

An aerial photograph showing a vast expanse of white, puffy cumulus clouds over a deep blue ocean. The clouds are dense and cover most of the frame, with some darker blue patches of water visible between the cloud masses. The lighting is bright, highlighting the texture of the cloud tops.

Water Vapor Monitor Status and Plans

Tom Roellig

SUG 8: 11/18/2015



Why Monitor Water Vapor?

- **SOFIA, the *Stratospheric* Observatory for Infrared Astronomy, flies between 35-45 kft to get above most of our atmosphere's water vapor (WV)**
 - 20x times more WV above the best Chilean ground-based sites on a median night than above SOFIA on a poor night.
- **Residual WV is still the dominant cause of opacity and background noise over entire IR - FIR - submm range.**
- **Often interested in precisely those wavelengths where WV absorbs since we are looking at WV itself in the cosmos**
 - Atmospheres of exoplanets
 - Star and planet formation regions
- **Especially in summer and in the tropics, the tropopause is so high that our stratospheric observatory can't reach the stratosphere**
 - So there's "weather" above SOFIA's flight altitude, and zWV needs to be measured to achieve our required 20% photometric accuracy.

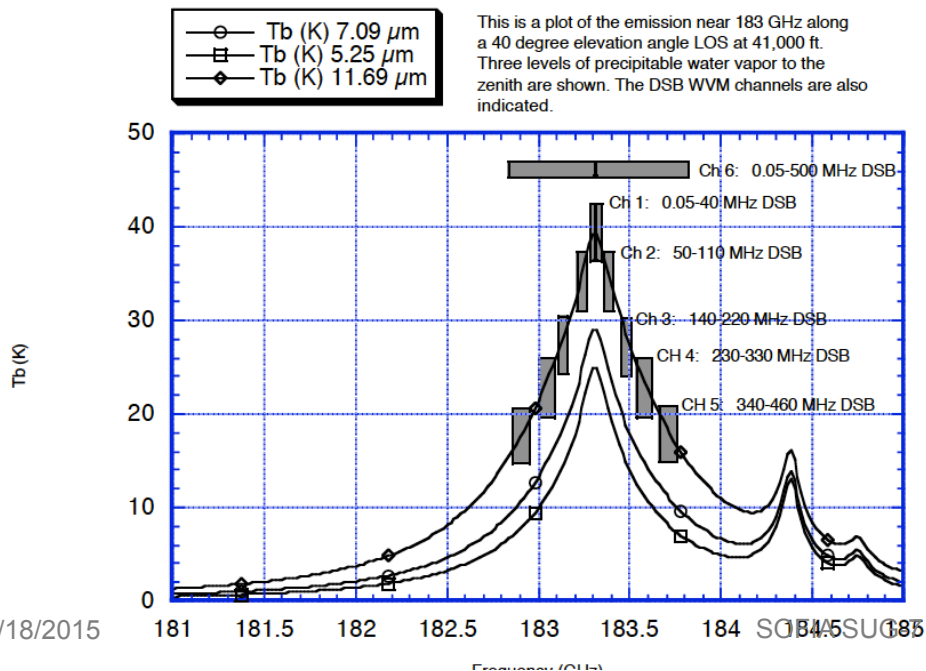
Tropopause – altitude at which air temperature stops decreasing with height, forming a barrier to WV and weather

zWV -- the depth of water in a column of the atmosphere above a certain altitude, same as "precipitable water" or "water vapor overburden"



Review of the SOFIA Water Vapor Monitor

- The microwave Water Vapor Monitor (WVM) continually measures zWV using the 183 GHz WV absorption line while the astronomical instruments are collecting data.
- Looks out same side of aircraft as the telescope, at a fixed elevation angle of 40 degrees
- Software calculates zWV and WV along telescope line-of-sight to write into FITS headers of science data and engineering housekeeping archive





Current Status

- **WVM hardware is installed on the aircraft and is collecting raw data that meets all of its sensitivity requirements**
- **A backup set of hardware is ready in Bldg 703 that can be exchanged in case of a hardware malfunction**
- **A second spare unit with an improved calibration motor controller system is being assembled at ARC and AFRC**
- **The onboard WVM software is not performing satisfactorily, so the raw data is post-flight processed on the ground by the WVM team and then given to the SMOC**
- **After a great deal of research it appears that it will be difficult to perform an absolute calibration of the WVM readings to precipitable water vapor, and it is not obvious what the SMOC would do with this information anyway (more on this later)**



