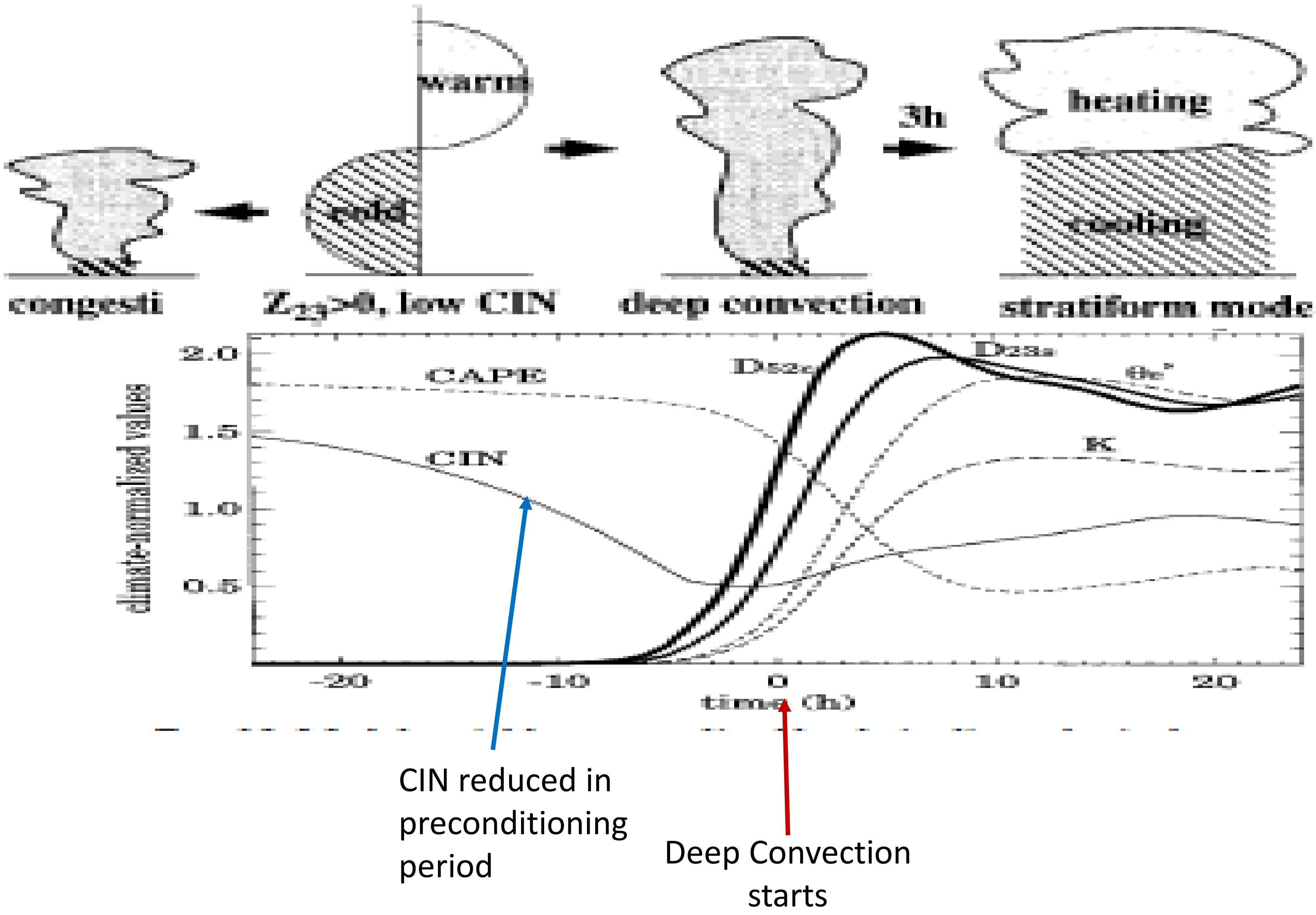
Convection Initiation and Large-Scale Moisture Transport: a HAMSR and GPM/IMERG Perspective

Sun Wong and Bjorn Lambrigtsen

JPL/California Institute of Technology

CPEX Science Team Meeting (Utah, 2018 June)

CIN-Controlled Convection Initiation (Mapes JAS 2000)



- A wave propagates to a region
- Lower tropospheric T reduced, congesti formed
- CIN reduced, triggered deep convection

Description of Moisture Transport

$$P - E + \frac{\partial Q}{\partial t} = -Q\nabla \cdot \boldsymbol{V} - \boldsymbol{V} \cdot \nabla Q$$

QCNVG

QADVT

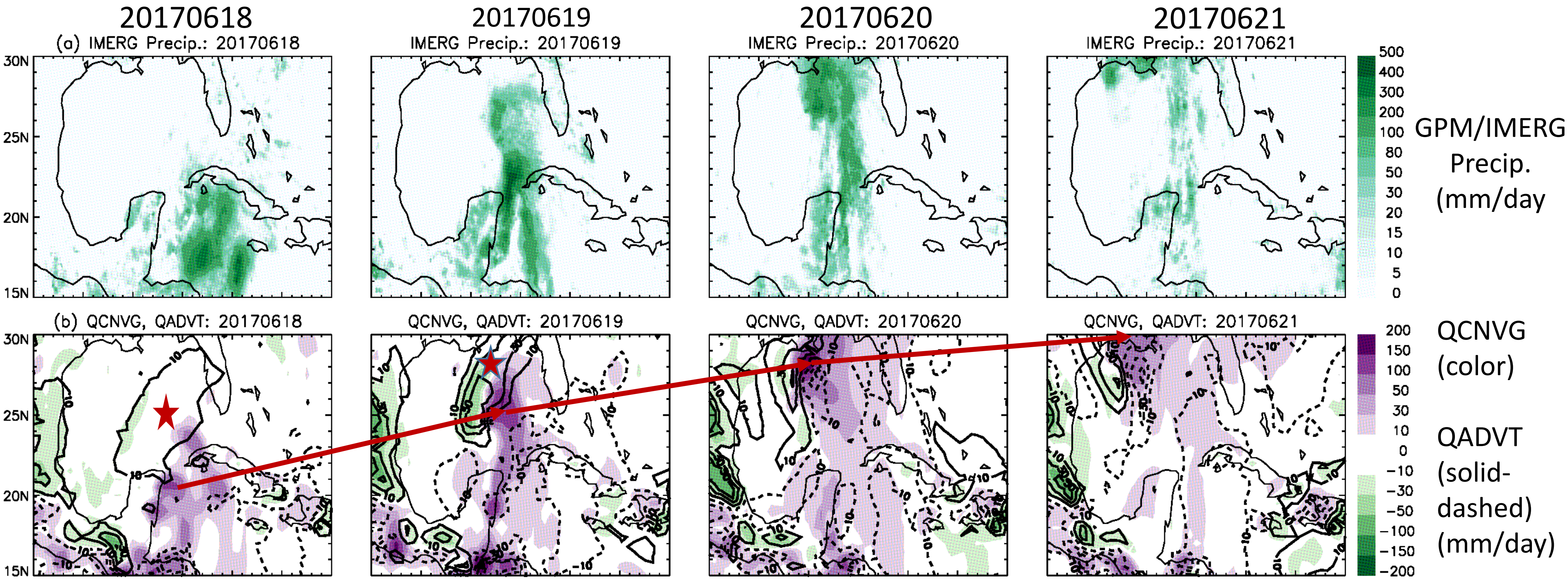
Where

$$Q = \int_{ptop}^{psrf} q \frac{dp}{g}$$

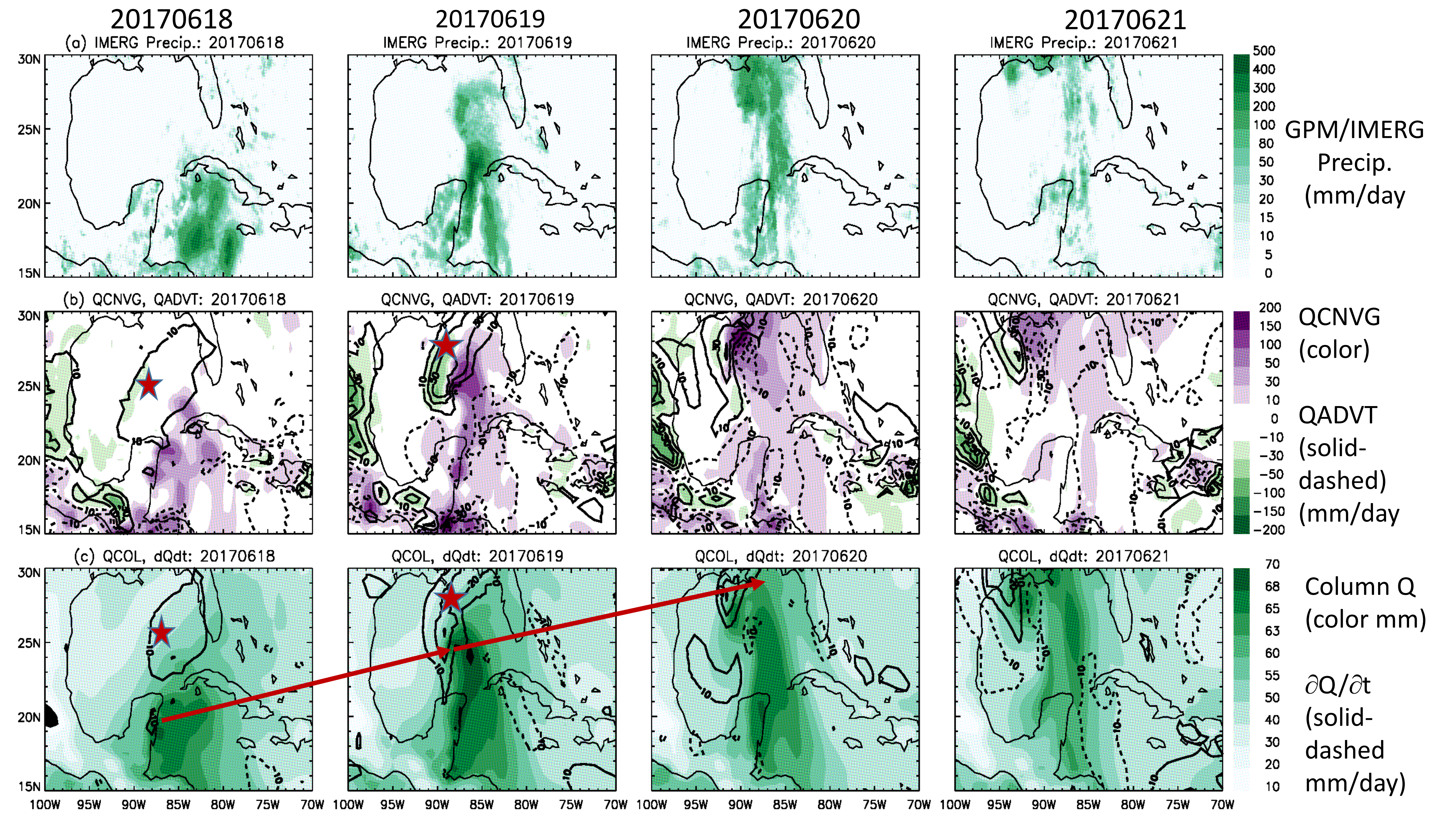
$$\boldsymbol{V} = \frac{1}{Q} \int_{ptop}^{psrf} (q\boldsymbol{v}) \frac{dp}{g}$$

P: Precipitation
E: Evaporation
q: Specific humidity
p: Pressure altitude

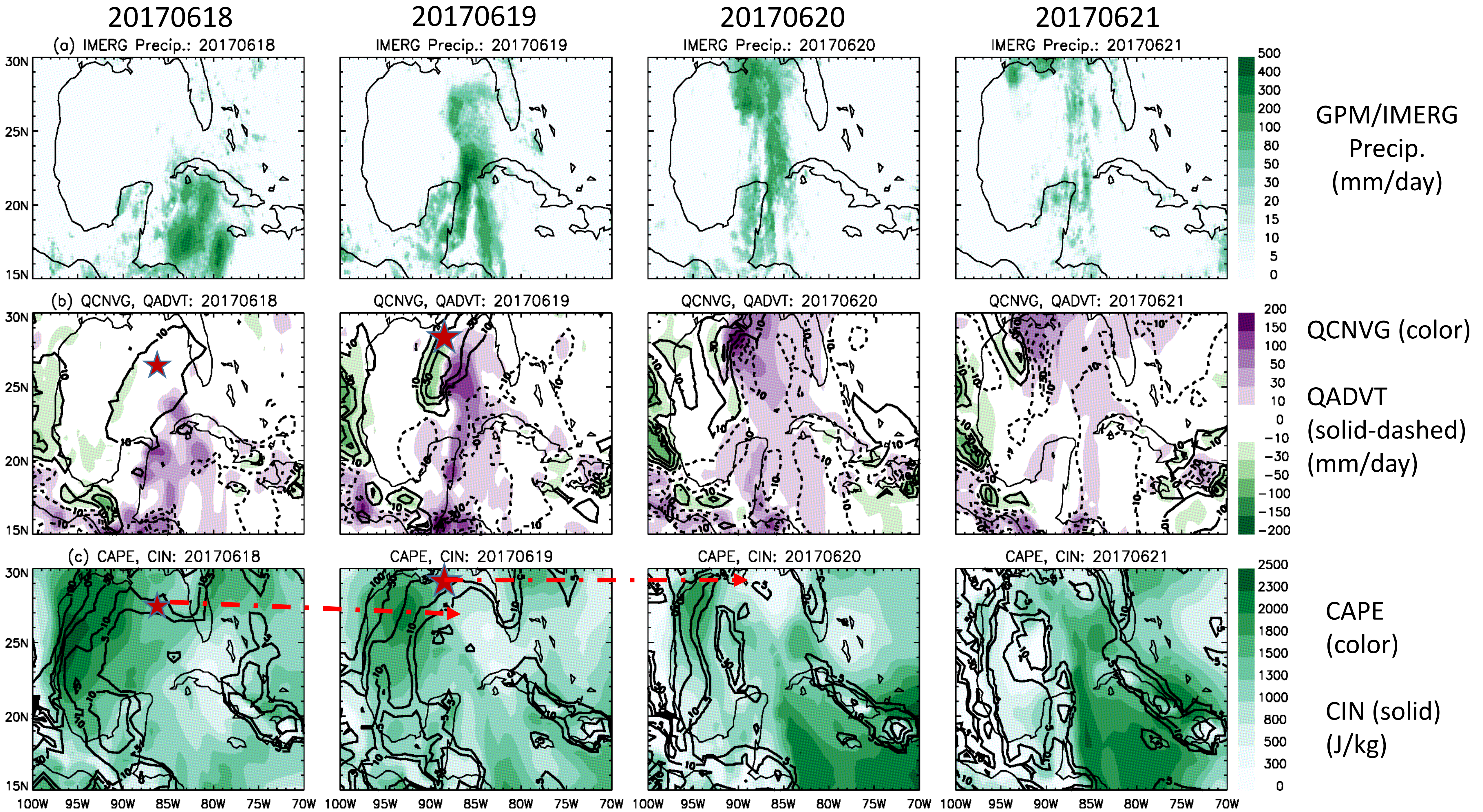
(Wong et al. 2016 J. Climate)



