Inrtoduction of STAR Integrated CalVal System (ICVS)

Fuzhong Weng
NOAA Center for Satellite Applications and Research

2015 STAR ICVS Annual Instrument Performance Review, May 8, 2015

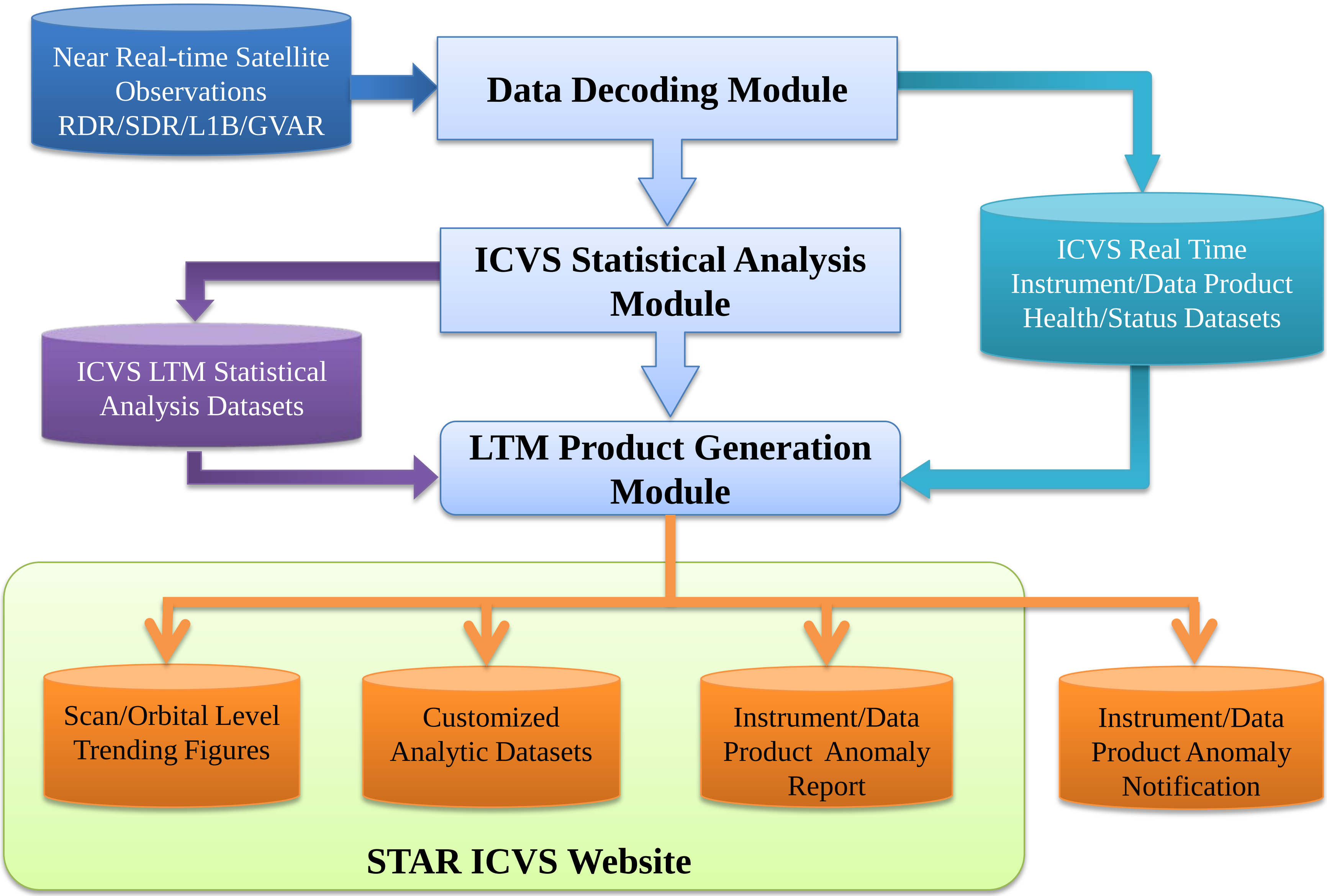
NOAA Integrated CalVal System (ICVS)

Monitor on-orbit performance of NOAA satellite instruments

- Monitors over 400 parameters for 28 instruments onboard NOAA/METOP/SNPP satellites
- Monitors and trends the SNPP spacecraft parameters , supporting NASA flight team
- Monitors the instrument performance through trending the instrument house-keeping and telemetry parameters
- Detects the anomaly events and automatically sends the warning messages to NOAA satellite operators, NASA instrument scientists, and senior program managers
- Characterizes the sounder SDR data quality with respect to the numerical weather prediction model (NWP) simulations
- Integrates the state-of-the art CalVal sciences into operations to serve the broad applications

NOAA Integrated CalVal System (ICVS) Online Access: http://www.star.nesdis.noaa.gov/icvs

