Goddard Latent Heating (LH) Retrieval Algorithm

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CSH V6 algorithm (its differences from V5)

CSH V6 improvements

CSH V6 performance (vs combined derived surface rainfall rate)

CSH V6 retrieved LH for TRMM and GPM

Key words:

CSH: Convective-Stratiform Heating

GCE: Goddard Cumulus Ensemble

NU-WRF: NASA Unified WRF

LH LUT: Look-Up Table

Q_1-Q_R: Apparent heat source subtract Radiation

"Equivalent" surface rain rates: Vertically-integrated Q_1-Q_R

Highlights	Reference	
First paper to use a CRM to develop a LH algorithm - LH structure estimated from vertical hydrometeor profiles	Tao *et al*. (1990)	
First paper on the CSH algorithm - composite both sounding estimated and CRM modeled convective and stratiform heating profiles into a simple look-up table (LUT)	Tao *et al*. (1993)	
Examined the performance of the CSH algorithm using CRM simulated (consistency check), SSMI and ship borne estimated rainfall and stratiform percentages. Retrieved LH sensitive to surface rainfall amount and stratiform percentage.	Tao *et al*. (2000)	
First paper to retrieve LH based on one-month of TRMM-estimated rainfall products.	Tao *et al*. (2001)	
Improved CSH by using several CRM-simulations to build the LUTs, individual heating components retrieved separately, LUTs separated into many surface rain rate intensity bins and stratiform fractions	Tao *et al*. (2010)	V4
Improved CSH by using even more CRM simulations with better microphysics at finer resolution to build the LUTs and added new metrics for echo top heights and low-level dBZ gradients to the LUTs	Lang and Tao (2018)	V5
Expanded the retrieval of LH to higher latitudes and the cold season using NU-WRF simulations of synoptic storms to build separate LUTs	Tao *et al*. (2019)	V6
Review papers on LH algorithms, applications and evaluations	Tao *et al*. (2006, 2016)	

Chronology of the Goddard CSH algorithm with key improvements and references. Adapted from Tao *et al*. (2019)

Differences/similarities between Goddard CSH V5 and V6

	V5	**V6**
Cases	6 Ocean + 4 Land	same
Microphysics	4ICE	same
GCE grid size	***1000 m***	***200 m****
GCE domain size	***512 km***	***1024 km***
Echo top Height bins	0-2, 2-4, 4-6, 6-8, >8 km	same
Low-level (0-2 km) vertical DBZ gradient*	Increasing or decreasing dBZs toward the surface	same
Look-Up Tables	36 intensity bins 2 convective-stratiform bins** Land vs ocean Rainy, near rain, far from rain	Same except no "Rainy, near rain and far from rain" for LH
Vertical Levels	80	same
Horizontal Resolution	pixel	same
Conv-Strat Separation	***GCE method at model (1 km) resolution***	***2A23-like method at 4-km resolution***

***. The 200 m grid is averaged for 4-km for the LUTs and convective – stratiform separation**

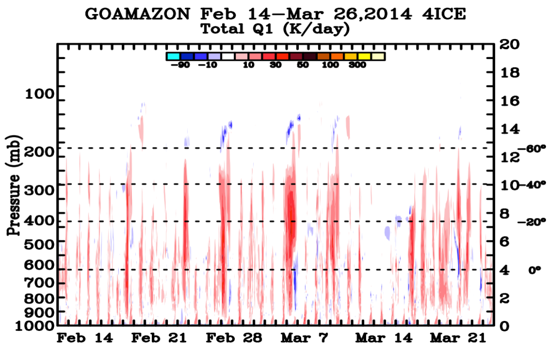
****. The V5 gridded product had 20 stratiform fraction bins (every 5%) that are not used for V6**

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

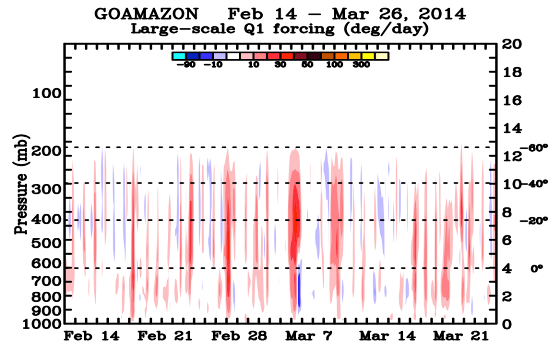
Field Campaign	Geographic Location	Dates	Modeling Days	Reference(s)
ARM-SGP-97	Land (Southern Great Plains)	June - July, 1997	29	Tao et al. (2004); Zeng et al. (2009)
ARM-SGP-02		May - June, 2002	20	Zeng et al. (2007, 2009)
SCSMEX/NESA	Ocean (South China Sea)	May – June, 1998	45	Tao et al. (2003b), Zeng et al. (2008)
TOGA-COARE	Ocean (Equatorial West Pacific)	November, 1992 – February, 1993	61	Das et al. (1999); Johnson et al. (2002); Zeng et al. (2009)
GATE	Ocean (Tropical Atlantic)	August – September, 1974	20	Tao et al. (2004); Zeng et al. (2009)
KWAJEX	Ocean (Marshall Islands)	July – September, 1999	52	Zeng et al. (2008)
TWP-ICE	Ocean (Darwin, Australian)	January – February, 2006	24	Zeng et al. (2013)
MC3E	Land (Southern Great Plains)	April – March, 2011	33	Zeng et al. (2007)
DYNAMO	Ocean (Equatorial Indian Ocean)	November – December, 2011	31	Li et al. (2018)
GoAMAZON	Land (Amazon Basin)	February – March, 2014	40	Lang and Tao (2018)

In all, the GCE model CSH database has more than ***three hundred fifty-five days*** (122 days **continental cases** and 233 days **oceanic cases**) of model integration – **large-scale advective forcing from sounding network (semi-prognostic approach)**

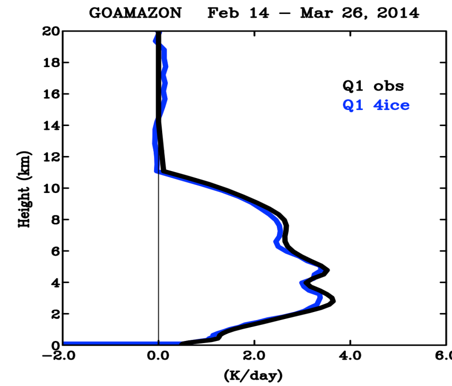
GCE-simulated and sounding-estimated rainfall and Q_1 for the GoAMAZON case.

