GOES Aviation Products: Progress and Recent Developments

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Overview

- Develop and evaluate potential new products or techniques, or improve existing products, derived from GOES to improve detection and short range forecasting of aviation hazards including:
  - Volcanic ash clouds
  - Aircraft icing
  - Convective downburst winds
  - Turbulence

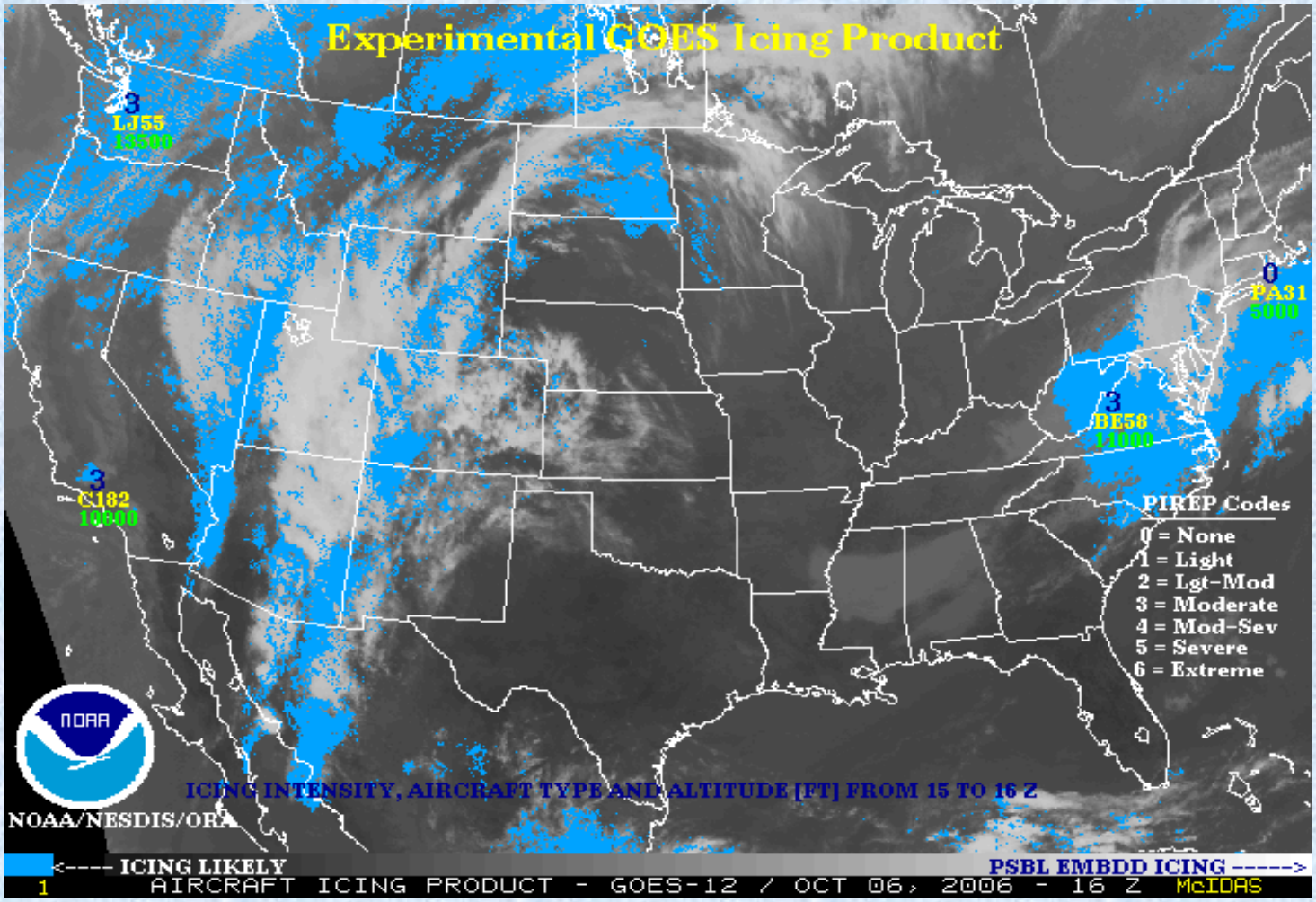
Overview

- The GOES aviation products are developed primarily for implementation into the National Weather Service Advanced Weather Interactive Processing System (AWIPS).
- Fog, icing, and volcanic ash products, derived from the GOES imager, are generated utilizing algorithms that employ temperature differencing techniques to highlight regions of elevated risk to aircraft.

Overview

- GOES microburst products employ the GOES sounder to calculate microburst risk based on conceptual models of favorable environmental profiles for convective downburst generation.
- Current suite of aviation products will be adapted for GOES-R with possible modifications and enhancements to the algorithms.

Icing


Experimental GOES Icing Product
3
LJ55
13500
0
PA31
5000
3
BE58
11000
3
C182
10000
PIREP Codes
0 = None
1 = Light
2 = Lgt-Mod
3 = Moderate
4 = Mod-Sev
5 = Severe
6 = Extreme
NOAA
NOAA/NESDIS/ORA
ICING INTENSITY, AIRCRAFT TYPE AND ALTITUDE [FT] FROM 15 TO 16 Z
<---- ICING LIKELY
PSBL EMBDD ICING ----->
1 AIRCRAFT ICING PRODUCT - GOES-12 / OCT 06, 2006 - 16 Z McIDAS

Icing

- GOES Imager data in three IR bands (3.9 μm, 10.7 μm, and either 12.0 or 13.3 μm, satellite-dependent) and the daytime visible band (0.6 μm) are sequentially analyzed to remove pixels in which conditions do not satisfy various thresholds relevant to icing (Ellrod 2004).

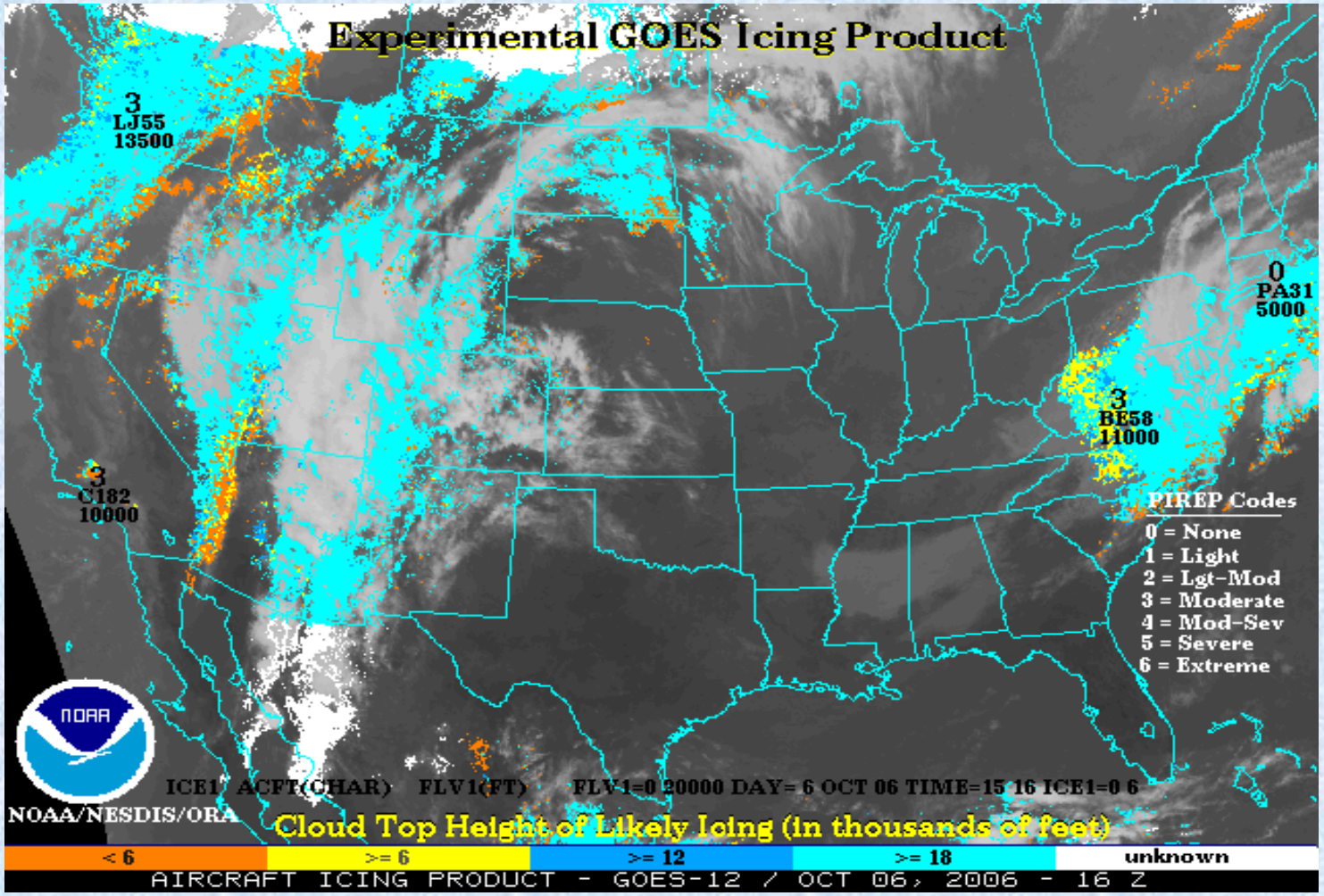
Icing

- An improved daytime icing technique was implemented to provide better discrimination of supercooled clouds vs. ice clouds (cirrus) through the use of GOES-12 visible imagery corrected for satellite viewing angle. The technique partially compensates for loss of a 12 μm IR band.
- Cirrus over snow cover or warm low clouds can result in a false indication of icing, and is minimized using an IR technique based on Bands 4 (10.7 μm) and 6 (13.3 μm).

