The 2017 STAR JPSS Annual Science Team Meeting, August 14-18, 2017
NOAA Center for Weather and Climate Prediction, College Park, Maryland

A Modified Destriping Algorithm Applicable to ATMS Surface-Sensitive Channels

Xiaolei Zou

Earth System Science Interdisciplinary Center (ESSIC)
University of Maryland, USA

August 15, 2017

Outline

- A Look Back of ATMS Striping Noise Research
- Challenges for Surface-Sensitive Channels
  - — Artifacts are generated by the SNM when scanlines are aligned with coastal lines and edges of heavy precipitation
- An Ideal Illustration on Artifacts Generation by Destriping
  - — Large jumps of TB are aligned with scanelines
  - — Large jumps of TB are aligned in along-track direction
- A Modified Striping Noise Mitigation Algorithm
  - — Algorithm description
  - — Applications to ATMS channels 1-4, 17-18
- Summary and Future Plan

A Look Back of ATMS Striping Noise Research

- SNPP ATMS upper air sounding channels display clear striping noise in NWP model O-B fields that was not seen in AMSU-A upper air sounding channels
- Striping noise are also seen in prelaunch TVAC data and pitch maneuver data
- A destriping algorithm was developed to eliminate the striping noise in ATMS temperature sounding channel observations (Qin, Zou and Weng, 2013, JGR)
- At the19th International TOVS Study Conference (ITSC) in 2014, NWP users requested the ATMS CalVal team to develop an operational destriping algorithm
- An operationally feasible ATMS destriping algorithm was developed (Ma and Zou, 2015, JGR)
- ATMS CalVal team provided 45 days of de-striped ATMS data NWP centers
- ECMWF (Dr. Heather Lawrence) reported that artefacts were found in the 45-day ATMS destriped dataset for window channels at "NOAA Worksop on JPSS Life-Cycle Data Reprocessing to Advance Weather and Climate Applications, May 17-18, 2016"
- A modified destriping algorithm was developed to eliminate the striping noise in ATMS surface sensitive channel observations (Zou et al., 2017, QJRMS)

Striping Noise Mitigation Algorithms

- The PCA/EEMD Algorithm (for theoretical analysis of striping noise)
  Qin, Zou and Weng (2013, JGR)

  Step I: Compute principal components of ATMS data matrix
  Step II: Extract the first few highest frequency IMFs from the 1st PC mode to remove striping noise

- The PCA/SymFilter Algorithm (for operational implementation)
  Ma and Zou (2015, JGR)

  Step I: Compute principal components of ATMS data matrix
  Step II: Apply a symmetric filter to the 1st PC mode to filter striping noise

PCA	—— Principal Component Analysis
EEMD	—— Ensemble Empirical Mode Decomposition
SymFilter	—— Symmetric Filter
IMFs	—— Intrinsic Model Functions

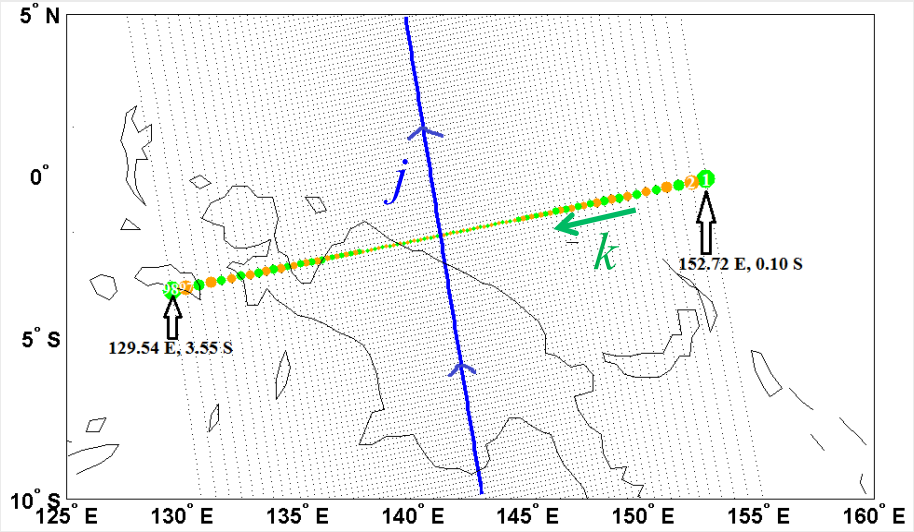
Step I: Compute PCs of ATMS Covariance Matrix

1. Form ATMS data matrix

$$\mathbf{A} = \begin{pmatrix} TB_{1,1} & TB_{1,2} & \cdots & TB_{1,j} & \cdots & TB_{1,N} \\ TB_{2,1} & TB_{2,2} & \cdots & TB_{2,j} & \cdots & TB_{2,N} \\ \vdots & & \ddots & & & \\ TB_{k,1} & & & TB_{k,j} & & TB_{k,N} \\ \vdots & & & & \ddots & \\ TB_{96,1} & & & & & TB_{96,N} \end{pmatrix}$$

k, cross track

j, along track



2. Construct covariance matrix

$$\mathbf{S} = \mathbf{A}\mathbf{A}^T$$

$$\mathbf{S}\vec{e}_i = \lambda_i \vec{e}_i$$

PC modes

3. Mapping ATMS radiance in PC modes

$$\mathbf{A} = \sum_{i=1}^{96} \vec{e}_i \vec{u}_i$$

PC coefficients

The highest frequency noise in $\vec{u}_1$ represents the ATMS striping noise feature in the along-track direction — high frequency random noise

$$\begin{pmatrix} \vec{\mathbf{u}}_1 \\ \vdots \\ \vec{\mathbf{u}}_{96} \end{pmatrix} = \begin{pmatrix} \vec{\mathbf{e}}_1 \\ \vdots \\ \vec{\mathbf{e}}_{96} \end{pmatrix} \mathbf{A}$$

Step II: Extract IMFs from the 1st PC Coefficient

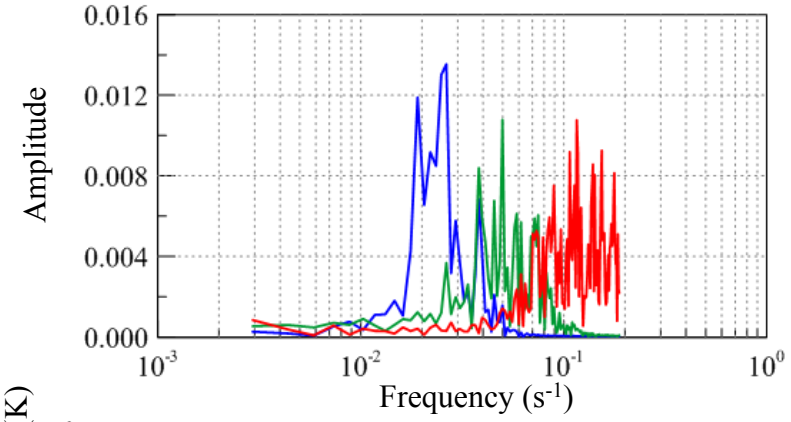
EEMD decomposition:

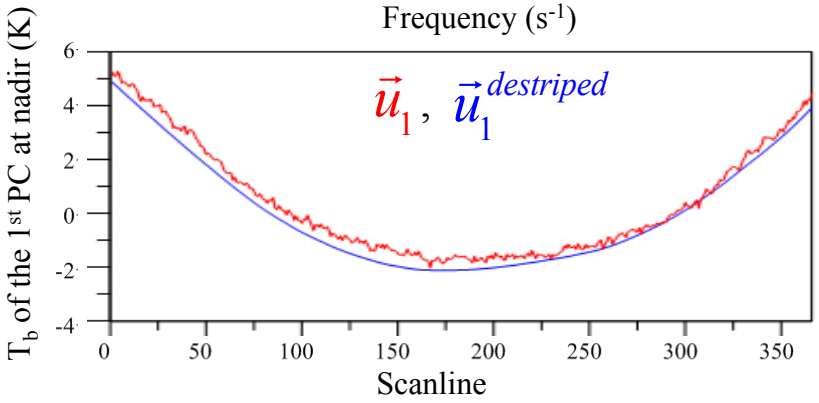
$$u_i(j) = \sum_{j=1}^{n} C_j(t) + R_n(t)$$

