A Quantitative Analysis of Convective Mass Flux Parameterizations Using Direct Observations from DYNAMO

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Background on Atmospheric Convection

Marine Convective Regimes		
REGIME	HEIGHT SCALE	DRIVERS
Cloud-Free	Zi	Surface U, Buoyancy
Stratocumulus	Zb (LCL), Zi	Surface U, Buoyancy Cloud Top IR Cooling
Trade cumulus	Zb, Zi	Surface U, Buoyancy Latent Heat Release
Shallow (Warm)	Zb, LFC	Latent Heat Release
Deep	Zb, LFC	Convergence Latent Heat Release Ice-Liquid Microphysics

Mass Flux Parameterization

First order closure models the vertical fluxes in the following manner:

$$\overline{w'x'} = -K\frac{\partial X}{\partial z}$$

where x is the concentration of some atmospheric variable separated into mean (X) and turbulent (x') components.

Mass flux approach divides the atmosphere into updrafts and downdrafts such that: $X = \sigma_{up} X_{up} + \sigma_{dn} X_{dn}$

where X_{up} and X_{dn} are the mean concentrations during updrafts and downdrafts respectively.

And the fluxes are modeled as: $\overline{w'x'} = M_*\left(X_{up} - X_{dn}\right)$

Hybrid

$$\overline{w'x'} = -K\frac{\partial X}{\partial z} + M_*\left(X_{up} - X_{dn}\right)$$

Why Mass Flux Parameterization

Mass flux parameterizations offer an inherently non-local approach. It captures the fluxes through estimation of the updraft/downdraft fractions and mass flux velocity.

The updraft fraction (σ) and mass flux velocity (M_*) are estimated by the 2nd and 3rd moments of w′ in the following way (Lappen and Randall 2001):

$$\sigma = \frac{1}{2} - \frac{S_w}{2\left[4 + S_w^2\right]^{1/2}}$$

$$M_* = \left[\frac{\overline{w'^2}}{4 + S_w^2}\right]^{1/2}$$

The model derived values will be compared to directly measured values.

σ_{up} is the fractional updraft coverage defined as the percentage of time $w(t) > 0$ m s^{-1};
σ_{up} is the fractional downdraft coverage defined as the percentage of time $w(t) < 0$ ms^{-1}

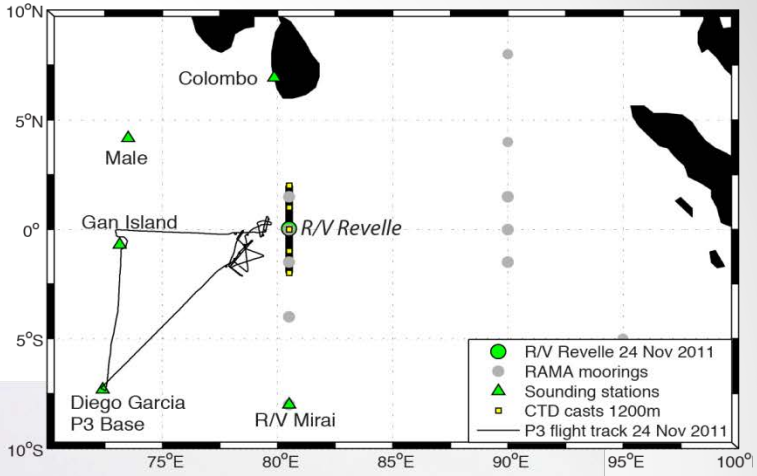
M_* is calculated as follows:

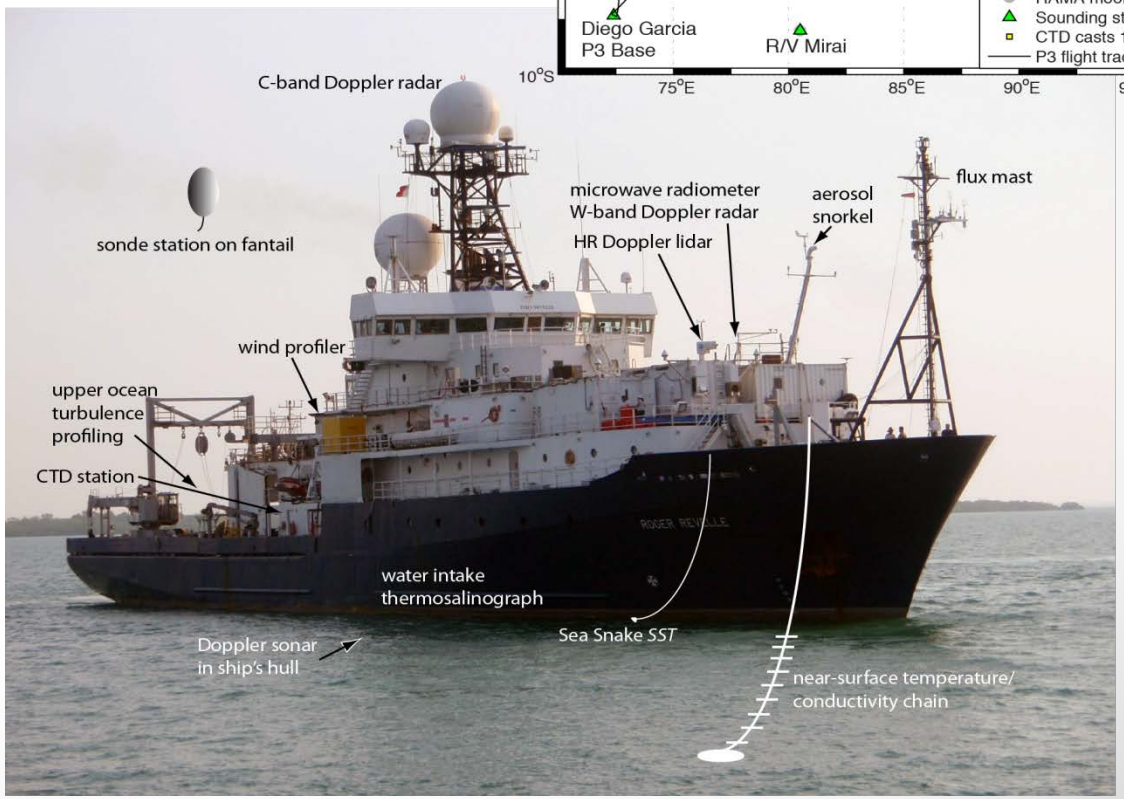
$$M_* = \sigma_{up} \times \sigma_{dn}\left(w_{up} - w_{dn}\right)$$

