Observations of Convectively Generated Gravity Waves within the Stratiform Region of Mesoscale Convective Systems

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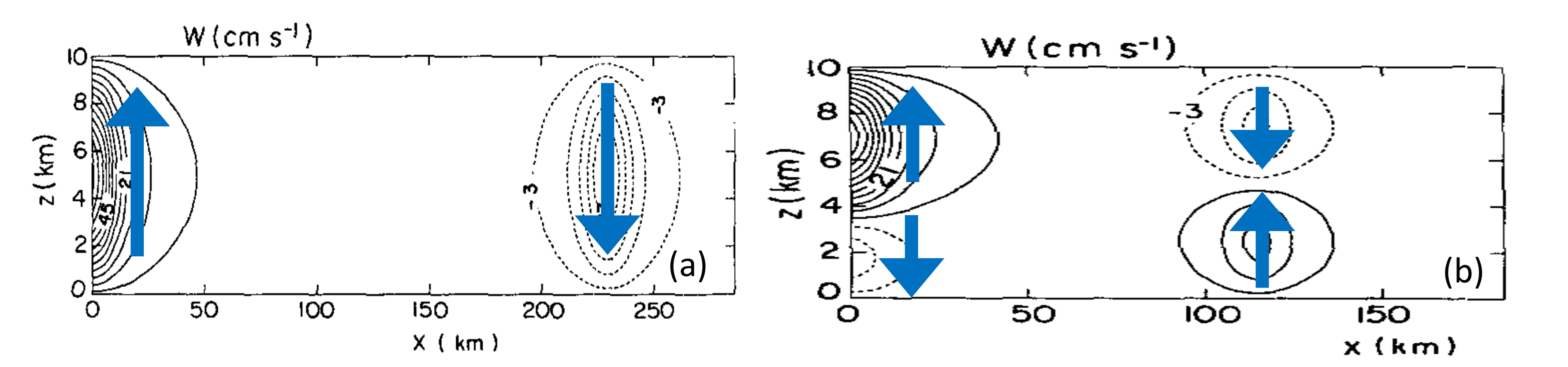
Introduction

- Diabatic heating/cooling within MCSs generate low-frequency gravity waves.
- Differing heating profiles in convective and stratiform region create different types of gravity waves
  - Convective region (node 1)
    - Deep heating/cooling → up/down motion through the depth of the troposphere
    - Propagate at ~ 50 m/s
  - Stratiform region (node 2)
    - Dipole of heating/cooling → dipole of up/down motion
    - Propagate at ~ 30 m/s



Vertical velocities induced by a (a) 2 J kg^{-1} s^{-1} convective heating source and (b) 1 J kg^{-1} s^{-1} stratiform dipole heating source at x = 1. Figure made 2 hours after initiation. Contours are 3 cm s^{-1}. Adapted from Nicholls et al. (1991)

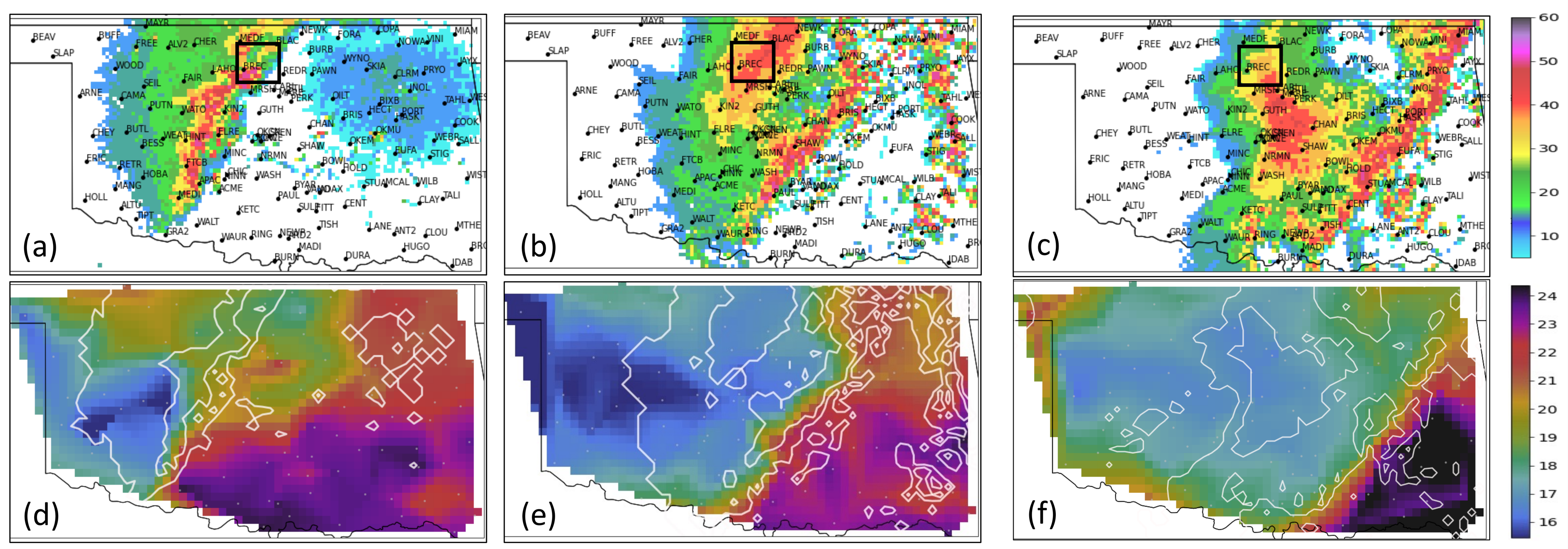
- Gravity waves propagate outward in all directions
  - Cause small perturbations in the pressure, temperature, and winds fields
    - Often overshadowed by synoptic features, but become apparent when data is filtered
- Previous studies have shown to impact pre-storm environment ahead of the storm
- Little research done into how these gravity waves impact the stratiform region
  - Especially from an observational perspective

