CIRA

Connecting Models and Observations

WALTER SCOTT, JR.
COLLEGE OF ENGINEERING
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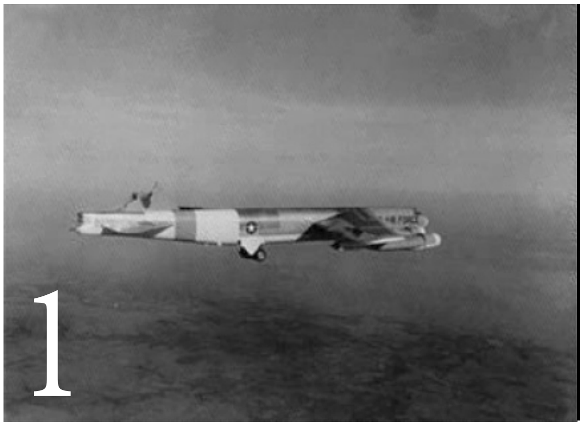
Contents



Editor and Designer: Ivy Jones
Cover Photo: Moonrise over the limb of the Earth captured by GOES-16 and processed at CIRA.

From the Director's Desk

February 16, 2018

It is with great pleasure that I can get back to our Magazine that took a bit of an hiatus for us to concentrate on our new Web pages that we will unveil very shortly. One of the articles featured in this issue relates to turbulence forecasts being worked on by our Jung-Hoon Kim at the Aviation Weather Center in Kansas City. As I travel these days, I often find myself going from the HRRR forecast site put up with help from CIRA folks in Boulder, to the Wind and Turbulence forecast put out with help from CIRA folks in Kansas City, and back. My wife accuses me of being a nerd but I actually find that it is extremely cool to work in an environment where we actually produce forecasts that matter to so many people.

The magazine also highlights CIRA's role in releasing the first light images from the new GOES-16 satellite. The true color imagery that is seen so often was developed by CIRA and NESDIS folks in Fort Collins, not only to look good, but to aid forecasters in that it is always easier to recognize atmospheric features when they correspond to what our own eyes are used to seeing. While it is not trivial to synthesize a green channel when the instrument does not actually measure the band, the resulting imagery is truly spectacular. Aside from the new "Loops of the day" that we display on our CIRA Web (almost) every day, you can also see the imagery if you log into our "Slider" web page at http://rammb-slider.cira.colostate.edu. It loops over the last few hours of global imagery and lets you experiment with some of the channels and channel comparisons.

Also in this issue is a bit about work that was done with the solar eclipse and the GOES-16 imagery. It is actually amazing to see this natural experiment in what amounts to a very rapid sunset and sunrise and how it impacts the atmospheric stability and clouds.

In looking back over our previous issues of the CIRA magazine, it has indeed been quite a while since our last magazine and the comments I made last time about a joint project between CIRA folks in Fort Collins and Boulder to improve forecasts for the Winter Olympics in Pyeongchang are no longer in the planning stages but have transitioned to operations as we watch the Olympics unfold. GOES-R has become GOES-16, JPSS has also launched and is providing great new data, and we are now awaiting the launch of GOES-S. Some of the people we are welcoming in the back pages of this issue have in fact been with us for quite some time. We welcome everyone – or perhaps I should say, "We're glad you joined us".

Chris Kummerow

Chris Kummerow,
CIRA Director

Upper-Level Wind and Turbulence Forecasts for Aviation Operation

Jung-Hoon Kim

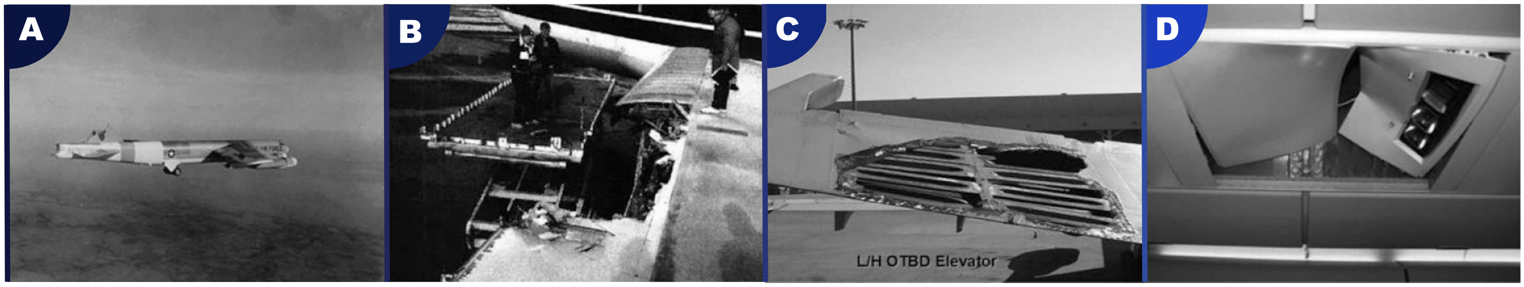
*CSU/CIRA in affiliation with NOAA/NWS/NCEP/Aviation Weather Center,
Kansas City, MO, USA*

Due to the global economic boom, the volume of global air transportation for travel and business has increased dramatically in recent decades. For the safety and efficiency of aircraft operations, better predictions of aviation weather hazards such as turbulence, icing, convective clouds, and gust winds become more important. Without precautions, encountering unexpected turbulence at cruising altitudes (about z = 5-12 km) is dangerous for crews and passengers-who are most likely unbuckled. This often results in discontinued service, in-flight injuries, structural damage, and flight delays (Fig. 1).

There are three categories for turbulence directly affecting aircraft depending on its generation mechanisms: Clear-Air Turbulence (CAT), Mountain-Wave induced Turbulence (MWT), and Convectively Induced Turbulence (CIT). CAT happens frequently near upper-level jet and frontal system (Fig. 2). Above and below the jet core, strong vertical wind shear generates shear-induced Kelvin-Helmholtz Instability (KHI). On the cyclonic shear side of jet streak, upper-level frontogenesis along with tropopause folding can cause CAT. This is sometimes detected by a boundary of cold and dry air intrusion into the jet stream in water vapor and ozone channels of satellite data. On the anticyclonic shear side of jet stream or anticyclonic curvature near the exit region of the jet stream, spontaneous imbalance of geostrophic wind can cause initial instability and emit inertia gravity wave via the geostrophic adjustment, which also causes CAT in theses areas.

Flow across the mountain generates mountain wave due to the complex terrain. The flow propagates vertically and then breaks down near tropopause, where background stability and wind are changing dramatically, creating strong vertical mixings and turbulence (Fig. 2). Near this breaking region of mountain wave, wind and temperature gradients are dramatic due to the mixings, directly affecting cruising aircraft. Overshooting deep convection can generate CIT, which is classified to in-cloud CIT and out-of-cloud CIT (Fig. 2). Strong updraft and downdraft are the cause inside of CIT. This means it may be viable to avoid with this use of airborne radar or detecting visual cloud boundaries. But, out-of-cloud CIT can occur when convectively induced gravity waves propagate both horizontally and

Figure 1



A USAF B-52H tail damage caused by an encounter with severe mountain wave turbulence on January 10, 1964. Photo from White Eagle Aerospace History Blog.
B In-flight engine separation of Japan Airlines 747-121 that occurred in extreme turbulence after takeoff from Anchorage, AK on March 31, 1993.
C MD-11 damage to left outboard elevator upper skin due to encounter with severe in-cloud turbulence over the Pacific in January 2004.
D Damage to overhead as a result of an unbuckled passenger in a B737 during severe turbulence event over Korea in April 2006. Photo from Sharman and Lane (2016).

vertically, sometimes several hundred and thousand kilometers away from the main convection. So, even if an aircraft is detouring away from the cloud boundary and is confirmed to fly in clear-air condition, it could still encounter strong CIT due to this reason.

Aviation Turbulence Forecasting System

Operational Numerical Weather Prediction (NWP) model output is being used to diagnose turbulence likelihood. The strategy is to compute a set of diagnostics that identify regions of strong spatial gradients of wind and temperature. To take into account many turbulence generation mechanisms, as well as uncertainties in the NWP model forecasts, a combination of several turbulence diagnostics from the different mechanisms and from the different ensemble forecast members is essential. It is also more reliable than using a single diagnostic or simple rule-of-thumb predictor. This method is a sequence of four different processes, which is summarized as follows.

1) A high-resolution NWP forecast model is used to produce 3D meteorological data at a given valid time. Time-lagged ensembles are constructed from the forecast fields for different lead times but are valid at the same time. Other ensemble forecasts from different initial perturbations, model physical parameterization, and stochastic approach are also available to take into account NWP uncertainty.

2) To infer turbulence likelihood, multiple diagnostics for CAT, MWT, and CIT are calculated. These turbulence diagnostics are primarily based on combinations of horizontal and/or vertical gradients of 3D meteorological variables from the NWP model.

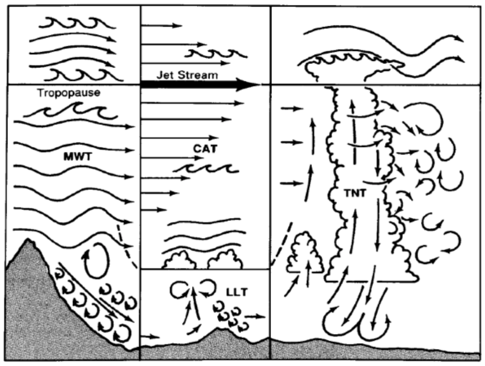
3) The calculated diagnostics from the ensemble forecasts are mapped into an equivalent Energy Dissipation Rate (EDR) to the 1/3 power. This atmospheric turbulence metric is the International Civil Aviation Organization (ICAO) standard for aircraft reporting and thus provides a convenient basis for verification.

4) All EDR-scale metrics are combined as an ensemble mean to produce both deterministic and probabilistic turbulence forecasts using different weights as a function of turbulence forecasting skill of each diagnostic against observed EDR data (Fig. 3).

Wind and Turbulence Forecasts for Air-Traffic Management

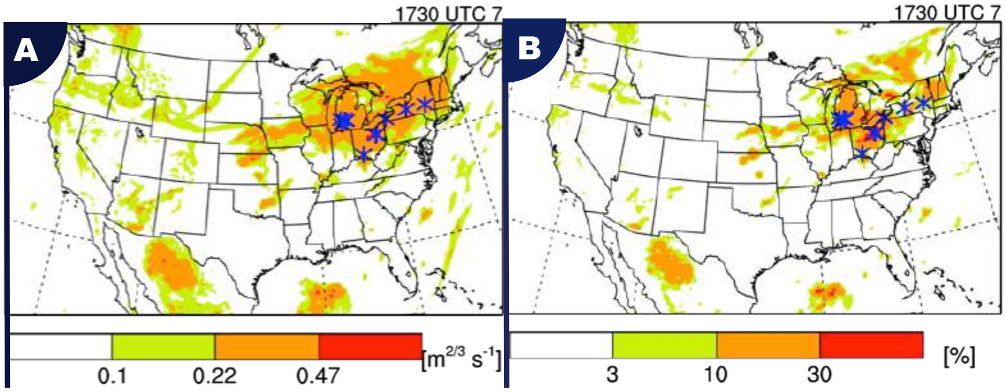
For maximum efficiency, airliners tend to optimize flight routes with wind, which is called the Wind-Optimal Route (WOR). In this way, they can minimize total travel time, total fuel consumption, and aviation-induced anthropogenic emissions. However, the WOR may not be viable if CAT is embedded near upper-level jets or if any kind of turbulence potentially blocks the proposed flight path. Therefore, it becomes necessary to develop routes that minimize both fuel

Figure 2



Aviation turbulence classifications. Photo by Lester (1994).

Figure 3



A Deterministic ensemble EDR and
B Probabilistic ensemble EDR for Severe-Or-Greater (SOG) intensity turbulence at 30,000 ft (about z = 9.5 km) from 3-km HRRR valid at 1730 UTC 7 Sep 2012.

use and the potential for turbulence encounters, which is the concept of Lateral Turbulence Avoidance Route (LTAR). For the same case in Fig. 3, the WOR and LTAR applications were developed to show the utility of wind and turbulence forecast products for route planning applications in Fig. 4.

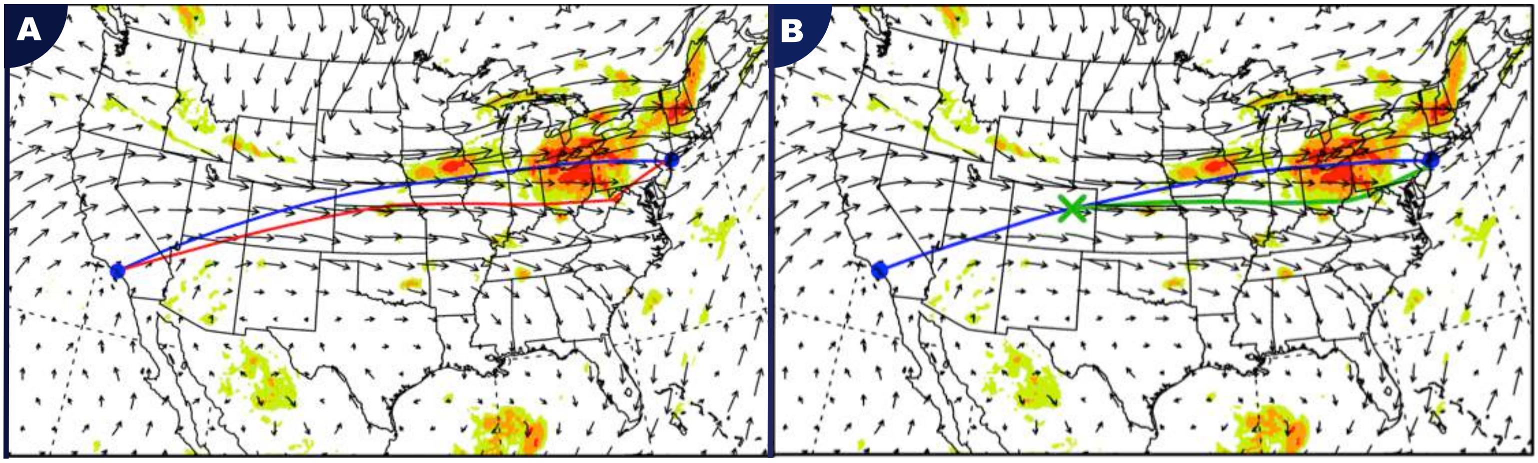
Using the WOR while ignoring turbulence maneuvers, the WOR from Los Angeles (LAX) to New York (JFK) experiences areas of turbulence (orange-red shadings) for 52 minutes (blue line in Fig. 4A). Since the potential turbulence area along this WOR is vertically deep (not shown), laterally deviating around the turbulence areas seems the best option to avoid turbulence. To laterally detour around these potential areas of turbulence from the departure airport (LAX), an aircraft would incur 16 min (6.7%) more travel time to fly to its destination (JFK) (red line in Fig. 4A) than following the WOR (blue line). Delaying the horizontal maneuver would result in a savings of 10 minutes in total flight time if the maneuver were delayed 1.5h after leaving LAX with up-to-date forecast data (green line in Fig. 4B). Saving 10 minutes is significant because this reduction is roughly equal to about 160km less flying distance and about 760 kg of fuel savings. So, in this case, it would be the best scenario to take the WOR for 1.5-hr from LAX, and then take the LTAR to get to JFK safely and efficienty.

