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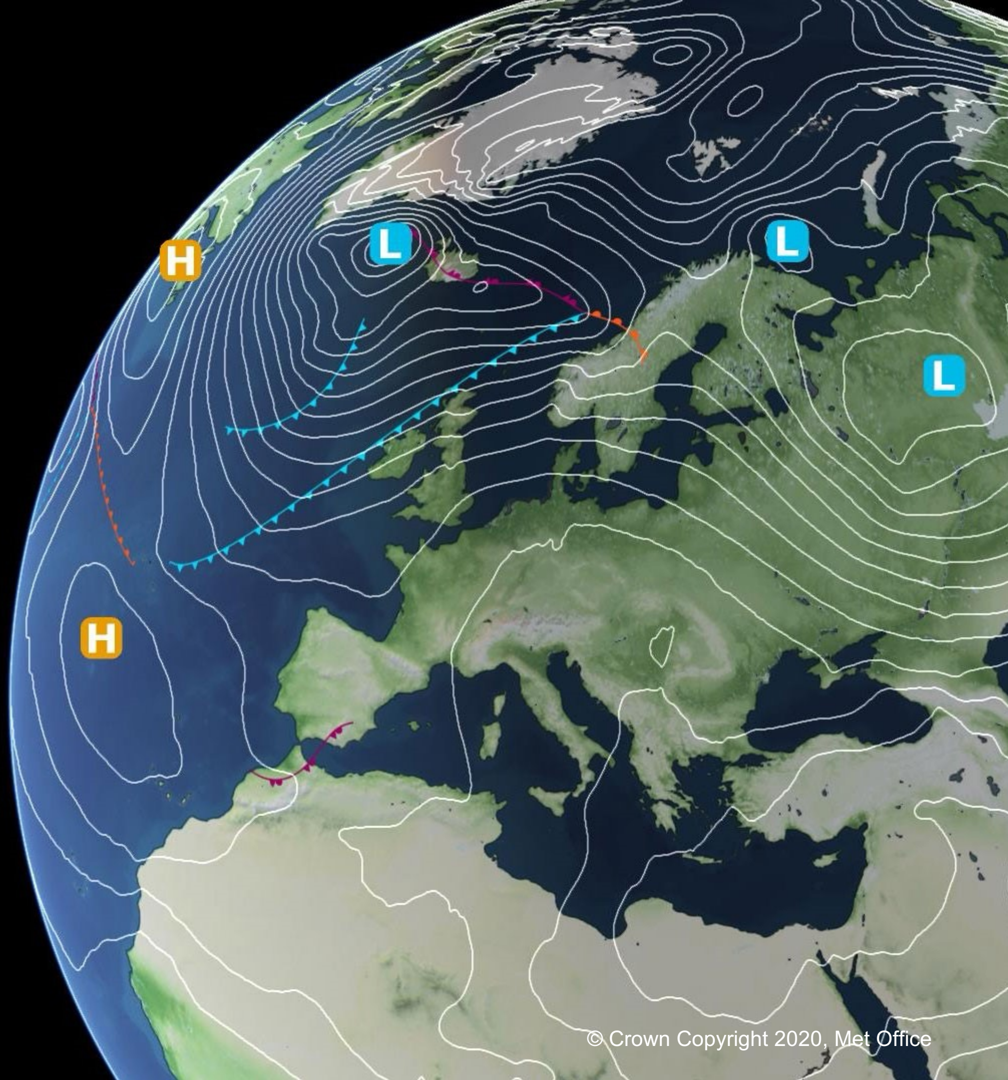
Future directions for convection-permitting climate modelling at the Met Office

Chris Short

2024 BoM Annual R&D Workshop

11/09/2024



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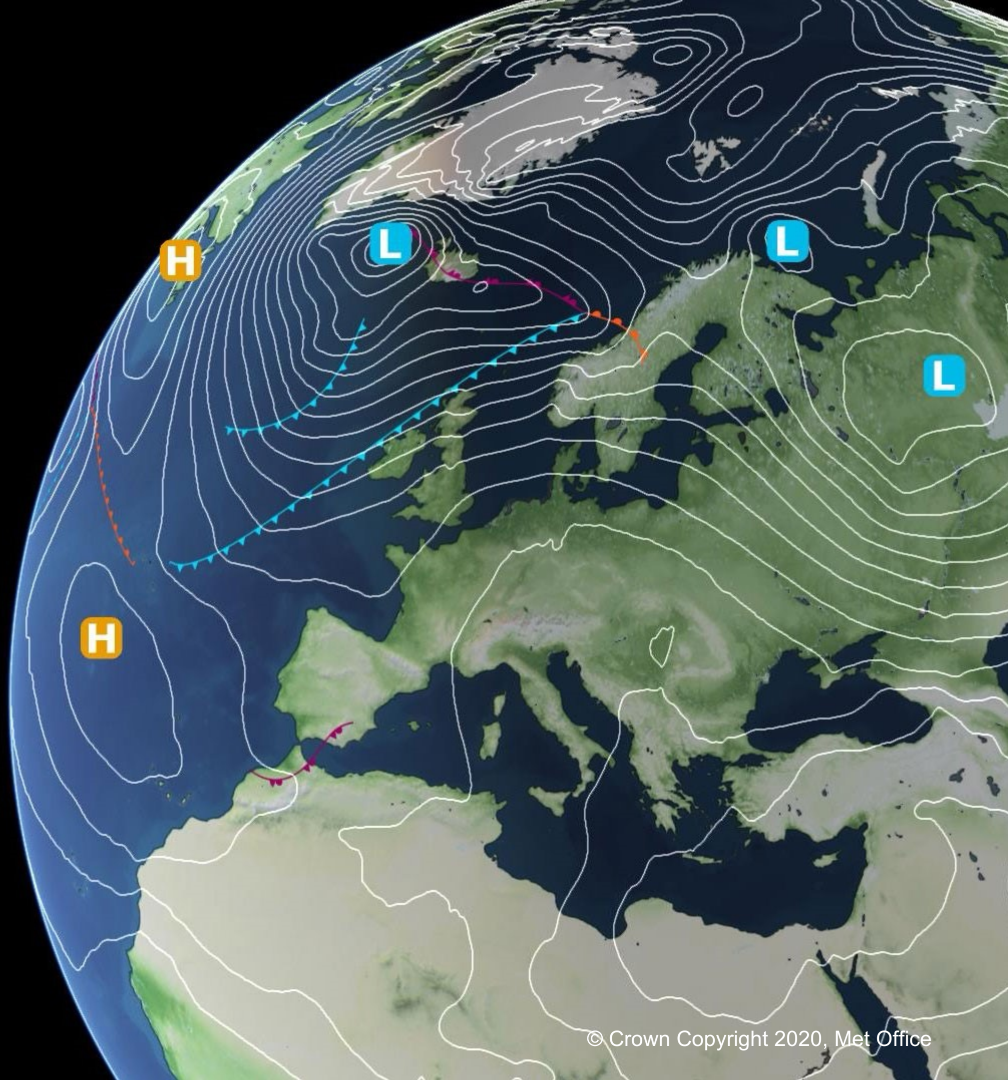
Adding environmental complexity to UK climate projections

