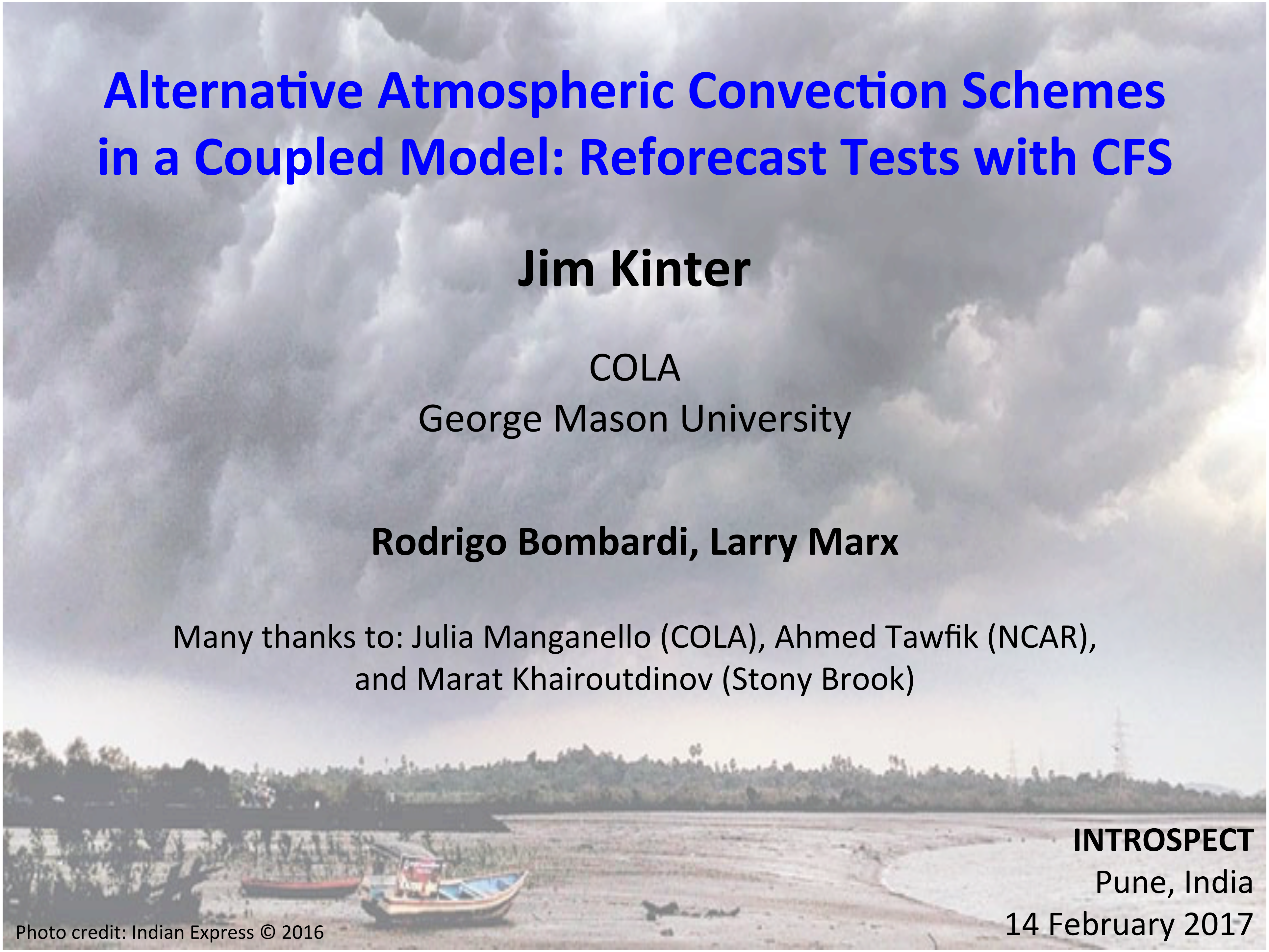

Alternative Atmospheric Convection Schemes in a Coupled Model: Reforecast Tests with CFS

Jim Kinter

COLA
George Mason University

Rodrigo Bombardi, Larry Marx

Many thanks to: Julia Manganello (COLA), Ahmed Tawfik (NCAR), and Marat Khairoutdinov (Stony Brook)

INTROSPECT
Pune, India
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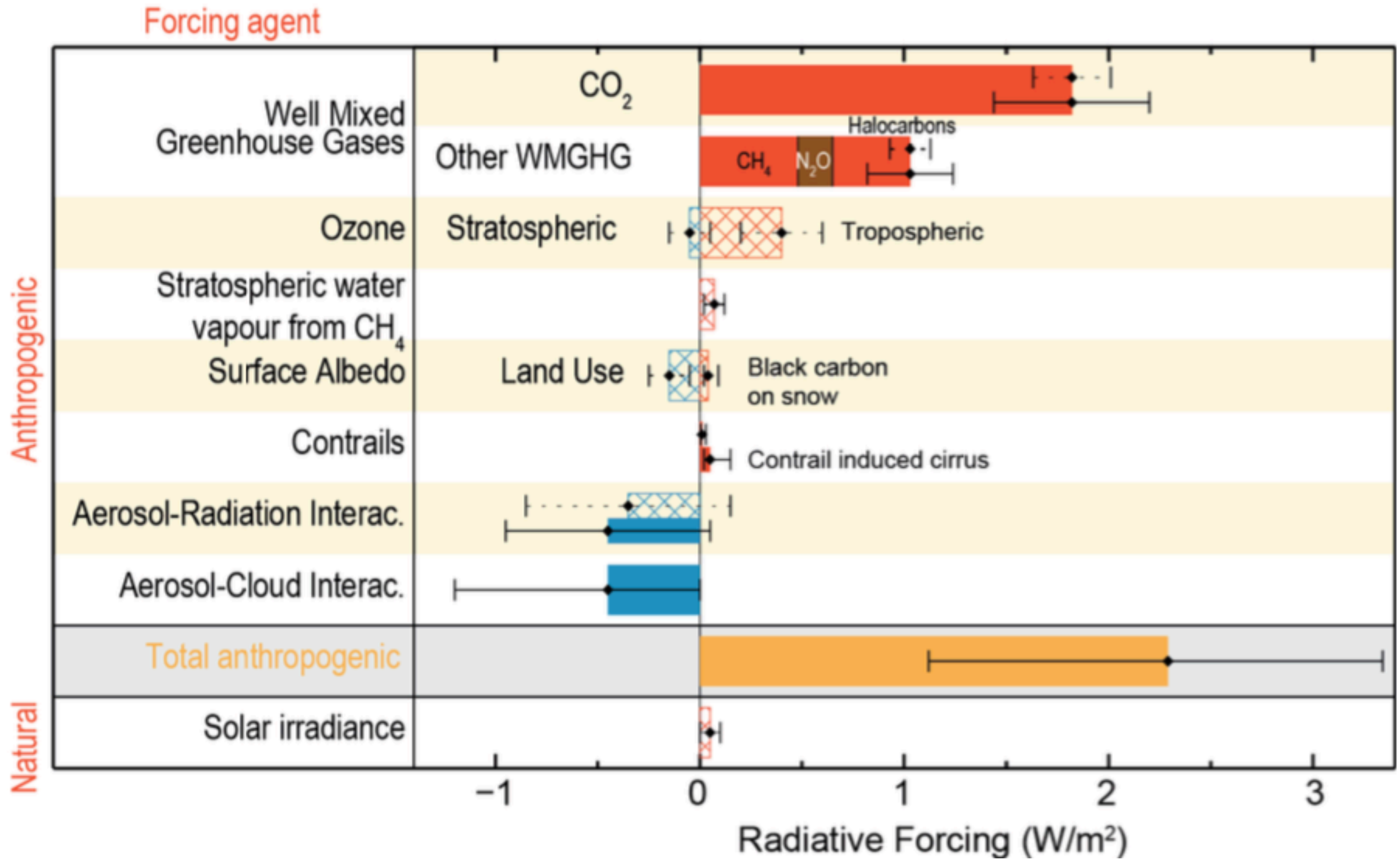
Motivation

- Clouds and convection are known to be among the largest sources of model uncertainty in current generation coupled ocean-atmosphere and Earth system models.
- The deficiencies in modeling convection may be broadly characterized as errors in:
  - Triggering convection
  - Development and equilibration of convection
  - Microphysical processes
  - or a combinations of these
- Tests of alterations to convection in reforecasts have been conducted with the NCEP Climate Forecast System using alternative parameterizations that:
  - Change the trigger mechanism for convection - OR –
  - Include the vertical motion in clouds explicitly to provide a better representation of the development of convective clouds

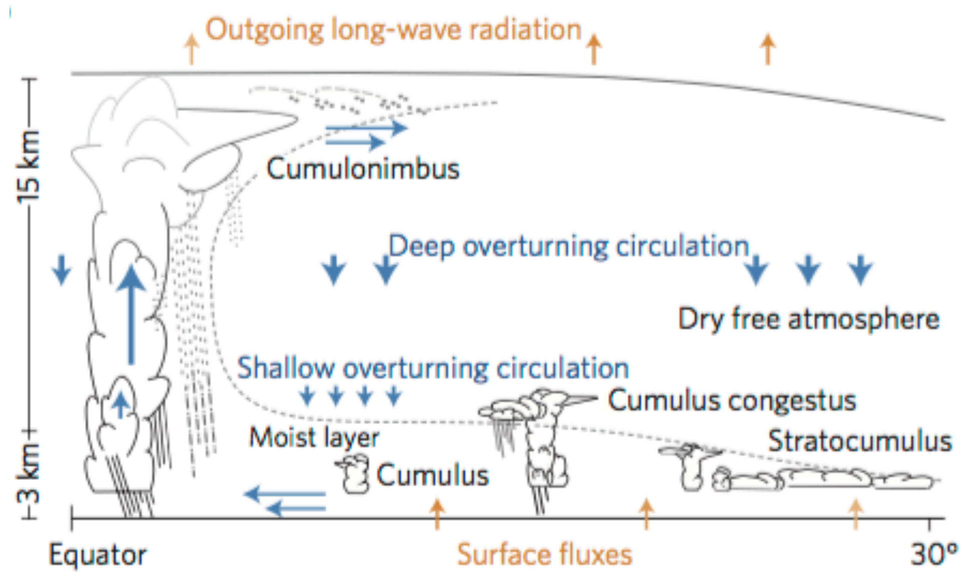
Radiative Forcing of Climate Between 1750 and 2011



Based on IPCC AR5 WGI, 2013

Climate models are very sensitive to how shallow convective clouds (top ~ 2.5 km) are coupled to the larger-scale circulation, the vertical distribution of water vapor, the surface turbulent fluxes and atmospheric radiation.

