An approach of Multiscale multicloud parameterization to improve the CFS model fidelity of monsoon weather and climate through better-organized tropical convection

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Motivation and Main Objective

- Current GCM have systematic biases in both mean rainfall and mean circulation as well as variability on both intraseasonal and synoptic scales
- There is consensus in scientific community that cumulus paramaterizations are to blame in large part!
- Based on recent observations and their success in simplified/ idealized situations, we propose to use multicloud and stochastic model parameterizations in CFS to improve its fidelity in representing monsoon weather and climate
- Unlike the column based cumulus parameterizations used in current GCMs, the multicloud model, by design, reproduces the self-similar morphology of tropical convective systems and captures their interactions across scales.

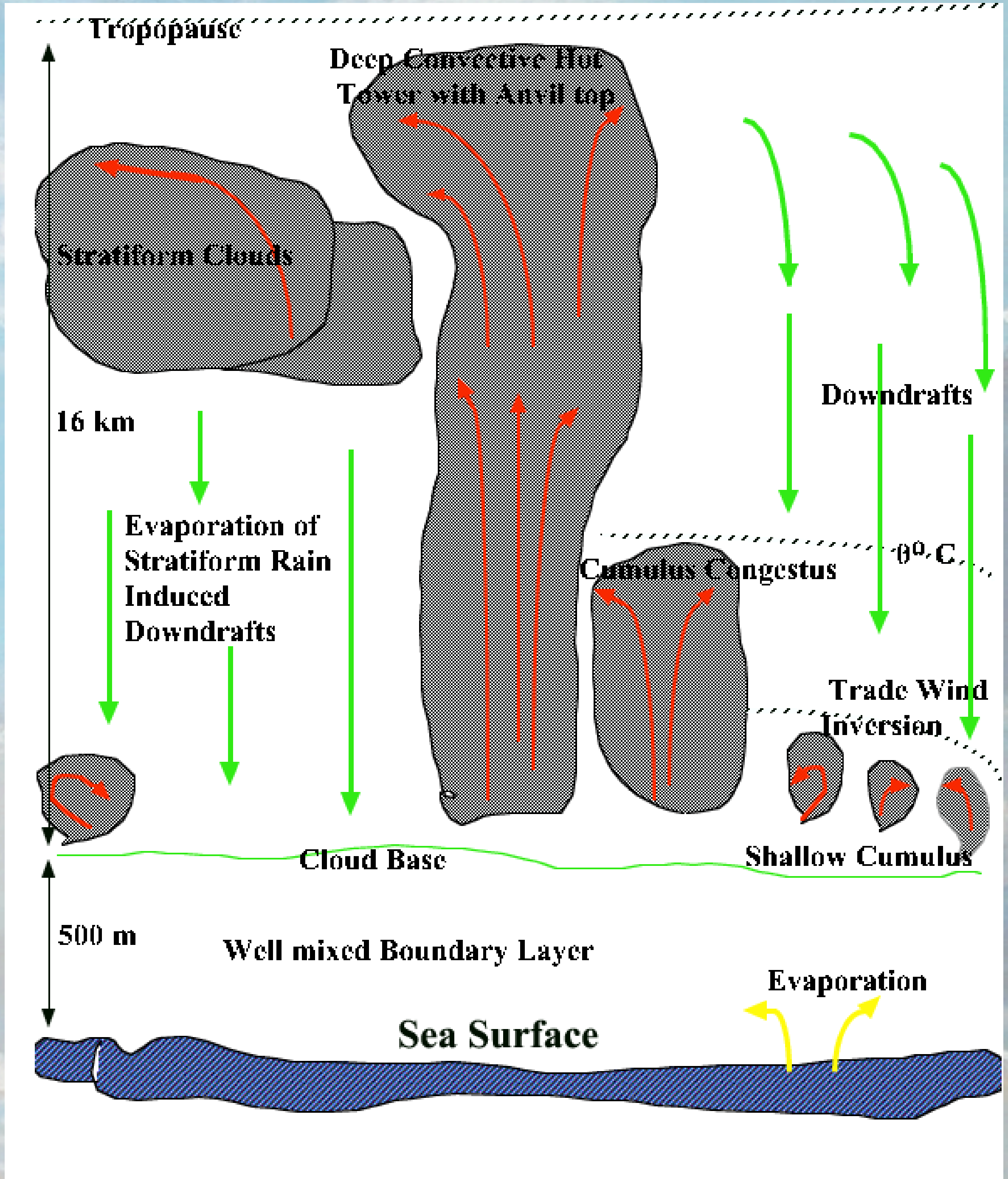
Specific Research Tasks

- Testing MCM parametrization in monsoon environment-like in aquaplanet setting
- Zonally symmetric simple stochastic model to diagnose and understand northward propagation mechanism and statistics of cloud-type distribution
- Implementation and testing of the stochastic multicloud model in CFS
    - ➡ Using prescribed heating profiles as currently implement in aquaplanet model
    - ➡ Comprehensive bulk mass flux parametrization

Background

- Mulitcloud model is based on three cloud types, congestus, deep, and stratiform, observed to characterize convective systems of all scales
- When lower troposphere is dry model makes congestus clouds and deep convection is inhibited
- Congestus clouds then precondition the environment for deep convection in various ways
- Stratiform clouds lag deep convection
- Prescribed heating profiles then force the first two baroclinic modes, important for synoptic and planetary scale tropical waves
- Captures well CCWs and MJO in simple models and aquaplanet GCMs

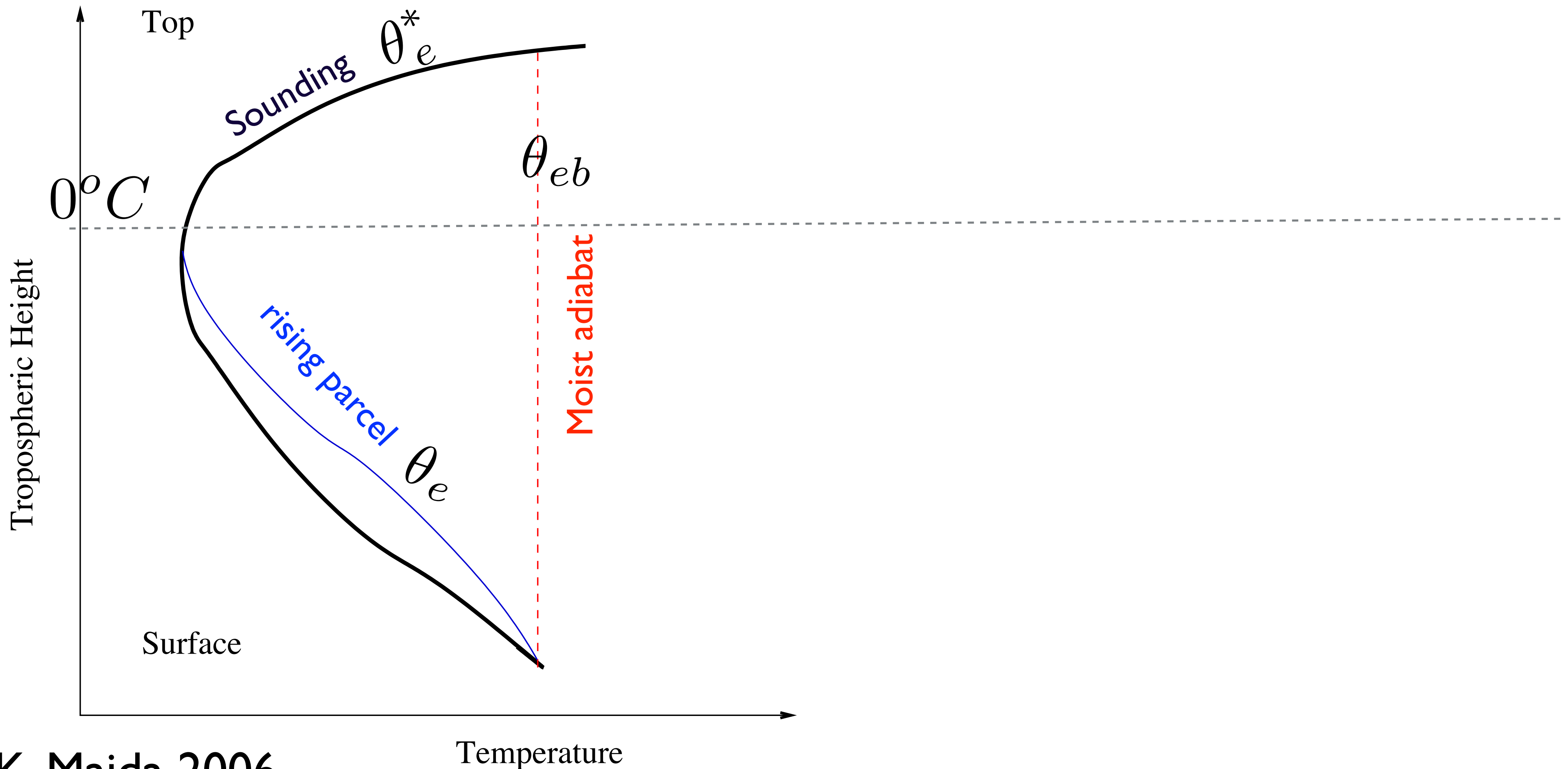
The Three cloud model: An idealized picture