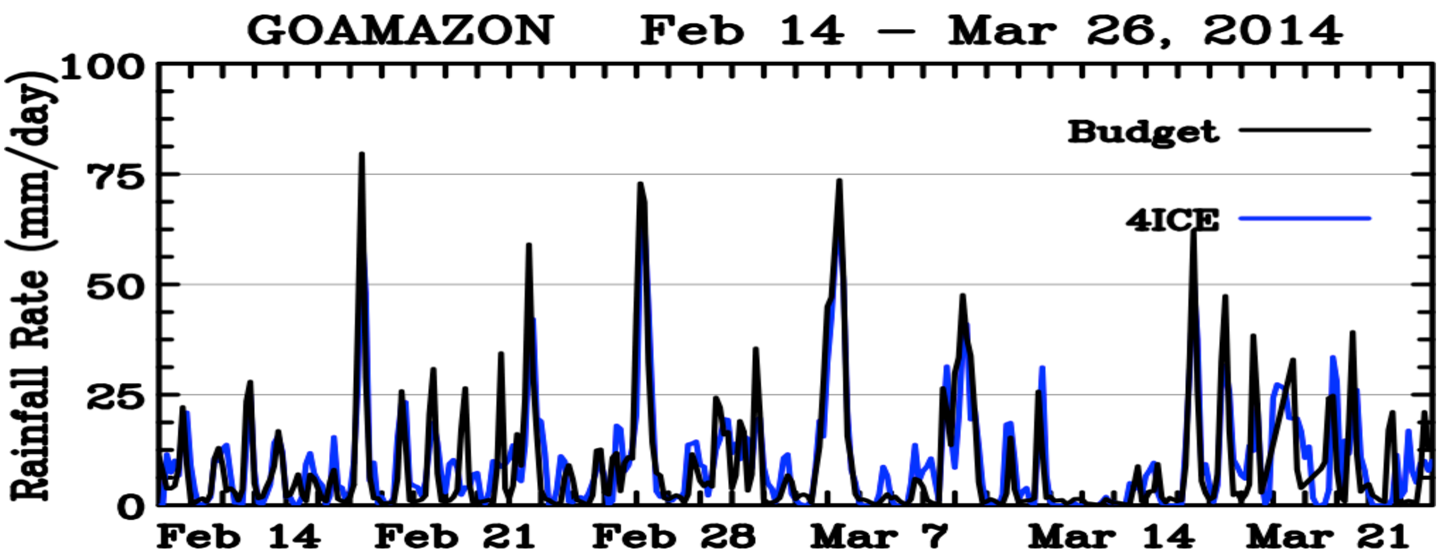


GCE Simulated Q_1



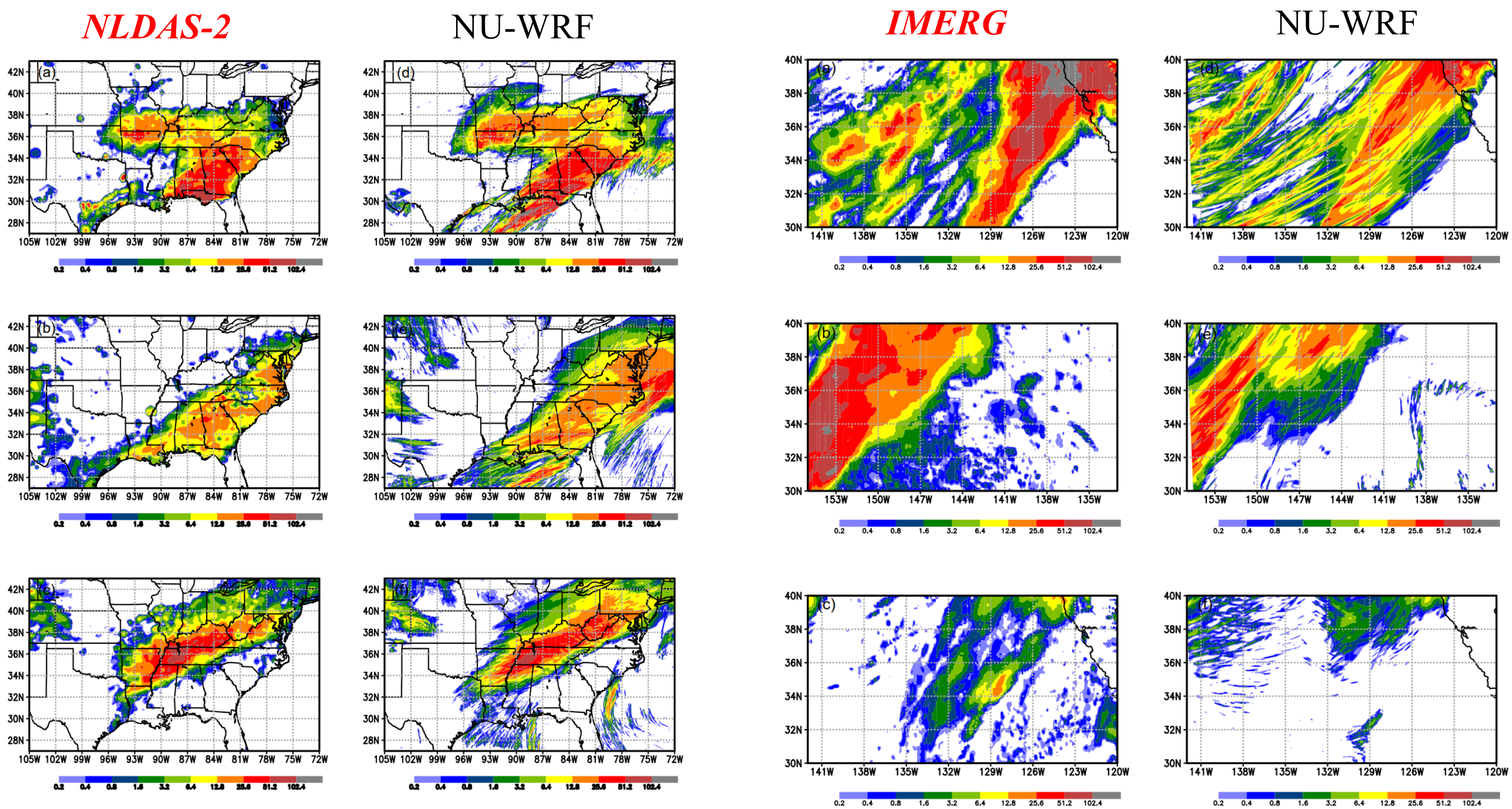
Sounding Derived Q_1





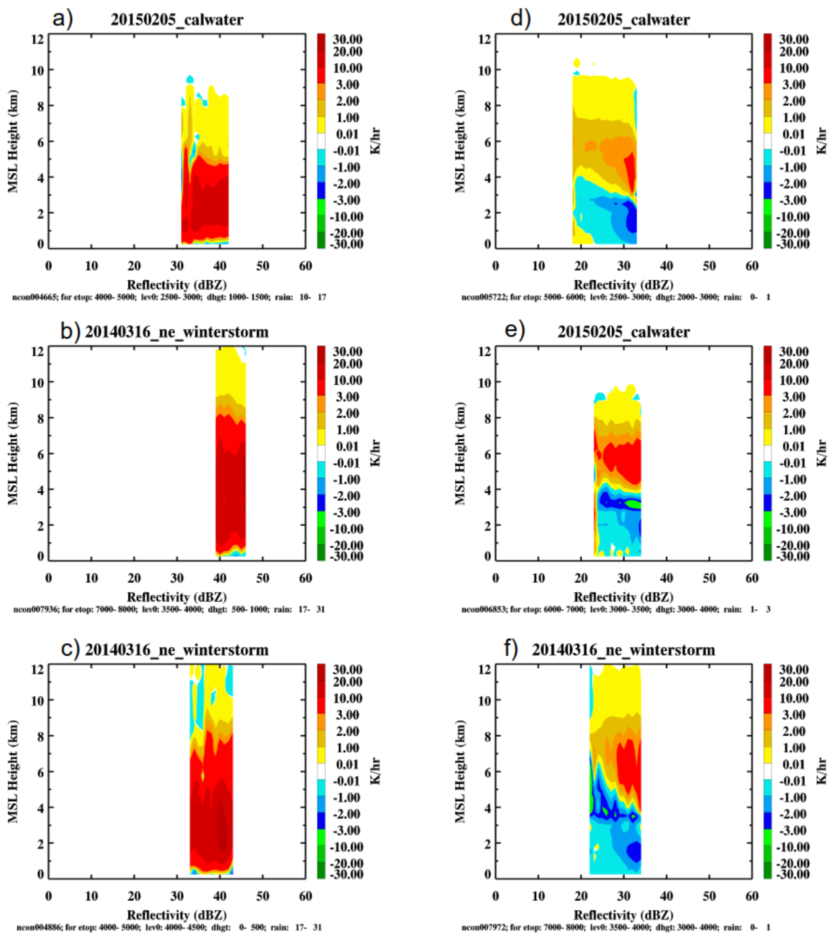
Time series of domain-averaged surface rainfall

NU-WRF simulated rainfall for 3 US east coast and 3 CalWater cases. NLDAS-2 and IMERG are used for comparison.

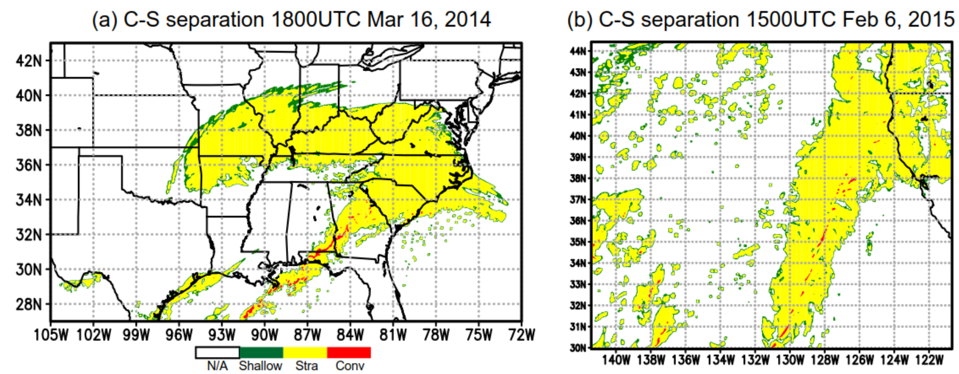


