GPM (CSH) Latent Heating Retrieval

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Improvement of the Goddard Convective/Stratiform Heating (CSH) Algorithm for GPM - Tropics

Development of the Goddard Heating Algorithm for GPM - high latitude (Extra Tropics)

GPM CSH-LH (V5) products

Goddard CSH: Convective – Stratiform Latent Heating (Tao, Lang)
SLH: Spectral Latent Heating (Takayabu, Shige)

CRM Simulated Q_1 Budget

LH: Latent Heat - phase change of water

$$Q_1 - Q_R = \bar{\pi}[-\frac{1}{\bar{\rho}}\frac{\partial \bar{\rho} w'\theta'}{\partial z} - \vec{V}' \bullet \nabla\theta'] + \frac{L_v}{C_P}(c-e) + \frac{L_f}{C_P}(f-m) + \frac{L_s}{C_P}(d-s)$$

Q1R= Q_1-Q_R

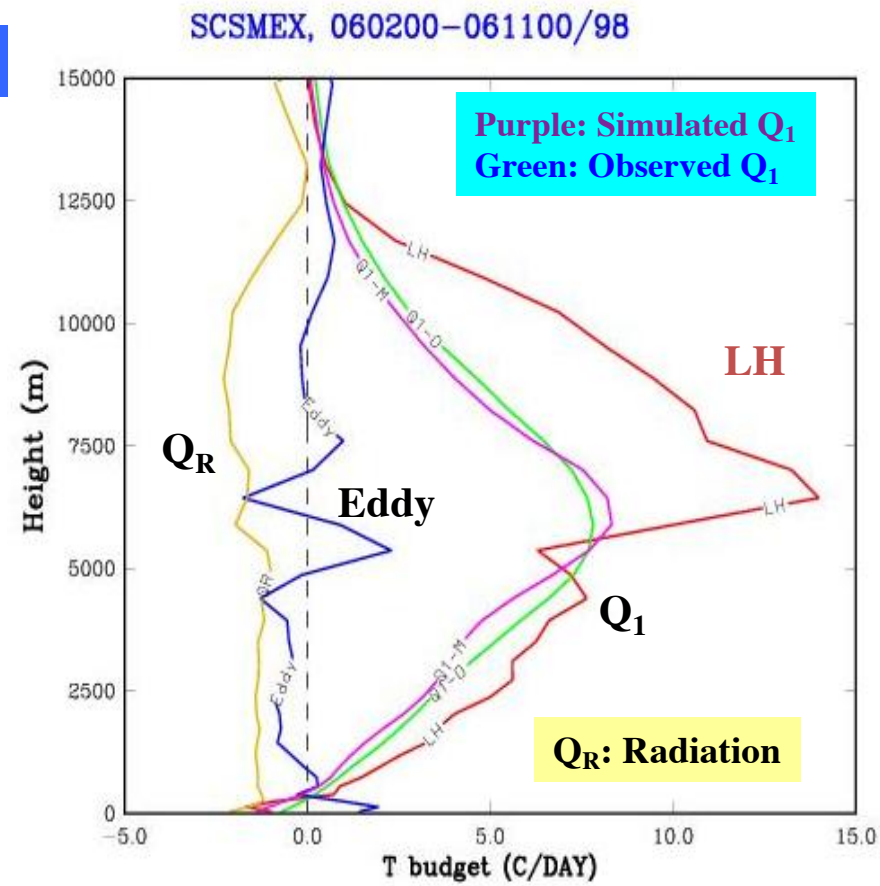
Eddy - heat transport by cloud dynamics

$$\frac{1}{g}\int_{Lx}\int_{Ptop}^{P_{base}}(Q_1 - Q_R)\Delta p \Delta x = LP_o + S_o$$

Rainfall + Sensible heat fluxes

Sounding Estimated Q_1 Budget
(Yanai *et al*. 1973)

$$Q_1 = \bar{\pi}[\frac{\partial\bar{\theta}}{\partial t} + \bar{V} \bullet \nabla\bar{\theta} + \bar{w}\frac{\partial\bar{\theta}}{\partial z}]$$



- **Role of convection in tropical intraseasonal variability and quasi-stationary circulation/ITCZ/MJO**
- **Improvement/Validation of Cumulus parameterization in GCMs/Climate Models**

GPM Standard LH Products (2017)

	Spatial Scale	Temporal Scale	Algorithm	Name
Gridded	0.25 x 0.25 degree 80 vertical layers	Monthly	SLH-DPR CSH-Combined	3GCSH
Orbital	Pixel 80 vertical layers	Instantaneous	SLH-DPR CSH-Combined	2HCSH
Gridded Orbital	0.25 x 0.25 degree 80 vertical layers	Instantaneous Time Stamps on each grid	SLH-DPR CSH-Combined	3HCSH

Goddard Convective-Stratiform Latent (CSH) Heating Algorithm

Tropical (TRMM area):

Look-up Table improvements (**GCE**, more cases, 4ICE Microphysics)

CSH retrievals are now linearly transitioned as a function of freezing ‘
level height from Tropical (> 4 km) to Extra-tropical (< 3 km) values

Lang and Tao (2017, revised and submitted)

High Latitude (GPM Extra-tropic):

Look-up Table based on 6 **NU-WRF** simulated winter events

Without using convective-stratiform separation

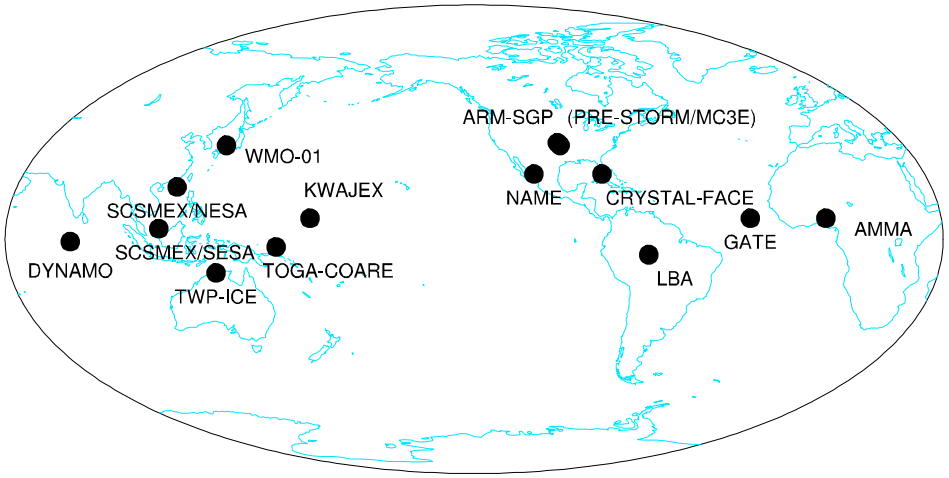
Tao, Lang and Iguchi (2017, to be submitted)

Improved CSH look-up tables for **Tropics**

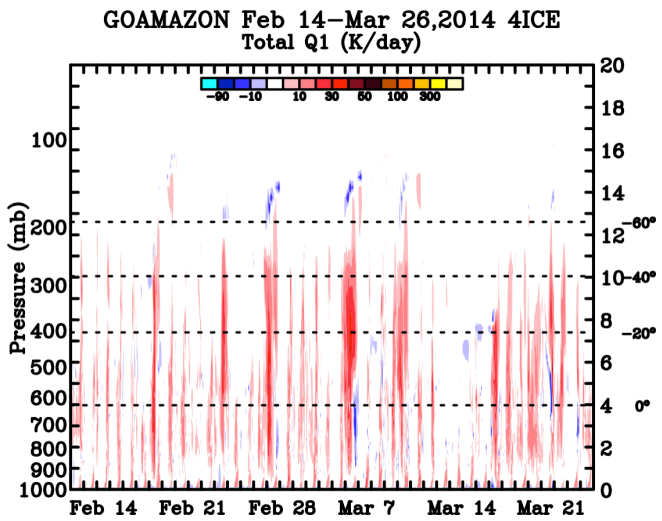
- 4ICE (cloud ice, snow, graupel and hail) scheme
- Large domain and 1 km resolution (better for MCS simulations: Tompkins, 2000; Patch and Gray, 2001; Johnson *et al.* 2002; Ooyama, 2001)
- Additional Cases (MC3E, DYNAMO, GoAmazon)
- Additional categories based on

