Exploration of CSET high-rate data

Chris Bretherton
Department of Atmospheric Sciences
University of Washington

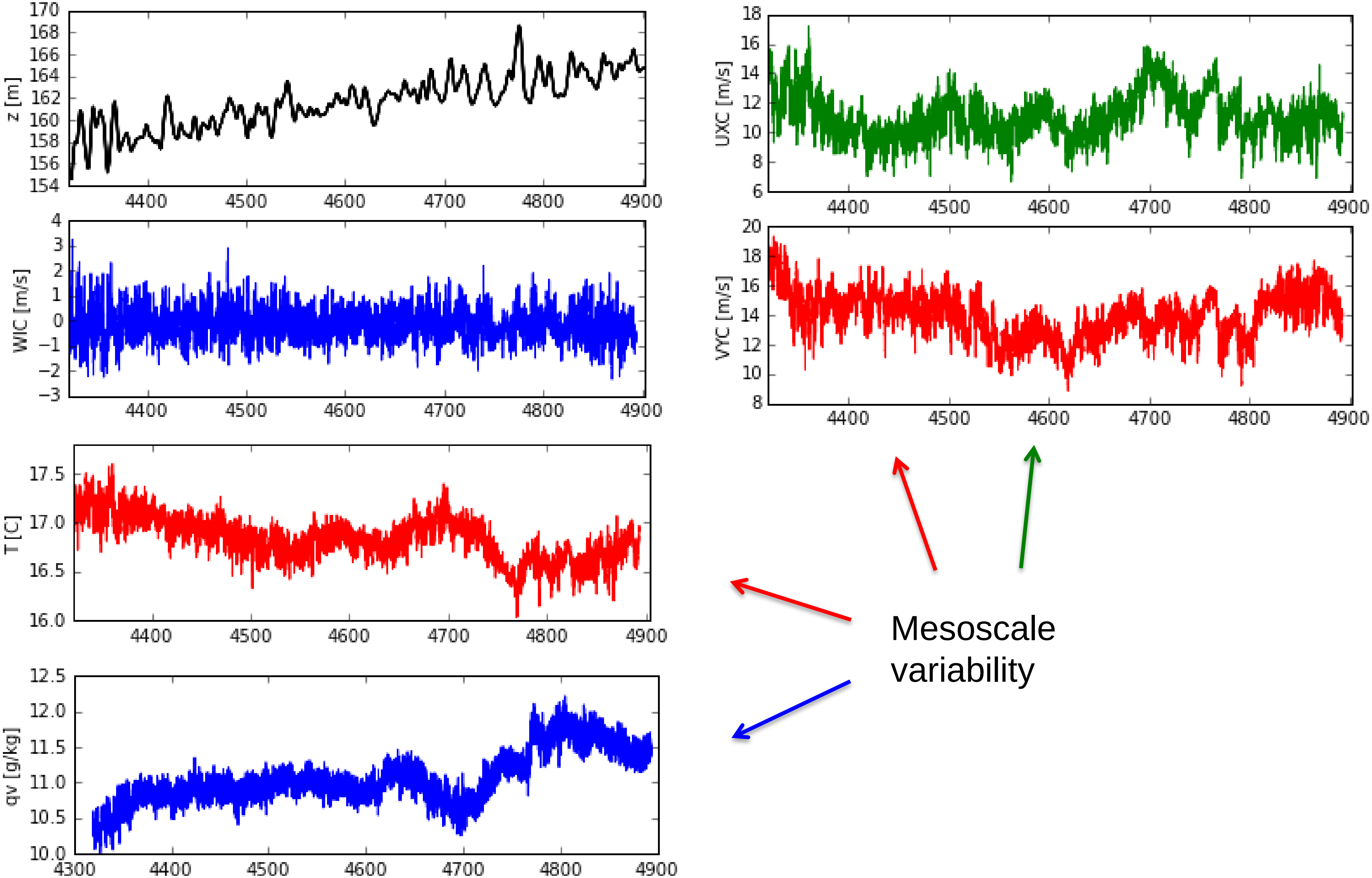
(thanks for conversations with Virendra, Rob, Hans, Andy O)

Outline

- Which data are meaningful at >1 Hz sample rate?
- Subcloud time series and time-height sections of high-frequency vertical velocity variance and TKE dissipation
- Use of whi2 in cloud-layer legs

(I will only minimally review my previous ppt of turbulence in RF06 subcloud legs. Unlike that presentation, this is based on the final high-rate data release.)

