Process-Oriented Diagnostics to Inform Model Development

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CMIP5 Task Force
Sponsored by NOAA Climate Program Office
Modeling, Analysis, Prediction and Projection (MAPP) program

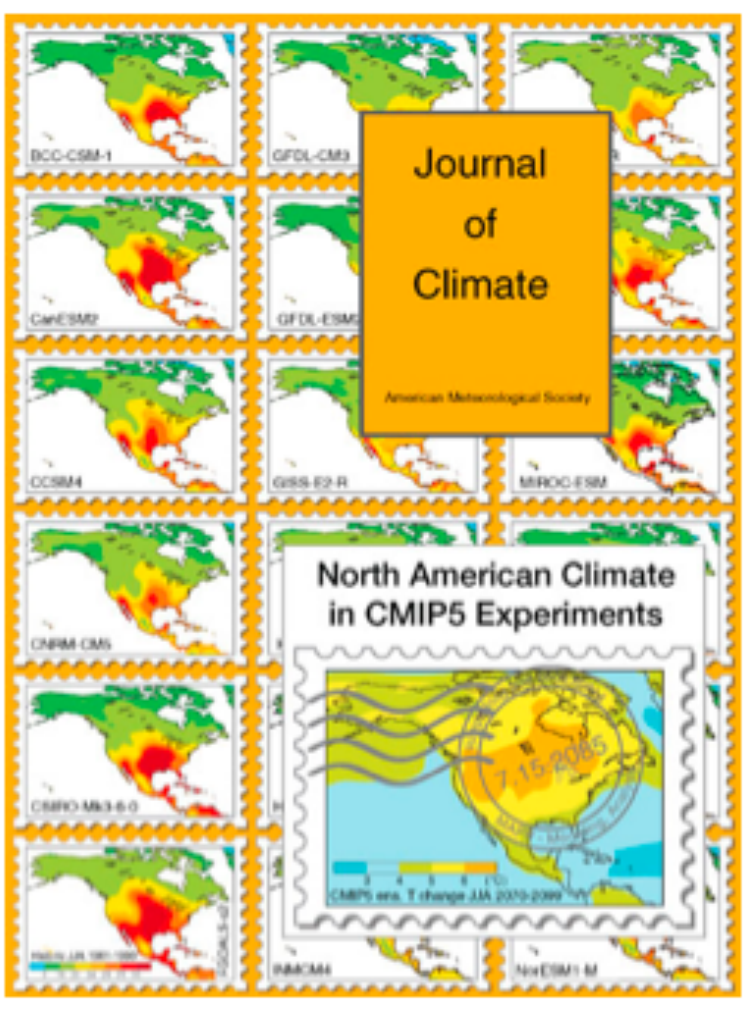
Overview of NOAA CMIP5 Task Force

- **GOAL**: Evaluate CMIP5 20th century historical simulations and uncertainties in long-term 21st century projections, with a focus on North American climate (initiated Nov. 2011)
- Work carried out by 37 MAPP-funded PIs and co-PIs
- Each analysis uses ensembles from multiple climate models
- Synthesis across a range of climate features from basic climate variables to regional climate features to inter-annual to decadal variability and trends
- **RESULT**: Special Collection in *J. Climate* with 22 original contributions and 3 synthesis papers:
  http://journals.ametsoc.org/page/CMIP5

J. Climate Special Collection
NOAA MAPP CMIP5 Task Force

- 3 synthesis papers
  - Sheffield et al. 2013a
  - Sheffield et al. 2013b
  - Maloney et al. 2014
- 22 papers – lead authors

Neelin	Rupp
Thibeault	Koven
Geil	Dirmeyer
Serra	Hung
Carvalho	Jiang
Seth	Camargo
Langenbrunner	Smith
Colle	Vecchi (2)
Chang	Chen
Pan	Liu
Kumar	



CMIP5 TASK FORCE

Applications of Task Force members' funded projects

Projections of North American climate informing applications (e.g., National Climate Assessment)

Process-based model evaluation metrics geared toward informing model development

- To-be-delivered NCA is based on CMIP3 results
- Task Force responded to a series of questions on CMIP3/CMIP5 differences, changes in North American climate
- Working on a NOAA technical report and publication detailing findings; a contribution to the assessment process

Process-based model evaluation metrics geared toward informing the user community and stakeholders

- Process- as opposed to variable-oriented evaluation of model biases
- Extension to modeling center development efforts

