National Environmental Satellite, Data, and Information Service

NOAA Operational Microwave Calibration in Support of CDR Program

Dr. Fuzhong Weng, Chief
Satellite Calibration & Data Assimilation Branch
Center for Satellite Applications and Research
NOAA/NESDIS

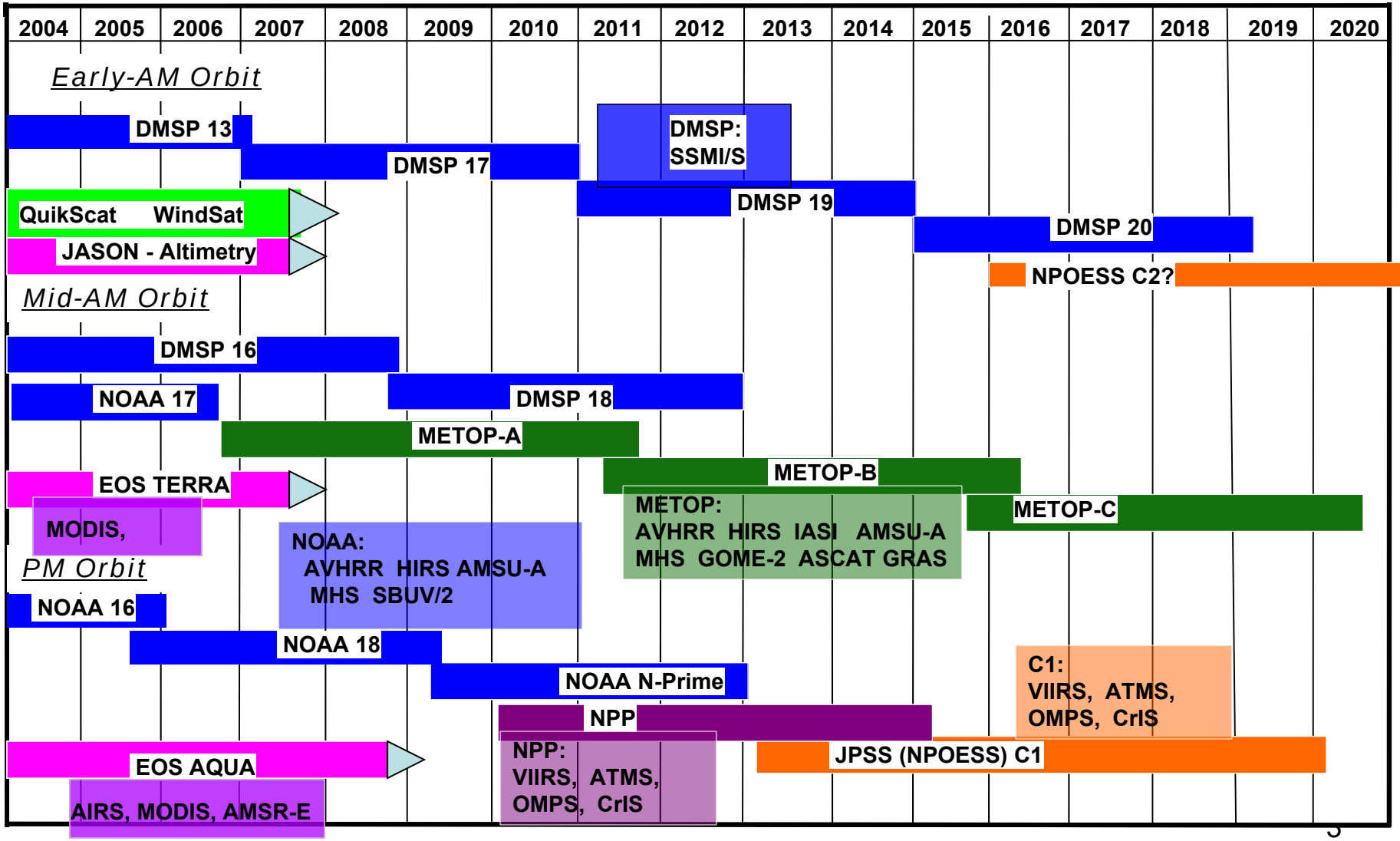
2010 Workshop on Climate Data Records from Satellite Microwave Radiometry
NOAA Science Center, Silver Spring, MD, March 22-24 2010

Outline

- Overview of NOAA Satellite Program
- Post-launch/Operational Calibration
- Long-Term Monitoring for Climate Data Records
- Cross-Calibration through Best Practices
- MSU and AMSU Derived Temperature Trends
- Summary and Conclusions

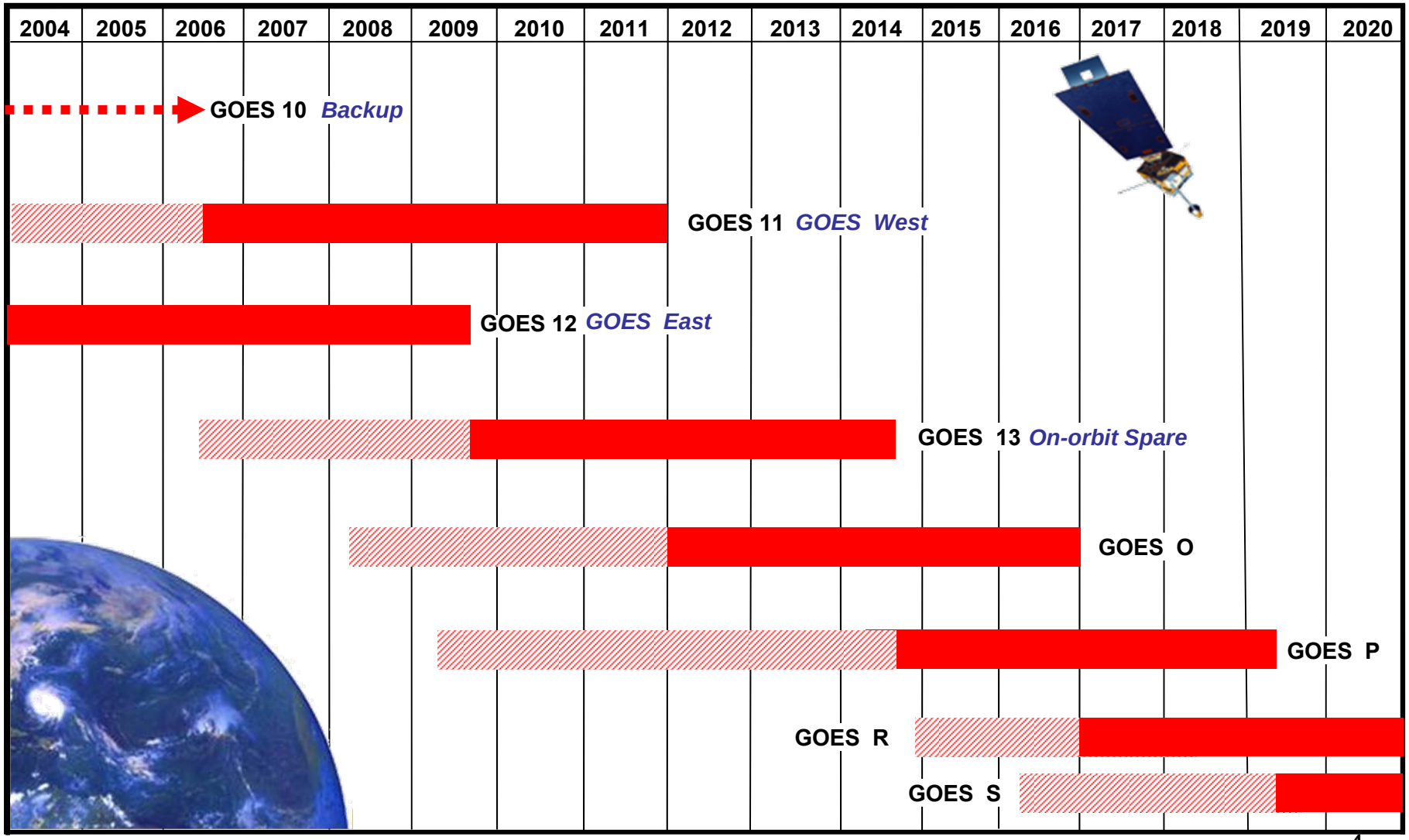
National Environmental Satellite, Data, and Information Service

US Planned Missions - Polar



National Environmental Satellite, Data, and Information Service

NOAA Planned Missions - Geostationary



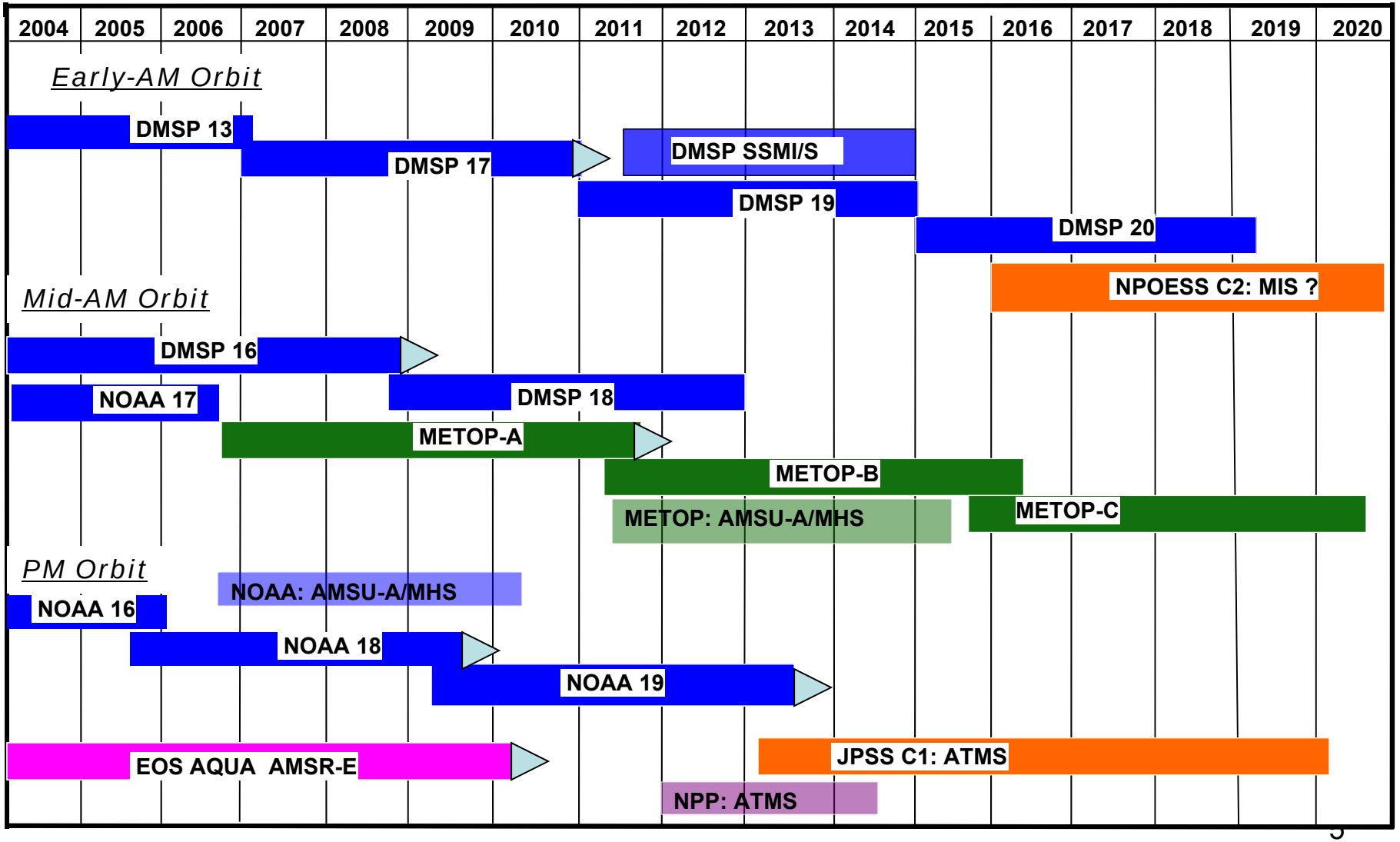
On-orbit GOES storage

Operational

Satellite is operational beyond design life

National Environmental Satellite, Data, and Information Service

US Polar Missions with MW Sensors for Operational Uses



NOAA Cal/Val Program Components

- **Pre-launch**
  - Pre-launch characterization
  - Common standards for vendor calibration
  - Traceability to system international units
  - New calibration models and algorithms
- **Post-launch**
  - Maintenance of operational satellite calibration
  - Inter-and Intra-calibration of satellite sensors
  - Online monitoring system for satellite instrument trending
  - Inter-comparison of satellite observations with simulations
- **Product validation**
  - Existing products from newly launched
  - New products from research satellites
  - Define validation sites
  - Consensus algorithm and error budget models
- **Impact assessment of new cal/val procedures**
  - NWP forecasts
  - Climate trend analysis
  - Special Applications (e.g. Land cover analysis, Severe weather forecast)

Near-Term Cal/Val Priorities

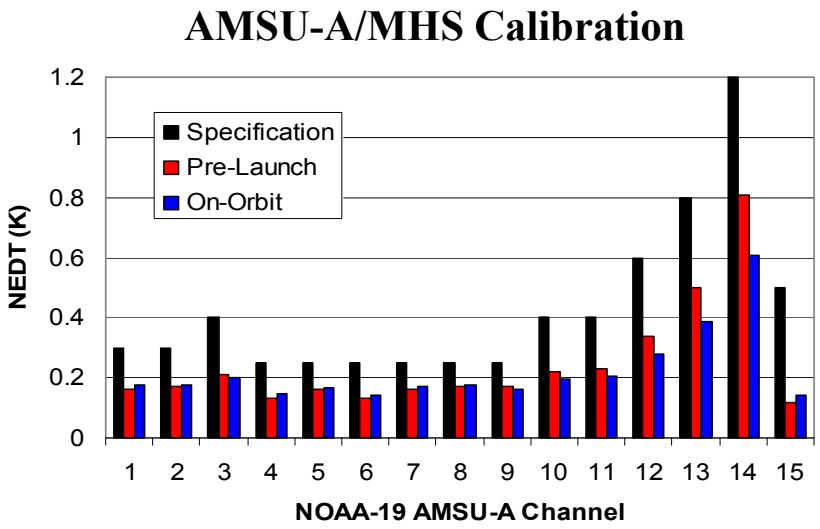
- **Prepare for New Mission In-Orbit Verification (IOV)**
  - METOP-B (AMSU, MHS, HIRS, AVHRR)
  - GOES-15 (VIS/IR imager and IR sounder)

