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

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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

\[ P - E + \frac{\partial Q}{\partial t} = -Q \nabla \cdot \mathbf{V} - \mathbf{V} \cdot \nabla Q \]

Where

\[ Q = \int_{p_{top}}^{psrf} q \frac{dp}{g} \]

\[ \mathbf{V} = \frac{1}{Q} \int_{p_{top}}^{psrf} (q \mathbf{v}) \frac{dp}{g} \]

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
• 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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• Need to pick preconditioning condition with QADVT > a positive threshold
• Rain (IMERG) histograms for QADV > 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
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.

Mid-tropospheric moistening begins around 50-55 mm and reaches a peak at 55-60 mm.
• Rain (IMERG) histograms for QADVT > 15 mm/day show smaller rain.

• A transition is still seen between 55-60 mm.

• Contours for probability for high CIN decrease between 50-55 mm.

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

- PDF of $\theta_e$ 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 ~ 50-60 mm
SST (Hot Spot) and Deep Convection Analysis during June 2017, Prior to, During, and After Tropical Storm Cindy

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CPEX, STM
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“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
Low over the Caribbean with lots of convection/high cloudiness

June 18
High CF increases in SE-to-NW orientation

June 17
Clouds deepen/get colder over the Caribbean

June 18
Clouds deepen/get colder over the Caribbean

Front of leading warmer convection
Same as previous slide, but now for June 19\textsuperscript{th} (left) and 20\textsuperscript{th} (right)

Note: Cindy officially becomes a tropical storm on the 20\textsuperscript{th}!

June 19\textsuperscript{th} (left)

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

June 20\textsuperscript{th} (right)

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

June 19\textsuperscript{th} (left)

- CTTs: Clouds coldest on eastern flank

June 20\textsuperscript{th} (right)

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

By June 19$^{th}$ – 20$^{th}$, ascent encompasses entire domain, coinciding with Cindy becoming a tropical storm. By the 21$^{st}$ – 22$^{nd}$, 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 QADV > 15 mm/day show smaller rain.

A transition is still seen between 55-60 mm.

Contours 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 GHRSSST 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

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