Early insights into momentum flux impacts on tropical cyclones in CAM6

Colin Zarzycki (@weatherczar)
Penn State University
czarzycki@psu.edu

Kyle Nardi
Penn State University

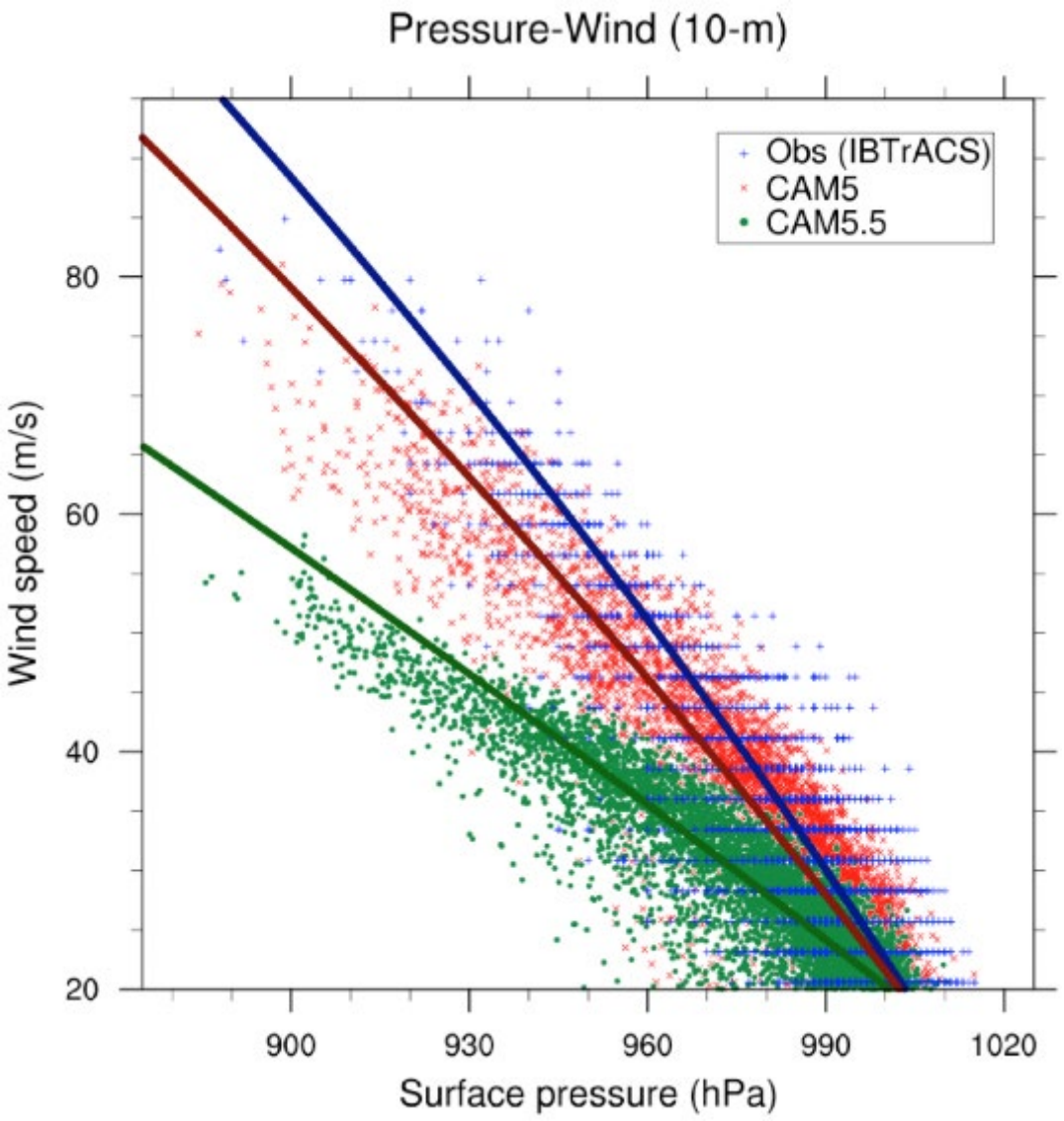
Vince Larson
University of Wisconsin-Milwaukee

George Bryan, Julio Bacmeister
NCAR

What got us thinking about this?

PennState

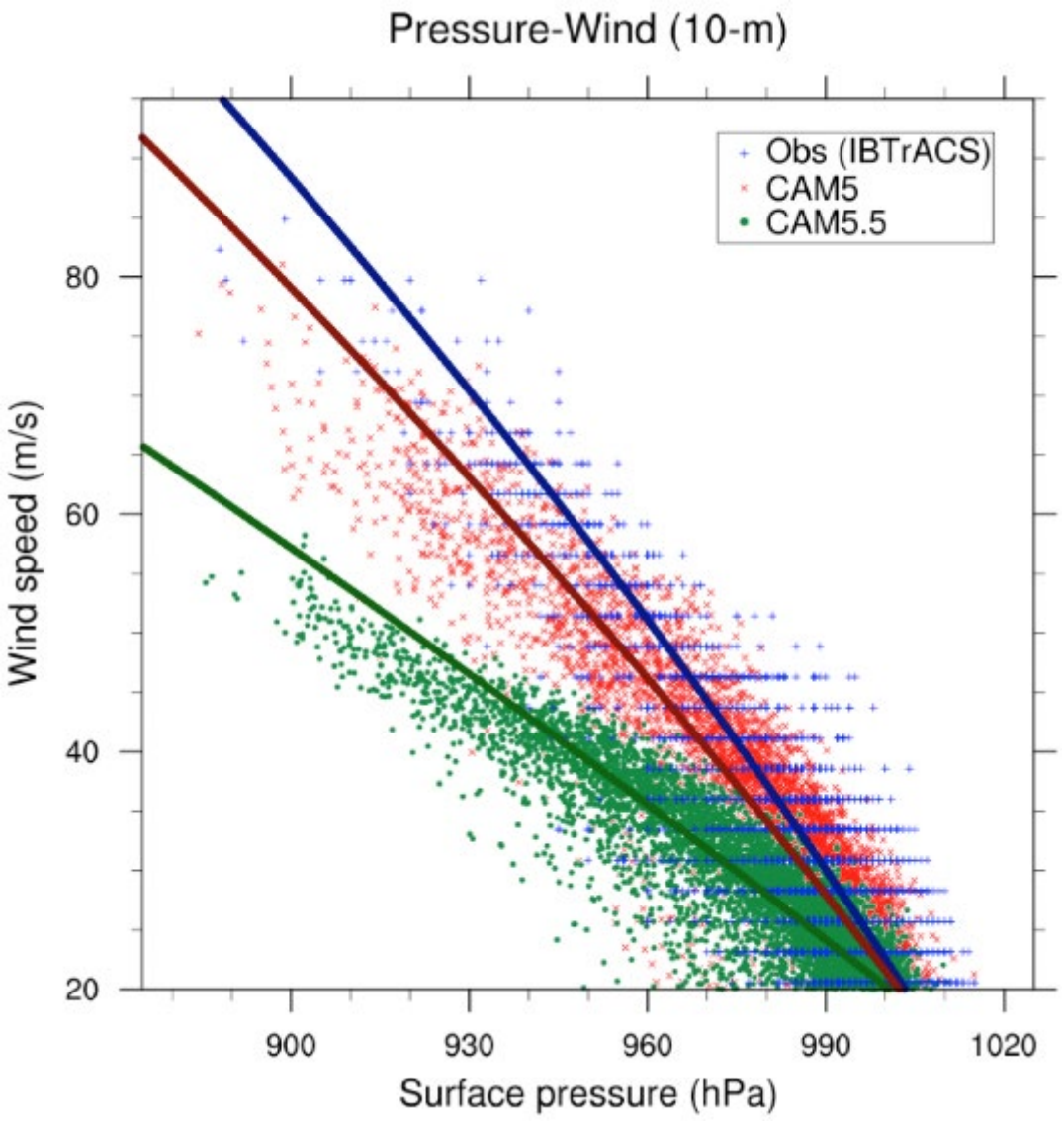
- CAM6 > (or even >>!) CAM5 in many cases
- One noted "regression" at 0.25° is tropical cyclone (TC) climatology
- Particularly noted in "pressure-wind" relationship