NOAA ICVS Data Processing Flowchart



Impacts of ICVS NEDT on NWP Users

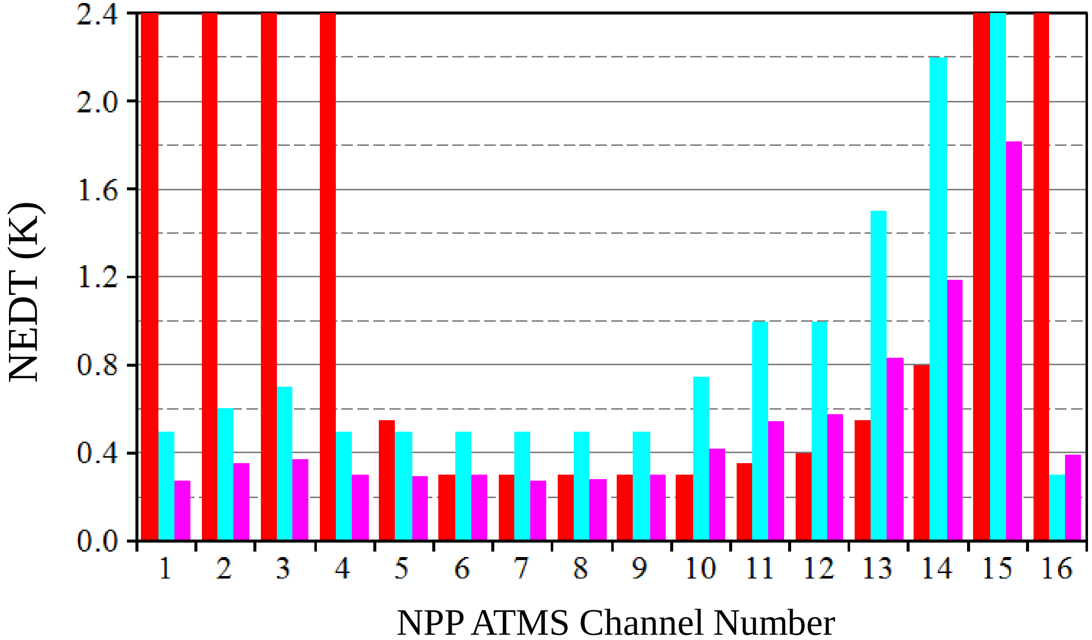
Weights Assigned to AMSU-A Observations

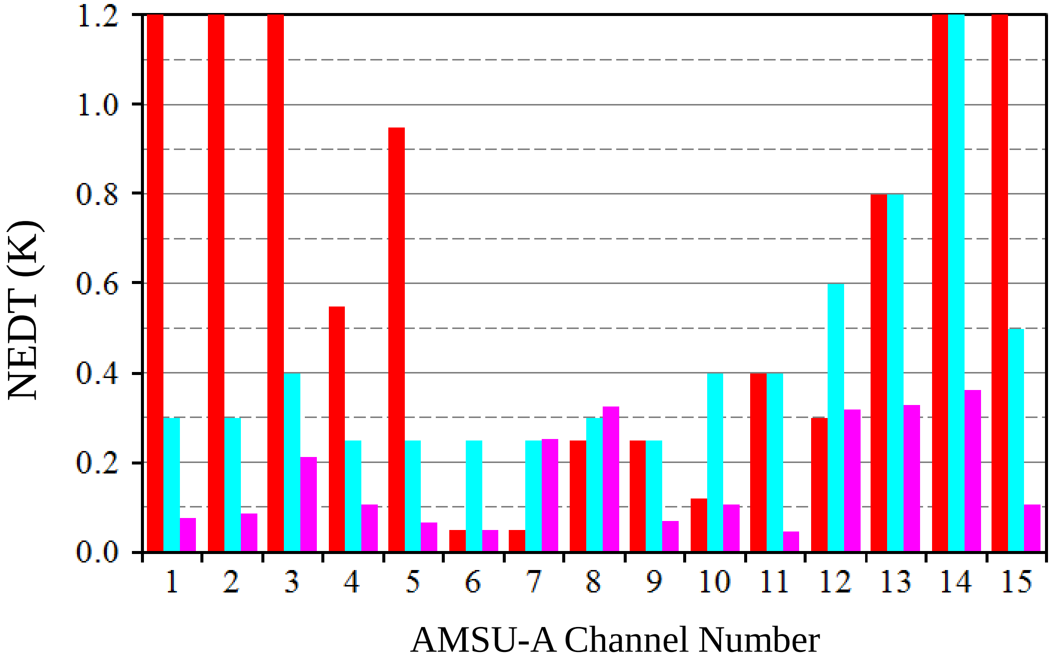
$$J(\mathbf{x}) = \frac{1}{2}(\mathbf{x} - \mathbf{x}_b)^T \mathbf{B}^{-1}(\mathbf{x} - \mathbf{x}_b) + \frac{1}{2}(H(\mathbf{x}) - \mathbf{y}^{obs})^T (\mathbf{O} + \mathbf{F})^{-1}(H(\mathbf{x}) - \mathbf{y}^{obs})$$

$$J(\mathbf{x}_a) = \min_{\mathbf{x}} J(\mathbf{x}) \quad \forall \mathbf{x} \text{ near } \mathbf{x}_b$$

- $\mathbf{x}$ – analysis variable
- $\mathbf{x}_a$ – final analysis
- $\mathbf{x}_b$ – background
- $\mathbf{B}$ – background error covariance
- $\mathbf{y}^{obs}$ – observations
- $\mathbf{O}$ – observation error covariance
- H – observation operator
- $\mathbf{F}$ – forward model error covariance

ATMS and AMSU-A Observation Errors





Impacts of ICVS NEDT on Climate Analysis

The uncertainty of the trend is

$$\sigma_a^2 = \frac{12\left(\sigma_o^2 + \sigma_n^2\right)}{M^3 - M}$$

where:

M —— Data length

σ_o^2 —— Observation error

σ_n^2 —— Natural variability

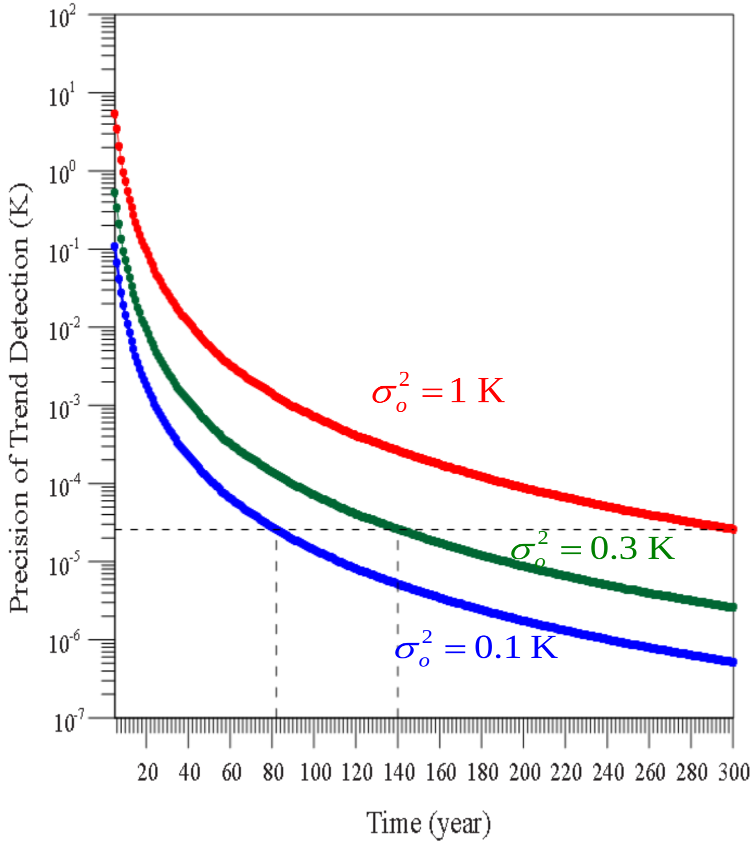


Fig. 2 Variations of σ_{trend} with respect to data length for the trends shown in Fig. 1

Zou , X, 2012, Advances Meteor. Sci.&Tech. (1), 42-43

ICVS Noise Trending is Now SI Traceable Though Using Allan Deviation

- Allan Deviation was proposed by NIST for characterizing the random noise from a time series which has a variable mean
- It was never implemented for meteorological satellite instruments . Currently, all the NOAA instrument noises are computed by the standard deviation which is only valid for the stationary mean.
- With Allan deviation, all the NEDT and NEDN are SI traceable

D. W. Allan, Should the classical variance be used as a basic measure in standards metrology Instrumentation and Measurement, IEEE Trans. on, IM-36, pp.646-654, 1987

Summary

- NOAA ICVS is critical for earlier detection of instrument anomalies and provides the critical information for the root-cause analysis

- NOAA ICVS monitors the instrument noises and biases that are being used by broader users including NWP communities

- NOAA ICVS is designed with the modern software architecture and meets the enterprise standard

- NOAA ICVS is becoming a gold standard for all the space agencies and is recommended as part of the NOAA common ground system

Backup slides

ICVS Instruments Status Summary

JPSS	S-NPP PM Primary 10-28-2011 ~ 3 yr	POES	MetOp-B AM Primary 09-17-2012 ~ 2 yr	NOAA-19 PM Primary 06-02-2009 ~ 5 yr	MetOp-A AM Backup 10-19-2006 ~ 8 yr	NOAA-18 PM Backup 05-20-2005 ~ 9 yr
ATMS	SD Main Motor Current	AMSU-A1	A1-2 PRT Dispersion	Ch. 7, 8 NEΔT	**Ch. 3, 7, 8 NEΔT**	
CrIS		AMSU-A2				Ch1, 2 NEΔT
VIIRS		MHS		H3 NEΔT		
OMPS		AVHRR				Ch. 1 SNR
		HIRS		Ch. 1, 2, 4, 5, 6, 7, 10, 14 NEΔN Ch.20 NEΔa		Ch. 2, 4, 5, 6, 7, 9, 10, 19 NEΔN

Nominal Condition (green) | Performance Degraded (orange) | Anomaly Detected/Investigation On-going (yellow)

ICVS Summary of SNPP Instruments

- **SNPP Spacecraft status**
  - Health and status – **Nominal condition**
  - Instrument health and status – **Nominal**
- **SNPP ATMS status**
  - Instrument sensitivity (NEΔT) – **Nominal**
  - Instrument health and status – **SD Main Motor Current Anomaly Detected**
  - TDR data product quality – **Nominal**
- **SNPP VIIRS status**
  - Instrument performance (F-/H-factor) – **Major update applied**
  - Instrument health and status – **Nominal**
  - SDR data product quality – **Nominal**
- **SNPP CrIS status**
  - Instrument performance (NEΔN) – **Nominal**
  - Instrument sensor health and status – **Nominal**
  - SDR data product quality – **Nominal**
- **SNPP OMPS status**
  - Instrument performance – **Nominal**
  - Nadir Mapper (NM) health and status – **Nominal**
  - Nadir Profiler (NP) health and status – **Nominal**
  - Limb Profiler (LP) health and status – **Nominal**

ICVS Summary of NOAA/METOP Instruments

- **POES AMSU/MHS status**
  - MetOp-B AMSU/MHS
    - AMSU NEΔT within specification
    - AMSU PRT maximum dispersion is higher than specification – ongoing investigation
    - MHS NEΔT within specification
  - NOAA-19 AMSU/MHS
    - AMSU Ch.7 and Ch.8 NEΔT out of specification, Ch.8 Gain jump
    - MHS H3 NEΔT out of specification
  - MetOp-A AMSU/MHS
    - AMSU Ch.3 and Ch. 8 NEΔT out of specification, Ch.7 is fail
  - NOAA-18 AMSU/MHS
    - AMSU-A Channel 1 and 2 NEΔT out of specification
    - MHS NEΔT within specification

