Analysis of antenna position measurements and weather station network data during the ALMA Long Baseline Campaign of 2015

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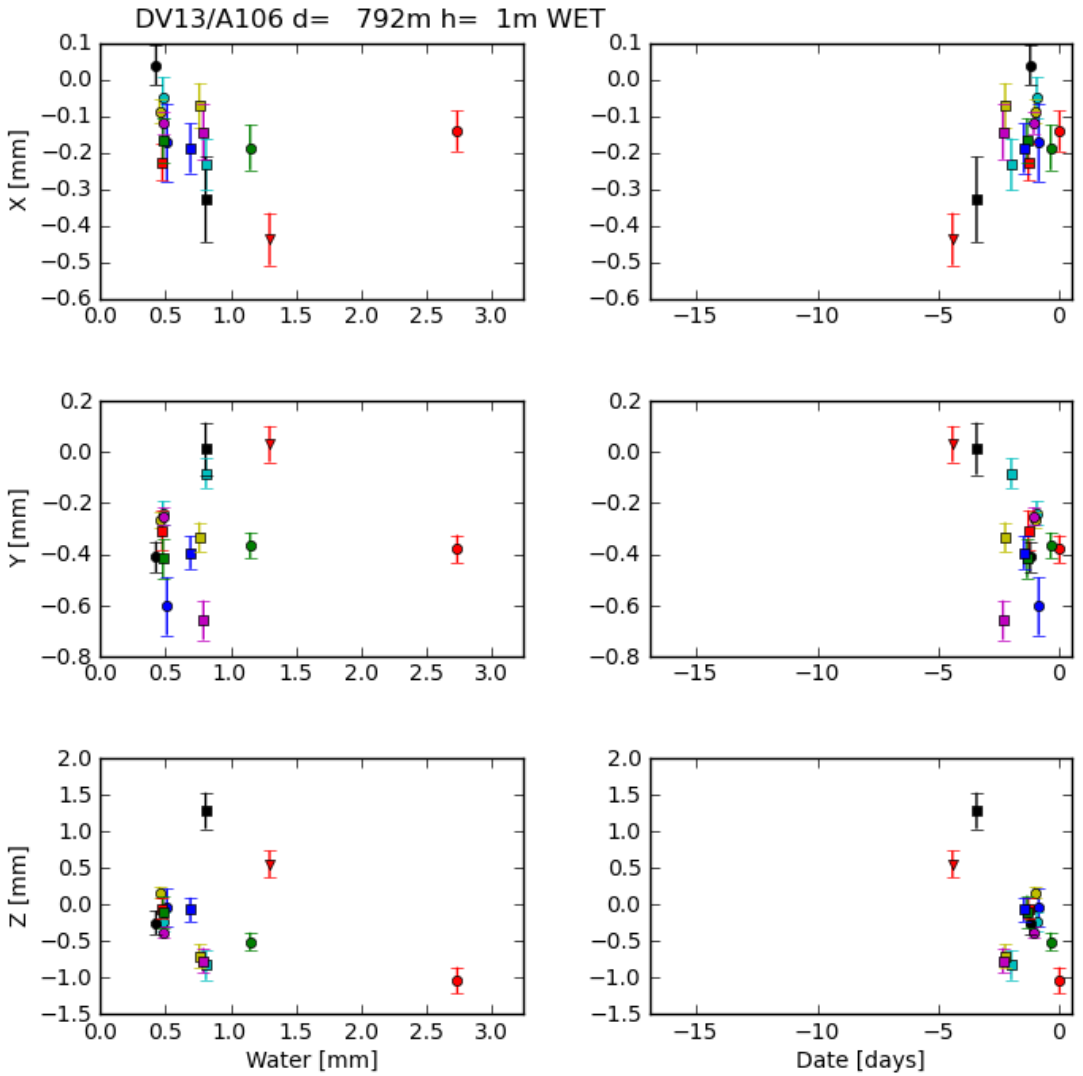
Context

- During initial Long Baseline Campaign (2014), the antenna position solutions derived by TelCal varied significantly with time and/or weather conditions (several mm on distant pads).
- Robert Lucas explored the full wet path option of tc_antpos applied to the raw datastream (i.e. no phase correction) to determine the geometric antenna positions most consistent with the measured delays across the sky, independent of the current wet path.
- When the antenna positions determined in this manner were applied to the SDP81 Science Verification data, it eliminated the need for a single phase-only self-calibration correction per execution to reach the best image quality.
- Therefore, the plan going into the 2015 LBC was to use the "uncorrected, full wet path" option, but also gather additional (daily) weather data on the dry term.

TelCal results for DV13 (A106) - Oct 1-15, 2015



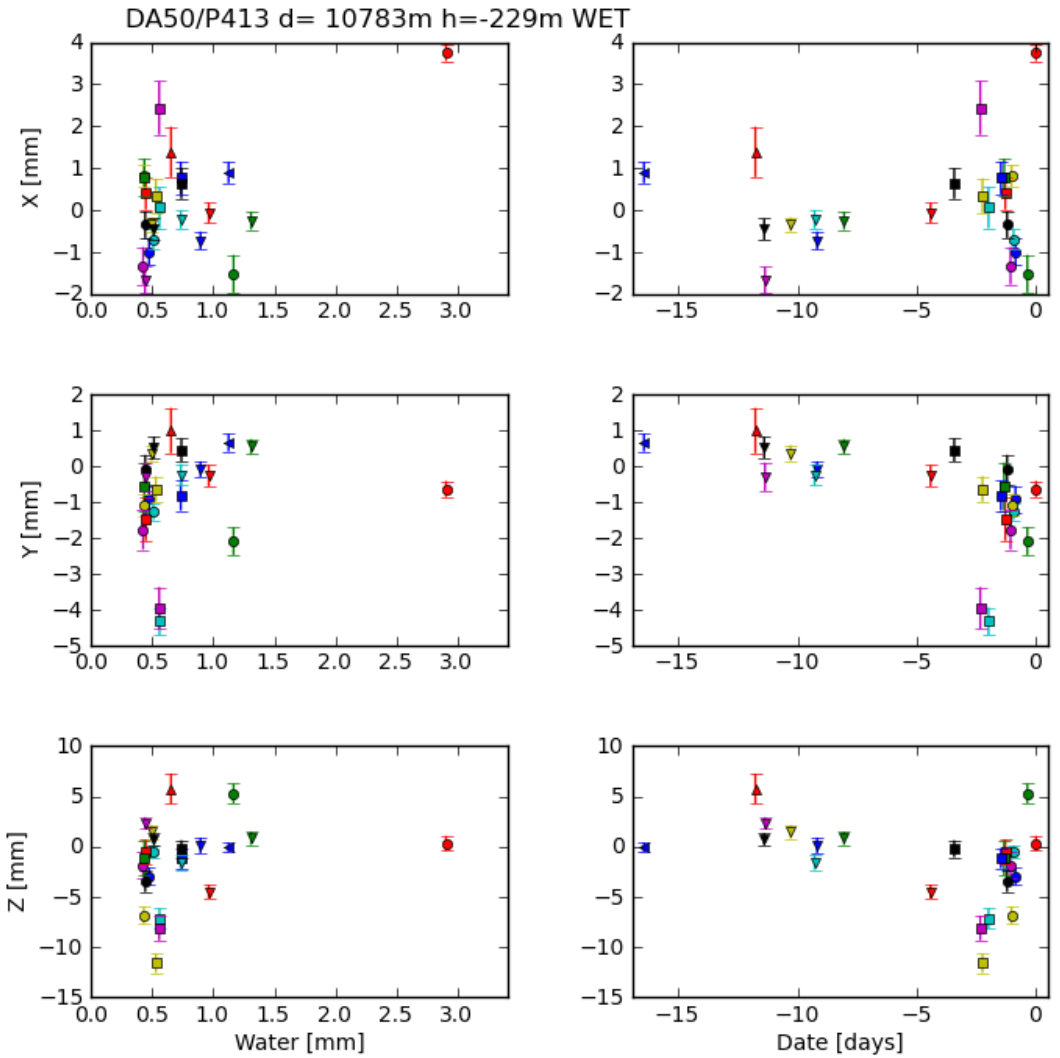
Antenna near array center.

