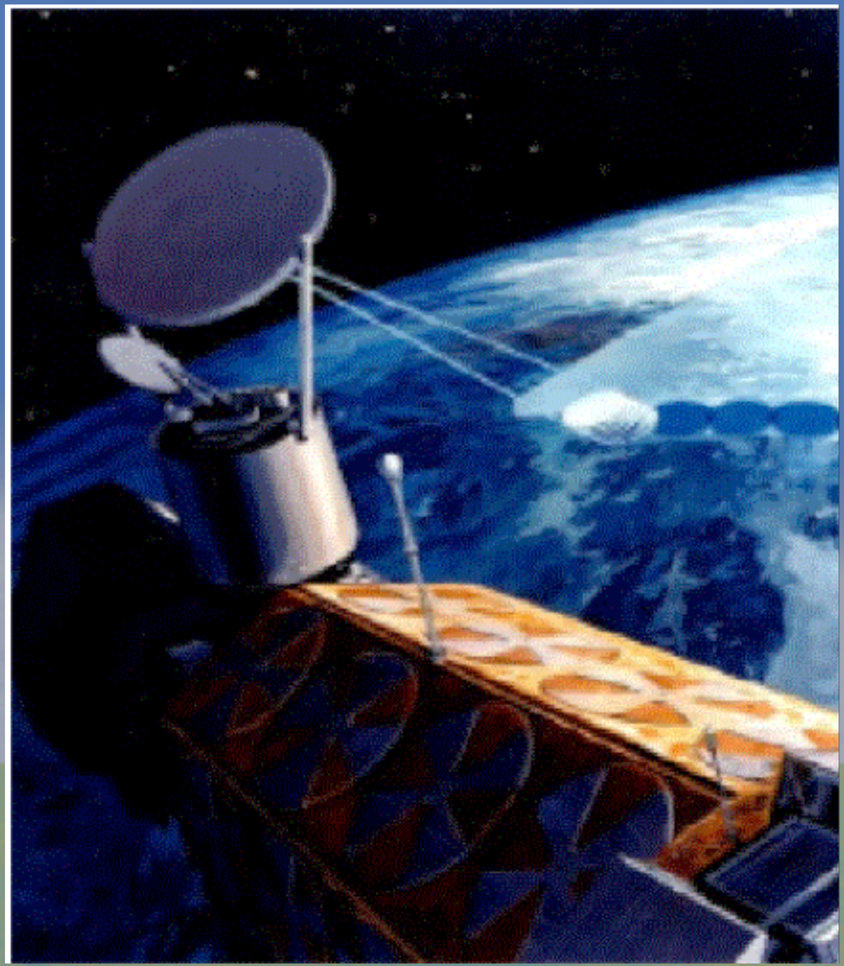
SSMIS AVTP, AVMP Cal/Val:
Ground-Truth or Consequences



John Wessel
Ye Hong
Bob Farley
Bruce Thomas
Don Boucher
Al Fote
Dave Kunkee
Arlene Kishi
Ann Mazuk
Steven Beck
} Aerospace

Steve Swadley, NRL
Gene Poe, NRL

Oct. 16th 2008

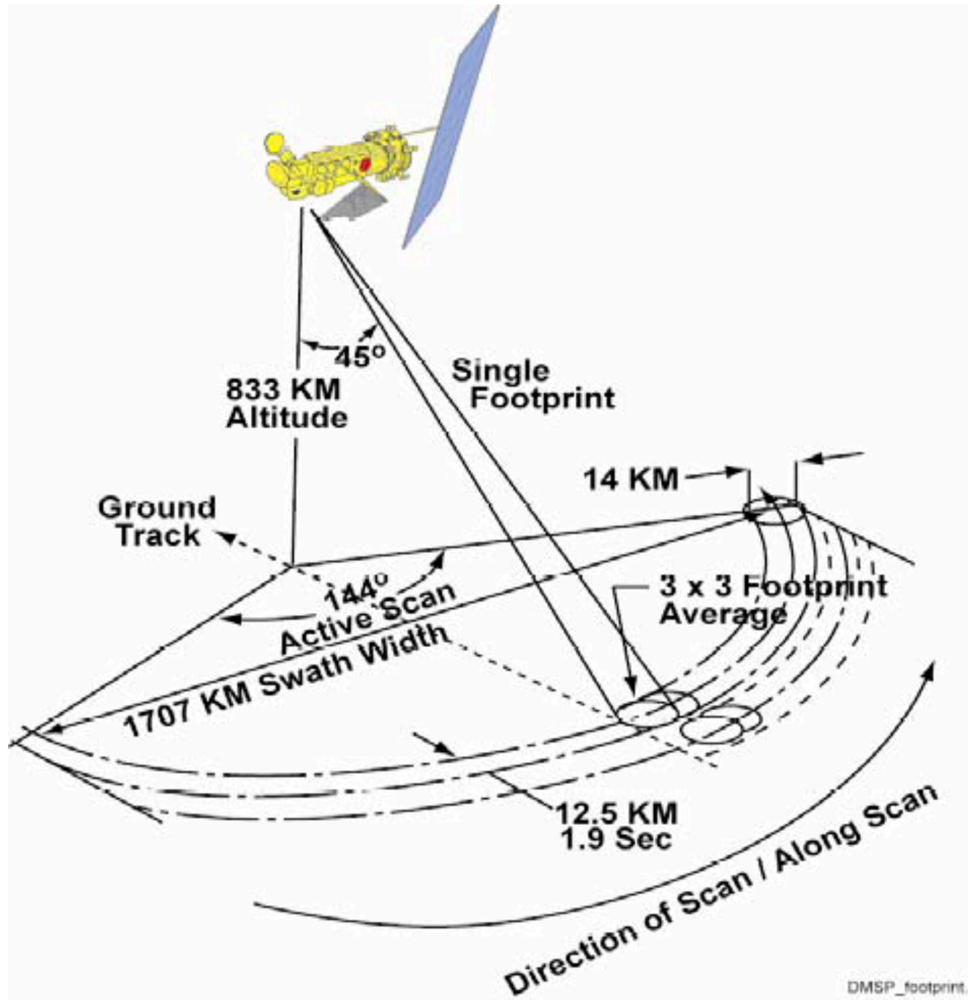
SSMIS Scan Pattern

•The first **SSMIS** instrument was successfully launched on October 18th, 2003, aboard the Defense Meteorological Satellite Program satellite F16 (DMSP-F16)

•**SSMIS** is a conically-scanning passive microwave radiometer that includes 7 temperature sounding channels peaking below 30 Km, and 7 peaking between 30 Km and 80 Km, 4 water vapor channels, along with imaging channels from the heritage SSMI instrument

•The tropospheric and stratospheric temperature sounding channels are similar to those of the **AMSU-A** instrument aboard NOAA satellites 15-18, which have tremendous positive impact on numerical weather prediction (NWP) systems

•The **AMSU-A** instruments have cross track scanners, as opposed to the conically-scanning SSMIS.



Channel Characteristics of F16 SSMIS

(Poe et al., 2001)

Channel Center Freq (GHz)	. (MHz)	3-db Width (MHz)	Freq. Stab	Pol. (K)	NEDT	Sampling Interval(km)
1. 50.3	380	10	V	0.34		37.5
2. 52.8	389	10	V	0.32		37.5
3. 53.596	380	10	V	0.33		7.5
4. 54.4	383	10	V	0.33		37.5
5. 55.5	391	10	V	0.34		37.5
6. 57.29	330	10	RCP	0.41		37.5
7. 59.4	239	10	RCP	0.40		37.5
8. 150	1642(2)	200	H	0.89		12.5
9. 183.31+/-6.6	1526(2)	200	H	0.97		12.5
10. 183.31+/-3	1019(2)	200	H	0.67		12.5
11. 183.31+/-1	513(2)	200	H	0.81		12.5
12. 19.35	355	75	H	0.33		25
13. 19.35	357	75	V	0.31		25
14. 22.235	401	75	V	0.43		25
15. 37	1616	75	H	0.25		25
16. 37	1545	75	V	0.20		25
17. 91.655	1418(2)	100	V	0.33		12.5
18. 91.655	1411(2)	100	H	0.32		12.5
19. 63.283248+/-0.285271		0.08	RCP	2.7		75
20. 60.792668+/-0.357892		0.08	RCP	2.7		75
21. 60.792668+/-0.357892+/-0.002		0.08	RCP	1.9		75
22. 60.792668+/-0.357892+/-0.0055		0.12	RCP	1.3		75
23. 60.792668+/-0.357892+/-0.016		0.34	RCP	0.8		75
24. 60.792668+/-0.357892+/-0.050		0.84	RCP	0.9		37.5

SSMIS Lower Atmospheric Soundings Cal/Val

Results

•LAS channels are stable over short time intervals

•Bias varies monthly as a function of latitude and orbit

  –Noticeable for temperature channels

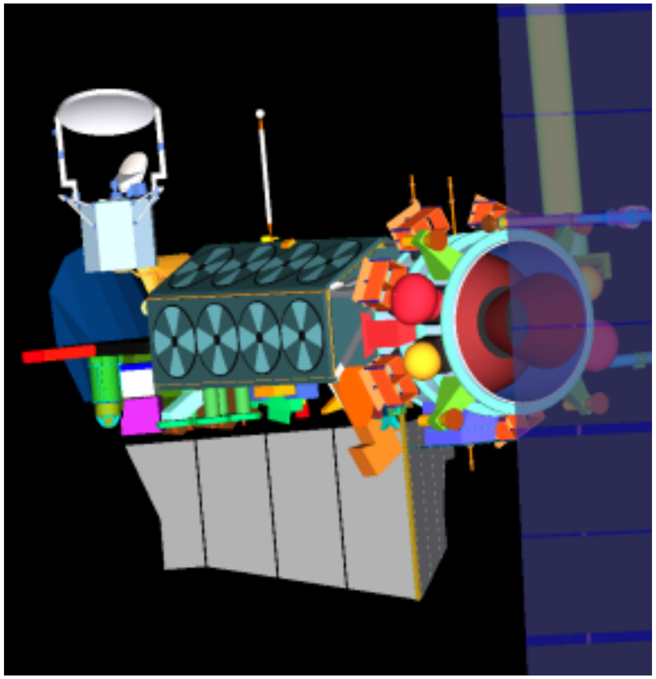
  –Major perturbation for moisture channels

    –*Caused by variable heating of the primary reflector*

    –*Additional contribution from solar heating of warm load surface*

  – *Reproducible over annual time cycle*

•Channels 1-5 V-polarized rather than specified H-pol



DGS view of F-16 from sun

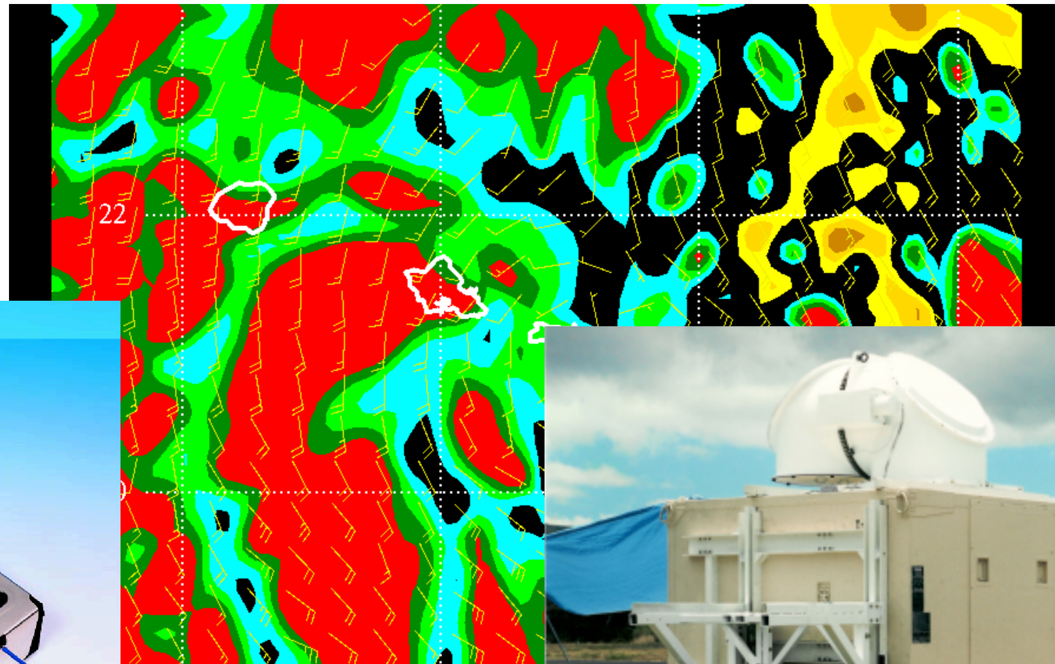
SSMIS Lower Atmospheric Soundings Cal/Val