K. Majda 2006

Dilute parcel lifting

Dry environment

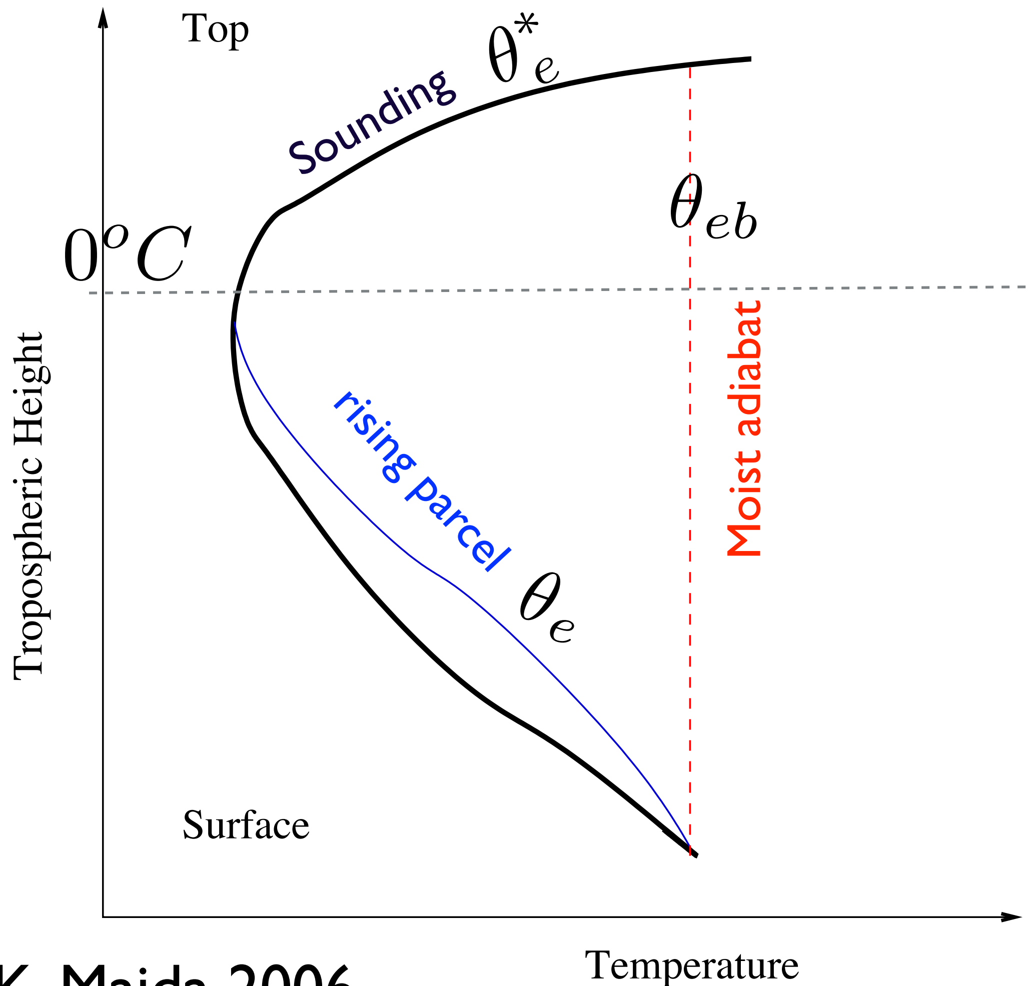


K. Majda 2006

Dilute parcel lifting

Dry environment

Moist environment

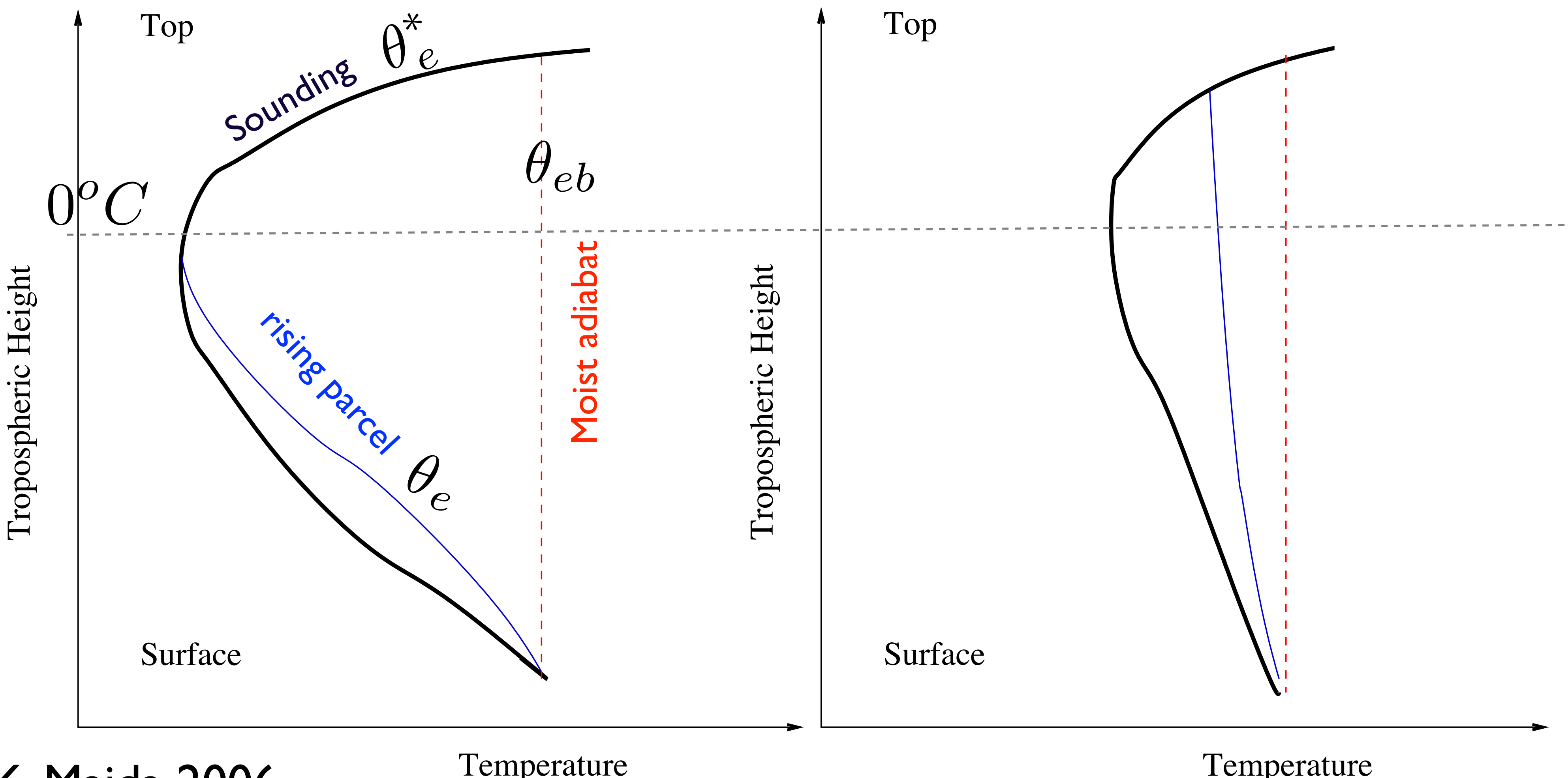


K. Majda 2006

Dilute parcel lifting

Dry environment

Moist environment

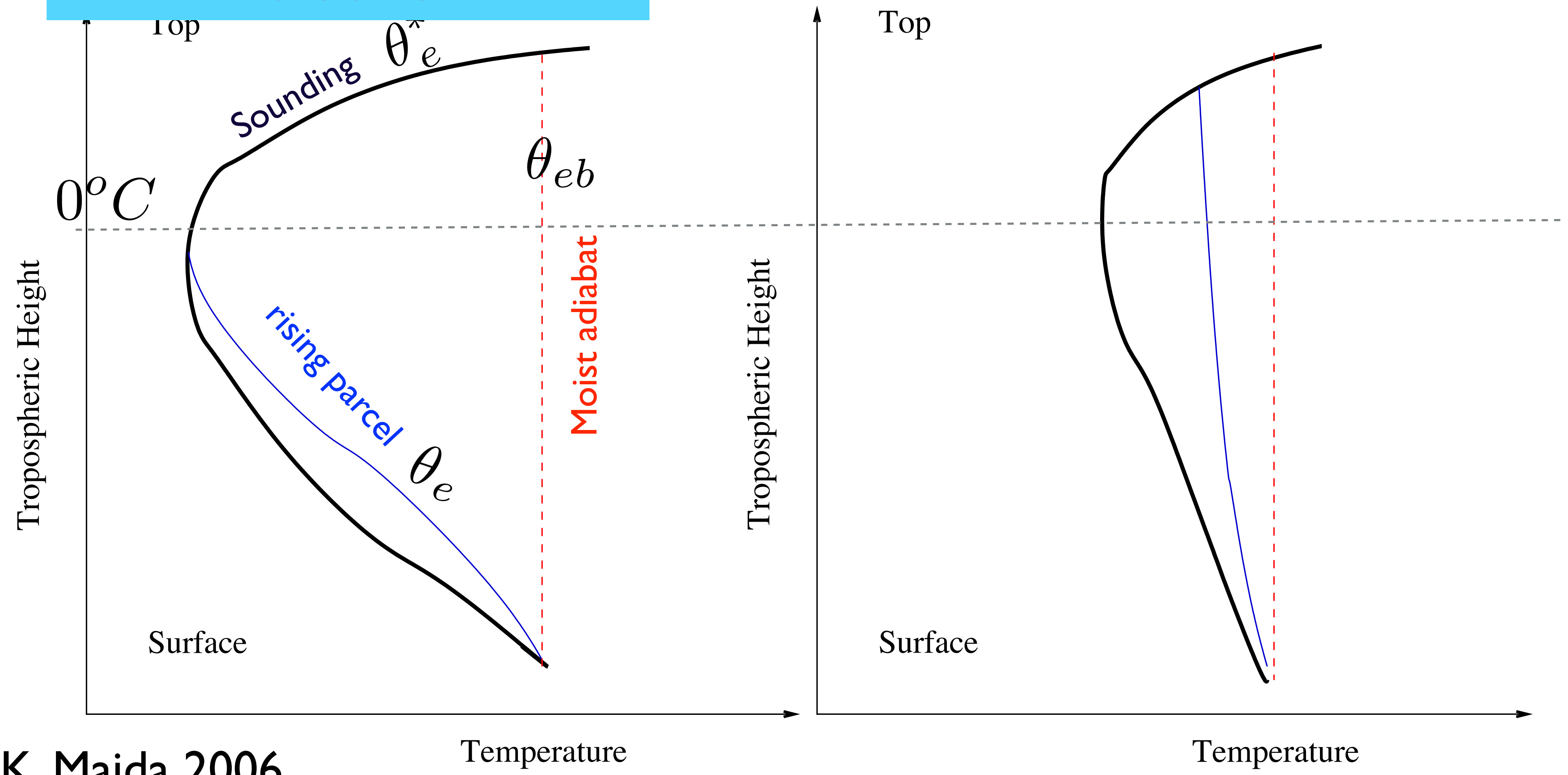


K. Majda 2006

Dilute parcel lifting

Dry troposphere with positive CAPE favors congestus clouds

Moist environment

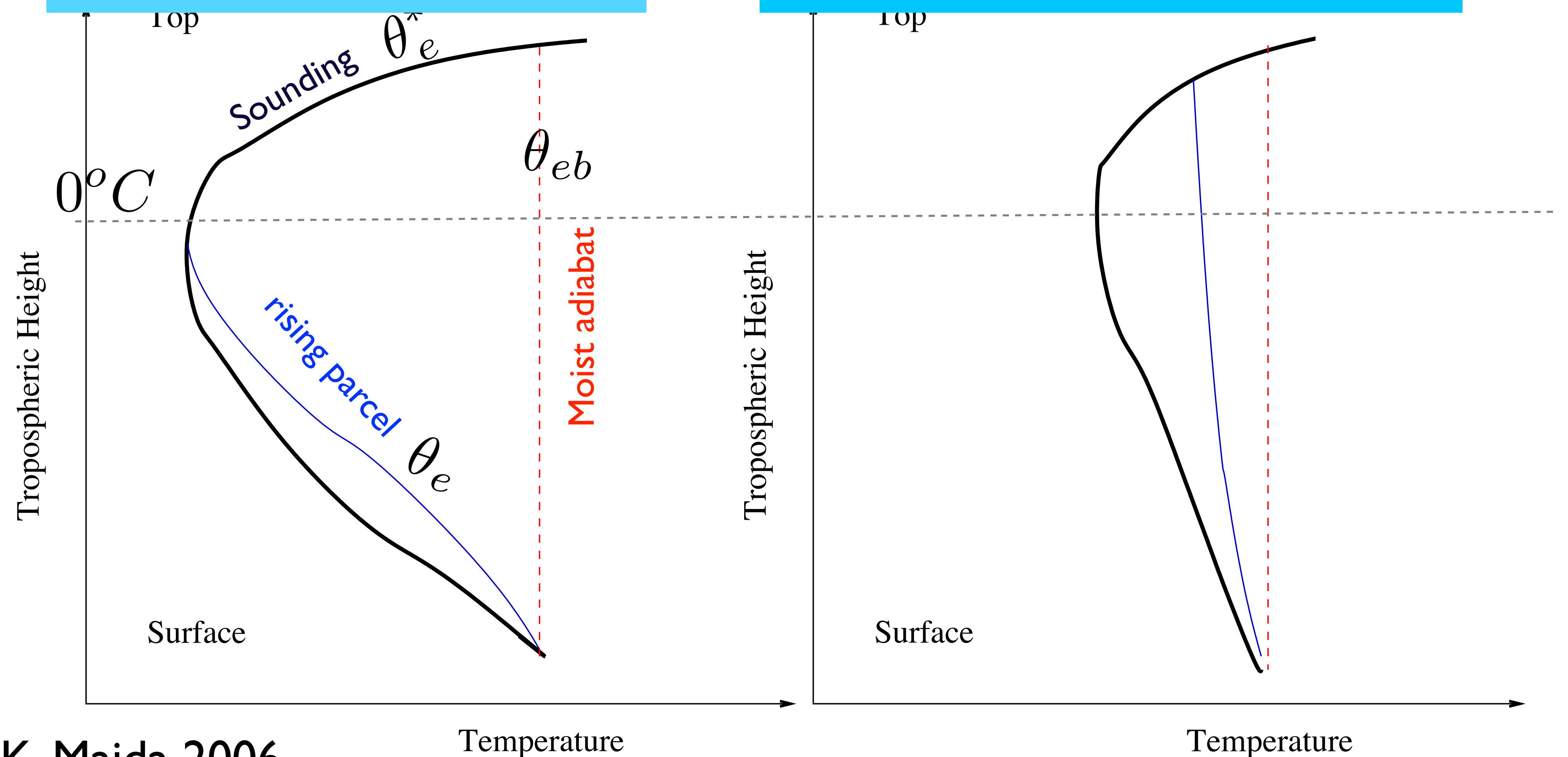


K. Majda 2006

Dilute parcel lifting

Dry troposphere with positive CAPE favors congestus clouds

Deep convection is allowed (beyond freezing level) when troposphere is moist

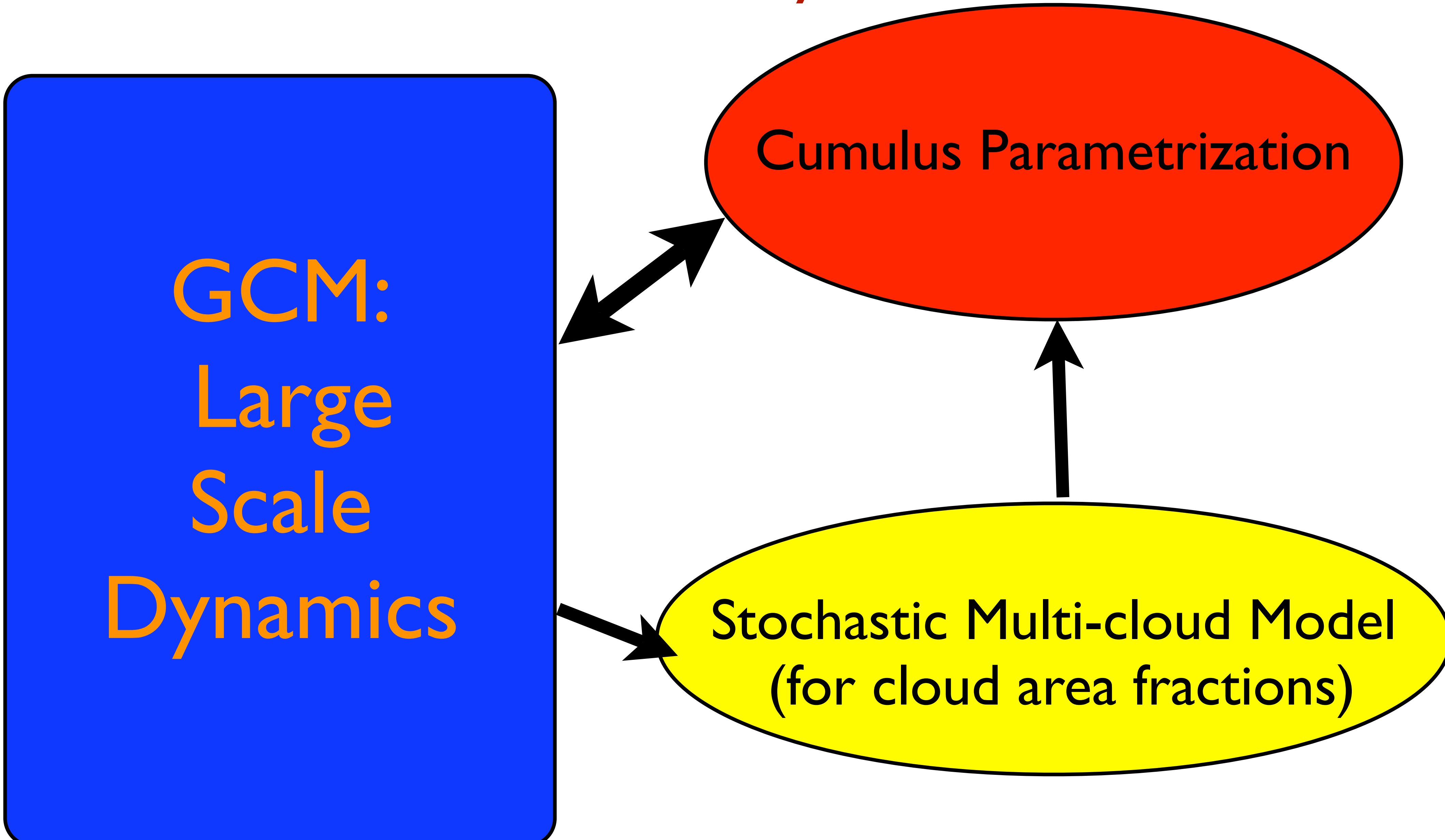


K. Majda 2006

The stochastic multicloud model

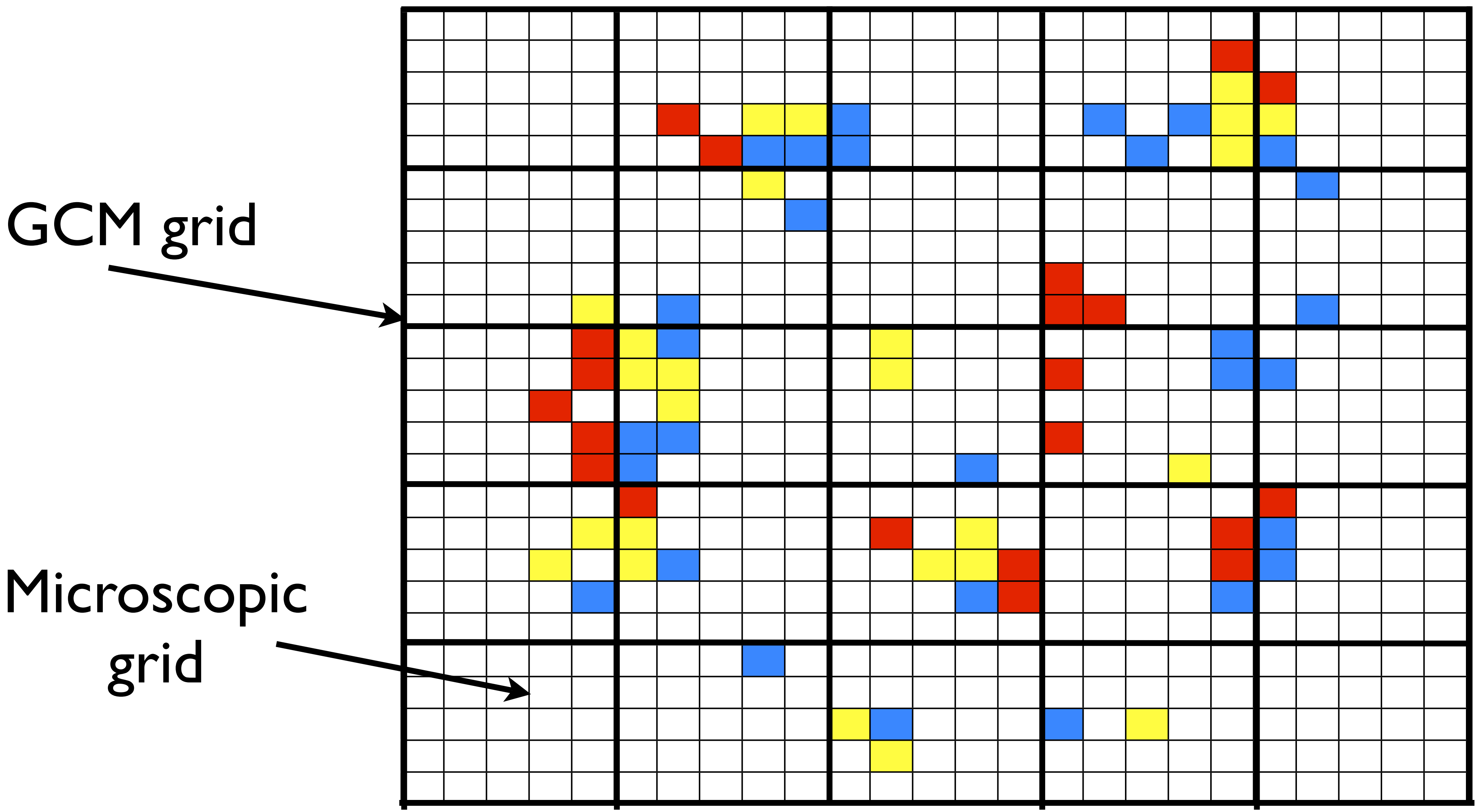