Time series, RF06 subcloud leg 1

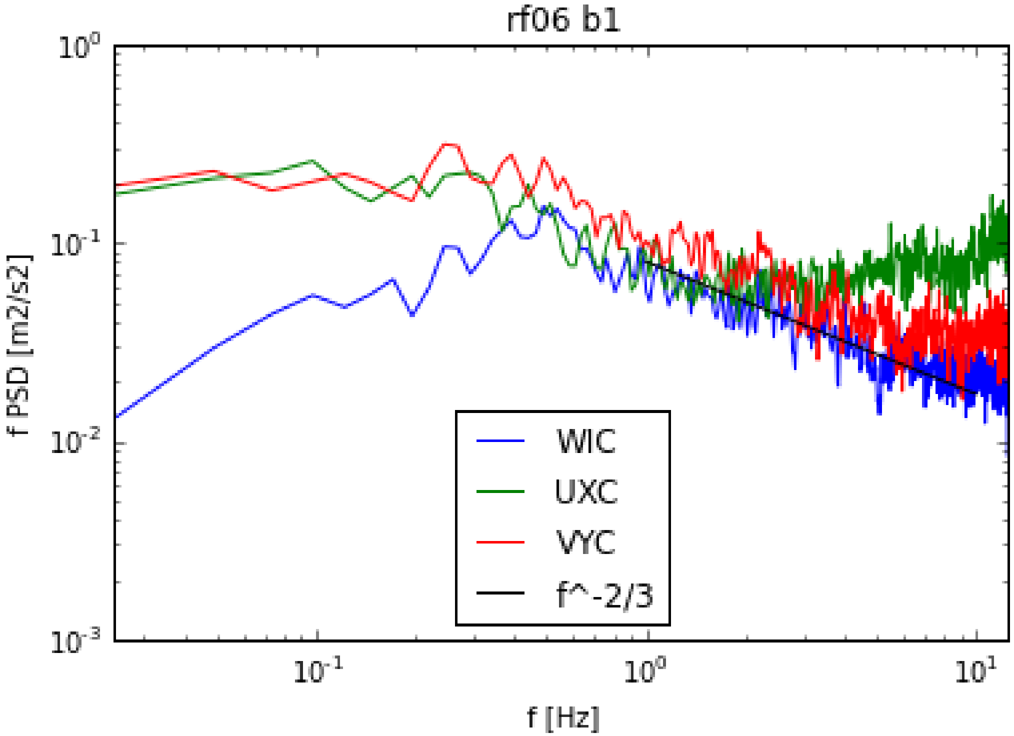


Power spectra (using final data)

- In the inertial range of fairly homogeneous turbulence we expect $k^{-5/3}$ scaling of power spectra of velocity components and conserved scalars ($k = f/U_0$, U_0 = G-V air speed).
- Lack of $k^{-5/3}$ at high k may indicate high-rate sensor inaccuracies
- Spectrum of WIC, UXC, VYC, RF06 subcloud leg 1

  512 sample (=20 s) windows, Hann taper

  Plot f*PSD(f) (units of variance) since using log f as ordinate



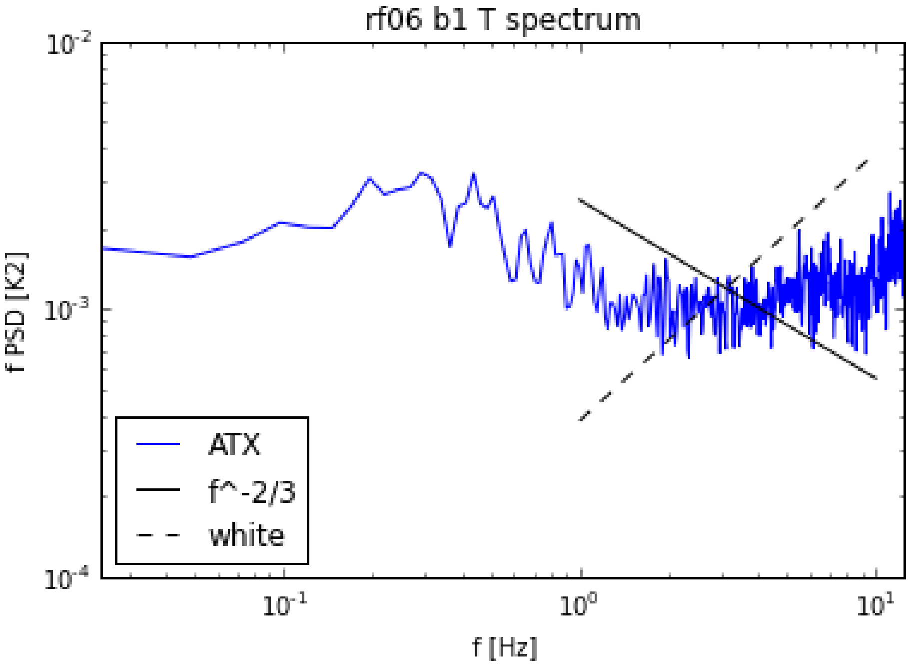
WIC has expected (black) scaling
UXC inaccurate for f > 1 Hz
VYC noisy for f > 5 Hz
Inertial range f > 0.5 Hz

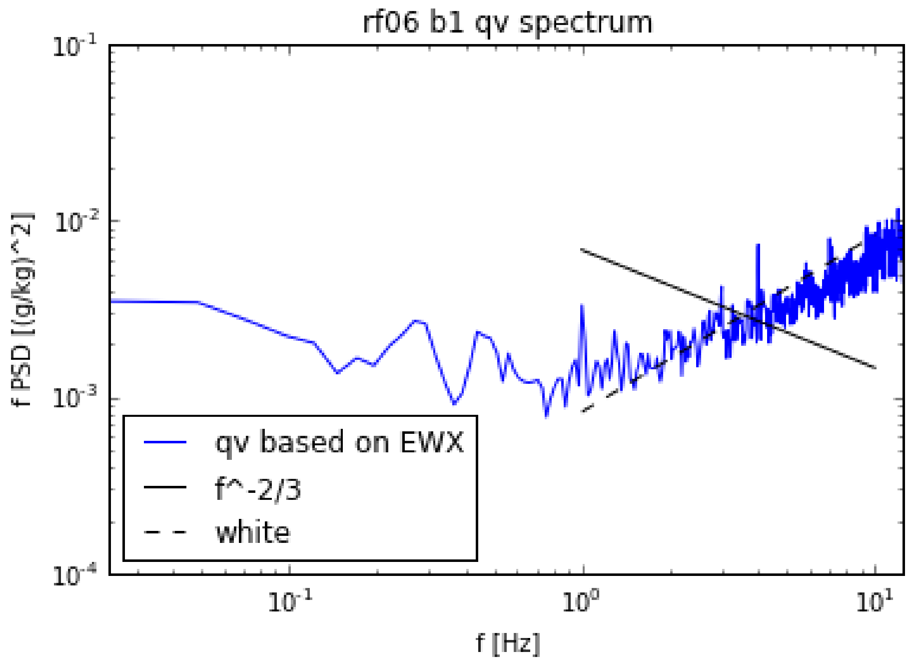
Similar issues on other subcloud legs.

