2009 IEEE International Geoscience and Remote Sensing Symposium
Earth Observation – Origins to Applications
July 12-17, 2009 • Cape Town, South Africa

MODIS Applications

MODIS direct broadcast data for enhanced forecasting and real-time environmental decision making

CIMSS

NASA

8 July 2009

Kathleen Strabala

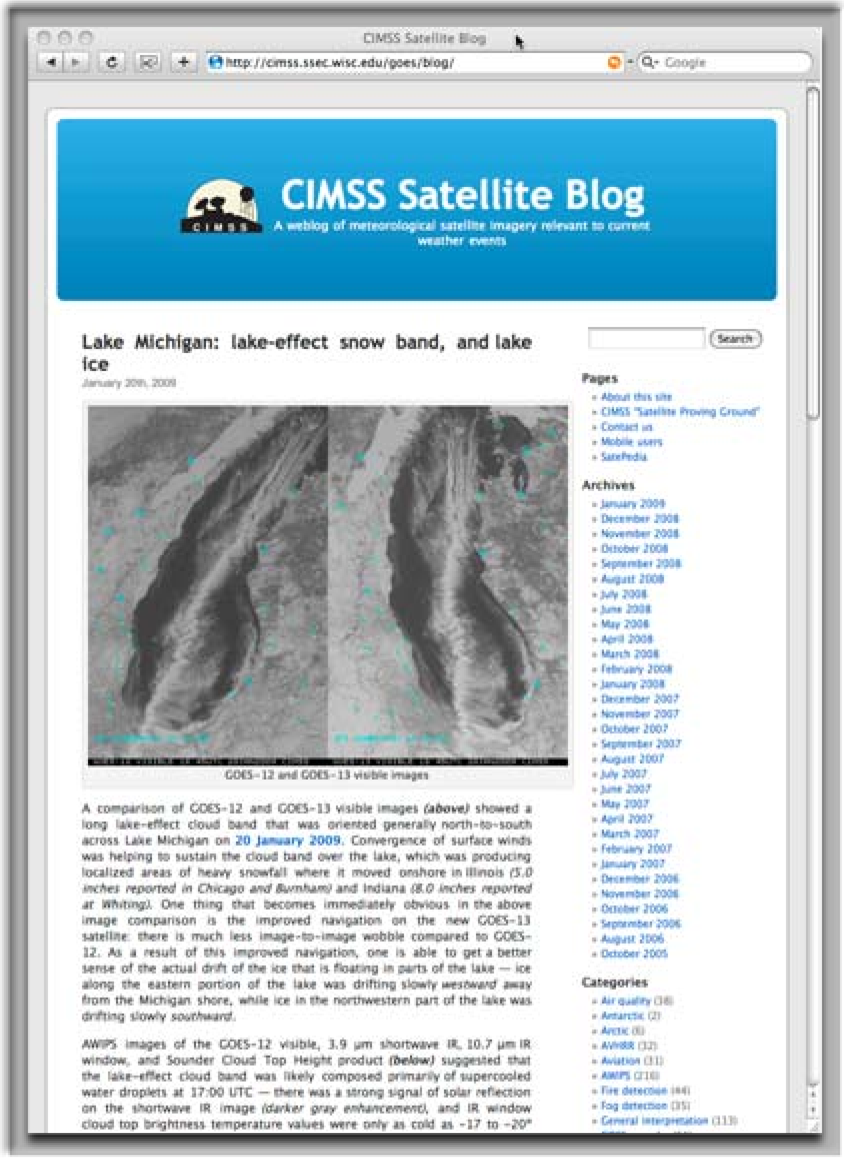
Part 1

Cooperative Institute for Meteorological Satellite Studies
University of Wisconsin-Madison USA

Sources

- Publications
- Conference Papers
- User Feedback including US National Weather Service
- CIMSS satellite blog – Scott Bachmeier
  - http://cimss.ssec.wisc.edu/goes/blog/

CIMSS Satellite Blog



cimss.ssec.wisc.edu/goes/blog

Slide References

- Liam Gumley, Scott Bachmeier, Jordan Gerth, Lorraine Remer, Paul Menzel

MODIS DB Applications

- Weather Observation and Forecasting
  - Originally thought of as research satellite
  - Compliment to Geostationary
    - Higher Spatial Resolution (data at 250 m - 1 km, products at 250 m - 5 km)
    - Unique spectral bands (such as 1.38μm)
    - New products (such as true color imagery)
    - Preparation for next generation of geo instruments
  - Key for forecasts is timeliness of data
    - UW provides NWS with data end to end within 1.5 hours of start of pass time.
  - Post analysis – timeliness not as important
  - Temporal coverage is limiting

MODIS DB Applications

- Public Safety and Public Interest
  - Nighttime Fog Detection
  - Snow/Ice Detection
  - Fires !!!! - Philip Frost
  - Severe Weather
- Aviation Interest
  - Everything clouds
    - Cloud composition, Height and Temperature
  - Turbulence
  - Ash Detection
- Numerical Weather Prediction
  - IMAPP DCRAS
- Aerosols
  - Detection
  - IDEA
- Others

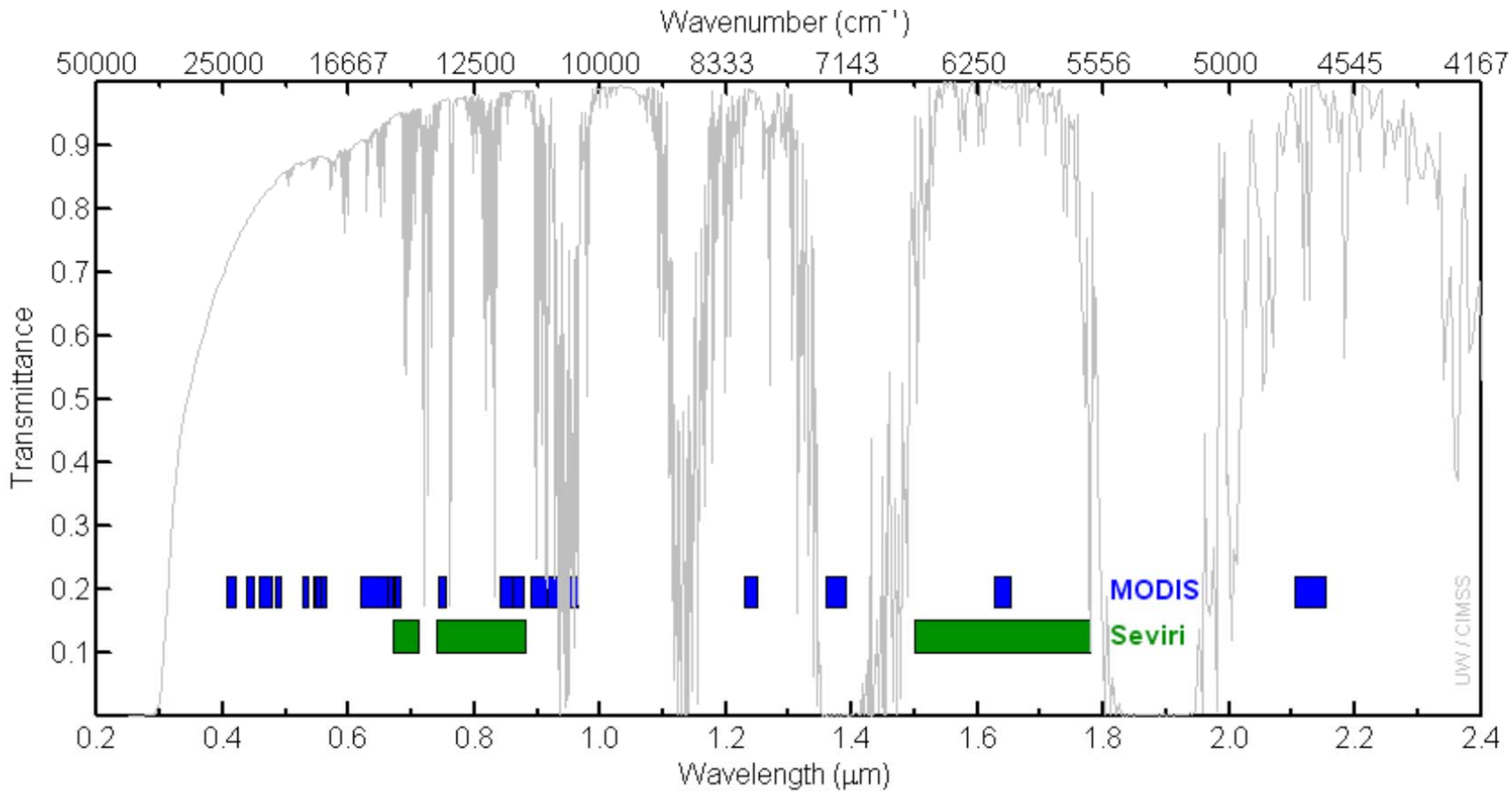
Weather and Forecasting

Complimentary to Geostationary

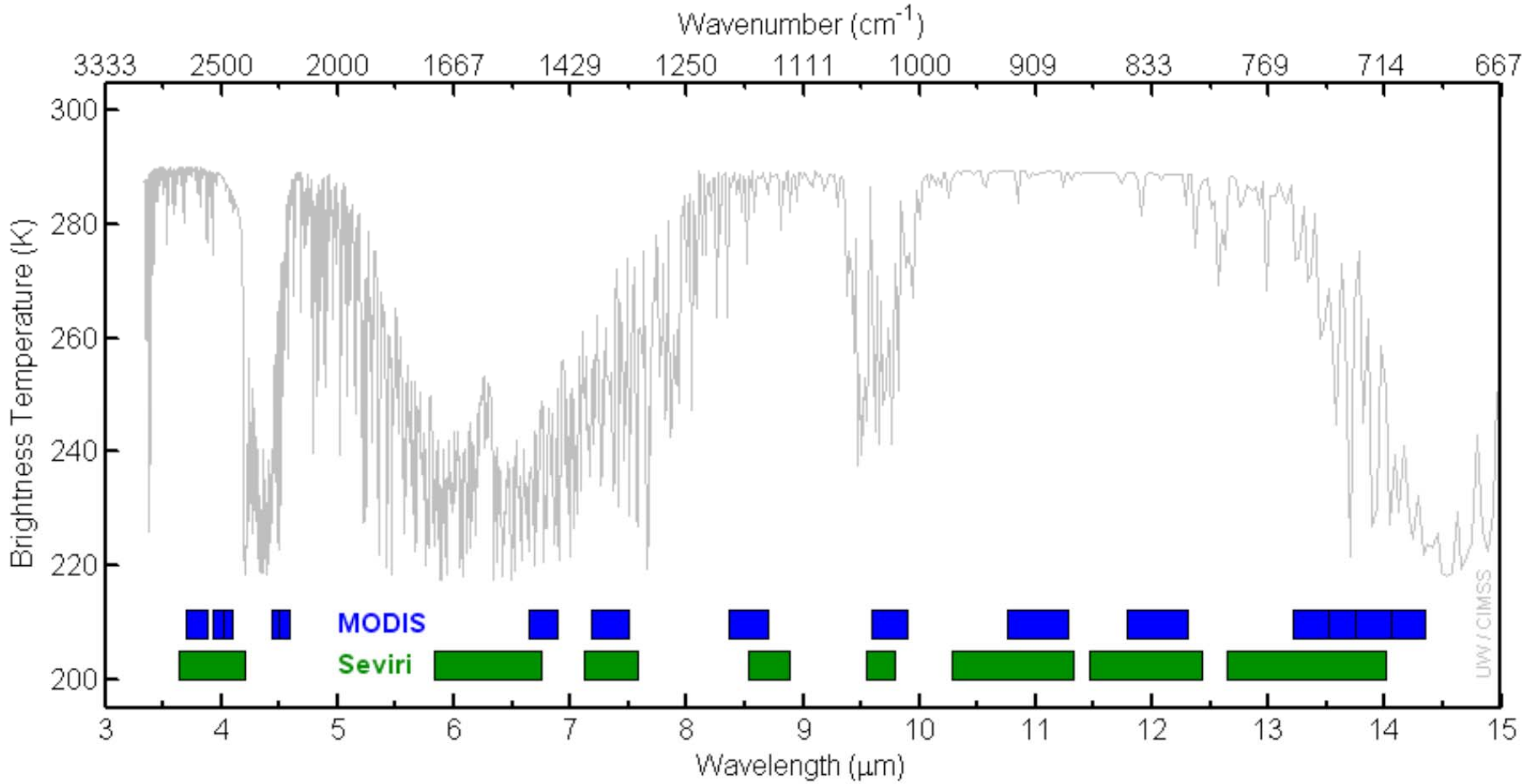
Comparison to Geostationary Instruments

- SEVIRI
  - 12 bands
  - 1 band 1.67 km, 11 bands at 4.8 km spatial resolution
  - 10 bit quantization
  - Temporal coverage – 15 minutes
- MODIS
  - 36 bands
  - 2 at 250 m, 5 at 500 m, 29 at 1 km
  - 12 bit quantization
  - Temporal coverage – two satellites, 4 times per day

SEVIRI and MODIS Visible bands



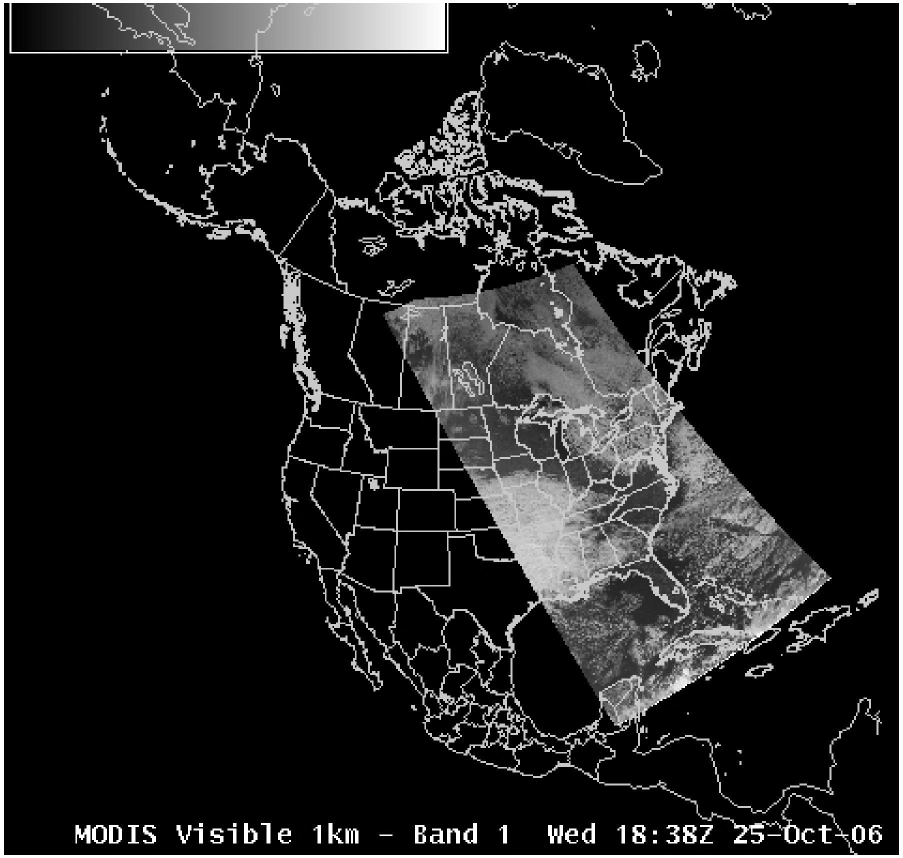
SEVIRI and MODIS thermal bands



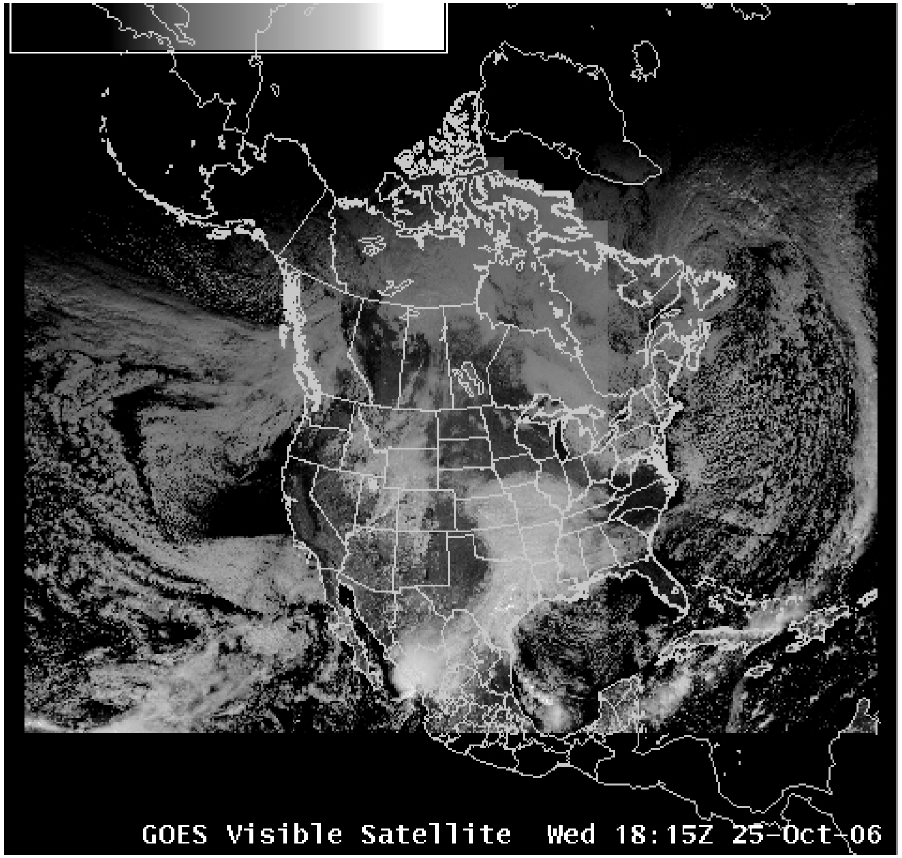
Example of Improved Spatial Resolution

MODIS Imagery in AWIPS

Band 1: Visible channel (0.6µm)



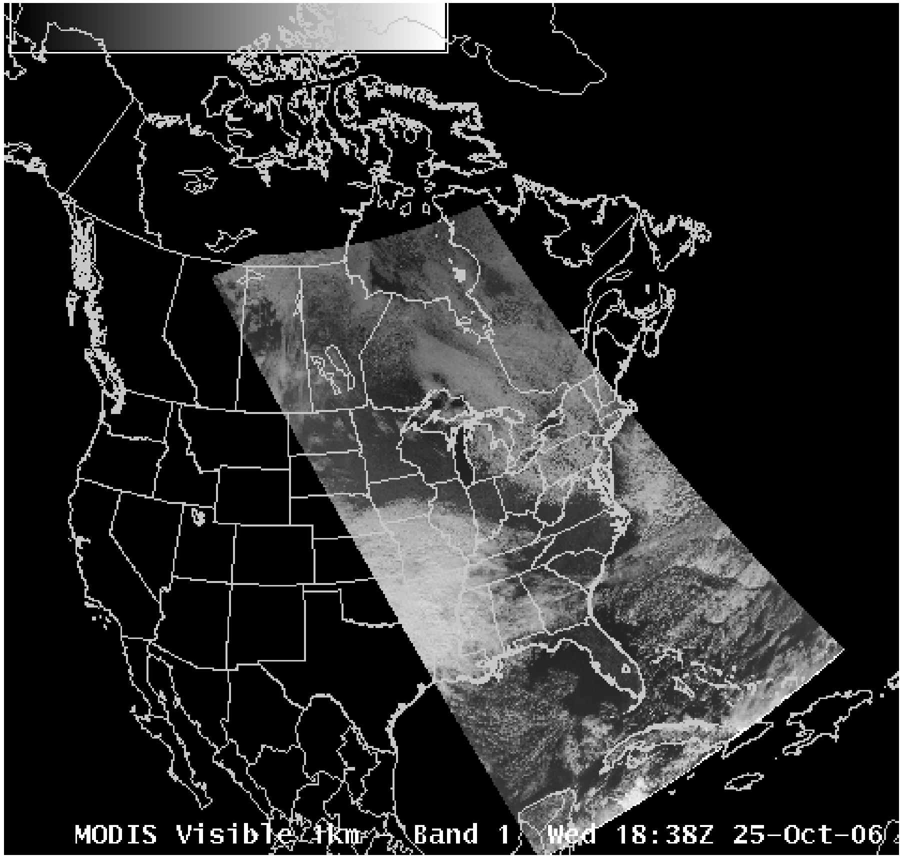
MODIS visible channel



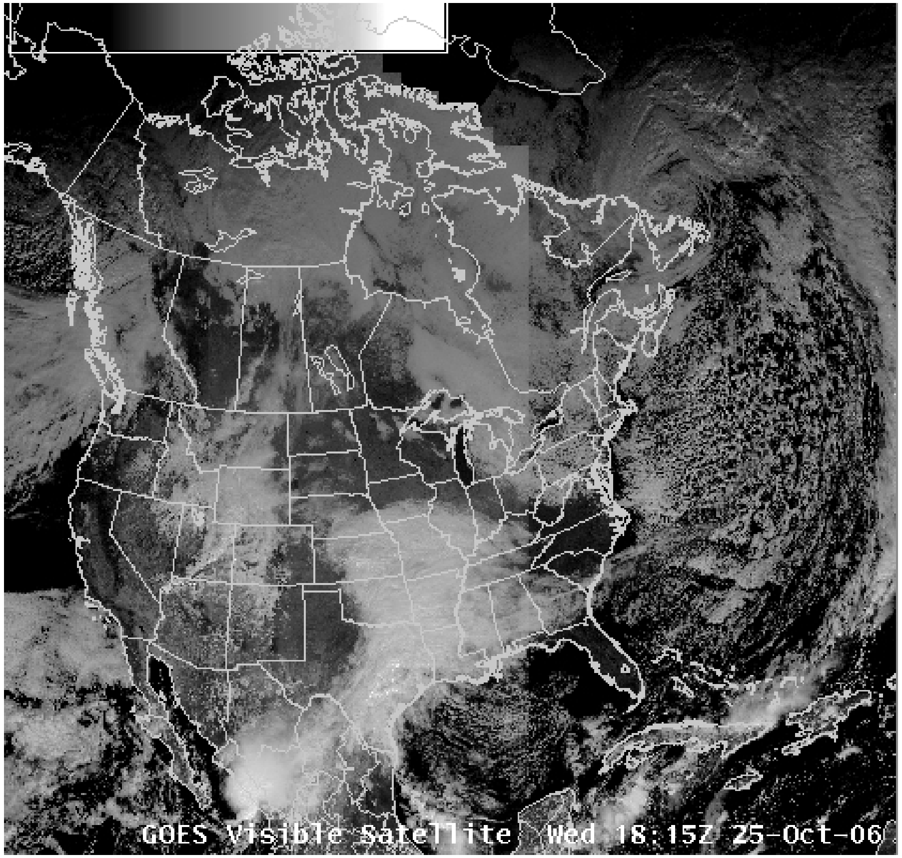
GOES visible channel

MODIS Imagery in AWIPS

Band 1: Visible channel (0.6μm)



