Global high resolution climate modelling – plans and progress towards multi-centennial coupled 10km resolution

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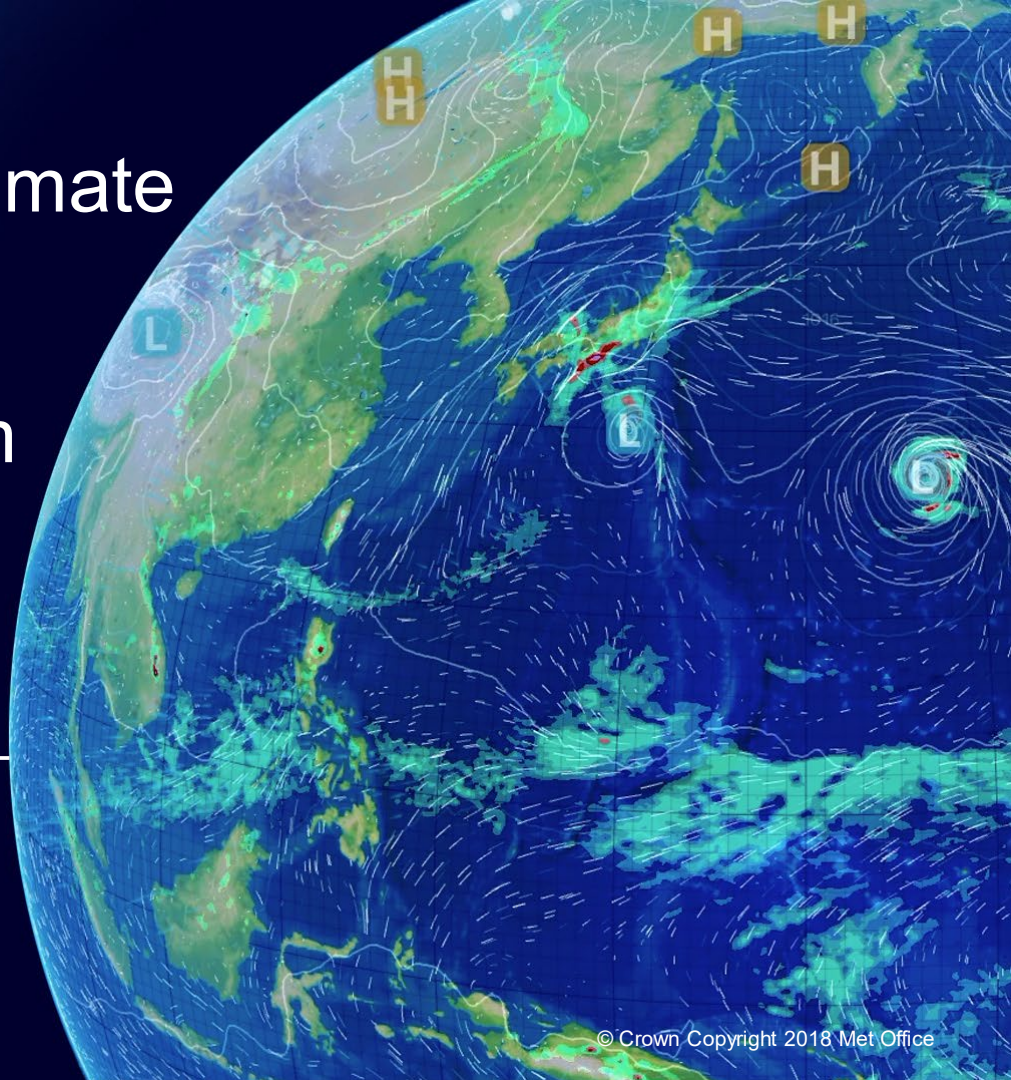
Pier Luigi Vidale (Univ. of Reading) – EERIE co-coordinators

IS-ENES3 Final General Assembly
Jan 2023



Outline

- Post-PRIMAVERA and CMIP6 HighResMIP
- EU EERIE
  - Science
  - Data challenges

CMIP6 HighResMIP and EU PRIMAVERA

- HighResMIP
  - new experimental design for CMIP6
  - ~17 international modelling groups participated (7 of which were in PRIMAVERA)
  - ~150 papers published so far
  - 156+ references in IPCC AR6 WG1 report

- EU PRIMAVERA
  - 19 groups across Europe
  - Ran global atmosphere-only and coupled simulations following HighResMIP at standard and higher resolution (~100km and ~25km)
  - Analysis to understand role of resolution in climate, particularly affecting Europe

What have we found – 25km vs 100km?

