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D3.1 Common set of forcing scenarios

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Marine Ecosystem Evolution in a Changing Environment

D3.1 Common set of forcing scenarios

Lead by Jason Holt, NERC-POL

1. Introduction

A principle objective of MEECE WP3 is to define the envelope of response to climate and circulation drivers of marine ecosystem function on both a global and a regional scale. To accomplish this we must establish a range of scenarios that encompass possible future conditions that are scientifically and societally plausible. Coupled atmosphere-ocean general circulation models (AO-GCM's) provide the best available source of information for this purpose on a global scale, but this information is generally on too coarse a grid scale to be relevant for regional scale studies and a downscaling procedure is typically necessary. In MEECE we adopt the dynamical downscaling approach, since we are interested in complex biophysical interactions that are not amenable to a statistical downscaling. In the dynamical downscaling approach output from the AO-GCM is used to provide boundary conditions for regional models of finer resolution and more appropriate process representation than is considered at the global scale. Here we are necessarily concerned with downscaled coupled hydrodynamic-ecosystem models as they are the prime focus of this work. Downscaled atmospheric models are relevant to this work, but are not themselves in the scope of MEECE, and hence common downscaled atmospheric forcing is not available for all regions. Likewise, downscaled terrestrial models are also relevant to considerations of changes at the land-ocean interface, but are not considered further here.

While MEECE has some AO-GCM model effort which is focused on climate change impacts on ecosystems at the global scale within it we must generally look to external effort for the provision of large scale forcing information, specifically the simulations from the CMIP activities that feed the IPCC Assessment Reports and the FP7 ENSEMBLES project, specifically those from the IPSL climate model.

Alongside the choice of AO-GCM forcing are two important considerations: the emissions scenario(s) and the forecast horizon. The emissions scenarios prescribe the atmospheric concentrations of radiatively active constituents, which in turn determine the radiative forcing of the AO-GCM. These are either derived from a socio-economic ‘story-line’ or prescribed to specific values. The design of future scenarios/story-lines is not within the scope of MEECE, but we are able to choose among those used in the CMIP experiments and the ENSEMBLES project. The forecast horizon dictates how far into the future the model simulations will be conducted. The choice is then to run either a full transient simulation or timeslices. In the latter, statistics of a future period are compared with a present day control simulation. A hindcast reference simulation is also required to allow comparison with contemporary observations (since the AO-GCM reference can only be validated in a statistical sense) and to assess the accuracy of the present day AO-GCM forcing.

These considerations come together in the analysis of the uncertainty of a future projection; an aspect that is central to this work. In the context of global models this is built up of three aspects: scenario uncertainty (reflecting the unknown future socio-economic landscape), model uncertainty (reflecting inaccuracies in the model; this can be characterised to some extent by comparing different modelling approaches) and internal variability (reflecting the difficulty in detecting a clear climate change signal until this ‘averages out’). This is well illustrated by the work of Hawkins and Sutton (2009). Figure 1 shows an example from this work, which demonstrates how model and “internal variability” uncertainty decrease with lead time, but scenario uncertainty increases. It also demonstrates, how, by moving from a global to a regional scale the model and “internal variability” uncertainty can substantially increase.

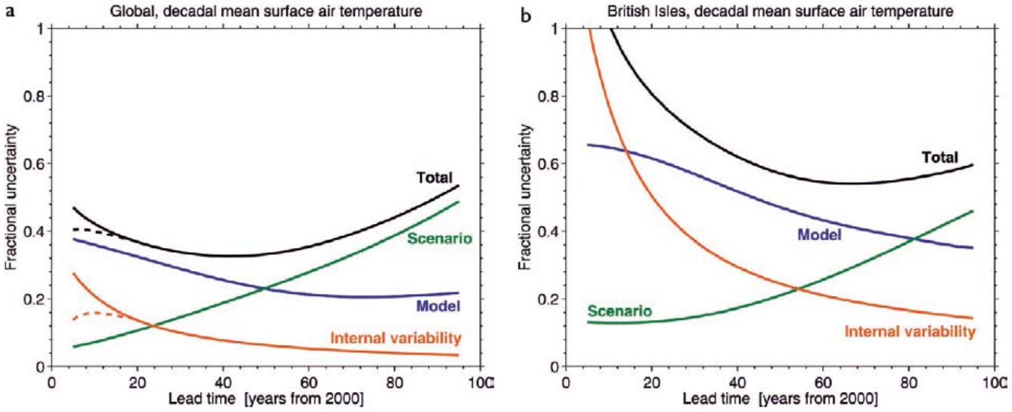

Figure 1 Estimates of sources of uncertainty from 15 AR4 OA-GCMS (reproduced from Hawkins and Sutton, 2009). Left shows global values and right shows values for the British Isles.

When we move to the climate impacts arena we add other aspects of uncertainty arising from, and propagating through, the downscaled models. While we aspire to ensemble simulations to map the uncertainty, practicalities limit us to at best span aspects of the uncertainty with a very limited number of simulations. Such an approach is an important first step and allows us to explore the system's response to the range of different drivers both qualitatively and quantitatively. However, the usefulness of such simulations as 'forecasts of future conditions' is questionable and should be viewed with an appropriate degree of caution.

