Statistical analysis of turbulence-induced fluctuations in in-cloud saturation ratio and rates of cloud droplet growth

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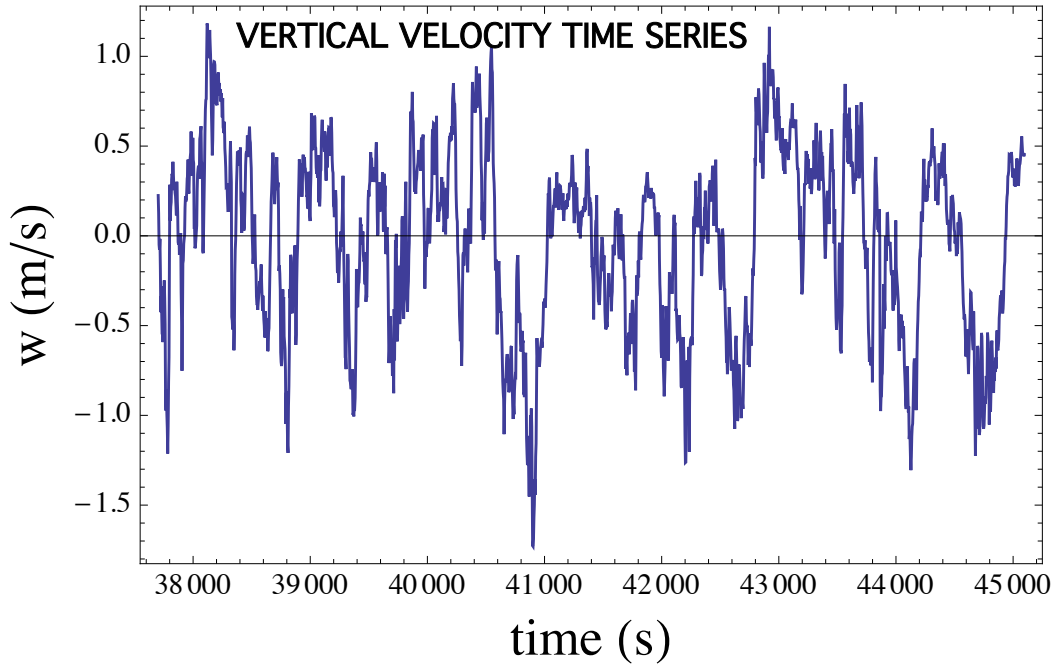
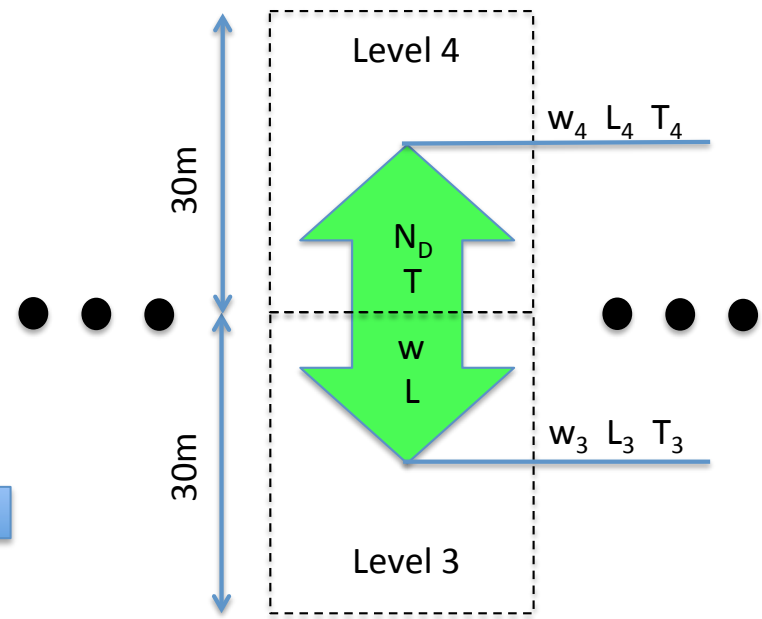
OVERVIEW

Two-hour segment of vertical velocity (w) from SGP (9/16/12, mid-cloud level 3)