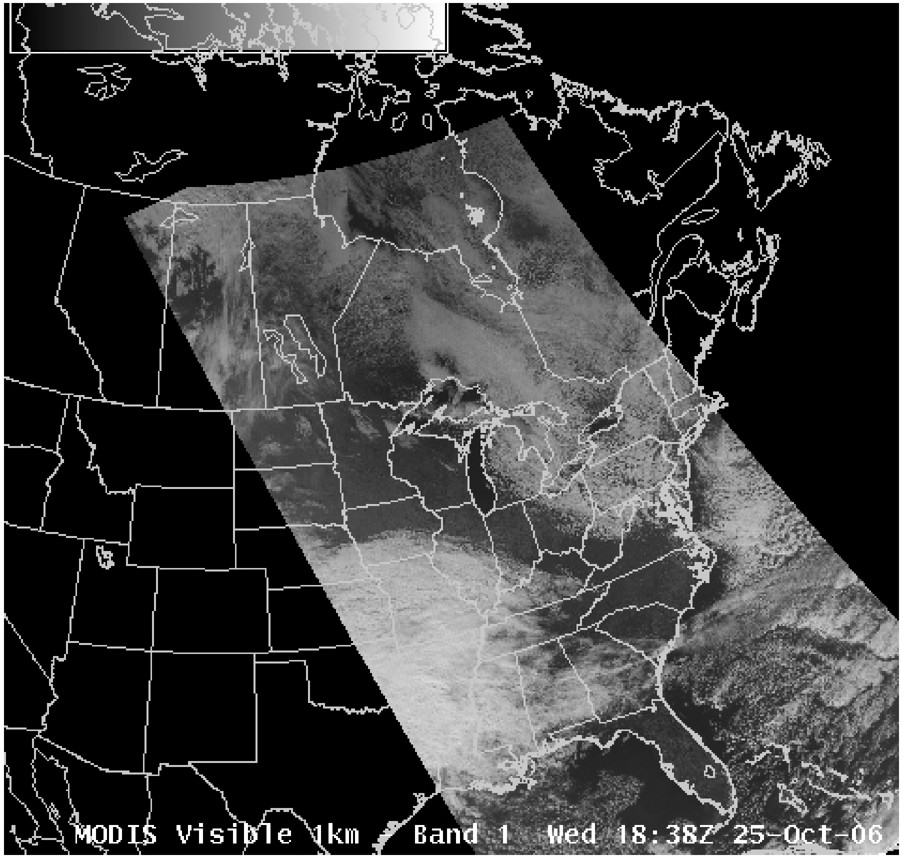
MODIS visible channel



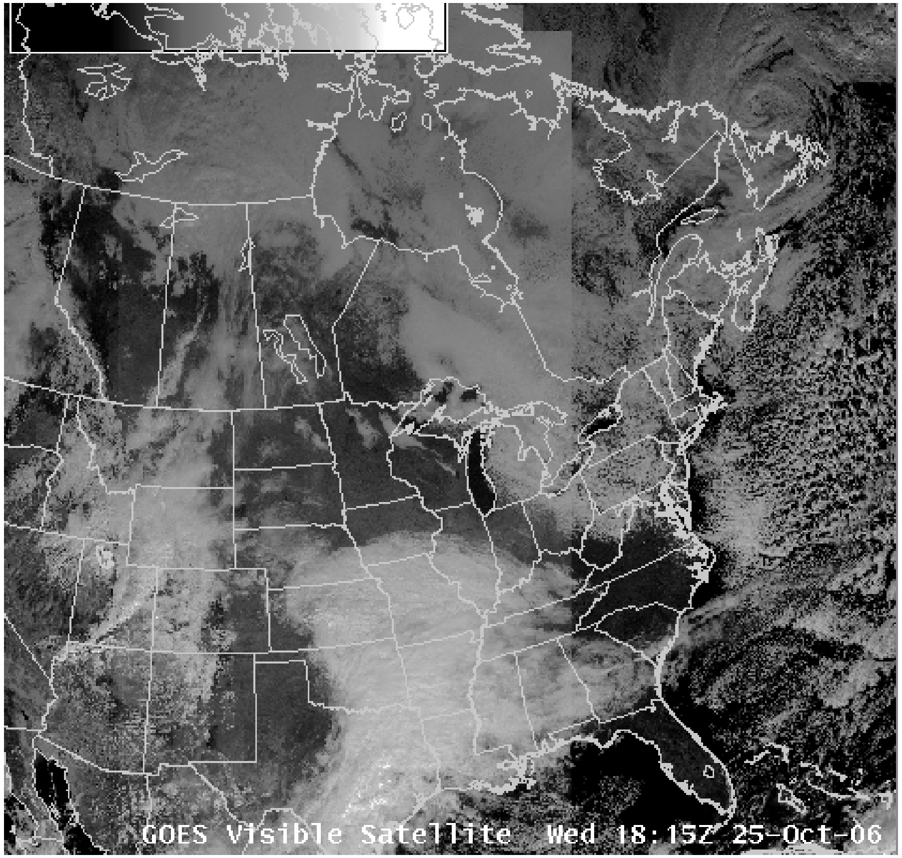
GOES visible channel

MODIS Imagery in AWIPS

Band 1: Visible channel (0.6μm)



MODIS visible channel



GOES visible channel

MODIS Imagery in AWIPS

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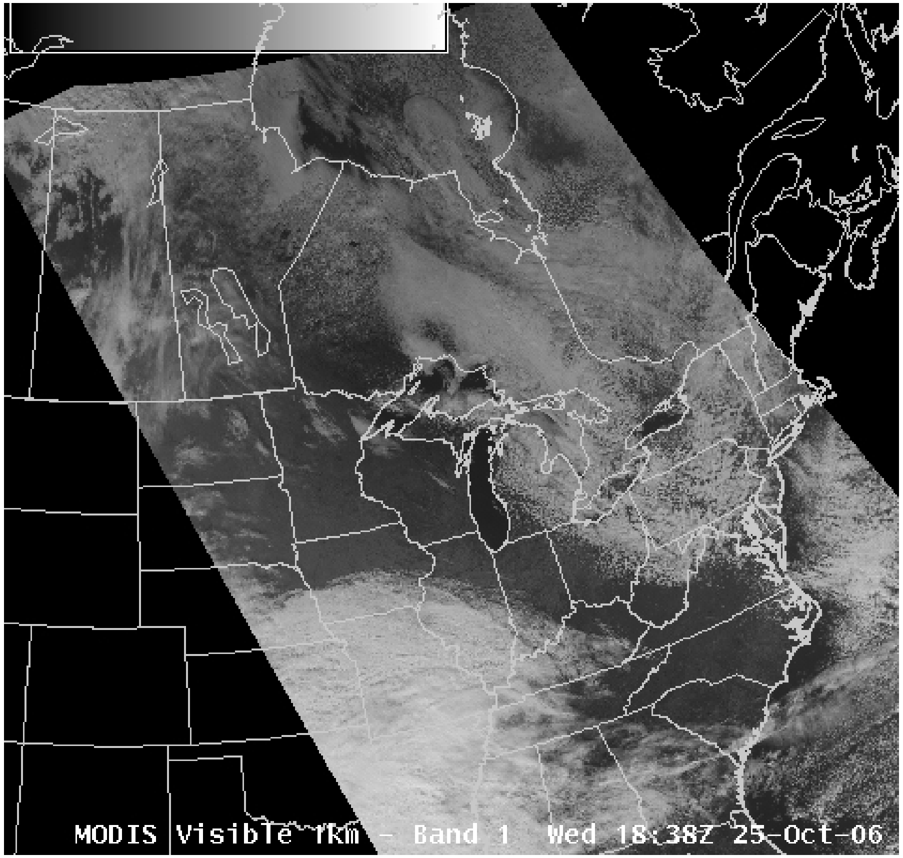
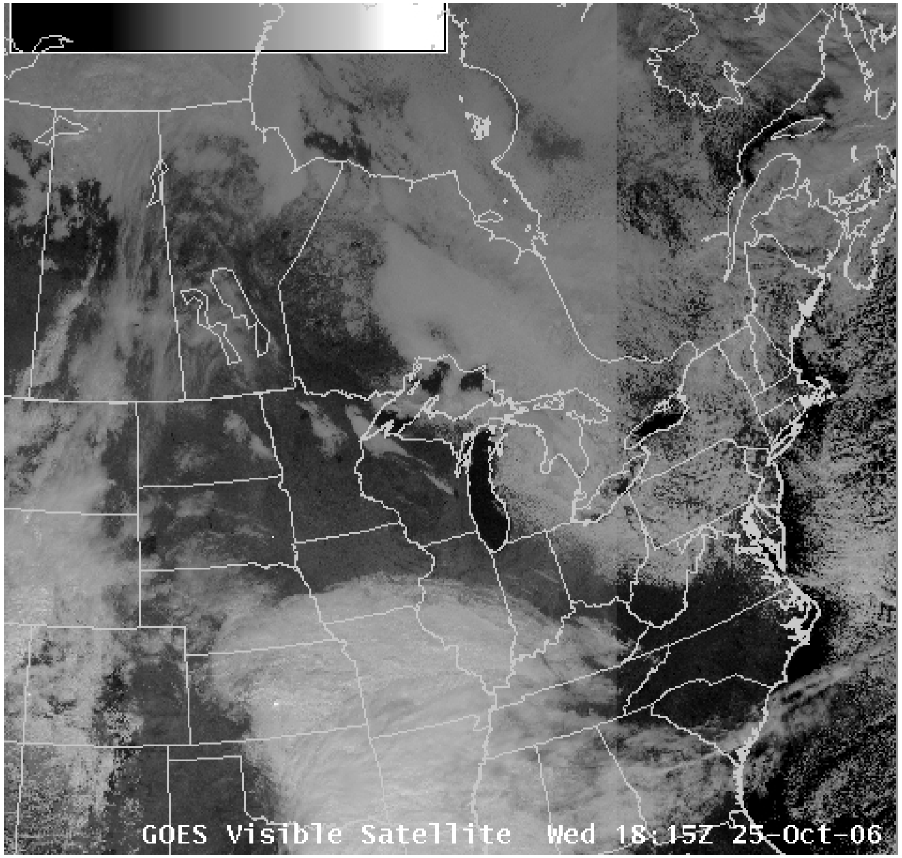


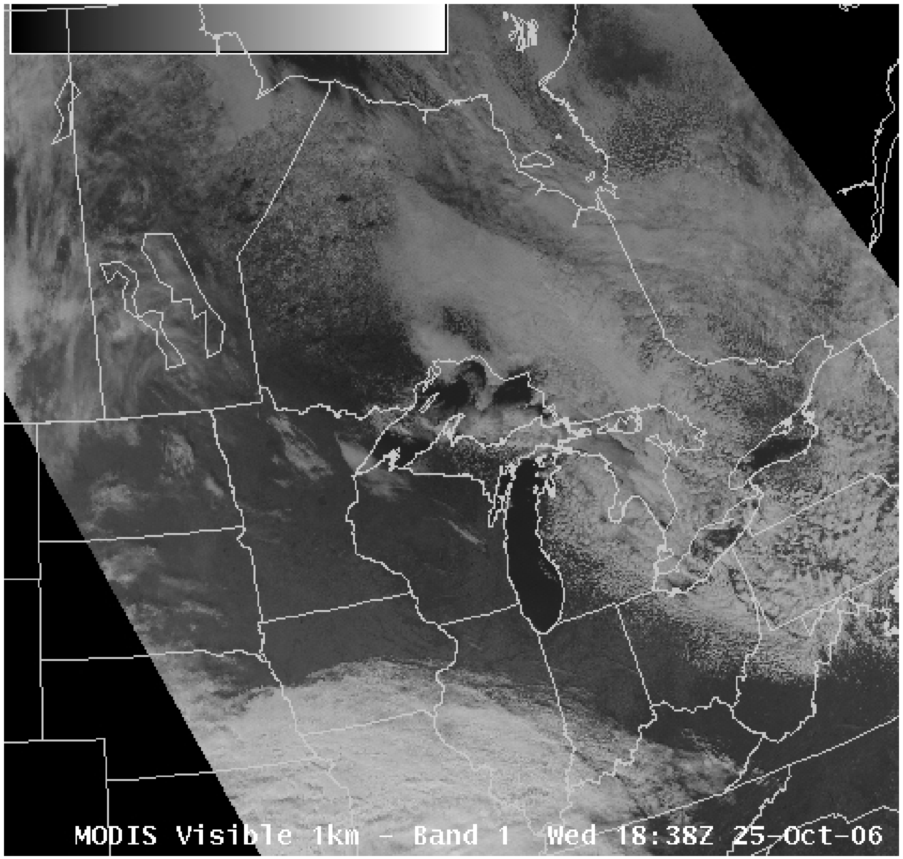
MODIS visible channel



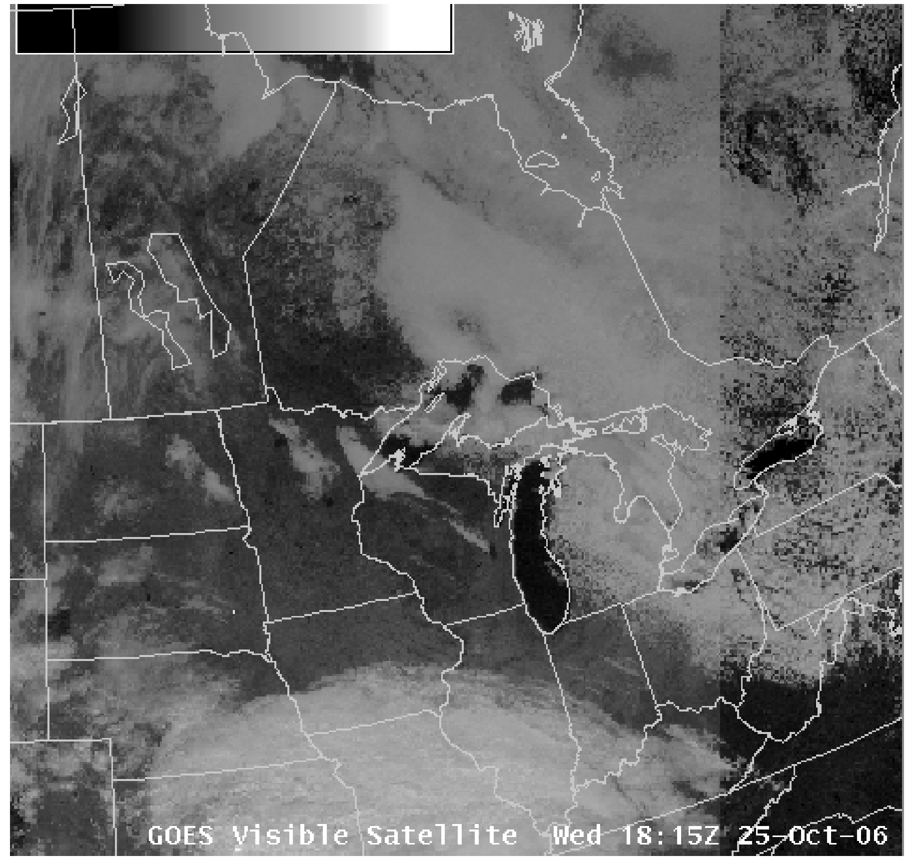
GOES visible channel

MODIS Imagery in AWIPS

Band 1: Visible channel (0.6μm)



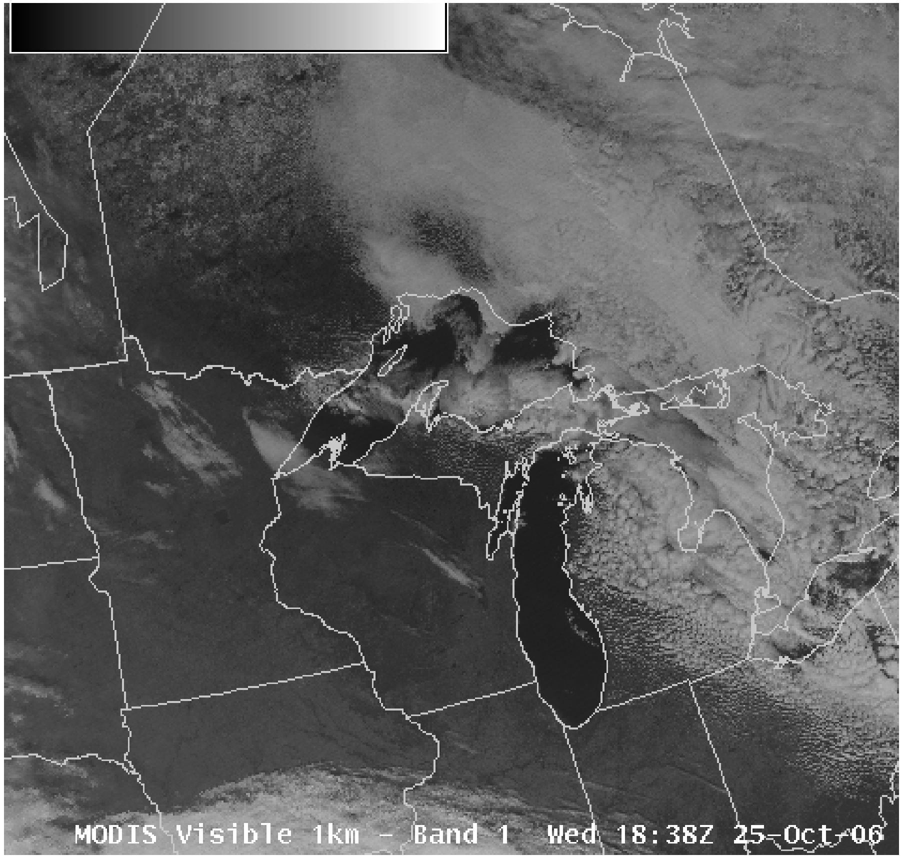
MODIS visible channel



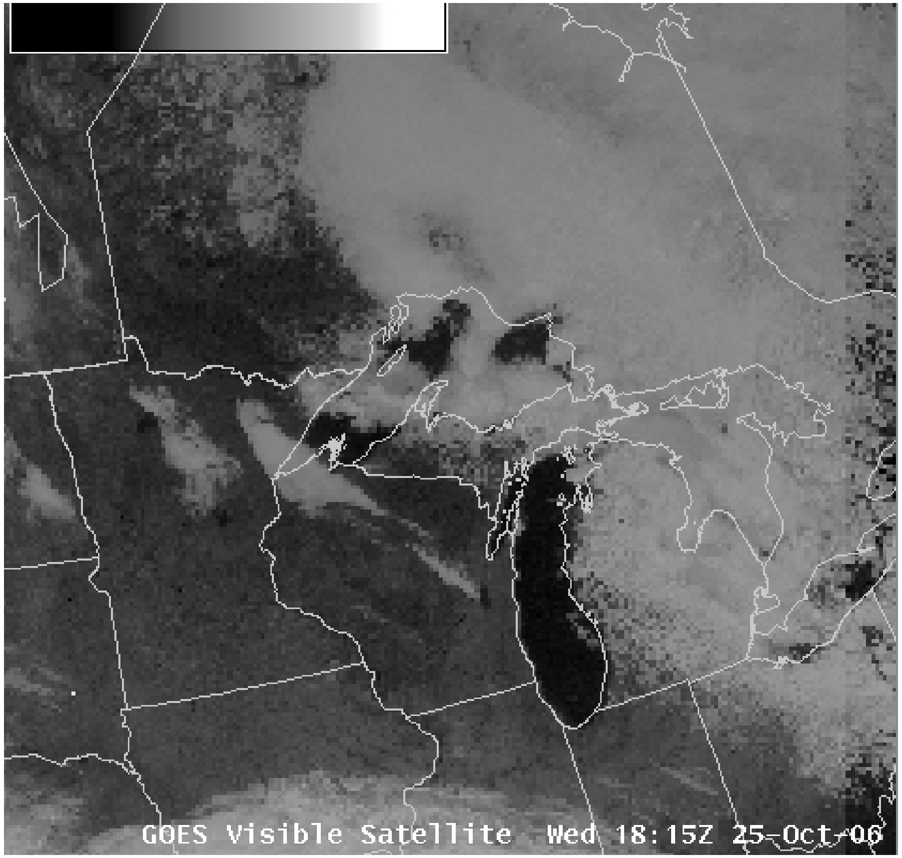
GOES visible channel

MODIS Imagery in AWIPS

Band 1: Visible channel (0.6μm)



MODIS visible channel



GOES visible channel

MODIS Imagery in AWIPS

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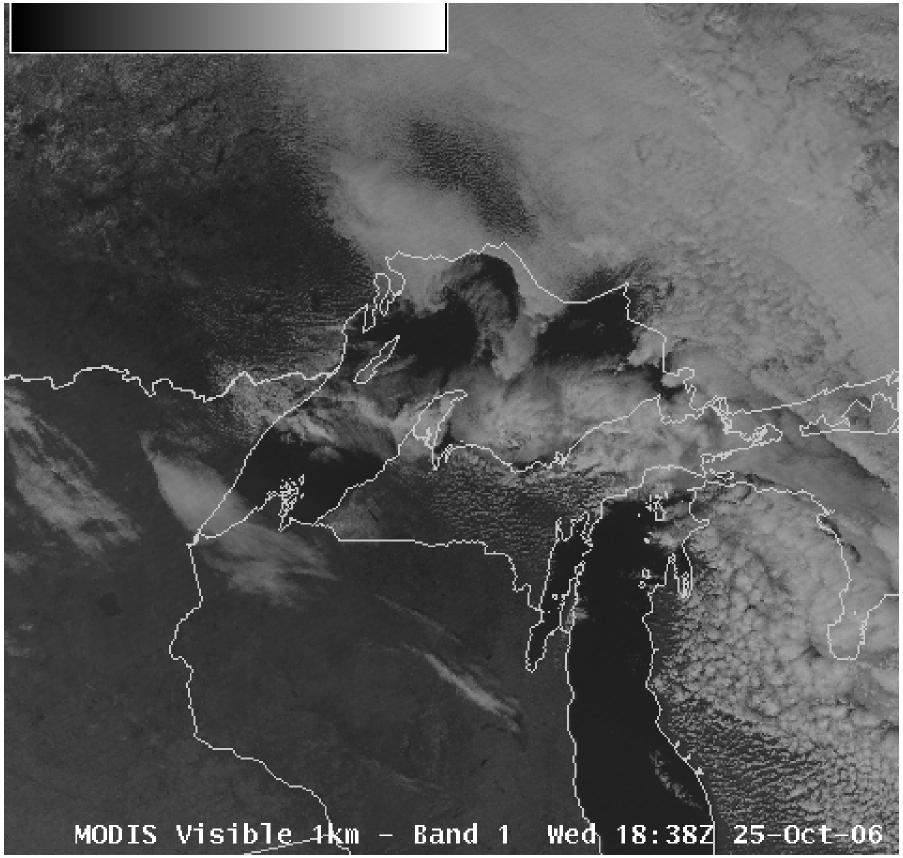
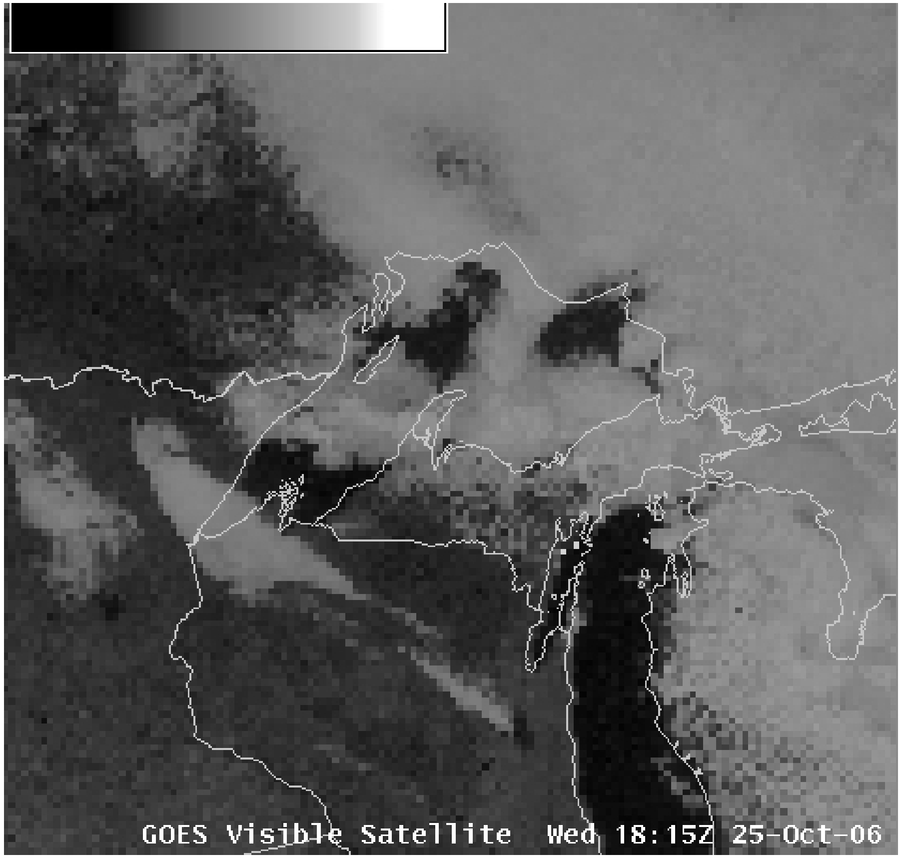