$R_0(t) = u_i(j)$

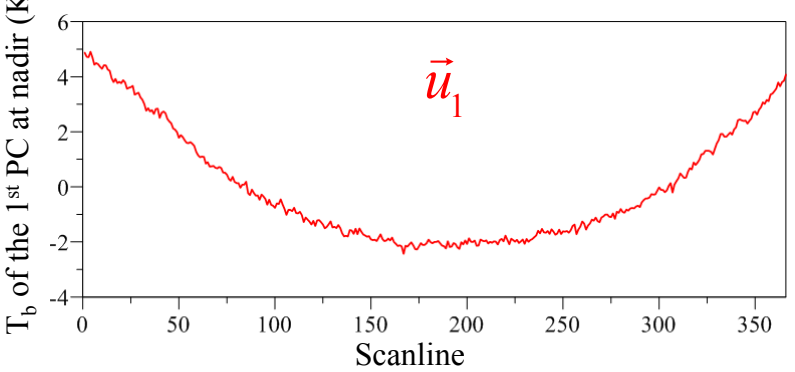
$C_n \leftarrow$ R_{n-1} minus the mean of the envelopes of R_{n-1}

$R_n(t) = R_{n-1}(t) - C_n$

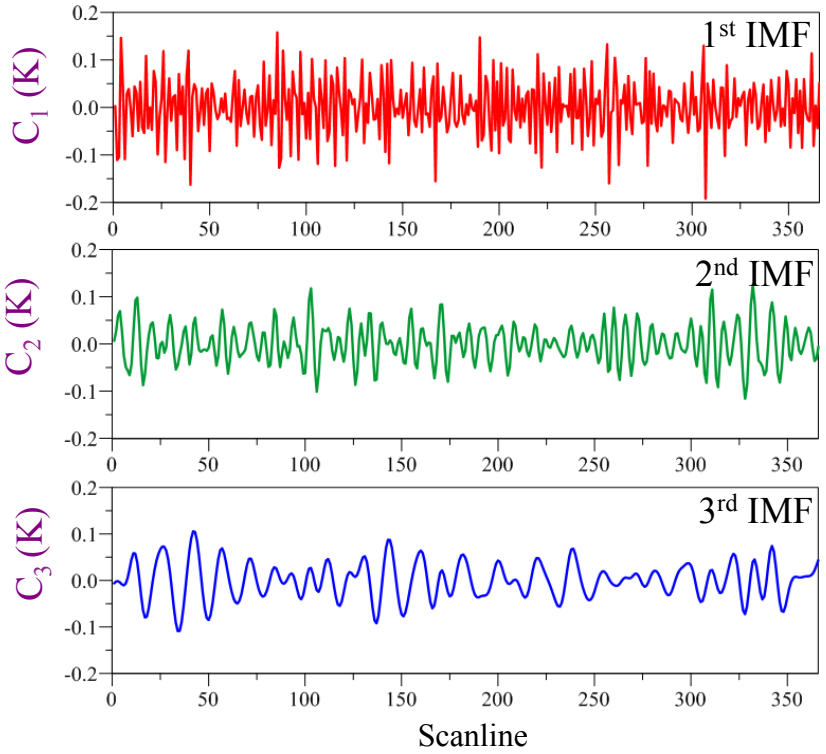




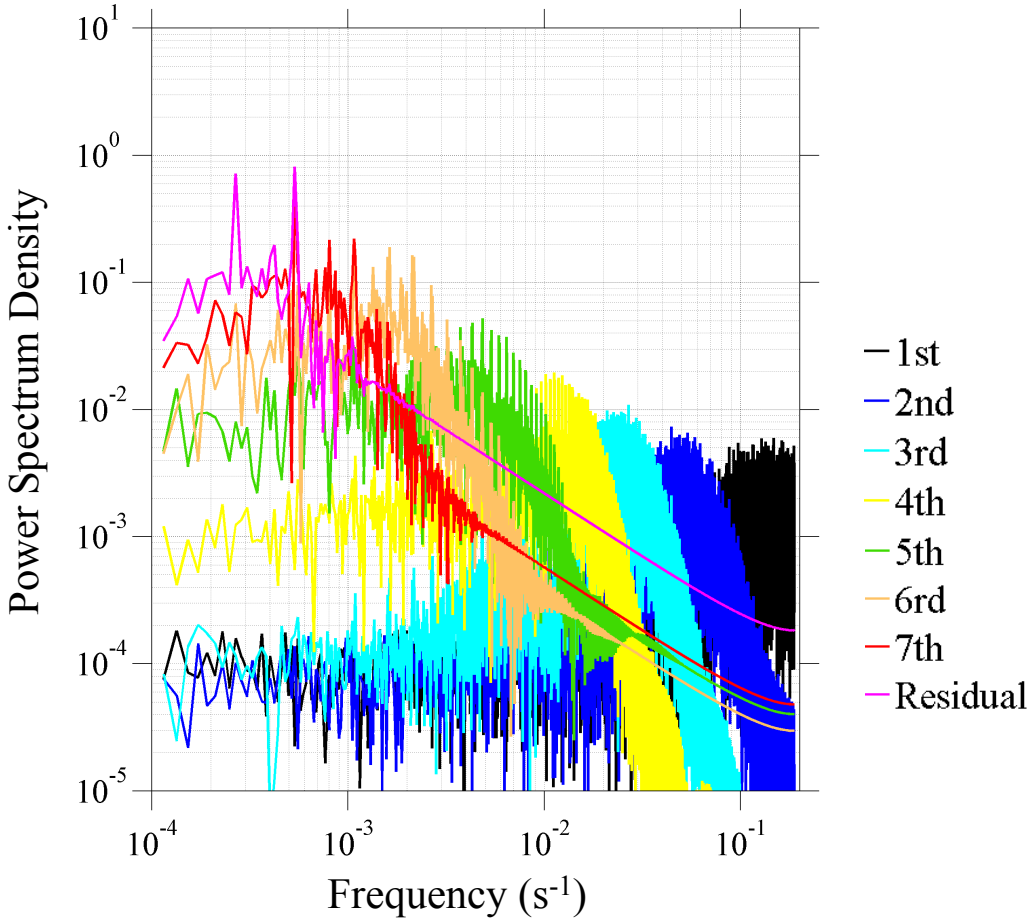
The 1st PC coefficient at Nadir



The first three IMFs of the above data series



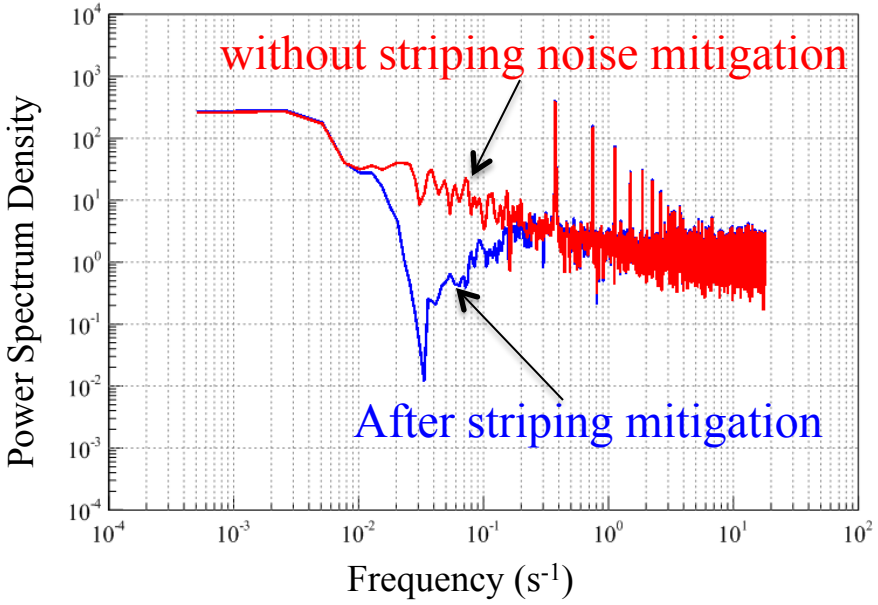
Why Removing the First Three IMFs from the 1st PC Coefficient?



