Systematic Eastward Propagation of Summertime Diurnal Rainfall over the Conterminous U.S.

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In the summer, it is important to know when an ill-timed thunderstorm can interrupt a round of golf, baseball and softball games, outdoor barbecues, maybe even an outdoor wedding -- and the timing of storms can also have important bearing on human health and safety. This study investigates what time (on average) it is most likely to rain during a summer day over the conterminous U.S.

This study used a 10-year climatology spanning 1998-2007 of radar-gauge assimilated hourly rain data from the North American Land Data Assimilation System (NLDAS-2). The results clearly indicate a peak in rainfall over the Rocky Mountains around at noon, and this peak shifts later and later in the day, heading eastward into the Great Plains, until it becomes an early morning peak. Other regions, including Mountain and Eastern to Deep South, tend to have peaks in the early afternoon.

Hovmöller diagrams reveal that rainfall propagation signals vary in different geographical regions. Rainfall propagation speeds in Maryland appear to be 5 m s^{-1} faster than in the High Plain region.

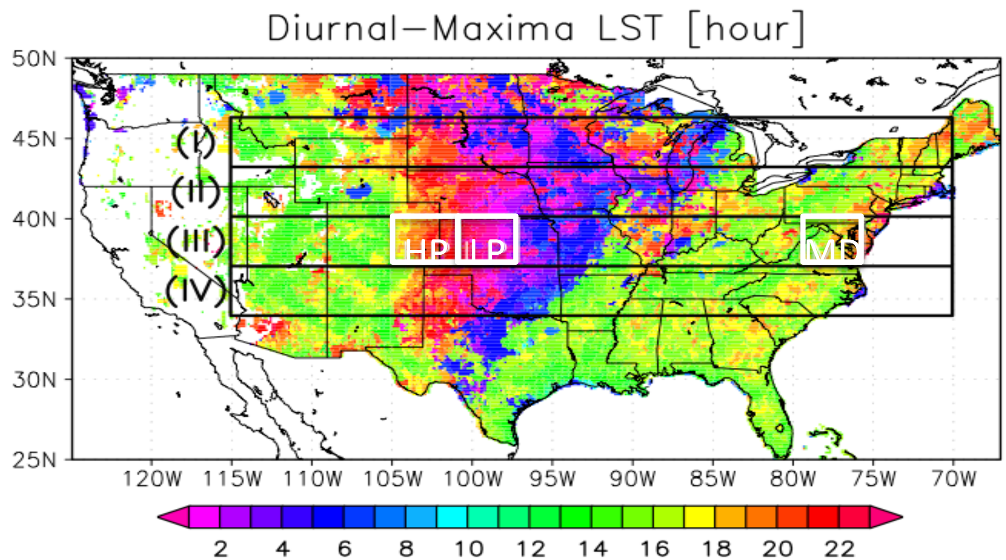

Figure1: 10-year June-July-August (JJA) climatology of diurnal rainfall maxima Local Solar Time (LST).

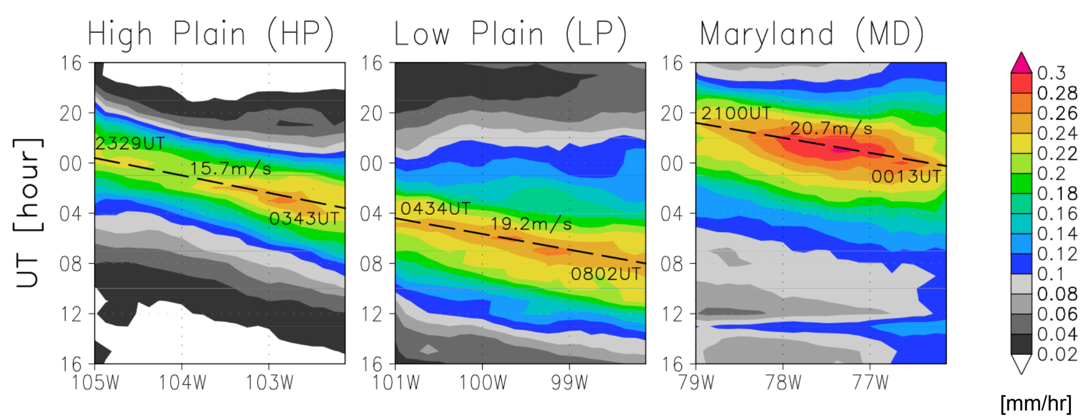

Figure 2: Hovmöller diagrams of rainfall rate [mm/hr] for HP, LP, and MD domains (37°N~40°N). Intercepts (Universal Time: UT) at the western and eastern edges of domains are starting and ending UT, respectively. Estimated zonal phase speeds of rainfall are also shown.

