A Preliminary Assessment of the HRRR's Ability to Predict the Great Lakes Lake-Breeze Front and Marine Atmospheric Boundary Layer Structure

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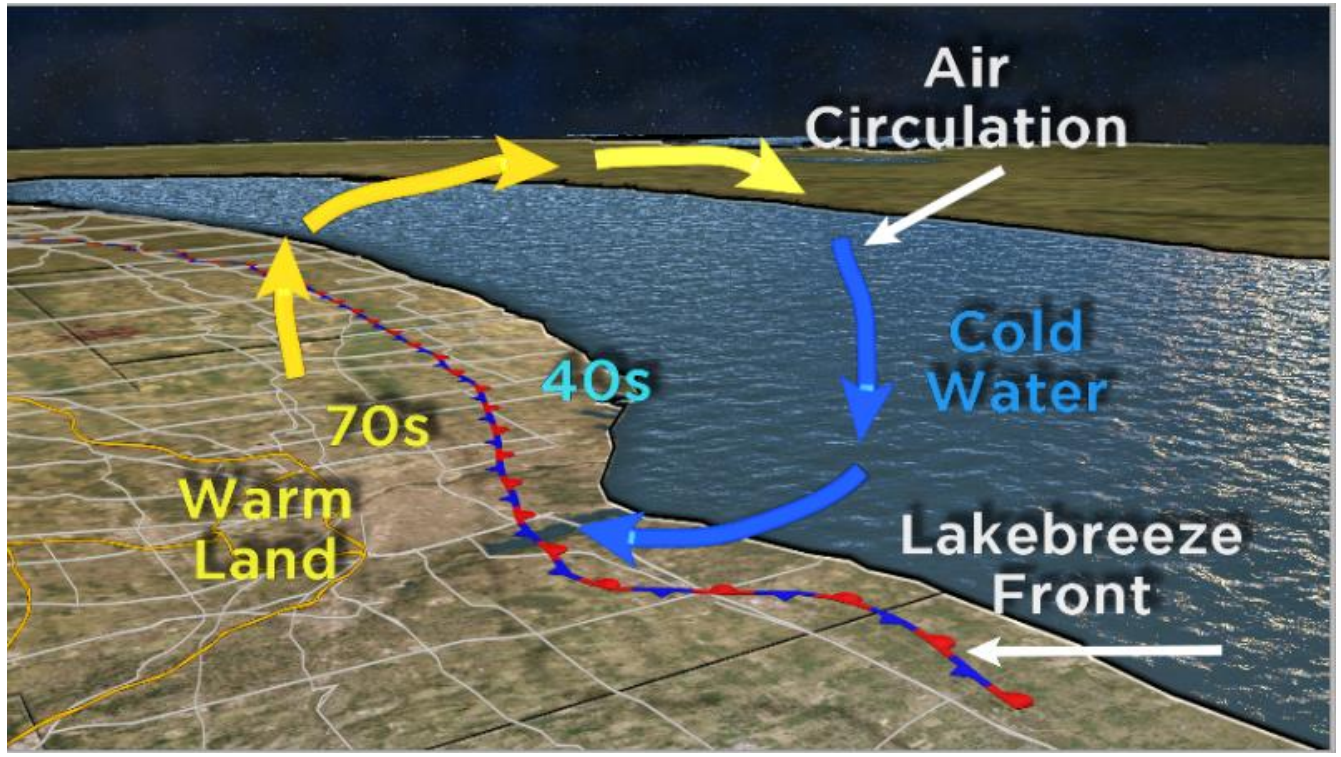
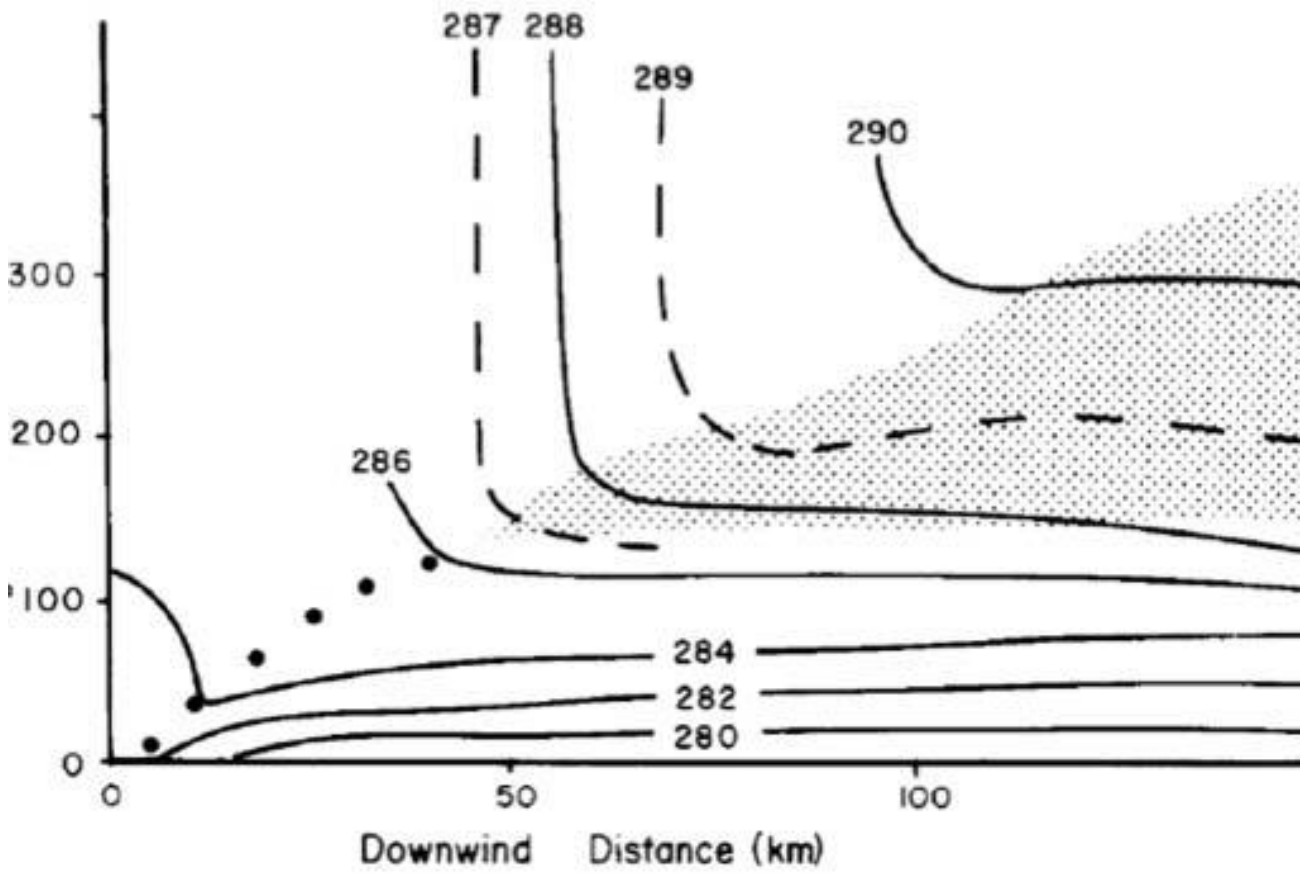
What causes the lake breeze front to develop?

- A warm-season phenomenon
- Lake breeze (LB) initiates a few hours after sunrise and dissipates near sunset (Sills et al. 2011)
- Large temperature difference (ΔT) between the land and water
- Weak prevailing winds



Meteorologist Michael Gouldrick (2020)

What is the environment like behind the lake breeze front?



Wylie & Young (1979)

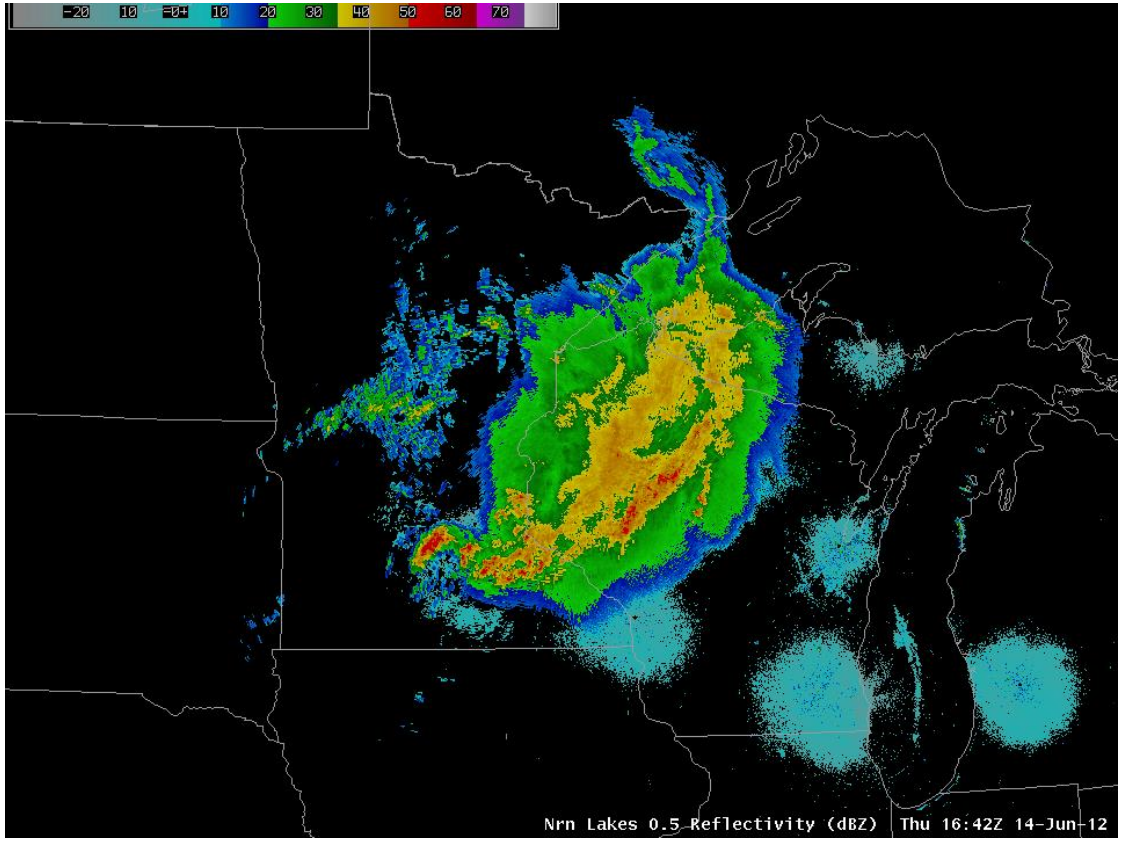
- Significant heat exchange between water and the air above
  - Cold, dense, stable air
- Shallow depth of the marine atmospheric boundary layer (MABL)
- Air behind the LB front retains the MABL airmass characteristics

Predicting the lake breeze: Model data

- Few studies have investigated NWP model predictability of the LB
  - Fine-scale LB details are mitigated by grid-cell averaging (Hawbecker & Knievel 2021)
- Our research goals:
  1. Assess the *ability* of a high-resolution mesoscale model (the High-Resolution Rapid Refresh, or HRRR) to resolve the LB
  2. Assess the *predictability* of the LB position and evolution
  3. Determine the impact of the model's MABL representation on LB representation and predictability

Why do we care about the lake-breeze front?

1. Accurate predictions of the LB front and marine airmass can improve coastal forecasts
2. The LB interacts with large-scale convective systems in the warm season frequently (Metz & Bosart 2019)
3. Deposition of pollutants in the boundary layer behind the LB front (Lyons & Cole 1976; Dye et al. 1995)



CIMSS (2012)

Lake-breeze identification and prediction metrics

- Criteria based on observations (Wagner et al. 2021)
  1. Shift in the zonal component of the surface wind
  2. Abrupt drop in the surface temperature at a given location
  3. Decrease in the mixing ratio height
  4. No precipitation
- Criterion for a model domain (Hawbecker & Knievel 2021)
  1. Onshore 10m wind
  2. Significant directional vertical wind shear
  3. Significant static stability behind LB front
  4. Minimal precipitation and cloud cover

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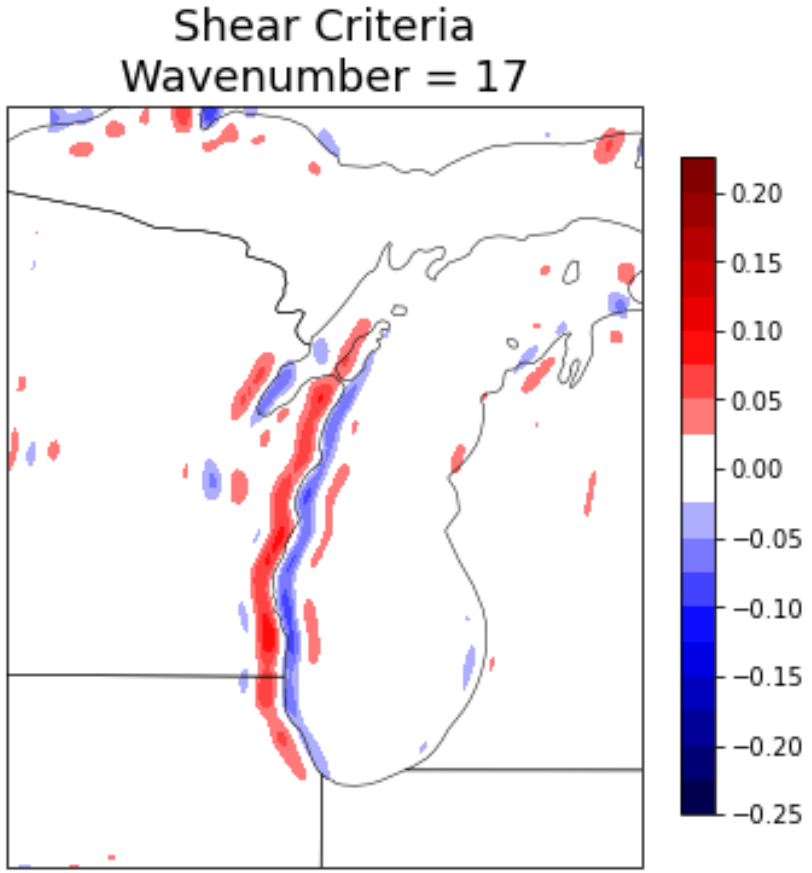
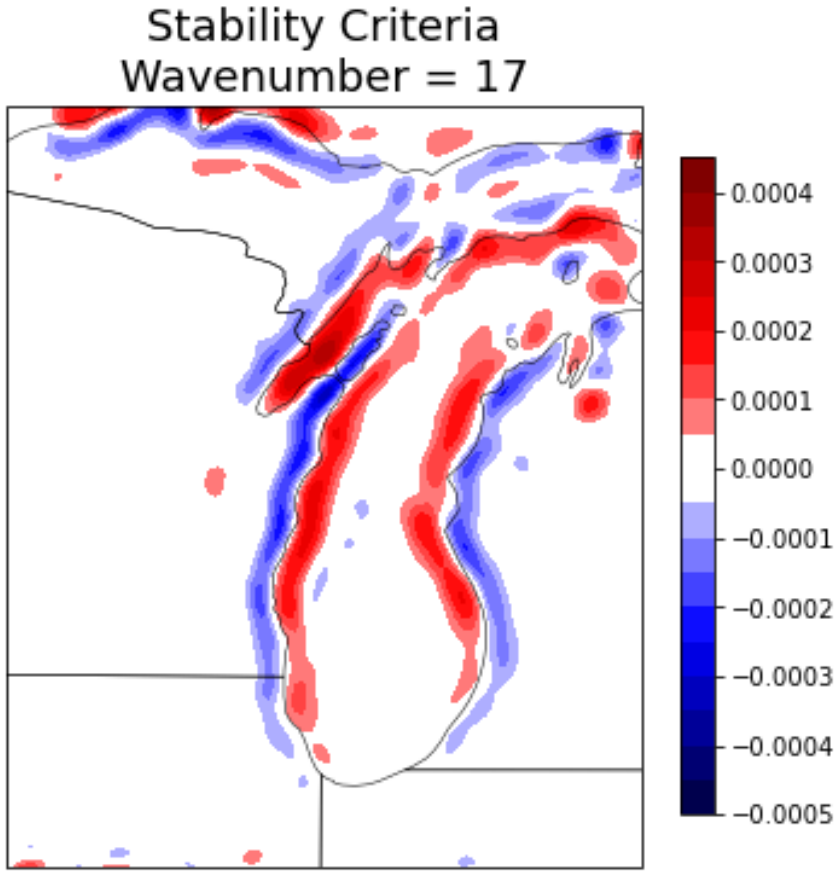
Lake-breeze detection algorithm

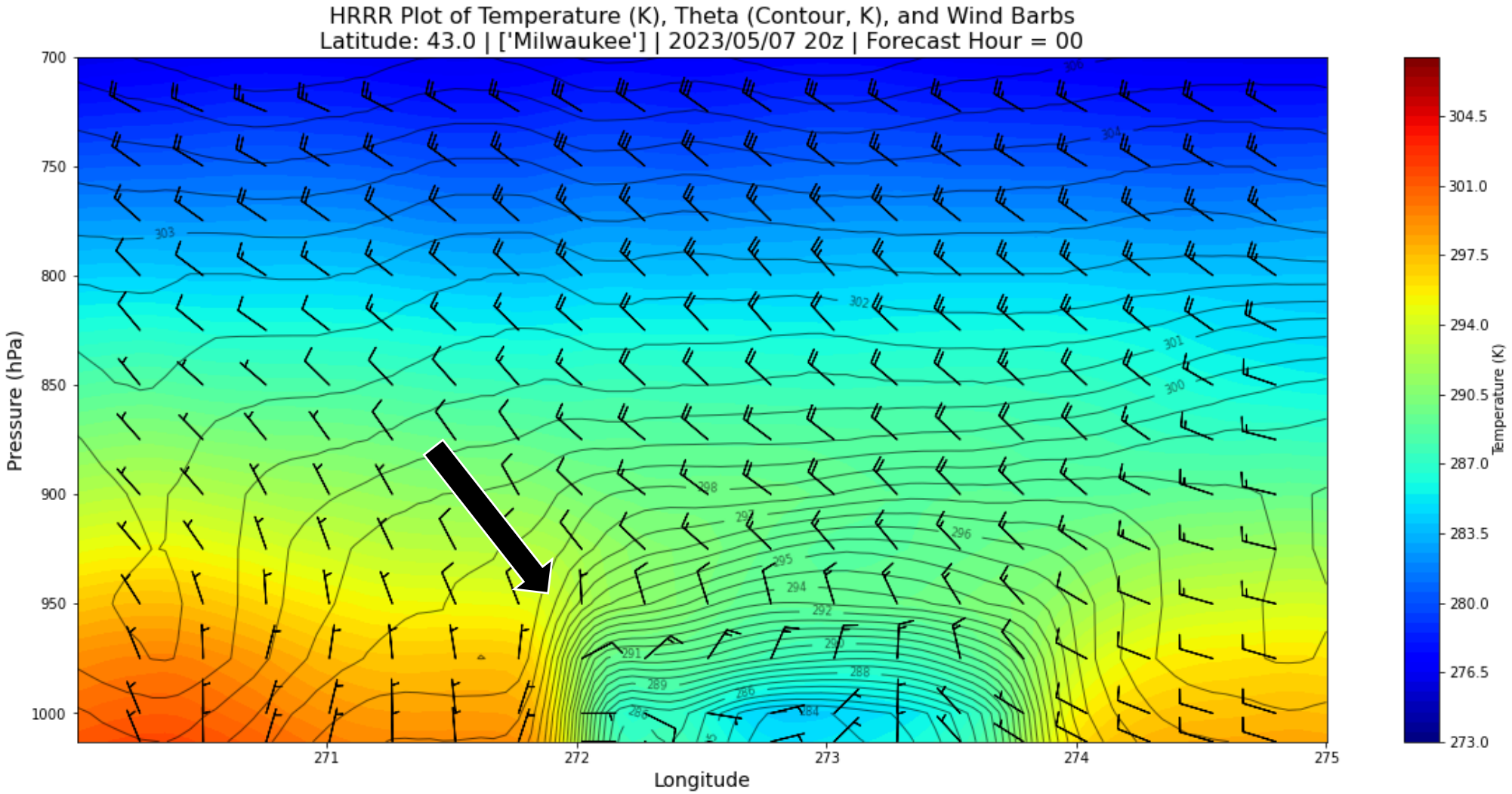
Shear criteria – Leading edge of LB front will have a positive gradient maxima

Stability criteria – Leading edge of LB front will have a negative gradient maxima





