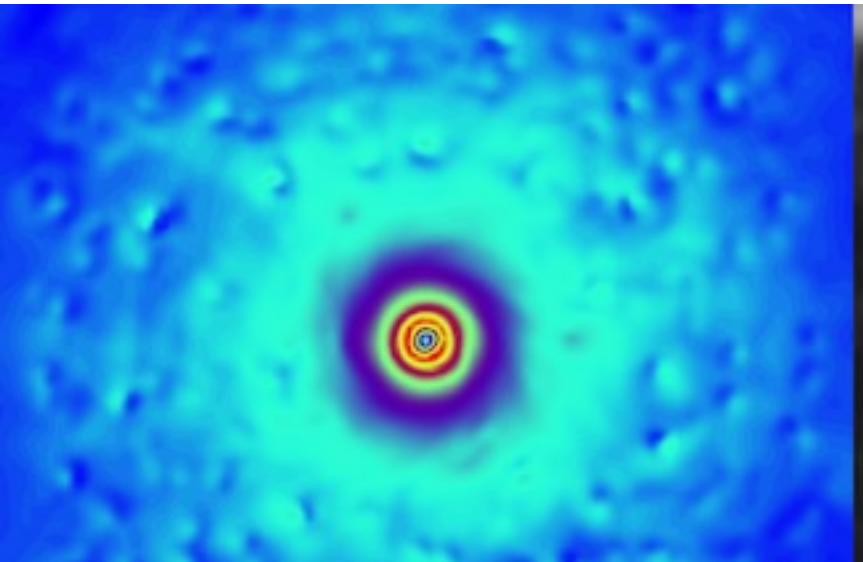
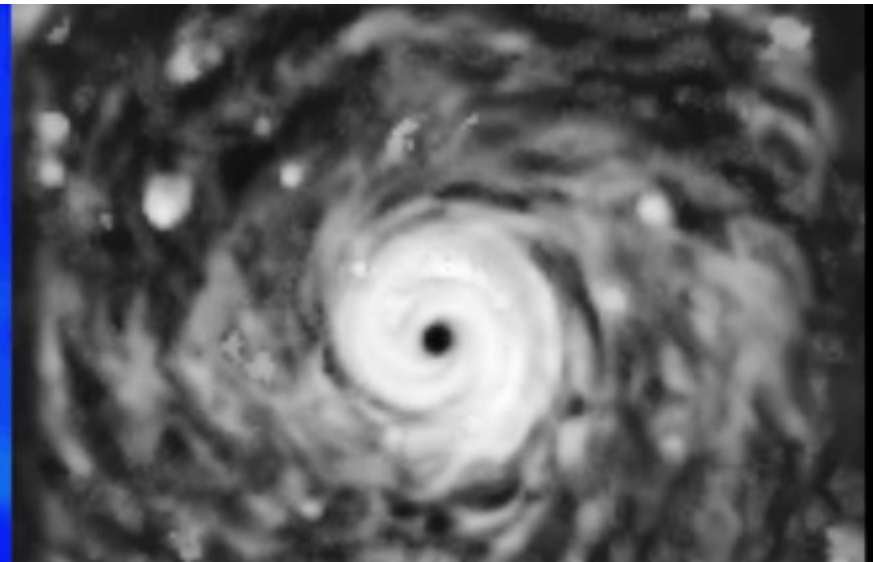
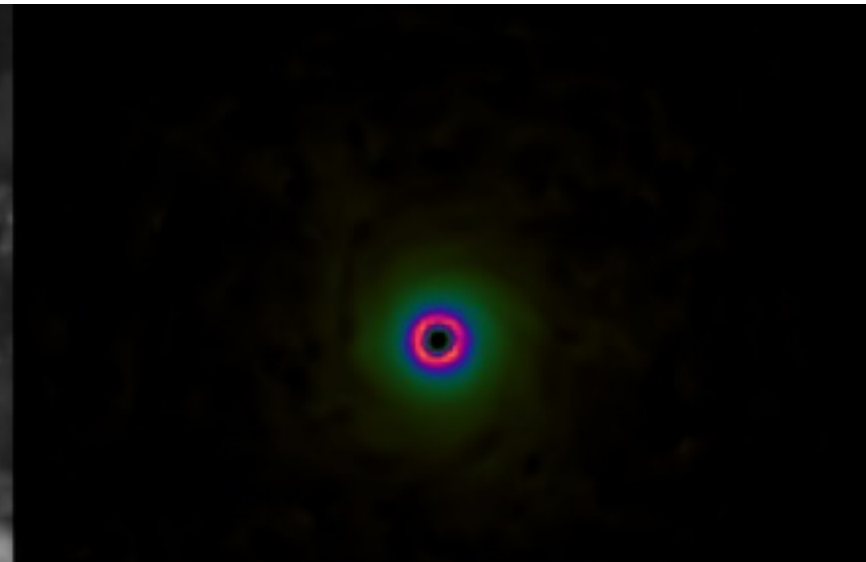
Recent updates on interrogating momentum fluxes and wind profiles in CLUBB

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

The team

PennState


Colin Zarzycki


Kyle Nardi


Coralis Friedman Álvarez


Vince Larson


Joakim Pyykkö

Stockholm University


Gunilla Svensson


Julio Bacmeister


George Bryan


Kate Thayer-Calder


Chris Kruse

NCAR

Geophysical Fluid Dynamics Laboratory GFDL NOAA


Xiaowei Zhu


Leo Donner


Ming Zhao

The one-slider…

- Focus is bottom up! ***Credibility*** is a big word (maybe one step back to go two steps forward?)
- Two primary research foci…
  - Directly prognosing momentum fluxes in CLUBB

