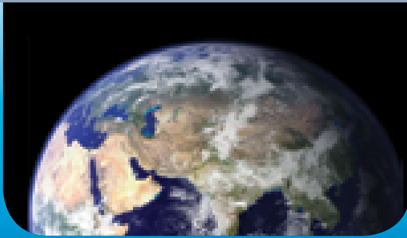
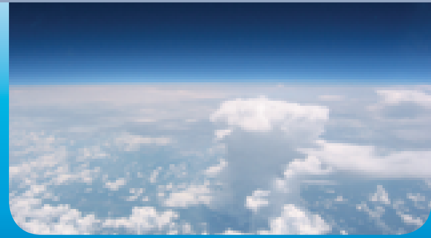
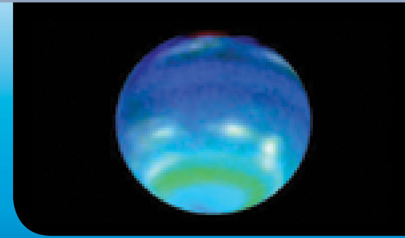
SPACE SCIENCE AND ENGINEERING CENTER ▪ COOPERATIVE INSTITUTE FOR METEOROLOGICAL SATELLITE STUDIES ▪ UNIVERSITY OF WISCONSIN-MADISON

TtA 2013
Winter / Spring

through the atmosphere

Following Convective Clouds with Satellites

Most detailed Uranus weather revealed p.22

Detecting volcanic ash cloud p.12

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INSIDE This Issue

COVER Image

Dryline thunderstorm in western Oklahoma, May 2011. Photographer: Dima Smirnov, UW-Madison AOS.

Through the Atmosphere: A Special Issue on Clouds

Photo credit: Jeff Miller, UW-Madison Communications

Steve Ackerman
CIMSS Director

"The nature of satellite observations provides a key method to study changing cloud properties across the globe."

DIRECTOR'S Note

Clouds are the subject of endless curiosity. We look for shapes in them and poets write about their inspirational beauty. Parents struggle to explain to their children how something so solid in appearance stays floating in the sky and then suddenly vanishes. Clouds, from the fair-weather wisps of cirrus to the mightiest cumulonimbus embedded in hurricanes, are composed of nothing more than tiny particles of liquid water and particles of ice. In this edition of *Through the Atmosphere*, we examine clouds in the context of the weather feature that creates them.

The air in thunderstorms rises so rapidly that their tops may briefly overshoot the tropopause and penetrate the stratosphere. These overshooting tops are identifiable on satellite images. Methods of identifying these dynamic cloud features are being developed to improve severe weather forecasting. Satellites are able to identify the fast moving updrafts in the developing stages of a thunderstorm, providing a first opportunity to warn about potential storm threats.

Thunderstorm study is important on its own, but thunderstorms are also an important component of tropical cyclones. Observations and modeling studies are being used to explore the relationship between hurricanes and their convective storms. The simple conceptual models of hurricanes include thunderstorms embedded in the eyewall. We are learning that the regions surrounding these convective cells can vary and impact the behaviors in multiple regions within the hurricane. Satellite observations have demonstrated that over half of all major tropical cyclones develop at least one secondary eyewall, a phenomena once thought to be rare. Why this occurs in hurricanes is not well understood, but efforts at SSEC/CIMSS are helping to uncover this mystery.

We need more than satellite observations and model simulations to understand hurricanes. We can gain additional knowledge by direct measurements achieved during field programs. This issue describes an exciting field program that flew UW instruments on un-manned aircraft where the data were transmitted back to UW in near real time for analysis.

Clouds affect the water and energy cycles of Earth. Storm clouds strongly influence both cycles through the formation, precipitation and dissipation phases. The article on CALIPSO and MODIS cloud observations directly addresses how clouds impact the radiative component of Earth's energy cycle. By combining direct observations (e.g. lidar) with indirect measurements (e.g. imager), a discrepancy in observed cloud radiative properties is unraveled.

While satellites are a modern tool for weather analysis and forecasting, time series now extend back to 1980. The nature of satellite observations provides a key method to study changing cloud properties across the globe. To achieve the needed time series requires addressing the challenge of combining observations from instruments flown on different satellites. The result is a 30+ year time series of data that provide observations of global change and validation data sets for global model simulations.

Clouds form from substances other than water. Researchers are detecting and tracking volcanic clouds, made of ash, water and sulfuric acid. Following these clouds is important in air traffic control, as we all learned with the grounding of airline fleets due to the Eyjafjallajökull eruption in 2010. Efforts to detect an eruption and track the resulting volcanic plume in near-real time are explained in this issue.

Clouds also occur on other planets, marking the weather that occurs there as they do on Earth. These clouds provide information on large-scale weather patterns of that planet. Stunning results from new ground based observations of clouds on Uranus will cause scientists, poets and children among us to wonder how they form and what they are made of, as well as provide an opportunity to observe as they take on interesting and recognizable shapes.

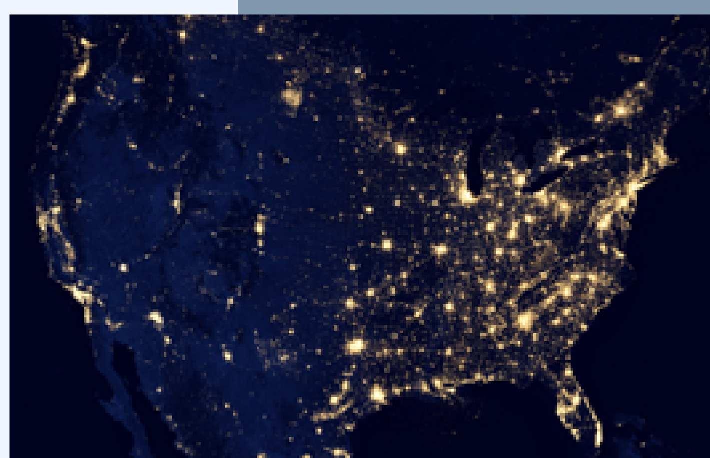
Suomi's Vision Continues to Illuminate

In the late 1950's, UW-Madison Professor Verner Suomi had a vision. He saw a future where orbiting satellites could look down from the heights and study our home planet from a perspective never before available. Known as the Father of Satellite Meteorology, Suomi, along with Professor of Engineering Robert Parent, created such innovations as the spin-scan camera which supplied the first full-color images of Earth from space, pioneering continuous viewing of weather from space and revolutionizing how we see our planet. For decades since, spectacular images of the "blue marble," Earth bathed in the light of the sun, have been the quintessential satellite view of Earth.

In January of 2012, NASA and NOAA re-named their newest Earth-observing satellite in Suomi's honor: the Suomi National Polar-Orbiting Partnership. The Suomi NPP has been supplying valuable science, and incredible images since it was launched.

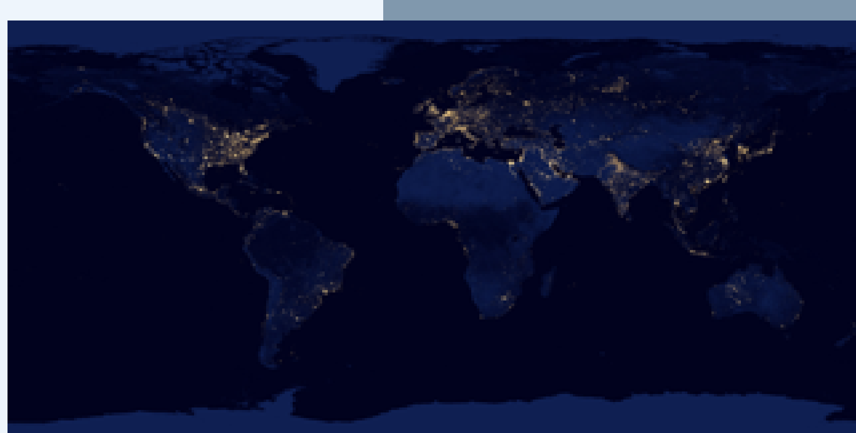
And on December 19, 2012, NASA and NOAA released unprecedented new images – a cloud free image of planet Earth, at night, and yet alive with light.

One of five advanced instruments aboard the Suomi NPP is the Visible Infrared Imaging Radiometer Suite (VIIRS), which gathers photons in 22 different wavelengths. One of the channels of the VIIRS is the Day-Night Band (DNB). The DNB, which detects light in a range of wavelengths from green to near-infrared, is sensitive enough to capture the light of a single ship at sea, the aurora, or even clouds lit by very faint, nocturnal atmospheric light called airglow.



Under the light of the moon, the DNB can discern details previously only available to visible channels during the day. Such details were seen as Hurricane Sandy struck New Jersey on the evening of October 29. Wildfires can be distinguished from oil field gas flares; city lights can be studied to track urban and suburban growth or how quickly power is restored after a natural disaster. Dense marine fogs, which often form at night, can be seen and tracked, giving confidence to forecasters as they issue advisories to the public.

SSEC has been providing the National Weather Service (NWS) with data from VIIRS, including the Day Night Band, using data from the direct broadcast antenna at the University of Wisconsin, which is processed using the Community Satellite Processing Package (CSPP), also developed at SSEC.



As a polar-orbiting satellite, Suomi NPP covers almost the entire Earth twice each day; once at 1:30 am local time and once at 1:30 pm local time, collecting a 3,000 kilometer wide swath of information as it passes over.

Professor Suomi's vision of examining the Earth with greater detail and better understanding from space will continue into the future.

These views of Earth's city lights are composites assembled from data acquired by the Suomi National Polar-orbiting Partnership (Suomi NPP) satellite. Image and caption credit for all three images: NASA Earth Observatory/NOAA NGDC.

Following Convective Clouds with Satellites

Credit: Grant Petty, UW-Madison AOS

What Scientists are Learning about Severe Storm Development and Hurricanes

As countless storms have proved, the need to not just predict, but accurately predict, the when, where, and strength of each storm is critical. Our ability to detect storm development in its earliest stages and to understand a storm's internal processes allows us to help forecasters to provide the best information possible to decision makers and the public. Simply stated, early warnings save lives.

CIMSS researchers are studying convective clouds in a number of different ways. First, you'll learn how scientists are improving our ability to forecast thunderstorm development using satellite data and how satellite data can improve warning lead-times. Second, you'll learn what scientists have discovered about the internal processes of hurricanes and what that can tell us about hurricane intensity, a critical, but elusive, part of hurricane research. Both areas are showing great promise.

The Beginnings of Severe Storms

National Weather Service (NWS) forecasters tend to rely heavily on radar to detect severe storms. With their satellite data expertise, CIMSS scientists have explored ways to leverage information from satellite data to provide forecasters with additional tools to assist them in preparing forecasts, and in particular to demonstrate satellite products that can indicate severe storm development before it is evident on radar. CIMSS researchers are currently focusing on two avenues of investigation: cloud-top cooling and overshooting top detection for in field Proving Ground testing.

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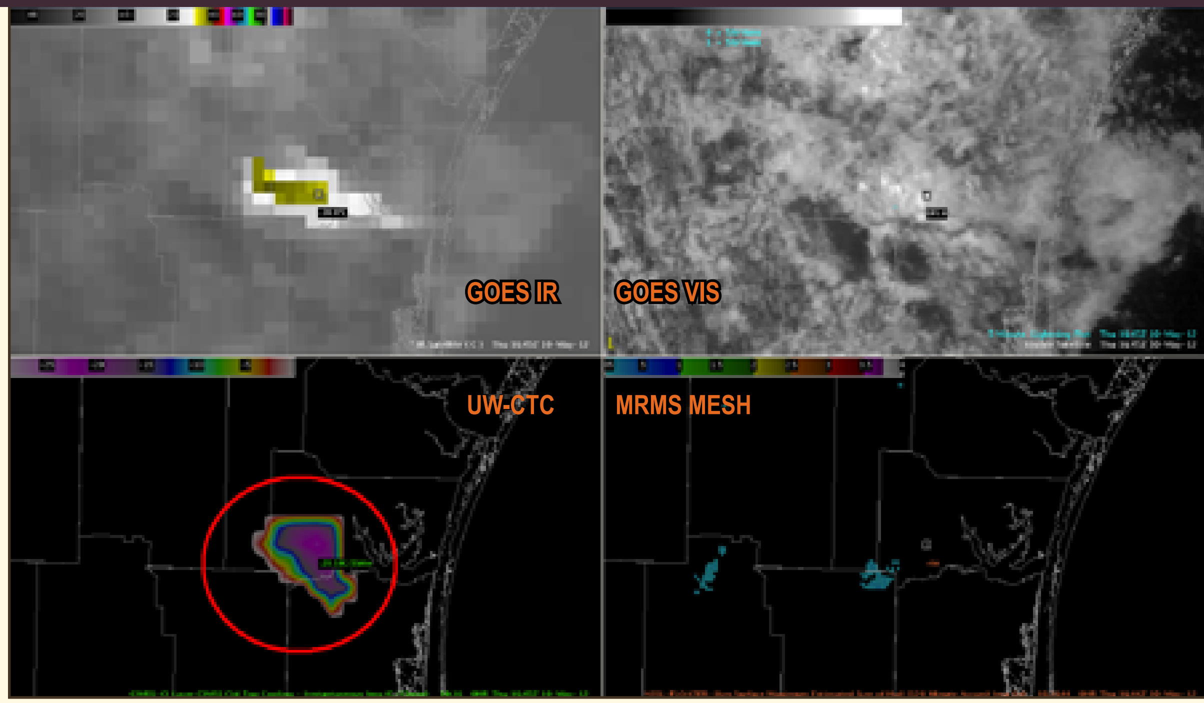

Figure 1: Strong UW-CTC signal of ~ -23 K / 15 min over Kleberg County, TX at 1645 UTC on 10 May 2012. The MRMS MESH at 1724 UTC was 3.00+". The UW-CTC lead-time of radar-indicated severe hail was 30-40 minutes. The UW-CTC lead-time of first severe hail report was ~ 60 minutes (1742 UTC 1.00").

Cloud-top Cooling (CTC)

The Cloud-top Cooling (CTC) product detects clouds that are rapidly cooling (growing vertically), which indicates convective development. The CTC algorithm combines information from the GOES(-R) Cloud Mask, GOES(-R) Cloud Phase, GOES(-R) Cloud Optical Depth, and IR-window brightness temperatures.

NWS forecasters had the opportunity to evaluate the current CTC product at the 2012 Hazardous Weather Testbed (HWT) 7 May - 15 June 2012 in Norman, OK. Based upon forecaster feedback from the 2009-2011 HWT spring field experiments, the CTC product had been improved to mitigate the effects of cirrus clouds on detecting storm development. Forecasters were also interested in seeing any connection between the CTC intensity product and future NEXRAD observations, particularly composite reflectivity and Maximum Expected Size of Hail (MESH). Could the CTC help improve severe thunderstorm warning lead-times?

Forecasters at the HWT found that the CTC product often provided lead-times ahead of the first occurrence of 60 dBZ composite reflectivity and radar-estimated severe hail (1.0"+ MESH) with lead-times ranging between 10-90 minutes (fig. 1). The NWS forecasters used this information to increase lead-time of severe thunderstorm warning issuance compared to radar-only based warnings by 5-20 minutes (1-4 radar scans).

One issue noted by the forecasters was the need to take into account the environmental conditions, including terrain effects, of the particular CTC observation. In some instances convection was induced by higher terrain and would later die out when it moved on to lower elevations. Despite this caveat, forecasters at the HWT were excited to have another tool at their disposal, especially one that could accurately increase their lead-time for warnings.

