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Cyclones at Quarter-Degree Resolution:

Updated CAM with Prognostic Vs. Diagnostic Momentum Fluxes, Compared to CAM5 and CAM6

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Prognostic vs. Diagnostic Momentum Fluxes in CAM/CLUBB

CAM5/CAM6

- CAM5 used a “moist turbulence scheme” with downgradient diffusion
- CAM6 used CLUBB, but also with diagnostic momentum fluxes (downgradient scheme), where K=Lscale*sqrt(TKE)

$$\overline{u'w'} = -K_m \frac{\partial \overline{u}}{\partial z}$$

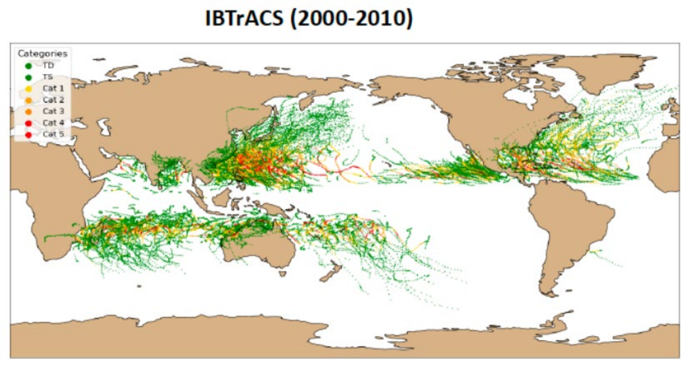
$$\overline{v'w'} = -K_m \frac{\partial \overline{v}}{\partial z}$$

Updated CAM/CAM7

- Will use CLUBB’s prognostic momentum flux code by default. This development work was done under the momentum CPT.
- Can revert to diagnostic momentum fluxes by namelist flag

$$\frac{\partial \overline{u_h'w'}}{\partial t} = \underbrace{-\overline{w}\frac{\partial \overline{u_h'w'}}{\partial z}}_{ma} \underbrace{-\frac{1}{\rho_s}\frac{\partial \rho_s \overline{w'^2 u_h'}}{\partial z}}_{ta} \underbrace{-\overline{w'^2}\frac{\partial \overline{u_h}}{\partial z}}_{tp} \underbrace{-\overline{u_h'w'}\frac{\partial \overline{w}}{\partial z}}_{ac} \underbrace{+\frac{g}{\theta_{vs}}\overline{u_h'\theta_v'}}_{bp}$$
$$\underbrace{-\frac{C_6}{\tau}\overline{u_h'w'}}_{pr1} \underbrace{+C_7\overline{u_h'w'}\frac{\partial \overline{w}}{\partial z}}_{pr2} \underbrace{-C_7\frac{g}{\theta_{vs}}\overline{u_h'\theta_v'}}_{pr3} \underbrace{+C_{\mathrm{shr}}^{\mathrm{uu}}\overline{w'^2}\frac{\partial \overline{u_h}}{\partial z}}_{pr4}$$
$$\underbrace{+\frac{\partial}{\partial z}\left[(K_{w6}+\nu_6)\frac{\partial}{\partial z}\overline{u_h'w'}\right]}_{dp1}$$

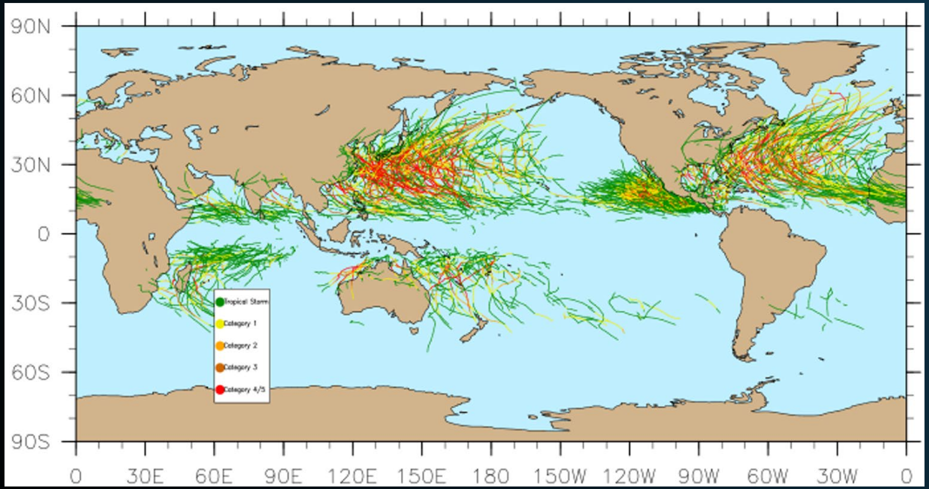
Large-scale characteristics – storm tracks from TempestExtremes