- Multi-type particle interacting Markov process on a lattice whose sites takes values 0,1,2,3 depending on it is clear sky or it is occupied by a cloud of one of the three types: Congestus, deep, or stratifrom
- Intuitive probability rules are used to make transitions from one state to another depending on the environmental conditions
- Unlike column based traditional parametrization, in addition to specifically representing the key three cloud types, the Markov chain induces across grid communications; these features together contribute to facilitate the interactions across multiple time and spacial scales

Stochastic Multi-cloud Model to inform cumulus parametrization: represent the missing sub-grid scale variability



Lattice Model for Convection

University of Victoria

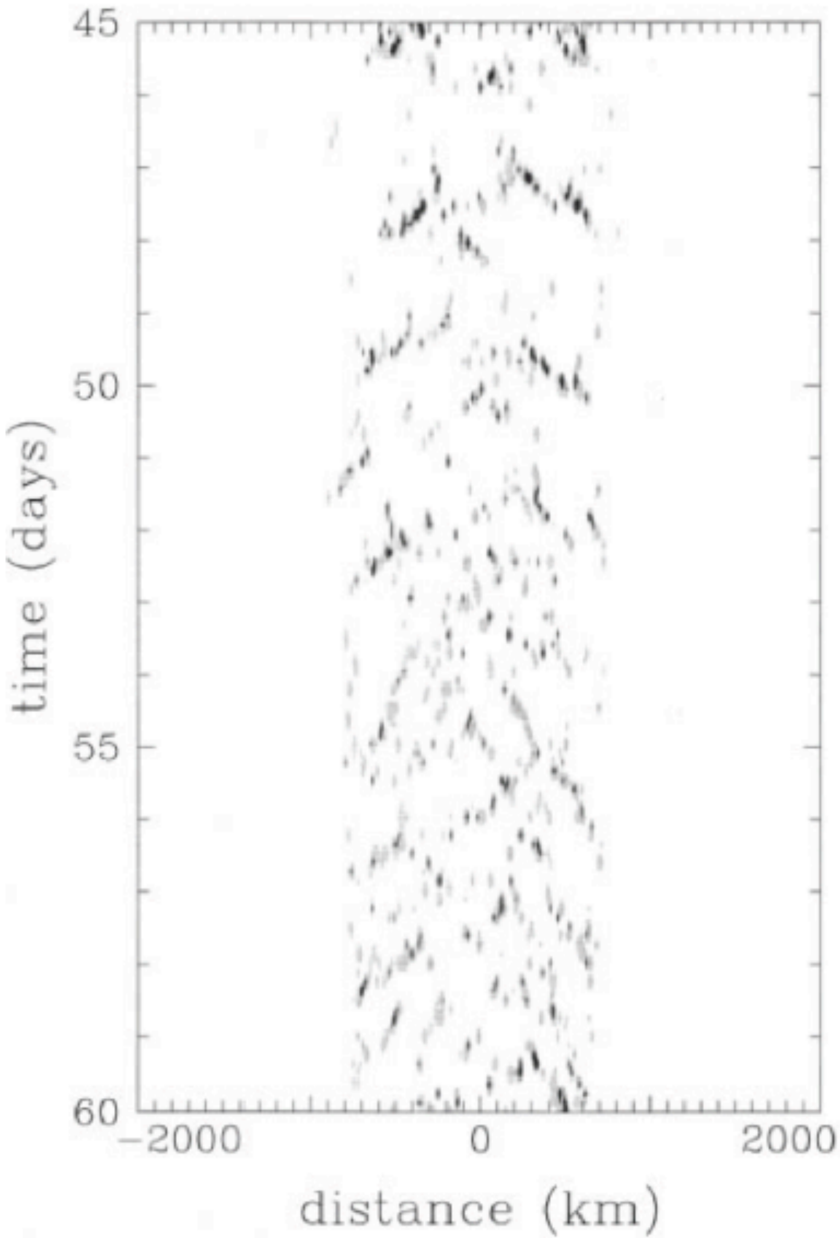


Grid-to-grid communications are possible through nearest neighbour stochastic interactions

