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Fine-scale kinematic structure of a gravity wave within a midlatitude cyclone

Kevin Knupp[1], Dustin Phillips[1], Tim Coleman[1], Robert Rauber[2] and Brian Jewett[2]
[1]University of Alabama in Huntsville
[2]University of Illinois

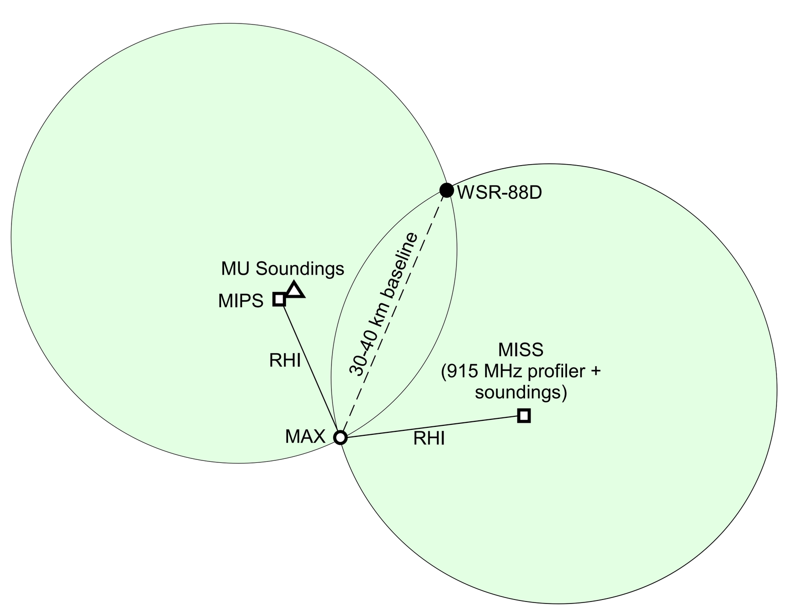
Introduction

The primary objective of this work is to improve understanding of the kinematics of gravity waves within midlatitude cyclones. This work has important applications to recent research examining the relationship between gravity waves and mesocyclones within supercell storms. A primary hypothesis is that ducted gravity waves can simultaneously enhance horizontal vorticity, tilt it into the vertical, and then amplify it via stretching. Better observations of the evolving thermodynamic environment and internal structure of gravity waves are required, and we strive to obtain these observations as part of a field campaign entitle *Profiling of Winter Storms*, or PIOWS.

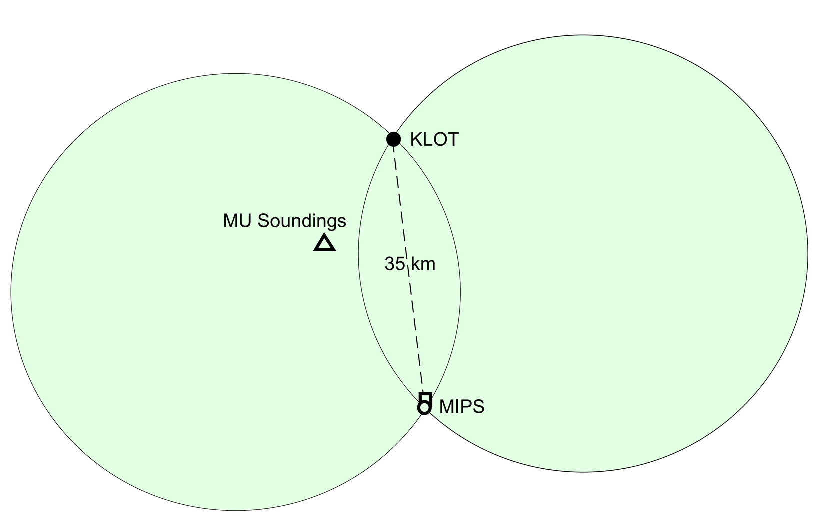
The PIOWS observational assets are well-suited to obtain comprehensive measurements of gravity waves and their environment. In this paper, we present preliminary observations of two major ducted gravity waves observed during the first IOP of the PIOWS pilot study on 11 February 2009. The primary field campaign will occur between 1 November 2009 and 1 March 2010.