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Matsui, T., D. Mocko, M.-I. Lee, W.-K. Tao, M. J. Suarez, and R.A. Pielke Sr. (2010), Ten-year climatology of summertime diurnal rainfall rate over the conterminous U.S., *Geophysical Research Letters*, 37, L13807, doi:10.1029/2010GL044139.

Christian Science Monitor, "Scientists study time of day for US summer rains", (http:www.csmonitor.com/Science/2010/0615/Scientists-study-time-of-day-for-US-summer-rains)

GES DISC web news: Research using data assimilation models investigates summer rainfall timing. (http://disc.sci.gsfc.nasa.gov/hydrology/gesNews/diurnal_precipitation_patterns)

Data Sources:
The North American Land Data Assimilation System (NLDAS-2) hourly rainfall product. The Modern Era Retrospective-Analysis for Research and Analysis (MERRA) for atmospheric state, such as temperature, humidity, and wind profiles. Both data are archived and distributed through Goddard Earth Sciences, Data and Information Services Center (GES DISC: http://disc.sci.gsfc.nasa.gov/).

Technical Description of Figures:
Figure 1: Over southern and northeast regions, the diurnal maxima typically range from local noon to the late afternoon. Local noon maxima are particularly well defined over the Appalachian Mountains and coastal regions, while late-afternoon maxima appear between these two regions. Also evident is a triangular region with a gradual change of diurnal-maxima LST over the Great Plains. The diurnal-maximum LST changes approximately from local early afternoon to early morning, as it moves eastward, due to long-lasting (300km~1000km), eastward-propagating convective systems.

Figure 2: Zonal phase speed of propagating rainfall systems are estimated in High Plain (HP: 105°W ~ 102°W), Low Plain (LP: 101°W~98°W), and Maryland (MD: 79°W~76°W). Each of these domains represents robust signals of rainfall propagation with different zonal phase speeds of propagating rainfall systems

Scientific significance:
Historically, diurnal rainfall over the conterminous U.S. has been studied over four decades. Using the best possible assimilated rainfall product, this research not only augments the previous finding, but also reveals that the geographic differences in rainfall propagation patterns in three regions. This study applies simple linear theories to explain the zonal phase speeds of rainfall in three different geographic domains. Results qualitatively indicate that the latent heat release (as a function of convective available potential energy) together with the background steering wind speed is a more robust hypothesized mechanism that explains the unique rainfall propagation speeds in the three different geographic domains, rather than the effect of boundary-layer gust front disturbance (as a function of boundary-layer dryness).

Relevance for future science and relationship to Decadal Survey:
Global Precipitation Measurement (GPM) mission will detect rainfall rate globally approximately every three hours using an international constellation of satellites. One of the grand challenges is to improve over-land rainfall rate using improved rainfall sensors and rainfall algorithms. Thus, this 10-year climatology of rainfall diurnal cycle, using best possible ground-based assimilated rainfall data, will be the new benchmark for validating the upcoming GPM mission.

Aerosols Enhance Convective Vigour and Lightning for Maritime Clouds

Tianle Yuan, L. A. Remer, K.E. Pickering, H. Yu, Code 613.2, NASA GSFC

Volcanoes can emit sulphur dioxide gases. These gases can be oxidized in the atmosphere and turn into tiny particles called aerosols. NASA satellites are capable of observing this process: the map in Figure 1A shows sulphur dioxide gas concentration measured by NASA's OMI instrument on June 14, 2005, and the map in Figure 1B shows the corresponding aerosol concentration measured by MODIS.