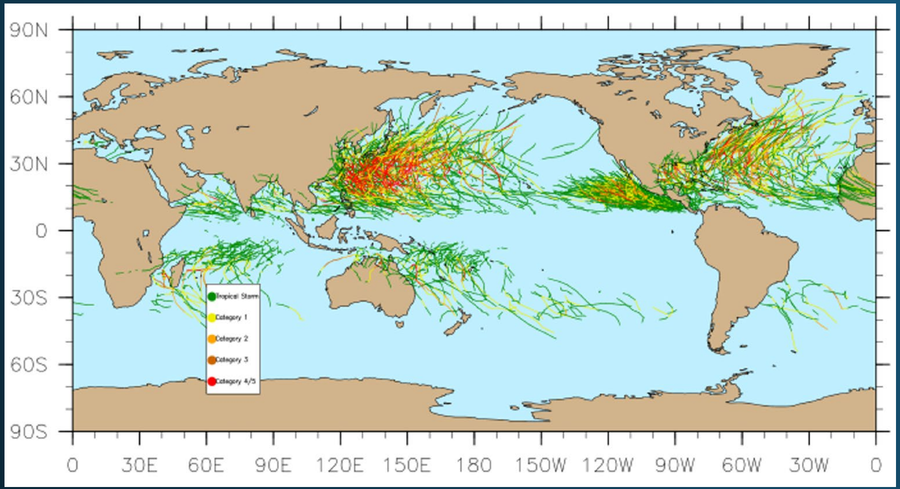
Thanks to Julio Bacmeister for IBTrACS scripts and Peter Lauritzen for the IBTrACS plot; lower plots I created from updated CAM quarter-degree tests using Tempest Extremes–thanks to Colin Zarzycki for help.

Prognostic looks better in East Atlantic

Diagnostic momentum flux



Prognostic momentum flux



Colin Zarzycki's takeaways on the large -scale results

Positives:

1. DMF is better than CAM5 for spatial patterns of TC count, genesis, and ACE/PACE (integrated intensity). The PMF runs further improve on that.
2. Temporally, the runs seem to better match TC activity globally (i.e., active/inactive months) with the PMF being slightly better than DMF (albeit both aren't great seasonally in the NATL).
3. Both DMF and PMF very much improve the high Central Pacific bias from CAM5 (PMF being a bit better).
4. From a storm-scale perspective (i.e., averag e duration of TCs, average max intensity, etc.), both DMF and PMF do better than CAM5.

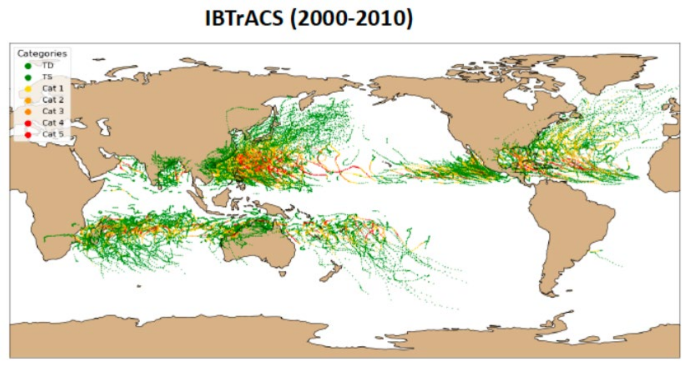
Remaining challenges:

1. Both DMF and PMF produce WAY too many TCs. Globally, this is about 2x what is observed–it's also not just a "weak" TC problem, since the integrated intensity metrics (ACE/PACE) are also way too high.
2. There remain some persistent biases, like the northward bias of TCs in the Western Pacific.
3. Some concern that this occurs even with MG2. Previously, we found that the TC frequency was sensitive to MG1 vs. MG2, and MG2 was an improvement over MG1.

