Observations of KH wave fall-streaks over complex terrain by airborne radar and in-situ probes

Coltin Grasmick, Bart Geerts, Jeff French, and Bob Rauber

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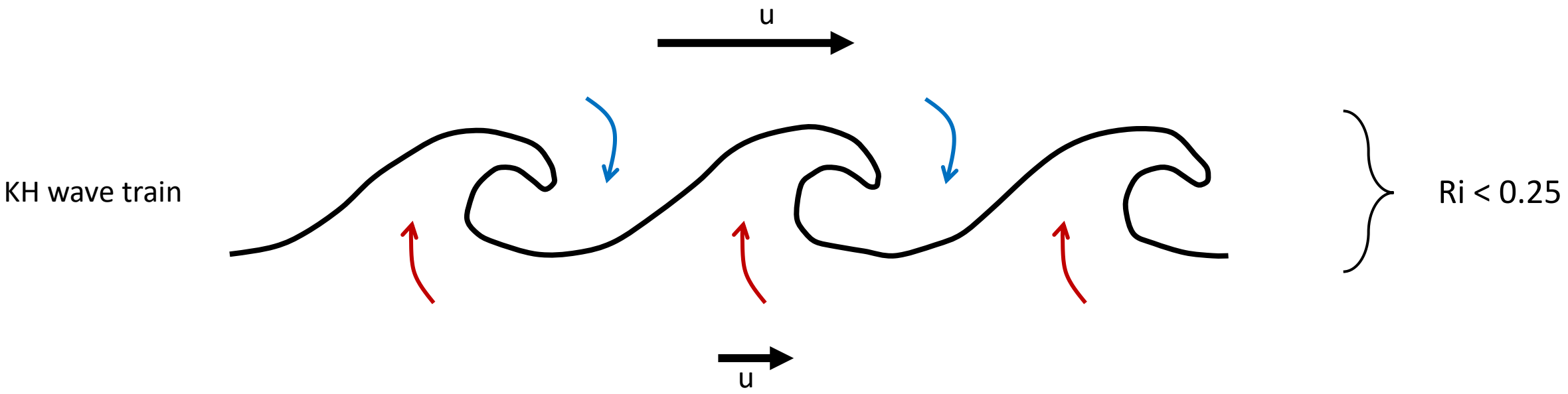
University of Wyoming

Do Kelvin-Helmholtz (KH) waves effect precipitation?

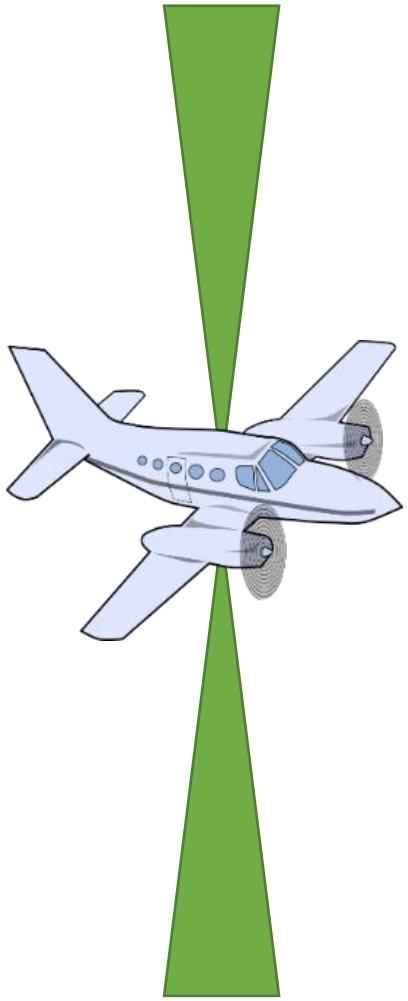


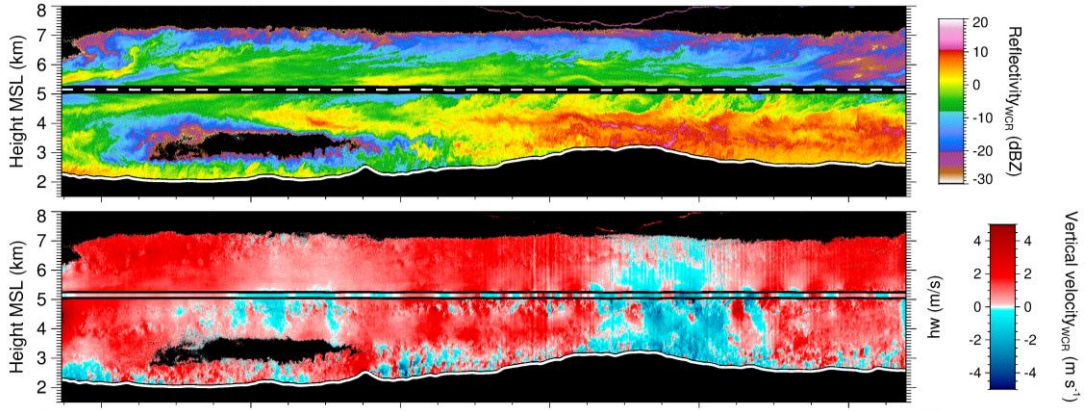
- KH waves form in a layer of high shear where the Richardson number is low
- Turbulent mixing within the layer reduces the windshear and thus the instability
- Up and downdrafts grow then dissipate, often in cycles

UW King Air Wyoming Cloud Radar

- Wyoming Cloud Radar (WCR)
  - 3 mm wavelength (95 – GHz)
  - 37.5 m resolution & 0.7° beamwidth
  - Reflectivity and radial velocity

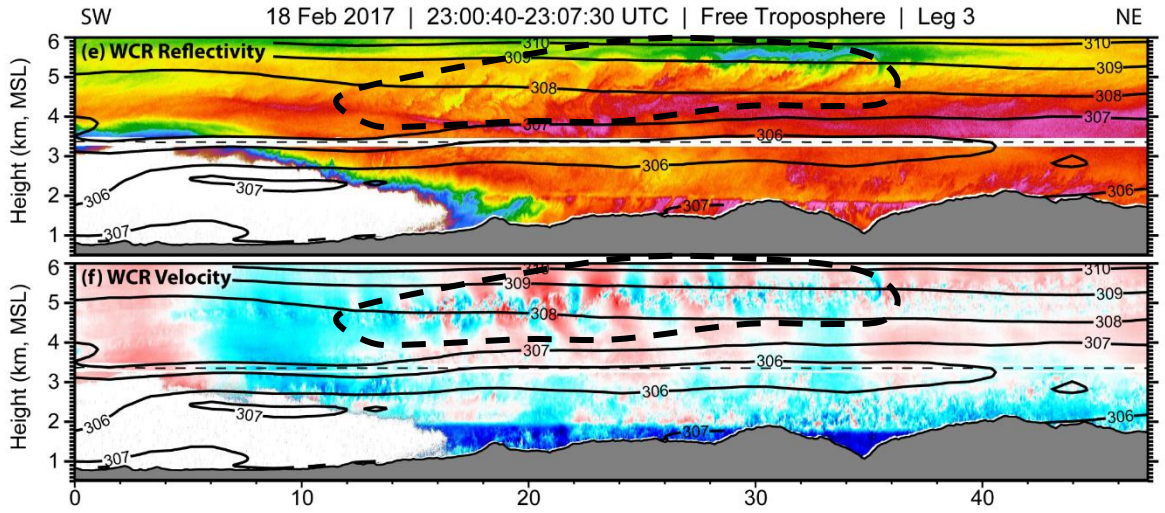
  - Additional down-forward beam provides dual-Doppler capabilit