MODIS visible channel



GOES visible channel

MODIS Imagery in AWIPS

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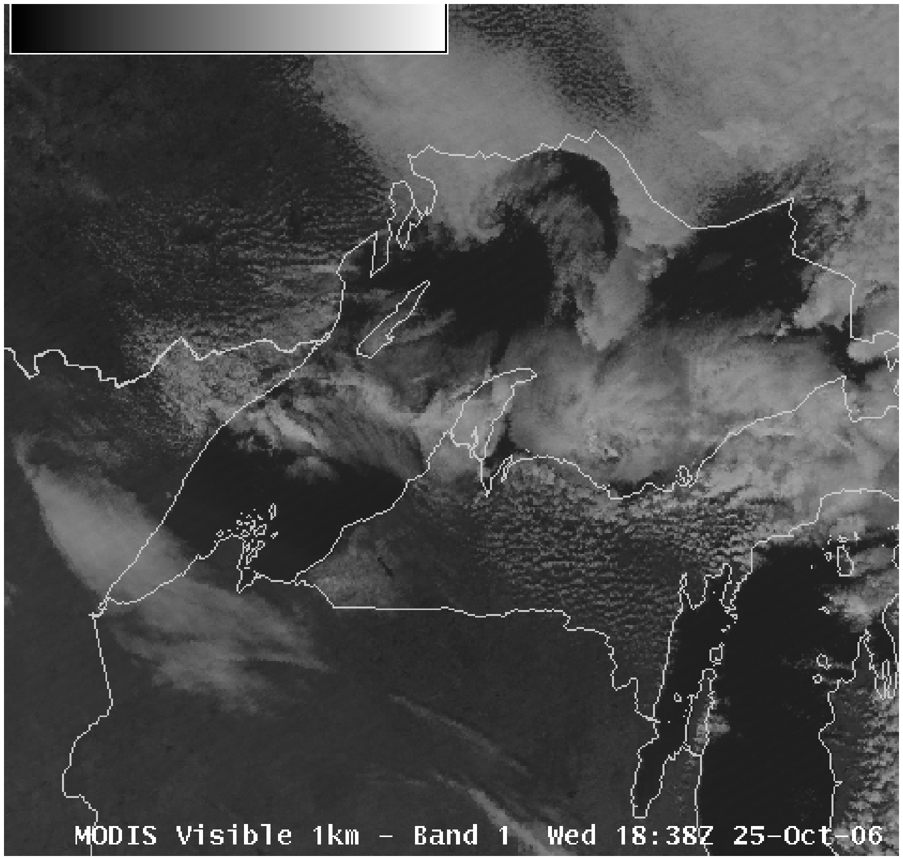
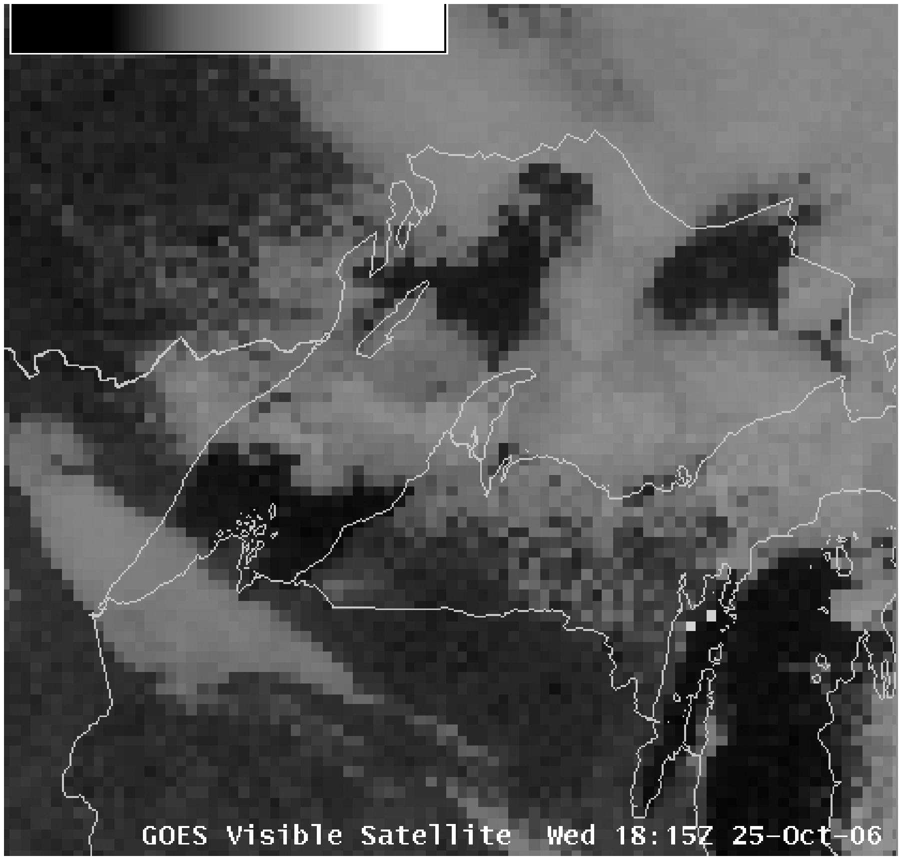
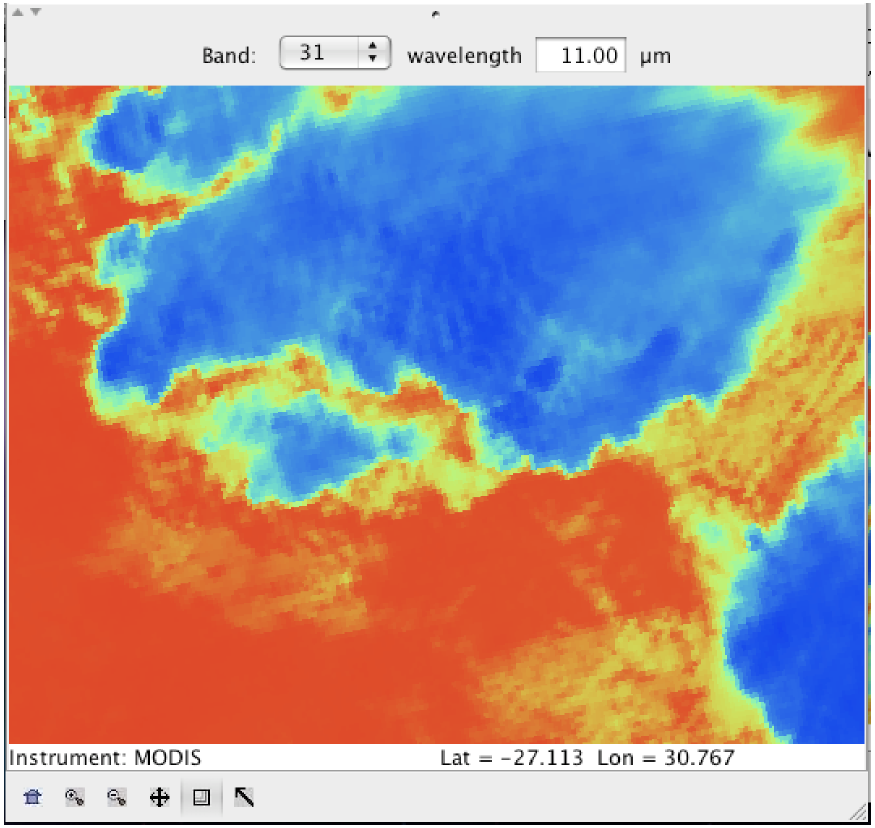


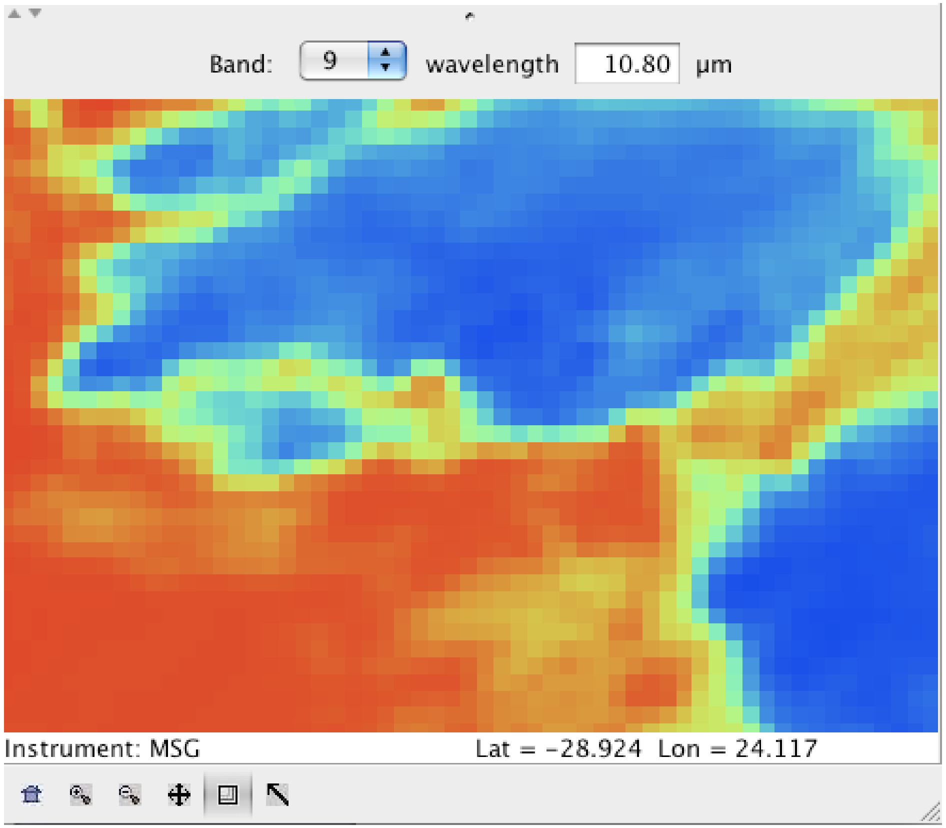
MODIS visible channel



GOES visible channel

MODIS versus SEVIRI





How Important Is Spatial Resolution?

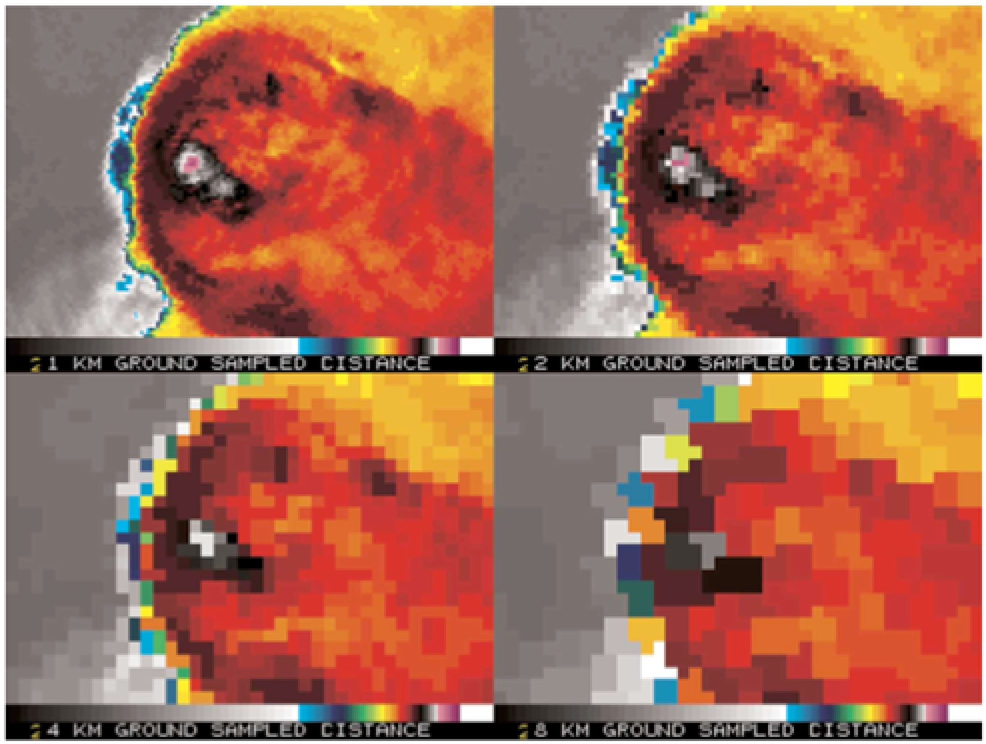


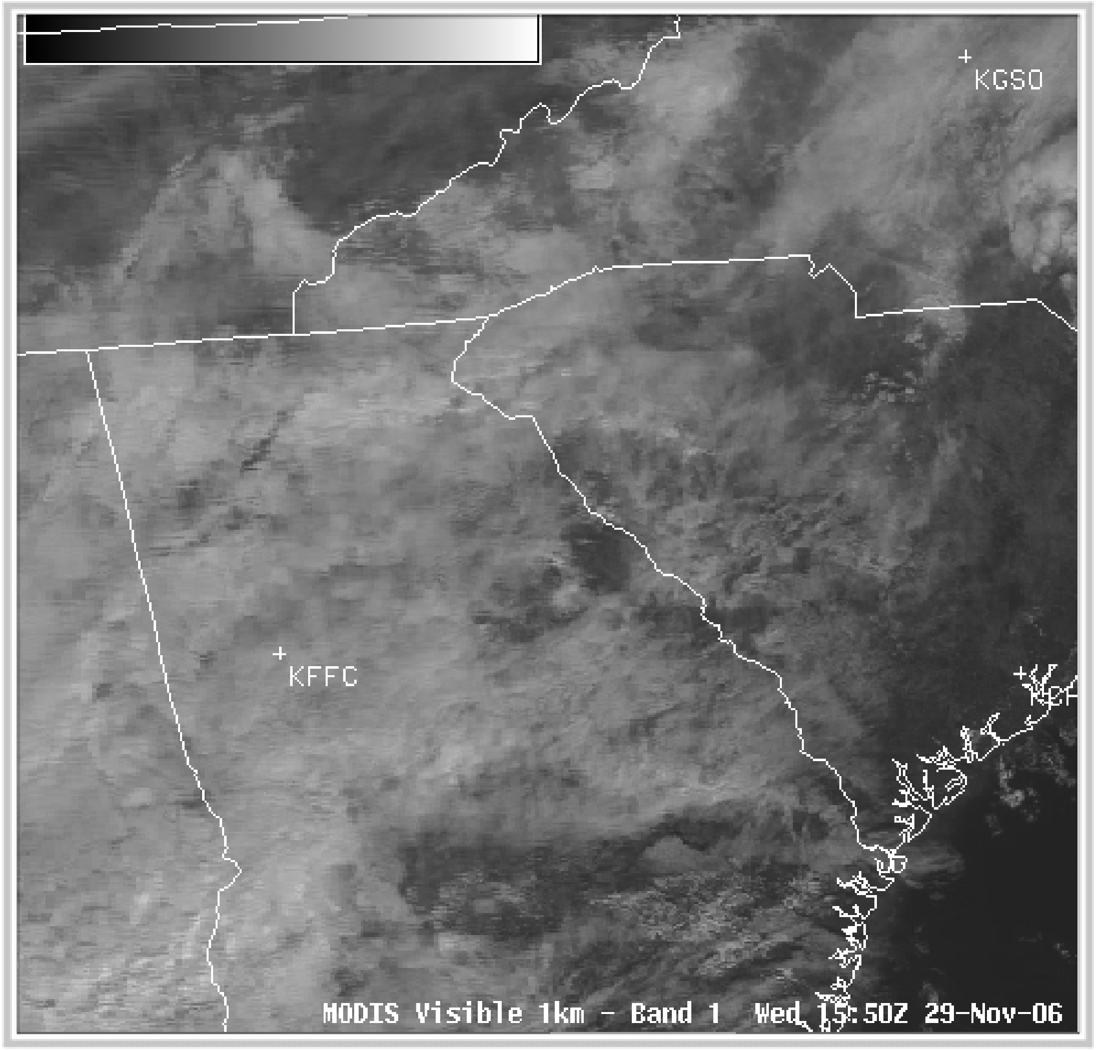
FIG. 3. Zoomed-in image of an enhanced-V feature located over northeast OK observed from enhanced LEO satellite imagery at 2218 UTC 6 May 2003 for 1-, 2-, 4-, and 8-km ground-sampled distances. The purple and white colors in the location of the updraft and overshooting top represent colder BTs, while the surrounding black and red colors represent warmer BTs.

A Quantitative Analysis of the Enhanced-V Feature in Relation to Severe Weather Jason C. Brunner, Steven A. Ackerman, A. Scott Bachmeier, and Robert M. RabinWeather and Forecasting Volume 22, Issue 4 (August 2007) pp. 853–872

Example of Increased Spectral Resolution

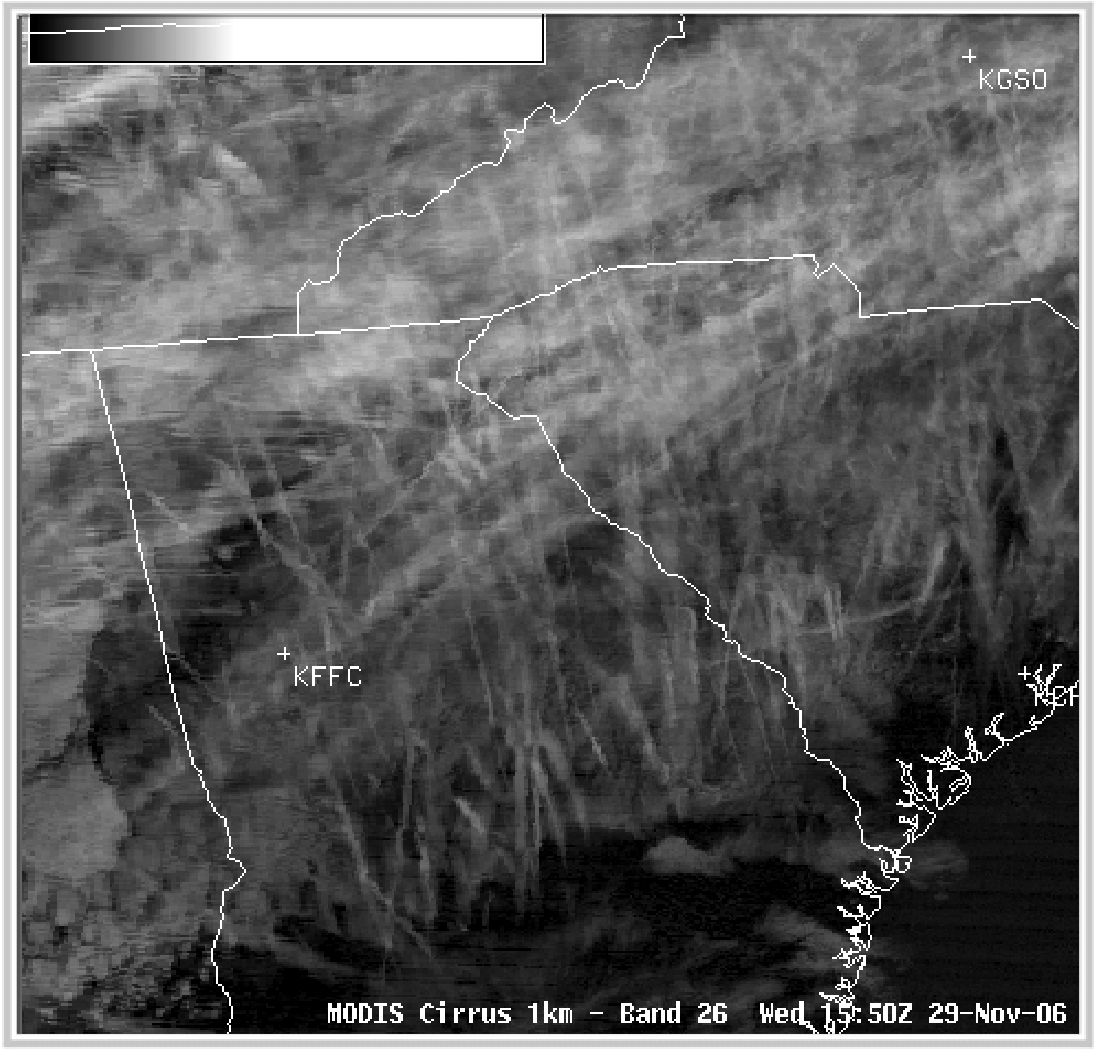
MODIS Imagery in AWIPS

Band 26: Cirrus detection (1.38 μm)



MODIS Imagery in AWIPS

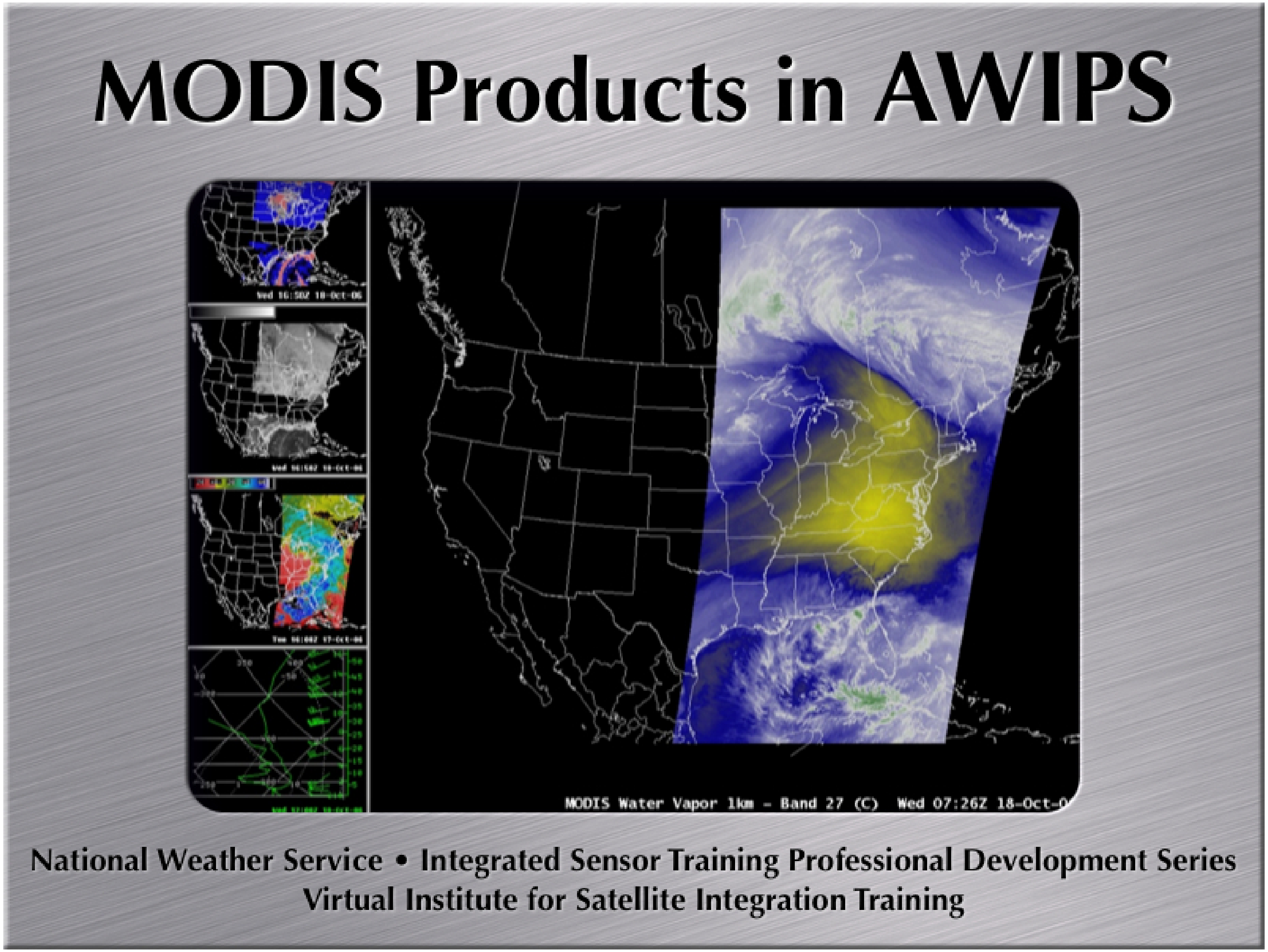
Band 26: Cirrus detection (1.38 µm)



Can Polar Orbiter Data Really Be That Useful to Forecasters?

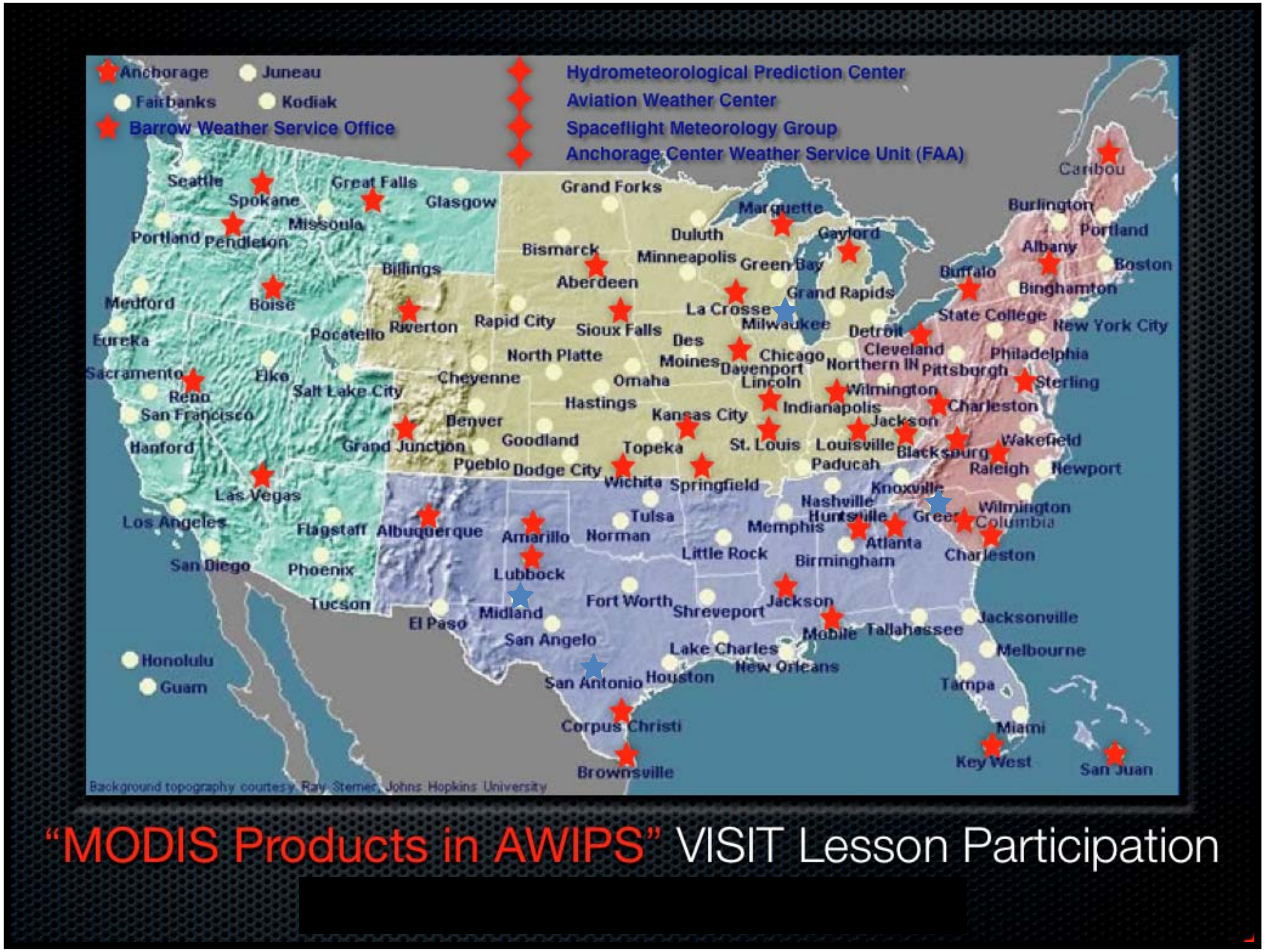
US National Weather Service

- University of Wisconsin providing Direct Broadcast MODIS products NWS in June 2006
- Reflectances and Brightness Temperatures
    - Bands 1 (.68 μm), Band 26 (1.38 μm), Band 7 (2.1 μm)
    - Band 20 (3.7 μm), Band 27 (6.7 μm), Band 31 (11 μm)
- Products
  - 1 km
    - Sea Surface Temperature, NDVI, Land Surface Temperature, Fog Product
  - 5 km
    - Cloud Top Pressure, Total Precipitable Water, Cloud Phase
- True Color 250 m Imagery



Virtual Institute for Satellite Integration Training (VISIT) lesson - offered since October 2006

MODIS Products in AWIPS



53 NWS forecast offices participating so far

MODIS Products in AWIPS

AREA FORECAST DISCUSSION
NATIONAL WEATHER SERVICE MILWAUKEE / SULLIVAN WI
436 AM CDT WED JUL 16 2008

WEAK BOUNDARY VCNTY OF KMTW EXPCD TO SAG SLOWLY SOUTHWARD THIS MORNING WITH LIGHT SOUTHWEST WINDS BECOMING NORTHEAST AND THEN SOUTHEAST. WIND SPEEDS SHOULD BE MOSTLY LIGHT...LESS THAN 10 KNOTS...HOWEVER BRIEF GUSTINESS POSSIBLE AS BOUNDARY MOVES THROUGH. PER LATEST MODIS SST IMAGES...NEARSHORE HAS WARMED SEVERAL DEGREES FROM EARLIER UPWELLING EPISODE...NOW GENERALLY IN THE LOWER TO MIDDLE 50S. WITH INLAND DEWPOINTS IN THE MIDDLE 60S...WILL NEED TO WATCH FOR PATCHY FOG AS WINDS TURN ONSHORE.