+ L, T, N_D

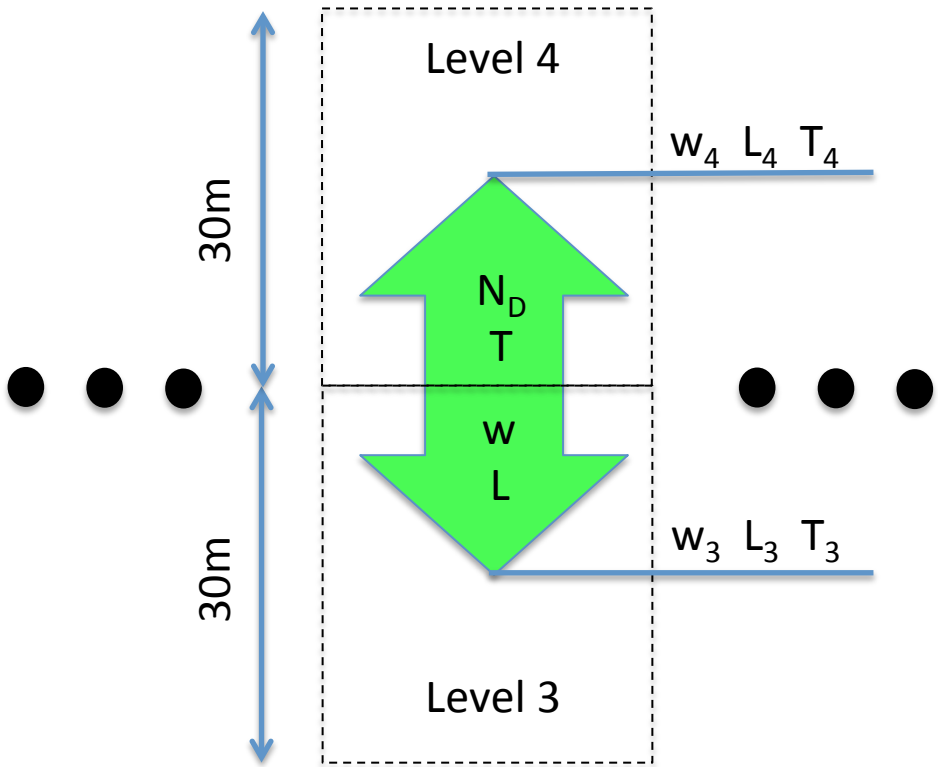


PARCEL MODEL

MICROPHYSICS

- Supersaturation (S – 1)
- Droplet growth rate
- Turbulence parameter

MOMENT-BASED (LOCAL) PARCEL MODEL



$$\mu_k = \int_0^\infty r^k f(r)\,dr$$

$$\frac{d\mu_0}{dt} = 0 \quad (N_D)$$ ← *an assumption*

$$\frac{d\mu_1}{dt} = \frac{k(T)}{2}(S-1)\mu_{-1} \quad \text{(radius)}$$

$$\frac{d\mu_2}{dt} = k(T)(S-1)\mu_0 \quad \text{(surface area)}$$

$$\frac{d\mu_3}{dt} = \frac{3}{2}k(T)(S-1)\mu_1 \quad \text{(volume)}$$

$$\vdots$$

$$\frac{d\mu_6}{dt} = 3k(T)(S-1)\mu_4 \quad (Z \propto \mu_6)$$

$$\frac{dr^2}{dt} = k(T)(S-1)$$ ⇨ Growth law (diffusion-controlled growth)

McGraw, AS&T 27, 255-265, 1997

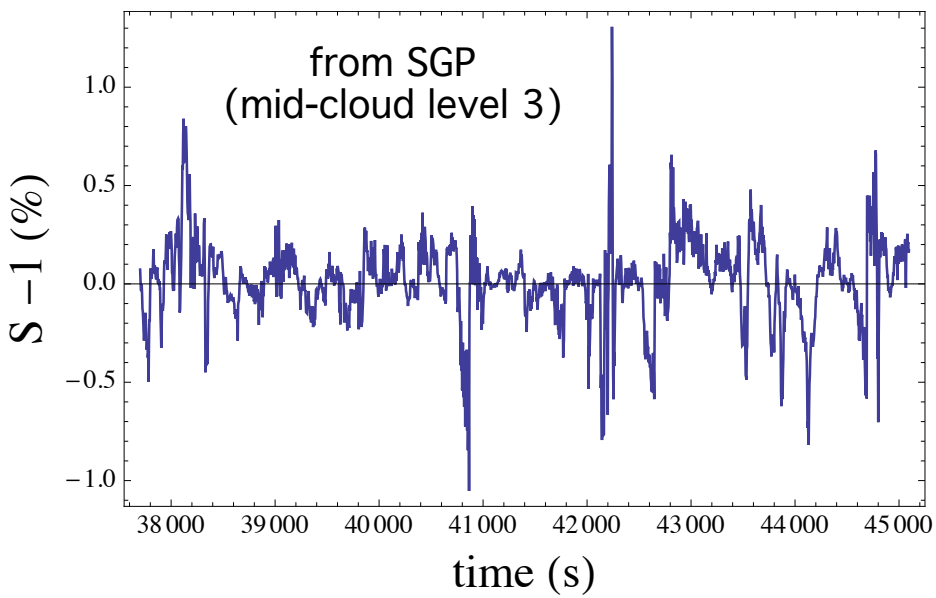
PARCEL MODEL RESULTS FOR SUPERSATURATION

