Microwave Remote Sensing:
1. Microwave Radiometry Principle

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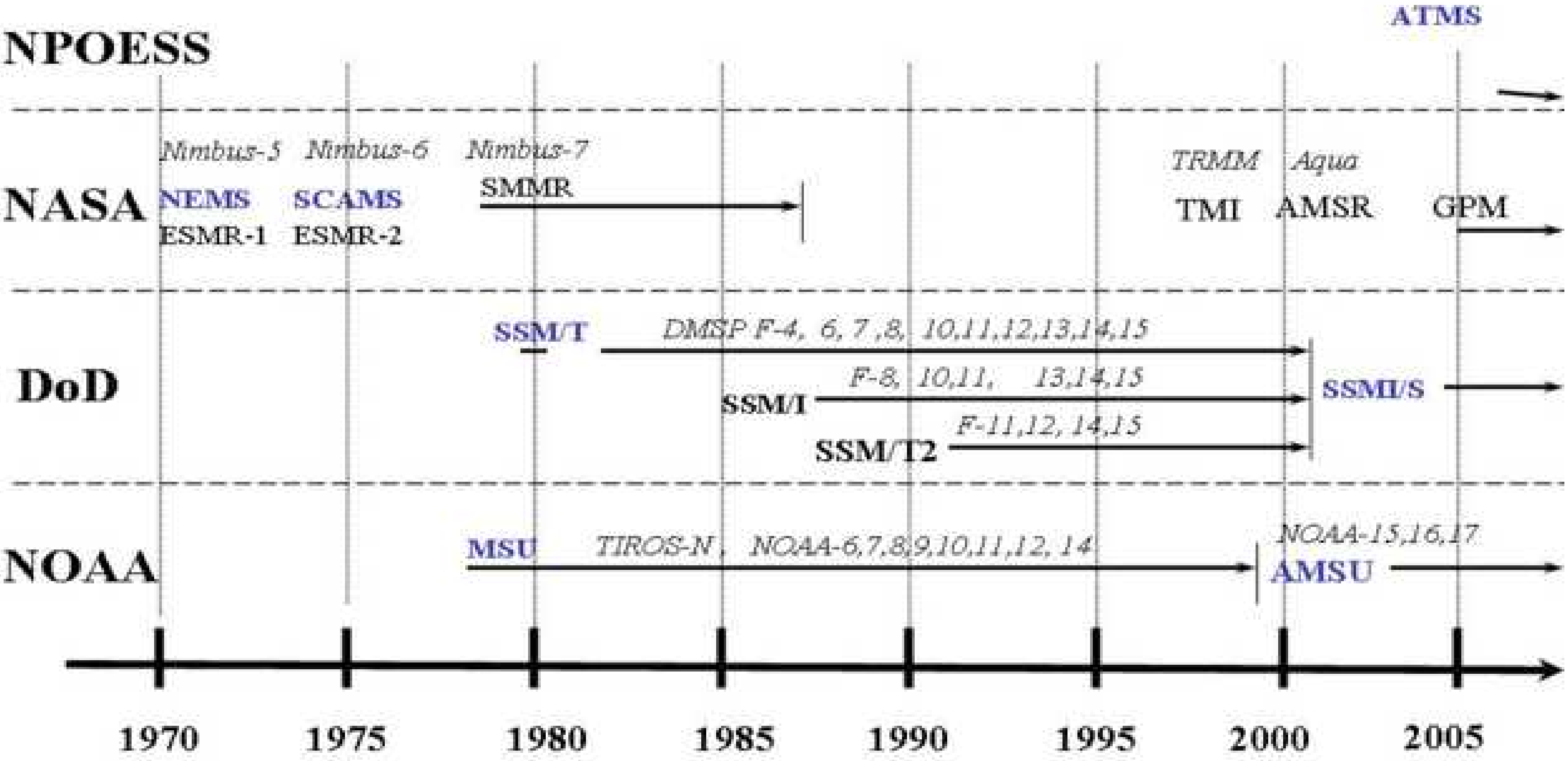
2009 Update

Outline

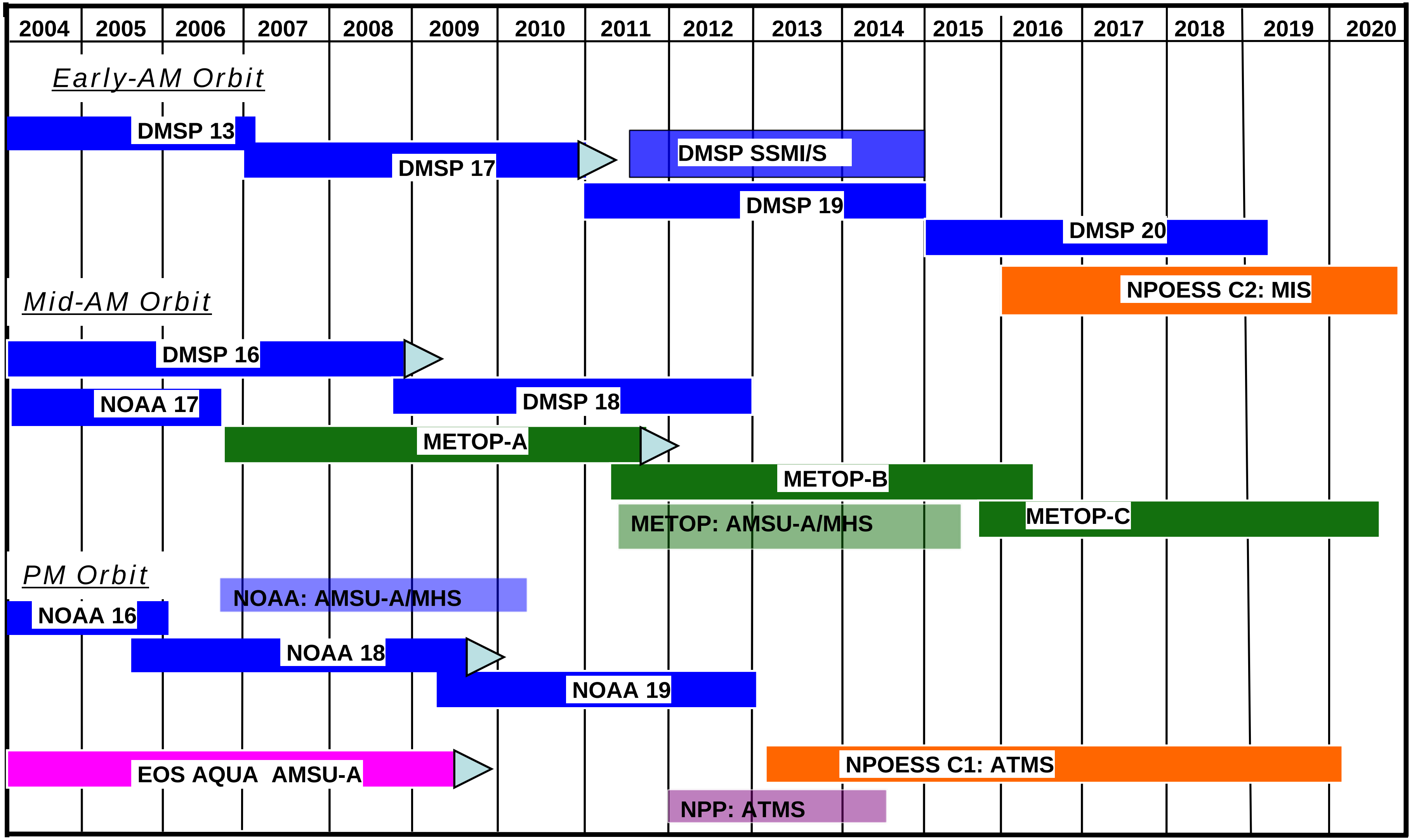
1. **Why do we need microwave sensors?**
2. **History of microwave instruments**
3. **Microwave radiometry system**
4. **Instrument calibration and intersensor calibration**
5. **Microwave sensing principle and products**

