Advances in Downburst Monitoring and Prediction with GOES-16

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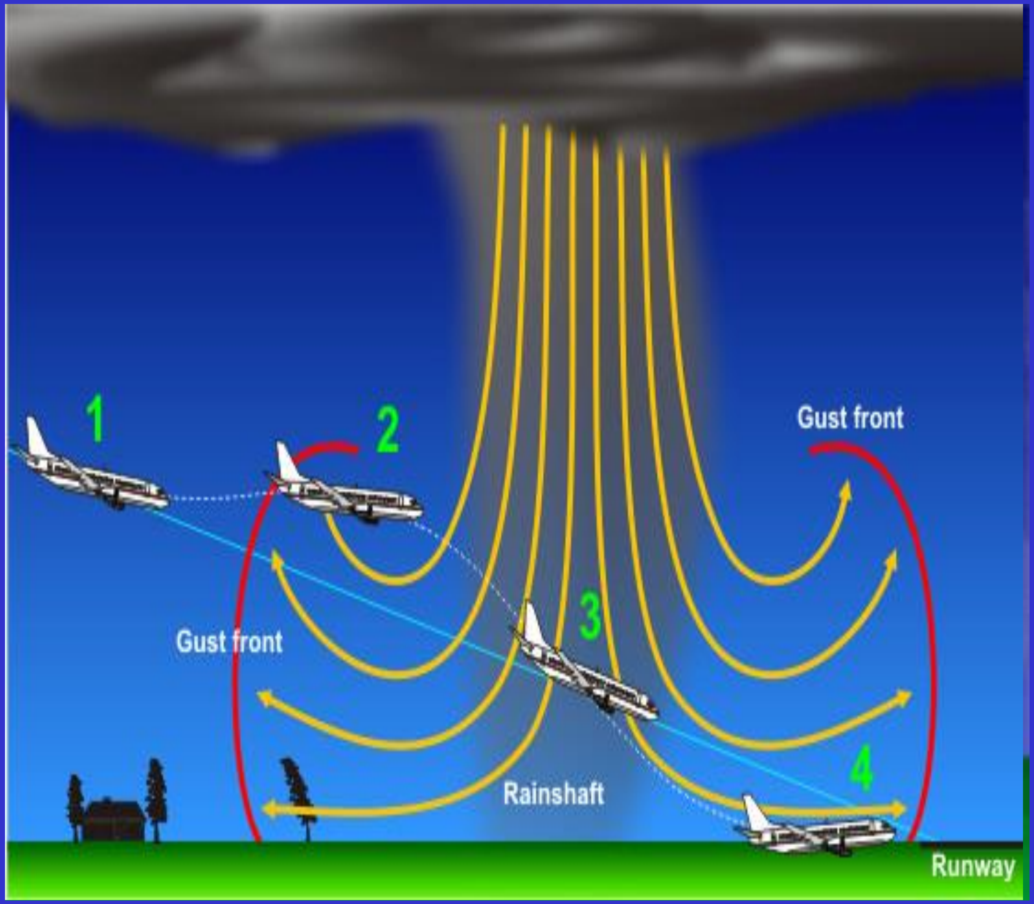
Topics of Discussion

- Thunderstorm downbursts and downburst prediction technique
  - GOES Imager and Sounder
  - NWP model proxy data
  - Python algorithm implementation
- Case Study:
  - Northwestern U.S., 4 June 2017
- Conclusions and Future Plans

Thunderstorm Downburst



- Strong downdraft produced by a convective storm (or thunderstorm) that causes damaging winds on or near the ground.
- Precipitation loading, sometimes combined with entrainment of subsaturated air in the storm middle level, initiates the downdraft.
- Melting of hail and sub-cloud evaporation of rain result in the cooling and negative buoyancy that accelerate the downdraft in the unsaturated layer.

Since 2000, the NTSB has documented ten fatal microburst-related general aviation aircraft accidents, mostly over the southern and western U.S.

Microburst Windspeed Potential Index (MWPI)

- Based on factors that promote thunderstorms with potential for strong winds:
  - Convective Available Potential Energy (CAPE): Strong updrafts, large storm precipitation content (esp. hail, rain)
  - Large changes of temperature and moisture (humidity) with height in the lower atmosphere.
  - Index values are positively correlated with downburst wind strength.
- $\text{MWPI} \equiv \text{CAPE}/1000 + \Gamma/5^{\circ}\text{C km}^{-1} + [(T - T_d)_{LL} - (T - T_d)_{UL}]/5^{\circ}\text{C}$
  - Γ = temperature lapse rate (°C km^{-1}) between lower level (LL) and upper level (UL). **LL = 850 mb or 700 mb** **UL = 670 mb or 500 mb**
  - Based on analysis of 50 downburst events over Oklahoma and Texas, scaling factors of 1000 J kg^{-1}, 5°C km^{-1}, and 5°C, respectively, are applied to the MWPI algorithm to yield a unitless MWPI value that expresses wind gust potential on a scale from one to five.