Tao, W.-K., T. Iguchi, and S. E. Lang, 2019: Expanding the Goddard CSH Algorithm for GPM: New Extra-tropical Retrievals. *J. Applied Meteor. Climatol.*, **58**, 921-946, doi: 10.1175/JAMC-D-18-0215.1

Convective-Like **Stratiform-Like**



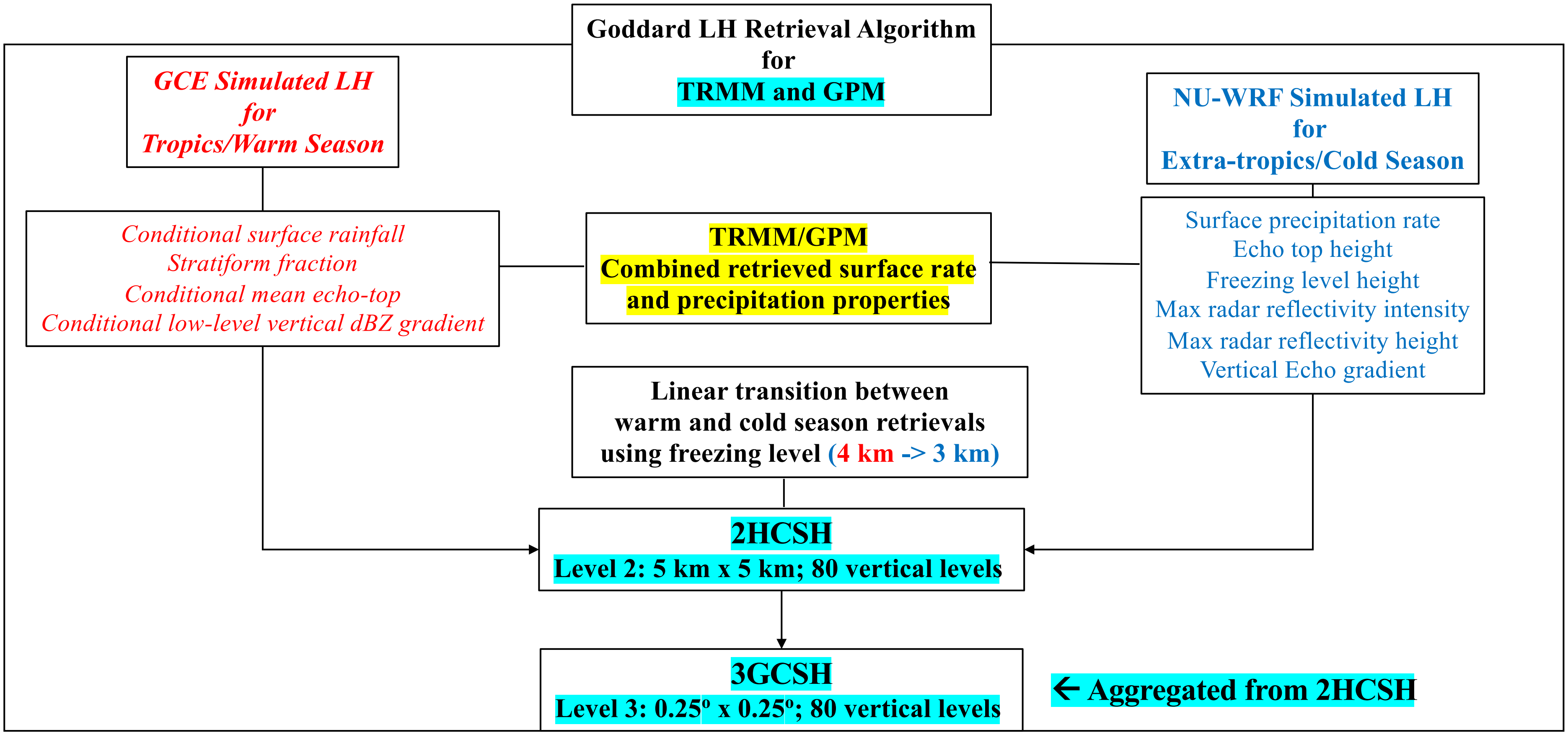
Convective-stratiform classification based on a Steiner separation algorithm for March East Coast winter storm case and for February CalWater case (Yellow: Stratiform; Red: Convective)



