3.2. Simulation description

We explored the sensitivity of the model to different microphysical, planetary boundary layer (PBL) and convective schemes, and to spatial resolution, especially when approaching the cloud-permitting range (4-10 km).

The WRF model setup used in this project for high-resolution simulations consists of 2 domains: an external domain corresponding exactly to the standard Euro-CORDEX area, resolved with spatial resolution 0.11°, corresponding to about 10^7 grid points; two-way nested model simulations have been performed with an innermost domain covering most of continental Europe with spatial resolution 0.037° (about 4 km), corresponding to about $4 \cdot 10^7$ grid points. Lower resolution runs (at 0.11° resolution) used only the exterior domain. This setup was used to perform the main model experiments, for the period 1979-2008 with ERA-Interim forcing at the boundaries. ERA-Interim data were also used to define the initial conditions on Janyary 1st, 1979. Due to numerical constraints, the high-resolution run was performed in chunks of 3 years, starting in 1979, all initialized from ERA-Interim.

We focused on three recently developed microphysics schemes, namely Thompson et al. (2004), Morrison and Gettelman (2008) and WSM6 (Hong and Lim 2006) microphysics. Second, we investigated the sensitivity of the model to the convection schemes, exploring Kain and Fritsch (1990) and Betts et al. (1986). The high resolution run (4 km) used explicit convection. Vertical resolution is kept fixed with 56 vertical pressure levels.

Two experiments using the (WSM6/Kain-Fritsch) configuration were also performed at 0.11° resolution, forcing the model with EC-Earth CMIP5 data instead of ERA-Interim. One was a historical run in the period 1979-2005, the other was a scenario run, using RCP 4.5 boundary conditions from EC-Earth, in the period 2006-2049, continuing the previous run.

The following table, Table 2.3.1, summarizes all experiments:

Table 2.3.1: Experiments performed with WRF

Experiment	**Grid**	**Microphysics**	**Convectivescheme**
c1ei	0.11°	Thompson	Kain-Fritsch
c2ei	0.11°	Morrison	Kain-Fritsch
c3ei	0.11°	WSM6	Kain-Fritsch
c4ei	0.11°	Thompson	Betts-Miller-Janjic
h1e4	0.04°	Thompson	Explicit
hist	0.11°	WSM6	Kain-Fritsch
rcp45c3ei	0.11°	WSM6	Kain-Fritsch

2.3.3. References

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2.3.4. Data access

The data can be downloaded from the CINECA THREDDS service at the following address:

http://nextdataproject.hpc.cineca.it/thredds/catalog/NextData/eurocdx/catalog.html

The directory structure is as follows (following CMIP5 CMOR format):

http://nextdataproject.hpc.cineca.it/thredds/catalog/NextData/eurocdx/<EXP>/<VAR>/<FREQ>/catalog.html

where EXP=experiment, FREQ=[3hr,day,mon,yr], VAR=variable.

2.3.4 Available data

The experiments have required the production of 750TB of output and restart data. The raw output has been post-processed to extract important selected variables in a format agreeing with internationally defined standards (nectdf CF). The size of the postporcessed archive is 3.6TB for the high resolution run and 260 GB for each of the 12km-resolution runs.
The following table presents a list of the postprocessed variables available on the THREDDS server. Variables for the coarser 12 km runs are also available as daily, monthly and yearly averages. All high-resolution variables are available at 3hr frequency.

CMOR name	**Longname**	**Unit**	**12km**	**4km**
pr	Total precipitation	[Kg m-2 s-1]		1
evspsbl	Evaporation	[Kg m-2 s-1]	1	1