2. Overview

Following workshops in Sète and Bologna, a set of common model experiments were agreed (the Common Scenario; see D1.5 for further details), based on forcing that was immediately available to all partners, using the IPSL-CM4 climate model, and fitted within the computational resource generally available. Using a common forcing has two immediate advantages: access to data and inter-comparability. This particular choice of common forcing has three operational and scientific advantages: access to high frequency forcing (see below), the inclusion of the PISCES global ecosystem model output in the forcing set and the presence of the originators as partners in this project, allowing a ready scientific discourse on the downscaling challenge across the group. Issues of data access arise because regional seas are sensitive to non-linear aspects of the forcing (such as the wind stress effects on thermocline depth). Hence, they often require high frequency (sub-daily) forcing. Such forcing is often not readily available from international data repositories (such as for IPCC AR4), which mostly only hold monthly or lower frequency data, and must be sought from individual climate modelling organisations. Inter-comparability is an important aspect of this work, since a primary objective is to identify the relative susceptibility of different regions to different drivers. Using a common forcing set significantly facilitates this inter-comparison. It should be born in mind however, that responses of regional models driven by different forcing data can still be rigorously compared. In this case, a detailed comparison of the different forcing and a diagnosis of the consequence of this are also required. Hence a comparison without common forcing is possible but is significantly more involved and may well not yield unambiguous conclusions.

A more in-depth analysis of the common forcing data set raised questions as to whether this is 'fit for purpose' in all regions. This is in no way a specific issue with the IPSL-CM4 model, but rather an issue with the class of model used in IPCC AR4 and subsequent work. Generally, AO-GCM's perform best at a continental scale and show substantial variability between models at a regional scale. It is currently unlikely to find a single AO-GCM that performs well for the diversity of regions under consideration here. Therefore it is necessarily to strike a balance between harmonising on a single set of forcing and producing a set of simulations that are scientifically credible, and we must necessarily weight this balance towards the latter. To this end, a second set of regionally specific scenarios is also considered. These expand on the Common Scenario, both to overcome its short comings and to build an ensemble of opportunity. The selection of these models and approaches is made by the individual regions, and discussed in detail below. A rigorous selection exercise would be to evaluate all available models against a set of ‘fit for purpose’ criteria and select those that meet these criteria in each region. Such an exercise has been carried out for the Arctic by Overland and Wang (2007). This is not itself within the scope of the project, although we draw on the lessons learned, and does not guarantee that appropriate forcing data from the selected set is available.

While every effort is made to maintain commonality among the chosen forcing, this cannot be ensured owing to factor such as access to data, available computer resources, and the appropriateness for a specific forcing in a particular region. However, two aspects of alignment can be maintained across all scenarios: a common emissions scenario and a common set of timeslices, these follow those outlined in the Common scenario.

3. The Common Scenario

The common scenario is based on the IPSL-CM4-V2 model run for the ENSEMBLES project. Here we use the member identified as LU20C2.

3.1 THE OA-GCM

The IPSL-CM4 (Marti et al 2006) model uses the LMDZ-4 atmospheric model at a 2.5^{o}x3.75^{o} resolution with 19 levels in the vertical, the OPA-8 open model at ~2^{o} resolution and 31 vertical levels, the LIM sea ice model and the ORCHIDEE global vegetation model and the PISCES marine ecosystem model. Here it is run from 1860-2100 under a range of emissions scenarios.

3.1.1 Emissions Scenarios

Here we focus on the Special Report on Emissions Scenarios (SRES) A1B and A2 scenarios and ENSEMBLES E1 scenario. The SRES Story lines are:

A1: World markets: *Technology and markets fail to deliver sustainable solutions*

- People aspire to personal independence, material wealth and greater mobility, all of which have a negative effect on wider societal and environmental goals.
- Pressure grows to reduce taxes, and more public services are privatized or privately managed.
- Social and environmental governance is achieved through international legal frameworks setting minimum standards, and through market-based approaches.
- Marine ecosystems are heavily degraded by human activity.
- Increased pressures are placed on marine biological resources, either through utilization or through increasing levels of ‘stressors’ (for example, loss of habitats and changes in water quality).

A2: Fortress Nation: *National identity gets in the way of global sustainability*

- People aspire to personal independence and material wealth but within a national cultural identity.
- The balance of opinion favours increased national isolation and independence in economic, foreign and defence policy.
- Long-term economic growth is limited by government policies, which protect important national industries.
- By 2020, marine ecosystems come under greater pressure than at present.
- Efforts to reduce the effects of human activity are abandoned where they conflict with issues of national self sufficiency.
- Large-scale, environmentally damaging projects such as tidal barrages and wide-scale oil exploration develop under the Fortress Britain scenario.
- Governments fail to deal with global problems;

Scenario E1 is an aggressive mitigation scenario where the aim to limit the global temperature rise to 2^{o}C is met.

Of these A1B is the (mandatory) priority simulation and A2 and E1 are desirable.

3.1.2 Timeslices

Computational resource limitations generally make multiple centennial scale transient simulations impractical, hence for the common scenarios we focus on timeslices and transient simulations are considered in the regional specific scenarios. Moreover, timeslice simulations are more amenable to the chosen downscaling methodology (see below). The tension in choosing a timeslice period is between the computational resources, the need to sample sufficient natural variability to be able to average out this variability, and ideally the statistics within the time slice should be approximately stationary. Previous experience suggests 20 years is an (minimum) acceptable period. We adopt the following time slices

- ERA40 and/or NCEP present day reference
- Recommended:
  1980-2000 (control; LU20C2);
  2080-2100 (climate change); A1B, A2, E1 (LUA1BR2)
- Minimum: 1980-2000; 2080-2100; A1B

In addition the timeslice 2030-2040 under A1B is used for multiple driver simulations. These timeslices are augmented by a ‘spin-up’ period appropriate to each region, to allow the dynamics, biogeochemistry and ecosystem to adjust to the prevalent conditions. The timeslice approach assumes the time history of the system can be safely neglected. This is generally true for the physics and basic biogeochemistry of the system on decadal time scales, but far less clear for ecosystems, particularly when related to the ecology of the system.

