# Sensitivity Test and Further Validation of Cross-track Infrared Sounder Spectral Gap Filling in Inter-comparisons

Hui Xu, Likun Wang, Yong Chen, Fangfang Yu, Fred Wu and Mitchell D. Goldberg

GSICS Annual Meeting 2019
03/07/2019

# Outline

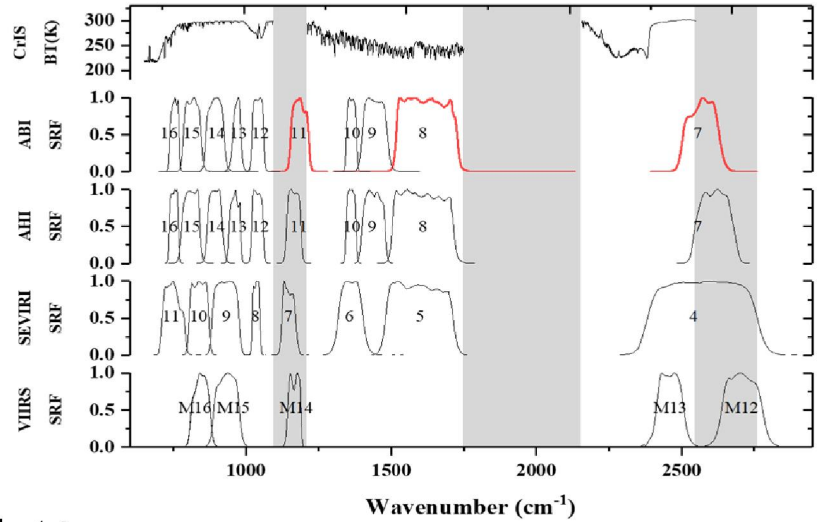
## I. The performance of CrIS spectral gap filling in inter-comparisons

- Training dataset analysis
- Scene and scan angle dependency analysis
- Stability analysis
- Accuracy analysis

## II. Conclusions and future works

# Background

Previously, a **Principle Component Regression (PCR)** based spectral gap filling method was successfully developed to **solve the channel missing issue in the satellite inter-comparisons** between CrIS and other broadband instruments.




**The detailed information of the gap filling method can be found at :**

- **H. Xu, Y. Chen and L. K. Wang**, 2019, Cross-Track Infrared Sounder Spectral Gap Filling Toward Improving Intercalibration Uncertainties, IEEE Transactions on Geoscience and Remote Sensing, 57(1), pp. 509-519.
- GSICS annual meeting 2018: http://gsics.atmos.umd.edu/pub/Development/20180319/4d_2018_GSICS_HUIXU.pptx

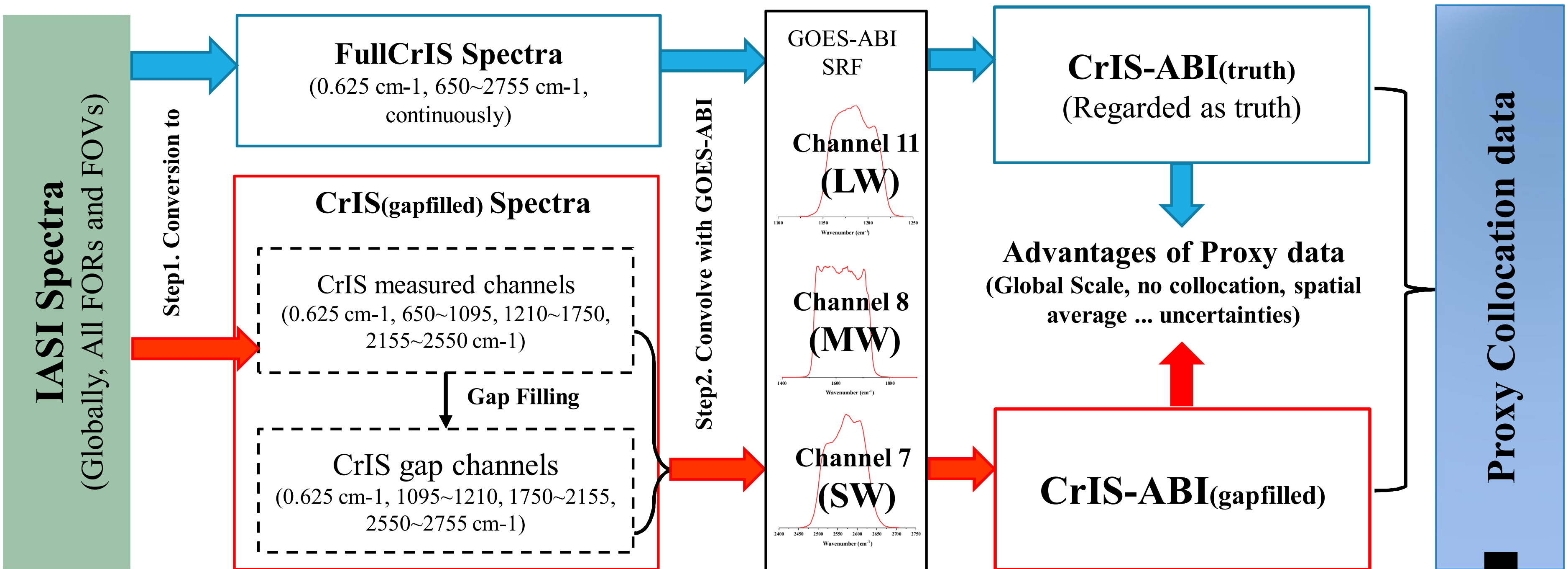
## GSICS annual meeting 2018 suggestion and action

