Investigating Kilometer-Scale Atmospheric Waves in Winter Storms

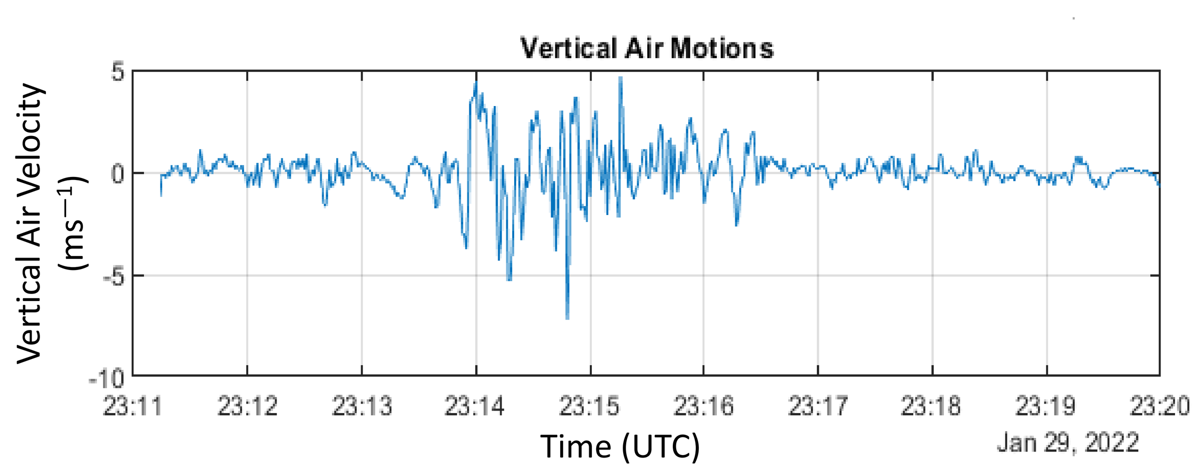
Wayne Johnson[1], Sandra Yuter[1,2], Luke Allen[1,2], and Matthew Miller[1]

[1]Department of Marine, Earth, and Atmospheric Sciences and the [2]Center for Geospatial Analytics, North Carolina State University