Objective

The first step in this study is to identify gravity waves generated by MCSs observed during the Mid – Latitude Continental Convective Clouds Experiment (MC3E).

May 20th, 2011 Case

- Leading line, trailing stratiform MCS propagated across Oklahoma
- Accompanied by cold pool that moves east-northeast at 14-15 m/s.



Radar reflectivity [dBZ] from the KVNX radar at (a) 9, (b), 12, and (c) 15 UTC on May 20, 2011. (d-f) Similar to (a-c) except shows surface temperatures from the Oklahoma Mesonet (shading) [deg C] and reflectivity contours of 15 and 30 dBZ shown in white.

Data

Oklahoma Mesonet

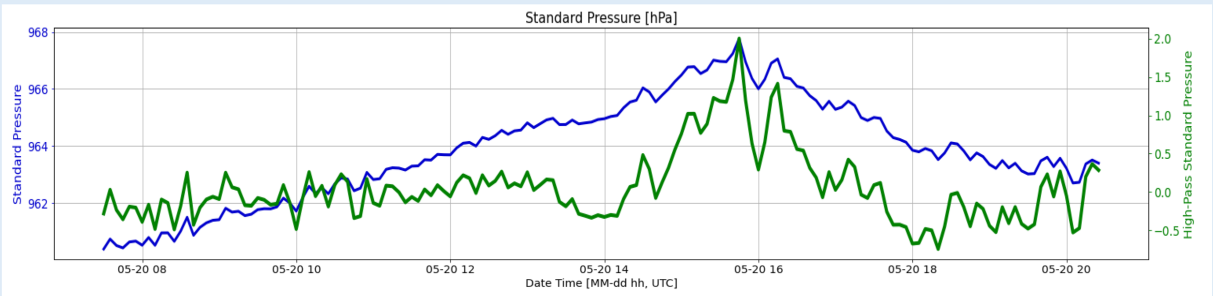
- 120 locations
- 5 – minute resolution pressure, temperature, and wind data

Radars

- 3D winds from DOE ARM's Hydrometeor and Kinematic data products from Scanning Radars (HKSR)
  - Derived using C-SAPR and X-SAPR data.
  - Data is available on a 50 km grid centered on Lamont, OK.