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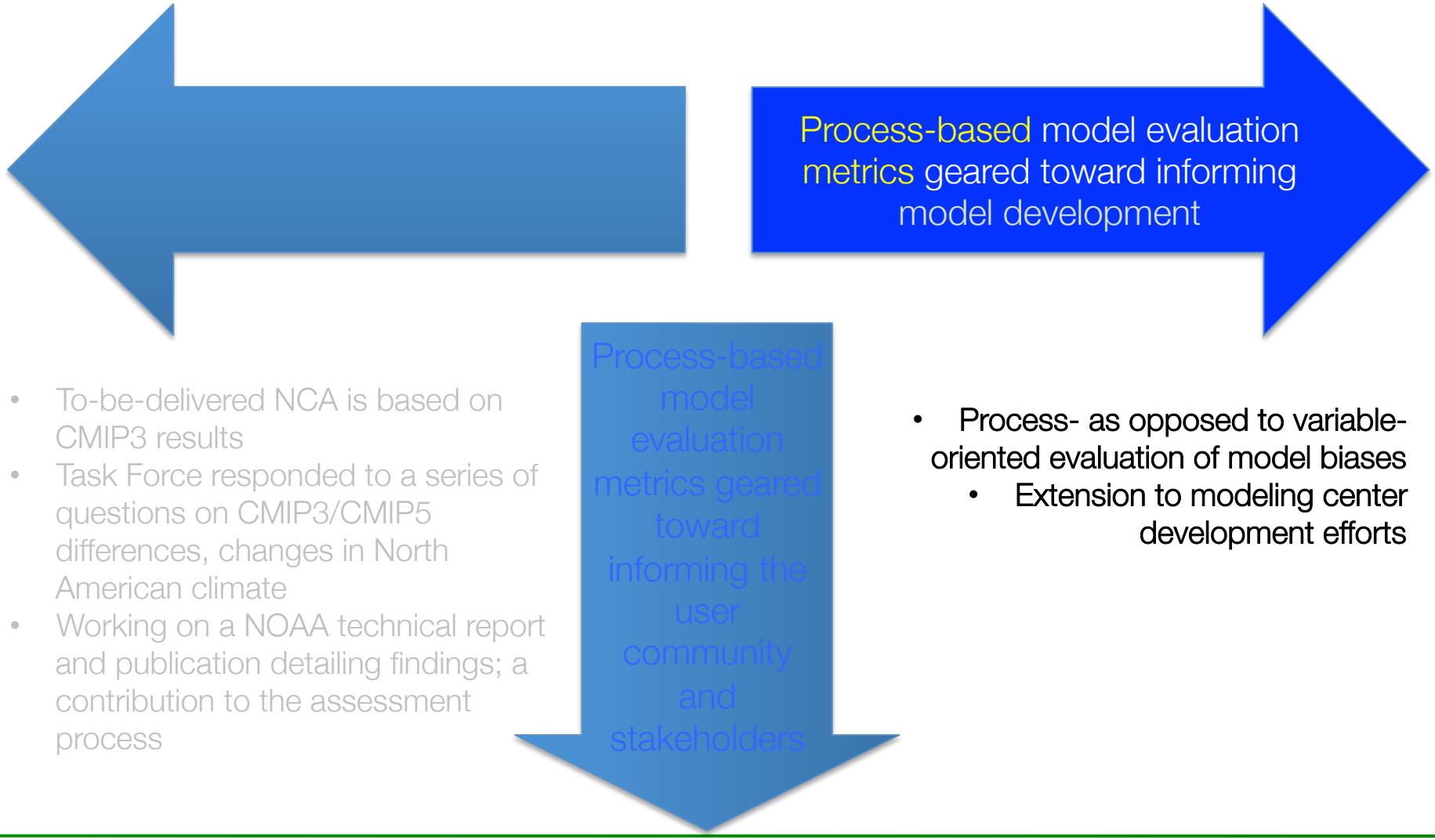

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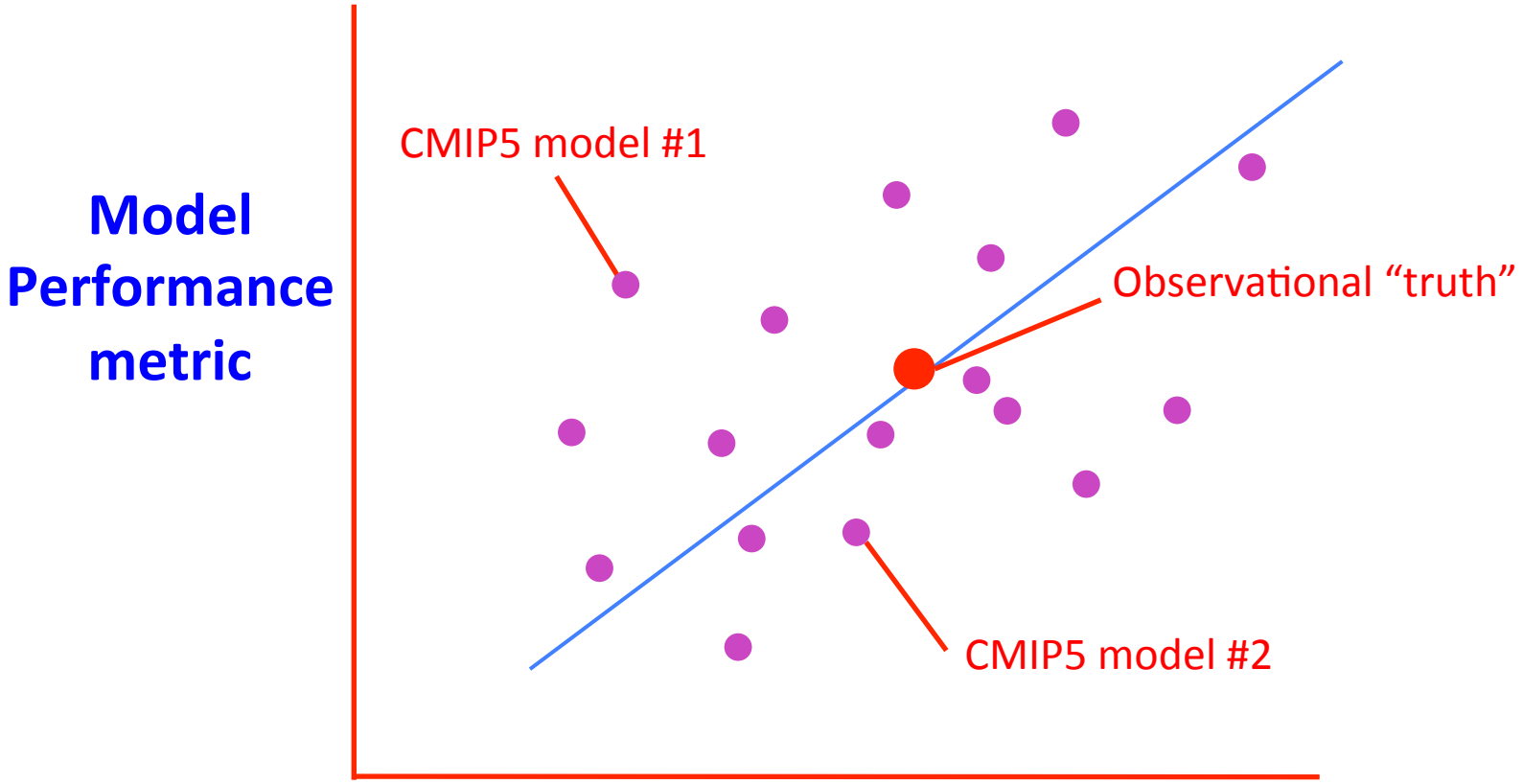
NOAA MAPP CMIP5 Task Force
Process-Oriented Diagnostics Efforts