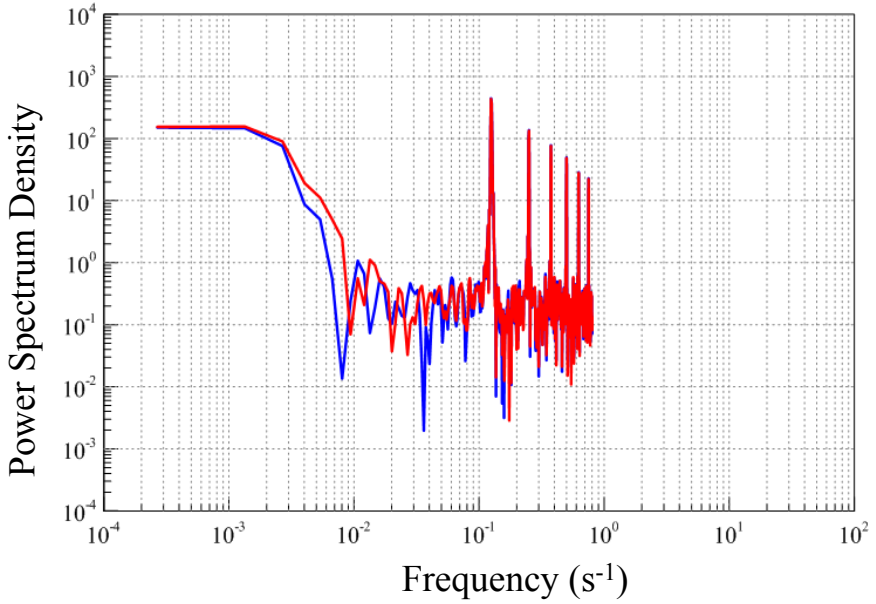
The 4th, 5th and higher order IMFs contain information of those weather scales with their frequencies lower than 10^{-2} s^{-1} which are resolvable by ATMS SDR. Therefore, they should be retained in the destriped ATMS SDR.

Impacts of Striping Noise Mitigation on ATMS SDR

S-NPP ATMS Channel 10



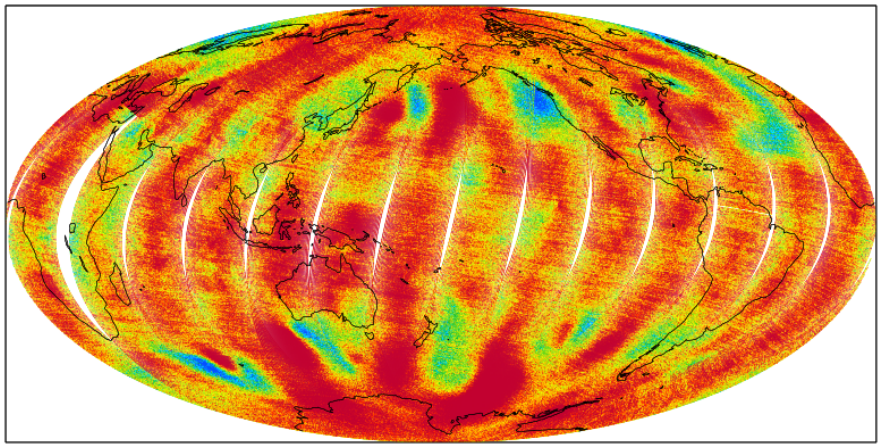
NOAA-18 AMSU-A Channel 9



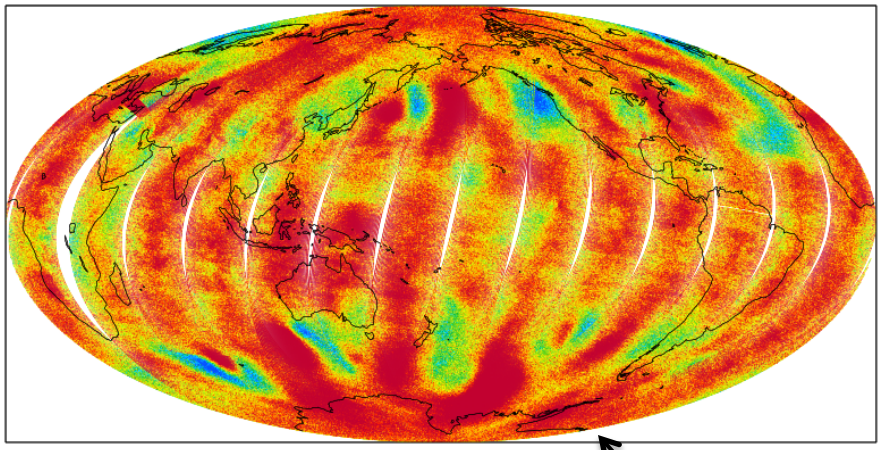
The power spectrum of ATMS SDR is significantly reduced only within the frequency range 10^{-2} -10^{-4} s^{-1}, which are scales not resolvable by ATMS sampling rate in the along-track direction, by the proposed striping noise mitigation.

Global O-B Distributions for ATMS Channel 10

Before

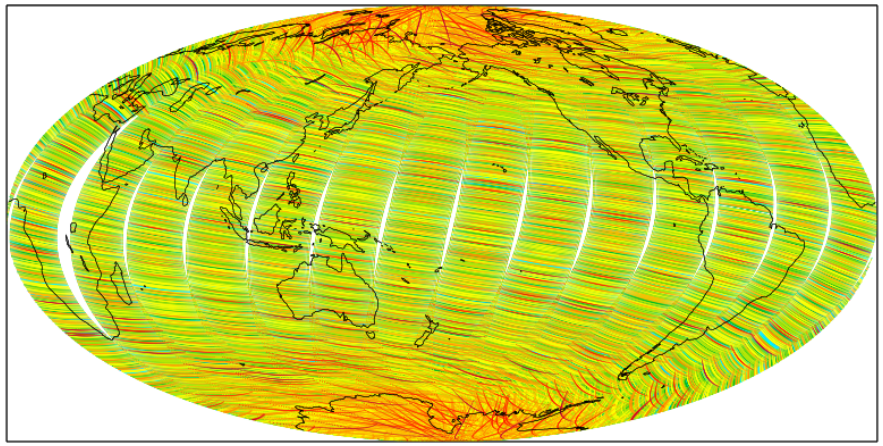


After



Striping noise is removed.