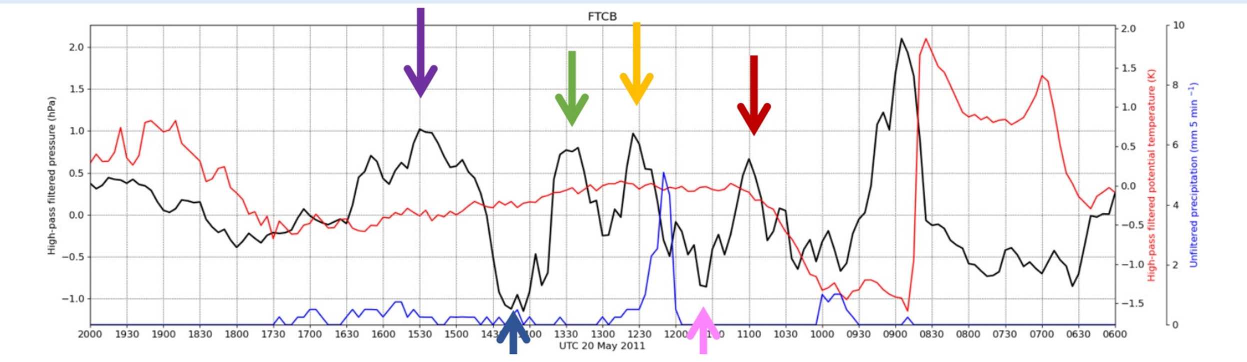
Gravity Waves in Oklahoma Mesonet Data

- Potential gravity wave features are characterized by:
  - Perturbations in standard pressure not accompanied by significant temperature changes
  - Perturbations consistent across multiple locations
  - Estimated propagation speed consistent with gravity waves

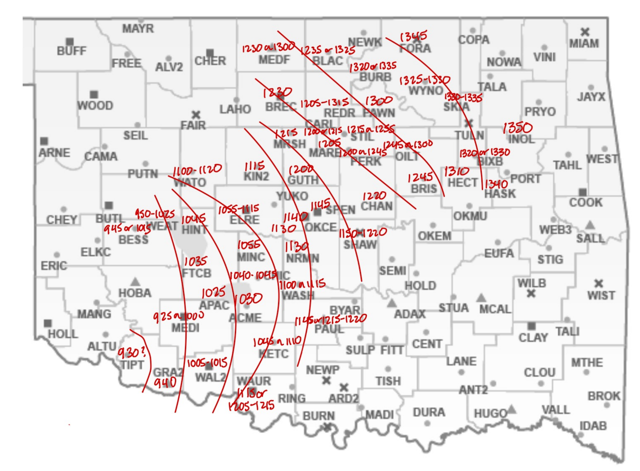


Time series of raw (blue) and high-pass filtered (green) standard pressure [hPa] from Kenton, OK, on May 20th, 2011 between 730 and 2030 UTC.

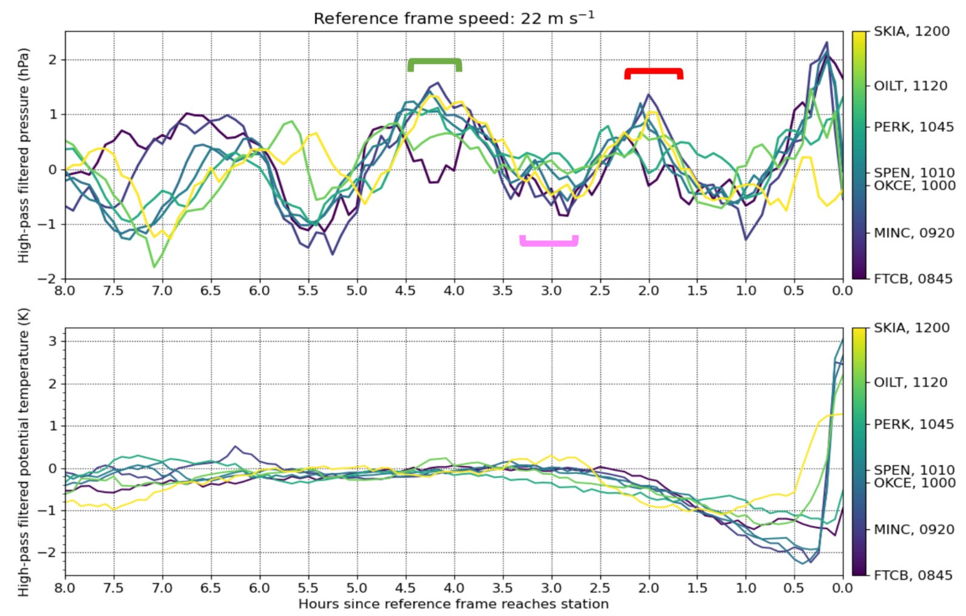
- Analysis based on Adams – Selin and Johnson 2010, 2013)
  - Pressure converted to standard pressure to remove impact of altitude
  - Apply Lancozs high – pass filter Fourier filter to remove synoptic features (Duchon 1979)
  - Create time series of filtered for each location. Identify potential gravity wave perturbations.
  - Determine if pressure perturbations occur at other locations and track wave crests.
  - For the subset of locations within the path of the wave, translate the timeseries by different reference speeds to isolate the wave propagation speed.
- *We have found evidence of several wave features during the May 20th, 2011 MCS.*
  - The wave shown here
    - Occurs behind the cold pool and is accompanied by relatively small potential temperature changes
    - Propagates independently from the cold pool at approximately 22 m/s toward the northeast