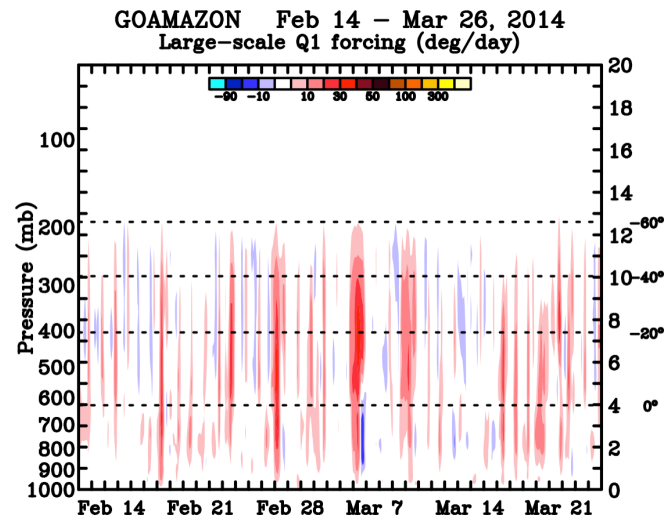
  Echo tops

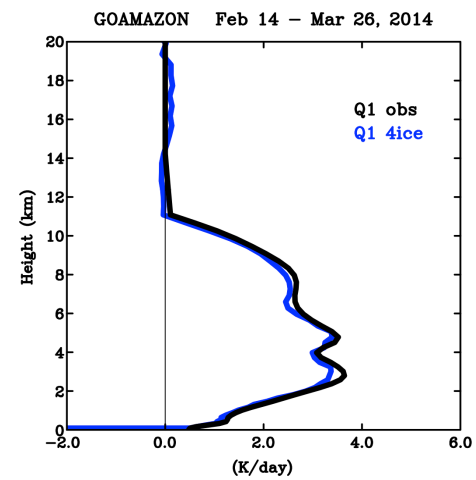
  Low-level dBZ gradient



FIELD CAMPAIGNS



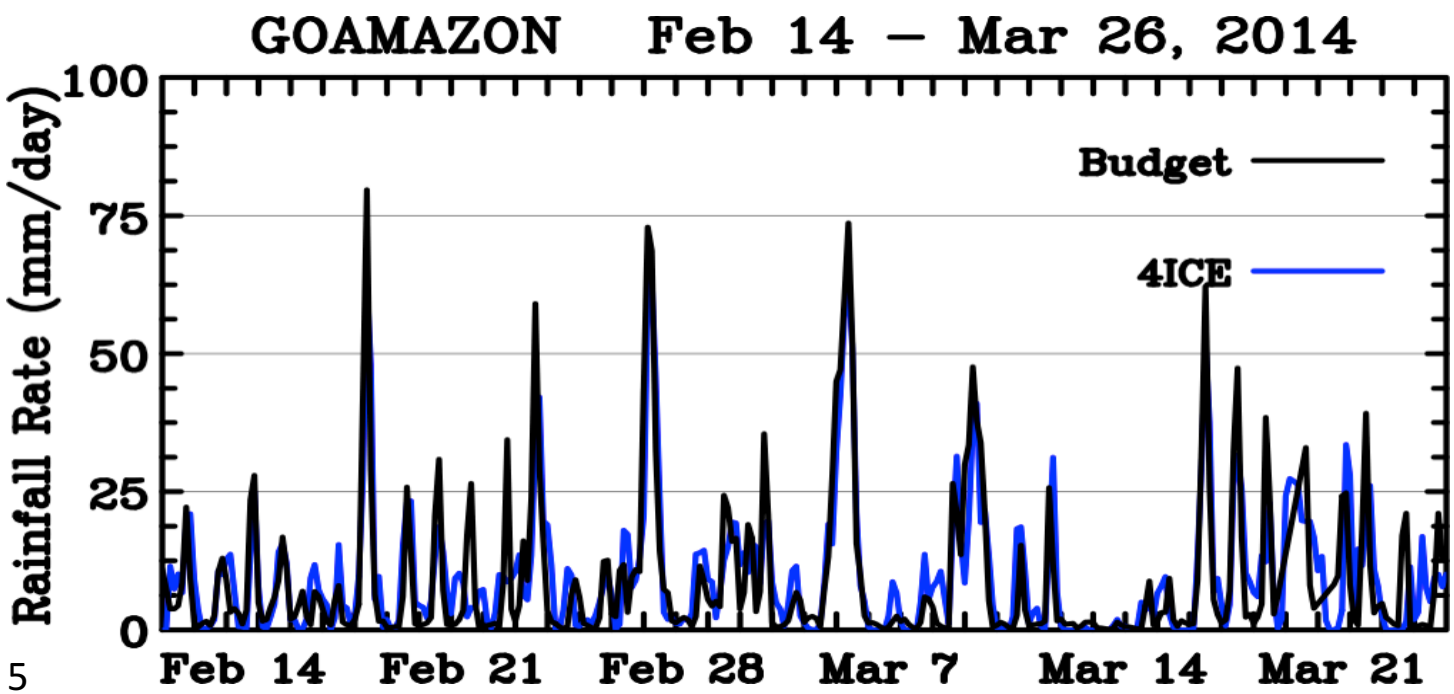




GCE Simulated Q1

Sounding Derived Q1

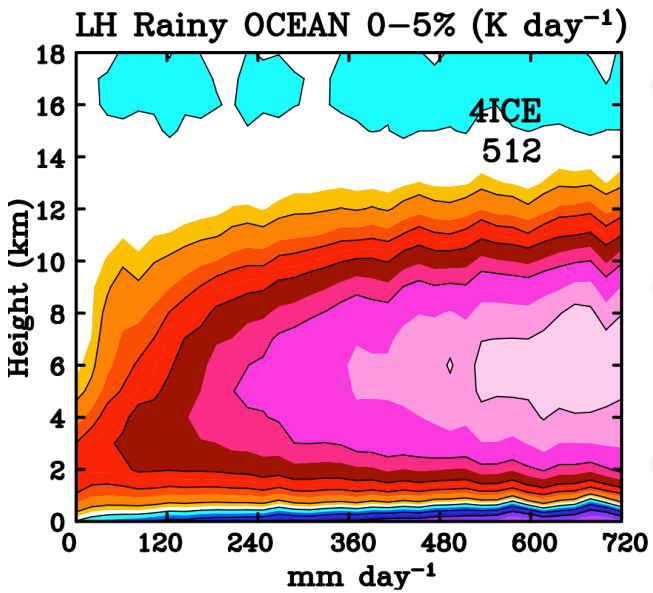
S. America



Time series domain averaged surface rainfall

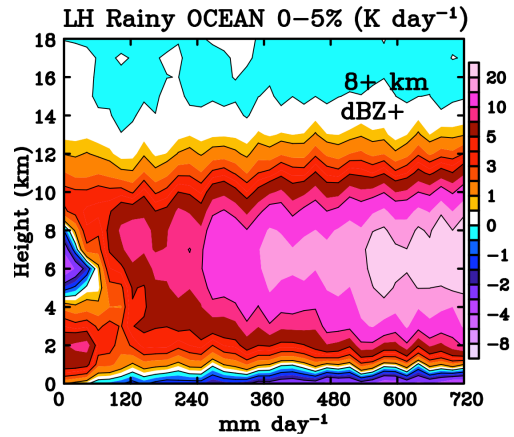
Echo Tops

Ocean

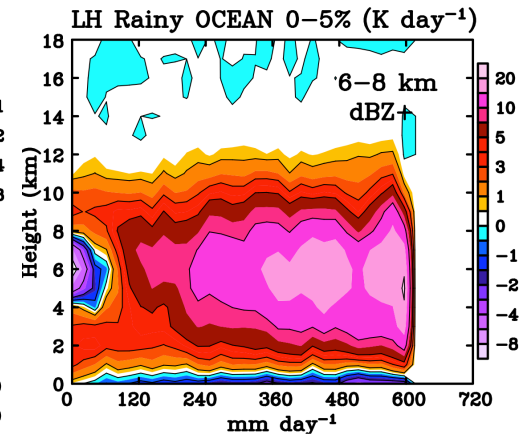


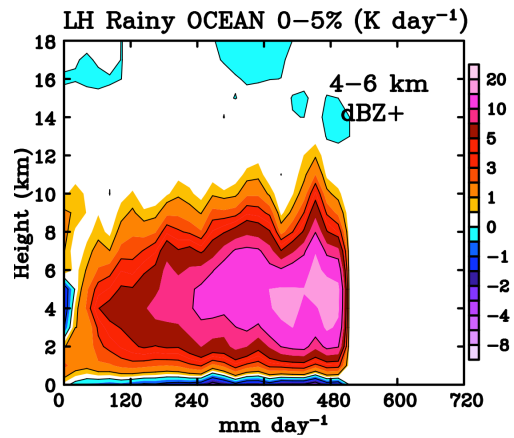
Most Convective (95% convective)

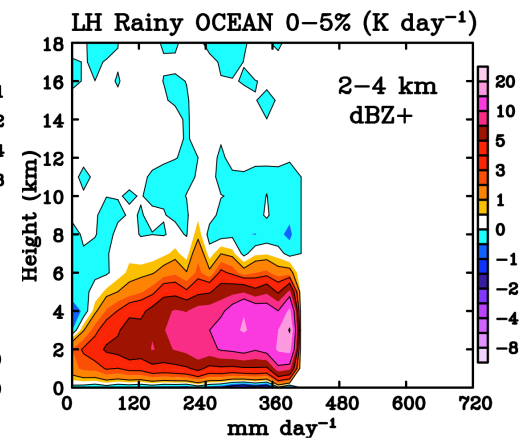
Echo Top: > 8km



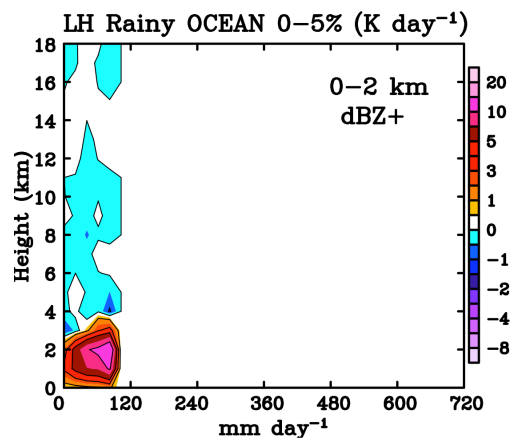
Echo Top: 6-8 km







Echo Top: 0-2km



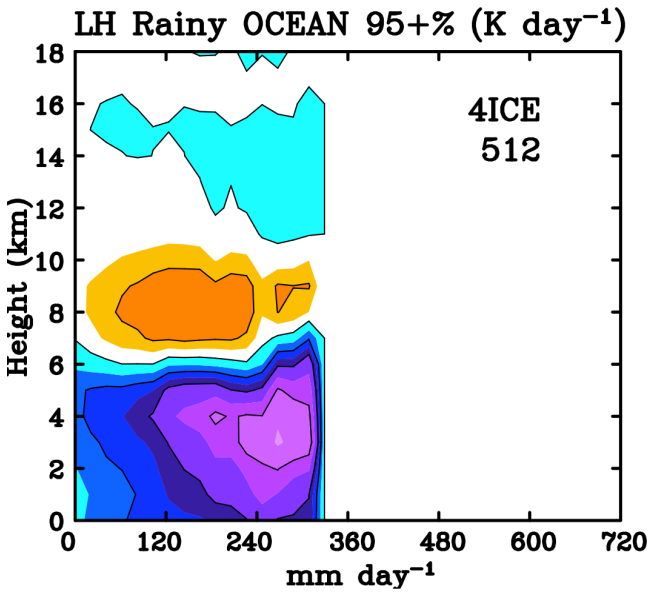
Echo Top: 2-4km

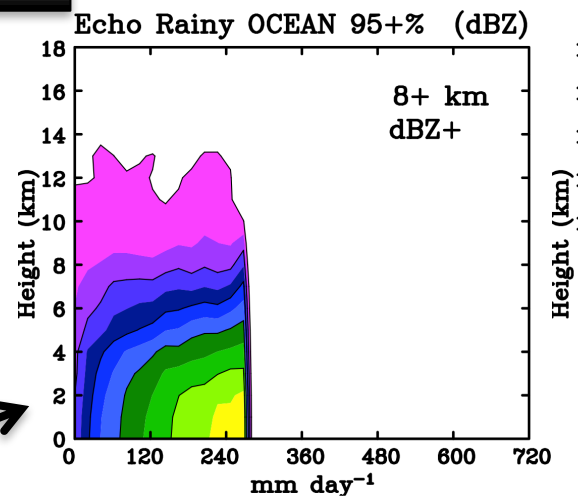
Vertical dBZ Gradients

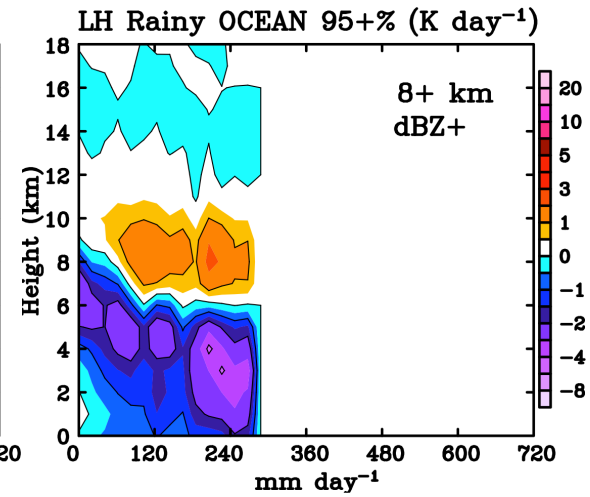
Deepest (Echo Top > 8km) Most Stratiform (95% stratiform)