LAS Cal/Val Methods

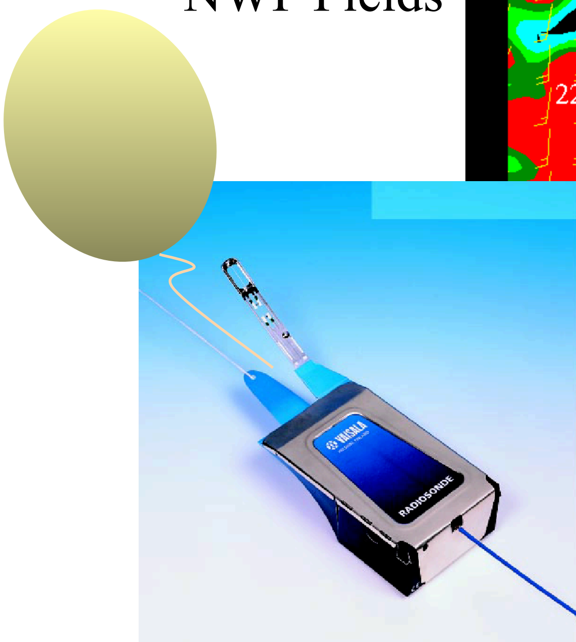
Radiative Transfer-based Calibration

•SDRs compared with radiative transfer calculations based on:

NWP Fields



Lidar

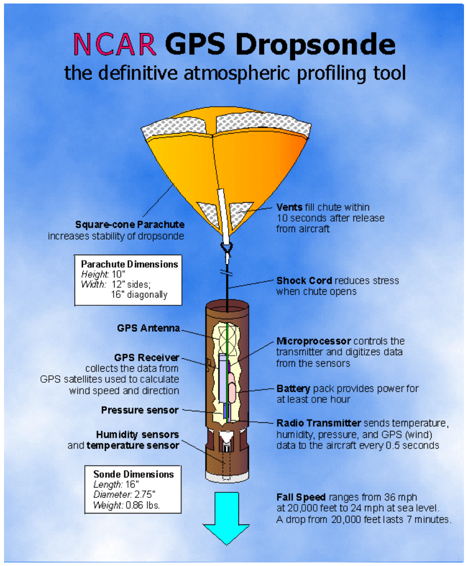


Special and Operational Radio-sondes

SSMIS Lower Atmospheric Soundings Cal/Val

Special Measurement Campaigns

- Aircraft-based dropsondes
- Shipboard radiosonde launches



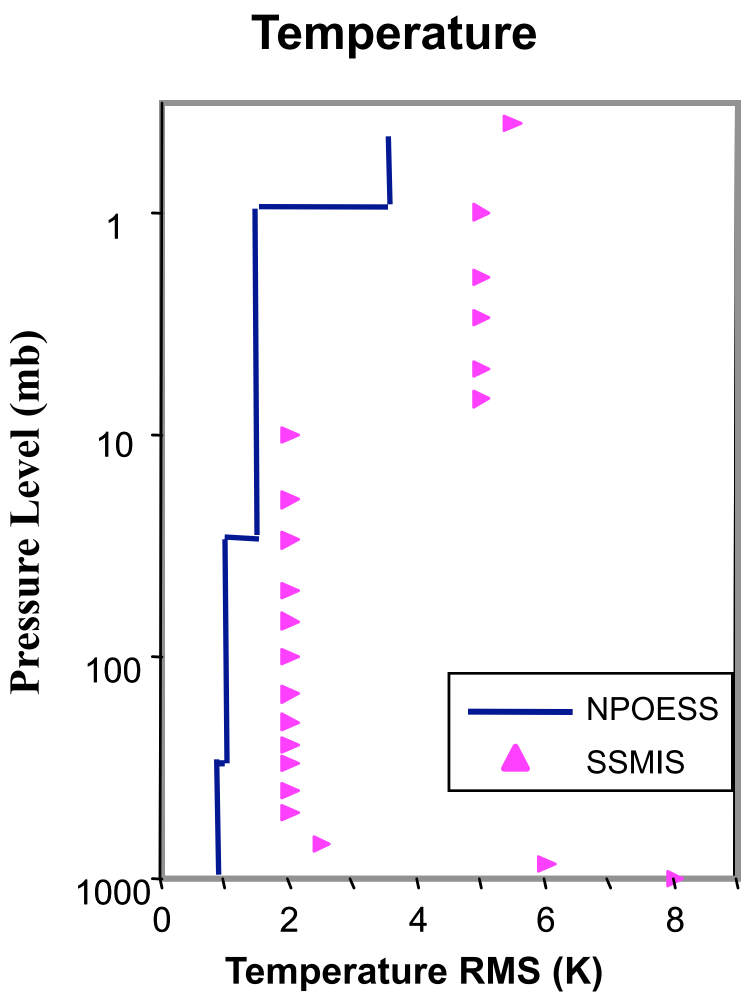
Direct Aircraft-based Radiometer Calibration

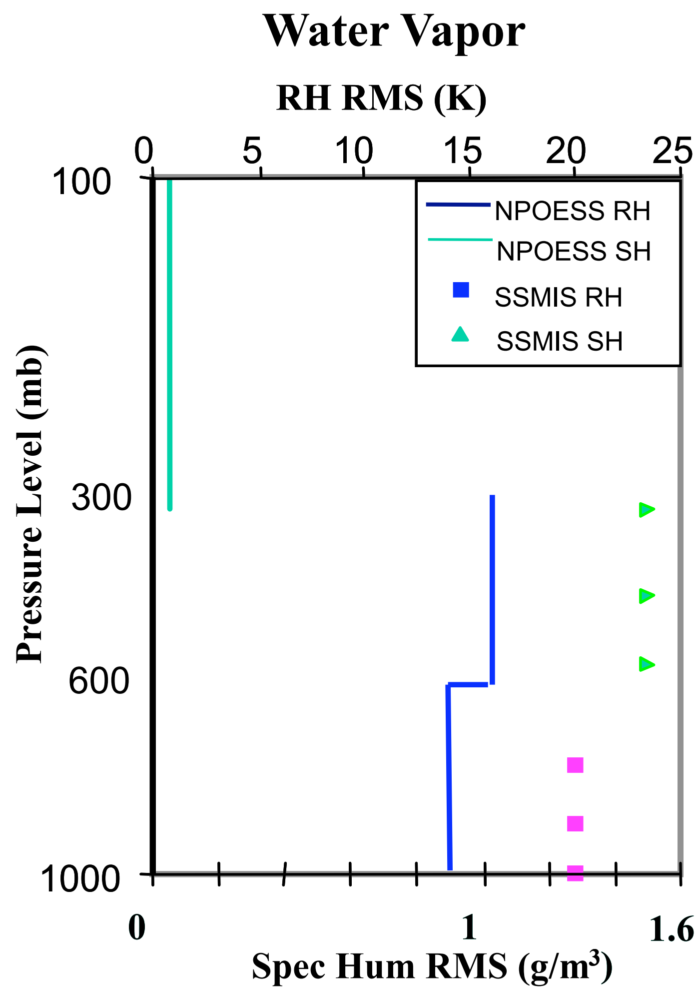
- NASA Goddard CoSMIR for soundings channels

Other tools: DGS, Thermal Modeling, SIMS

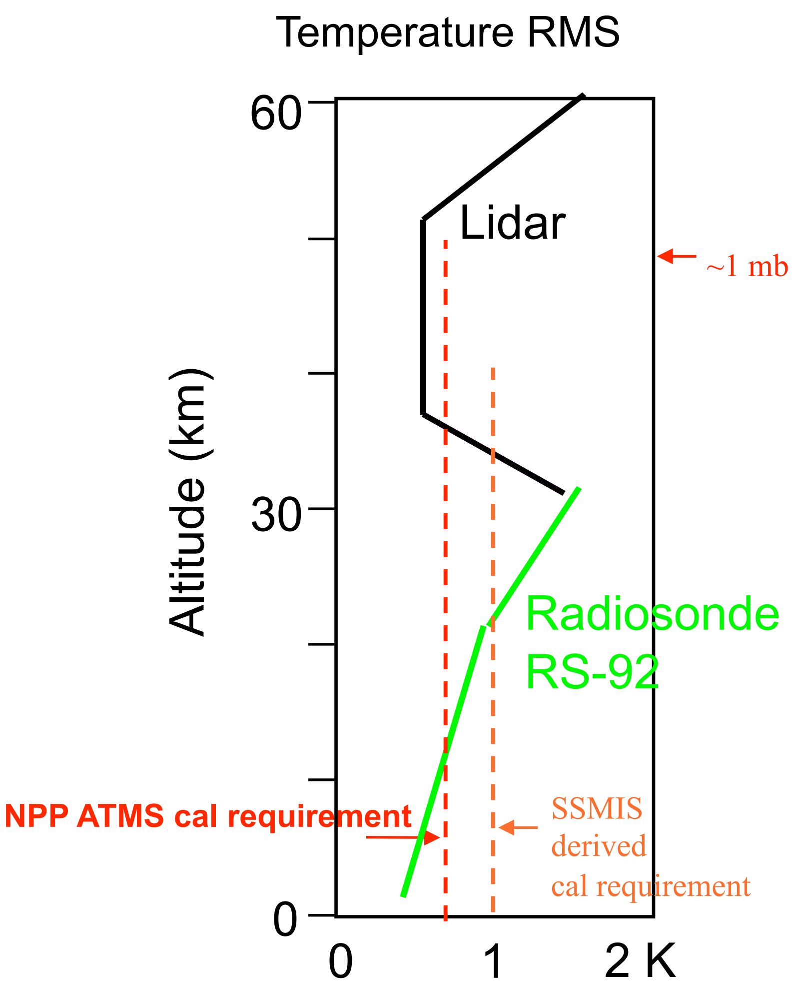
Special measurements coordinated by Steve Swadley, NRL

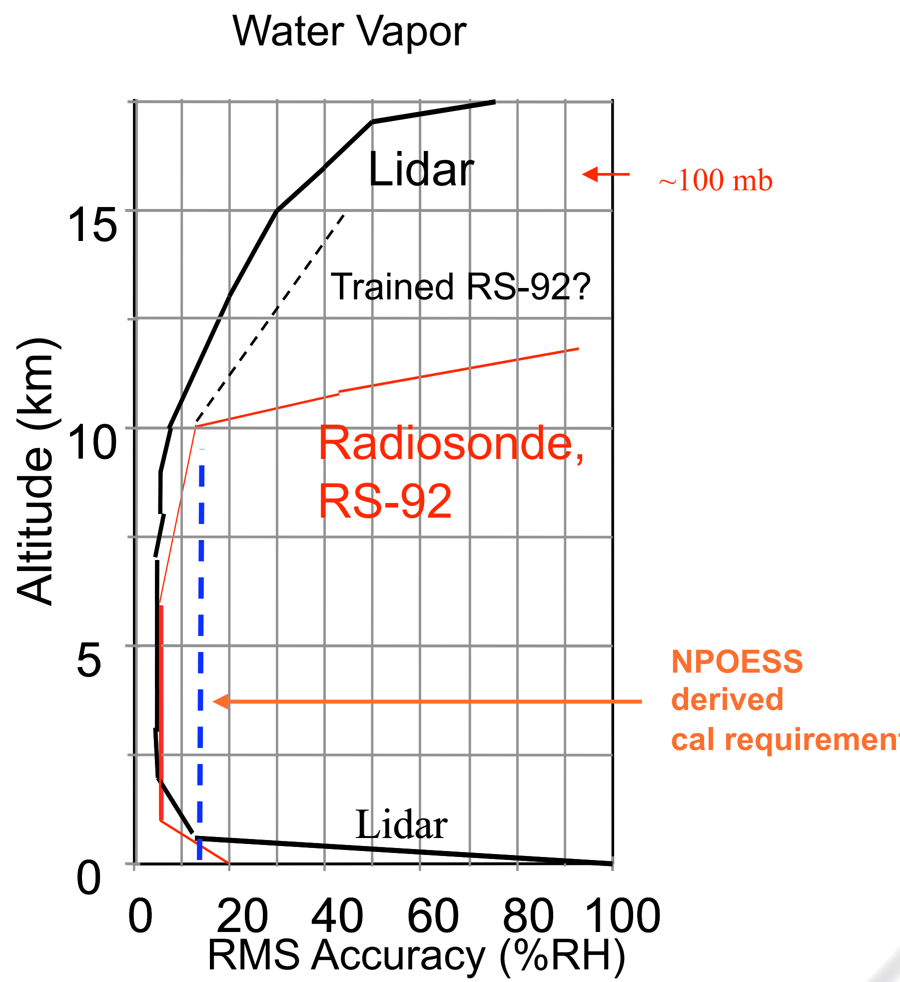
NPOESS Sounding Requirements More Stringent than for SSMIS