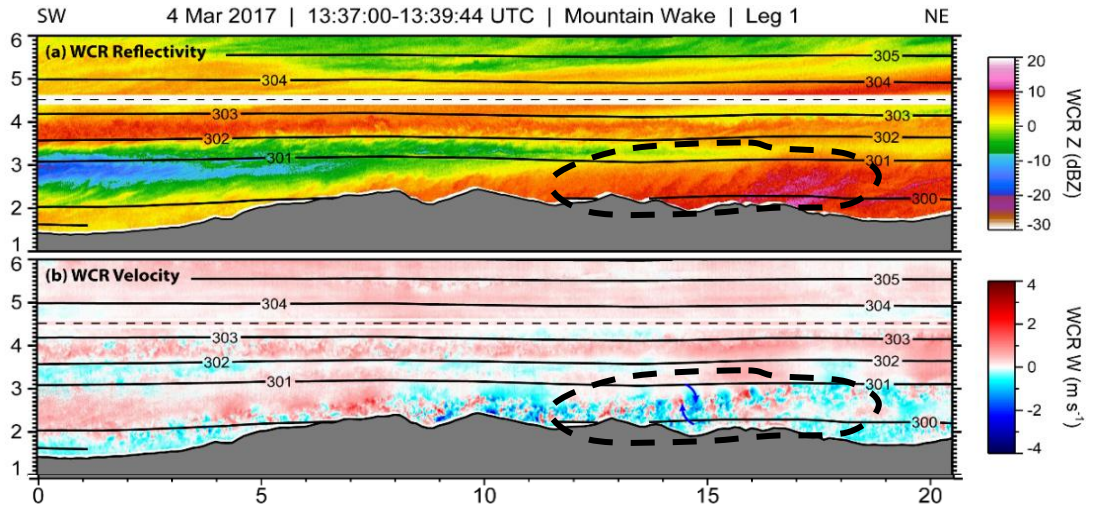




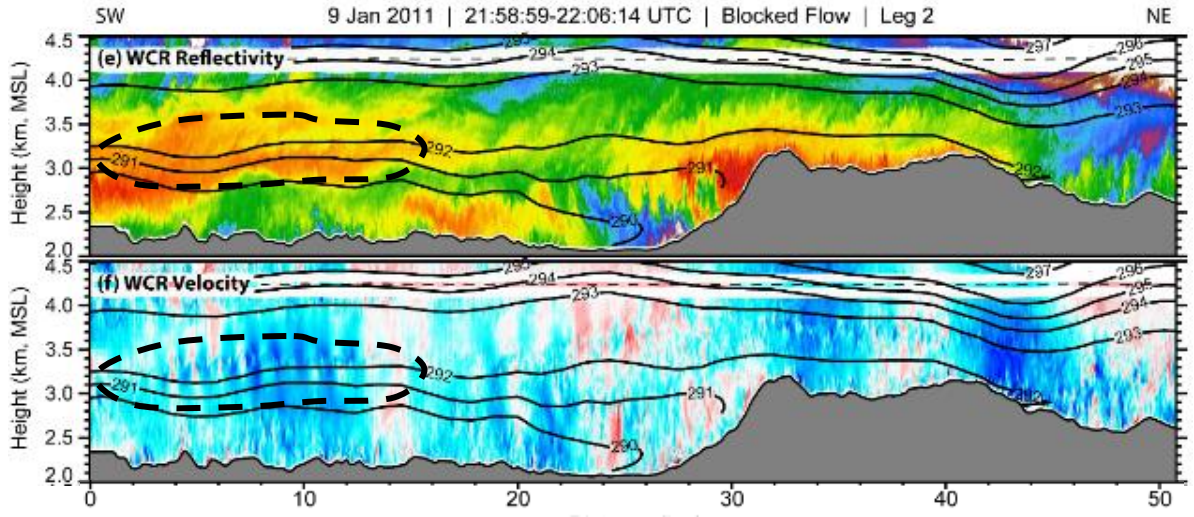
KH waves are ubiquitous over mountainous terrain

