SI Traceable NEDT Algorithm for Microwave Sensors

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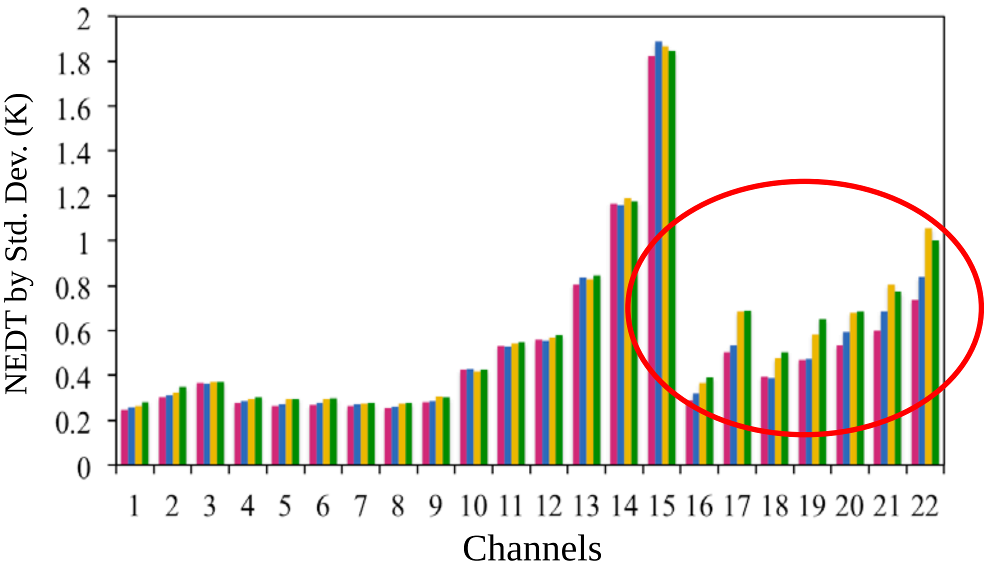
Contents

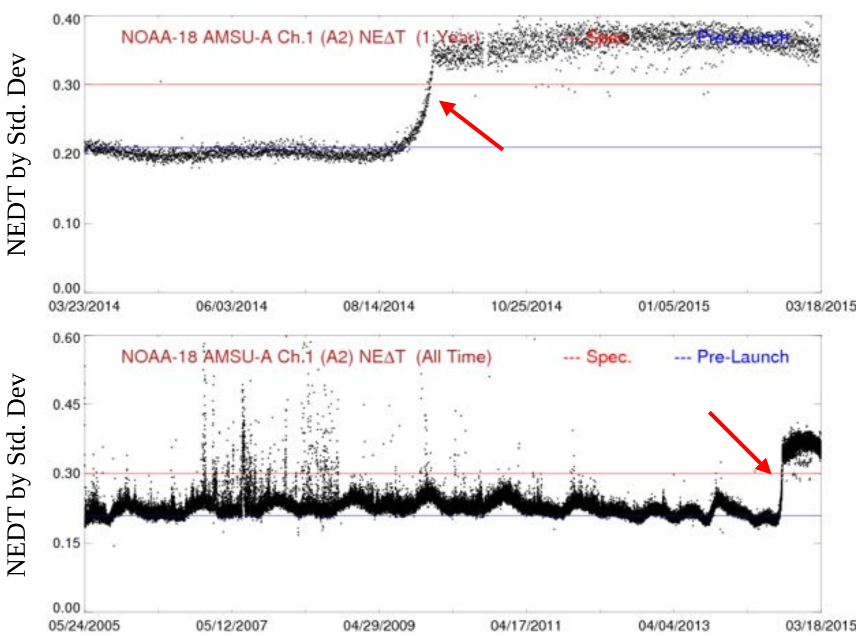
Motivation

The noise equivalent differential temperature (NEDT) is used for evaluating the instrument sensitivity or noise. It has direct impacts on the data assimilation (DA) systems and also the long-term climate trend detection.

However, current method to calculate NEDT yields



ATMS warm counts used in calculation:
100 - purple, 300 - blue, 1000 - orange, 2034 - green



Purpose

Currently for most microwave/infrared sensors, the NEDT are calculated based on the standard deviation.

- Issues related to the standard deviation are:
  1. It is valid for a data having stable mean.
  2. For non-stationary data, determination of optimal averaging window size is unclear and *ad hoc*, causing inconsistent estimation results.
- **Allan deviation**[1,2] is proposed as a candidate for NEDT
  1. Allan deviation has been applied in many research areas, such as frequency stability[2,4], noise identification[2] and characterization[3,5].
  2. One form of Allan deviation, overlapping Allan deviation was recently recommended for ATMS sensitivity characterization[1].
  3. The neighborhood or two-sample Allan deviation is proposed in this report.

1. F. Weng, et al., "Calibration of Suomi national polar-orbiting partnership advanced technology microwave sounder (ATMS)", *JGR: Atmospheres*, vol. 118, issue 19, pp. 11,187-11,200, October, 2013.
2. W. J. Riley, *Handbook of frequency Stability Analysis*, Sec. 5.2.9, Hamilton Technical Services, 2007.
3. R. Schieder and C. Kramer, "Optimization of heterodyne observations using Allan variance measurements," *Astronomy and Astrophysics*, vol. 373, pp. 746-756, 2001.
4. V. Ossenkopf, "The stability of spectroscopic instruments: a unified Allan variance computation scheme," *Astronomical Instrumentation*, vol. 479, no. 3, pp. 915-926, Mar. 2011.
5. Z. Malkin, "Study of Astronomical and Geodetic Series using the Allan Variance," *Kinematics and Physics of Celestial Bodies*, vol. 27, no. 1, pp. 42-49, 2011.

Introduction to Allan Deviation

The standard deviation based NEDT is calculated via[1]

$$\mathrm{NEDT}_{ch} = \sqrt{\frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N}\left(\frac{C_{ch}^{w}(i,j) - \overline{C_{ch}^{w}}(i)}{\overline{G_{ch}}}\right)^2} \quad (1)$$

where C_{ch}^{w} represents the warm counts per channel, $\overline{G_{ch}}$ is the averaged calibration gain, N is the number of the warm count views during each cycle, for example in ATMS, $N = 4$.