Evolution of Passive Microwave Sensors

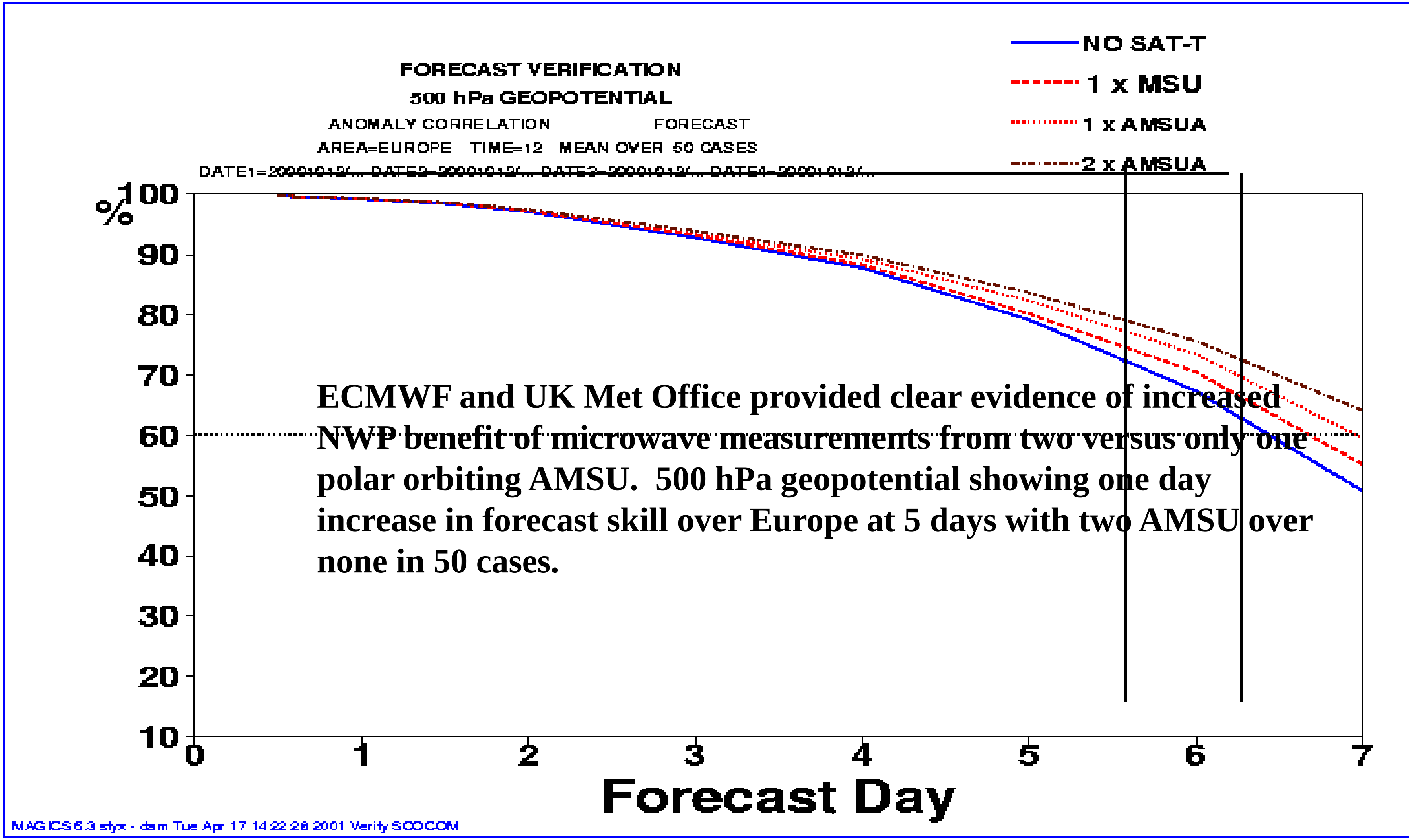


The instruments with a bold font contain temperature sounding channels

US Polar Missions with MW Sensors for Operational Uses

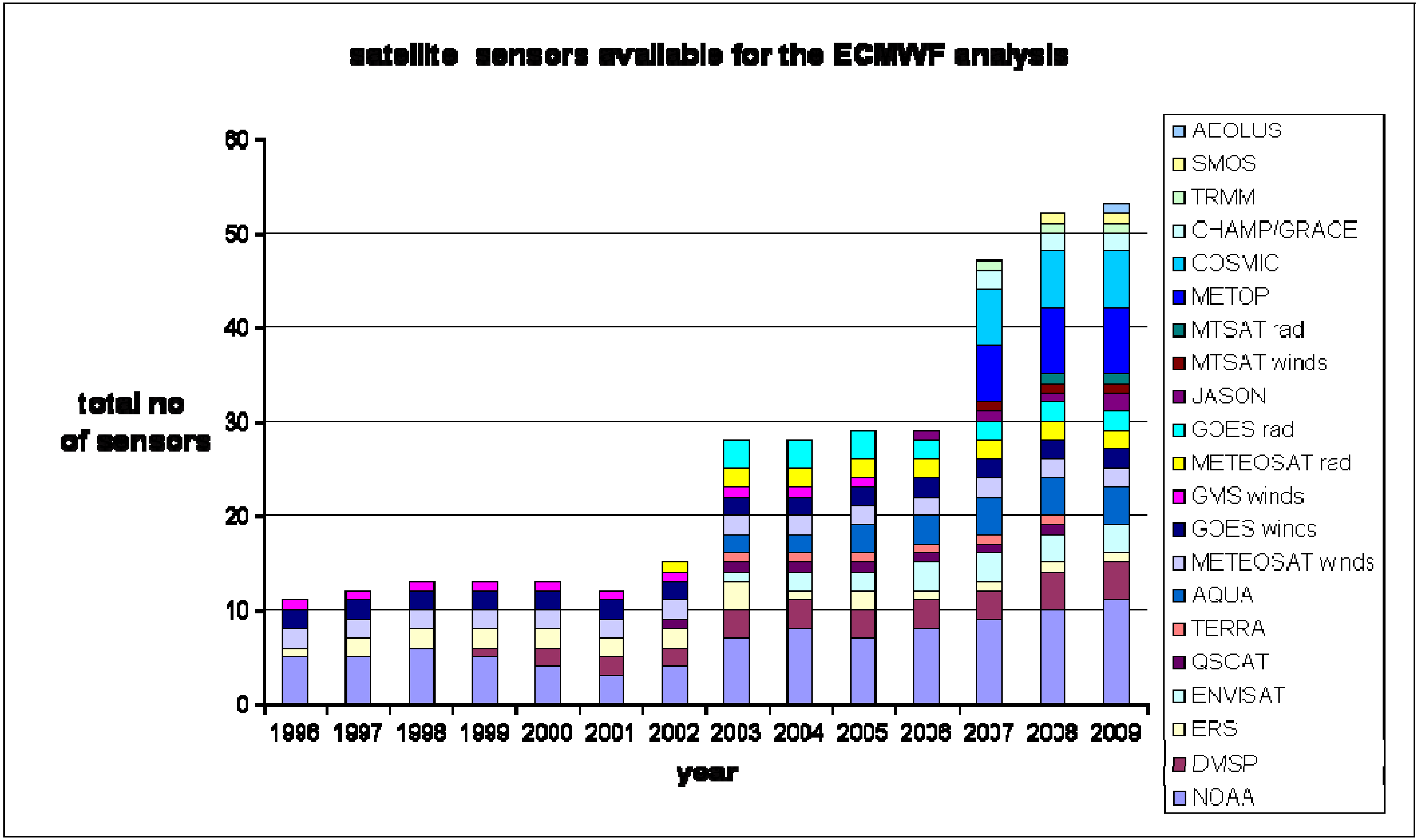


Impacts of AMSU on Global Medium Range Forecasting



ECMWF and UK Met Office provided clear evidence of increased NWP benefit of microwave measurements from two versus only one polar orbiting AMSU. 500 hPa geopotential showing one day increase in forecast skill over Europe at 5 days with two AMSU over none in 50 cases.

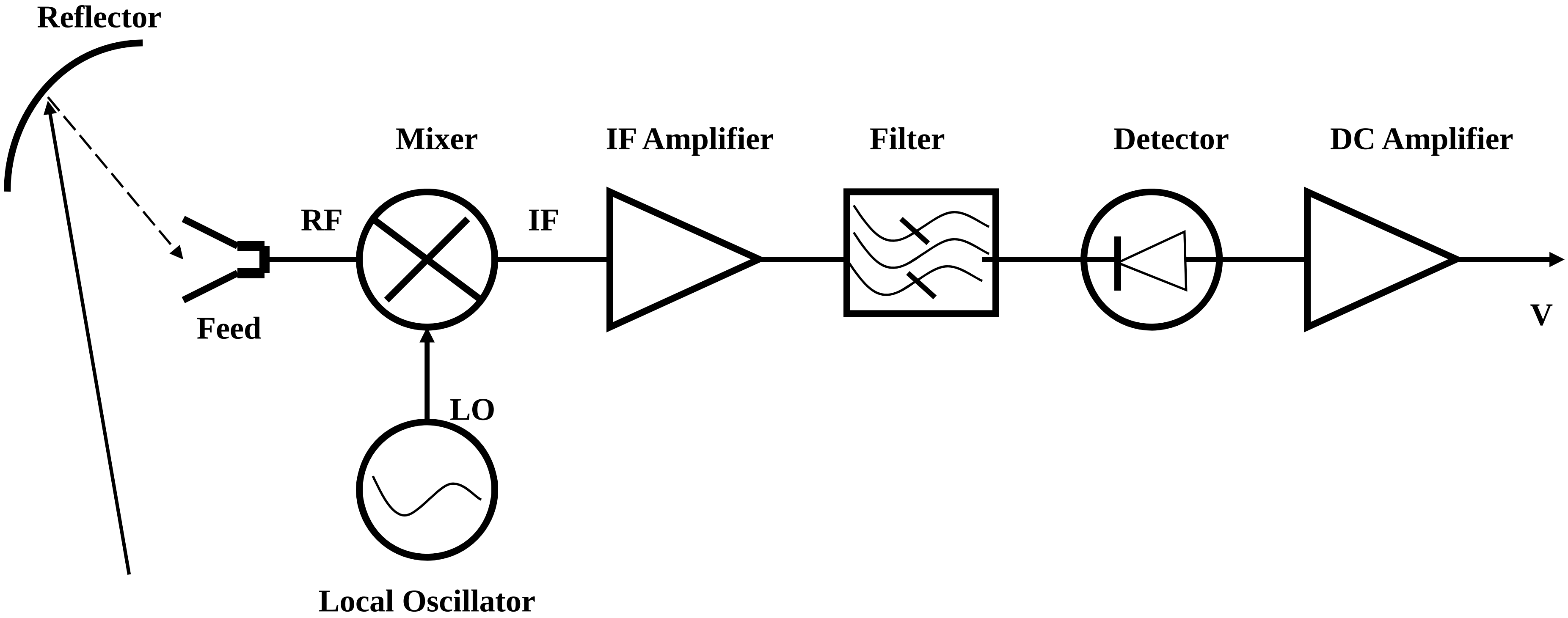
Number of satellite sensors that are or will be soon assimilated in the ECMWF operational data assimilation.



SATELLITE DATA STATUS in NCEP GFS – May 2008

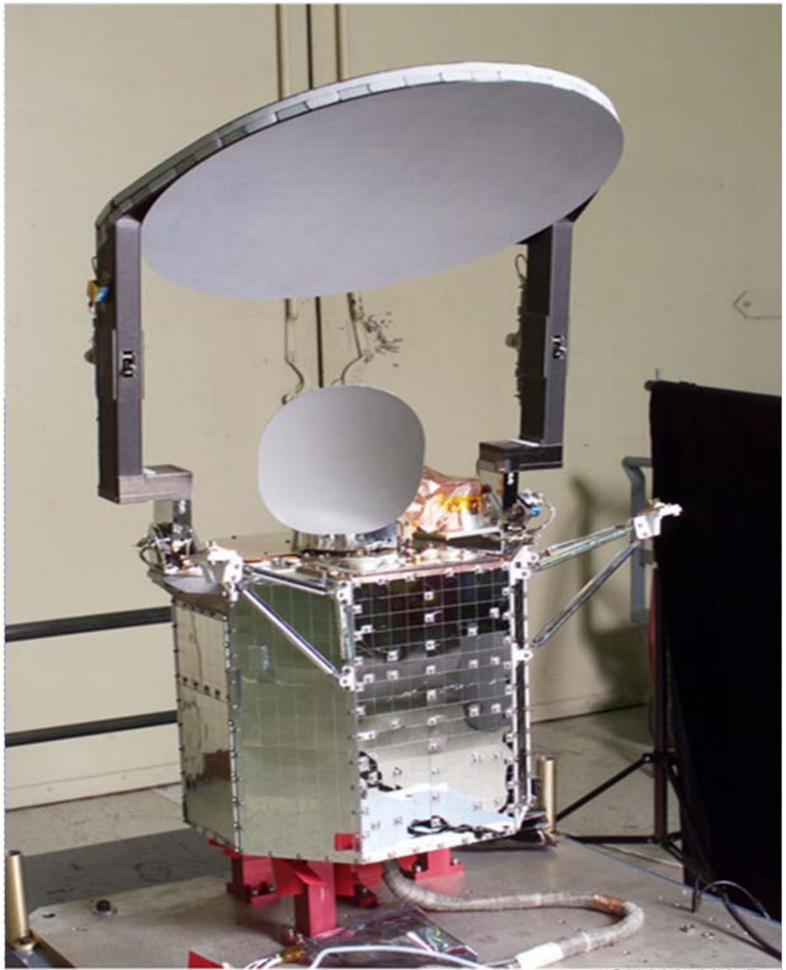
Jason Altimeter	Implemented into NCEP GODAS
AIRS with All Fields of View	Implemented – 1 May
MODIS Winds	Implemented– 1 May
NOAA-18 AMSU-A	Implemented– 1 May
NOAA-18 MHS	Implemented– 1 May
NOAA-17 SBUV Total Ozone	4 December 2007
NOAA-17 SBUV Ozone Profile	Implemented– ???
SSMI/S Radiances	Preliminary forecast assessment completed
GOES 1x1 sounder radiances	Implemented 29 May 2007
METOP AMSU-A, MHS, HIRS	Implemented 29 May 2007
COSMIC/CHAMP	Implemented (COSMIC – 1 May) CHAMP Data in prep.
MODIS Winds v2.	Test and Development
WINDSAT	Preliminary forecast assessment completed
AMSR/E Radiances	Preliminary forecast assessment completed
AIRS/MODIS Sounding Channels Assim.	Data in Preparation
JMA high resolution winds	Implemented 4 December 2007
GOES Hourly Winds, SW Winds	To be Tested
GOES 11 and 12 Clear Sky Rad. Assim(6.7µm)	To be Tested
MTSAT 1R Wind Assim.	Data in Preparation
AURA OMI	Test and Development
TOPEX,ERS-2 ENVISAT ALTIMETER	Test and Development (Envisat) ERS-2 (dead) TOPEX implemented in NCEP GODAS
FY – 2C	Data in Preparation

Microwave Radiometry System



Microwave Antenna Subsystem and Calibration Subsystem

- **Main-reflector conically scans the earth scene**
- **Sub-reflector views cold space to provide one of two-point calibration measurements**
- **Warm loads are directly viewed by feedhorn to provide other measurements in two-point calibration system**



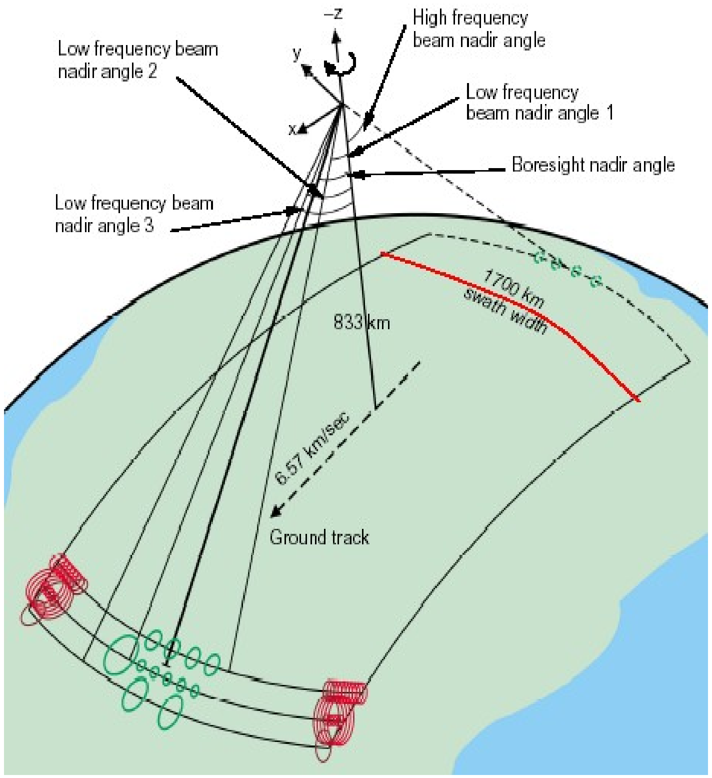
CN600-136-D

Microwave Radiometers Deployed in Space

•Mixed Polarization: AMSU, ATMS (I only)

•Dual Polarization: SSM/I, SSMI/S, TMI, AMSR (I_l, I_r)

