# STAR's Capabilities and Interests in Exploiting Long-Term Satellite Data Records for Climate and Environmental Applications

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# Outline

- Sensitivity of Trend Uncertainties to Measurement Precision
- Mission Life-Cycle Reprocessing of SDR and EDR
- STAR's Capabilities and Interests in Exploring Satellite CDRs
- Examples of CDR Applications
- Summary and Conclusions

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

For a time series of surface temperature, its linear trend can be derived as

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

where a is a linear regression coefficient and is obtained by a least-square fit which minimizes the difference between observations and linear regression model. M is the record length in year.

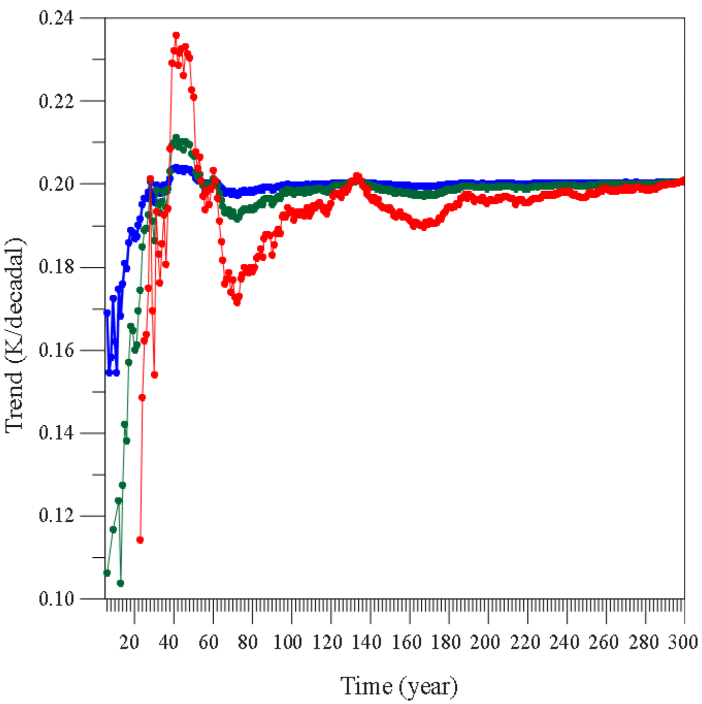



Fig. 1 Climate trend calculated from different lengths of time series with three different observation error variances: 0.1K (blue line), 0.3K (green line) and 1K (red line)

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

# Climate Trend Error from Observations

The uncertainty of the trend (a) is

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

where:

$M$ — Data length

$\sigma_o^2$ — Observation error

$\sigma_n^2$ — Natural variability

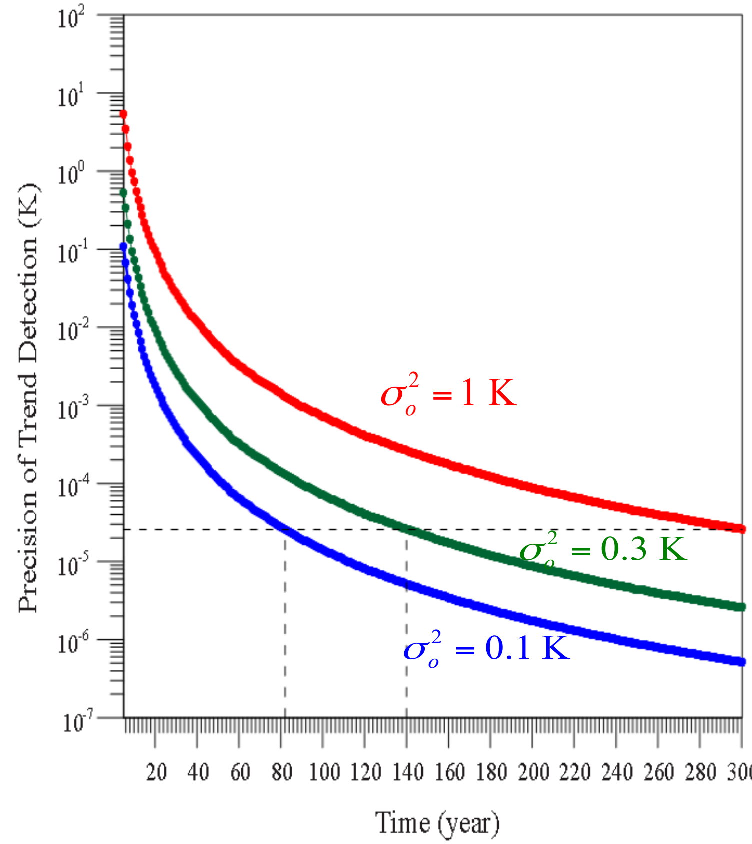



Fig. 2 Variations of $\sigma_{trend}$ with respect to data length