Experimental Design

The PIOWS will include both ground-based mobile platforms and the NCAR C-130 aircraft equipped with an array of cloud physics probes, the Wyoming Cloud Radar, and the Wyoming Cloud Lidar. The ground-bases assets include a WSR-88D radar which serves as one of 12 anchor points includng Omaha, Minneapolis, Des Moines, LaCrosse, Milwaukee, Davenport, Chicago, Lincoln, St. Louis, northern Indiana, Indianapolis, and Evansville. Other mobile assets will complete a meso-γ-scale network that will cover a domain of ~2000 km^2. The *Mobile Alabama X-band* (MAX) dual polarization radar will form a dual Doppler network with a baseline of 30-40 km, as shown in the figures below. The *Mobile Integrated Profiling System* (MIPS) will be placed on one dual Doppler lobe, and the NCAR *Mobile Integrated Sounding System* will be located in the other. The MIPS will include a 915 MHz wind profiler, an X-band profiling radar, a microwave profiling radiometer, and a lidar ceilometer. Surface instrumentation will consist of a Parsivel disdrometer, a snowflake imager, and conventional meteorological instrumentation. The University of Missouri sounding system will be co-located with the MIPS. The MIPS, MAX, and MISS sites will also include electric field mills.



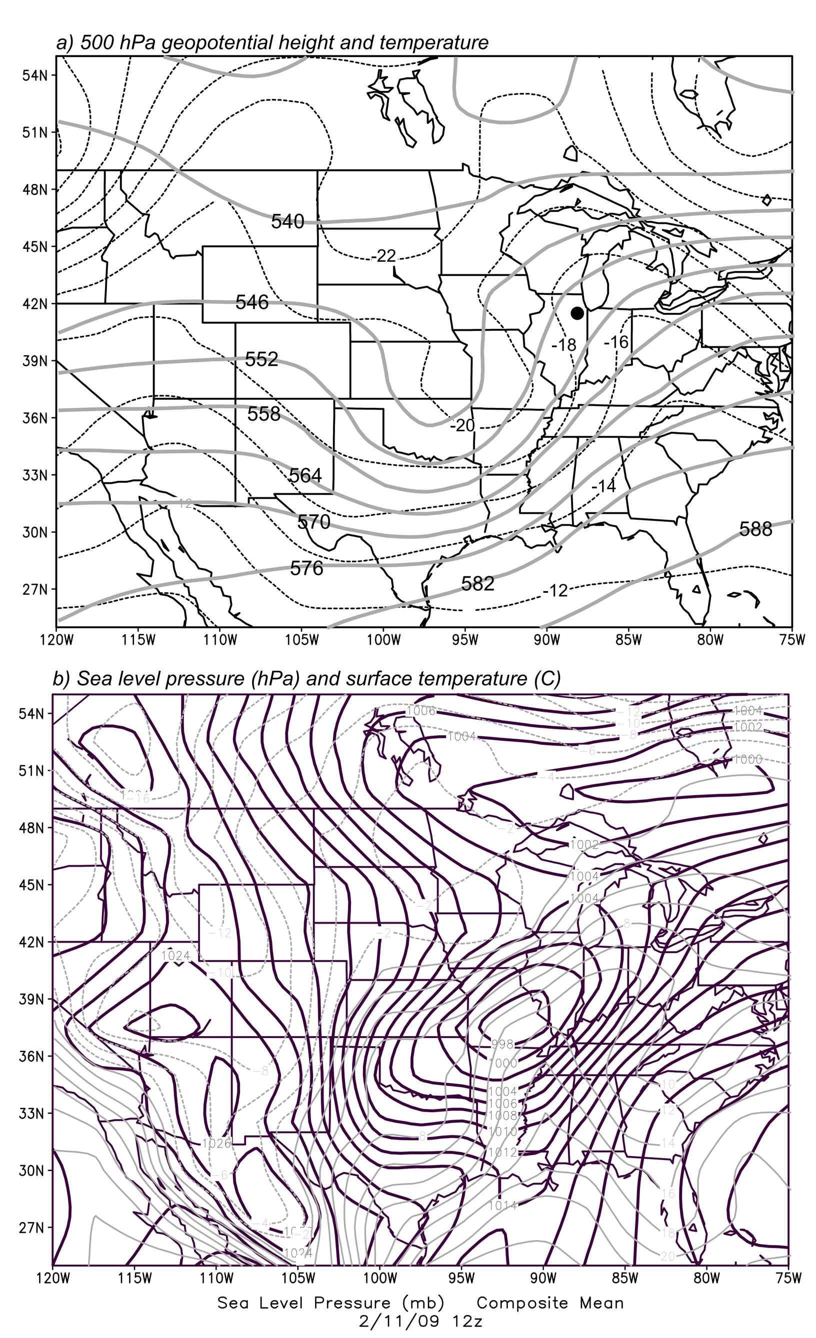
Generic experimental design for the primary PIOWS filed campaign between 1 Nov 2009 and 1 Mar 2010



