Circulations in MCS Stratiform Regions

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MCS Flow Partitioning

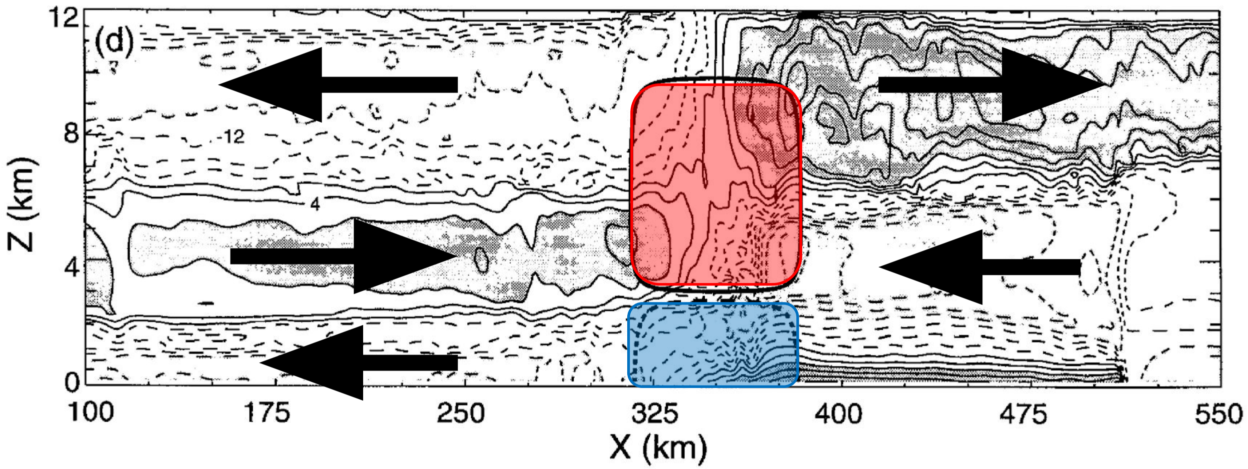
The total pressure gradient driving the rear inflow can be divided into (Weisman 1993; Grim et al. 2009):

$$\delta P_T = \delta P_B + \delta P_I + \delta P_V + \delta P_S$$

δP_T	=	δP_B	+	δP_I	+	δP_V	+	δP_S
Total		Buoyancy		Irrotational		Vorticity		Synoptic/ Environmental

MCS Flow Partitioning

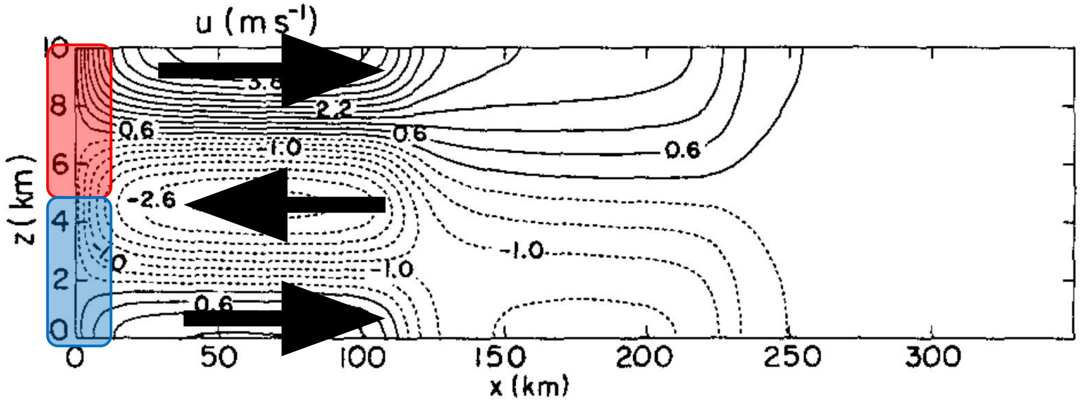
But…we know low-frequency changes in potential temperature/buoyancy affect more than the immediate area…



- Horizontal perturbation velocity (m s^{-1})
- Thermal forcing (color) applied to dry simulation for 6 hours
- Pandya and Durran (1996, JAS, Fig. 20d)

MCS Flow Partitioning

…through convectively generated gravity wave responses:



- Horizontal perturbation velocity (m s^{-1})
- Thermal forcing applied for 2 hours
- Pure n=1, n=2 modes
- Nicholls et al. (1991, JAS, Fig. 5a)