High-pass filtered station pressure [hPa, black], potential temperature [K, red], and unfiltered precipitation rate [mm 5 min-1, blue] from Fort Cobb, OK from 06 to 20 UTC on 20 May 2011. The arrows indicate potential gravity wave perturbations. Time increases to the left



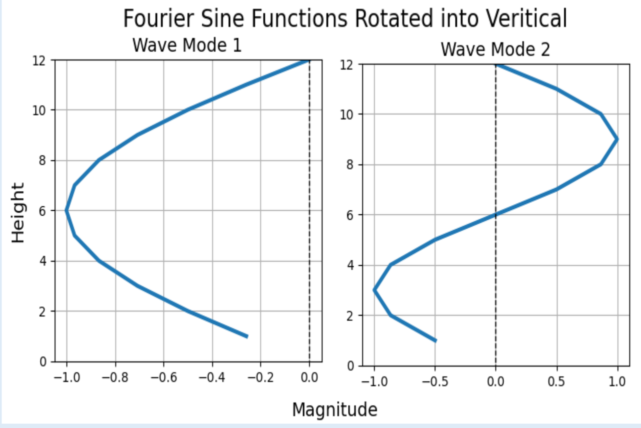
Contour plot of the arrival time of the pressure perturbation marked by the red arrow above at each mesonet location.



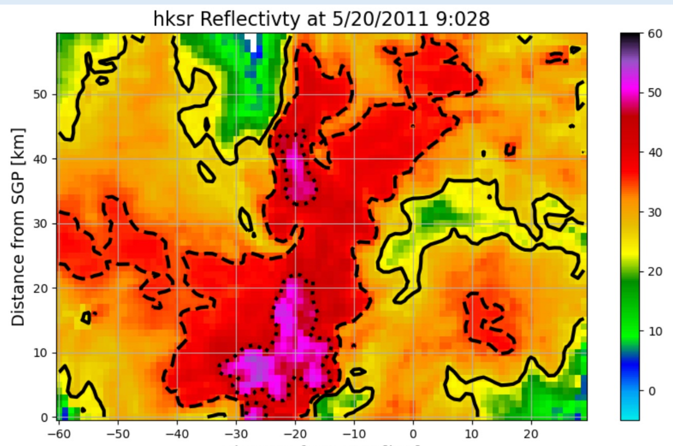
High-pass filtered station pressure (top) and potential temperature (bottom) in a reference frame moving along a vector from station FTCB to FORA at 22 m s-1. The times (UTC) when the start of the reference frame reaches each station (hour 0) is identified in the color bar. Time increases to the left.