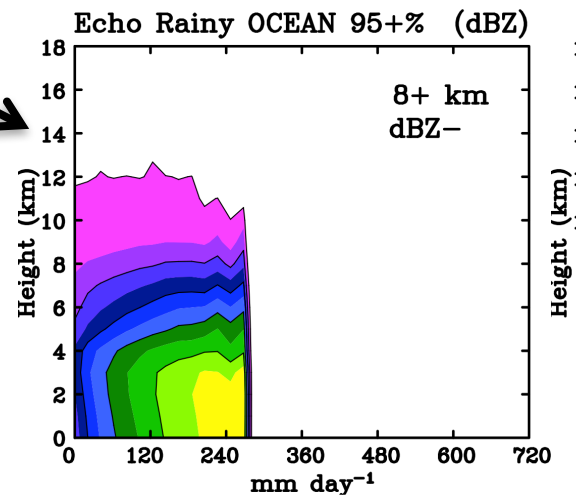
dBZs increasing Towards surface

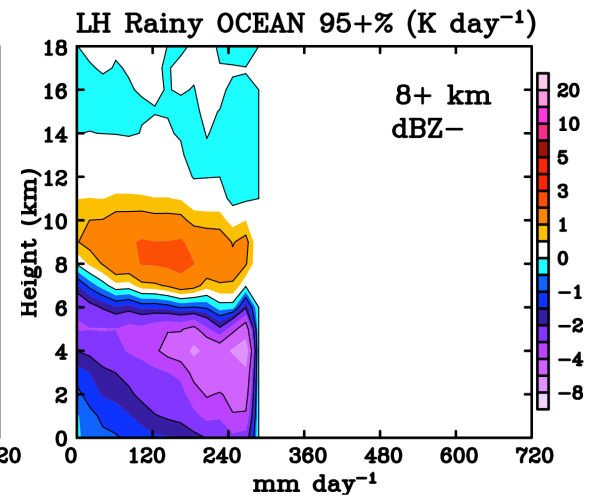
Ocean









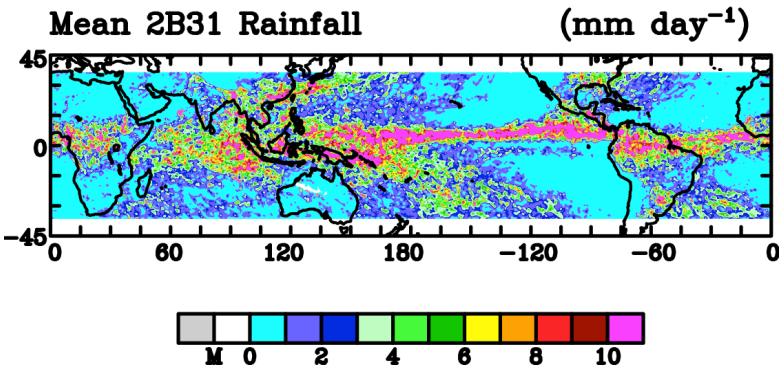


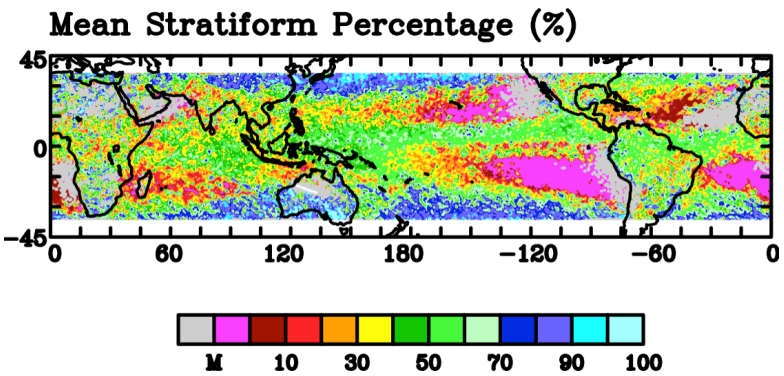
dBZs decreasing Towards surface

Stronger evaporative cooling

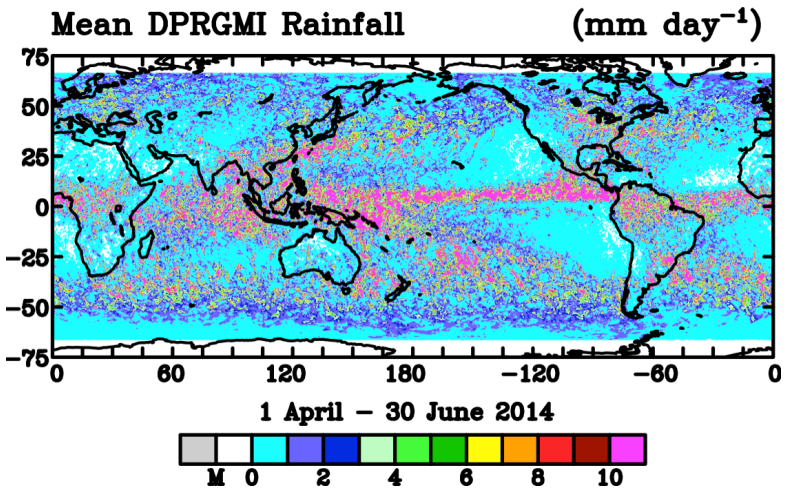
PMM Precipitation - April-May-June 2014

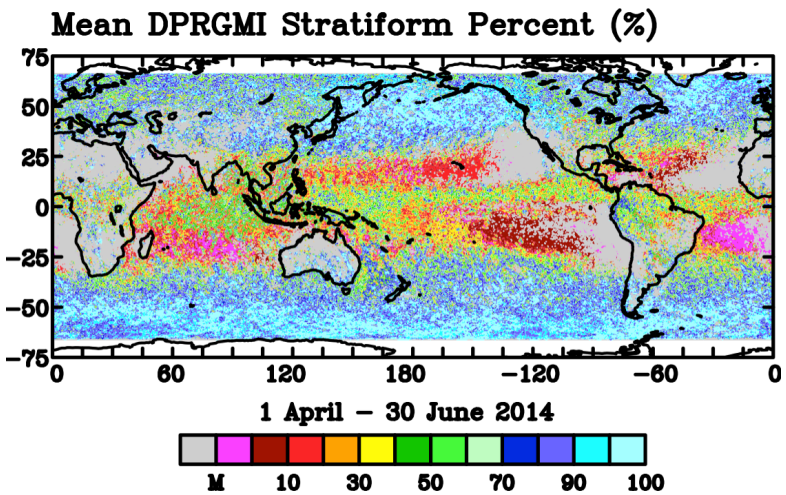
TRMM





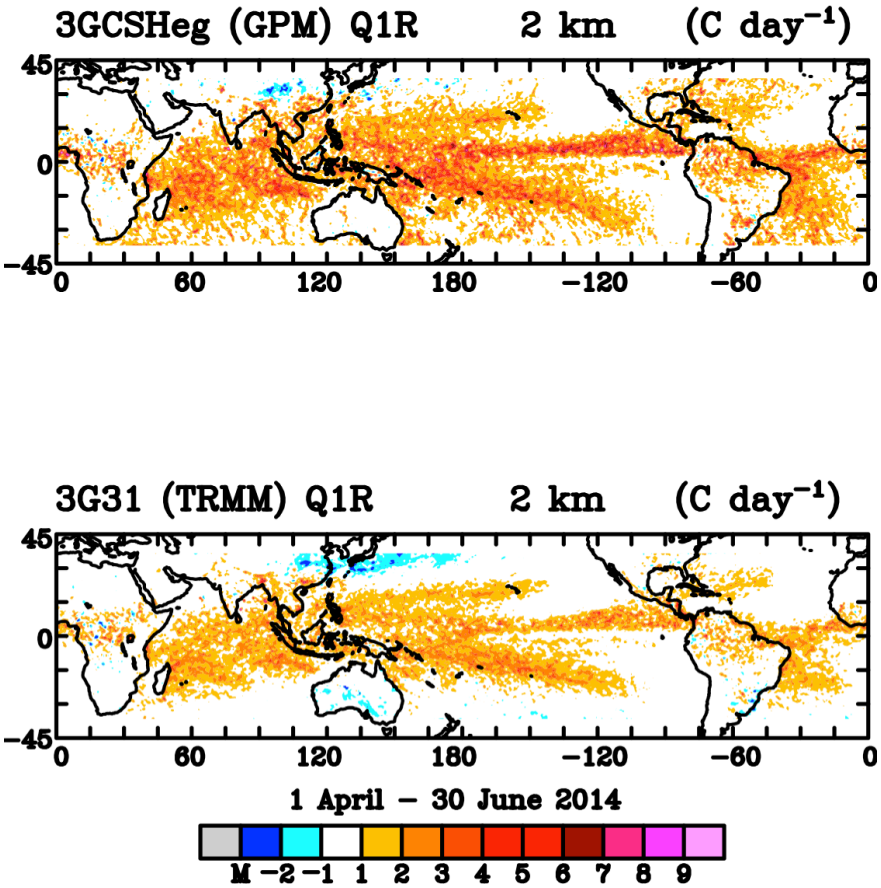
GPM



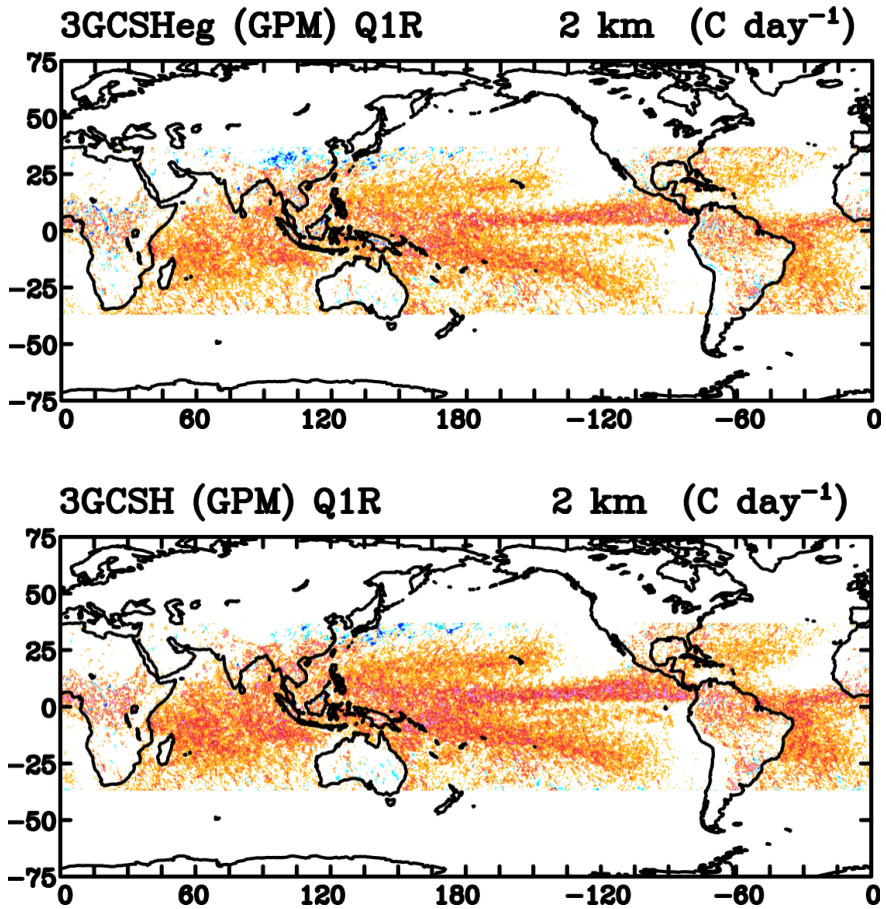


New Tropical Retrievals at 2 km level

Echo Tops + LL dBZ (0.5 x 0.5)



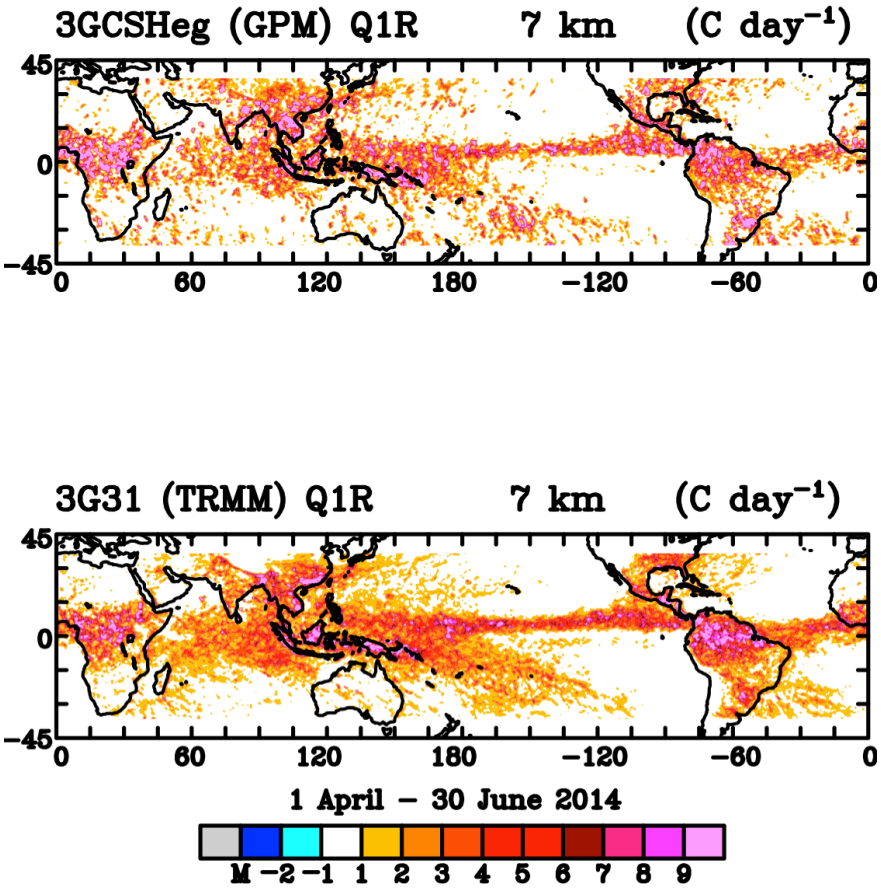
Echo Tops + LL dBZ (V5)