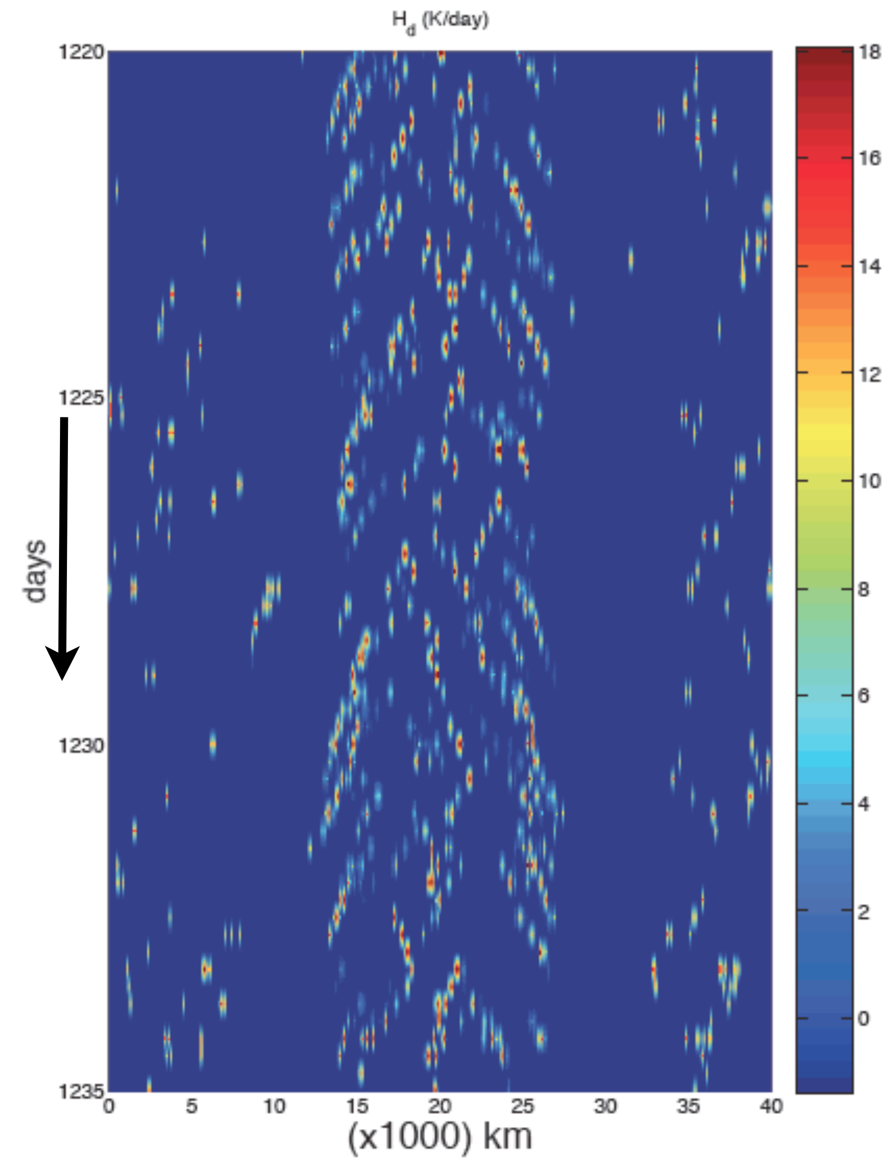
Warm Pool Simulation using the stochastic MC Model

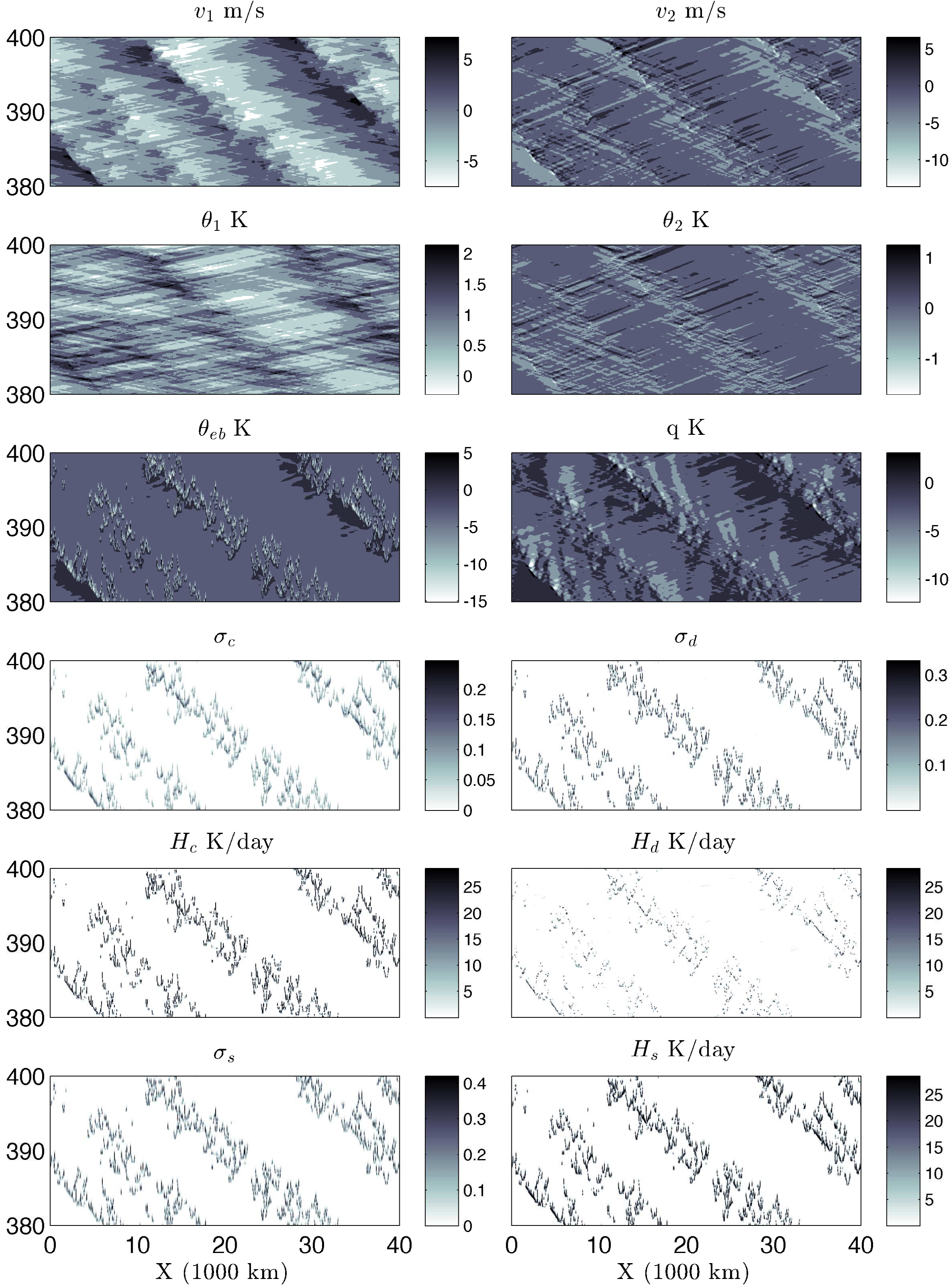
University of Victoria

CRM (Grabowski et al. 2000)



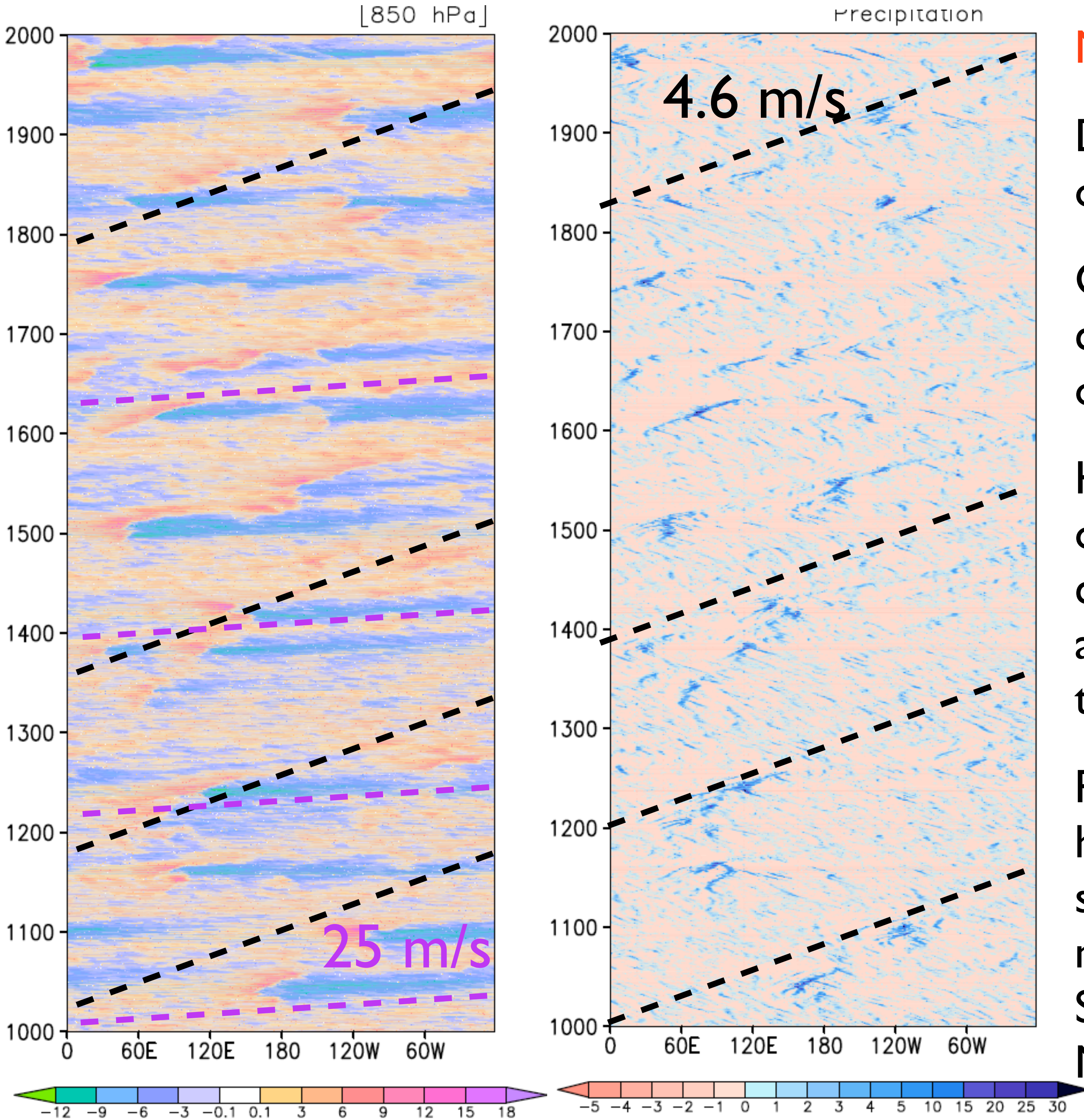
Stochastic MC (Frenkel, Majda &K., 2012)





Diagnostic (Lag) Stratifrom Closure n=100:

Waves are more organized, less chaotic, and locked. Close to mean field limit-deterministic behaviour...forced convection "regime"



MJO in Warm Pool

Dry Kelvin Waves outside warm pool

Circle the glob and coincide with initiation of succeeding MJO...

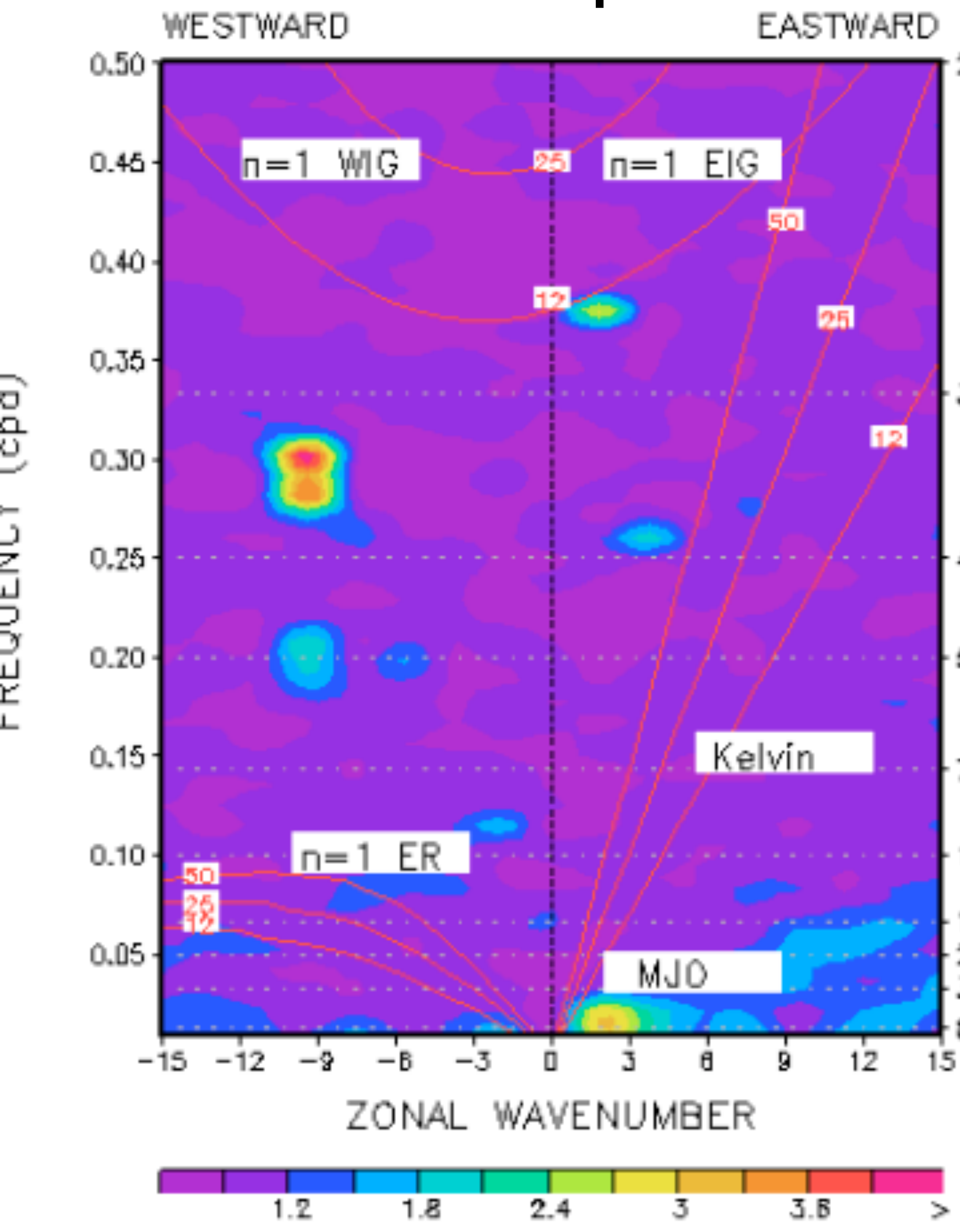
Helps organize otherwise chaotic convective mesoscale and synoptic waves on the planetary scale...