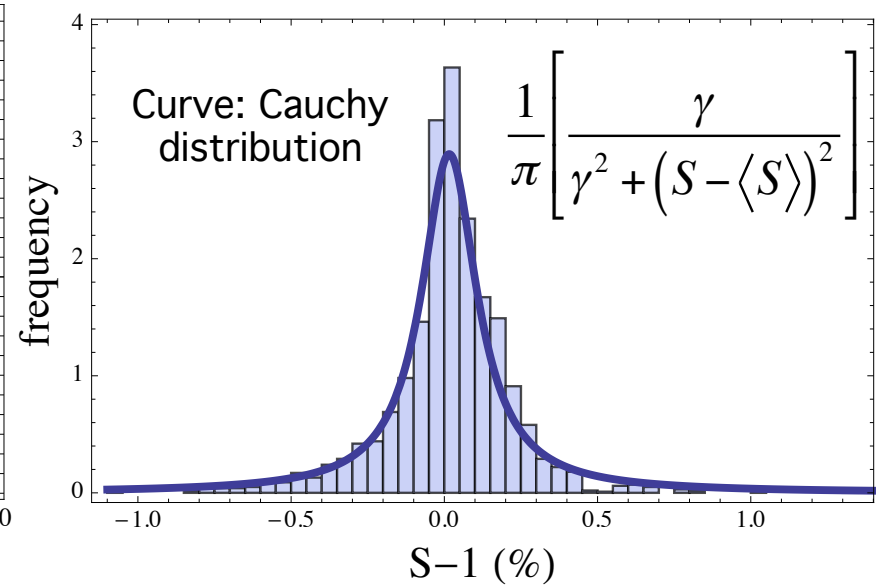
For steady rate of growth within the radar sampling volume:

$$(S-1) = \frac{d\ln L}{dz}\frac{w}{\pi k(T)}\left(\frac{L}{N_D}\right)^{2/3}$$

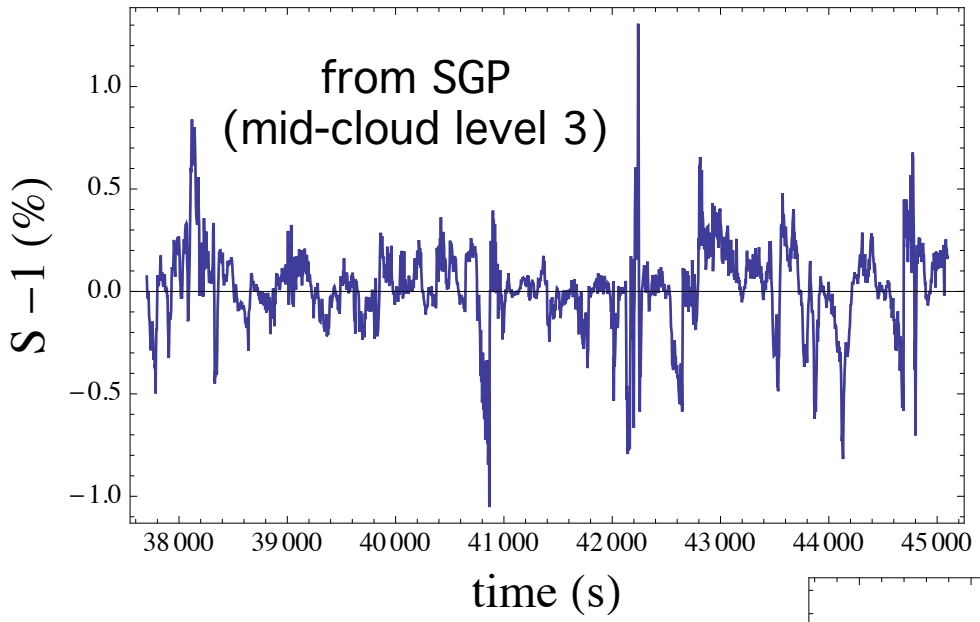
Supersaturation (S – 1) from moments-based parcel model (assumes Weibull distribution for closure)

z = height (m)
w = vertical velocity (m/s)
L = liquid water fraction ($\mu m^3/cm^3$)
$k(T)$ = drop growth rate ($\mu m^2/s$)
N_D = cloud droplet conc (cm^{-3})