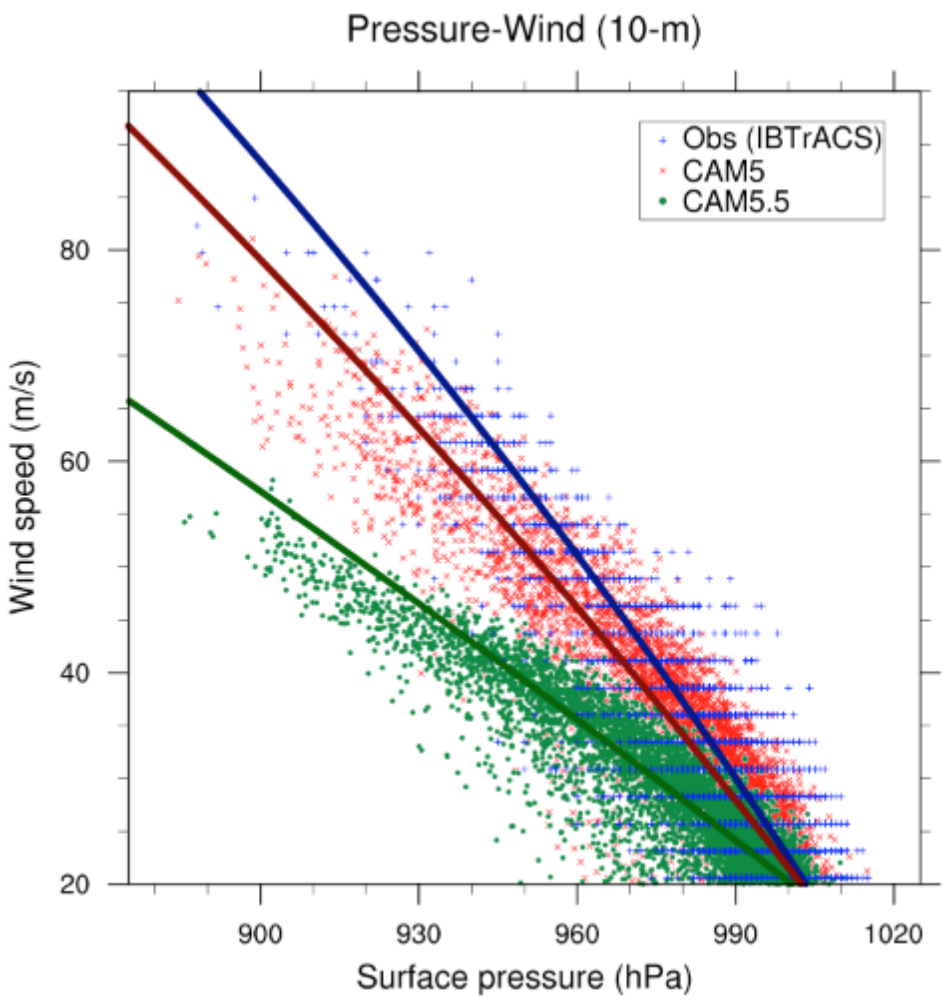
Pressure-wind relationship

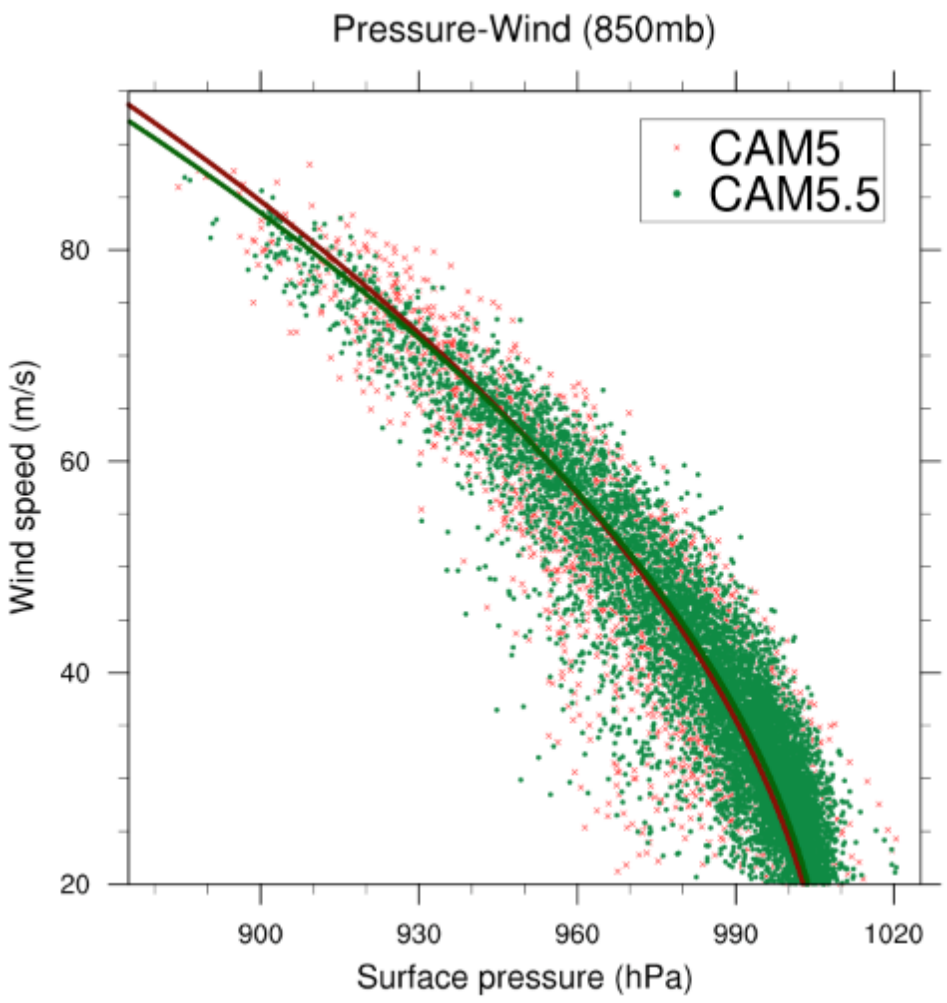
PennState

- PSL essentially a "macro" quantity
- U10 explicitly dependent on surface characteristics, PBL parameterization
- PSL/U10 fundamentally ties large-scale prognosed dynamics to near-surface parameterizations



Pressure-wind curves





Not just a CAM problem...