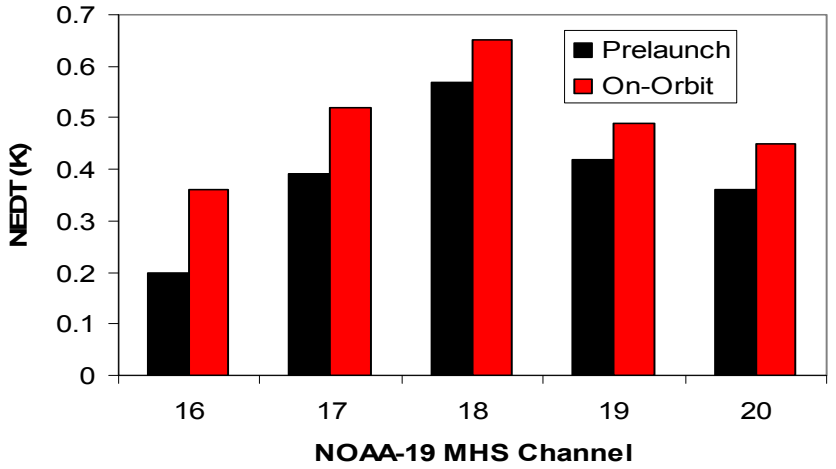
- **Operational Calibration Updates and System Maintenance**
  - Updates of Calibration Coefficients
  - Online Instrument Performance Monitoring
  - Global Bias Monitoring System (GBMS)

- **Support to WMO Global Space Based Inter-calibration System (GSICS)**
  - GSICS Research/Data Archival (e.g. metadata, algorithm coefficients, inter-sensor bias)
  - GSICS Coordination Center (GCC) (e.g. Quarterly News, Website, Product Acceptance)

AMSU/MHS NEDT Characterization

- Pre-launch
  - Pre-launch characterization
  - Common standards for vendor calibration
  - Traceability to system international units
  - New calibration models and algorithms
- Post-launch
  - Maintenance of operational satellite calibration
  - Inter-and Intra-calibration of satellite instruments
  - Online monitoring system for satellite instrument trending
  - Inter-comparison of satellite observations with simulations

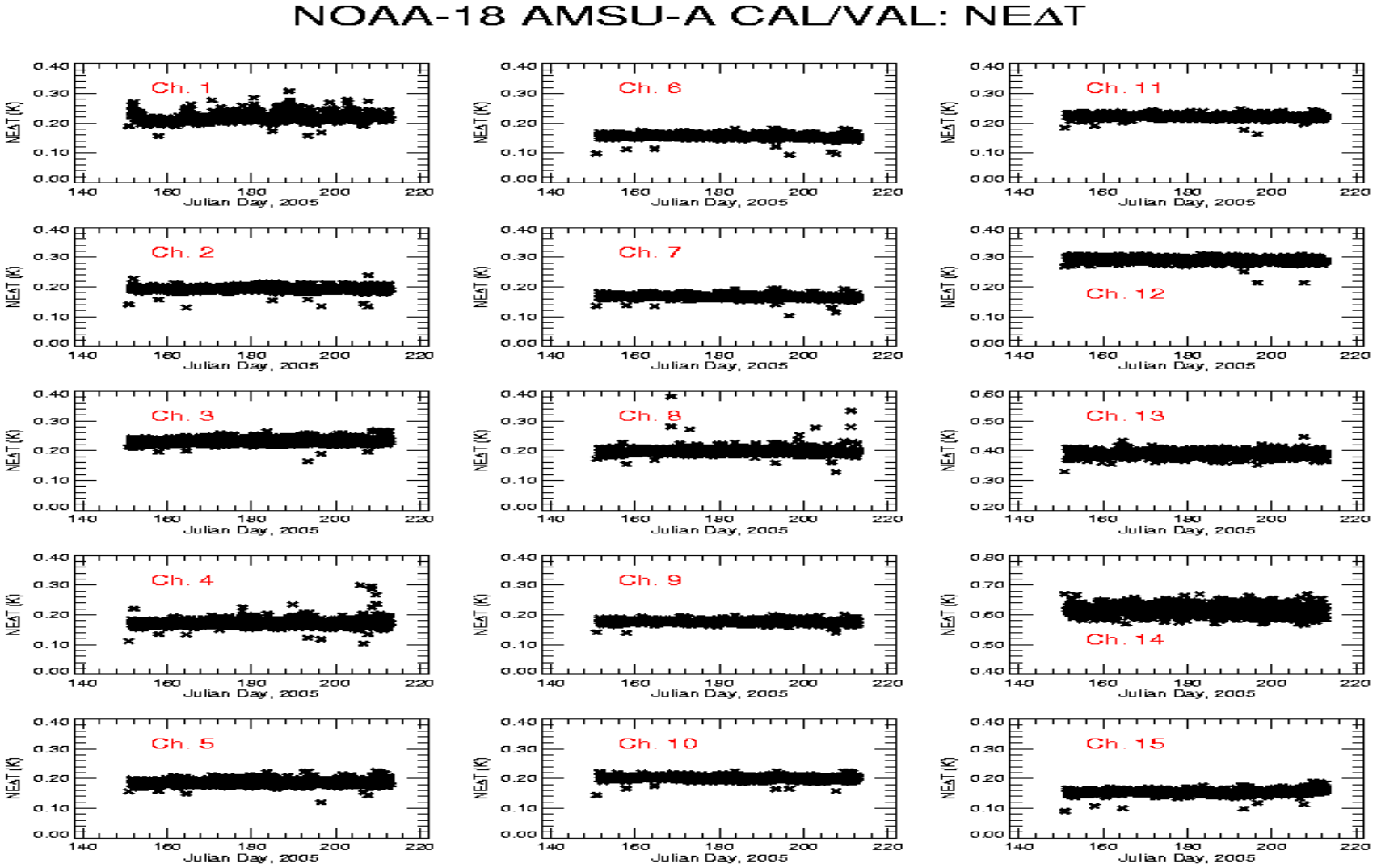




National Environmental Satellite, Data, and Information Service

AMSU-A NEDT Trending

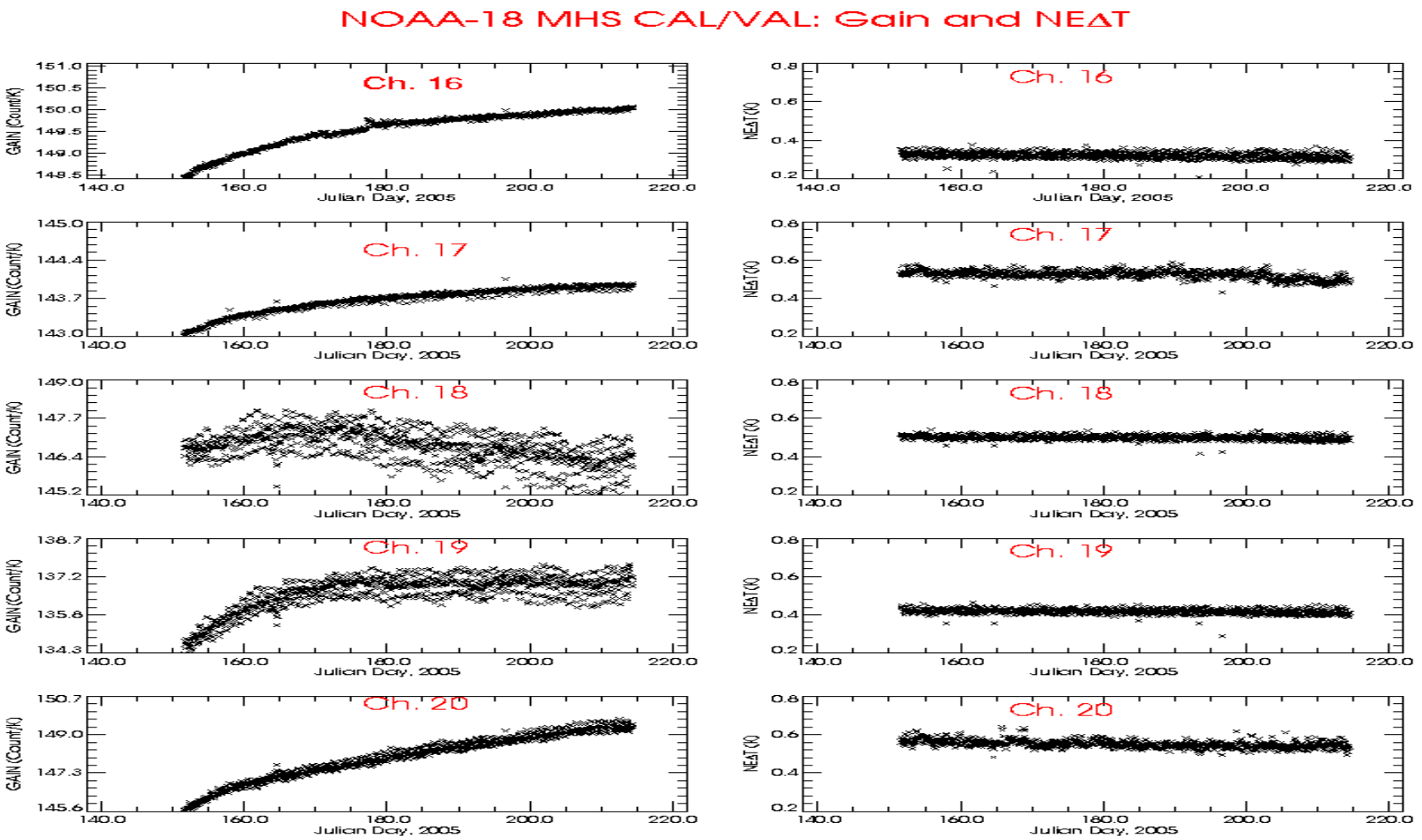
Trending over 65 days



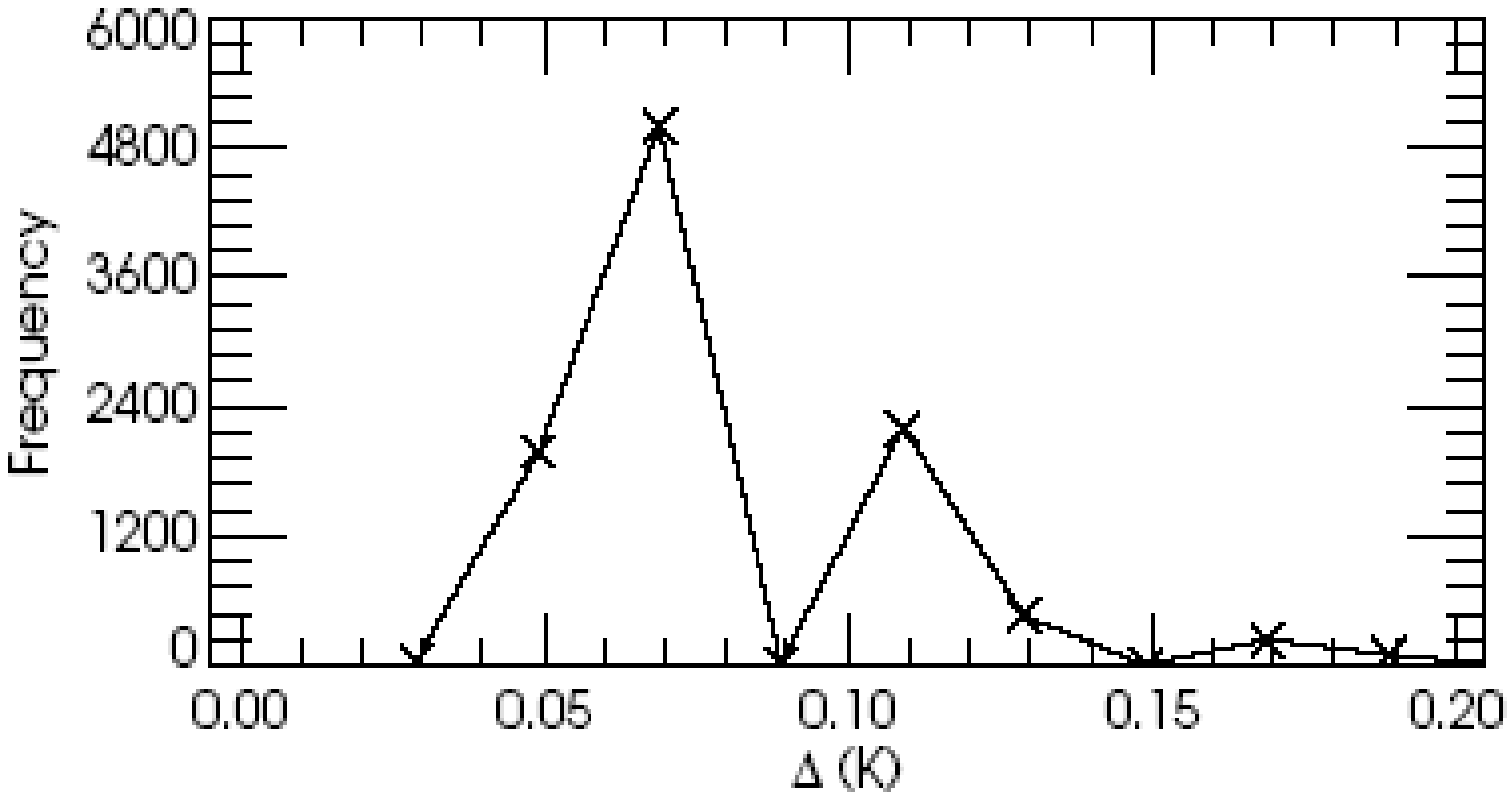
National Environmental Satellite, Data, and Information Service