RMS ~ 100 microns in X,Y
400 microns in Z

(ALMA spec = 75 microns)

Axis	Mean (mm)	RMS (mm)
X (east)	-0.136	0.093
Y (north)	-0.291	0.144
Z (up)	-0.214	0.422

TelCal results for DA50 (P413) - Oct 1-15, 2015



Antenna near end of P branch.
RMS ~ 1200 micron in X,Y
3400 microns in Z

Dispersion does not correlate simply with PWV or time

Note: y-axis scale change on Z

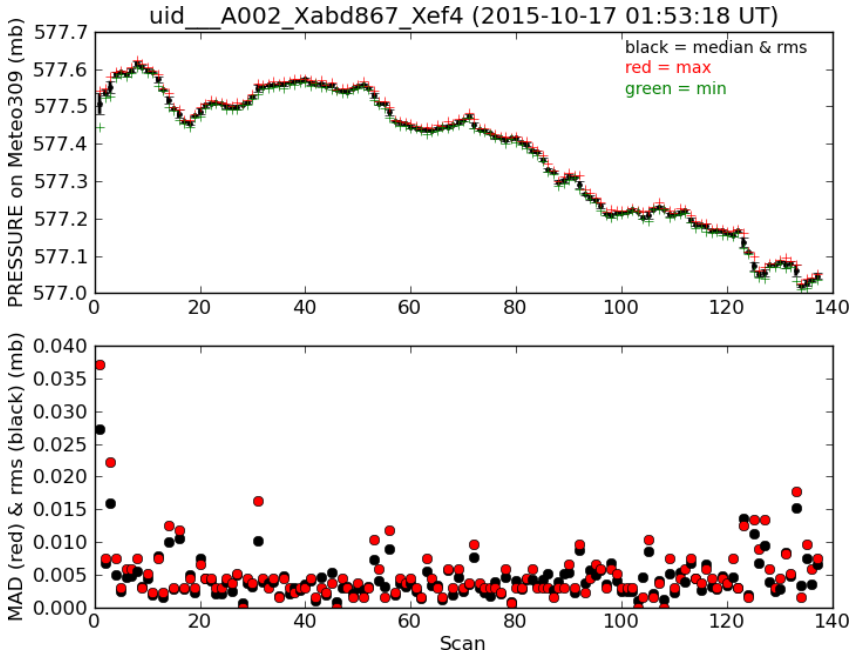
Axis	Mean (mm)	RMS (mm)
X (east)	+0.144	1.289
Y (north)	-0.416	1.068
Z (up)	-0.999	3.395

Weather station network (Oct. 2015 – Jan. 2016)

7 stations, each consists of:
* Vaisala PTU300 (T, P, RH)
* Vaisala WMT52 (wind speed and direction)

Pressure sensor is class A:

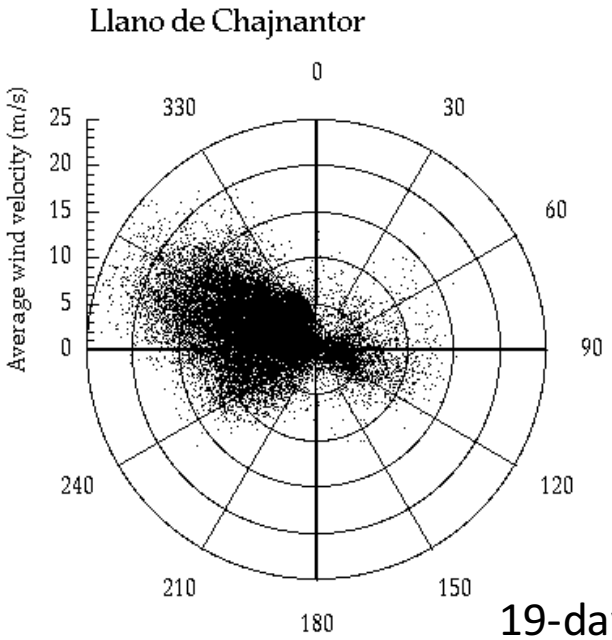
- repeatability and hysteresis are both +- 0.03 mb
- Linearity = +- 0.05 mb
- Total rss absolute accuracy is 0.10 mb
- Readback “noise” on the datastream is 0.01 mb
- Settling time ~ 2 seconds (100% response)



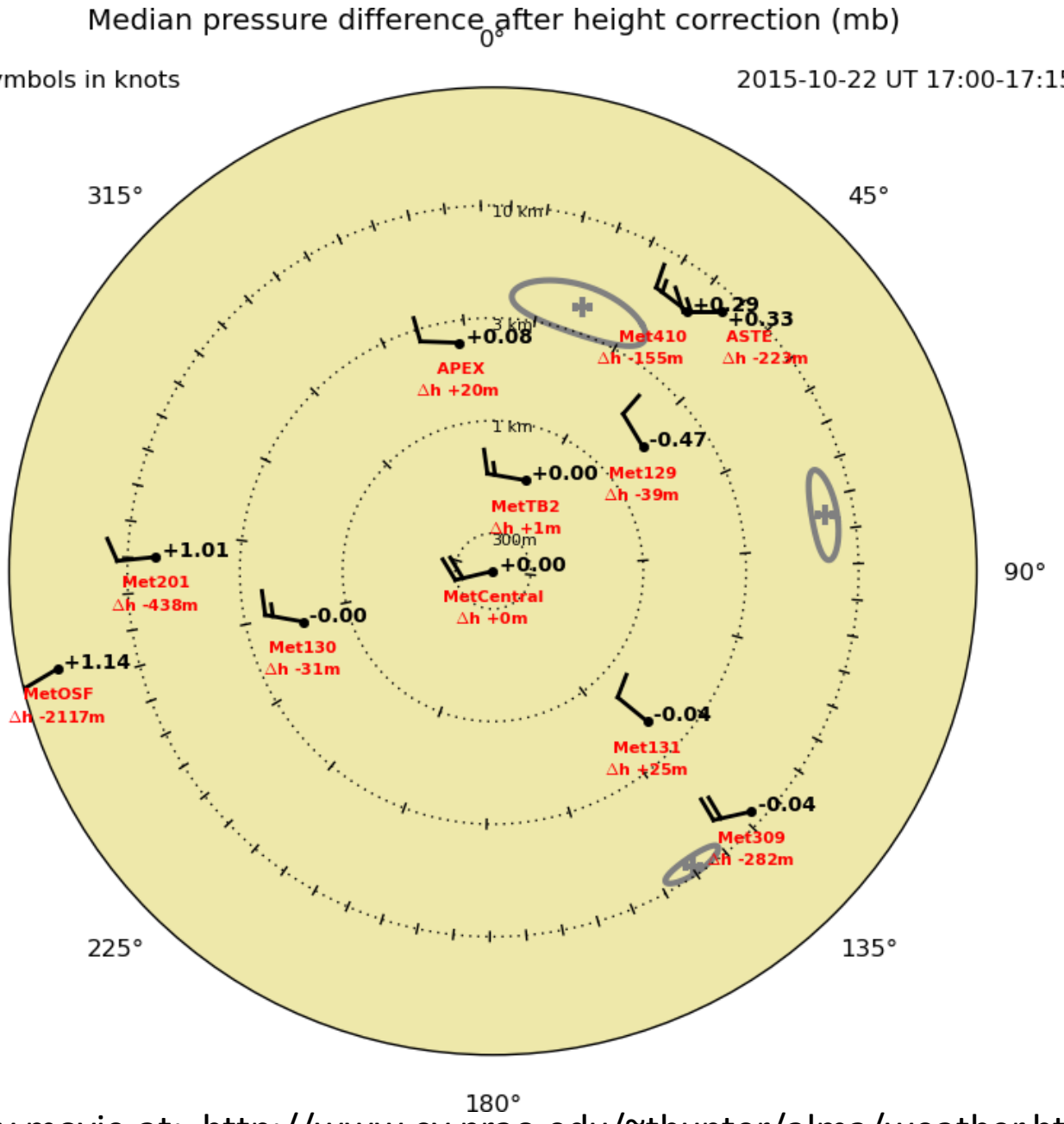
Weather station network
(as of October 2015)