Impact of NWP Model to Turbulence Forecast

In spite of recent increases in operational NWP model resolution, end users from commercial airlines have been reporting that turbulence forecasts tend to overestimate smooth-to-light turbulence to be light-or-stronger turbulence, especially over the western US mountainous region. On 2 November 2015, unrealistically large areas of light-or-stronger turbulence were predicted by the WRF-RAP (Weather Research and Forecast Rapid Refresh)-based operational turbulence forecast system over the western U.S. mountainous regions. This prediction was not supported by available observations as shown in Fig. 5A.

Pursuing this forecasting error further, it is found that the operational WRF-RAP system does not include topography smoothing in the model initialization in order to include more realistic small-scale terrain features. This appears to create unrealistically large areas of light-or-stronger turbulence due to the spurious small-scale mountain wave features induced by the unfiltered small-scale energy of the topography (see Fig. 5A). In this study, the WRF model for the same configuration in the operational WRF-RAP system on the 2 November 2015 case is conducted with additional terrain smoothing. So, the impact of additional terrain smoothing in the initialization of the NWP model on the

Figure 4



A Ensemble EDR forecast (shading) with horizontal wind vectors using 4.5-hr forecast data and Wind-Optimal Routes (WORs, blue line) and Lateral Turbulence Avoidance Route (LTAR, red line) at 30,000 ft from Los Angeles international airport (LAX) to John F. Kennedy international airport (JFK).
B Image B is the same as Image A except for the LTARs (green line) initiated 1.5-hr after departure with up-to-date 2.5-hr forecast data.

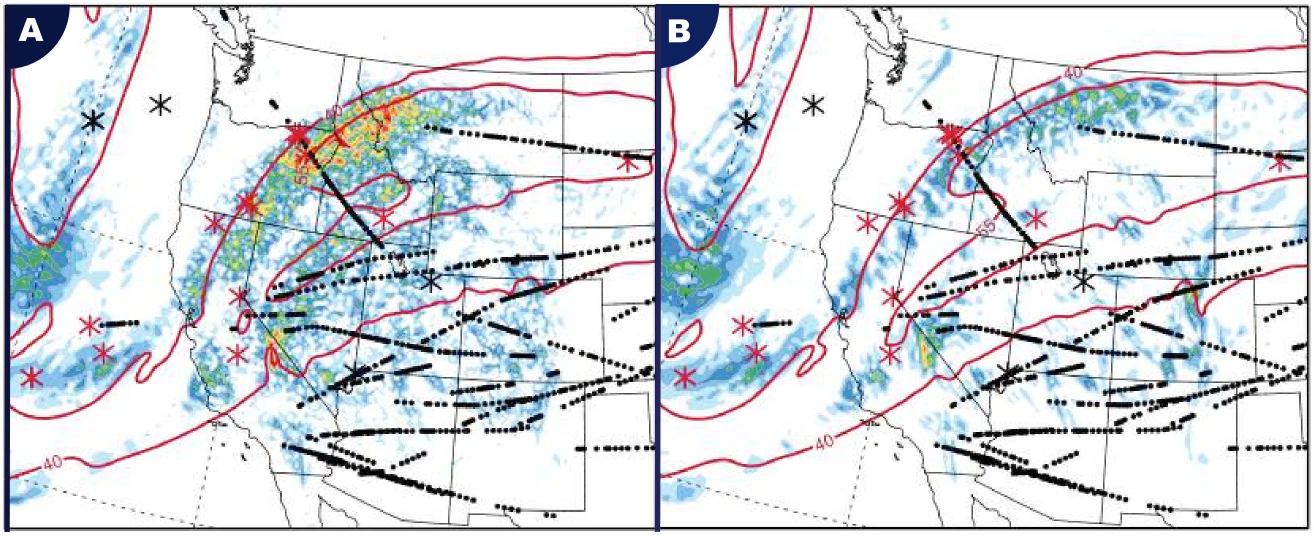
subsequent reduction of light-or-stronger turbulence forecasts over mountainous regions is examined.

The WRF-RAP model forecasts a high potential of stronger upper-level turbulence but only smooth-to-light turbulence reports were received from on-board turbulence measurements from commercial aircraft. From the FFT analyses along the high mountain region in the CTL, high energy is included in the smaller scales ($\sim 2\Delta x$) of the spectrum (not shown), which is unphysical and should be damped out by numerical smoothing accordingly. Additional smoothing experiments along with additional terrain-averaging in the model initialization show that the large and mesoscale energy spectra are almost identical to the WRF-RAP. However, here is a significant reduction of energy near the grid scale ($\sim 2\Delta x$) (not shown), which reduces turbulence forecast intensity over that region (Fig. 5 Img. B). This is consistent with the observational data for this case. The results strongly suggest that the additional terrain averaging is beneficial in the initialization of the NWP model to reduce spurious wave-like patterns trapped in each model column, and would enhance the performance of operational turbulence forecasts.

Impact of Climate Variability to Aviation Operation

The variation of wind-optimal transatlantic flight routes and their turbulence potential is investigated to understand how upper-level winds and large-scale flow patterns can affect the efficiency and safety of long-haul flights. In this study, the wind-optimal routes (WORs) that minimize the total flight time by considering wind variations are modeled for flights between John F. Kennedy International Airport (JFK) in New York, New York, and Heathrow Airport (LHR) in London, United Kingdom, during two distinct winter periods of abnormally high and low phases of North Atlantic Oscillation (NAO) teleconnection patterns (Fig. 6). Eastbound WORs approximate the JFK–LHR great circle (GC) route following northerly shifted jets in the +NAO period (Fig. 6A and C). Those WORs deviate southward following southerly shifted jets during the -NAO period (Fig. 6D), because eastbound WORs fly closely to the prevailing westerly jets to maximize tailwinds, which is shifted southward (Fig. 6B). Westbound WORs, however, spread meridionally to avoid the jets near the GC in the +NAO period to minimize headwinds (Fig. 6E). In the -NAO period, westbound WORs are north of the GC because of the southerly shifted jets (Fig. 6F). Consequently, eastbound

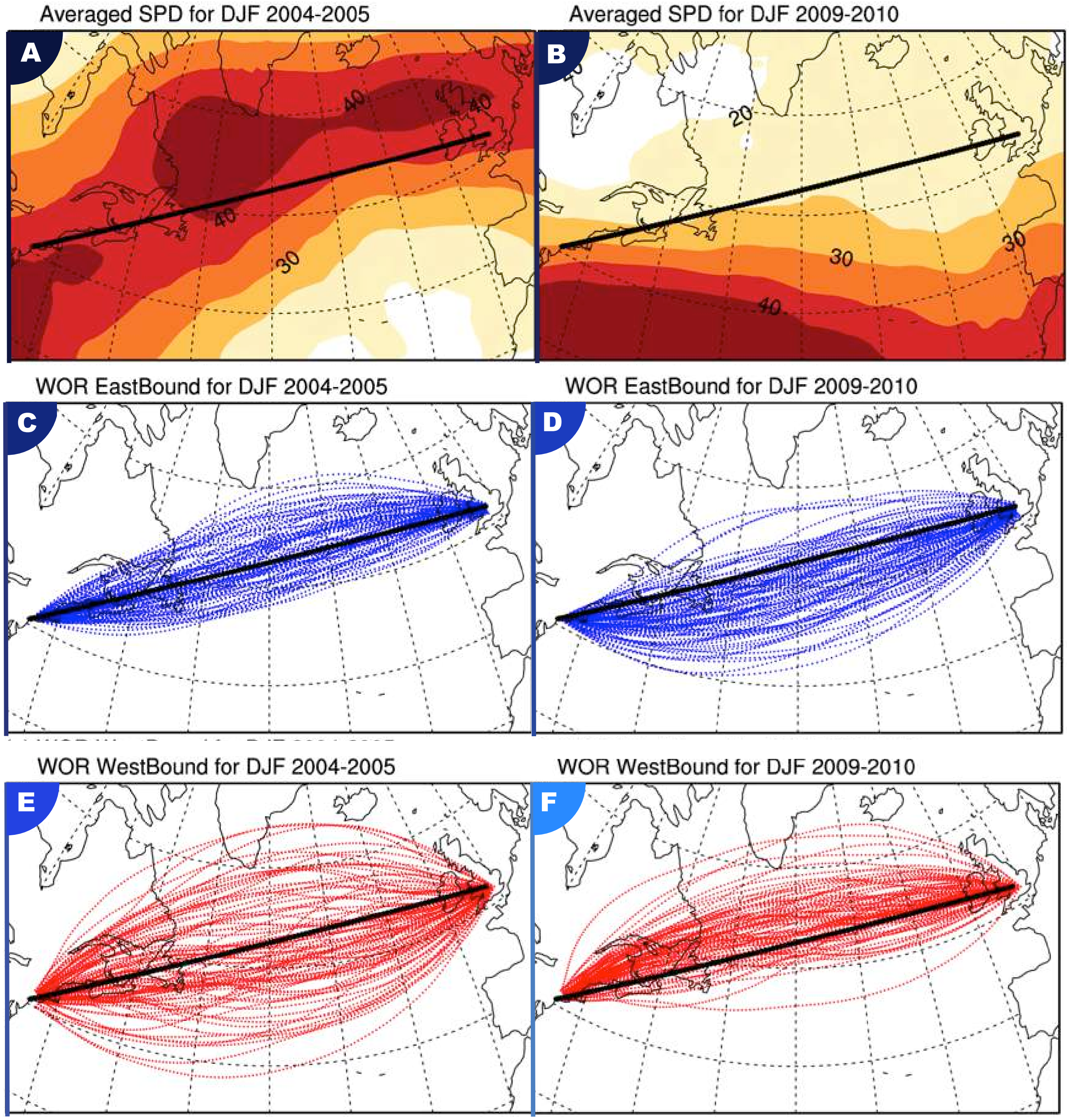
Figure 5



Color shadings of the Eddy Dissipation Rate (EDR; $m^{2/3}\ s^{-1}$) turbulence forecasts red contours of horizontal wind speed (40 and 55 $m\ s^{-1}$) valid at 18 UTC 2 November 2015 from (Image A) WRF-RAP and (Image B) smoothing experiments. Observed in situ EDR and smooth pilot reports (PIREPs) corresponding to EDR < 0.05 at ± 2-hr around 18 UTC and ± 2,500 ft around 35,000 ft are depicted as black dots and asterisks, respectively. Light intensity of in situ EDR and PIREPs observations corresponding to 0.05 < EDR < 0.1 are indicated with red asterisks.

WORs are faster but have higher probabilities of encountering clear-air turbulence than westbound ones. This is because eastbound WORs are close to the jet streams, especially near the cyclonic shear side of the jets in the northern (southern) part of the GC in the +NAO (-NAO) period. This study suggests how predicted teleconnection weather patterns can be used for long-haul strategic flight planning, ultimately contributing to minimizing aviation's impact on the environment.

Figure 6



A and B Averaged horizontal wind speed (shadings from 10 to 50 $m\ s^{-1}$ with 10 $m\ s^{-1}$ interval) and variations of the WORs at 250 hPa between JFK and LHR for
C and D Eastbound (blue-dotted lines) and
E and F Westbound (red-dotted lines)
during (a, c, e) December 2004 – February 2005 and (b, d, f) December 2009 – February 2010. Great Circle between JFK and LHR is depicted as a reference (black line) in all plots

THE GREAT AMERICAN ECLIPSE OF 2017:
FROM THE GROUND UP AND FROM ORBIT DOWN

From antiquity through the present day, the experience of a total solar eclipse is one that excites, terrifies, and inspires the human imagination. Alone among the planets of our solar system, the Earth and its Moon are the only planetary-satellite pair that features the correct geometry for the Moon to completely shut out the disk of the Sun as viewed from the surface of the Earth. Far from rare, total solar eclipses occur at least twice every year, during periods when the orbital plane of the Moon around the Earth aligns with the plane of the Earth orbiting the Sun. When a new Moon happens during these eclipse seasons, some part of the Earth will be treated to an eclipse, generally lasting from between one and six minutes.

> What is rare, however, is the occurance of a prolonged total solar eclipse over a heavily populated region.

