

Designing experiments to assess the need for high resolution models for coupled prediction

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Development of coherent designs and collaborations for experiments

- This talk: provoke discussion on experiments
- Broadly arranged by prediction timescales
- What is the evidence for high resolution at this timescale?
How would we produce the evidence?
- Discussion also of observational requirements and opportunities



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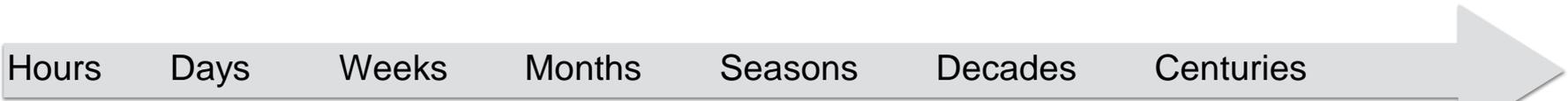
Outline

- **Introduction**
- **Coupled NWP**
- **Initialised seasonal and decadal prediction**
- **Climate projection**
- **Summary**

Global Physical Modelling



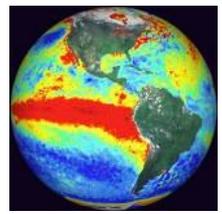
Unified Prediction across Timescales



NWP - Atmosphere, Ocean, Waves
Deterministic

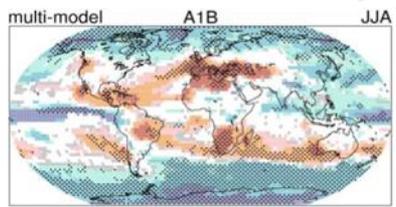


MOGREPS



GloSea

Decadal



Climate Change &
UKESM1

Component Models
GA7 , GL7, GO6, GSI7/8

Coupled AOIL Model
GC3.0



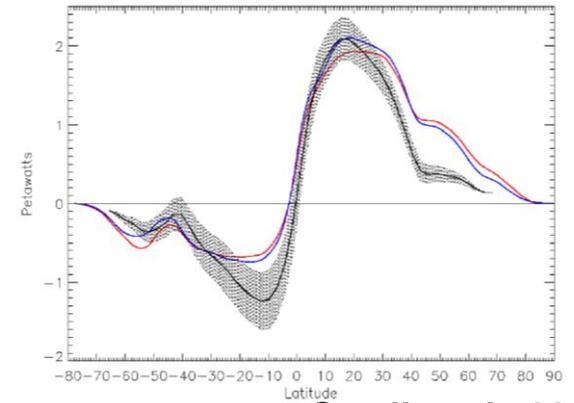
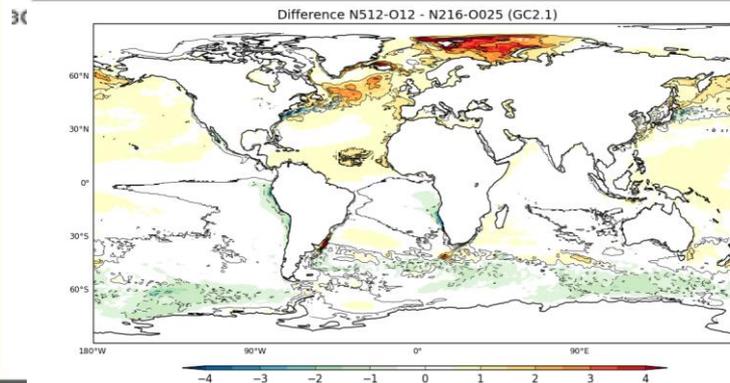
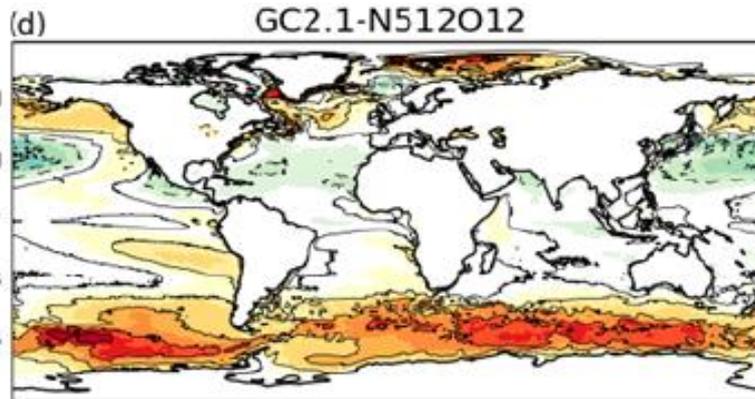
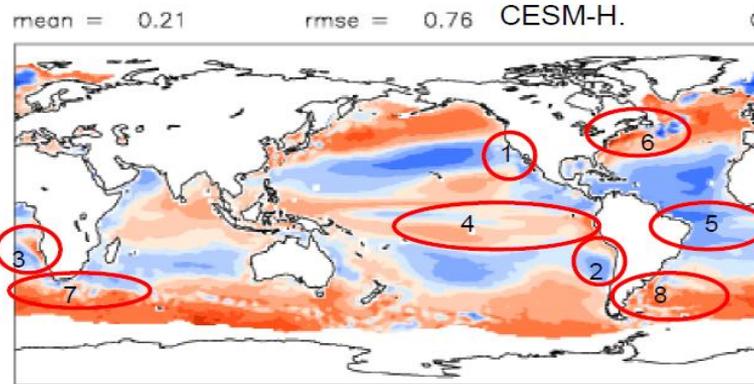
The case for High Performance Computing capacity

- The case for HPC requirements needs to be written years in advance of any increases in computing capacity
- To justify the increases in capacity that would be required for high resolution ocean models across a range of timescales, we need to produce evidence that the increase in resolution will improve forecasts and projections
- Hence the growing need for coordinated experiments which demonstrate this as well as allow differences between models to be explored
- Experiments need to have as small a computational cost as possible

