Tropical Cyclones in High-Resolution CAM5: Exploring the Effects of Nudging in the Western North Pacific

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CESM AMWG Meeting, February 19, 2019

With thanks to Nan Rosenbloom (NCAR) and Alyssa Stansfield (SBU)

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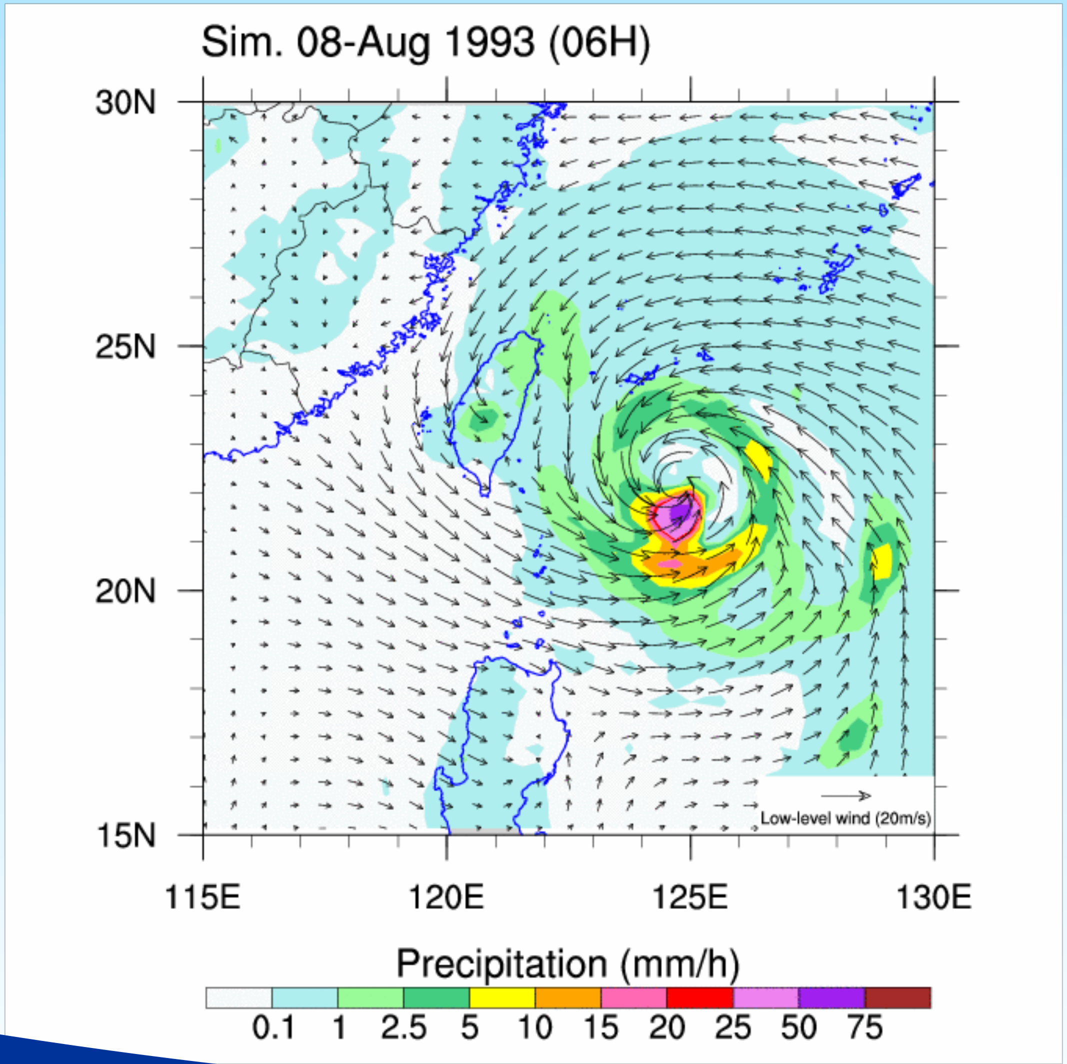
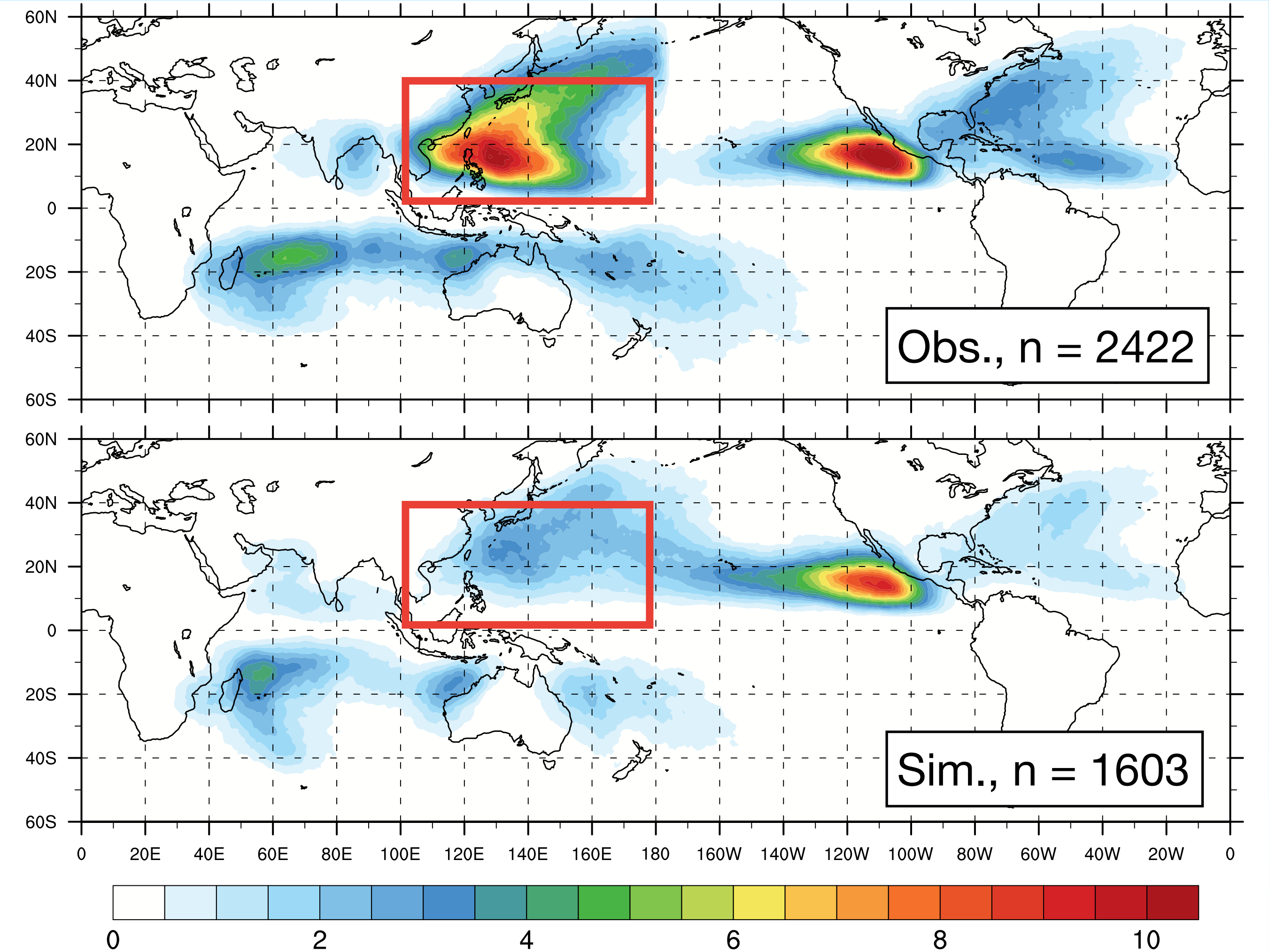
High-res. CAM5 permits tropical cyclones