- "RIGHT ARROW" GOAL: Develop process-oriented model diagnostics to understand why some models produce a good simulation of NA climate, and why others do not … with an eye toward providing actionable feedback to model developers.

- Go beyond a simple diagnosis of whether models can or cannot simulate a particular phenomenon, and provide physical understanding (including why improved simulation of some phenomena degrades other aspects of climate).

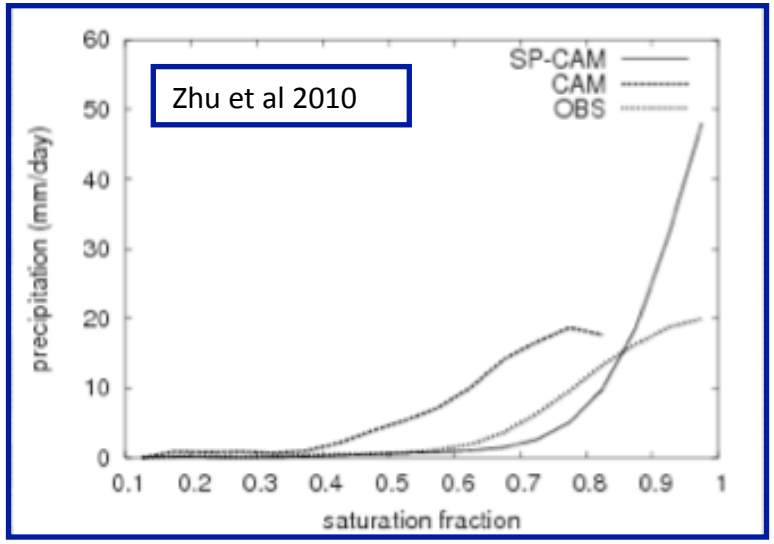
- Provide guidance to model development community (and the applications community – "down arrow")

Conceptual Framework



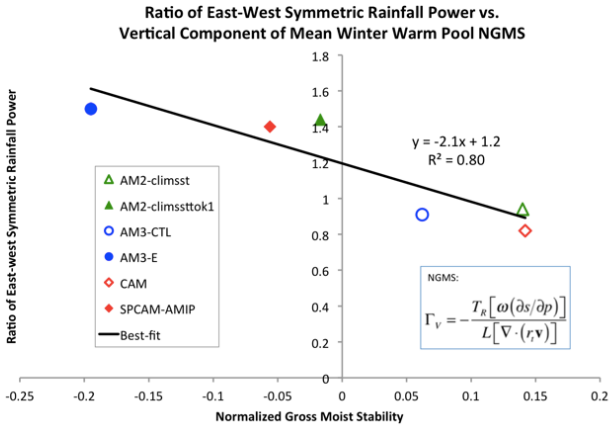
Other diagnostic frameworks are obviously possible