-- Bony et al. 2015



Motivation

- Clouds and convection are known to be among the largest sources of model uncertainty in current generation coupled ocean-atmosphere and Earth system models.
- The deficiencies in modeling convection in climate models may be broadly characterized as errors in:
  - Triggering convection (e.g. diurnal cycle of p_{max} too regular, too early)
  - Development and equilibration of convection; linkage to large-scale
  - Microphysical processes; linkage to radiation
  - Combinations of these
- Tests of alterations to convection in reforecasts have been conducted with the NCEP Climate Forecast System (CFSv2) using alternative parameterizations that:
  - Change the trigger mechanism for convection – OR –
  - Include the vertical motion in clouds explicitly to provide a better representation of the development of convective clouds (SP)

Climate Forecast System version 2 (CFSv2)

- **Global coupled model: Atmosphere, Ocean, Land Surface, Sea Ice**

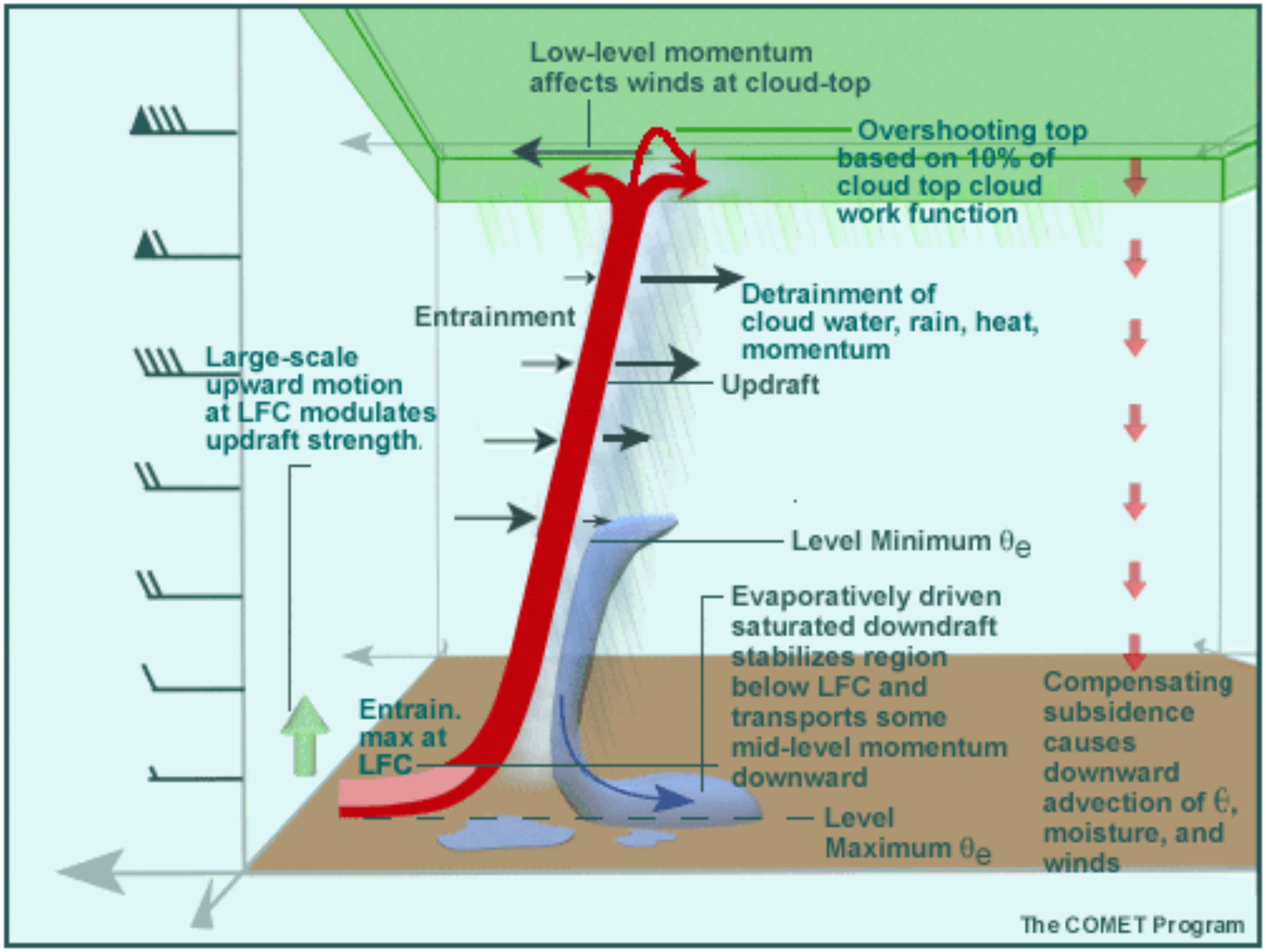
- **Atmosphere:** based on the NCEP Global Forecast System (GFS) used for global numerical weather prediction
  - spectral discretization at T126 resolution (~100 km grid spacing)
  - 64 vertical levels
  - **SAS (Han and Wu 1995; Hong and Pan 1996) cumulus parameterization**

- **Ocean:** Geophysical Fluid Dynamics Laboratory (GFDL) Modular Ocean Model version 4 (MOM4)
  - 1/2° horizontal grid spacing; 1/4° meridional grid spacing in the tropics
  - 40 vertical levels

- **Land Surface:** Noah (GFS grid)

- **Sea Ice:** a modified version of the GFDL Sea Ice Simulator (MOM4 grid)

Convective Cloud Parameterization: The Simplified Arakawa-Schubert (SAS) Scheme



Source: MetEd http://www.meted.ucar.edu/nwp/pcu2/avncp1.htm

NCEP Column Physics

	SAS	NewSAS
Operational model:	**CFSv2 (2010)**	**GFS (2013+)**
Cloud Scheme	Turbulent diff. shallow convection Mass flux DC (Hong & Pan 1996)	Mass flux shallow & deep (Han & Pan 2011)
PBL	Troen & Mahrt 1986	Lock et al. 2000
Entrainment/ detrainment	Quasi-equilibrium (Arakawa & Schubert 1974 cloud work function), saturated downdraft (Grell 1993)	Bechtold et al. 2008
Cumulus momentum transport	None	Han & Pan 2006
Deep convection trigger	**CSL – LFC <= 150 hPa**	**120 <= CSL – LFC <= 180** **f(large-scale ω)**

CSL = convection starting level = MSE_{max} level
LFC = level of free convection

Alternative Trigger: Heated Condensation Framework

- **Quantify how close atmosphere is to moist convection**
- **Does not require parcel selection**
- **Uses typically measured quantities (*q* and θ profiles)**
- **Is "conserved" diurnally**
- **Can be used any time of year or any time of day and interpretation stays the same**

(Tawfik and Dirmeyer 2014 *GRL;* Tawfik et al. Parts 1 & 2 2015 *JHM*)

Heated Condensation Framework

Heated Condensation Framework

Threshold Variables:

BCL = Buoyant Condensation Level [m]
θ_{BM} = Buoyant mixing temperature [K]

Convection is initiated when:

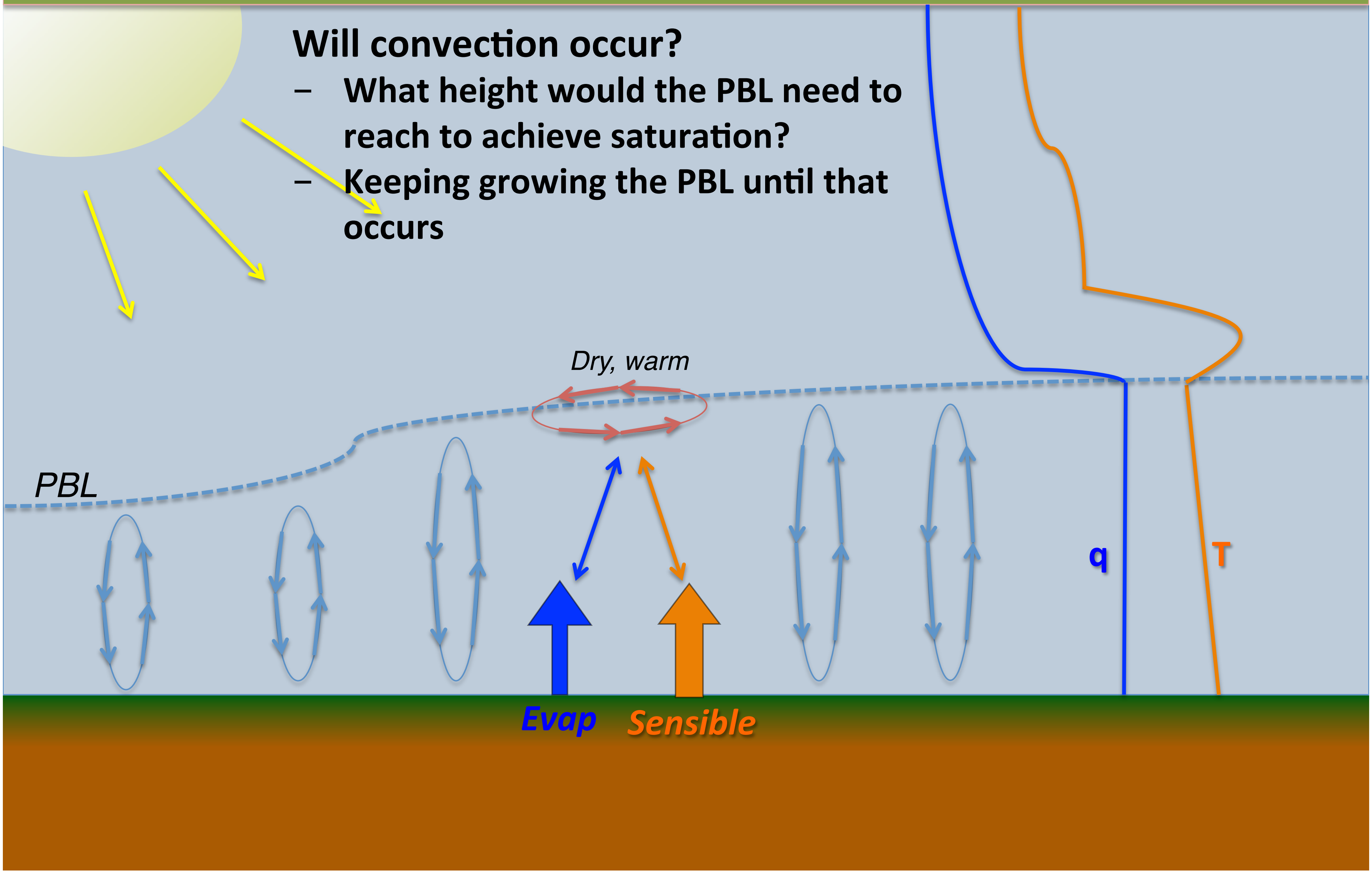
PBL *intersects* **BCL**
θ_{2m} *reaches* **θ_{BM}**

(Tawfik and Dirmeyer 2014 *GRL*)

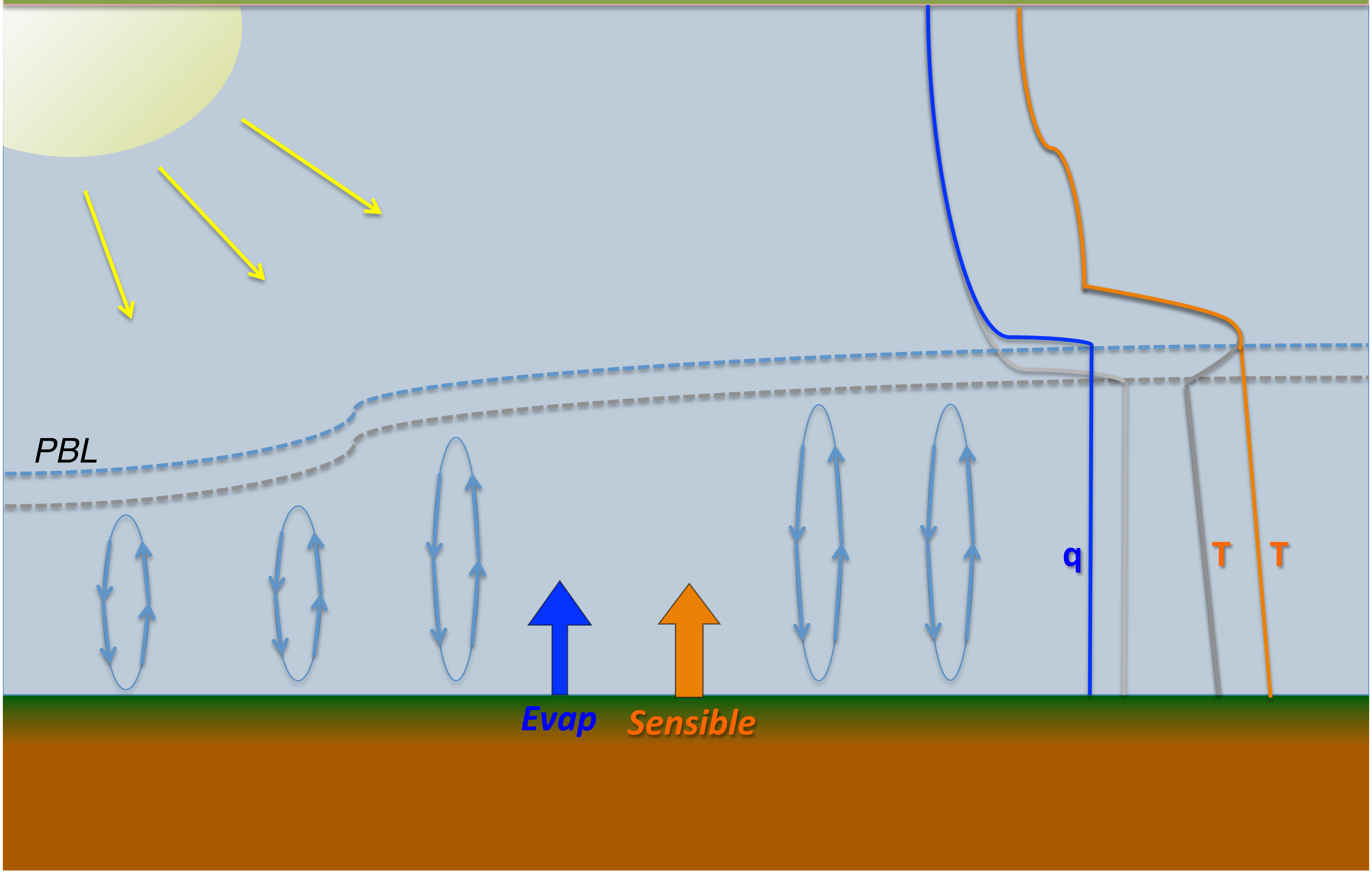
Surface-Convection Coupling

Will convection occur?

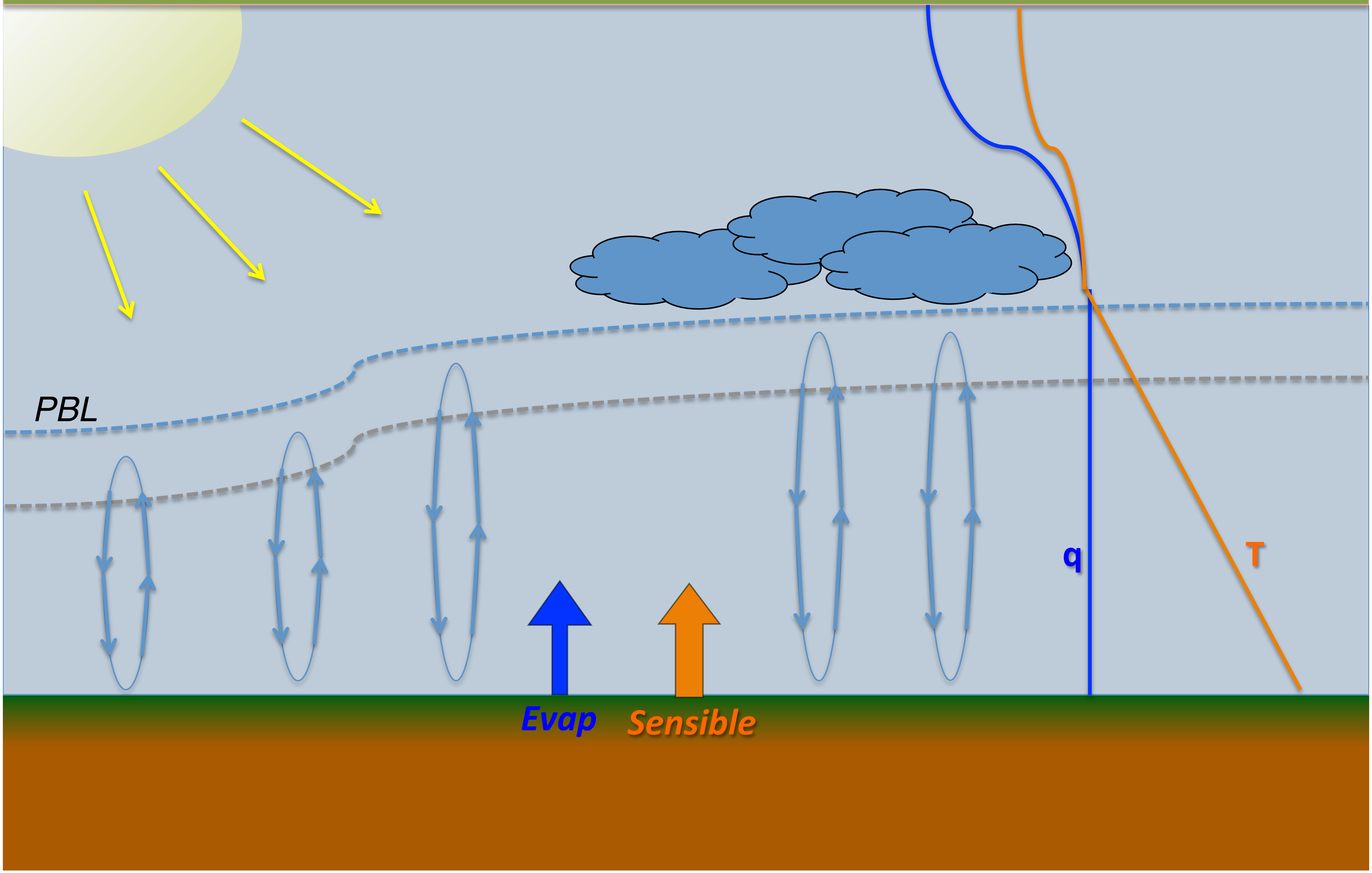
- **What height would the PBL need to reach to achieve saturation?**
- **Keeping growing the PBL until that occurs**