*The **good** news* is that if we could suppress the cyclone counts somewhat (e.g. zm_tau, dt_phys, entrainment,etc.) without really impacting the patterns of activity, updated CAM would be one of the better global models at 25km. It's mostly the TC genesis that's the issue.

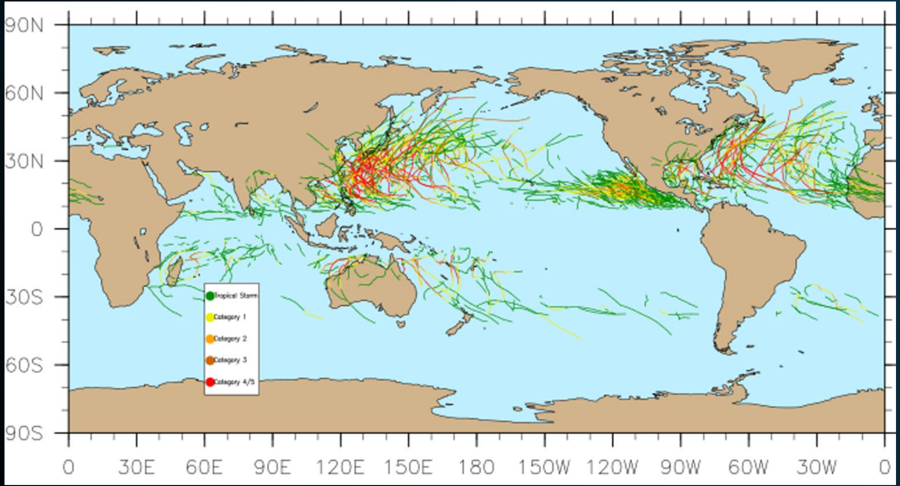
Tuning update: fewer storms now with ZM tau reduced

Thanks to Julio Bacmeister for IBTrACS scripts and Peter Lauritzen for the IBTrACS plot; lower plots I created from updated CAM quarter-degree tests using Tempest Extremes–thanks to Colin Zarzycki for help.

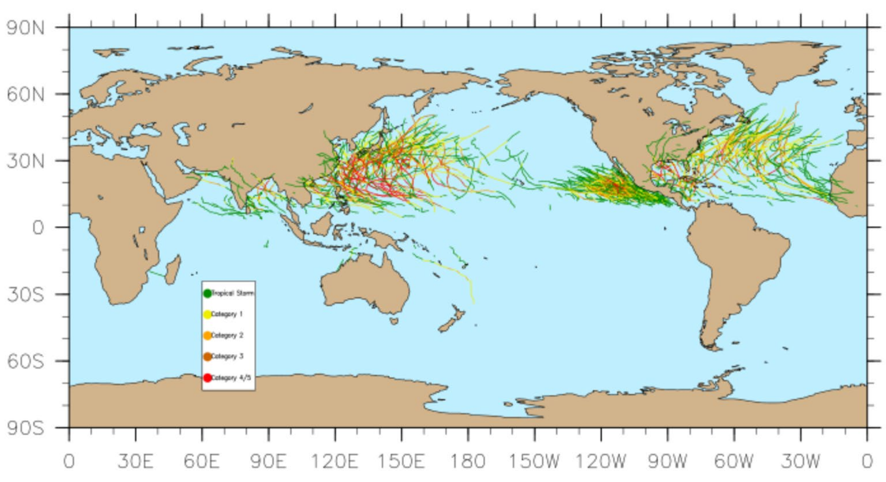


These show ~40% fewer storms (via reduced ZM tau 3600 → 1200), and the right plot is regionally refined in the Northern Hemisphere ocean basins so doesn't resolve SH storms. Left plot 8 yrs, right 10 yrs.

