Vertical velocity retrievals in marine stratocumulus clouds

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Abstract

Cloud and drizzle microphysics and vertical velocity statistics are remotely sensed with millimeter cloud radars. Different methods are available to separate rain drop gravitational settling fall speed from air velocity.

The motion-stabilized NOAA W-band Doppler cloud radar was deployed on a ship in the southeastern tropical Pacific in the VOCALS (VAMOS Ocean Cloud Atmosphere Land Study) 2008 experiment to sample the stratocumulus cloud deck. In CAP-MBL (Clouds, Aerosol, and Precipitation in the Marine Boundary Layer) the ARM mobile facility (AMF) WACR Doppler cloud radar was deployed at Graciosa, Azores in 2009-2010.

We retrieve vertical air velocity from stratocumulus clouds in these locations using radar reflectivity and mean Doppler vertical velocity moments. The empirical separation technique uses the constraint that gravitational settling of hydrometeors is independent and uncorrelated to air vertical motion (Pinsky et al. 2010).

Method

1.

The Pinsky et al. (2010) air vertical velocity retrieval first constructs a lookup table of mean fall speeds $V_g(Z, h)$ as a function of reflectivity and height in the cloud.

$$V = V_g(Z, h) + U$$

We find that the mean fall speed dependence on height and reflectivity is variable, changing slightly with variation of the cloud drizzle microphysics.

Longer time-averaged lookup tables may be more robust, but less representative of clouds observed in a local neighborhood. Our objective is make $V_g(Z, h)$ both representative and robust.

2.

The first step separates Doppler velocity into mean fall speed and a residual velocity U. The second part of the Pinsky et al. (2010) retrieval separates the residual velocity into two parts

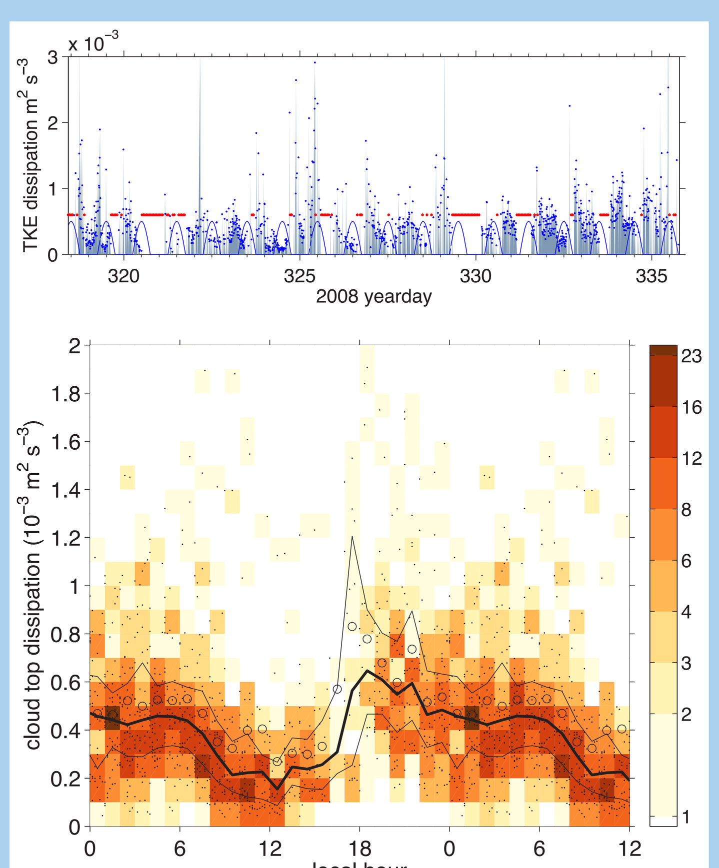
$$U = V_g' + W,$$

with air vertical velocity W. The relative partition between W and V_g'

- assumes W and V_g' are uncorrelated
- depends on the standard deviation of U in each lookup table bin $\theta=\sigma_U(Z, h)$: more bin standard deviation $\theta \rightarrow$ more of U assigned to V_g' and less to W.