Surface-Convection Coupling



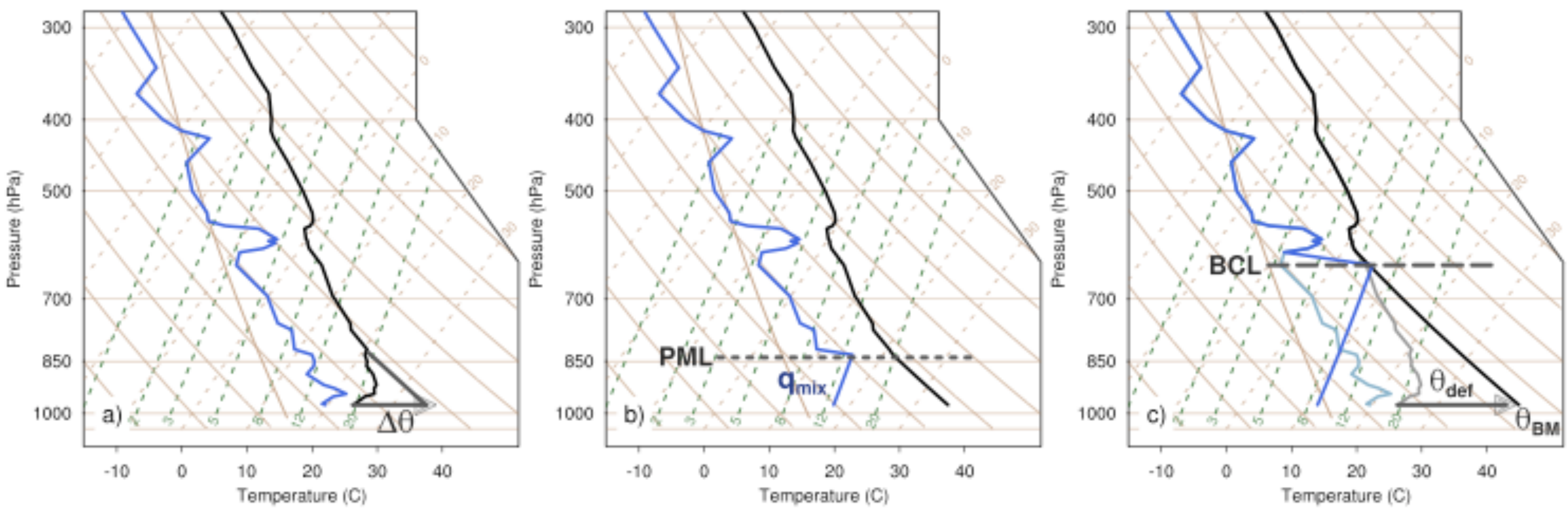
Surface-Convection Coupling



Heated Condensation Framework (HCF)

The HCF was designed to better couple land surface fluxes and column physics and avoid parcel method.

SkewT-LogP diagram of **temperature (black)** and **dew point (blue)** illustrating the steps to calculating the conditions for triggering convection.



Tawfik and Dirmeyer (2014)

Experiments

Exper-iment	Simulation Length	Number of Years/ Events	Range of Years	Number of Members per Year/ Event	Initialization Date	Spatial Resolution		Temporal Resolution	Model Physics
						ATM/LS	OCN/Sea ice		
CTRL	7 months	13	1998 - 2010	4	April 1,2,3,4	T126/L64	0.5-degL40	Daily	Operational
HCF	7 months	13	1998 - 2010	4	April 1,2,3,4	T126/L64	0.5-degL40	Daily	Operational + HCF trigger
CTRL2	7 months	13	1998 - 2010	4	April 1,2,3,4	T126/L64	0.5-degL40	Daily	New SAS + Shalow Cu
HCFv2	7 months	13	1998 - 2010	4	April 1,2,3,4	T126/L64	0.5-degL40	Daily	New SAS + Shalow Cu + HCF trigger
CTRL2	1 month	24	-	7	[Landfall, -1, …, -6]	T382/L64	0.5-degL40	6-hourly	New SAS + Shalow Cu
HCFv2	1 month	24	-	7	[Landfall, -1, …, -6]	T382/L64	0.5-degL40	6-hourly	New SAS + Shalow Cu + HCF trigger

Bombardi et al. 2015 "**B15**"
(Trigger criteria relaxed)
(SAS *or* HCF)

Bombardi et al. 2016 "**B16**"
(Trigger criteria restricted)
(HCF in place of NewSAS trigger)

Experiments:

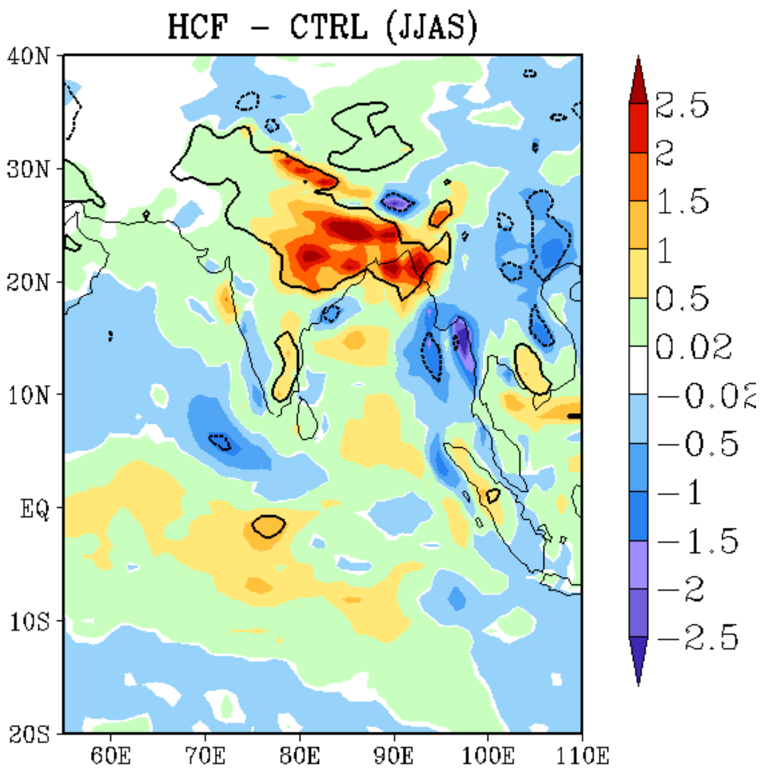
- Seasonal Runs: 4 members per year (1998 – 2010). Starting on April 1,2,3, 4
- Short Runs: 4 members per year (1998 – 2010). Starting on July 14,15,16,17
- Hurricane Runs: 7 members per event. Starting daily for 7 days before landfall

