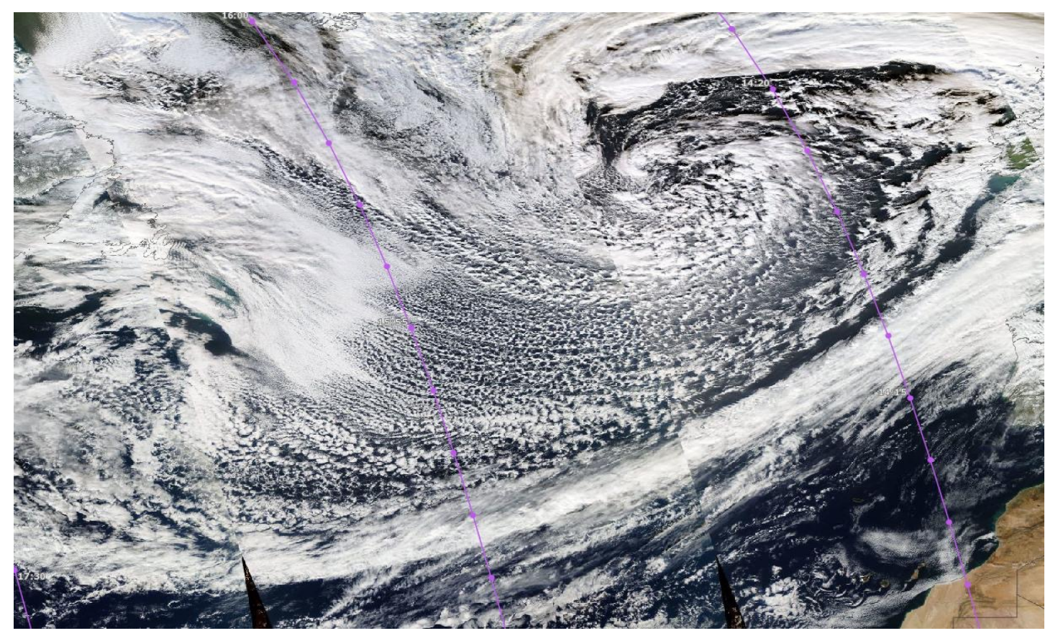
Insight Into Cold Air Outbreak Surface Wind Speed Through Remote Sensing, Perturbed Parameter Ensembles And Global Storm Resolving Models

Geethma Werapitiya[1], Daniel McCoy[1], Gregory Elsaesser[2,3], Paul Field[4], Paquita Zuidema[5], Andrew Gettelman[6], Trude Eidhammer[6]
wgeethma@uwyo.edu
[1]University of Wyoming, [2]Columbia, [3]NASA-GISS , [4]UK MetOffice, [5]Miami, [6]NCAR

Background



Cold Air Outbreaks (CAO) are high-impact weather events in which air masses of polar or cold continental origin are advected over relatively warm open ocean. These events are associated with a range of severe weather phenomena such as polar lows, strong surface winds and intense ocean atmosphere heat exchange playing an important role for deep water formation. They can occur throughout the year, but they are most frequent in the northern hemisphere in winter.

CAO index (M) = $\Theta_{SST} - \Theta_{800}$: Positive M defines an unstable lower troposphere hence a cold air outbreak.

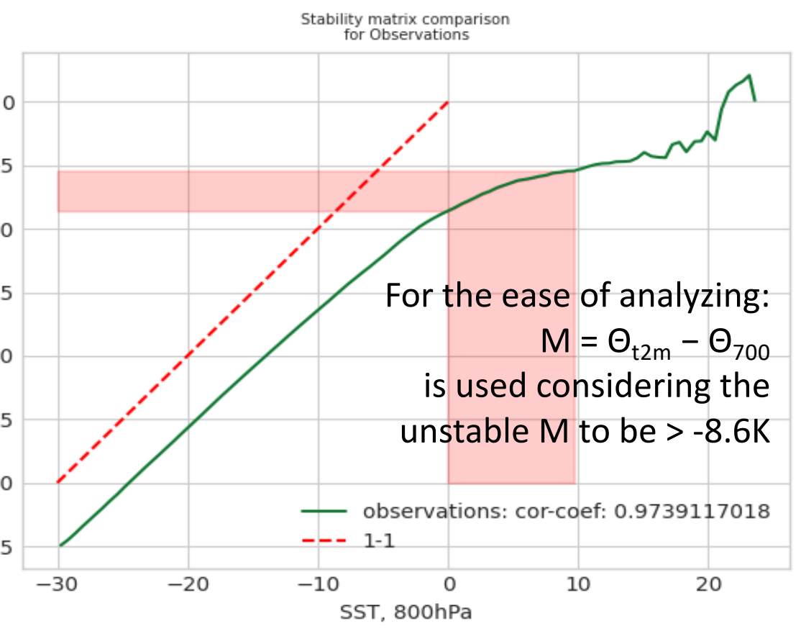


Figure 1: M calculated using temperature at 2m and temperature at 700hPa vs M calculated using sea surface temperature and temperature at 800hPa over the Northern hemisphere extra-tropics (30N-80N) ocean for MERRA2 reanalysis data.