- QADVT indicates region of preconditioning for development of deep convection



20170618
20170619
20170620
20170621
(a) IMERG Precip.: 20170618
IMERG Precip.: 20170619
IMERG Precip.: 20170620
IMERG Precip.: 20170621
GPM/IMERG Precip. (mm/day)
(b) QCNVG, QADVT: 20170618
QCNVG, QADVT: 20170619
QCNVG, QADVT: 20170620
QCNVG, QADVT: 20170621
QCNVG (color)
QADVT (solid-dashed) (mm/day)
(c) QCOL, dQdt: 20170618
QCOL, dQdt: 20170619
QCOL, dQdt: 20170620
QCOL, dQdt: 20170621
Column Q (color mm)
∂Q/∂t (solid-dashed mm/day)
30N
25N
20N
15N
100W
95W
90W
85W
80W
75W
70W



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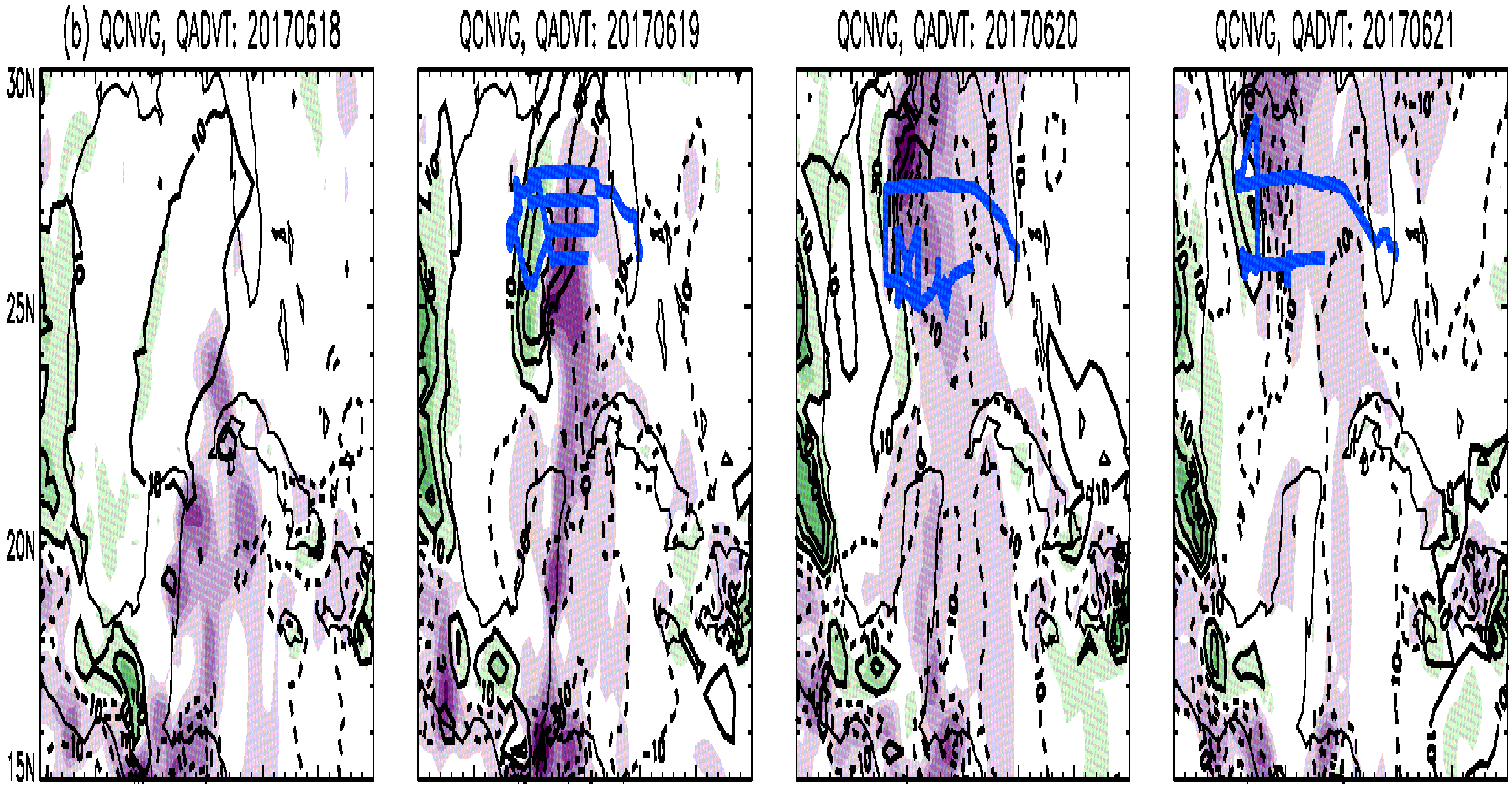
QCNVG (color)
QADVT (solid-dashed) (mm/day)
(c) CAPE, CIN: 20170618
CAPE, CIN: 20170619
CAPE, CIN: 20170620
CAPE, CIN: 20170621
CAPE (color)
CIN (solid) (J/kg)
30N
25N
20N
15N
100W
95W
90W
85W
80W
75W
70W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30N
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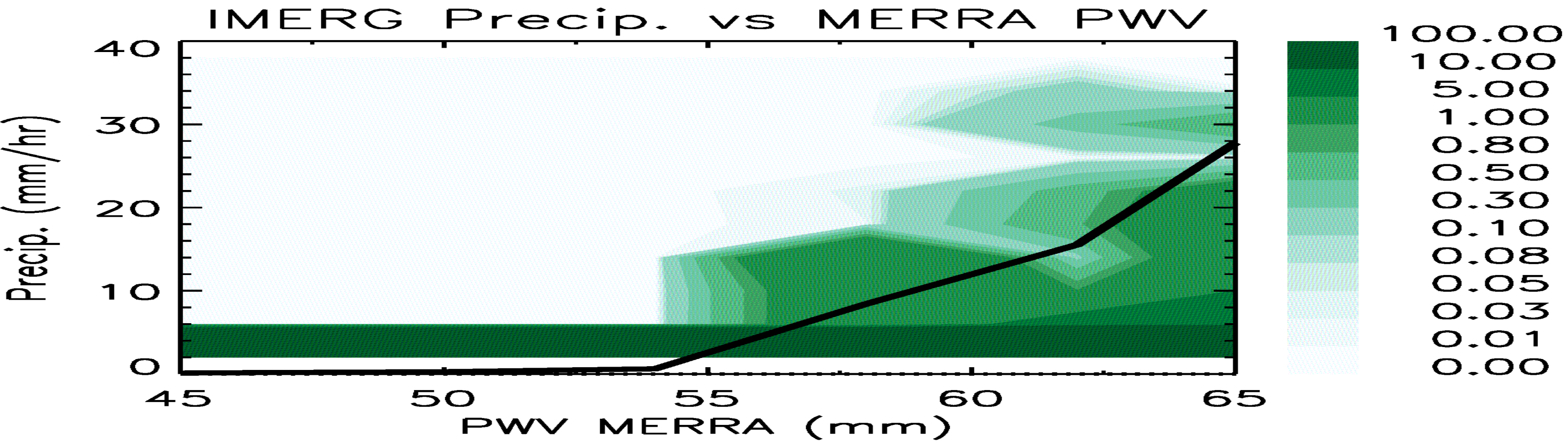
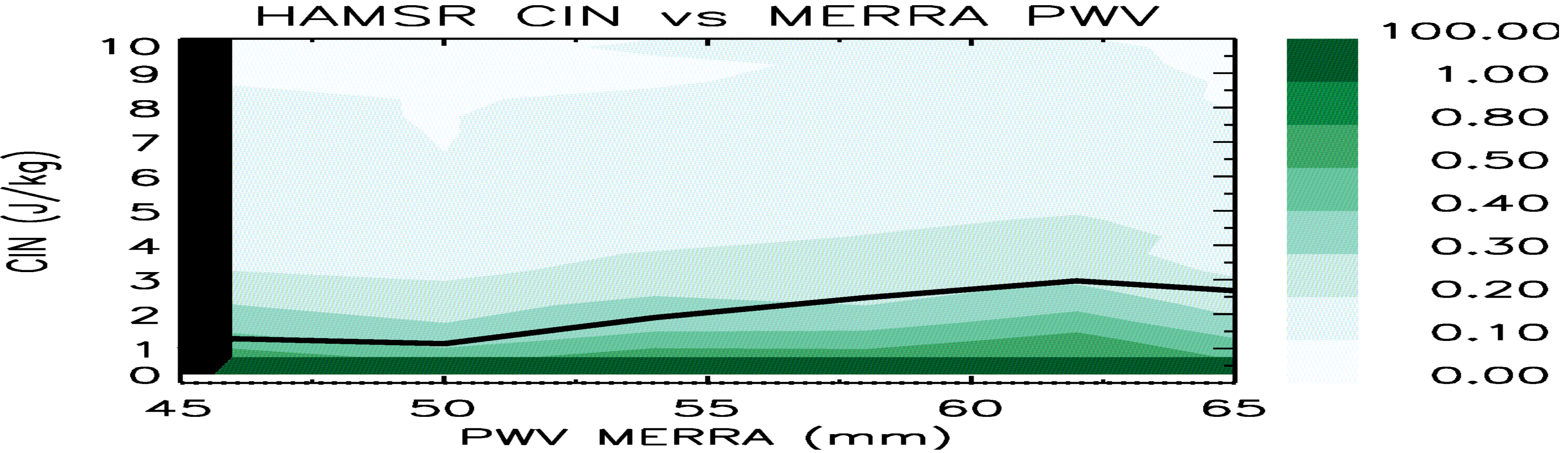
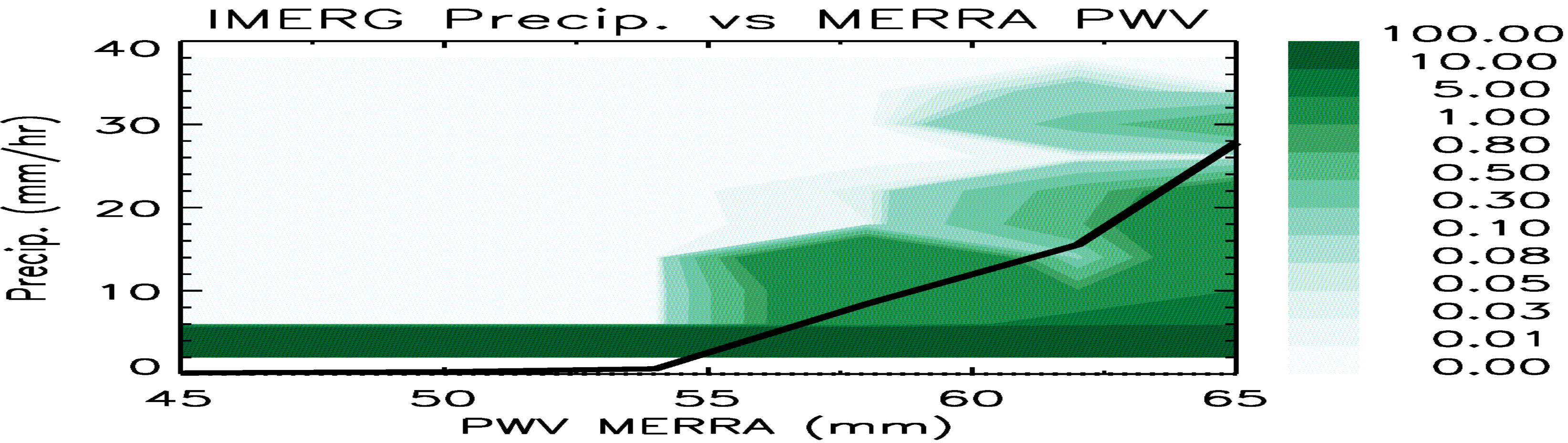
15N



- Rain (IMERG) histograms as a function of MERRA-2 precipitable water vapor (PWV)
- A transition is seen between 55-60 mm



- Nope! CIN (HAMSR) reduction is not obvious before 55-60 mm



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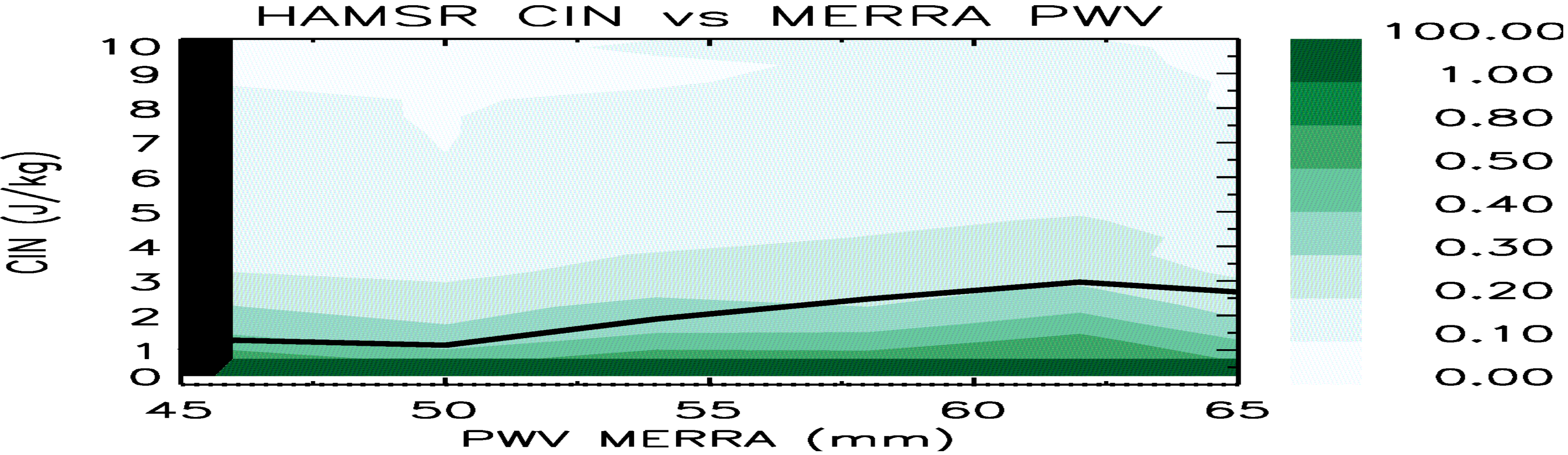

