Detection of Gravity waves and Infrasound Signals at the USArray

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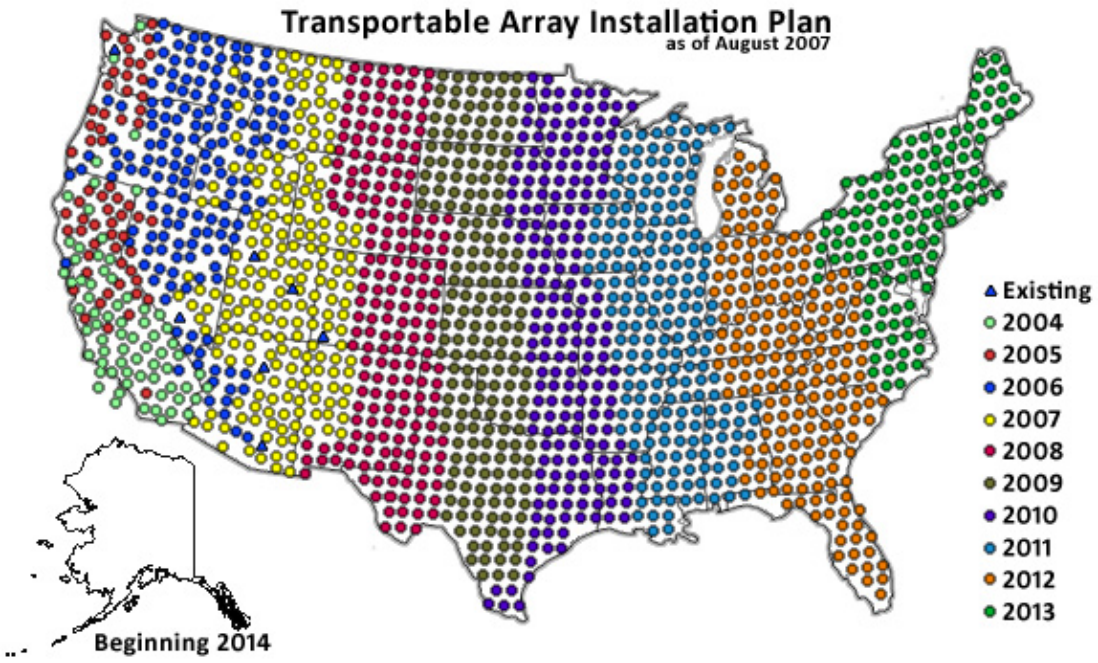
Acoustic studies at the US Transportable Array



Infrasound studies at the USArray based on **seismic** data

- Atlantis, 2007 overflight
- Bolide studies
- Infrasound source catalog

Beginning in 2009, pressure sensors have been installed along with the seismometers

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Outline

1) The automated Gravity Wave detector

- The USArray is divided into non-overlapping 3 components sub-arrays
- Coherent processing is performed at each triad to find signal directions & phase velocities
- The ensemble is examined to find gravity waves of varying scale sizes

3) Applications to gravity wave detections

4) Comparisons to satellite observations of gravity waves

5) Other applications

Pressure movie

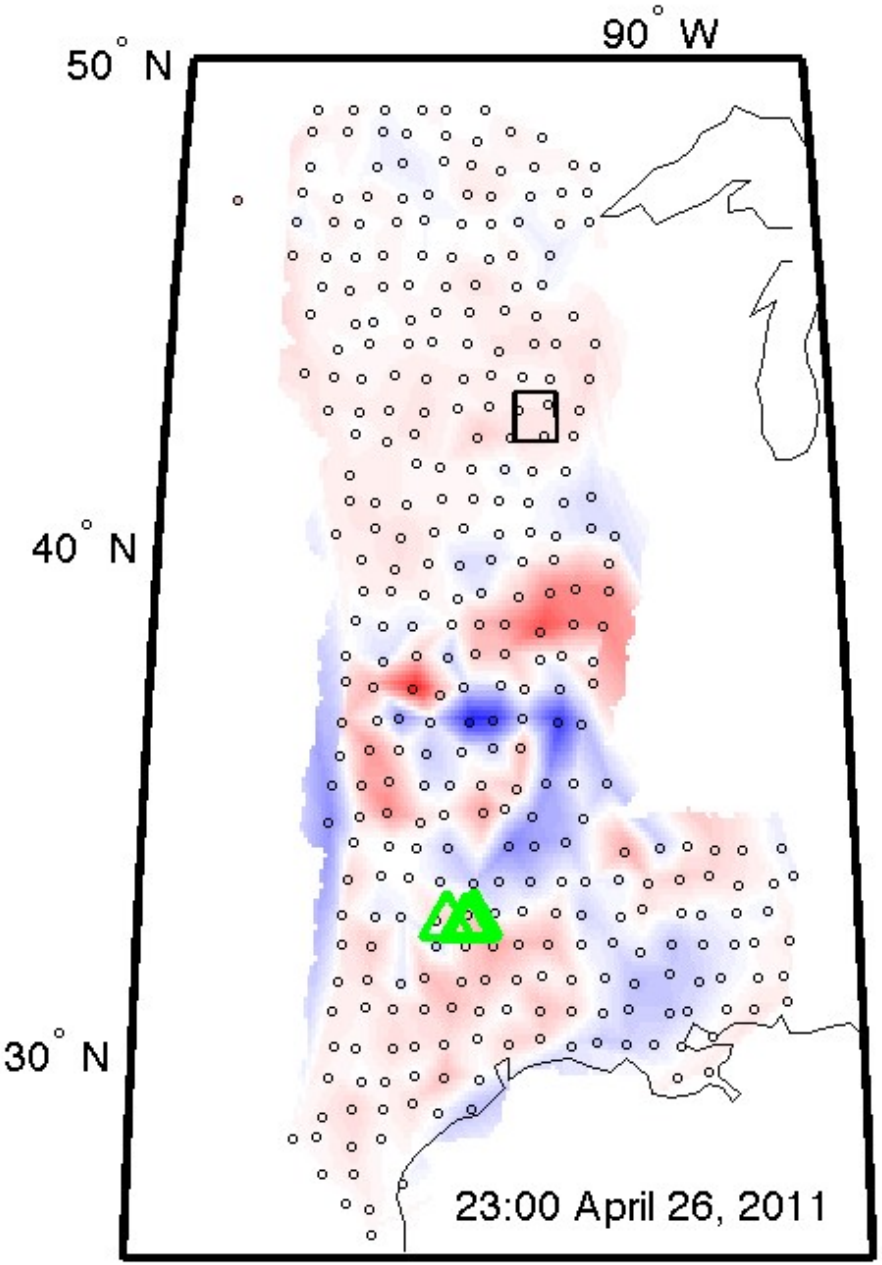
Severe tornados swept past the TA on April 26 & 27, 2011 (green triangles)

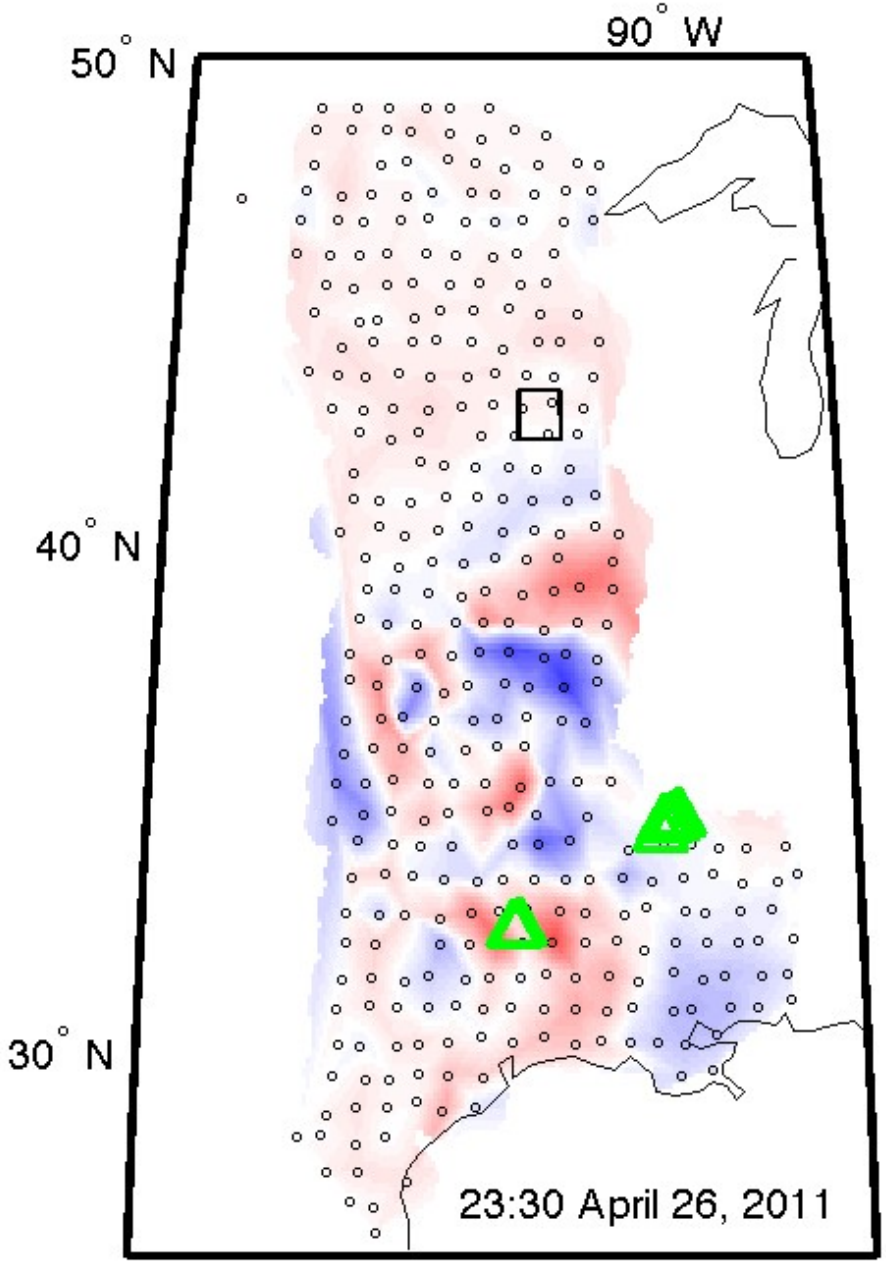
2-4 hour bandpass has been applied to the pressure data

At this frequency, the wavelengths are 100s of km long

Station spacing are ~ 70 km apart

Gravity waves are coherent between stations, so pressures are interpolated between stations