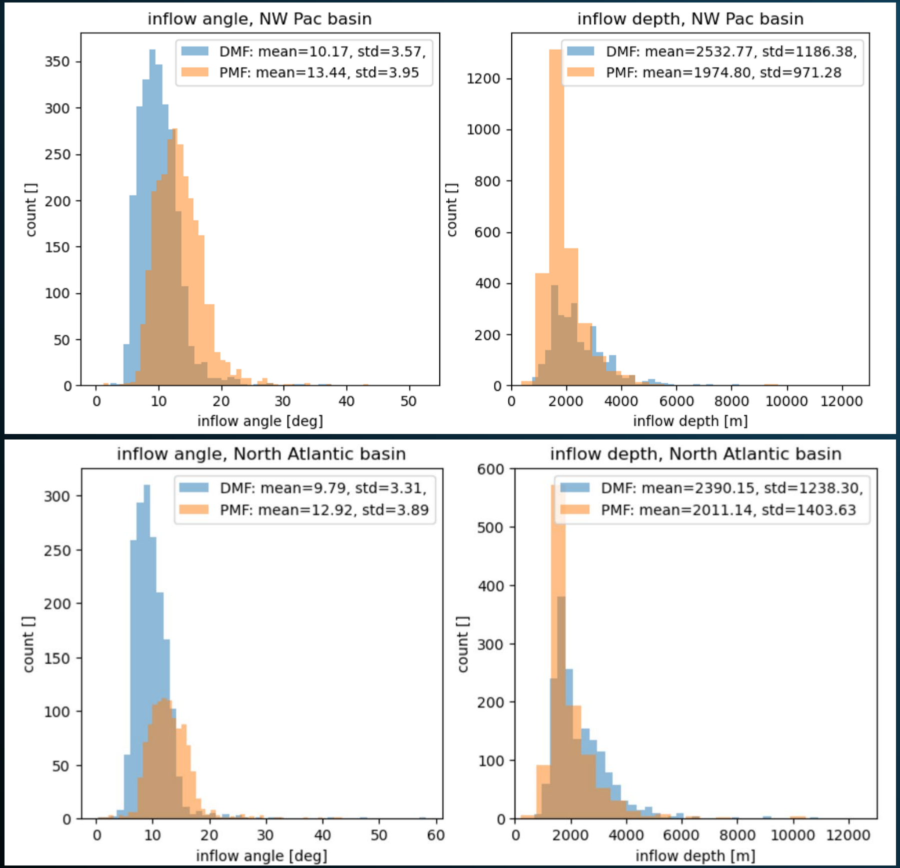
Prognostic with ZM tau=1200



Prognostic with ZM tau=1200, regional refinement

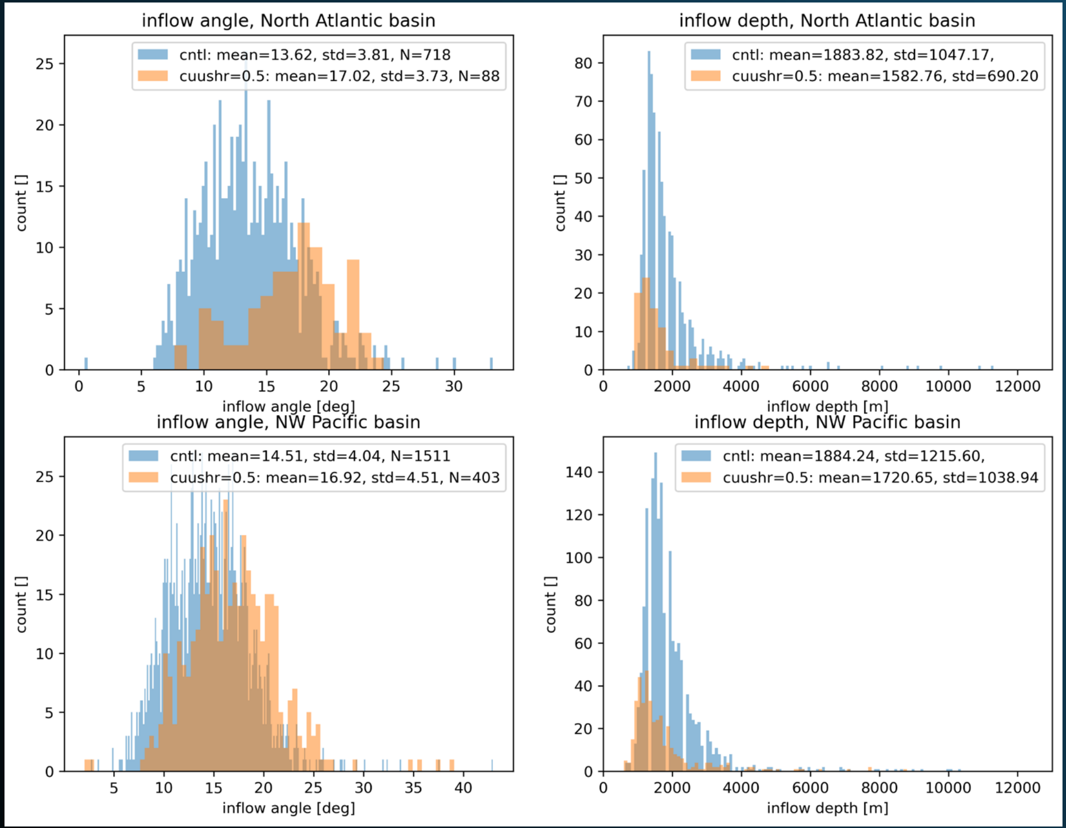


Storm structure – Inflow Angle and Depth



Especially when using PMF, the mean inflow angle has improved with respect to CAM6 (where we think it was closer to 10 