It is important to bear in mind that, while the AO-GCM year are identified with the real calendar, because these are free running simulations, the variability will not match the specific years and so can only be compared with actual present day conditions in a statistical sense.

3.1.3 Downscaling methodology and forcing data

The specific data required for model forcing depends on the boundary condition algorithms of the individual models. A typical forcing data set might be: atmospheric data (available 6-hourly): surface air temperature, winds, pressure and relative humidity; (available daily) shortwave radiation and precipitation and monthly ocean currents, sea level, temperature and salinity. Land forcing data (river runoff, nutrient, DIC and alkalinity) is not prescribed by the Common Scenario and each region uses the best available forcing.

For a given choice of forcing data there are several methods whereby this can be used to drive a regional hydrodynamic-ecosystem model. These downscaling methods can be grouped into 5 different approaches:

- Direct forcing
- Delta change approach
- Bias correction (linear) or statistical downscaling (nonlinear)
- Dynamic downscaling of atmosphere only
- Dynamic downscaling using an atmosphere-ocean model
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Here refers to the large scale forcing and the regional model simulation. Subscripts are either ‘data from’ or ‘forced by’:

- *p,f:* past and future forcing data sets
- *REF*: the reanalysis reference (e.g. ERA40 or NCEP for atmosphere and equivalent oceanic data/model simulations)
- *CNTRL*: the AO-GCM control period (e.g. IPSL-CM4 LU20C2; 1980-2000)
- *A1B* the future scenario period; (e.g. IPSL-CM4 LUA1B2; 2080-2100)

A. Direct forcing

A straight forward approach is the direct usage of the climate model data as boundary and initial condition for the present day reference run and the future climate change scenario. The climate change signal is then the difference between both regional climate impact realisations:

$$\Phi_{p,f}(x,t) = \Phi_{CNTRL,A1B}(x,t)$$

$$\Delta\Psi = \Psi_{A1B}(x,t) - \Psi_{CNTRL}(x,t)$$

The problem with this approach is that the climate model output shows area and parameter dependent biases, which typically also varies with season. This applies to both the atmospheric and ocean components. Such a bias will have a significant impact on processes such as stratification, upwelling, sea ice development and consequently primary production. Where these are non-linearly dependent on the forcing variables, this bias will not cancel when the climate change signal is calculated. Particularly significant problems have been identified for the Benguela upwelling region (upwelling, resolution), the Black Sea and Baltic Sea (initial condition), the Adriatic (resolution) and the Barents Sea (sea ice). Hence this method is disregarded as the Common Method here. This approach remains useful for some regions however, as it does permit long transient simulations to be performed and all the information from the AO-GCM is retained.

B. Delta change approach

An alternative downscaling and climate impact assessment method is the delta change method. In this approach, the present day climate forcing is provided by a present day reference forcing, typically derived from atmospheric re-analysis NCEP or ERA40 alongside appropriate oceanic conditions. The climate change forcing is then derived by perturbing the reference forcing by a function of the future climate change forcing in relation to its present day control. The delta change method has the advantage that it only requires one additional simulation for each global climate model realisation applied; hence it allows multi-model ensembles with reasonable computational effort, facilitating the estimation of uncertainties in the projection. Here we consider a multiplicative change defined by:

$$\Phi_f = \Phi_{REF}(x,t)F(x,t^*),$$
$$F(x,t^*) = \Phi_{A1B}(x,t^*)/\Phi_{CNTRL}(x,t^*)$$
$$\Delta\Psi = \Psi_f(x,t) - \Psi_{REF}(x,t)$$

An additive change was disregarded owing to problems with negative values of several variables (e.g. nutrients, radiation, temperature). Since the interannual variability of the future and control simulations are not related (in time), the fields must be appropriately time averaged before calculating the perturbation to the reference simulation. Here we use mean monthly values (t*), so preserving changes to the annual cycle. These are imposed on the full time resolution of the reference simulation, and so retain the inter-annual variability of reference simulation. Essentially we ask: ‘how would condition in 2080-2100 differ from those in 1980-2000, if 2080-2100 happen to have the same inter-annual variability as 1980-200 period but had imposed on it a particular climate change signal’.

The general disadvantage of the delta change method is related to the loss of dynamic consistency in the forcing; i.e. the atmospheric conditions do not match the underlying ocean. This has to be acknowledged and carefully explored. However, this is a common problem and most forced regional models are in some sense inconsistent, relying as they do on the best available information from a range of sources. In addition, information on changes to the inter-annual variably is lost in this case so we may not be making full use of the available information. The value of this information, however, is still the matter of scientific debate. Finally, the delta approach is inherently linear in its consideration of climate change and is limited to the timeslice (rather than the transient approach), so shares the disadvantages of this noted above.