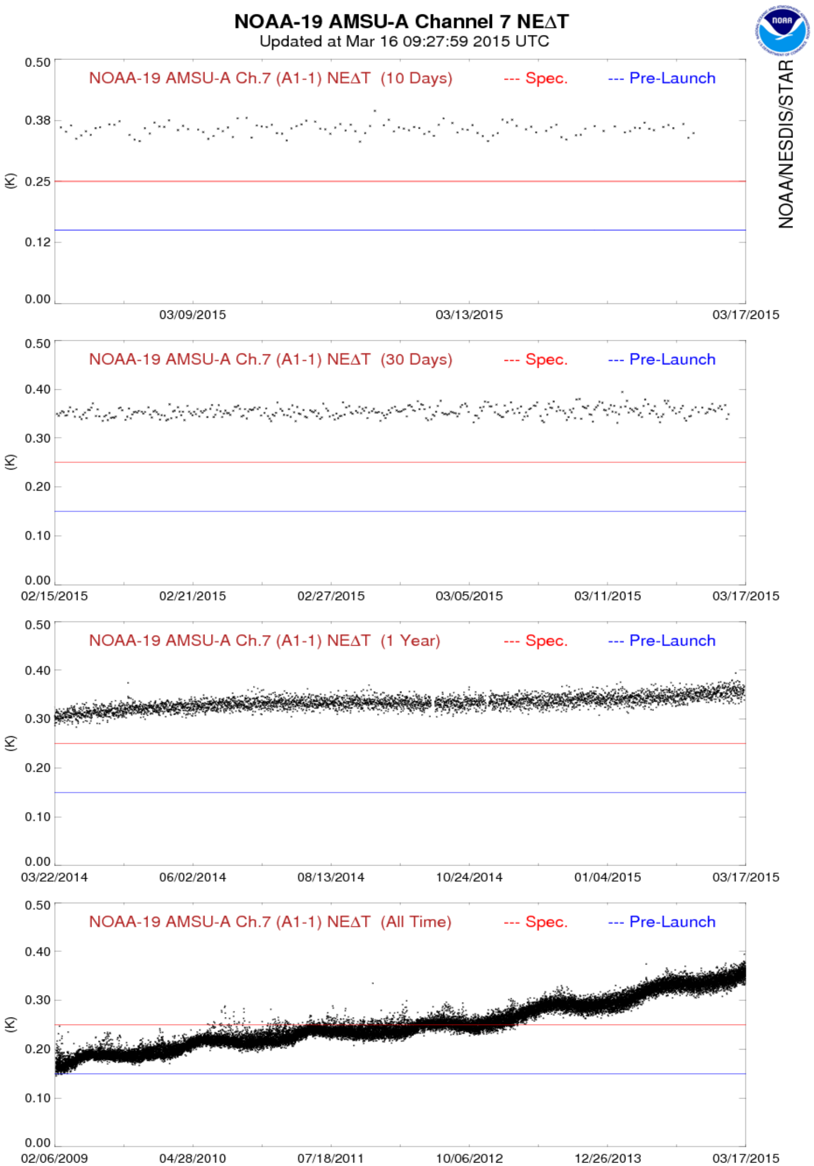
- **POES AVHRR status**
  - MetOP-B AVHRR in normal condition
  - NOAA-19 AVHRR in normal condition
  - MetOP-A AVHRR in normal condition
  - NOAA-18 AVHRR
    - Ch. 1 SNR slightly out of specification

- **POES HIRS status**
  - MetOP-B HIRS
    - NEΔN within specification
  - NOAA-19 HIRS
    - Ch. 1, 2, 4, 5, 6, 7, 10, and 14 calibration target out of limits
  - MetOp-A HIRS
    - NEΔN within specification
  - NOAA-18 HIRS
    - Ch. 2, 4, 5, 6, 7, 9, and 10 NEΔN out of specification

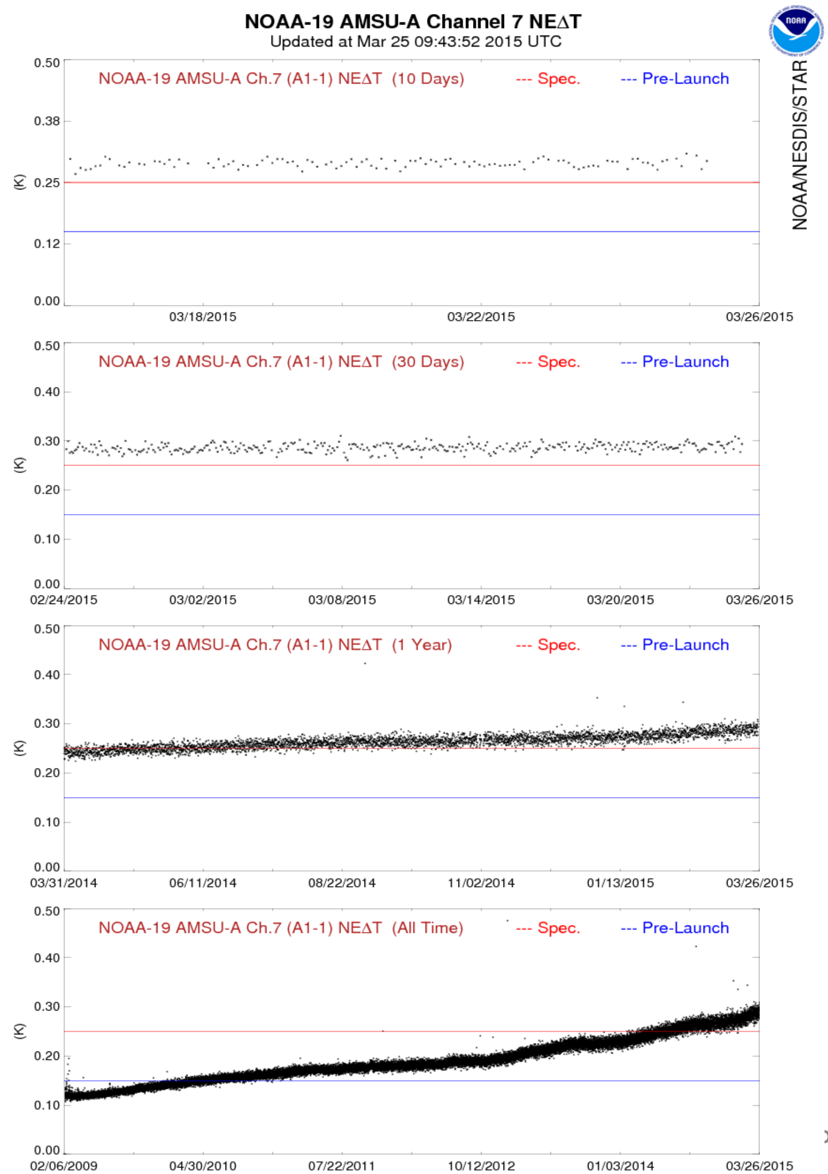
Comparison of Traditional NEDT vs Allan Deviation