Overshooting Tops

Another key to the early detection of severe storms using satellite data are overshooting tops (OTs). While OTs appear deceptively small and often disappear within 15 minutes, they are also the scene for potentially hazardous weather conditions, including aviation turbulence, frequent lightning, heavy rainfall, large hail, damaging winds, and tornadoes.

To better detect OTs, CIMSS and NASA Langley Research Center researchers have been working on an "IRW-texture" method that combines spatial infrared window (IRW) brightness temperature gradients and NWP-based tropopause temperature information, along with OT size. Research on this approach has shown that it offers a more consistent method of day/night OT detection compared to other methods, such as the WV-IRW BTD (water vapor minus infrared window brightness temperature difference).

Figure 2 shows a CloudSat and CALIPSO overpass of an OT located in the Atlantic Ocean off the coast of North Carolina. Also shown are the Aqua MODIS IRW and WV BT data and IRW-texture OT detections in order to compare the performances of the IRW-texture and WV-IRW BTD techniques. The IRW-texture captures the ~8 km wide OT quite well. In contrast, if a 2 K WV-IRW BTD threshold had been used for OT detection, no OT pixels would have been detected. Equally problematic, a positive BTD would have detected nearly the entire anvil cloud, which would result in a very high false alarm rate.

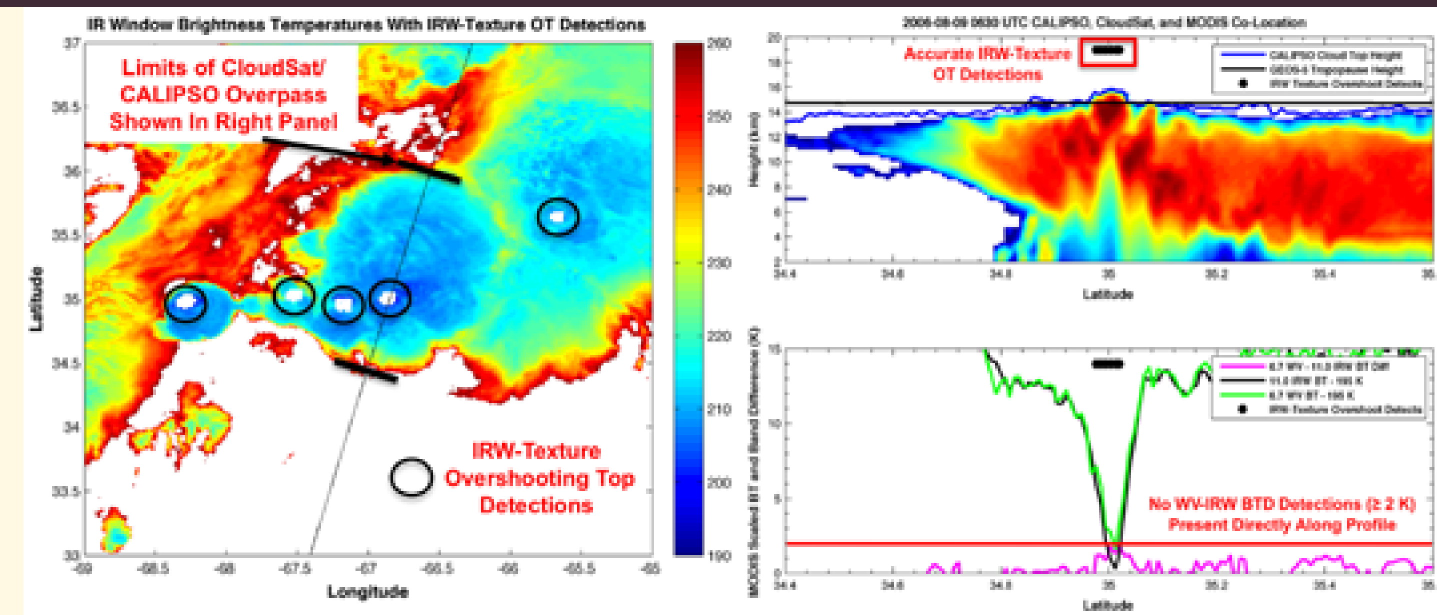

Figure 2: (left) Aqua MODIS 1 km 10.7 µm brightness temperature imagery with IRW-texture OT detections (white dots). (right) IRW-texture OT detections co-located with MODIS brightness temperatures, CloudSat radar reflectivity, CALIPSO cloud top height, and the NASA GEOS-5 model tropopause height analysis.

Storms Within a Hurricane

The local kinematic and thermodynamic conditions surrounding individual convective elements vary considerably over small spatial scales in a hurricane. This situation leads to a wide variety of convective modes and behaviors in various regions within the hurricane. Generally, convection drawing from the ocean's heat energy is the primary driving mechanism for the hurricane's maintenance, evolution, and subsequent convective development. Consequently, to make progress in understanding hurricane intensity and structure change, it is important to account for the convective details within hurricanes. A number of research activities at CIMSS seek to investigate the variability of convective behaviors within hurricanes in order to better understand their impact on the hurricane.

One way in which CIMSS is tackling this problem is through idealized modeling. For this approach, a high-resolution (i.e., $D x = 250$ m), nonhydrostatic model is being used to examine individual convective clouds in a variety of environments.

In hurricanes, the vertical shear of the horizontal wind can become quite strong and is also quite variable in space. Moreover, the horizontal shear of the wind can be substantial in a hurricane, particularly immediately outside of the eyewall. Thus, numerical experiments have been performed to study the behavior and properties of convective clouds when subjected to varying degrees of vertical and horizontal wind shear.

Figure 3 provides an example of midlevel vertical vorticity and vertical motion from several of the numerical experiments (see page 4 for figure 3). This image shows the results of what happens shortly after a single convective cell has been initiated from a low-level warm bubble. It should be noted that this warm bubble is identical in all experiments. In a simulation without any background flow or vertical vorticity, a single convective updraft emerges but it fails to produce vertical vorticity (Fig. 3a). The addition of vertical shear of the meridional wind creates a vertical vorticity dipole due to the updraft's tilting of horizontal vorticity associated with the vertical wind shear (Fig. 3b). Adding hurricane-like low-level veering to the vertical wind profile strengthens the low-level shear and drastically changes the convective morphology towards a more asymmetric updraft/vorticity configuration (Fig. 3c). Here, similar to classic right-moving supercells in midlatitude severe weather situations, dynamic pressure perturbations favor the sustenance of the updraft containing positive vertical vorticity. The results of Figs. 3a-3c are consistent with many previous studies on the role of vertical wind shear on convective organization.

The new wrinkle to our study is the addition of horizontal wind shear. Figures 3d-3f show the impacts of adding horizontal wind shear to the experiments depicted in Figs. 3a-3c. Our results show that horizontal shear can have competing impacts on convection. On the one hand, analysis of our simulations shows that strong horizontal wind shear weakens convection, producing shallower clouds and weaker updrafts. On the other hand, as seen in Fig. 3c, this compromised convection can still efficiently spin up existing vertical vorticity, especially where vertical vorticity is already enhanced. Moreover, horizontal wind shear also expands convection and its

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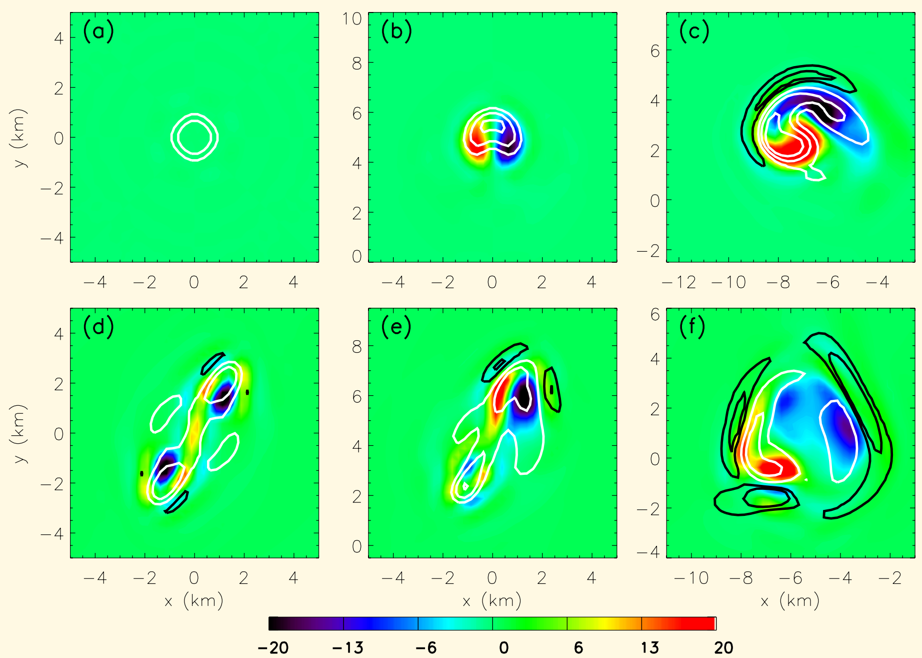
Figure 3: The vertical component of vorticity (10-3 s-1; shaded) and vertical velocity (contoured in black at -1 and -3 m s-1 and in white at 5, 10, and 15 m s-1) at 2.6-km height above ground in 6 numerical experiments for a single convective cell: (a) no wind shear, (b) unidirectional vertical wind shear, and (c) vertical wind shear with low-level veering in the vertical wind profile. Panels (d), (e), and (f) are the same as (a), (b), and (c), but with moderate horizontal wind shear included. All panels are from 0.5 h into the simulation.



vertical vorticity perturbations over a broader region due to the rapid differential advection of convective activity, which allows convection to have more widespread impacts on the surrounding environment. Overall, subtle changes to a storm's environment can have profound and complex impacts on convective structure and evolution. These types of differences may significantly impact hurricane intensity and structure.

Another research avenue at CIMSS for exploring hurricane convection is to examine the convection in high-resolution (i.e., D x = 1 km) WRF simulations of hurricanes. There have been a number of interesting findings so far.

• Immediately outside the eyewall of intense, simulated hurricanes, the horizontal wind shear and storm relative helicity are both quite strong. Consistent with the idealized cloud model results described above, convection tends to be shallower here. In fact, a significant portion of the precipitation appears to be stratiform and organized as vortex Rossby waves.

• In regions further away from the eyewall, the horizontal shear becomes weaker, although the vertical wind shear can still be quite strong. Here, most of the convection is organized into spiral rainbands. Individual convective cells embedded in these rainbands are often supercellular and produce many small-scale, high-amplitude negative and positive vertical vorticity perturbations.

• While study of the intricate ways in which various modes of convection can impact the hurricane's evolution itself is underway, a recent CIMSS publication (Rozoff et al. 2012; J. Atmos. Sci.) shows how general convective activity can lead to secondary eyewall formation (SEF) in a WRF simulation of a hurricane (e.g., Fig. 4). SEF is particularly important to understand since such an event can lead to a rapid expansion of the hurricane's destructive winds. Our results show that enhanced and sustained rainband activity can concentrate angular momentum outside a hurricane's primary eyewall and radius of maximum winds (Fig. 5). This activity causes the wind field to expand outward from the eye. As the wind field expands, convection becomes increasingly efficient at spinning up the tangential wind in the region of sustained convection. At the same time, the Ekman pumping in the boundary layer increases in this region as the tangential wind increases, which favors the redevelopment of more convection. As such, a positive feedback loop appears to unfold so that an outer eyewall and outer wind maximum can develop.

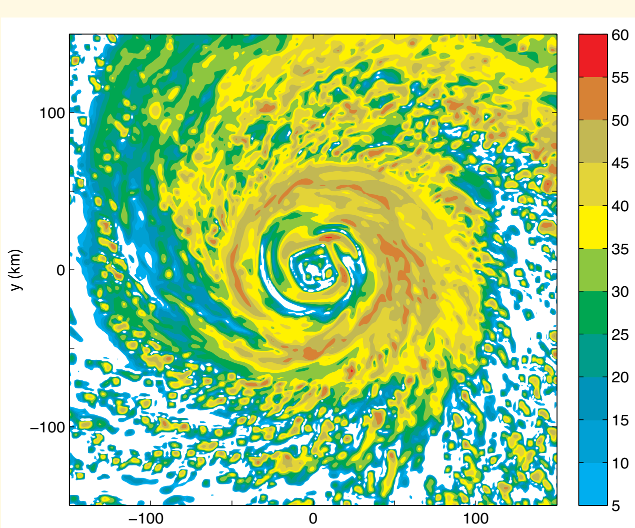


Figure 4: Synthetic radar reflectivity at 1-km height above ground from a WRF simulation of a hurricane with concentric eyewalls.

Leanne Avila
Kris Bedka
Wayne Feltz
Chris Rozoff
Justin Sieglaff

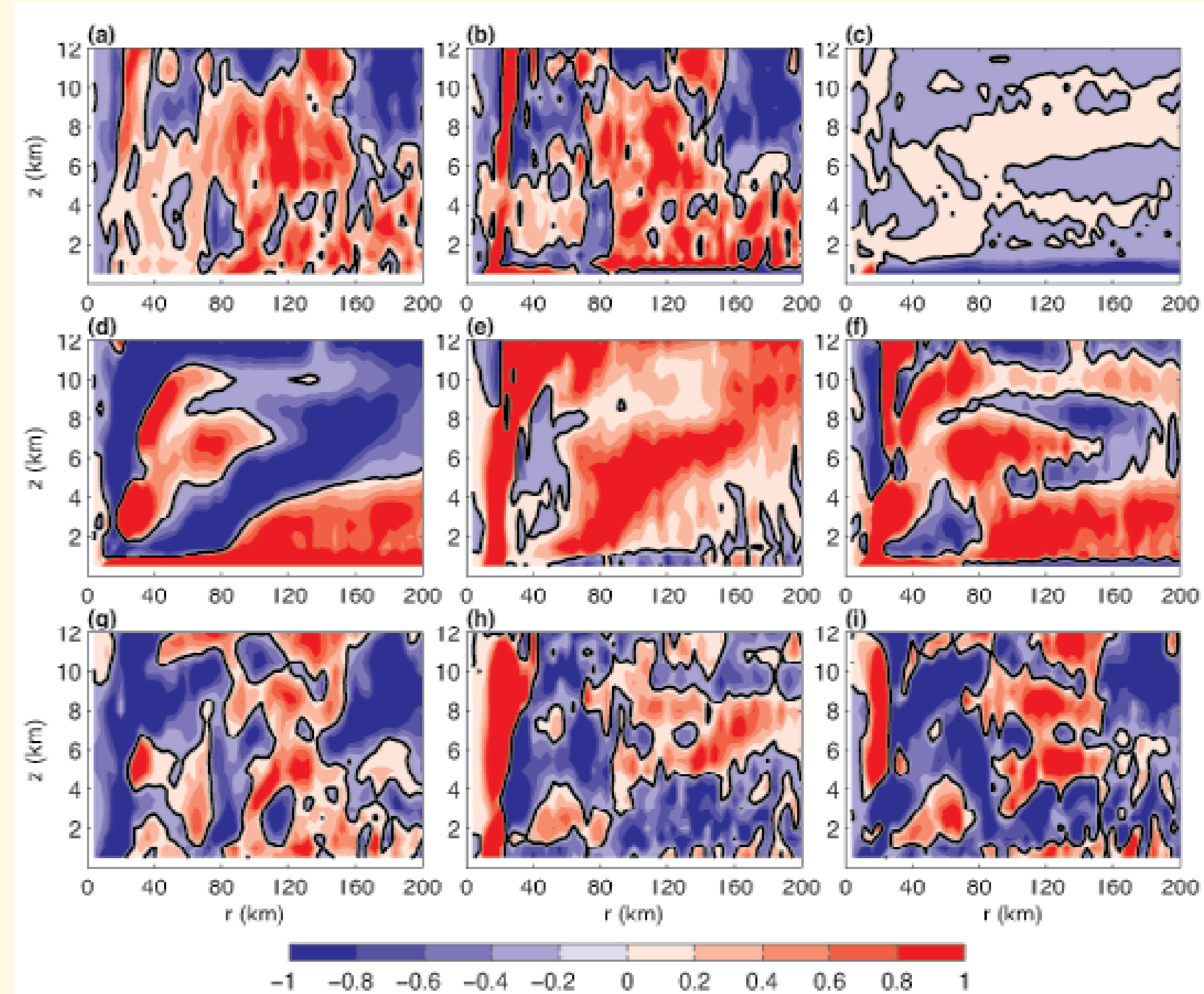


Figure 5: An absolute angular momentum (AAM) budget shows the mechanisms that expand the simulated hurricane's wind field. Vertical cross sections are shown, where the horizontal coordinate is radius (i.e., distance from the storm's center) and the vertical coordinate is height above ground. The above figure shows various contributions to changes in AAM (expressed in units of 105 m2 s-1 h-1).