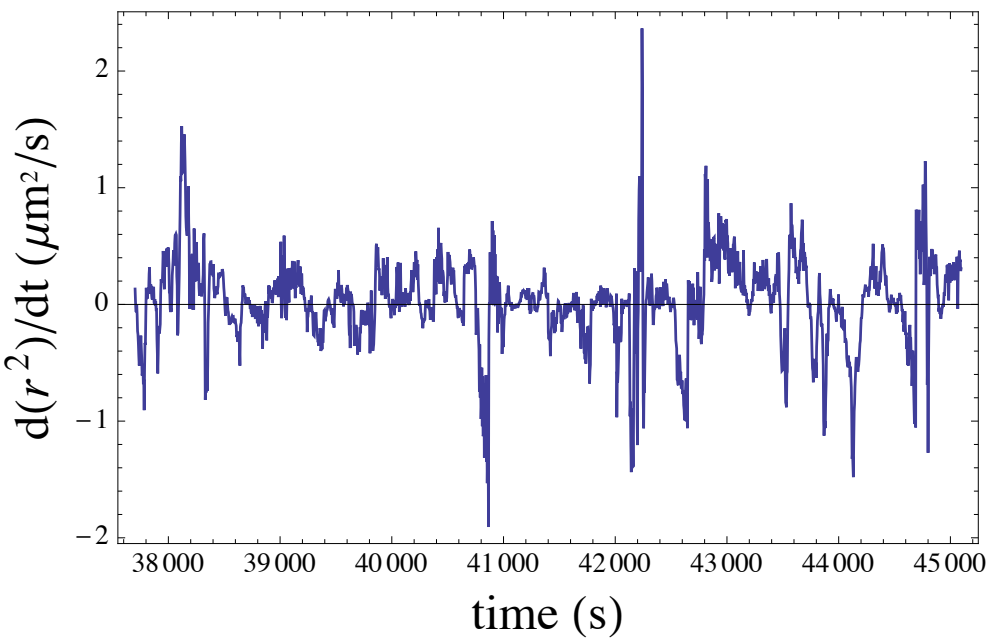




PARCEL MODEL RESULTS FOR DROPLET GROWTH RATE

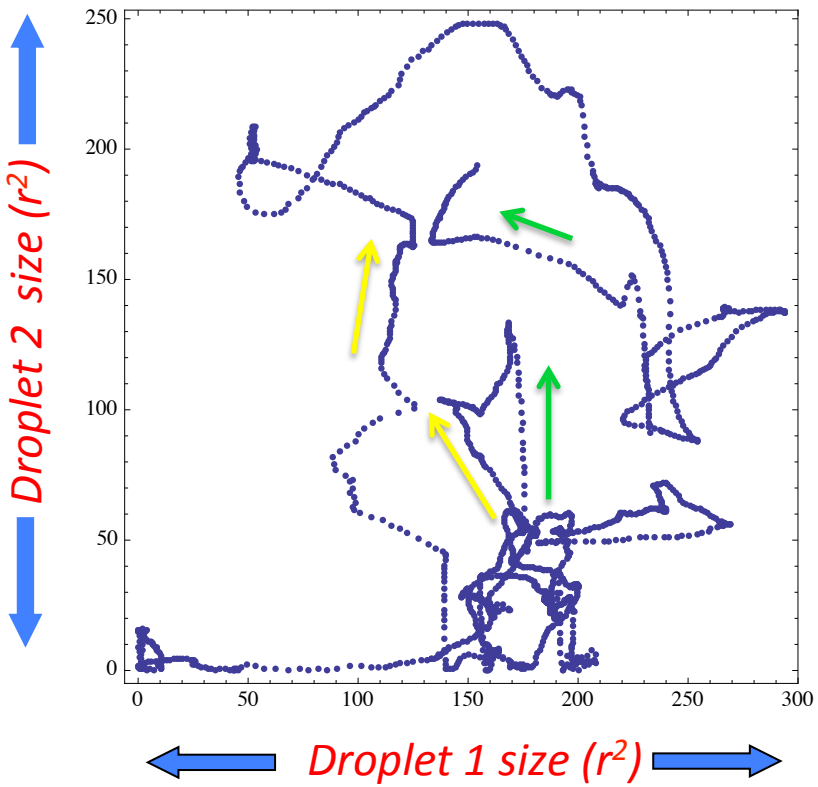


$$\frac{dr^2}{dt} = k(T)(S-1)$$



IMPLICATIONS OF "PATHOLOGICAL" GROWTH RATE DISTRIBUTION

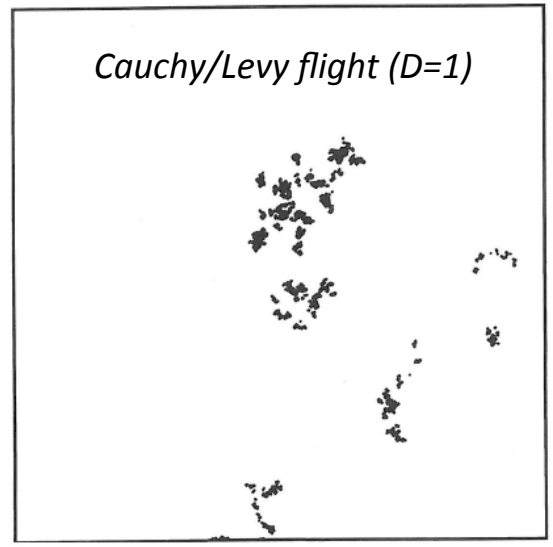
3.7s sampling time snapshots of droplet size for two independent particles along time sequence