MHS Gain and NEDT Trending

Trending over 65 days



Monitoring Uniformity of Warm Load PRT Temperatures



ΔT =Max – Min T

Spec: ΔT < 0.2 K

Linear and Non-linear Calibration

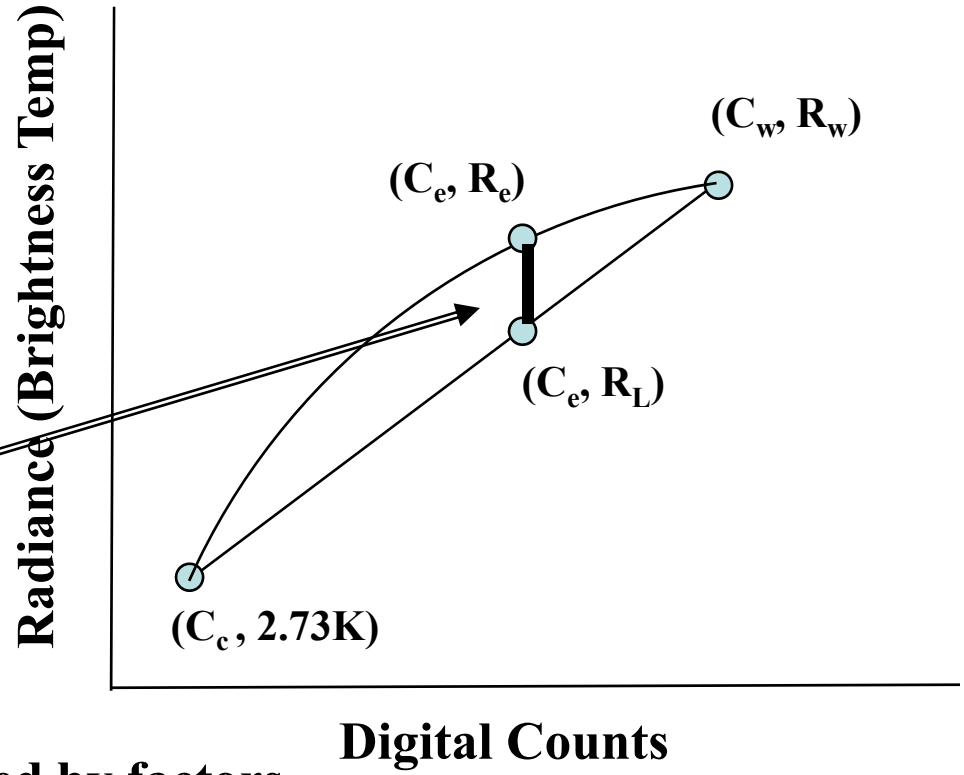
Two Point Radiometer Linear Calibration:

$$R_{e,L} = R_c + S(C_e - C_c)$$

$$S = \frac{R_w - R_c}{C_w - C_c}$$

Two Point Radiometer with Nonlinear Calibration Correction:

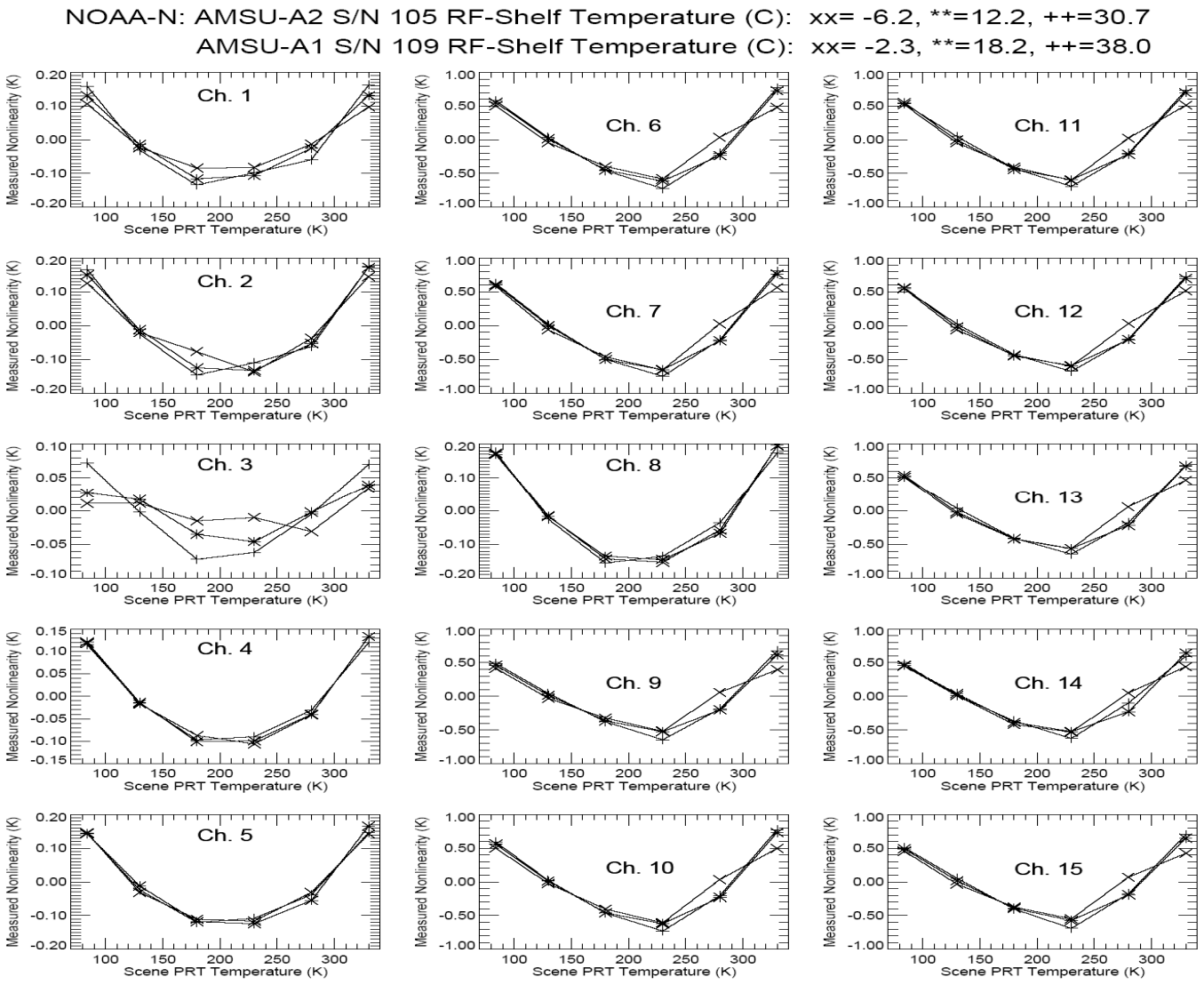
$$R_e = R_{e,L} + \mu Z - \delta R$$



where δR is the post-launch bias caused by factors other than non-linearity

$$Z = S^2 (C_e - C_c)(C_e - C_w)$$

AMSU-A Non-linearity from Prelaunch Analysis



Nonlinearity Spec:

Ch.1, 2, 15: 0.5 K

Ch.3-14: 0.375 K

A1-1 Channels: Out of spec

The lunar contamination (LC) in space counts, ΔCc, is calculated by the formula,

$$\Delta C_c = \left[\frac{C_w - C_c}{T_w - (T_c + \Delta T_c)} \right] \Delta T_c$$

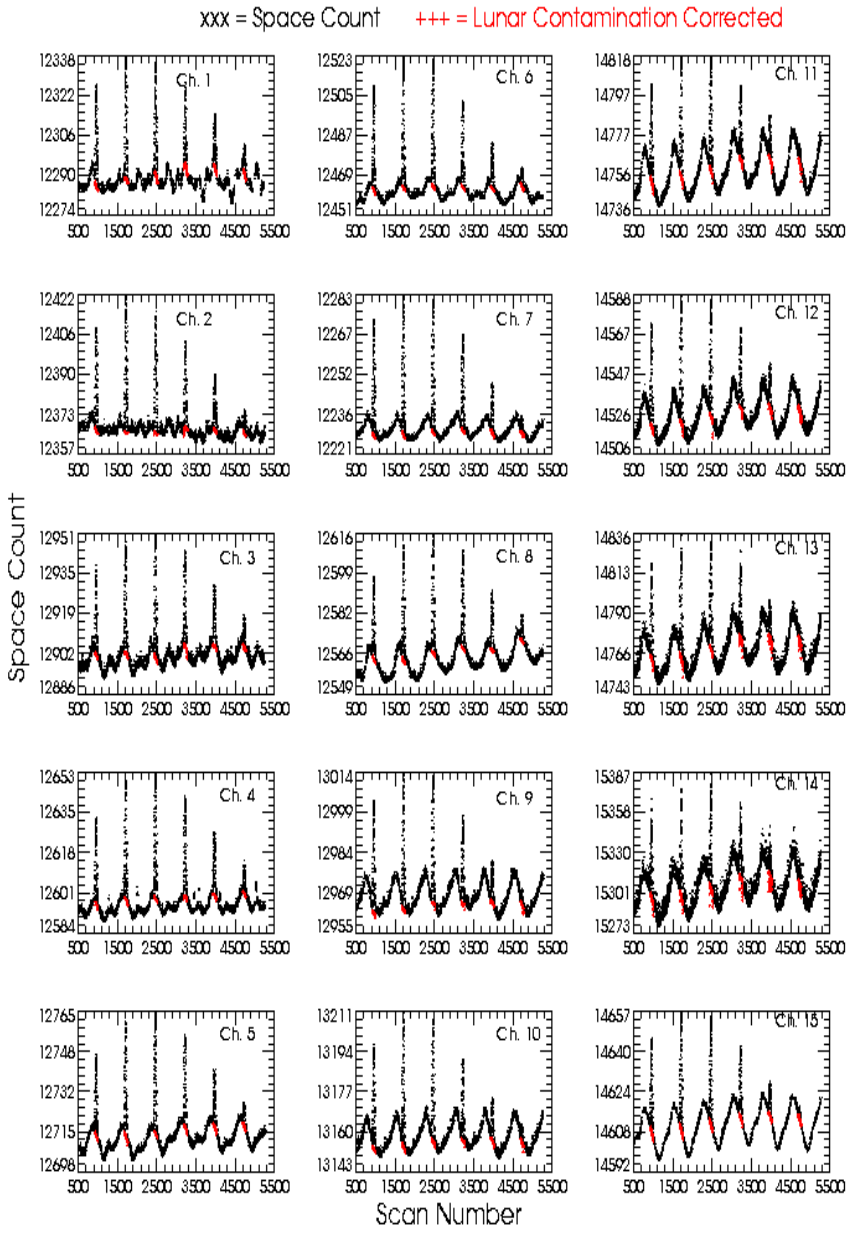
Where the increased space temperature ΔTc is related to the effective lunar surface temperature by

$$\Delta T_c = \exp\left[-\frac{(\alpha - \alpha_0)^2}{2\alpha_S^2} \right] \exp\left[-\frac{(\delta - \delta_0)^2}{2\delta_S^2} \right] \beta T_{moon}\, r$$

$$T_{moon} = 95.21 + 104.63(1 - \cos\theta) + 11.62(1 + \cos 2\theta)$$

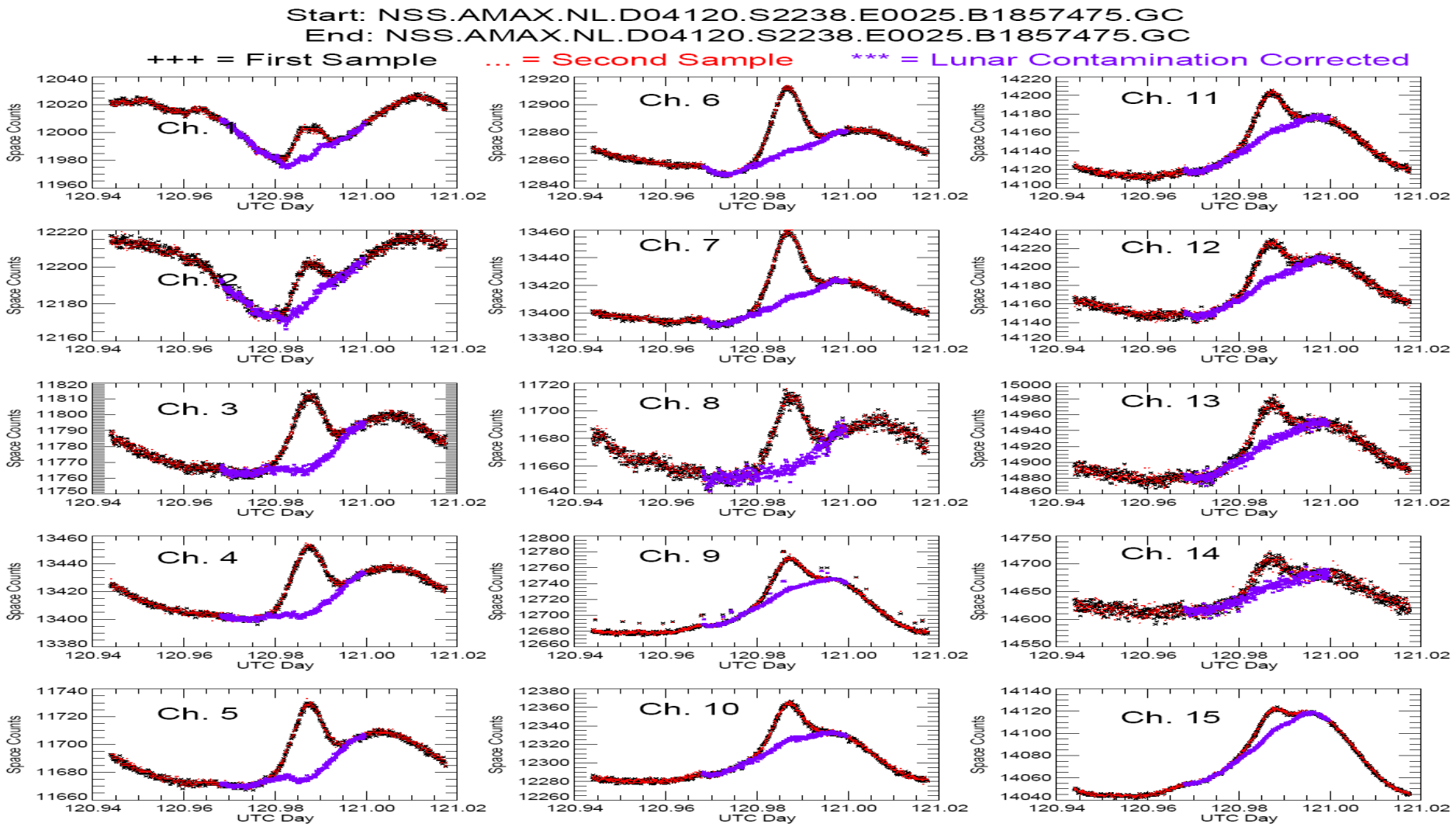
Where:

θ	separation angle between the moon and sun
Cw	*blackbody count*
Cc	*observed space counts, including lunar contamination*
Tw	blackbody temperature
Tc	deep space cosmic background temperature
α	*lunar azimuth angle*
$\alpha 0$	*field of view (FOV) center of lunar azimuth angle*
αS	*lunar azimuth size factor*
δ	*lunar elevation angle*
$\delta 0$	*FOV center of lunar elevation angle*
δS	*elevation size factor*
β	*area ratio of lunar disk to FOV convolved with the antenna patterns powers [3].*
r	*distance ratio = (60.3x6378/d)2, where d is the distance (in km) between the satellite and moon*



National Environmental Satellite, Data, and Information Service

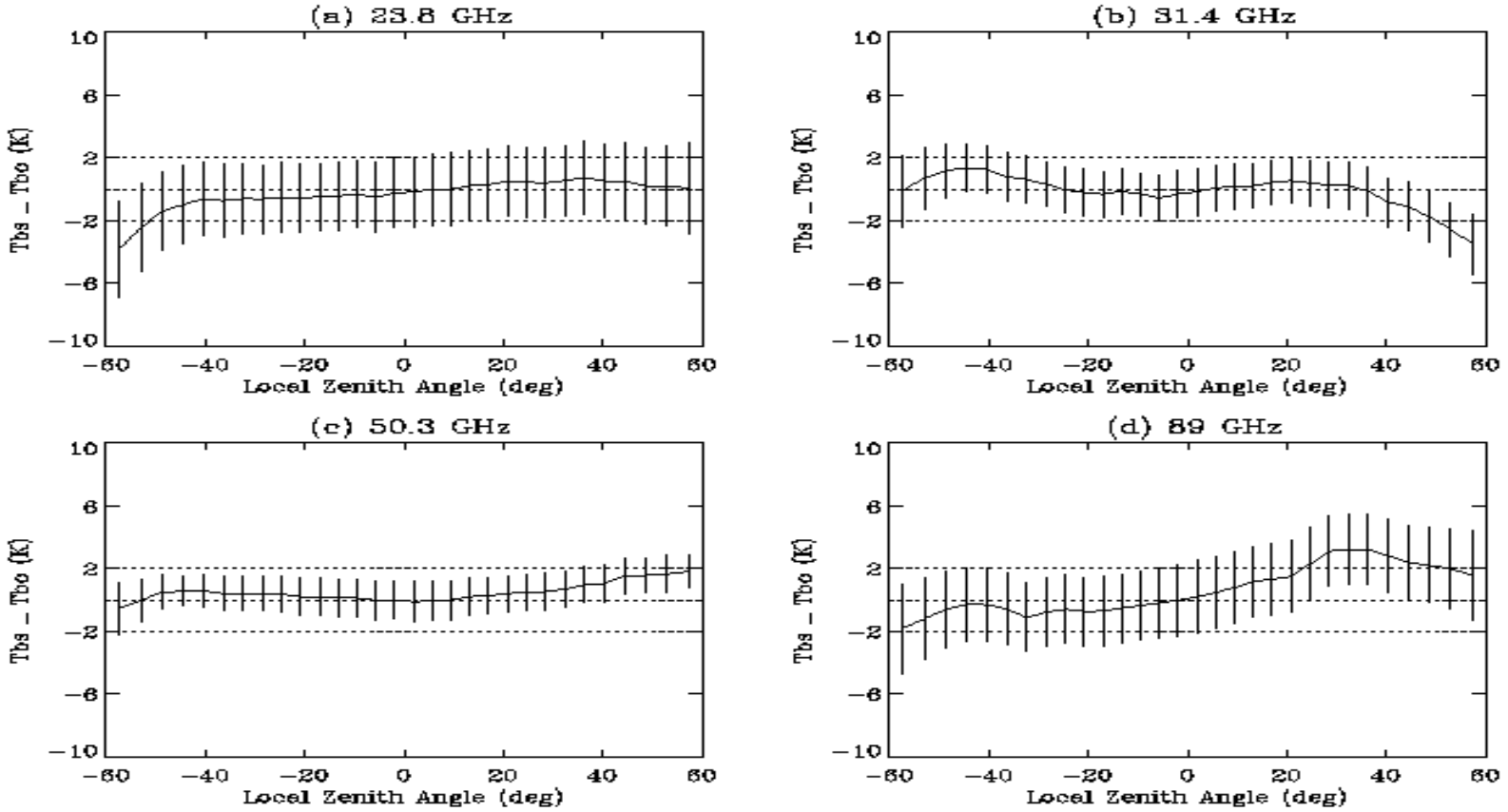
Correction for Lunar Contamination on Cold Space Calibration



AMSU Cross-Scan Asymmetry

- **A misalignment of AMSU polarization vector**
  - Mostly noticeable at clean window channels
- **Errors in Instrument pointing angle**
  - It is unlikely because the cross-track pointing error (0.1 to 0.3 degree) is not large enough to produce this kind of asymmetry.
- **Side lobe intrusion to the solar array**
  - There should be some latitudinal dependence
  - The response would occur at multiple channels

AMSU-A Scan Asymmetry



$$\Delta T = A_0 \exp\{ -0.5[(\theta - A_1)/A_2]^2 \} + A_3 + A_4 \theta + A_5 \theta^2$$

A misalignment of AMSU polarization vector may be one of causes (Weng et al., 2003)

Instrument Performance and Bias Monitoring Systems

- **Provide real-time diagnose and root-cause analysis for any major instrument anomaly, i.e.,**
  - NOAA-18 HIRS filter wheel loose len
  - NOAA-19 MHS Ch 3 and 4 front end associated with RF/IF
- **Build a high quality of QC data for CDR reprocessing**
  - Noise spikes and anomaly events associated with SDR data
  - Retrospective check of historic sensor data
- **Assist in NWP community to diagnose major forecast bursts and drop-out related to satellite data**
  - Correlation of NWP bias monitoring/data utilization rate with NEDT

National Environmental Satellite, Data, and Information Service

STAR Integrated Cal/Val System: Online Capability

STAR - Satellite Integrated Calibration / Validation System (ICVS) - NOAA-19 Instrument Monitoring - AMSU-A - Mozilla ...

File Edit View History Bookmarks Tools Help

http://www.star.nesdis.noaa.gov/smcd/spb/icvs/satMonitoring_n19_amax.php

Google

Enter search term(s) Go

This site only All of NOAA

Advanced Search

» Integrated Cal/Val System

» Satellite Monitoring >>

- NOAA-19 AMSU-A >>
- NOAA-19 MHS
- NOAA-19 AVHRR
- NOAA-19 HIRS
- MetOP-A AMSU-A
- MetOP-A MHS
- NOAA-18 AMSU-A
- NOAA-18 MHS

» Products Demonstration

» Meetings

» Publications

Data and images displayed on STAR sites are provided for experimental use only and are not official operational NOAA products. More information>>

Satellite Integrated Calibration / Validation System (ICVS)

NOAA-19 AMSU-A Instrument Performance Monitoring

Please select the instrument performance index & press 'Display' Button

AMSU-A NEΔT/Gain: Last Week NEΔT Snapshot — Display

AMSU-A Instrument Temperature: A1-1 Warm Load — Display

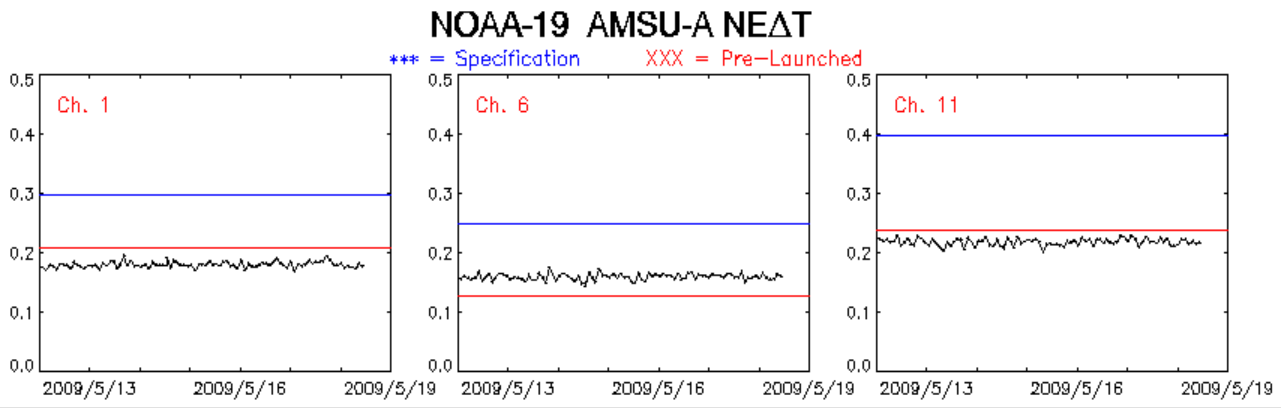
AMSU-A Mixer/IF Amplifier Temperature: Last Week Snapshot — Display

AMSU-A Local Oscillator Temperature: Last Week Snapshot — Display

AMSU-A Cold Calibration Count: Last Week Snapshot — Display

AMSU-A Warm Calibration Count: Last Week Snapshot — Display

AMSU-A Status: Last Week Orbit Status — Display



Done

Start | Presenta... | NOAA M... | NOAA-1... | Mozilla F... | Time ser... | STAR - ... | EN | 10:30 AM

National Environmental Satellite, Data, and Information Service

ECMWF Online Monitoring

Time series of area averages - Mozilla Firefox

File Edit View History Bookmarks Tools Help

http://www.ecmwf.int/products/forecasts/d/charts/monitoring/satellite/atovs/amsua/o_noaa_

ECMWF

Home Your Room Login Contact Feedback Site Map Search:

About Us: Overview, Getting here, Committees
Products: Forecasts, Order Data, Order Software
Services: Computing, Archive, PrepIFS
Research: Modelling, Reanalysis, Seasonal
Publications: Newsletters, Manuals, Library
News&Events: Calendar, Employment, Open Tenders

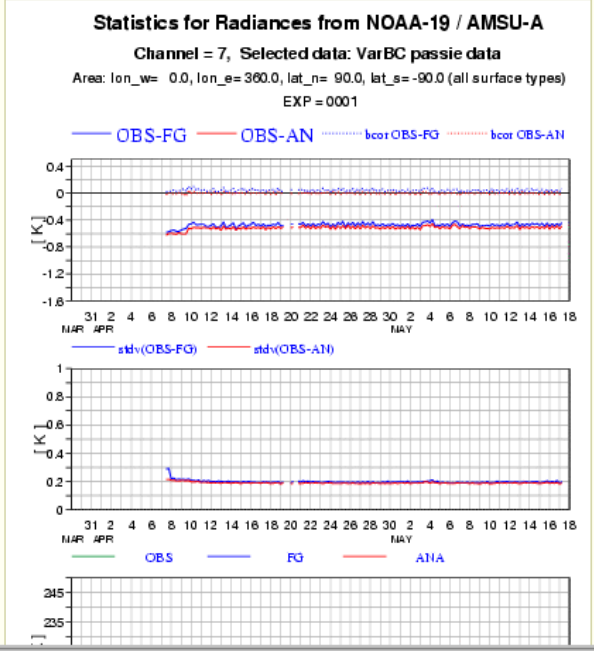
Mean sea level pressure and 24h c

Home > Products > Forecasts > Data reception statistics > Satellite Data Monitoring > ATOVS monitoring > Advanced Microwave Sounding Unit A (AMSU-A) > Time series of area averages>

Time series of area averages

Satellite
METOP-A
NOAA-15
NOAA-16
NOAA-18
NOAA-19
AQUA

Channel
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15



Done

Start | NOAA MW S... | Time serie... | STAR - Satel... | 10:34 AM

AMSU-A/MHS Parameter Trending

- Cold Calibration Counts (20 Channels)
- Warm Calibration Counts (20 Channels)
- NEΔT (20 Channels)
- Gains (20 Channels)
- Warm Load PRT Temperature/Maximum Difference Mode (A11/A12/A2)
- RF Shelf Temperature (A11/A12/A2)
- RF MUX Temperature (A11/A12/A2)
- Feedhorn Temperature (A11/A12/A2)
- Mixer/IF Amplifier Temperature (A11/A12/A2 15 Channels)
- Mixer/LNA Temperature (5 MHS channels)
- Local Oscillator Temperature (20 Channels)
- Orbit Status

STAR Integrated Cal/Val System: A Powerful Tool for Assessments of Instrument Performance

AMSU-A

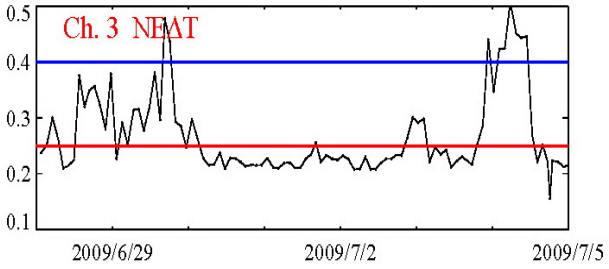
- NOAA-19 Ch3 NEΔT anomaly
- MetOP-A Ch7 NEΔT Drop

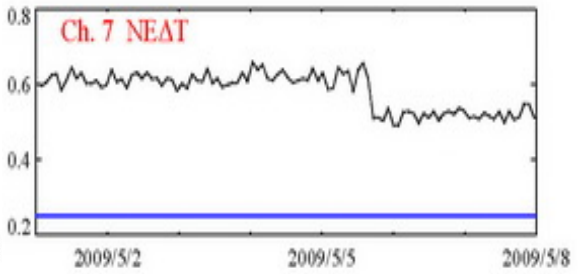
MHS

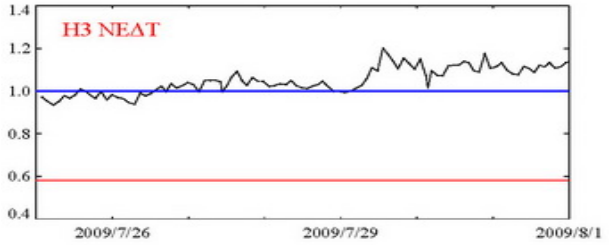
- NOAA-19 H3 NEΔT is out of specification (1K)
- NOAA-19 H4 Cold Calibration Count jump