Anatahan is an active volcano on the northern Mariana Islands (red dots in Figures 1A and 1B). It was active in summer 2005 and increased aerosol concentrations downwind (west of it) by 60% (the bump in Figure 1C). We show that as a result the number of lightning flashes increased dramatically (by 150%) above its usual value over the same area downwind of the volcano, the bump in Figure 1D. This solves a long-standing mystery surrounding tall towers of cumulonimbus over tropical warm waters: unlike their continental counterparts, these clouds are very quiet and lightning is seldom observed inside them. Our study indicates that the lack of lightning over ocean is at least partially due to the lack of aerosols. The theory behind the lightning increase by aerosols is detailed in Yuan et al. (2011) and can be summarized by the following chain reaction: aerosols slow down the rain process, enhance the vigor inside clouds, create more charges, and produce more lightning.

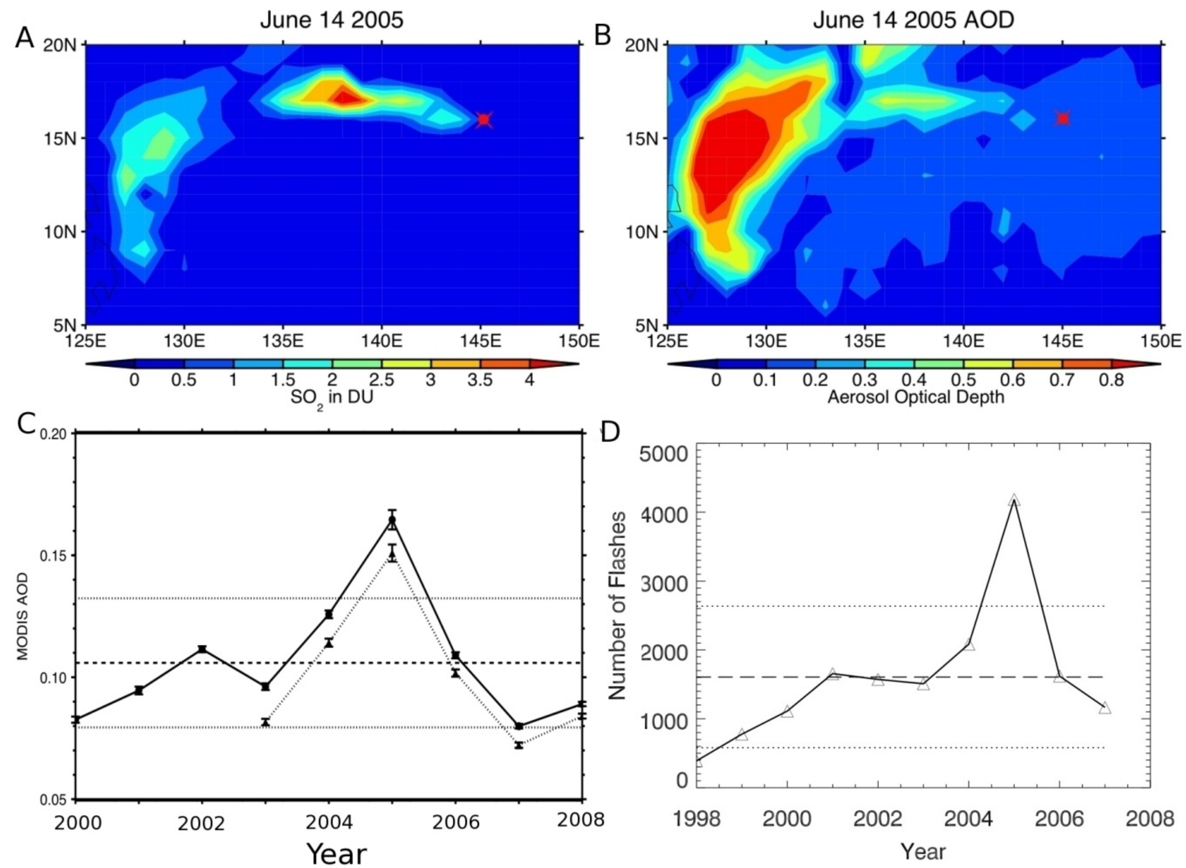

Figure 1: A) sulphur dioxide concentration map measured by Ozone Monitoring Instrument on June 14, 2005. The volcano is noted as the red dot in the map. B) On the same date, aerosol concentration map measured by MODIS. C) Time series of aerosol concentration year by year from both Terra and Aqua MODIS (dotted thin line). D) Time series of number of lightning flashes measured by TRMM Lightning Imaging Sensor. Note there is a big bump in both the aerosol concentration and number of lightning flashes in 2005.