7 stations, each consists of:
* Vaisala PTU300 (T,P,RH)
* Vaisala WMT52 (wind)

Figure 5 from
ALMA Memo 322:
S. Sakamoto et al.



Wind statistics
from 1997



19-day movie at: http://www.cv.nrao.edu/~thunter/alma/weather.html

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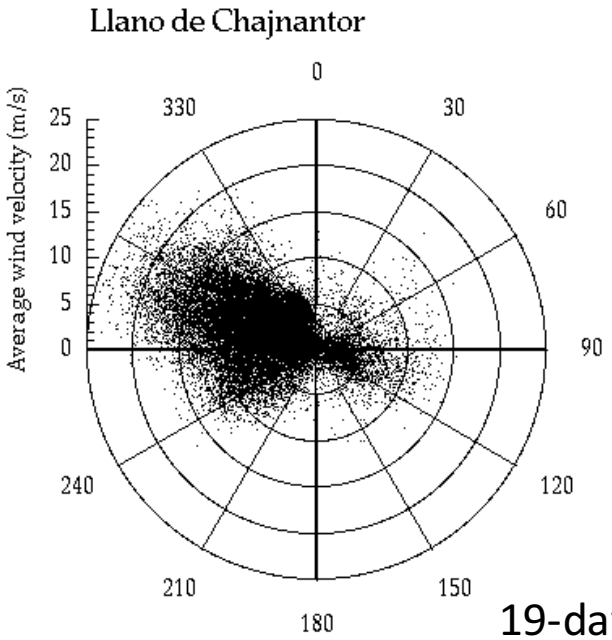

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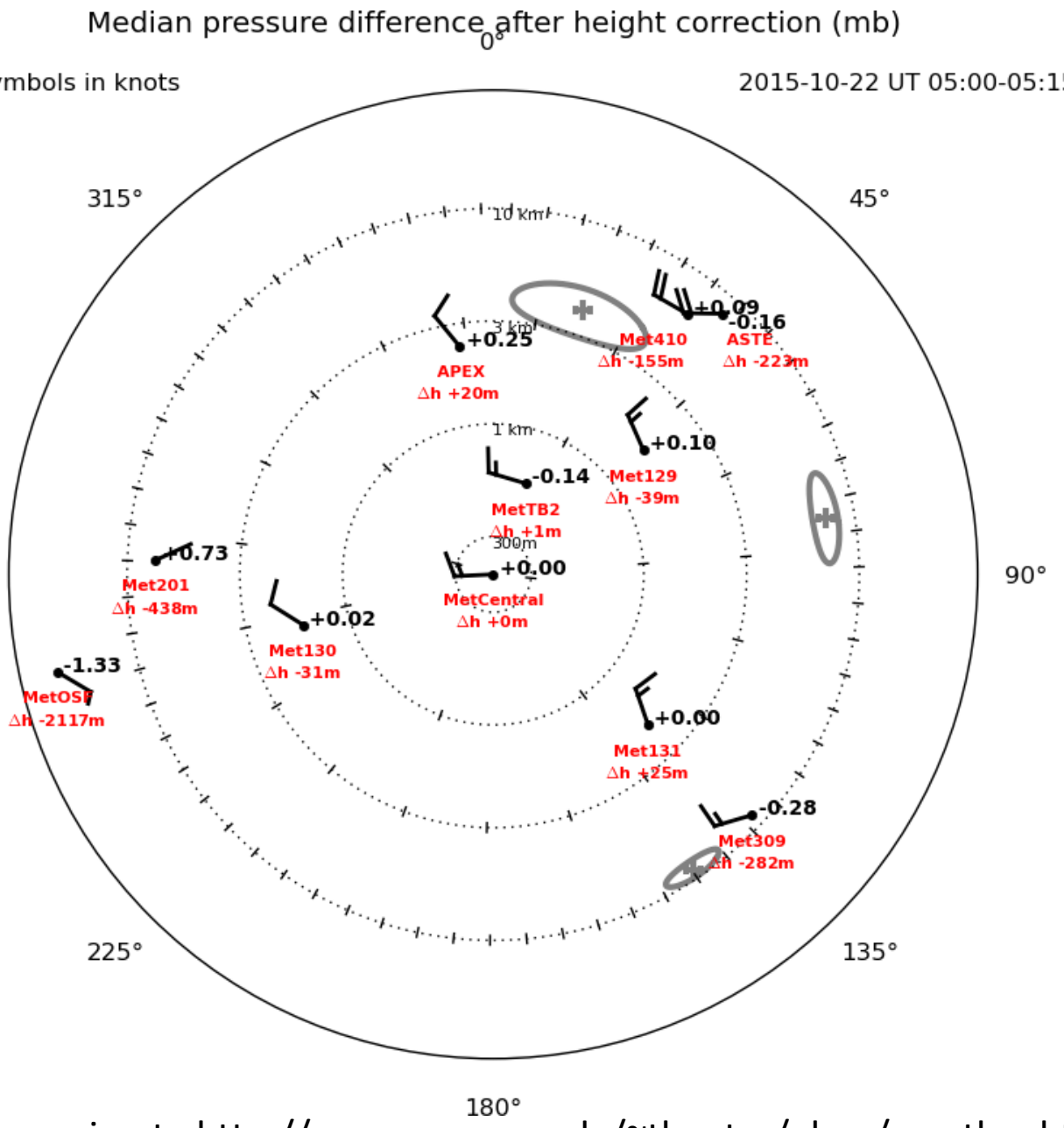