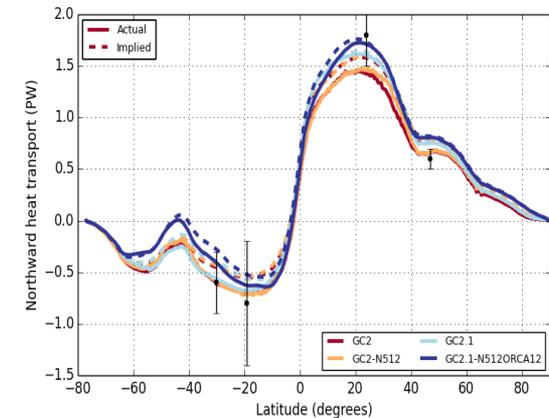


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Control climate experiments



Small et al., 2014



Hewitt et al., 2016

Similar improvements in both NCAR and Met Office in SST errors and heat transports

BUT no demonstration of impact on forecasts or projections

Insufficient to argue for increased HPC resource



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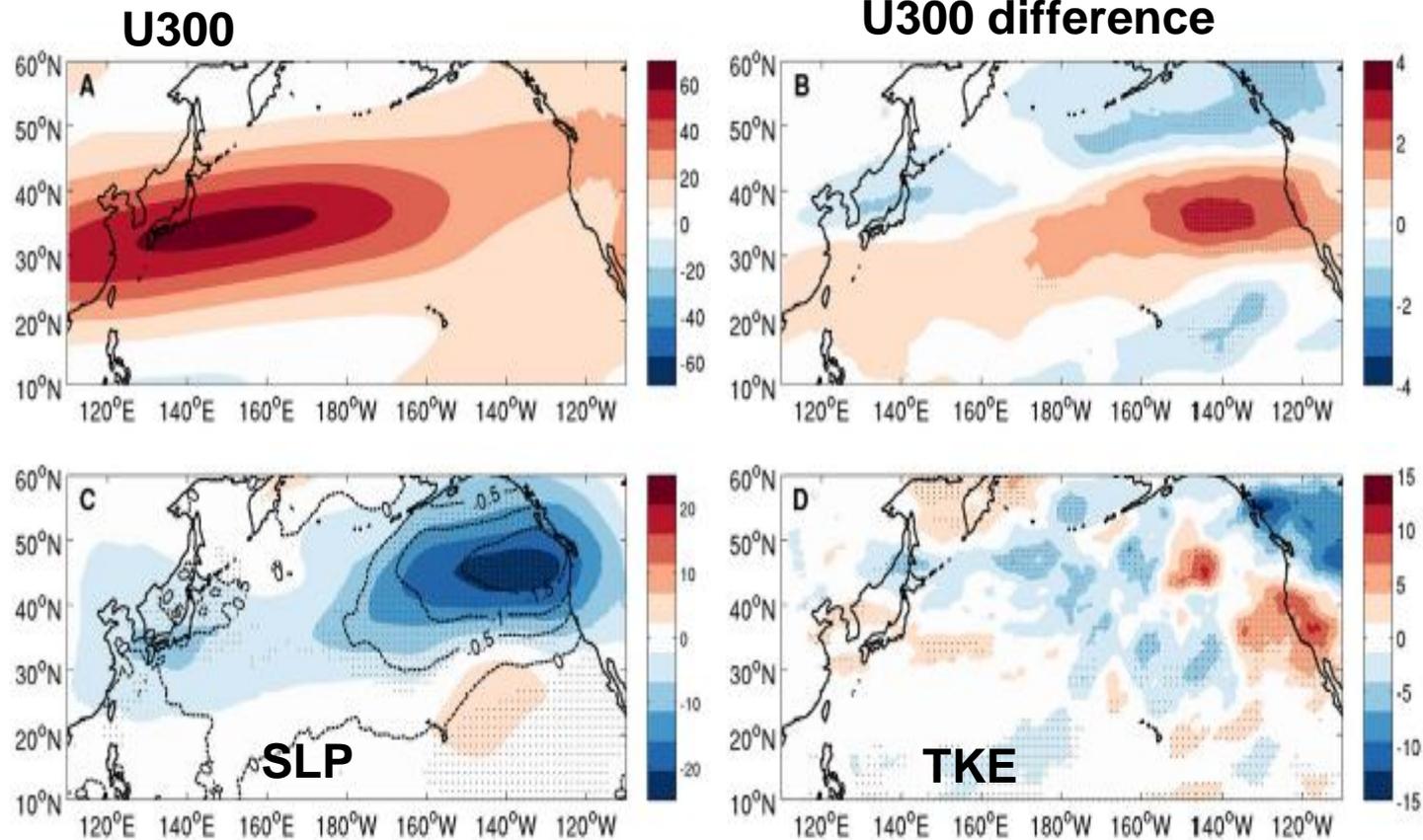
NWP

- **Goal is to improve weather forecasts**
- **Is the ocean mesoscale important?**
 - **Resolution of SST fields**
 - **HighResMIP**
- **Is high resolution ocean component likely to be necessary?**
 - **NCAR results**
 - **The jury is still out....**
 - **Need for coordinated experiments**



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Impacts of SST resolution on atmosphere simulation