GOES Sounder Downburst Prediction

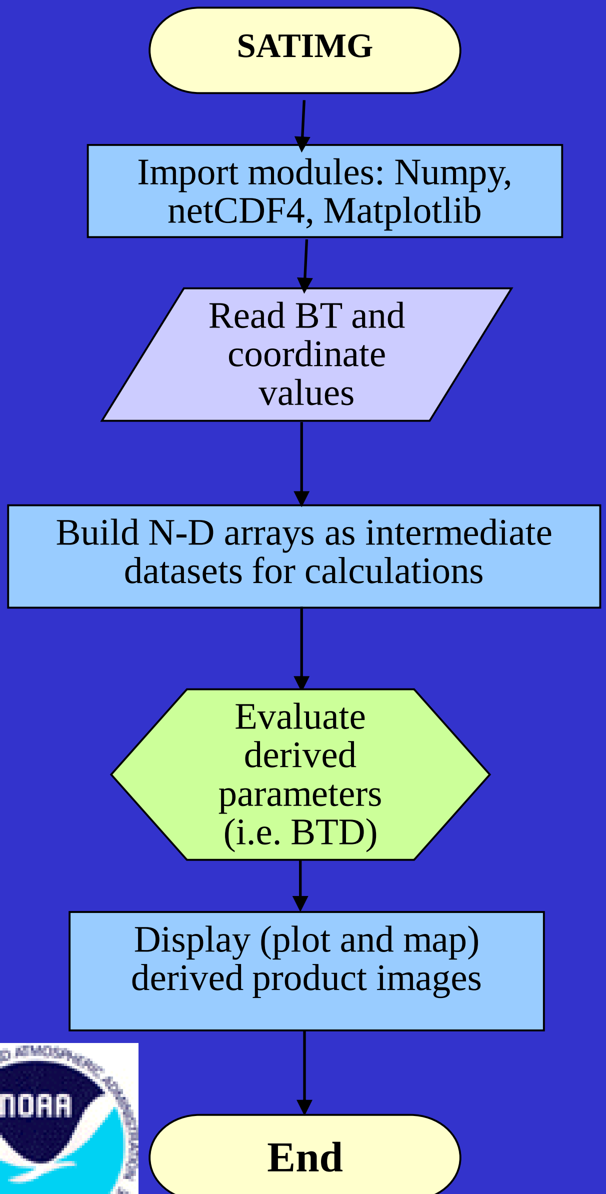
Table 1. Summary of the wavelengths, resolution, and sample use and heritage instrument(s) of the ABI bands. The minimum and maximum wavelength range represent the full width at half maximum (FWHM or 50%) points. [The Instantaneous Geometric Field Of View (IGFOV).]

Future GOES imager (ABI) band	Wavelength range (µm)	Central wavelength (µm)	Nominal subsatellite IGFOV (km)	Sample use	Heritage instrument(s)
1	0.45–0.49	0.47	1	Daytime aerosol over land, coastal water mapping	MODIS
2	0.59–0.69	0.64	0.5	Daytime clouds fog, insolation, winds	Current GOES imager/ sounder
3	0.846–0.885	0.865	1	Daytime vegetation/burn scar and aerosol over water, winds	VIIRS, spectrally modified AVHRR
4	1.371–1.386	1.378	2	Daytime cirrus cloud	VIIRS, MODIS
5	1.58–1.64	1.61	1	Daytime cloud-top phase and particle size, snow	VIIRS, spectrally modified AVHRR
6	2.225–2.275	2.25	2	Daytime land/cloud properties, particle size, vegetation, snow	VIIRS, similar to MODIS
7	3.80–4.00	3.90	2	Surface and cloud, fog at night, fire, winds	Current GOES imager
8	5.77–6.6	6.19	2	High-level atmospheric water vapor, winds, rainfall	Current GOES imager
9	6.75–7.15	6.95	2	Midlevel atmospheric water vapor, winds, rainfall	Current GOES sounder
10	7.24–7.44	7.34	2	Lower-level water vapor, winds, and SO_2	Spectrally modified current GOES sounder
11	8.3–8.7	8.5	2	Total water for stability, cloud phase, dust, SO_2 rainfall	MAS
12	9.42–9.8	9.61	2	Total ozone, turbulence, and winds	Spectrally modified current sounder
13	10.1–10.6	10.35	2	Surface and cloud	MAS
14	10.8–11.6	11.2	2	Imagery, SST, clouds, rainfall	Current GOES sounder
15	11.8–12.8	12.3	2	Total water, ash, and SST	Current GOES sounder
16	13.0–13.6	13.3	2	Air temperature, cloud heights and amounts	Current GOES sounder/ *GOES-12+* imager

Source: Schmit, T.J., Gunshor, M.M., Menzel, W.P., Gurka, J.J., Li, J., Bachmeier, A.S., 2005, Introducing the Next-Generation Advanced Baseline Imager on GOES-R, Bulletin of the American Meteorological Society, v. 86, p. 1079-1096.

- Radiometer that senses specific data parameters for atmospheric temperature and moisture profiles.
- Current MWPI program ingests the vertical temperature and moisture profiles derived from GOES sounder radiances.
- GOES-16 Advanced Baseline Imager (ABI) legacy soundings:
  - Improved temporal and spatial resolution: 5 min, 2 km
  - ABI moisture profile in the warm-season sub-cloud layer will be especially reliable
  - Radiance noise can be reduced by spatial and temporal averaging

Methodology: Algorithm Implementation and Data Acquisition



- Algorithms implemented to display geostationary satellite, Doppler radar, numerical weather prediction (NWP) model image datasets in the Python programming language.