•Full Polarimetry: WindSAT, MIS (I_l, I_r, U, V)



$$\mathbf{I} = [I_l, I_r, U, V]$$

$$I_l = E_l E_l^*, I_r = E_r E_r^*$$

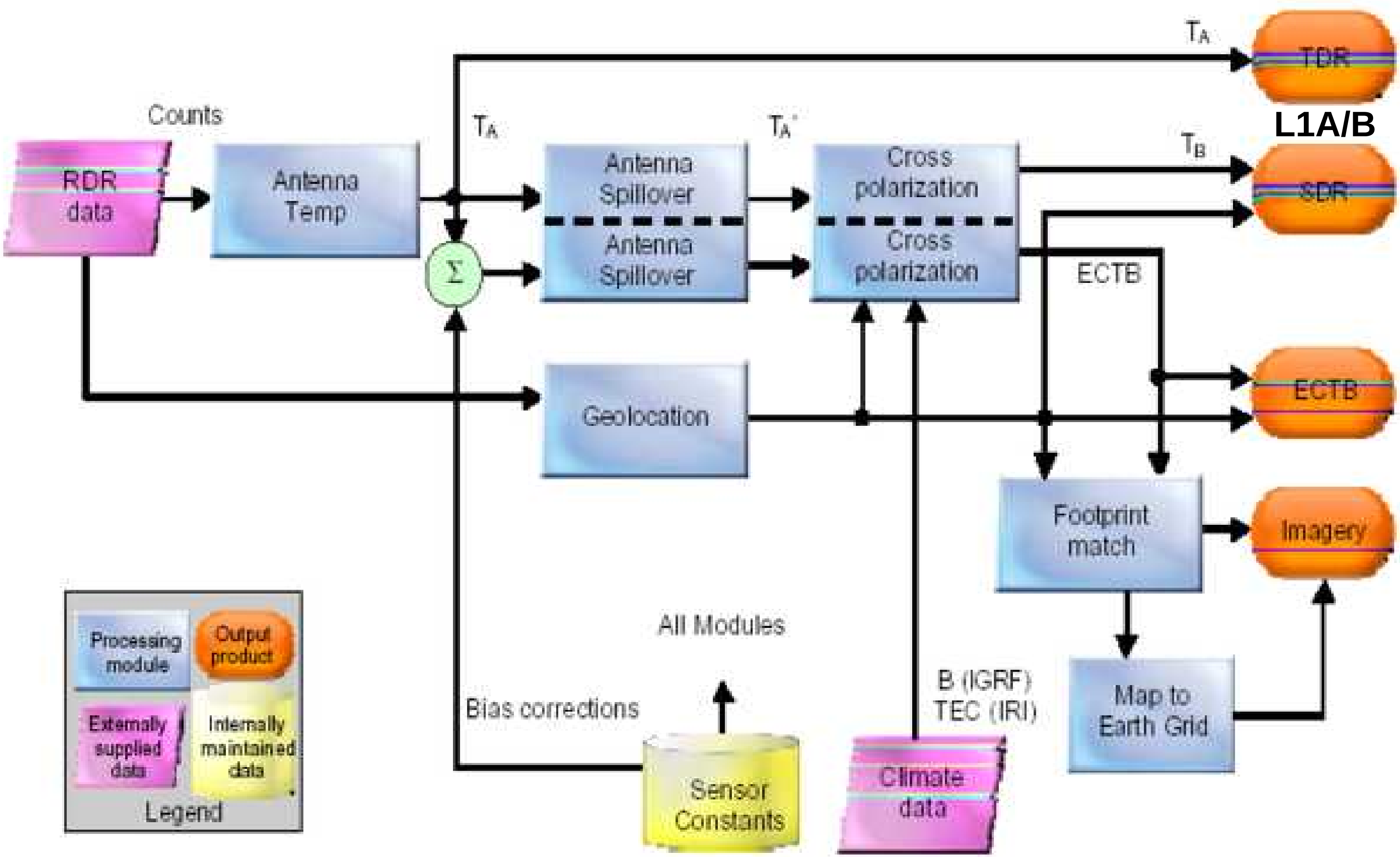
$$U = 2\,\mathrm{Re}(E_r E_l^*), V = 2\,\mathrm{Im}(E_r E_l^*)$$

Scan Geometry of Current and Future Sensors:

•Cross-track: AMSU, ATMS

•Conical: SSM/I, SSMI/S, TMI, AMSR,WindSAT, MIS

Microwave Measurement Data Records

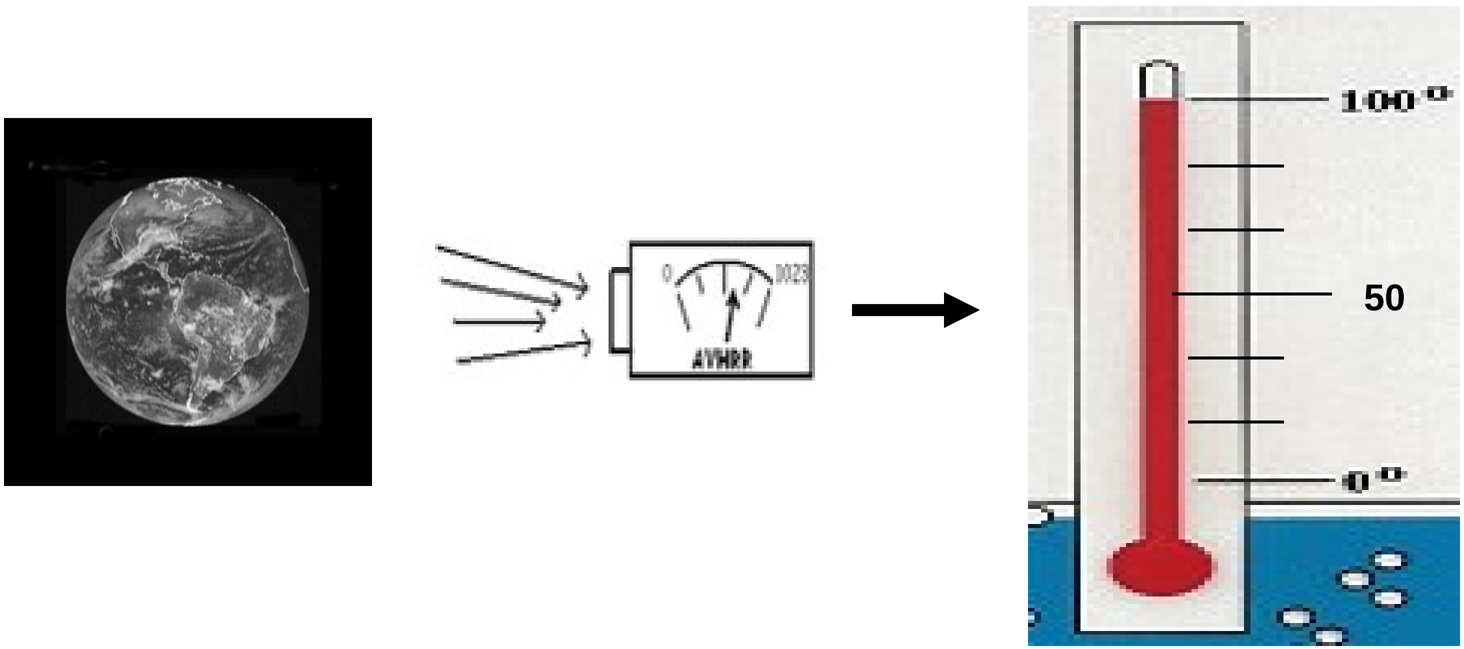


What is calibration and validation?

- **Calibration is the process of quantitatively defining the system or instrument response to known, controlled signal inputs**

- **Validation is the process of assessing by independent means the quality of the data products derived from the system outputs**

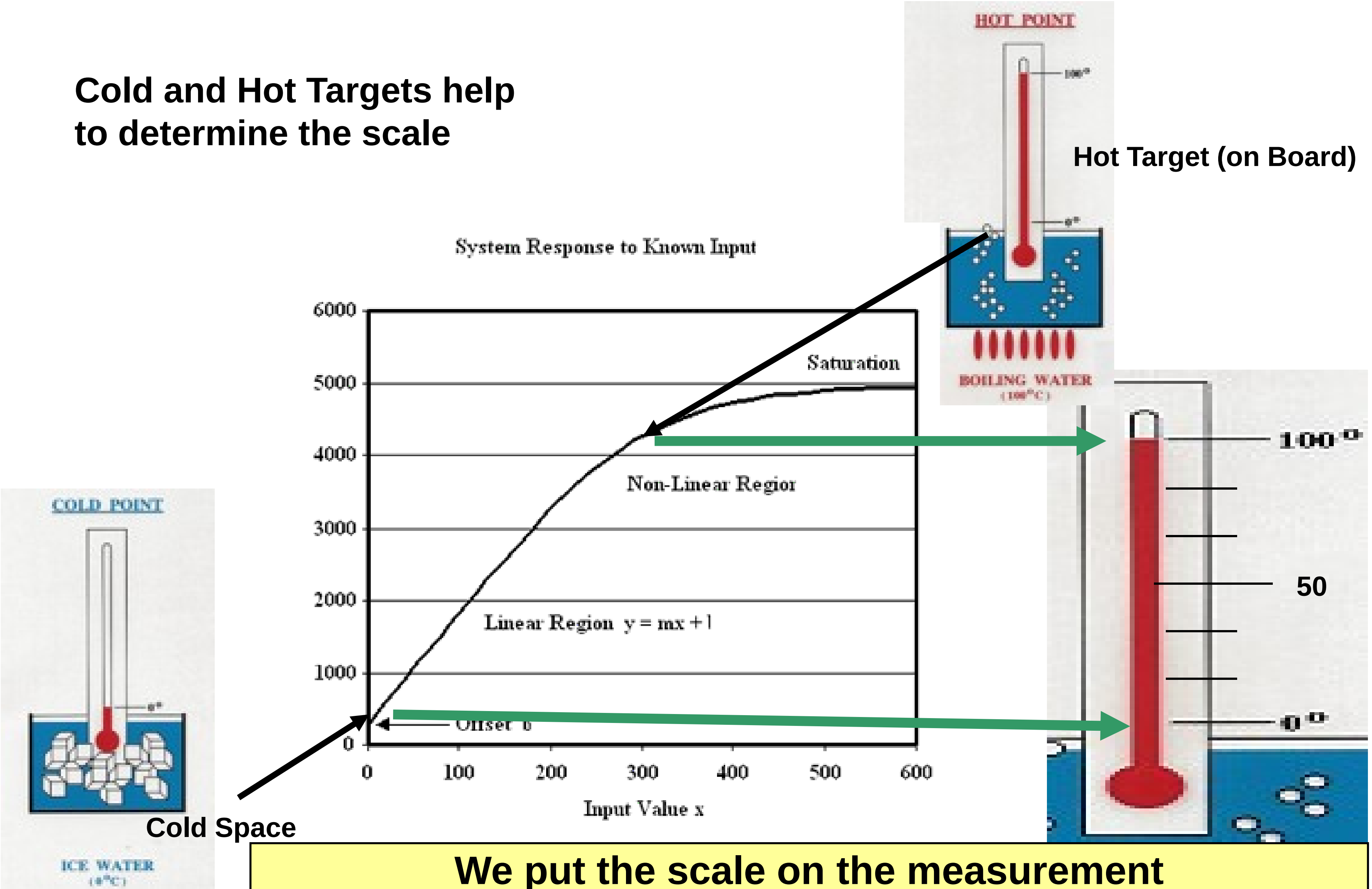
Satellite Instrument Calibration
What we do



We turn satellite instrument voltages into environmental quantities like temperature

How We Perform Satellite Calibration

Cold and Hot Targets help to determine the scale



We put the scale on the measurement

Microwave Radiometry Calibration

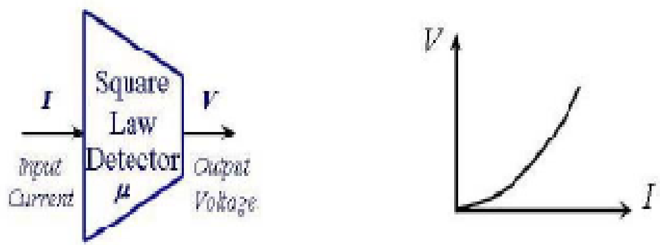


Figure 1.4: Microwave square law detector

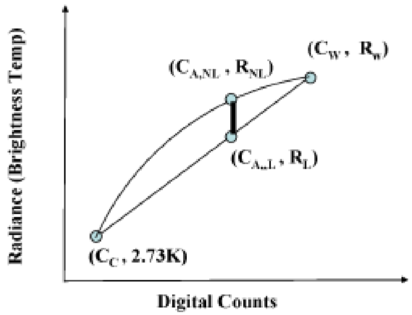


Figure 1.3: Two-point calibration algorithm used for microwave instrument calibration

The calibration error can be also introduced by neglecting the non-linearity effects. This is mainly because the microwave total power radiomeneter is not a perfect square law detector in which its output voltage, V, is a polynomial function of input current, I, as shown in Fig. (1.2.1).

$$V = a_1 I + a_2 I^2 + a_3 I^3 + a_4 I^4. \tag{1.1}$$

After the integration in time, its average voltage is a function of current square in that

$$\langle V \rangle = (a_2 + 3a_4 \langle I^2 \rangle) \langle I^2 \rangle. \tag{1.2}$$

Calibration including non-Linearity Effect

Using Nyquist theorem, this current square is related to the total power input to the IF system which is the radiance from either calibration targets or earth scenes such that

$$\langle I^2 \rangle \quad = \quad KBG[R(T_A) + R(T)], \tag{1.3}$$

where G, B and T is the amplifier gain, bandwidth and temperature, respectively, and K is the Baltzman constant. Combining 1.13and 1.15 results in

$$\langle V \rangle \quad = \quad b_0 + b_1 R(T_A)[1 + \mu R(T_A)], \tag{1.4}$$

where μ is the non-linear parameter and b_0 and b_1 are linear term parameters that can be determined from two-point calibration directly. They are expressed as

$$\begin{aligned} b_0 &= [a_2 + 3a_4 KBR(T)]KBGR(T), \\ b_1 &= [a_2 + 6a_4 KBR(T)]BG, \\ \mu &= 3a_4 \frac{KBG}{a_2}, \end{aligned}$$

Two-point calibration will eliminate b_0 and b_1 from Eq.(1.4) and result in

$$R_A = R_C + S(C_A - C_C) + \mu S^2 (C_A - C_C)(C_A - C_W), \tag{1.5}$$

where S is a parameter and its inverse is often referred as the radiance gain.