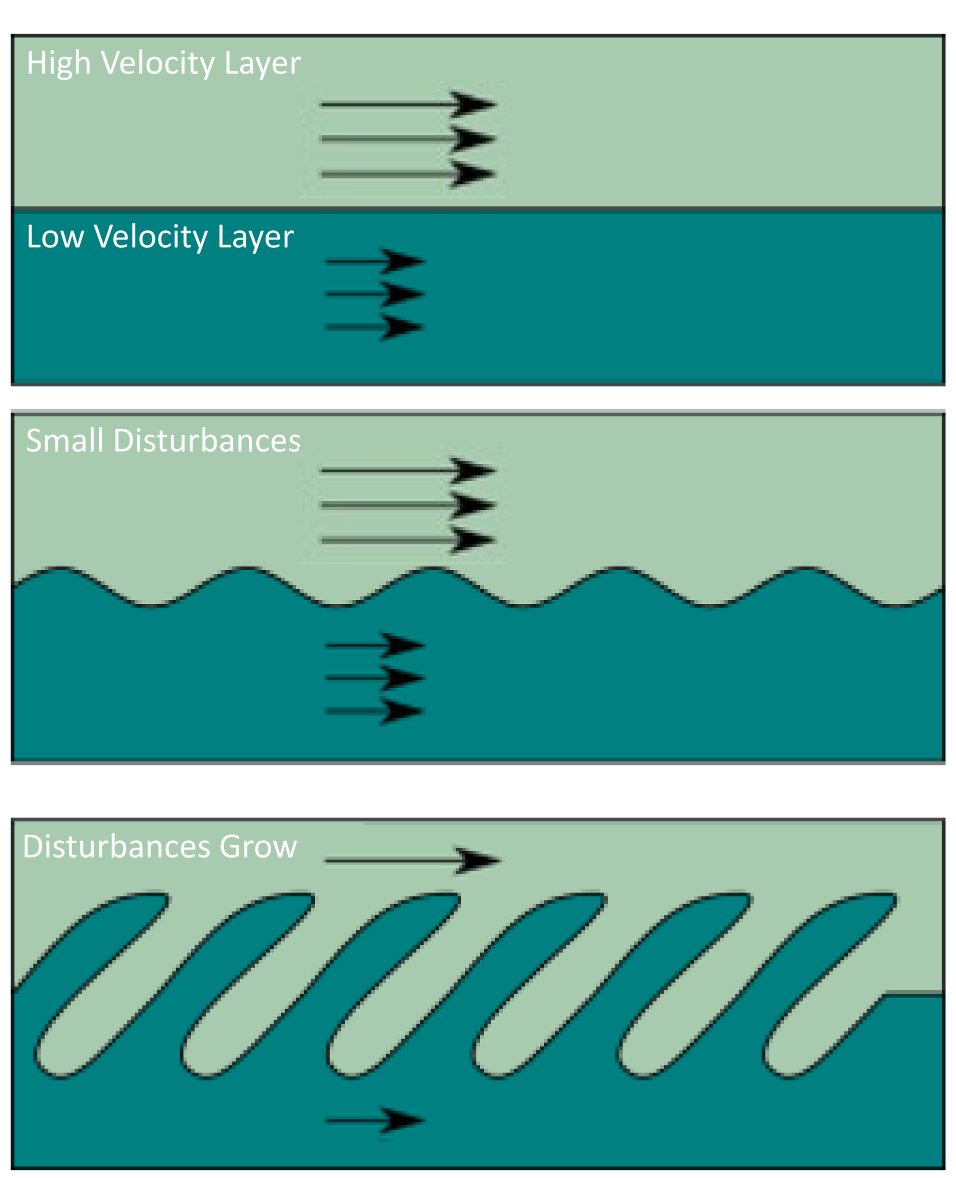
Motivation

The NASA IMPACTS (Investigation of Microphysics and Precipitation for Atlantic-Coast Threatening Snowstorms) campaign flew two research aircraft equipped with weather instruments into storms over three winter seasons. On a flight over the Gulf of Maine on 30 Jan 2022, one of the airplanes experienced severe turbulence, which is unusual in winter storms. Initial analysis of airborne radar data showed a distinct atmospheric wave signature in the same region as the turbulence. We hypothesize that these waves were a result of Kelvin-Helmholtz (K-H) instability. K-H instability occurs in the atmosphere when two adjacent layers of air have different wind velocities. The velocity difference is called vertical wind shear. This causes the boundary between the two layers to fold, forming cresting waves of air.