Motivation behind selected criteria



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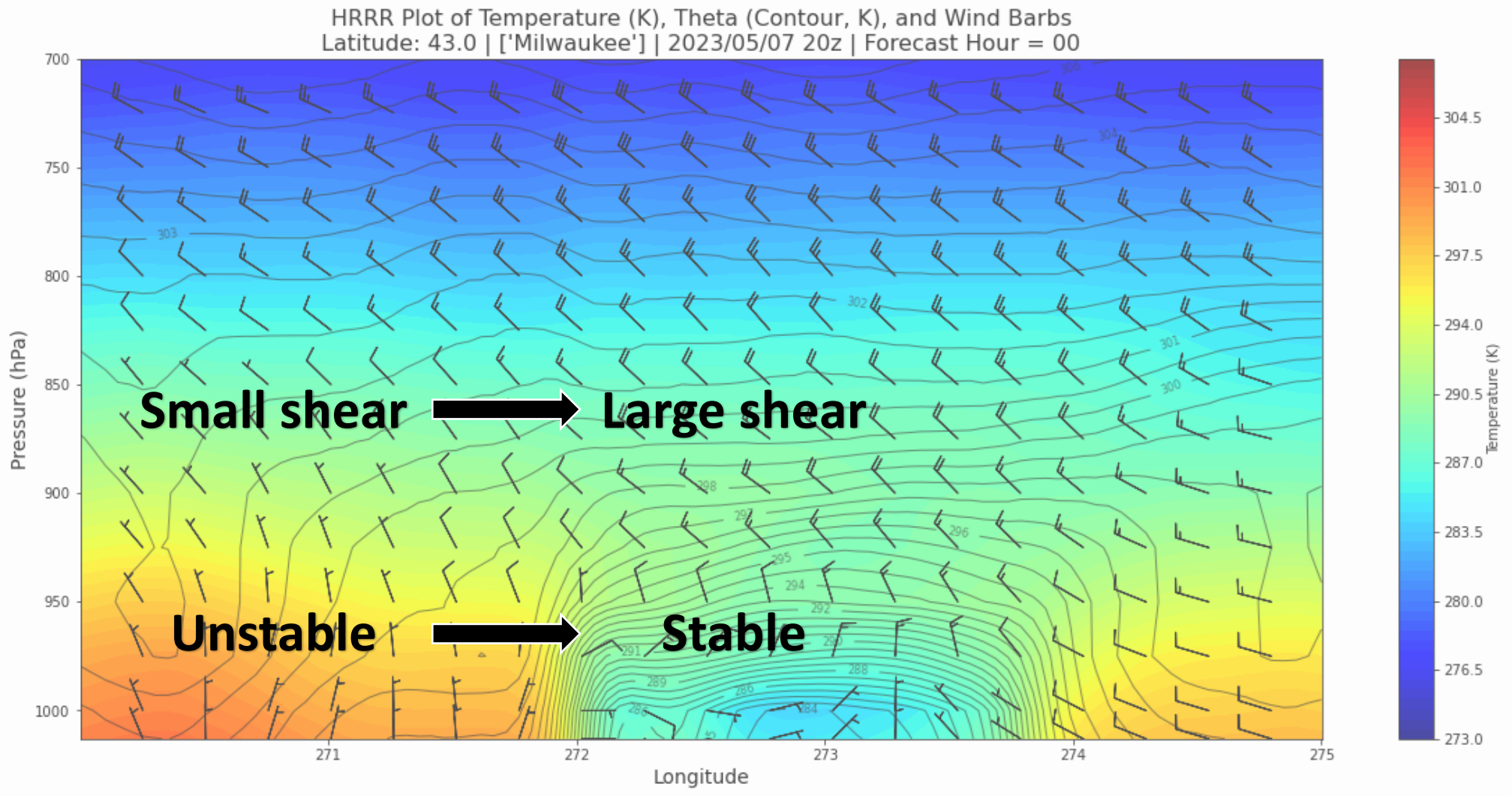


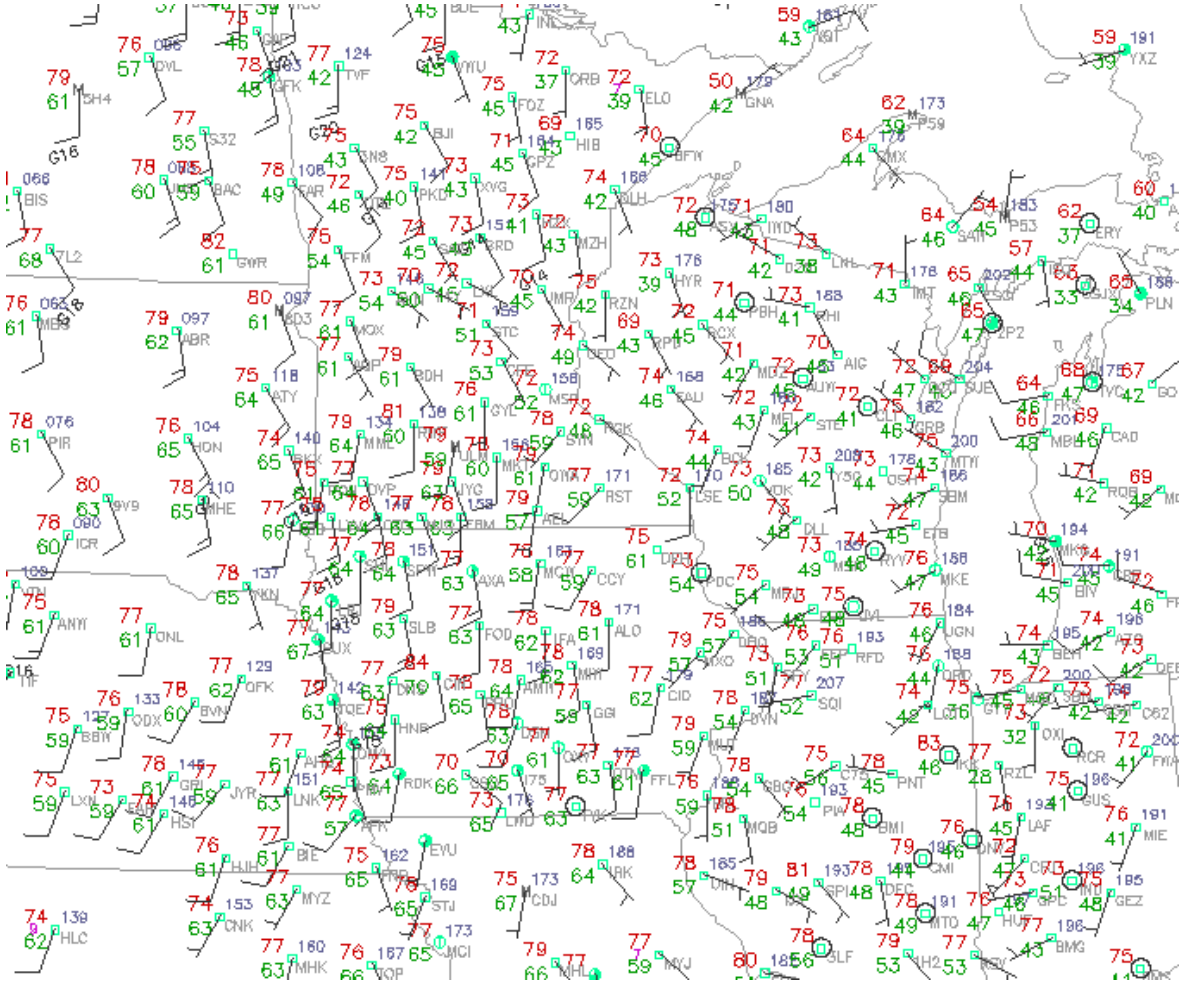
Lake-breeze detection algorithm

Second-order partial derivatives were used to identify the location of the LB front within the HRRR using the following fields:

1. Shear – horizontal gradient of the vertical wind shear magnitude *f*
   - $f = \sqrt{(u_{900} - u_{sfc})^2 + (v_{900} - v_{sfc})^2}$
   - $\nabla^2 \vec{V} = \frac{d^2}{dx^2}(f) + \frac{d^2}{dy^2}(f)$
2. Stability – horizontal gradient of the vertical theta gradient
   - $\nabla^2 \theta = \frac{d^2}{dx^2}\left(\frac{d\theta}{dz}\right) + \frac{d^2}{dy^2}\left(\frac{d\theta}{dz}\right)$

Case 1: June 2, 2017 from Wagner et al. (2021)

15:10Z



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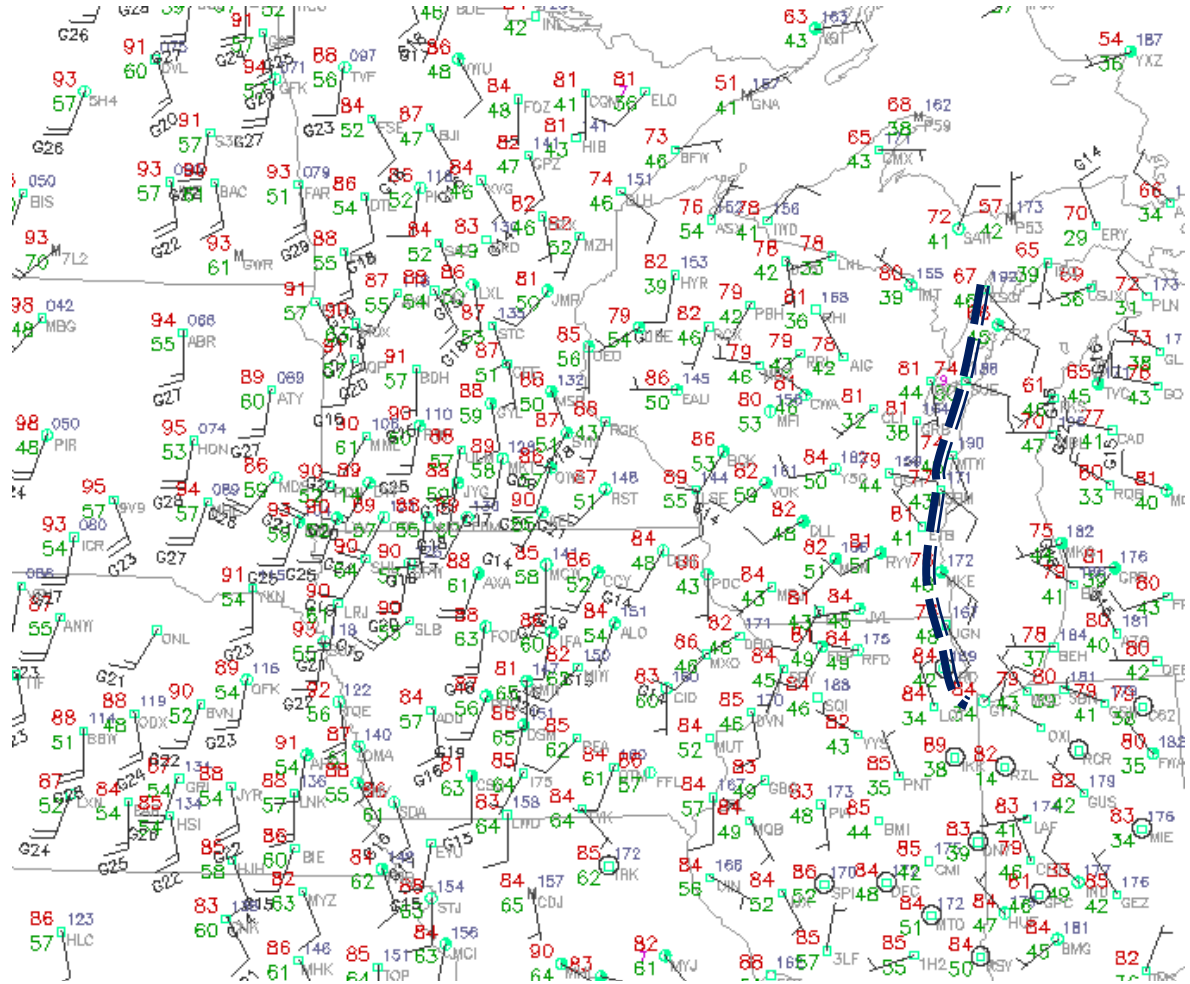


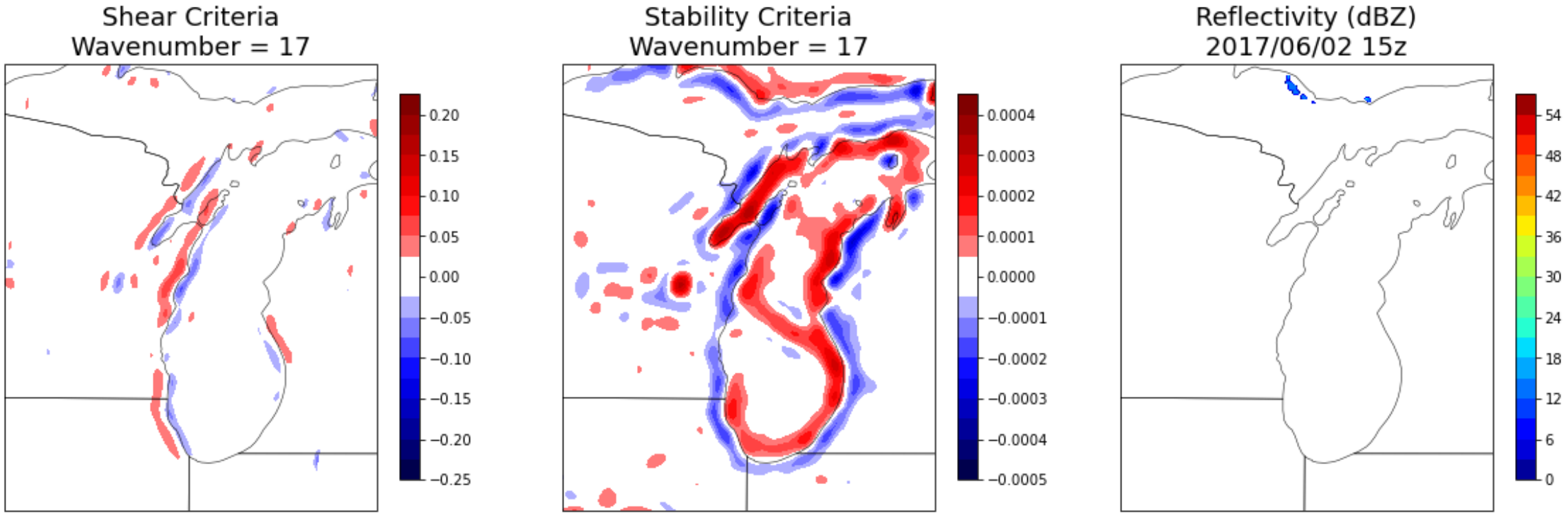
UCAR Image Archive

Lake-breeze detection:
June 2, 2017, HRRR
Initialization data

Time of Arrival

Sheboygan, WI – 1542 UTC

Zion, IL – 1448 UTC



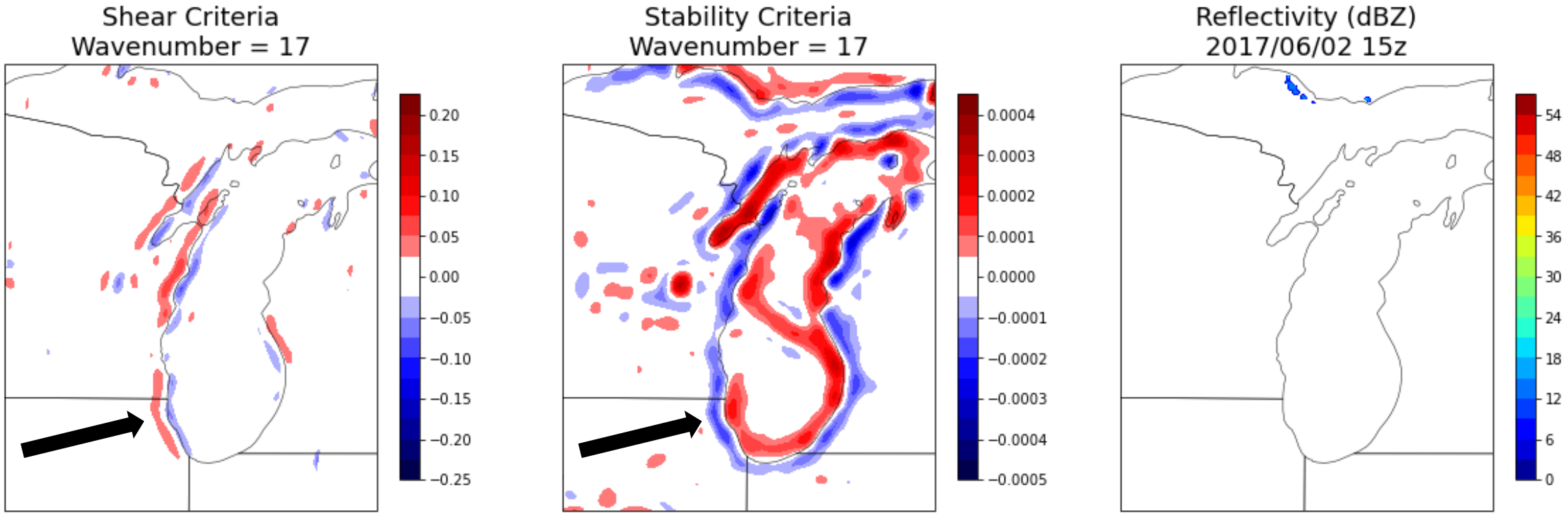
0-h HRRR Analysis Valid 1500 UTC 2 June 2017

Lake-breeze detection:
June 2, 2017, HRRR
Initialization data

Time of Arrival

Sheboygan, WI – 1542 UTC

Zion, IL – 1448 UTC



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Lake-breeze detection:
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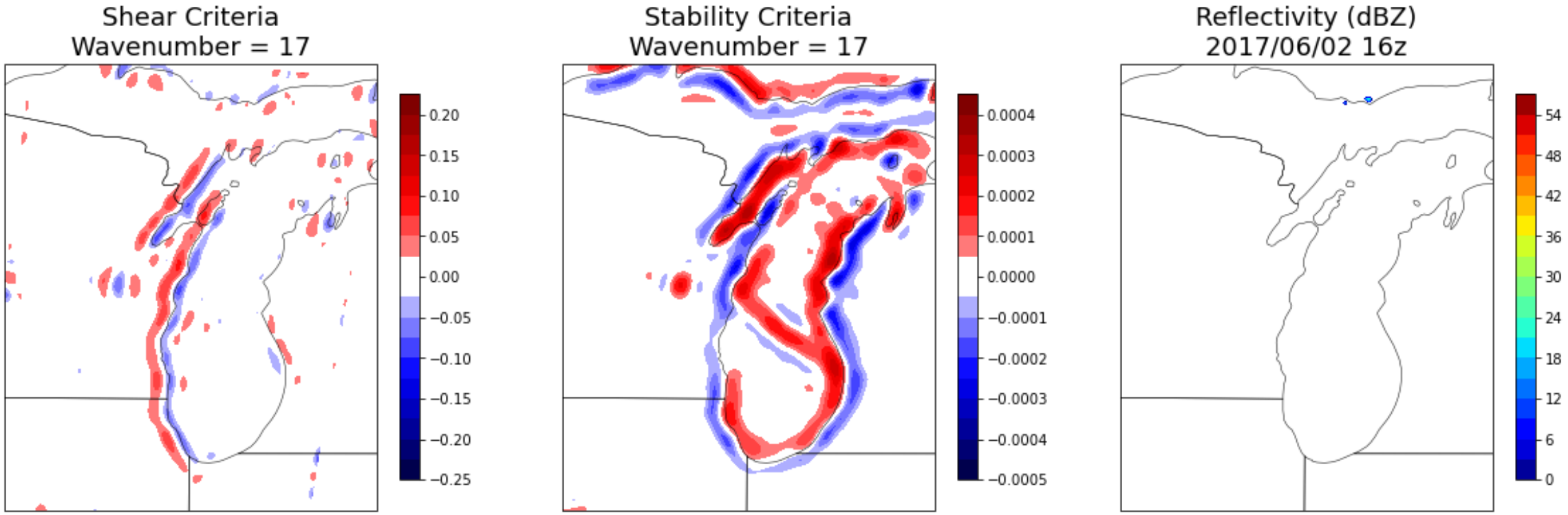


