Assessing air-sea interaction in the evolving NASA GEOS model

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Developing an approach to evaluate air-sea interactions in the NASA GEOS model

- The NASA Goddard Earth Observing System (GEOS) model is an evolving system and has recently had updates to both its surface layer and PBL parameterizations

- These changes span a series of GMAO products including MERRA, a large set of of seasonal-to-interannual (S2I) hindcasts, and soon MERRA-2

- The goal of this work is to evaluate the surface turbulent fluxes in this evolving system and characterize improvements and limitations

Datasets examined here:

- MERRA

- GEOS-5 Seasonal-to-Interannual Hindcasts
  - Initializations on Nov 02, Nov 07, Nov 12, Nov 17, Nov 22

Period: 1988 – 2007

Month: November

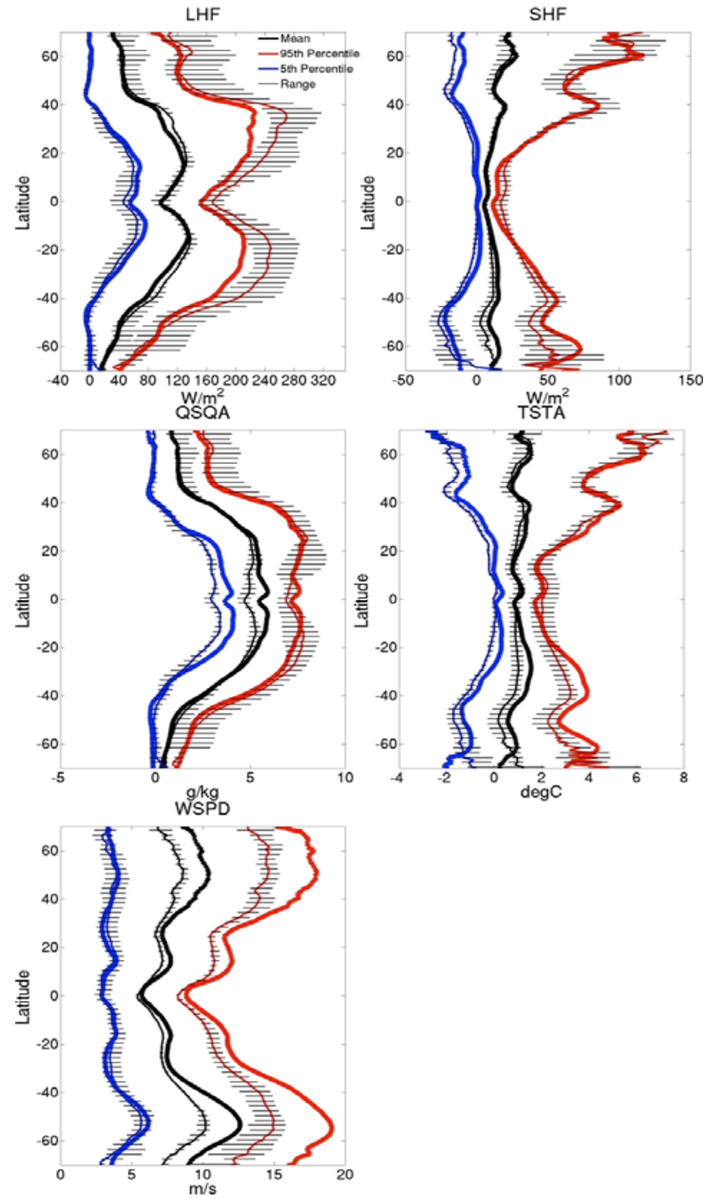
- *Chosen to go along with other work examining the fluxes over the Indian Ocean and MJO*