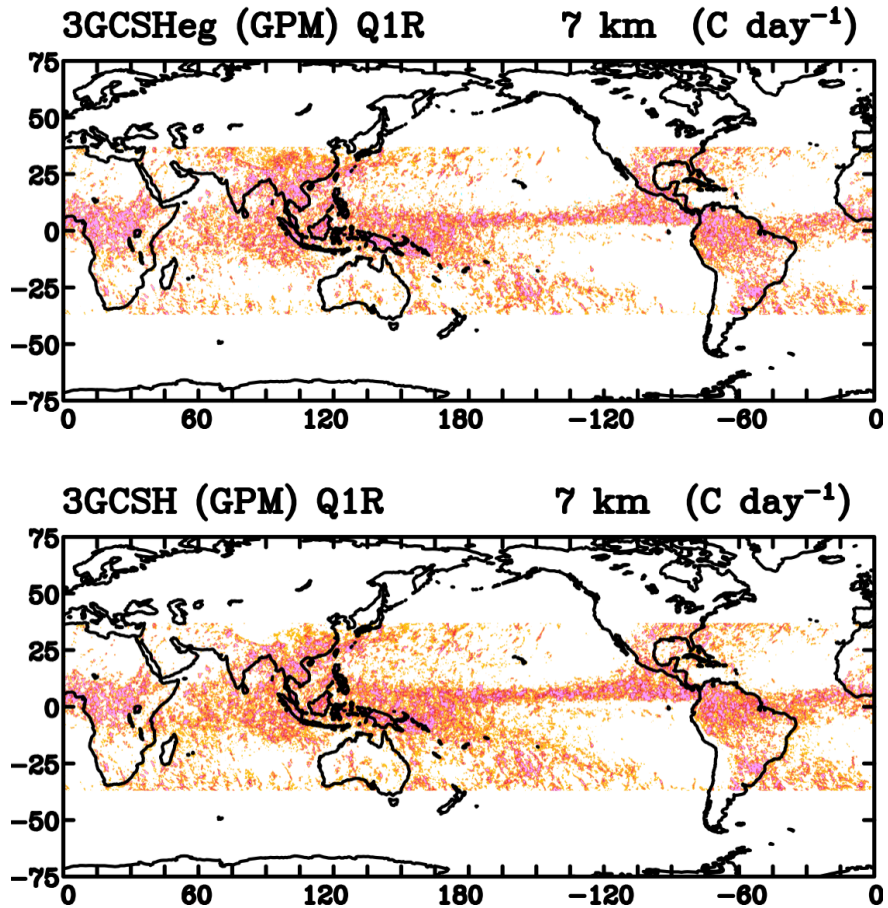
New 512 Simulations

New Tropical Retrievals at 7 km level

Echo Tops + LL dBZ (0.5 x 0.5)



Echo Tops + LL dBZ V5

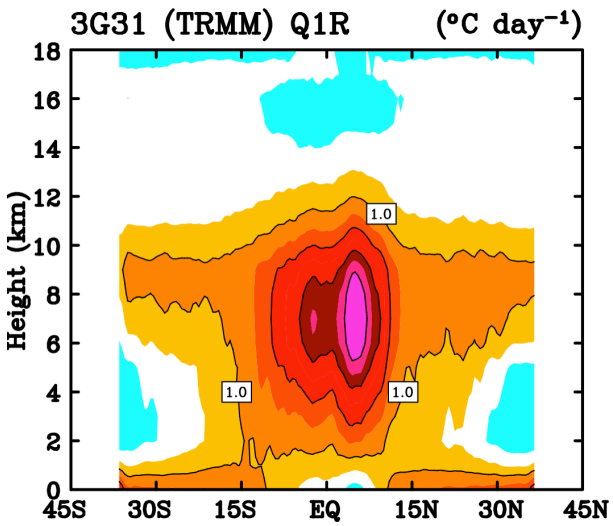


New 512 Simulations

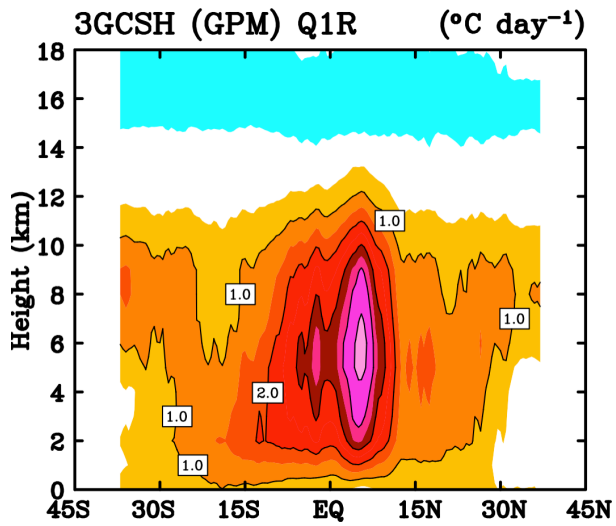
Mean Zonal Heating – TRMM Domain

AMJ 2014

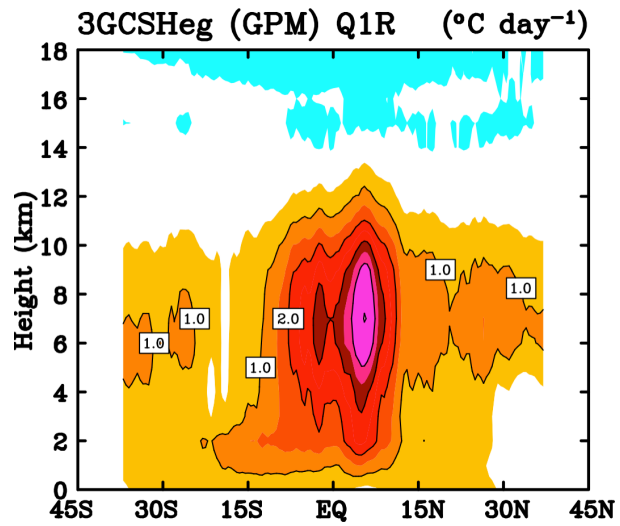
TRMM



New 512 Simulations



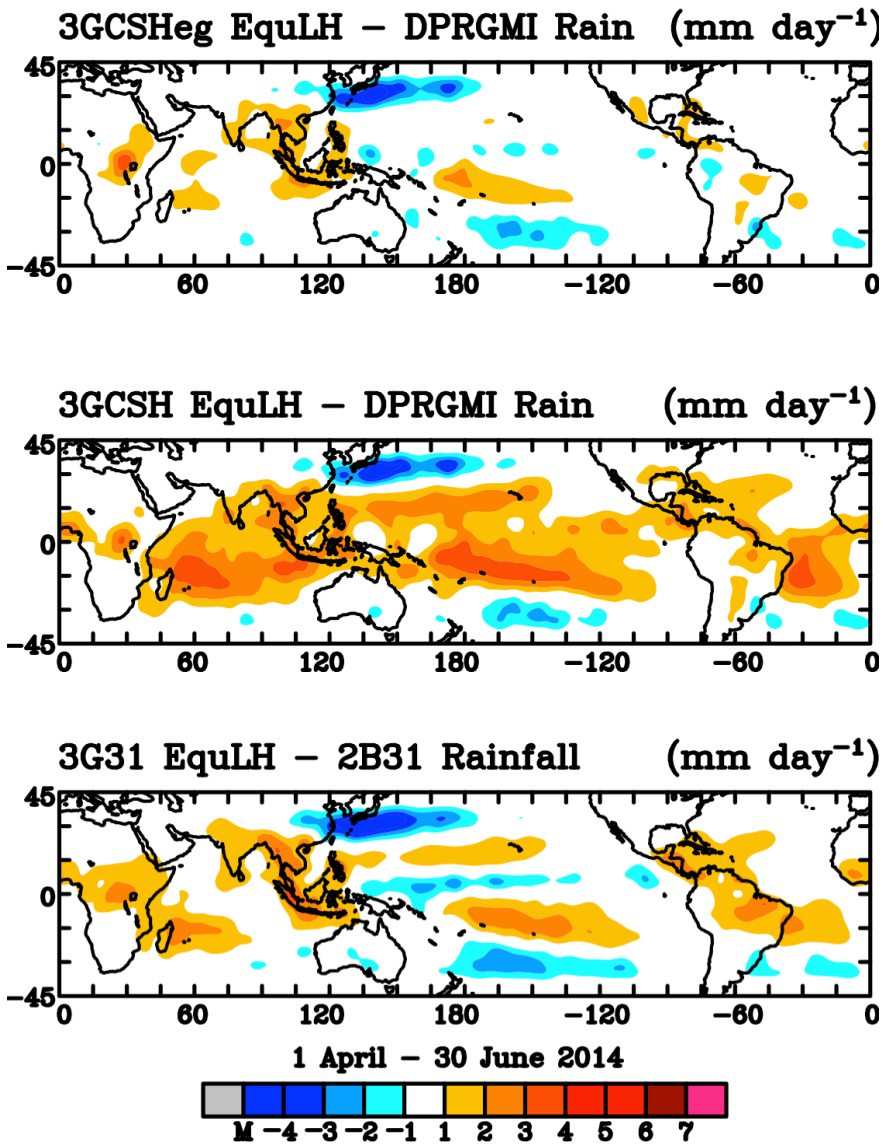
Echo Tops + LL dBZ



Heat Balance – LH vs Rainfall

$$\frac{1}{g}\int_{Lx}\int_{Ptop}^{P_{base}}(Q_1 - Q_R)\Delta p \Delta x = LP_o + S_o$$

Less Bias in V5 - Tropics



Echo Tops + LL dBZ (V5)

New 512 Simulations

TRMM V7

Generate Cold Season (V5) LH LUT

1. **NU-WRF simulation output** (3-km resolution, 60 vertical levels, 6 winter cases)

2. **Interpolation to Cartesian coordinates (1/4 degree) and 80 vertical levels with 250m intervals** (above MSL)

   Non-conditional grid averaging for Q_1 variables (LH, etc.)
   Conditional grid averaging for dBZ

3. **Calculate average LH as a function of radar reflectivity, and vertical height**

936 different regions in total in category map:

- **Freezing level height AGL** [-1, 0, 500, 1000, … , 6000 m]
- **Echo top height AMSL** [0, 2000, 4000, … , 12000 m]
- **Height of maximum dBZ** AMSL [0, 2000, 4000, … , 12000 m]
- **Anvil or Non-anvil**

Six Winter Events (3 US East and 3 West Regions)