- Global models
  - improve some mean biases – SST, precipitation
  - air-sea interactions
    - ocean boundary currents enabling ocean dynamics to play more active role at mid-latitudes
  - extremes processes such as tropical cyclones, particularly variability
  - hydrological cycle
    - chains of processes, e.g. convection and moisture transports by dynamics (rather than 1D physics)
    - blocking
  - ocean models in Southern Ocean tend to have (strong) warm bias
    - not resolving mesoscale properly exacerbates existing atmospheric biases

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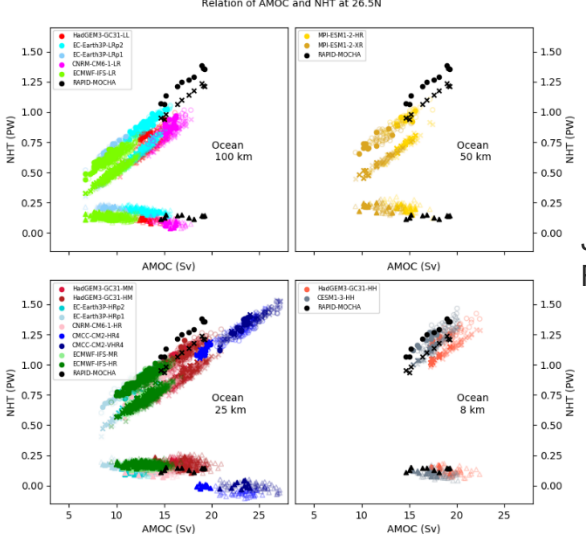
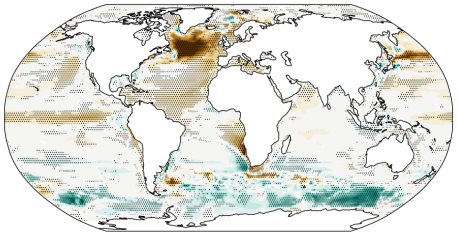


Atlantic AMOC vs heat transport at different resolutions

Jackson et al., 2020; Roberts et al., 2020

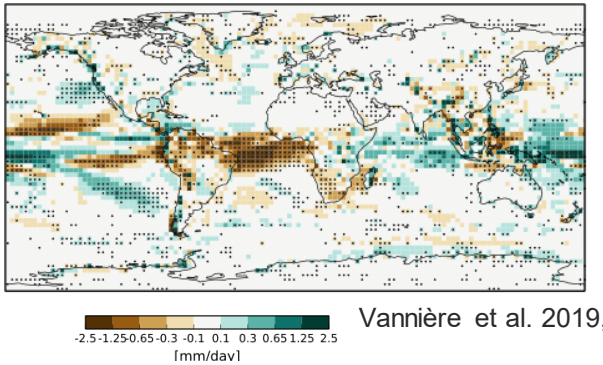
Impact of model resolution (to ~25km) on climate simulation



Resolution SST RMSE difference

Bock et al., 2020; IPCC AR6 Ch 3

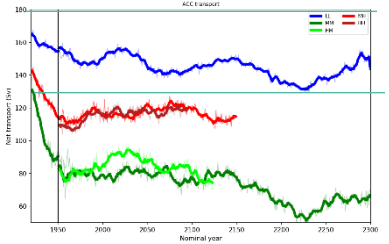
Coupled precipitation



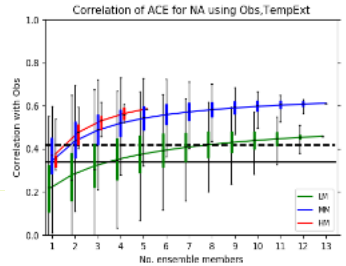
Precipitation bias change: Reduction in bias at higher res; Increase in bias at higher res