hfss	Surface sensible heat flux	[W m-2]	1	1
hfls	Surface latent heat flux	[W m-2]	1	1
rsds	Surface SW Radiation Downward	[W m-2]	1	1
rlds	Surface LW Radiation Downward	[W m-2]	1	1
rsus	Upwelling SW at SFC	[W m-2]	1	1
rlus	Upwelling LW at SFC	[W m-2]	1	1
rlut	Outgoing LW Radiation	[W m-2]	1	1
ps	Surface Pressure	[Pa]	1	1
psl	Mean sea level pressure	[Pa]		1
tas	Air temperature at 2m	[K]	1	1
ts	Surface temperature	[K]	1	1
huss	Surface specific humidity	[kg kg-1]	1	1
hurs	Surface relative humidity	%	1	1
tasmin	Minimum Temperature at 2m	[K]	1	
tasmax	Maximum Temperature at 2m	[K]	1	
clt	Total cloud cover	[0-1]	1	1
zg	Geopotential Height	[m]		1
ta	Temperature	[K]	1	1
hus	Specific humidity	[kg kg-1]	1	1
uas	U wind speed at 10m	[m s-1]	1	1
vas	V wind speed at 10m	[m s-1]	1	1
sfcWindmax	Daily Maximum Near-Surface Wind Speed	[m s-1]	1	
prsn	Snowfall	[Kg m-2 s-1]	1	1
mrros	Runoff	[Kg m-2 s-1]	1	1
mrso	Soil water	[kg m-2]	1	1
clh	High Cloud Cover	[%]	1	1
clm	Medium Cloud Cover	[%]	1	1
mrro	Total Runoff	[kg m-2 s-1]	1	1
mrsos	Moisture in Upper Portion of Soil Column	[kg m-2]	1	1
mrros	Surface Runoff	[kg m-2 s-1]	1	
rsdt	TOA Incident Shortwave Radiation	[W m-2]	1	1
rsut	TOA Outgoing Shortwave Radiation	[W m-2]	1	1
snc	Surface Snow Area Fraction	[]	1	1
snd	Surface Snow Thickness	[m]	1	1
snm	Surface Snow Melt Flux	[kg m-2 s-1]	1	1
snw	Surface Snow Amount	[kg m-2]	1	1

2.3.5 Publications

1. Pieri, A. B., von Hardenberg, J., Parodi, A., & Provenzale, A. (2015). Sensitivity of Precipitation Statistics to Resolution, Microphysics, and Convective Parameterization: A Case Study with the High-Resolution WRF Climate Model over Europe. *Journal of Hydrometeorology*, *16*(4), 1857–1872. https://doi.org/10.1175/JHM-D-14-0221.1

2. Viterbo, F., von Hardenberg, J., Provenzale, A., Molini, L., Parodi, A., Sy, O. O., & Tanelli, S. (2016). High-Resolution Simulations of the 2010 Pakistan Flood Event: Sensitivity to Parameterizations and Initialization Time. *Journal of Hydrometeorology*, *17*(4), 1147–1167. https://doi.org/10.1175/JHM-D-15-0098.1

2.4. Thredds data access

All the data described above can be accessed through a THREDDS data service at the indicated addresses. The implemented THREDDS servers provide the following main functionalities and data access services for each file:

1. *OPENDAP:* Metadata info on the stored file and full OPENDAP remote software API
2. *HTTPServer:* direct download of the file through http protocol
3. *NetcdfSubset:* User interface and API for subsetting (cutting) a selected spatial region and/or time period and vertical level (when applicable)

The data can be downloaded either directly through the THREDDS web interface or using direct requests to the API. For example they **can be easily retrieved using wget scripts.**

A sample script would be:

wget --user=USERNAME -- password=PASSWORD https://nextdataproject.hpc.cineca.it/thredds/fileServer/SPHINX/${exp}/post/Post_${year}/ifs/${frequency}/${exp}_${frequency}_${year}_${var}.nc

for example we could retrieve snow depth from year 1980 of experiments lab0 at monthly frequency:

wget --user=USERNAME --password=PASSWORD https://nextdataproject.hpc.cineca.it/thredds/fileServer/SPHINX/lab0/post/Post_1980/ifs/mon/lab0_mon_1980_snd.nc

Spatial and temporal subsetting options are available through a NetCDF Subset Service. For instance, a subdomain can be extracted (lon1-lon2-lat1-lat2 identifies the subdomain borders):

wget --user=USERNAME --password=PASSWORD "https://nextdataproject.hpc.cineca.it/thredds/ncss/SPHINX/${exp}/post/Post_${year}/ifs/${frequency}/${exp}_${frequency}_${year}_${var}.nc?var=${var}&maxy=${lat2}&minx=${lon1}&maxx=${lon2}&miny=${lat1}&horizStride=1&temporal=all&addLatLon=true

3. <u>ENEA</u>: (Contribution by: A. Dell'Aquila)

3.1. Calibration of the high resolution Regional Earth System Model (ENEA-regesm) over the MED-CORDEX domain

In this deliverable, ENEA presents preliminary results are from the calibration of the new version of coupled high resolution Regional Earth System Model (RegCM4) for the Mediterranean Area. Over land, climate model bias is cold during winter and dry-hot during summer. Over the ocean, the bias is weaker, with a constant wet bias throughout the year and a cold bias during winter. After this evaluation phase, the climate model will be used to downscale CMIP5 climate scenarios over the MED-Cordex domain. All the simulations will be available on the Nextdata server thredds as they are finalised and checked.