Current Ground Truth Accuracy Insufficient for NPOESS Requirements





DMSP/Aerospace Cal/Val Data Archive

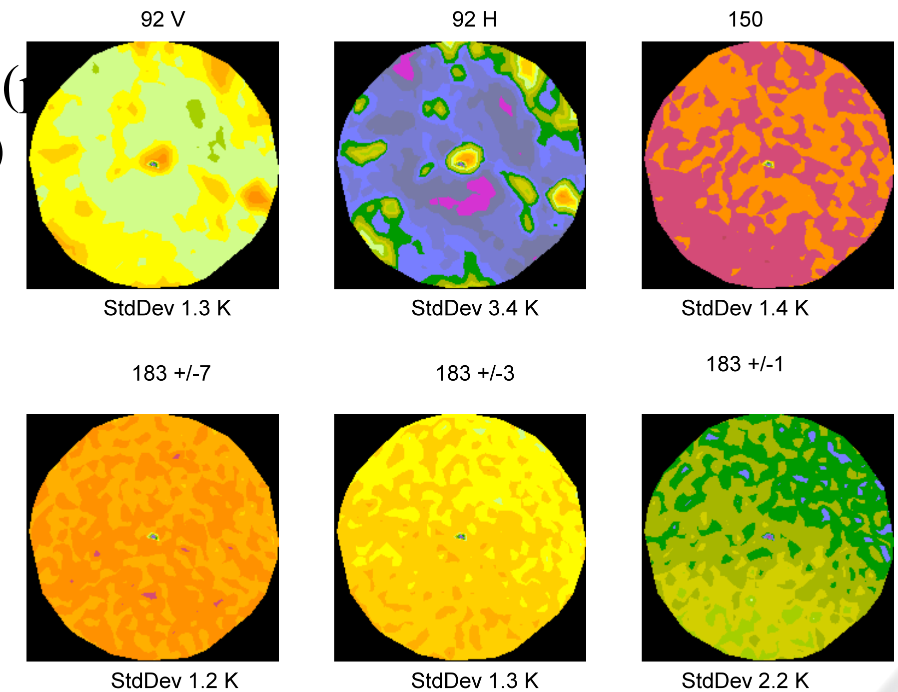
Satellite and ground truth data acquired by Aerospace at AFWA

Collocations performed on daily basis

- •SSMIS, SSM/T-1, SSM/T-2, SSM/I, AMSU, OLS
- •RSDRs, TDRs, SDRs, EDRs
- •NWP—AVN, NOGAPS, ECMWF (through NRL, courtesy of ECMWF)
- •CDFSII
- •Operational RAOBs
- •Surface data

•Software developed by Aerospace

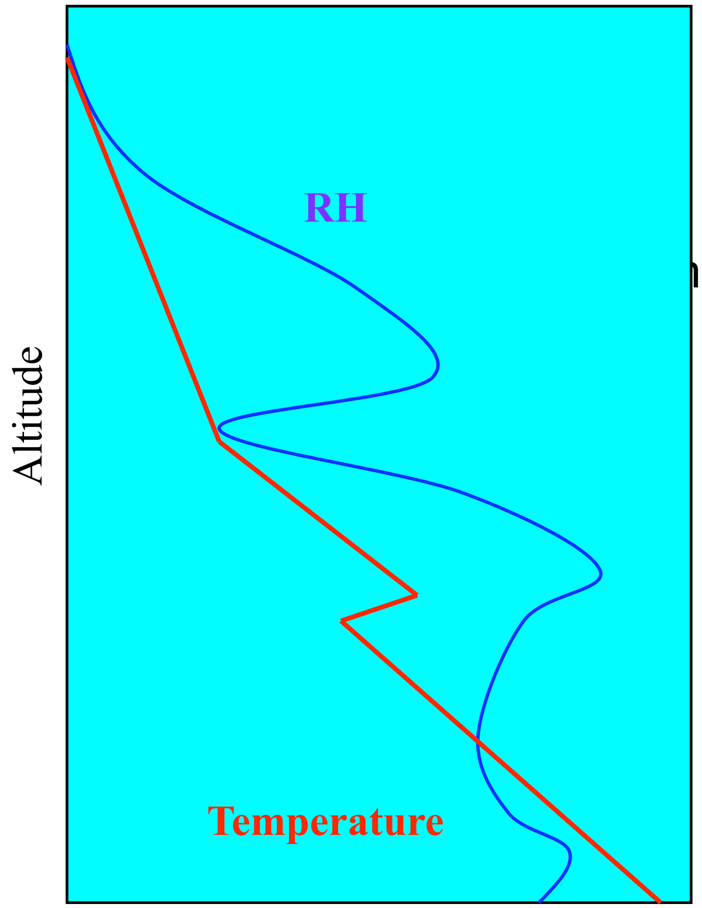
- •Standardized IDL data readers
- •Collocation software
- •Data analysis software
- •RAOB QC software



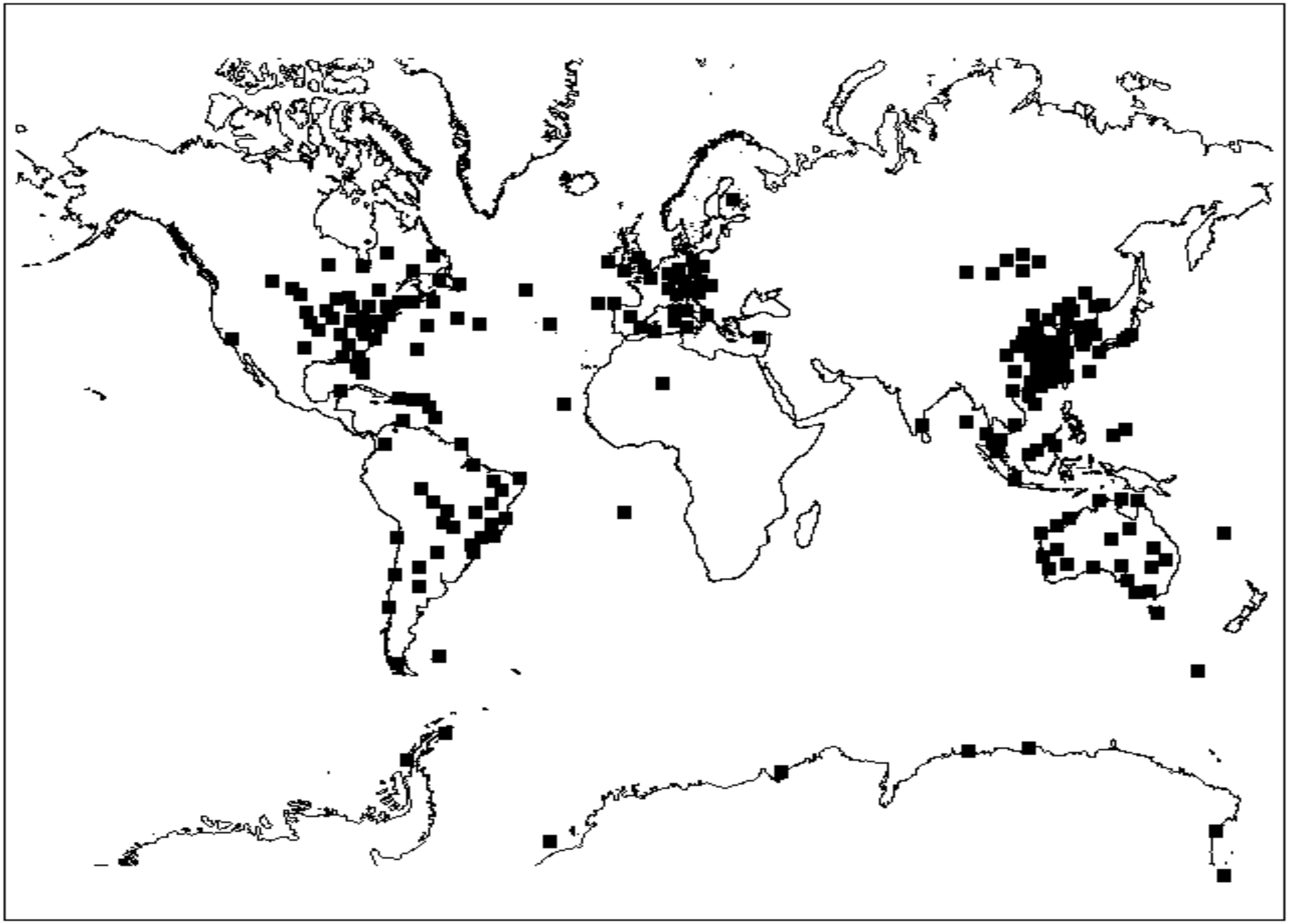
SSMIS Water Vapor TDRs
Barking Sands Region
6 Nov 2003

Automated Quality Control Software Essential for Radiosonde Data Screening

- Aerospace wrote its own QC Code which checks for:
  - *non-physical temps.*
  - *temp continuity*
  - *Non-physical lapse rate*
  - *Continuity at the tropopause*
  - *Many other conditions*
- Code corrects certain conditions
- Code rejects non-compliant profiles
  - *More than 60% rejection rate*



Operational Radiosonde Sites Contributing to SSMIS Cal/Val



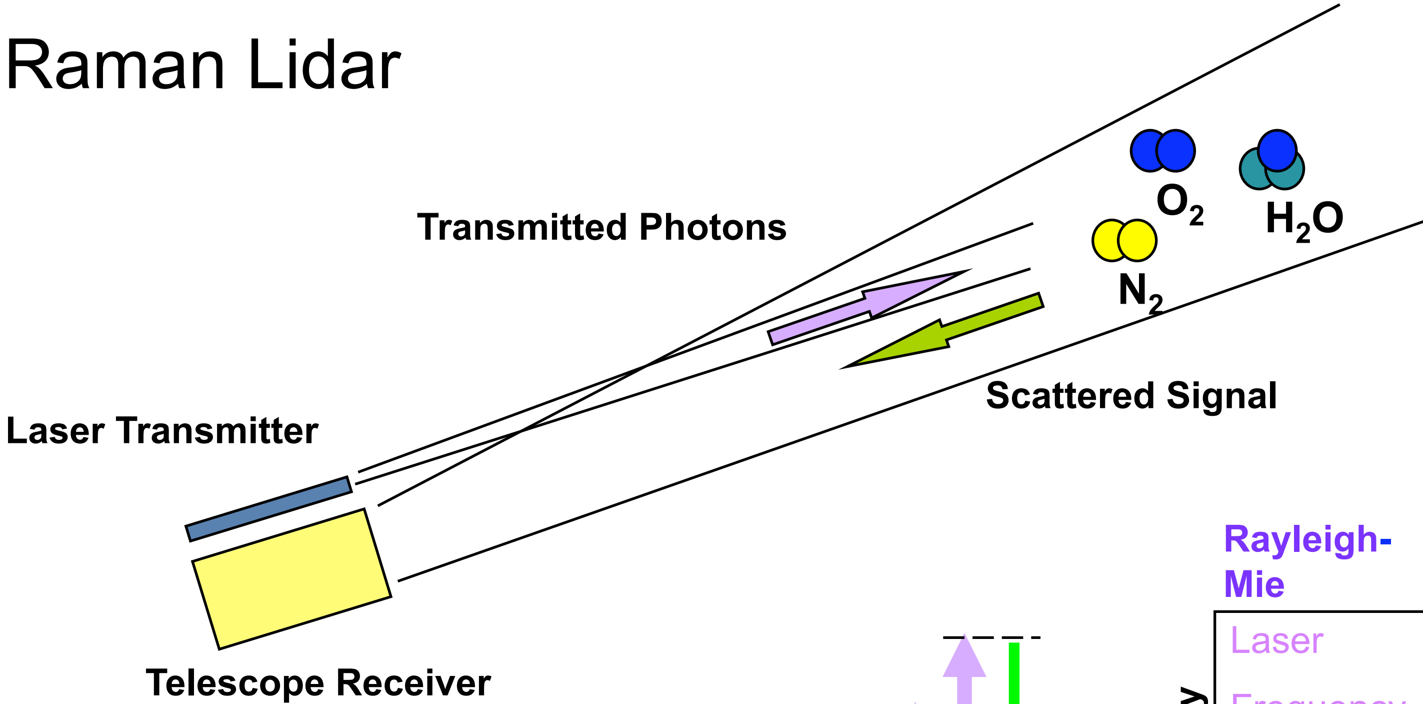
Atmospheric Lidar at Aerospace

AEROSPACE
Assuring Space Mission Success

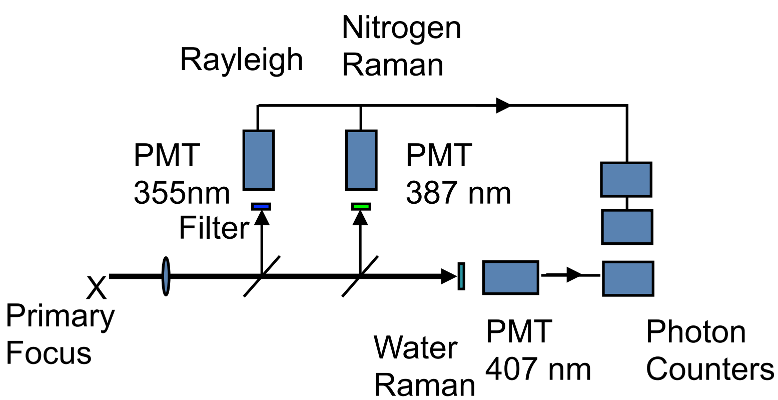
History of Lidar at Aerospace

- Raman Lidar of water at Malabar FL –1996
  - *Proof of value to DMSP Cal/Val efforts*
- Development of ATLS – 1996
  - *ATLS operational 1997*
- DMSP cal/val using ATLS -SSMI, SSM/T1, SSM/T2
  - *F14 and F15*
  - *Kauai*
  - *San Nicolas Is.*
  - *Table Mtn. Facility*
- DMSP F16 SSMIS cal/val
  - *Kauai*
- DMSP F17 SSMIS cal/val
  - *Kauai*