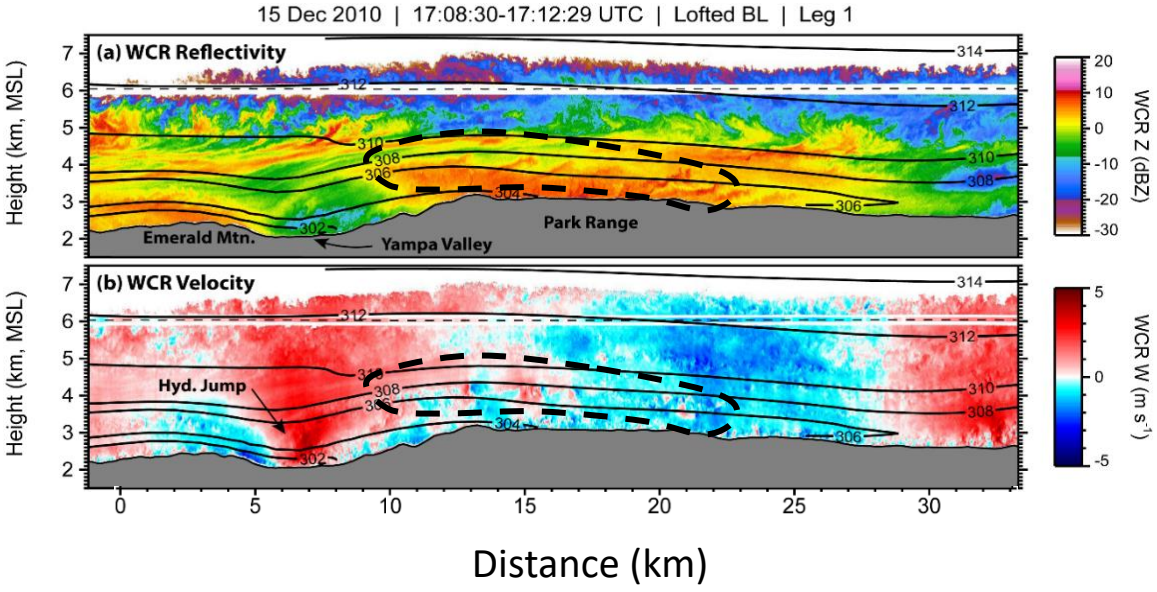
SNOWIE
Payette Mtns, ID



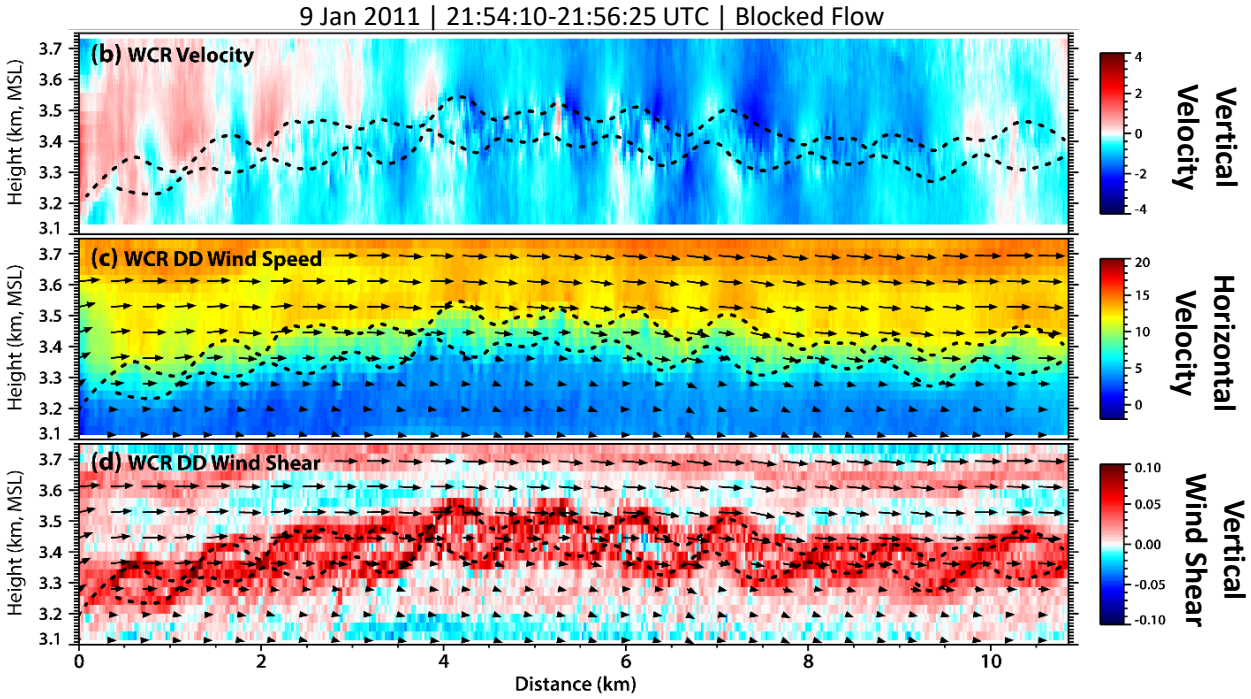


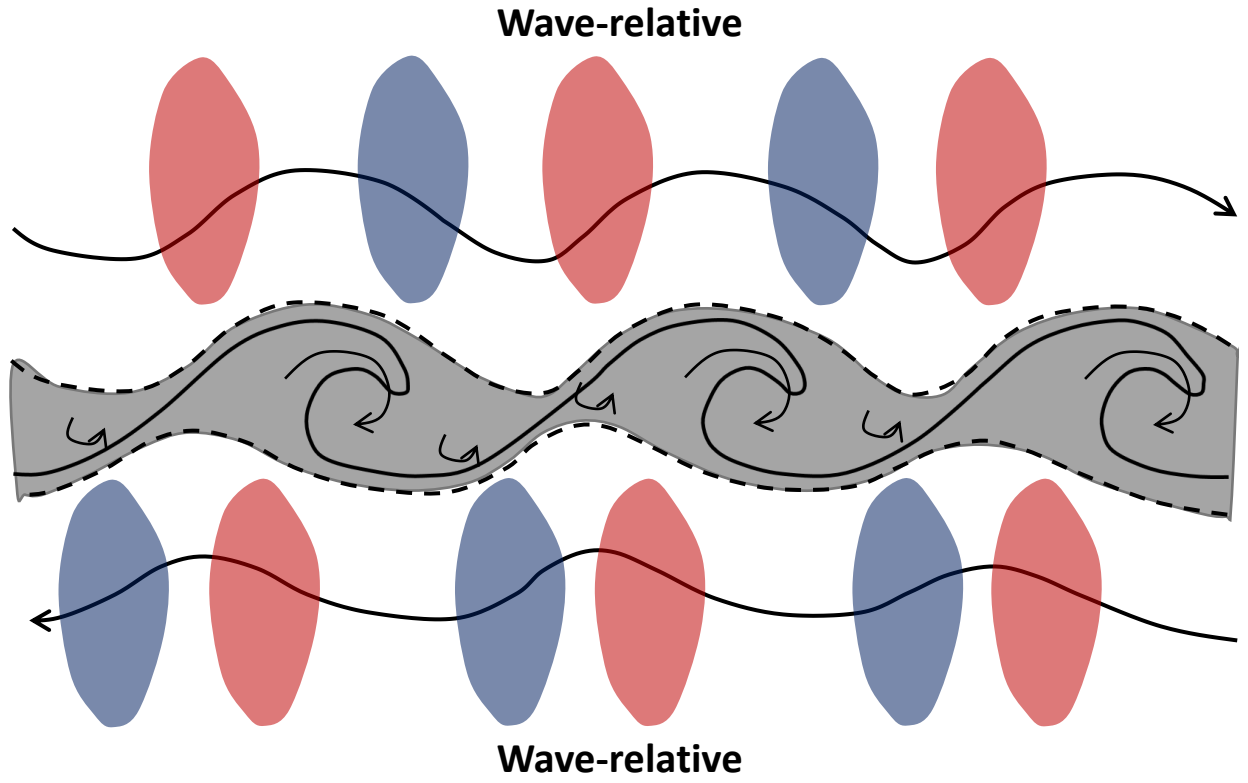
CAMPS
Park Range, CO





Dual-Doppler reveals additional kinematic information





Possible Microphysics impacts

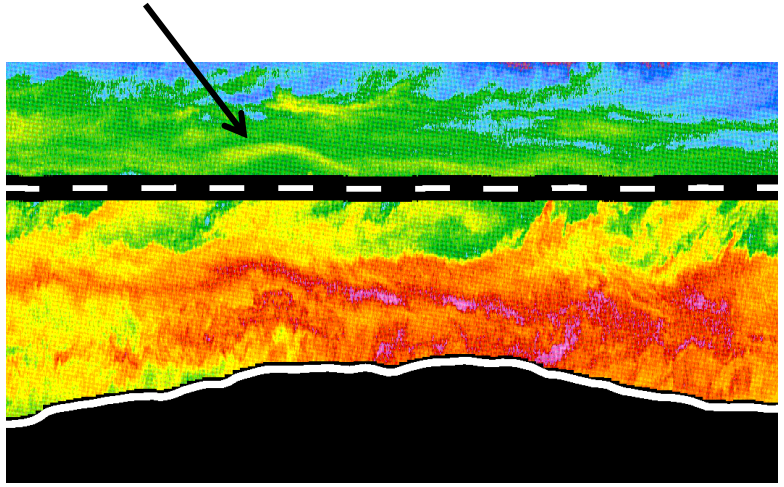
1) Gravity wave train where repeated up/down drafts produce repeated supersaturation fluctuations.
2) Overturning KH billows with the greatest updraft velocities and parcel displacements.
3) Fine-scale turbulence from breaking KH billows