(a) The actual change in AAM over an hour-long period prior to SEF (13 h prior to Fig. 4).

(b) The AAM budget estimate of the change in AAM over the same time period.

(c) The impact of friction and diffusion on AAM, which is negative over much of the boundary layer.

(d) The symmetric radial flux of absolute vorticity, which shows the low-level flux of vorticity into the region of rainband convection spins up the wind field outside of the eyewall.

(e) The symmetric vertical advection of AAM, which shows convection distributes higher AAM upward.

(f) The sum of panels (c), (d), and (e) (i.e., the total symmetric contribution to the change in AAM).

(g) The asymmetric radial flux of absolute vorticity.

(h) The asymmetric vertical advection of AAM.

(i) The sum of panels (g) and (h) (i.e., the total asymmetric contribution to the change in AAM), which, when compared with (f), shows that the symmetric circulation contributes most to the spin up of the wind field outside of the hurricane's primary eyewall. Note that the sum of panels (f) and (i) yields panel (b).

New Insights from Recent Field Campaigns

TROPICAL CYCLONE CHASING

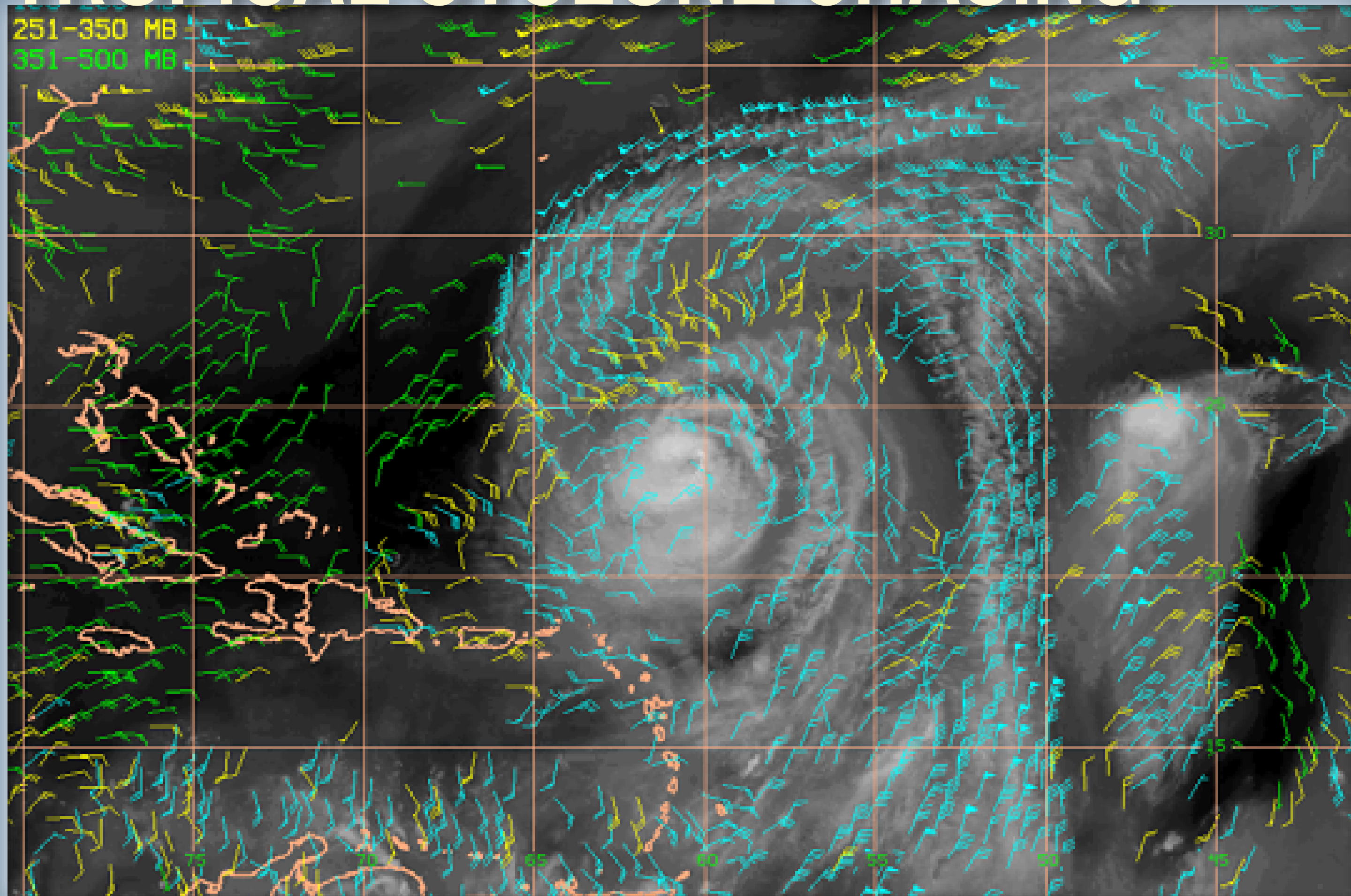


Figure 1: Upper-level (150-500hPa) satellite-derived winds (kts) overlain on GOES WV imagery for TC Igor on 17 September at 1800 UTC: Cyan 150-250hPa, Yellow 251-350hPa, Green 351-500hPa.

Hurricanes capture our attention unlike any other storms due to their unforgiving nature and the sheer size of the damage left in their wake, whether it is property that has been destroyed or lives that have been lost. Researchers at SSEC and elsewhere have been studying hurricanes (a subset of the more generic "tropical cyclone" (TC) terminology) for decades in the hopes of finding those elusive pieces of the puzzle that allow us to better understand and predict them. In particular, the dynamics of the TC and its environment figure strongly into the processes that affect the formation, track, and intensity.

To this end SSEC scientists and graduate students have participated in two recent field experiments related to TC genesis and intensity: Pre-Depression Investigation of Cloud-Systems in the Tropics (PREDICT) in 2010, and Hurricane Severe Storm Sentinel (HS3) which began in 2012.

PREDICT

During the late summer of 2010, an NCAR/NSF Gulfstream-V jet made 25 flights over the Atlantic Ocean as part of the PREDICT experiment to test new hypotheses on TC genesis known collectively as the "marsupial paradigm" (the name coming from the theory's similarities with a marsupial being born and developing in its mother's pouch). Despite significant advances over the years in our ability to track TCs, determining which tropical disturbances will develop remains a complex problem without an easy solution. Carrying a number of sensors and dropsonde capability, the aircraft flew into promising areas for TC genesis (predicted by the "pouch theory") to take in situ measurements the researchers hoped would provide answers.

While the pouch theory focuses on what is occurring in the lower tropospheric levels of the TC environment, CIMSS researchers have also been investigating the influences of upper tropospheric level conditions; their prevailing theory is that while favorable low-level pouch conditions may be necessary for genesis, they are not sufficient, and upper level conditions can act to modulate TC development as well.

"Our primary post-field experiment activity has been to crunch data from the aircraft and dropsondes in concert with the satellite products (winds)… to deduce if we can find upper-level outflow linkages," states Chris Velden, CIMSS Senior Scientist, one of the PIs on the PREDICT experiment. "We believe there is a link between the outflow setup for supporting the developing secondary circulation ('in-up-and-out') and TC genesis."

Figure 1 shows an example of the upper-level (150-500hPa) satellite-derived winds produced from GOES by CIMSS overlain on water vapor imagery for TC Igor on 17 September 2010. Strong outflow has established as depicted by the cyan wind barbs. During the course of the PREDICT field campaign, CIMSS created similar wind fields to assist the PIs and forecasters in monitoring the flow evolution over potential areas of interest. Now the images and data are being carefully analyzed to look for clues on how, when, where, and why TCs may form.

Figure 2 illustrates one of the results of analyzing the pre-genesis upper level conditions of all 13 developing TCs from the PREDICT experiment. The figure shows a strong outward horizontal mass flux signal prior to TC genesis, consistent with a developing outflow channel.

Velden notes that their research "is short of being conclusive due to the low number of cases, but is very suggestive. And the satellite data is helping us come to that conclusion." The work has already resulted in a Master's dissertation by Velden's graduate student, John Sears (the thesis won the UW-Madison AOS department Lettau Award for outstanding thesis), and has been submitted for journal publication.

The CIMSS Tropical Cyclone group researchers will be bringing in additional cases from the HS3 field experiment (described below) to continue their investigation on the connection between the upper level environment and tropical cyclogenesis.

HS3

Late summer of 2012 offered the beginnings of another opportunity for SSEC/CIMSS researchers to gather in situ measurements of TCs. The five-year HS3 mission includes three years of field campaigns using two Northrop Grumman Global Hawks, unmanned aircraft, to fly over the Atlantic Ocean to investigate the environment surrounding hurricanes, as well as the inner workings of hurricanes.

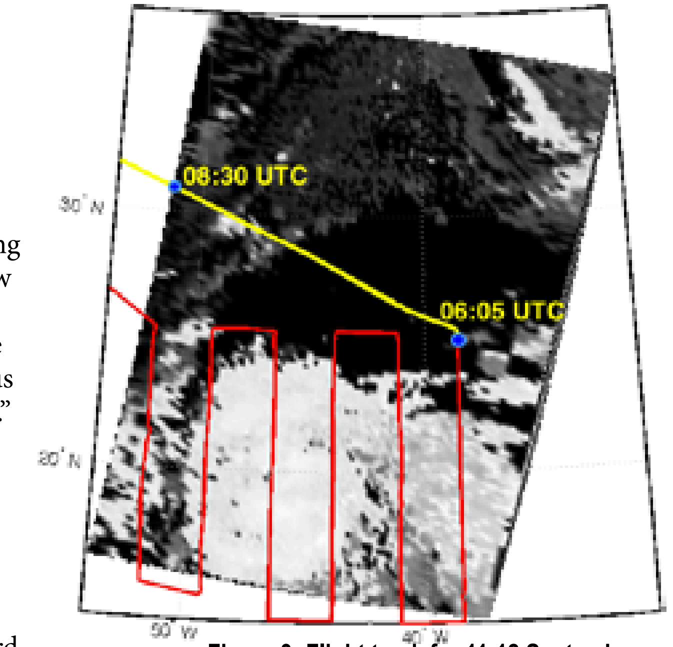


Figure 3: Flight track for 11-12 September 2012 flight over the newly named Tropical Storm Nadine.

SSEC's Scanning-HIS (S-HIS) was included as part of the environmental aircraft's payload to obtain temperature and water vapor measurements. From the temperature and moisture data scientists can determine the equivalent potential temperature, important information about the amount of energy and the ability of air to rise, which allows scientists to determine the heights at which clouds will form. These details provide another way to monitor the intensity of a storm.

In addition to the S-HIS data, researchers have been bringing in satellite data for comparison. CIMSS graduate student Elise Garms has been processing AIRS overpasses that coincide with flights over the storm. She has been applying the Dual Regression retrieval algorithm

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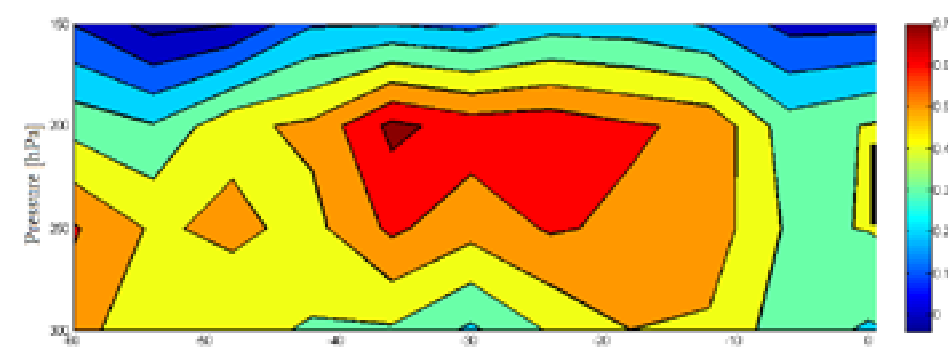


Figure 2: Genesis-time-relative x-section of composited, pouch-centered, upper-level, azimuthally-averaged horizontal mass flux [kg/m2s] within a 10-degree radius from pouch center, for the 13 developing cases in our PREDICT sample. Warmer colors indicate increased outward mass flux from the center. Time 0 = genesis time, and negative time (hrs.) indicates pre-genesis.

developed by Bill Smith and Elisabeth Weisz to get temperature and moisture from the cloud tops.

Of particular interest has been a case study from 11-12 September 2012 (see figure 3 on page 7). On the way back from gathering data over Tropical Storm Nadine, the flight track of the Global Hawk passed directly over the Saharan Air Layer, one area of investigation for HS3.

Figures 4 and 5 show results from AIRS Dual Regression retrieved relative humidity of Tropical Storm Nadine.

While the analysis is in its early stages, there are plans to compare the S-HIS and dropsonde data with that from the satellite. As a result of the cooperation and sharing of data (including that from the Cloud Physics Lidar), between all involved in the HS3 field campaign, Garms notes, "We will eventually have a very impressive dataset." From this dataset researchers will continue their investigations of tropical storms with the goal of increased understanding of these complex systems.

Leanne Avila
Elise Garms
Bob Knuteson
Chris Velden

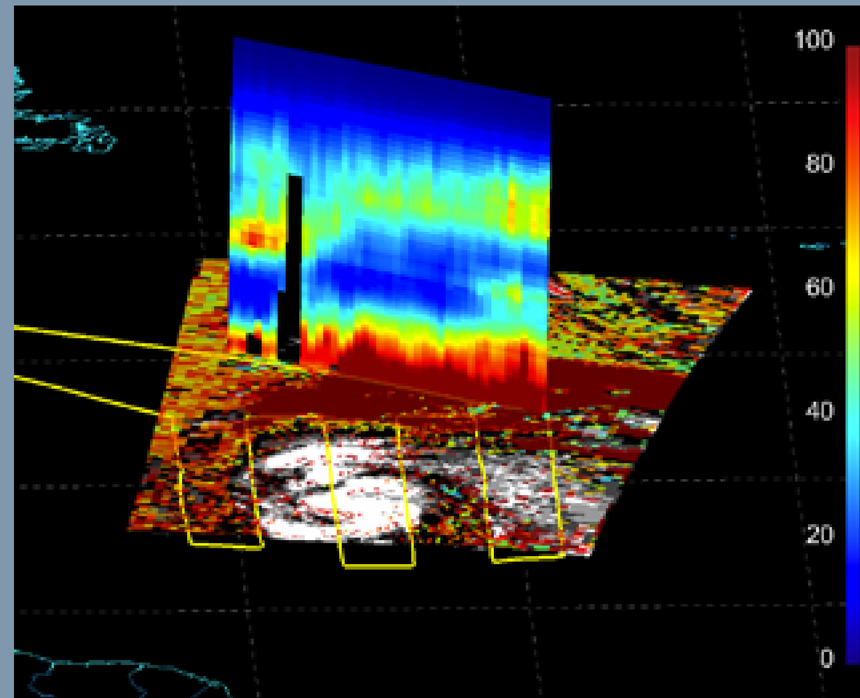


Figure 4: AIRS Dual Regression retrieved relative humidity at 986.1 hPa of Tropical Storm Nadine at 04:42 UTC on 12 September 2012, with flight track shown in yellow. The final leg of the flight passed over a Saharan Air Layer region, along which a relative humidity cross-section is shown.