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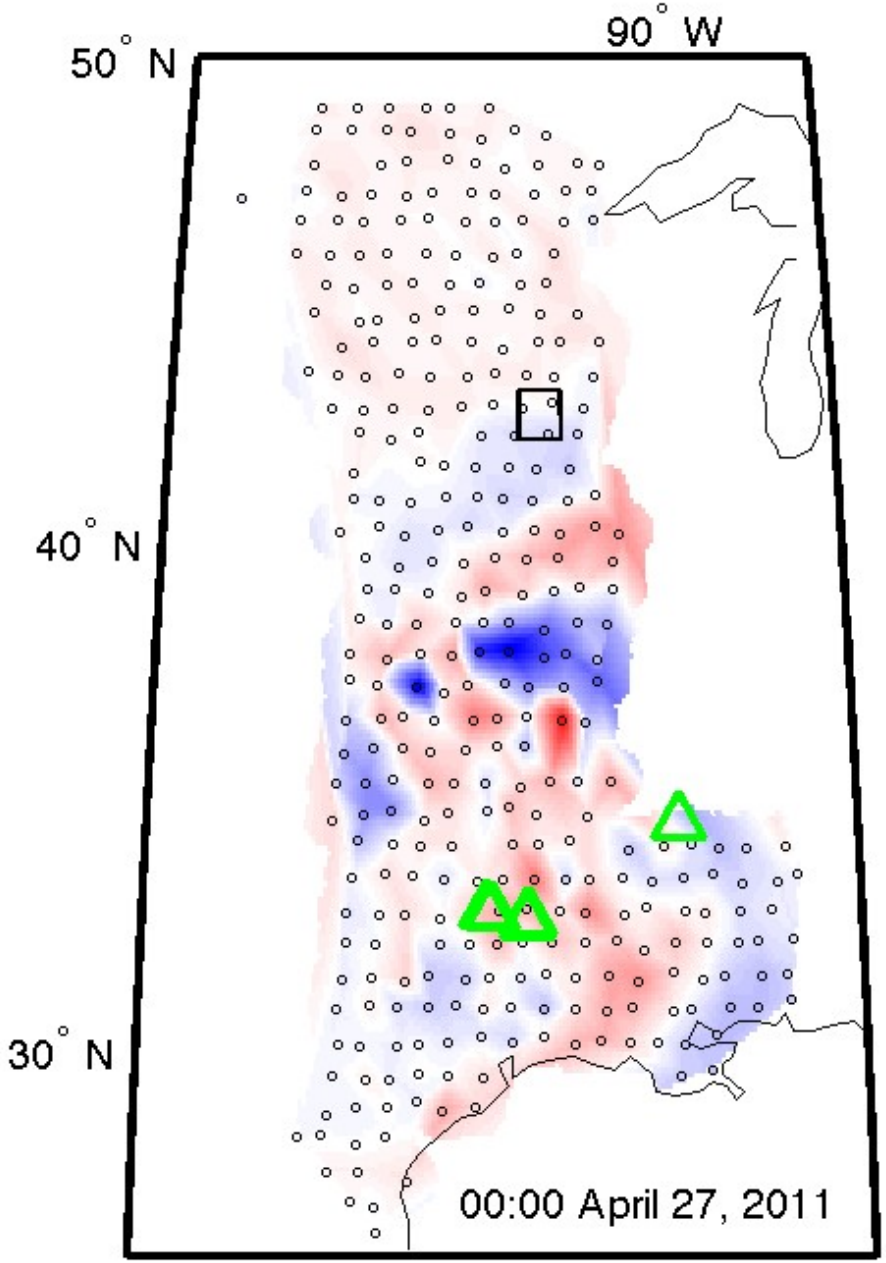
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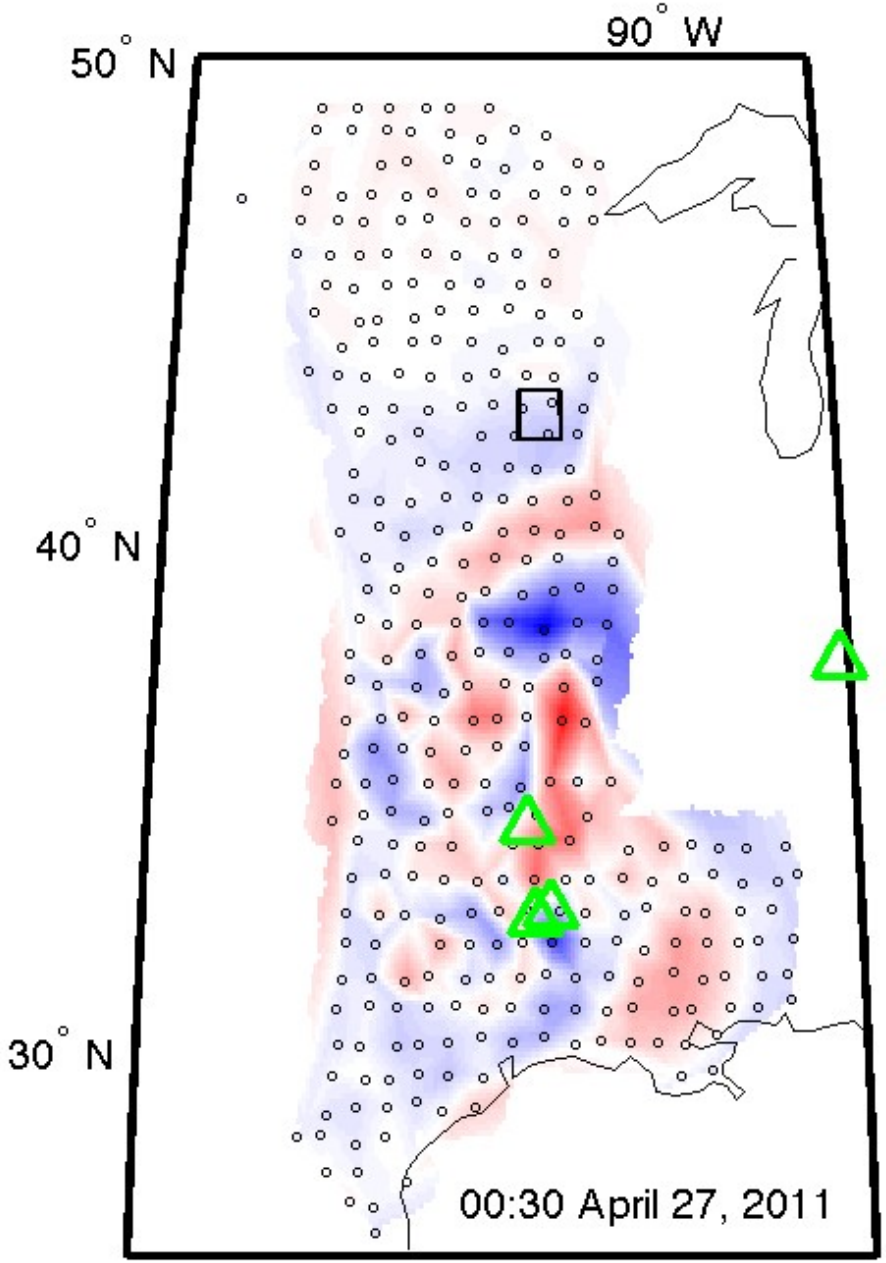
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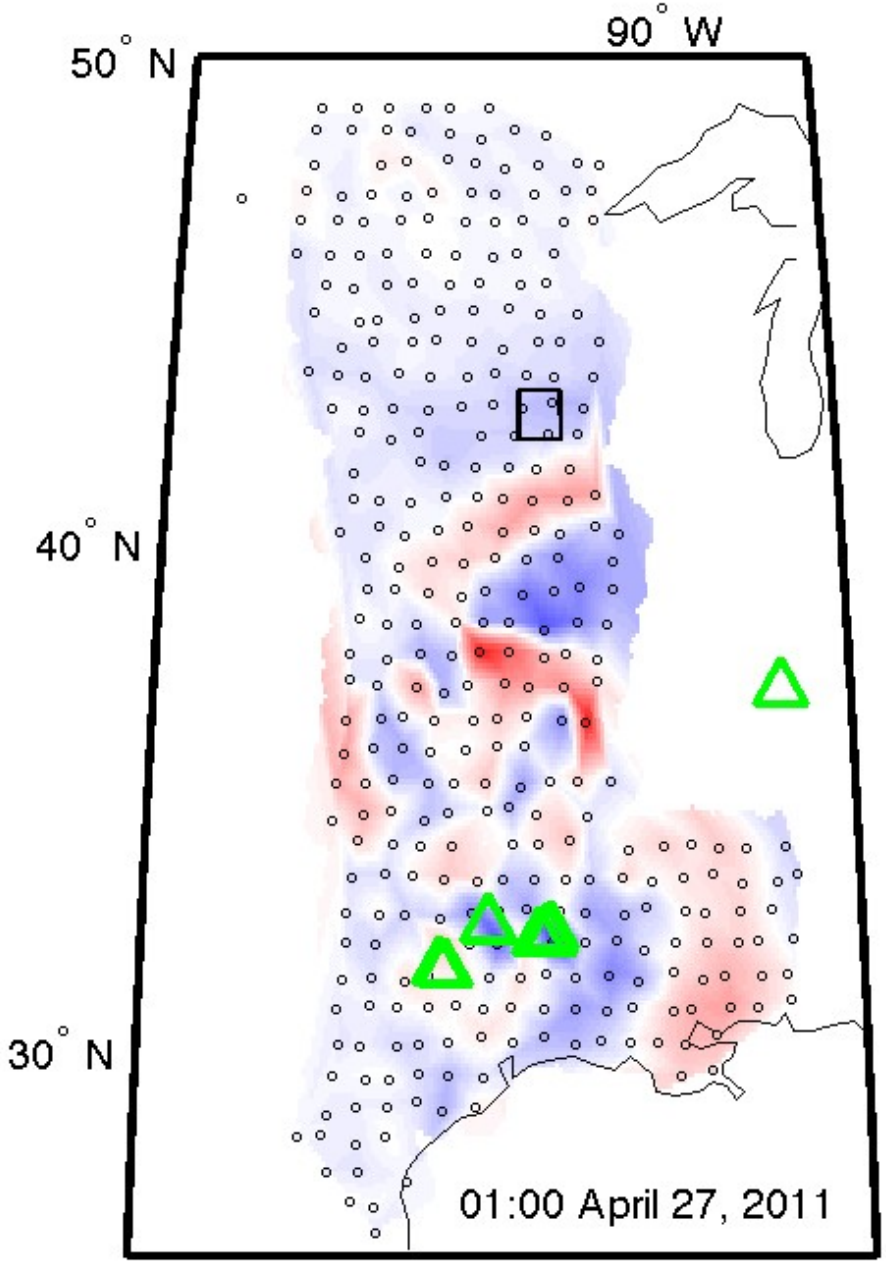
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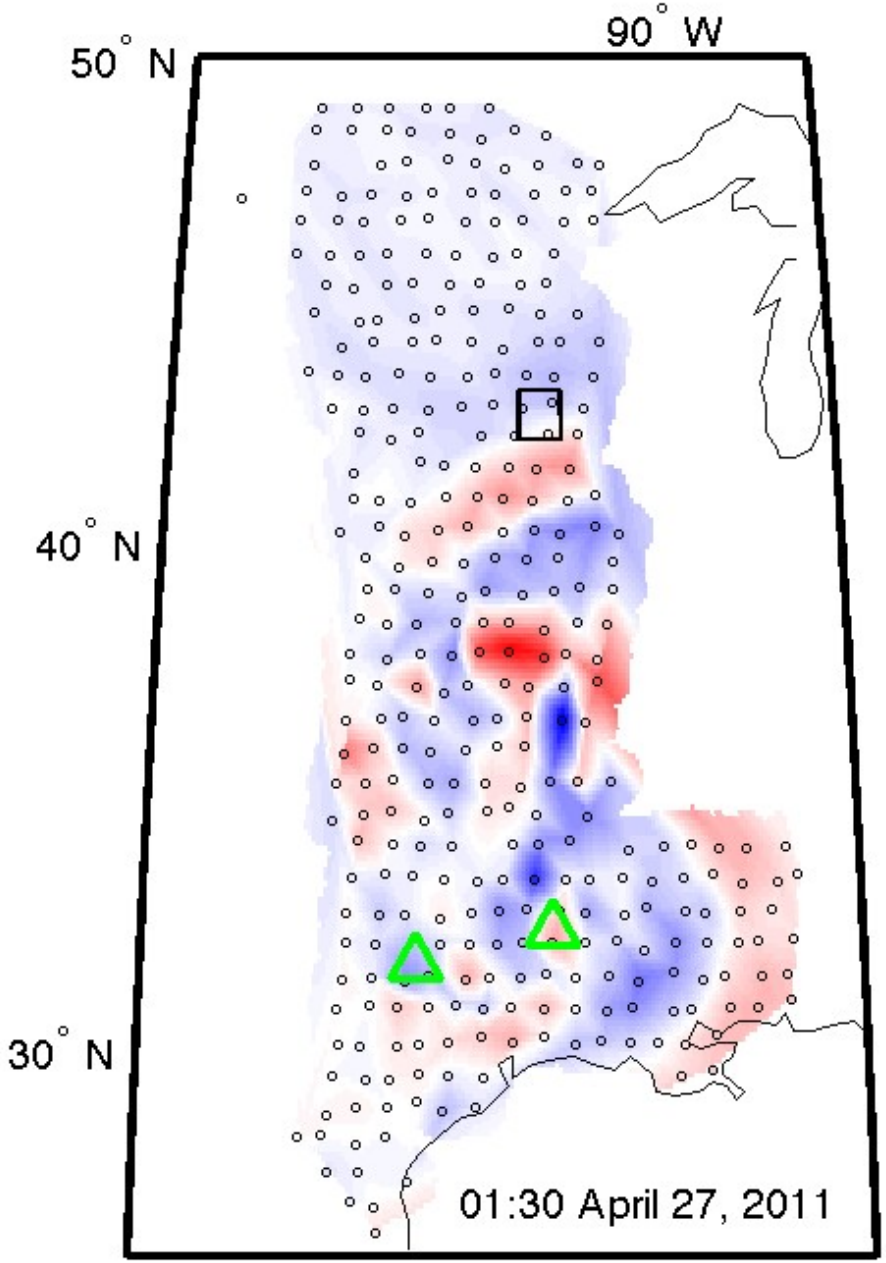
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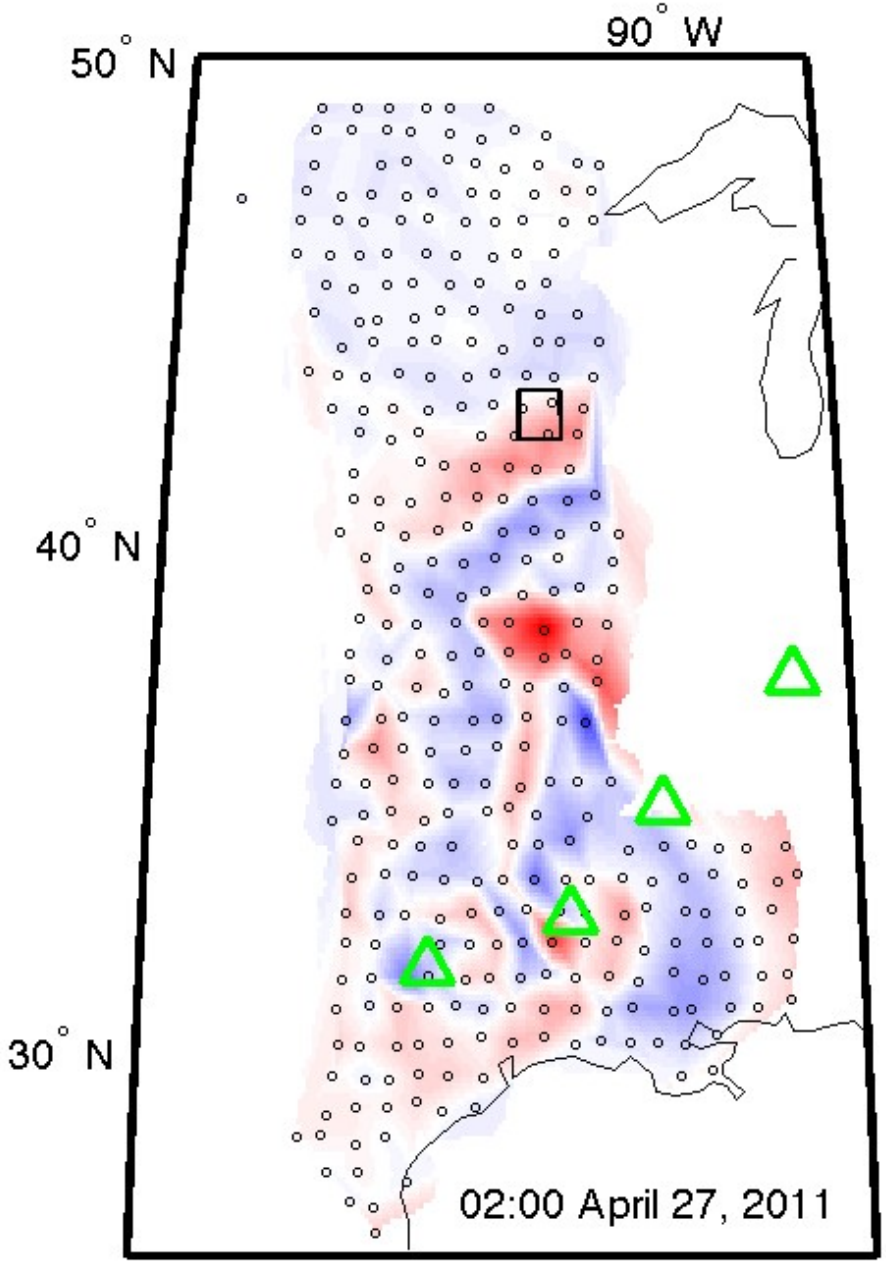
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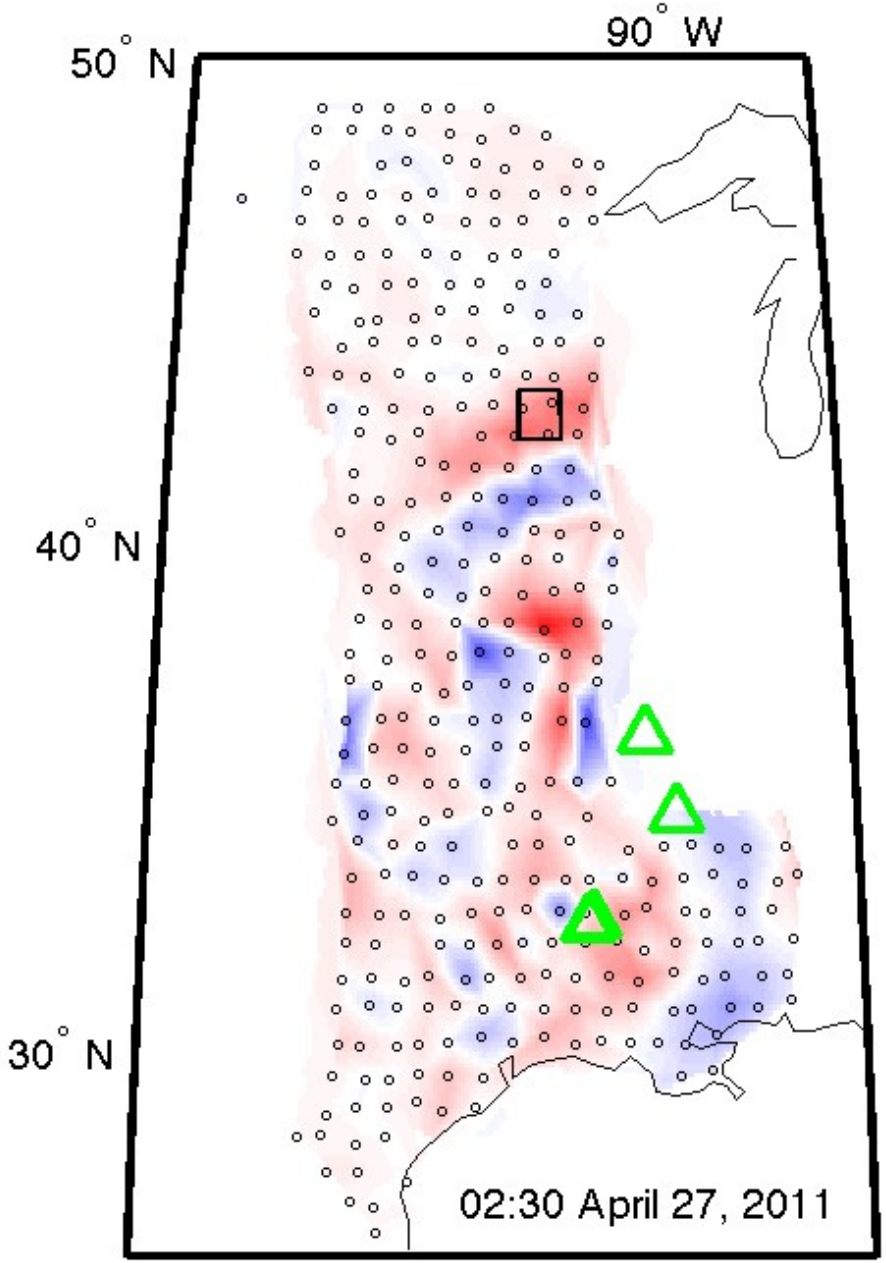
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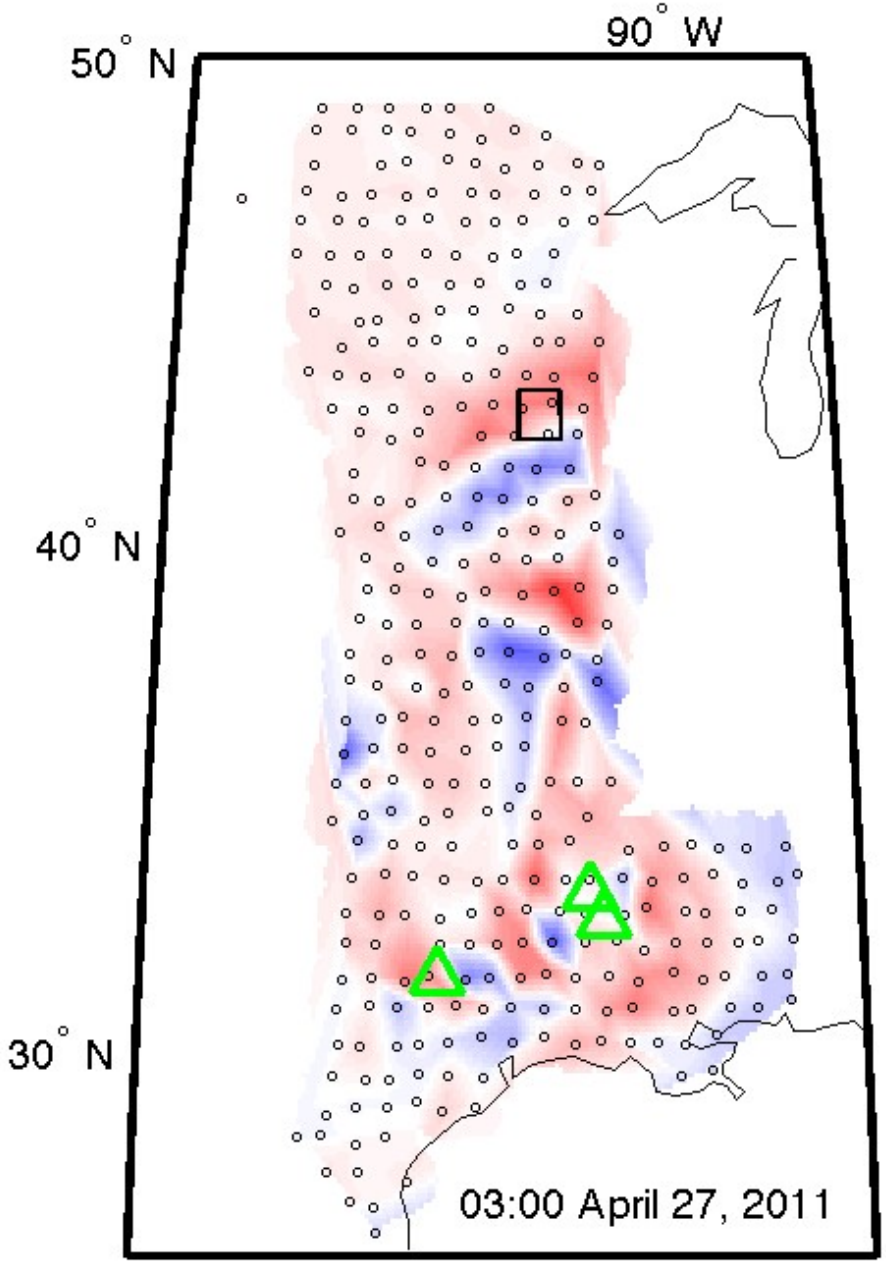
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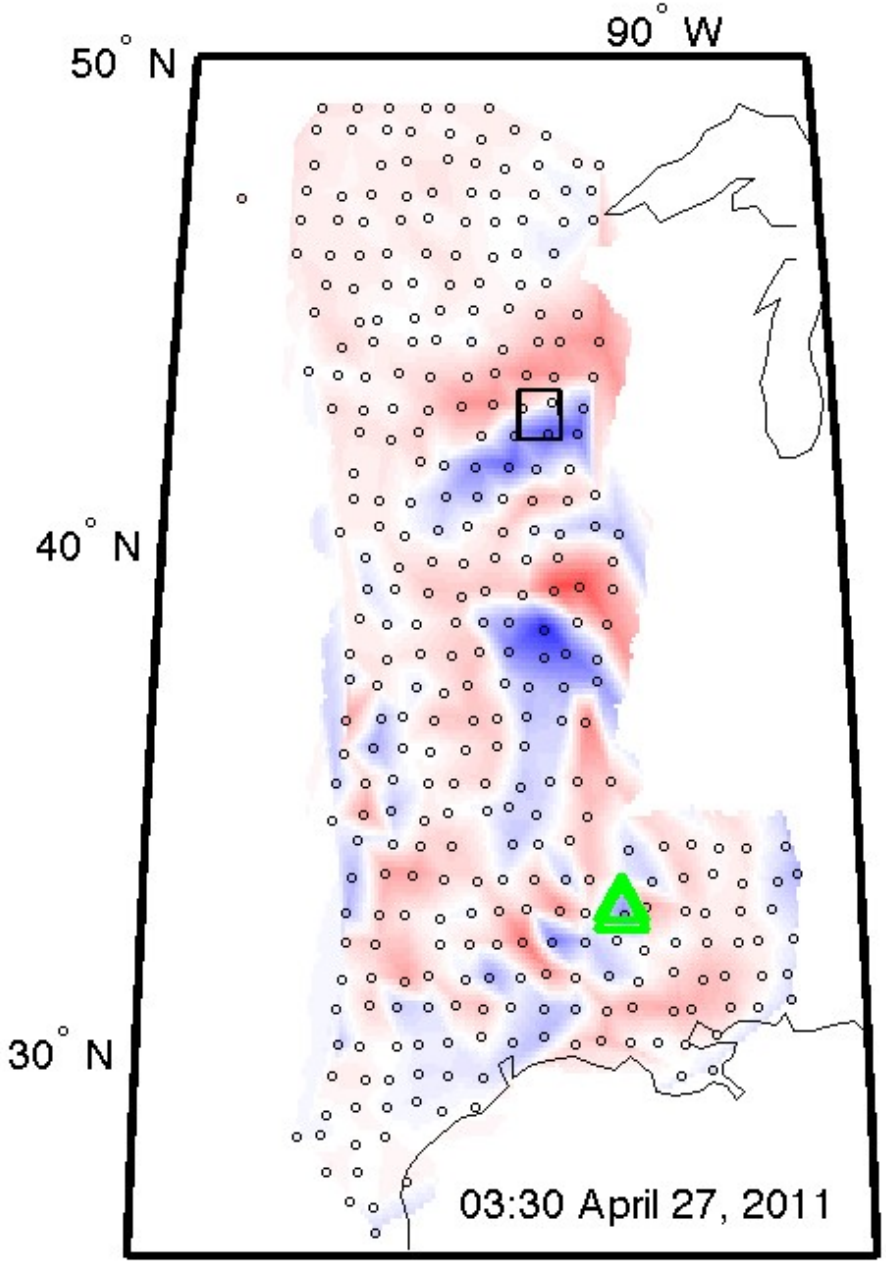
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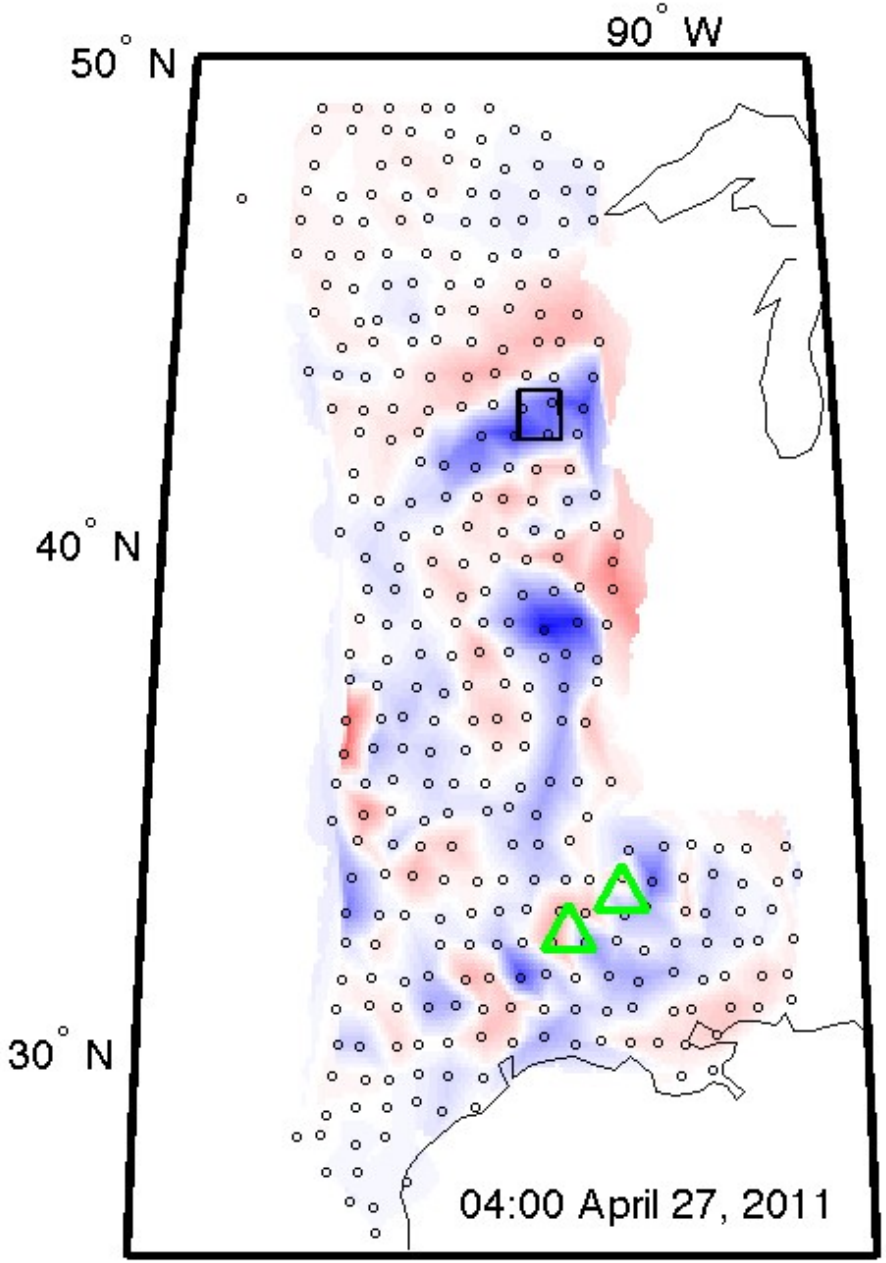
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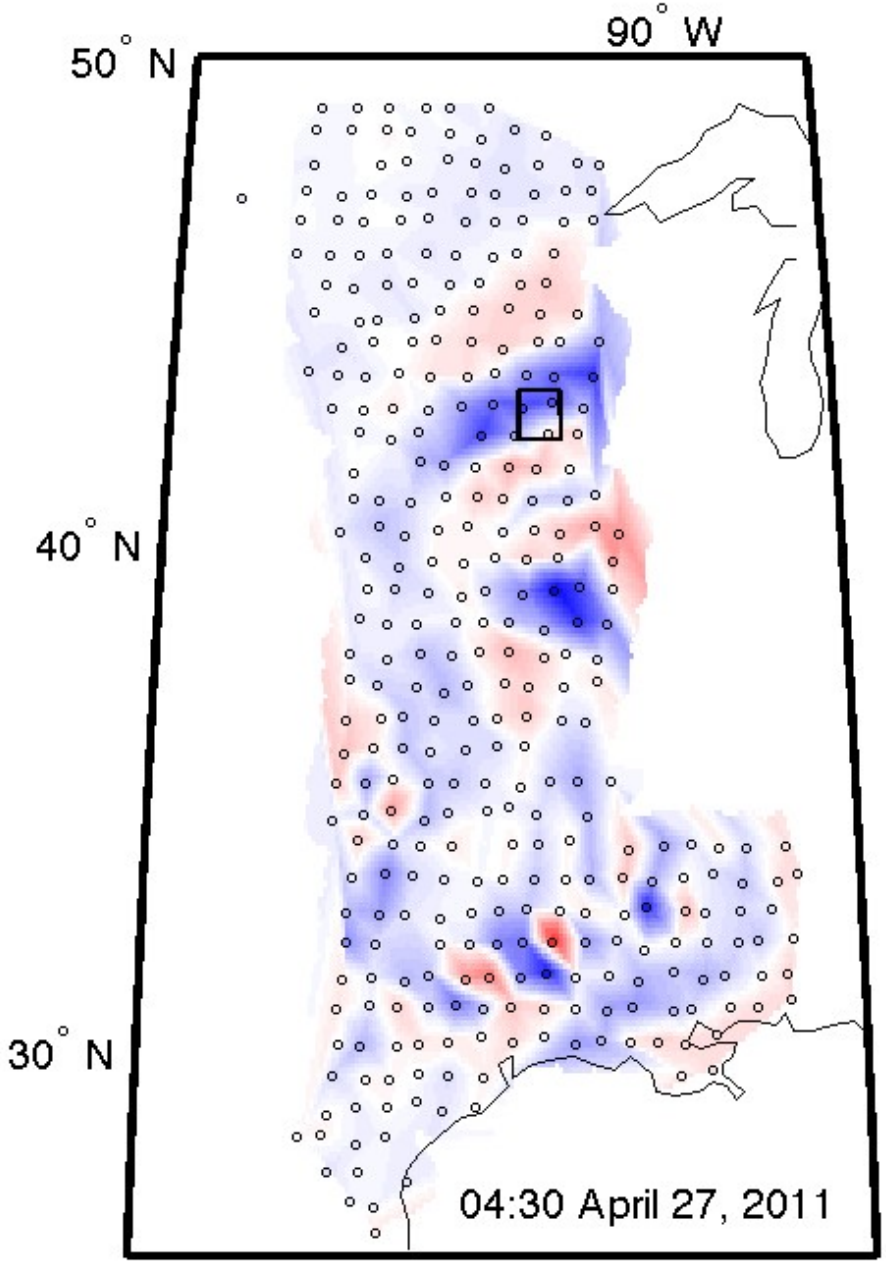
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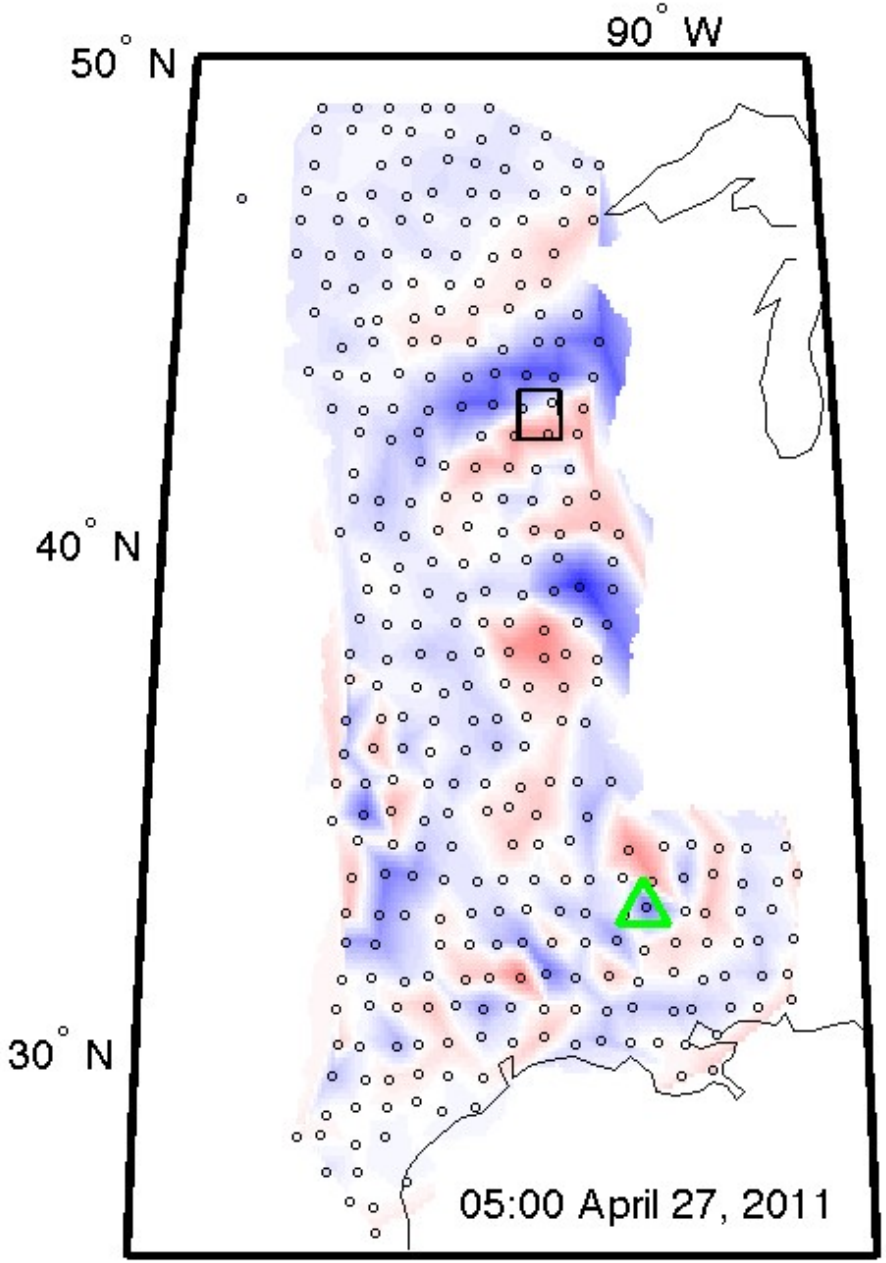
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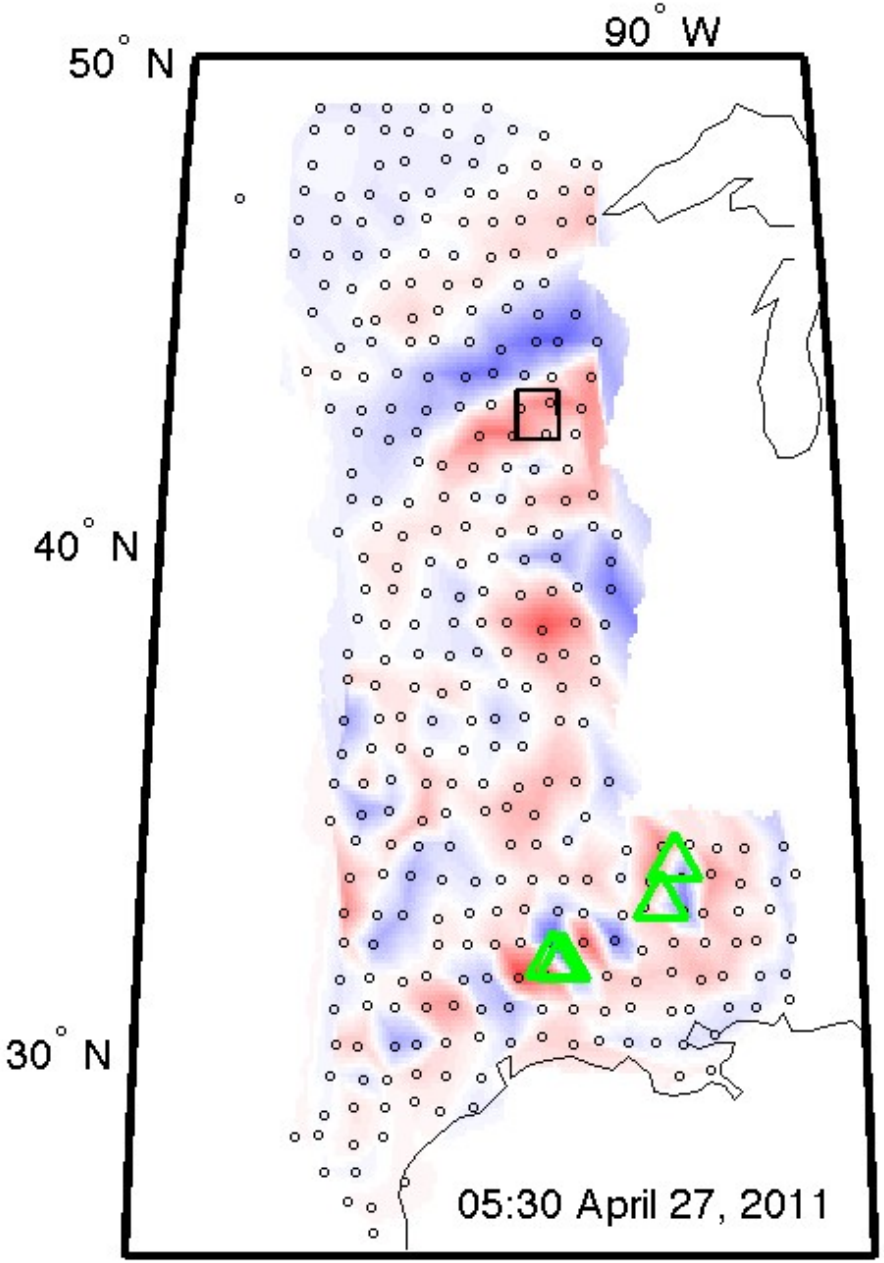
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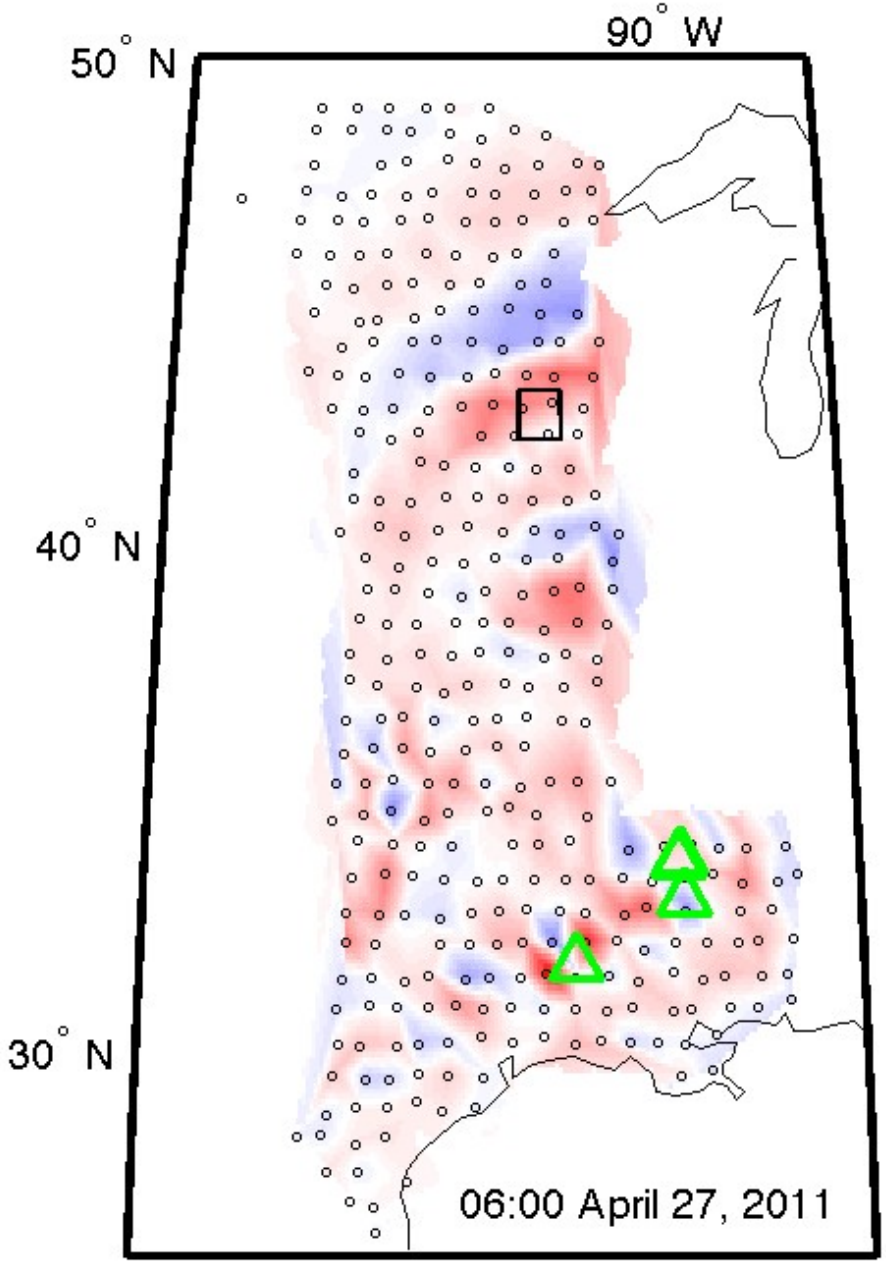
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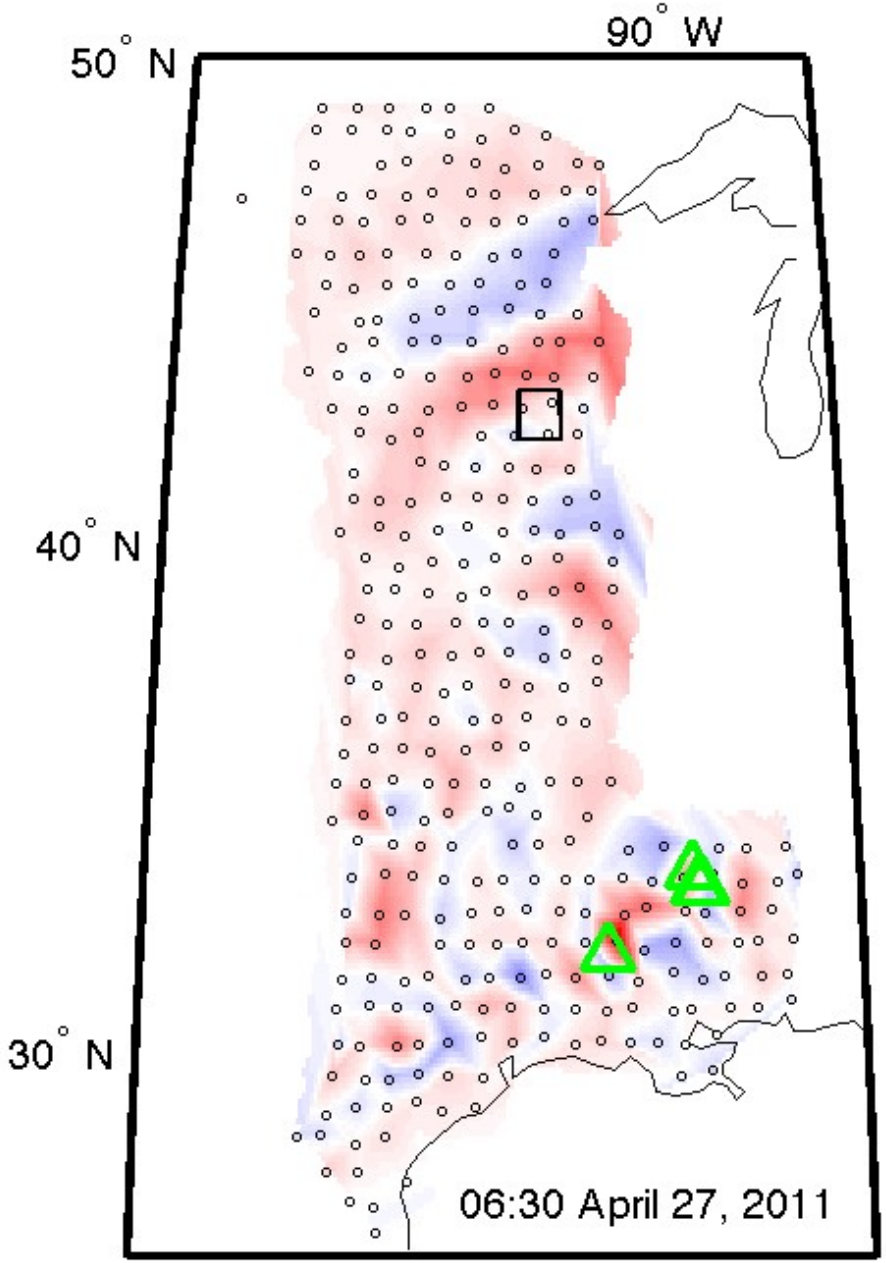
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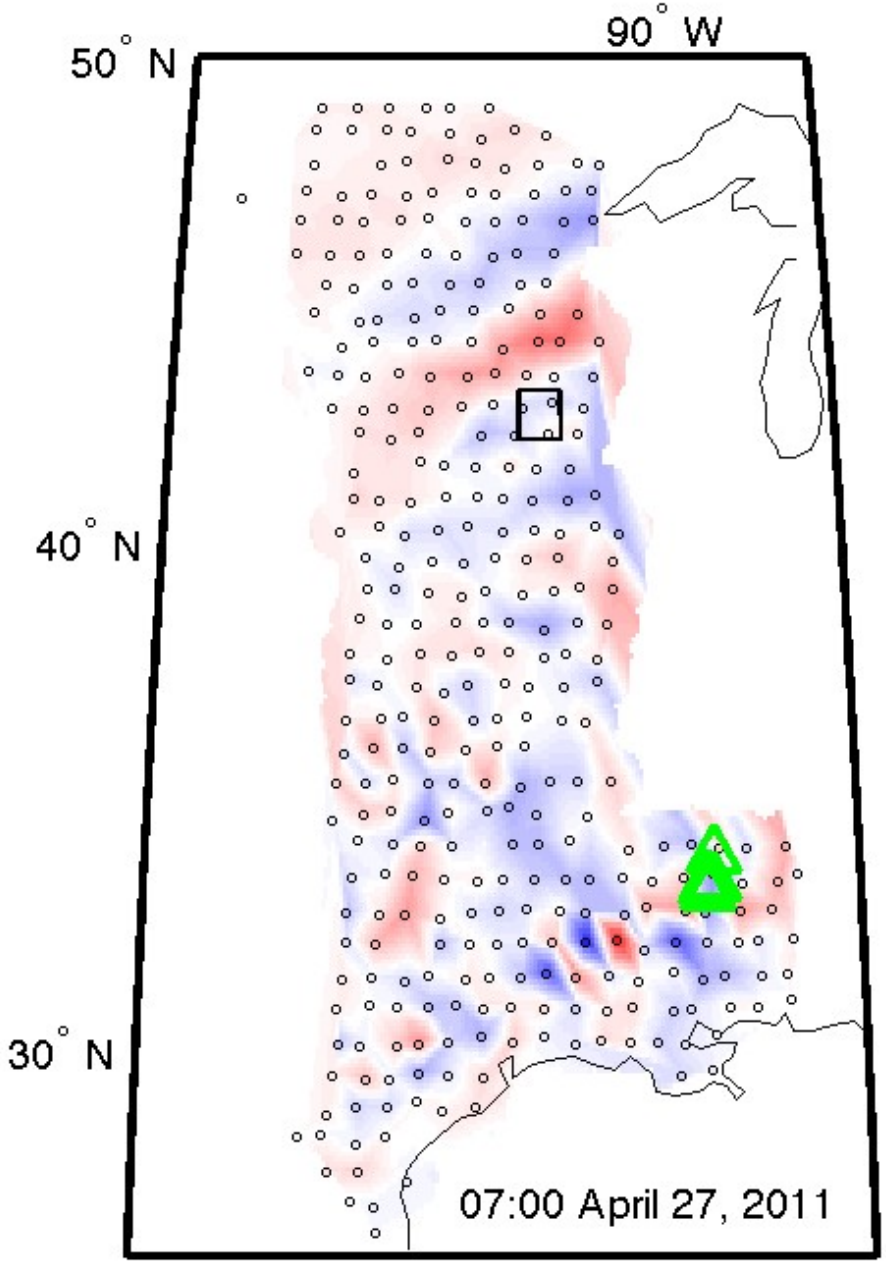
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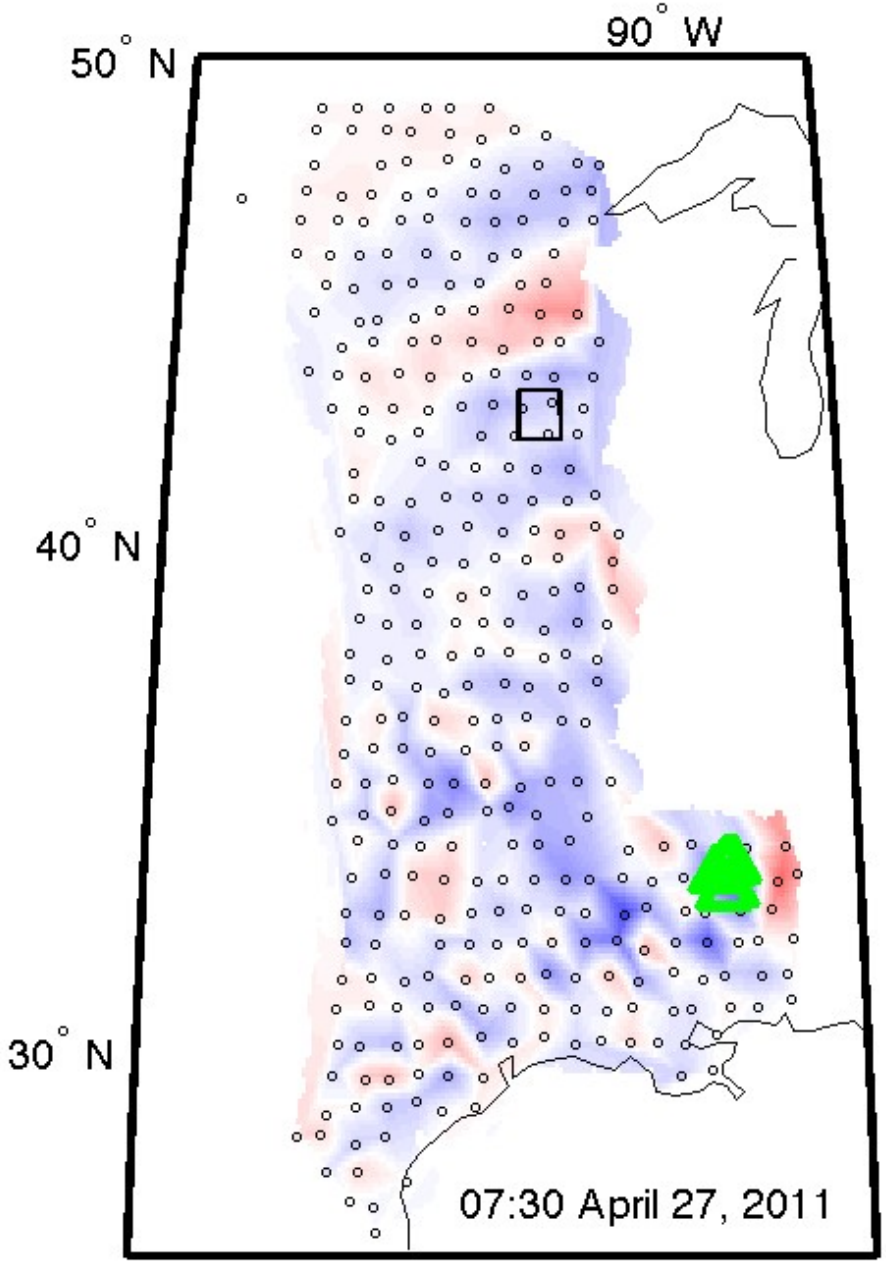
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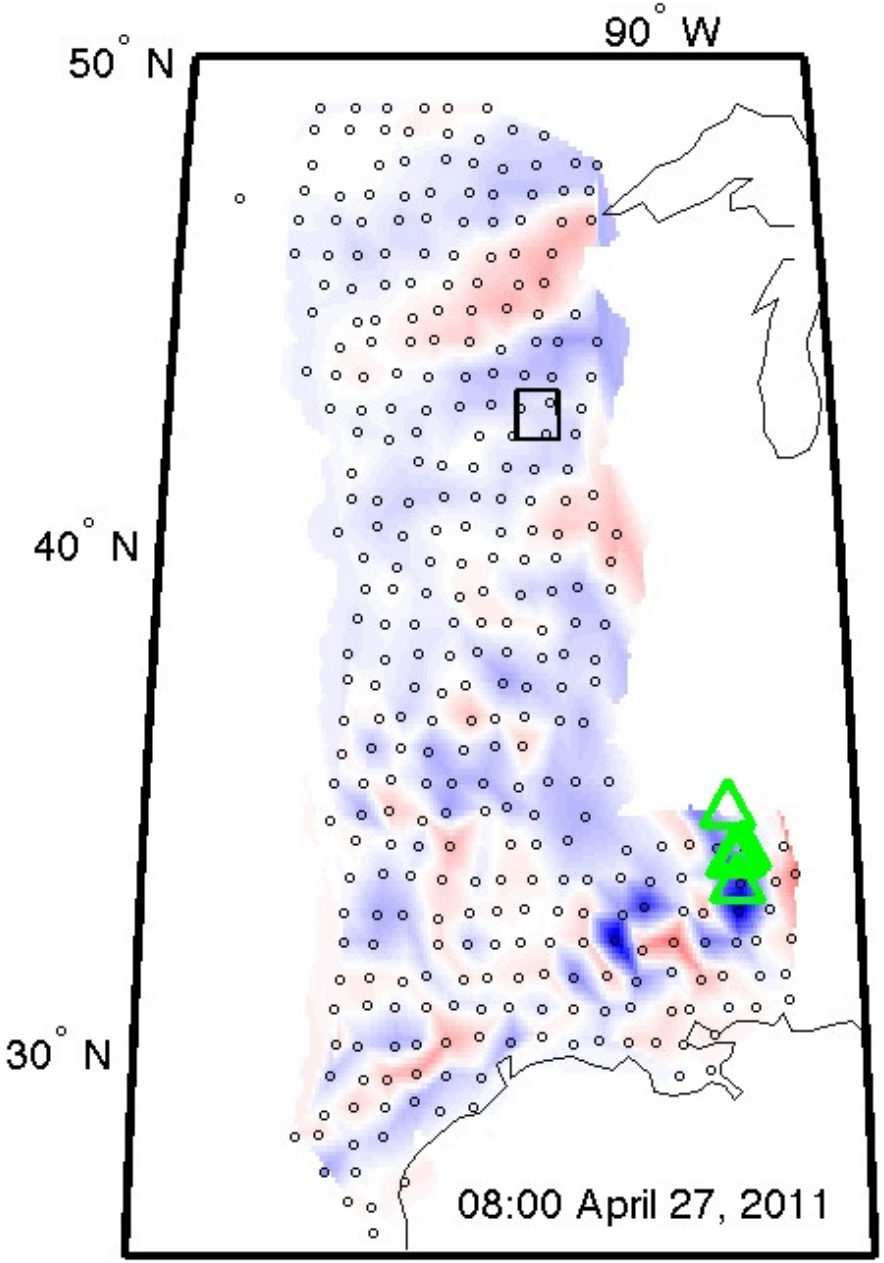
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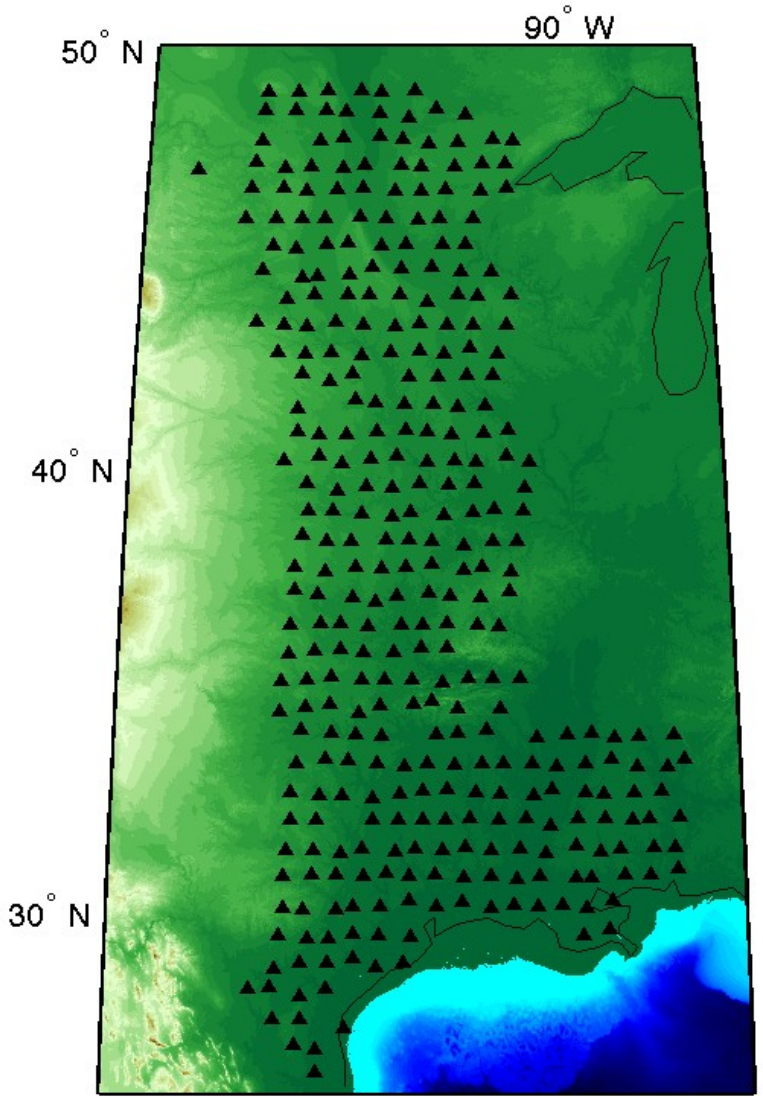
339 stations had continuous data over 2 day period April 26 & 27 , 2011