Hardware Issues/Fixes

- **Issue:** The hardware currently installed on the aircraft was used for qualification testing and was rather severely “shaked and baked”. It is currently functioning well but may be less reliable in the long term.
- **Fix:** The current hardware on the aircraft will be replaced with new built-to-print flight hardware. Eventually the qual unit hardware will live in the HILS lab at AFRC
- **Issue:** The COTS motor controller hardware used to run the internal calibration motors in the WVM has proven to be unreliable.
- **Fix:** New custom motor controller hardware has been designed by AFRC and will be retrofitted into the WVM hardware, starting with the Flight Unit #2 now under construction



Software Issues/Fixes

- **Issue:** The current software on the aircraft does not calculate the the WV overburden correctly, and the raw WVM data that is used for the proper post-flight processing of the data is not part of the housekeeping stream and has to be retrieved off of the onboard Archiver.
- **Fix:** A new version of the onboard software has been developed hand is ready to test in the HILS with subsequent installation on the aircraft. However, as noted below the final WV overburden values will be calculated in the SMOC pipelines using the raw data from the WVM. The ICDs and WVM and MCCS software will be modified in the future so that the raw WVM data is part of the normal engineering data stream.
- **Fix 2:** Ongoing WVM flight software maintenance will be taken over by the AFRC MCCS team (only a part-time job)



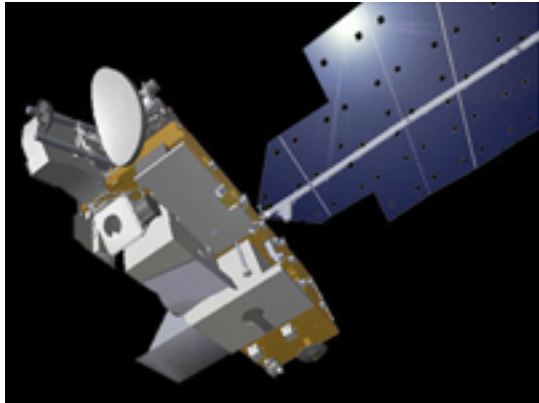
WVM Calibration Issues/Fixes

- **The original plan: Calibrate the WVM using known “truth” so that the absolute water vapor overburden was measured using the 183 GHz water line. Then use this value in atmospheric models to accurately predict the effects of this residual water vapor for each instrument filter/mode.**
- **The issue: There is no accepted “truth” WV values available. Satellites, balloons, LIDAR, and SOFIA SI data are not in agreement with each other. Furthermore, the atmospheric model predictions do not match the observed signals in the SOFIA Sis.**
- **The fix: A database of SOFIA IR calibrator object observations vs. WVM measured water vapor will be built up over time. This database will then be used to correct the IR signals to meet the absolute flux accuracy requirements.**

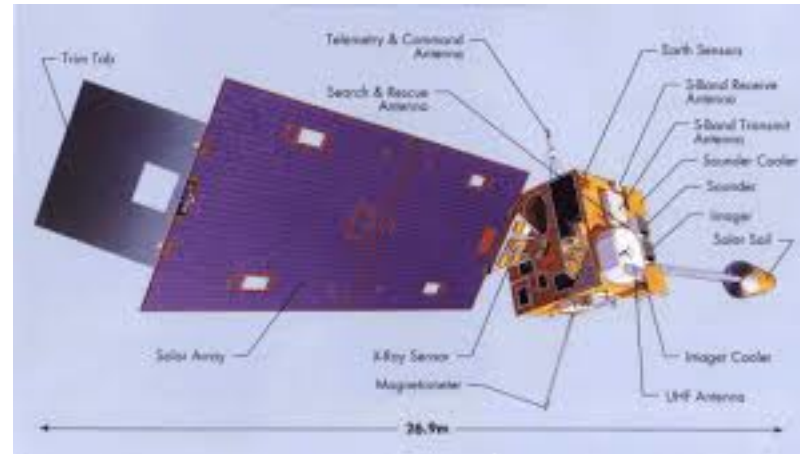


Observation Systems Overview

AURA-Microwave Limb Sounder (MLS)



GOES Sounder *Multiband mid-IR*



water vapor Raman LIDAR (JPL TMF and EAFB)



NOAA Frost Point Hygrometer (FPH) – “Gold Standard”