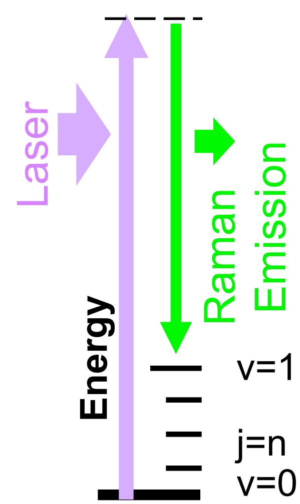
Raman Lidar



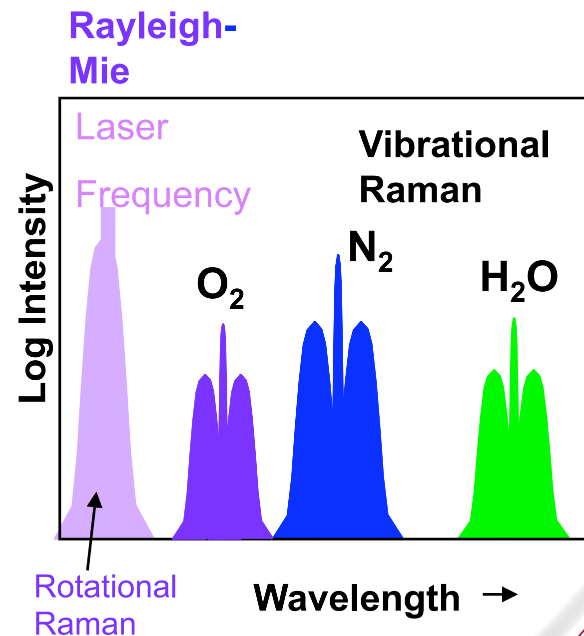
Transmitted Photons
O_2
H_2O
N_2
Scattered Signal
Laser Transmitter
Telescope Receiver



Rayleigh
Nitrogen Raman
PMT 355nm
Filter
PMT 387 nm
X
Primary Focus
Water Raman
PMT 407 nm
Photon Counters



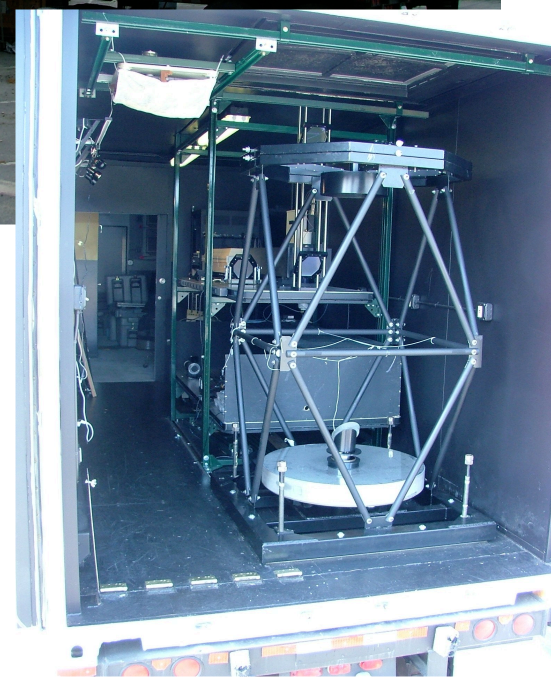
Laser
Raman Emission
Energy
v=1
j=n
v=0

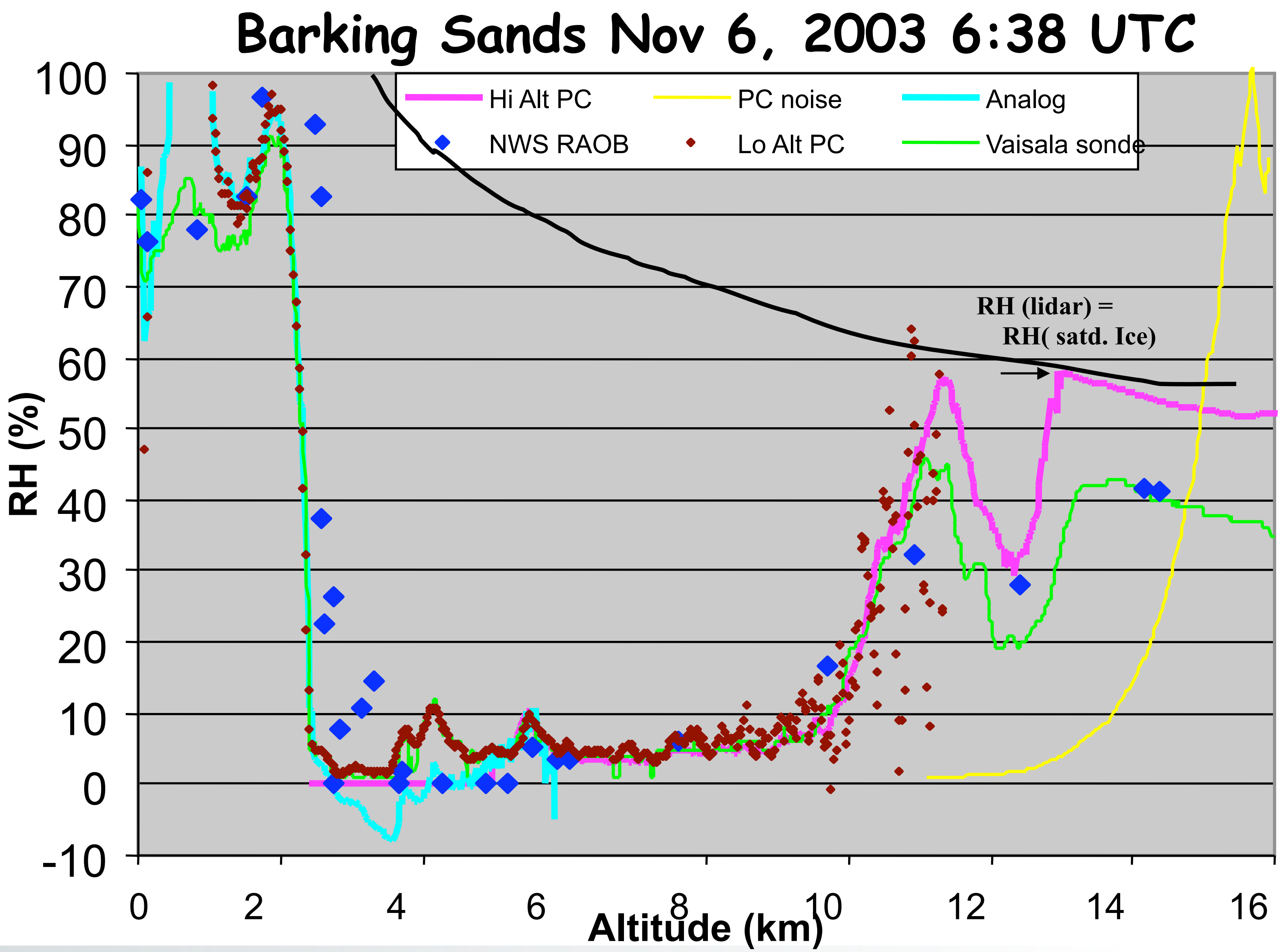


Rayleigh-Mie
Laser Frequency
Vibrational Raman
O_2
N_2
H_2O
Log Intensity
Rotational Raman
Wavelength →

ATLS-2

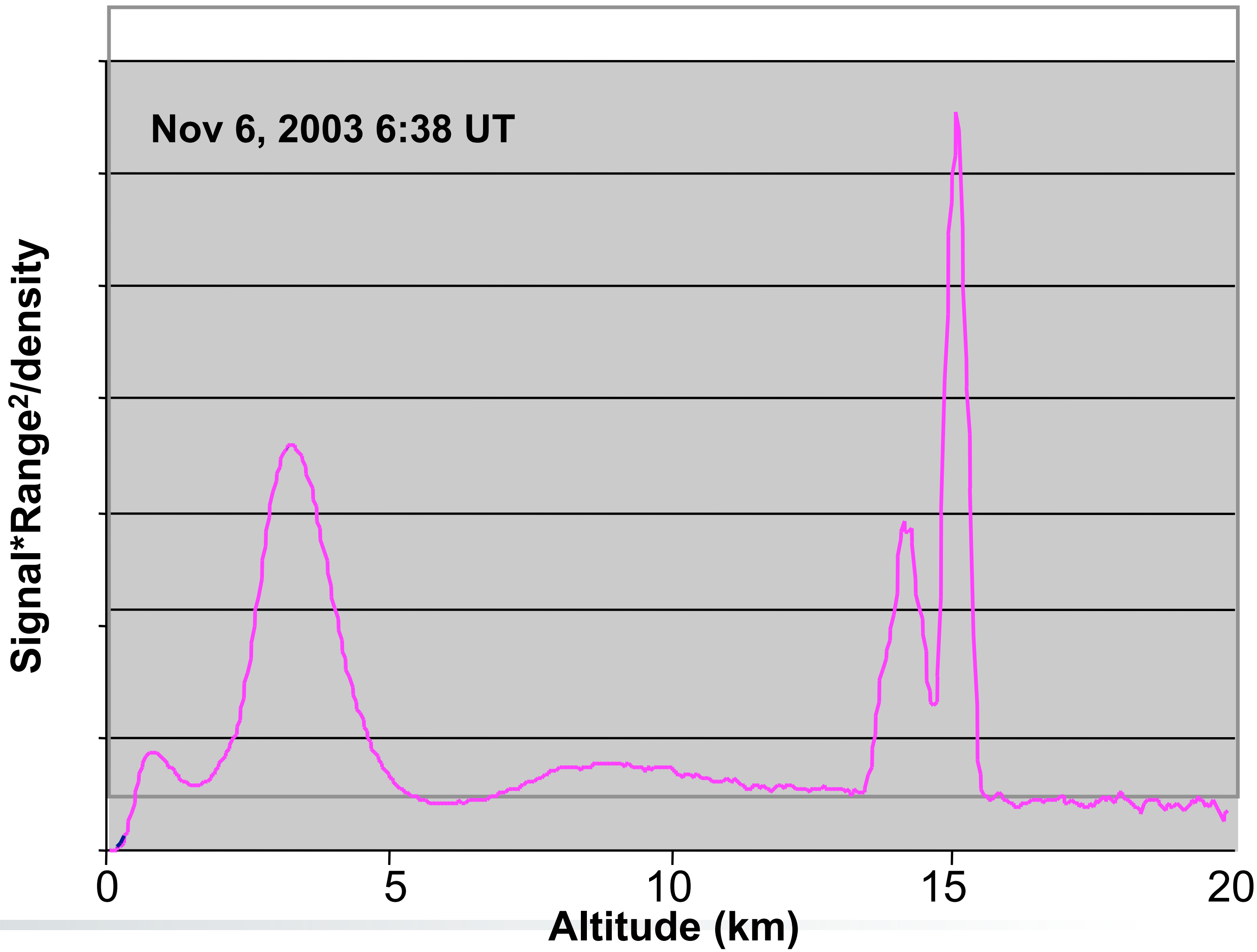
- 40’ std. shipping container
- Zenith pointing only
- 1 meter aperture receiver
- 12 W 355 nm
- 2.5 W 374 nm tunable
  - *Seeded, doubled Alexandrite laser*
- Mesospheric Temperature
  - *85-105 km alt.*
- Water , tropo and stratospheric temperature