Vannière et al. 2019, Clim. Dyn

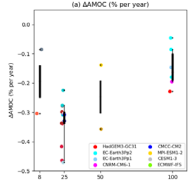
ACC transport at different resolutions



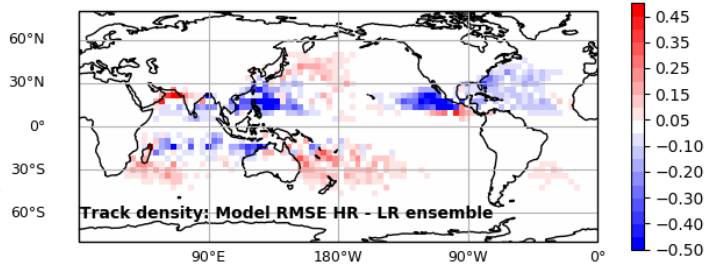
Tropical cyclone interannual variability
Correlation with obs vs ensemble size vs resolution
Roberts et al. 2020

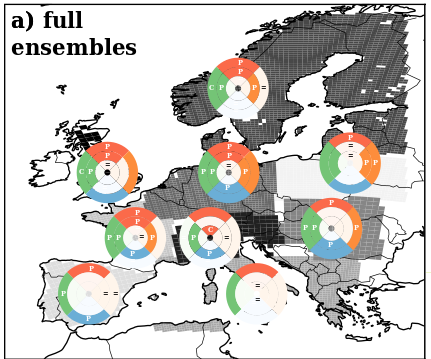


AMOC future change



Tropical cyclone track density RMSE
Roberts et al. 2020





Comparison with CORDEX
Demory et al. 2020

PRIMAVERA

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Extending the resolution to 1/12° in the ocean

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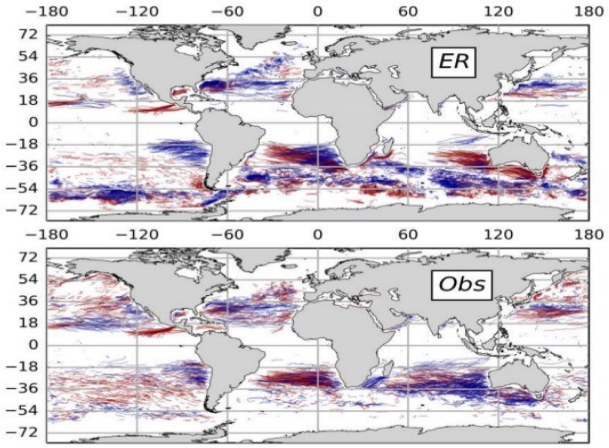
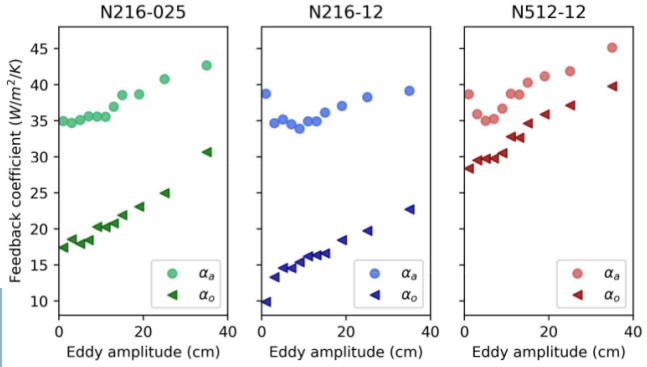
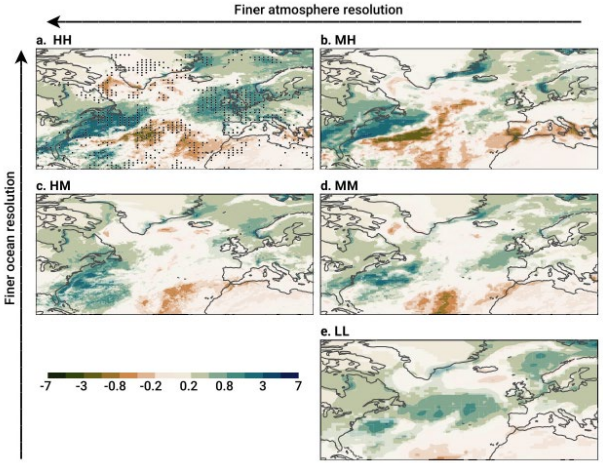