NOAA-19 AMSU-A Ch.7 (54.9 GHz)

Standard Deviation



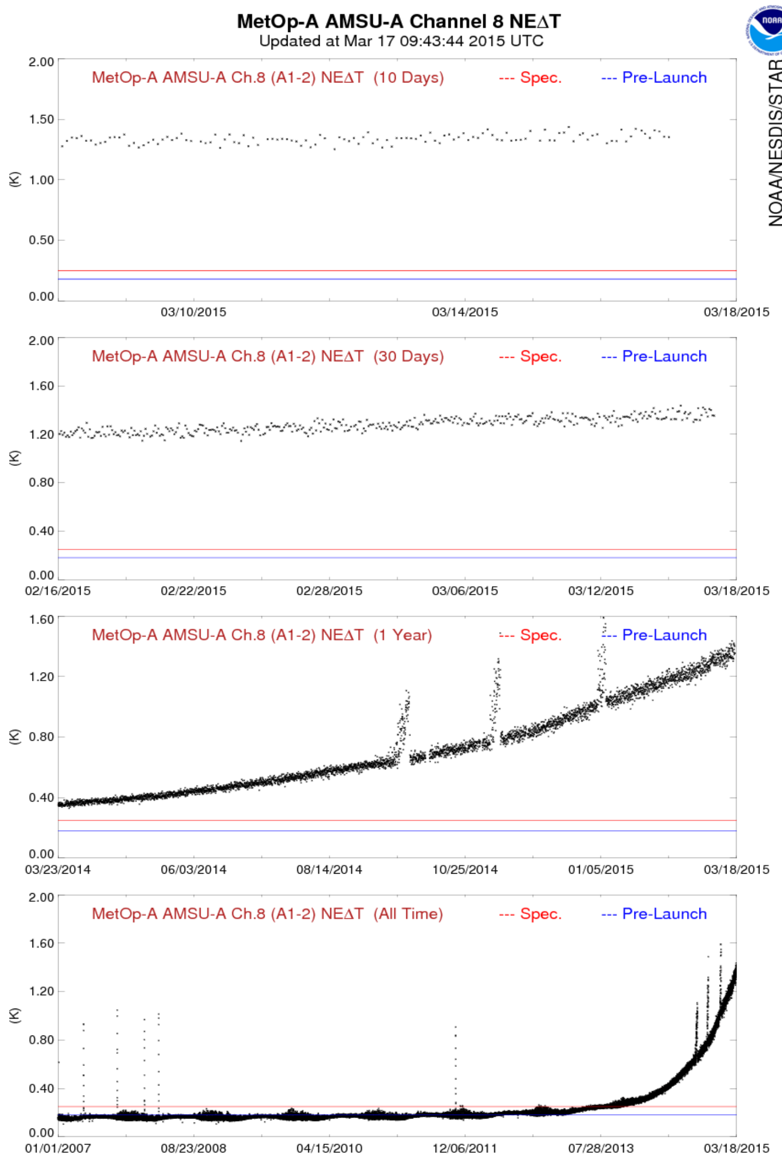
Allan Deviation



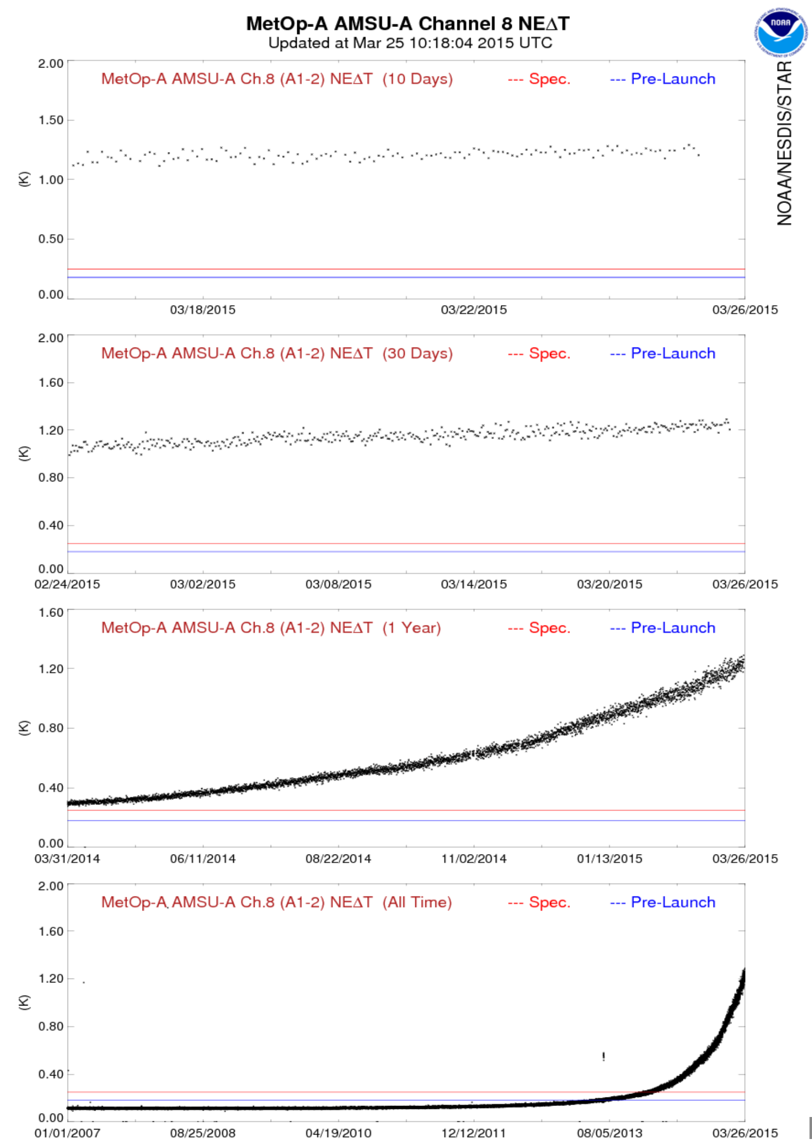
Comparison of Traditional NEDT vs Allan Deviation

