Met Office

Discovering the impact of the ocean mesoscale on multi-centennial climate

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US CLIVAR Mesoscale and frontal-scale air-sea interactions workshop
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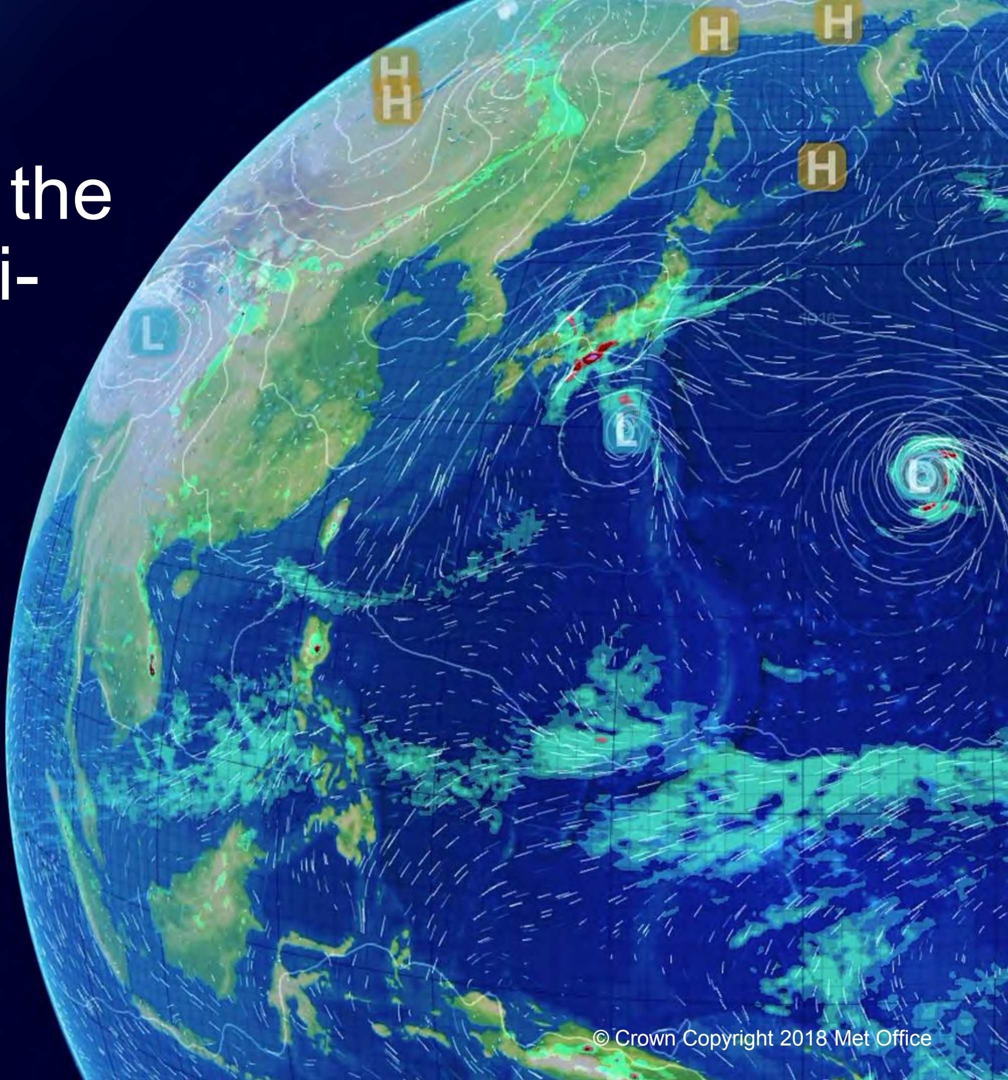
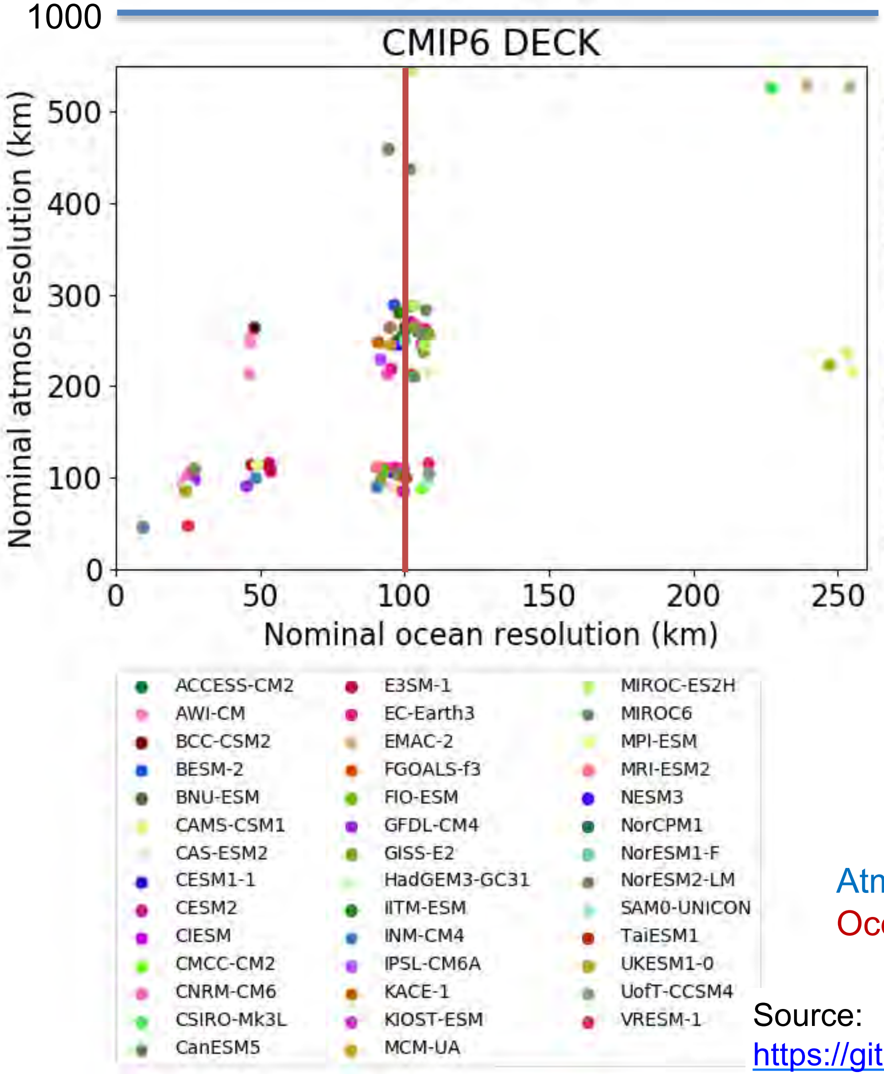