Ma et al. 2015

Compare atmosphere
model with actual and
filtered SST fields



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HighResMIP

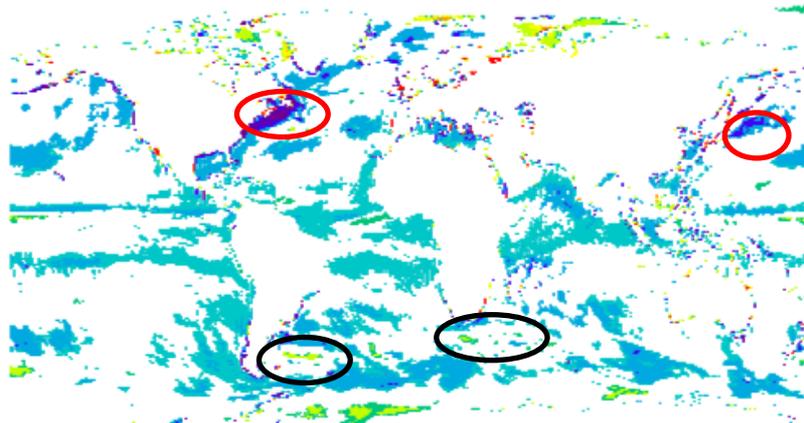
- Coordinated experiments
- Reference HighResMIP simulation is AMIP run with daily $\frac{1}{4}^{\circ}$ SST forcing (HadISST2; Rayner et al.)
- Twin experiment with spatially low-pass filtered SST to dissect the effect of mesoscale air-sea coupling (for further details see Haarsma et al.)



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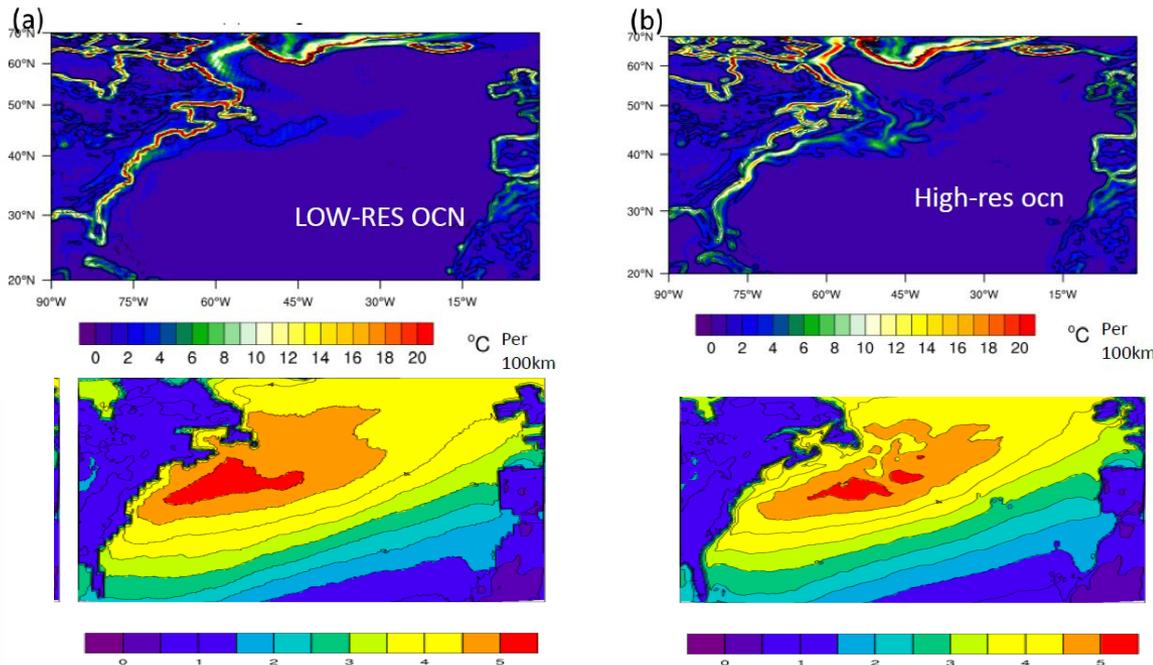
- Very little sensitivity of storm track to including high resolution ocean model
- Storm track activity amplified by SST gradients
- Storm track location governed by SST gradients and air-sea stability i.e. “anchored”
www.metoffice.gov.uk

Storm tracks in coupled experiments



Difference between run with HR-OCN minus LR-OCN, showing 95% significant values, based on 30 winters.