Gravity waves are not coherent over the entire TA

Break the array up into small sub-arrays (sets of 3 stations)

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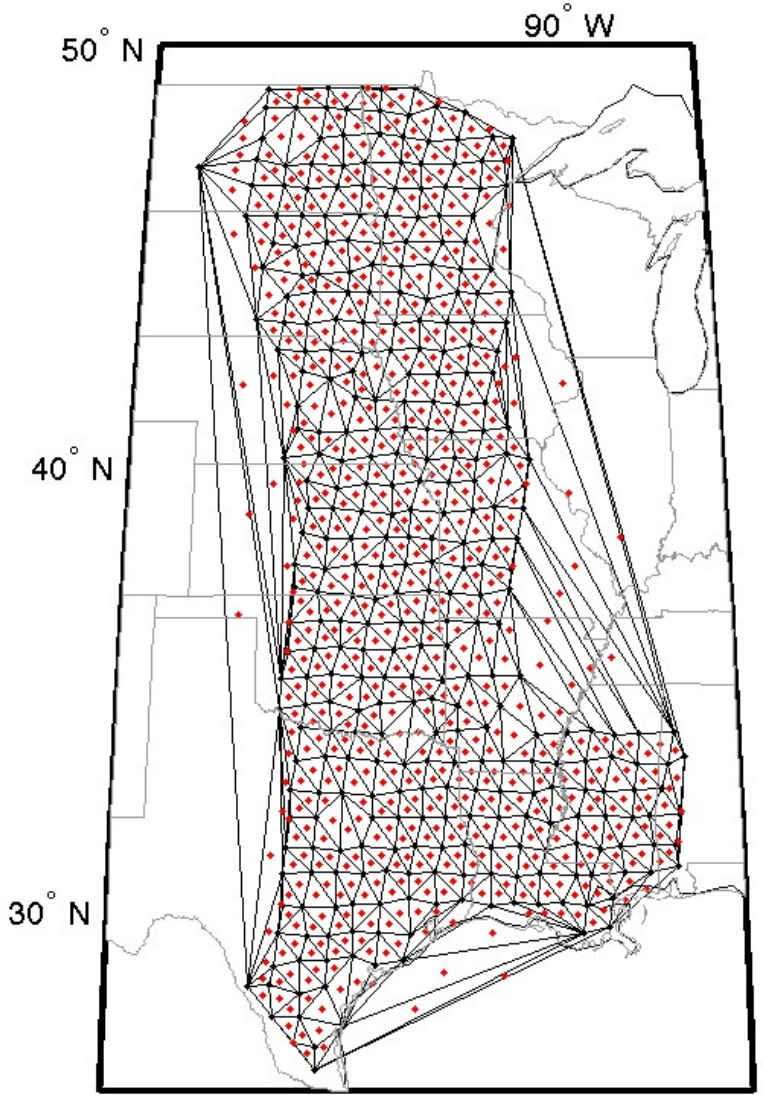
Delauney triangulation



Method to divide a grid of points into non-overlapping triangles

-seeks set of triangles such that triangles are as nearly equilateral as possible, ideal for accurate azimuth estimation

-still, many remaining triangles are very uneven

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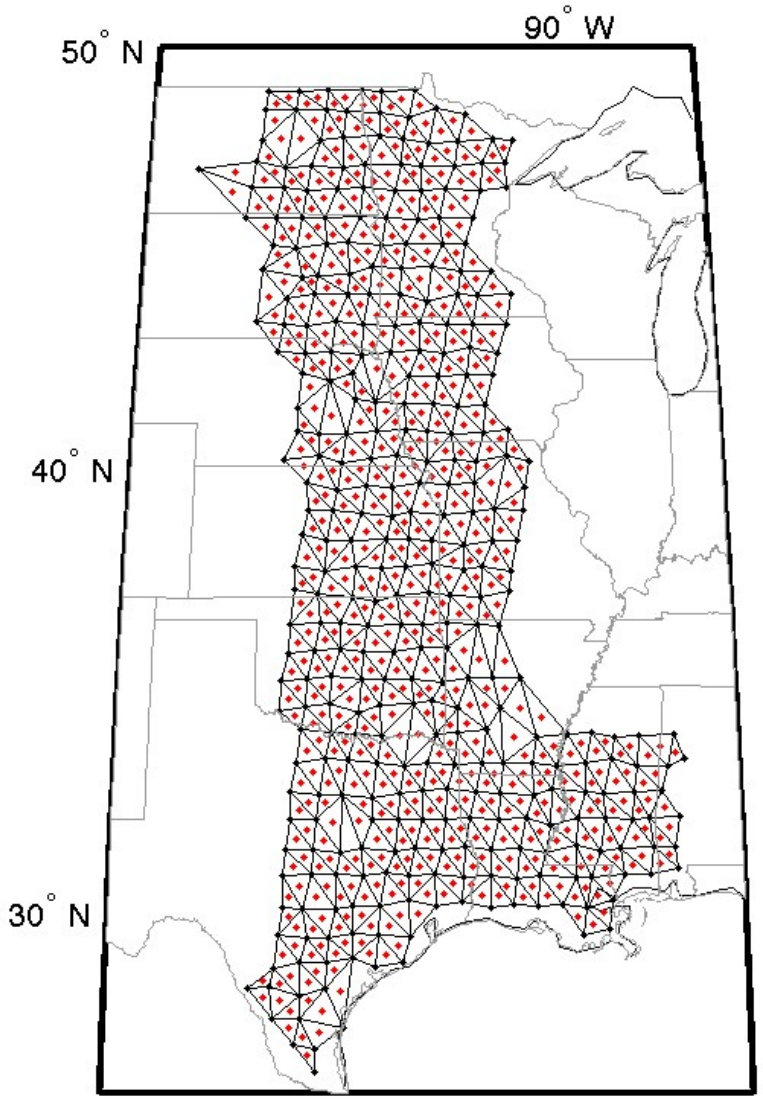
Reduced set of triads



Throw out all triangles with interior angles < 25° or > 110°

This leaves 576 triads – phase velocity and azimuth are derived for each one.

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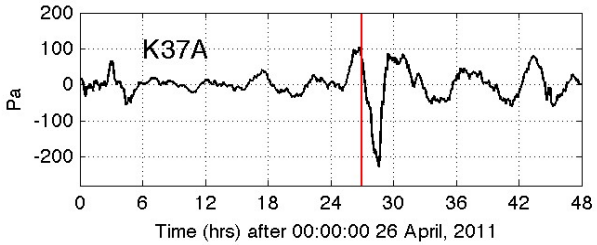
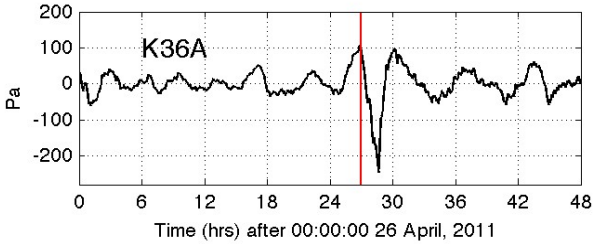
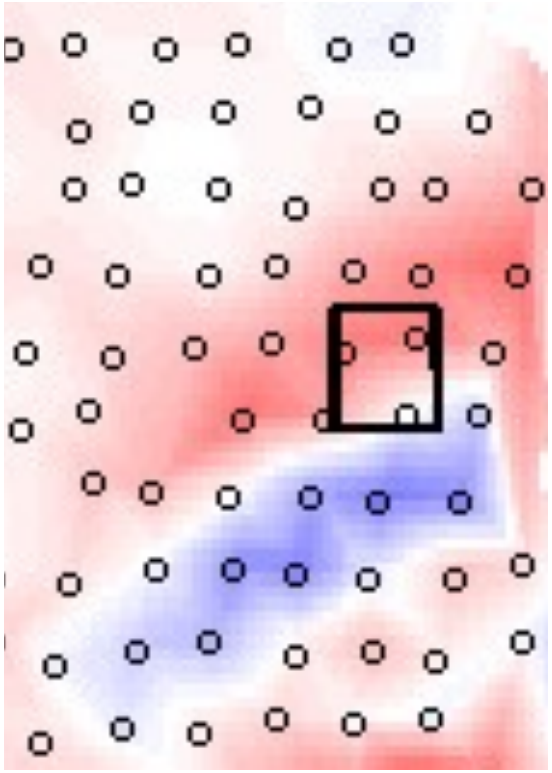
Coherent processing
at 3 adjoining stations







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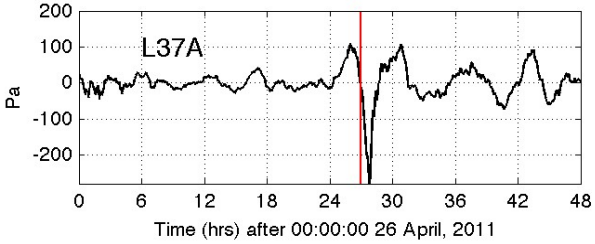
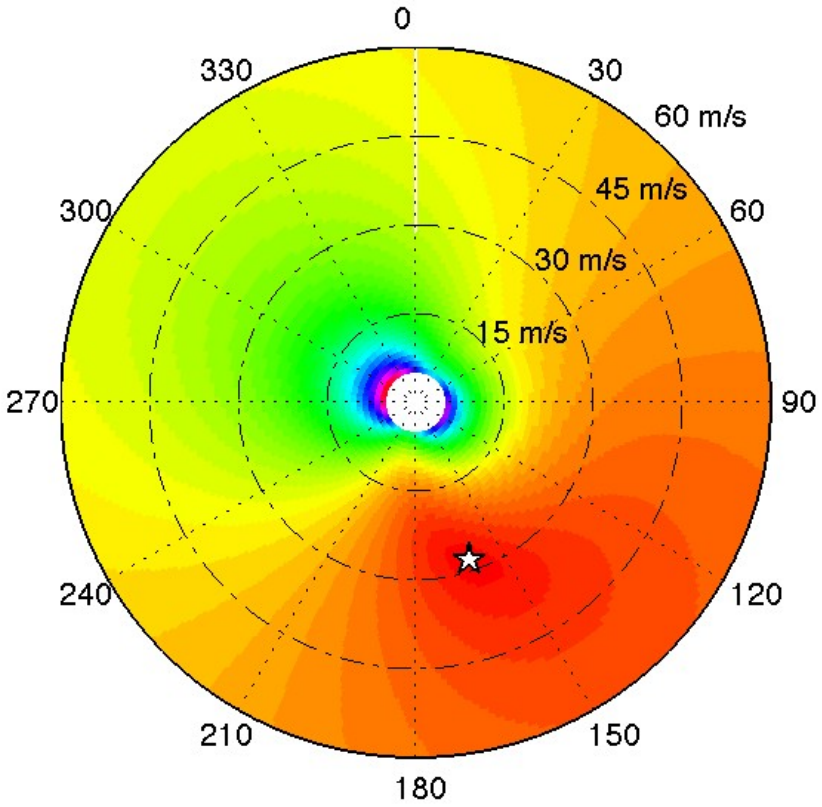
Waveforms are coherent from station to station

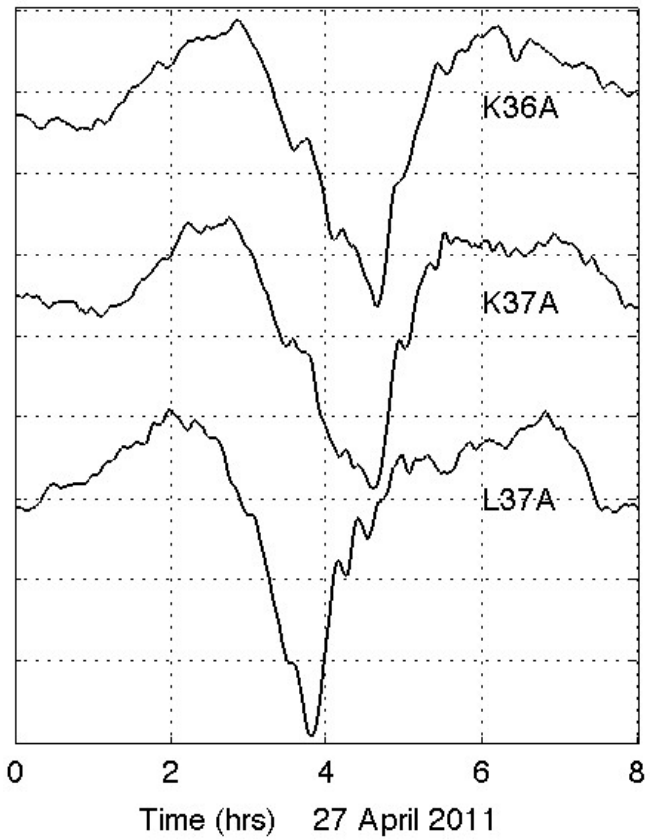


Array processing at each group of 3 stations

Use X-correlations to derived time delays between stations

Time delays → phase velocity and direction of propagation





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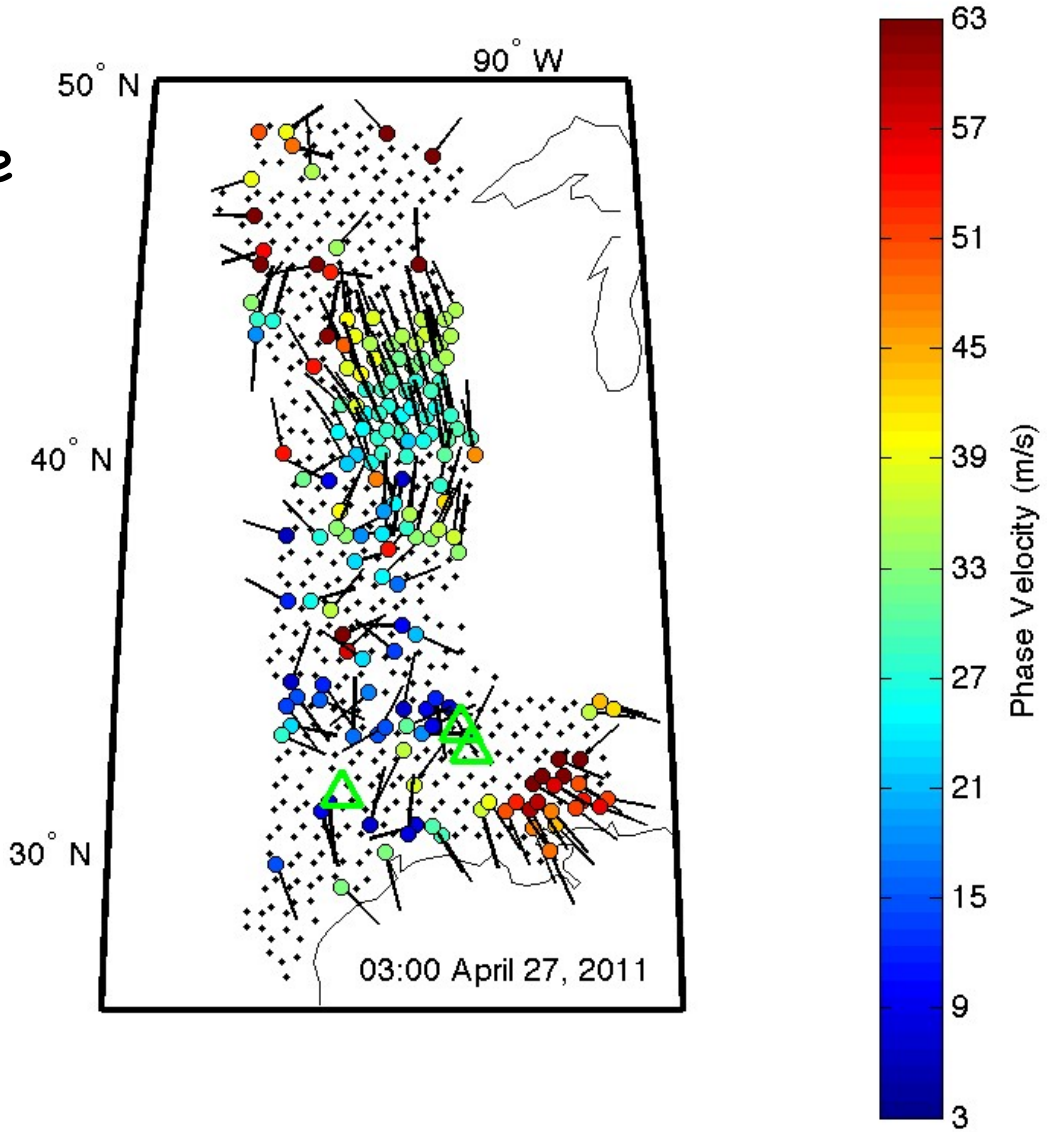
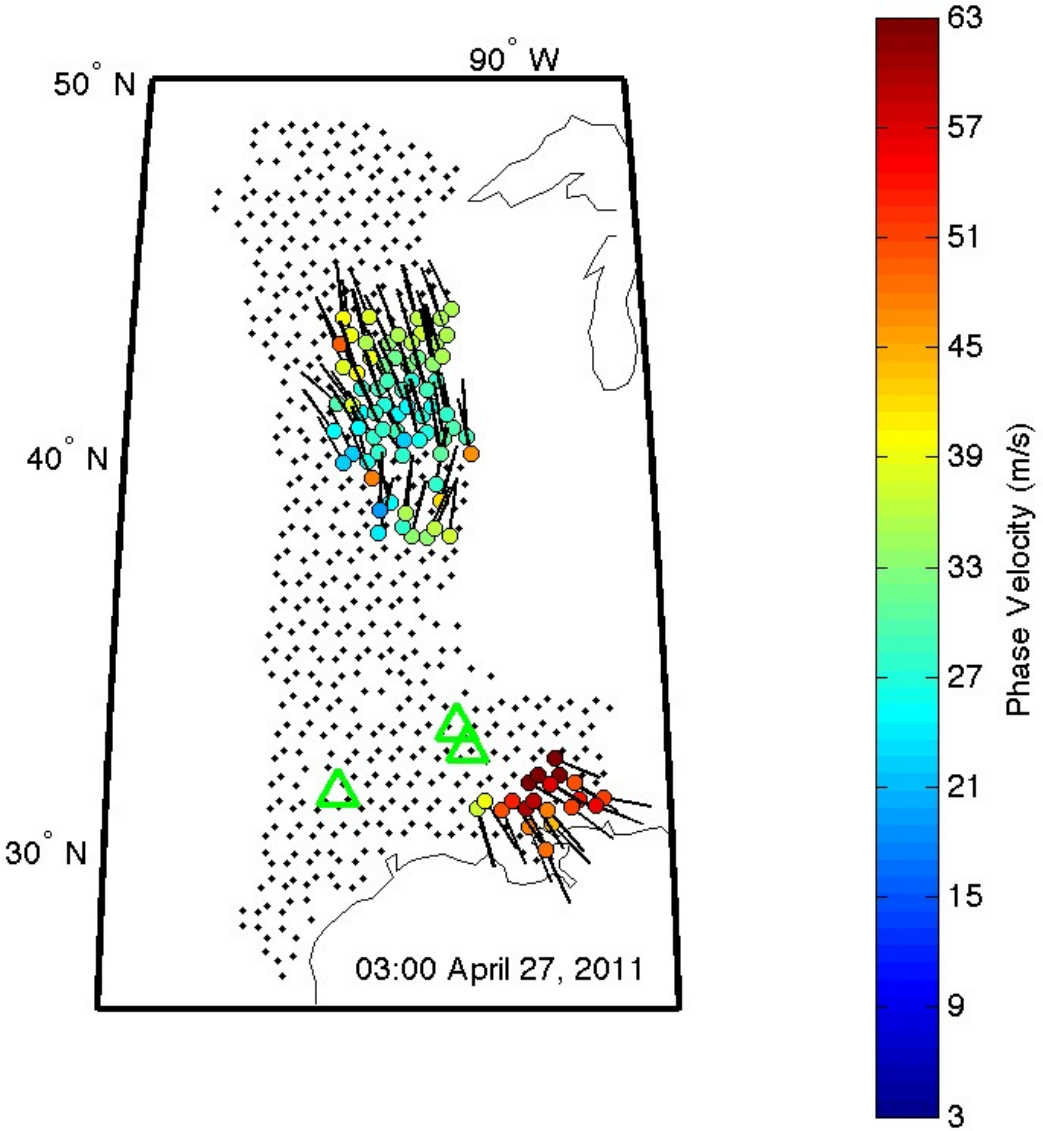
Array analysis for 576 triads

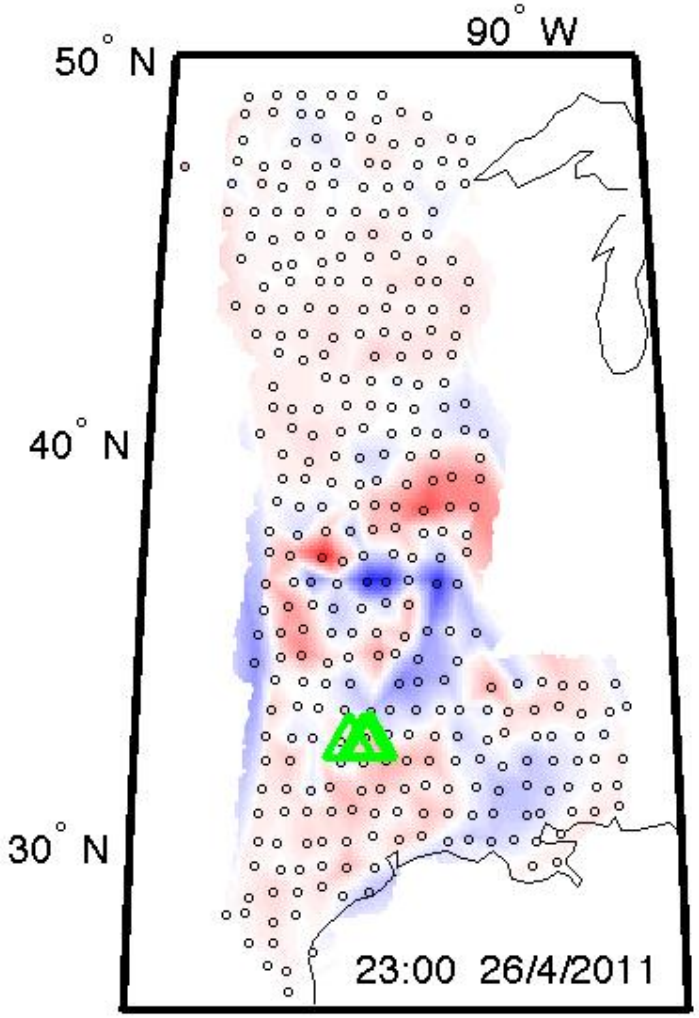
Small dots show center of triads where detections were not registered