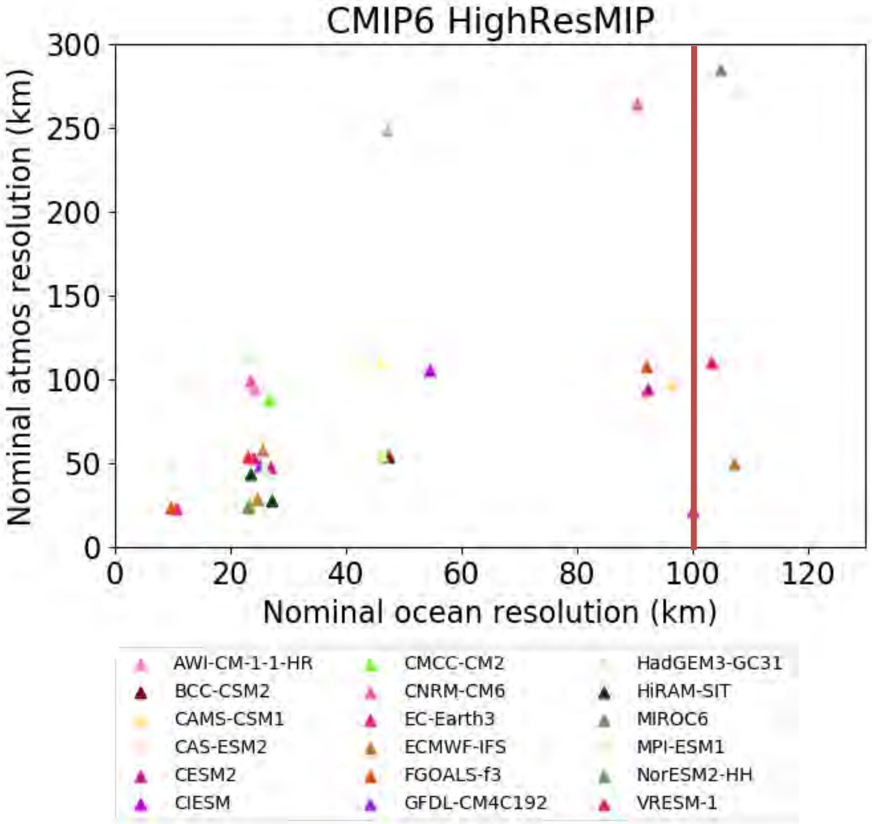
Spoiler alert

- I'm not able to tell you the answer!
- We're beginning to be able to run the model simulations needed to try to answer the question
  - and ideally better understand the observations we need and/or better exploit the observations we have
- But we still have many questions about:
  - what the most useful model simulations might be,
  - what diagnostics/data do we need to produce, and how can we keep the volumes manageable
  - how should the data be processed to enable the most efficient distribution and access
  - what other observations we might need

The challenges

- Need climate models with sufficient model resolution (and physics and...) to capture key processes
- Need observations with sufficient resolution (space and time) to be able to constrain such models, e.g. surface fluxes as just seen
- Designs for model simulations that:
  - are feasible by a diverse set of modelling groups and models
  - can produce the diagnostics and metrics to enable assessment of processes of air-sea interactions (as we've learnt this week)
  - methods to share such data for community analysis
- CMIP6 HighResMIP may be a good first step
  - simulations were general and long (1950-2050), and provided a common framework for ~17 groups that participated in at least some experiments
  - diagnostic lists were large to enable climate analysis, but not specific for e.g. air-sea interactions (very restricted sub-daily outputs)