MetOp-A AMSU-A Ch.8 (55.5 GHz)

Standard Deviation

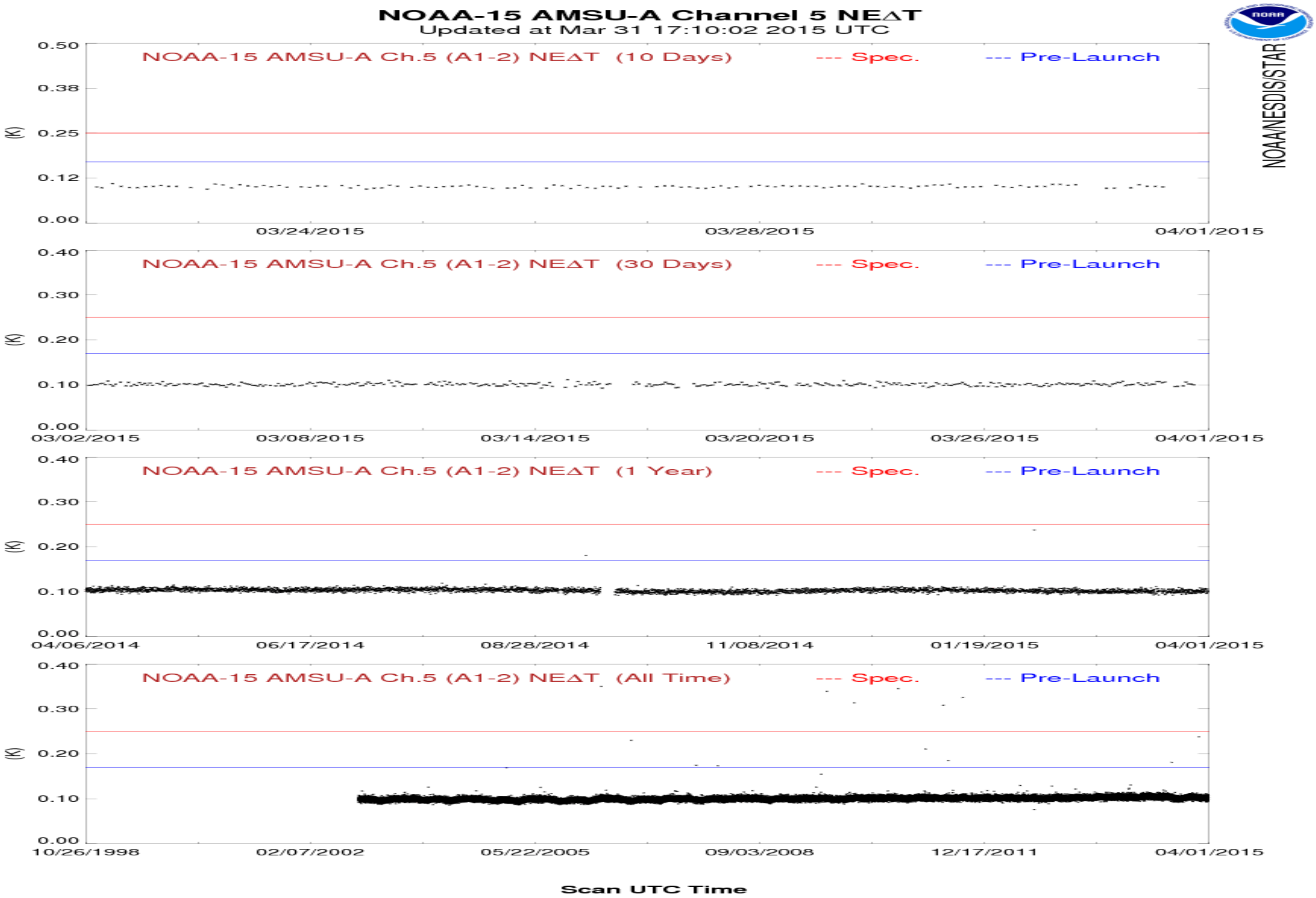


Allan Deviation

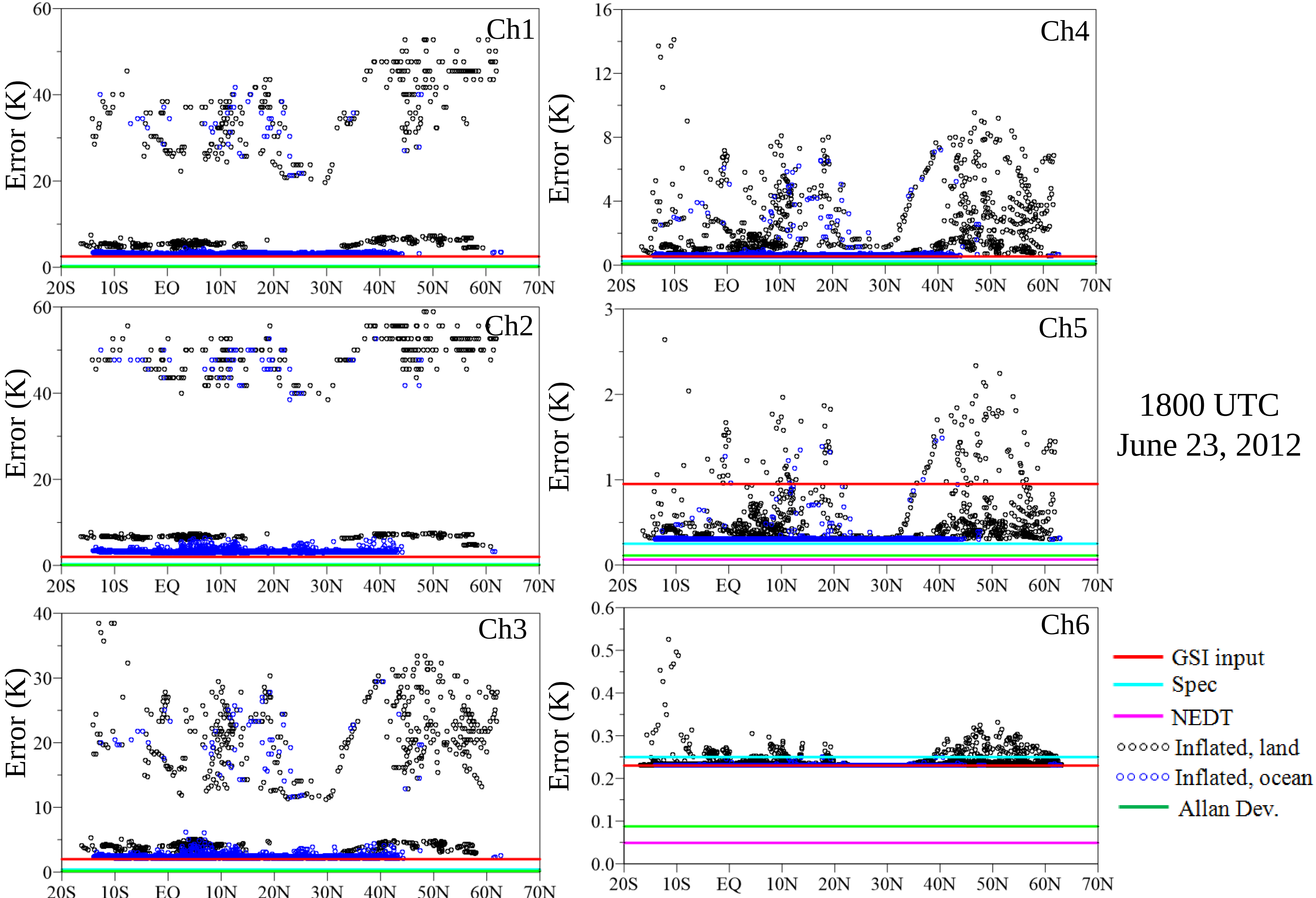