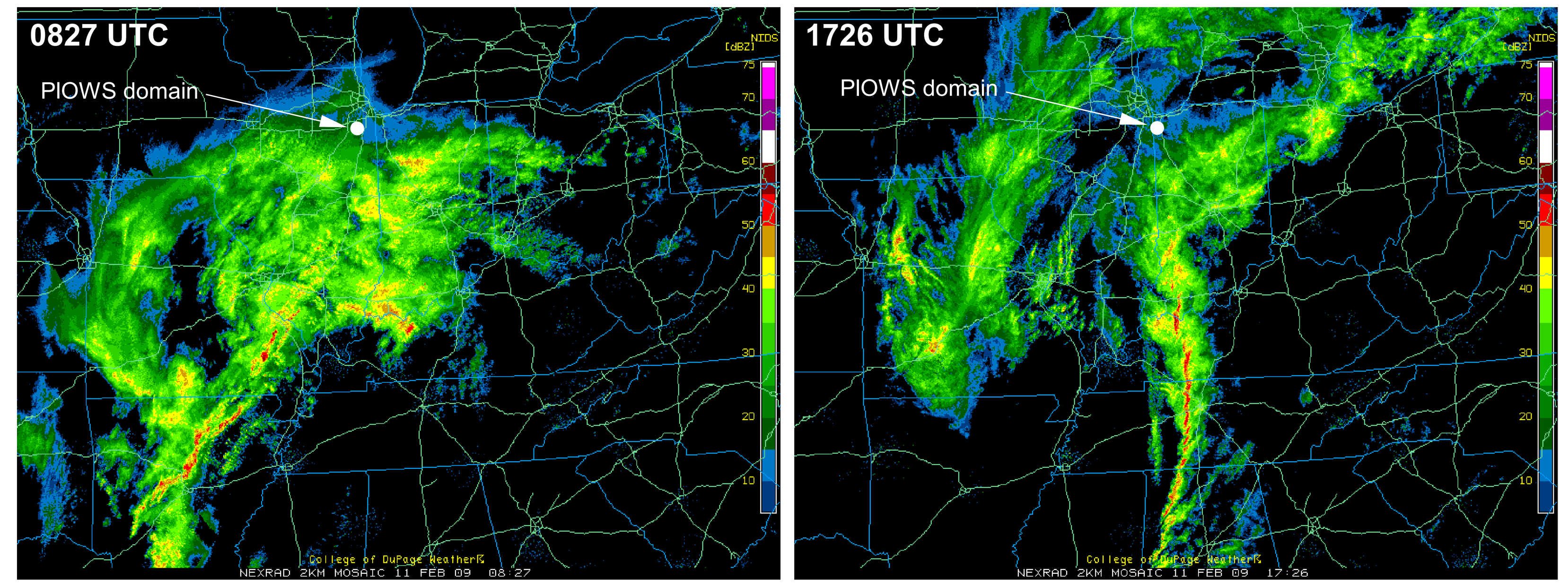
Experimental design for the pilot PIOWS field phase on 11 February 2009. The MIPS and MAX were co-located for comparison between MAX and 915 MHz wind profiler vertically-pointing measurements

Synoptic setting

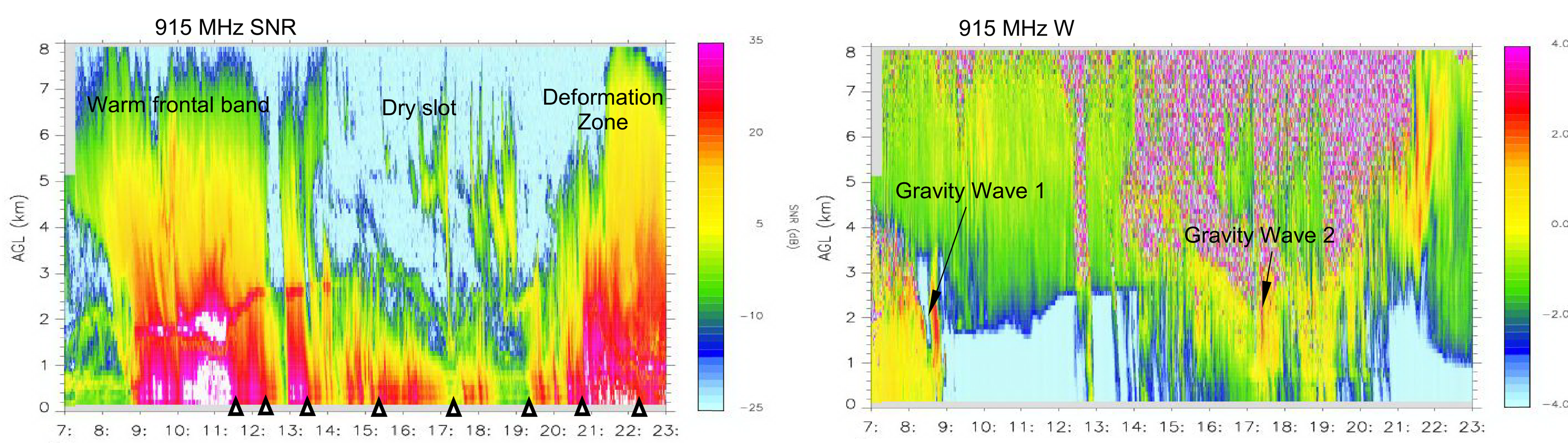
Figures on the right show the 500 hPa analyhsis (top) and surface analysis (bottom) at 0600 UTC, 11 February 2009. The 500 hPa chart includes geopotential height and isotherms. The surface analysis includes sea level pressure isobars drawn every 2 hPa and isotherms drawn at 2 °C intervals. In this case, an intensifying cyclone located over Missouri passed just south of the PIOWS experimental domain, marked with a dot in the top panel. Due to warm temperatures at lower levels, all precipitation at the surface was rain.