Alex Arnold, Segolene Berthou, Juan Castillo,
Chris Short, Simon Tucker



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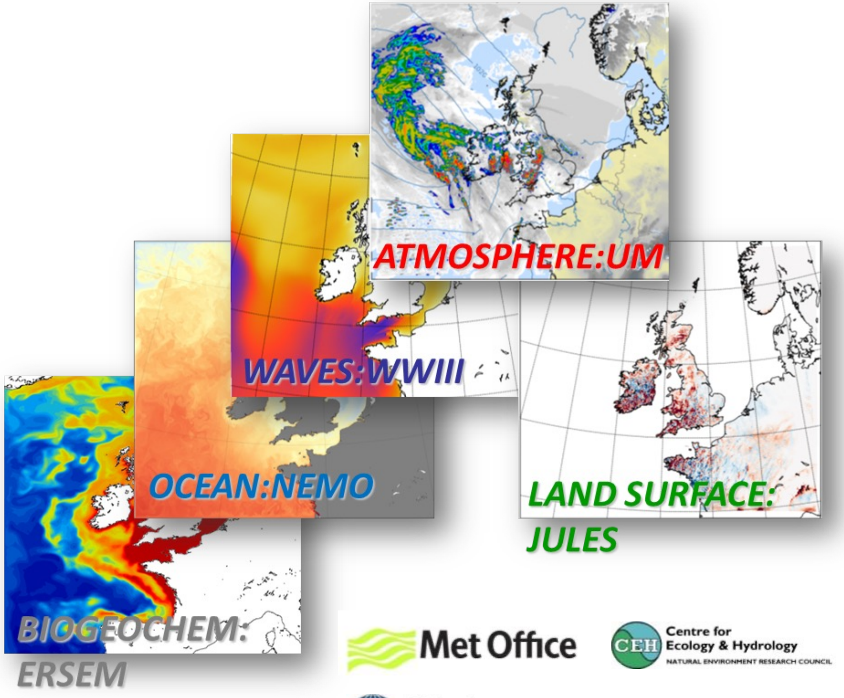
Motivation

- Current set of UK national climate projections (UKCP18) included a 12-member 2.2 km CPM for the first time
  - Atmosphere coupled to land, SSTs imposed as daily means from driving GCM
- Aim to run climate change experiments with the Regional Environmental Prediction (REP) system
  - Fully coupled: atmosphere, land, ocean (with explicit tides), waves, rivers
- Key topics to investigate:
  - The importance of processes missing from atmosphere-only simulations for regional climate change projections (e.g. coupled system feedbacks, tidal mixing, river outflows)
  - The impact of climate change on multi-hazard compound events
  - The interdependence of compound marine and land heat waves



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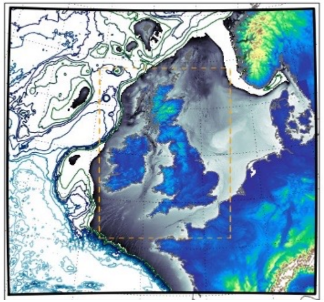
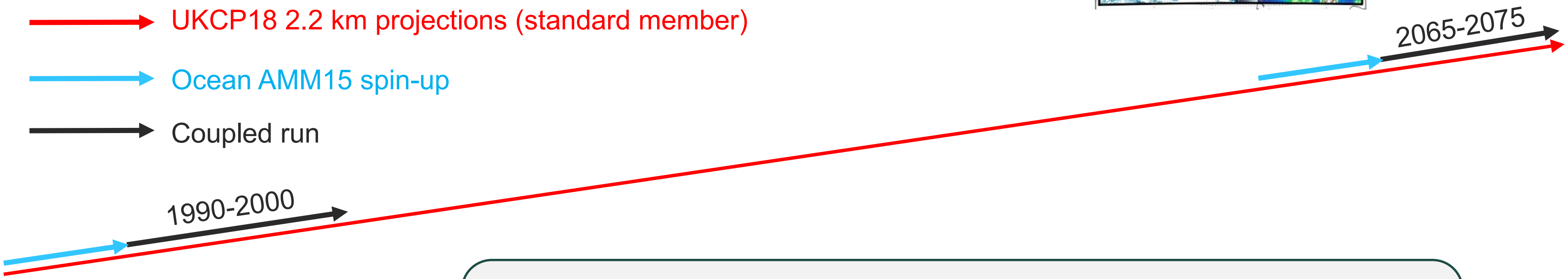
UK climate runs with the Regional Coupled Suite

Configuration:
- Atmosphere/land: RAL3.3.1
- Ocean/waves: CO8
- Explicit tides
- Rivers: River Flow Model (RFM)

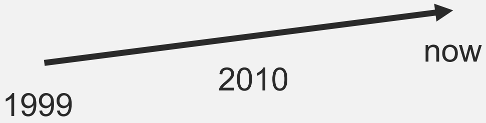
Resolution:
Atmosphere/land: 4.4km -> 2.2km
Ocean:1.5km
Waves: 3km -> 1.5km



3x timeslice runs (RCP8.5)



Hindcast run
ERA-5 boundaries (atmosphere & waves)
GloSea5 boundaries (ocean)



Alex Arnold

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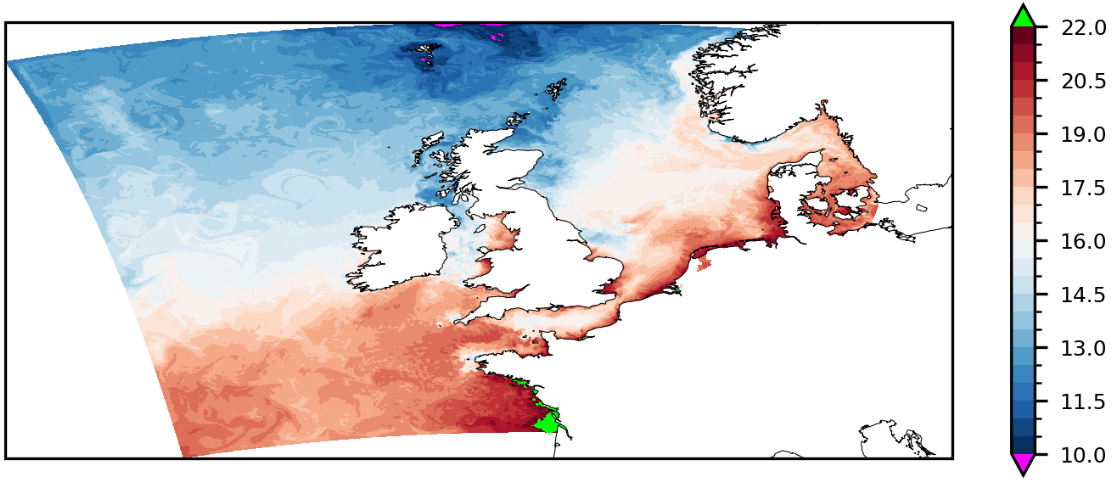
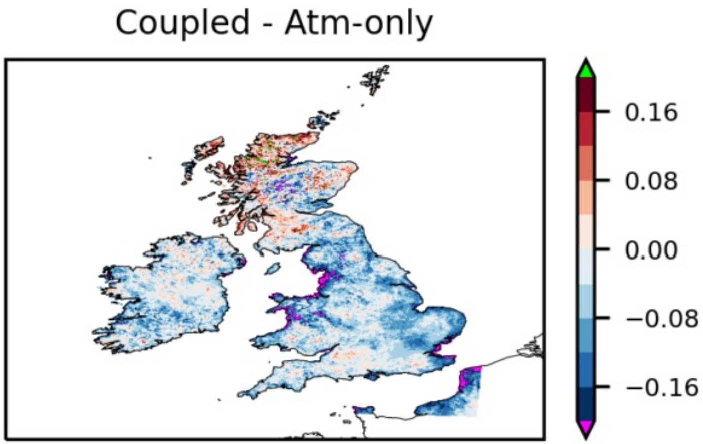
Current status and future directions

- Runs are underway:
  - Hindcast atm-only: ~4.5 yrs in
  - Hindcast cpld: ~3.5 yrs in
  - Present-day atm-only: ~2.5 yrs in
  - Present-day cpld: ~0.5 yrs in
  - Future atm-only: ~2 yrs in
  - Future cpld: ~0.5 yrs in

- This will be the first look at the REP in UK climate mode:
  - Opportunities for inclusion in next generation of UK climate information