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References:

Yuan, Tianle, Zhanqing Li, 2010: General Macro- and Microphysical Properties of Deep Convective Clouds as Observed by MODIS. *J. Climate*, **23**, 3457–3473, doi: 10.1175/2009JCLI3136.1.

Yuan, T., J. V. Martins, Z. Li, and L. A. Remer (2010), Estimating glaciation temperature of deep convective clouds with remote sensing data, *Geophys. Res. Lett.*, 37, L08808, doi:10.1029/2010GL042753.

Yuan. T., L.A. Remer, K.E. Pickering, and H. Yu (2011), Observational evidence of aerosol enhancement of lightning activity and convective invigoration, *Geophys. Res. Lett,* in press.

Data Sources: MODIS level 2 and level 3 aerosol product; MODIS level 2 cloud product; TRMM precipitation radar level 2 data; TRMM lightning imaging sensor data; OMI/Aura SO_2 level 2 retrieval

Technical Description of Figures:
Figure 1: A) A map showing sulphur dioxide concentration measured by OMI onboard of NASA's Aura satellite on June 14, 2005. The volcano is represented by the red dot. B) A map of aerosol optical depth, a measure of aerosol concentration in the atmosphere, on the same day is produced using MODIS onboard of both Terra and Aqua satellites. C) summer time mean aerosol optical depth time series for 2000-2008. Our study region (5-20N, 125-150E) is generally very clean with mean aerosol optical depth around 0.1 as indicated by the middle horizontal line. In 2005, aerosol concentration is increased to two standard deviations higher than the mean due to volcanic sulfate. D) Time series of lightning flash counts observed by TRMM LIS. The climatological mean (middle horizontal line) and one standard deviation are plotted out using horizontal lines. In 2005, lightning is increased by more than two standard deviations above the mean.

Scientific significance: Our results provide critical and one of the first observational evidence to a long-standing debate on the role of aerosols in determining cloud electrification properties. We show aerosols can fundamentally alter cloud electrification process. With the past changes in anthropogenic aerosol source strength especially upwind of major maritime convection centers, we can expect significant changes in cloud lightning activities due to the chain reaction demonstrated in our study. It has implications for atmospheric chemistry, latent release structure, precipitation, and atmospheric dynamics.

Relevance for future science and relationship to Decadal Survey: Aerosol-cloud-precipitation interactions are a key set of unresolved processes in our understanding of the climate system. They are also a critical component of the Decadal Survey and a major goal for future NASA missions.

A-train Sensors Detect Merapi Volcano SO_2 and Aerosol Injections into Tropical Tropopause

Due to multiple volcanic eruptions in 2008-10, stratospheric sulfate aerosol concentrations are elevated compared to recent years, with possible impacts on atmospheric chemistry and radiation.

Gaseous and aerosol clouds from major explosive eruption of Indonesia's Merapi volcano on Nov 4-5, 2010 were measured by multiple A-train sensors:

Figure 1. Aura/Ozone Monitoring Instrument (OMI) measured ~0.2-0.3 Tg volcanic sulfur dioxide (SO_2) injected

into UTLS;

Figure 2. CALIPSO space lidar detected volcanic aerosol layers near tropical tropopause