What *is* rare, however, is the occurrence of a prolonged total solar eclipse over a heavily populated region. On August 21, 2017, a total solar eclipse occurred over the continental United States, beginning near Portland, Oregon and continuing across the country on a line extending through Idaho, Wyoming, Nebraska, Kansas, Missouri, Kentucky, Tennessee, northern Georgia, and North and South Carolina, exiting the coast near Charleston, South Carolina (Fig. 1). The first coast-to-coast total solar eclipse in the United States since 1918, the 70-mile-wide path of totality covered an estimated 12 million people. And with CIRA right next door to that path, more than one member of the CIRA family made a trip to see the event of a lifetime.

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Safety, of course, is key when viewing any eclipse – even the faintest sliver of direct sunlight can be blinding to eyes. As part of an outreach campaign to CIRA employees, 500 pairs of eyeglasses that make direct solar viewing safe were ordered and distributed to CIRA staff and families, as well as to students, faculty, and staff of the Department of Atmospheric Science. With eclipse fever hitting the country, finding verified-safe viewing glasses became difficult, with online vendors occasionally shipping less-than-safe products. Leveraging CIRA's ability to contract with scientific supply companies, the CIRA family was able to stay safe and confidently enjoy the view (Fig. 2).

Protected from the dangers of the direct Sun, CIRA was prepared when the eclipse rolled around. Monday, August 21st may not have been the most productive day for research at CIRA, but nevertheless, significant science was done that day. Many researchers and staffers, unable to make the trip to the path of totality, nevertheless enjoyed the experience of interesting optical effects as the eclipse progressed. One such example is crescent shadows: when light is projected through small openings (such as between the leaves of trees) the effect is one of a pinhole camera, projecting a mostly focused image of the circular Sun on the ground below. When taken in aggregate, the blended projections create a repetitive, monotonous pattern that makes for our everyday experience. During a solar eclipse, however,

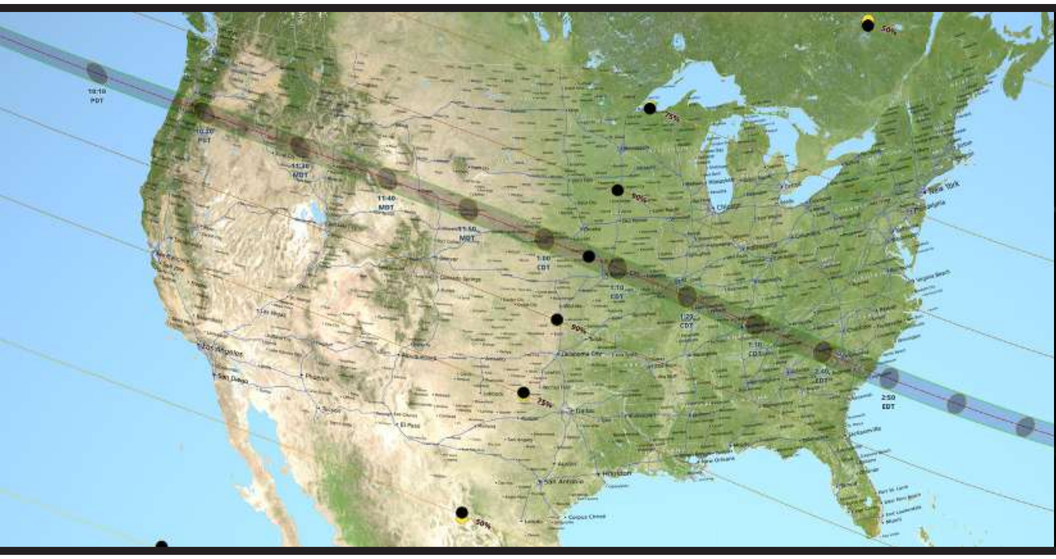


Figure 1: The solar eclipse path of totality through the U.S.

Figure 2: Winona Rogers safely experiencing the eclipse.

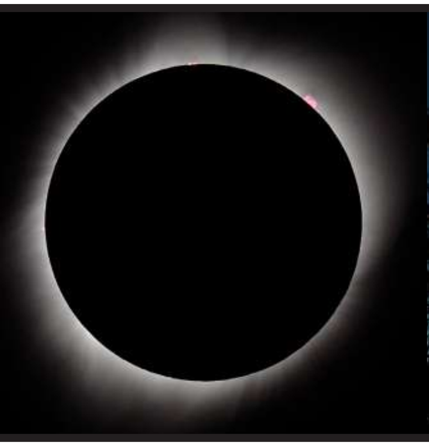


Figure 5: A close-up of totality.

Figure 6: Totality.

Figure 7: The shadow of the moon over eastern Kansas in the GeoColor product developed at CIRA.

the pinhole projection is not of the solar disk, but rather projects the crescent of light from the occluded disk of the Sun. As the eclipse progresses this effect becomes more pronounced (Fig. 3), making for an interesting view of the Sun.

the Sun itself existed only as a ghostly corona, easily visible to the naked eye, surrounding an impossibly black ball in the sky.

For members of the CIRA family who made the trip to the path of totality, still more interesting phenomena awaited them. The experience of totality is not easily described- as relayed by several CIRA researchers, the following phenomena were widely mentioned. As the eclipse progressed, colors took on flatter, less familiar tones. The sky, while still bright, began to lose its luster while the sensation of the Sun on one's skin disappeared entirely, an eerie sensation during otherwise bright sunshine. As totality approached, a 360-degree sunset appeared, reddening the horizon all around, and then finally, the Moon obscured the Sun completely. The sky darkened suddenly as though a rheostat had been turned rapidly towards 'off', or as if inside a theater whose house lights have been dimmed too rapidly. At this point, the Sun itself existed only as a ghostly corona, easily visible to the naked eye, surrounding an impossibly black ball in the sky. For several minutes this situation held, before reversing back through the stages – house lights come up, skin begins to feel

Figure 3: Crescent shadows created by pinhole projection.

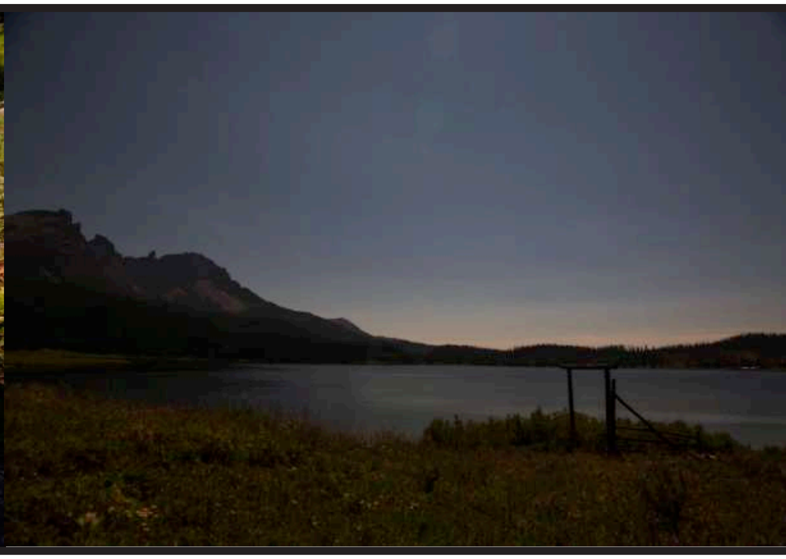


Figure 4: A 360-degree sunset at totality.

the heat of the Sun, colors return, shadows lose their crescent shape. Figures 4, 5, and 6 show some of the experiences had by CIRA researchers in the field.

Meteorologically speaking, a total eclipse of the sun has interesting effects – temperatures were reported to drop as much as fifteen degrees Fahrenheit from some CIRA observers, and local winds paused without apparent reason. As the heating of the Sun was interrupted, the impacts were felt on cloud formation as well. Finally, depending on where the observer was located, totality was either heralded by the hoots and hollering of the assembled crowds drawing closer as it approached, or by an eerie silence as birds and insects paused for the moment of darkness. From above the Earth, the nation's newest geostationary weather satellite, GOES-16, had a stunning view of the eclipse as well, and CIRA researchers, even while out in the field, were capturing the data available from the ABI aboard GOES-16. Figure 7 shows an example of the shadow of the Moon over eastern Kansas as seen in the GeoColor product developed at CIRA. The GOES-16 Loop of the Day was widely used by the media to demonstrate the capabilities of the nation's newest weather satellite. And aside from just taking pretty photos, researchers were able to utilize the high temporal resolution of GOES-16 data to discover some interesting atmospheric phenomena related to the eclipse.

Meteorologically speaking, a total eclipse of the sun has interesting effects – temperatures were reported to drop as much as fifteen degrees Fahrenheit from some CIRA observers, and local winds paused without apparent reason.

Figure 8 shows a four-panel image of cumulus cloud development over northern Arkansas prior to and after the passage of the umbra. Prior to totality, fair-weather cumulus development, powered by sunlight, was in full swing – as the shadow from the eclipse arrived, the source of energy powering the thermals driving the cumulus field was cut off, and the cloud field collapsed. For several minutes after the passage of the umbra the skies over Arkansas were clear, until eventual heating from the Sun became strong enough to allow redevelopment of the cloud field. Other cases may yet be found in examining GOES-16 data from the eclipse.

The next total solar eclipse will be in July of 2019, and will be visible to the inhabitants of central Chile and Argentina. Surplus eclipse glasses, collected from CIRA staff, will be donated to schools in this region to allow students in South America to enjoy the same safe view seen by CIRA personnel during the 2017 eclipse. The next total solar eclipse over the United States will occur in April of 2024, and CIRA will again be at the ready to study this unique natural phenomenon – either in the field, or from orbit.

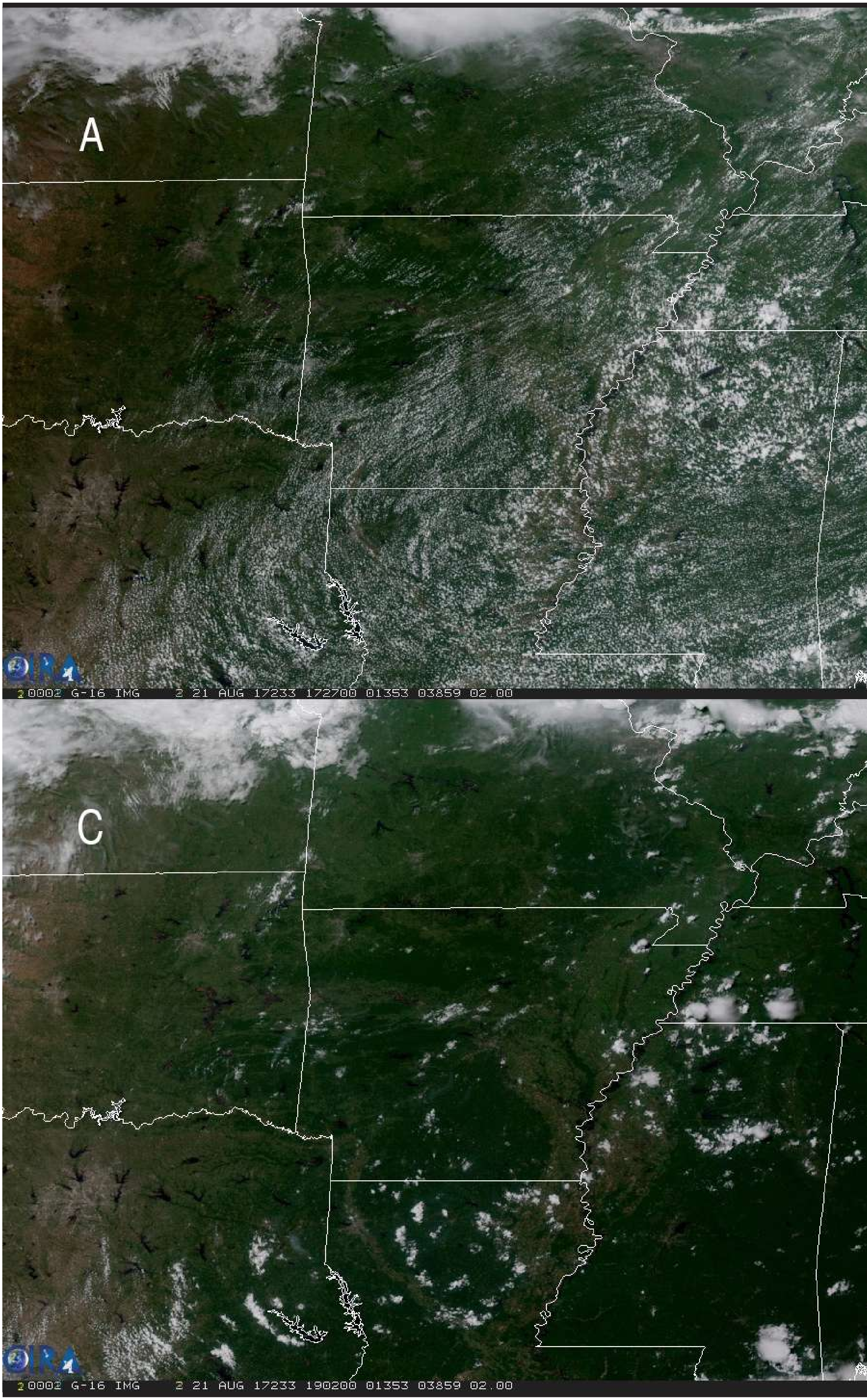
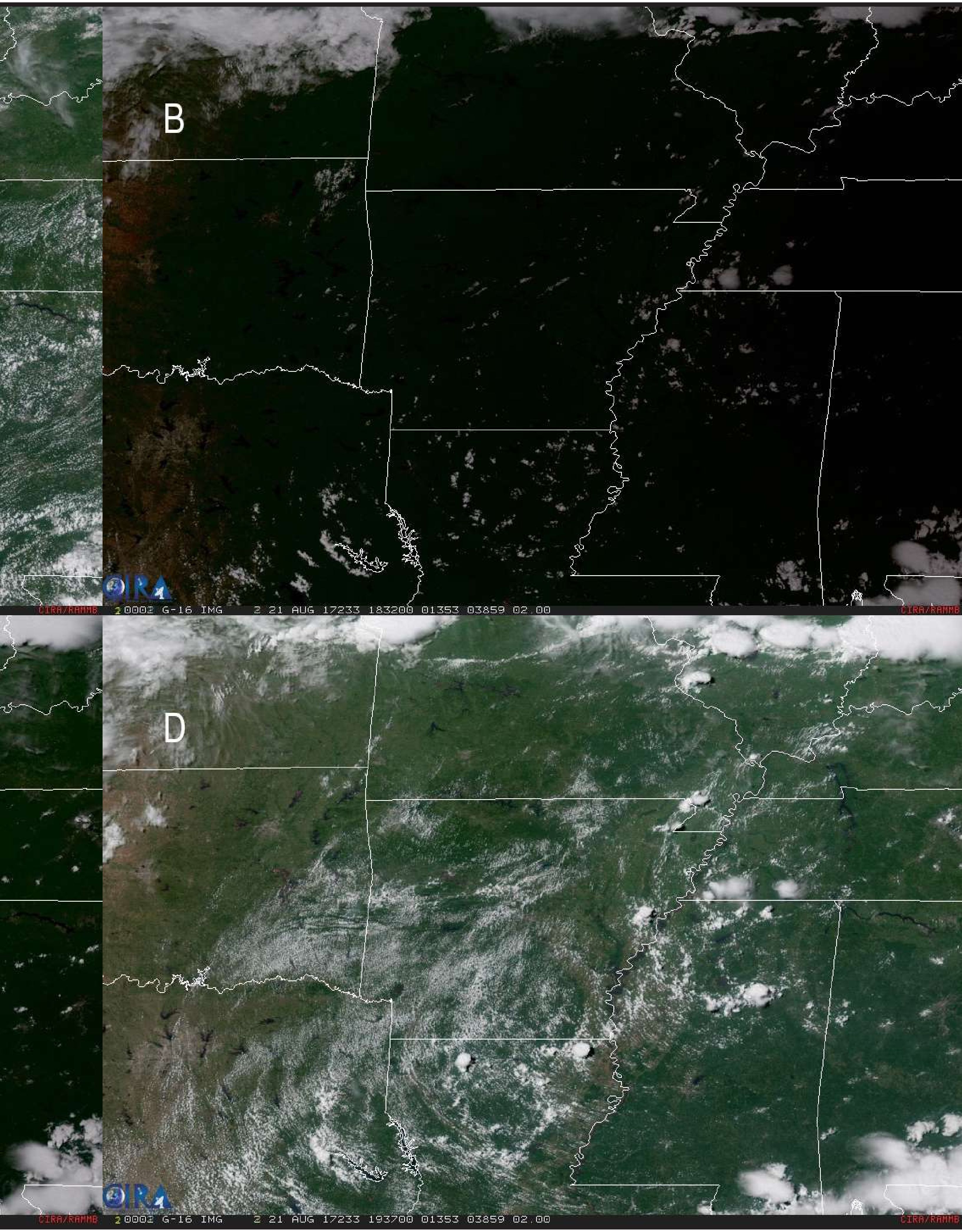