By using the overlapping Allan deviation[1], NEDT is calculated via

$$\sigma_{ch}^{Allan} = \sqrt{\frac{1}{2m^2(M-2m+1)}\sum_{i=1}^{M-2m+1}\sum_{k=i}^{i+m-1}\left[\frac{C_{ch}^{w}(k+m) - C_{ch}^{w}(k)}{\overline{G_{ch}}}\right]^2} \quad (2)$$

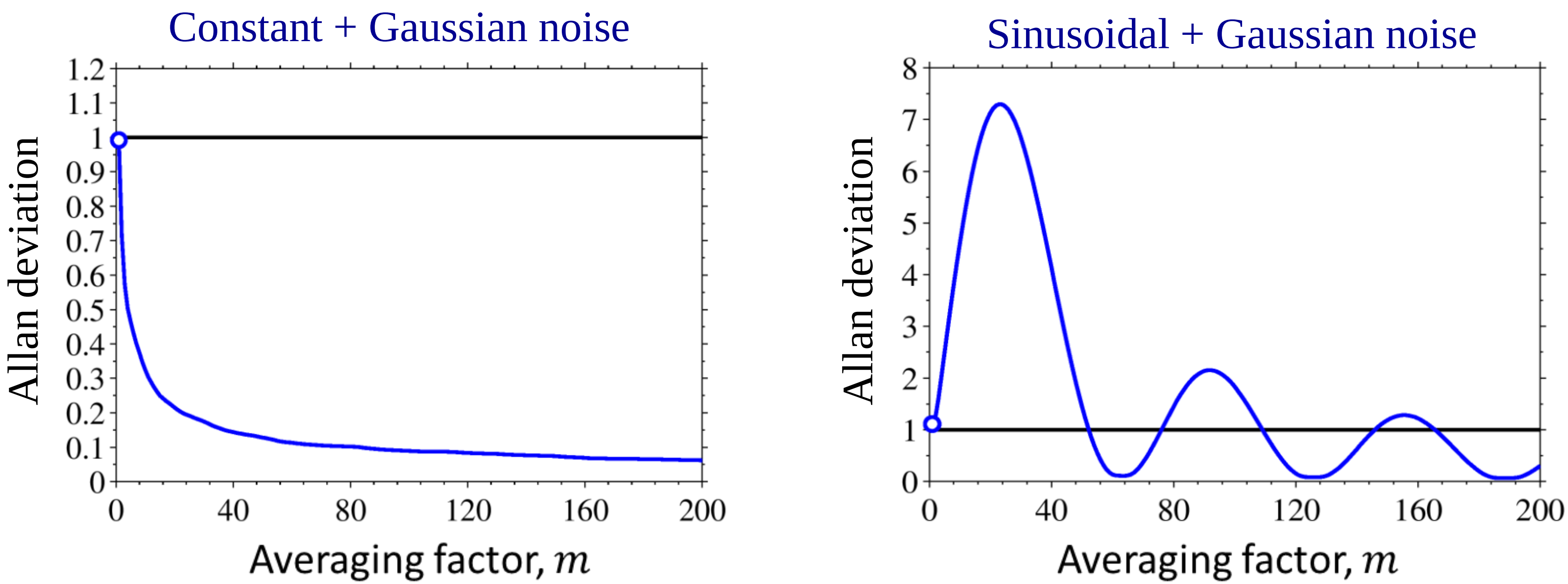
When $m = 1$, (2) becomes the NEDT by the **neighborhood Allan deviation**

$$\sigma_{ch}^{Allan} = \sqrt{\frac{1}{2(M-1)}\sum_{i=1}^{M-1}\left[\frac{C_{ch}^{w}(i+1) - C_{ch}^{w}(i)}{\overline{G_{ch}}}\right]^2} \quad (3)$$

Comparison between the two Allan deviations, eqs.2-3

Data 1: Stationary data: constant + Gaussian noise, $N(0,1)$

Data 2: Non-stationary data: sine + Gaussian noise, $N(0,1)$



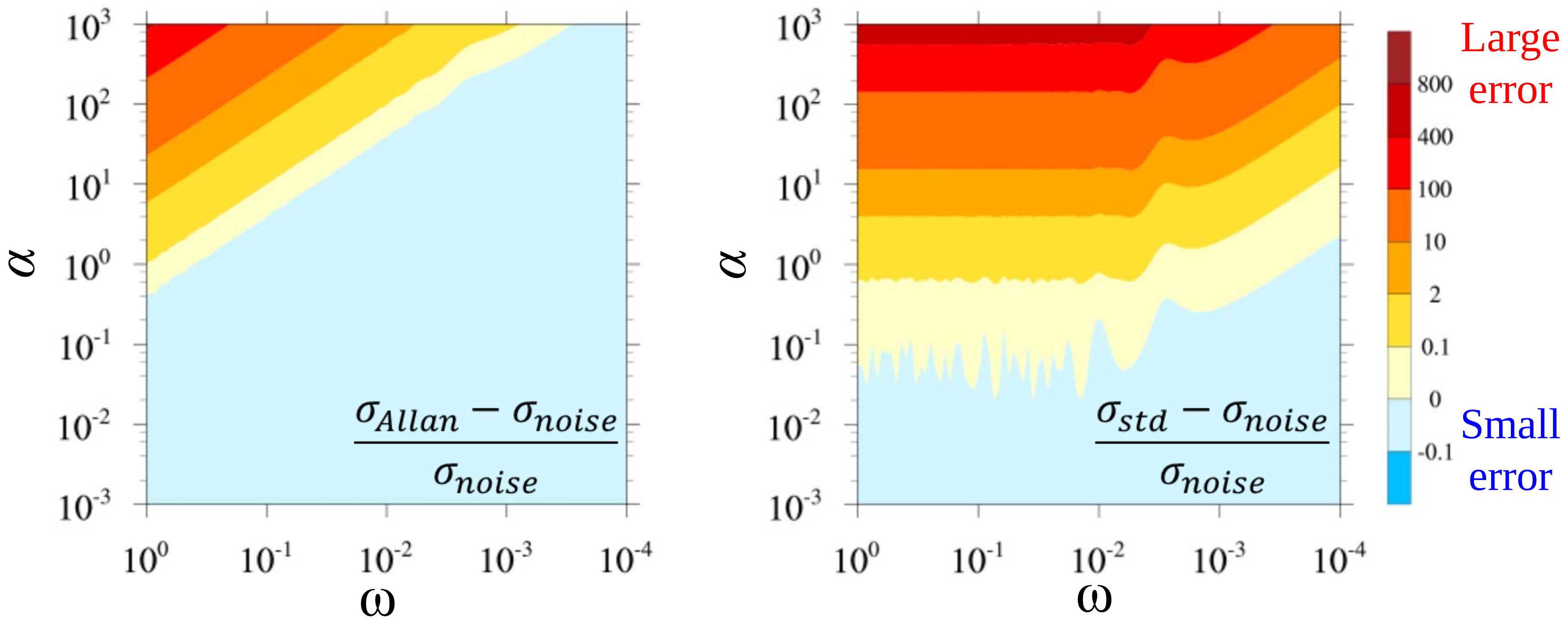
Black line: Noise Std. Dev. **Blue line**: Overlapping Allan **Blue circle:** Two-sample Allan

Conclusion: In both cases, the neighborhood Allan deviation outperforms the overlapping Allan deviation.