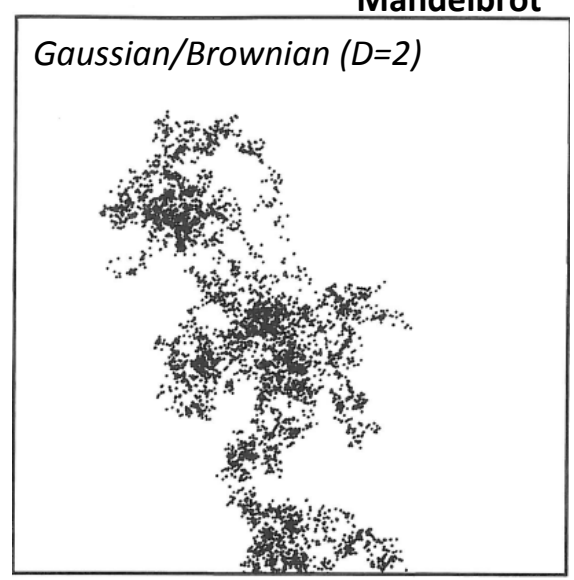
Slow growth rate fluctuations

Fast growth rate fluctuations

Mandelbrot



Mandelbrot



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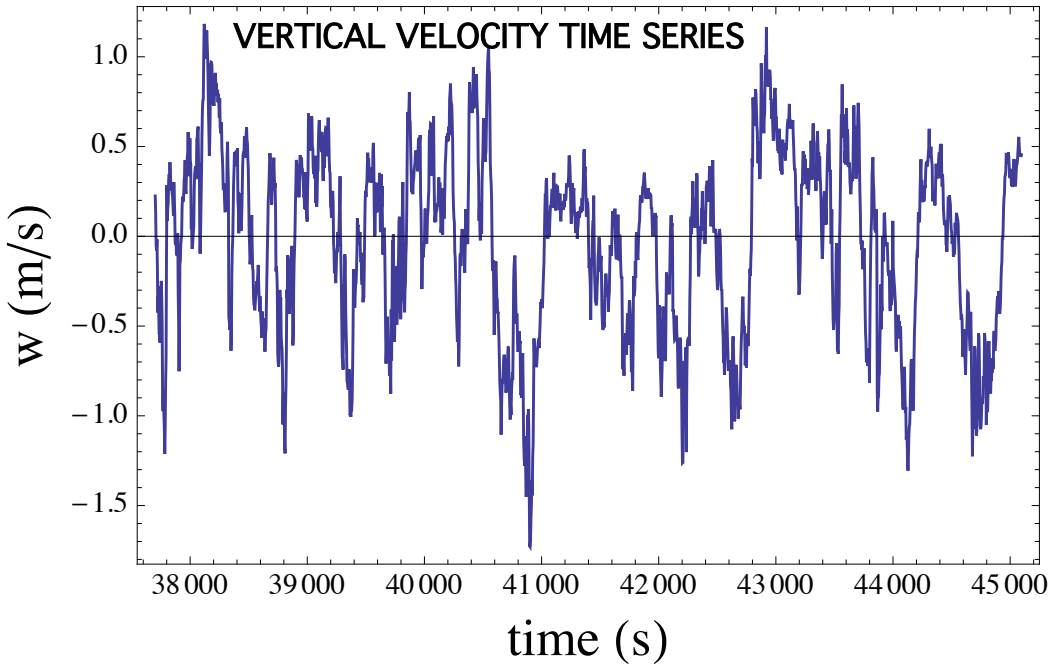

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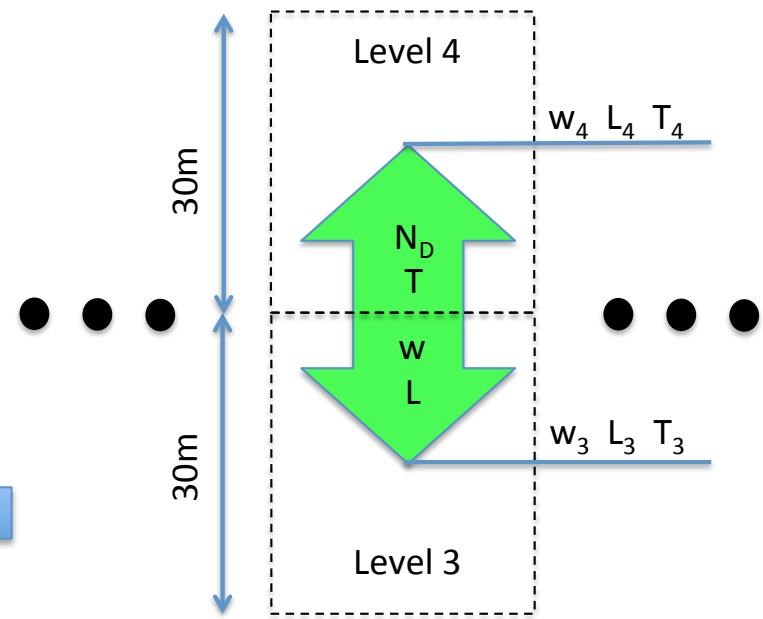