Example: WGNE MJO Task Force Subproject: Process-Oriented Diagnostics

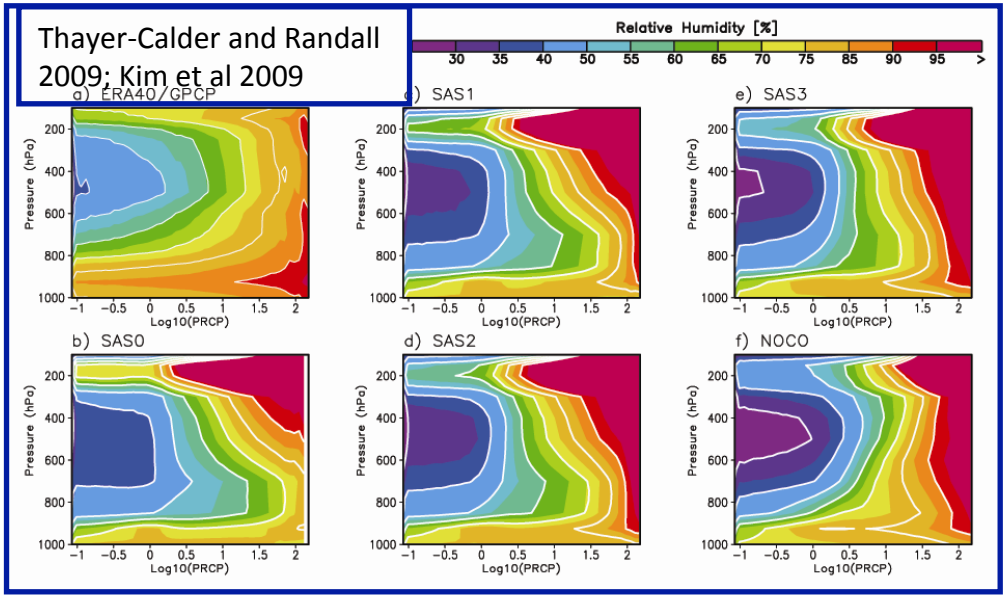


- Exploring Diagnostics/Metrics that provide more insight into why a model may have a good/poor MJO
- Facilitate improvements in convective and other physical parameterizations relevant to the MJO

Hannah and Maloney 2011; Benedict et al. 2014



Thayer-Calder and Randall 2009; Kim et al 2009



Process-Oriented Diagnostics: Examples in CMIP5 TF

- Local forcing
  - Convective onset statistics vs. transition to shallow convection
  - Great Plains precipitation vs. precipitation recycling efficiency
  - **Tropical intra-seasonal variability (e.g. MJO) vs. gross moist stability**
  - Sensitivity of tropical convection to free troposphere humidity and east Pacific mean state wind
- Model specifications
  - Extra-tropical cyclone track density and central pressure vs. horizontal resolution
  - Tropical cyclone formation rate vs. horizontal resolution
  - Low level jet and Great Plains precipitation vs. model resolution
- Remote/large-scale forcing (e.g. SST)
  - Frequency of drought/pluvial periods vs. P partitioning to E_T & runoff
  - mid-summer drought amplitude & timing vs. air-sea interaction deficiency

Column-Integrated MSE (h) Budget Diagnostics for the MJO

$$\langle \partial_t h \rangle = -\langle \mathbf{v} \cdot \nabla h \rangle - \langle \omega \partial_p h \rangle + \langle Q_R \rangle + LHF + SHF$$

$$h \equiv c_p T + gZ + L_v q$$

- Vertical Gross Moist Stability (GMS): $-\langle \omega \partial_p h \rangle = \Gamma_V C \qquad \Gamma_v = \dfrac{-\langle \omega \partial_p h \rangle}{C}$

  Depends on vertical heating, MSE profiles

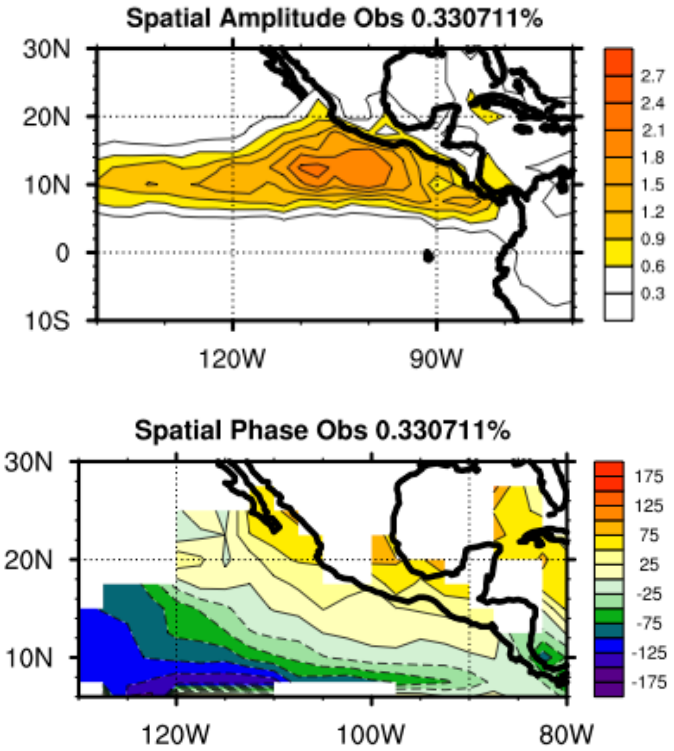
- Effective Gross Moist Stability: $-\langle \omega \partial_p h \rangle + \langle Q_R \rangle = \Gamma_{eff} C$