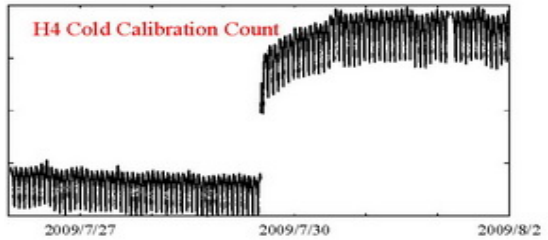
HIRS

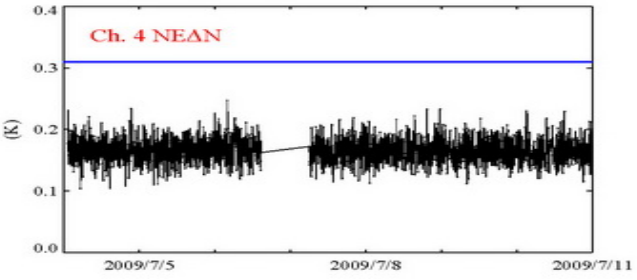
- NOAA-19 Ch4 Data Gaps
- NOAA-18 Ch5 NEΔN Anomaly

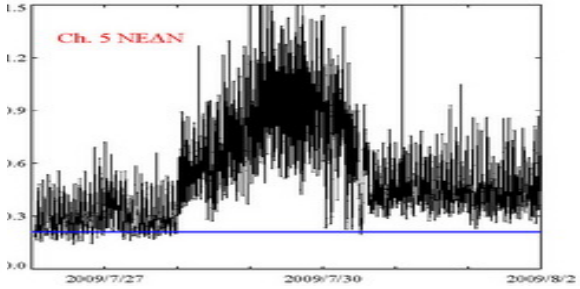








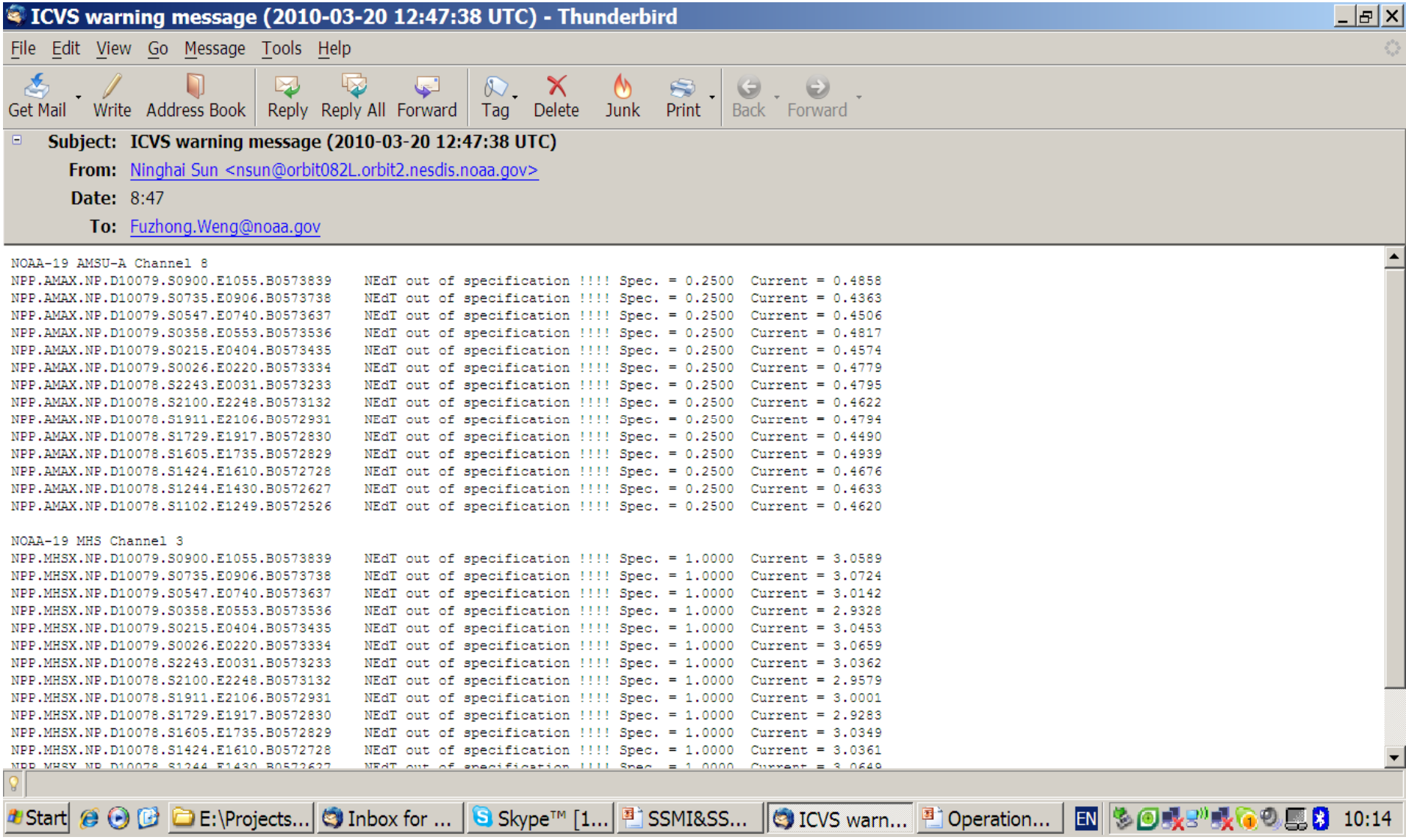




URL: http://www.star.nesdis.noaa.gov/smcd/spb/icvs/satMonitoring_n19_amax.php

National Environmental Satellite, Data, and Information Service

Daily Calibration Email Report to STAR Calibration Branch Chief



ICVS warning message (2010-03-20 12:47:38 UTC) - Thunderbird

File Edit View Go Message Tools Help

Get Mail | Write | Address Book | Reply | Reply All | Forward | Tag | Delete | Junk | Print | Back | Forward

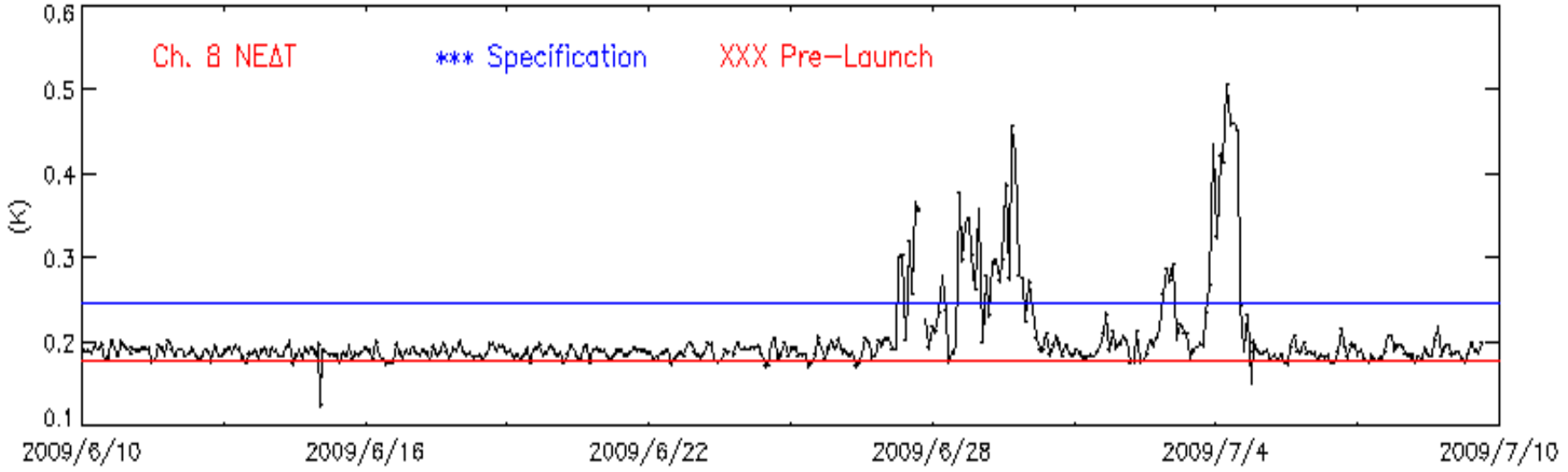
Subject: ICVS warning message (2010-03-20 12:47:38 UTC)
From: Ninghai Sun <nsun@orbit082L.orbit2.nesdis.noaa.gov>
Date: 8:47
To: Fuzhong.Weng@noaa.gov

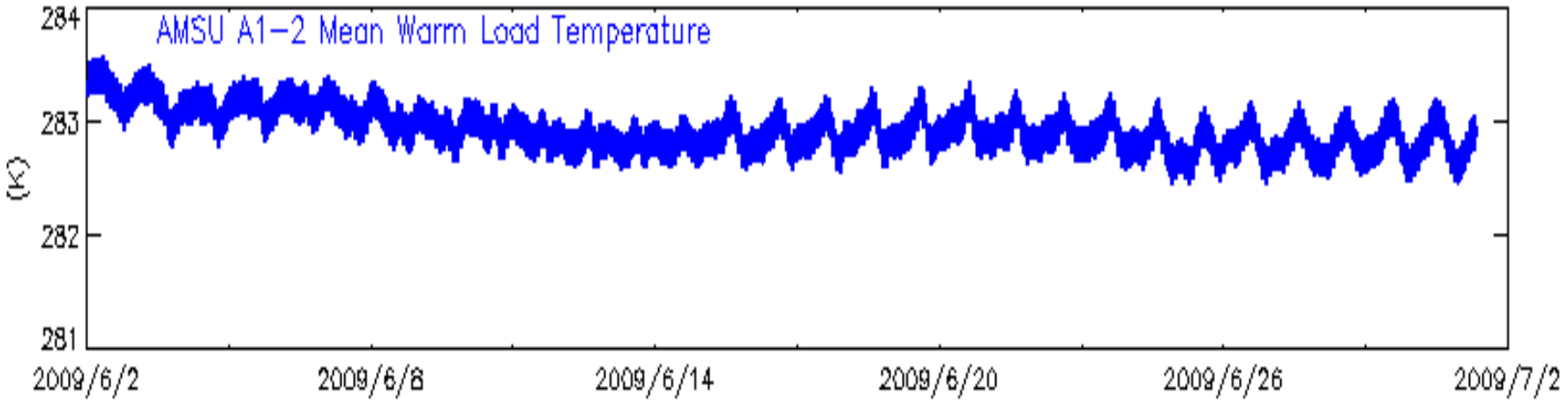
```
NOAA-19 AMSU-A Channel 8
NPP.AMAX.NP.D10079.S0900.E1055.B0573839    NEdT out of specification !!!! Spec. = 0.2500  Current = 0.4858
NPP.AMAX.NP.D10079.S0735.E0906.B0573738    NEdT out of specification !!!! Spec. = 0.2500  Current = 0.4363
NPP.AMAX.NP.D10079.S0547.E0740.B0573637    NEdT out of specification !!!! Spec. = 0.2500  Current = 0.4506
NPP.AMAX.NP.D10079.S0358.E0553.B0573536    NEdT out of specification !!!! Spec. = 0.2500  Current = 0.4817
NPP.AMAX.NP.D10079.S0215.E0404.B0573435    NEdT out of specification !!!! Spec. = 0.2500  Current = 0.4574
NPP.AMAX.NP.D10079.S0026.E0220.B0573334    NEdT out of specification !!!! Spec. = 0.2500  Current = 0.4779
NPP.AMAX.NP.D10078.S2243.E0031.B0573233    NEdT out of specification !!!! Spec. = 0.2500  Current = 0.4795
NPP.AMAX.NP.D10078.S2100.E2248.B0573132    NEdT out of specification !!!! Spec. = 0.2500  Current = 0.4622
NPP.AMAX.NP.D10078.S1911.E2106.B0572931    NEdT out of specification !!!! Spec. = 0.2500  Current = 0.4794
NPP.AMAX.NP.D10078.S1729.E1917.B0572830    NEdT out of specification !!!! Spec. = 0.2500  Current = 0.4490
NPP.AMAX.NP.D10078.S1605.E1735.B0572829    NEdT out of specification !!!! Spec. = 0.2500  Current = 0.4939
NPP.AMAX.NP.D10078.S1424.E1610.B0572728    NEdT out of specification !!!! Spec. = 0.2500  Current = 0.4676
NPP.AMAX.NP.D10078.S1244.E1430.B0572627    NEdT out of specification !!!! Spec. = 0.2500  Current = 0.4633
NPP.AMAX.NP.D10078.S1102.E1249.B0572526    NEdT out of specification !!!! Spec. = 0.2500  Current = 0.4620

NOAA-19 MHS Channel 3
NPP.MHSX.NP.D10079.S0900.E1055.B0573839    NEdT out of specification !!!! Spec. = 1.0000  Current = 3.0589
NPP.MHSX.NP.D10079.S0735.E0906.B0573738    NEdT out of specification !!!! Spec. = 1.0000  Current = 3.0724
NPP.MHSX.NP.D10079.S0547.E0740.B0573637    NEdT out of specification !!!! Spec. = 1.0000  Current = 3.0142
NPP.MHSX.NP.D10079.S0358.E0553.B0573536    NEdT out of specification !!!! Spec. = 1.0000  Current = 2.9328
NPP.MHSX.NP.D10079.S0215.E0404.B0573435    NEdT out of specification !!!! Spec. = 1.0000  Current = 3.0453
NPP.MHSX.NP.D10079.S0026.E0220.B0573334    NEdT out of specification !!!! Spec. = 1.0000  Current = 3.0659
NPP.MHSX.NP.D10078.S2243.E0031.B0573233    NEdT out of specification !!!! Spec. = 1.0000  Current = 3.0362
NPP.MHSX.NP.D10078.S2100.E2248.B0573132    NEdT out of specification !!!! Spec. = 1.0000  Current = 2.9579
NPP.MHSX.NP.D10078.S1911.E2106.B0572931    NEdT out of specification !!!! Spec. = 1.0000  Current = 3.0001
NPP.MHSX.NP.D10078.S1729.E1917.B0572830    NEdT out of specification !!!! Spec. = 1.0000  Current = 2.9283
NPP.MHSX.NP.D10078.S1605.E1735.B0572829    NEdT out of specification !!!! Spec. = 1.0000  Current = 3.0349
NPP.MHSX.NP.D10078.S1424.E1610.B0572728    NEdT out of specification !!!! Spec. = 1.0000  Current = 3.0361
```