Example of Turbulent Vertical Air Velocities

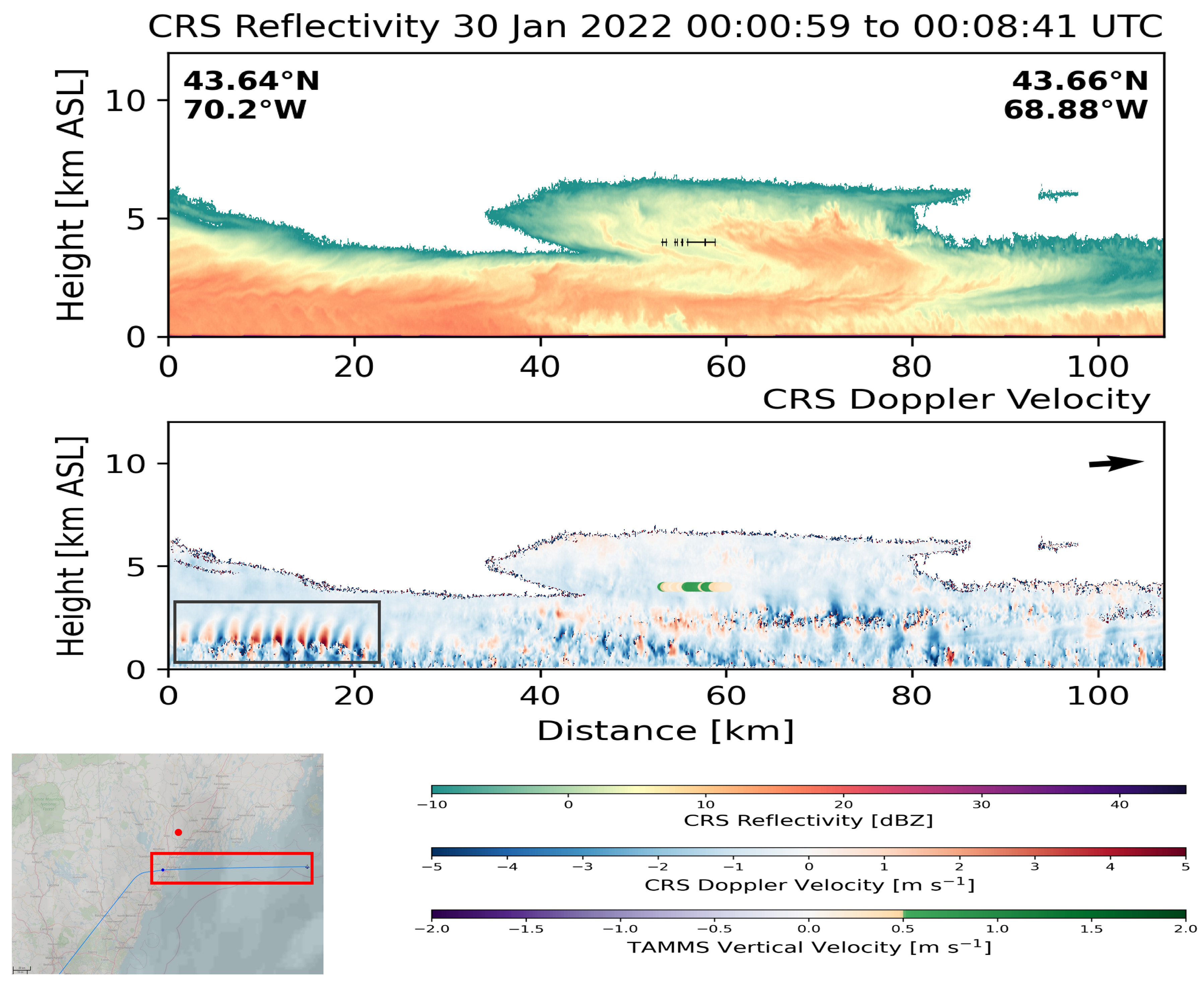


Timeseries of vertical air velocities recorded by the P-3 aircraft during a turbulent flight leg near the recorded wave event.



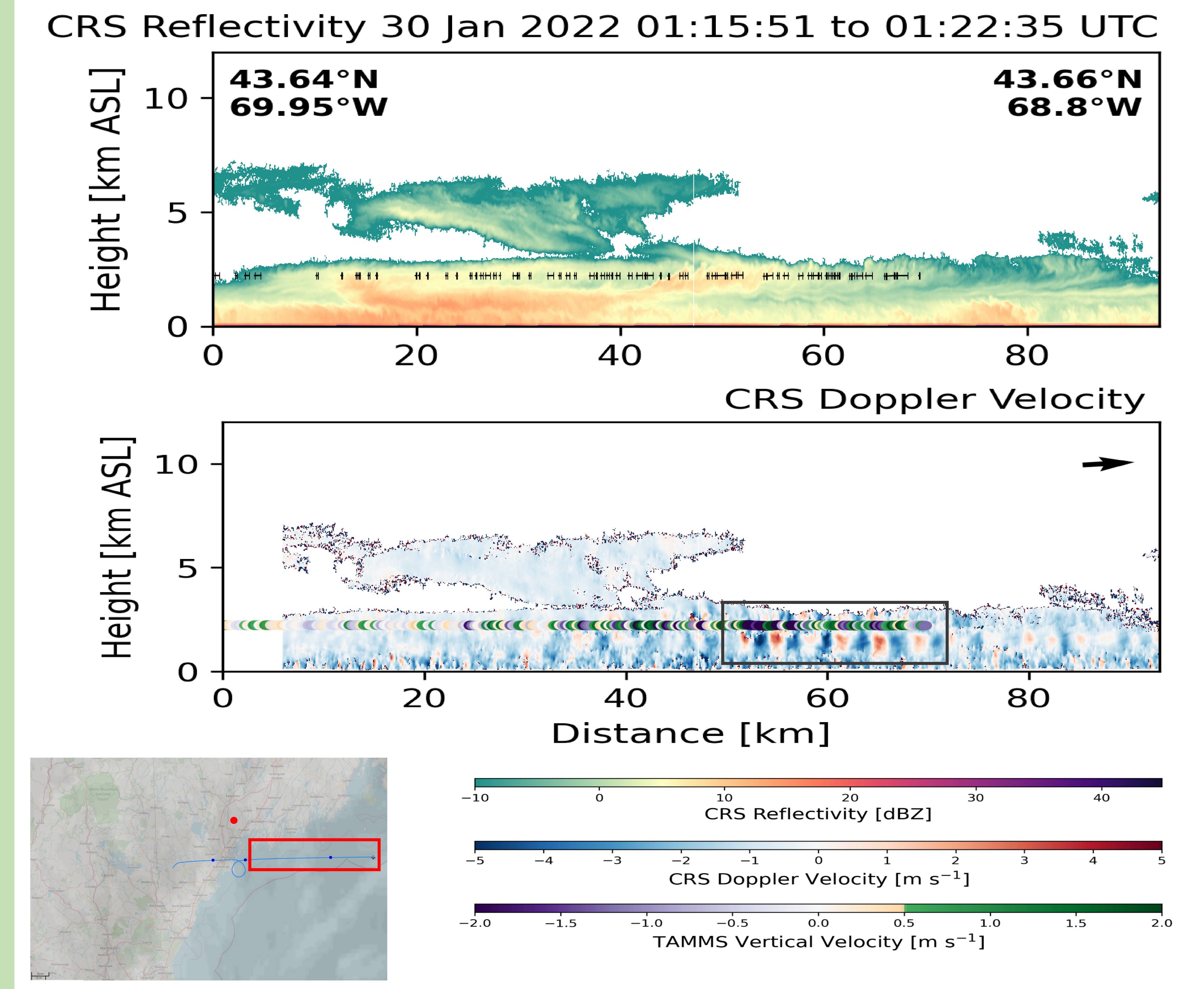
Schematic diagram illustrating how wind shear leads to a Kelvin-Helmholtz instability in the atmosphere.[1]