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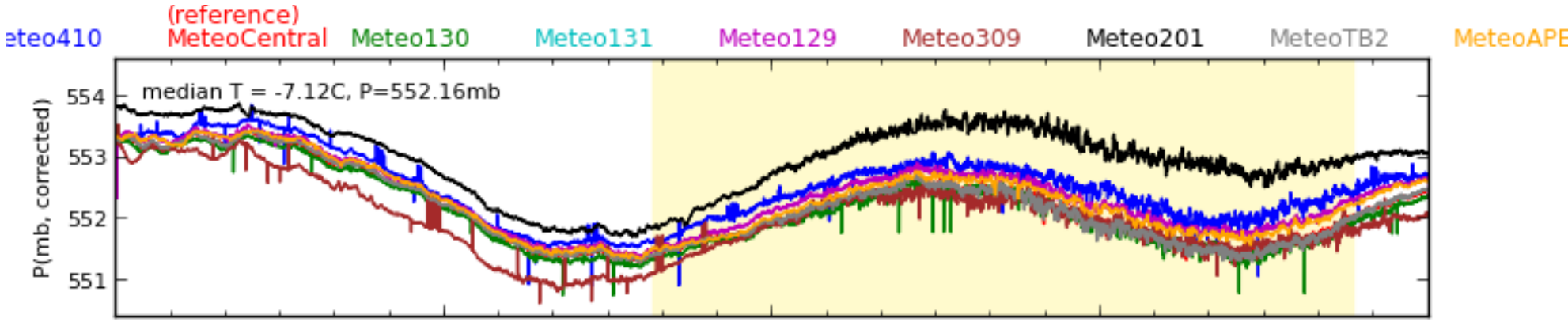
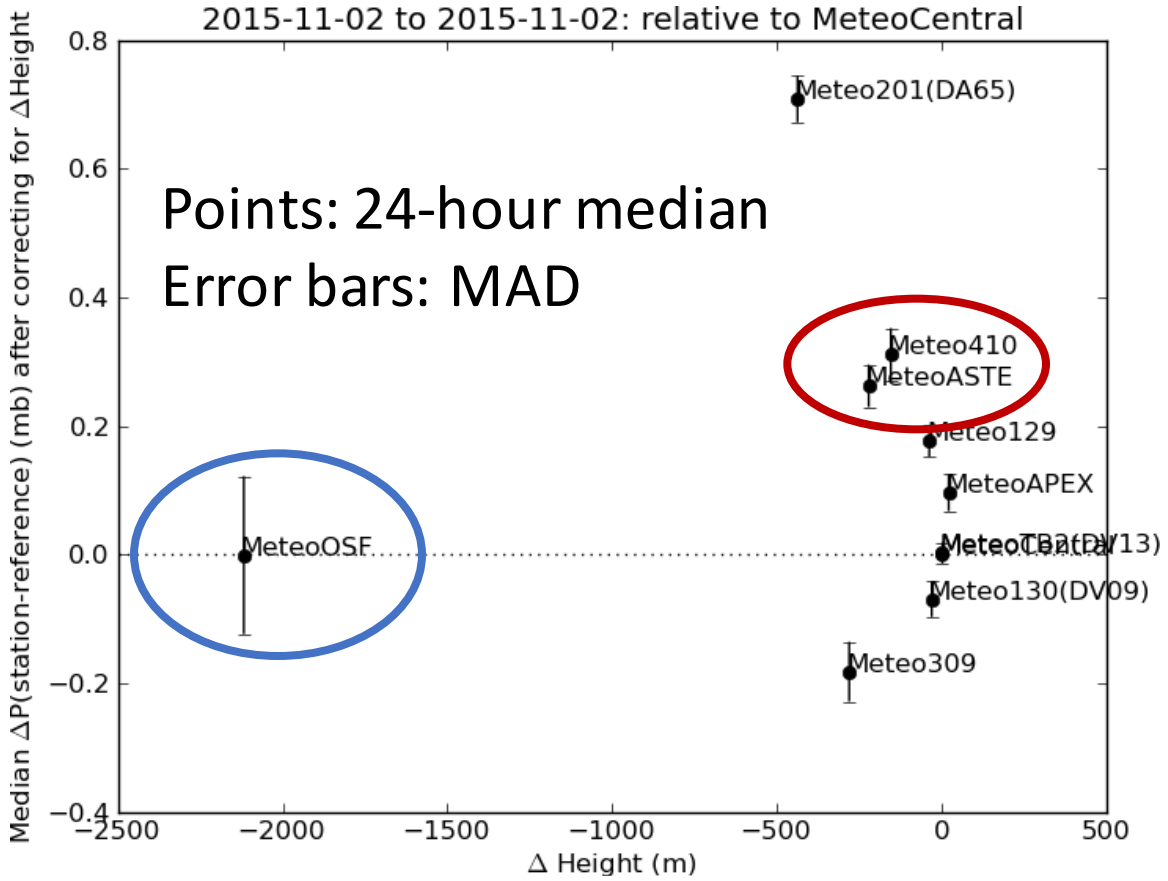
Pressure over 1 day

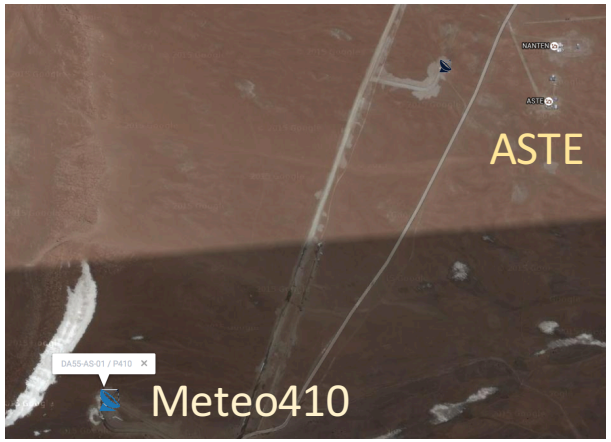


Hydrostatic equilibrium correction factor applied for height difference: $(1-0.0065\Delta H/T)^{5.257}$