Comparison between the Allan deviation and standard deviation

It is well known that the neighborhood Allan deviation is equivalent to the standard deviation for stationary data. For non-stationary data, such as

$$y(x) = \alpha \sin(\omega x) + \varepsilon$$



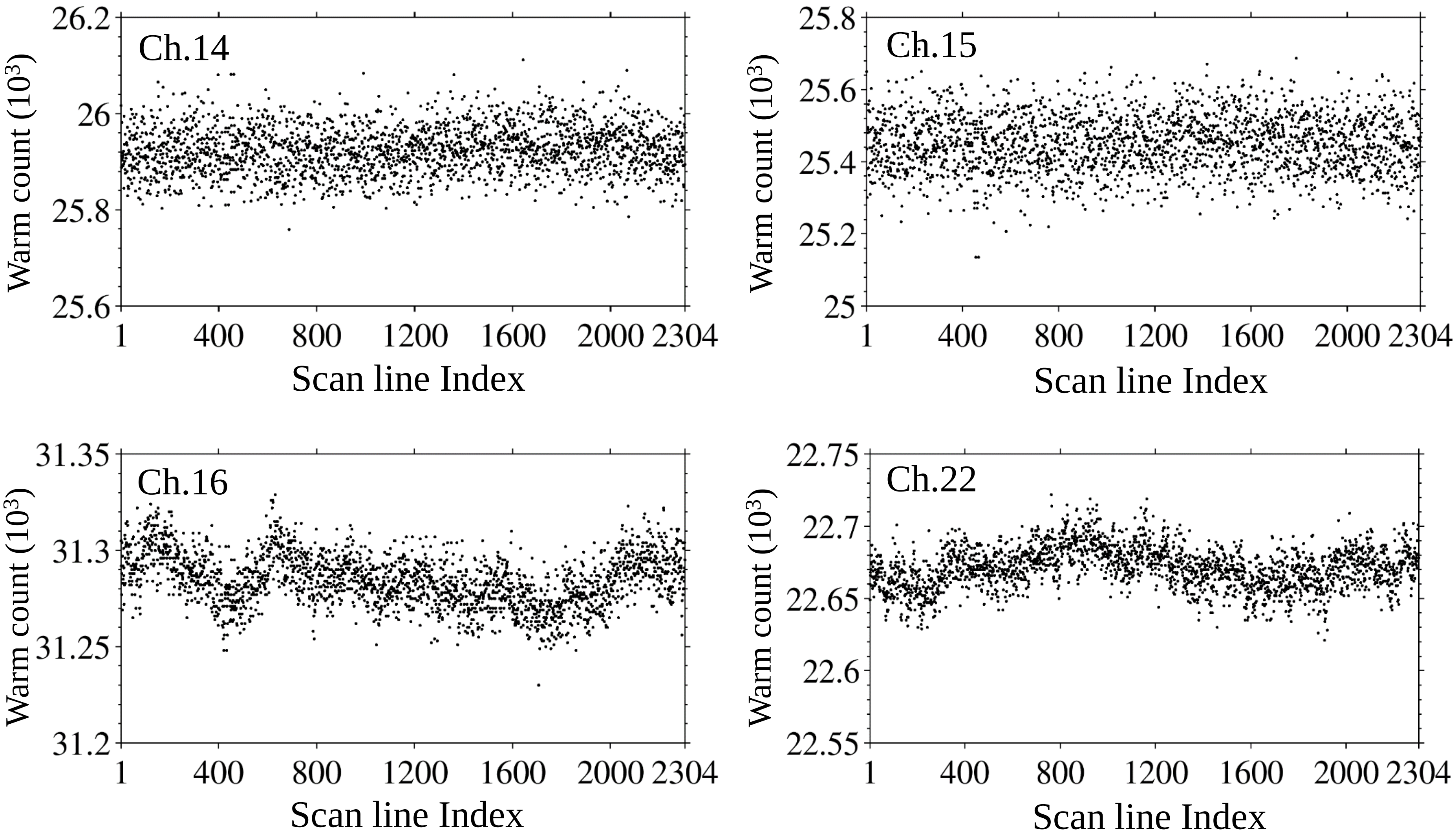
Conclusion: the overall performance of the neighborhood Allan deviation is better than that of the standard deviation.

Application to Microwave Sensors

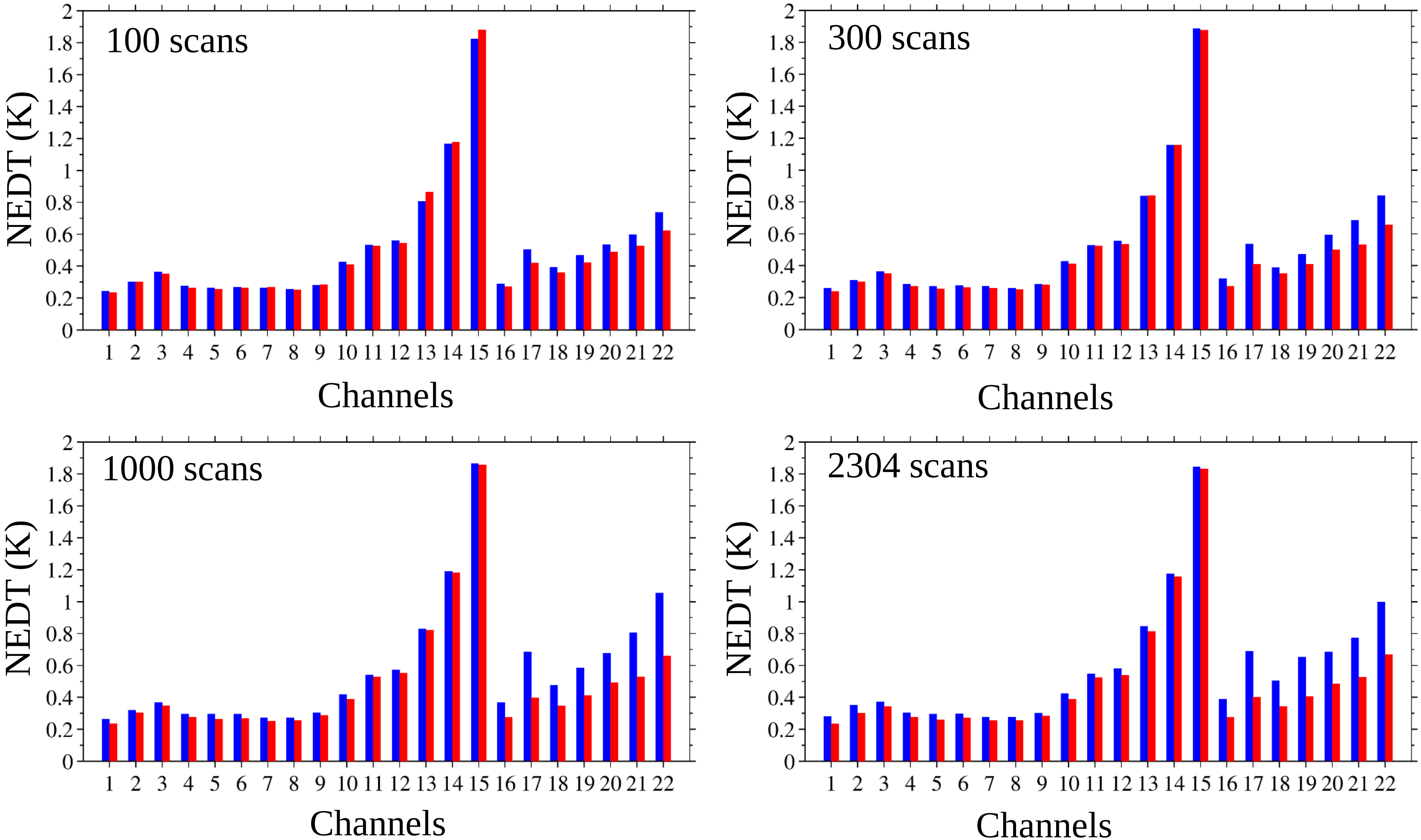
The neighborhood Allan deviation has been applied to multiple microwave sensors: SNPP ATMS and AMSU series. Examples shown here are:

1. Comparison of SNPP ATMS NEDT
2. Comparison of NOAA-18 AMSU-A/MHS
3. Special case: NOAA-18 AMSU-A Chs.1 & 2 NEDT anomaly

ATMS On-orbit Warm Counts

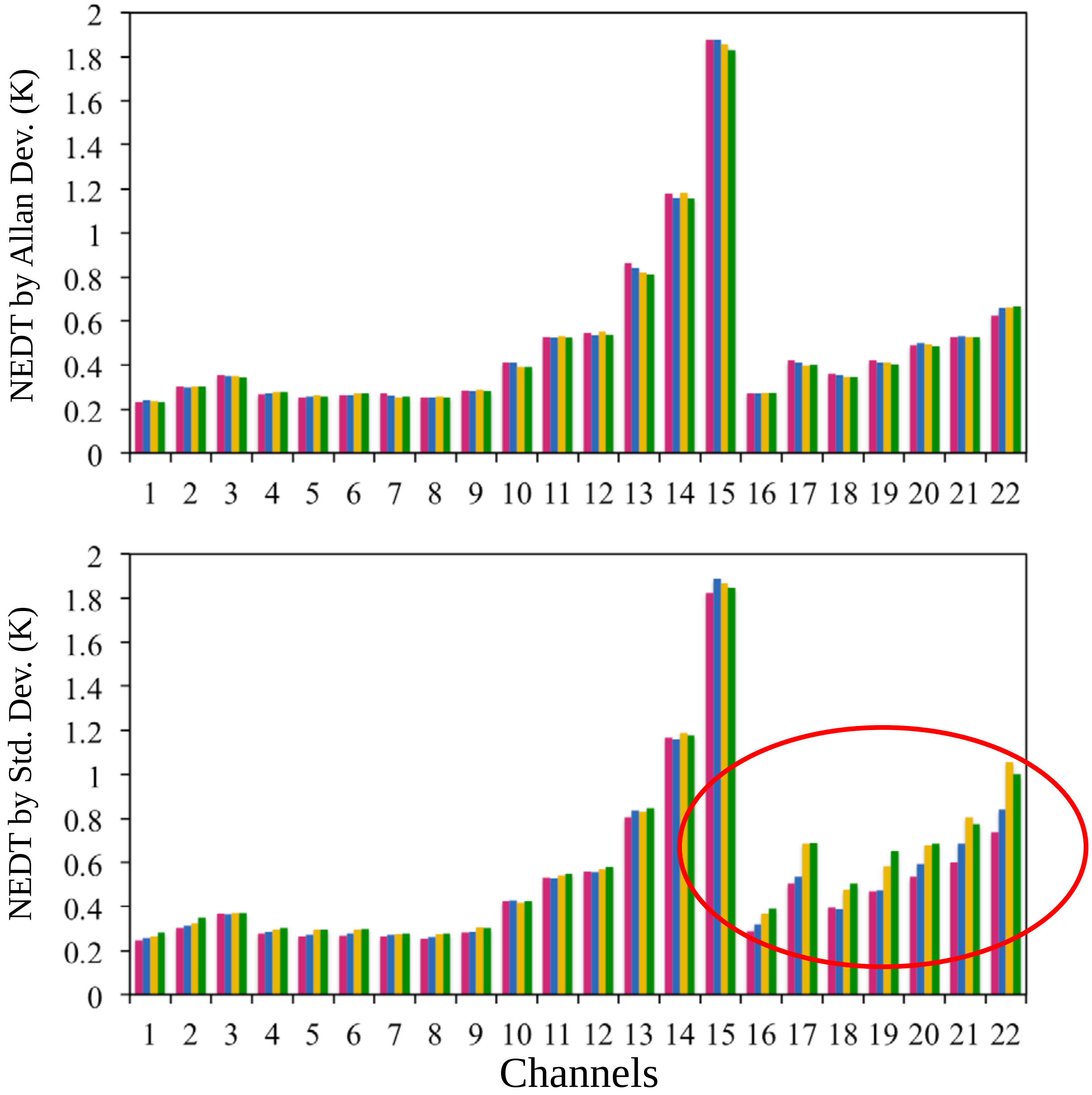


ATMS NEDT by Allan Dev. and Std. Dev.



Blue: Std. dev. Red: Allan dev.

Stability Study



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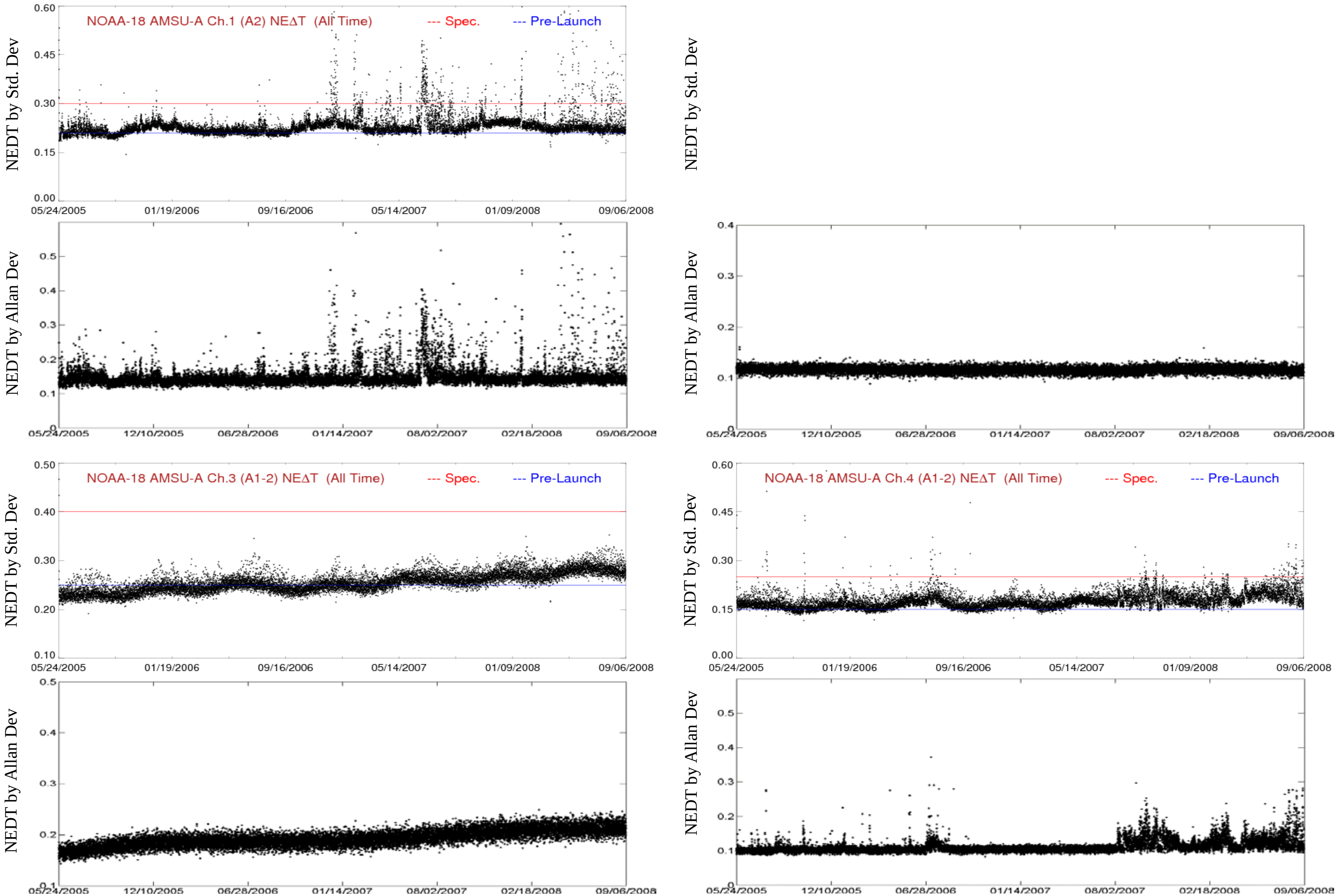
NOAA-18 AMSU-A: 3-yr Data