00:00:59 – 00:08:41 UTC ER-2 Flight Leg



NASA ER-2 cloud radar plots of a flight leg (boxed in red on the lower left map) with strong (0-20 km along leg, boxed in the Doppler velocity plot) and moderate (rest of leg) vertical air velocity variations. The flight path of the NASA P-3 plane is overlaid on the radar plots, the reflectivity plot uses hash marks to denote the path and the dots on the Doppler velocity plot denote in situ vertical velocity measurements made by the P-3 along the flight path.

01:15:51 – 01:22:35 UTC ER-2 Flight Leg

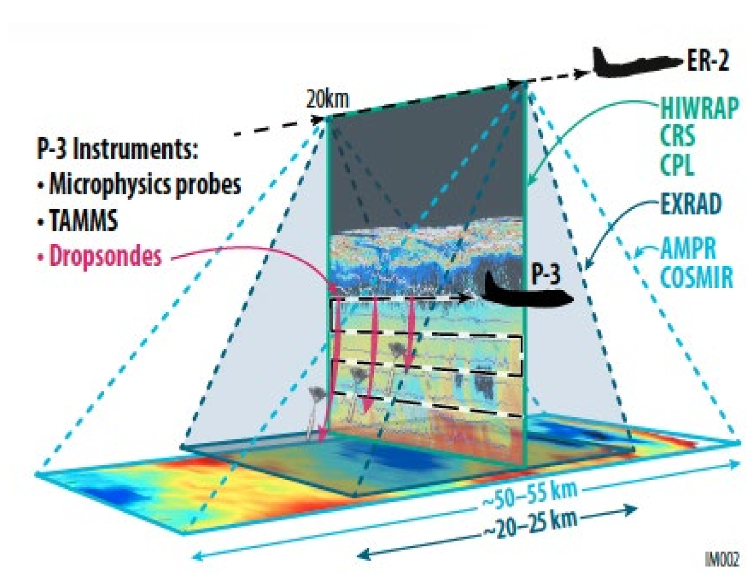


NASA ER-2 cloud radar plots of a flight leg (boxed in red on the lower left map) with strong (50-70 km along leg, boxed in the Doppler velocity plot) and moderate (rest of leg) vertical air velocity variations. The flight path of the P-3 plane is overlayed on the CRS plots, with the dots on the Doppler velocity plot denoting in situ vertical air velocity measurements made by the P-3 plane.