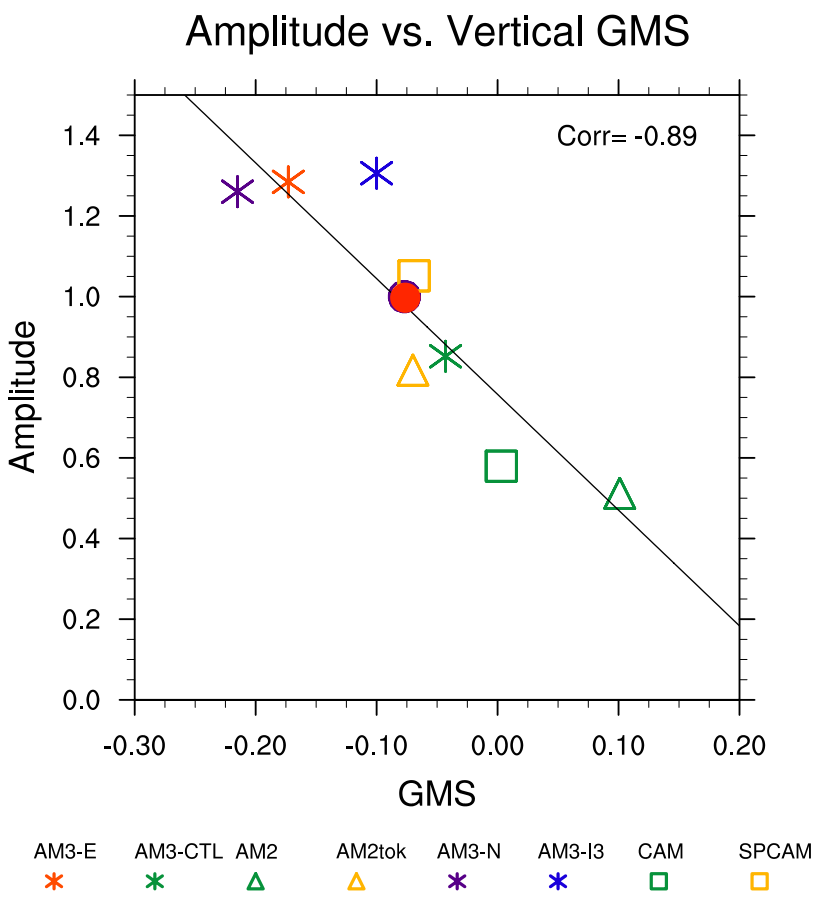
- Horizontal Gross Moist Stability: $-\langle \mathbf{v} \cdot \nabla h \rangle = \Gamma_H C \qquad \Gamma_h = \dfrac{-\langle \mathbf{v} \cdot \nabla h \rangle}{C}$

- C is a measure of convective activity, and might be: vertically integrated moisture convergence, dry static energy export, mass flux, precipitation, etc.
- Γ_H and Γ_V provide measures of how efficiently horizontal and vertical advection discharge m from the column.

Vertical Component of GMS (Γ_v) Versus Boreal Summer East Pacific Leading Mode Amplitude

Leading 30-90d precipitation complex EOF mode

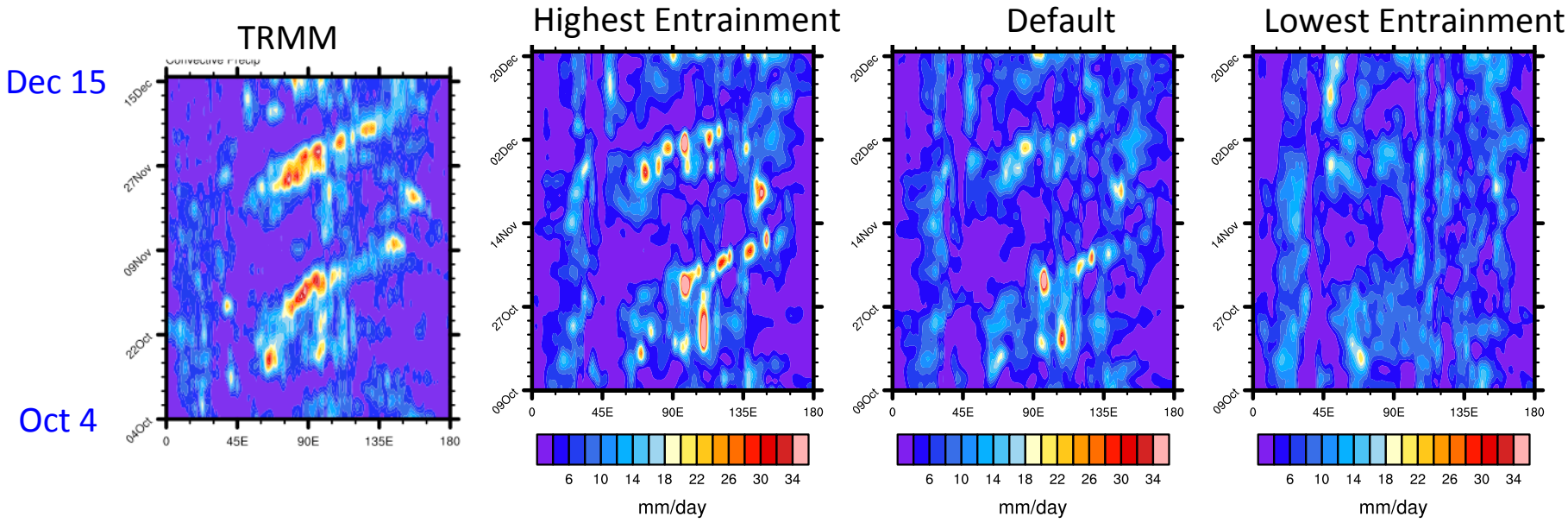




- Models have significant spread of leading mode amplitudes
- VGMS lower in models with stronger variability.