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

Larson et al., 2019

  - Defining a "regime-specific" eddy timescale formulation

$$L_{scale} = \tau \sqrt{TKE}$$

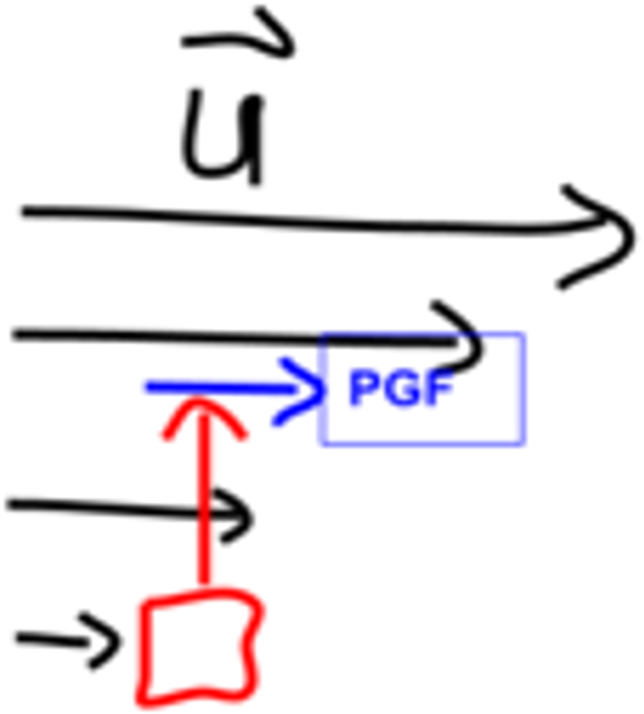
$$\frac{1}{\tau} = \underbrace{\frac{C_{\tau,back}}{\tau_{ref}}}_{1} + \underbrace{C_{\tau,sfc}\left(\frac{u^*}{K}\right)\left(\frac{1}{z - z_s + z_{dis}}\right)}_{2} + \underbrace{C_{\tau,shear}\left(\left(\frac{\partial u}{\partial z}\right)^2 + \left(\frac{\partial v}{\partial z}\right)^2\right)^{\frac{1}{2}}}_{3} + \underbrace{C_{\tau,N}\sqrt{\max(N^2, 0)}}_{4}$$

Guo et al., 2021, Nardi et al., in prep.

New terms: P fluctuations on momentum flux reduce diffusivity

$$\frac{\partial}{\partial t}\overline{(u'w')} = 0 = -\overline{w'^2}\frac{\partial \bar{U}}{\partial z} - \frac{1}{\bar{\rho}}\frac{\partial}{\partial z}\left(\bar{\rho}\,\overline{u'w'^2}\right) + \frac{g}{\bar{T}_v}\overline{u'T'_{vL}} - \left(\overline{\frac{w'}{\bar{\rho}}\frac{\partial p'}{\partial x}} + \overline{\frac{u'}{\bar{\rho}}\frac{\partial p'}{\partial z}}\right) + \text{HTrans}$$

- Horizontal momentum is subject to a horizontal pressure gradient
- When a parcel is lifted to an altitude with different momentum, it creates a flux <u'w'>, but that flux is opposed by pressure, which pushes the parcel's momentum toward the environmental value.
- This effect is parameterized in CLUBB-upwp, and it reduces the effective eddy diffusivity of *momentum* (allows for less "hammering" on C_k10)