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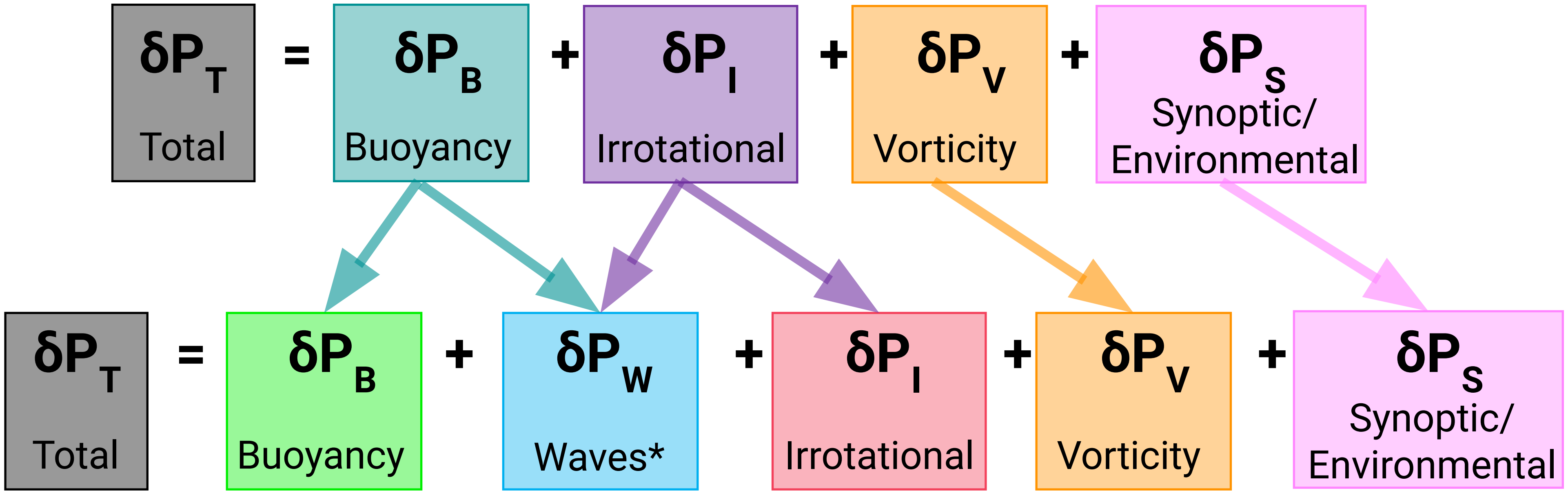
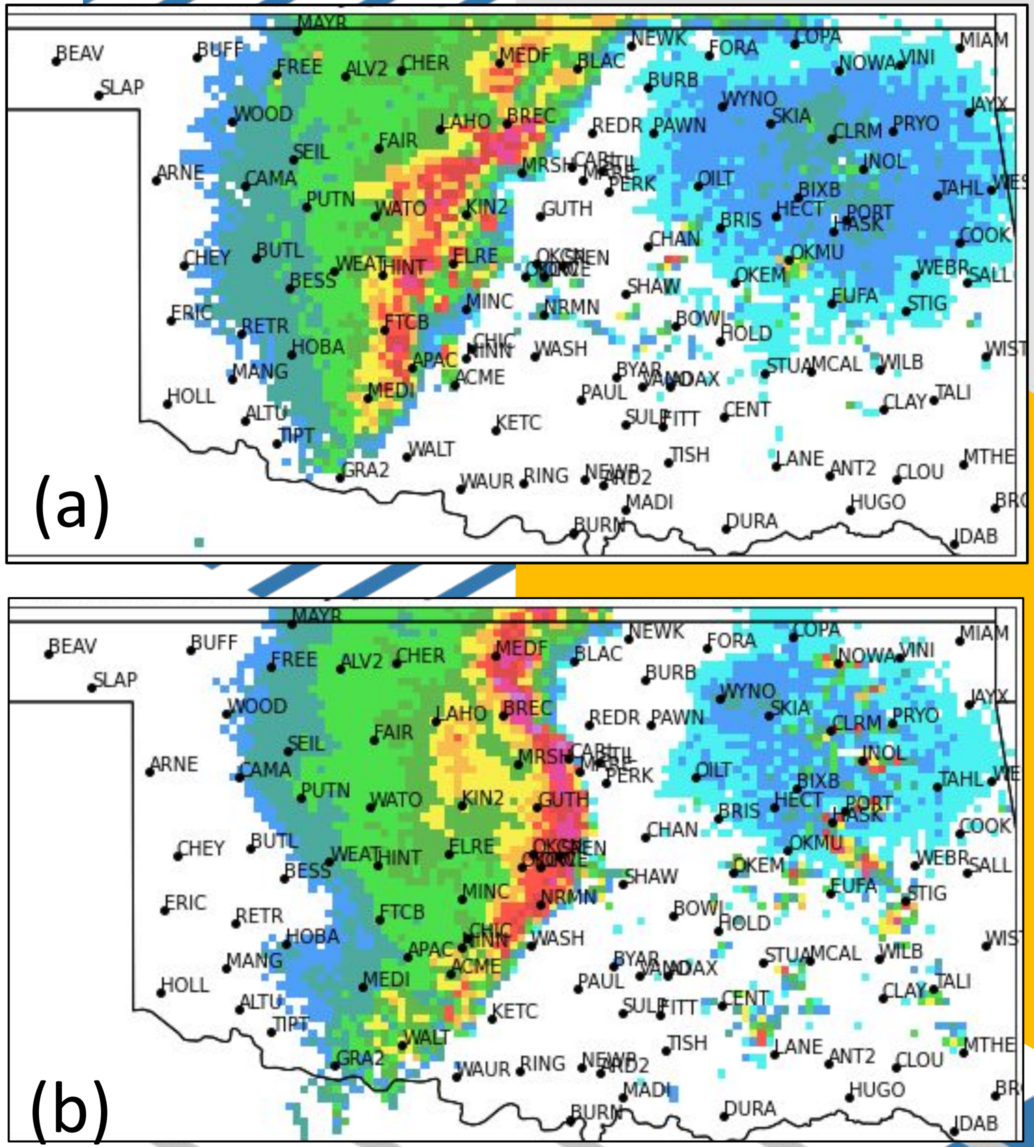


*Low-frequency gravity wave response

Initial Objectives

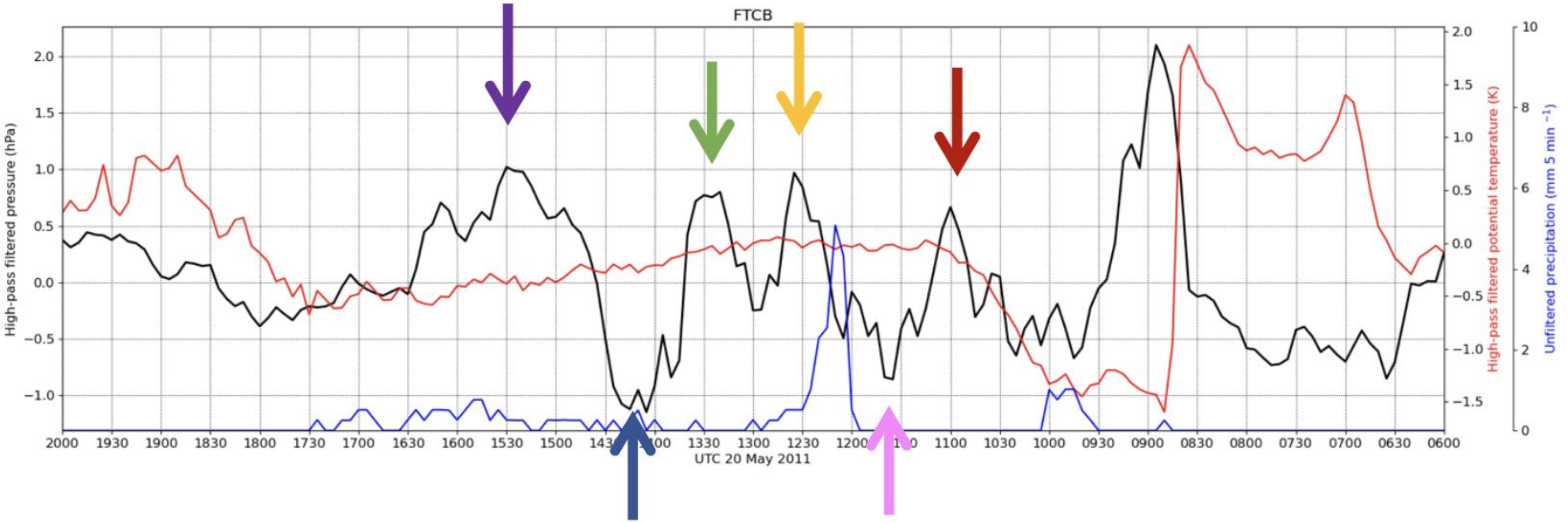
Within the 20 May 2011 MCS observed during the MC3E field campaign:

1. Identify potential low-frequency gravity waves using surface pressure observations.
2. Confirm gravity-wave identification using multi-Doppler-derived vertical velocity.
3. Determine line-end vortex flow contribution through vorticity inversion applied to 3D multi-Doppler-derived flow fields.



