



**Water Vapor Monitor Status – Updated  
from the Last SUG**

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**SUG 9: 5/26/16**



# Why Monitor Water Vapor?

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- **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.

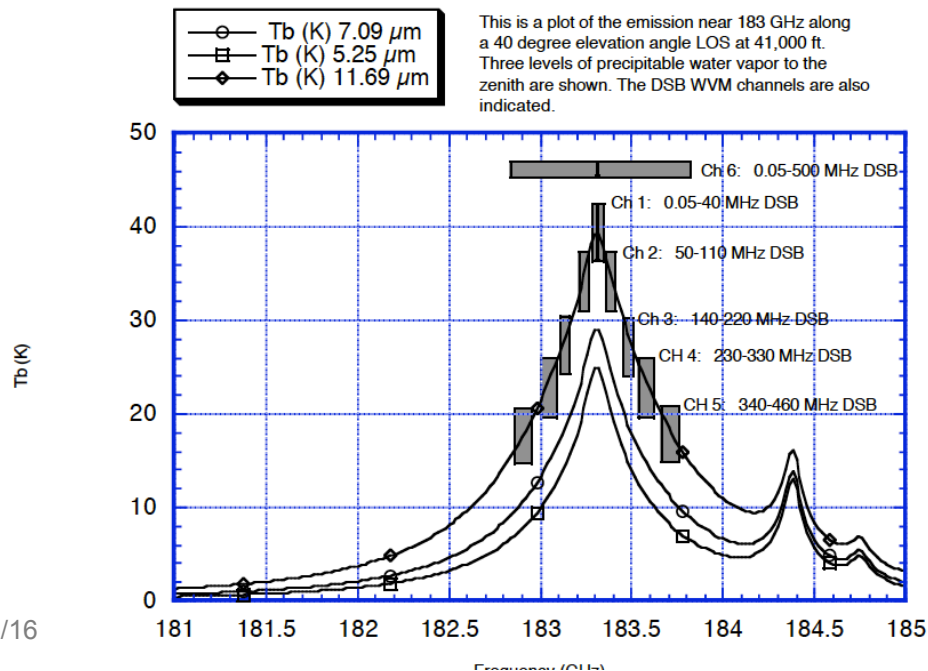
Tropopause – altitude at which air temperature stops decreasing with height, forming a barrier to WV and weather

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 – Updated from Last SUG

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- **WVM hardware is installed on the aircraft and is collecting raw data that meets all of its sensitivity requirements (No change from last SUG)**
- **A backup set of hardware is ready in Bldg 703 that can be exchanged in case of a hardware malfunction (However, we have found it more expedient to reprogram the balky motor controllers)**
- **A second spare unit with an improved calibration motor controller system is being assembled at ARC and AFRC**
- **The onboard WVM software is performing satisfactorily for in-flight decisions, but better results are found when the raw data is post-flight processed on the ground by the WVM team and then given to the SMOC.**
- **The SMOC will incorporate the WV extraction from the raw WVM data as part of their data pipelines.**



## Hardware Issues/Fixes – Updated from last SUG

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- **Issue:** The hardware currently installed on the aircraft was used for qualification testing and was rather severely “shaked and baked”. **It is currently functioning but is less reliable than it should be.**
- **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 **and built by AFRC** and **was** retrofitted into the WVM hardware, starting with the Flight Unit #2 now under construction.
- **New requirements for any, including built-to-print, hardware that is installed on the plane requires environmental testing of Flight Unit #2 hardware (albeit at significantly lower levels than the qual unit).**



## Software Issues/Fixes – Updates from Last SUG

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- A new version of the onboard software has been developed **and has been installed 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 – Updates from Last SUG

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- **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.**
- **Currently the ATRAN program is used within the SMOC pipelines. Calibration for the time being will concentrate on “the truth according to ATRAN”, although there are still some issues with finding good long wavelength calibrators.**