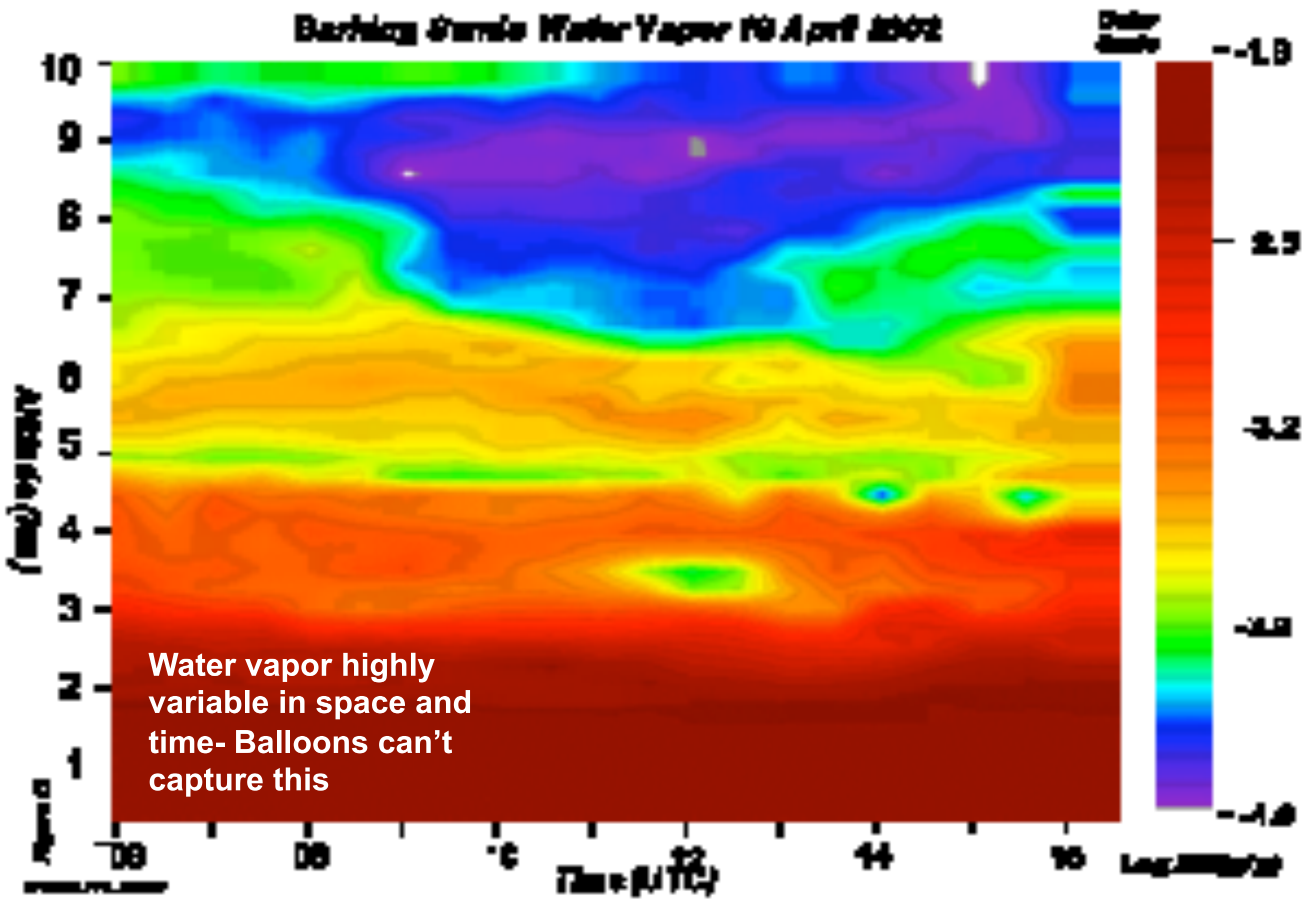


Barking Sands Nov 6, 2003 6:38 UTC
Hi Alt PC
PC noise
Analog
NWS RAOB
Lo Alt PC
Vaisala sonde
RH (lidar) =
RH(satd. Ice)
RH (%)
Altitude (km)
100
90
80
70
60
50
40
30
20
10
0
-10
0
2
4
6
8
10
12
14
16

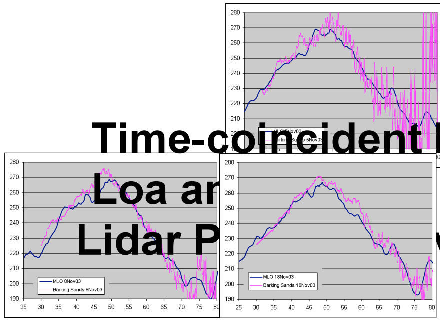
Depolarization Elastic Scattering



Barking Sands Water Vapor, April 19, '02



Time-coincident Mauna Loa ar… Sands Lidar P… vember



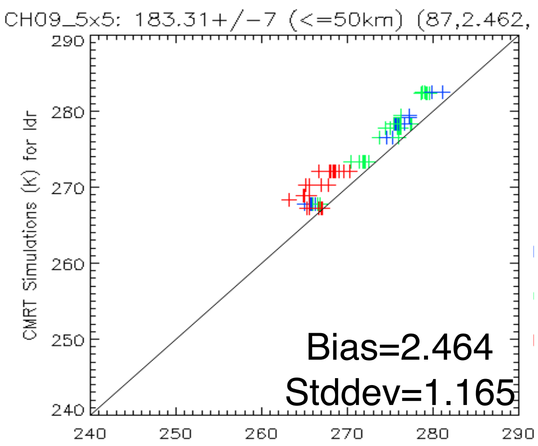
Temperature (K)

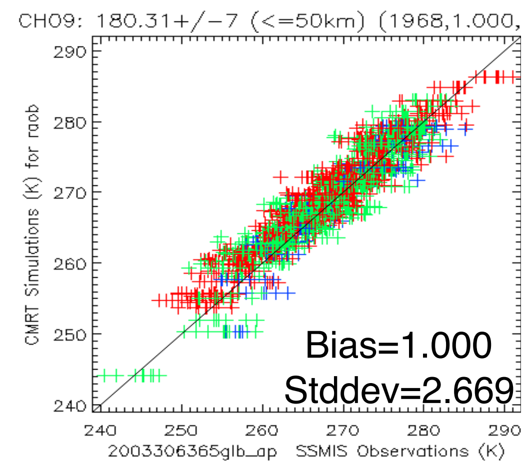
Altitude (km)

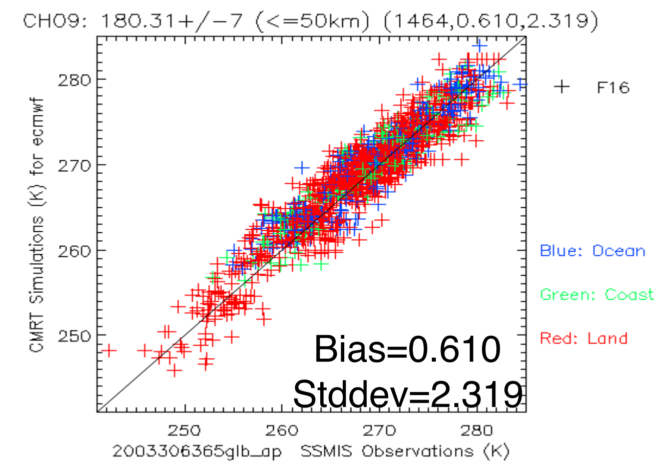
Altitude (km)

Scatter Plots of RTM Versus SDRs
SSMIS LAS Moisture Channels

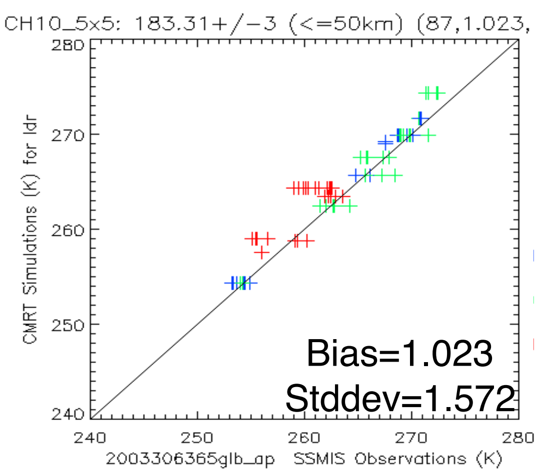
CH9

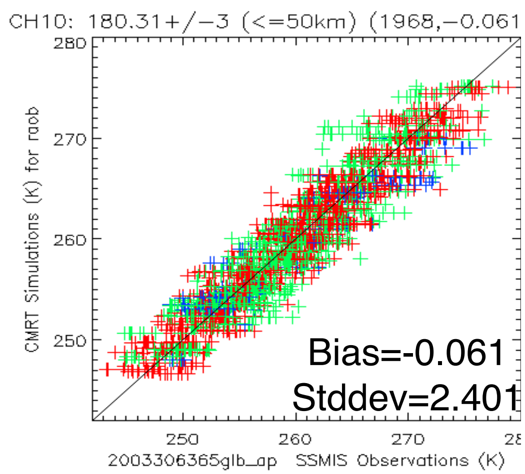


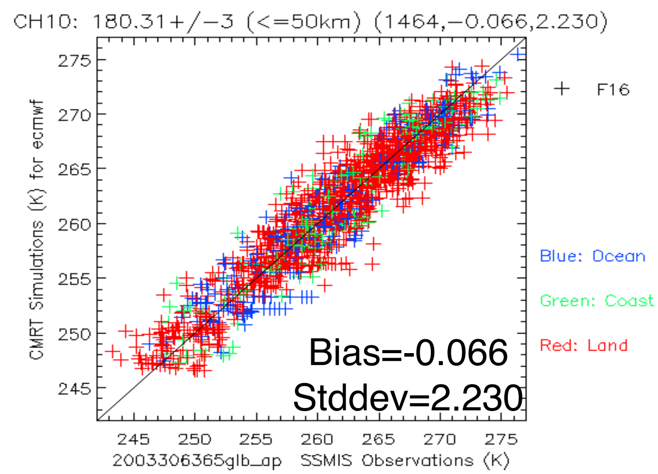




CH10 **Lidar** **RAOB** **ECMWF**







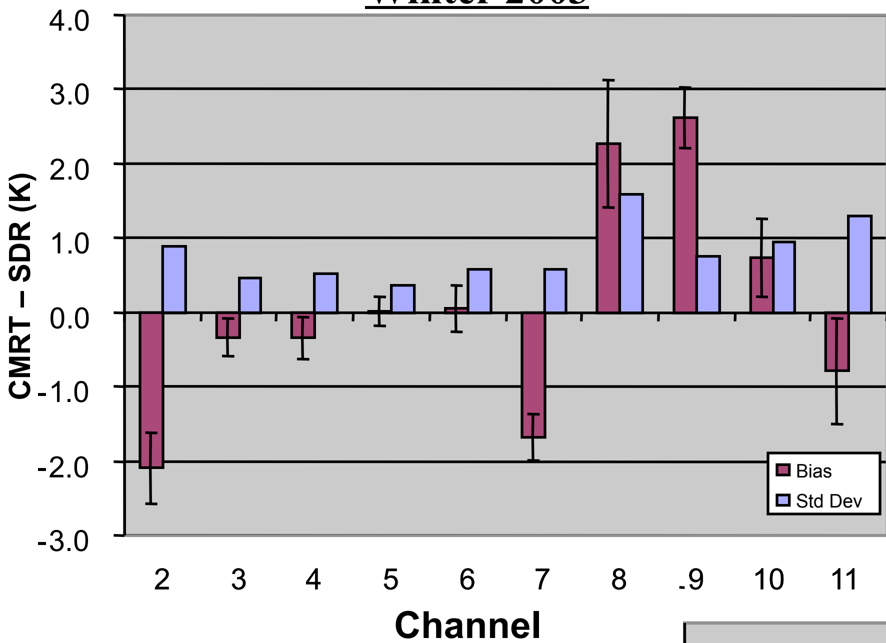
Collected charts4.ppt
yh040629b.ppt
SSMIS SSMT2 AMSUB-RT-Calibn-summaryppt