**Suggestions from Mitchel & A.GIR.2018.4d.3**: *Evaluate the NOAA proposed gap filling method with IASI data*. "To pretend IASI has gaps and fill them with this method and check it with real IASI data. That would be the best validation."

**Respond**: A comprehensive sensitive test and validation were made on this issue, by using the GOES-16 **Advanced Baseline Imager (ABI)**'s three gap channels (11, 8 and 7) as examples. *This was achieved through a set of* ***CrIS and ABI proxy datasets*** *that directly simulated* ***from the MetOp-A/B IASI measurements***.

# The performance of CrIS spectral gap filling in inter-comparisons

## Flow chart of the CrIS gap filling method evaluation using IASI proxy data




CRIS SPECTRAL BAND COVERAGE FOR GOES-16 ABI.

| Channel id | Central wavenumber ($cm^{-1}$) | SRF covered by CrIS spectrum with gap (%) |
|---|---|---|
| 7 | 2570.373 | 32.904 |
| 8 | 1620.528 | 99.789 |
| 11 | 1184.220 | 10.692 |

The difference between **CrIS-ABI(gapfilled)** and **CrIS-ABI(truth)** can be regarded as the uncertainty of gap filling which is mainly caused by the following two parts:

1) *fitting error of the gap filling method*
2) *the original IASI instrument noise.*

In the following analysis, their difference refer to **CrIS-ABI(gapfilled) minus CrIS-ABI(truth)**.

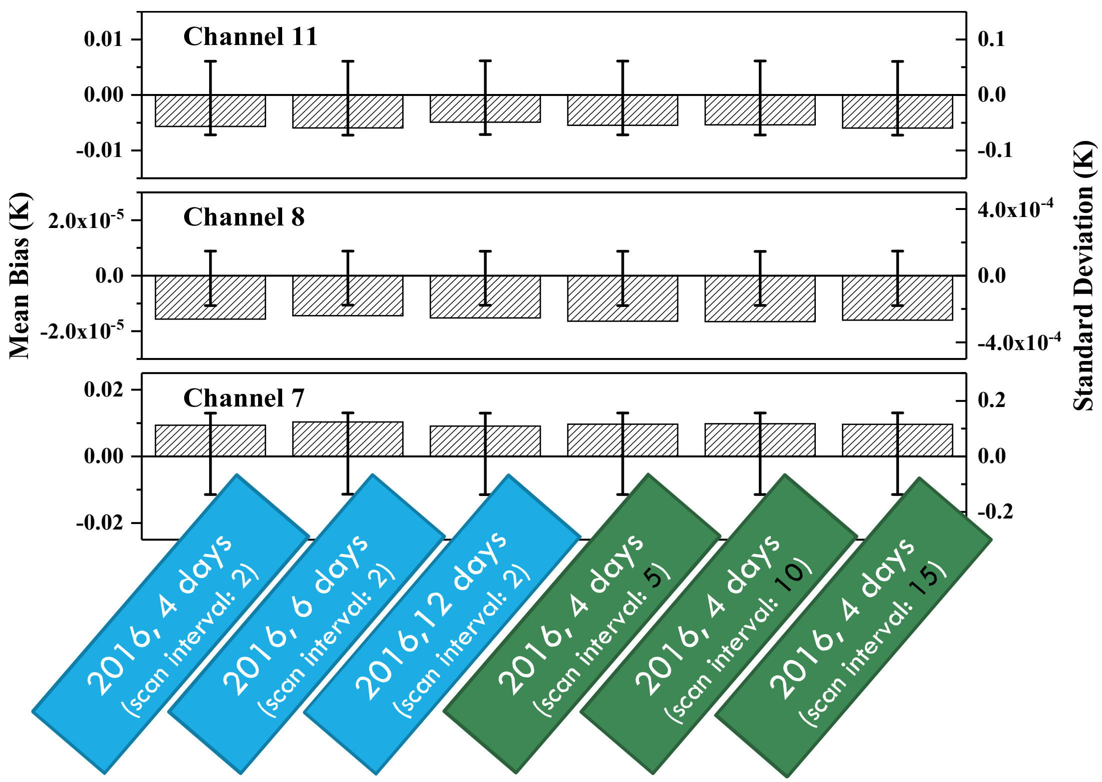
# The performance of CrIS spectral gap filling in inter-comparisons

Training dataset matters

## A. Training dataset analysis

A set of different training datasets randomly selected from different months and seasons in the years between 2014 and 2018 are investigated. The testing data used in checking the variability of the gap filing results, is selected from one-day of MetOp-B IASI global spectra (on 10 April 2015) which is not included in the training dataset.

