# Airborne cloud radar observations of orographic precipitation

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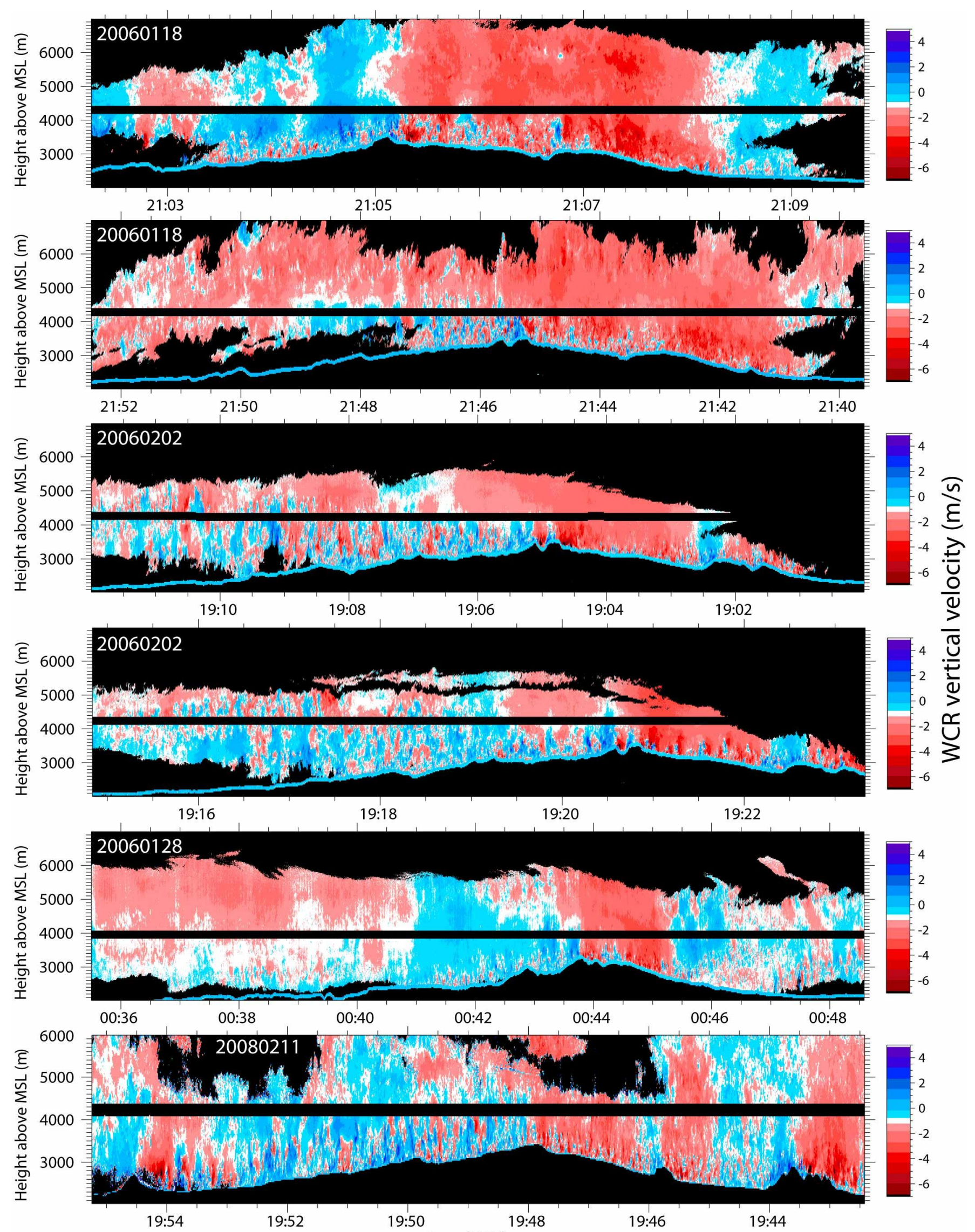
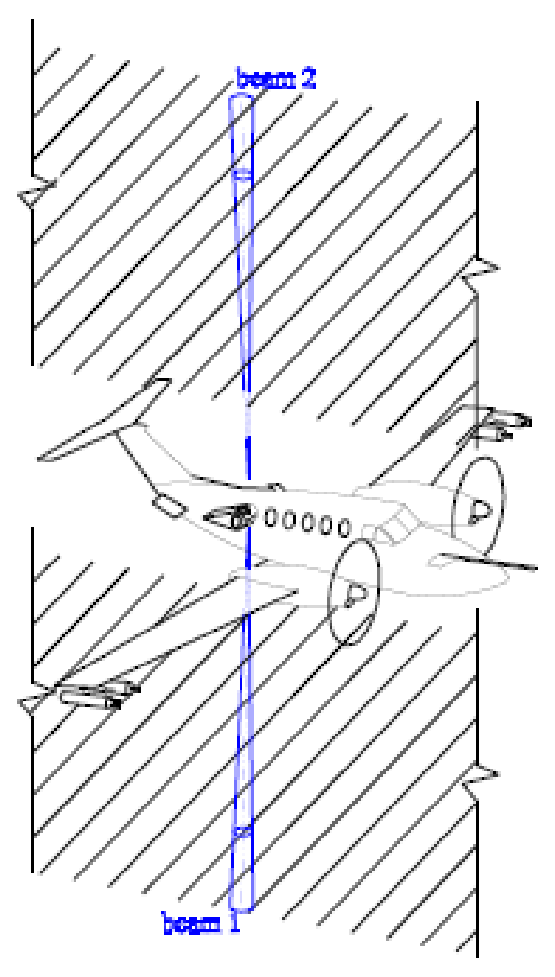
## Advantages of airborne vertical-incidence radar data