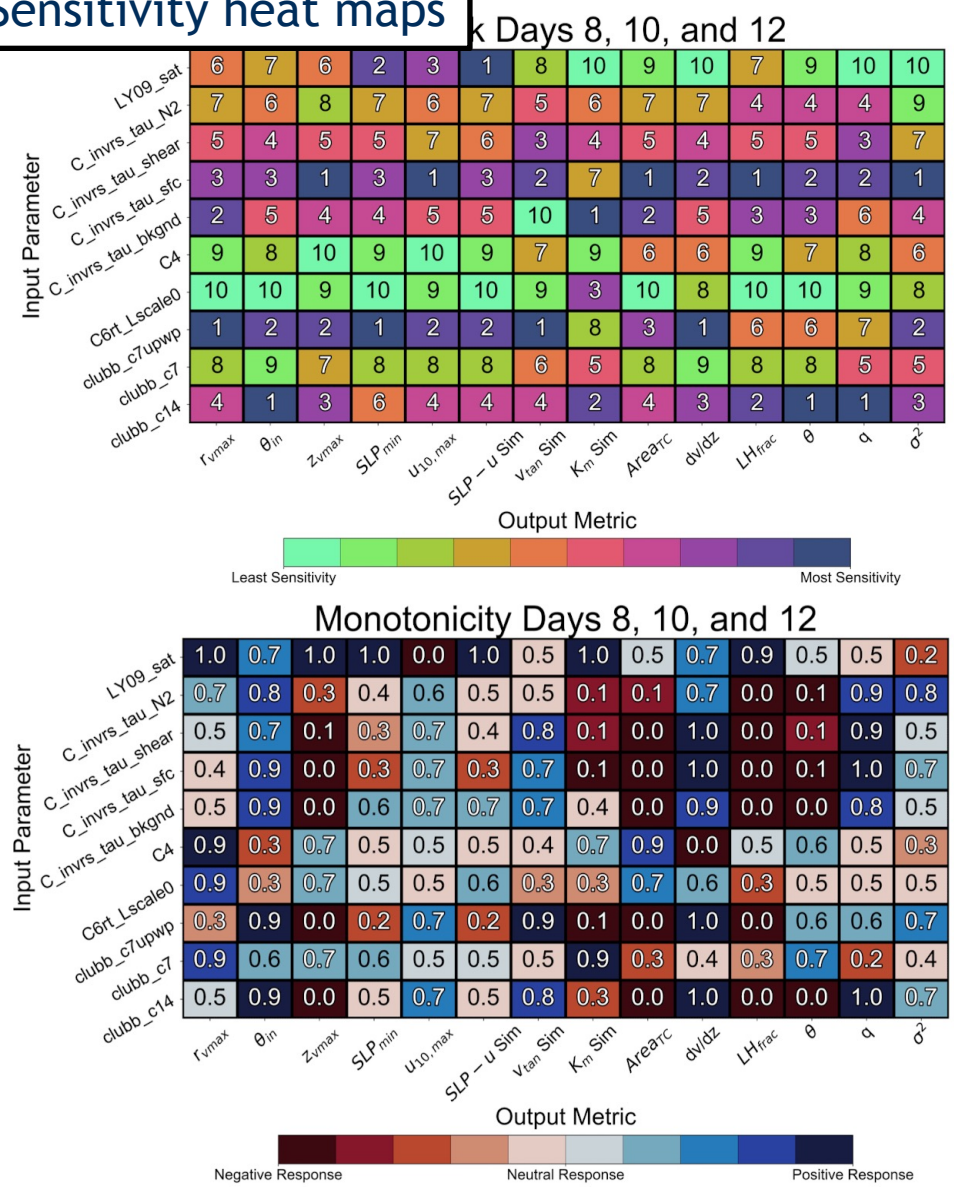


Vince Larson

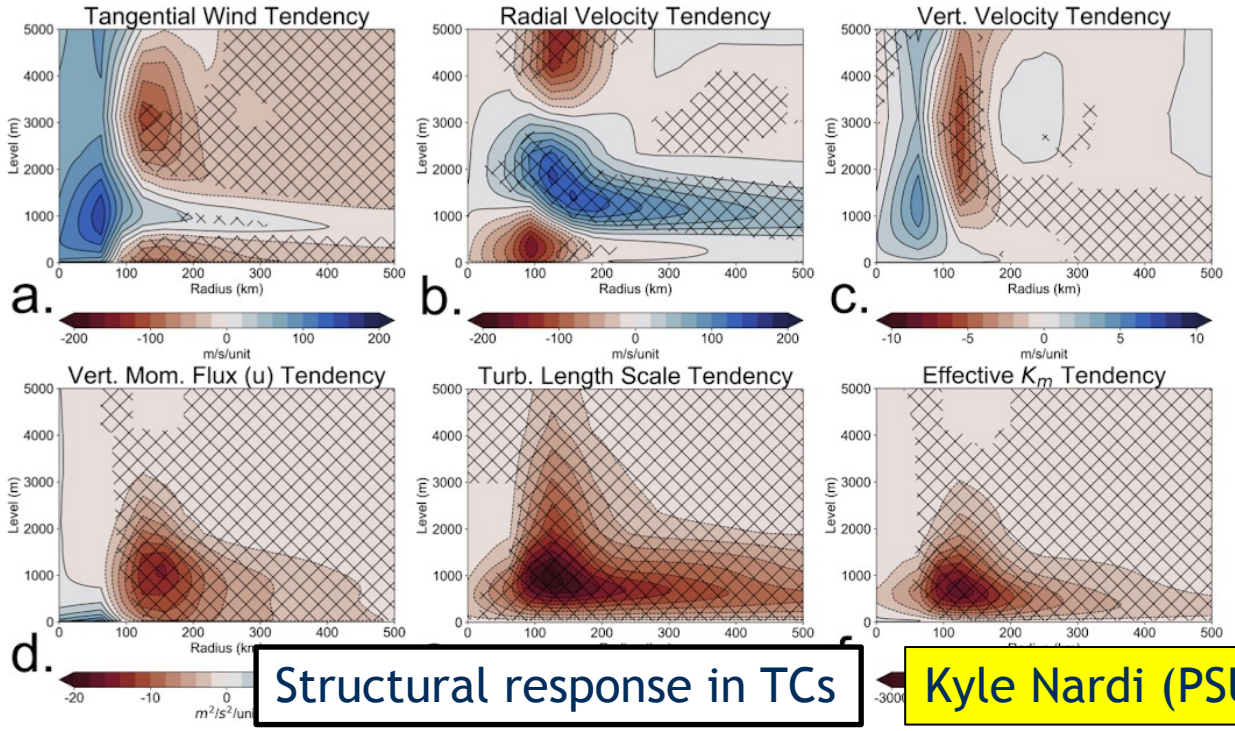
Simple models improve tropical cyclone structure

PennState

Sensitivity heat maps



- Sensitivity analysis w/ prognostic momentum + eddy timescale turbulence formulation can predict free-running 3-D response!
- Multiple pathways for process-oriented improvement in TCs, for example