TRAINING DATASETS ARE SELECTED FROM **THE SAME YEAR**




- Similar statistical results are observed for different training datasets selected from different months of the same year.
- The training data sample increasing (from four days of different seasons to twelve days of a whole year) does not bring significant improvement in the gap filling result.
- The gap filling results still keep negligible change in all the three gap channels even we increase the scan interval from two to fifteen in the training dataset selection

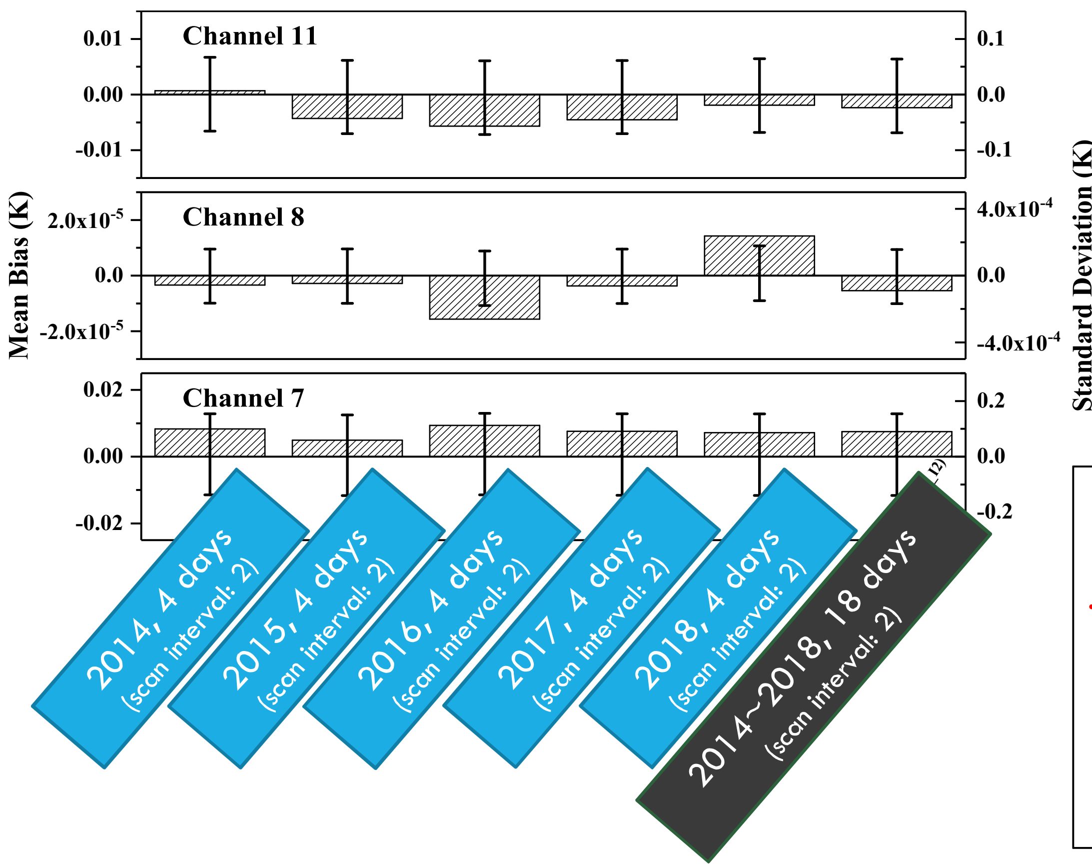
**Column bar** is the mean bias between $\text{CrIS-ABI}_{(\text{gapfilled})}$ and $\text{CrIS-ABI}_{(\text{truth})}$, **Y-error bar** is their standard deviation.