Reanalysis vs. Observations of turbulent fluxes

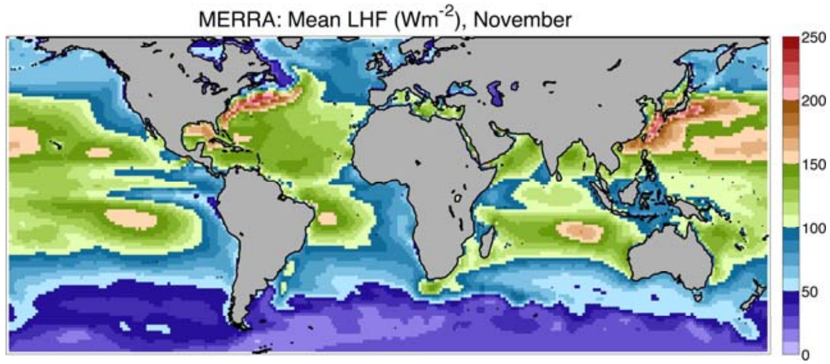
- MERRA turbulent latent and sensible heat fluxes have been examined before (e.g. Roberts et al. 2012)
  - Found the fluxes to show reasonable agreement ***in the mean*** but often underestimated high-amplitudes found in observational products (e.g. boundary currents)
  - The distributions were also more narrow than in observations

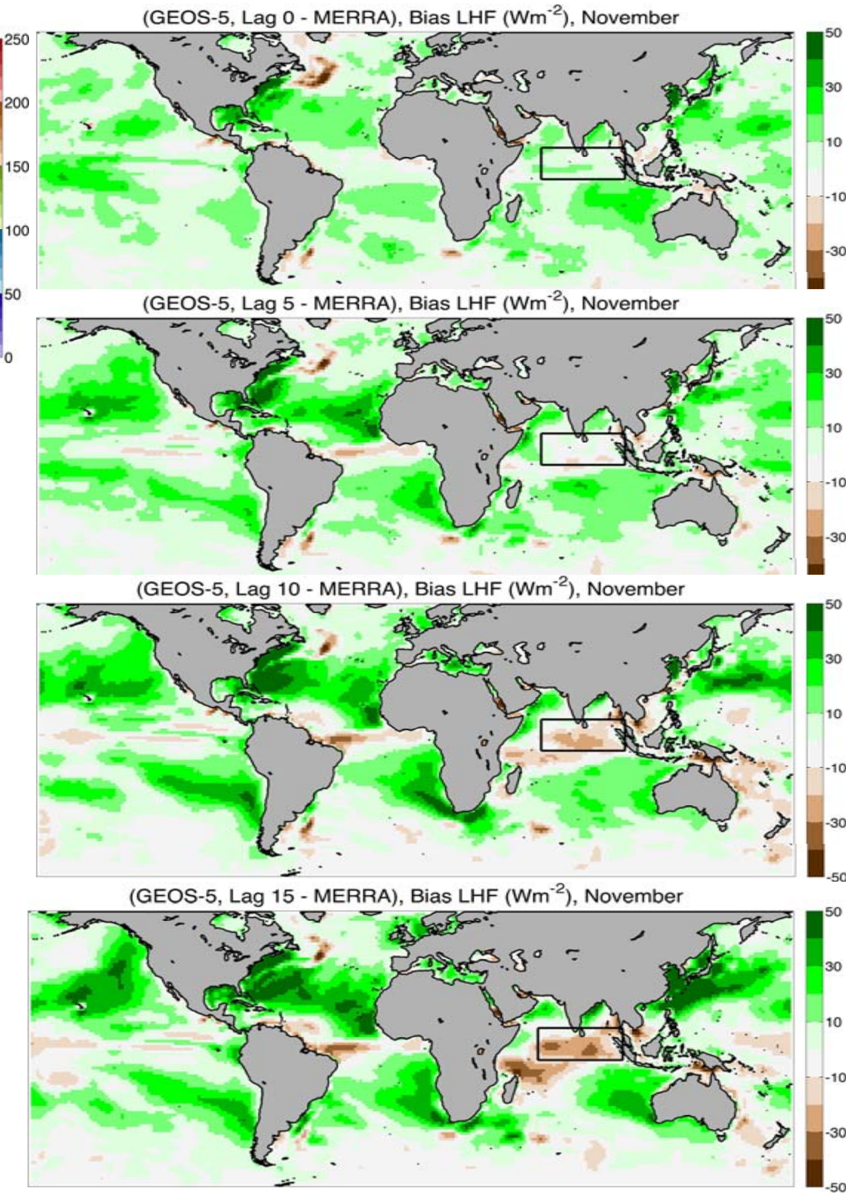
- Errors can be traced to errors in the near-surface variables

- While a start, diagnosing the shortcomings in the bulk variables does not have strong ties to the source of parameterization deficiencies



MERRA vs. GEOS-5 Latent Heat Flux





- The GEOS-5 has a stronger November mean surface evaporation in comparison to MERRA over most of the oceans
- The November climatology of Day 0 forecasts shows the smallest differences with MERRA
- As the GEOS-5 simulations move away from their initialization dates, the model drifts quickly to its own climatology and the differences with MERRA are amplified.

