The Nature of Turbulence

Program at Kavli Institute of Theoretical Physics - Feb 7th, 2011 - Jun 3rd, 2011

Physics Of Stratocumulus Top (POST)

Apr 28th, 2011

Szymon P. Malinowski

**Patrick Y. Chuang, Hermann Gerber,Krzysztof E. Haman,
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Turbulence Observed At Stratocumulus Top (TOAST) !!!

Apr 28th, 2011

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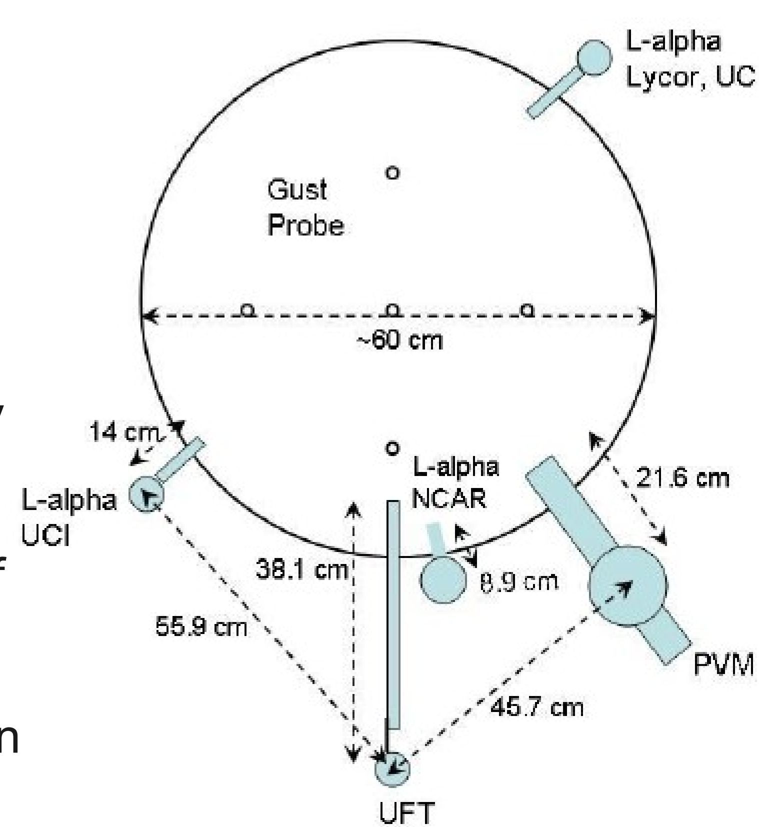
POST (Physics of Stratocumulus Top)
Data from POST available at http://www.eol.ucar.edu/projects/post/

POST (Physics of Stratocumulus Top) - aircraft field study off the California Coast in 2008. A single aircraft was used to primarily investigate unbroken stratocumulus clouds (Sc) near cloud top. The aircraft was instrumented with a full suite of probes for measuring state parameters of the atmosphere, drop spectra, CCN , irradiances, wind velocity and turbulence.

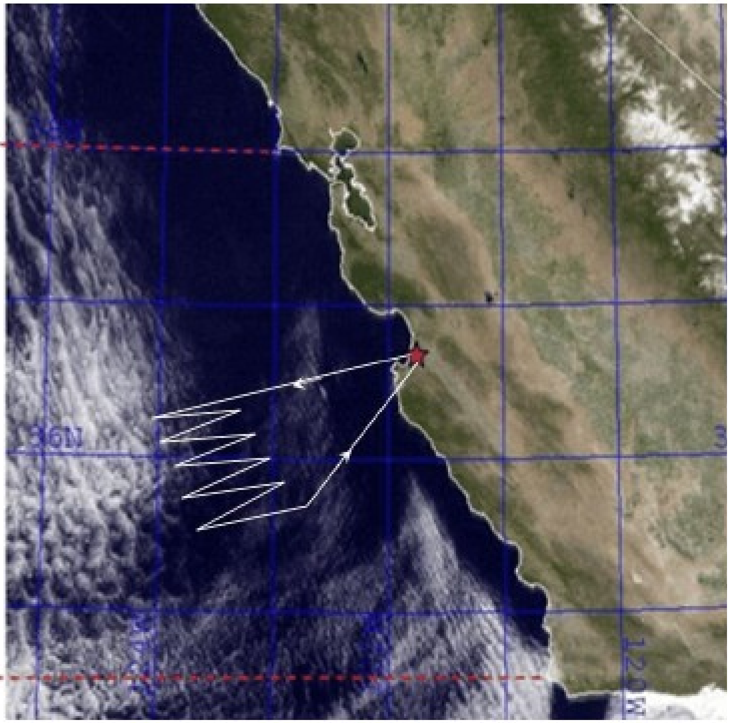
Gerber et al., 2010

INSTRUMENTATION on T.O. NOSE

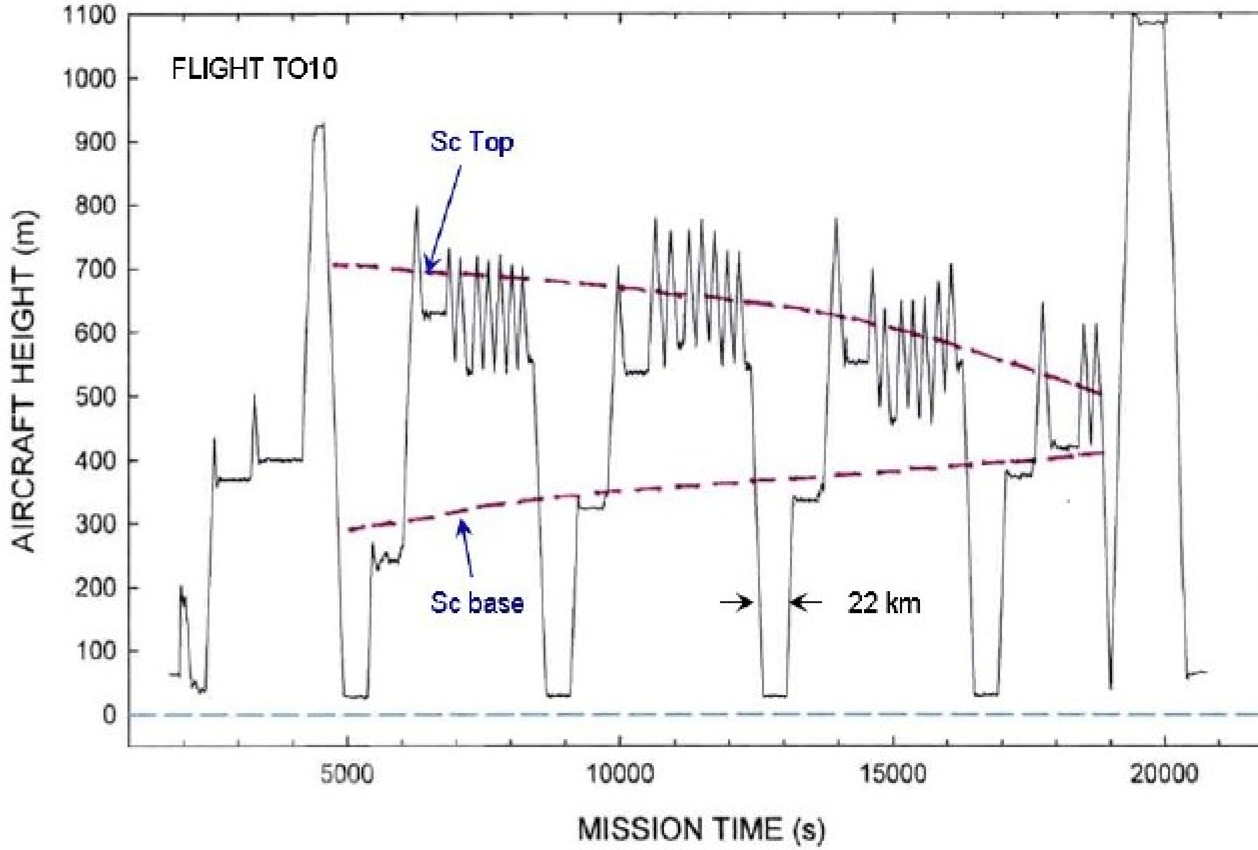


The Ultra-Fast Temperature (UFT) probe provided by the U. Of Warsaw (Kumala et al., 2011) and the PVM (liquid water content and effective radius; Gerber et al.,1994) provided high rate data to take advantage of the close separation (~1m) to the gust probe.
Both probes produced 1000-Hz data, and their averaged 40-Hz data is consistent with that separation at the TO aircraft speed of ~55 m /s.

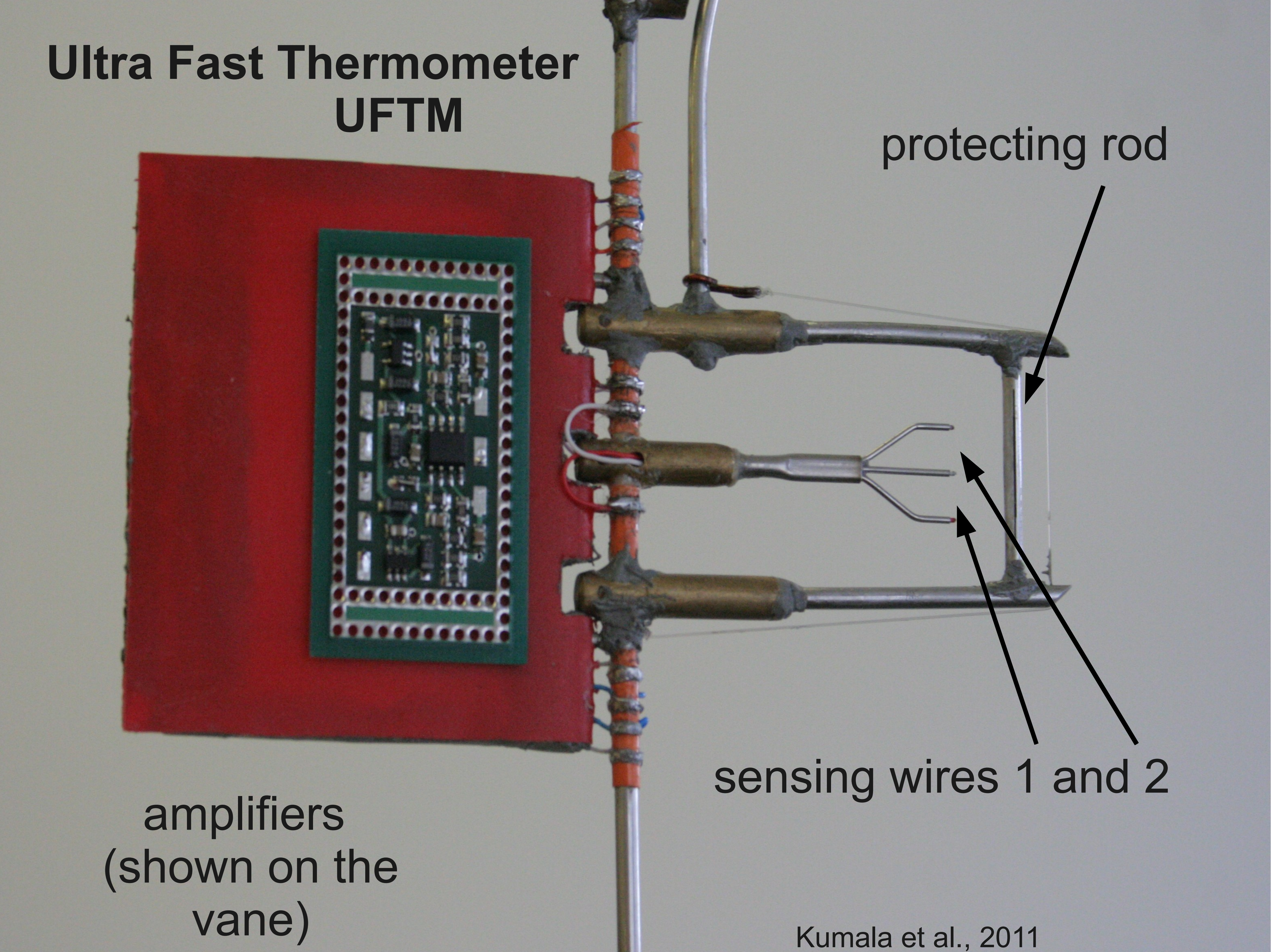
Measurement strategy



NexSat image (courtesy Naval Research Laboratory, Monterey) of CA and the Pacific Ocean showing the typical horizontal flight track used for each quasi Lagrangian Twin Otter flight. The red star indicates the Marina airport near Monterey Bay.

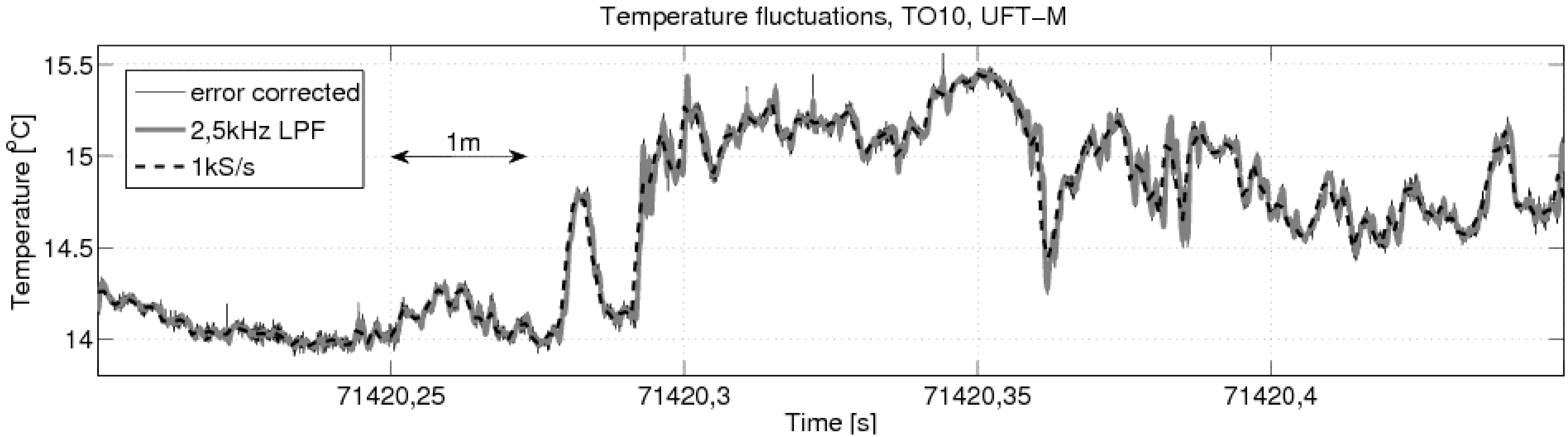


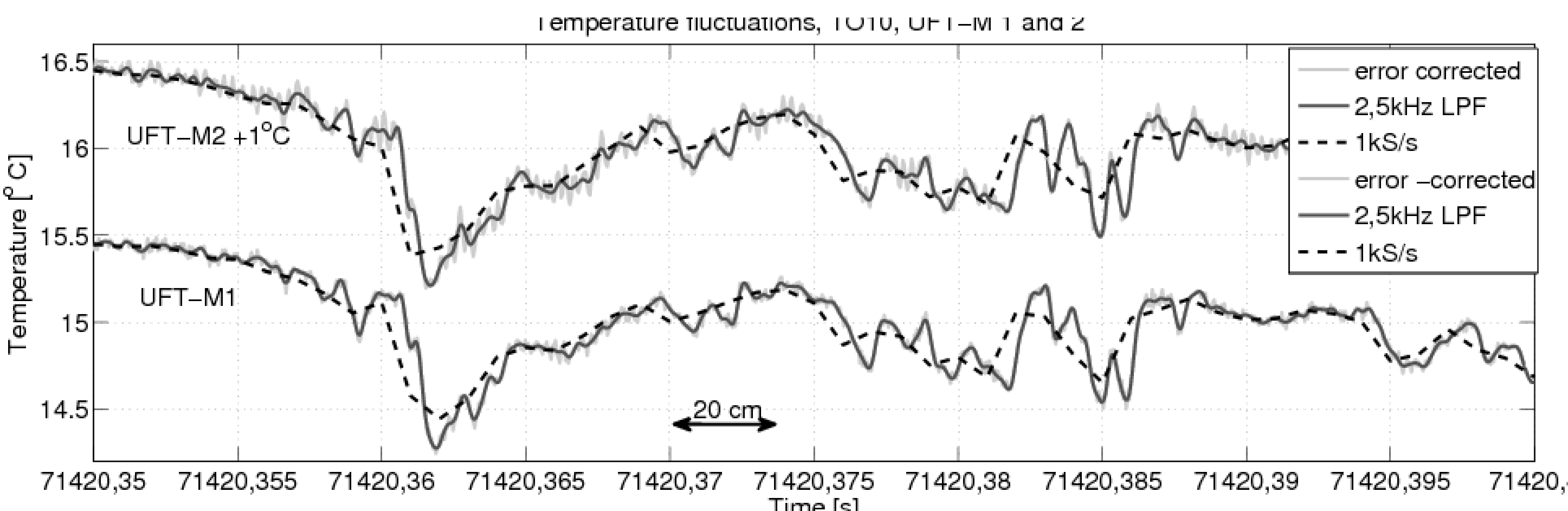
Typical vertical flight pattern of the Twin Otter during POST flights. Porpoising through cloud top is the dominant feature.
Notice that cloud deck does not have to be stable in course of flight.