Atmos deformation radius ~1000 km

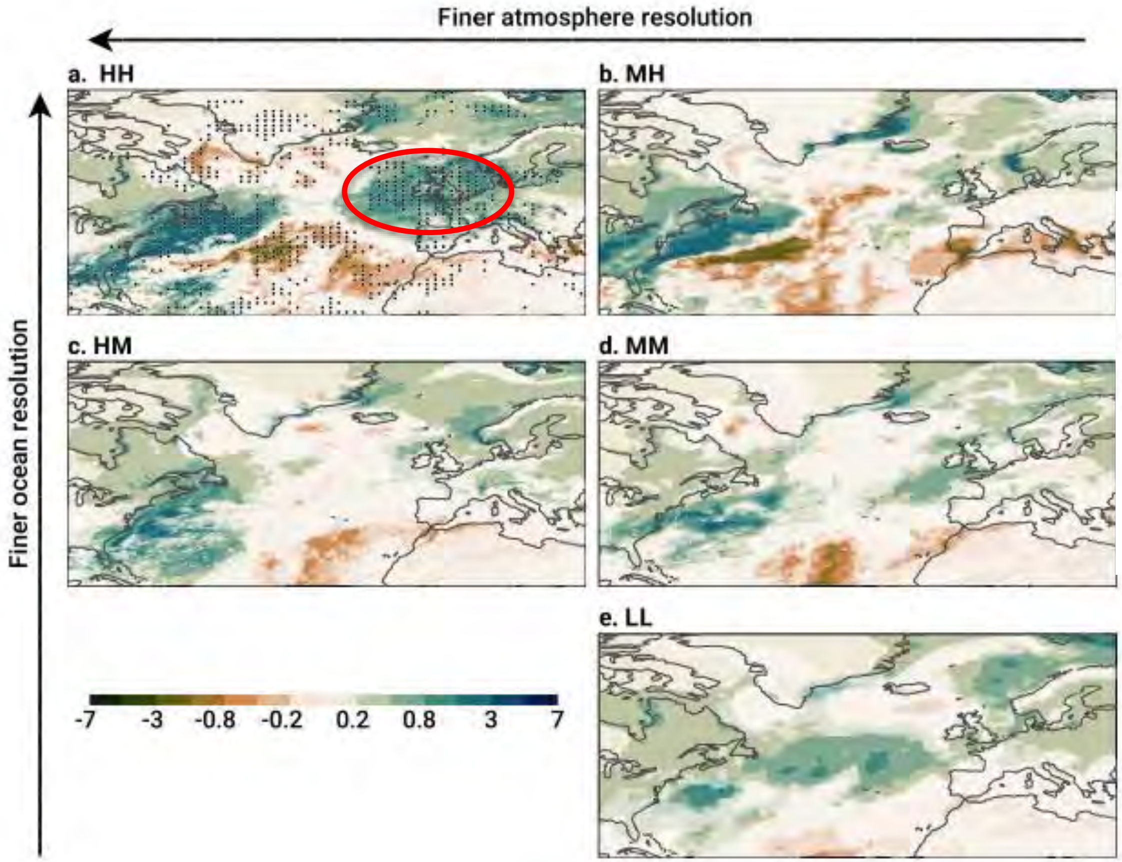
Ocean deformation radius ~100 km (at low latitudes)

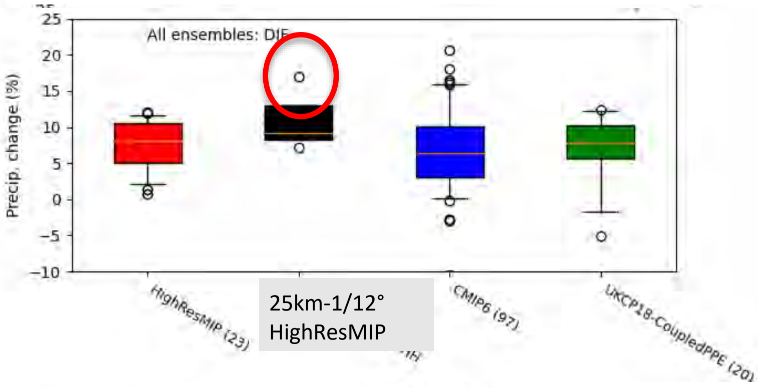
Source:
https://github.com/WCRP-CMIP/CMIP6_CVs/blob/master/CMIP6_source_id.json