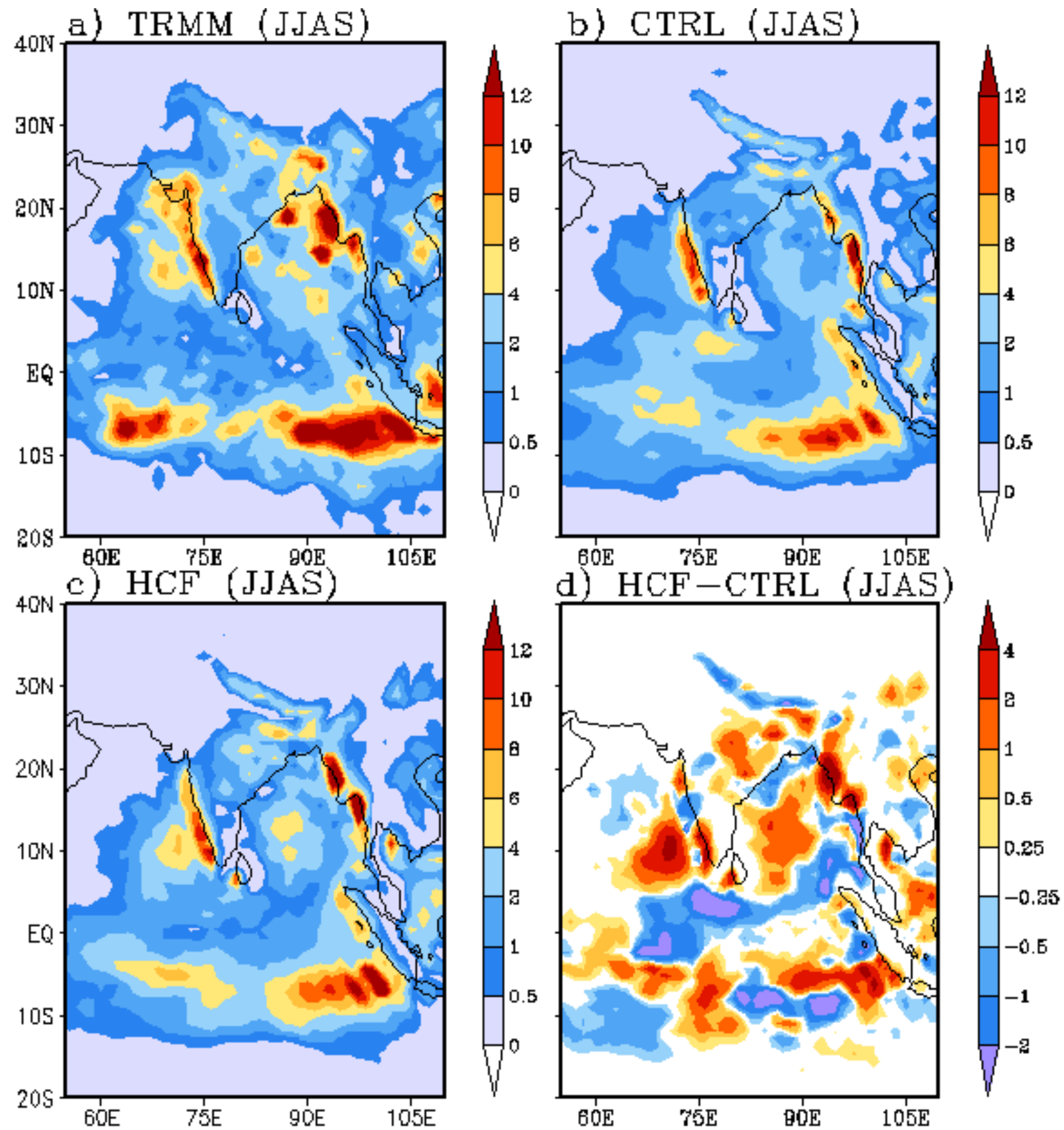
Exp. Name	Type	# of years/ events	# of members	Horizontal Resolution	Temporal Resolution	Trigger Criteria
CTRL	Short (~2 weeks)	13	4	T126 (~1.0 deg.)	3-hourly	Original (pressure difference)
	Seasonal (7 months)	13	4	T126 (~1.0 deg.)	Daily	
	Hurricanes (30 days)	24	7	T382 (~0.31 deg.)	6-hourly	
HCFv2	Short (~2 weeks)	13	4	T126 (~1.0 deg.)	3-hourly	HCF
	Seasonal (7 months)	13	4	T126 (~1.0 deg.)	Daily	
	Hurricanes (30 days)	24	7	T382 (~0.31 deg.)	6-hourly	

Seasonal Precipitation

B15 HCF *or* SAS trigger – relaxed criteria:

- Small, significant improvement of seasonal totals
- Improvement of seasonal precipitation variability



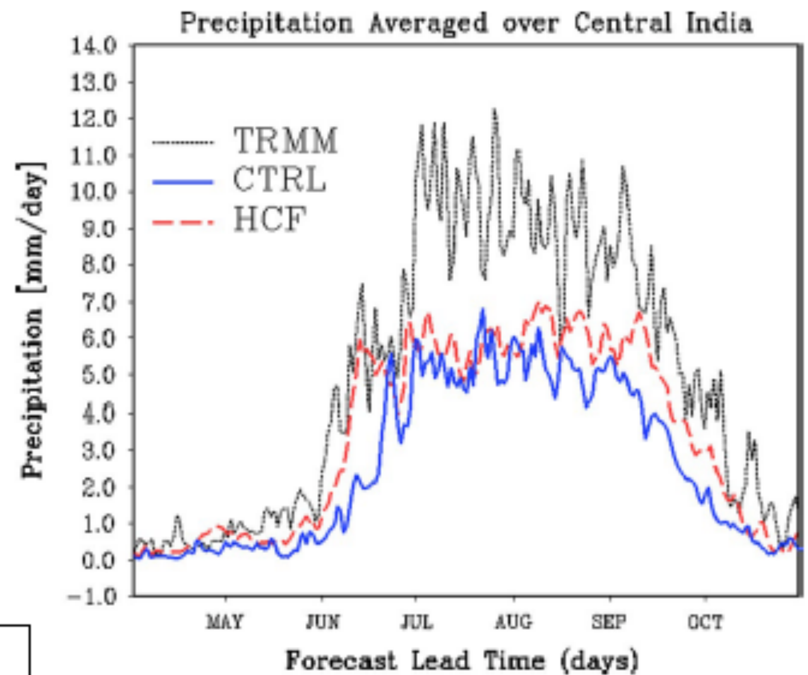


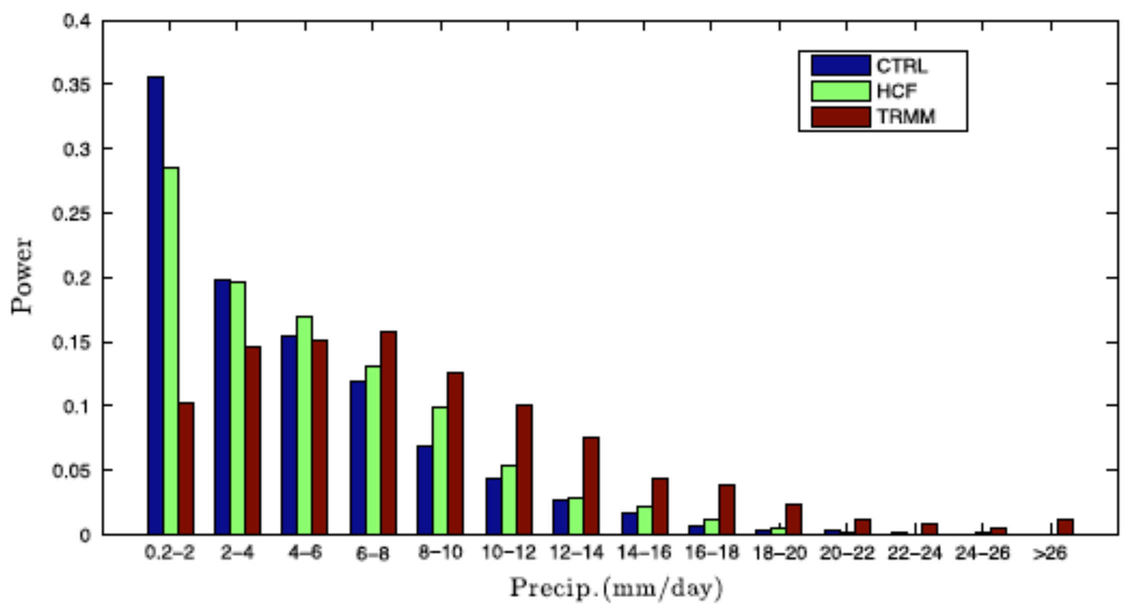
Precipitation over Central India

Problem:
Dry precipitation bias over India caused by too much light rain & not enough intense precipitation

Dataset: TRMM precipitation

Period: 1998 - 2010

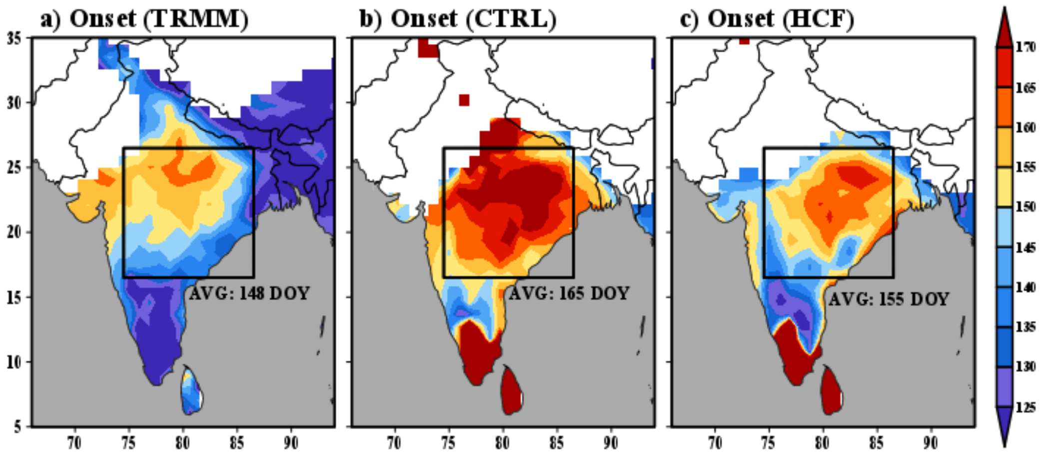




B15 Mechanism:
By allowing the model to trigger convection more often there was a reduction in light precipitation and an increase in heavy precipitation.