for the trends shown in Fig. 1

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

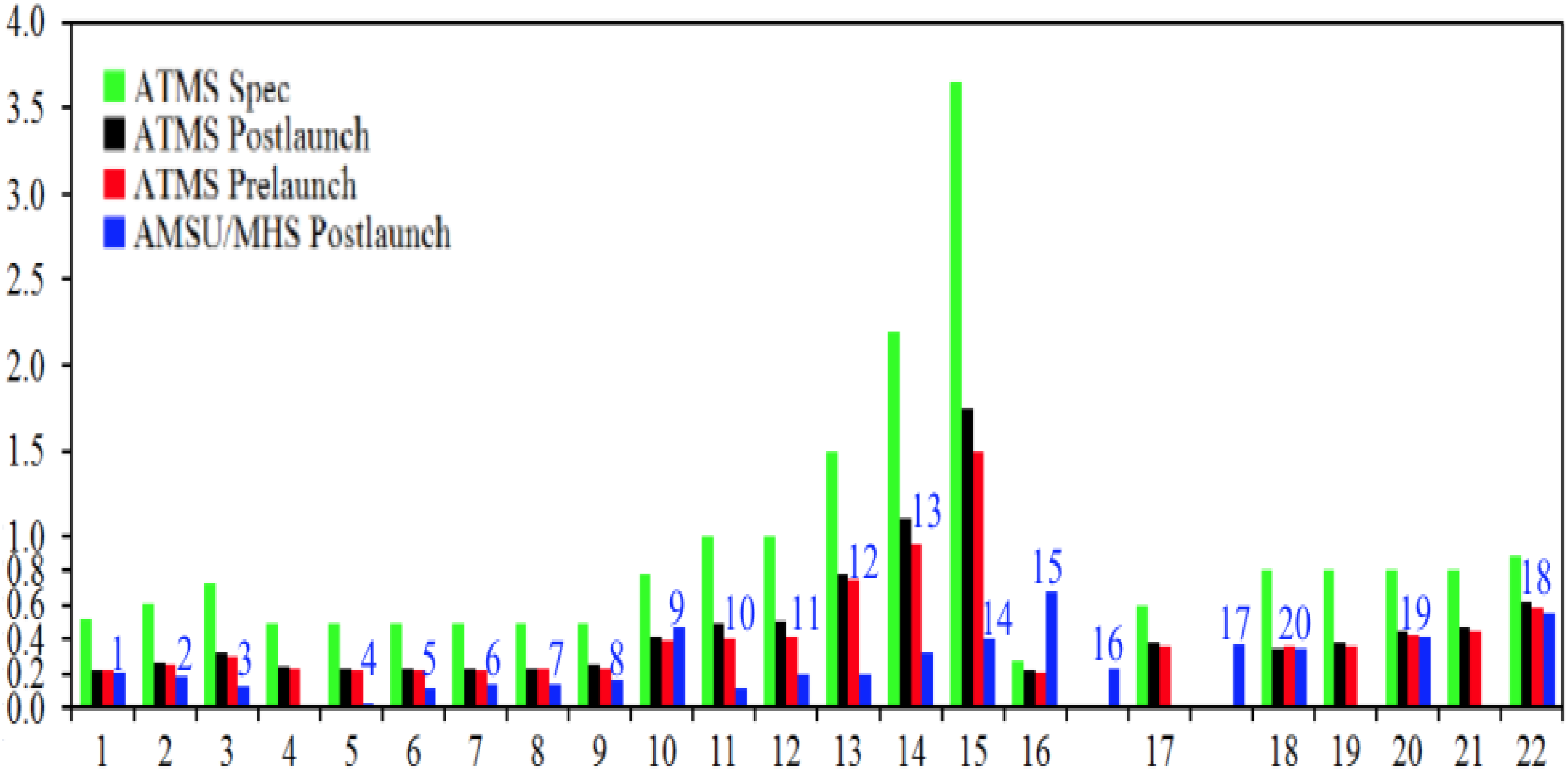
# Requirements for Construction of Satellite Climate Data Record