ICECAP

- The **ICing Enhanced Cloud-top Altitude Product (ICECAP)** (Ellrod 2004) is created each hour by merging a composite of the Imager Icing Product for the past two hours (using three N. Hemis. Scans, each an hour apart) with the latest Sounder CTP (about one hour old).

ICECAP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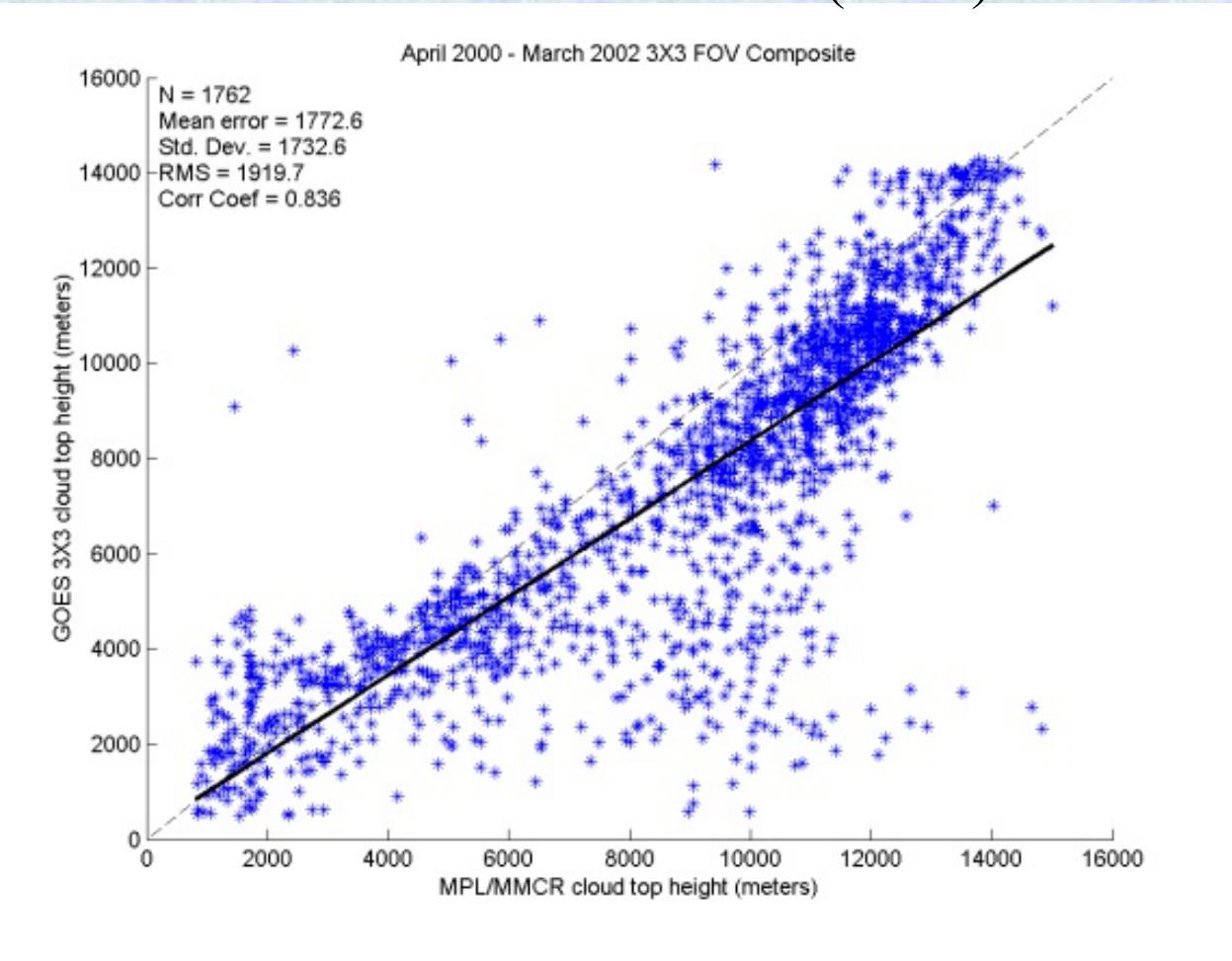
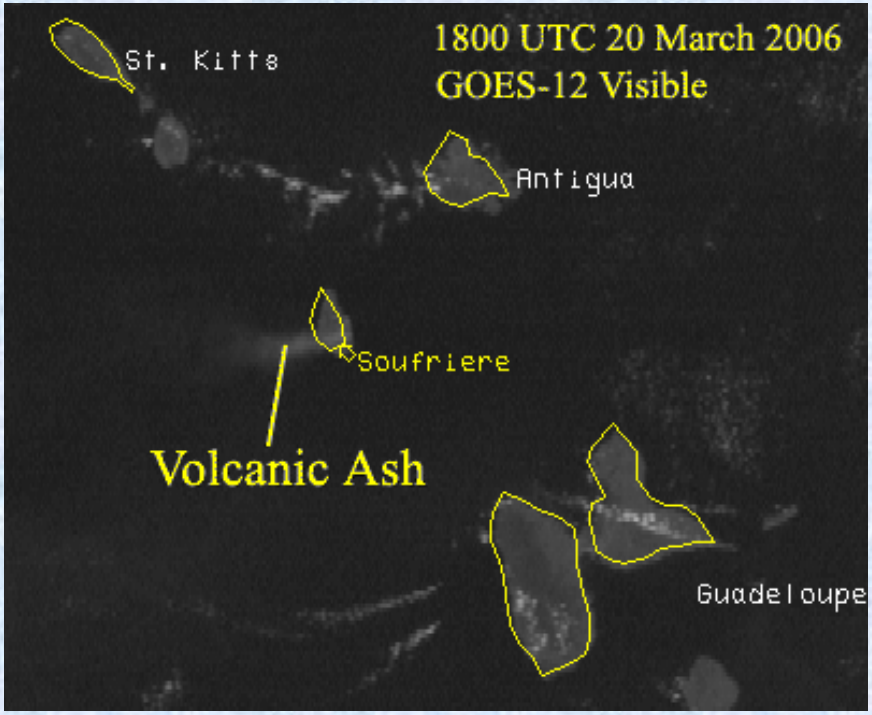
6 = Extreme
NOAA
NOAA/NESDIS/ORA
ICE1 ACFT(CHAR) FLV1(FT) FLV1=0 20000 DAY= 6 OCT 06 TIME=15 16 ICE1=0 6
Cloud Top Height of Likely Icing (in thousands of feet)
< 6
>= 6
>= 12
>= 18
unknown
AIRCRAFT ICING PRODUCT - GOES-12 / OCT 06, 2006 - 16 Z

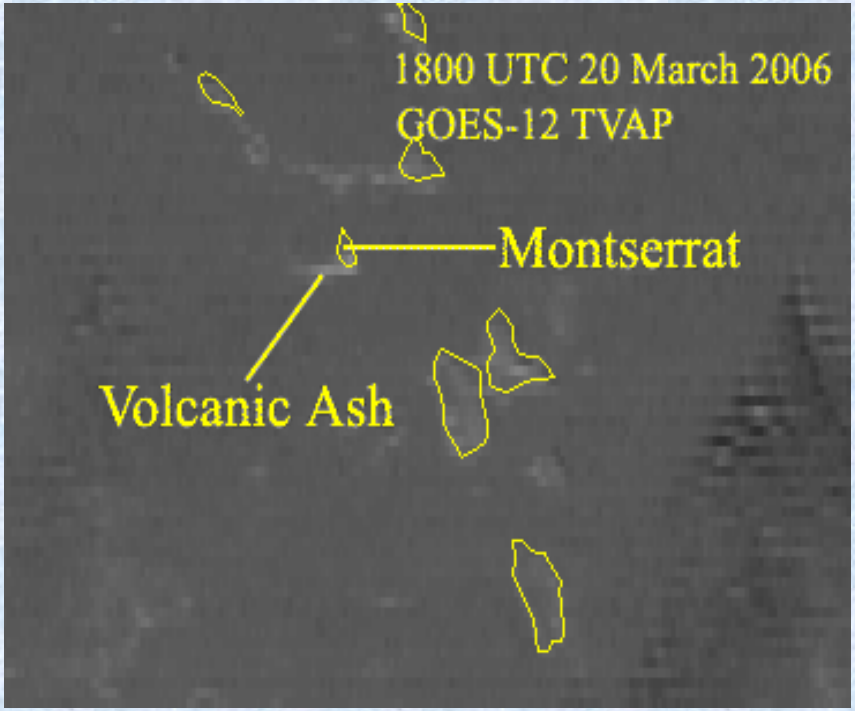
Icing: Validation

From Hawkinson (2003)



Volcanic Ash Detection





Comparison of three-band method using GOES-12 Bands 2, 4, 6 (right) to GOES-12 visible image (left).