Where w_{up} and w_{dn} is average vertical velocity in the updrafts and downdrafts respectively

Measurements Used

- Measurements used from the RV Revelle
- Met measurements - Air Temp, Water vapor, Wind
- Aerosol Measurements – sub 10µm scattering
- Doppler Lidar – wind and aerosol backscatter
- W-band Doppler radar





Source: Moum et al. (2013)

High Resolution Doppler Lidar (HRDL)

- Mounted on the forward O2 deck of the RV Revelle
- Measures line-of-site wind speed and aerosol backscatter Intensity
- 30m along beam resolution, 2 Hz data rate
- Motion stabilized / hemispheric scanning
- Provided continuous coverage Legs 1, 2, & 3
- Scanning strategy gives 50% vertical staring

94-GHz Cloud Doppler RADAR (Wband)

- Mounted on the forward O2 deck of the RV Revelle
- Measures mean Doppler velocity, Doppler width (σ_w), backscatter (dBZ)
- 25m along beam resolution
  2 Hz data rate
- Motion stabilized vertical pointing
- No scanning, 100% vertical stare

I. Retrieval of Clear Air Velocity from Wband Radar: Development from NOAA VOCALS Stratocumulus Field Program

Retrieval of Clear Air Velocity from Wband

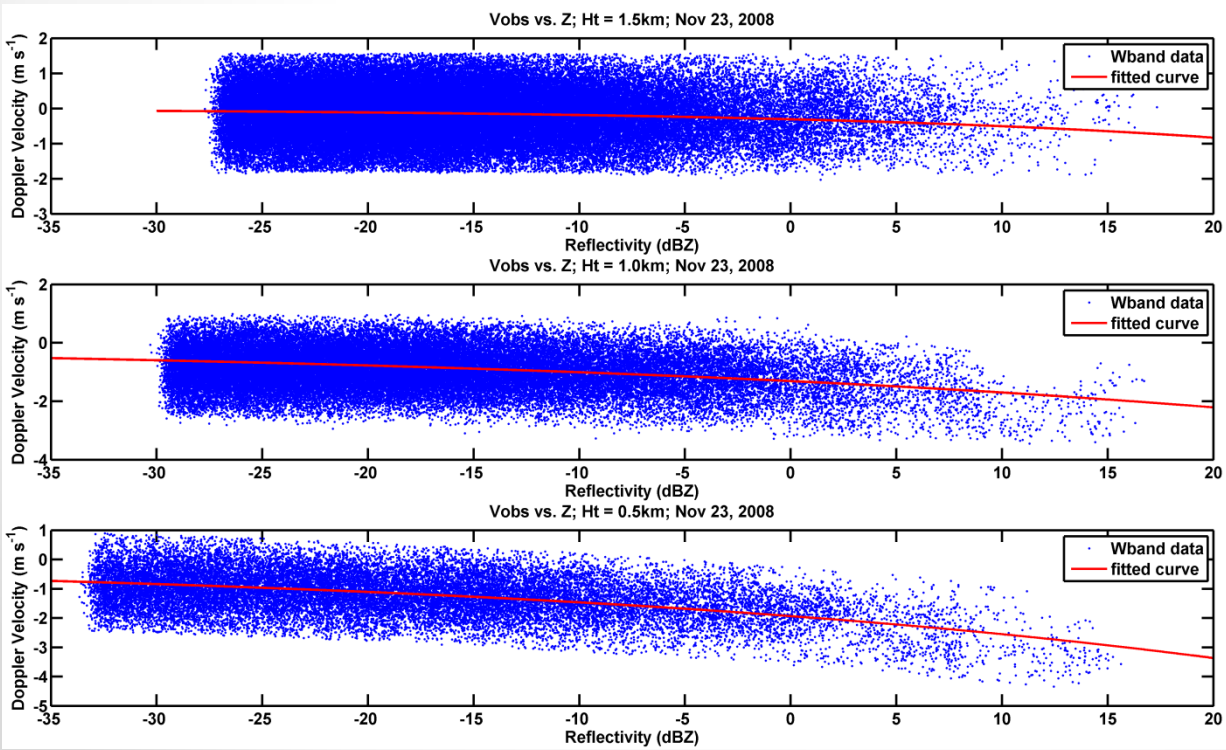
Radar Vdoppler=Vturbulence + Vgravity

Pinsky et al. (2010) method to retrieve the clear air components.
Cloud (0.01 mm) Vg=0.01 m/s
Drizzle (0.1 mm) Vg=1 m/s
Rain (1 mm) Vg=8 m/s

The measured velocity, V, is split into:

$$V(h,t) = W(h,t) + V_g(h,t) = \overline{W}(h,t) + W'(h,t) + \overline{V}_g(h,t) + V_g'(h,t)$$