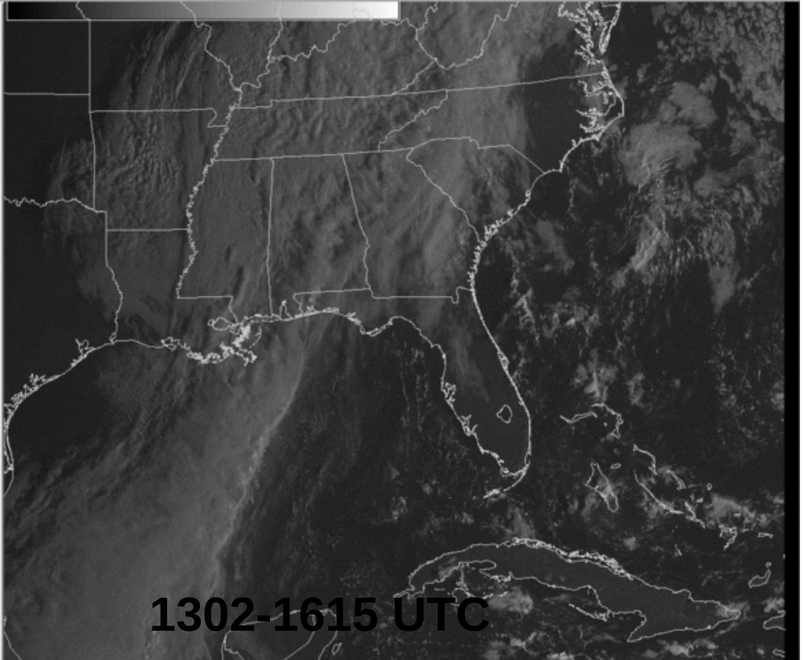
MODIS has been mentioned in 88 NWS Area Forecast Discussions so far

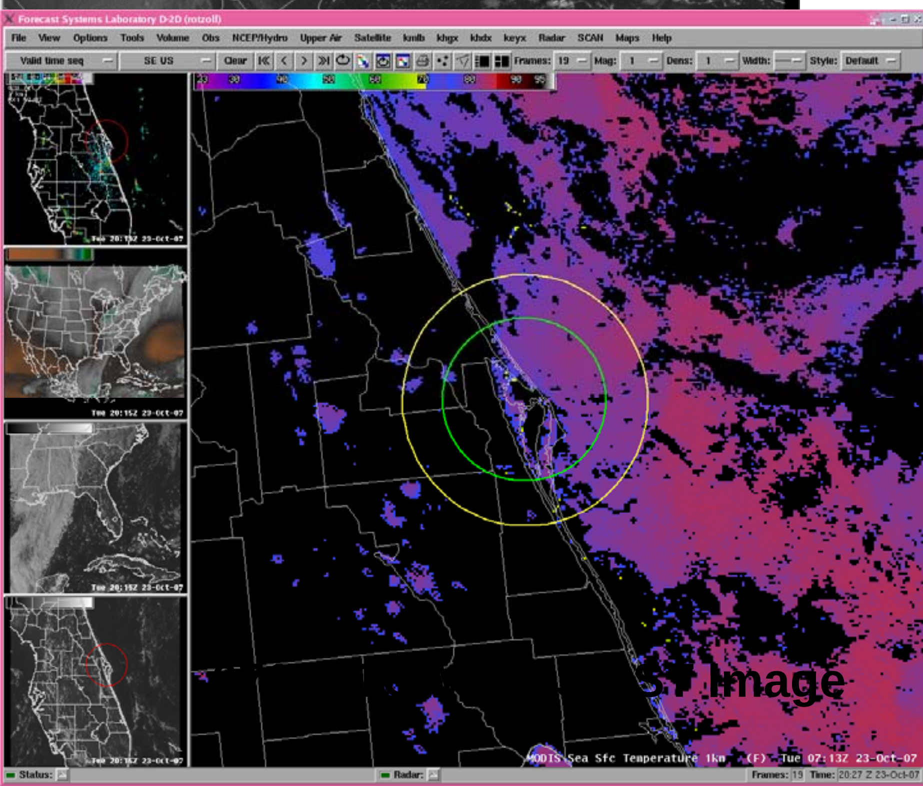
MODIS Products in AWIPS

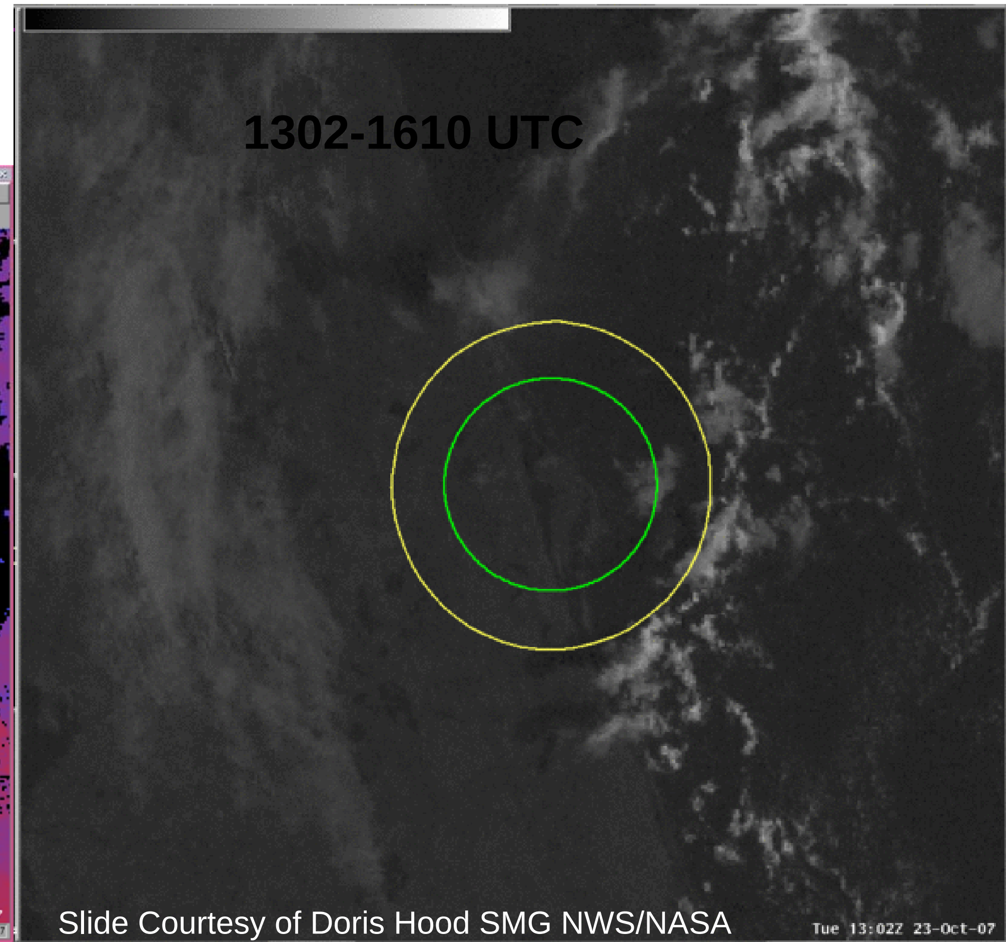
AREA FORECAST DISCUSSION
NATIONAL WEATHER SERVICE RENO NV
337 AM PST TUE NOV 4 2008

ANOTHER BIG STORY WITH THIS LOW HAS BEEN THE WINDS WITH MANYLOCATIONS REMAINING QUITE WINDY OVERNIGHT AS THE COLD FRONTPASSED. HIGH RES MODIS WATER VAPOR IMAGERY SHOWS GOOD MOUNTAIN WAVE ACTIVITY ALONG THE SIERRA AS THE SUPPRESSED TROPOPAUSE MOVED THROUGH OVERNIGHT. THIS UPPER FEATURE LIKELY HELPED TO DUCT STRONGER WINDS ALOFT DOWN TO THE SURFACE IN THE STABLE PRE-FRONTAL ENVIRONMENT SOUTH OF THE RENO AND TAHOE AREAS.

Support for Space Shuttle Launch Oct 23, 2007 1038 am CDT







Nighttime Fog Detection

Nighttime Fog Detection

- Why is This Important?
  - Low visibilities and low cloud ceilings can be hazardous to transportation operators on land, sea and air

FleetWatch 2005

THE DEFINITIVE TRUCKING SITE

Past Issues — August 2005

BEWARE THE FOG

Summertime in South Africa is a dangerous season for road users. The rain pelts down, the roads get slippery, the December holidays bring greater volumes of traffic on our national roads and the festive season pours hordes of drinkers behind their steering wheels. When one considers winter time on our roads, one imagines the odd bit of ice or snow here and there with not much else to pose an 'out-of-the-ordinary' threat to road safety. How wrong this is! A recent report of an accident on the N12 suggests that winter may be even 'sillier' than summer' and highlights the need for drivers to exhibit extreme caution and slow down their speed when they come into foggy or misty conditions writes *Paul Collings*.

The N12 between Mpumalanga and Gauteng is a well traversed heavy truck route. Witbank is a mining town on this route and famous for its coal and other raw materials. For some reason, it hasn't been famous for its fog - until now that is.

On Thursday July 28th, in a fog bank where visibility was down to 2m on certain stretches of the N12, 12 trucks and two light vehicles were involved in a pile-up. Thankfully, no one was killed but there were several seriously injured drivers and passengers. The cost to the vehicle owners is still being tallied but you can bet your bogey, accidents like these don't come cheap. **(pictures at the bottom of this page)**

According to SAPS Inspector Benny Kotze, "there's a 20km stretch of the N12 as it passes through Witbank where the fog gets very dense. Visibility is always limited and on that particular day, it was reduced to between 50m and 2m."

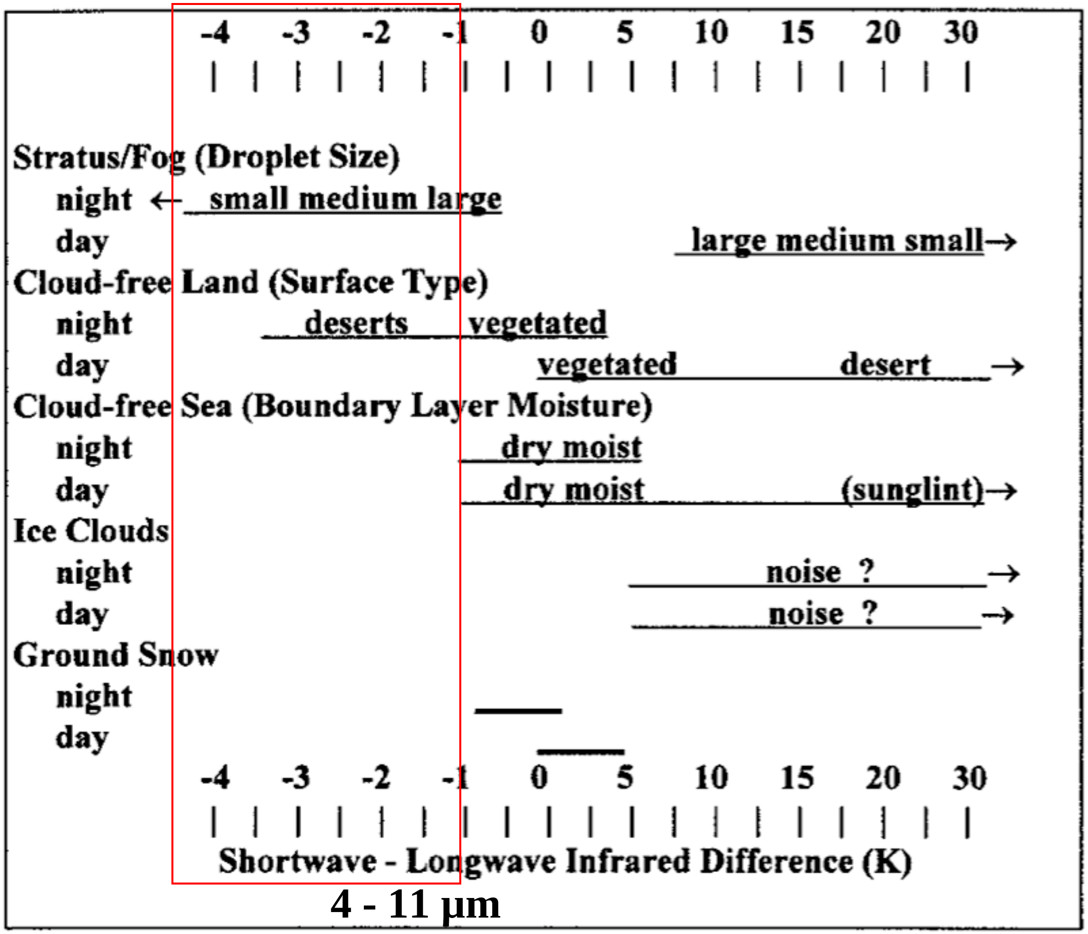
Fog/Stratus Algorithm

- Simple Brightness Temperature Difference
  - 4 µm - 11 µm Brightness Temperature Difference (BTDIF)
- Takes advantage of water cloud emissivity difference between the wavelengths
  - 4 µm opaque water cloud emissivity less than 1
  - 11 µm opaque water cloud emissivity $\approx$ 1
  - Leads to water cloud 4 µm BT < 11 µm BT
- Simple threshold < -1 means opaque water cloud
  - BTDIF image enhancement leads to quick stratus cloud and/or fog identification (orange, red to purple)

Fog/Stratus Algorithm (2)

- Nighttime only
  - Solar reflectance component can dominate 4 μm signal

4-11 micron BTDIF



Lee, T. F., F. J. Turk, and K. Richardson, 1997: Stratus and fog products using GOES-8-9 3.9 µm data. Wea. Forecasting, 12, 664-677.

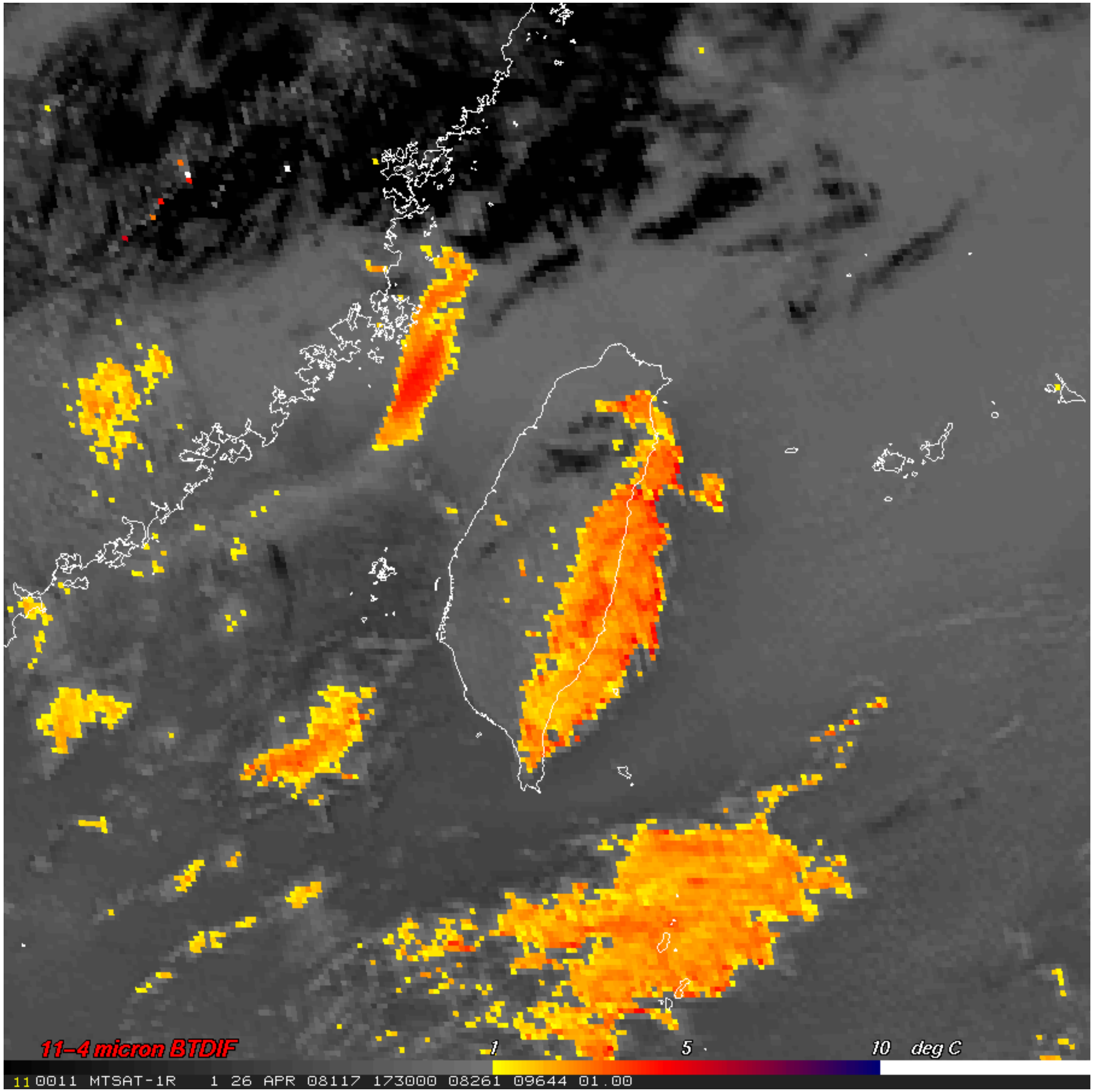
Algorithm Limitaions

- Silicate soils
  - Emissivity variations in silicate soils can cause false positives
- Higher layer clouds obscure low cloud signal
- Single detection threshold

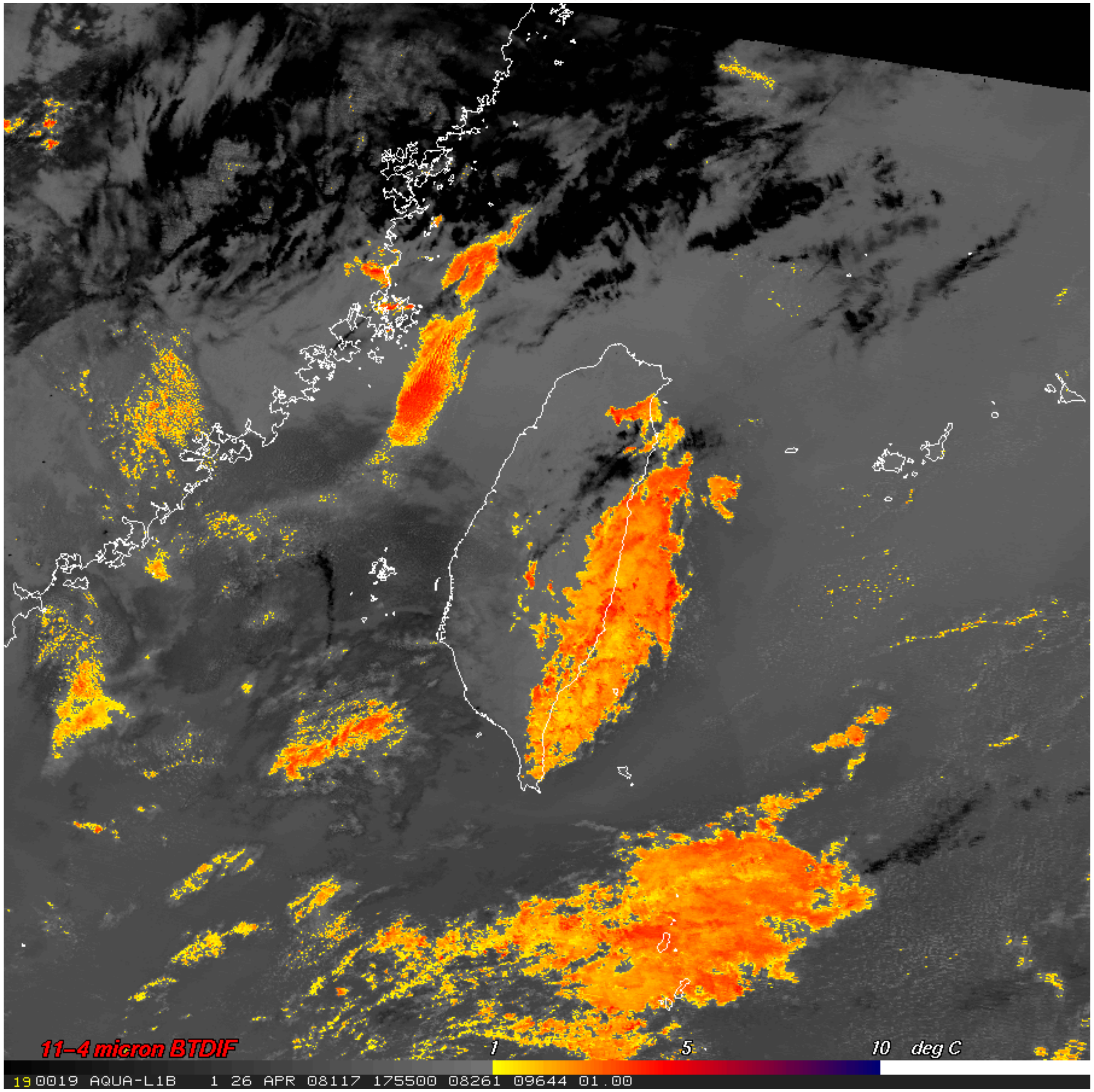
Algorithm Strengths

- Easy to implement
- Validated
  - Used by US National Weather Service for many years
- Provides nighttime information when:
  - No visible data
  - Temperatures of surface and cloud layers can be very close
- Implementation on Geo and Leo means it combines the strengths of both instruments
  - High temporal resolution of METEOSAT
  - High spatial resolution of MODIS