Projects onto a hypothetic MJO skeleton /Moisture mode (Majda and Stechmann, Sobel and Maloney)

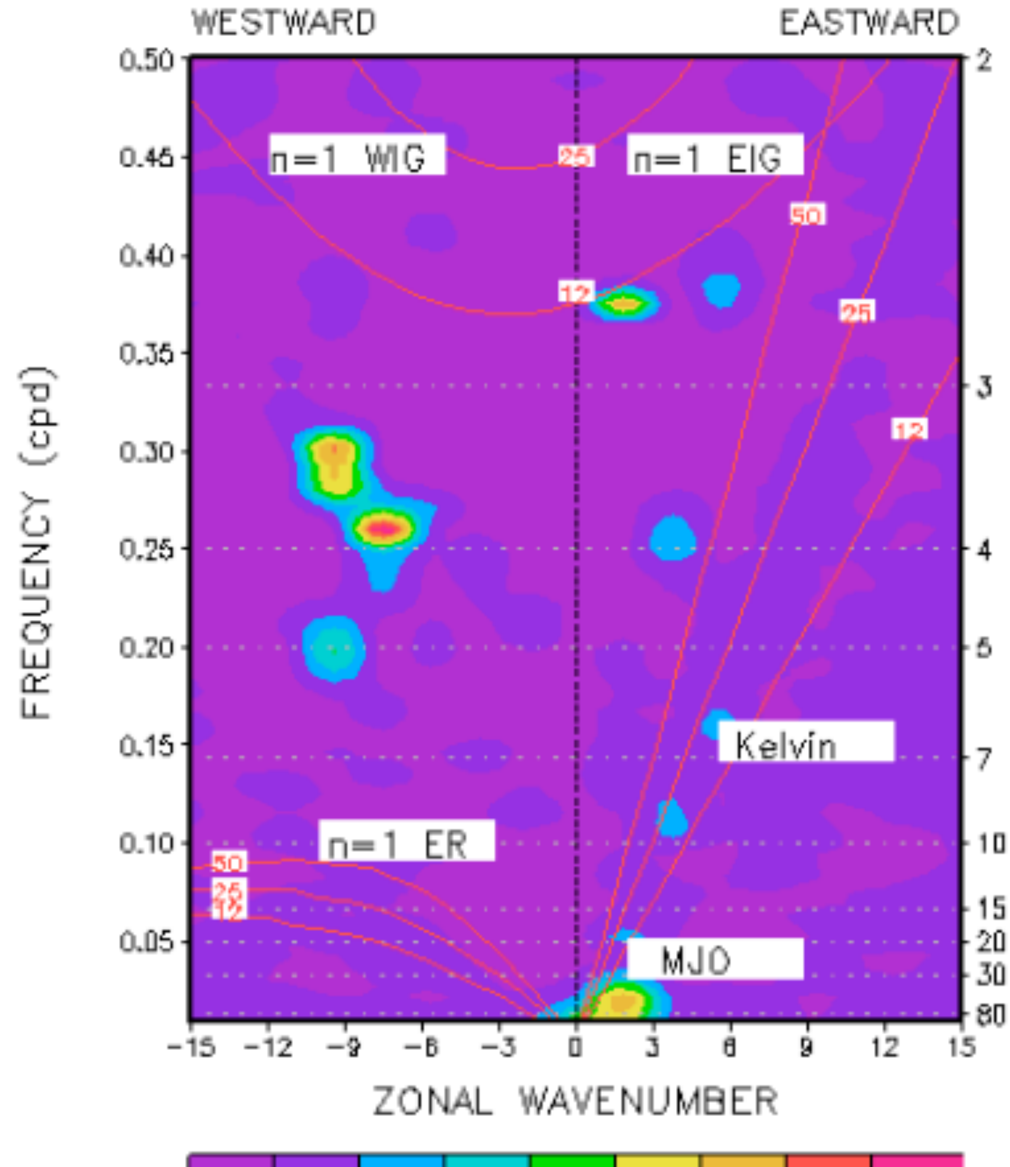
Ajayamohan et al. 2013 (GRL)

Spectral Analysis

Precip.



U (200 hPa).



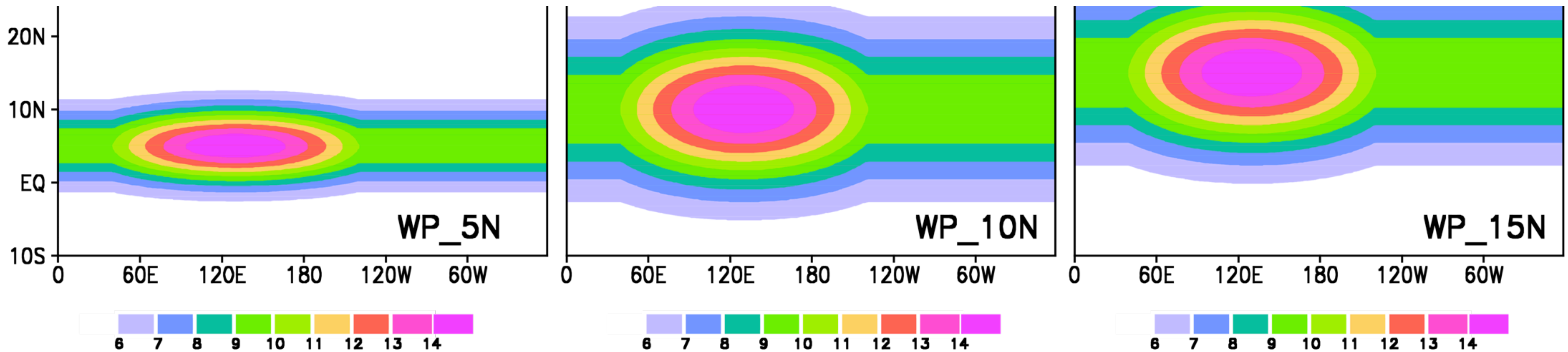
Ajayamohan et al. 2013 (GRL)

Progress Achieved

- Test of multicloud parametrization in monsoon environment in Aquaplanet setting
- Work published in:

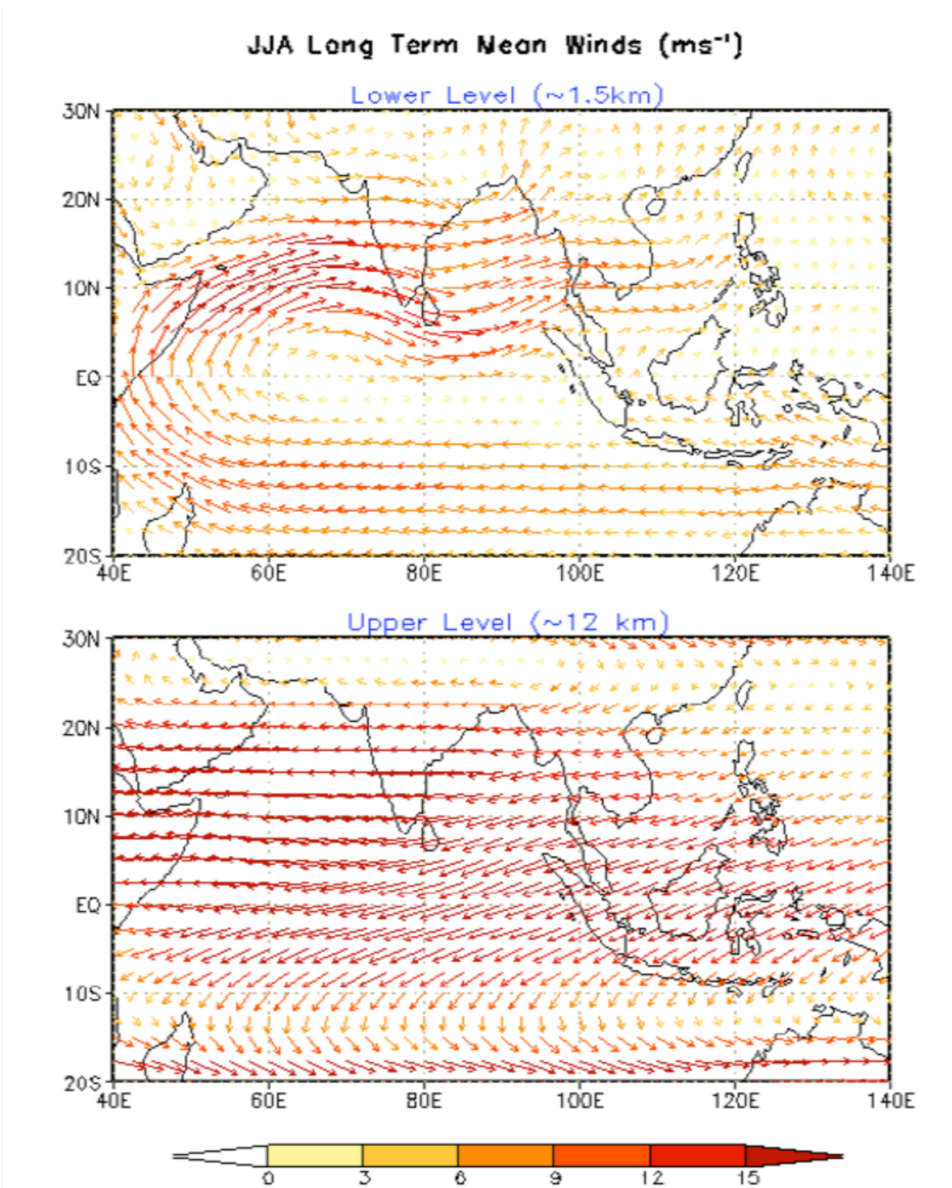
  [R.S. Ajayamohan, B. Khouider, and A. J. Majda, 2014: Simulation of monsoon intraseasonal scillations in a coarse-resolution aquaplanet gcm. Geophys. Res. Lett., 41, 5662-5669, doi:doi:10.1002/2014GL060662]

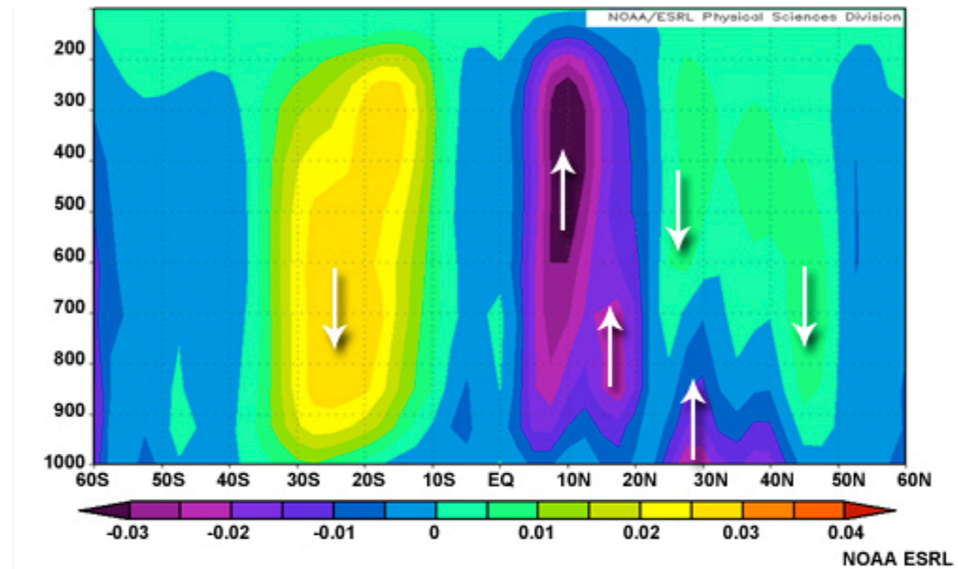
Monsoon Environment



- Off Equatorial heat source mimicking poleward movement of TCZ
- Boreal summer ISO propagates northward at ~ 2 m/s. Monsoon breaks when IO convection is at the Equator. Eastward propagation is also observed at the same time.
- Can MC-HOMME aquaplanet model reproduce these features when the WP is shifted north ?

