Perturbed-parameter hindcasts of the MJO with CAM5

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PCMDI

Program for Climate Model Diagnosis and Intercomparison

Rationale

- The Madden-Julian Oscillation (MJO):
  - Eastward-propagating envelope of tropical convection with a predominant time-scale of 30 – 60 days
  - Dominant mode of intra-seasonal variability
- Research has emphasized that MJO characteristics are determined by the interactions of many processes
  - Large-scale dynamics
  - Shallow and deep convection
  - Stratiform heating
  - Surface fluxes
  - Radiation

Rationale (Continued)

- Although changing, MJO simulation has historically been poor in large-scale models
  - MJOs are generally weak with a poor simulation of precipitation anomalies
  - CAM4 does reasonably well *(Subramanian et al. 2011)*
  - CAM5 somewhat less well
- Modelers would like to understand how their climate models could better simulate an MJO
  - This is hard given the complexity of the MJO and models
  - How can one efficiently explore the degrees of freedom offered by the adjustable constants in the physical parameterizations?

Approach

- Here, we systematically explore dependencies of CAM5's MJO simulation on uncertain physical parameters with 2 goals:
  - Guide modelers on how to better represent the MJO
  - Provide some understanding of what process representations are critical to a good MJO simulation
- For a systematic exploration, an inexpensive modeling framework is required
  - We utilized the hindcast approach for a single strong MJO event

Details

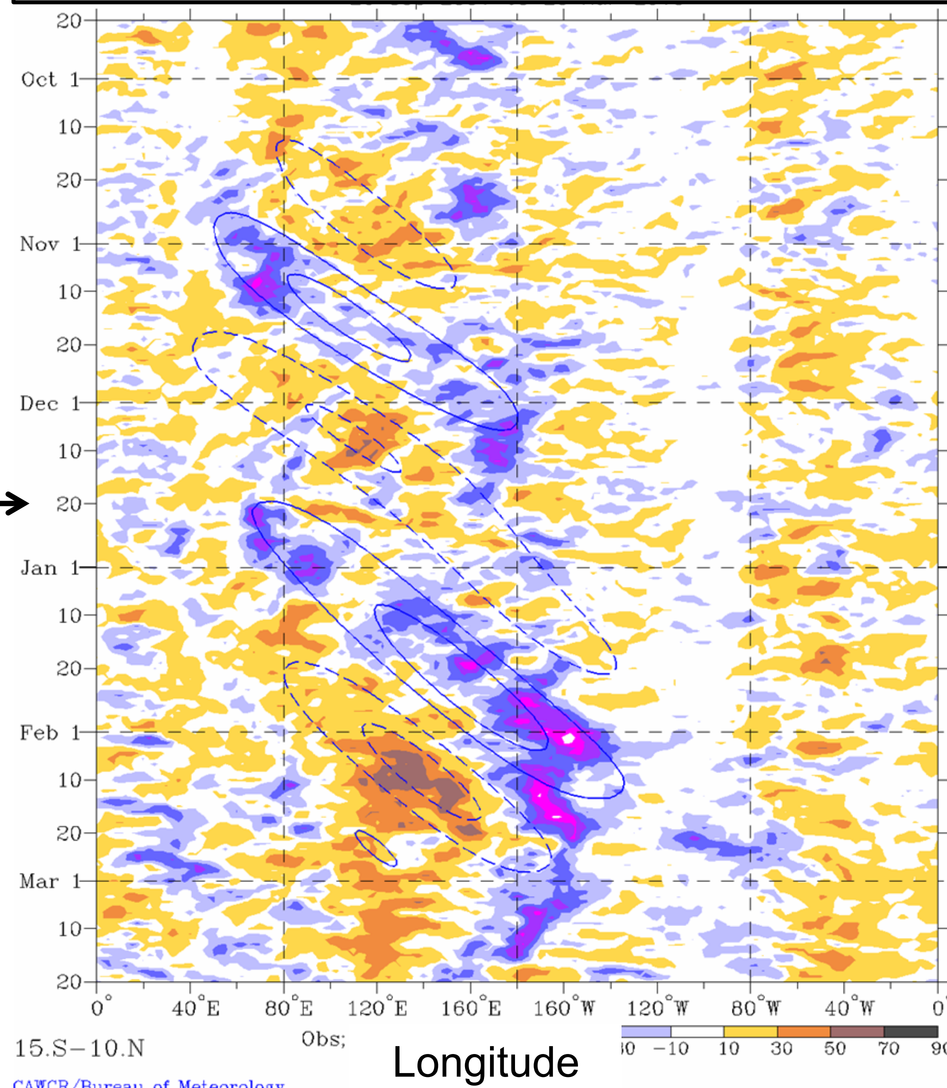
- Base model: CAM5.1 at ~1° latitude-longitude resolution
- 500 member ensemble of 20-day forecasts beginning from 12-20-2009
- CAM5.1 is initialized with operational ECMWF analysis
- 500 member ensemble consists of model versions realized by perturbing simultaneously 16 parameters in CAM's physical parameterizations using latin hypercube sampling