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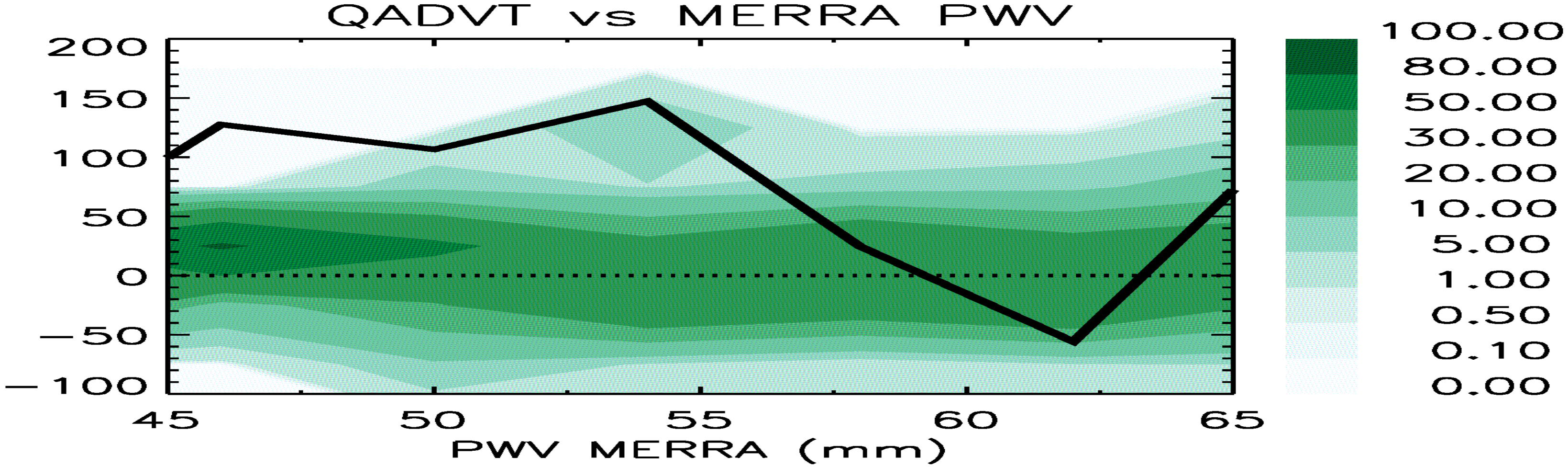
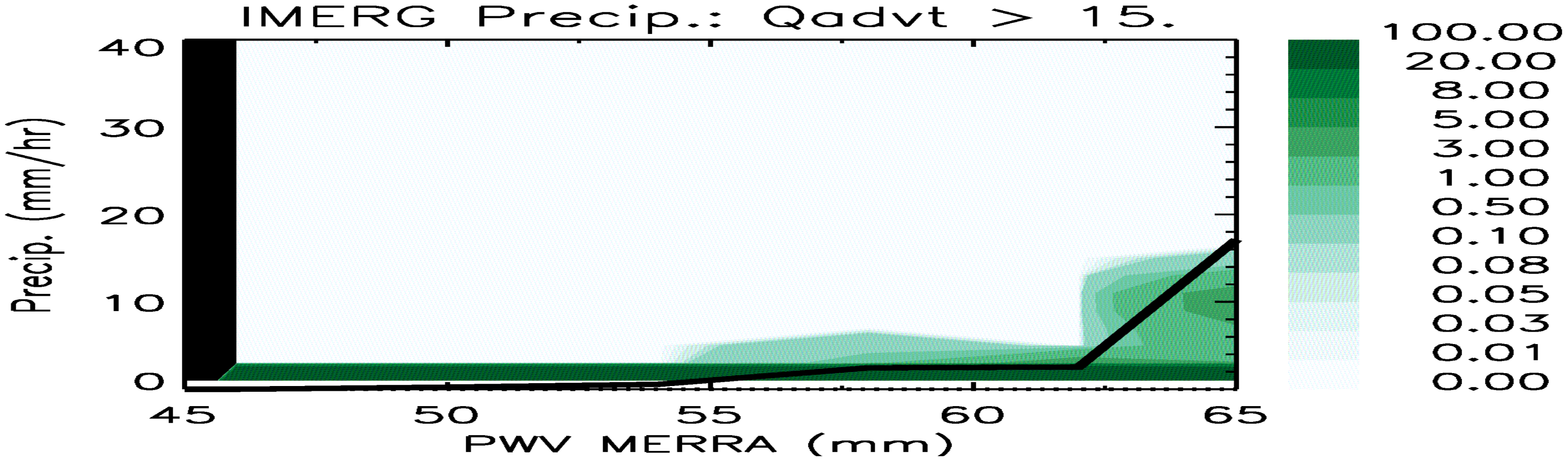
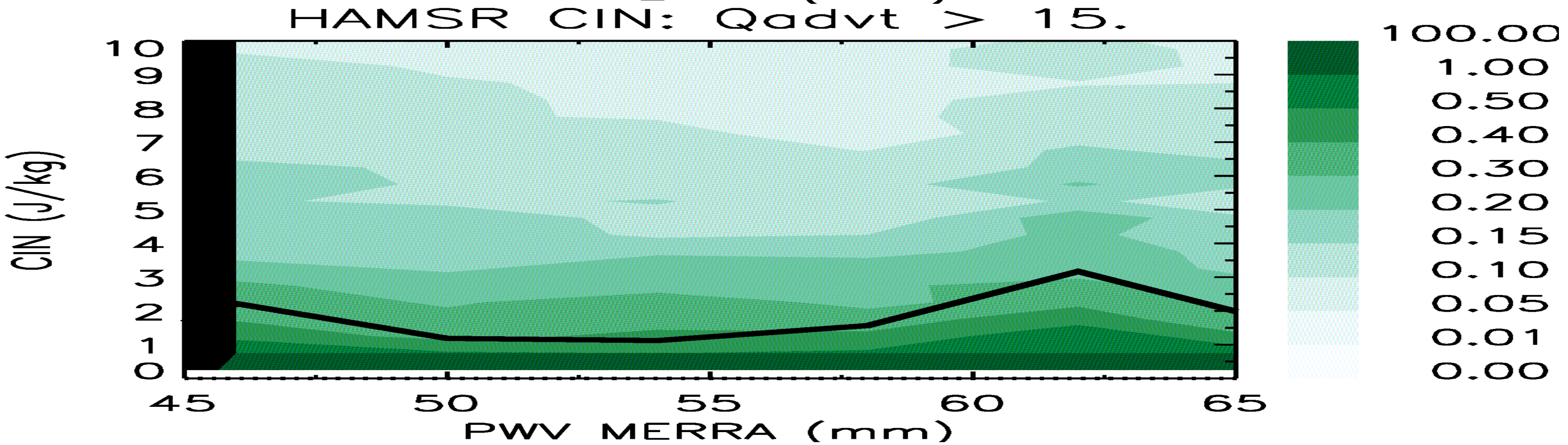


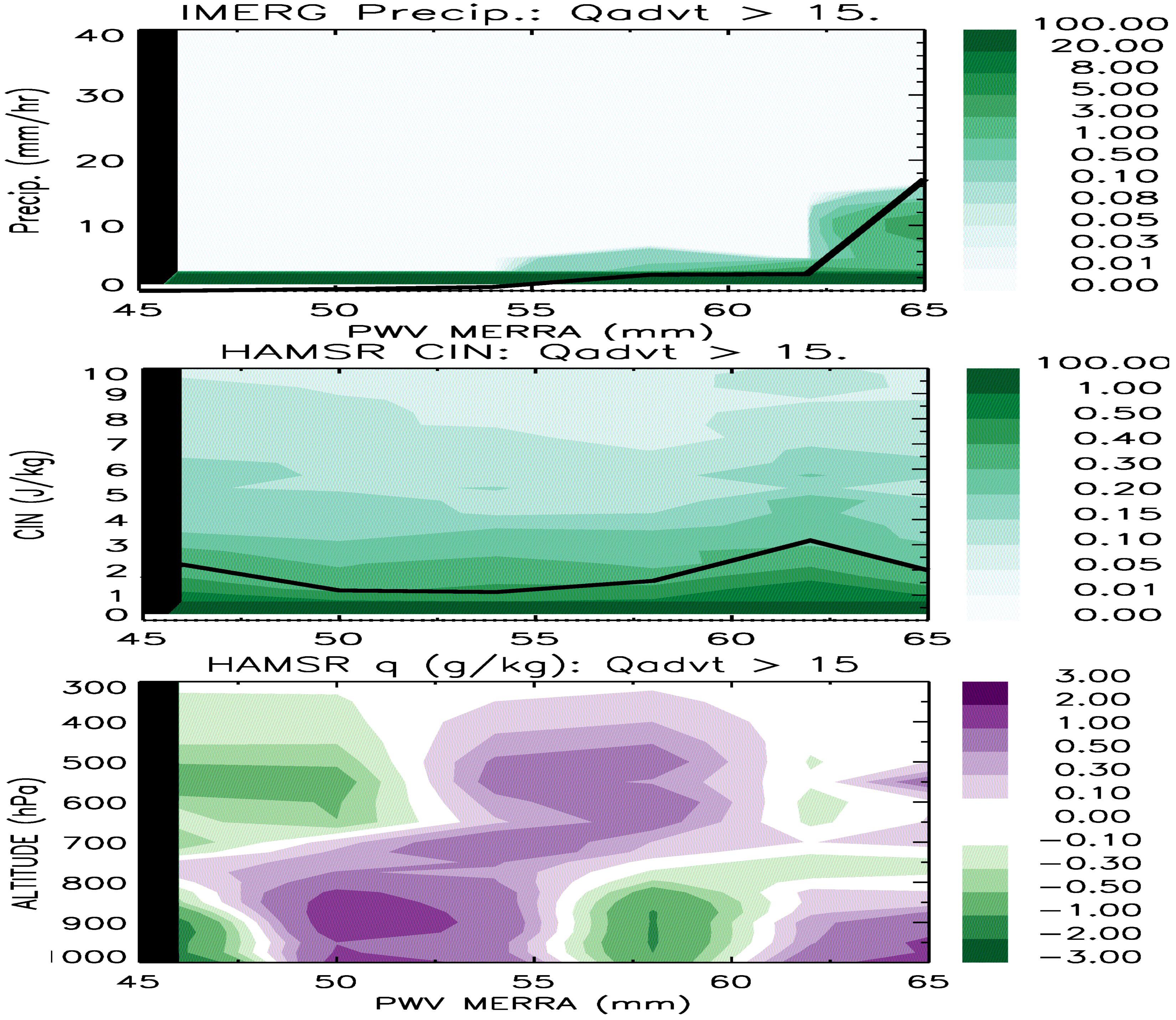
- Need to pick preconditioning condition with QADVT > a positive threhold



- Rain (IMERG) histograms for QADVT > 15 mm/day show smaller rain
- A transition is still seen between 55-60 mm



- Countours for probability for high CIN decrease between 50-55 mm



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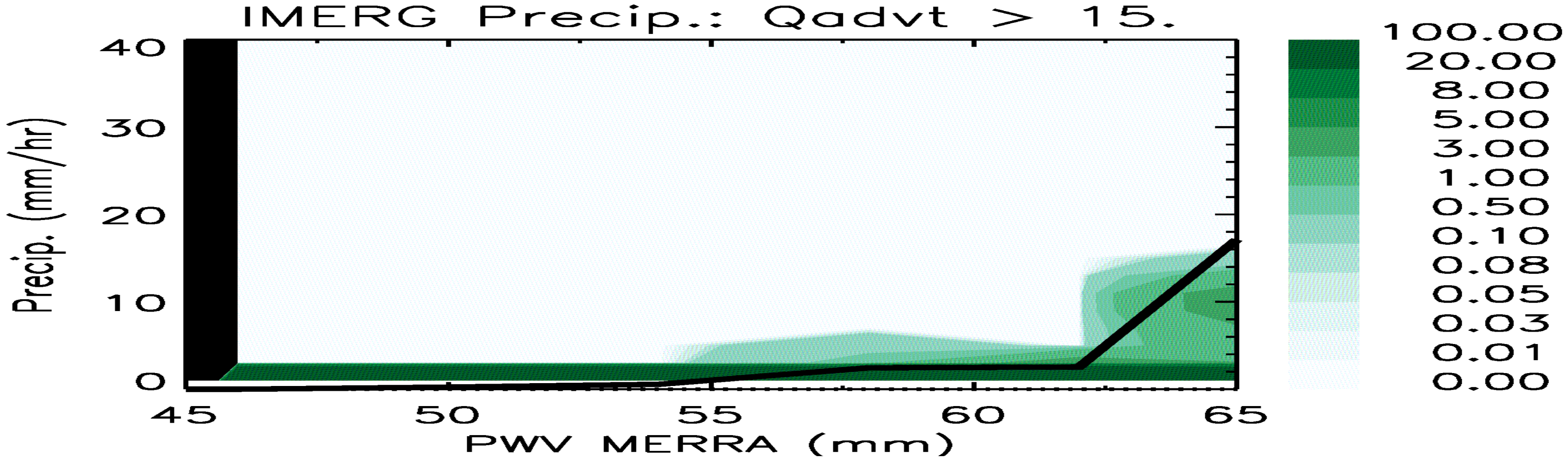
- Mid-tropospheric moistening begins around 50-55 mm and reaches a peak at 55-60 mm