Overview

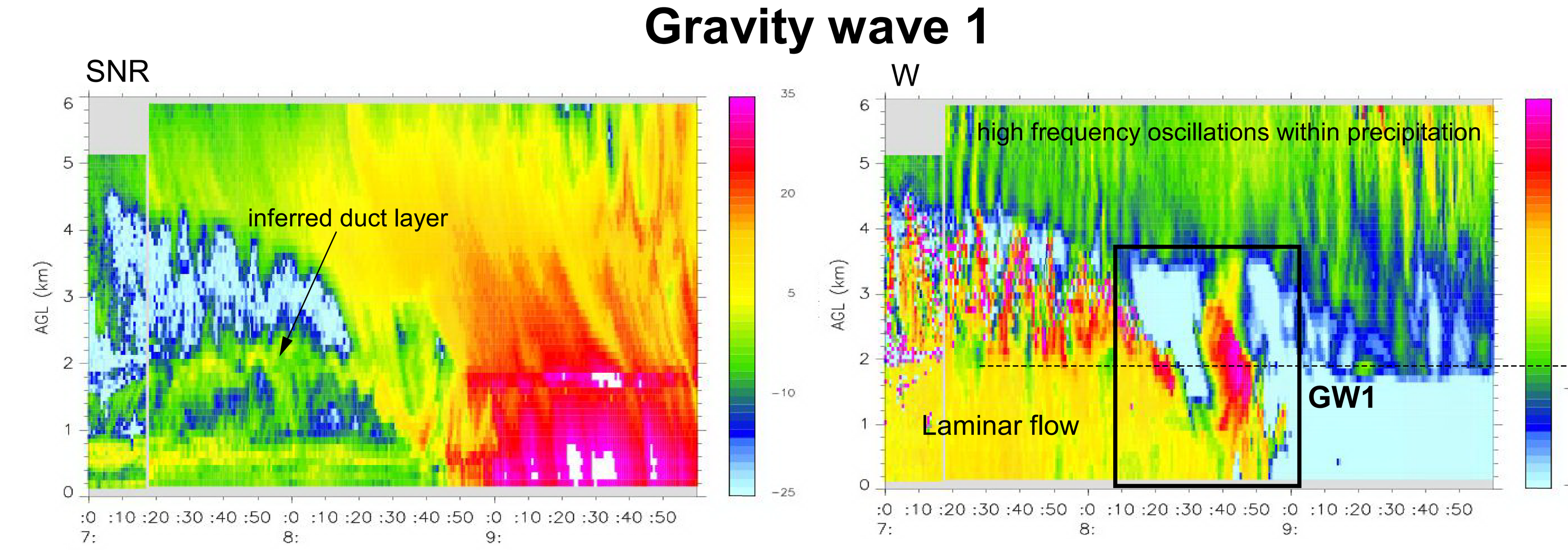


Composite radar at the times of passage of gravity waves 1 and 2 are shown above. The first gravity wave preceded the warm frontal precipitation band, while the second occurred within the dry slot near the times shown. The white dot indicates the location of the PIOWS domain.

