How are gravity waves influencing clouds and precipitation?

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Background

Gravity (buoyancy) waves are common in the atmosphere. Prior research has highlighted their role in and creating propagating bands of clouds such as the Morning Glory (Christie, 1992, Aus. Met. Mag.), conditioning the environment for formation of mesoscale convective systems (Mapes, 1993, JAS) and triggering the formation of cellular convection well ahead of squall line thunderstorms (Fovell et al., 2006, MWR). All gravity waves require a trigger and far propagating waves also require a layer of static stability to act as a duct or waveguide.

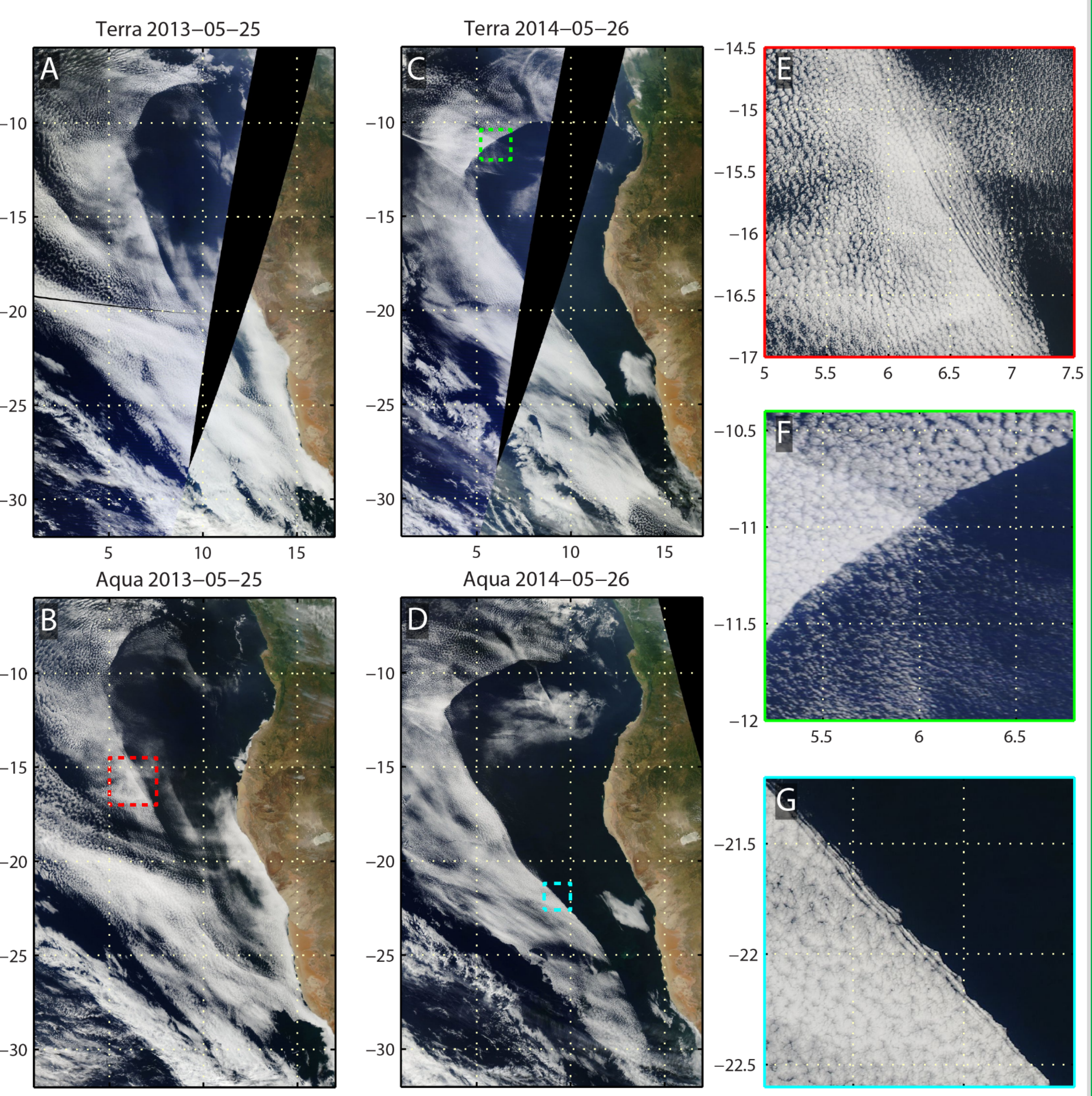
We illustrate pressure sensor measurements of gravity waves and examples where gravity waves likely cause large scale cloud erosion in the southeast Atlantic and influence mesoscale snow banding in winter storms.

