Progress on Merging SSU with AIRS toward Stratospheric Temperature Climate Data Records

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Content

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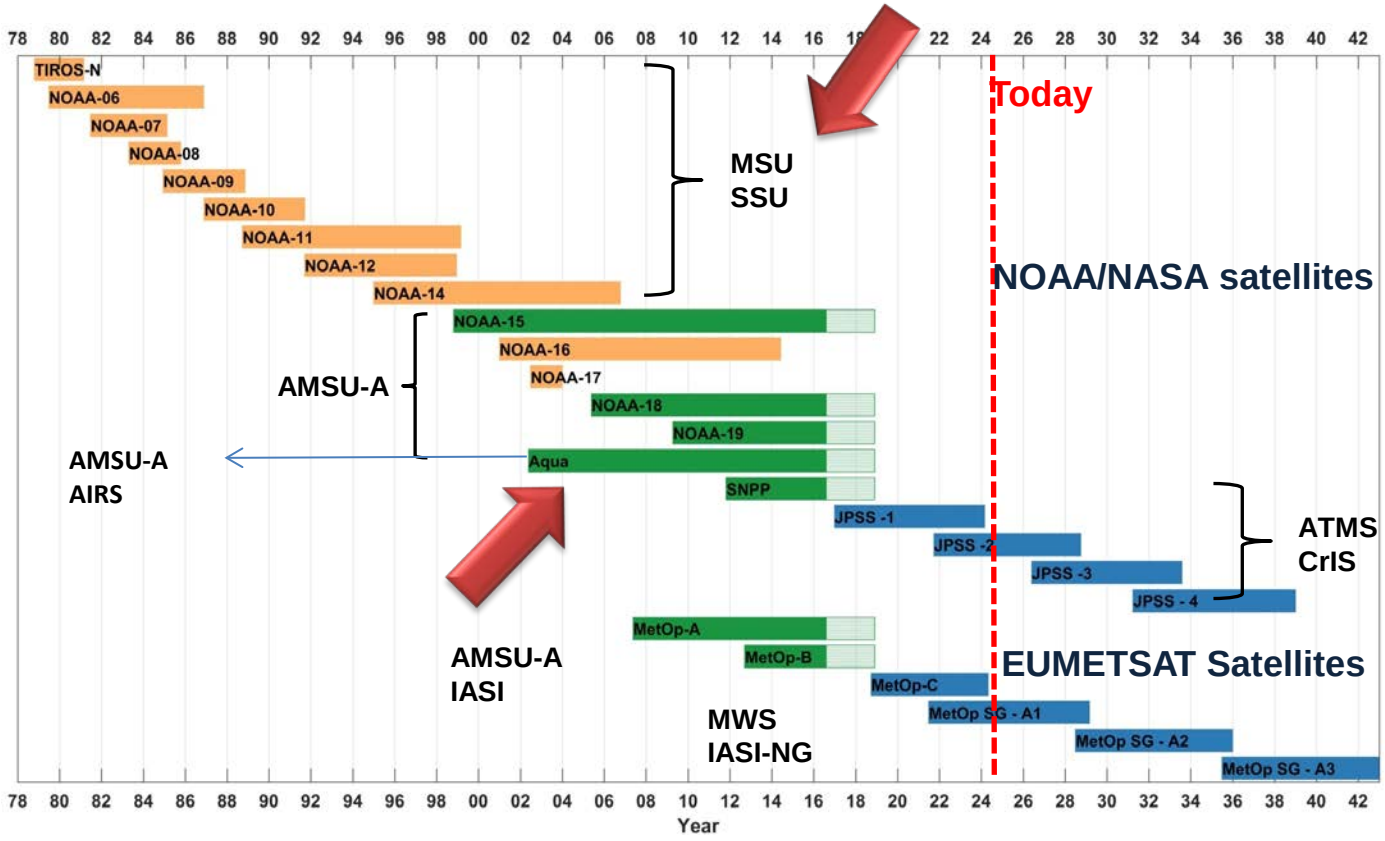
- From SSU to AIRS/CrIS hyperspectral data series
  - An approach to convert AIRS level1c data to equivalent SSU data
  - Removing the trend due to CO2 increasing
- SSU/AIRS versus SSU/AMSU/ATMS
- Conclusion

Satellite Series for Stratospheric Temperature Observations

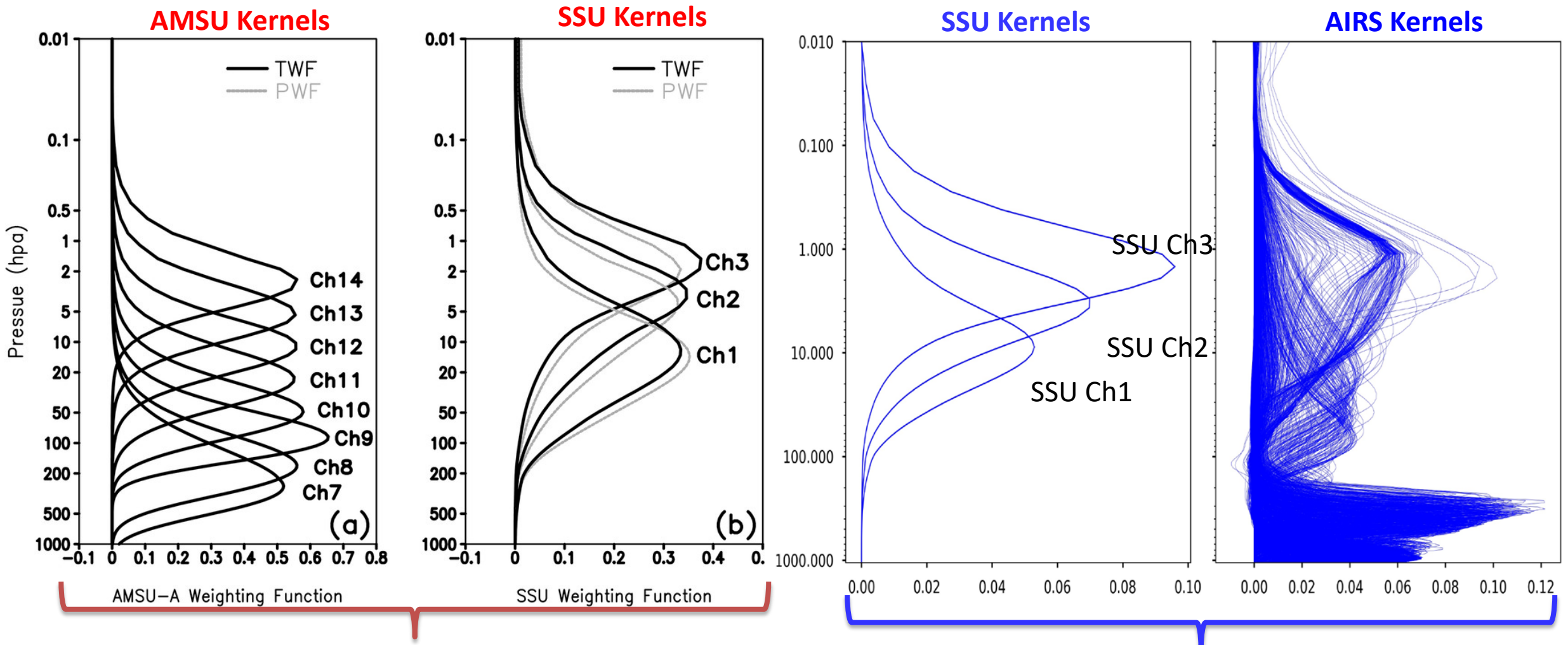
- SSU is an IR radiometer using pressure modulation technique to provide stratospheric temperature observations in1978-2006

- AMSU-A/ATMS are microwave sounders to provide stratospheric temperature observations since 1998

- AIRS/IASI/CrIS are hyperspectral IR sounders to provide stratospheric temperature observations since 2012



SSU/AMSU/ATMS versus SSU/AIRS



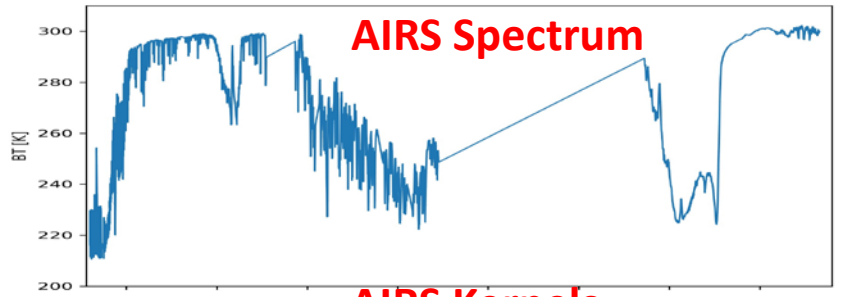
SSU data are merged with AMSU/ATMS (Zou and Qian 2016)

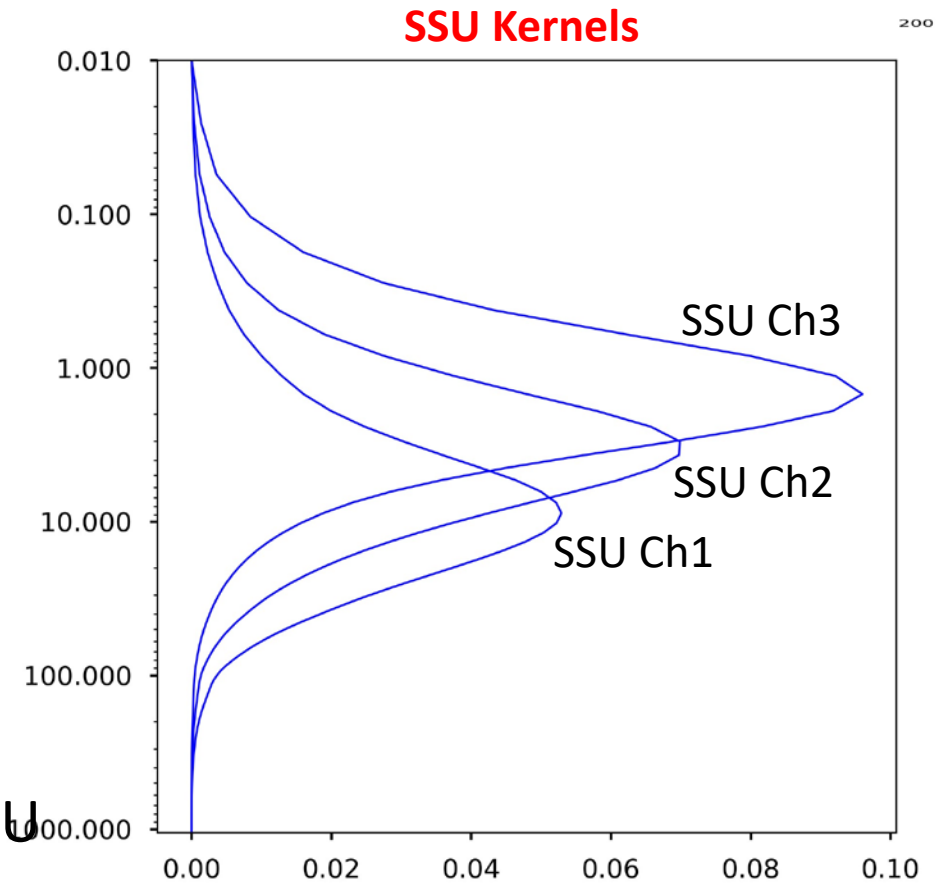
SSU data are merged with AIRS/CrIS: This Work

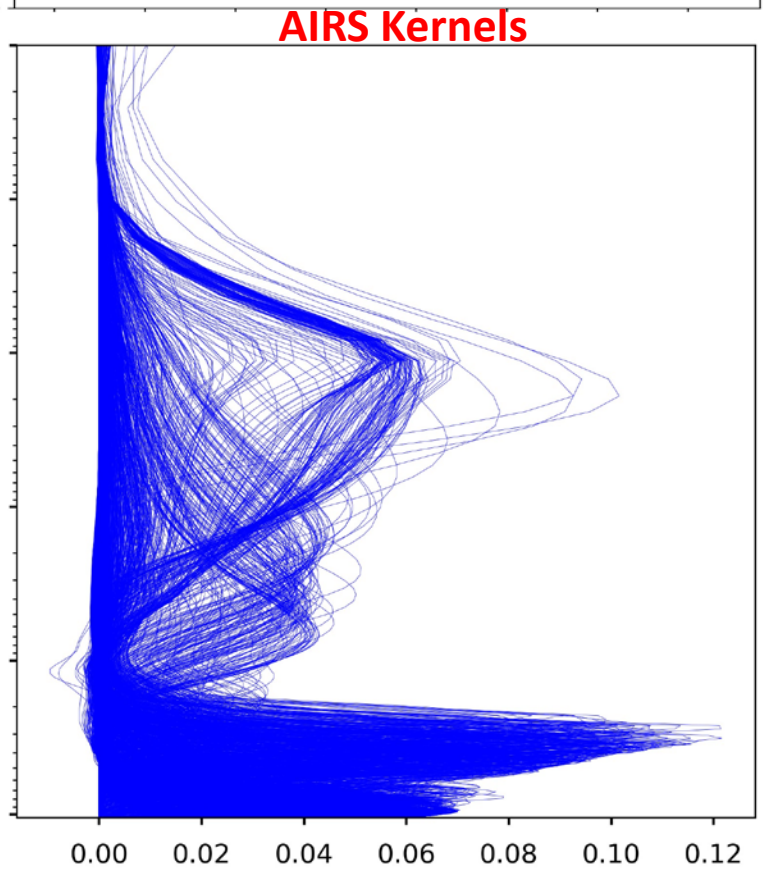
Comparable?

From AIRS to equivalent SSU

- AIRS overlapped with SSU during 2002-2006
- AIRS/CrIS have enough channels to cover the three SSU channels
- Plan to generate equivariant SSU channels from multiple AIRS/CrIS channels
- Merge the equivalent SSU channels with the original SSU channels







Problem Definition and Challenges

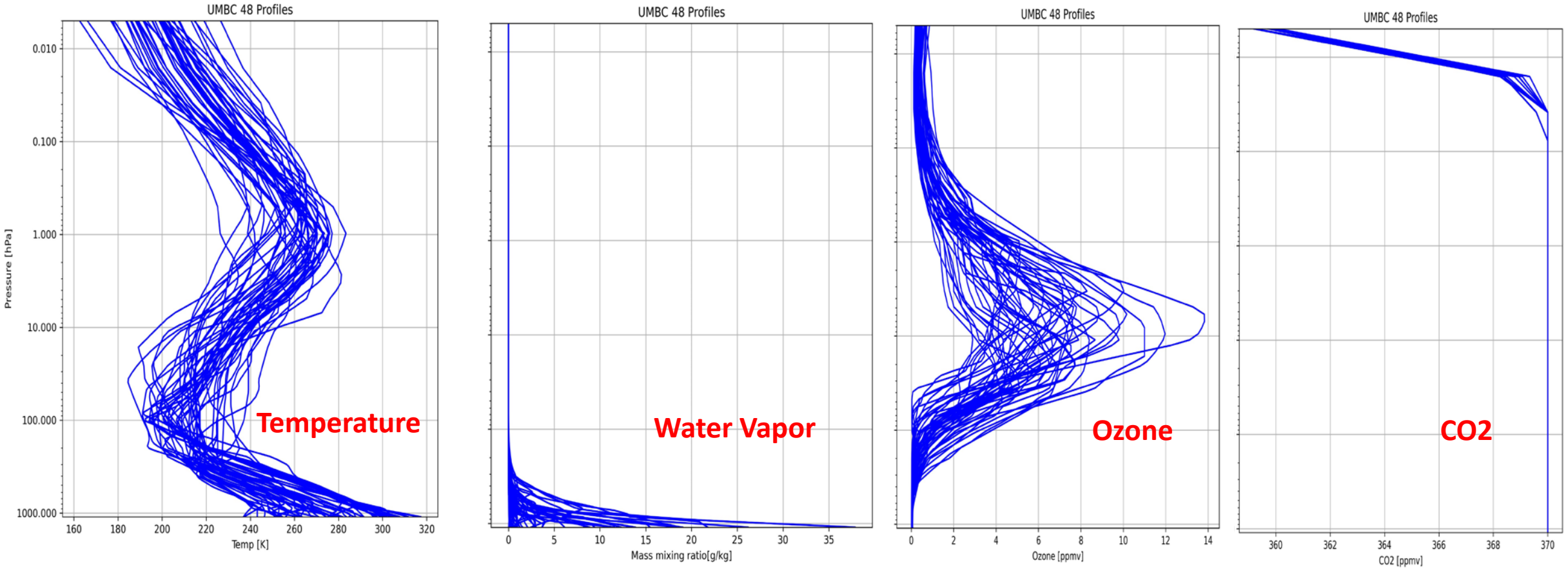
- **Linear Regression**: select several AIRS channels and use linear regression to combine these channels into SSU

- **Training Datasets for Regression**: large variability but not redundant

- **Constrains**
  - Representativeness: Using weight function as constrains
  - Noise:
    - Cannot use too many channels (10-13)
    - The coefficients for each channels is less than 0.5

- **AIRS data**
  - Level 1B: very noisy but has RTM support
  - Level 1C: reconstructed from level 1B but with new spectral grids
  - Using Level1C data but choosing the spectral channels that both level1C and level1B have common spectral grid
  - Longwave channels with high priority

UMBC 48 Atmospheric Profiles



UMBC 48 profiles, which contain typical atmospheric profiles in different location and season, are used for CRTM. We uses them to simulate both AIRS and SSU observations.