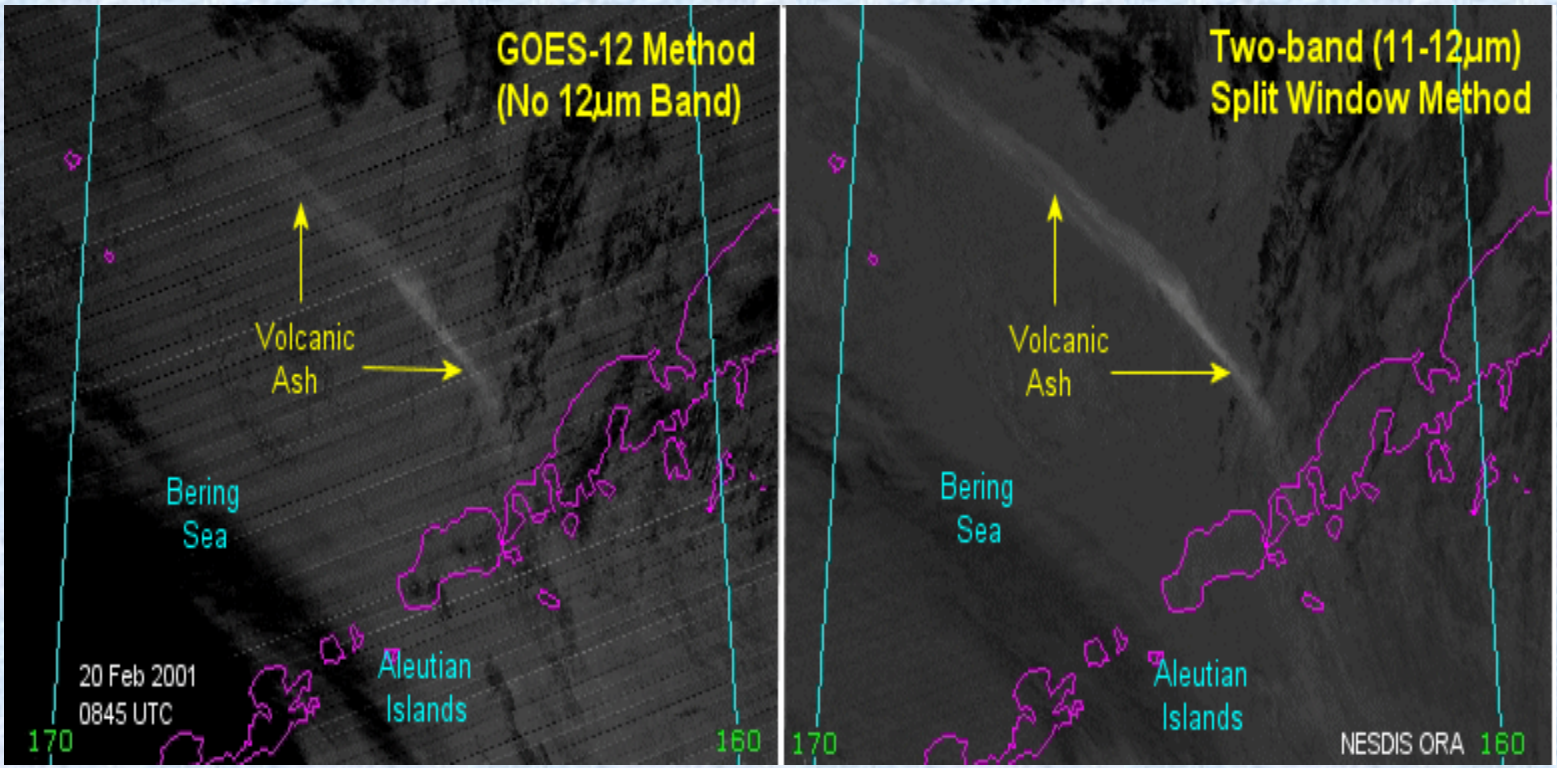
Volcanic Ash Hazards

- Damage to leading edge surfaces of aircraft.
- Ash ingested into jet engines results in loss of performance, and possibly complete shutdown.
- The continued increase in international air traffic will lead to a higher likelihood of volcanic ash encounters. .

Three-channel Volcanic Ash Products (TVAP)

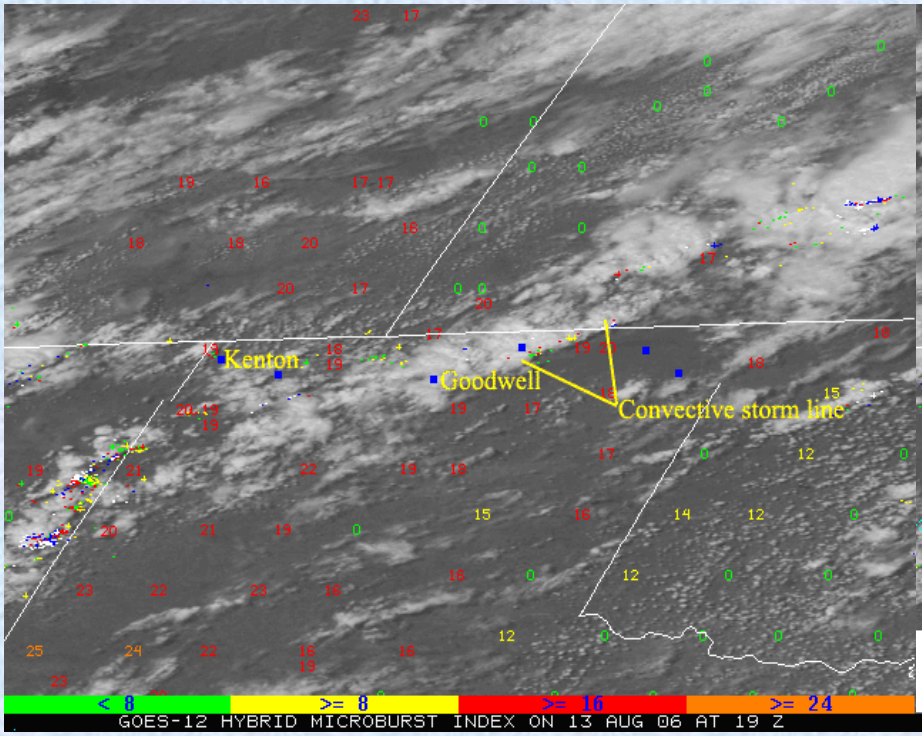
- Combines data from the shortwave (3.9 μm) IR channel (Band 2), with two longwave window IR channels at 10.7 μm (Band 4) and either 12.0 μm (Band 5 on GOES-11) or 13.3 μm (Band 6 on GOES-12 and beyond) (Ellrod and Schreiner 2004).
- Temperature differences in Bands 4 and 5 from GOES-11 (referred to as the "Split Window") can help identify areas of volcanic ash due to it's unique properties at these wavelengths.
- The Band 4-6 combination on GOES-12 is not as effective for this purpose, but can help distinguish ash from cirrus.

Volcanic Ash Detection

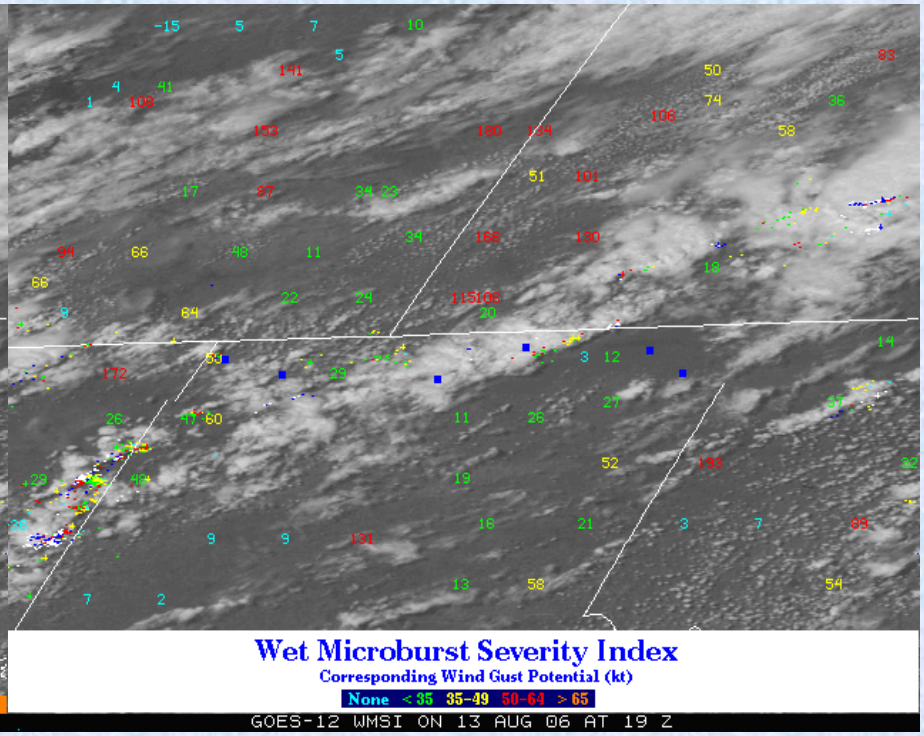


Comparison of three-band method using IR channels available on GOES-12 (left) versus traditional two-band method based on 11-12 µm IR (right). Images were derived from Terra MODIS at 0845 UTC, February 20, 2001. Striping in left hand image is from MODIS 13.3 µm IR band.

Convective Downburst Potential



Large HMI values indicate the presence of a dry, well-mixed convective boundary layer.