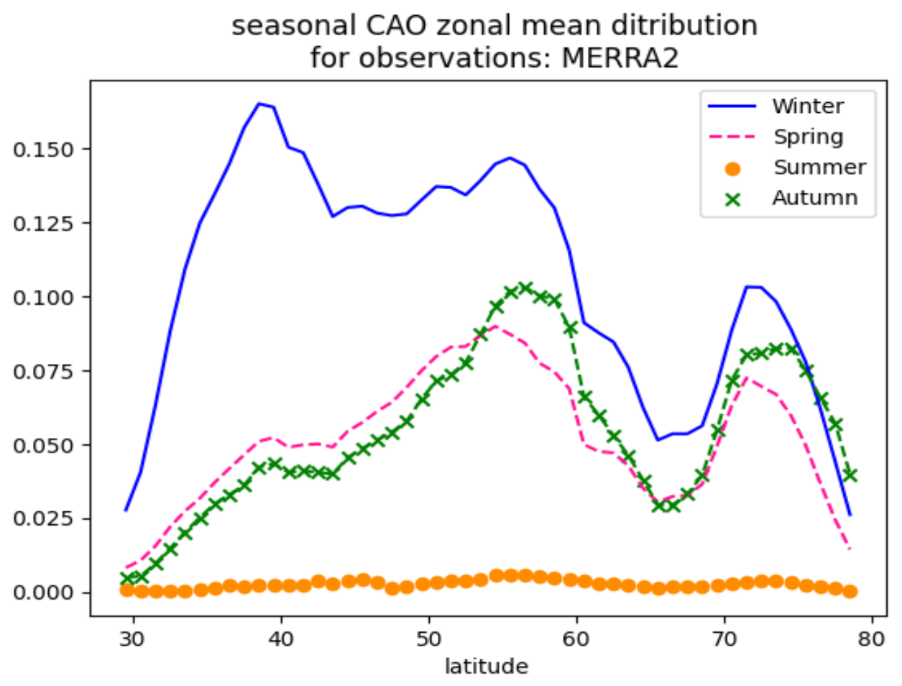


Figure 2: Zonal mean of the seasonal relative frequency of CAOs occurrence. Seasons were defined as follows: winter is December-February (DJF); spring is March-May (MAM); summer is June-August (JJA) and autumn is September-November (SCN)