Regime-based Analysis

How can we go beyond a simple mean/statistical summary of differences?

Fundamentally, we want to move from a view of unconditional statistics to one that examines the resulting data as a mixture distribution

- *This should be intuitive, in that it is often the case observed data are generated by series of episodic, distinct weather patterns with particular characteristics*

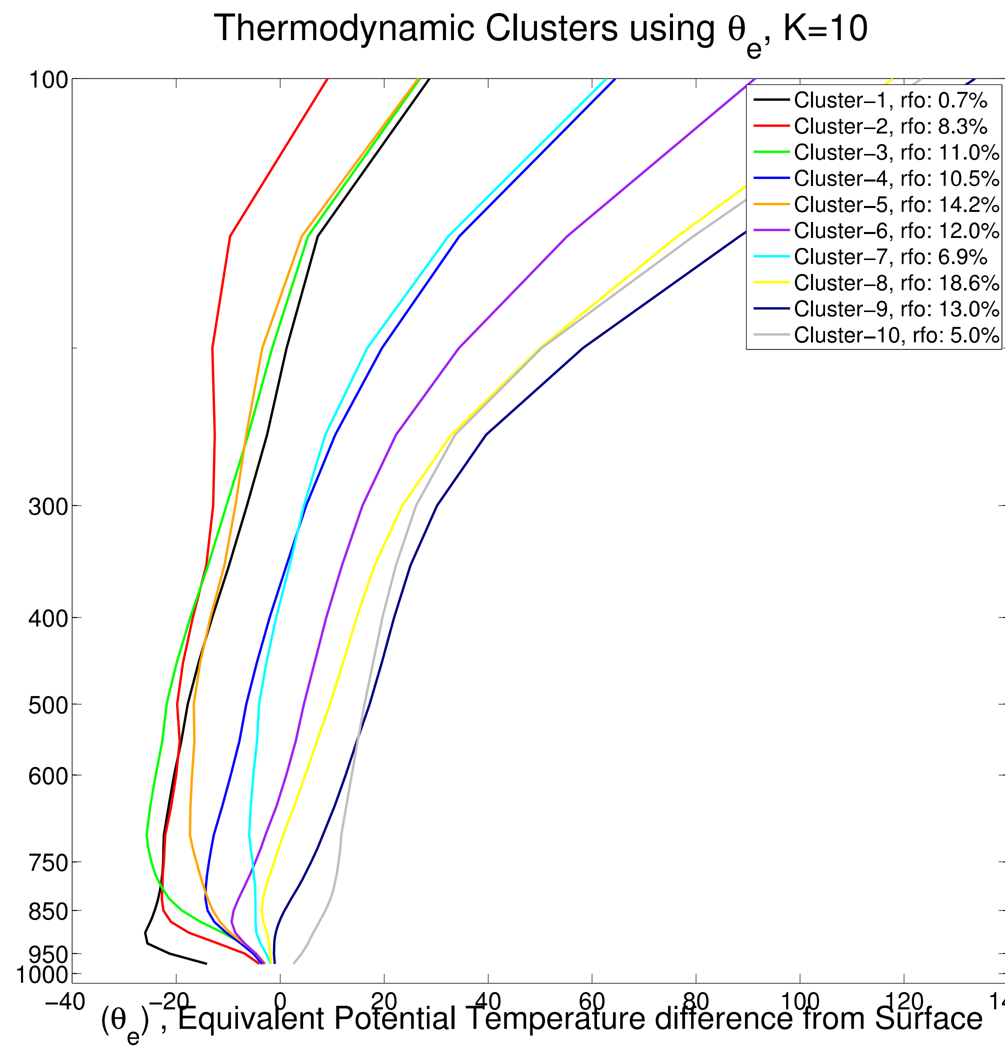
In this framework, we can examine model/observational differences in a more nuanced way.