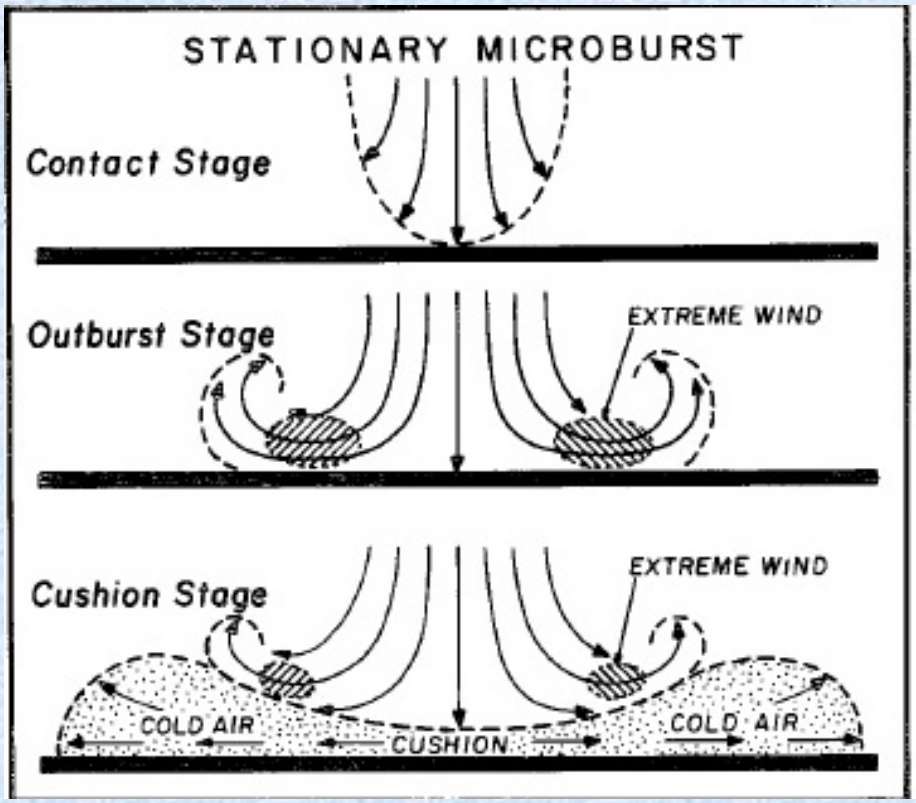


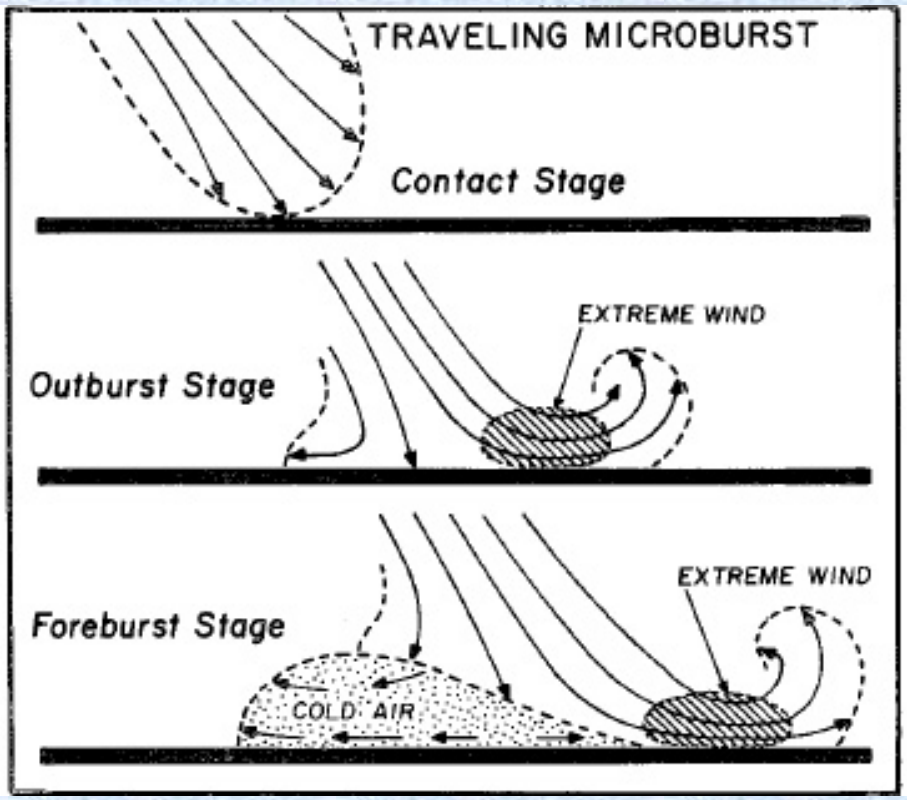
Large WMSI values indicate the presence of strong static instability and buoyancy.

The Downburst

- The **downburst** is defined as a strong downdraft produced by a **convective storm** that induces an **outburst of damaging winds** on or near the earth's surface (Fujita and Wakimoto 1983).
- Due to the **intense wind shear** they produce, downbursts are a **hazard to aircraft** in flight, especially during takeoff and landing phases.

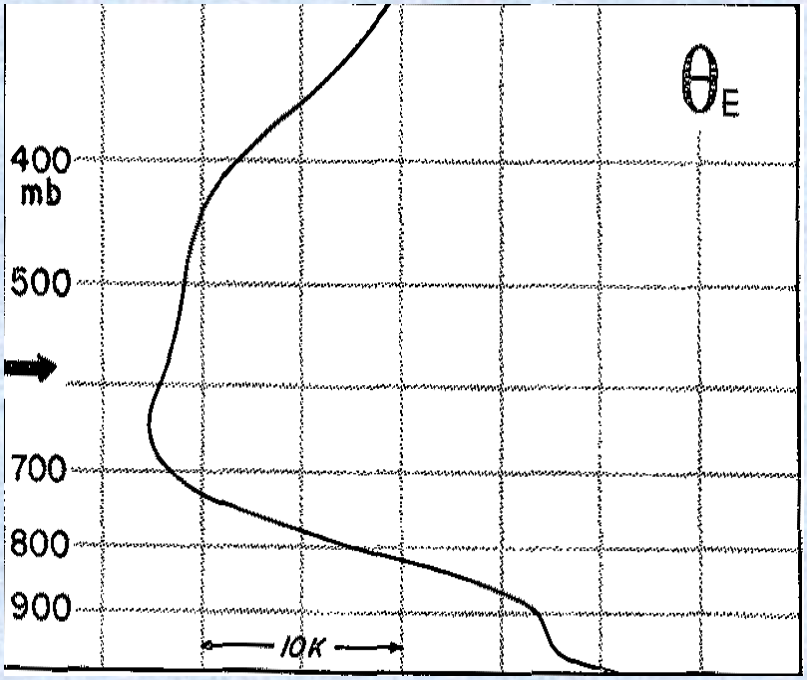
Microburst Aircraft Hazards





From Fujita (1981)

Theta-e Deficit (TeD)



- Maximum vertical difference in equivalent potential temperature (θ_e) from the surface to the middle troposphere (Atkins and Wakimoto 1991).

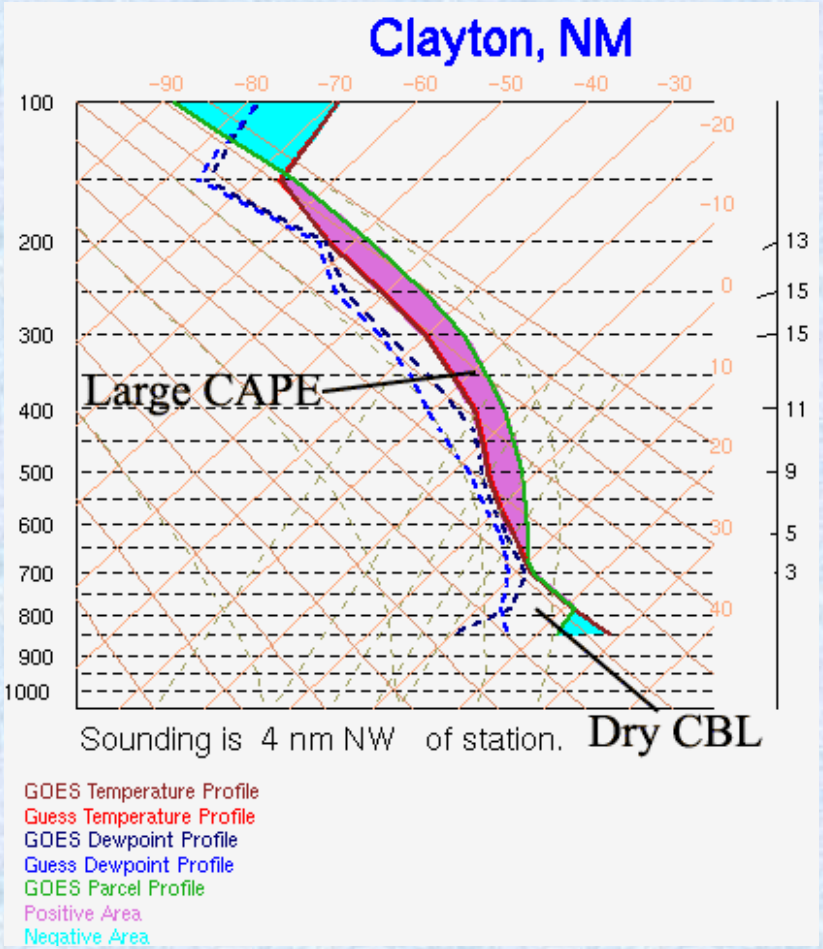
Wet Microburst Severity Index (WMSI)

WMSI = (CAPE)(TeD)/1000

(Pryor and Ellrod 2005)

- Large CAPE (positive buoyancy) results in strong updrafts that lift the precipitation core within a convective storm to minimum theta-e level.
- TeD indicates the presence of a dry (low theta-e) layer in the middle troposphere that would be favorable for the production of large negative buoyancy due to evaporative cooling.