Cloud-top dissipation

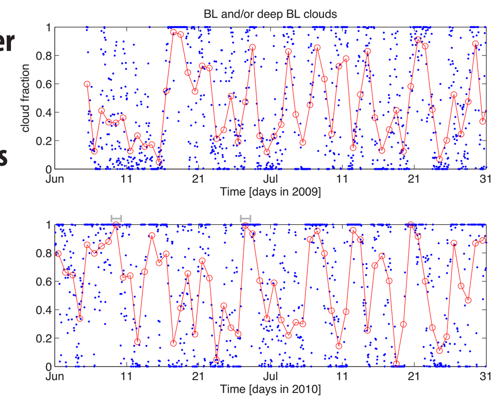
Droplet fall speeds are relatively small at cloud top. In a preliminary calculation from the VOCALS stratocumulus cloud radar Doppler vertical velocity data, we assumed velocities in the highest range gate had negligible contribution from droplet fall speed, and interpreted the Doppler velocity as air velocity. Using a slowly-varying horizontal wind and Taylor's hypothesis we computed the turbulence kinetic energy (TKE) dissipation at cloud top from velocity spectra. The time series from VOCALS cruise leg 2 (upper) has diurnal variability and extreme outliers. We composited the time series on the local time of day (below), computed the histogram (shaded), and the median dissipation (bold line) in each hour.



Median TKE dissipation doubles quickly at sunset (18 h local), presumably due to negative buoyancy generated by longwave cloud-top radiative cooling unbalanced by solar warming. TKE dissipation stays high most of the night, and decreases from sunrise (6 h) to noon. Strong dissipation values above 0.8×10^{-3} m^2 s^{-3} are more common at night than daylight.

CAP-MBL: Azores subtropical Atlantic clouds

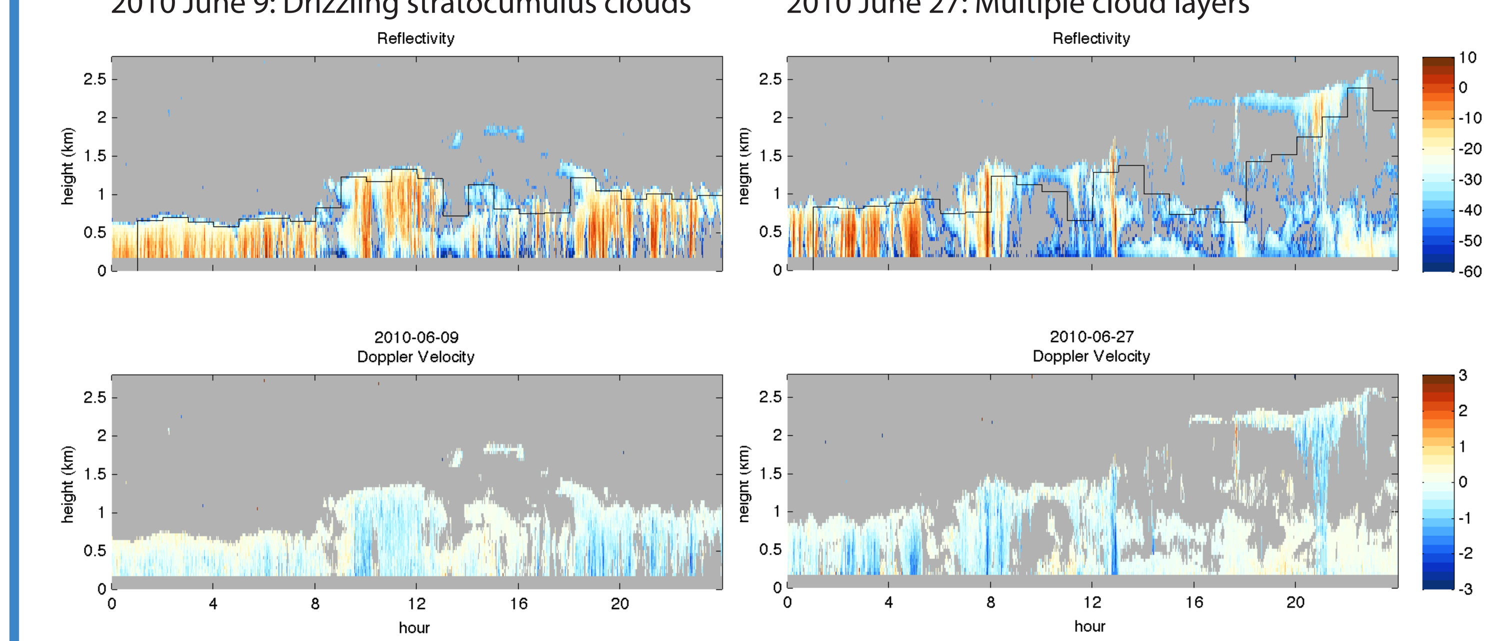
Cloud height and type varied considerably in CAP-MBL on synoptic time scales, due to the influence of midlatitude synoptic weather patterns (Rémillard et al 2012). We compute the lookup table for two days chosen for their relatively uniform boundary layer clouds, and use it for vertical velocity retrievals on those days.