C. Linear or statistical nonlinear bias correction

The third method is the application of a bias correction to both the reference and climate change forcing from the global climate model. The objective is to improve the agreement between the reference and contemporary observation or reanalysis. This correction is assumed to remain constant with time. The correction might either be a linear correction (fractional or additive), e.g. to correct for a bias of the mean condition, or the correction might be a more complex nonlinear function derived e.g. by a statistical downscaling approach. For a linear multiplicative or additive corrections this is:

$$\Phi_{p,f}(x,t) = \Phi_{CNTRL,A1B}(x,t)B(x,t^*)$$

$$or$$

$$\Phi_{p,f}(x,t) = \Phi_{CNTRL,A1B}(x,t) + B(x,t^*)$$

$$B(x,t^*) = \Phi_{REF} / \Phi_{CNTRL} \quad or \quad B(x,t^*) = \Phi_{REF} - \Phi_{CNTRL}$$

$$\Delta\Psi = \Psi_f(x,t) - \psi_p(x,t)$$

These corrections can be applied to one or more climate model variables, each with a difference approach. More sophisticate operators correlating the present state of the climate model can be used. Simple temporal corrections (as considered here) are readily applied. Spatial corrections (e.g. to correction the location of the storm track) are significantly more involved. Similar to the delta change approach, the forcing derived by a bias correction is no longer dynamically consistent. Application of a non-linear statistical downscaling to one or more forcing variables might even change the climate change signal from the global climate model. This method has the potential advantage that changes to the inter-annual variability are retained, but the disadvantage (compared to the delta approach) is that high frequency forcing data is required and both a climate change and control simulation must be run. Moreover, the assumption that the bias correction statistics are stationary with time is doubtful.

D. Dynamic downscaling of atmospheric conditions

In this approach a high resolution atmospheric model is used to force the coupled hydrodynamic ecosystem model. Again this ultimately leads to dynamically inconsistent forcing, since the regional atmospheric boundary condition will not ‘feel’ the underlying ocean, but rather the ocean boundary condition from the global climate model run. This will deviate significantly from the regional model solution and dynamic consistency is not ensured. However, it is useful when the resolution of the global climate model is too coarse for modelling the regional scale (e.g. for the Adriatic) and statistical downscaling is not appropriate.

E. Dynamic downscaling with coupled atmosphere ocean models.

In this case high resolution regional coupled ocean-atmosphere simulations are run. This downscaling method is dynamically consistent. However, this approach requires significant technical development and so is not readily available for use in MEECE. To our knowledge this approach has yet to be applied to the fully coupled atmosphere-ocean-ecosystem case. Hence, this is not considered further here.

3.2 Preferred MEECE approach

As is apparent from the above discussion, the approach to regional downscaling is far from settled and clear-cut, and is the subject of on-going scientific investigation. Given this diversity of approaches (even after a common forcing is agreed), clear harmonisation is required here as well. The preferred MEECE downscaling strategy is the Delta change approach (B), using a multiplicative factor applied to atmospheric boundary conditions, marine boundary conditions and marine initial conditions. This approach is chosen because it removes the influence of biases from the climate model forcing and preserves the mean climate change signal. This is seen as the most robust part of the signal from the climate models, and outweighs the disadvantages noted above. For the present day reference atmospheric forcing (needed for B. and C.), the choice is either NCEP or ERA40. NCEP forcing is more readily available so is recommended for most of the regions.

4. Regional assessments and deviation

For scientific reasons several MEECE regions need to deviate from the Common Scenario approach noted above. These now discussed on a region by region basis, with some details of assessment that has been performed.

4.1 Benguela region

The marine ecosystem in this region is driven by frequent dominant upwelling events, which bring nutrient rich waters to the sea surface. The atmospheric forcing leading to this upwelling is not resolved in the IPSL-CM4 model forcing; the IPSL winds are far too low in intensity over the domain thereby underestimating the upwelling strength. Since the frequency of these events is assumed to significantly impact on the productivity, the delta change approach or a linear bias correction is not considered appropriate, and a non-linear statistical downscaling needs to be applied.

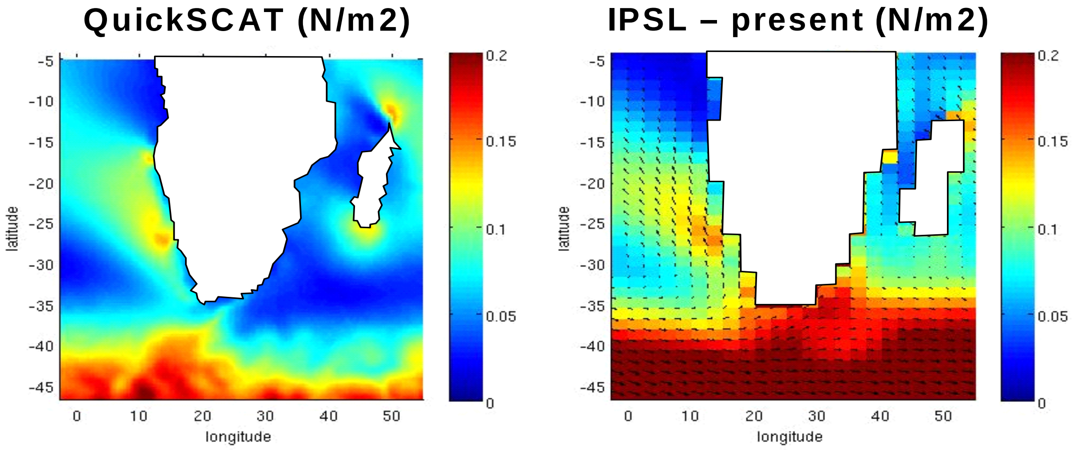


Figure 2 Annual wind stress from satellite data (left) and IPSL model outputs (right)

Hence, in addition to the IPSL-CM4 forced simulations, we run present day simulations with statistically downscaled winds over the wider SAfE domain. The downscaled winds (stress, speed and direction) were obtained from a comparison between QuikSCAT and NCEP (2000-2008) products from which downscaling statistics are derived and applied to the IPSL output winds. Goubanova et al. (2010) applied this methodology on the Peru-Chile upwelling and Figure 3 illustrates the result obtained over the Benguela domain.