An animation showing relative humidity at more pressure levels can be found at: http://go.wisc.edu/f1k3q6

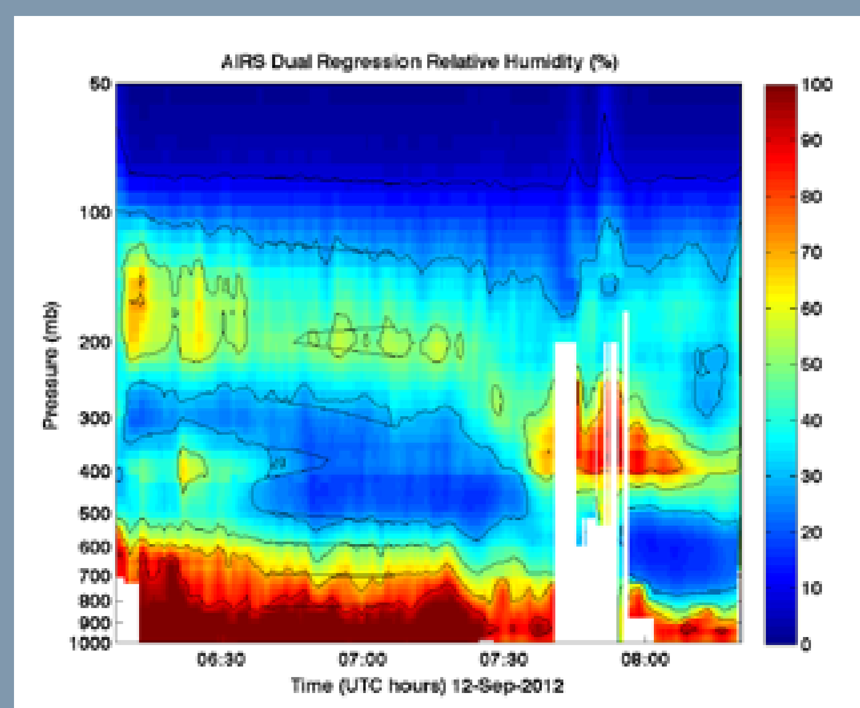
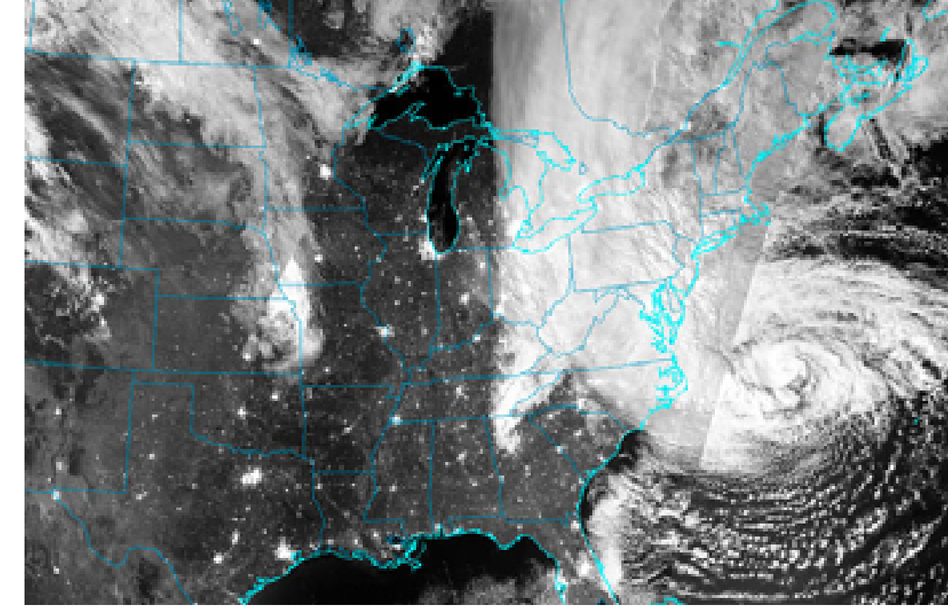


Figure 5: Cross-section of AIRS Dual Regression (DR) relative humidity along the flight path from 06:05 to 08:20 UTC on 12 September 2012. S-HIS and dropsonde measurements taken during the HS3 field experiment will be used to validate this satellite product. This segment crosses through a region of Saharan Air Layer.

The DR product was generated using IMAPP software, available at: http://cimss.ssec.wisc.edu/imapp.

Tracking Hurricane Sandy

> " The 1-minute super rapid scan imagery allowed us to see what was happening, as opposed to what had already happened. "



Hurricane Sandy seen by Suomi NPP VIIRS Day Night Band. 29 October 2012 (night).

Hurricane Sandy began its savage life on 22 October 2012 when a tropical depression in the Western Caribbean Sea was upgraded to tropical storm status. Two days later, Sandy had made the grade to hurricane and was sweeping northward across Jamaica and eastern Cuba, spreading death and destruction in its wake. Roaring up the East Coast, Sandy made a fateful left turn and thundered into the mid-Atlantic states, some of the most densely populated areas in the United States, on the evening of 29 October 2012.

As fearful as Sandy became, its effects could have been far worse had the warnings not come so early and been so clear.

Researchers at SSEC provided critical data from satellites - wind speed, temperature and moisture - that forecasters depended on to analyze the path and intensity of Sandy. Computer models based on this data were predicting that the storm would hit New Jersey late Monday afternoon.

"This was an unprecedented forecast, giving the coastal population a good five to six days of lead time," said Chris Velden, senior researcher at the CIMSS. "The models gave the National Hurricane Center adequate time to fine-tune their forecasts, which ultimately saved a lot of lives."

Polar-orbiting satellites, such as the Suomi NPP which was able to supply visual spectra images of the storm even at night, and geostationary satellites, with their broad range of scanning abilities, followed the storm's every move.

The Geostationary Operational Environmental Satellite (GOES)-13, in orbit at the equator and 75 W longitude, was placed into Rapid Scan Operations mode to monitor Sandy. GOES-14, the eventual replacement satellite for GOES-13, focused its Super-Rapid Scan Operations for GOES-R (SRSOR) imager on Sandy beginning on 25 October, providing a nearly steady stream of unique 1-minute interval scans which, given the scale of the storm, was very close to a live feed.

As research meteorologist Tim Schmit (NOAA/NESDIS) said, "The 1-minute super rapid scan imagery allowed us to see what was happening, as opposed to what had already happened."

These unique scans were collected and made available to the National Hurricane Center and others on a daily basis by SSEC and the NOAA NESDIS Advanced Satellite Products Branch at the UW-Madison.

The special 1-minute imagery also foreshadows what will be routinely available from the next generation geostationary satellite series (GOES-R), scheduled to be launch ready in October 2015.

The SSEC Data Center collated their images into many YouTube videos which were quickly posted (and gathered a combined total of over one million views). These animations enhanced researchers' abilities to visualize the storm. Never before has a hurricane's development been scanned so frequently over such a long period of time.

In many ways – its sheer size, the central pressure, and the still-undetermined scope of the damage it caused – Hurricane Sandy was a record-breaker. Since there is no way to prevent such a natural disaster, our best protection is early and accurate predictions of each storm's expected behavior. Computer models are making better and better predictions of these events. Satellite data and products such as provided by NOAA/NESDIS and SSEC are major contributors to that success.

Mark Hobson
Tim Schmit
Chris Velden

Detecting Volcanic Ash Cloud

> " Soon we will begin testing the complete automated alert system in real-time using current satellite technologies such as MODIS, VIIRS, GOES, and SEVIRI. "

Eyjafjallajökull volcano ash plume taken by the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Aqua satellite on April 17, 2010.

In April of 2010 millions of airline passengers across Europe were bumped from their flights because of the Eyjafjallajökull volcanic eruption in Iceland. The ash cloud that spewed from the volcano reached jet cruising altitudes within busy North Atlantic and European air routes. The majority of air traffic in this region was grounded to prevent jet aircraft engines from being damaged or disabled by the ash clouds.

"Most volcanoes are unmonitored," says Mike Pavolonis, a National Oceanic and Atmospheric Administration (NOAA) researcher working at the UW-Madison Cooperative Institute of Meteorological Satellite Studies (CIMSS). "Eruptions can go unnoticed for hours, particularly in remote areas. And even remote areas may have heavily travelled air traffic lanes that would be threatened by volcanic ash clouds."

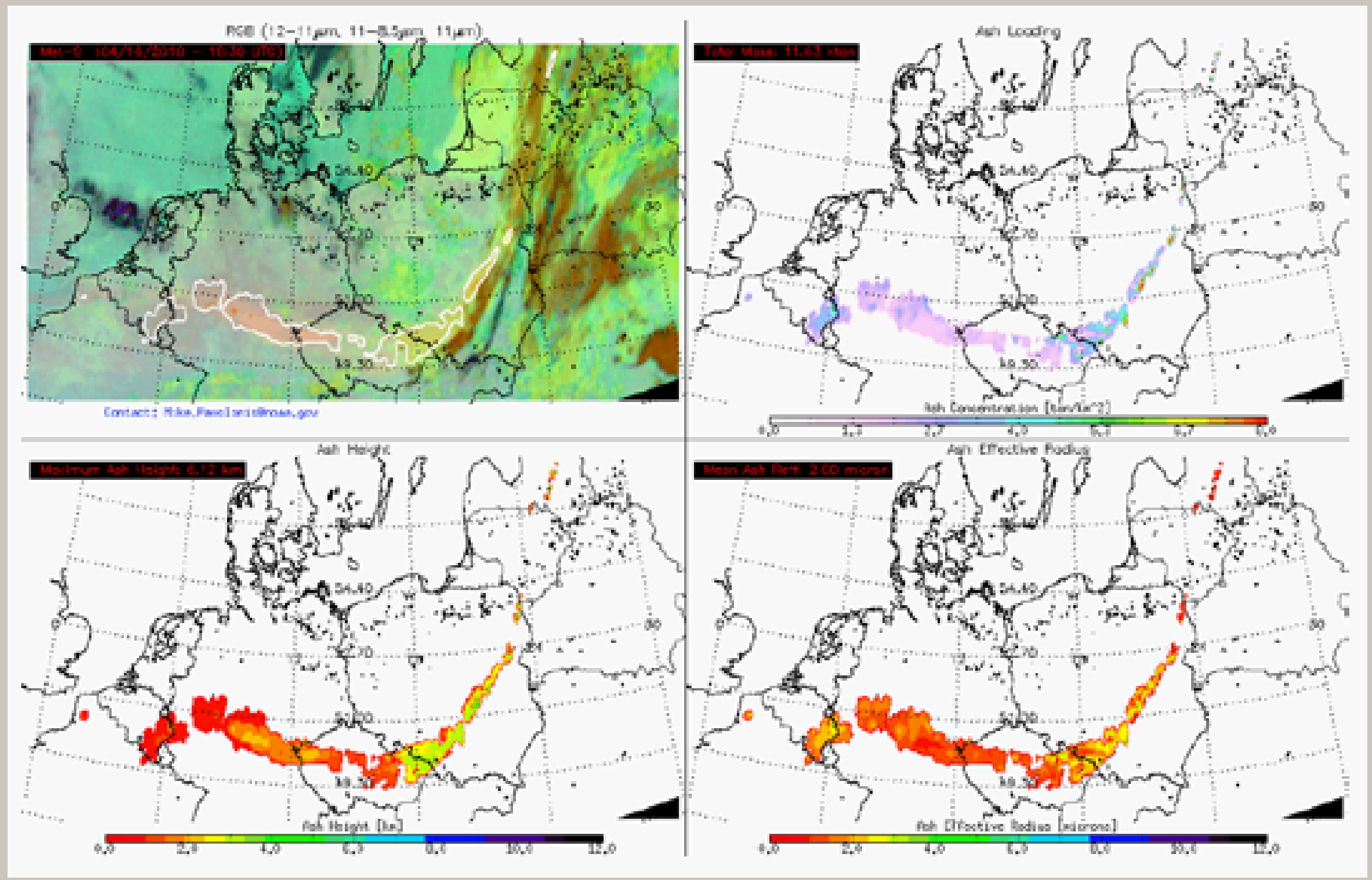
Even though satellite imagery provides, in essence, a 24-7 view of volcanoes around the world, volcanic clouds are difficult to distinguish from regular clouds, at least from orbit. Traditional satellite observations have not supplied sufficient information to determine ash cloud height and content, and have not been able to automatically detect volcanic eruptions.

"A computer algorithm to search satellite data for volcanic clouds is very difficult to do," Pavolonis says. "Difficult, but not impossible. Our goal is to make real-time volcanic cloud alerts for all volcanic cloud types available to the Volcanic Ash Advisory Centers that are responsible for issuing advisories to the public."

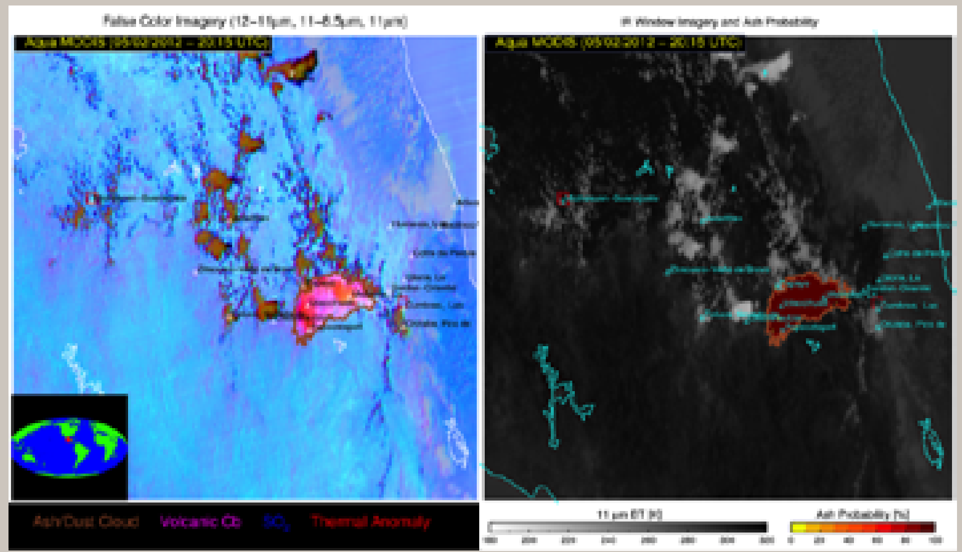
To that end, Pavolonis is developing a fully automated, globally applicable algorithm to retrieve ash cloud properties from infrared satellite measurements. The algorithm, which will serve as the official operational algorithm of the next generation Geostationary Operational Environmental Satellite (GOES-R), utilizes an optimal estimation framework that can take into account uncertainties in the measurements and forward model, as well as determine uncertainty estimates for each of the retrieved parameters.

