Insight Into Ocean Surface Wind Speed Through Remote Sensing, CMIP6 models, CAM6 PPE and WRF

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BACKGROUND & MOTIVATION

Surface wind is a critical measure of the atmospheric state and govern air sea exchange and affect boundary layer evolution.

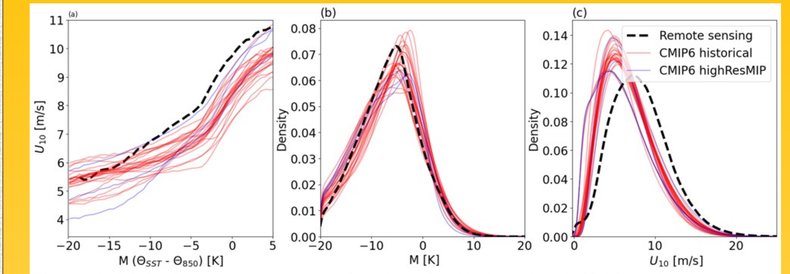

Figure 1: ***(a)*** *Surface windspeed as a function of cold air outbreak (CAO) index ($\mathcal{M}$ = Θ_{SST} – Θ_{850}) compared to CMIP6 GCMs (25 historical models, 3 HighResMIP models) over oceans between 30°N and 80°N.* ***(b)*** *the distribution of M* ***(c)*** *the distribution of windspeed.*

Figure 1a suggests that the ocean surface windspeed over the Northern Hemisphere extra tropics in the GCMs is slow compared to microwave MAC-LWP observations. This bias in the global models is concerning and the processes driving this bias should be investigated. Biases in $U10m$ for $M > -5K$ in GCMs may have gone undetected partially because GCMs tend to have boundary layers that are relatively unstable (Figure 1b).

Hypotheses (not mutually exclusive)

1. Wind enhancement tied to convection induced circulations and surface convergence.
2. Cold pool formation driving downdrafts that enhance surface windspeeds.
3. Poorly resolved surface temperature gradients.

Data Used:

- Microwave Multi-Sensor Advanced Climatology of Liquid Water Path (MAC-LWP)

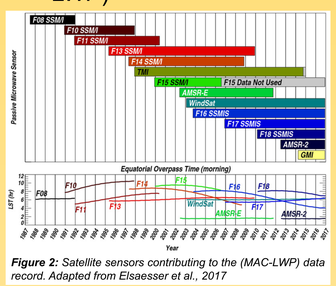

Figure 2: *Satellite sensors contributing to the (MAC-LWP) data record. Adapted from Elsaesser et al., 2017*

- Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA-2)
- Coupled Model Intercomparison Project Phase 6 (CMIP6): historical and HighResMIP
- Community Atmosphere Model version 6 (CAM6) perturbed parameter ensemble (PPE)
- Weather Research and Forecasting (WRF)

PARAMETER DEPENDANCE

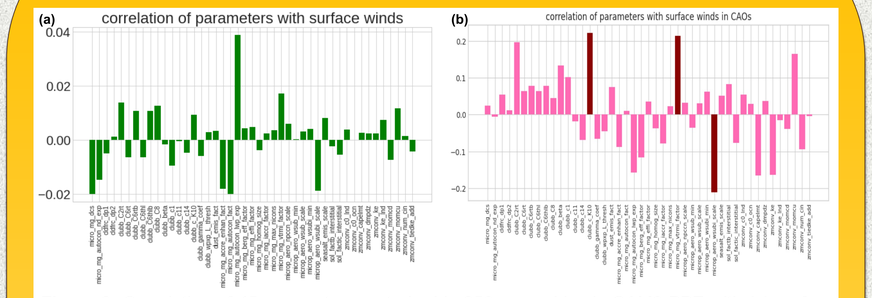

Figure 3: *Correlation of 45 parameters perturbed in 250 ensembles in CAM6 PPE with* ***(a)*** *surface winds* ***(b)*** *surface winds in the CAO regime. Dark red bars (momentum in clubb, ice number limit, sub-grid scaling for vertical velocity for ice nucleation) show the most significant correlation.*

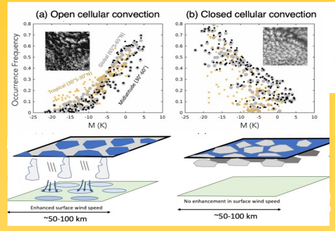

Figure 4: *The frequency of occurrence of open and closed cellular convection as detected in MODIS imagery by a neural network as a function of $\mathcal{M}$. Adapted from McCoy et al. (2017)*

Figure 3 suggests a parameter correlation to the surface winds particularly stronger in CAOs. Shift from closed to open cellular convection, precipitation and cold pool formation with CAO occurrence enhance surface windspeeds (Figure 4).

A WRF simulation of horizontal resolution 1km over a CAO in an area correspond to the COMBLE field campaign shows enhanced surface windspeeds formed at the downwind of cold pools. A vertical cross section of a transect through this area shows coaligned cold pools, strong downdrafts, precipitation and enhance surface wind speeds (Figure 5,6,7).