Monitor NOAA-15 AMSU-A NEDT

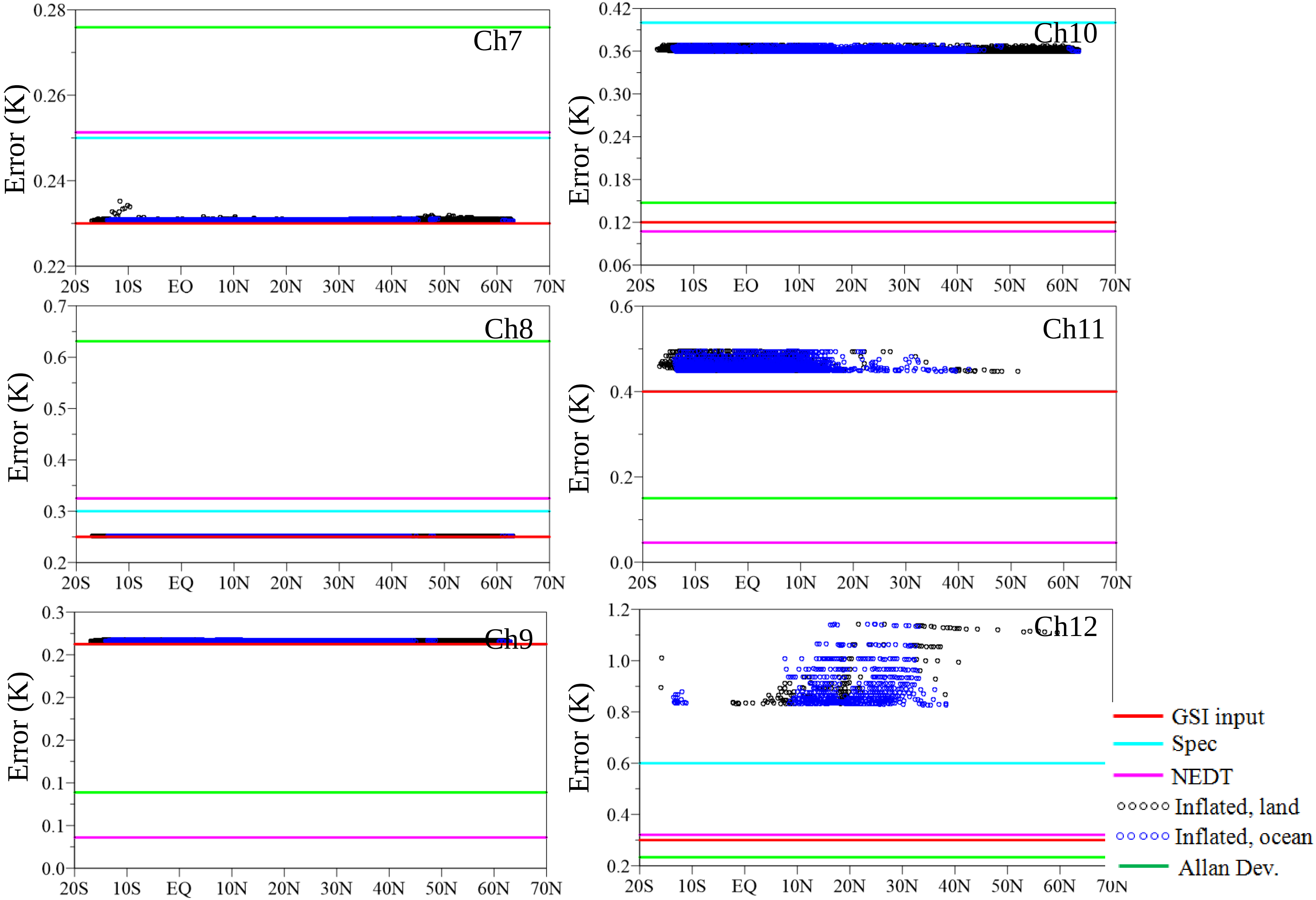
A Long-Lived Microwave Sounder still Used in NOAA operation