Forecast Start Date

- Start date is at the beginning of a strong MJO

Start Date →

Observed OLR Anomalies, 10°N– 15°S, September 20, 2009 – March 20, 2010



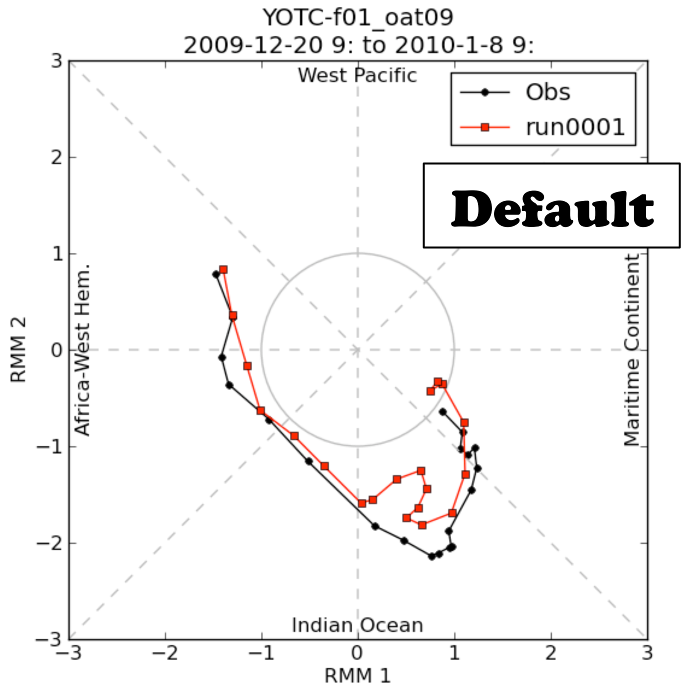
Time ↓

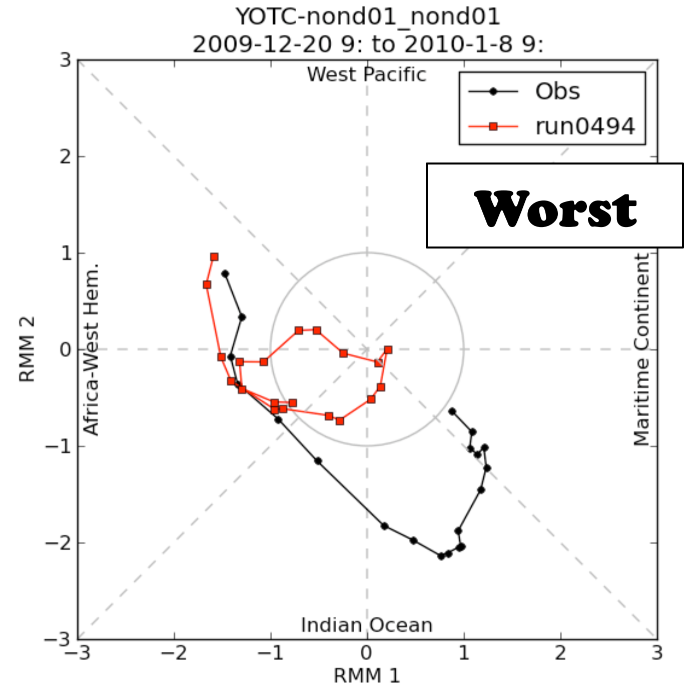
Longitude

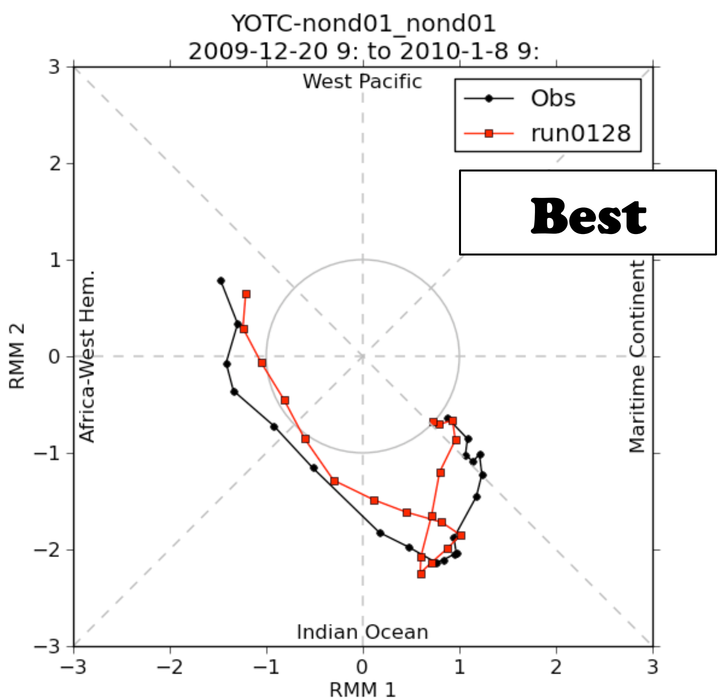
Figure courtesy of Matt Wheeler, CAWCR

Parameters Perturbed

			Min	Default	Max	
Large-Scale Cloud	1	rhminl*	0.80	0.8975	0.99	Threshold RH for fraction low stable clouds
	2	ai	350.0	700.0	1400.0	Fall speed parameter for cloud ice
	3	as	5.86	11.72	23.44	Fall speed parameter for snow
	4	dcs	100.0e-6	400.0e-6	500.0e-6	Autoconversion size threshold for ice to snow
PBL Turb.	5	a2l	10.0	30.0	50.0	Moist entrainment enhancement parameter
Shallow Conv.	6	criqc	0.5e-3	0.7e-3	1.5e-3	Maximum updraft condensate
	7	kevp	1.0e-6	2.0e-6	20.0e-6	Evaporative efficiency
	8	mon_scal_fac	0.001	1.000	1.200	Momentum scale factor; applied to both uflx & vflx
	9	rkm	8.0	14.0	16.0	Fractional updraft mixing efficiency
	10	rpen*	1.0	10.0	15.0	Penetrative updraft entrainment efficiency
Deep Conv.	11	alfa	0.05	0.10	0.60	Initial cloud downdraft mass flux
	12	c0_ocn*	1.0e-3	45.0e-3	100.0e-3	Deep convection precipitation efficiency over ocean
	13	dmpdz	|0.2e-3|	|1.0e-3|	|2.0e-3|	Parcel fractional mass entrainment rate
	14	ke*	0.5e-6	1.0e-6	10.0e-6	Evaporation efficiency parameter
	15	mon_cu_cd	0.001	0.400	0.800	Constant for updraft & downdraft pressure gradient term
	16	tau	1800.0	3600.0	28800.0	Convective time scale