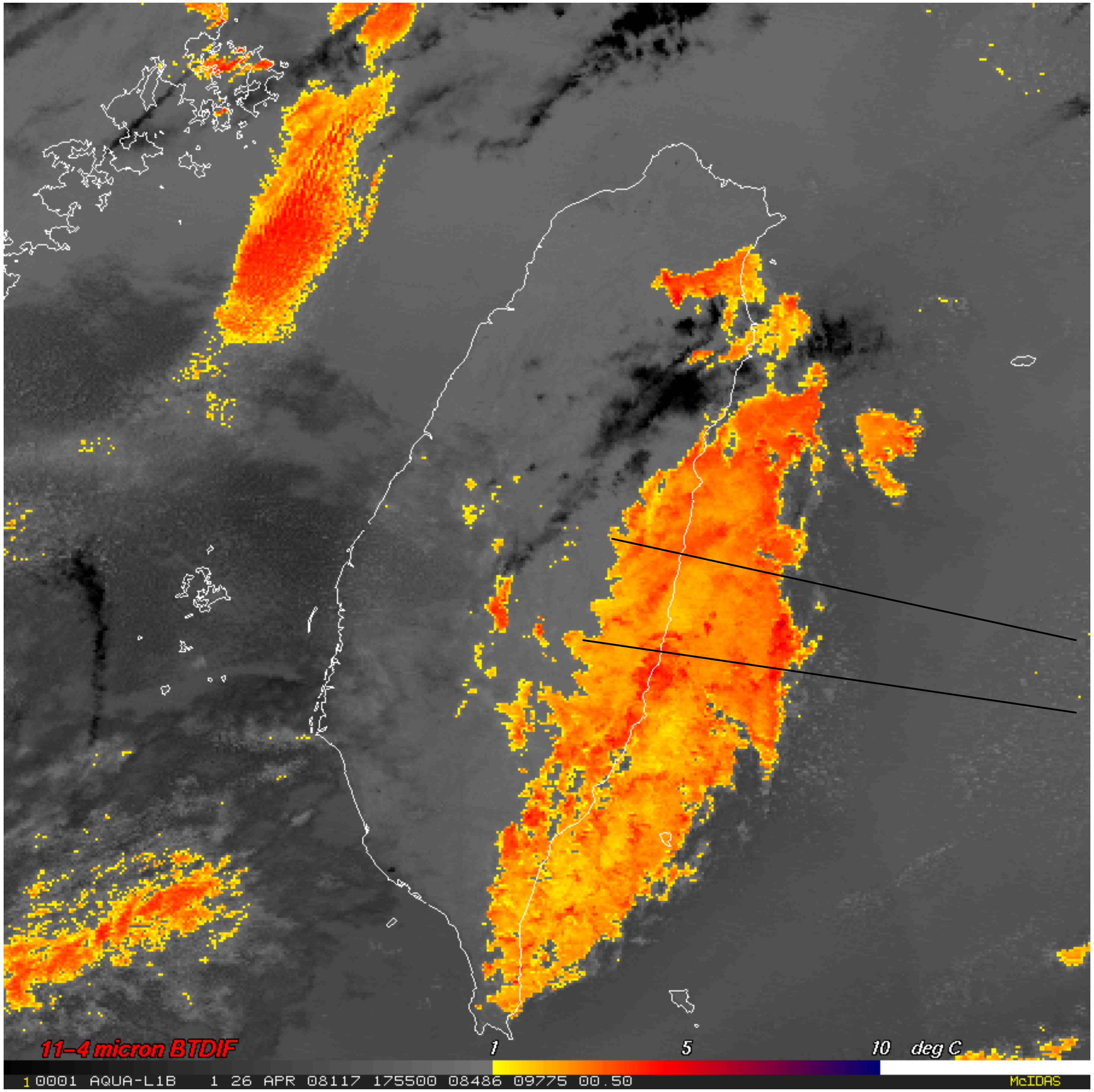
Example MTSAT Low Cloud Fog Product



Example MODIS Low Cloud Fog Product

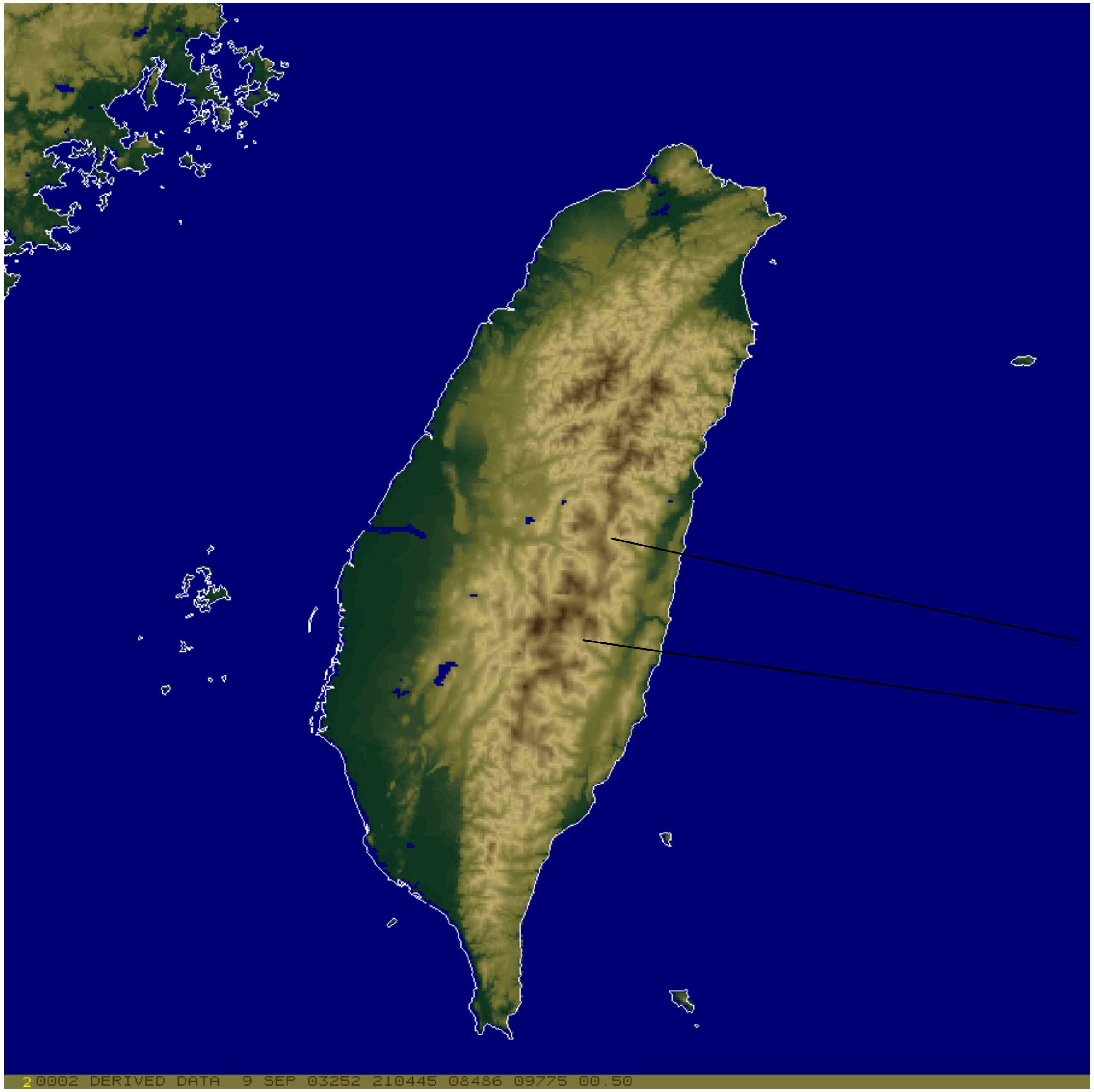


MODIS Fog and Topography



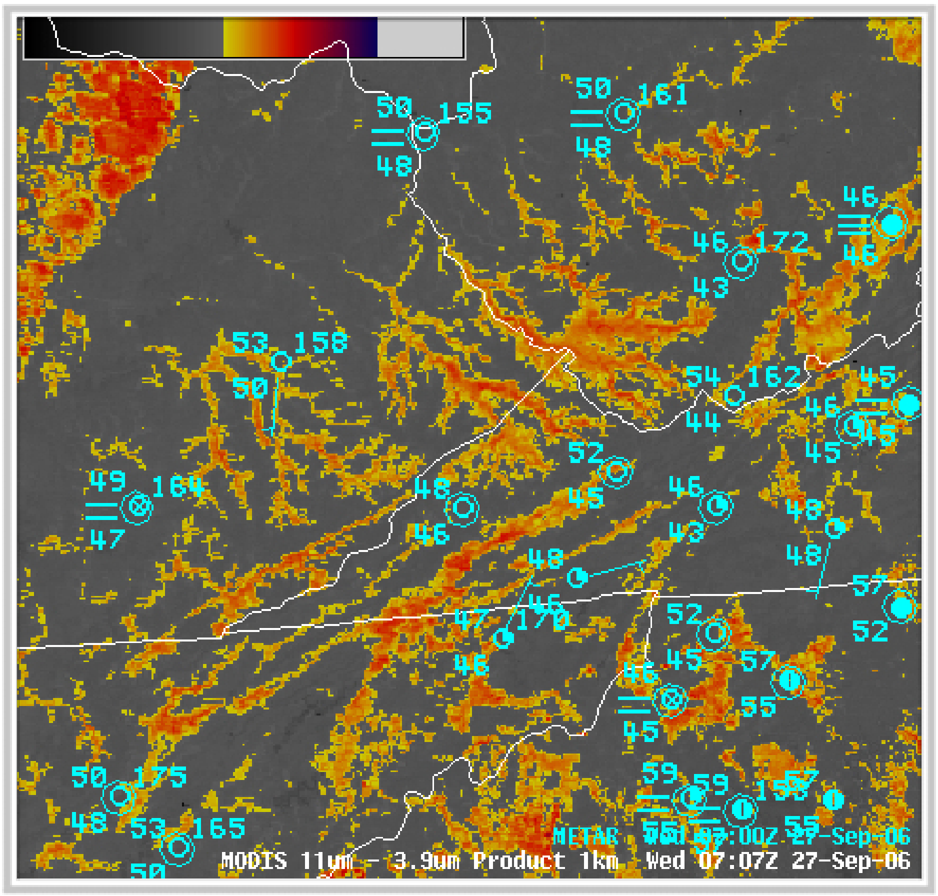
Fog entering into valleys

MODIS Fog and Topography

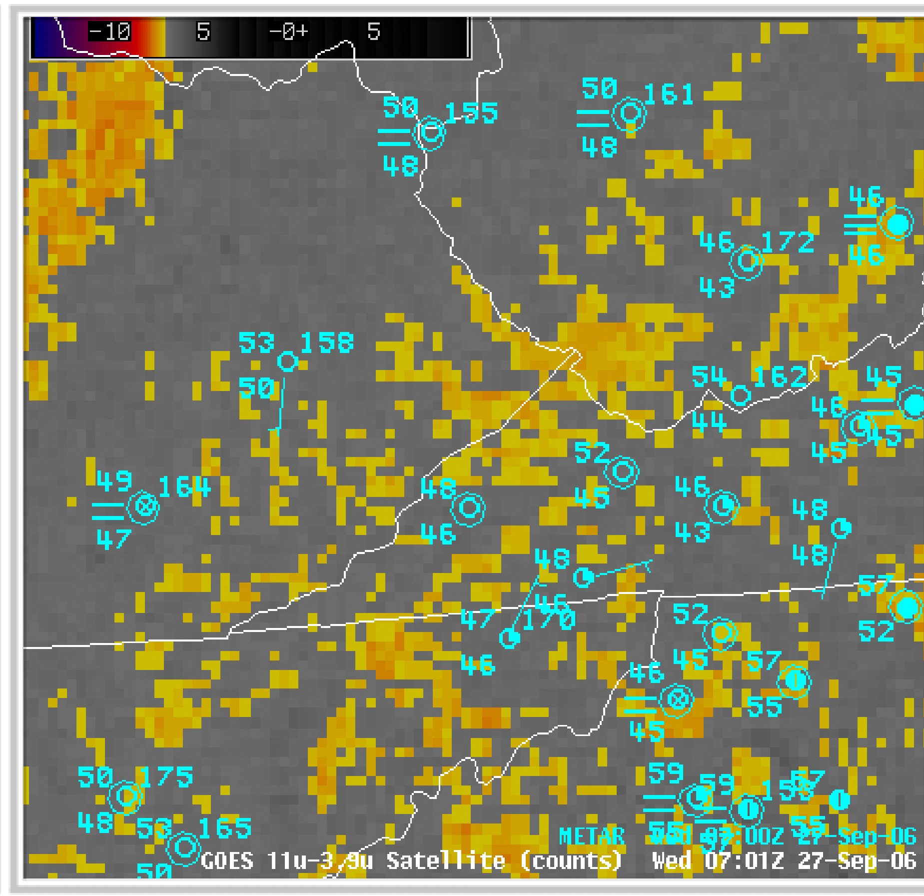


MODIS Imagery in AWIPS

Fog/stratus product (11.0µm - 3.7µm)



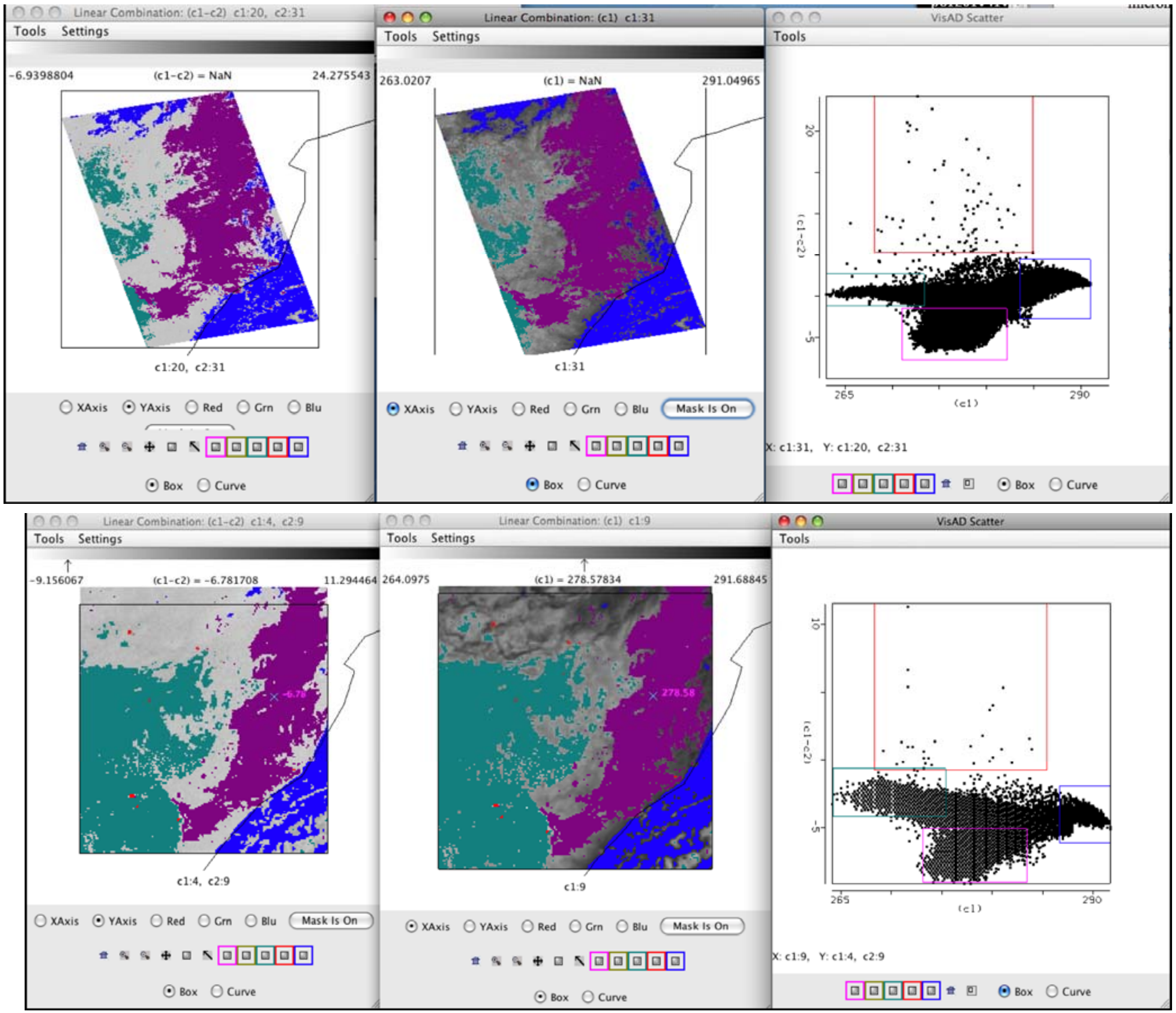
1-km MODIS



4-km GOES

Improved fog/stratus detection capability

MODIS and SEVIRI Fog Detection



Is This Product Useful?

Case Example of the Utility of the GOES Aviation Fog Depth and Low Cloud Base and MODIS Fog Products by the NWS Albuquerque, NM Weather Forecast Office

Date of the Event: January 7, 2009

AREA FORECAST DISCUSSION
NATIONAL WEATHER SERVICE SPOKANE WA
249 AM PST WED FEB 20 2008

.DISCUSSION...
TODAY AND TONIGHT...LOOKS LIKE A FAIRLY QUIET PERIOD. ONLY FEATURE ON SATELLITE THIS MORNING WAS NEGATIVELY TILTED BAND OF MID/HIGH CLOUDS EXTENDING FROM THE SOUTHERN TIP OF VANCOUVER ISLAND TOWARD THE NE CORNER OF OREGON. …… MAIN FORECAST PROBLEM FOR TODAY WILL BE WHAT TO MAKE OF FOG. THUS FAR...FOG FORMATION HAS BEEN SOMEWHAT MINIMAL...AT LEAST ACCORDING TO THE CONVENTIONAL 4KM FOG PRODUCT. FORTUNATELY THE 1KM FOG PRODUCT FROM THE MODIS POLAR ORBITER DEPICTED A MUCH NICER PICTURE WITH AREAS OF FOG OVER THE VALLEYS IN NORTH IDAHO EAST OF COEUR D'ALENE AS WELL AS SOME BY PRIEST LAKE AND NORTH OF DEER PARK. THERE WAS ALSO ANOTHER POCKET OF FOG BETWEEN RITZVILLE AND SPRAGUE IN THE EASTERN COLUMBIA BASIN.

Is This Product Useful?

- Operational Fog Detection System was Installed at the Taiwan Central Weather Bureau in November 2009

References

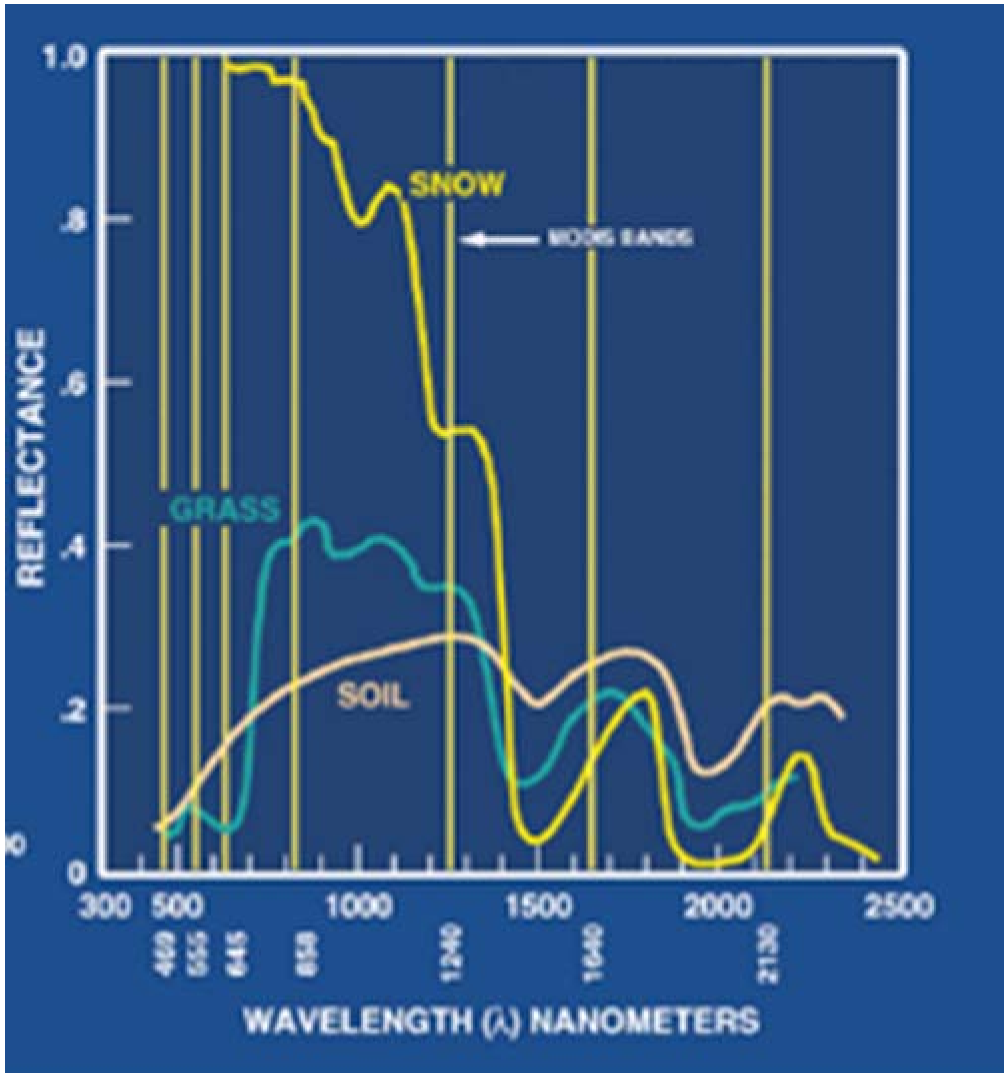
- Ellrod, Gary P. and A. Scott Bachmeier, 2003: Inter-comparison of GOES and MODIS Imagery in the Analysis of Fog and Stratus, 12 Conference on Satellite Meteorology and Oceanography, P1.15, Long Beach California.
- Eyre, J. R., J. L. Brownscombe, and R. J. Allam, 1984: Detection of fog at night using Advanced Very High Resolution Radiometer (AVHRR) imagery. Meteorological Magazine, 113, 266-275.
- Lee, T. F., F. J. Turk, and K. Richardson, 1997: Stratus and fog products using GOES-8-9 3.9 μm data. Wea. Forecasting, 12, 664-677.

Snow and Ice Detection

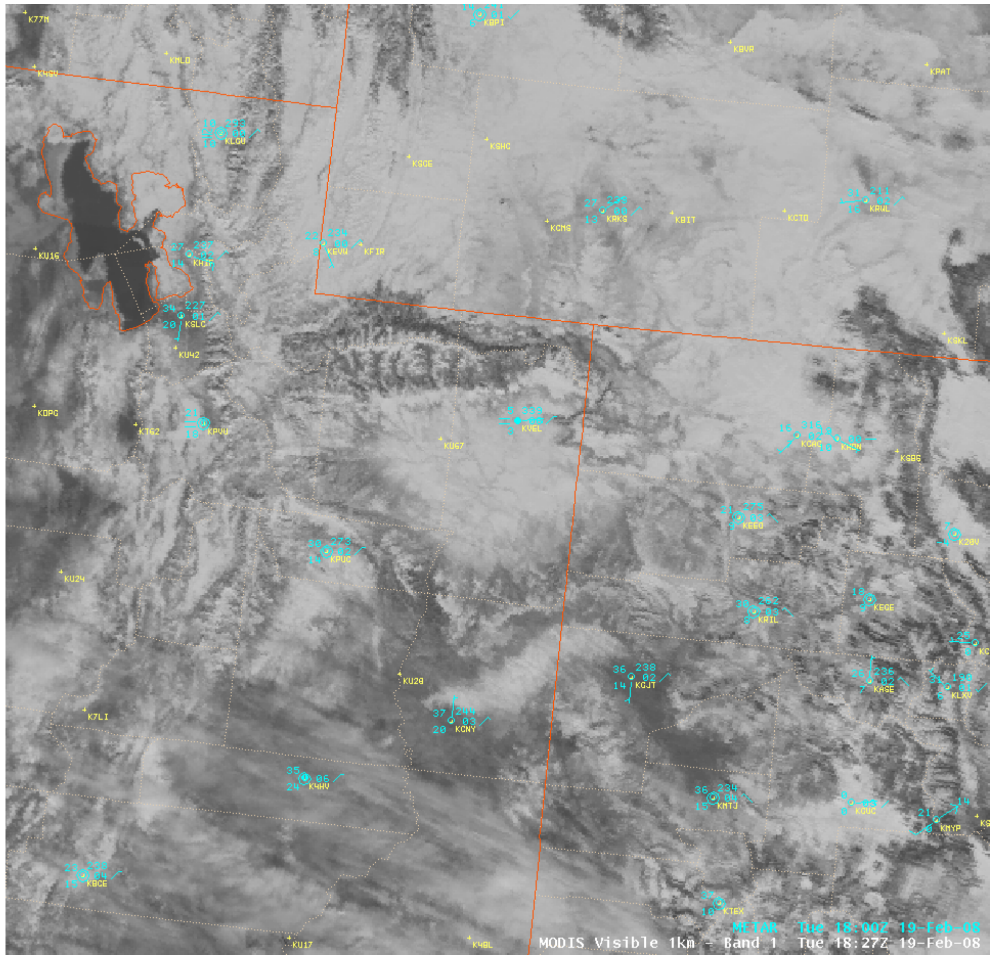
Snow and Ice Detection

- Take advantage of change of absorption properties of snow and ice in visible and near-infrared region
- Normalized Difference Snow Index (NDSI)
  - analogous to the normalized-difference vegetation index (NDVI)
  - Snow has strong visible reflectance but absorbs strongly in the short-wave IR
    - Band 4 (.56µm) – Band 6 (1.6µm) (or 7 -2.1µm for Aqua) ---
    - Band 4 (.56µm) + Band 6 (1.6µm) (or 7 - 2.1µm for Aqua)
  - Hall DK, Riggs GA, Salomonson VV. 1995. Development of methods for mapping global snow cover using Moderate Resolution Imaging Spectroradiometer (MODIS) data. *Remote Sensing of Environment* ***54: 127 – 140.***

MODIS – Snow/Ice and Ice Clouds



Discriminating Ice from Clouds



Why is this important?

Stellenbosch University student Johann Swart gets smothered with snow at the Matroosberg Nature Reserve. (Leanne Stander, Die Burger)

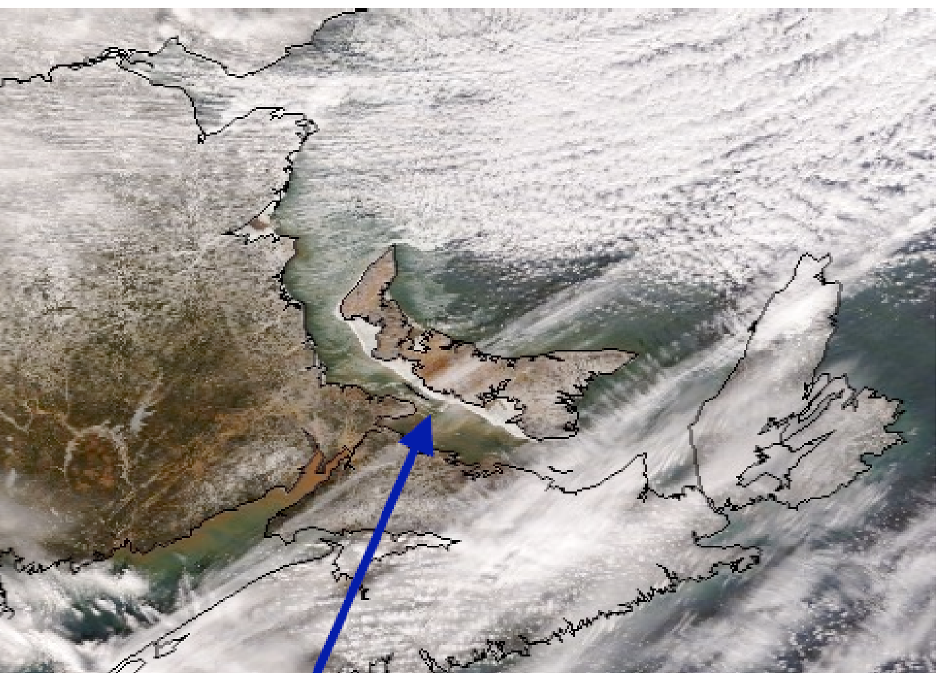
Canadian Ice Service integrates MODIS into operational data stream for ice monitoring

CIS data suite includes RadarSat and Envisat (SAR); AMSR, QuikScat and SSM/I (microwave); MODIS, OLS, NOAA and GOES (visible images).