where: $$V_g = \frac{1}{Z}\int_0^\infty r^6 N(r) V_d(r)\,dr$$



Assume: $\overline{W} = 0$

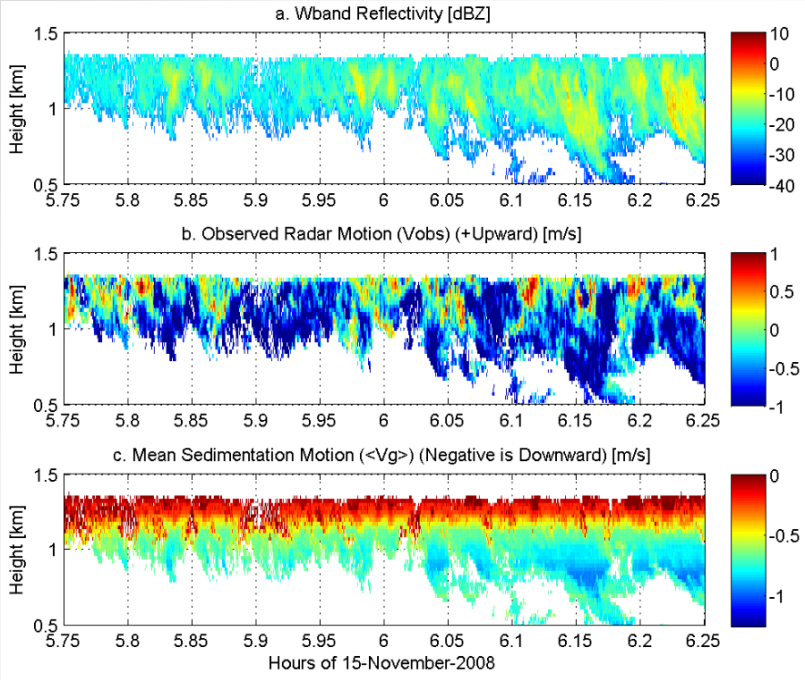
Then, estimate:

$$\langle V \rangle = \langle V_g \rangle = \varphi(\langle Z \rangle)$$

And therefore,

$$U(h,t) = V(h,t) - \varphi(h, \langle Z \rangle)$$
$$= W'(h,t) + V_g'(h,t)$$

Pinsky Results for ½ hour



Mean vertical drop velocity (-Vg)

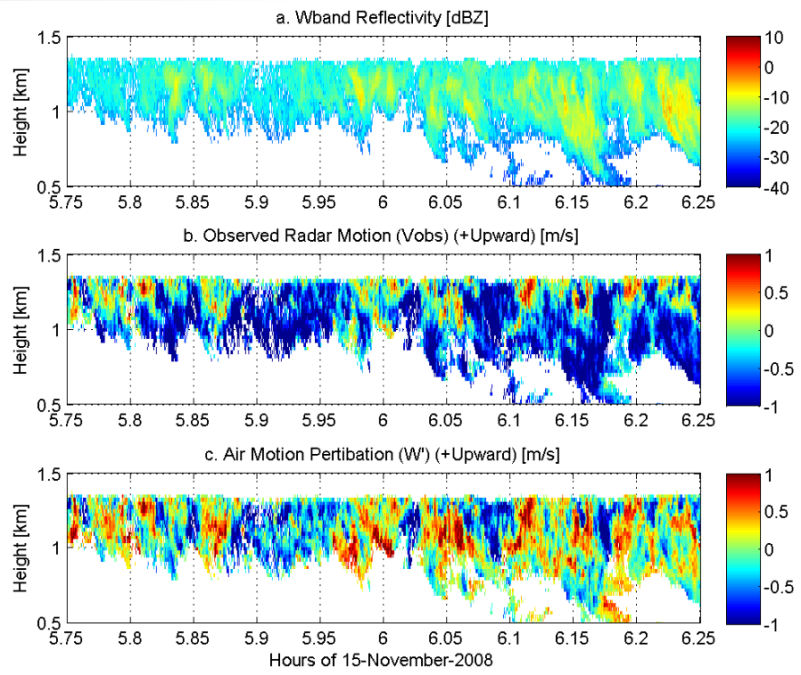
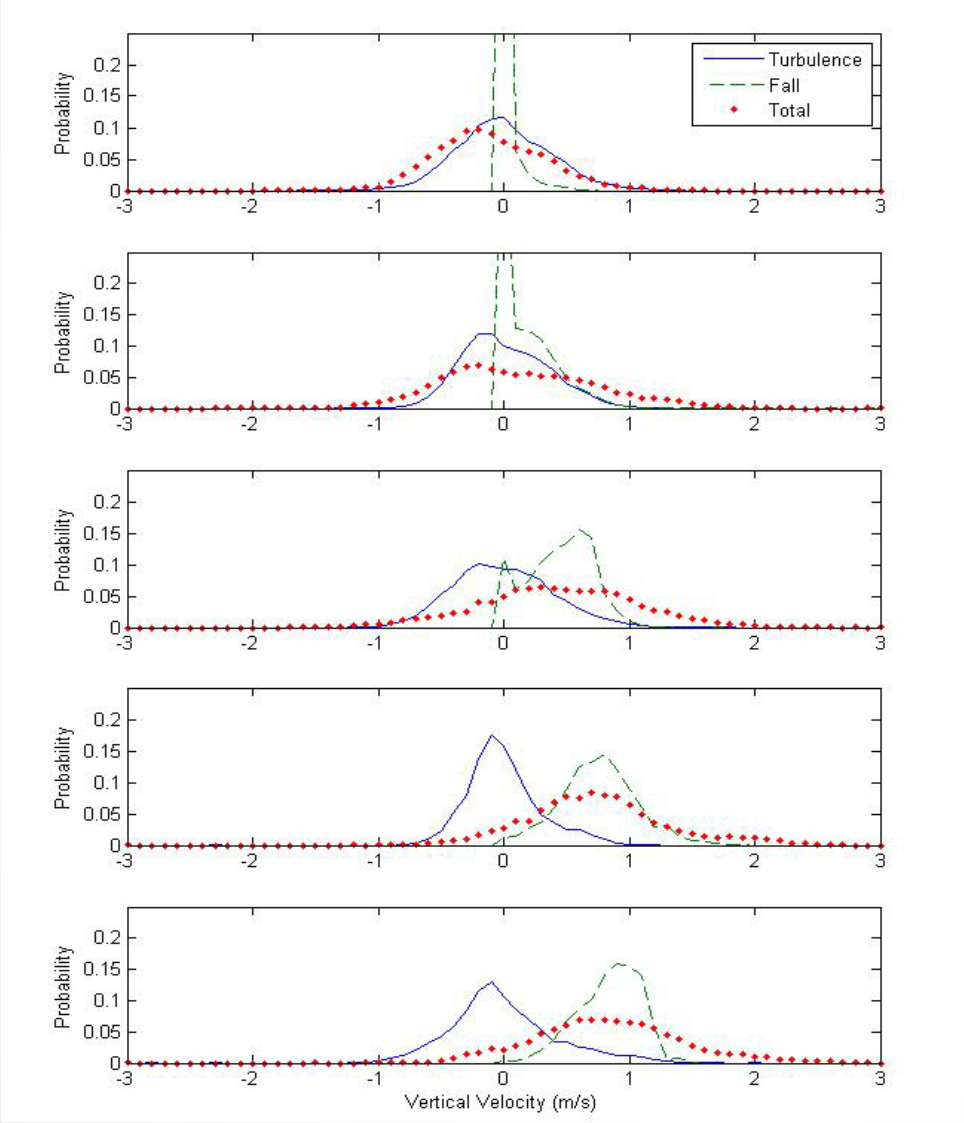