REDUCTION in storm track strength due to stability



Justin Small

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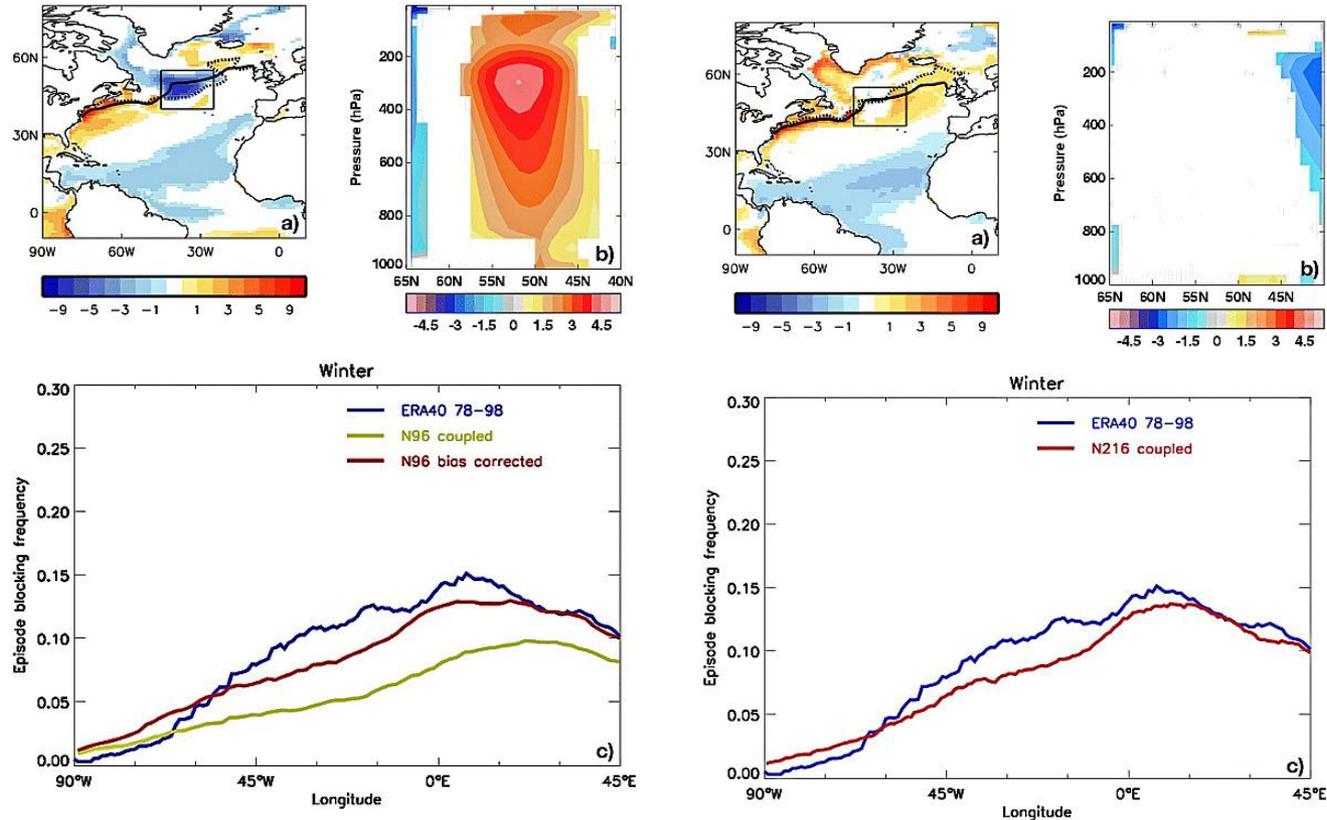


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Seasonal Prediction

- Increased resolution has already demonstrated evidence for improved prediction
 - Horizontal
 - Vertical
- How do we move forward as the resolutions gets finer and the costs get greater?

Improved winter blocking at eddy permitting resolution



Improved current path likely due to increased communication between surface and deep ocean (and may not be for entirely correct reasons)

Scaife et al., 2011



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Evidence for high vertical domain - impact surface winter climate

Oct

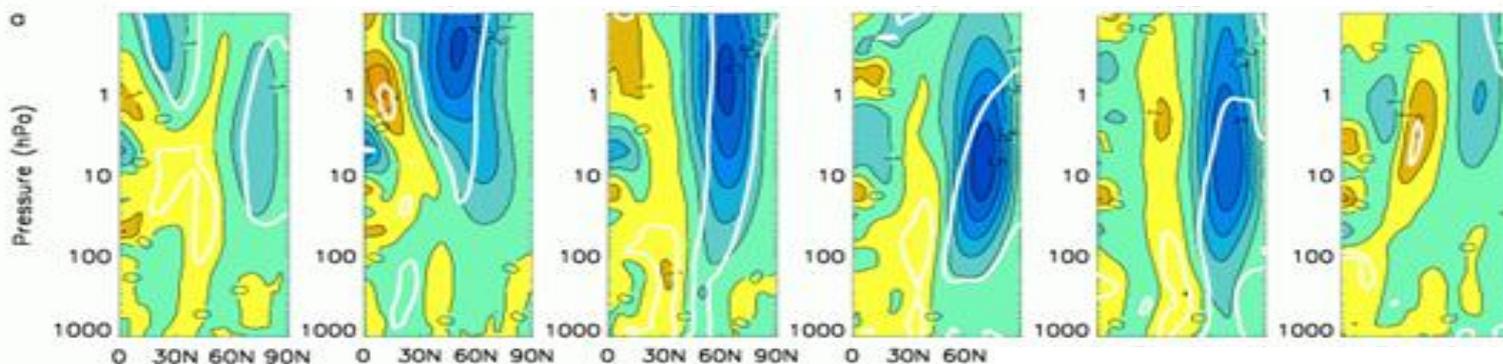
Nov

Dec

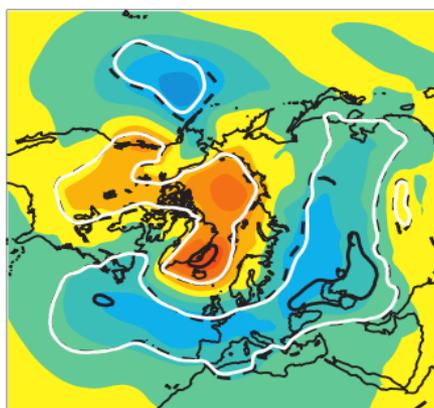
Jan

Feb

Mar

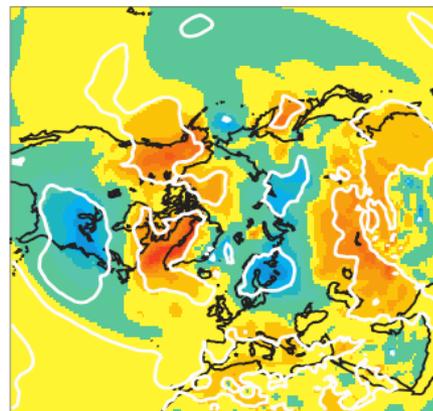


Sea Level Pressure

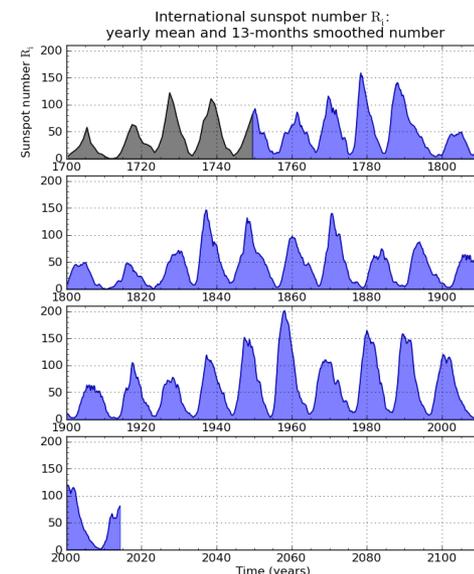


Model sea-level pressure difference (hPa)

2m Temperature



Model temperature difference (K)



SILSO graphics (<http://sidc.be>) Royal Observatory of Belgium 01/12/2014

Ineson et al, 2011.