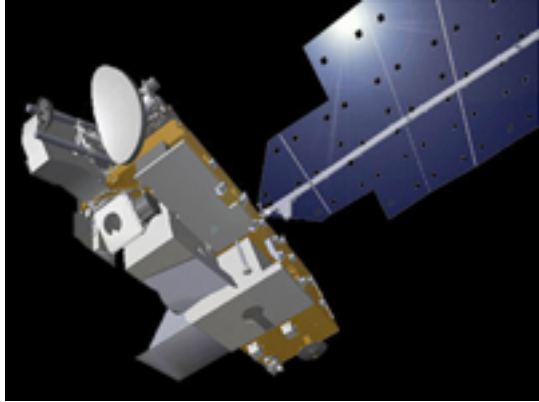
## Backup Slides



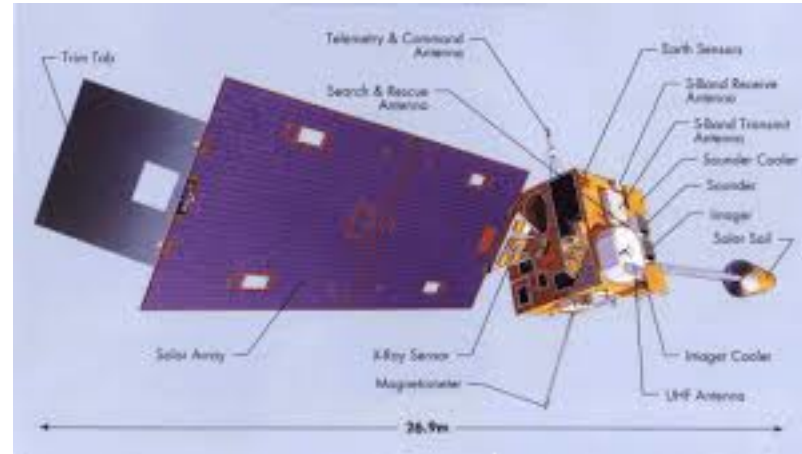


# Observation Systems Overview

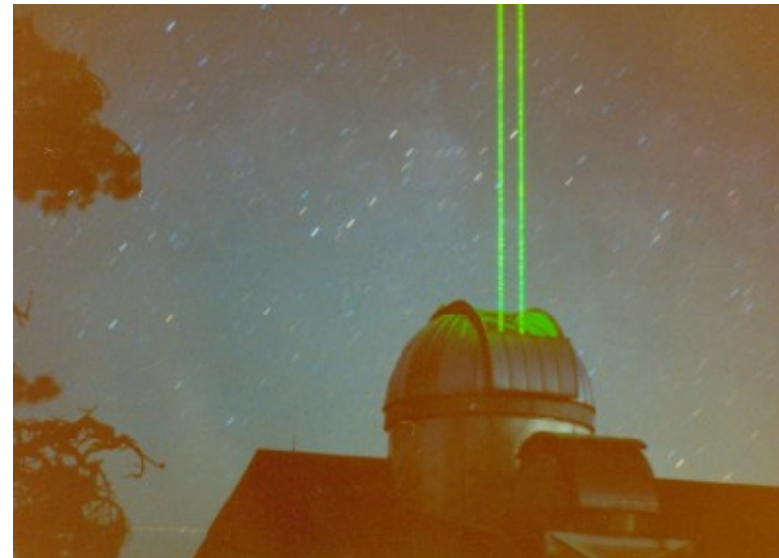
## AURA-Microwave Limb Sounder (MLS)