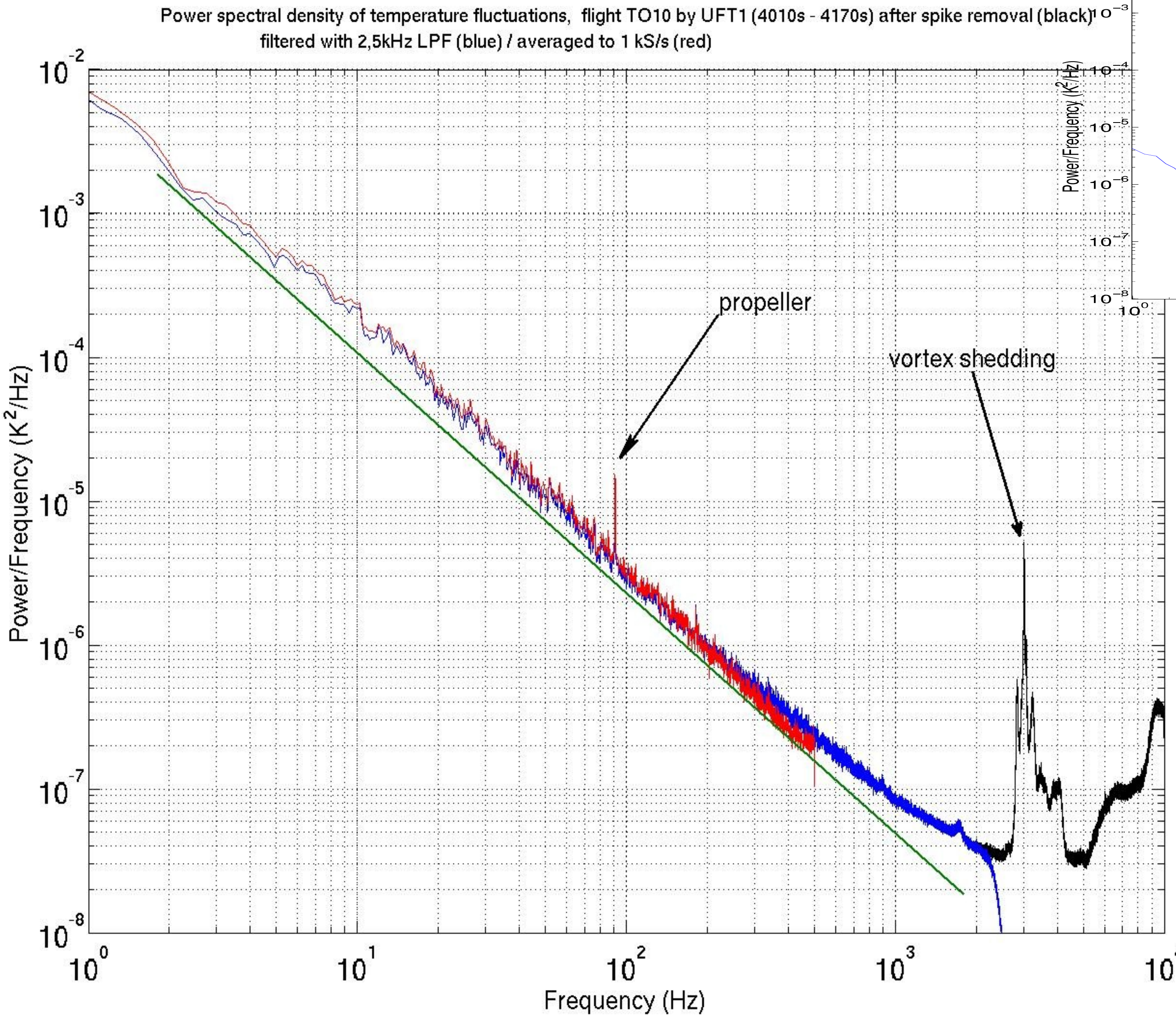


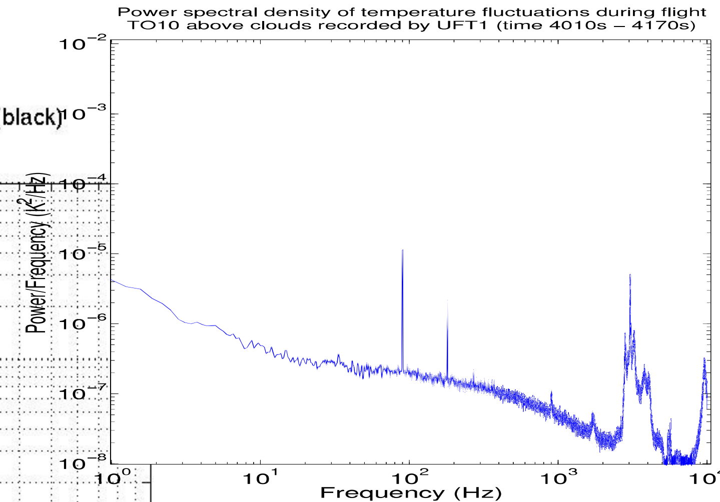
Ultra Fast Thermometer
UFTM
protecting rod
sensing wires 1 and 2
amplifiers
(shown on the
vane)
Kumala et al., 2011

Example records from UFTM



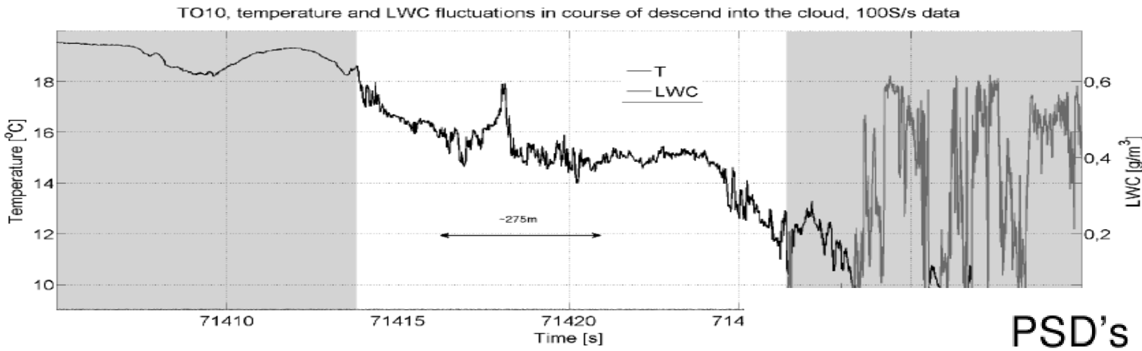


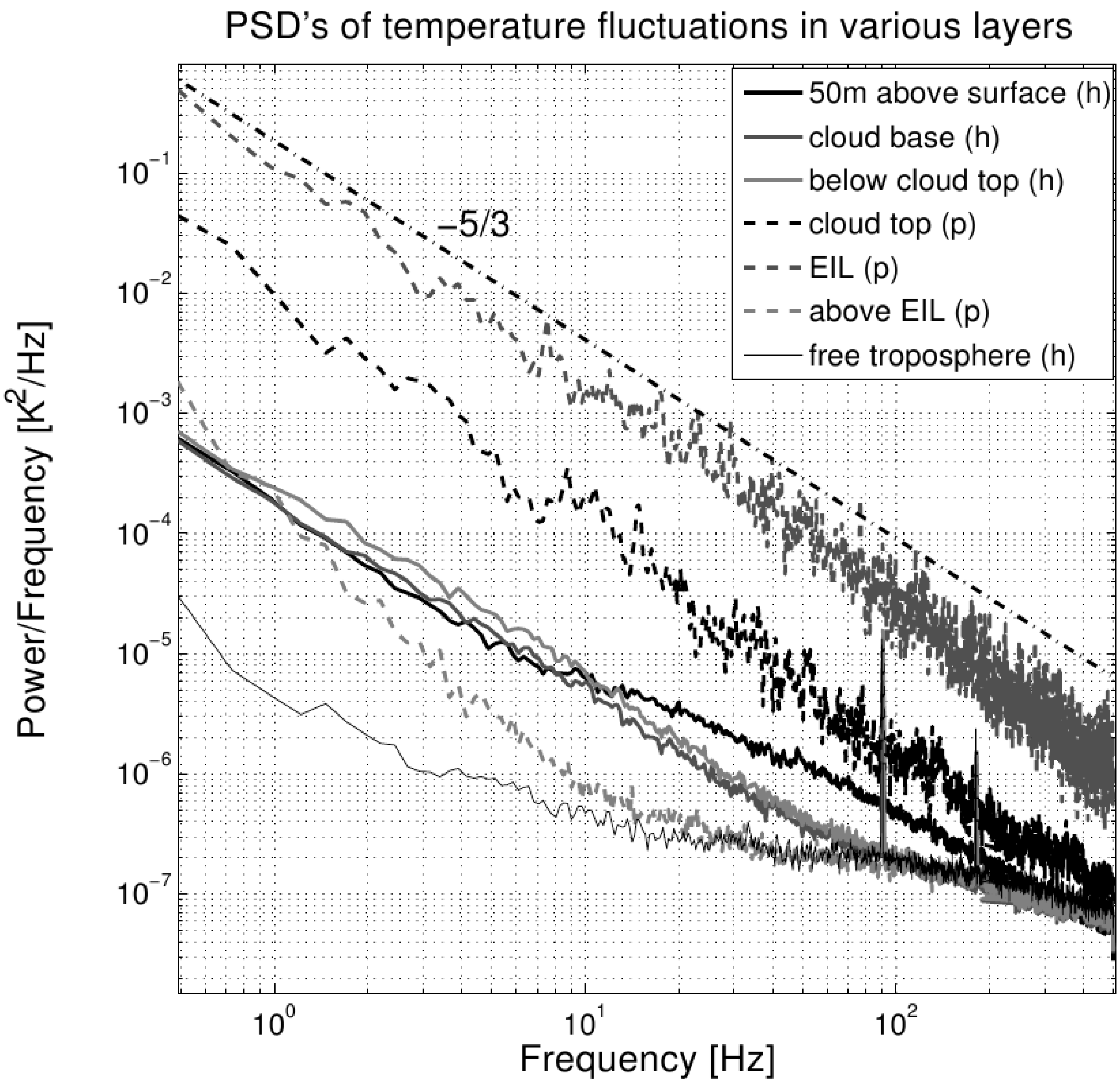




UFTM:
very fast temperature measurements, up to 2kHz (spatial resolution ~1cm)

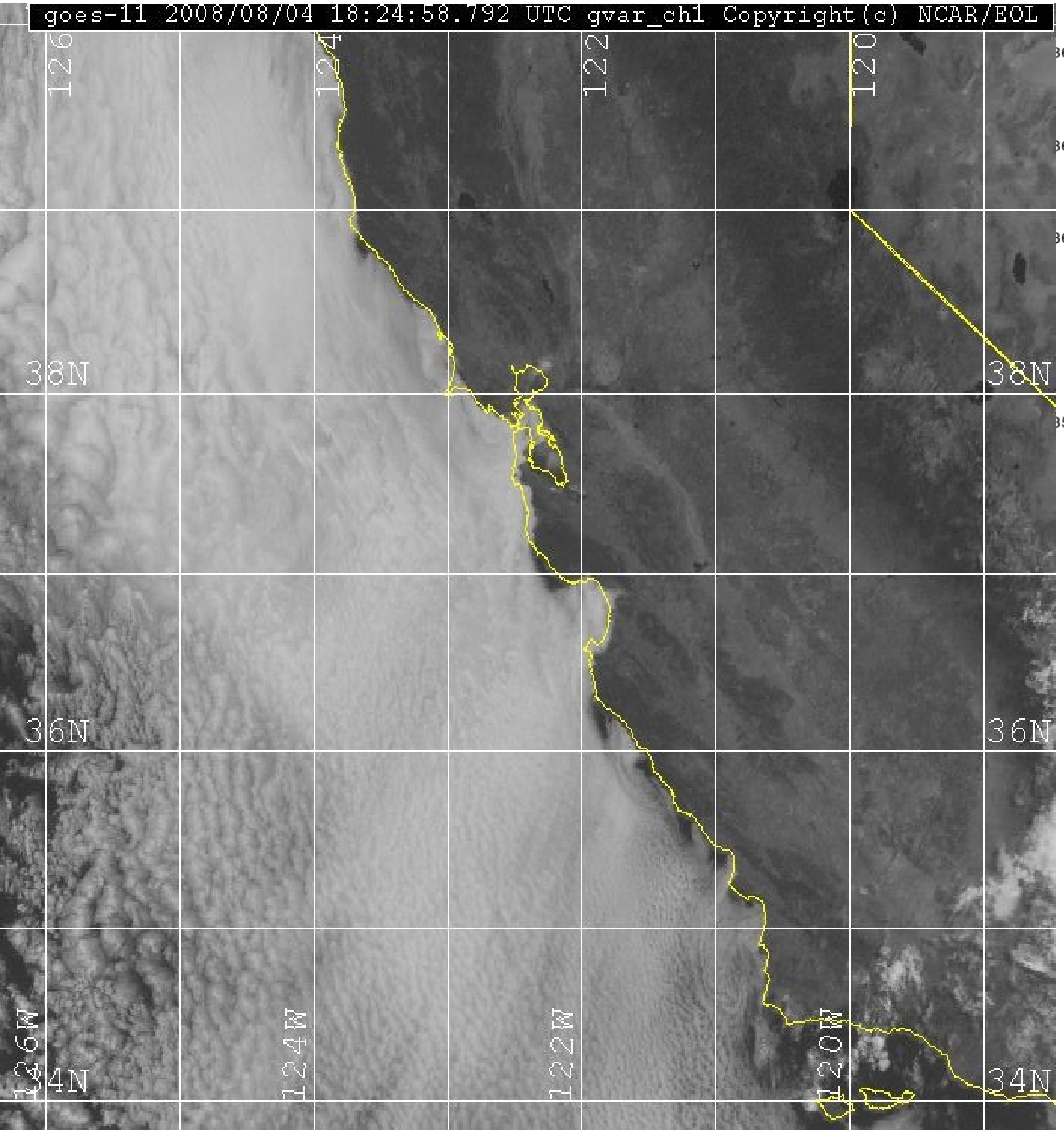
Power spectral density of temperature fluctuations in cloud-top region.
-5/3 slope plotted for reference.

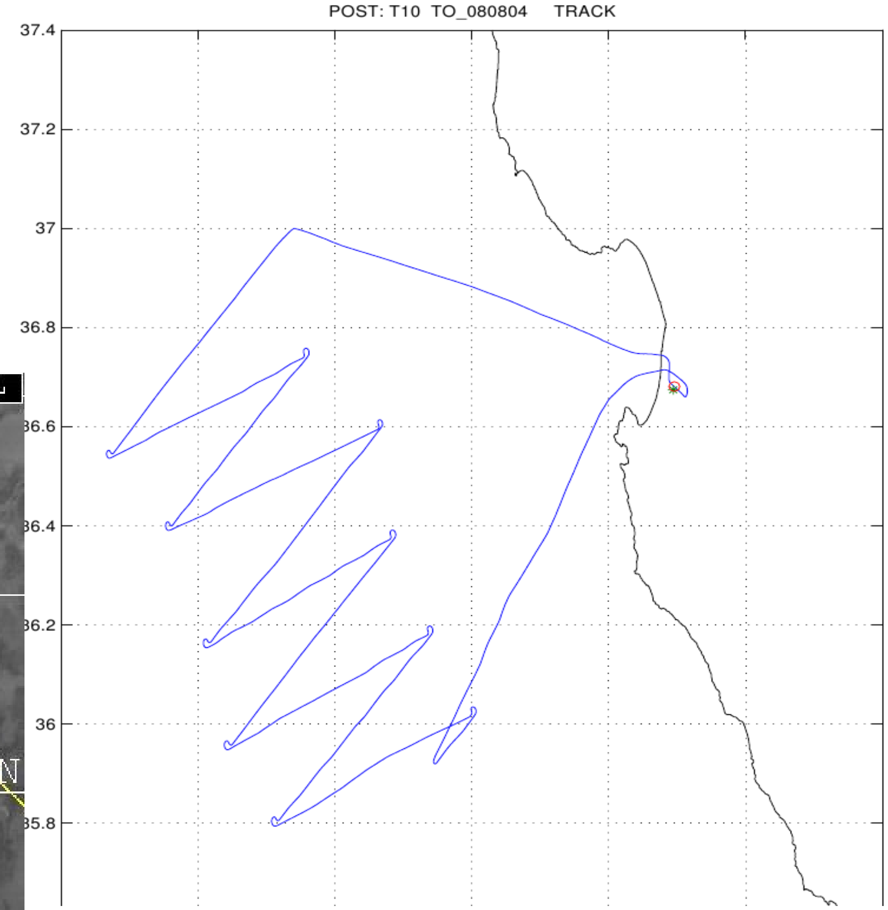




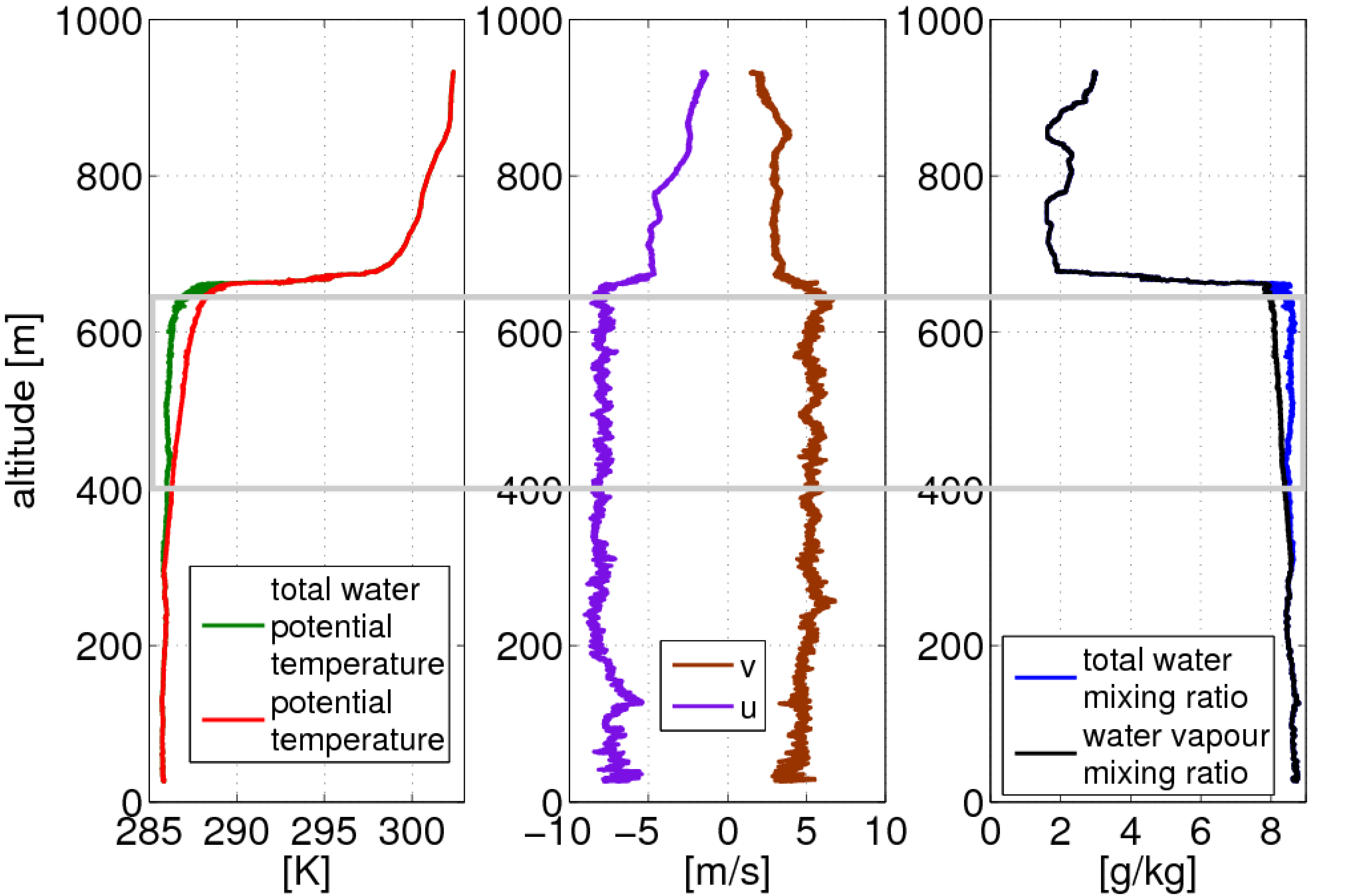
Typical PSD's of temperature fluctuations of 1kS/s signal collected in various regions of the atmosphere.