Regression Problems with Constraints

For SSU BT at each channel:

$$y = \sum_i \beta_i X_i$$

X: AIRS channel BT (LW+SW)
y: SSU channel BT
β: weights for each channels, sum(β_i) = 1
For each β_i, less than 0.5

The goal is to find an assignment β to that minimizes the cost function:

$$f(\beta) = \|\mathbf{X}\,\beta - \mathbf{Y}\|_2^2 + \lambda\|\mathbf{W}^{\boldsymbol{x}}\,\beta - \mathbf{W}^{\boldsymbol{y}}\|_2^2$$

X: Training Dataset from AIRS selected channels , Y: Training Dataset of SSU BT
W^x: Weighting function of AIRS selected channels, W^y: Weighting function of SSU
λ: a hyperparameter that controls the balance between BT and weighting function fitting

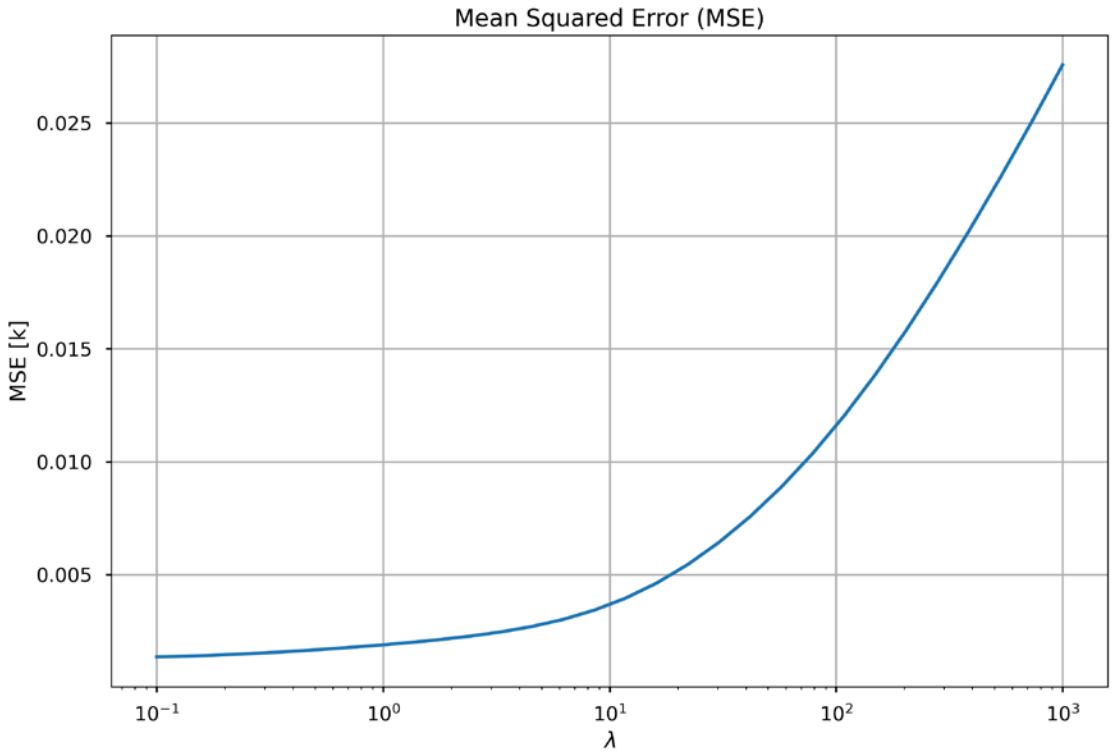
The problem is solved using CVXPY, a domain-specific language for convex optimization embedded in Python Citing CVXPY — CVXPY 1.3 documentation

Steven Diamond and Stephen Boyd. 2016. CVXPY: a python-embedded modeling language for convex optimization. J. Mach. Learn. Res. 17, 1 (January 2016), 2909–2913. https://doi.org/10.48550/arXiv.1603.00943

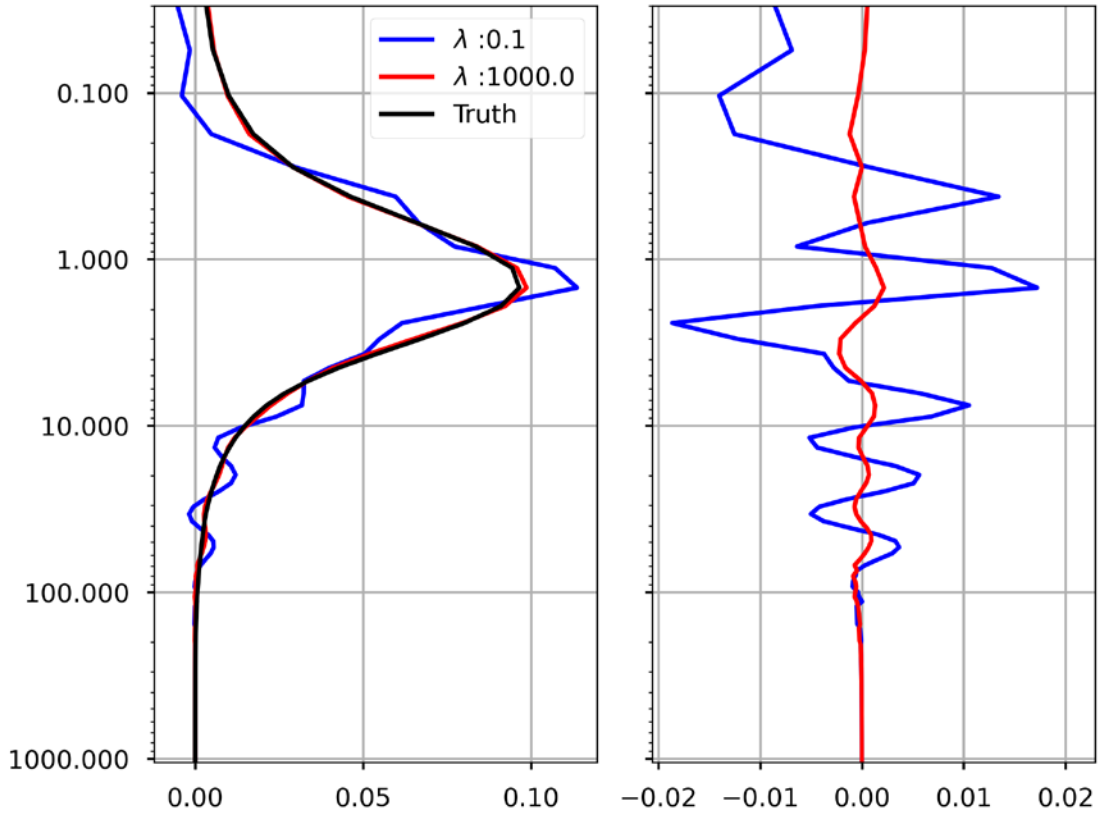
Goldberg, M. D., and H. E. Fleming, 1995: An Algorithm to Generate Deep-Layer Temperatures from Microwave Satellite Observations for the Purpose of Monitoring Climate Change. *J. Climate*, **8**, 993–1004, https://doi.org/10.1175/1520-0442(1995)008<0993:AATGDL>2.0.CO;2.

SSU channel 3: Example

Brightness Temperature MSE varying with penalty factor



Weighting Function Fitting varying with penalty factor

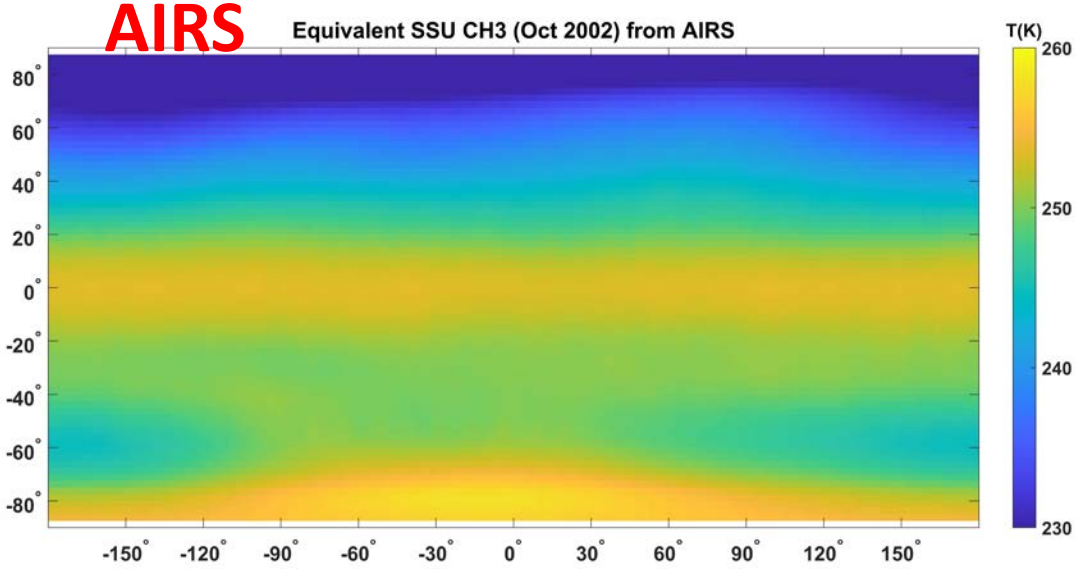


The goal is to find an assignment β to that minimizes the cost function:

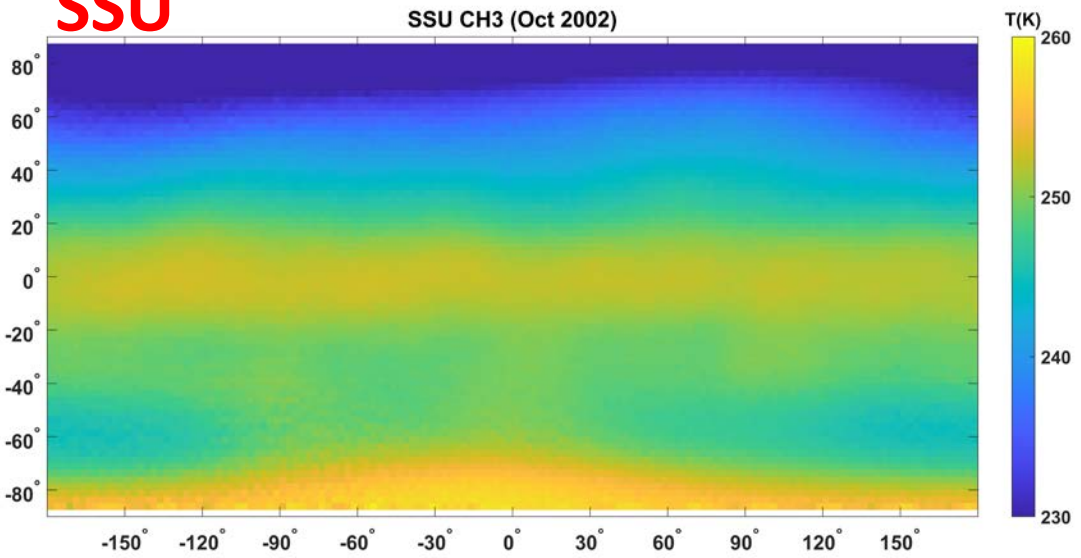
$$f(\beta) = \|\mathbf{X}\,\beta - \mathbf{Y}\|_2^2 + \lambda\|\mathbf{W}^{\boldsymbol{x}}\,\beta - \mathbf{W}^{\boldsymbol{y}}\|_2^2$$