Bombardi et al. (2015)

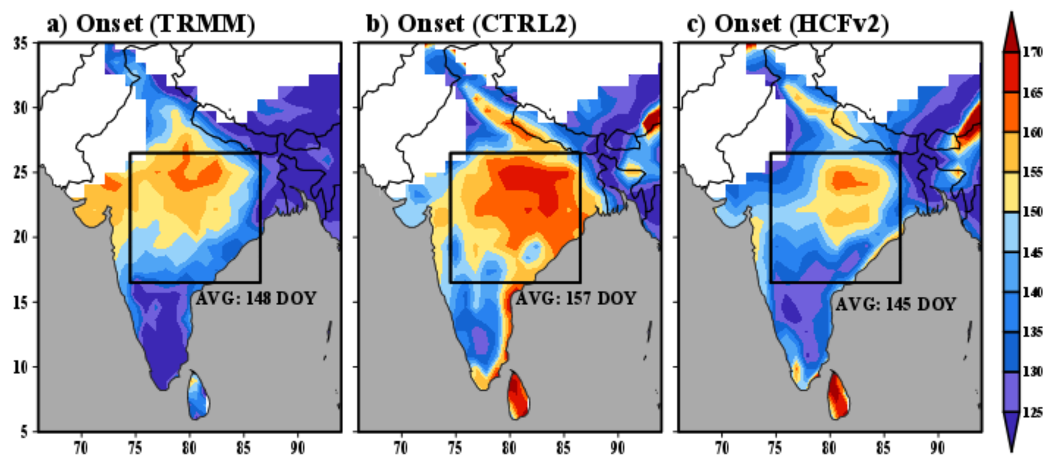
- **B15:** HCF trigger as alternative condition (CFSv2 operational)
- Old SAS triggers more often → increase in the Summer Indian Monsoon Rainfall → Improvement of rainy season onset date.



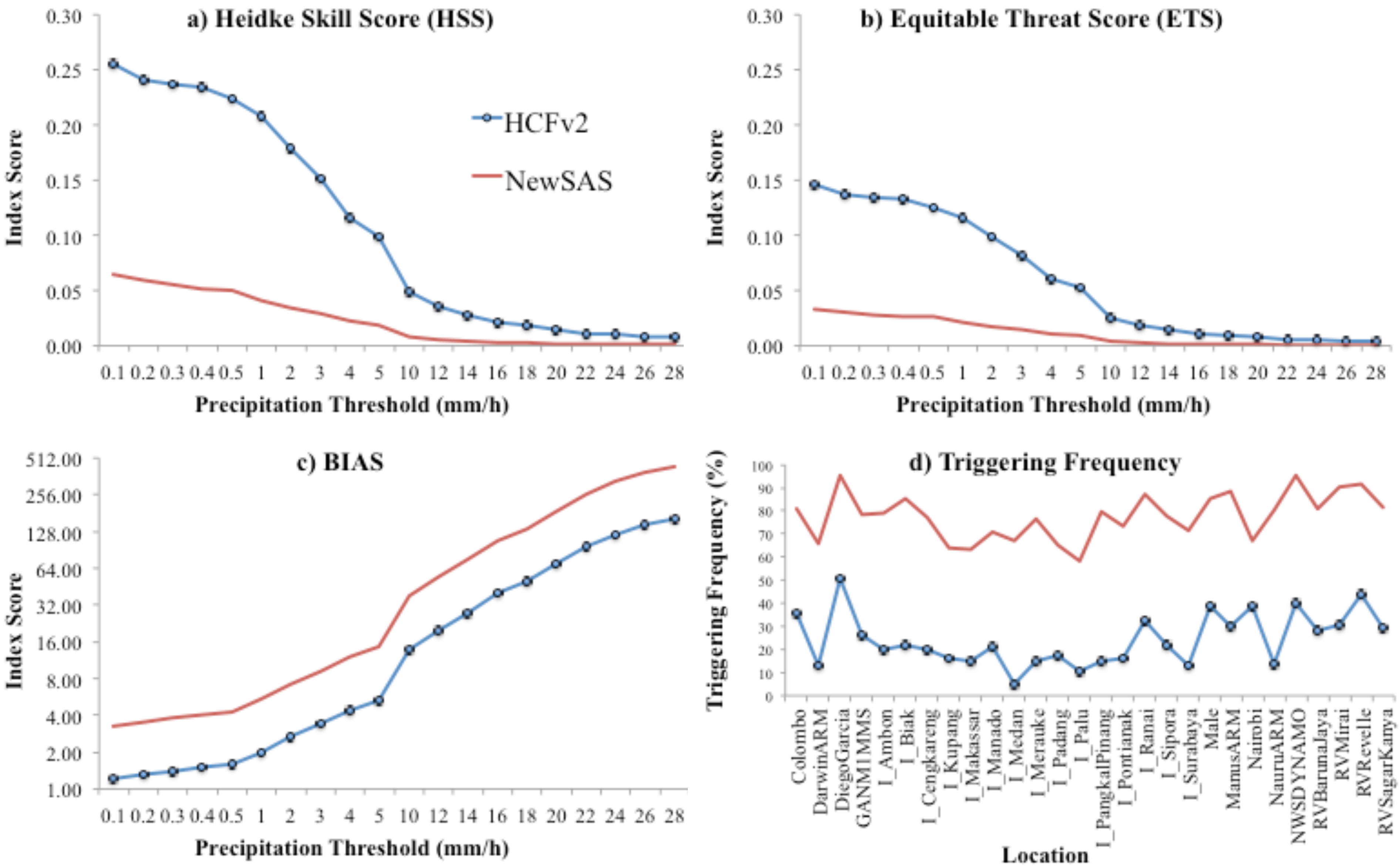
Bombardi et al. (2015)

- **B16:** HCF trigger replaces original trigger (HCFv2)
- New SAS triggers less often → also changes Summer Indian Monsoon Rainfall and rainy season onset date

Bombardi et al. (2016)



B16 Convective Trigger Criteria → DYNAMO Soundings



Hurricane Track & Intensity

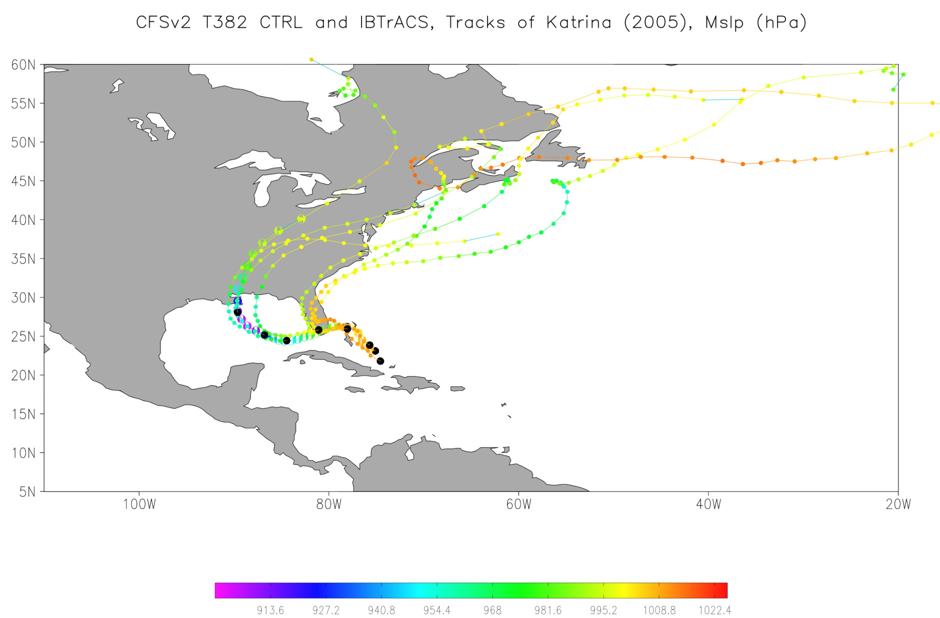
7 members initialized daily for the 7 days leading to landfall

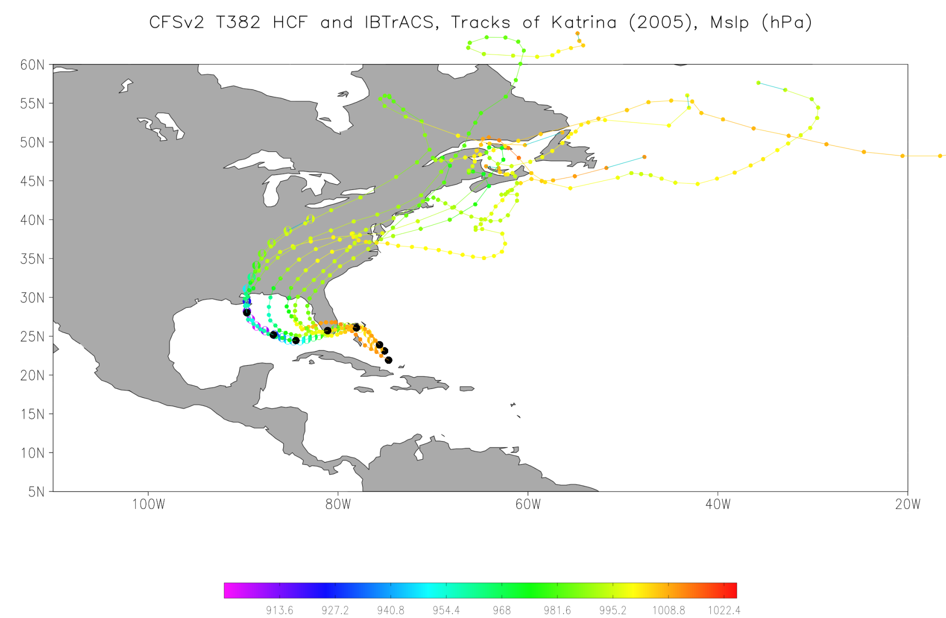
● = IBTracks;