Using a combination of radiative transfer theory and image processing techniques, such as cloud object analysis, the algorithm has been able to detect volcanic ash clouds with a level of accuracy comparable to that of a trained human analyst. The algorithm takes qualitative information offered by combinations of manually-scaled, multispectral false color images and quantifies it into a single probability using a naïve Bayesian classifier. This classifier utilizes multivariate predictors which are radiometrically analogous to the information displayed on the red, green, and blue color guns in a false color image.

This retrieval approach can be applied globally because background atmospheric water vapor, surface temperature, and surface emissivity are explicitly accounted for on a pixel-by-pixel basis. The validation analysis shows that the retrieved ash cloud height, cloud emissivity, and effective particle radius generally agree well with lidar measurements. The retrieved ash cloud properties can be used to initialize ash transport and dispersion forecast models.



Results from the automated next generation Geostationary Operational Environmental Satellite (GOES-R) volcanic ash detection and retrieval system are shown for ash clouds produced by eruptions of Eyjafjallajökull, Iceland on 15 April 2010. These images show the ash cloud over Germany, the Czech Republic, and Poland on 16 April 2010 at 18:30 UTC. (upper left) A false color image, the outline of the ash clouds detected by the automated algorithm is contoured in white. (upper right) The ash mass loading. (lower left) The ash cloud height. (lower right) The ash cloud effective particle radius.



Automatically generated output from the GOES-R volcanic cloud alert system for a 02 May 2012 eruption of Popocatepetl in Mexico. (left) Automatically annotated false color imagery, where colored contours are overlaid to depict volcanic features detected by the alert system. The images allow users to quickly assess the alert content and make decisions. (right) An image showing the ash probability overlaid on an infrared image.

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```
@********* VOLCANIC ALERTS *********

STARTING DATE/TIME OF IMAGE: 2012-05-02 20:15:00[UTC]
PRIMARY INSTRUMENT: MODIS
WMO SPACECRAFT ID: 784
LOCATION/ORBIT: LEO

NUMBER OF ASH CLOUD ALERTS: 1
NUMBER OF VOLCANIC Cb ALERTS: 0
NUMBER OF VOLCANIC THERMAL ANOMALY ALERTS: 3
NUMBER OF SO2 CLOUD ALERTS: 0

&
-------------------------------------------------------
POSSIBLE VOLANIC ASH CLOUD FOUND
Alert Status: Newly detected feature
Latitude of Radiative Center: 19.219 [degree]
Longitude of Radiative Center: -97.816 [degree]
Mean Viewing Angle: 41.42 [degree]
Mean Solar Zenith Angle: 26.02 [degree]
Nearby Volcanoes (meeting alert criteria):
      Malinche, La (22.69 km)
   Serdan-Oriental (37.13 km)
      Cumbres, Las (58.30 km)[Thermal Anomaly Present]
        Gloria, La (60.86 km)
    Orizaba, Pico de (61.38 km)
      Humeros, Los (64.43 km)
   Cofre de Perote (76.29 km)
      Iztaccihuatl (86.88 km)
      Popocatepetl (87.51 km)
            Papayo (93.39 km)

Cloud Object Probability: 100.00000 [%]
Mean Probability of Object Pixels: 95.83303 [%]
Area of Unambiguous Pixels: 2751.96 [km^2]
Maximum Height [AMSL]: 16.4 [km] (53972.01 [ft])
1-sigma Uncertainty of Maximum Height [AMSL]: 7.6 [km]
(25054.14 [ft])
Mean Tropopause Height [AMSL]: 16.9 [km] (55458.54 [ft])
Total Area: 4601.99 [km^2]

Geographic Regions of Nearby Volcano: Mexico
VAAC Regions of Nearby Volcanoes: Unknown
FIR Regions of Nearby Volcanoes: Unknown
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Vocanic text alert, complete with a summary of the ash cloud properties.

Pavolonis says, "Unlike false color images, where optimal feature enhancement requires scene dependent manual adjustments, our predictors are corrected for background influences, where possible, so that the predictors scale consistently across the broad range of background conditions encountered globally. The ash detection results can be used to issue alerts to users when an ash cloud is detected, and this fully automated technique can be adapted to a wide range of satellite sensors."

"We are now at a point where we have a prototype system that is ready for testing in operations," Pavolonis says. "Soon we will begin testing the complete automated alert system in real-time using current satellite technologies such as MODIS, VIIRS, GOES, and SEVIRI. And with the next generation of satellites we are going to obtain images more frequently, and in more wavelengths. We will be detecting these dangerous clouds in a more timely manner, and characterizing their properties more accurately."

Mark Hobson
Mike Pavolonis

Types of Volcanic Clouds

"Different eruptions produce different types of clouds," Pavolonis says. "Some are easier to distinguish than others. We look at the different wavelengths and how the cloud evolves in time."

There are three main categories of volcanic clouds: semi-transparent ash-dominated clouds, opaque volcanic clouds, and SO_2 clouds.

Semi-transparent ash-dominated clouds

This type of volcanic cloud is semi-transparent to infrared radiation and is primarily composed of volcanic ash particles. Lightning is usually not present. Clouds of this variety are very common and, as such, regularly (e.g. daily) impact aviation to some degree.

Opaque volcanic clouds (volcanically initiated convection)

These clouds are mostly observed as a result of a major eruption and have caused in-air engine failures so early detection is critical. Early detection, however, is difficult because the cloud can easily be mistaken for meteorological convection (e.g., a thunderstorm). Lightning is often present in these clouds, but its presence is not sufficiently unique to differentiate it from meteorological convection.

SO_2 clouds

This type of cloud is composed of sulfur dioxide (SO_2 gas), which is invisible to the naked eye, but it is still regarded as an aviation hazard, especially in large concentrations. Some eruptions produce large amounts of SO_2 and very little ash and vice-versa. Lightning is not present in "pure" SO_2 clouds. SO_2 absorbs and reflects detectable amounts of radiation only at select wavelengths.

Photos: (left) The first units of iPads distributed at 2012 ESIP teacher workshop in Madison, WI. (right) Teachers with iPads making sky observation with SatCam app.

The CIMSS iPad Library

Facilitating Interactive Learning Experience

With its new iPad Library, the Cooperative Institute for Meteorological Satellite Studies (CIMSS) has launched an innovative program to support teachers as they engage students in data acquisition and regional climate studies. Teachers can borrow iPads like books, for the entire school year! This unique lending library was funded by the NASA Global Climate Change Education program as part of the CIMSS Climate Literacy Ambassadors project and is managed by the SSEC Schwerdtfeger Library.

The first unit of iPads were distributed at a NOAA NESDIS funded teacher workshop held during the 2012 Earth Science Information Partners (ESIP) Conference in Madison, Wisconsin. The theme of the ESIP Teacher Workshop was climate literacy and technology. Several climate-related apps were presented and shared during the workshop. The favorite by far was SatCam, where users make observations of local cloud and surface conditions coordinated with polar orbiting satellites. The first observation the teachers made with their new iPads involved the Suomi-NPP satellite.

The first of its kind, the CIMSS iPad Library hopes to harness the potential creativity and educational benefits afforded by tablet computers. Already, two Wisconsin teachers are developing lesson plans at the middle and high school level where students will use SatCam to observe and document changes in weather conditions in their backyards, across the region, and around the country. The app enables student-to-student sharing, cross disciplinary dialogue, and an in-depth understanding of weather and climate change over time.

Margaret Mooney

SatCam Looking at Clouds from Both Sides

The SatCam Satellite Image Capture app is a new application created for iOS devices by an SSEC development team. From any location in the world, users can capture observations of cloud and surface conditions with their devices' built-in camera at the same time a polar orbiting satellite is flying overhead. When users submit their pictures, SSEC will send the corresponding satellite image back to users' devices in less than an hour.

Along with the observational pictures, users are asked to classify cloud coverage and their surrounding environment using a pre-defined set of categories. This will help SSEC scientists validate the quality of the cloud products created from the satellite data.

Currently SatCam supports three satellites, Terra, Aqua, and Suomi NPP, and displays a list of available satellite overpasses in the next seven days. Users can see each satellite's orbit path and the time remaining until the next overpass. Worrying about missing an observation? SatCam has a voice cue that users can turn on to be notified 10 minutes prior to a satellite overpass.

In the near future SSEC plans to provide a SatCam website where users can see and rate observations for quality and accuracy. This will help eliminate poor observations. High quality observations will be used to validate satellite products.

Hsuan-Yun Pi

SatCam app is now available at the App Store. For more information, visit: http://satcam.ssec.wisc.edu/index.html

Studying Clouds and Uncovering Biases with CALIOP and MODIS

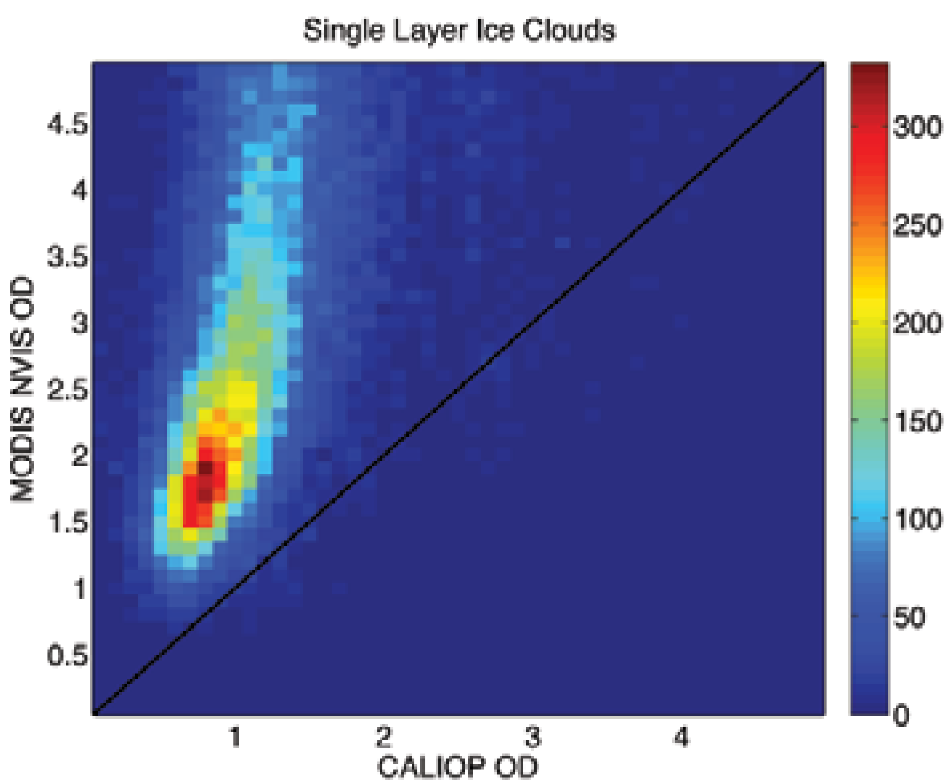

Figure 1: The comparison between the CALIOP and MODIS cirrus OD for 1 month of comparisons. Notice the factor of two bias between the retrievals.

Cloud products are generated from several visible and infrared instruments in space. The NASA MODIS instrument, with its 36 spectral bands and high spatial resolution supports several cloud products. One such product is the visible optical depth of cirrus clouds (MYD06 - developed by Steve Platnick's group at NASA). To evaluate the accuracy of these products, researchers compare them to those produced by other observations. With the launch of the NASA CALIPSO instrument, a NASA Langley team developed a CALIOP extinction retrieval.

About 4 years ago as part of the SSEC Atmospheric PEATE activities, SSEC/CIMSS scientist Bob Holz started comparing results from the two products. The comparison revealed a surprisingly large (more then a factor of two) bias between the two independent observations. After an extensive vetting of the analysis, it was concluded that the bias was real and not an artifact of the comparison methodology (Figure 1).

The impact of the bias in characterizing uncertainties in cloud radiative forcing was investigated and found to be significant with a mean Top of Atmosphere (TOA) flux calculations using the CALIOP and MODIS Optical Depth differing by 14 watts with differences as large as 50 watts (see figure 2).

Over the next two years, the investigation was dedicated to understanding the cause of the bias. Which retrieval had the bias? CALIOP being the new and "better" technology was initially thought to have lower uncertainties compared to the MODIS OD retrieval. For this reason a significant effort was undertaken to investigate the MODIS retrieval algorithm with a focus on the simulated scattering properties of ice crystals used as part of the retrieval. The result of this analysis was that the uncertainties in the scattering properties could explain about 50% of the bias but not the factor of two bias found in the comparison with CALIOP. Thus the question remained, what was causing the 100% bias between the sensors?

To resolve these bias issues, it was necessary to come up with an independent measurement that could be used as a baseline to compare to both MODIS and CALIOP. A significant source of the Optical Depth uncertainty for both MODIS and CALIOP was the complexities of calculating the cloudy radiative transfer (dealing with scattering) in the visible wavelengths. Unlike the visible frequencies, the InfraRed (10 -11 um) is primarily dominated by absorption (emission) processes, which significantly simplifies and reduces the uncertainties in calculating the cloud radiative transfer. Leveraging these properties, the well calibrated MODIS 11 um window channel was used to calculate the cloud Top of Atmosphere (TOA) radiance using as input the cirrus Optial Depth retrieved by MODIS and CALIOP. The calculated TOA from the MODIS measured radiances was then compared for each collocated CALIOP and MODIS FOV; the results are presented in Figure 3.

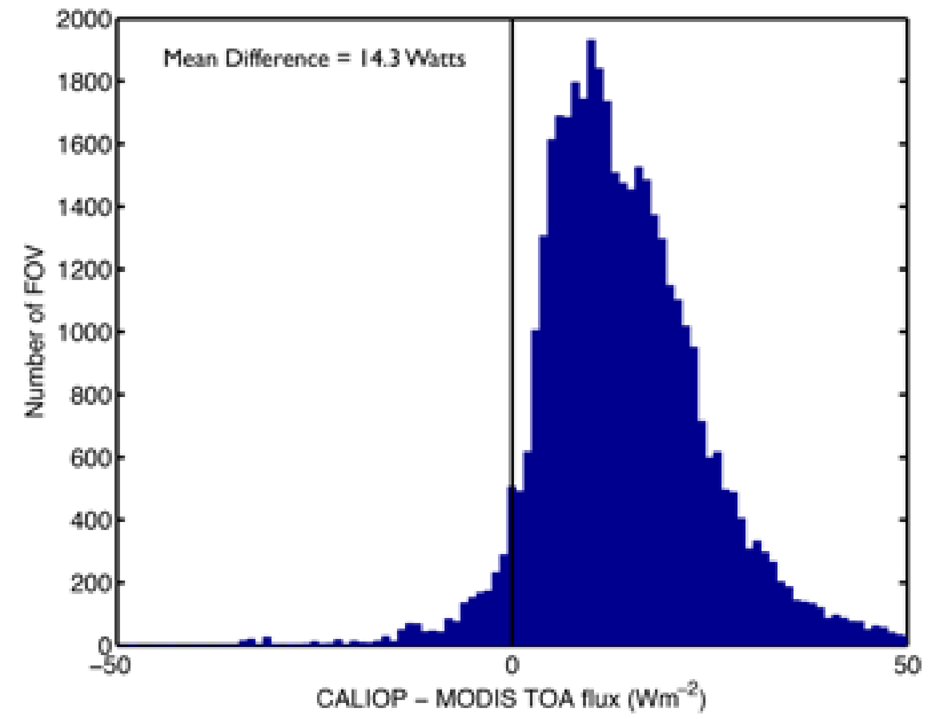

Figure 2: The differences in calculated TOA flux when using CALIOP or MODIS cirrus Optical Depth.