(a) 0900 & (b) 1200 UTC 20 May 2011

Wave ID with Surface Pressure Observations



- High-pass Lanczos filter of Oklahoma Mesonet station pressure observations (black)
- Identify noteworthy pressure features also evident at other nearby stations

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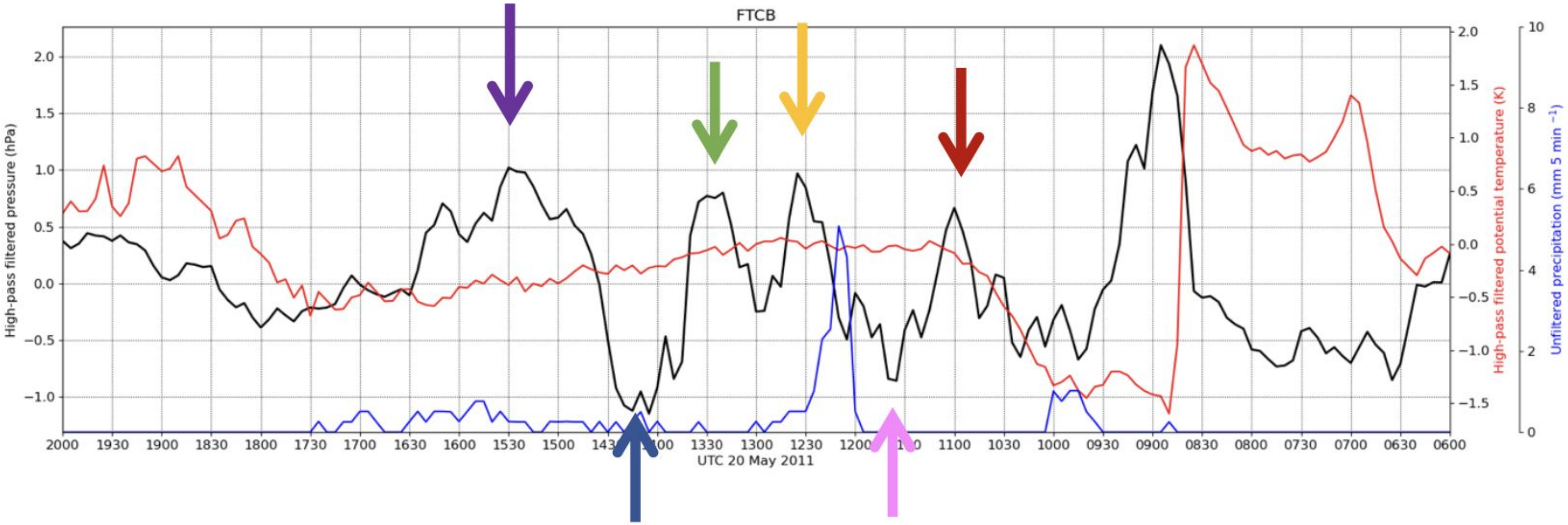

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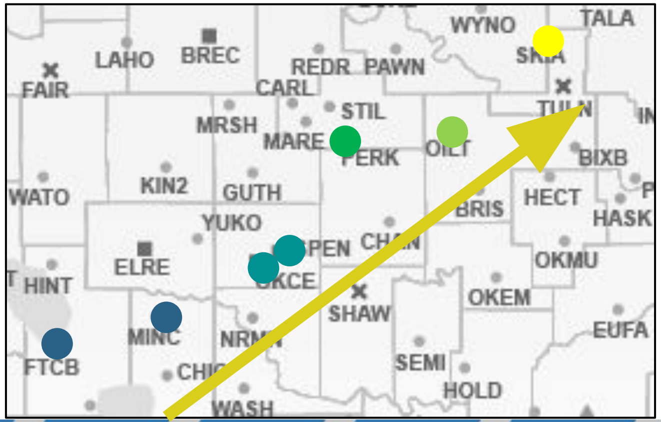
- Compare pressure patterns to identify propagation



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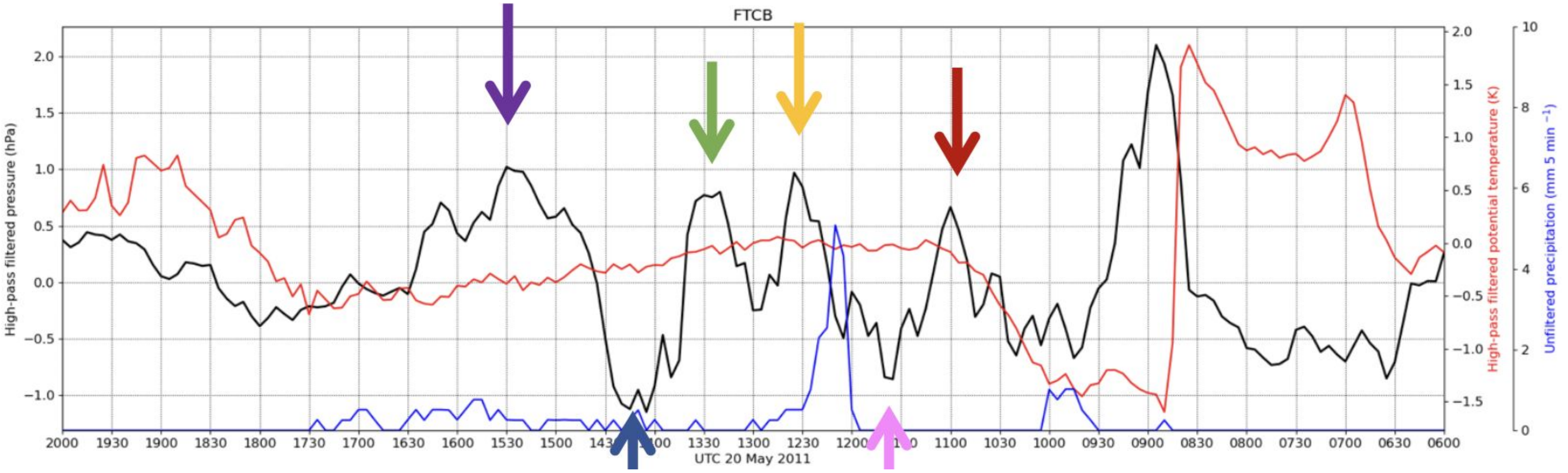