Start | E:\Projects... | Inbox for ... | Skype™ [1... | SSMI&SS... | ICVS warn... | Operation... | EN | 10:14

National Environmental Satellite, Data, and Information Service

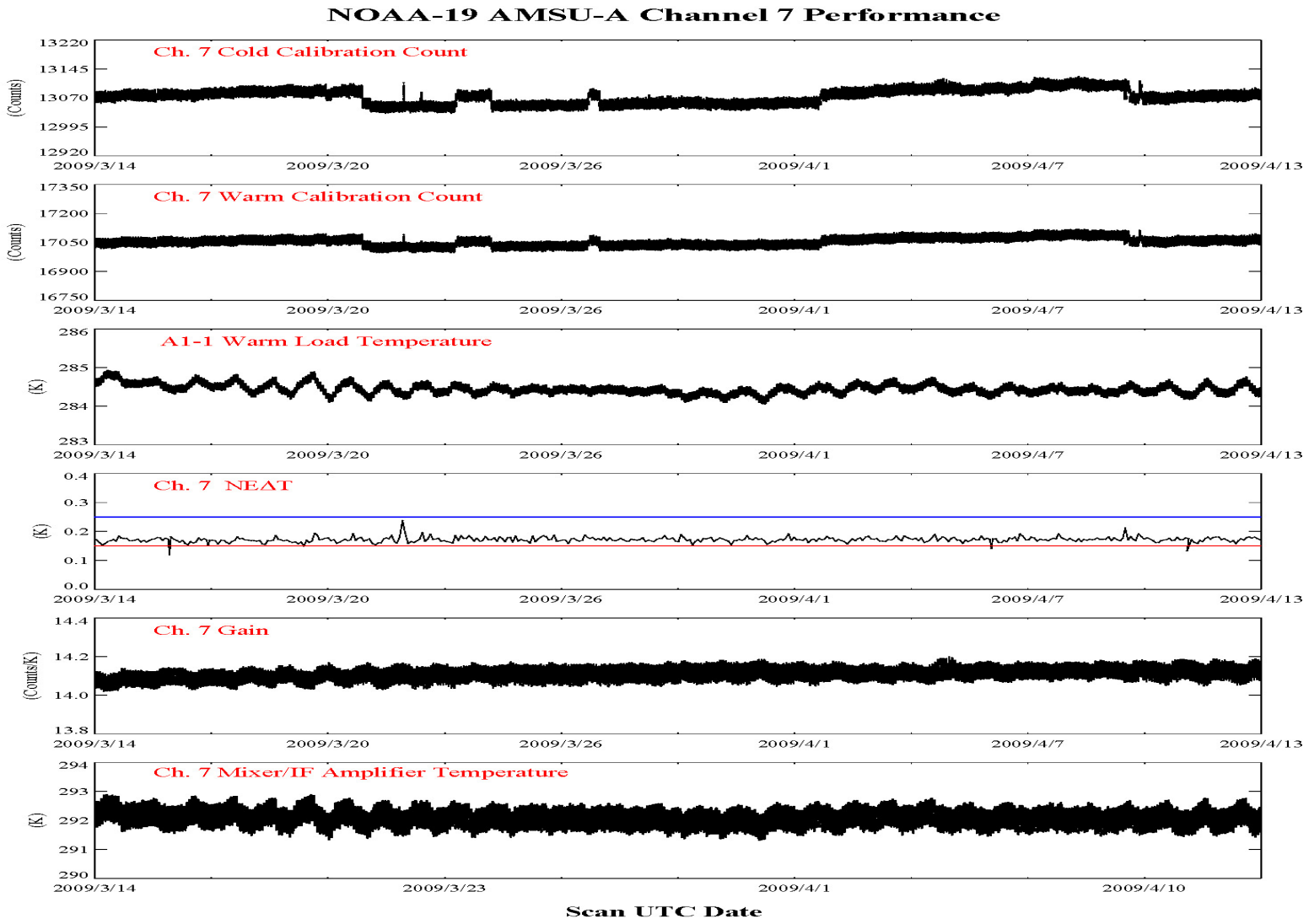
AMSU-A Trending



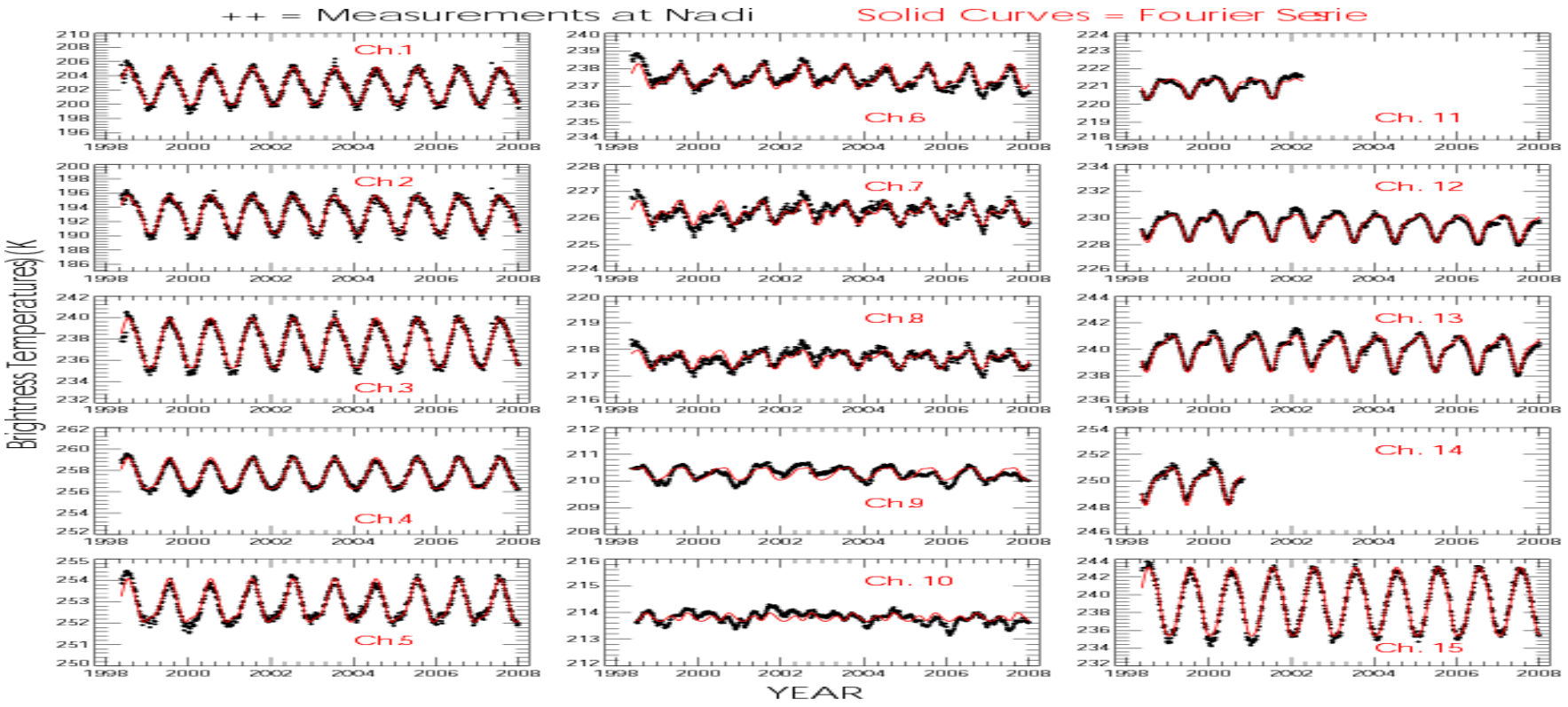


National Environmental Satellite, Data, and Information Service

On-Line Trending of AMSU-A Calibration and Telemetry



Brightness Temperature Series



Mo, T. (2009), A study of the NOAA-15 AMSU-A brightness temperatures from 1998 through 2007, J. Geophys. Res., 114, D11110, doi:10.1029/2008JD011267.

Channel 15 measurements are closest to the Earth's surface

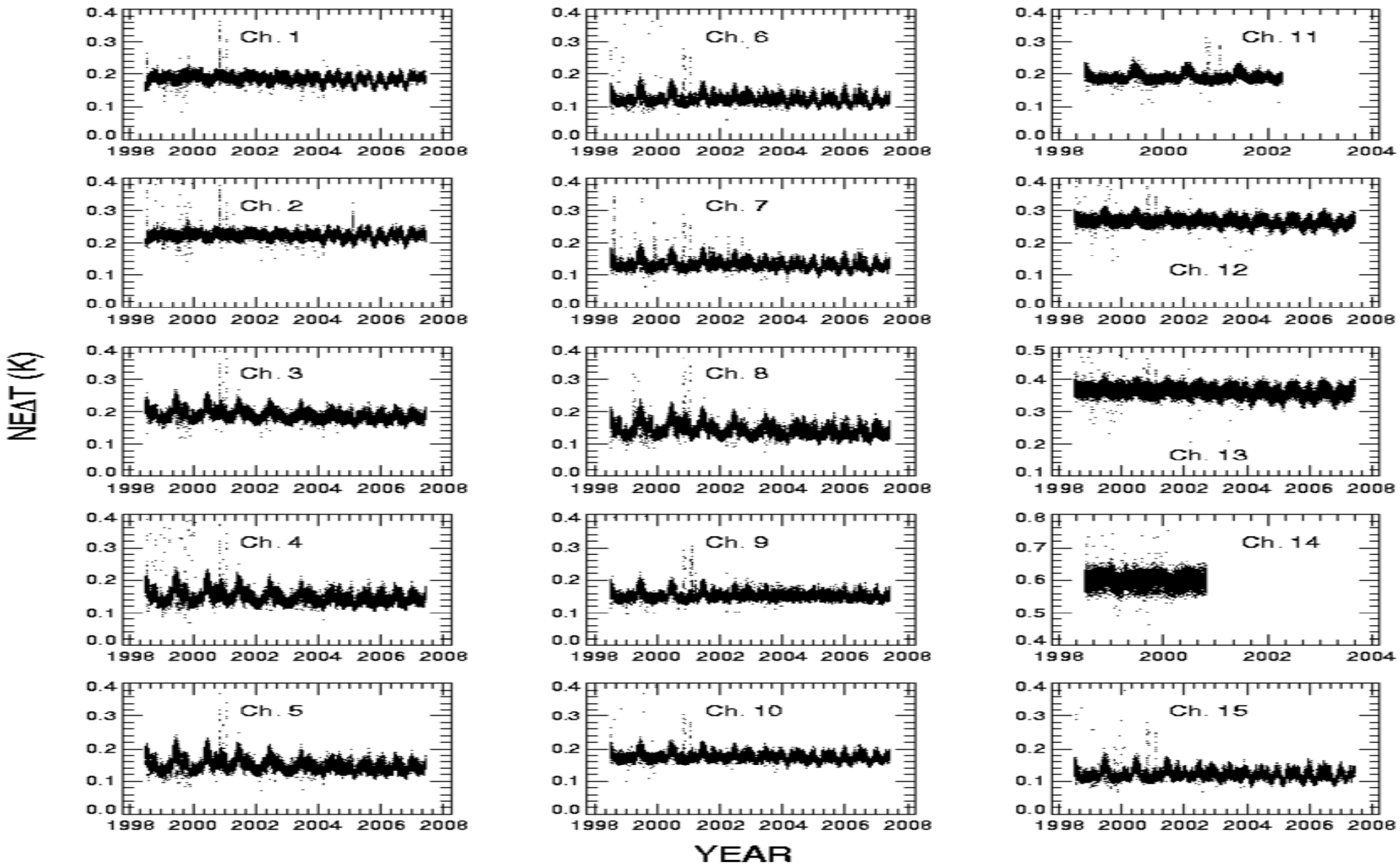
Channel 9 measurements are near tropopause

Channels 15 and 1-8 measurements are at multiple levels in troposphere

Channels 9-14 measurements are at multiple levels in stratosphere

National Environmental Satellite, Data, and Information Service

N15 AMSU-A NEDT from 1998 to 2008

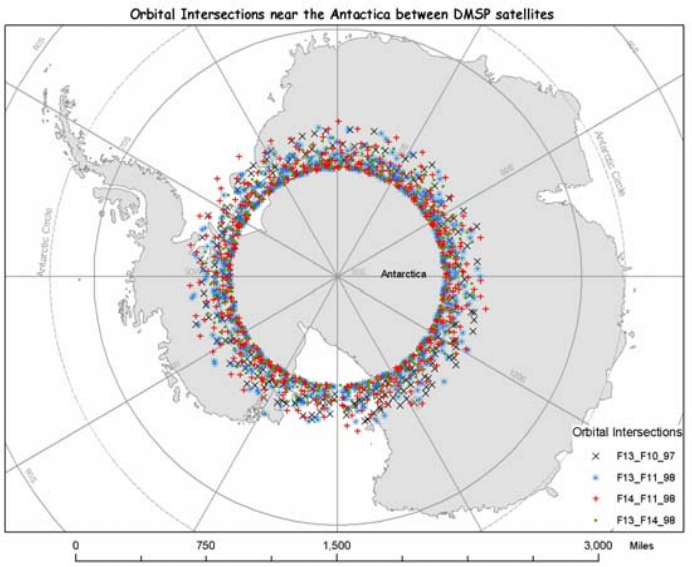


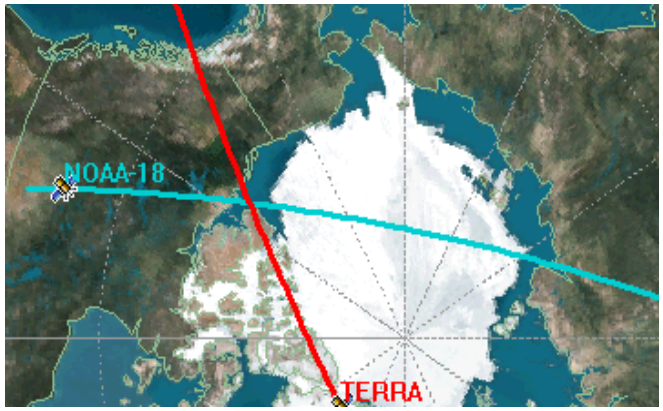
Cross-Calibration through Best Practices

- WMO GSICS Supports
- Global Bias Monitoring System
- DMSP SSMIS Unified Preprocessor
- GPM XCal Group
- CEOS Working Group CalVal (WGCV)