PennState

Seasonal mean activity bias

	Count	TCDays	ACE1	ACE2	LMI	ACE1/ACE2
OBS	75.03	368.62	577.71	563.28	19.55	1.02
CFSR	-9.17	43.60	-340.65	-258.22	2.79	1.32
JRA	-2.23	115.72	-314.84	-195.47	3.46	1.61
MERRA2	23.83	232.37	-290.68	-107.84	-1.23	2.71
MERRA	-27.94	-98.81	-473.16	-354.15	5.30	1.33
ERA5	3.59	133.97	-315.36	-122.20	3.97	2.58
ERAI	-30.78	-100.66	-467.21	-361.26	3.95	1.29
CR20	-18.61	-3.71	-357.58	-202.18	0.15	1.76

Low Bias — High Bias

Zarzycki et al., in prep

ACE1 – Integrated wind speed energy

ACE2 – Integrated "surface pressure" energy

Varying ratios mean disconnect between macro PSL prediction, near-surface U10!

modulation of surface fluxes under high winds, I did not found any significant changes in the pressure-wind relationship. I did those tests some times ago and I may look at the results more deeply if the discussion comes to that point. For now,the best hypothesis that I am working on is the new CBR (Cuxart-Bougeault-Redelsperger) turbulent scheme. In addition to 10 years simulations, I am now testing the different parameterizations in a transpose-AMIP-like configuration in which I isolated 3 TCs in the control run that I initialize for different configurations and look at the TC life cycles. Turbulence is clearly at play in these runs since when introduce in the old CMIP5 physics I get as intense a TC as in CMIP6 physics.

CLUBB's momentum

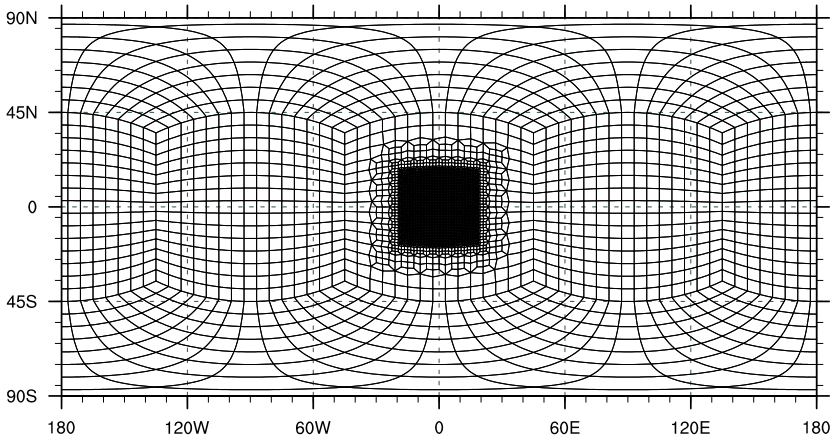
$$\overline{u'w'} = \underbrace{-\tau \overline{w'^2} \frac{\partial \overline{u}}{\partial z}}_{\text{turb production}} \underbrace{- \frac{\tau}{\rho} \frac{\partial}{\partial z} \left(\rho \frac{\overline{w'^3}}{\overline{w'^2}} \overline{u'w'} \right)}_{\text{turb advection}} \underbrace{+ \tau \frac{g}{\theta_{vs}} \overline{u'\theta'_v}}_{\text{buoy production}}$$

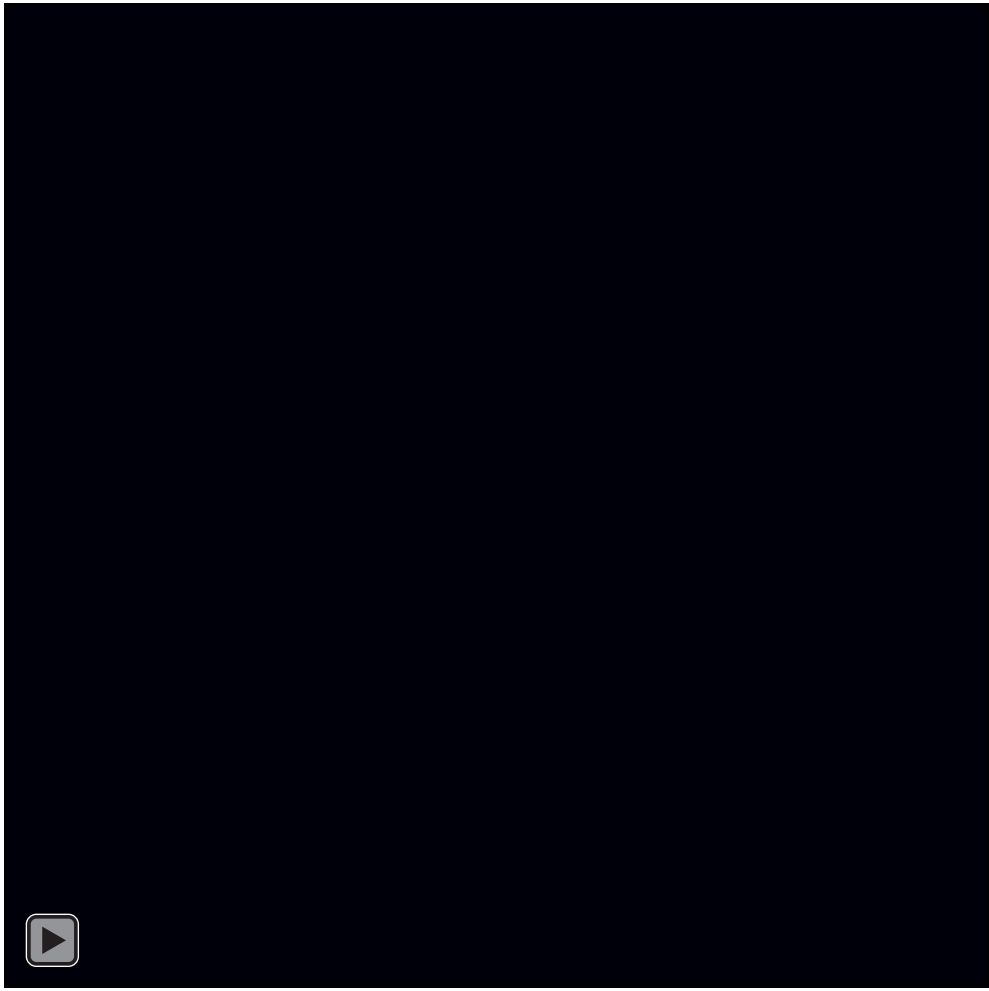
- Simple downgradient diffusion w/ eddy diffusivity
- Certain phenomenon, latter two terms important
  - Tropical cyclones
  - Low-level jets
  - Shallow cumulus
  - Orographic gravity waves
- Can we use LES + observations to constrain climate results?

