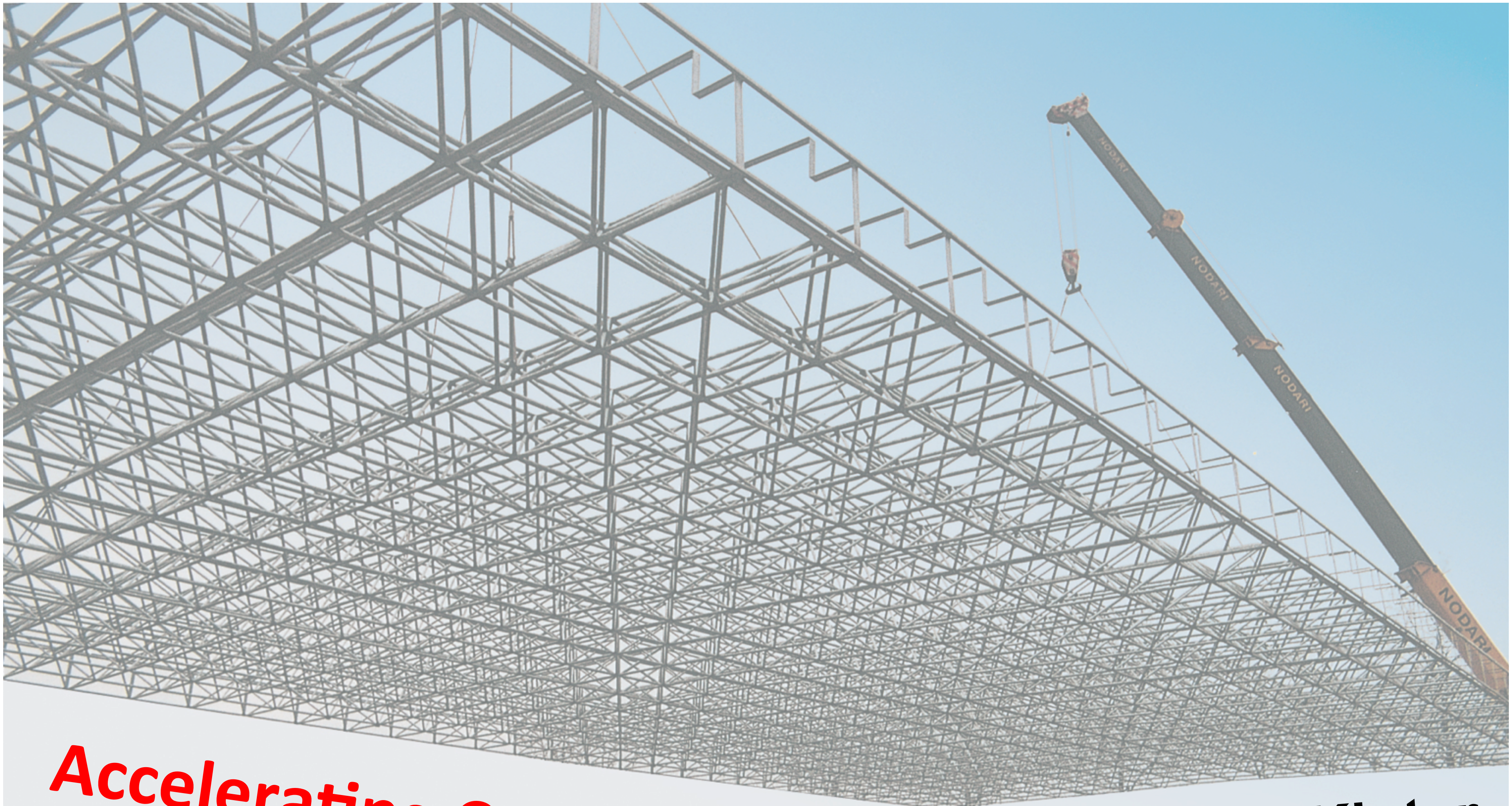

Accelerating Coupled NGGPS Development for Predicting Weeks 3 and 4

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Accelerating Development of NOAA's NGGPS for Week-3 and Week-4 Weather Prediction

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  - Larry Marx

Background - Requirements

- In order to systematically forecast the weather at lead-times of 3-4 weeks:
  - Determine the degree and sources of predictability
  - Improve representation in models of relevant processes
- Apply methods successful at predicting seasonal climate
  1. Employ coupled ocean-atmosphere-land-sea-ice(-waves) model
  2. Produce ensembles of forecasts from many initial states that are equi-probable and equally consistent with the available observations at the initial time to estimate probabilities
  3. Target space and time averages, e.g., week-3 mean and week-4 mean
- *Adequately represent the relevant spatial scales*, including mesoscales in the atmosphere and possibly also the ocean
- *Adequately represent the relevant physical processes*, especially clouds and convection.

Background – Seasonal Prediction

- Main determinants of predictability of *seasonal* weather are:
  - Annual cycle
  - El Niño and the Southern Oscillation (ENSO)
  - Antecedent soil moisture anomalies
  - Secular temperature trend associated with global climate change
- Credible forecasts of PDF of future monthly and seasonal means are now being issued by NWS
- Combination of empirical methods and numerical guidance products
  - Coupled CGCMs
  - Ensembles and Multi-Model Ensembles
- Skill:
  - Admittedly modest; applicable primarily for the seasonal mean, with marked seasonality; forecasts of opportunity during large ENSO events
  - Some regions more or less predictable due to ENSO impact, climatological aridity or vegetation type

What about Weeks 3-4? Sub-Seasonal Prediction

- Predictive power on all time scales, including sub-seasonal (Hoskins 2013)
- Origins of predictability in this time range (+ seasonal predictability):
  - Rossby wave dispersion
  - Persistent blocking states in the atmosphere
  - Tropical-extratropical interactions
  - Antecedent soil moisture anomalies that alter surface fluxes and PBL stability
  - Persistent ocean anomalies in both tropics and extratropics
- Despite progress in NWP and seasonal prediction, forecasts are not truly "seamless": lead-times of 3-4 weeks having received little attention
  - Weeks 3 & 4: beyond *deterministic* limit of instantaneous weather prediction
  - Disappointing past attempts to make weather predictions for weeks 3 and 4
    - Large signal-to-noise ratio in the seasonal average is smaller at weekly and monthly time scales
    - Representations of ocean-atmosphere and land-atmosphere interactions in CGCMs that could enhance forecast skill are still insufficiently accurate
    - Information in the initial conditions of the oceans, land surface and sea ice is only beginning to be exploited.