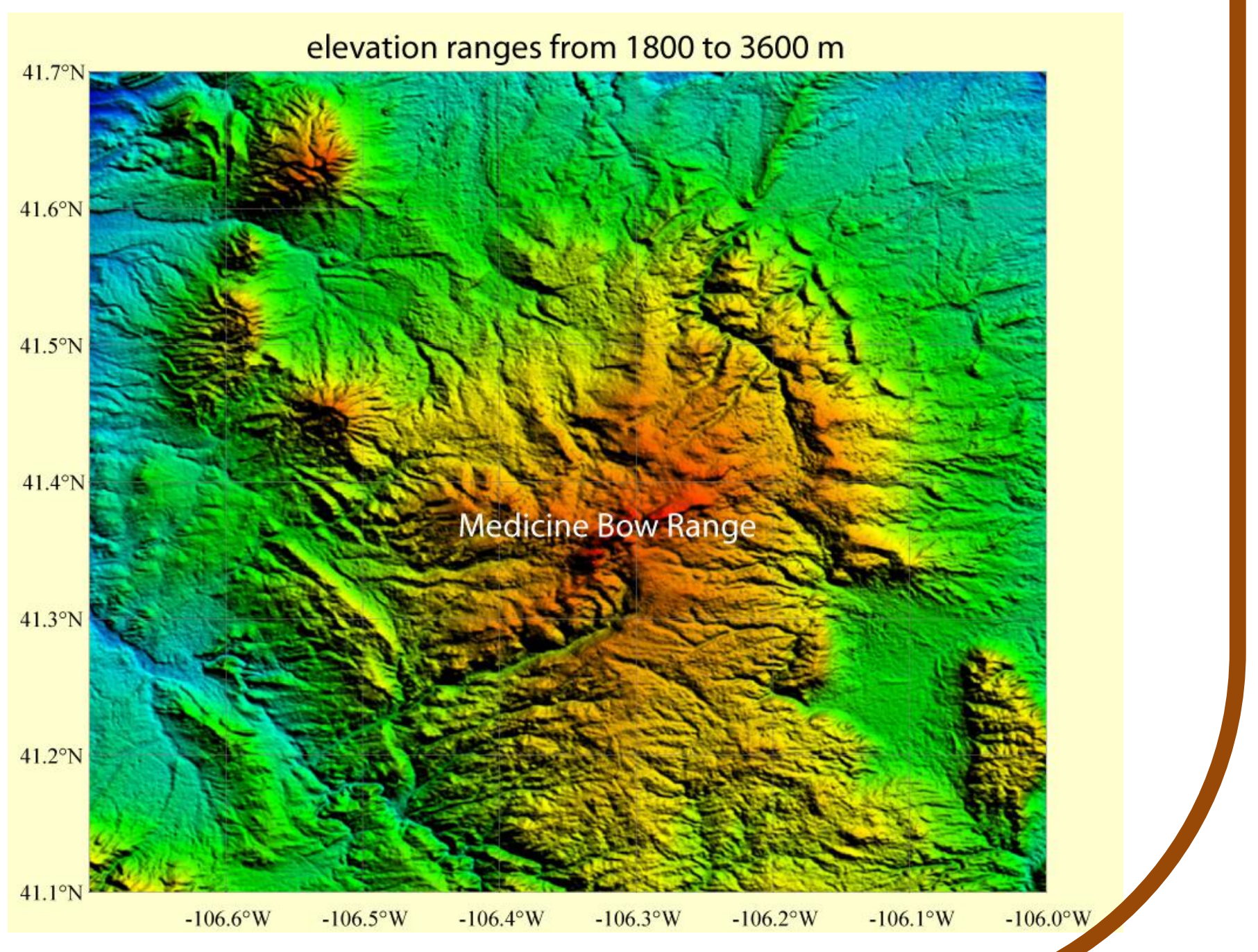
1. High-resolution data can be collected very close to the surface, even in complex terrain.
2. Synergy between flight-level data (within the radar blind zone) and radar profiles.
3. The dual-Doppler vector field represents the true horizontal and vertical motion of hydrometeors.

## Diversity of vertical-plane vertical velocity structures in along-wind transects of winter storms over a mountain (Medicine Bow Range, Wyoming)