$$S = \frac{R_W - R_C)}{C_W - C_C}. \tag{1.6}$$

For microwave application, we often write

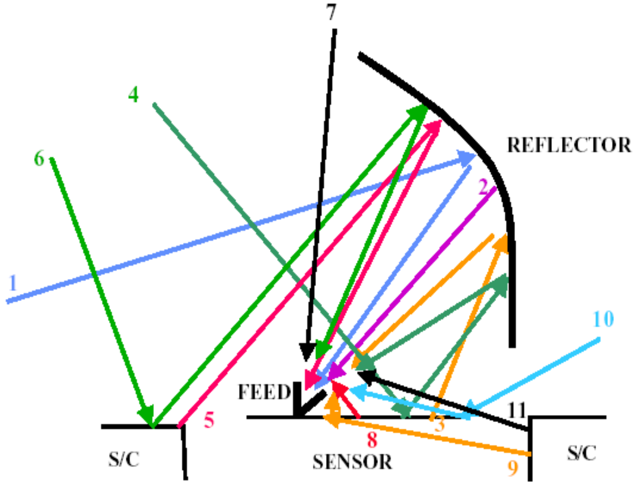
$$T_A = T_C + S(C_A - C_C) + \mu S^2 (C_A - C_C)(C_A - C_W), \tag{1.7}$$

and

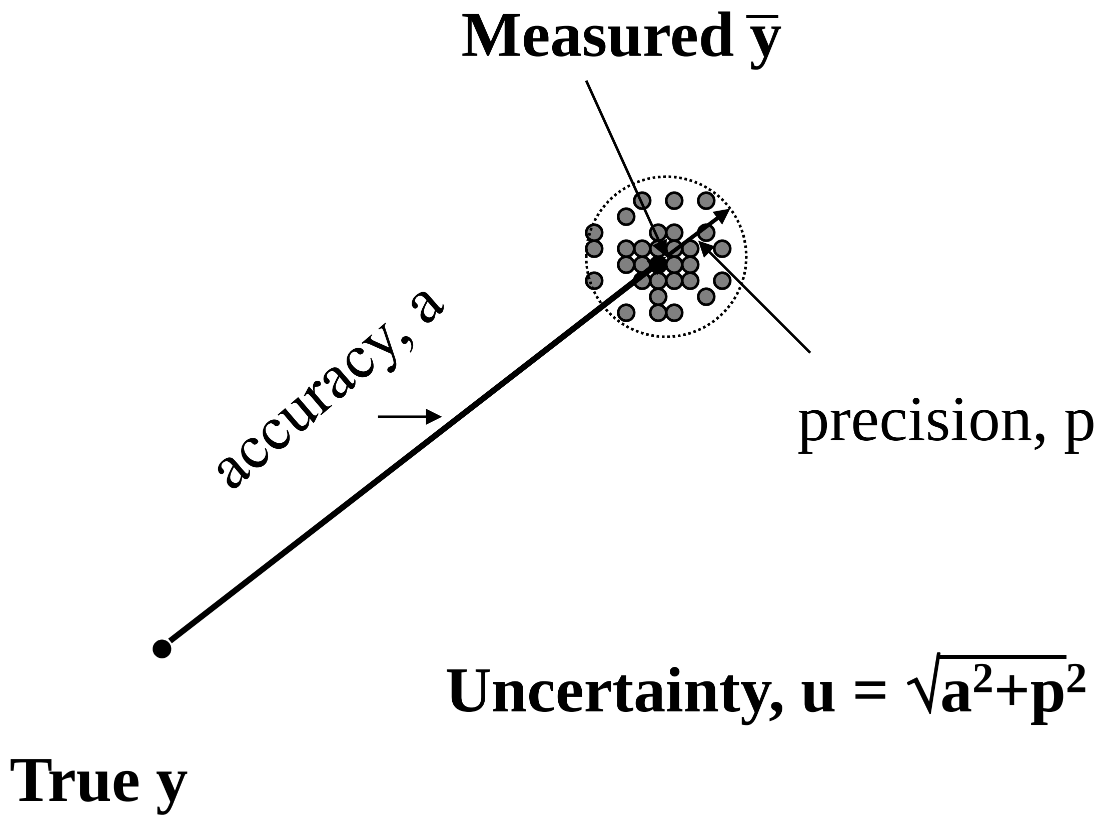
$$S \quad = \quad \frac{T_W - T_C}{C_W - C_C}. \tag{1.8}$$

Microwave Instrument Calibration Components

- Energy sources entering feed for a reflector configuration
- Earth scene Component,
- Reflector emission
- Sensor emission viewed through reflector,
- Sensor reflection viewed through reflector,
- Spacecraft emission viewed through reflector,
- Spacecraft reflection viewed through reflector,
- Spillover directly from space,
- Spillover emission from sensor,
- Spillover reflected off sensor from spacecraft,
- Spillover reflected off sensor from space,
- Spillover emission from spacecraft

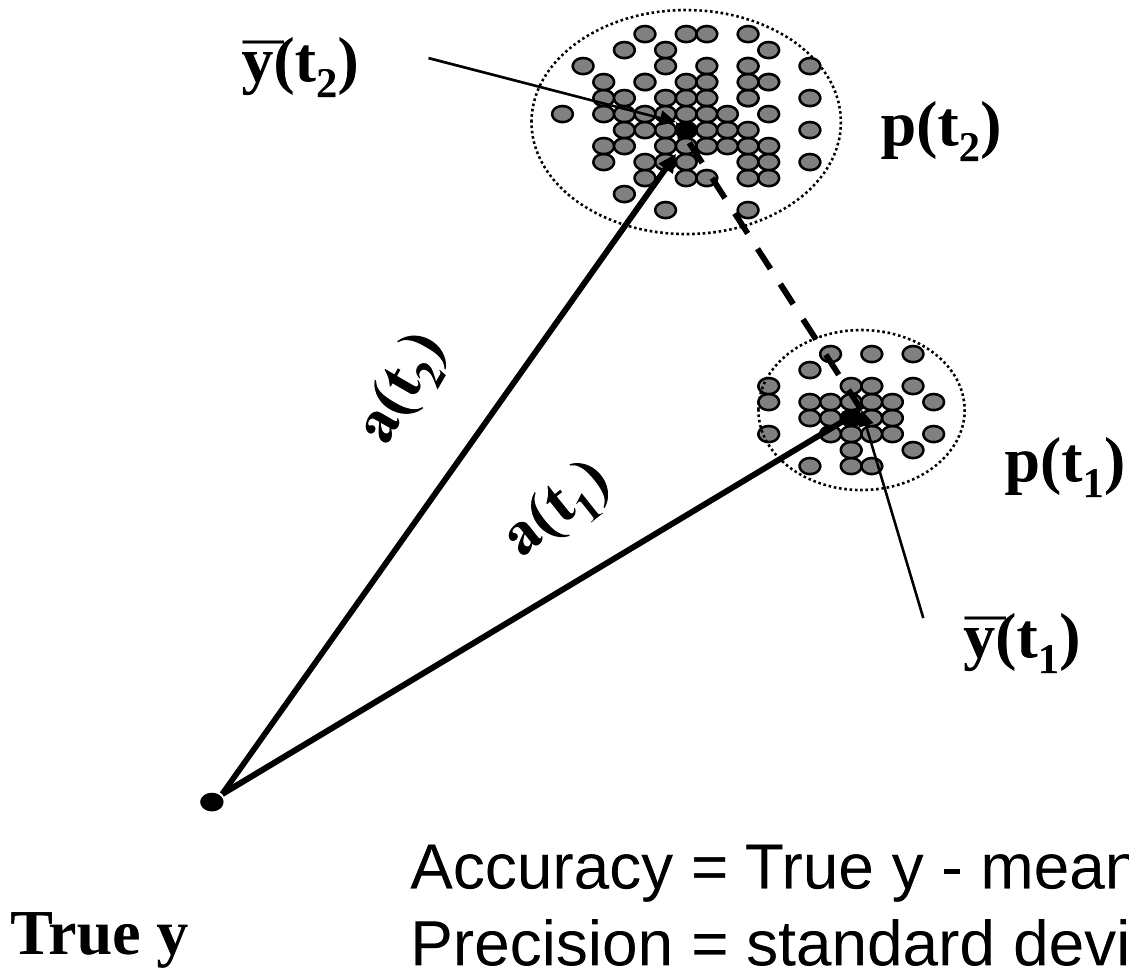


Traits: Accuracy, Precision and Uncertainty (After Stephens, 2003)



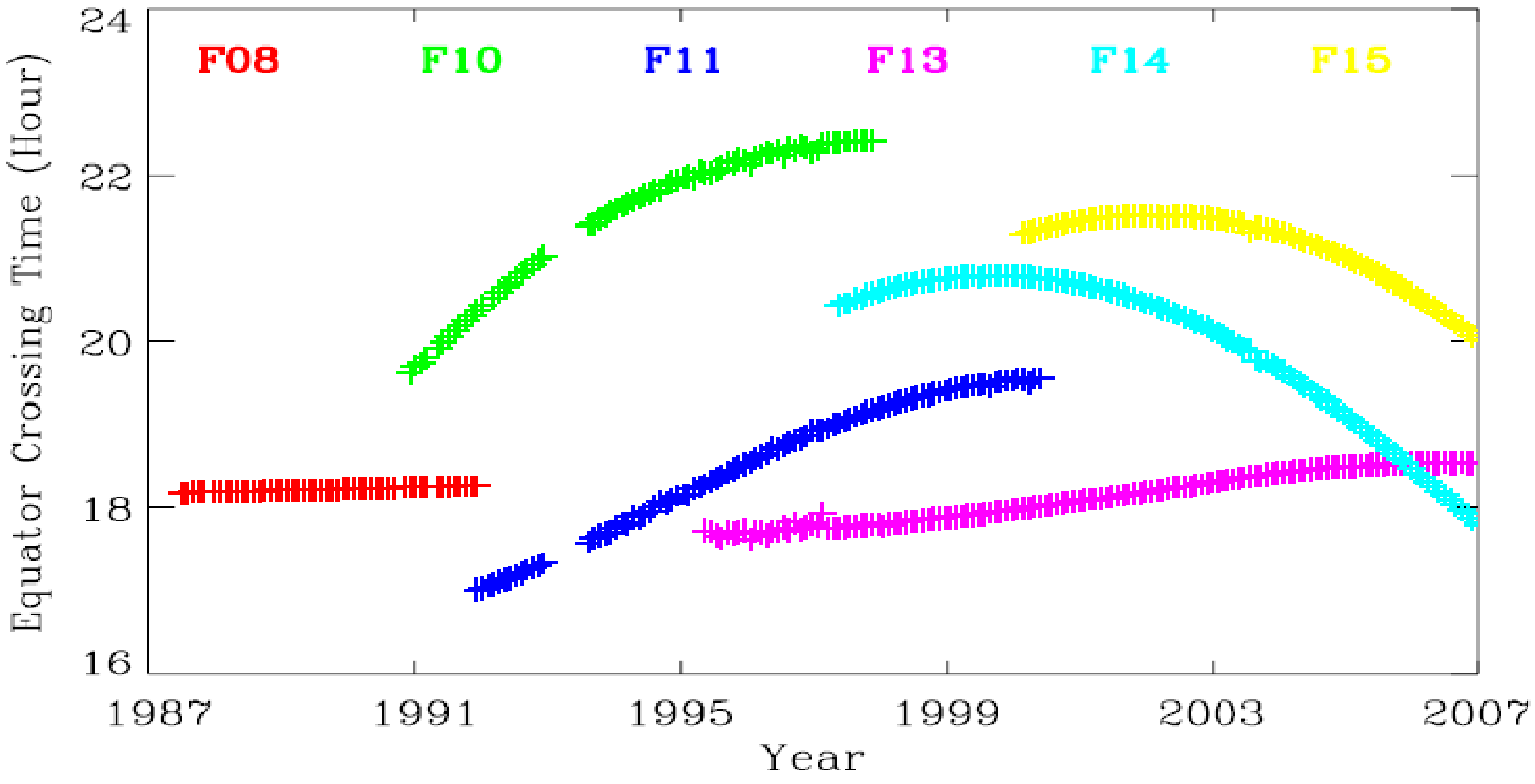
Uncertainty, $u = \sqrt{a^2+p^2}$

Accuracy, Precision, Stability (after Stephens)



Accuracy = True y - mean y
Precision = standard deviation of y
Stability = change of accuracy with time