Figure 8: This four-panel image shows the development of cumulus clouds over northern Arkansas prior to and after the eclipse. In the upper-left (A), prior to eclipse; upper-right (B), during eclipse, lower-left (C), immediately after eclipse, lower-right (D), about an hour after the eclipse.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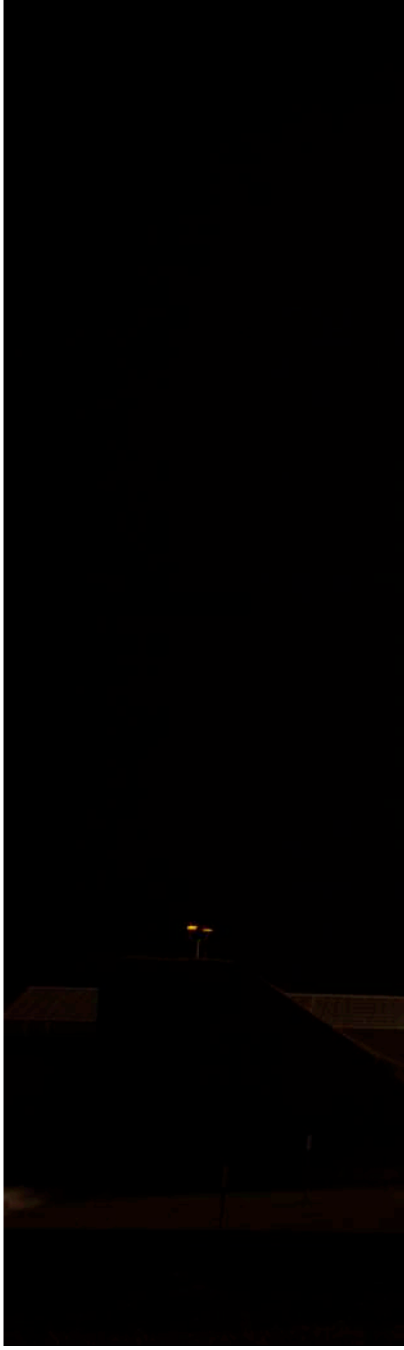
GOES-R Launch Success-

A New Era in Geostationary Observations

Matt Rogers

As Hurricane Matthew bore down on the Atlantic coast of Florida in mid-October, 2016, technicians hurriedly secured space launch complex 41 at Cape Canaveral Air Force Station. Meanwhile, across the Banana and Indian rivers separating the Cape from mainland Florida, the nation's newest geostationary spacecraft, GOES-R was being battened down in a secure facility. As the storm churned the waters to the east of the Space Coast, the previous generation of GOES spacecraft provided forecasters with information about the path of Matthew while launch technicians monitored the impact of the storm on the launch facility.

After the storm passed, technicians conducted comprehensive checks of the pad and transfer facilities before transferring the GOES-R spacecraft to the top of an Atlas V rocket for its 22,000-mile trip to orbit. Fast-forwarding a few weeks - November 19th, 2016 was the first day of a new era for satellite observations for the United States, when the GOES-R spacecraft launched from Cape Canaveral. Once the spacecraft completed its multi-day trip to geostationary orbit, unfurled its antennae and solar panels, and started radioing back confirmation that all systems were 'go', the former GOES-R became GOES-16, the newest and most sophisticated geostationary Earth observation platform ever flown.



GOES-R lifts off from Cape Canaveral Air Force Station aboard an Atlas V Rocket.

GOES-16 – Instruments and Capabilities

The Geostationary Operational Environmental Satellite (GOES) program dates back to 1975, and has long provided arguably the most important spaceborne instruments for forecasting the weather. GOES-13 and -15, launched in 2006 and 2010, respectively, had been shouldering the load as the easternmost and westernmost weather observing satellites for the nation using their third-generation GOES-N instruments. These venerable spacecraft see the Earth at five different colors of light – one channel covers visible light, and four channels look at different forms of infrared light.

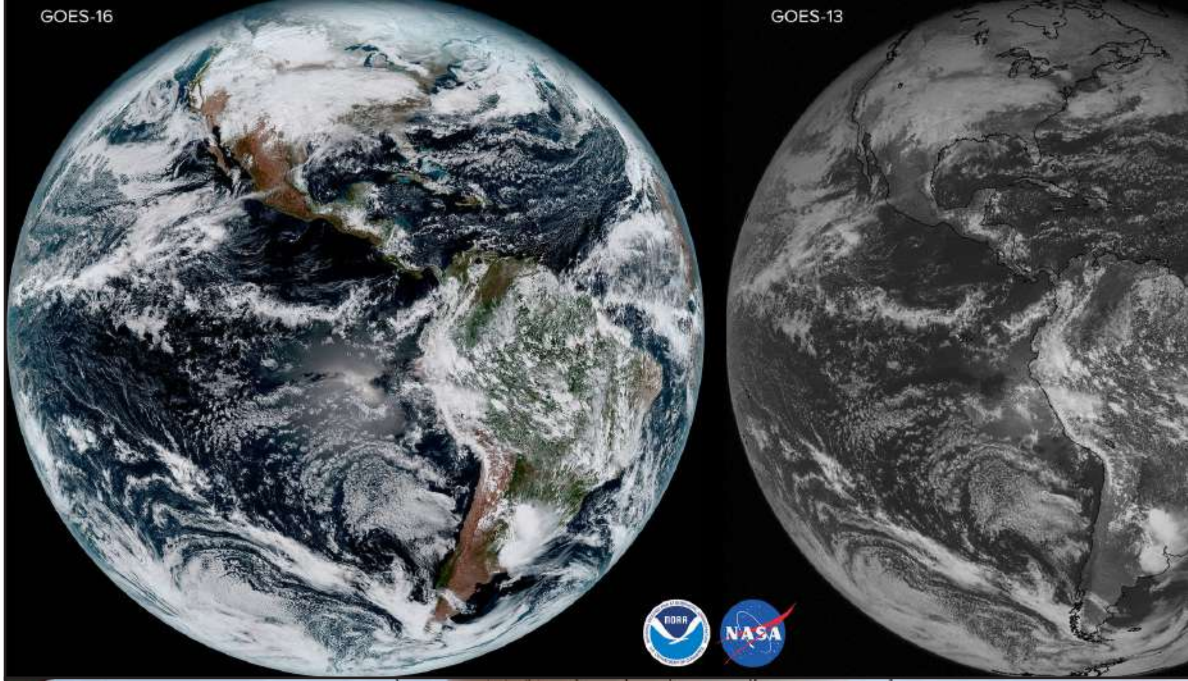
The next-generation ABI instrument that launched on GOES-R will provide *sixteen* channels, giving us far more information about the Earth, including for the first time in over fifty years, a true-color picture of the planet (compared to the black-and-white imagery we get from the current GOES series). Moreover, the new instrument sees the Earth at four times the resolution, and will scan the planet much more quickly than the 15-minute resolution of the old series – sometimes scanning features of interest (such as hurricanes or thunderstorms) at one-minute resolution. A huge number of satellite-derived products are under development or are being tested using the vastly enhanced data made available by the ABI. This includes the GeoColor product developed here at CIRA, as well as other useful products giving information about atmospheric moisture depth, cloud-phase information, distinguishing cloud cover from surface snow/ice, dust measurement, and more.

Also on-orbit is the Geostationary Lightning Mapper (GLM) instrument – a first-of-its kind instrument that collects the transient, faint signals of lightning from geostationary orbit, giving researchers real-time information about where severe storms are forming. Lightning flashes are highly correlated with strong updrafts in cumulonimbus clouds, and counting the flash rate tells researchers and forecasters alike where the strongest updrafts are occurring. This information can be used to improve tornado detection and forecasting, update cloud information for ingest into numerical weather prediction models, provide information about severe storms in locations where radar coverage is weak or unavailable (especially due to outages) and many other features.

Getting There – The Long, Strange Trip to Geostationary Operations

Many of the satellites familiar to readers of CIRA Magazine are polar-orbiting satellites, the bulk of which reside in sun-synchronous low-Earth orbits. Circling the Earth at altitudes between 400-500 miles, launching these satellites requires precision and timing to boost the spacecraft to exactly the right place in space, but not much time: these spacecraft are typically close to their final orbits within a couple hours or so from launch.

Geostationary orbit is a special place, where the speed of a spacecraft circling the Earth matches exactly the rotation of the Earth below it, giving the



Left:
Comparison images of GOES-16 (left) and GOES-E (right) on January 15th, 2017.

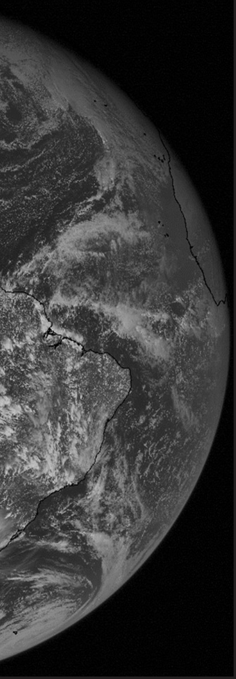
Right:
Three-dimensional computer rendering of GOES-R on top of the Centaur booster over the Bahamas.

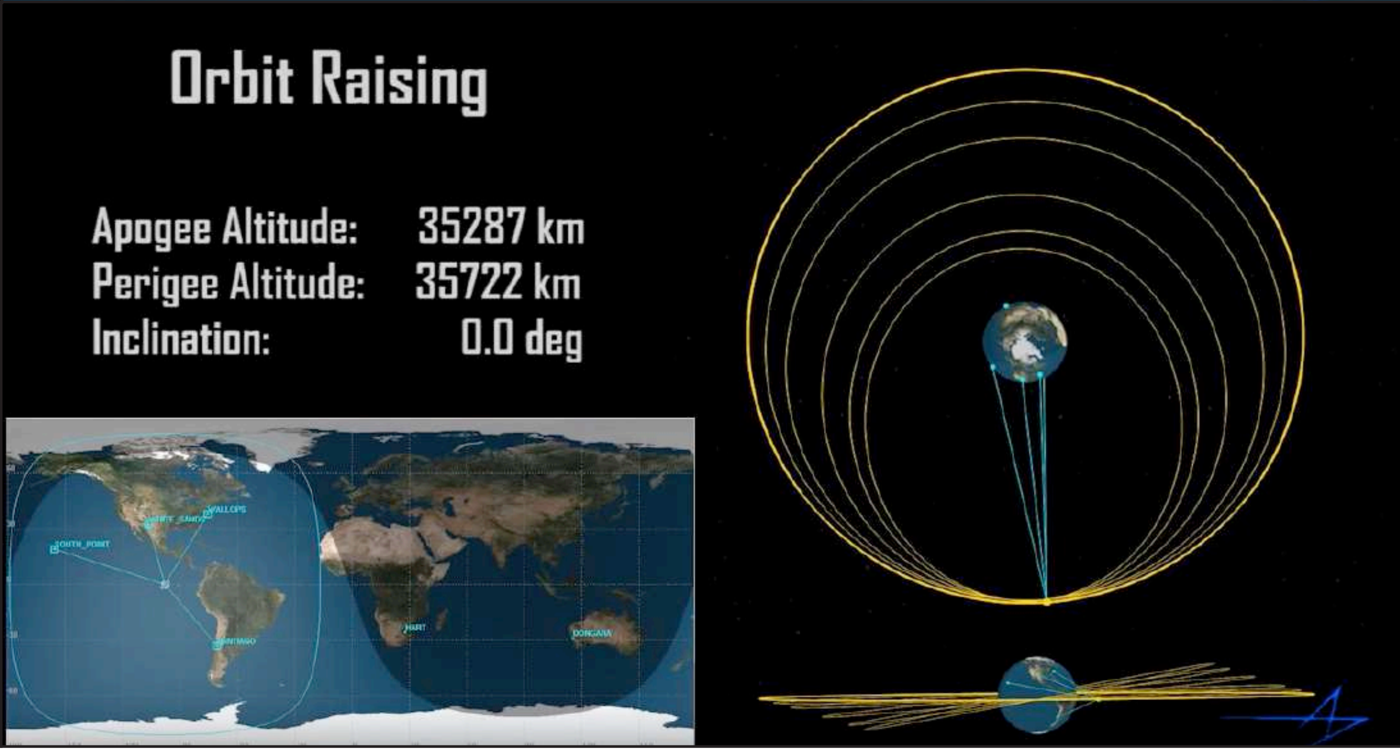
Left:
The loading stack for GOES-R.