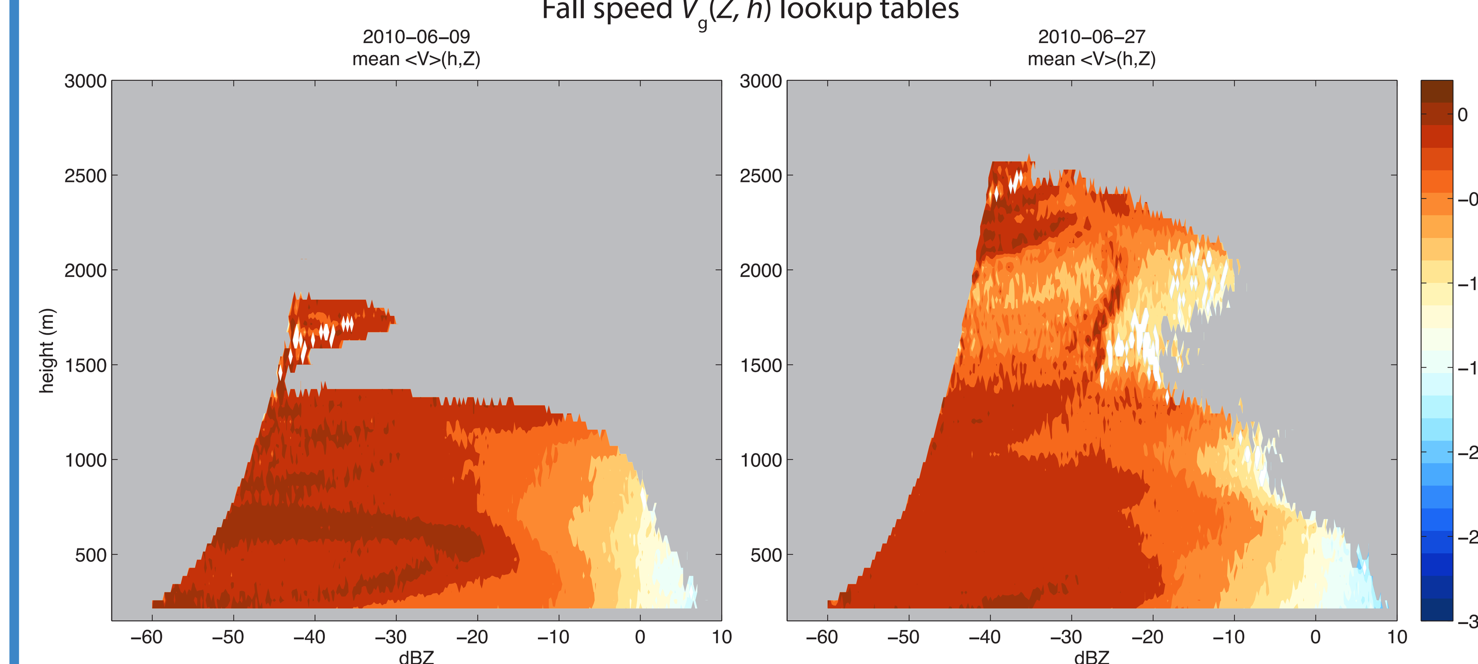
Hourly (blue) and daily (red, by UTC day) boundary layer cloud fraction from the CAP-MBL cloud synthesis data set (Rémillard et al. 2012). Two days (2010 June 9 and 27) when there were nearly solid boundary layer clouds were chosen based on these data.