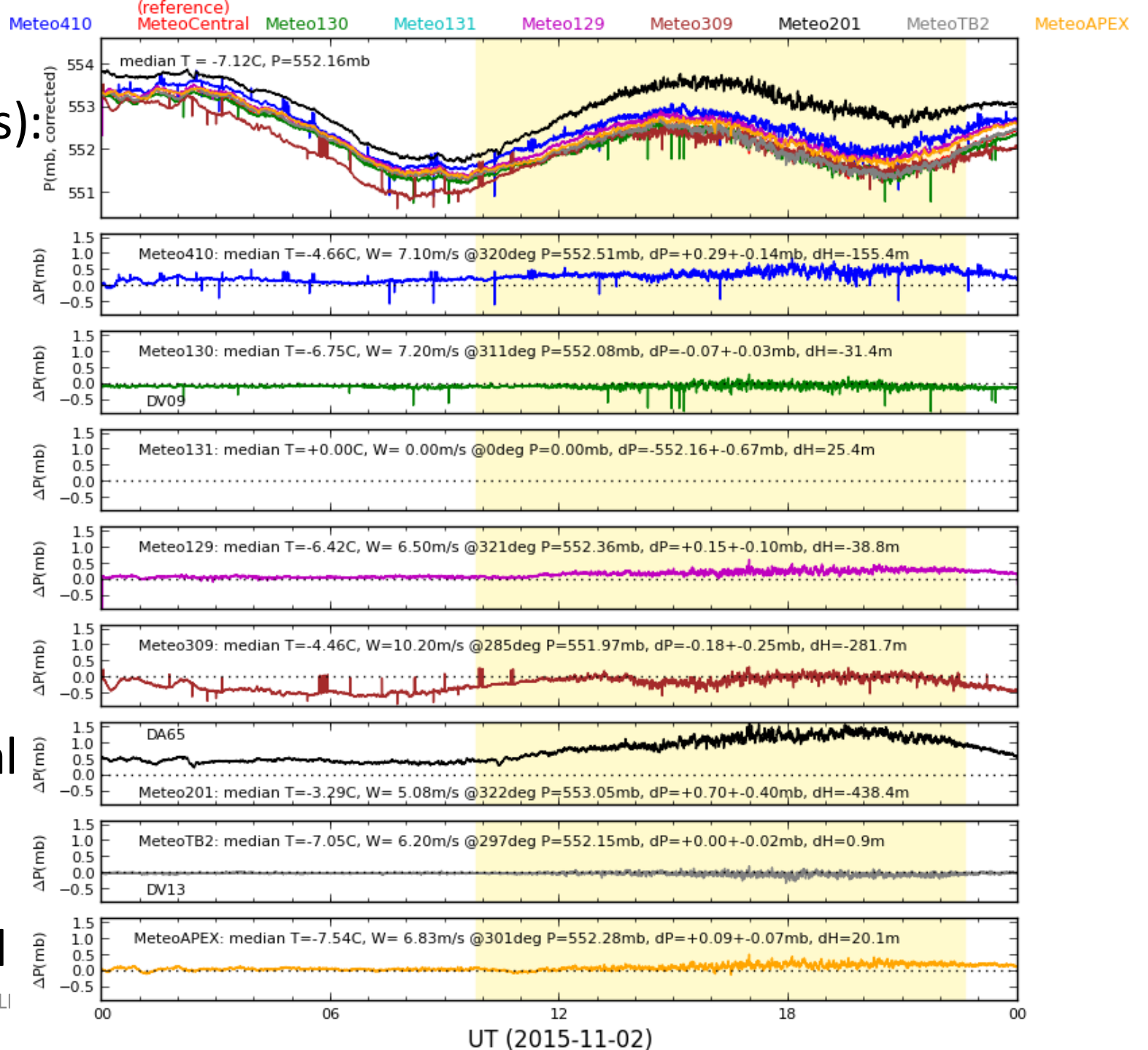


Note 1:
MeteoOSF lies at the expected pressure

Note 2:
good agreement between Meteo410 and ASTE (1.85 km)

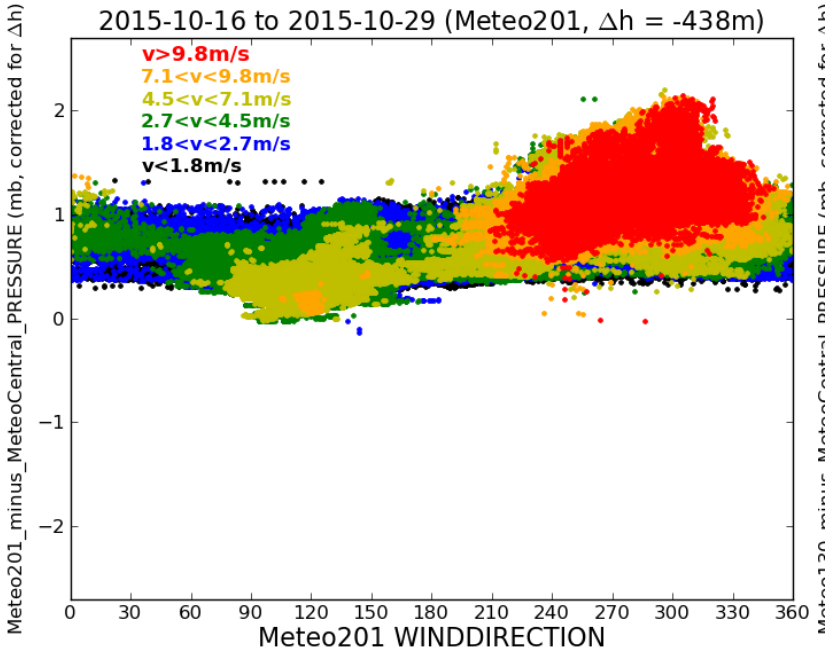


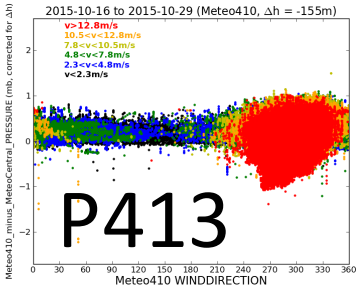
Pressure over 1 day (all stations):