- Well characterizes the errors of satellite measurements through comprehensive calibration campaign

- Increases the data record length through cross-calibrating all the operational satellite data into a reference instrument

- Understands the natural variability from other data sources and weather and climate models

# Characterization of AMSU/ATMS Noise



# STAR Just Implemented New SI Traceable NEDT Algorithms for All the Sounding Instruments

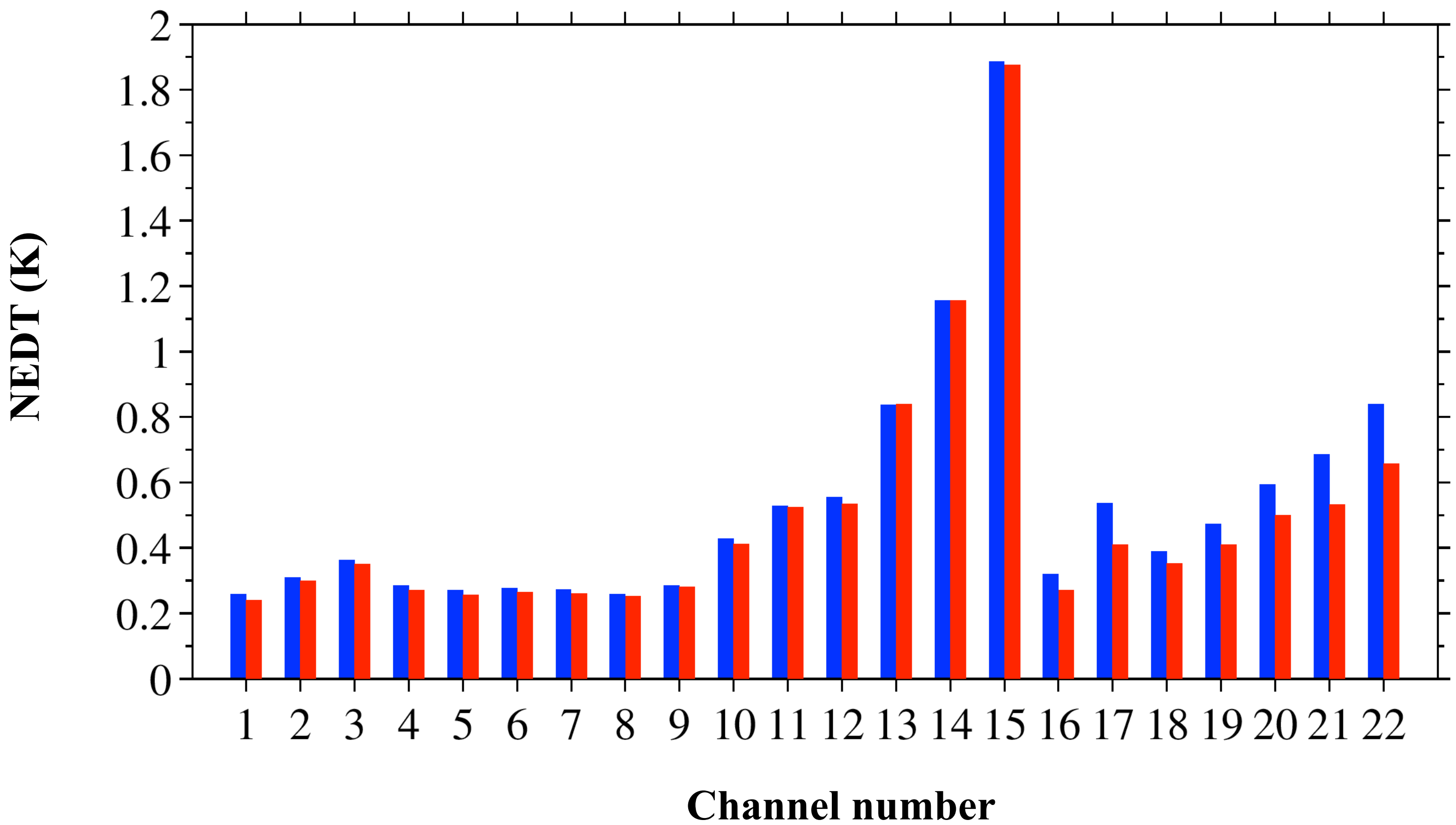
- Allan Deviation was proposed by NIST for characterizing the random noise from a time series which has a variable mean