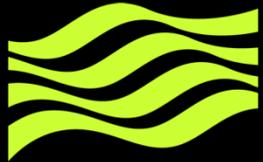
Solar min => negative NAO/AO



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Cost of seasonal predictions

- Testing the impact of resolution in the full seasonal prediction system will be very expensive
 - 20 years x 6 start dates x 7 members
 - 840 members = ~490 simulation years!
- Large ensembles are required because signal to noise is typically fairly low
 - Is resolution likely to have any impact on the signal to noise?
- Experiments for testing
 - Hypothesis experiment
 - or 2 years x 1 start date x 20 members
 - 40 members = ~23 simulation years



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Signal to noise

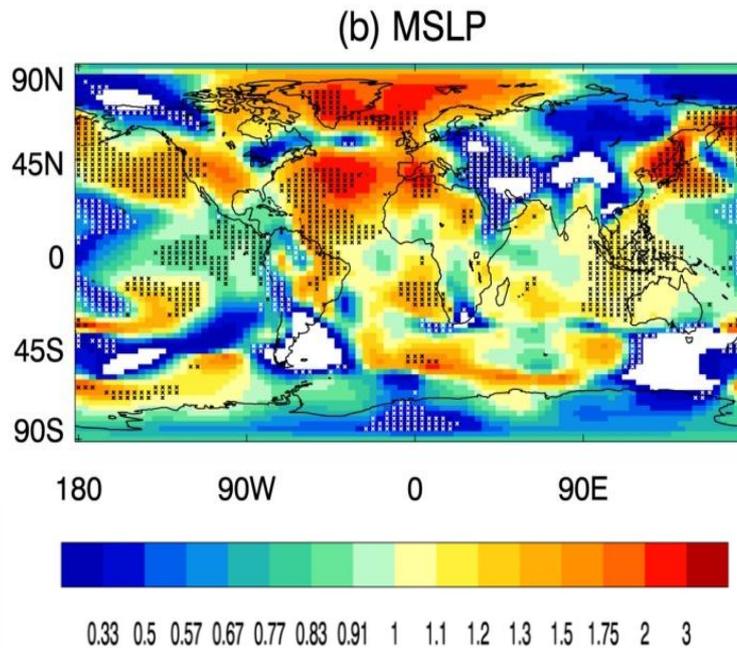
$$RPC = \frac{PC_{obs}}{PC_{mod}}$$

$$= \frac{corr(ens.mean, obs)}{\sigma_{ens.mean} / \sigma_{ens.members}}$$

Perfect forecast system: $RPC = 1$

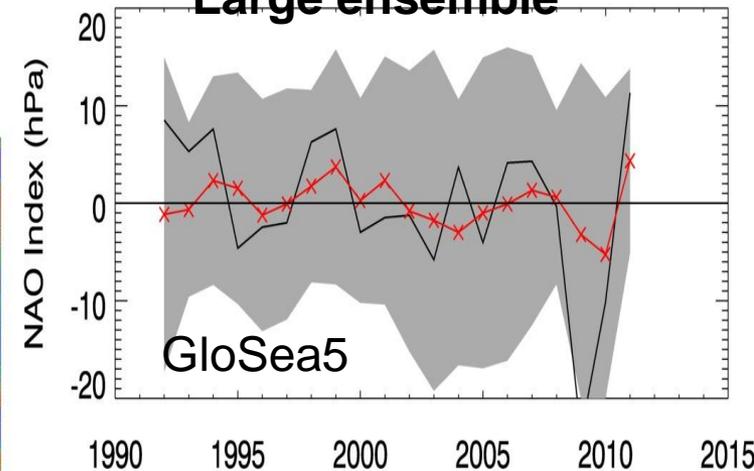
$RPC \ll 1$: over-confidence, ensemble members agree well with one another but not with observations

$RPC \gg 1$: under-confidence, ensemble mean agrees well with observations but members agree less well with each other