- CAM5 present-climate set-up: Finite-volume (FV) dynamical core at ~28 km horizontal resolution; prescribed sea surface temperature and greenhouse gases; modal aerosol model
- Tropical cyclone (TC) precipitation and wind field capturing the topographic interaction

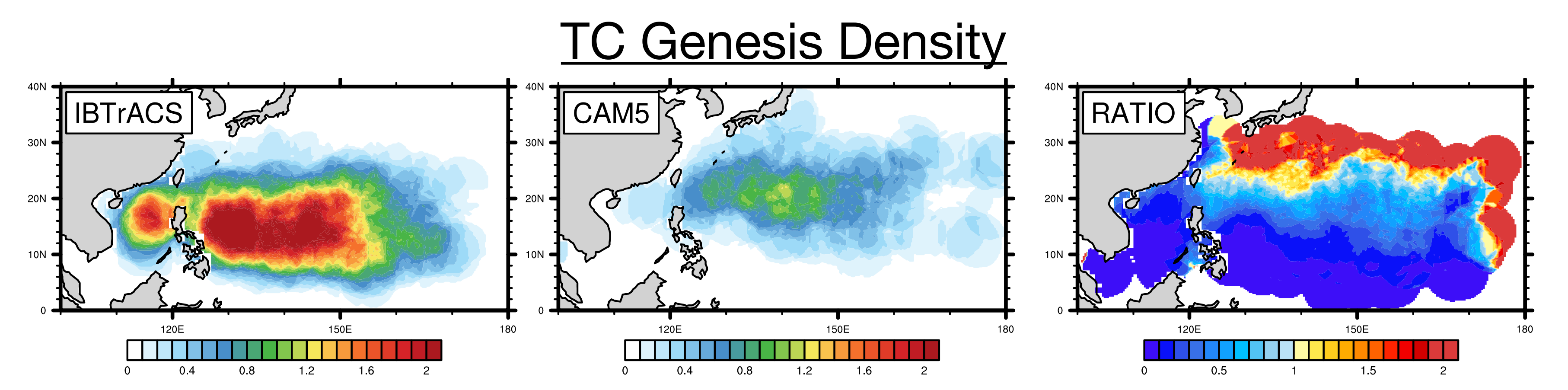
CAM5 global TC climatology is reasonable



[Wehner et al., 2014; Bacmeister et al., 2018]

- Global TC track density (number of TCs within a 5° radius per year) from IBTrACS (Knapp et al., 2010) and CAM5 decadal (1980-2005) simulation
- The simulated global average TC frequency is lower than observation by ~1/3

...but less so in the Western North Pacific



- For WNP peak season July-October (JASO), TC genesis frequency in CAM5 simulation (**N = 191**) falls short of observation (**N = 465**) by 59%, beyond the global average bias of 34%
- TC genesis location in CAM5 simulation is biased towards north of 20° N

Genesis Potential Index (Emanuel, 2010)