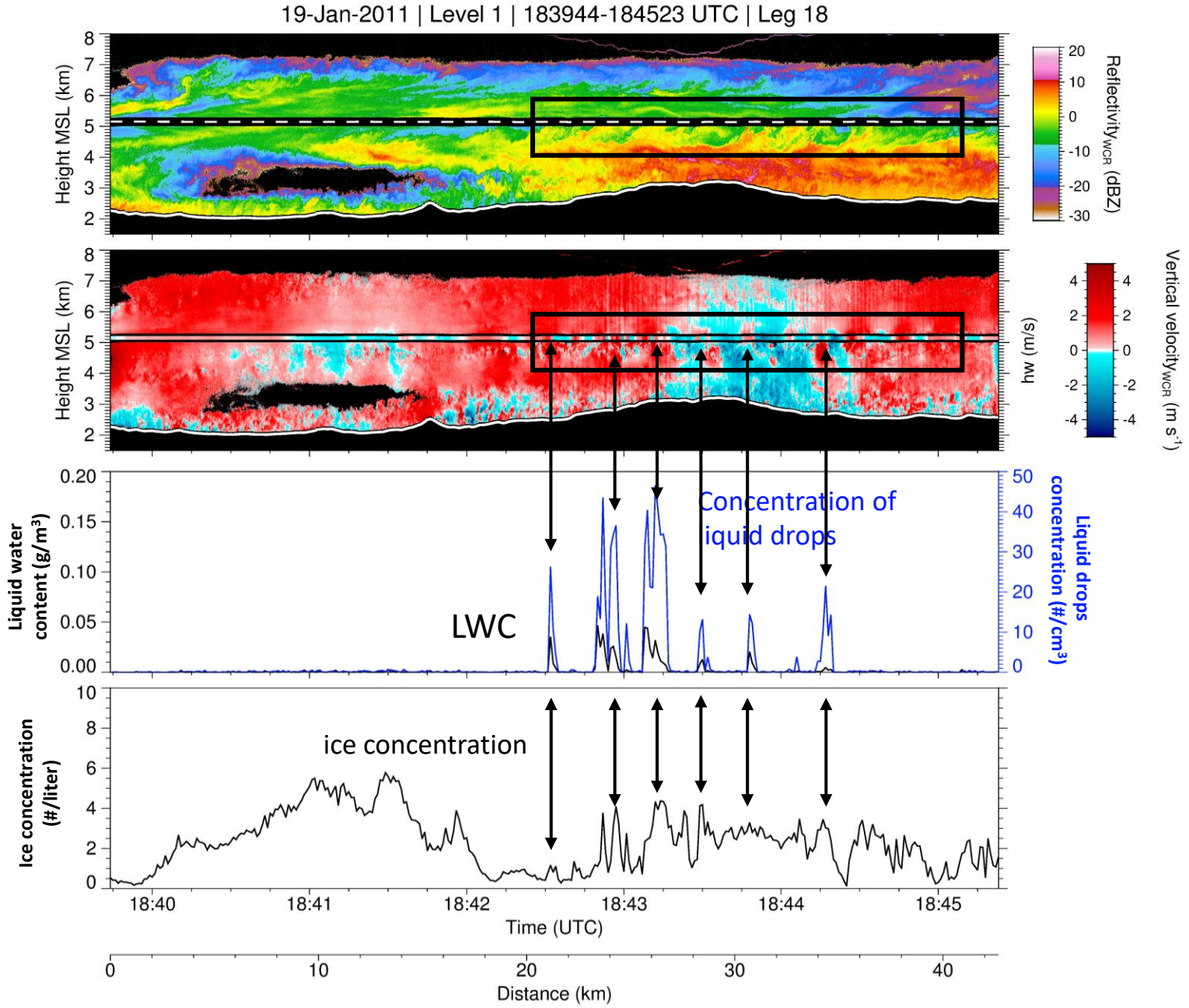
Examples of KH wave fall-streaks

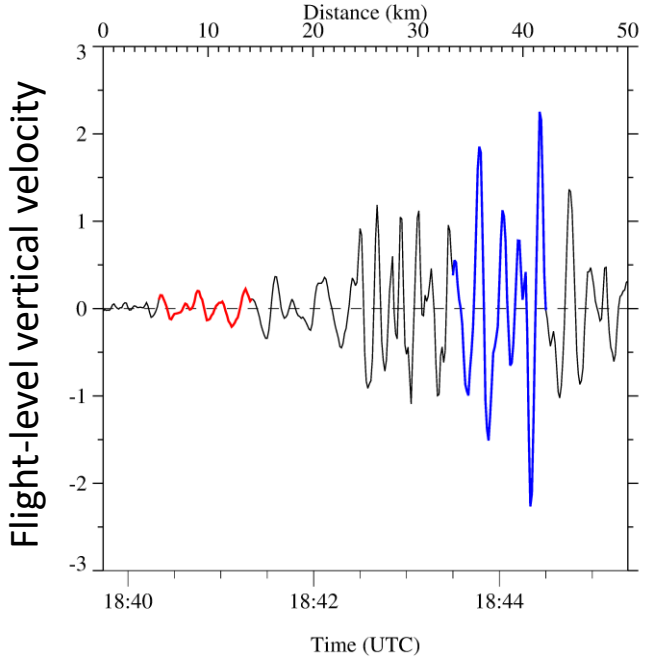
Case #1: Flight-level billows

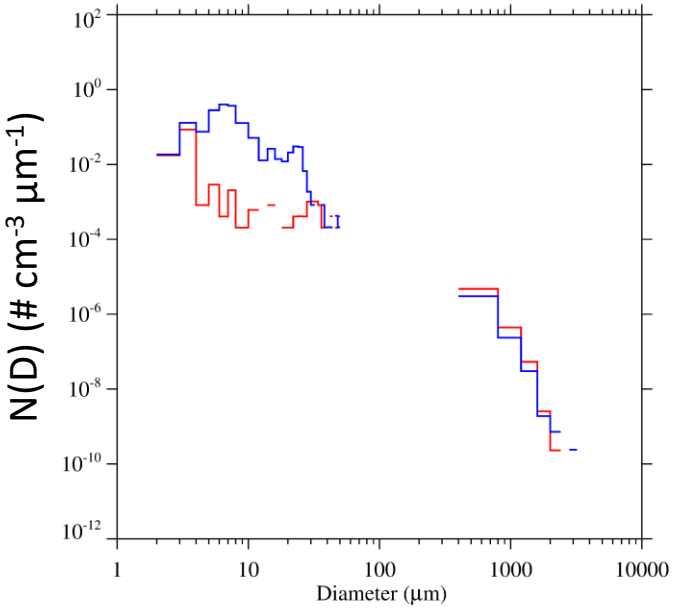
- KH billow updrafts contain additional liquid water
- KH billow updrafts have increased quantities of ice particles

Gravity wave effects?