Simultaneous near Nadir (Conical) Overpassing (SNO/SCO)

- **Instruments on different satellites are intercalibrated as they pass over polar latitudes, where paths cross**
- **The technique has been applied to Microwave Sounding Unit observations on multiple NOAA satellites since 1979**

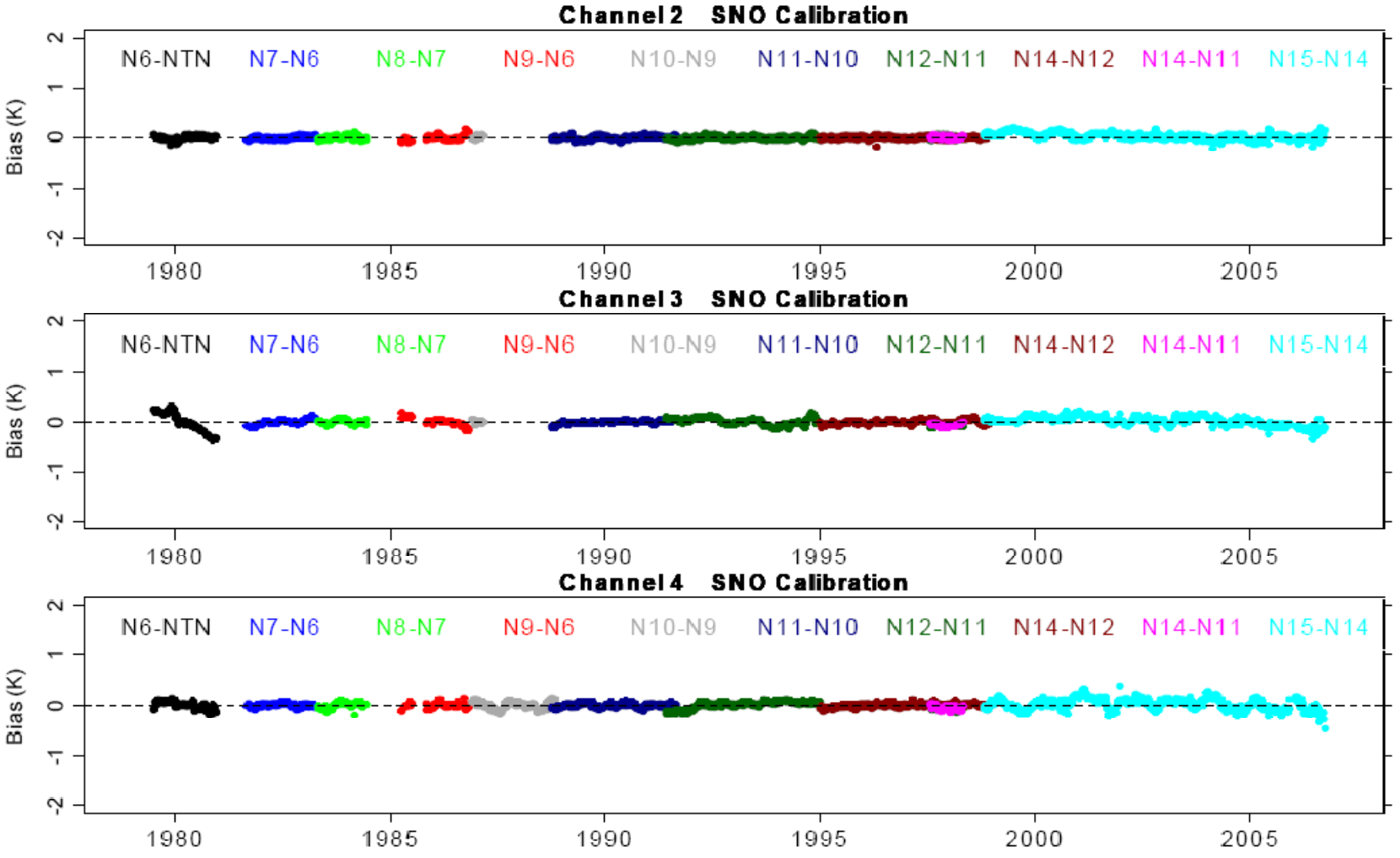




Simultaneous Nadir Overpass (SNO)

Simultaneous observations from DMSP F10 and F11 satellites over Antarctic continent

Climate Calibration for MSU-AMSU



Roles of NWP in CalVal

- **More satellite data assimilation makes forecasts more accurate**
  - Spatial distribution of O-B, O - A
  - O – B, O - A histogram distribution
- **Easy collocation with any observation including satellites, complement to SNO technique which is limited to polar conditions**
- **Uses for xcalibration through double difference technique (DDT)**
  - (O1 - B1) – (O2 –B2)

Why DDT works well in estimating the cross-sensor biases

- **It reduces the impact related to temporal difference when two instruments have distinct orbits**
- **It reduces the errors related to forward models and from forecast models**
- **It works in any region where the forward model has the same error characteristics for both instruments**

$$(O_1 - B_1) - (O_2 - B_2)$$
$$= dO_{ins} + dO_{time} - dB_{rtm} - dB_{time}$$
$$\approx dO_{ins}$$

Assumptions:

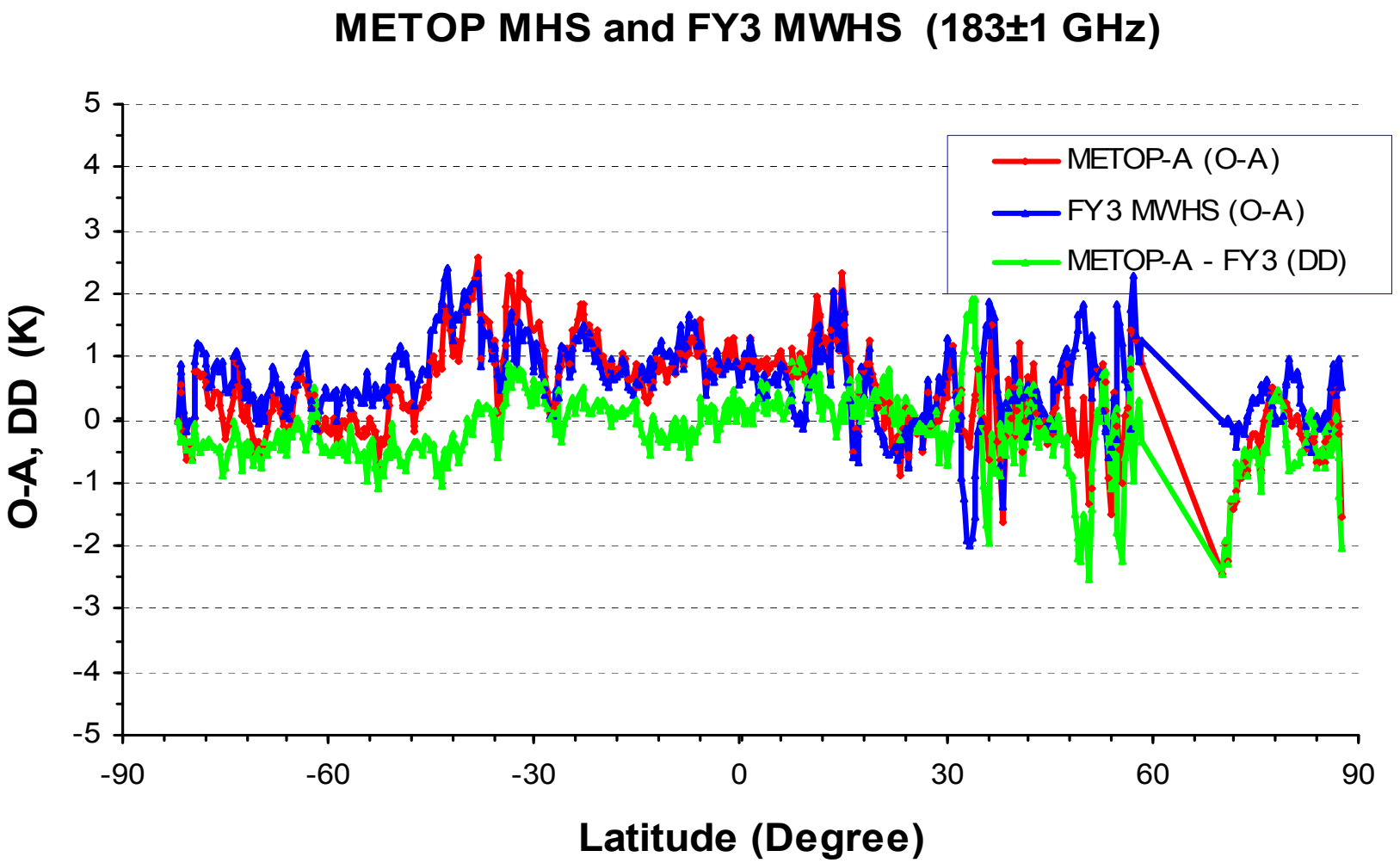
The same temporal difference from observations and simulations

$$dO_{time} - dB_{time} \approx 0$$

Negligible forward model biases for two instruments

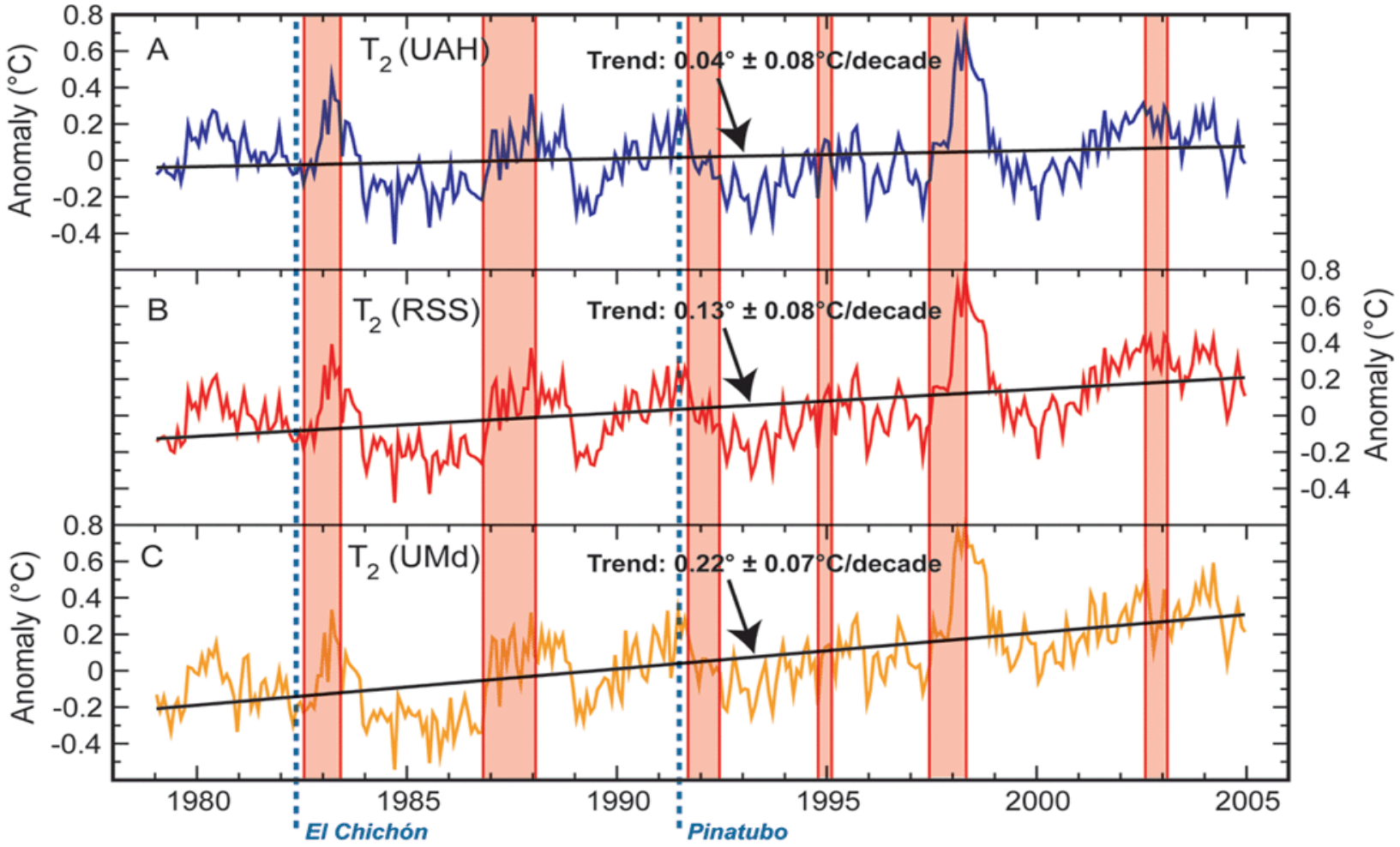
$$dB_{rtm} \approx 0$$

Double Difference Technique (DDT)



National Environmental Satellite, Data, and Information Service

Climate Trends from Microwave Sounders



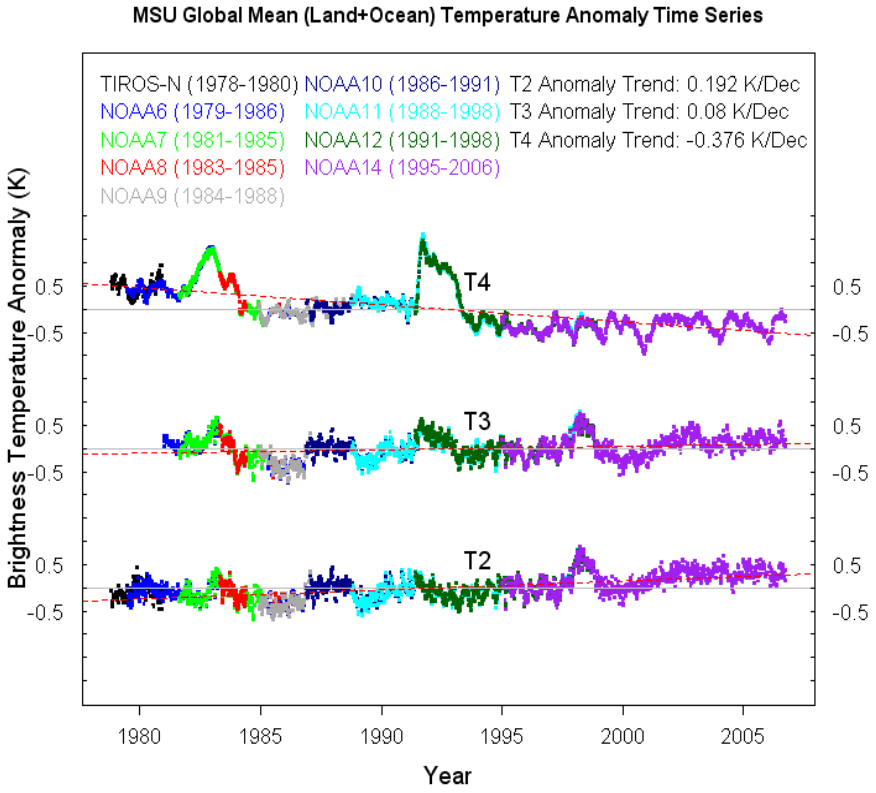
National Environmental Satellite, Data, and Information Service

Climate Data Record from the Climate Calibrated MSU Version 1.2

- Created well-merged gridded temperature products using climate calibrated radiances for reanalysis validation and trend studies; products include diurnal correction, incident angle adjustment, and warm target error correction.