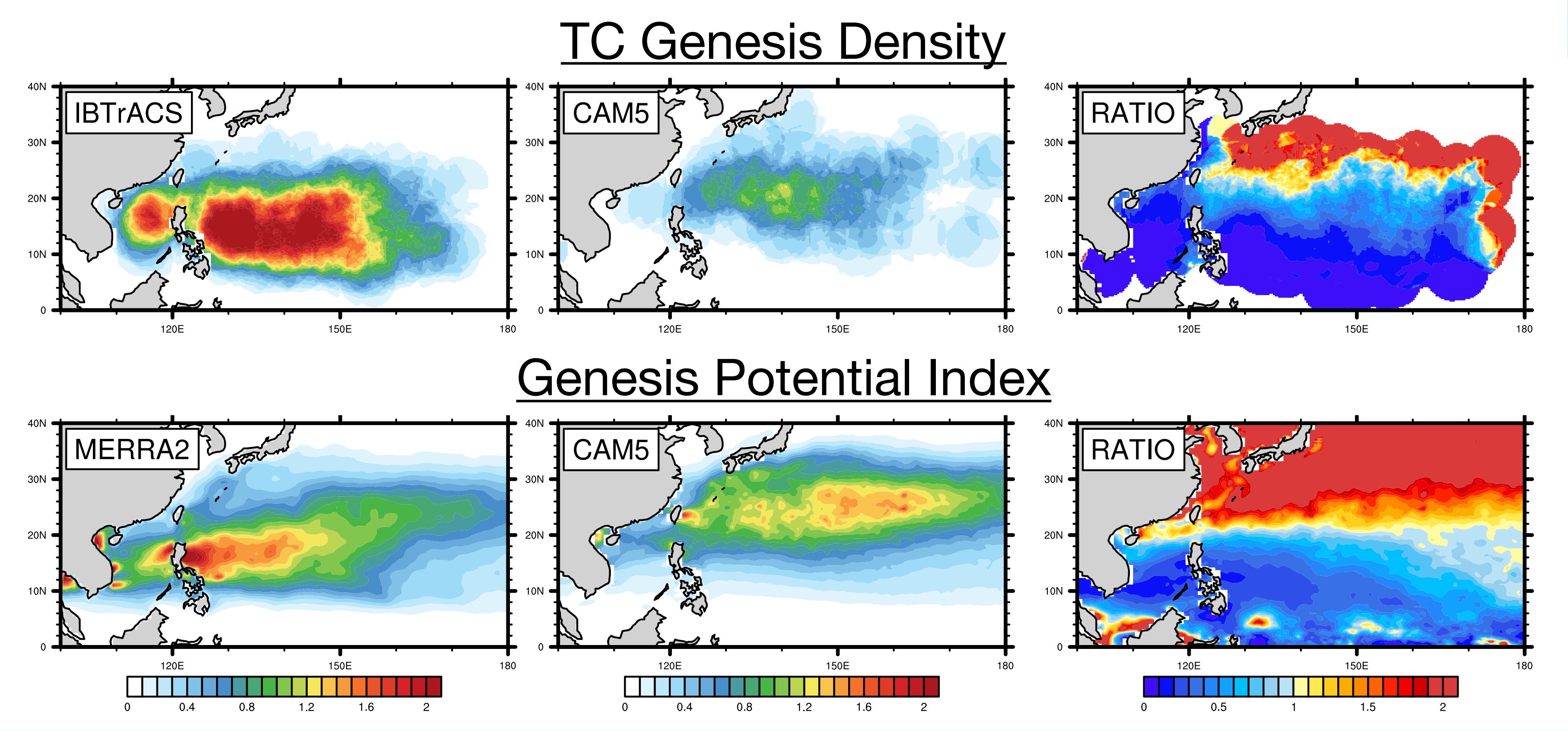
$$GPI = \underbrace{(|Vort._{850}|)^3}_{Abs.\ Vort.} \times \underbrace{\chi_{600}^{-4/3}}_{Entropy\ Deficit} \times \underbrace{[Max(PI - 35,0)]^2}_{Pot.\ Intensity} \times \underbrace{(25 + VWS)^{-4}}_{Vert.\ Wind\ Shear}$$

Empirically determined relationship between TC genesis and large-scale environmental controls

- Thermodynamic (T, Q): Moist entropy deficit, potential intensity (Bister and Emanuel, 1998)
- Dynamic (U, V): Absolute vorticity, vertical wind shear

$$\chi_{600} \equiv \frac{s_{600}^{sat.} - s_{600}}{s_{surf.}^{sat.} - s_{600}^{sat.}},\ s \equiv c_p lnT - R_d lnP + \frac{L_v Q}{T} - R_v Q lnRH$$

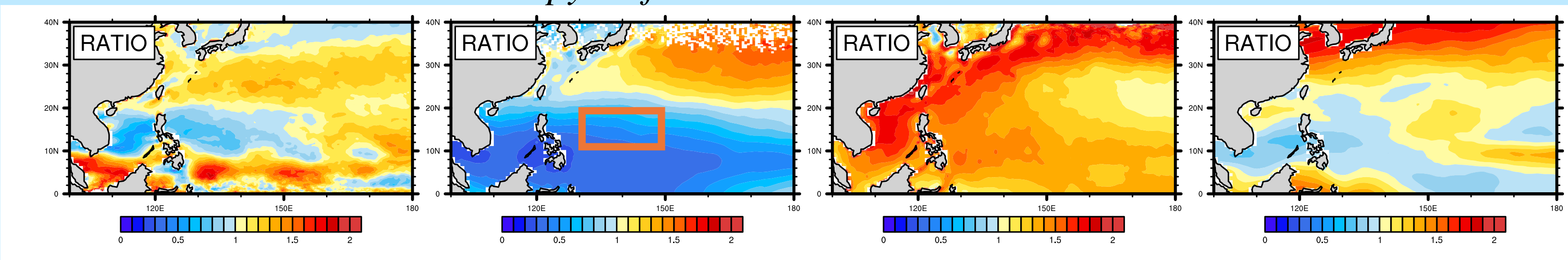
GPI reflects biases in TC genesis



The biases in GPI and the large-scale environment correspond to simulated TC genesis frequency and location