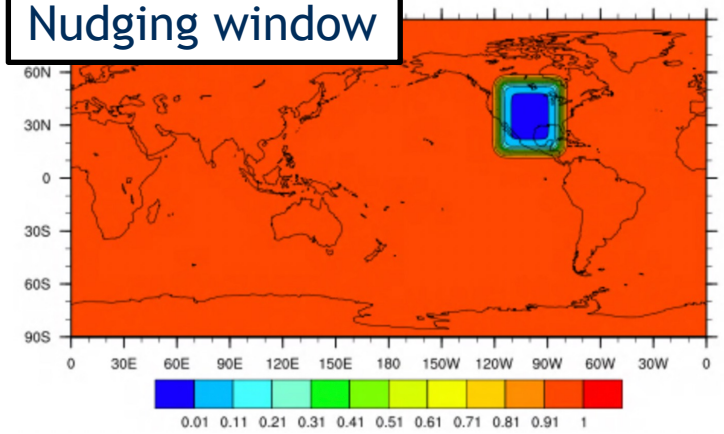


Structural response in TCs — Kyle Nardi (PSU)

Can we improve the Great Plains low level jet?

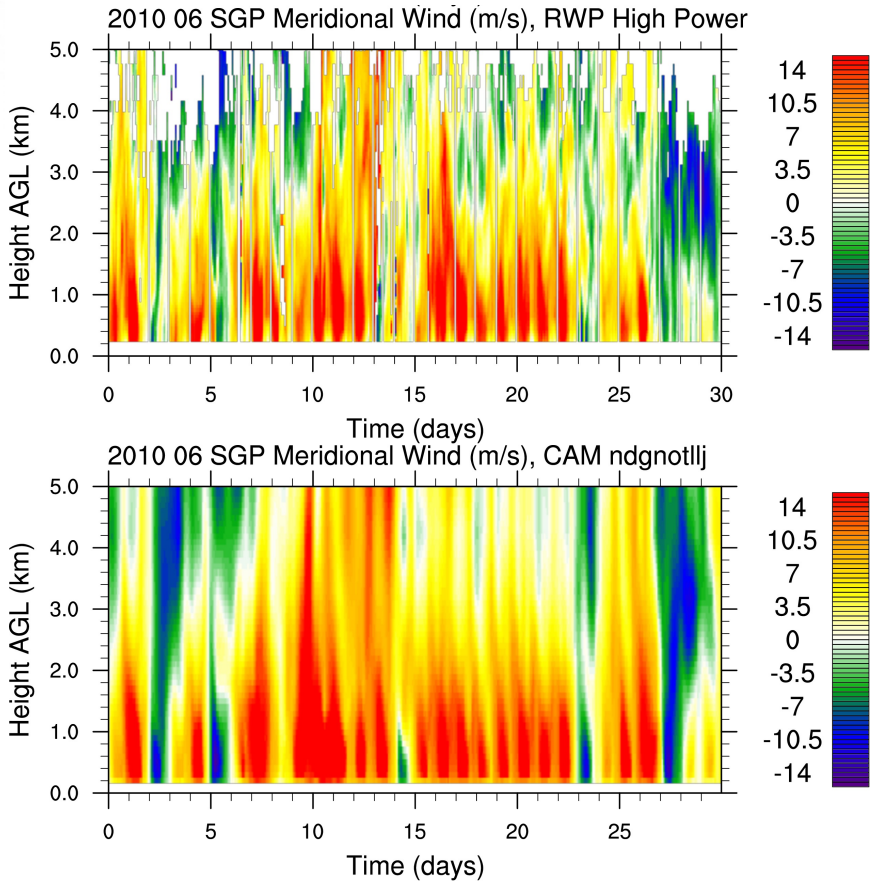
PennState

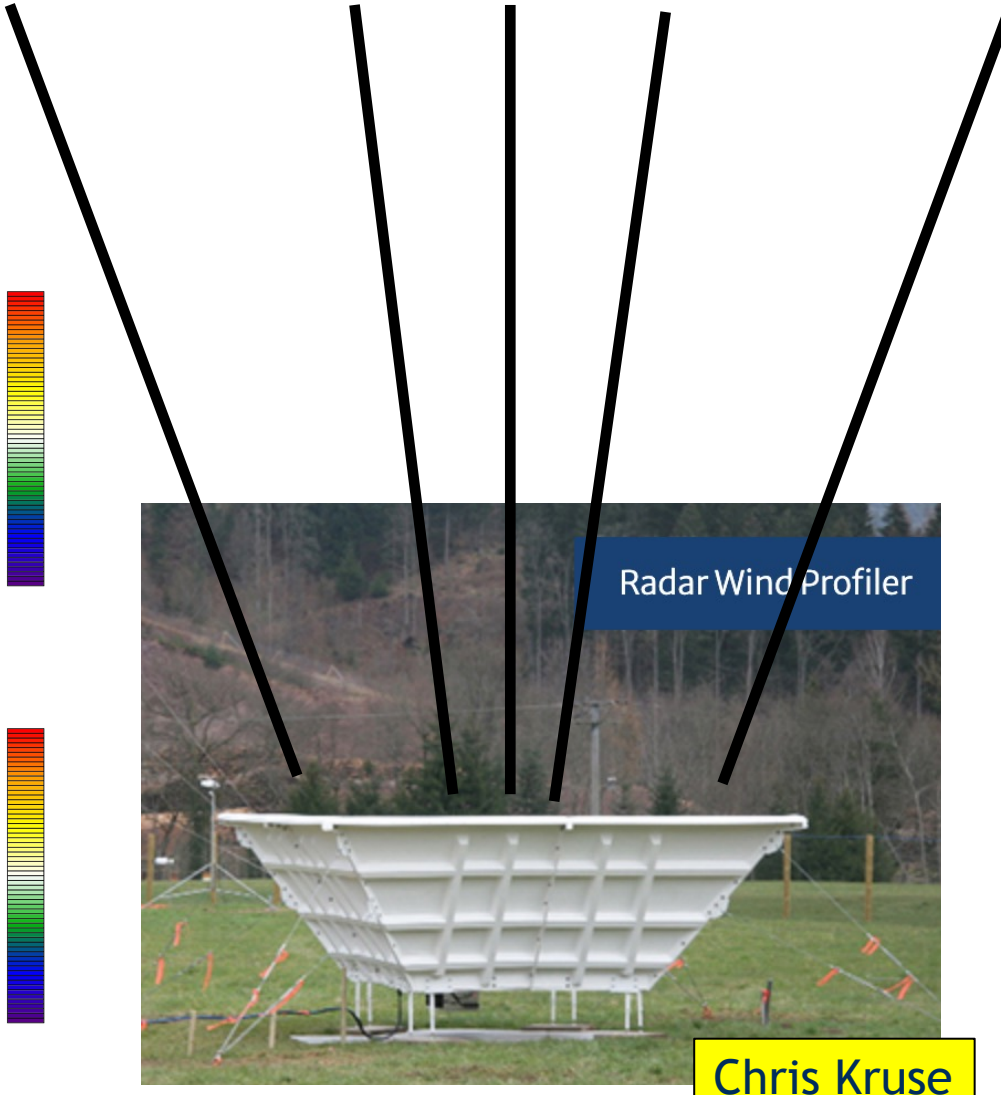
Nudging window