Lou suggested the pressure transducers (last replaced before HIPPO-II) might be the problem.

Temperature (ATX) and humidity (EWX) spectra

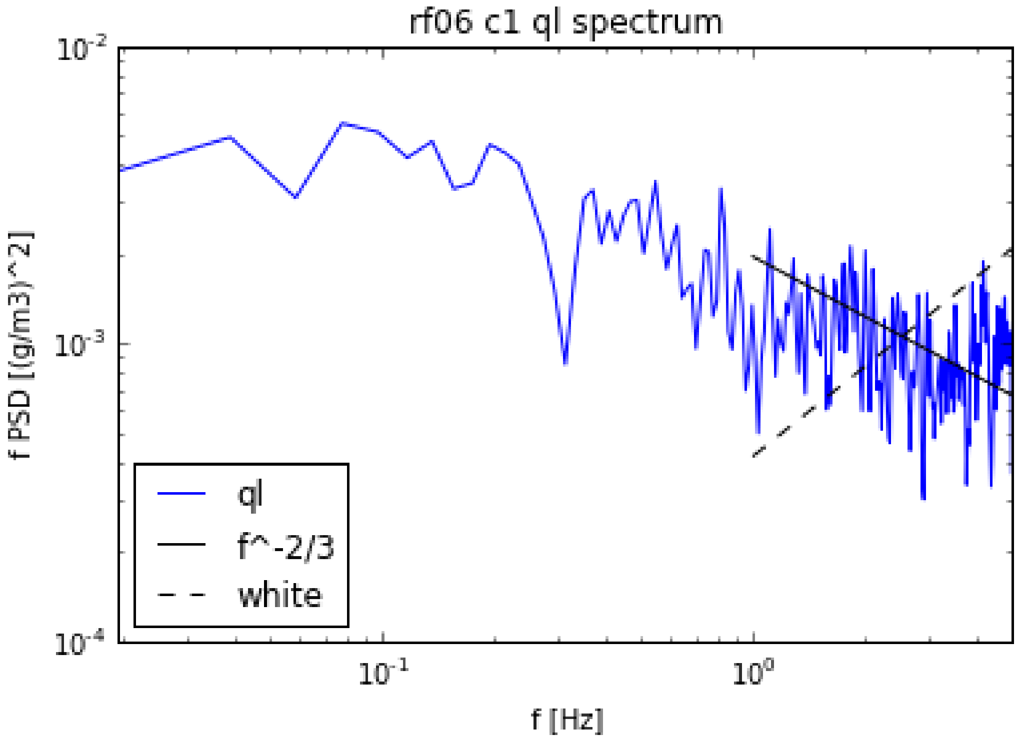
- Also suggest noisiness for f > 1 Hz



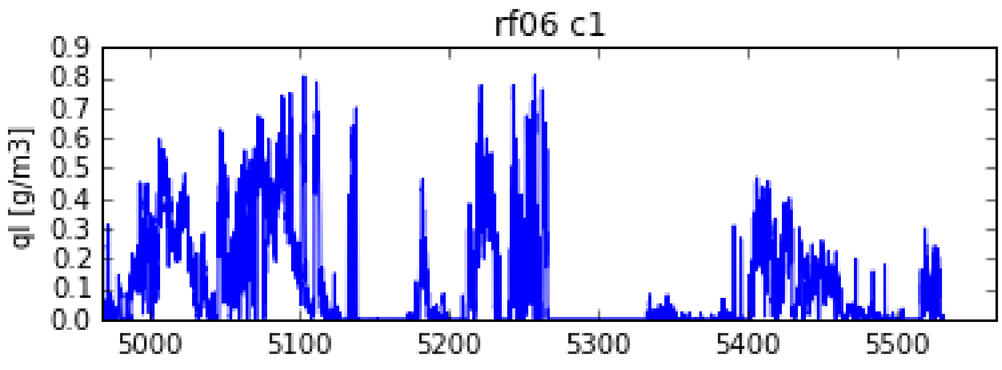


- Similar behavior on other subcloud legs and flights.
- Suggests the HR data has limited incremental benefit for temperature and moisture fluxes or variances. Luckily, at 150 m and in the cloud layer, most of the T, q fluxes are carried by larger eddies well measured by the G-V data.