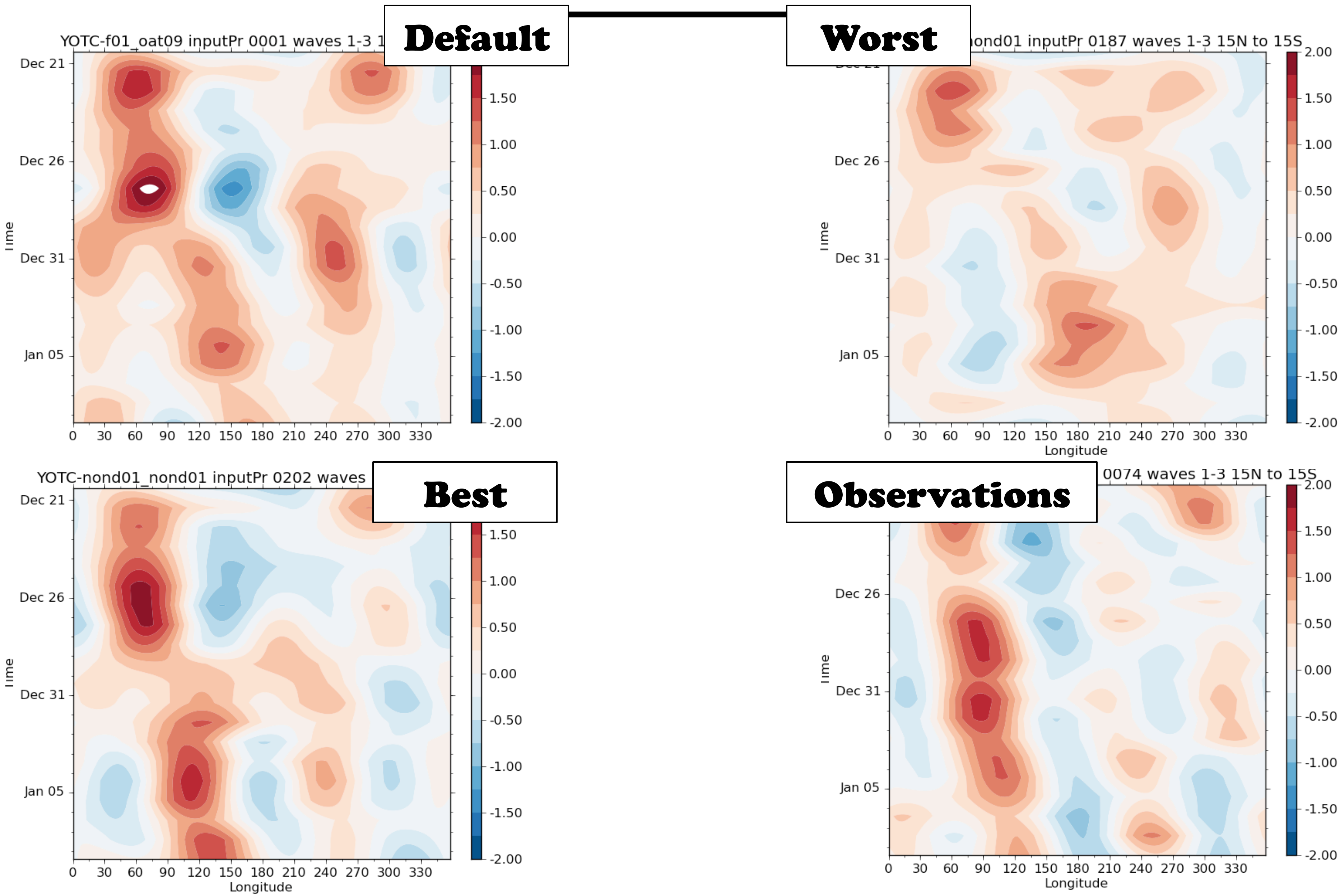




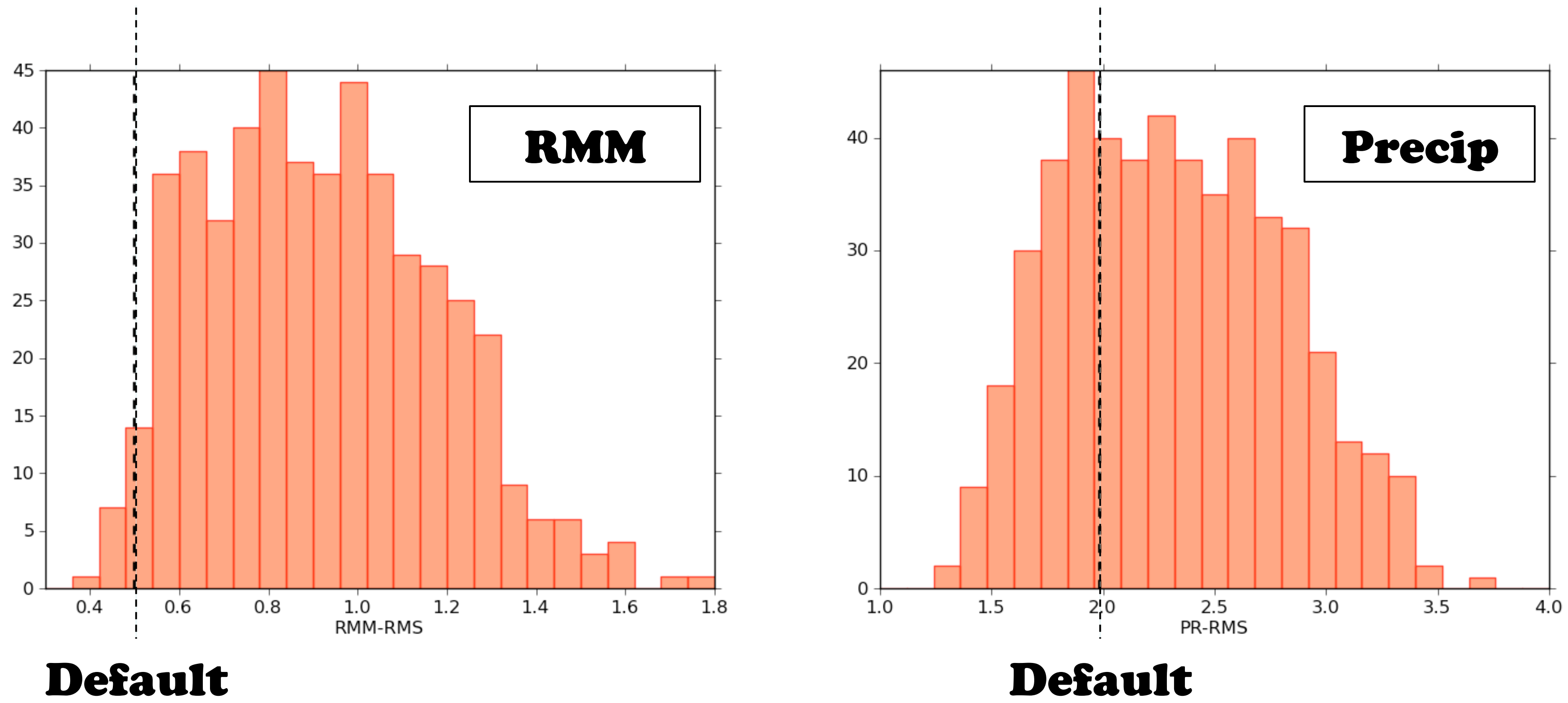
MJO Phase Plots

- Real-time Multivariate MJO Indices (RMM1 and RMM2) *(Wheeler and Hendon 2004, Gottschalck et al. 2010)*
  - Based on anomalies of 200 hPa and 850 hPa zonal wind and Outgoing Longwave Radiation (OLR)

Precip Hovmöllers