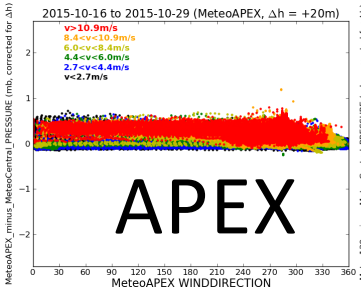


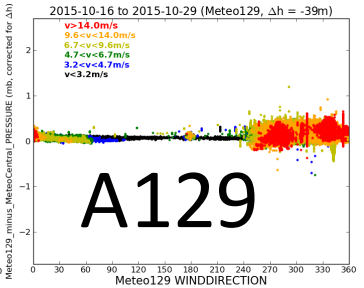
ALI

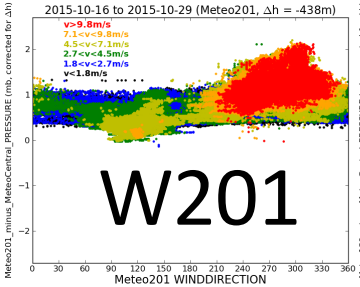
ΔP vs. wind direction

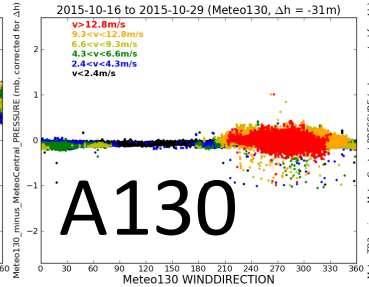


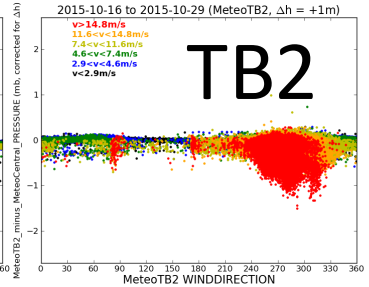


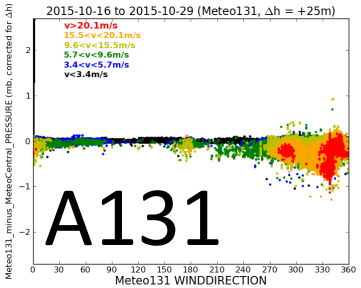


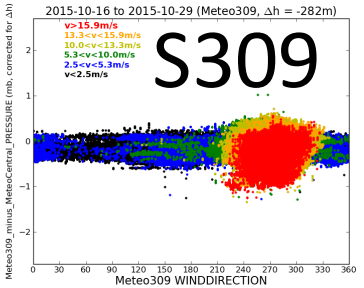






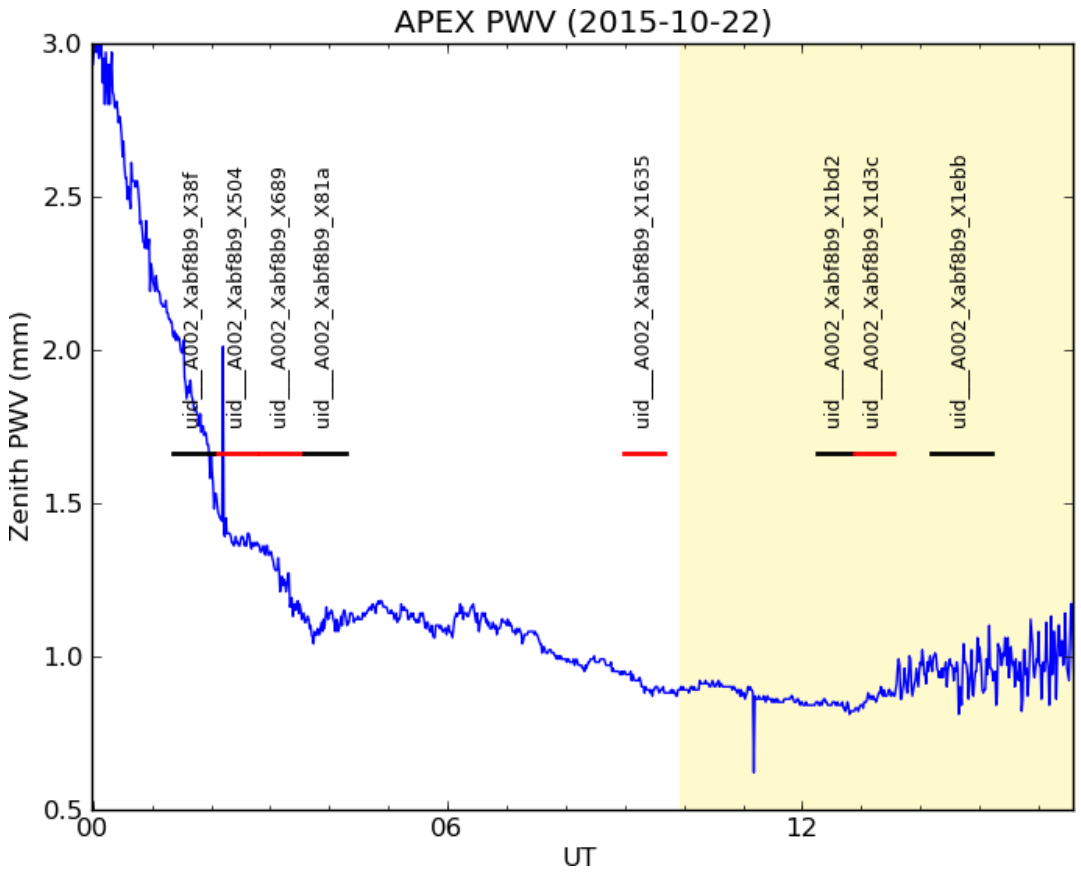


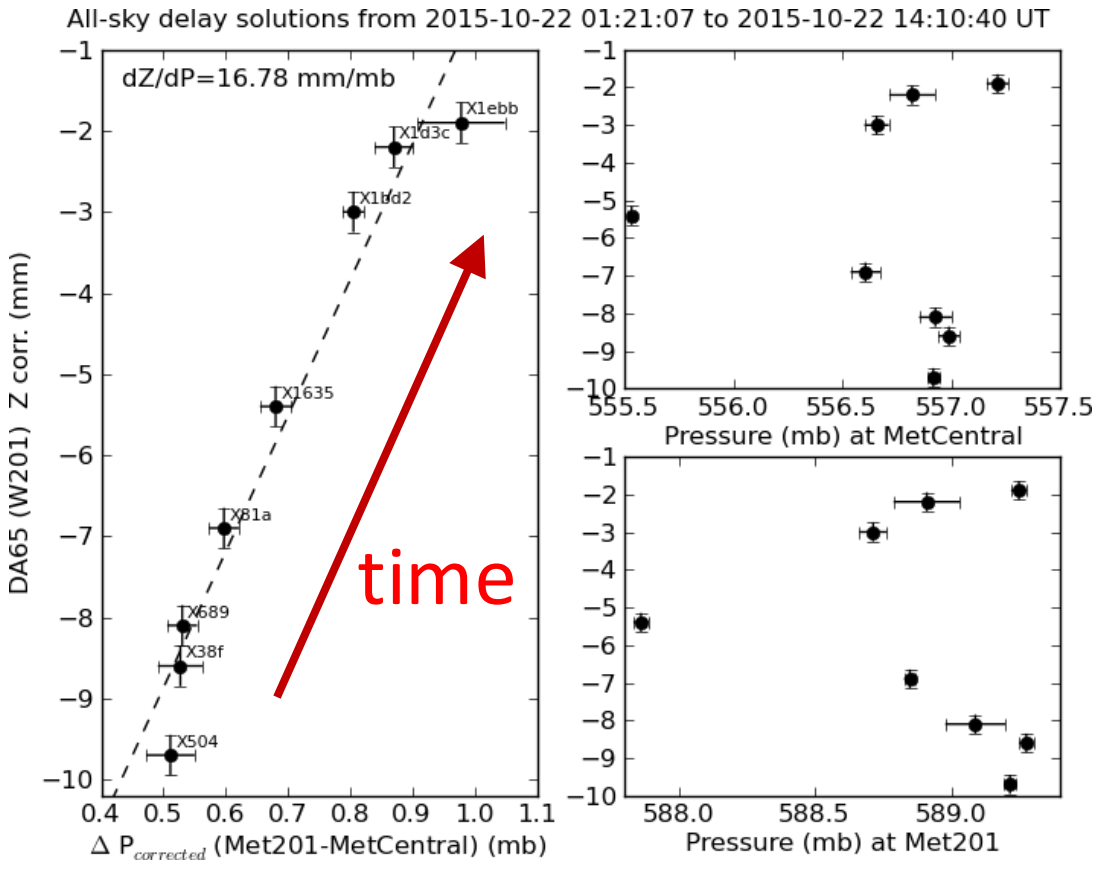




Reversal of wind leads to reversal in differential pressure at W201 / DA65

Once upon a night when PWV was steadily dropping





We see a trend of 17 mm/mb, but dry air should be only 2.3mm/mb!