Inflated Errors of NOAA-19 AMSU-A Channels 1-6



Inflated Errors of NOAA-19 AMSU-A Channels 7-12



Detection of Climate Trend and Its Sensitivity to Measurement Precision and Data Length

Given an observed time series: $\left\{ x_i^o, i = 1, 2, \ldots, M \right\}$

Using a linear-regression model: $x^n = a(t - \bar{t})$

True value of variable x at any time: $x^t = x^n + \varepsilon^n \equiv a(t - \bar{t}) + \varepsilon^n$

The observed time series: $x^o = x^t + \varepsilon^o \equiv a(t - \bar{t}) + \varepsilon^n + \varepsilon^o$

which can be expressed in a matrix form : $\mathbf{x}^o = \mathbf{A}a + \boldsymbol{\varepsilon}$

where:

$$\mathbf{x}^o = \begin{pmatrix} x_1^o \\ x_2^o \\ \ldots \\ x_M^o \end{pmatrix} \qquad \mathbf{A} = \begin{pmatrix} t_1 - \bar{t} \\ t_2 - \bar{t} \\ \ldots \\ t_M - \bar{t} \end{pmatrix} \qquad \boldsymbol{\varepsilon} = \begin{pmatrix} \varepsilon_1^n + \varepsilon_1^o \\ \varepsilon_2^n + \varepsilon_2^o \\ \ldots \\ \varepsilon_M^n + \varepsilon_M^o \end{pmatrix}$$

Detection of Climate Trend and Its Sensitivity to Measurement Precision and Data Length

The linear regression coefficient (a) is obtained by a least-square fit which minimizes the difference between observations and linear regression model:

$$J = (\mathbf{x}^o - \mathbf{A}a)^T (\mathbf{x}^o - \mathbf{A}a)$$

For a twelve month/year time series, we can obtain the trend as

$$a = \frac{12\sum_{i=1}^{M} x_i^o \left(t_i - \overline{t}\right)}{\left(M^3 - M\right)}$$

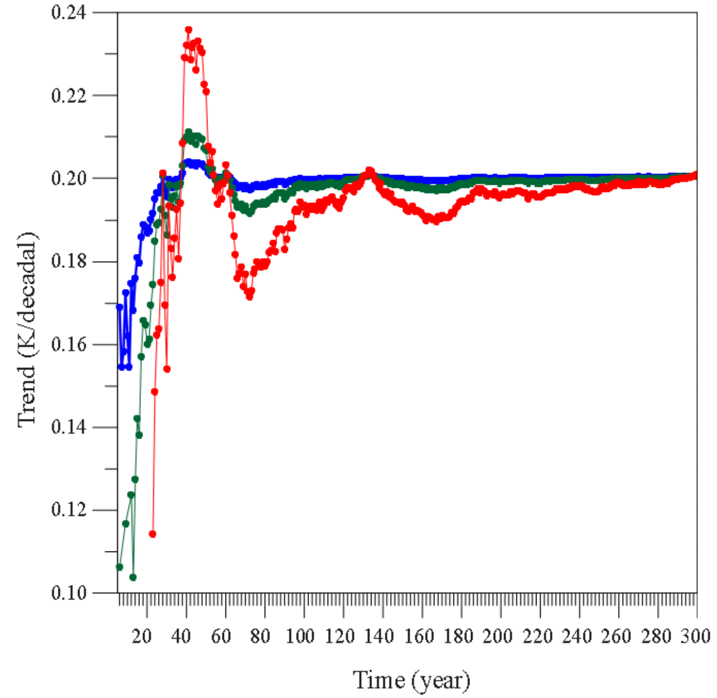


Fig. 1 Climate trend calculated from different lengths of time series with three different observation error variances: 0.1K (blue line), 0.3K (green line) and 1K (red line)

Zou , X, 2012, Advances Meteor. Sci.&Tech. (1), 42-43