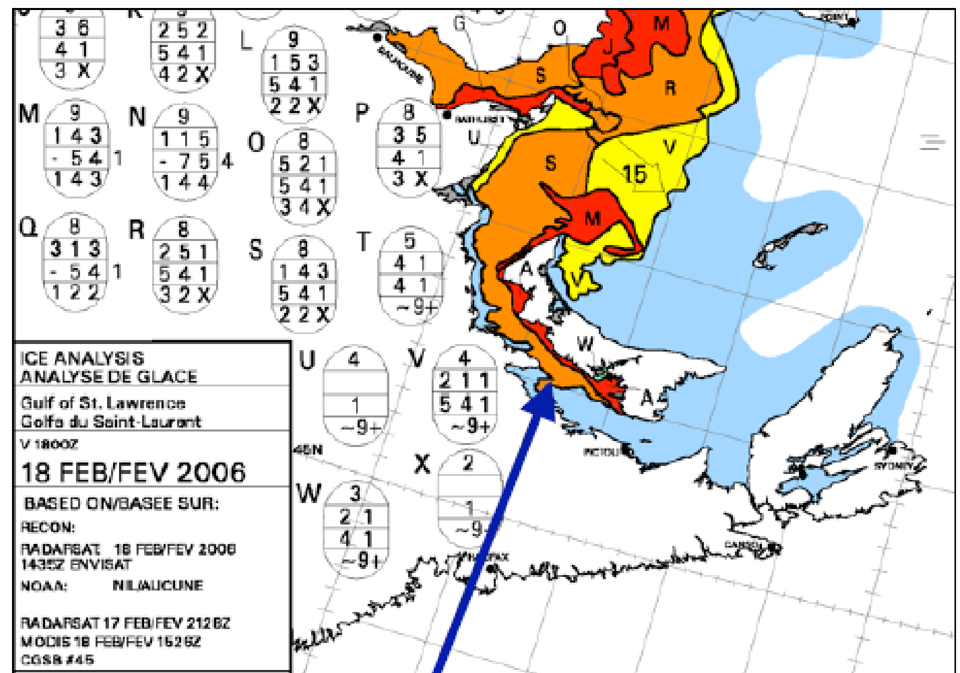
•MODIS supplements SAR data in clear sky conditions.

• 250 meter resolution true color GeoTIFF images are obtained daily from SSEC for Great Lakes, Hudson Bay, Labrador coast, and Gulf of St. Lawrence.

MODIS helps to define ice boundary along southern Prince Edward Island



MODIS DB image 2006/02/18 15:26 UTC



CIS Ice Analysis 2006/02/18

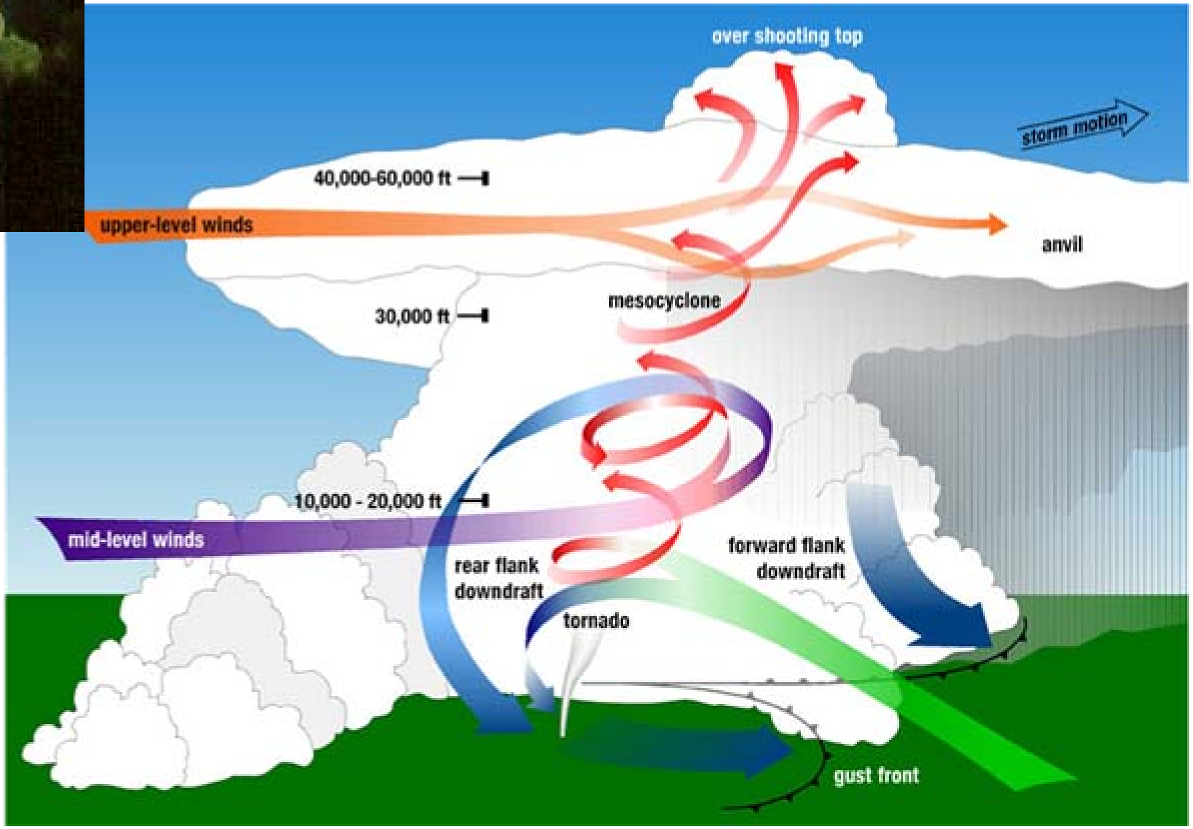
Severe Weather

Extreme Winds, Thunderstorms, Rainfall, Hail

Thunderstorms

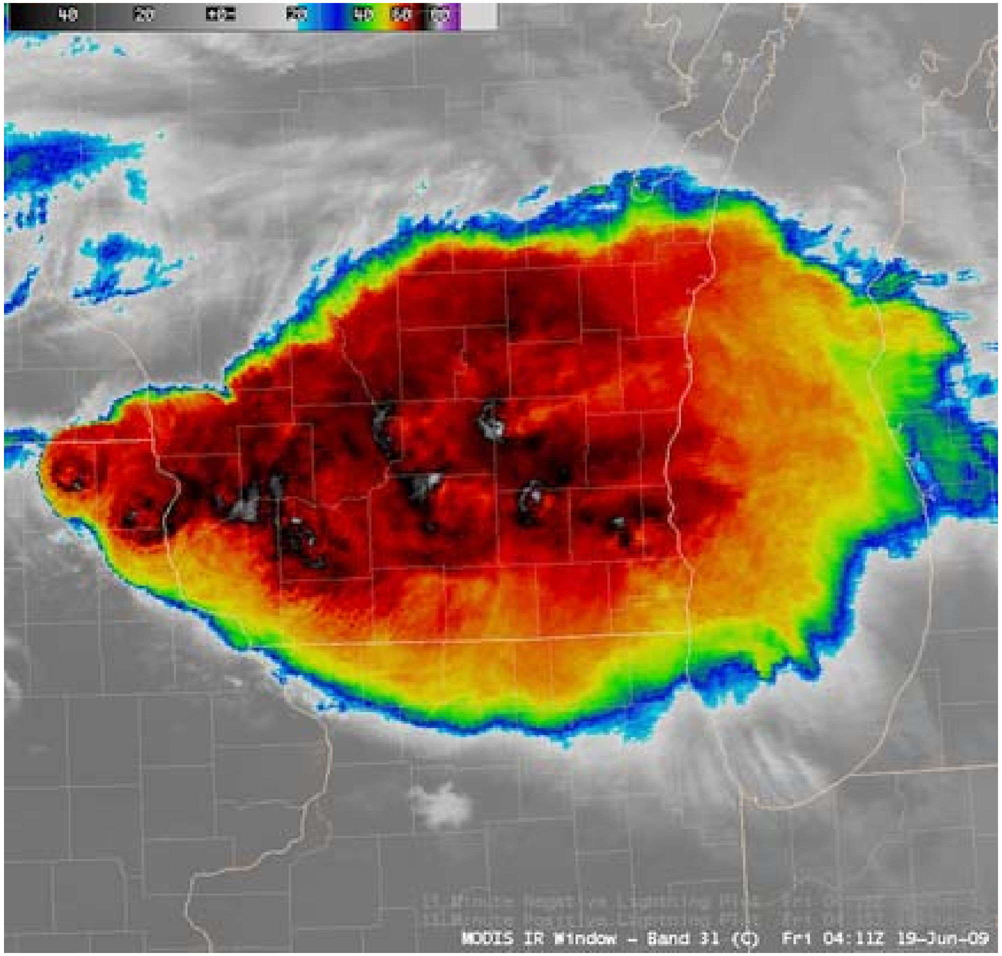
- Characteristics of Severe Weather as Observed from Satellite
  - Overshooting Tops
  - Gravity Wave Generation

Overshooting Top



A dome-like protrusion above a thunderstorm anvil, representing a very strong updraft and hence a higher potential for severe weather with that storm. A persistent and/or large overshooting top often is present on a supercell.

Severe Thunderstorm Example 2

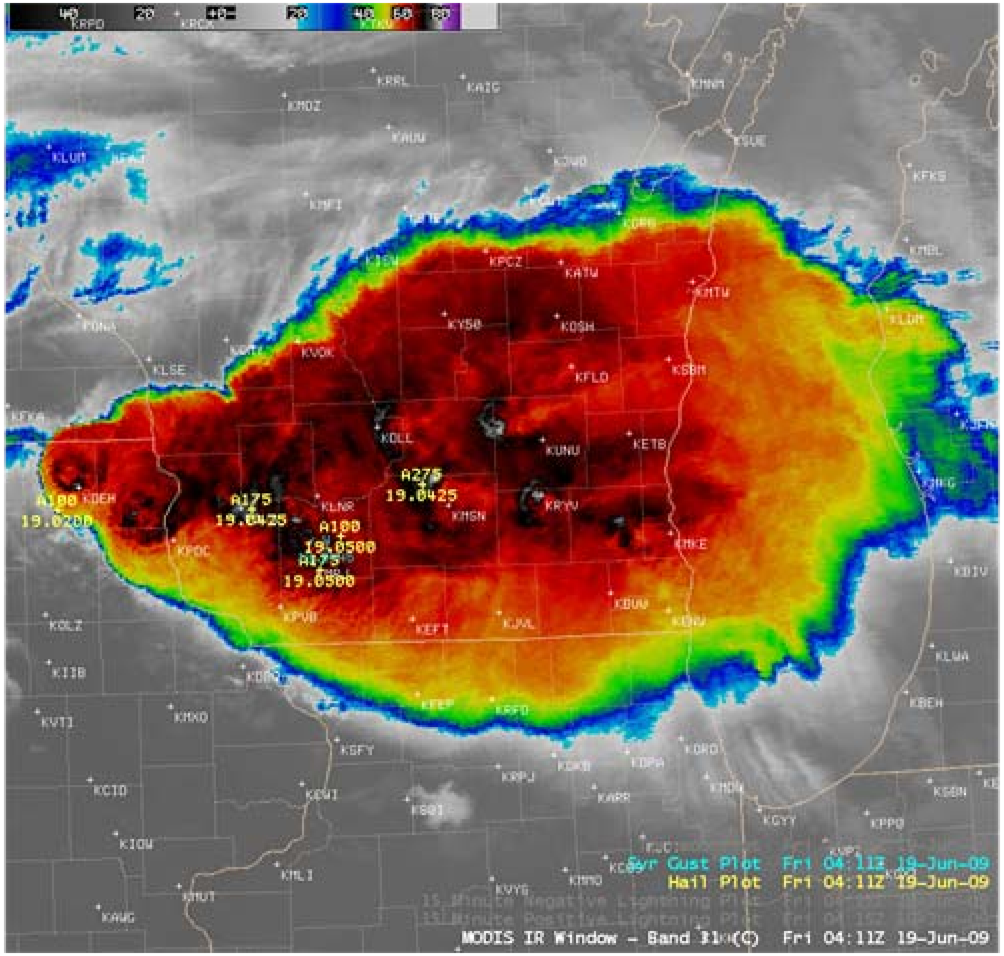


Including
Lightning
Detection

04:11 UTC
19 June 2009

During the 15-minute interval ending at 04:15 UTC this storm produced over 900 lightning strikes

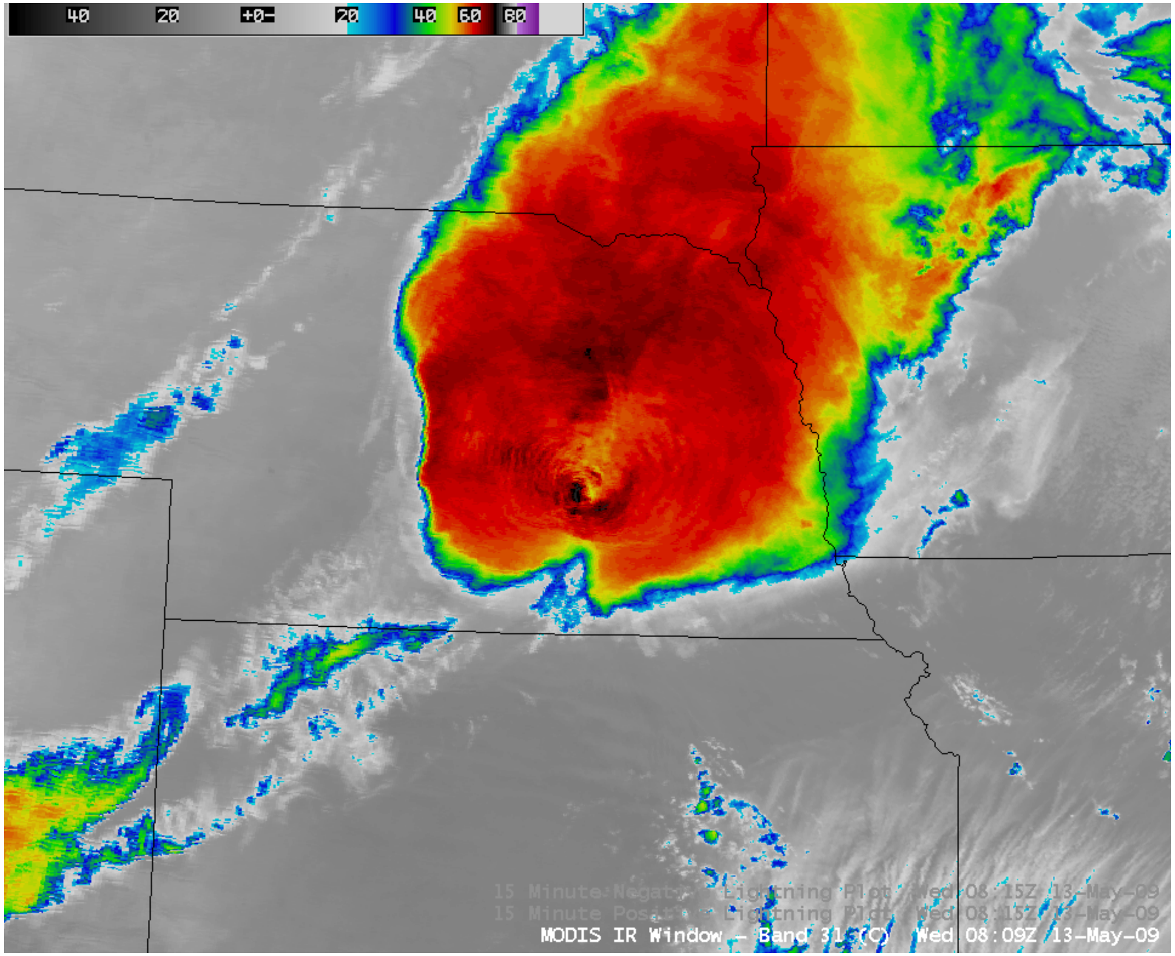
Severe Thunderstorm Example 1



Including Severe Winds and Hail Reports
04:11 UTC
19 June 2009

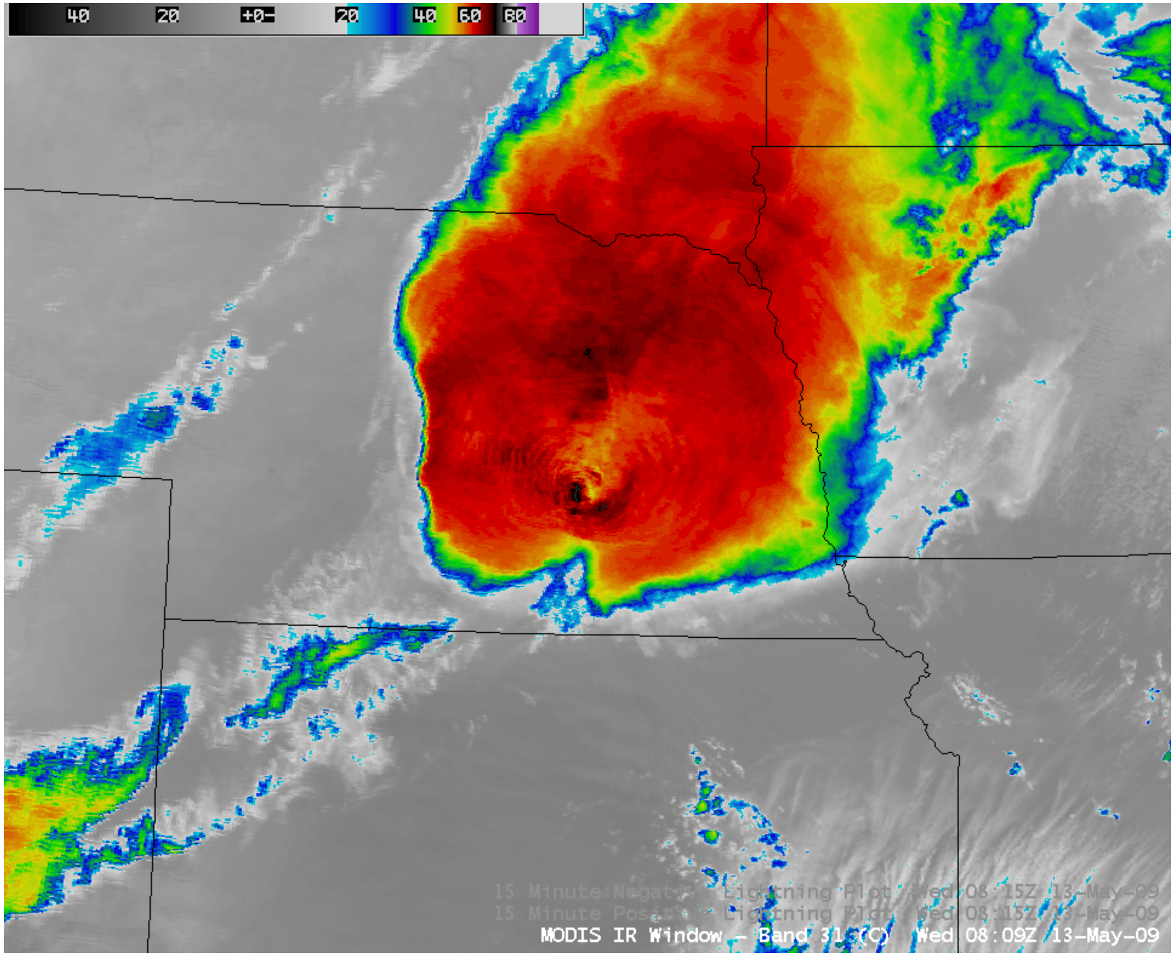
During the 15-minute interval ending at 04:15 UTC this storm produced over 900 lightning strikes

Severe Thunderstorm Case 2



Including
Lightning
and Hail
Reports
13 May 2009

Severe Thunderstorm Case 2

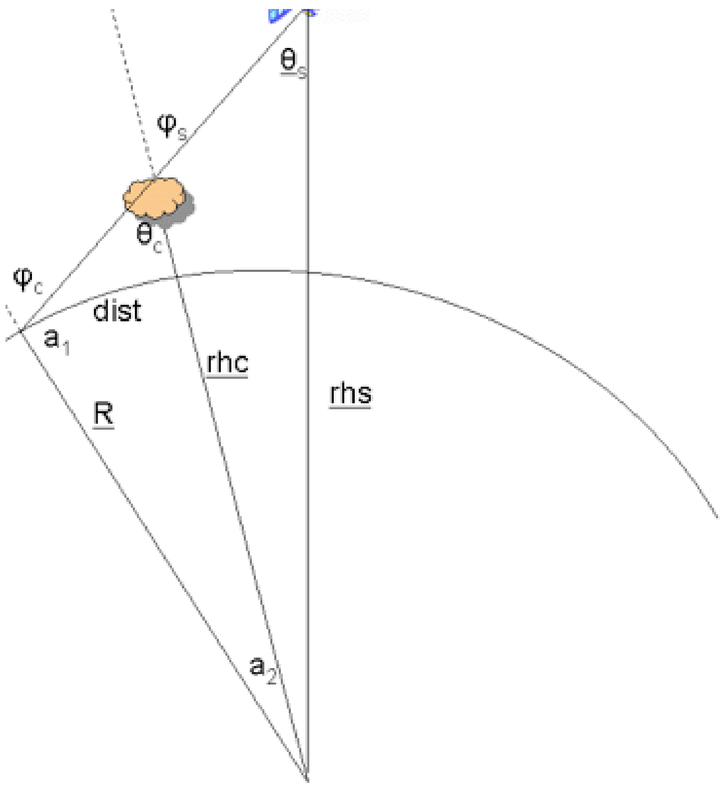


Comparison MODIS versus GOES 13 May 2009

Parallax

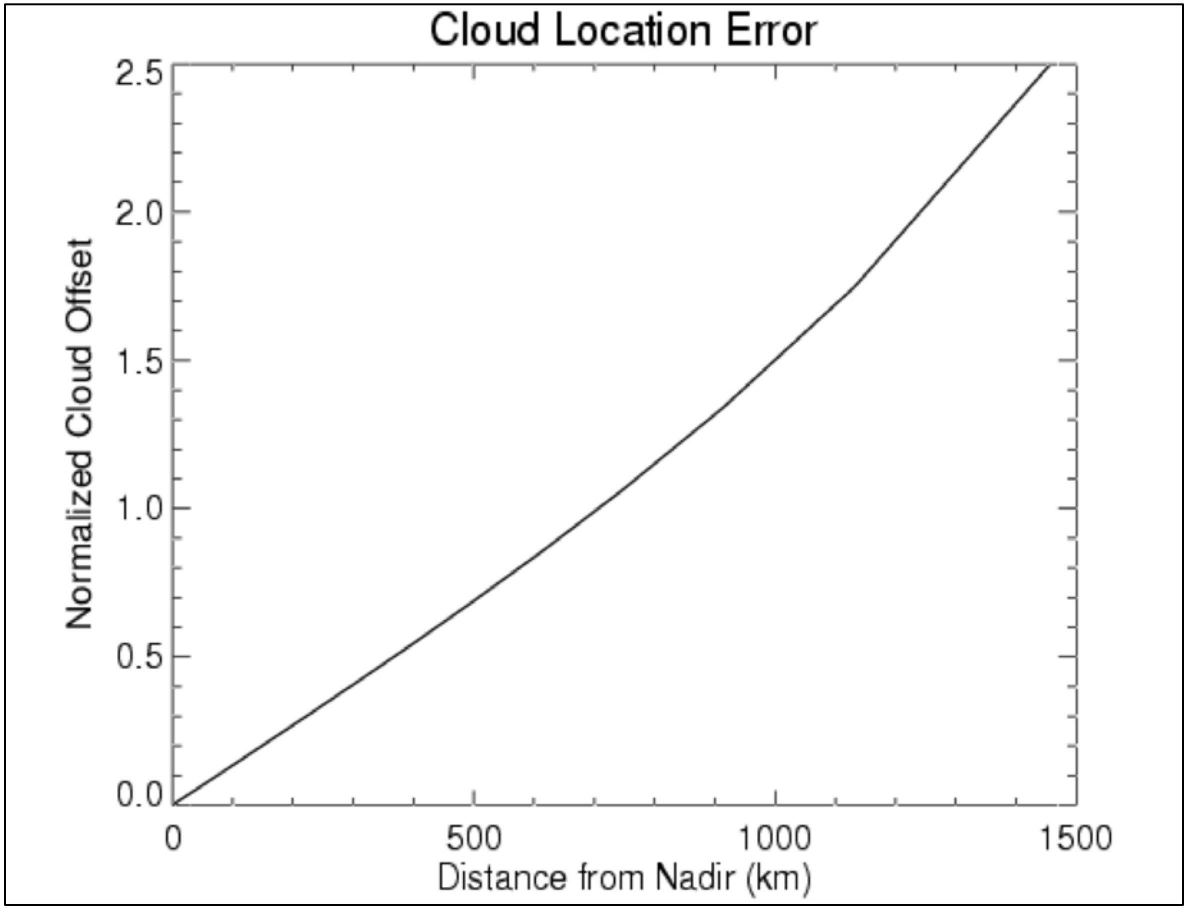
- The apparent displacement of a feature above ground that results from non-nadir viewing angles.
- Fortunately, there has been shown to be a relationship between cloud displacement, cloud height and distance from nadir
- Cloud top pressure (hPa) is part of the MOD06 product, and cloud height will be a part of the collect 6 product