## GOES Sounder *Multiband mid-IR*



## water vapor Raman LIDAR (JPL TMF and EAFB)



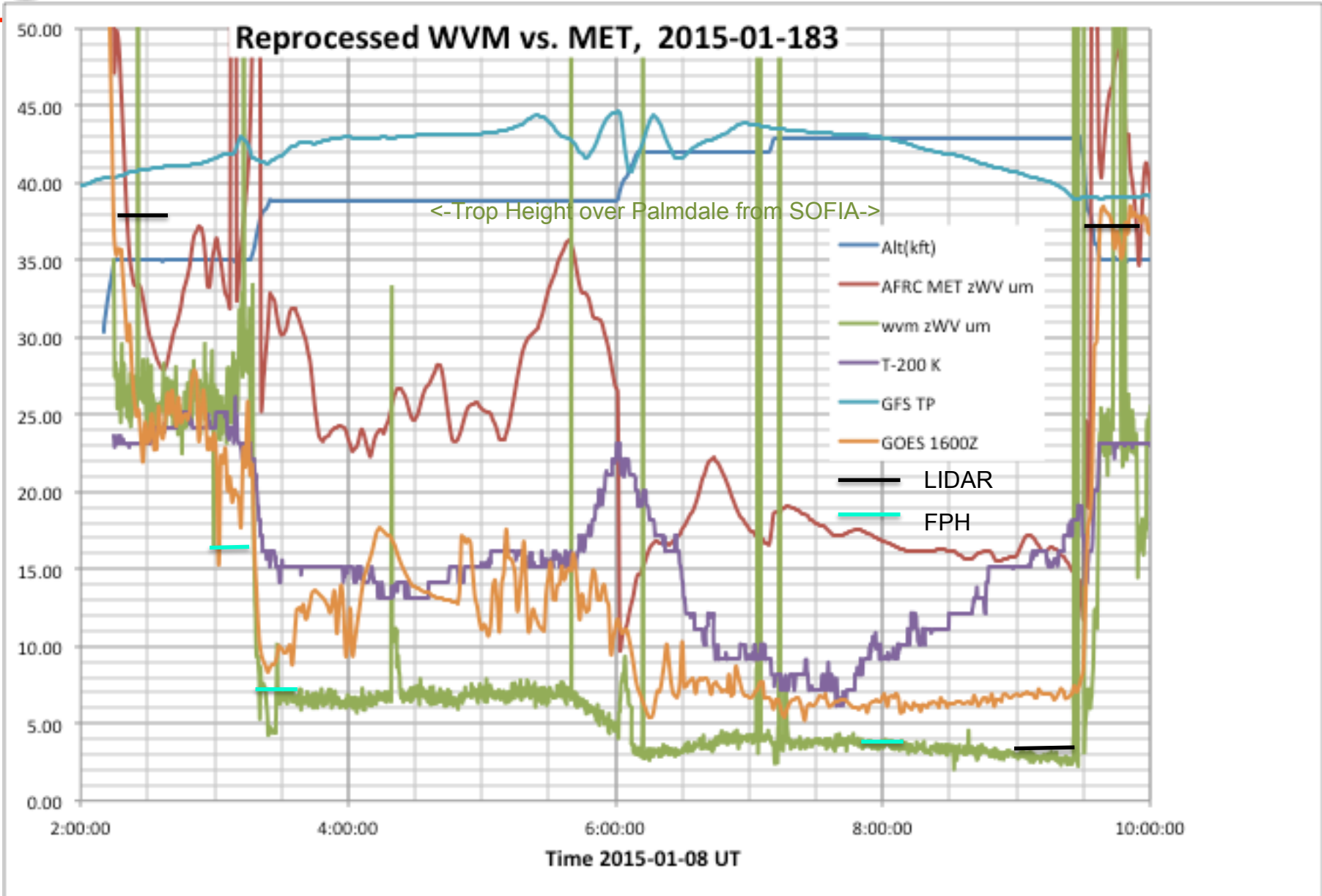
NOAA Frost Point Hygrometer (FPH) – “Gold Standard”