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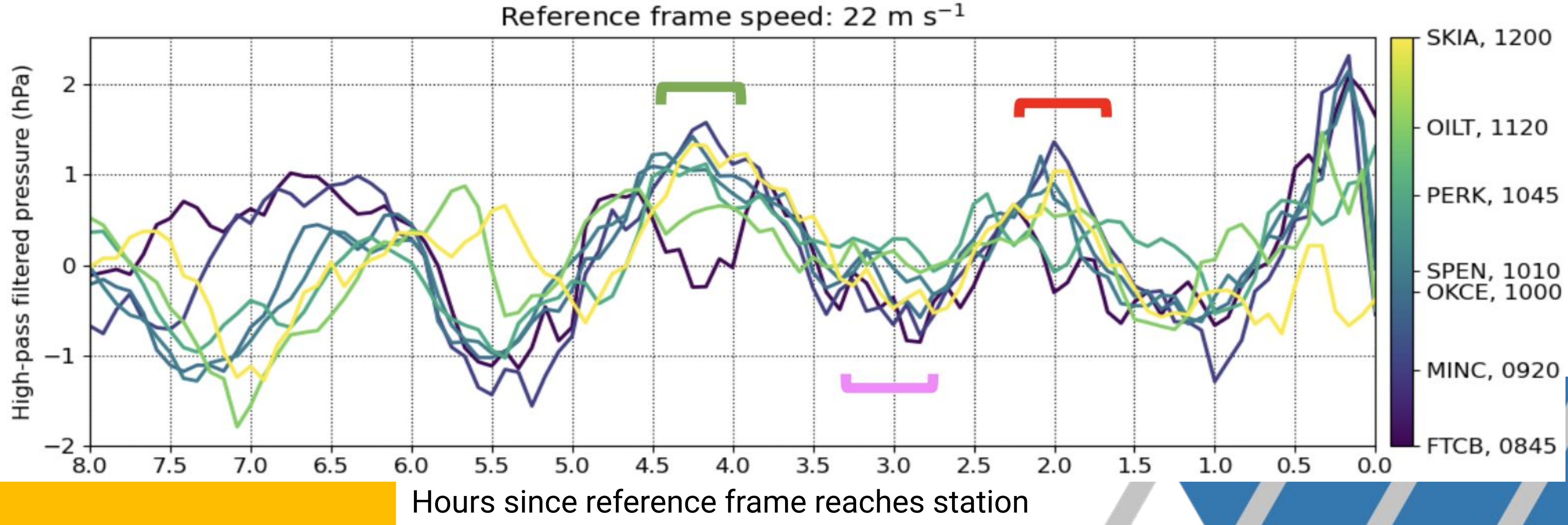
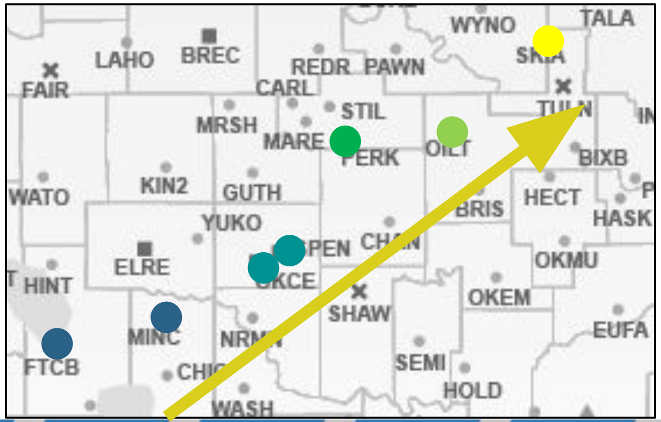
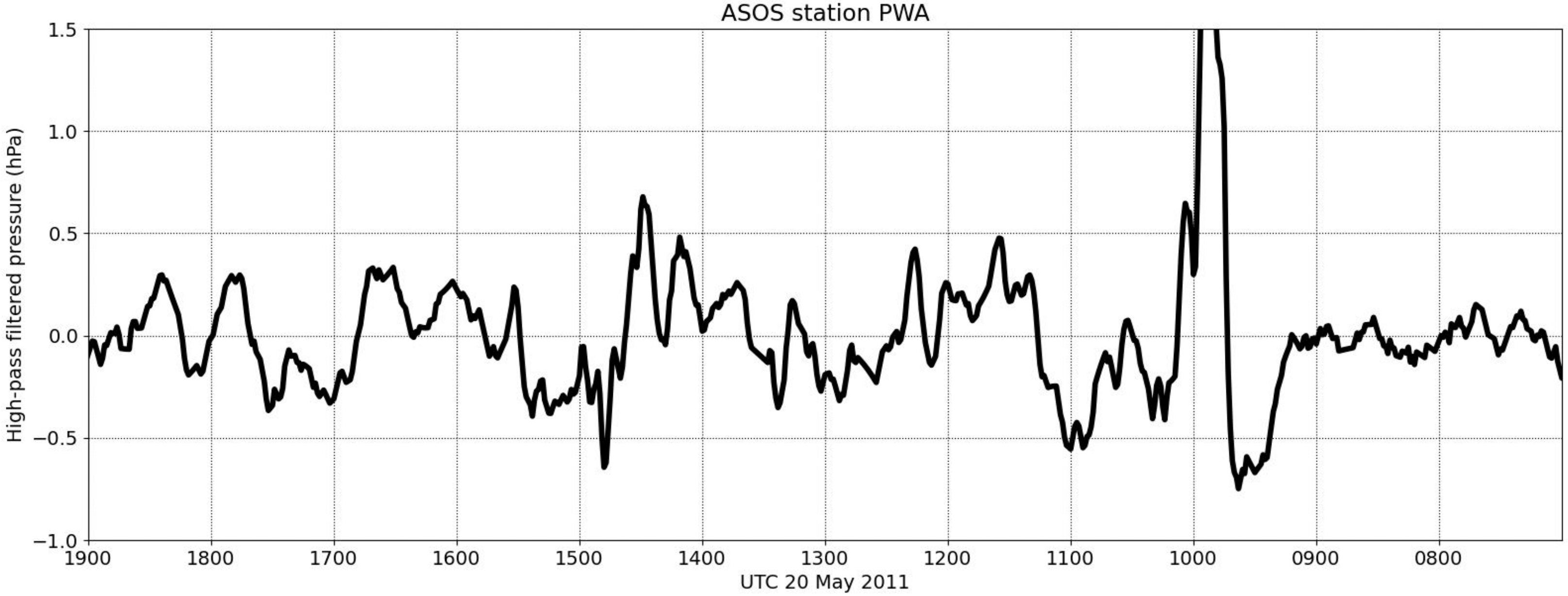