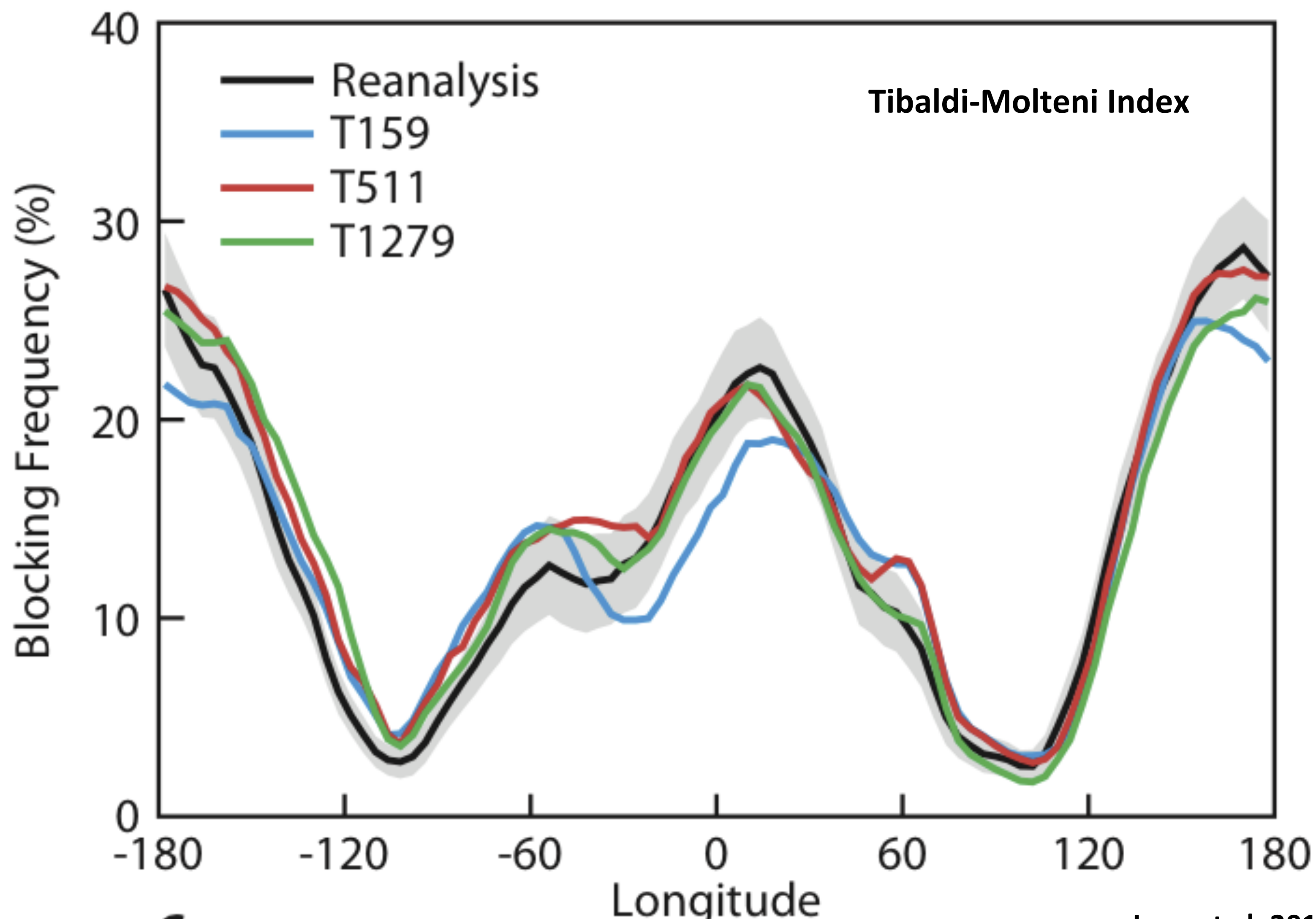
Important Questions

1. ***What active components should be included in a forecast system for weeks 3 & 4?*** → **A, L, O, SI**
   - Initial state of soil moisture, snow and vegetation and interactions between the land surface and the atmosphere critical
   - Coupled ocean-atmosphere interactions lead to predictable variations at lead-times of 3-4 weeks, e.g., the MJO
   - Error introduced by neglecting tropical ocean/atmosphere feedback is largest at sub-seasonal to seasonal time scale
   - Arctic sea ice state influences movement and intensity of mid-latitude wx
2. ***How important is model spatial resolution?*** → **Very!**
   - Demonstrable improvement in NWP due to spatial resolution
   - Critical to resolve atmospheric and oceanic mesoscale circulations
3. ***What are impacts of model errors on forecasts for weeks 3 & 4?*** **TBD**
   - Substantial well-known biases in coupled climate models
   - Errors in the representation of many climate-relevant processes
   - The impact of these errors on weeks 3 and 4 has not been evaluated

Motivation – Spatial Resolution

- Million-fold increase in computing capability since 1980
- **Numerical weather prediction** has advanced by exploiting computing power through:
  - Increasing spatial resolution
  - Improving understanding of physical processes
  - Improving data assimilation methods
- **Climate simulation** has improved, primarily through the inclusion of more processes that are relevant to climate variability and change
- There is evidence that **increasing spatial resolution**
  - Improves climate model fidelity
  - Changes qualitative/quantitative understanding of climate dynamics