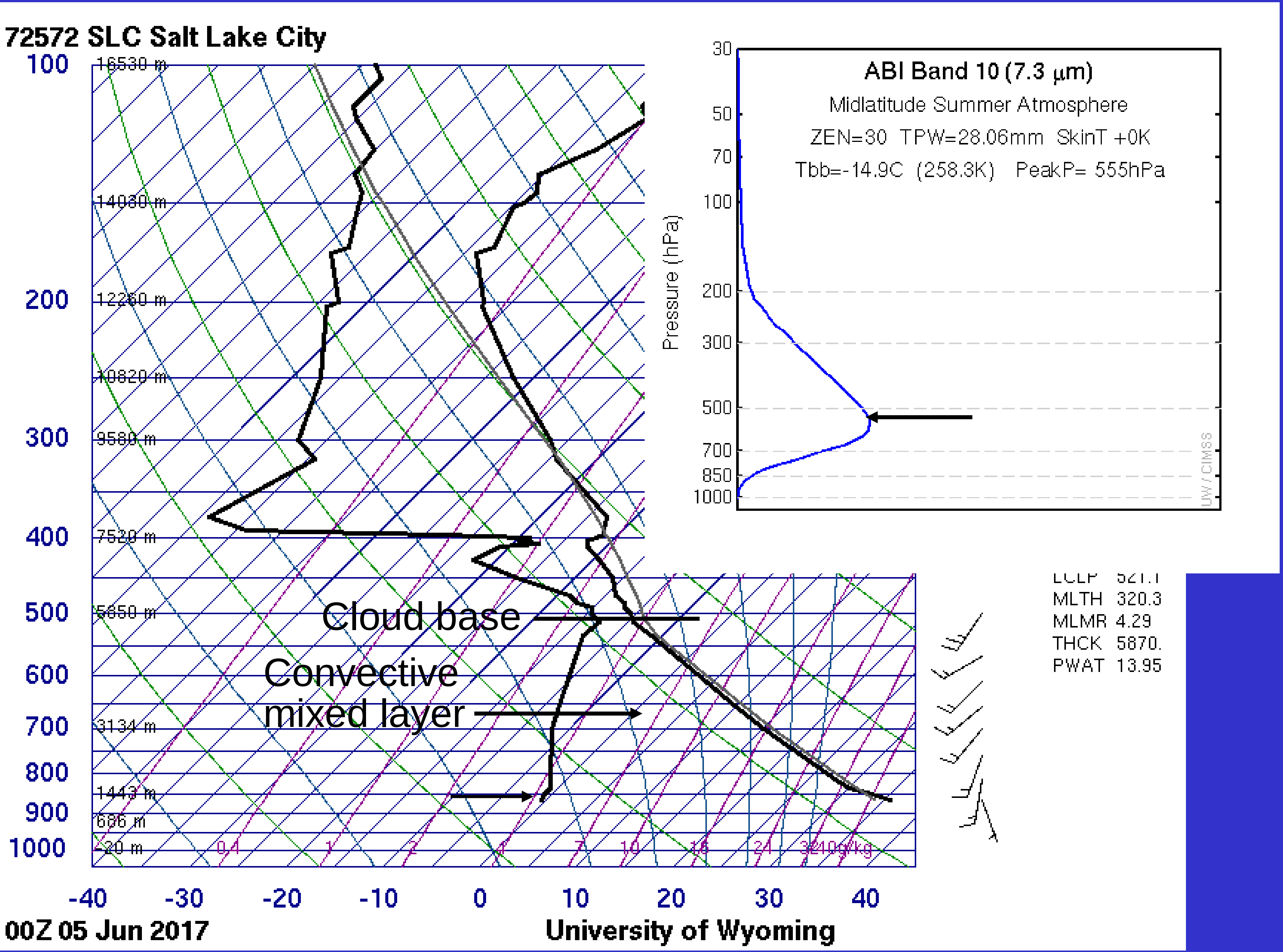
- Function definition and application of Python modules to read datasets, build intermediate datasets for parameter calculation, and display derived product images (DPI):
    - Basemap
    - NetCDF4
    - Numpy
    - Matplotlib

- GOES-16 ABI level 2 data files are obtained from the NESDIS/STAR Central Data Repository (SCDR):
    - Level 2 Cloud and Moisture Imagery product (CMIP) brightness temperature (BT)