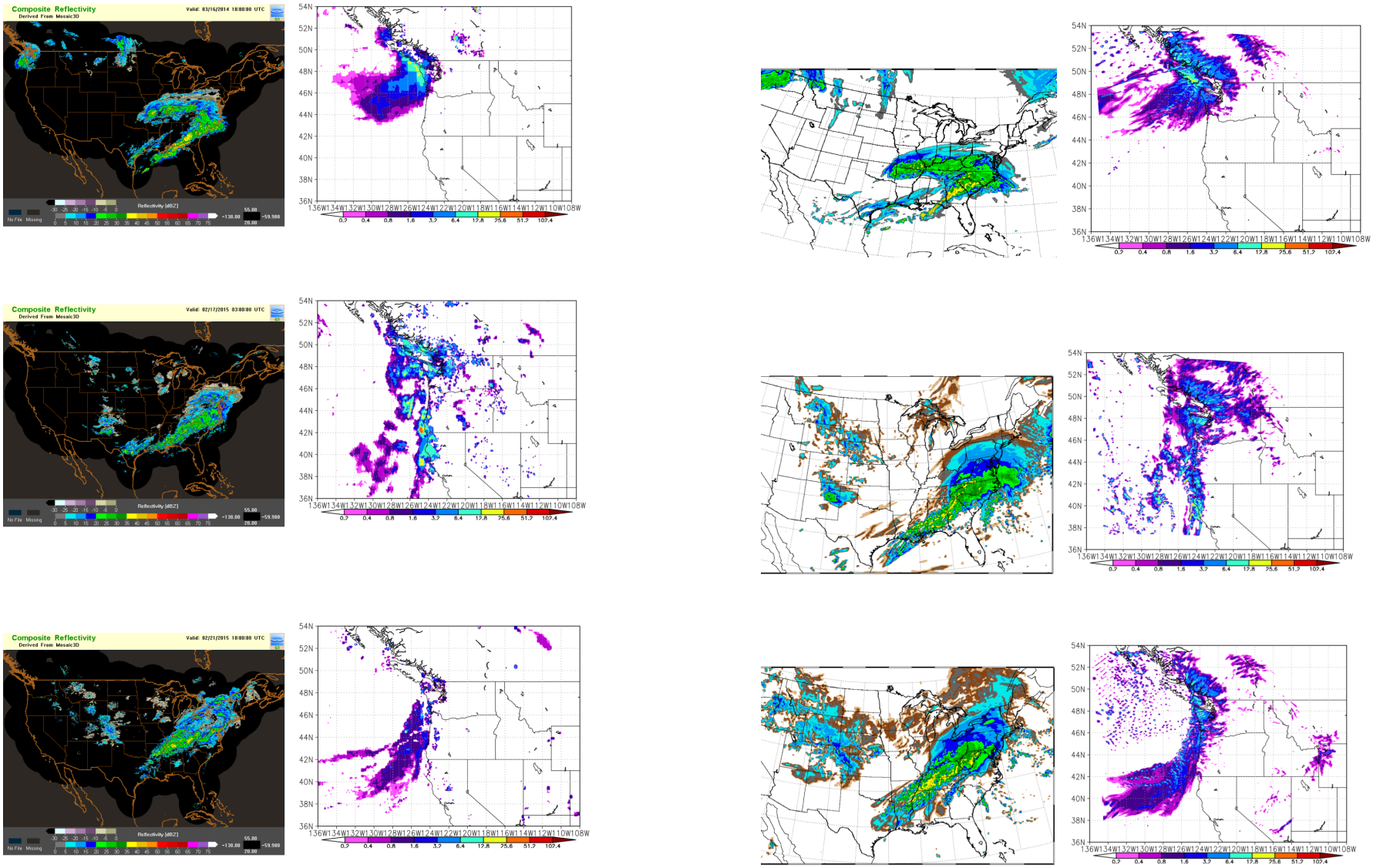
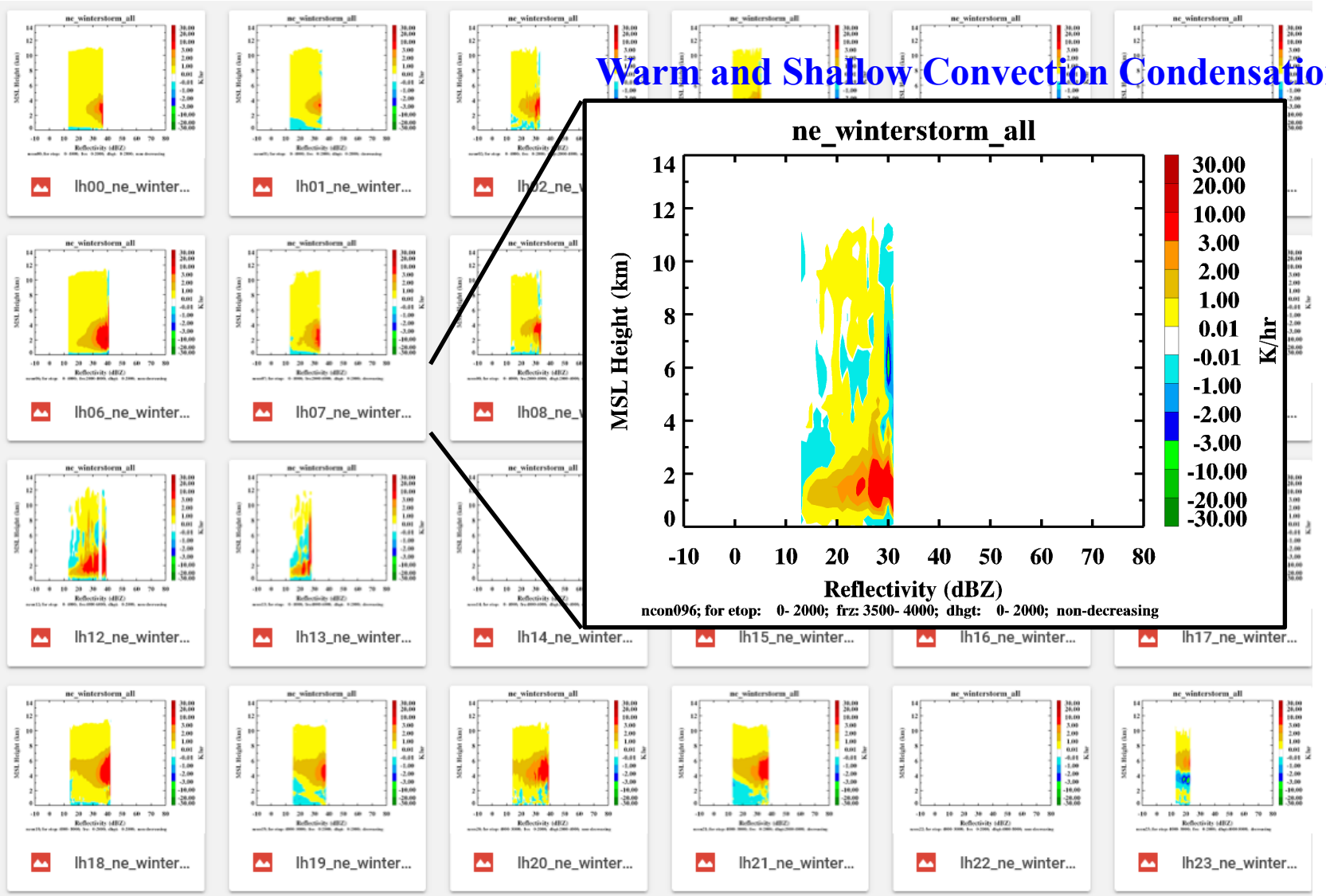


Fig. 1

Observation

NU-WRF Simulated

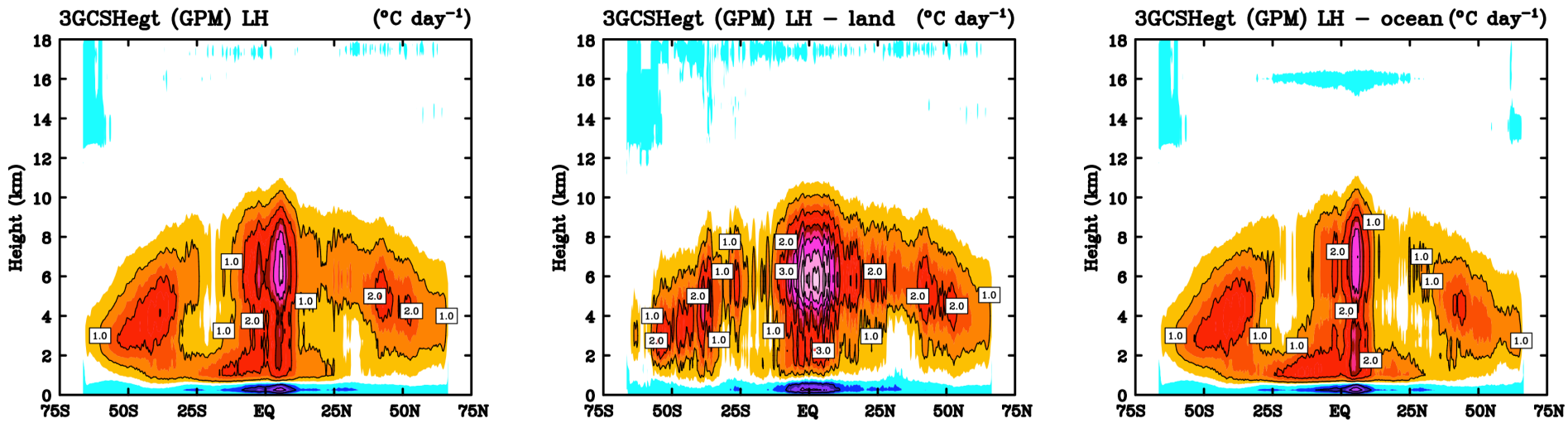
Cold Season (V5) LH LUT

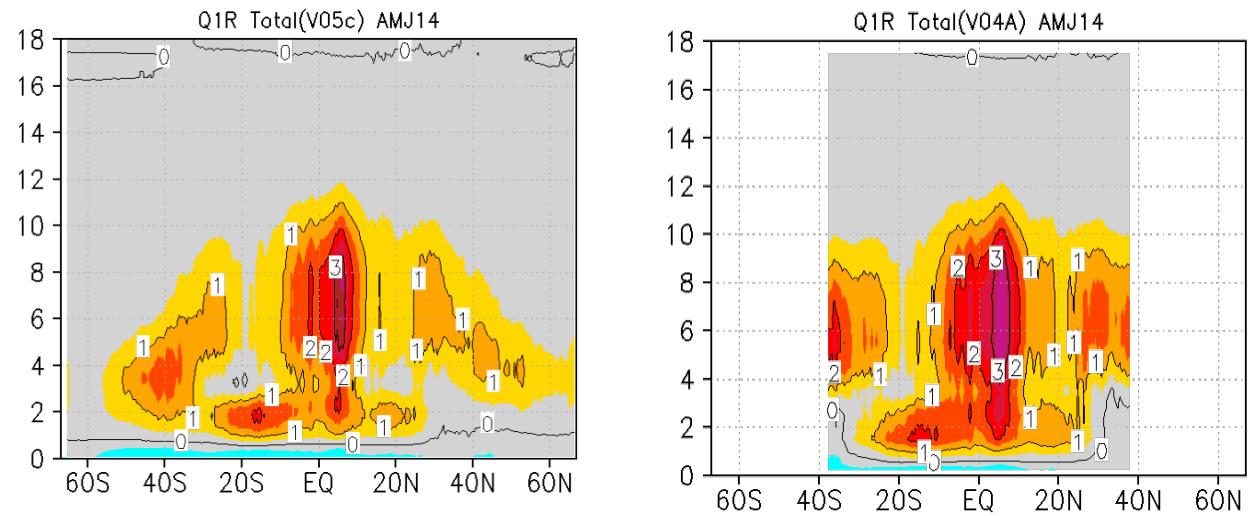


CSH GPM V5 Zonal Latent Heating (only)

April – May – June 2014

TOTAL **LAND** **OCEAN**





SLH – Q1R

Right: 19 vertical layer
Left: 80 vertical layer

Note – high latitude:
CSH retrieved is LH
SLH retrieved is Q_1-Q_R

Summary

- **CSH Tropical/Warm Season LUT database was enhanced with new GCE simulations** using the Goddard 4ICE scheme (better radar structures, surface rain rates, bin-based rain evaporation correction), larger domains, more cases (2 land + 1 ocean)
- **2 New Metrics were added to the selection of tropical LUTs:** mean echo top heights (2-km bins, better heating depth) and low-level (0-2 km) vertical reflectivity gradients (decreasing/increasing towards the surface, strong vs weak low-level evaporation and possibly convective growth stage)
- **Increased detection of shallow rains leads to more low-level heating in GPM retrievals**; without new metrics, mid-level heating becomes excessive → worse heat balance; new metrics produce very good heat balance; retrievals similar aloft in deep tropics
- **New Cold Season LUT** (LH only) derived from 6 NU-WRF simulated synoptic events (3 East Coast snow storms + 3 West Coast ARs), LUTs mapped using freezing level, echo tops, height of max dBZ, vertical dBZ gradients, and composite dBZs for intensity
- **Transition from tropical to extra-tropical retrievals** based on freezing level height (4 → 3 km)
- **Relative to SLH (Q1-Qr), CSH retrieved heating (LH) is stronger both in the Tropics and Extra-tropics; however, the heating structures are very similar (similar rainfall pattern)**