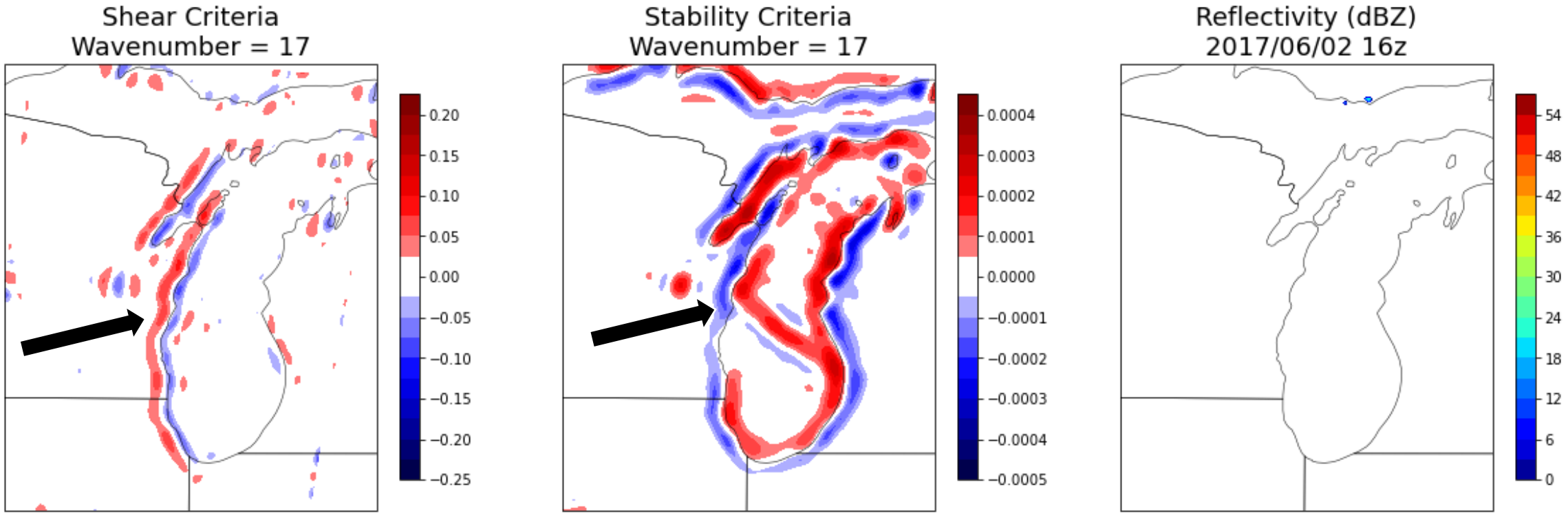
0-h HRRR Analysis Valid 1600 UTC 2 June 2017

Lake-breeze detection:
June 2, 2017, HRRR
Initialization data

Time of Arrival

Sheboygan, WI – 1542 UTC

Zion, IL – 1448 UTC



0-h HRRR Analysis Valid 1600 UTC 2 June 2017

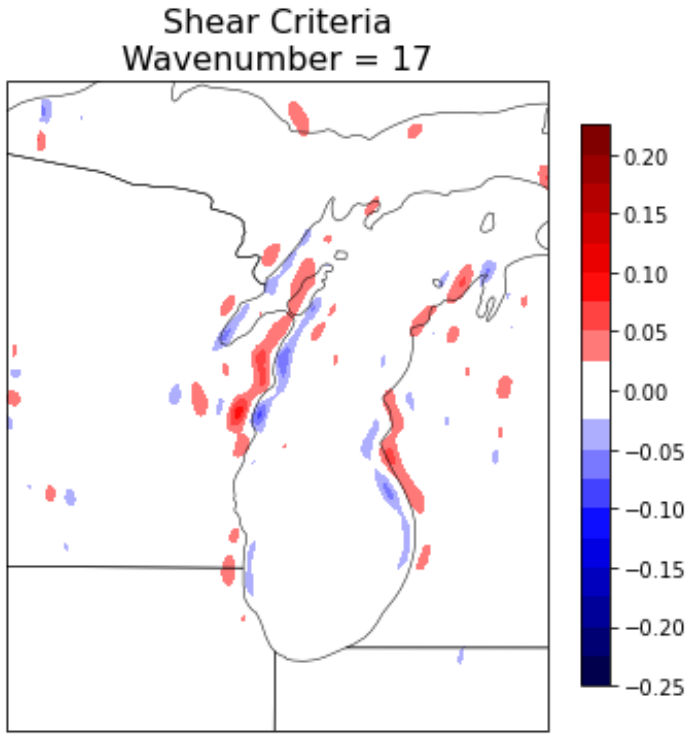
The HRRR seems capable of resolving the boundary between the lake breeze and continental airmasses.

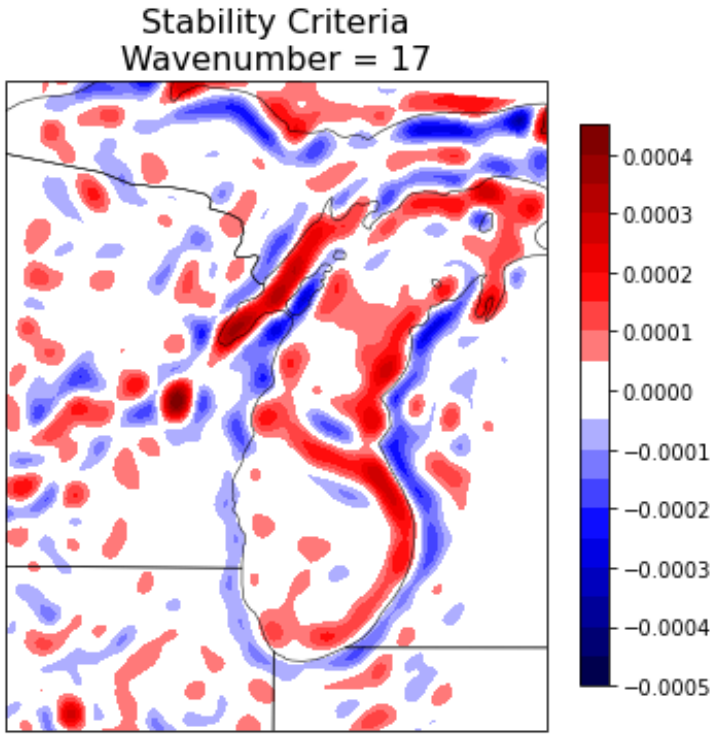
What about the forecast data?

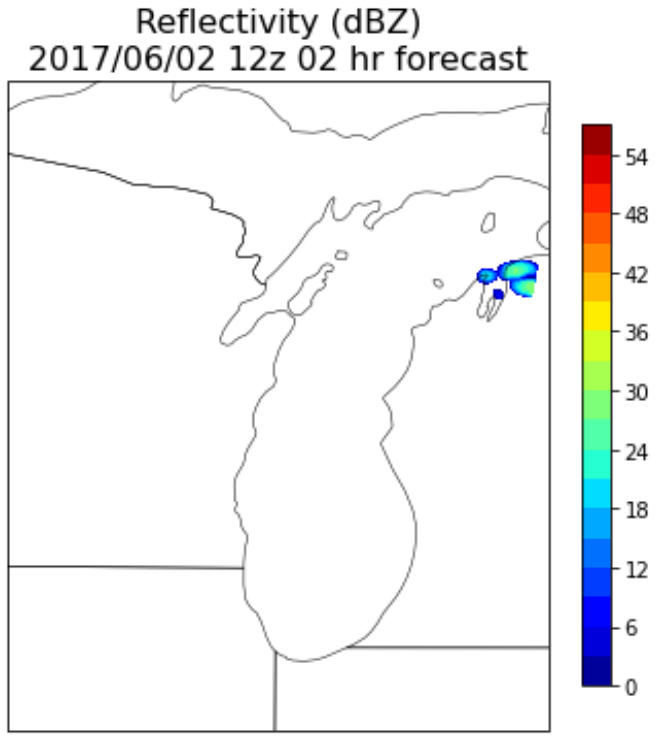
Lake-breeze forecast: June 2, 2017 Forecast

Initialization – 1200 UTC

Forecast – 1400 UTC (forecast hour 2)



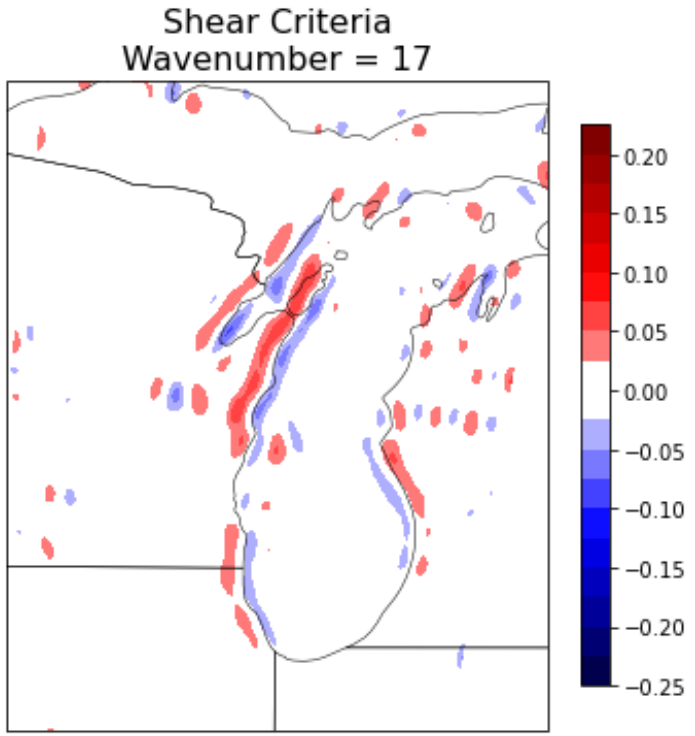


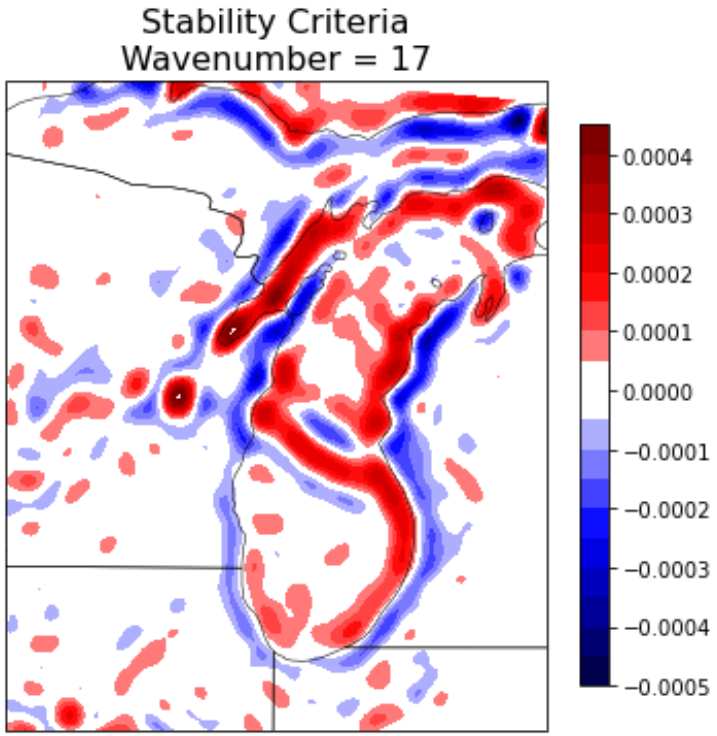


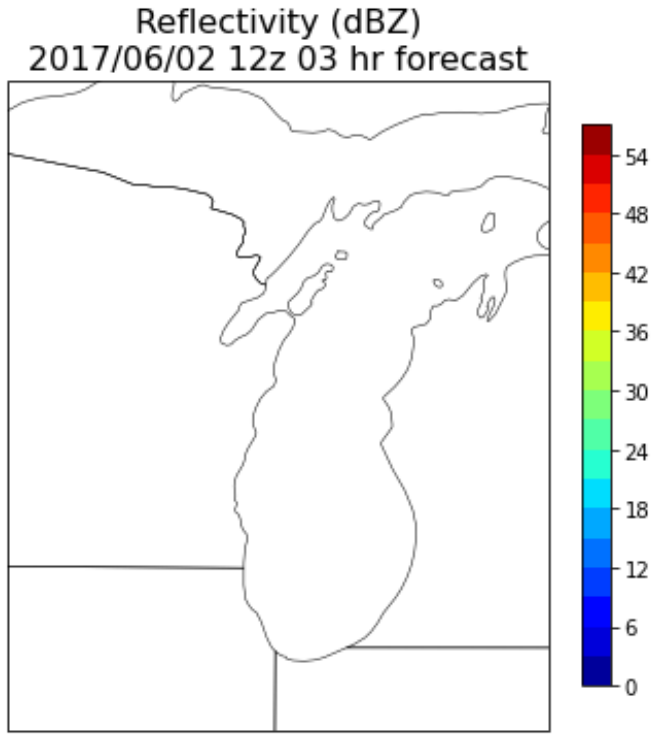
Lake-breeze forecast: June 2, 2017 Forecast

Initialization – 1200 UTC

Forecast – 1500 UTC (forecast hour 3)



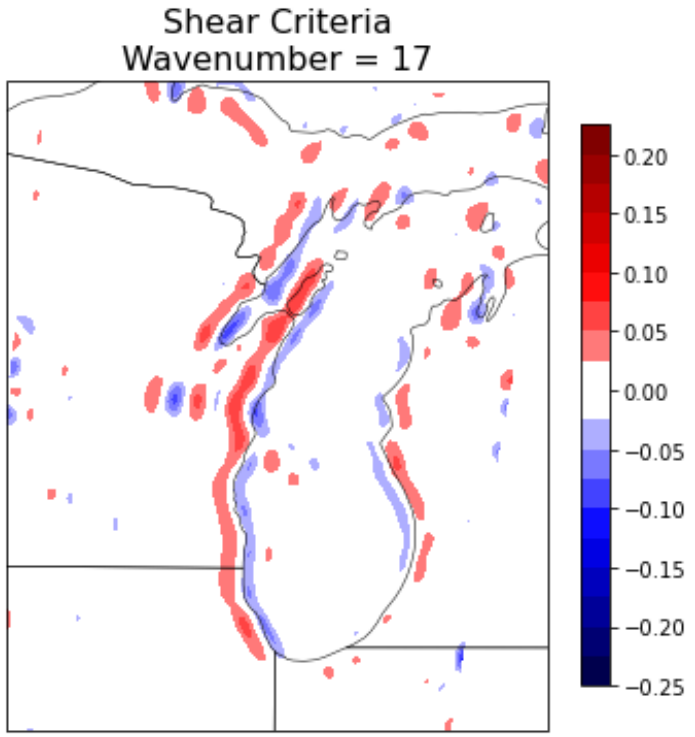


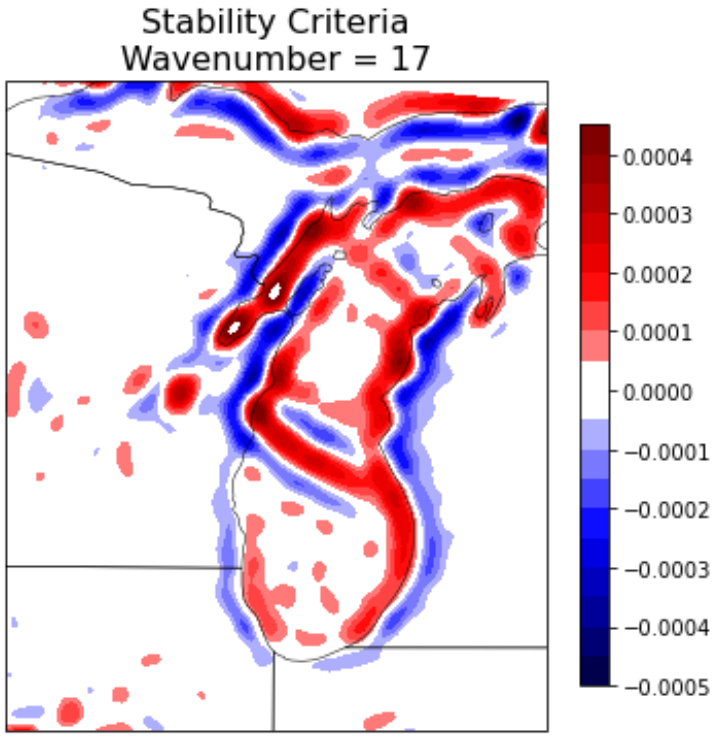


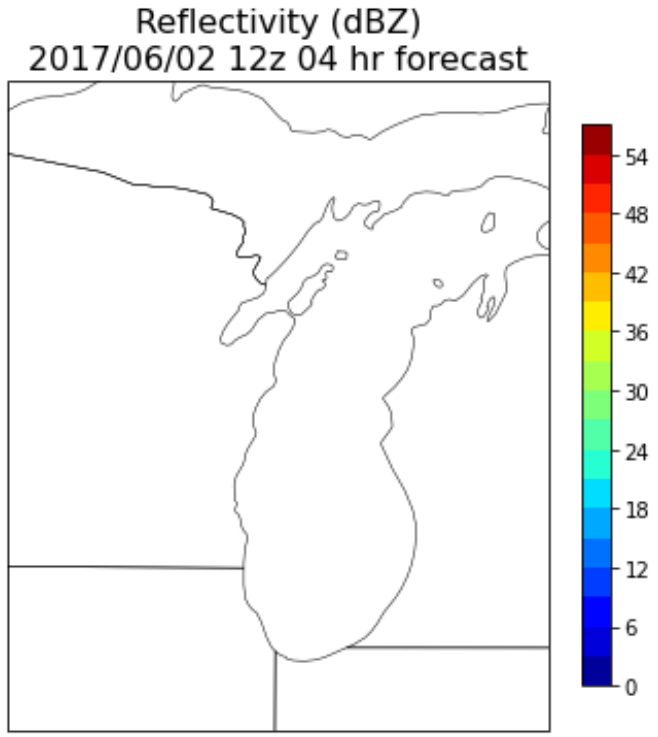
Lake-breeze forecast: June 2, 2017 Forecast

Initialization – 1200 UTC

Forecast – 1600 UTC (forecast hour 4)



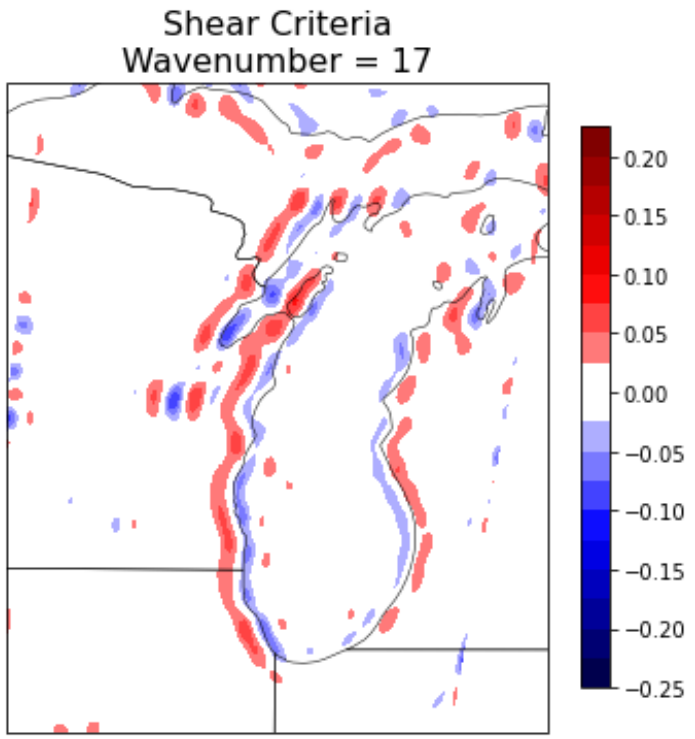


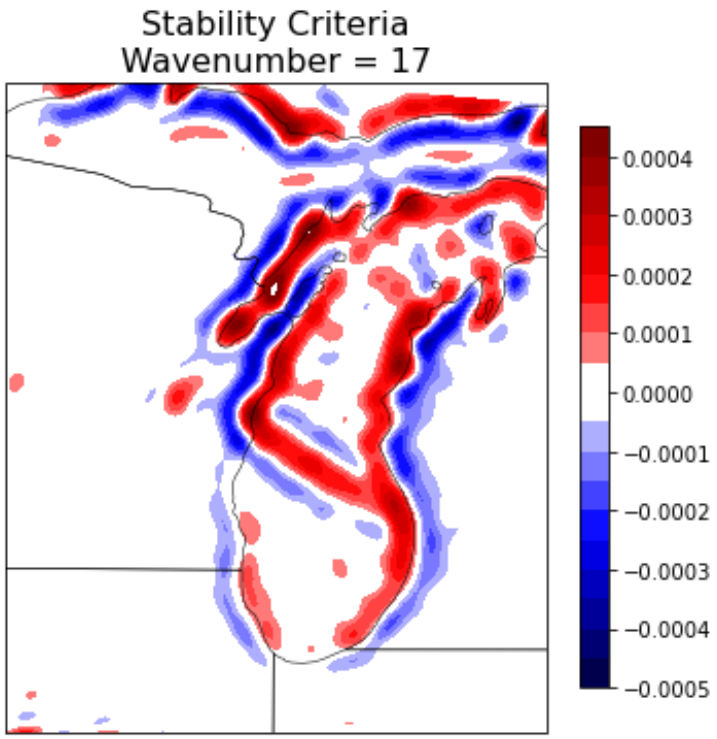


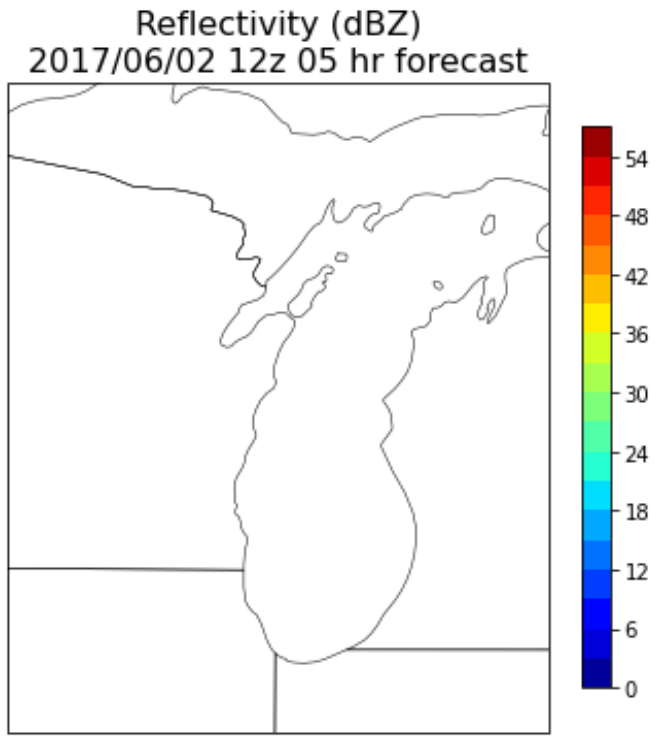
Lake-breeze forecast: June 2, 2017 Forecast