# The performance of CrIS spectral gap filling in inter-comparisons

Training dataset matters

## ➢ A. Training dataset analysis

TRAINING DATASETS ARE SELECTED FROM **DIFFERENT YEAR**

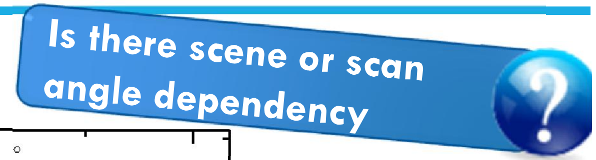


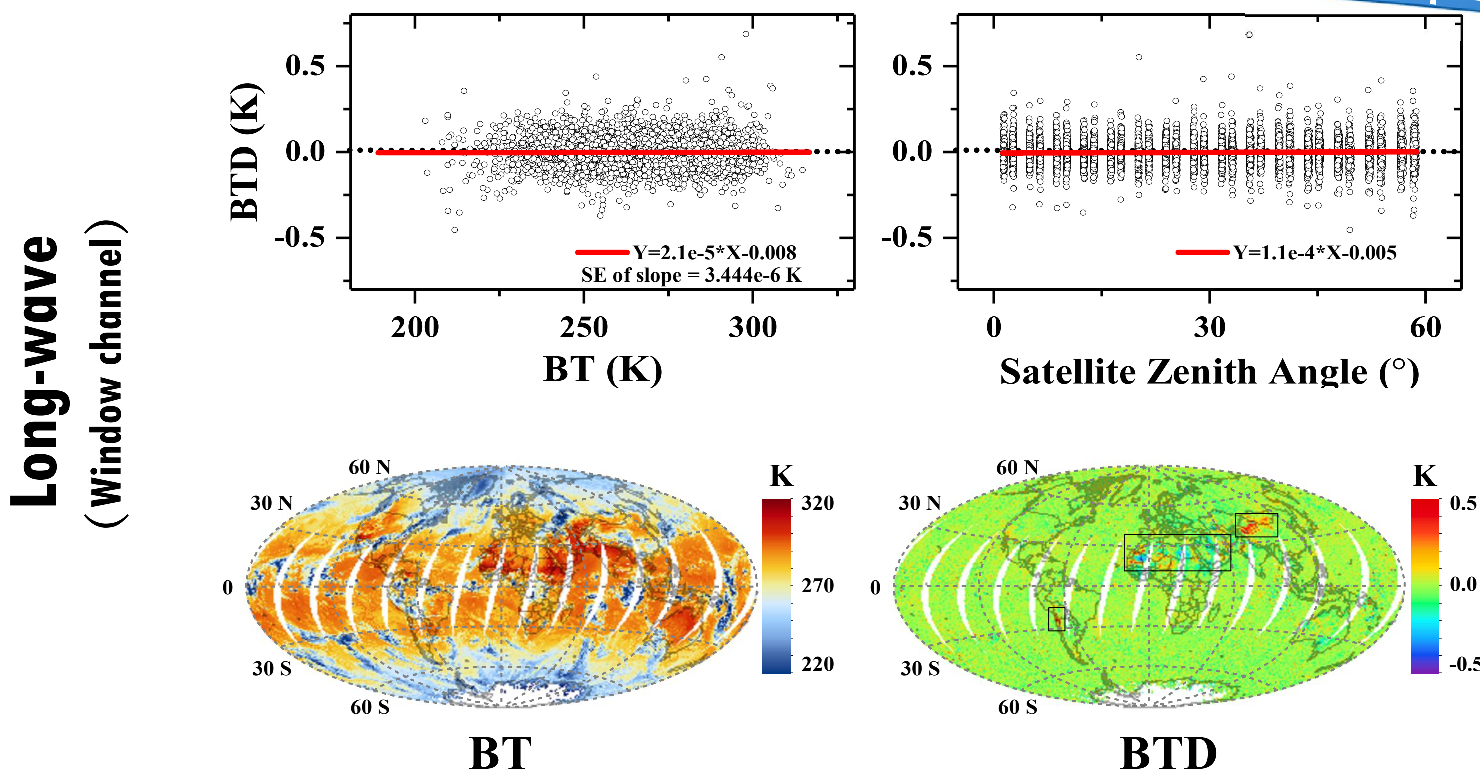

- Similarly, tiny differences are observed in the gap filling results with different year derived coefficients.
- Particularly, the result calculated with the multi-year (Black) training data derived coefficients is quite like those from the yearly (Blue) derived coefficients both in mean and standard deviation.

All these suggest that ***the four-day training dataset selected from different seasons within a year that used in our previous study***, ***are enough to have a general representative of the earth's different atmospheric and surface conditions***. Further validations will be conducted in the future, to see if extending of the training dataset could reduce the uncertainties in extreme cases.

# The performance of CrIS spectral gap filling in inter-comparisons

- B.Scene and scan angle dependency analysis




GOES-ABI Channel 11

- ***The scene and scan angle dependencies can be hardly found in the LW window gap channel.***
- For the majority scenes, such as the ocean areas, their BTD values caused by the spectral gap filling are generally within the range of -0.1 and 0.1 K.
- However, relatively larger BTD values are observed over the middle-latitude arid and semi-arid areas, such as the Sahara Desert.