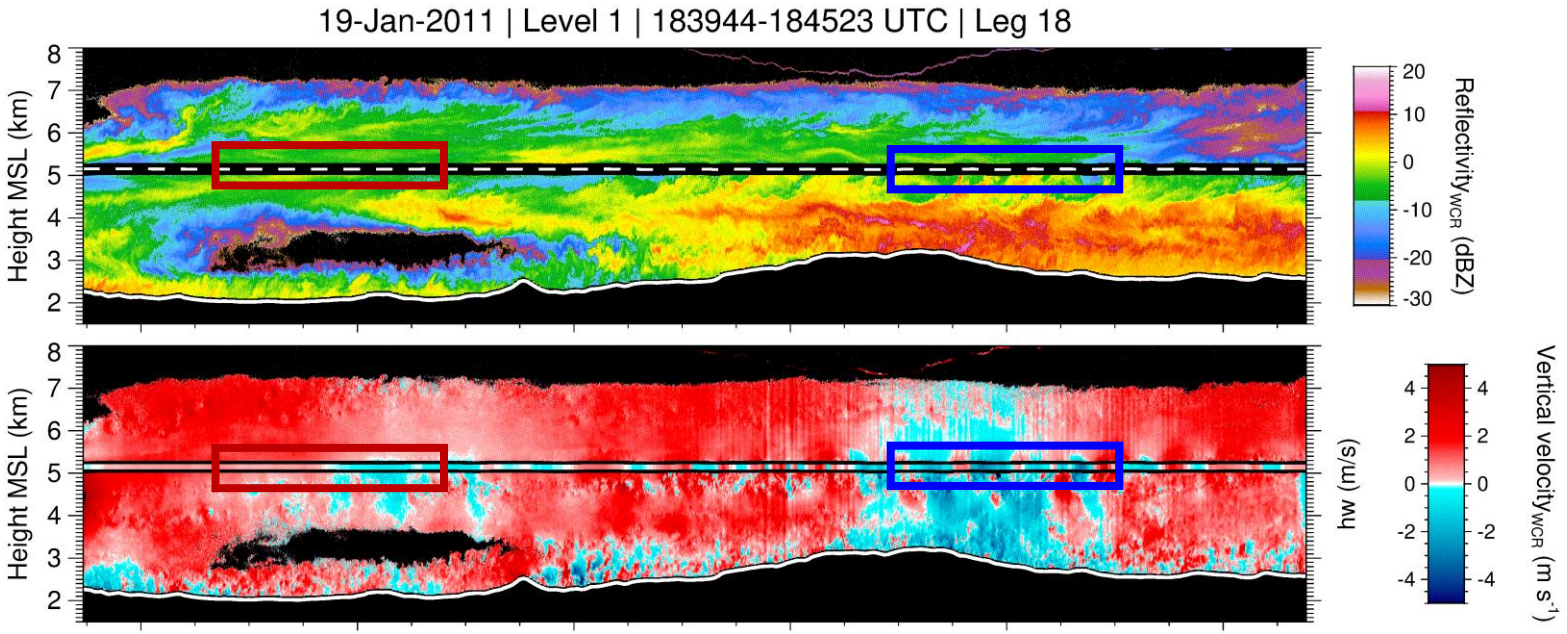








Looking before and after KH wave train to glean net effect.

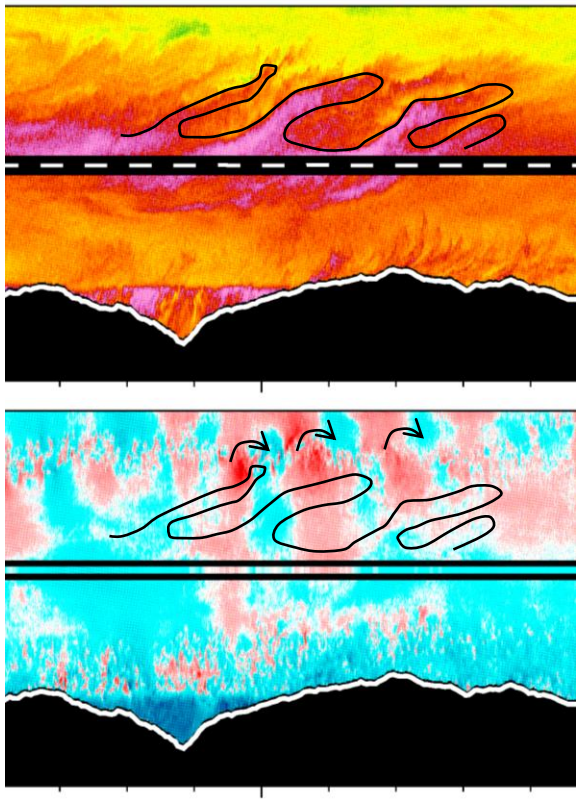


- Before the KH wave train low concentrations of cloud droplets are difficult to measure
- Much higher amounts of cloud water exists at the end of the KH waves.

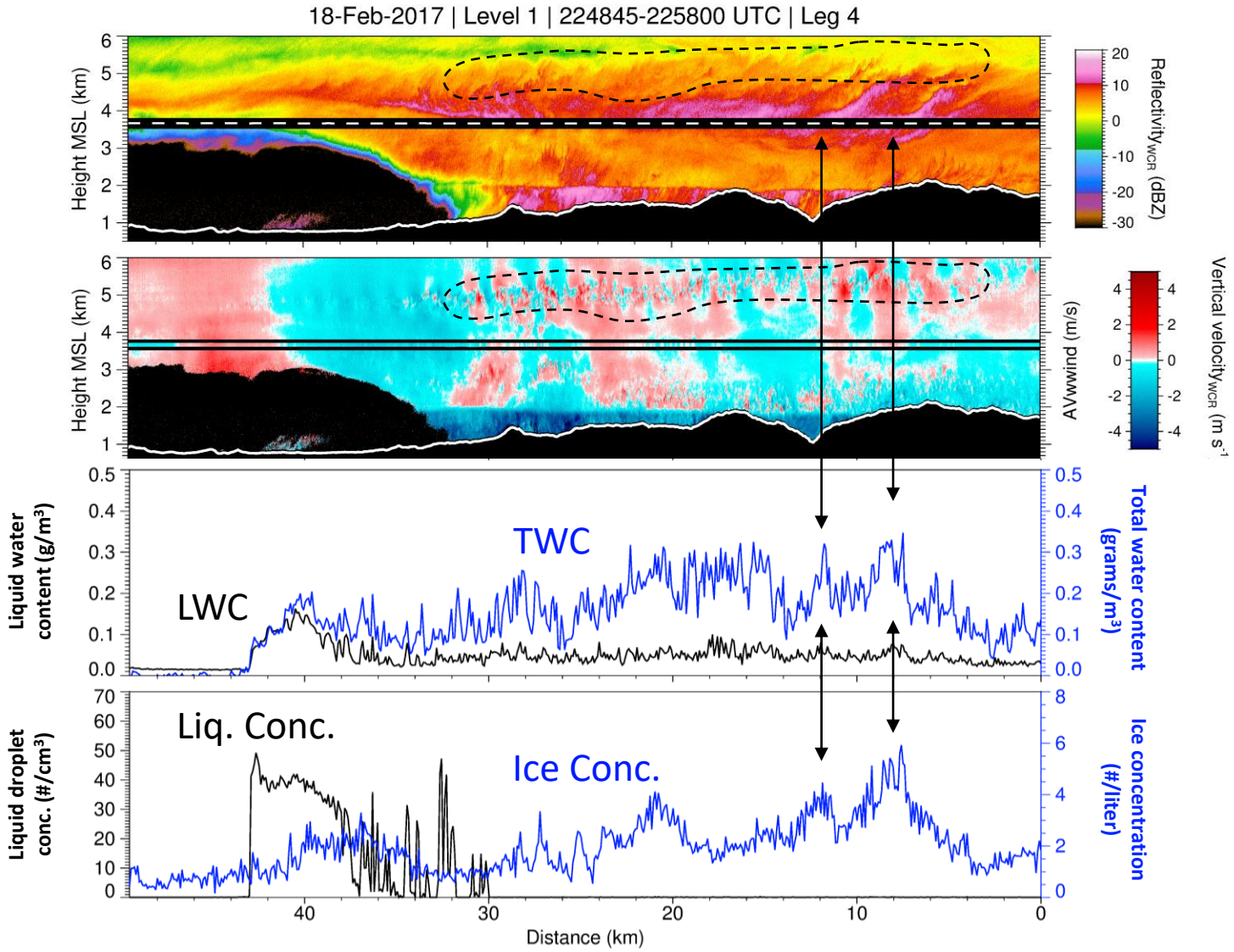
Case #2: Fall-streaks through flight-level