Flight TOF-10, 2008/08/04 17:15 - 22:15 UTC
(daytime: local time = UTC -8)

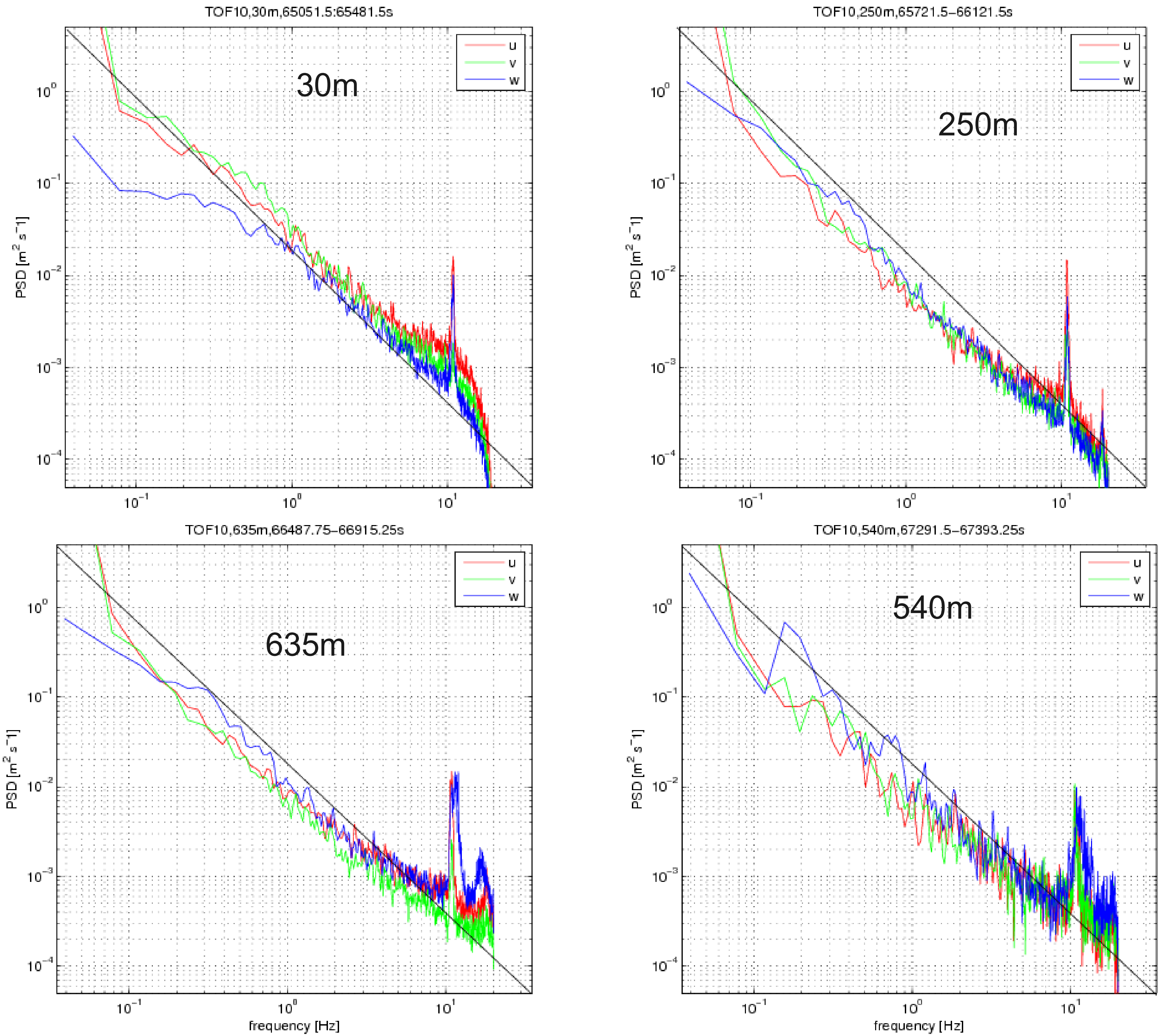




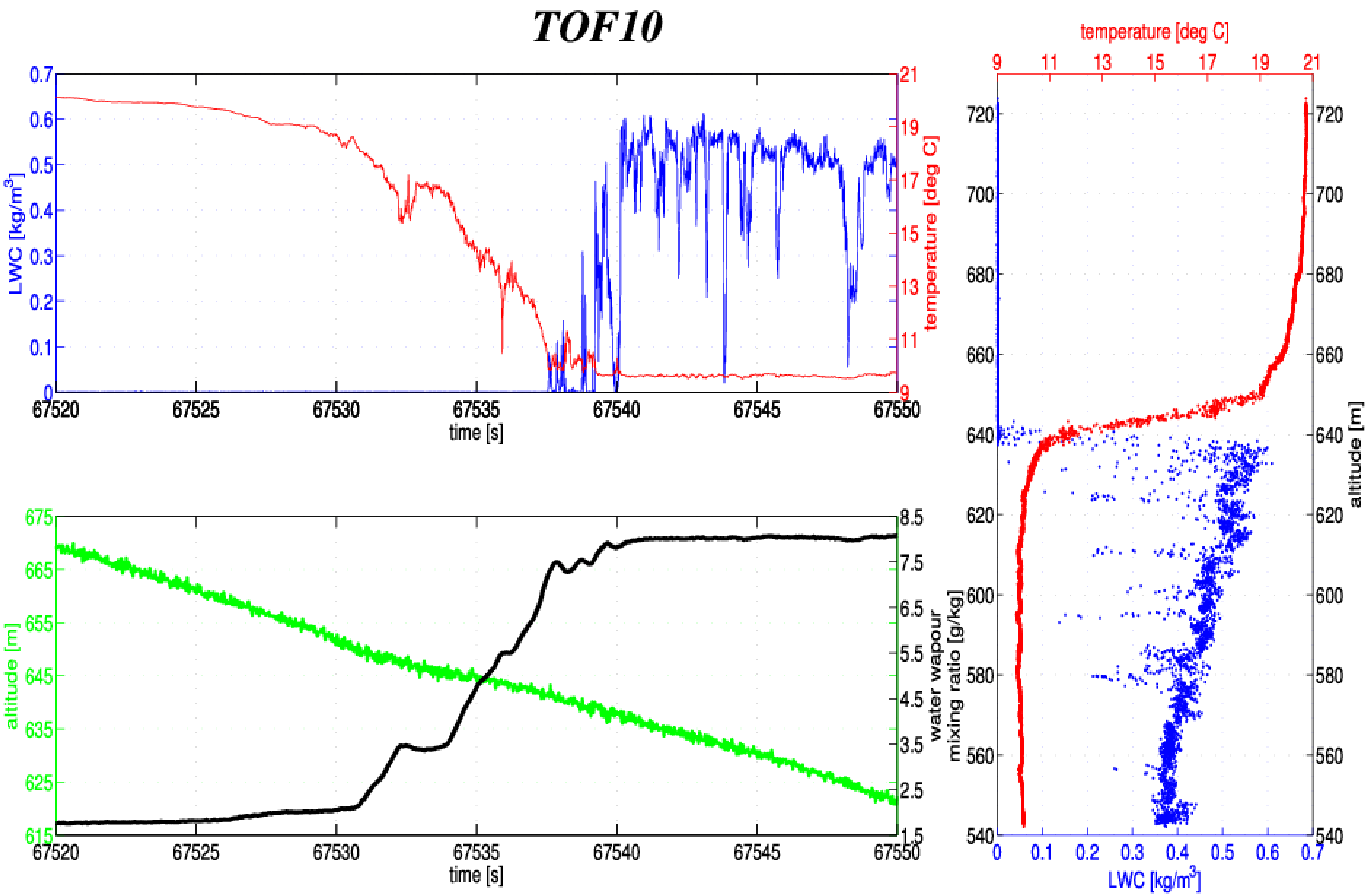
TOF10 – typical sounding: remarkable inversion (10K) and a shear layer just above the cloud top

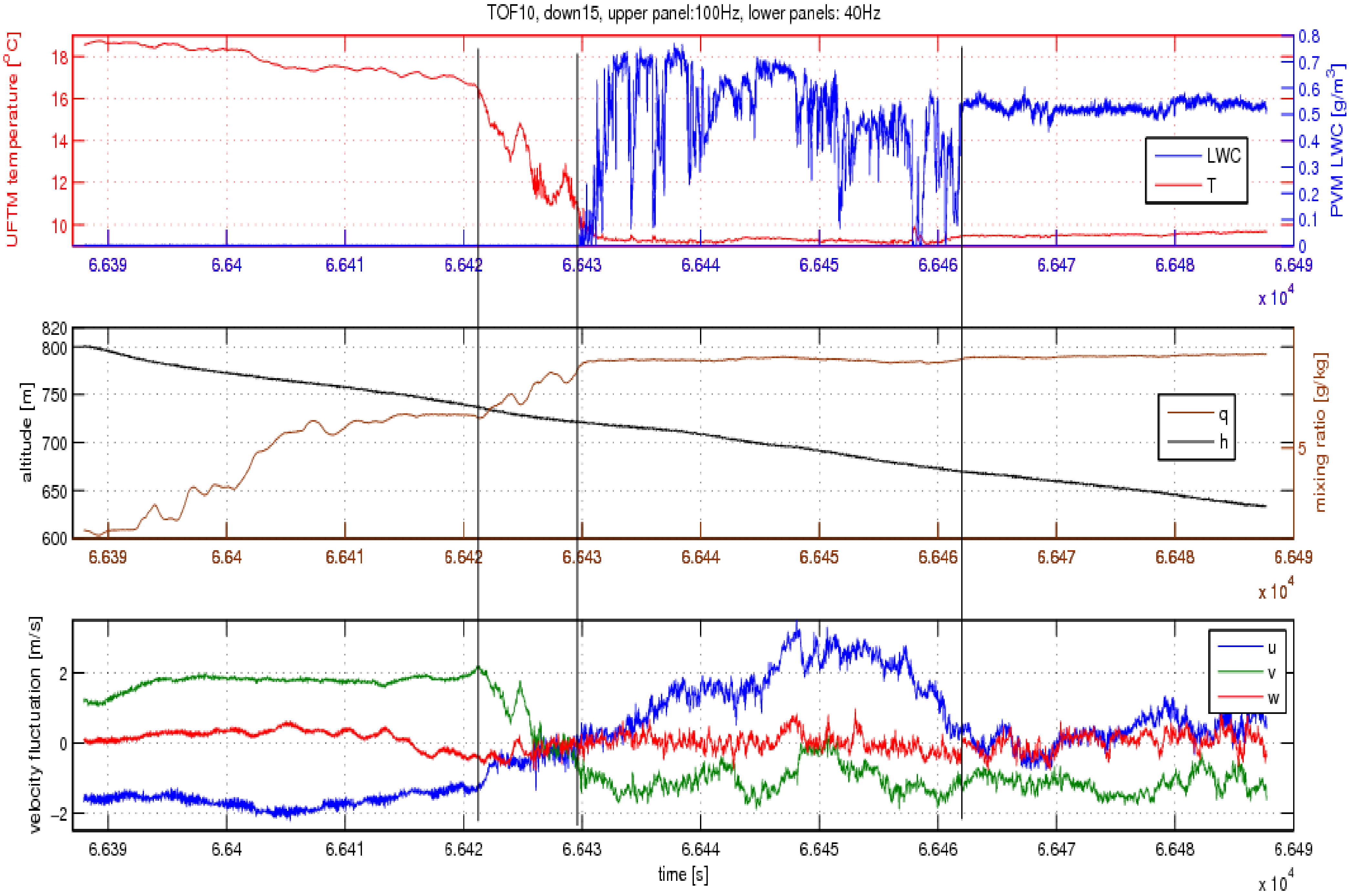


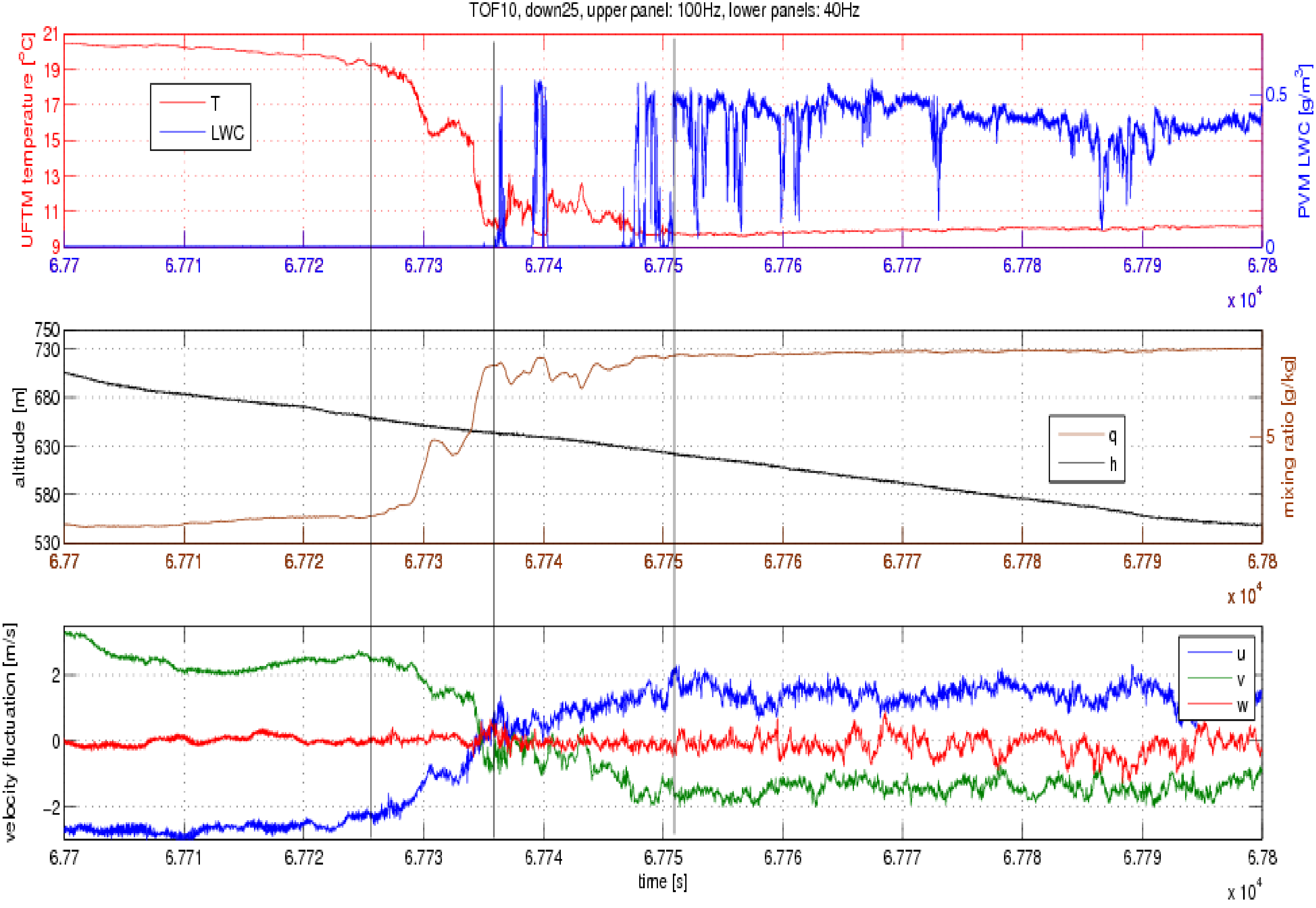
PSD's
of velocity
fluctuations
from horizontal
legs