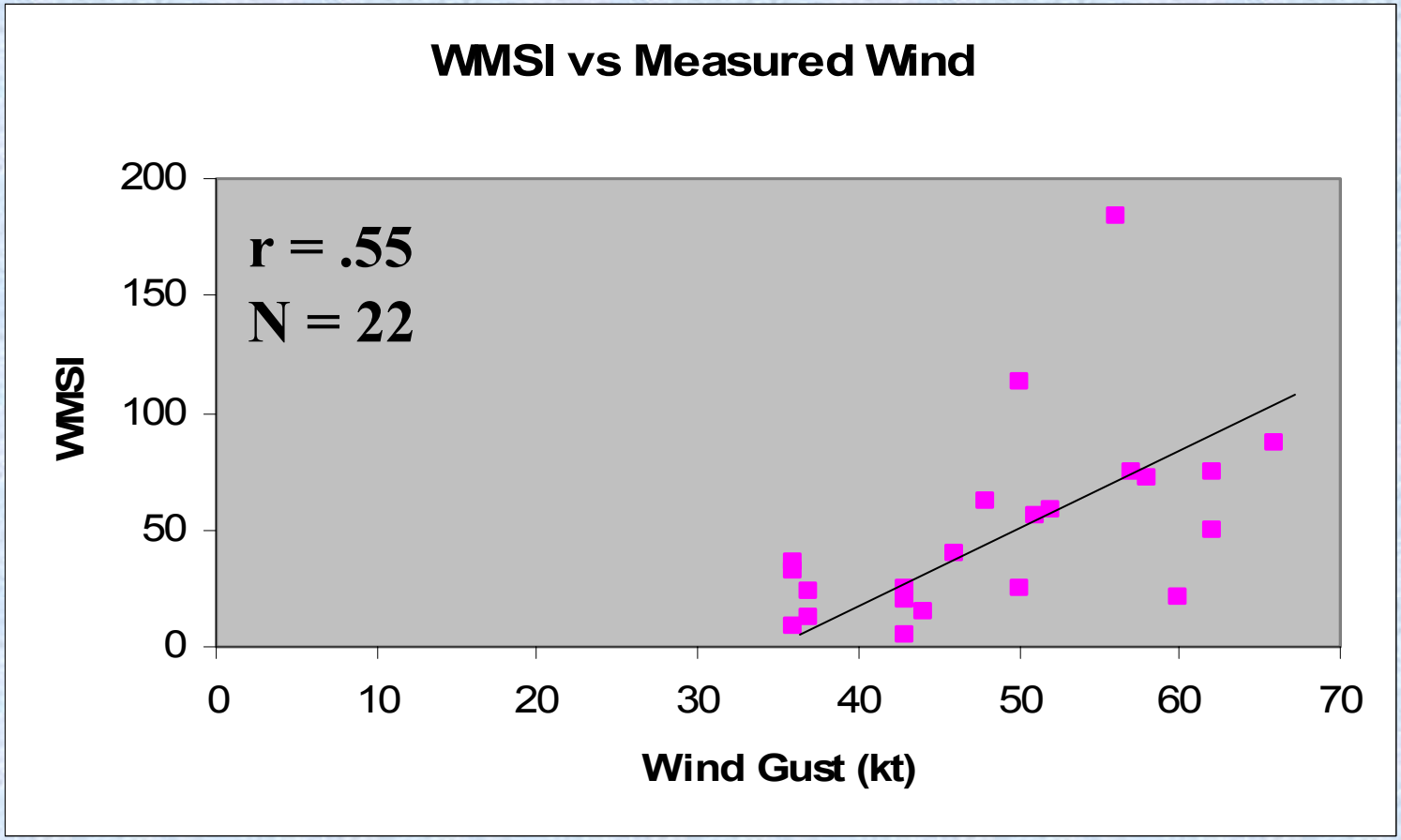
Hybrid Microburst Index (HMI)



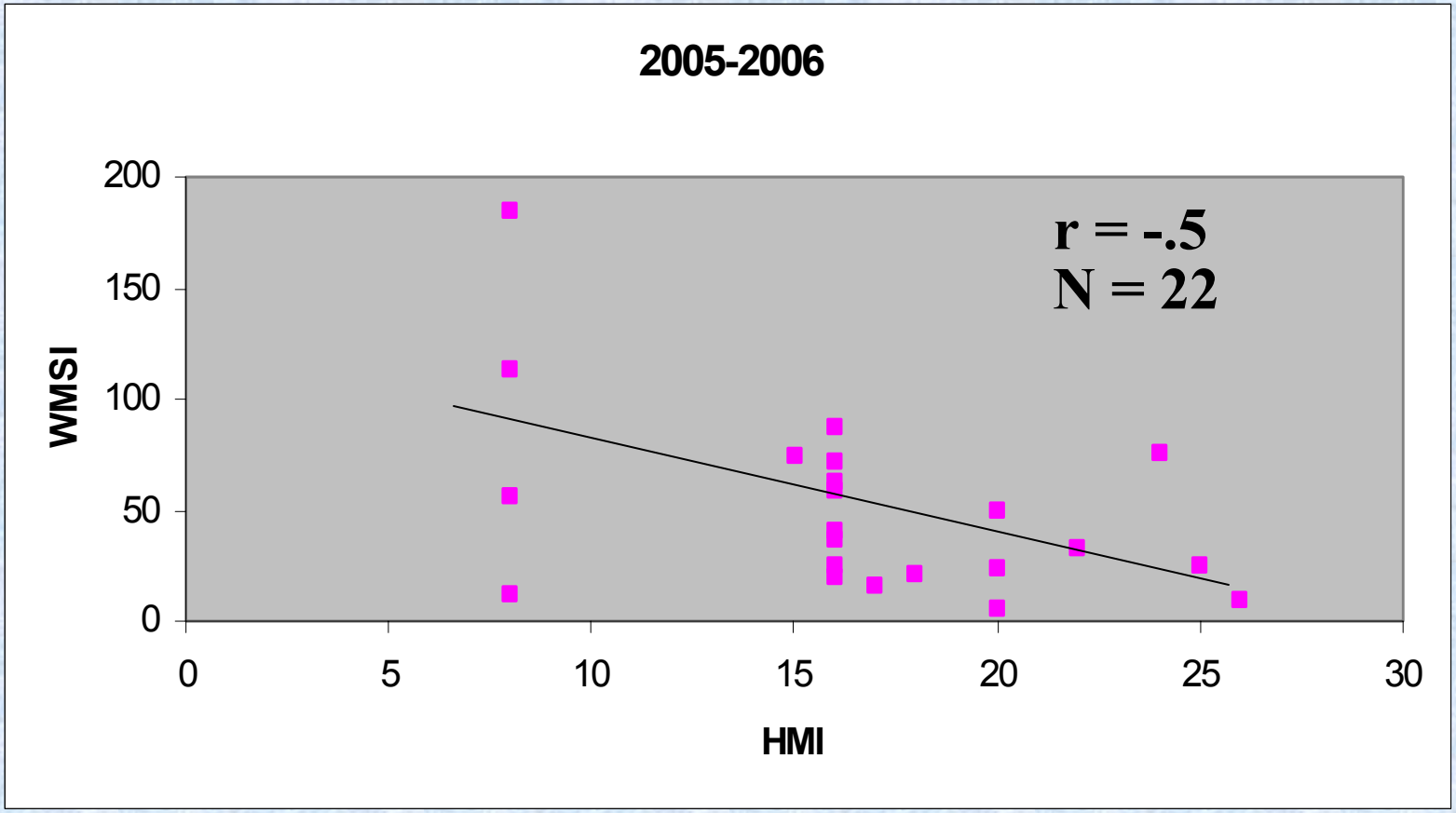
HMI = $\Gamma + (T - T_d)_{850} - (T - T_d)_{670}$ (Pryor 2006)

- Γ = temperature lapse rate (°C km^{-1})
- T = temperature (°C)
- T_d = dew point temperature (°C)
- Use with WMSI to forecast downburst magnitude over Great Plains