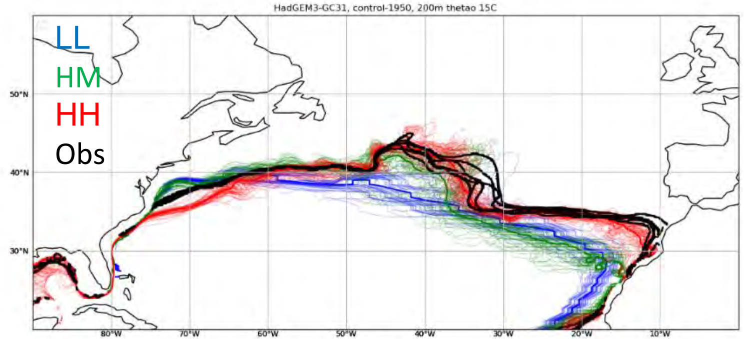
Eddy-rich simulations indicate potential for enhanced climate risk

- Impact of representation of the Gulf Stream in an eddy-rich global, coupled climate simulation
- With a different separation path (compared to ALL CMIP6 models), there is potential to produce significant climate impacts over northern Europe (as a combination of mean state changes, and variability)
- Change in Gulf Stream over time, in conjunction with enhanced air-sea coupling, leads to increased precipitation
- Variability also plays a role

Rainfall %age change, DJF, 2030-50 - 1960-80, over Europe 20W-30E, 40-65N from different multi-model ensembles





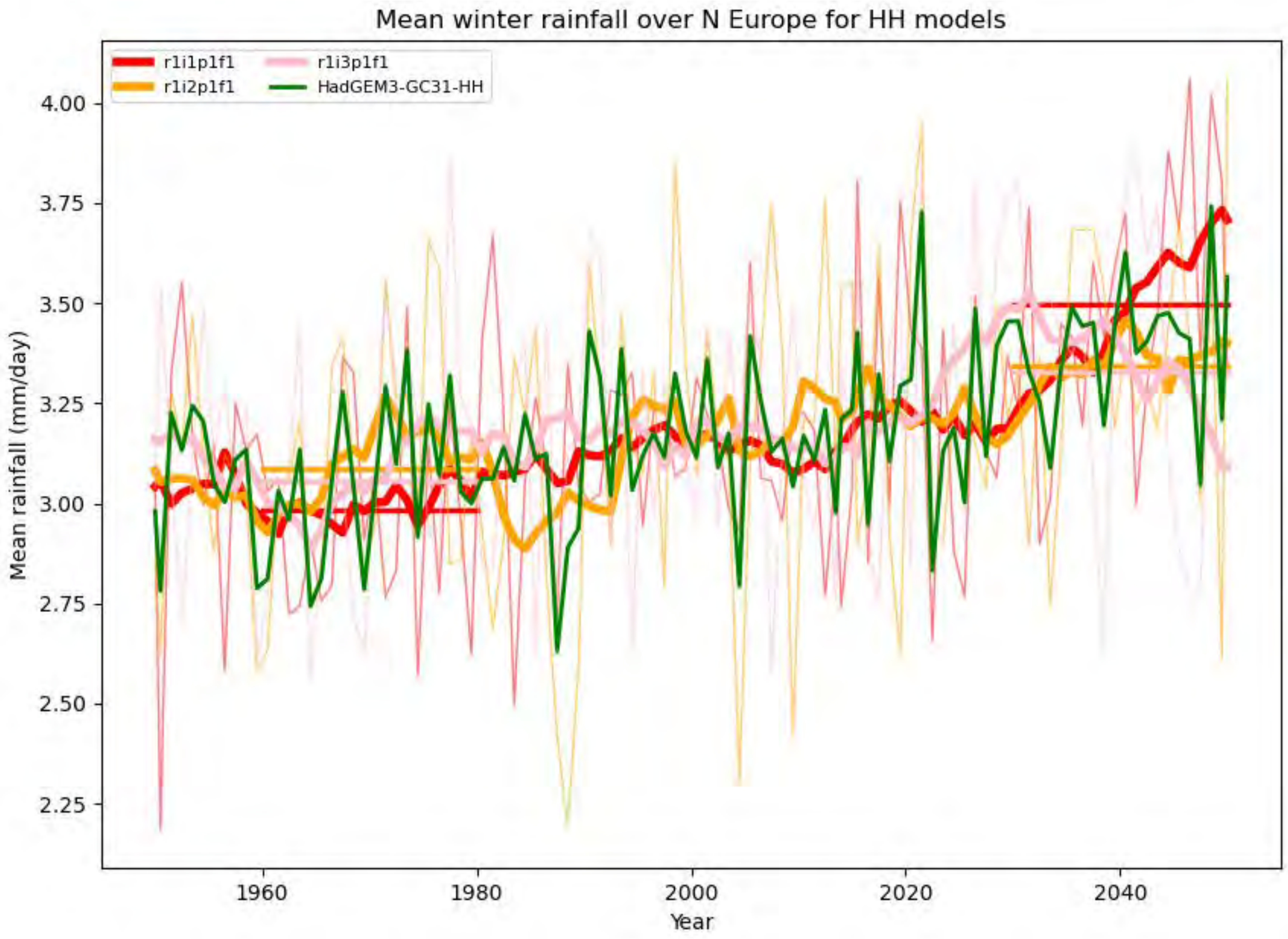


Anomalies in winter precipitation between 2030–2050 and 1960–1980
Stippling in (a) indicates anomalies in HH falling outside a distribution including anomalies from all the other resolutions

Result needs **both** atmosphere and ocean resolution

Moreno-Chamarro et al., ERL, 2021;
Grist et al., GRL, 2021.