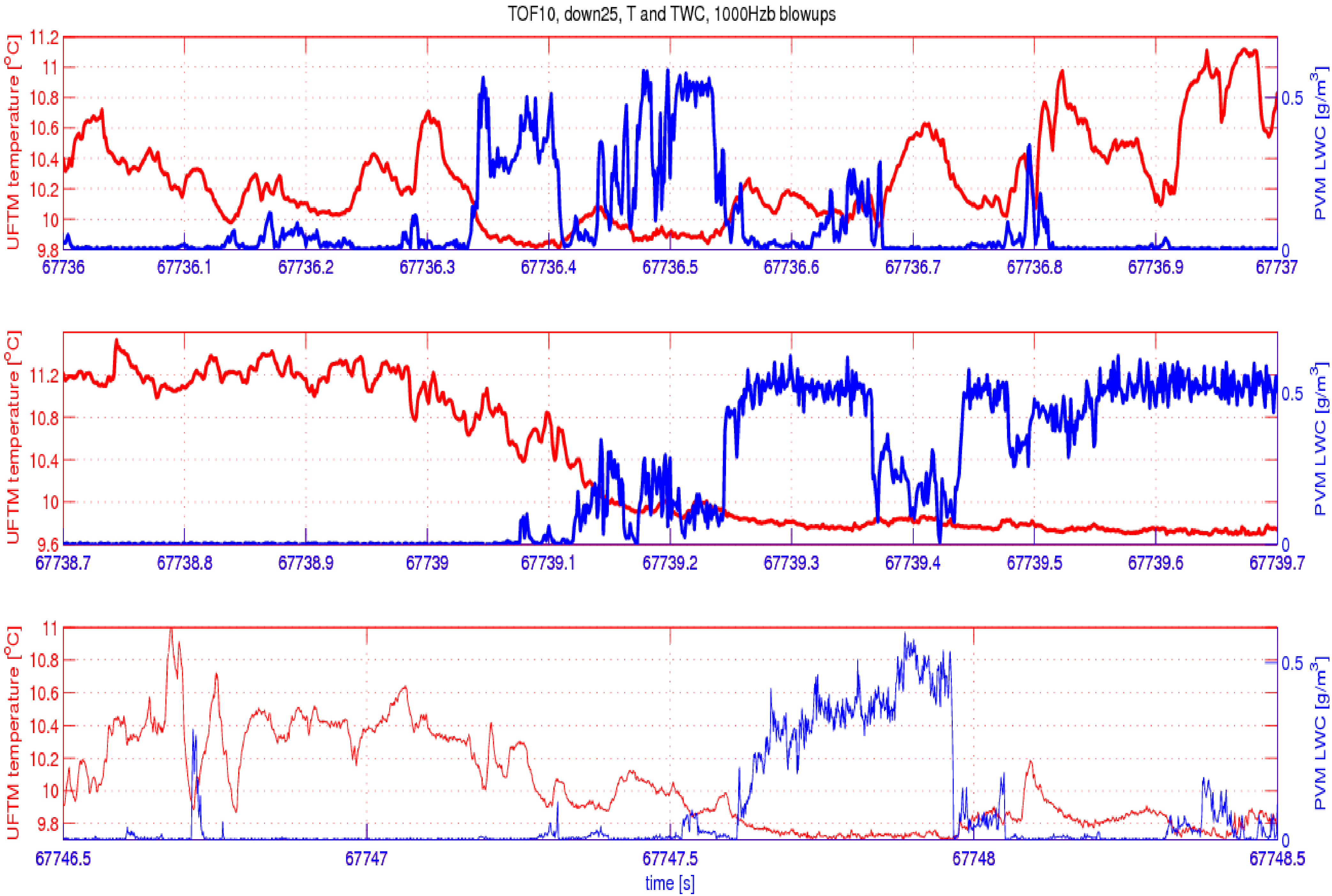


Descend into SC deck: time series vs vertical profile

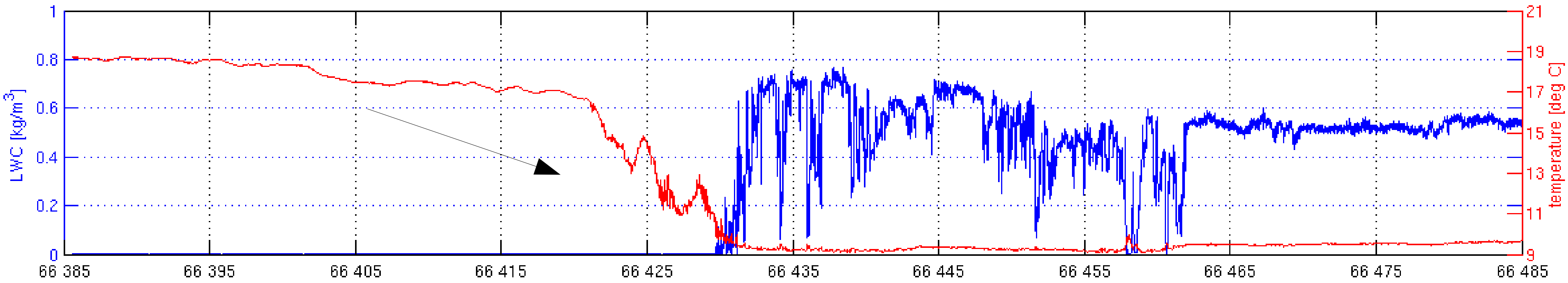


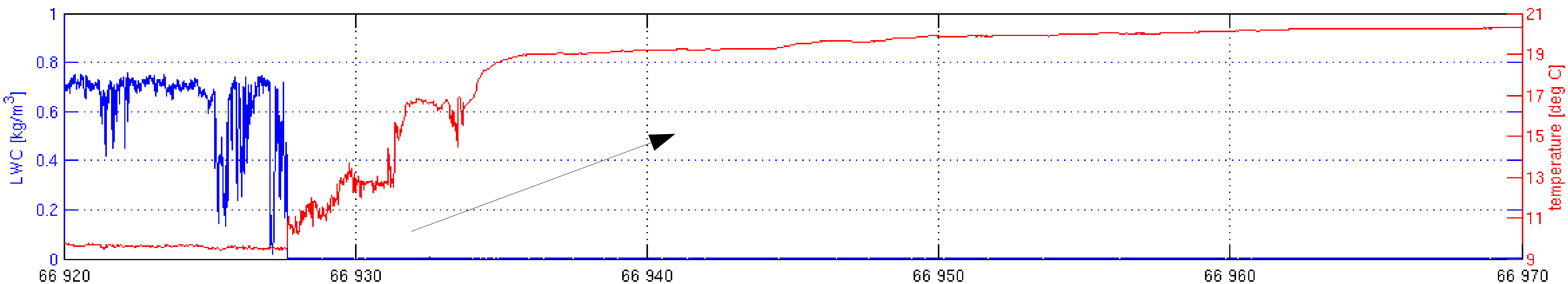

TOF10, down15, upper panel:100Hz, lower panels: 40Hz
UFTM temperature [°C]
PVM LWC [g/m³]
LWC
T
x 10⁴
altitude [m]
mixing ratio [g/kg]
q
h
velocity fluctuation [m/s]
u
v
w
time [s]

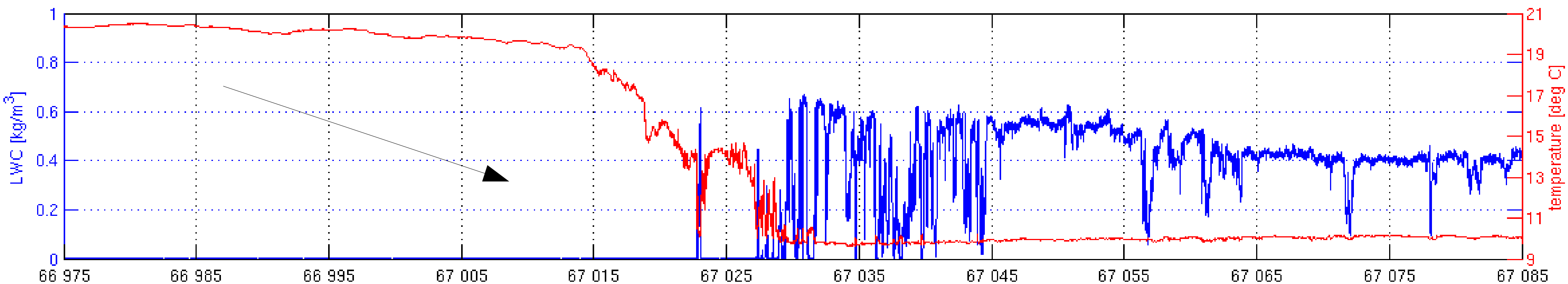

TOF10, down25, upper panel: 100Hz, lower panels: 40Hz
UFTM temperature [°C]
PVM LWC [g/m³]
T
LWC
altitude [m]
mixing ratio [g/kg]
q
h
velocity fluctuation [m/s]
u
v
w
time [s]
x 10⁴


TOF10, down25, T and TWC, 1000Hzb blowups
UFTM temperature [°C]
PVM LWC [g/m³]
time [s]

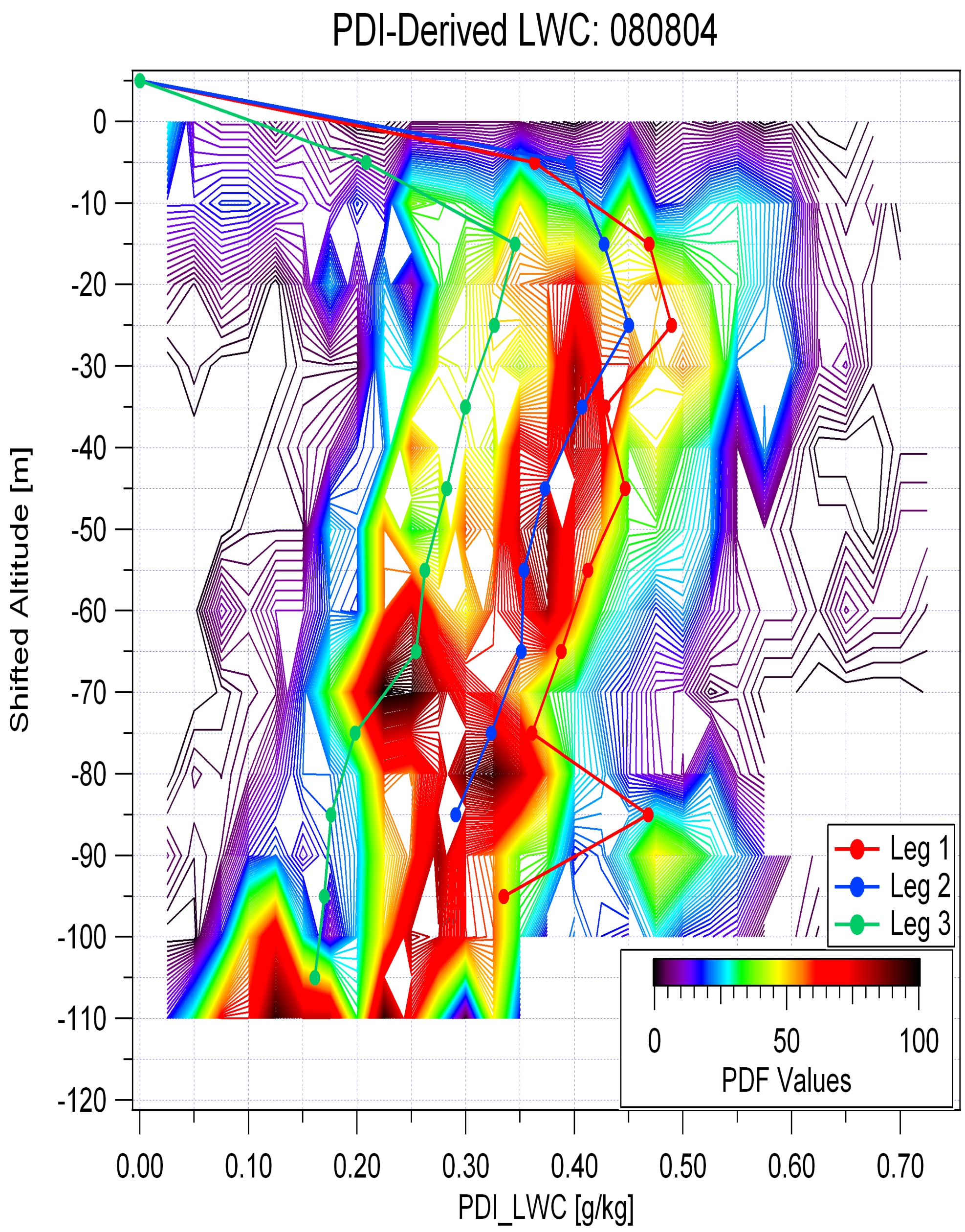
TOF10, typical penetrations of the cloud top seen at 100Hz (~55cm spatial resolution).
Red – temperature, notice relatively sharp inversion above the cloud.
Blue – LWC, notice maximum values just below the cloud top.

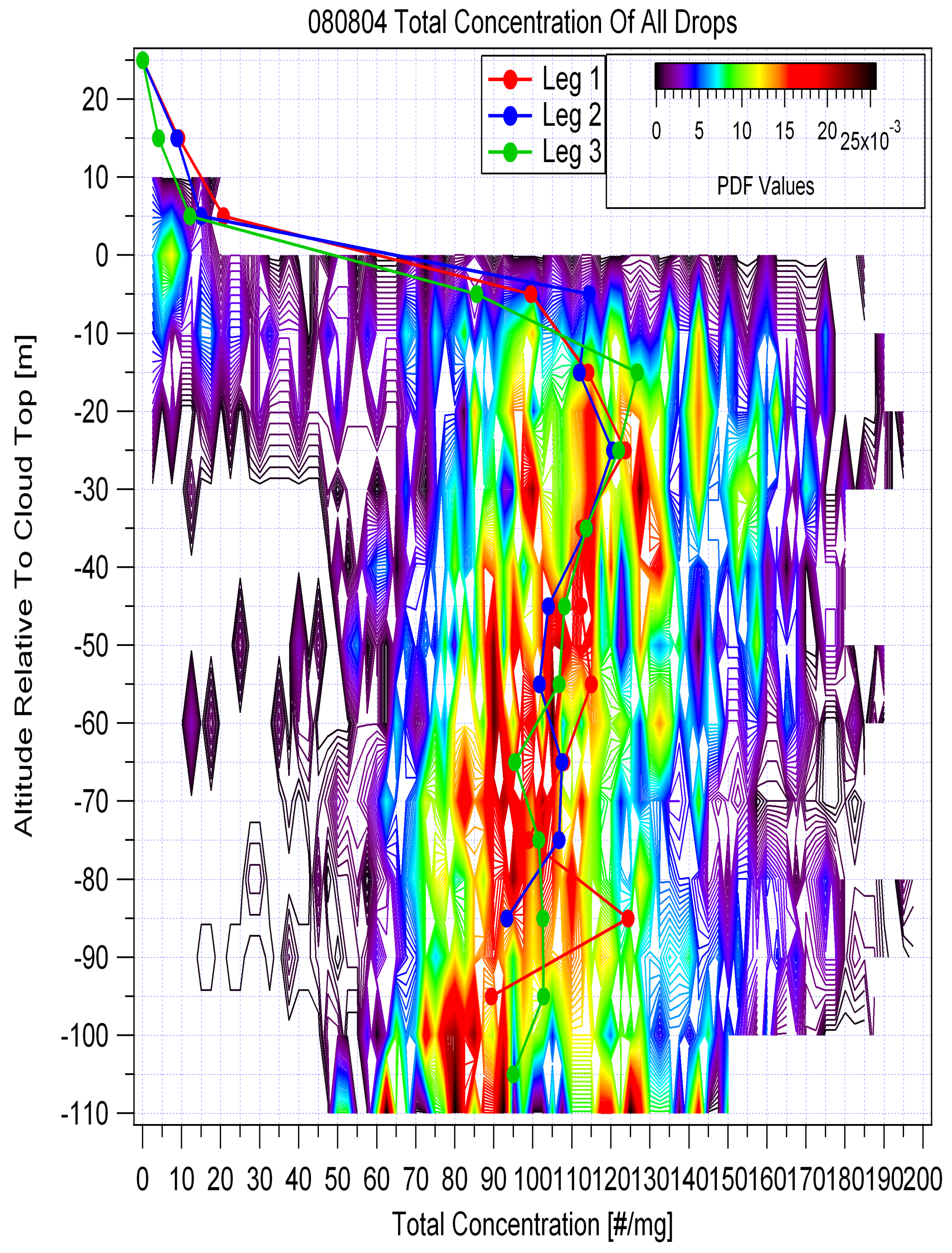




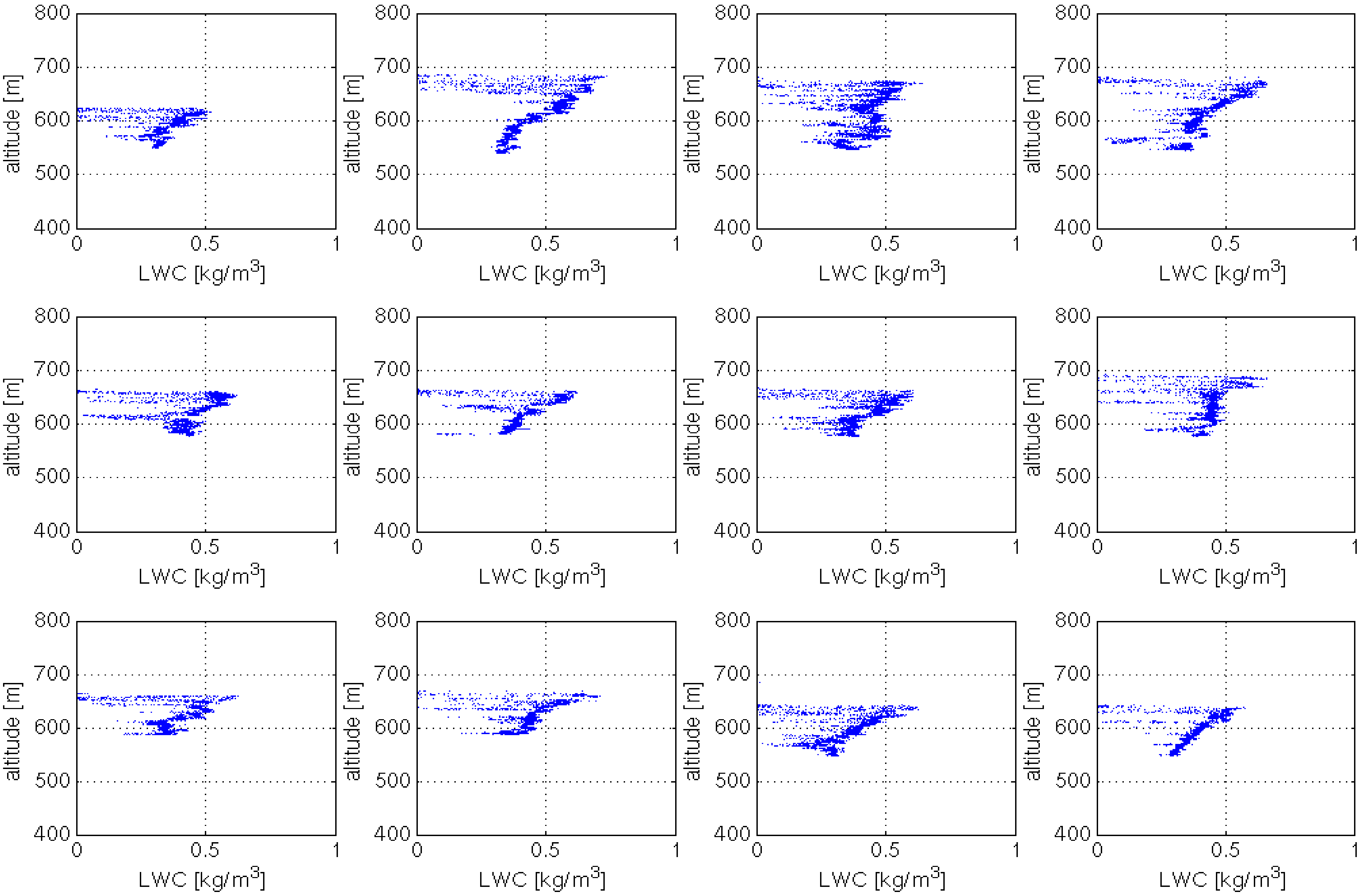


TOF 10: PDF's of LWC and droplet concentrations (courtesy Partick Chuang)