Example: Examining differences in means can be decomposed as changes in class mean (A), changes in RFO (B), and covariant changes (C)

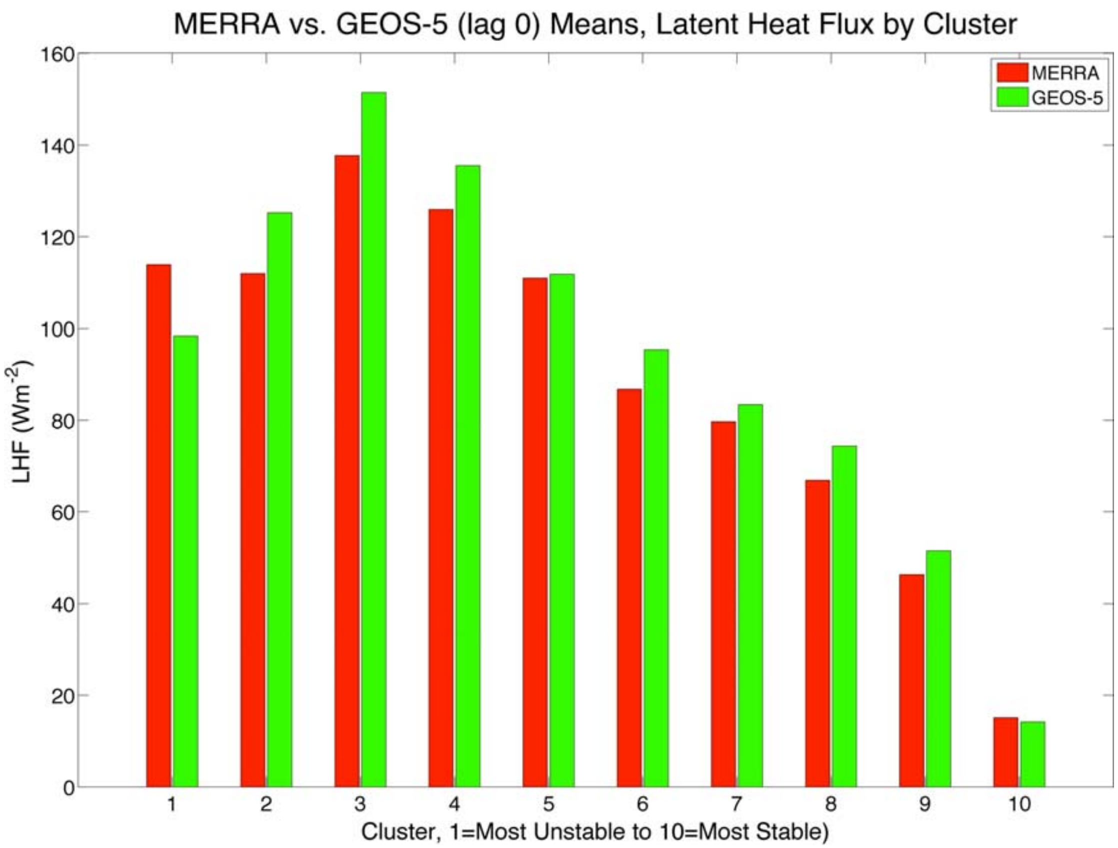
$$\Delta\overline{X}_{(2-1)} = \sum_{i=1}^{K} \underbrace{RFO_i^1 \delta\overline{x}_i}_{A} + \underbrace{\overline{x}_i^1 \delta RFO_i}_{B} + \underbrace{\delta\overline{x}_i \delta RFO_i}_{C}$$

But what regimes?

- Previous studies have defined weather states based on cloud properties (e.g. CTP-COD histograms)
  - These can be more difficult to intercompare between satellite observations and models
- We have chosen to use temperature and humidity profile information from the model
  - Easier to intercompare/access state variables in "model world"
- Combined T/Q information into a single thermodynamic variable (θ_e)
  - K-Means cluster analysis to obtain 10-clusters
  - Cover a range of both typical and atypical stability regimes