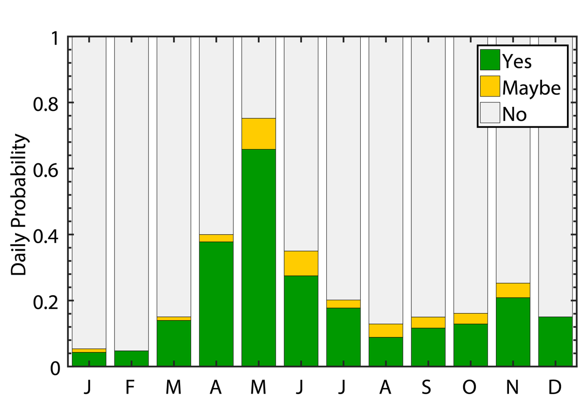
Southeast Atlantic Cloud Clearing and Waves

Throughout the year, the subtropical southeast Atlantic has extensive areas of marine stratocumulus that contribute to regional net cooling. The marine low cloud decks exhibit substantial multi-day variability. Large areas of stratocumulus can be abruptly eroded, yielding partial or complete clearing behind sharp transitions the length of California. Cloud-eroding boundaries move westward at 8 to 12 meters per second and travel as far as 1000+ km from the African coast (*A-D*).

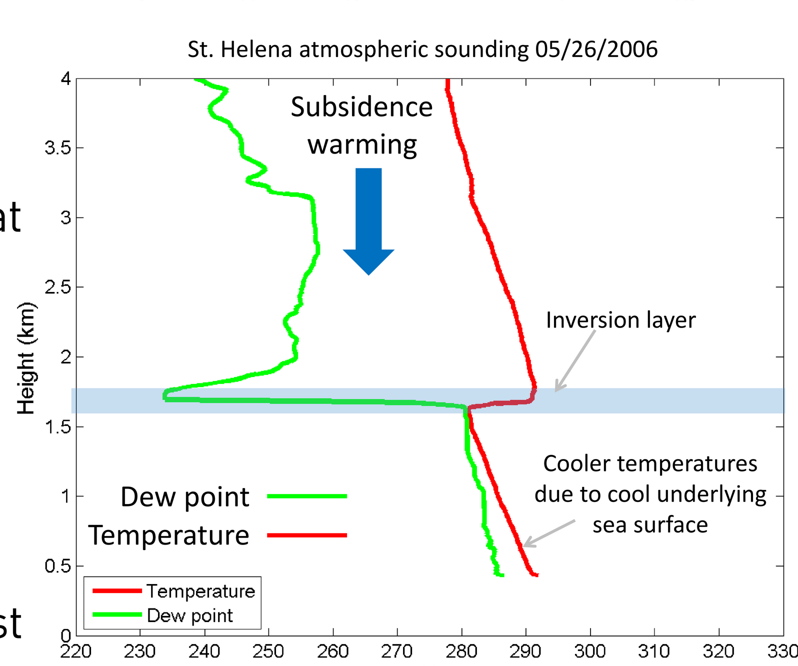
The cloud-eroding boundaries have an annual peak in occurrence in the period from April through June (*below*).

The cloud erosion boundaries often feature small-scale wave features signified by scalloped edges and/or visible wave trains (*right, E-G*).





The cloudiness transitions move west in an environment of prevailing southerly and southeasterly cloud-level winds and a persistent, large-scale stable layer topped by an inversion that can serve as a waveguide (*right*).



We hypothesize that abrupt cloud erosion along sharp boundaries is a consequence of rapid entrainment of warm and dry air from the free troposphere into the cloud layer by enhanced turbulence associated with a solitary wave train excited by offshore flow emanating from southwest Africa.