Northern Hemisphere extra-tropics ocean

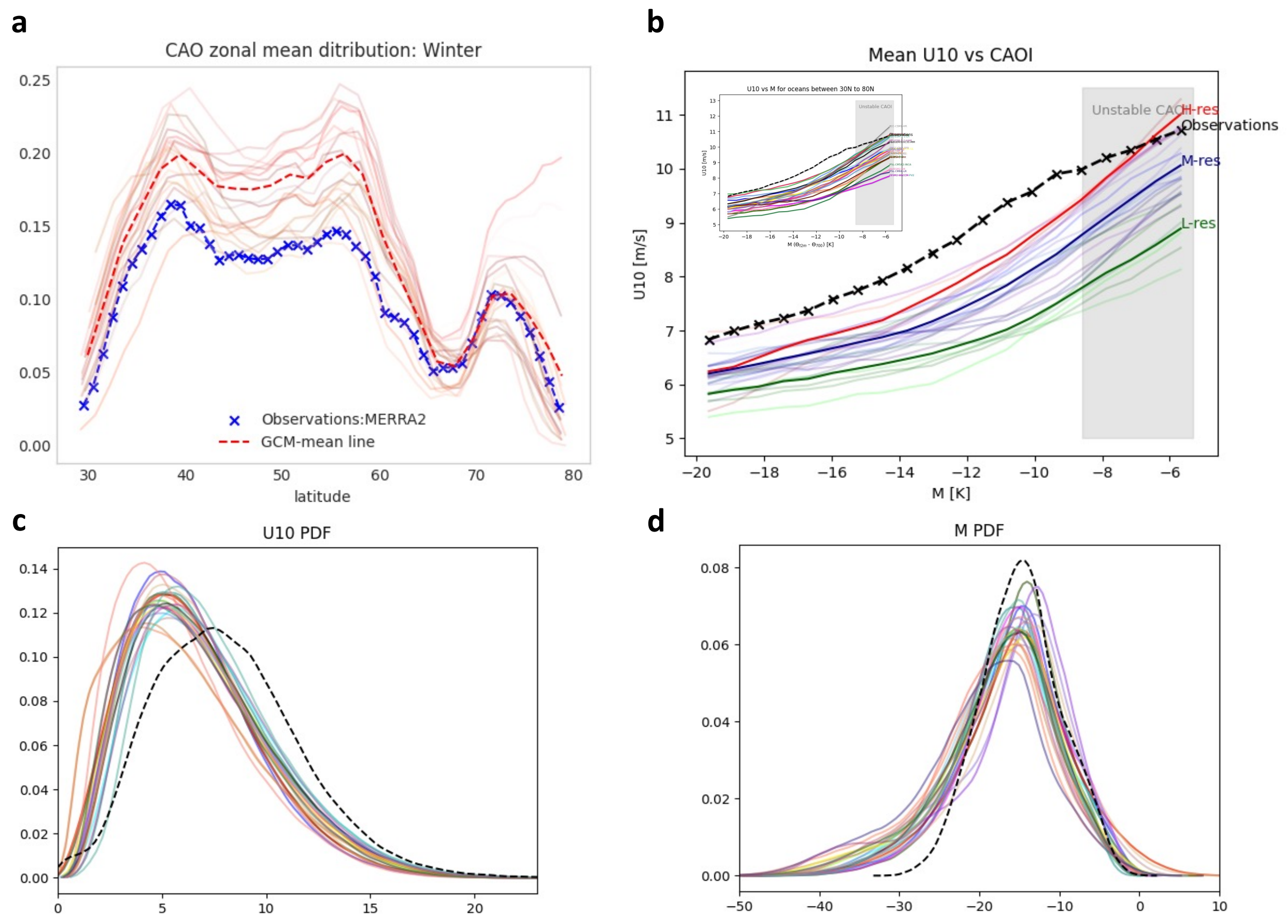


Figure 3: a: Zonal mean of the relative frequency of CAOs occurrence in winter for MERRA2 and 24 CMIP6 models. Red dashed line is the multi-model mean. Solid lines are the models; **b:** Surface wind speed observed by microwave (Elsaesser et al. 2017) as a function of M compared to CMIP6 GCMs over oceans between 30°N and 80°N. H/M/L-res are the mean lines for high/medium/low resolutions shown in Figure 8. Inset shows U10 vs M for 27 models.; **c:** the distribution of M in GCMs and observations; and **d:** the distribution of wind speed in GCMs and observations.

Motivation: Wind speed at the ocean surface is key to our understanding of the atmospheric state. It is critical to topics ranging from the availability of wind energy over the oceans (Possner and Caldeira 2017), to how climate is affected through air sea exchanges of heat and gas (Fu et al. 2019), and the transition from shallow to deep convection (Elsaesser and Kummerow 2013).

Preliminary analysis of the MAC microwave ocean winds data set (Elsaesser et al. 2017) as a function of cold air outbreak index ($M = \Theta_{t2m} - \Theta_{700}$) shows that in CMIP6 GCMs surface wind speed is too low in unstable boundary layers compared to the observations.
This systematic bias in winds in the global models in meteorological states consistent with mesoscale cellular convection in cold air outbreaks. This bias in the global models we rely on to forecast weather and predict future climate is concerning and the processes driving this bias should be investigated.

Hypothesis:
The bias is due to:

1. Cold pool formation driving downdrafts that enhance surface wind speed.
2. Enhanced winds tied to small convection induces circulations and induces surface convergence.
3. Lower resolution in GCMs only crudely resolve surface temperature gradients.
4. Unreliable observations of wind speed.

(a) Open cellular convection

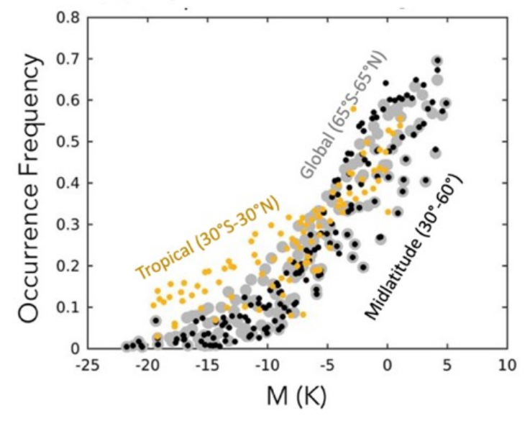


Figure 4: The frequency of occurrence of open cellular convection as detected in MODIS imagery by a neural network. Frequency of occurrence is shown for open cellular convection as a function of M. Adapted from (McCoy et al. 2017)