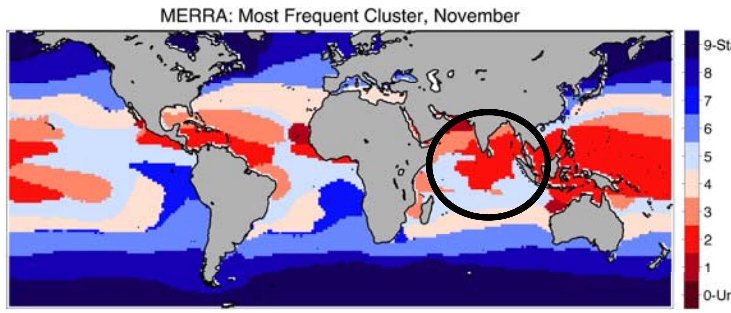


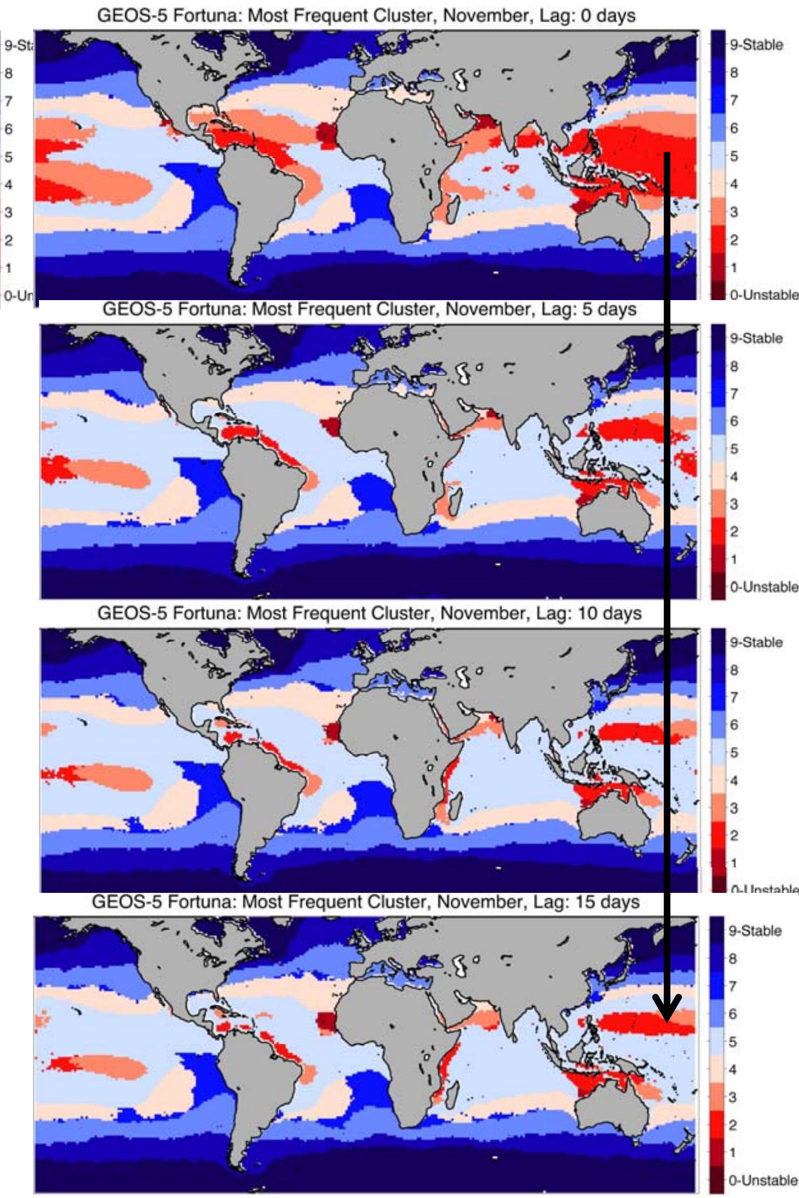
LHF Regime Mean Differences



- We can sort out the overall biases as a function of stability regime
- Overall, GEOS-5 shows systematically higher evaporation rates, but this “bias” is higher for the more unstable conditions (~15Wm^{-2}) vs. more stable (~5Wm^{-2})
- Closest agreement is in the more neutral condition and very stable conditions.