Figure 4. Clear-air velocity retrieval process. (a) Estimate of mean sedimentation velocity, (b) Estimate of turbulent air motion

Turbulence

Velocity Stats: Turbulence and Microphysics



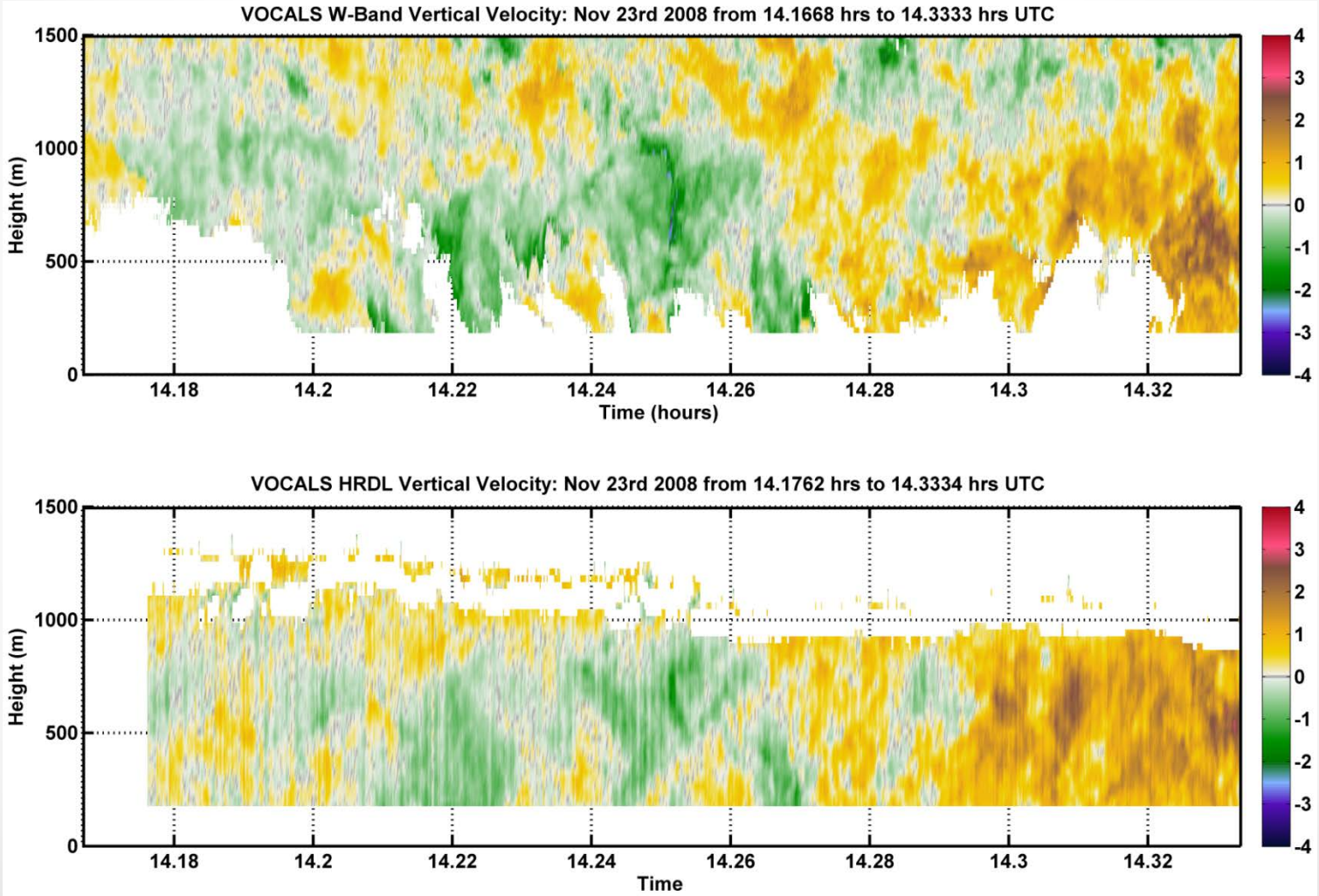
Probability distributions of vertical velocity at different heights in the cloud:

Red dots=raw Doppler

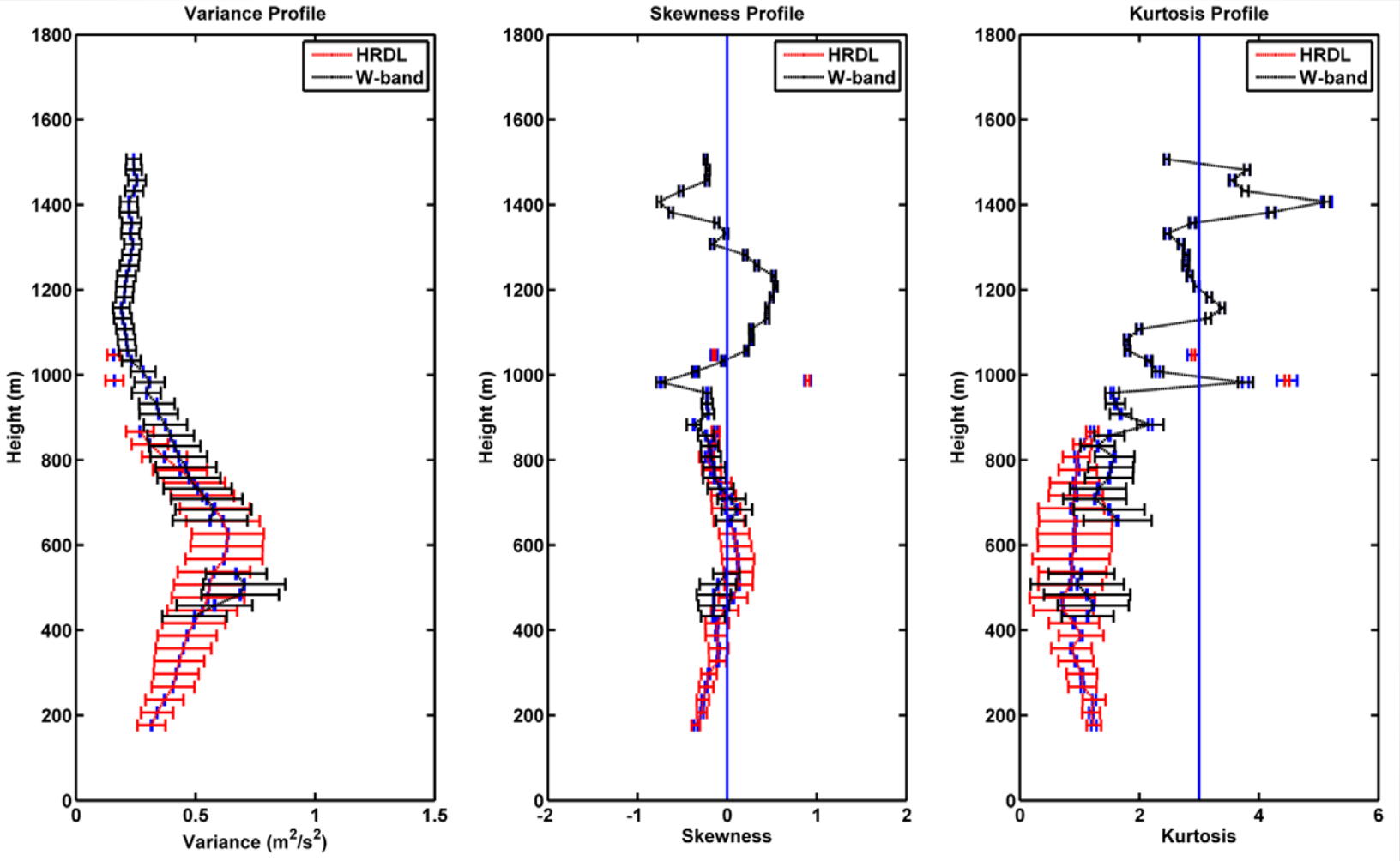
Blue line=turbulence

Green line=Vg

Comparison of Wband Turbulence Retrieval with Lidar Measurements



Comparison of Wband Clear Air Retrieval with Lidar Measurements



II. Evaluation of Mass Flux Closure

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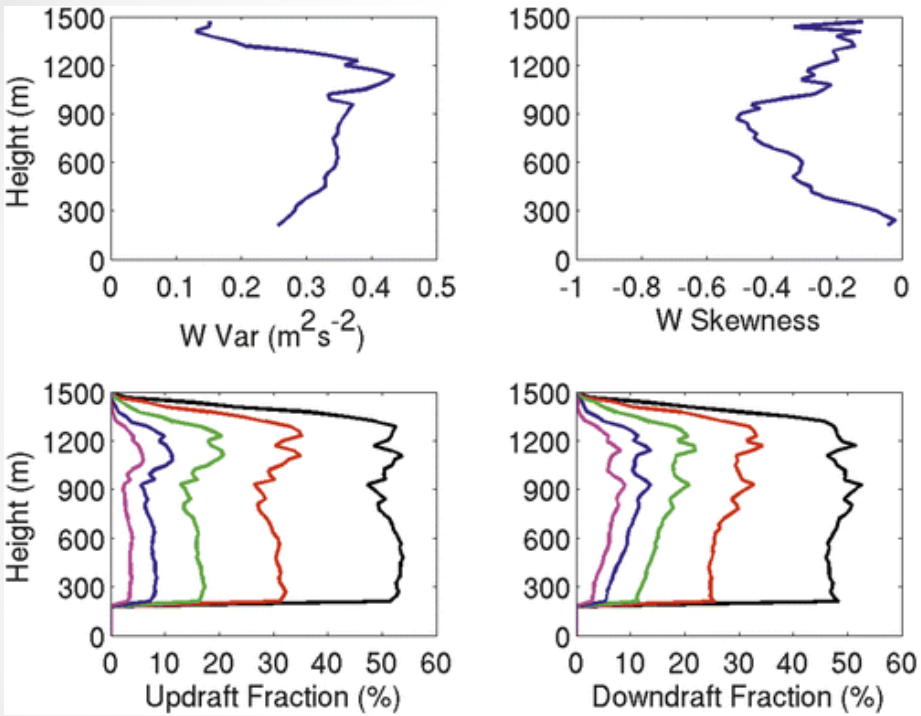
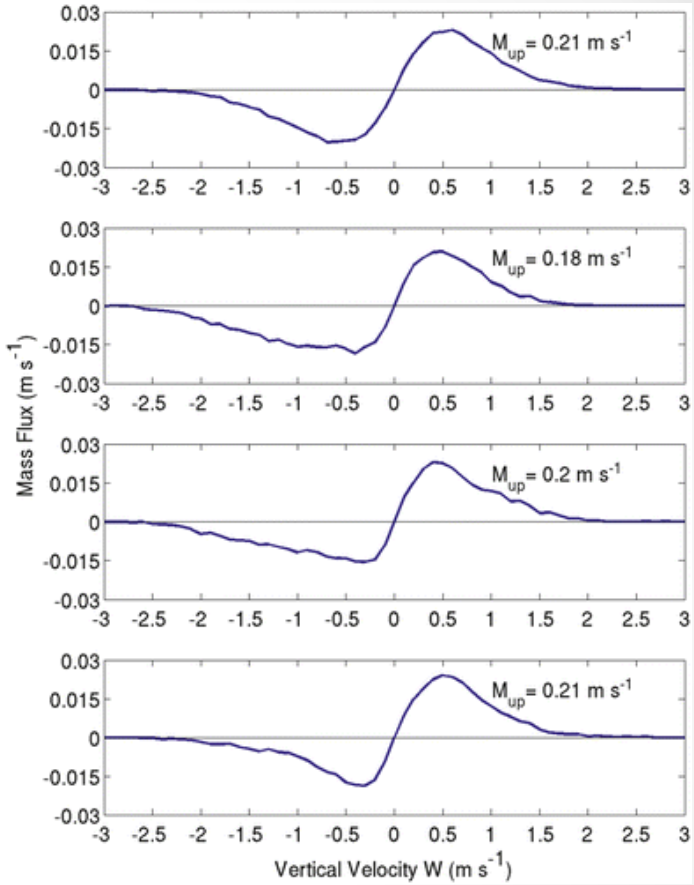
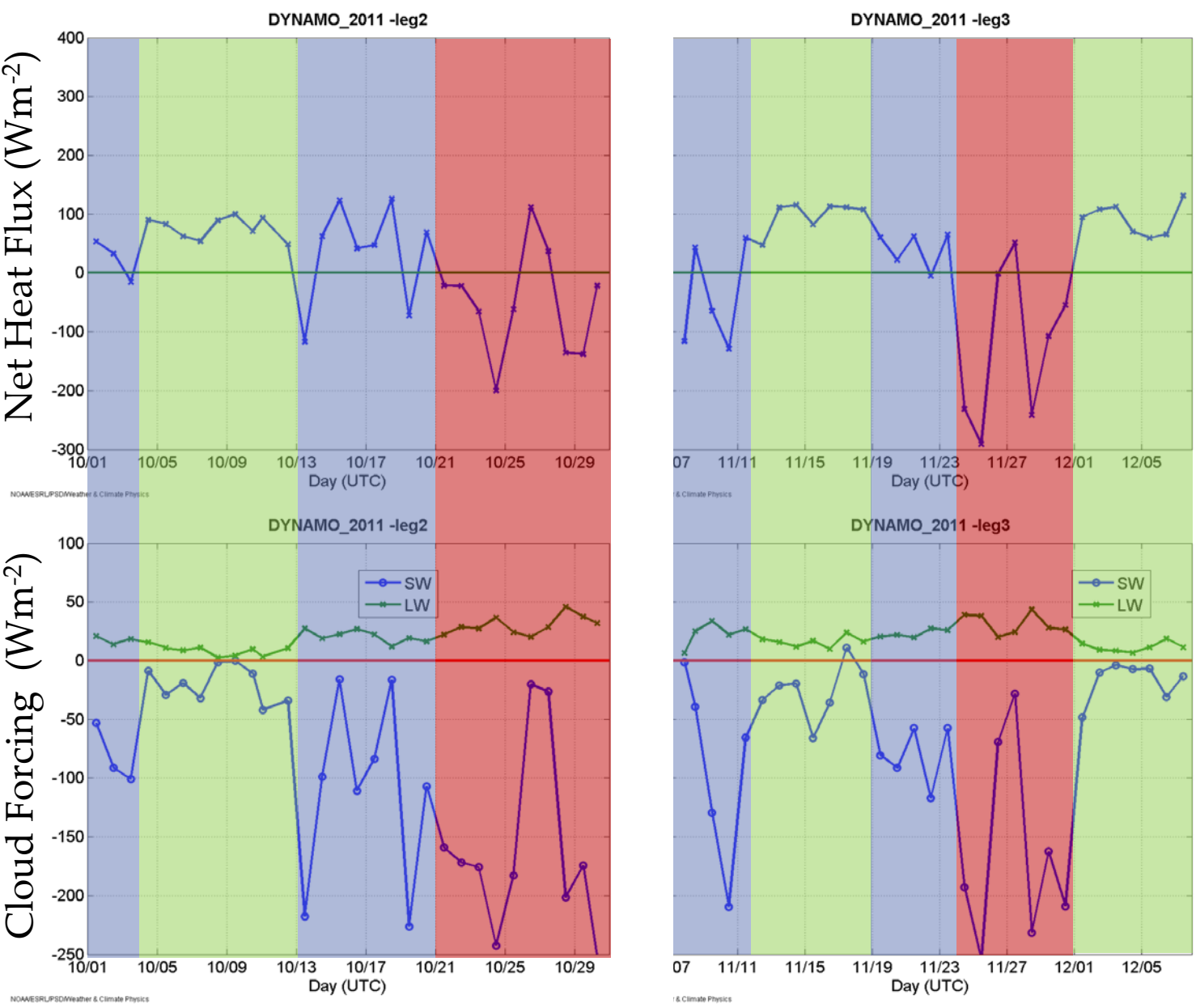
VOCALS Stratocumulus:November 27, 2008



Averaged profiles of (top left) vertical velocity variance and (top right) vertical velocity skewness. The (bottom left) updraft and (bottom right) downdraft fractions are shown with thresholds of 0 (black), 0.25 (red), 0.50 (green), 0.75 (blue), and 1 (magenta) m s^{-1}.



Averaged profiles of velocity binned mass flux at (top to bottom) 1200, 900, 600, and 300 m. The updraft mass flux at each level is also reported in the respective panels.