Reflectivity and vertical velocity for these two days appear below. The black line shows the hourly average cloud top height from Rémillard.

2010 June 9: Drizzling stratocumulus clouds — 2010 June 27: Multiple cloud layers

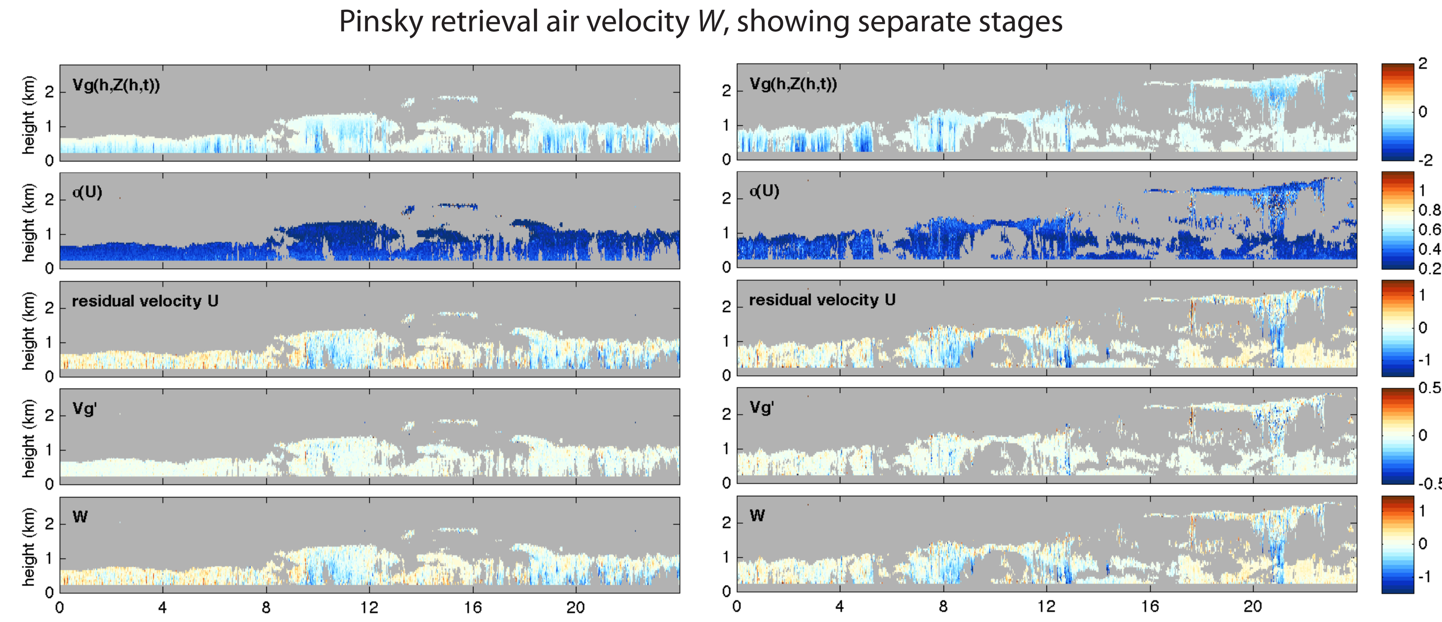


Fall speed $V_g(Z, h)$ lookup tables



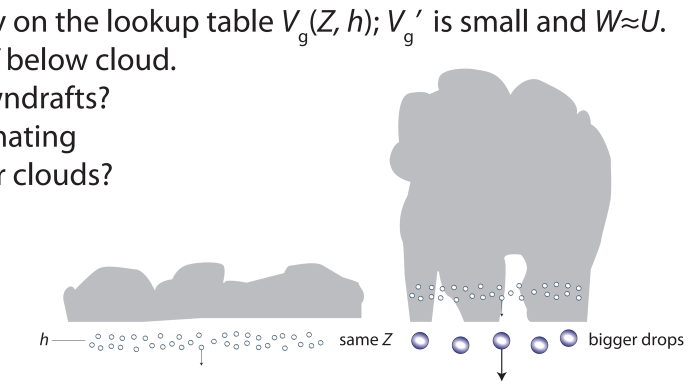
The lookup tables of gravitation fall speed $V_g(Z, h)$ are similar for these two days with boundary layer clouds. Drizzle fall speeds are on the order of 1 m s^{-1}. High reflectivity and weak fall speeds in shallow drizzling clouds dominate larger fall speeds in isolated showers.