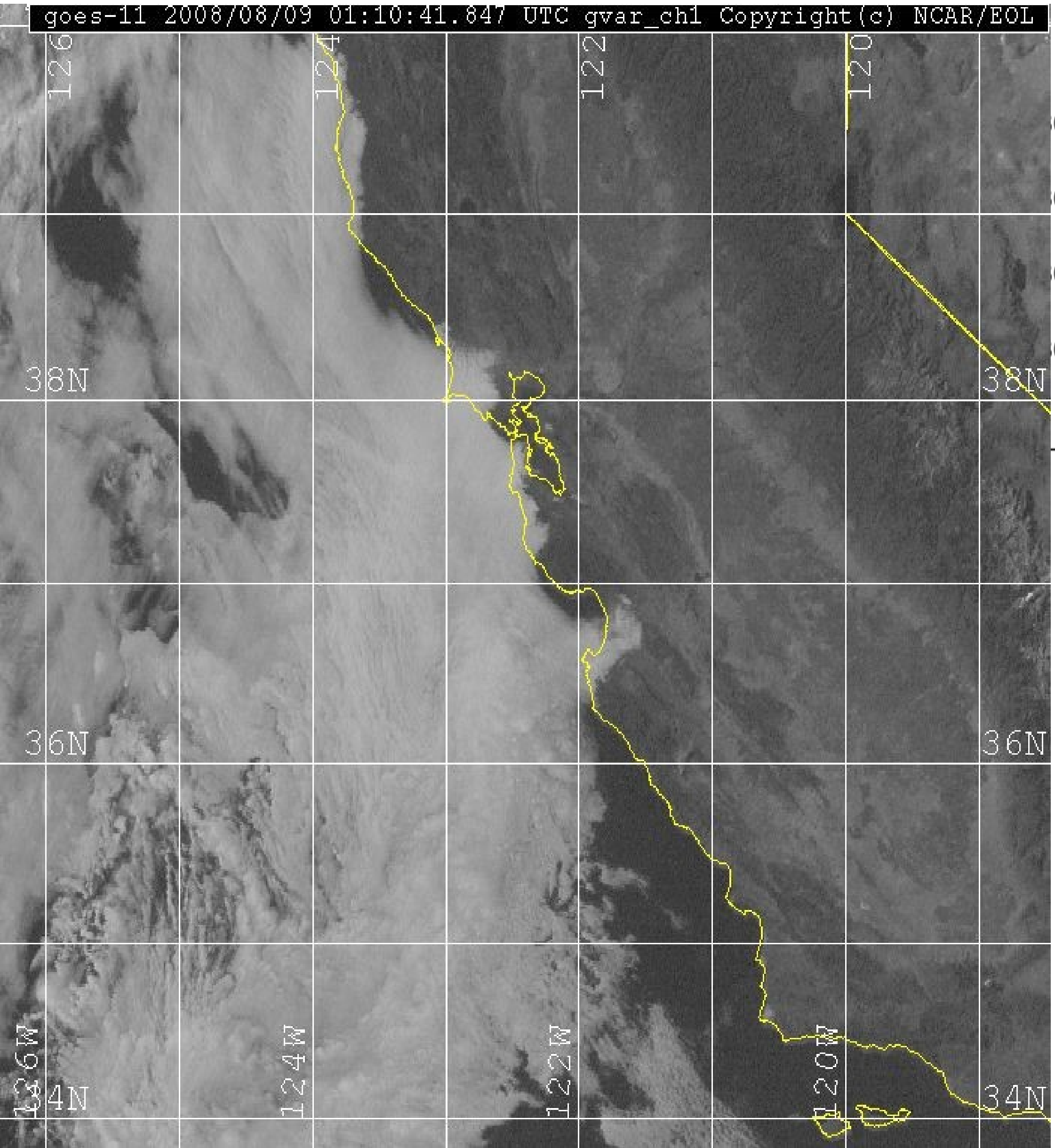


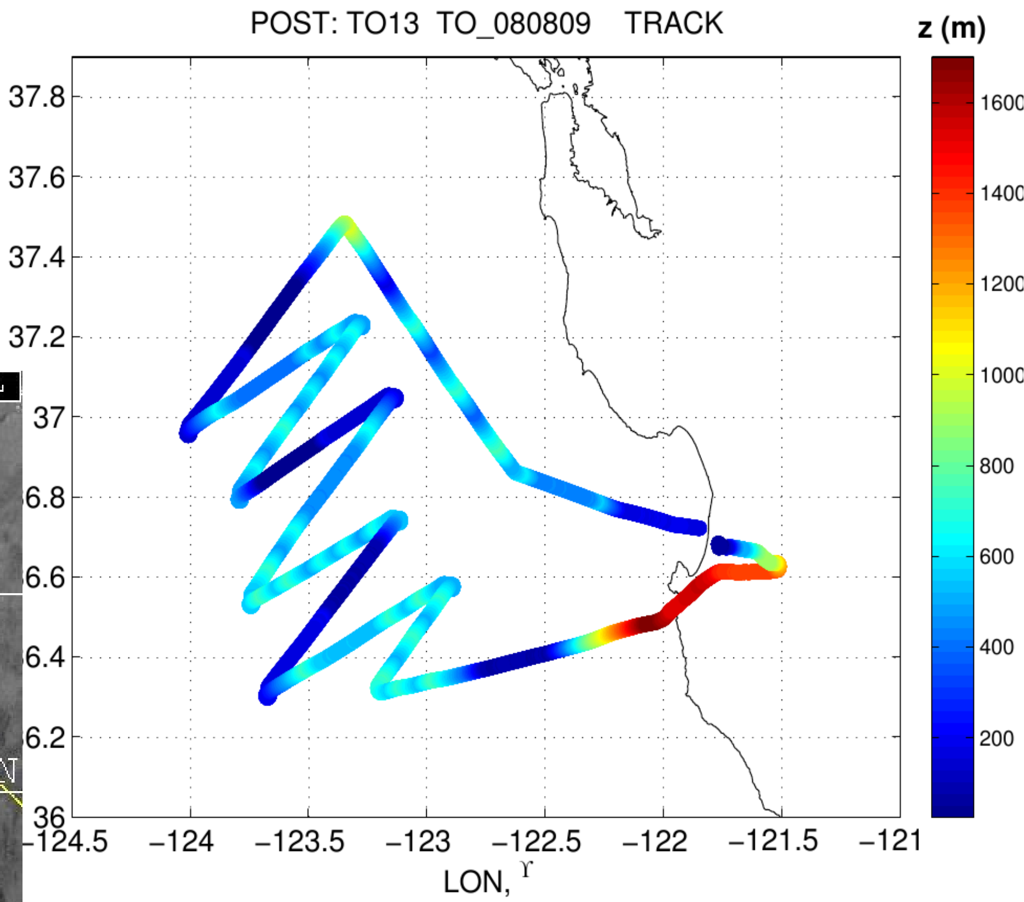


TOF10: LWC on ~1.2m long samples (40Hz):
maximum on the top, gradual decrease down except on dilution in mixing events

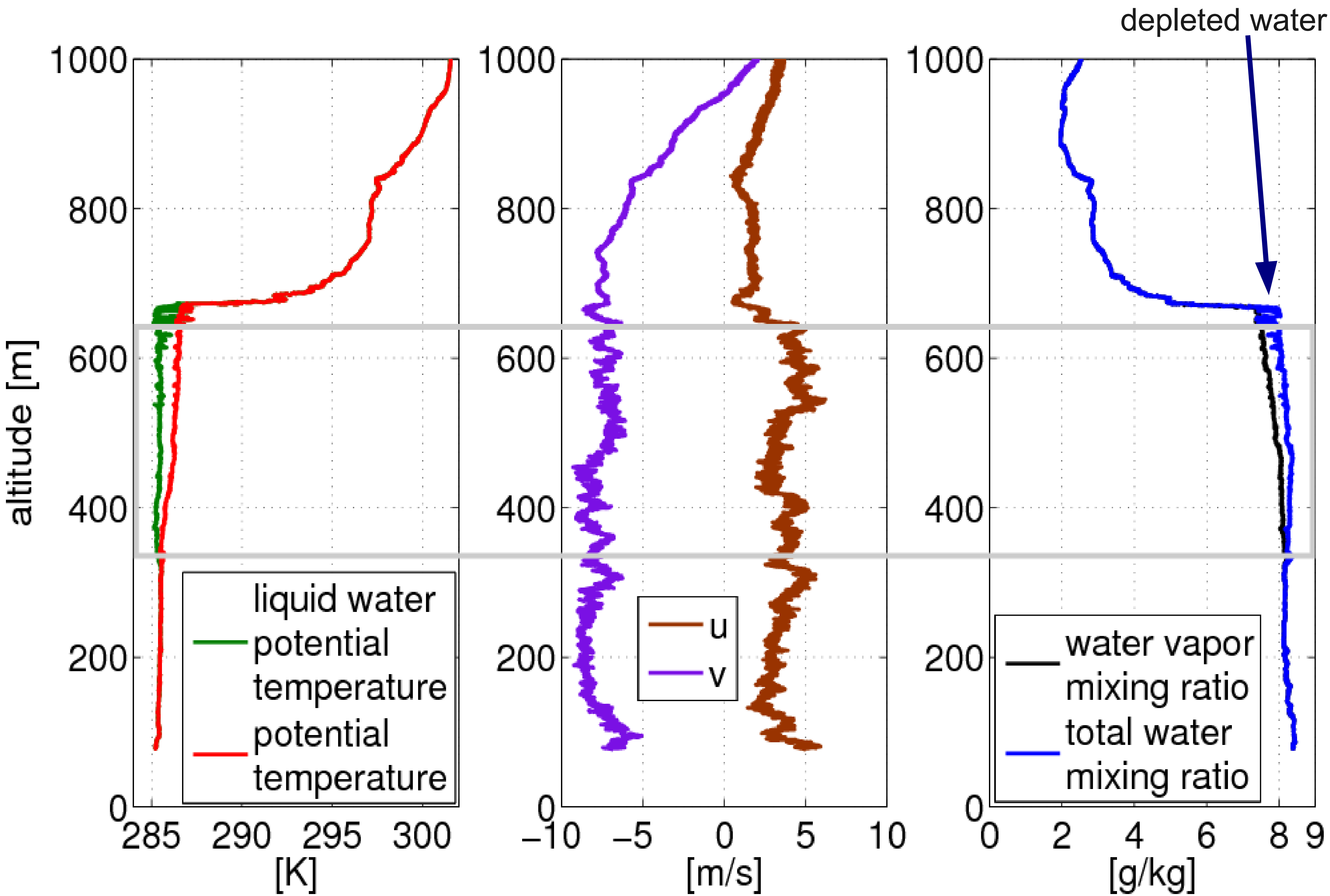


Flight TOF-13, 2008/08/09 00:52 – 06:00 UTC (evening)

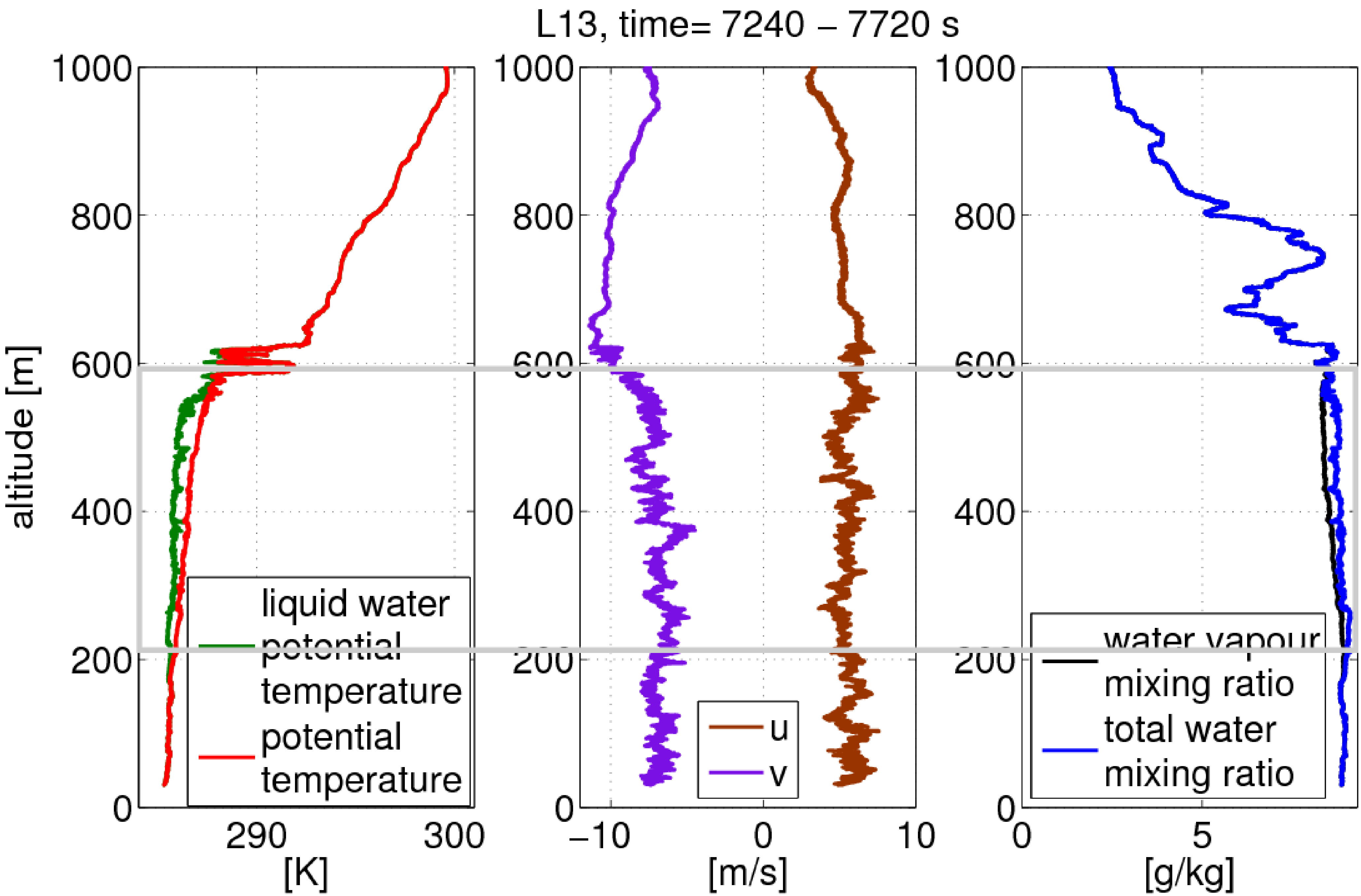




TOF13 – typical sounding: no narrow shear layer at the cloud top, weaker inversion
Second mixed layer above cloud tops????



No, just heterogeneity. General conditions in the cloud-top region: weak inversion, weak wind shear, high humidity.