Automate Wave ID with Wavelet Analysis



- High-pass filtered station pressure (hPa) of ASOS station PWA (near OKC)

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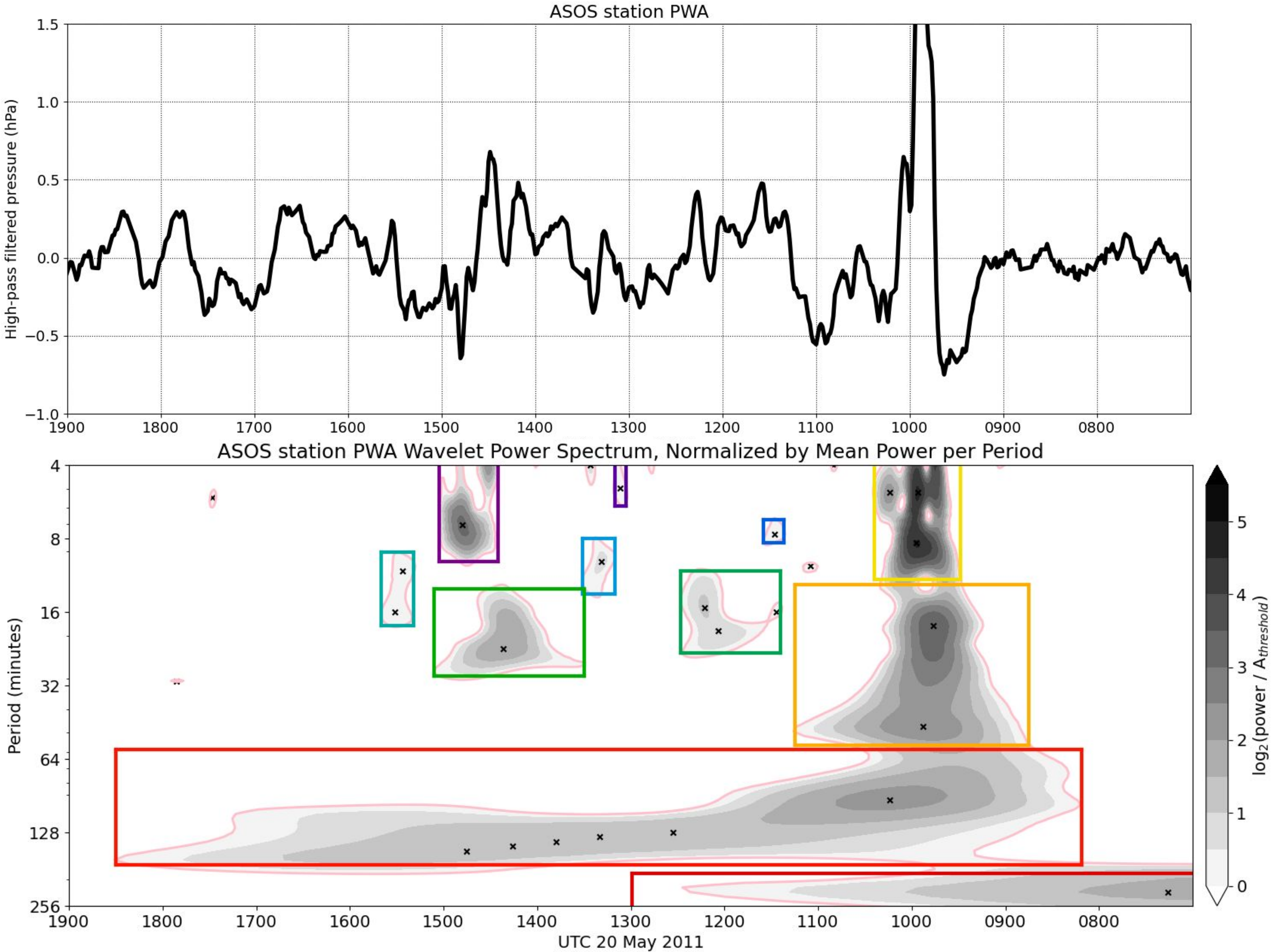

- High-pass–filtered station pressure (hPa) of ASOS station PWA (near OKC)
- Wavelet analysis using Morlet wavelet following Allen et al. (2023) and Torrence and Compo (1998, BAMS)
  - Normalize by mean power per period
  - Identify significant objects

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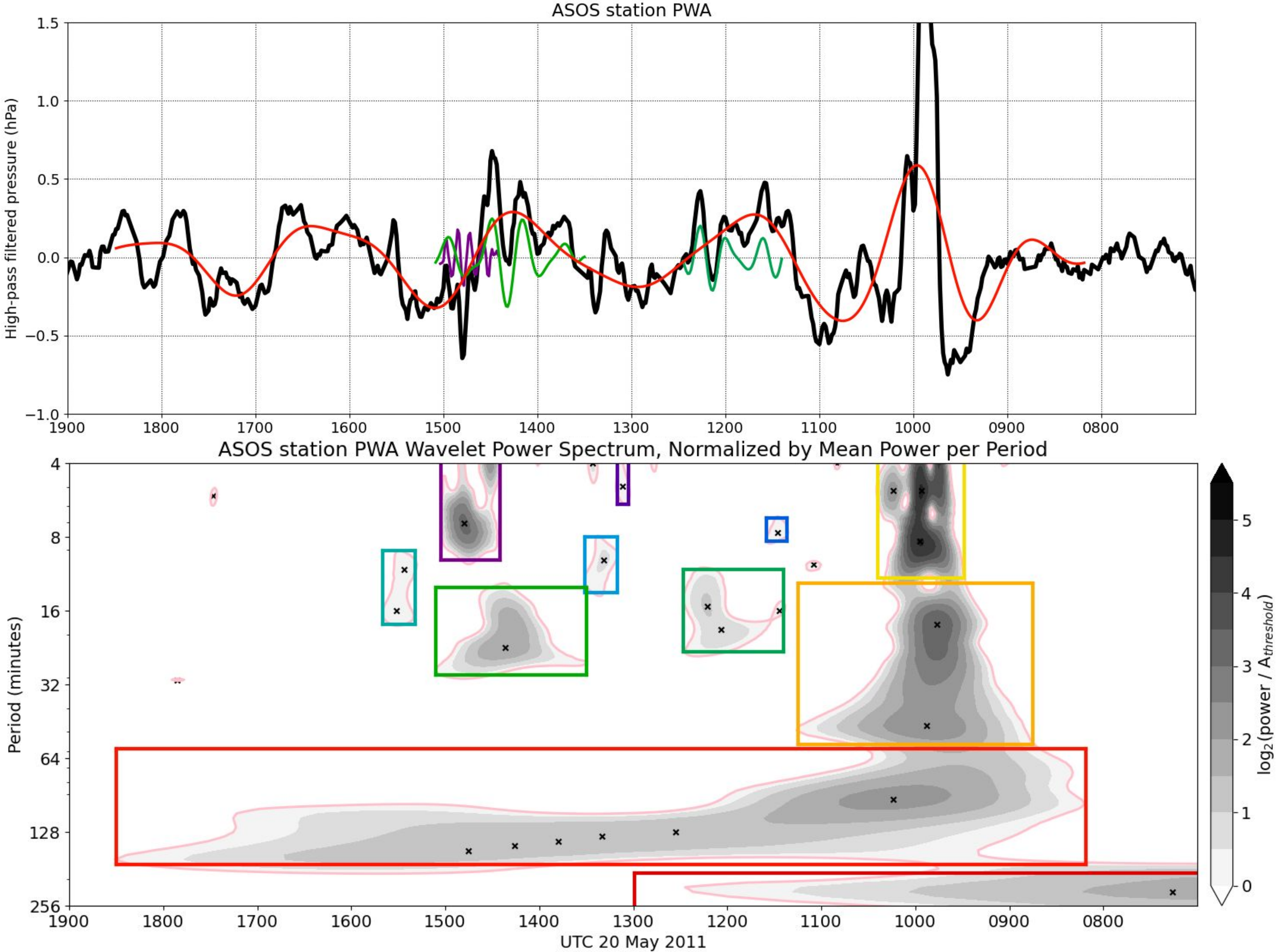