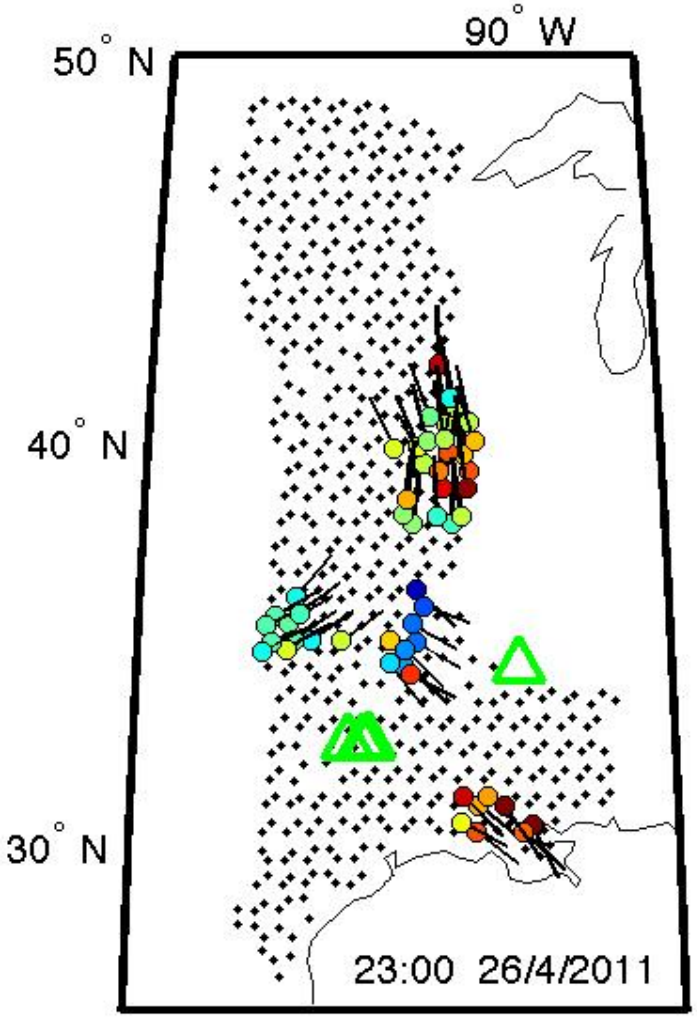
Many spurious 'detections' - delete detections if < 4 adjoining triads are consistent



Array analysis for 576 triads







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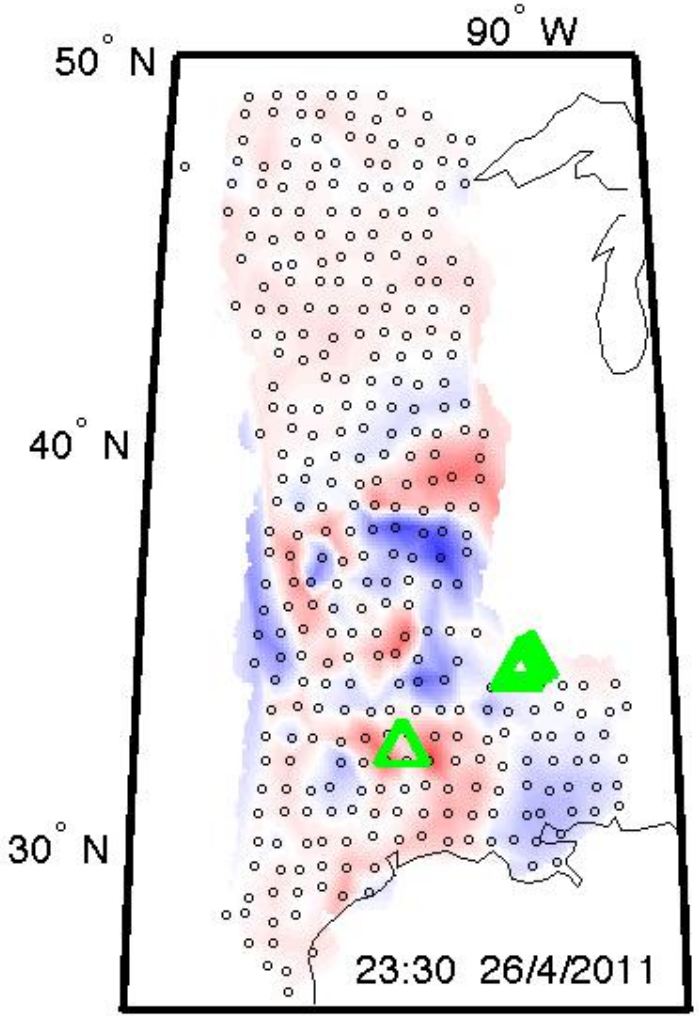

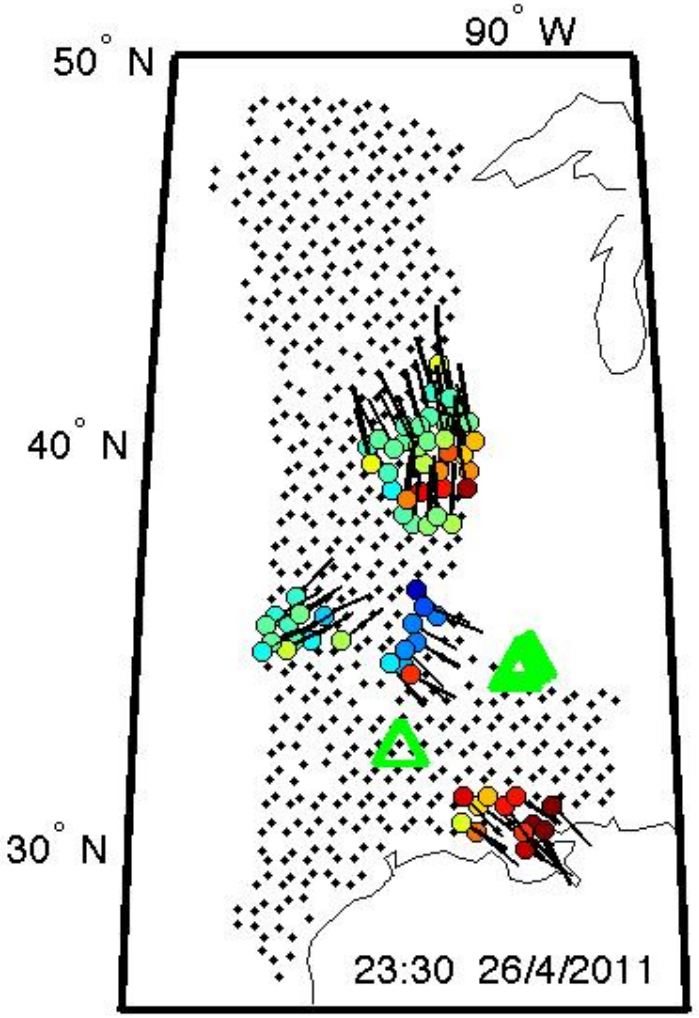

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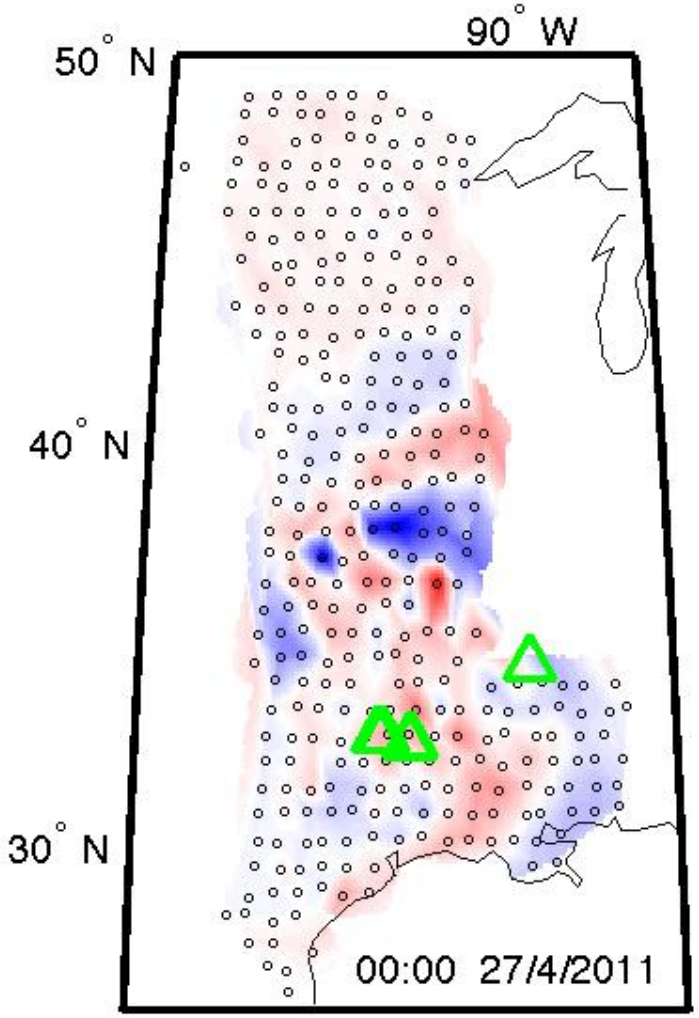

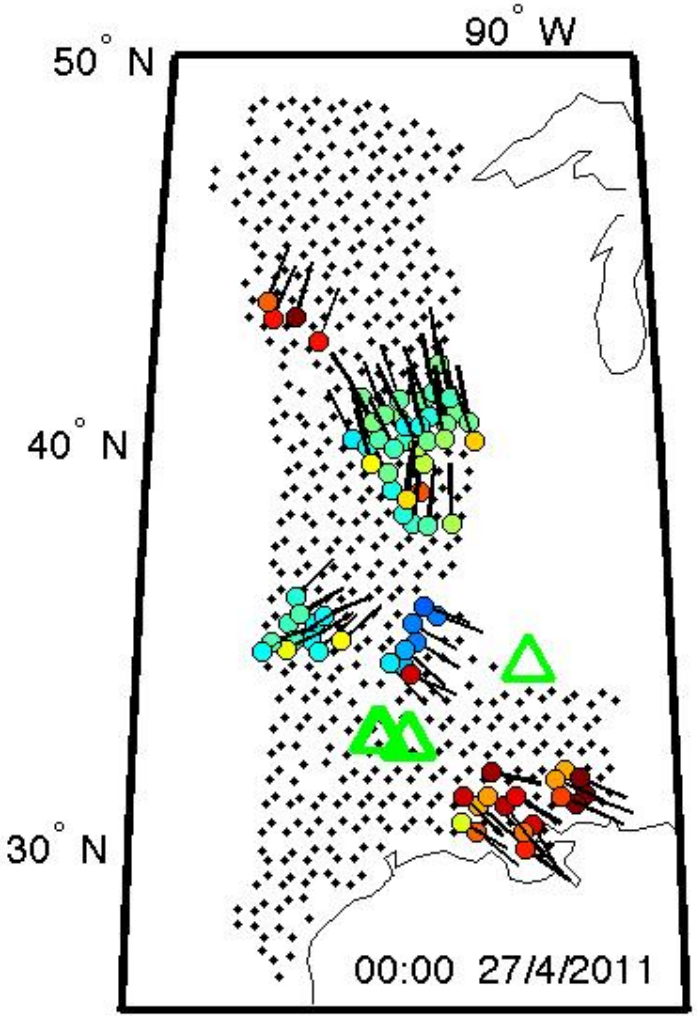

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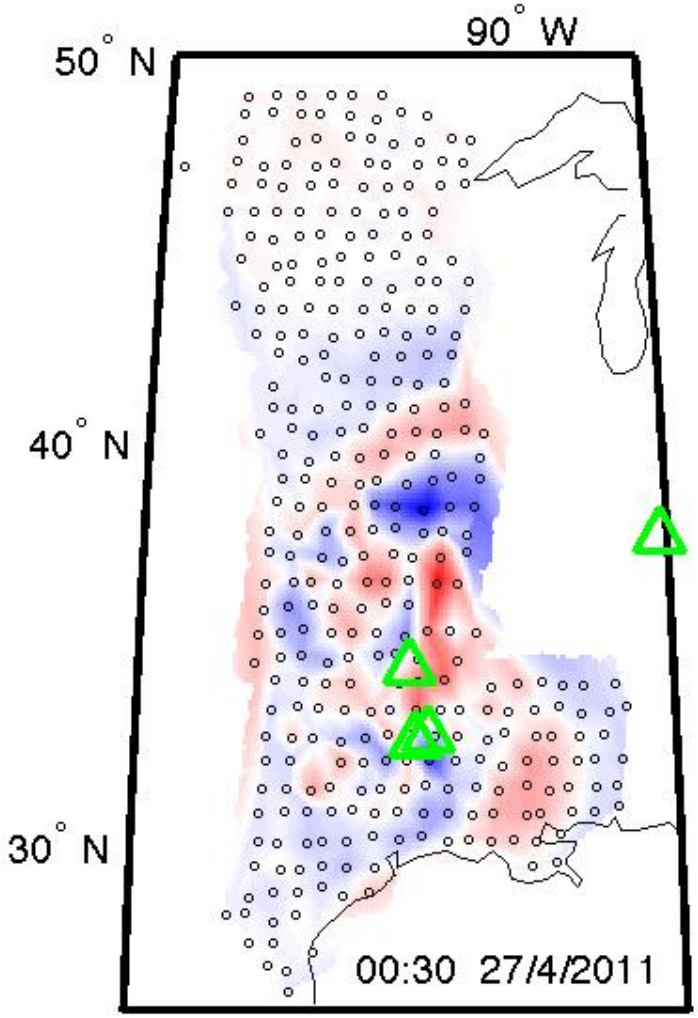

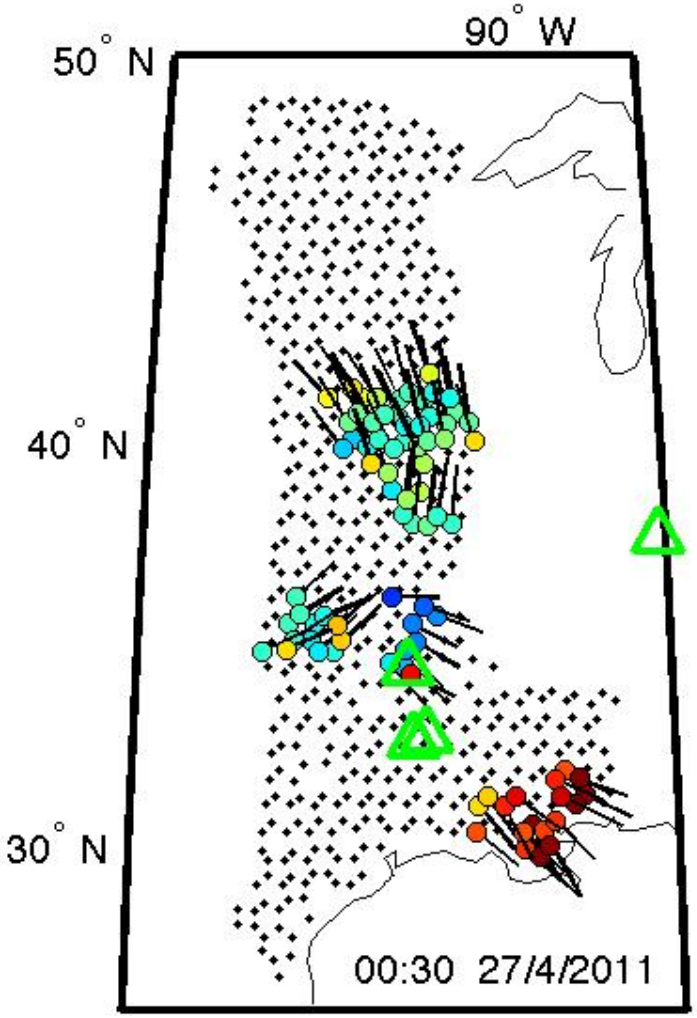

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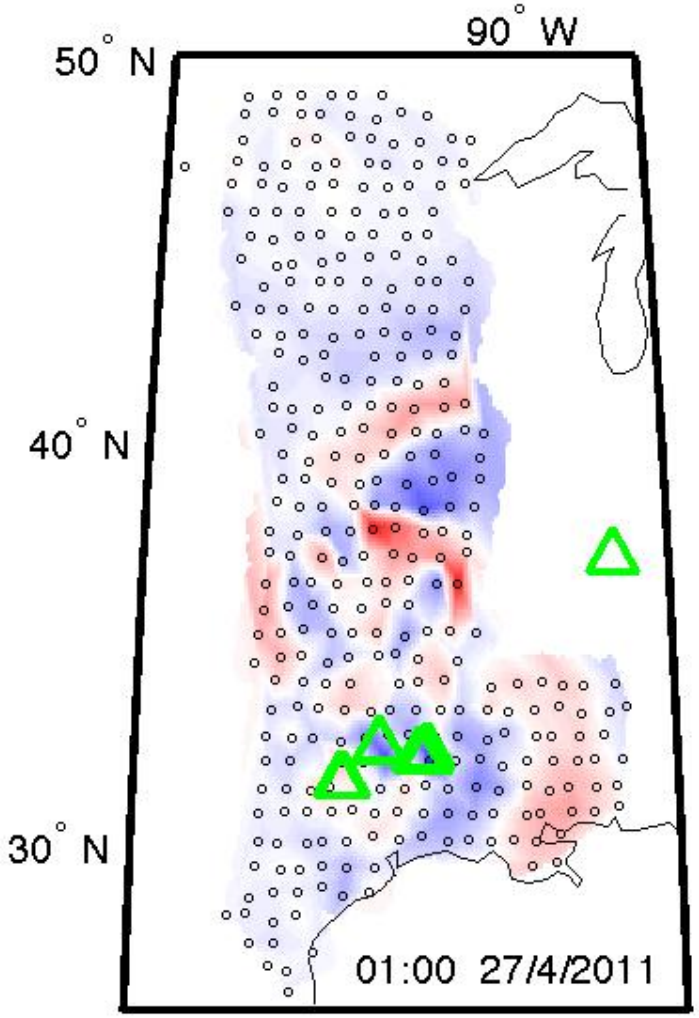

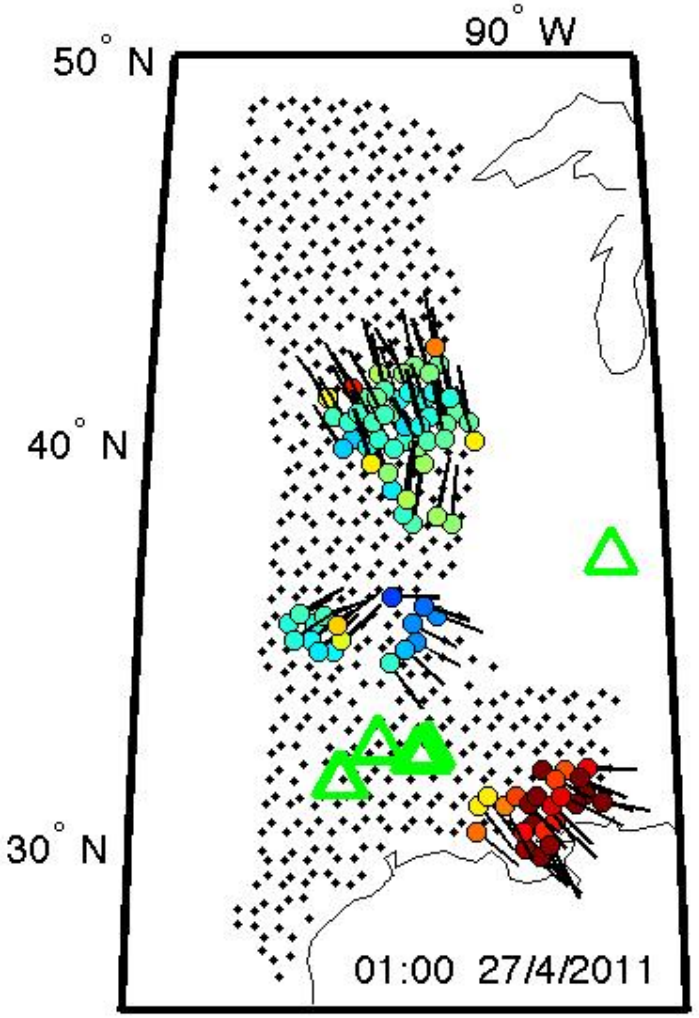

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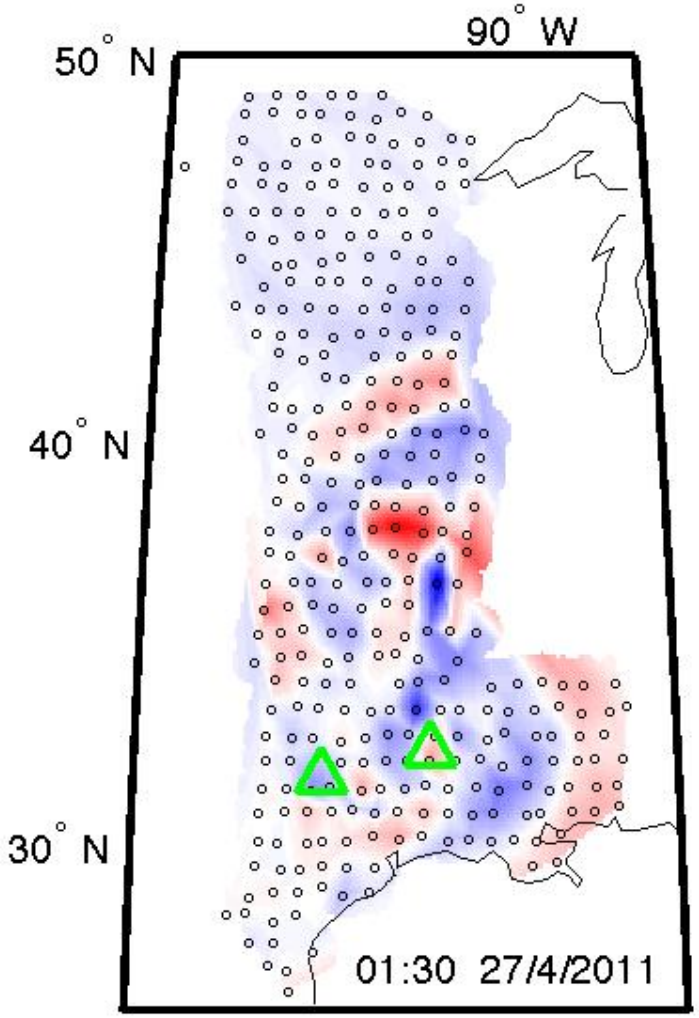

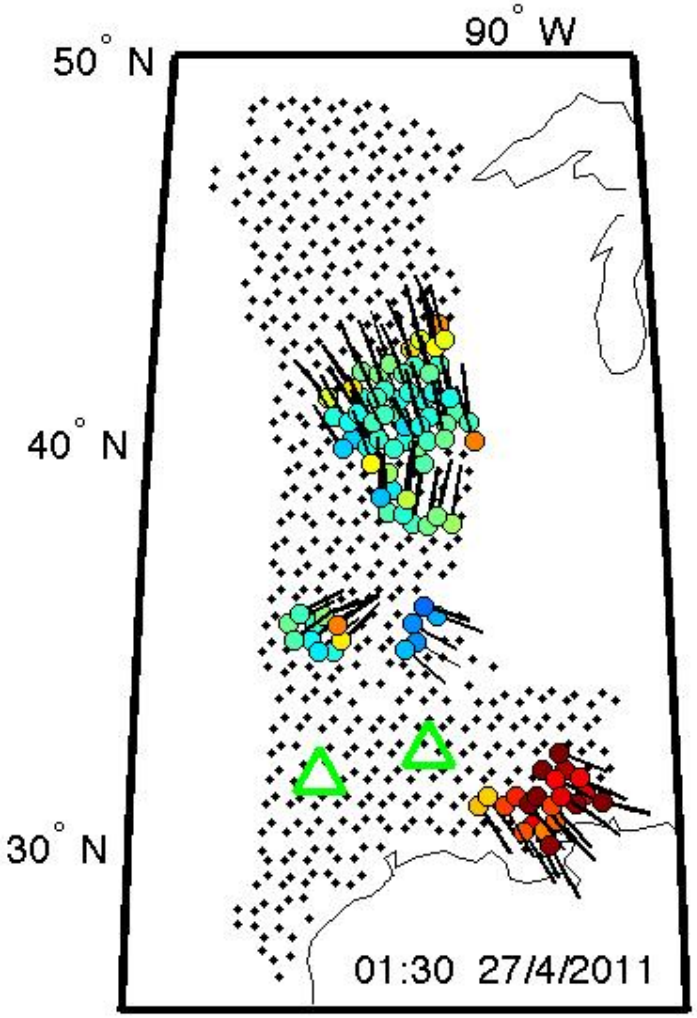

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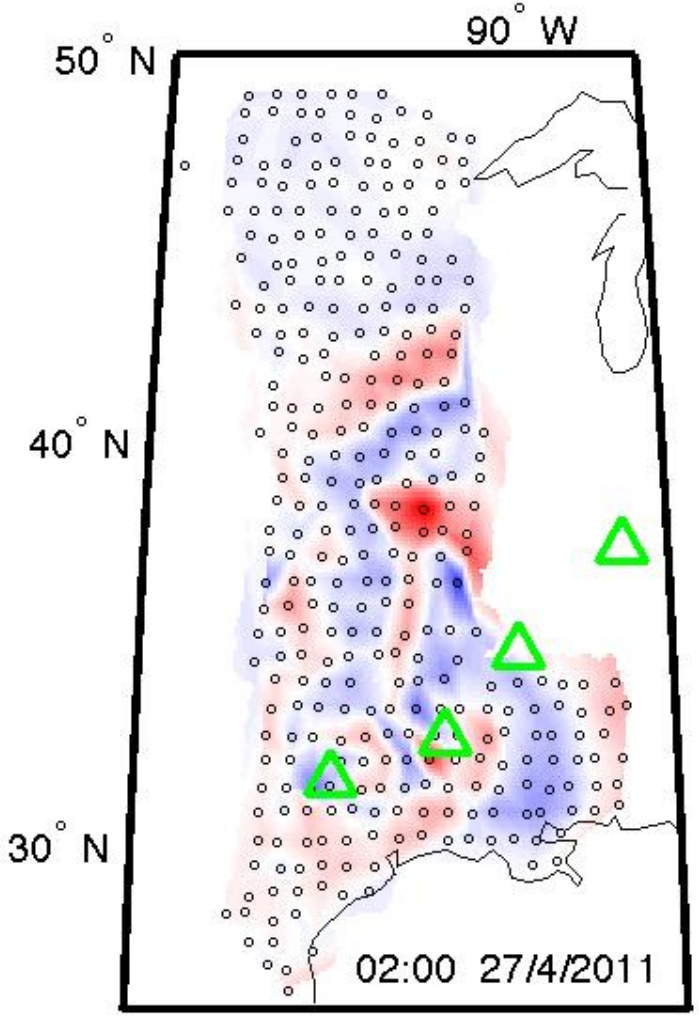

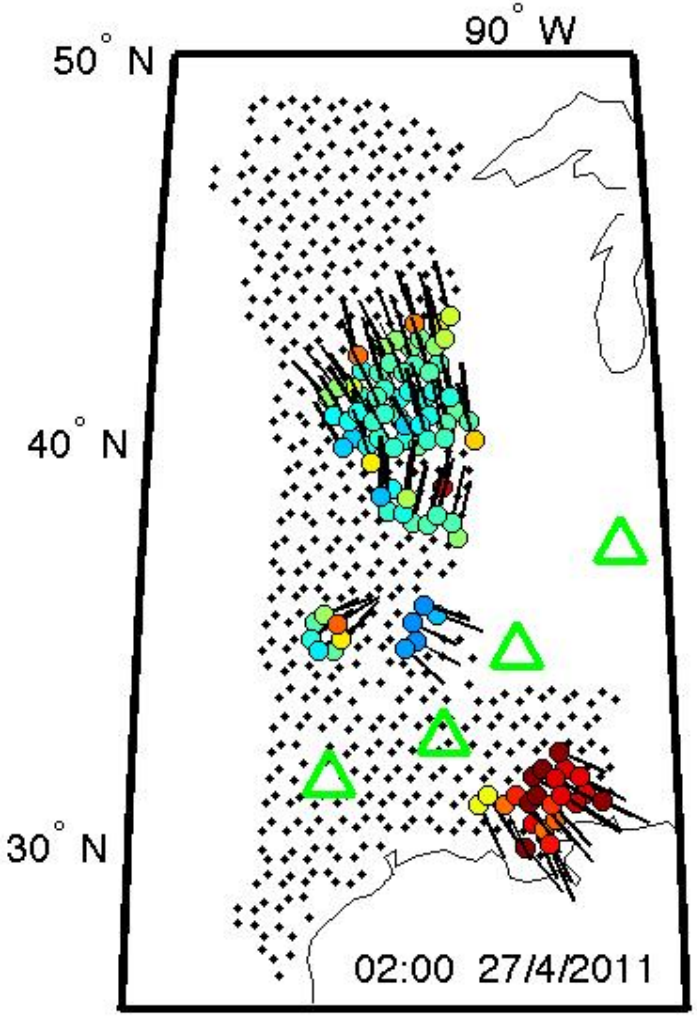

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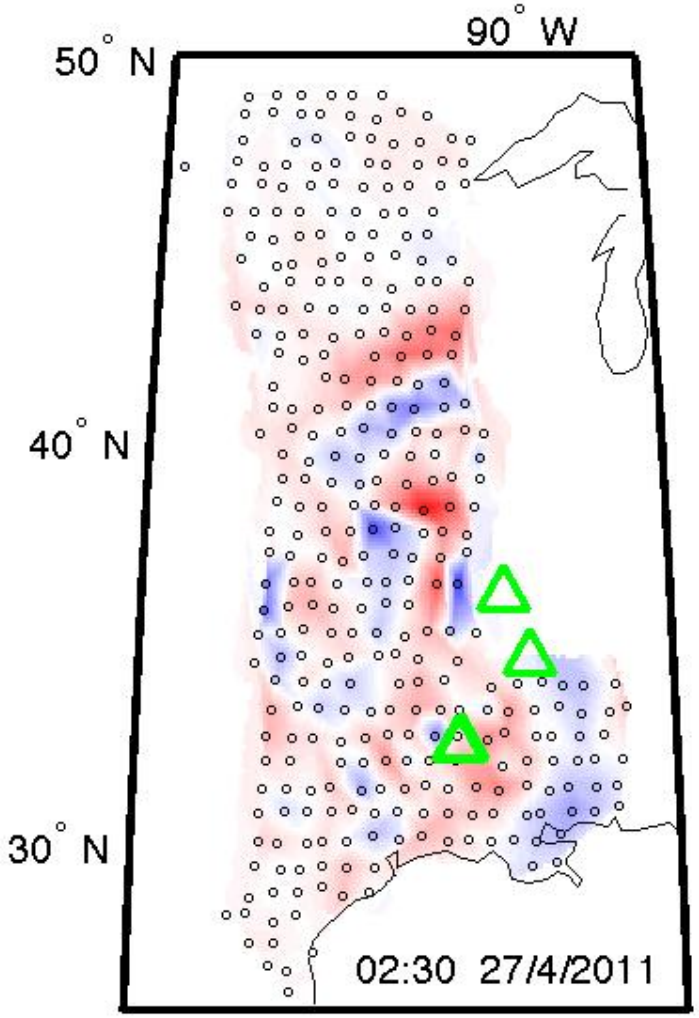