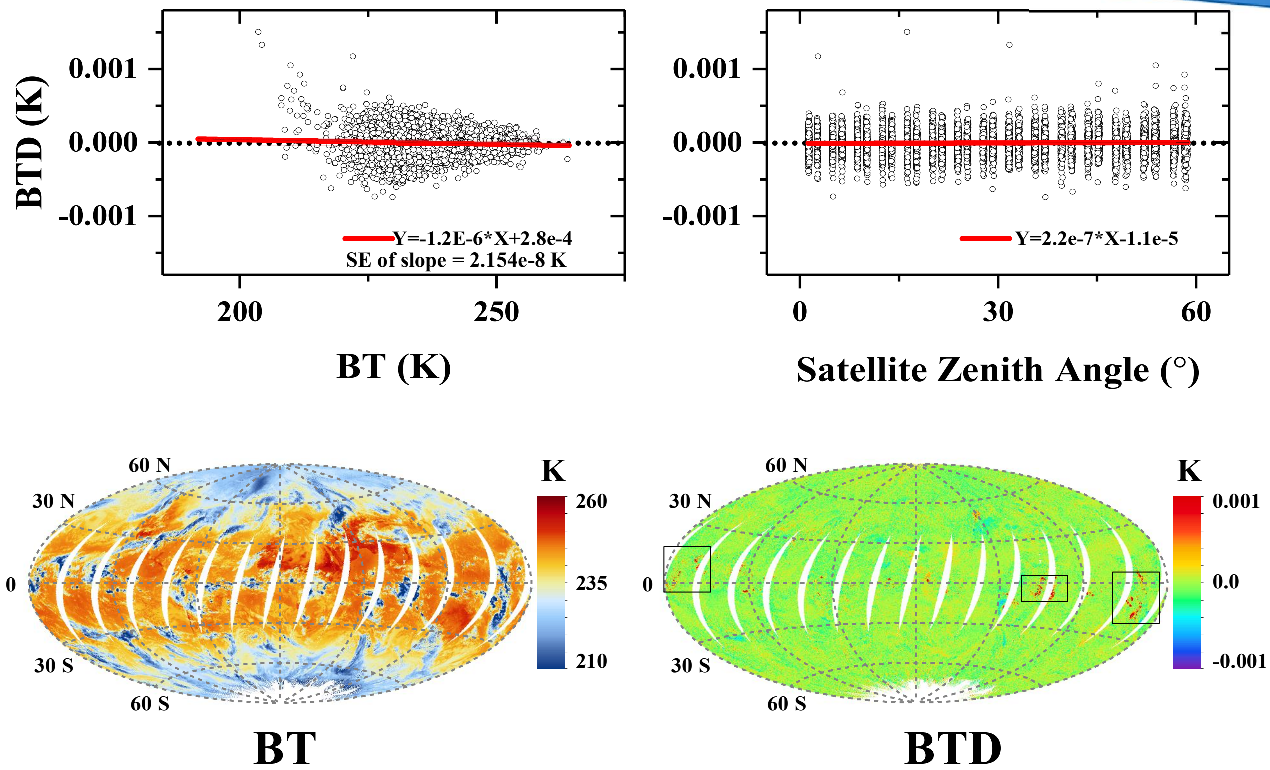
# The performance of CrIS spectral gap filling in inter-comparisons

Is there scene or scan angle dependency?

- **B. Scene and scan angle dependency analysis**

10 April 2015

Middle-wave (Water vapor channel)




GOES-ABI Channel 8

- *__As expected, the scene and scan angle dependences are still not found in this MW channel.__*
- The gap filling method performs well for most of the global scenes from the Polar to the Tropical areas except for several cloudy regions as marked.
- However, a tiny positive bias are observed at some of the cold scene. These anomaly areas are most distributed in the tropical region and possibly the deep convective clouds (DCC).

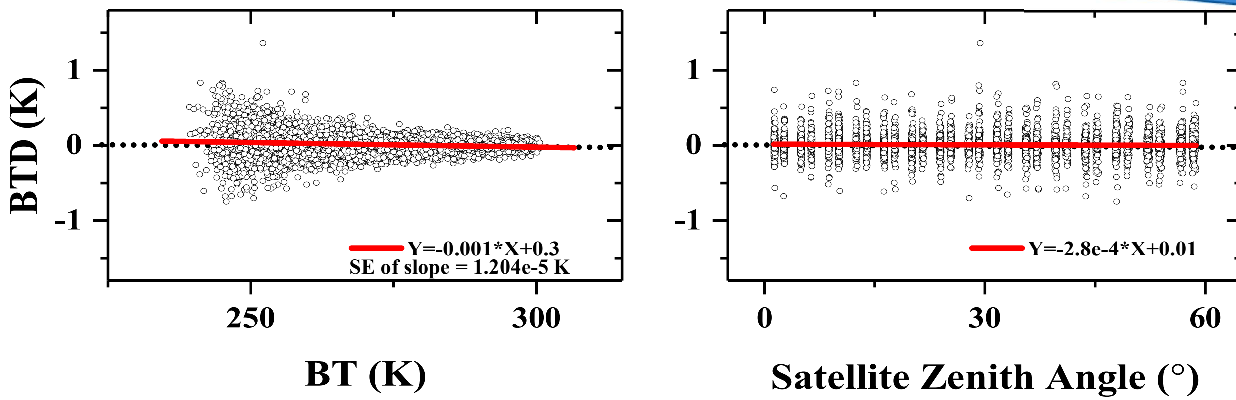
# The performance of CrIS spectral gap filling in inter-comparisons