Rev 4 data

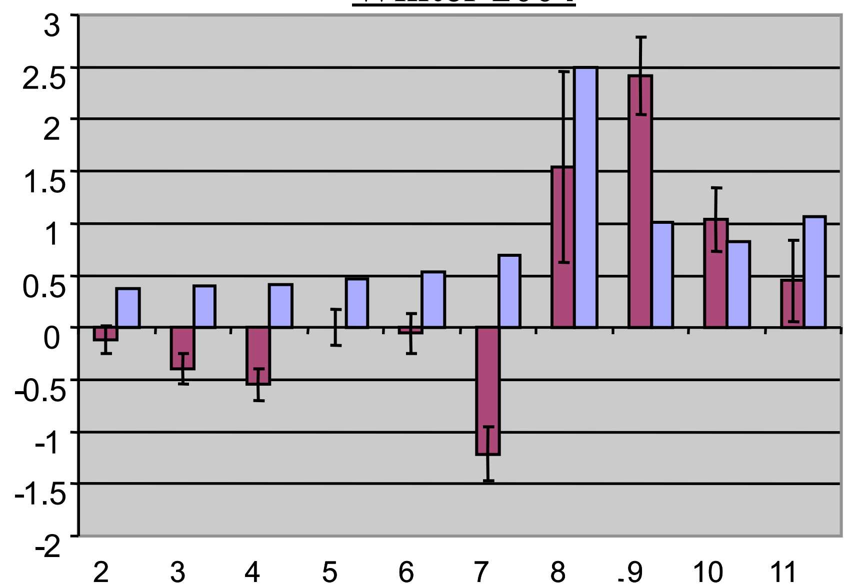
Lidar-Based RTM Resolved Seasonal Changes in SSMIS Bias

Barking Sands, Kauai Lidar Measurements

<u>Winter 2003</u>



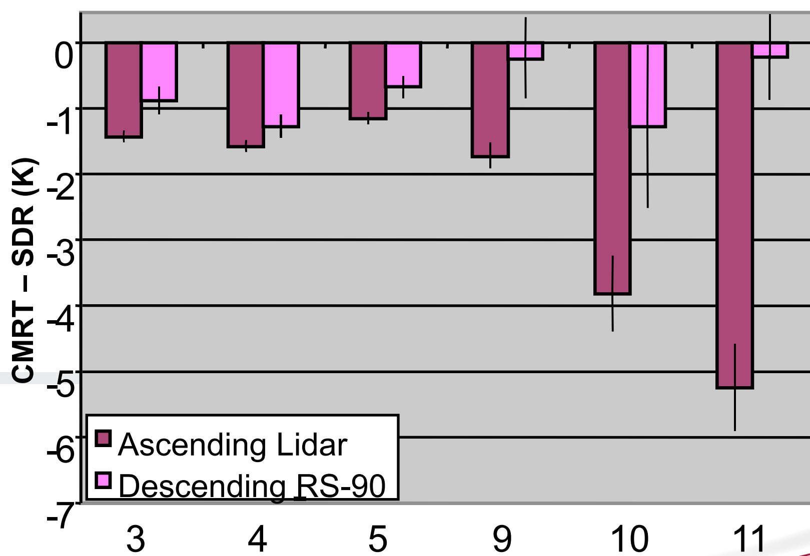
<u>Winter 2004</u>



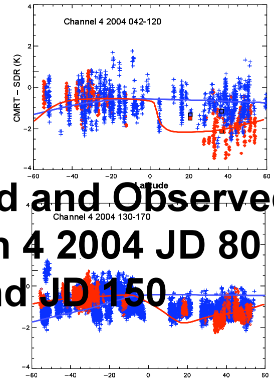
<u>Spring 2004</u>

Bias

Ascending and Descending Orbits



Cal/Val Discovered Significant SSMIS Bias Changes



Simulated and Observed Bias Ch 4 2004 JD 80 and JD 150

- During specific seasons SSMIS data show strong dependence on ascending/decending node and lattitude

SSMIS Cal/Val Lessons Learned: Critical Sources of Ground Truth

- Operational Radiosondes – **Critical for LAS**
- NWP – **Critical for LAS –ECMWF**
- Special Radiosondes – **Critical for LAS**
- Lidar
  - *Barking Sands* – **Critical for LAS**
  - *JPL* – **Critical for UAS --MLO**
  - *ARM/CART SGP* – *Unsuccessful, RS90 Supporting*
  - *Other* – *Insufficient data*
- Aircraft
  - *CoSMIR* – **Very Helpful for LAS**
  - *APMIR* – **Critical for Surface Channels**
  - *Special Campaigns* – *Supporting LAS*
  - *ACARS* – *Insufficient matchup data*

Lidar played an important role in SSMIS cal /val

- *Deployed to Kauai over two-year period*
- *Made water vapor measurements to 18 km altitude coincident with F-16 over-flights*
- *Made temperature measurements to 85 km altitude coincident with F-16 over-flights*
- *Supported ER-2 data showing polarization problem*
- *Helped to uncover reflector emissivity issue producing bias errors*

BACKUP SLIDES

NPOESS Sounding Requirements

Applicable ground truth methods

NWP and/or RAOBs | **Lidar + Radiosondes**

Scientific Radiosondes | **Exceeds current state-of-art**

AVMP performance requirements and current estimates

Subject	**Specified Values**	**Threshold Values**
Clear, Surface to 600 mb	14%	0% or 0.2g/kg)
Clear, 600 mb to 300 mb	15%	35% (or 0.1g/kg)
Clear, 300 mb to 100 mb	12% (or .05g/kg)	35% (or 0.1g/kg)
Cloudy, Surface to 600 mb	16%	20% (or 0.2g/kg)
Cloudy, 600 mb to 300 mb	17%	40% (or 0.1g/kg)
Cloudy, 300 mb to 100 mb	16% (or.05g/kg)	40% (or 0.1g/kg)

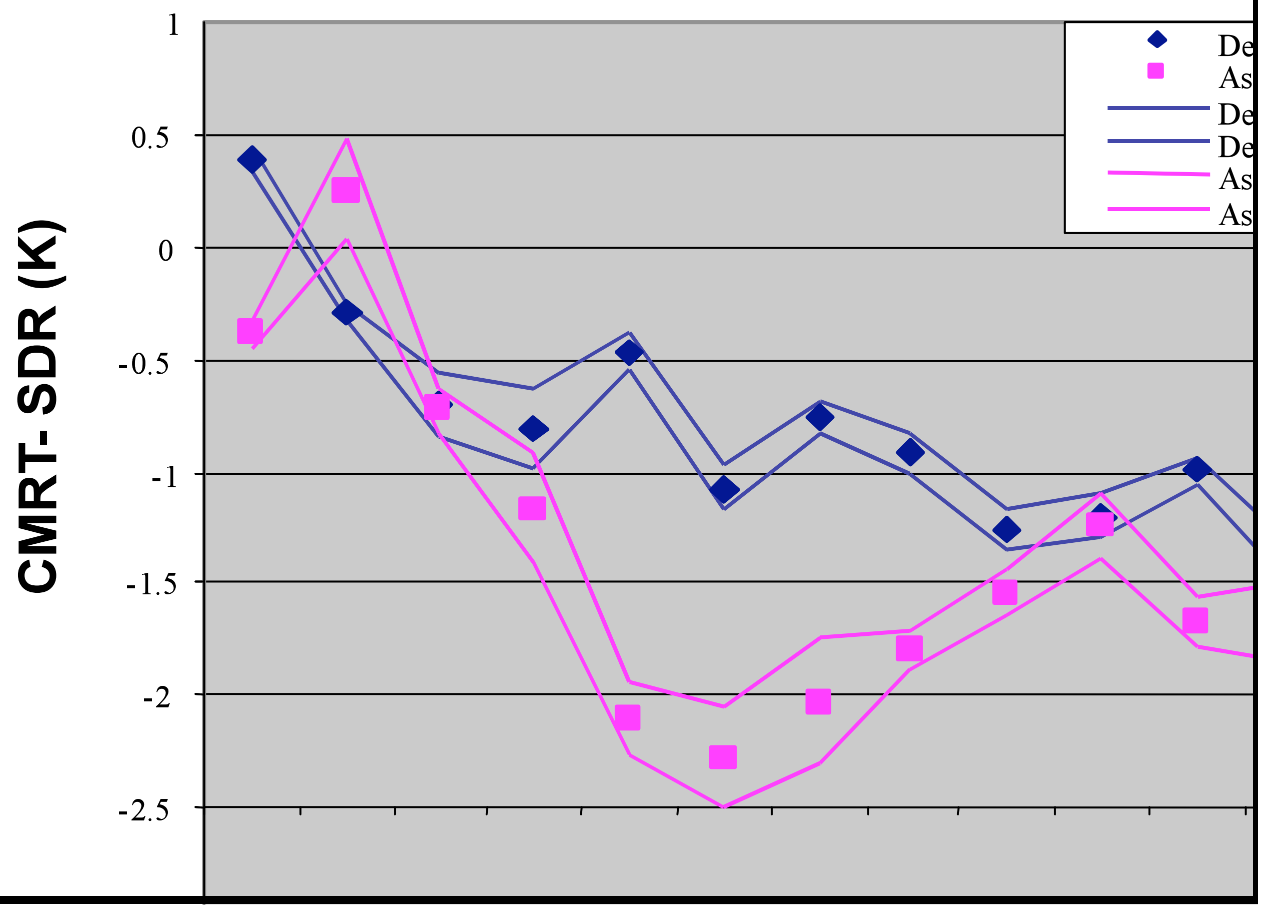
AVTP performance requirements and current estimates

Clear, Surface to 300 mb	0.9 K / 1 km Lyr	1.6K
Clear, 300 mb to 30 mb	1 K / 3 km Lyr	1.5K
Clear, 30 mb to 1 mb	1.5 K / 5 km Lyr	1.5K
Clear, 1 mb to 0.5 mb	3.5 K / 5 km Lyr	3.5K
Cloudy, Surface to 700 mb	2.0 K / 1 km Lyr	2.5K
Cloudy, 700 mb to 300 mb	1.4 K / 1 km Lyr	1.5K
Cloudy, 300 mb to 30 mb	1.3 K / 3 km Lyr	1.5K
Cloudy, 1 mb to 0.5 mb	3.5 K / 5 km Lyr	3.5K

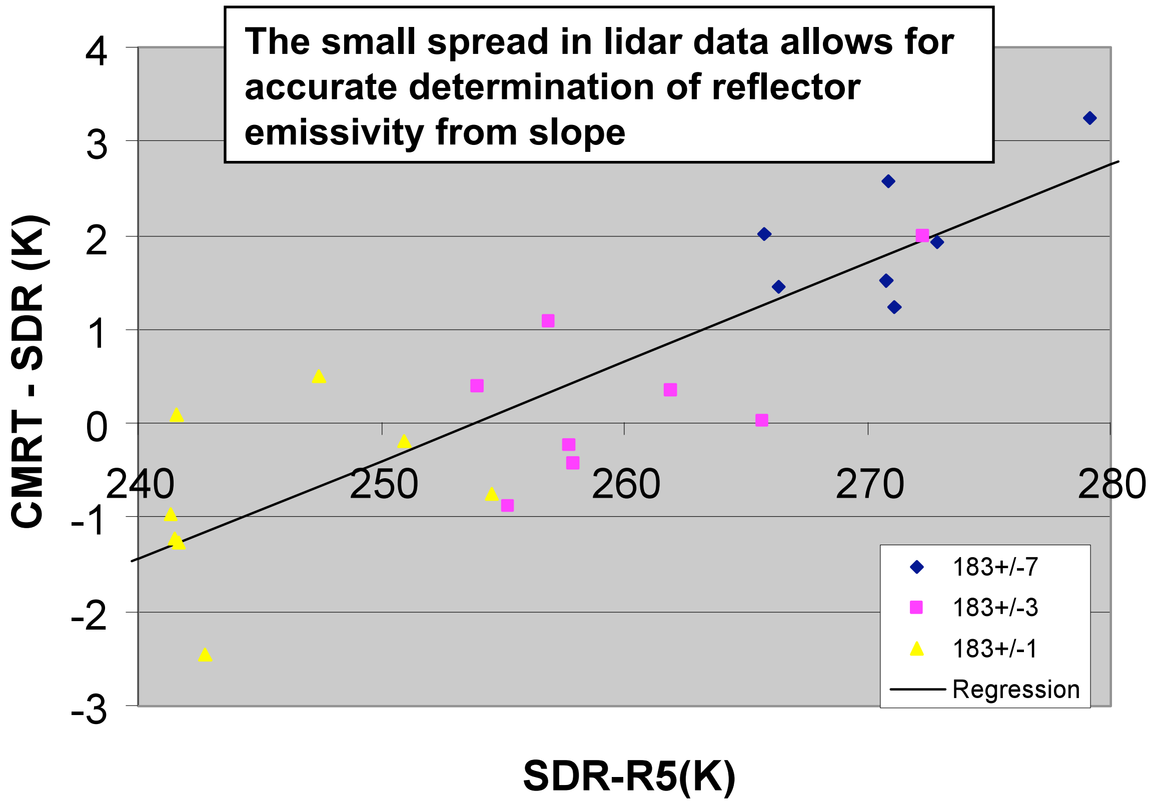
NPP ATMS Radiometric calibration error limit: ~0.5**K** (pg 41 NPP Cal/Val Plan, Dec 30, 2001)

