Tentative summary of the workshop:

"Predicting midlatitude circulation changes: what might we gain from high res modelling of air sea interactions?"

25-26 Feb 2019, the Grantham Institute at Imperial College

NB. Focus here is specifically on the positive/negative results brought about by changing model horizontal resolution and the effect this has on the jet stream / storm track system.

Brief overview of the workshop

The workshop was attended by about 35 participants, covering universities and climate centres worldwide. A total of 14 talks were presented, and two plenary discussion sessions took place.

Positive results (evidence that increase in resolution strengthens the oceanic forcing of the jet stream-storm track system or overall improves simulations)

Mechanisms. Better understanding of the moisture transport by cyclones: less emphasis on "chaotic advection", that is, the sweeping of moisture from deep in the tropics to high latitudes (the "pineapple express" view), but more emphasis on local air sea interactions and local convergence of moisture organised by cyclones as they move poleward (Helen Dacre, Reading Uni). Western boundary currents were highlighted as an important source of moisture for the cyclones. This view might help to understand the results presented by X. Ma (Qingdao Uni, see below) that ocean mesoscale eddies boost the moisture influx into the marine boundary layer. Similarly, a general increase in precipitation in the storm track is seen in PRIMAVERA in high res models compared to low res models (but see below). R. Parfitt (FSU) suggested that 25km might represent a threshold resolution in the atmosphere at which oceanic and atmospheric fronts can start "seeing each other" (this can be rationalised by requiring at least four gridpoints to resolve frontal features on a scale of ~100km). He showed that simple thermal damping and strengthening arguments based on the relative orientation and "packing" of oceanic and atmospheric isotherms can explain the changes in precipitation seen in ERAint when the resolution of the forcing SST dataset was changed.

Coupled set ups. An improvement of forecast skill on short (1-4 weeks) lead times when coupling a 31km atmosphere to a ¼ degree ocean compared to a 1 degree ocean was found (C. Roberts, ECMWF). A shift of the jet stream was also observed, possibly in response to the mean bias in SST on these short timescales. In a similar set up, S. Drijfhout (Southampton Uni and KNMI) showed that interannual surface pressure variability was enhanced in winter near the Kuroshio and Gulf Stream in the ¼ degree ocean configuration of EC-Earth, compared to that found in the 1 degree ocean case (at fixed T255 atmosphere, but the T511 Atmosphere coupled to the ¼ degree ocean also showed enhanced SLP variance there). B. Vannière (PRIMAVERA) showed that the high res coupled version of HadGEM3 generally performs better than the high res AMIP version in terms of European blocking frequency. Likewise, M. Roberts (UK Met Office) showed that biases in extra-tropical cyclone track densities in the PRIMAVERA models are reduced in coupled models when the resolution is increased (but see below). Finally J Small (NCAR) showed that the location of surface storm track was better in a coupled simulation with 0.1deg ocean, compared to 1deg., including reduced surface storm track bias off the US East coast compared to ERA-Interim, most notably in CESM (however see the comments below on storm track strength).

-*Prescribed SST set ups.* In a regional model of the North Pacific (WRF at 27km resolution), X. Ma (Qingdao Uni) presented evidence for a rectified response of the storm track to the presence of oceanic mesoscale activity. This response (southward shift of the storm track when mesoscale SST signals are removed) was not captured by the low resolution version of the model (162km). Similarly, C. Frankignoul (UPMC) showed that CAM5 developed an upper level response to an SST anomaly along the Kuroshio when run at 25km resolution, but no symmetric response (warm-cold case) was found at 100km resolution (but see Negative results section below).

Negative results (no indication that increasing resolution strengthens the oceanic forcing or improves simulations)

-NAO hindcast experiments by the Met Office showed a degradation of predictive skill (correlation between observed and ensemble mean NAO decreasing from ~0.6 to ~0.3) when going from a 60km atmosphere to a 25km resolution atmosphere both coupled to a 25km ocean (N. Dunstone, UK Met Office). Although this might be expected for a forecast at a given location (assuming increased "noise" at higher resolution), it is more surprising for a large scale pattern such as the NAO. This might actually reflect a higher level of noise (eddy mean flow interaction) in the high res simulations, a possibility supported by the increase in (synoptic) eddy vorticity forcing of the NAO with increasing resolution (60km, 25km and even 10km cases were shown by N. Dunstone, reporting on results from Scaife et al., in preparation). Or it could reflect the fact that at 25km the atmospheric model starts responding to the incorrect ocean dynamics resolved by the ocean component (itself 25km) of the forecasting system. Comparison of the hindcasts of the strong 2009-10 and 2012-13 NAO estimated with a 1/12, ¼ and 1 degree ocean by the UK Met Office did not show a strengthening of the NAO signal when the resolution was increased (but note that the atmospheric resolution was fixed at 60km). Attempts to show that the lack of Atlantic multidecadal variability in coupled models might result from insufficient resolution failed: indeed, I. Simpson (NCAR) reported that the higher resolution models in PRIMAVERA did not display a larger response in zonal winds at 700hPa in the North Atlantic when forced with the (1985-2000)-(1950-1965) global SST change.

-In the experiments with CAM5 discussed by C. Frankignoul (UPMC) the response of the atmosphere is asymmetric and non stationary. Surprisingly, it was found that the response of the low resolution configuration produced a similar response to the warm and cold SST anomaly, explaining the lack of signal at upper levels when considering the warm-cold response. In addition, the upper level response in both the high and low resolution version of CAM5 shows a complex time evolution between early and late winter (i.e., it is different in each separate month and does not reflect the winter average).