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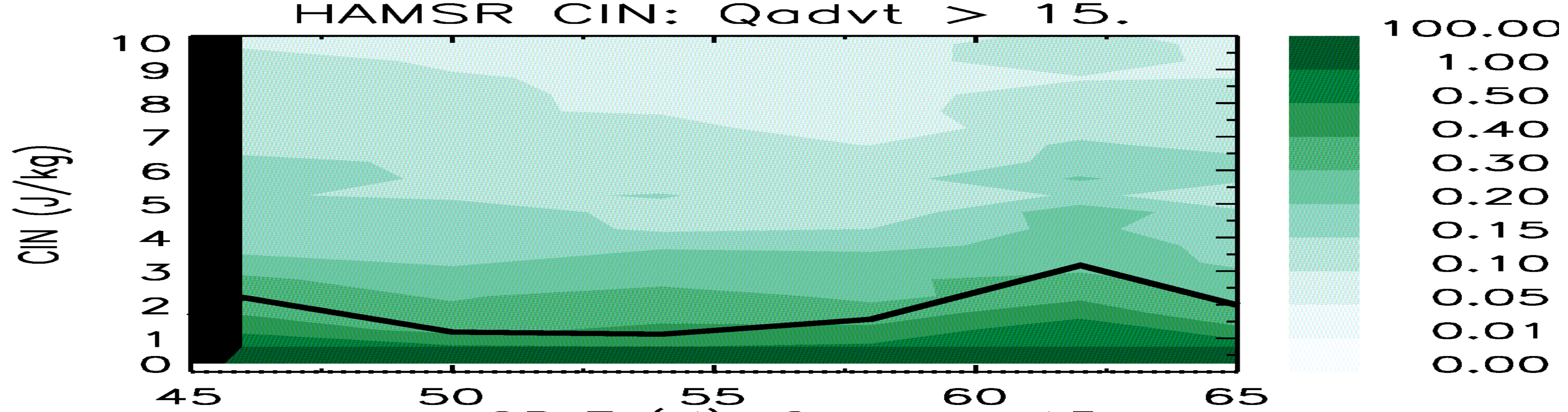

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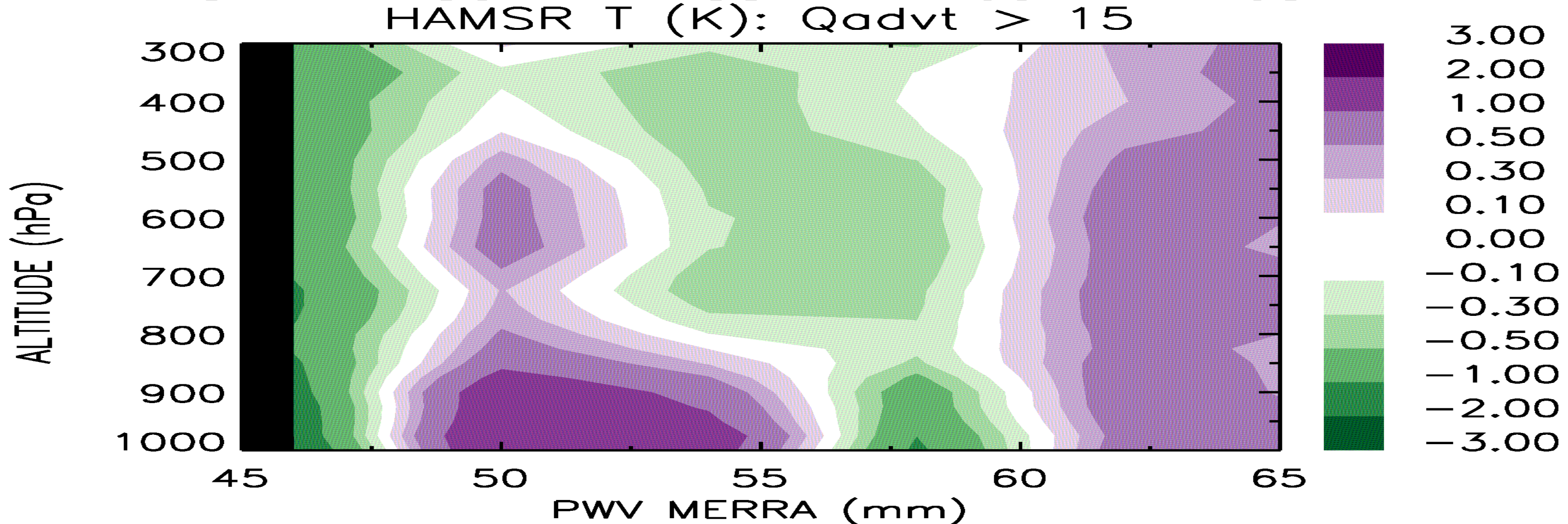
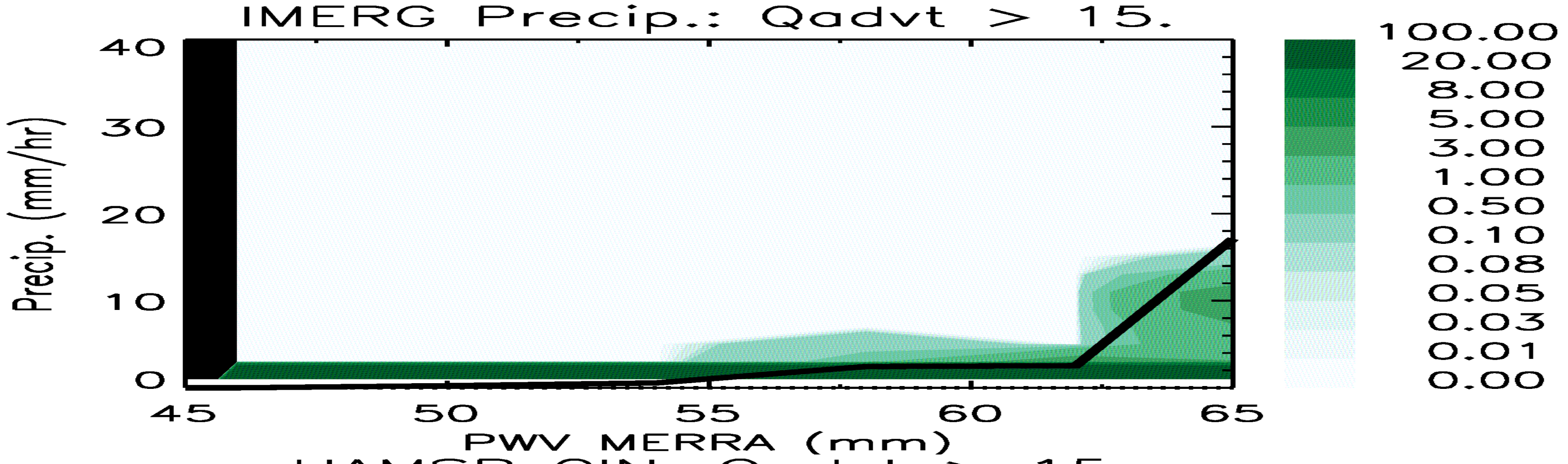


- Cooling at top of PBL begins around 50 mm and develops deeper into the PBL between 50-60 mm.



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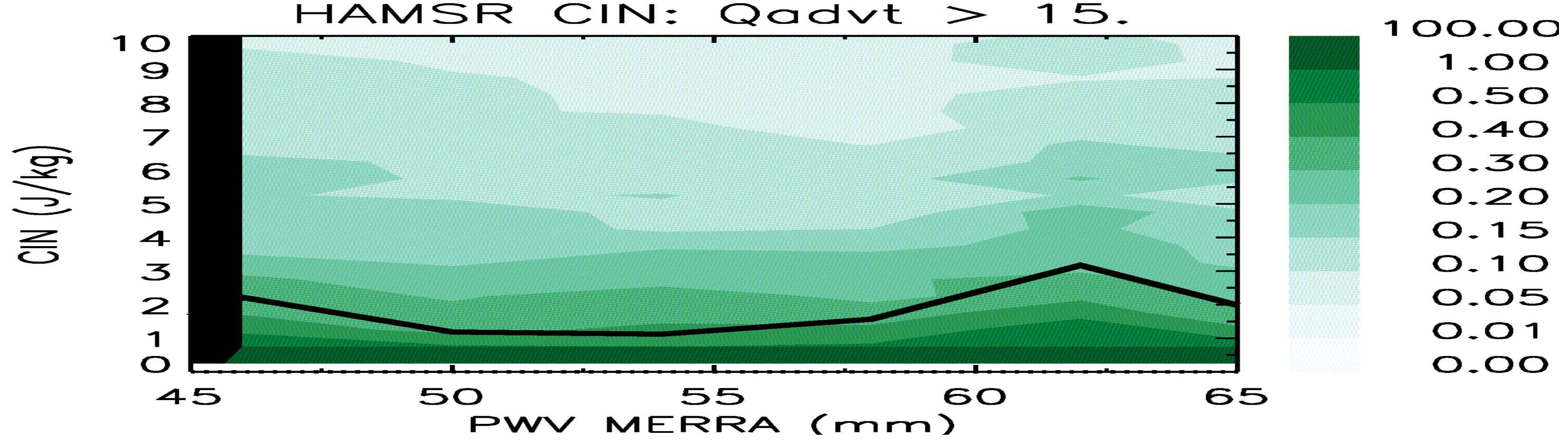

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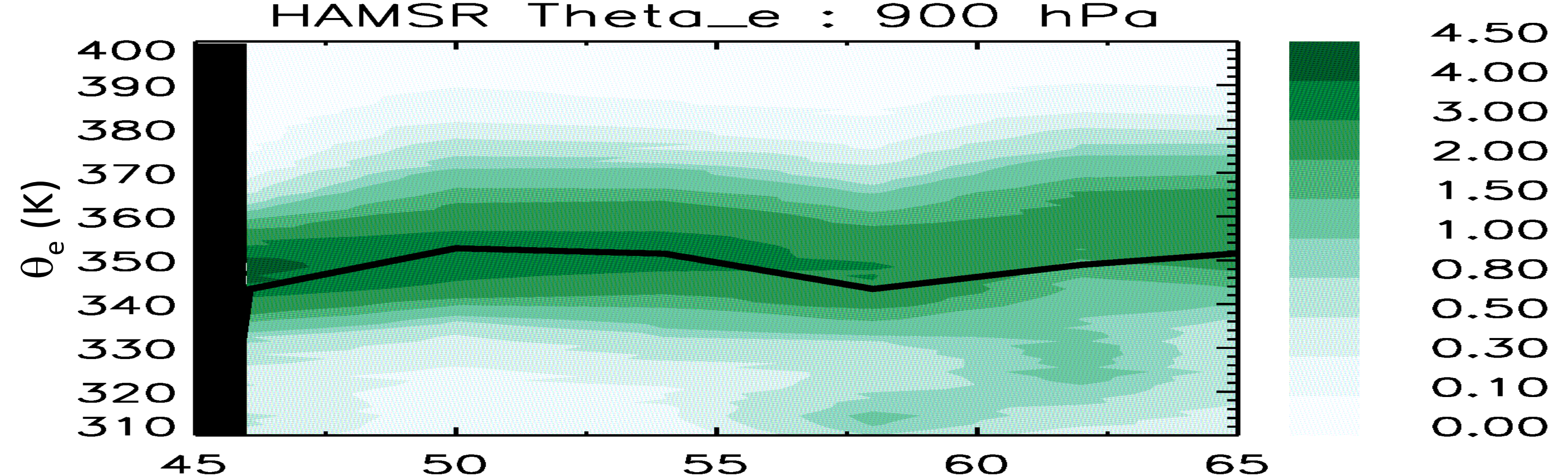


- PDF of θ_e in the PBL spreads when there begins to have rainfall.

Conclusions:

- Large moist advection ($-\mathbf{V}\cdot\nabla Q$) signifies preconditioning and forebode the upcoming occurrence of deep convection
- Convection inhibition decreases with increasing moisture loading during the preconditioning period ($-\mathbf{V}\cdot\nabla Q > 15$ mm/day)
- Increases in humidity in the boundary layer propagate upward to mid-troposphere when Q ~ 50-60 mm
- Decreases in temperature at the top of PBL propagate downward to the surface when Q ~ 50-60mm

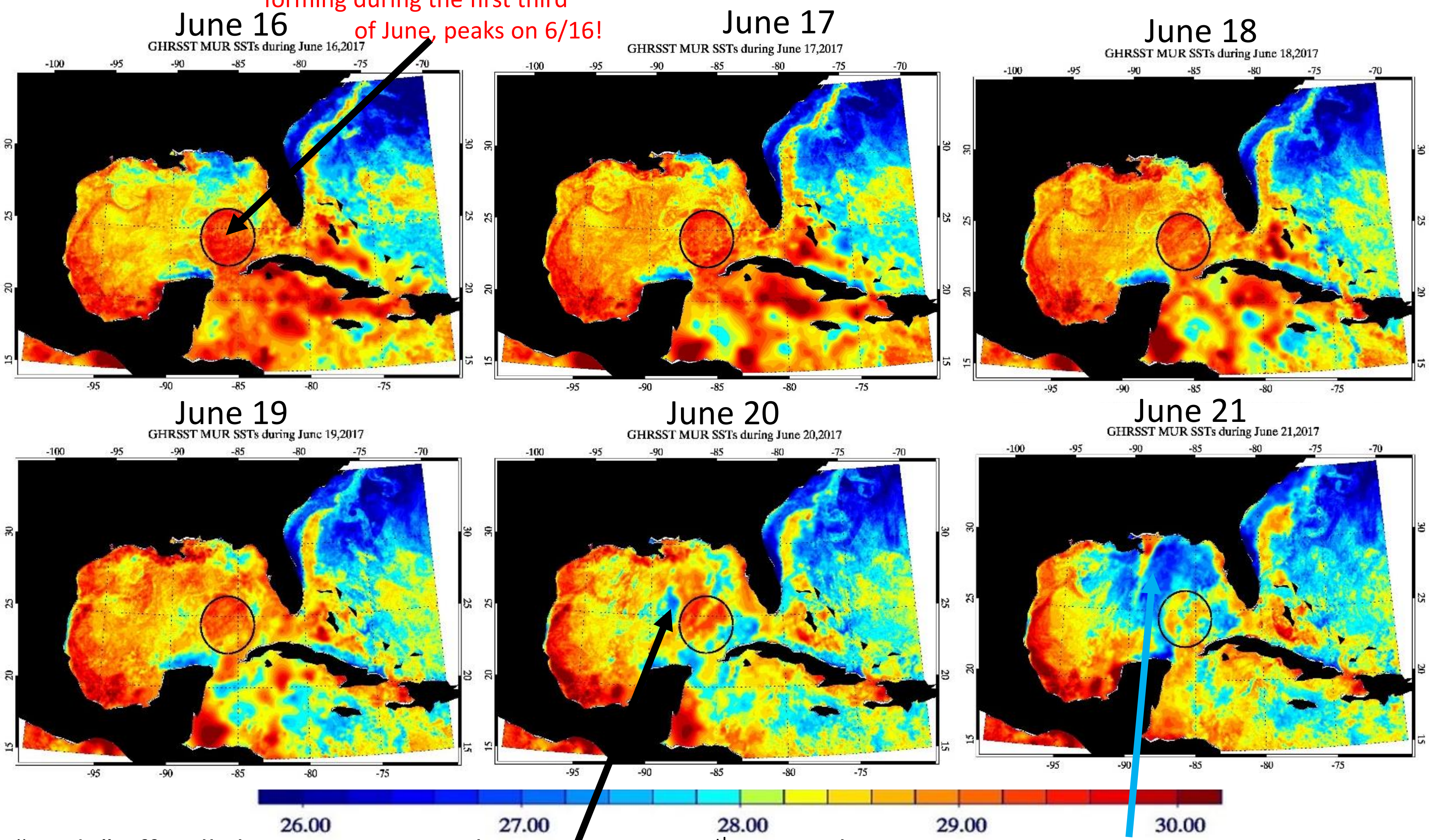
SST (Hot Spot) and Deep Convection Analysis during June 2017, Prior to, During, and After Tropical Storm Cindy

[1]Terry Kubar, [2]Ali Behrangi, and [3]Bjorn Lambrigtsen
[1]UCLA/JIFRESSE
[2]University of Arizona at Tucson
[3]JPL/California Institute of Technology

CPEX, STM
June 2018

GHRSST MUR High-Resolution SSTs Before and During Tropical Storm Cindy from June 16th – 21st, 2017

Circular region of very high SST starts forming during the first third of June, peaks on 6/16!