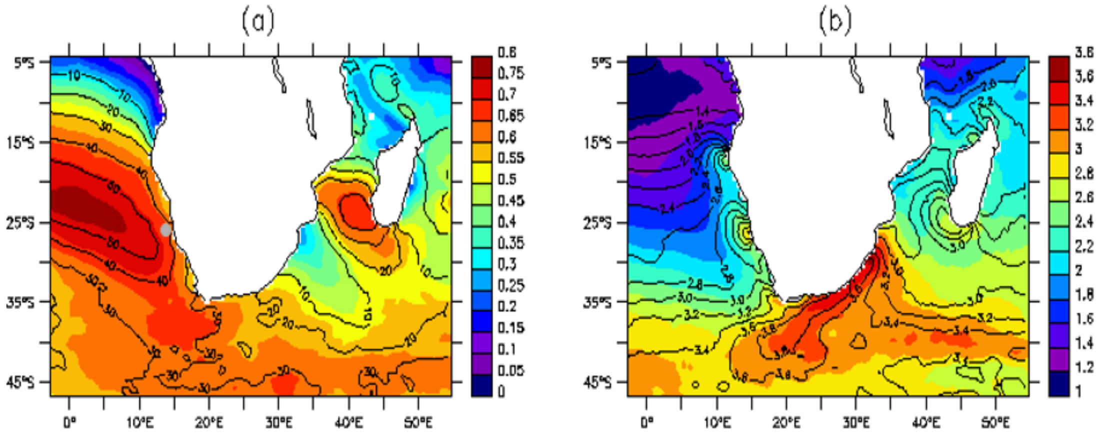
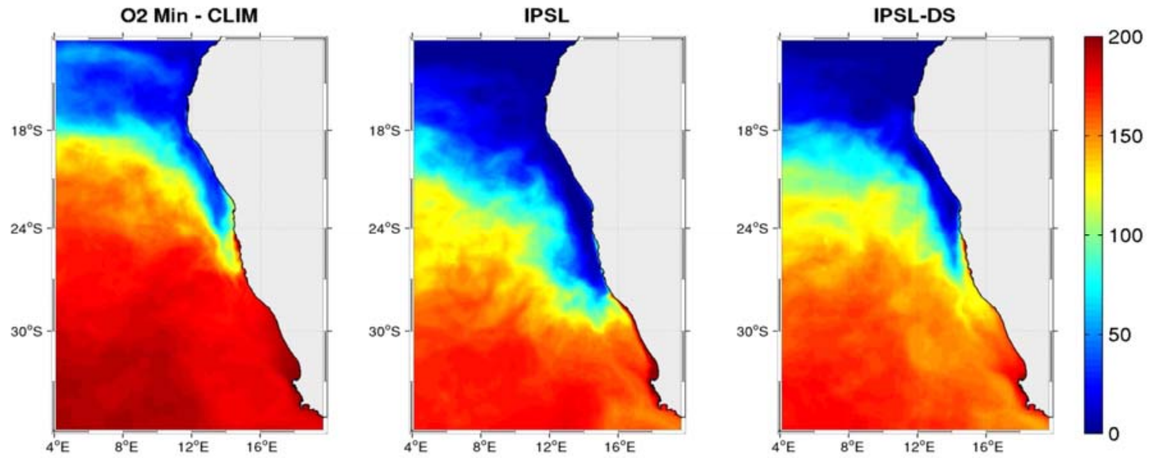


Figure 3 Maps of correlation (a) (b) (a left panel) and RMS difference (in m/s, b right panel, in m/s) between observed by QuikSCAT and downscaled wind speed (1980-2000). Contours on the left panel indicate the percentage of observed variance explained by the downscaled wind. Contours on the right panel indicate the RMS (in m/s) of the observed wind (Goubanova, pers. Com.)

This method has been applied to the IPSL outputs of wind and wind stress from the present scenario, keeping the other fields (atmospheric and oceanic) unchanged. Forcing scenario modified with this downscaled wind makes the model able to reproduce the upwelling features (low sea surface temperature and oxygen minimum zone) better than without downscaling. See for example minimum O_2 concentration over the entire column in the Figure 4. By extrapolation the same statistical relationship will be applied to IPSL outputs of winds in the future scenario.


O2 Min - CLIM

IPSL

IPSL-DS

Figure 4 Annual minimum oxygen concentration (mmol/m3) over the water column after 3 years of simulation when the model is forced by climatological data (left), IPSL outputs (middle) and IPSL outputs with downscaled winds (right).

4.2 Barents Sea

The IPSL-CM4 model forcing has a pronounced sea ice bias in the Barents Sea region. In the present day climate reference situation, the regional climate is influenced by the de-coupling between the atmosphere and the ocean, and climate change signals are artificially large (e.g. > 20^{o}C for air temperature and O(100) wm**2) short wave radiation; Figure 5). The same applies to the oceanic initial and boundary conditions. Corrections for these artificial errors are not possible, and the IPSL-CM4 model is not ‘fit for purpose’ for downscaling in this region, in general agreement with Overland and Wang (2007). Hence it is necessary to use climate forcing from other IPCC models, which show more realistic climate conditions in the Barents Sea. To this end IMR will use the GFDL GISS model as forcing, as this shows improved results in the Barents Sea region. UiB will use the ECHAM5-OM and NorESM (AR5 scenarios) for the ECOSMO model.