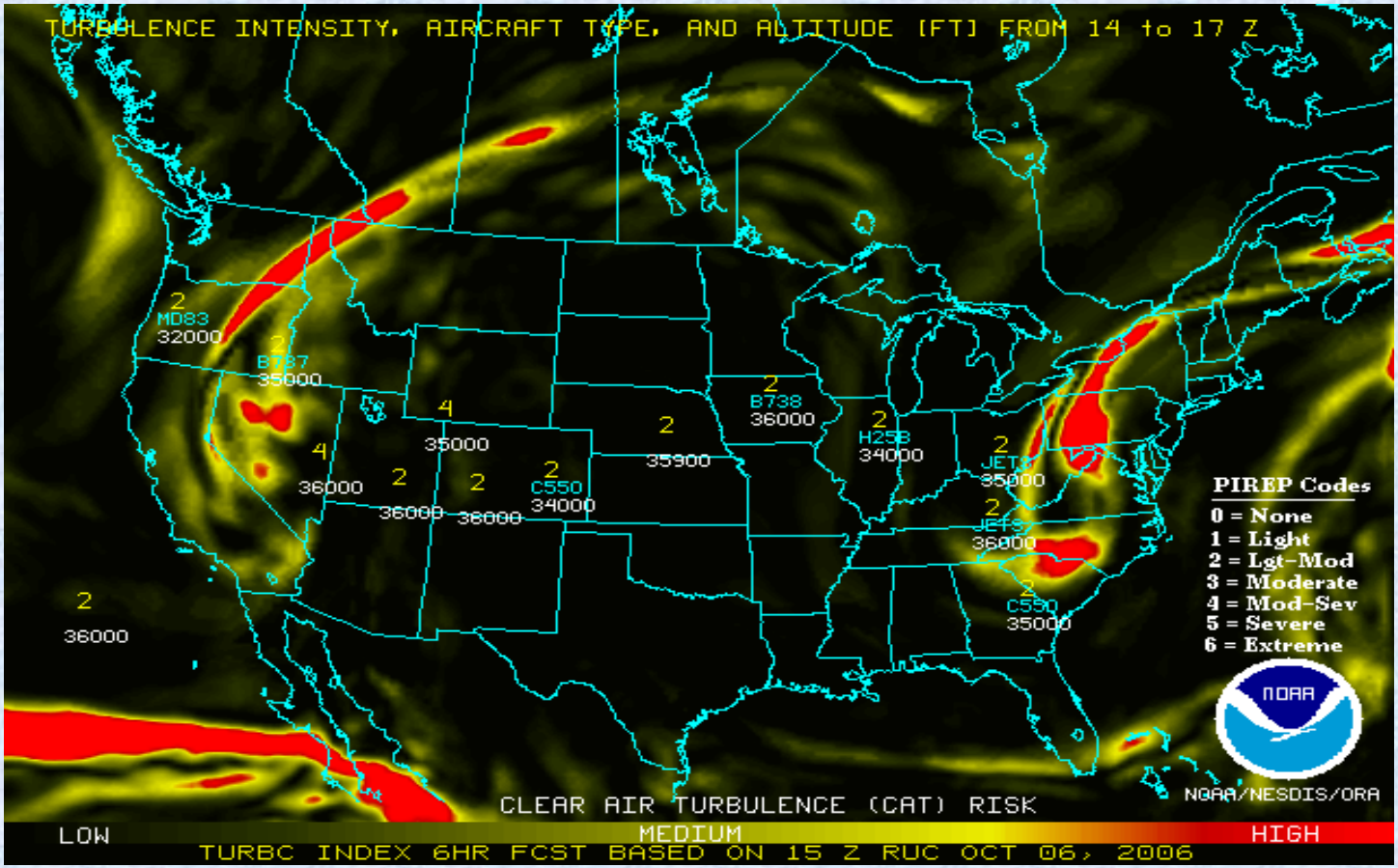
Microburst Products: Validation



Microburst Products: Validation



Turbulence



Yellow areas denote where there is a good chance (50% or better) of occasional moderate or greater clear-air turbulence (CAT). Red shows where there is a high risk of occasional moderate or greater CAT.

Turbulence

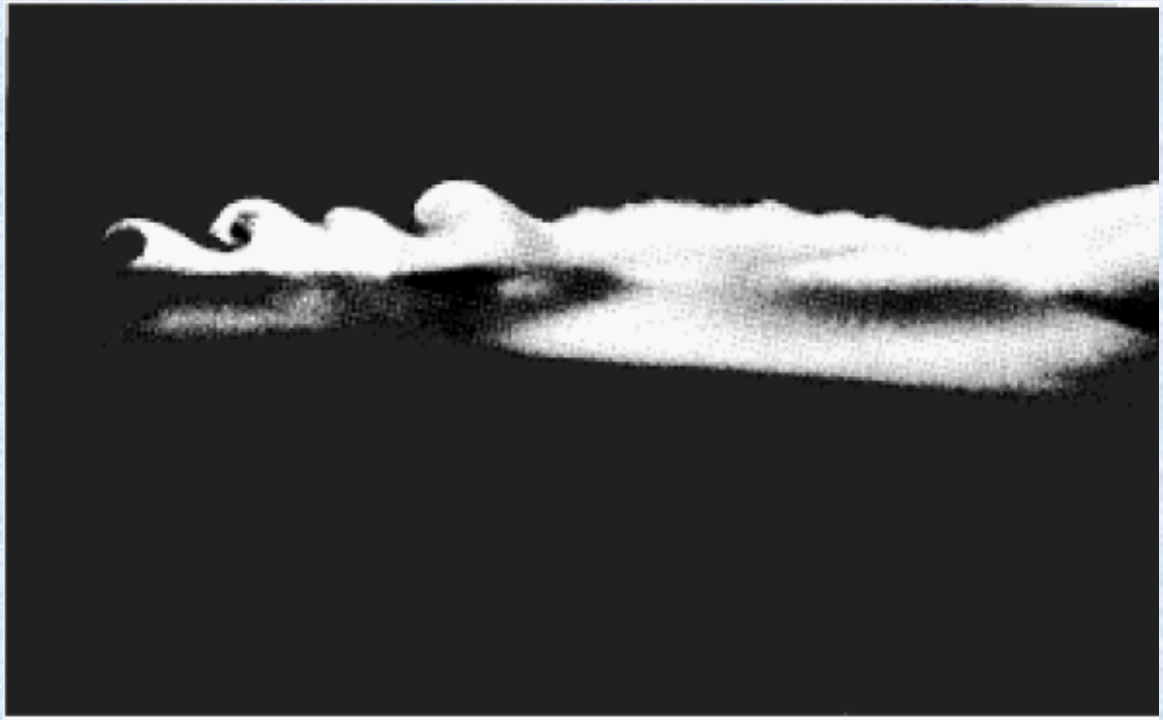


Figure 13. Kelvin-Helmholtz instability, revealed by the cloud patterns in the atmosphere (NCAR.NSF Photo Archive)

Destabilizing influence of wind shear overcomes the stabilizing effect of buoyancy force. Waves (perturbations) break and dissipate into smaller scale complex and chaotic motion.

Turbulence

- Obtained from the North American Model (NAM) and Rapid Update Cycle (RUC2) model.
- The Deformation- Vertical Shear Index (DVSI) is the product:
  - **DVSI = DEF x VWS**
  - Knox et al. (2006)

$$\mathbf{DEF} = [(\delta u/\delta x - \delta v/\delta y)^2 + (\delta v/\delta x + \delta u/\delta y)^2]^{1/2}$$

$$\mathbf{VWS} = \delta \bar{V}/\delta z$$

where: $\bar{V} = (u^2 + v^2)^{1/2}$

u = East-West wind component ($m\ sec^{-1}$)

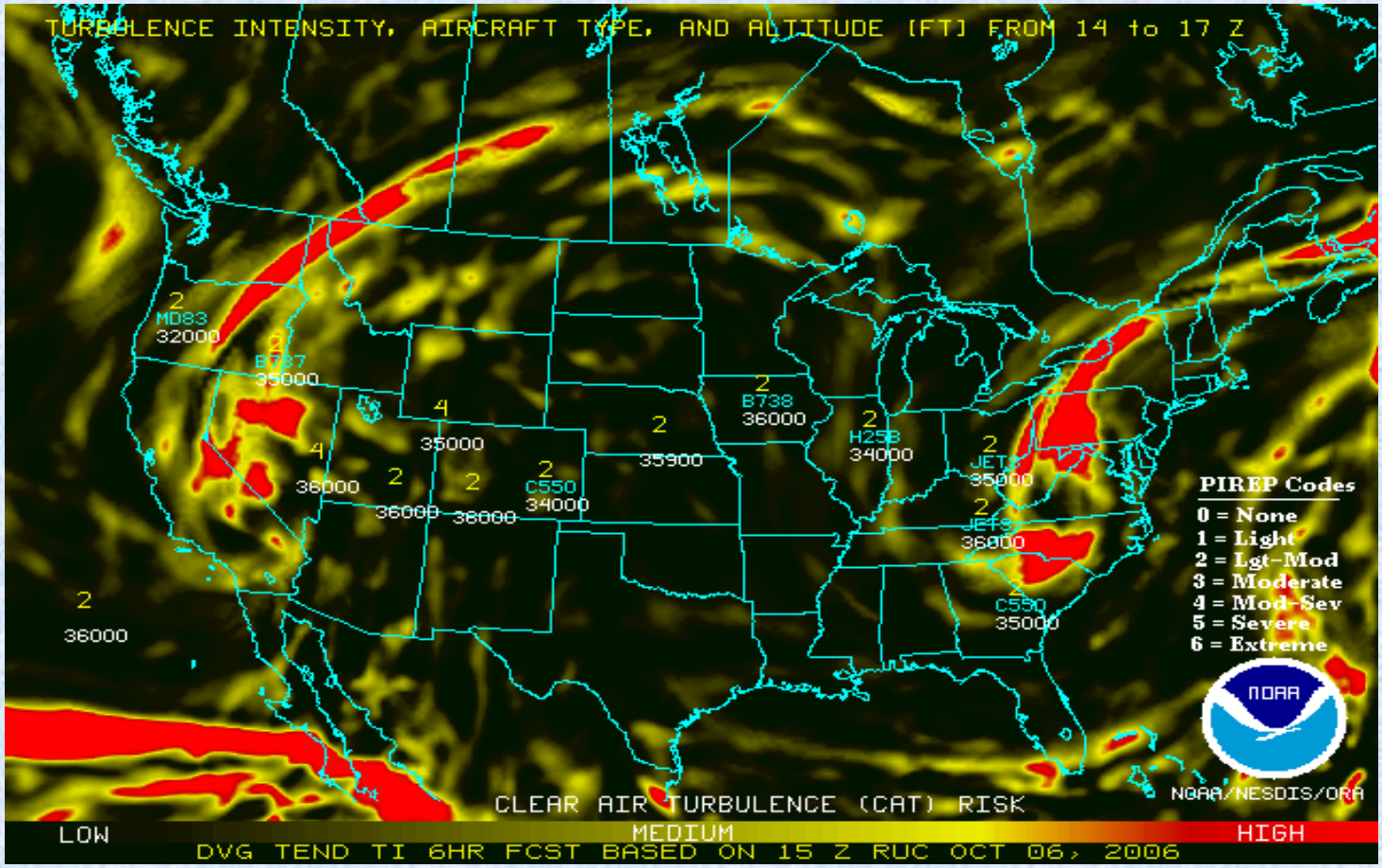
v = North-South wind component ($m\ sec^{-1}$)

z = Height (m)