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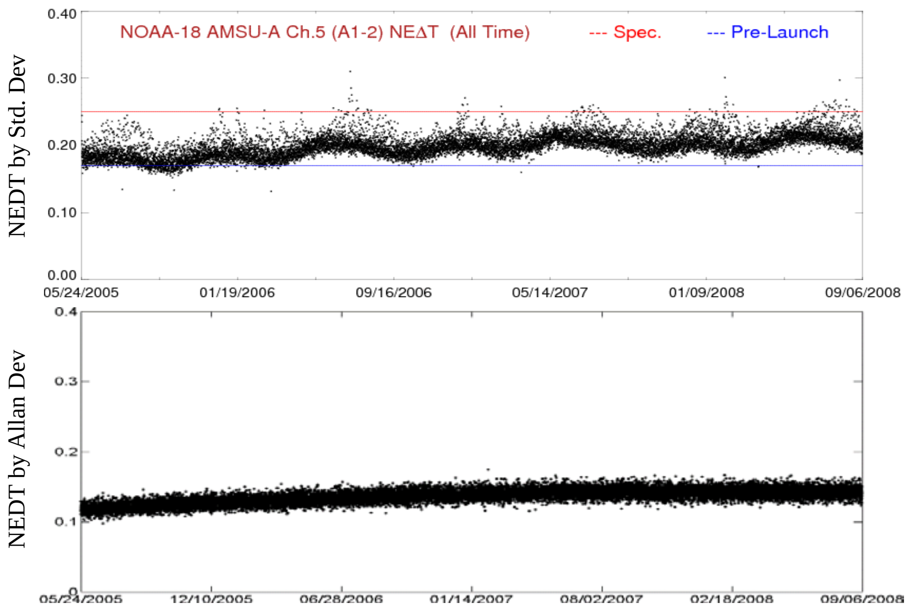