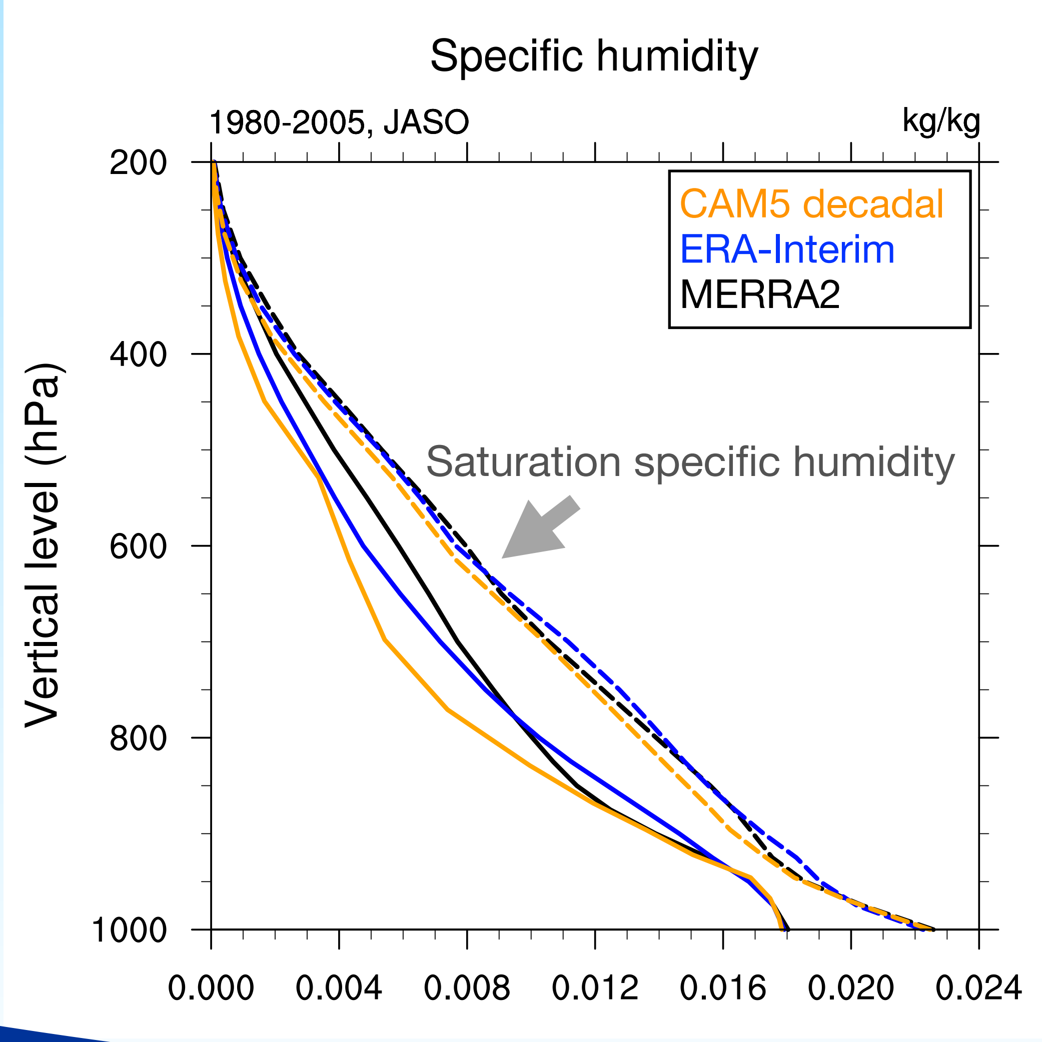
GPI components help to find leading cause:

$$GPI = \underbrace{(|Vort_{.850}|)^3}_{Abs.\ Vort.} \times \underbrace{\chi_{600}^{-4/3}}_{Entropy\ Deficit} \times \underbrace{[Max(PI - 35,0)]^2}_{Pot.\ Intensity} \times \underbrace{(25 + VWS)^{-4}}_{Vert.\ Wind\ Shear}$$