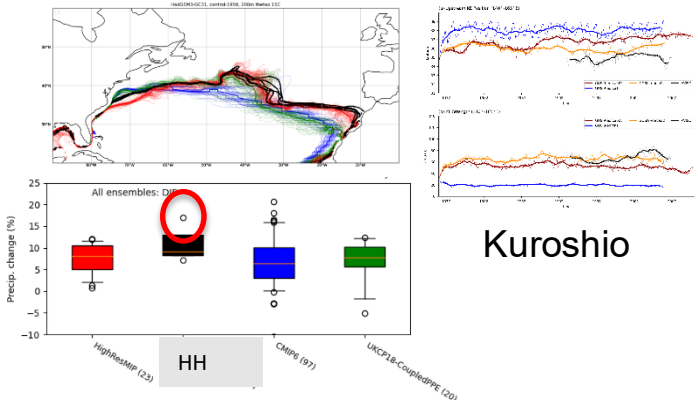
Eddy trajectories lasting more than 6 months

Moreton et al. 2020, 2021

SST flux-feedback and atmos/ocean resolution ratio





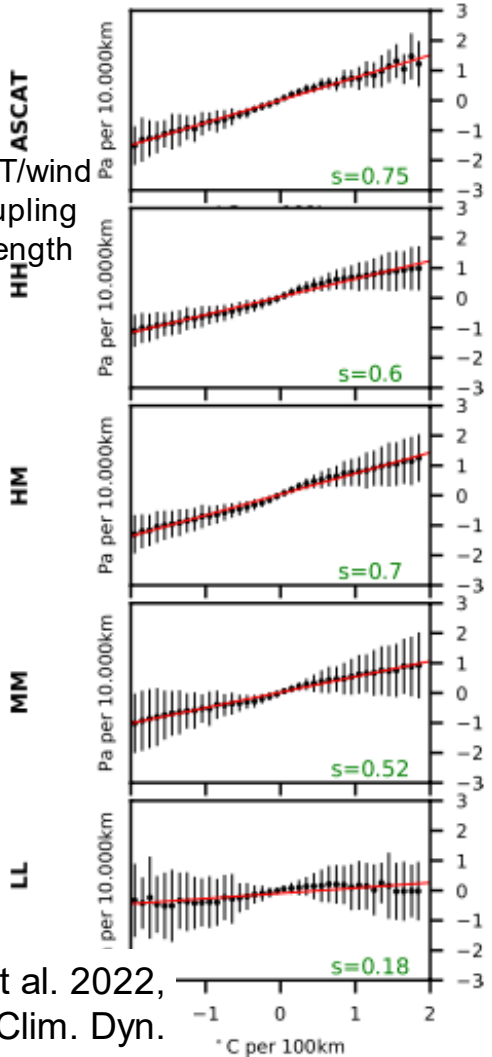


Kuroshio

Northern European future rainfall and resolution/Gulf Stream change by 2050

Moreno-Chamarro et al 2021; Grist et al 2021