Different surface precipitation rate, composite radar reflectivity, echo-top height, freezing level height, maximum radar reflectivity height,

<-- ***Different LH profiles***

(No use of convective-stratiform separation)



Schematic diagram of Goddard latent heating retrieval algorithm for GPM/TRMM

CSH (SLH) standard LH products

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

CSH: Convective-Stratiform Heating
SLH: Spectral Latent Heating (Input data – DPR)

Vertically-integrated LH (equivalent surface rain) vs *Combined retrieved* surface rain

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

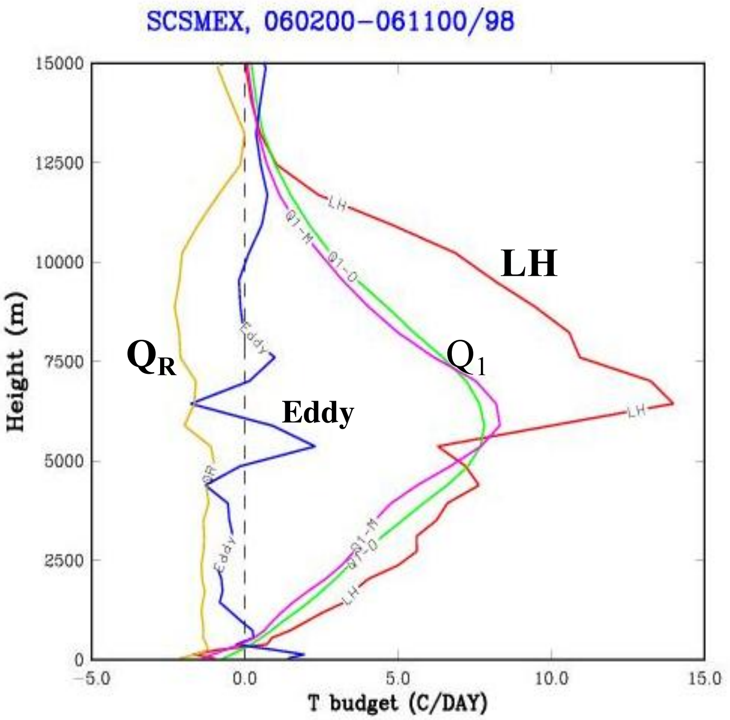
Q1R= Q_1-Q_R **Eddy Heat Transport** **LH: Latent Heat - phase change of water**

$$\frac{1}{g}\int_{Lx}\int_{P_{top}}^{P_{base}}(Q_1 - Q_R)\Delta p \Delta x - \boldsymbol{S_0} = \boldsymbol{LP_0}$$

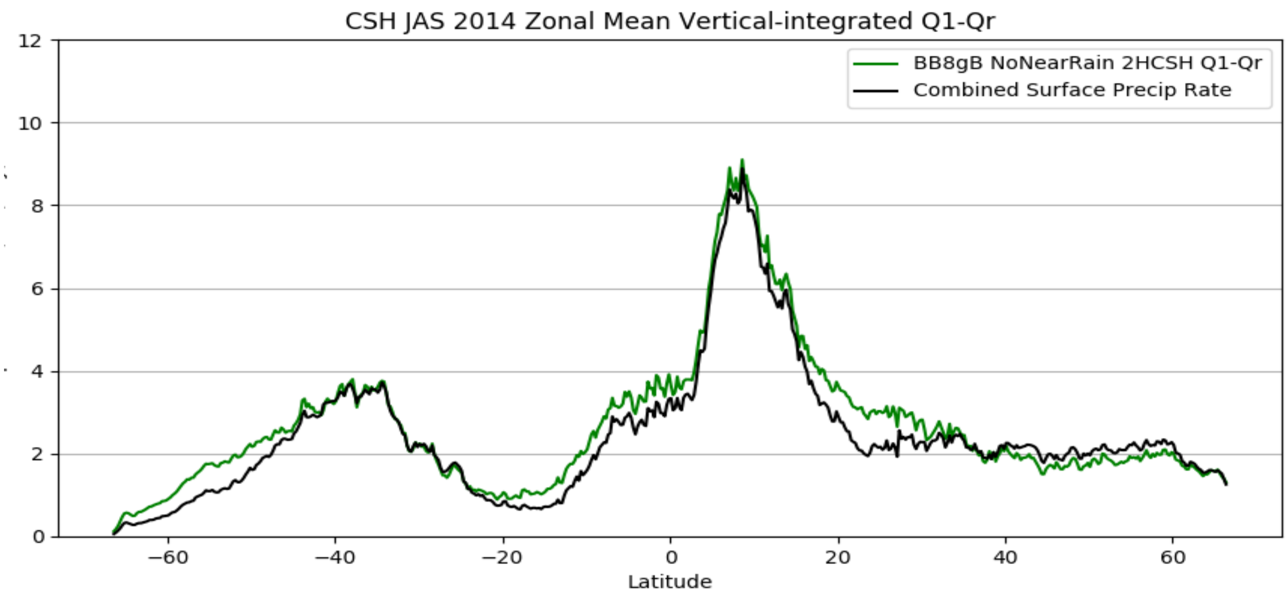
S_o: Surface sensible heat flux
P_o: Surface rainfall rate

There is an assumption for the above equation: Yanai *et al.* (1973) stated: "***we consider an ensemble of cumulus clouds, which is embedded in a tropical large-scale motion system, then we imagine a horizontal area that is large enough to contain the ensemble of clouds, but small enough to be regarded as a fraction of the large-scale system (~ a GCM Grid Size)***"

No direct measurement on LH fort validation!