5/26/16

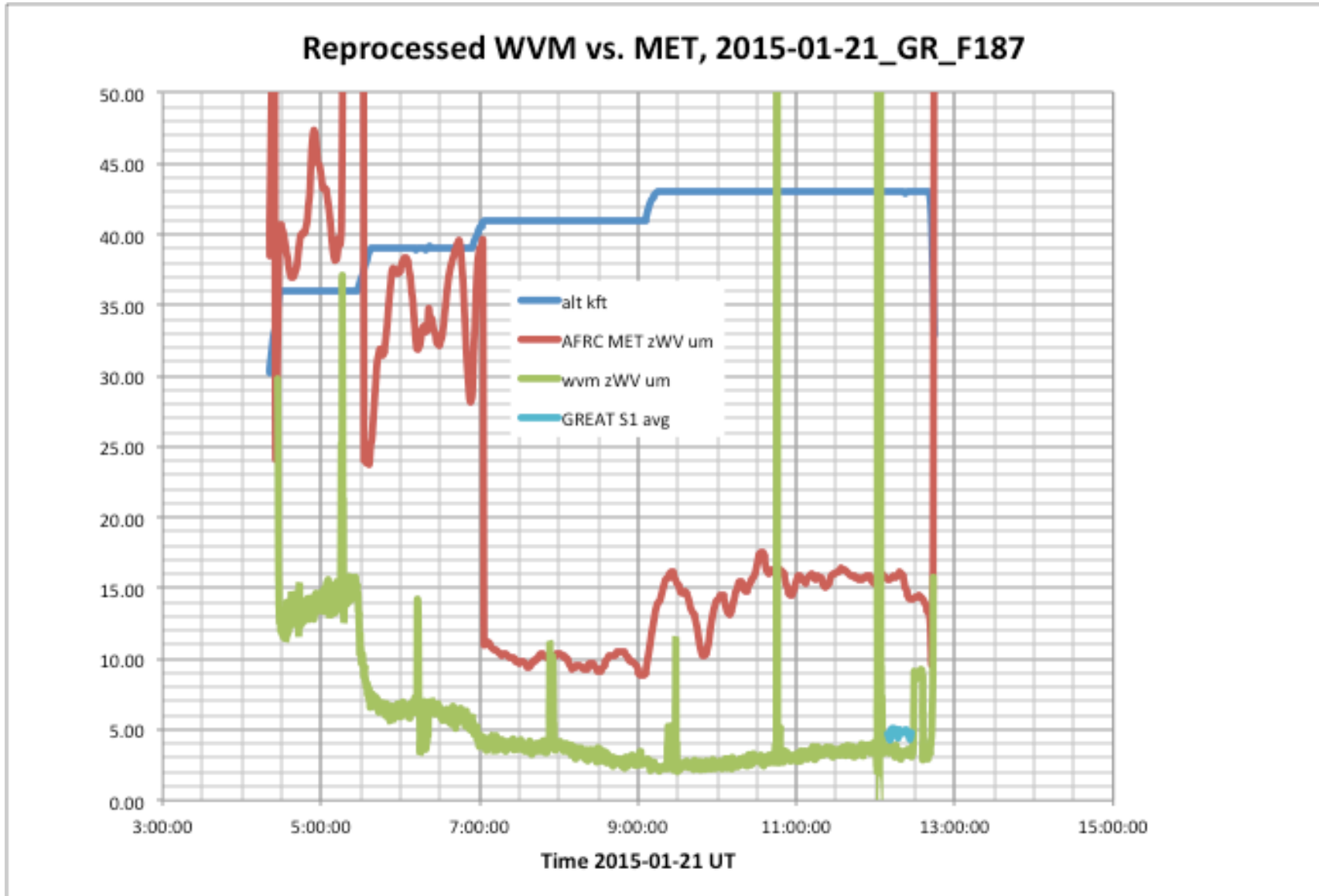


# WVM and Various "Truths"





# WVM and GREAT





## **Slides from a Program Briefing Given March 16, 2016**



# WVM Current Status

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- **Hardware**

- There are three sets of RHD/IFC hardware (the RHD and IFC hardware has to be paired together to maintain proper calibration)
  - *WM Qual hardware (serial # 001, the most beat-up with testing but currently in the aircraft because it is the most reliable – see below).*
  - *Flight Unit Number 1 (serial # 002)– currently at AFRC serving as a flight spare, although past experience has shown that it is much less reliable than #001*
  - *Flight Unit Number 2 (serial # 003) – currently at ARC undergoing retrofit with new motor controller hardware, final assembly, and lab calibration*
- The current WVM hardware meets all of its performance requirements
- However, the COTS stepper motor controllers in the IFC have proven to be unreliable. For reasons that are understood by nobody they occasionally lose their simple code upon WVM power-up
- Matt Reaves has developed new custom WVM motor controller hardware/software. This was successfully tested last month in the RHD/IFC Serial #003 hardware at ARC, although Matt still wants to do some more work on its internal fault detection
- There are two sets of WVM CPU hardware. One set is installed on the aircraft and the other is a flight spare that resides in the HILS



## WVM Current Status (2)

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- **Environmental considerations**

- The previous environmental verification approach – to build a qual set of hardware and shake and bake it to high levels, and then build-to-print additional set(s) of flight hardware, has been abandoned at AFRC
- Now ALL new or revised SOFIA hardware has to undergo environmental acceptance testing
- With the modification of the stepper motor controllers all the WVM IFC and RHD hardware will have to undergo environmental testing at AFRC
- The new environmental test requirements also necessitate the addition of a thermal switch in the WVM A/C power line, since the temperature test levels are higher than the recommended operating temperature of one of the A/D converters in the IFC (although the survival temperatures are fine). This switch is being developed at AFRC



## WVM Current Status (3)

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- **Software**

- No changes are anticipated in the software in the IFC, with the exception of the updates to the fault detection code within the new motor controllers
- The software in the WVM CPU is working, but :
  - *It currently needs to be re-coded with every change of an RHD/IFC hardware set.*
  - *The water vapor derivation part of the code is being constantly revised as more in-flight calibration data becomes available. Therefore the best data comes from post-flight processing of the raw WVM data on the ground*