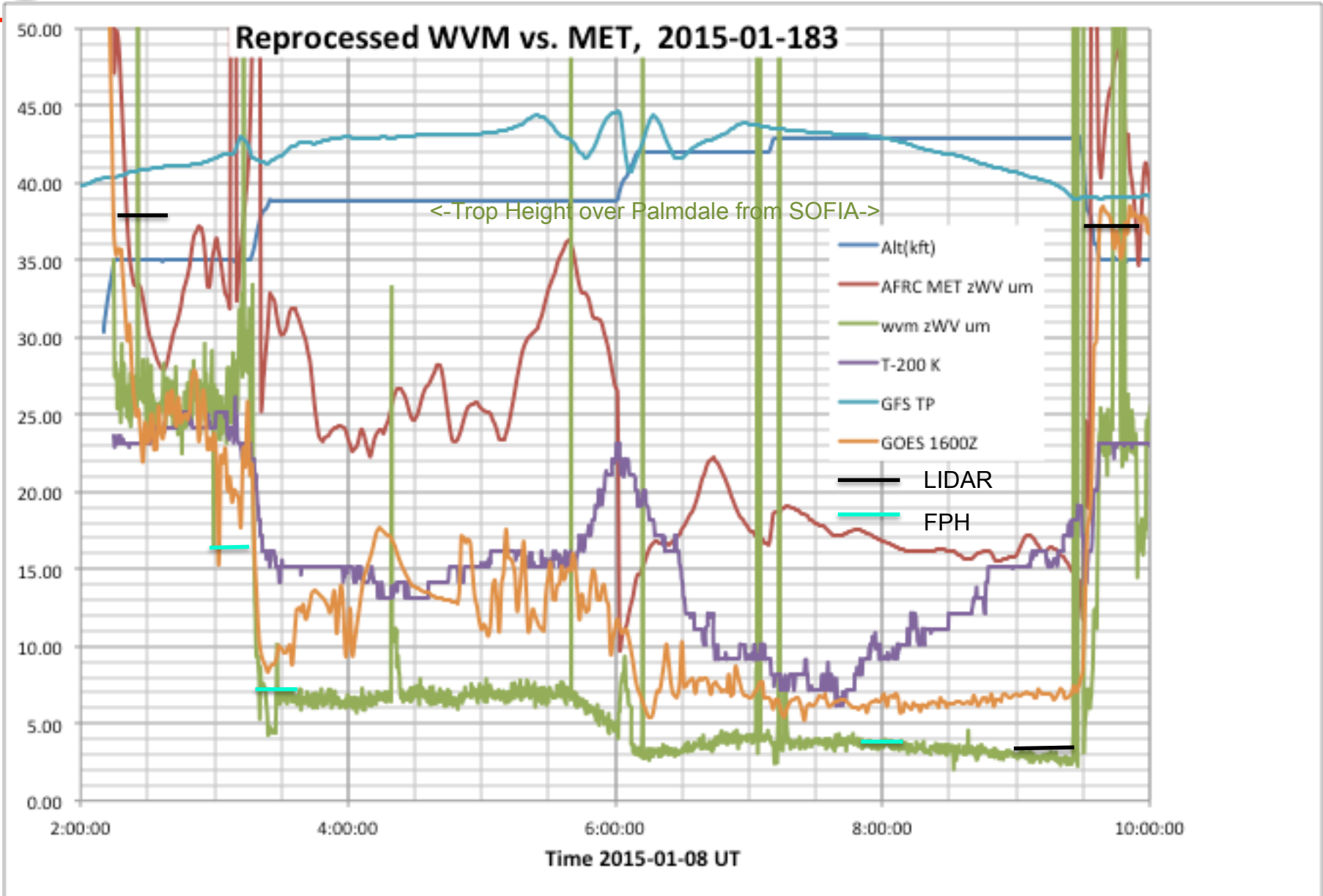


11/182015

SOFIA SUG-7

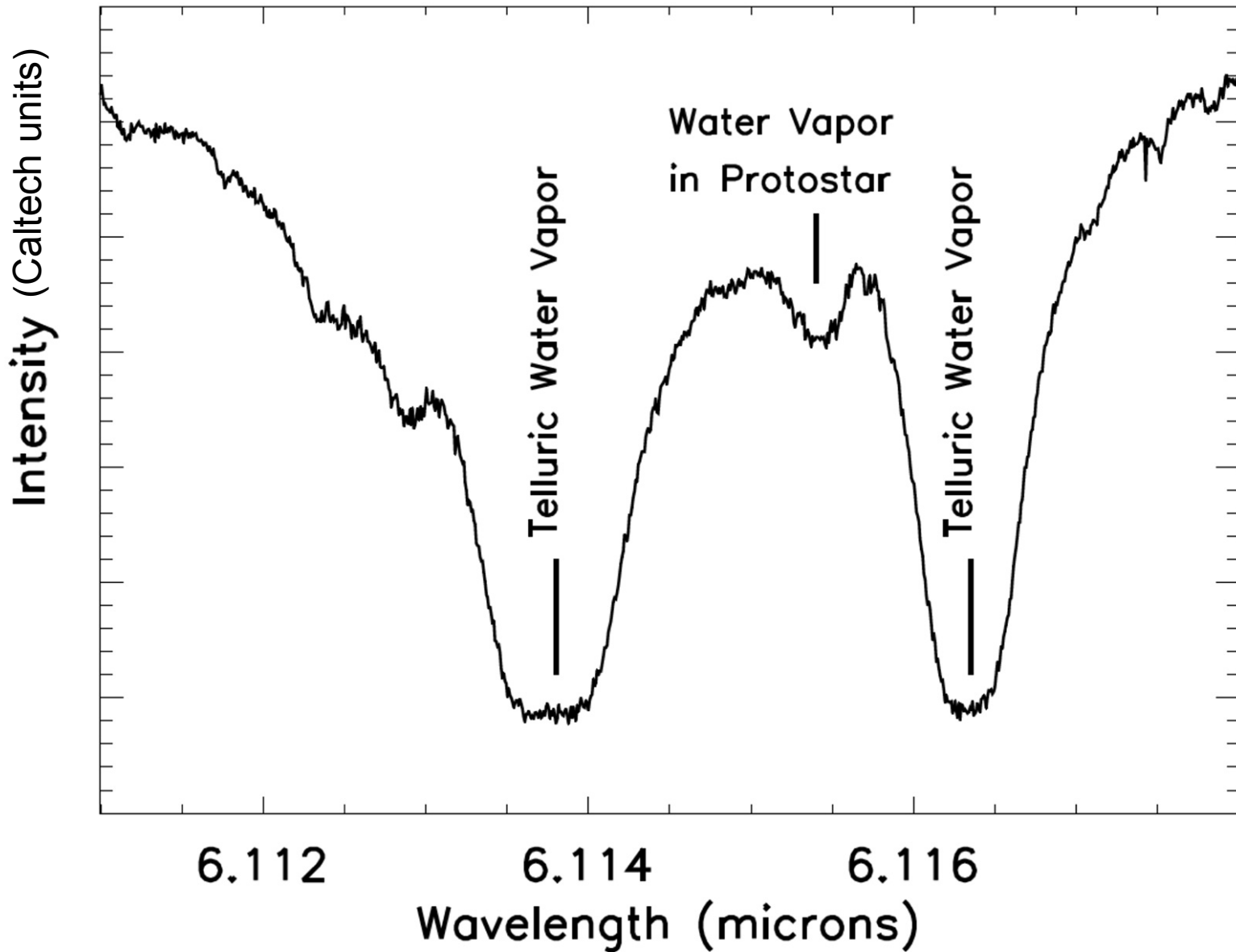


WVM and Various "Truths"





H₂O detected by EXES in the high-mass protostar AFGL 2591





GREAT/SOFIA atmospheric calibration

- **Guan+ (2012, Special Issue A&A GREAT Early Science) could not self-consistently fit the atmospheric emission simultaneously for the L1 and L2 bands**
 - independent fits to the individual receiver bands converge well, but on solutions with different values of zWV for each band
 - Typical science observations intentionally avoid strong water lines
- **Dedicated tests to directly calibrate the water vapor monitor (WVM) against GREAT on 2015-01-21_GR_F187 and 2015-01-23_GR_F189**
 - Deliberately centered the optical depth ~1 lines in the middle of GREAT band
 - Will use atmospheric models to deduce the precipitable water vapor along the line of sight (science team focusing on science papers right now)