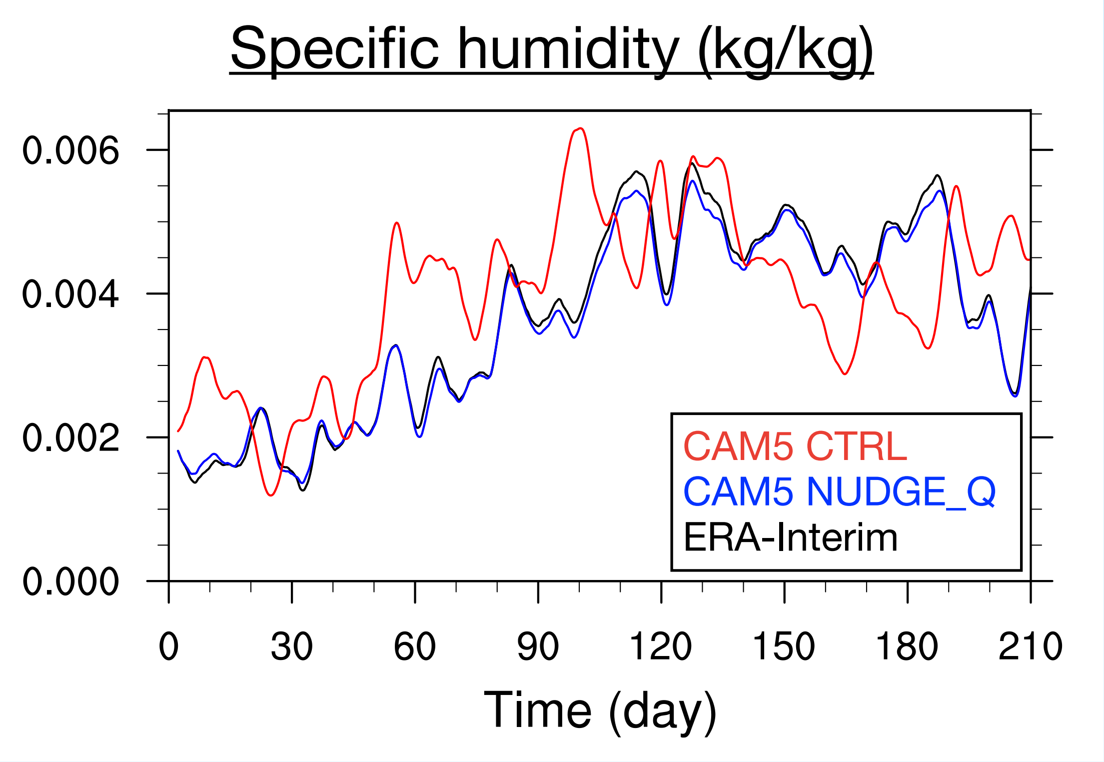
- The moist entropy deficit component is the most responsible for GPI underestimation over WNP TC main development region
- Contribution from each GPI component calculated by averaging the ratio between CAM5 monthly fields and MERRA2 reanalysis

Lack of mid-level moisture links to lack of TC genesis



- Lack of specific and relative humidity throughout the mid-levels
- Possible links: Deficit in Pacific warm pool precipitation at high-res. (Bacmeister et al., 2014); East Asian Summer Monsoon circulation and moisture transport

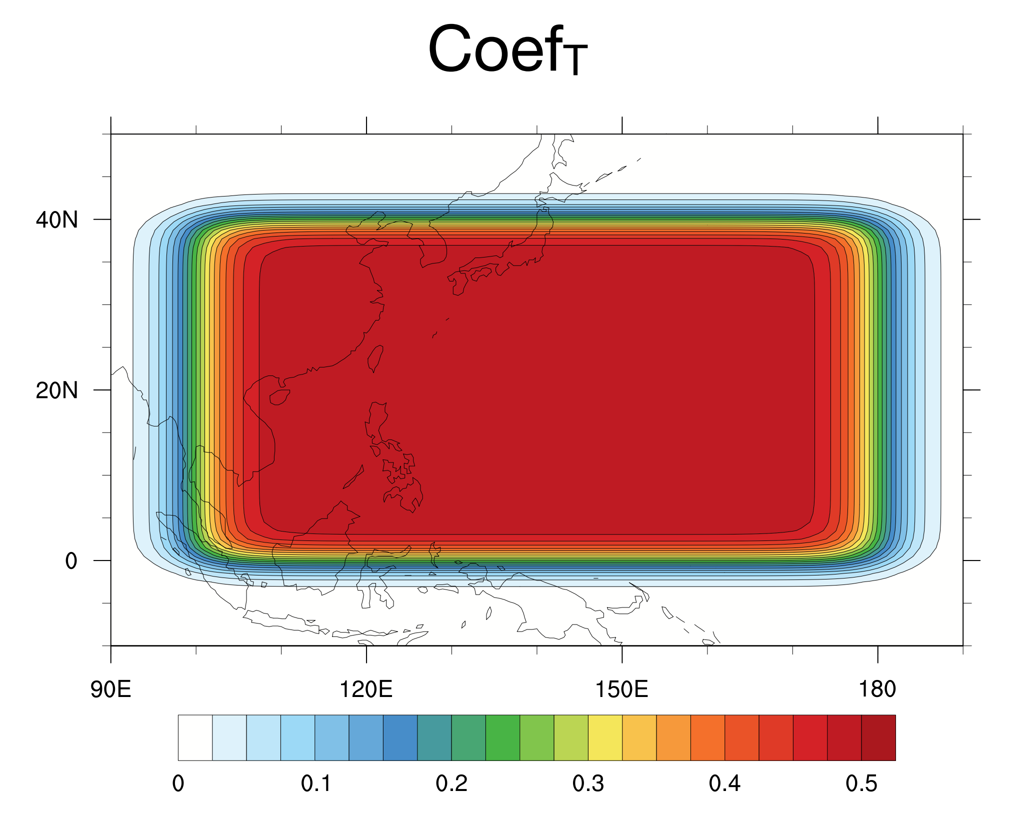
How nudging works (Callaghan and Bacmeister, 2014)



- Extra forcing term for model prognostic variables (T, Q, U, V) towards a prescribed state from reanalyses
- Rest of model machinery stays as in free run
- Nudging strength and 3D structure adjustable

$$\dot{Var}_{ndg} = Coef_{Var}(x, y, z, t)\frac{Var_{model}(t_{model}) - Var_{ana}(t_{ana})}{\tau_{ndg}}, \; 0 \leq Coef_{Var} \leq 1$$