SST/wind coupling strength

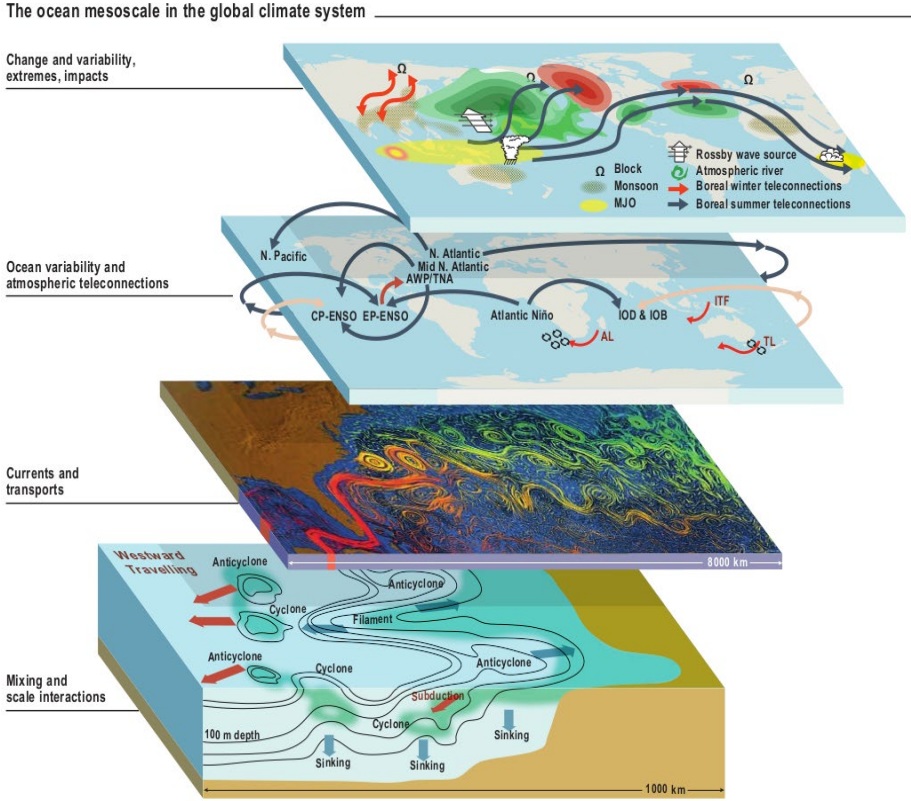


Tsartsali et al. 2022, Clim. Dyn.

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)



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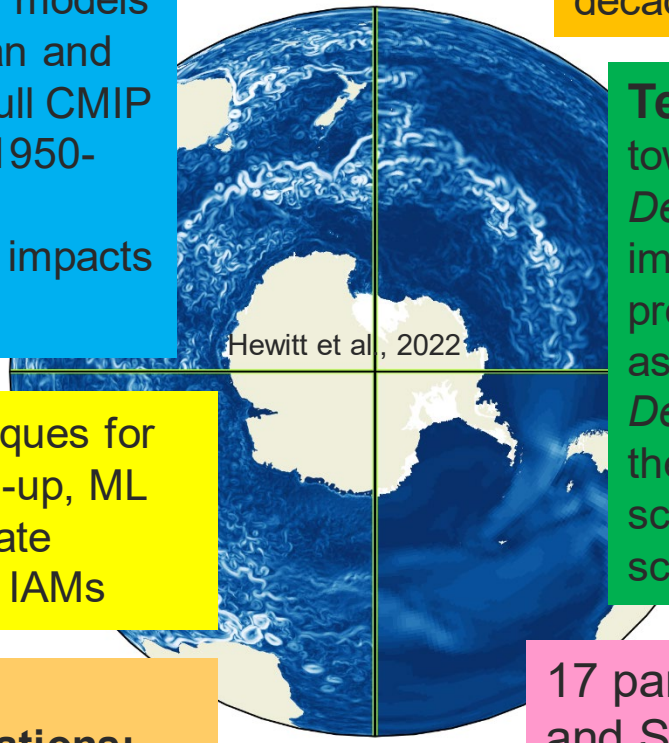
EERIE – European Eddy-Rich ESMs

Key question: what is the role of the ocean mesoscale in climate?