Leg 10

engineering leg

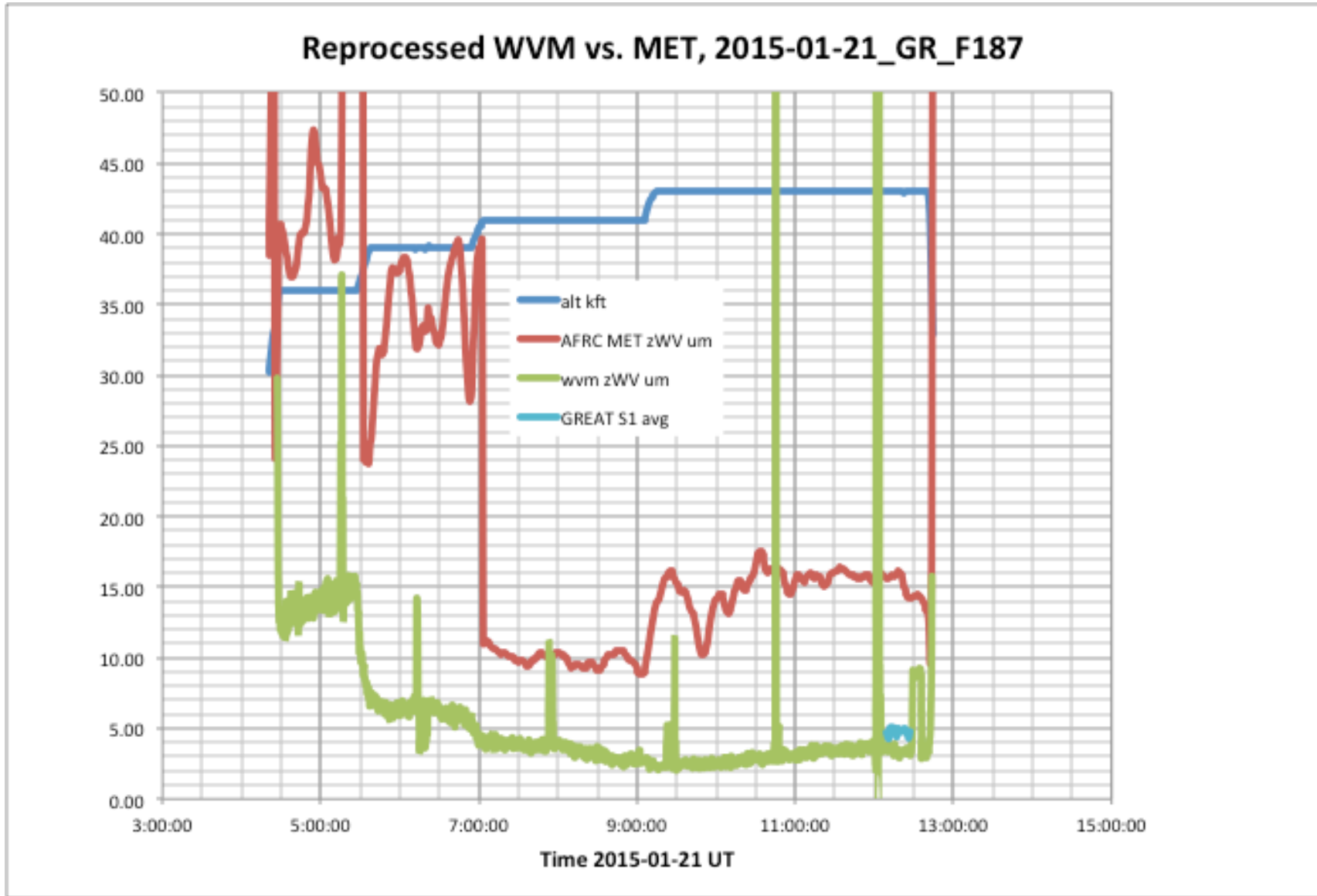
to cross-calibrate WVMonitor

		L1: H2O_1	L2: H2O_3	43 kft
12:11	19.47 elev	hot-cold-sky	11711-12	
12:12-15	21.32		11713 (went into local), repeat: 11715	
12:15	23.58		11716	
12:18	30.00		11717	
12:20	41.81		11718	
12:22	60.4		11719	

Snippet of Göran's log on Flight 187



WVM and GREAT





Plans Forward - Responsibilities

- **Hardware reliability upgrade: Joint ARC/AFRC responsibility. All three units to be upgraded by the end of FY2016. Start with Flight Unit #2, then Flight Unit #1, then Qual Unit**
- **WVM flight S/W maintenance and upgrades to MCCS and updated ICDs to put raw WVM data in the engineering stream to be transferred over to AFRC in the next 5 months.**
- **Post-flight processing of the raw WVM data to be incorporated into the SMOC pipelines within the next 5 months. USRA responsibility with help and advice as needed from ARC.**
- **Maintenance of the WVM/SI calibration database a SMOC/USRA responsibility. Added to USRA contract.**