Eade et al. (2014), GRL

NAO correlation=0.6
Large ensemble



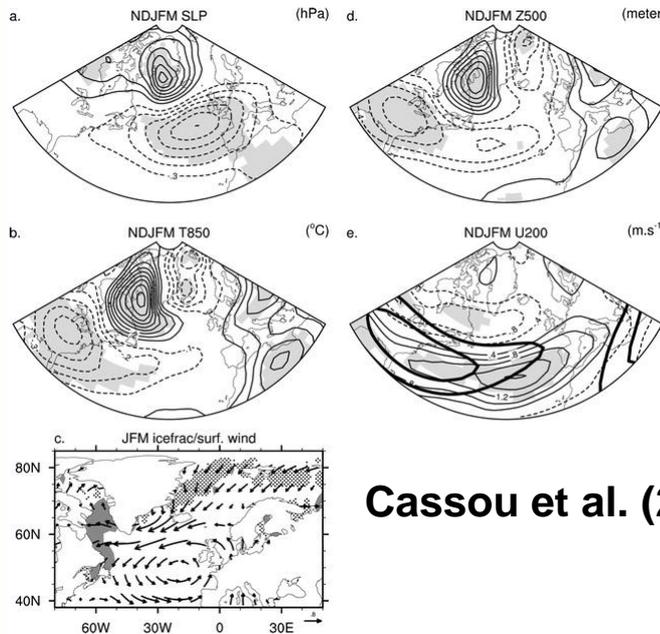
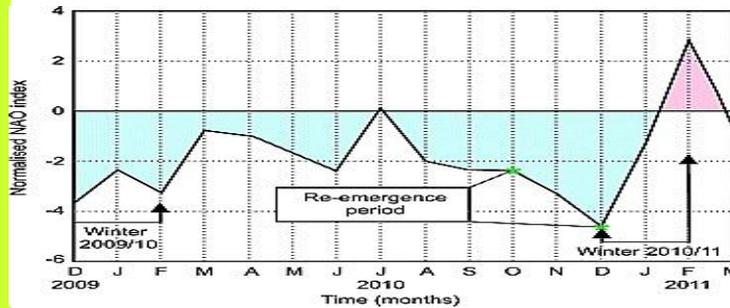
- $RPC = 2.3 \gg 1$, i.e. under-confident (correlation not matched to signal-to-noise ratio)
- Correct variances to make $RPC = 1$

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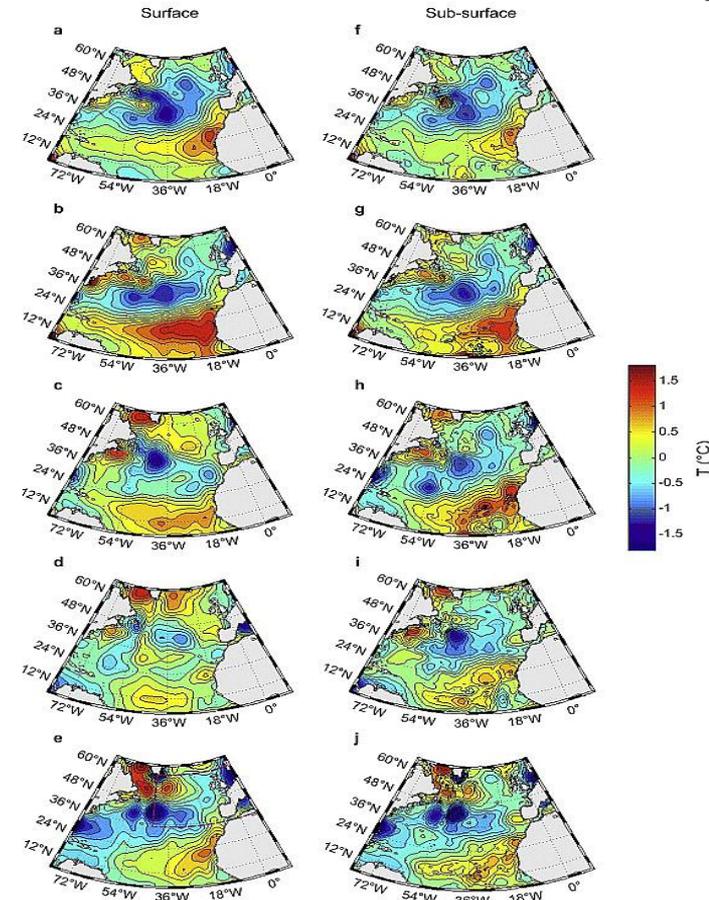


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Experimental design for impact of resolution on seasonal forecasting?



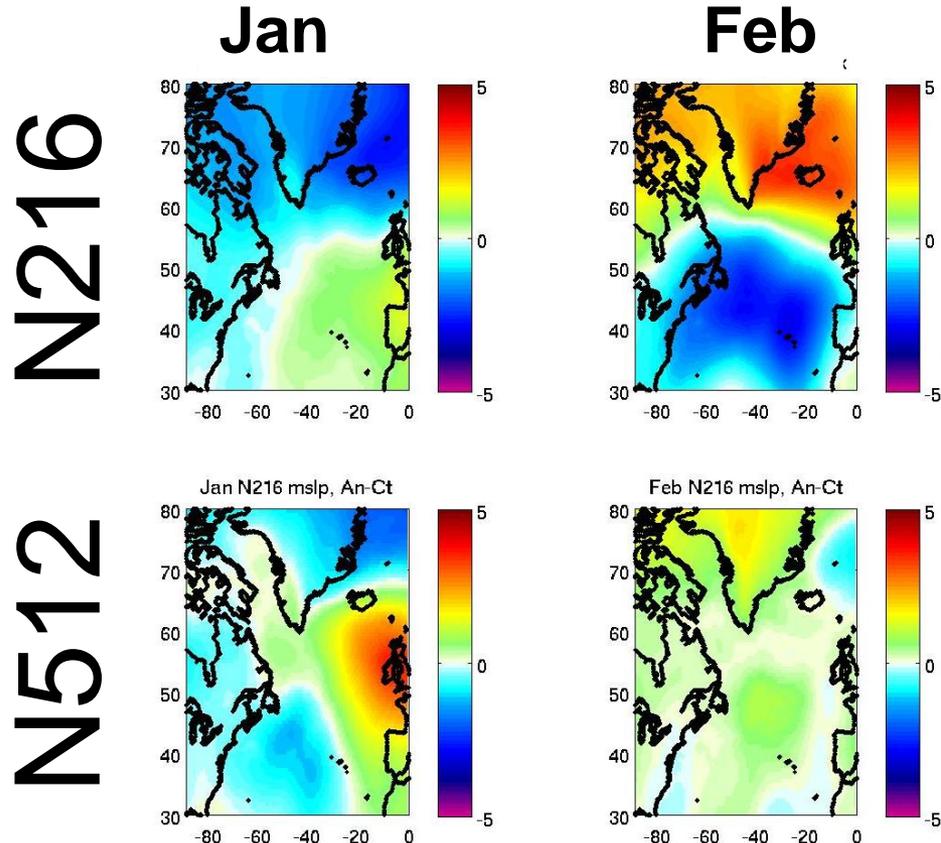
Cassou et al. (2007)