degrees). Observationally it should be perhaps 20-22 degrees, so we are still low, but using prognostic momentum fluxes shows a clear improvement over diagnostic. The inflow angle and inflow depth also show the correct (anticorrelated) relationship.

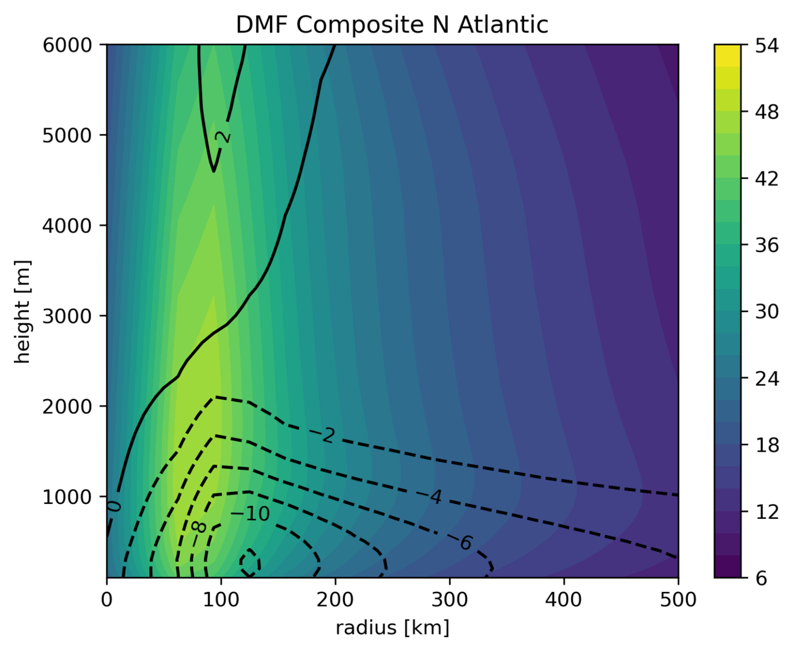
Storm structure update – Inflow Angle and Depth with tuning