PRIMAVERA



Monthly timeseries of winter DJF precipitation over Northern Europe for 3xHH members and ensemble mean (green)

It is clear that the 1st member r1i1p1f1 is slightly lower in the 1960-80 period, and considerably higher in the 2030-50 period (straight lines indicate means in these periods), hence producing the larger extreme when differencing these periods

All these HH models show an increasing trend

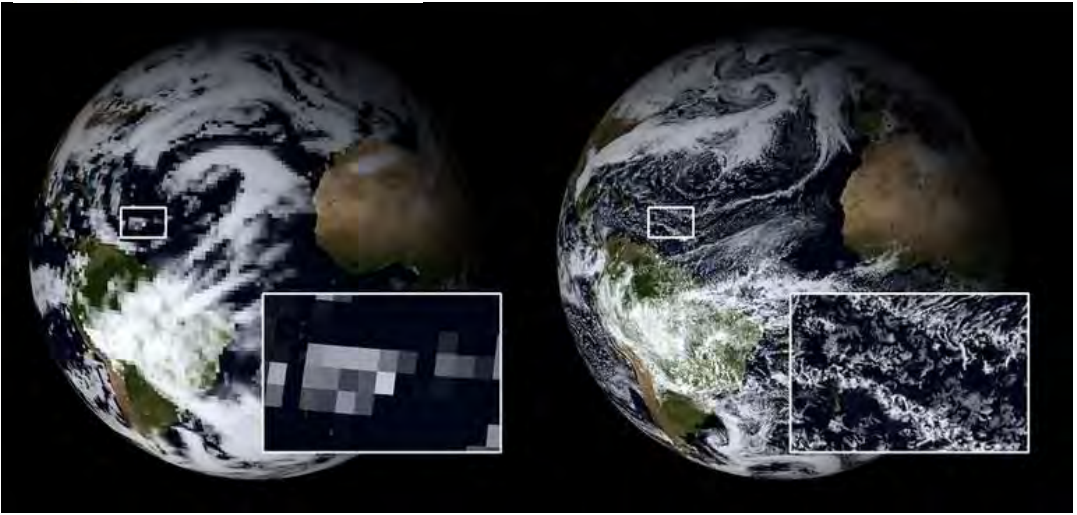
Some coupled climate modelling efforts at 10km scales and below

- EU nextGEMS – aiming at 2.5-5km coupled modelling over decades
- EU EERIE – started Jan 2023, aiming at multi-centennial simulations ~10km
- TAMU + NCAR (NSF MESACLIP)
  - CESM1.3 global 25km-1/10° for full CMIP simulation suite, including 1850-2100 + ensembles + decadal (Xiaoqi Wang’s talk)
- many other initiatives on sub-10km global modelling

The EU H2020 **NextGEMS** project

next GEMS

https://nextgems-h2020.eu/



ICON @ 80km and 5km

- Two prototype storm-resolving ESMs (**ICON-A/O**, **IFS/FESOM**)
- Produce multi-decadal projections of future climate change.