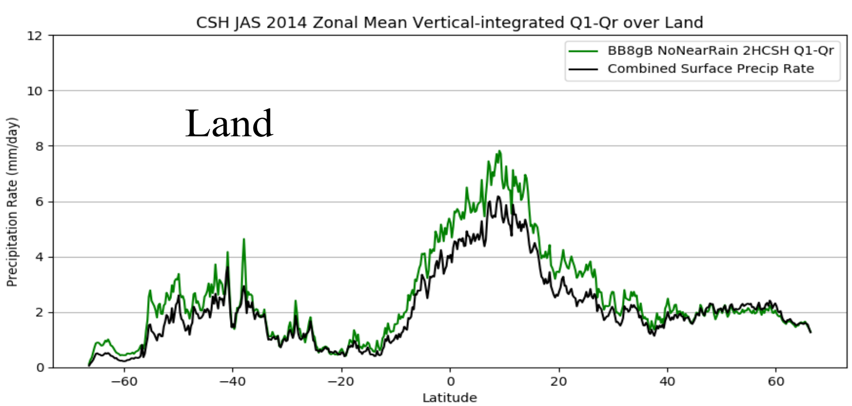


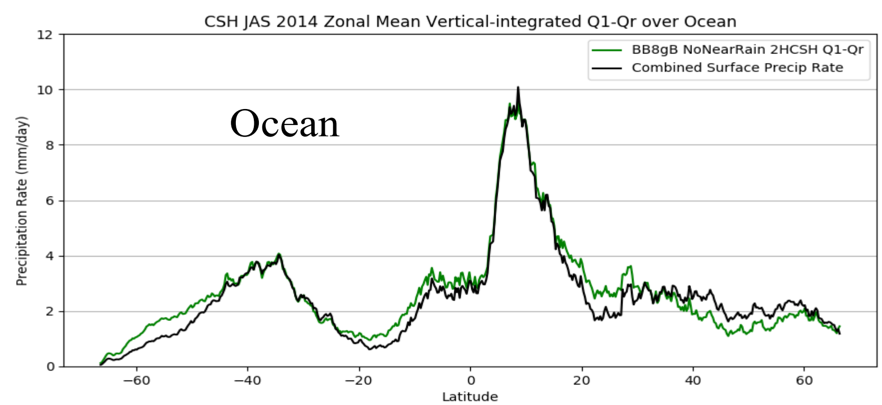
CSH retrieved zonal mean vertically-integrated Q_1-Q_R ***for July, August and September 2014***



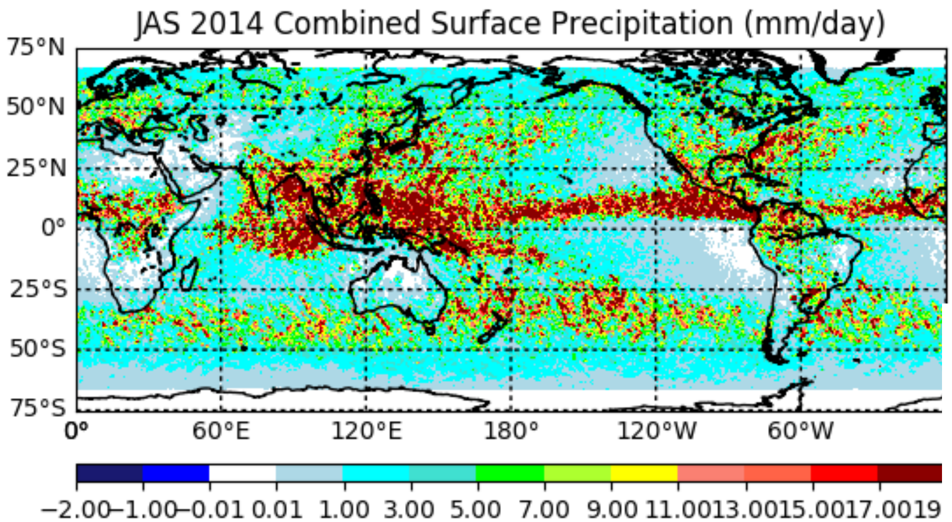
Goddard LH algorithm "**equivalent" surface rain rate" is** stronger (or higher) than the **Combined** rain rate over land.

But it is in agreement with the Combined surface rain rates over the ITCZ region over ocean