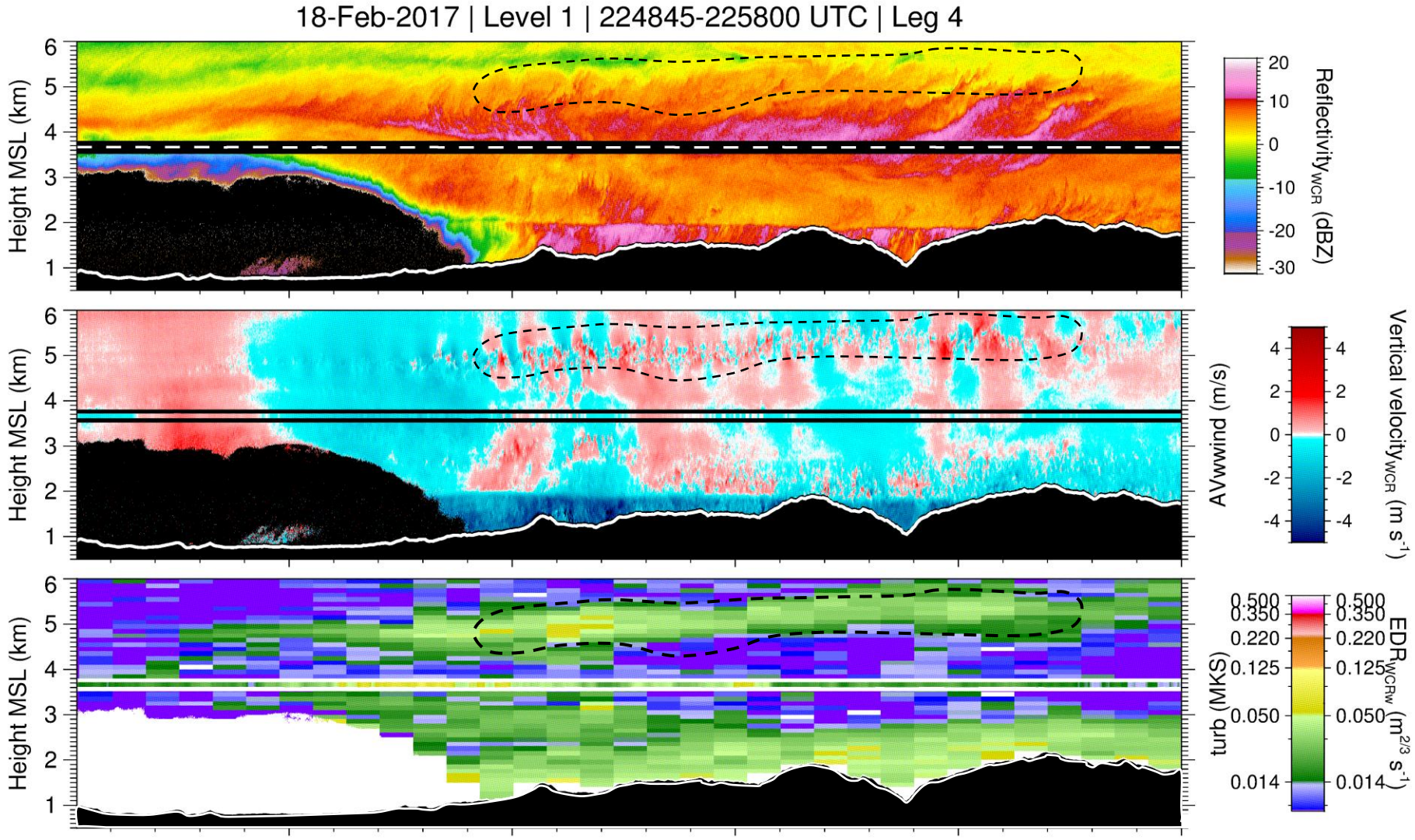
Enhanced reflectivity plumes descend from KH waves to be measured at flight level.