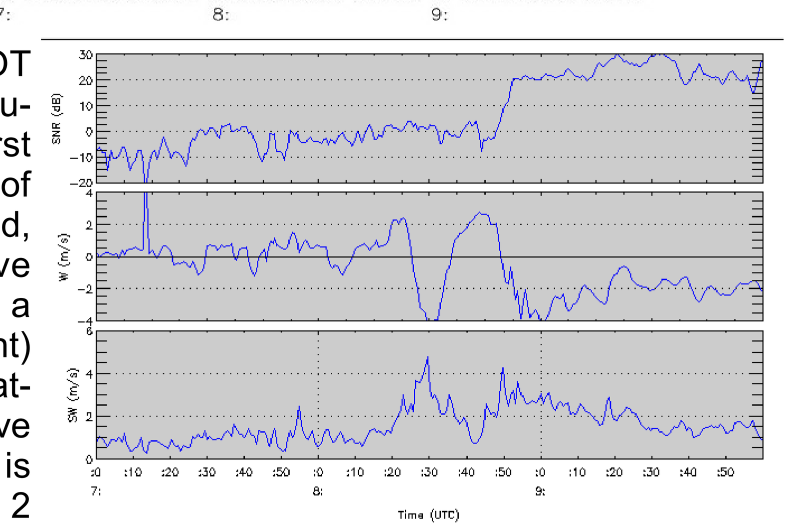


Time vs. height section of vertical beam measurements from the MIPS 915 MHz wind profiler during the cyclone passage. Signal-to-noise ratio is shown on the left, Triangles indicate times of sounding releases. Doppler velocity (W = w + V_T) is shown on the right, with the gravity wave passage times annotated.