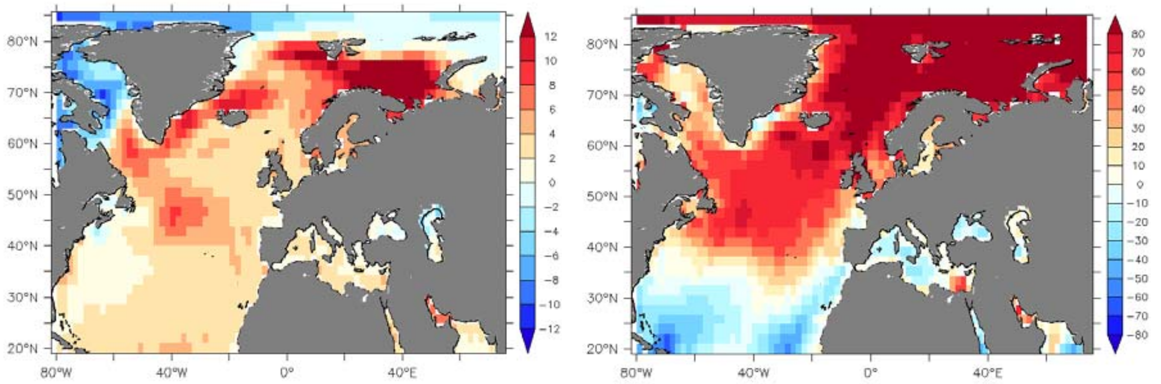


Figure 5: Difference between IPSL present day climate (from run LUC20C3) and NCEP climate (1970-1999, NCEP-IPSL), left: winter temperature, right: summer net short wave radiation.

4.3 Black Sea

Here we assess the performance of the IPSL-CM4 and ERA40 models for the Black Sea region in some detail as an example of the range of issues that can arise. The conclusion is that a statistical downscaling method needs to be applied. Moreover, it is not appropriate to use the IPSL-CM4 data to form initial conditions for the Black Sea due to the absence of the permanent halocline. Instead we opt to spin up the model for 5 years from present-day climatological data.

Surface wind stress

Both IPSL and ERA40 Black Sea wind fields have been assessed through a comparison with remotely sensed wind data (Table 1), using the Cross-Calibrated, Multi-Platform Ocean Surface Wind Velocity CCMP data product[1]. The conclusions of this assessment are as follows:

- Remotely sensed wind speeds are more than 100% greater than ERA40 wind speeds on average.
- Extreme values are more than 300% greater in the remotely sensed data set compared to ERA40.
- To correct the ERA40 data set a statistical downscaling technique has been applied using the Cumulative Distribution Function CDF transform method described by Déqué (2007). The CDF method has been applied independently to velocity vectors in the positive and negative u and v directions, in order to correct wind direction as well as wind speed.
- IPSL-CM4 (LU20C2) mean wind speeds are ~350% larger than remotely sensed wind fields.
- It is intended to apply the same downscaling procedure used for the ERA40 forcing to the IPSL-CM4 LU20C2 and A1B2 forcing fields (assuming a static relationship between the IPSL data and the CCMP data).

	IPSL(u)	**IPSL(v)**	**ERA40(u)**	**ERA40(v)**	**CCMP(u)**	**CCMP(v)**
Minimum	-29.30	-11.32	-6.05	-4.75	-17.66	-20.27
Maximum	53.17	16.39	5.38	7.5	17.4	17.4
Mean	11.77	2.5	1.08	1.18	2.78	2.66

Table 1: Minimum, maximum and absolute mean wind vectors over the Black Sea during 1998 and 1999, from ERA40, CCMP and IPSL (LU20C2).

Surface heat flux

IPSL-CM4 heat flux data have been compared with ERA40 heat flux data. The ERA40 heat flux data is significantly correlation to observed SST records between 1970 and 1999, and exhibits realistic interanual and multiannual variability.

- Both the ERA40 and IPSL data sets suggest that the Black Sea gains heat on an almost annual basis between 1970 and 1999 (Figure 6). The net heat input to the Black Sea over this period is almost identical in both data sets.
- Decadal and smaller scale variability in the surface heat flux is not represented in the IPSL data which exhibits less overall variability over interannual to multiannual timescales
- Seasonal variability is similar in both data sets.

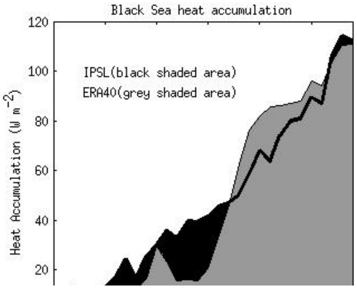


Figure 6 Annual mean heat flux accumulation between 1970 and 1999.

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[1] CCMP wind fields were obtained through the online PO.DAAC Ocean ESIP Tool (POET) at the Physical Oceanography Distributed Active Archive Centre (PO.DAAC), NASA Jet Propulsion Laboratory, Pasadena, CA, USA.

Water column structure

The Black Sea is characterised by a thin relatively fresh surface layer overlaying saline waters of Mediterranean origin. A permanent halocline at 160-200 m depth prevents deep winter convection resulting in a shallow anoxic interface associated with the base of the pycnocline. Accurate characterisation of both the seasonal thermocline and the permanent pycnocline is vital in order to describe biogeochemical cycling in the Black Sea.

In Figure 7 characteristic temperature, salinity and density profiles in the centre of the Black Sea obtained from the IPSL model and the POM reanalysis are compared to CTD data.

- The IPSL model does not show realistic salinity profiles for the Black Sea. Salinity is almost constant with depth and the permanent halocline is absent.
- During summer, a shallow, warm and saline surface layer forms in the IPSL model which counteracts the development of a seasonal thermocline. The result is that density increases almost linearly with depth throughout the year.
- The seasonal thermocline exhibits a realistic seasonal cycle with appropriate summer mixed-layer depths of ~5 m, but winter mixed layer depths are too deep due to the absence of the permanent halocline.