Blocking Frequencies: DJFM 1960-2007



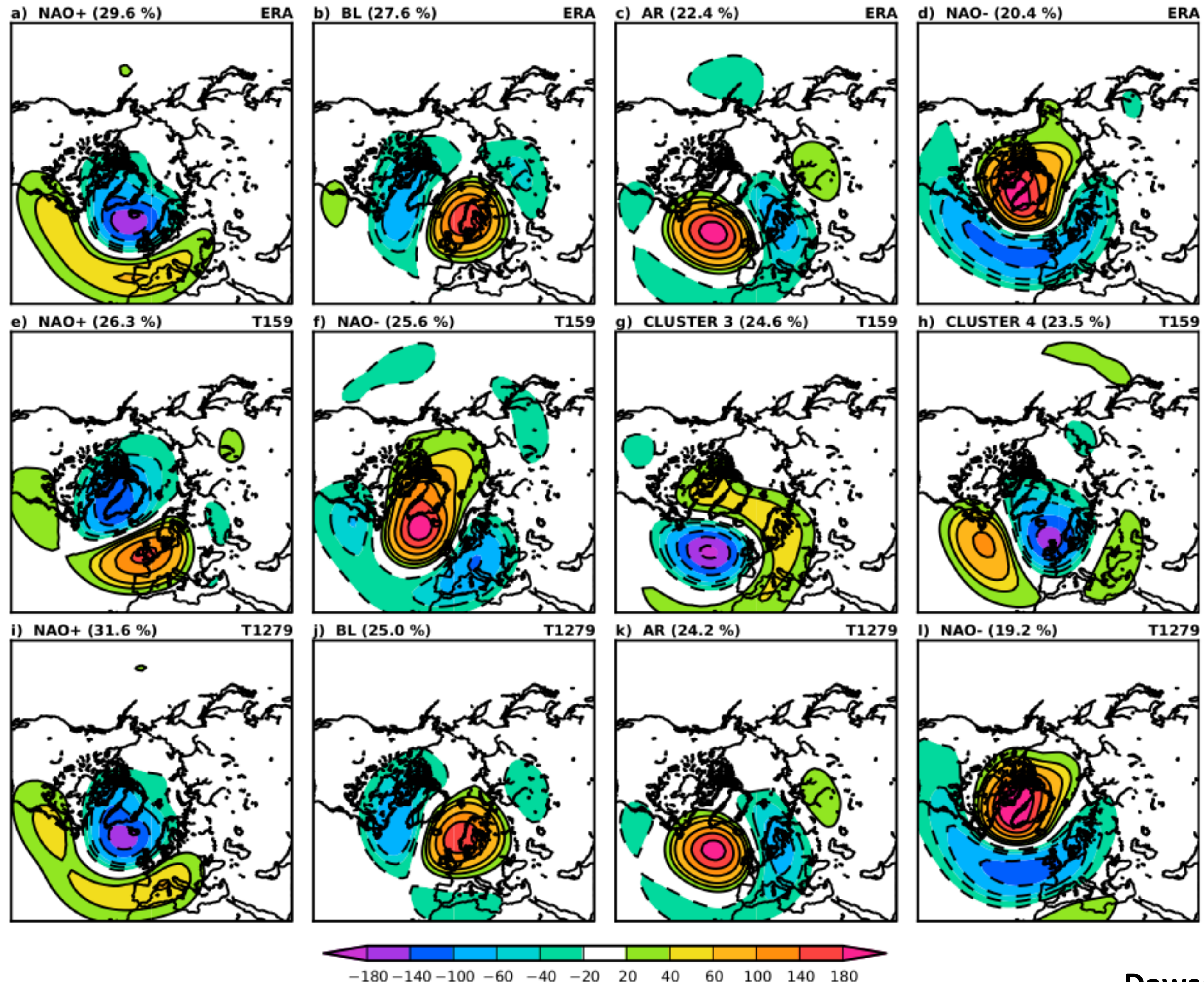
Jung et al. 2011

Regime Structures

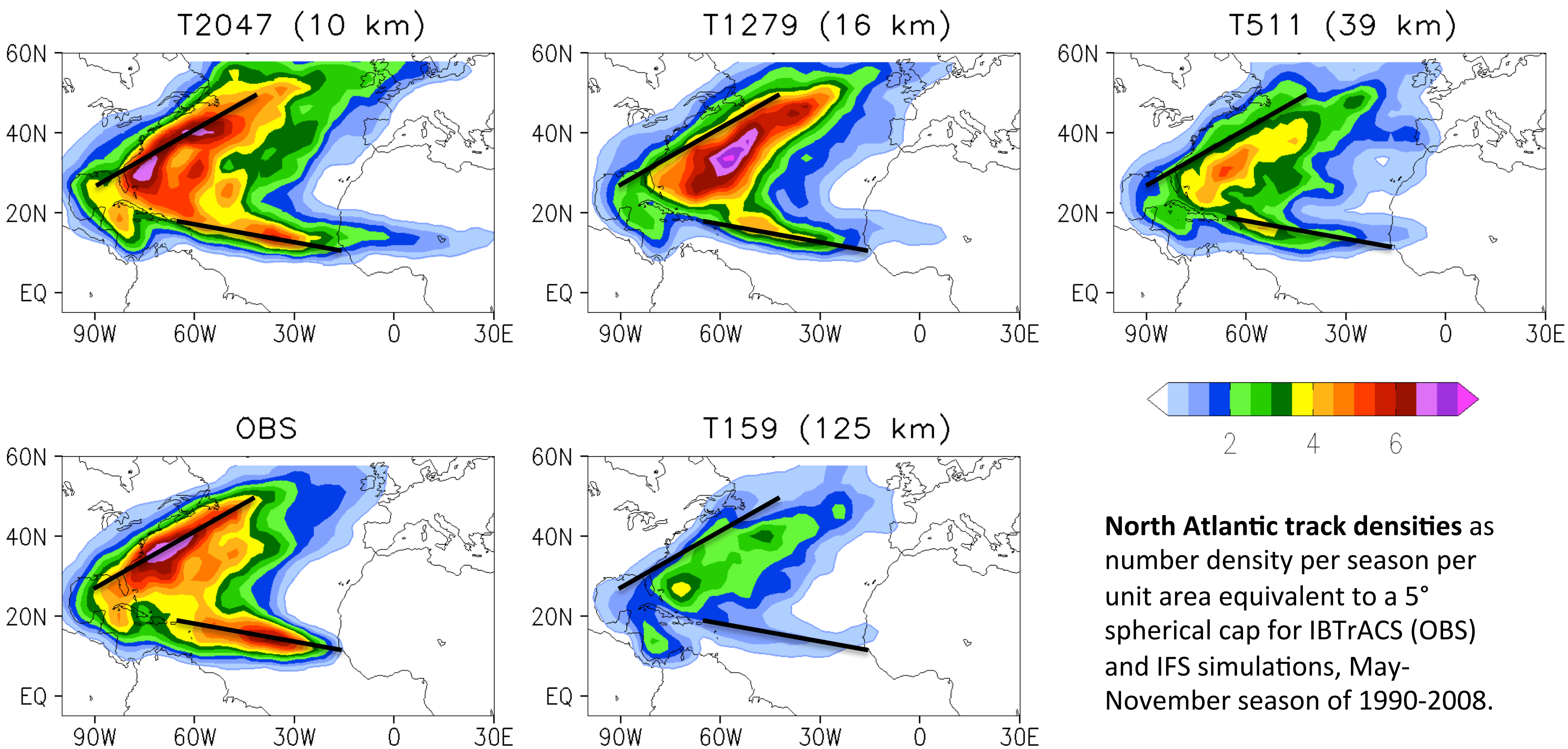
ERA-I

T159

T1279



Dawson et al. 2012



North Atlantic track densities as number density per season per unit area equivalent to a 5° spherical cap for IBTrACS (OBS) and IFS simulations, May-November season of 1990-2008.

Mean TC frequency

OBS	T2047	T1279	T511	T159
12.5	10.7	**9.2**	**7.2**	**5.3**

- Units are numbers per MJJASON season.
- Model values in bold are significantly different from the OBS (at 95% confidence level).

Manganello et al. 2012

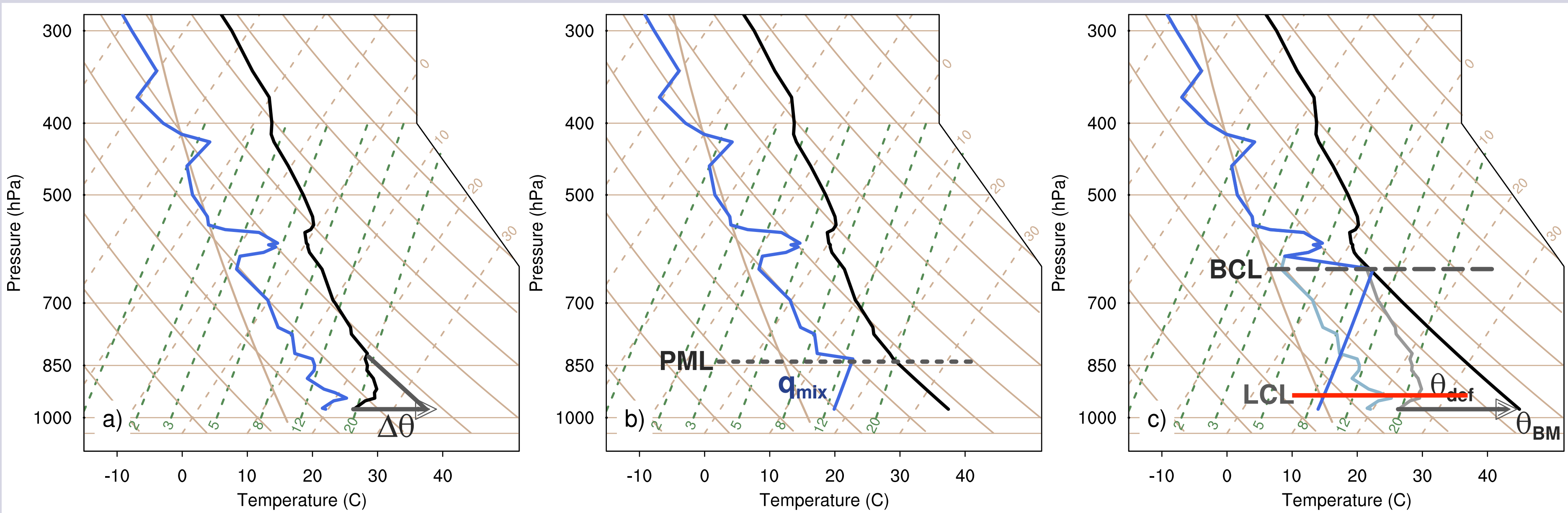
Motivation - Physics

- **Subgrid-scale physical processes are major sources of error**
- Representation of sub-seasonal-relevant processes can be greatly improved
  - Processes leading to deep convection over the Great Plains and other regions (atmosphere-land surface or "A-L" interactions)
  - Low clouds in the tropics (O-A interactions)
  - Formation, movement and disappearance of sea ice (A-SI)
- Assuming that models are far from directly resolving these processes, **changes in parameterizations** can improves climate model fidelity