Applying this correction on other nights simply moves the solutions (does not reduce scatter

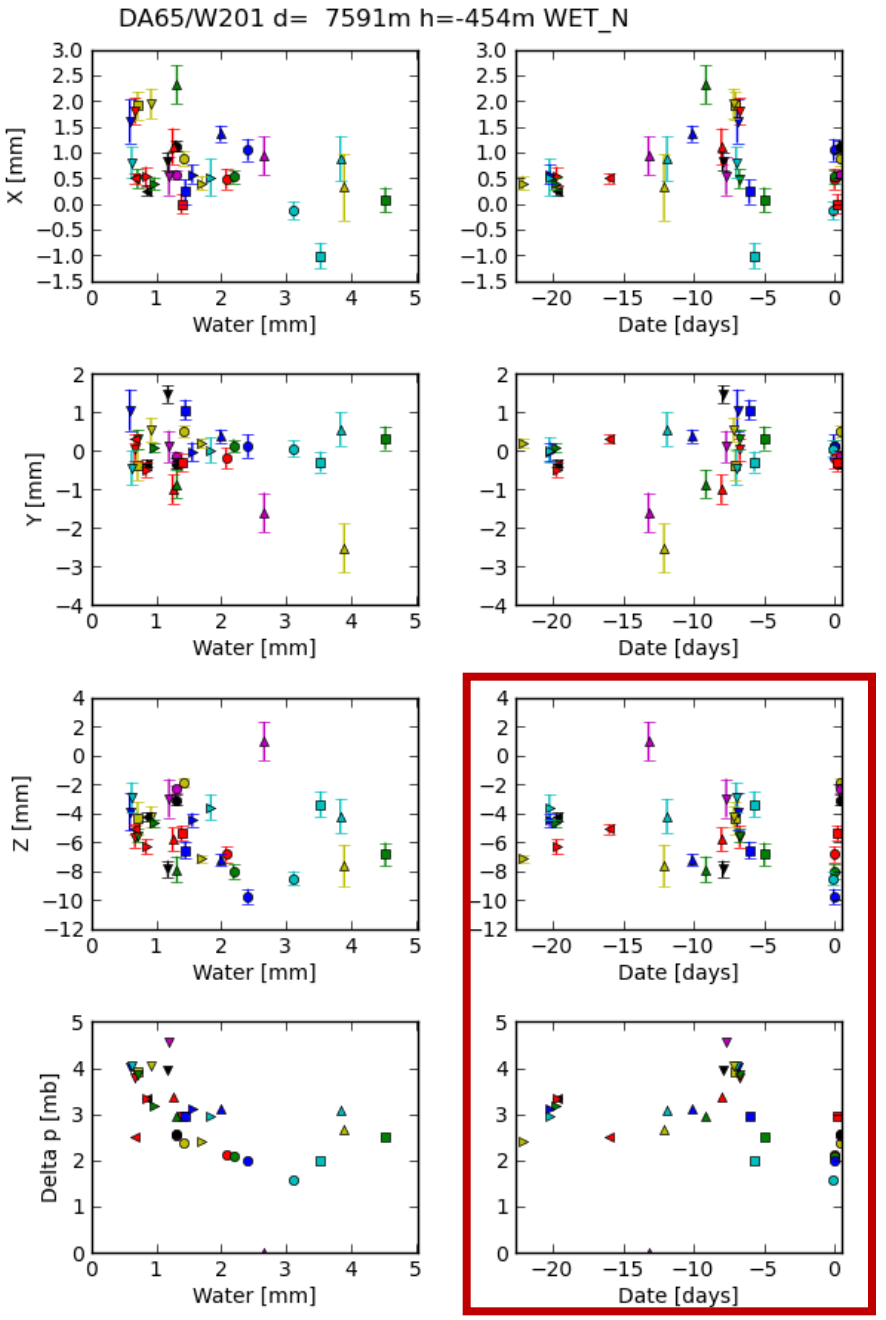
Correction for partial pressure of water

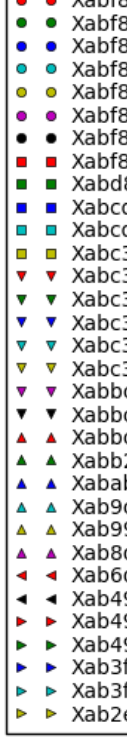
ALMA delay server currently corrects total barometric pressure (which includes partial pressure of water) from reference station to apply to each pad by its relative height.

We tried separating the water pressure (offline):

1) Remove partial pressure at reference station (PWV)
2) Scale the dry term for height difference
3) Add the partial pressure at the target pad (PWV)
4) Compute a new difference in total pressure (Δp)

The Δp pattern appeared promising, similar to Z correction on D65. But the trend did not repeat on other distant antennas, and the dispersion was not reduced. So we did not pursue further.