20 days

23 days

16 days

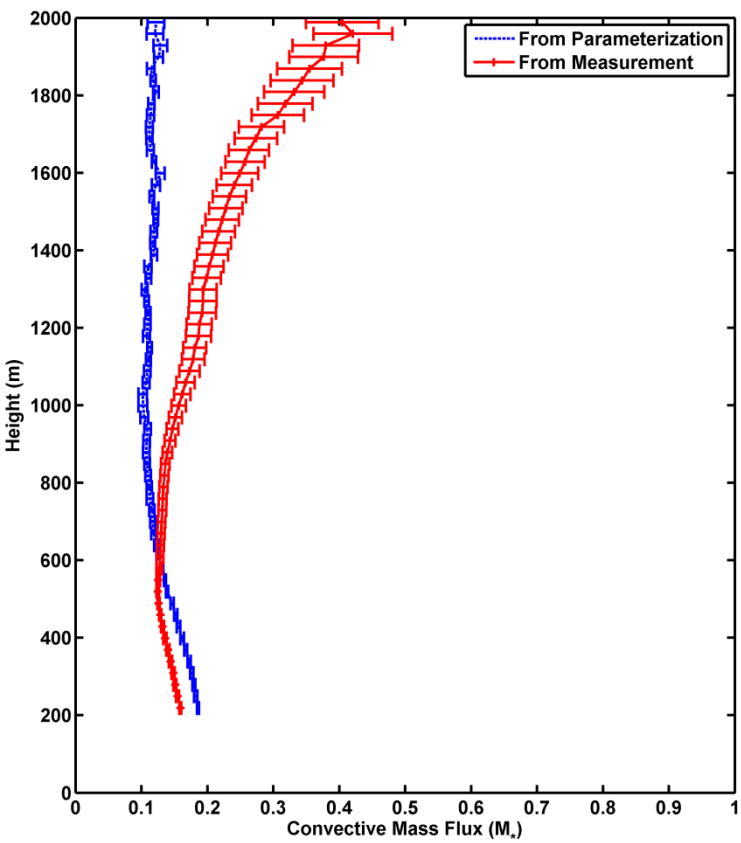
Combined measure threshold & variability