CDP liquid water spectrum in RF06 cloud leg 1

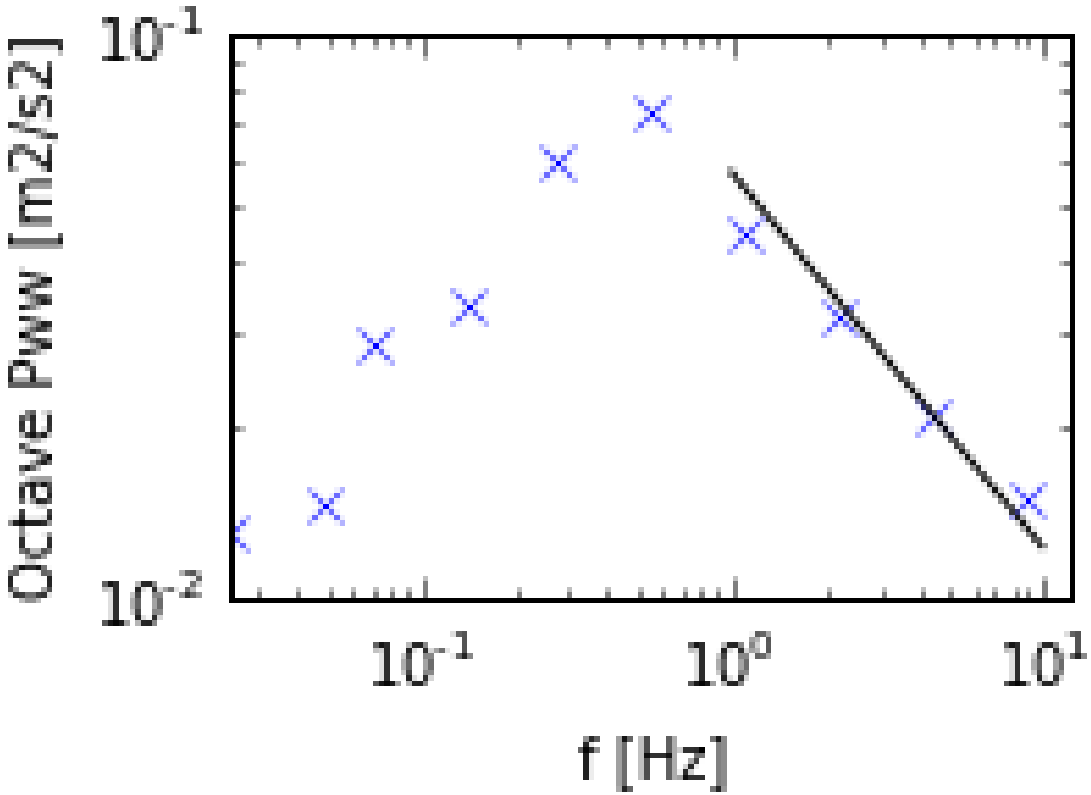


- PLWCD_LWOI
- Kolmogorov scaling out to 3 Hz, suggesting HF data meaningful.
- Similar behavior on other Sc legs and flights.

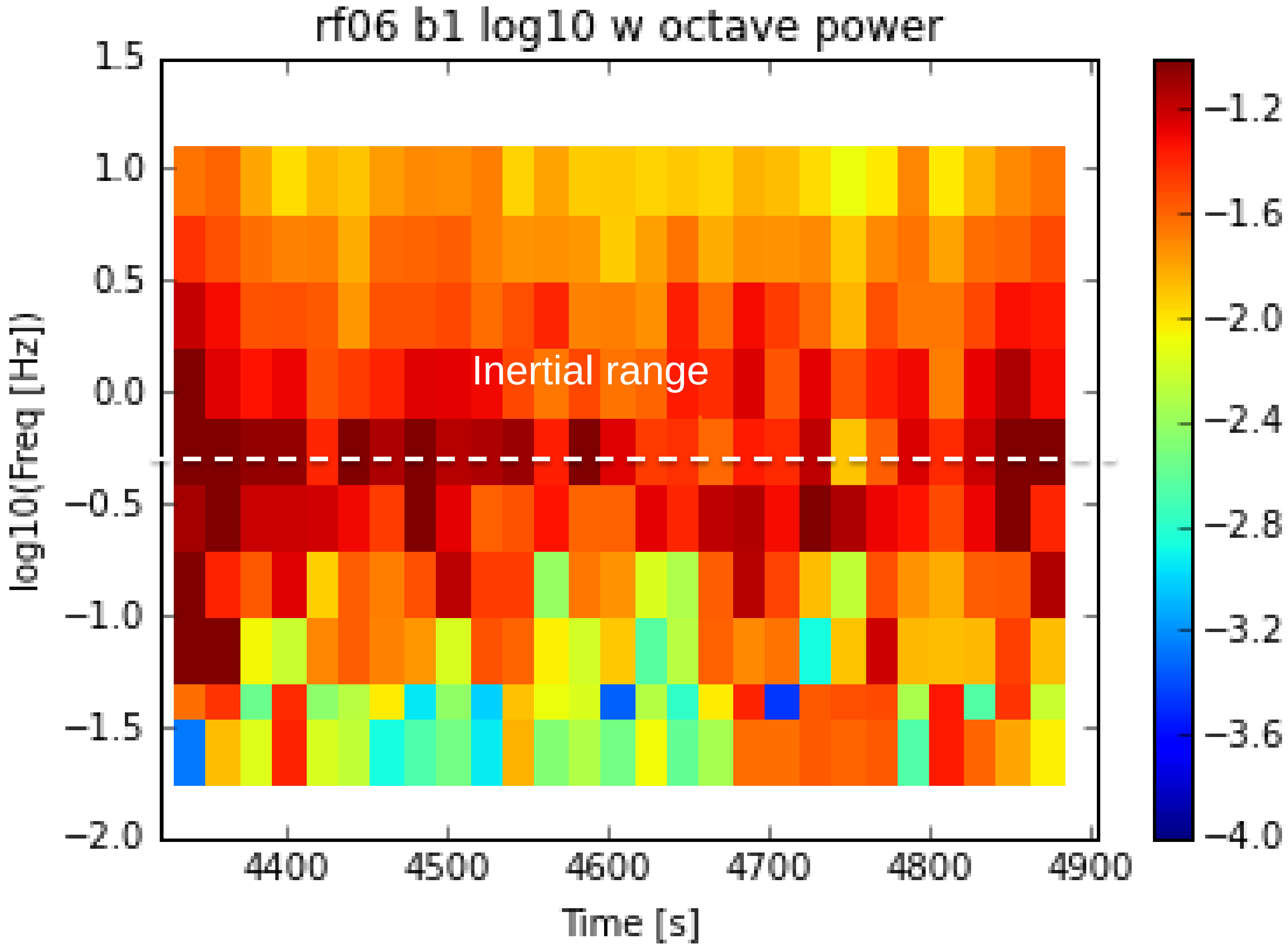


RF06 subcloud leg 1 octave spectrum of w

- Sum spectral power over octaves of frequency
- Robust and simple portrayal of a broad-band spectrum
- Again, see decent fit to $f^{-2/3}$ (black) in inertial range