Analysis: assess and understand ocean mesoscale (boundary currents, eddies) and interactions with atmosphere from sub-daily to decadal/centennial timescales

Simulations: four coupled models with eddy-rich (<10km) ocean and ~10km atmosphere, either full CMIP 1850-2100 or HighResMIP 1950-2100 – (multi-)centennial
Tipping point experiment for impacts of AMOC change



Technical: *Optimise* models towards 5 SYPD at ~10km coupled
Develop in-line and other tools for improved, automated diagnostic production (e.g. cyclone tracking) and assessment
Develop and improve models for these scales – e.g. help develop scale-aware CoMorph convection scheme with Foundation Science

Machine learning: techniques for causal networks, ocean spin-up, ML emulator to incorporate climate variability and extremes into IAMs

Inform Digital Twins;
Exploit and inform observations:
(e.g. global high frequency fluxes)

an Eddy-Rich E

17 partners including from Cameroon and South Africa
4 years starting Jan 2023

Data challenges

- Data volumes
  - simulations either
    - CMIP-like: PI-spinup, PI-control, historical, scenario to 2100: > 650 years
    - HighResMIP-like: spinup-1950, control-1950, hist-1950, highres-future (to 2100): > 300 years
  - Aiming for resolutions ~10km in atmosphere and ocean
  - High frequency (sub-daily) output important for feature tracking, extremes, air-sea interactions etc
- Limited disk storage
  - DKRZ ~1.6 PB
  - JASMIN 0.3 PB for analysis

Data management

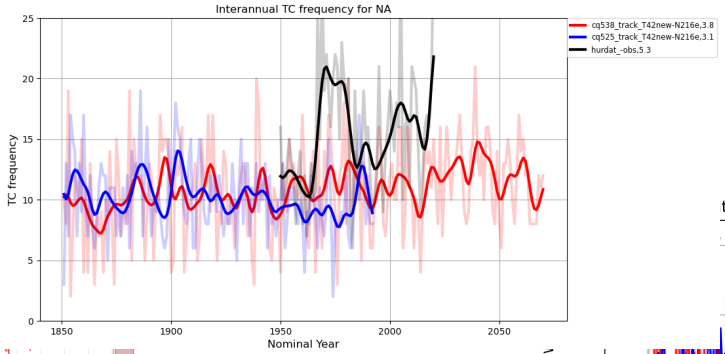
- Plan is for each group to publish data on home ESGF node
- Then replicate required data at CEDA-JASMIN for multi-model analysis by all project members
- Currently estimated raw output data volumes (Data Request still TBD):
  - IFS-FESOM2: 20 TB / SYear
  - IFS-NEMO (ORCA12): 4 TB / SY
  - ICON: 6 TB / SY
  - UM-NEMO (ORCA12): > 10 TB / SY
- Hence will need to consider many options to reduce data:
  - native grid output, coarse grained, single level, regional, time slice, newer file formats, compression, quantization (truncation)

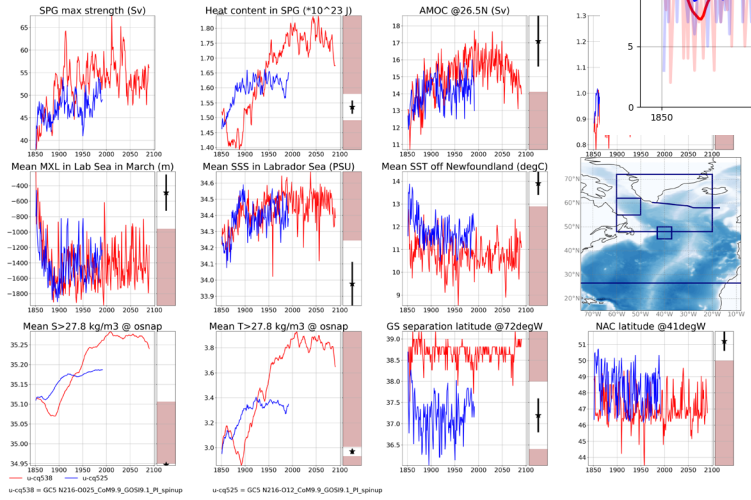
Developing model workflow and infrastructure