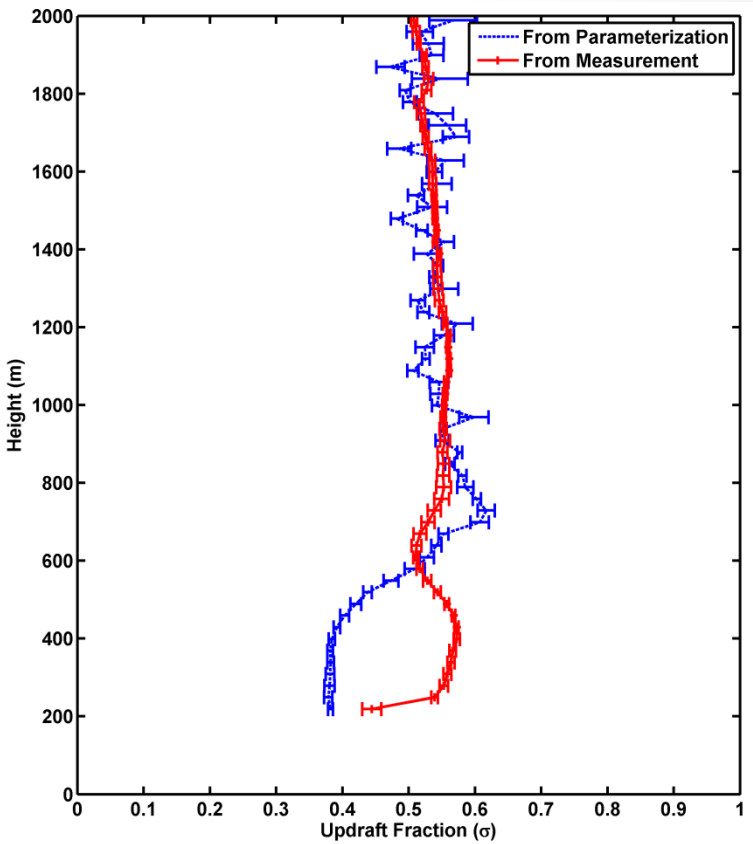
Maintain a regime for several days

Regimes Suppressed Disturbed MJO

Updraft fraction and Mass Flux Velocity

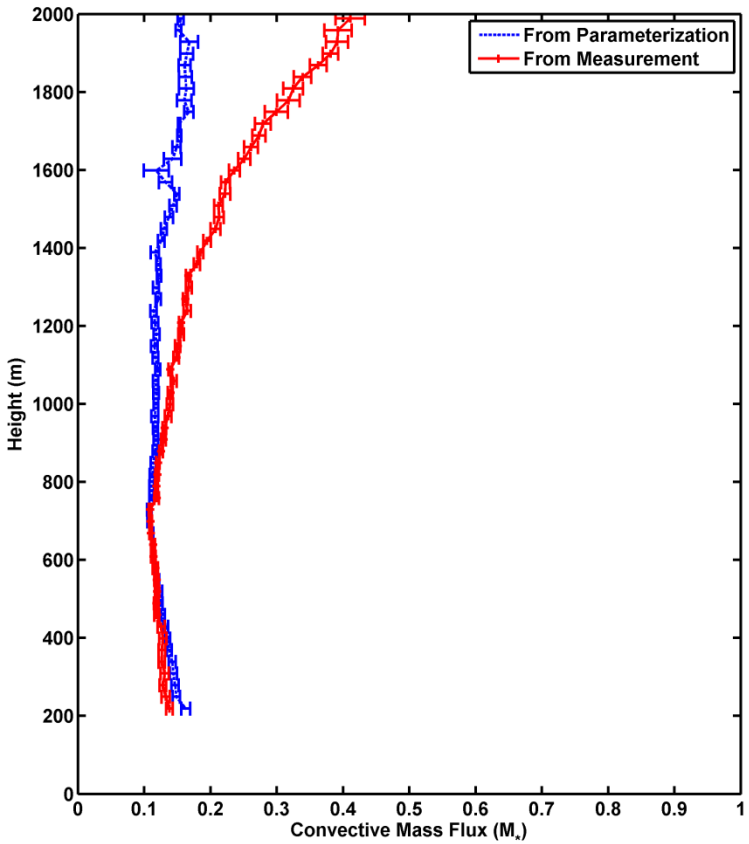
Suppressed Phase

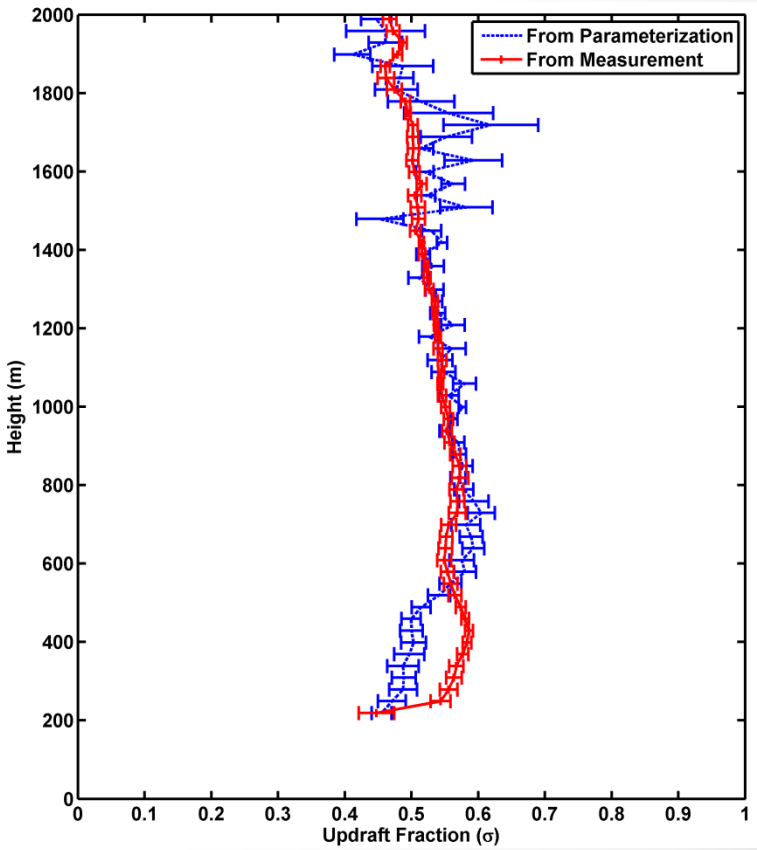




Updraft fraction and Mass Flux Velocity

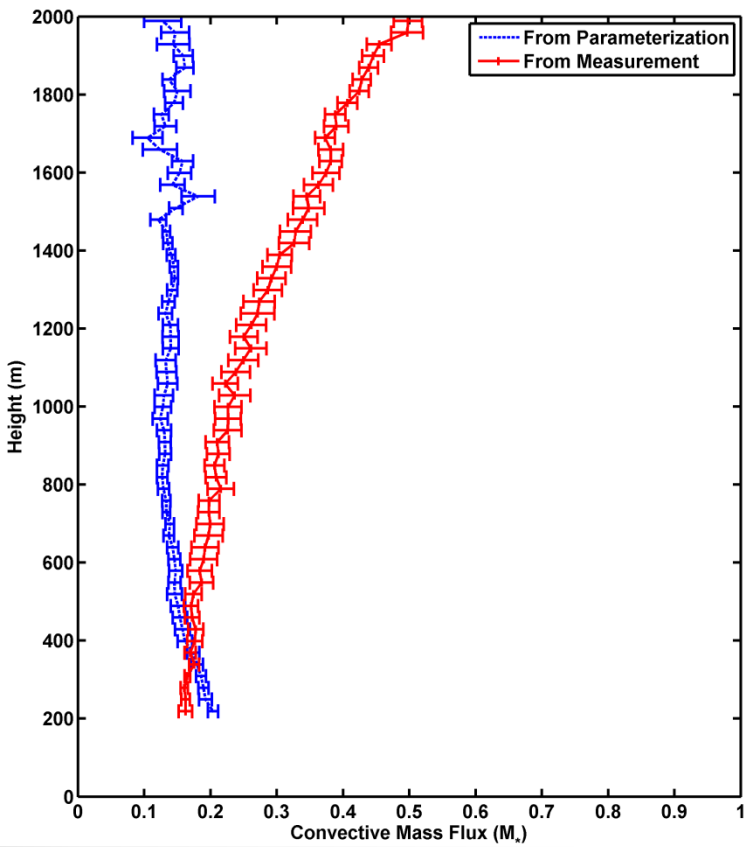
Disturbed Phase

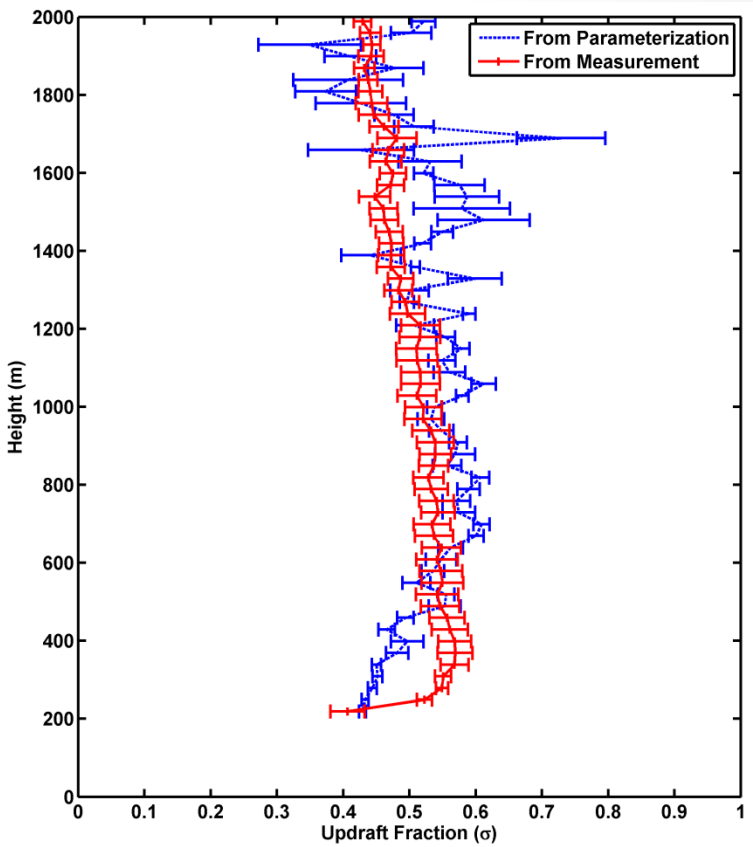




Updraft fraction and Mass Flux Velocity

MJO Phase





Future Work

- Improve turbulence retrievals in DYNAMO-type clouds
- Improve selection of sampling periods
- Combine Wband and HRDL data to achieve continuous coverage in cloudy and non-cloudy conditions
- Investigate the differences clear and cloudy parcels for for mass flux closure