"Cindy" officially becomes a tropical storm on June 20th, near where there's an area of locally reduced SST, as shown by MUR. The high SSTs in the circular region begin to erode (they actually peak on ~6/16!)

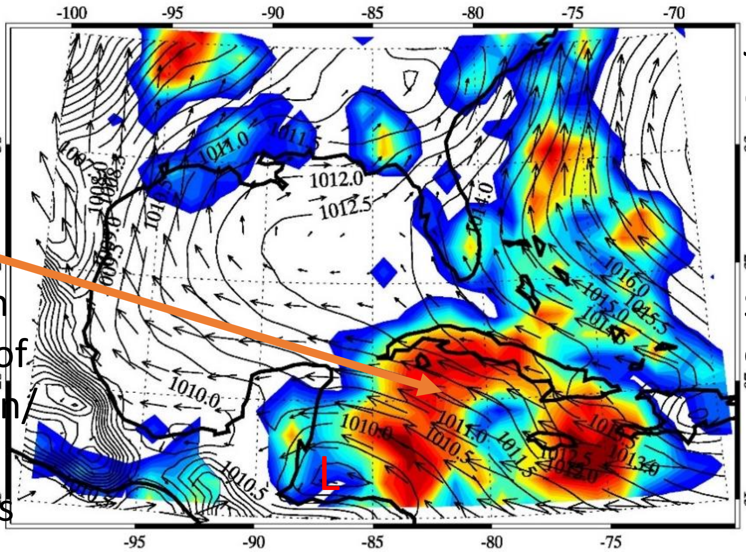
During and following Cindy, surface ocean temperatures fall due to strong winds, cloud cover, and precipitation

MODIS Anvil (5<τ<30) and Thick (τ>30) Ice Cloud Fraction (Top) and MODIS Anvil Cloud Top Temperatures with ECMWF Sea-Level Pressure

June 17 CF

Low over the Caribbean with lots of convection/ high cloudiness

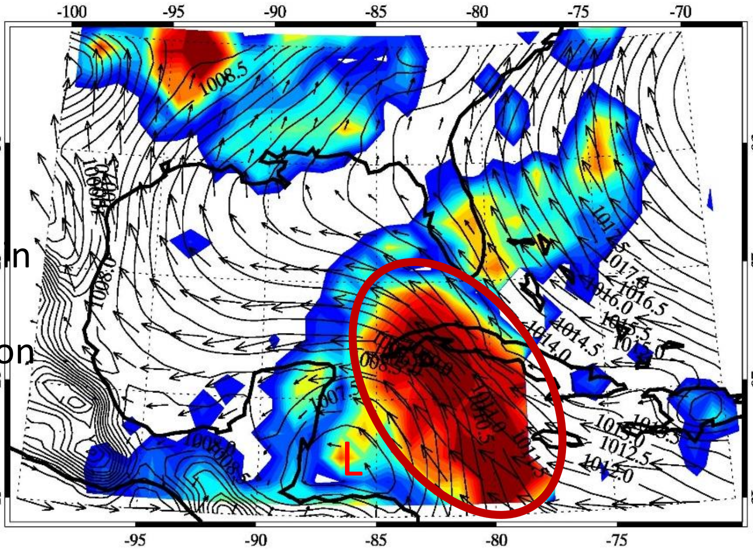
MODIS Anvil+Thick Cloud Fraction on June 17,2017



June 18 CF

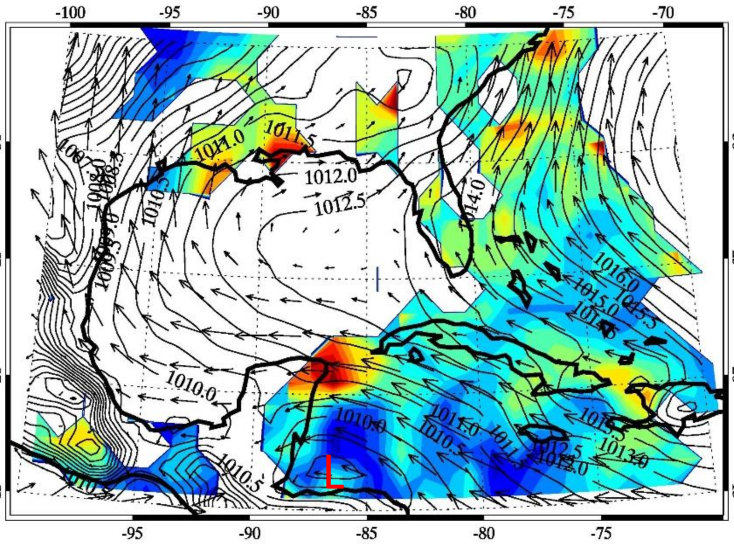
High CF increases in SE-to-NW orient-ation

MODIS Anvil+Thick Cloud Fraction on June 18,2017



June 17 CTTs

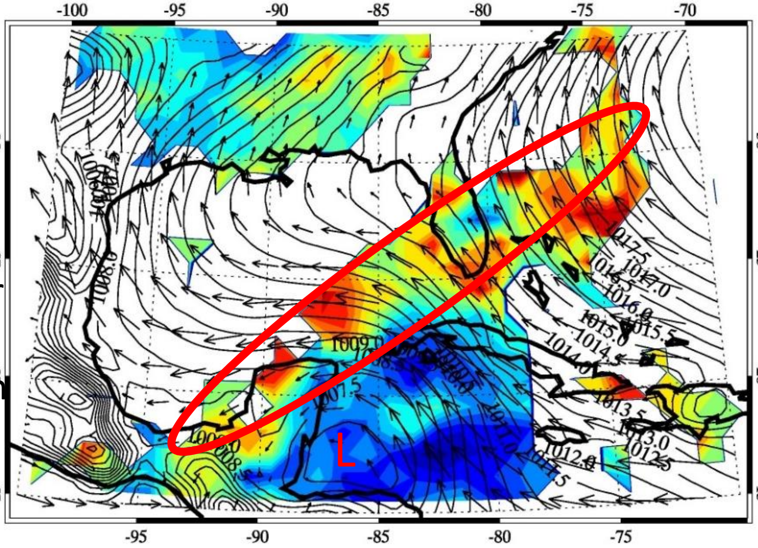
MODIS Anvil Cloud Top Temperatures on June 17,2017



June 18 CTTs

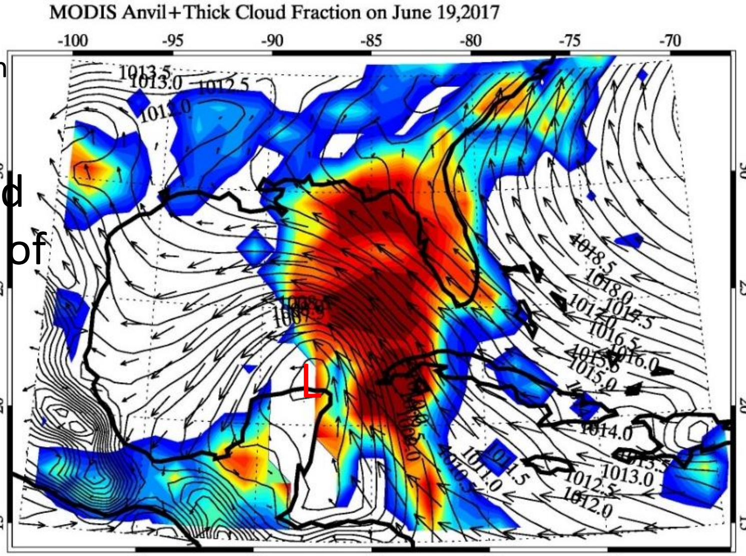
Clouds deepen/ get colder over the Caribbean

MODIS Anvil Cloud Top Temperatures on June 18,2017

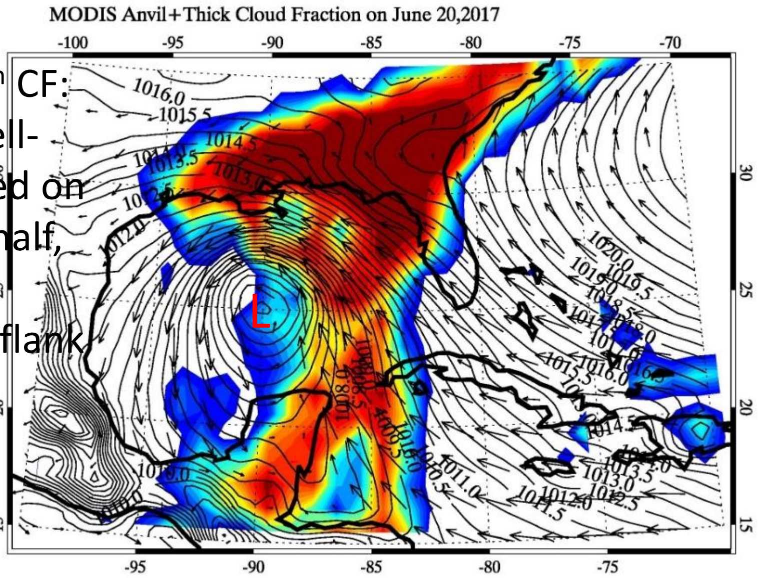


Front of leading warmer convection

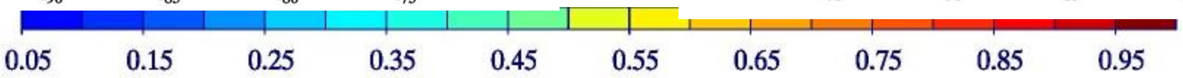
Same as previous slide, but now for June 19th (left) and 20th (right)
Note: Cindy officially becomes a tropical storm on the 20th!