Before minus After



Striping noise



Data on 24 February 2012

ECMWF Finding:

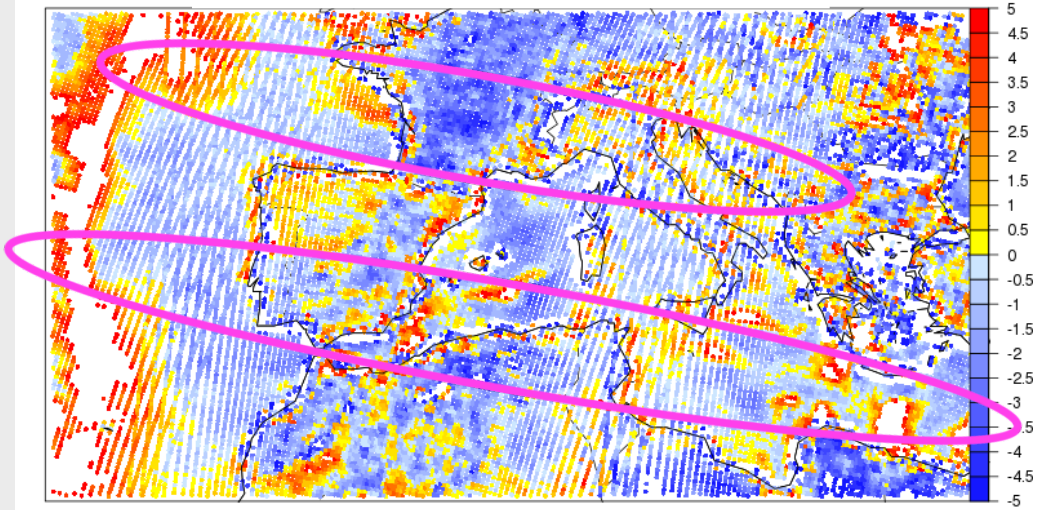
Artefacts Are Found in ATMS Destriped Dataset for Window Channels!

An evaluation of the destriped dataset at ECMWF lead to the following conclusions:

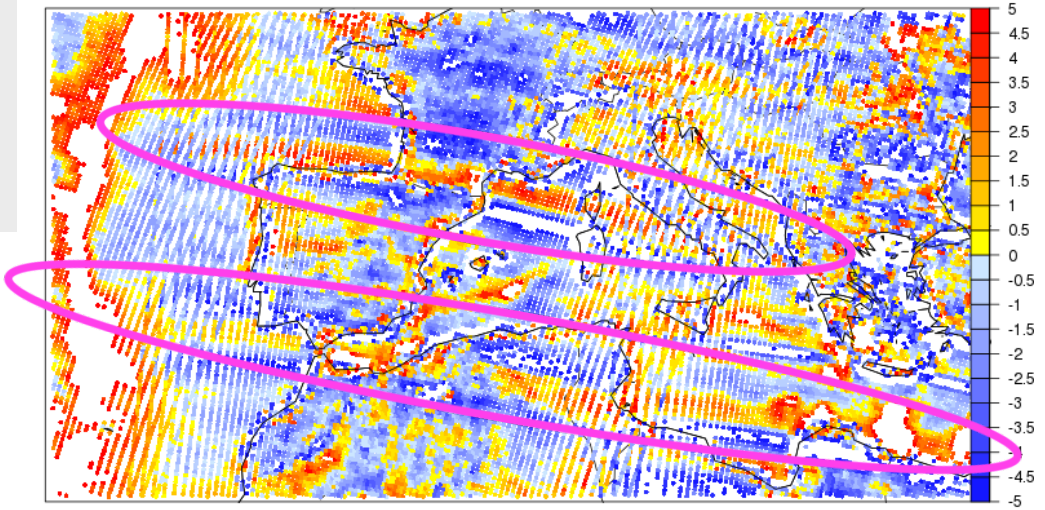
- Destriped dataset appears to reduce the striping for temperature-sounding channels
- Evidence of artefacts for window channels and lower humidity sounding channels in regions where there are sharp contrasts of Tb (e.g., terrain, cloud) that are aligned with ATMS scanlines
- The benefits of striping noise removal through post-processing are therefore not clear
- The striping noise should be avoided at source, i.e., at the instrument design level

The content on this slide is from the talk by Dr. Heather Lawrence at "NOAA Worksop on JPSS Life-Cycle Data Reprocessing to Advance Weather and Climate Applications. May 17-18, 2016. ESSIC, College Park, MD.

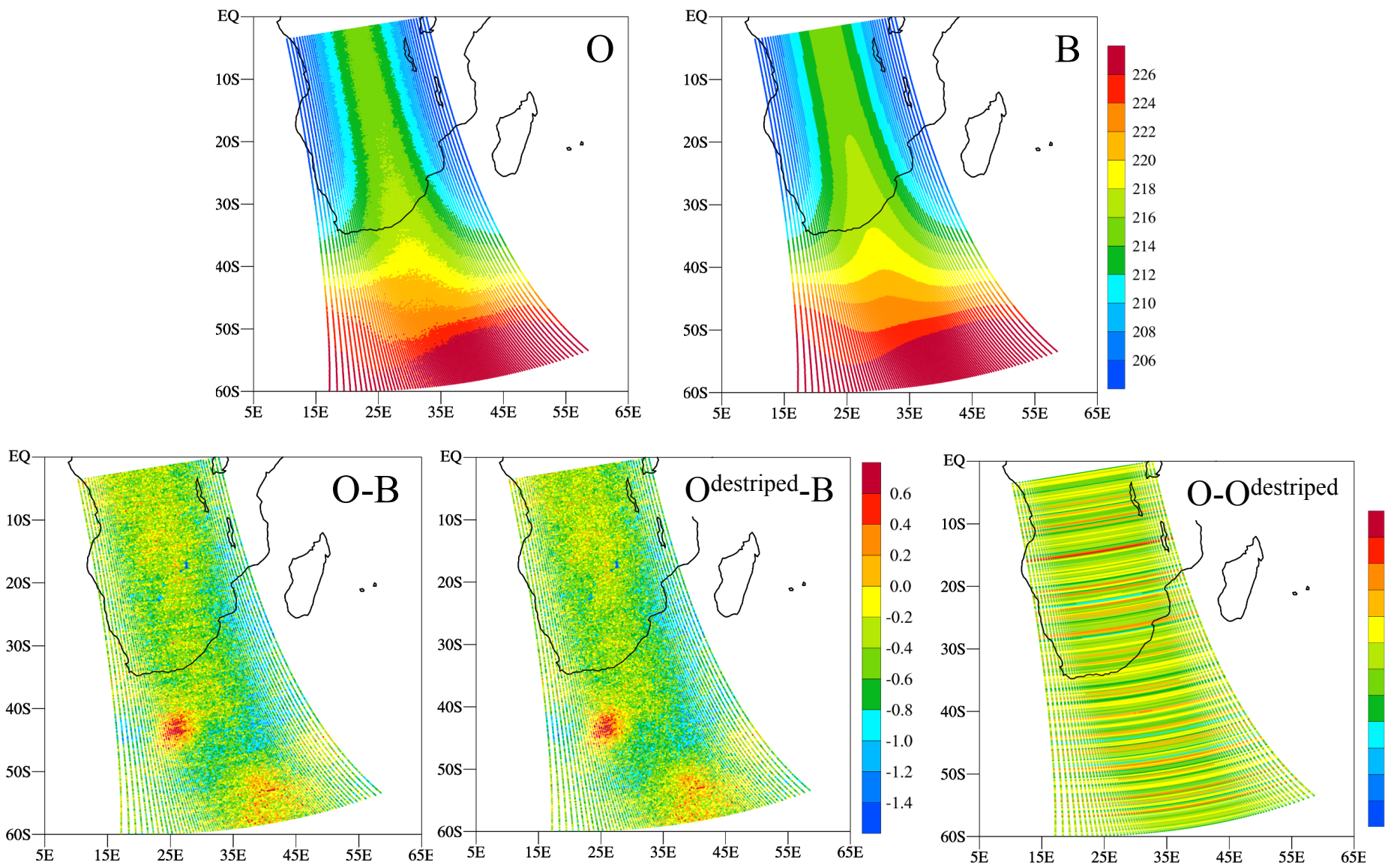
$O\text{-}B^{clear\text{-}sky}$ (ATMS Channel 3)