3.1.1. Model and Experimental set-up

In its current configuration, ENEA-RegESM (Turuncoglu et al 2017) active components are atmosphere (RegCM 4.5), ocean (MITgcm) and river routing (HD), all of them merged and managed by the driver, the Earth System Modeling Framework (ESMF) which is responsible for the interaction between the components (i.e. boundary data exchange, regridding) and their synchronization.

RegCM4 modelling system is a hydrostatic, compressible, sigma-p vertical coordinate model run on an Arakawa B-grid in which wind and thermodynamical variables are horizontally staggered. The RegCM configuration adopted for this this work has 23 vertical levels and the following physical parameterizations: the CCM3 radiative transfer scheme (Kiehl et al 1996) ; a modified version of the the Holtslag parameterization of the planetary boundary layer (Giorgi et al 2012); the NCAR land surface model. For moist processes, the RegCM4 configuration adopted for this study uses the Grell cumulus convection model (Grell et al 1994) with a Fritsch-Chappell scheme for unresolved convection.

A *hindcast* simulation (aimed to reproduce realistically the recent past climate) has been run with the objective of calibrating the parameterizations of the atmospheric component of the RegESM model. Moreover, it is necessary to evaluate the possible biases of the model, that must be properly taken into account when future scenario simulations are performed. The ERA-interim reanalysis dataset is used as initial and lateral boundary condition for the atmosphere.

The model is run on CRESCO4 in a sequential mode on 256 cpus, which turns out to be the best choice in terms of scalability of the models, over the given domain at the given resolution. The average CPU time for one year of simulation is around 1 day. However, given the relatively low requirements in terms of CPUs, multiple simulation might be performed if necessary.

Three-dimensional 6-hourly output data is stored during the model simulation. Therefore, the amount of storage required for the whole hindcast simulation, covering the years from 1980 to 2013, is of the order of 10 Tb. NetCDF libraries are used by RegESM to manage I/O format.

The atmospheric resolution is about 20 km for the domain greater then the usual med-Cordex domain (Ruti et al 2016), while the oceanic resolution is 1/12° .

In addition of this , the atmospheric stand-alone corresponding simulation is actually running

3.1.2. Main results

Building on our past experience on the use of the RegCM, ARTALE et al 2010 we have tested several aspects of the climate modelling platform.

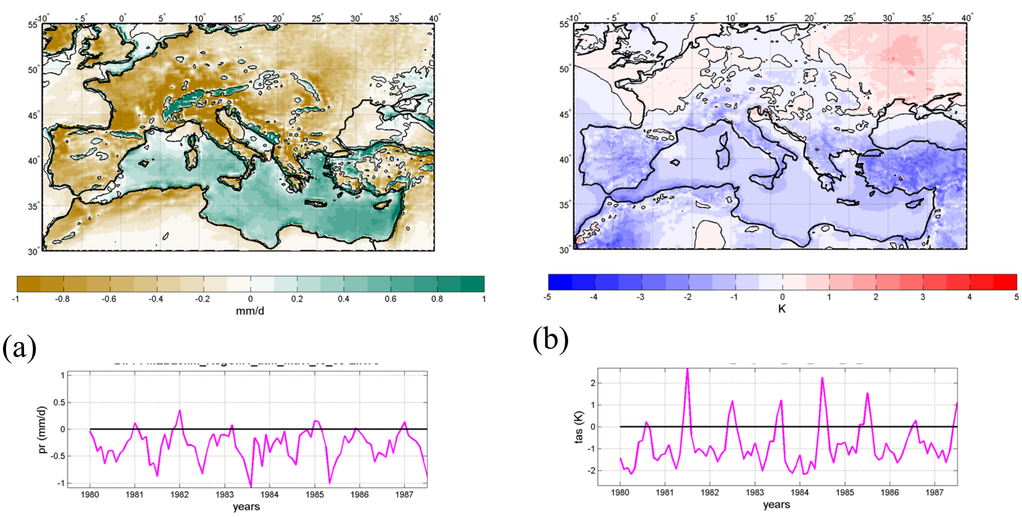
The Grell paramterization for small-convection has been thoroughly tested with a specific focus on the parameters that control the maximum precipitation efficiency, i.e. the maximum attainable rate of conversion in updrafts. A maximum precipitation officiency of 0.8 has been chosen to avoid too intense rainfall events associated to atmospheric convection, especially during the summer months.