- Trend results reported in the upcoming BAMS article on 2008 climate

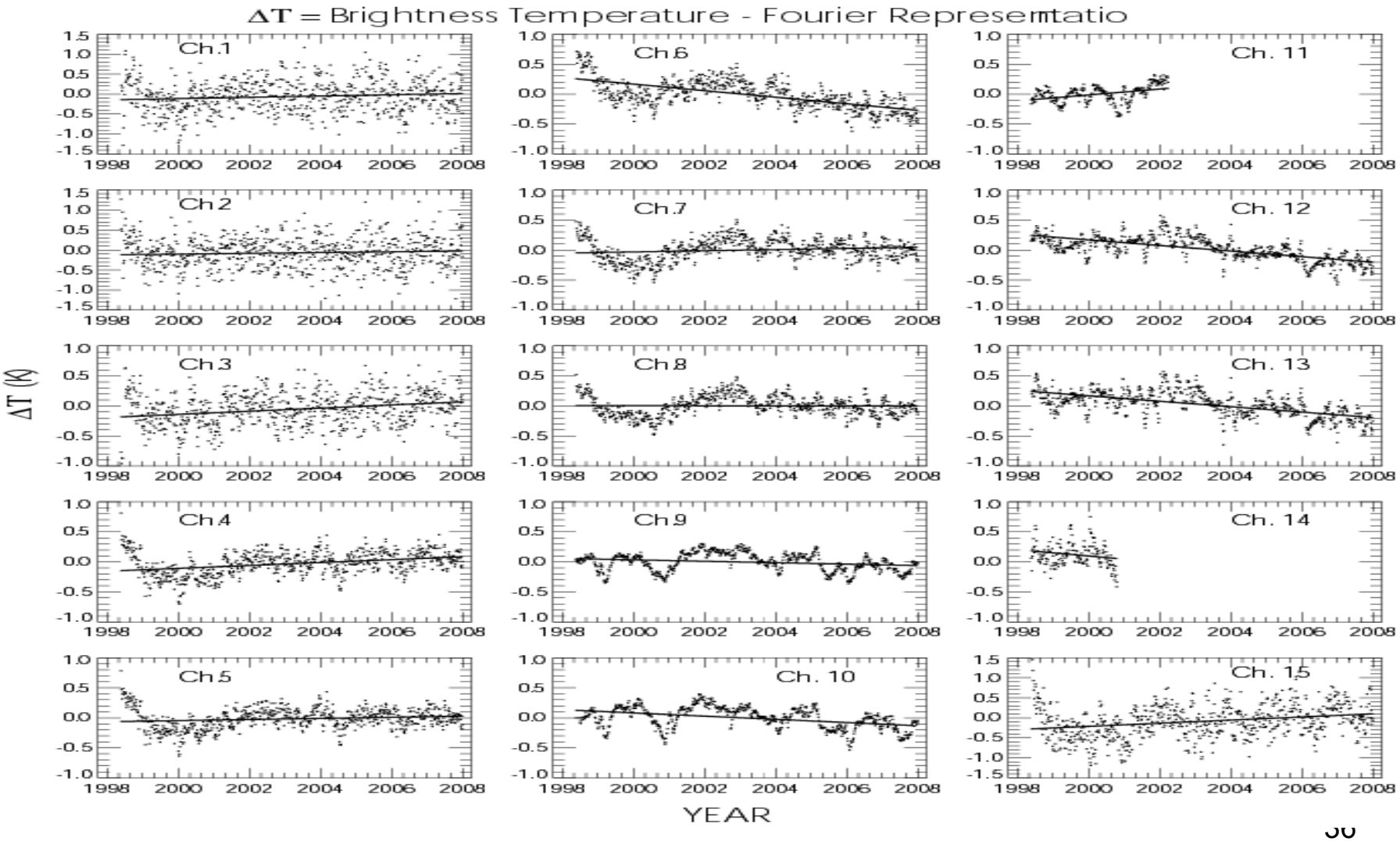
From Chengzhi Zou



Global mean temperature anomaly time series for MSU channels 2 (T2), 3 (T3), and 4 (T4) onboard TIROS-N through NOAA-14. T2, T3, and T4 respectively represent deep-layer temperatures of the Mid-Troposphere, Tropopause, and Lower Stratosphere

National Environmental Satellite, Data, and Information Service

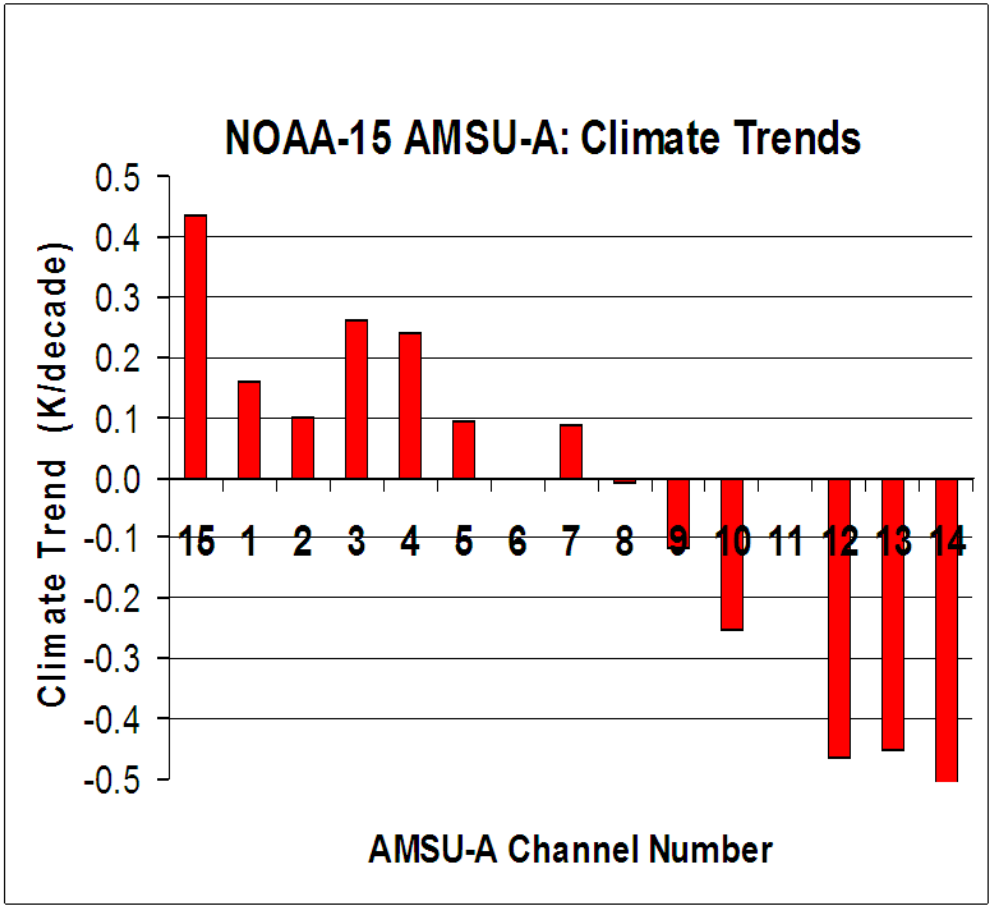
Single AMSU Tb Trending and its Variance



National Environmental Satellite, Data, and Information Service

Climate Trend from N15 AMSU-A

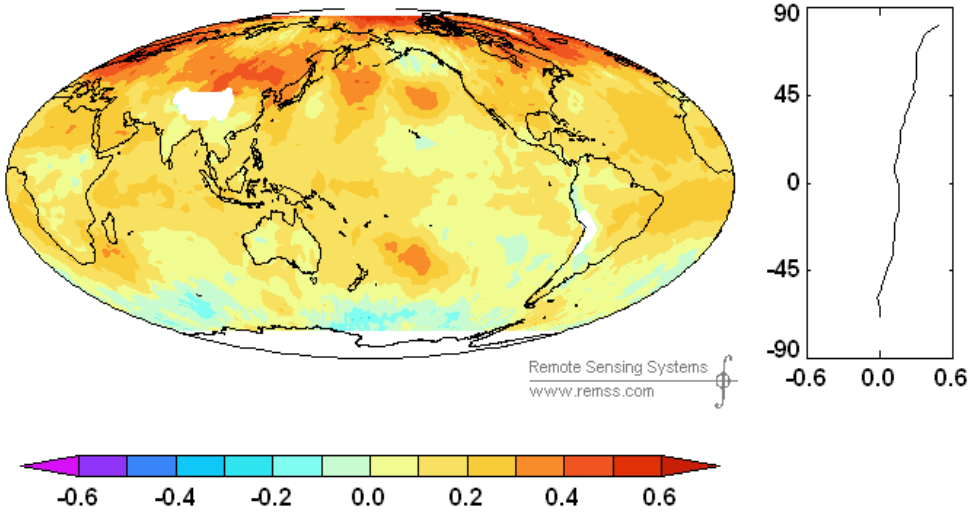
Channel number	Slope (K/year)	σ (K/year)
1	0.015791	0.007385
2	0.009719	0.007923
3	0.026084	0.003619
4	0.024127	0.001419
5	0.009231	0.001119
6[a]	-0.054639	0.001196
7	0.008483	0.001475
8	-0.000692	0.001045
9	-0.011833	0.000911
10	-0.025347	0.001021
11[b]	0.049435	0.003368
12	-0.046527	0.000937
13	-0.045161	0.001106
14[c]	-0.052129	0.009751
15	0.043287	0.004248

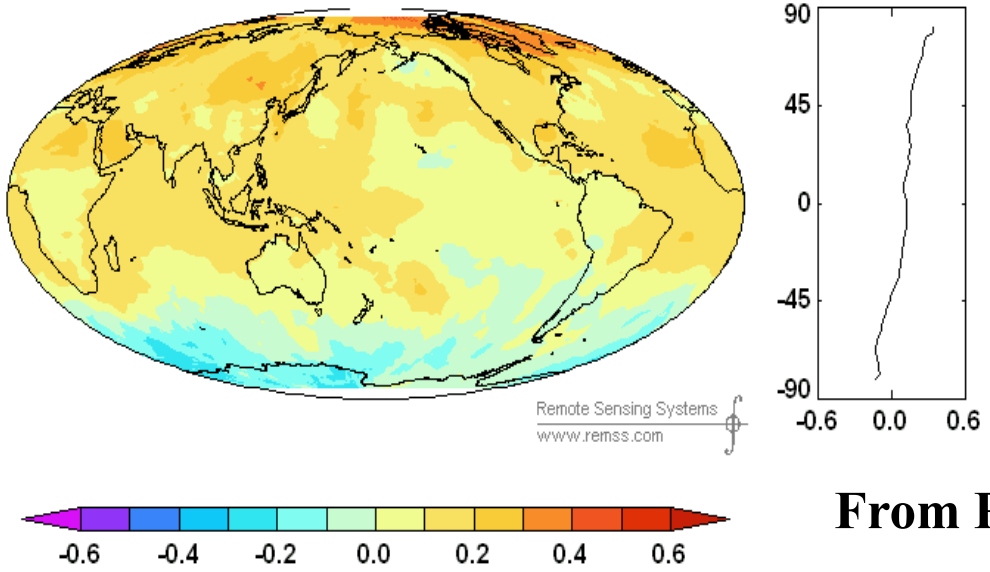


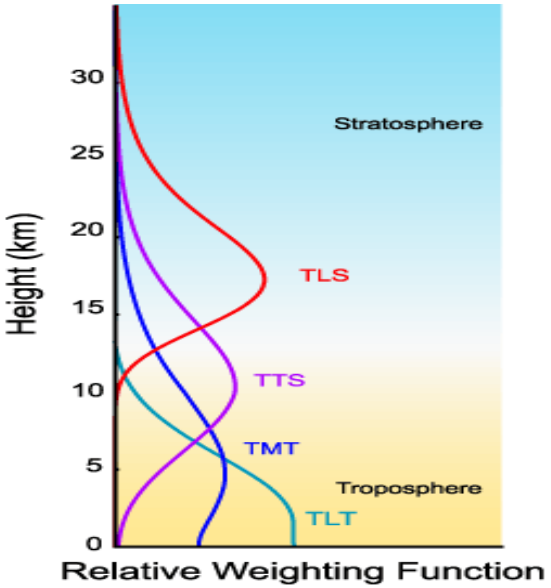
Slopes from linear regression of the extra-annual variations.
The σ represents the 1-sigma uncertainty estimates for the slope

[a] Slow deterioration in measurement accuracy since early 2004.
[b] Ceased in operation on April 10, 2002
[c] Ceased in operation on October 30, 2000

What did MSU Tell Us on Regional Climate Trend?







Surface and stratosphere on TLT, TMT channels need to Be removed from channels

From Remote Sensing System (RSS)

Summary and Conclusions

- **NOAA satellite microwave sensors (MSU, AMSU-A/B, MHS) are well calibrated to produce a high-quality of level 1b radiances for real-time operations.**

- **The instrument performance monitoring (IPT) capability through STAR ICVS provides powerful tools for satellite IOV (e.g. root cause analysis of instrument anomalies) and will critically support NOAA CDR, JPSS and GOES-R programs.**

- **We are working and collaborating closely with community on consensus calibration approaches (GSICS, GPM-Xcal, SSMIS UPP)**