Simple models: idealized TC on f-plane

PennState

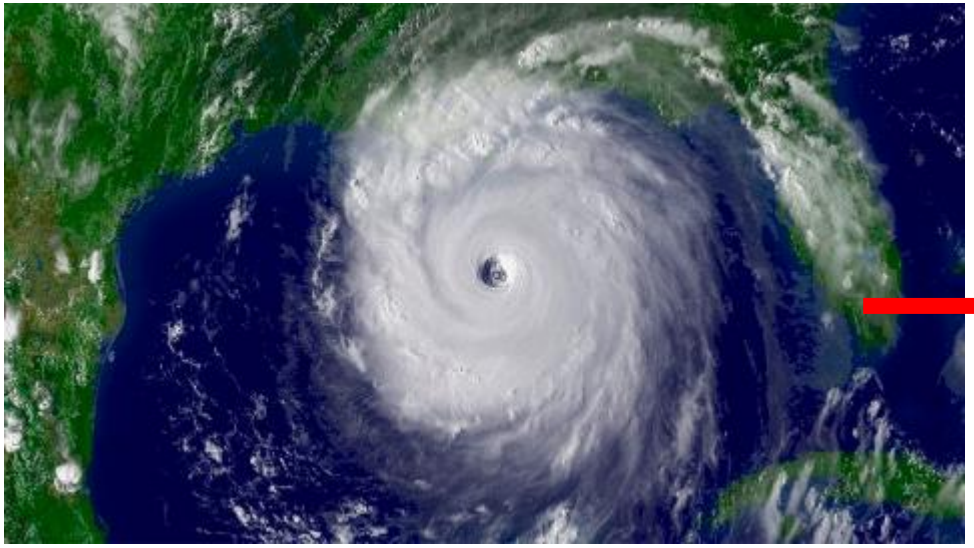
- *f*-plane aquaplanet, ~RCEMIP config.
- Initialize with Reed + Jablonowski (DCMIP 2016, Test #2)
- Can run 20 ensemble members for the cost of 1 global ne120 simulation