Initialization – 1200 UTC

Forecast – 1700 UTC (forecast hour 5)



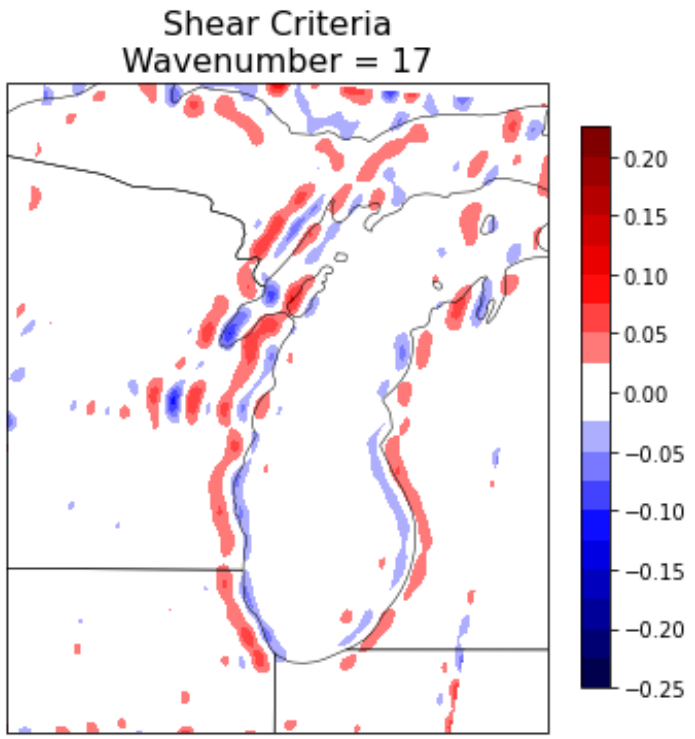


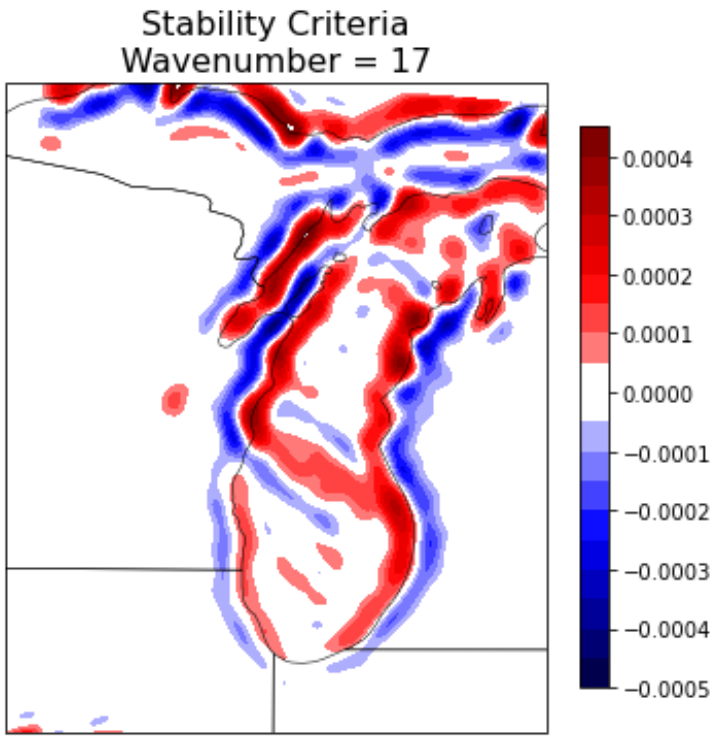


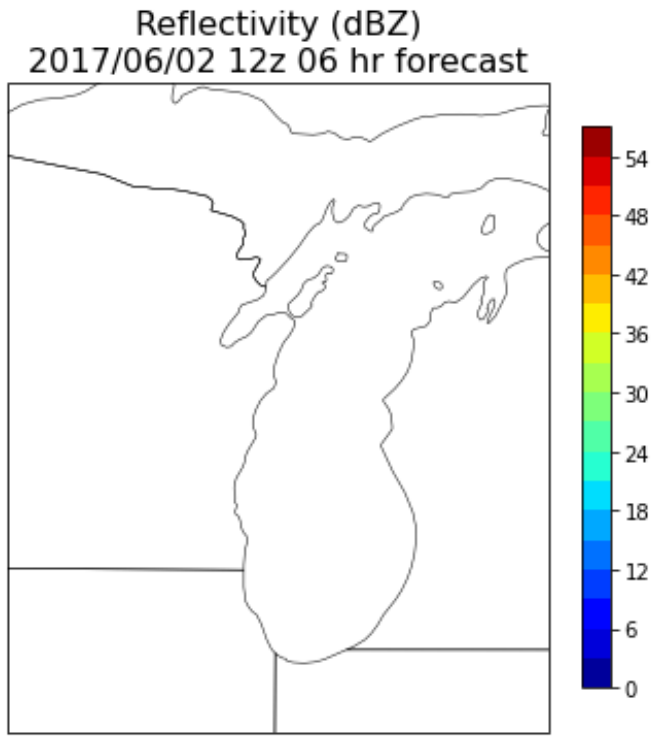
Lake-breeze forecast: June 2, 2017 Forecast

Initialization – 1200 UTC

Forecast – 1800 UTC (forecast hour 6)



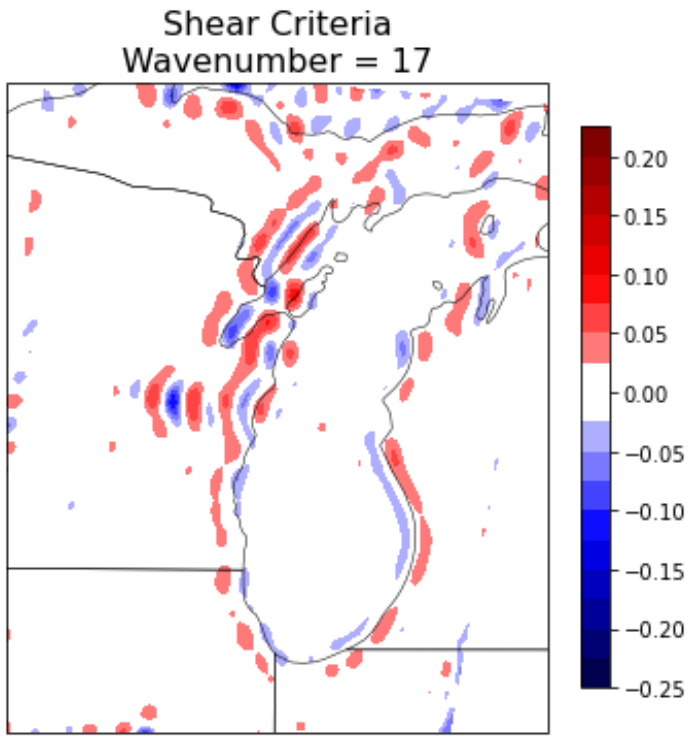


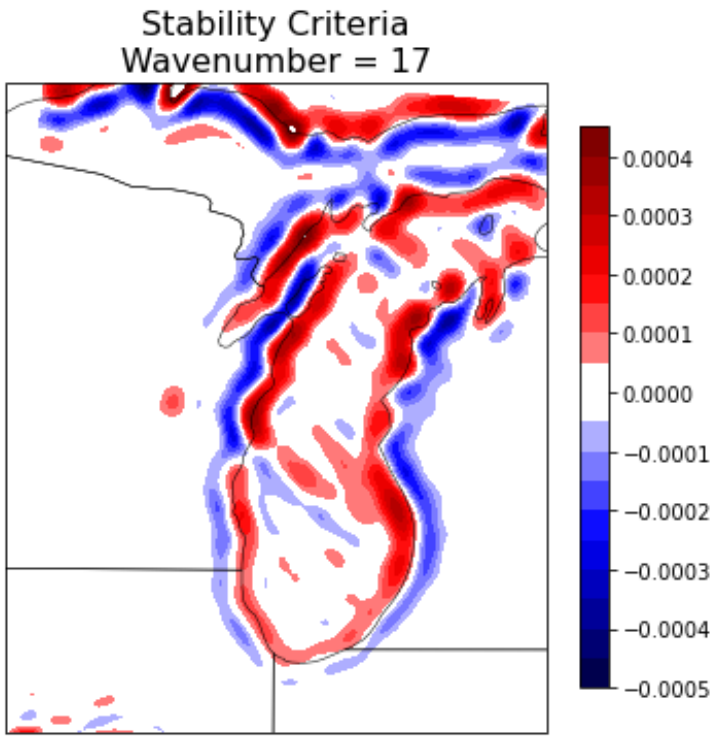


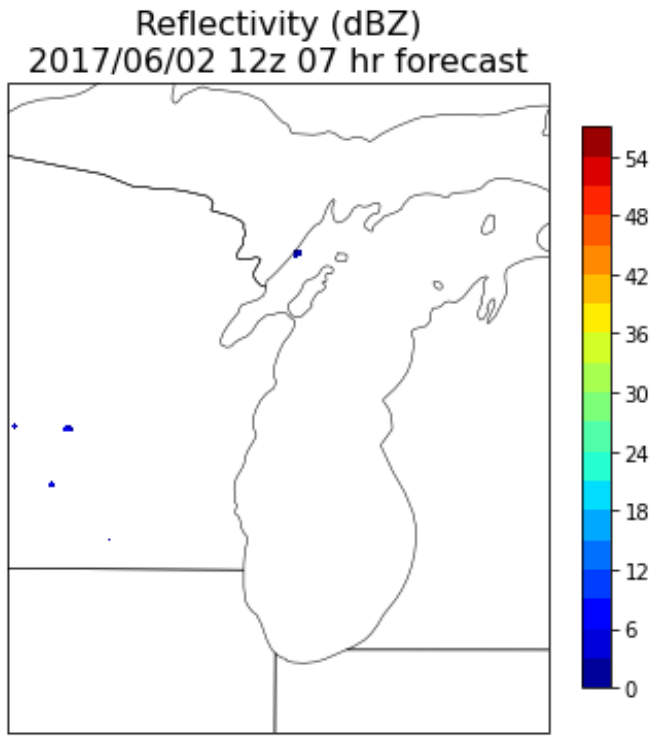
Lake-breeze forecast: June 2, 2017 Forecast

Initialization – 1200 UTC

Forecast – 1900 UTC (forecast hour 7)



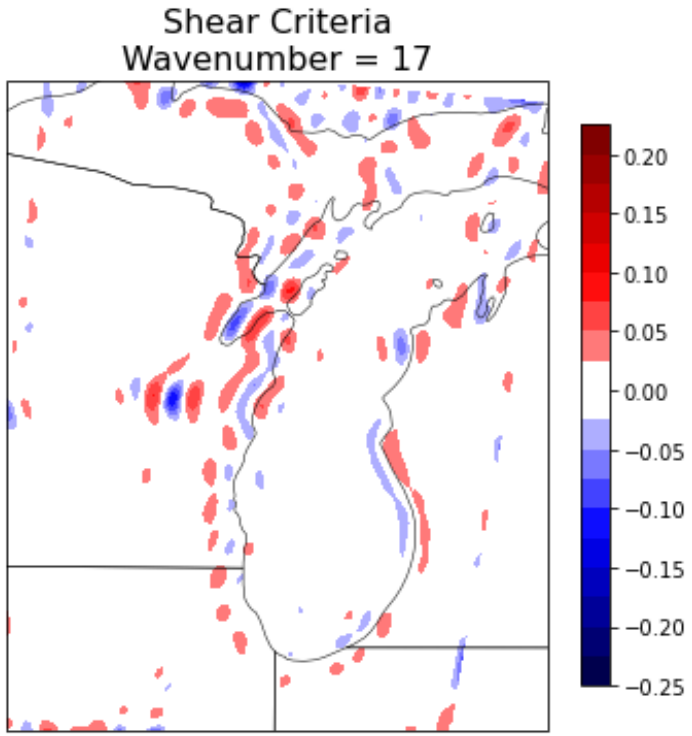


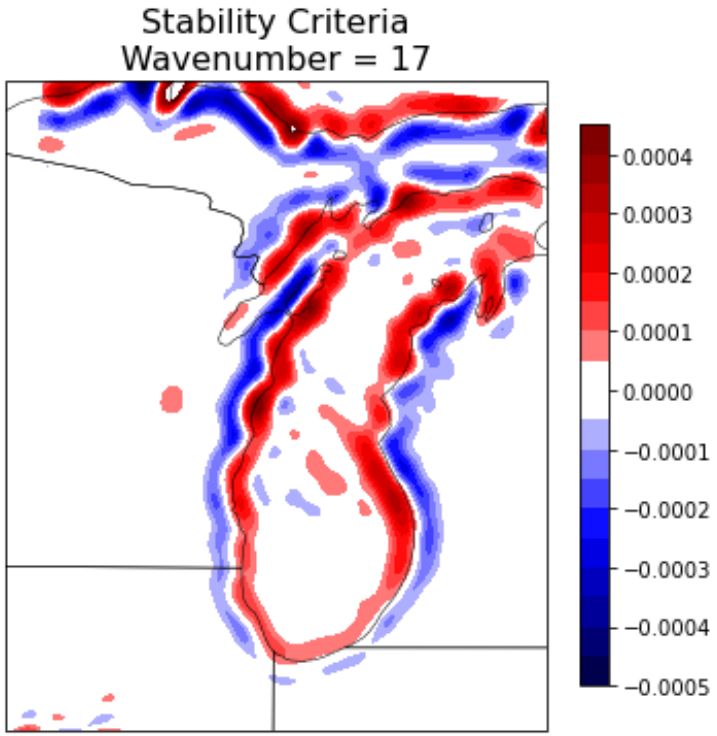


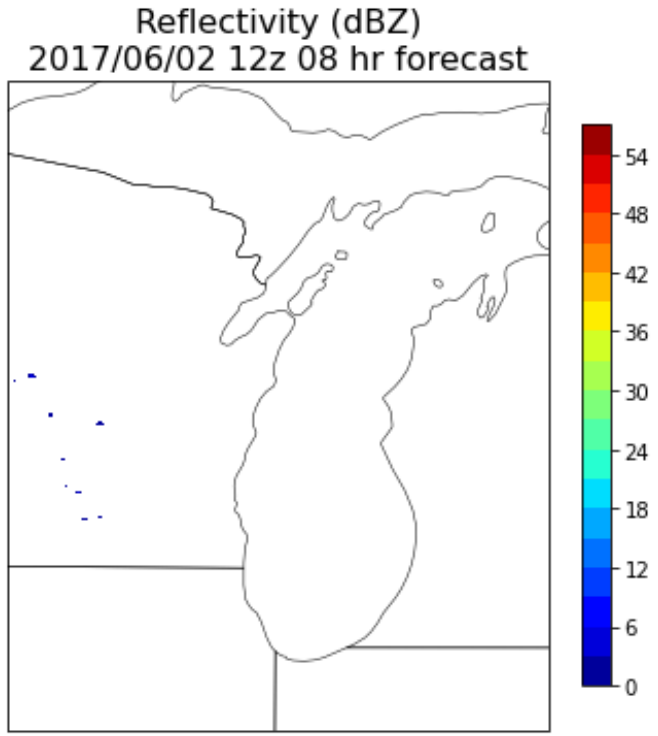
Lake-breeze forecast: June 2, 2017 Forecast

Initialization – 1200 UTC

Forecast – 2000 UTC (forecast hour 8)



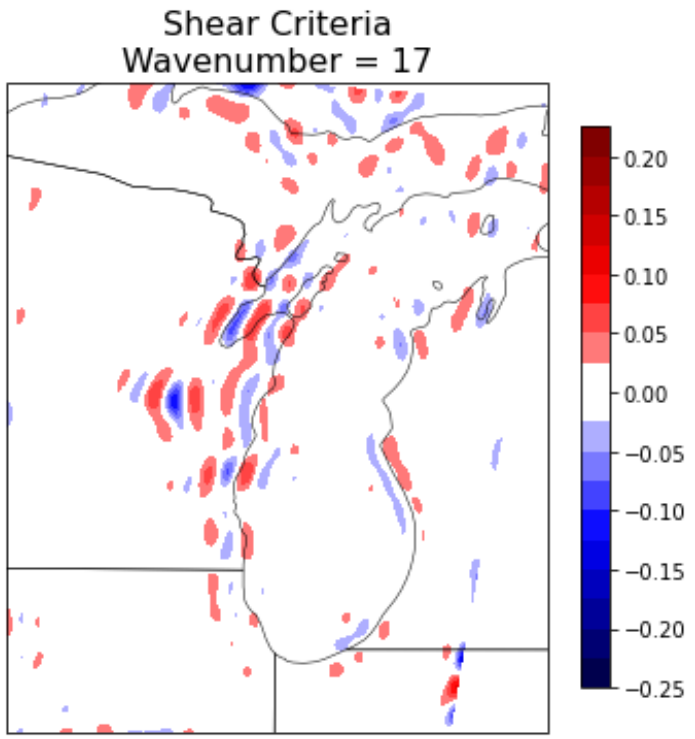


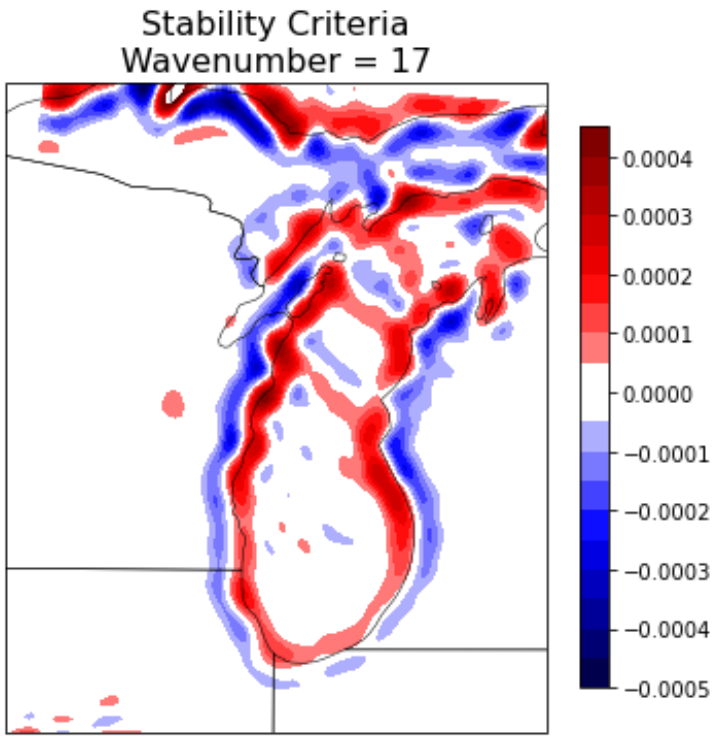


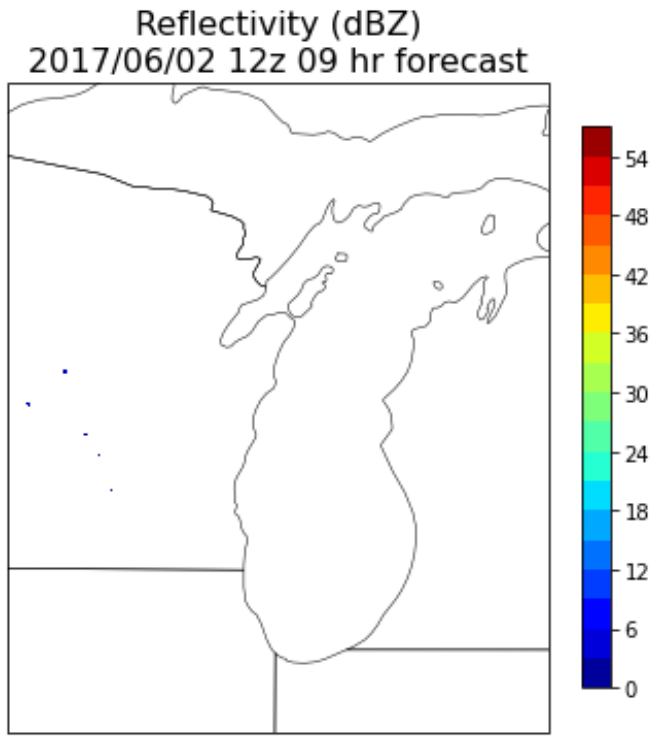
Lake-breeze forecast: June 2, 2017 Forecast