- 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

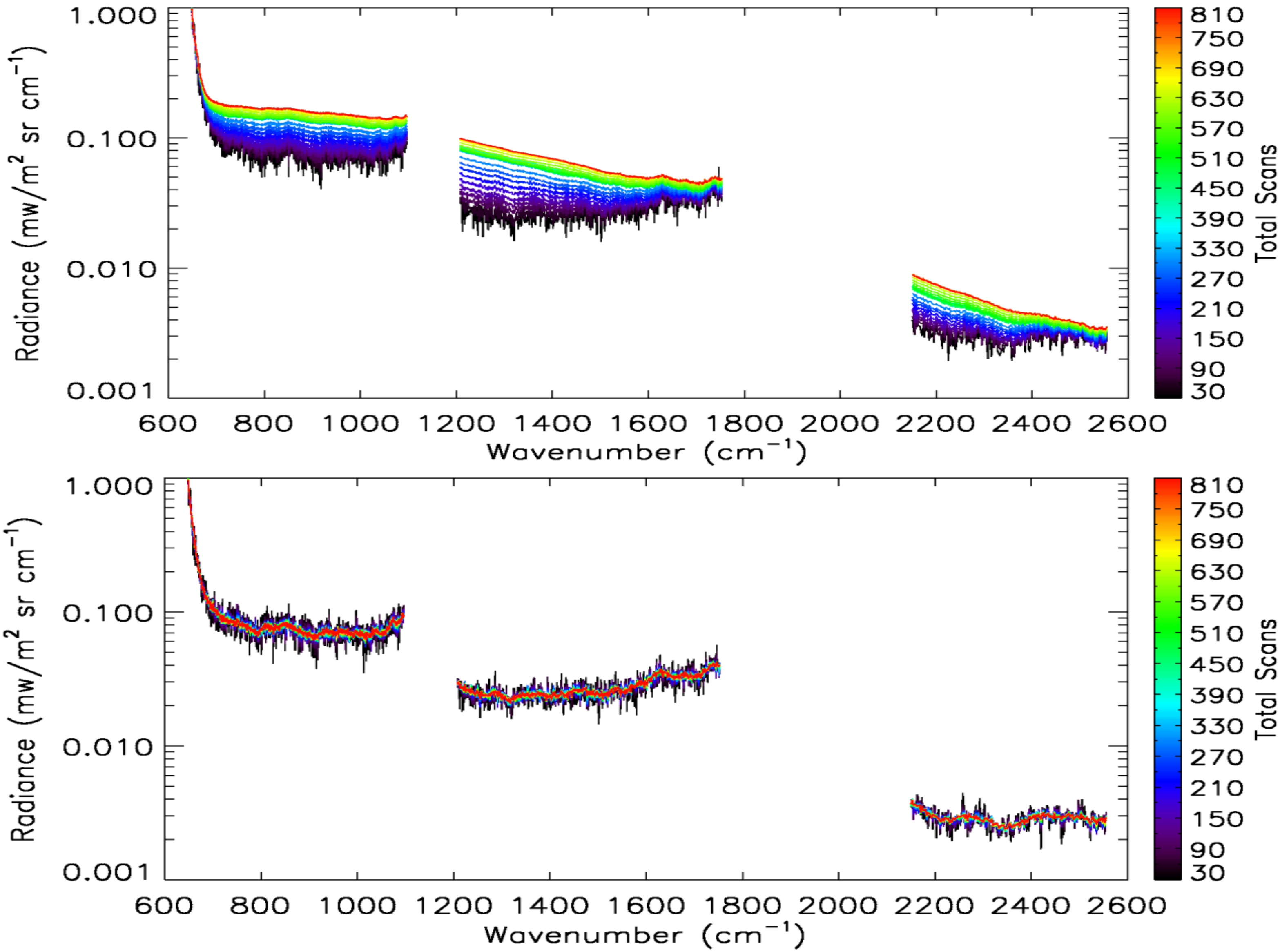
*D. W. Allan, Should the classical variance be used as a basic measure in standards metrology Instrumentation and Measurement, IEEE Trans. on, IM-36, pp.646-654, 1987*