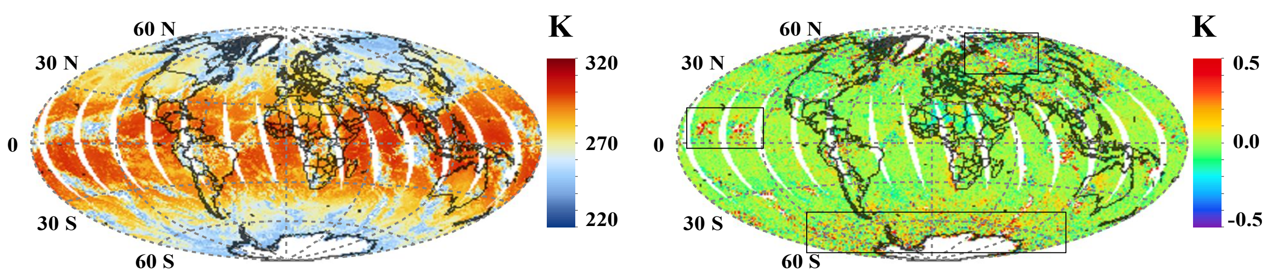
Is there scene or scan angle dependency?

- B. Scene and scan angle dependency analysis

10 April 2015

Short-wave (Window channel)




BT BTD

GOES-ABI Channel 8

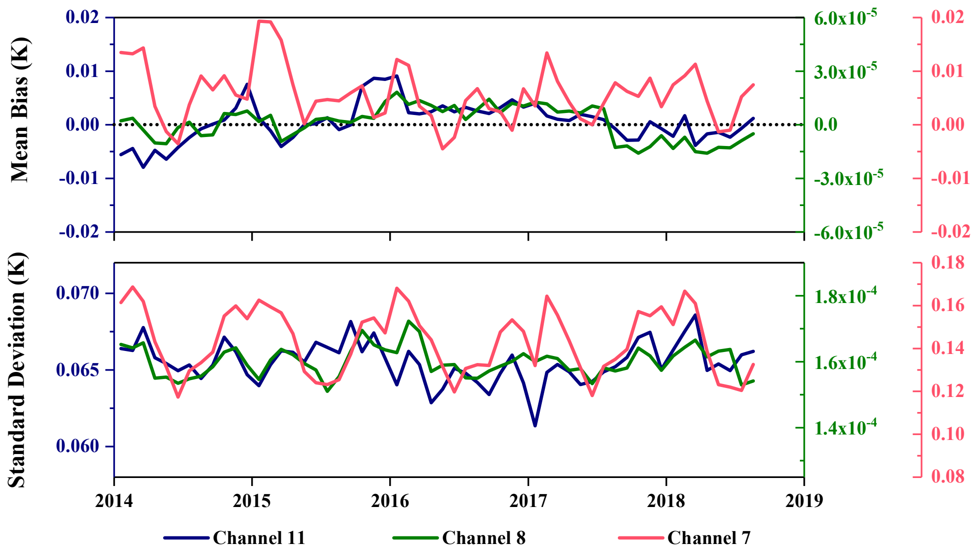
- *Similarly, there is no scene as well as scan angle dependency at this SW channel too.*
- Different from the other two channels, large BT differences between them are mainly observed in the very cold scenes (e.g., the cloudy and the high-latitude Polar regions, highlighted by the black rectangles).

# The performance of CrIS spectral gap filling in inter-comparisons

Long-term performance

## ➢ C. Stability analysis

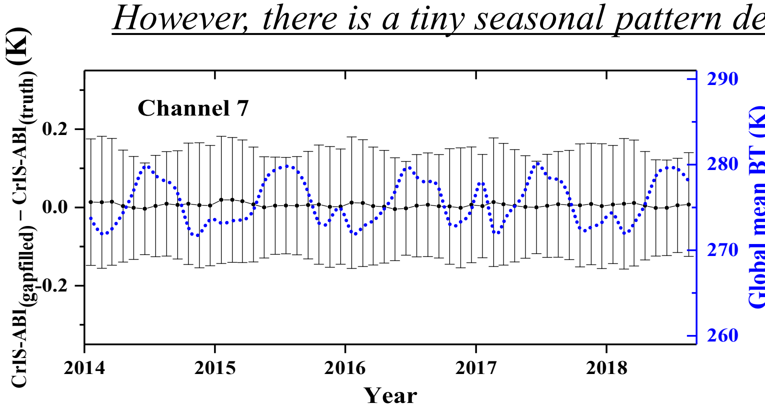
The long-term stability of the CrIS spectral gap filling method is analyzed based on a time series daily data ensemble randomly selected from different months of MetOp-B IASI during the year from 2014 to 2018.