Taws et al. (2011)

Charisma results

Impact on SLP after initialisation in September



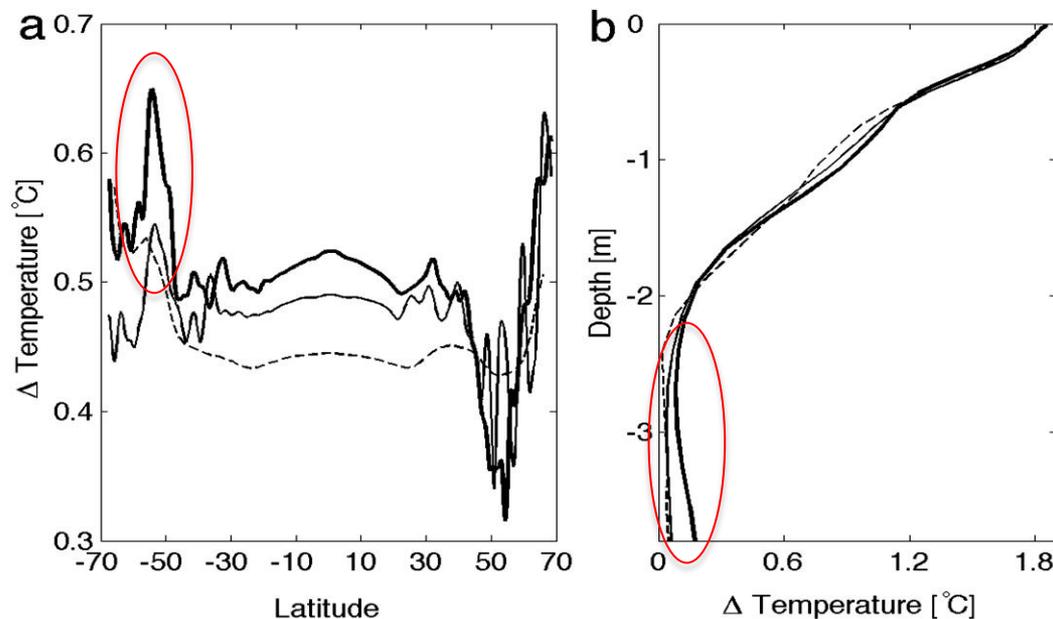
Talk by Jeremy Grist



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Climate projections

- The magnitude and pattern of ocean heat uptake determines the climate change response
- Is resolution important?

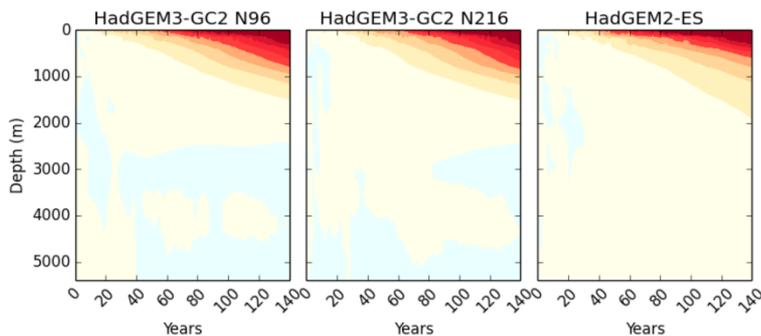


Zhang and Vallis, 2013



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Impacts of resolution on ocean heat uptake in HadGEM3

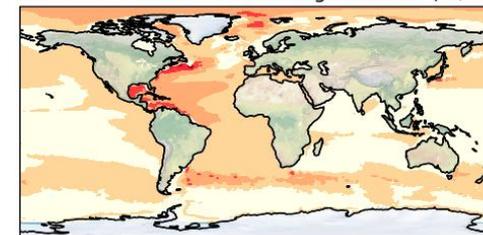


1% runs

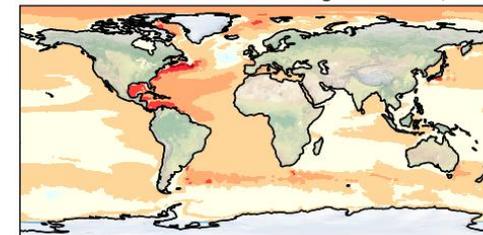
Impact of ocean
(and atmosphere)
resolution

Senior et al., submitted

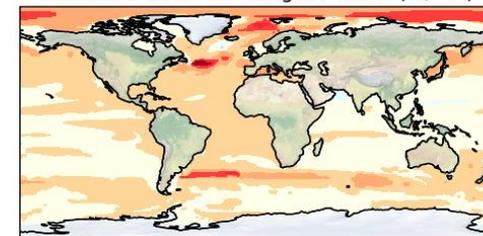
HadGEM3-GC2 N96 OHC change 0-814m (W/m^2)



HadGEM3-GC2 N216 OHC change 0-814m (W/m^2)



HadGEM2-ES OHC change 0-793m (W/m^2)