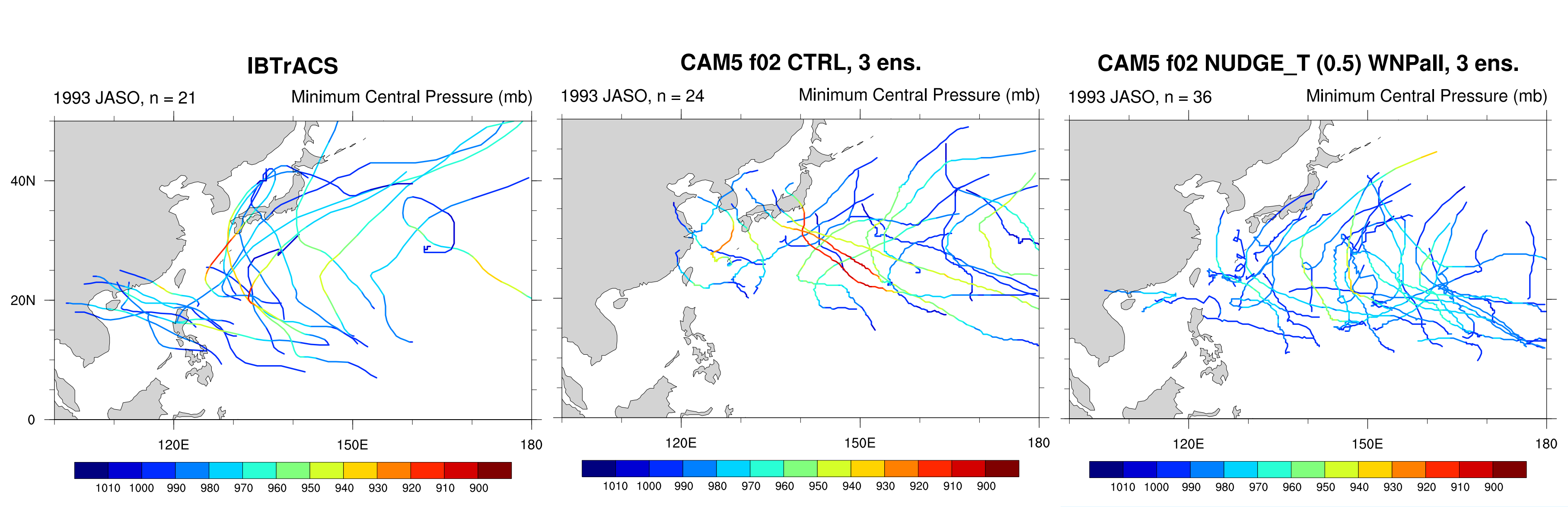
1993 seasonal runs with temp. nudging



- 1993: an ENSO-neutral year with average number of WNP TCs
- CAM5 initialized from ERA-Interim on Apr. 1st, and ran through Oct. freely (CTRL) or with nudging (NUDGE_T); 3-run ensemble
- NUDGE_T:
  - Towards ERA-Interim;
  - Horizontal window covering WNP, vertically uniform;
  - Max($Coef_T$) = 0.5
- TC tracks from Jul.-Oct. (JASO) by TempestExtreme (Ullrich and Zarzycki, 2016)

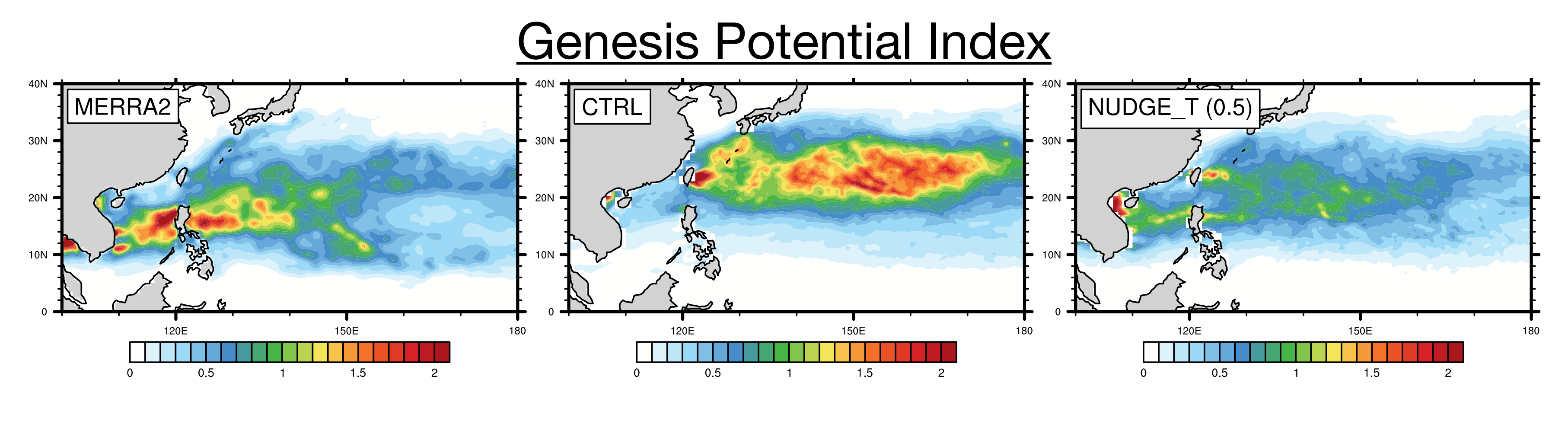
$$\dot{T}_{ndg} = Coef_T(x,y)\frac{T_{model}(t_{model}) - T_{ana}(t_{ana})}{\tau_{ndg}},\ 0 \le Coef_T \le 0.5$$