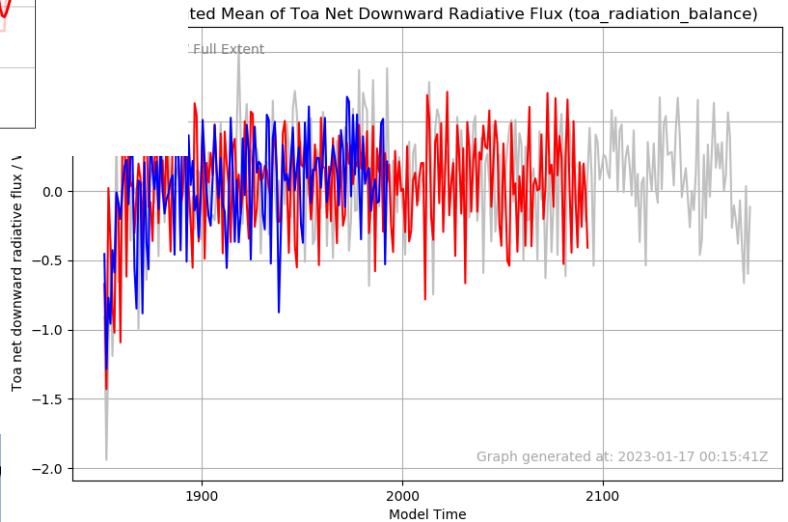
- Inline/on-the-fly diagnostic production as model runs
  - e.g. feature tracking (storms, atmospheric rivers, ocean eddies, fronts, MCS(?) etc)
    - diagnose, store and publish features to CMIP ESGF
    - doing this as model runs gives option not to store all raw data – needs agreement on common algorithms
  - automated standard assessment as model runs, tools e.g. ESMValTool, icclim
    - ENSO, AMV, MJO, PDO, ocean metrics, as well as TCs etc
  - find ways to reduce data storage footprint by developing these methods
    - e.g. on-the-fly hourly storm tracking but only save 6 hourly data for offline analysis
- Need further options to reduce data volumes
  - PRIMAVERA produced ~5 TB per year of simulations
  - higher frequency outputs more valuable at these resolutions, but large storage footprint
  - coarse-graining (regridding) model output where native grid not required (or cannot be validated)
  - other options?

Workflows to enable ongoing/real time monitoring of model simulations as is done for observations

Obs, e.g. https://climate.metoffice.cloud/climate_modes.html#datasets







ean Eddy-Rich ESI

Other EU project links

- Strong links with many other (new) EU and European projects
  - nextGEMS, OptimESM, ASPECT, DestinE, WarmWorld, ...
- and will be using tools and developments from many others
  - IS-ENES, ESiWACE, IMMERSE, PRIMAVERA, ...
- and we hope to learn from many others

HighResMIP future plans

- Started discussions within HighResMIP community about what experimental designs we should be considering
  - CMIP6 HighResMIP simulations were:
    - 1950-2050, atmosphere-only and coupled, only one SSP585 high scenario
    - coupled model initialised from EN4 in 1950, few decades spin-up
  - Global km-scale have shorter simulations
    - case studies, DYAMOND 40-day simulations, idealised/analytical cases
    - may be better/easier to compare models for specific processes
  - Is there a simulation that can combine both:
    - maybe ~1 year long, look at processes, that could include both km-scale and HighResMIP-type models?
- HighResMIP2 likely to:
  - go to 2100 at least; use more likely future scenarios; allow tuning and no restrictions on aerosols etc
  - try to agree more standardised production of processed diagnostics such as storm tracking, atmospheric rivers etc, to be published on ESGF

Summary

- PRIMAVERA and CMIP6 HighResMIP have been successful in producing multi-model global climate simulations at higher resolutions, as well as managing to analyse such large datasets – ESGF publication key to this
  - 17 international groups took part in HighResMIP
  - >150 papers so far, > 150 references in IPCC AR6 WG1 report
- Indications that going to eddy-rich ocean resolutions important, at least for regional climate change and potentially global processes
  - this produces new challenges in data volumes and analysis techniques
- Projects including EU EERIE to push towards ~10km in atmosphere and ocean (in EERIE's case for multi-centennial simulations)
- Need to remember physics as well as grid spacing, as well as ensembles

Questions