DJF mean daily tasmin

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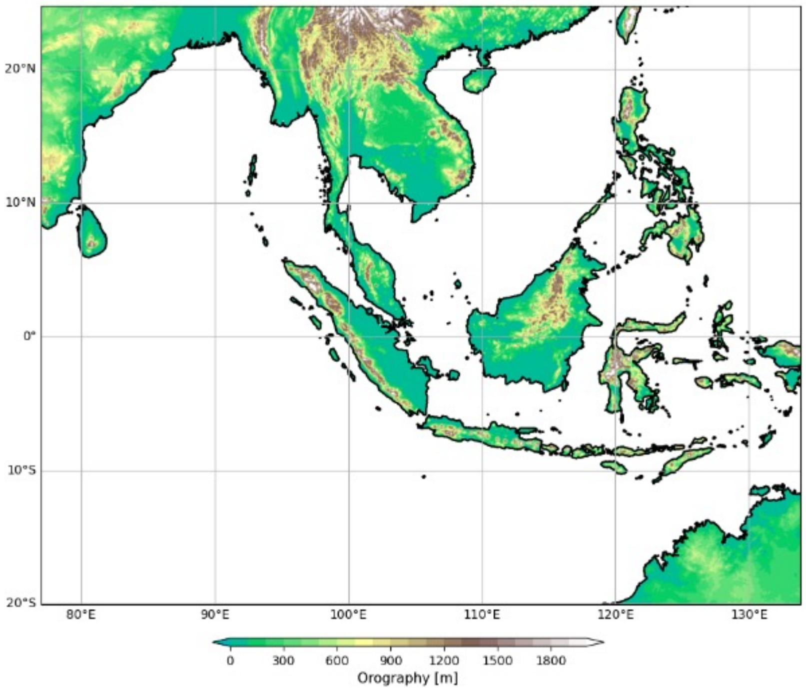
Advert: Coupled Maritime Continent runs

- Recently completed a pair of simulations over the Maritime Continent:
  - **Atmosphere-only:** 4.4 km atmosphere (RAL3.1/3.2) with hourly LBCs from ERA5 and daily mean SSTs prescribed from an ocean-only run of the 1/12 deg NOC regional ocean model (forced by Drakkar renanalysis)
  - **Coupled:** same as above but with the regional atmosphere fully coupled to the 1/12 deg NOC regional ocean model. Ocean LBCs and ICs from NOC.
- NOC 1/12 deg regional ocean model is shelf-enabled with explicit tides
- 10 years long 2002 – 2012
- Access to data available upon request
  - Email me if interested: **christopher.short@metoffice.gov.uk**



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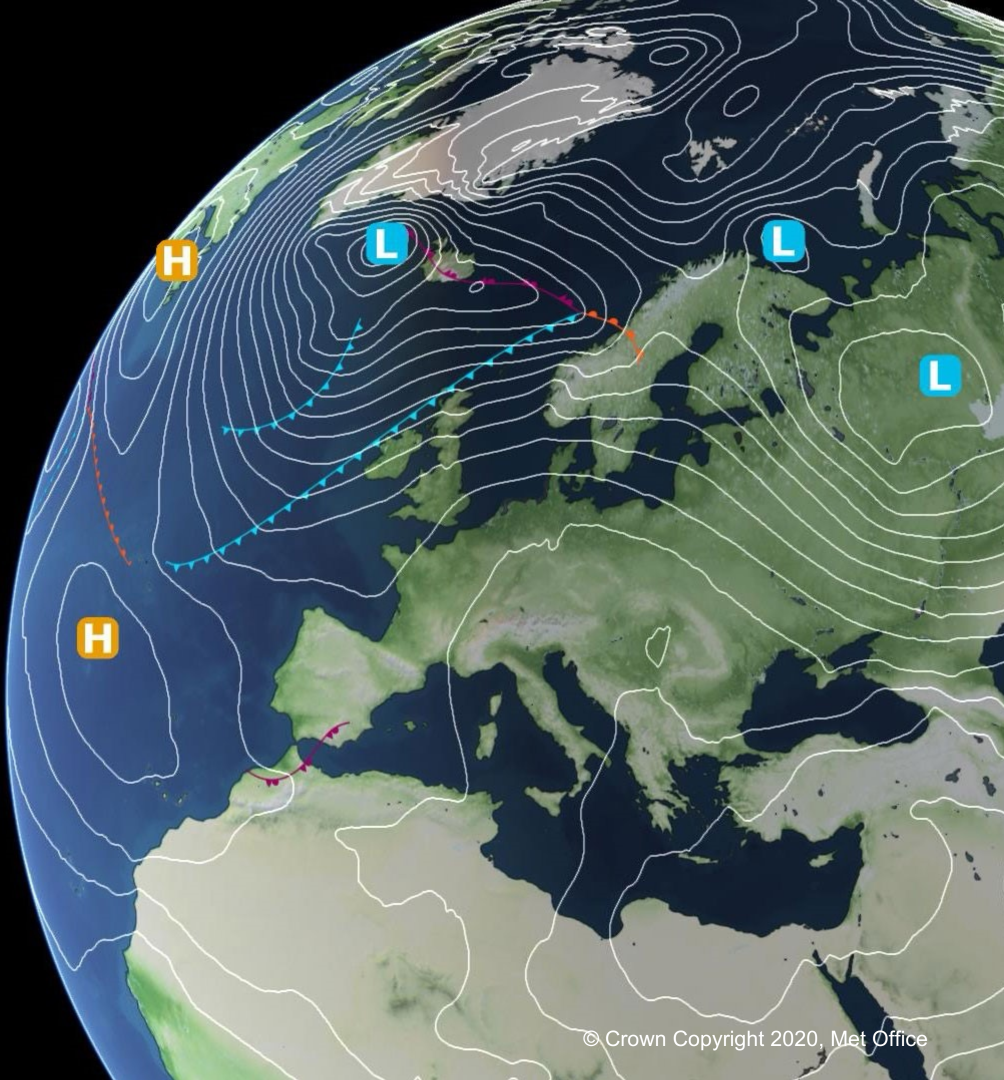
Preparing for km-scale global climate models of the future

Calum Scullion, Chris Short + the wider K-Scale team



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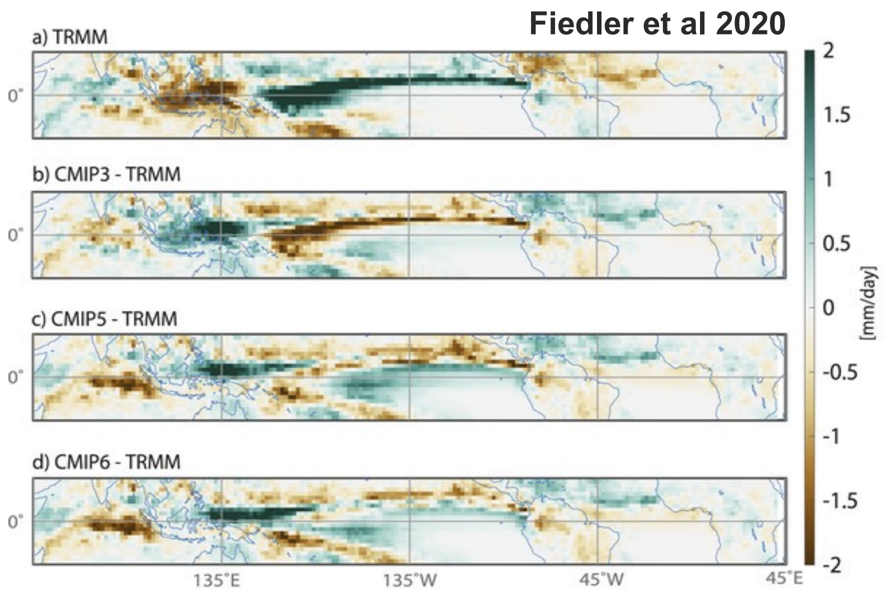
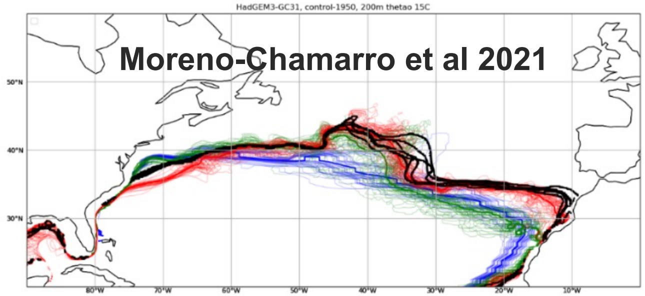
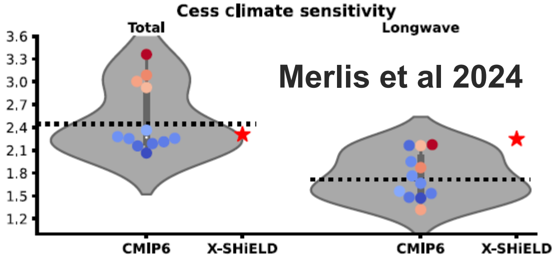
Motivation