Models:
AWI-CM-XR: OpenIFS/FESOM

ICON-ESM: ICON-A/ICON-O

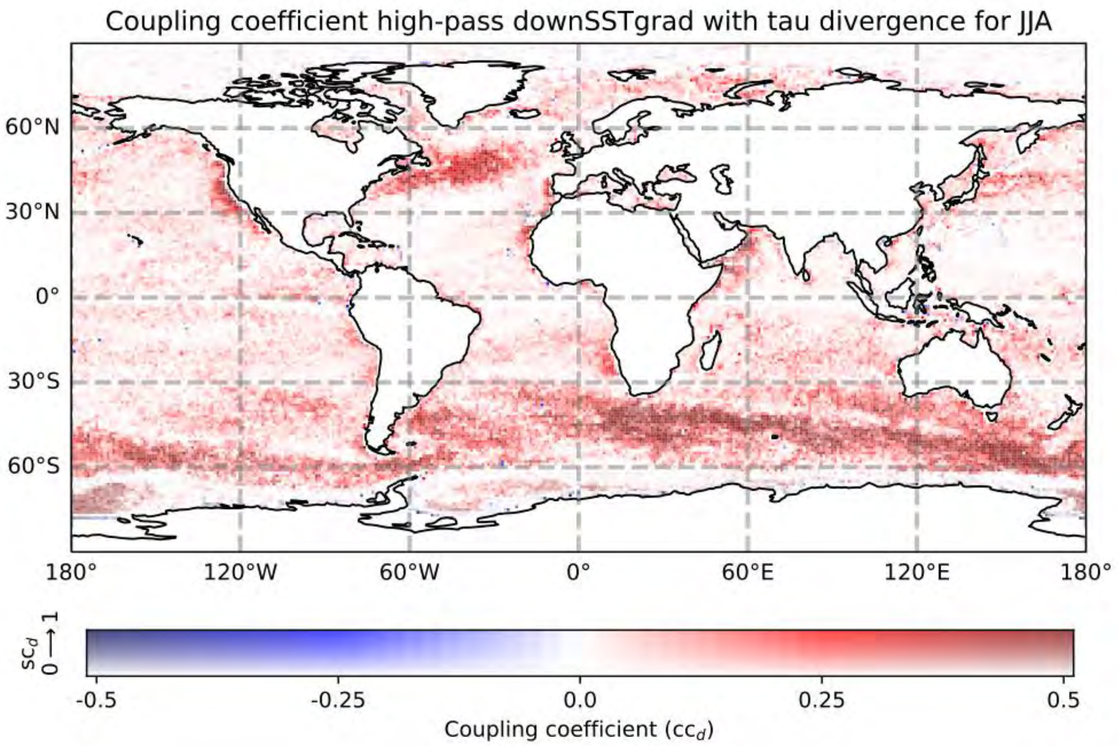
globally 2.5-5 km atm/ocean

Courtesy: Johann Jungclaus

Geographical distribution of vertical mixing mechanism coupling coefficient (cc_d)

cc_d computed from regression slope of bin-scatter plot per 1^o box => strength of coupling

sc_d spatial correlation per 1^o box => confidence in coupling strength



- Strong coupling in eddy-rich, SST frontal regions, Southern Ocean (entire channel), and upwelling eastern boundary current systems
- Absence of coupling in tropical oceans is due to 2deg scale cut-off of spatial filter

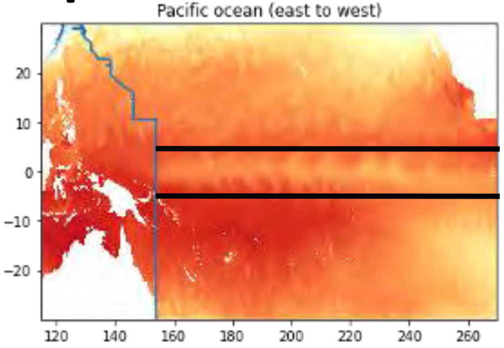
- **First time a global map of the geographical distribution of air-sea coupling via vertical mixing mechanism is produced**