Gravity Waves in Radar Derived Vertical Velocity Data

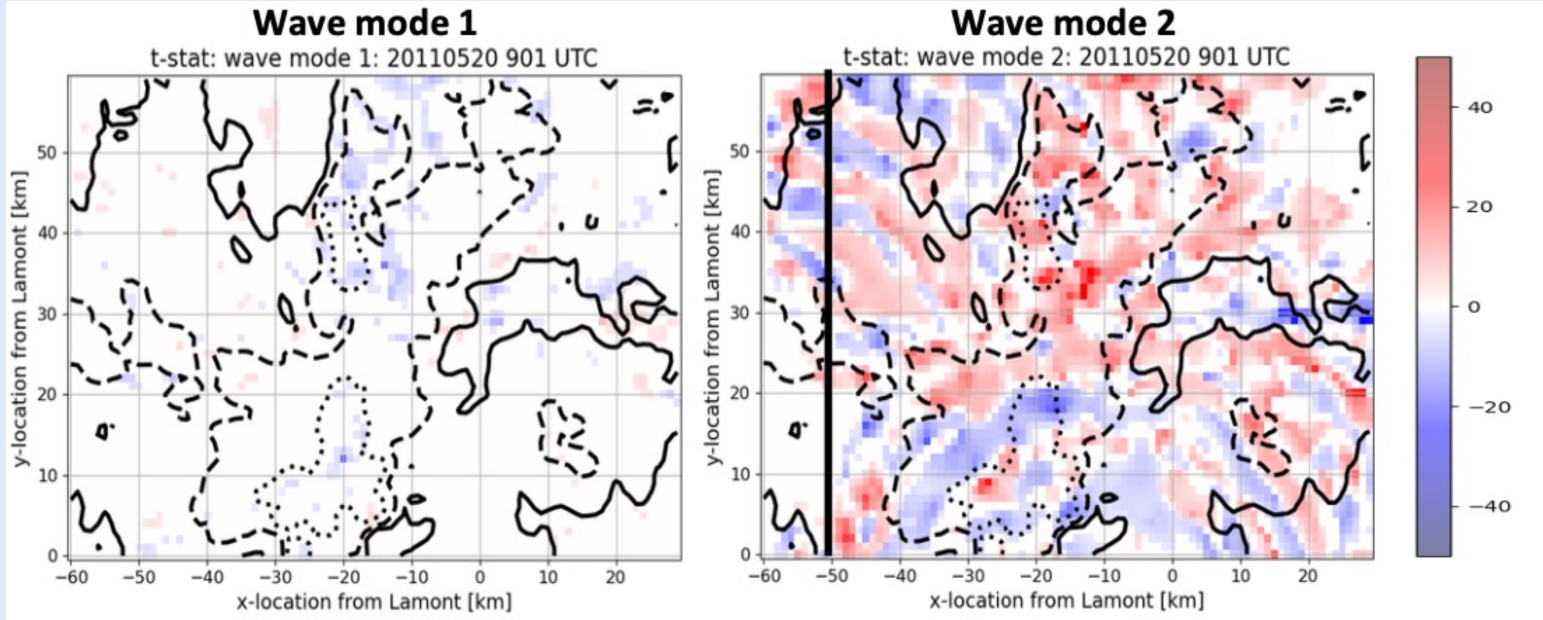
- Analysis based on Adams – Selin (2020)
  - Synoptic scale features are filtered out of the data using Fourier transformations
    - The wave modes used in the transformation are vertically rotated sine functions.
  - Manually review maps for wave features.
  - Create hovmollers to determine if waves are consistent in time and their speed.
- *Some evidence of waves in HKSR data. However, HKSR only contains a small portion of the stratiform region.*



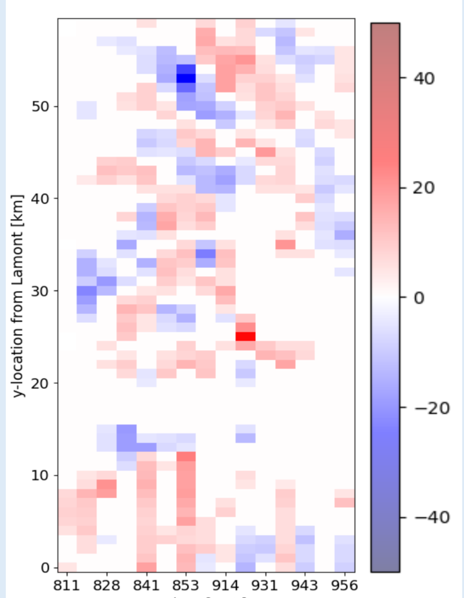
The mode 1 and 2 assumed wave modes used in the Fourier transformation.



Reflectivity[dBZ] from HKSR at 901 UTC.



The magnitude of the t-statistic (shading) from the Fourier transformation of HKSR vertical velocity data for assumed wave modes 1 and 2 at 901 UTC . Colors are only shown if the decomposition is statistically significant. The contours are reflectivity at 25 (solid), 25 (dashed), and 35 (dotted) dBZ. Solid black line in the mode 2 panel shows the location of the hovmoller.



Hovmoller of the magnitude of the t-statistic for mode 2 taken from x=-50 between 811 and 956 UTC

Conclusions

- Oklahoma Mesonet data has been used to identify convectively generated gravity waves in the stratiform region of the May 20th, 2011 MCS during MC3E.
  - Waves occur behind the cold pool and propagate separately from the cold pool.
- The 3D winds provided in ARM's HKSR data is not sufficient for our analysis. We need to derive 3D winds in the stratiform region.

Next Steps

- Retrieve 3D winds in the stratiform region of this MCS using NEXRAD data and PyDDA.
- Investigate how these waves impact the stratiform region and its evolution.
- Analyze additional MCS cases from MC3E and PECAN.

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