Temp.-nudging improves TC genesis



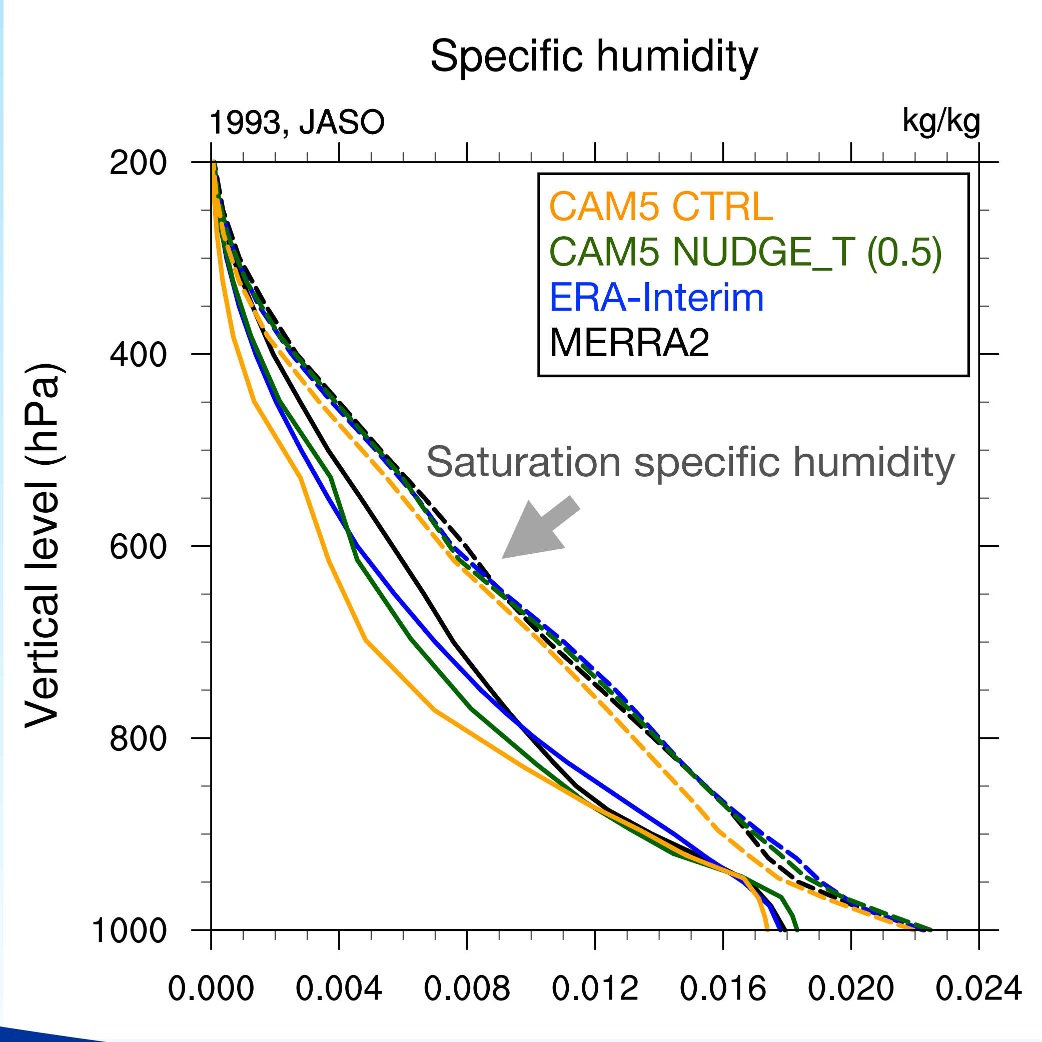
- For JASO 1993, CAM5 free-running simulation (middle) replicates the biases in TC genesis frequency and location as in 1980-2005 climatology
- Temperature nudging (right) improves TC genesis, while dampening intensity development

Temp.-nudging improves GPI



- For JASO 1993, GPI from CAM5 free-running simulation (middle) replicates the biases as in 1980-2005 climatology, consistent with TC genesis
- Temperature nudging (right) improves GPI, with major contribution from the moist entropy component