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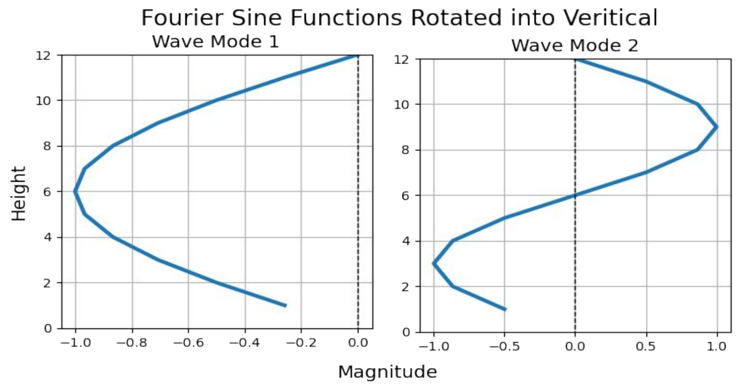
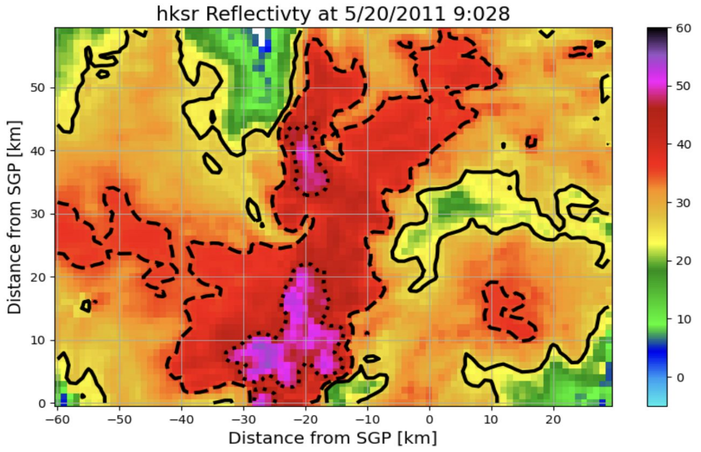
- Wavelet analysis using Morlet wavelet following Allen et al. (2023) and Torrence and Compo (1998, BAMS)
  - Normalize by mean power per period
  - Identify significant objects
- Invert wavelet transform over time, frequency space of selected objects
- TBD: cross-correlate among surrounding stations for direction, speed and compare to subjective analysis

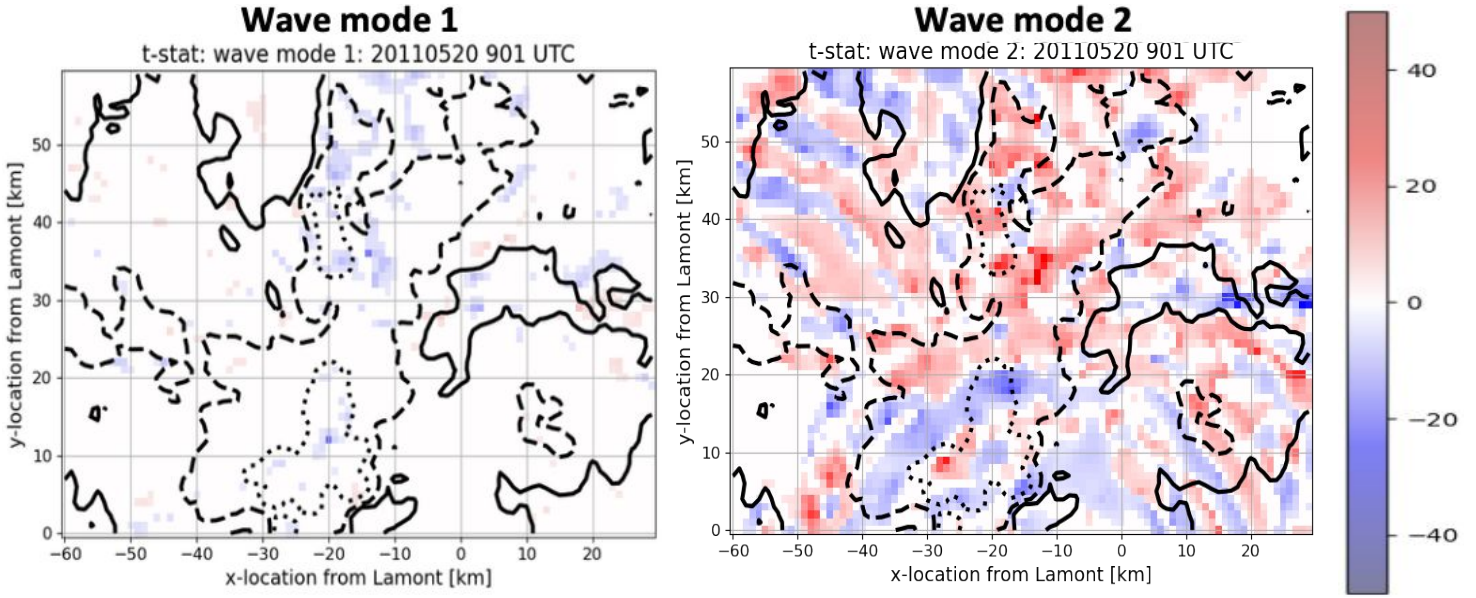
Wave ID with Multi-Doppler Retrieved Winds