- Can km-scale global models offer a step-change over conventional CMIP-class models?
  - Local impacts: explicit convection improves representation of precipitation extremes – critical for adaptation
  - Upscale impacts: improved representation of tropical precipitation affects mid-latitude climate via global teleconnections
  - Different cloud distributions and properties, modifying feedbacks and impacting climate sensitivity
  - Ocean mesoscale important for regional climate change too
- Challenges:
  - Computationally expensive
  - Huge data volumes
  - Convection not fully resolved
  - Tuning







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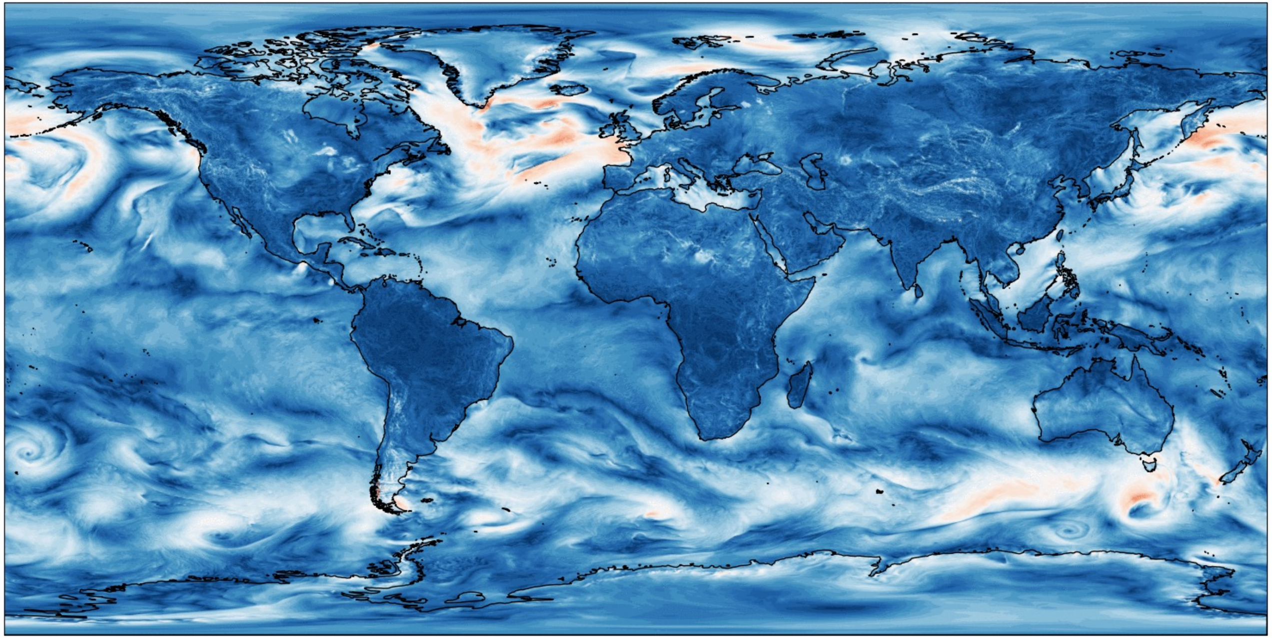
Current status and future directions

- N2560 global model with RAL3.2 and GAL9 ancils now runs!
- Next steps:
  - Design year-long atm-only and atm-only +4K SST runs to contribute to DYAMOND v3 and HighResMIP2
  - Potentially a year-long run with ocean coupling for DYAMOND v3 too
  - Can we extend to multi-decadal on new HPC for full AMIP and AMIP +4K SST runs?!

N2560 L70 80km - RAL3 WIND at T+01 20171230T0000Z



DYAMOND v3 protocol: https://www.researchsquare.com/article/rs-4458164/v1
HighResMIP2 protocol: https://egusphere.copernicus.org/preprints/2024/egusphere-2024-2582/

Huw Lewis

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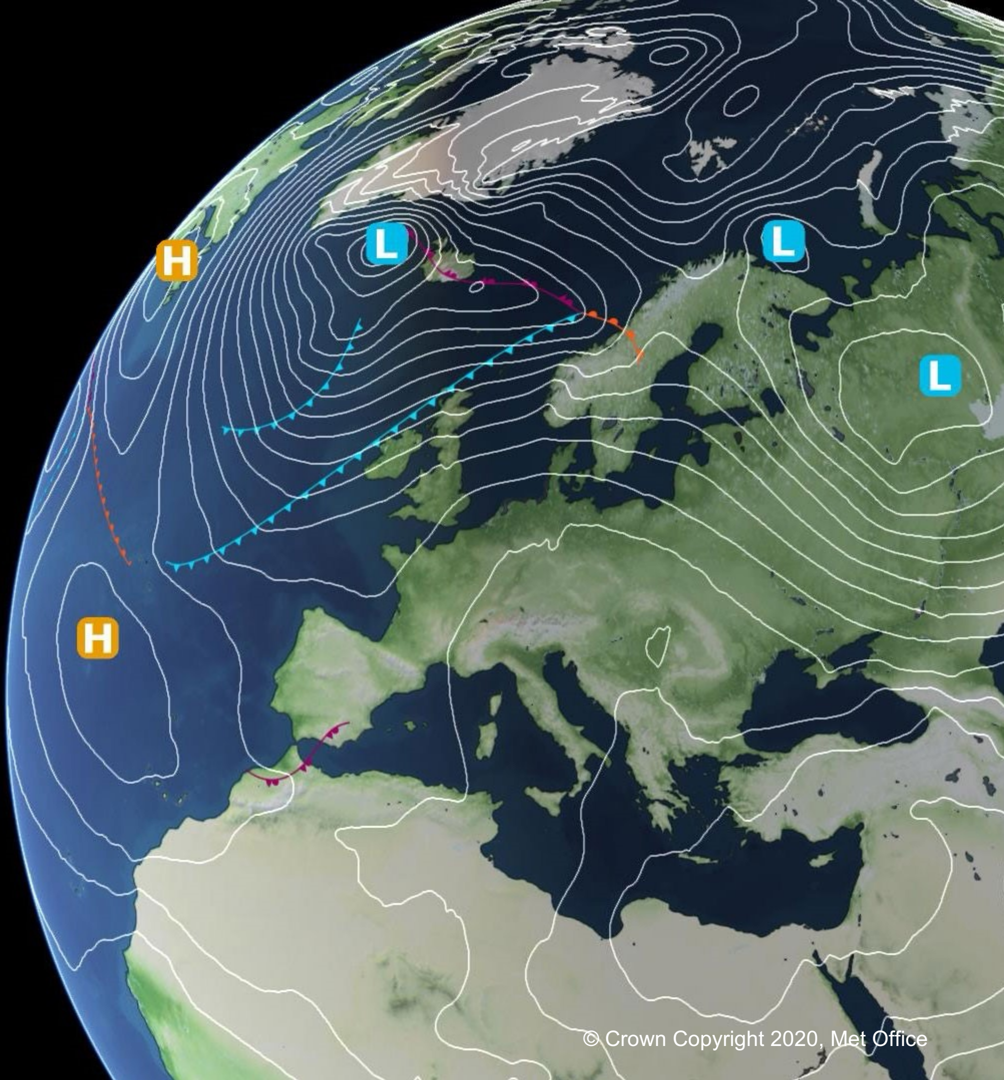
Emulation of CPMs using machine-learning techniques

Lizzie Kendon, Henry Addison, Antoine Doury, Ben Booth, Samuel Somot, Peter Watson, Erika Coppola, Jose Manuel Gutierrez, James Murphy, Calum Scullion