Maloney et al. (2014)

NCAR CAM5 DYNAMO Hindcasts at One-Week Lead Time



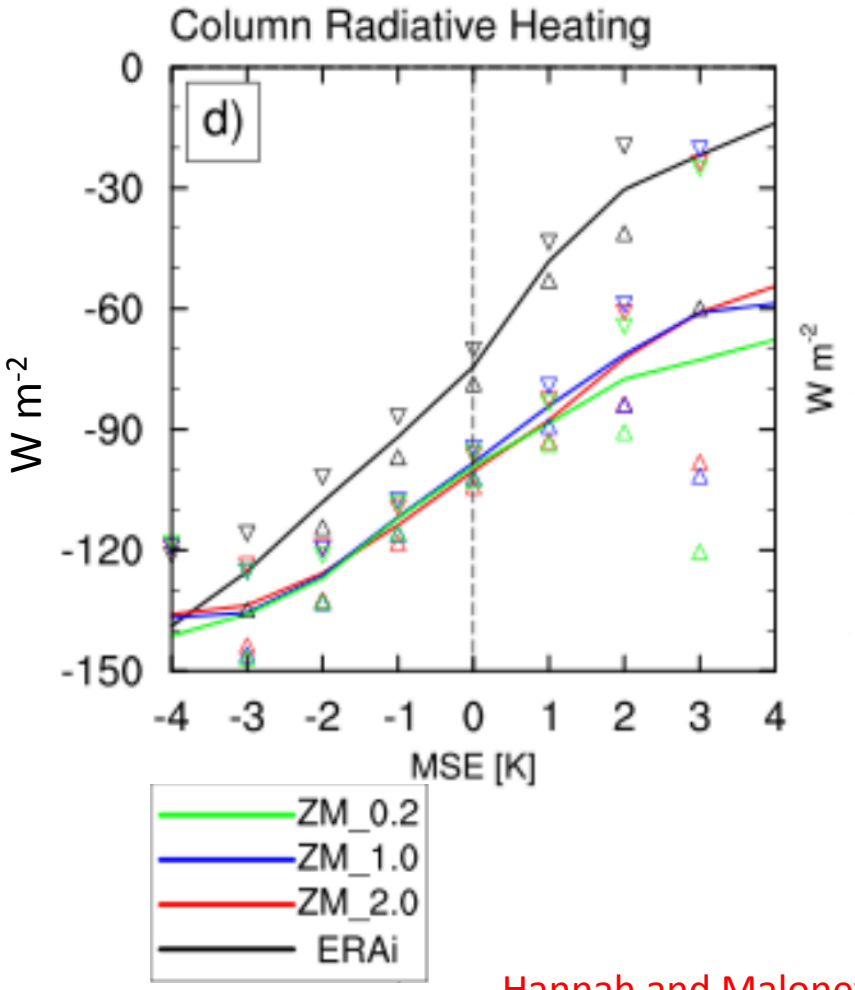
Stronger MSE anomalies maintained in the higher entrainment runs

Lower entrainment leads to less coherent precipitation variability and weaker MJO amplitude

Hannah and Maloney (2014)

Radiative Feedbacks in CAM5 Appear Too Weak

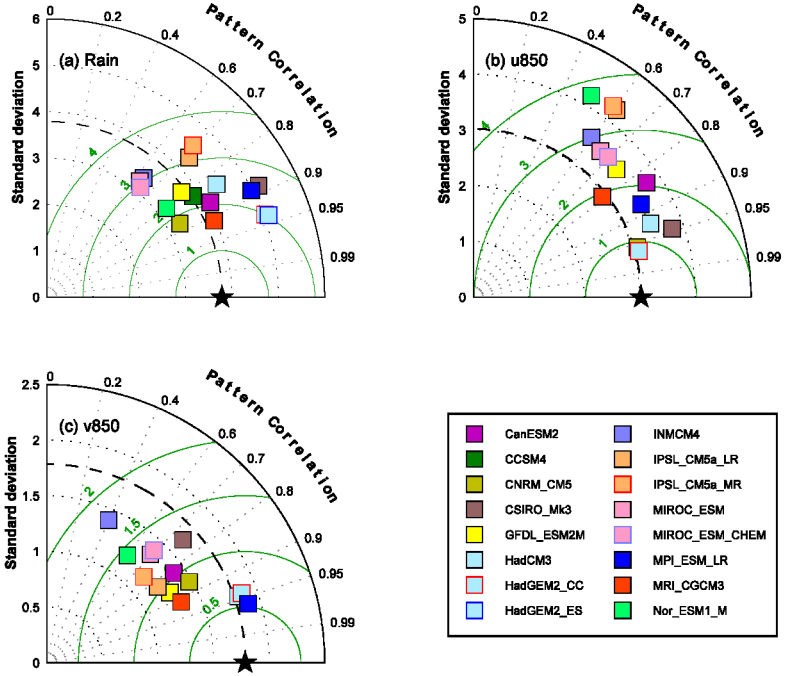
- Radiative feedbacks in CAM5 are too weak in all simulations (compared to ERA-I at least).
- Too low GMS may be compensating for too weak radiative feedback in the high entrainment cases to produce a reasonable MJO
- Similar to results recently found by Daehyun Kim