- Perform a Fourier decomposition on vertical velocity field to identify low-frequency wave modes.
- Initially use the ARM HKSR VAP
  - C-SAPR and X-SAPR centered on SGP
  - Data ends at 1000 UTC





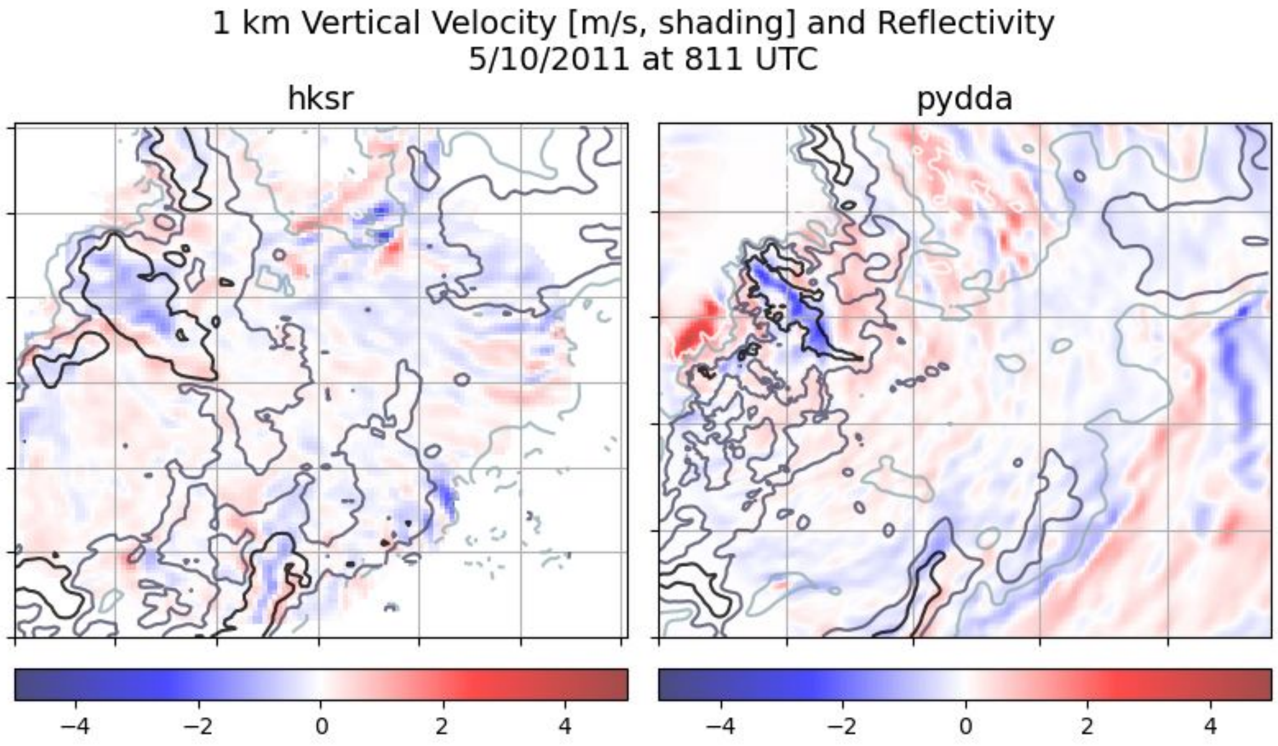
Reflectivity [dBZ] from HKSR at 0901 UTC



Results of Decomposition

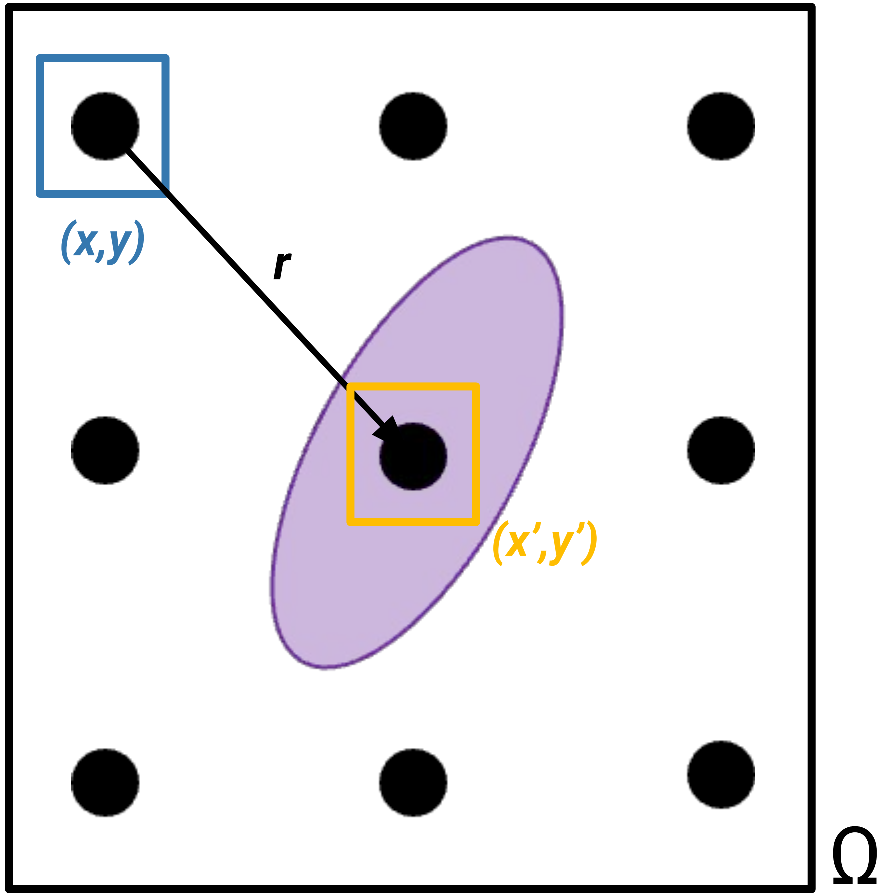
Wave ID with Multi-Doppler Retrieved Winds