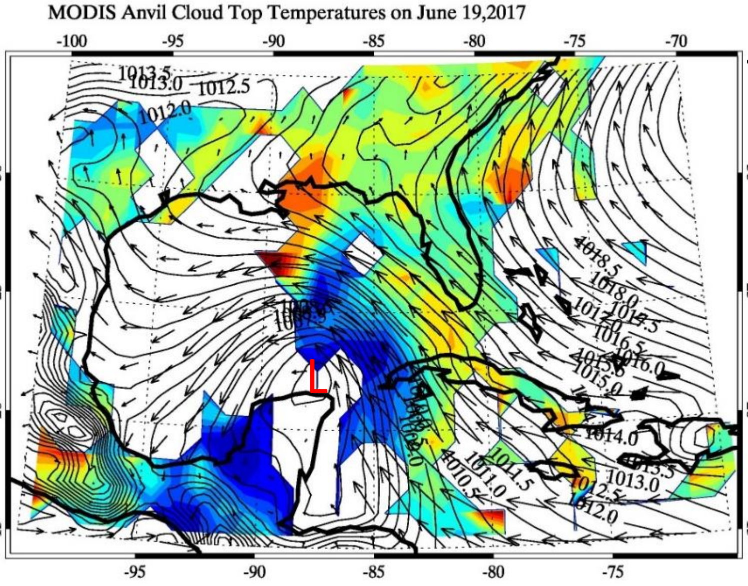


June 19th CF: Note elongated S-N area of deep conv./ anvil clouds

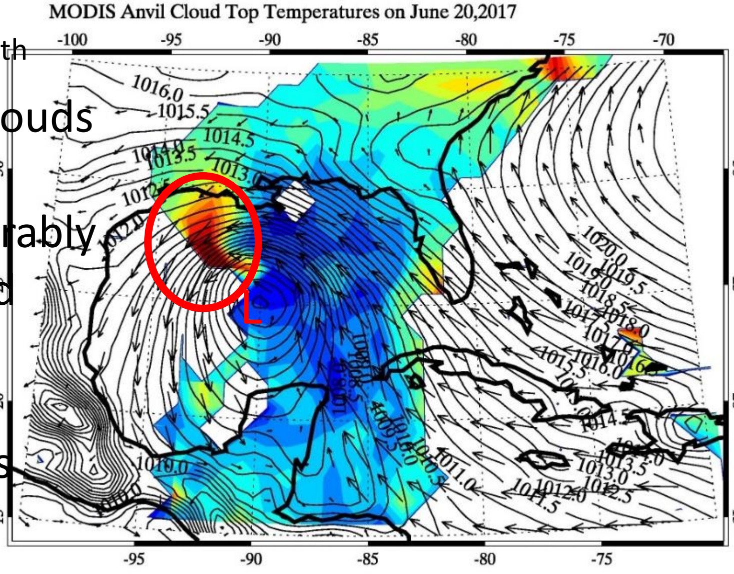


June 20th CF: Cindy well-developed on eastern half, but dry western flank

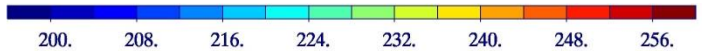




June 19th CTTs: Clouds coldest on eastern flank



June 20th CTTs: Clouds deepen considerably and cold cloud shield expands

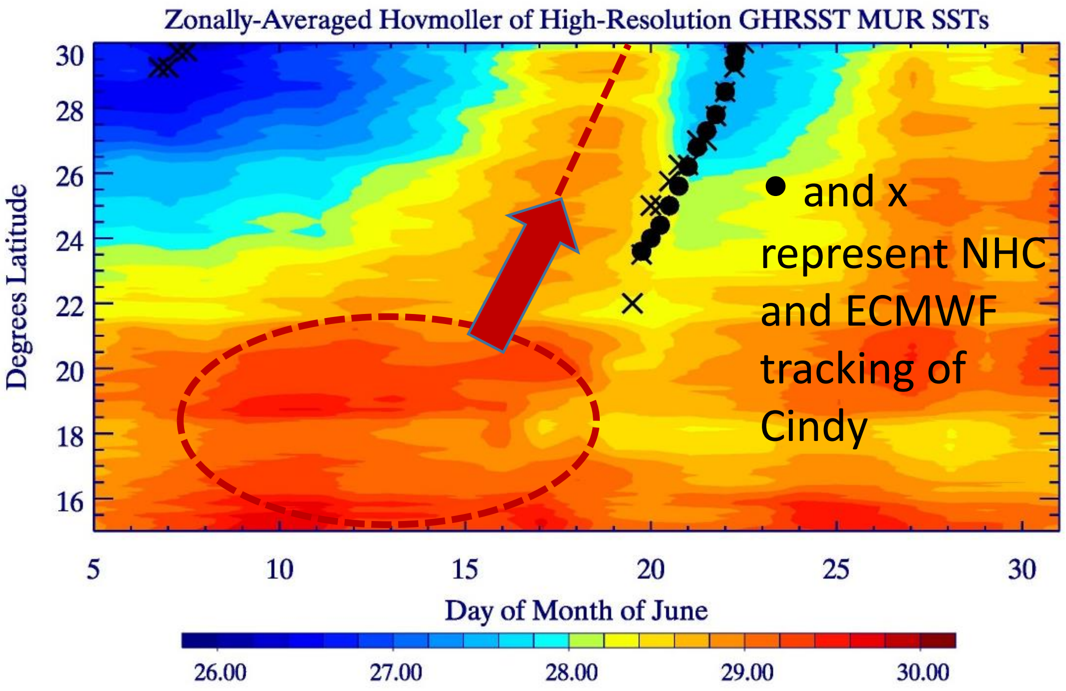


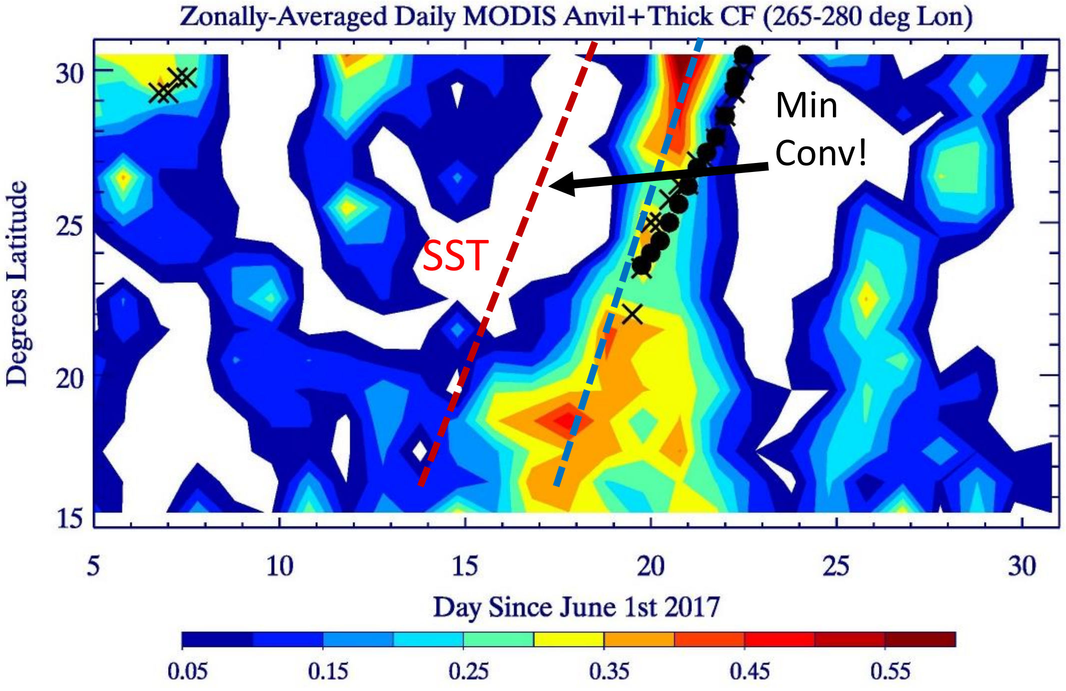
Warmer clouds west/northwest of the minimum SLP

Let’s now step back and try to track the source and then propagation of the very warm SSTs, subsequent convection, and tropical cyclone development by constructing zonally averaged (between 80°-95°W) Hovmoller diagrams from June 5-30, depicting SSTs prior to, during, and after Tropical Storm Cindy (top) and Anvil+Thick Clouds from MODIS (Bottom); this time the cloud tops must be **colder than 225 K!**

Very Warm SSTs over Caribbean prior to development of Cindy; these shift north with time; max SSTs prior to Cindy by ~3-4 days

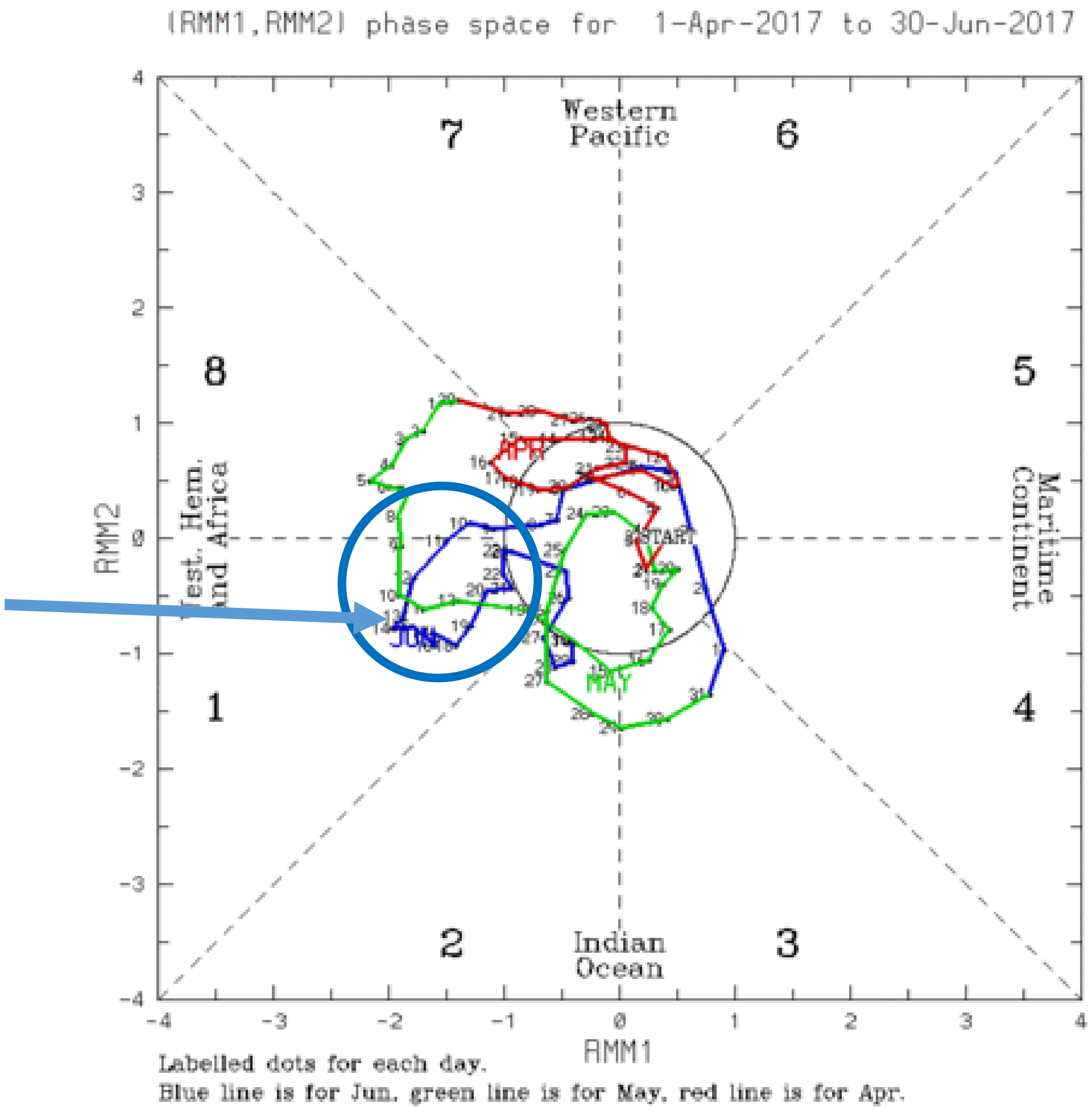
Deep convection begins in the Caribbean & moves northward, lagging max SST axis by ~3 days; most of convection is north of Cindy’s center





Any Connection Between Development of Cindy and MJO?

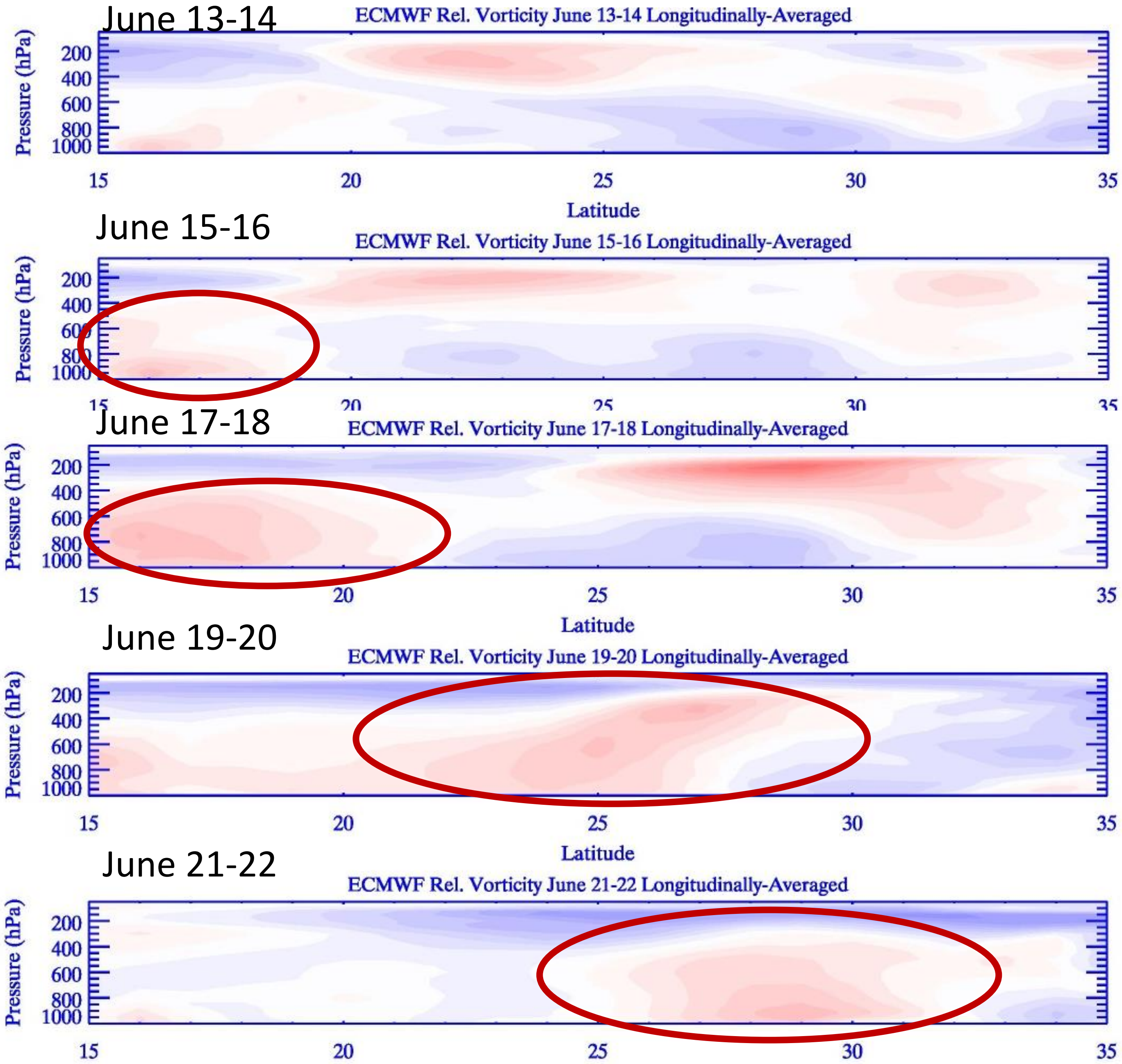
- From Maloney and Hartmann (Science Mag, Mar 2000), Gulf of Mexico/Caribbean Tropical Cyclones are ~ 4 times more likely during the MJO with a westerly wind anomaly phase (versus an easterly anomaly phase), coinciding with cyclonic vorticity in this region. Prior to Cindy, the MJO peaked in Phase 1 on June 14th, the phase associated with enhanced rainfall over the equatorial Atlantic, eastern Pacific, and more weakly over the Gulf of Mexico



Relative Vorticity Profiles in mid-to-late June 2017, zonally averaged (as before) between 265° - 280° (Reds: Cyclonic Vorticity, Blues: Anticyclonic)