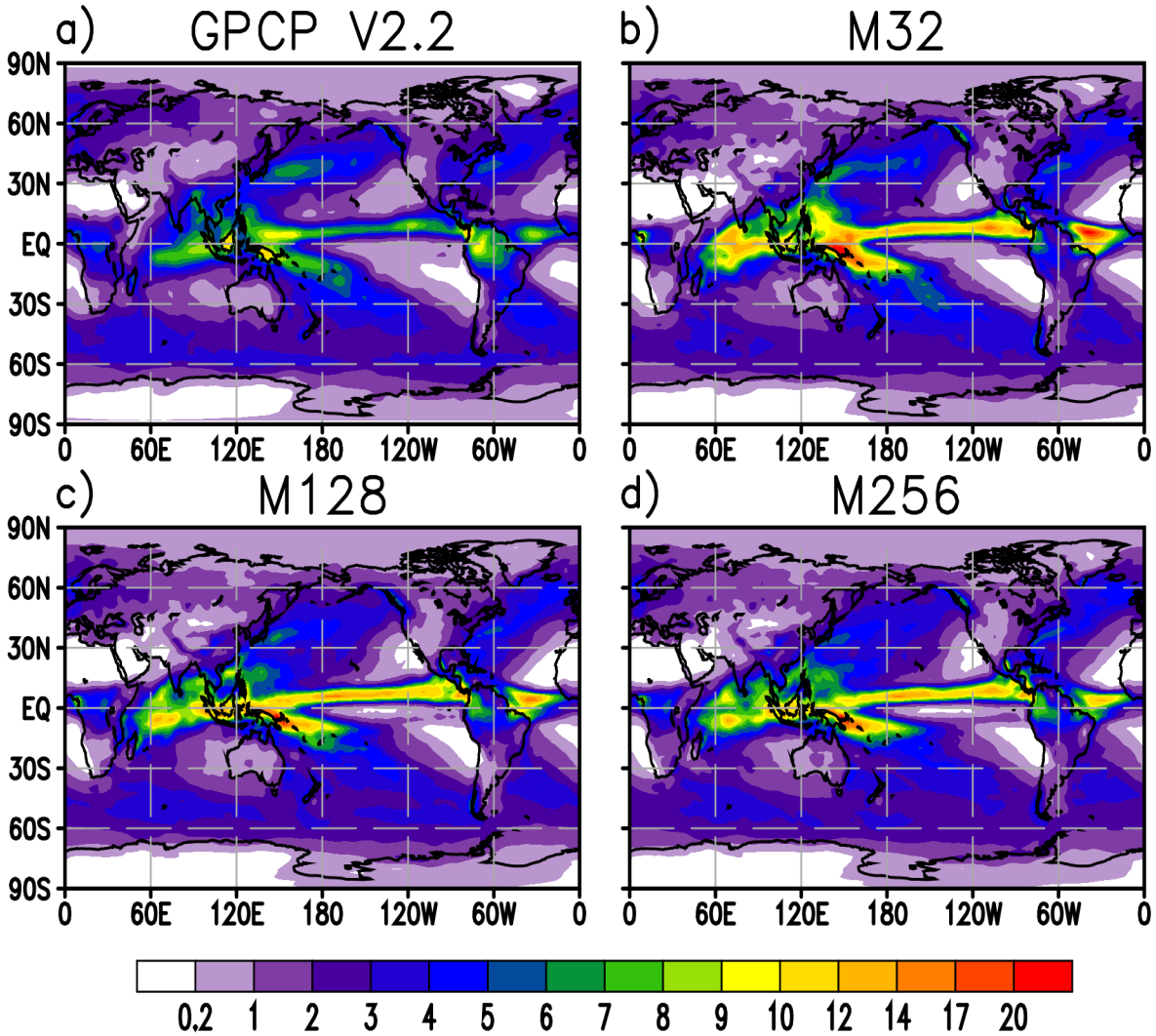
Action Items (toward V6?)

- **Test additional model grid configurations** (3D), domain sizes (1024 or more) and resolutions (200 m – smaller, shallower clouds) for LUTs
- **Refinement** of CSH algorithm
- **Convective-Stratiform Classifications** (R. Houze)
- **Validation** (integrated heating vs rainfall at higher latitudes, model self consistency tests)
- **Collaboration between CSH and SLH algorithm team** (share cases – look-up) – will meet this afternoon
- **Collaboration with precipitation feature team**
- **Radiation profiles** as part of Q1 (strong request from users)

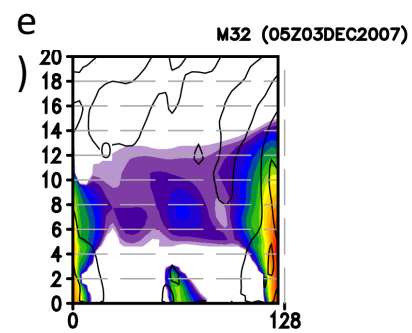
The impact of mesoscale convective systems on the multi-scale modeling framework (MMF): Rainfall and its characteristic

Tao and Jiundar (2017)

2-year (2007-2008) mean precipitation

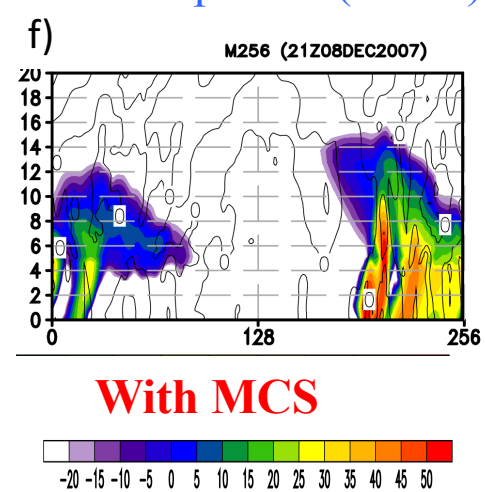


CRM dBZ profile (M32)



With Isolated Convection

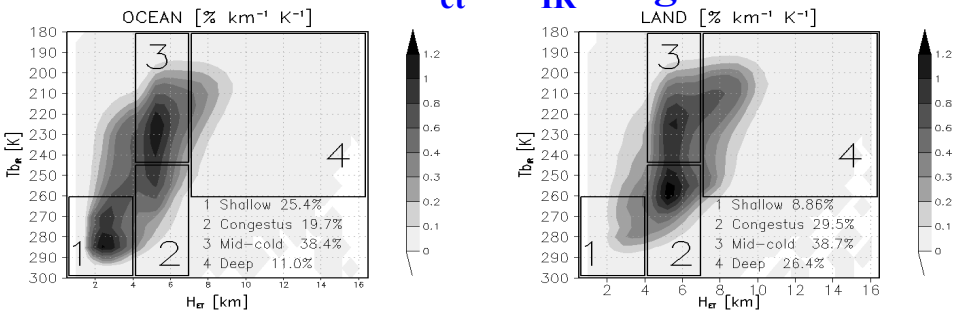
CRM dBZ profile (M256)



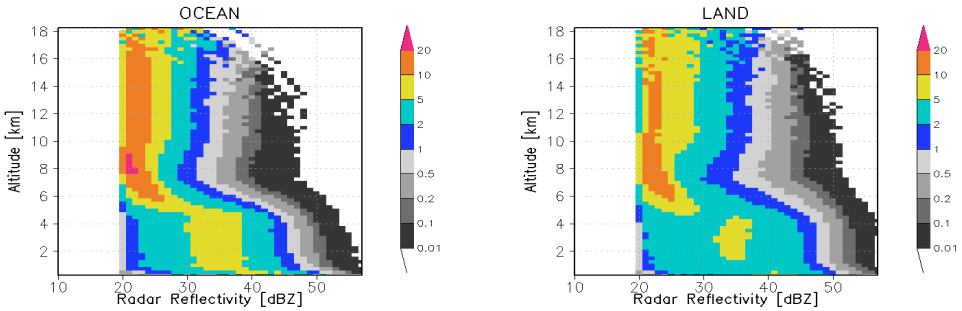
With MCS

Goddard MMF: 3ICE and 4ICE Evaluation Against T3EF

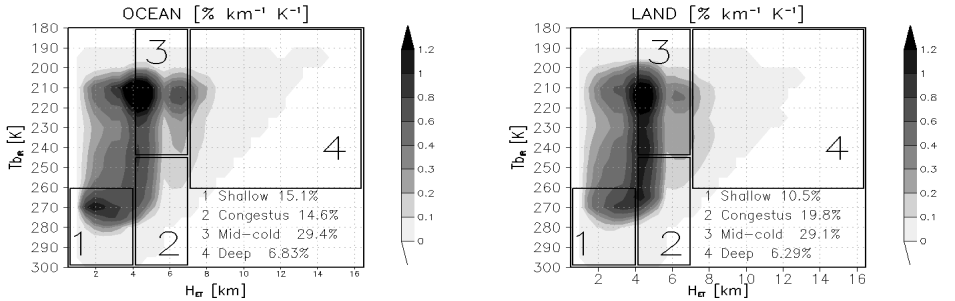
TRMM H_{et}-Tb_{IR} diagram



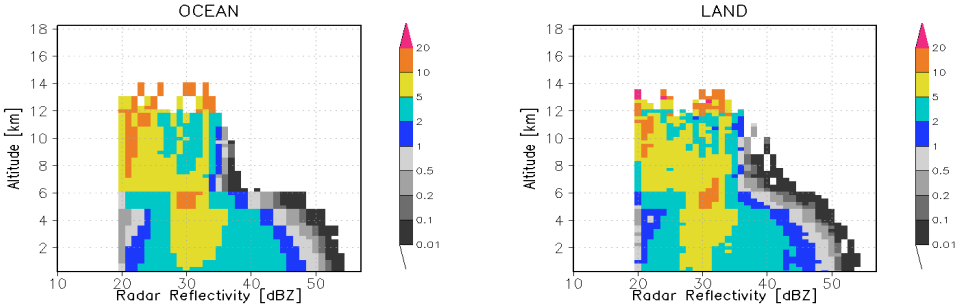
TRMM PR CFADs



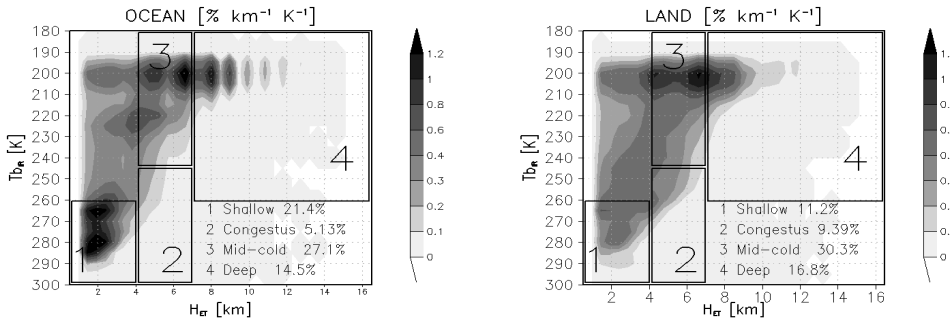
MMF H_{et}-Tb_{IR} diagram

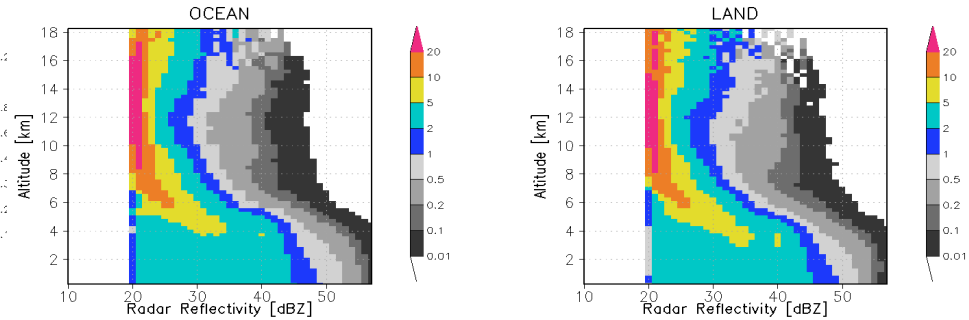


MMF PR CFADs



Goddard 3ICE with Temp-Dependent Snow Size



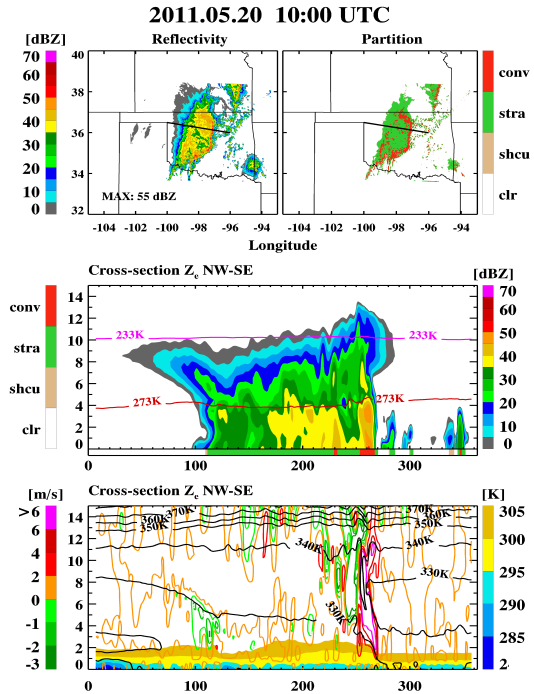


Goddard 4ICE

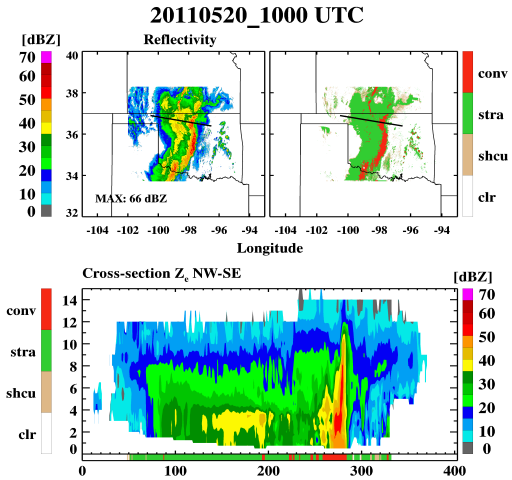
Matsui et al. (2016)

Tao, W.-K., D. Wu, S. Lang, J. Chern, C. Peters-Lidard, A. Fridlind, and T. Matsui, 2016: High-resolution NU-WRF model simulations of MC3E, deep convective-precipitation systems: Comparisons between Goddard microphysics schemes and observations, *J. Geophys. Res.*, 121, 1278-1306. doi:10.1002/2015JD023986.