$O^{destriped}\text{-}B^{clear\text{-}sky}$ (ATMS Channel 3)



TB Observations of ATMS Channel 9 on 14 June 2016



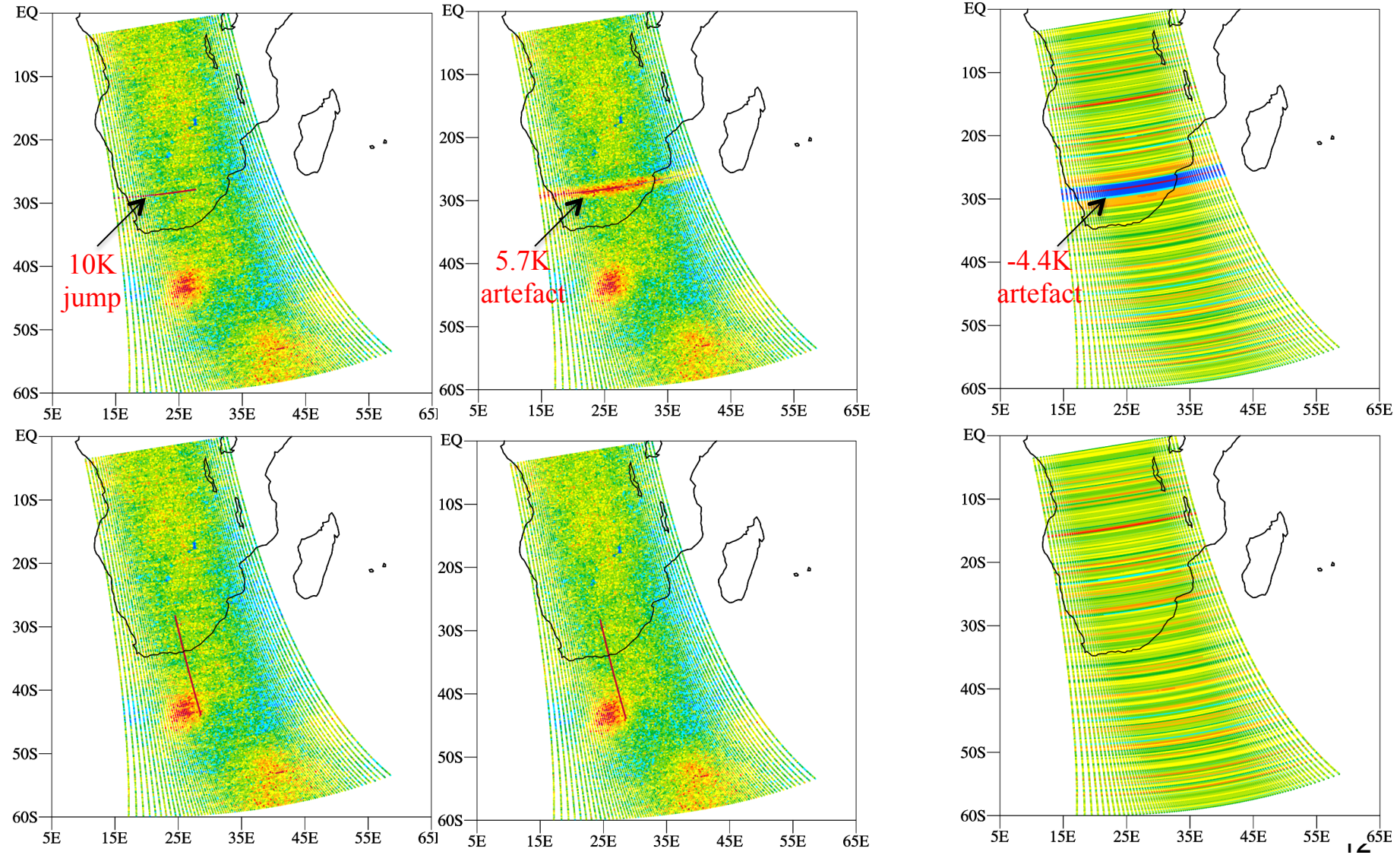
- Striping noise are visible in O and O-B fields
- Striping noise are successfully eliminated by the mitigation algorithm

Impacts of TB Jumps on Destriping

O-B (no destriping)

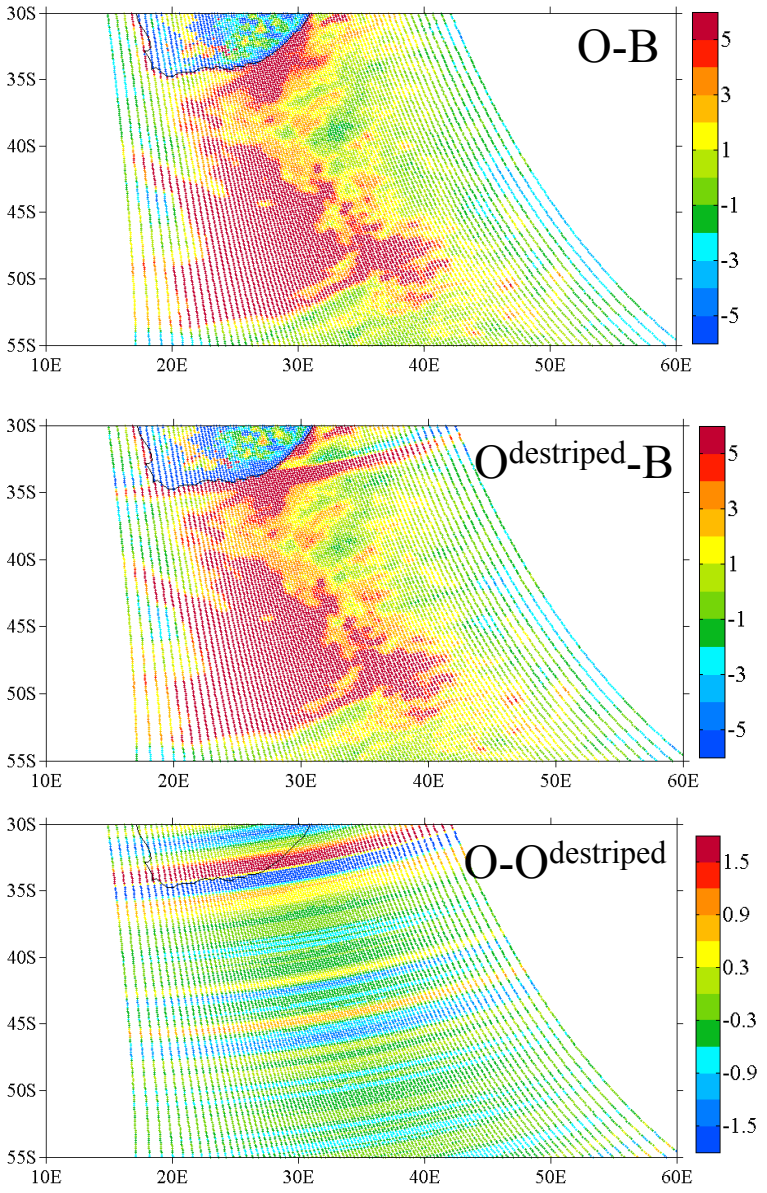
$O^{destriped}$-B (after destriping)