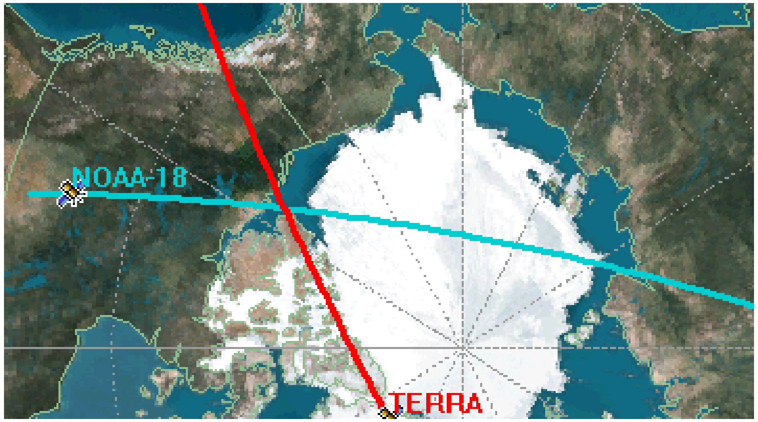
DMSP SSM/I Orbit Draft

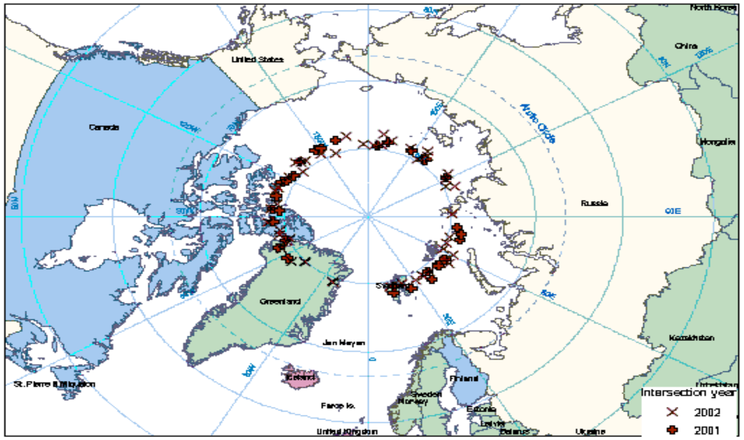


F13 provides the stable and longest time series for inter-sensor calibration

Intersatellite Calibration Using the Simultaneous Nadir Overpass (SNO) Method

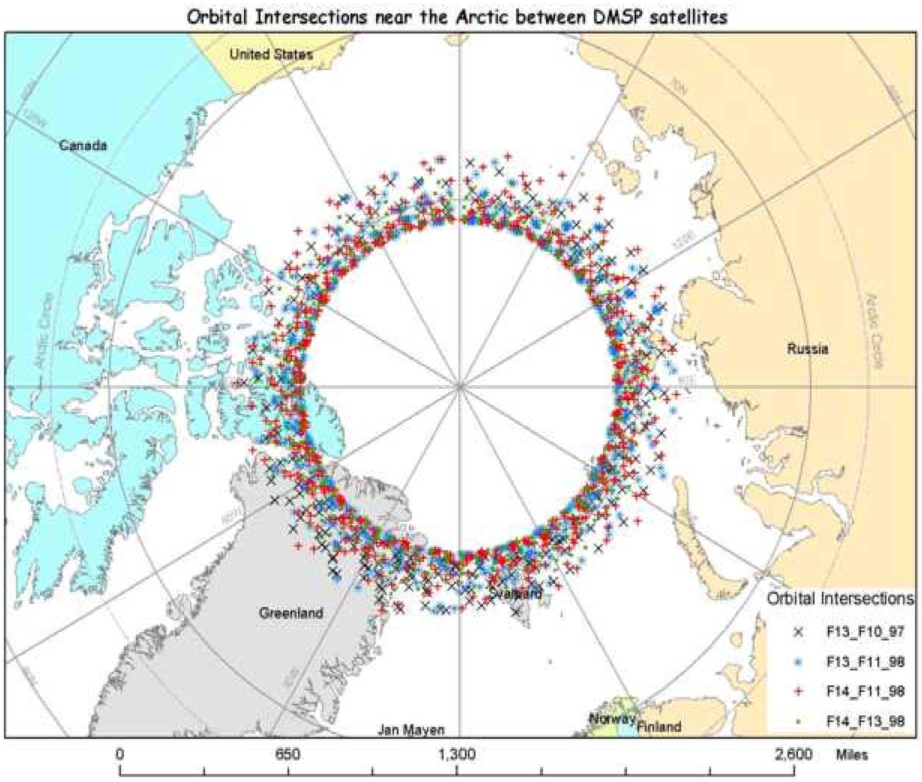
- **SNO – every pair of POES satellites with different altitudes pass their orbital intersections within a few seconds regularly in the polar regions**
- **Precise coincidental pixel-by-pixel match-up data from radiometers provides reliable long-term monitoring of instrument performance**
- **The SNO method has been used for operational on-orbit longterm monitoring of AVHRR, HIRS, AMSU and for retrospective intersatellite calibration from 1980 to 2003 to support climate studies**
- **The method is expanded for SSM/I with the Simultaneous Conical Overpass (SCO) method**



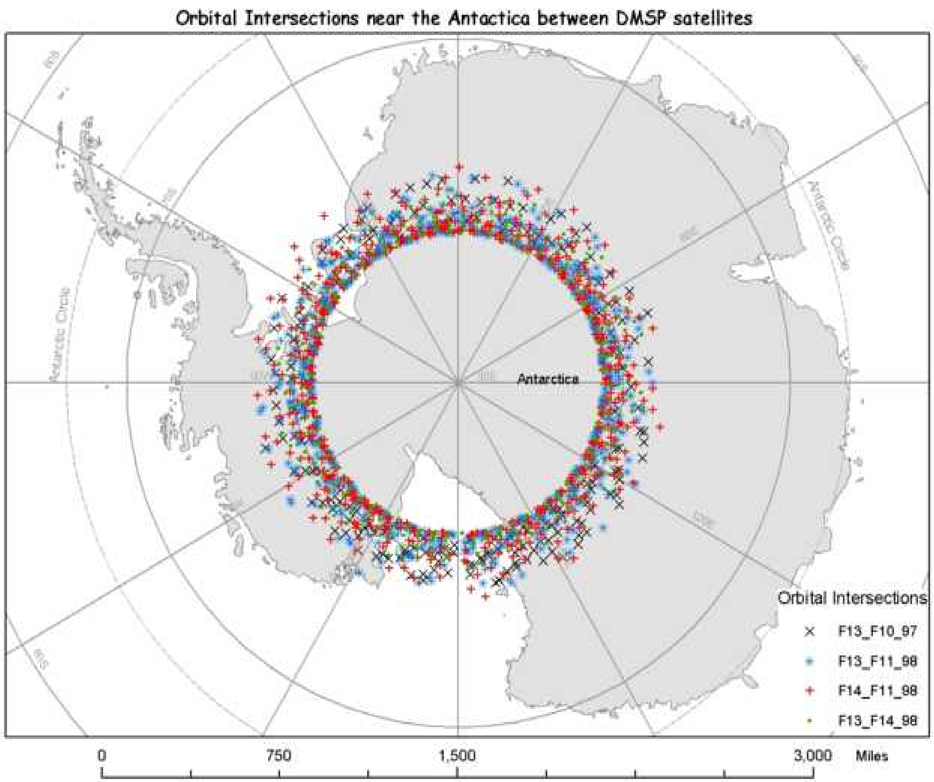


SNOs occur regularly in the +/- 70 to 80 latitude

DMSP Satellite SCO Intersections



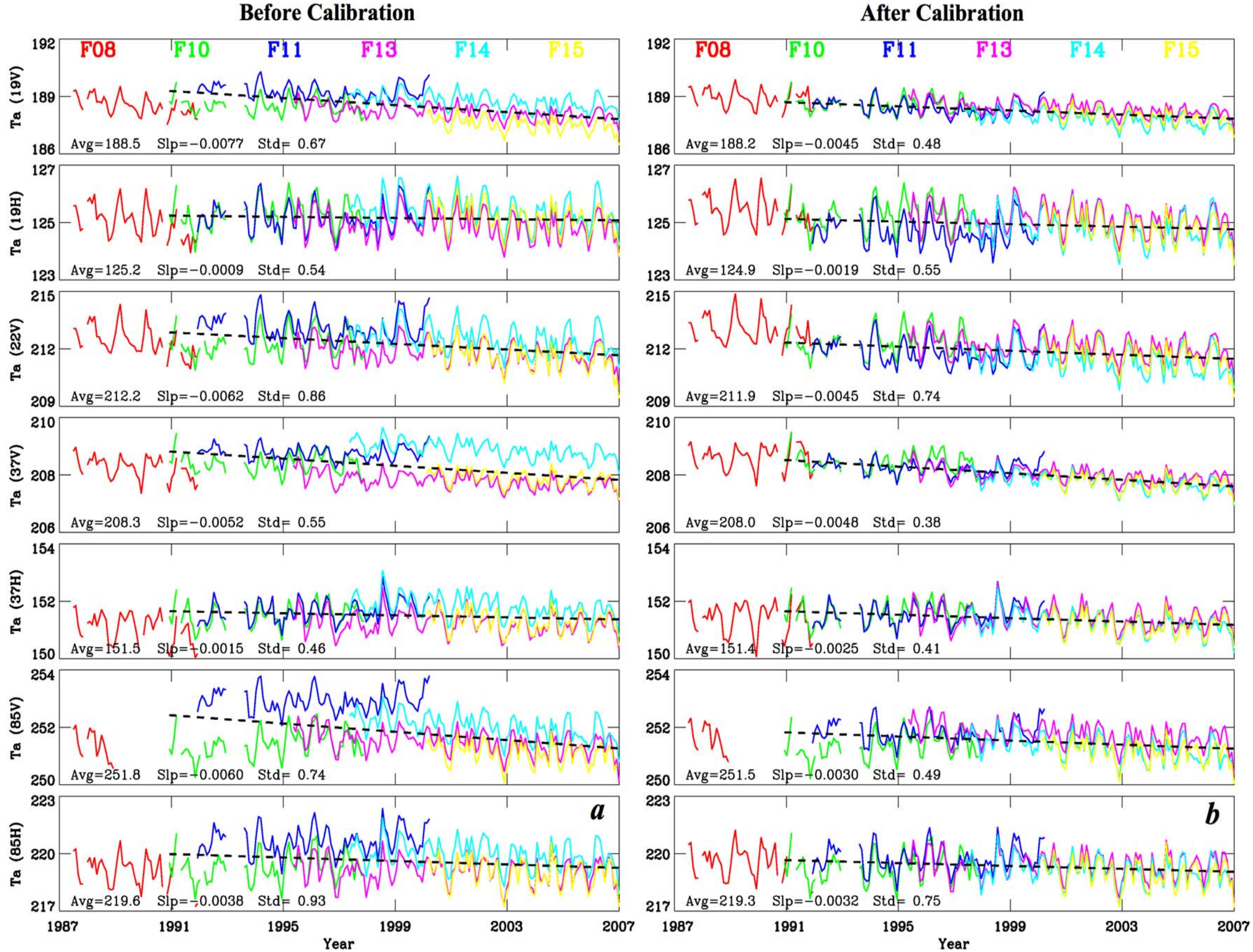
North Pole Region



South Pole Region

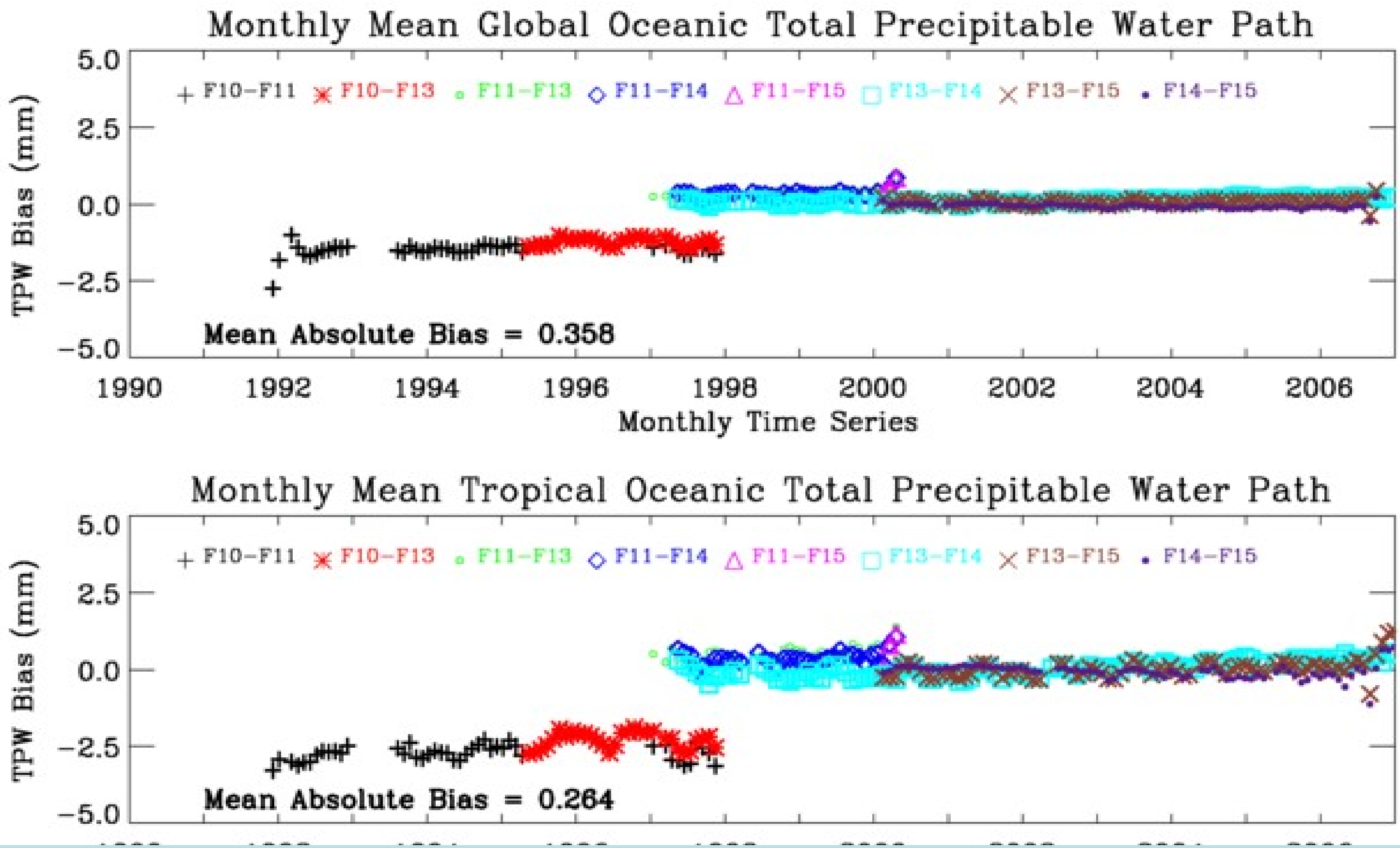
SCO selection criteria 1) $|\Delta t| \leq$ 30 sec, , 2) $|\Delta d| \leq$ 3 km, 3) std $\leq$ 2 °K