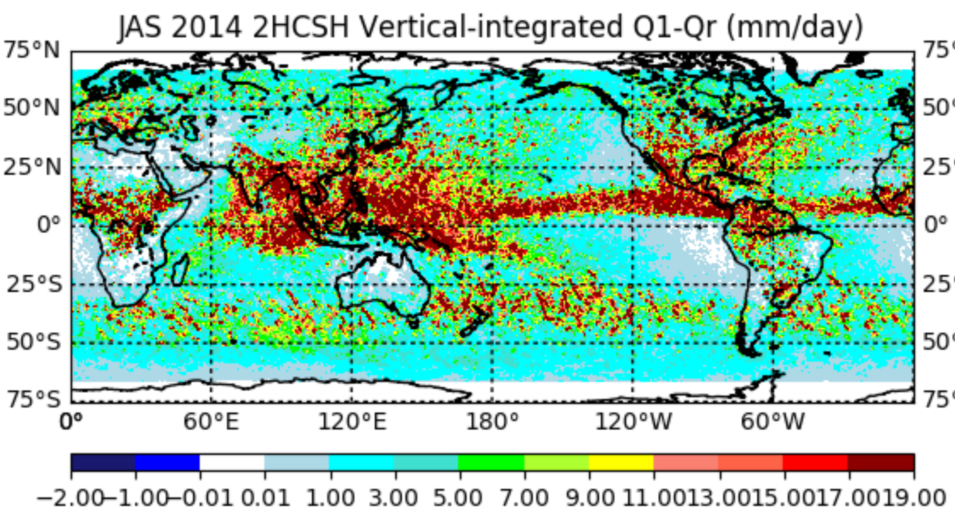


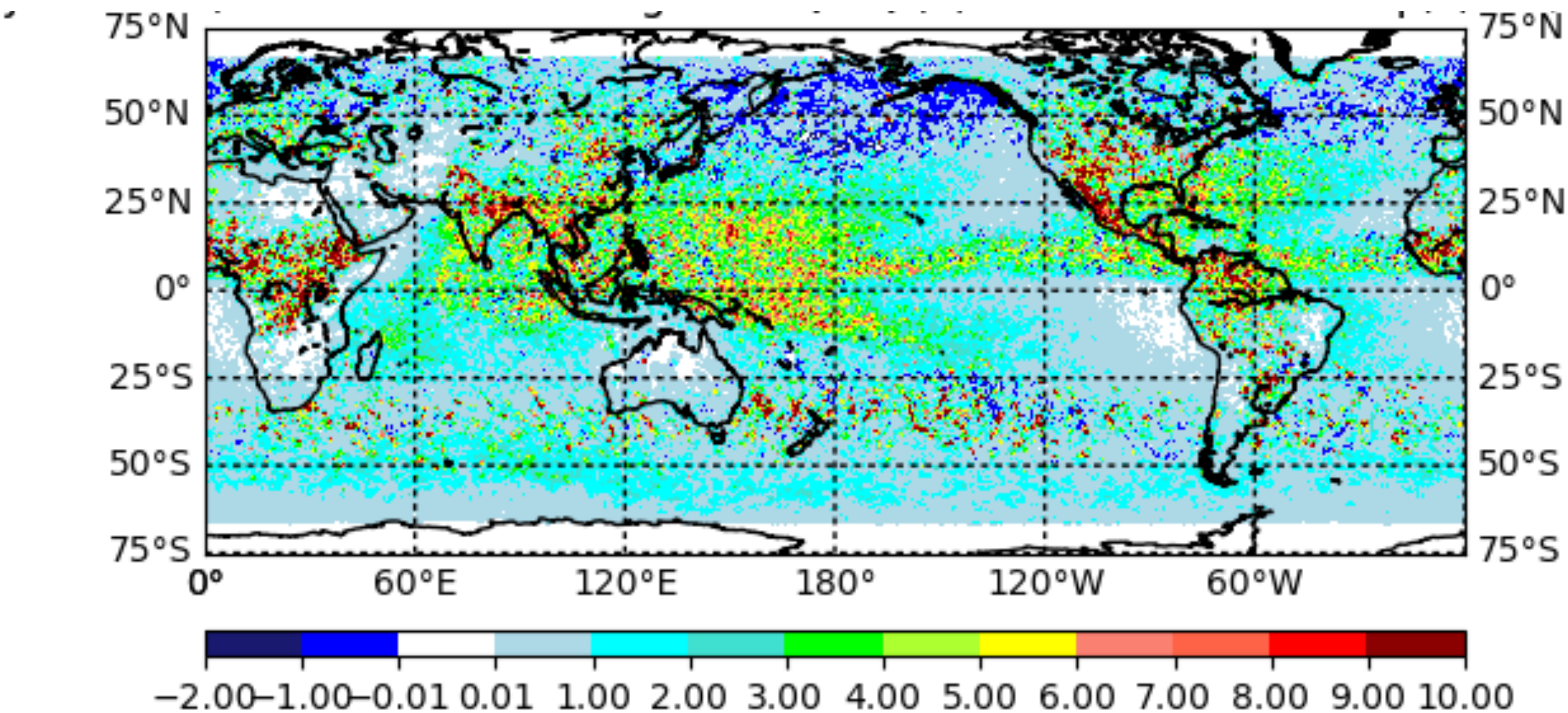
Very similar pattern (distribution) between Combined and vertically-integrated Q_1-Q_R (equivalent" surface rain rate) at 0.25° x 0.25° resolution



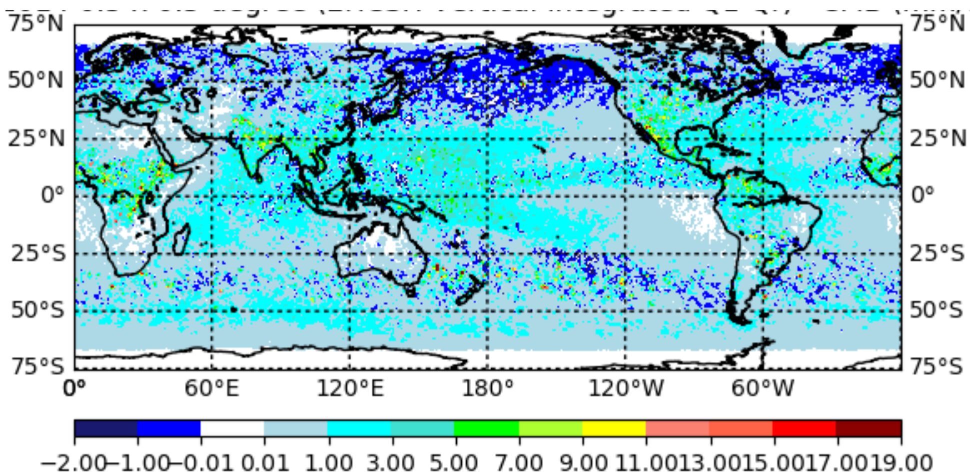
Combined retrieved mean surface rain rate

2HCSH vertically-integrated surface rain rate





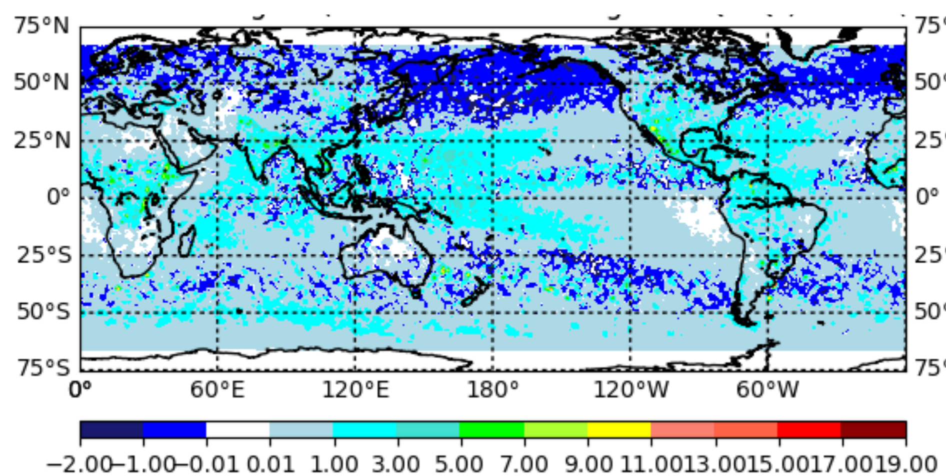
Differencing the mean surface rainfall rate from the Combined algorithm and from the mean column-integrated 3GCSH cloud diabatic heating rates ($Q_1 – Q_R$) for the 3-month period at **0.25^{o} x 0.25^{o} resolution.** ***The difference (plot) can be used as a flag for Goddard Latent Heating Retrieval!***



Differencing the mean surface rainfall rate from the Combined algorithm and from the mean column-integrated 3GCSH cloud diabatic heating rates ($Q_1 - Q_R$) for the 3-month period at **0.5^o x 0.5^o resolution (bottom) and 1.0^o x 1.0^o resolution (left)**

The difference between the Combined algorithm and the mean column-integrated cloud diabatic heating rate from 3GCSH depends on the horizontal resolution.