Schematic Diagram of the Geometry used in Parallax Correction



e distance from earth's center
distance from earth's center
adius
viewing angle from satellite nadir
position viewing angle from cloud nadir
zenith angle from cloud
enith angle from ground
km) of cloud ground position

Estimating Parallax Error
Dave Santek

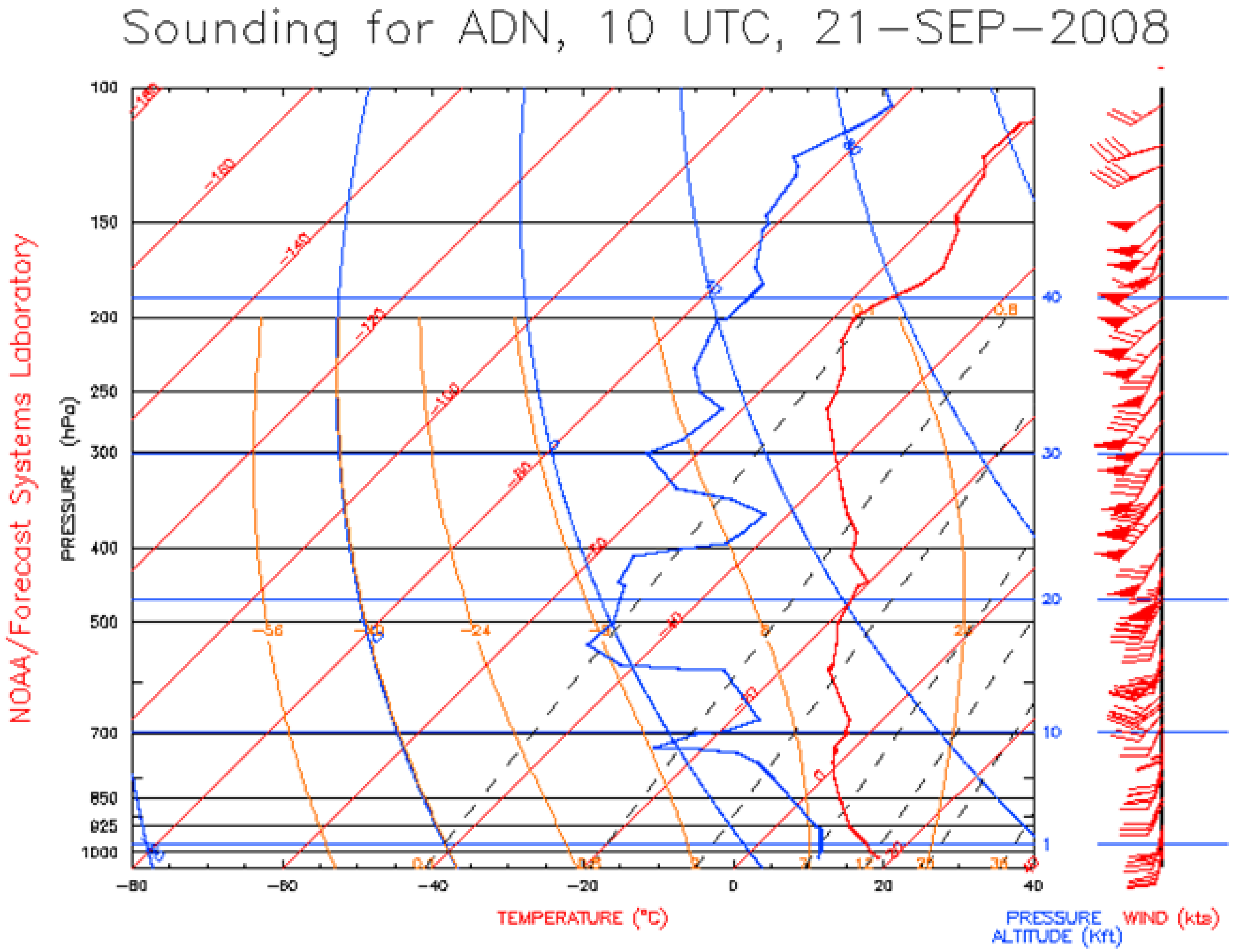


So if you have a cloud at a pixel that was 1000 km from nadir, the parallax correction would be 1.5 x the height of the cloud. Ex: 4 km x 1.5 = 6 km 10 km x 1.5=15 km

Cloud Pressure to Cloud Height

- Radiosonde
- Standard Atmosphere
- MOD07 has geopotential heights for 20 pressure levels (clear sky only)
- Geopotential Height Equation
  - Height adjustment to geometric height taking into account using the variation of gravity with latitude and elevation

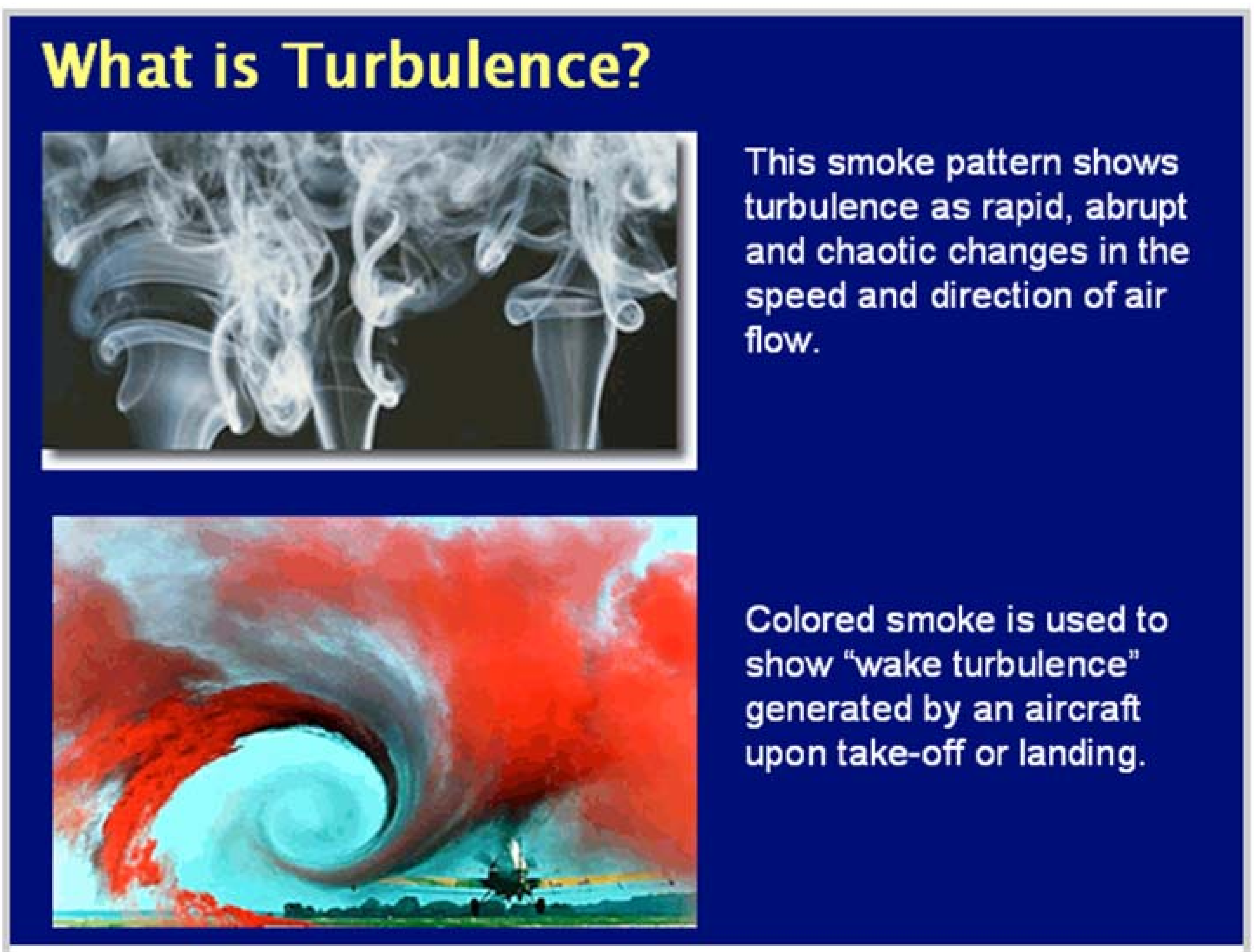
Example Radiosonde from Durban



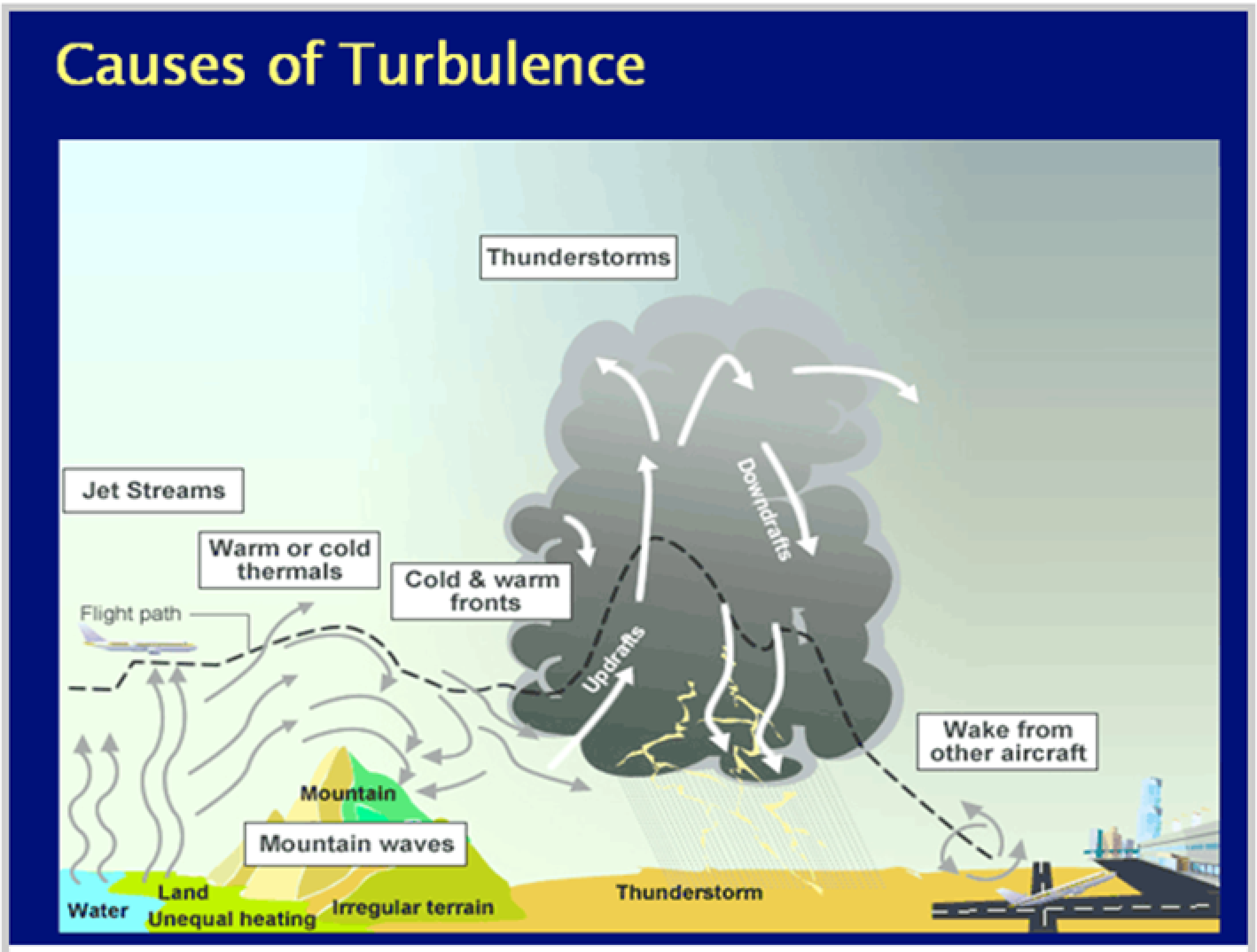
Aviation Applications

Turbulence, Clouds, Ash Detection

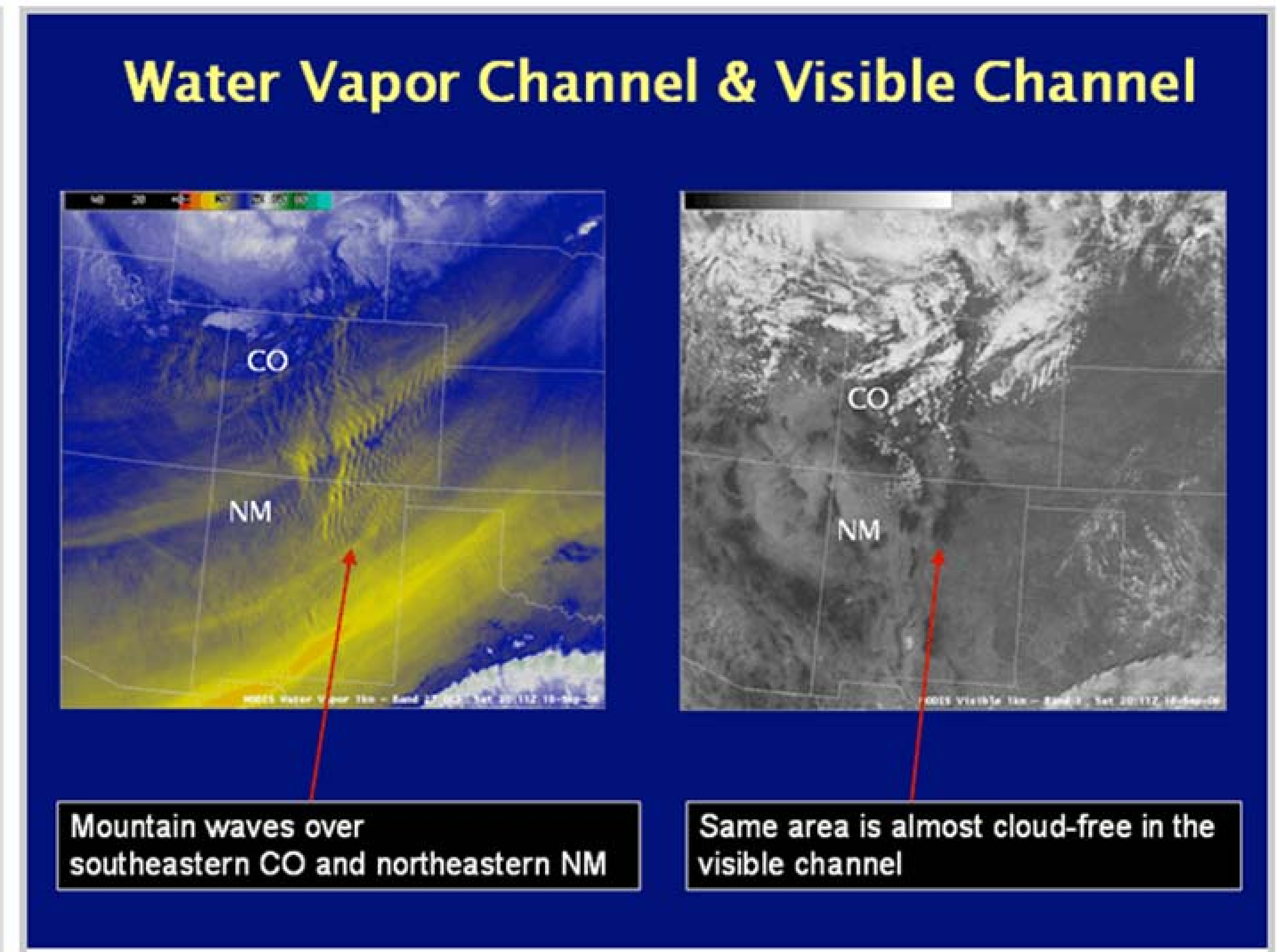
Atmospheric Turbulence



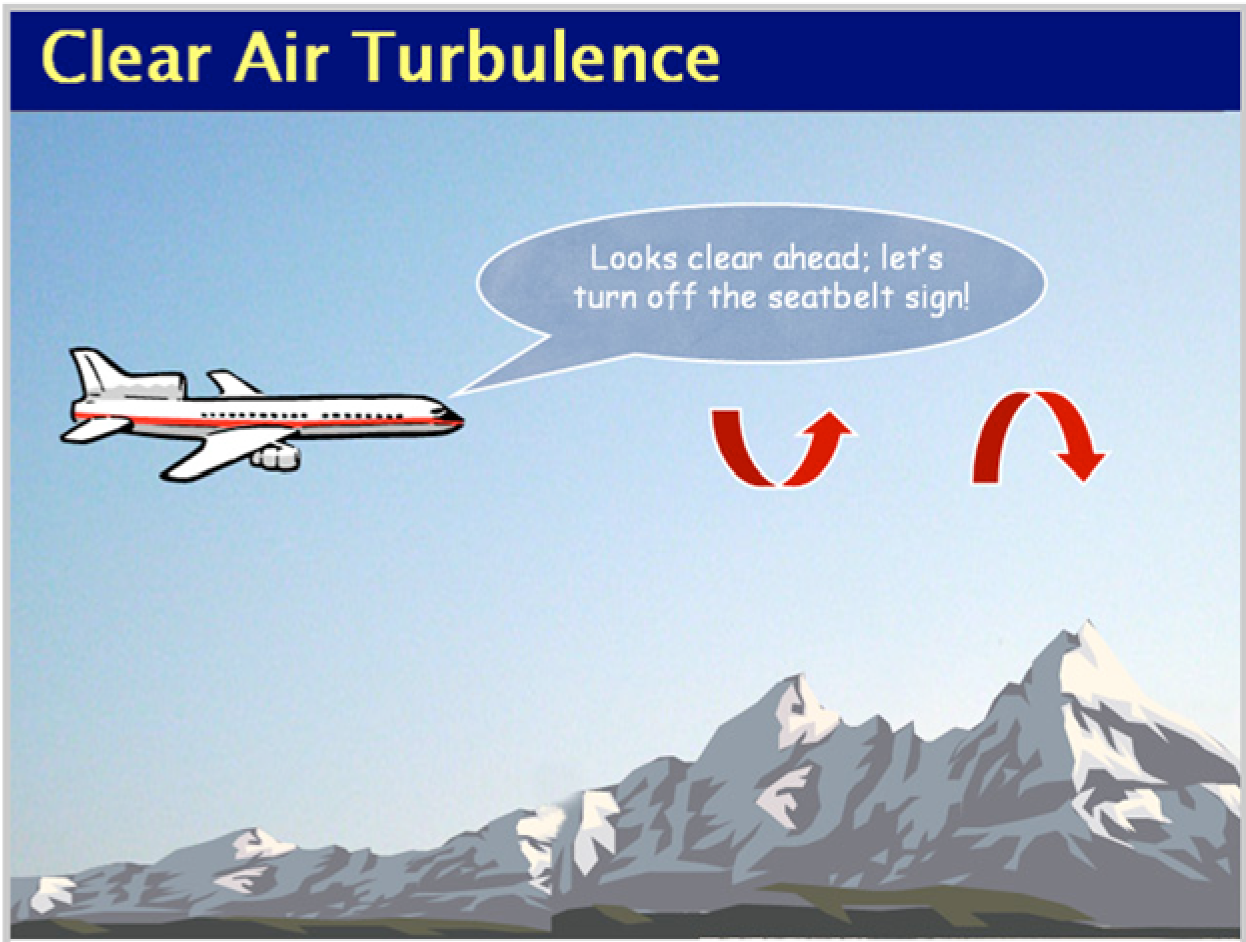
Atmospheric Turbulence



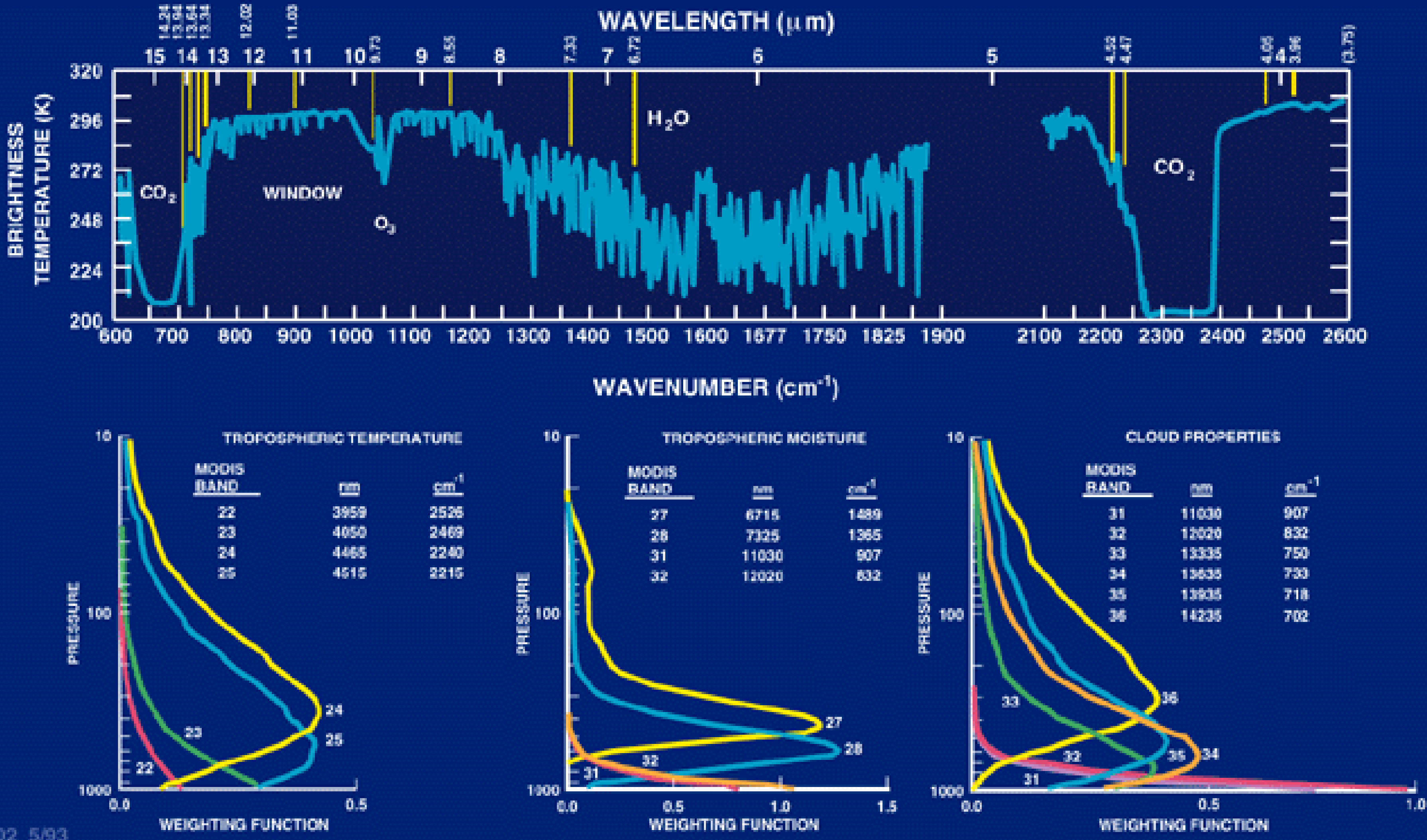
Why is 6.7 μm Important for the Detection of Turbulence?