Comparison of SSM/I Monthly Oceanic Rain-free TDR Trend



Monthly TPW Bias between Overlapped Sensors

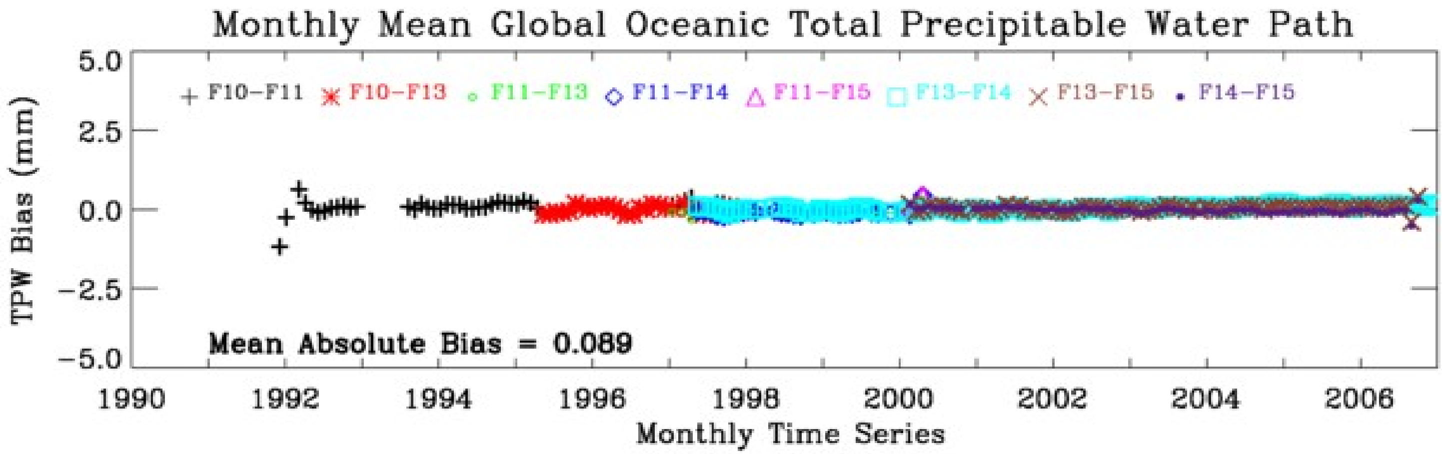
Before Intercalibration

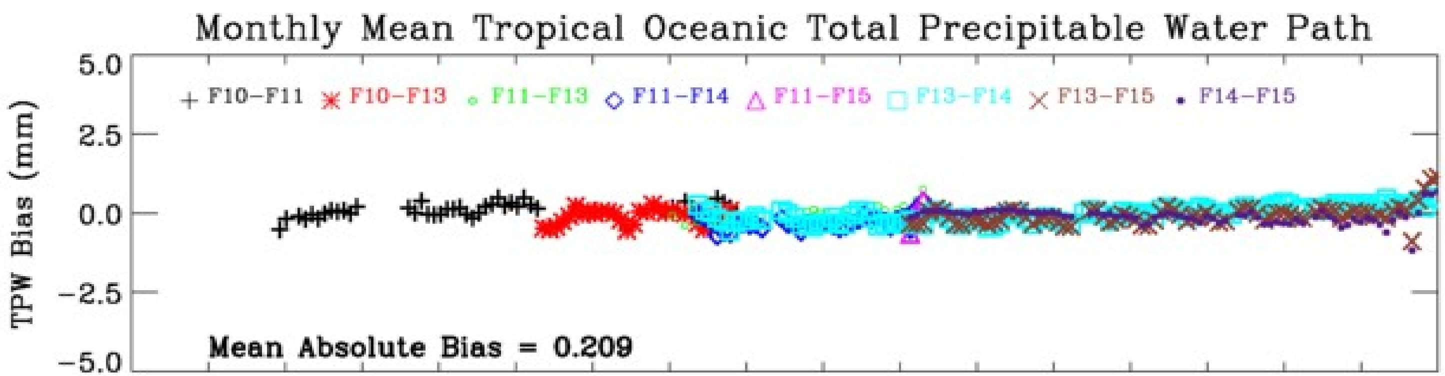


Monthly total precipitable water path (TPW) bias between any overlapped SSM/I sensors for F10, F11, F13, F14, and F15. Large biases between F10-F11 and F10-F13 are obvious. Since TPW = 232.89-.1486*TV19-.3695*TV37-(1.8291-.006193*TV22)*TV22, (Alishouse et al., 1991), any radiance biases in lower SSM/I frequencies will be directly translated into TPW biases

Monthly TPW Bias between Overlapped Sensors

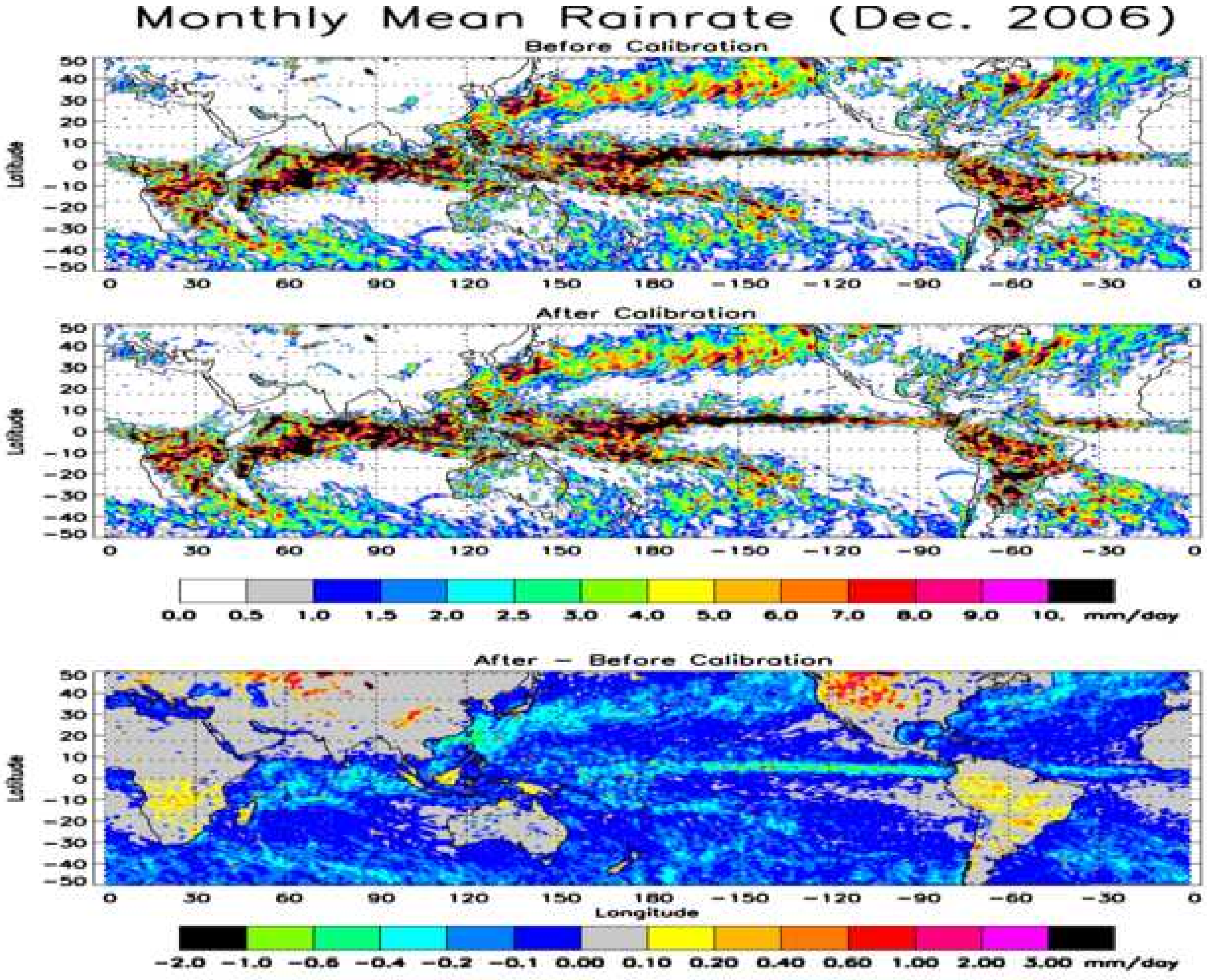
After Intercalibration





The inter-sensor TPW biases become much smaller and consistent between different sensors. The averaged absolute bias after calibration is reduced by 75% and 21% over global ocean and over tropical ocean, respectively .

Impacts of Calibration on Global Precipitation Products

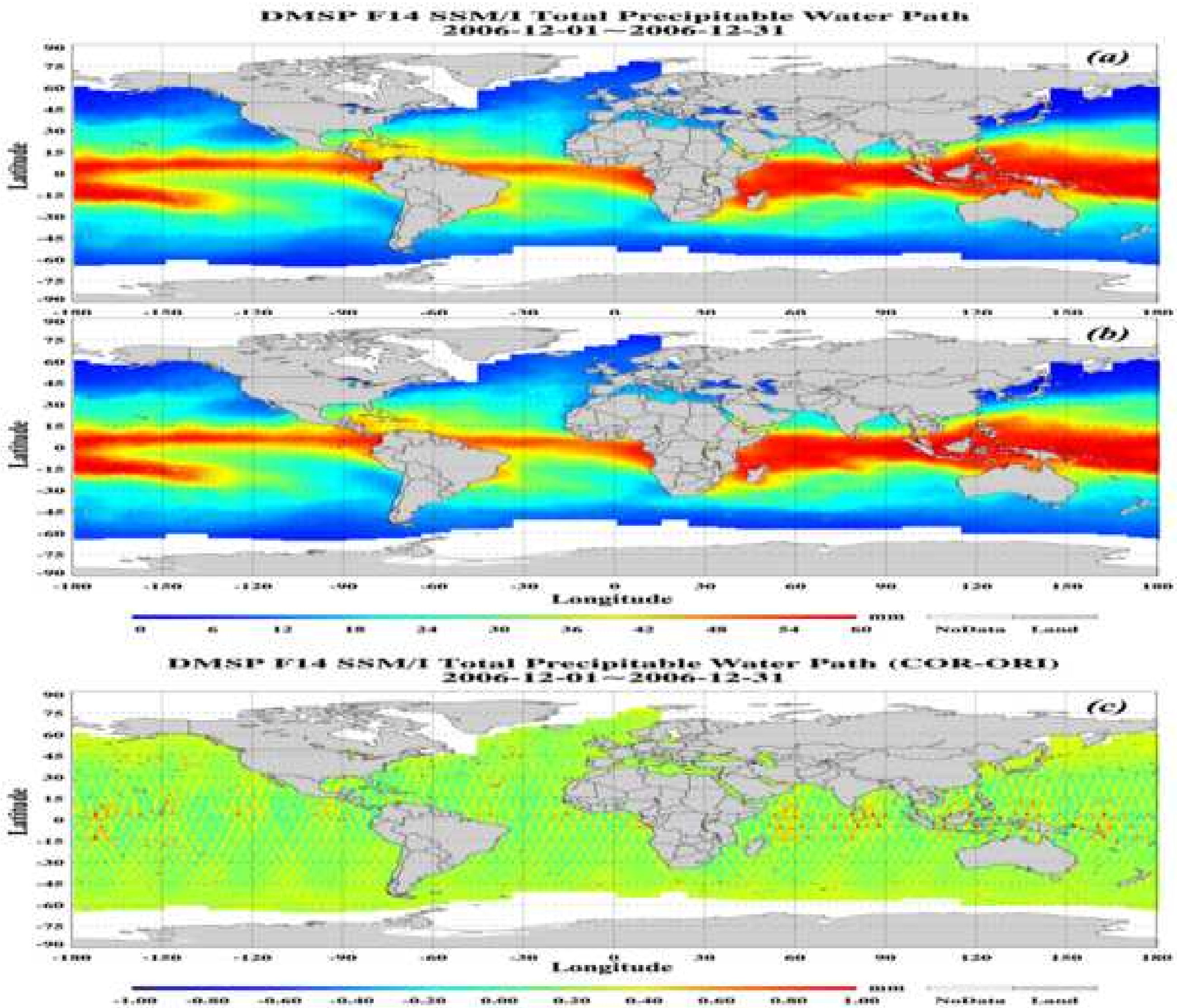


Before Calib.

After Calib.

Difference (aft - bef)

Impacts of Calibration on Global Water Vapor Product



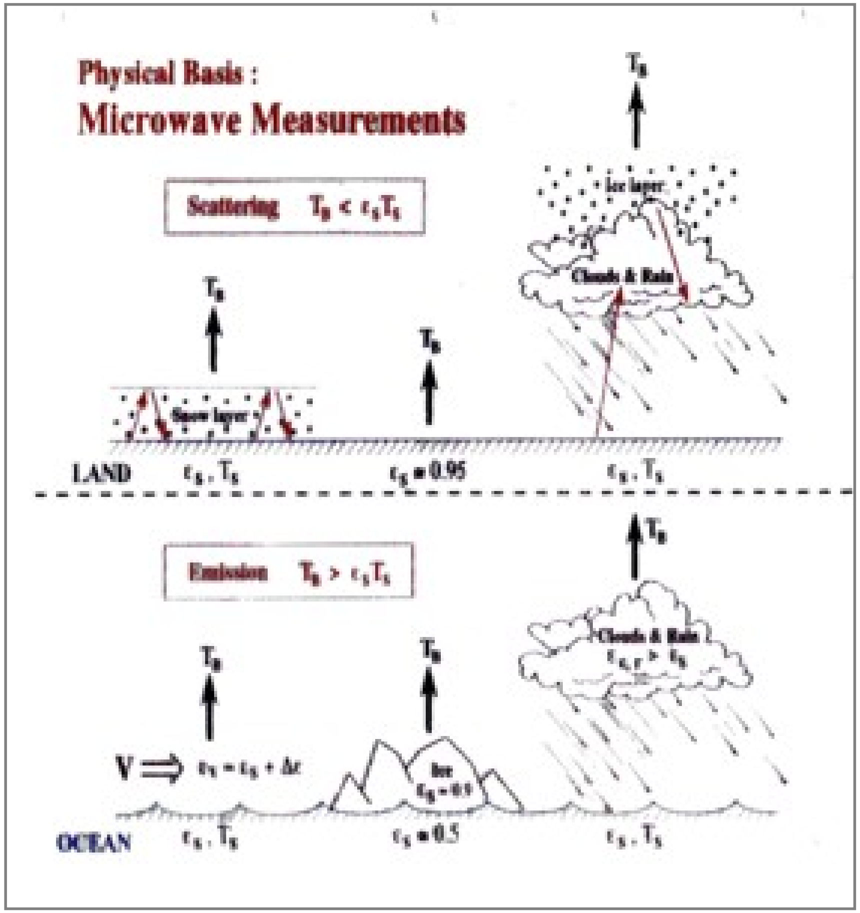
Before Calib.