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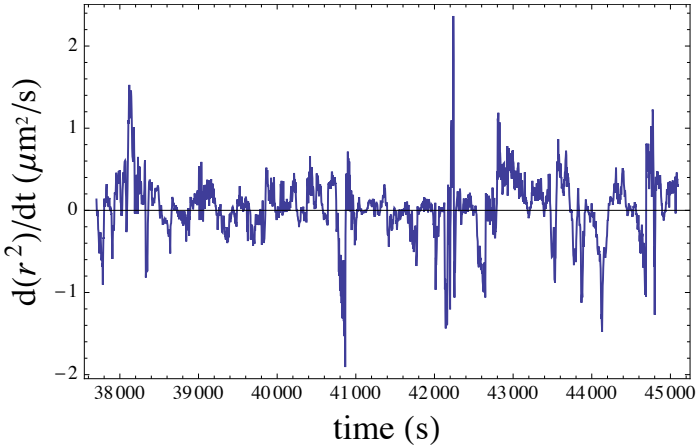
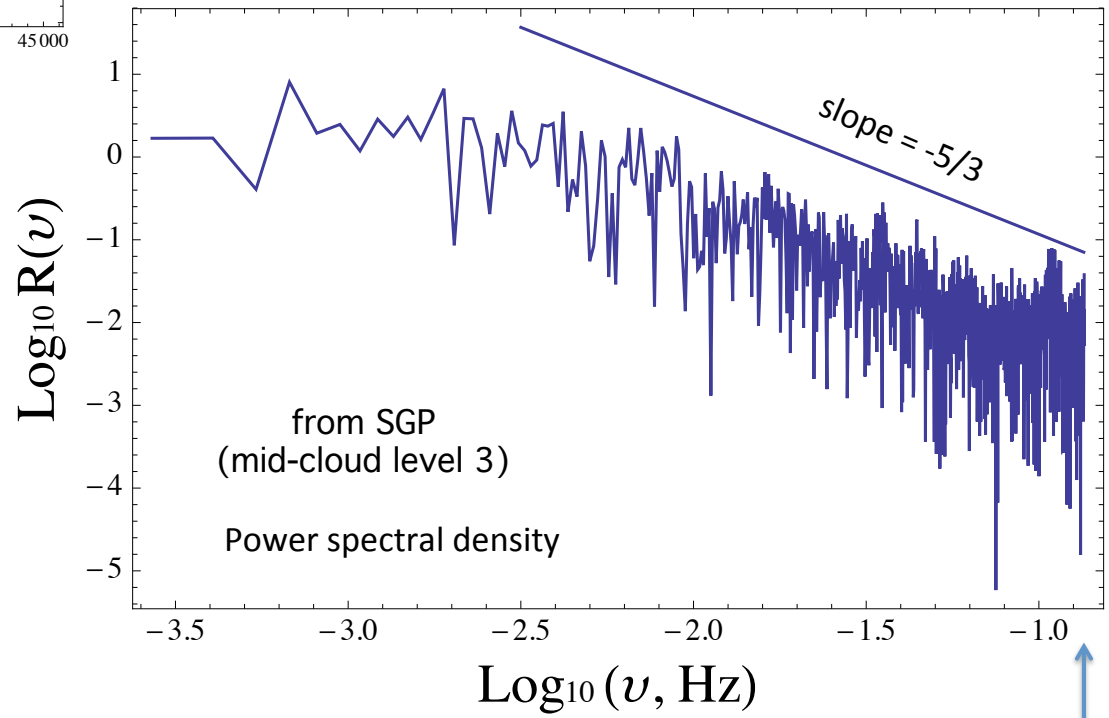
TURBULENCE PARAMETER (STEP 1)



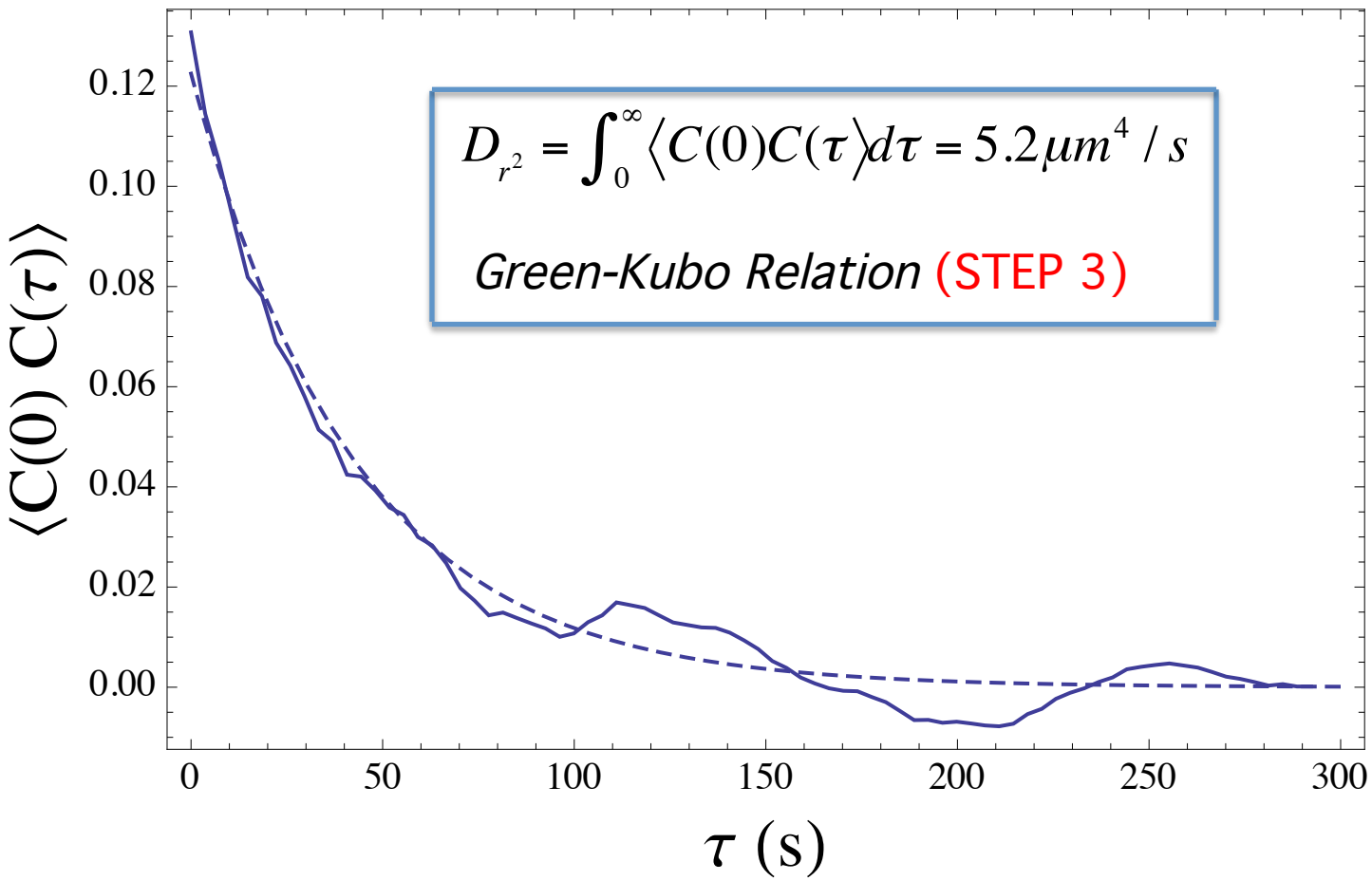
Power spectrum of fluctuations In droplet growth rate



