Progress in Oceanography 138 (2015) 211–237

Contents lists available at ScienceDirect

Progress in Oceanography

journal homepage: www.elsevier.com/locate/pocean

Validation of an ensemble modelling system for climate projections for the northwest European shelf seas

Jonathan Tinker [a,*], Jason Lowe [a], Jason Holt [b], Anne Pardaens [a], Andy Wiltshire [a]

[a] *Met Office Hadley Centre, FitzRoy Rd, Exeter, Devon EX1 3PB, UK*
[b] *National Oceanography Centre, Joseph Proudman Building, 6 Brownlow Street, Liverpool L3 5DA, UK*

ARTICLE INFO

Article history:
Received 23 December 2013
Received in revised form 24 June 2015
Accepted 4 July 2015
Available online 10 July 2015

ABSTRACT

The aim of this study was to evaluate the performance of a modelling system used to represent the northwest European shelf seas. Variants of the coupled atmosphere–ocean global climate model, HadCM3, were run under conditions of historically varying concentrations of greenhouse gases and other radiatively active constituents. The atmospheric simulation for the shelf sea region and its surrounds was downscaled to finer spatial scales using a regional climate model (HadRM3); these simulations were then used to drive a river routing scheme (TRIP). Together, these provide the atmospheric, oceanic and riverine boundary conditions to drive the shelf seas model POLCOMS. Additionally, a shelf seas simulation was driven by the ERA-40 reanalysis in place of HadCM3. We compared the modelling systems output against a sea surface temperature satellite analysis product, a quality controlled ocean profile dataset and values of volume transport through particular ocean sections from the literature.

In addition to assessing model drift with a pre-industrial control simulation the modelling system was evaluated against observations and the reanalysis driven simulation. We concluded that the modelling system provided an excellent (good) representation of the spatial patterns of temperature (salinity). It provided a good representation of the mean temperature climate, and a sufficient representation of the mean salinity and water column structure climate. The representation of the interannual variability was sufficient, while the overall shelf-wide circulation was qualitatively good. From this wide range of metrics we judged the modelling system fit for the purpose of providing centennial climate projections for the northwest European shelf seas.

1. Introduction

The world's shelf seas are very important to the world economy, ultimately supporting 95% of global fish catches, and they play an important role in the global marine ecosystems. The UK's marine industry (predominantly located on the continental shelf) includes fisheries, oil and gas, shipping, renewable energy, and aggregate extraction (Pugh, 2008). Despite the importance of this region, during the UK's first Climate Change Risk Assessment (CCRA, a statutory requirement of the UK's Climate Change Act, 2008) there was found to be too little known about potential climate change impacts on UK's shelf seas (Pinnegar et al., 2012). Lack of regional scale projections for temperature, salinity and stratification have all been identified as important research areas (MCCIP, 2012).

The effects of climate trends and variability have already been observed on the North West European (NWE) shelf for a wide range of parameters (e.g. Cannaby and Hüsrevoğlu, 2009). There has been a rapid increase in the north east Atlantic Sea Surface Temperature (SST) around the UK and Ireland between 1983 and 2012 (HadISST; Rayner et al., 2003; Holt et al., 2012b) with the largest increase evident in the southern North Sea and the eastern English Channel, at a rate of 0.4–0.5 °C/decade (Dye et al., 2013b). In addition to these observed trends there is also substantial year-to-year variability. SST variability is greatest in the eastern North Sea, while Near-Bed Temperature (NBT) variability is greatest in the eastern and southern North Sea (Holt et al., 2012b). Salinity on the shelf responds to changes in precipitation, evaporation and river inflow, in addition to effects of the link to open ocean salinity variations. Salinity records are characterised by their long-term variability. The present period is the most saline since the 1950, and has remained stable since 2003 (Dye et al., 2013a).

There is a clear requirement for marine climate projections for the NWE shelf seas (e.g. Pinnegar et al., 2012). Despite the useful skill in global climate model simulation of aspects of large-scale ocean behaviour (e.g. Shuckburgh, 2012), the shelf seas are poorly represented in Atmosphere–Ocean Coupled General Circulation

* Corresponding author. Tel.: +44 1392 885680.
E-mail address: jonathan.tinker@metoffice.gov.uk (J. Tinker).

http://dx.doi.org/10.1016/j.pocean.2015.07.002
0079-6611/Crown Copyright © 2015 Published by Elsevier Ltd.

Models (AOGCM, or GCM). In addition to the poor spatial representation of the geography of shelf seas (e.g. GCMs often omit the English Channel and the Irish Sea) important shelf seas processes are excluded. Perhaps the most important of these is tides, which are often the dominant source of mixing energy on the shelf. One solution is to "dynamically downscale" the ocean component of the GCM, as is routinely done for the atmosphere. A higher resolution, regional shelf sea model is driven by forcings derived from a global model simulation. This approach has been used for a number of studies of the NWE shelf. There has been considerable modelling of the NWE shelf seas (e.g. Skogen et al., 1995; Holt and James, 2001; Proctor et al., 2003; Schrum et al., 2003; Holt and Proctor, 2008; O'Dea et al., 2012; Wakelin et al., 2012; Mathis et al., 2013), with several projections of the future climate (Meier, 2006; Ådlandsvik and Bentsen, 2007; Ådlandsvik, 2008; Holt et al., 2010, 2012a; Friocourt et al., 2012; Olbert et al., 2012; Gröger et al., 2013; Mathis et al., 2013). Most climate modelling studies have focused on individual basin, such as the Baltic Sea (Meier, 2006), the North Sea (Ådlandsvik and Bentsen, 2007; Ådlandsvik, 2008; Friocourt et al., 2012; Mathis et al., 2013) or the Irish Sea (Olbert et al., 2012), whereas here we look at the wider shelf seas region, including the North Sea, Celtic Sea, Irish Sea, English Channel.