PSD's
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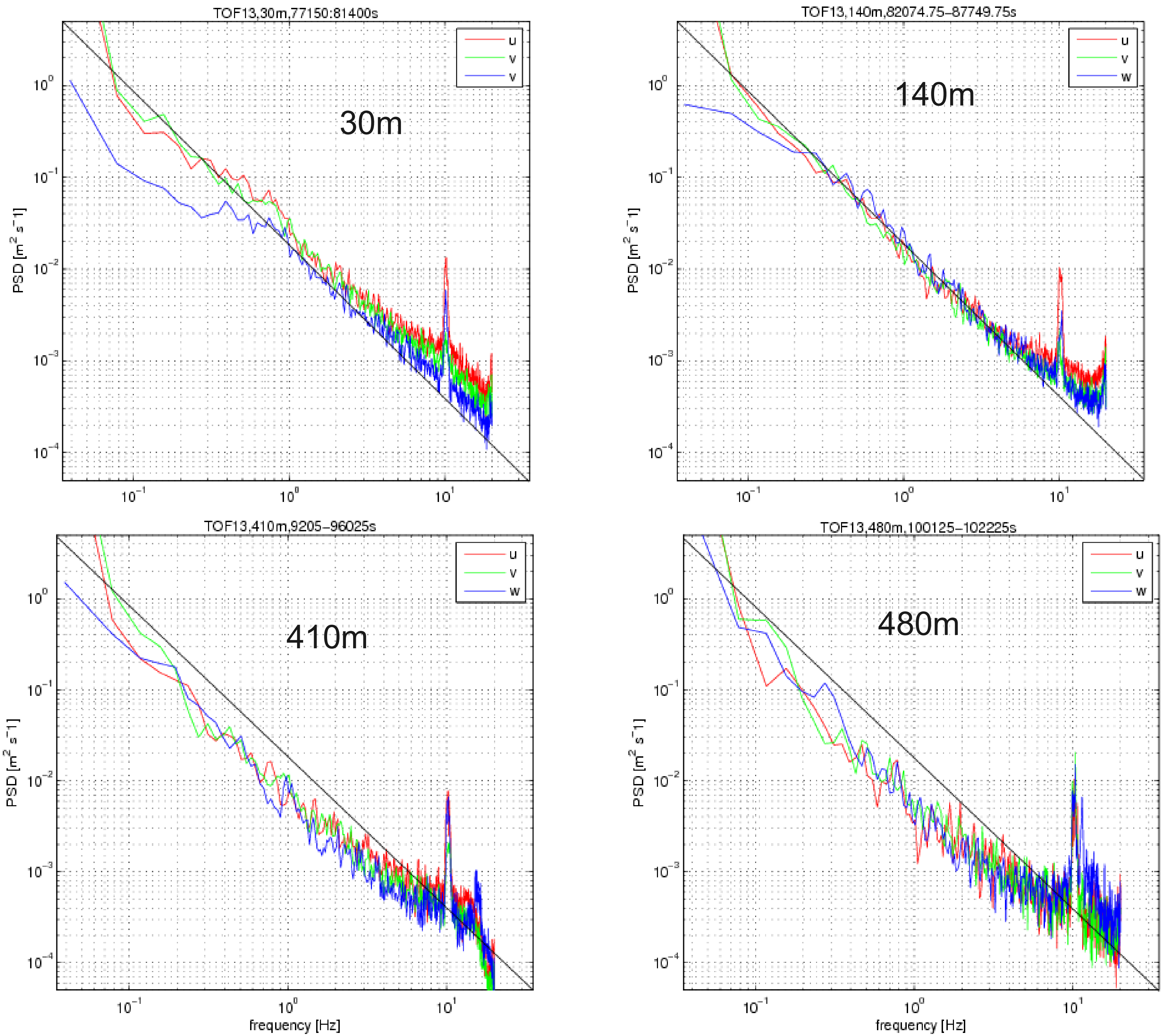
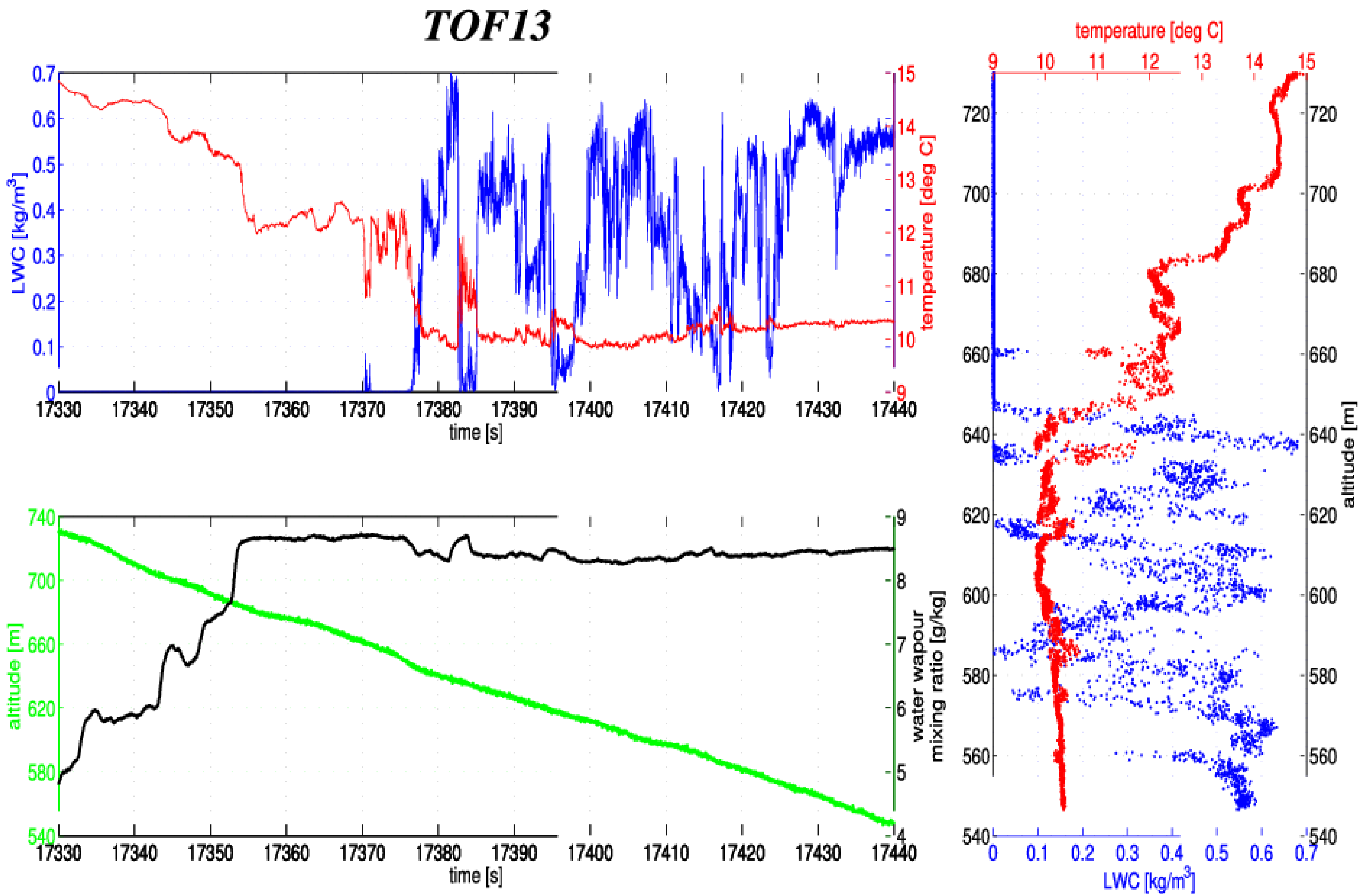
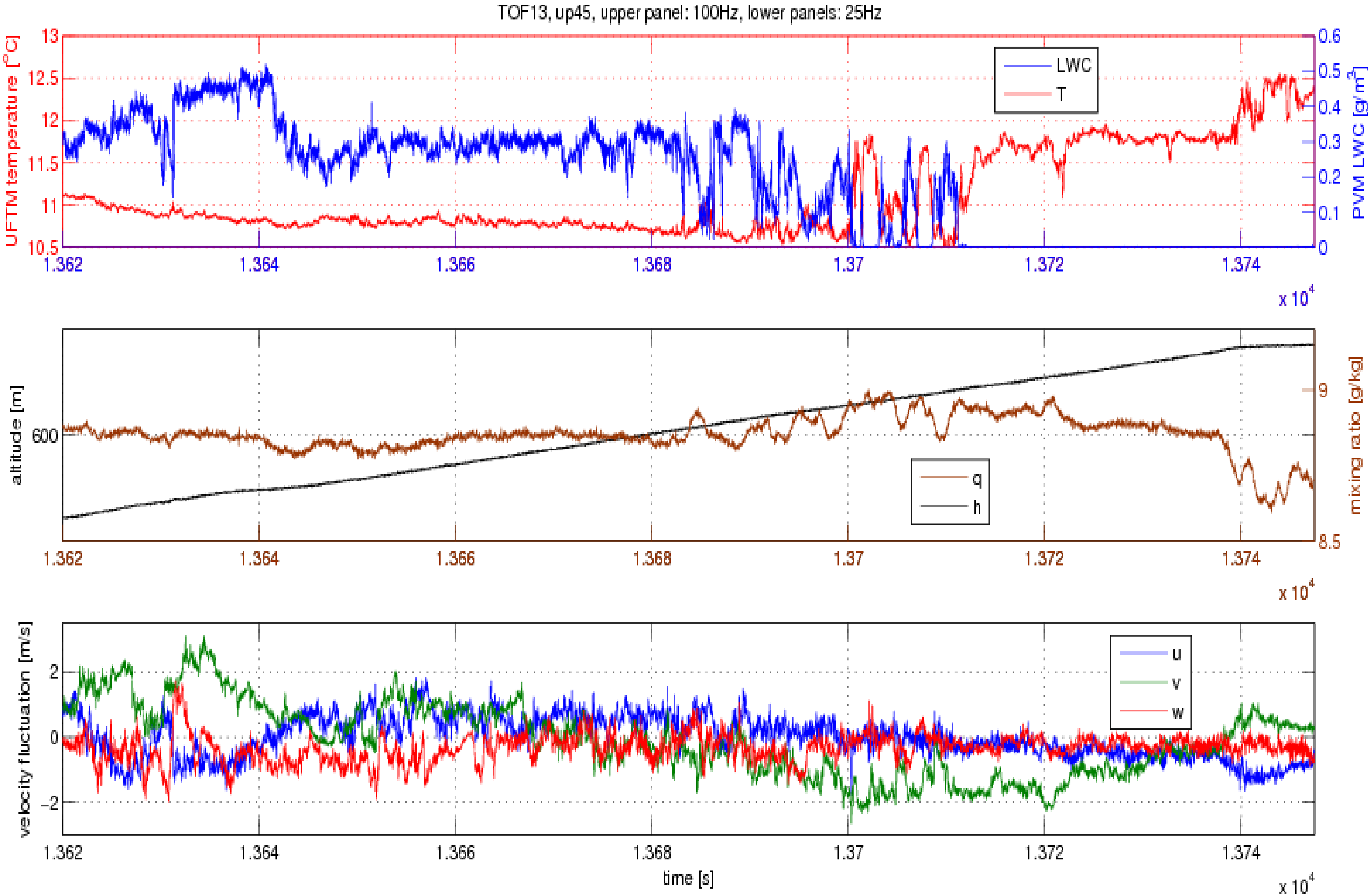
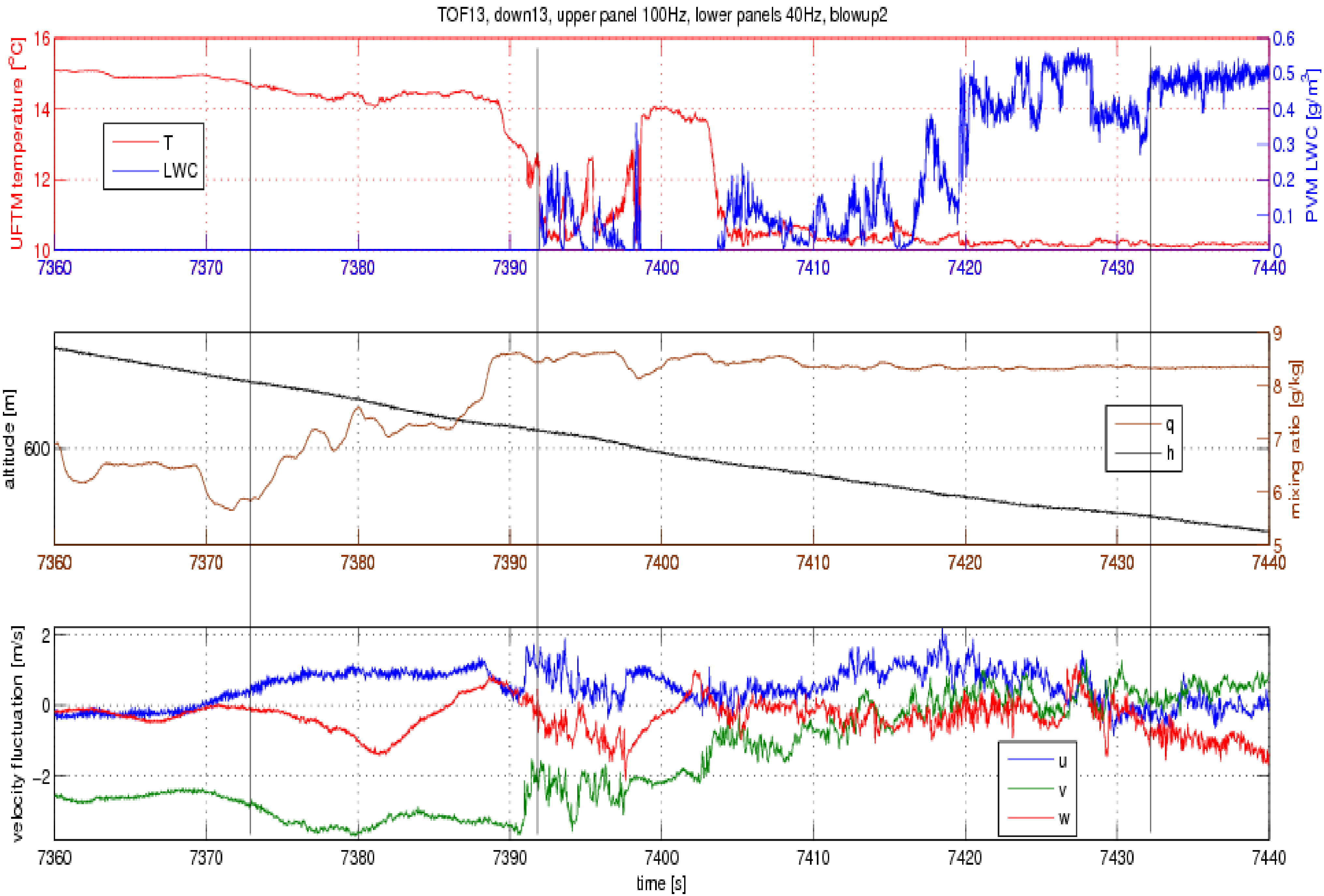


Descend into SC deck: time series vs vertical profile

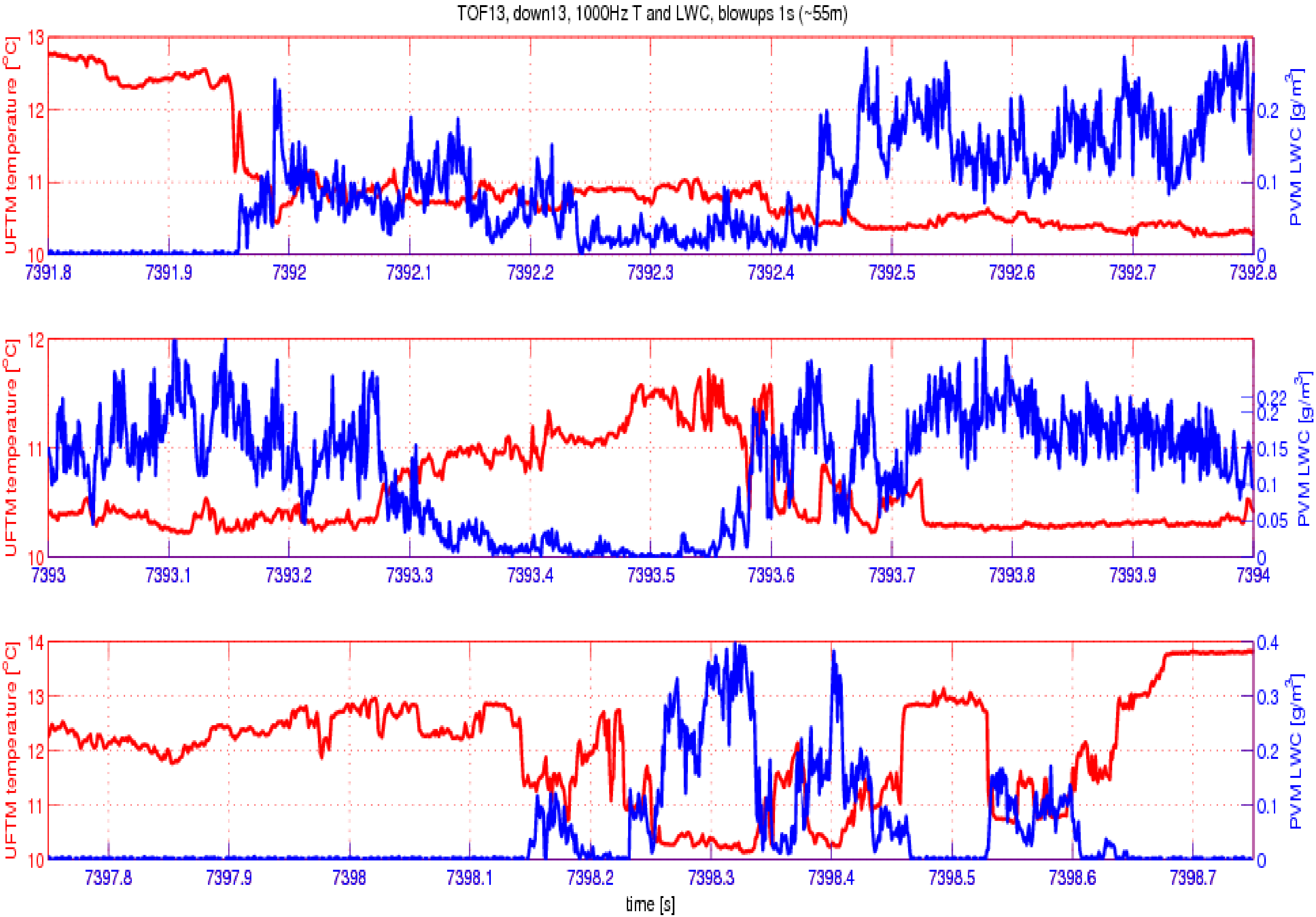



TOF13, up45, upper panel: 100Hz, lower panels: 25Hz
UFTM temperature [°C]
PVM LWC [g/m³]
LWC
T
altitude [m]
mixing ratio [g/kg]
q
h
velocity fluctuation [m/s]
u
v
w
time [s]
x 10⁴