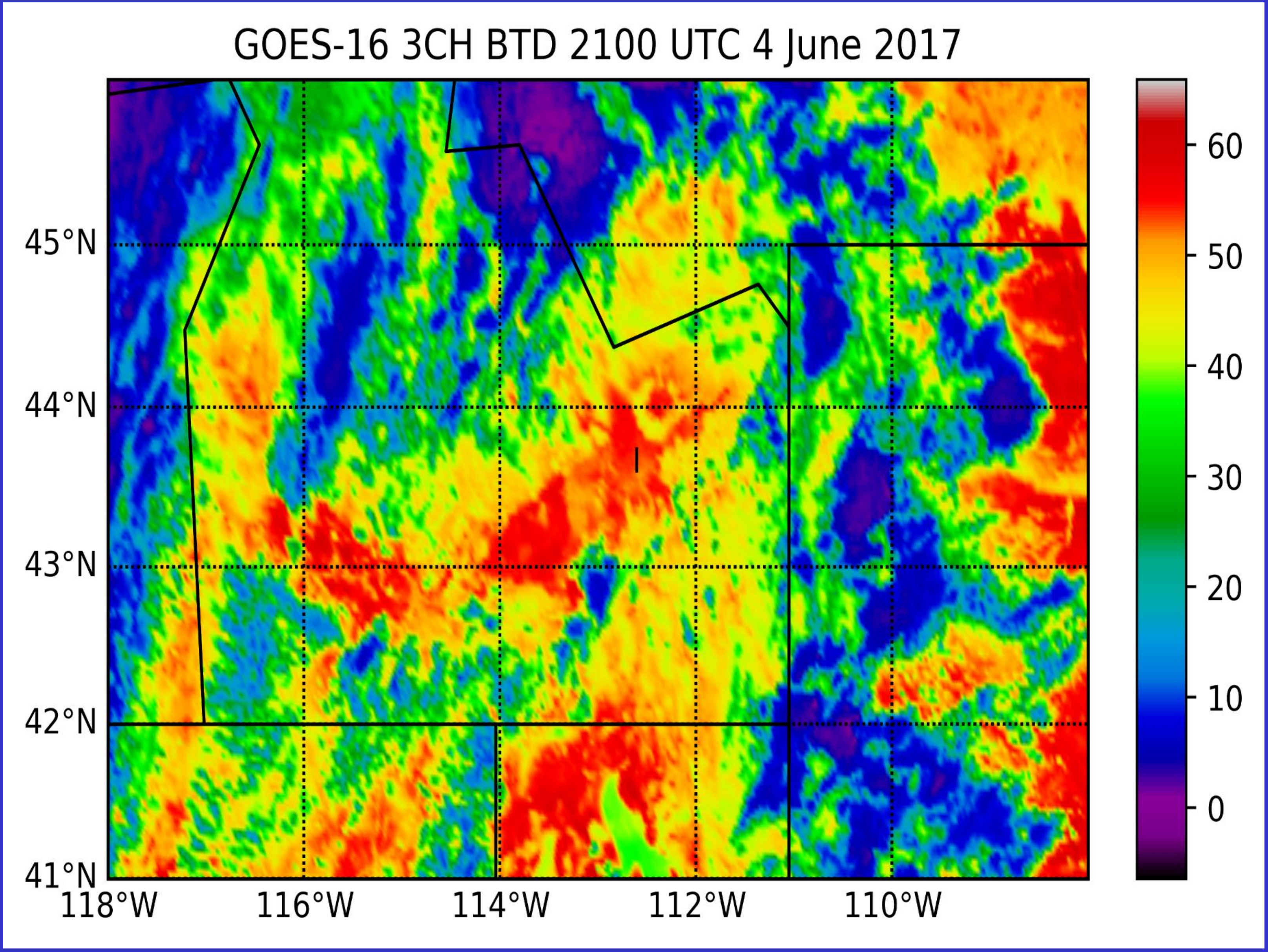
Case Study:
4 June 2017 Northwestern U.S. Downbursts

- During the afternoon of 4 June 2017, strong thunderstorms developed along a cold front over the northwestern United States and produced severe winds over southern Idaho and in the Salt Lake City, Utah area.
- Downburst-related wind gusts of 52 to 54 knots were recorded by NOAA Air Resources Laboratory (ARL) wind sensors at the Idaho National Laboratory (INL) between 2255 and 2325 UTC.
- GOES-16 water vapor (WV) – longwave infrared (LWIR) channel BTD and Doppler radar reflectivity (Z) imagery indicated structural patterns favorable for downburst producing thunderstorms.
- MWPI values generated from Rapid Refresh (RAP) model data and GOES-16 3-channel brightness temperature difference (BTD: WV, split-window LWIR) values indicated a favorable lower-tropospheric thermodynamic structure for downburst generation.
- Split window LWIR channels: 14 (11 μm), 15 (12 μm); Low-level water vapor channel 10 (7.3 μm)