Observations





- Low level cross-equatorial flow
- south westerlies
- Deep baroclinic vertical structure
- Upper level Easterlies

Simulated climatology

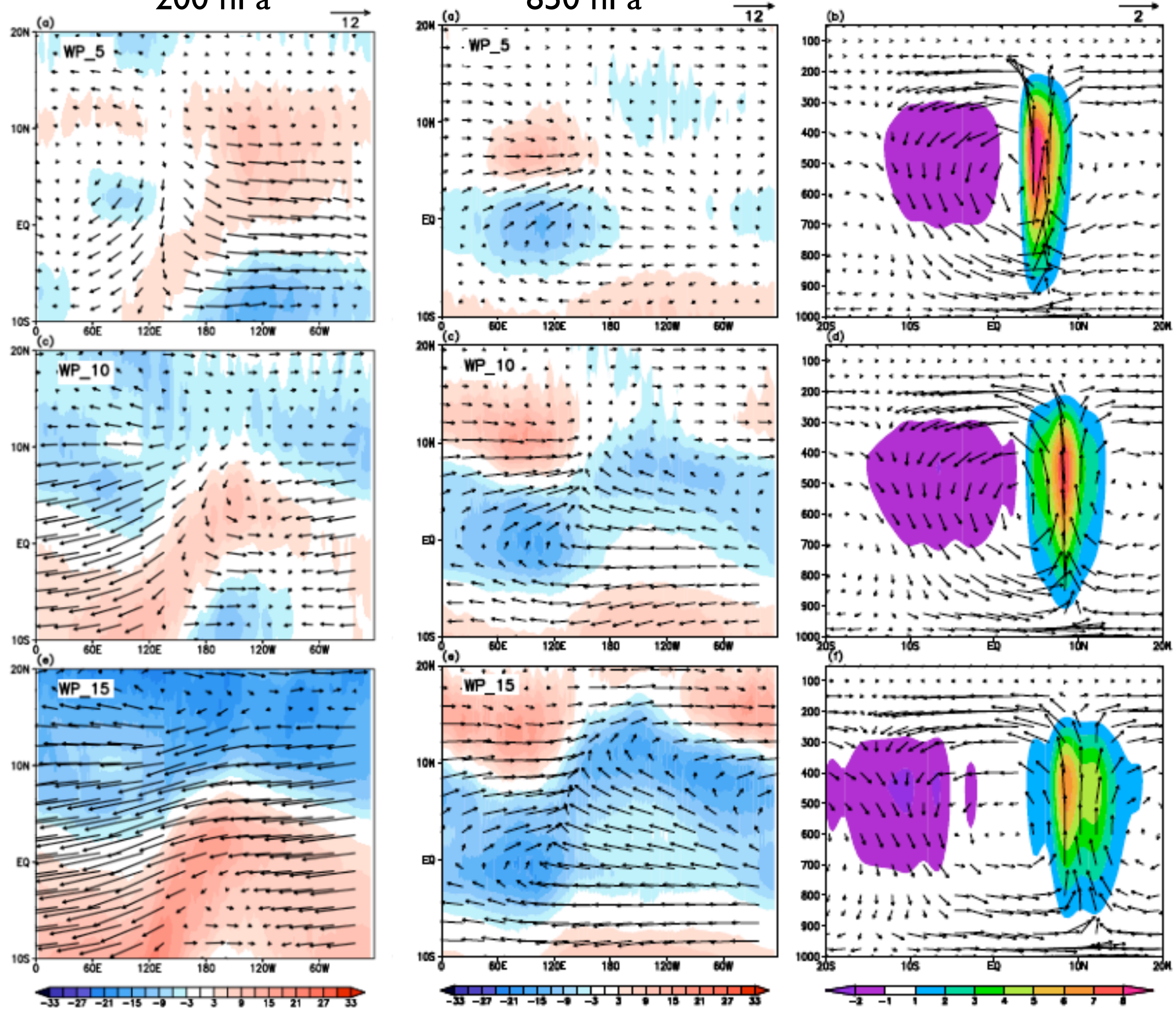
200 hPa

850 hPa

5N

10N

15N



Left: 200 & 850 hPa Horizontal winds and relative vorticity

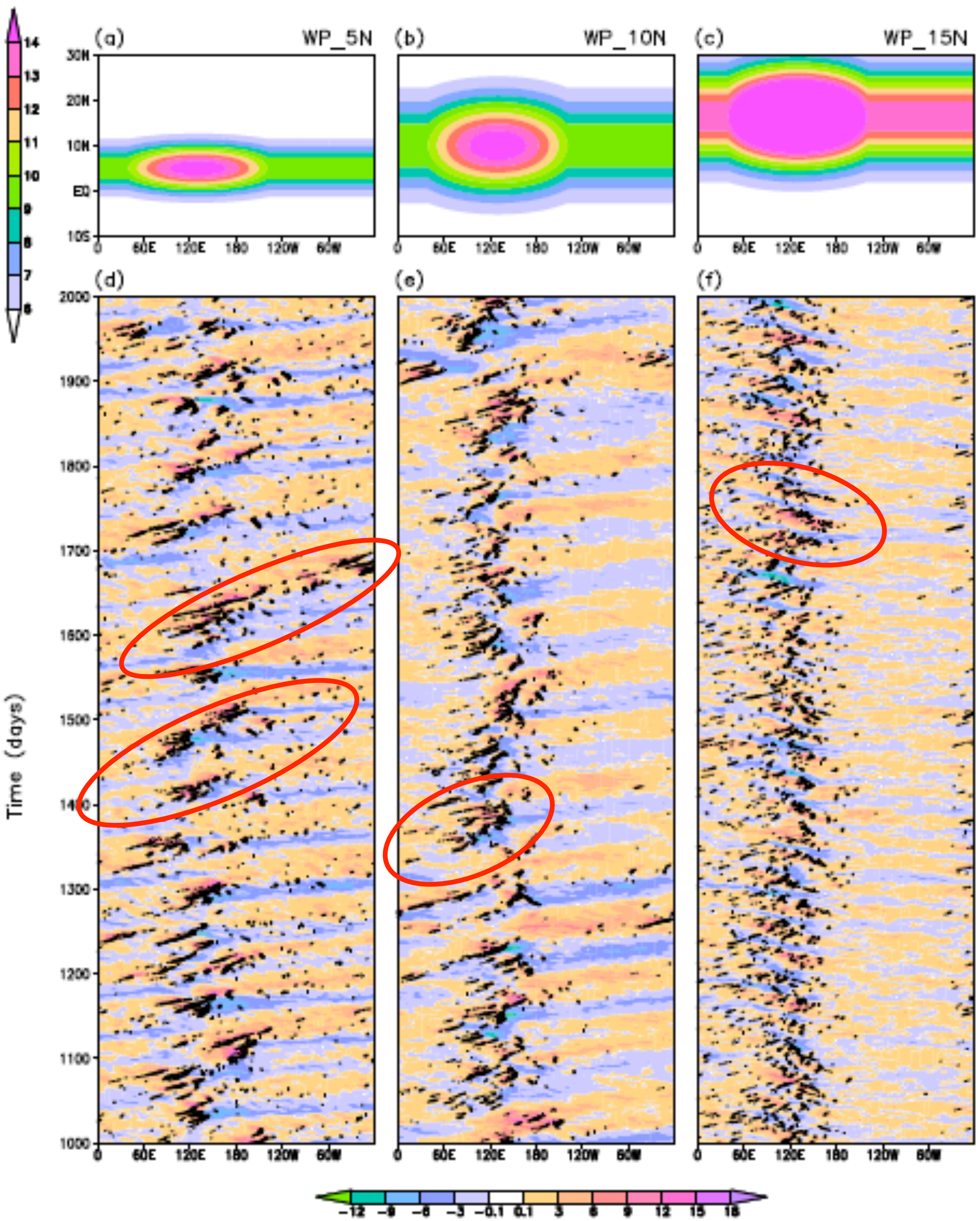
Right: local Hadley cell--vw winds and heating anomalies

Monsoon Trough develops and strengthens as heats source is moved Northward.