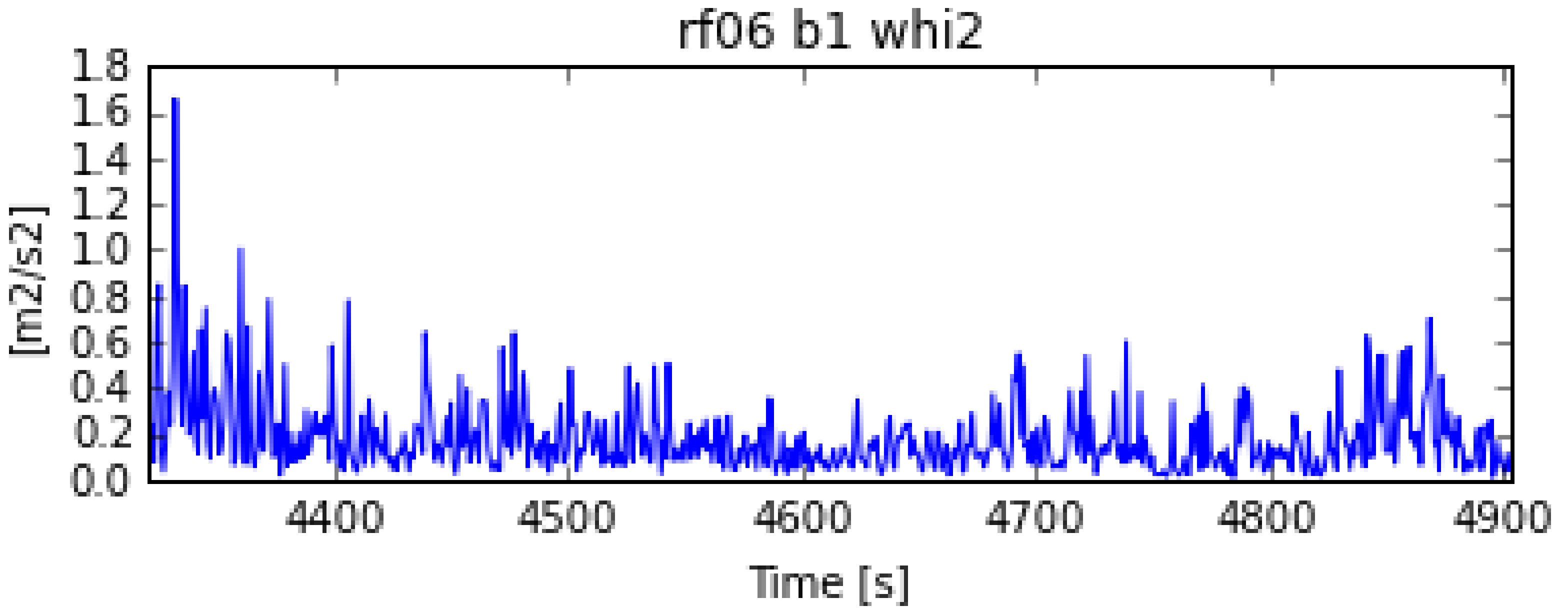
Mesoscale variability of octave spectra - spectrograms



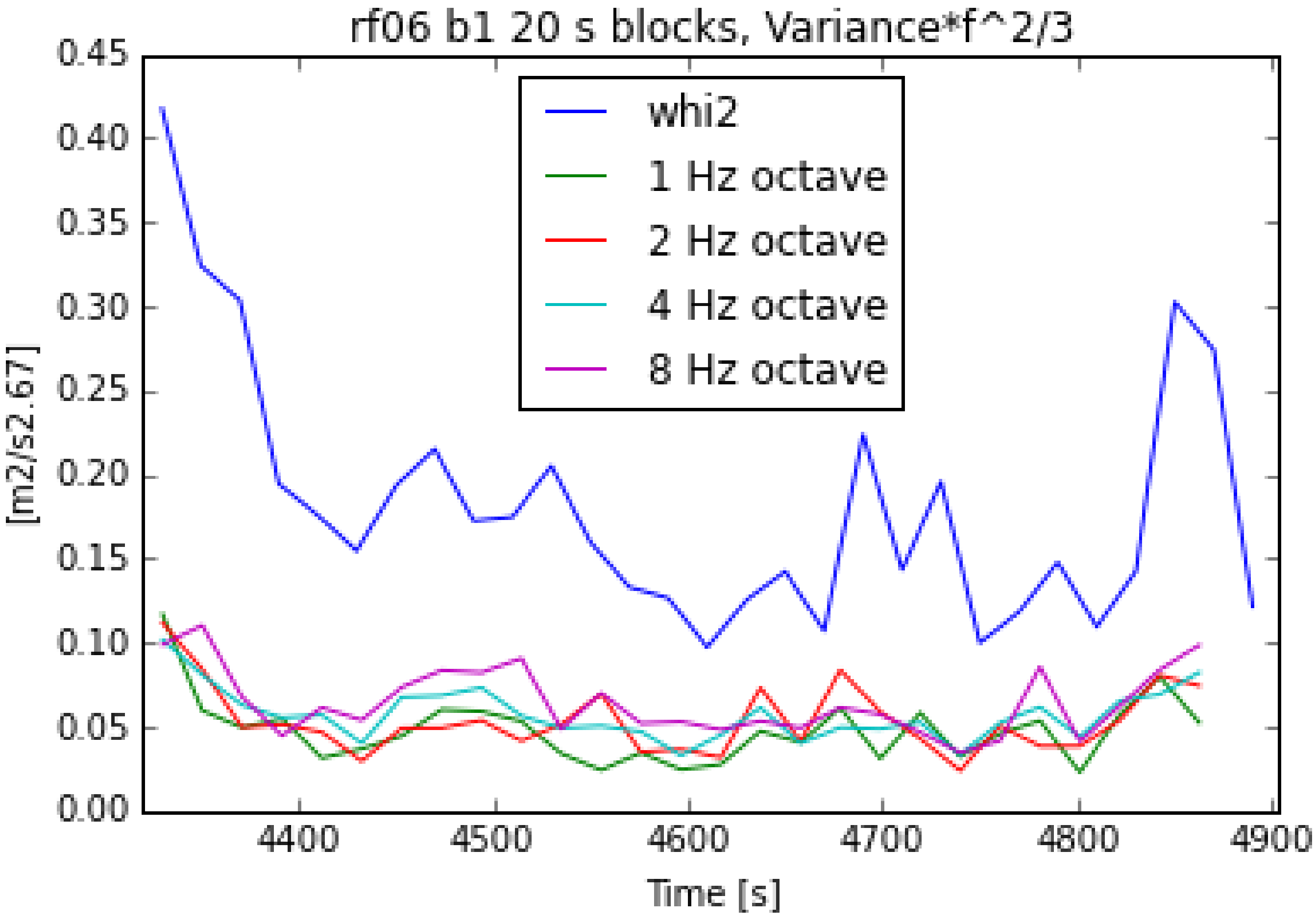
Inertial-range fluctuations of w don't vary too much with time over this leg