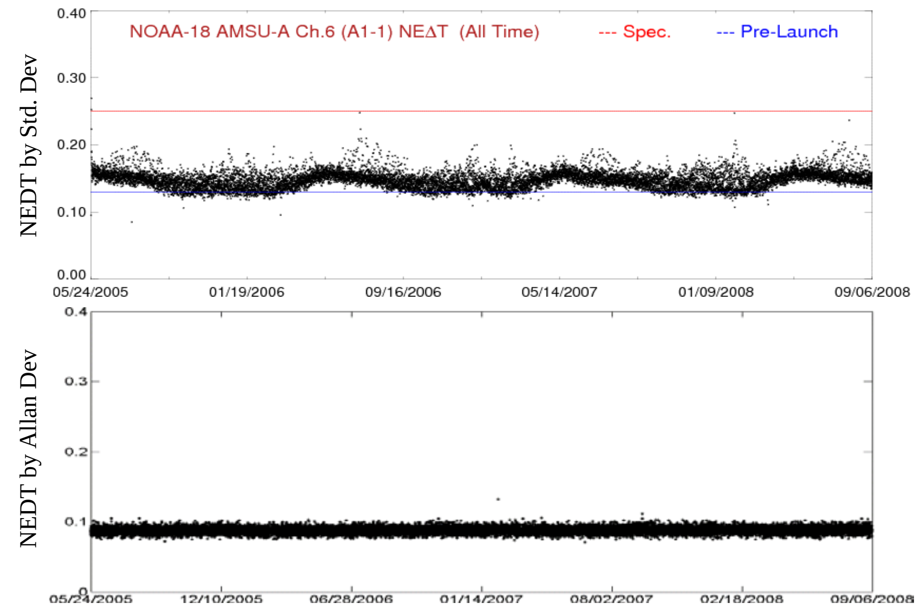

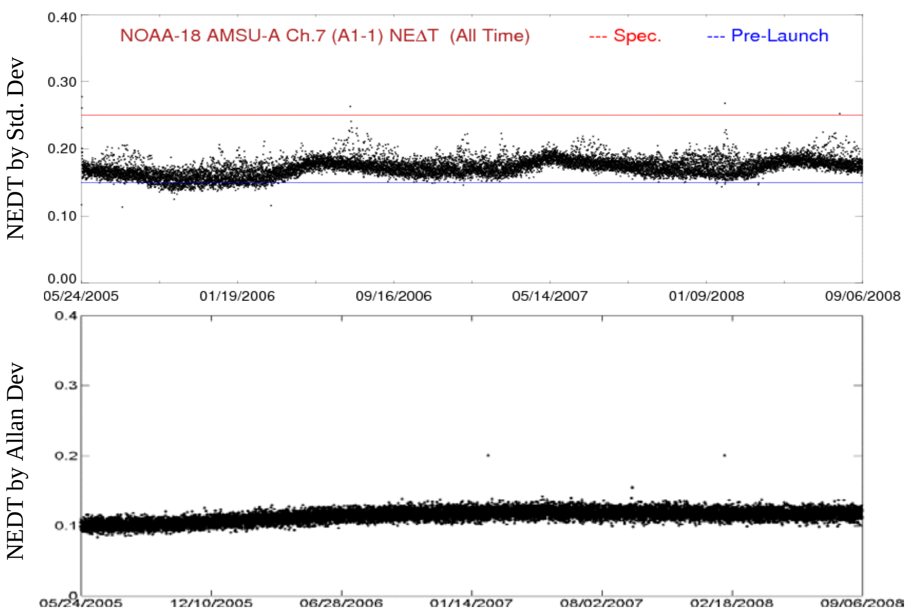

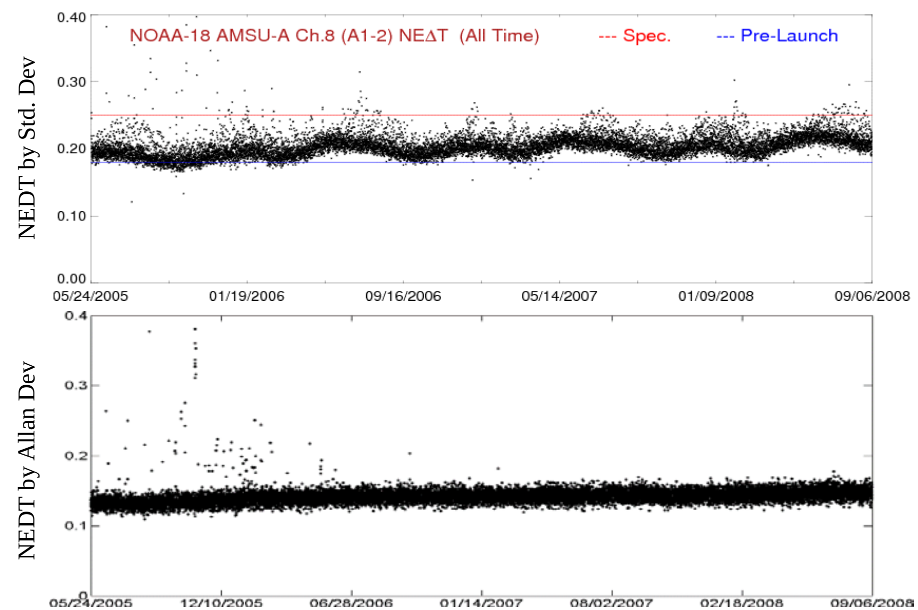

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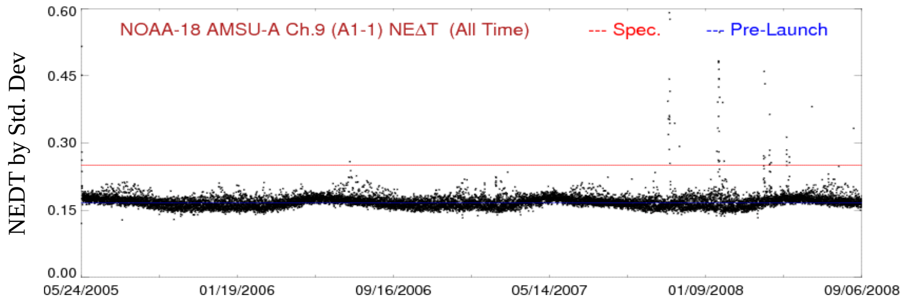
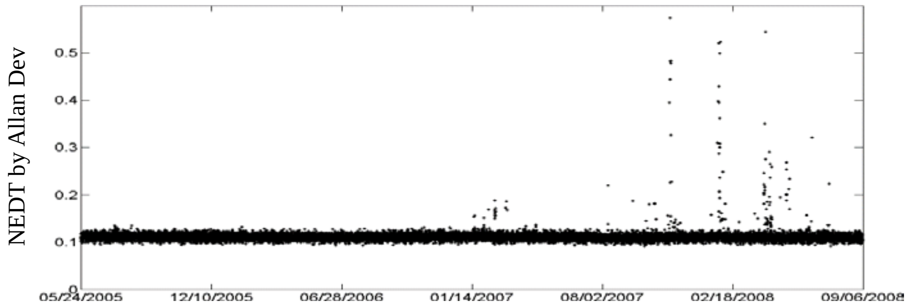
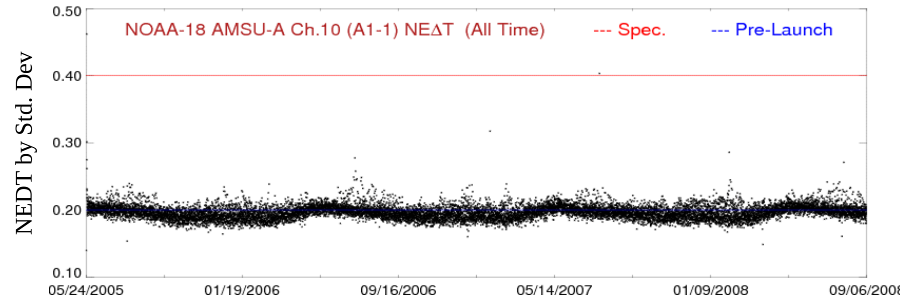
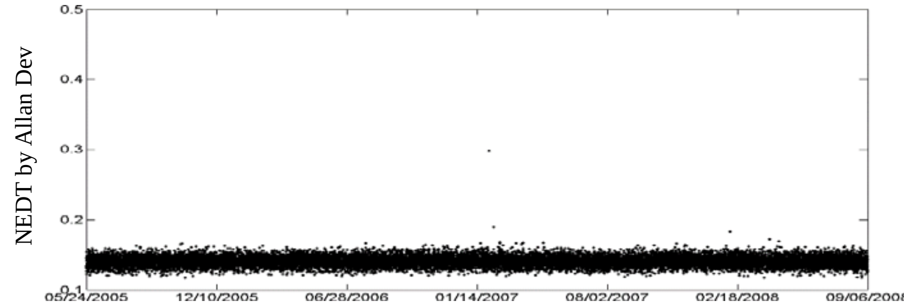
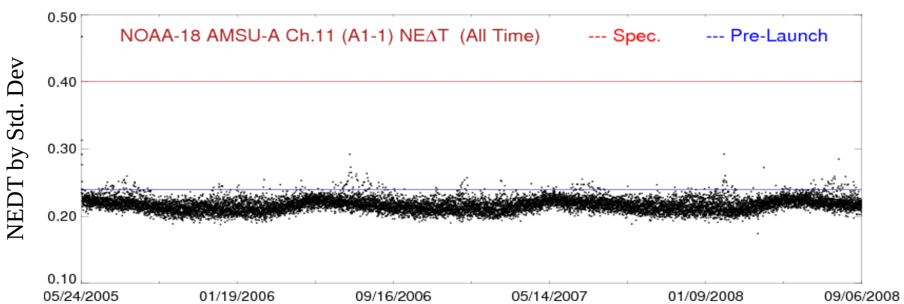
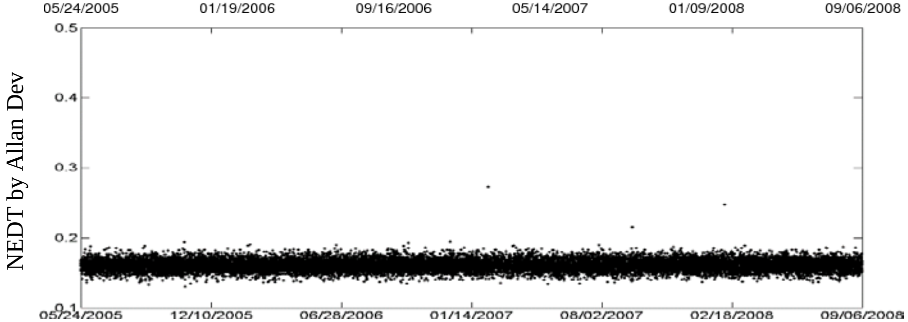