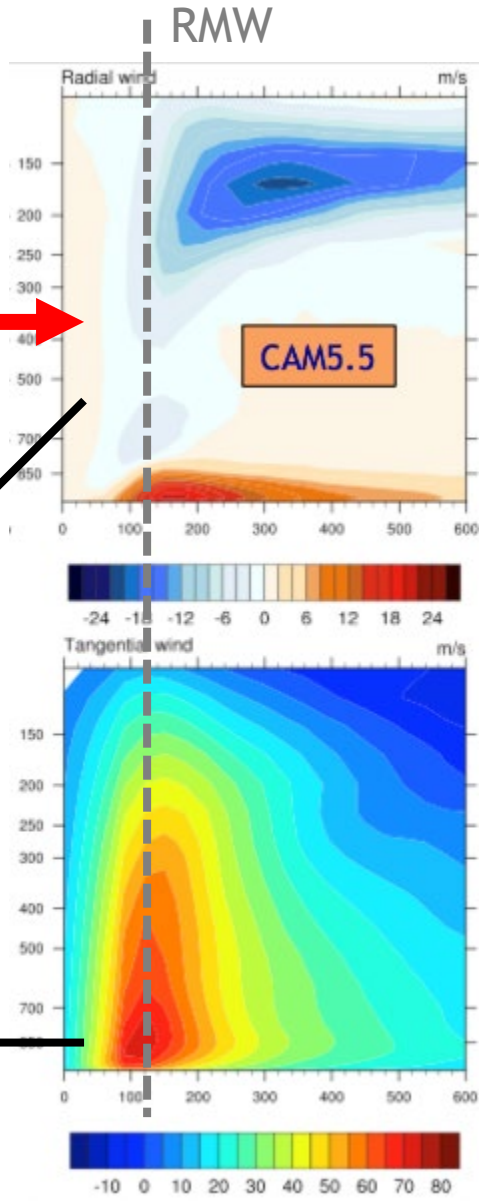


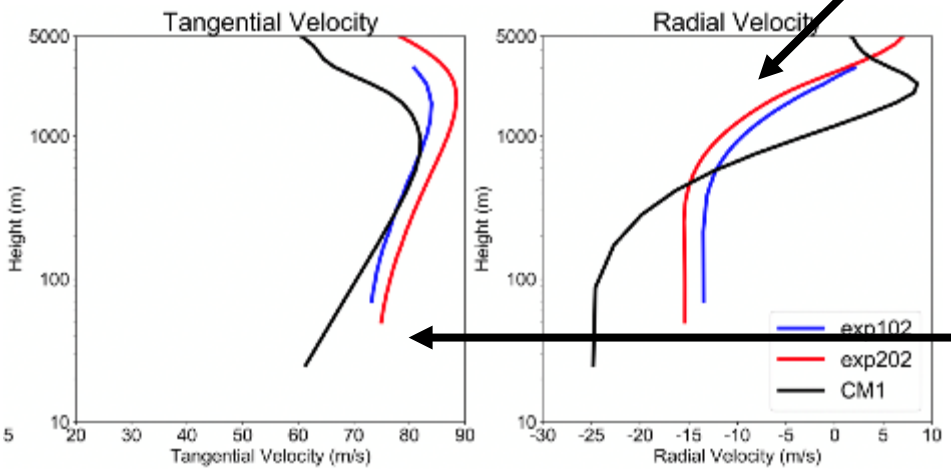


~14km resolution

Axisymmetric budgets

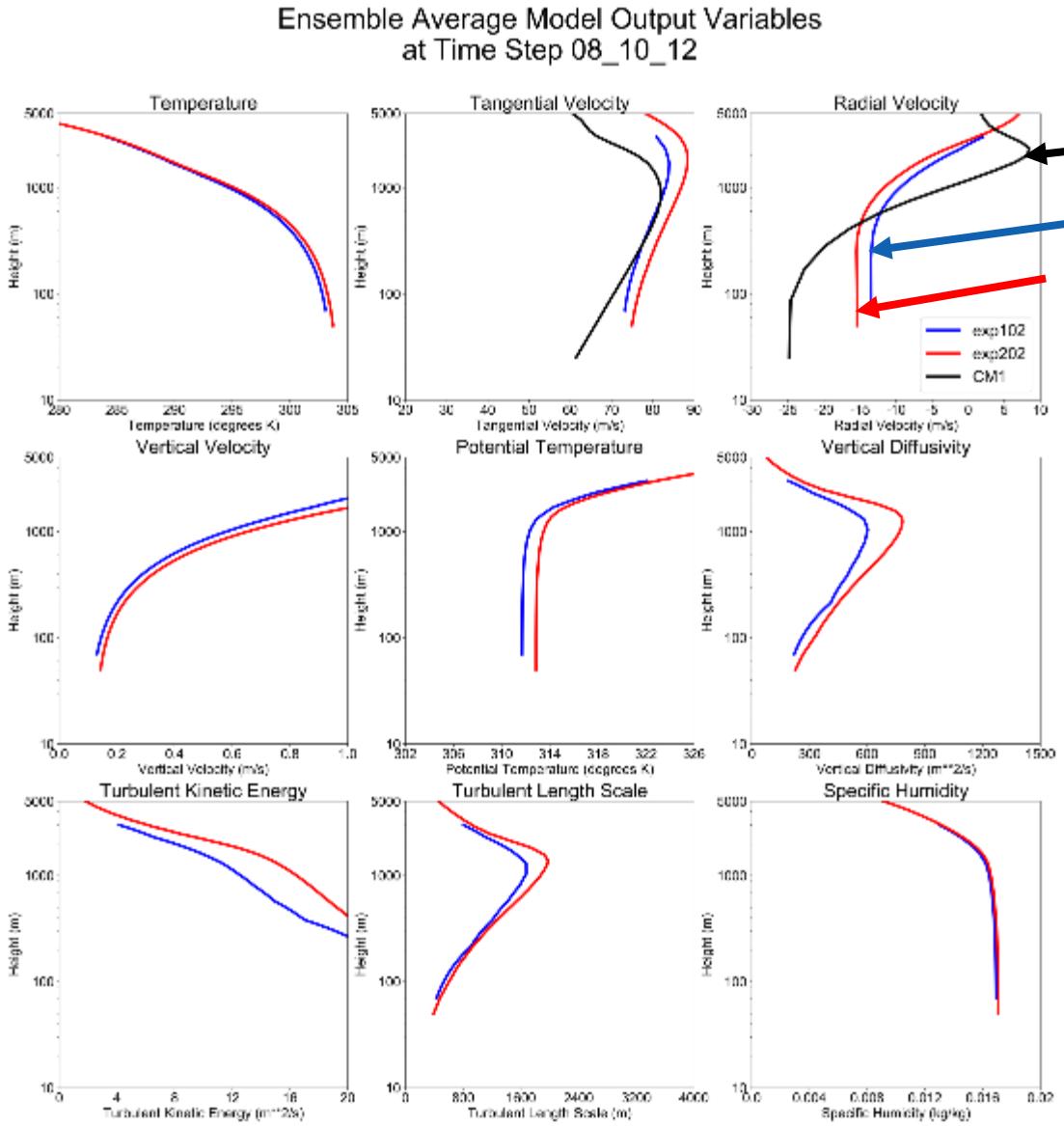






Is this a vertical resolution problem?

PennState



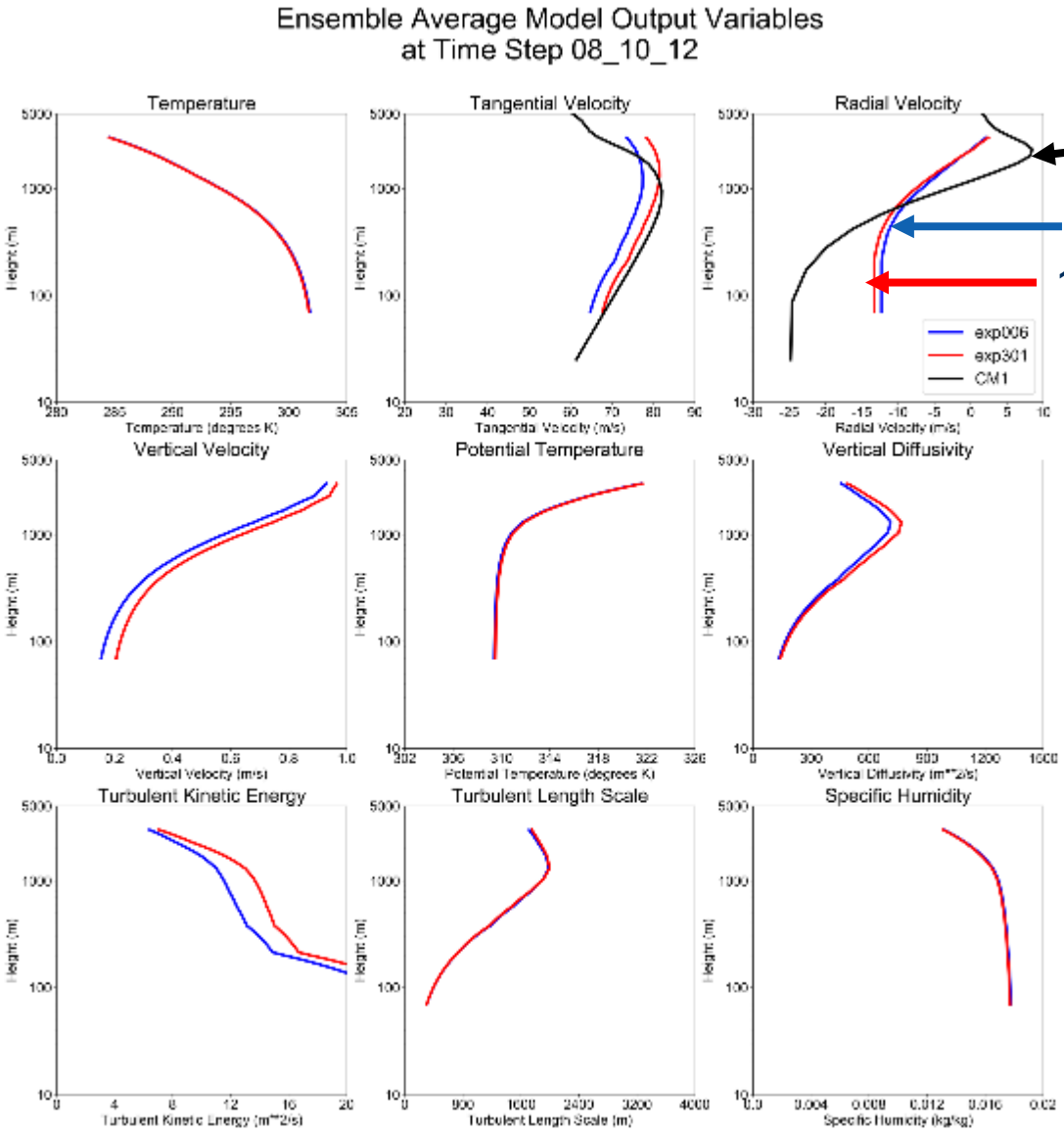
O(1km) CM1

L32 CAM6

L64 CAM6

Is this a horizontal resolution problem?

PennState



O(1km) CM1

28km CAM6

14km CAM6

What else can we do?