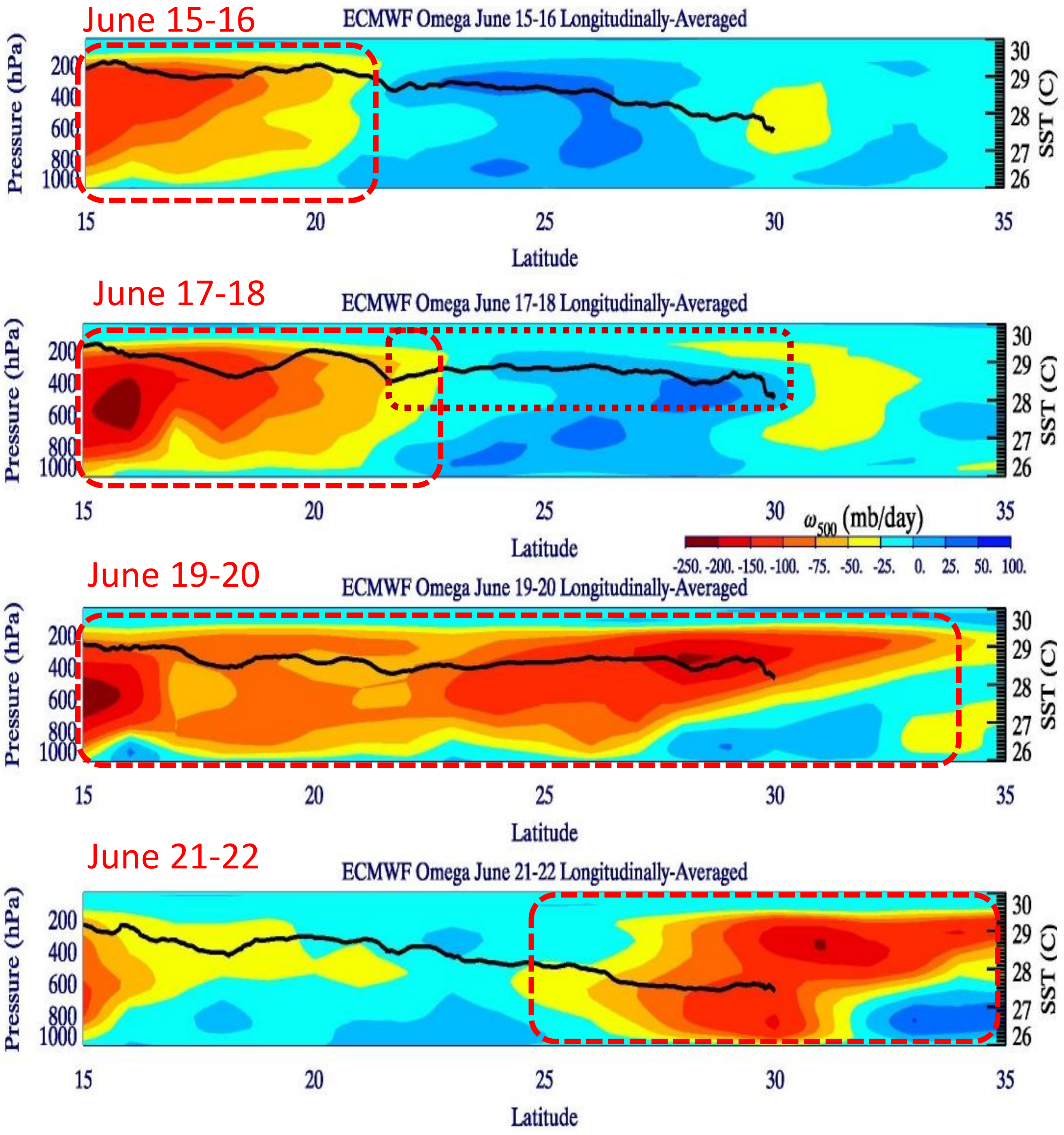
Low-level cyclonic vorticity over the Caribbean by June 15-16; strengthens and spreads north by June 17-18th

By June 19th – 20th, cyclonic vorticity spreads north to GOM; by the 21st-22nd it's near the coast!



Pressure vertical velocity (ω) profiles in bi-daily chunks from June 15th – June 22nd. During June 15th – 18th, strong ascent over the Caribbean spreads to just north of 20°N by June 18th. Corresponding subsidence over the entire Gulf of Mexico, with warming SSTs through June 20th

By June 19th – 20th, ascent encompasses entire domain, coinciding with Cindy becoming a tropical storm. By the 21st – 22nd, Cindy makes landfall and rising motion focused near the coast/over land; SSTs cool as well



Brief Summary

- Up to over a week prior to the development of Tropical Storm Cindy, High-resolution MUR SST data show a warming Caribbean and a warm circular region over the Gulf of Mexico, just to the northwest of Cuba. Deep convection is active over the Caribbean by mid-June, about five days prior to Cindy becoming a tropical storm over the GOM

- Hovmoller Diagram analysis indicates that very warm SSTs from the Caribbean spread northward into the GOM about three days prior to maximum spreading northward anvil + thick high cloud fraction from MODIS. Initially, Cindy's center coincides with maximum high CF, but then the northward-moving large cloud shield outpaces Cindy's northward trajectory

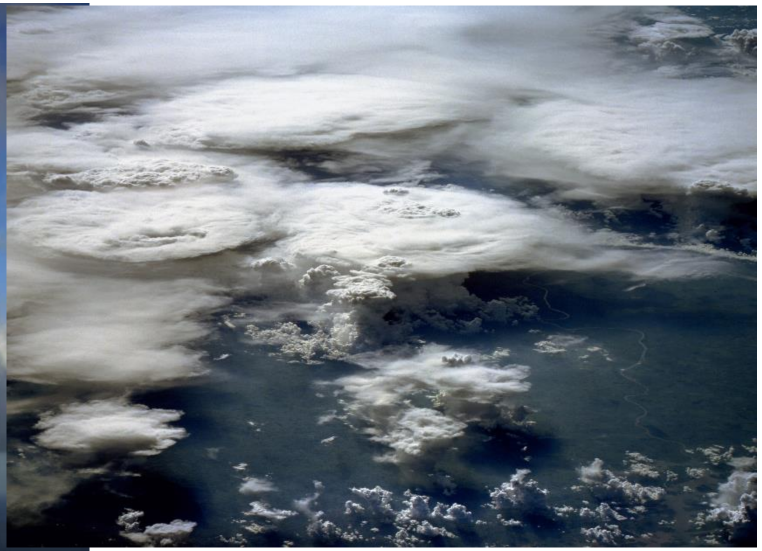
- On June 18th, two days prior to tropical storm status, a wide front of shallower anvil clouds (cloud top temperatures > 240 K) lead the colder cloud tops over the Caribbean; throughout the storm, shallower convection leads the deepest convection by about one day. The deepest, most widespread convection over the GOM is on 6/20

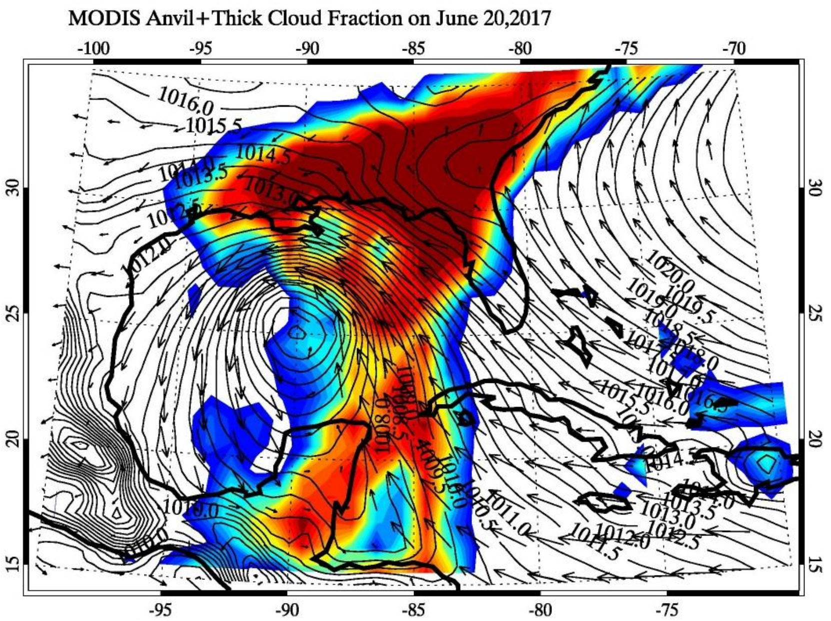
- Favorable phase 1 of the MJO, cyclonic vorticity over the Caribbean, and warming SSTs in mid-June set the stage for Cindy. Subsidence/minimal clouds days prior to Cindy over the Gulf of Mexico allow SSTs to further warm and aid in intensification of the storm when the low from the Caribbean moves north over the Gulf of Mexico.

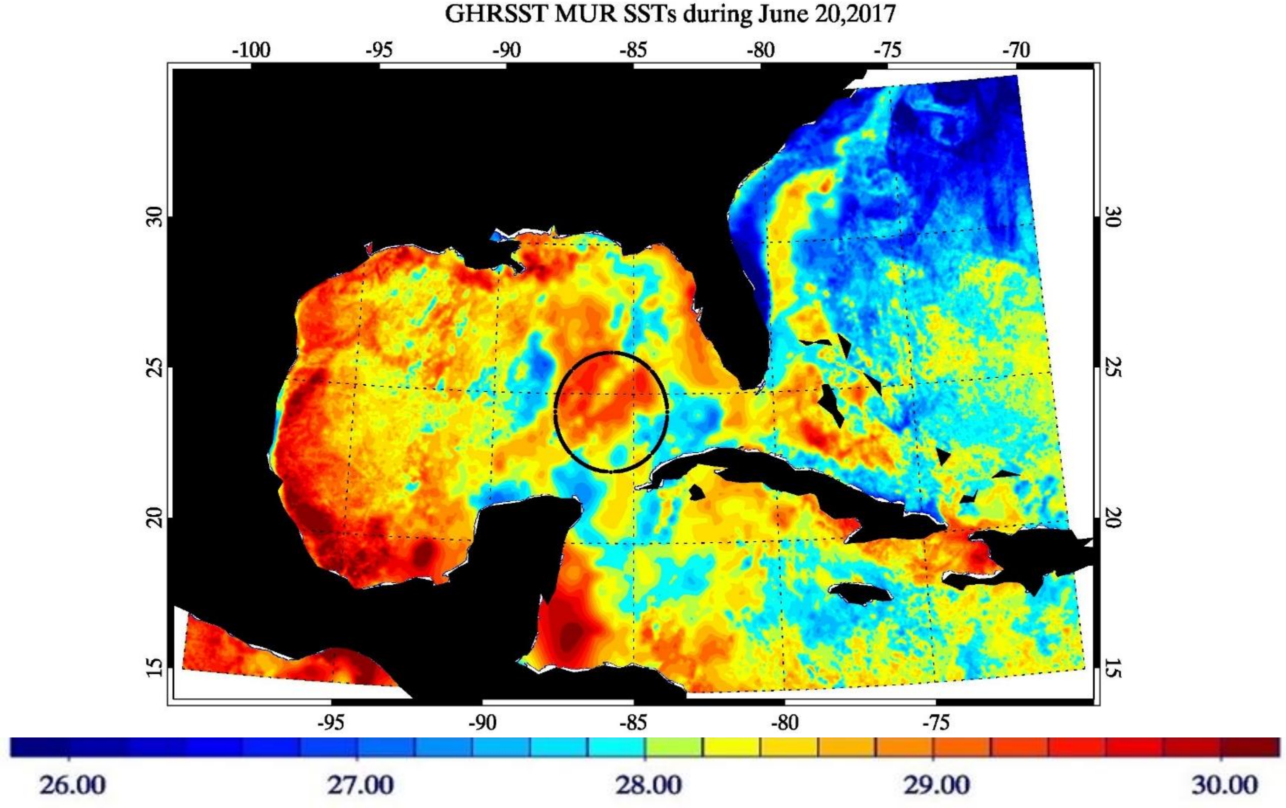
Thank you!
Any questions are welcomed!