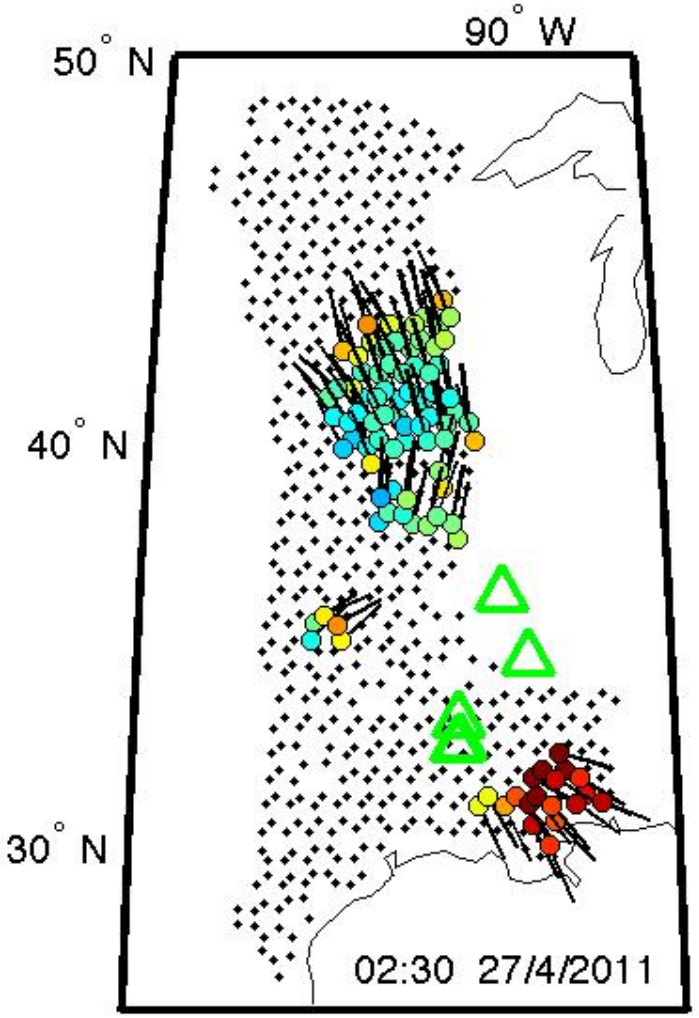

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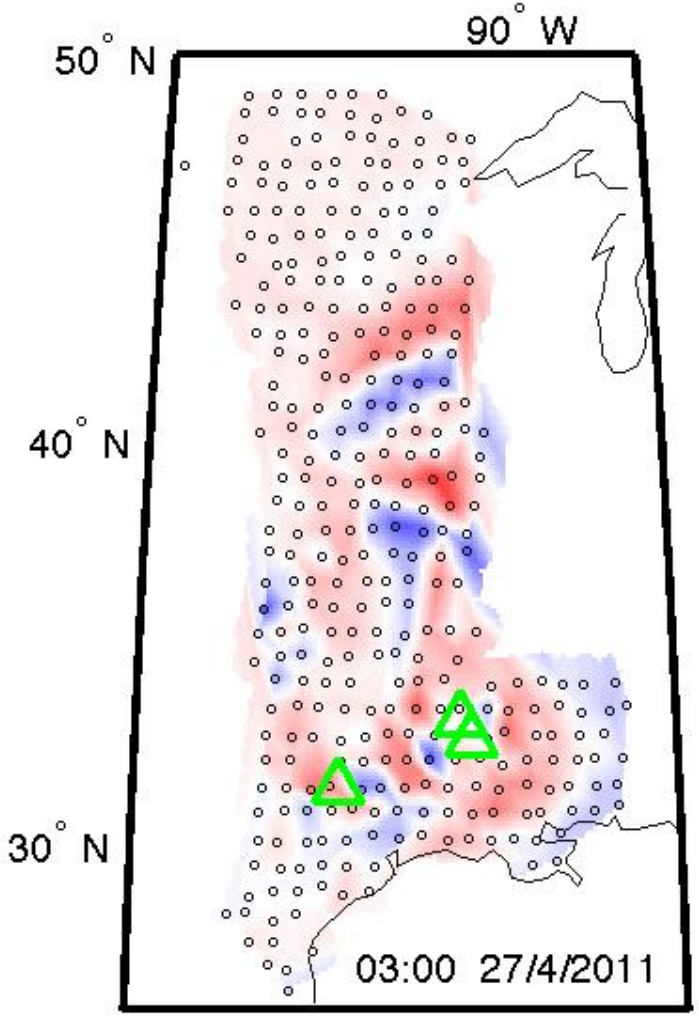

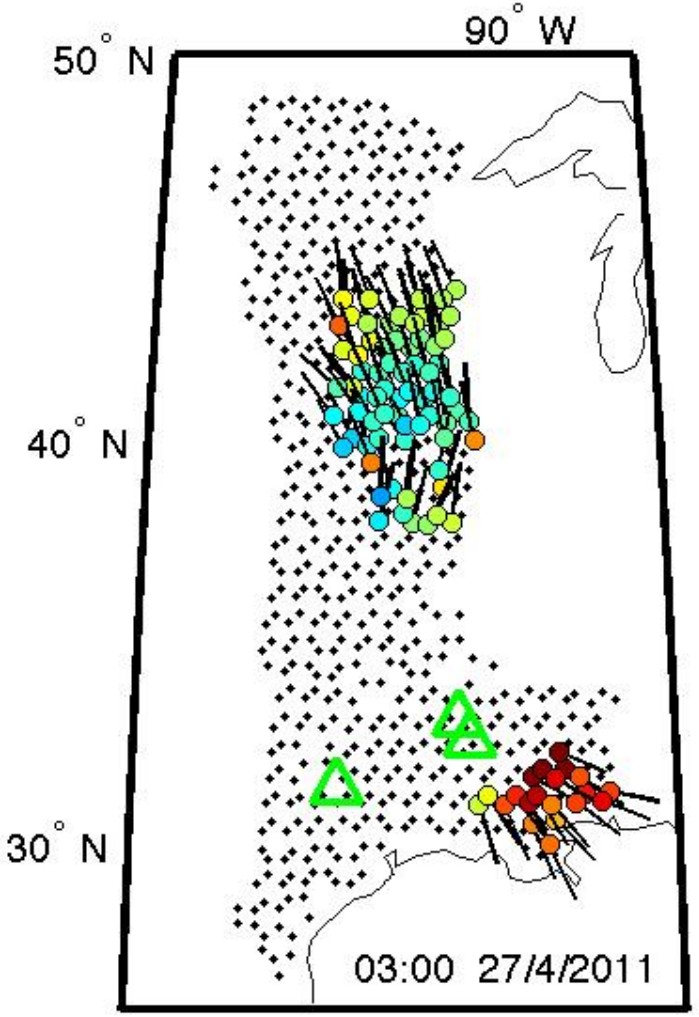

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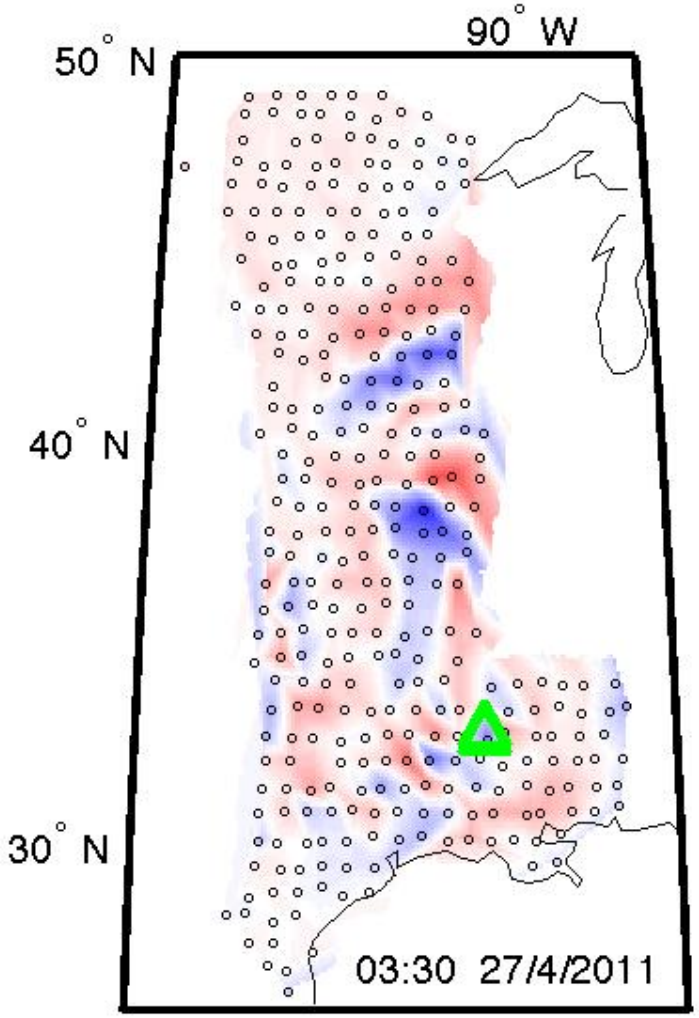

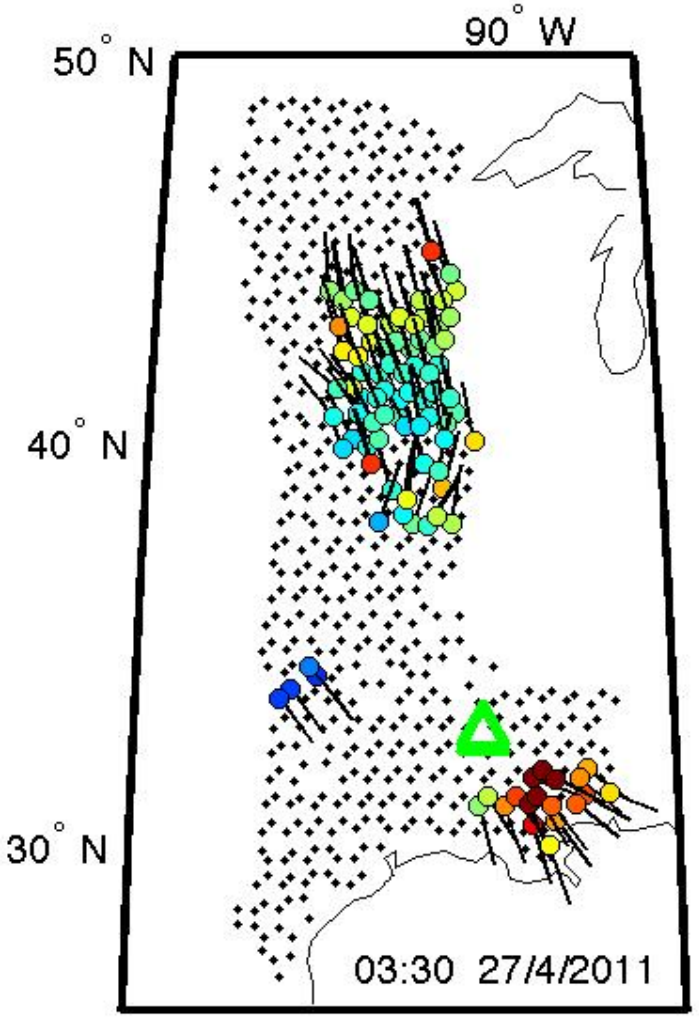

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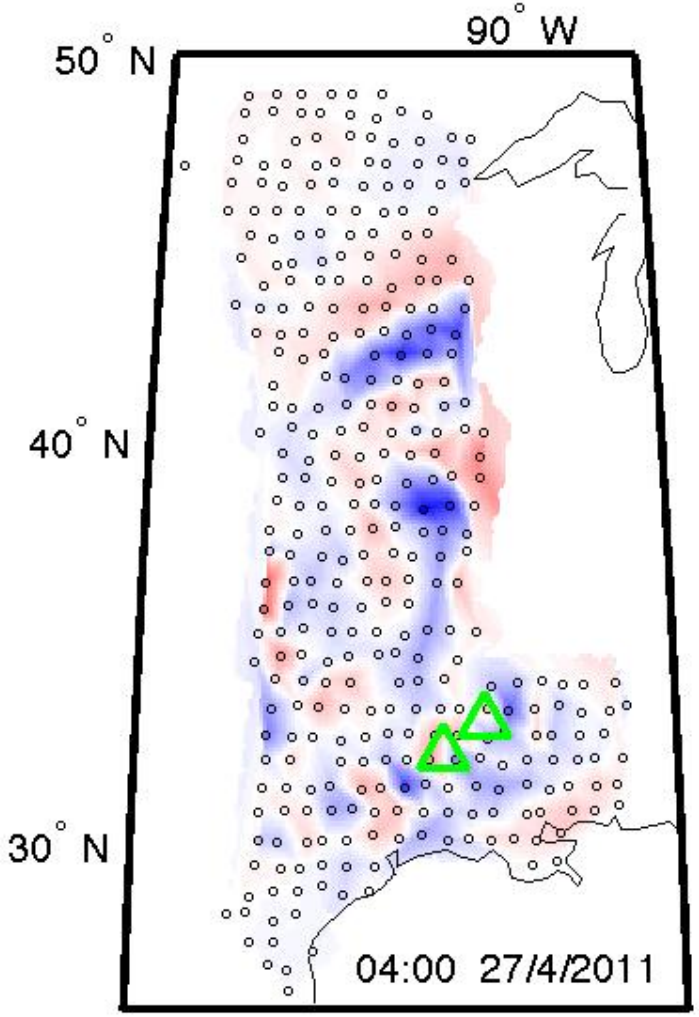

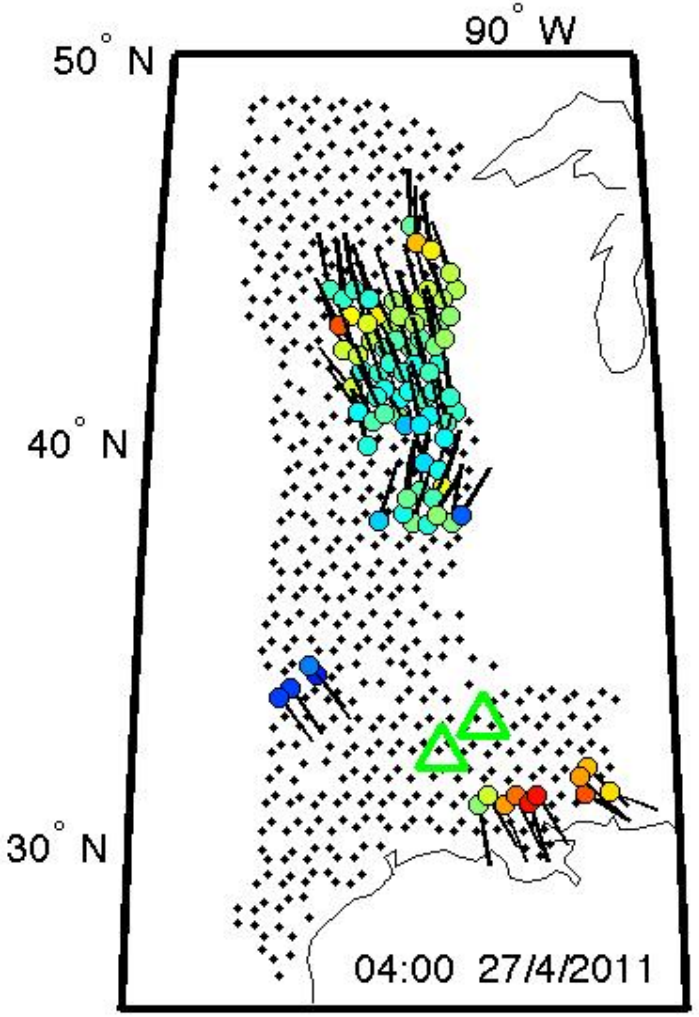

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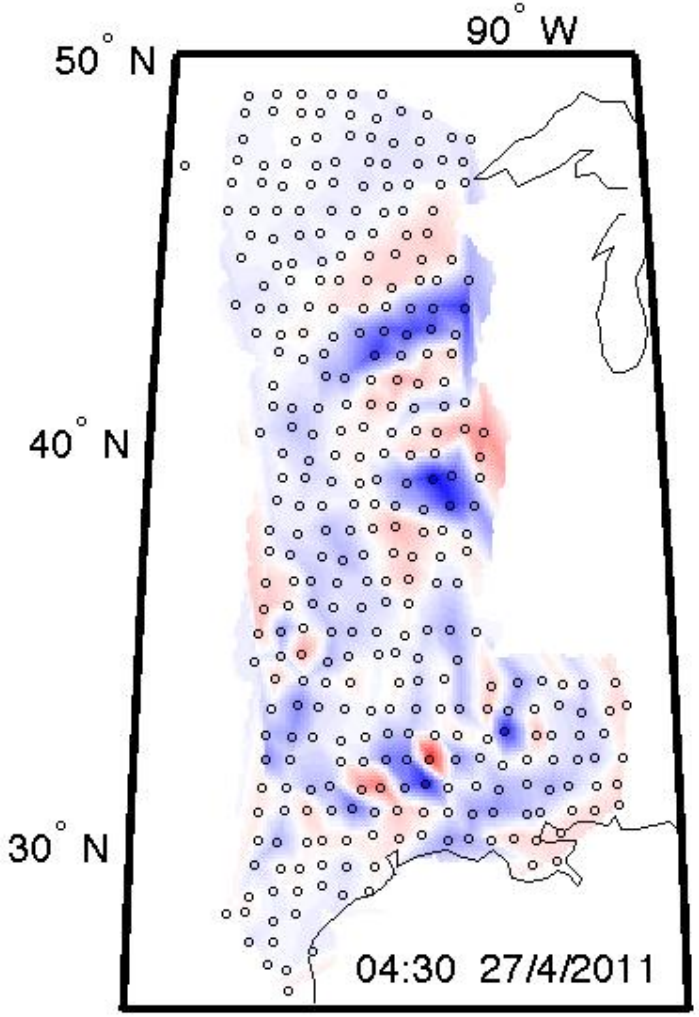

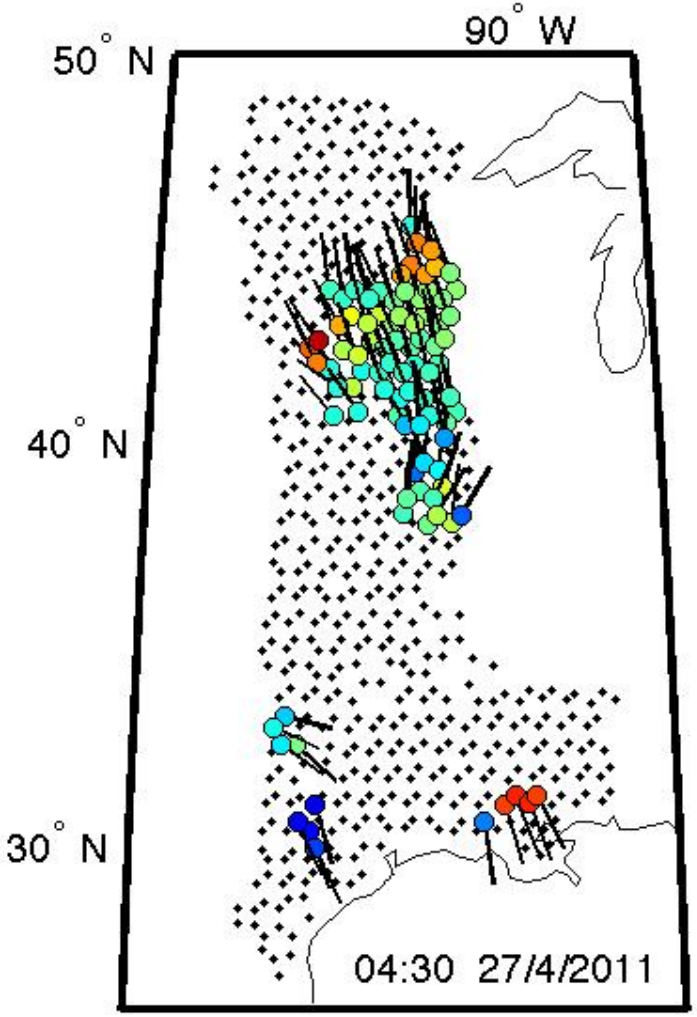

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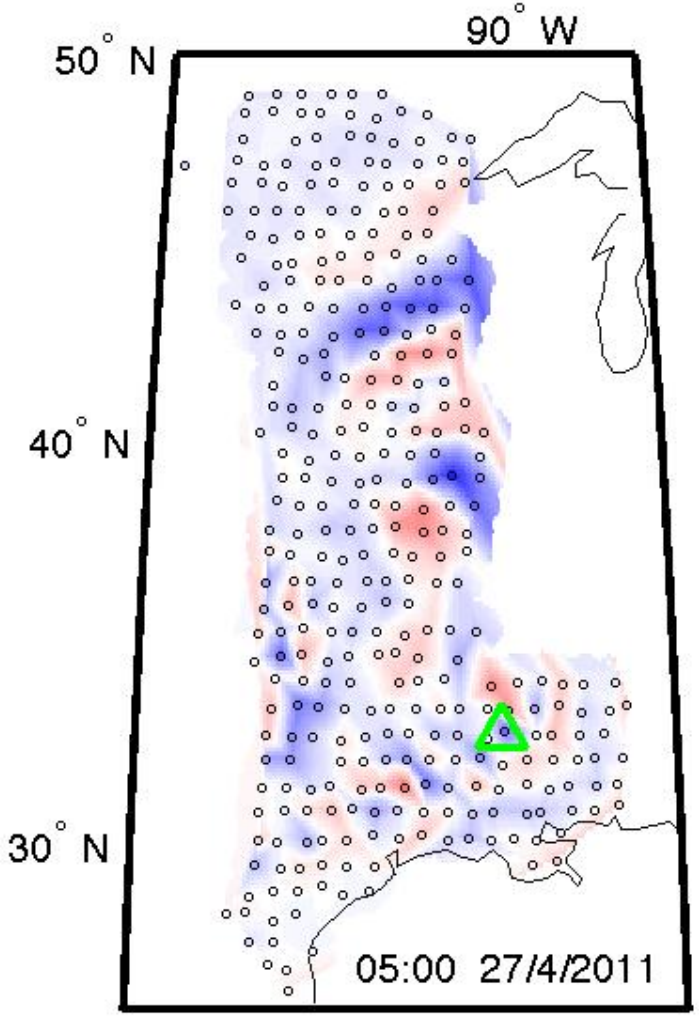

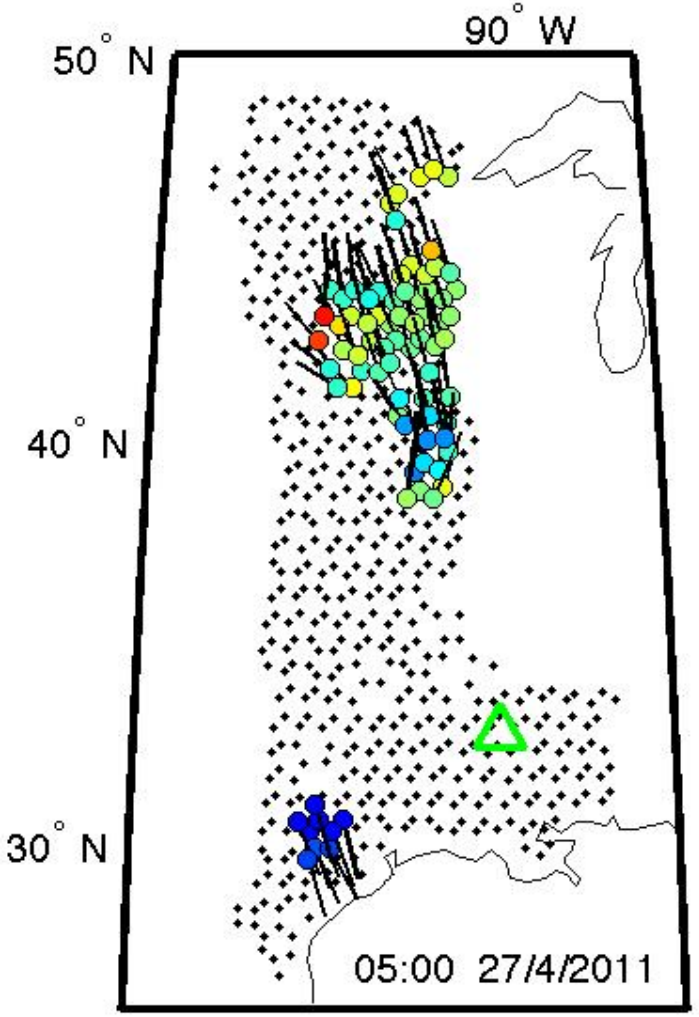

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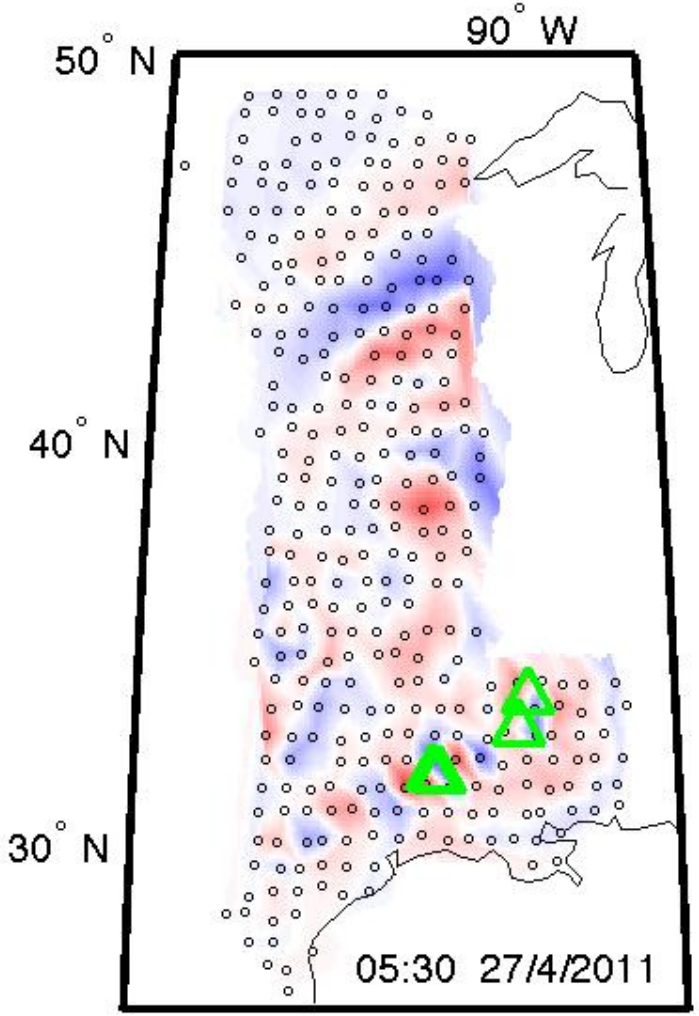

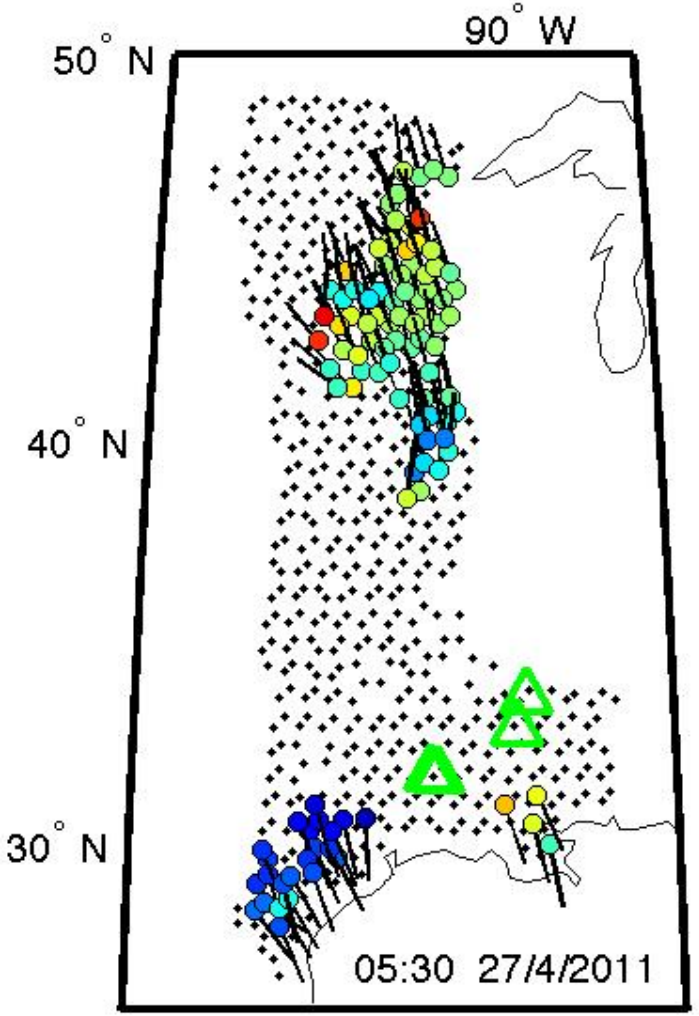

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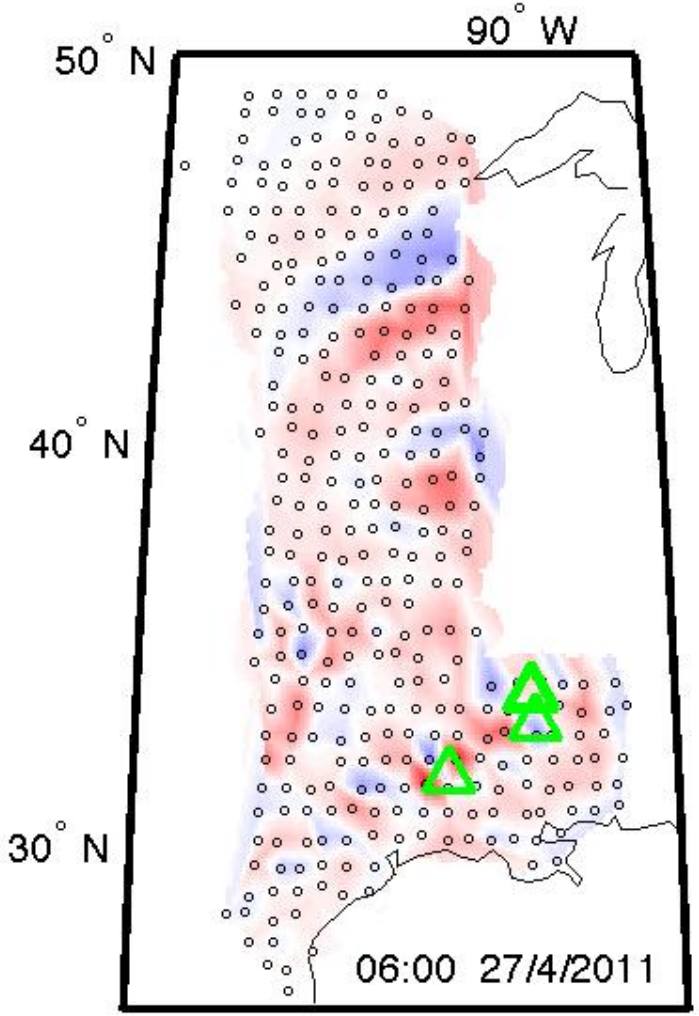

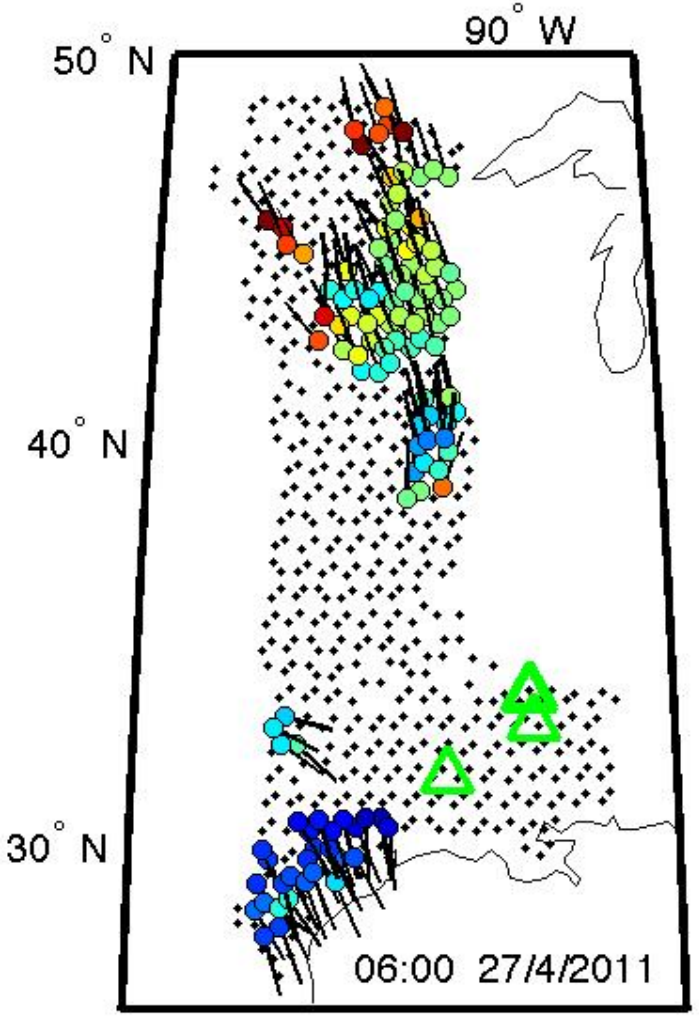

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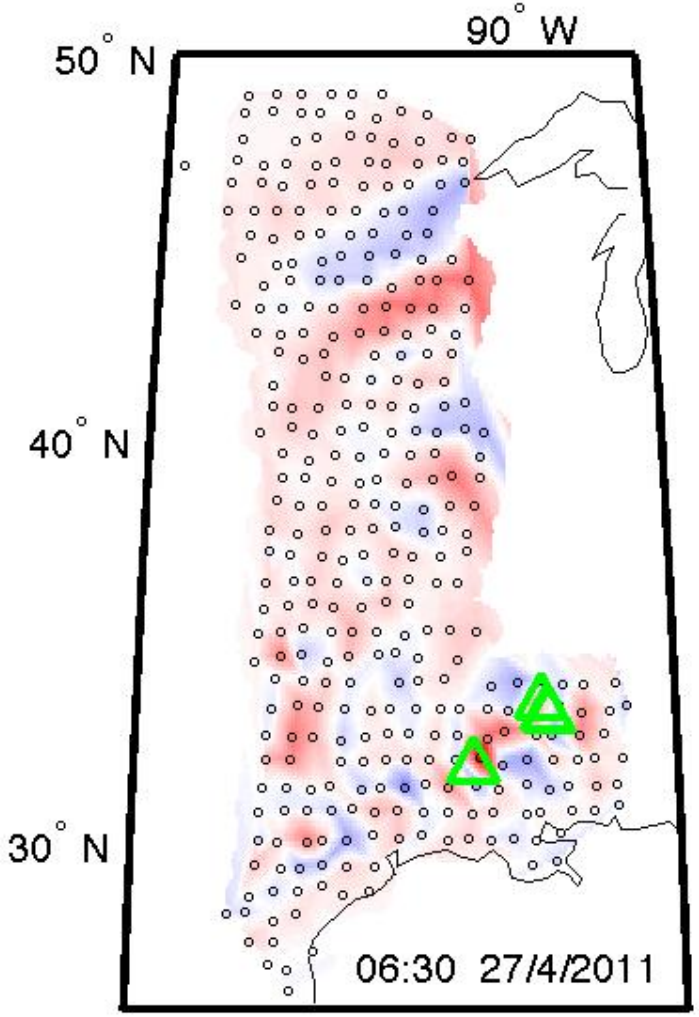