After Calib.

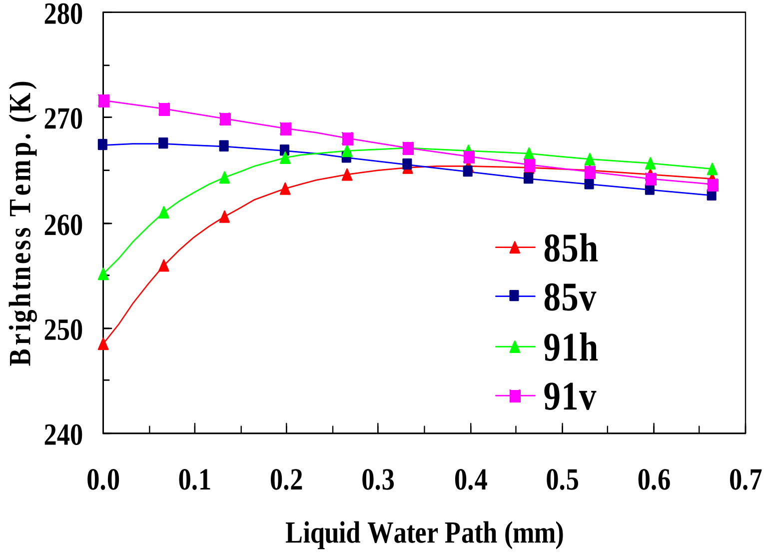
Difference (aft - bef)

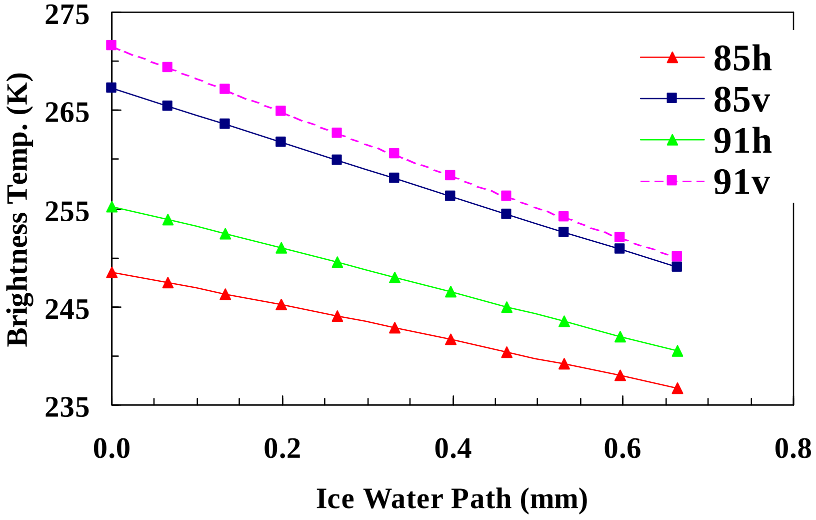
Physical Basis and Phenomenology

- **In microwave region, surface emissivity over oceans is typically low and therefore emits less thermal radiation**
- **Clouds and raindrops in atmosphere absorb the emitted radiation from surface and re-emit higher radiation**
- **A retrieval of a lower amount of cloud liquid water is significantly affected by sea surface conditions**
- **The absorption coefficient of cloud liquid water is dependent on cloud temperature.**
- **Land remote sensing of clouds are still largely un- pursued due to variability of emissivity**



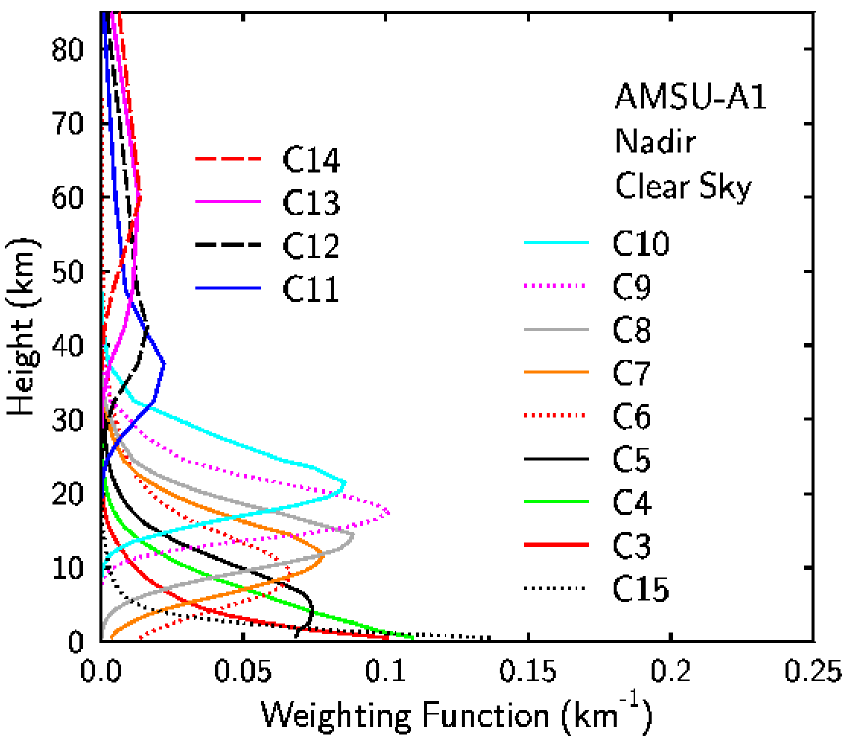
Cloud Emission and Scattering (over Oceans)





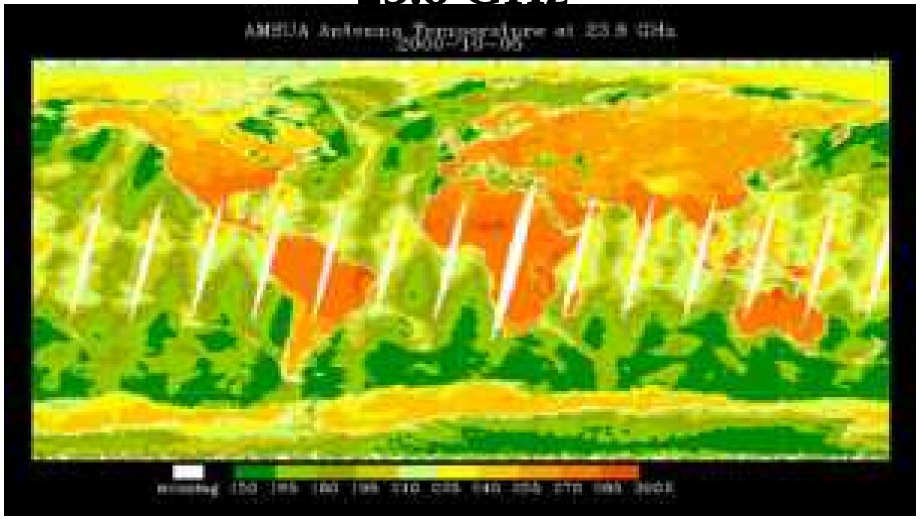
Microwave Sounding Principle Under All Weather Conditions

- **Satellite microwave radiation at each sounding channel primarily arises from a particular altitude, indicated by its weighting function**
- **The vertical resolution of sounding is dependent on the number of independent channel measurements**
- **Lower tropospheric channels are also affected by the surface radiation which is quite variable over land**