Initialization – 1200 UTC

Forecast – 2100 UTC (forecast hour 9)



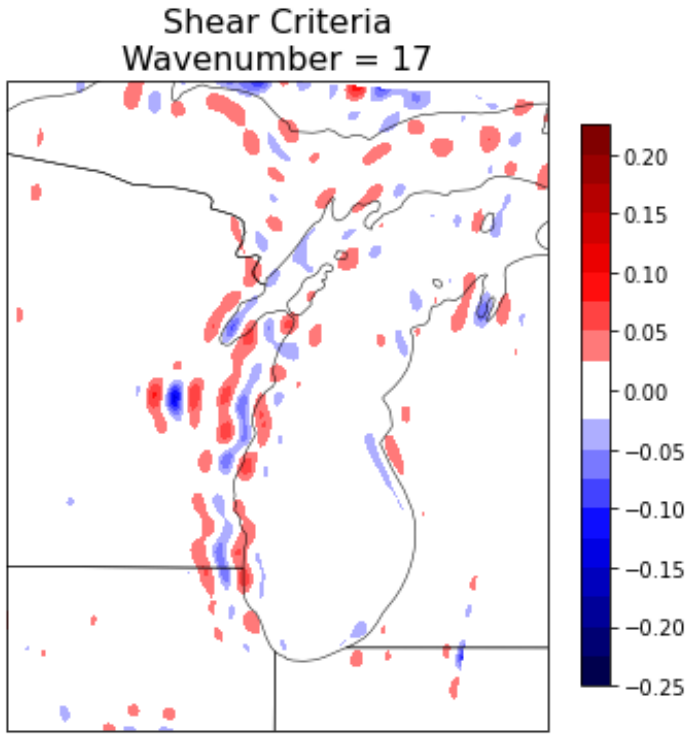


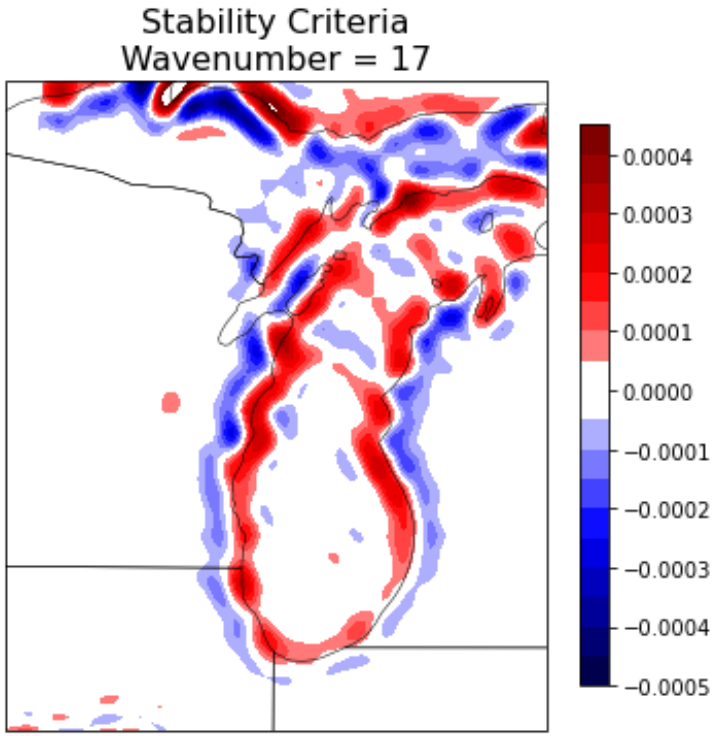


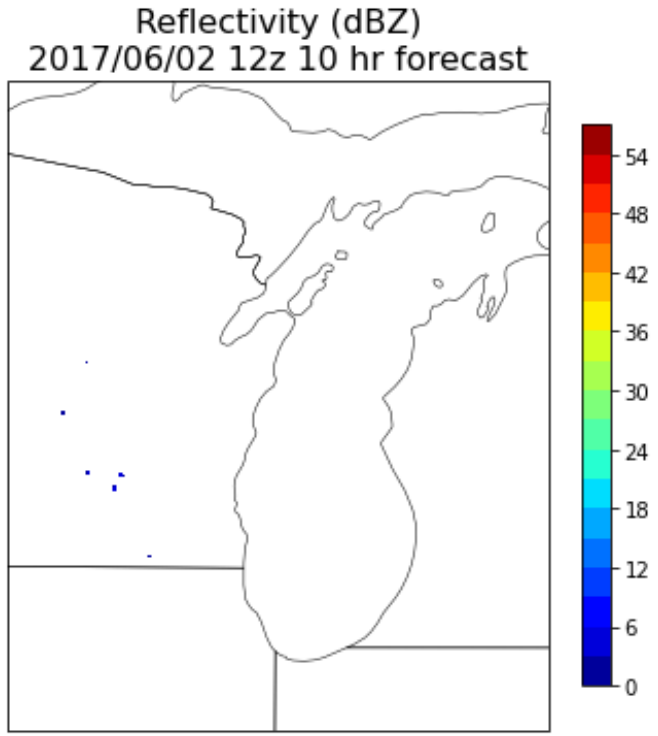
Lake-breeze forecast: June 2, 2017 Forecast

Initialization – 1200 UTC

Forecast – 2200 UTC (forecast hour 10)



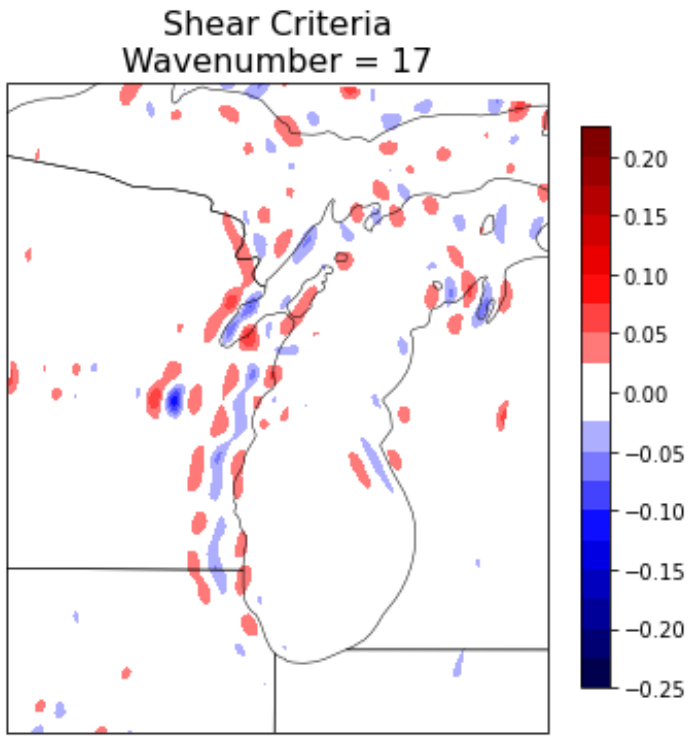


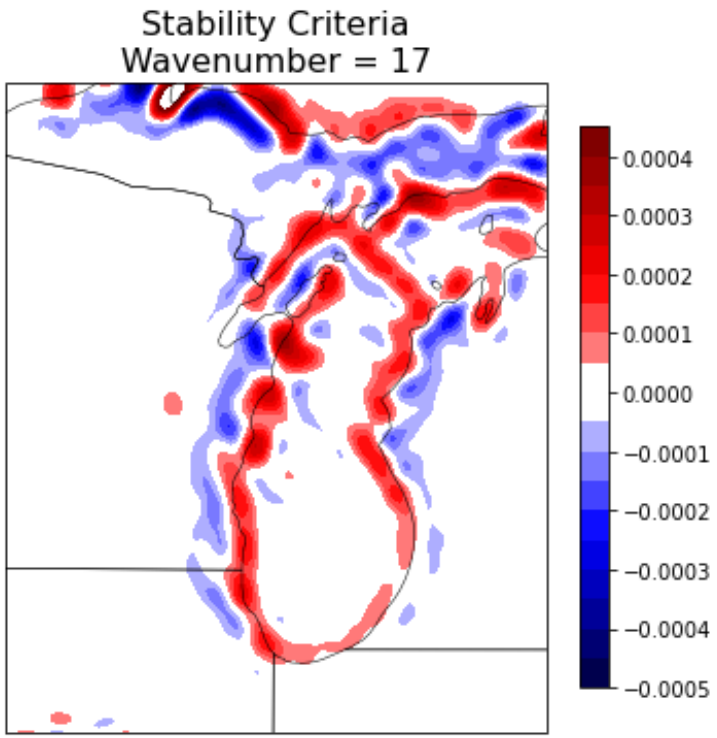


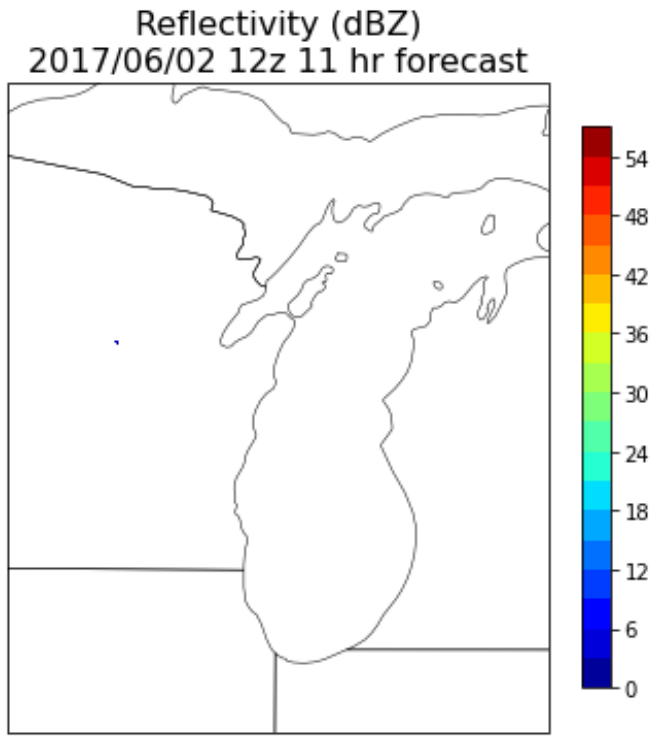
Lake-breeze forecast: June 2, 2017 Forecast

Initialization – 1200 UTC

Forecast – 2300 UTC (forecast hour 11)

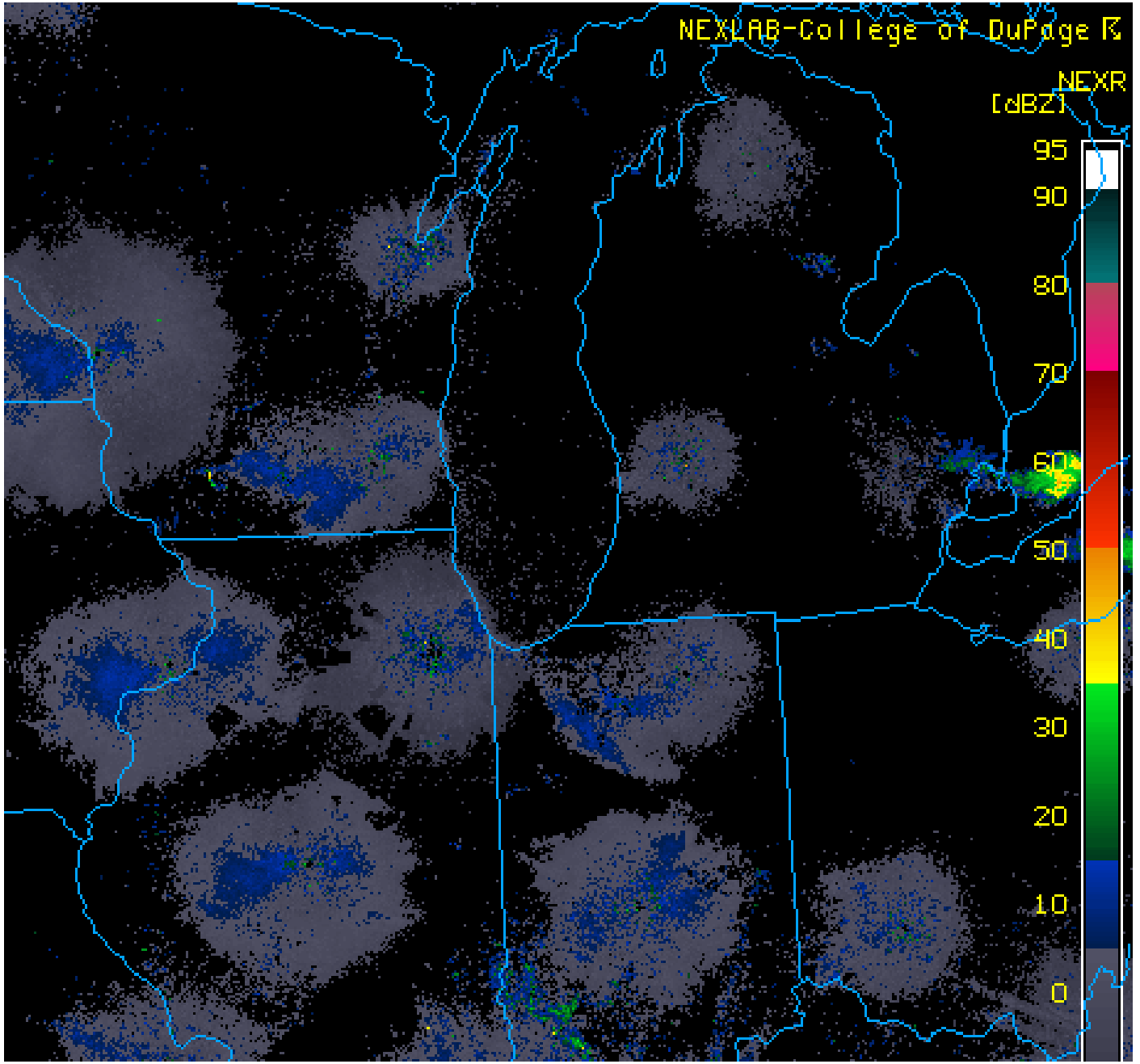






Case 1: Comparison to Observations

The HRRR appears to reasonably depict the inland propagation of the LB on Lake Michigan's western shore on this day.

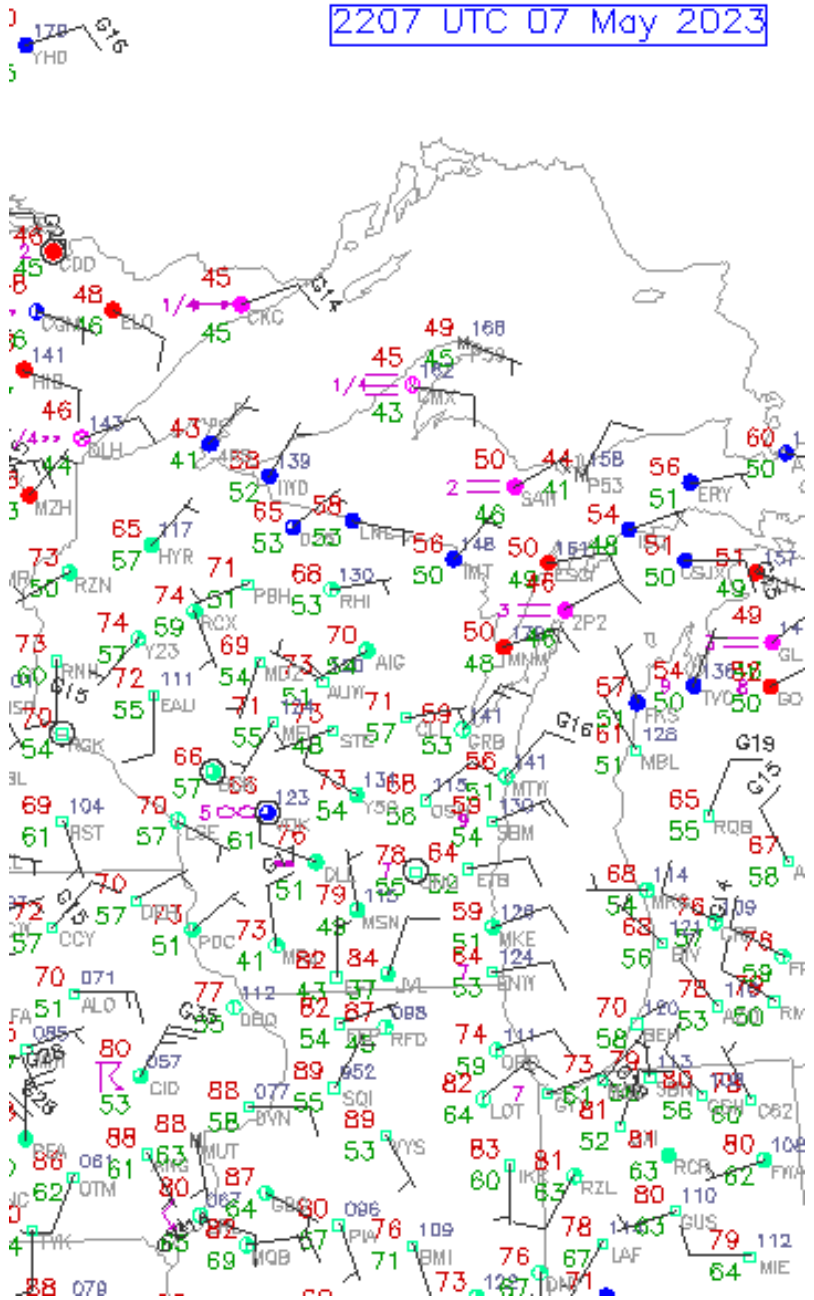


UCAR Image Archive

Case 2: May 7, 2023

- Far inland penetration of the LB on the western/southwestern shore of Lake Michigan

- Significant difference between the air temp & water temp
  - Chicago high temp = 84°F
  - Chicago water temp ≈ 50°F estimated from Atwater Buoy near Milwaukee (National Data Buoy Center 2023)