Larger difference at higher horizontal resolution.

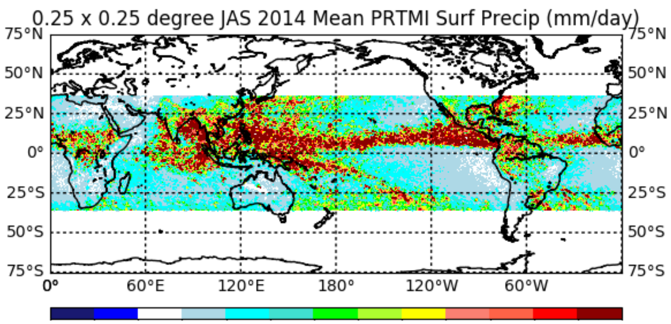


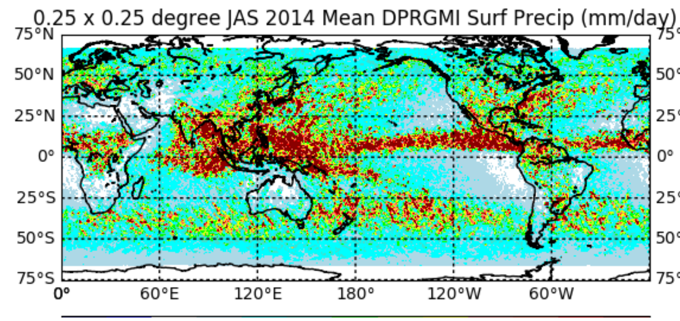
PMM Precipitation - July –August-September 2014

TRMM

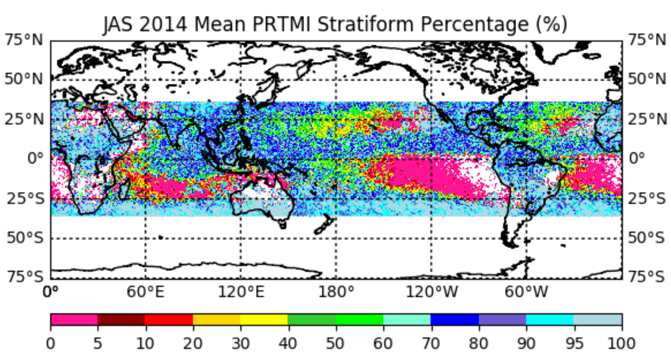
GPM

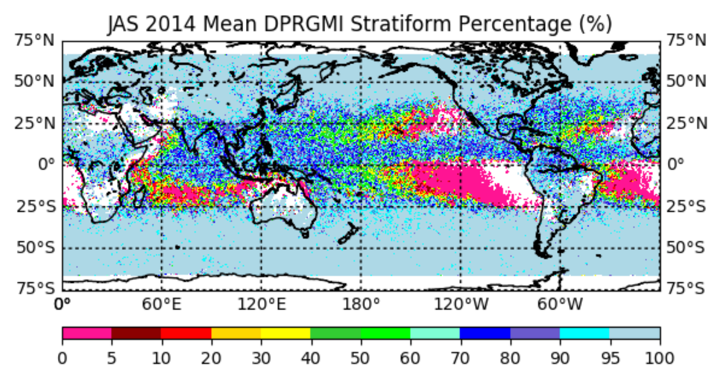
Surface Rainfall Rate

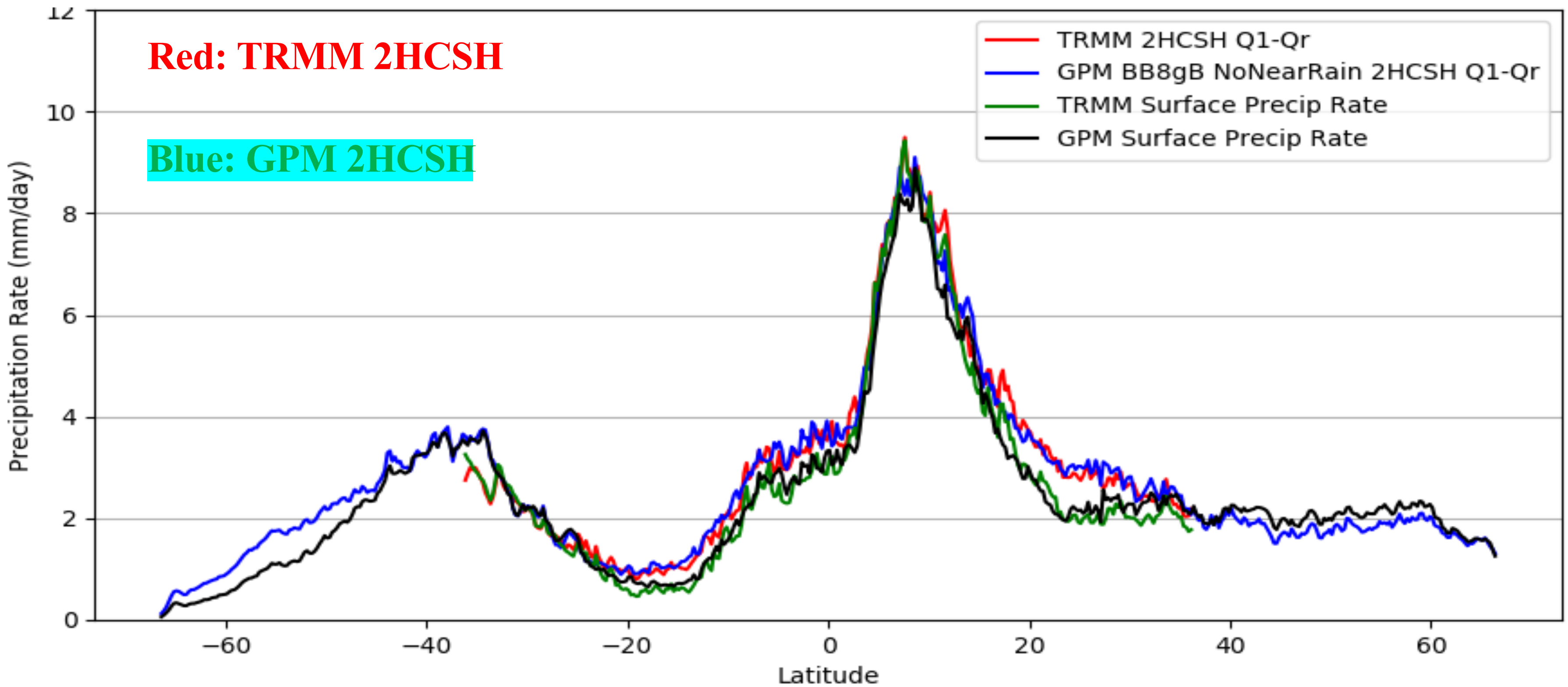




Stratiform Percentage







2HCSH retrieved vertically-integrated Q_1-Q_R ("equivalent" rain rates) for TRMM and GPM.