RMSE histograms for Ensemble



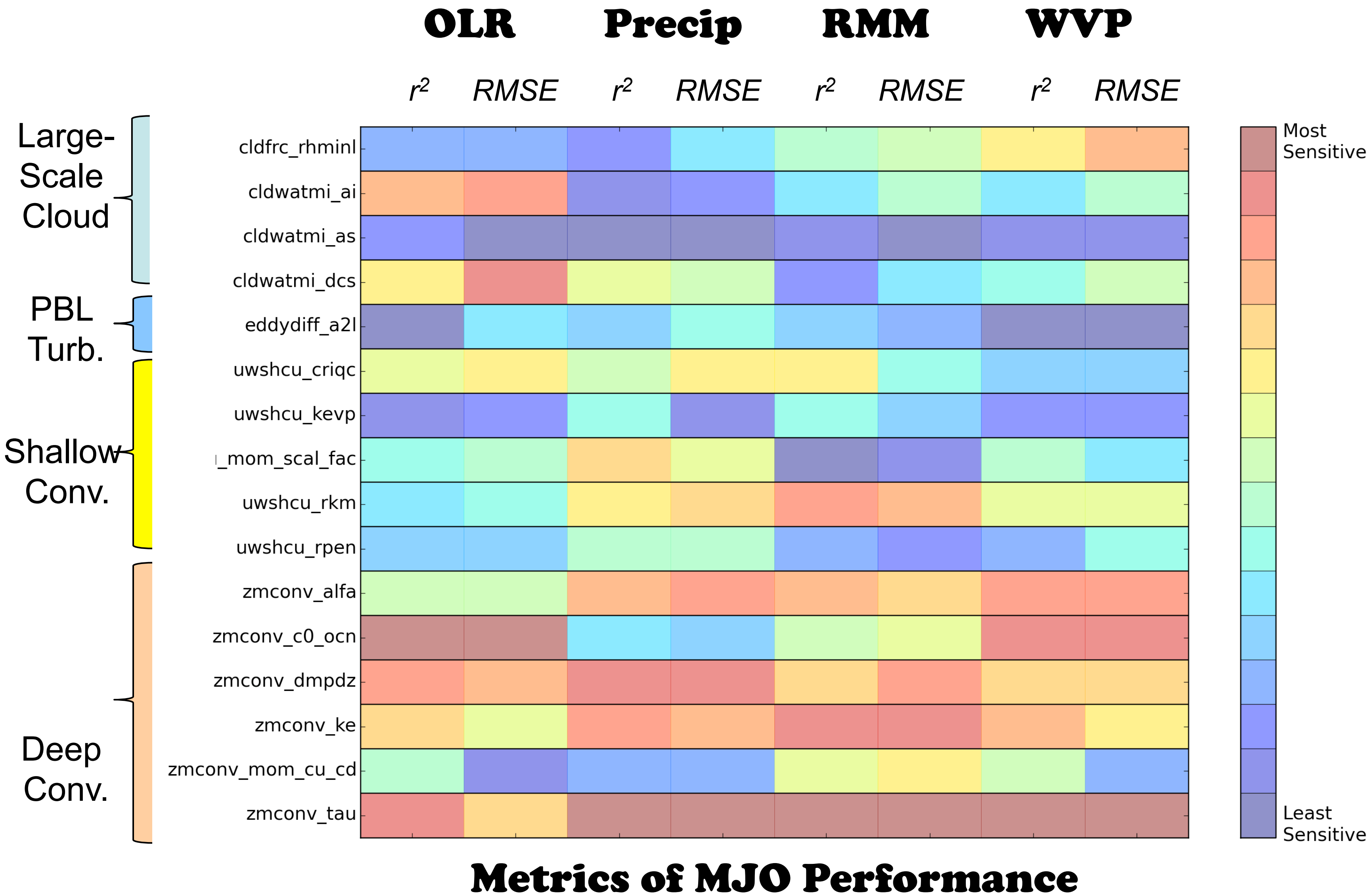
- Root-mean-square error (RMSE) in RMM calculated from the principal component time series according to Gottschalck et al. (2010)
- Precipitation RMSE calculated from smoothed anomalies in longitudes 58°E – 210°E

How to Analyze Results in a 16-Dimensional parameter Space?