Flight level temp: -9°C



SNOWIE IOP-14

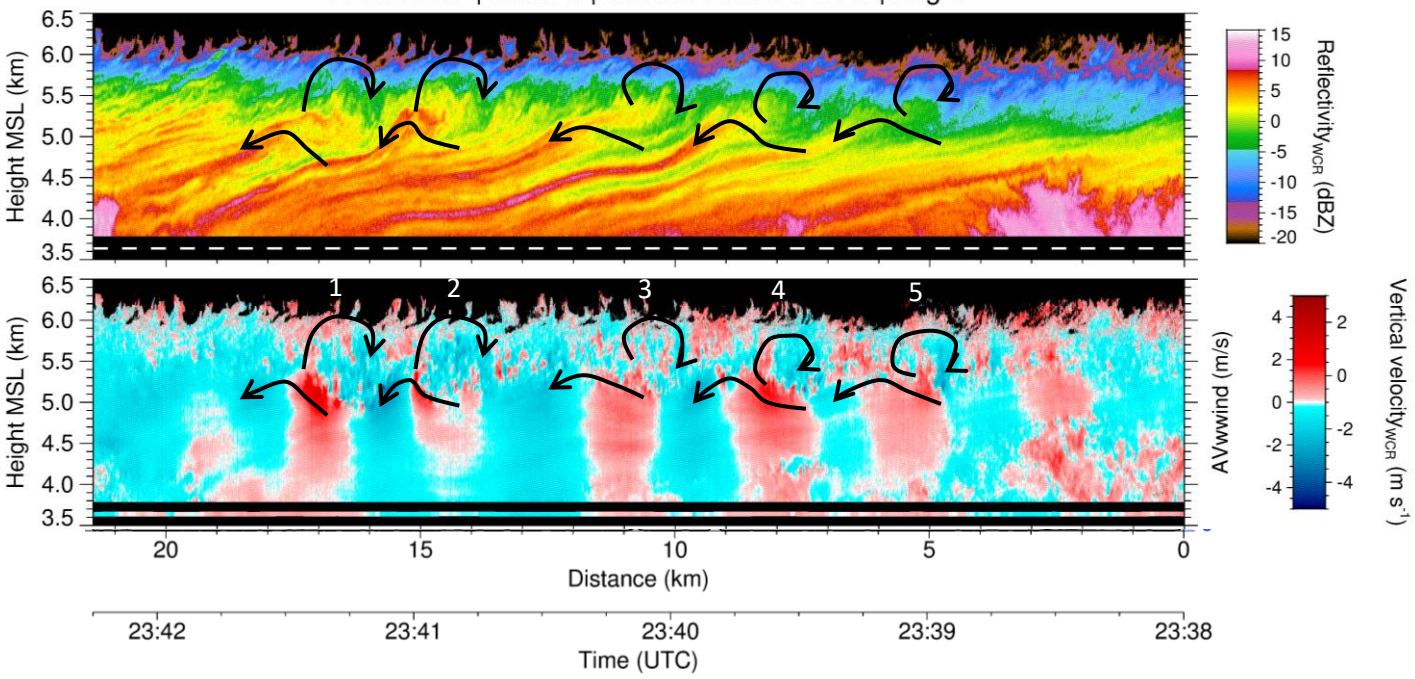


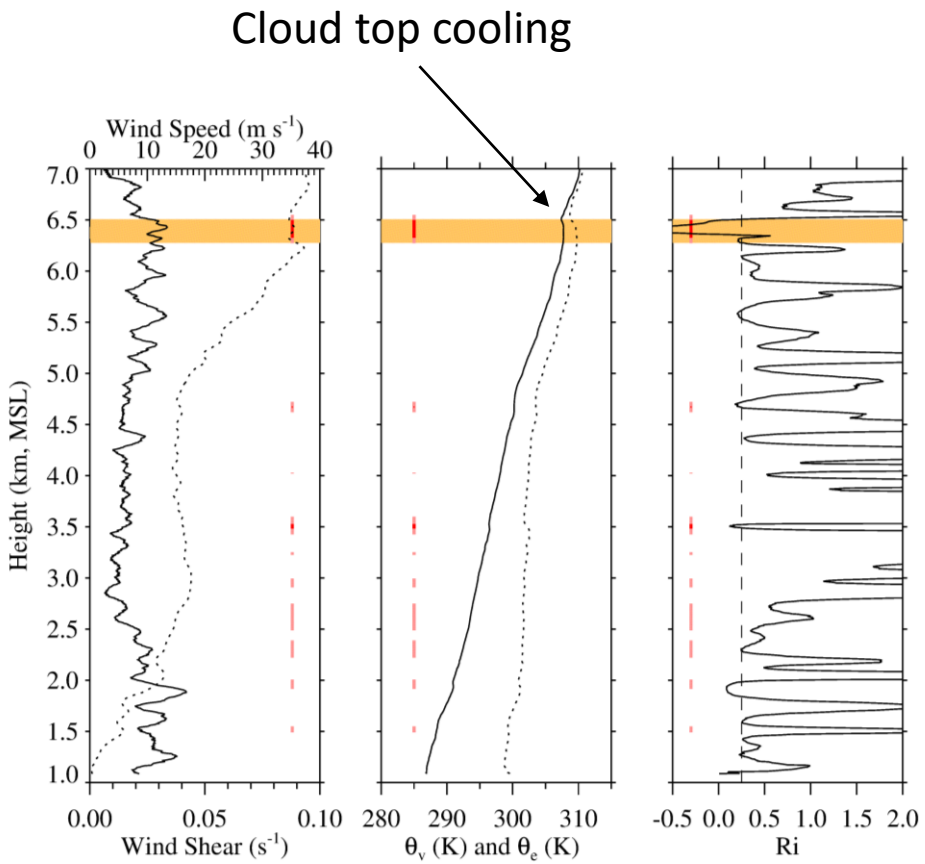


Energy Dissipation Rate →

In situ and WCR-derived Energy Dissipation Rate (EDR) provide a connection between turbulence intensity and measured microphysics. In addition to collision-coalescence, turbulence may increase ice concentrations through secondary ice-nuclei activation or multiplication processes.

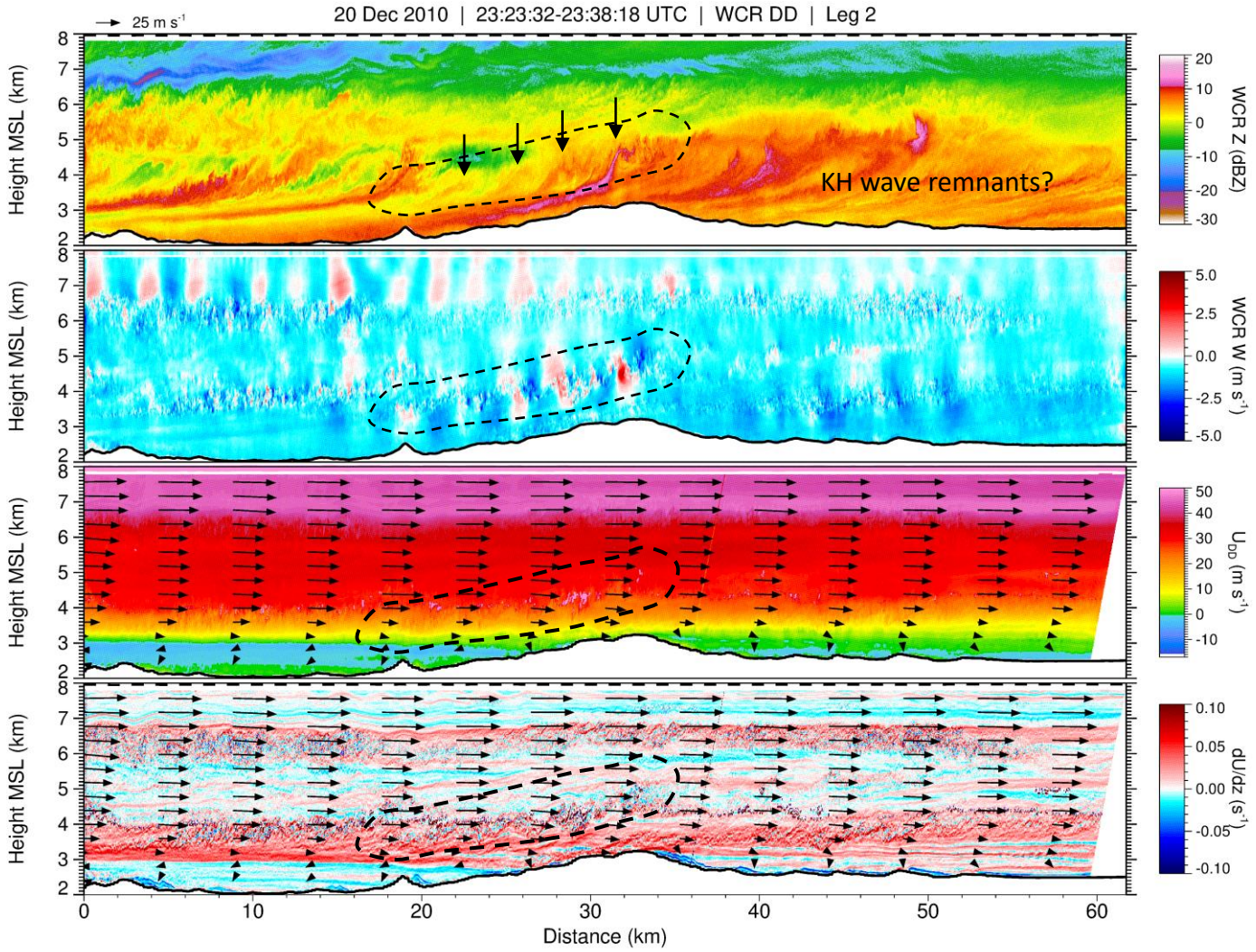
Case #3: Cloud top instability + KH waves

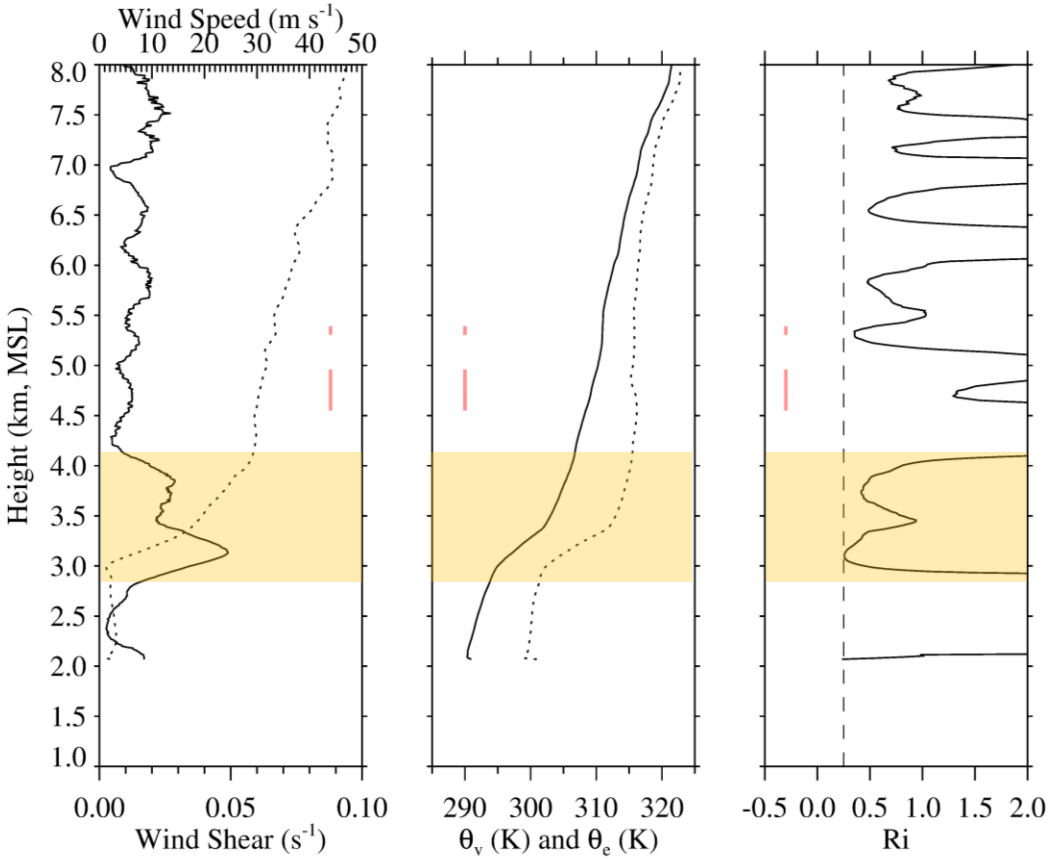




Cloud top cooling may reduce stability and lower the Richardson number below critical value.