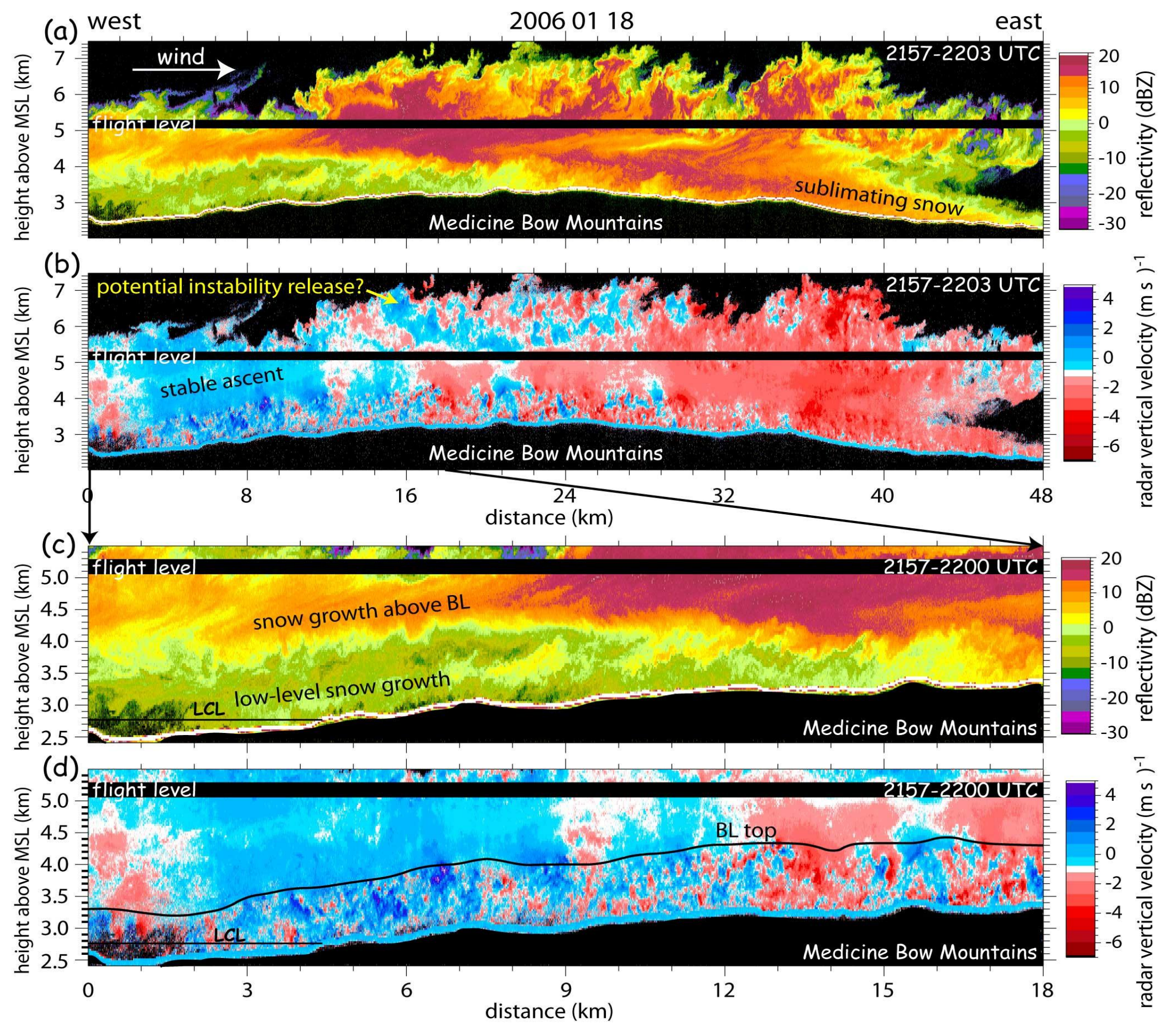


Hydrometeor vertical motion above and below flight level for a series of along-wind flight legs across the Medicine Bow Mountains. The wind is from left to right. Positive (blue) is upward. Note that the color key is centered at -1 m s$^{-1}$ rather than at 0, such that the color field can be interpreted as air vertical motion, assuming a snow fallspeed of 1 m s$^{-1}$. The black belt is the radar blind zone centered at flight level.