Example of simulated SSU CH3 with AIRS

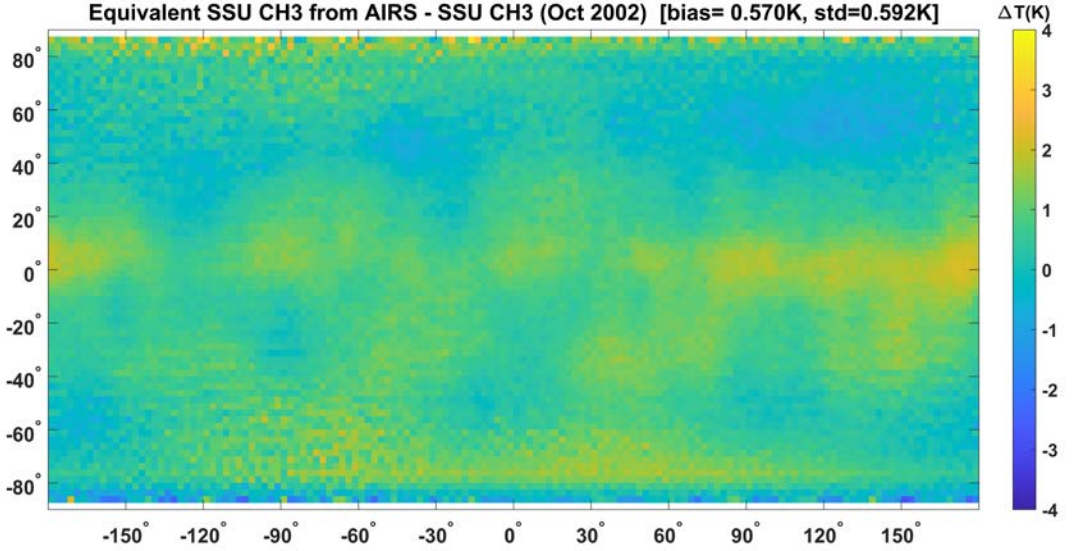
AIRS



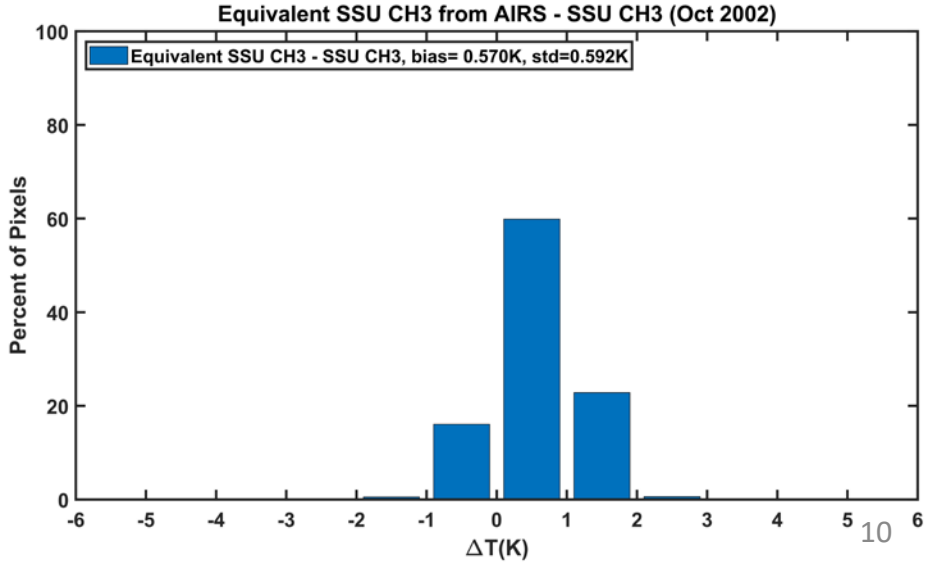
SSU



AIRS - SSU



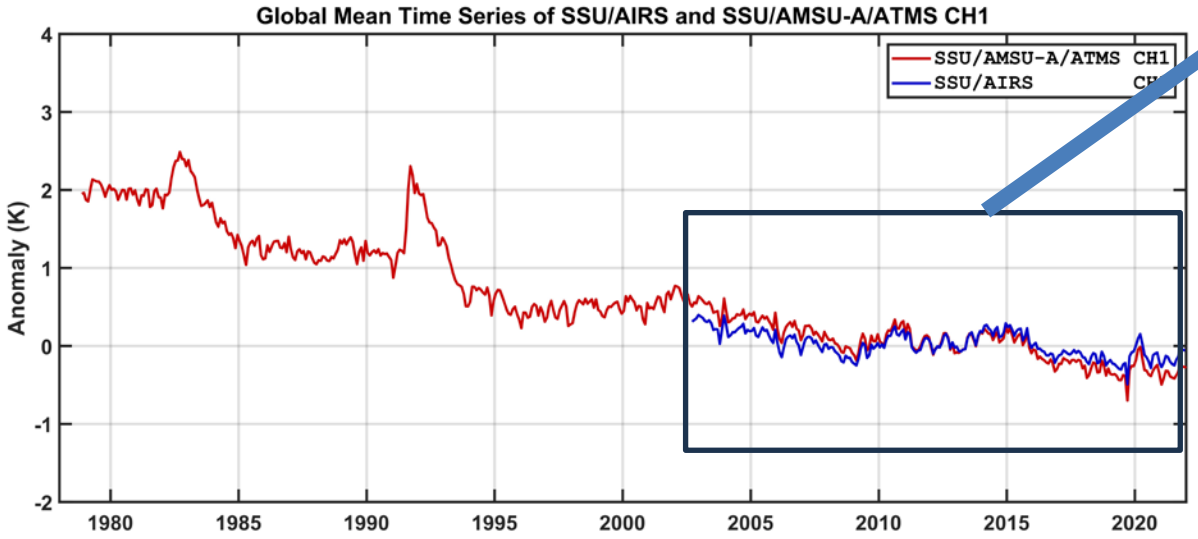
AIRS - SSU

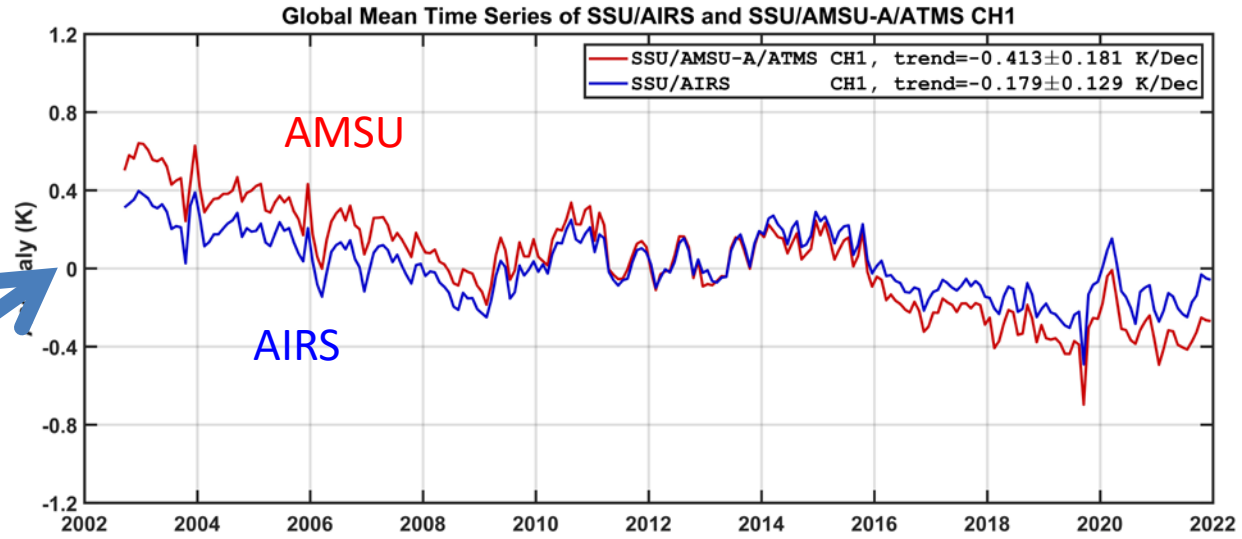


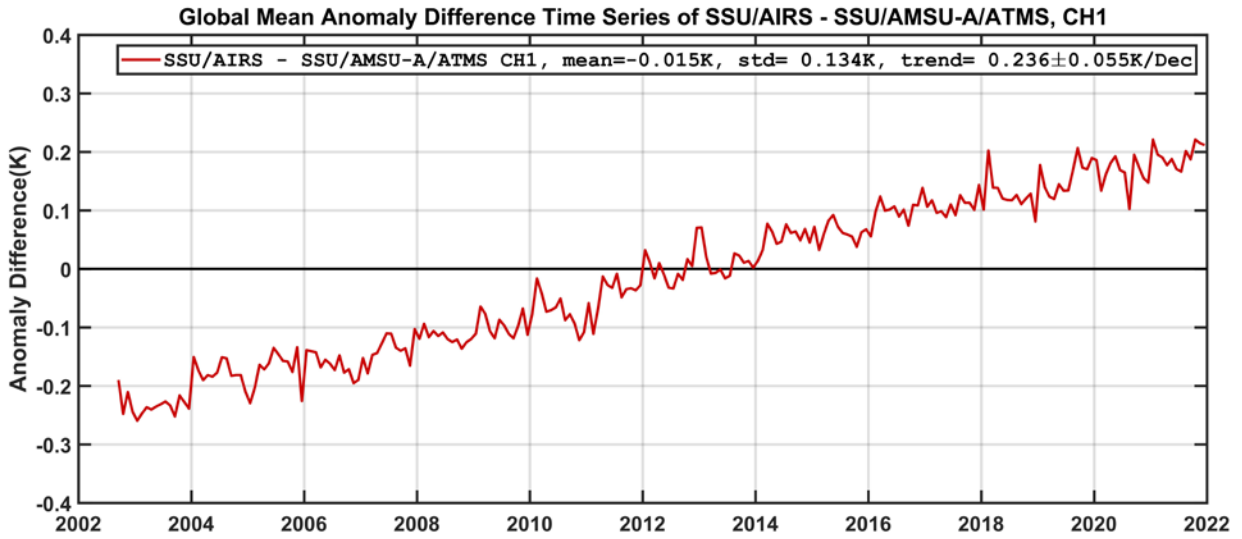
Global Mean Anomaly Time Series
SSU/AIRS vs SSU/AMSU/ATMS CH 1

The trend of Infrared Sounder data:

- Stratospheric temperature cooling
- **CO2 increasing effects**



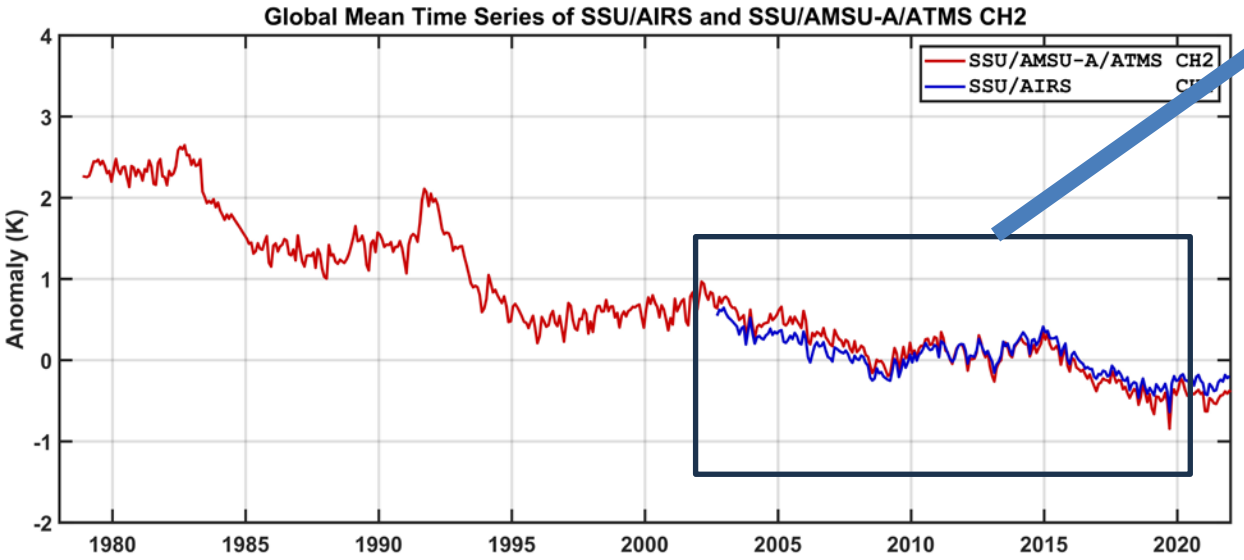


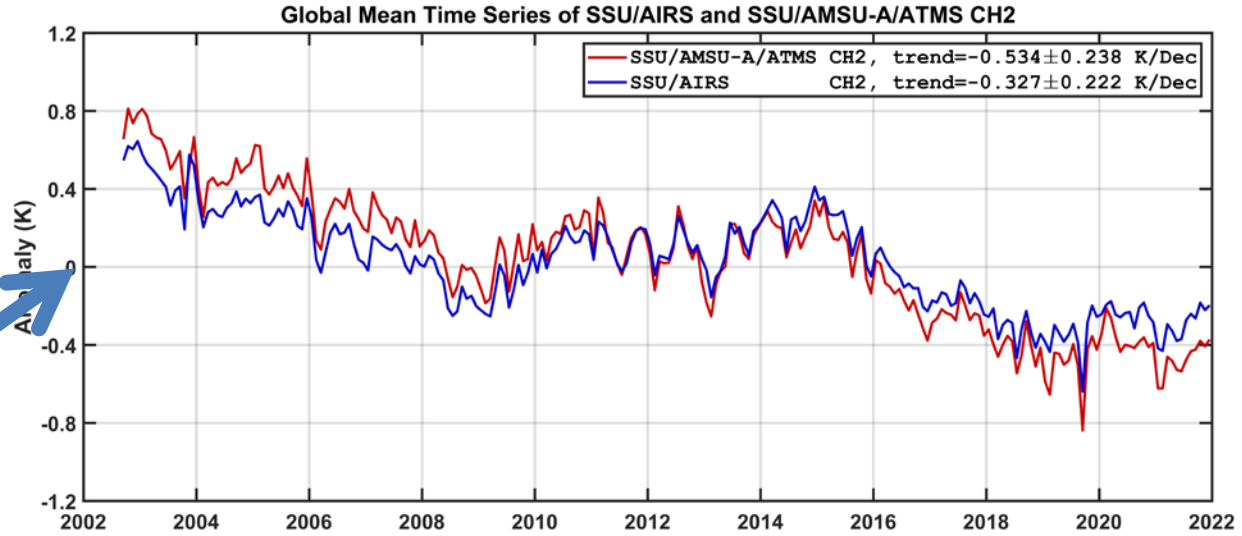


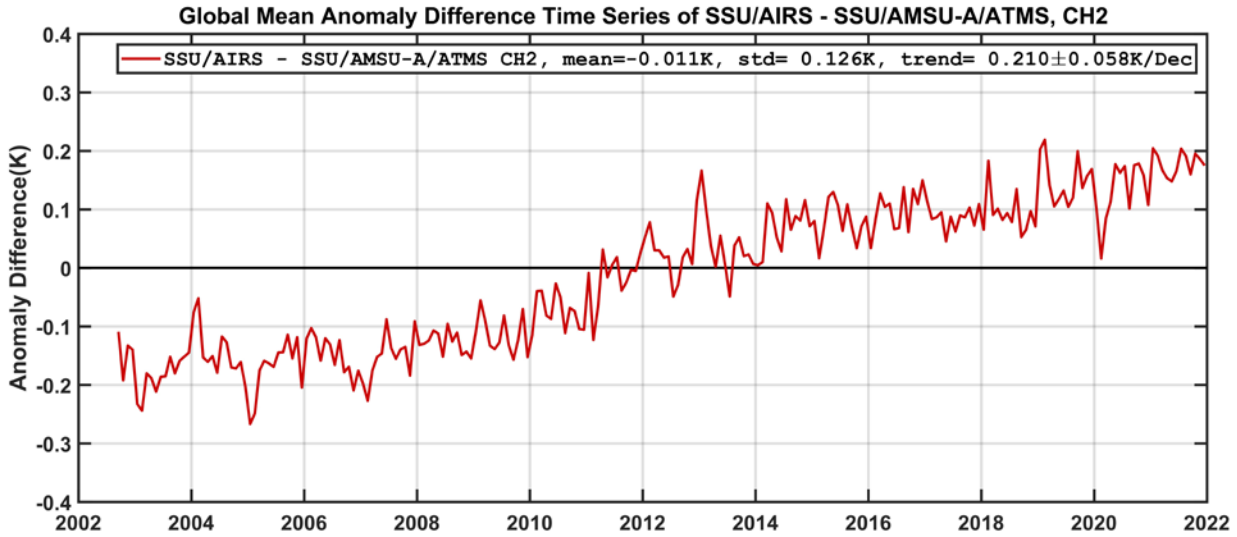
The trend difference is caused by the CO2 increasing effects