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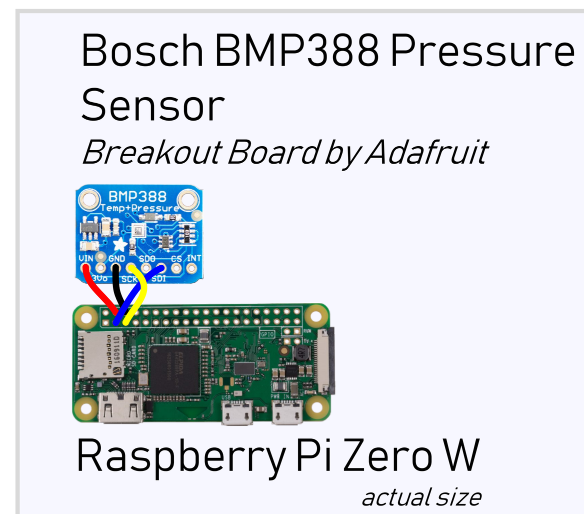
Other References

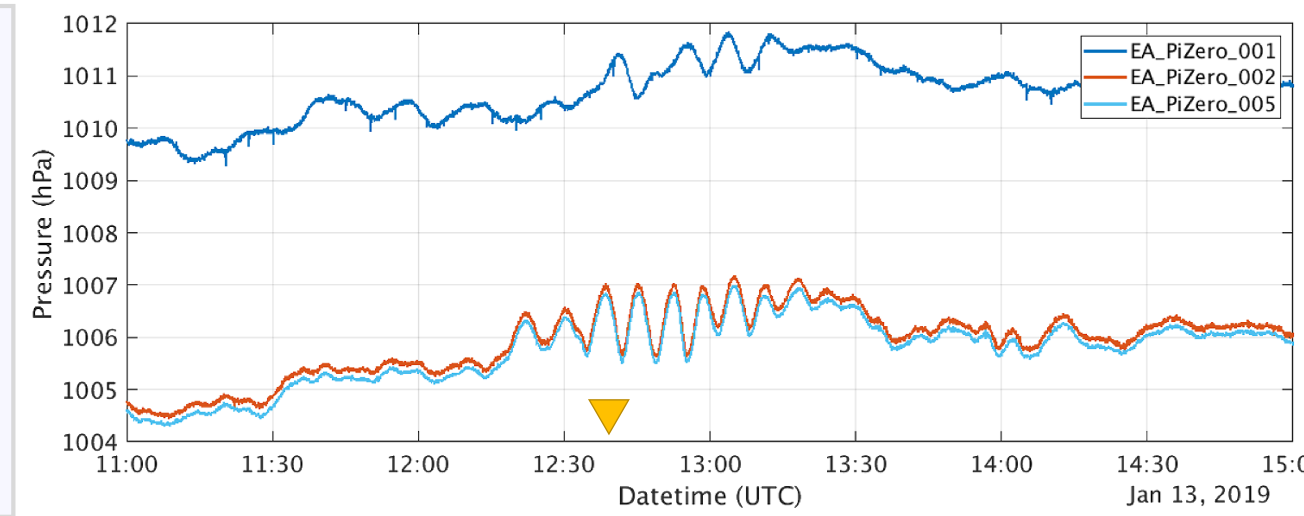
Hoban, N. P., 2016: *Observed Characteristics of Mesoscale Banding in Coastal Northeast U.S. Snow Storms* (master's thesis). North Carolina State University.
Yuter, S. E., J.D. Hader, M. A. Miller, D. B. Mechem, 2018: Abrupt cloud clearing of marine stratocumulus in the subtropical southeast Atlantic, *Science*, DOI: 10.1126/science.aar5836.

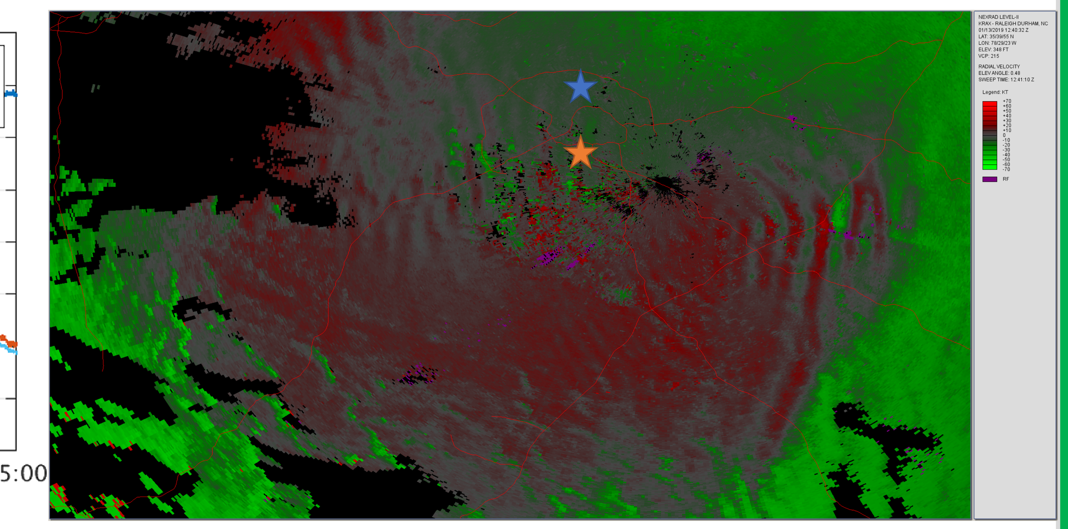
Detecting Gravity Waves with Low-Cost Pressure Sensors