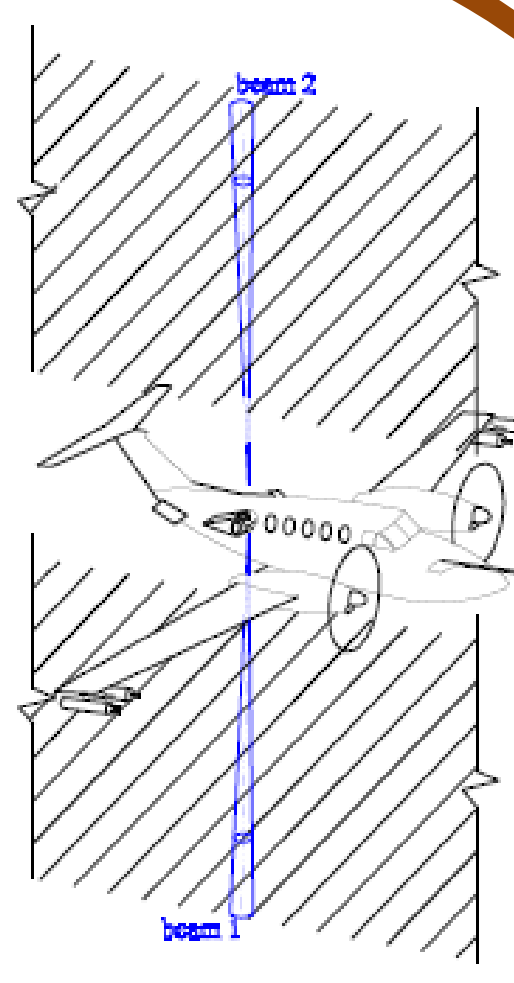


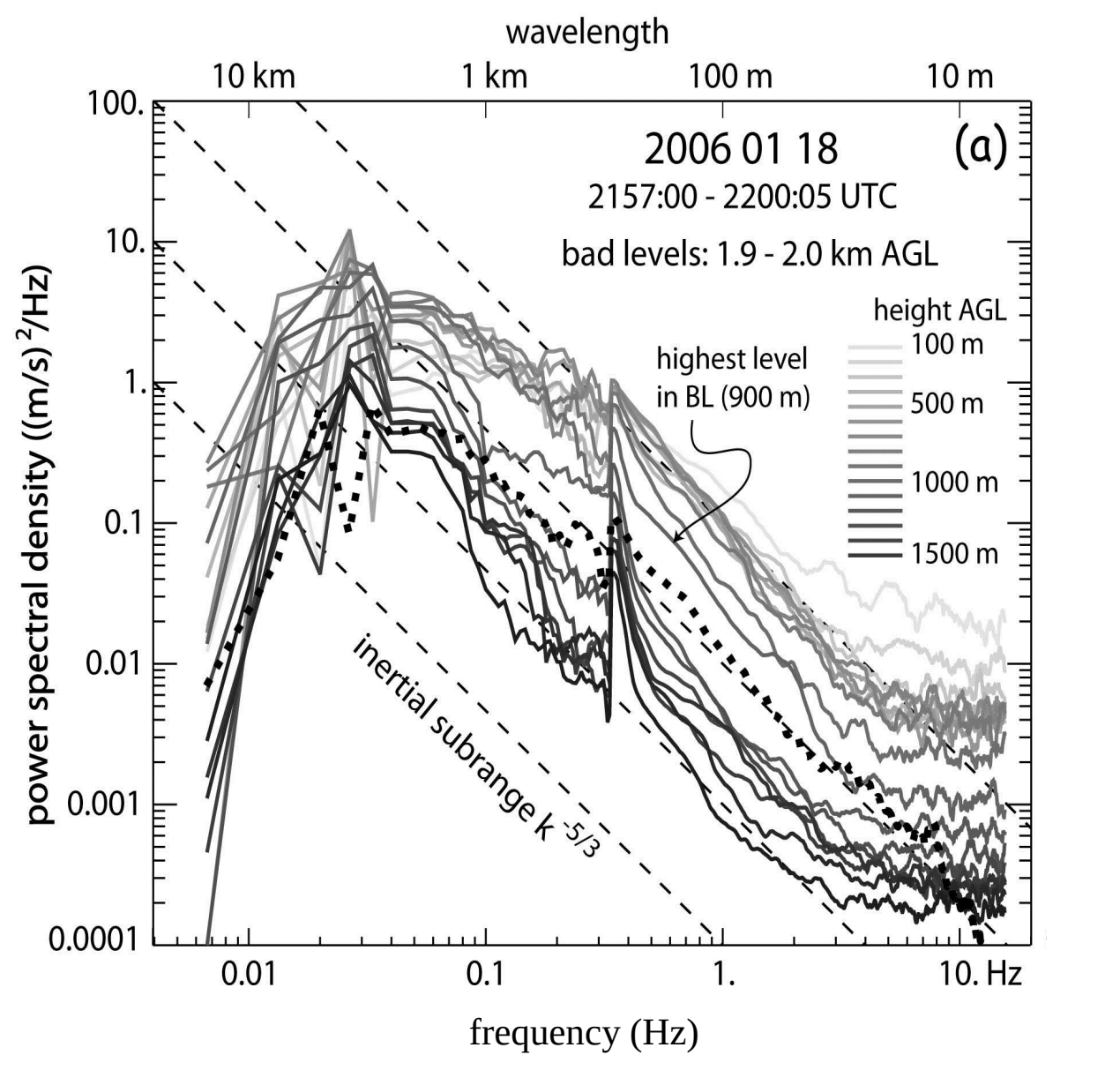


## PBL turbulence and snow growth over mountains

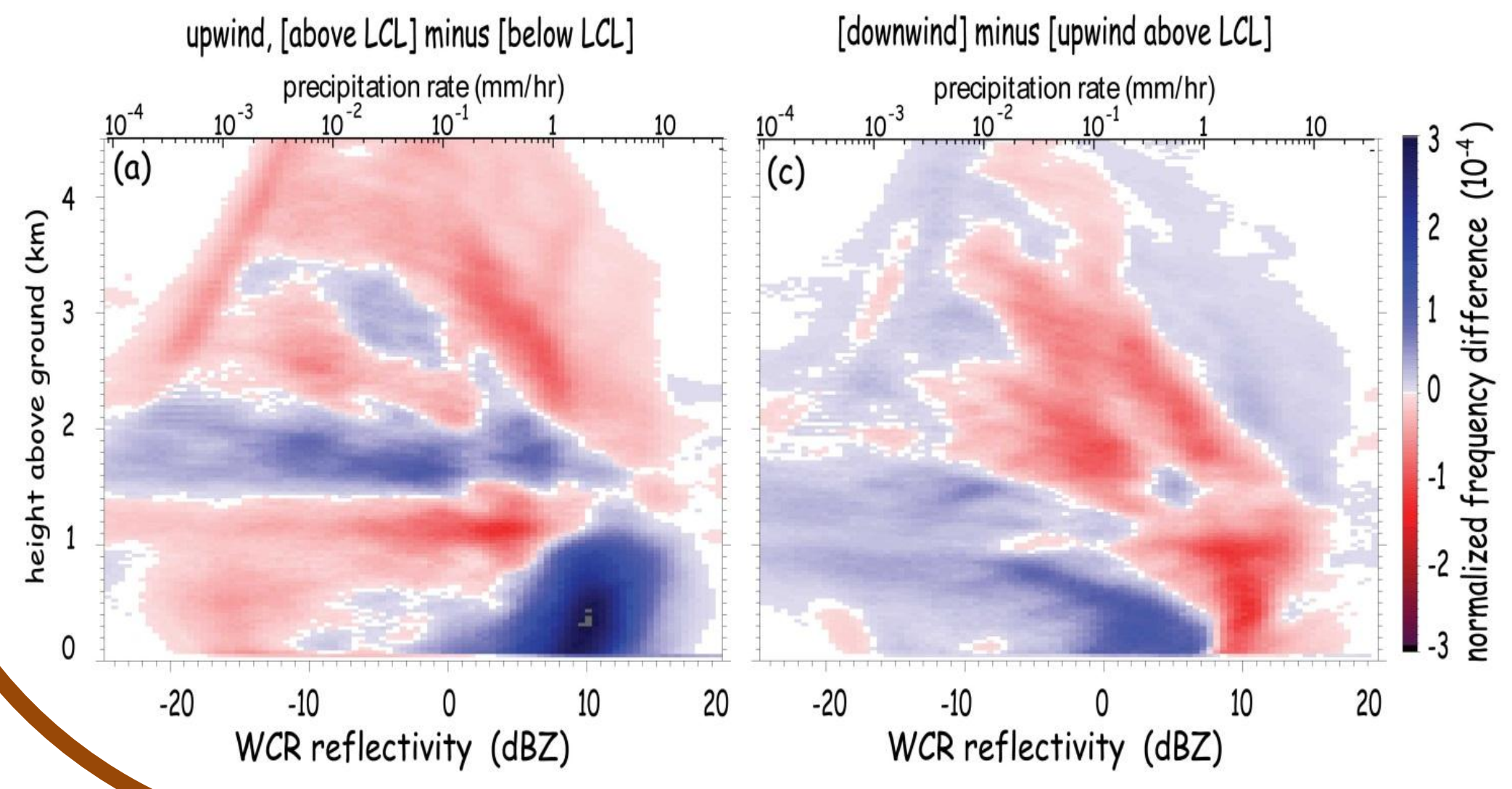


Example of WCR data collected along a flight track aligned with the wind over the Medicine Bow Range, on 18 January 2006. The radar data readily reveal the terrain profile. Panels (c) and (d) repeat the top two panels, but zoomed-in on the upwind slope. A well-defined layer of turbulent vertical motions drapes over the terrain, especially on the upwind side. This turbulence is believed to contribute significantly to precipitation growth over these mountains and elsewhere (Geerts et al. 2011).