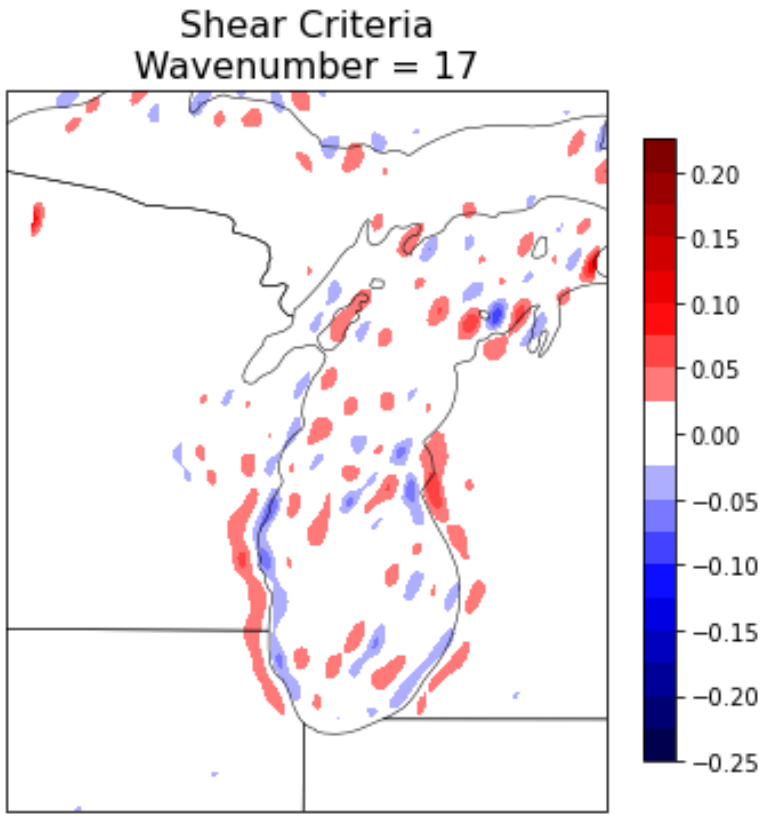


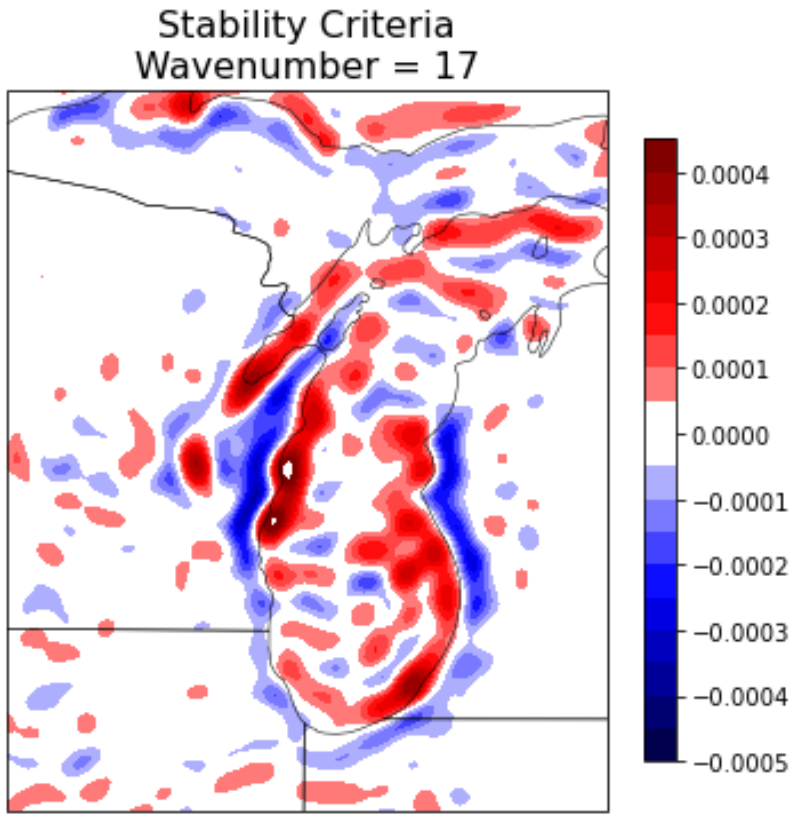
UCAR Image Archive

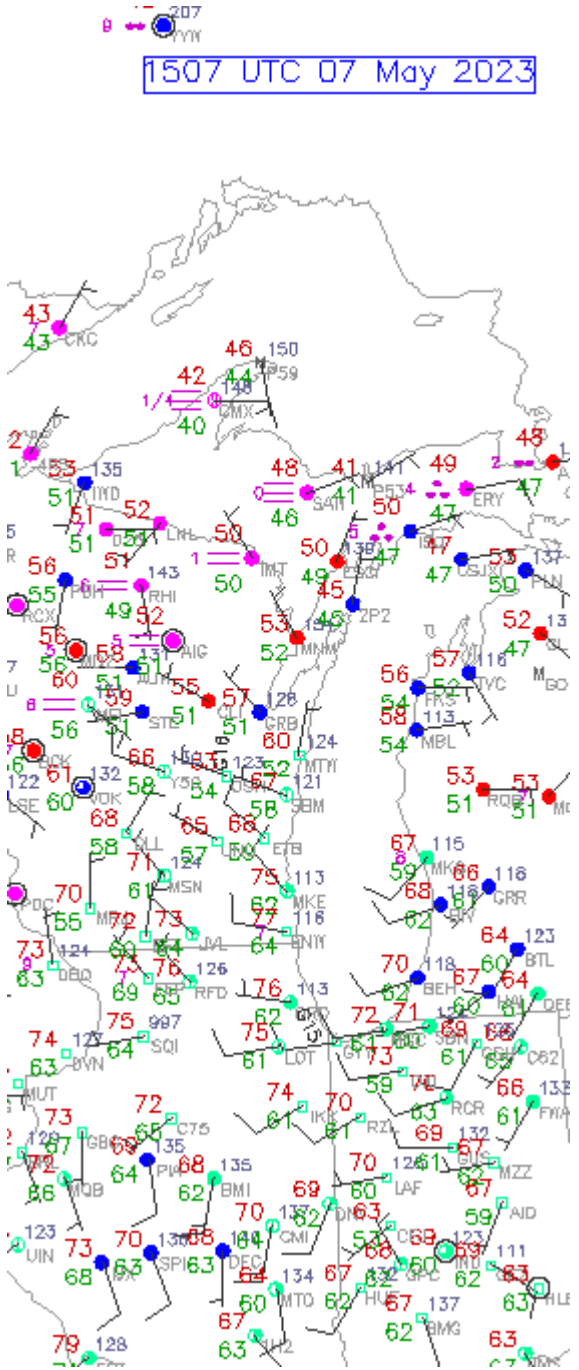
Lake-breeze forecast: May 7, 2023

Initialization – 1200 UTC

Forecast – 1500 UTC (forecast hr 3)





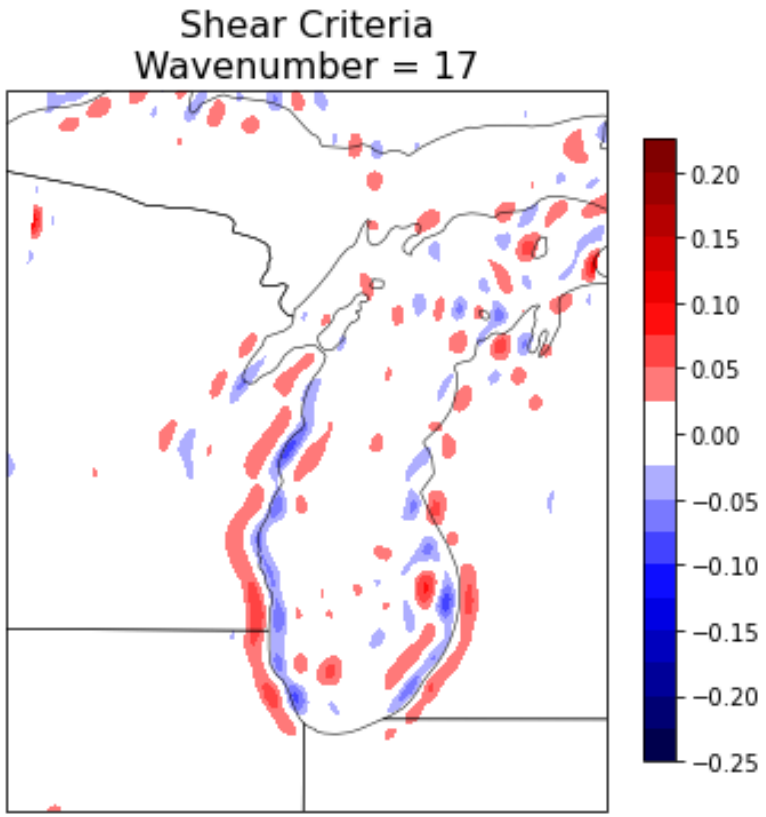


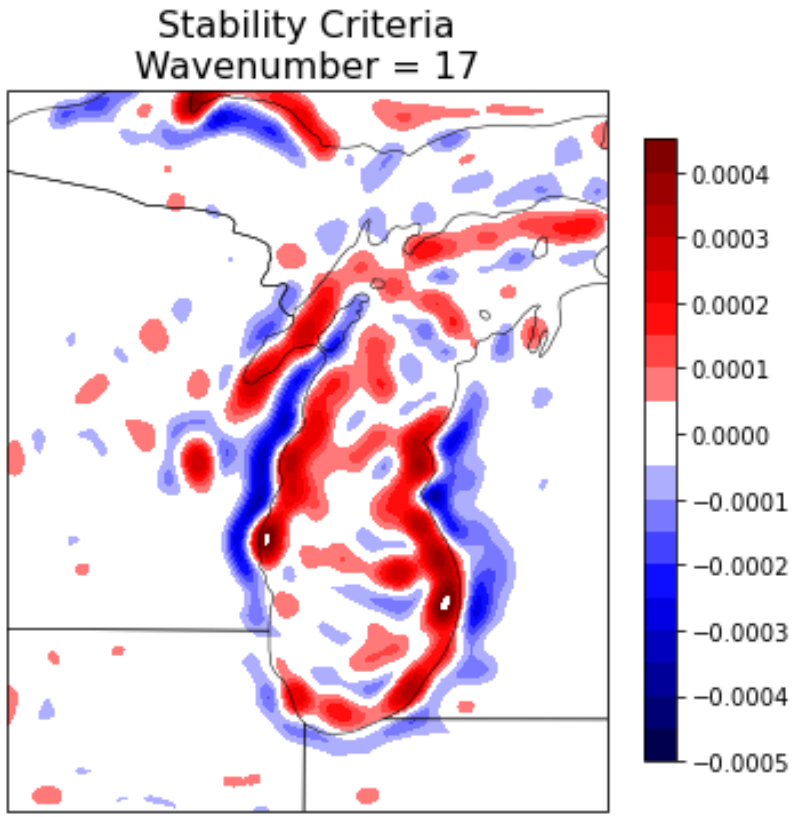
UCAR Image Archive

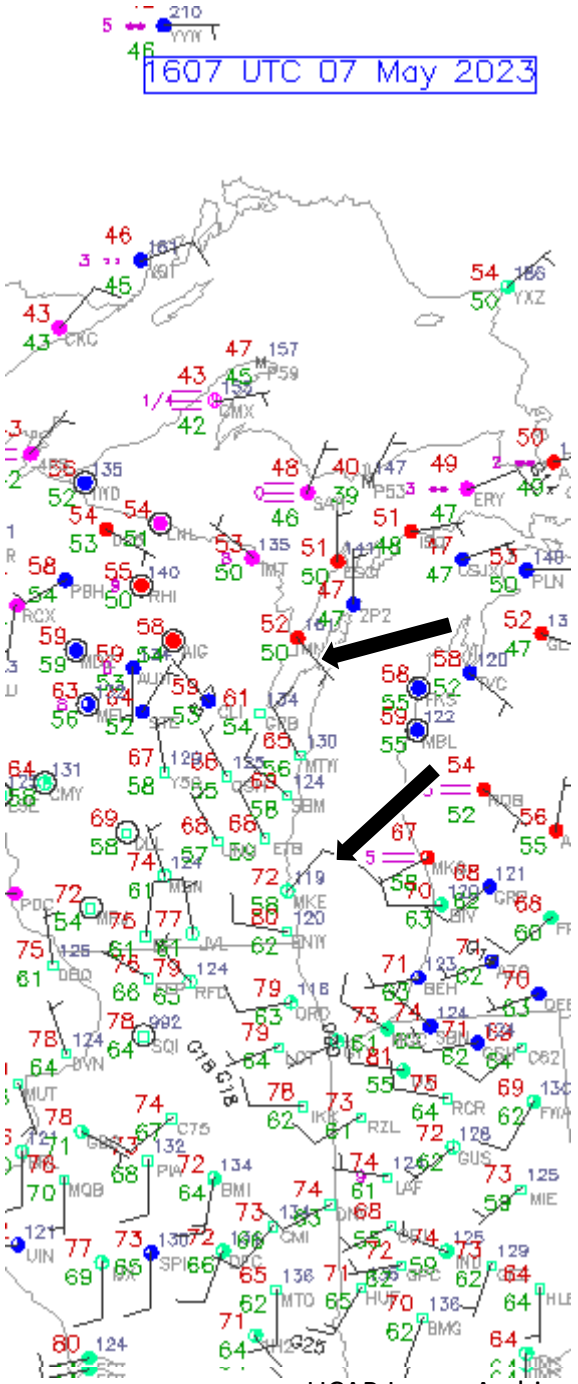
Lake-breeze forecast
May 7, 2023

Initialization – 1200 UTC

Forecast – 1600 UTC (forecast hr 4)





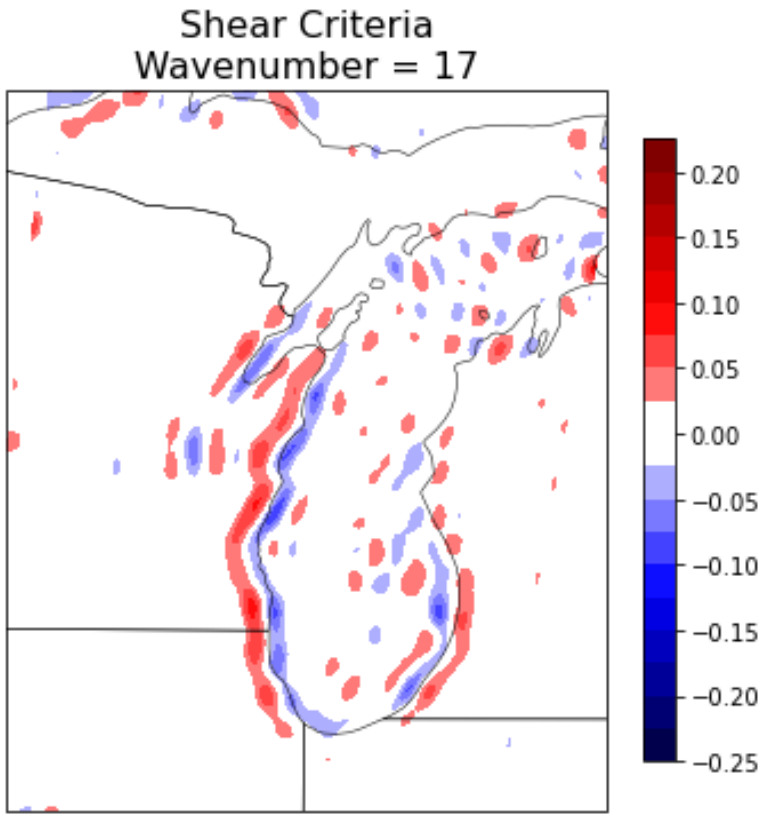


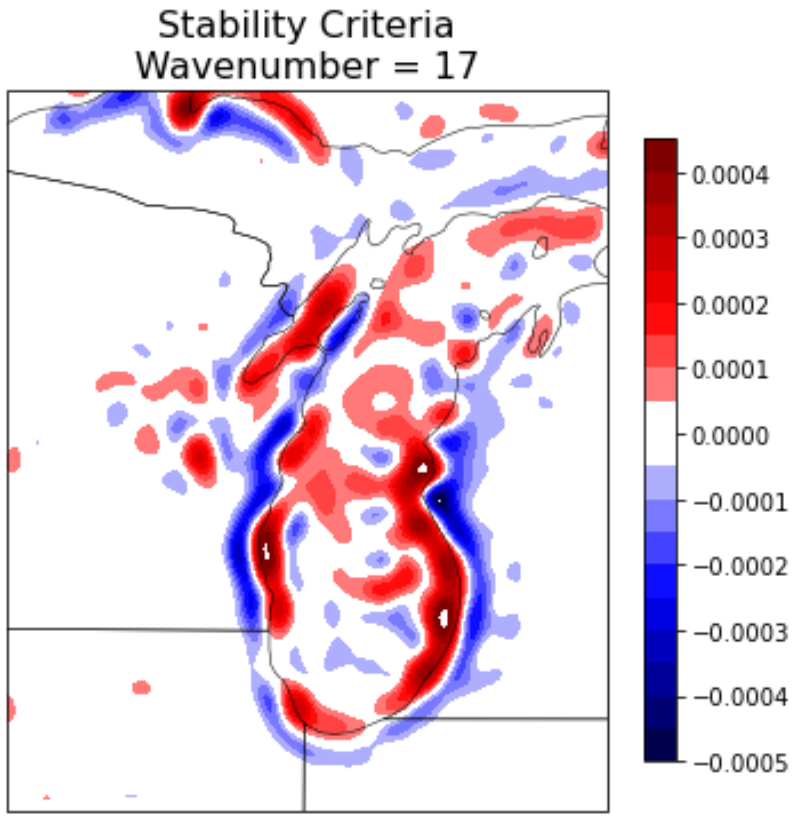
UCAR Image Archive

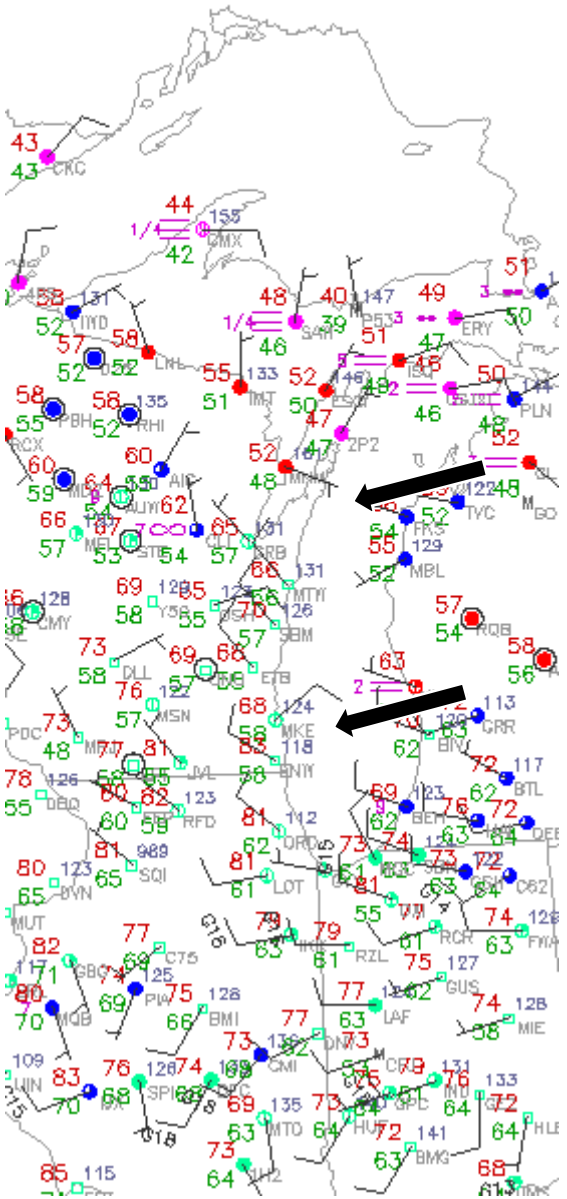
Lake-breeze forecast
May 7, 2023

Initialization – 1200 UTC

Forecast – 1700 UTC (forecast hr 5)







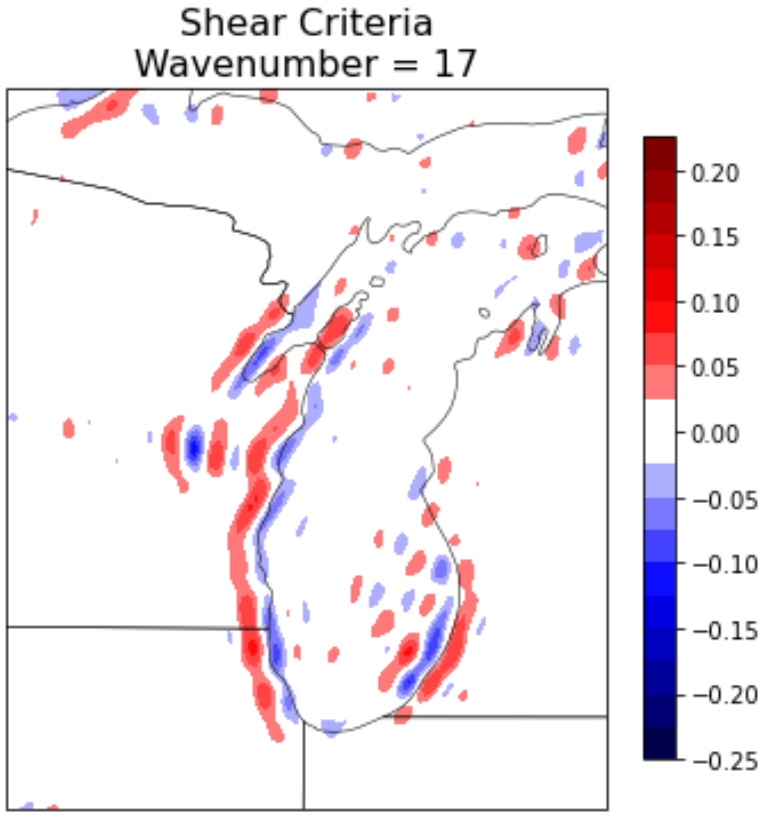
UCAR Image Archive

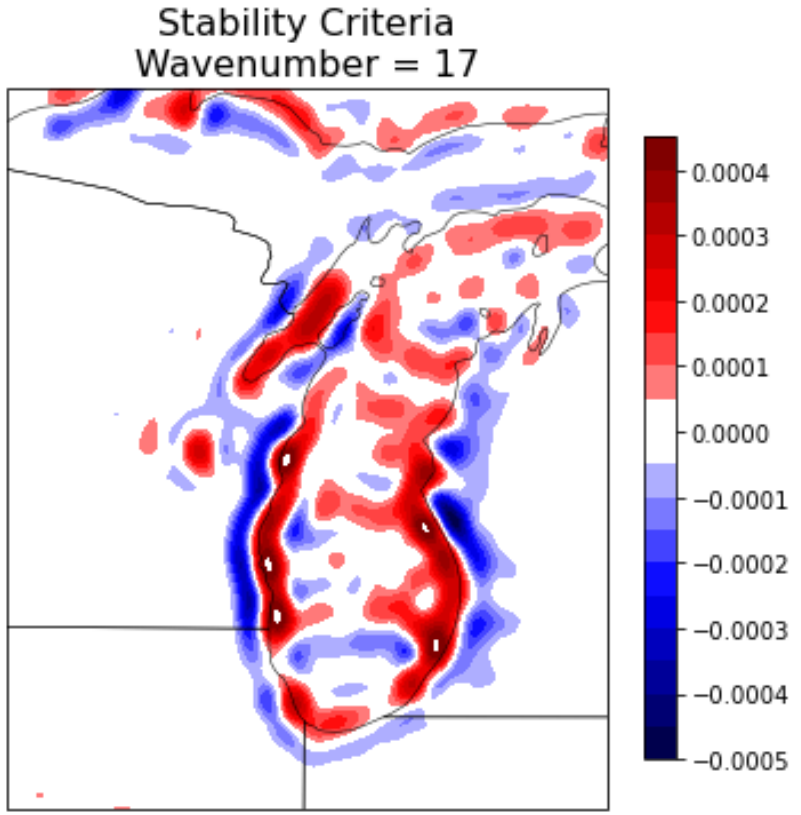
Lake-breeze forecast
May 7, 2023

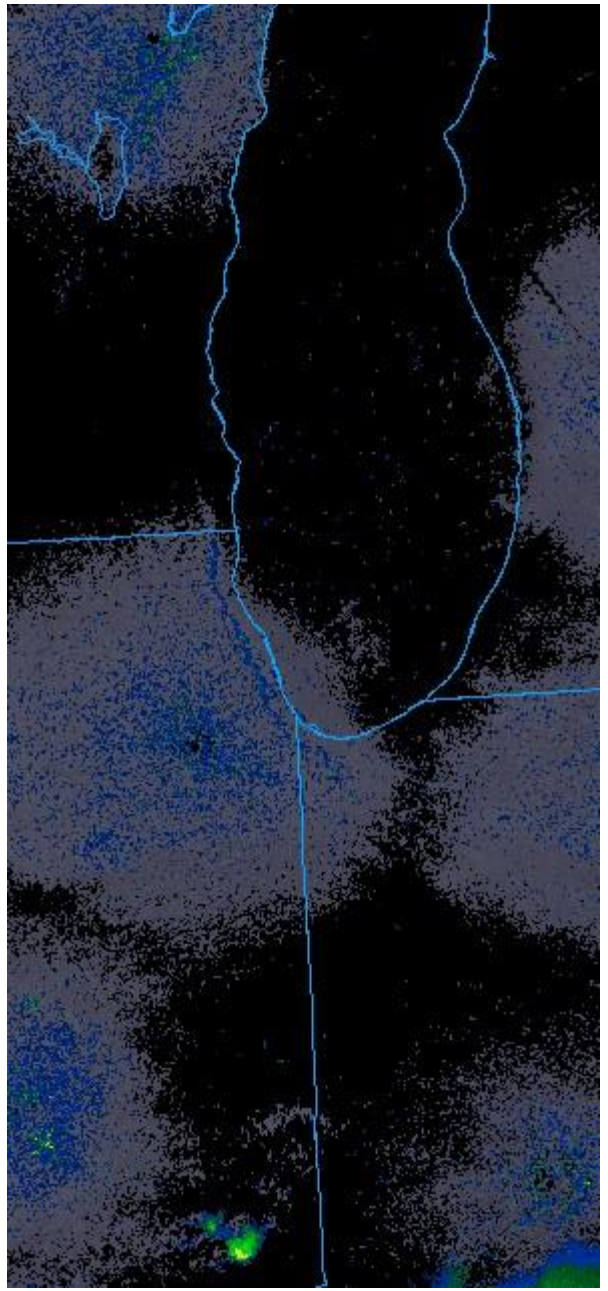
Initialization – 1200 UTC

Forecast – 1800 UTC (forecast hr 6)