-Although the skill was improved in the IFS when using a ¼ degree as opposed to a 1 degree ocean model (C. Roberts, ECMWF), the increase in the ensemble spread in SST near the Gulf Stream was not matched by an increase in the spread of the atmospheric members in the North Atlantic. This is difficult to explain if the working hypothesis is that the atmosphere is responding to the ocean in this region.

-The mean state (zonal wind) simulated by high res models in PRIMAVERA is generally less realistic than the lower resolution version of the models in both fixed SST and coupled set-ups (B. Vannière, Reading Uni). The hydrological cycle is enhanced but in midlatitudes the increase in precipitation reflects cold sector dynamics rather than an enhancement of precipitation in the warm sector of the cyclones, as might have been anticipated from the better representation of frontal circulations at higher resolution (this needs to be confirmed by a further partitioning of precipitation into parameterised and resolved precipitation in the warm sector).

-Track density biases in PRIMAVERA atmosphere-only models appear insensitive to resolution change and SST forcing dataset, in either winter or summer (M. Roberts, UK Met Office).

-The coupled simulations of J. Small et al in CESM and GFDL coupled models showed there was little sensitivity of storm track strength between ocean resolutions of 0.1deg and 1deg. This contrasts sharply with the significant sensitivity found in atmosphere-only simulations forced by realistic or smoothed SSTs in the North Pacific and Atlantic, suggesting that the role of the ocean circulation in the coupled problem might not simply be viewed as an enhancer of SST gradient.

New diagnostics

-S. Minobe (Hokkaido Uni) presented a new experimental set up where an AGCM experiences sensible or latent heat flux only forcing. This tool suggested that the response of a regional model (iRAM run at 50km resolution) to a smoothing of SST pattern in the North Atlantic is shaped jointly by sensible and latent heating (for example the vertical velocity field seems to respond to sensible heat flux at low levels and latent heat flux higher up in the air column). It was suggested that a comparison of dynamics between the Gulf Stream and Kuroshio would be a very useful study to disentangle further mechanisms. A discussion of this issue indeed suggested that the dynamics might be quite different because of the particular geometry of the US East coast, where the high surface temperature associated with Gulf Stream advection reinforces the background SW-NE land-sea temperature contrast.

-R. Lee (Reading Uni) showed that some of the biases seen in the global configuration of the UK Met Office model (GC2) can be explained by biases in SST associated with an inaccurate representation of the Gulf Stream and also larger scale SST biases in the North Atlantic. The skill is seen in the vertical velocity field in the western Atlantic as well as the meridional velocity field (850hPa and 250hPa) in the North Pacific and Atlantic. A fair amount of time mean signal is generated in the North Pacific by North Atlantic SST biases, irrespective of whether they reproduce or not the biases seen in the coupled model. This emphasizes the challenges in understanding the origins of changes obtained when comparing low res and high res *global* simulations.

-The issue of vertical resolution was briefly touched upon and the overall suggestion based on numerical weather forecast was that it was not obvious that vertical resolution would matter so much as horizontal resolution. Nevertheless, for a resolved mesoscale motion (Rossby number $Ro = U/ fL = 1$), the vertical velocity scales like $W = U H/L = fH$. If the mesoscale motion is deep ($H=10km$) the updraft will be $W=1m/s$ in midlatitudes. It is possible that a fine enough vertical grid is required to reduce numerical diffusion to allow these large velocities to develop.

Further remarks

(i) We seem to be back to the late 1990s when there were quite a few experiments showing response to SST anomalies in midlatitudes but also a lot of spread between the responses and changes produced by the models. At that time, several paradigms and simplified models were developed (e.g., Peng and Whitaker, 1999; Barsugli and Battisti, 1998; Peng and Robinson, 2001) and, as a result, there was the feeling that understanding was improved (see for example the reviews by Robinson et al., 1999 and Kushnir et al., 2002). We seem to be currently lacking an equivalent.

(ii) At an even more basic level, there is a need to design controlled experiments to help in the interpretation of global coupled modelling studies. Indeed, the comparison of HR and LR in global coupled models, either on timescales shorter or longer than seasonal, is difficult to interpret as so many things can change (e.g., midlatitude vs tropical state). One wonders whether, as a result of the need for high resolution forecast and climate predictions, one has not “put the cart before the horses”.

(iii) A popular modelling strategy is to consider a high res model (e.g., WRF) forced by prescribed lateral boundary conditions and SSTs (e.g., the study discussed by X. Ma). The limitations of this set-up are currently not well understood: how much are the simulated changes in storm development and jet stream motions impacted by fixed conditions at lateral boundaries? Results must thus be taken with caution and more tests must be performed. No results were shown at the workshop using high res atmospheric models coupled with 1D ocean column with mixed layer physics although this seems to be a promising tool to investigate the mechanisms of air-sea coupling on scales of ~10km, albeit only for short (~seasonal at most) timescales.

(iv) Very large number of simulations are required to match the demands of large ensemble (to separate signals from noise), multiple scenarios (to account for policy decisions) and multiple models (to account for model uncertainties). For some years this will not be achieved at the 10km scale globally and alternative strategies for coupled ocean-atmosphere modelling must be considered. A possibility is to use the mesoscale parameterisations developed in the 1990s (e.g. Lindstrom and Nordeng, 1992) in a coarse (~100km) AGCM coupled to a high resolution (~10km) OGCM (one can argue that the oceanic side of the problem is simpler and mostly a fluid dynamics problem so convergence is expected as the resolution increases –see discussion in the review by Hewitt et al., 2017). This is just one possibility out of many: the workshop motivated the feeling that one shouldn’t just crank up the resolution of the current generation of CGCMs.