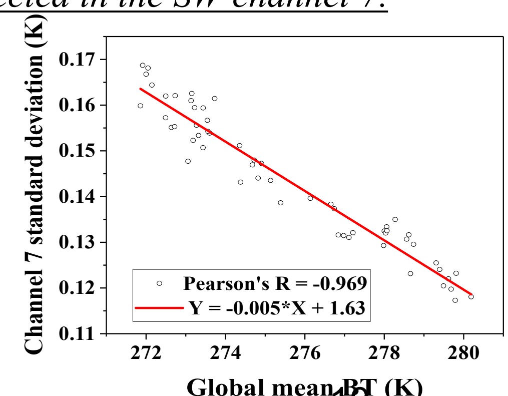



- For all the LW, MW and SW gap channels, their mean biases fluctuate around the zero-line during 2014 to 2018.
- Their standard deviations also vary in a very small dynamical range less than 7.0e-3, 2.1e-5, and 0.05 K respectively.
- trends are not found for both the mean bias and standard deviation time series here, indicating that ***<u>the spectral gap filling method in general is quite stable.</u>***

*<u>However, there is a tiny seasonal pattern detected in the SW channel 7.</u>*

The explanation is that more cold scenes are observed in the winter than in the summer time.
This is because the land coverage in Northern Hemisphere is higher than that in the Southern Hemisphere.



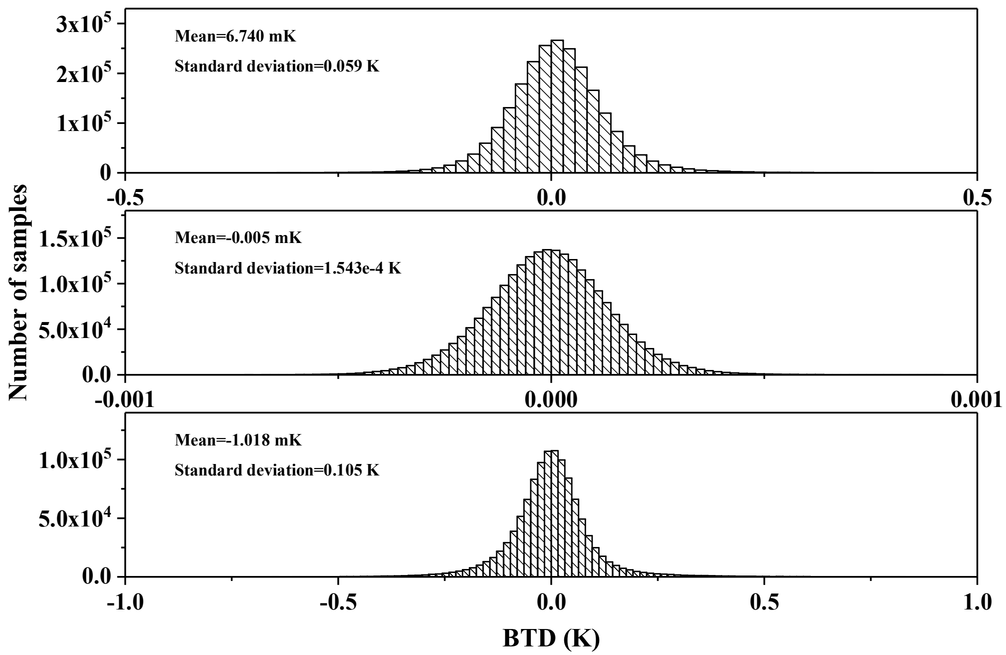



# The performance of CrIS spectral gap filling in inter-comparisons

Convolution Uncertainty

## ➢ D. Accuracy analysis

- The simulated proxy data is further constrained into **the CrIS and GOES-16 ABI potential collocation area from 125° W to 25° W in longitude and 50° S to 50° N in latitude**.
- **MetOp-A IASI was used in the CrIS-ABI proxy data simulation** instead of the MetOp-B IASI.
- Finally**, twelve days of MetOp-A IASI randomly selected from each months of year 2016** are simulated into CrIS-ABI(truth) as well as the CrIS-ABI(gapfilled) proxy data, to quantitatively analyze the convolved gap filling accuracy in the CrIS and ABI inter-comparisons.




- **LW** channel 11, the channel 11 gap filling accuracy is in a mean of 6.740 mK and standard deviation of 0.059 K.
- **MW** channel 8, the gap filling mean bias and standard deviation are around -0.005 mK and 1.543e-4 K respectively.
- **SW** channel 7, same normal distribution pattern is also observed with a mean bias of -1.018 mK and standard deviation of 0.105 K.