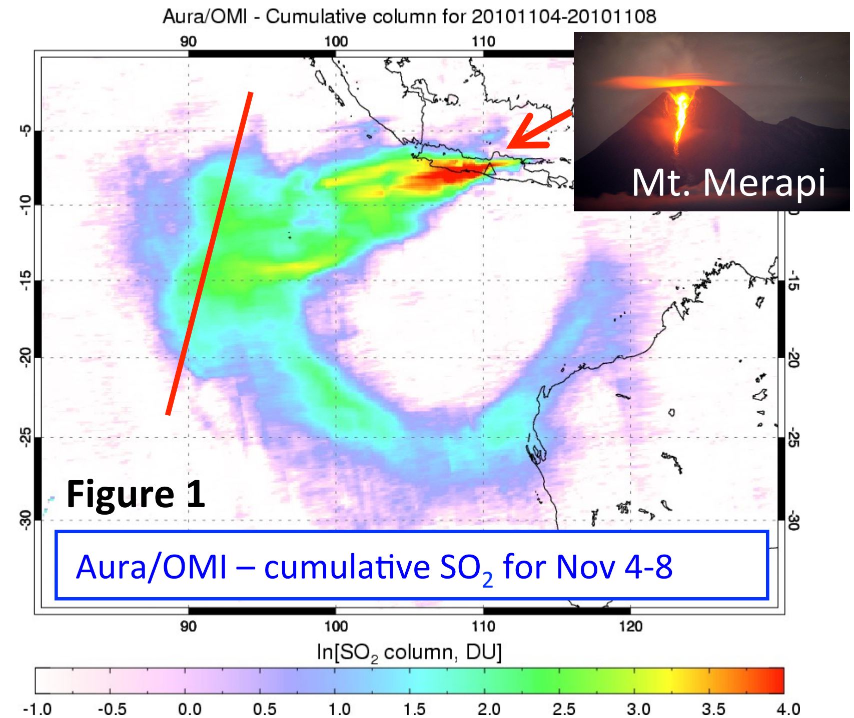
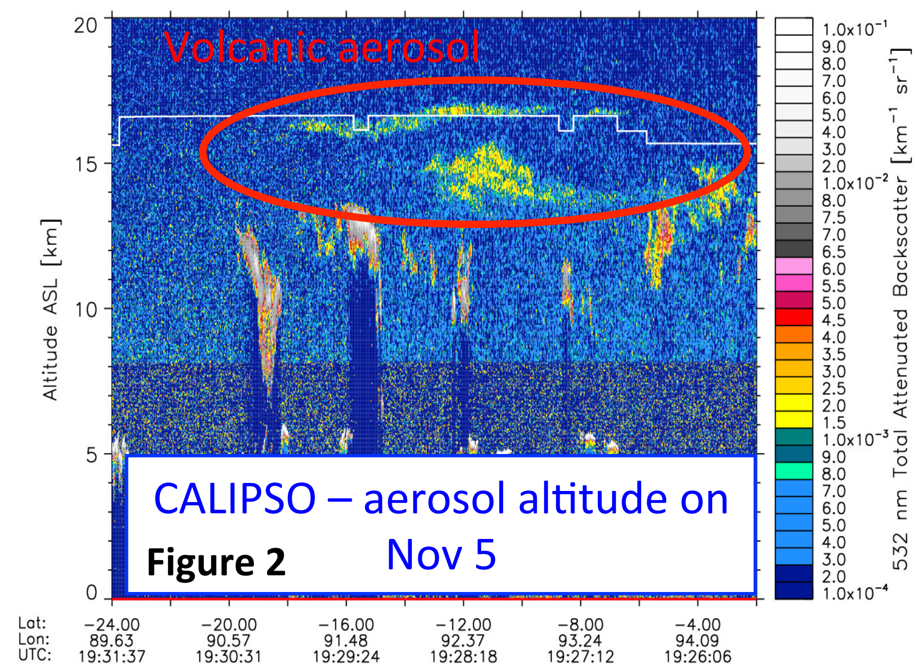


Figure 1

Aura/OMI – cumulative SO_2 for Nov 4-8



CALIPSO – aerosol altitude on Nov 5

Figure 2

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References:

OMI SO_2: Krotkov N.A., M. Schoeberl, G. Morris, S. Carn, and Kai Yang (2010) Dispersion and lifetime of the SO2 cloud from the August 2008 Kasatochi eruption, *J. Geophysical Research*, 115, D00L20, doi:10.1029/2010JD013984, 2010; Carn, S.A., A.J. Krueger, N.A. Krotkov, K. Yang, and K. Evans (2009). Tracking volcanic sulfur dioxide clouds for aviation hazard mitigation. *Nat Hazards* (2009) 51(2), 325–343, doi: 10.1007/s11069-008-9228-4

CALIPSO: Winker, D. M., M. A. Vaughan, A. H. Omar, Y. Hu, K. A. Powell, Z. Liu, W. H. Hunt, and S. A. Young, 2009: "Overview of the CALIPSO Mission and CALIOP Data Processing Algorithms", J. Atmos. Oceanic Technol., **26**, 2310-2323, doi:10.1175/2009JTECHA1281.1.