In this study we present and evaluate a new ensemble modelling system which will be used in subsequent work to provide climate projections for the NWE shelf seas. The modelling system uses a shelf seas model (POLCOMS) to dynamically downscale the HadCM3 model. The ocean lateral forcings are taken directly from the ocean component of HadCM3 (the ocean boundary is beyond the shelf break giving the POLCOMS control over exchange with the open ocean (e.g. Holt et al., 2010)). The HadCM3 atmosphere over the European region is downscaled with the physically consistent regional climate model, HadRM3, which provides the surface forcing to POLCOMS. The HadRM3 run-off fields provide the riverine forcings via the river routing model TRIP. Thus POLCOMS can receive information about changes in the climate mean and variability from HadCM3 via the ocean, atmosphere or rivers.

We use this modelling system to downscale a Perturbed Physics Ensemble (PPE) designed to allow us to consider uncertainty in shelf sea projections arising from uncertainty and limitations in HadCM3. The coarseness of climate models (such as HadCM3) necessitates the use of (imperfect) parameterisations, which may have some poorly constrained parameters, to represent sub-grid scale processes. The ensemble is designed to sample the range of uncertainty associated with the parameters of the HadCM3 atmosphere. Other potential sources of uncertainty, which are outside the scope of this study, include: the forcing model or shelf sea model structure and grid size; the driving methodology; the effect of unforced climate variability on initial conditions and the future emissions of greenhouse gas. In addition, the regional atmosphere model is not coupled to the shelf seas model, introducing an additional source of uncertainty.

This paper focuses on evaluation of the present day NWE shelf seas, as given by our modelling system. Climate models are generally not initialised from, or constrained by, observations, and so the phases of the natural variability in a historical simulation are not expected to be as observed in the real world. This does not invalidate their use in looking at many of the statistics of natural variability or long-term climate trends. We typically compare 30-year modelled and observed mean (and variance) fields, so as to reduce the effect of natural year-to-year climate variability. Low frequency natural variability, however, will still influence the comparison against observations. To make an assessment of the role of low frequency variability, we run a shelf sea simulation using forcings from a long HadCM3 "control" climate simulation, which has fixed, pre-industrial radiative forcings.

2. Method

Our ensemble of shelf seas simulations is produced by POLCOMS (Proudman Oceanographic Laboratory Coastal Ocean Modelling System), which is driven by consistent atmosphere, ocean and riverine forcings derived from an 11-member PPE. The methodology is based on, but further developed from, that of Holt et al. (2010). Each shelf seas simulation is run as a transient experiment over the 1952–2098 period (here we focus on the historical period). The overall chain of models in our modelling system is as follows (Fig. 1): HadCM3 is run with historically time-varying concentrations of greenhouse gas and other radiatively active constituents; the ocean component of the HadCM3 provides the oceanic boundary forcing; the HadCM3 atmosphere over the NWE shelf sea region is dynamically downscaled with an ensemble of physically consistent variants of the (atmosphere-only) regional climate model HadRM3 (Jones et al., 2004) providing the surface forcing for the shelf seas model; The river inflow to the shelf seas is provided by passing the HadRM3 run-off through the river routing model TRIP (Total Runoff Integrating Pathways; Oki and Sud, 1998; Oki et al., 1999). This chain of models is run for each member of the PPE to span the range of uncertainty of the PPE. This hierarchy of models provides a set of self-consistent forcing with which to simulate the shelf seas, albeit with the limitation of not allowing the shelf seas to feedback to local atmosphere of the wider climate.

2.1. Climate forcings

The HadCM3 model (Gordon et al., 2000; Pope et al., 2000), on which the PPE is based, has been used extensively, both for climate projections, including in the IPCC (Intergovernmental Panel on Climate Change), Third Assessment Report (TAR), and Fourth Assessment Report (AR4) (IPCC, 2001, 2007), and also for investigations of climate variability (e.g. Gregory et al., 2004; Knight et al., 2005). The atmosphere has a horizontal resolution of $2.5^\circ \times 3.75^\circ$ with 19 vertical levels. The ocean has a resolution of $1.25^\circ \times 1.25^\circ$, with 20 depth levels. The PPE that we use was developed by the Quantifying Uncertainty in Model Projections (QUMP) project, and is described in detail in Collins et al. (2011) and Harris et al. (2013). Here we give a brief overview.

The PPE basis model differs from the CMIP3 (third phase of the Coupled Model Intercomparison Project) version of HadCM3 by using flux adjustment. Flux adjustment allows a wide range of parameter perturbations to be explored, while limiting model climate drift under fixed greenhouse gas conditions. Around 30 parameters of the atmosphere component (given in Table 1 in Rougier et al., 2009) were perturbed within expert-specified ranges. A wide range of single and multiple parameter perturbation simulations (~280) were run to equilibrium, using slab-ocean-model versions and under both fixed-present-day and doubled-CO_2 conditions. The resulting estimates of equilibrium climate sensitivity (a measure of how much the global mean temperature eventually rises with a doubling of CO_2) were divided into 16 equally probable bins and the parameter-set that best validated against observations in each bin was noted. This gave an ensemble of 17 multiple perturbed parameter settings, with inclusion of the unperturbed or standard ensemble member, with a range of equilibrium climate sensitivity ranging from (2.26–5.46 °C, Harris Pers. Comm.). The perturbations from this set were then applied to the fully coupled HadCM3 version for transient policy-relevant