whi2: a simple measure of high-frequency variability

- 1 Hz windowed HF variance (whi2): Calculate the variance of 25 Hz w within each second.
- Measures inertial-range turbulence, since f = 1 Hz (130 m wavelength) is within the inertial range.
- Noisy, requires further time block-averaging for statistics



20 s windowed avg of whi2 vs. octave spectra

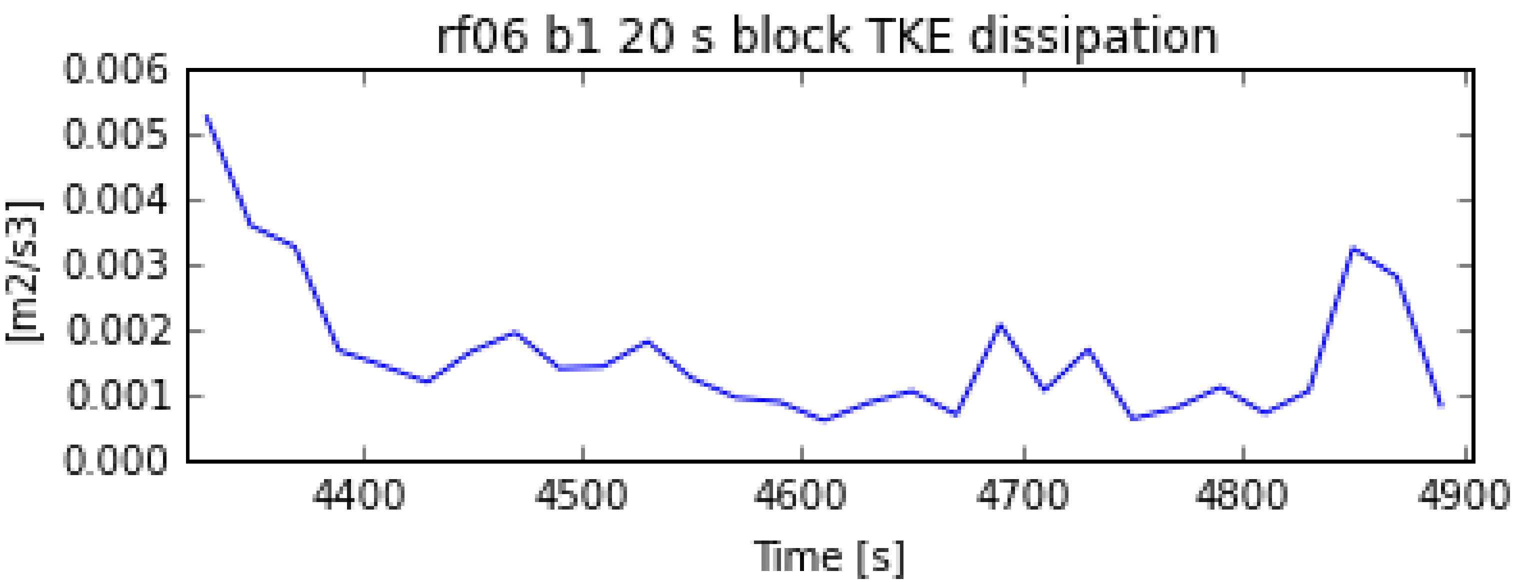


- whi2 tracks with power P_{oct} of w in all high-frequency octaves as Kolmogorov predicts:
  whi2 ≈ a $P_{octave}\, f^{2/3}$, a = 3.2;
- Octave power can be related to power spectrum at octave center frequency:
  $P_{octave} = f\, P_{ww}/b$, b= 1.4