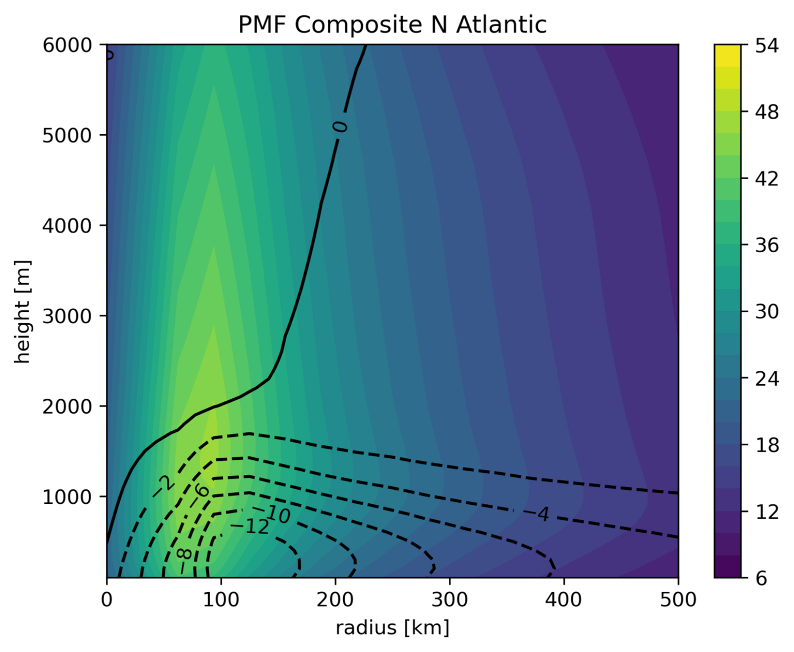


Using regionally refined experiments, we've found that the CLUBB (turbulence) parameter c_uu_shr, which controls dissipation on momentum fluxes and variances, is effective at increasing the inflow angle and decreasing the inflow depth. Increasing c_uu_shr reduces turbulent production of momentum flux and makes the boundary layer shallower.

Storm structure – Wind Contours, N Atlantic

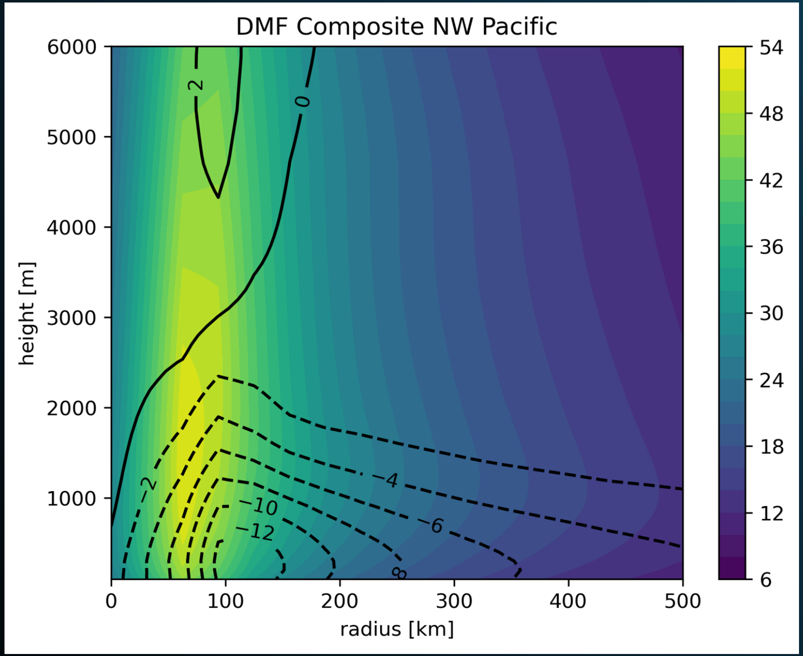
Diagnostic momentum flux (left) vs. prognostic momentum flux (right) wind contours for the North Atlantic. Color contours are for tangential wind, black contour lines are for radial winds. The maximum winds are confined to a lower region in the prognostic momentum test, a strength over the diagnostic test; however, the maximum winds should ideally be closer to the surface.