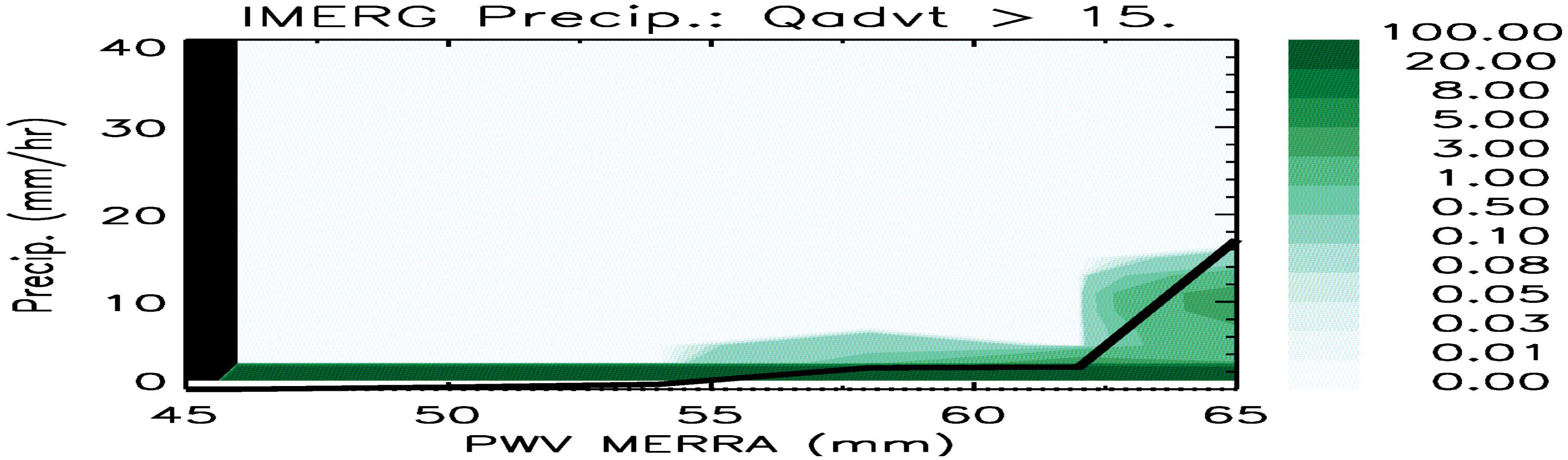
Or, send emails to

terry.kubar@jpl.nasa.gov or tkubar@ucla.edu

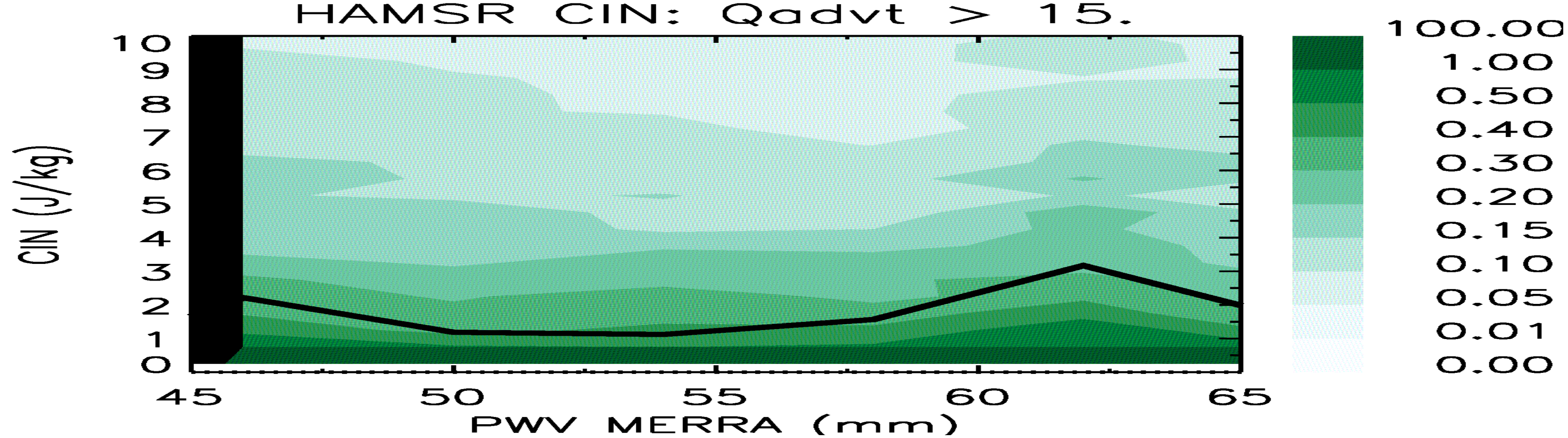




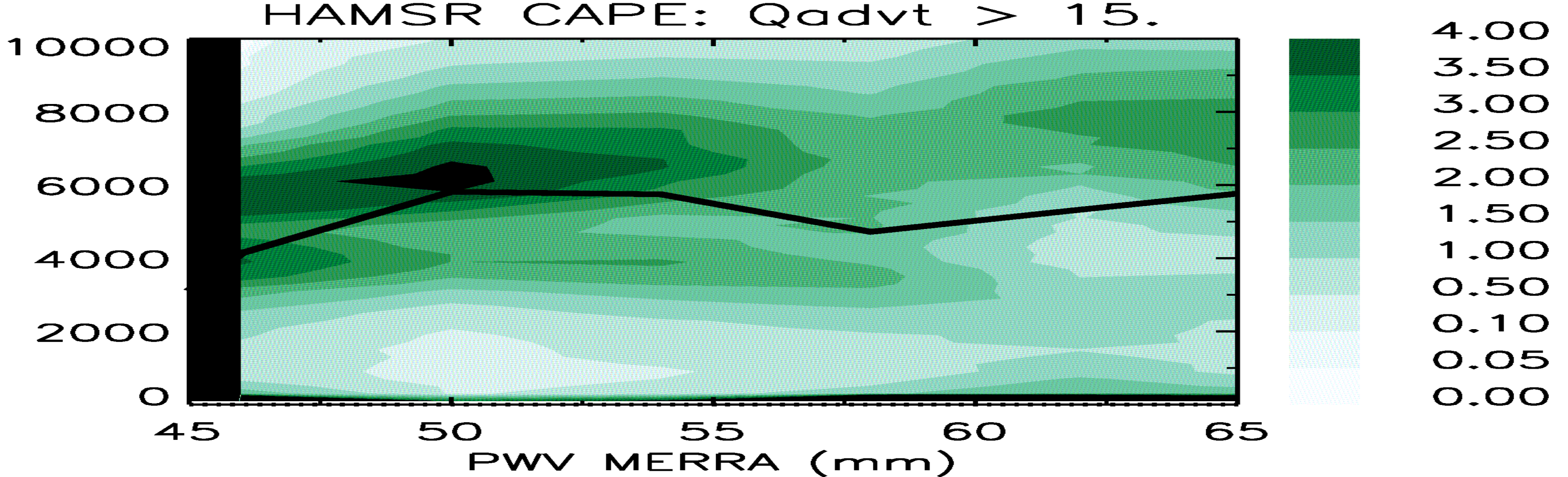




- Rain (IMERG) histograms for QADVT > 15 mm/day show smaller rain
- A transition is still seen between 55-60 mm



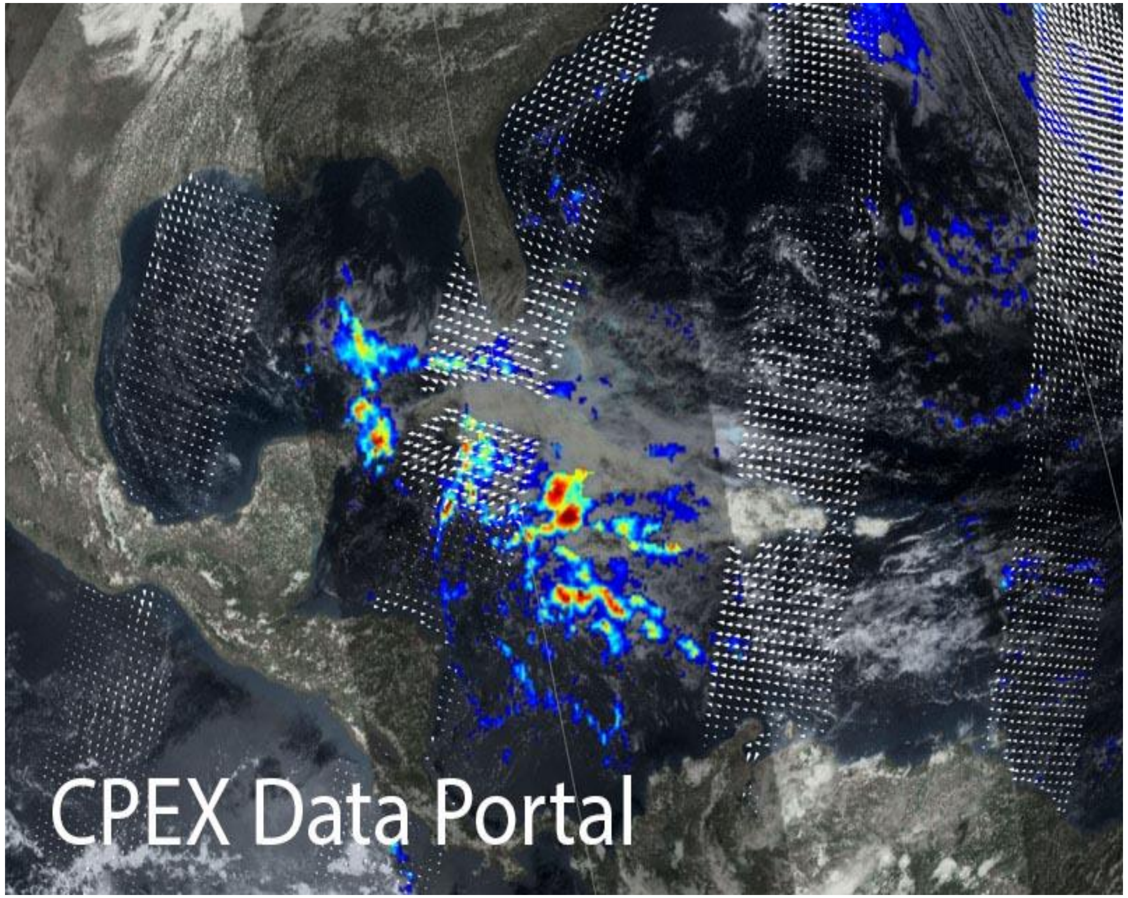
- Countours for probability for high CIN decrease before 55 mm



- Averaged CAPE remains steady between 4000-6000 J/kg
- A bifurcation in CAPE histograms before 55 mm

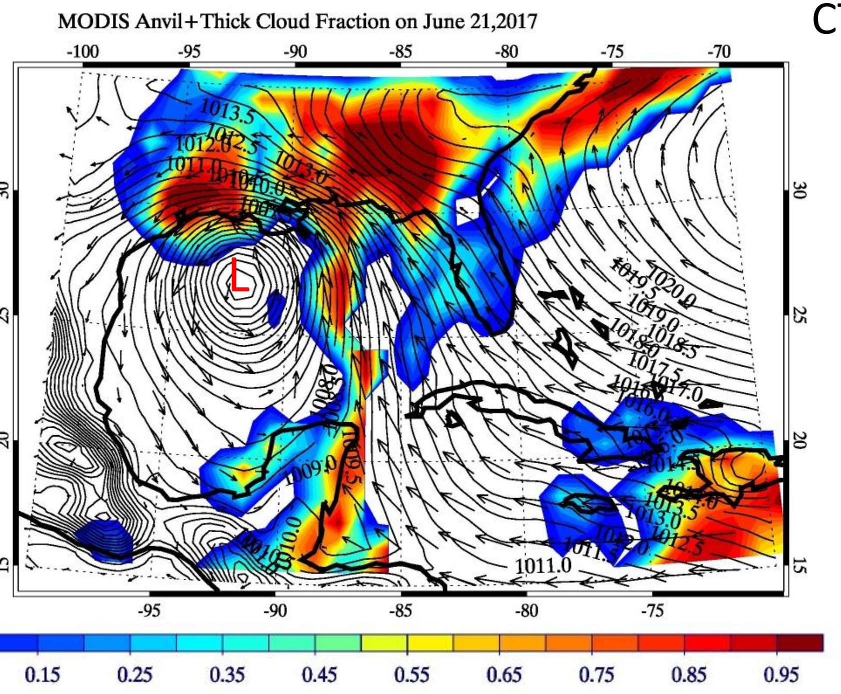
Tasks / Objective for this Talk:

- Use the GHRSST Level 4 MUR Global Foundation SST Analysis product (0.01°x0.01°) to examine both the fine-scale and large-scale SST structure during the month of June 2017, including prior to, during, and after Tropical Storm Cindy.
- Focus on source regions of convection, including the Caribbean, as well as a circular region just north of Cuba of very high SSTs; analyze corresponding daily thick high cloud cover from MODIS as a proxy for convection, and vertical velocity profiles from ECMWF-Interim
- Construct zonally-averaged Hovmoller diagrams showing South-to-North propagation of SST/convection prior to and during Cindy.
- **Goal: Examine the role of the structure of SSTs, SST gradients and the large-scale environment in aiding in the development, organization, and possible intensification of large-scale convection and T.S. Cindy**

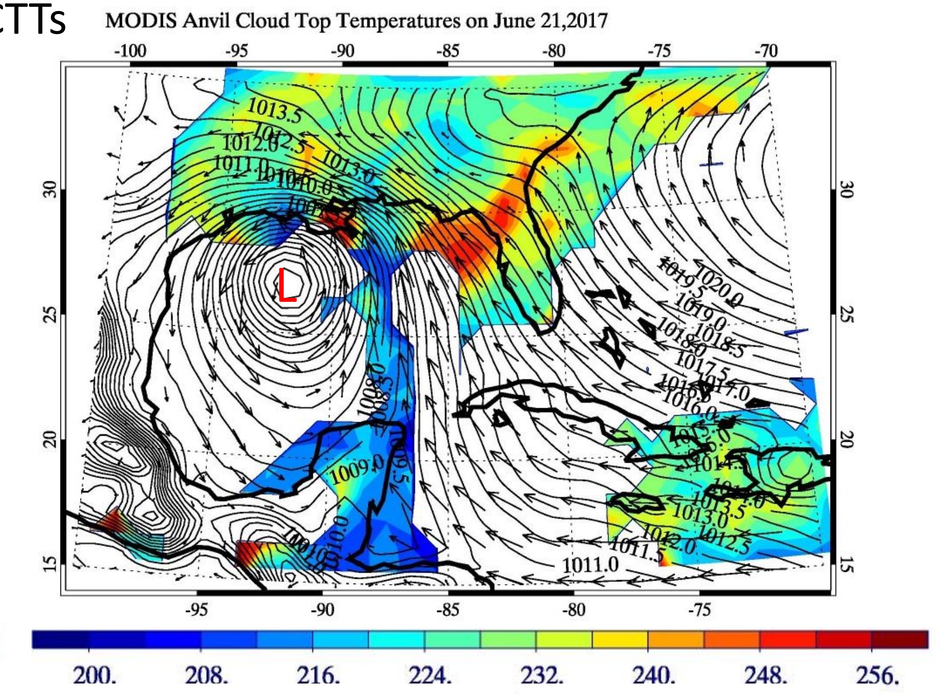


Final Day (June 21st) Before Tropical Storm Cindy Makes Landfall

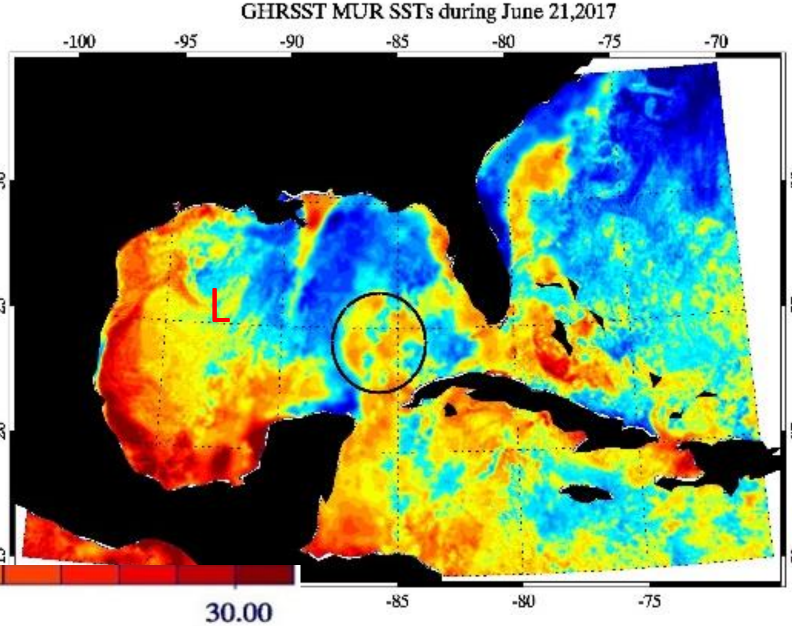
CF

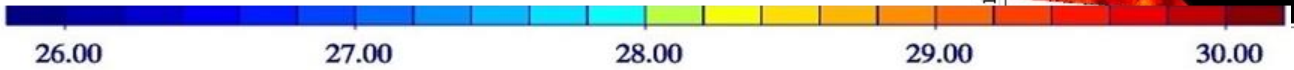


CTTs



Compared to previous day, high cloud shield reduces in size somewhat (top left), and cloud heights are a little lower (top right). West/Southwest quadrants completely free of high-topped clouds. Cloudiness predominantly to the east and north of the lowest pressure. Cold wake especially east of Cindy (lower right), but even the Caribbean has cooled.





Longer Period Hovmoller (June 5th – July 31st) Demonstrates how unique the long fetch of south-to-north deep convection is; the closest, albeit weaker analog, is about ~7 days following the organized convection associated with Cindy (this is also associated with a south-to-north high SST period)

In mid-to-late July, there is more organized convection, particularly over the Gulf of Mexico north of ~25°N