  - *The S/W change process is relatively onerous for software that resides on the plane so this is being addressed by updating the code to recognize the different RHD/IFC hardware sets and switches the calibration constants accordingly, and moving the final water vapor derivation processes from the WVM CPU to the science data pipelines at the SMOC.*
- In the future the inflight WVM software will only provide a quick look display of the calculated WV overburden and the SMOC pipelines will use the WVM raw data to make the final determinations of the WV



## WVM Current Status (4)

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- **Software (cont.)**

- Currently the raw WVM data is stored on the onboard Archiver (along with a backup record on the SSM in the WVM CPU). This works, but in the future it may be better to include the WVM raw data in the MCCS engineering data stream. This would require modification to the MCCS code and a change to the MCCS-WVM ICD.

- **Calibration**

- After a significant amount of investigation by the WVM team, and especially Jeff van Cleve of USRA, it has become apparent that we will not be able to use the WVM to make an absolute determination of the WV overburden and then use atmospheric models to predict its effects on the SI data (disagreement among atmospheric researchers what “truth” is, and models are not good enough to predict the effects on the IR signal to the required accuracy).
- Instead a more laborious continuous calibration will be done to empirically associate the WVM measurements with SI measurements of standard astronomical calibration objects





## WVM Current Status (5)

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- **Documentation**

- WVM risks need to be updated
- WVM Calibration Plan needs to be updated
- The Water Vapor Monitor Engineering Design Memos that describe the water vapor data reduction algorithms need to be revised to reflect the updated post-flight data reduction processes based on the lessons-learned to date
- There are still 10 open WVM DRs assigned to either Yuen or Roellig
- If we decide to modify the MCCS software to provide a more direct path for the WVM raw data then the MCC-WVM ICD will need to be changed



## WVM Organizational Changes

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- **In the future, all the activities associated with those parts of the WVM that fly on the plane, both hardware and software, will be transferred to AFRC. As part of this transfer of knowledge and responsibilities Lunming Yuen at ARC has been working with Mike Pratt and Russ Franz at AFRC to transfer his knowledge of the WVM CPU code. Lunming's last official day as a SOFIA Wylie contractor is currently March 25.**
- **The final calculations of the WV overburden from the WVM raw data will now be the responsibility of the SMOC. The current WVM team (me) will provide updated algorithm descriptions so that this can be properly coded.**
- **The continuous calibration of the WVM measurements to the SI signals on calibration targets will be done by the SMOC**