- Nudging effective for reproducing local meteorology!
- Will compare
  - jet strength
  - height of max wind
  - time of max wind
- Turbulence theory

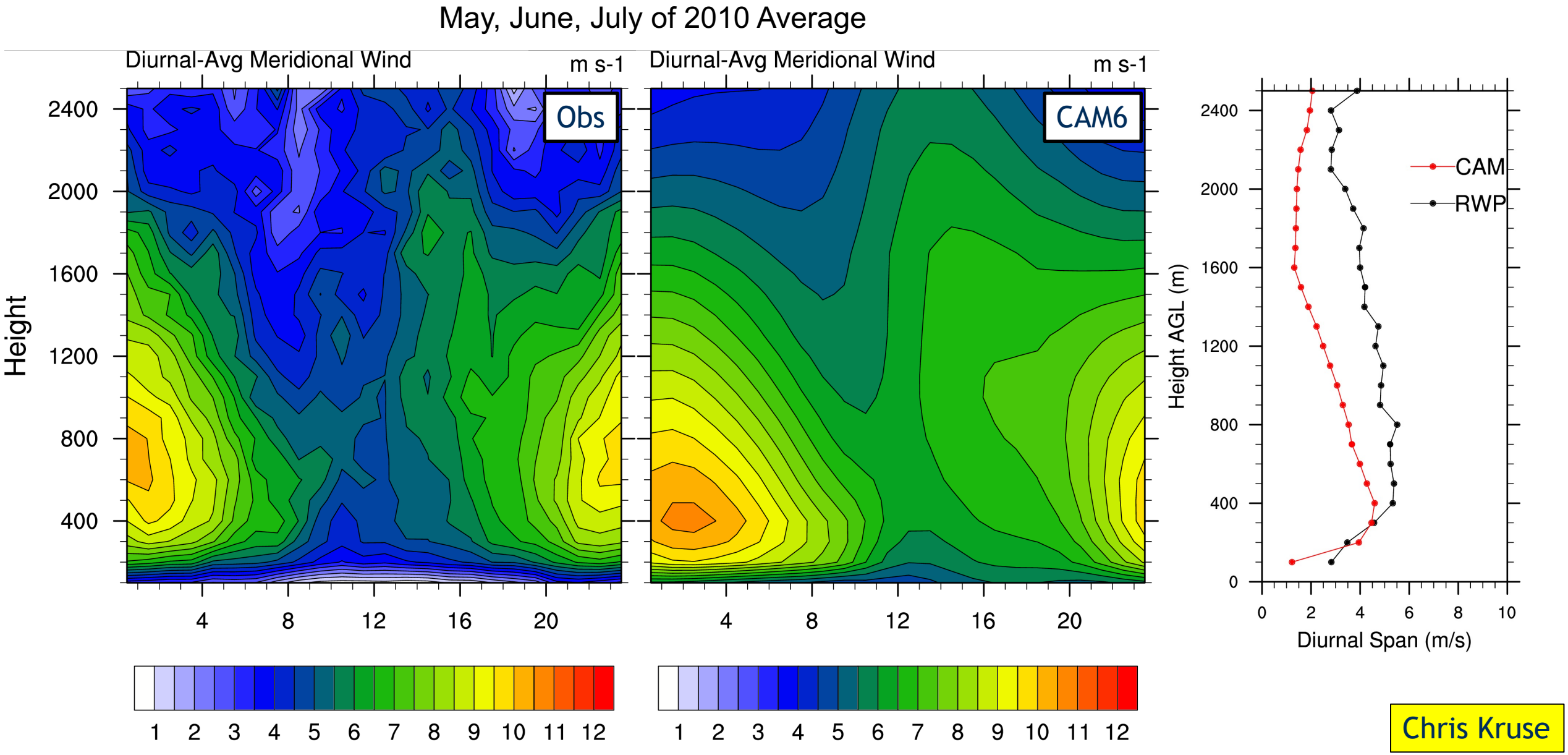
RWP, CAM (ndgnotllj) Comparison





Chris Kruse

Can we improve the Great Plains low level jet?