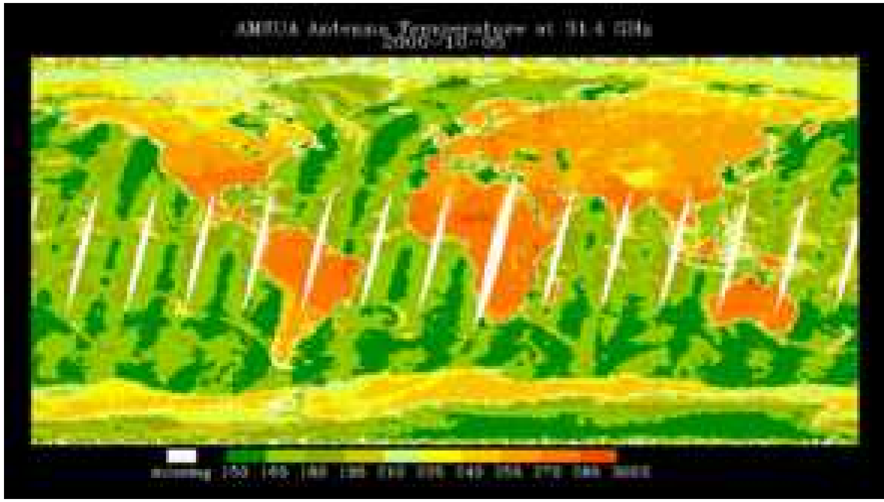


Advanced Microwave Sounding Unit Window Channels

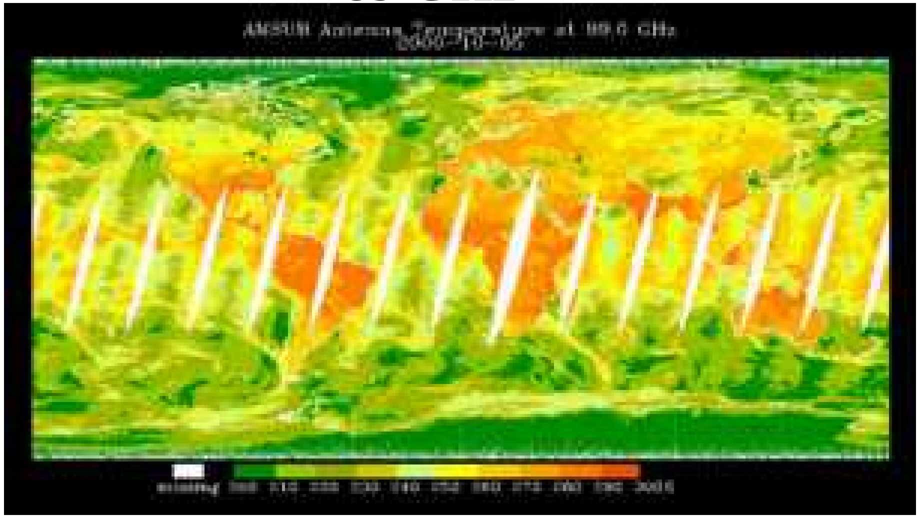
23.8 GHz



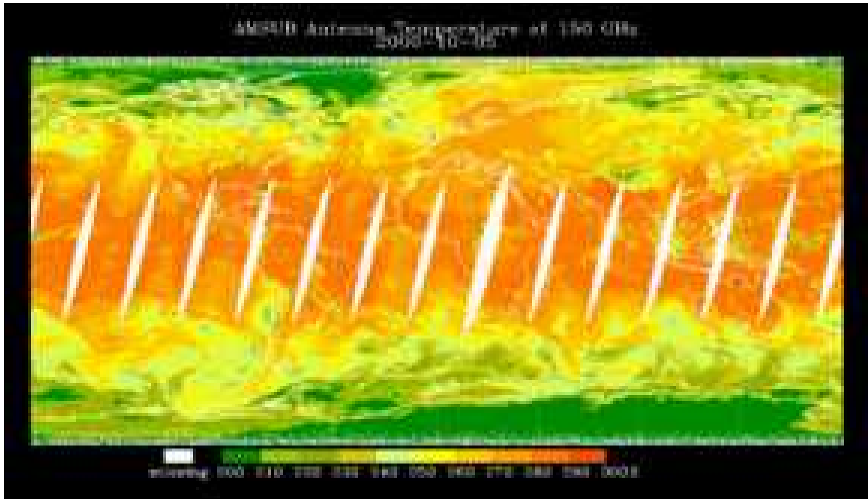
31.4 GHz



89 GHz

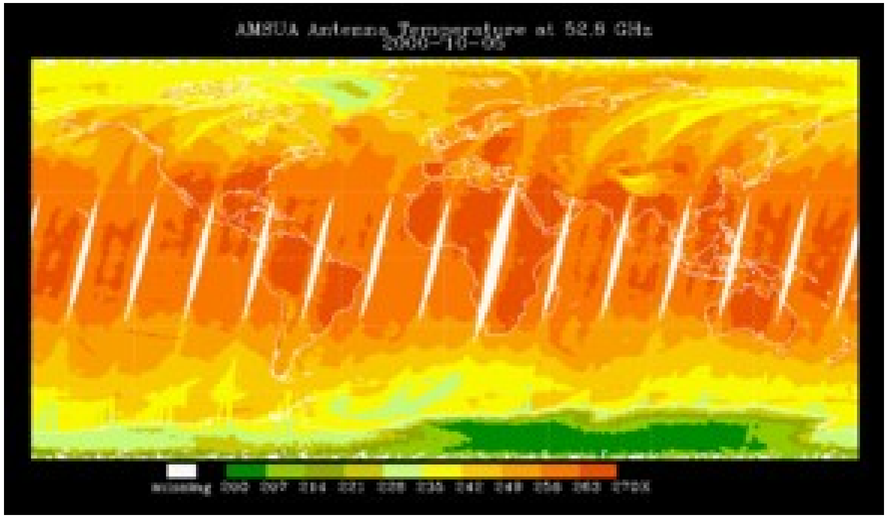


150 GHz

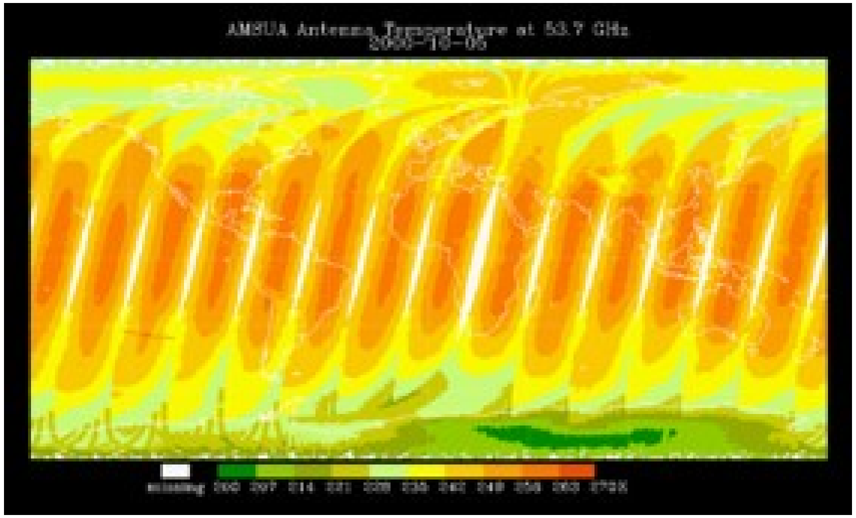


Advanced Microwave Sounding Unit
Sounding Channels

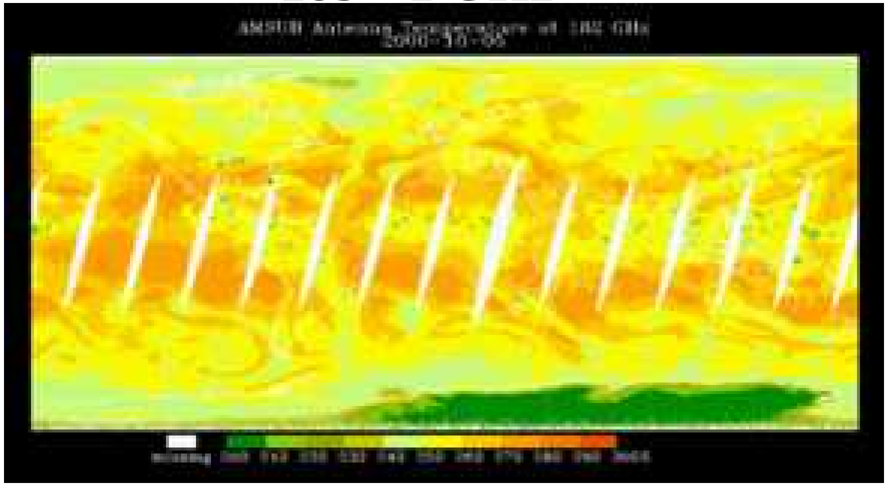
52.8 GHz



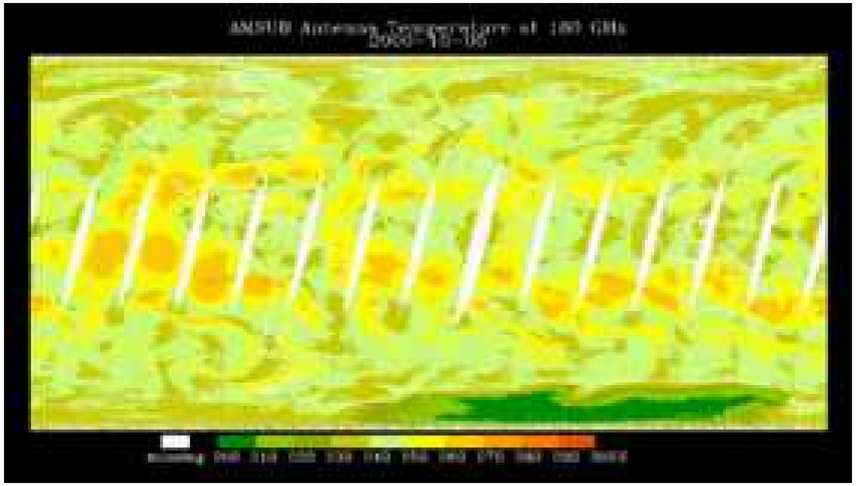
53.7 GHz



183+-1 GHz



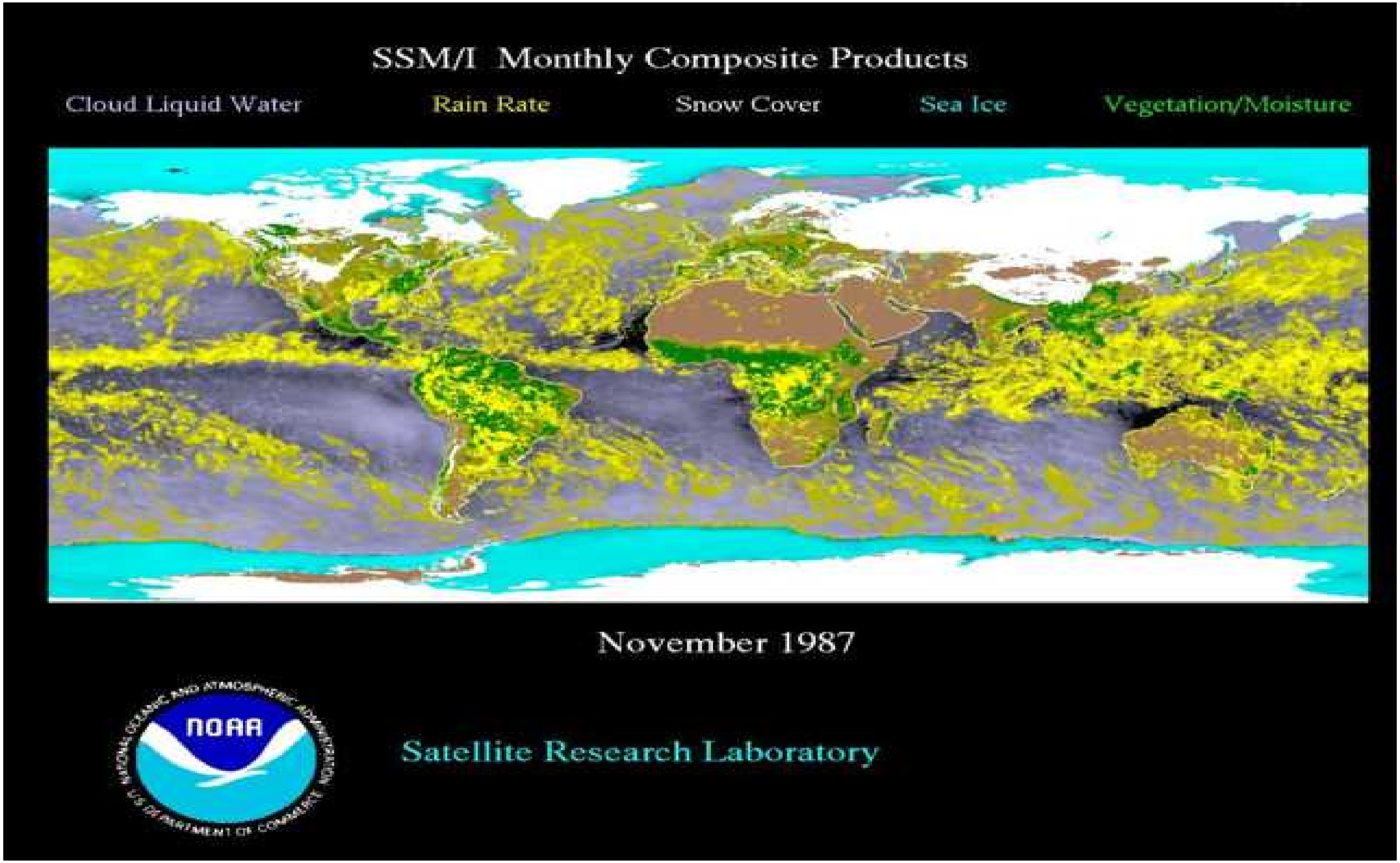
183+-3 GHz



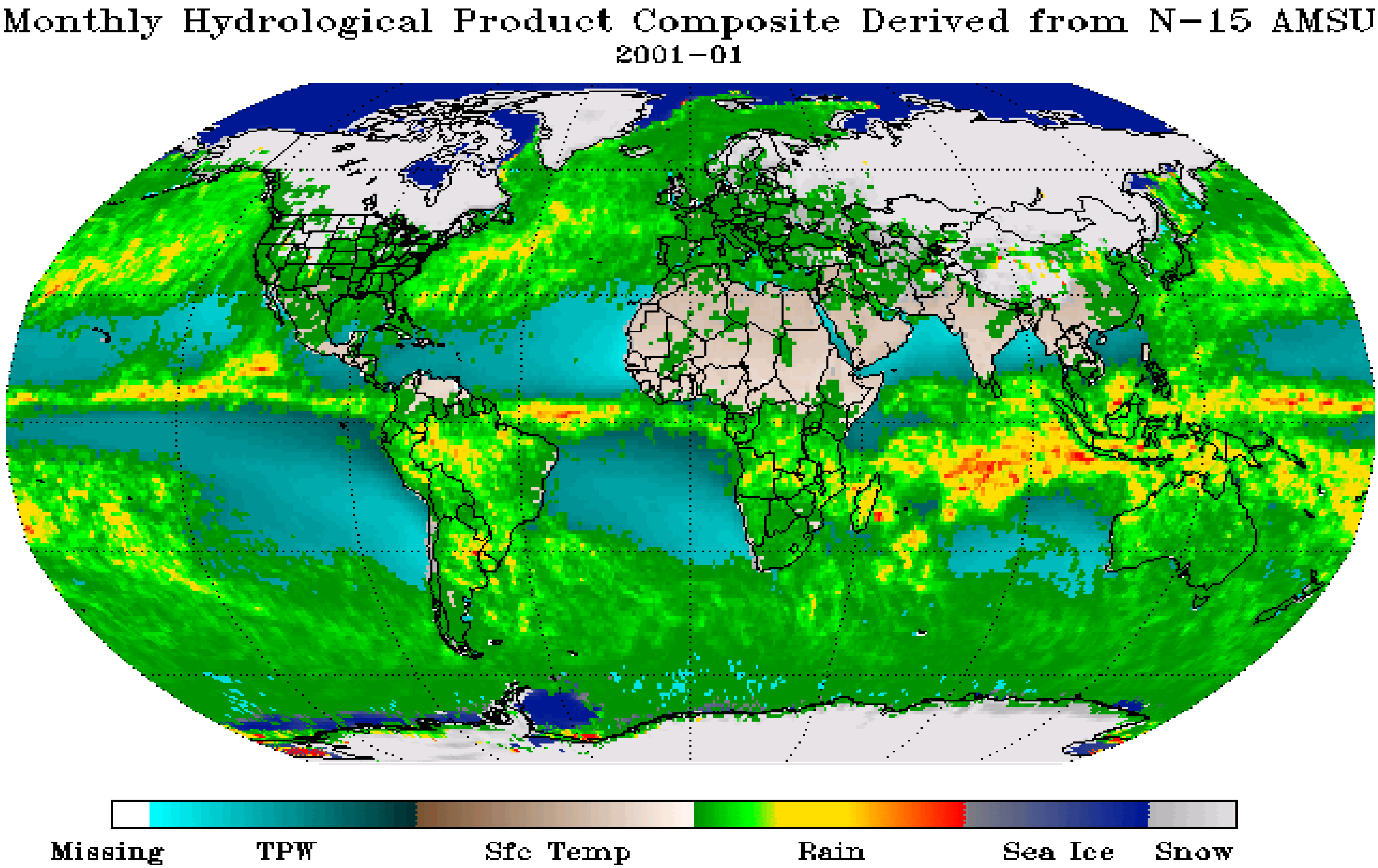
Microwave Environmental Data Records

SDR/EDR	POES/METOP AMSU-A/B; MHS	DMSP SSMIS	NPOESS ATMS/MIS
Radiances	✓	✓	✓
Temp. profile	✓	✓	✓
Moist. profile	✓	✓	✓
Total precipitable water*	✓	✓	✓
Hydr. profile	✓	✓	✓
Precip rate*	✓	✓	✓
Snow cover*	✓	✓	✓
Snow water equivalent*	✓	✓	✓
Sea ice *	✓	✓	✓
Cloud water*	✓	✓	✓
Ice water*	✓	✓	✓
Land temp*	✓	✓	✓
Land emis*	✓	✓	✓
Soil moisture/Wetness Index		✓	✓

NESDIS SSM/I Climate Data Records Started Since 1987



Microwave Products from NOAA Operational Sensor: AMSU



Summary

1. **Satellite Microwave Observations:** critical for sounding and imaging under all weather conditions

2. **Microwave Sensor Calibration:** Convert analog signal to physical quantity, 2 systems: Linear and non-linear

3. **Climate Data Records from Satellites**: Cross sensor calibrations to remove intersensor biases

4. **Microwave Sensing Principle:** Imaging clouds over lower oceans, and sounding atmosphere from O2 and H2O absorption lines