Radar Kinematic Information as Surrogate for Thermodynamic Information in Stratiform Precipitation Systems

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Introduction

Field campaigns studying precipitation systems typically are rich in kinematic information from Doppler radar systems, but relatively poor in thermodynamic information. Thermodynamic information (temperature, humidity) can be inferred from a variety of experimental and operational remote sensing techniques using spaceborne or ground-based platforms, but such information is either unavailable or challenged in clouds and/or precipitation. This explains why the old technology of radiosondes is still in high demand in field campaigns studying precipitation systems, even though radiosonde data are just one-dimensional. Here we illustrate that thermodynamic information can be gleaned from radar-derived kinematic data in stratiform precipitation systems. This study is based on the fortuitous discovery that horizontal vorticity, derived from highly-resolved vertical-plane Doppler radar data, is found to be highly striated in laminar flow.

The Discovery of Vorticity Layers

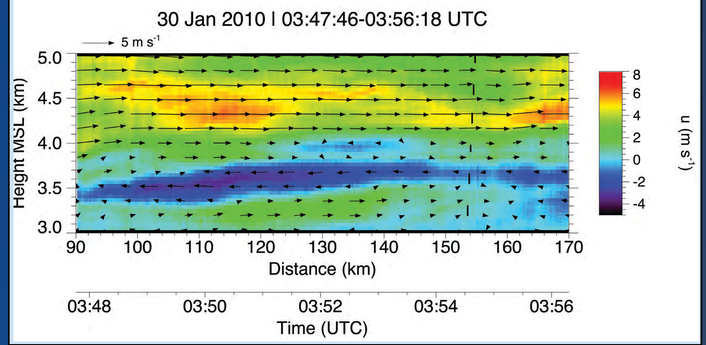

Figure 1: Dual-Doppler synthesis of the horizontal wind aligned with the flight track on 30 January 2010 from the Profiling of Winter Storms (PLOWS) field campaign.

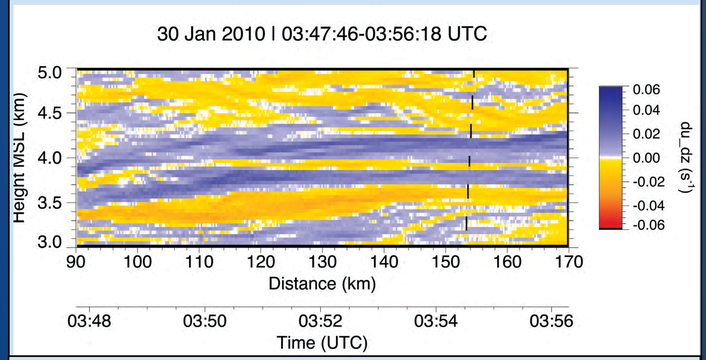

Figure 2: Dual-Doppler synthesis of the vertical shear of the horizontal wind on 30 January 2010 from the PLOWS field campaign.

Conservation of Horizontal Vorticity

Horizontal vorticity is relatively conserved in laminar flow and above the planetary boundary layer, as shown in Fig. 1. While horizontal vorticity can be modified in several ways:

- Stretching and reorientation of vorticity is greatly reduced in laminar flow
- Baroclinic generation is minimized in weak horizontal temperature gradients along the flight track
- Viscous effects are minimal above the planetary boundary layer

Under these conditions, horizontal vorticity may act as a streamline/tracer for a material surface (a thermodynamic variable).

Relevance to the 2017 AMS Mission "Observations Lead the Way"

Q: Can these horizontal vorticity layers be detected and monitored using operational radars?
A: No: operational radar networks apply *volume* coverage patterns, not vertical transects (RHIs).

Q: What is needed to make this operational?
A: Even if radars do conduct RHIs, their vertical resolution degrades rapidly with range (i.e., ~160 m resolution within 10 km of radar and ~800 m resolution within 50 km of radar). Thus, a dense network of narrow-beam radars would be needed. X-band radars would suffice for this purpose.

Synoptic Conditions During Flight Tracks

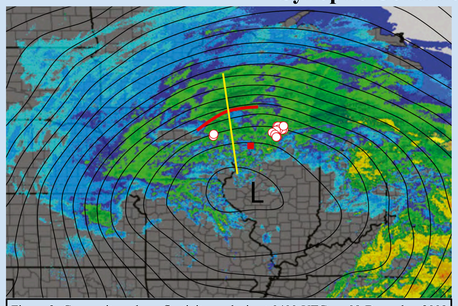

Figure 3: Composite radar reflectivity analysis at 0400 UTC on 09 December 2009 during the PLOWS field campaign. The flight track is shown by the yellow line (source: Rauber et al. 2014a[a]).