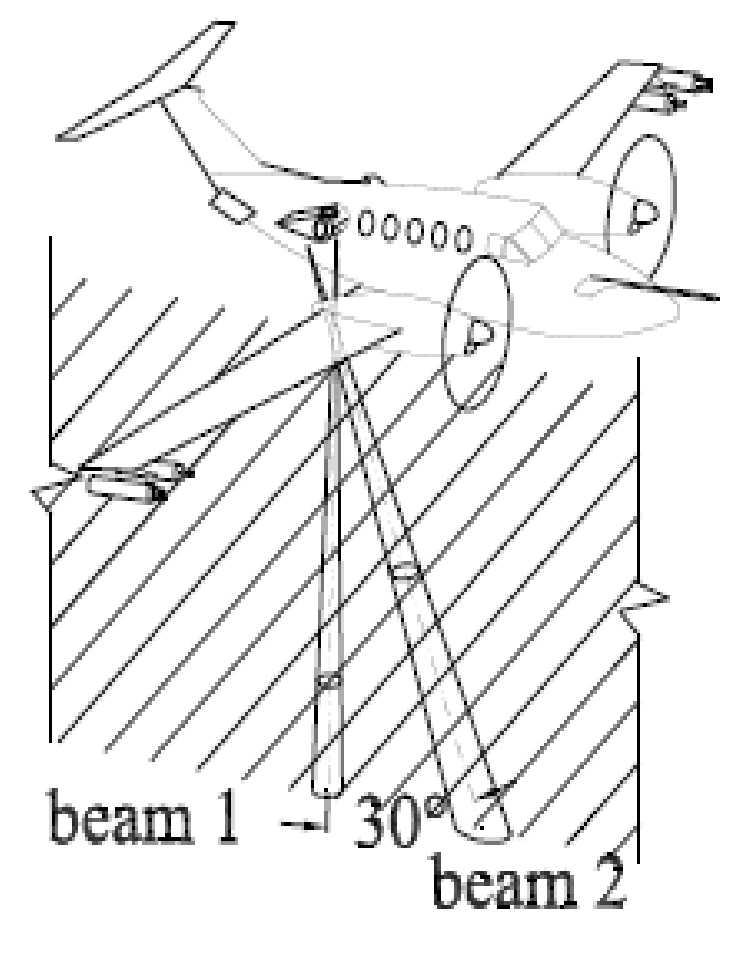
Power spectra of WCR vertical velocity as a function of height above ground level for the upwind slope shown on the left. The spectra are plotted at 100 m intervals, starting at 100 m AGL. The power spectra are measured in time (lower abscissa), and converted to spatial spectra by dividing by the aircraft speed (upper abscissa). The bold dashed line is the power spectrum of the underlying terrain profile (terrain-forced eddies).



(left) Difference in normalized frequency by altitude of WCR reflectivity Z. The left panel shows the difference between [above cloud base] and [below cloud base] on the upwind side of the mountain, for 10 flights over the Medicine Bow Range in winter storms (~26 hours of WCR profiles). This shows the growth of snow as the PBL enters into cloud. The right panel shows [downwind] minus [upwind] of the mountain crest, showing sublimation of snow in the lee. The precipitation rate (S) shown in the upper abscissa is inferred from $S=0.11\ Z^{1.25}$

## WCR vertical-plane Dual-Doppler synthesis

- The conceptual basis of the airborne vertical plane dual-Doppler (VPDD) synthesis is that a specific volume illuminated almost simultaneously by two non-parallel beams (6 sec delay per km range). The radial velocities from the beams are then synthesized to provide orthogonal components of the mean velocity in the specific volume (Damiani and Haimov 2006; Leon et al 2006).
- A common grid is needed for merging the beam data before synthesis. The grid layout can be constructed as a 3D curtain, or as a 2D vertical plane, by projecting the three dimensional data from the two beams onto this vertical plane along the average flight track direction.



Fixed antenna configuration.