U10 in cold air outbreaks in warming

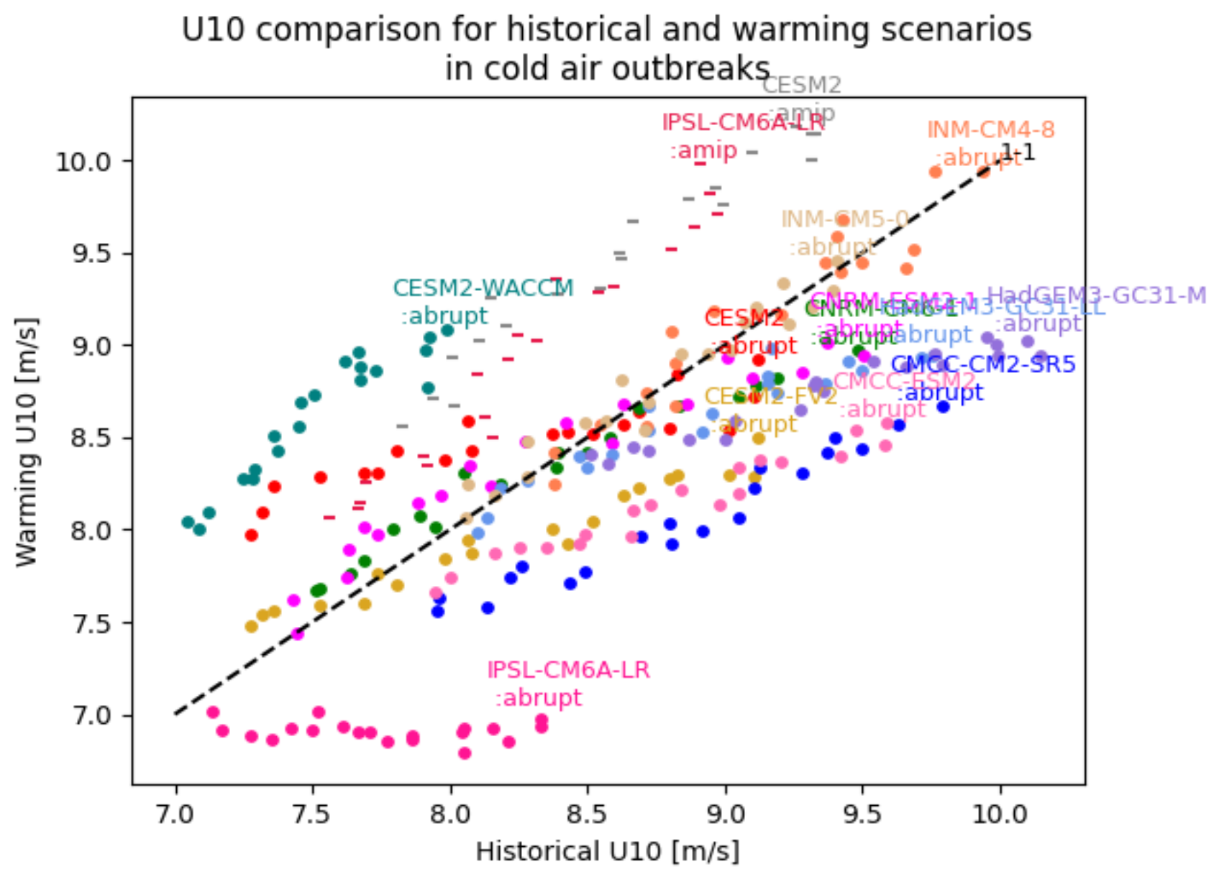


Figure 5: The surface wind comparison for different warming scenarios of CMIP6 in the CAO regime. Data over Northern hemisphere extra tropics oceans considered. Dots are for the abrupt-4xCO2; Hyphens are for amip-p4K

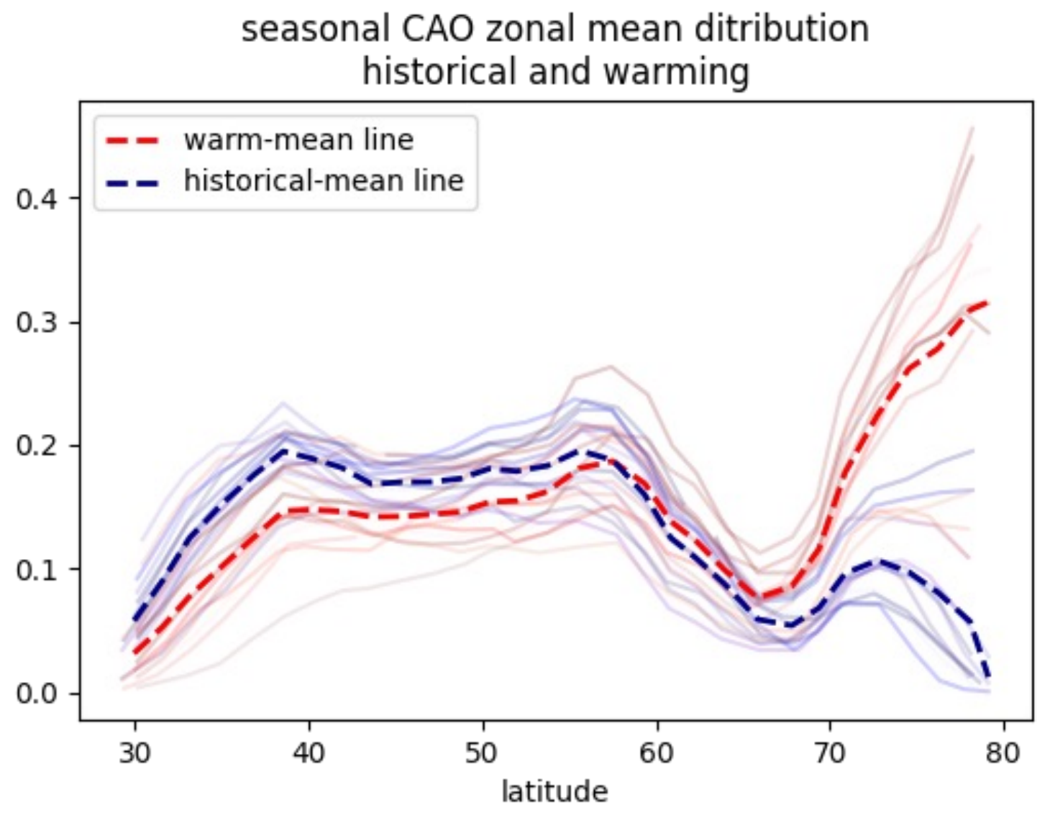


Figure 6: The zonal mean of the winter relative frequency of CAOs occurrence for historical and abrupt-4xco2 scenarios. Dashed lines are multi model means; Red colors represent the warming (abrupt-4xco2); Blue colors represent the historical CMIP6.