Temp.-nudging improves moisture

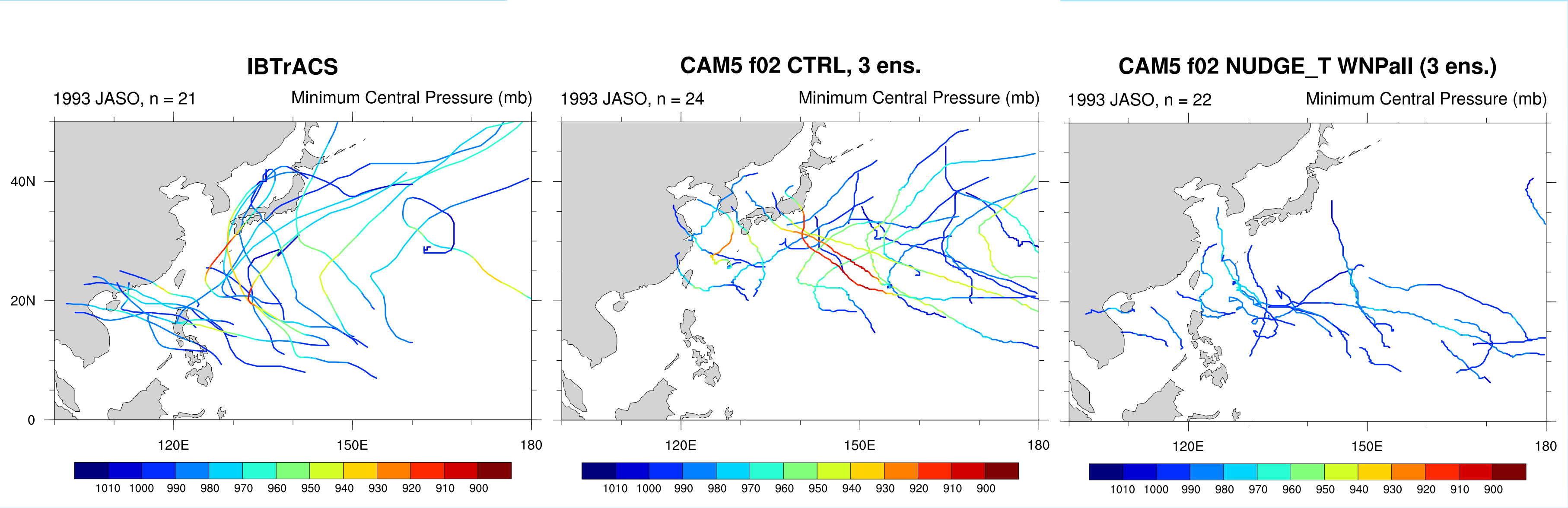


- Mid-level moisture improves with temperature nudging
- Pacific warm pool precipitation, as well as East Asian Summer Monsoon moisture transport, also show improvement

Discussion

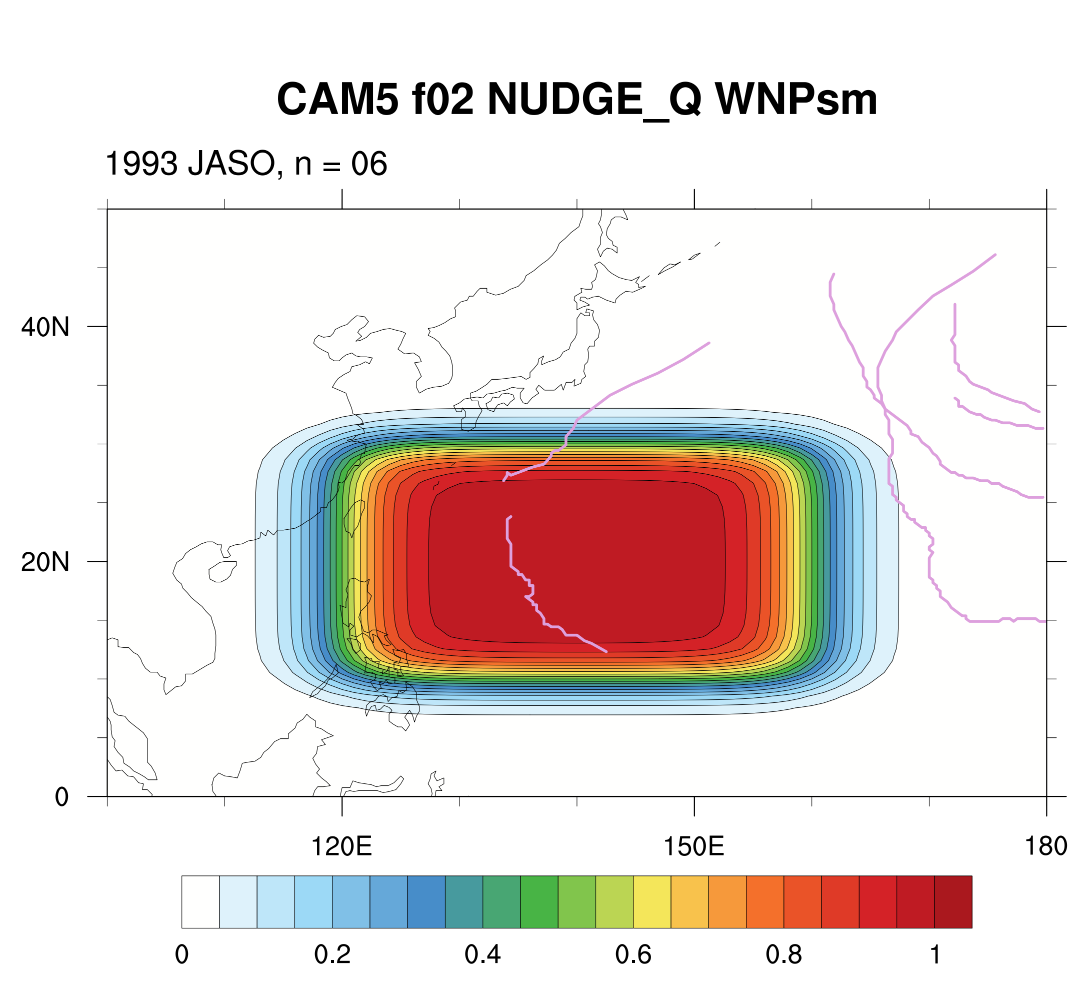
- GPI decomposition identifies the lack of mid-level moisture in WNP TC main development region as the leading cause of the biases in simulated TC genesis
- This lack of moisture is potentially linked to:
  - Previously identified deficits in Pacific warm pool precipitation in high-res. CAM5 (Bacmeister et al., 2014)
  - Biases in the East Asian Summer Monsoon circulation and moisture transport
- Temperature nudging helps improve large-scale environmental controls and TC genesis
- How to achieve these improvements mechanistically?

Temp. nudging at full strength



- Full-strength temperature nudging (right): Same horizontal window, setting Max($Coef_T$)=1
- TC genesis location improves
- Too much damping inhibits TC intensity development

Moisture nudging at full strength



- Full-strength specific humidity nudging: Smaller horizontal window over WNP main development region, setting Max($Coef_Q$)=1
- Too much damping inhibits TC genesis or persistence