Global Mean Anomaly Time Series

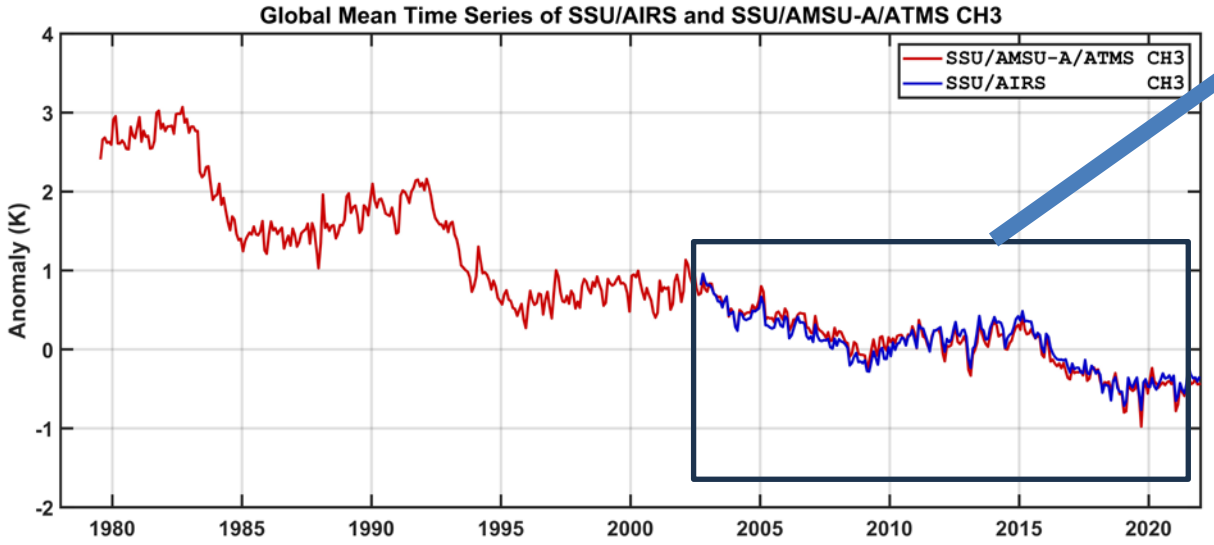
SSU/AIRS vs SSU/AMSU-A/ATMS Ch 2

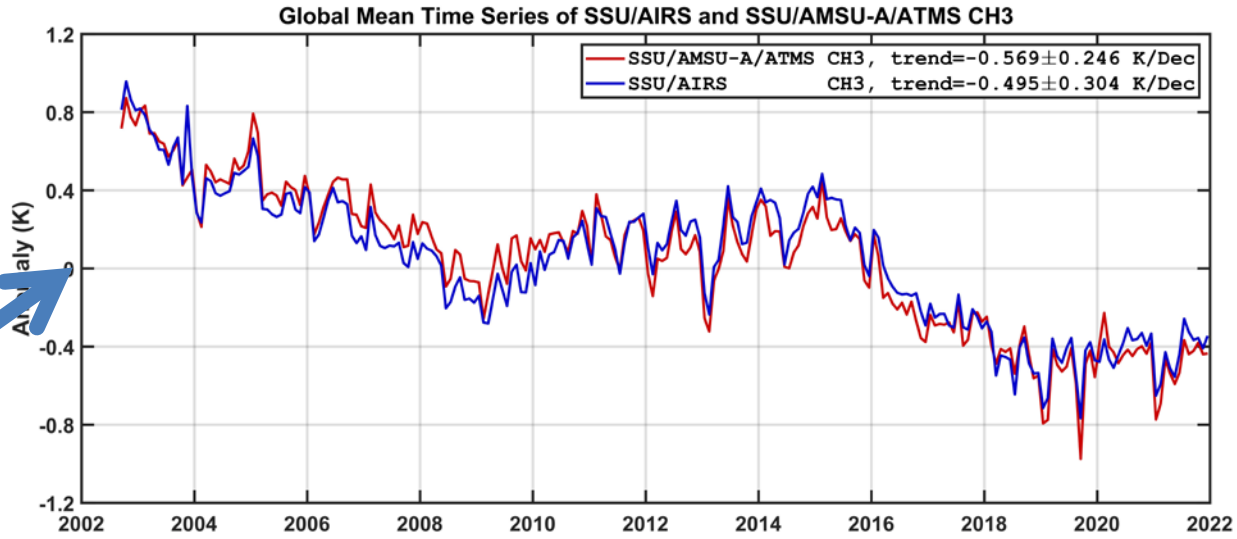


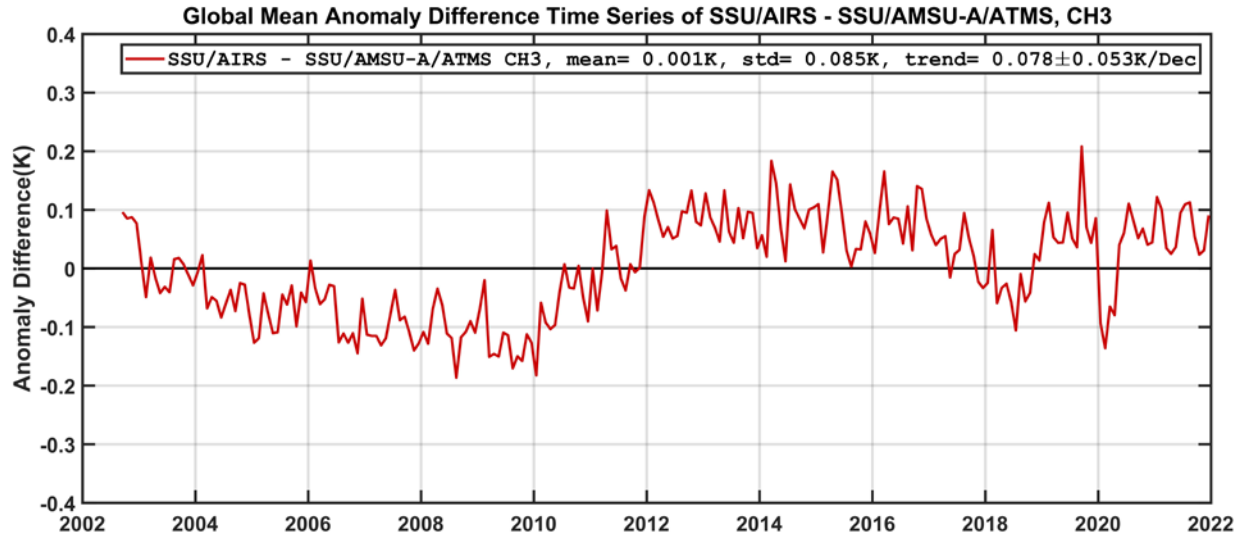




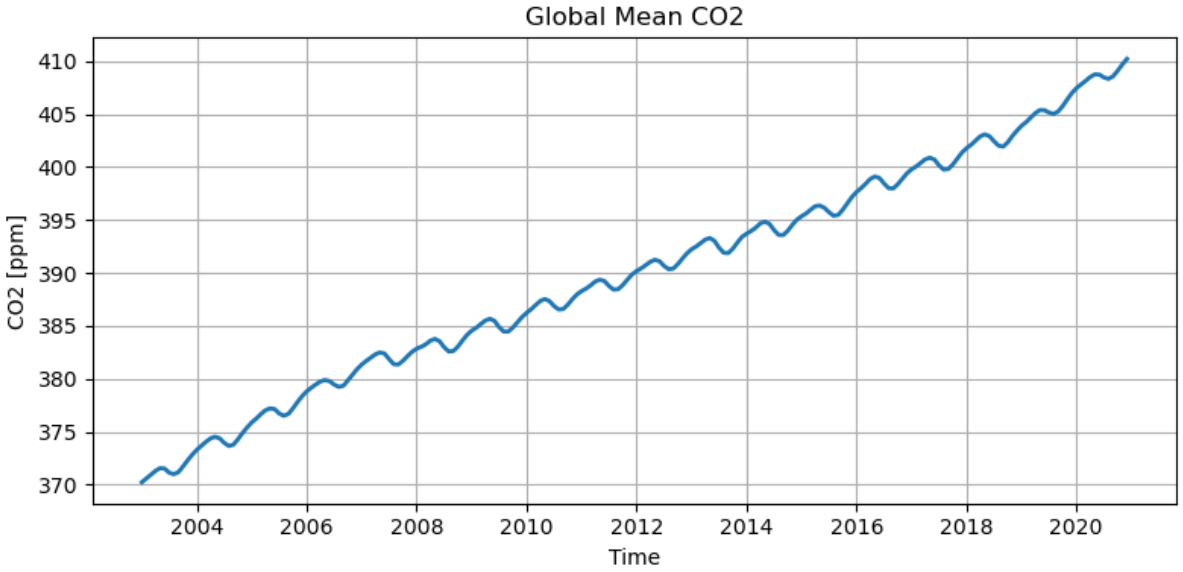
Global Mean Anomaly Time Series of SSU/AIRS vs SSU/AMSU/ATMS Ch 3