Sampling time = 3.70s
Log_{10} (Nyquist frequency) = -0.87

TIME CORRELATION FUNCTION FROM POWER SPECTRUM (STEP 2)

Wiener-Khintchine Theorem: $\langle C(0)C(\tau)\rangle = \left(1/N^{1/2}\right) Fourier^{-1}\left[R(\nu)\right]$

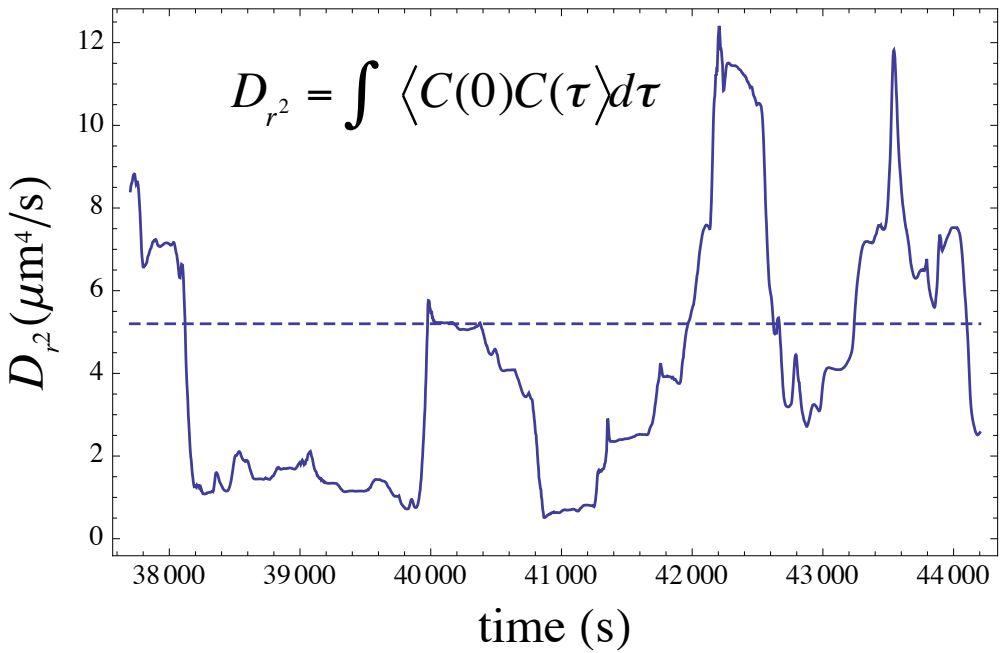


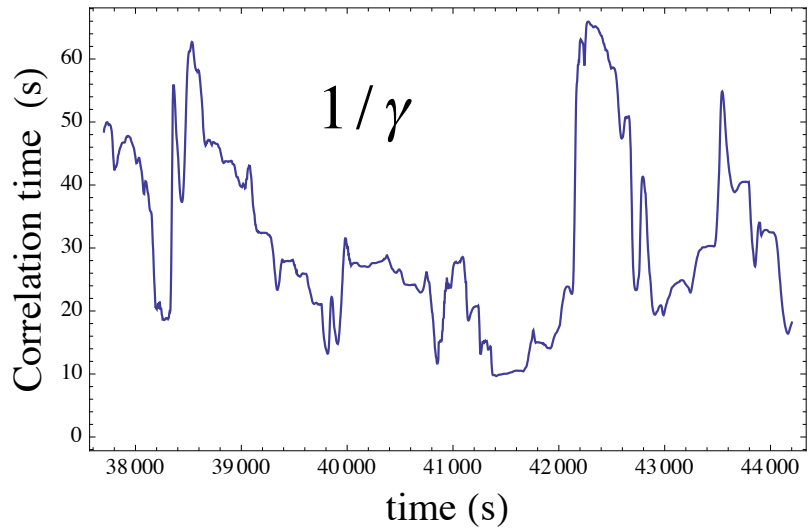
$$D_{r^2} = \int_0^\infty \langle C(0)C(\tau)\rangle d\tau = 5.2\mu m^4 / s$$