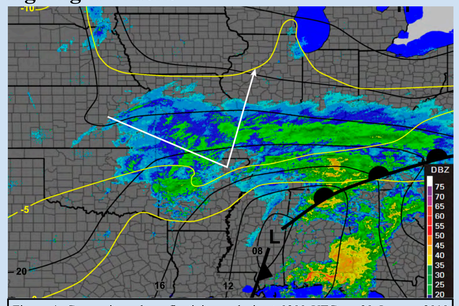

Figure 4: Composite radar reflectivity analysis at 0300 UTC on 30 January 2010 during the PLOWS field campaign. The flight track is shown by the north-south oriented white line (source: Rauber et al. 2014b[b]).

Are these Layers Material Surfaces?

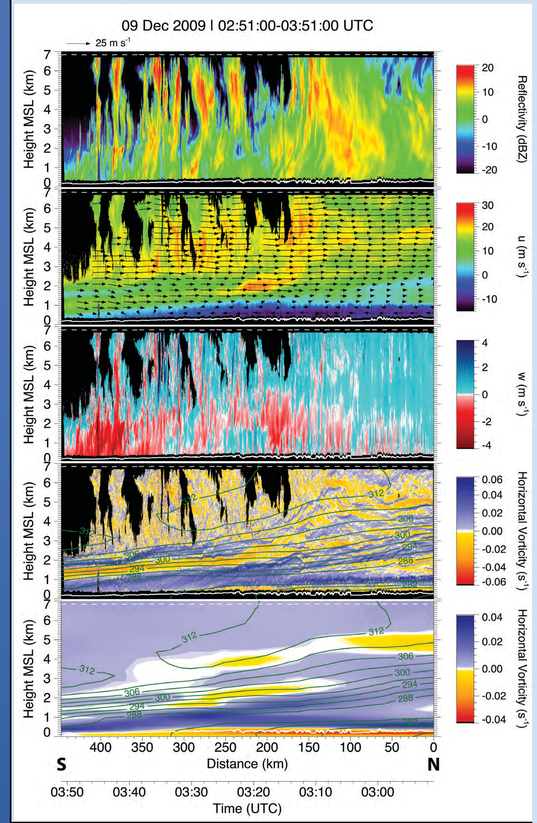

Figure 5: (a) WCR reflectivity, (b) horizontal wind aligned with the flight track, plus 2D wind vectors, (c) vertical velocity, (d) radar-derived horizontal vorticity, and (e) model horizontal vorticity for the flight track on 09 December 2009 during PLOWS. Horizontal vorticity in (d) and (e) are overlaid with model θ_e. The dashed white line near the top of each panel is the flight level, and the solid white line near the bottom is the ground.

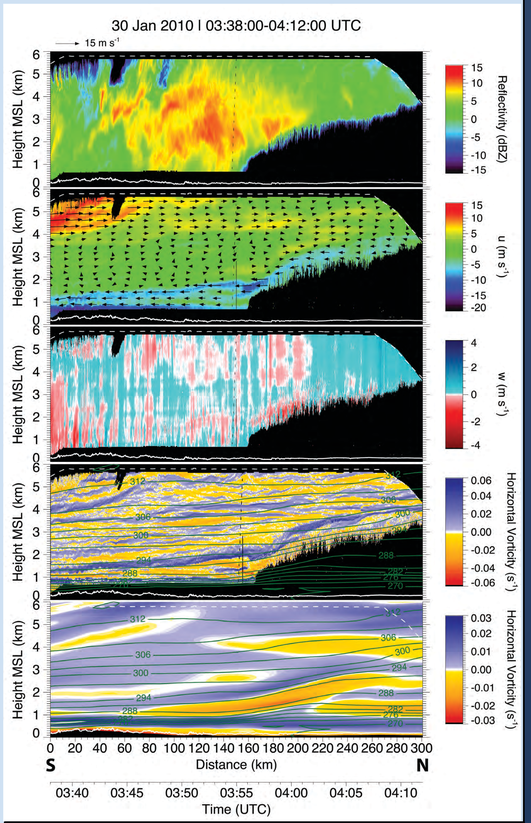

Figure 6: (a) WCR reflectivity, (b) horizontal wind aligned with the flight track, plus 2D wind vectors, (c) vertical velocity, (d) radar-derived horizontal vorticity, and (e) model horizontal vorticity for the flight track on 30 January 2010 during PLOWS. Horizontal vorticity in (d) and (e) are overlaid with model θ_e. The dashed white line near the top of each panel is the flight level, and the solid white line near the bottom is the ground.