Tawfik et al. 2015:

HEATED CONDENSATION FRAMEWORK

Calculating Convective Threshold



BCL = level at which saturation would occur through buoyant mixing alone due to surface SH

BCL = height a growing PBL needs to reach for saturation to occur without Δq

θ_{BM} = buoyant mixing θ, identifies the near-surface θ required to attain the BCL height

By iteratively incrementing θ_{sfc} one can determine BCL, which can be used as determinant of convection triggering → Heated Condensation Framework (HCF)

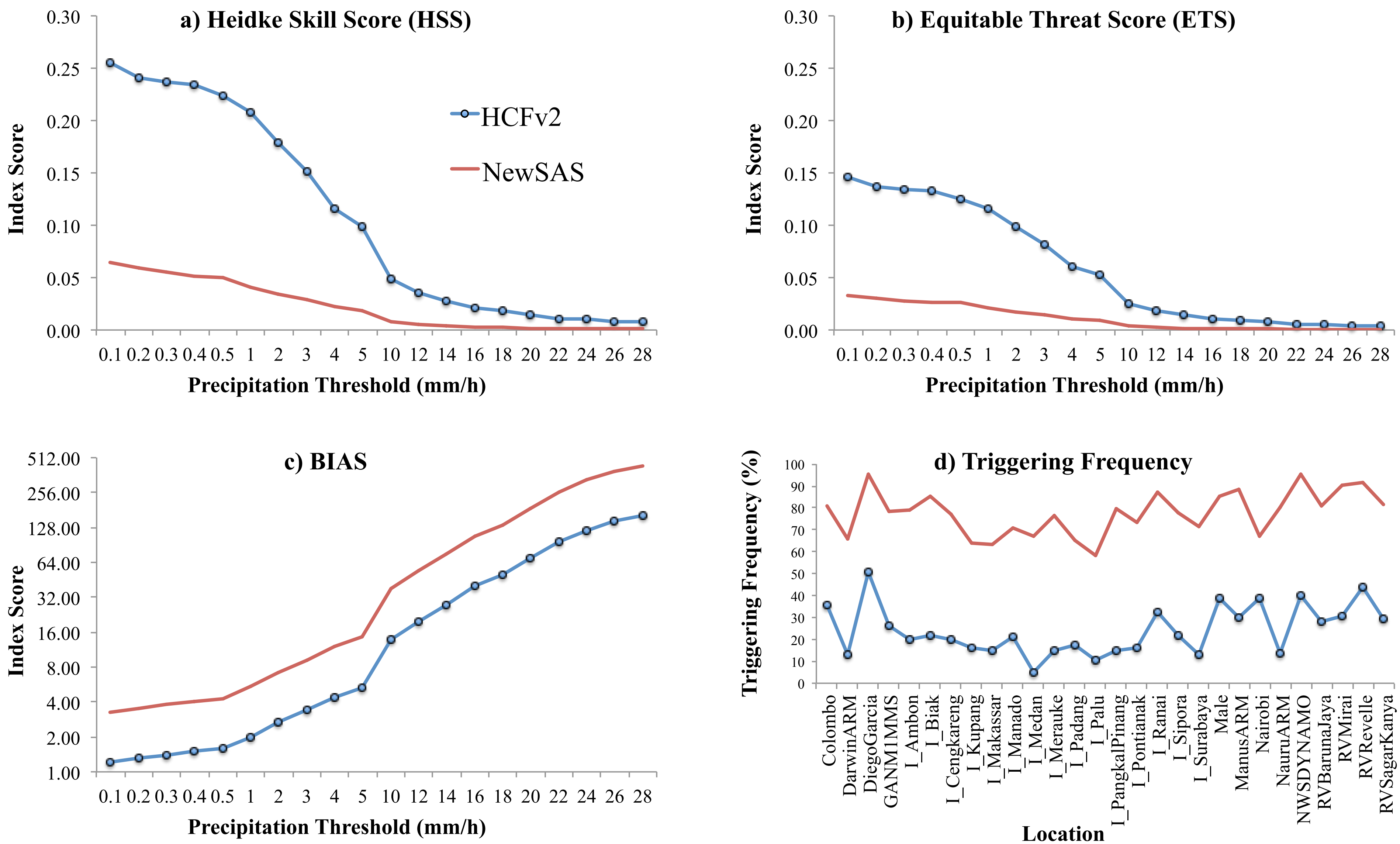
(Tawfik and Dirmeyer 2014 *GRL*)

Experiments with CFSv2: HCF

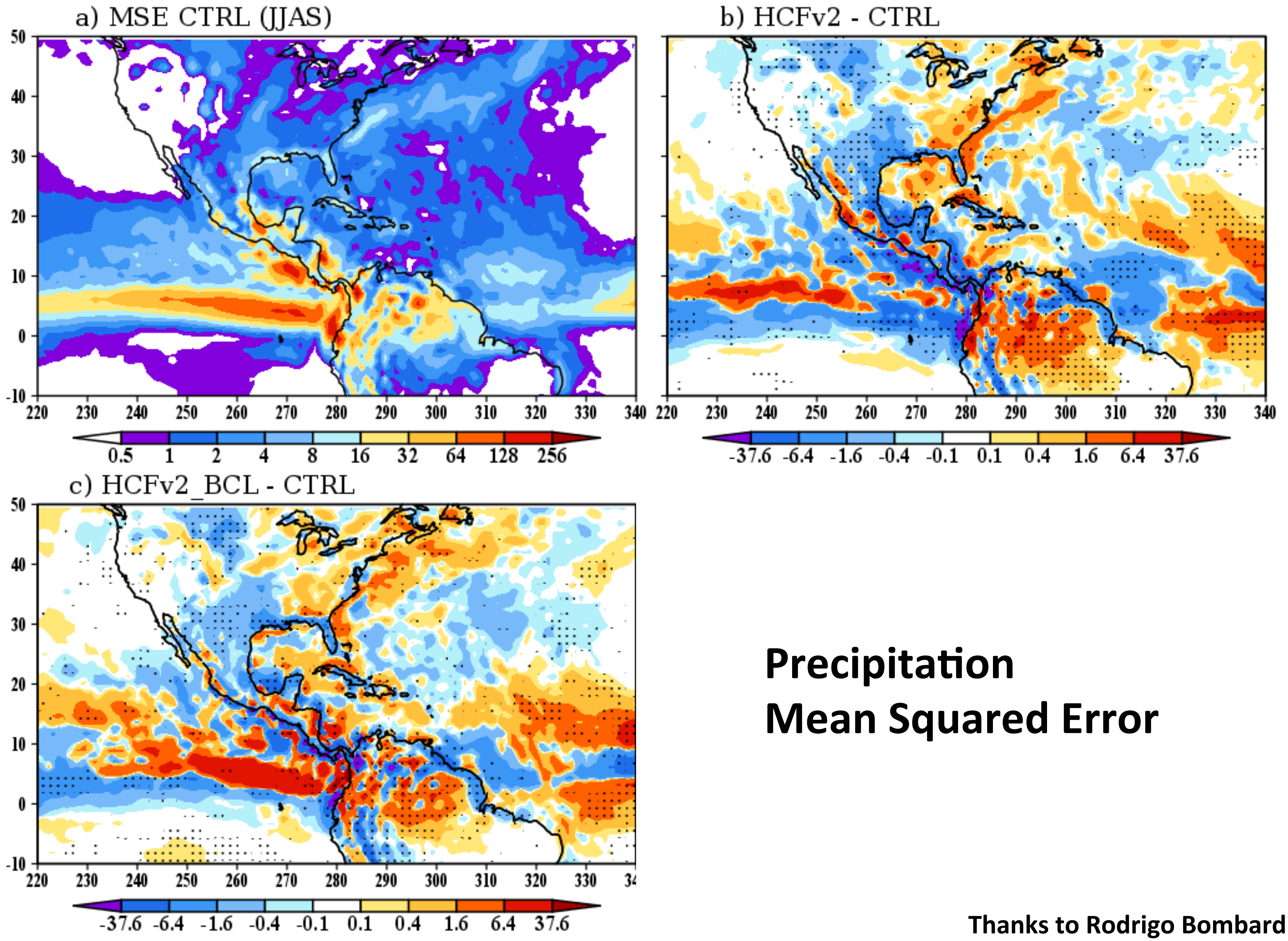
Experiment Name	Type	Deep Convection	Shallow Convection	Trigger Function	Convective Cloud Base
CTRL	Short (~2 weeks) Seasonal (7 months)	New SAS	SAS based	Original (pressure difference)	LFC
HCFv2	Short (~2 weeks) Seasonal (7 months)	New SAS	SAS based	HCFv2	LFC
HCFv2_BCL	Short (~2 weeks) Seasonal (7 months)	New SAS	SAS based	HCFv2	BCL