3ICE - Graupel

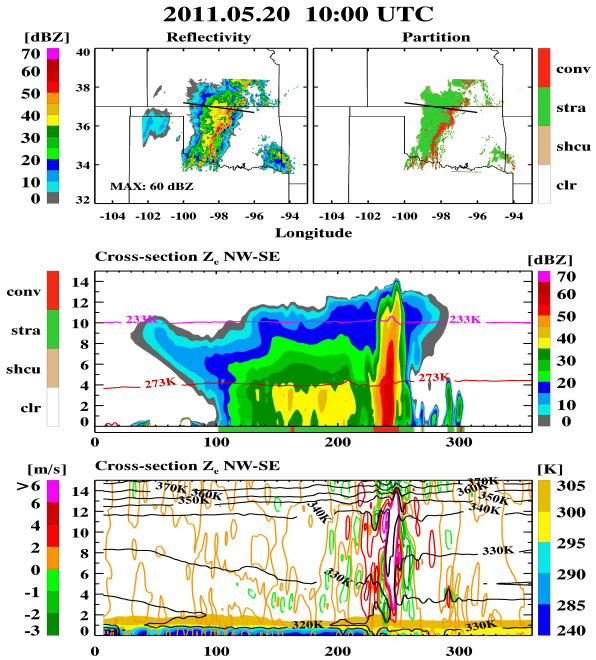


Observed



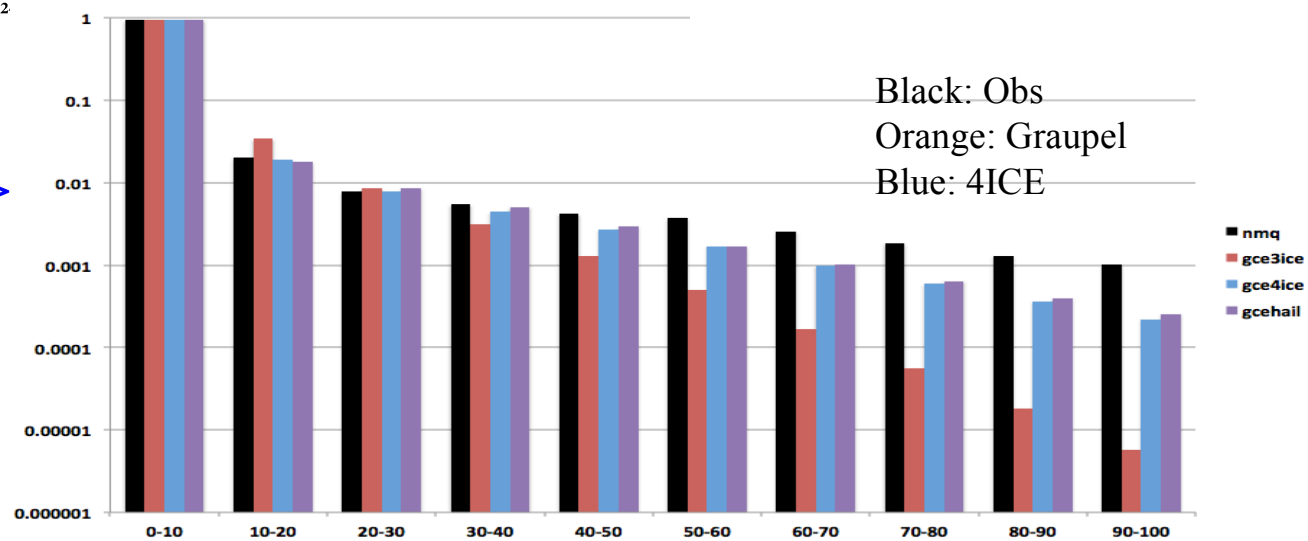
RED: Convective
Green: Stratiform

4ICE



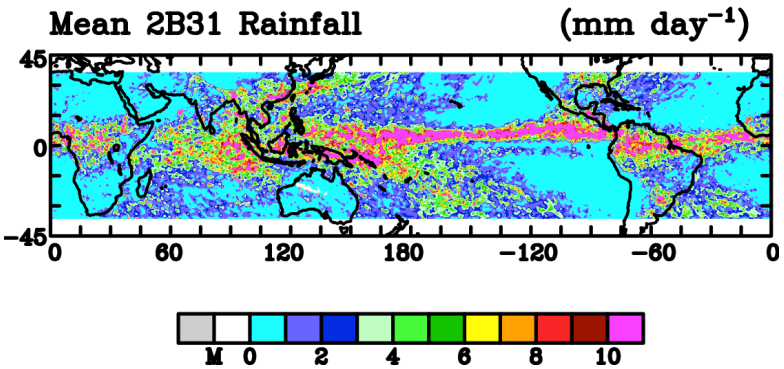
PDF – Rainfall Intensity >

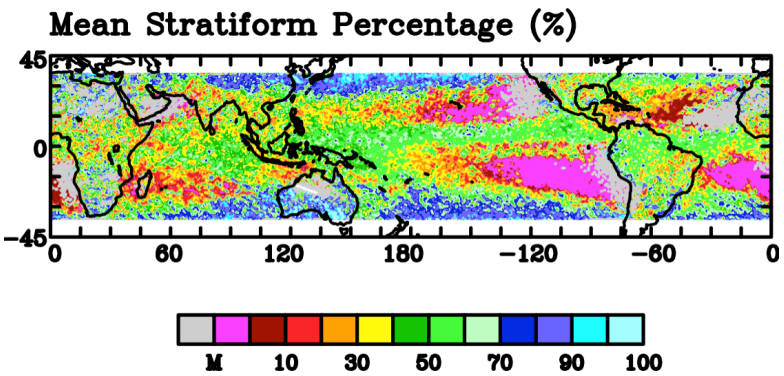
Both 4ICE and 3ICE-Hail simulated more heavy rainfall (30 mm/h) than 3ICE-Graupel