Resolution dependence

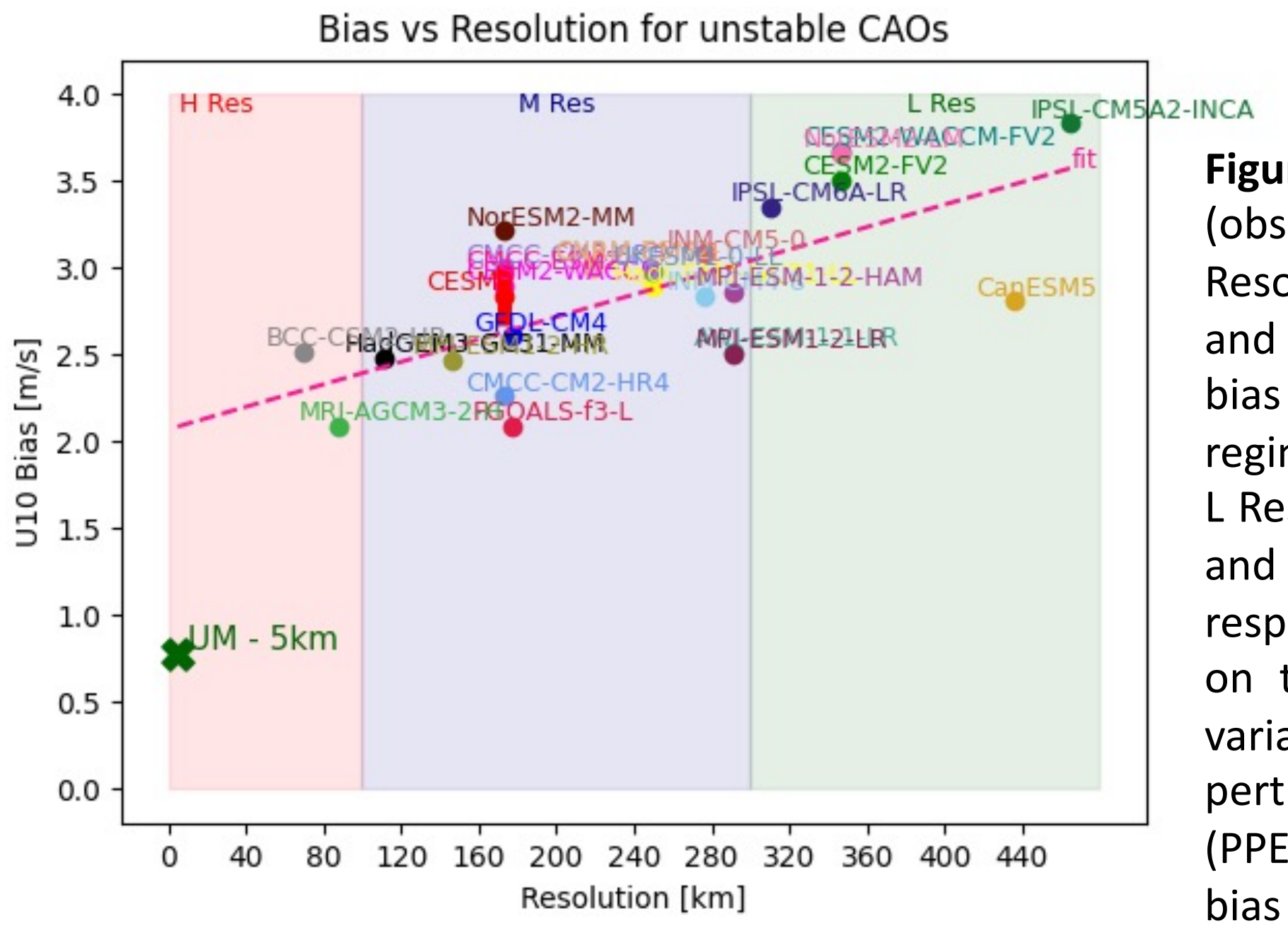
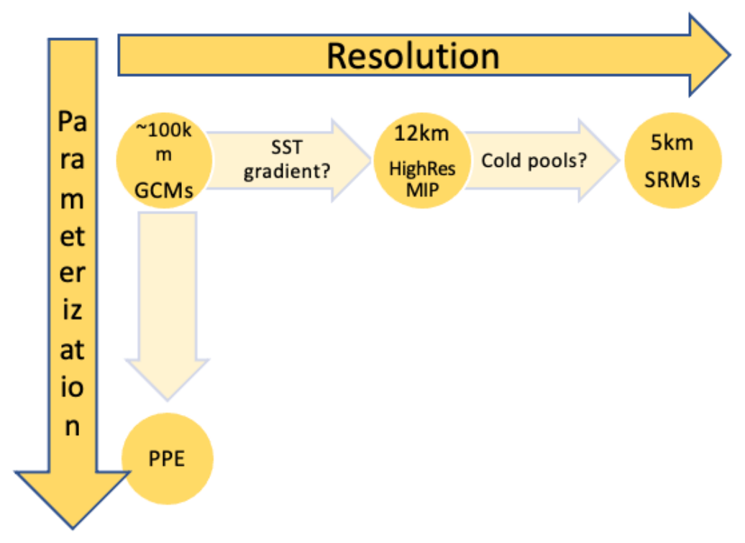
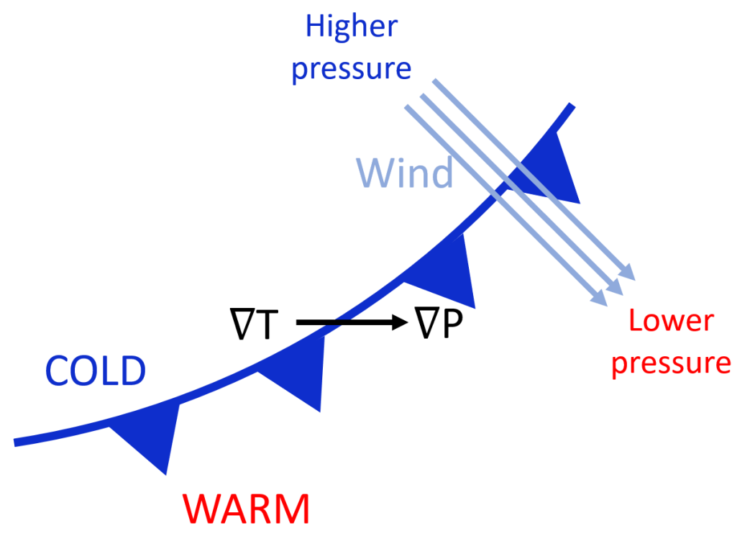