LHF Regime Frequency Differences

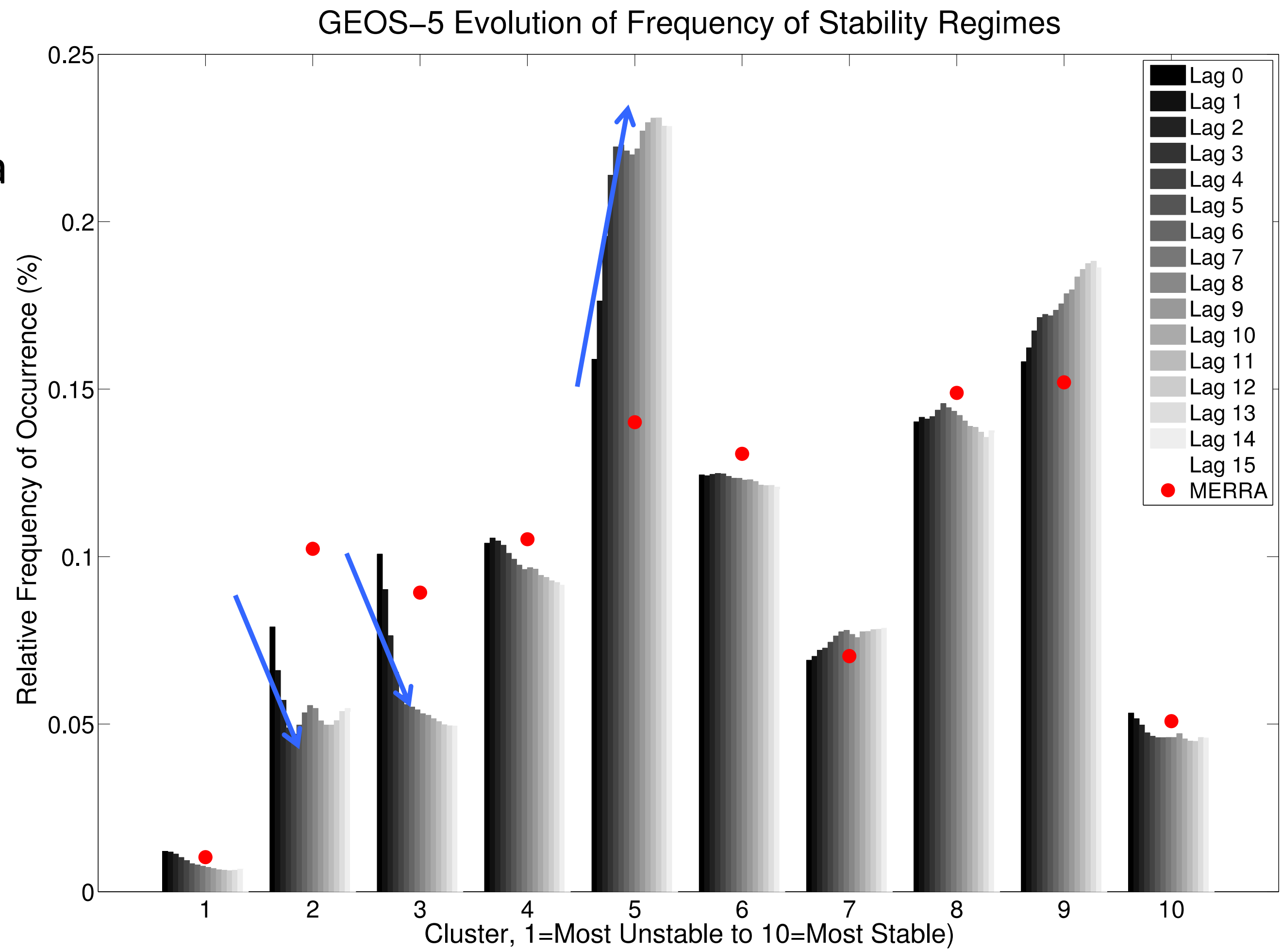




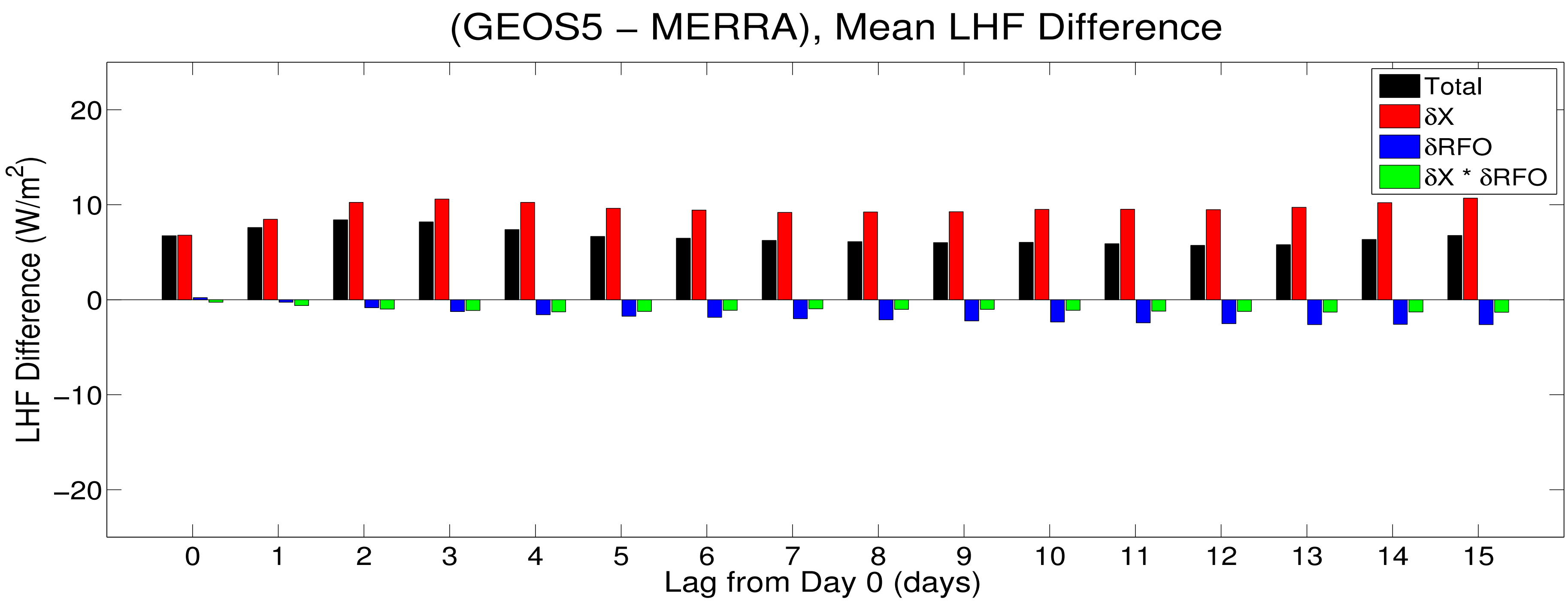
- In addition to difference between the regime means, the frequency of a regime can also impact the difference in total mean fields
- For day 0 —*when GEOS-5 is most data constrained* — the relative frequency of occurrence of regimes is remarkably similar to that in MERRA, albeit with some difference
- Moving away from initialization however, GEOS-5 is unable to maintain the proper distribution of unstable regimes, particularly over the West Pacific and Atlantic Warm Pool

LHF Regime Frequency Differences – Another View

- Looking globally, we can see the transition of stability regimes as a function of lag for each regime.
- Because the regimes frequencies partition the full distribution, we can see the compensation between regimes
- *Here, there is a clear preference for GEOS-5 to eliminate the most unstable profiles within the first few days toward a more neutral profile*



LHF Regime Frequency Differences – Total Decomposition



- Upon decomposition, it is evident that the systematic differences within regime are the leading influence on total mean LHF differences for all lags

- However, the changes in the underlying frequency of distribution can play a role and perhaps even leading for select regions.

Summary and Future Work

- The GEOS model has recently undergone changes to its surface and PBL parameterization that have indeed impacted the turbulent surface fluxes. Generally, the latent heat fluxes have increased (at least for November) in the new GEOS model.
- Yet, its climatology is still not adequate as evidenced by the fact that the model's estimate of the mean state quickly drifts away from that found when it is closer to initialization — and presumably more constrained by data.
- We can use a "regime-based" definition to provide a better understanding of how the mean biases arise --- these occur through both within-regime differences and the relative frequency of those regimes.
- Shortly after initialization, the GEOS-5 model forecasts remove the higher population of unstable profiles and move towards a more neutral state, likely through convective adjustment.
- Next, we plan to try to incorporate DYNAMICS into the weather-regime state vector and to apply the method to more months, observational and model (CMIP-5, MERRA-2) datasets.