- Overall, all their BT differences are normally distributed with a near-zero mean bias, suggesting that ***the errors transferred from the spectral gap filling are negligible in CrIS and ABI inter-comparison studies, as they will be cancelled out during the scene average***.

# The performance of CrIS spectral gap filling in inter-comparisons

Convolution Uncertainty

**CrIS spectral gap filling accuracy for broadband instruments**

| | Instrument | Potential collocation area with CrIS | Channel id | Central wavenumber ($cm^{-1}$) | SRF covered by CrIS spectrum (%) | Spectral gap filling accuracy (mK ± K) |
|---|---|---|---|---|---|---|
| Geostationary | Meteosat-11 SEVIRI | 50W~50E, 50S~50N | 5 | 1596.080 | 99.920 | -0.004 ± 4.511e-5 |
| | | | 7 | 1147.433 | 0.303 | -6.415 ± 0.101 |
| | Meteosat-8 SEVIRI | 10W~90E, 50S~50N | 5 | 1588.790 | 99.915 | -4.164e-4 ± 4.744e-5 |
| | | | 7 | 1148.277 | 0.069 | -5.159 ± 0.106 |
| | INSAT-3D IMAGER | 30E~130E, 50S~50N | 3 | 2548.401 | 52.658 | 0.846 ± 0.078 |
| | FY-4A AGRI | 55E~155E, 50S~50N | 8 | 1604.837 | 97.384 | 0.039 ± 0.002 |
| | | | 10 | 1164.468 | 18.173 | 1.299 ± 0.058 |
| | Himawari8 AHI | 90E~170W, 50S~50N | 7 | 2575.767 | 30.580 | -2.113 ± 0.120 |
| | | | 8 | 1609.241 | 99.896 | 0.002 ± 8.194e-5 |
| | | | 11 | 1164.443 | 0.082 | 4.690 ± 0.081 |
| | GOES-15 IMAGER | 175E~85W, 50S~50N | 3 | 1526.432 | 99.995 | -3.152e-5 ± 2.723e-6 |
| | GOES-16 ABI | 130W~25W, 50S~50N | 7 | 2570.373 | 32.904 | -1.018 ± 0.105 |
| | | | 8 | 1620.528 | 99.789 | -5.202 ± 1.543e-4 |
| | | | 11 | 1184.220 | 10.692 | 6.740 ± 0.059 |
| Sun-synchronous | SNPP VIIRS | 180W~180E, 90S~90N | M13 | 2460.010 | 99.585 | -0.004 ± 7.755e-4 |
| | | | M14 | 1165.960 | 0.019 | 6.167 ± 0.080 |
| | Aqua MODIS | 180W~180E, 90S~70S & 70N~90N | 21 | 2511.829 | 99.582 | 0.057 ± 0.007 |
| | | | 29 | 1169.656 | 1.453 | 13.0 ± 0.074 |
| | FY-3D MERSI2 | 180W~180E, 90S~70S & 70N~90N | 22 | 2473.160 | 99.230 | 0.025 ± 0.003 |
| | | | 24 | 1168.665 | 0.358 | 15.0 ± 0.081 |

**Full name of above listed broadband instruments are described as follows,**

SEVIRI, Spinning Enhanced Visible and InfraRed Imager; AGRI, Advanced Geosynchronous Radiation Imager; AHI, Advanced Himawari Imager; ABI, Advanced Baseline Imager; VIIRS, Visible Infrared Imaging Radiometer Suite; MODIS, Moderate Resolution Imaging Spectroradiometer; MERSI, Medium Resolution Spectral Imager.

- ***Similar spectral gap filling accuracies are observed when these instruments are compared with the CrIS measurement over the LW, MW and SW spectral regions.***
- However, as they were deployed at different locations as well as orbits, and the channel spectral responses are also not identical, the accuracy of the spectral gap filling varies from instrument to instrument and channel to channel.

# Conclusions and future works

## Conclusions

- To address the channel missing issue in the satellite inter-comparisons between CrIS and other broadband channel instruments, **a principle component regression based spectral gap filling method was developed**.
- Sensitive test shows that **the selected training dataset are enough** to have a general representative of different atmospheric and surface conditions.
- **Neither the scene nor the scan angle dependency is observed in the gap filling results**, implying that the gap filling coefficients can be applied to both the cold and warm scenes at all scan views.
- The gap filling result varies only in a very small range from year to year, illustrating that **the gap filling method is stable** and can be confidently applied to the long-term inter-comparison studies as well.

## Future works

- We do hope our community could use and test the newly developed CrIS spectral gap filling method in the inter-comparisons, to forward and improve this issue step by step.
- We will continually collaborate with other colleagues on the IASI SW beyond extension.

# Thanks

(Thank all the IR group colleagues for providing valuable suggestions on this topic)

**Hui Xu**

**(CICS/ESSIC/Univ. of Maryland, College Park, MD)**

**Email: huixu@umd.edu**