Right:
Diagram of orbit raising burns to take GOES-R from low-Earth orbit to its final geostationary orbit.

satellite the ability to 'stare' at the same side of the Earth continuously. This orbit location occurs at 22,236 miles, or more than 40 times further than the more familiar low-Earth orbits. To get there, GOES-16 was launched on top of its own booster rocket, a Centaur stage that burned three times on-orbit to help get GOES-16 to a temporary orbit 21,926 miles from home. After separating from its booster stage, GOES-16 made several timed, short burns over the next eight days to boost itself to its current orbit, over the equator at 89.5ºW longitude.

After a long coast, where launch and atmospheric gases were allowed to boil away, GOES-16 took its first image on January 15th, 2017, and preliminary data from both the ABI and GLM instruments starting working its way Earthward. After final checkout, GOES-16 will change its orbit again, one last time, to a position over 75ºW longitude, and will assume the duty of GOES-EAST in November of 2017. Although, the presence of active tropical storms for GOES-16 to study may delay the shift in orbit.





What's Next – GOES-S, CIRA, and the Future of Geostationary Observations

The next satellite in the GOES-R series, GOES-S, is currently being assembled in the Lockheed plant in Colorado and is scheduled to launch sometime in 2018. Carrying an ABI and GLM instrument, GOES-S will likely take over the role of GOES-WEST after a successful launch. Along with its sister satellite GOES-16 and cousin Himawari-8 and -9 spacecraft, GOES-S will add to the growing family of high-definition geostationary satellites already on-orbit. As part of planning for GOES-S, CIRA is working with NOAA and NASA to develop products and training materials to get data from the GOES-R-series spacecraft into operational use. Software to quickly view GOES-16 data and products useful for severe and tropical storm forecasting, aviation planning, and everyday weather forecasting are being tested and validated on GOES-16 for use with all satellites of the series. The future is now for satellite researchers, and CIRA is leading the way in a new world of sixteen-channel wonder.

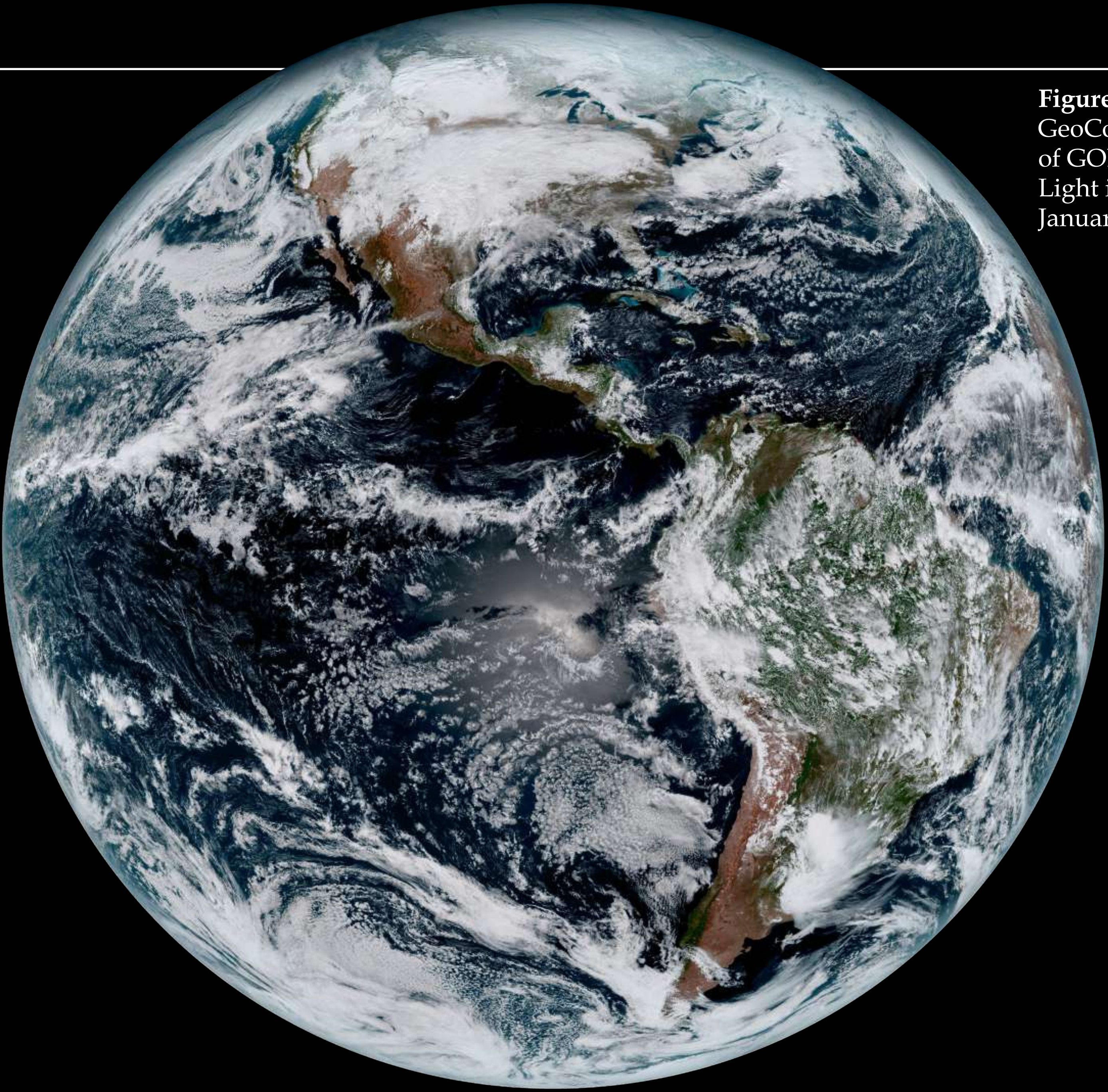


Figure 1: GeoColor image of GOES-16 First Light image from January 15th, 2017.

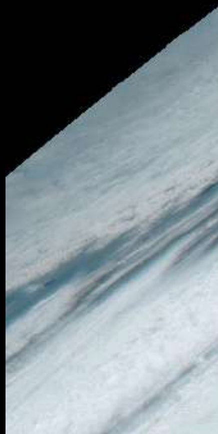
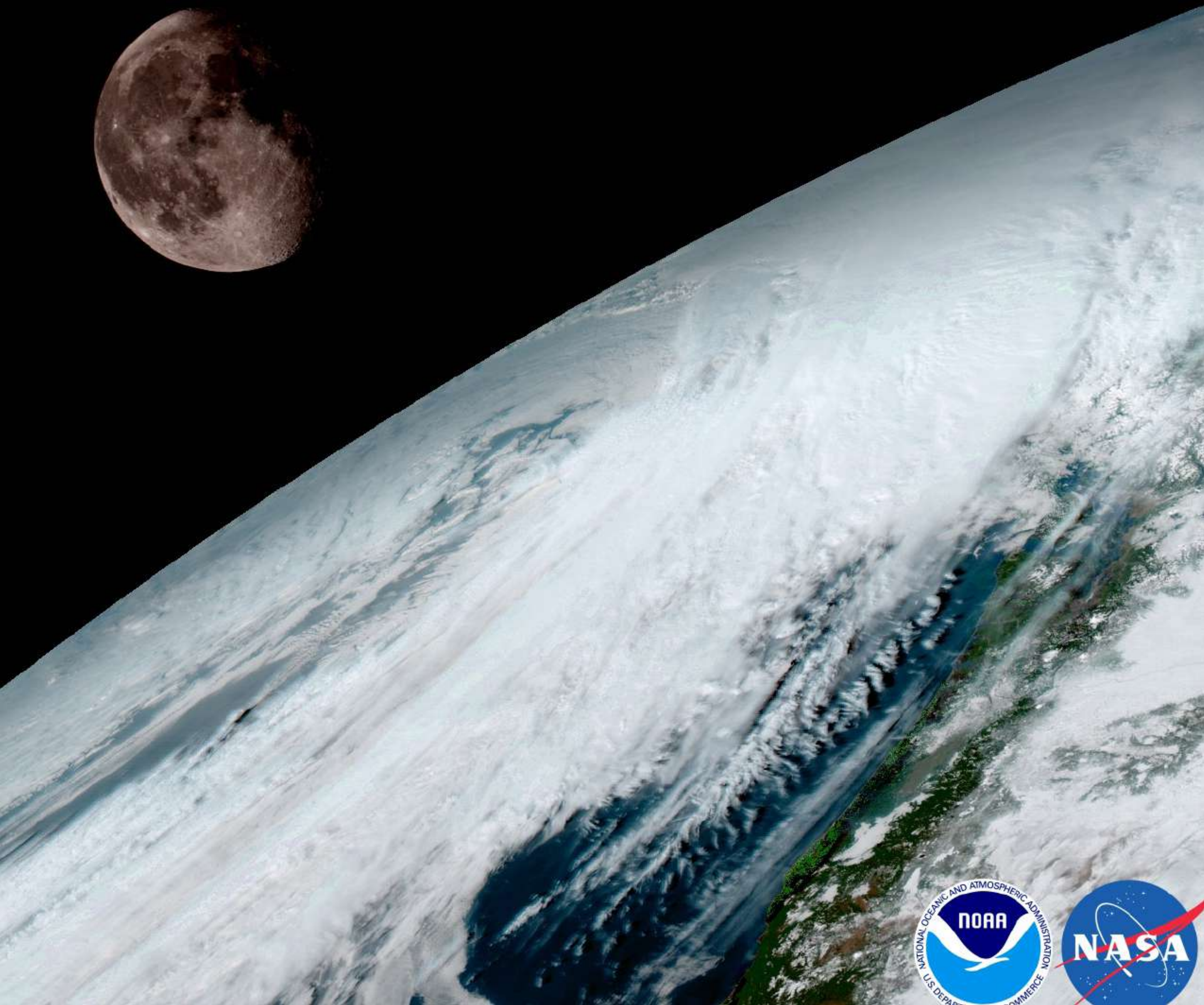


Figure 2: Moonrise over the limb of the Earth captured by GOES-16 and processed at CIRA.

GOES-R First Light Imagery: NOAA and CIRA Make a Splash



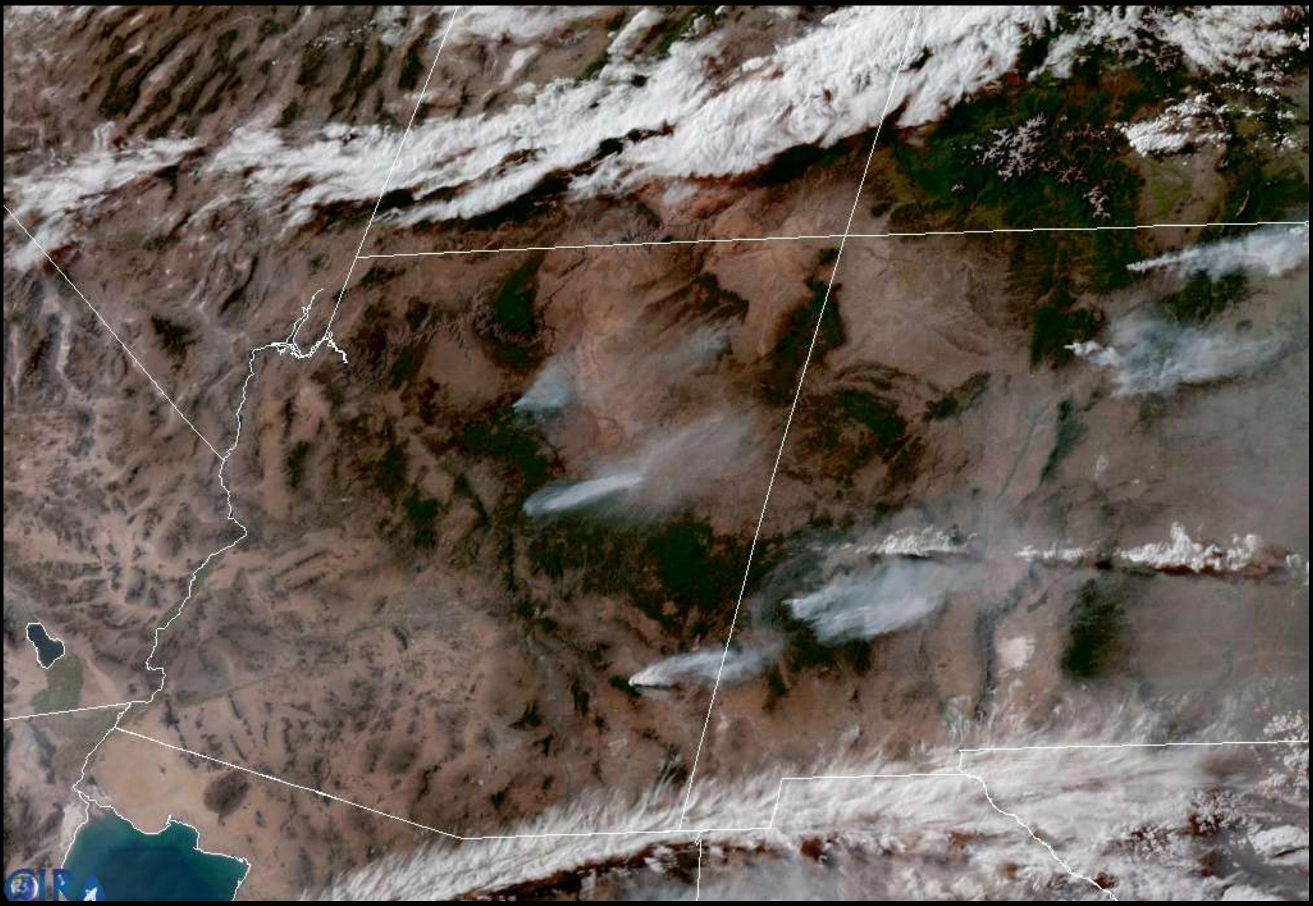


Figure 3:
Plumes from wildfires over the desert southwest in this GeoColor image from GOES-16 on June 16th, 2017.