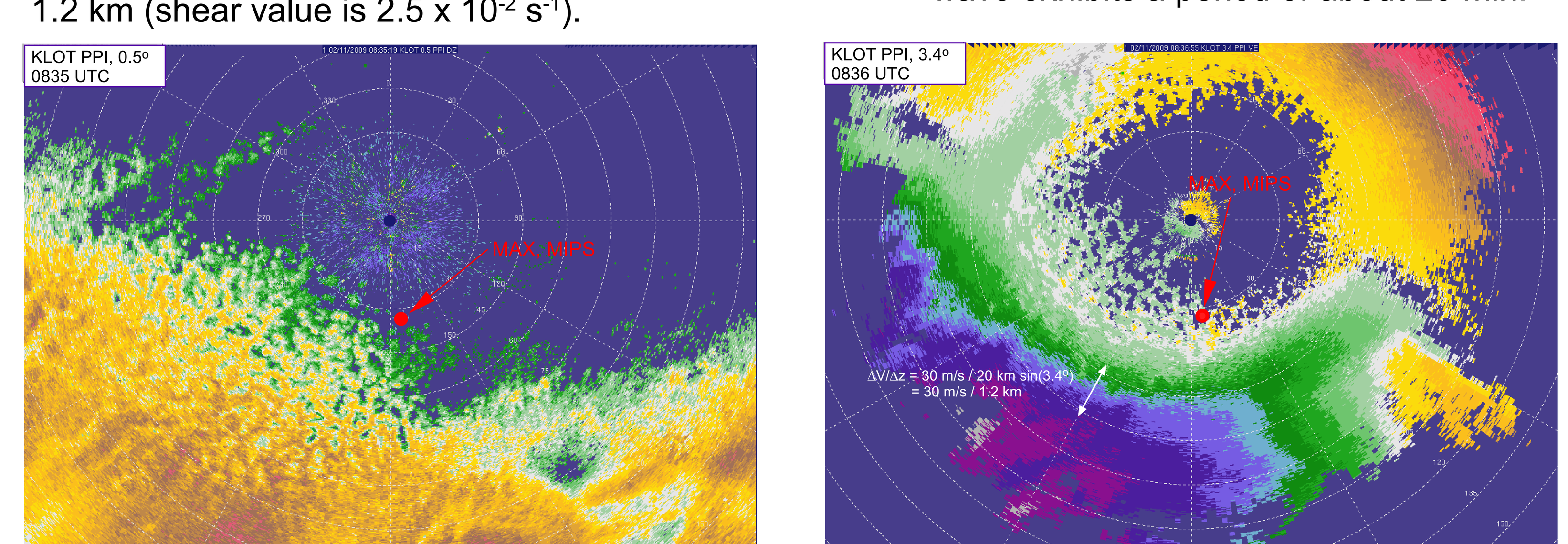
Gravity wave 1



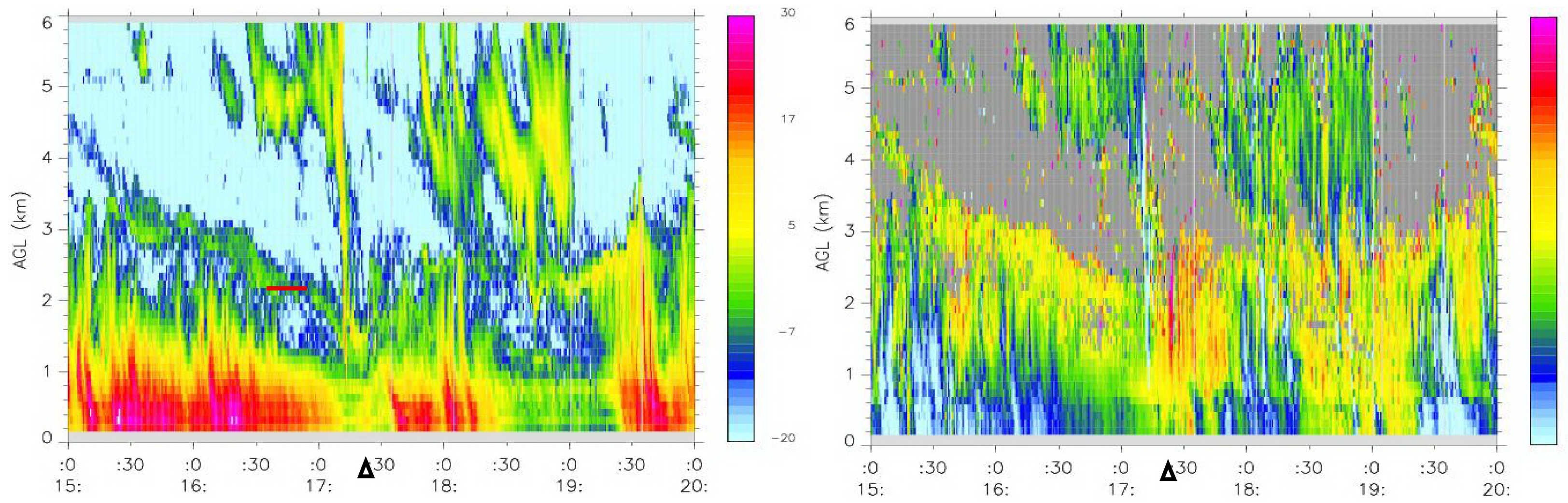
Gravity wave 1 was sampled by the MIPS and KLOT radar, but surface data were not yet available to document the surface pressure oscillation. Since the first sounding was 3 h later, the environment in advance of the warm frontal precipitation band was not well defined, but we are reasonably certain that the gravity wave shown in the right panel (above) was located within a well-defined duct. The variation in vertical motion (right) was about +/- 3 m/s. The 915 SNR enhanced backscatter centered near 2 km implies a gradient in refractive index (and hence a