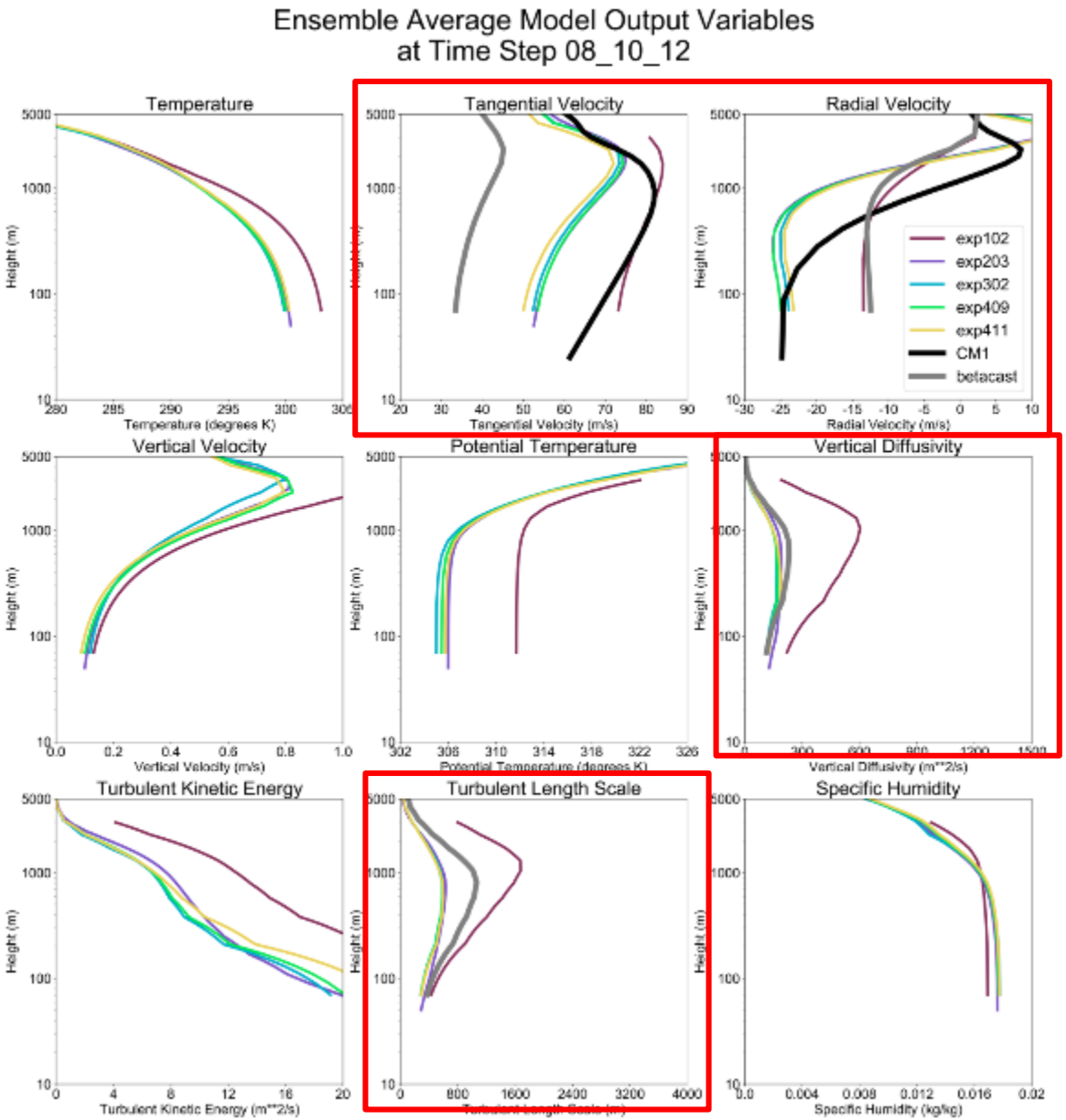
PennState

- New modifications to CLUBB break eddy timescale (**τ**) into 4 terms:
  - Background
  - Surface
  - Sheared
  - Buoyant

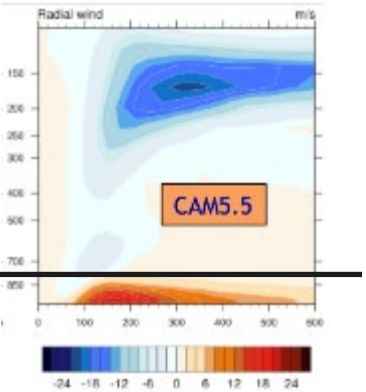
$$\tau_i = \begin{cases} \dfrac{L_i}{\sqrt{\overline{e}}}; & \dfrac{L_i}{\sqrt{\overline{e}}} \leq \tau_{\max} \\ \tau_{\max}; & \dfrac{L_i}{\sqrt{\overline{e}}} > \tau_{\max} \end{cases}$$

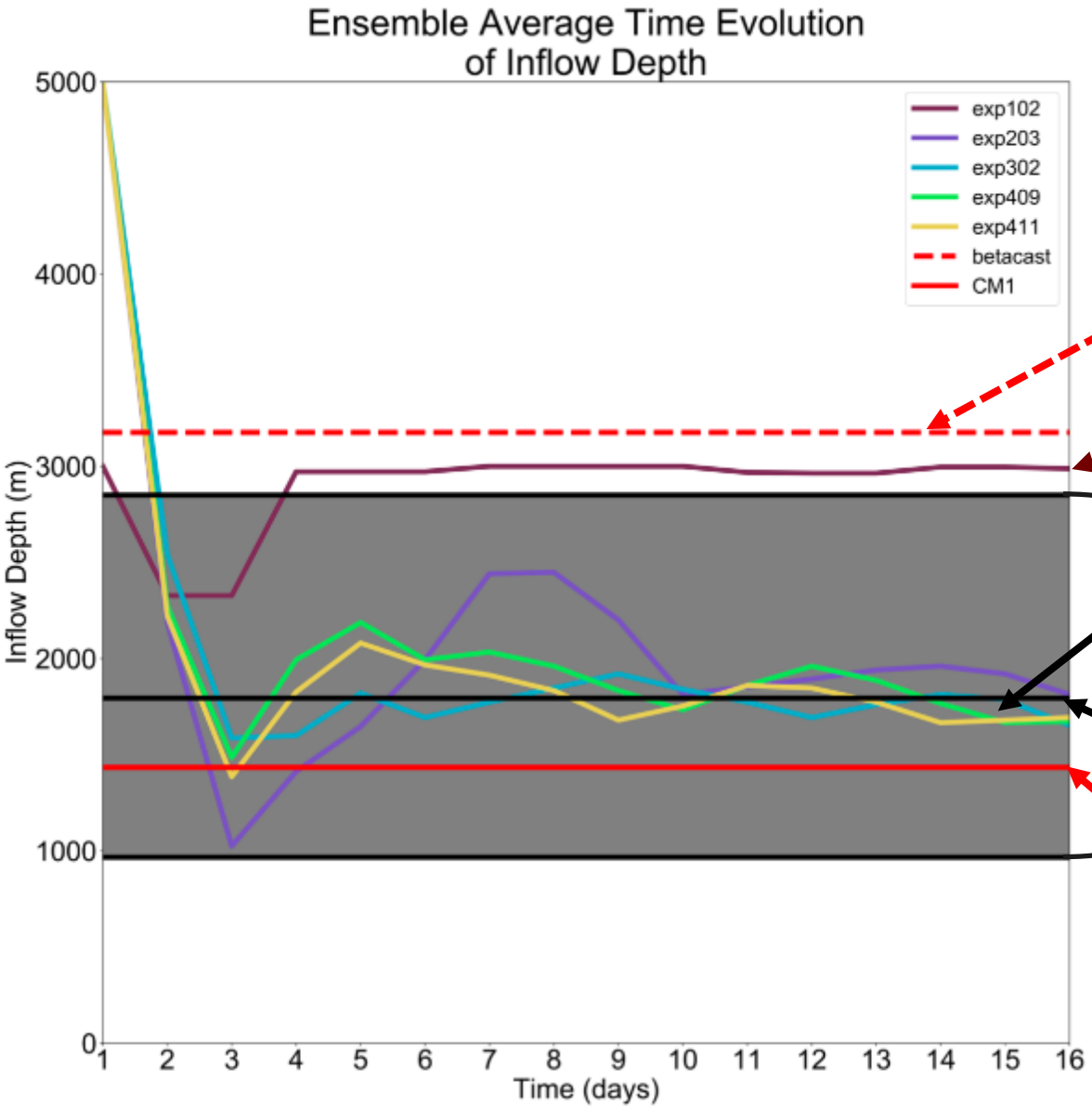
- **Decrease timescale (τ), decrease eddy length scales (L), contain turbulent energy closer to surface versus transporting vertically?**