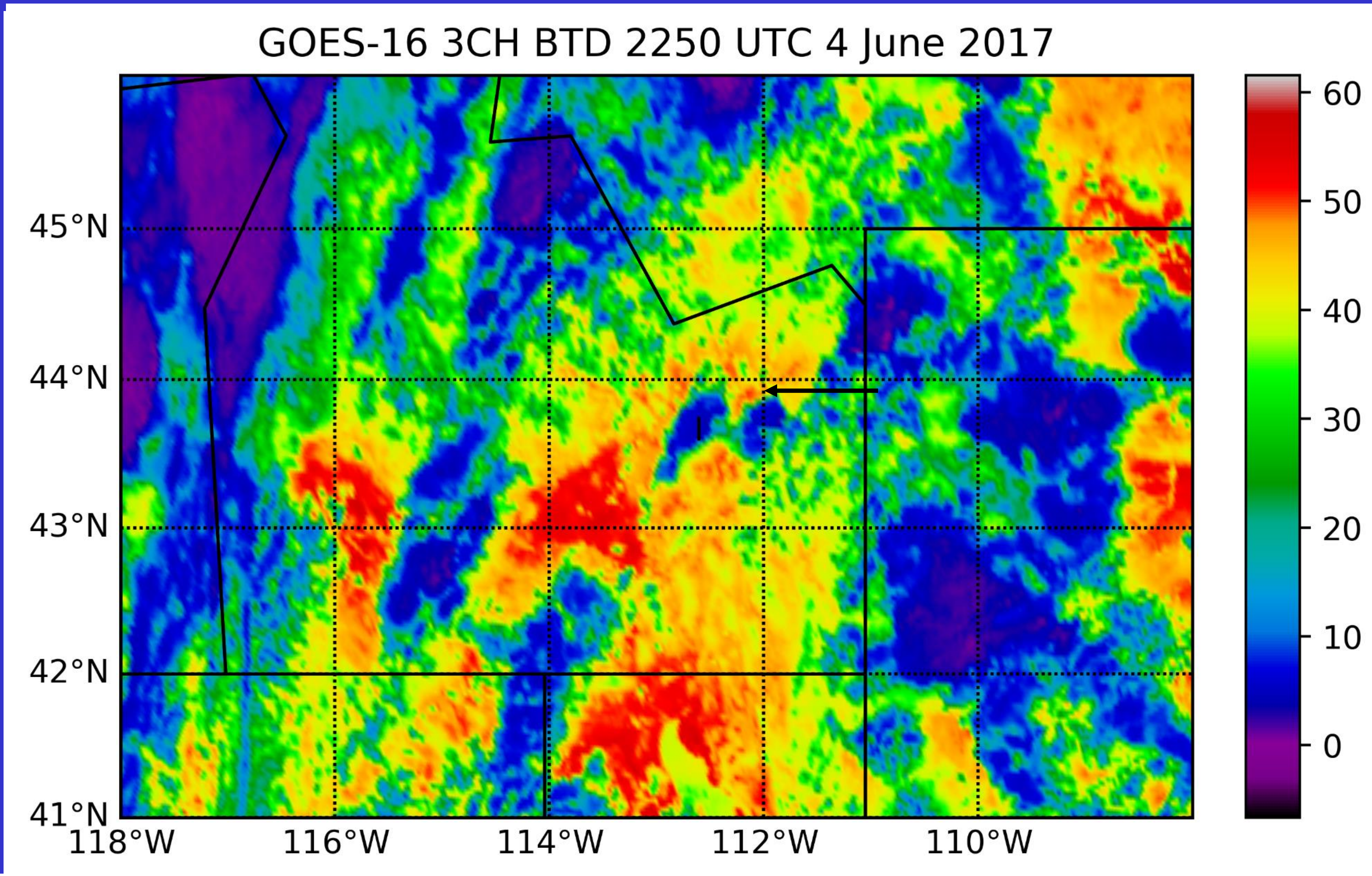
RAOB Sounding Analysis



RAP Model:
Downburst Prediction Algorithms

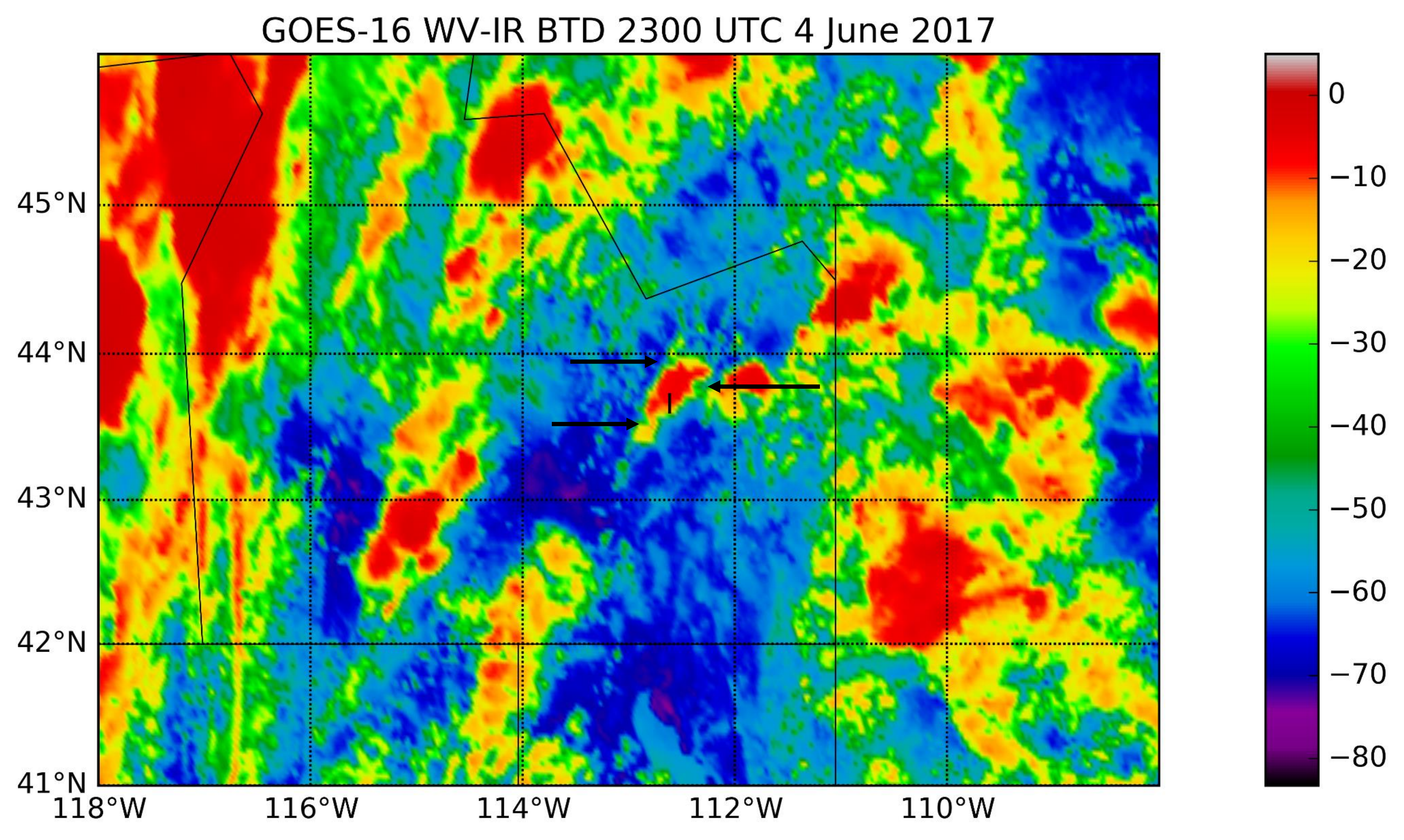


GOES-16 DPI Generation

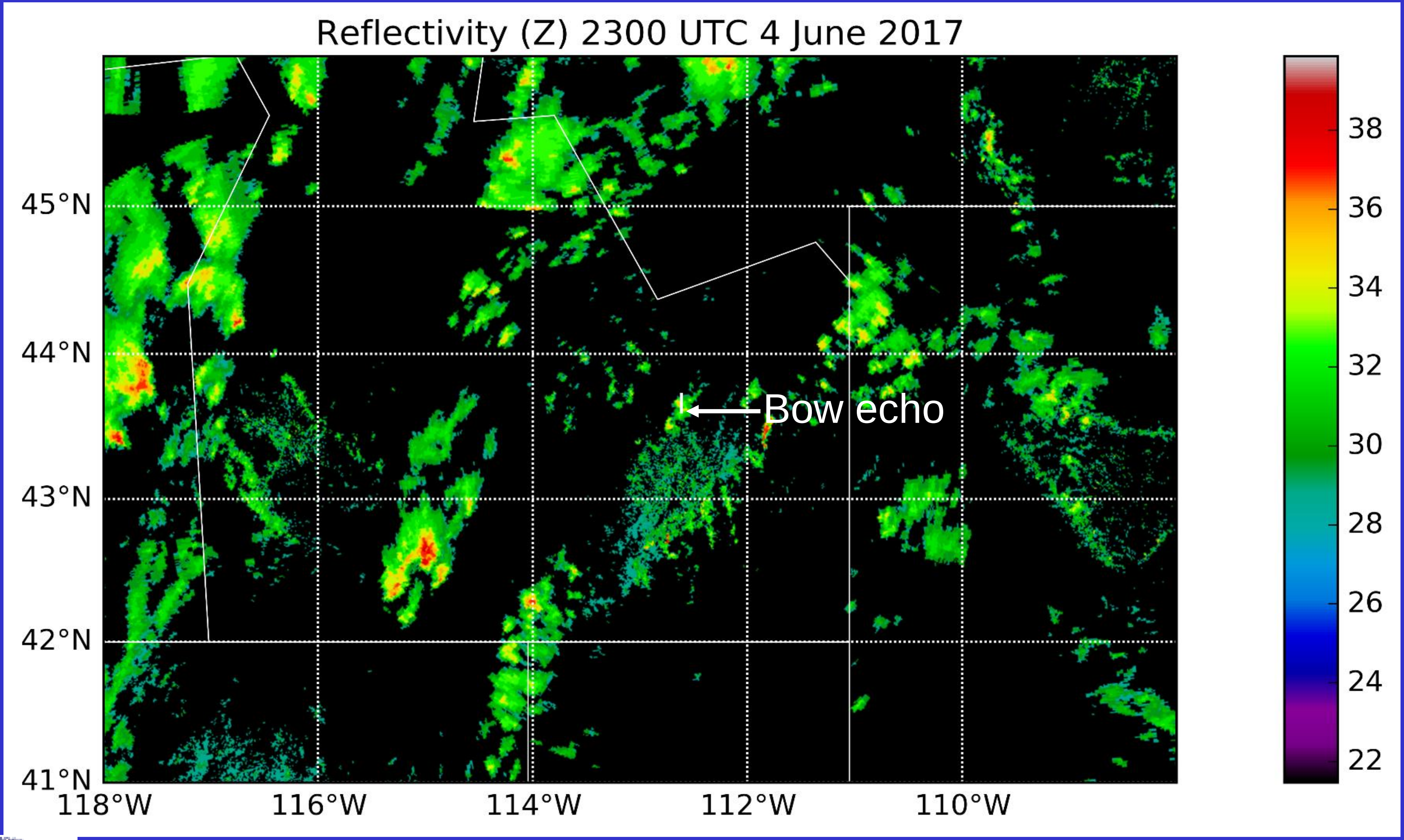


$$MBR = (T_{14} - T_{15}) + (T_{15} - T_8)$$

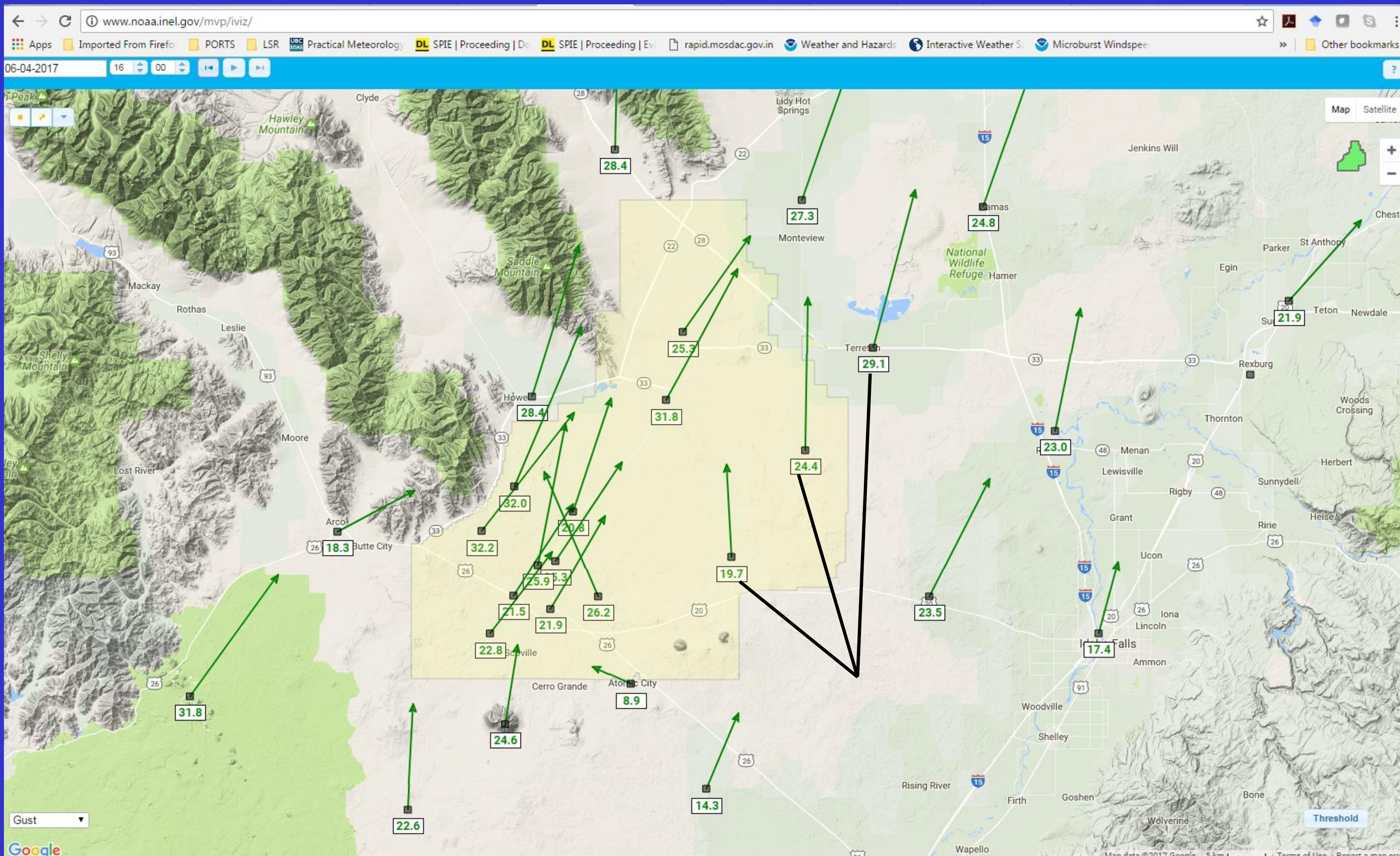
GOES-16 Derived Imagery



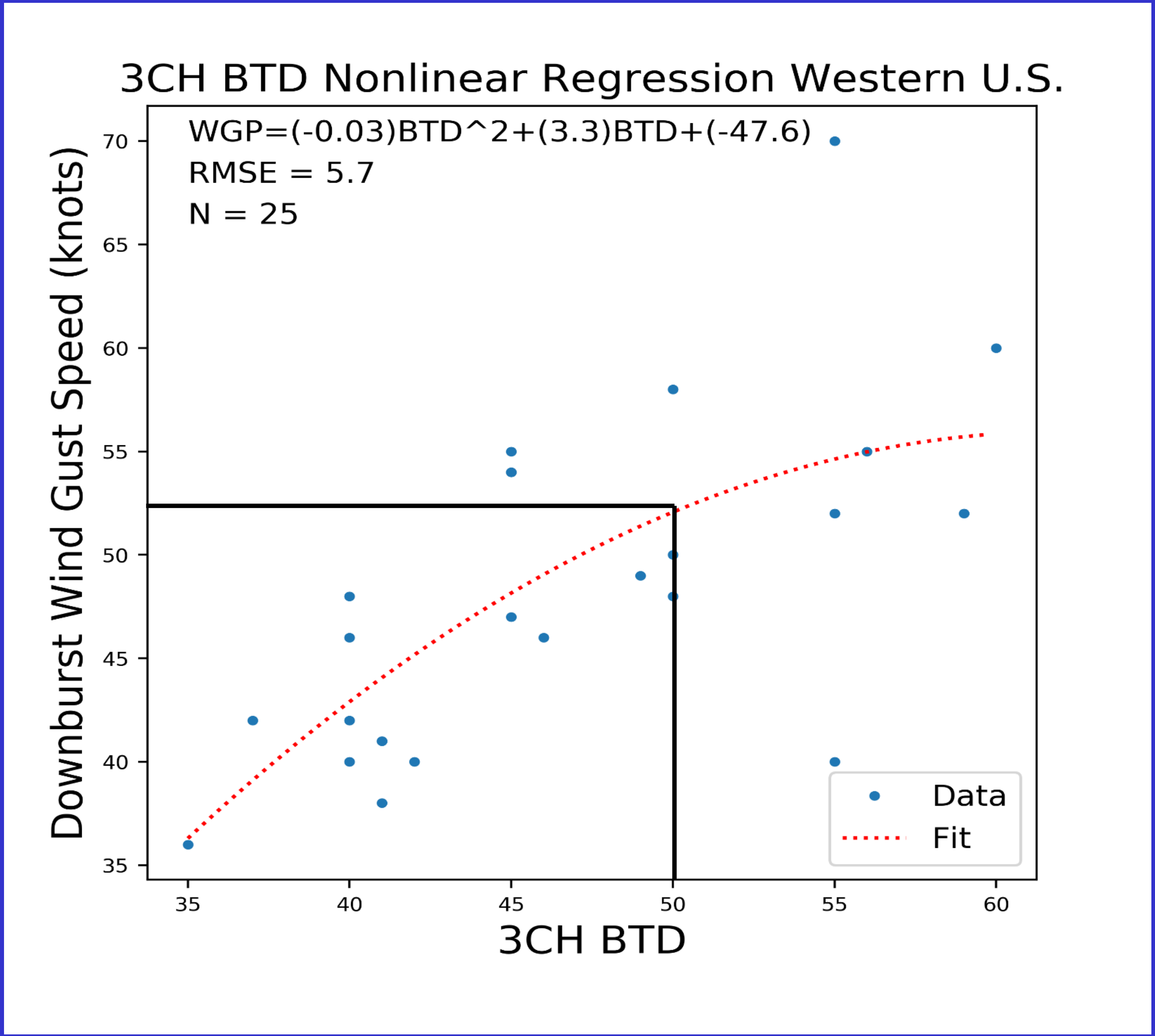
Doppler Radar Imagery



Wind Obs: INL Network



Thunderstorm Wind Prediction



Conclusions and Future Plans

- Downbursts are an important component of hazardous winds produced by thunderstorms:
  - The MWPI product demonstrates conditional capability to forecast, with up to two hours lead time, thunderstorm-generated wind gusts that could present a hazard to aviation transportation.
  - Most intense downburst occurrence is found near local maxima in MWPI and BTD values.
  - The MWPI product can be effectively used with GOES-16 and NEXRAD imagery to nowcast downburst intensity.
- Further product validation to obtain a larger sample size should produce more robust linear/quadratic regression and reduce error between microburst product values and observed wind speeds.

References

Caplan, S.J., A.J. Bedard, and M.T. Decker, 1990: The 700–500 mb Lapse Rate as an Index of Microburst Probability: An Application for Thermodynamic Profilers. *Journal of Applied Meteorology*, **29**, 680–687.

Pryor, K. L., 2015: Progress and Developments of Downburst Prediction Applications of GOES. *Wea. Forecasting*, **30**, 1182–1200.

Pryor, K. L., and S. D. Miller, 2016: Downburst Prediction Applications of GOES over the Western United States. arXiv:1611.01407v1 [physics.ao-ph]

Schmetz, J., S. A. Tjemkes, M. Gube, and L. van de Berg, 1997: Monitoring deep convection and convective overshooting with METEOSAT. *Adv. Space Res.*, **19**, 433–441.

References

Schmit, T.J., J. Li, J. J. Gurka, M. D. Goldberg, K. J. Schrab, J. Li, and W. F. Feltz, 2008: The GOES-R advanced baseline imager and the continuation of current sounder products. *Journal of Applied Meteorology and Climatology*, **47**, 2696-2711.

Soden, B.J. and F.P. Bretherton, 1996: Interpretation of TOVS water vapor radiances in terms of layer-average relative humidities: Method and climatology for the upper, middle, and lower troposphere. *J. Geophys. Res.*, **101**, 9333-9343.

Srivastava, R.C., 1987: A model of intense downdrafts driven by the melting and evaporation of precipitation. *J. Atmos. Sci.*, **44**, 1752-1773.

Wakimoto, R.M., 1985: Forecasting dry microburst activity over the high plains. *Mon. Wea. Rev.*, **113**, 1131-1143.


Thank You!