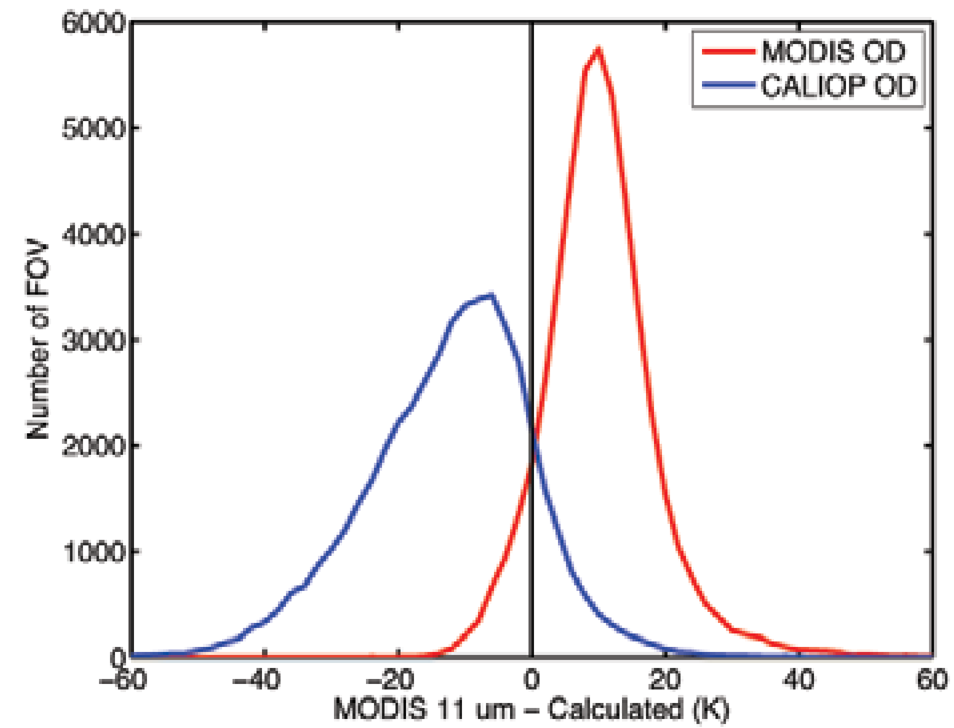

Figure 3: The histogram of the differences between the calculated vs measured MODIS BT using the CALIOP (blue) and MODIS (red) cirrus OD. If the retrieval agreed, the peak of the distributions should be centered at zero.

The research found that neither MODIS nor CALIOP calculated Top Of Atmosphere Brightness Temperature compared closely with the measured MODIS 11 um Brightness Temperature as presented in Figure 3 with the MODIS calculated BT being too cold (thick) and the CALIOP BT too warm (thin). This result suggested that the MODIS Optical Depth retrieval was systematically overestimating the cirrus Optical Depth and the CALIOP retrieval was underestimating the Optical Depth. This finding suggested that CALIOP was significantly underestimating the cirrus OD.

The question remained, with both MODIS and CALIOP Optical Depth not proving closure in the InfraRed, how are the biases resolved? An InfraRed retrieval of cirrus Optical Depth was used that provides an independent (spectral) retrieval with uncorrelated uncertainties relative to the visible retrievals (CALIOP and MODIS). For the InfraRed we used two retrievals (Heidinger and Holz) with direct comparison demonstrating very good agreement. When compared to the InfraRed retrieved Optical Depth, we found that MODIS is biased high and CALIOP biased low by approximately 50% each, respectively.

Based on these results, the CALIOP and MODIS teams investigated their respective Optical Depth algorithms. For MODIS, the primary source of Optical Depth bias results from the assumed ice crystal Single Scatter Properties (SSP) which are used as part of the radiative transfer calculations to relate the measured reflectance to ice cloud properties (effective radius and OD). The current (MODIS V5) SSP use single scatter calculations based on non-roughened calculations and an empirical mixture of habits and size distributions. Further investigation

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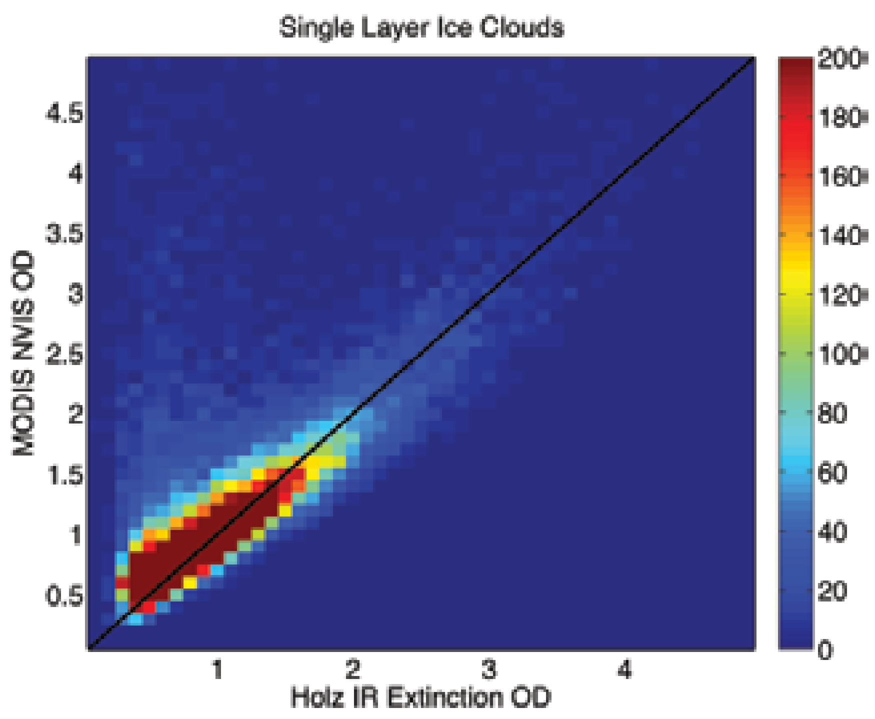


Figure 4: The MODIS OD compared to the IR OD retrievals after the algorithm was modified based on the collocated analysis. Notice the significantly improved biases relative to Figure 1.

revealed that a likely source of the MODIS Optical Depth bias resulted from the SSP. New models are now available which include roughened particles. Leveraging the processing capabilities of Atmospheric PEATE to process multiple SSP databases, the products were tested and inter-compared to both the InfrarRed and CALIOP retrievals. Based on these comparisons it was discovered that a single habit (roughened aggregated columns) with an analytic size distribution (modified gamma) provided the best agreement with the InfraRed cirrus Optical Depth retrievals for thin cirrus. This will be the habit used in the up coming V6 of the MODIS cloud optical property retrievals scheduled for release in early 2013.

An investigation of the CALIOP TOA product revealed that the current CALIOP algorithm used a lidar ratio, a parameter needed to convert the measured backscatter intensity into optical thickness that was too small. The CALIOP team provided a modified algorithm that included an updated lidar ratio (larger) with the new retrievals integrated into the UW atmospheric PEATE processing system and compared against both the InfraRed and the updated MODIS retrievals.

Figure 4 presents the new (C6) version of the MODIS retrievals compared against the IR retrieval. Notice the very good agreement between the IR and MODIS.

Bob Holz

Highlights of Recent Publications

July - November 2012

♦ **Denlinger, R.P., M. Pavolinis, and J. Sieglaff, 2012: A robust method to forecast volcanic ash clouds. J. Geophys. Res., 117, D13208.**

A framework for optimal volcanic ash cloud forecasts and their uncertainties given any model and any observational data is provided. The nature of ash clouds is used to accelerate probability assessment, producing a method to rapidly generate a prediction of future ash concentrations and distribution based on assimilation of satellite data as well as model and data uncertainties.

♦ **Emanuel, K., F. Fondriest, and J. Kossin, 2012: Potential economic value of seasonal hurricane forecasts. Wea. Climate Soc., 4,110-117.**

Potential utility of seasonal Atlantic hurricane forecasts to a hypothetical property insurance firm covering properties on the US Gulf and East Coasts is explored. Potential value of seasonal hurricane forecast is assessed by comparing the overall probability density of the company's profits to various test strategies in which the amount of risk varies according to whether the season is active or quiet.

♦ **Foster, M.J., S.A. Ackerman, A.K. Heidinger, and B.C. Maddux, 2012: State of the climate in 2011: Cloudiness. Bull. Amer. Meteor. Soc., 93, S27-S28.**

Global cloudiness in 2011 was 1.5% lower than the climatological annual mean relative to 1981-2010 making it the seventh least-cloudy year on record and global cloudiness in 2011 reflected La Nina. The dataset used for this analysis was the PATMOS-x, a 30-year record of cloud retrievals taken from AVHRR.

♦ **Lazzara, M.A., G.A. Weidner, L.M. Keller, J.E. Thom, and J.J. Cassano, 2012: Antarctic Automatic Weather Station Program: 30 years of polar observations. Bull. Amer. Meteor. Soc., 93, 1519-1537.**

A quest for automated meteorological observations in the Antarctic leads to a continent-wide network of automatic weather stations supporting research and forecasting.

♦ **Liu, Yinghui, J.R. Key, S.A. Ackerman, G.G. Mace, and Q. Zhang, 2012: Arctic cloud macrophysical characteristics from CloudSat and CALIPSO. Remote Sens. Env., 124, 159-173.**

Presentation of a new cloud macrophysical property characteristic analysis for the Arctic, including cloud occurrence fraction, vertical distributions and probability density functions of cloud base and top heights. Lidar and radar profiling capabilities of CloudSat and CALIPSO satellites provide opportunities to improve the characterization of cloud properties.

♦ **Monette, S.A., C.S. Velden, K.S. Griffin, and C.M. Rozoff, 2012: Examining trends in satellite-detected tropical overshooting tops as a potential predictor of tropical cyclone rapid intensification. J. Appl. Meteor. Climatol., 51, 1917-1930.**

Description of the adaption of the midtatitude overshooting-top detection algorithm to the tropics and provides an initial exploration of possible correlations between tropical-overshooting-top parameter's potential as a predictor of rapid intensification.

♦ **Otkin, J.A., 2012: Assimilation of water vapor sensitive infrared brightness temperature observations during a high impact weather event. J. Geophys. Res., 117, D19203.**

A regional-scale Observing System Simulation Experiment was used to examine impact of water vapor sensitive infrared brightness temperature observations on the analysis and forecast accuracy during a high impact weather event across the central U.S. Results demonstrate ability of water vapor-sensitive infrared brightness temperatures to improve their utility within a data assimilation system.

♦ **Remer, L.A., S. Mattoo, R.C. Levy, A. Heidinger, R.B. Pierce, and M. Chin, 2012: Retrieving aerosol in a cloudy environment: Aerosol product availability as a function of spatial resolution. Atmos. Meas. Tech., 5, 1823-1840.**

Investigation of aerosol retrieval availability at different instrument pixel resolutions using the standard MODIS aerosol cloud masks applied to MODIS data and supplemented with a new GOES-R cloud mask applied to GOES data. Large difference in results strongly reinforce that cloud masks must be developed with specific purposes in mind and that a generic cloud mask applied to an independent aerosol retrieval will likely fail.

♦ **Rozoff, C.M., D.S. Nolan, J.P. Kossin, F. Zhang, and J. Fang, 2012: The roles of an expanding wind field and inertial stability in tropical cyclone secondary eyewall formation. J. Atmos. Sci., 69, 2621-2643.**

The Weather and Research and Forecasting Model is used to explore the intricacies of tropical cyclone secondary eyewall formation.

♦ **Smith, W.L., Sr., E. Weisz, S.V. Kireev, D.K. Zhou, Z. Li, and E.E. Borbas, 2012: Dual-regression retrieval algorithm for real-time processing of satellite ultraspectral radiances. J. Appl. Meteor. Climatol., 51, 1456-1476.**

A fast physically based dual-regression method is developed to produce, in real time, accurate profile and surface- and cloud-property retrievals from satellite ultraspectral radiances observed for both clear- and cloudy-sky conditions resulting in higher accuracy retrievals.

♦ **Sromovsky, L.A., P.M. Fry, H.B. Hammel, I. de Pater, and K.A. Rages, 2012: Post-equinox dynamics and polar cloud structure on Uranus. Icarus, 220, 694-712.**

Discussion of post equinox images of Uranus by HST, Keck, and Gemini telescopes which have enabled new measurement of winds over previously sampled latitudes as well as measurements at high northern latitudes that have recently come into better view.

♦ **Sromovsky, L.A.; H.B. Hammel, I. de Pater, P.M. Fry, K.A. Rages, M.R. Showalter, W.J. Merline, P. Tamblyn, C. Neyman, J.-L. Margot, J. Fang, F. Colas, J.L. Dauvergne, J.M. Gomez-Forrellad, R. Hueso, A. Sanchez-Lavega, and T. Stallard, 2012: Episodic bright and dark spots on Uranus. Icarus, 220, 6-22.**

Discussion of the observations from Gemini, HST and Keck of episodes of bright cloud formations in the northern mid-latitudes of Uranus.

♦ **Walther, A., and A.K. Heidinger, 2012: Implementation of the Daytime Cloud Optical and Microphysical Properties algorithm (DCOMP) in PATMOS-x. J. Appl. Meteor. Climatol., 51, 1371-1390.**

Description of the daytime cloud optical and microphysical properties retrieval for the Pathfinder Atmosphere's Extended climate dataset. Comparisons with the MODIS collection-5 dataset are used to estimate performance.

♦ **Weisz, E., W.P. Menzel, N. Smith, R. Frey, E.E. Borbas, and B.A. Baum, 2012: An approach for improving cirrus cloud-top pressure/height estimation by merging high-spatial-resolution infrared-window imager data with high-spectral-resolution sounder data. J. Appl. Meteor. Climatol., 51, 1477-1488.**

Discussion of the effect of combining imager and sounder to improve cloud top pressure retrievals. The results demonstrate the ability of the merging gradient algorithm to add spatial definition to sounder retrievals with a higher accuracy and precision than those obtained solely from the imager.

For all the recent SSEC publications, please visit: http://library.ssec.wisc.edu/research_Resources/bibliographies/ssec

Honors and Awards

Bryan Baum, Rich Frey, Tommy Jasmin, Hank Revercomb, Tom Rink, Dave Tobin, Xuanji Wang

NOAA/NASA "Certificate of Recognition, presented in appreciation for all your hard work and dedication which contributed to the successful launch and commission of Suomi National Polar-orbiting Partnership Satellite System"

William Line

1st place Poster Presentation, NWA 2012, Graduate Student category.

Jacola Roman

Best Student Oral Presentation, AMS 2012 Annual Meeting (New Orleans).

Tommy Jasmin

ESIP Student Fellowship.

Chris Beley

1st Place and $10,000 in the Qualcomm Wireless Innovations Competition.

4th Place and $1,500 in the G. Steven Burrill Business Plan Competition.

The words “climate change” conjure up visions of extreme changes in weather, weather that appears far less predictable. Surprisingly, clouds have not changed over time, or at least not as much as scientists speculated they might have. However they do play an important, but as yet not well-tested role in global climate.

Long Term Cloud Studies at CIMSS

Early HIRS work

With High-resolution Infrared Radiation Sounder (HIRS) data now spanning nearly forty years, scientists at CIMSS/SSEC are taking advantage of the fact that HIRS has continued to appear on successive NOAA and Meteorological Operational satellite programme (MetOp) spacecraft, enabling sustained, long-term collection of global cloud observations from one sensor. Bill Smith from NOAA, along with CIMSS scientists, played a major role in making the case to include the HIRS instrument on TIROS-N in 1978.