Data Sources:

Figure 1: NASA Aura Ozone Monitoring Instrument (OMI) archived stratospheric SO2 dataset: http://disc.sci.gsfc.nasa.gov/Aura/data-holdings/OMI/index.shtml/omso2g_v003.shtml; OMI global near real time SO_2 and Aerosol Index data: http://satepsanone.nesdis.noaa.gov/pub/OMI/OMISO2/ help modelers in volcanic ash advisory centers improve forecasting models and issue more accurate warnings to aviation

Figure 2: A joint mission between NASA and the French Centre National d'Etudes Spatiales (CNES), Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) data are processed and archived at NASA Langley Research Center produces and archive the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) satellite dataset: ***http://www-calipso.larc.nasa.gov/products/lidar/browse_images/show_calendar.php***

Technical Description of Image:

Figure 1: The image shows cumulative burdens of volcanic sulfur dioxide (SO2) gas emitted by explosive eruption of Indonesia's Merapi volcano on November 4–8, 2010, as observed by the Dutch/Finnish Ozone Monitoring Instrument (OMI) on NASA's Aura spacecraft. Sulfur dioxide is measured here in Dobson Units: The greatest concentrations appear in red; the lowest in lavender. Typically used to measure ozone, the Dobson Unit is the number of molecules of gas that would be required to create a layer 0.01 millimeters thick at a temperature of 0 degrees Celsius and a pressure of 1 atmosphere (the air pressure at the surface of the Earth). **Insert:** Molten lava flows from the crater of Mount Merapi captured in long exposure photograph taken from Klaten district in Central Java province late on November 2, 2010. (SONNY TUMBELAKA/AFP/Getty Images) Assessed on January 8 2010: http://www.boston.com/bigpicture/2010/11/mount_merapis_eruptions.html

Figure 2: NASA's CALIPSO satellite carries a pulsating laser (lidar) that sends short pulses of light through the atmosphere. Some of the light bounces off clouds and particles in the atmosphere and returns to the satellite. The CALIPSO "curtain plot" shows a vertical profile of a slice of the atmosphere indicated with red line in Figure 1, revealing that the volcanic aerosol layer was above 15 kilometers. The strength of the returning signal (attenuated backscatter shown in the color bar on the right) provides information about the characteristics of the clouds or aerosols (particles).

Scientific significance: If a volcano injects a sufficient quantity of sulfur dioxide into the stratosphere, the resulting chemical reactions can create reflective and chemically reactive aerosols that linger for months or even years, cooling climate by reflecting sunlight. At just 7.5 degrees south of the equator, Mount Merapi is positioned to have such an impact. But in November 2010, Merapi had cumulatively emitted just 1 percent of what was released by Mount Pinatubo in 1991. For more information see http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=46881

Relevance for future science and relationship to Decadal Survey:

Aura OMI will continue monitoring volcanic and anthropogenic SO_2 from space to detect trends in volcanic and anthropogenic aerosol precursors and will provide overlap with ESA Sentinel-5 precursor mission (TropOMI) planned to launch in 2014. NASA/NOAA Ozone Monitoring and Profiling Suite (OMPS) instrument is slated for the NPP launch in 2011 and subsequent JPSS satellites. OMPS will continue the total ozone and SO_2 observational record.
Decadal Survey recommended the Geostationary Coastal and Air Pollution Events (*GEO-CAPE*) mission is planned to launch after 2020. It will allow more frequent monitoring of volcanic and anthropogenic SO_2 pollution over N and S America.