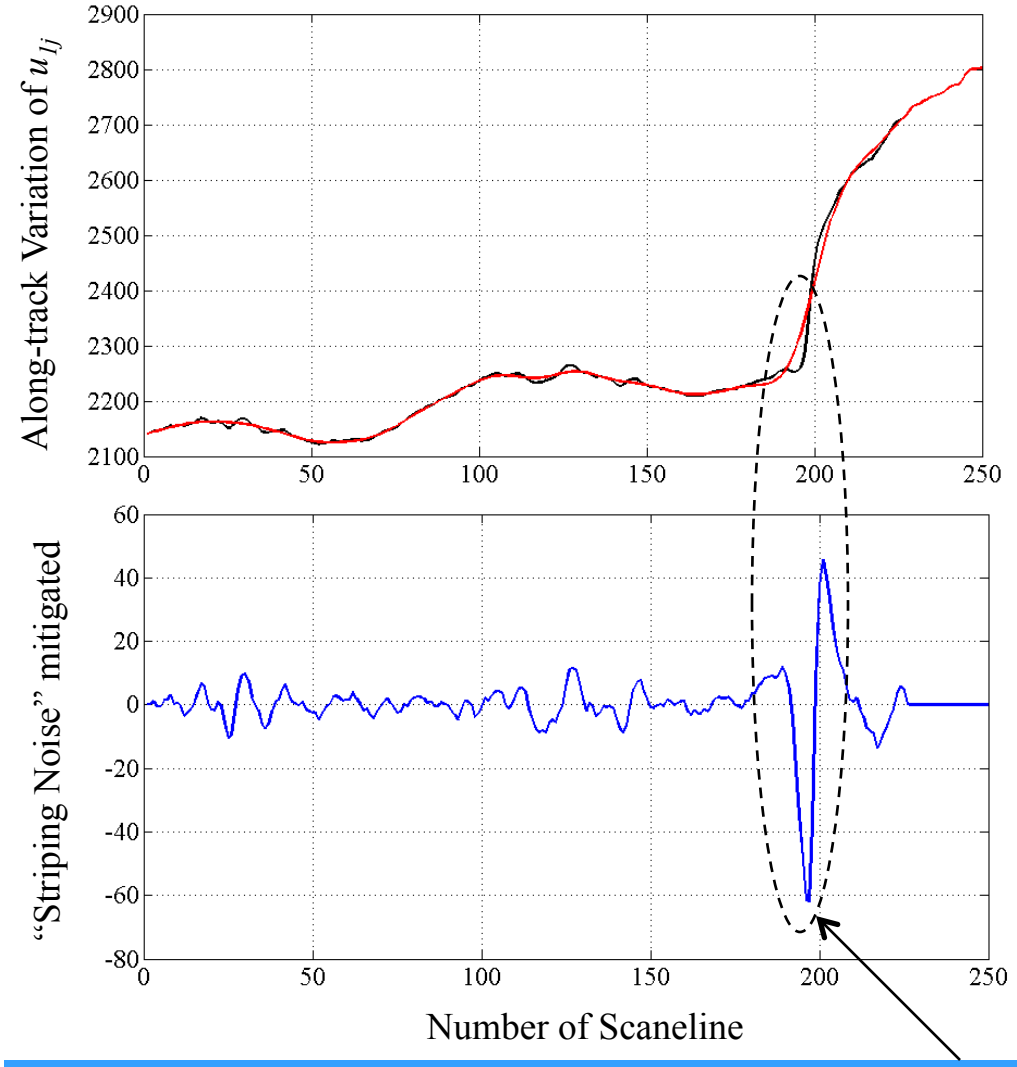
O-$O^{destriped}$, Striping noise



What Happened When TB Experienced a Jump?

ATMS Channel 3 on January 2, 2013





The sharp change that TB experiences from ocean to land is taken wrongly as part of the extracted highest frequency striping noise in the along-track direction.

A Modified Striping Noise Mitigation Algorithms for Surface Sensitive Channels

Step 1: An EEMD procedure is applied to the data series of brightness temperatures in the along track direction at the same scan angle (i.e., the FOV number). The The ATMS brightness temperature observations at those scan lines and FOVs where the values of the 1st IMF are greater than 1 K are recorded and subtracted from the brightness temperature observations. The 1-K threshold is determined on the basis that the striping noise extracted from ATMS earth scene observations is not similar in magnitudes to those in the ATMS pitch manoeuvre data.

Same as the sounding channel method (Qin et al., 2013, JGR)

Step 2: A PC decompositions of ATMS SDR data

Step 3: Remove the first few highest frequency IMFs from the 1st PC mode

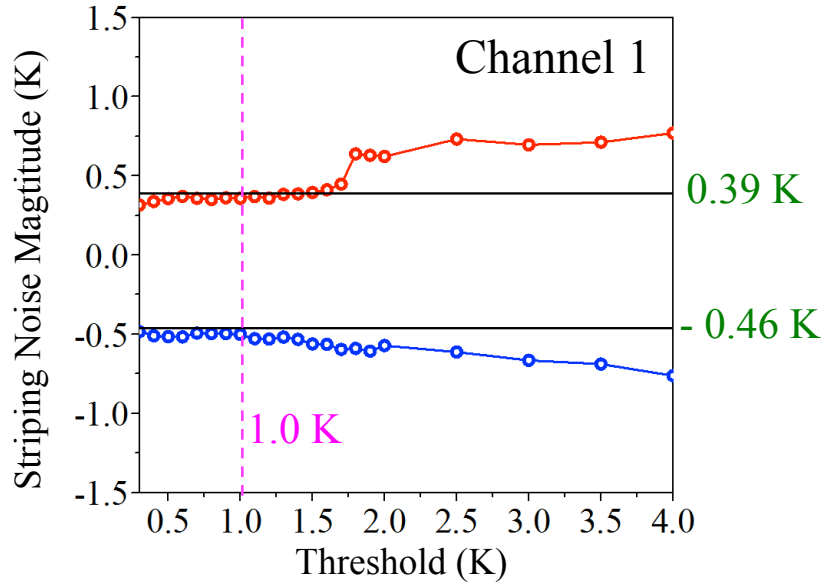
Step 4: The values of the 1st IMF at those scan lines that are recorded and subtracted from the brightness temperature observations in the first step are added back to the destriped brightness temperature observations.

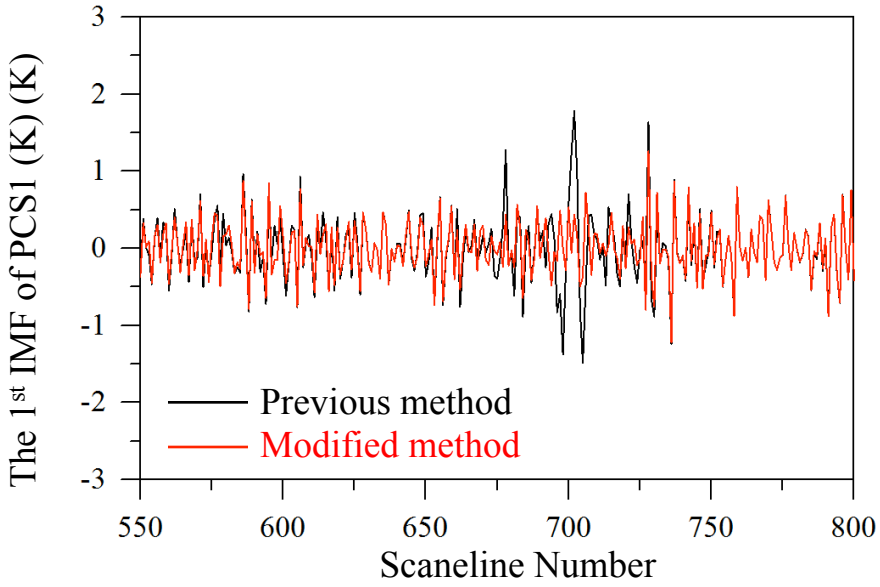
Zou, X., H. Dong and Z. Qin, 2017: Striping noise reduction for ATMS surface-sensitive channels using a modified destriping algorithm. *Quart. J. Roy. Meteor. Soc.*, doi: 10.1002/qj.3107.