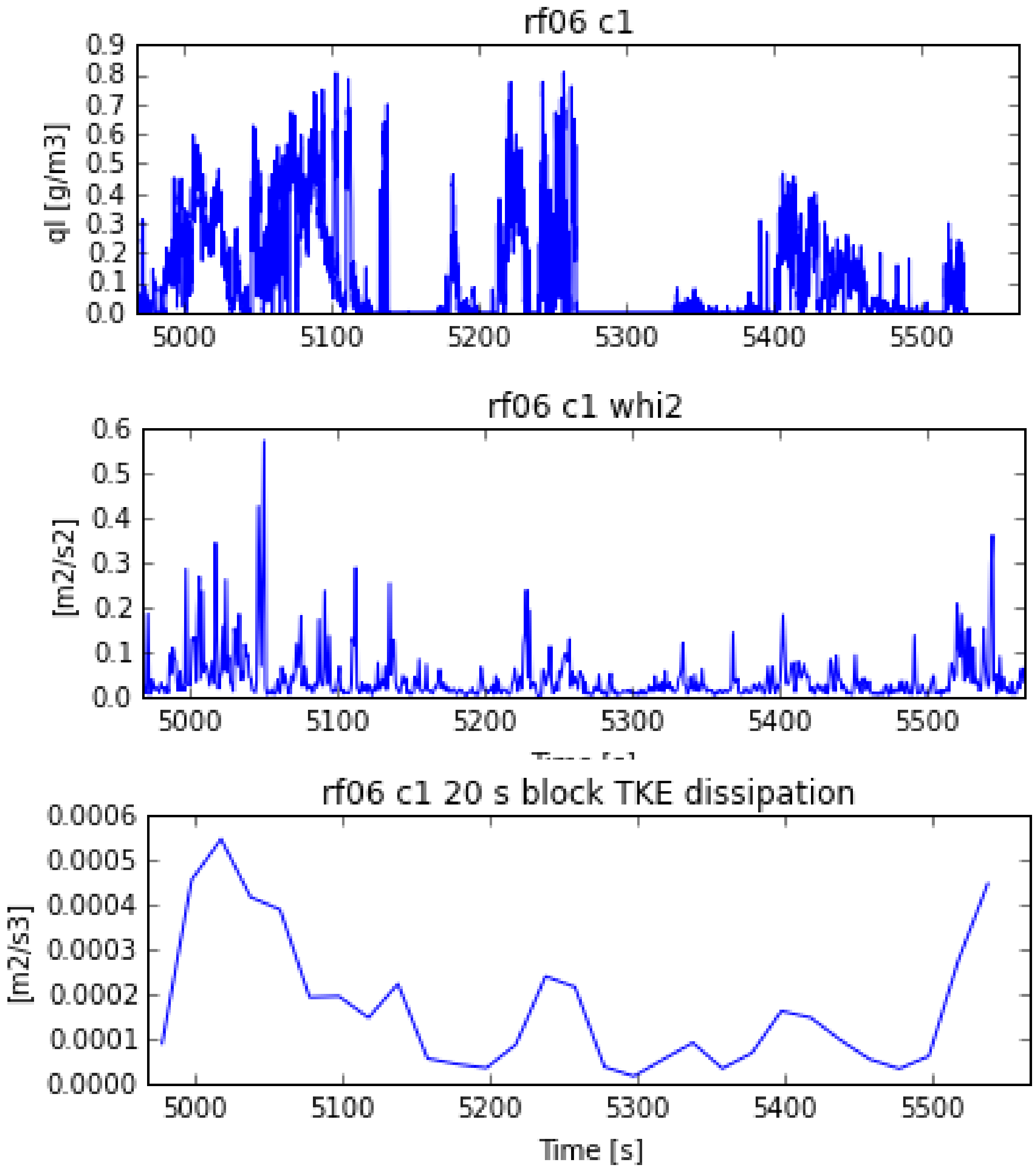
TKE dissipation rate estimate

- TKE dissipation rate ε obtainable from inertial range spectral power P_{ww} and hence whi2.

$$e = \frac{2p}{U_0}(1.25 P_{ww} f^{-5/3})^{3/2} \quad \Rightarrow \quad e = \frac{C}{U_0}(\mathrm{whi2})^{3/2},\ C = 2p\left(\frac{1.25b}{a}\right)^{3/2} \approx 2.5 s^{-1}$$