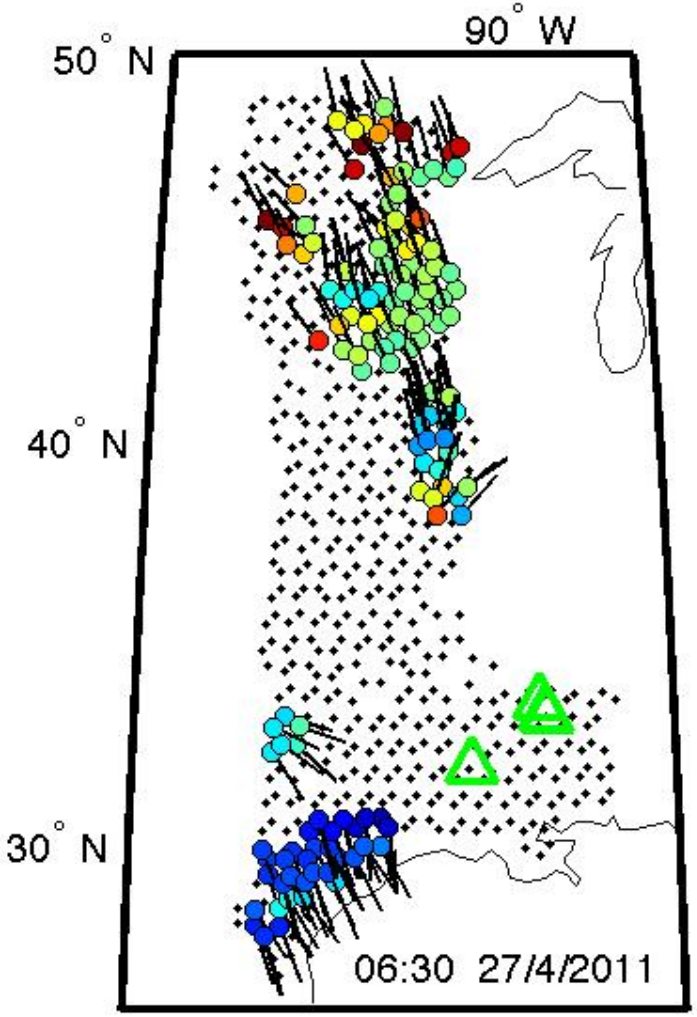

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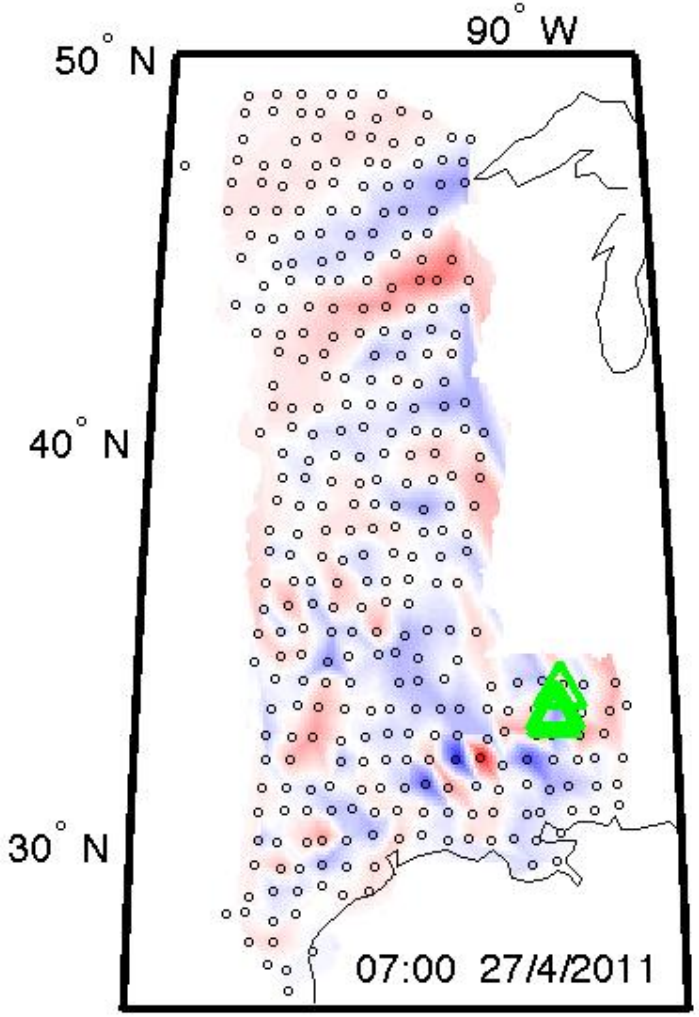

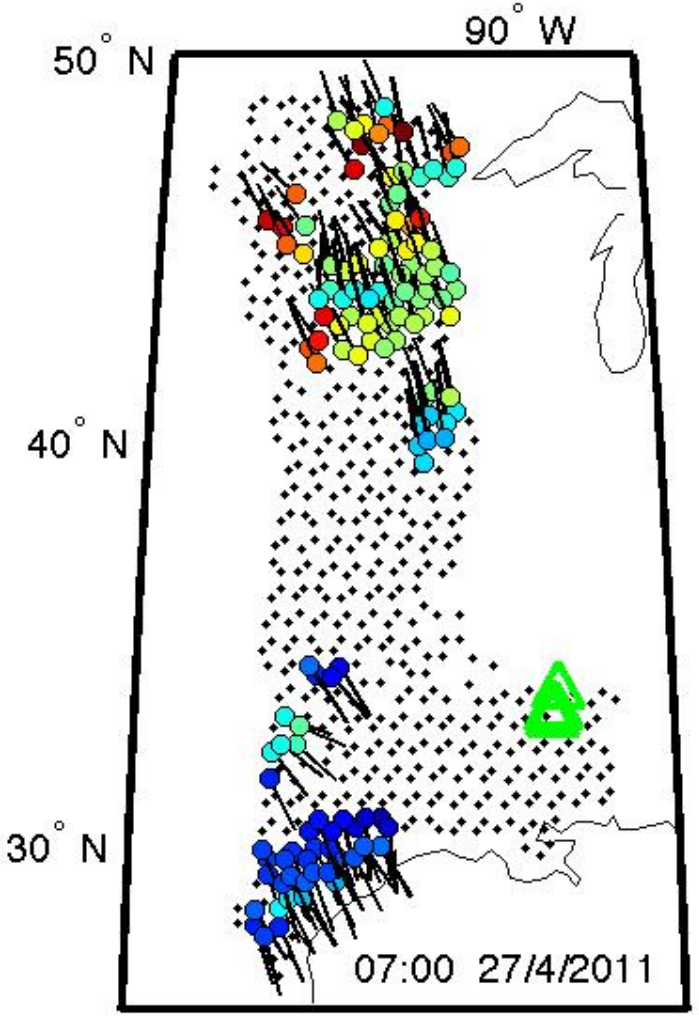

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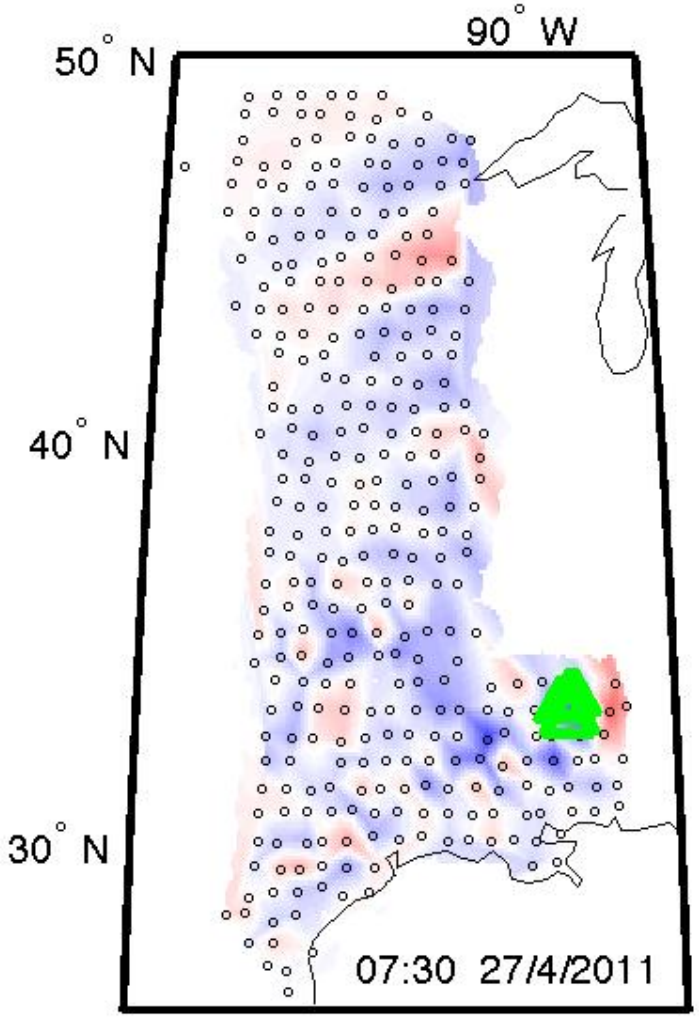

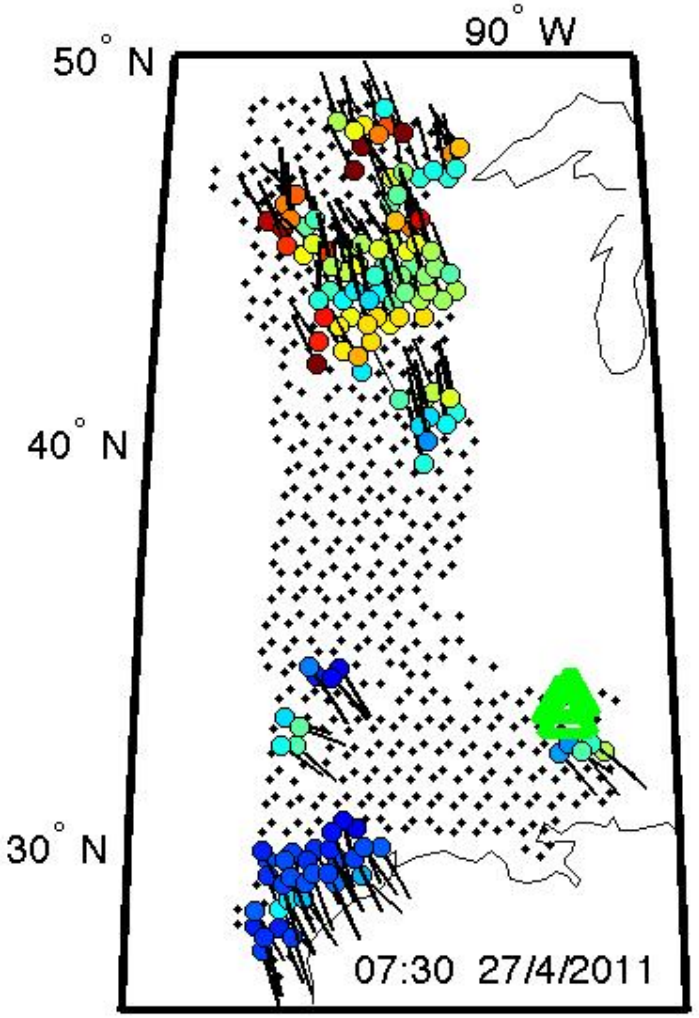

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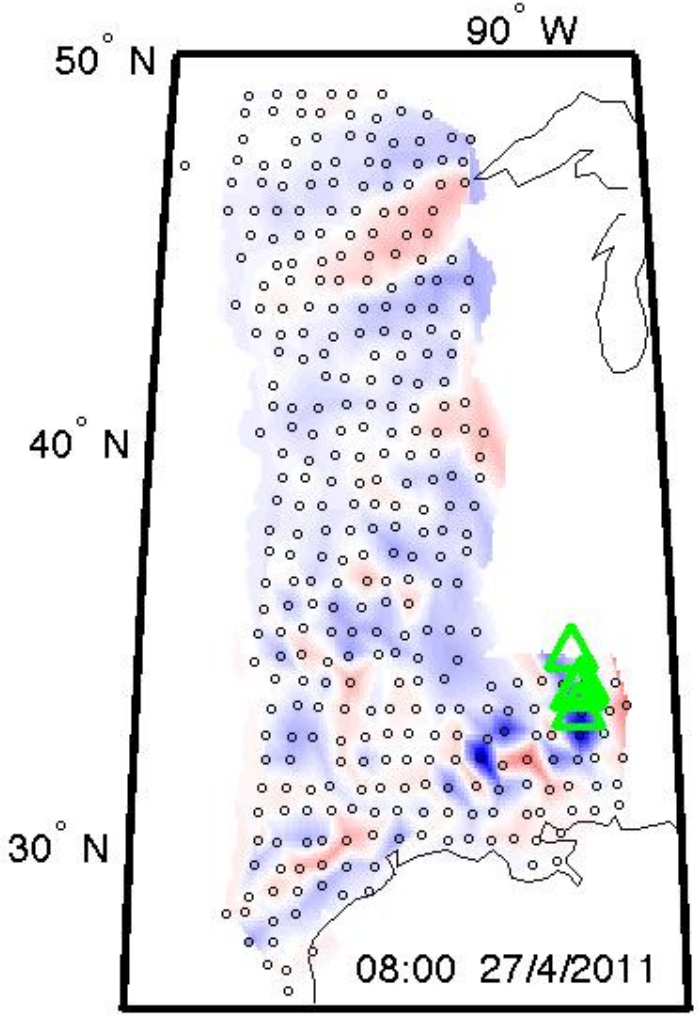

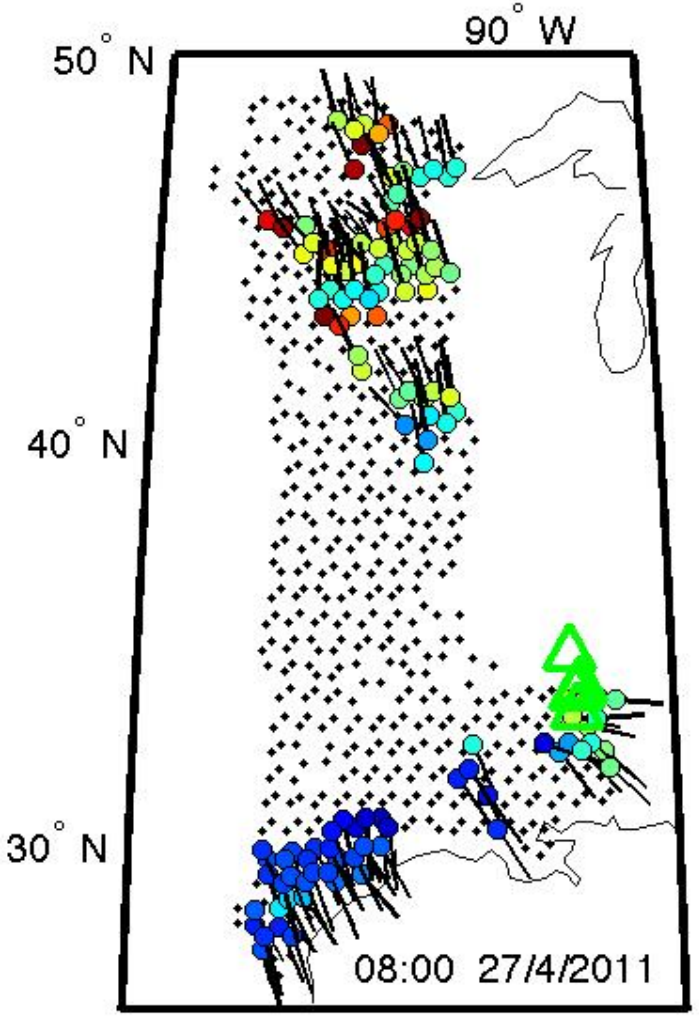

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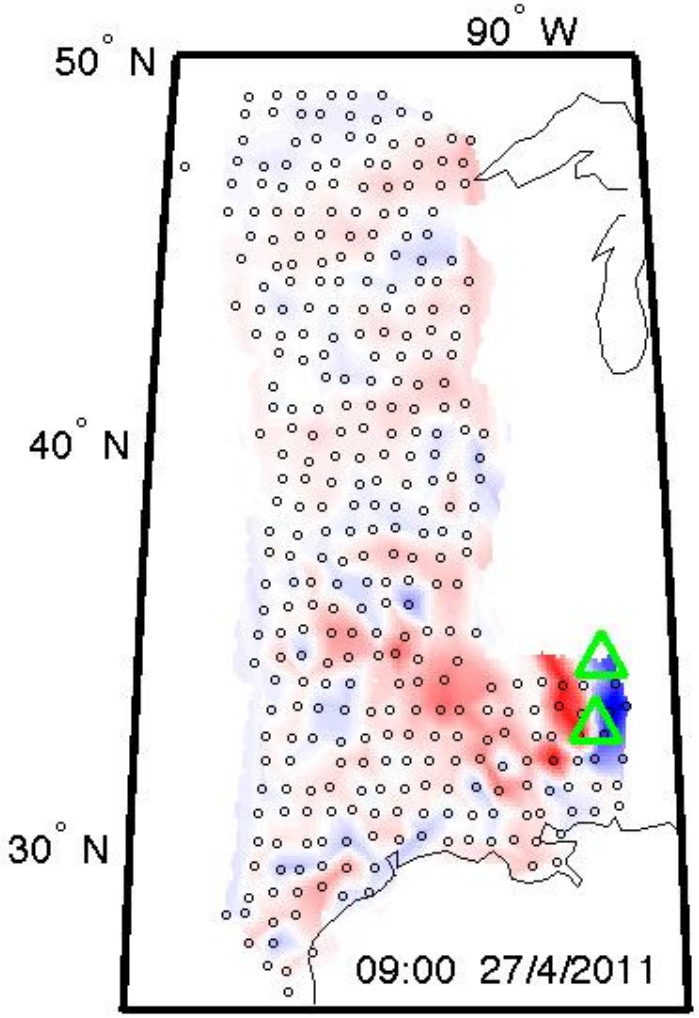

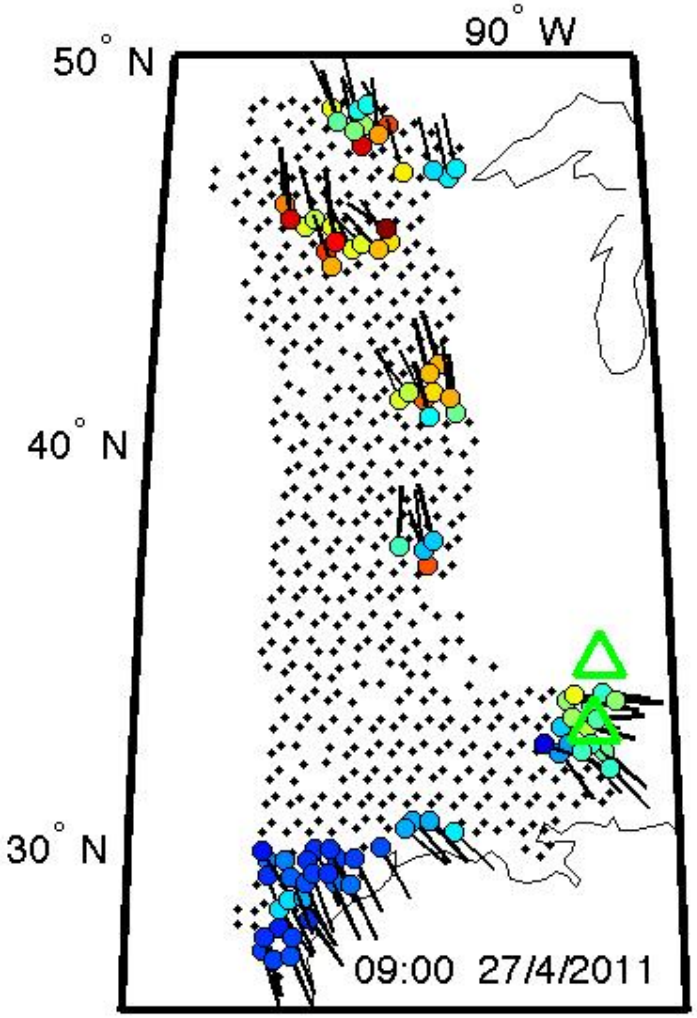

We examine the ensemble of triads to characterize gravity wave dynamics

→ Compute the area of each Gravity Wave to define a detection function

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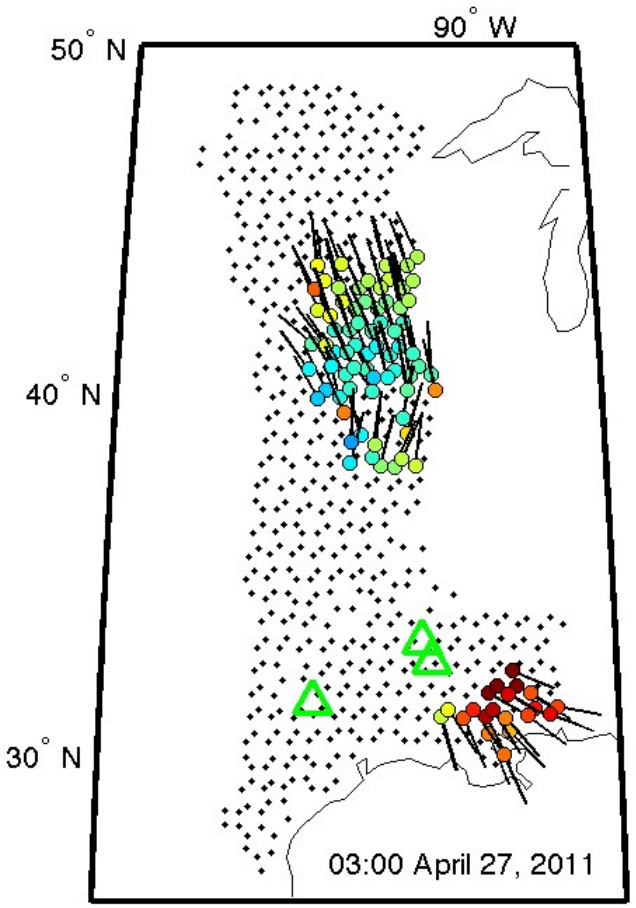

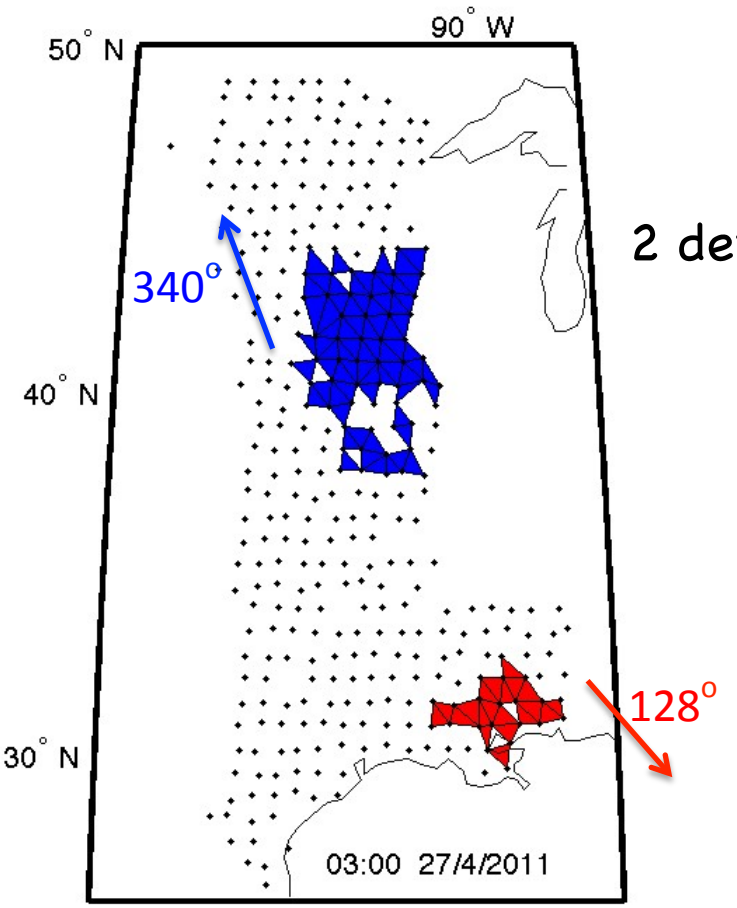

2 detections at this time

If a detection is registered at a triad, the gravity wave is considered to cover the entire area of the triangle

The area of each Gravity Wave = sum of areas of adjoining triad detections

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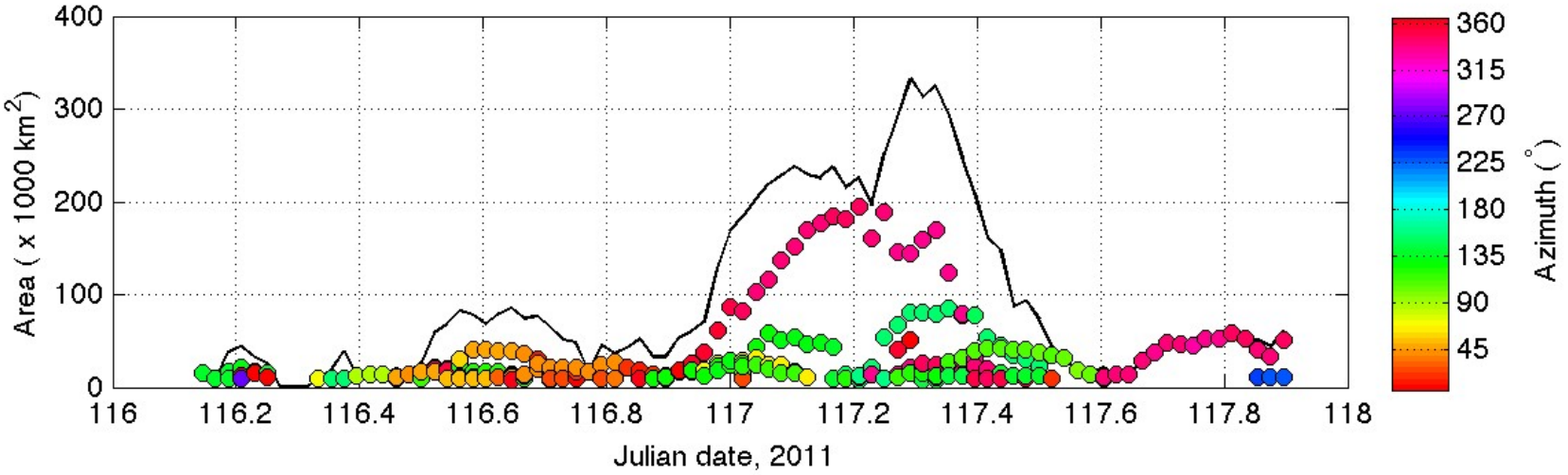
Gravity wave detector for 2 day period April 26 & 27, 2011



Circles are color-coded to show the azimuth of each gravity wave area

The solid line gives the total area of all detections

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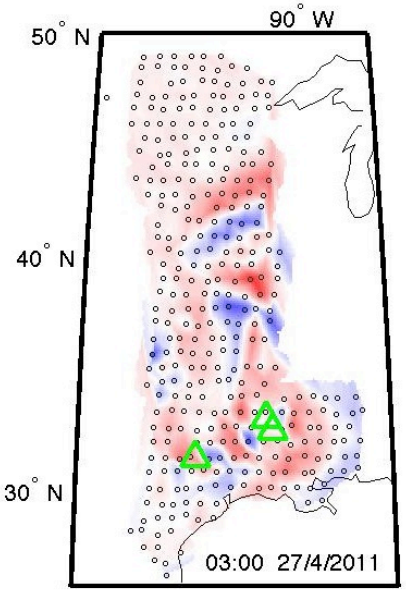
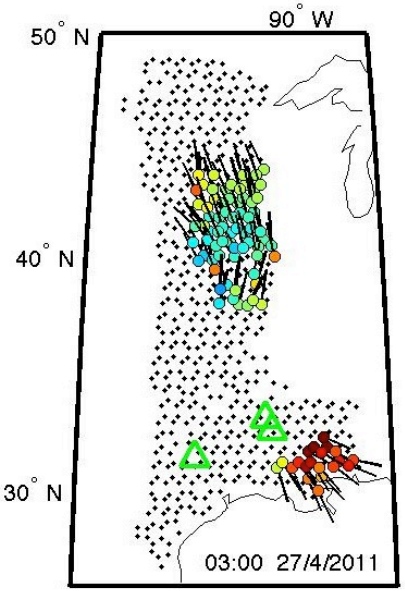
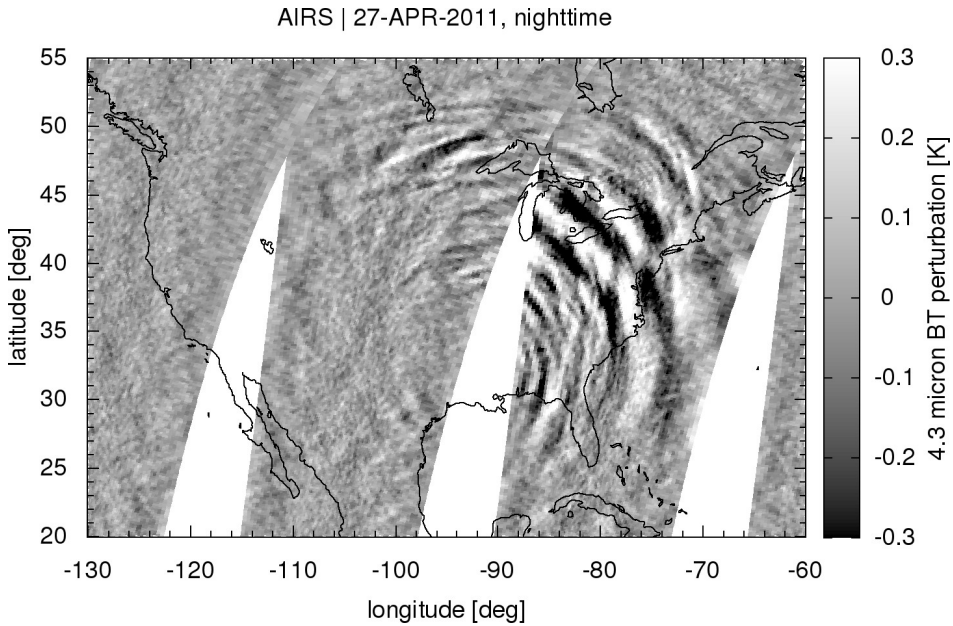
Comparison with satellite observations