Determination of Threshold Values for the 1st Step of the Modified Striping Noise Mitigation Algorithm Based on Striping Noise Extracted from Pitch Maneuvor Data

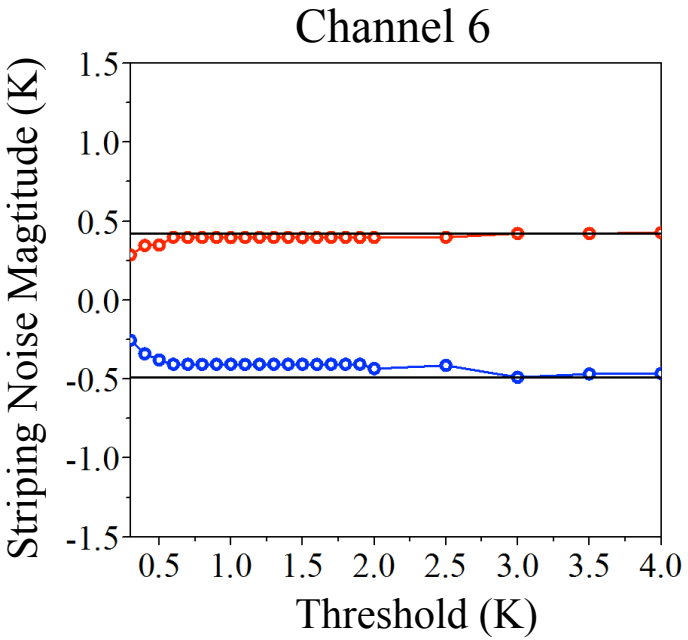
Channel Number	Striping Noise Interval (K)	Threshold (K)
1	[-0.46, 0.39]	1.0
2	[-0.43, 0.32]	1.2
3	[-0.48, 0.47]	1.3
4	[-0.46, 0.30]	1.3
5	[0.35, 0.38]	0.8
16	[-0.77, 0.68]	2.0
17	[-0.85, 0.91]	1.6
18	[-0.71, 0.73]	1.4

The artefacts generated by the previous method are avoided using the modified method for for striping noise mitigation.



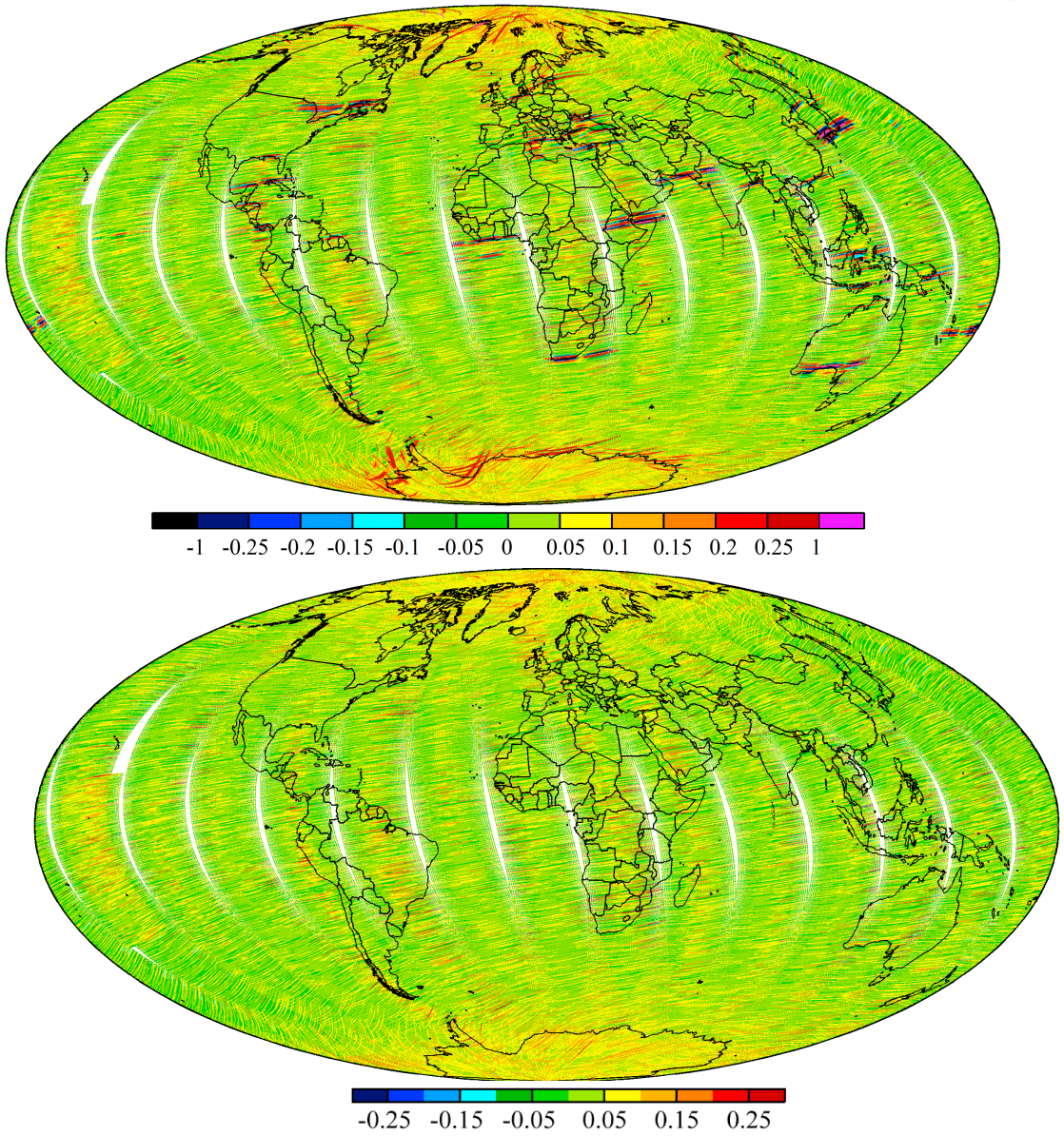


The Previous Striping Noise Mitigation Method Works for Sounding Channels 6-15, 19-22



No artefacts are generated for sounding channel 6 in any regions over the globe by the previous method, i.e., steps 1 and 4 are not necessary. The same is true for ATMS channels 8-15, 19-22.