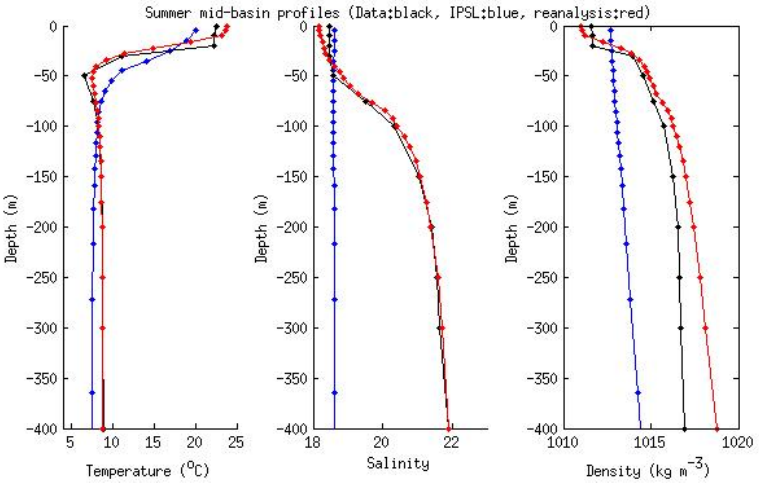

Figure 7 July mean temperature, salinity and density profiles near the centre of the Black Sea basin. Data are from IPSL member LU20C2 (blue), POM reanalysis (red), and observations (black).

Temporal variability

Annual mean SST records from the IPSL model and the POM reanalysis are compared to gridded *in situ* (HadSST2) and remotely sensed (AVHRR) data in Figure 8.

- The IPSL SST record shows annual mean values persistently ~1.8 °C cooler than observations.
- The amplitude of variations in IPSL-CM4 are less than in HadSSt2 or AVHRR

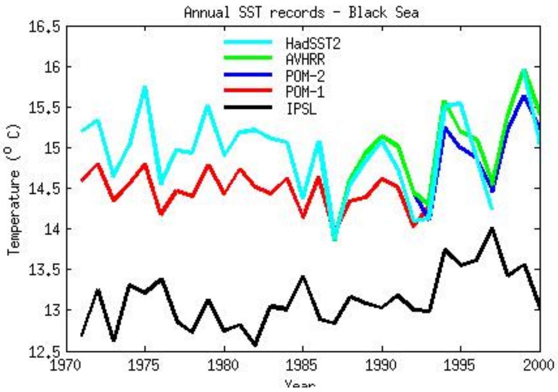

Figure 8 Annual Mean SST records for the Black Sea from IPSL LU20C2 (black), POM reanalysis (red and blue), HadSST2 (cyan) and AVHRR (green).

4.4 Baltic Sea

Similar to the Black Sea, the Baltic Sea is stratified throughout the season with fresh water in the surface layer and more saline water in lower layers and a permanent halocline is present. This structure is not resolved by the IPSL model and initial conditions are a challenge for the climate change time slice experiments since the characteristic time scale of the Baltic Sea is about 20yrs, hence a similar order to the length of the timeslice. For the Baltic Sea, we aim at a combination of a transient approach with ensemble simulations of delta change experiments and different initial conditions.

4.5 Adriatic Sea

The resolution of the IPSL-CM4 forcing is too coarse to force the Adriatic Sea model. It therefore has been decided to use forcing data from a regional dynamic downscaling (atmosphere only; Figure 9). The downscaled data have a resolution of 0.25°. The modelling system generating the downscaled data is the EBU-POM system, and is composed of the “ETA Belgrade University” Atmospheric Model (EBU) and the Princeton Ocean Model (POM).The modelling system was implemented over the whole Mediterranean Sea area, as depicted in Figure 9.The following time slices are available: 20th century: 1960 2000; and 21st century: 2001-2030 and 2070-2100. The 21st century timeslice has been obtained adopting the IPCC A1B scenario for the CO2 emission into the atmosphere. These cover requirements of the MEECE Common Scenario. The winter and summer 2m air temperature differences computed from the 20th century (1960-1990) and the 21st century (2070-2100) time slices are shown in Figure 10.

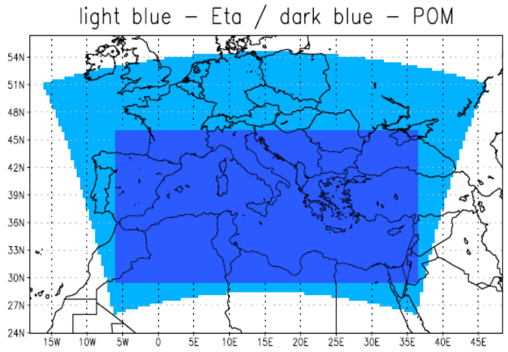

Figure 9 The EBU-POM modelling domain. Light Blue: Atmospheric modelling Domain. Dark Blue Oceanic modelling domain

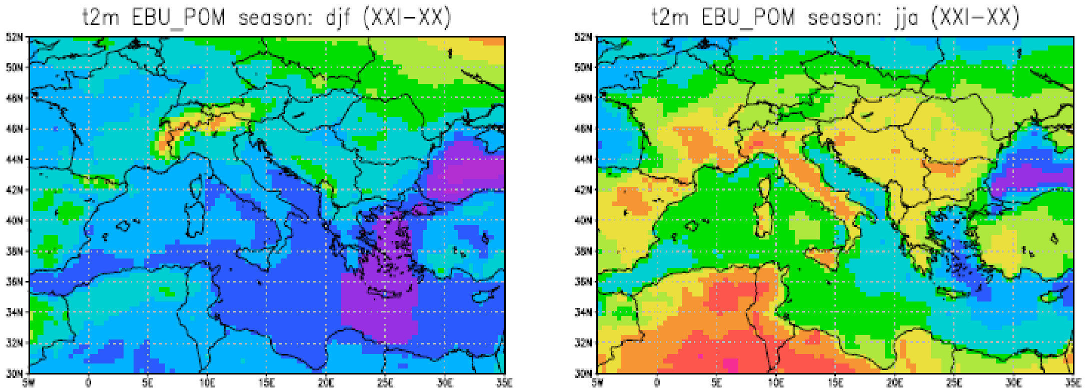

Figure 10 Winter and summer 2m Temperature differences over the Mediterranean Sea area from the 20th and 21st century simulations with the EBU-POM modelling system.