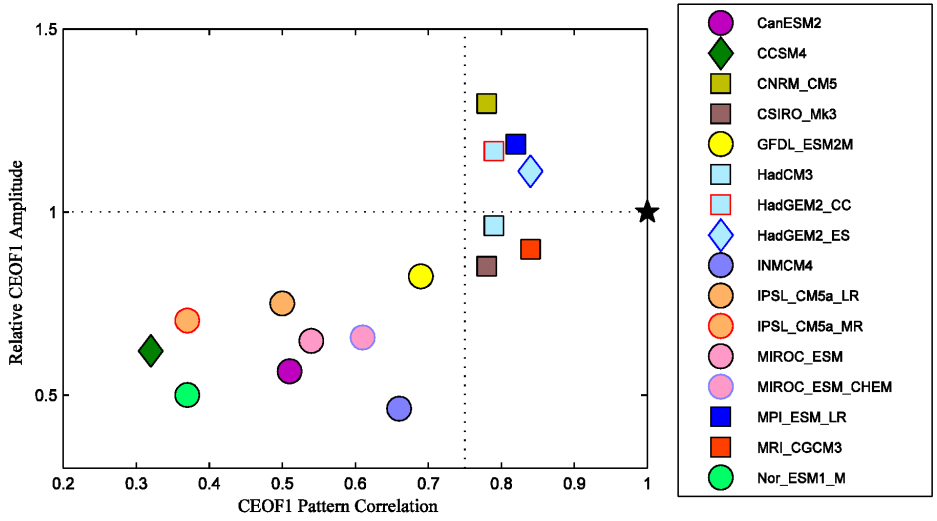


Hannah and Maloney (2014)

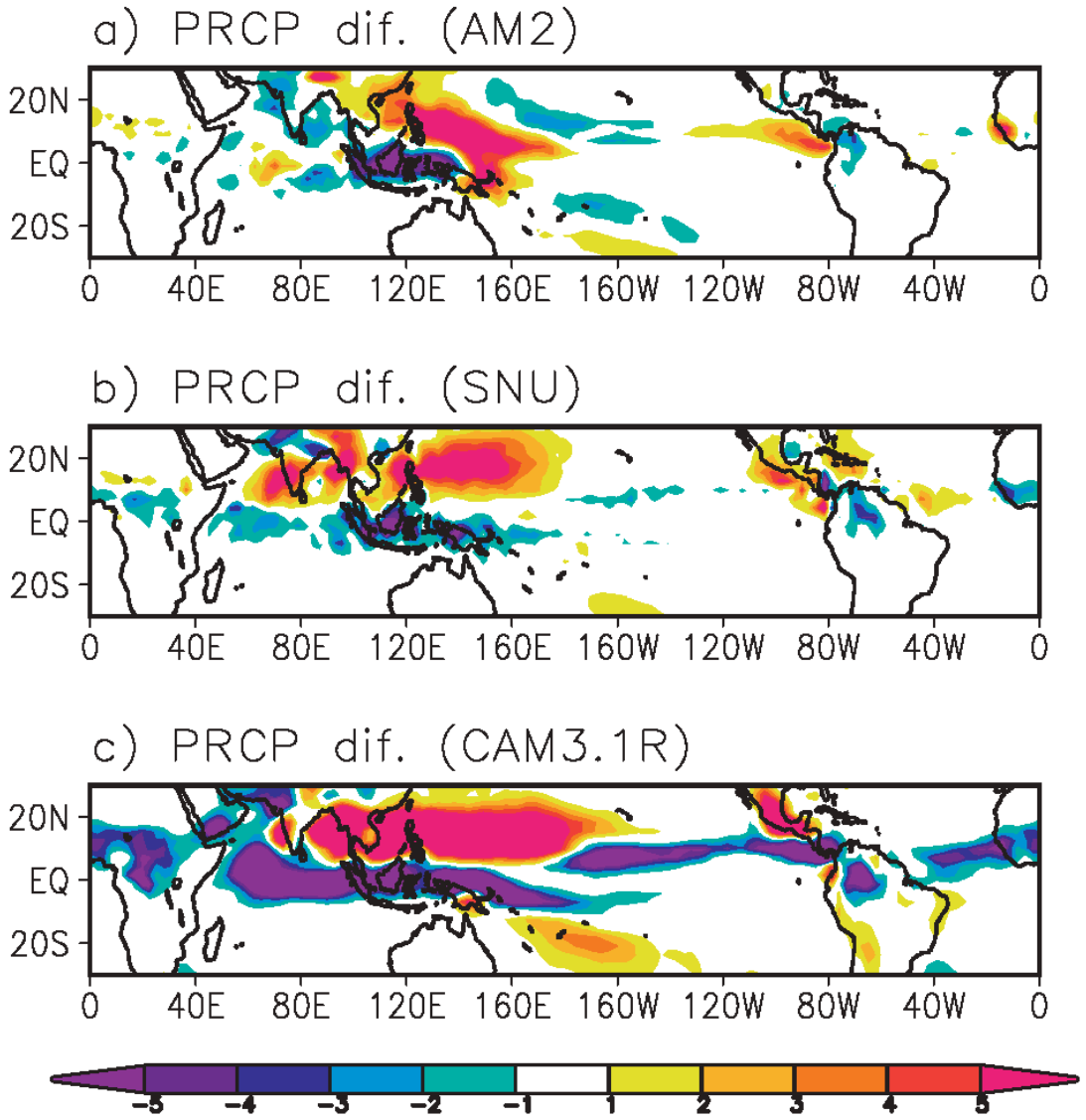
East Pacific Intraseasonal Variability

- East Pacific ISV versus gross moist stability
- East Pacific ISV versus basic state low-level flow