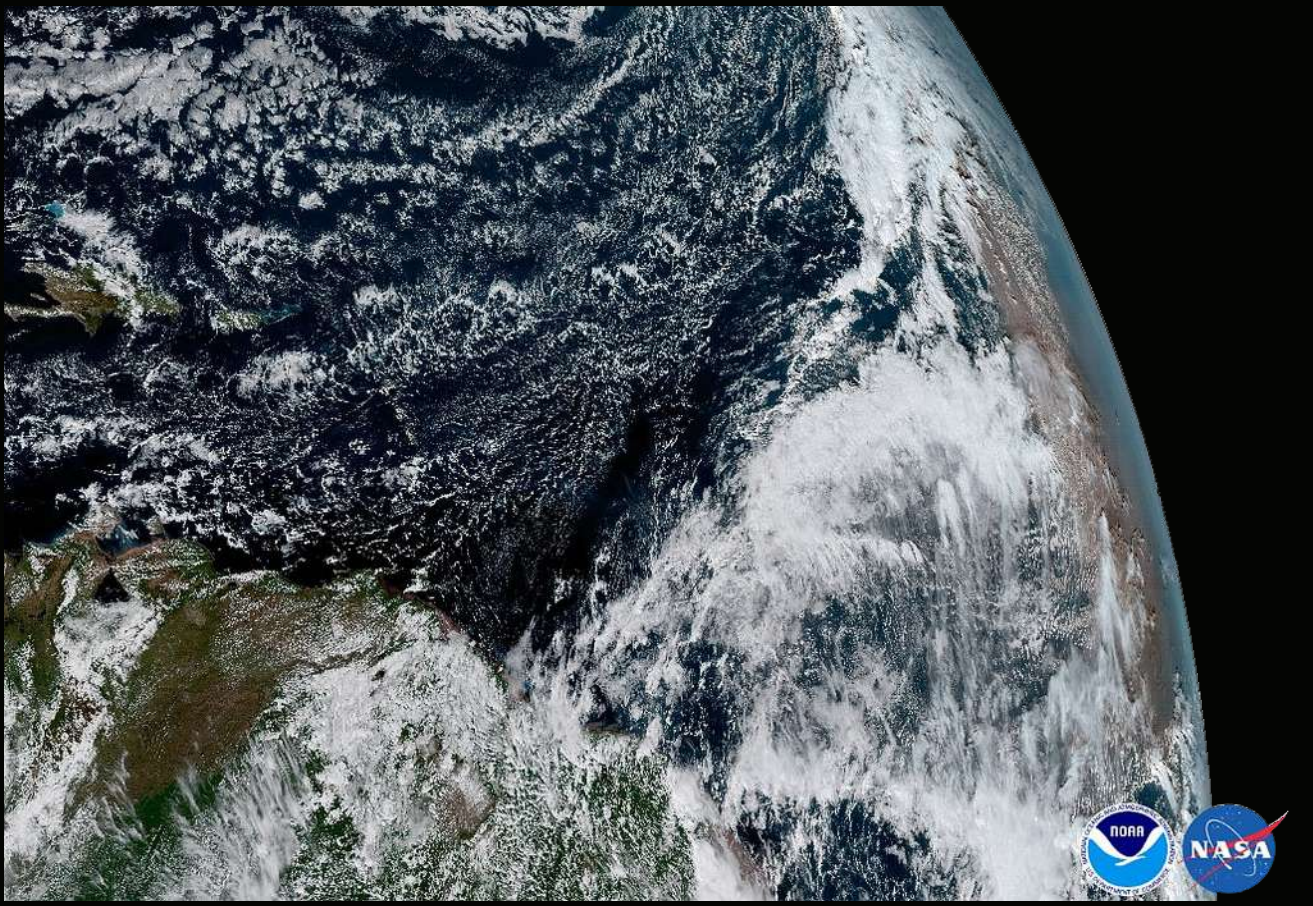


Figure 5:
Dust off the coast of Africa in this early GOES-16 GeoColor image appears on the limb as a brown patch.

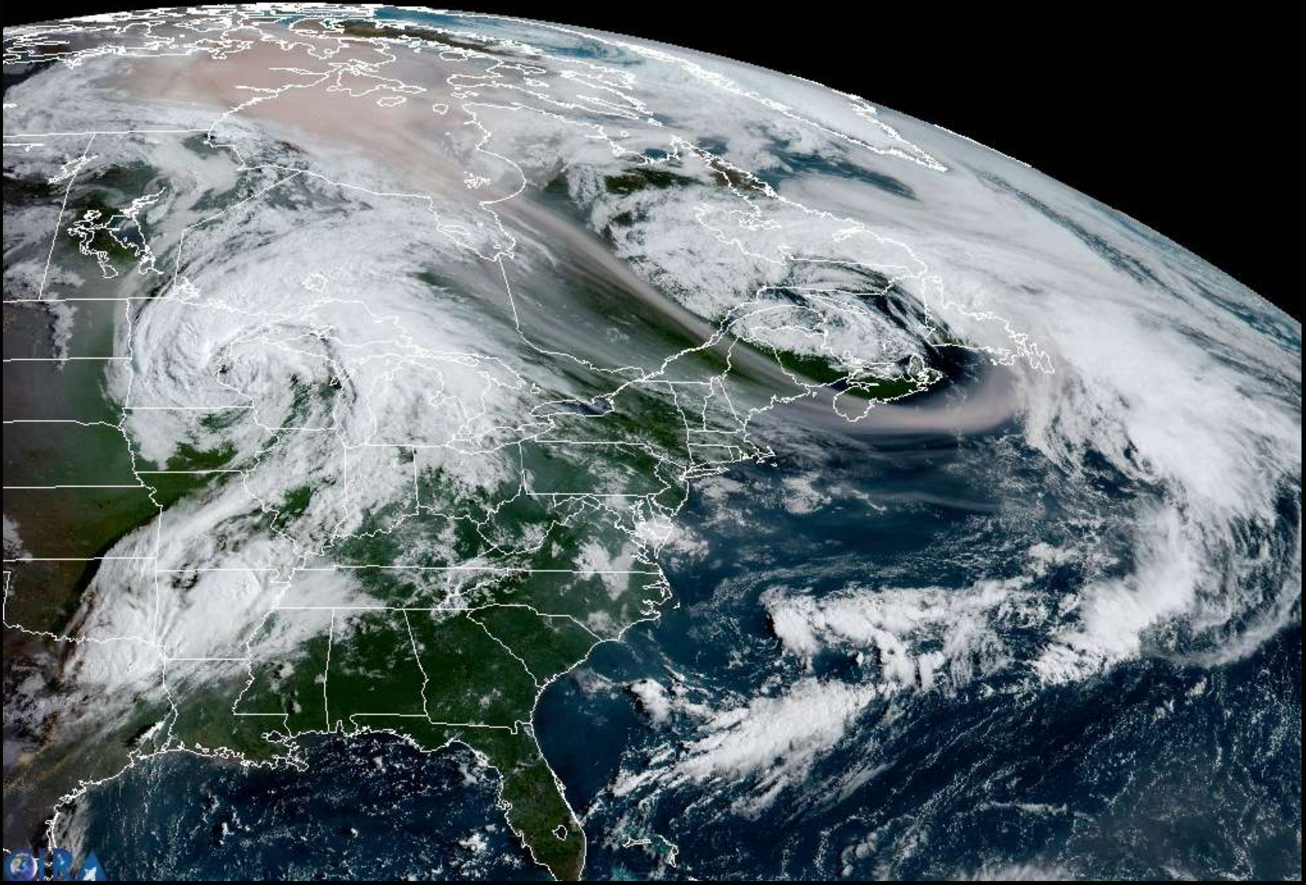


Figure 4:
Smoke from Canadian wildfires is pulled across the eastern seaboard by a low-pressure system in this GOES-16 GeoColor image from August 17th, 2017.

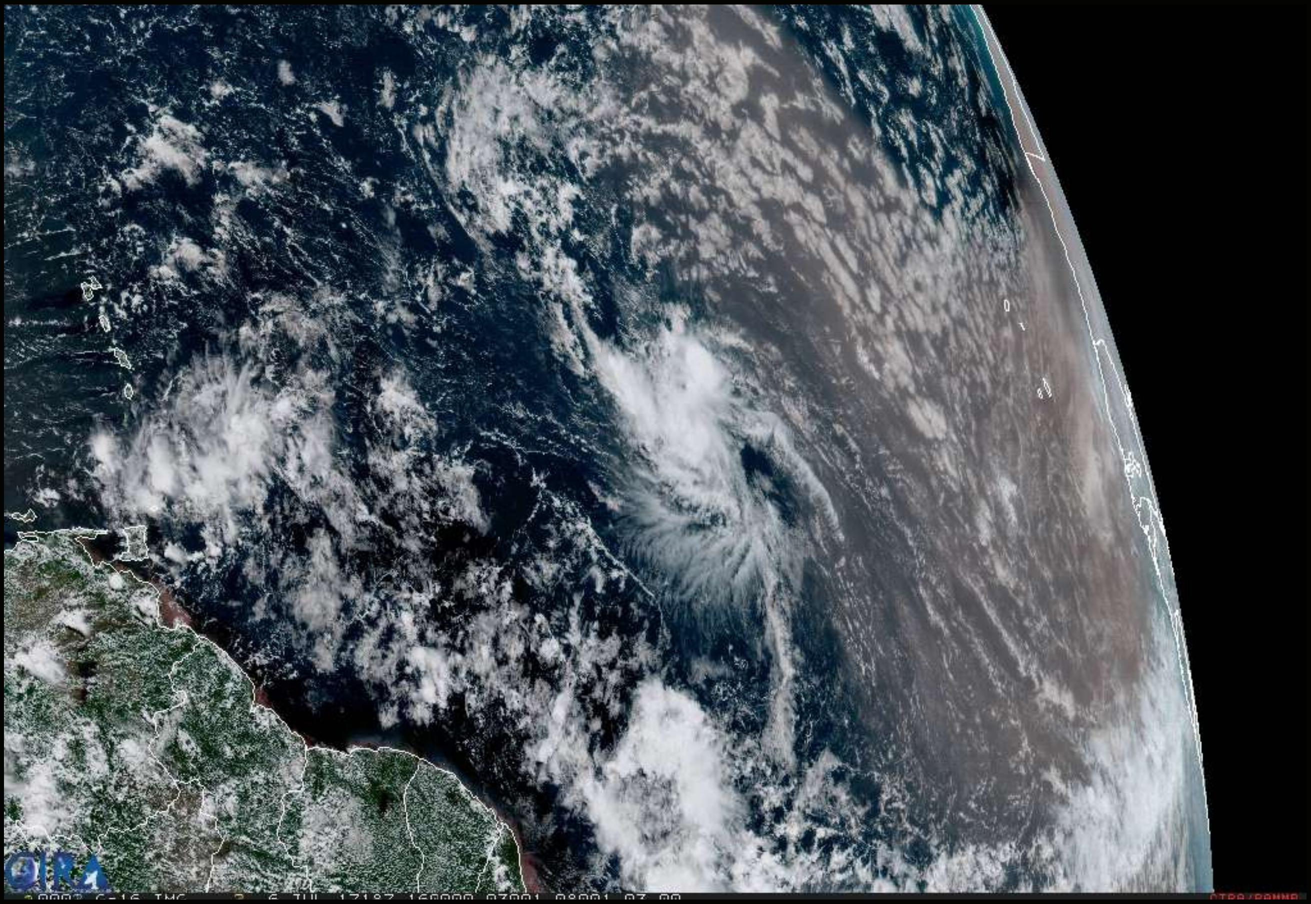


Figure 6:
Dust and dry air trail a tropical depression in the Atlantic, as seen by GOES-16.