Researchers at CIMSS set out to study clouds, specifically high, thin clouds. The HIRS channels with partial CO_2 absorption from 13-15 microns, provided a better means of detecting semi-transparent high clouds than other cloud analyses. The technique, referred to as “CO_2 Slicing” uses the most opaque spectral bands seeing the cloud for cloud property determination, thus mitigating any confusion caused by the radiation emanating from the earth surface. Since 1978 sixteen HIRS sensors have flown on satellites: TIROS-N, NOAA-6 to -19, and MetOp-A and -B in morning and afternoon orbits. The constancy of flight has allowed for accumulation of a continuous record of clear and cloudy sky radiances in 19 spectral bands at 20 km resolution, including overlapping coverage as new sensors are brought on-line.

In an attempt to minimize sensor to sensor measurement differences over time (1978-to date), a reference sensor was established through intercalibration with the Infrared Atmospheric Sounding Interferometer (IASI). Using IASI as a calibration reference or benchmark, scientists can more accurately determine which part of the spectrum the MetOp HIRS is actually measuring. Simultaneous Nadir Overpasses (SNO) for overlapping sensors, which occur primarily in the polar regions, are then used to adjust the spectral response functions on earlier HIRS measurements. Using this approach, the inter-satellite radiance differences from one HIRS sensor to another have been minimized. The resulting cloud trends (see Fig. 1) show good sensor to sensor consistency in a more than twenty year HIRS data set.

When reprocessing HIRS cloud properties CIMSS researchers have plans to incorporate the sub-HIRS-pixel information available from the AVHRR at 1km resolution. The PATMOS-X data set generated by Andy Heidinger of NOAA’s Center for Satellite Applications and Research (STAR), offers very good lower cloud detection that now can be complemented with the very good higher cloud detection of HIRS, resulting in a more complete dataset.

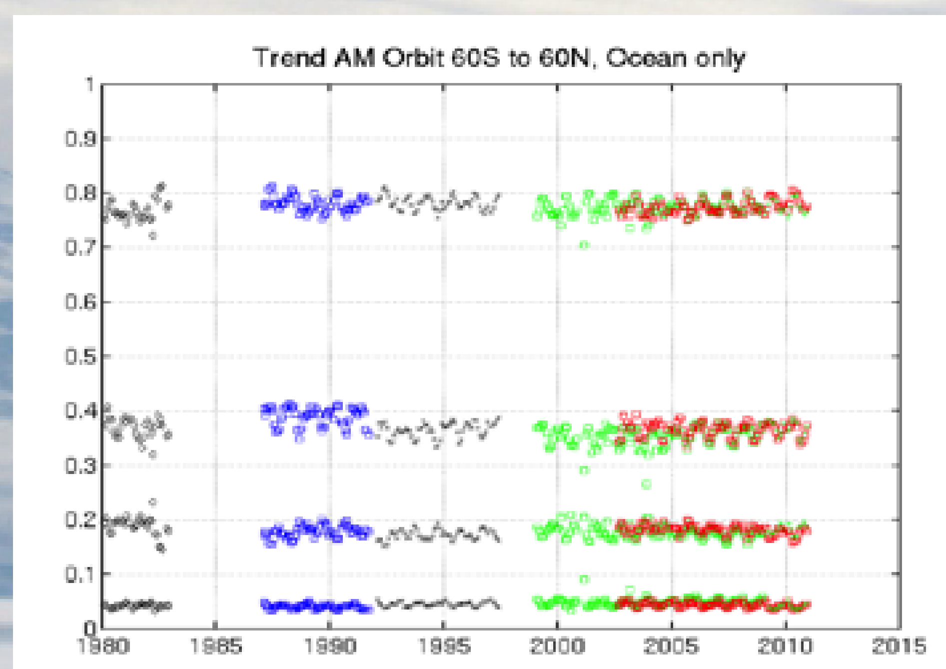


Figure 1: Twenty-two year trend in morning orbit HIRS (from NOAA-6, -10, -12, -15, and -17) detection over oceans of all clouds (near 75% of all observations), high clouds (cloud top pressures less than 440 hPa are found in about 35% of all observations), clear skies (a little less than 20% of all observations), and uncertain skies (about 5% of all observations are deemed to be uncertain; this occurs when the thermal contrast between clear and cloudy skies is too small). AVHRR visible and near infrared spectral measurements can help with cloud determinations.

Background image source: Marginal Hack, Public Domain, via USA.gov

Looking to the future

Looking to the future, we now have the opportunity to compare MODIS and VIIRS instrument data against the established HIRS trends. For MODIS, trends are similar in terms of regional and global cloud detection; however, absolute comparison of HIRS to MODIS data remains a challenge. MODIS (one in a morning orbit on Terra and another in an afternoon orbit on Aqua) measures radiances in 36 spectral bands at 1 km resolution using ten detectors and hence sees finer resolution features in clouds than HIRS. Figure 2 shows the global distribution of seasonal mean cloud top pressures detected by MODIS for the last ten years.

The Visible Infrared Imaging Radiometer Suite (VIIRS), part of the instrument suite on the Joint Polar Satellite System (JPSS), offers measurements at 380m resolution, but lacks spectral bands sensitive to CO_2 or water vapor. The CrIS (Cross track Infrared Sounder) on JPSS has sounding bands in carbon dioxide and water vapor regions, but at 15 km resolution. By combining the data from both, it is thought that the information content of high spatial resolution and high spectral resolution data will yield and thus sustain the MODIS level of characterization of cloud properties.

The real strength of a global climatology is not necessarily the global averages but the regional changes. To date, scientists have not provided timely characterization if a given month at a given time of year is unusual (in terms of cloudiness and/or types of cloud) compared to the preceding 30 or 40 years. However, CIMSS researchers will soon be able to focus in on regions, like Wisconsin, every month and assert how it compares, whether it is in-family or out-of-family, with the 40-year record for that particular month and that region. This capability will enhance and renew researchers’ interest in studying global change on a smaller scale.

Beyond regional trend analyses in real time, engaging global climate scientists in incorporating the CIMSS global cloud climatology dataset into their models offers exciting prospects for seeing the role of clouds in climate change.

Paul Menzel
Jean Phillips

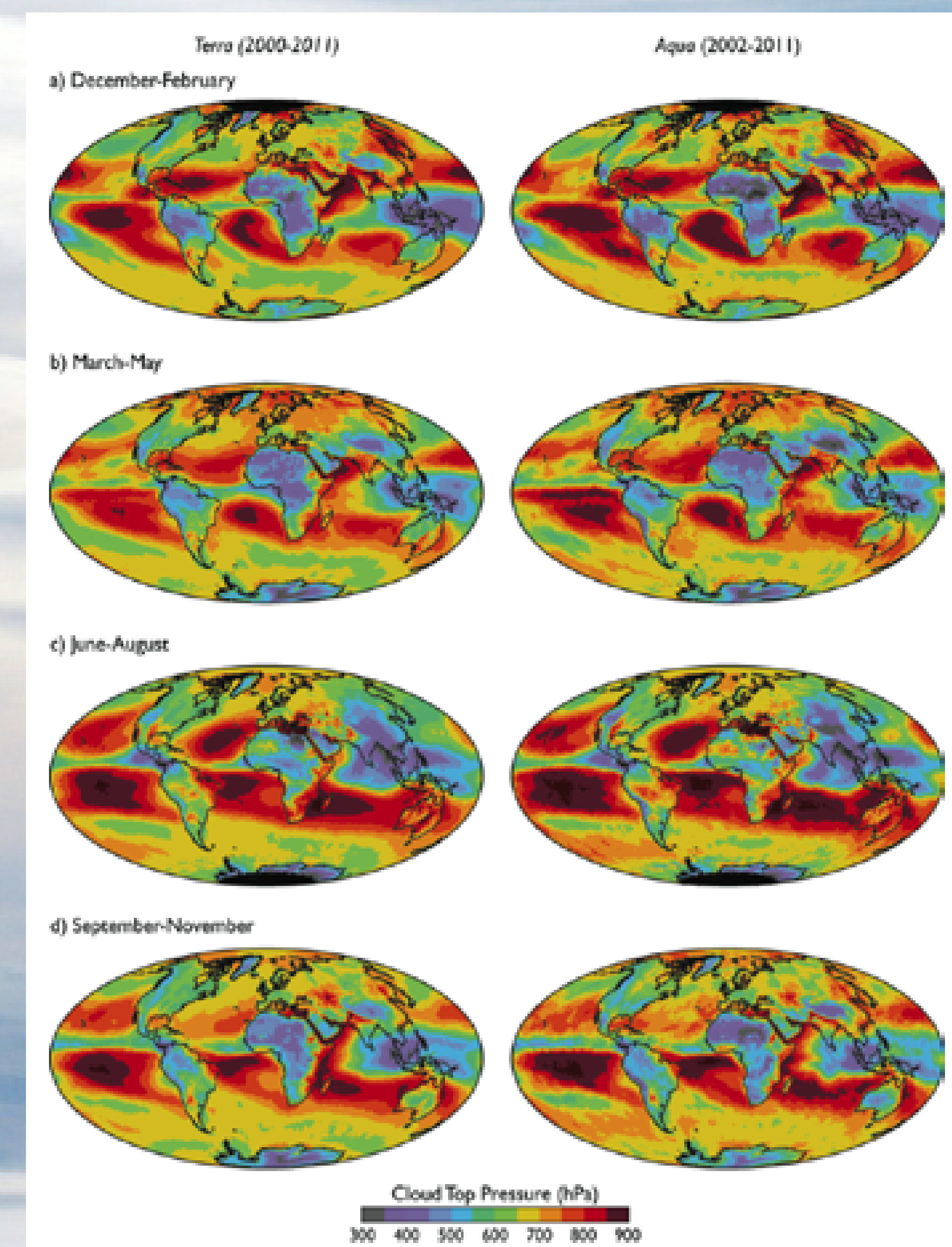


Figure 2: MODIS seasonal mean daytime cloud top pressure from Terra (2000-2011) and Aqua (2002-2011) for (a) December-February, (b) March-May, (c) June-August, and (d) September-November (from King et al., 2013: Spatial and Temporal Distribution of Clouds Observed by MODIS onboard the Terra and Aqua Satellites. Accepted for publication by IEEE Transactions on Geoscience and Remote Sensing).

Capturing the most detailed ever views of weather on Uranus

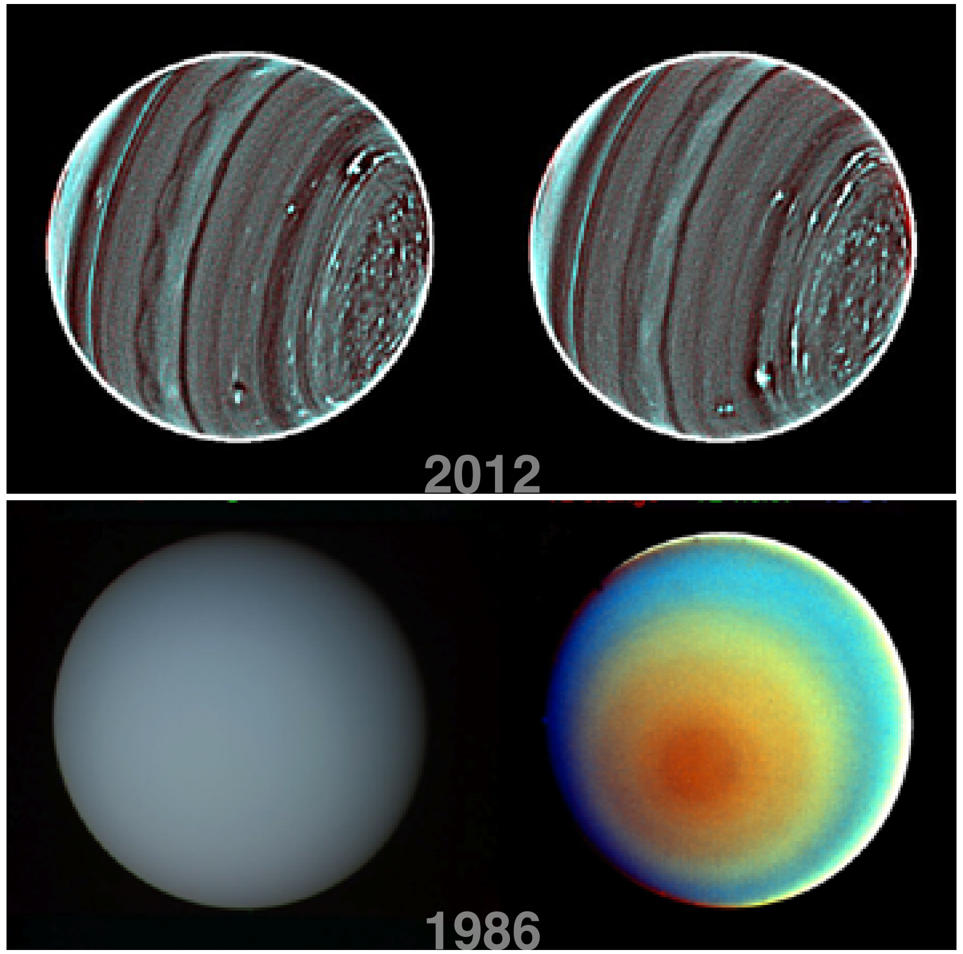
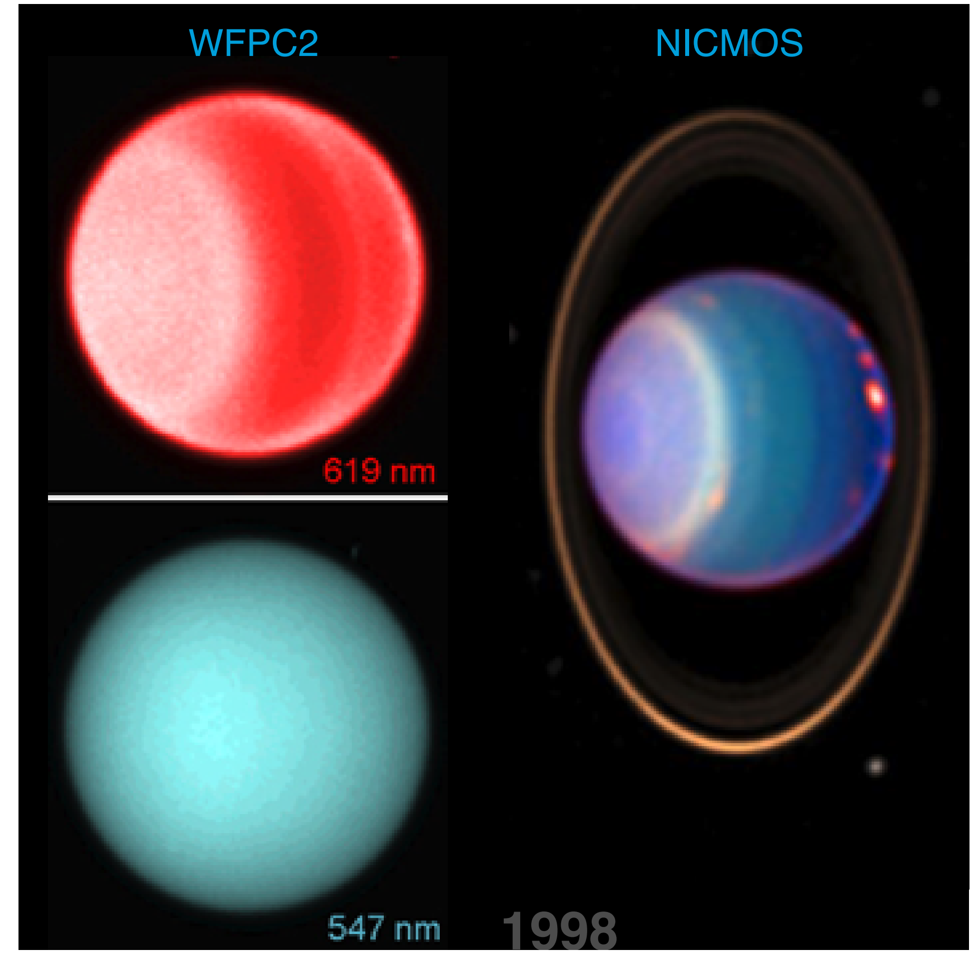


Figure 1 (top): Keck views of opposite sides of Uranus on 25-26 July 2012, the mostly richly detailed images of Uranus ever obtained.