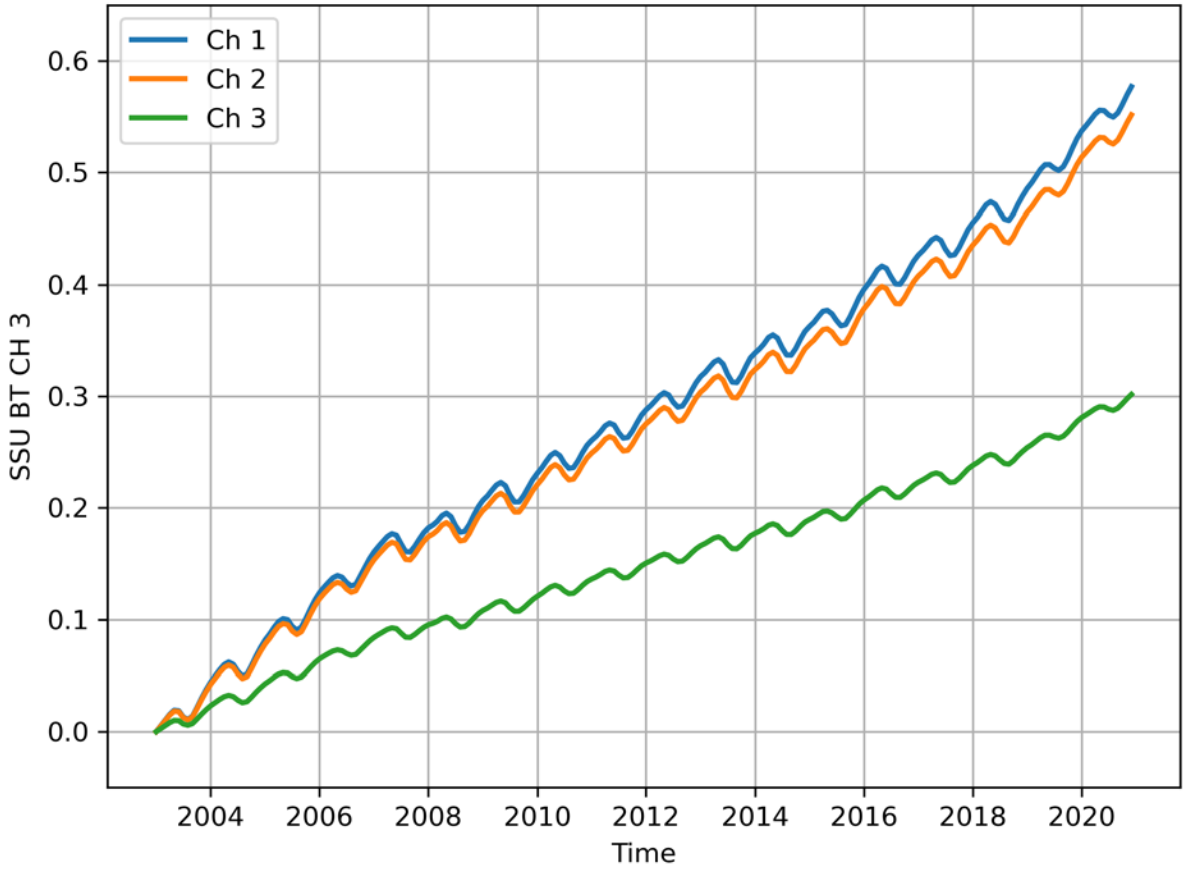




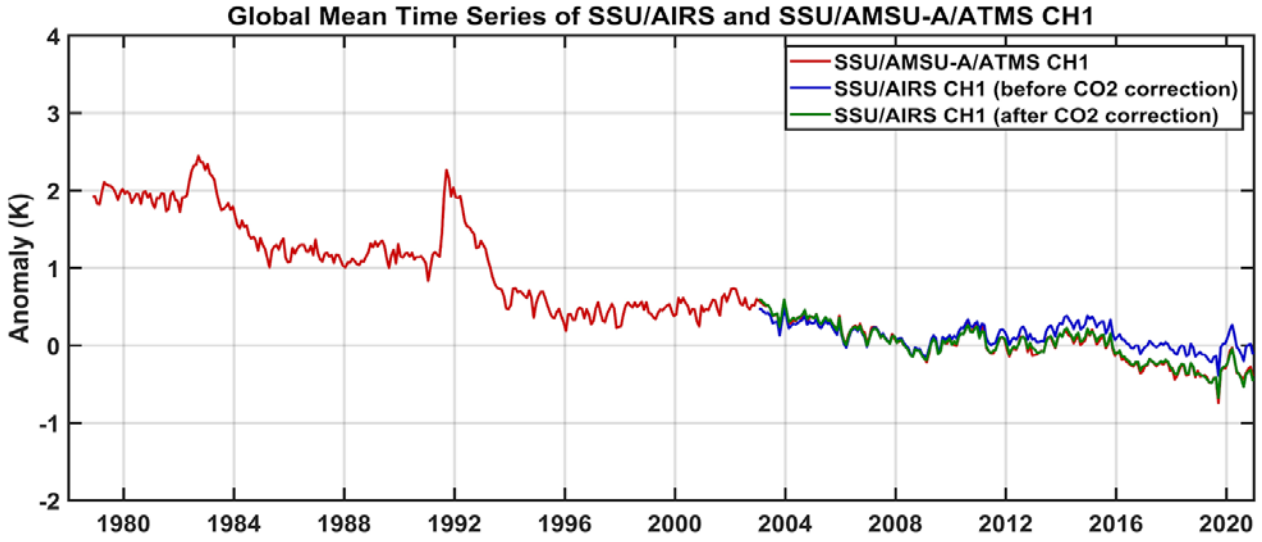


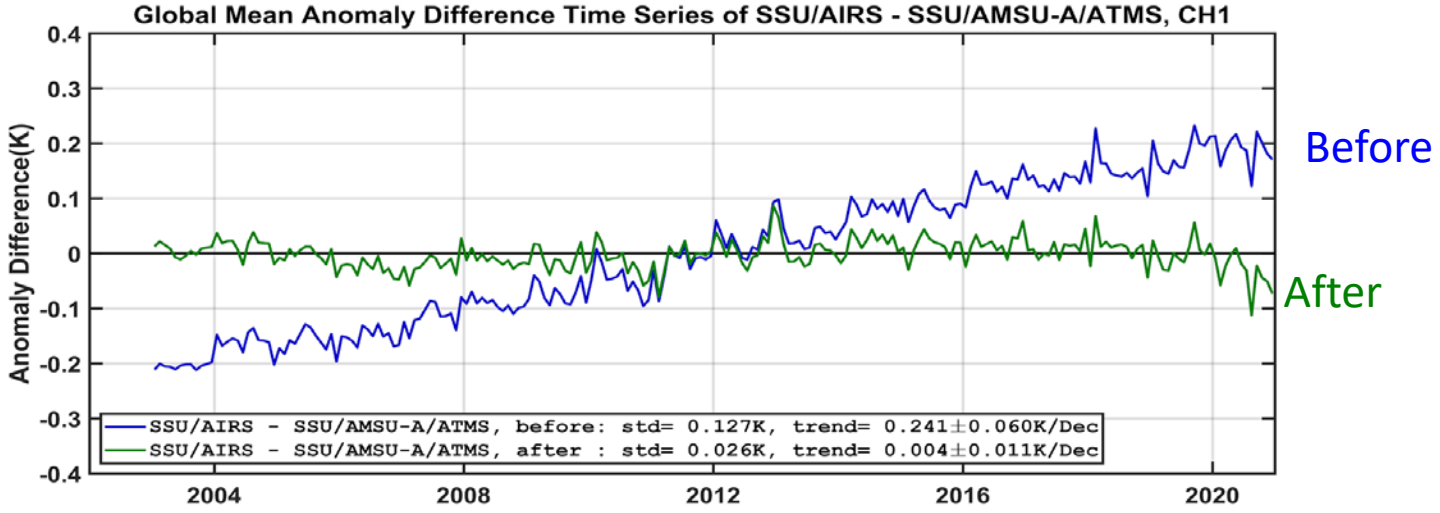
SSU Trend due to CO2 increasing





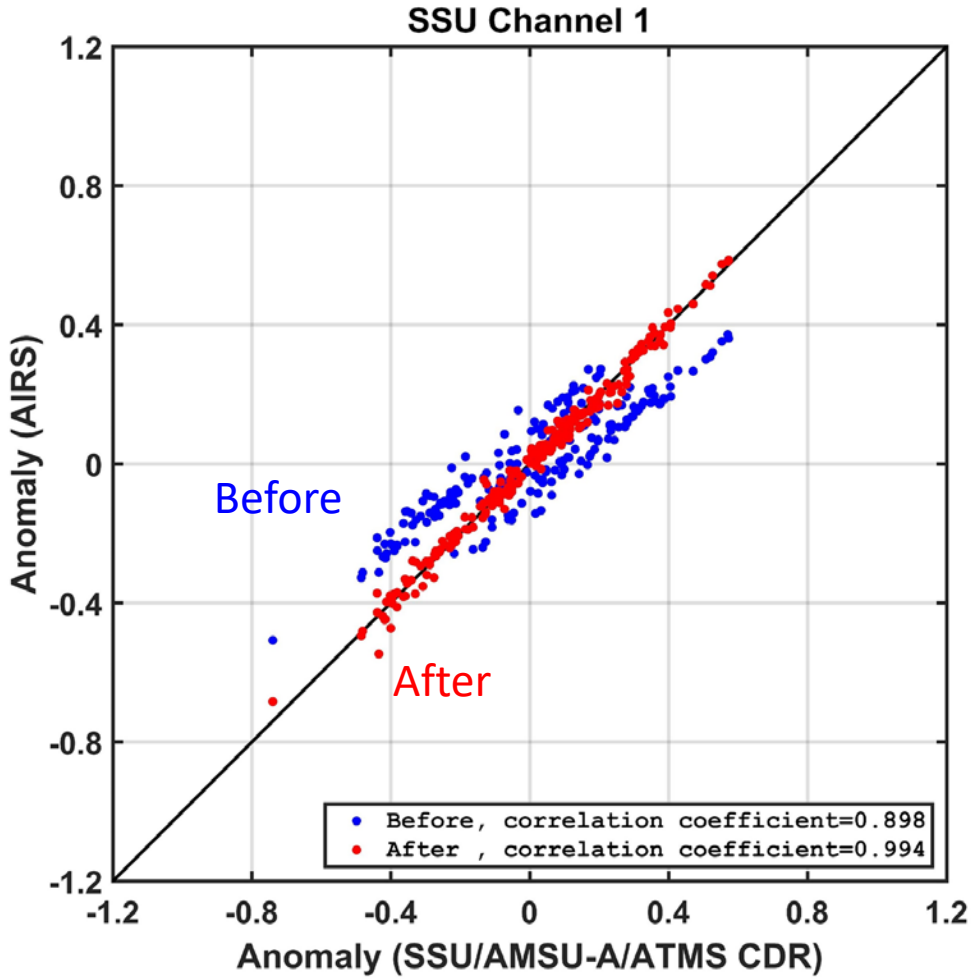
Global Mean Anomaly Time Series
SSU/AIRS vs SSU/AMSU/ATMS CH 1