Thanks to Rodrigo Bombardi

Testing HCF – DYNAMO Soundings

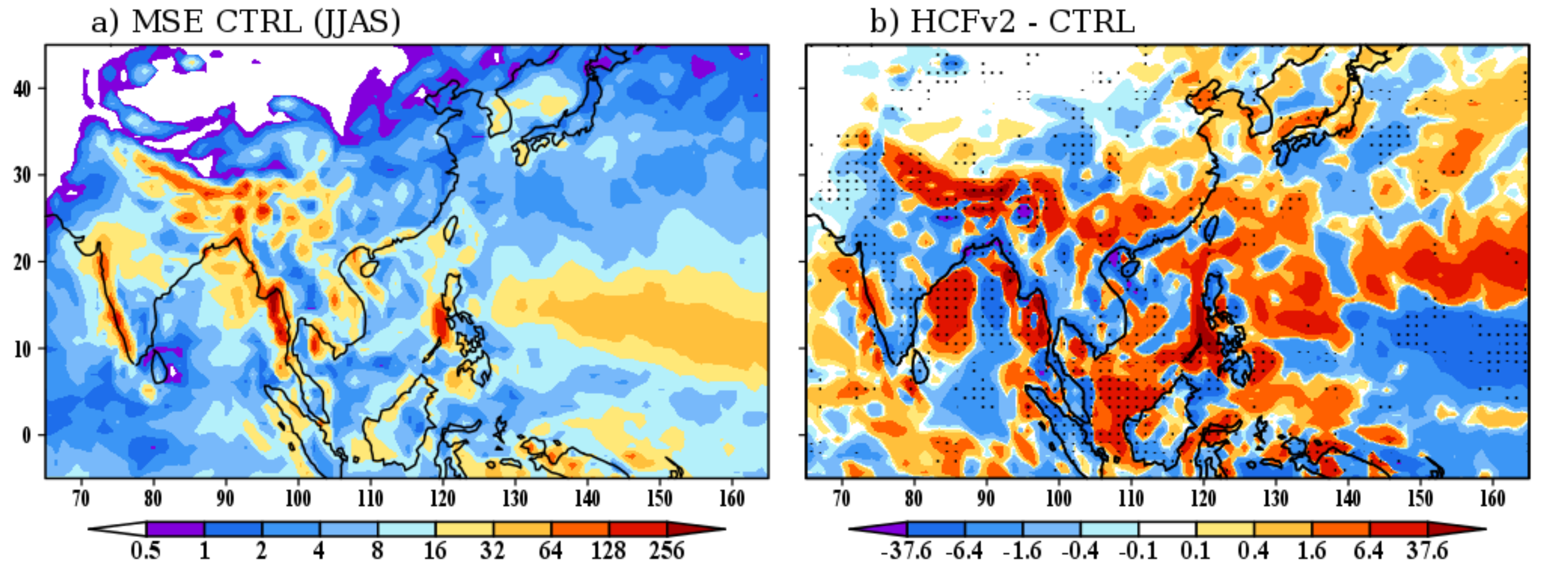


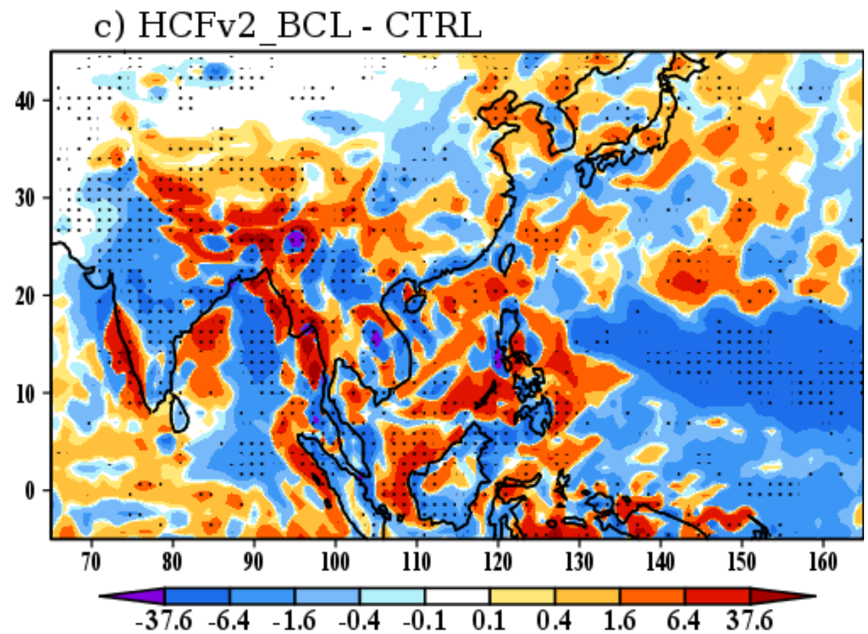
Thanks to Rodrigo Bombardi



Precipitation Mean Squared Error

Thanks to Rodrigo Bombardi