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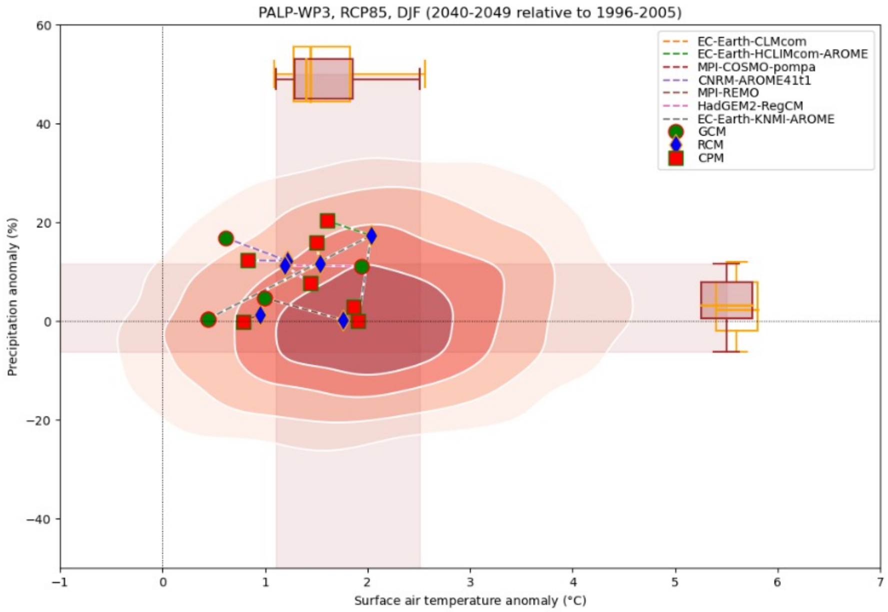
Motivation

- Key potential benefits of ML down-scaling:
  - Augment high resolution regional climate simulations at a fraction of the cost
  - Provide a more comprehensive sampling of uncertainty (downscaling other GCMs/scenarios) to support decision making
  - Downscale a much larger set of GCMs (not just those for which LBC data is available)
  - Allow rapid production of local climate information
- See "*Potential for machine learning to augment regional climate simulations in provision of local climate change information*", Kendon et al 2024, submitted to BAMS.

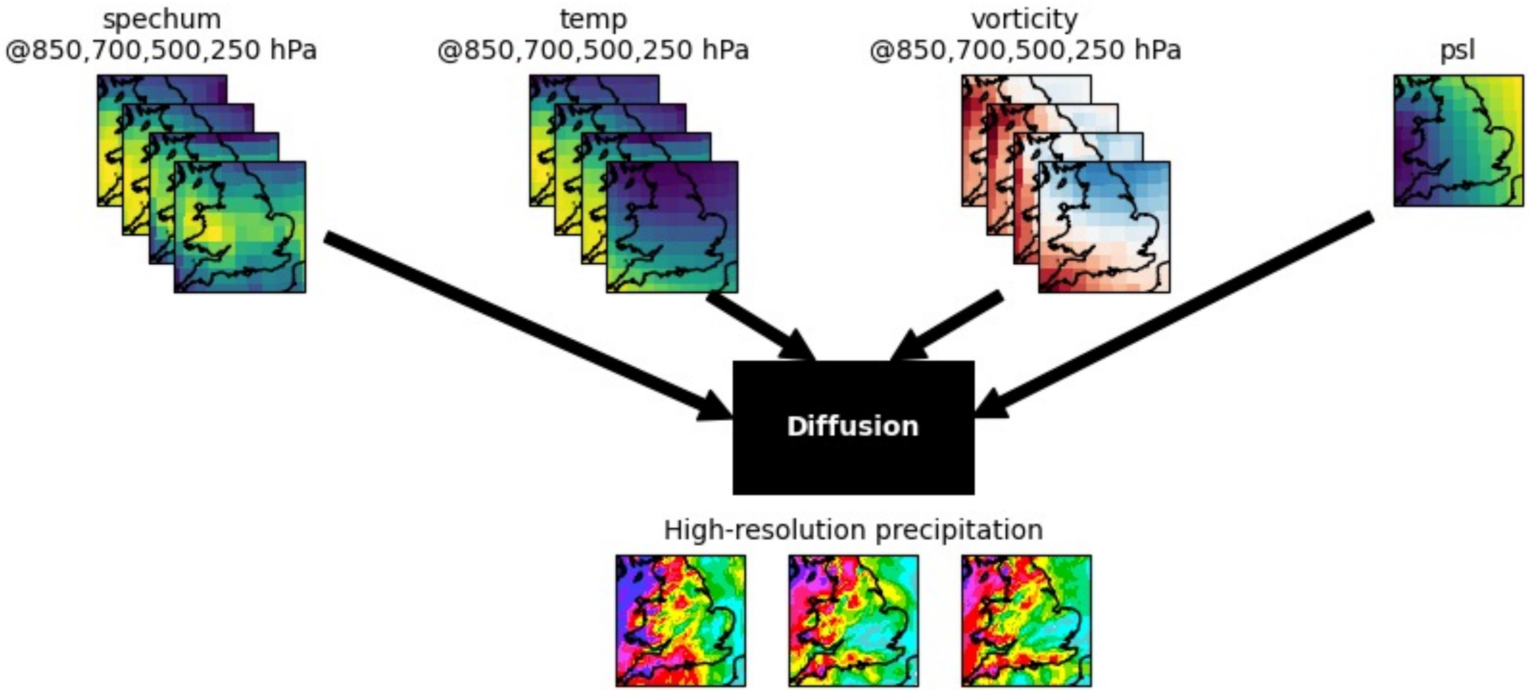


Kendon et al 2024

Emulating UKCP Local precipitation with ML

Input
Low-res predictors (60km)

Output
High-res daily precipitation



Addison et al in prep

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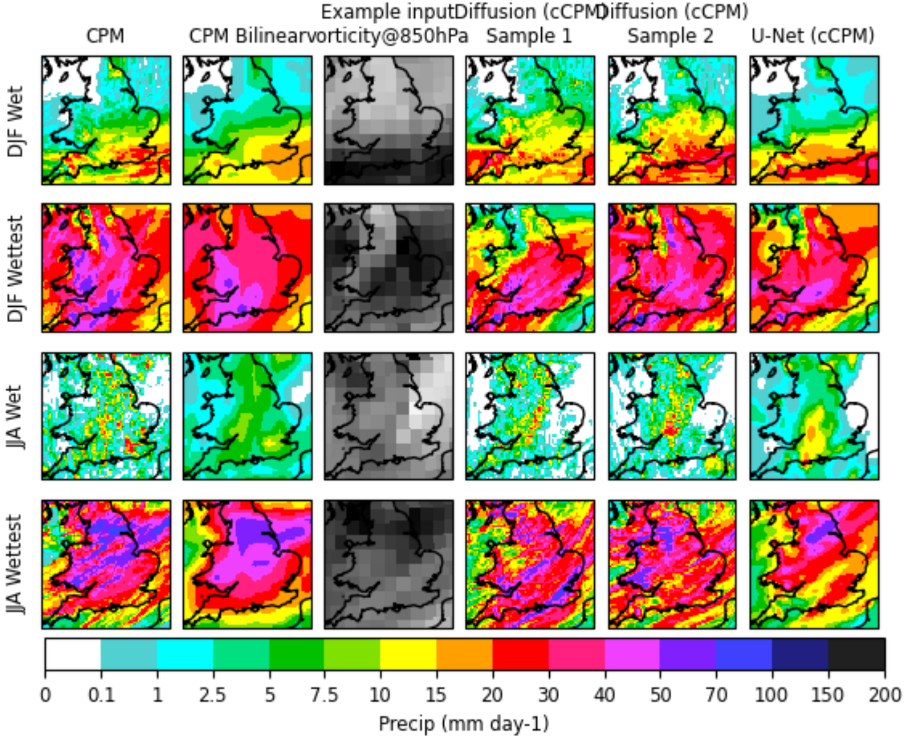
Example output