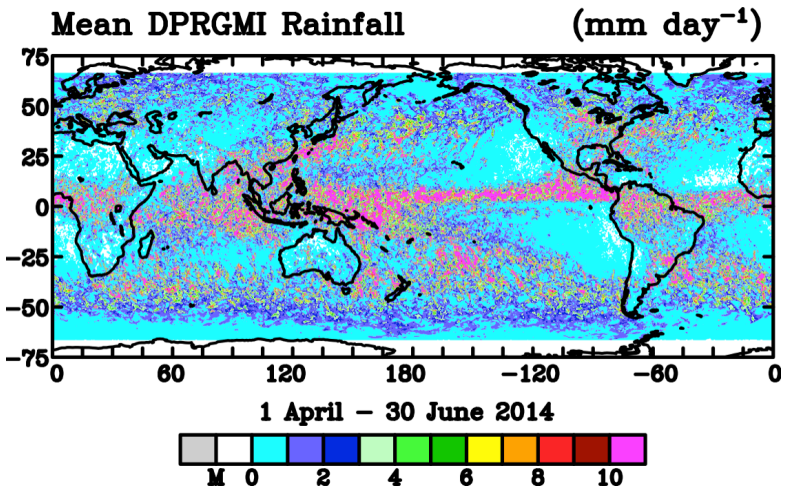
PMM Precipitation - April-May-June 2014

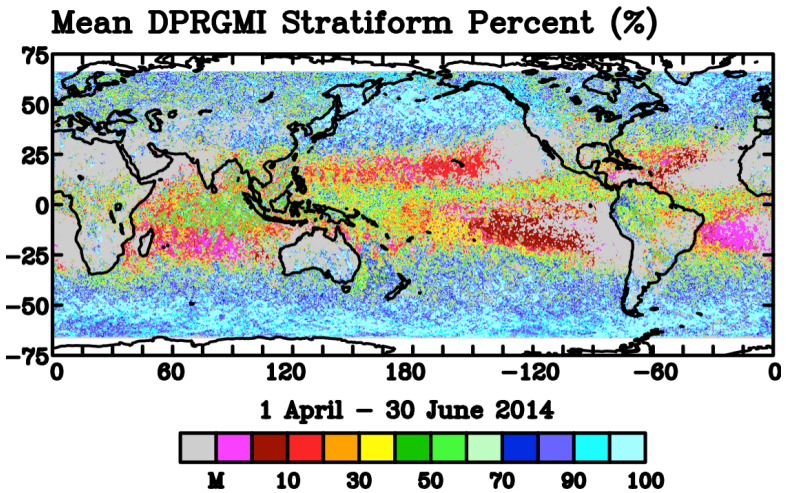
TRMM





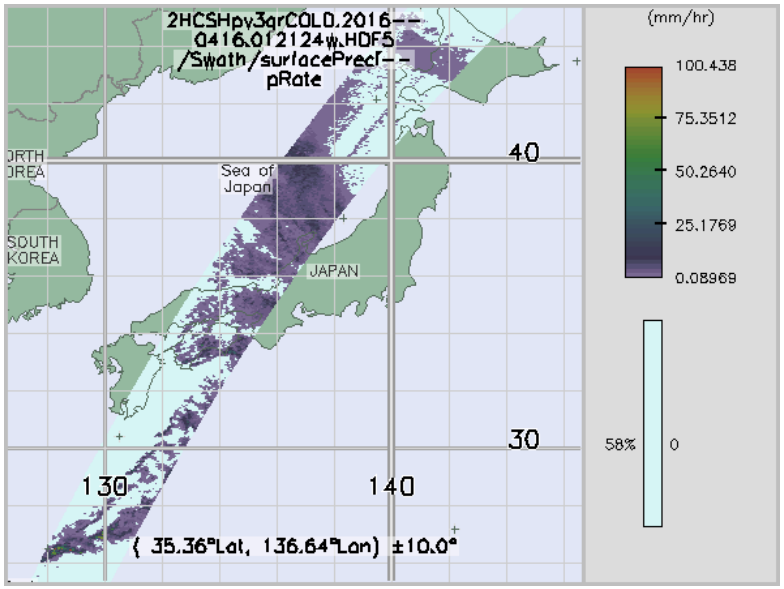
GPM



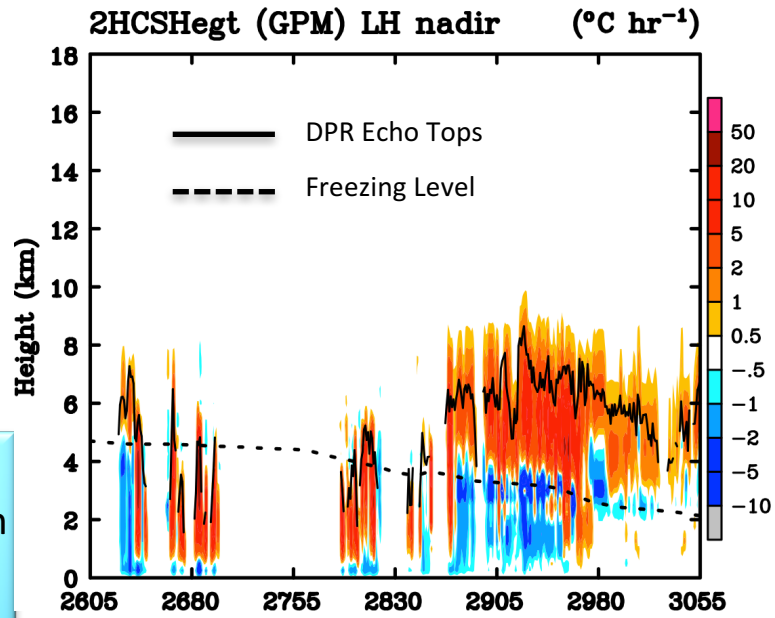


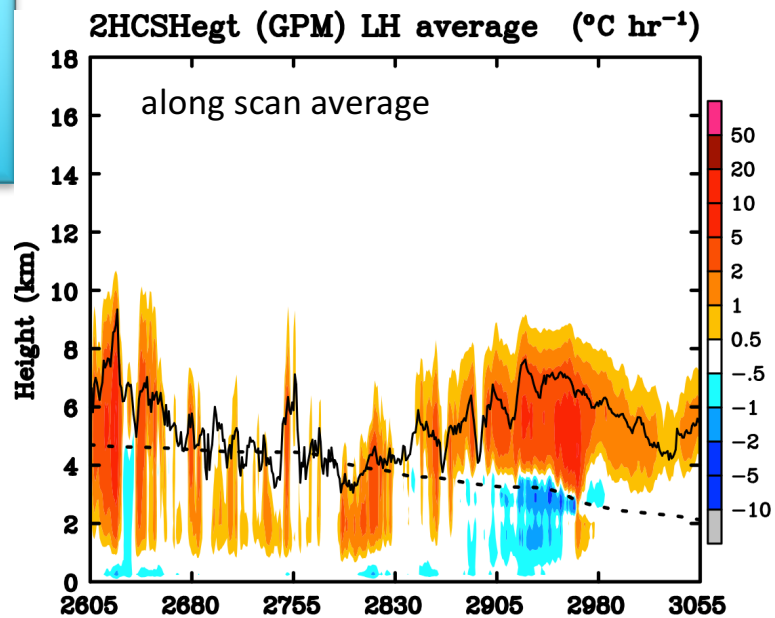
CSH GPM Pixel (2HCSH) - 16 April 2016

Synoptic system near Japan



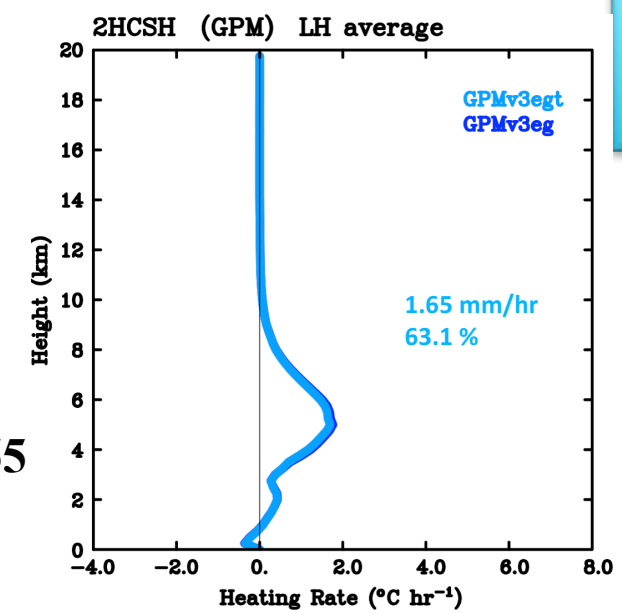
CSH retrievals transition from Tropical to Extra-tropical based on Freezing level 4 → 3 km





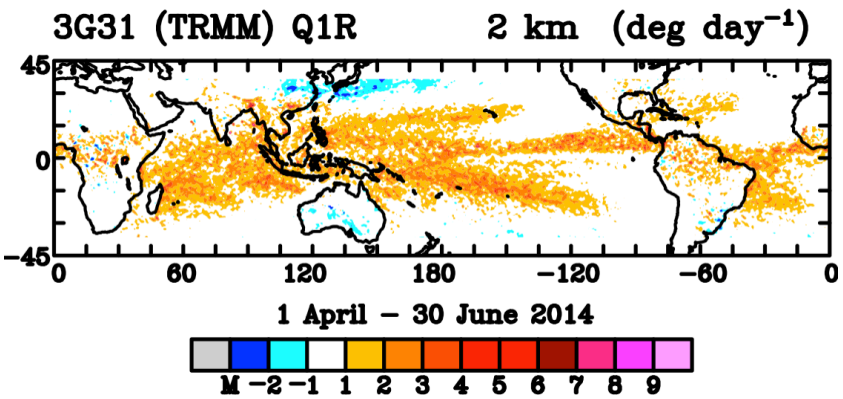
Mean LH Profile

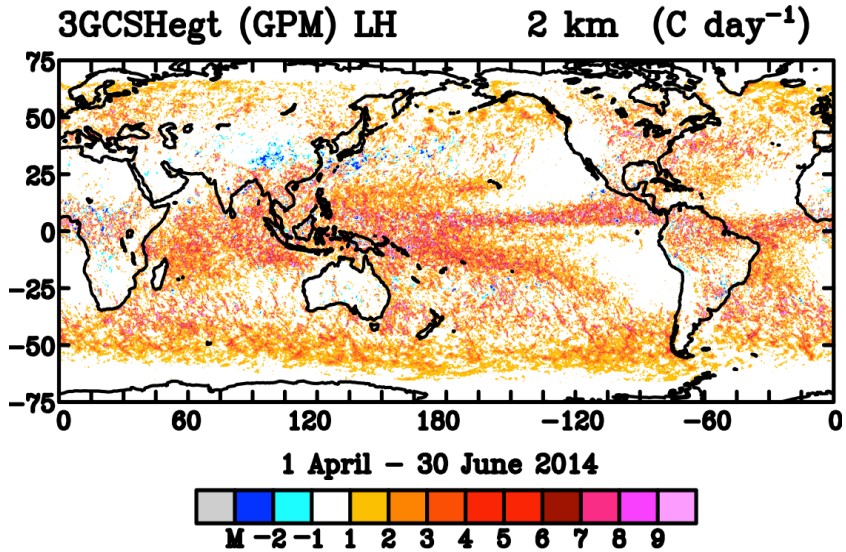
Scan 2605 - 3055



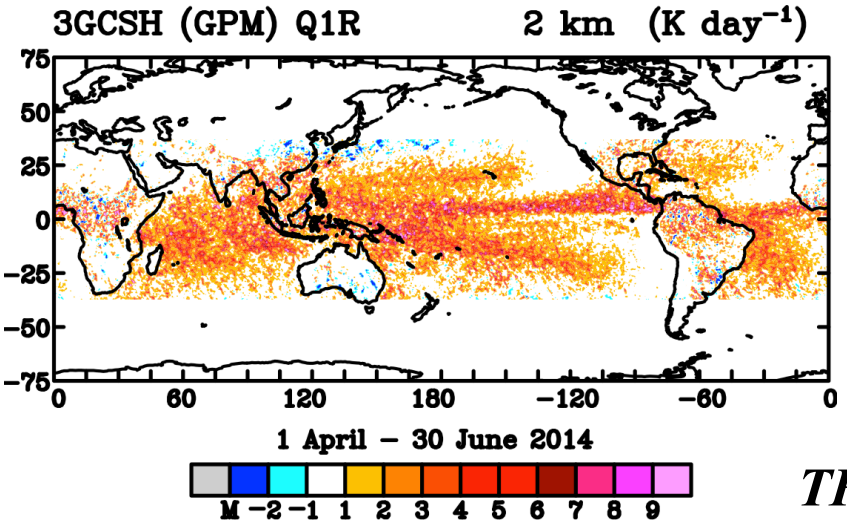
CSH Heating - April-May-June 2014 at *2 km*

TRMM V7





GPM V05 (LH)

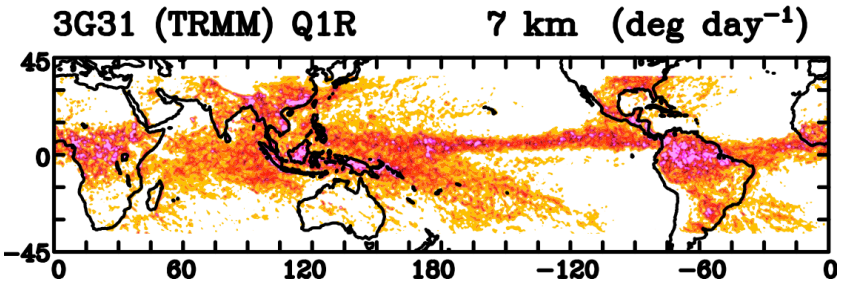


GPM V04

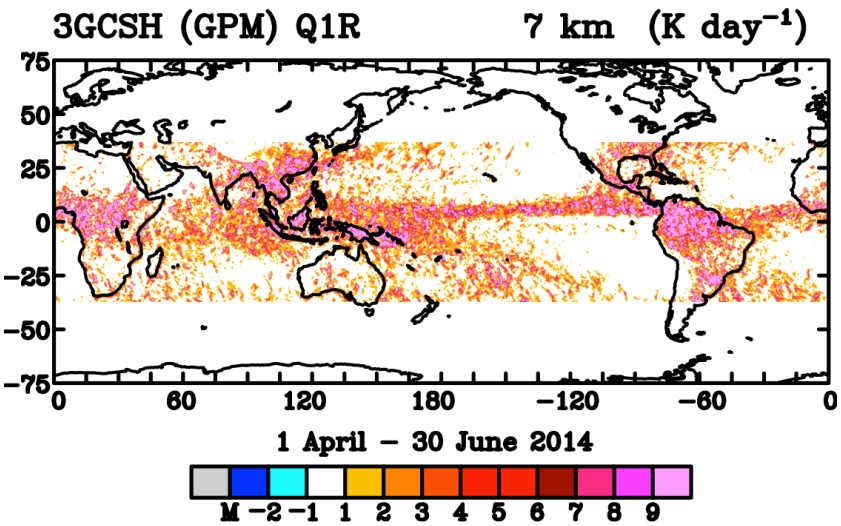
TRMM vs GPM: stronger low-level heating in GPM V4

V4 vs V5: More but weaker low level heating in GPM V5

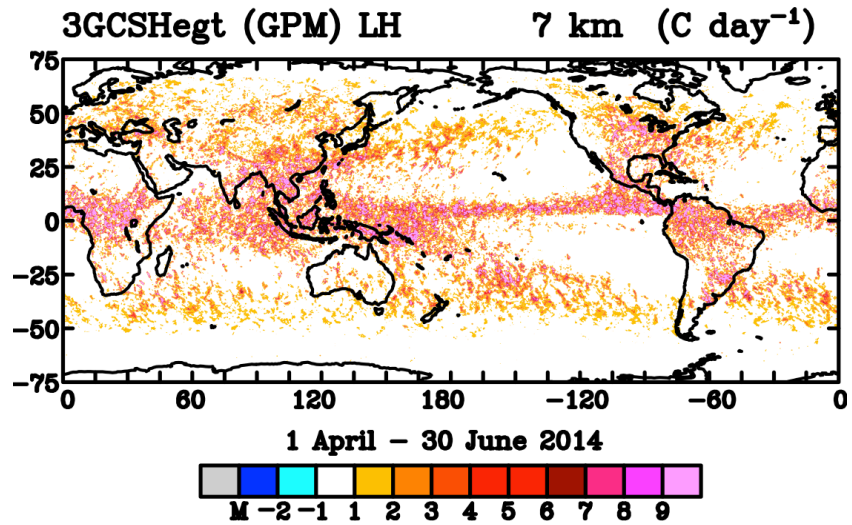
CSH Heating - April-May-June 2014 at *7 km*



TRMM V7



GPM V04



GPM V05 (LH)

TRMM vs GPM: Stronger upper-level (less area) heating in GPM V5

V4 vs V5: Slightly weaker upper-level heating in GPM V5

More difference over land area (TRMM and V5)