Figure 2 (bottom): Voyager's images of Uranus revealed little detail.



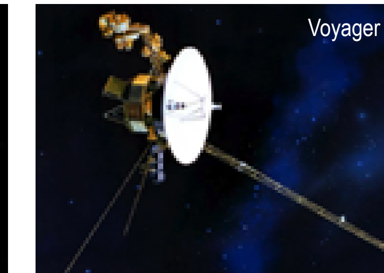


Figure 3: Comparing Voyager's wavelengths (WFPC2) with Hubble's near-IR wavelengths (NICMOS).

" Even better than obtained by the one mission that actually visited the planet "

Courtesy Rick Peterson / W. M. Keck Observatory

This July 25th and 26th, we got lucky. Pat Fry and I were on the big island of Hawaii, with control of the Keck II telescope, the largest and best telescope on the planet. We were using a near-infrared camera and a special observing method to obtain what we hoped would be the most detailed images ever taken of Uranus. Not only did we get time on this fabulous telescope, we also got the weather to cooperate by being clear and stable. This was our third attempt to get these very special images and this was the first time everything was falling into place. The result of the effort, which was not obvious until a great deal of image processing was done, is shown in Fig. 1. These turned out to be "the most richly detailed images of Uranus ever obtained from Earth." That's what our press release said. But, we could have said "ever obtained" period. They are better than the Hubble Space Telescope could get and even better than obtained by the one mission that actually visited the planet.

In 1986 Voyager 2 took close up images of Uranus after traveling 8.5 years to get there. Its pictures were disappointingly bland, as can be seen in Fig. 2. Only 8 discrete cloud features could be found after searching through hundreds of images. As Jim Pollack, a prominent Voyager Imaging Team scientist put it, "Uranus was almost a photometrically perfect planet," containing only the slightest of blemishes (discrete clouds). Uranus is so far away (30 Astronomical Units, or 2.8 billion miles) that it takes sunlight 4 hours to get there (it takes 8 minutes to get to Earth). At that distance the solar flux is 900 times weaker than at Earth's orbit (only 1.6 W/m2). It is no surprise then that Uranus is a very cold place. Not only is solar heating so small, but Uranus has no detectable internal heat. So perhaps it really ought to be a dull place with so little energy available to power its weather.

But the real reason Voyager 2 didn't see much is that its cameras didn't look at the right wavelengths. Uranus has a deep atmosphere with a relatively small burden of aerosols, which makes its atmosphere very bright at visible wavelengths, where Rayleigh scattering is seen with little absorption. The atmosphere would be white if it weren't for the absorption of methane gas at red wavelengths, making the planet appear blue-green in visible light. Voyager was trying to do the equivalent of imaging cirrus clouds on a background of snow and ice – a very tough job.

However, at the longer near-infrared wavelengths (2-5 times the length of visible light waves), methane absorption gets much stronger and the bright atmosphere turns very dark, while the cloud particles retain most of their reflectivity because they are so much larger than molecules. This produces a tremendous increase in contrast, making it possible to see what was previously invisible. Hubble images in 1998 proved this effect very nicely by taking images at both Voyager wavelengths using WFPC2 (Wide Field Planetary Camera 2) and at near-IR wavelengths using NICMOS (Near IR Camera and Multi-Object Spectrometer). Check the comparison in Fig. 3.

But even Hubble could only show the more prominent cloud features because it did not have enough spatial resolution. Its limitation is the small size of its telescope. (In space, resolution is proportional to telescope diameter and Hubble's was only 2.4 meters compared to Keck's 10 meters).

The problem with the Keck telescope was that it was not in space. It sat underneath much of the earth's atmosphere. Because the atmosphere has time-dependent density variations due to atmospheric turbulence, its refractive index (ability to bend light) also varies both in space and time. This causes incoming light rays to have slightly different angles of entry at different points within the aperture of the telescope, and this makes them end up at different places on the focal plane, resulting in a blurred image. The effect of this bending can be seen by looking across a hot blacktop road on a sunny summer day. The shimmering and wavering image of what's on the other side of the road is similar what atmospheric turbulence does to images obtained with large ground-based telescopes.

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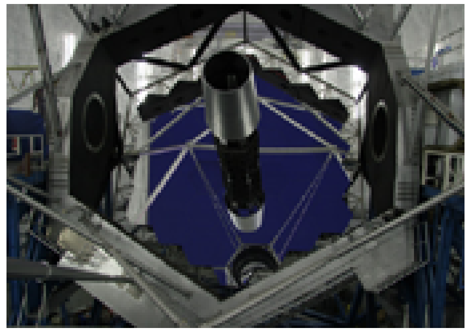
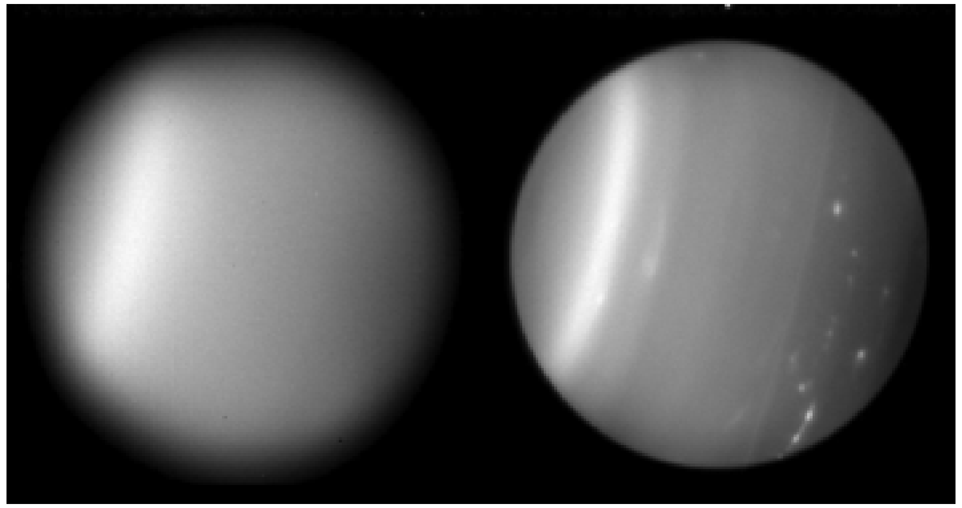


Courtesy W. M. Keck Observatory

Figure 4: Keck II telescope's adaptive optics improved resolution by a factor of 10.



Fortunately, the Keck telescope has a way to deal with these annoying effects of atmospheric turbulence. It's called Adaptive Optics. It deserves to be capitalized and praised and put on a pedestal and worshipped. It is truly amazing. It has the ability to effectively launch the telescope into space without actually leaving the ground. By using a deformable mirror that corrects for different incoming angles at different parts of the mirror, it can improve the resolution by a factor of 10 in linear dimensions, so that in place of one original resolved pixel one can now resolve 100! An example of what this means is shown in Fig. 4.

But even that is not good enough. There are many cloud features on Uranus that can't be seen in a single image because they have very low contrast even at these high-contrast near-IR wavelengths. They need higher signal to noise ratios to be resolved. Normally, taking a much longer exposure solves the problem. The signal increases linearly with exposure time while the noise, which contributes randomly in both directions only grows as the square root of the exposure time. So after 100 times the exposure, the signal to noise ratio improves by a factor of ten. The problem with doing that however is that Uranus rotates during the exposure (360 deg in 17.24 hours). We can't really expose for much longer than 1-2 minutes without smearing the feature longitudinally by an unacceptable amount.

That means that we have to take short exposures to prevent smear, remap them to a planet-fixed coordinate system so that the planet's rotation is removed, then average them together, and finally remap them to the original disc view. This is the procedure we follow for short averaging periods, using eight 2-minute exposures. But to obtain the exceptional images in Fig. 1, we averaged even more images together, about 100 in each case. But to do that we had to also correct for the displacement caused by atmospheric winds, which reach speeds up to 250 m/s (560 mph).

" We've had trouble in the past of finding features to track near the equator. That's one of the motivations for trying to get better quality images."

One final step is needed to see the subtle features. We need to enhance their contrast relative to that of large-scale variations of brightness. This is done by subtracting a smoothed image from the original image, a process that is essentially a high-pass filter. After this high-pass filtered image is produced, its contrast can be boosted by a factor of 25 so that the low contrast features become visible. That is what is shown in Fig. 1. Once the subtle features have this large contrast boost, we can also add back the original image so that the large-scale latitude variations can be seen as well as the small-scale features. That is shown below, with a latitude-longitude grid, but it does reduce the visibility of the more subtle features. The color is based on two different filters that we used. One, the Hcont filter, samples a window region at 1.59 microns, where methane absorption is minimized. Images in this filter are given the red channel. The other is the H filter, which is centered at about the same wavelength, but has a wider bandpass that samples both weak and fairly strong methane absorption. That is given to the blue and green channels. The composite makes high and dense clouds look white, high and thin clouds look blue-green, and deep clouds look red.

So what do we see in these exceptional images? Starting with the north pole, which is at about the 4 o'clock position, and reaching down to about 55 deg N, we see what looks like a field of cumulus convective features. These do not seem to be very dense clouds, however, and they are relatively large (typically about 450 km across). This was not expected because we had never seen any such features in the south polar region. And the last time we had good looks at the south was in its early southern fall (1997-2003).

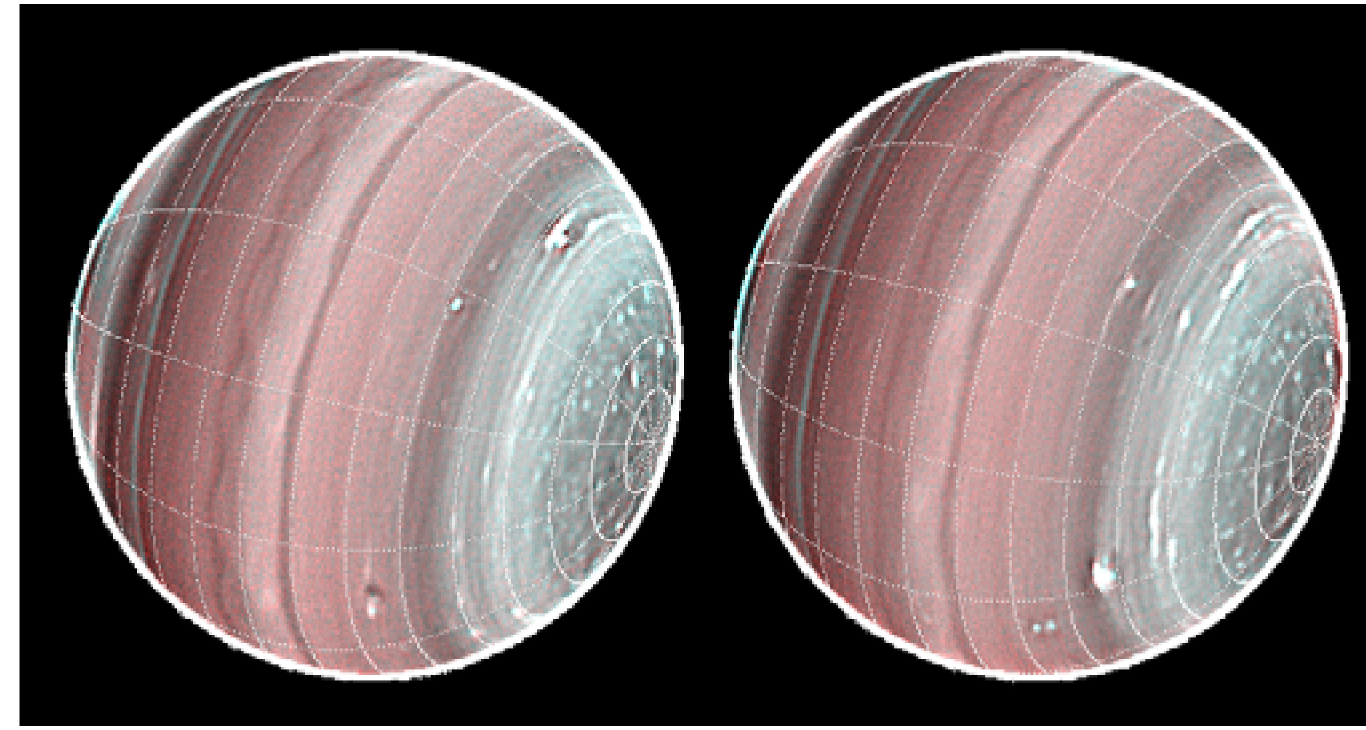


Figure 5: High-pass filtering, with contrast and color adjustments, reveals much more detail.

Now we are looking at late northern spring. (The last equinox was in 2007.) So this seems to be a seasonal effect. It appears that a long winter of cooling promotes polar convection and a long summer of heating suppresses it. That makes sense if the cooling and heating occur above the region that is convective. We are expecting that this "convective" activity might continue for a while as the northern hemisphere moves into summer, but we expect it to eventually dissipate as summer heating intensifies. We also expect the formation of a polar cap cloud.

The streaky bands we see from about 55 deg N to 45 deg N, have been commonly seen, though not with as much detail as obtained in Fig. 1. We don't know why these bands exist, nor why they are streaky. There is no obvious feature in the zonal wind profile that correlates with these structures.

Another feature of note is the small dark spot with bright companion clouds. The dark spot is thought to be a vortex, and because the surrounding wind shear is anti-cyclonic, the vortex is probably also an anti-cyclone (rotating opposite to the direction of planet rotation).

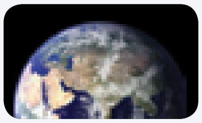
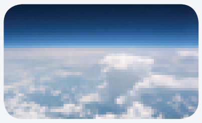
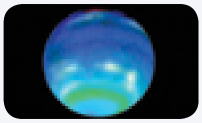
Just south of the equator we see a never-before-seen-on-Uranus scalloped wave feature, which is similar to what is seen in regions of high horizontal wind shear (rapid change of wind speed with latitude). The strange thing about this is that we have never seen any evidence of large wind shears near the equator. But lack of evidence doesn't necessarily imply lack of wind shear. We've had trouble in the past of finding features to track near the equator. That's one of the motivations for trying to get better quality images.

You might wonder what these clouds are made of. There is no direct measurement that can tell us for sure. But we do have a good idea. Spectral observations show that the main condensable in the upper troposphere is methane (the main component of natural gas). At the pressures and temperatures of the brighter clouds (about 1 bar and 77 Kelvin) it seems certain that they are mainly made of frozen methane particles. The deeper clouds, at pressures near 1.6 bars, are less certain. H_2S (the gas responsible for the smell of rotten eggs) is a good candidate for these clouds, along with ammonia for the even deeper layers.

We also got more high quality images in August, and again in November, the latter in collaboration with Imke de Pater, from UC-Berkeley. Most of these data sets used two filters with different sensitivity to methane absorption (H and Hcont again), so that we can estimate the pressure levels of these clouds. With all these high-quality data sets in hand, we are hoping to produce significant improvements in defining the circulation and weather features on Uranus. We also will continue to make observing proposals to track the seasonal changes that we expect to occur on this distant planet. We only have to wait until 2028 for the next northern summer solstice.

Larry Sromovsky

through the atmosphere

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