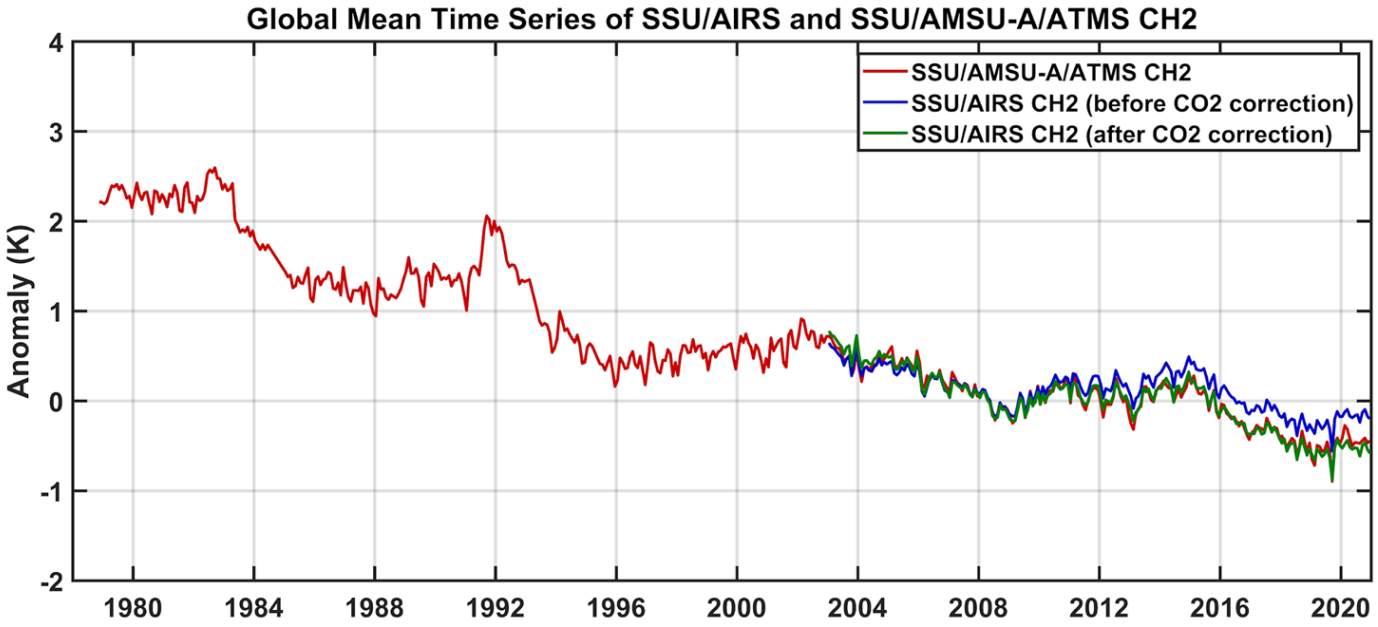


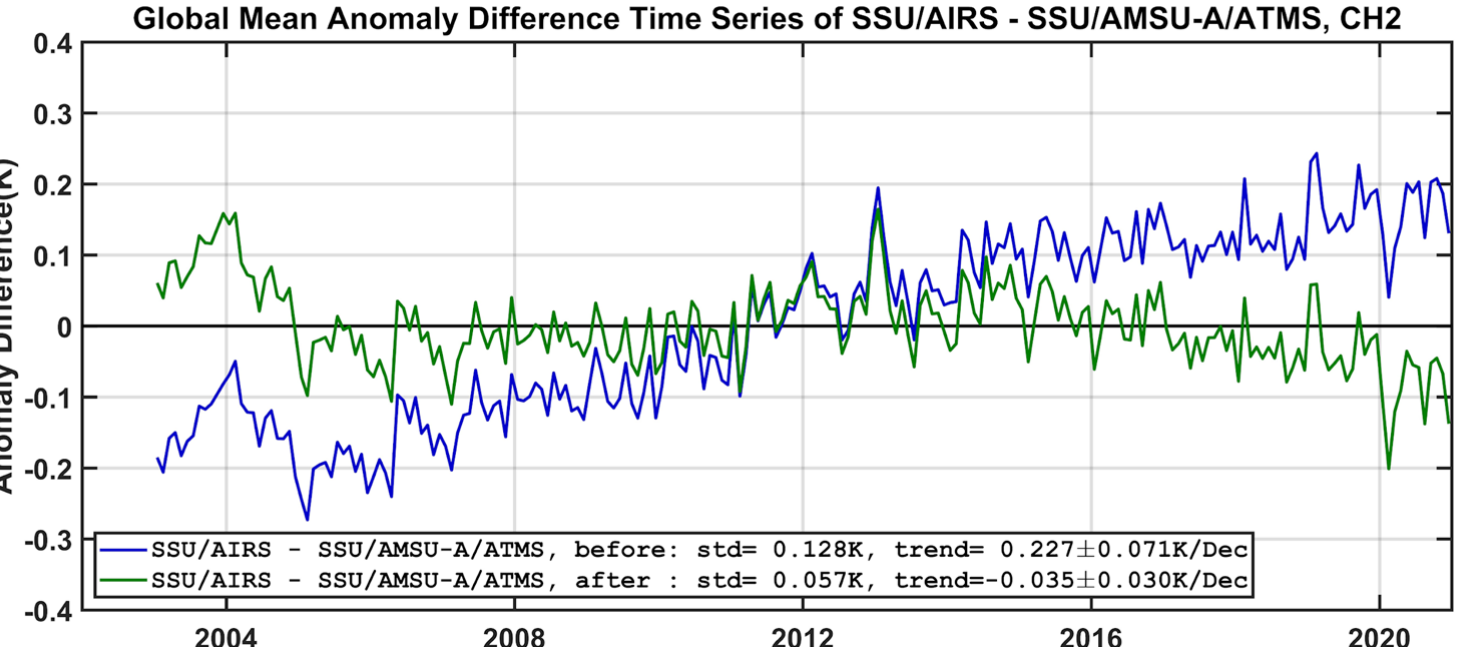


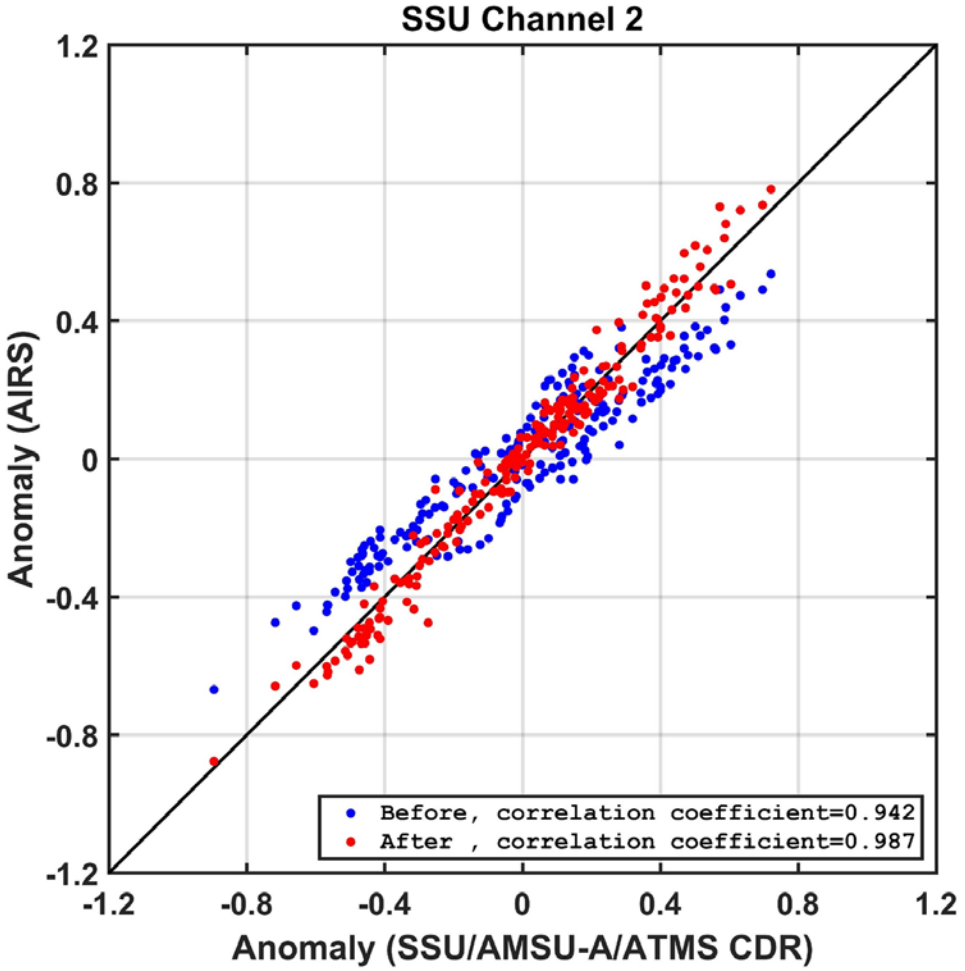
Before

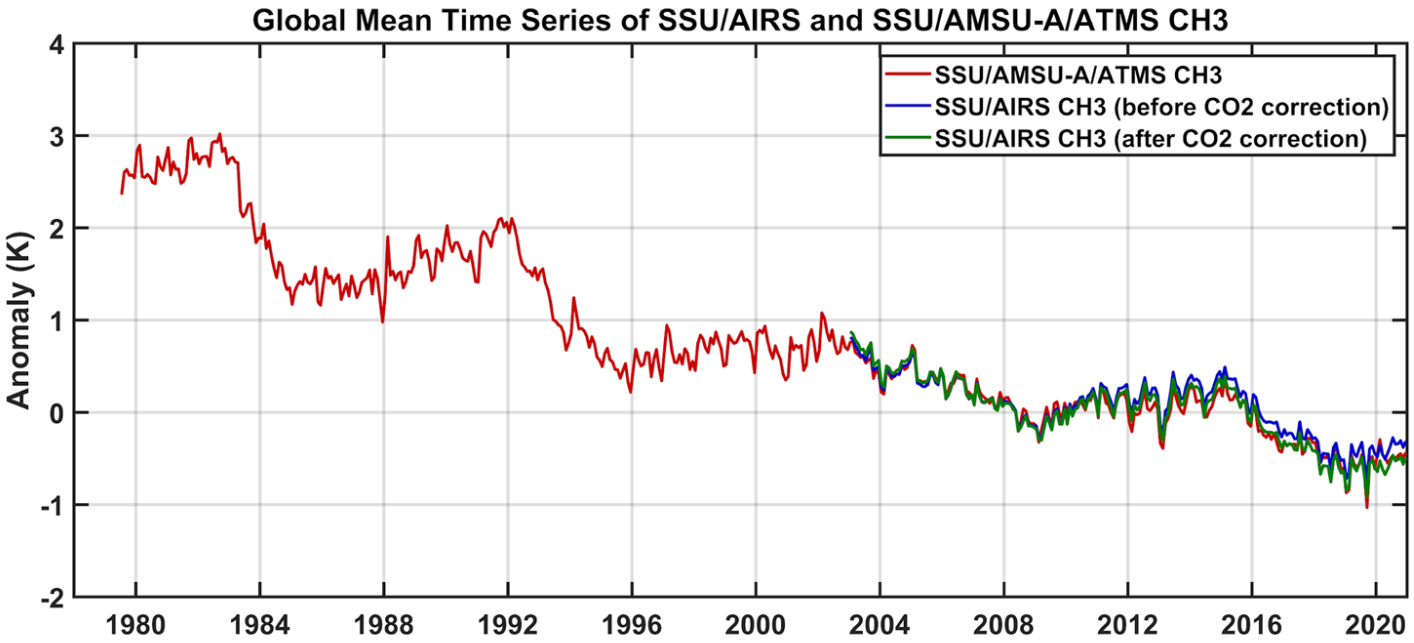
After

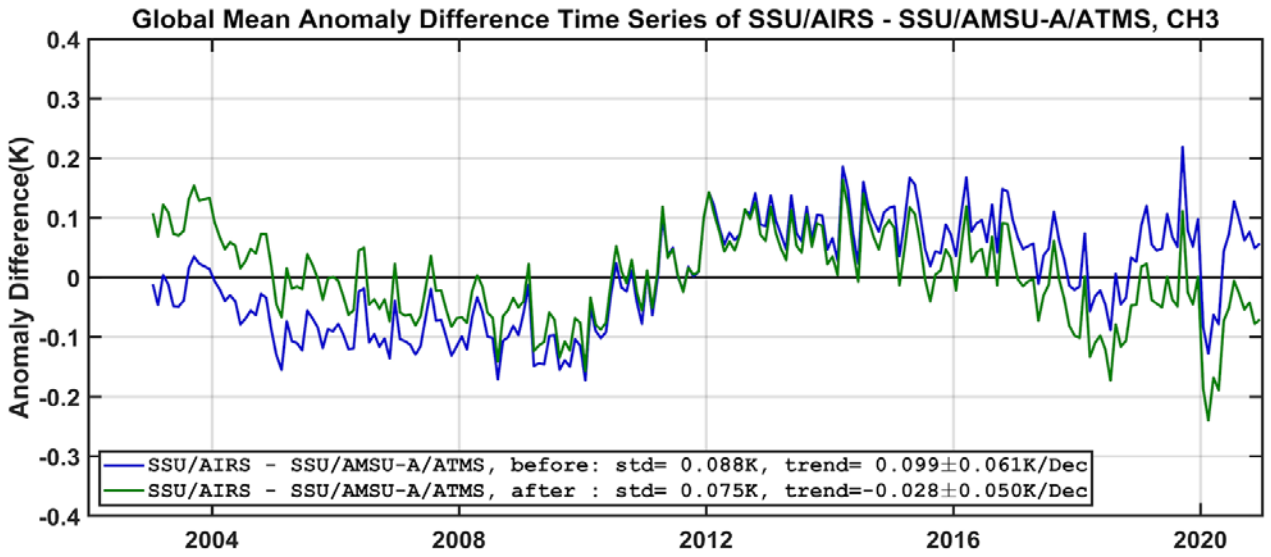


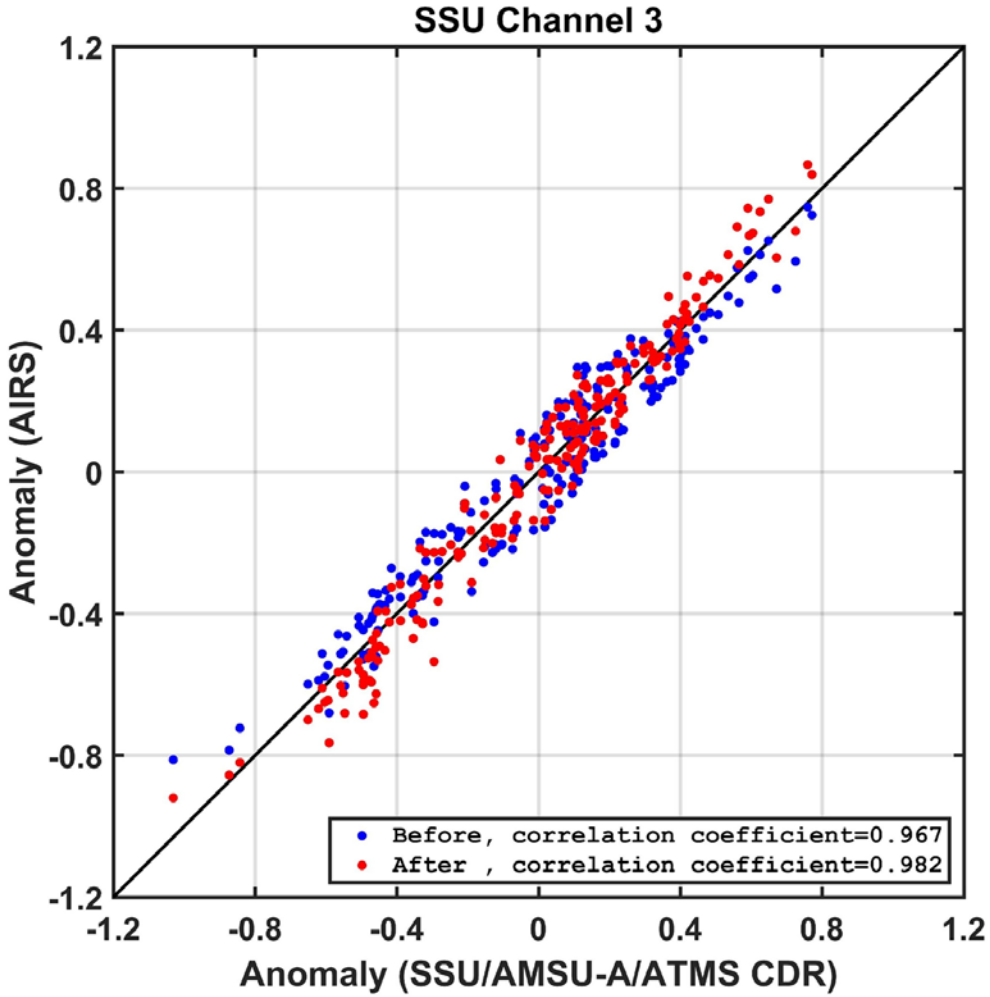

Global Mean Time Series of SSU/AIRS and SSU/AMSU-A/ATMS CH2
SSU/AMSU-A/ATMS CH2
SSU/AIRS CH2 (before CO2 correction)
SSU/AIRS CH2 (after CO2 correction)
Anomaly (K)
4
3
2
1
0
-1
-2
1980
1984
1988
1992
1996
2000
2004
2008
2012
2016
2020


Global Mean Anomaly Difference Time Series of SSU/AIRS - SSU/AMSU-A/ATMS, CH2
Anomaly Difference(K)
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
SSU/AIRS - SSU/AMSU-A/ATMS, before: std= 0.128K, trend= 0.227±0.071K/Dec
SSU/AIRS - SSU/AMSU-A/ATMS, after : std= 0.057K, trend=-0.035±0.030K/Dec
2004
2008
2012
2016
2020


SSU Channel 2
Anomaly (AIRS)
1.2
0.8
0.4
0
-0.4
-0.8
-1.2
Before, correlation coefficient=0.942
After , correlation coefficient=0.987
-1.2
-0.8
-0.4
0
0.4
0.8
1.2
Anomaly (SSU/AMSU-A/ATMS CDR)

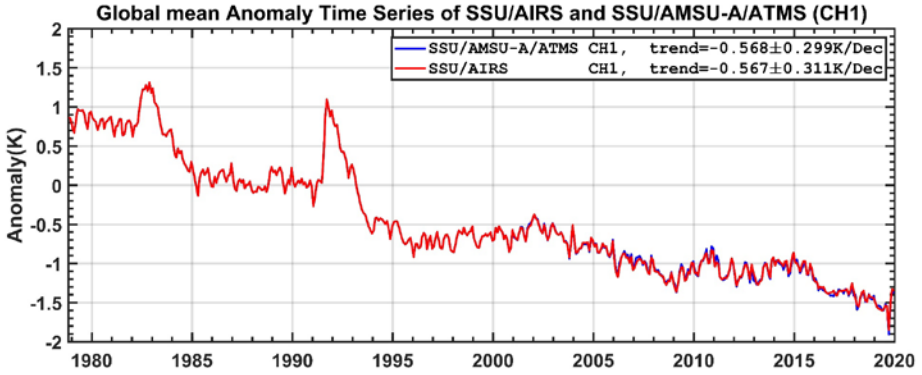

Global Mean Time Series of SSU/AIRS and SSU/AMSU-A/ATMS CH3
SSU/AMSU-A/ATMS CH3
SSU/AIRS CH3 (before CO2 correction)
SSU/AIRS CH3 (after CO2 correction)
Anomaly (K)
4
3
2
1
0
-1
-2
1980
1984
1988
1992
1996
2000
2004
2008
2012
2016
2020

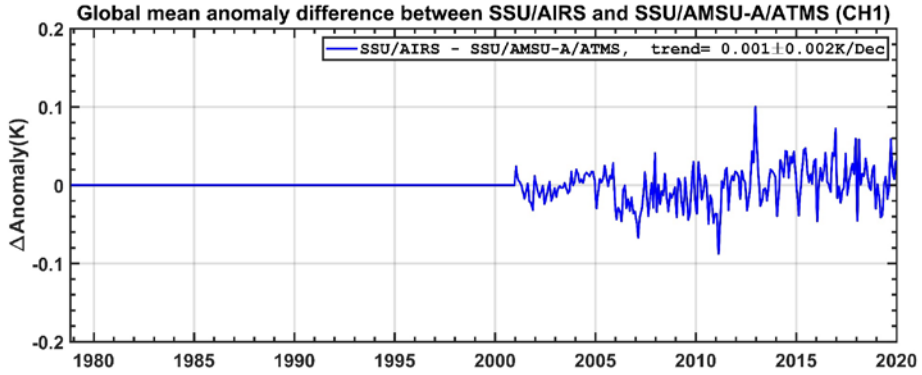

Global Mean Anomaly Difference Time Series of SSU/AIRS - SSU/AMSU-A/ATMS, CH3
Anomaly Difference(K)
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
SSU/AIRS - SSU/AMSU-A/ATMS, before: std= 0.088K, trend= 0.099±0.061K/Dec
SSU/AIRS - SSU/AMSU-A/ATMS, after : std= 0.075K, trend=-0.028±0.050K/Dec
2004
2008
2012
2016
2020

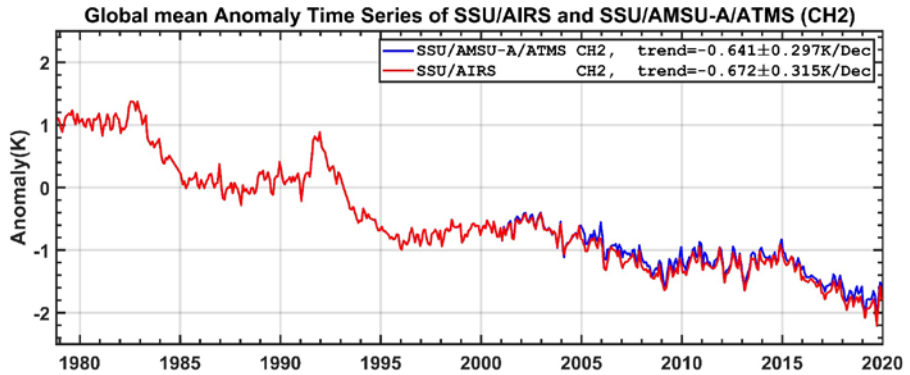

SSU Channel 3
Anomaly (AIRS)
1.2
0.8
0.4
0
-0.4
-0.8
-1.2
Before, correlation coefficient=0.967
After , correlation coefficient=0.982
-1.2
-0.8
-0.4
0
0.4
0.8
1.2
Anomaly (SSU/AMSU-A/ATMS CDR)