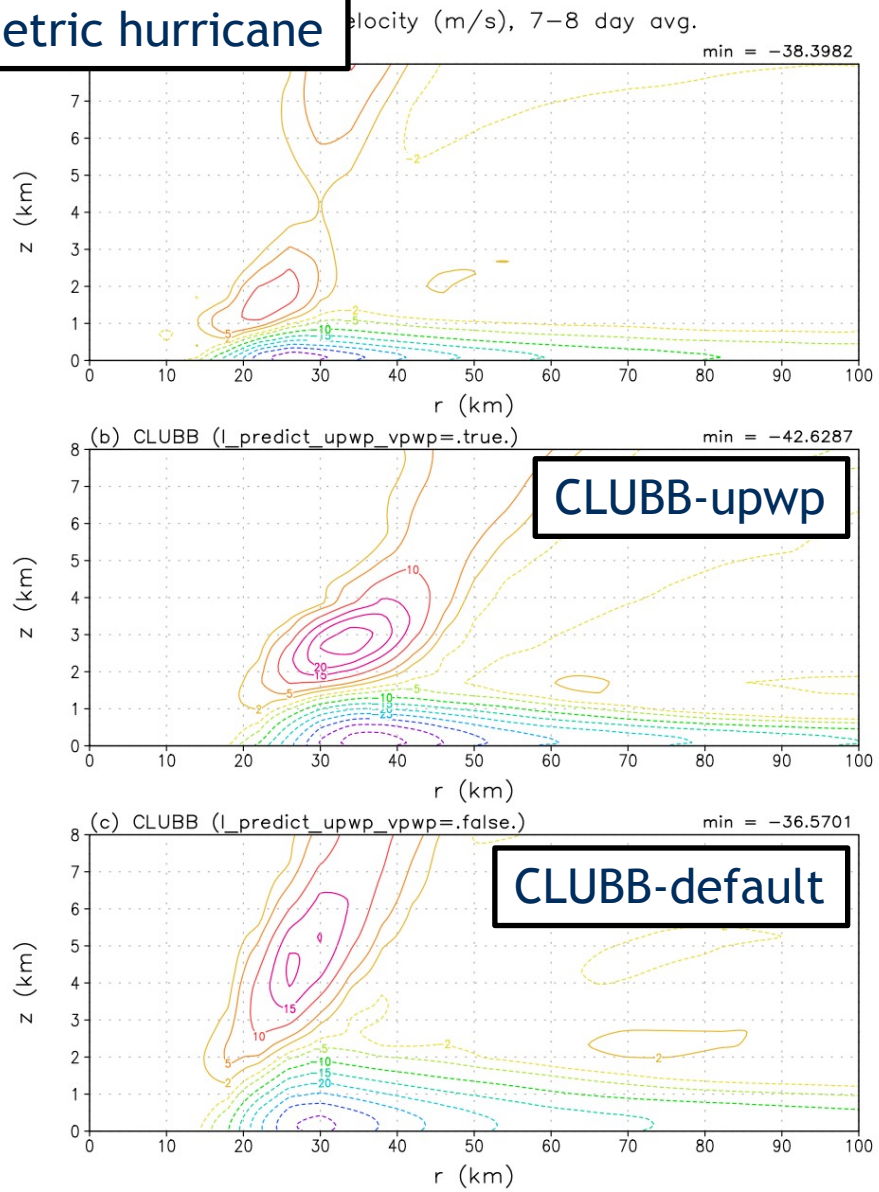


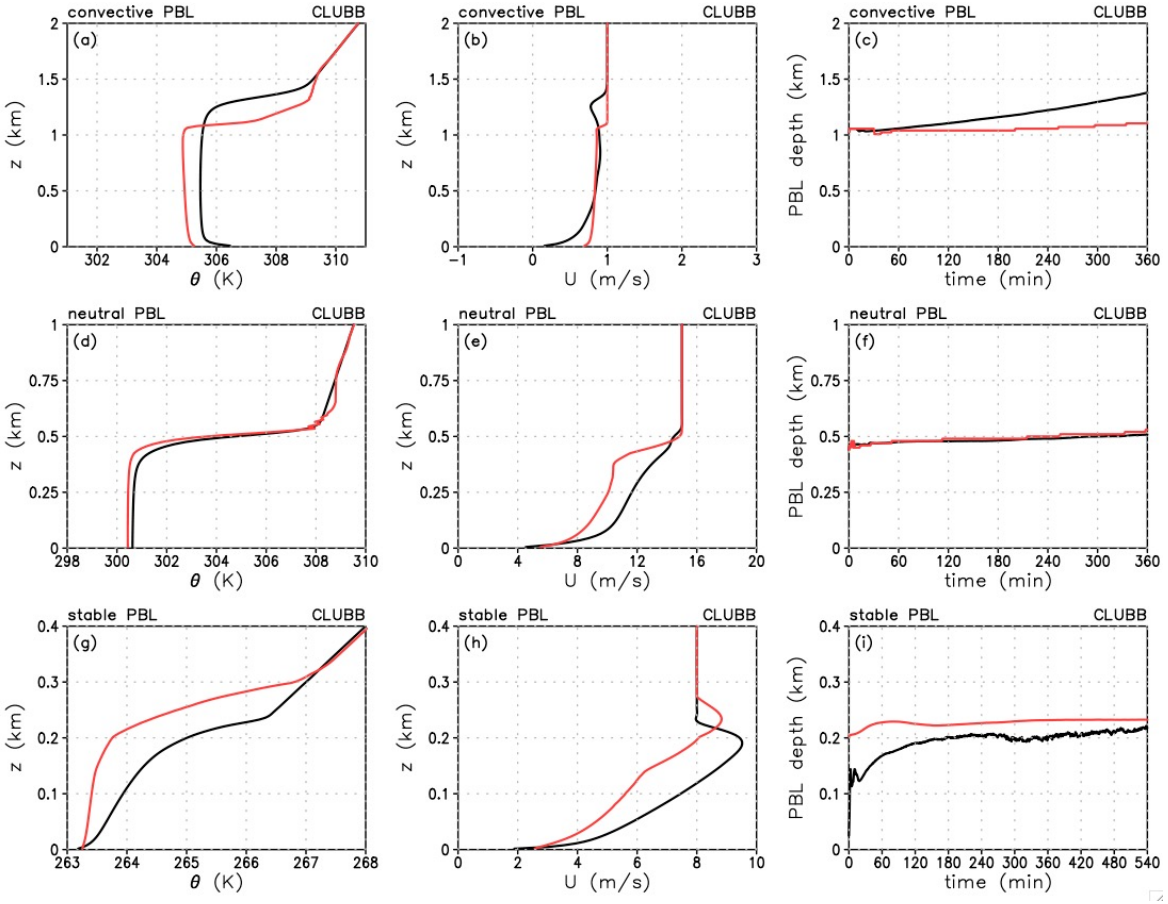
Chris Kruse

CLUBB in CM1

PennState

Axisymmetric hurricane





George Bryan

Surface wind oscillations

- Use sub-cycled sfc winds + aerodynamic roughness to update surface stress inside CAM physics improves oscillations
- Problematic with…
  - High surface roughness
  - Low lowest model level
  - Low PBL diffusivity (dycore in play?)
- **Adam Herrington** = reordering strategy?
- **Sean Santos** = increase coupling frequency?
- **Thomas Toniazzo** also looking at this…

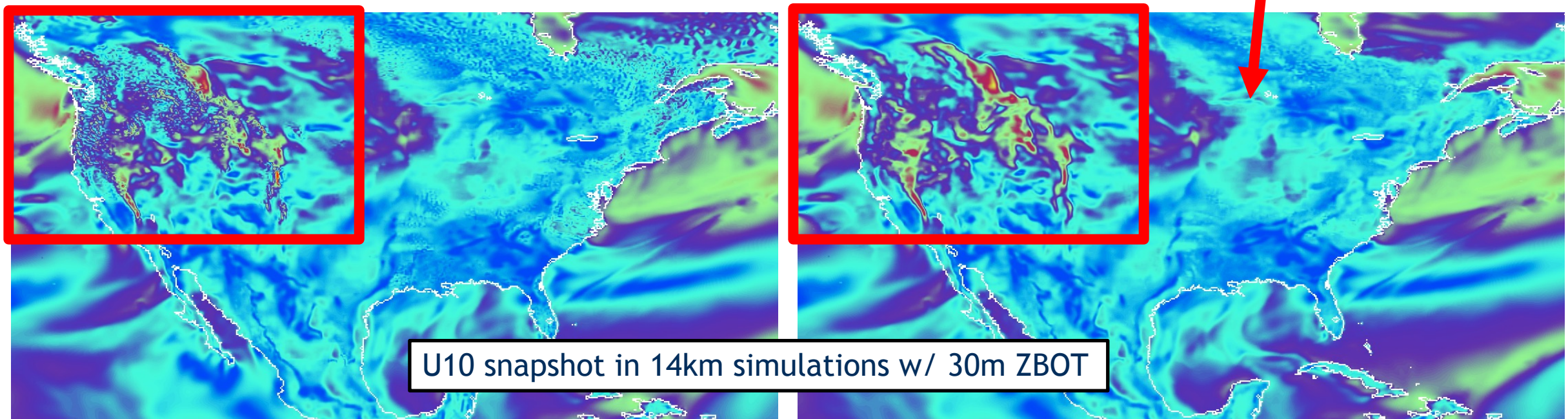
do 0,macmic

$$\tau_x = -\rho_{atm}\frac{(u_{atm} - u_s)}{r_{am}}$$

$$\tau_y = -\rho_{atm}\frac{(v_{atm} - v_s)}{r_{am}}$$

CLUBB, MG, etc.

end do



U10 snapshot in 14km simulations w/ 30m ZBOT

New CAM Feature: complete, closed momentum budgets

PennState

- Complete, closed momentum budget tendencies now easily output
  - Either set “history_budget = .true.” or include desired variables in fincls
  - On development branch!
  - Feature is configuration/physics scheme agnostic
    - Budgets close with different configs, though, difference schemes may contribute to different tendencies (e.g. UW shallow convection in UTEND_SHCONV while CLUBB in UTEND_MACROP)

UTEND_TOT = **UTEND_CORE** + **UTEND_PHYSTOT**

UTEND_PHYSTOT =

UTEND_DCONV + UTEND_SHCONV + **UTEND_MACROP** + UTEND_VDIFF + UTEND_RAYLEIGH + UTEND_QBORLX + UTEND_LUNART + UTEND_IONDRG + **UTEND_NDG**