Pinsky retrieval air velocity W, showing separate stages



2010 June 9: Drizzling stratocumulus clouds — 2010 June 27: Multiple cloud layers

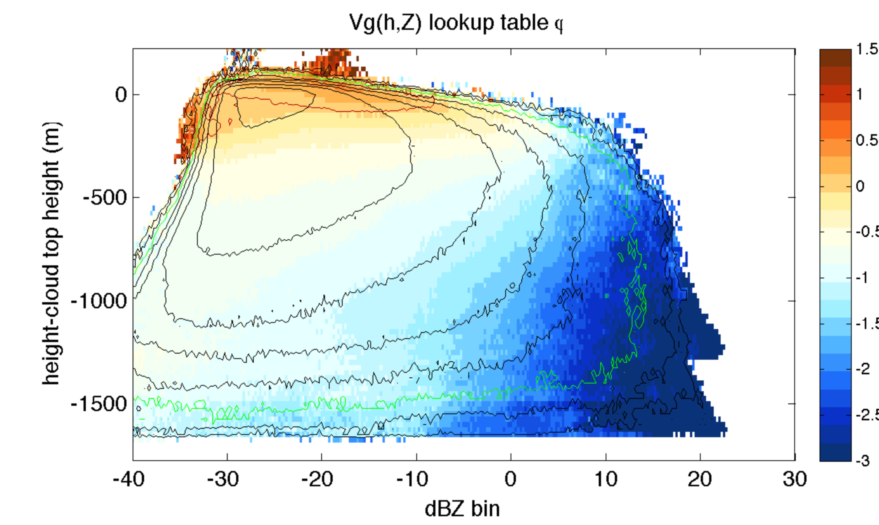
- The retrieved air velocity W depends mostly on the lookup table $V_g(Z, h)$; V_g' is small and $W \approx U$.
- Deeper clouds have downward retrieved W below cloud.
  - Do deeper rain shafts induce true air downdrafts?
  - Or are they artifacts of $V_g(Z, h)$ underestimating rain fall speed in rain shafts below deeper clouds?
- To do: Refine cloud top estimate and construct lookup table with vertical coordinate *relative to cloud top height*.



VOCALS: eastern tropical Pacific Ocean stratocumulus clouds

For VOCALS, in the southeastern Pacific Ocean, more than 400 hours of continuous observations of marine stratocumulus clouds are available from the motion-corrected NOAA W-band cloud radar (Moran et al. 2012). The cloud height varied diurnally, synoptically, and with distance to the coast, but 1-2 km high stratocumulus clouds were observed overhead ~90% of the time (de Szoeke et al. 2012).