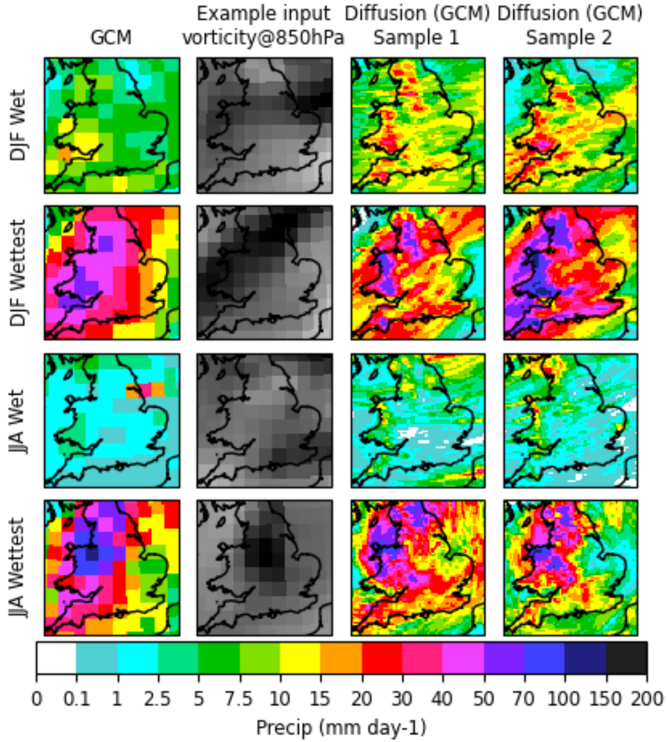
University of BRISTOL

Target Coarsened CPM

Samples using coarse-grained CPM as input



Samples using inputs from GCM



Addison et al in prep

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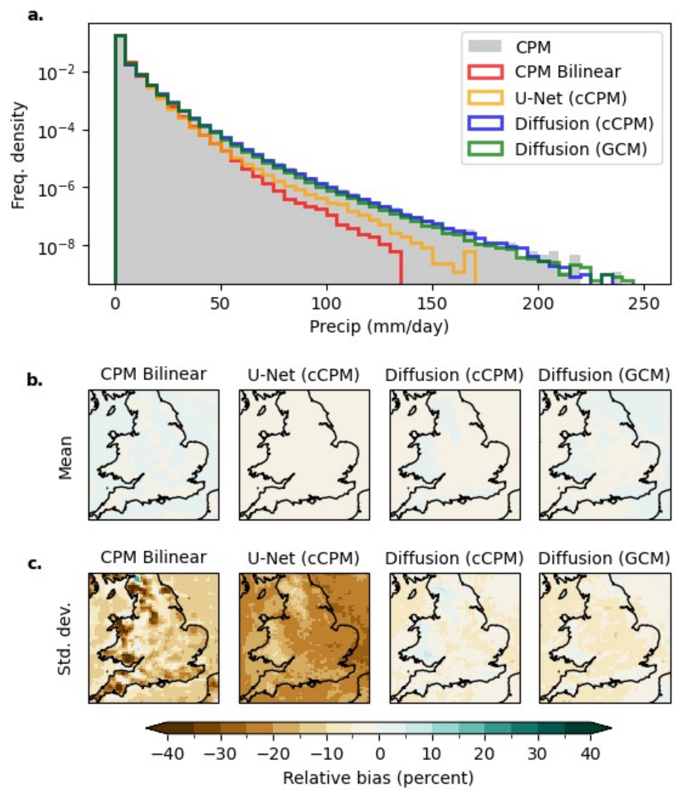
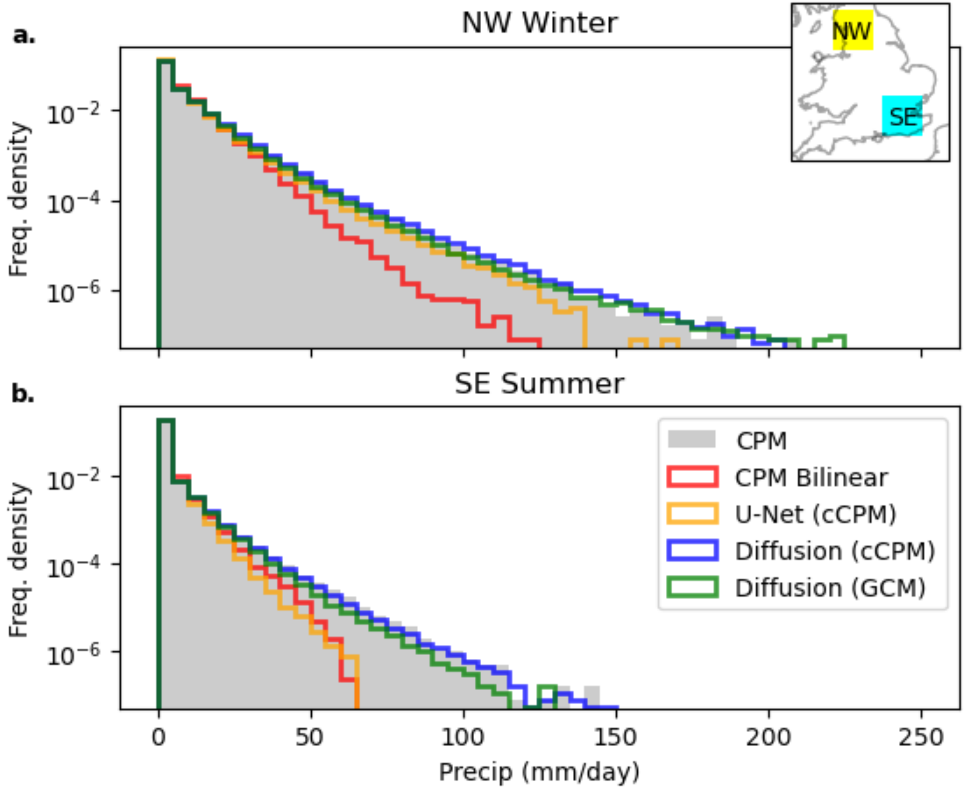
Skill for emulating daily precipitation

University of BRISTOL





Addison et al in prep

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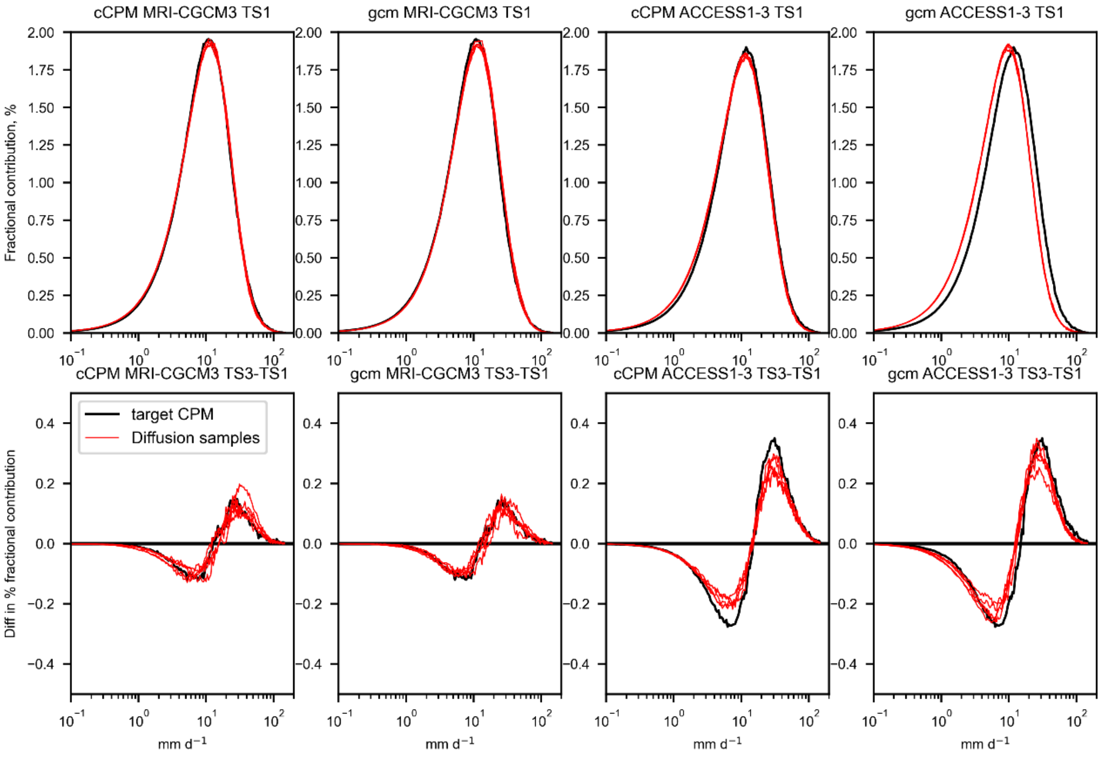
Transferability to other GCMs