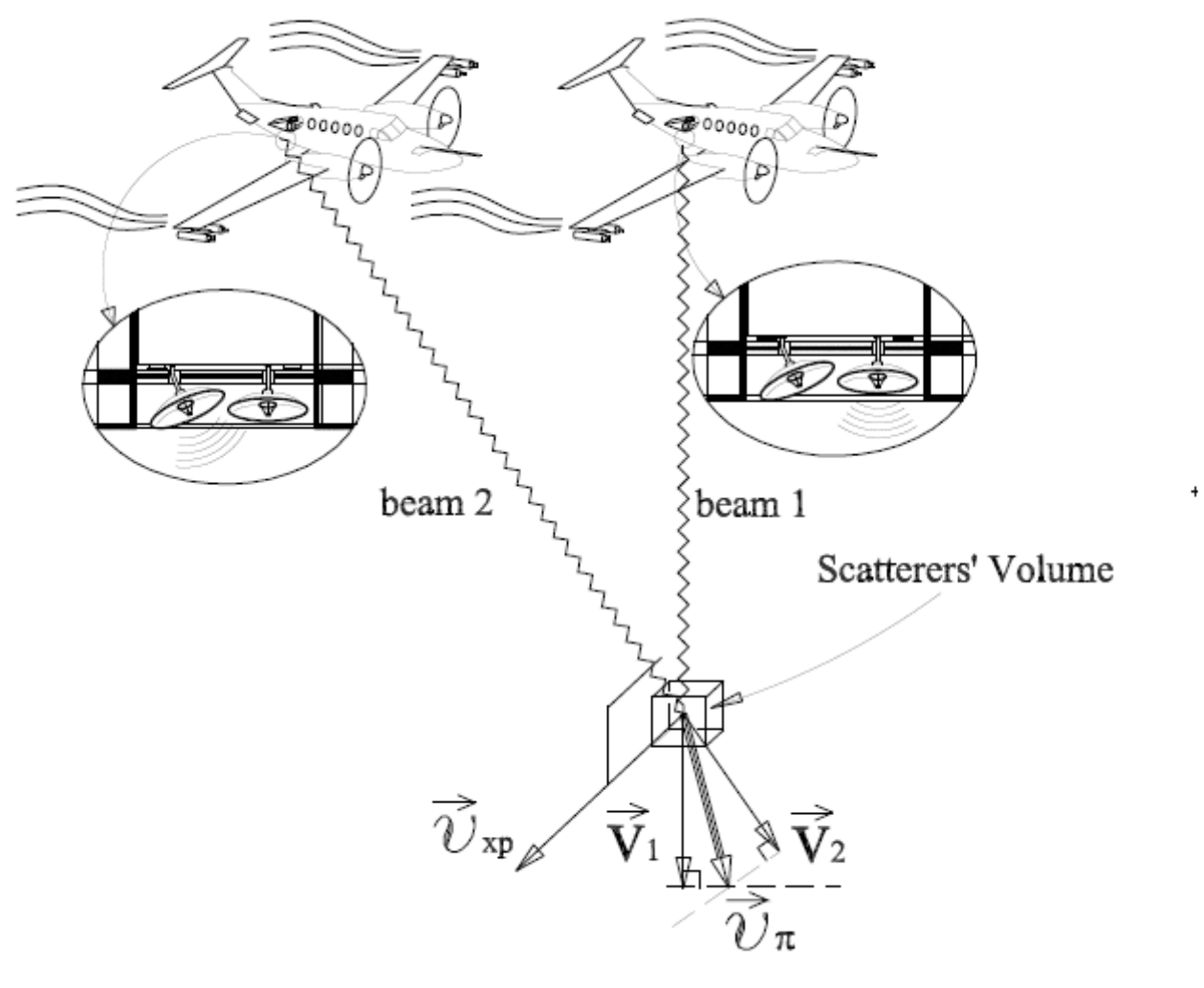
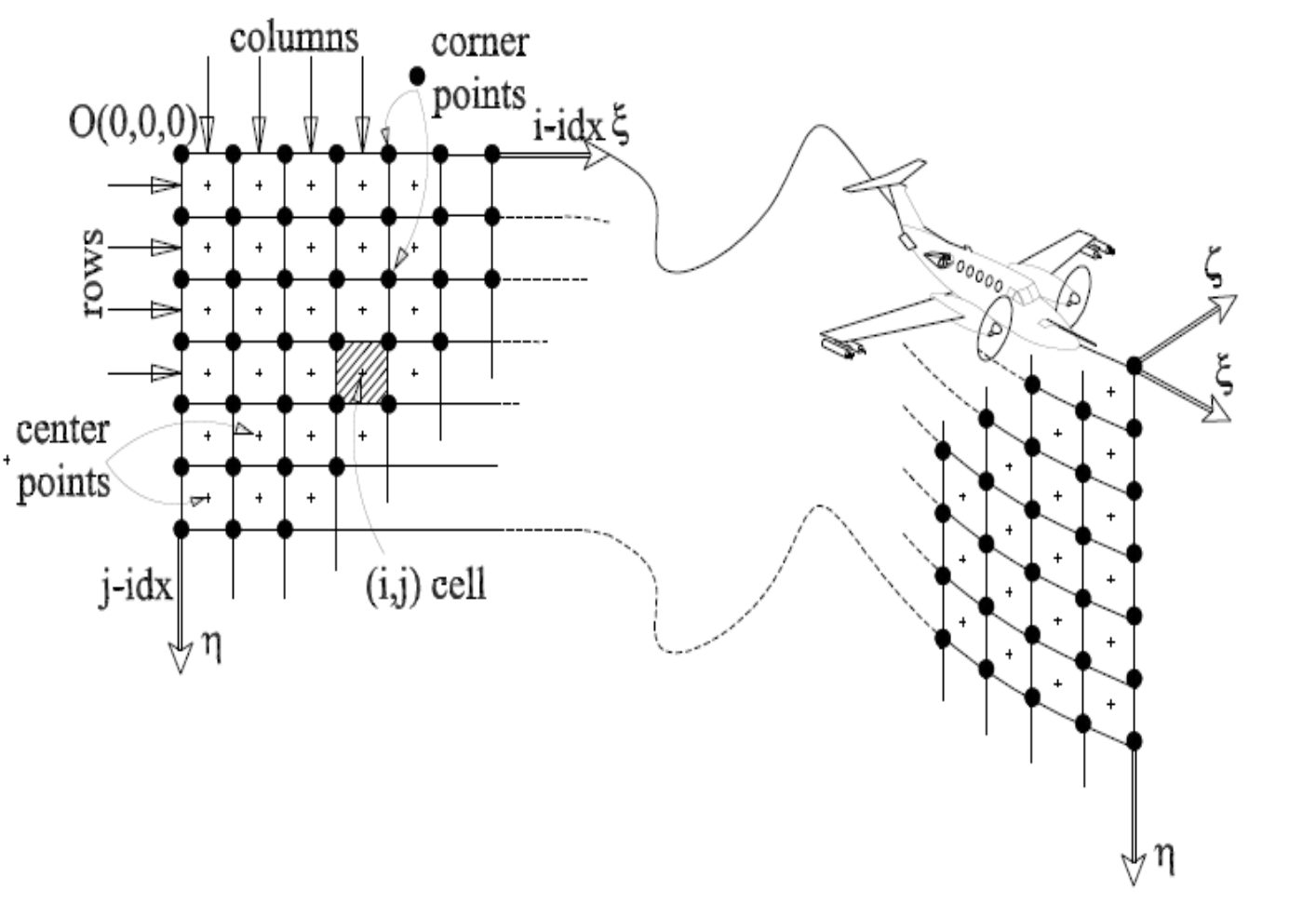
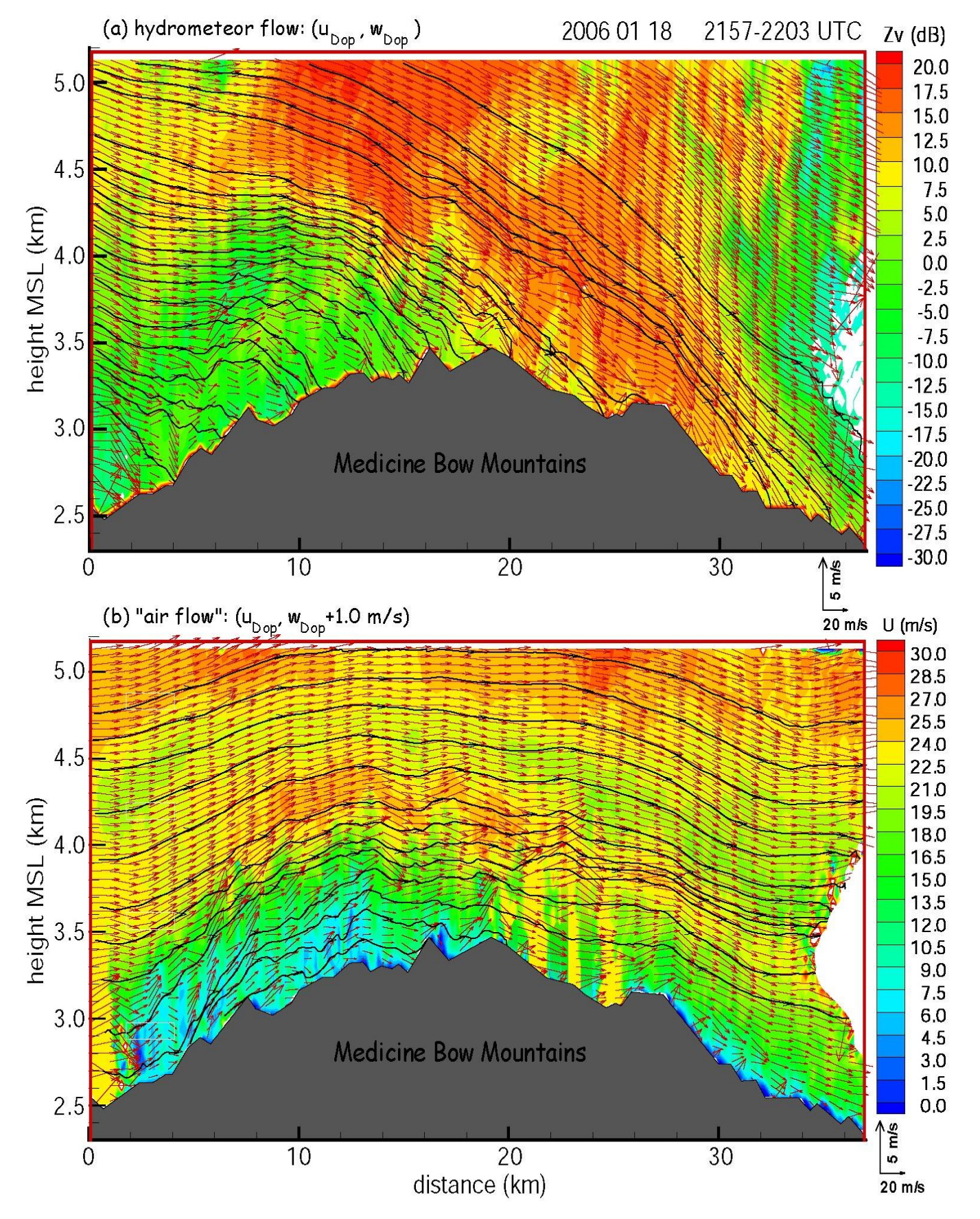