Mathematical Analysis

- 2^{nd} order Polynomial-Chaos Expansion *(Sudret 2007)*
  - Partitions variance across the ensemble in a target metric (e.g. root-mean square error of RMM or anomaly correlation of precipitation) into terms that represent linear and quadratic dependencies on perturbed parameters individually as well as terms that represent the joint interaction of parameters
- The relative importance of parameters is quantified by the magnitude of the coefficients of the expansion

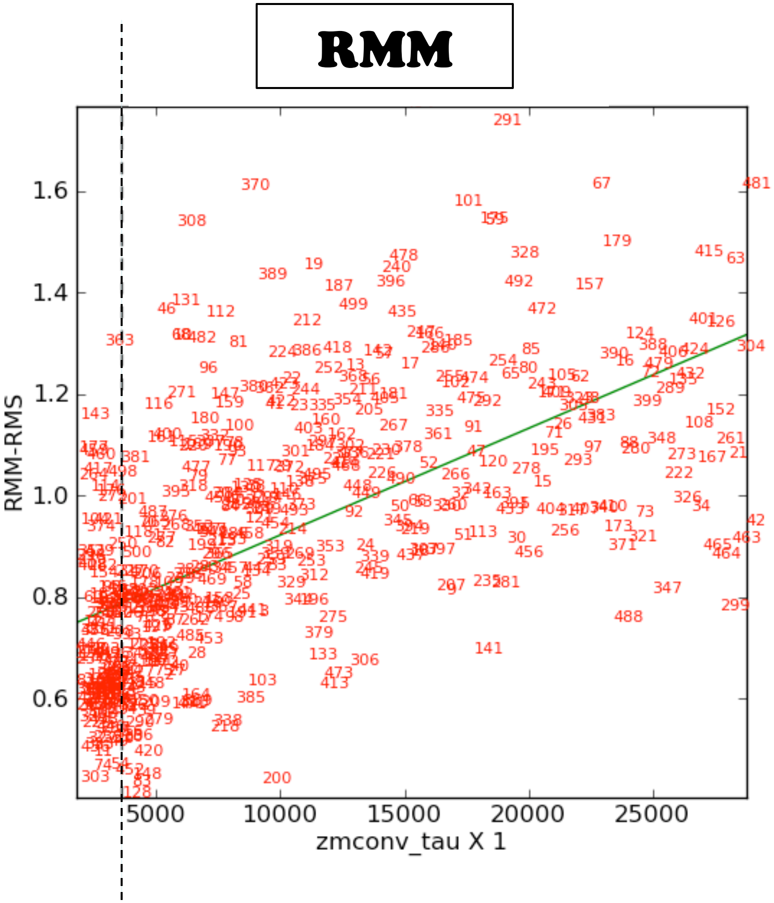
Relative importance of parameters



Scatterplots: RMSE vs. zmconv_tau

Deep Convection Timescale

RMM



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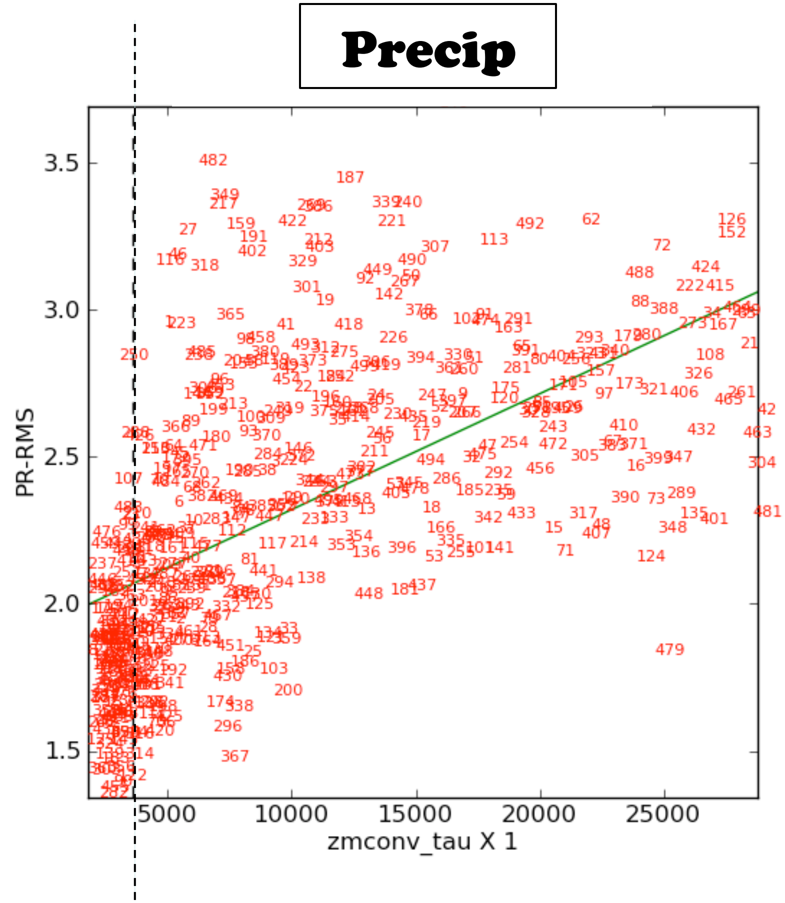
Precip