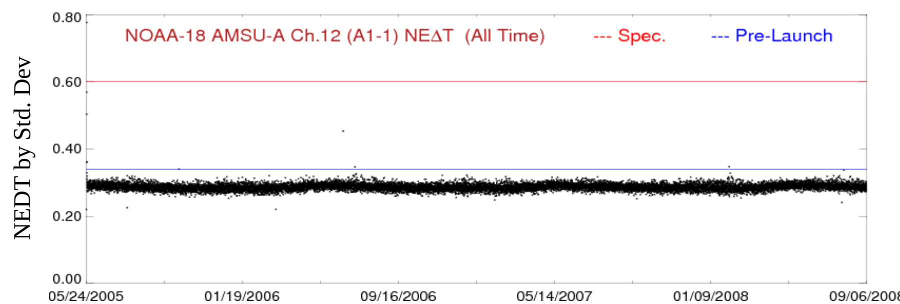


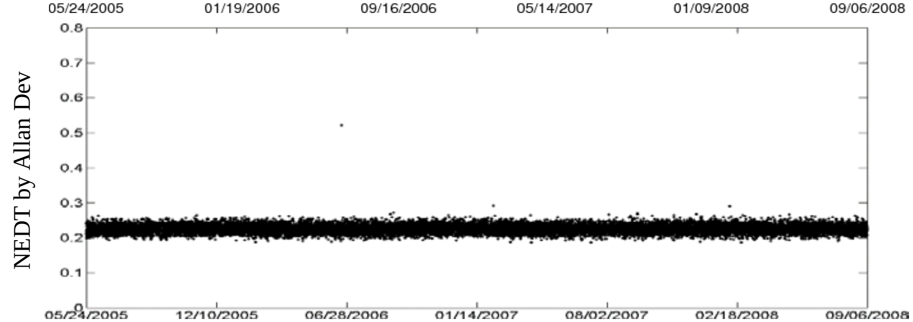




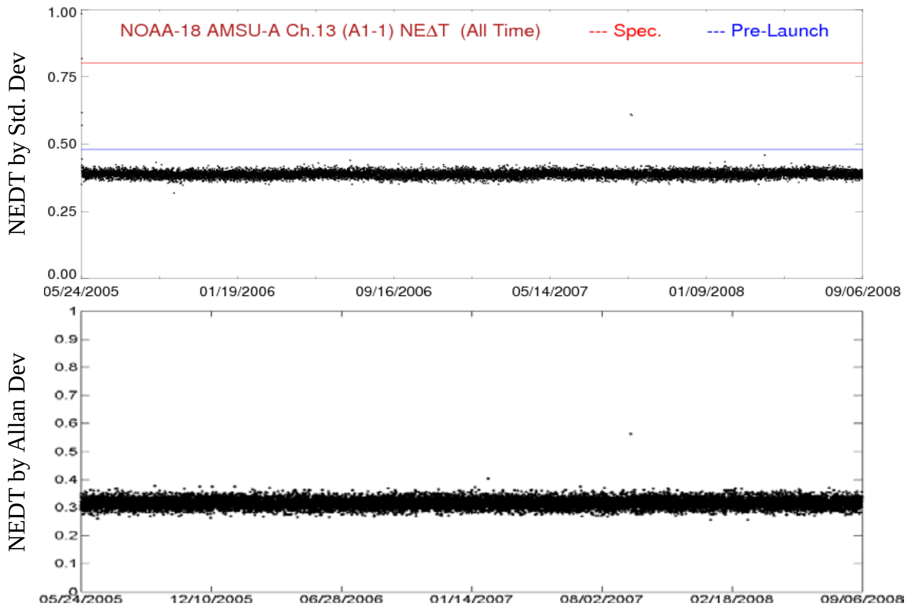


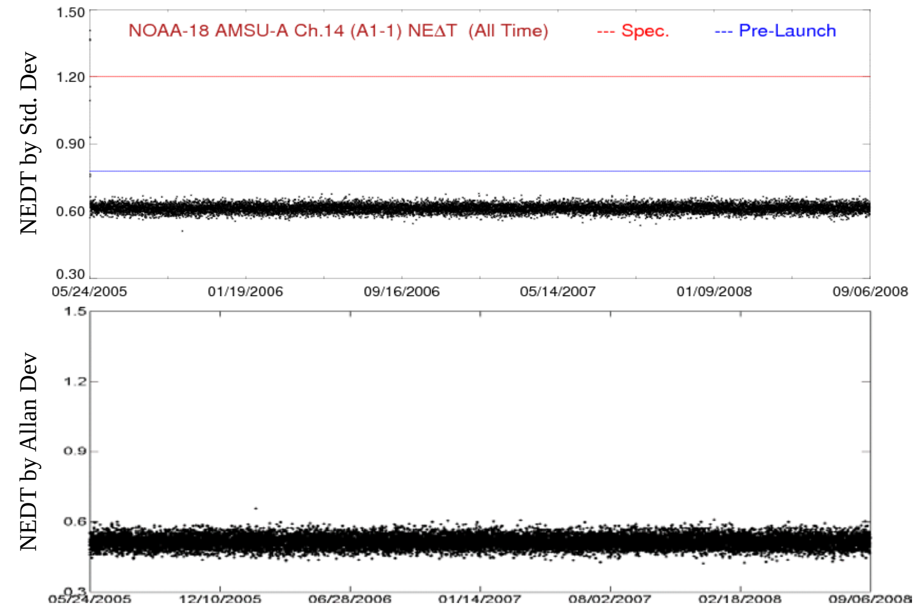


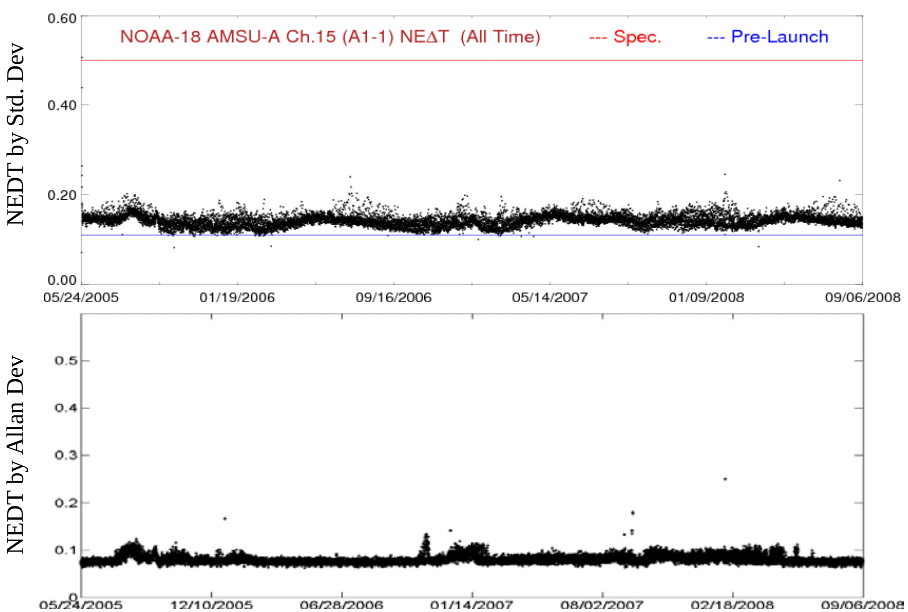




NOAA-18 AMSU-A: 3-yr Data



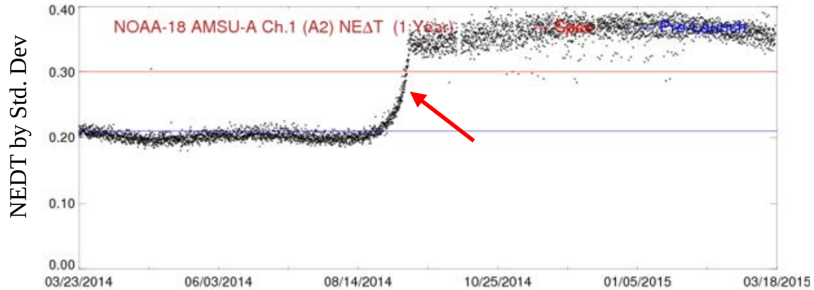


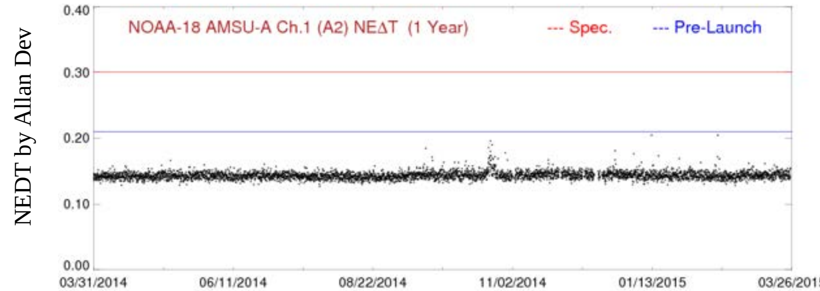


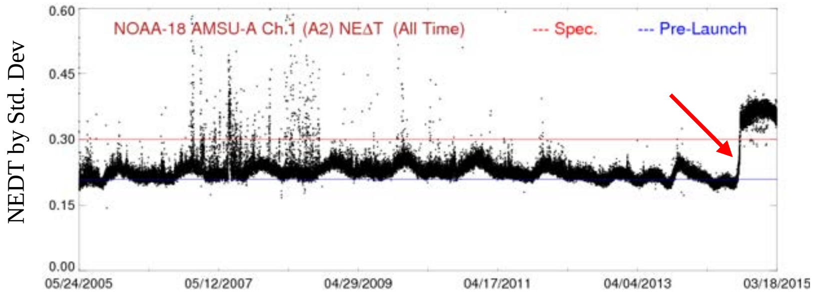
Short Summary:

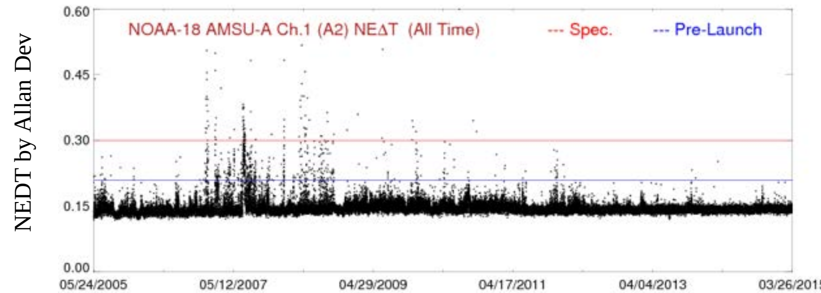
1. Allan deviation is more stable with much less local oscillation (i.e., daily).
2. Allan deviation still captures the long term trend (e.g., yearly), which may be due to the instrument initialization and later on aging.
3. Allan deviation still captures some events, like the jumps in N18 AMSU-A chs. 1, 4, 8, 9, and 15.

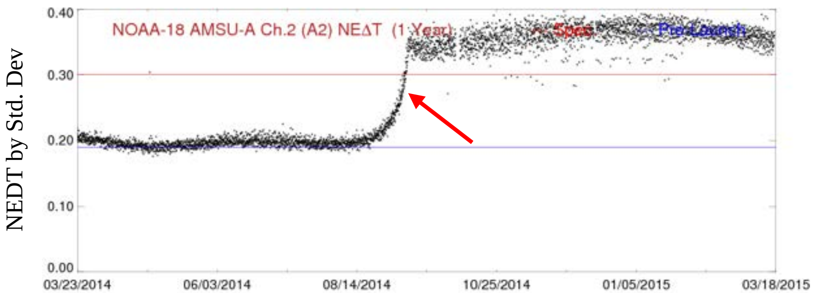
Special Case: N18 AMSU-A Chs.1 & 2 NEDT Anomaly