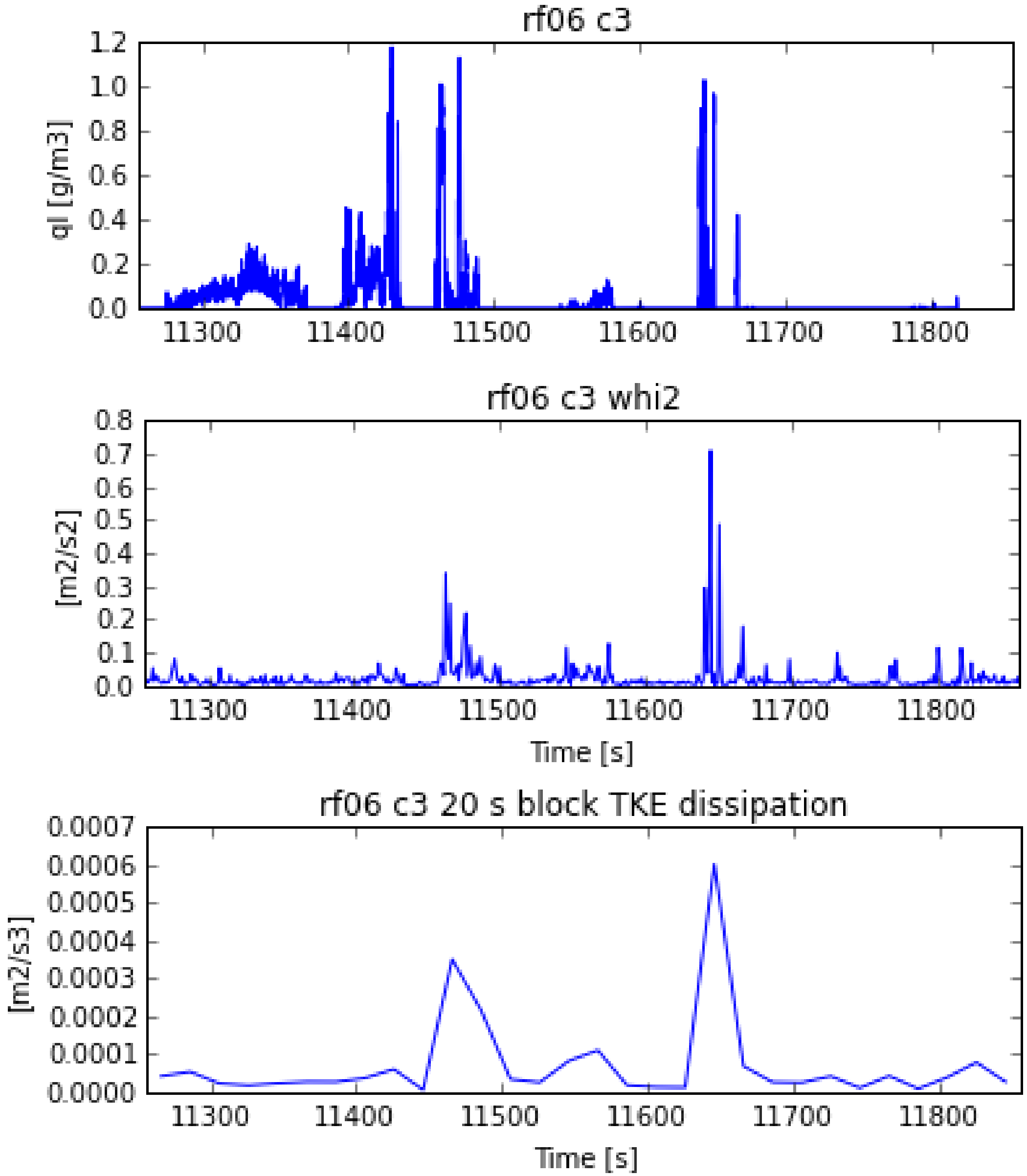


RF06 cloud leg 1 example (Sc)



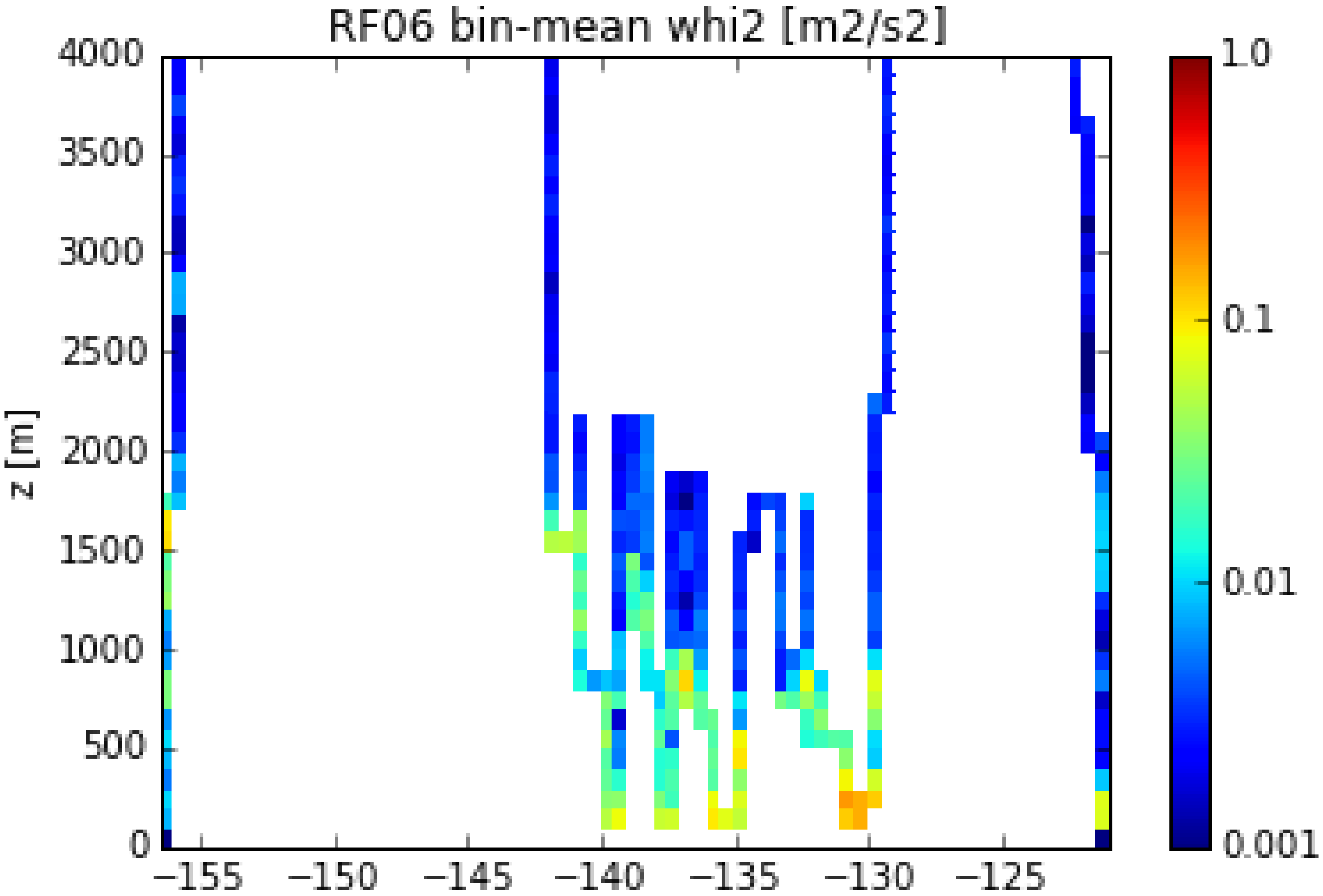
More turbulent dissipation in mesoscale Sc patches, as expected.

RF06 cloud leg 3 example (Cu)



Turbulent dissipation localized around Cu updrafts (nearly nonturbulent veil? cloud sampled at leg start)

Lon-z plots of estimated whi2 are easily made



Conclusions

- The WIC and CDP LWC appear to have the best high-frequency fidelity of the CSET G-V obs I have looked at.
- UXC and EWX are particularly noisy at high frequency.
- The whi2 statistic (on Dropbox CSET share) is an excellent measure of small-scale turbulence on 1 Hz timescales…but
- Getting a quantitatively accurate TKE dissipation rate from whi2 requires ~20s time averaging.
- High-rate data not helpful for improving eddy-correlation estimates of heat and moisture fluxes, but 1 Hz data should suffice for a start (I have explored this a bit, but fluxes need to be compared with bulk estimates).
- Thanks to EOL personnel for this nice CSET dataset.