## WVM Work to Be Done (*in priority order*)

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### 1) **Post-flight process the latest WVM flight data.**

- Since we recently did some WVM hardware swaps this isn't as straightforward as normal, particularly since the changes have been more significant than seen in the past.
- Are investigating, among other things, if there has been a change in the ventilation system that keeps the WVM window frost-free
- We need to determine new calibration coefficients, although we believe that we have all the necessary lab data to derive these
- The FIFI team has been active in voicing their need for these data
- About 2 weeks of (*mostly uninterrupted*) work by Roellig, plus further post-processing for future flights

### 2) **Knowledge, software code, and documentation transfer from Yuen at ARC to Pratt and Franz at AFRC**

- Yuen current position terminated on 3/25/16
- Wylie suggests that they keep Yuen on a part-time, sub-contractor basis until the end of current contract 7/31/16. Suggest allocating 100 hours for this purpose. This will keep his hard badge, keys, and NASA computer accounts alive
- Note that Pratt is currently flying a lot and cannot devote full-time to this task



## WVM Work to be Done (2)

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- 3) **Finish assembly and lab calibration of the RHD/IFC serial# 003 hardware at ARC**
  - About 3 weeks of (*mostly uninterrupted*) work by Roellig
- 4) **Construct test hardware for WVM environmental testing at AFRC**
  - In work by Christel Gesterling at AFRC, completed by ?
- 5) **Develop thermal switch for WVM**
  - AFRC, must be complete for environmental testing (*Done*)
- 6) **Conduct environmental testing of RHD/IFC serial # 003 hardware at AFRC**
  - Duration perhaps 2 weeks by?
- 7) **Install serial #003 hardware on aircraft**
  - Want to do this before NZ deployment



## WVM Work to be Done (3)

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### 8) Update WVM flight software -1

- Done at AFRC, with consulting with Roellig and as-needed support from Yuen
- Revise code to make switching RHD/IFC hardware easier
- Duration ?

### 9) Revise WVM Engineering Design Memos describing WV extraction algorithms

- Delivery to SMOC so that they can start coding to incorporate into their pipelines
- About 2 weeks of (*mostly uninterrupted*) work by Roellig

### 10) Incorporate WVM derivation in SMOC pipelines

- Done at SMOC
- Duration ?
- Cost 0.2 WYE at USRA \*

### 11) Repeat tasks 3-6 for RHD/IFC serial number 002

- About 5 weeks per hardware set of (*mostly uninterrupted*) work by Roellig



## WVM Work to be Done (4)

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### **12) Update WVM Risks and Calibration Plan documentation**

- About 1/2 week of (*mostly uninterrupted*) work by Roellig

### **13) Close out remaining open WVM DRs**

- About 2 weeks of (*mostly uninterrupted*) work by Roellig

### **14) Repeat Tasks 3-6 for RHD/IFC serial number 001**

- About 5 weeks per hardware set of (*mostly uninterrupted*) work by Roellig

### **15) Update motor controller software to include more fault detection and response**

### **16) Perform ongoing WVM calibration**

- Done at SMOC
- Ongoing
- Cost 0.2 WYE at USRA (labor shared with \* above)
- Roellig will also assist in this work



## WVM Work to be Done (5)

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- 17) Update WVM motor controller firmware with additional fault detection**
  - Done at AFRC
  - Duration ?
- 18) Update WVM flight software -2**
  - Done at AFRC, with consulting with Roellig and as-needed support from Yuen
  - Update WVM and MCCS software to put raw WVM data in engineering data stream
  - Update fault response and communication to accommodate new motor controller code
  - Duration ?
- 19) Update MCCS-WVM ICD to reflect new WVM raw data flow**

**About 1 week of (*mostly uninterrupted*) work by Roellig**