Kendon et al 2024

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Future directions

- Several key areas for future work:
  - Can ML approaches give reliable predictions for extremes?
  - Transferability to other GCMs
  - Multi-variate emulation: required for risk assessments of compound hazards and impact metrics such as drought and heat stress
  - Evaluation of ML skill:
    - Weather and climate knowledge required to define what “good” looks like
    - Develop open benchmark datasets to assess ML added value (e.g. compared to classical statistical down-scaling)
    - Interpretability – right answers for right reasons?

Lapuschkin et al 2019

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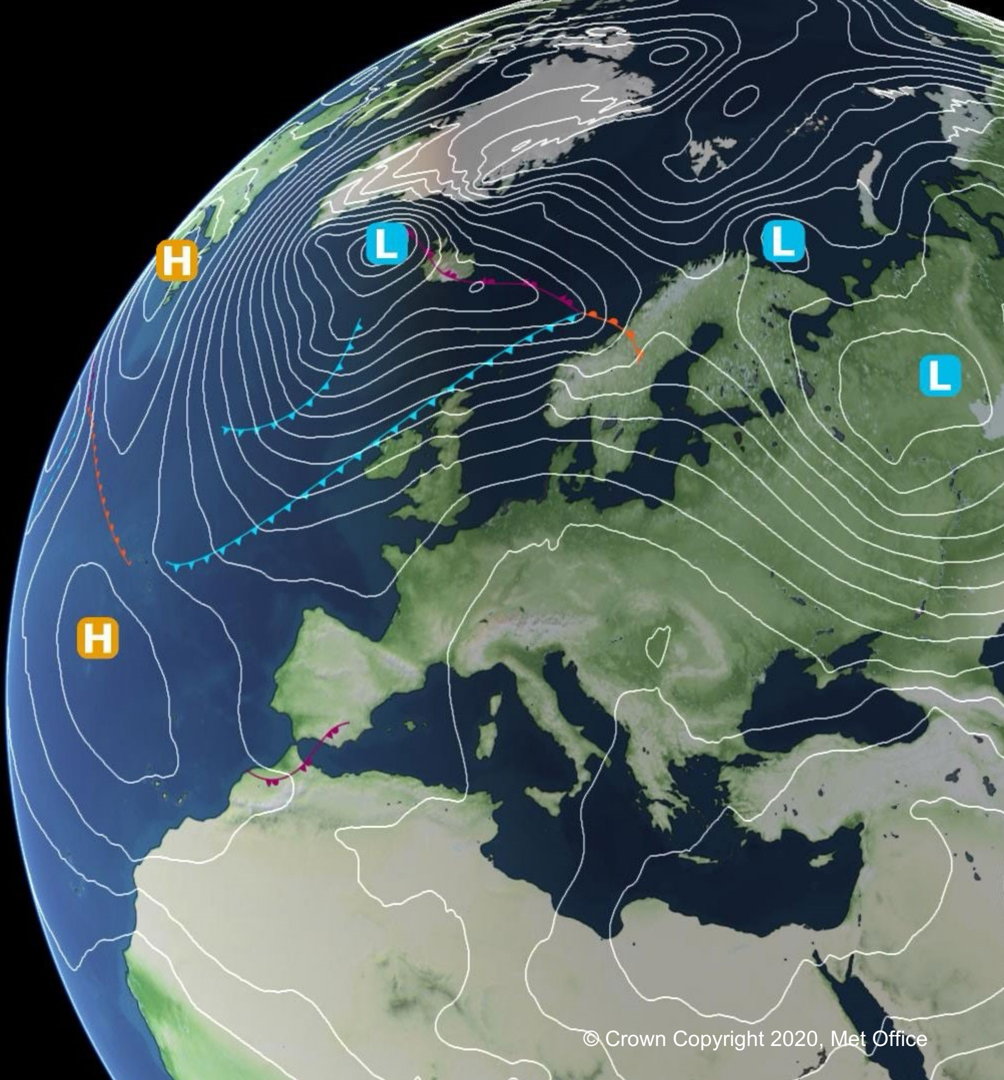
Thank you!



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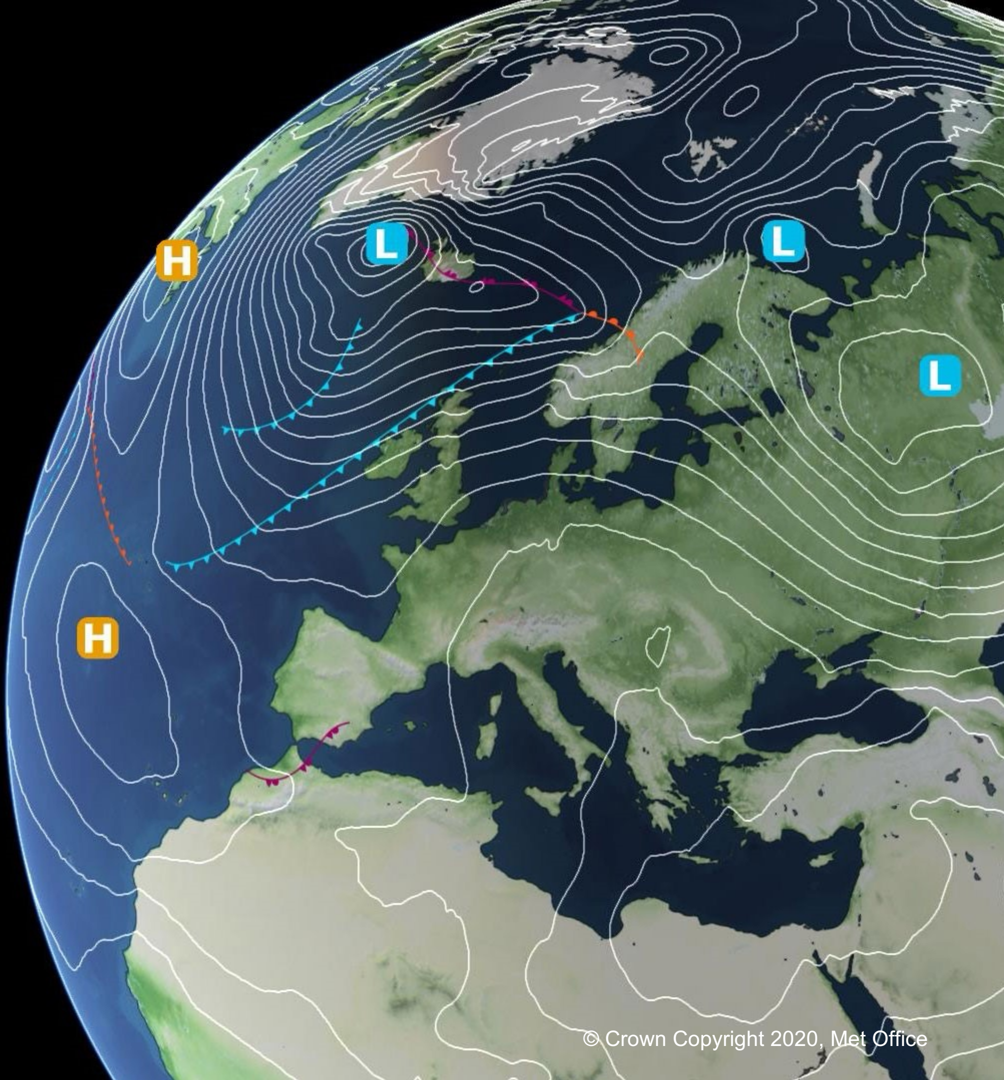
Spare slides