The SubEx model for cloud formation has also been tested. We have found that, over the area of interest, a correct description of large scale cloud formation processes is obtained by releasing all constraints to the cloud model. In particular, in our configuration the model is enable to generate cloud on all but the first – near ground – vertical levels and the maximum allowed fraction cover is 1, i.e. the entire grid-cell is allowed to become cloud covered, which is a reasonable choice for a high-configuration resolution.
Particular attention has been devoted to the tuning of the Biosphere Atmosphere Transfer Scheme (BATS) (Dickinson et al 1986). By default, land emissivity is computed in the BATS scheme by adopting a formula which relates emissivity to the corresponding estimated values of albedo. For desert and semi-desert regions, land surface emissivity has been set to the values estimated from direct satellite retrievals (column *Exp2* in Table 1) (Jin and Liang 2006) , and then slightly corrected to reduce the temperature model bias over the desert area which represent a large fraction of the entire model domain. The values of land surface emissivity adopted for our final configuration are reported in Table 1 under the column *Exp3.*
In the BATS scheme, the stomatal resistance of different soil types (crop and evergreen broadleaf) has been also adjusted by following the same rule adopted in previous studies (Dickinson et al 1986).

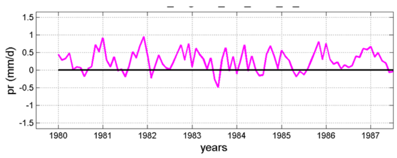
The performance of the calibrated configuration is summarized in Figure 3.1.1. The model has a positive (wet) mean annual bias of rainfall over the ocean and a negative (dry) bias over land. For temperature the model is slightly cold over the entire domain except for a small warm bias in the eastern part of the domain. However, the model systematic bias shows a clear seasonal cycle. Such cycle is more pronounced over land which is generally cold during winter and dry-hot during summer. Over the ocean, the positive bias is mostly persistent during the entire year, while the temperature bias shows a cold phase during summer.

Table 3.1.1. *Tuning of the land-surface emissivity.*

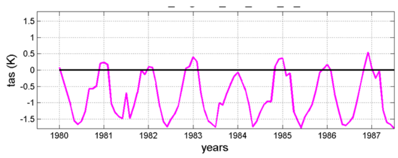
BATS param	Soil type	Exp0	Exp1	Exp2	Exp3
lndemiss(11)	Emissivity - Semidesert	def	0.97	0.85	0.91
lndemiss(8)	Emissivity - Desert	def	0.965	0.76	0.86
lndemiss(19)	Emissivity - Forest/Mosaic field	Def	0.981	0.981	0.985



(a) (b)
(c) (d)



(e)



(f)

Figure 3.1.1. The RegCM4 systematic bias against ERA-Interim for rainfall (left column) and temperature (right column) in the calibrated configuration for the period 1980-87 . The panels show the mean annual bias (a,b); the time behavior of the bias over land (c,d) and over sea (e,f).

3.1.3. Outlook

The calibration of an high-resultion configuration of RegCM4 for the Mediterranean area will enable ENEA to produce climate scenarios over the Med-CORDEX domain (Ruti et al 2016) . The current plan is to run climate scenarios using at least 3 low resolution global models from the CMIP5 archive to provide lateral boundary conditions to RegCM4 (GFDL-ESM2M, Had-GEM2-ES, CNRM-CM5). For each global model, the three main RCPs scenarios are available and will be considered for the downscaling by giving priority to the scenario RCP45. Depending on available resources a maximum of 9 climate scenarios will be performed. This corresponds to a maximum 1350 years of simulations. Although the corresponding disk usage for the raw model output is huge (approximately 409Tb), a selection of the most required model variables can reduce the long term archive needs substantially, up to a factor 10. The expected storage requirement will be therefore of about 50Tb for the long-term archive.

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