Figure 7: Bias of the surface winds (observation – model) vs Resolution for 27 CMIP6 models and UM-5km model*. The mean bias in the cold air outbreak regime is scattered. H Res., M Res, L Res represent the high, medium and low-resolution models respectively. The red vertical bar on the CESM2 point shows the variance of bias in CAM6 perturbed parameter ensembles (PPE). Dark green cross show the bias of the 5km Unified model. *This has only 1 month (January) data.



Resolution
Parameterization
~100km GCMs
SST gradient?
12km HighRes MIP
Cold pools?
5km SRMs
PPE



The effects of model resolution on boundary layer processes and surface winds is examined by using CMIP6 models (~100km – 400km), few HighResMIP models (~80km) and one storm resolving model (5km). More HighResMIP models which go down to ~12-25km horizontal resolution and global storm resolving DYAMOND simulations will be used in future work. These high resolution enable a more realistic simulation of small-scale phenomena. This work supports the hypothesis 3.

Parameter dependence

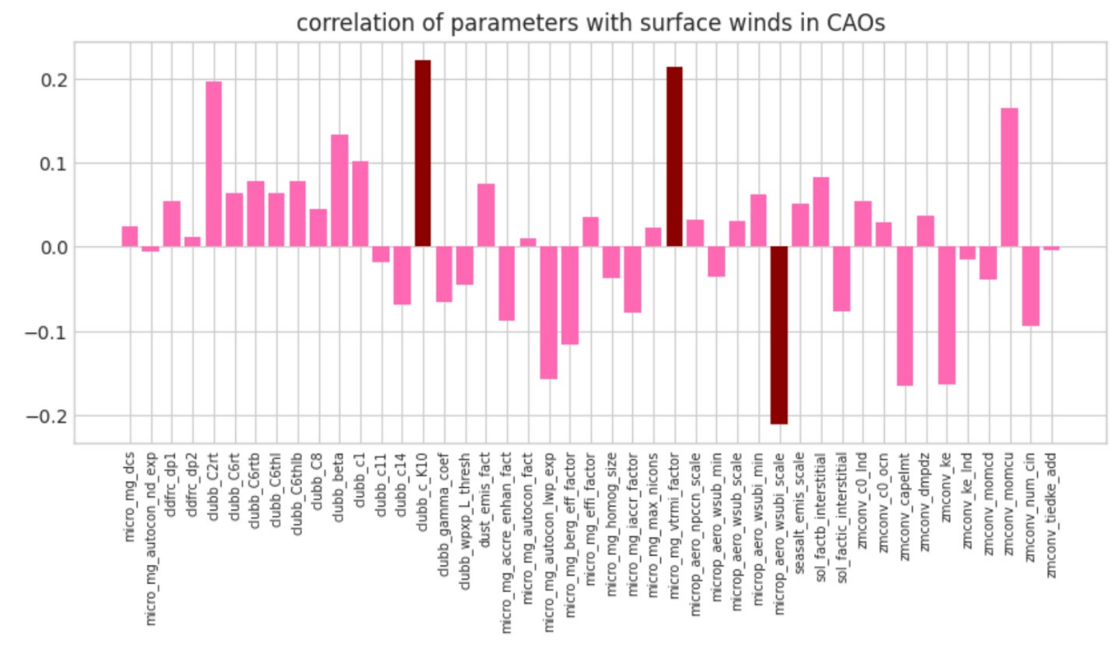


Figure 8: Correlation of 45 parameters perturbed in 250 ensembles in CAM6 perturbed parameter ensemble (PPE) with surface winds in the CAO regime. Parameters with dark red bars show the most significant correlation.