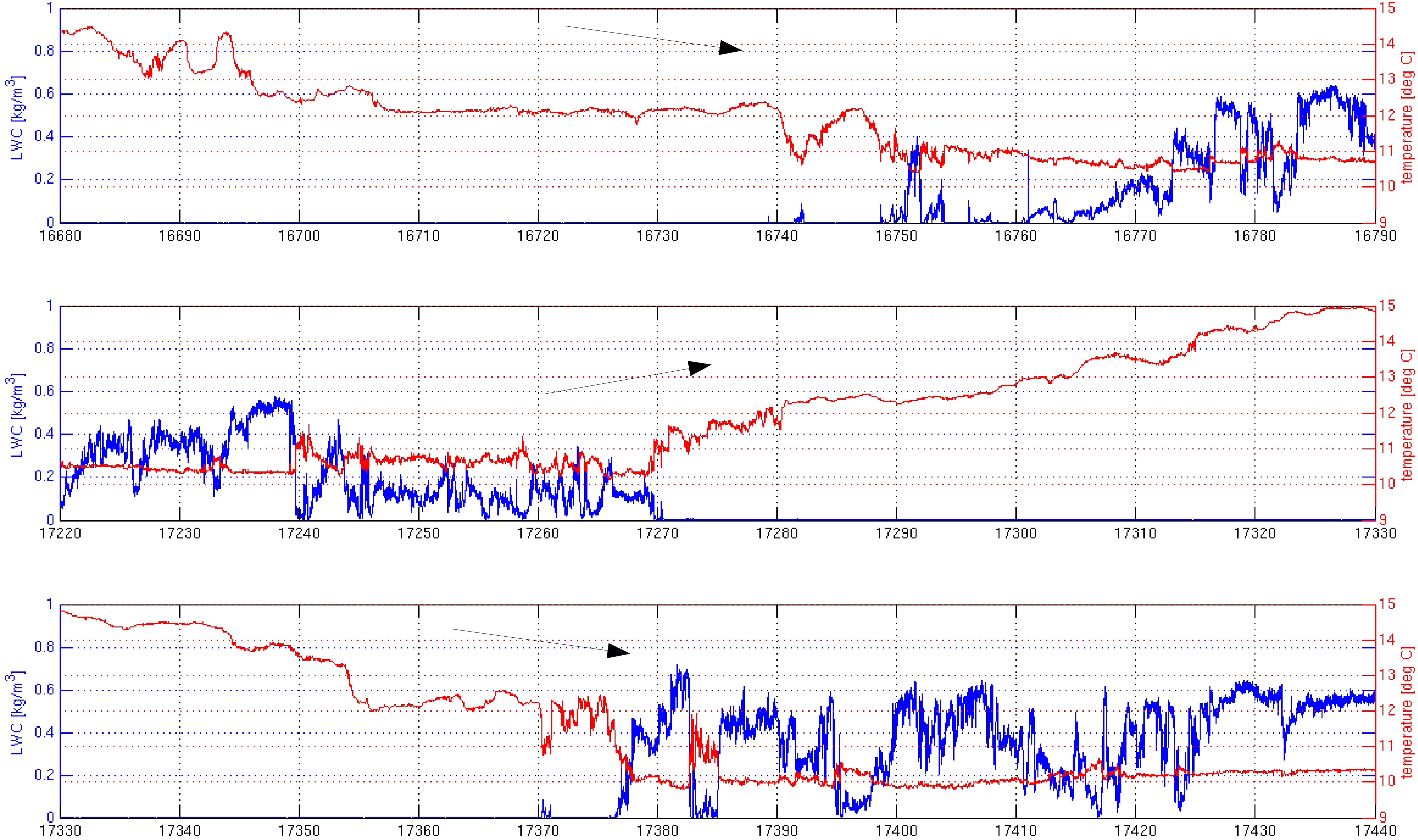


TOF13, down13, upper panel 100Hz, lower panels 40Hz, blowup2
UFTM temperature [°C]
PVM LWC [g/m³]
T
LWC
altitude [m]
mixing ratio [g/kg]
q
h
velocity fluctuation [m/s]
u
v
w
time [s]

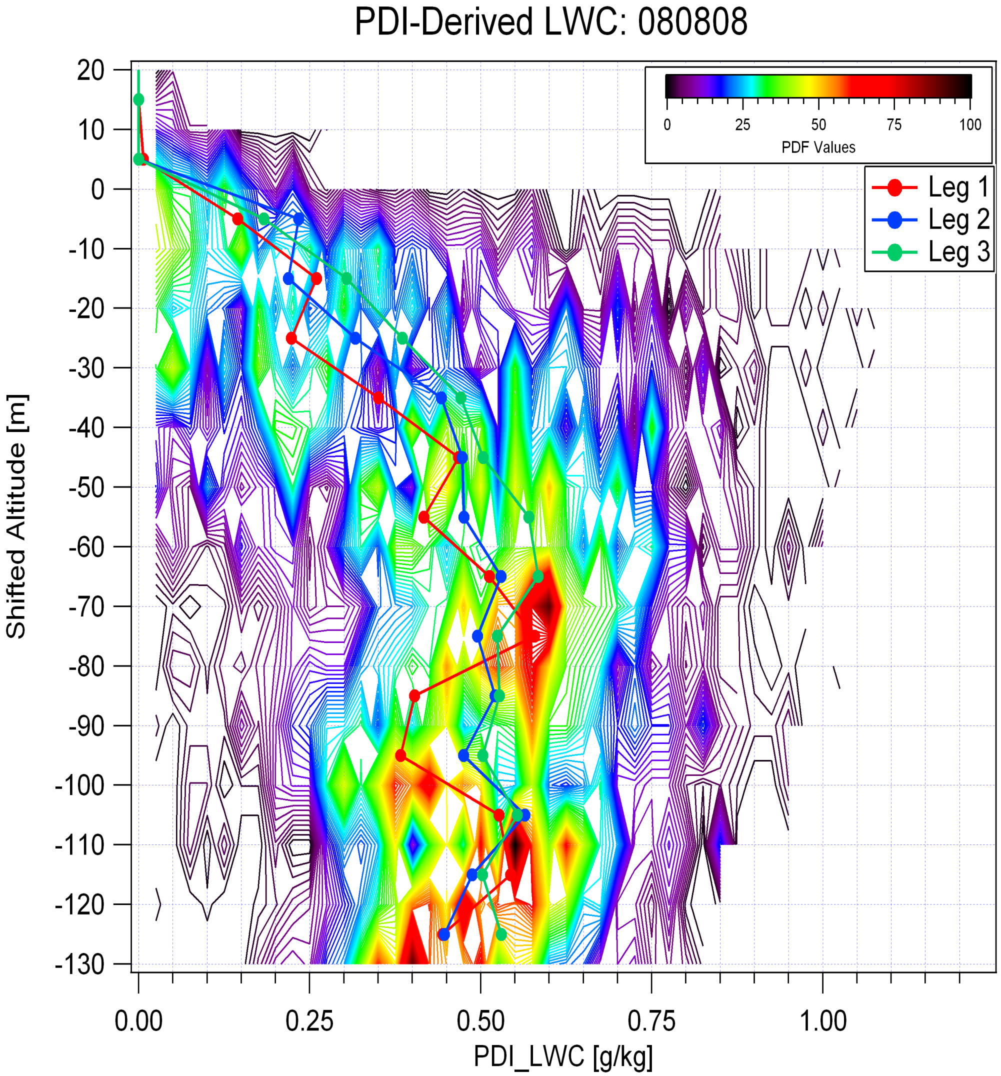
Notice steep temperature jumps: sharp edges of filaments (compared to TOF10)

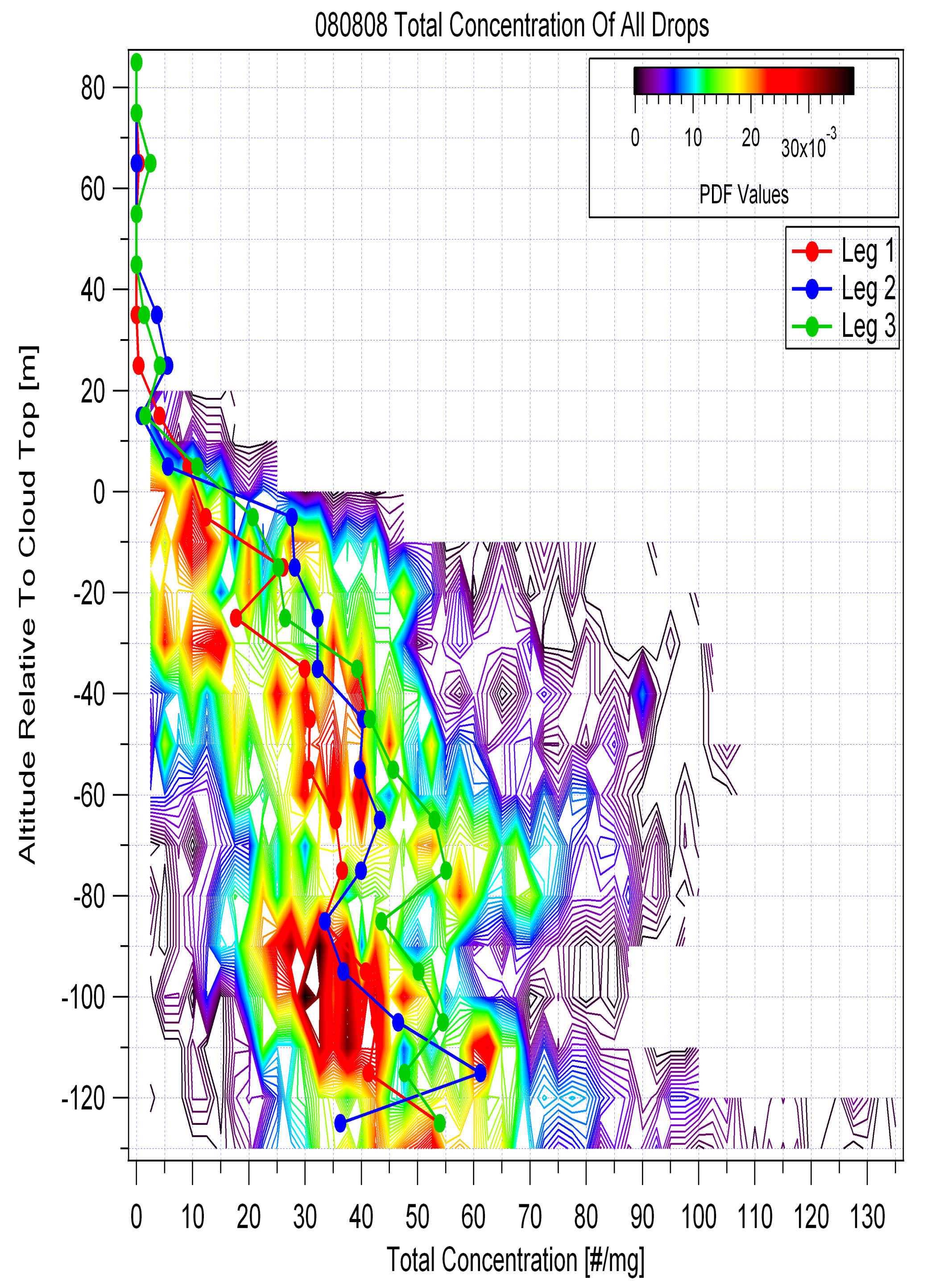


TOF13, typical penetrations of the cloud top seen at 100Hz (~55cm spatial resolution).
Red – temperature, notice gradual changes of temperature above cloud.
Blue – LWC, notice that most air samples at the cloud top contain diluted (with respect to adiabatic) liquid water.

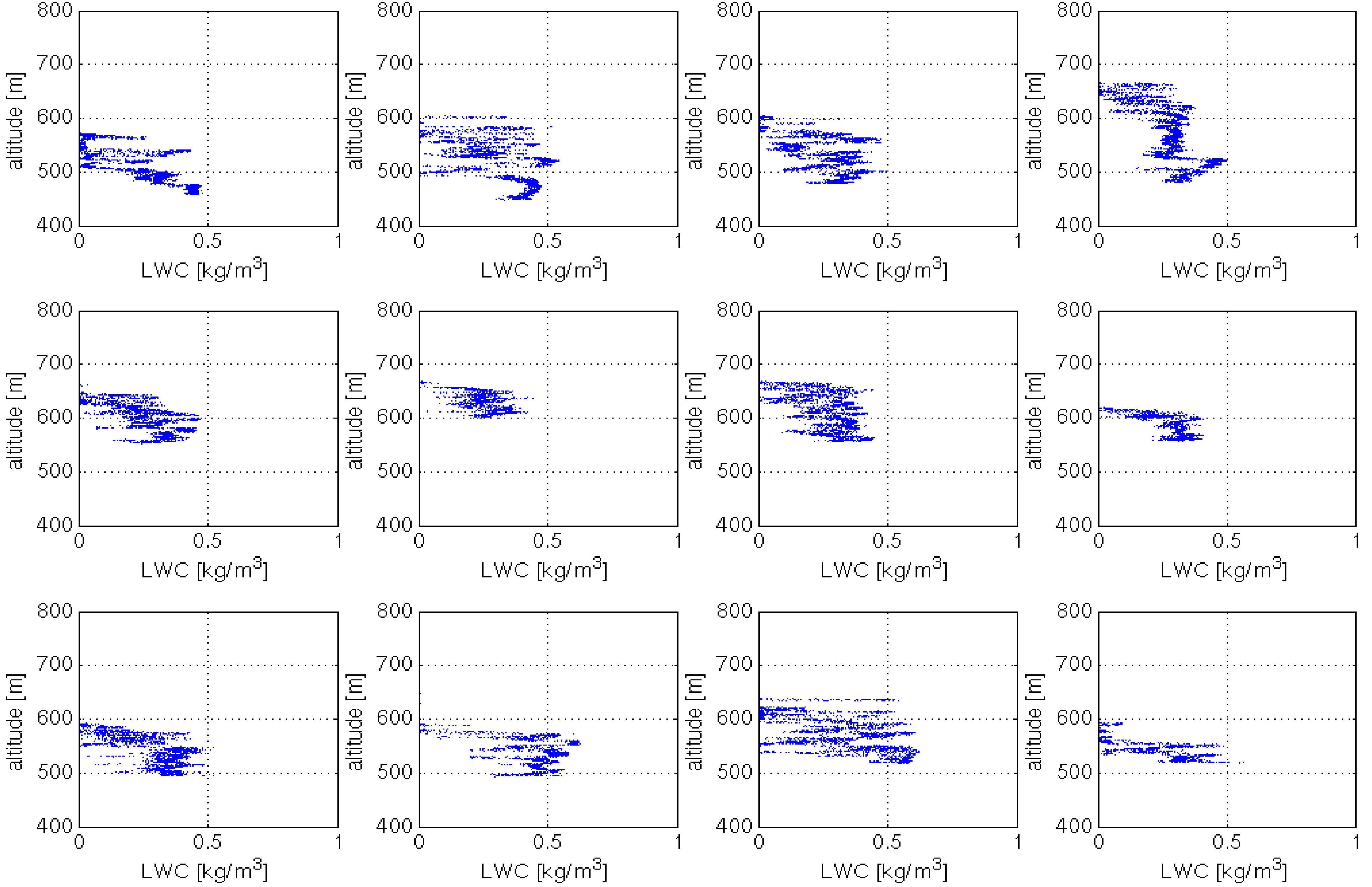


TOF 13: PDF's of LWC and droplet concentrations (courtesy Partick Chuang)

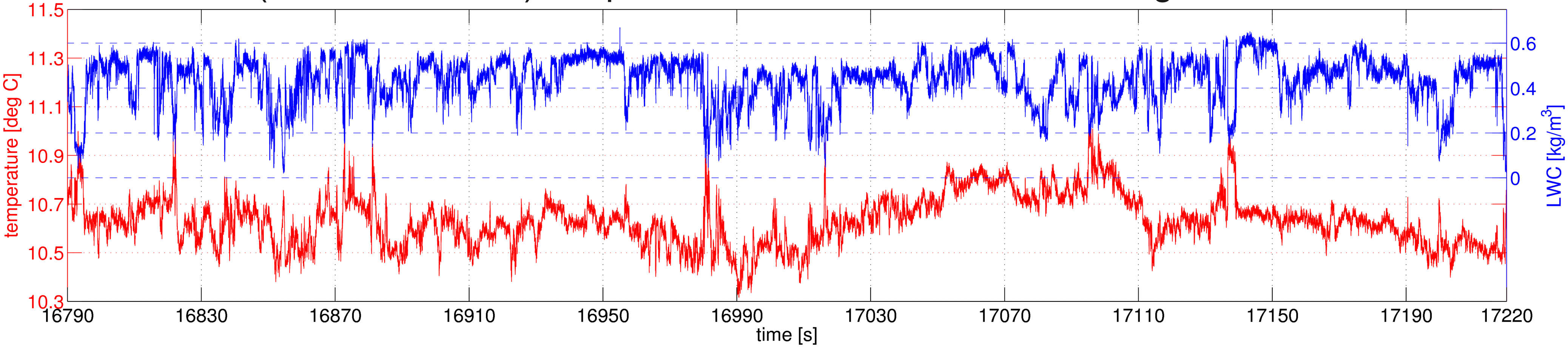


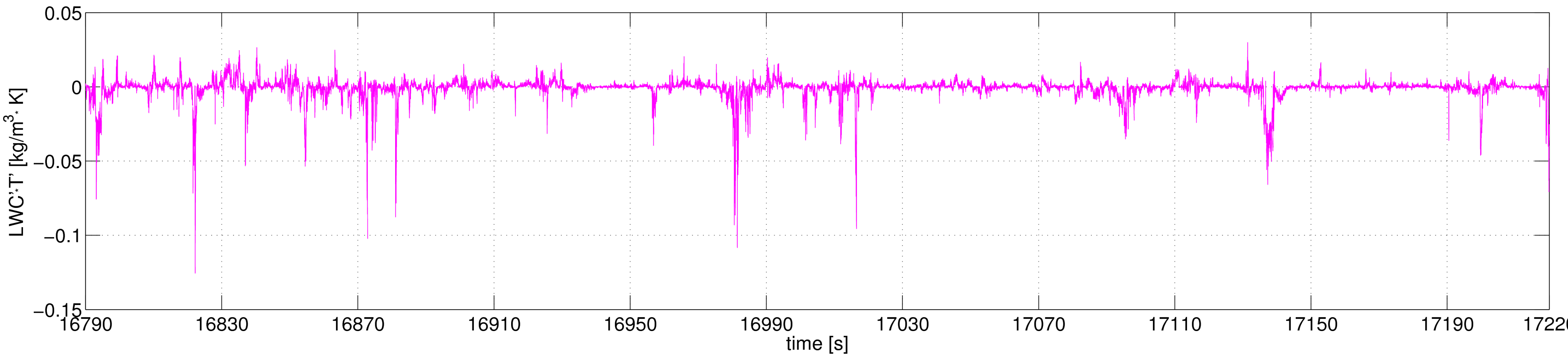


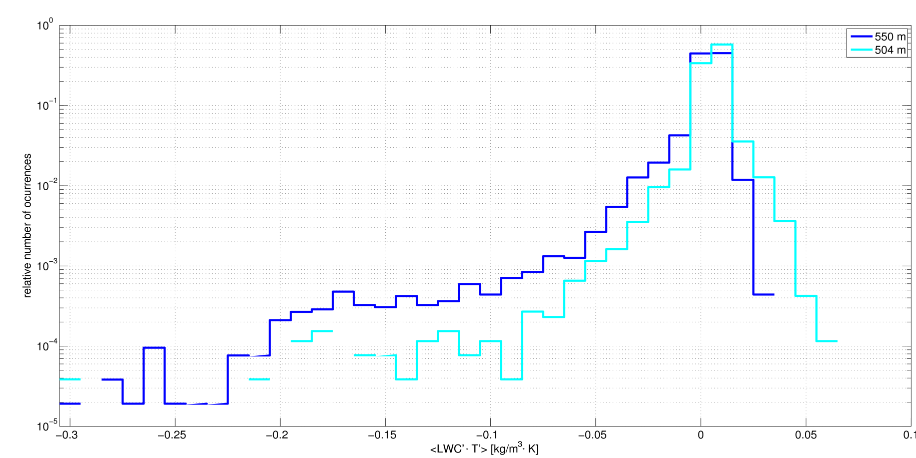
TOF13: LWC on ~1.2m long samples (40Hz):
Stronlgly diluted, no maximum on the top.