possible duct). The W pattern is laminar below this stable layer, and turbulent above 2 km within the conditionally unstable layer. The wave does not have a signature in the WSR-88D Z or Vr fields (below). The precipitation pattern is cellular, and a significant shear layer is centered near 4 km AGL, where the flow increases by ~30 m/s over a vertical depth of 1.2 km (shear value is 2.5 x 10^{-2} s^{-1}).



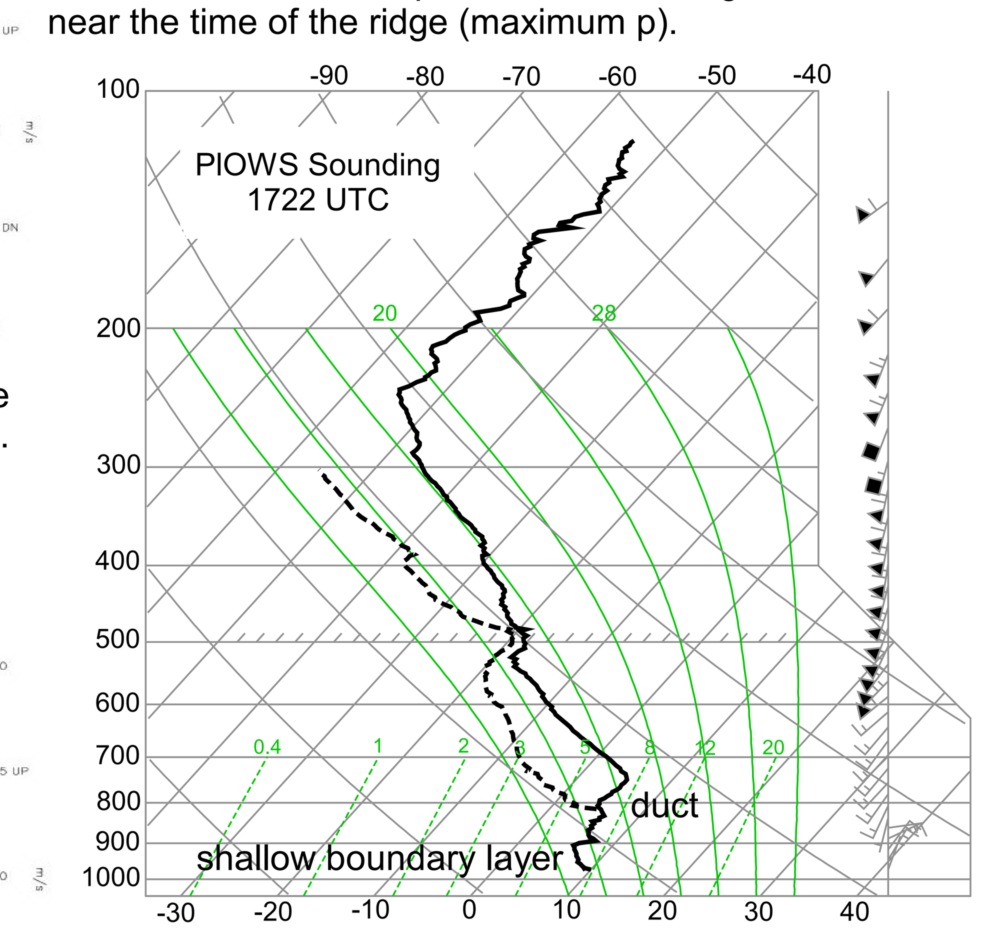
The figure above is a time series of profiler moments (SNR, top; W, middle; and spectrum width, bottom) at the 1.9 km level (refer to figure above this one). The gravity wave exhibits a period of about 20 min.