Radar time – 1755 UTC







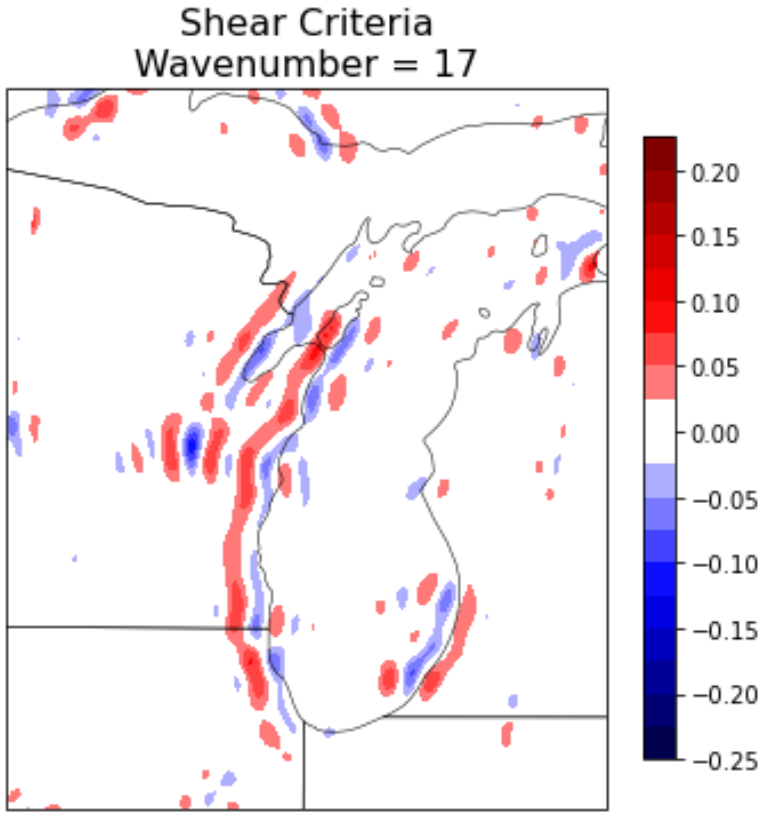
UCAR Image Archive

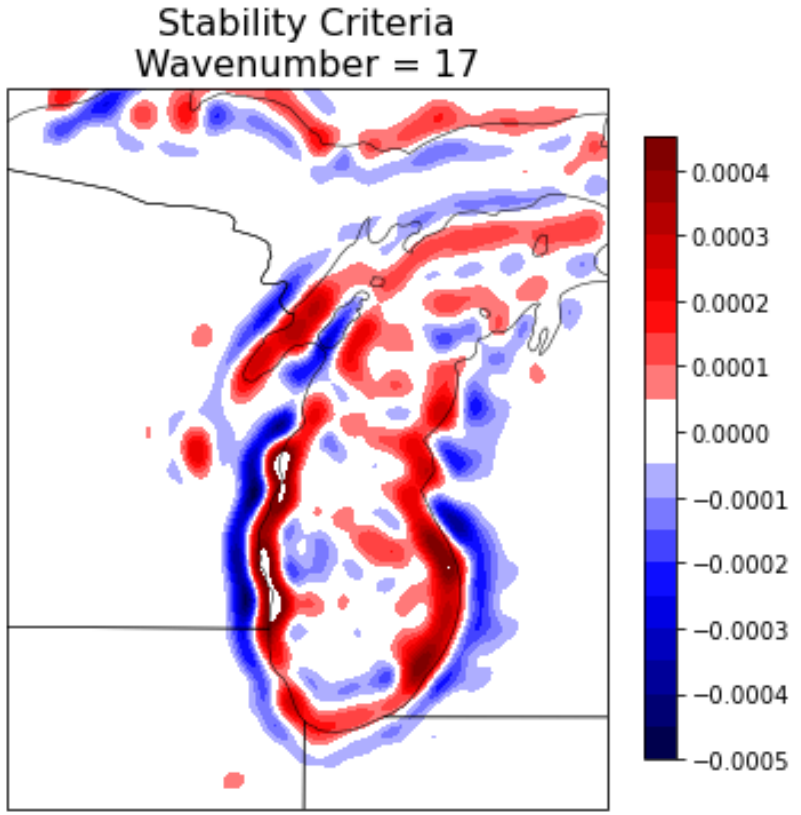
Lake-breeze forecast
May 7, 2023

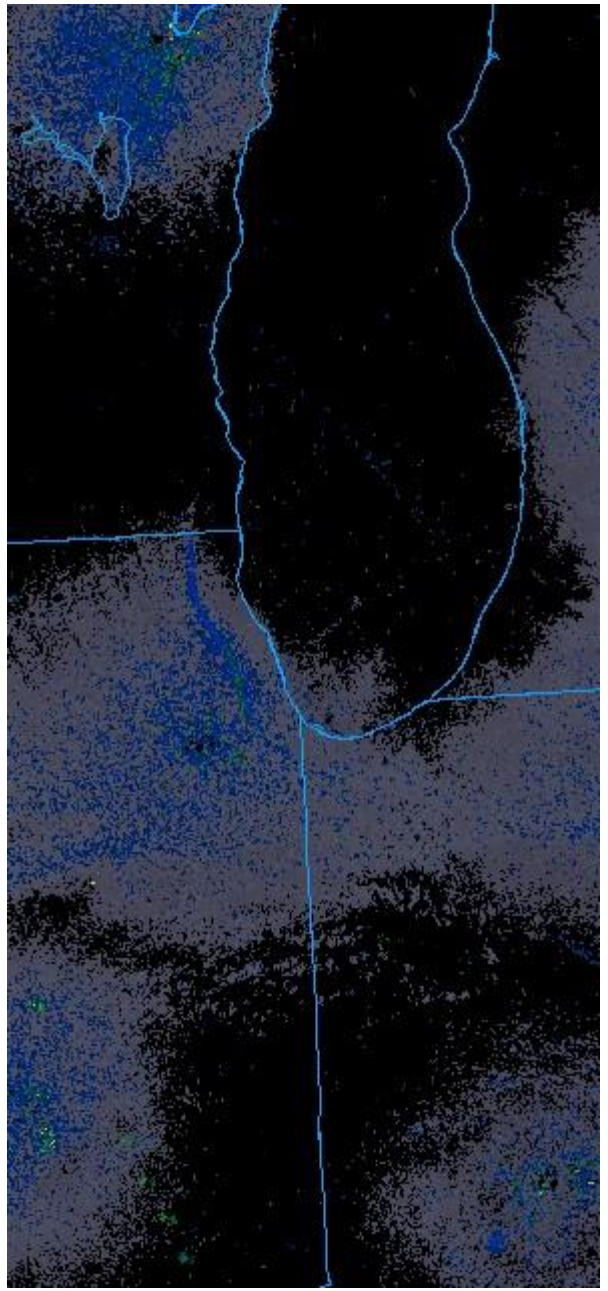
Initialization – 1200 UTC

Forecast – 1900 UTC (forecast hr 7)

Radar time – 1855 UTC







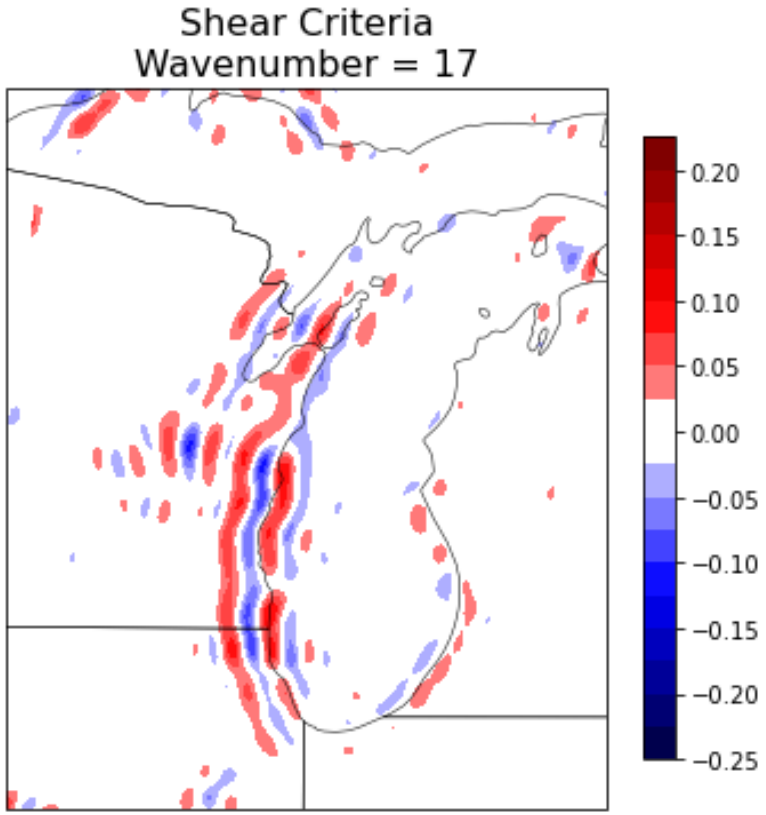
UCAR Image Archive

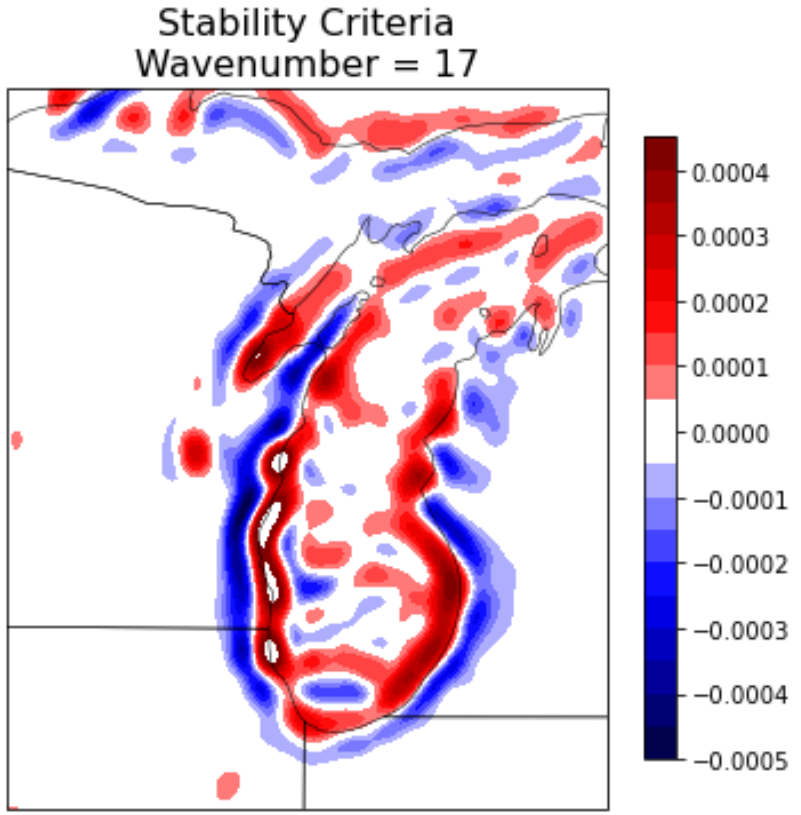
Lake-breeze forecast
May 7, 2023

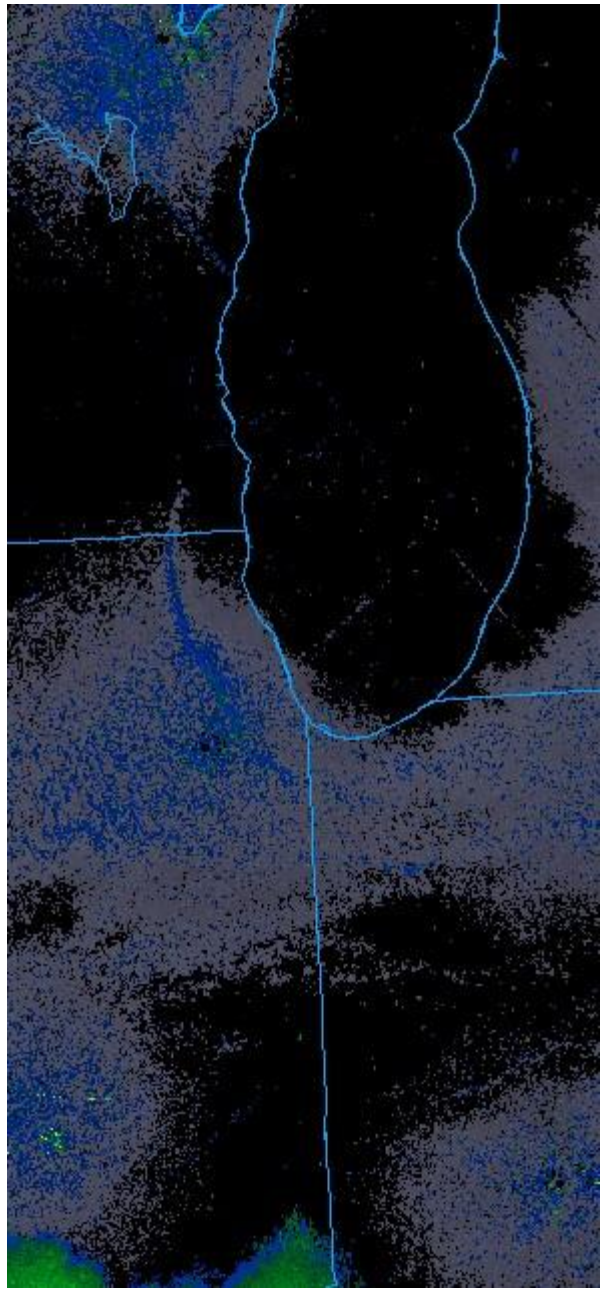
Initialization – 1200 UTC

Forecast – 2000 UTC (forecast hr 8)

Radar time – 1955 UTC







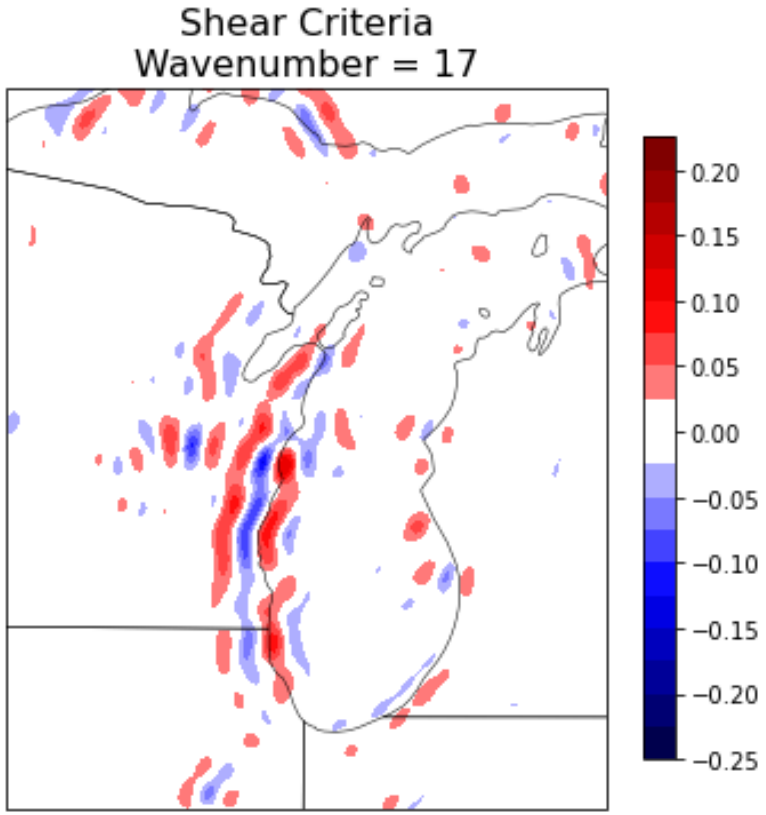
UCAR Image Archive

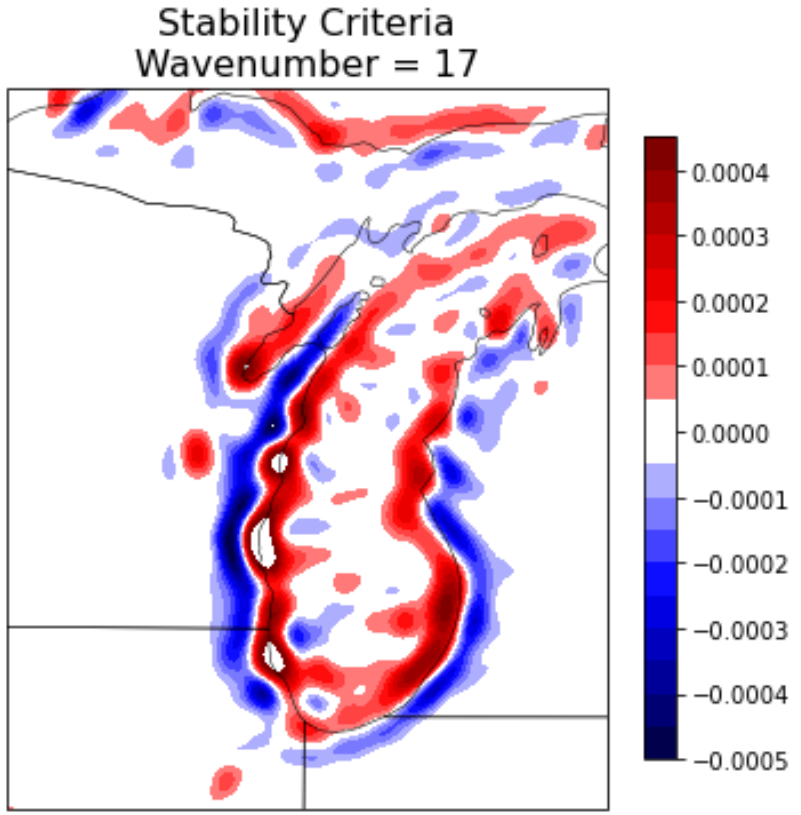
Lake-breeze forecast
May 7, 2023

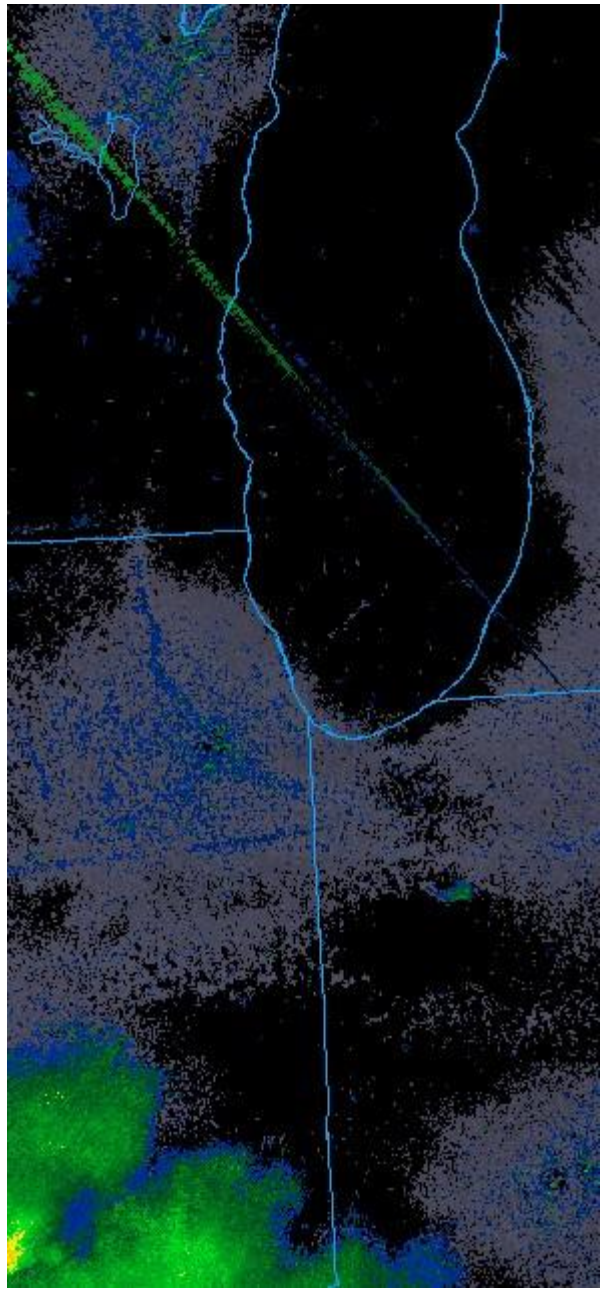
Initialization – 1200 UTC

Forecast – 2100 UTC (forecast hr 9)