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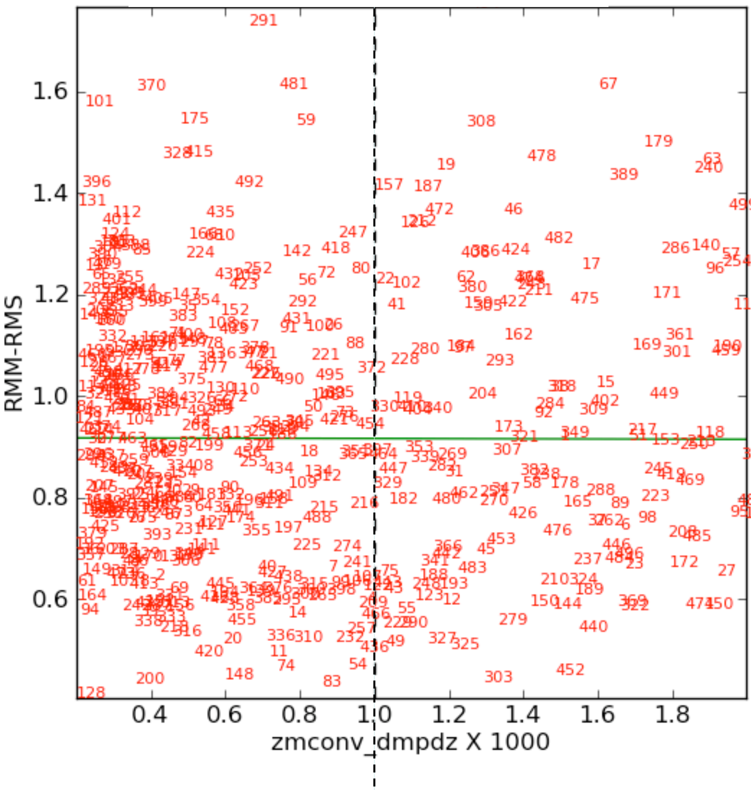
SCATTERPLOTS: RMSE VS. ZMCONV_DMPDZ

Entrainment Rate

RMM



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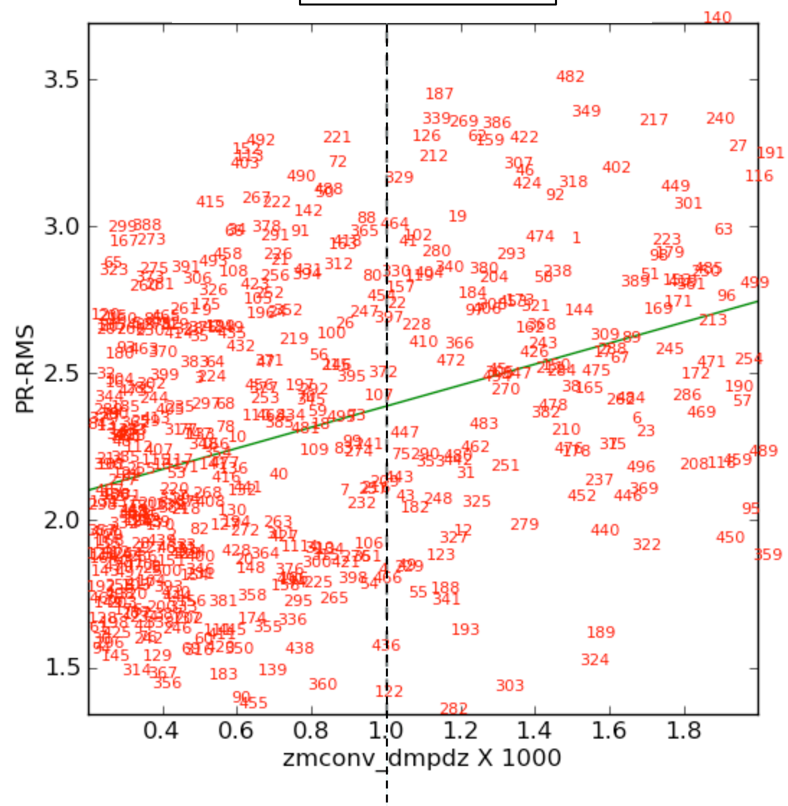
Precip