Why Horizontal Vorticity is not Associated with the Thermal Wind

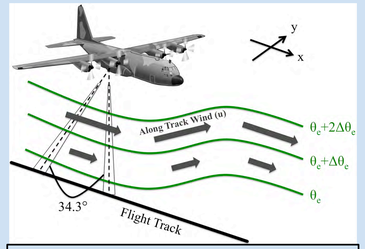

Figure 7: A schematic of the C-130 aircraft flown in the PLOWS field campaign.

- Horizontal vorticity is calculated via dual-Doppler synthesis along the flight track in the relative x-direction (Fig. 7)
- These horizontal vorticity striations follow isentropic layers along the flight direction

- The along track thermal wind component is given as: $v_t = -\frac{R_d}{f}\ln\left(\frac{p}{p}\right)\frac{\partial T}{\partial y}$
- The u-component of the thermal wind along the flight track is a function of the temperature gradient in the y-direction
- Since the along track thermal wind is associated with the temperature gradient perpendicular to the flight track, the horizontal vorticity examined is not associated with the thermal wind
- Furthermore, the temperature gradient along the flight track can be calculated, but results in the thermal wind into or out of the transect
- The across track thermal wind component is given as: $v_t = \frac{R_d}{f}\ln\left(\frac{p}{p}\right)\frac{\partial T}{\partial x}$
- This v-component of the thermal wind has no relationship to the along track wind and resulting horizontal vorticity

The Use of Horizontal Vorticity to Explore the Dynamics of Orographic Precipitation

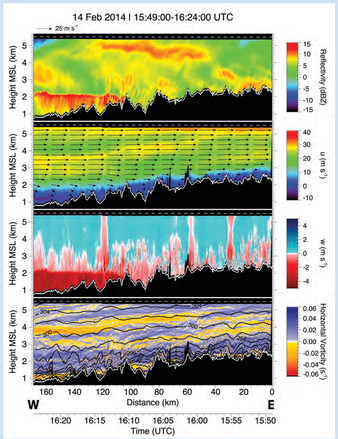

Figure 8: (a) WCR reflectivity, (b) horizontal wind aligned with the flight track, plus 2D wind vectors, (c) vertical velocity, and (d) radar-derived horizontal vorticity overlaid with model θ_e for the flight track on 14 February 2014 during the PRESNOWIE field campaign. The dashed white line near the top of each panel is the flight level, and the solid white line near the bottom is the ground.

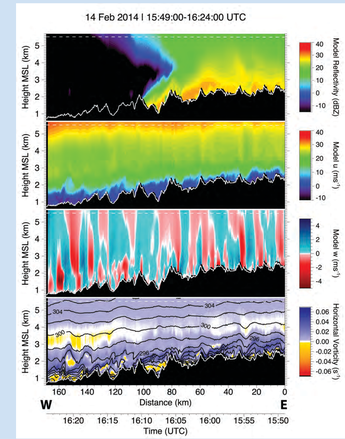

Figure 9: (a) WRF model reflectivity, (b) model horizontal wind aligned with the flight track, (c) model vertical velocity, and (d) model-derived horizontal vorticity overlaid with model θ_e for the flight track on 14 February 2014 during the PRESNOWIE field campaign. The dashed white line near the top of each panel is the flight level, and the solid white line near the bottom is the ground.

Summary

- Field campaigns are generally abundant in kinematic information, but lack thermodynamic information
- Through a fortuitous discovery, it was found that horizontal vorticity is highly striated in laminar flow
- This horizontal vorticity is mostly attributed to the vertical shear of the along track wind
- Horizontal vorticity is relatively conserved within laminar flow and above the planetary boundary layer
- The thermal wind is not associated with horizontal vorticity in the cases examined due to the fact that:
  - The along track thermal wind component results from the unobserved temperature gradient in the y-direction perpendicular to the flight track
  - The temperature gradient that can be calculated along the flight track results in the thermal wind component into or out of the transect
- Horizontal vorticity acts as a tracer for material surfaces (i.e., the thermodynamic variable of equivalent potential temperature)
- The relationship between horizontal vorticity and isentropes can be used to evaluate the large-scale and finescale structure of orographic precipitation

[a]Rauber, R.M., and co-authors, 2014a: Stability and charging characteristics of the comma head region of continental winter cyclones. *J. Atmos. Sci.*, **71**, 1559–1582, doi: 10.1175/JAS-D-13-0253.1.

[b]Rauber, R.M., M. K. Macomber, D. M. Plummer, A. A. Rosenow, G. M. McFarquhar, B. F. Jewett, D. Leon, and J. M. Keeler, 2014b: Finescale radar and airmass structure of the comma head of a continental winter cyclone: the role of three airstreams. *Mon. Wea. Rev.*, **142**, 4207–4229, doi: 10.1175/MWR-D-14-00057.1.