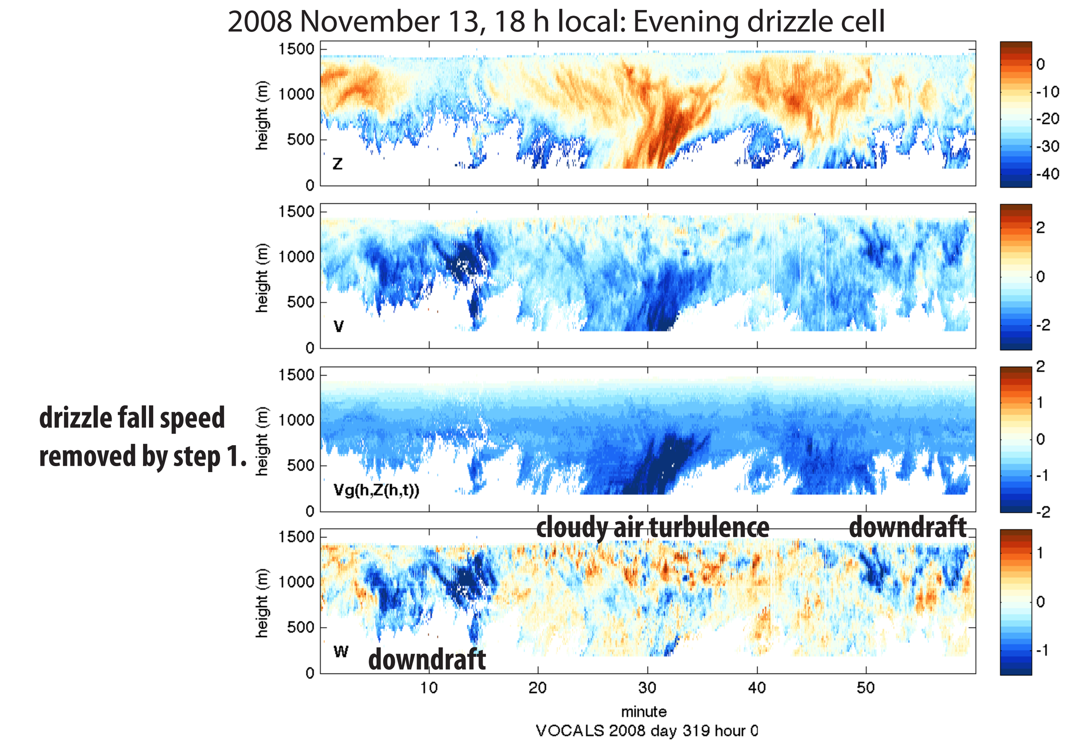
Because stratocumulus cloud top was so well defined for VOCALS, we compiled the settling velocity lookup table $V_g(Z, h')$ on the cloud-top relative vertical coordinate $h' = h - h_{cloud\ top}$.



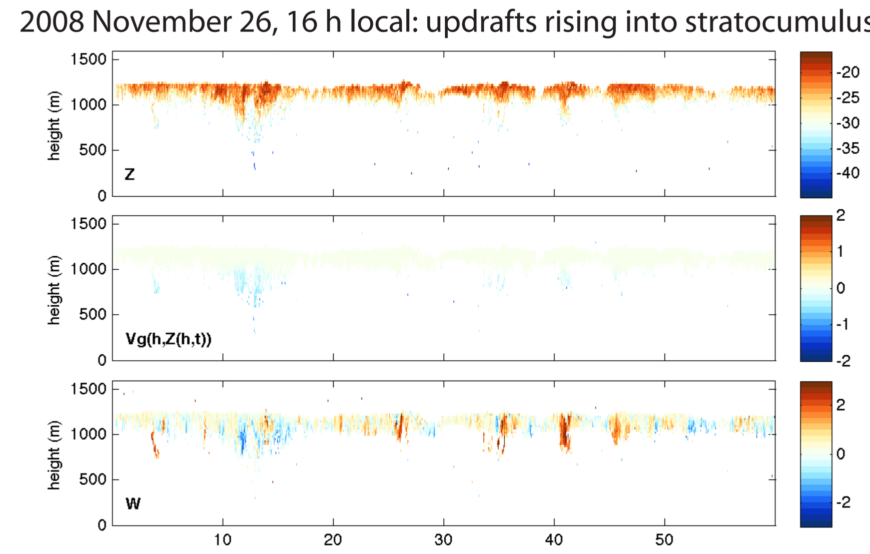
The lookup table $V_g(Z, h')$ averaged over the whole VOCALS research cruise (shaded). Number of observations in each Z, h' bin are contoured (black). Clouds (upper left) have negligible fall speed and are observed most frequently. Settling velocity V_g increases downward and with increasing reflectivity.

The lookup table is calculated hourly. To balance representativeness and robustness the lookup table used in the VOCALS retrieval was averaged over a 4-hour wide Gaussian time window.

2008 November 13, 18 h local: Evening drizzle cell



2008 November 26, 16 h local: updrafts rising into stratocumulus



We retrieve turbulent, updraft, and downdraft air velocities in clouds with and without drizzle; and in the drizzle below cloud.

Downward velocity features (~10 minute with low reflectivity, tenuous cloud and no drizzle) are seen near drizzle in the VOCALS radar data. These could be downdrafts at drizzle cell edges, perhaps driven by negative buoyancy or aided by entrainment of dry air from above the inversion.

References

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