Turbulence

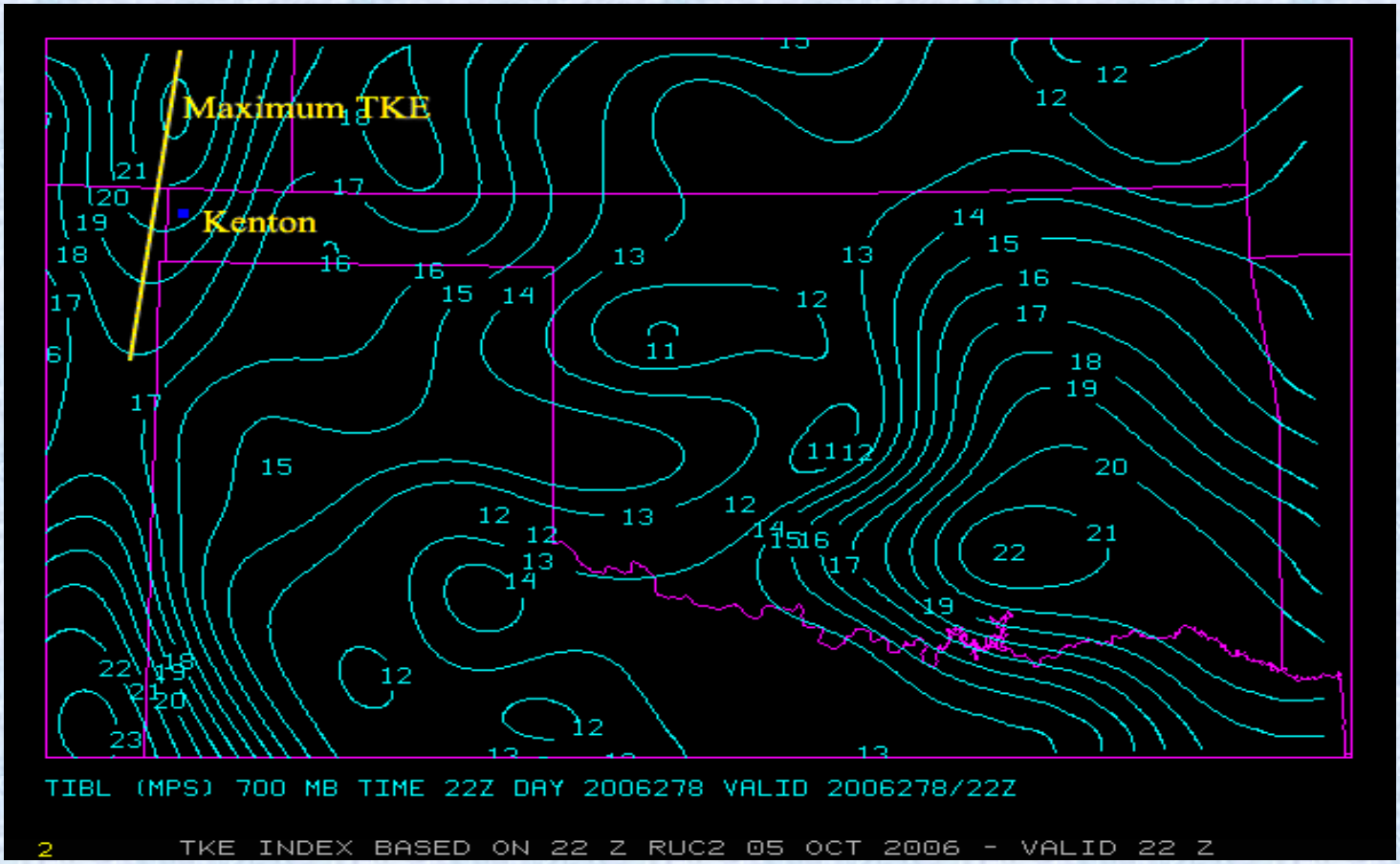
- To account for the time variation of divergence present in unbalanced anticyclonic jet streams, a simplified "divergence trend" term (DVT) was added to the DVSI algorithm:
- $DVT = C\,[(\delta u/\delta x + \delta v/\delta y)h2 - (\delta u/\delta x + \delta v/\delta y)h1]$

Turbulence



The result is an enhanced turbulence index product: divergence-trend-modified DVSI (D-DVSI)

Turbulence: Boundary Layer



Identify regions of boundary layer turbulence (Turbulence Kinetic Energy, TKE) and the potential for strong surface wind gusts. Incorporates vertical wind shear and temperature lapse rate to parameterize static instability.

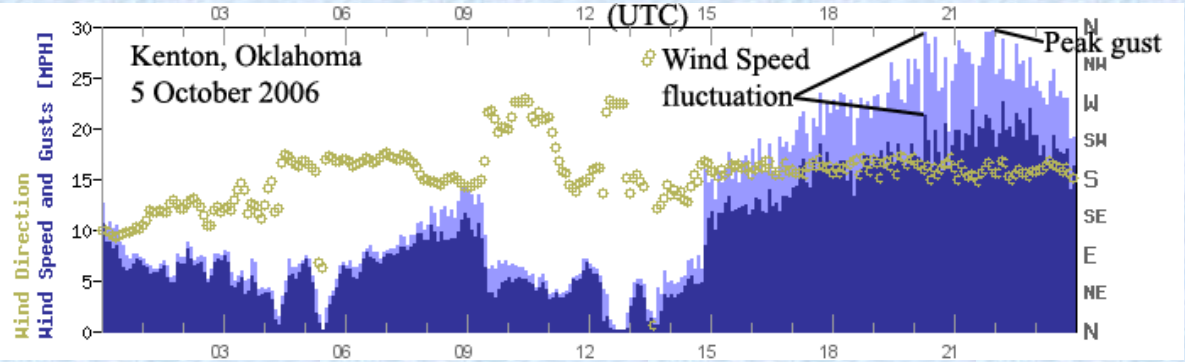
Turbulence: Boundary Layer

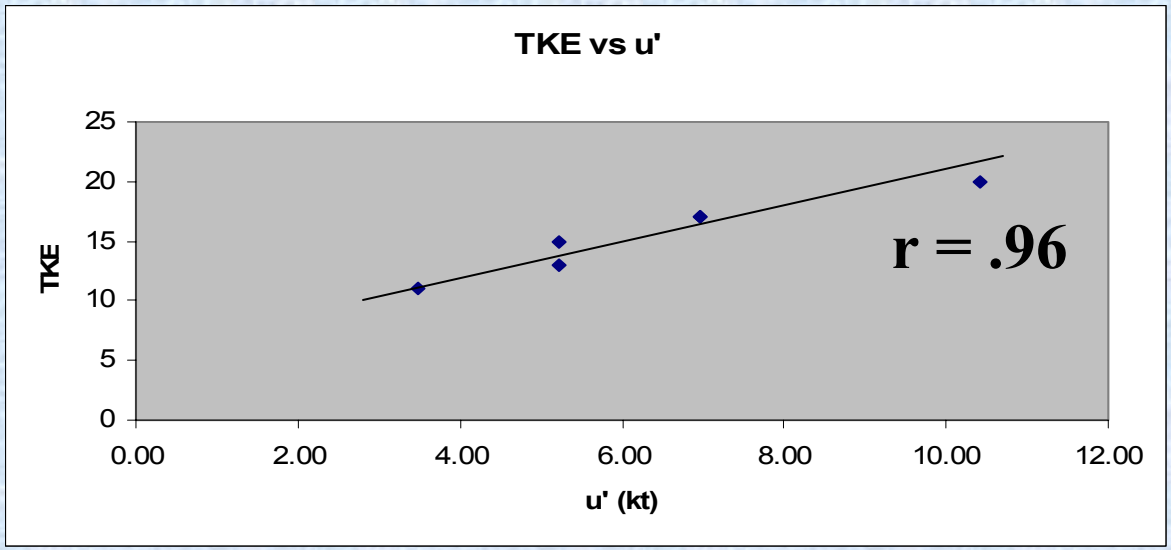
- **TKE = VWS + H**

  $\approx \delta \mathbf{V}/\delta z + \delta T/\delta z$

- Indicates favorable thermodynamic structure for convection and turbulence in the daytime mixed layer (Stull 1988, Sorbjan 1989).
- Levels:
  - 700 to 850 mb: Great Plains
  - 850 to 925 mb: Eastern U.S.