Jiang et al. (2013)

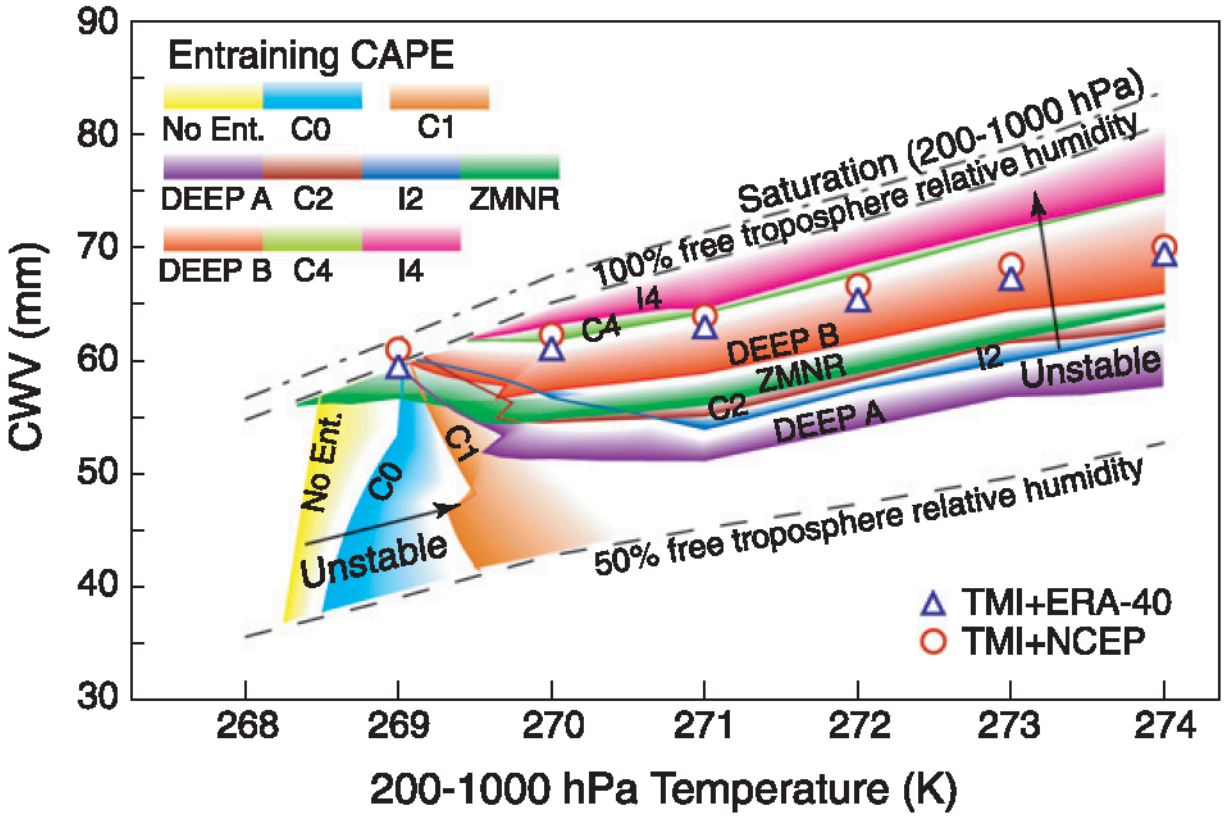


Link to Mean State Bias in Models with Strong MJO?

Strong horizontal advection associated with overactive rotational disturbances and common mean state biases characterizes many models with strong MJOs

Kim et al. (2011)

Convective Onset Diagnostics for Different Entrainment Profiles



Convective onset column water vapor content as a function of tropospheric temperature and treatment of entrainment

Sahany et al. (2012)

Modeling Center Discussions (NCAR, GFDL)

- Interest in expanding process-oriented diagnosis of models
- Need to focus efforts on incorporating process-oriented diagnostics to developmental model versions of ESMs (i.e. feed back more rapidly onto model improvement and bias reduction than a CMIP cycle)
- Incorporating diagnostic analysis into standard community diagnostic packages used by modeling centers, so diagnostics can be rapidly repeated across model versions
- Leverage and extend the utility of existing efforts (CPTs and task forces) and maximize their effectiveness.

Conclusions

- Process-oriented model diagnostics are being developed to provide insight into model behavior.
- Pilot project with NCAR called Climate Analysis Projects (CAP) to implement these diagnostics into development stream of NCAR CAM (Maloney et al.)
  - http://www.cesm.ucar.edu/working_groups/Atmosphere/metrics_diags/
- Joint efforts under discussion with other modeling centers (e.g. GFDL) and the applications community about this diagnostic framework and possible collaborations.
- NOAA MAPP CMIP5 Task Force actively developing diagnostics for N. American climate (as MJOTF is for MJO) ex: blocking, TCs, Great Plains precip, etc.
- NB: Most effort so far focused on atmospheric processes (clouds, convection, etc.) or land-atmosphere interactions, but CMIP models are coupled → need process-oriented diagnostics for ocean, sea ice

THANKS!