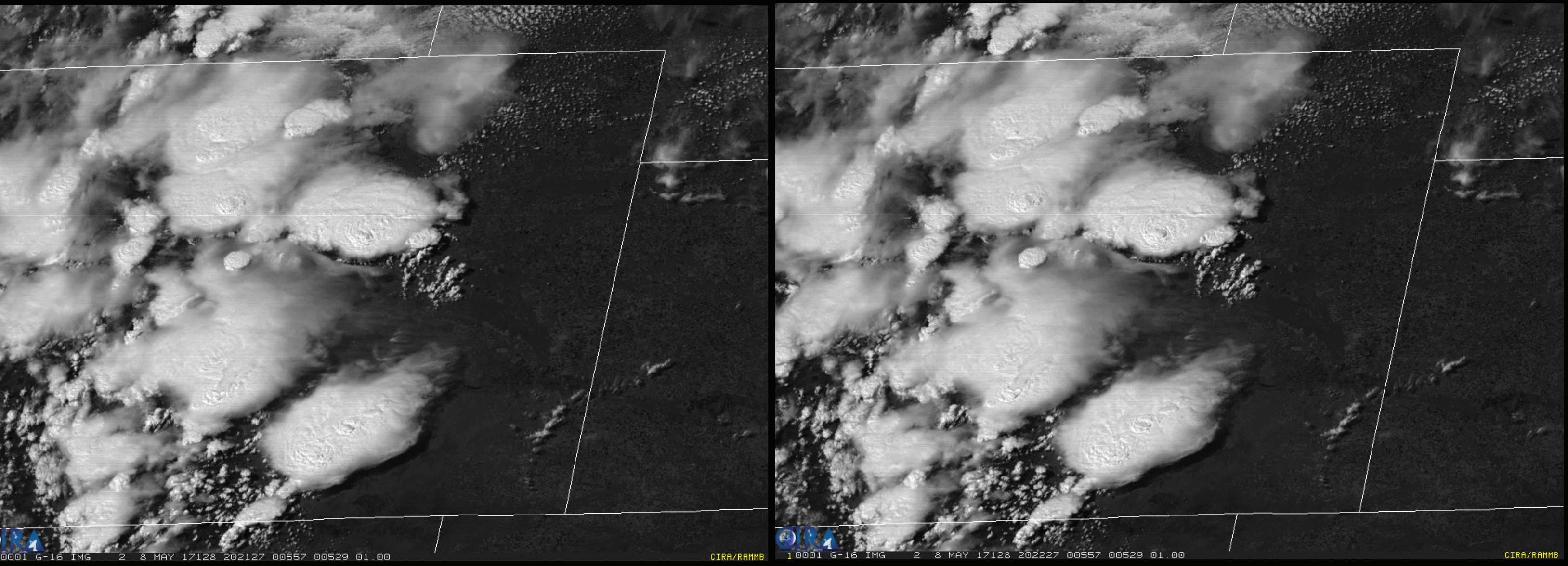


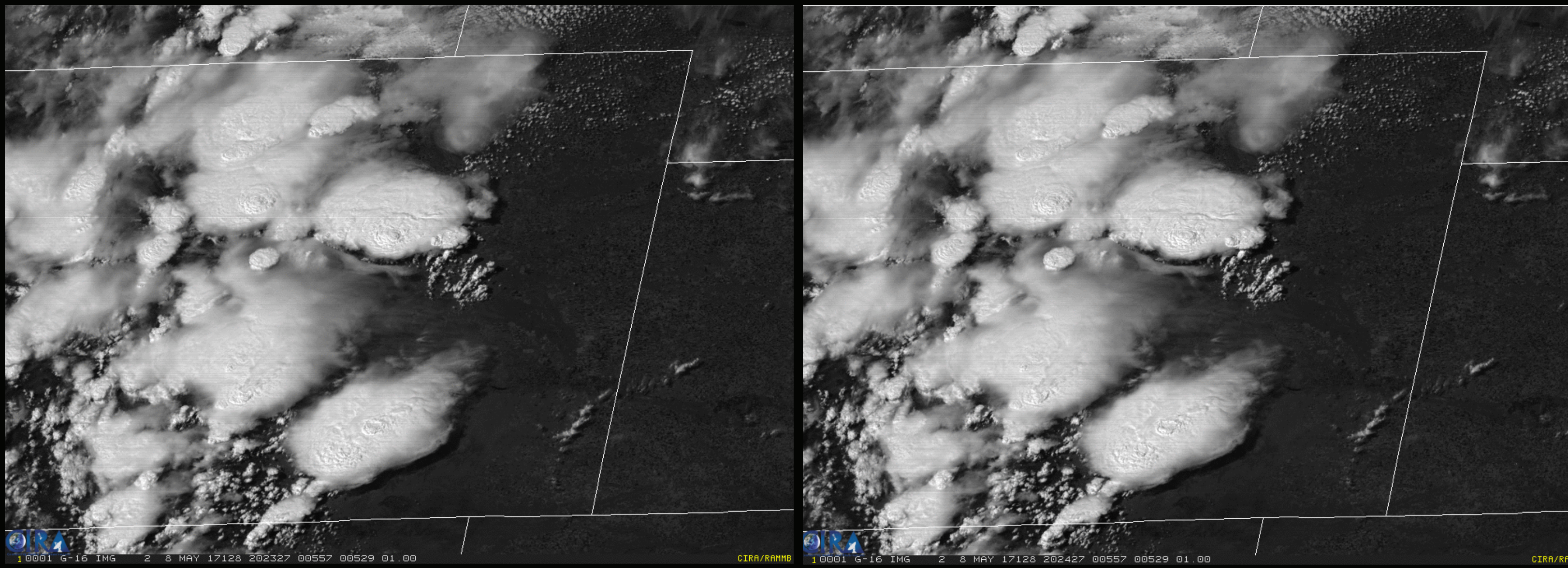
Figure 7:
One-minute imagery of severe thunderstorms over eastern Colorado, detailing the motion of overshooting tops in the storm.

The future of geostationary imagery began for the United States on January 26th, 2017. Two months earlier, the GOES-R spacecraft had launched successfully into an orbit more than 22,000 miles above the planet, and had been undergoing testing and stabilization. On January 15th, the sophisticated Advanced Baseline Imager (ABI) was used to take a test image. With the northern United States in the grip of a major snowstorm, the potential for sharp, compelling imagery was there – and the ABI delivered. Incredibly detailed data from each of the sixteen bands aboard the instrument were beamed down to advance users across the country, including CIRA, where a team led by CIRA Deputy Director Dr. Steve Miller and NOAA Researcher Dr. Dan Lindsey went to work, applying their GeoColor algorithm to the ABI's first-ever view of our planet.

The resulting image (Fig. 1), you'll agree, was spectacular, and for the first time since the 1960s, we were seeing our world in brilliant, vivid, and sharp color. NASA and NOAA agreed that the CIRA GeoColor product was amazing – for several months, in fact, if you saw GOES-16 sample imagery, it was usually a product developed at CIRA (and often the GeoColor product). Media use of the imagery skyrocketed, with GeoColor popping up at the NASA Earth Observatory, in official NASA and NOAA press releases, and at a GOES-16 'first light' presentation held at the annual meeting of the American Meteorological Society, held that year in Austin, Texas. The press took the intuitive and stunning imagery and ran with it – one image, carefully captured by Dr. Lindsey, captured the Moon peeking over the horizon off the northwest limb of the planet. It was a press favorite, even being featured by Al Roker of the 'Today Show' (Fig. 2).

Once the excitement over the sheer beauty of GOES-16 imagery abated, it was down to work – while the satellite was (and remains) in a pre-operational state, meaning images are still subject as of this writing to additional scrutiny, many operational uses of ABI data were being discovered. And once again, the CIRA GeoColor product was becoming known as a go-to for intuitive imagery – the careful blending of red, blue, and synthetically-generated green light from the ABI created an image that allowed the most sophisticated of all image processing devices, the human brain, to find detail and nuance in imagery that simply wasn't possible with monochromatic images available from the legacy GOES instruments.

One such application was wildfire. The spring and summer of 2017 were active fire seasons for much of the northern and northwestern United States. For weeks on end, large fires burned continuously while crews battled to save property and lives. Smoke from the fires drifted downwind to eventually cover most of the United States, even reaching as far as New England. With previous GOES instruments, detecting the presence of smoke was not necessarily difficult, but in many cases, the difference between smoke and cloud were minimal, and large regions of diffuse smoke



was less easy to detect. When viewed from GeoColor (Fig. 3), smoke plumes stand out clearly – moreover, the difference between smoke and cloud became much easier to detect (Fig. 4). Continued use of ABI data to detect wildfire smoke, and the many health hazards that come along with long-term exposure, are expected to improve air-quality and health forecasts for years to come.

In the same vein, understanding the interaction of dry air over the tropical Atlantic has long been a goal of tropical storm researchers. The interaction of Saharan dust often trapped in these dry air regions is a useful marker for noting the ingestion of dry air into forming tropical waves off the African coast, and can help forecasters make decisions about the likelihood of tropical storm formation. Because the GOES series of satellites are, for the most part, placed in orbit with direct views of the continental United States, seeing these dry, dusty regions from orbit required use of satellite imagery from European satellites, or attempting to diagnose dust through long atmospheric paths from GOES – not always a surefire solution. The ability of researchers to leverage ABI data to create color imagery helps detect these dust layers much more readily, just like with smoke – one of the first examples of this is shown as Figure 5. Here, dust blowing off the Sahara shows up at the limb of the Earth as a brownish patch. In a later image (Fig. 6) the interaction of dry air bearing a large amount of Saharan dust and a nascent tropical storm is clearly evident. Being able to see first-hand the complex interactions between moist and dry air in the immediate environment of a tropical storm is of immense value to researchers – one more advantage to true-color imagery.

Color, while a wonderful addition to the researchers' toolbox, isn't the only advantage GOES-16 has. In addition to much higher spatial resolution, the ABI can take imagery much more quickly. Previous GOES images were separated by as much as fifteen minutes – the ABI can, if the mesoscale imagery option is used, knock that down to one minute. Figure 7 shows an example of one-minute imagery of hail-producing storms over northeastern Colorado. Taken one minute apart, the four images here look, to the untrained eye, very similar to one another, but to the trained meteorologist, the data is a goldmine; at the 500-meter resolution of Band 2 aboard the ABI, it's easy to pick out the overshooting top features of these cumulonimbus clouds, representing the strongest updrafts in the storm. With one-minute data, a forecaster can see the evolution of the updraft as it happens in real time, giving the forecaster better information about whether the storm is strengthening, redeveloping, and where the storm might be going next. Continued analysis of these storms is also expected to better detect potential rotation of these storms, giving much longer lead times to the forecasting of severe supercell thunderstorms, including tornado warning improvements.

Welcome
to New CIRA Members

MAX MARCHAND joined CIRA as a post-doctoral researcher in November 2016. He is working on the GOES-R Short Term Forecasting project to use high resolution GOES-R data to initialize convection when and where it occurs in the operational HRRR model. Max came to CIRA from Florida State University's Department of Earth, Ocean and Atmospheric Science. His supervisor is Kyle Hilburn.

ERIC MOLTEN joined the CIRA staff in August 2016 as a student hourly coordinator, assistant to the CIRA facilities manager. He has completed a BS in Forestry Resources and a BS in Fire Ecology from the University of Idaho and is now working on a BS in Environmental Engineering. He expects to complete his degree here at CSU in the Fall of 2018. His supervisor is Marilyn Watson.

BARBRA LASHBROOK joined CIRA in January 2017 as the new website developer/designer. Barbra has been working in web development and graphic design for almost 10 years, the last five spent at the Center for Advising and Student Achievement (CASA) within CSU. She is a Front Range Community College graduate with an Associate degree in Graphic Design with an emphasis in Web Media. Initially, she will collaborate with key personnel to develop a new CIRA website. After completing the website redesign, her responsibilities will shift toward updates and maintenance to ensure that content is fresh and working properly. She will also be available to work with internal stakeholders to update content for individual profiles or research groups. Her supervisor is Beth Kessler.

KYLE HILBURN joined CIRA as an RA-III in January 2016. While Kyle has worked on a number of projects related to his previous position, his main focus at CIRA is a new project to assimilate GOES-16 information into the HRRR model at very high time resolution to assess if convective storm location and evolution can be forecast with sufficient accuracy to help firefighting efforts predict downdrafts with one-two hour lead times. His supervisor is Chris Kummerow.

DR. RUI ZHANG is a postdoctoral researcher who joined the CIRA-NPS group in September 2016. Rui came to CIRA from Rice University and has extensive experience in air quality modeling. At Rice, he worked on a project to integrate satellite data with biogenic emission and atmospheric models to characterize biogenic and anthropogenic influences on air quality and human health. Rui is now applying regional air quality modeling to investigate sources of nitrogen deposition to the Greater Yellowstone Area. His supervisor is Jenny Hand.

JOREL TORRES joined CIRA as an RAII in December 2015. He is working with the RAMMB group as a Satellite Training Liaison between the Joint Polar Satellite System Program (JPSS) and NOAA operational end users. His interactions serve to focus applications-oriented research and guide training directions to best serve operational forecaster needs. Jorel came to CIRA as a recent graduate of the Masters Atmospheric Science Program of the South Dakota School of Mines & Technology. His supervisor is Bernie Connell.

ERIN DAGG joined CIRA as an RAII in January 2016. She is working with the RAMMB group to support interdisciplinary atmospheric and social science research and training efforts that focus on Meteorological Satellite Applications. She is identifying, collecting, and preparing example data sets to highlight uses of the new imager channels and products associated with GOES-R/16 and JPSS. Erin came to CIRA as a recent graduate of the Masters Atmospheric Science Program at Colorado State University. Her supervisor is Bernie Connell.

DR. ARLENE LAING is an RA III who joined CIRA in September 2016 in Boulder, CO. She is working with ESRL/GSD in the Forecast Impact and Quality Assessment Section (FIQAS) to support the evaluation of aviation forecasts, develop impact-based verification metrics and assessment approaches, interface with current and potential sponsors, and work with aviation subject matter experts in the development of verification and decision support tools. Prior to coming to CIRA, Dr Laing worked at the NWS Weather Prediction center conducting research to operations evaluations for forecasting of high impact precipitation and temperature events. Her supervisor is Dr. Melissa Petty.