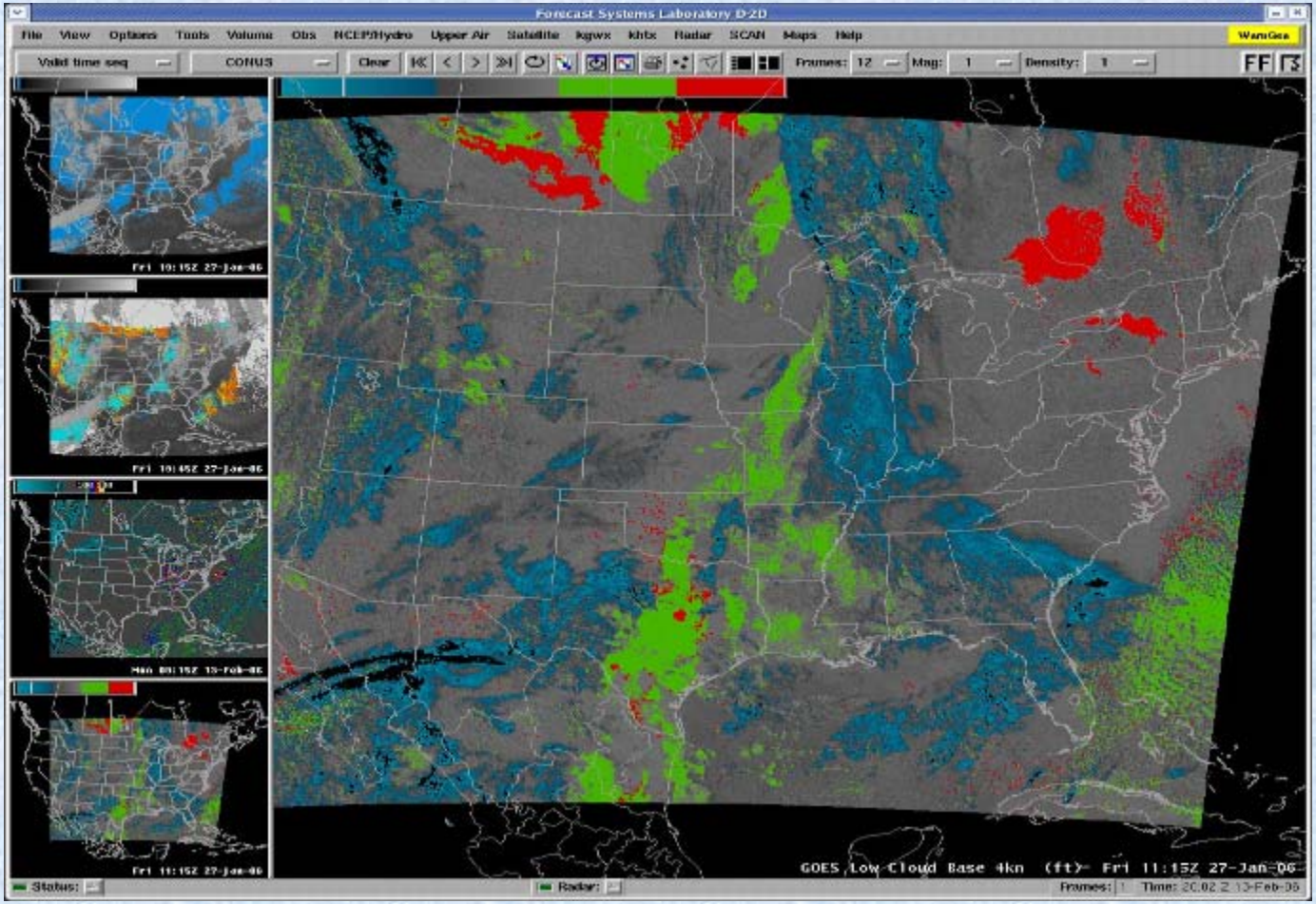
Turbulence: Boundary Layer





Validation includes comparison of boundary layer TKE values to wind measurements as recorded by Oklahoma Mesonet observation stations.

AWIPS Implementation



GOES Aviation Products

AWIPS Implementation

- Implementation includes fog depth, low cloud base, aircraft icing potential, and icing plus cloud-top heights (referred to as: ICing Enhanced Cloud-top Altitude Product (ICECAP)).
- Converted to AWIPS format at the National Aeronautics and Space Administration (NASA) Marshall Space Flight Center (MSFC) in Huntsville, Alabama for potential use by National Weather Service (NWS) Forecast Offices.

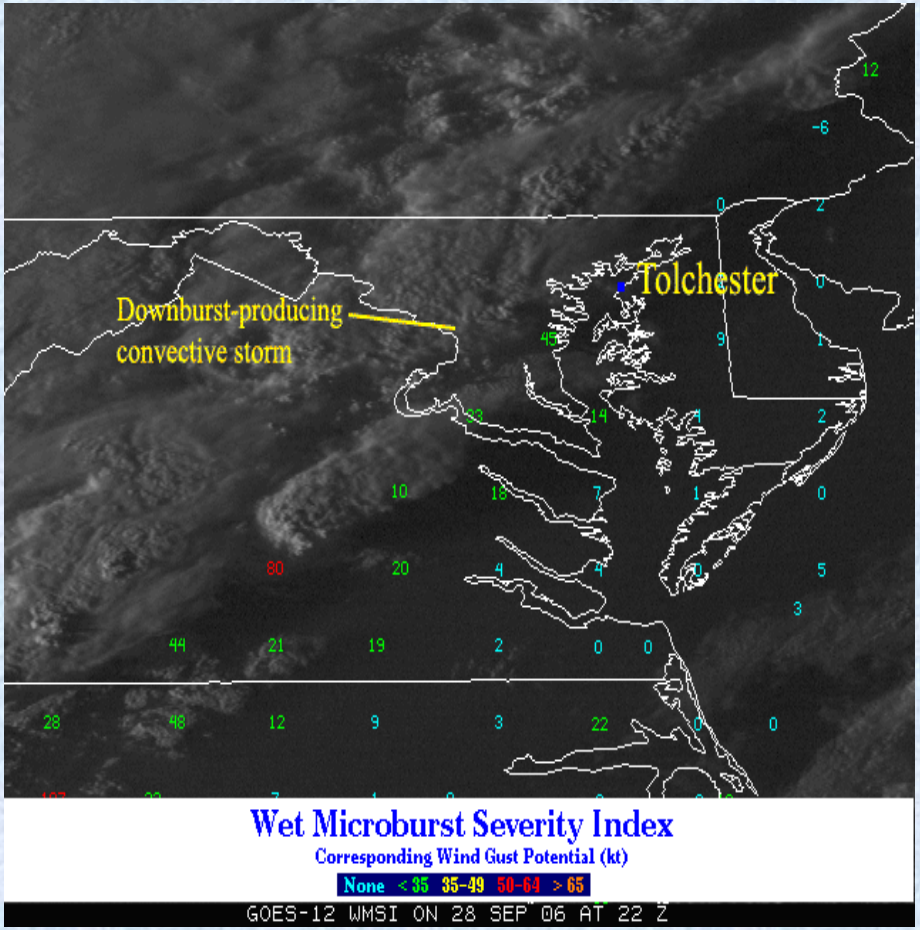
Future Research

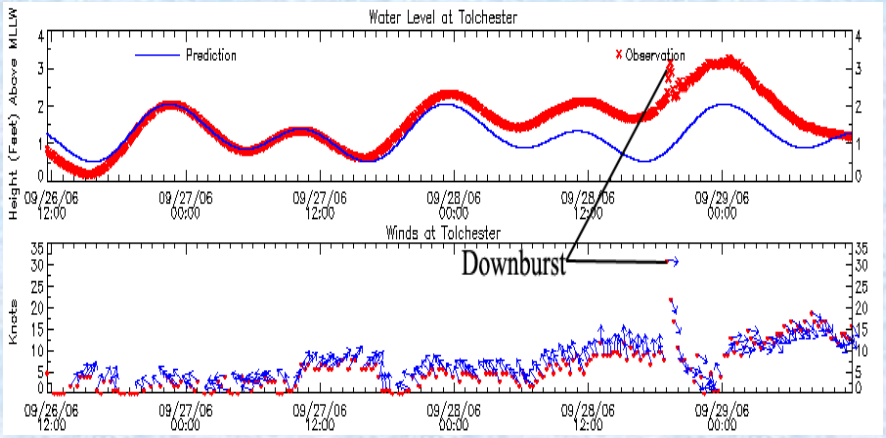
- Volcanic ash detection:
  - Continue assessment of loss of 12 μm band
- Icing:
  - Investigate the use of freezing level heights obtained from numerical model data in conjunction with ICECAP to estimate the depth of icing cloud layers.
  - Investigate the use of higher-resolution polar satellite data from AVHRR or MODIS instruments.

Future Research

- Microbursts:
  - Use of the microburst products during the cold season: environment, physical processes
  - Coordinated use of WMSI and HMI to forecast microburst magnitude over Southern/High Plains region
  - Marine transportation applications
- Turbulence:
  - Implementation of boundary layer turbulence index
  - Improved verification of DVSI and D-DVSI products

Marine Applications





-Potentially hazardous marine conditions resulting from downbursts.

-Establish the correlation between current microburst indices and resulting marine conditions.

References

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Thank You!