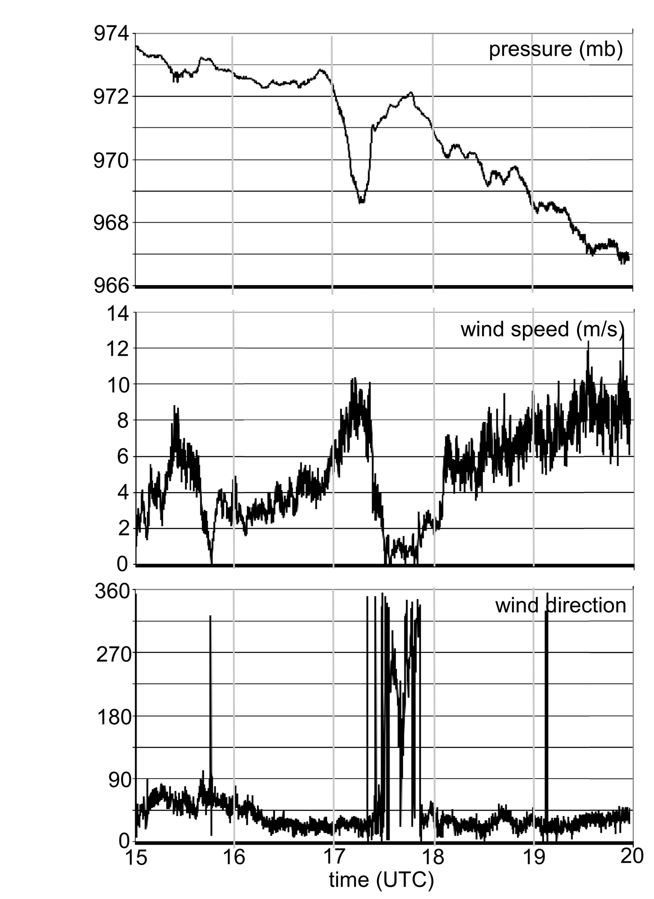


Gravity wave 2



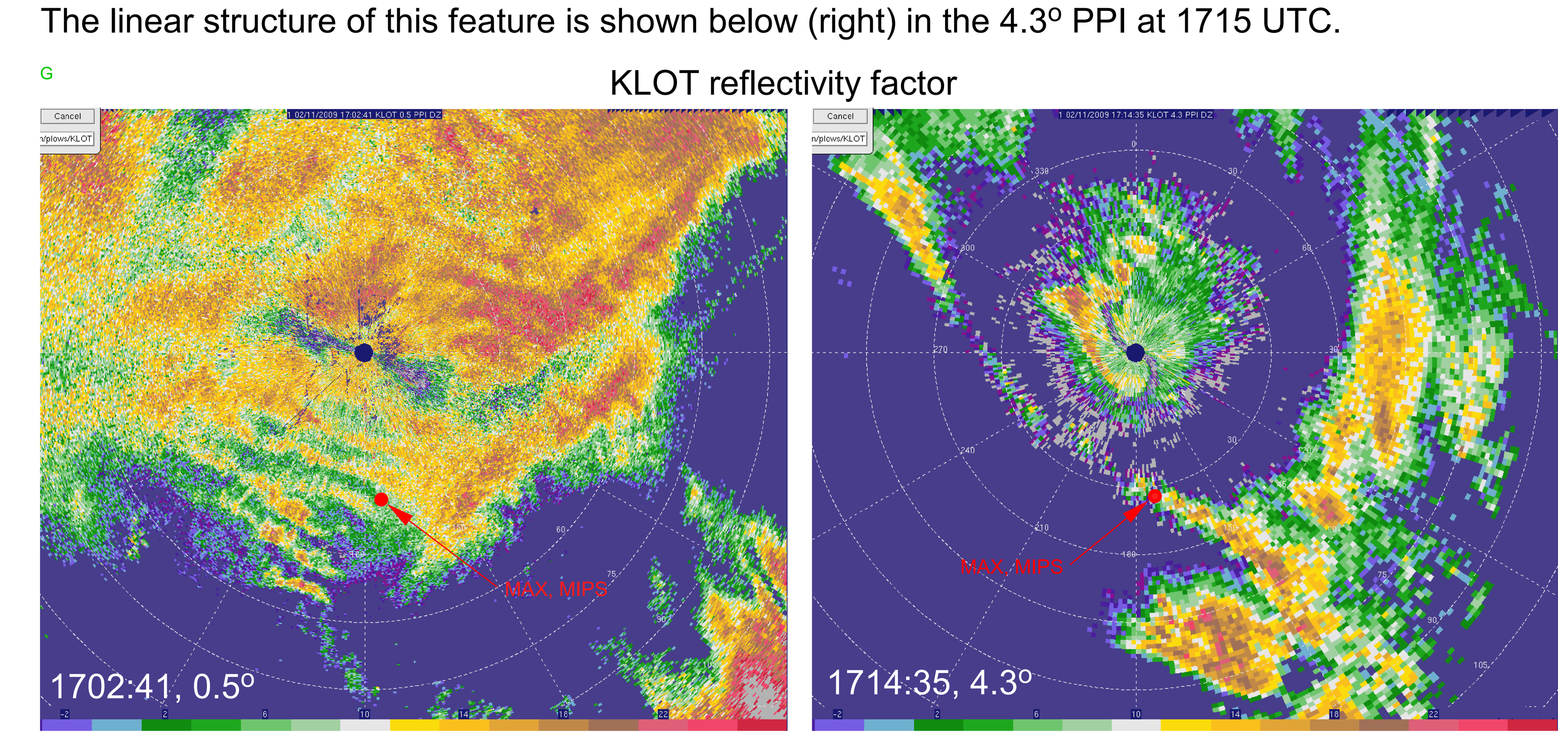
Gravity wave 2 occurred within the dry slot very near the time of a sounding release 20 km to the NNW. The sounding shows a prominent duct below 740 mb (~2.4 km AGL), which is shown in the SNR t-z section above as a red line segment. The sounding is generally isothermal between 900 and 740 hPa, and the top of a shallow boundary layer is indicated near 900 hPa. The SNR t-z section indicates a variable height of the duct layer. Interestingly, the dry slot is filled with scattered precipitation columns most prominent within the 3-6 km AGL layer. The W t-z section (above right) indicates a weaker oscillation in W when compared to gravity wave 1. Time series of pressure indicate one prominent wave with initial and secondary crests occurring near 1655 and 1745 UTC, yielding a period of about 50 min. The surface wind shows a corresponding oscillation consistent with that of a ducted wave, with the peak wind occurring near the time of the trough and a minimum wind speed near the time of the ridge (maximum p).





The KLOT Z and Vr images below indicate that wave activity was prominent around this time. A wave train consisting of 7 maxima in Z is indicated south of KLOT in the 0.5° PPI scan at 1703 UTC. The p time series reveals only subtle variations prior to 1702, and modest variations after 1800 UTC. The major pressure oscillation did not exhibit a prominent low-level signature in either the KLOT or MAX radar Z or Vr fields. Rather, a linear Z feature at higher levels corresponds to this major pressure oscillation. It is also noted in the 915 SNR t-z section as the vertical column between 1.5 and 5 km AGL at about 1715 UTC. The base of this column is close to the duct level. The linear structure of this feature is shown below (right) in the 4.3° PPI at 1715 UTC.

KLOT reflectivity factor



Summary

In this case two major gravity waves were observed, one at the leading edge of the warm frontal precipitation band, and the other within the dry slot. In general, gravity wave activity within the dry slot was common. A more extended analysis of this event will investigate the forcing mechnanisms of these gravity waves, which is not clear from this preliminary analysis.

The PIOWS data sets will provide a very comprehensive data set on fine details of gravity waves and their evolving mesoscale environment over a domain that offers very high temporal and spatial resolution of both the kinematics and thermodynamics.

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