TOF13: 100Hz (55cm resolution) temperature and LWC on horizontal leg inside cloud deck







Upper panel: 100S/s records of LWC and T and correlations <LWC' T'> on a horizontal leg inside the cloud at the altitude of 550m.

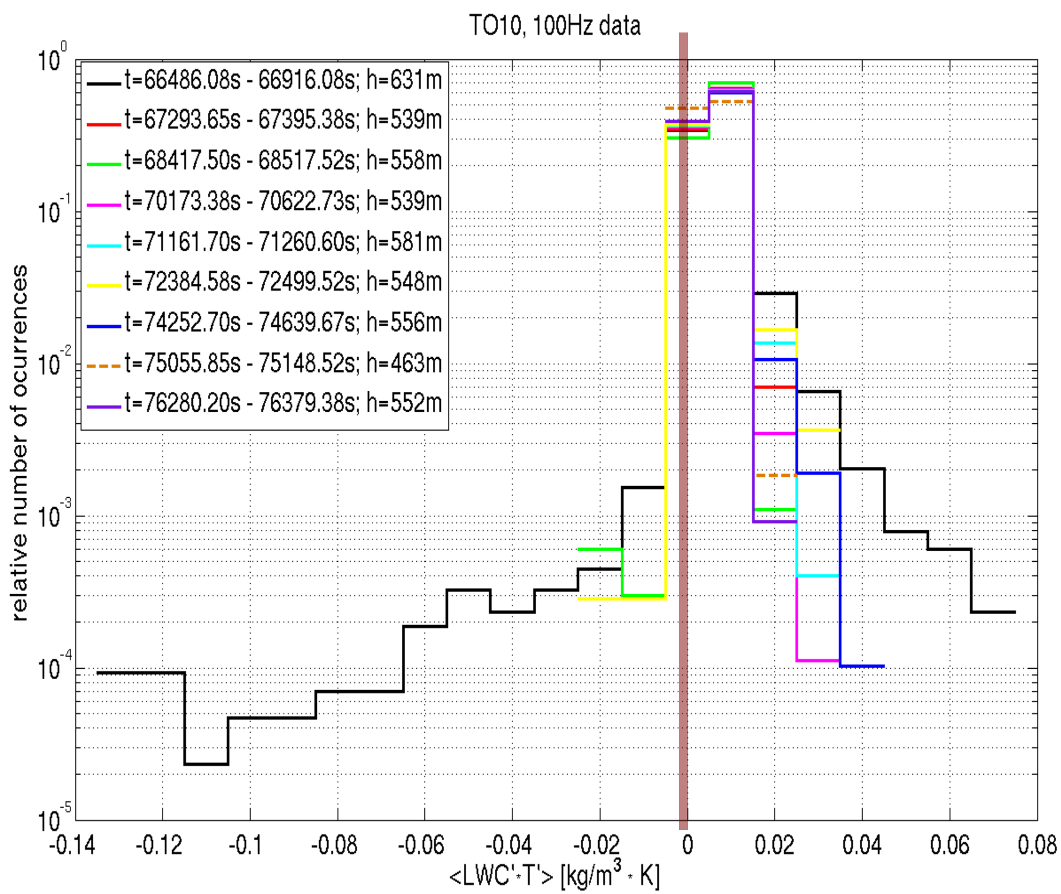
Right panel: histograms of <LWC' T'> at altitudes of 550m and 504m.

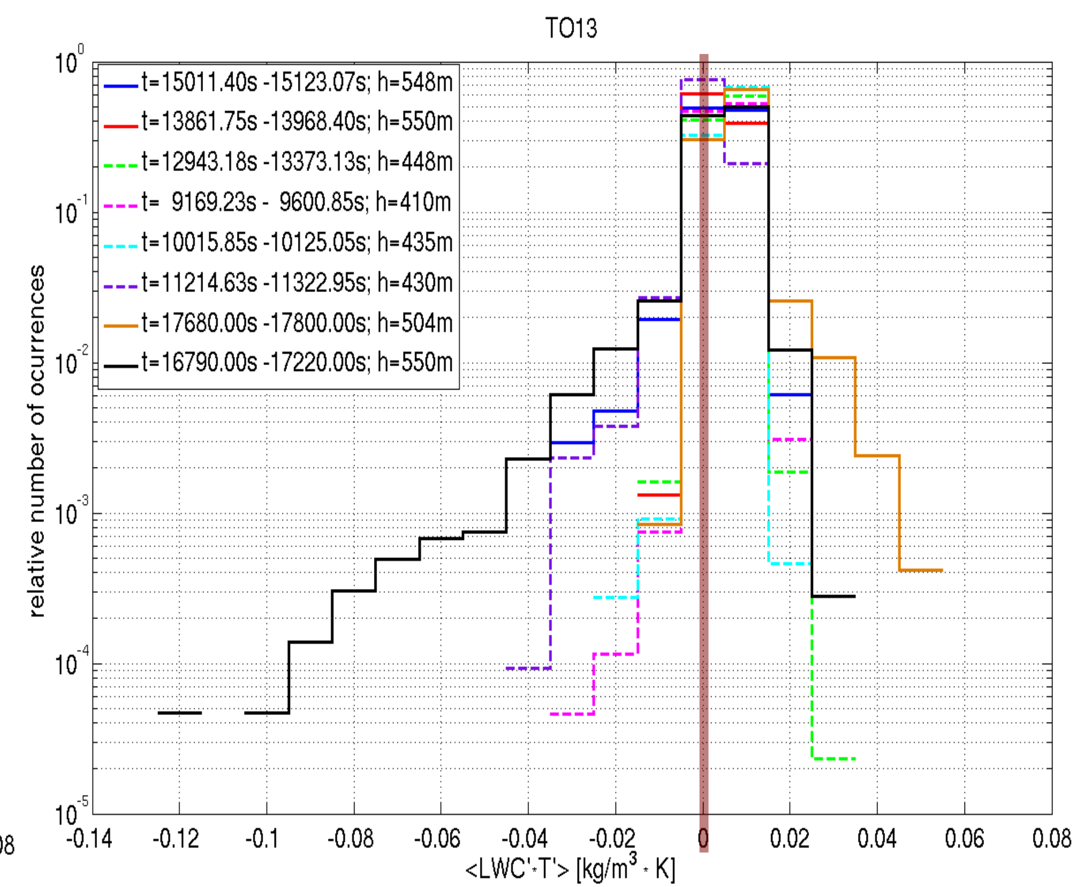
Positive buoyancy in cloud holes!!!???

Histograms of <LWC' T'> in horizontal legs **inside** the Stratocumulus deck.

LWC'<0 - depleted LWC
T'>0 - temperature excess

TO10 – left – negative buoyancy in cloud holes
TO13 – right – positive buoyancy in cloud holes??? on some legs

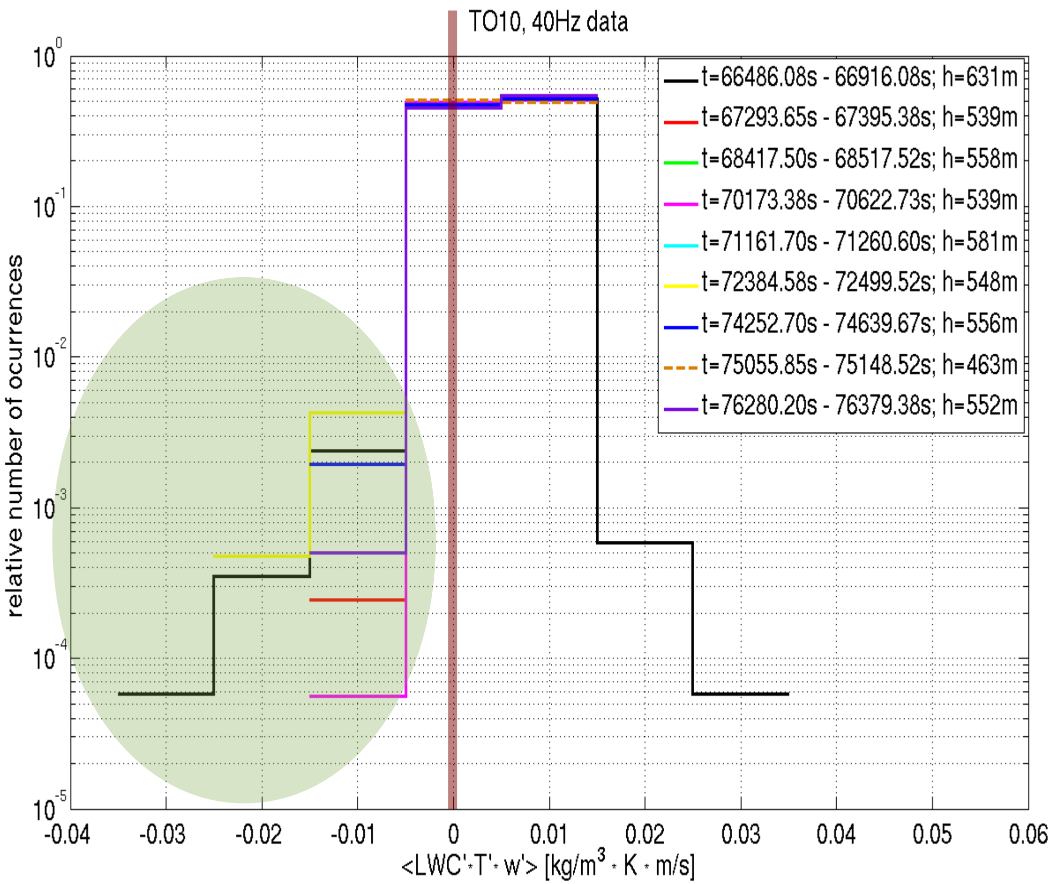


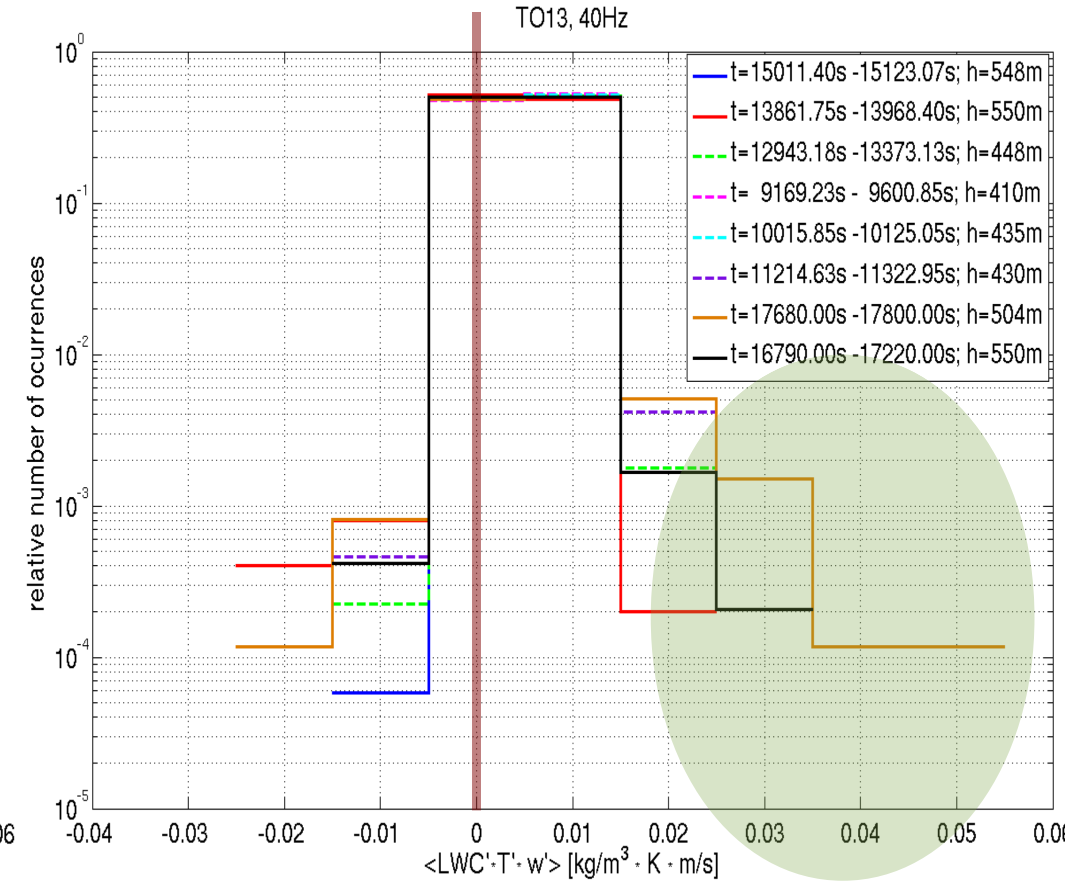


Histograms of <LWC' T'w'> in horizontal legs **inside** the Stratocumulus deck.
TO10 – left
TO13 – right

W' <0 -downdraft

How important are tails of the distribution?
Do they really represent entrainment events?





Summary

High-resolution measurements in POST allow to investigate fine-scales of mixing at SC top.

Preliminary data analysis suggests different dynamics of entrainment/mixing in two investigated cases:

TOF10 – typical case - narrow Entrainment Interfacial Layer (EIL), capped with strong inversion and thin shear layer.

TOF13 – diluted case - decreased LWC and total water in the cloud top region, capped with the weaker inversion and a thick layer of relatively weak shear and increased humidity.

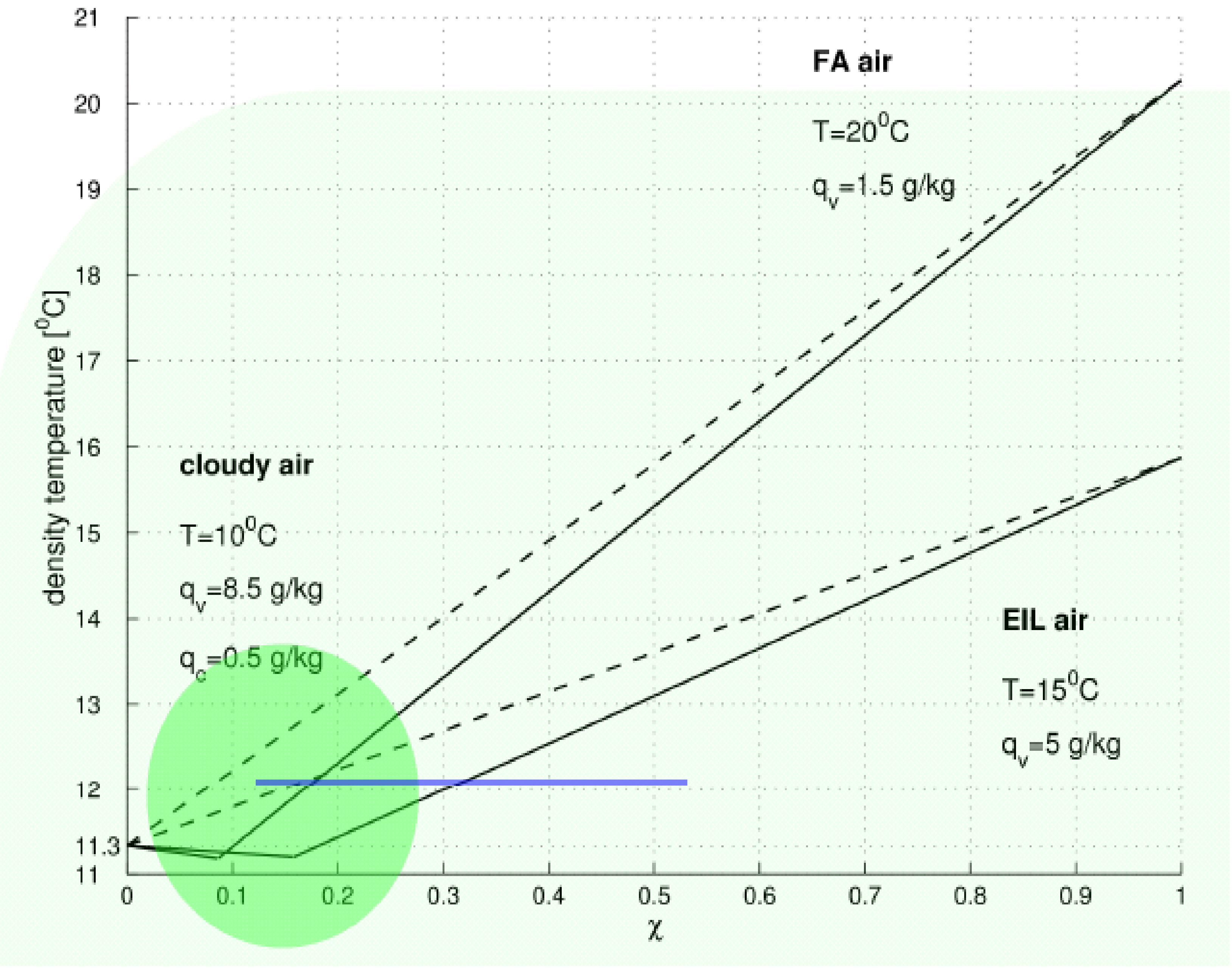
Correlations <T' LWC'> and <T' LWC' w'> suggest negative buoyancy in cloud holes in TOF10 (like during DYCOMS II) and a positive one in in TOF13.
It suggests different mechanisms of mixing in these cases.

Needs more investigation.....

POSSIBLE EXPLANATION

Mixing diagram showing buoyancy (density temperature) of mixture of cloud and free-tropospheric air (upper lines) and cloud and EIL air (lower lines).

Negative buoyancy – below the blue line.




POST (Physics of Stratocumulus Top)
Data from POST available at http://www.eol.ucar.edu/projects/post/