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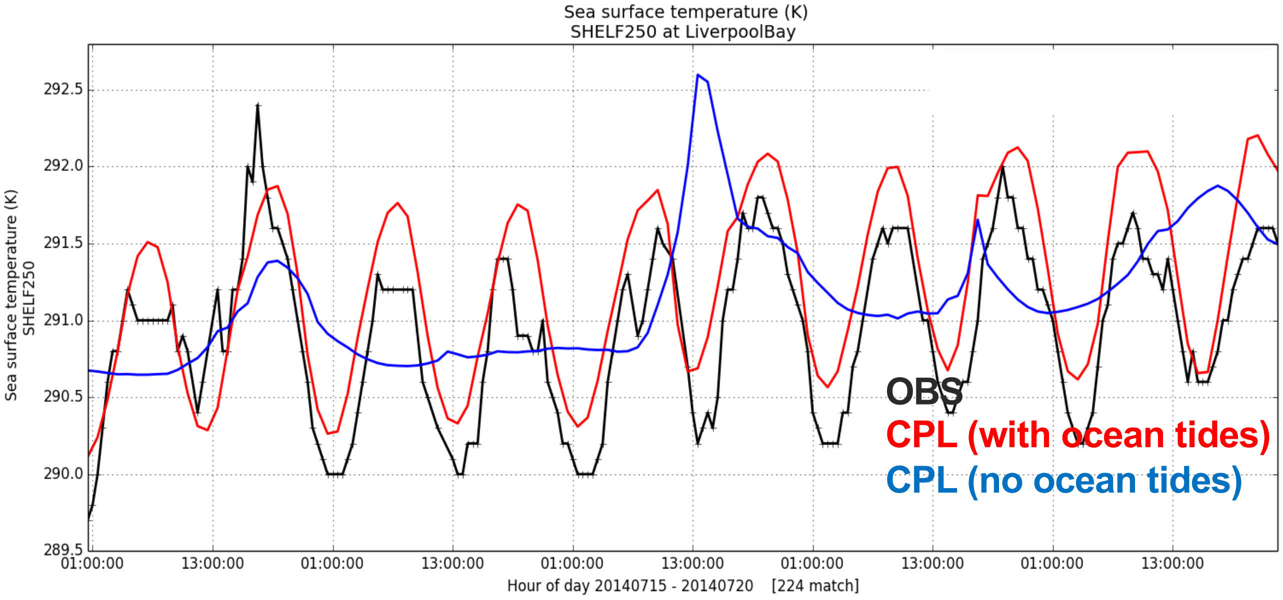
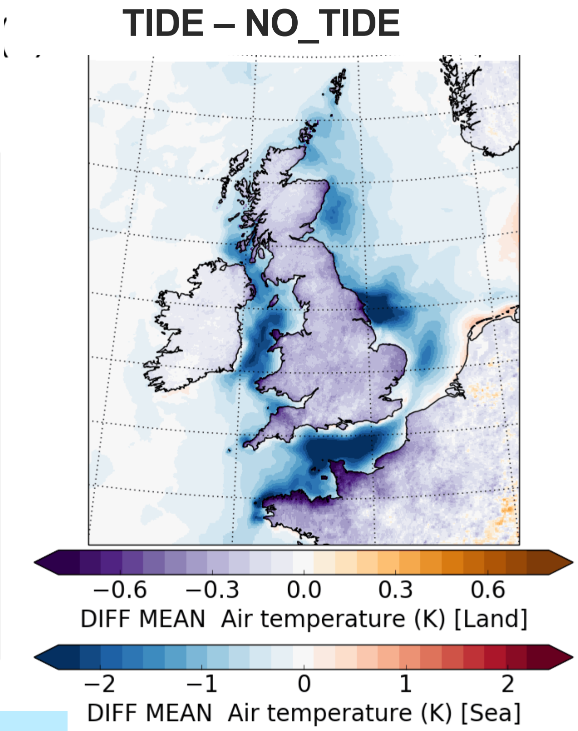
Improved understanding – REP as a 'laboratory'





- Tidal mixing reduces ocean stratification in the North West shelf
- Tides dampened the 2018 heatwave by 0.3K on average, locally 1K

Arnold et al., 2021, *GRL*

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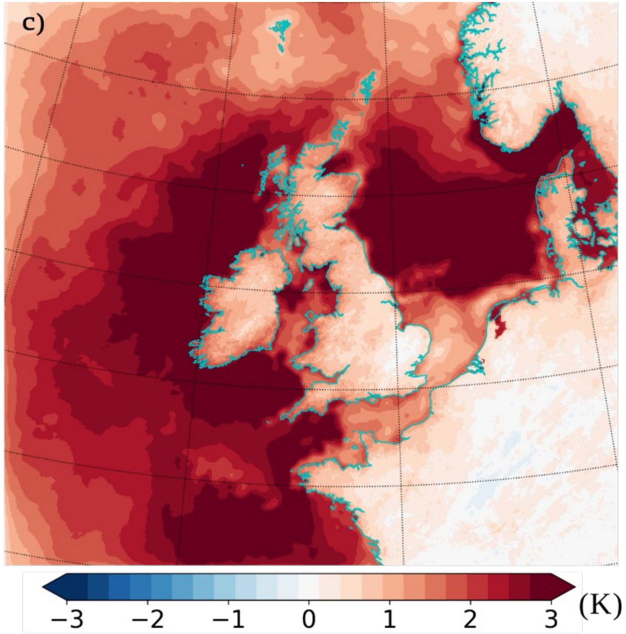
Feedback on the weather over land

Effect of the marine heatwave on air temperature on June 19th-26th



Warmest June on record in the UK (+0.9°C), of which 0.6°C came from the marine heatwave feedback on the atmosphere

Warmer temperatures advected by sea breezes (peak in the early afternoon)

Sea breezes increased, despite weaker land/sea contrast and increased rainfall by 20% for a week

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University of Bristol

Evaluation of ML skill

- Weather and climate knowledge needs to be employed to define what "good" looks like.
- Realism encompasses full spatial and temporal structure
- Visualisation of extreme cases important
- Benchmark important for assessing ML added value e.g. compared to classical statistical downscaling
- Use available RCM/CPM simulations as "truth" for future climate
- Interpretable AI – right answers for right reasons?

❖ Key area where climate science community can contribute

Some suggested evaluation metrics

Metric	Variable(s)
Seasonal mean	All
Daily (and potentially sub-daily) distribution	All
Wet day frequency and intensity	Precipitation
Joint distribution of intensity v duration	Precipitation, temperature
Joint distribution of intensity v spatial extent	Precipitation, temperature
Temporal correlation structure	All
Wet/dry or warm/cold spells	Precipitation, temperature
Diurnal cycle	Precipitation, temperature
Extremes on seasonal, daily (and potentially sub-daily) timescales (including 10y+ return period events)	All
Long-term stability	All
Temperature-precipitation scaling	Precipitation (and humidity)
Daily distribution by weather regime	All

Implications for CPM/RCM ensemble design

- For climate emulation: training and test data for future periods need to come from future climate model simulations
  - ➢ Hybrid approach with ML augmenting RCM/CPM simulations
- ML to provide uncertainty information, i.e. reducing need for large ensembles of dynamical simulations
  - ➢ In near future potential to help fill CORDEX GCM/RCM/CPM matrix
- Using ML can mine a wider range of GCMs for which expensive LBC data are not available
- Focus of dynamical simulations to provide the best training data for ML emulators

- Implications:
  - ➢ Dynamical simulations at the highest possible resolution and/or greatest complexity affordable
  - ➢ Work to address existing biases in CPMs key priority for coordinated community activity
  - ➢ Prioritise simulations of high-end cases, i.e. dynamically downscaling high climate sensitivity models/scenarios, and also extreme weather events
  - ➢ Training data needs to span the range of plausible climate and weather conditions
  - ➢ Focus coordination on spatial domains (difficulties in spatial transferability)