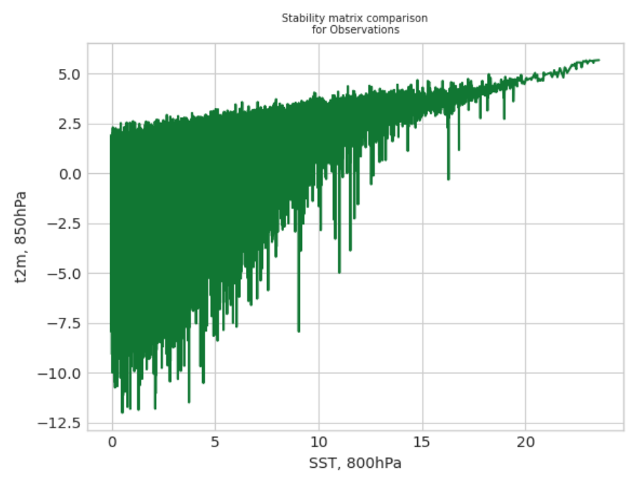


Figure 9: M calculated using temperature at 2m and temperature at 850hPa vs M calculated using sea surface temperature and temperature at 800hPa over the Northern hemisphere extra-tropics (30N-80N) ocean for MERRA2 reanalysis data. This is done to get the CAO regime for PPE data: M > -10K

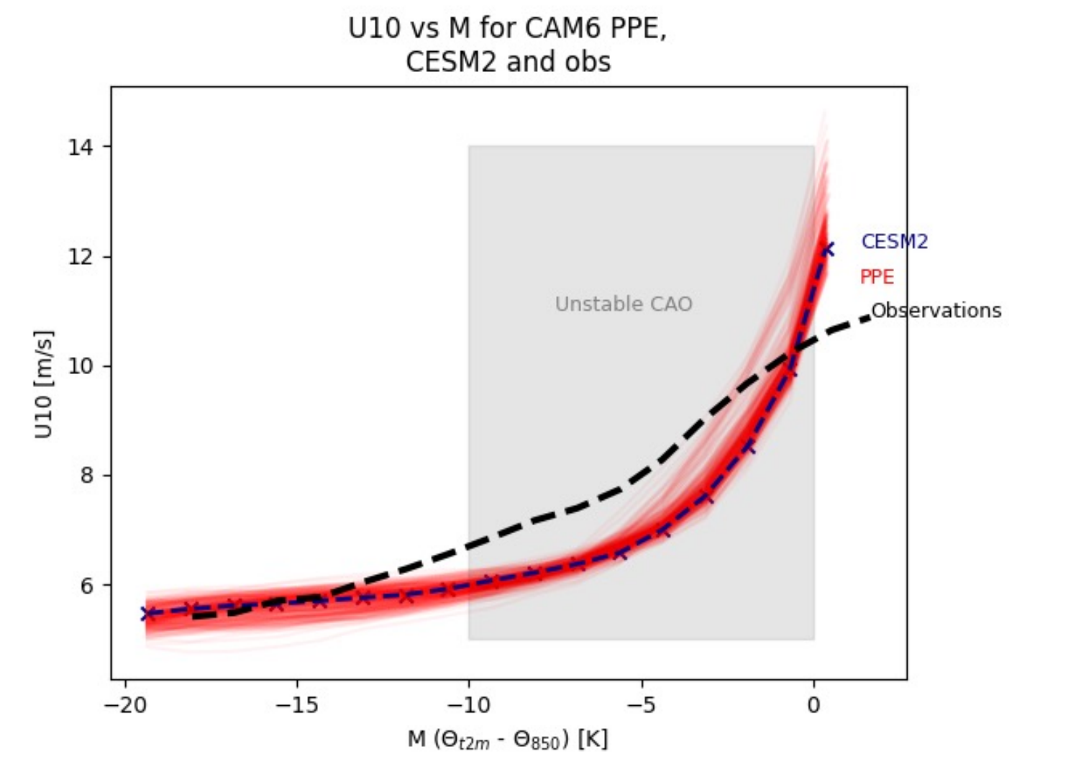


Figure 10: Surface wind with M for observations, CESM2 and CAM6 PPE over Norther hemisphere extra-tropical ocean. Red lines are the 250 ensembles of CAM6 PPE.

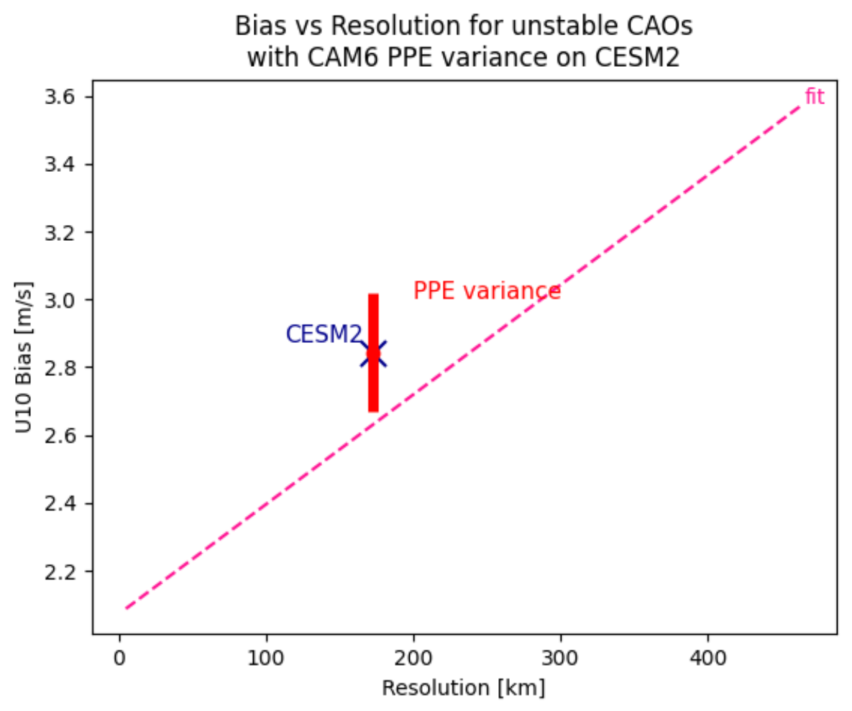


Figure 11: CESM2 model with the perturbation of bias of the surface wind (red line). Dashed pink line is the bias vs resolution fit obtained by the CMIP6 models.