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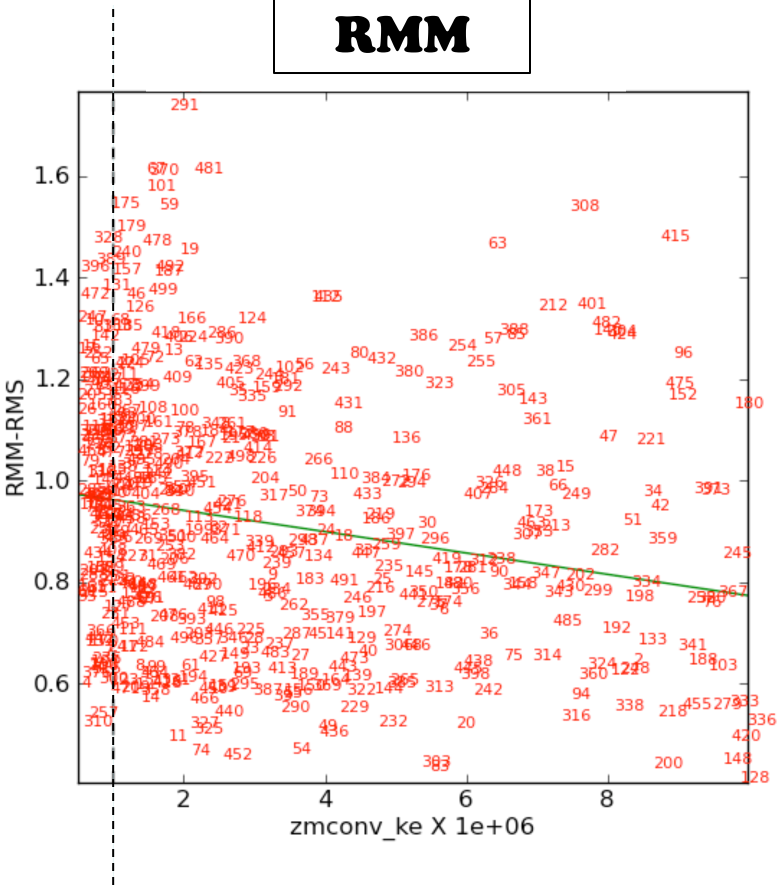
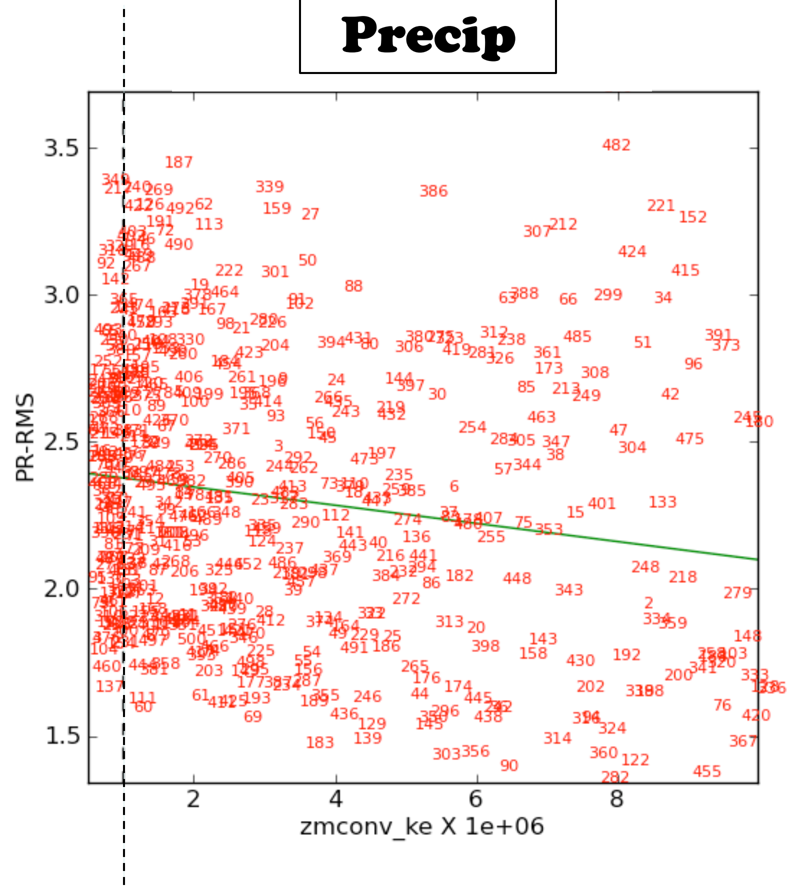
Scatterplots: RMSE vs. zmconv_ke

Evaporation of Convective Precipitation Constant

RMM



Precip



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Summary

- Short-range MJO hindcasts with CAM5.1 illustrate model sensitivities, largely to deep convection parameters:
  - Timescale
  - Entainment rate
  - Convective precipitation evaporation efficiency

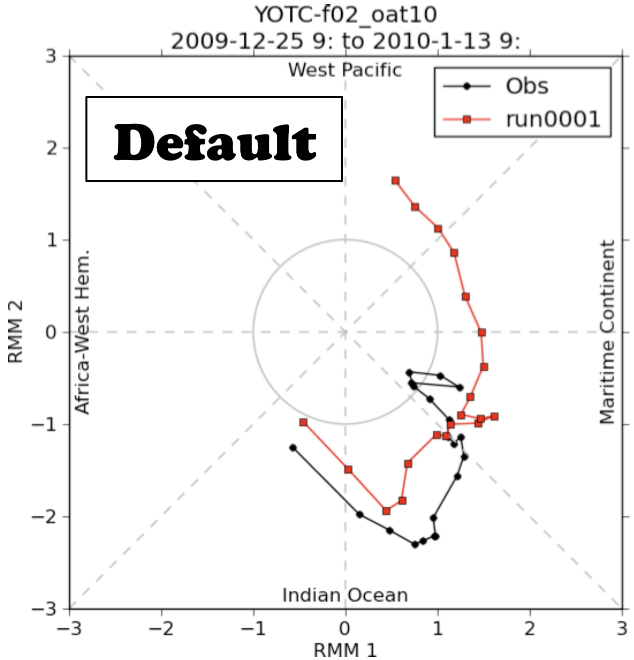
  These results appear similar to sensitivities of other models *(Maloney and Hartmann 2001, Bechtold et al. 2008)*