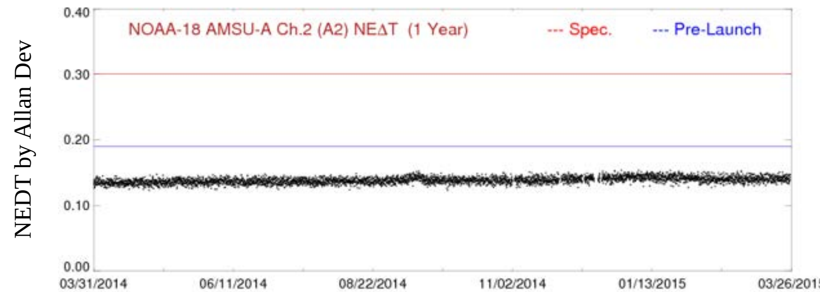


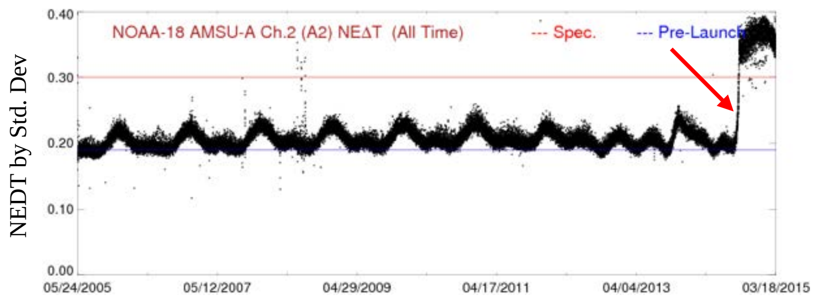


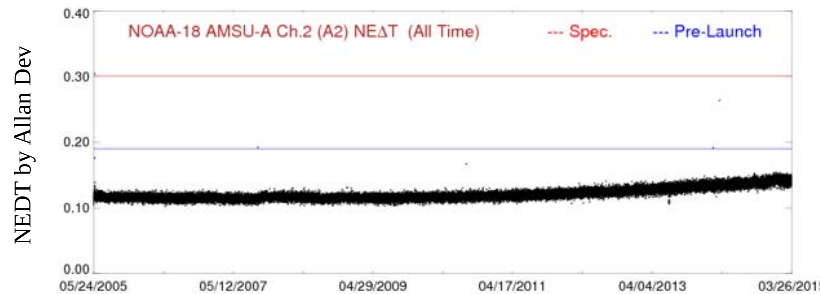












Summary and Path Forward

1. Comparing with the standard deviation and the overlapping Allan deviation, the proposed neighborhood Allan deviation provides better estimation of instrument noise/sensitivity in terms of accuracy and consistency.

2. Most importantly, the neighborhood Allan deviation does not require for deriving "optimal" averaging window size, can lead to an SI traceable noise characterization and is generally applied for all categories of instruments.

3. In future, we plan to apply the neighborhood Allan deviation to cover as many instruments as possible.

4. Impacts of this change to the related DA application and climate trend detection will also be interested areas.