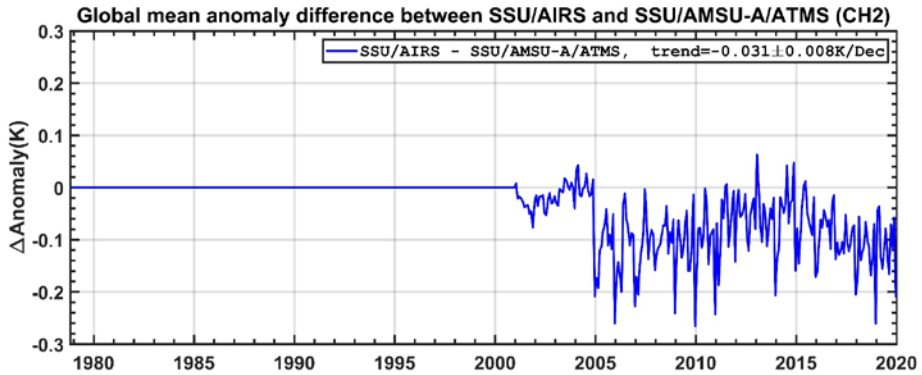
Global Mean Anomaly Time Series

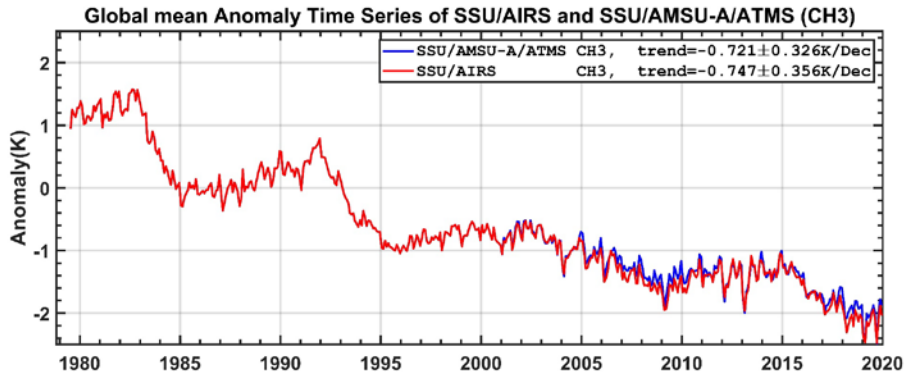
SSU/AIRS vs SSU/AMSU/ATMS

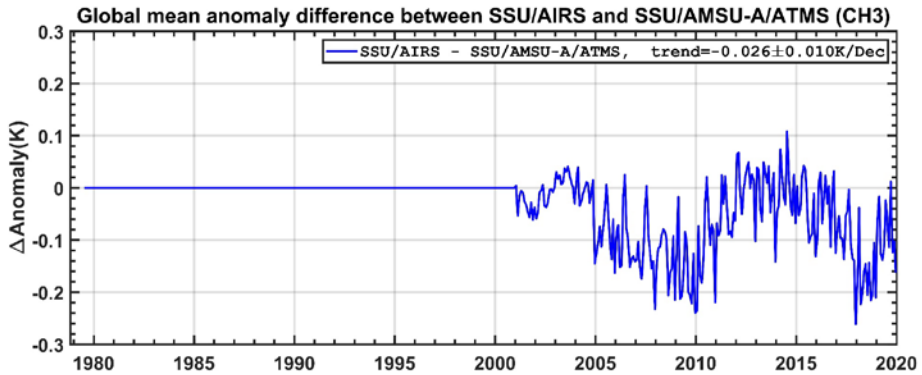




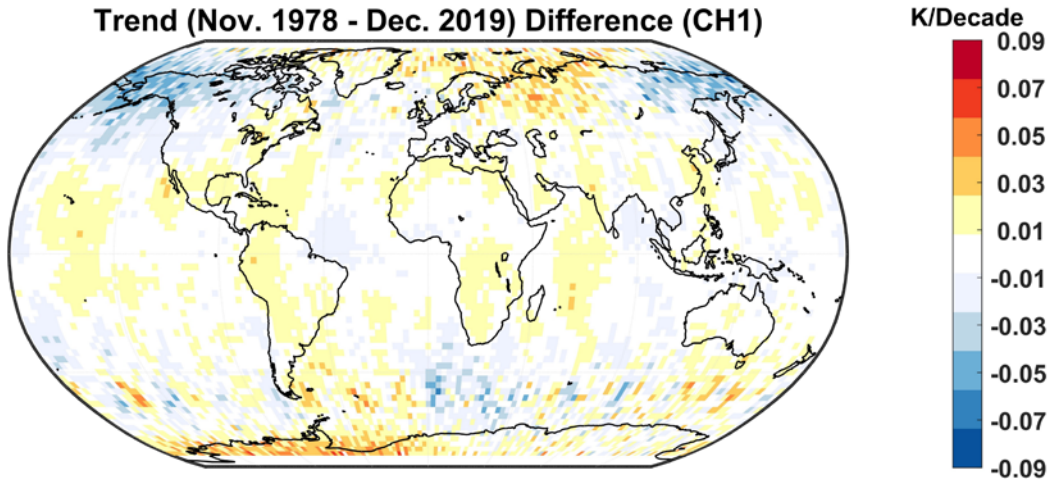


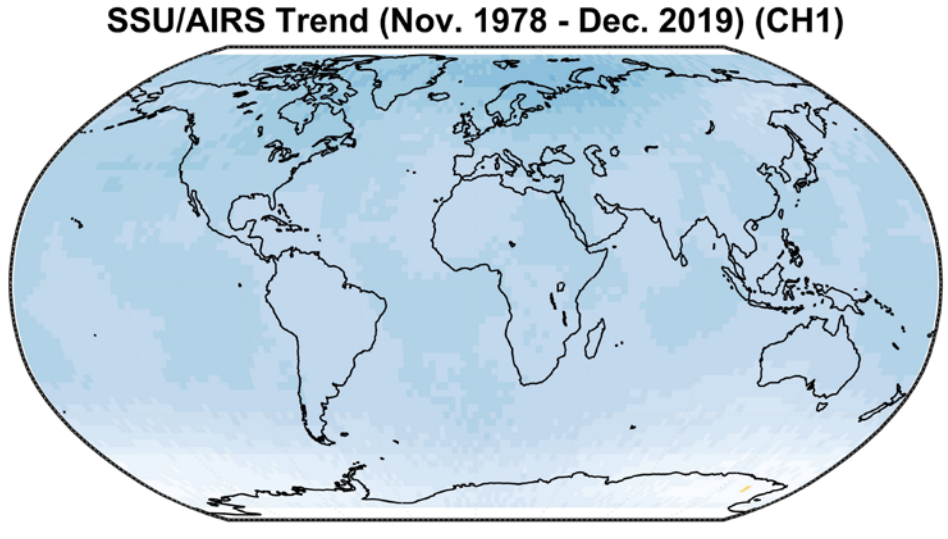


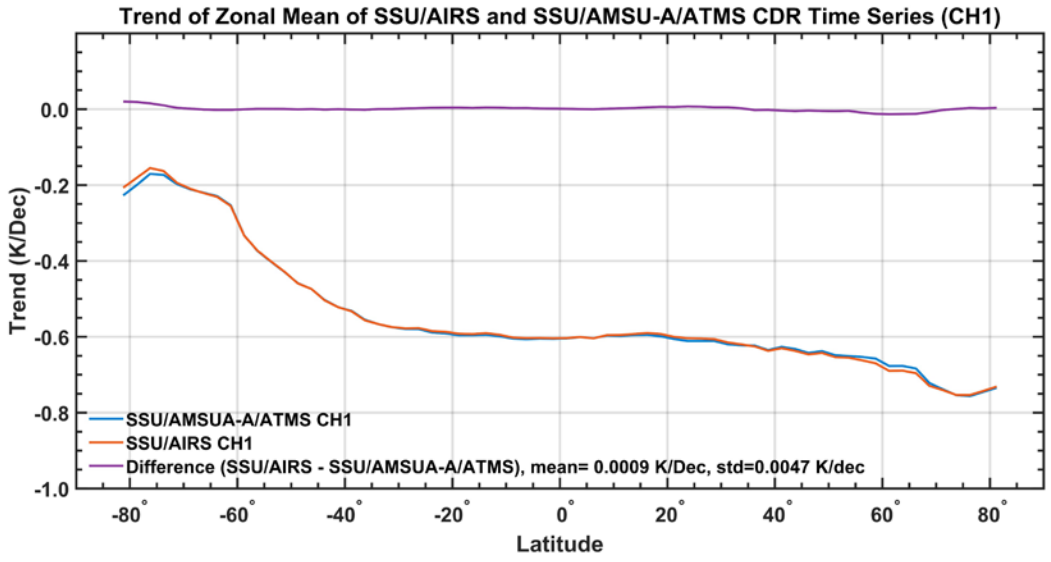


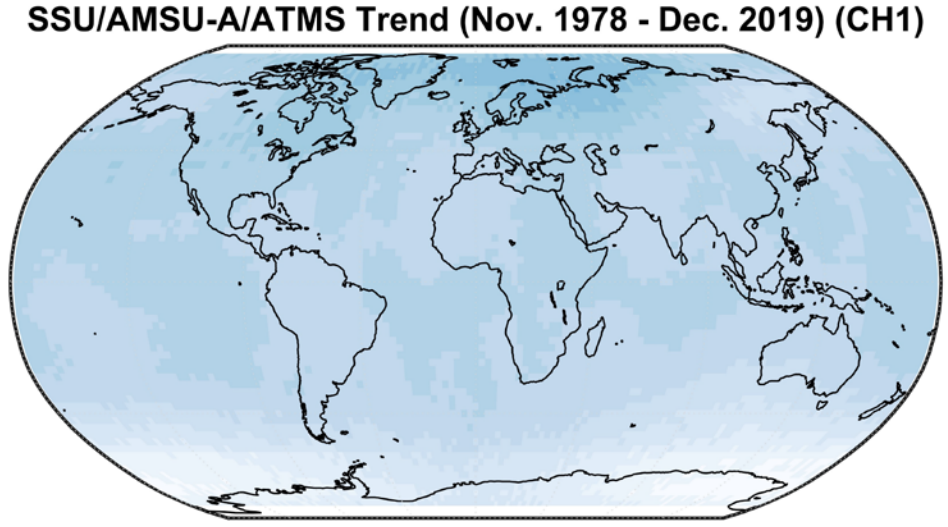


SSU CH1

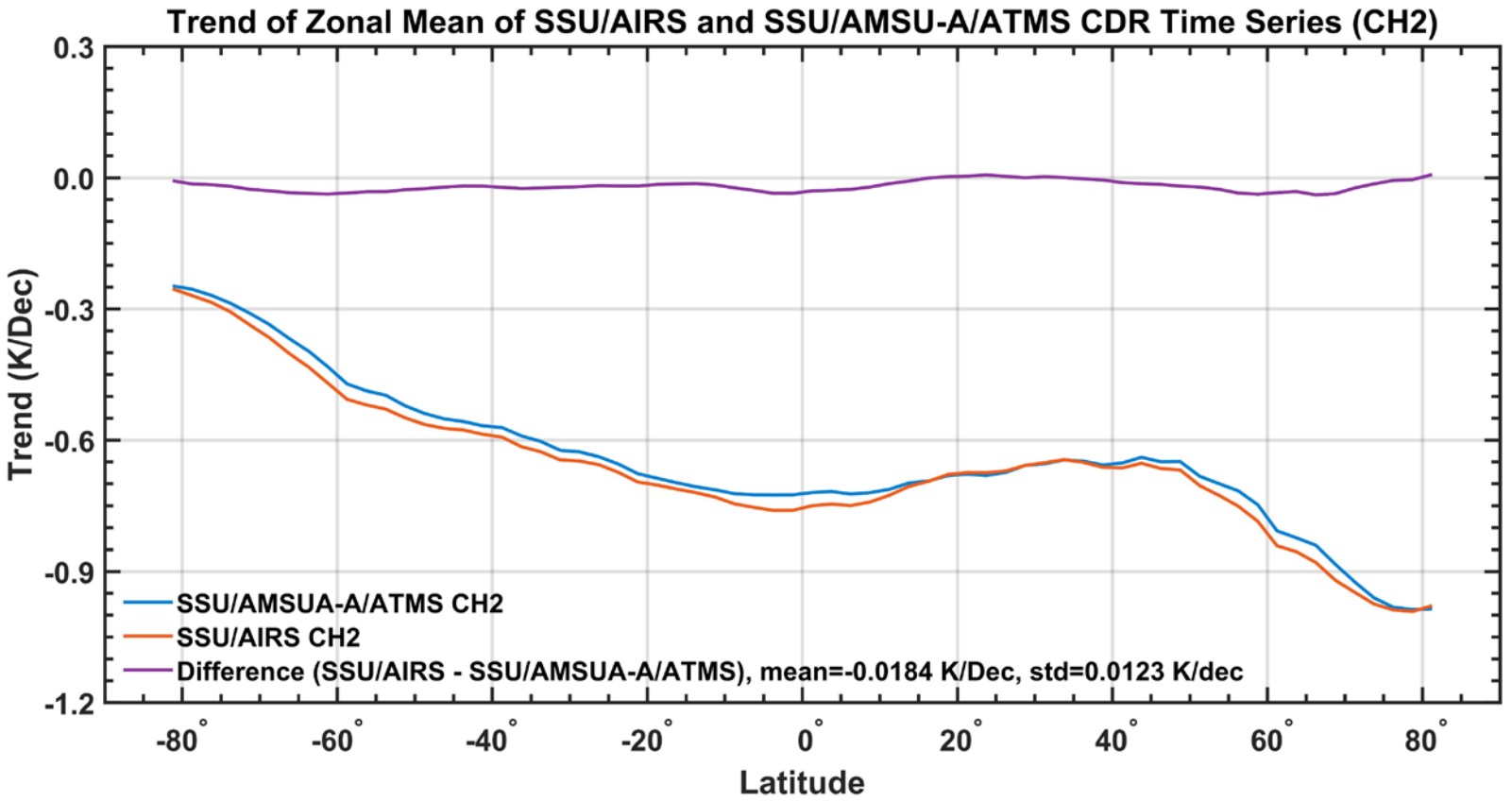

Trend (Nov. 1978 - Dec. 2019) Difference (CH1)
K/Decade
0.09
0.07
0.05
0.03
0.01
-0.01
-0.03
-0.05
-0.07
-0.09


SSU/AIRS Trend (Nov. 1978 - Dec. 2019) (CH1)
K/Decade
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
-1.6
-1.8
-2.0

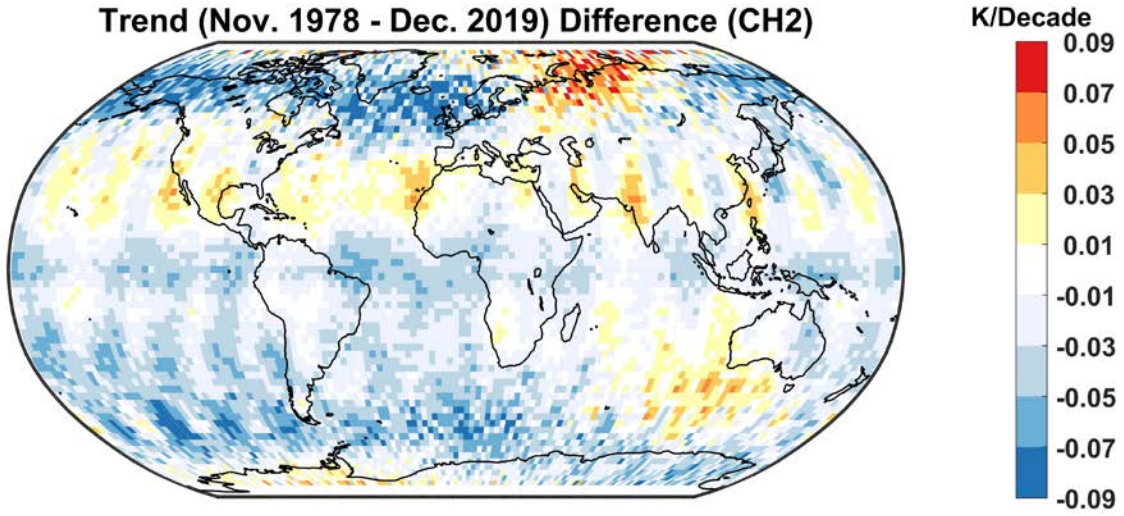

Trend of Zonal Mean of SSU/AIRS and SSU/AMSU-A/ATMS CDR Time Series (CH1)
Trend (K/Dec)
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
SSU/AMSUA-A/ATMS CH1
SSU/AIRS CH1
Difference (SSU/AIRS - SSU/AMSUA-A/ATMS), mean= 0.0009 K/Dec, std=0.0047 K/dec
-80°
-60°
-40°
-20°
0°
20°
40°
60°
80°
Latitude

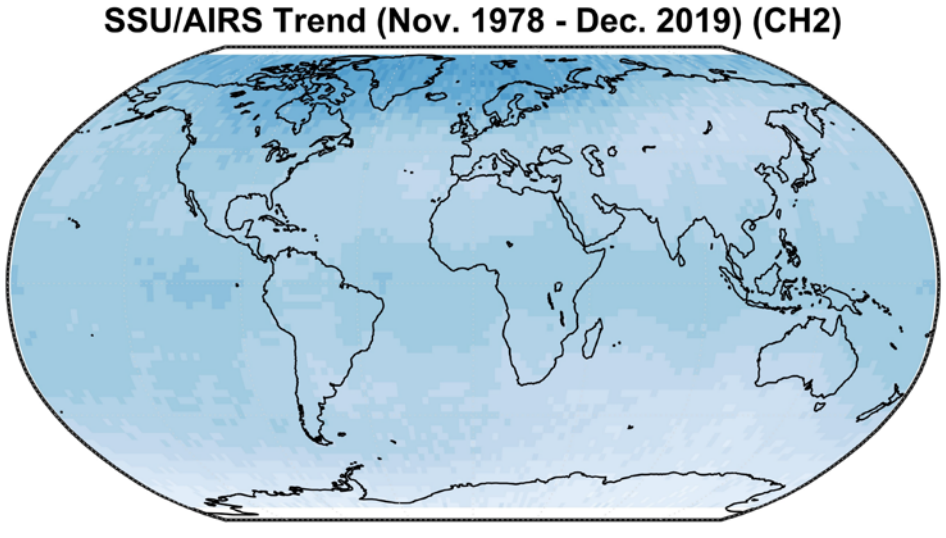

SSU/AMSU-A/ATMS Trend (Nov. 1978 - Dec. 2019) (CH1)
K/Decade
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
-1.6
-1.8
-2.0

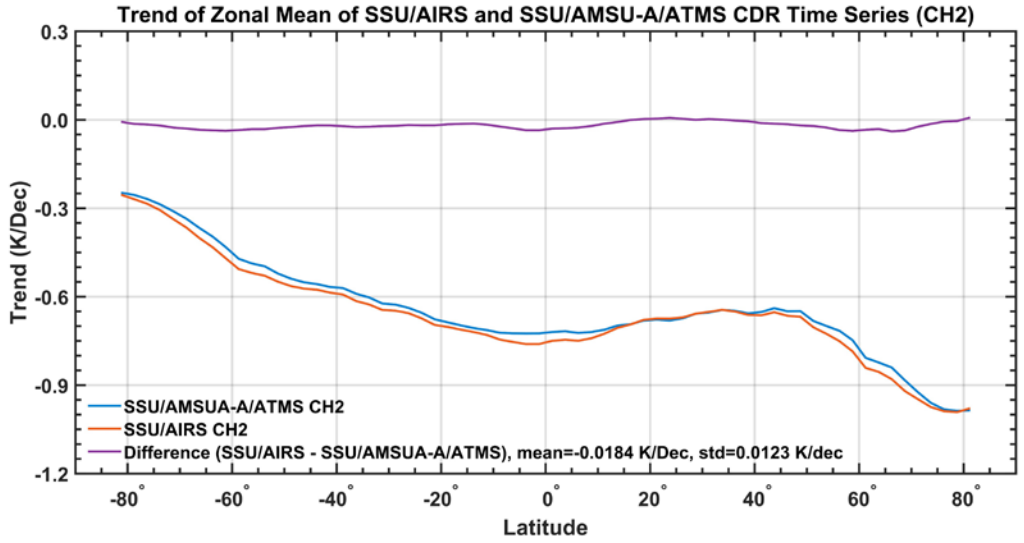
CH2


Trend of Zonal Mean of SSU/AIRS and SSU/AMSU-A/ATMS CDR Time Series (CH2)
Trend (K/Dec)
0.3
0.0
-0.3
-0.6
-0.9
-1.2
-80°
-60°
-40°
-20°
0°
20°
40°
60°
80°
Latitude
SSU/AMSUA-A/ATMS CH2
SSU/AIRS CH2
Difference (SSU/AIRS - SSU/AMSUA-A/ATMS), mean=-0.0184 K/Dec, std=0.0123 K/dec