Currently working to obtain vertical winds over a longer period by conducting our own retrieval:



- Using PyDDA
- Very preliminary
  - Using NexRAD radars
  - Some large–scale features similar to HKSR

Vorticity Inversion



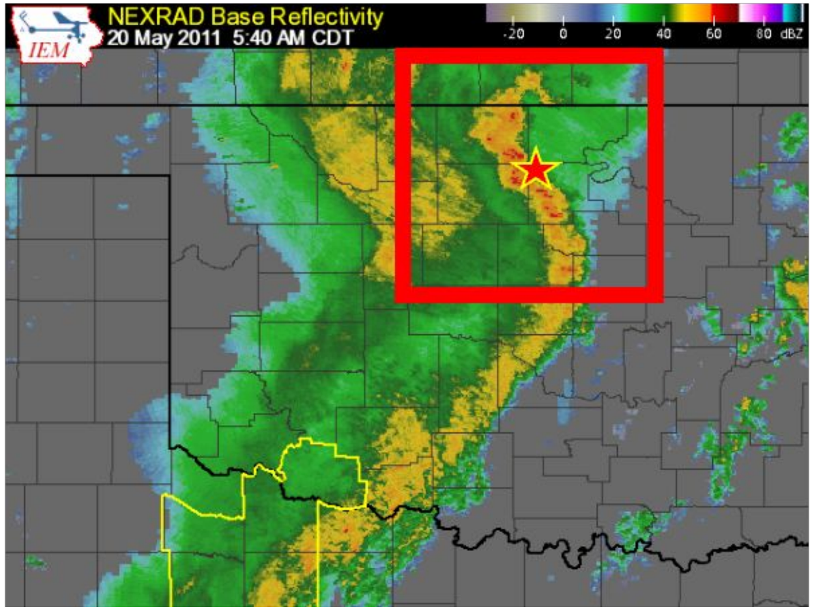
$$\nabla_h^2 \psi = \zeta$$

$$u_{\psi_\Omega}(x,y) = -\frac{\partial \psi_\Omega}{\partial y} = \frac{1}{2\pi}\int_\Omega \zeta(x',y')\frac{-(y-y')}{r^2}dx'dy'$$

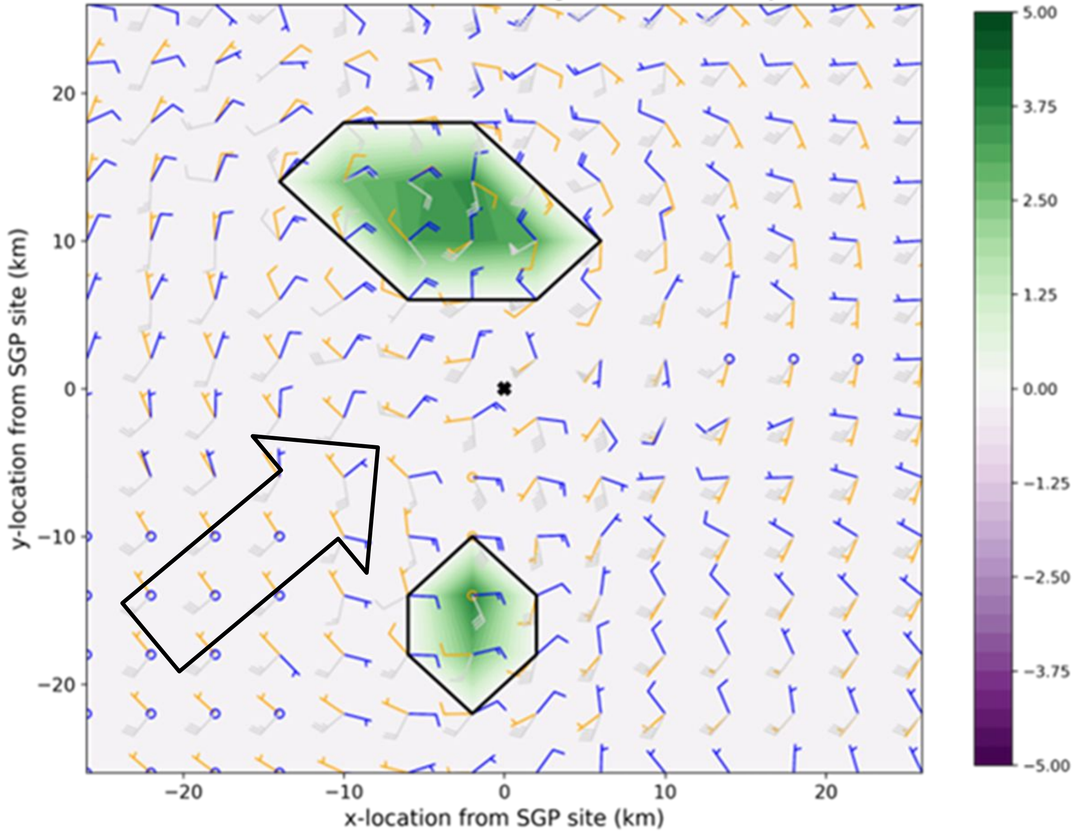
$$v_{\psi_\Omega}(x,y) = \frac{\partial \psi_\Omega}{\partial x} = \frac{1}{2\pi}\int_\Omega \zeta(x',y')\frac{(x-x')}{r^2}dx'dy'$$

following Oertel and Schemm (2021, QJRMS) and Bishop (1996, JAS)
Irrotational wind is similar, except in terms of χ and δ rather than ψ and ζ

Vorticity Inversion



3-km AGL at 10:24:13 UTC from the CONVV ARM VAP



Shading: pos. vertical vorticity ($\times 10^{-3}$ s^{-1}); 1.0 x 10^{-3} s^{-1} contour in black
Orange barbs: non-divergent (rotational) wind for $\zeta > 1.0 \times 10^{-3}$ s^{-1}
Blue barbs: irrotational (divergent) wind (δ not shown)
Grey barbs: total horizontal wind (m s^{-1})

Future Work

- Expand multi-Doppler 3D wind retrieval in time, space, and resolution in collaboration with the Py-ART team.
  - Use Fourier decomposition of 3D winds to confirm surface pressure wave identification.
  - Apply vortex inversion technique to new 3D wind dataset to quantify both non-divergent and irrotational flows.
- Quantify environmental flow contributions using low-pass filtering techniques.
- Quantify rear inflow contributions from low-frequency gravity waves, line-end vortices, buoyancy, irrotational flow, and the environment in a representative large-eddy–scale numerical simulation.
- Final goal: compare magnitudes of observational and modeling flow terms.