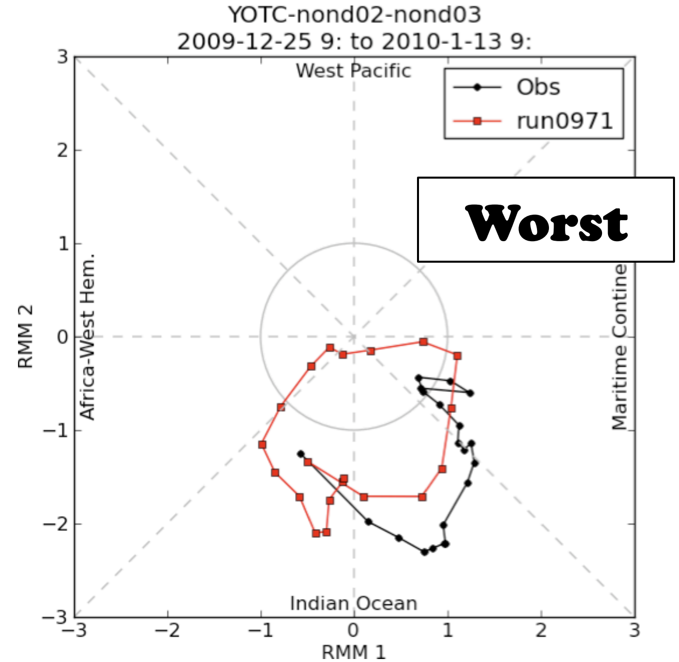
Questions

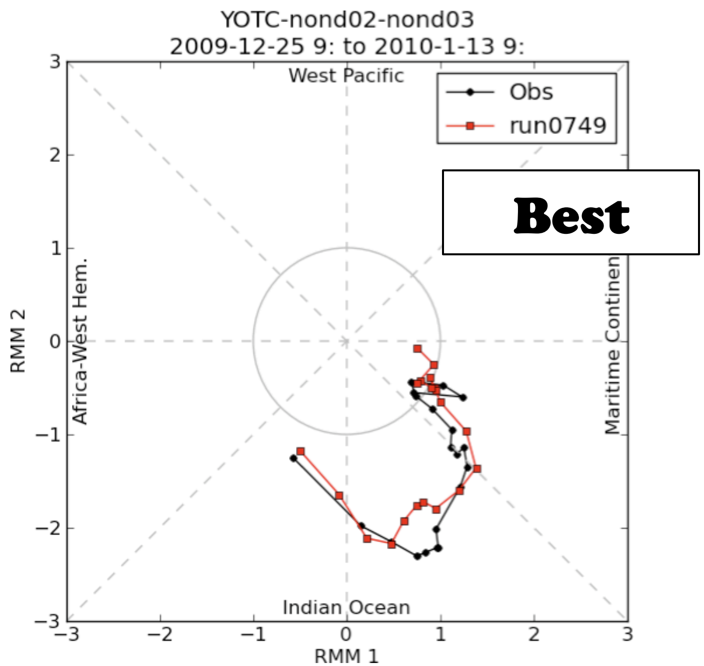
- How much do parameter sensitivities vary with the hindcast start date? (currently under exploration)
- Can we physically understand why parameter changes yield improved simulations?
- Can we identify what areas of parameter space yield an improved simulation?
- If we do, does improved simulation in hindcasts yield an improved simuation of MJO in climate mode?
- If it does, what are the impacts on other forms of tropical variability or mean climate?

Thanks for your Attention!

Extra Slides



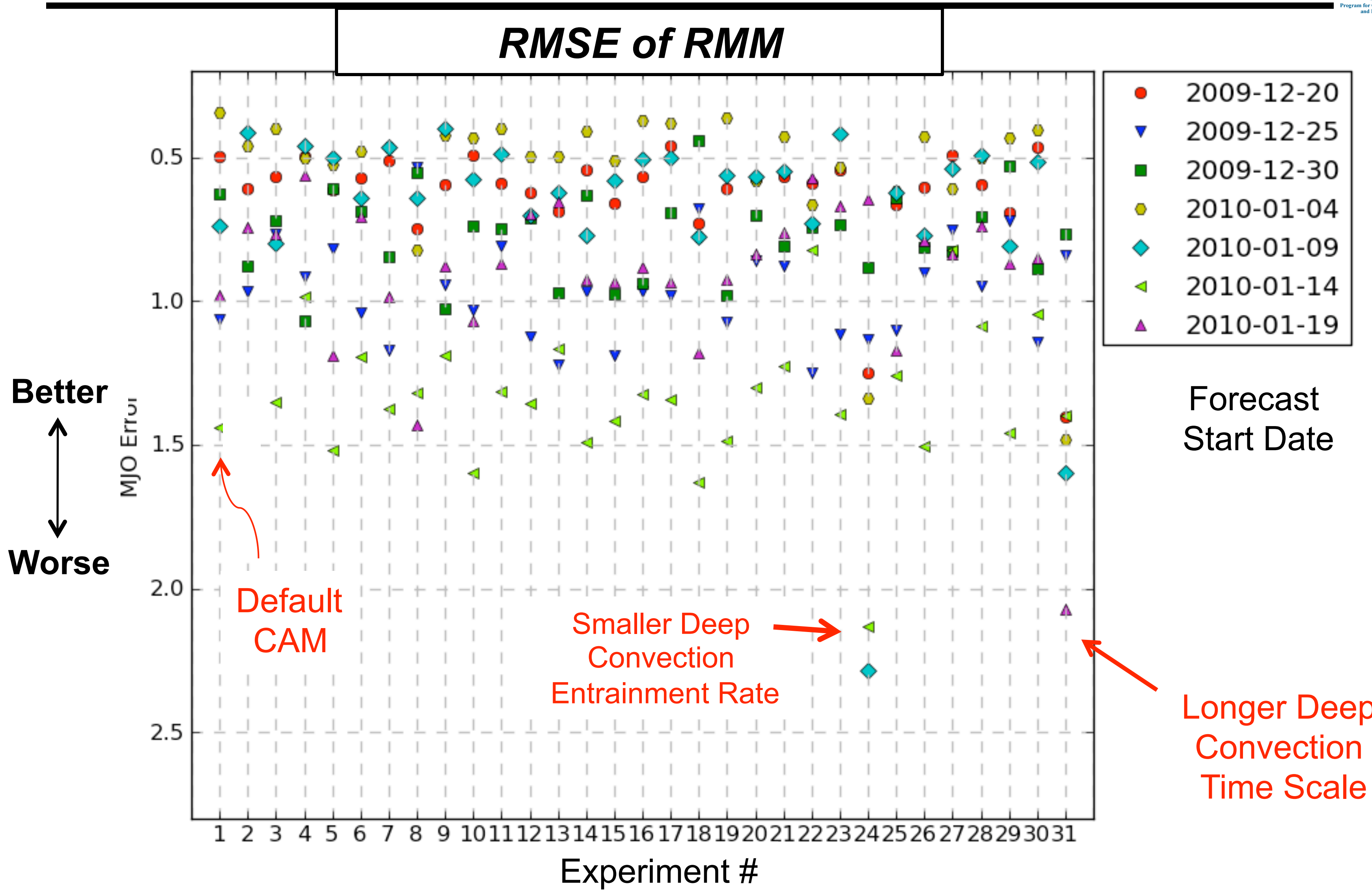




MJO Phase Plots

- Forecast Start Date:
  12-25-2009

Start Date Sensitivity



- These are One-At-a-Time Perturbations

"Social Network" for RMS of RMM and Precip