High-precision (0.8 Pa), high-frequency (1 Hz) measurements are needed to detect gravity waves. We have developed low-cost ($50), data-logging pressure sensors. These sensors can be positioned in networks to allow for detection of gravity waves and estimation of wave length, propagation direction and speed, and amplitude.

Pressure sensors at two locations captured a large amplitude gravity wave train during a storm which impacted central North Carolina. The gravity wave had a peak amplitude of at least 1.5 hPa. Radar radial velocity data shows the waves propagating eastward with a wavelength of 6 km.

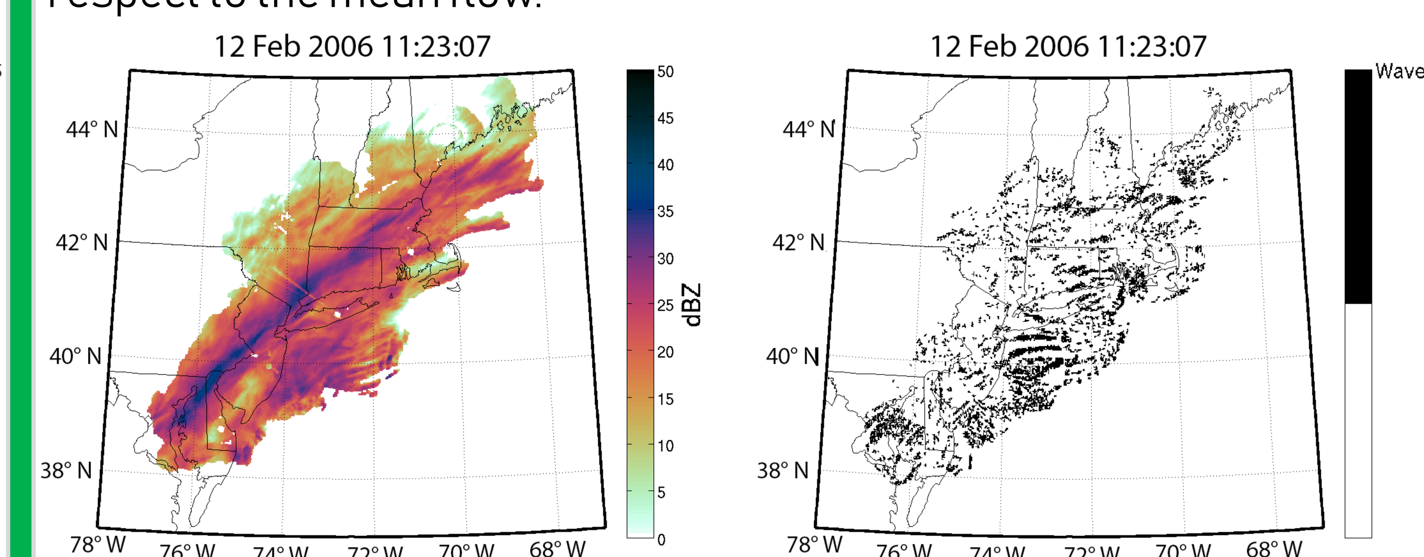




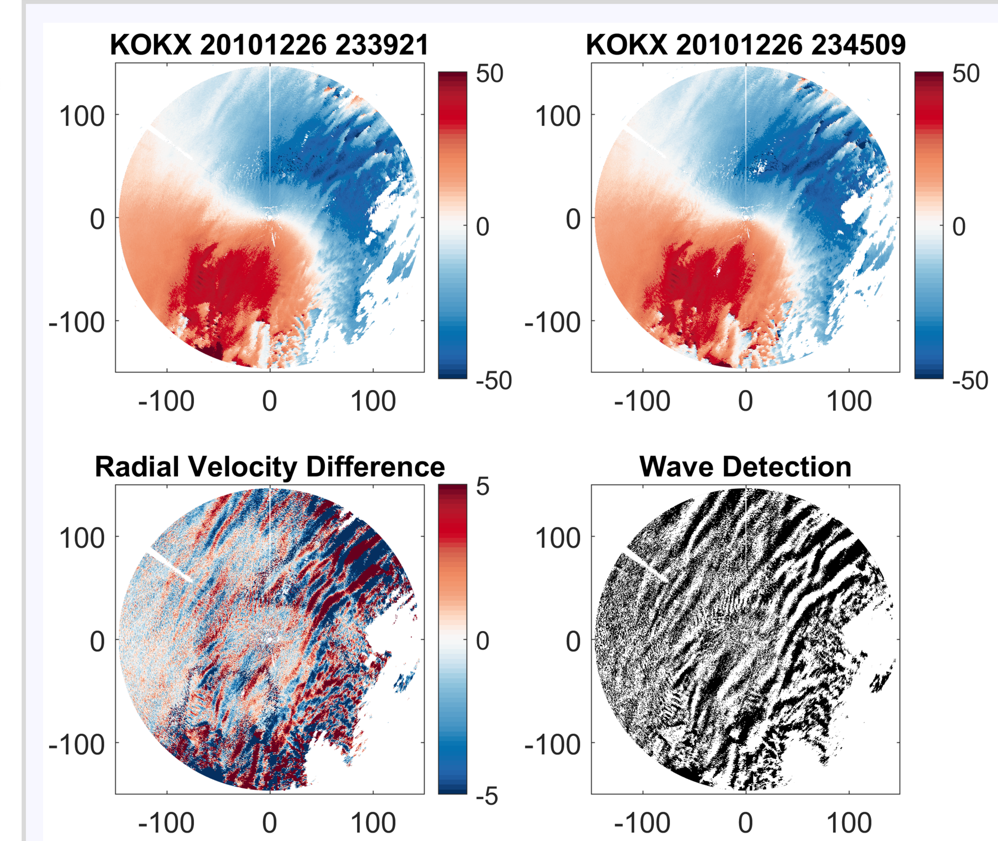


Winter Storms and Waves

Snow accumulation in winter storms in the northeast US is sensitive to the occurrence, intensity, and propagation of mesoscale bands of locally higher precipitation (Novak et al. 2004; Novak et al. 2008; Novak and Colle 2012; Ganetis et al. 2018). Investigation of Doppler radial velocity data for these storms has found the frequent occurrence of sets of transient, wave-like velocity perturbations that move off-axis with respect to the mean flow.



Radar reflectivity and wave detection for data stitched together from six radars in the NE US (*above*). A large SW to NE band of higher precipitation is associated with sets of smaller mesoscale parallel banded features. The wave detection data shows sets of moving velocity perturbations that are coherent and span multiple radar domains. These waves move with a different speed and direction than the precipitation band. Low-level stable layers can serve as waveguides.