Gravity waves detected at Earth's surface on MEMS sensor data

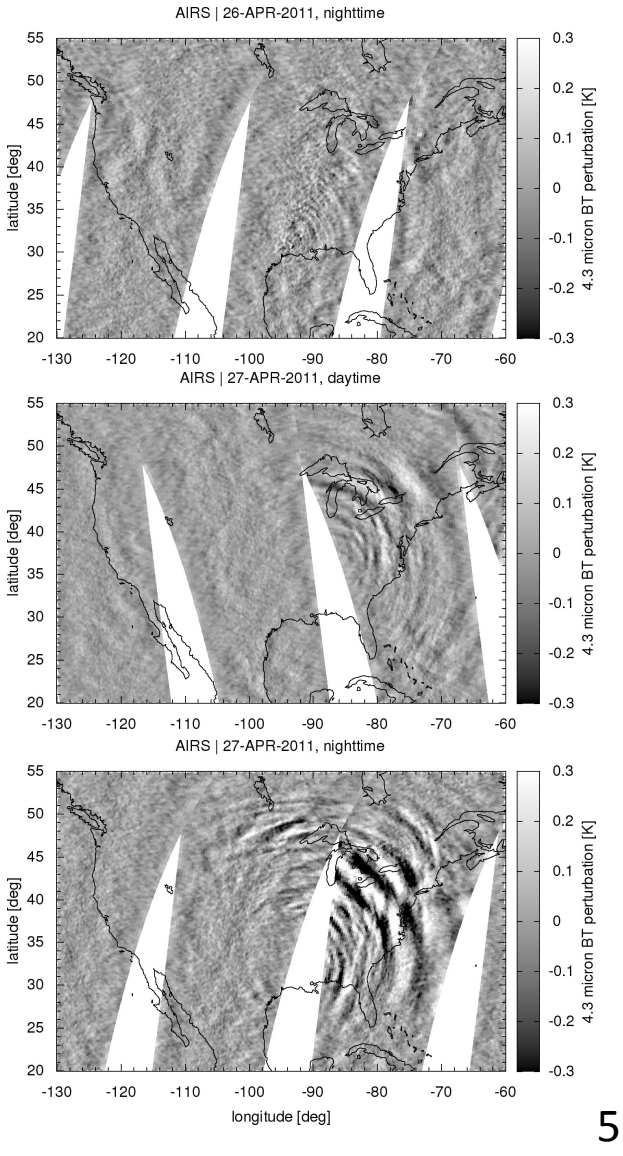




Stratospheric Gravity waves detected by the Atmospheric Infrared Sounder (AIRS) satellite



USArray data vs. satellite data

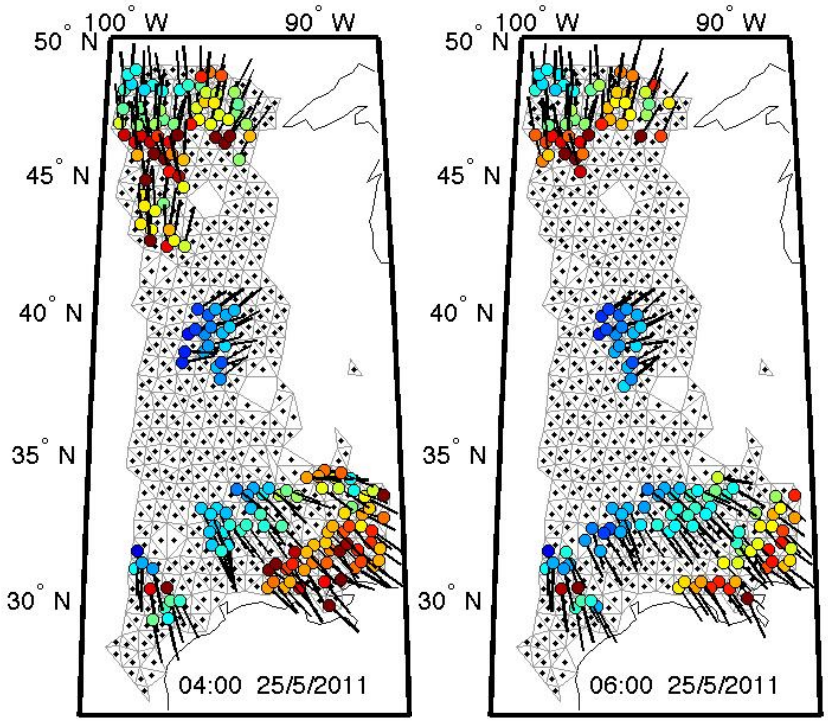


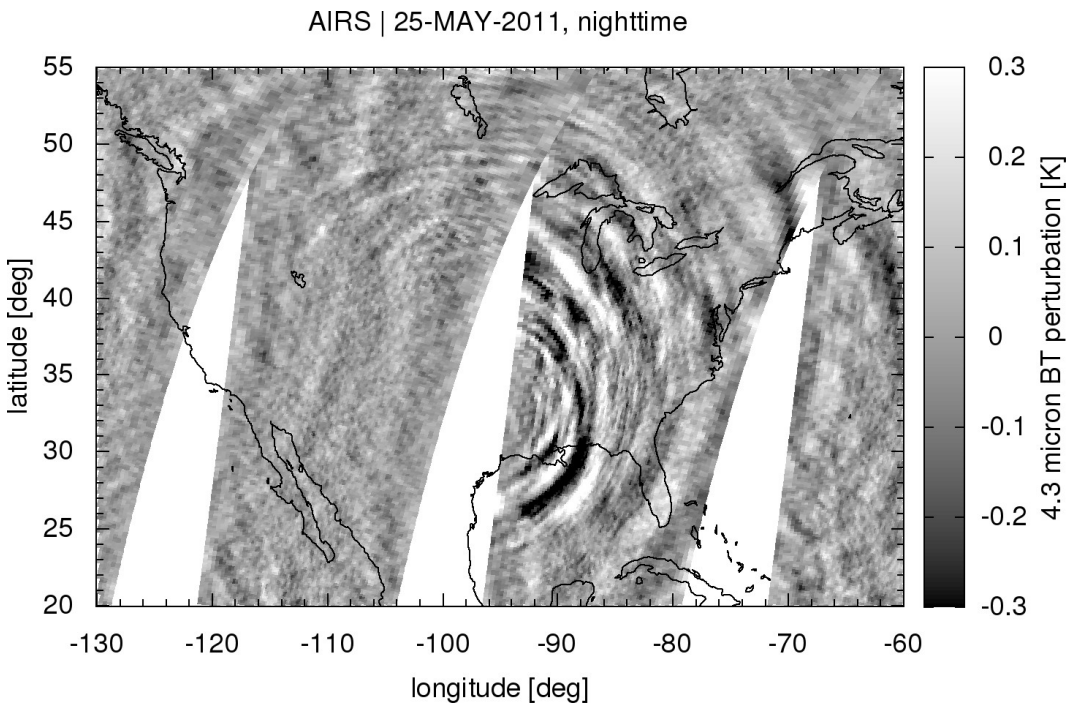
- **Time sampling rate:** The MEMS data are sampled at 1 sample per second vs. 2 snapshots per day for the AIRS satellite.
- **Spatial coverage:** The USArray covers a more limited spatial region than the satellite data.

2nd comparison with satellite – May 25, 2011

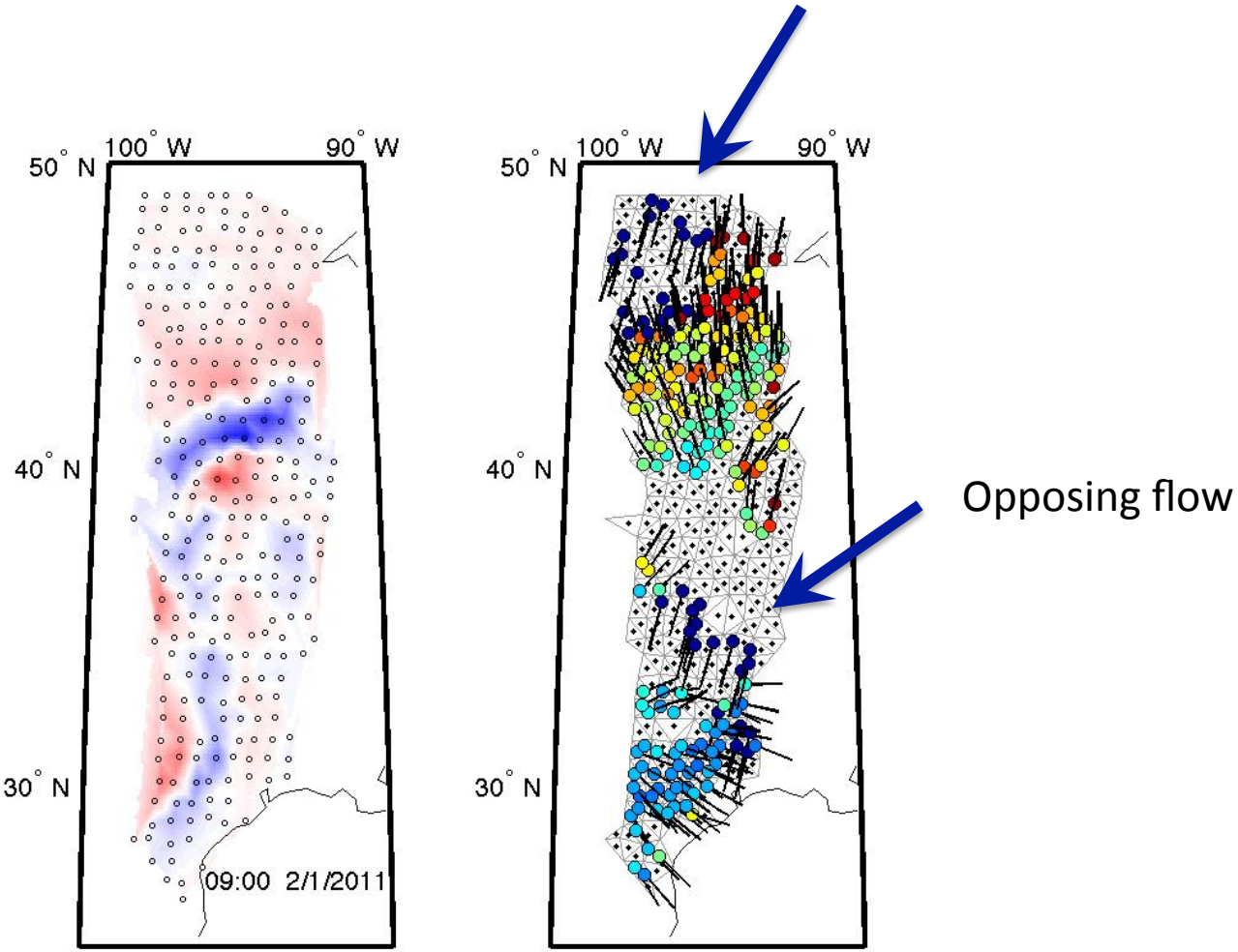
Separate gravity wave areas may in fact be connected

(Blue: slower, red: faster)

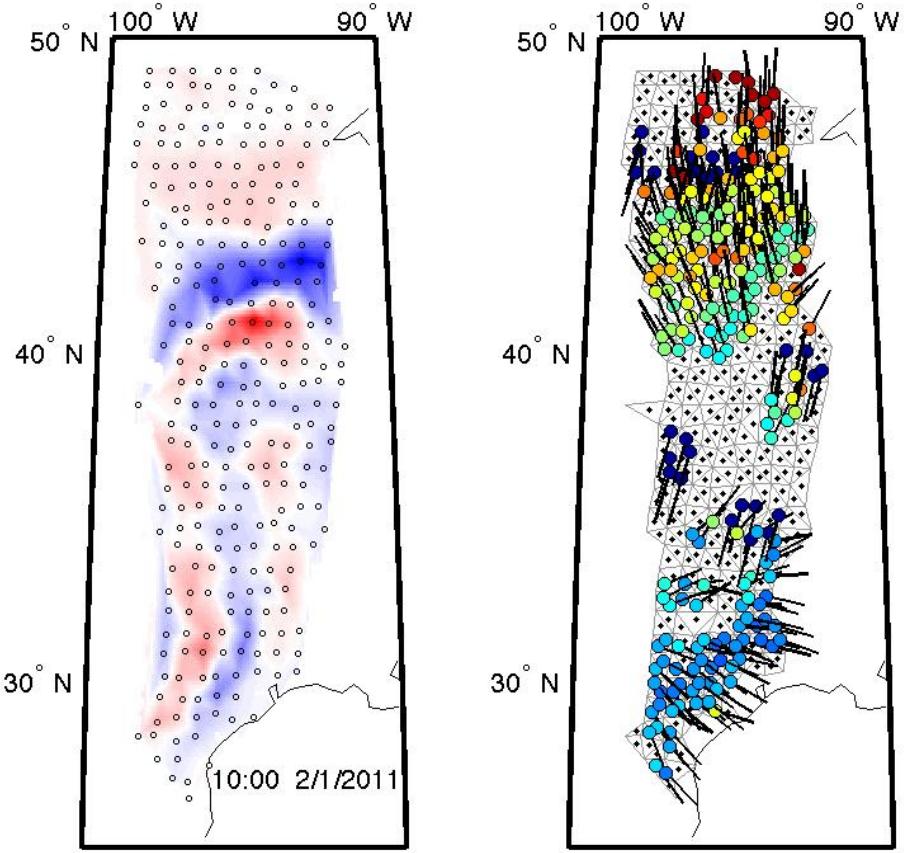


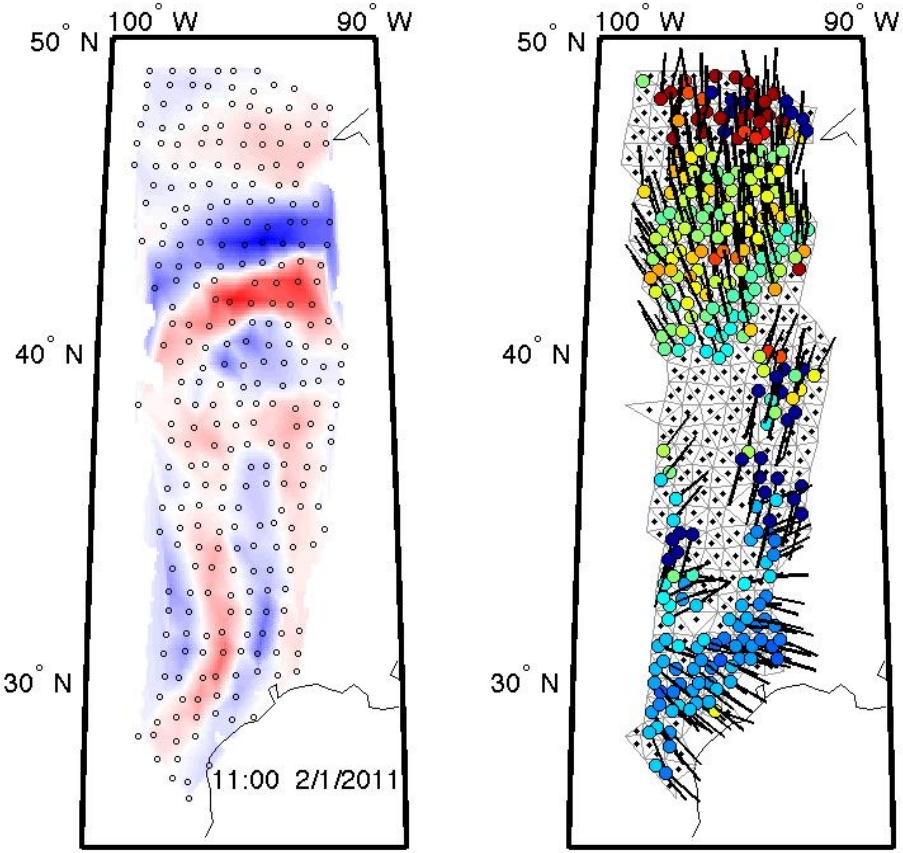


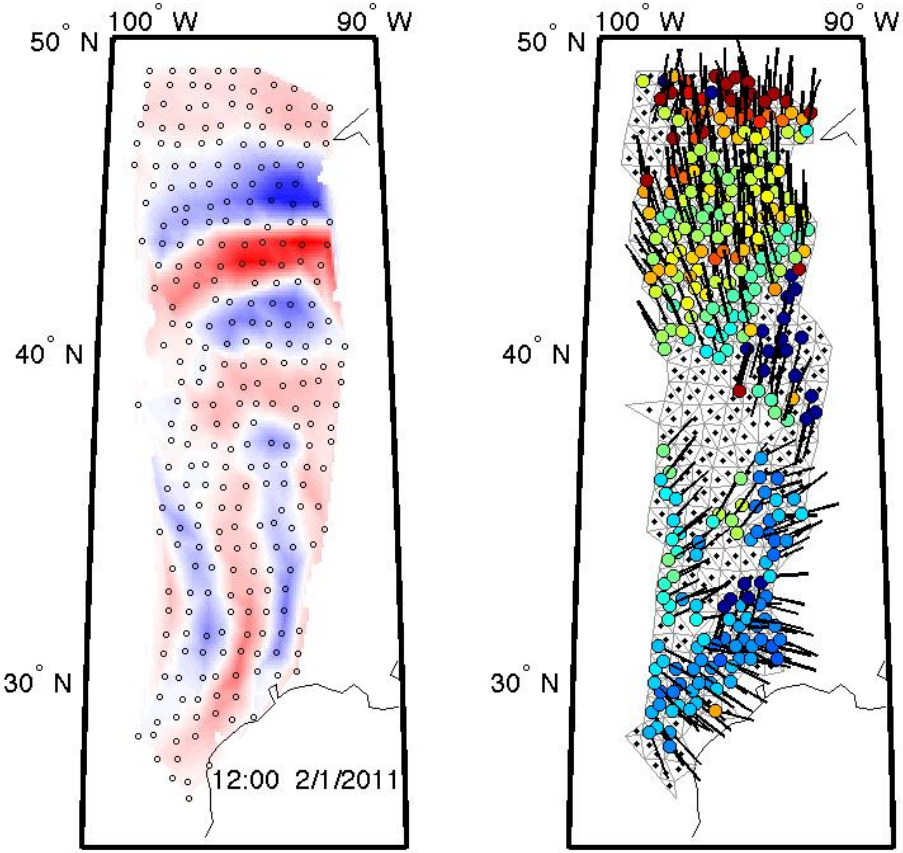
February 1, 2011 : Largest Event of 2011

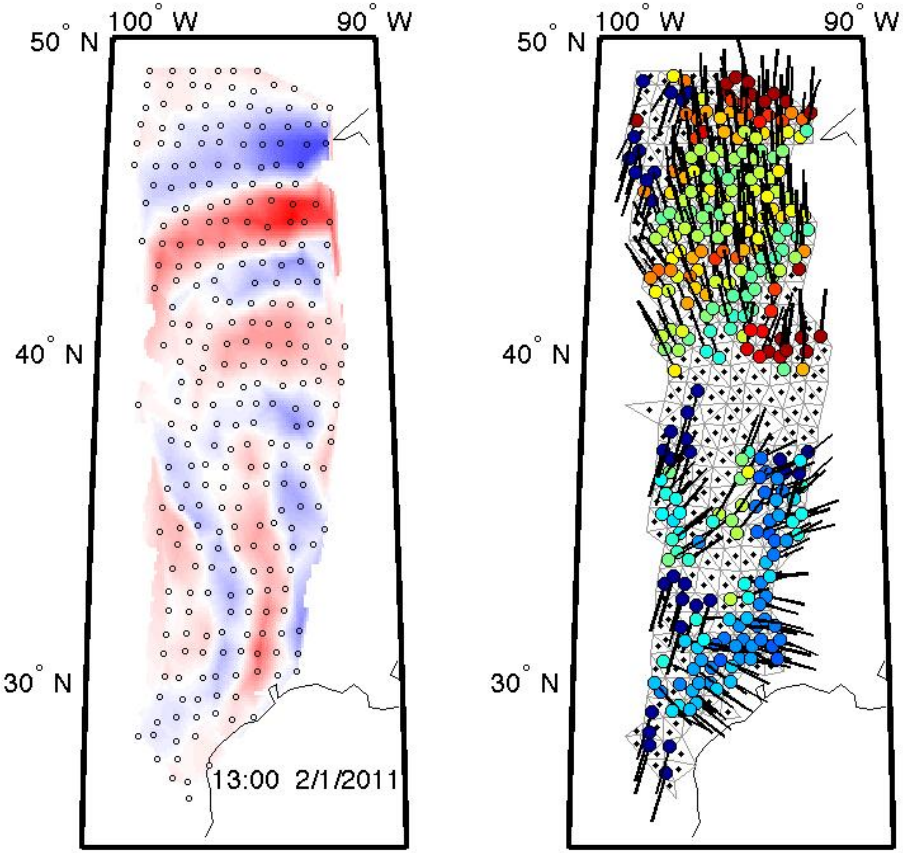


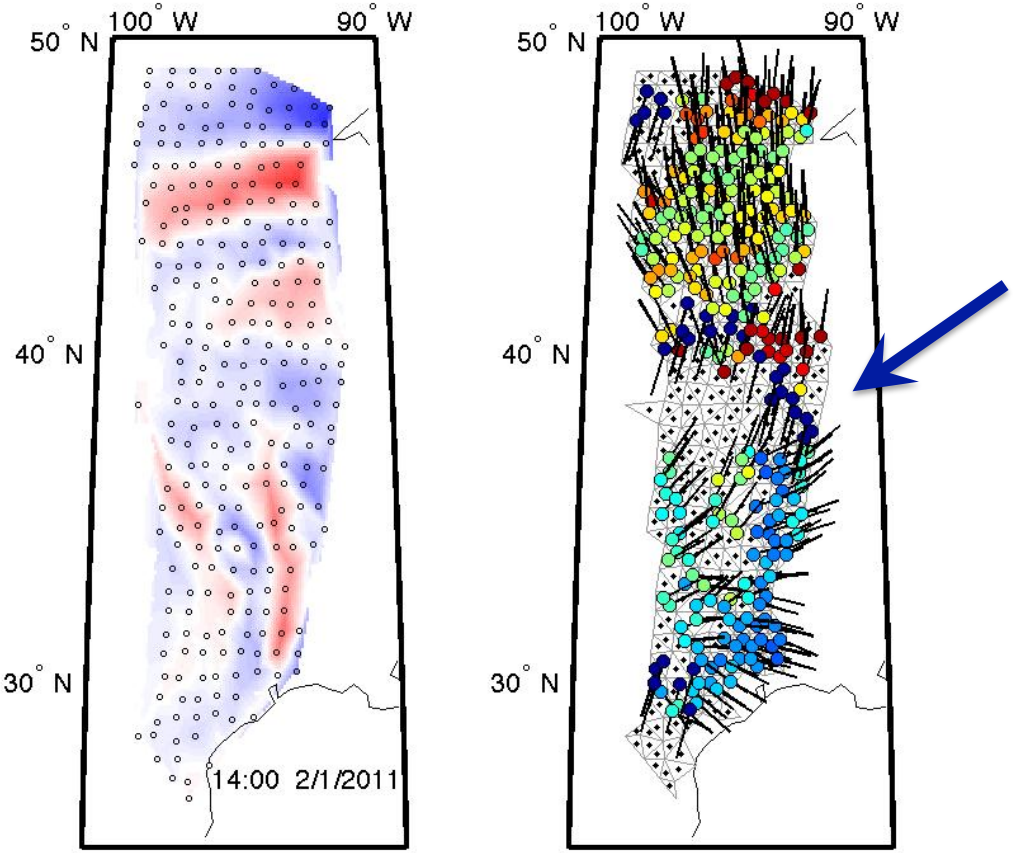
February 1, 2011 : Largest Event of 2011