Radar time – 2055 UTC







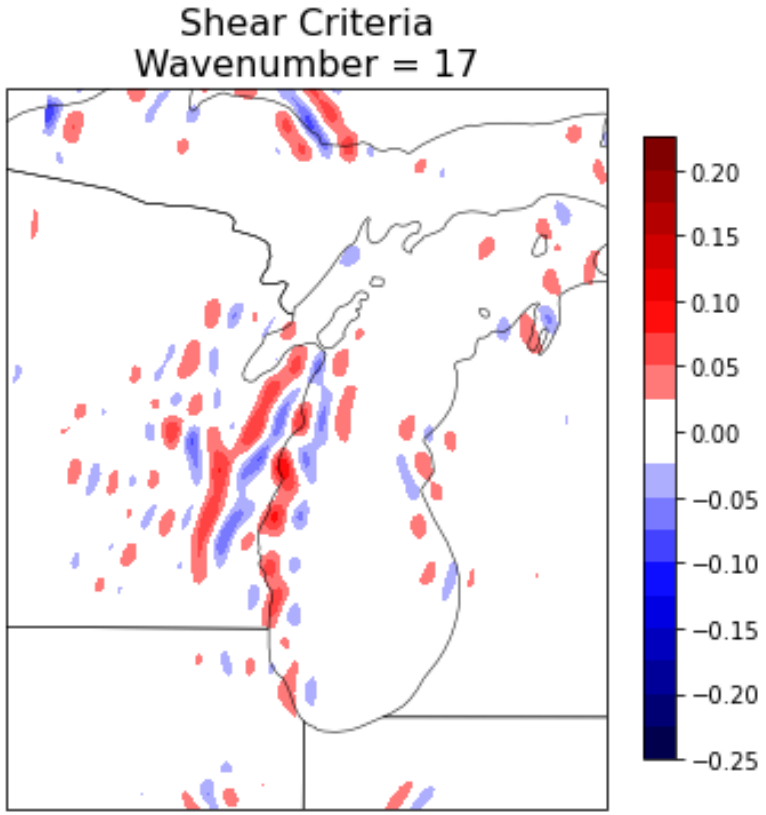
UCAR Image Archive

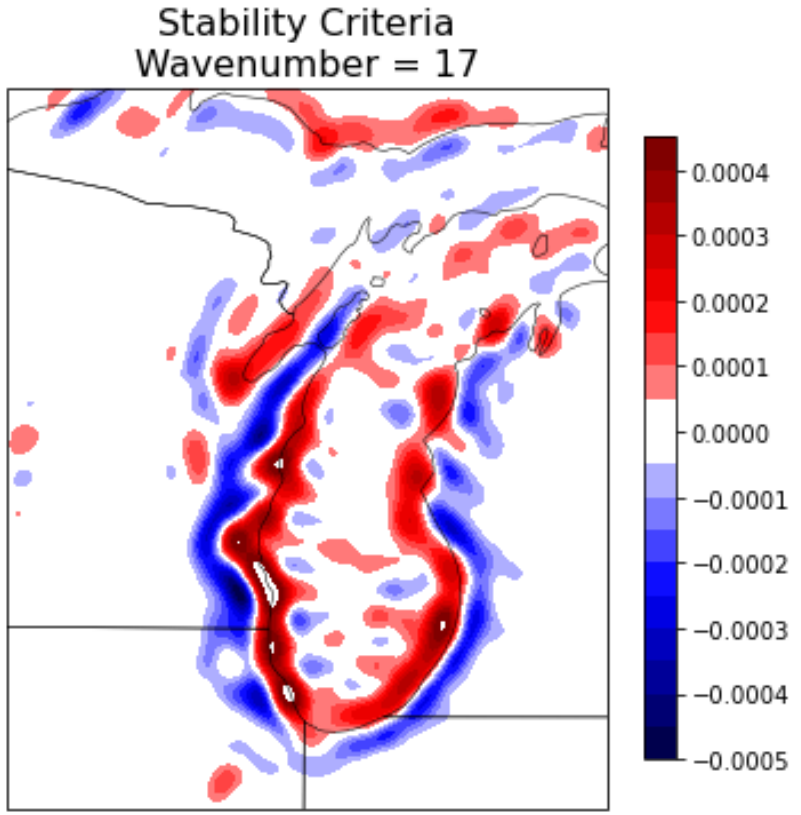
Lake-breeze forecast
May 7, 2023

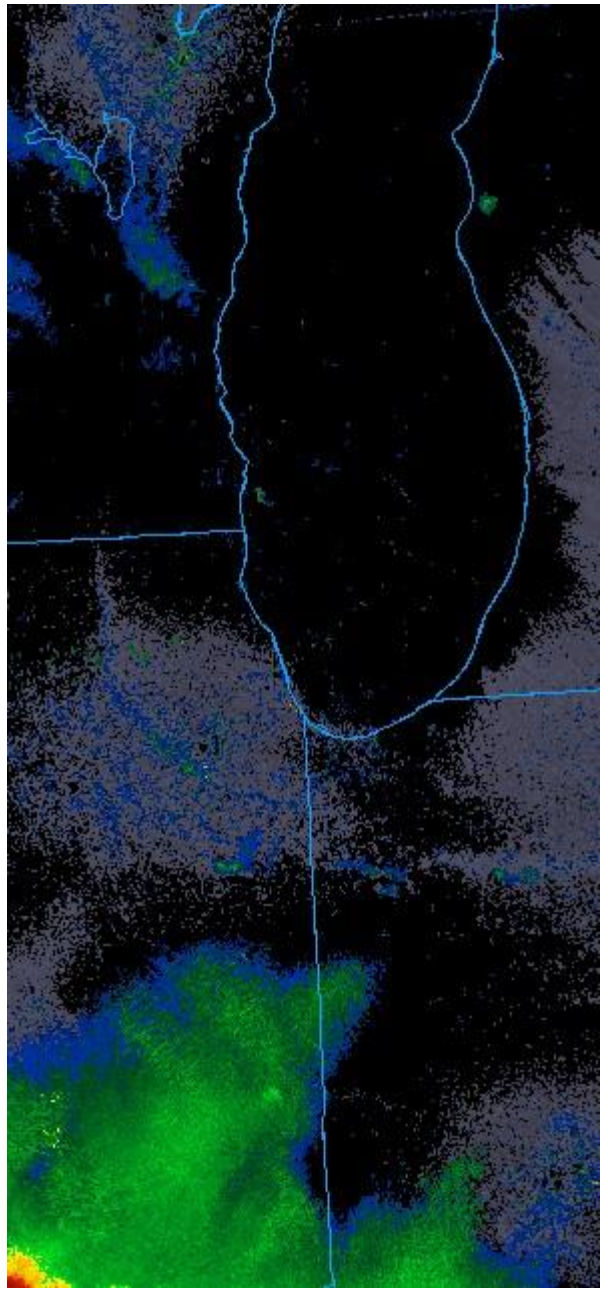
Initialization – 1200 UTC

Forecast – 2200 UTC (forecast hr 10)

Radar time – 2155 UTC







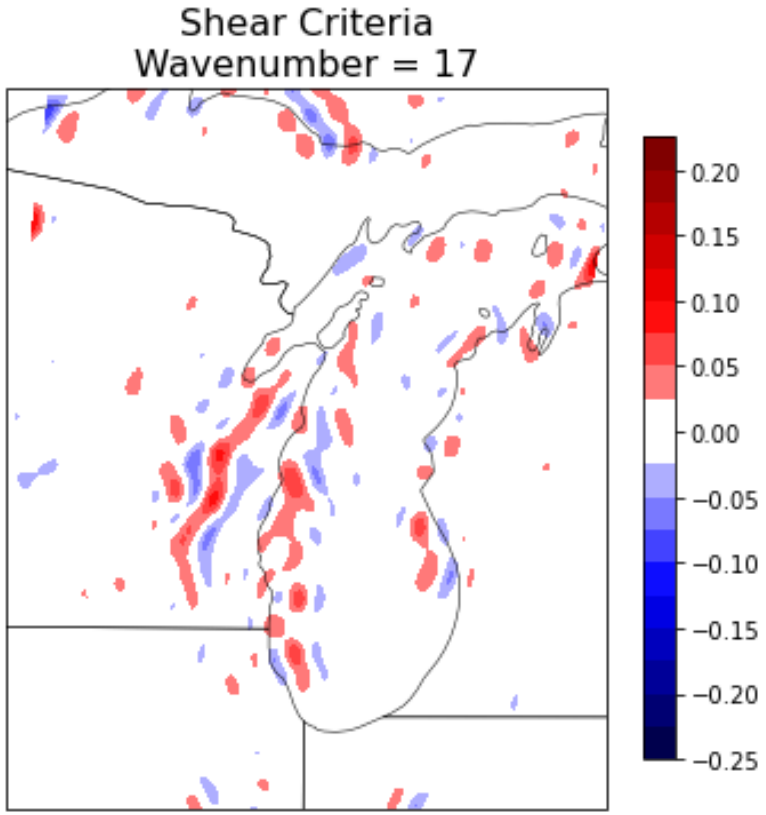
UCAR Image Archive

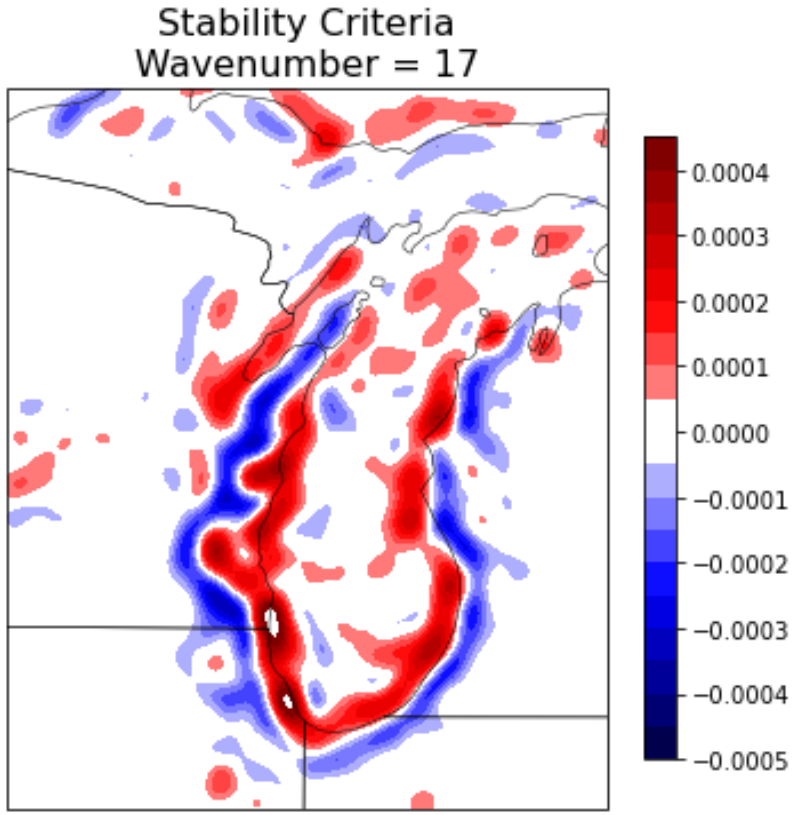
Lake-breeze forecast
May 7, 2023

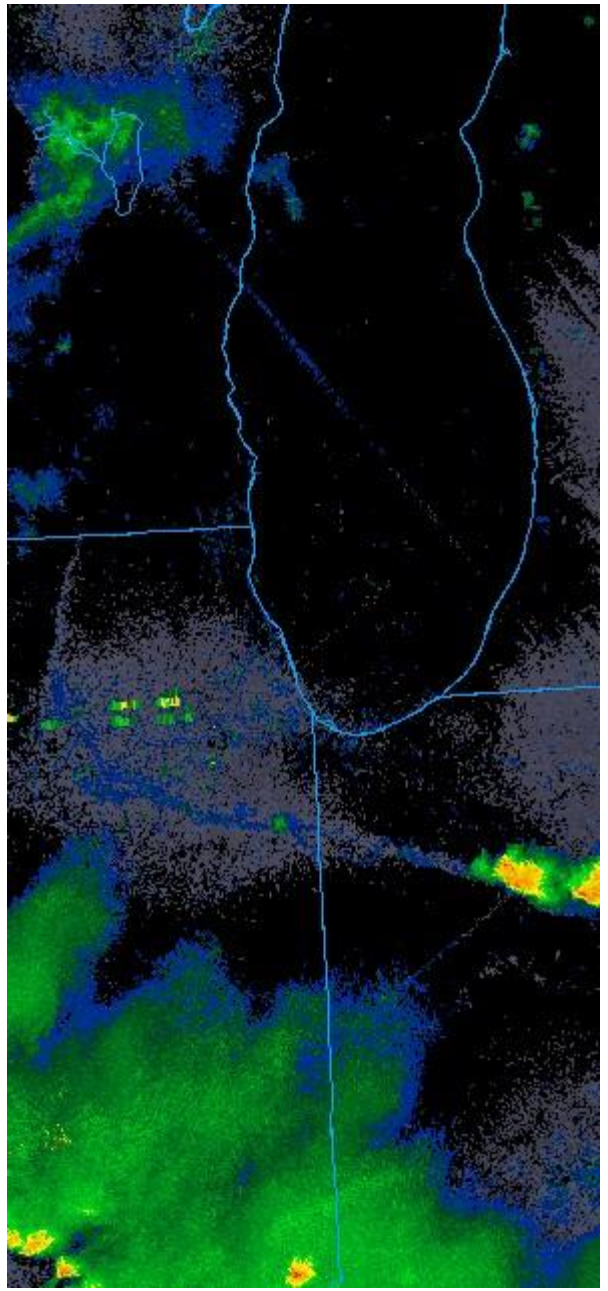
Initialization – 1200 UTC

Forecast – 2300 UTC (forecast hr 11)

Radar time – 2255 UTC



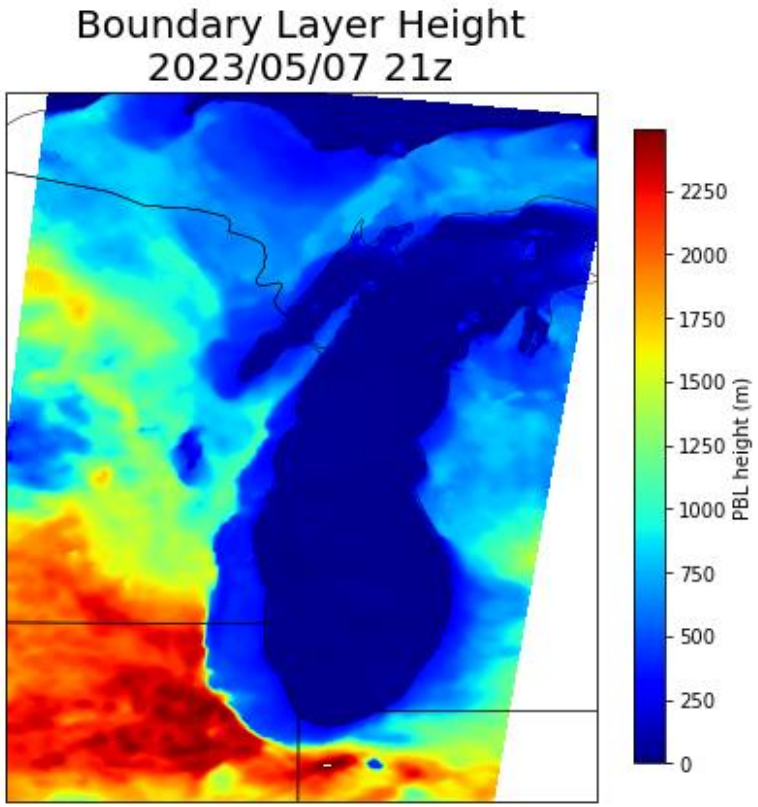


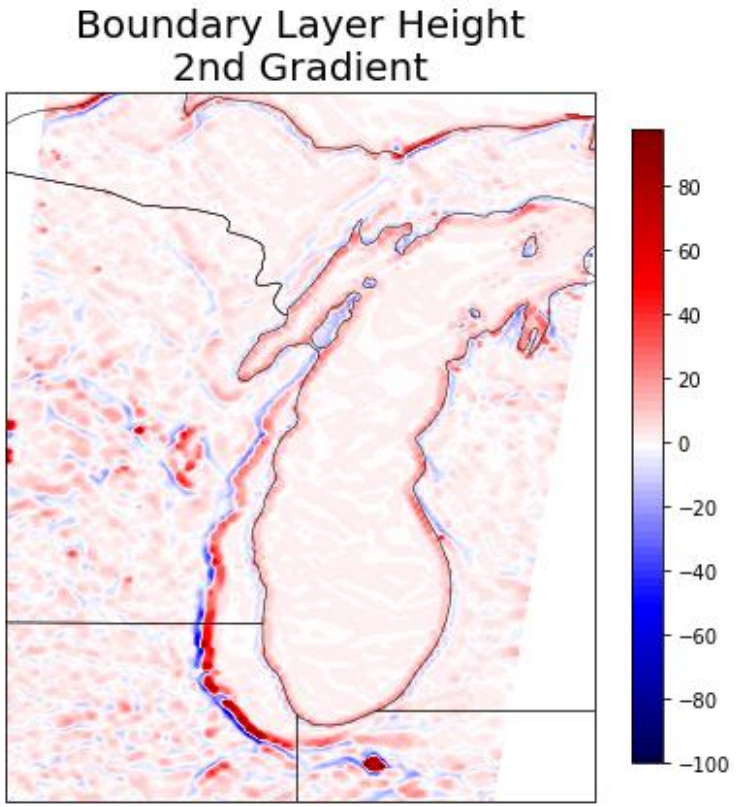


UCAR Image Archive

A revised lake-breeze identification algorithm: Planetary boundary layer height

- The LB front also separates regions of relatively deep from relatively shallow turbulent vertical mixing
- The LB front is a local minimum of PBL height, such that the positive 2nd derivative of PBL height effectively identifies LB front locations





The next step – Observations of the marine atmospheric boundary layer

Planned UWM R/V Neeskay Sampling Mission –
1300 – 2100 UTC 1 June 2023 (rescheduled from 18 May 2023)

- Minimal observations of the MABL spatiotemporal evolution
- Goals of these data are to…
  1. Better understand the development of the MABL over the course of a day
  2. Verify HRRR forecasts of MABL structure
  3. Assess the influence of any deficiencies in the HRRR's representation of the MABL

Discussion & Questions

The goal of this research is to improve lake-breeze front forecasts in specific and coastal forecasts in general for the Great Lakes region.

From an operational perspective, what is important to you in terms of verifying forecasts in the Great Lakes region?

What would you like to see from this research in the future?

Questions?