Chris Kruse

CLUBB profile diagnostics

CLUBB 's Diagnostics Package

Diags_output_test_f09_01_ANN

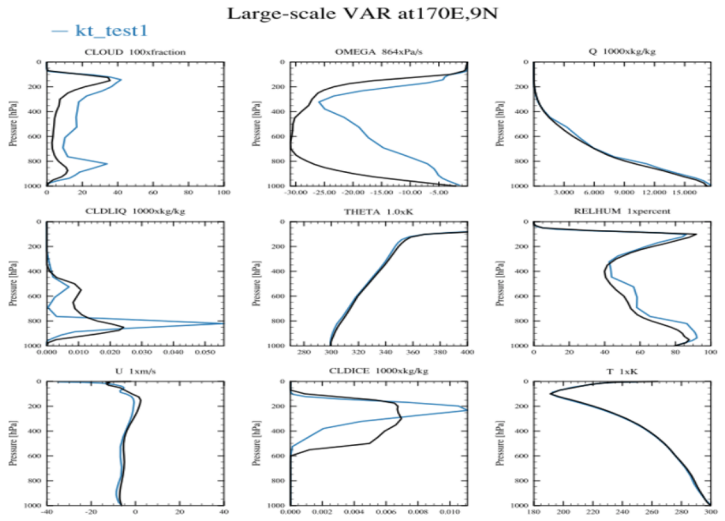
Set Description

0 Gitdiff
1 Horizontal plots
2 Marine Stratocumlus
DYCOMS 240E_27N
VOCAL 275E_-20N
VOCAL 285E_-20N
GulfGuinea 355E_-5N

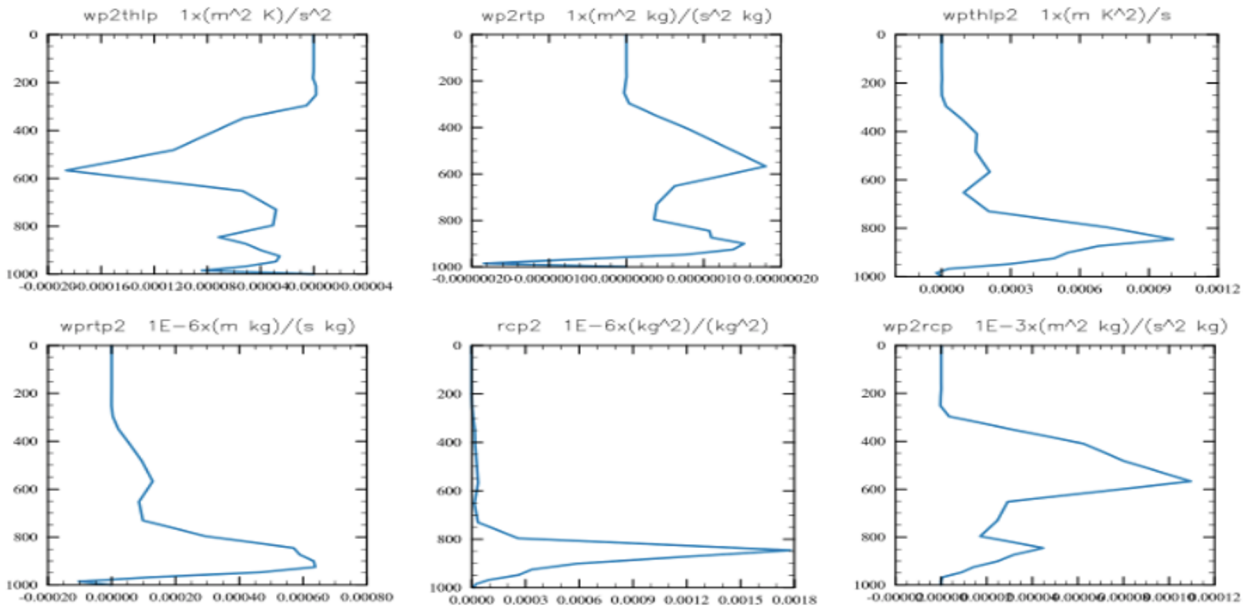
3 Marine Shallow Covections
Hawaii 190E_20N
Hawaii 205E_20N
BOMEX 300E_15N
RICO 300E_17N
BOMEX 300E_13N

4 Marine Deep Covections
BayBengal 90E_10N
WarmPool 140E_2N
ITCZ 170E_9N
ITCZ 229E_9N
ITCZ 259E_-1N
ITCZ 280E_5N
CAtantic 325E_0N

5 Continetal Deep Covections
CAfrica 25E_0N
ARM 263E_36N
LBA I 295E_0N
LBA II 305E_0N



kt_test1



- Python-based
- Supports FV and SE grids
- Choose any locations on the globe to plot profiles
  - Compare to obs for large-scale terms
  - Plot all of CLUBB's higher order moments
  - Future integration with AMWG Diags Framework (ADF)

Kate Thayer-Calder

Summary

- CLUBB-upwp now on CAM dev trunk
  - Prognostic momentum fluxes and eddy timescale formulation
  - Positive indications for regime-specific improvements in PBL turbulent processes
  - Nudging being exploited to constrain simulations, expose biases
- CLUBB in a mesoscale + large eddy model (CM1)
- Surface wind oscillations caused by long timesteps / CAM substepping
  - Multiple paths forward: tighter coupling? Nested updates? Process ordering?
- New diagnostics for CAM (momentum budgets, vertical profiles of CLUBB terms)

Contact czarzycki@psu.edu w/ questions!