Future Work

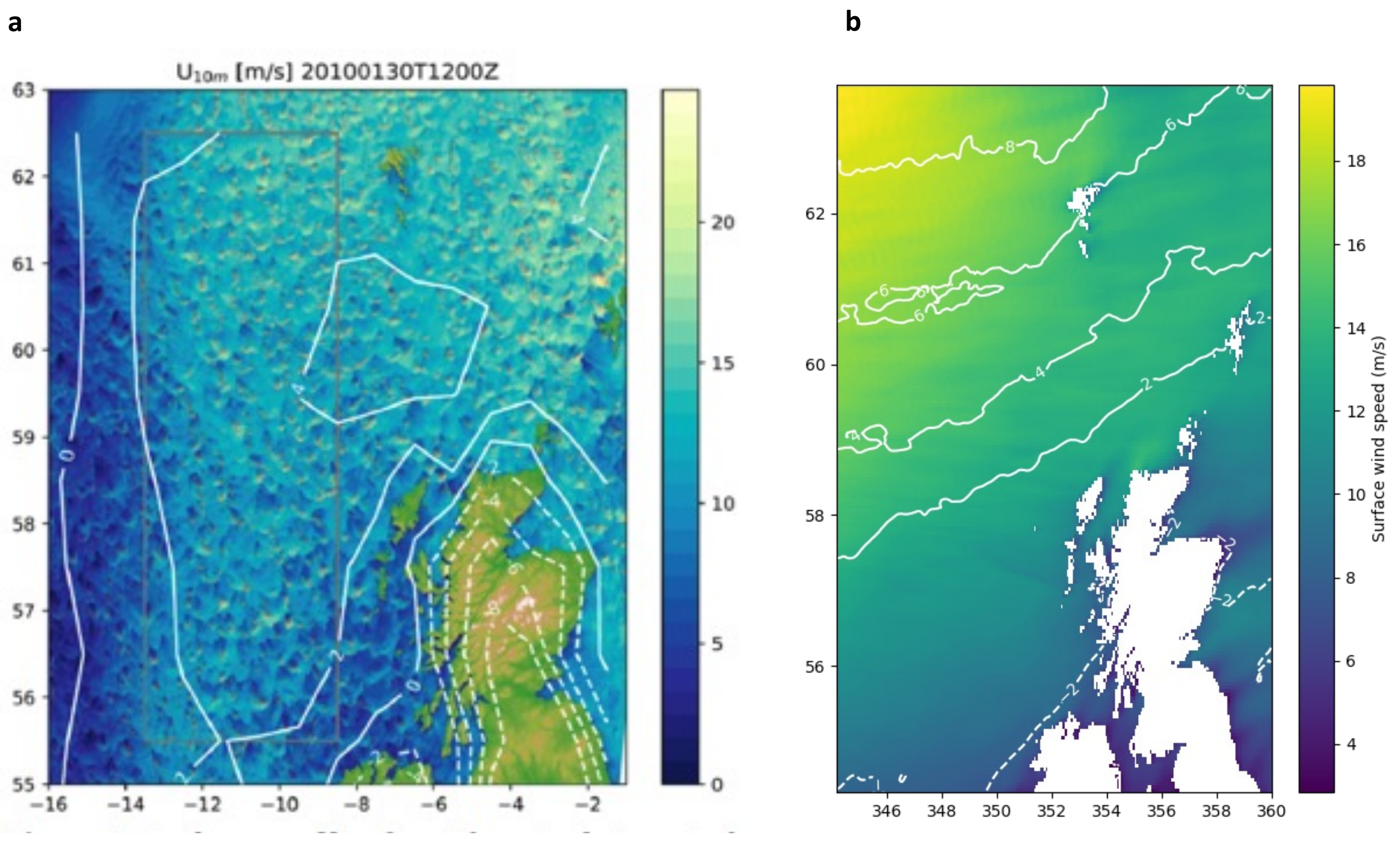


Figure 12: Daily mean U_{10m} from **a:** 1 km simulations **b:** 5 km simulations in the Met Office Unified Model (UM). M is shown by white contours . **a** shows enhanced daily mean $U10m$ associated with cold pools in the unstable postfrontal region (grey box), capable of reaching ~24 m/s in small regions associated with downdrafts (red dots). These are not properly captured on ~100km resolution models or even on 5km UM model **b**. A spatial aggregation of these perturbations would impact winds at ~100 km resolution. Thus, the possibility of systematic bias in GCM ocean wind speed driven by convective processes in turn driven by mesoscale convective features that are not resolved in a O~100km resolution GCM is reasonable.

To be done:

- Examine DYAMOND models for high resolution range
- km scale simulations: Investigating cold pools (using WRF)

Acknowledgement: NASA PMM Grant #80NSSC22K0599, NASA MAP Grant #80NSSC21K2014, DOE-ASR Grant #DE-SC002227, DKRZ and ESiWACE