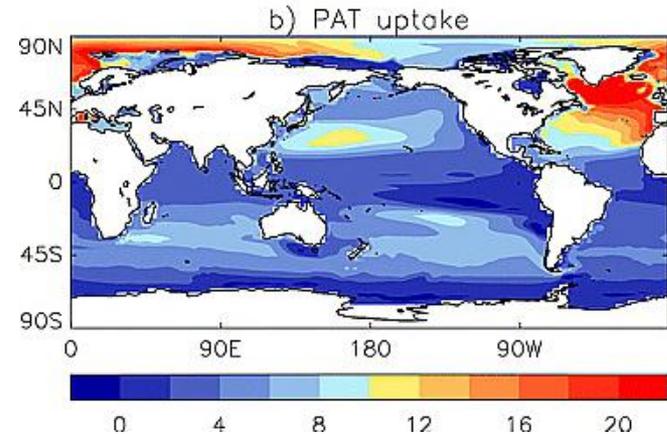
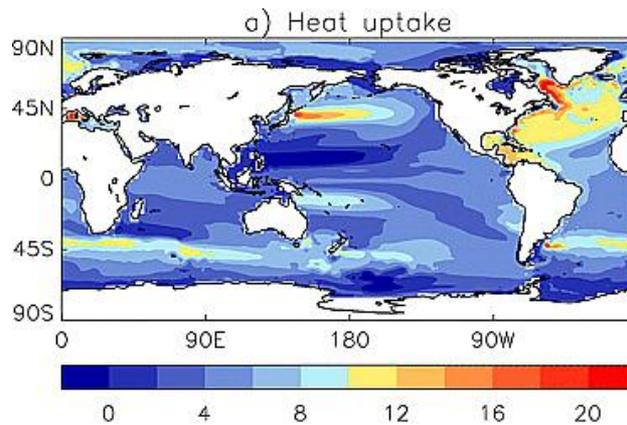




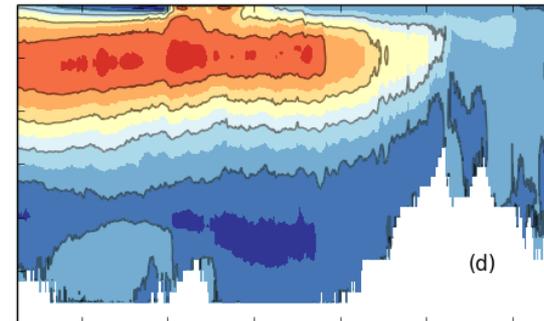
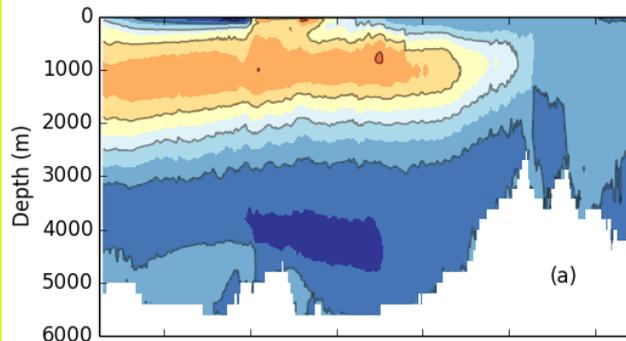
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Ocean heat uptake

- Both ventilation and redistribution important
- Improvements to the large-scale circulation with high-resolution ocean models could be important



Banks and Gregory, 2006

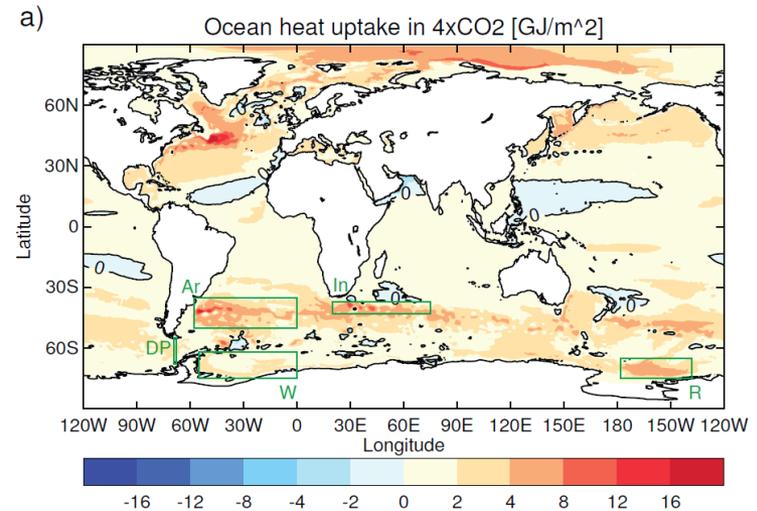


AMOC at $1/4^\circ$
and $1/12^\circ$

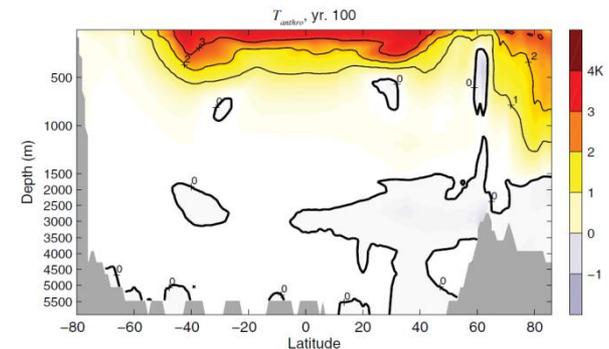
Hewitt et al.,
2016

What is the best choice of coordinated experiment?

- HighResMIP: 1950-2050 historical then RCP8.5
- RCP8.5: 2000-2100
- 4xCO₂: CMIP DECK experiment – 20 years
- Ocean only experiments (eg, Marshall et al., 2014)
- Ensembles? Eg, NCAR large ensemble



Kuhlbrodt et al., 2015



Marshall et al., 2014



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Summary

- Opportunity to define coordinated experiments to determine the role of ocean resolution over a range of prediction timescales
- HighResMIP presents an opportunity to examine the impact of the ocean mesoscale on atmosphere simulations
- CMIP6 includes experiments that could be carried out a low and high resolution to understand the climate change response
- Less clear on way forward on coupled forecasts on timescales of days to decades



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Any questions?