Illustration of the dual-Doppler concept.

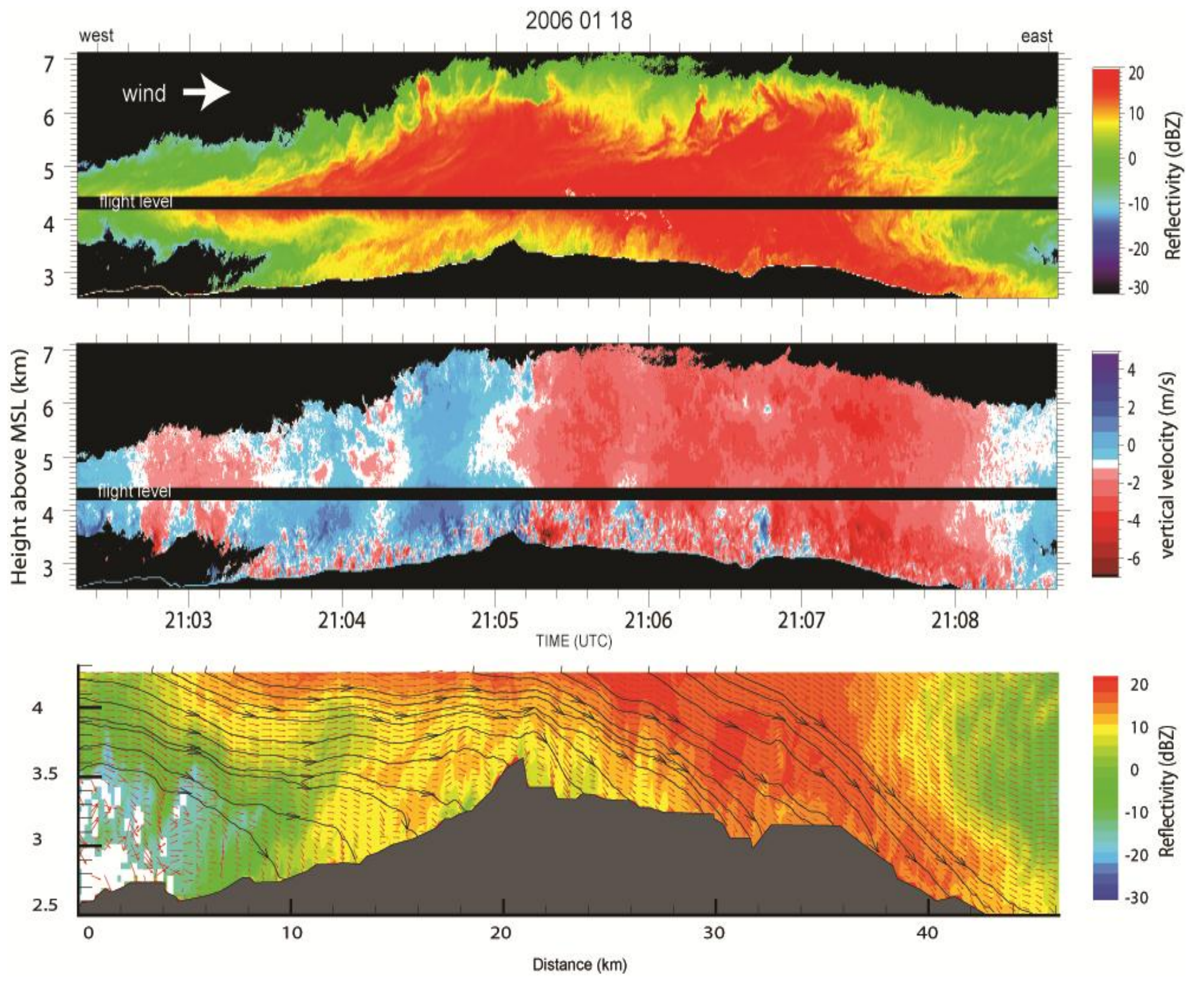


Typical grid arrangement and definitions of rows, columns, corners, center points, and the reference system for VPDD synthesis.