Black circle = hindcast start;

color = intensity

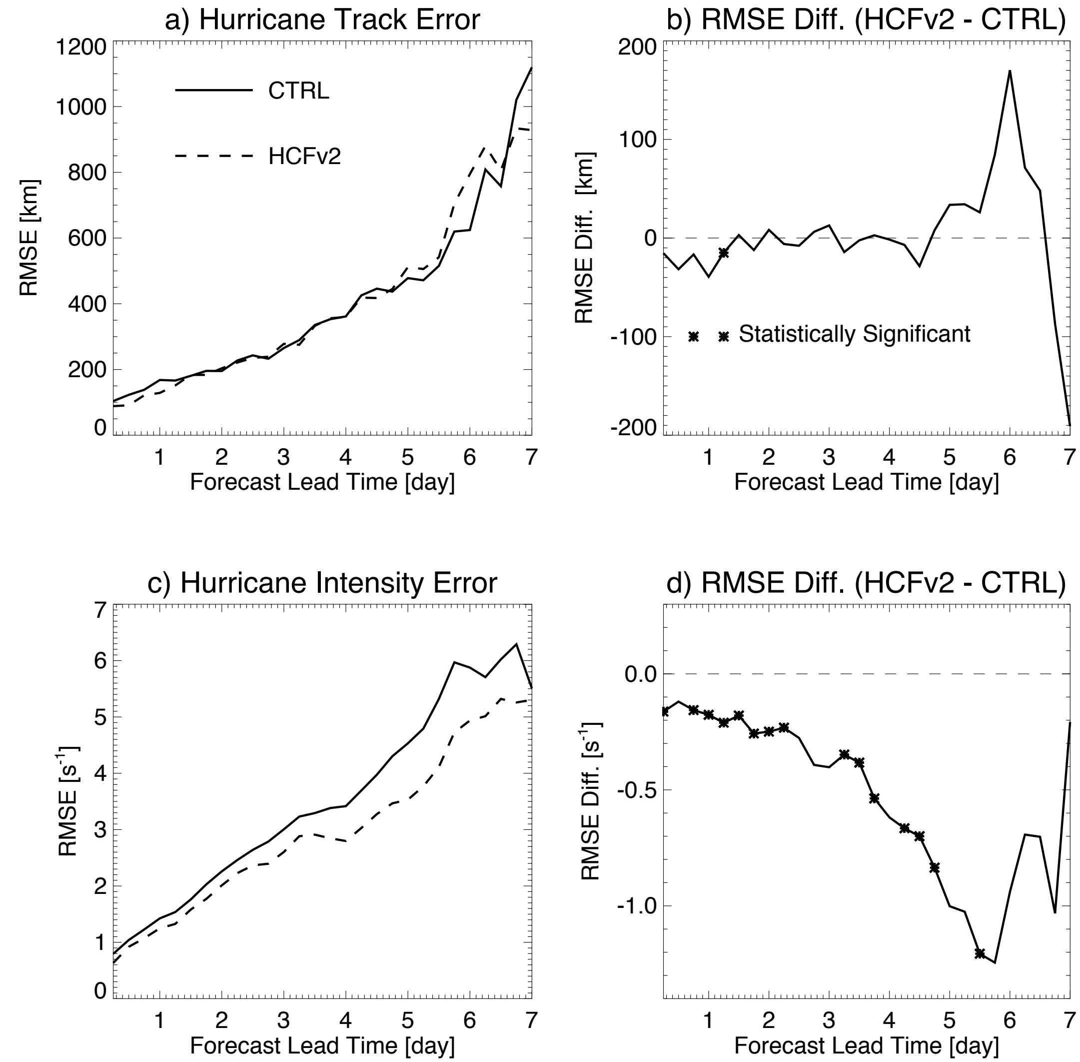
Hurricane Name	Year	Hurricane Name	Year [1]
Arthur	2014	Isabel	2003
Sandy	2012	Floyd	1999
Irene	2011	Georges	1998
Ike	2008	Bonnie	1998
Gustav	2008	Fran	1996
Dean	2007	Emily	1993
Wilma	2005	Andrew	1992
Katrina	2005	Bob	1991
Emily	2005	Hugo	1989
Ivan	2004	Gilbert	1988
Frances	2004	Charley	1986
Catarina	2004	Gloria	1985





Courtesy of Julia Manganello

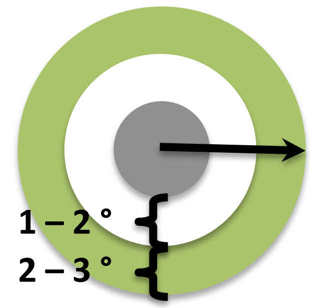
Simulating Hurricanes at T382 (~38 km) With and Without B16 Trigger



Stars = statistically significant at 5% level

Bombardi et al. (2016)

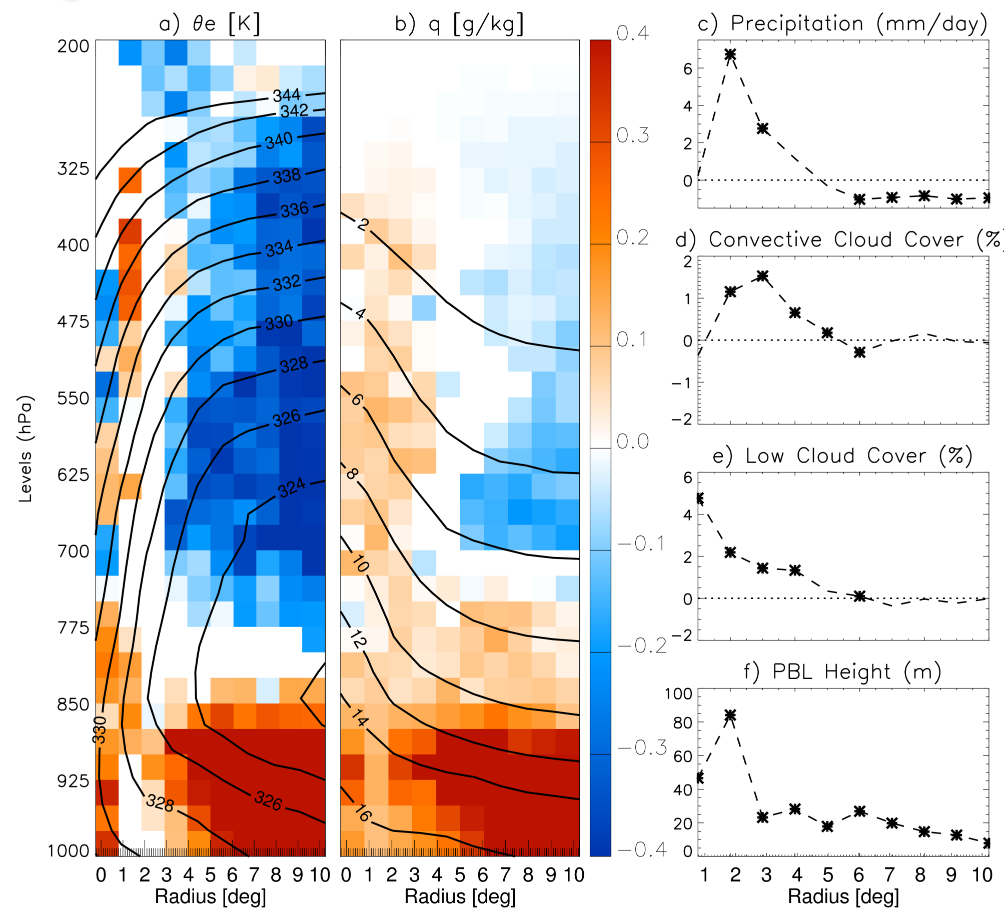
Mechanisms



Averaged over 1 degree bins
Averaged from 24h to 72h
Median Differences (shaded)

The **B16** HCF trigger activates the convective scheme less frequently

- increasing convective instability
- allowing the PBL to moisten and grow higher
- Increasing precipitation, shallow and convective clouds
- releasing latent heat intensifying hurricanes



Shading or stars = statistically significant at 5% level

Bombardi et al. (2016)

Summary: Convective Trigger

The HCF trigger produces different results in representing convection in hurricanes vs. that during the Indian Summer Monsoon, because there are two different problems in CFSv2.

- For monsoon rainfall, the model produces too much light precipitation and too little intense precipitation.
  - ✓ By allowing the convective scheme to trigger more often, more precipitation is generated and the dry bias is reduced.

- For hurricanes, the model produces too much convection.
  - ✓ By inhibiting the activation of the convective scheme, convective instability can build up, resulting in intensification of hurricanes.