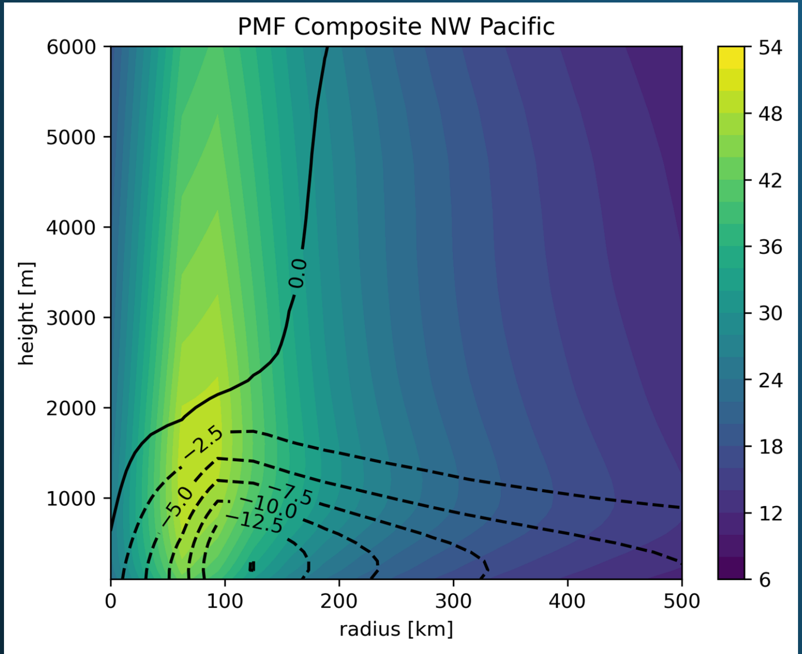




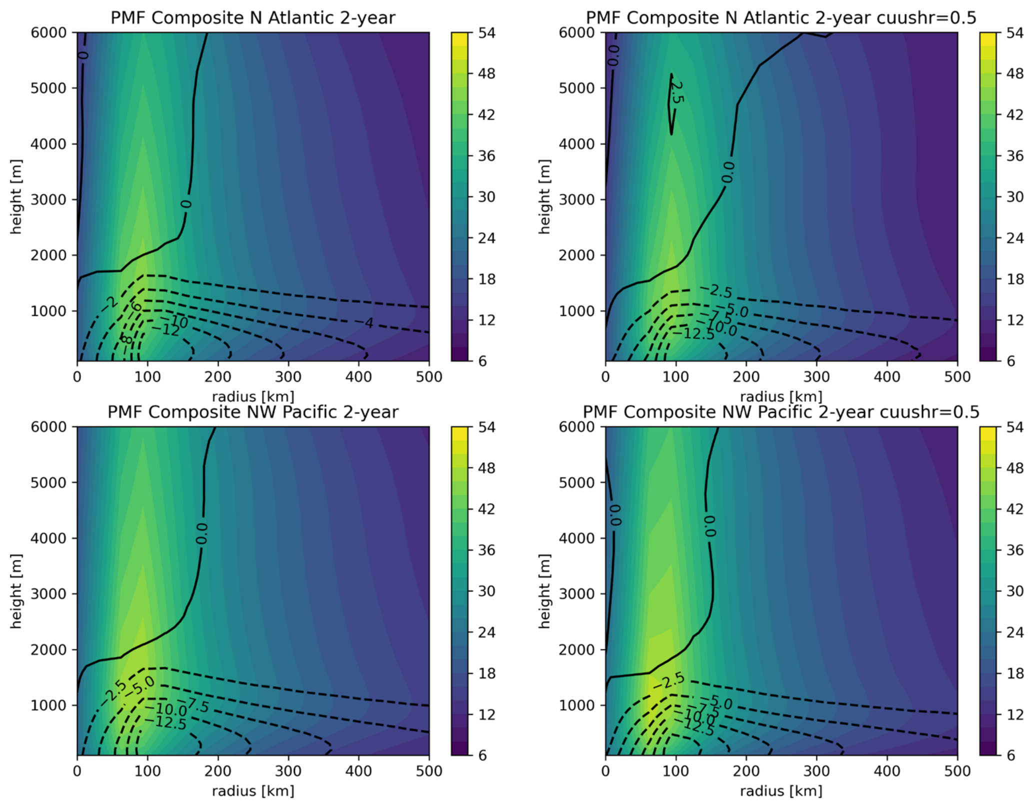
Storm structure – Wind Contours, NW Pacific

Diagnostic momentum flux (left) vs. prognostic momentum flux (right) wind contours for the NW Pacific. Color contours are for tangential wind, black contour lines are for radial winds. While the diagnostic test shows stronger winds, the maximum winds are confined to a lower region in the prognostic momentum test. But in both cases, the maximum winds should ideally be closer to the surface.