Local Hadley cell widens and weakens

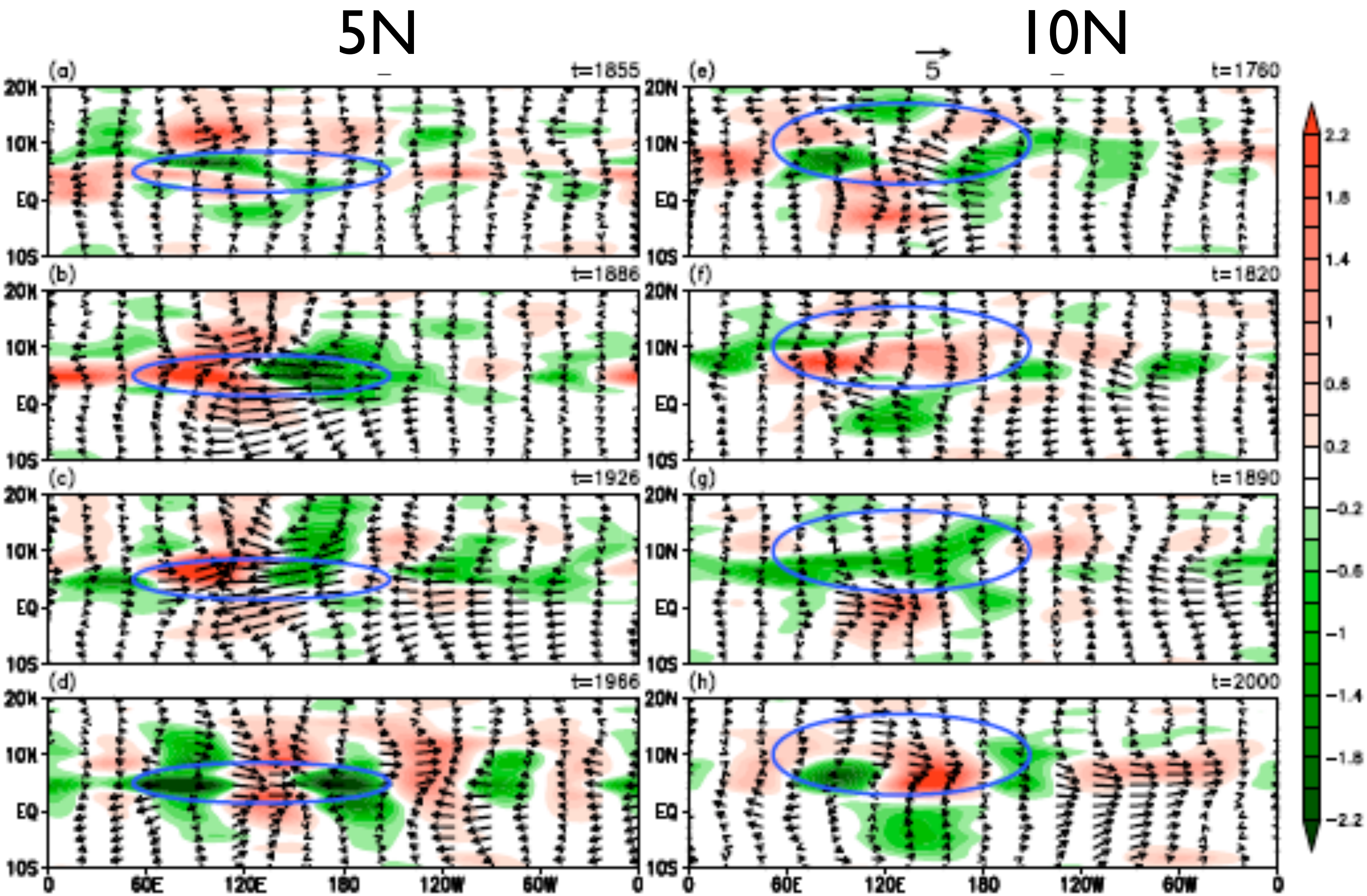
Notice Baroclinic flow

Lon-Time plots of precipitation and 850hPa U



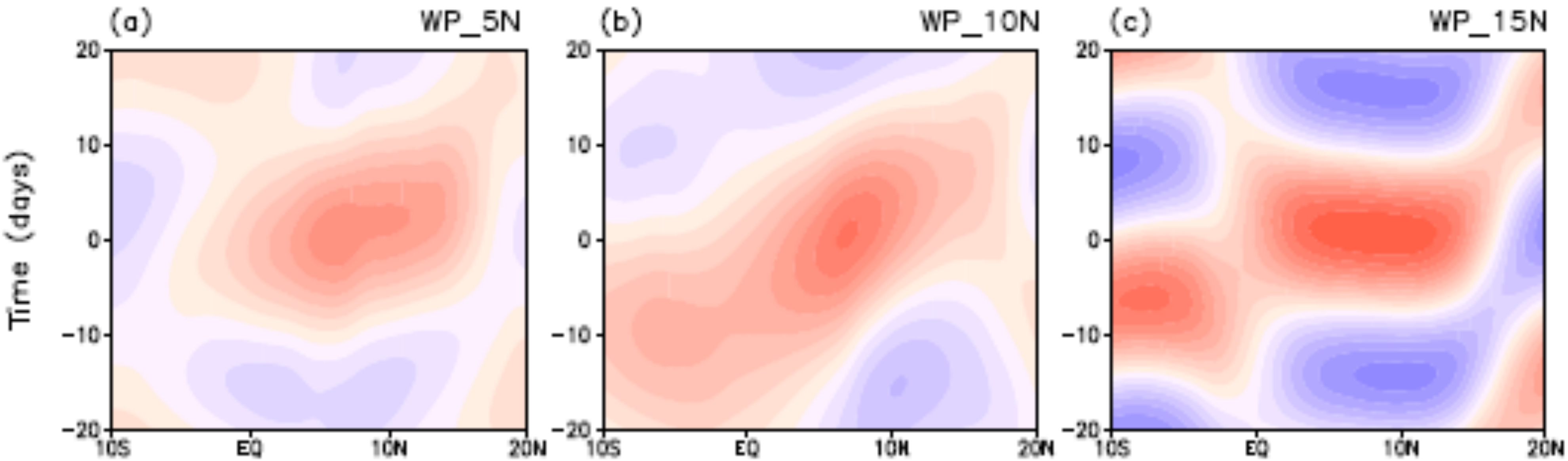
- Successive MJOs for 5N case
- Some Eastward movement for 10N but MJO stall at warm pool peak
- Westward propagation for 15N

Eastward and northward ISO movement

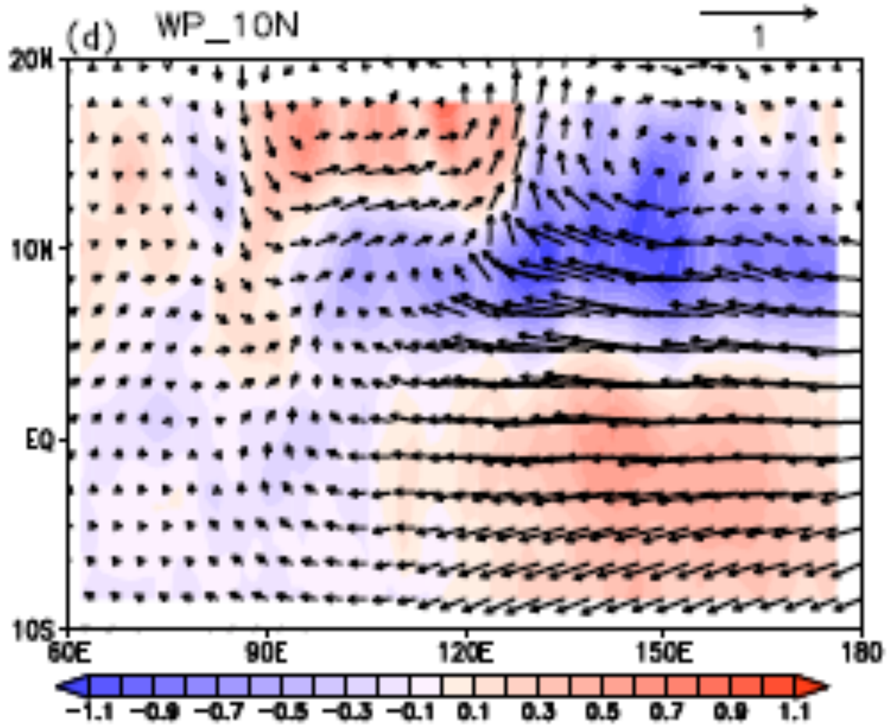


20-100 days filtered precip and 850hPa wind

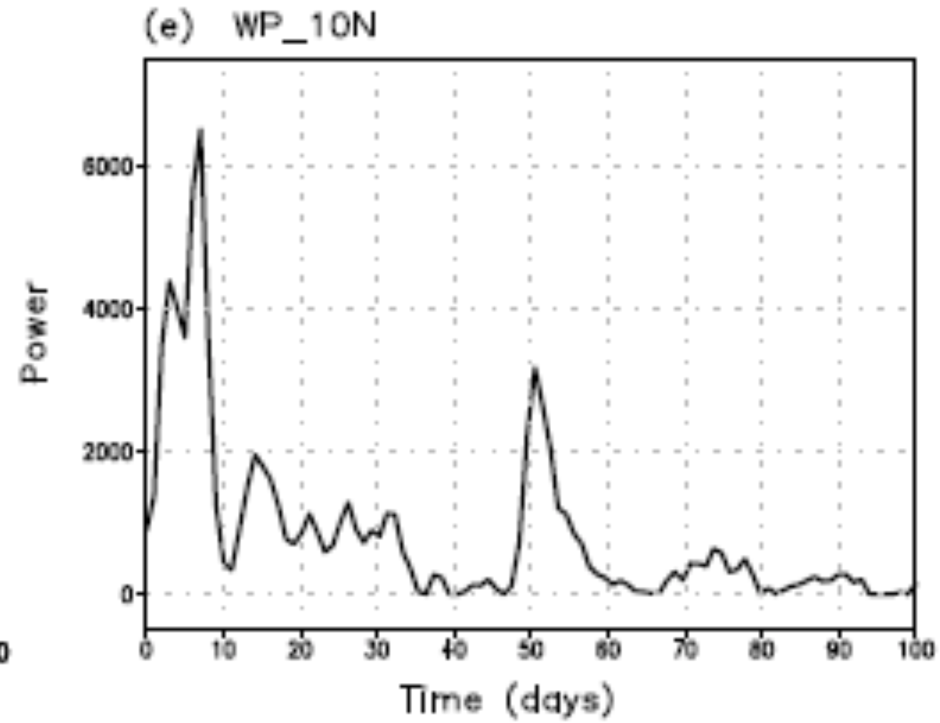
Northward Propagation for 10N case



Intraseasonal oscillating EOF1



EOF 1



Spectral power of PC1

See-Saw Oscillation:Northward/Eastward propagation
Consistent with observation ...
Dry over India when convection is at the equator and vis versa

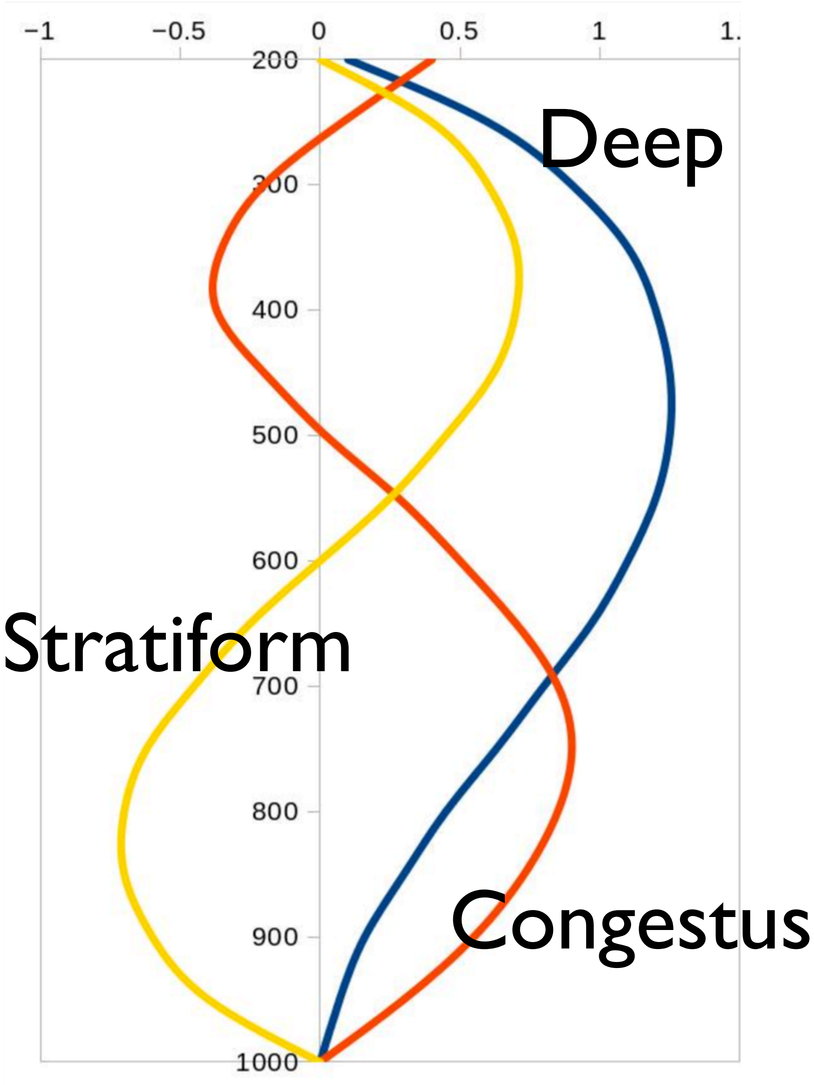
Summary of results

- Multicloud-HOMME model is used as a virtual lab to understand MJO dynamics and climate variability
- Based on building block paradigm of key three cloud types and their interaction with/through mid-level moisture: Congestus clouds precondition mid-troposphere prior to deep convection. Stratiform induced downdrafts play role of cold pools
- Eastward and northward propagation of ISO successfully simulated
- In WP simulation: second baroclinic dry Kelvin waves circling the globe seem to help organize convection to effectively project onto a planetary-scale MJO skeleton/moisture mode
- Northward propagation of ISO is captured under "summer monsoon conditions", suggesting same multicloud and multiscale mechanism as for MJO.
- Absence of mechanisms reported in literature as being important for MJO initiation and/or maintenance: Wave-CISK, WISHE, cloud radiative forcing, extra-tropical influence…