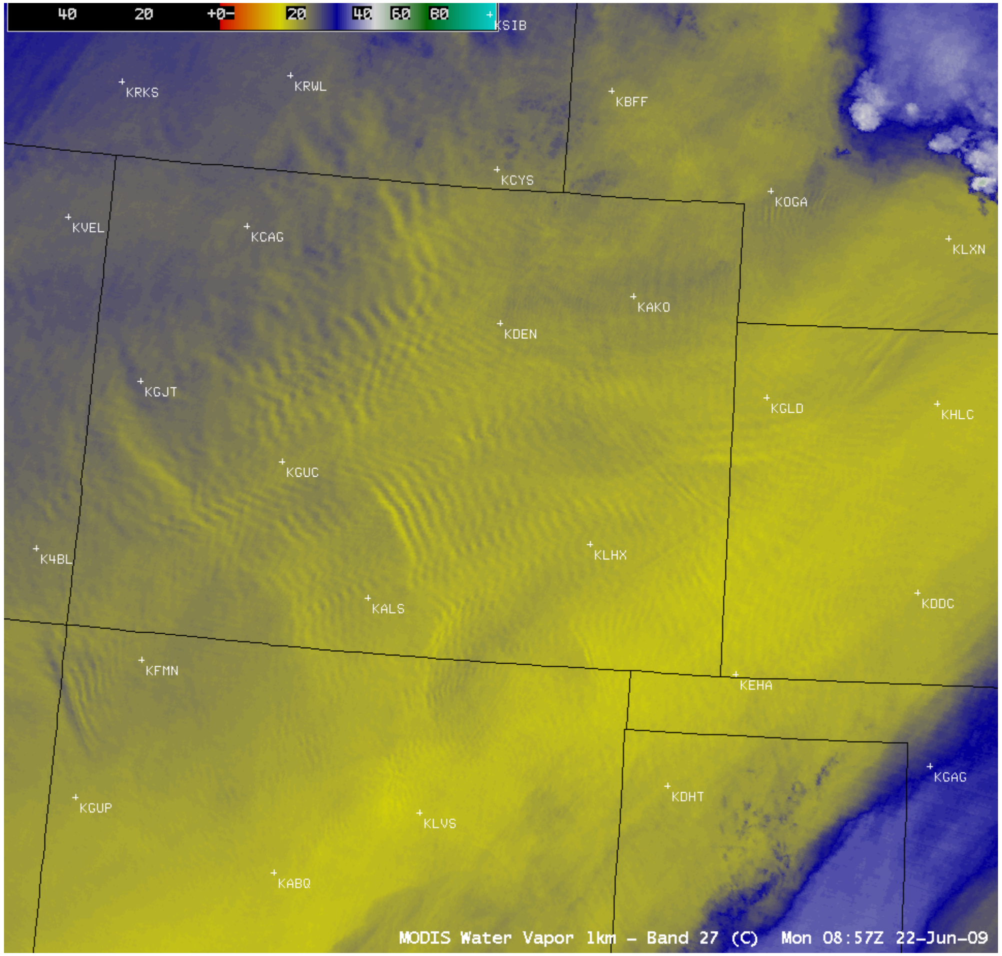
Why is This Important?



ATMOSPHERE - THERMAL RADIATION

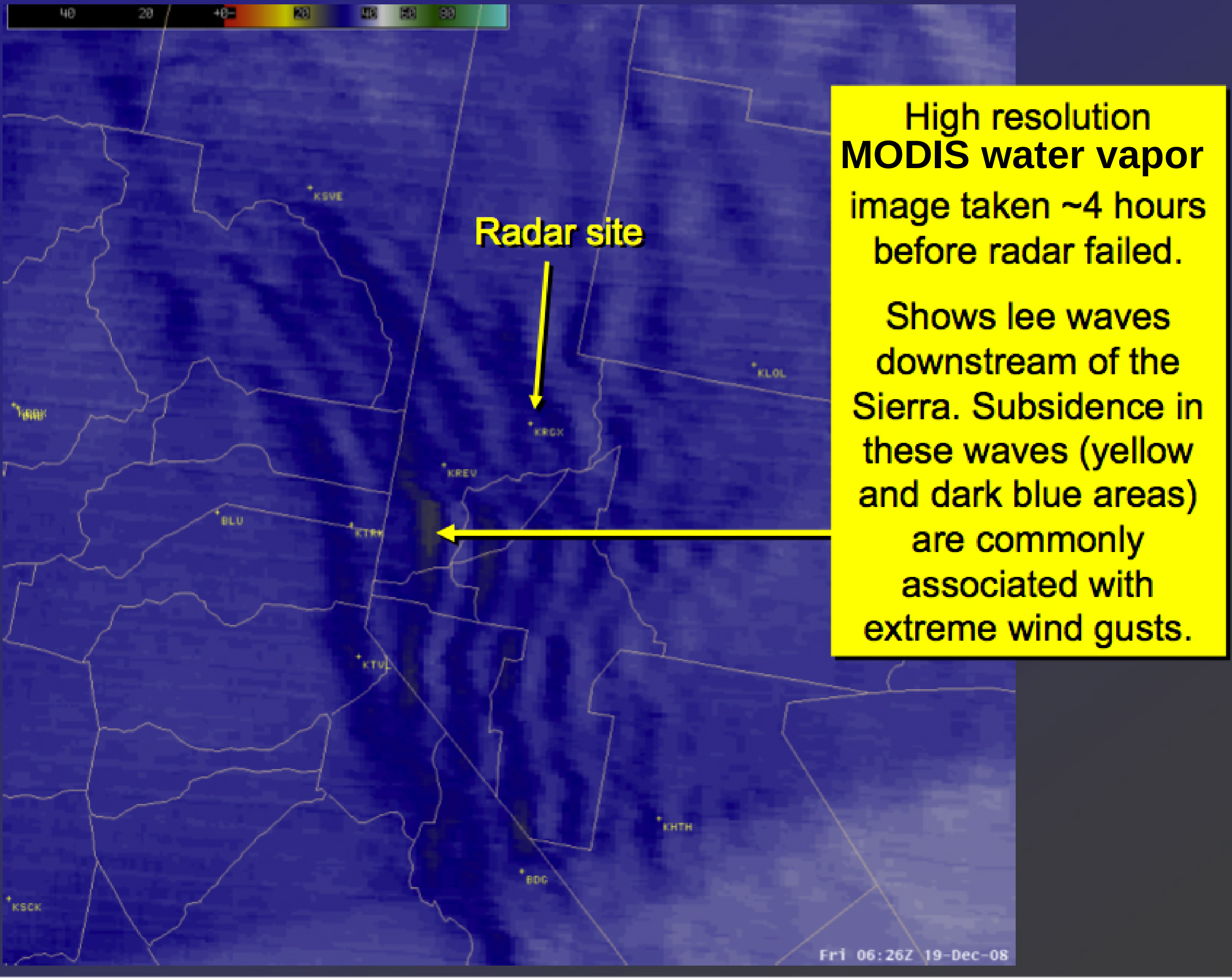


Mountain Wave Clouds in Clear Air



MODIS and GOES
08:57 UTC
22 June 2009

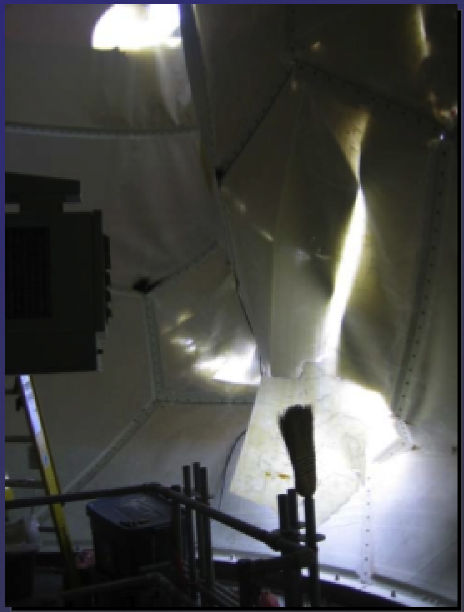
Lee Waves



(credit: NWS forecast office, Reno NV)

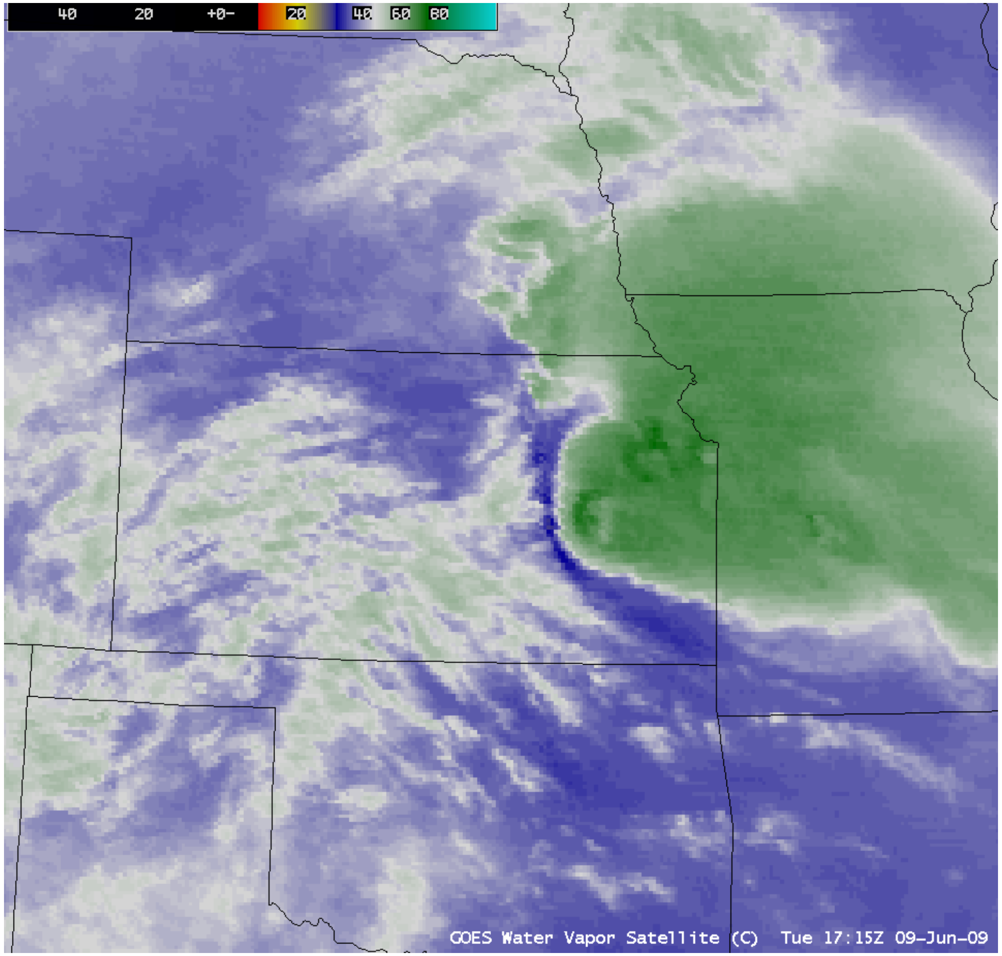
Photos

Photos taken by NWS Reno electronics team, on first visit to radar after dome failure (19 Dec.).



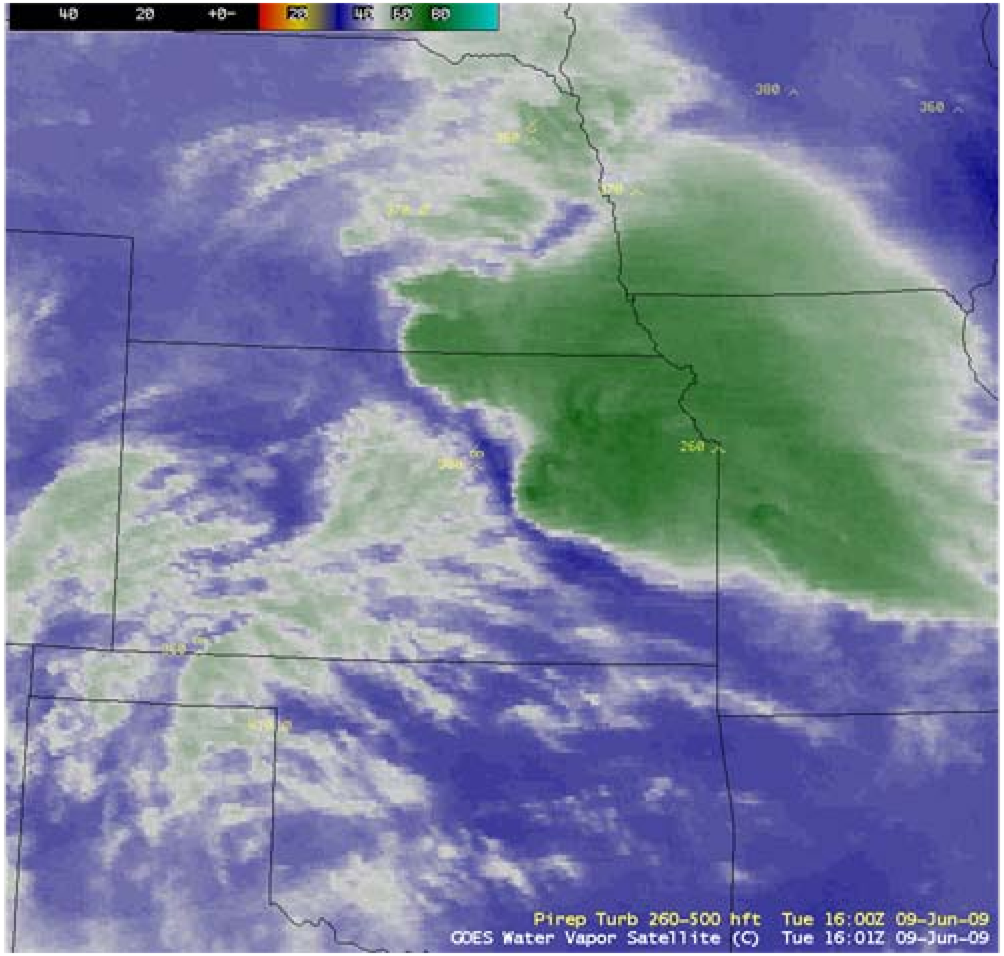
(credit: NWS forecast office, Reno NV)

Turbulence Not Just from Orography



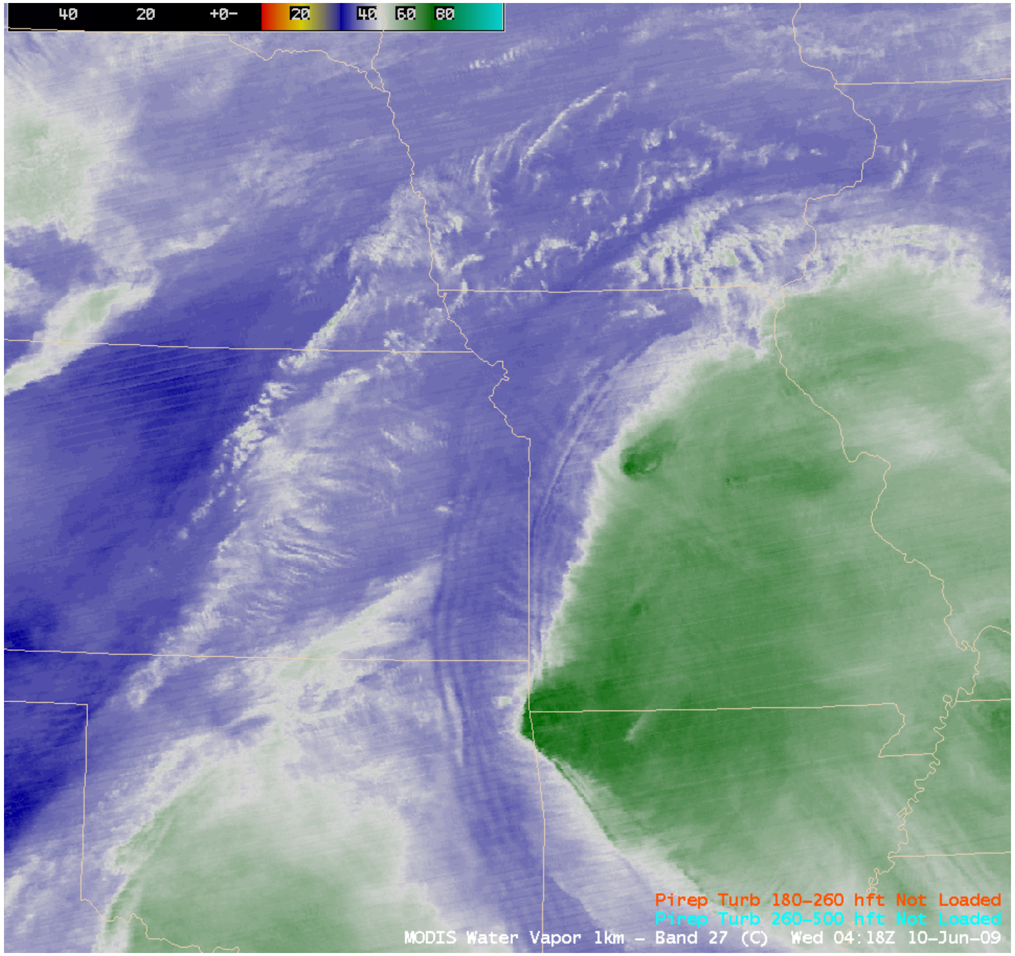
MODIS 6.7μm
Water Vapor
Band
17:15 UTC
9 June 2009

Pilot Reports of Turbulence



GOES 6.5μm
Water Vapor
Band
16:00 UTC
9 June 2009

Turbulence Not Just from Orography



MODIS 6.7 µm
Water Vapor
Band
04:18 UTC
10 June 2009

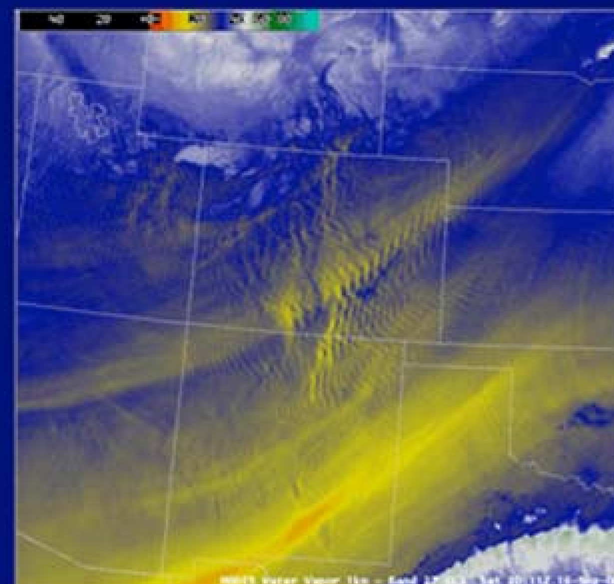
Why is 6.7 μm Important for the Detection of Turbulence?

Summary

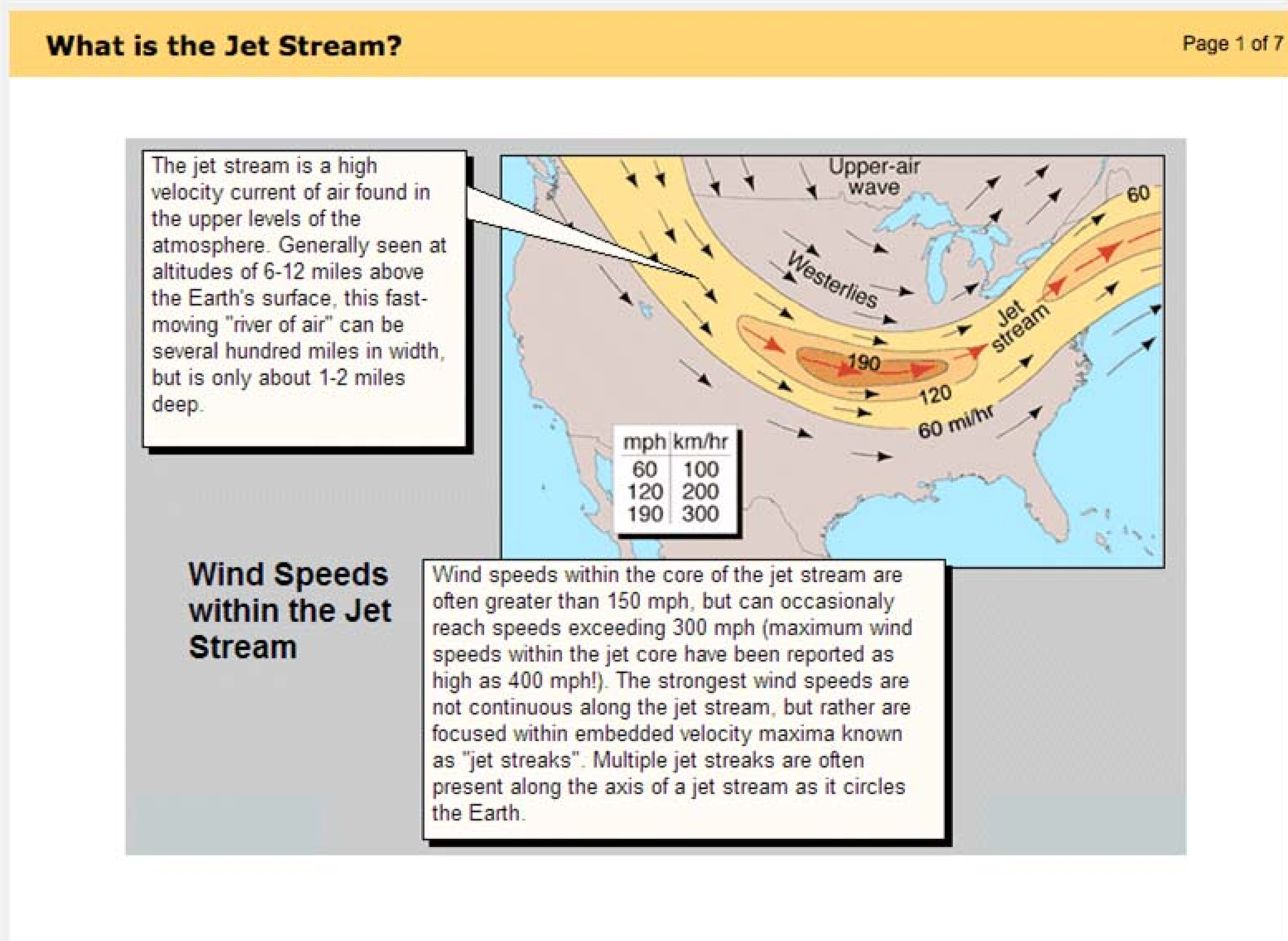
Turbulence is a significant hazard to aviation, and satellite imagery can sometimes be a helpful tool in turbulence detection.

Mountain waves are one common cause of turbulence, and water vapor channel imagery has the ability to detect areas where this type of turbulence may be present.

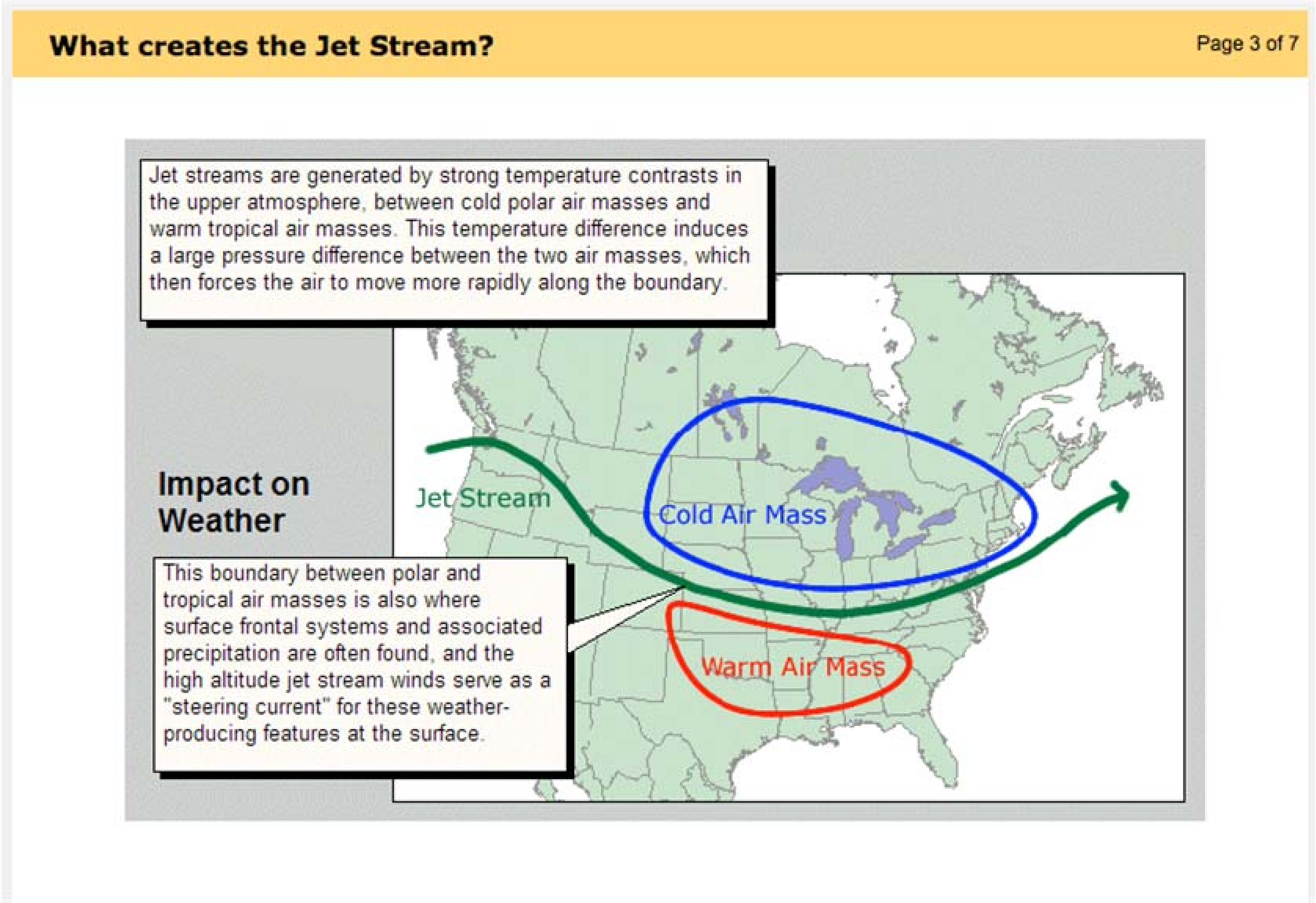
The typical "herringbone" signature of mountain waves often occurs in clear (cloud-free) air, making the water vapor channel the only tool for accurate turbulence detection in those cases.



More With Water Vapor



Jet Stream and Water Vapor



Atmospheric Turbulence