Storm structure update – Wind Contours with tuning

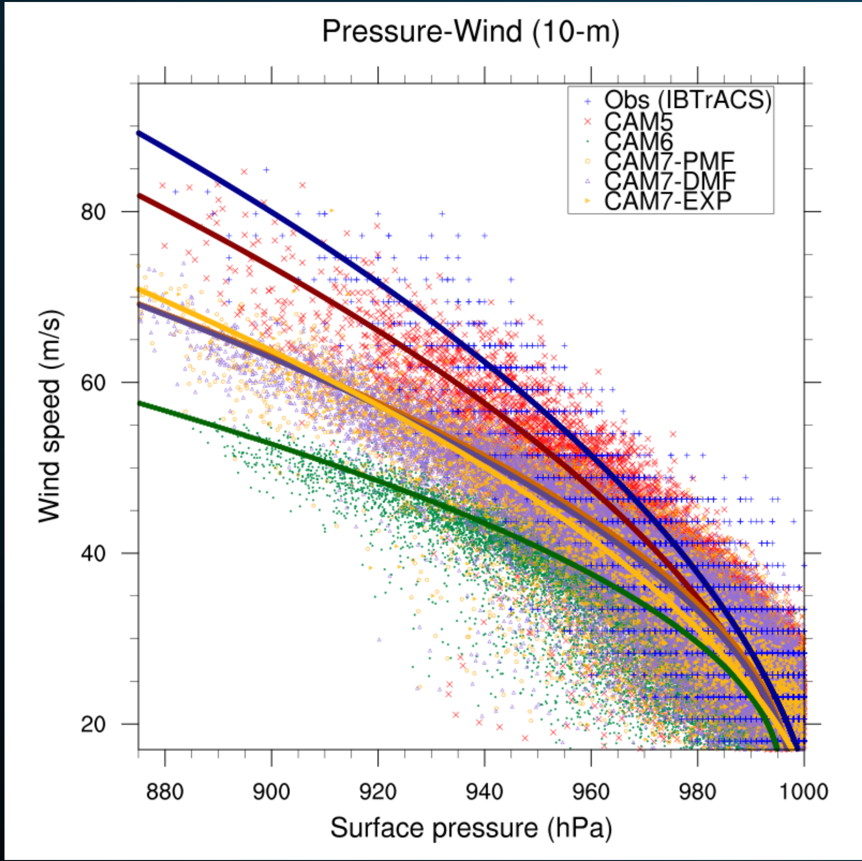


Regionally refined runs using zmconv_tau=1200:

Increasing c_uu_shr

- Lowers radial wind heights
- Strengthens tangential winds in the NW Pacific
- **Caveat**: while the left plots include 10 years of data, the plots on the right (c_uu_shr=0.5) only include 2 years of data here.

Pressure -wind relationship



While CAM5 (red; obs=blue) was the most skillful of recent CAM versions with respect to the pressure-wind relationship, CAM6 (green) showed a degradation. The updated version of CAM, both with (orange) and without (purple) prognostic momentum fluxes, does better than CAM6, and increasing CLUBB's c_uu_shr parameter (yellow) improves the profile slightly at the high speed end.

Plot by Colin Zarzycki

Summary and Conclusion

- The momentum CPT has made CLUBB’s prognostic momentum flux code the default in CAM7
- Two preliminary 10-year quarter-degree resolution tests from 2000-2009 show a number of improved large-scale cyclone results when using the prognostic momentum flux code vs. diagnostic
  - ACE/PACE improved over CAM5
  - Central Pacific bias improved over CAM5
  - TC duration/intensity improved over CAM5
- **Overproduction of TCs (2x obs) is mitigated by reducing ZM tau**
- Prognostic momentum flux shows better results vs. diagnostic for inflow angle and depth
- Composite storm structure seems marginally better using prognostic momentum flux (strongest winds seem focused at lower altitudes) vs. diagnostic
- Pressure-wind relationships have improved over CAM6, but are not yet as good as CAM5.
- **We can get control over inflow angle via reducing the diffusivity and boundary layer depth with CLUBB’s C_uu_shr parameter. Increasing this reduces turbulent production of momentum flux.**

Thank you!