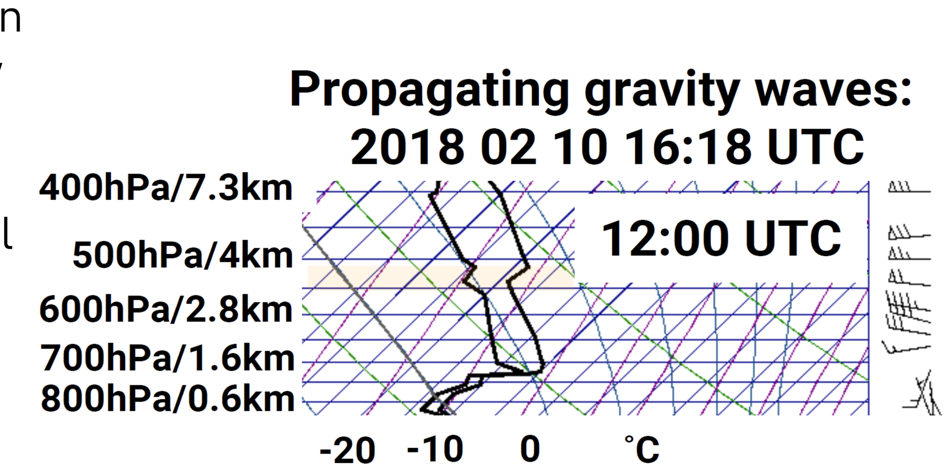


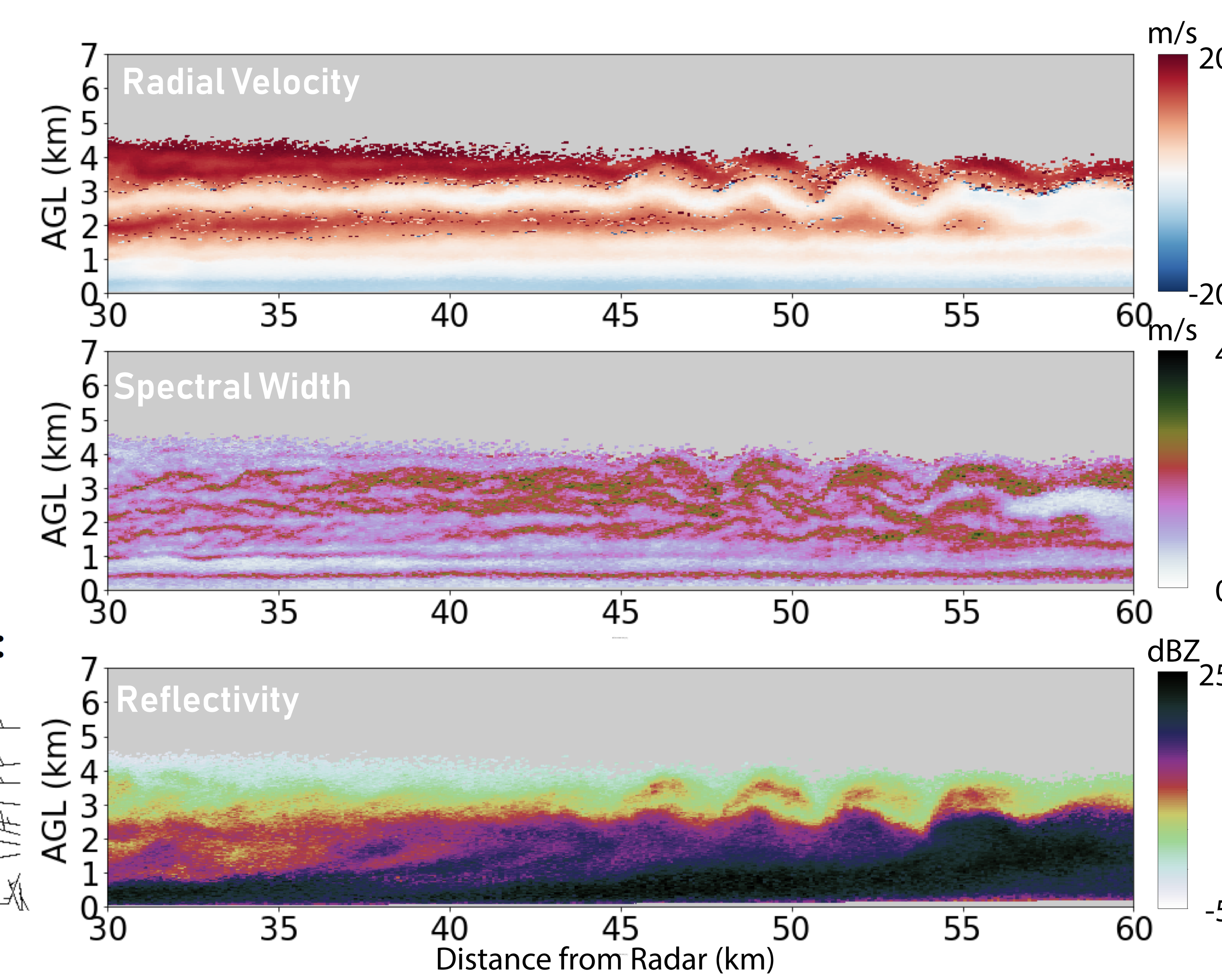
Radar Wave Detection
To identify waves in radial velocity data, we subtract two sequential radial velocity fields to get a difference field.

The difference field contains linearly banded features with both negative and positive values that represent a temporal change in the radial velocity field.

The difference field is converted to a binary field.

Vertical cross-sections from the Colorado State University CHILL radar in Greeley, CO (*right*) show gravity waves within a stable layer of a snow storm. Transient vertical motions caused by the waves may enhance riming.





Summary

- Traditionally gravity waves have been mainly associated with deep convection and transient, propagating cloud-enhancements. Recent analysis of observations has identified gravity wave like features that can erode clouds in the southeast Atlantic and enhance precipitation in winter storms in the U.S.
- Obtaining definitive proof of gravity waves requires networks of pressure sensors. Low-cost, high performance sensors, in combination with operational and research remote sensing observations, will be used to untangle the roles of gravity waves in modifying clouds and winter precipitation.