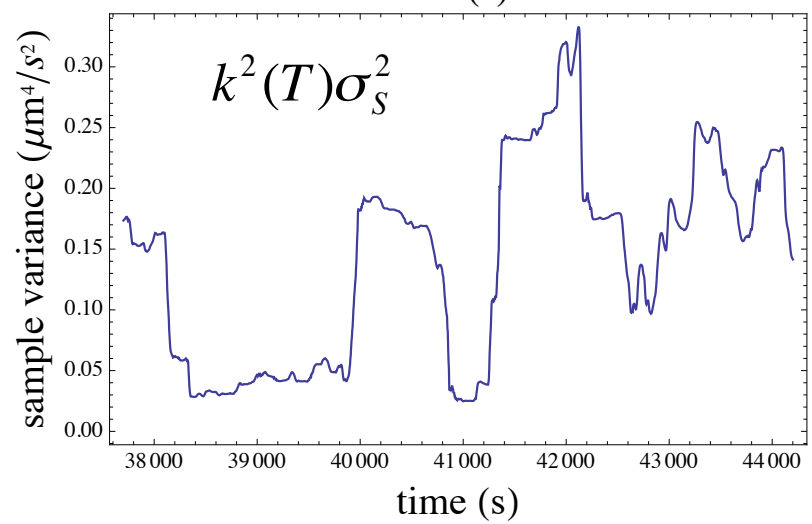
Green-Kubo Relation (STEP 3)

TURBULENCE PARAMETER VARIABILITY

Based on 15 minute running average





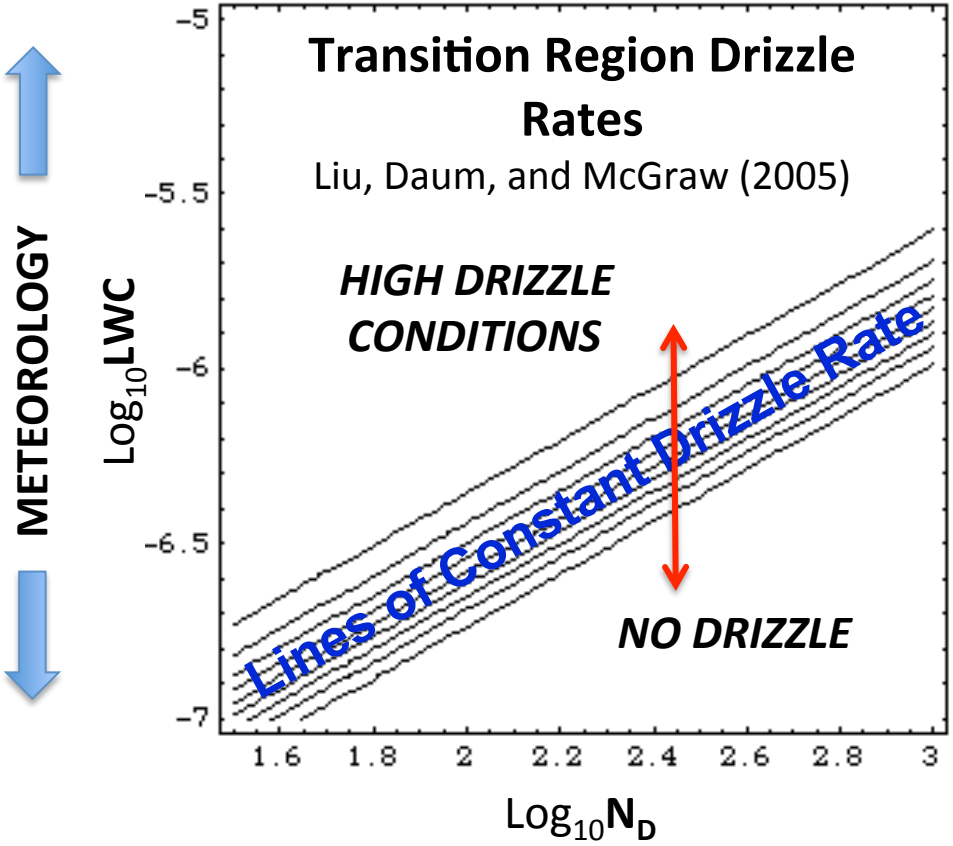


Compare with Brownian drift-diffusion model:

$$D_{r^2} = k^2(T)\sigma_S^2 / \gamma \approx 20.2 \mu m^4 / s$$

McGraw and Liu, GRL 33, L03802, 2006
The numerical estimate is based on aircraft studies (Lenschow et al. 1994)

Drizzle Onset: Separation of Aerosol & Meteorological Effects



AEROSOL/CCN

Use observations to test the theory

- Slope & linearity would confirm it
- Retrieve turbulence parameter ✓

Theory helps separate aerosol and meteorological effects

- LWC depends mostly on meteorology
- N_D depends mostly on aerosol loading

Endeavour to test the theory and see how aerosol and meteorological effects couple