KEN FENTON is an RA III who joined CIRA in August 2016 in Boulder, CO. He is working with ESRL/GSD in the Forecast Impact and Quality Assessment Section (FIQAS) to support the evaluation of aviation forecasts, develop impact-based verification metrics and assessment approaches, interface with current and potential sponsors, and work with aviation subject matter experts in the development of verification and decision support tools. Ken comes to CO fresh off finishing his MBA at the University of Chicago, Booth School of Business. Ken's background also includes time served with the US Airforce Weather Agency (AFWA). His supervisor is Dr. Melissa Petty.

DR. DUANE ROSENBERG is an RA III who joined CIRA in December 2016 in Boulder, CO. He is working with ESRL/GSD Advanced Technology Branch to support the High Performance Computing. Duane is working on the GPU parallelization and optimization of the FV3 model. He is collaborating with NVIDIA and PGI to identify and resolve bugs in their GPU compiler. Prior to coming to Boulder, Dr. Rosenberg worked at ORNL, serving as a liaison for INCITE products in fluid turbulence, climate and plasma. His supervisor is Sher Schranz.

BRYAN FLYNT is an RA III who joined CIRA in December 2016 in Boulder, CO. He is working with ESRL/GSD Advanced Technology Branch to support the High Performance Computing with GSD and JCSDA (Joint Center for Satellite Data Assimilation) staff on the development of the JEDI (Joint Effort for Data Assimilation Integration), an effort to re-architect the current data assimilation system called GSI (Gridpoint Statistical Interpolation) that is run operationally at the NWS. Since 2011, Bryan worked at United Launch Alliance, LLC System Integration and Analysis where he coordinated and assisted in migrating applications to the high performance computing environment and provided Linux system administration on the clusters when required. Bryan is currently working on his PhD in Mechanical Engineering. His supervisor is Sher Schranz.

BRET SORENSEN is a system support technician who joined CIRA in November 2016 in Kansas City, MO. He works at the Aviation Weather Center and is responsible for implementing and maintaining the information systems used to collect, process, and disseminate the weather-related data necessary to support AWC's mission. For the past three and a half years, he led the IT department for Novation iQ, a rapidly growing manufacturer in Lenexa, Kansas. During his time there, he worked with all aspects of IT and coordinated multiple projects, including a multi-million dollar company acquisition/plant construction/remodel project. His supervisor is Lee Powell.

DAVID MILLER joined CIRA as an RA III in December 2016. He is working with the NWS Meteorological Development Lab to design, develop and maintain systems to access quality operational and experimental NWS forecasts for the Modernized Product Generation and Delivery/Information Dissemination Program (IDP) and the interactive Map Viewer. David came to CIRA from KBRwyle Science, Technology and Engineering. His supervisor is Ken Sperow.

MICHAEL COULMAN joined CIRA as an RA IV in January 2017. Michael's working with the NWS Meteorological Development Lab. He serves as a working technical lead, focused on providing expertise, technical direction and development skill that will mature the LCAT program. Prior to joining MDL, Michael worked as a Senior Software Developer at Alert Logic. His supervisor is Ken Sperow.

GEOFFREY WAGNER joined CIRA as an RA III in January 2017. Geoff is working with the Weather Information Applications Branch of the NWS Meteorological Development Lab in support of the Model Output Statistics (MOS) and the National Blend of Models (NBM) programs. He came to CIRA from ACE Info Solutions. His supervisor is Ken Sperow.

DANIEL GILMORE began working for CIRA in December 2016 as an RA IV in the Weather Information Applications Branch of NWS/MDL. Daniel will be developing, implementing and evaluating new software to improve web service products offered by the Meteorological Development Lab, specifically through the Integrated Dissemination Program (IDP). Prior to joining CIRA, Daniel was working with ACE Info Solutions. His supervisor is Ken Sperow.

BRET LUCAS is an RA III who joined CIRA in January 2017 in Kansas City, MO. Bret will be supporting the Aviation Weather Center by providing a broad range of research, development, and program support for the AWC websites (www.aviationweather.gov and testbed.aviationweather.gov) and participating in exploratory web development, web tools evaluation, and operational implementation projects to enhance the AWC's web presence. Most recently he developed a modernized commercial website to offer e-commerce. His supervisor is Sher Schranz.

STEPHANIE AVEY is an RA III who joined CIRA in February 2017 in Kansas City, MO. Stephanie is working at the NWS/AWC Aviation Weather Testbed working closely with the NWS's Science and Technology Integration (STI) and the FAA's Aviation Weather Research Program (AWRP). For the past 8+ years, she worked as a research associate with the University of Utah, interpreting and analyzing large meteorological data sets, code development and facilitation of a cloud microphysics radar retrieval algorithm, as well as analysis of in situ aircraft data from multiple DOE-ARM/NASA field campaigns. Sher Schranz is her supervisor.

ADAM KANKIEWICZ returned to CIRA in March 2017 as an RA IV. Adam will be working at the NWS/AWC Aviation Weather Testbed as the Technical Lead in Kansas City, MO. Since leaving CIRA in 2007, Adam has been developing software for solar and wind forecasting in the private energy sector. Sher Schranz will be his supervisor.

AMANDA TERBORG came to CIRA at the Aviation Weather Center in Kansas City from the University of Wisconsin/CIMSS in March 2017 as an RA III. Amanda has been manager for the GOES-R Proving Ground at the Aviation Weather Center and has been the primary POC for all Aviation Weather Center satellite operations. In her new role with CIRA, she will be working with an R2O team to transition ESRL/GSD's INSITE tool to operations. Amanda received her Master of Applied Meteorology from Plymouth State University. Sher Schranz is her supervisor.

JASON LEAVIT came to CIRA in January, 2016 as an RA IV from a position at Weather Analytics, LLC. Jason will be working at NWS/Meteorological Development Laboratory in Silver Spring, MD. He is tasked with providing leadership and direction in the design and implementation of an updated version of the NWS Model Output Statistics (MOS) system. Jason's supervisor is Ken Sperow.

NATE HARDIN came to GSD from the Hurricane Center in February, 2016. Nate works in GSD's Evaluation and Decision Support Branch. Nate's focus has been on developing techniques to assist NWS aviation forecasters (at the Aviation Weather Center and the Alaska Aviation Weather Unit) in preparing in-flight advisories like the Convective SIGMET. These tools build on Hazard Services and GFE work that GSD has done, and are part of our AWIPS-II team's efforts to extend forecaster support into the NWS' National Centers. Nate's supervisor is Evan Polster.

DR. PAUL ROEBBER came to CIRA as an AP hourly working with NWS/Meteorological Development Laboratory in Silver Spring, MD. Dr. Roebber is a Distinguished Professor at the Atmospheric Science Group, University of Wisconsin at Milwaukee. His work with MDL will focus on exploring Artificial Intelligence (AI) methodologies such as Evolutionary Programming, Neural Networks, Genetic Algorithms, etc. as potential solutions for automated improvement and tuning of the National Weather Service's implementation of the NCAR AutoNowCaster (ANC) as part of the Multi-Radar, Multi-Sensor (MRMS) system. Ken Sperow is his supervisor.

JASON BURKS joined the CIRA team at NWS/MDL in Silver Spring, MD, on May 2, 2016 as a RA IV. He is working with Ken Sperow and the VLab team on developing tools for the AWIPS II system. Jason comes to us from a previous position at NASA SPoRT in Huntsville, AL, where he was also working on AWIPS II tool development, specifically in the area of visualization tools for GOES-R satellite data. Jason's supervisor is Ken Sperow.

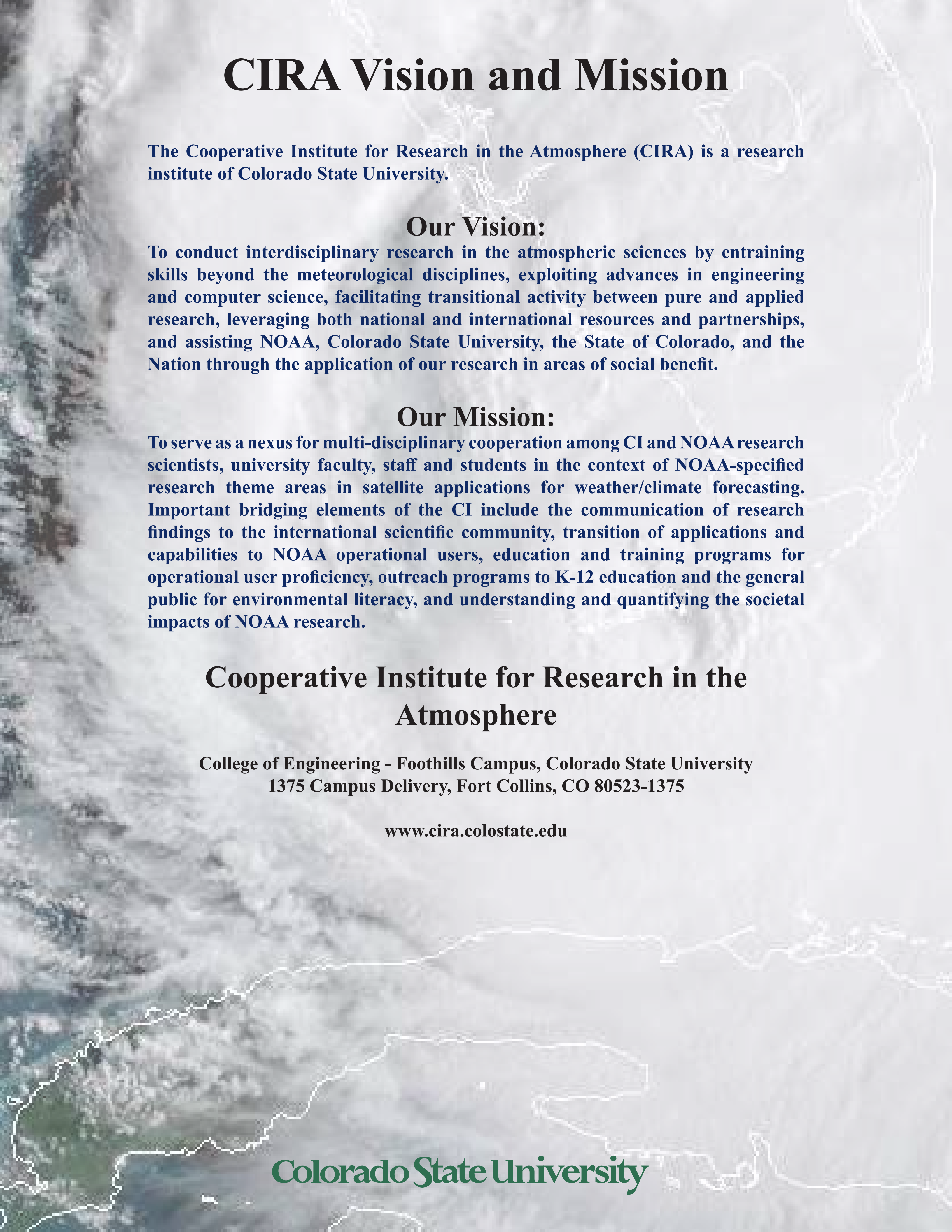
Awards

DR. DANIEL LINDSEY, NOAA/NESDIS was awarded the 2016 David Johnson Award for his work with high-temporal resolution observations from the legacy GOES platforms. The work Lindsey and his teammates are doing includes real-time demonstrations showing the capabilities of the new generation of geostationary satellites. His work paved the way for the transition from GOES 13, 14, and 15 to the GOES-R series of satellites. Dr. Lindsey was presented his award by the National Space Club and Foundation in a gala presentation in Washington, D.C.

PROF. CHANDRA VENKATACHALAM, CIRA FELLOW AND UNIVERSITY DISTINGUISHED PROFESSOR was awarded the Insignia of Knight, First Class of the Order of the White Rose of Finland, for efforts in radar research in collaboration with the Finnish Meteorological Institute. Prof. Chandra was awarded his knighthood in an on-campus ceremony held by Ambassador Kirsti Kauppi, the Finnish Ambassador to the United States, followed by a visit of the Ambassador to CIRA.

A SATELLITE RESEARCH TEAM LED BY CIRA DEPUTY DIRECTOR STEVE MILLER, ALONG WITH NOAA/NESDIS RESEARCHER DR. DANIEL LINDSEY AND CIRA RESEARCHER DR. CURTIS SEAMAN was awarded the 2017 CO-LABS Governor's Award for High-Impact Research for their work on GOES-16 imagery, in particular for the development of the True Color and GeoColor products used extensively by NOAA.

THE SCIENCE ON A SPHERE TEAM, JOINTLY RUN BY CIRA, THE COOPERATIVE INSTITUTE FOR RESEARCH IN THE ENVIRONMENTAL SCIENCES (CIRES) AND THE NOAA EARTH SYSTEMS RESEARCH LAB (ESRL) was also recognized at the 2017 CO-LABS awards, the team received an honorable mention award for their innovative use of technology to display satellite and model data in 3D format. They were honored at a gala awards ceremony hosted at the Denver Museum of Nature and Science in October, 2017.



CIRA Vision and Mission

The Cooperative Institute for Research in the Atmosphere (CIRA) is a research institute of Colorado State University.

Our Vision:

To conduct interdisciplinary research in the atmospheric sciences by entraining skills beyond the meteorological disciplines, exploiting advances in engineering and computer science, facilitating transitional activity between pure and applied research, leveraging both national and international resources and partnerships, and assisting NOAA, Colorado State University, the State of Colorado, and the Nation through the application of our research in areas of social benefit.

Our Mission:

To serve as a nexus for multi-disciplinary cooperation among CI and NOAA research scientists, university faculty, staff and students in the context of NOAA-specified research theme areas in satellite applications for weather/climate forecasting. Important bridging elements of the CI include the communication of research findings to the international scientific community, transition of applications and capabilities to NOAA operational users, education and training programs for operational user proficiency, outreach programs to K-12 education and the general public for environmental literacy, and understanding and quantifying the societal impacts of NOAA research.

Cooperative Institute for Research in the Atmosphere

College of Engineering - Foothills Campus, Colorado State University
1375 Campus Delivery, Fort Collins, CO 80523-1375

www.cira.colostate.edu

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