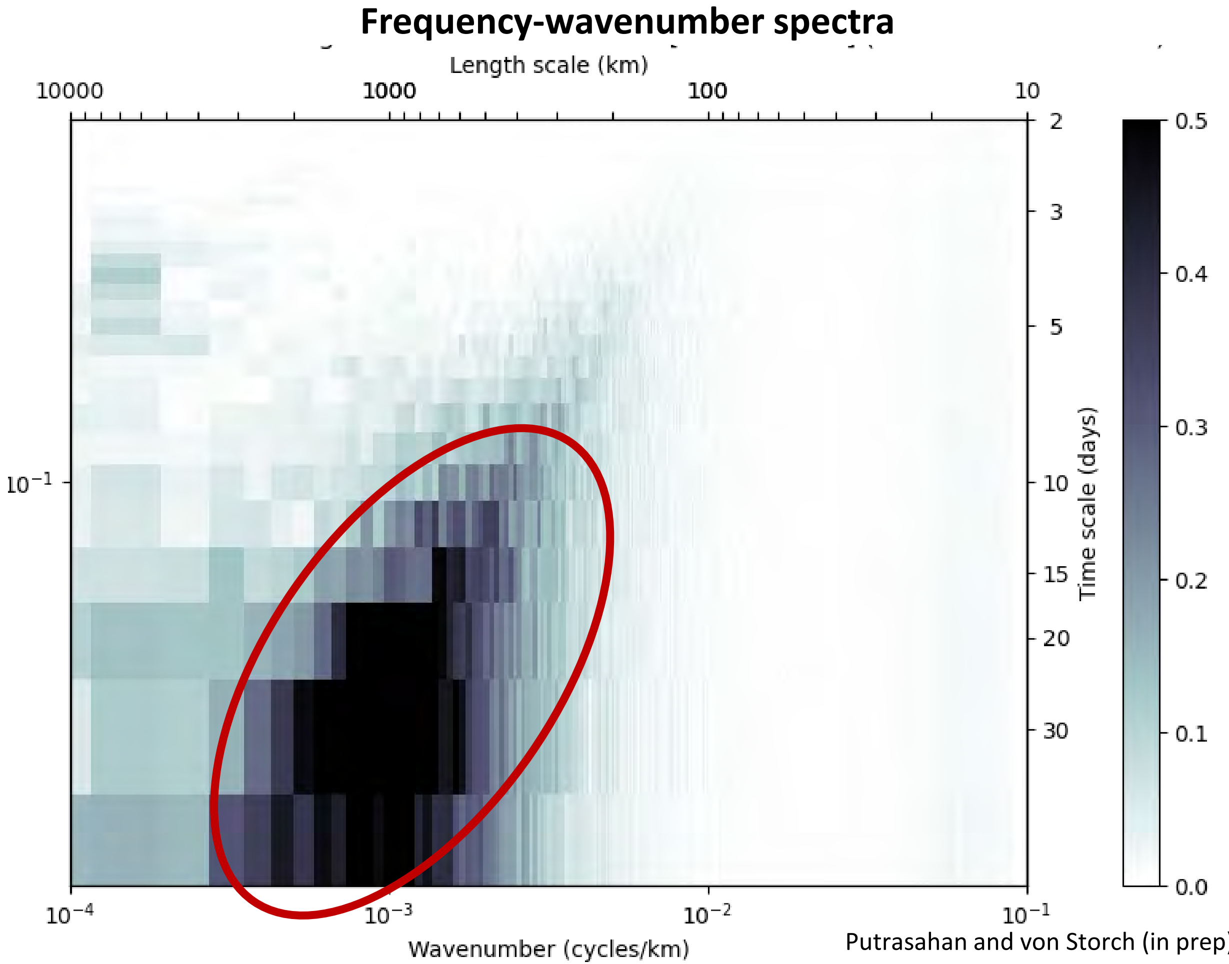
nextGEMS ICON model

Putrasahan and von Storch (in prep)

Tropical Pacific

Squared coherence between downwind SST gradients and windstress divergence



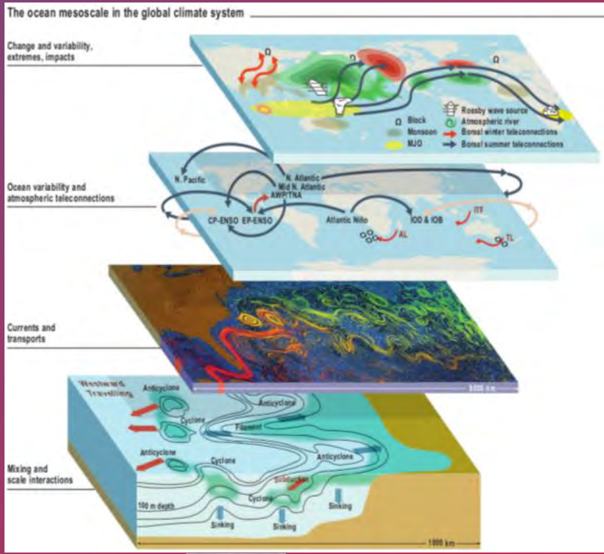


Putrasahan and von Storch (in prep)

- dominant spatial scale of 300-3000km (TIWs)
- timescales longer than 10-days
- Diagonal tilt: larger with longer, smaller with shorter
- **First time the spatio-temporal scale dependency of air-sea coupling via vertical mixing mechanism is quantified**

EERIE – European Eddy-Rich ESMs: To understand the role of the ocean mesoscale in climate

- Project start date: 1st Jan 2023
- for 4 years
- Coordinator: Thomas Jung (AWI)
- Co-coordinators: Malcolm Roberts (Met Office), Pier Luigi Vidale (Univ. of Reading)



This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI) under contract #22.00366.

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Funded by the European Union

EERIE models

Group	Model	Atm grid spacing	Ocn grid spacing	Simulation	Data volumes* (minimum per model year)
BSC	IFS-NEMO	Tco1279 (~9km)	ORCA12 (~9km)	HighResMIP	4 TB
AWI	IFS-FESOM2	Tco1279 (~9km)	NG5 (~13-4.5km)	HighResMIP	20 TB
MPI-M	ICON	R2B8 (~10km)	R2B9 (~5km)	HighResMIP	6 TB
Met Office	UM-NEMO	N640 (~20km)	ORCA12 (~9km)	CMIP6	10 TB