Ascending and Descending Bias over Conus Versus Month

SSMIS Channel 4 Based on Raobs



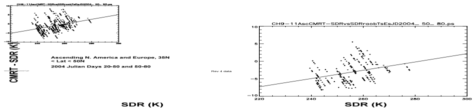
183 GHz Bias Versus SDR, SSMIS-Lidar Barking
Sands Nov03-Jan04



regression_F16_SSMIS_Lidar_BS_TsEs.xls

Rev 5 data

183 GHz Bias Derived from Operational Radiosondes



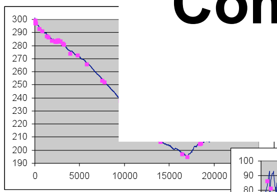
Slope = 0.128 +/−0.014
Intercept = 261 K

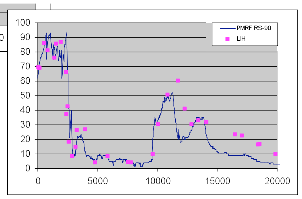
Slope = 0.118 +/−0.020
Intercept = 282 K

The large spread in balloon data does not allow for accurate determination of reflector emissivity from slope

Comparisons between Radiosondes

NWS Lihue Raob and Barking Sands RS-90 Radiosonde





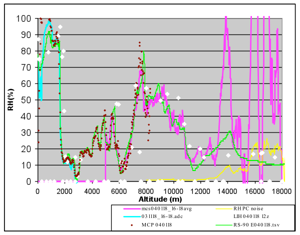
Ave Temp Dif	0.6 K
Std Dev	0.9 K
RMS	1.1 K
0-25 km	

Temperature (K)

Altitude (m)

Ave RH Dif	0.7%
Std Dev	13.3%
RMS	13.3%
0-15 km	

RH (%)



RH Calibration, Barking Sands Lidar

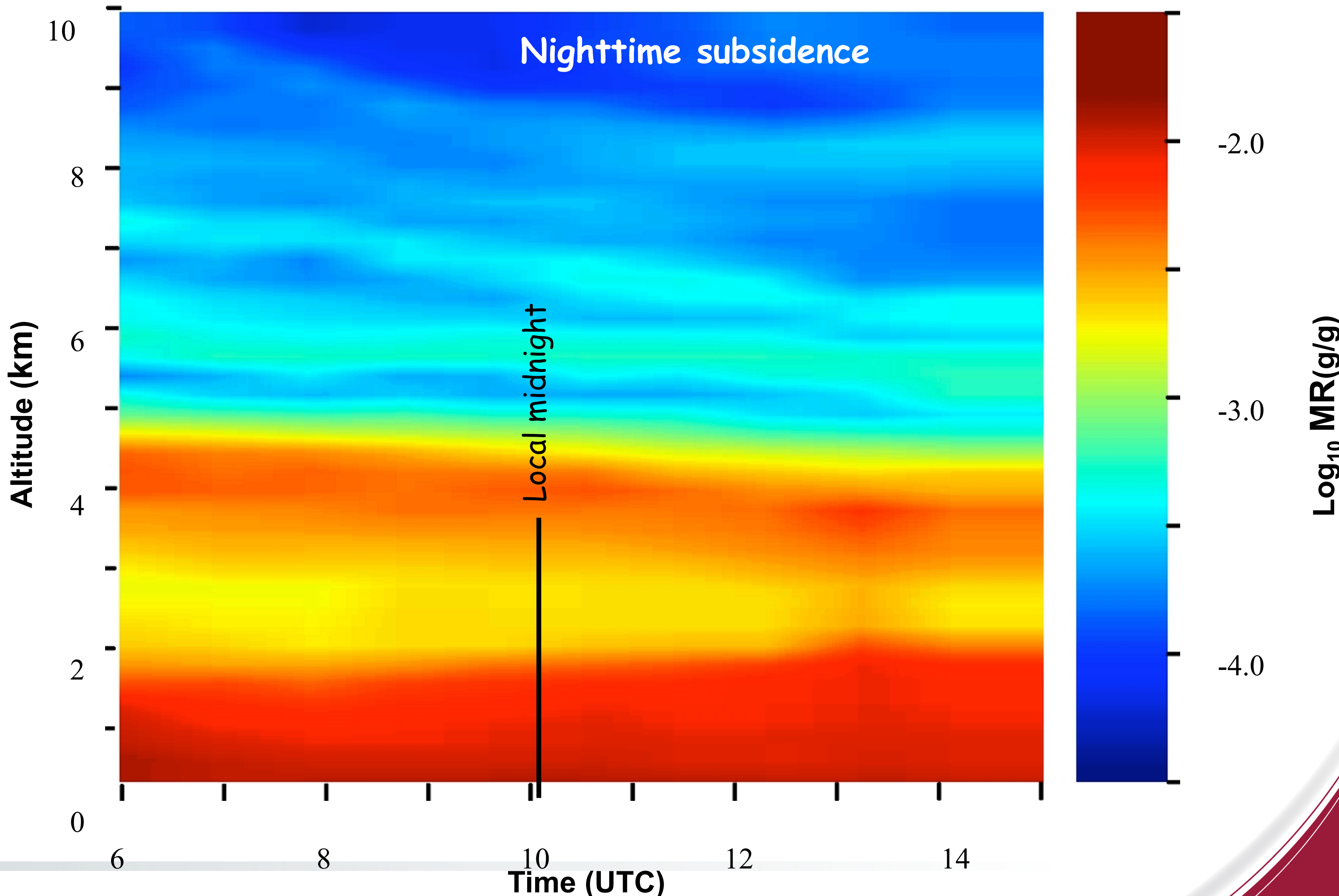
ATLS-1 Specifications

- Full sky scanning .75 m aperture
- 12W 10 nsec 355 nm transmit beam
- 9 channel receiver
  - *3 Water (high/low alt.)*
  - *2 Nitrogen(high/low alt.)*
  - *4 Elastic (2 polarizations/ high/low)*
- Transportable by truck or military aircraft (C-130, C-5, C-17)
- Water to 18 km
- Temp to 85 km
- 70 km range for cloud detection
- Requires 1-2 days setup
- Power (50 amps, 208 3 phase)

Water in the Atmosphere

- Water is not well mixed in the atmosphere
  - *Above the mixing layer water is found in layers, often not thicker than tens of meters*
  - *Lidar is sensitive to the presence of such thin layers*
- By measuring the mixing ratio and the temperature, relative humidity (RH) can be determined using lidar
- Excellent spatial and temporal resolution

Barking Sands Water Vapor, April 25, '02



Rayleigh Temperature Lidar

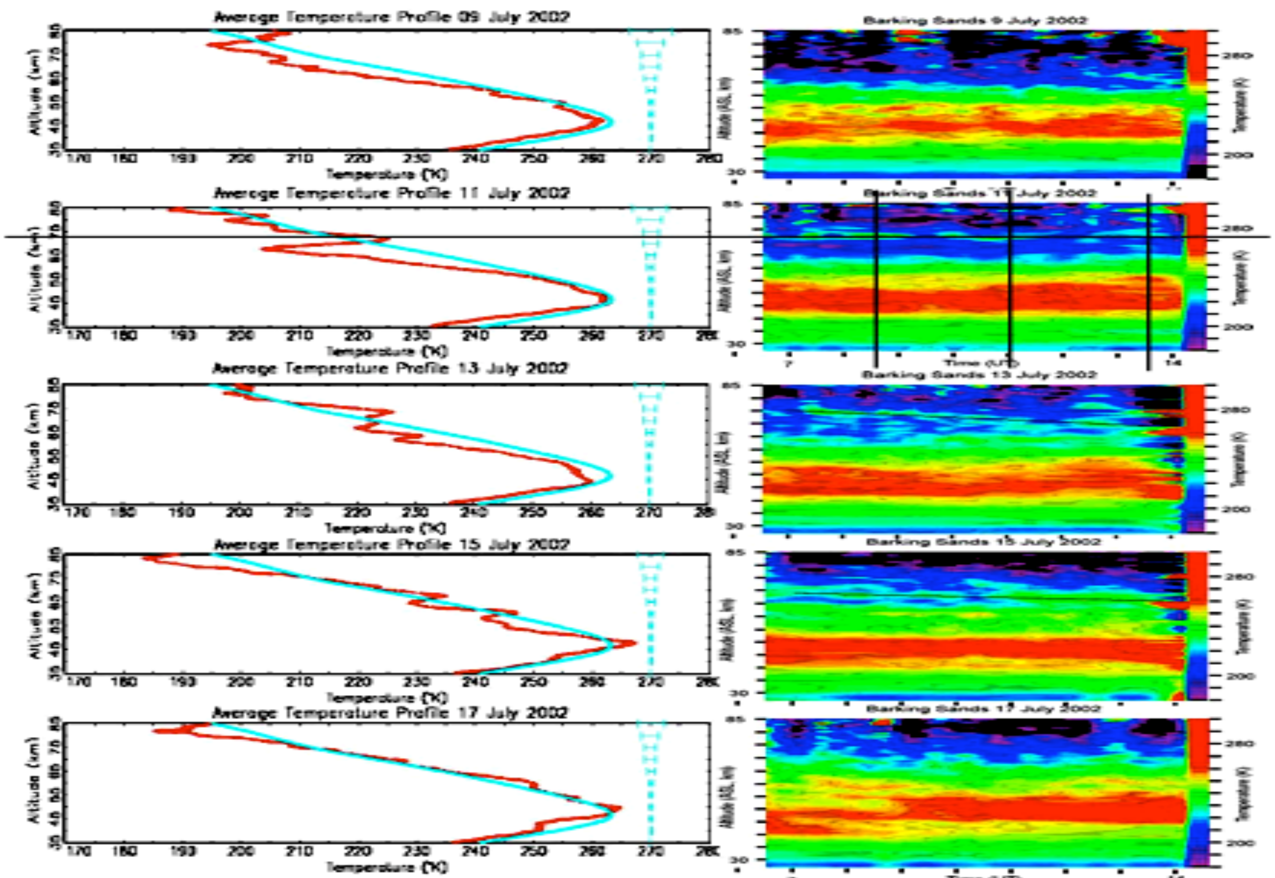


Figure 1: Nightly average temperatures for 9-17 July, 2002 (left) and corresponding false color plots of 16.5minute averages vs. UT on the right. A prominent thermal inversion at 72 km is apparent on the 11th, and oscillates with a period of approximately 2.5 hours. The MSIS 2000 profile average for 9-17 is superimposed on the nightly average, and error bars are to the right.

40

Lidar Siting

- ATLS is a mobile system, capable of being deployed anywhere on the globe by military aircraft, and in CONUS by truck
- Planned lidar data sites include
  - *CART ARM site (mid-CONUS)*
    - Water, temp, atms. Density, AOT
  - *Mid-Pacific*
  - *Eastern CONUS*

ATLS attributes for NPP/NPOESS cal/val

- Mobile
  - *Siting anywhere on the globe*
  - *Sea level siting important for water vapor*
- Flexible
  - *Can be configured for a variety of measurements*
- Scanning capability
  - *Cloud mapping*
  - *LOS with satellite sensor*
- Balloon sondes co-located with lidar
  - *Insures high quality data accuracy*
  - *Allow complete altitude coverage for temp and humidity, important for radiative transfer calculations*