Re-evaluating the Role of the Saharan Air Layer (SAL) in Atlantic Hurricane Evolution

Scott A. Braun, Code 613.1, NASA GSFC

Study Goal: Re-evaluate results from previous studies finding suppressing influences of the SAL on tropical storm formation and intensification.

Data used: Multiple NASA satellite data sets (TRMM, MODIS, CALIPSO, and AIRS/AMSU) and NCEP global meteorological analyses

Key findings: Previous studies often relied on false assumptions:

1) *That dry tropical air is necessarily SAL air* (we show that subsidence is a key driver of low humidity over the Atlantic)

2) *That the SAL is dry throughout its depth* (it is actually relatively moist at midlevels compared to the surrounding environment; see Fig. 1)

3) *That proximity of the SAL implies its role in inhibiting storm formation or intensification* (we show that storms that weaken after formation and storms that strengthen strongly after formation have nearly identical SAL characteristics)

The large-scale flow at upper levels above the SAL was found to be more important, with the environment of strengthening storms having very little vertical wind shear (weaker upper-level winds) and also favoring more expansive outflow from the storm (Fig. 2).

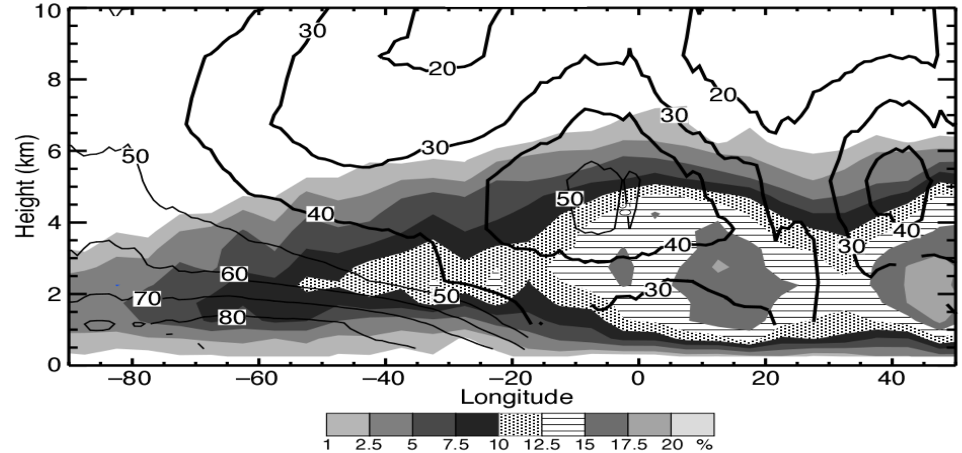

Figure 1: Shading shows CALIPSO derived aerosol frequency while contours show AIRS derived relative humidity, with humidities ≤40% drawn as solid lines, ≥50% drawn as dashed lines. Unlike typical descriptions of the SAL, the data show that the SAL generally moistens its upper layers compared to the very low humidities found above or below.