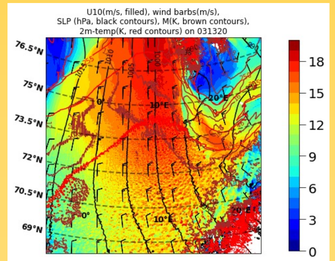

Figure 5: *WRF simulation of horizontal resolution 1km ran north of Scandinavian region over a strong CAO correspond to the recent COMBLE field campaign(Geerts, 2019)*

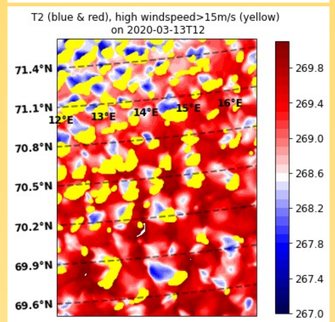

Figure 6: *zoomed area of Figure 5. Blue colors denote the cold pools formed. Yellow colors are enhanced wind speeds associated with cold pools.*

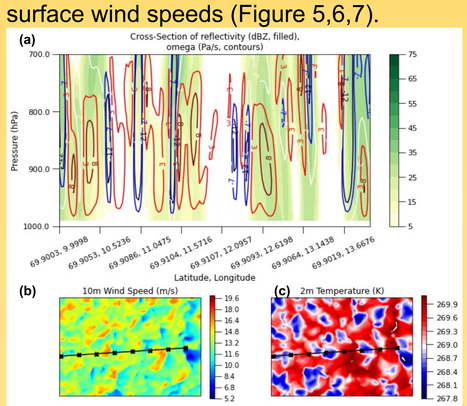

Figure 7: ***(a)*** *Vertical cross section of a selected transect of Figure 6, downdrafts (red contours), updrafts (blue contours)* ***(b)*** *10m windspeed* ***(c)*** *2m-Temperature; black lines on (b) and (c) shows the transect that (a) is taken. Black crosses correspond to the x-ticks on (a).*

RESOLUTION DEPENDANCE

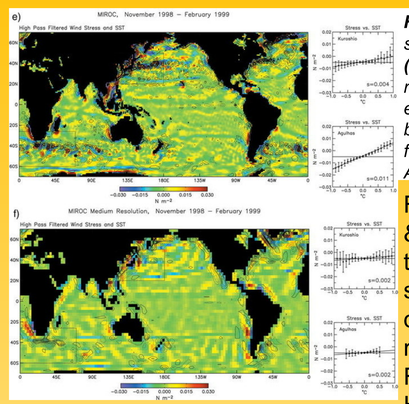

Figure 8: *Spatially high-pass-filtered wind stress (colors) and SST (contours) from the* ***(e)*** *high-resolution MIROC, and* ***(f)*** *medium-resolution MIROC models. To the right of each map are the corresponding model binned scatterplots of SST and wind stress for the Kuroshio and Agulhas regions. Adapted from Maloney & Chelton (2006)*

Figure 8 adapted from Maloney & Chelton (2006) suggests that the ability of climate models to simulate air–sea interactions degrade with decreasing grid resolution.

Figure 9 and Figure 10 support Hypothesis 3.

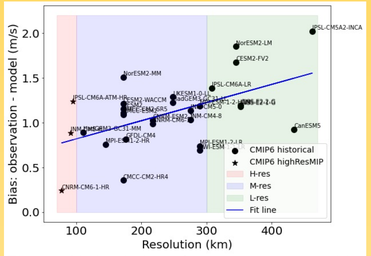

Figure 10: *Variation of ocean U_{10m} mean bias (observation - models) with the horizontal grid resolution of GCMs. Shaded red, blue and green regions are for high, medium, and low resolutions (High: resolution < 100 km; Medium: 100 km <= resolution < 300 km; Low: resolution > 300 km).*

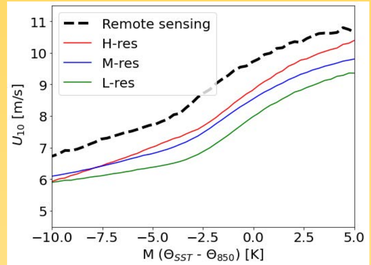

Figure 9: *U_{10m} observations as a function of $\mathcal{M}$ compared to model mean of CMIP6 models categorized into high, medium, and low resolutions (High: resolution < 100 km; Medium: 100 km <= resolution < 300 km; Low: resolution > 300 km).*

TAKE HOME MESSAGES

- GCM winds are too slow compared to MAC-LWP observations.
- 1km WRF model forming cold pools suggests enhanced surface wind in CAOs.
- 1km WRF cold pool associated downdrafts and enhanced surface windspeeds are coordinated with precipitation in CAOs.
- The surface wind bias of GCMs is horizontal grid resolution dependent

REFERENCE

- *Elsaesser, G. S., O'Dell, C. W., Lebsock, M. D., Bennartz, R., Greenwald, T. J., & Wentz, F. J. (2017). The Multisensor Advanced Climatology of Liquid Water Path (MAC-LWP). Journal of Climate, 30(24), 10193-10210. 10.1175/JCLI-D-16-0902.1*
- *Geerts, B. (2019). Cold-Air Outbreaks in the Marine Boundary Layer Experiment (COMBLE) Science Implementation Plan; Sponsor Org.: USDOE Office of Science (SC), Biological and Environmental Research (BER). (). United States: ARM user facility, Pacific Northwest National Laboratory, Richland, WA. 10.2172/1499128 https://www.osti.gov/biblio/1499128 https://www.osti.gov/servlets/purl/1499128*
- *Maloney, E. D., & Chelton, D. B. (2006). An Assessment of the Sea Surface Temperature Influence on Surface Wind Stress in Numerical Weather Prediction and Climate Models. Journal of Climate, 19(12), 2743-2762. 10.1175/JCLI3728.1*
- *McCoy, I. L., Wood, R., & Fletcher, J. K. (2017). Identifying Meteorological Controls on Open and Closed Mesoscale Cellular Convection Associated with Marine Cold Air Outbreaks. Journal of Geophysical Research. Atmospheres, 122(21), 11,678-11,702. 10.1002/2017JD027031*

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