*Raw data volumes, initial estimates, little sub-daily output

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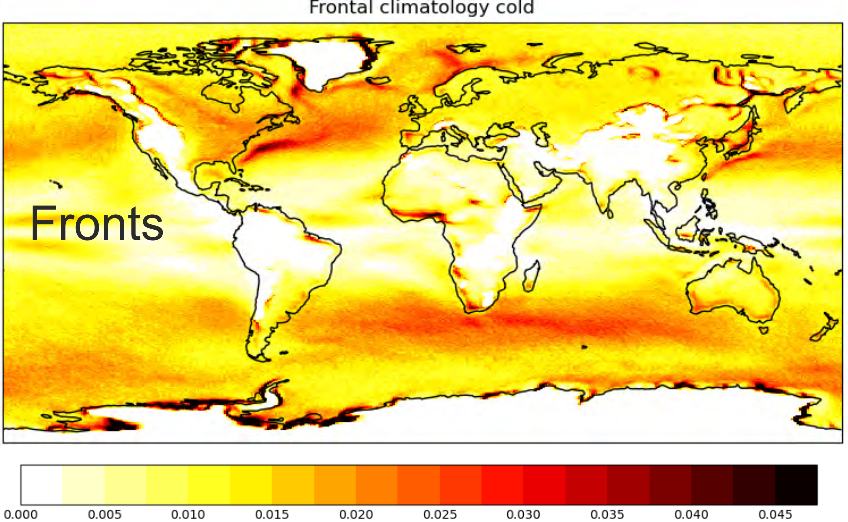
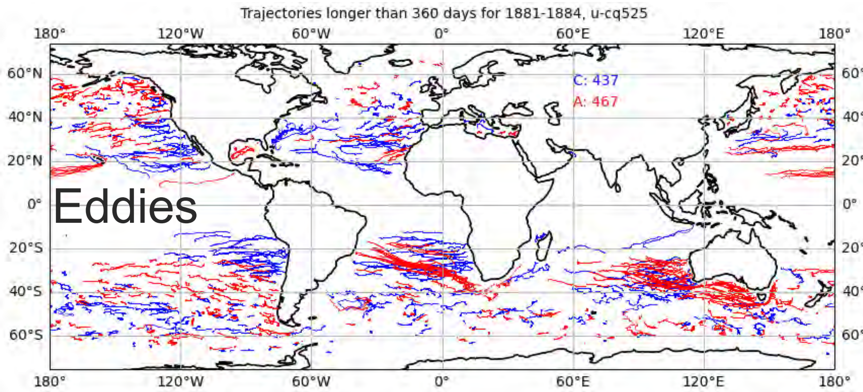
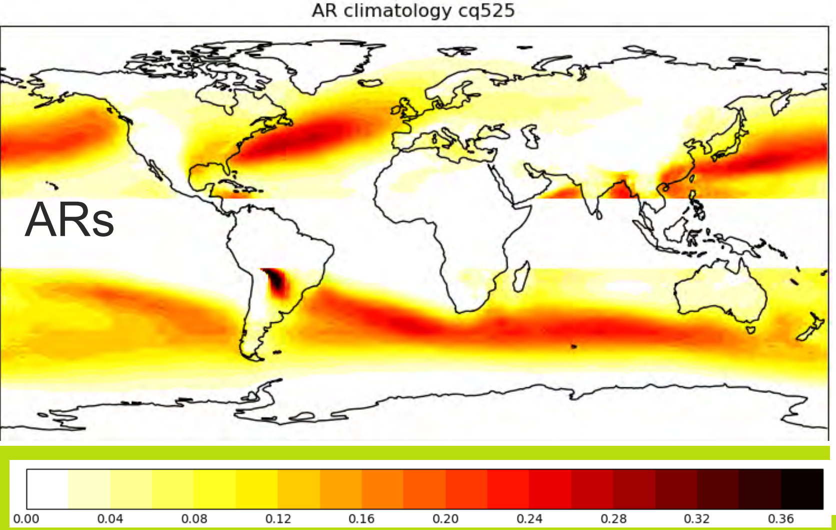
Ongoing processed diagnostics from N216-O12 (60km-8km) coupled model 1850 spin-up



Algorithm: Sansom and Catto, 2022



Algorithm: py-eddy-tracker (as used by AVISO for observations)



Algorithm: TempestExtremes2.1

Tropical and extra-tropical cyclones also being produced with two algorithms, TRACK and TempestExtremes

How to best combine models, experimental design, and diagnostics

- We have models capable of:
  - (sub)-mesoscale representation, and
  - multi-(decadal) centennial simulation
- Data volumes become large issue for long simulations
  - especially as we need more high frequency outputs
  - also likely near the native grid resolution
- Data volumes particularly a problem for longer simulations
- So...

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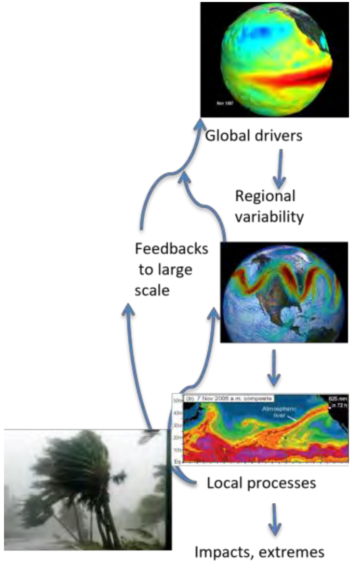
HighResMIP towards CMIP7

- Are there experiments that we can suggest to HighResMIP
  - Modifying existing experiments
  - Suggesting new experiments
    - e.g. shorter ~1 year long, can these be configured to be useful to many groups such as this one, links to e.g. DYAMOND project
    - potential to have more models particpiate
    - potential to have wider diagnostic list
    - potential to test automated production of metrics of e.g. air-sea interactions
  - as well as new longer simulations, such as
    - filter mesoscale (e.g. eddies) out of SST forcing data
- Together with new diagnostics for these particular experiments (new variables or new time frequencies)



Summary

- Increasingly large database of simulations at grid spacings at or beyond 25km
- Some of these model simulations extend decades to centuries
- Scope to develop new experiments to target specific process understanding
  - may be possible to have enhanced diagnostic requirements if simulations are short
- Potential to combine new modelling capability with new and planned observations to make progress in understanding the role of the ocean mesoscale in climate

Questions