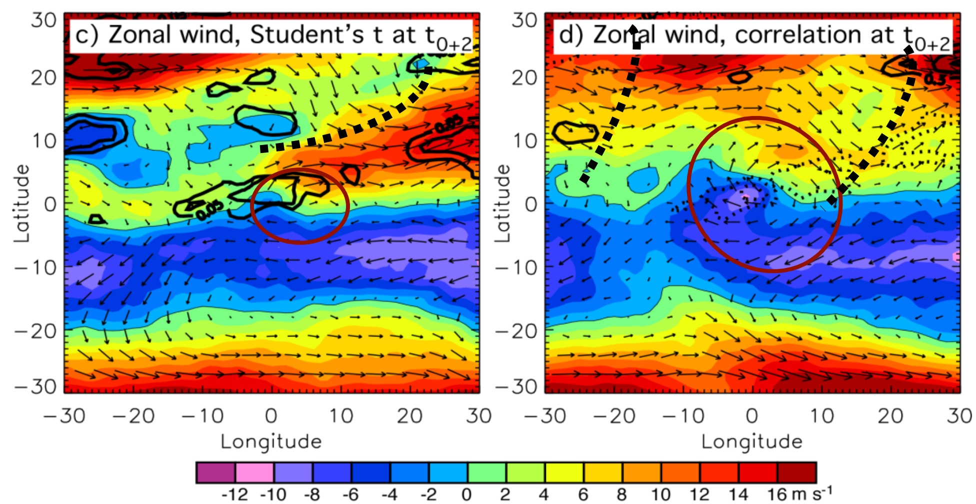

Figure 2: Shown are composite NCEP-derived 200 hPa zonal wind speeds (shading) and 200-hPa wind vectors for (left) weakening storms and (right) strengthening storms two days after storm formation. Black contours show (left) areas of statistically significant differences between the two groups and (right) correlation of zonal wind with intensity change. Trough axes are indicated by dashed lines, outflow areas by red circles.

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References:

Braun, S. A., 2010: Re-evaluating the role of the Saharan Air Layer in Atlantic tropical cyclogenesis and evolution. *Monthly Weather Review.*, **138**, 2007-2037.

Data Sources: TRMM 3B42 multi-satellite rainfall, MODIS (Aqua and Terra) aerosol optical depth, CALIPSO level 2 dust products, AIRS/AMSU level 2 and 3 retrieved temperature and relative humidity, and National Centers for Environmental Prediction final global meteorological analyses.

Technical Description of Figures:

Figure 1: This figure (shading) shows dust frequency, as detected by the CALIPSO satellite in the vertical plane extending from Saudi Arabia (right side) to over the Atlantic ocean (left side). The results show that dust is most prevalent at middle levels around 2 to 3 km in altitude and that dust frequency rapidly diminishes westward of Africa. The overlaid contours show relative humidity from AIRS/AMSU on the Aqua satellite. Many previous studies of the SAL characterize it as a dry layer, but the AIRS/AMSU observations show that, while dry at low levels, the SAL is typically more moist at middle levels compared to the background environment of otherwise very dry subtropical air as part of the descending branch of the Hadley circulation. The mid-level moist layer is a product of the deep dry convective mixing that occurs over Africa that acts to dry the lower portion of the boundary layer and moisten in upper layer.

Figure 2: This figure shows a result from a composite of NCEP global meteorological fields two days after tropical storm formation for storms that weaken after formation (13 cases) and for storms that strengthening by 20 knots 2 to 4 days after formation (18 cases). Similar composite fields for variables related to the SAL (Convective Available Potential Energy, Convective Inhibition, mid-levels winds and relative humidity) showed no significant differences between strengthening and weakening storms, suggesting that the SAL was not a determining factor in the intensity changes. The major statistically significant differences were found in the upper troposphere (here represented by the 200-hPa level winds), showing strong westerly winds near the storms for weakening events and very weak westerly flow (or even easterly flow) for strengthening events, suggesting much lower vertical wind shear in strengthening storms. Hence, the results suggest that intensity may be controlled more by the upper-level winds (locations of nearby upper troughs) that act to enhance vertical wind shear, a known weakening factor for storms. The 200-hPa flow also shows much broader and well defined outflow in strengthening events compared to weakening events.

Scientific significance: A number of studies have come out in recent years arguing that the SAL has a suppressing influence on hurricanes. This study examines previously proposed hypotheses that the Saharan air layer (SAL), a layer of warm, dry, dusty air that frequently moves westward off of the Saharan desert of Africa and over the tropical Atlantic Ocean, acts to inhibit hurricane formation and strengthening. The potential negative impacts of the SAL include 1) increased vertical wind shear; 2) increased thermodynamic stability that suppresses cloud development; and 3) dry air, which produces cold downdrafts in precipitating regions, thereby removing energy needed for storm development. This study finds little evidence for such influences and describes in detail the false assumptions that often lead to incorrect conclusions by these previous studies.

Relevance for future science and relationship to Decadal Survey: This study is relevant to TRMM, Aqua/Terra, and CALIPSO science because of its significant use of these NASA datasets. The work forms the basis for a key motivation for the Earth Venture-1 Hurricane and Severe Storm Sentinel (HS3) mission, which will use two Global Hawk aircraft to study hurricane formation and evolution. One aircraft will be specifically equipped to measure characteristics of the SAL in terms of dust, temperature, humidity, and winds.