- Prior to synthesis the beam data are advected to a common time, using flight-level measured wind. The data from the two beams are assigned to the grid cells according to their position, using an interpolation such as inverse distance weighting.
- The dual-Doppler synthesis package has many options. See poster by Sam Haimov for more details about the software.

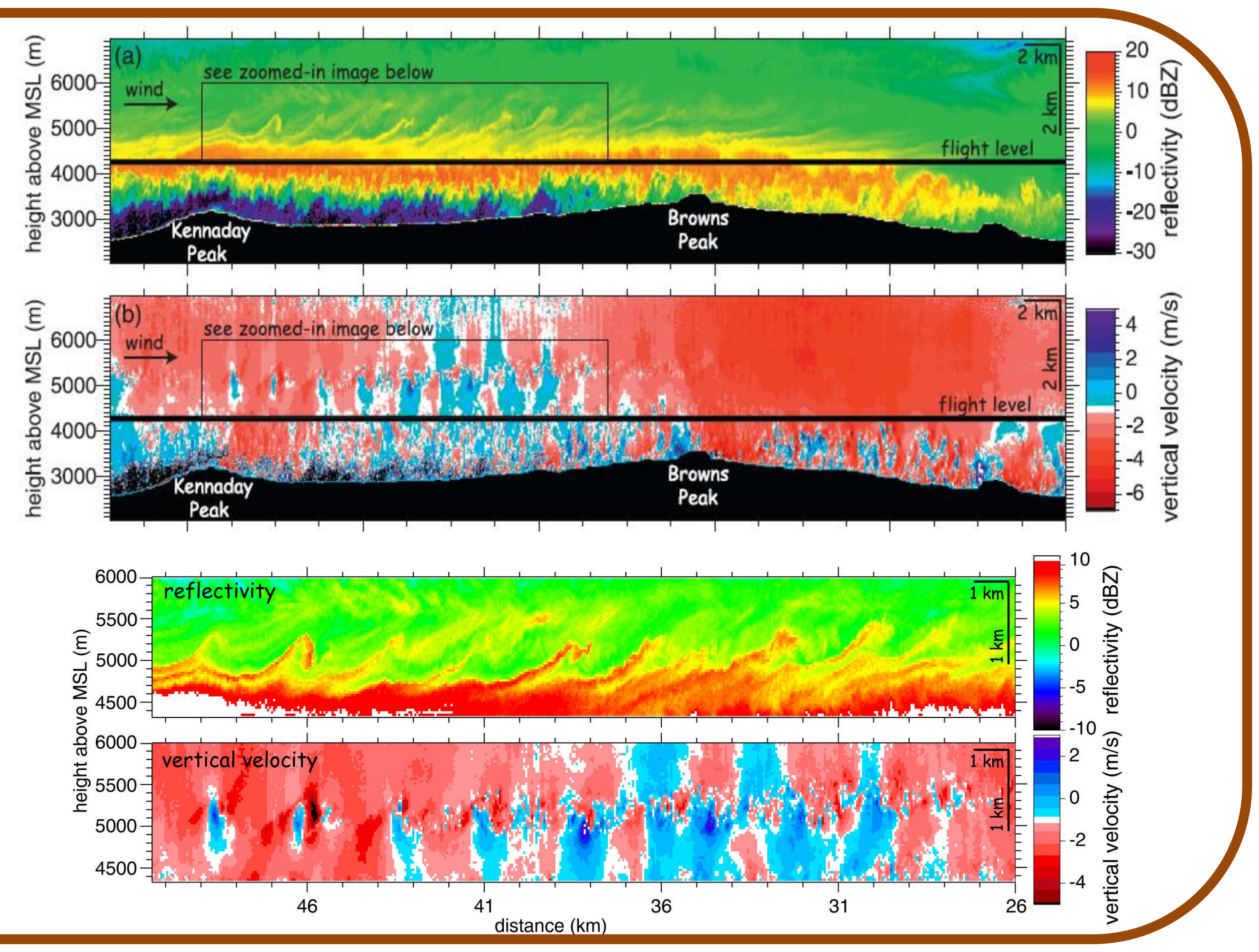


Along-track flow field for the same cross section as the lower-left image, between flight level and the terrain. The vectors and streamlines are derived from the VPDD synthesis. These vectors and streamlines represent the hydrometeor motion (a). Panel (b) shows the same, but 1 m/s is added to the vertical component, to remove the hydrometeor fallspeed.



WCR data for a transect flown on Jan 18 between 210216-210840 UTC. (a) Reflectivity above and below flight level. (b) Hydrometeor vertical motion. (c) Dual-Doppler synthesized along-track and vertical flow field (red vectors), with reflectivity in the background. Streamlines are shown (blue line), tangential to the local vectors.

## single-Doppler WCR view of Kelvin-Helmholtz billows in deep stratiform precipitation (Geerts and Miao 2010)



**Reference**:

- Damiani R., and S. Haimov, 2006: A high-resolution dual-Doppler technique for fixed multi-antenna airborne radar. *IEEE Trans. Geosci. Remote Sens.*, **44**, 3475–3489.
- Geerts B., Q. Miao, and Y. Yang, 2011: Boundary-layer turbulence and orographic precipitation growth in cold clouds: evidence from profiling airborne radar data. *J. Atmos. Sci.*, **68**, 2344-2365.
- Geerts, B., Q. Miao, 2010: Vertical pointing airborne Doppler radar observations of Kelvin-Helmholtz Billows. *Monthly weather review.*, **138**, 982-986.
- Leon, D., G. Vali, and M. Lothon, 2006: Dual-Doppler analysis in a single plane from an airborne platform. *J. Atmos. Oceanic Technol.*, **23**, 3–22.

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