4.6 North Aegean Sea

The resolution of the IPSL-CM4 forcing may be considered too coarse (2.5° x 1.26°) for the N. Aegean area, given the limited extension of the model domain (figure 11). The SINTEX-G (SXG) IPCC climatic forcing (EU-ENSEMBLES, Gualdi et al., 2007), provided within EU-SESAME project, presents a slightly higher resolution (1.21°x1.21°). Both climatic forcings show various and different types of biases as compared to ERA40 reanalysis forcing. The most important bias of the IPSL-CM4 forcing is the significantly lower wind speed over the Aegean (figure 12, table 2) that results in lower evaporation heat fluxes (table 2). The

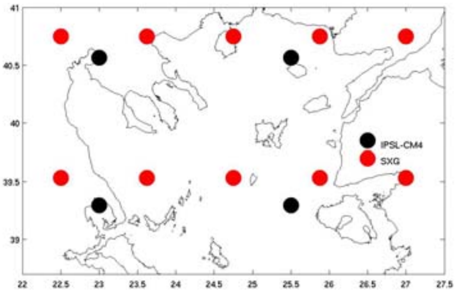

Figure 11: N. Aegean model domain with indicated IPSL-CM4 (black dots) and SXG (red dots) grid points.

SXG presents more realistic wind fields, while there is a slight positive bias of latent (evaporation) heat flux due to lower humidity during summer. Therefore, it was found preferable, both in terms of higher resolution and given the importance of dense water formation (triggered by evaporation heat/buoyancy loss) in the Aegean, to use the SXG forcing for the needs of the MEECE scenario simulations. However, the climate signals from these two available IPCC forcings will be further evaluated.
The SXG climatic forcing (A1B scenario) is available for 1980-2000, 2030-2050 and 2070-2100 time slices. A basin-scale Mediterranean hydrodynamic model ($0.1^o x 0.1^o$) simulation over the selected time-slices will provide boundary conditions to the N. Aegean regional model.

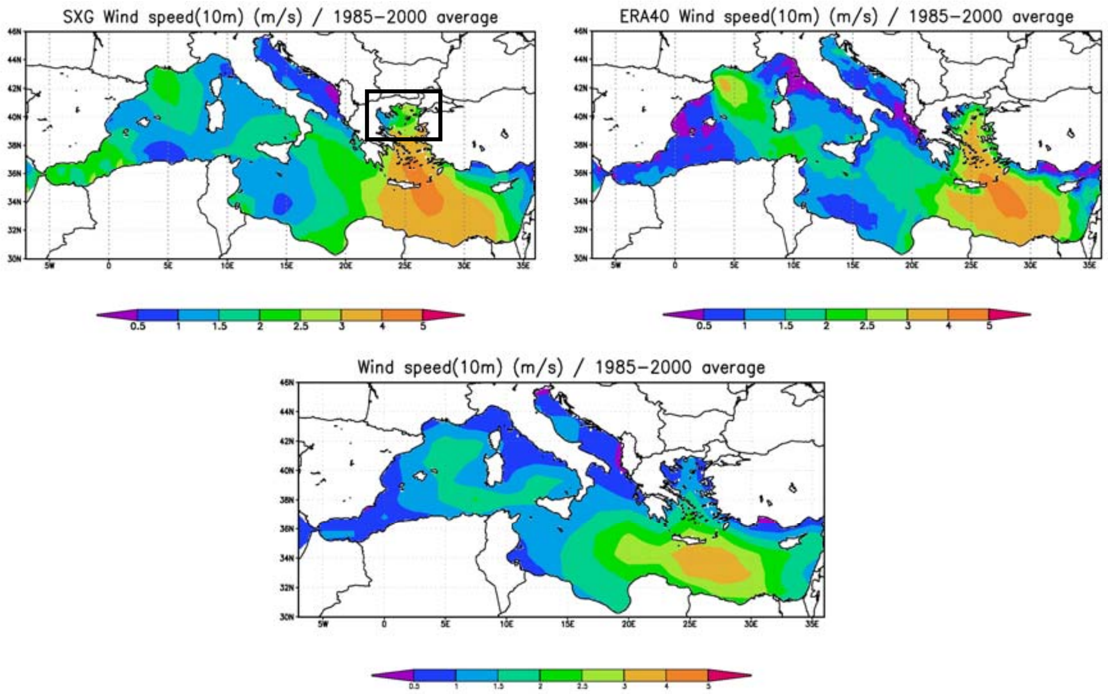

Figure 12: SXG (top-left), ERA40 (top-right) and IPSL-CM4 (bottom) average wind (10m) speed (m/s), over 1985-2000 period.

Table 2: N. Aegean average wind (10m) speed (m/s) and latent heat flux for IPSL-CM4, SXG and ERA40 forcing, over 1985-2000 period.

	Wind speed (m/s)	Qlat(W/m2)
ERA40	2.12	104
SXG	2.34	113
IPSL-CM4	0.96	64

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