Lessons Learned during SSMIS Cal/Val

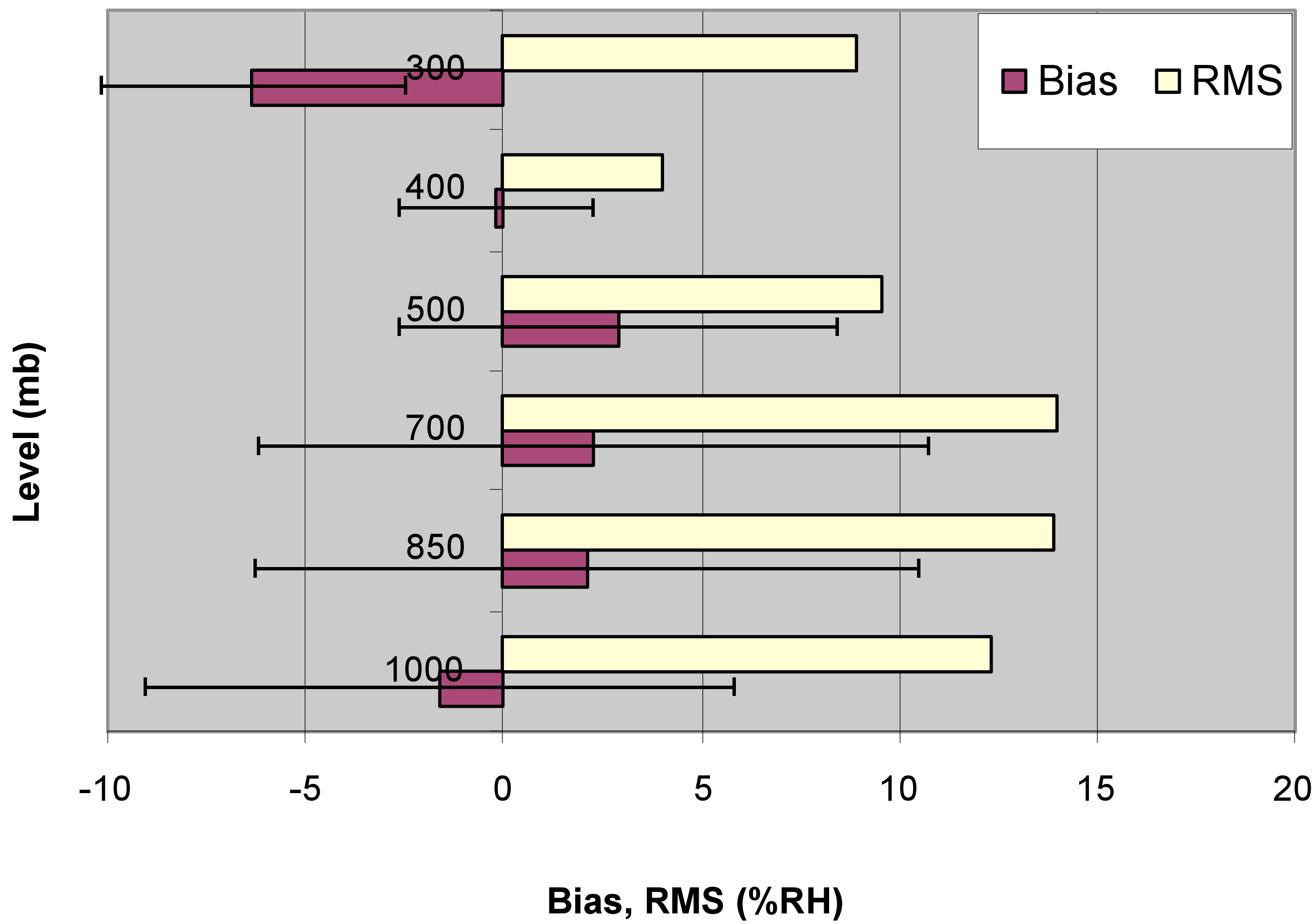
- Do not rely on derived performance estimates
- Verify calibration is stable to environmental temperature using sources emitting at measurement frequencies (Confirm frequency/bandpass drift is acceptable. Blackbody test is inadequate.)
- Verify polarization for each feedhorn
- Verify off-axis rejection for full system at all frequencies
- Verify calibration for full radiometric path
  - If reflector is outside calibration path, verify microwave emissivity at all measurement frequencies, verify reflector surface roughness, surface durability, and IR and visible characteristics
  - Verify intrusion-free field of view
  - Verify stable calibration in thermal vac under varying simulated solar loads to all instrument components

---

Verify is defined above as "develop and apply reliable laboratory test methods"

ECMWF RH Versus Lidar

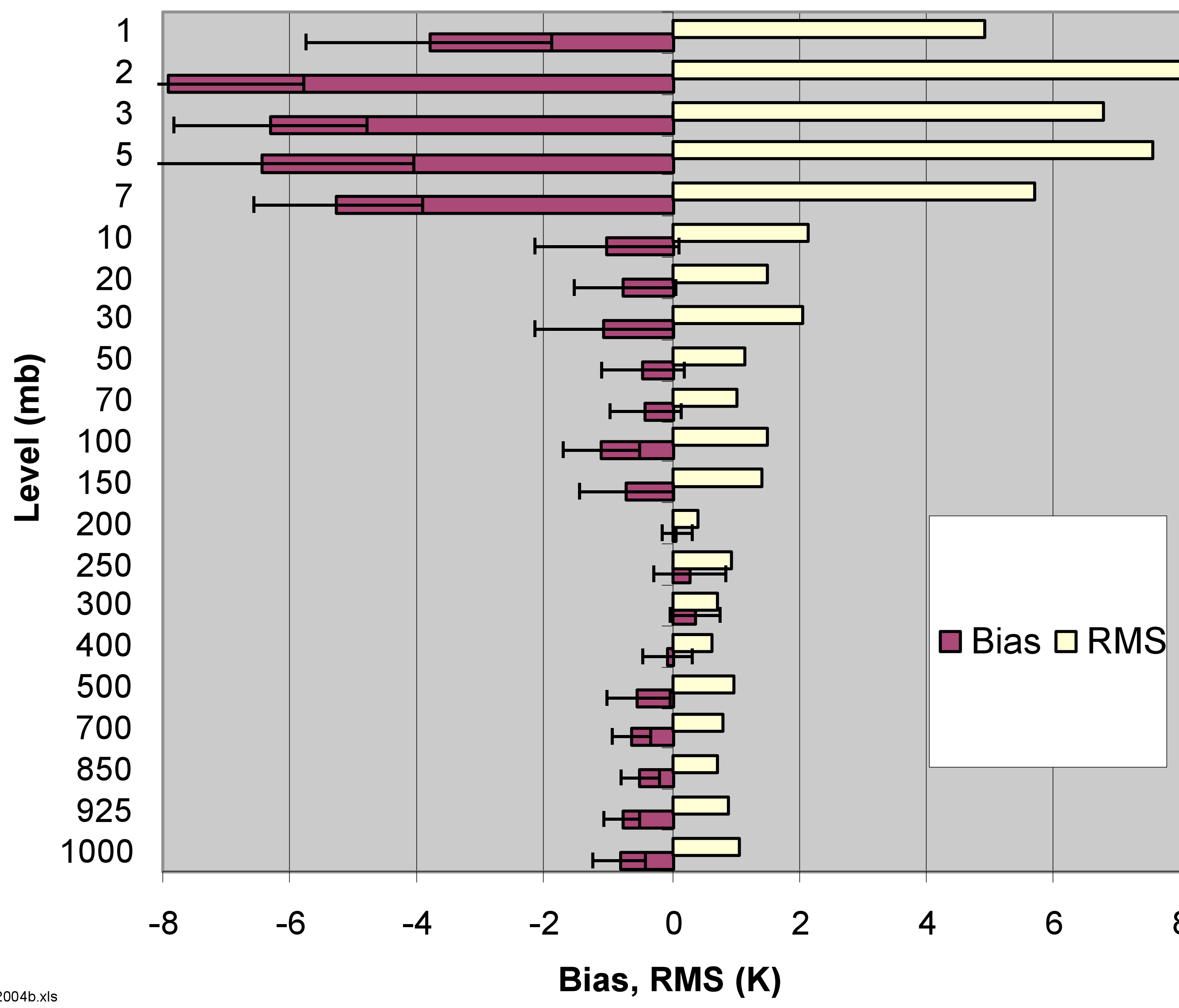
Barking Sands Nov 2003 – Jan 2004



ECMWFvsLidarBS2004b.xls

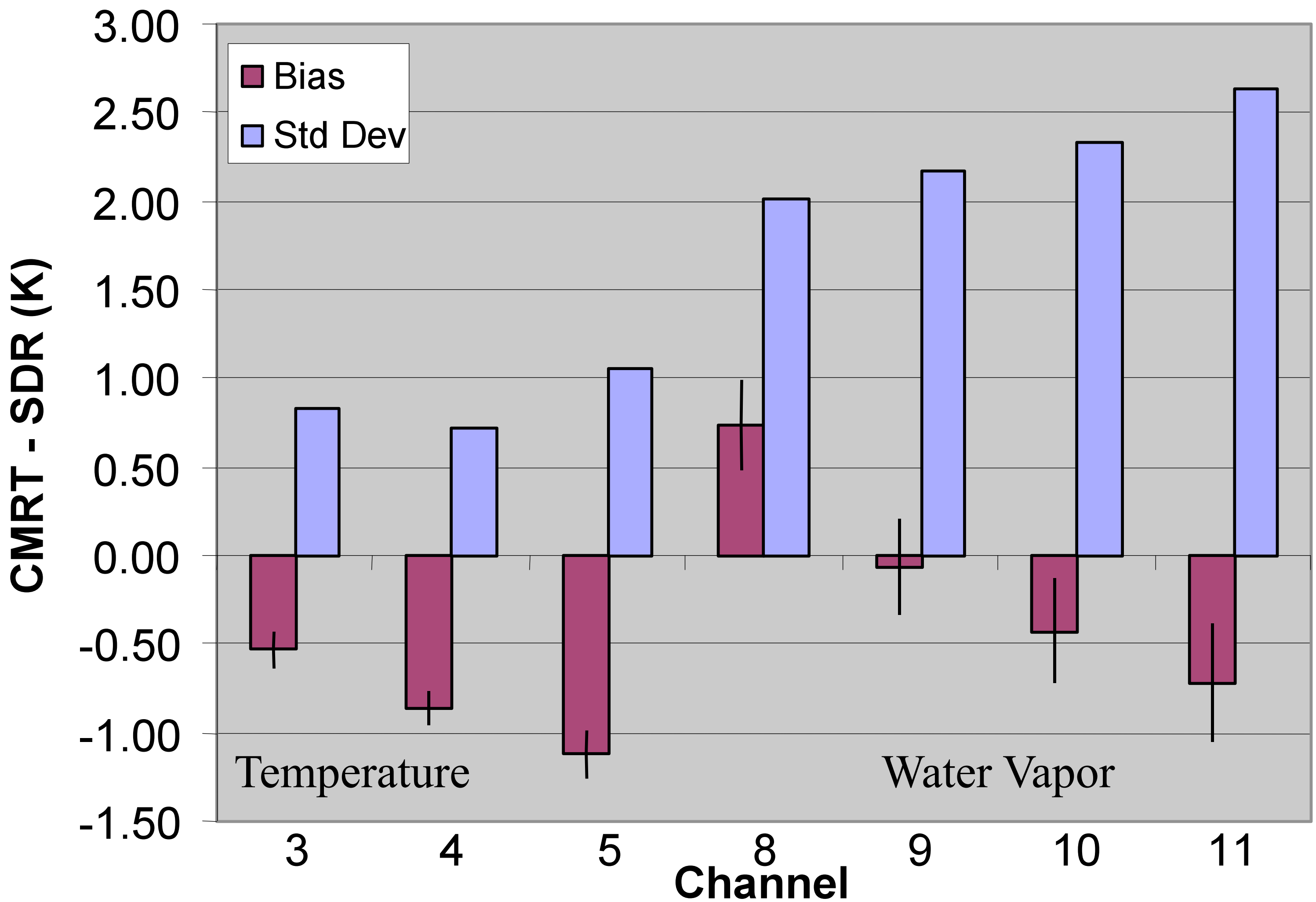
ECMWF Temperature Versus RS-90 & Lidar

Barking Sands Nov 2003 – Jan 2004



ECMWFvsLidarBS2004b.xls

SSMIS RTM Bias, Yearly Average
Measured by Global Operational Radiosondes



CMRT-SDRlatCDFSII2004JD13-113AllLocs.ppt

cdfsii_screenedCMRTraob-SDRs.xls

Rev 4 data

SSMIS Cal/Val Lessons Learned: Measurement Wish List

- Radiative transfer
  - –Improve atmospheric transmission model
  - –Improve surface model
- Operational Radiosondes
  - –Increase vertical resolution
  - –Improve moisture accuracy
  - –Improve ceiling altitude
  - –Improve high altitude accuracy
  - –Increase number of collocations
  - –Decrease ascent time

SSMIS Cal/Val Lessons Learned: Don't Underestimate Required Resources!

- Personnel
  - *Data archive management (Thomas, Kishi)* 2
  - *Radiative transfer (Hong)* 2
  - *Special Campaigns (Swadley)* 2
  - *Lidar (Farley)* 1
  - *Data Analysis (Wessel, Fote)* 3
  - *Program Management (Boucher, Bohlson)* 1
  - *Special Investigations (Kunkee, Plonski, Boucher)* 2
  - *DGS, thermal* 1

- Total 14 FTE yrs

SSMIS Cal/Val Lessons Learned: Measurement Wish List

- Improved NWP
  - *Improved vertical resolution*
  - *Improve moisture accuracy*
  - *Improve high altitude temperature accuracy and increase ceiling*
  - *Improve in frontal regions*
  - *Improve cloud characterization*
  - *Update hourly*
- Lidar
  - *Frequent operation, including daytime*
  - *Multiple locations, marine, continental, polar*
  - *Extend to 100 km*
  - *Avoid orographic influences*
  - *Improve calibration stability*
  - *Improve cloud diagnostics, add upward microwave*