CH2


Trend (Nov. 1978 - Dec. 2019) Difference (CH2)
K/Decade
0.09
0.07
0.05
0.03
0.01
-0.01
-0.03
-0.05
-0.07
-0.09


SSU/AIRS Trend (Nov. 1978 - Dec. 2019) (CH2)
K/Decade
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
-1.6
-1.8
-2.0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-80°
-60°
-40°
-20°
0°
20°
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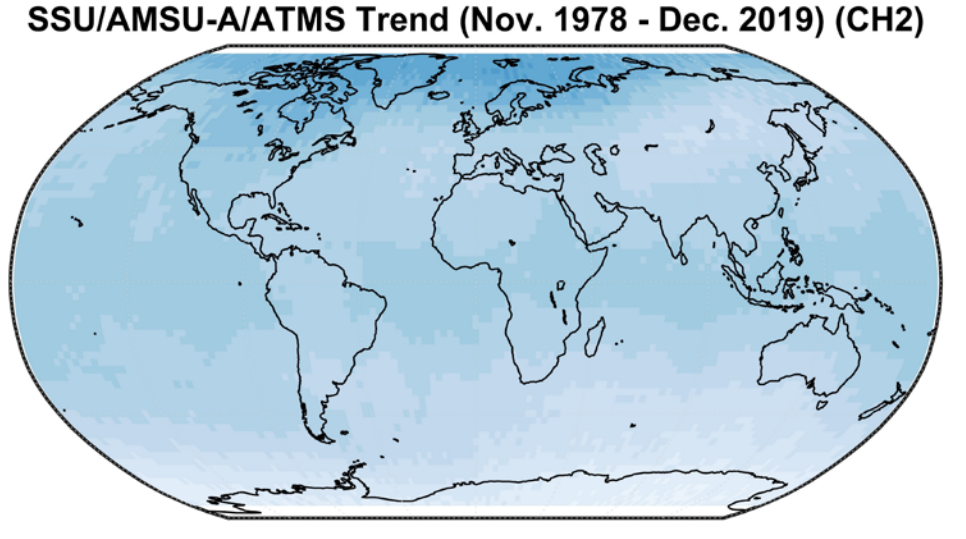
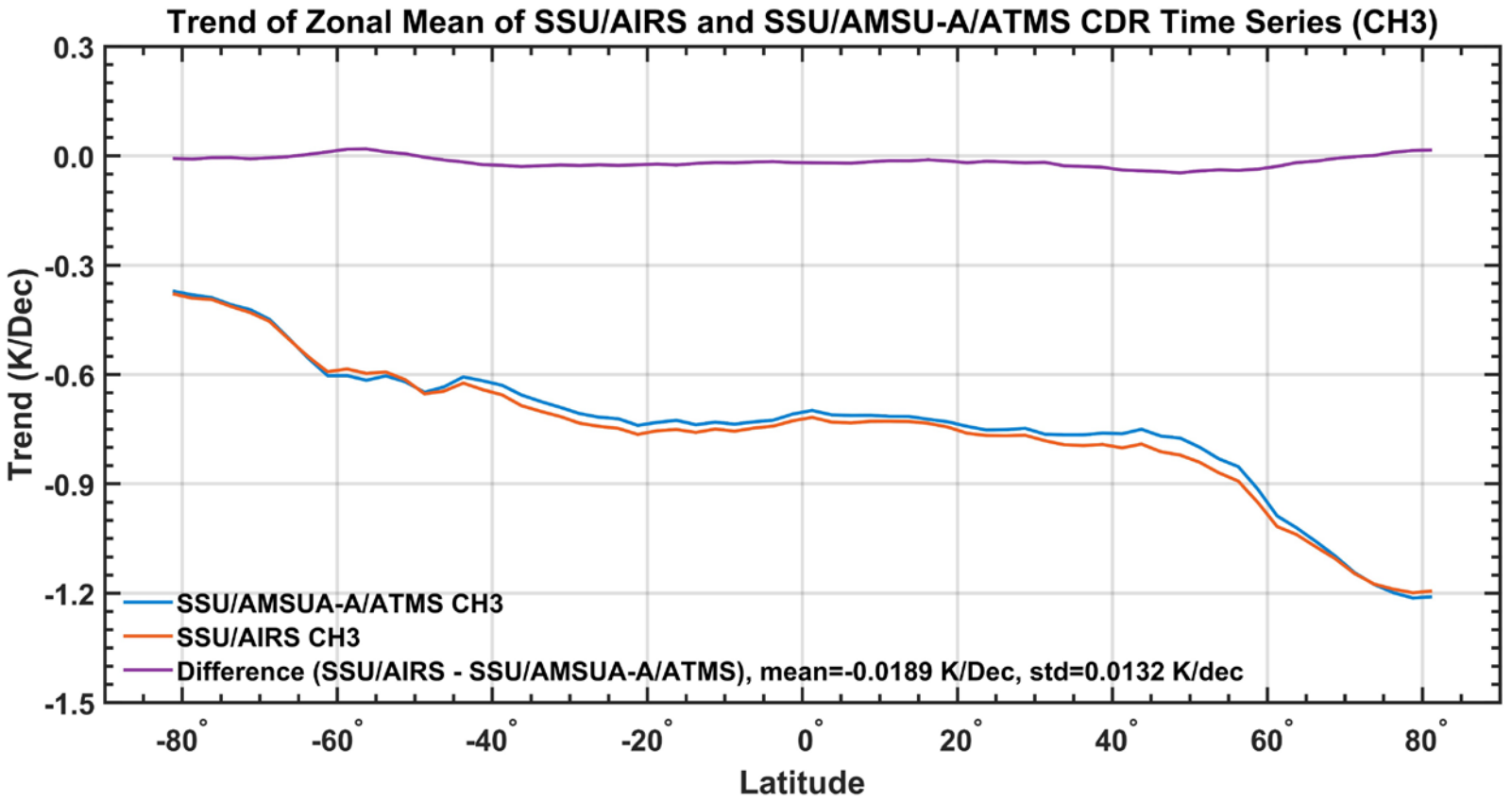
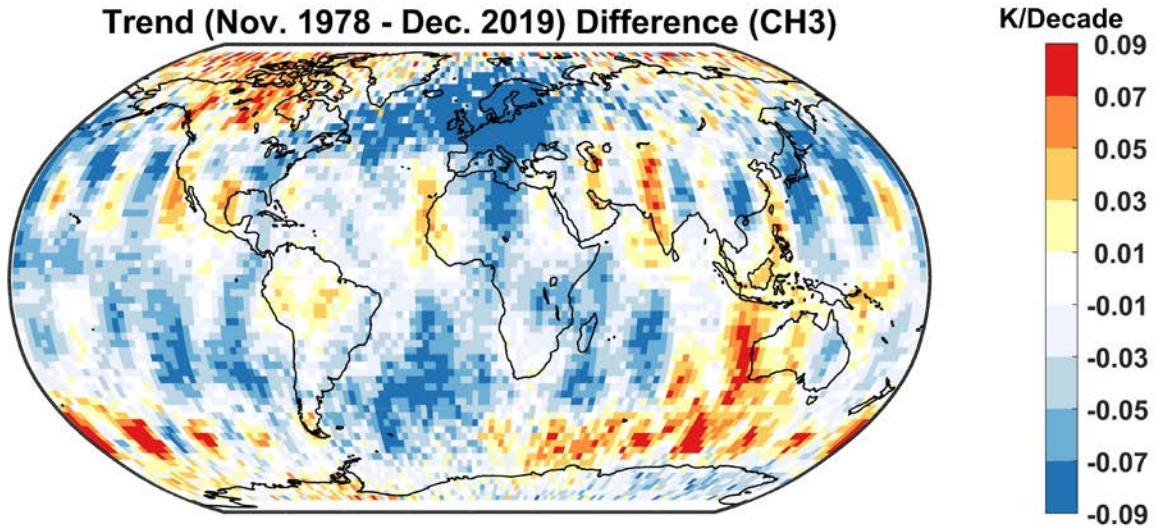
80°
Latitude
SSU/AMSUA-A/ATMS CH2
SSU/AIRS CH2
Difference (SSU/AIRS - SSU/AMSUA-A/ATMS), mean=-0.0184 K/Dec, std=0.0123 K/dec

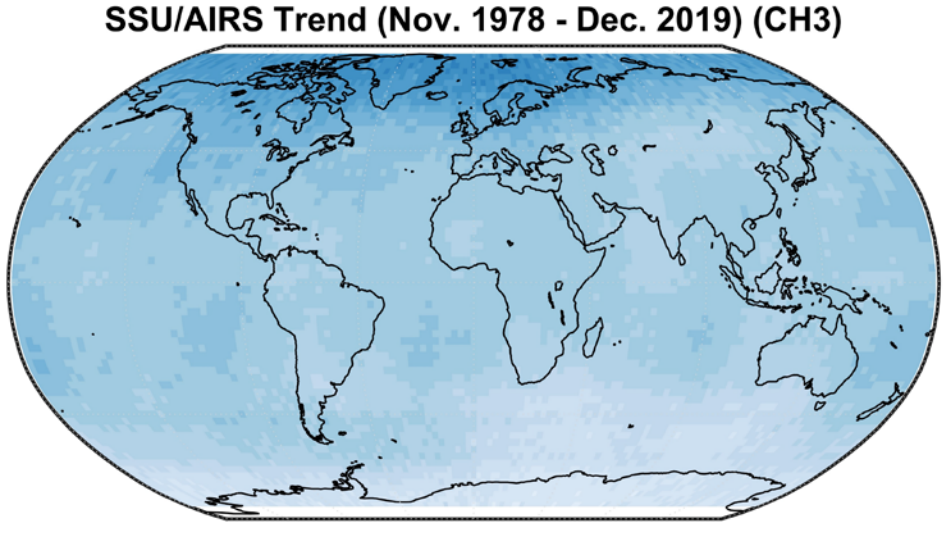

SSU/AMSU-A/ATMS Trend (Nov. 1978 - Dec. 2019) (CH2)
K/Decade
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
-1.6
-1.8
-2.0

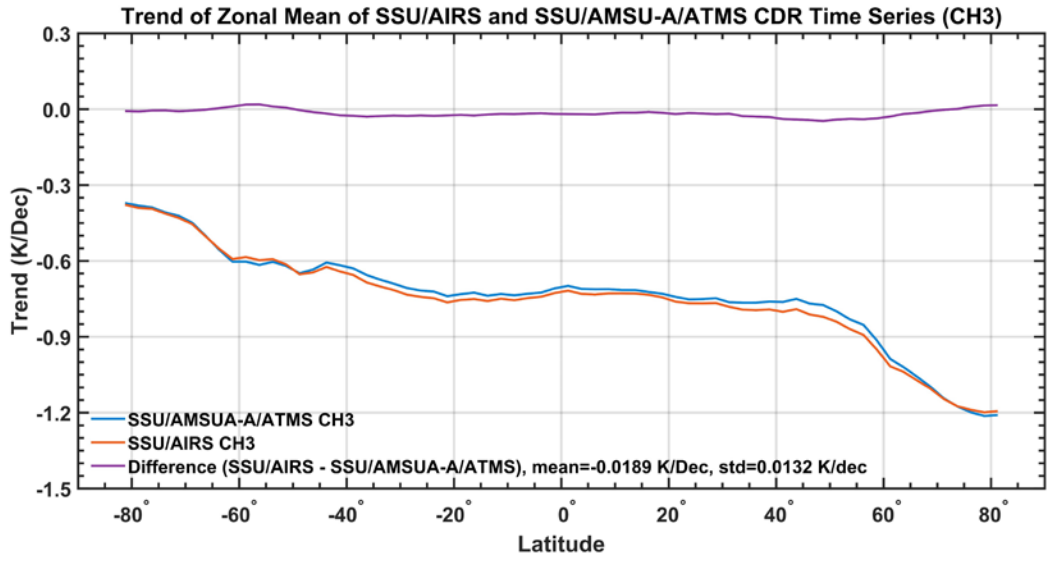
CH3


Trend of Zonal Mean of SSU/AIRS and SSU/AMSU-A/ATMS CDR Time Series (CH3)
Trend (K/Dec)
0.3
0.0
-0.3
-0.6
-0.9
-1.2
-1.5
-80°
-60°
-40°
-20°
0°
20°
40°
60°
80°
Latitude
SSU/AMSUA-A/ATMS CH3
SSU/AIRS CH3
Difference (SSU/AIRS - SSU/AMSUA-A/ATMS), mean=-0.0189 K/Dec, std=0.0132 K/dec

CH3


Trend (Nov. 1978 - Dec. 2019) Difference (CH3)
K/Decade
0.09
0.07
0.05
0.03
0.01
-0.01
-0.03
-0.05
-0.07
-0.09


SSU/AIRS Trend (Nov. 1978 - Dec. 2019) (CH3)
K/Decade
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
-1.6
-1.8
-2.0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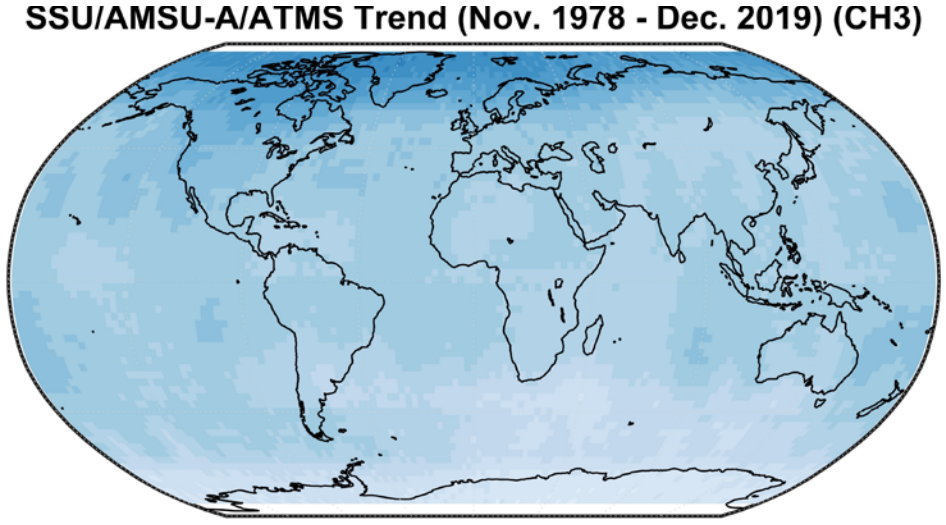
SSU/AMSUA-A/ATMS CH3
SSU/AIRS CH3
Difference (SSU/AIRS - SSU/AMSUA-A/ATMS), mean=-0.0189 K/Dec, std=0.0132 K/dec


SSU/AMSU-A/ATMS Trend (Nov. 1978 - Dec. 2019) (CH3)
K/Decade
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
-1.6
-1.8
-2.0

Conclusion and Future Work

- The efforts has been made to reprocess the SSU data sets for climate data records for stratospheric temperature monitoring in NOAA/NESDIS/STAR.
- The AIRS datasets is the key to carry the NOAA operational temperature sounding capability into the future by linking SSU to AIRS/CrIS.
- A method has been successfully developed to convert AIRS hyperspectral data into equivalent SSU observations.
- Global Mean Anomaly Time Series of SSU/AIRS vs. SSU/AMSU-A/ATMS agree very well.
- The new data SSU/AIRS data will be released soon.