X mean 0.620 rms 0.48

Y mean 0.051 rms 0.44

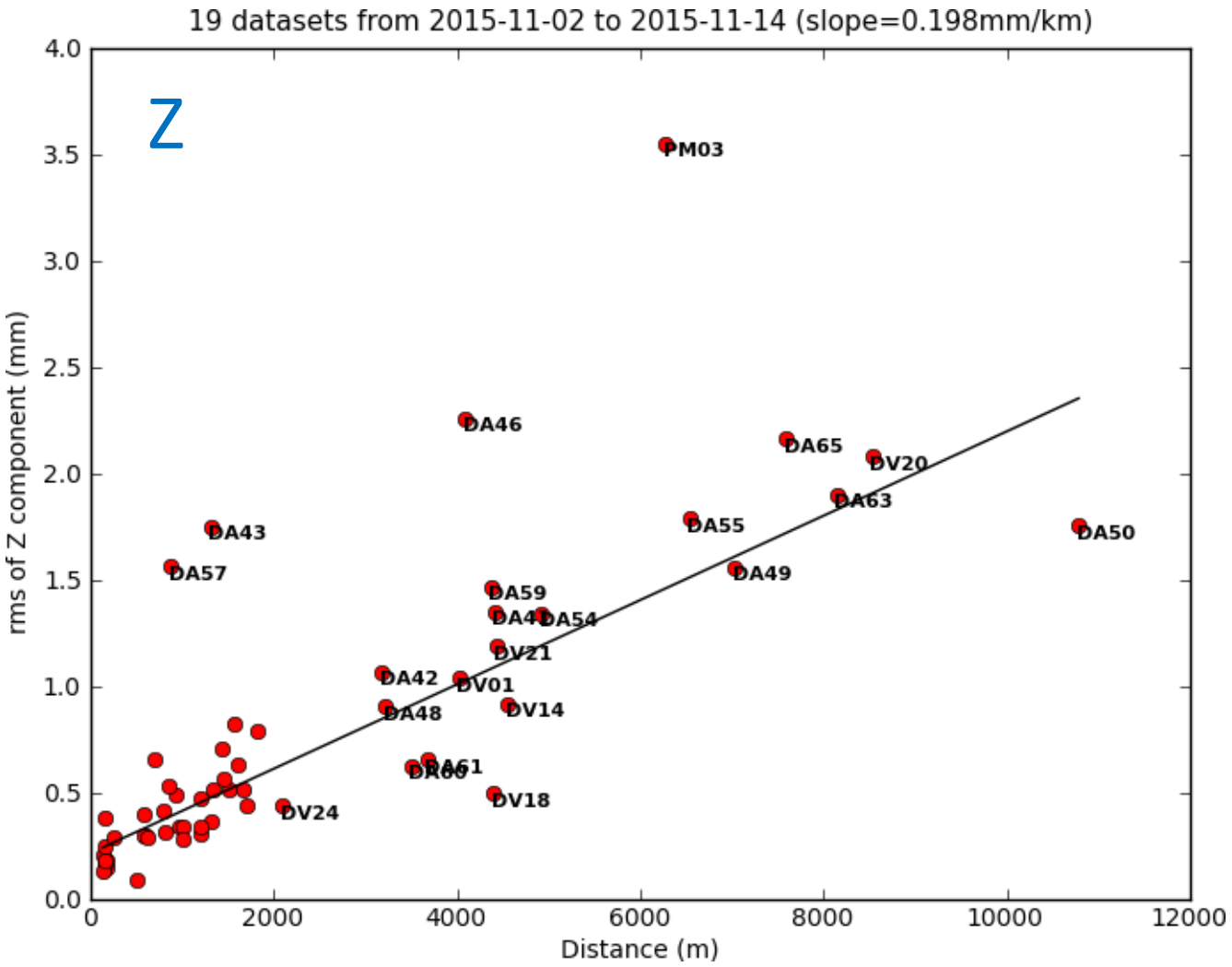
Z mean -5.133 rms 2.09

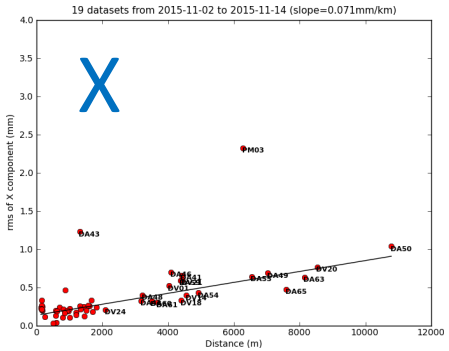
Position RMS vs. distance from center of array

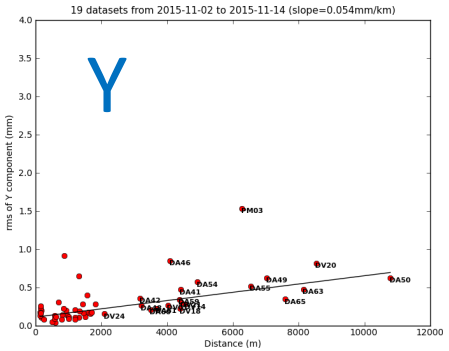
Averaging over the October datasets, we made an initial position update on Oct 24, followed by 19 all-sky runs in early November. Still see a large dispersion in Z.

Linear fit ~ 0.2 mm / km

Effect of baseline error goes as the error times sin(separation angle) to the phase reference quasar, so keeping this angle < 3 deg is critical, to reduce the effect by a factor of 20.



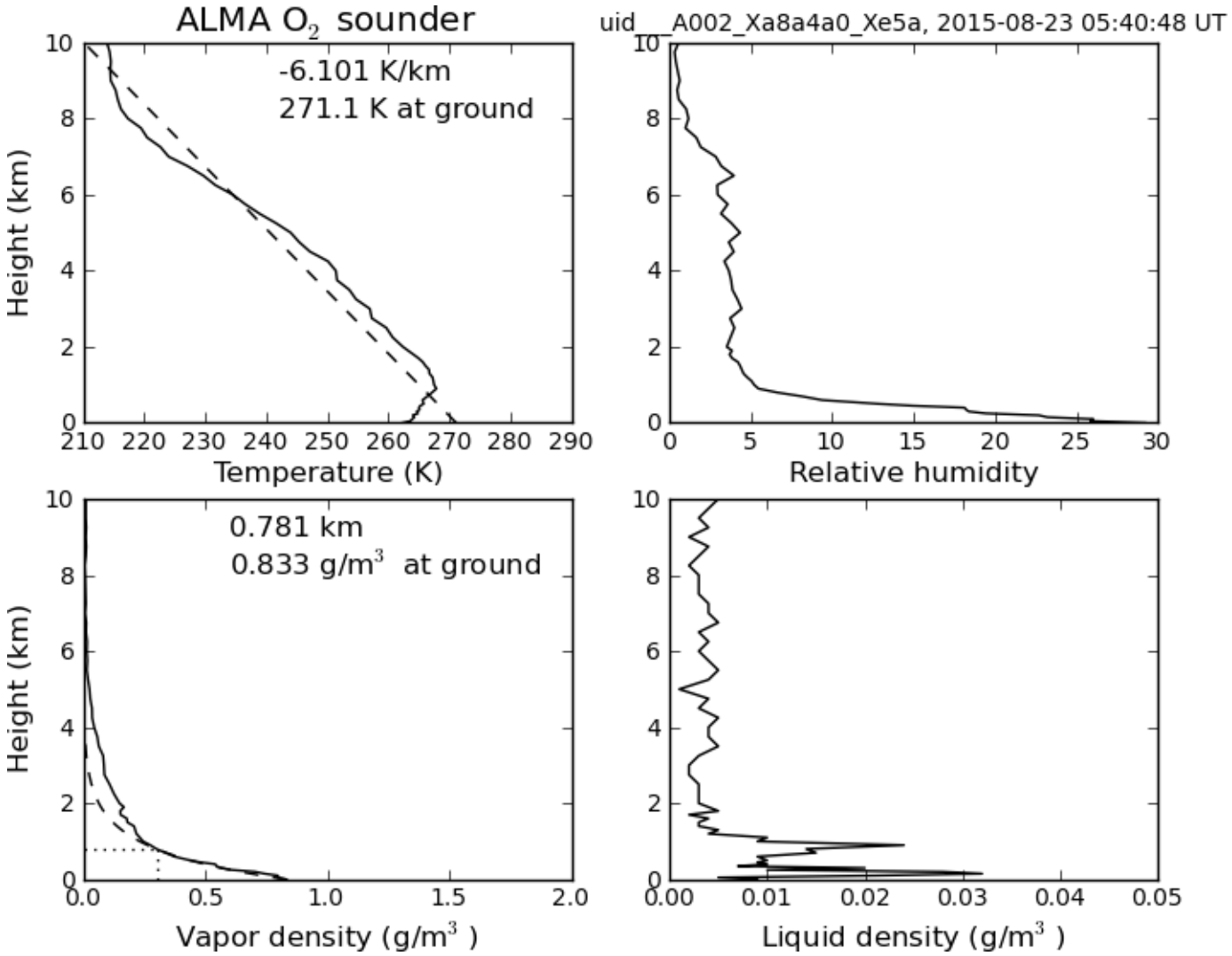




Inadequate model of water vapor?

In computing the wet path, tc_antpos uses a fixed linear lapse rate for temperature (6 K/km) and a single scale height for vapor density (1 km), which is only an approximation, as shown by the Oxygen sounder.
(Access: ssh login.alma.cl then ssh oxygen@vesta; cd data)

Two new parameters of tc_antpos allows one to specify these values (ICT-6267). Not yet attempted….



4-day movie at: http://www.cv.nrao.edu/~thunter/alma/o2sounder.html

Future directions

- Sort out WVR coupling efficiencies and re-run tc_antpos on LBC data
- Use temperature lapse rate and water vapor scale height measured by the Oxygen sounder when running tc_antpos (new parameters available since ICT-6267)
- Do these improvements reduce the scatter? If true, then inaccurate modeling of water may be a cause of inconsistent positions
- Populate more of the outermost pads at once, particularly on the W-branch, to be able to solve for positions with shorter baselines. Might bring systematic error further above the natural scatter.
- Insert mini all-sky runs into science executions?