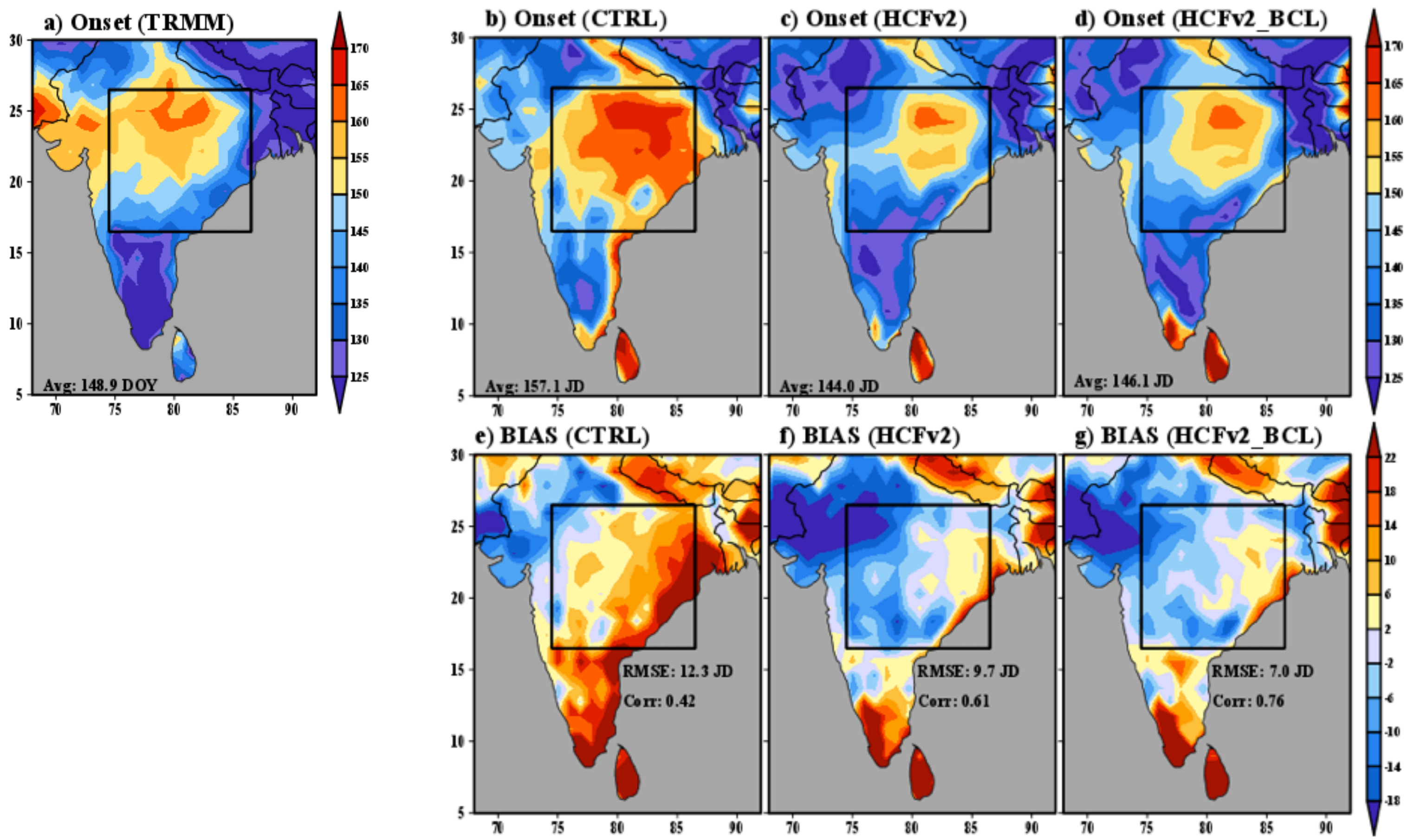




Precipitation Mean Squared Error

Thanks to Rodrigo Bombardi

Summer Monsoon Onset Date

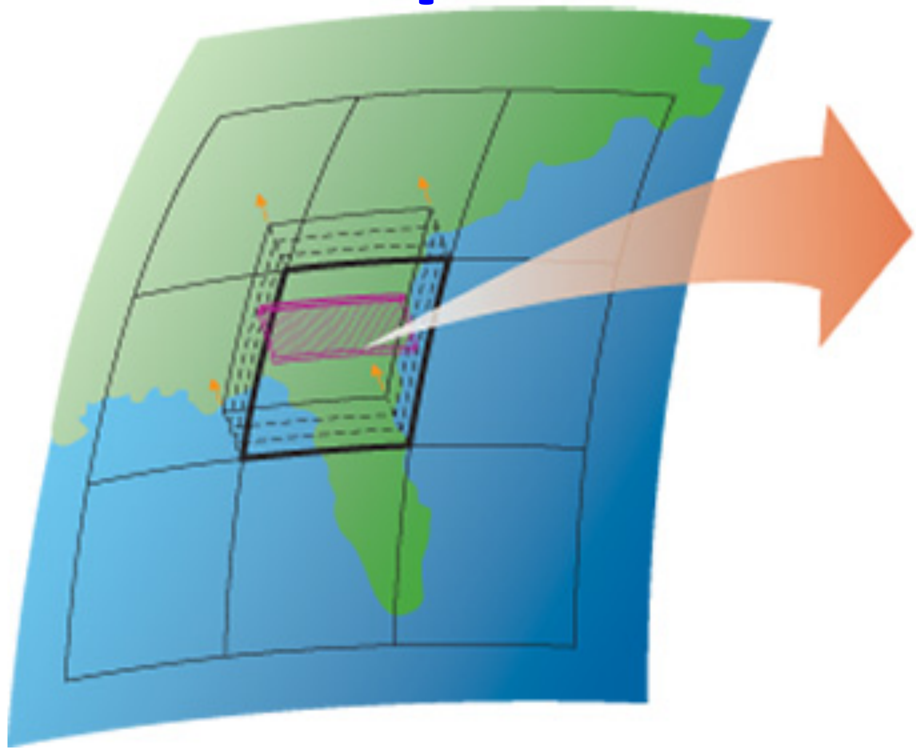


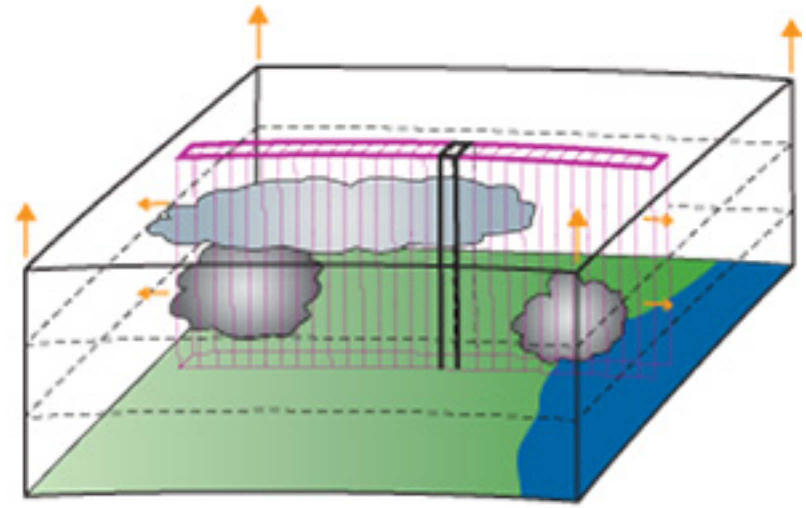
Thanks to Rodrigo Bombardi

Khairoutdinov and Randall, 2001:

SUPER-PARAMETERIZATION

Super-Parameterization





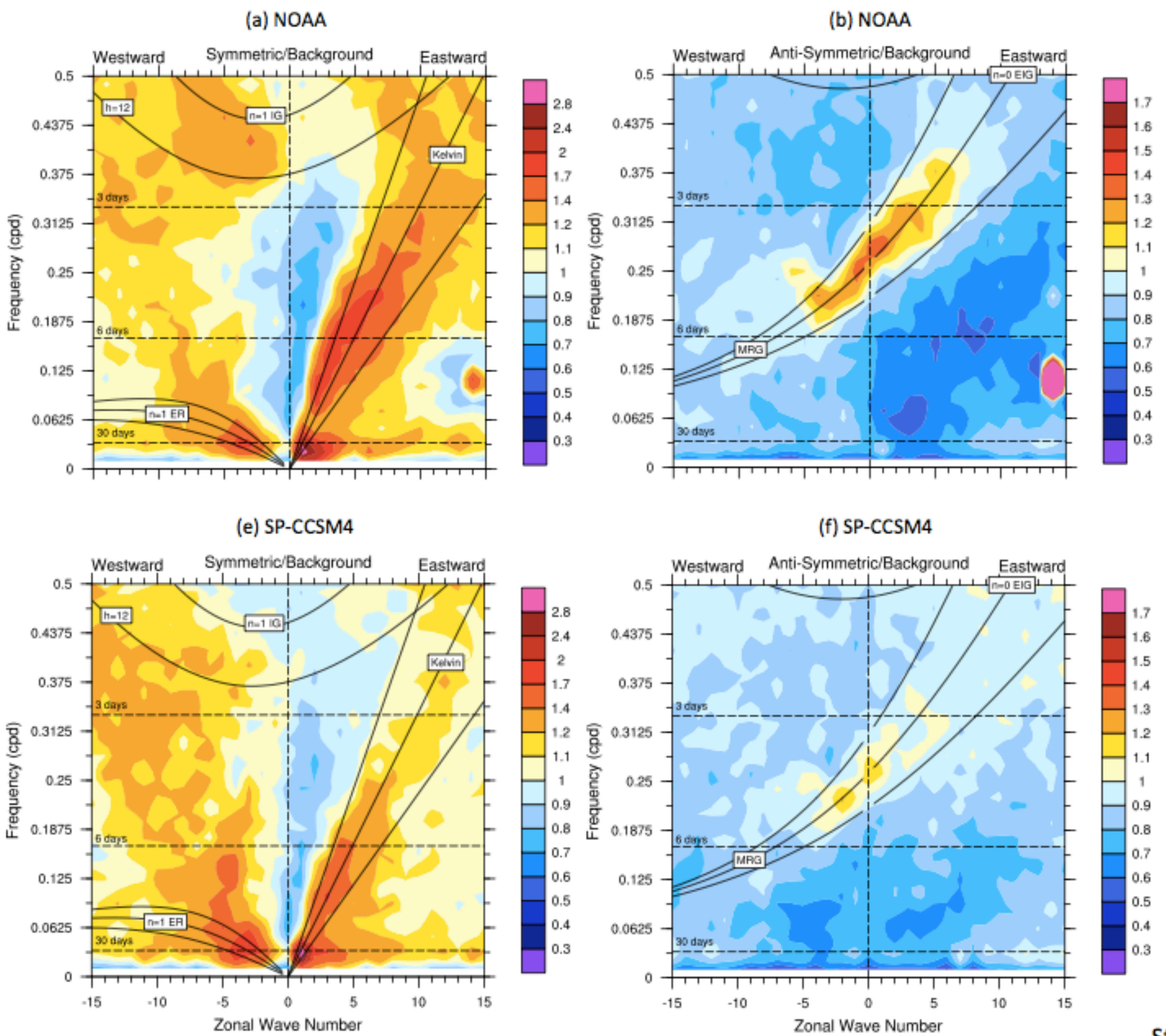
CRM

- 3-km clouds, aligned E-W
- Periodic domain
- Same vert. levels as host model

In a global climate model (left), each grid cell represents a large area of O(10^4) km^2. In the Multi-scale Modeling Framework, also called Super-Parameterization (SP), the clouds within each grid cell are represented with small cloud-system resolving models (CSRMs). A single cell might contain a row of 64 one-column CSRM models (right), each depicting clouds over a 3 x 3 km area. (Illustration by Mike Shibao, based on imagery from CMMAP.)