CLUBB modifications

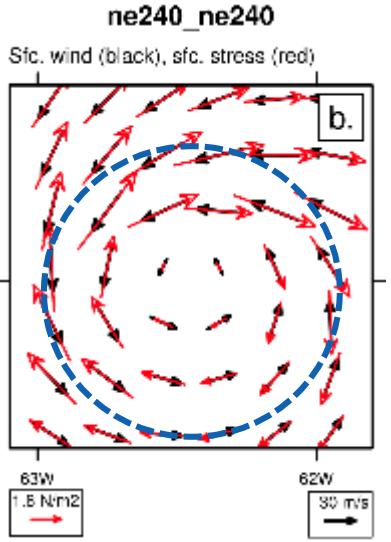


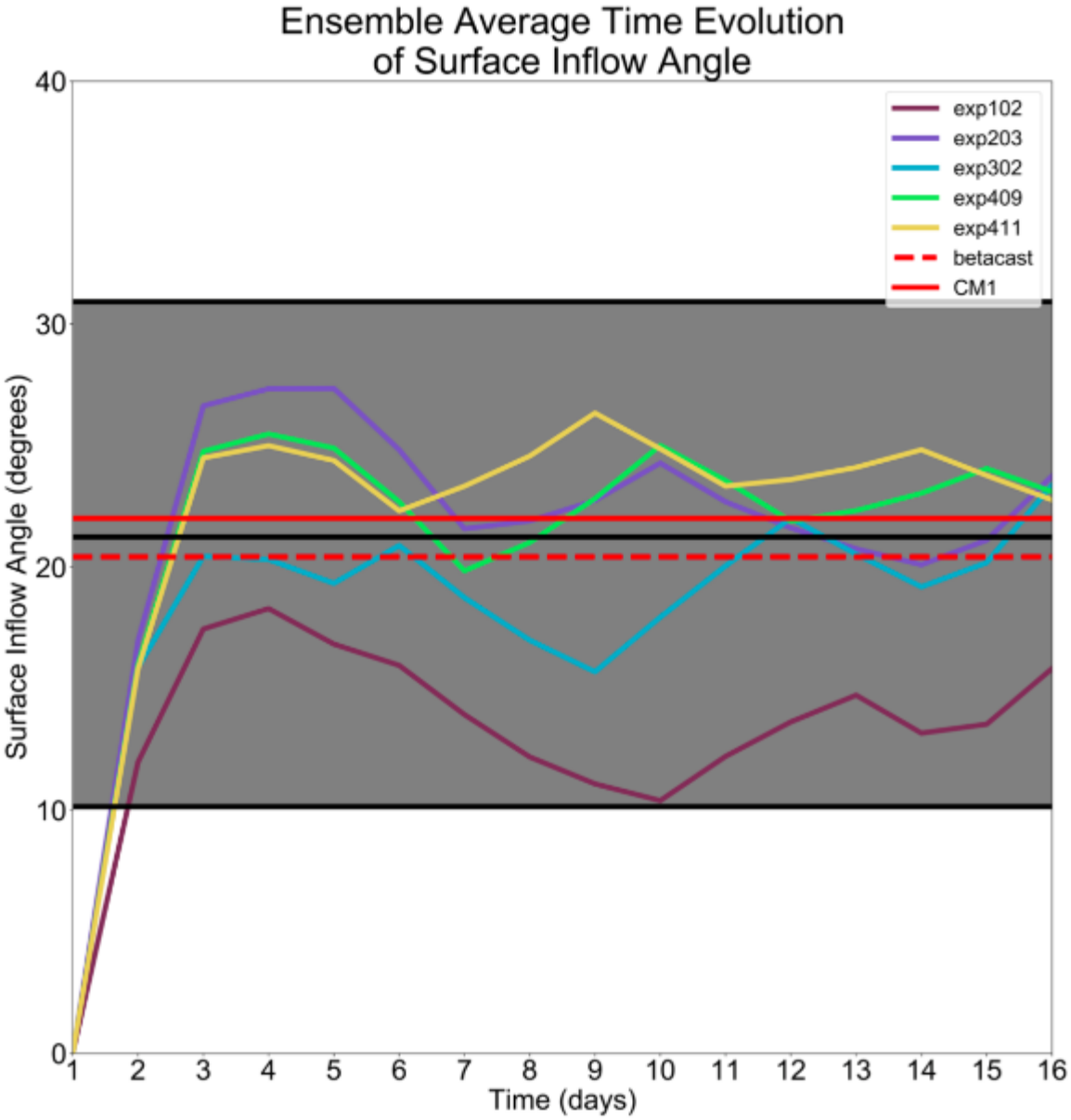
Metric #1: Inflow depth



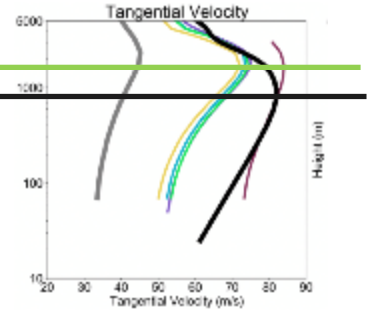


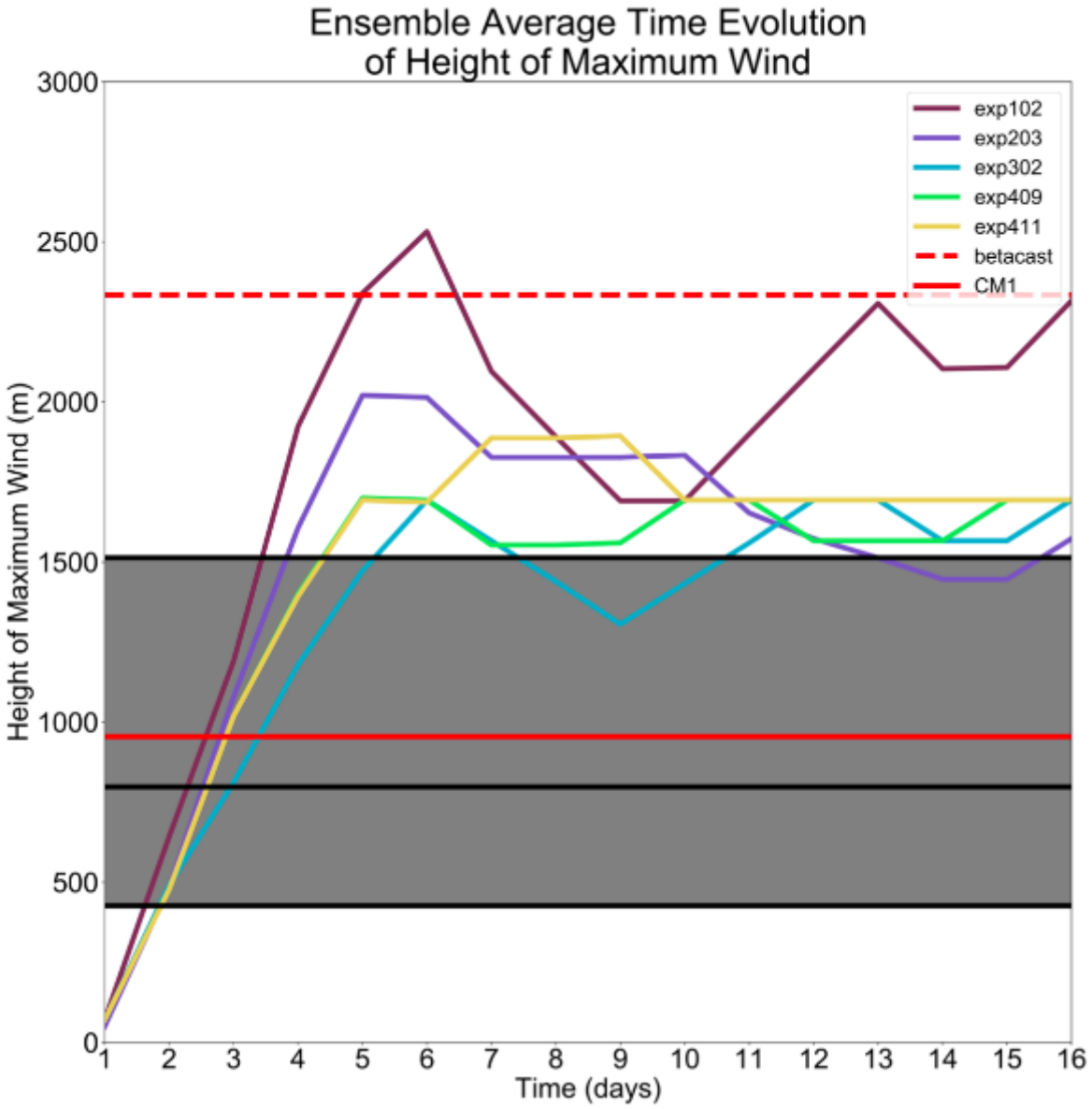
Metric #2: Inflow angle





Metric #3: Height of max wind

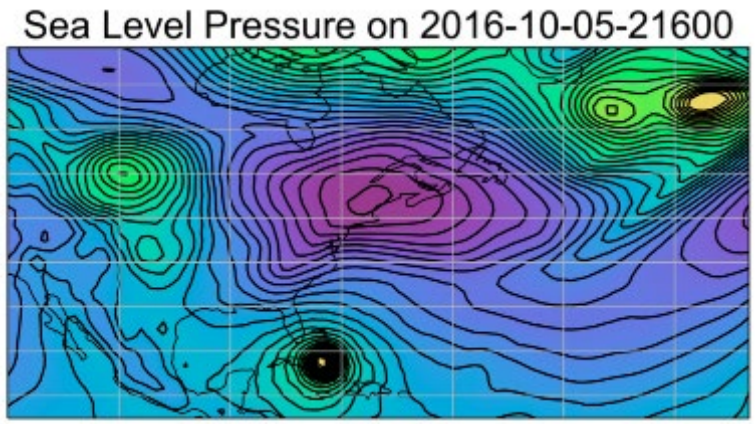


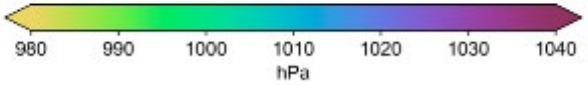


Betacasting

- Better constrained "real world" solution
- Run historical case simulations, compare to ***dropsondes + surface obs***.
- Initial runs show similar behavior to idealized runs

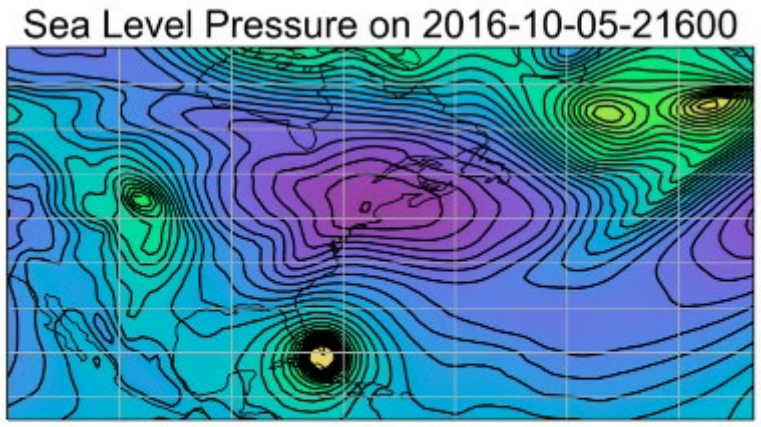
Out of box CLUBB

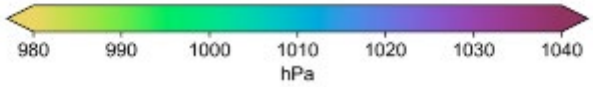




Caveat! ne30

Run with modified CLUBB





https://github.com/zarzycki/betacast

Summary

PennState

- Simple models useful for process evaluation
- TC errors in CAM6 not obvious resolution issue
- More scrutinized look at momentum flux in CAM6 TCs improve correspondence with LES + obs.
- Improvements in near-surface inflow
  - Target eddy timescales -> length scale -> turbulent transport
- Not solved – where max "jet" resides vertically
  - Near-surface turbulence, shape of profiles?
- The "**big enchilada**:" what does this mean for overall climate?
  - "Do no harm"
  - How much retuning? (c_k10?)