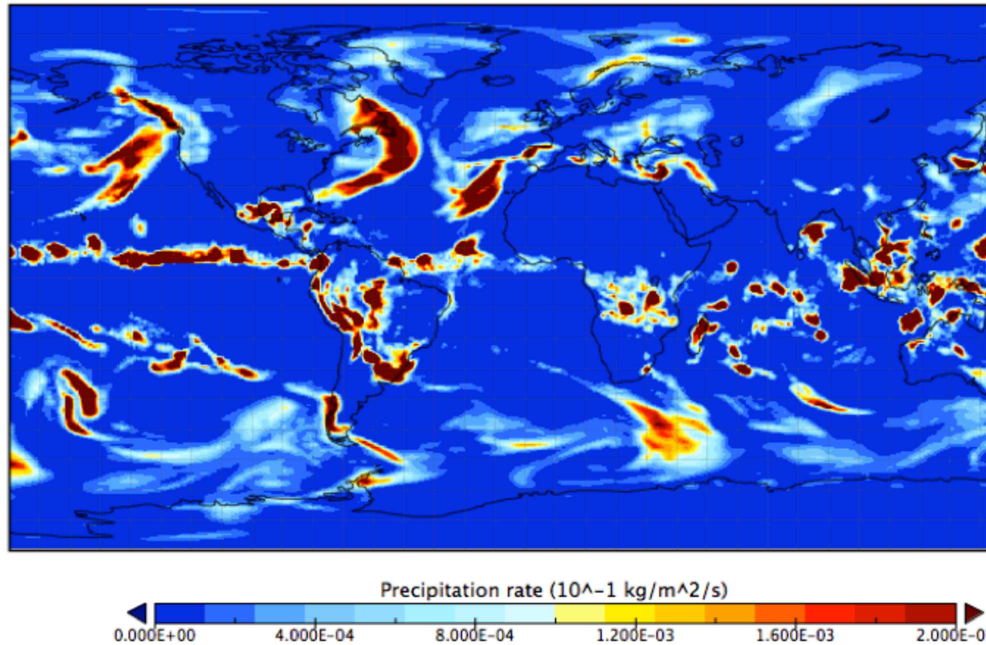
- May be moot with advent of unified schemes that handle PBL, SC and DC, but triggering frequency is valuable metric

Superparameterization and CFS

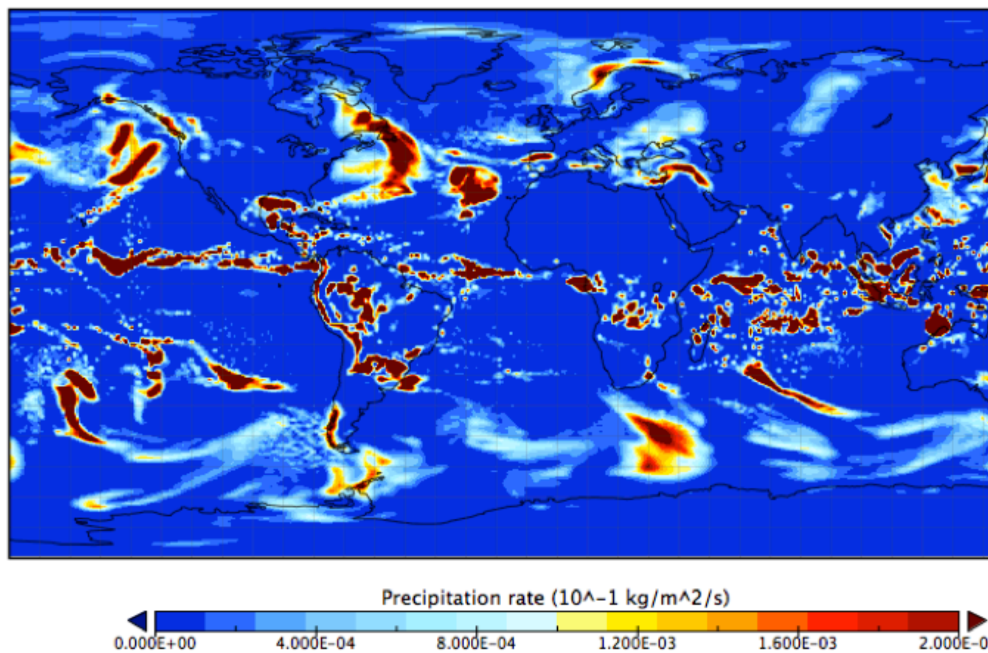
- Preliminary tests with a superparameterized version of CFSv2 were conducted
- Many thanks to Marat Khairoutdinov for essential assistance with implementation
- Very limited number of cases of landfalling hurricanes (Sandy 2012; Katrina 2005; Floyd 1999; and Bonnie 1998) – 3-week forecasts
- Comparison with OBS and T382 control runs (NewSAS)

Precipitation

CFS



SP-CFS

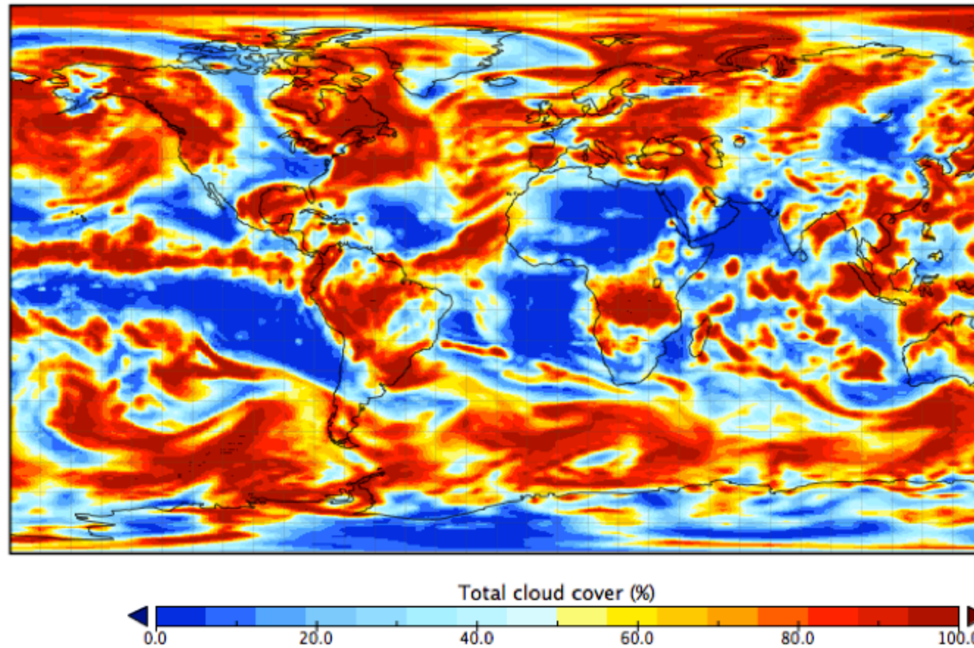


Sharper features; more spatial intermittency

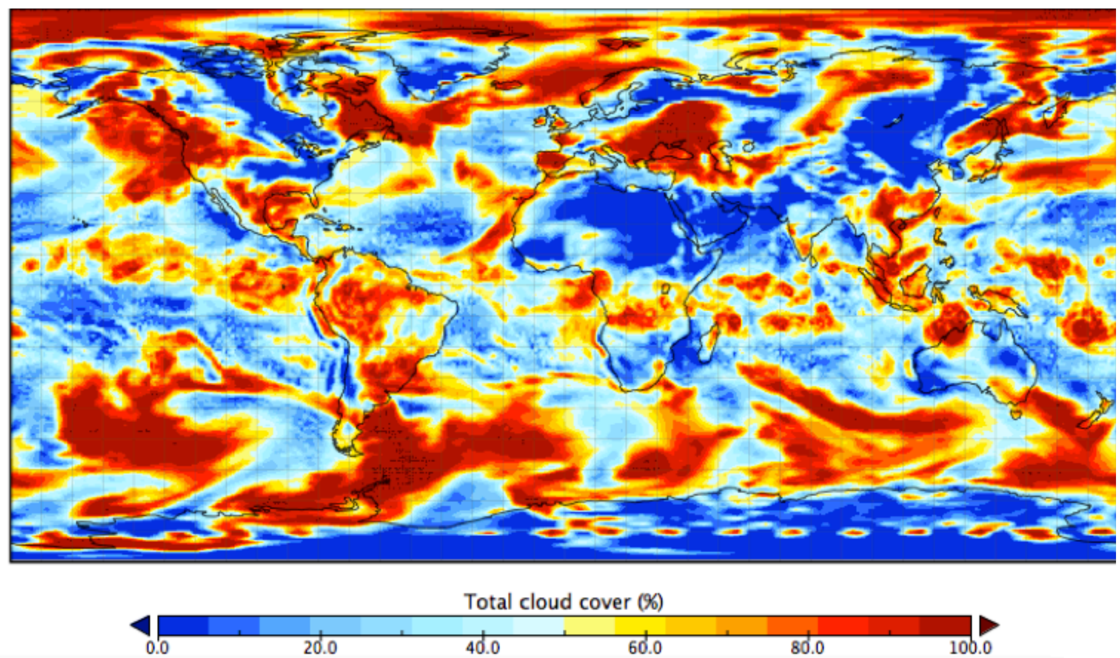
Hour 144; T126 host resolution

Total Cloud Cover

CFS



SP-CFS



Increased low cloud in tropics & sub-tropics

Hour 144; T126 host resolution

Superparameterization and CFS

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- Very limited number of cases of landfalling hurricanes (Sandy 2012; Katrina 2005; Floyd 1999; and Bonnie 1998) – 3-week forecasts
- Comparison with OBS and T382 control runs (NewSAS)

SP Comments

- Very early assessment – too few cases, too short forecasts, different host model resolutions → caution required for interpretation
- Some robust features:
  - Substantially different structures of precipitation
  - More shallow clouds in tropics and subtropics
- Negative impact on precipitation bias in monsoon region, ITCZ → more tuning needed (in contrast with SP-CAM experience)

Parting Thoughts

- Parameterized clouds and convection are a **major source of error** and uncertainty in current generation climate models
- There is considerable potential for convection-permitting, cloud-resolving and scale-aware schemes that remains to be rigorously tested in coupled climate simulation and prediction
- Attention should be paid to **several aspects of convection** that are all potentially important – initiation, development and equilibration, and coupling with the dynamics
- Experiments with alternative trigger algorithms that are either more or less restrictive suggest that there are **substantial gains to be made in improving the onset of convection**
- **Super-parameterization** (MMF) provides an interesting intermediate solution but the experience in different models varies
- **Metrics** include: diurnal cycle of P_{max}, histogram of P intensity, convection triggering frequency, connection to large scale (e.g. level of Q_{max}), and spatial (land/ocean, tropics/extratropics, decorrelation scale), and temporal distributions (propagating features, seasonal mean, monsoons) of rainfall