Data and Methods

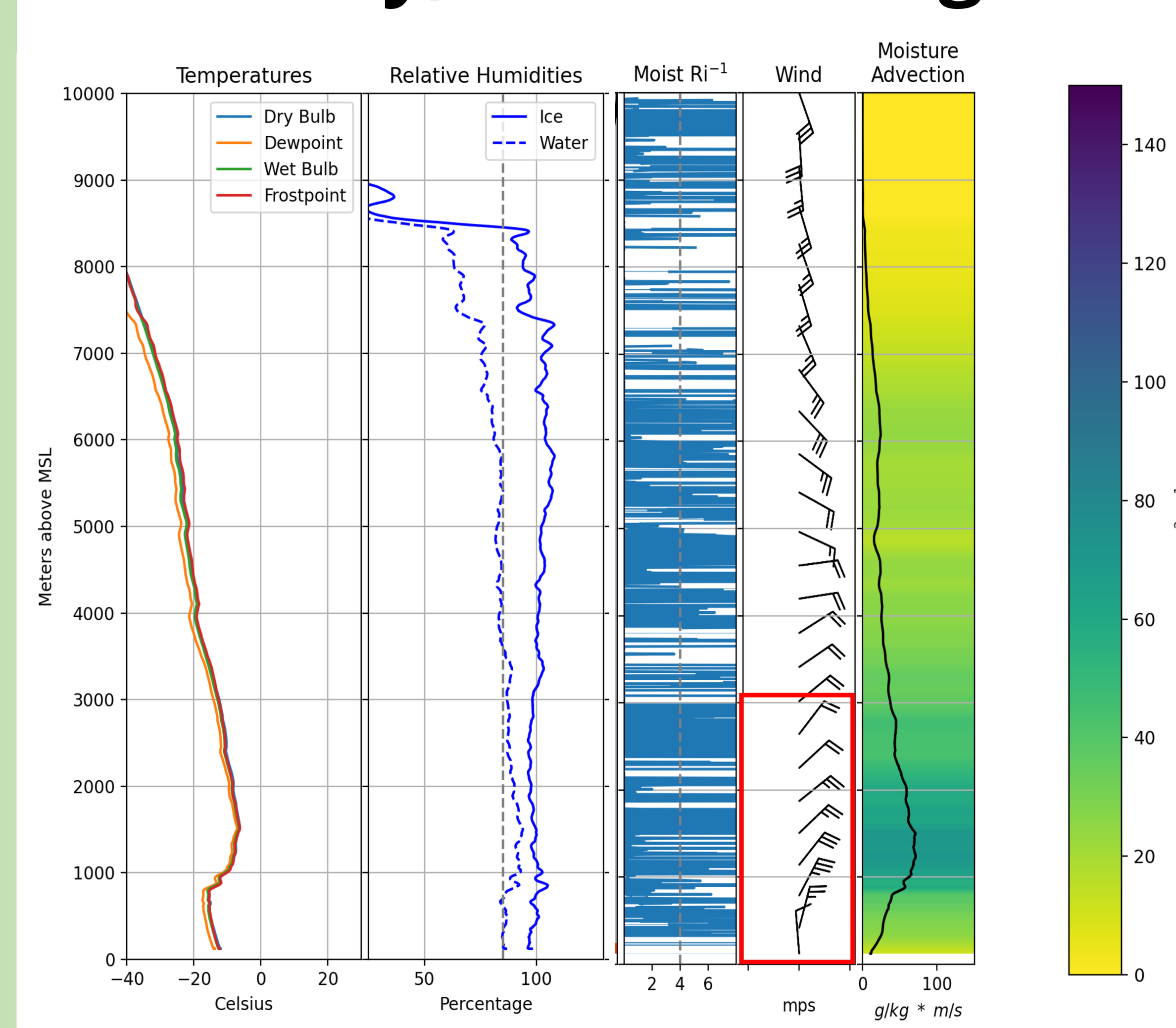
As a part of the IMPACTS campaign, the NASA ER-2 aircraft flew at 20 km altitude and had downward-looking sensors including a cloud radar (CRS). The NASA P-3 aircraft flew within the storm cloud and collected in situ measurements along the flight track including vertical air velocities.

We analyze data from two different flight legs with observed turbulence over the Gulf of Maine to look at metrics and potential causes of the K-H instability.



We also use data from a weather balloon launch in Gray, ME near the observed wave event. This sounding provides information on the vertical temperature, moisture, and wind profiles.

Gray, ME Sounding



Vertical sounding profile from a NOAA weather balloon launched from Gray, ME at 18:05:00 UTC on 29 January 2022. The location of this sounding is denoted by a red dot on each ER-2 flight leg map.

Summary and Future Work

The data suggest that the observed wave-like vertical air velocity variations are associated with Kelvin-Helmholtz instabilities:

- Significant vertical shear instability can be found in the sounding near the location the waves were observed, both in terms of wind direction and speed.
- Radar data shows strong, periodic vertical velocity contrasts for roughly 20 km segments along several flight legs, suggesting wave-like motion.

Moving forward, we will investigate other potential sources of instability for a more holistic view on the forcings that may have caused this strong turbulence event.

References and Acknowledgements

Sources:

(1) liquifun. *Kelvin-Helmholtz instability and Richardson number explained*. LiquiFun. https://liquifun.wordpress.com/2013/02/25/kelvin-helmholtz-instability-and-richardson-number-explained/.

(2) NASA IMPACTS. https://espo.nasa.gov/impacts/content/IMPACTS

Special thanks to Rebecca Moore, Cameron Gilbert, and Nathan Faulk for their feedback and assistance. This work is supported by NASA grant 80NSSC19K0354.