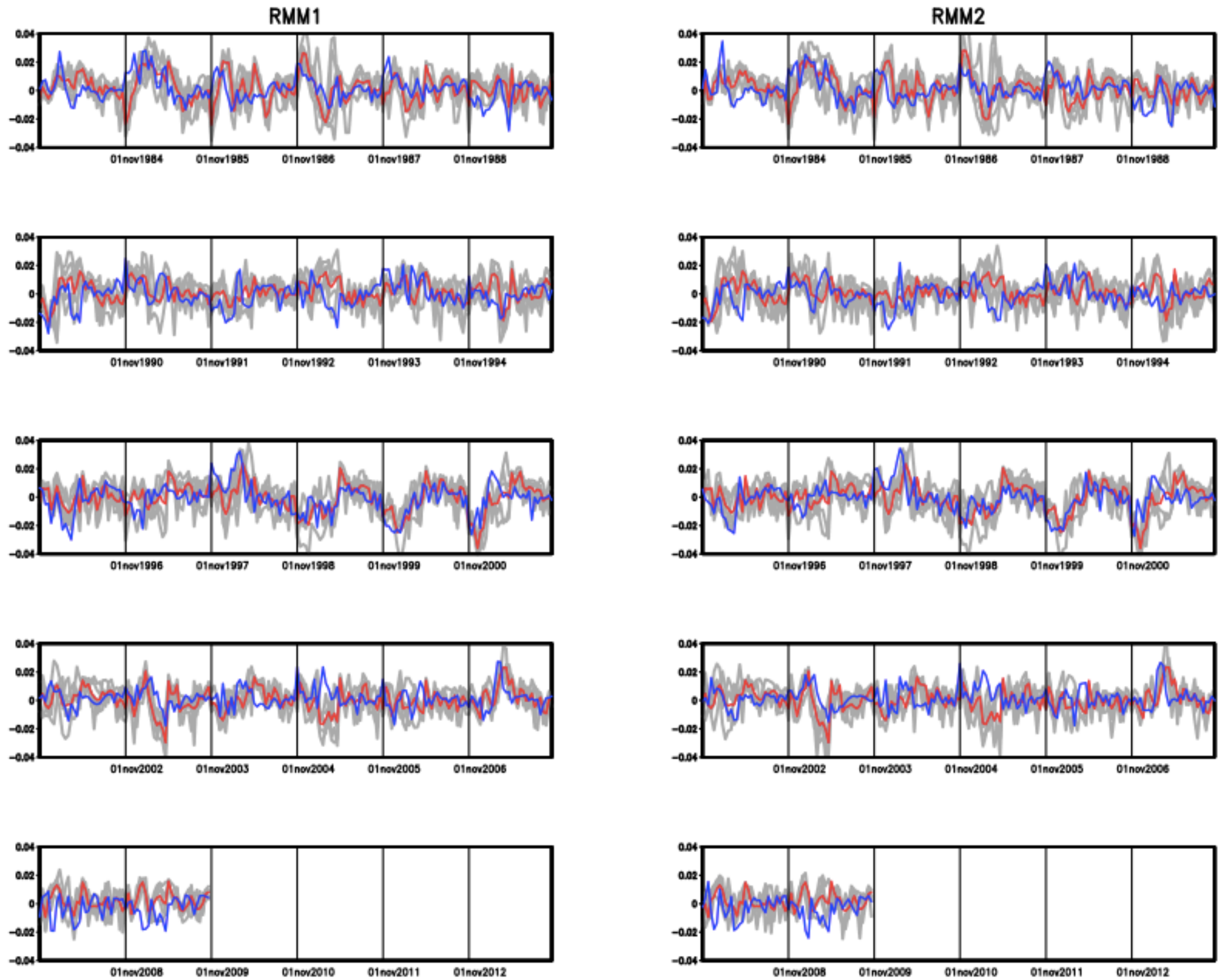
* *Khairoutdinov and Randall, 2001*

SP-CCSM4 Simulation of MJO



Stan and Xu, 2014

SP-CCSM4 30-Day MJO Forecasts

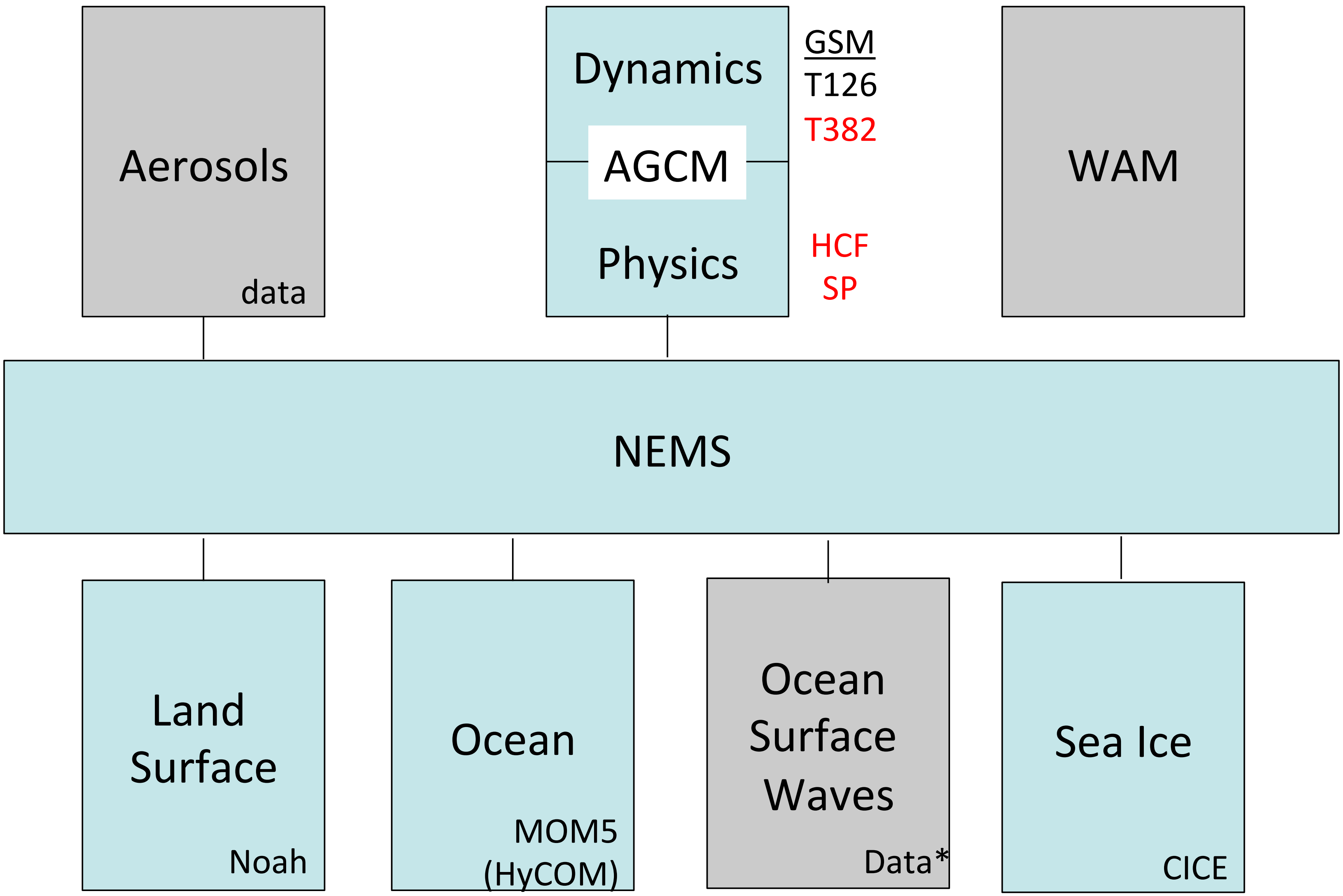


Objective of Proposed Work

- Improve 3-4 week lead-time forecasts, focusing on
  - Weather statistics over North America
  - Statistics of hurricane and typhoon formation
- The proposed work will:
  - Evaluate and correct systematic biases in the tropics to improve forecasts of weeks 3 and 4
  - Evaluate the sensitivity of predictability to model resolution, coupling, and initial states to identify best methods for utilizing potential skill at weeks 3 and 4.
  - Understand and correct errors introduced by unrealistic representation of small-scale processes in the climate system.

Proposed Work

- Develop a new global, coupled weather prediction system model, in close collaboration with EMC
- Adopt as development environment the coupled NOAA Environmental Modeling System (NEMS) framework
- Design experimental model versions and rigorous tests designed to:
  1. Correct systematic biases, especially deep convection in the tropics and extratropical fluxes between the ocean and the atmosphere
  2. Quantify the predictability and skill of weather forecasts for weeks 3-4, with special attention to diagnosing their sensitivity to the spatial resolution, predictability factors in the initial condition (e.g., state of the MJO, blocking conditions, etc.), and coupling between atmosphere and ocean.
- Use statistical optimization methods to comprehensively evaluate the predictability and skill at weeks 3-4.



*** May use WW3 if coupled by EMC**

Tasks

- ***Task 1: Ocean-Atmosphere & Land-Atmosphere Feedbacks***
  - Install and test HCF in 4-component NEMS-based model (delay the onset of deep convection, thereby allowing a more realistic distribution of heating and drying in convective clouds)
  - Install and test SP in 4-component NEMS-based model (embedded CRM in each gridpoint)
- ***Task 2: Increasing Spatial Resolution***
  - ~100-km control model → ~35-km experimental model
- ***Task 3: Evaluation and Analysis***
  - Ensemble predictability runs and re-forecasts
- ***Task 4: Sensitivity of Weeks 3 and 4 Predictability to Model Developments & Initial Conditions***
  - Evaluate the week 3-4 predictability using perfect model and information theoretic methods
  - Identify potential forecasts of opportunity associated with initial conditions using large ensembles from a long run of model

Deliverables

- Quantitative, statistically significant answers to the scientific questions.
- Alternative versions of a global four-component (AGCM, OGCM, LSM, SIM) prediction system under software version control.
  - Improved representations of clouds and convection
  - Increased spatial resolution sufficient to provide more accurate representation of mesoscale atmospheric circulations
  - All versions of the model will be documented and maintained under software version control in the NCEP repository for easy transition to operations as warranted.
- Rigorous, quantitative estimates of the skill of 3-4 week lead-time forecasts of weather in North America and the statistics of hurricane and typhoon formation for these alternative versions.
  - These assessments will advise NCEP and NOAA on the efficacy of adopting the investigated model developments for operational use.
- A software test suite for evaluating the skill of new versions of the model.

Project Milestones

MILESTONES	Task 1	Task 2	Task 3	Task 4
6/1/2015 – 11/31/2015	Obtain latest version of c-NEMS	Increase AGCM and LSM spatial resolution from T126 (100-km grid spacing) to T382 (35-km grid spacing)	Create codes for standard metrics of weeks 3-4 skill	Run AGCM-only 100-year run and begin perfect-model reforecasts to assess predictability
12/1/2015 – 5/31/2016	Add HCF and SP coupling to c-NEMS Begin reforecasts	Begin testing the 35-km (AGCM/LSM) version of c-NEMS	Apply standard and information theoretic metrics to available reforecasts	Continue reforecasts using initial conditions drawn from 100-year run
6/1/2016 – 11/31/2016	Complete reforecasts with all new versions of c-NEMS	Complete reforecasts with 35-km AGCM/ LSM configuration	Analyze and synthesize results from reforecasts	Evaluate predictability based on reforecasts from 100-year run Test difference between all forecasts and forecasts of opportunity
12/1/2016 – 5/31/2017	Deliver documented codes and papers for peer review	Deliver documented codes and papers for peer review	Deliver documented codes and papers for peer review	Deliver documented codes and papers for peer review

Expected Outcomes

- Demonstrated capability to improve skill of NOAA operational 3-4 weeks weather forecasts.
- Recommendations for future research to be done collaboratively by NGGPS community.