The Combined derived surface rain rates for TRMM and GMP are shown for comparison.

Very similar results between the Goddard LH algorithm-retrieved vertically-integrated Q_1-Q_R for both TRMM and GPM

Both retrieved "equivalent" surface rain rates are in agreement with the Combined derived over the ITCZ region

SUMMARY & FUTURE WORK

2HCSH retrieved Q_1-Q_R are in agreement with the combined surface rain rates for both TRMM and GPM (especially at and near the ITCZ)

2HCSH results are averaged to produce 3GCSH products (consistent with combined derived rain rates)

3GCSH vertically-integrated surface rain rate and its difference with combined derived surface rain rate can be used for flags

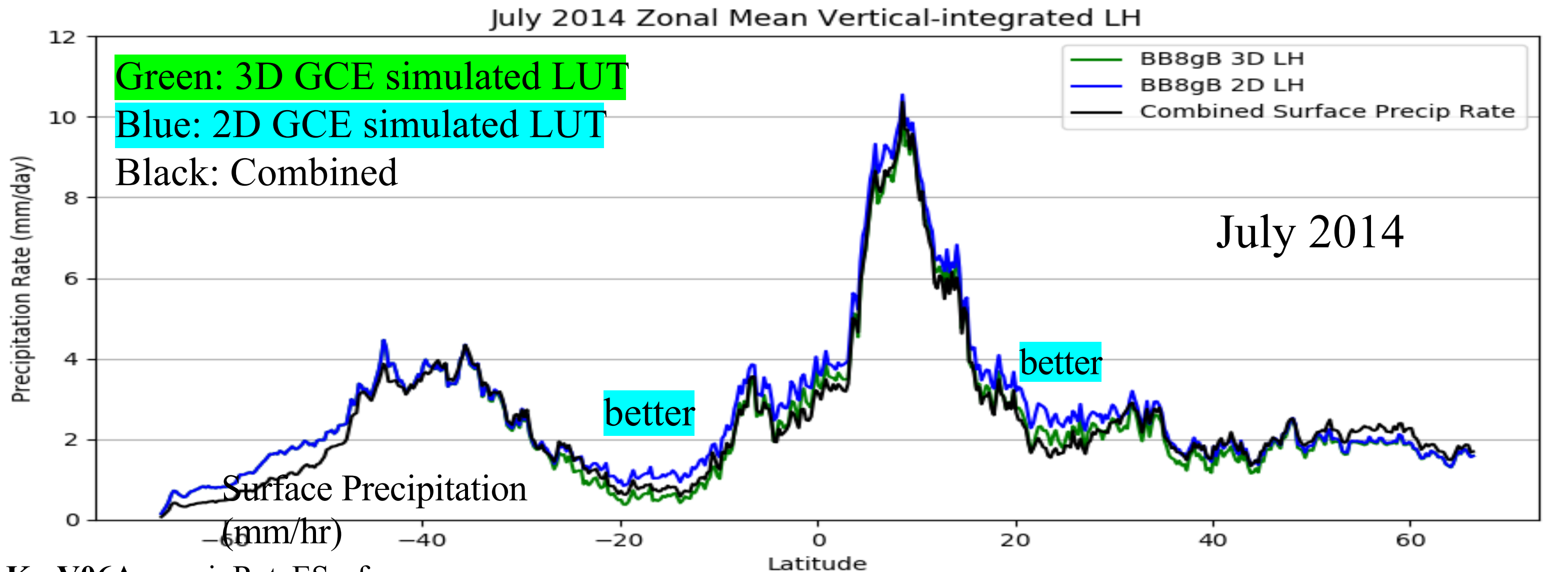
Will continue to examining the positive bias in the vertically-integrated LH in the sub-tropics (large heating over land regions)

Will use 3D GCE modeled LH for the next version of the Goddard LH algorithm look-up tables

Will use NU-WRF modeled LH for more cold season and high latitude cases (Japan Sea, C3VP, IFlooodS, LPVEx, NAMMA ….)

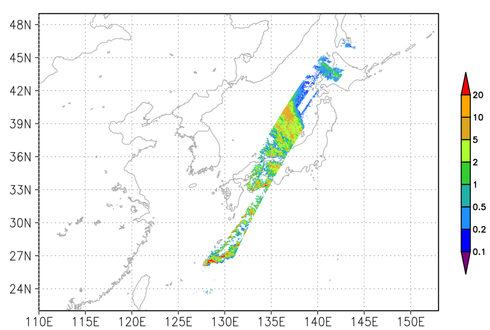
17/17 + 1 (3D GCE simulated look-up table + NU-WRF Japan Sea)

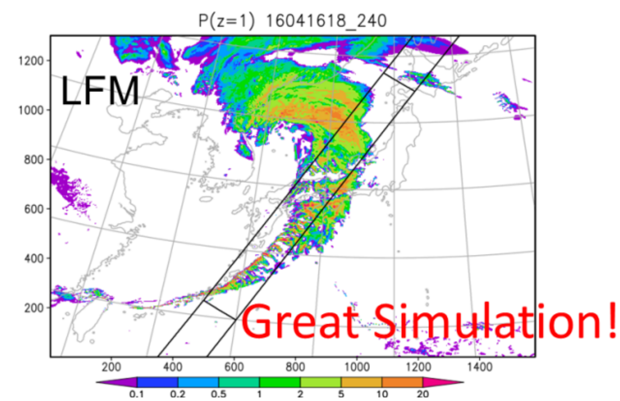
3D GCE Simulated LH - LUT

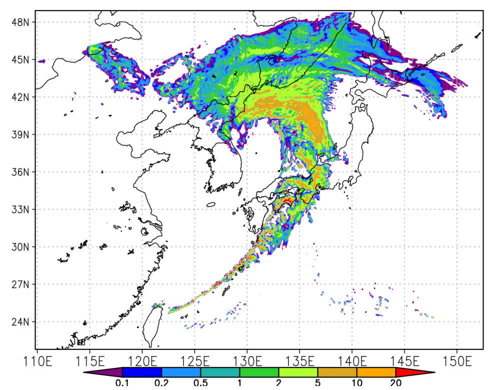


Japan Sea Case

2A.Ku.V06A_precipRateESurface







Plus 1

Surface Precipitation (mm/hr)

NU-WRF