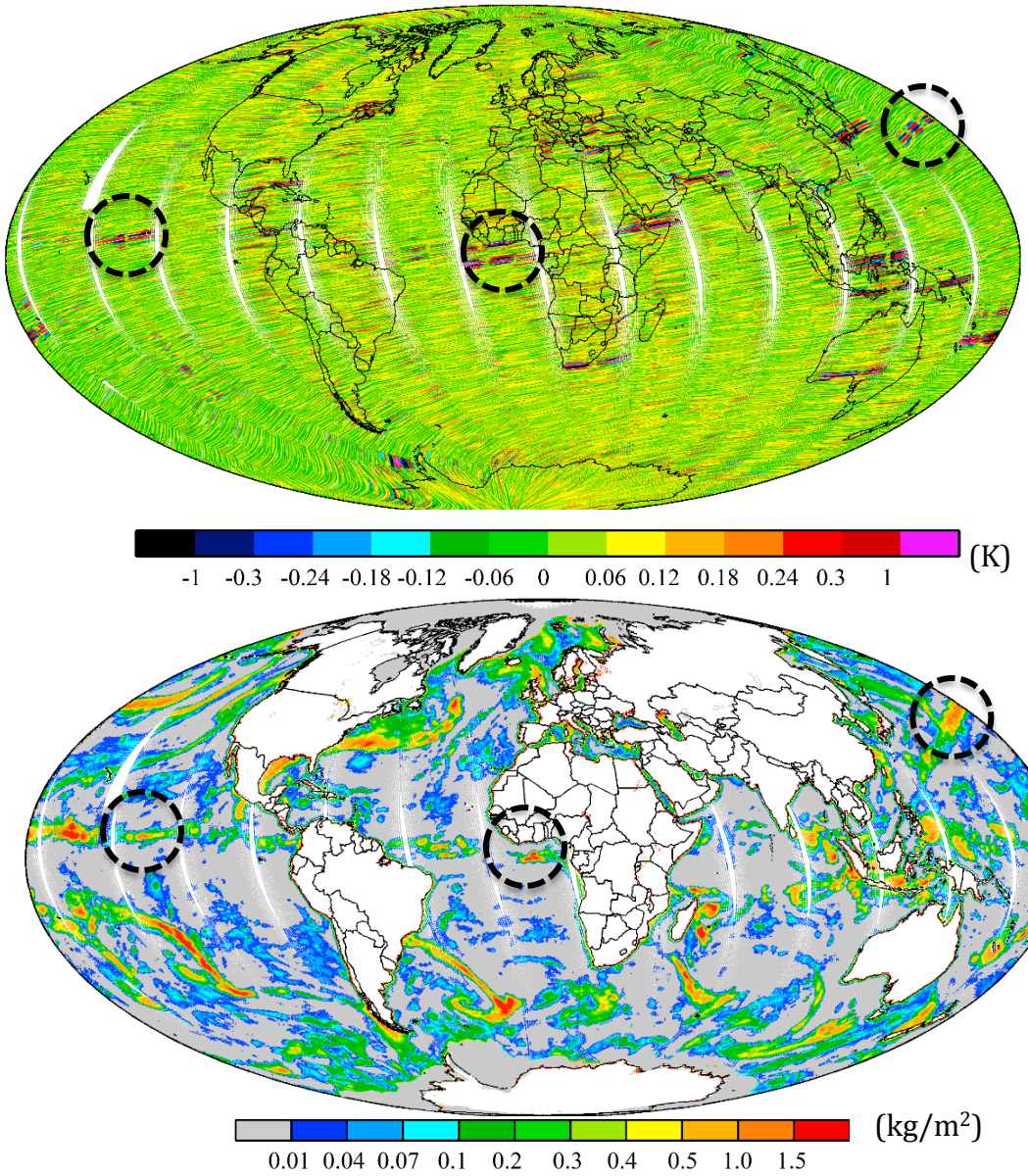
Striping Noise Extracted with and without Modifications



ATMS Channel 1
January 2, 2013

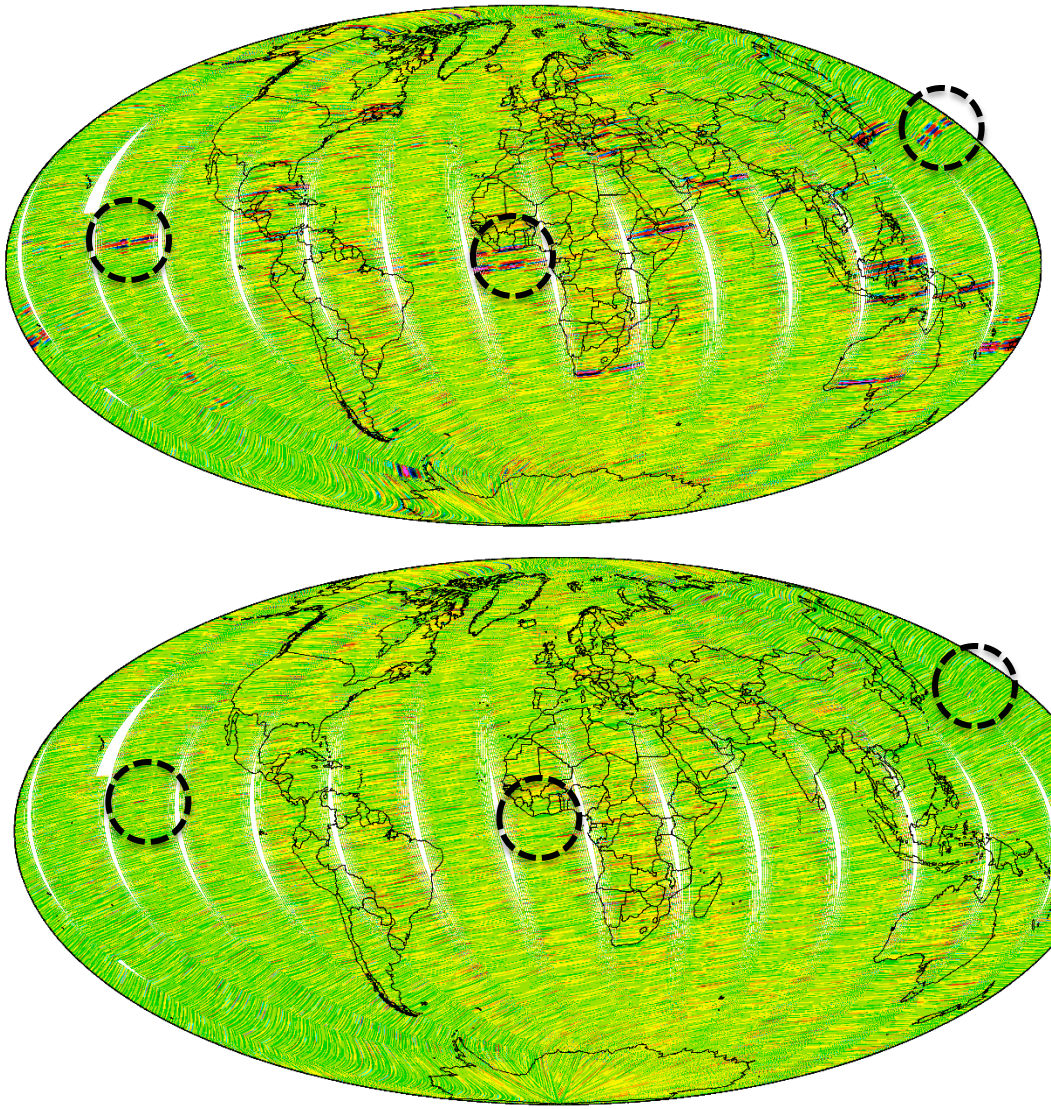
Artefacts in regions with land/ocean contrasts being aligned with ATMS scanlines dissappeared.

Artefacts for Channel 2 Appeared in Regions Where Edges of Heavy Precipitation Clouds That Are Aligned with ATMS Scanlines



ATMS Channel 2
January 2, 2013

Artefacts for Channel 2 That Appeared in Regions Where Edges of Heavy Precipitation Clouds Are Aligned with ATMS Scanlines Disappeared!



ATMS Channel 2
January 2, 2013

Summary and Conclusions

- The striping noise mitigation problems found by ECMWF when ATMS channel 3 swaths pass over Europe with complicated land/ ocean boundaries were confirmed. Same problems were found in other places over the globe
- Similar problems of striping noise mitigation were also found over oceanic areas with heavy precipitation
- The causes for the striping noise to be elevated were carefully analyzed by a sensitivity study. It was shown that such problems occur when large jumps of TB are aligned with ATMS scanelines
- A modified de-striping method was proposed that performs well for reducing the striping noise for ATMS surface sensitive channels without introducing the artefacts found in the de-striped brightness temperature fields.

More details can be found in the following paper:

Zou, X., H. Dong and Z. Qin, 2017: Striping noise reduction for ATMS surface-sensitive channels using a modified destriping algorithm. *Quart. J. Roy. Meteor. Soc.*, doi: 10.1002/qj.3107.

Acknowledgement

This work was supported by NOAA JPSS Proving Ground Program.