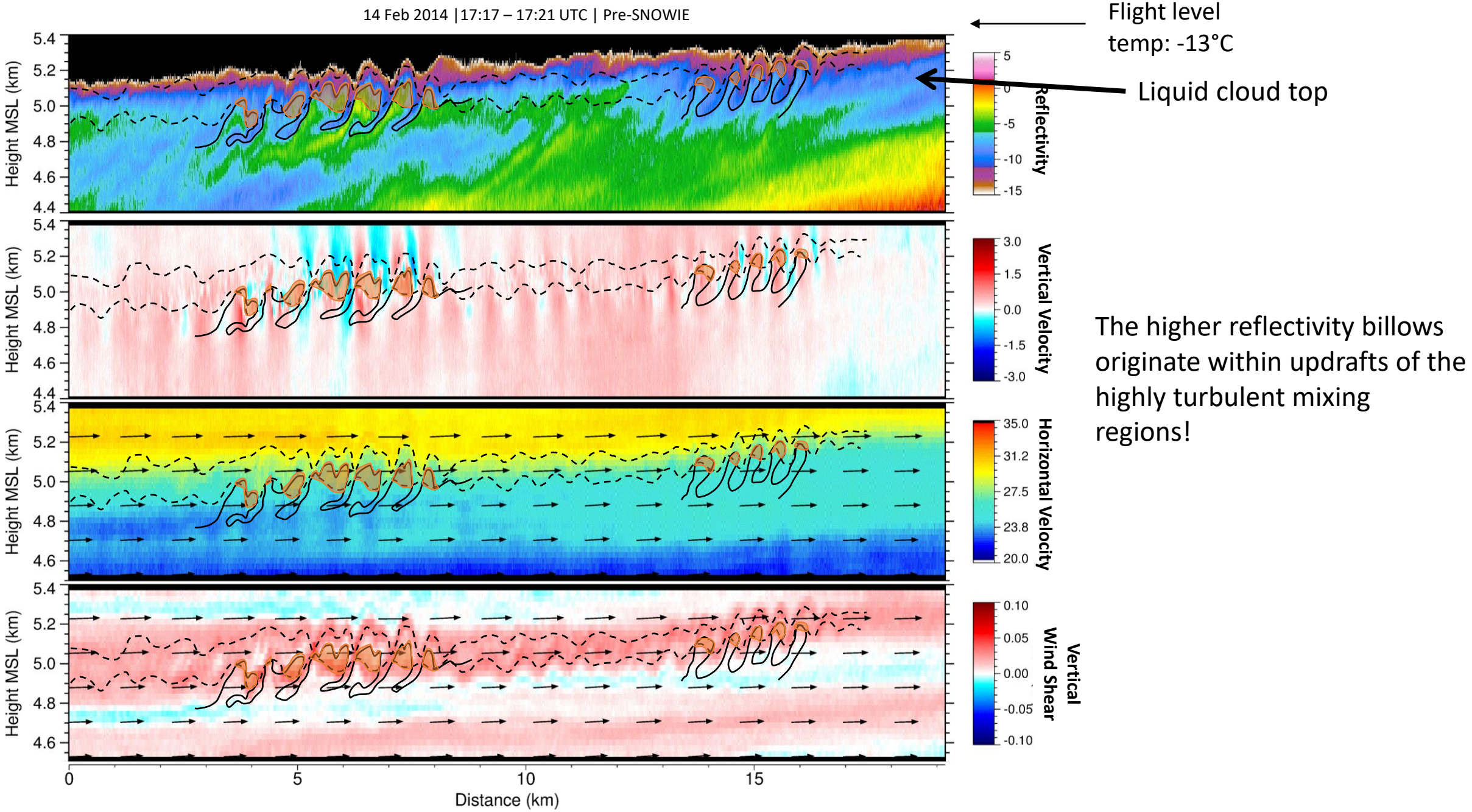
Case #4: Fall-streaks intersect the surface





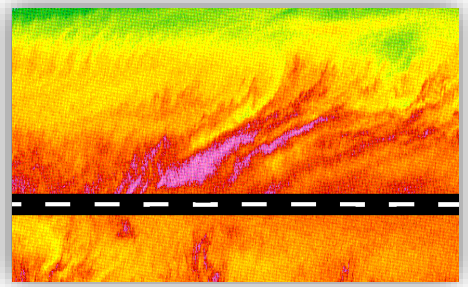
KH waves in shear below flight-level. Dual-Doppler synthesis provides wind along flight path and vertical shear.

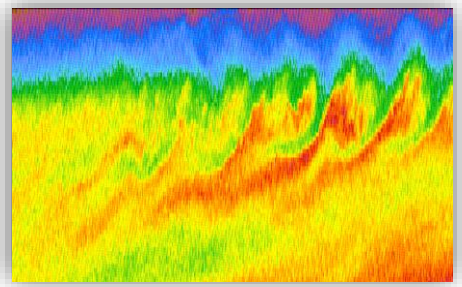
Case #5: KH waves fall-streaks in Liquid cloud

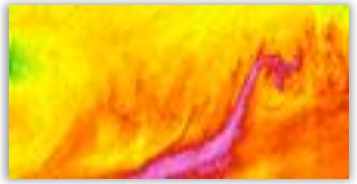


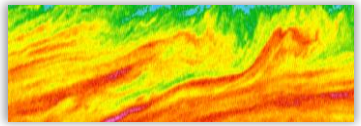
The higher reflectivity billows originate within updrafts of the highly turbulent mixing regions!

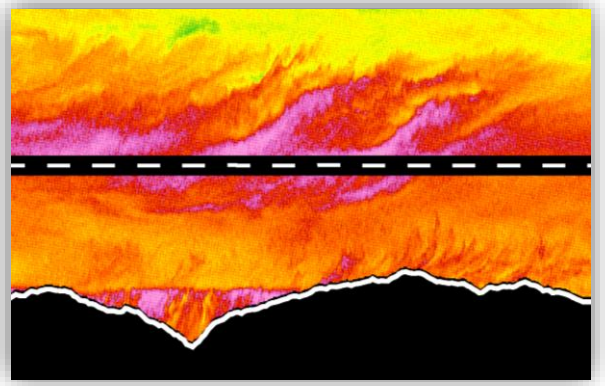
Conclusions











- "Stratiform" precipitation systems over complex terrain frequently contain KH waves as observed during the CAMPS and SNOWIE campaigns → **flow over terrain generates shear**.

- Radar and in-situ measurements of fall-streaks from the UWKA show that KH waves produce microphysical effects in mixed-phase clouds to **facilitate ice growth and remove cloud liquid**.

- Reflectivity and precipitation enhancement occurs from a combination of processes starting with **(1) the production of liquid water** in updrafts and **(2) collection and accretion** of water by fine-scale turbulence (breaking KH waves).

- The ability of KH waves to produce fall streaks likely **depends on the wave amplitudes as well as cloud characteristics** (e.g. mixed phased / kinetically limited).