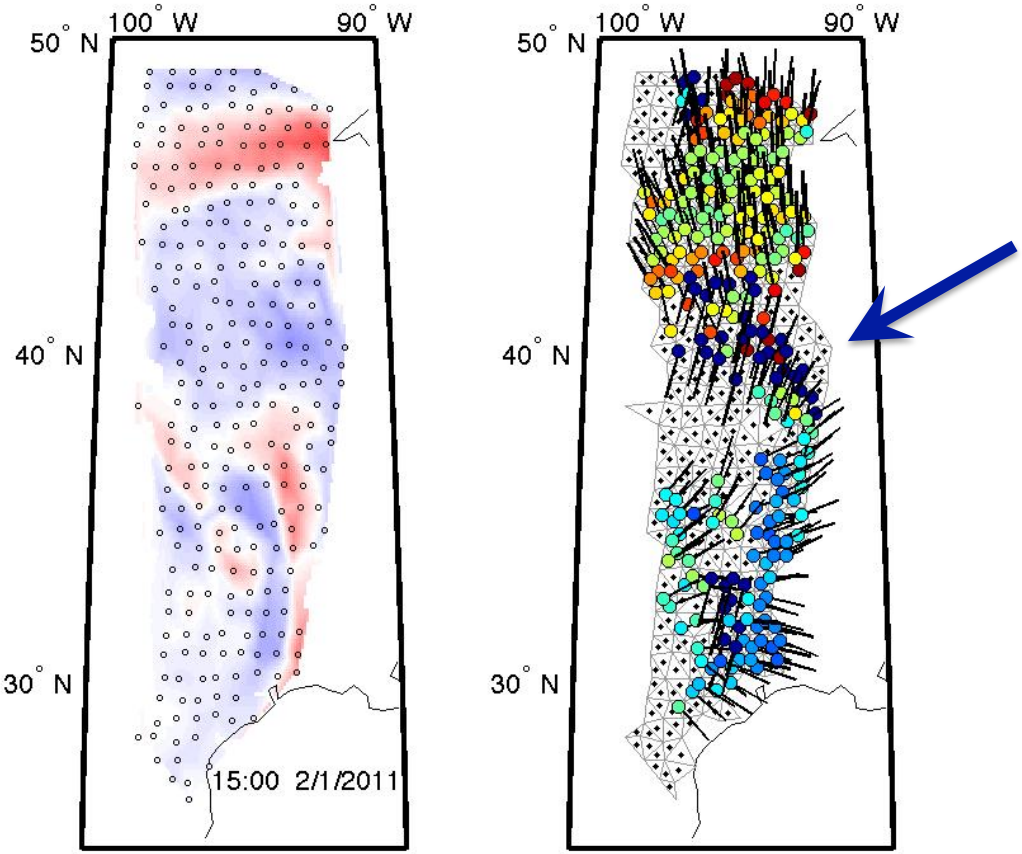


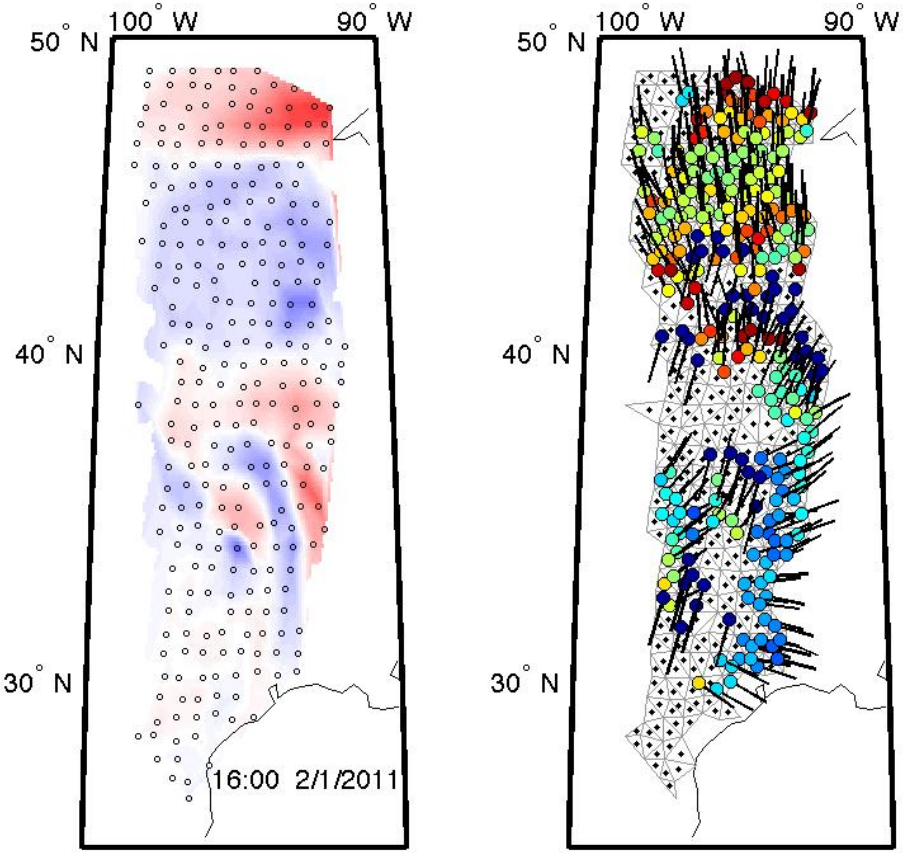


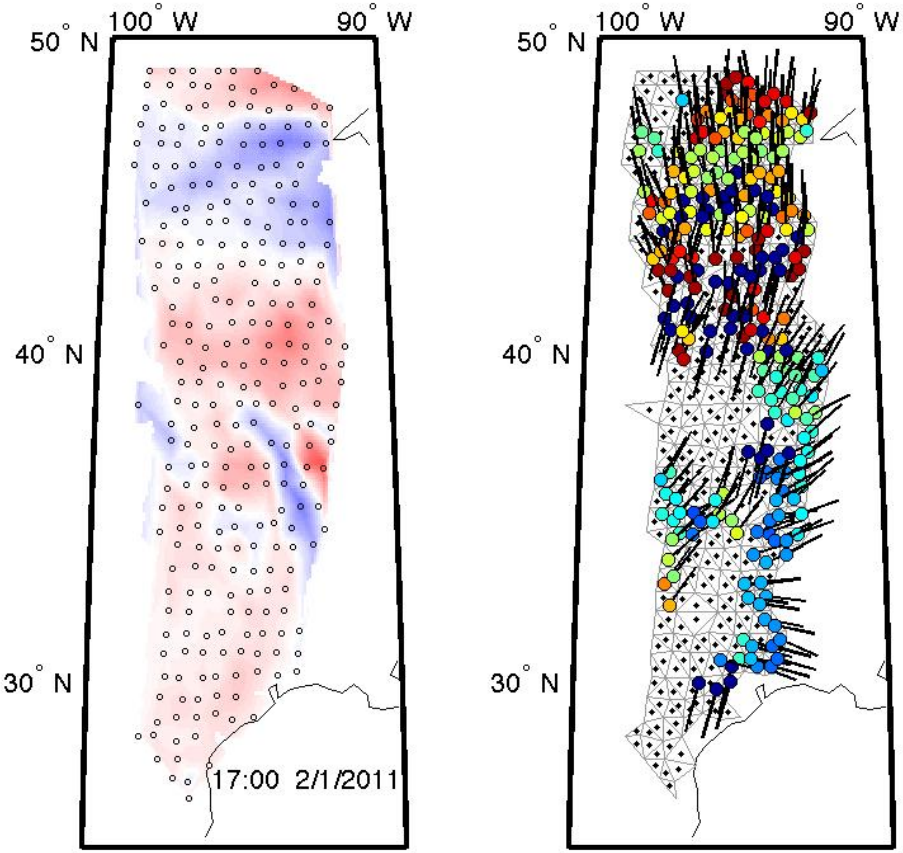


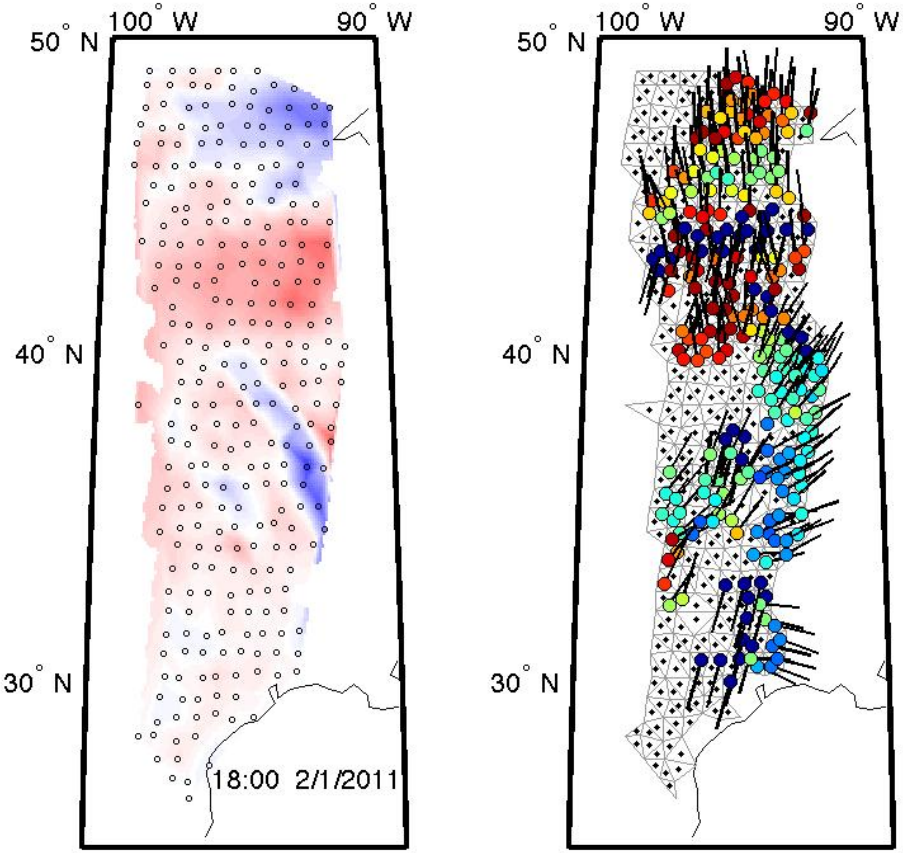


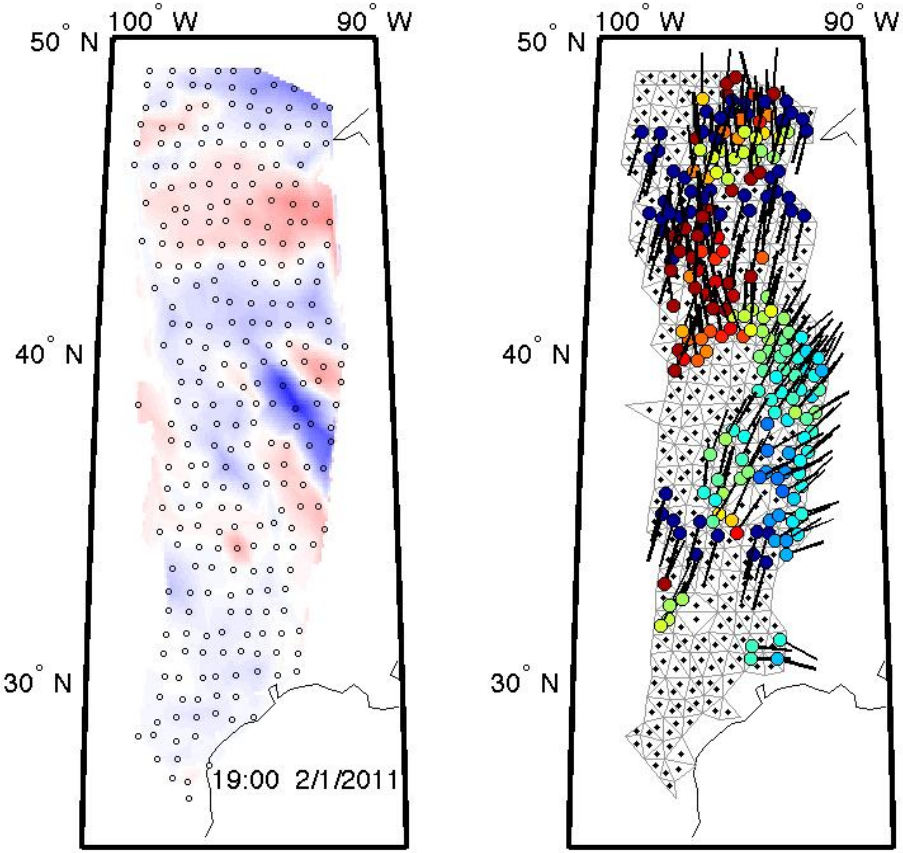


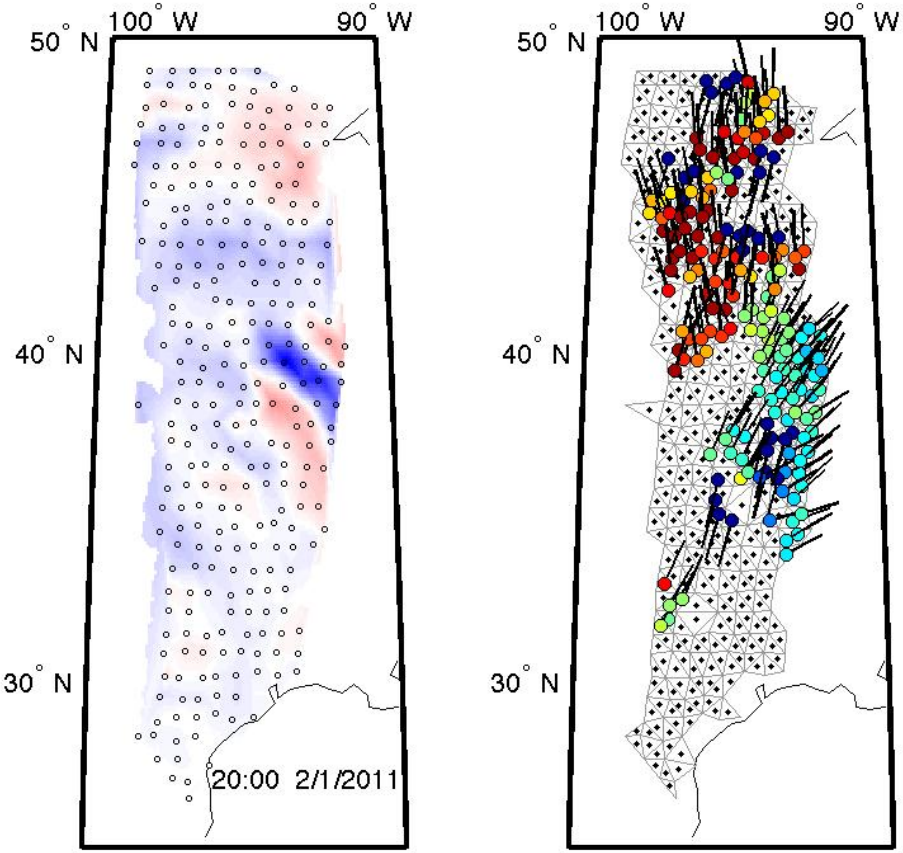


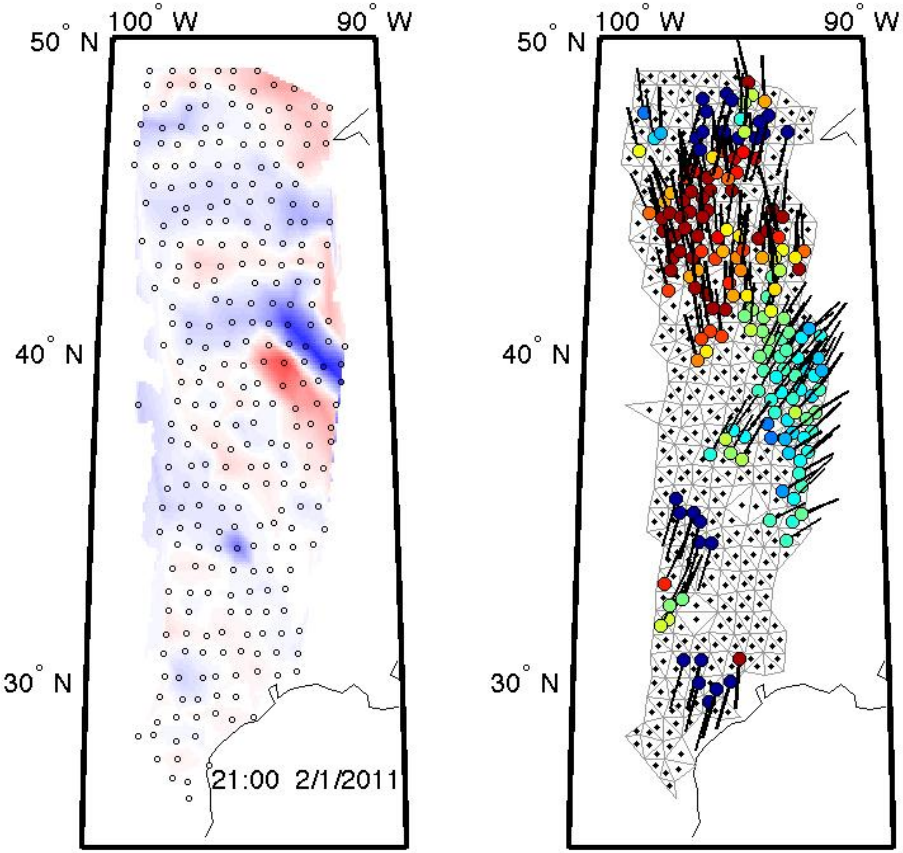




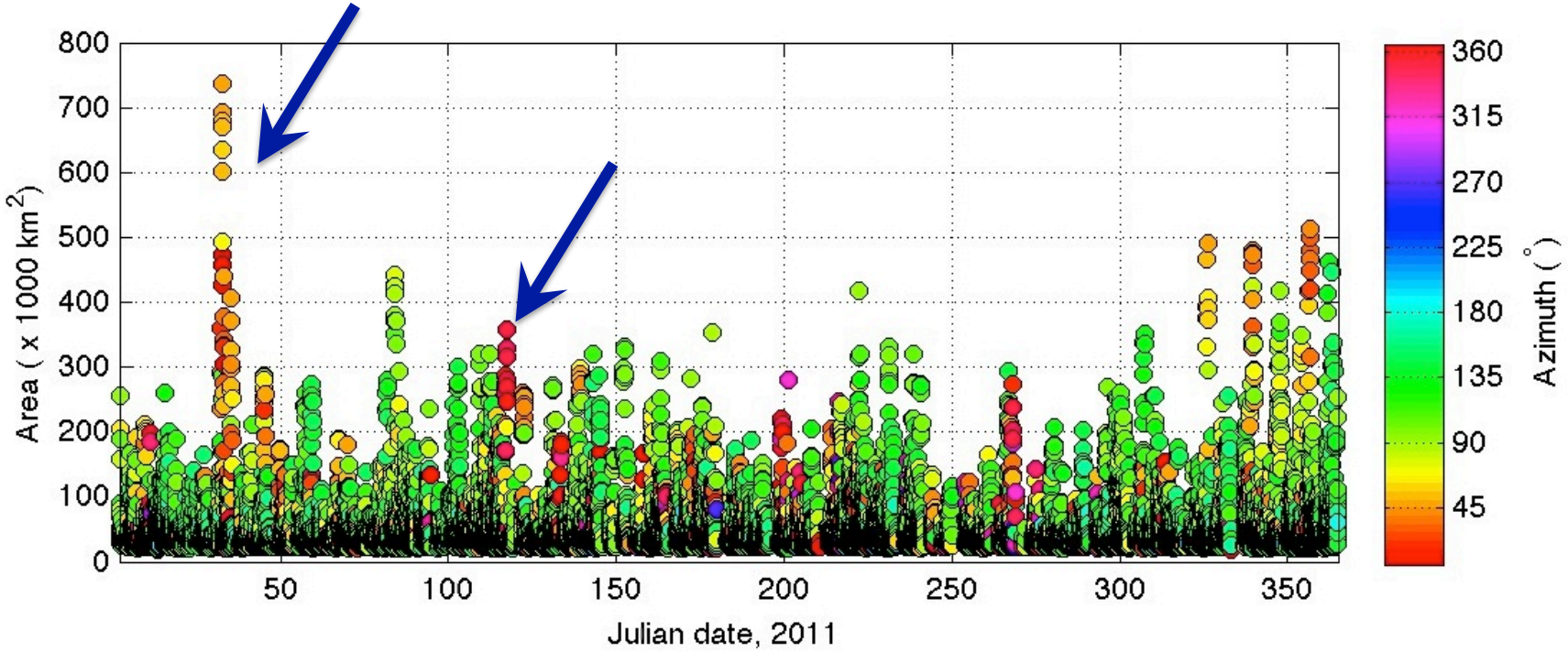








Gravity wave detector applied to 2011



The size of the gravity wave of April 27 was not unusual, but its direction was

Most gravity waves propagate across the array from West to East

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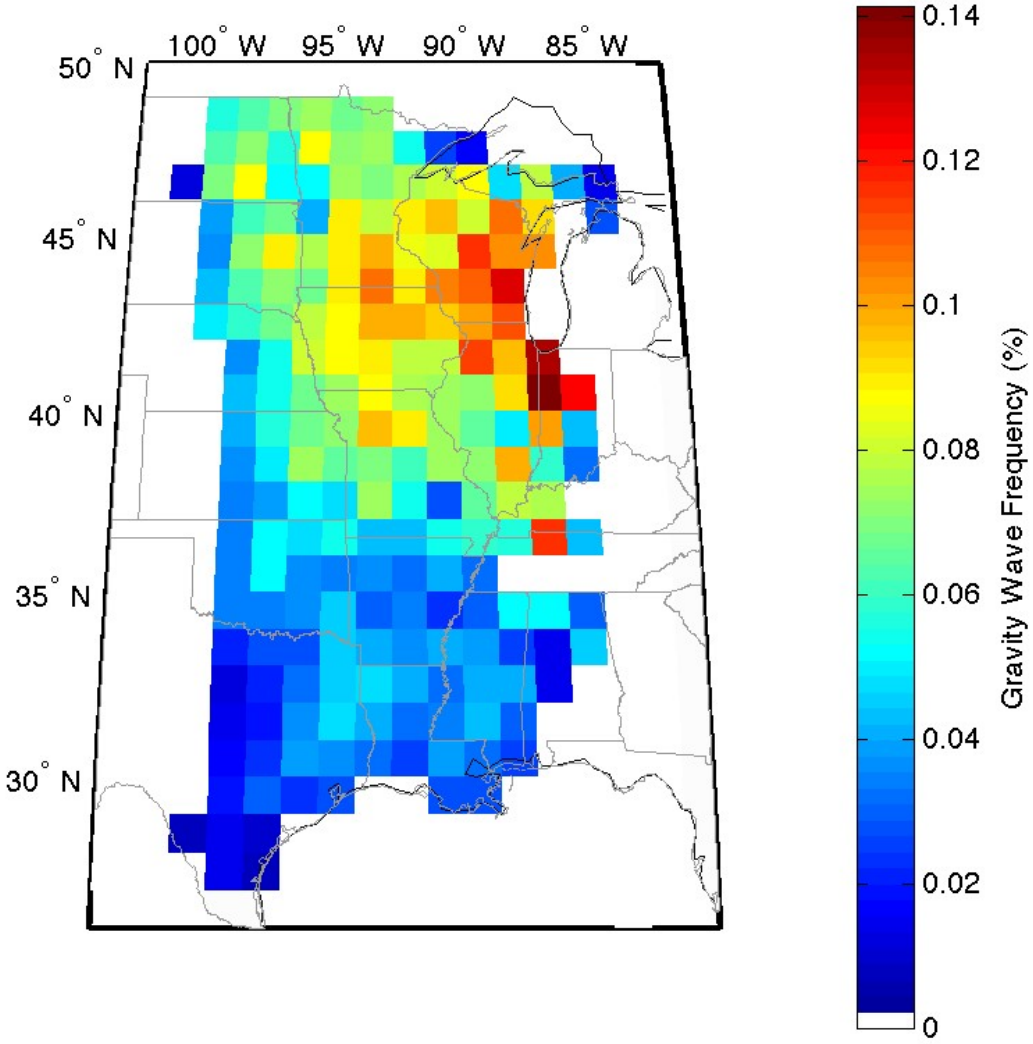
Gravity wave 'hotspots' over 2011



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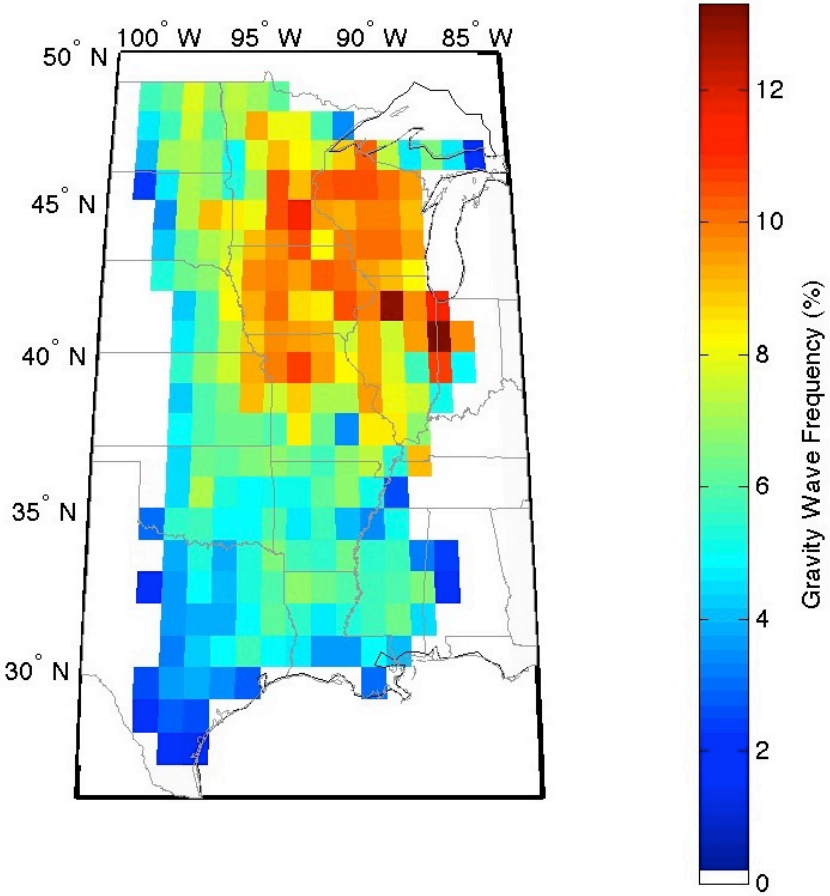
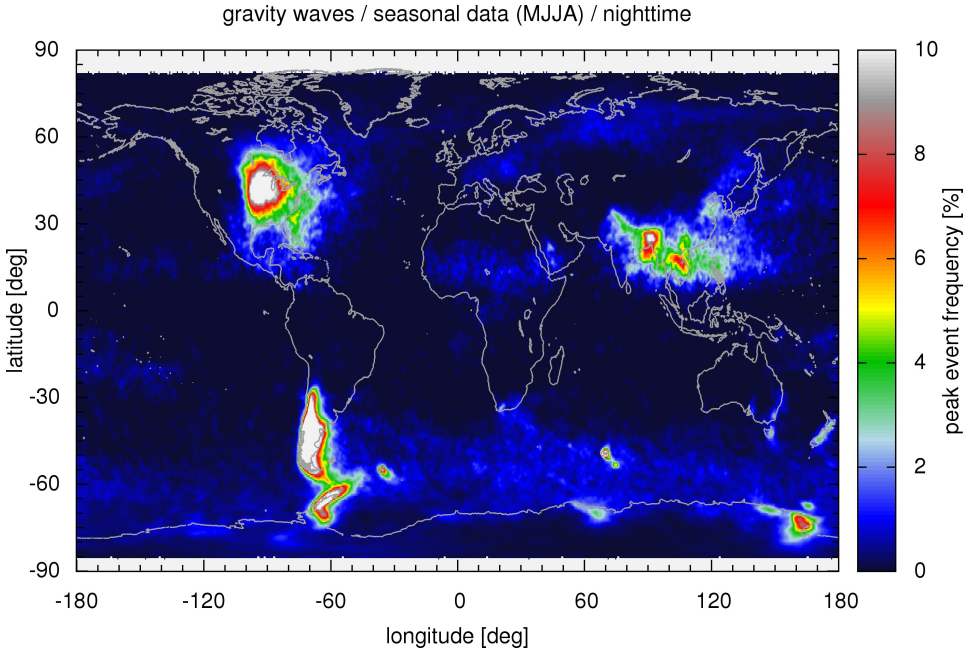
Comparison with satellite results

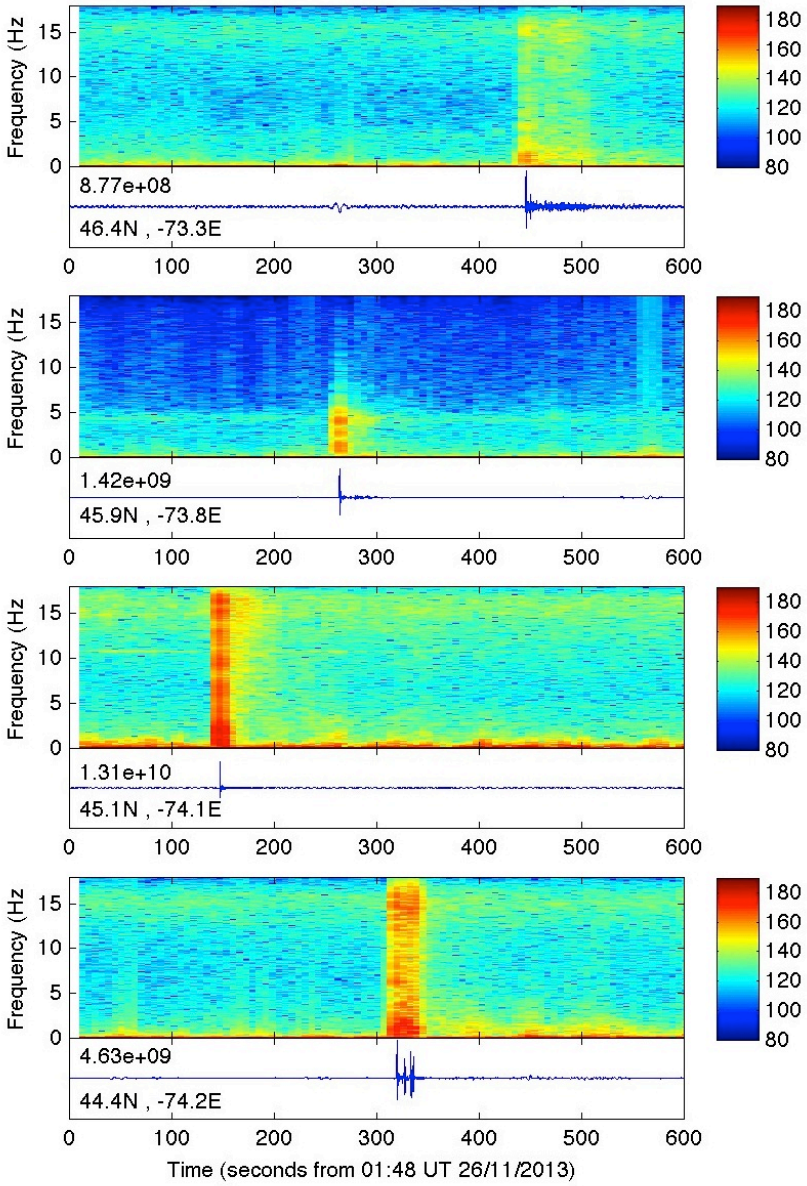


GW hotspots in USArray data



GW hotspots in satellite data

Application to infrasound detections - fireball over USArray

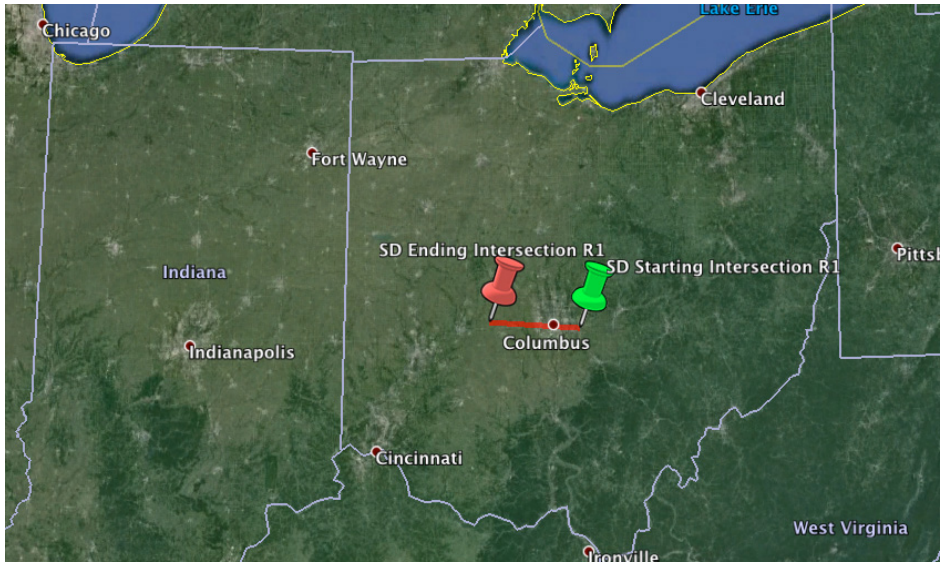


Infrasound signals are not coherent from station to station.

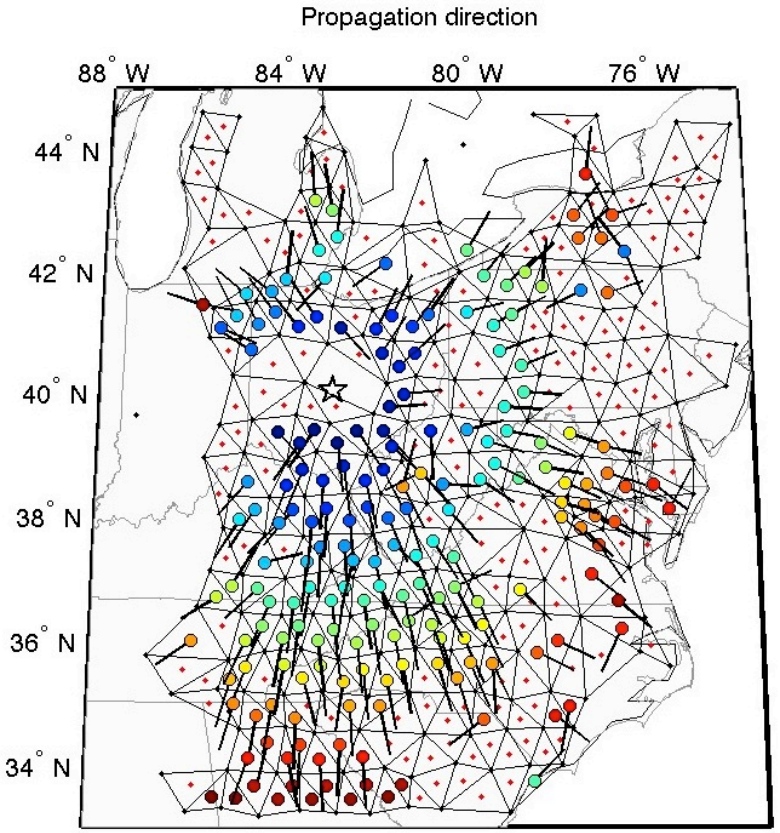
If signals are impulsive, signal envelopes can be x-correlated

→ Speed and direction of propagation

Ohio meteoroid



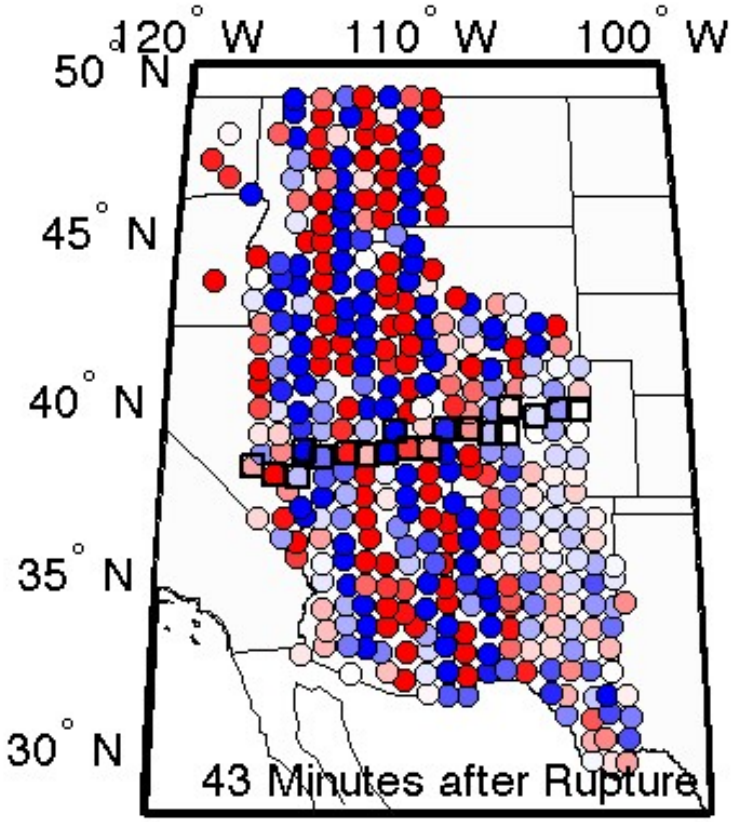
Trajectory based on eye witness reports

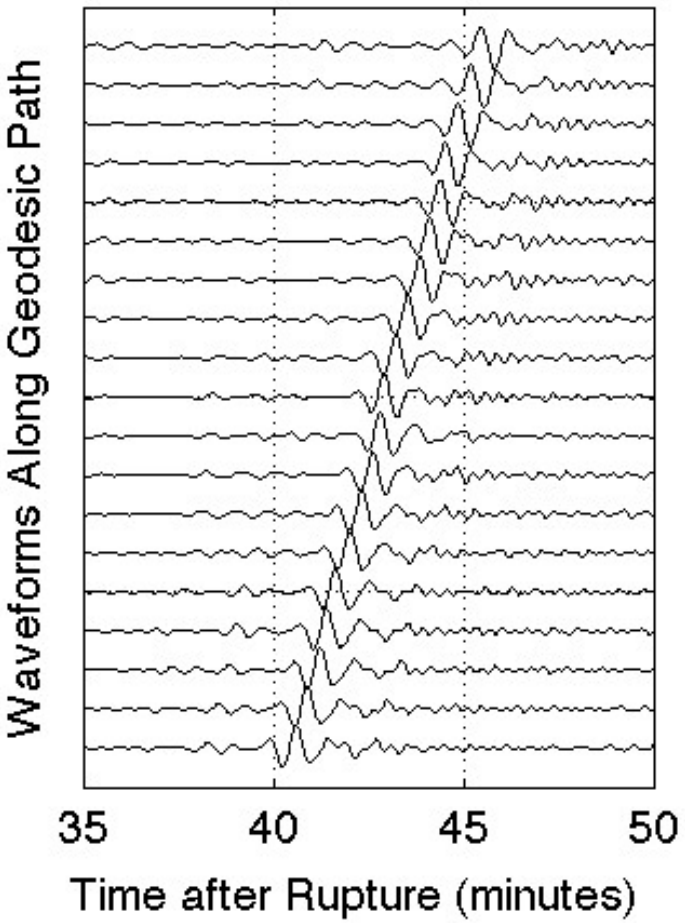


Direction of propagation derived from triad method

Application to Seismic data?

–surface waves from M=6.5 Santa Cruz islands event





Summary

Automated gravity wave detector:

- Gravity waves are coherent over much smaller scales than the entire TA
- Divide the TA into many sub-arrays to track the wavefield motion → USArray has characteristics of both array and network
- Yields a discretized view of the wave field
- Is an effective, automated approach of detecting & tracking gravity waves

Results:

- Large scale gravity waves are common over TA
- Gravity waves observed at the suface are also observed by satellite
- Opposing flow is observed for very large events

Other possible applications:

- Enhanced method of detecting infrasound
- Aid atmospheric scientists in GW detection

Project was supported by NSF Earthscope EAR-1147962

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