Multicloud Module in CFS: implementation in Progress

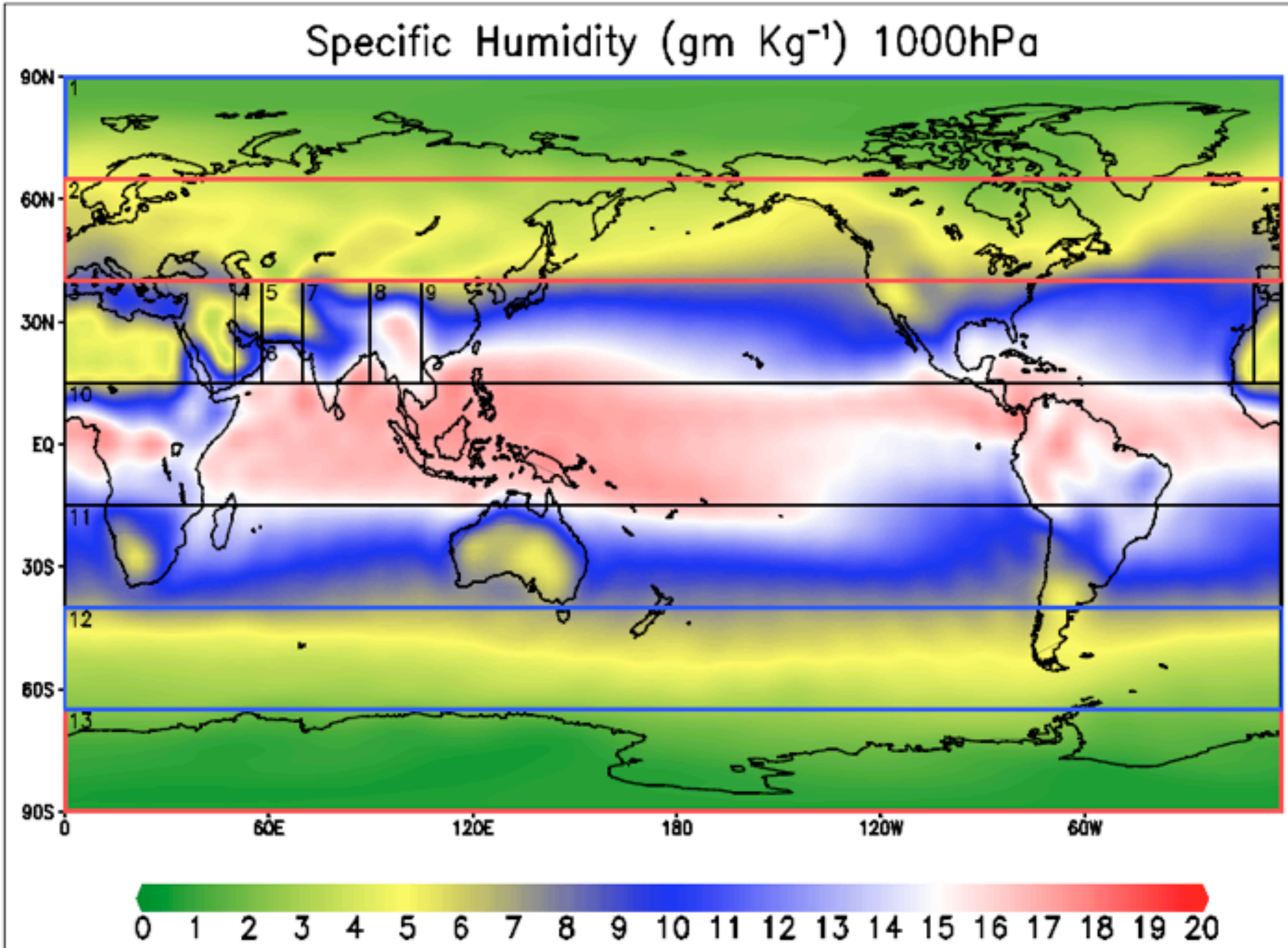
- First and cheapest approach --reproduce aquaplanet success in fully coupled earth system model!
- Choice of heating profiles: Used observed heating profiles instead of theoretically derived ones
- Specify background climatology in lieu of radiative convective equilibrium: 20 year NCEP average. Model deviations from this background are used as input for the multicloud paramaterization ... in spirit of Betts-Miller

Vertical heating profiles



- TRMM Radar (Schumacher et al. ,2004)
- Global reanalysis and TRMM (Ling and Zhang, 2011)

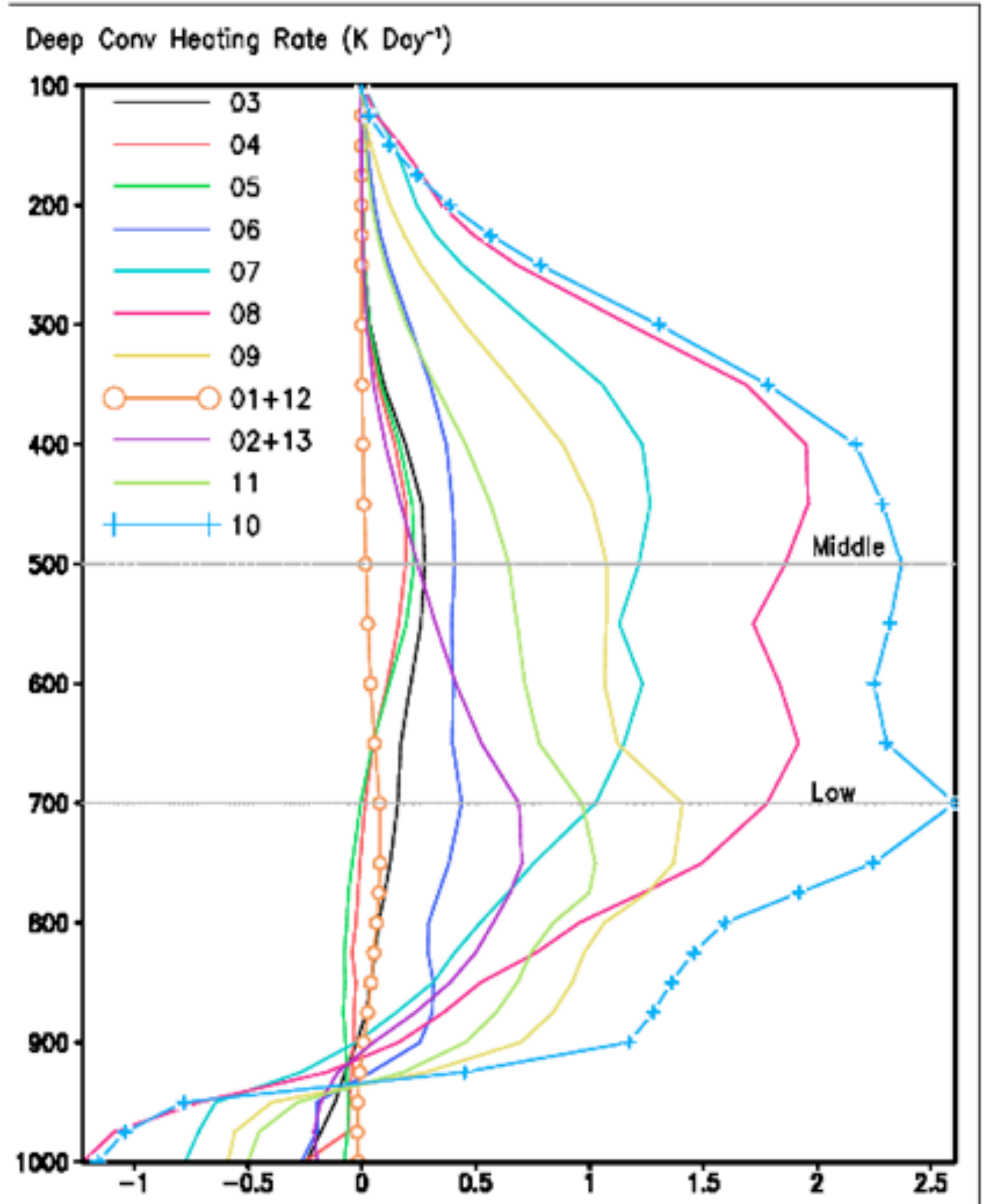
As moisture is the primary contributor in determining atmospheric instability, Specific humidity@1000hPa is chosen for determining the regions.



The middle troposphere is determined so as to include the higher level peak in convective heating (which is a result of the deep clouds) but exclude the lower level peak (which is possibly result of congestus clouds).

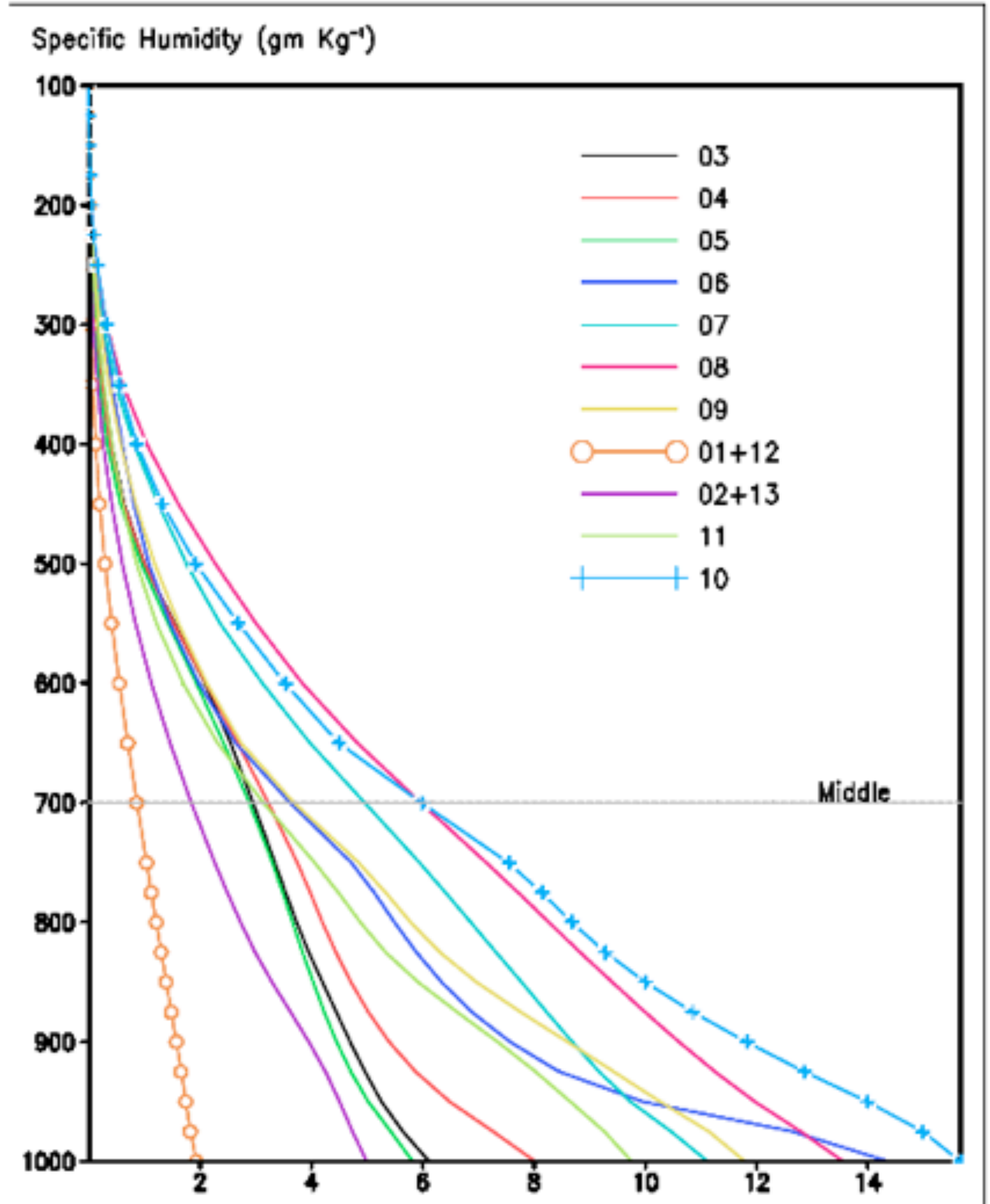
The heating profiles over tropics (line#10) and over the Indian monsoon domain (line#7 & 8) shows double peaked structure indicating abundance of deep and congestus convection. The moisture preconditioning mechanism perhaps is of the maximum relevance in these locations

We have projected these heating profiles on phiD, phiC and phiS to compute the values of Qd_bar, Qc_bar and Qs_bar.



Consistent with the heating profiles, tropics (line#10) and the Indian monsoon domain (line#7 & 8) shows maximum moisture indicating the ample moisture supply due to warm SST.

Noteworthy that, Antarctica (box-13) is more moist than southern hemisphere mid-latitude (box-12) and Arctic. This is in spite of the fact that Arctic is relatively warmer than the Antarctica (!!!). The moisture over the Antarctica may be is carried by the storms which form at the frontal boundary between cold Antarctic air mass and the mild mid-latitude maritime airmass.



BOX#	Qd_bar	Qc_bar
3	0.168940	0.004775
4	0.098031	-0.051966
5	0.102230	-0.054076
6	0.371620	0.045237
7	0.808590	0.541010
8	1.412300	0.654890
9	1.048700	0.138780
10	2.037700	0.482470
11	0.665480	0.139820
1+12	0.024607	0.039495
2+13	0.250090	0.330140

Significant congestus heating in tropical belt (Box#10) and some land regions like continental India (B#7) and China (B#8)!

$$H_d = (1-\Lambda)\max(\bar{Q}_d + \frac{1}{\tau_q}(q-\bar{q})_m + \frac{1}{\tau_c}(\theta_{eb} - a_0(\theta-\bar{\theta})_m), 0)$$

$$H_c = \Lambda \max(\bar{Q}_c + \frac{1}{\tau_c}({\theta'}_{eb} - \theta{*'}_{em}), 0)$$

Planned and Ongoing Activities

- Couple multicloud module and test in CFS
- Include stochastic element into multicloud module in test in CFS
- While heating profiles are physically meaningful, the use of background climatology has some limitations ...
- Test comprehensive bulk mass flux parametrization with multicloud stochastic area fractions (BMF-SMCM) in stand alone and in aquaplanet mode
  - ➡ *Incorporates multicloud paradigm*
  - ➡ *Sensitive to environmental conditions, moisture*
  - ➡ *Across grid communication*
- Implement and test BMF-SMCM in CFS