# ATMS NEDT Computed from Standard and Allan Deviation




**Use of Allan Deviation for Characterizing Satellite Microwave Sounders Noise Equivalent brightness temperature (Tian and Weng, 2015, GRSL accepted )**

# CrIS Noise Computed from Standard and Allan Deviations




SI traceable algorithm for characterizing hyperspectral infrared sounder CrIS noise (Chen and Weng, 2015, AO accepted)

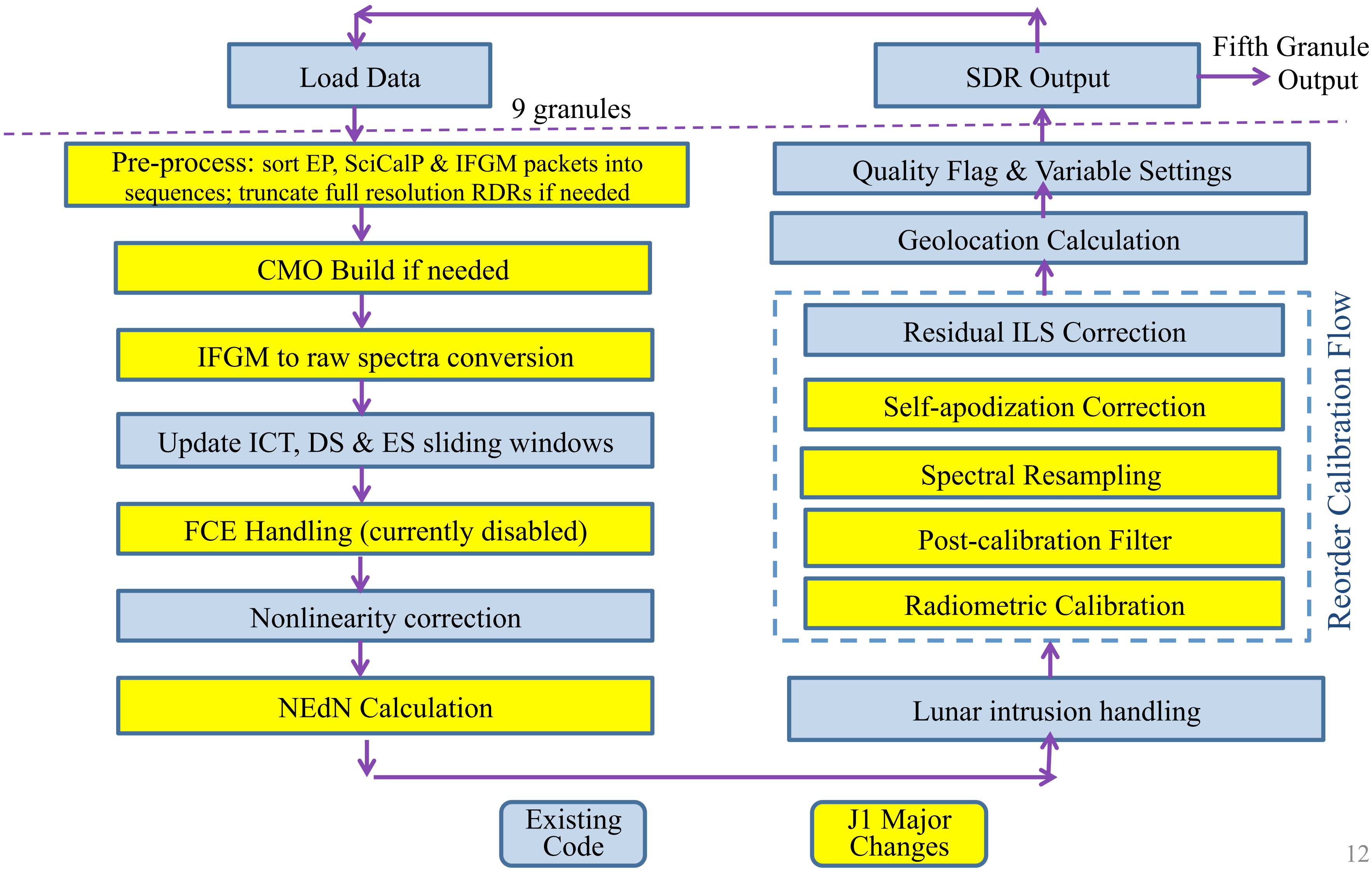
# STAR Satellite Cal/Val Program

- **Instrument Calibration**
  - Pre-launch characterization
  - Calibration standards and common practices
  - Traceability to system international units
  - New calibration models and algorithms
  - Postlaunch operational calibration
  - Assessments of geolocation accuracy and corrections
  - Cross calibration of satellite instruments
- **Product Developments and Validation**
  - Improvements in  EDR algorithms
  - Advancements in new products
  - Validation of EDR through field campaigns and against in-situ data
- **Long Term Monitoring**
  - Integrated CalVal System (ICVS)
  - Online monitoring for satellite instruments
  - Investigation of instrument anomalies
  - Reports to CGMS on all NOAA instrument performance
  - Archival of all the anomaly events into metadata for CDR processing
- **Mission Life Cycle Reprocessing**

# STAR Interests in JPSS Mission Life Cycle Reprocessing (L0 to L1 or RDR to SDR)

- SNPP SDR Processing Changes since November 2011
  - CrIS SDR from normal to full spectral resolution
  - ATMS SDR from Rayleigh-Jean to full radiance
  - VIIRS SDR changes from F/H factor updates
  - Over 1000 discrepancy reports (DR) filed to fix the anomalies, update in PCT, LUT, engineering packages, etc.
- Major SDR Processing Upgrades from SNPP to JPSS-1
  - CrIS FSR will implement several new modules to reduce the ring effects)
  - ATMS SDR will have some new modules in correction of antenna emission
  - OMPS will add more modules to compress and aggregate the RDR
  - VIIRS DNB requires special upgrades in geolocation and aggregation
- Starting 2016, SNPP SDR products will be reprocessed every other year
  - SNPP ATMS, CrIS and OMPS - 2016
  - SNPP VIIRS – 2017

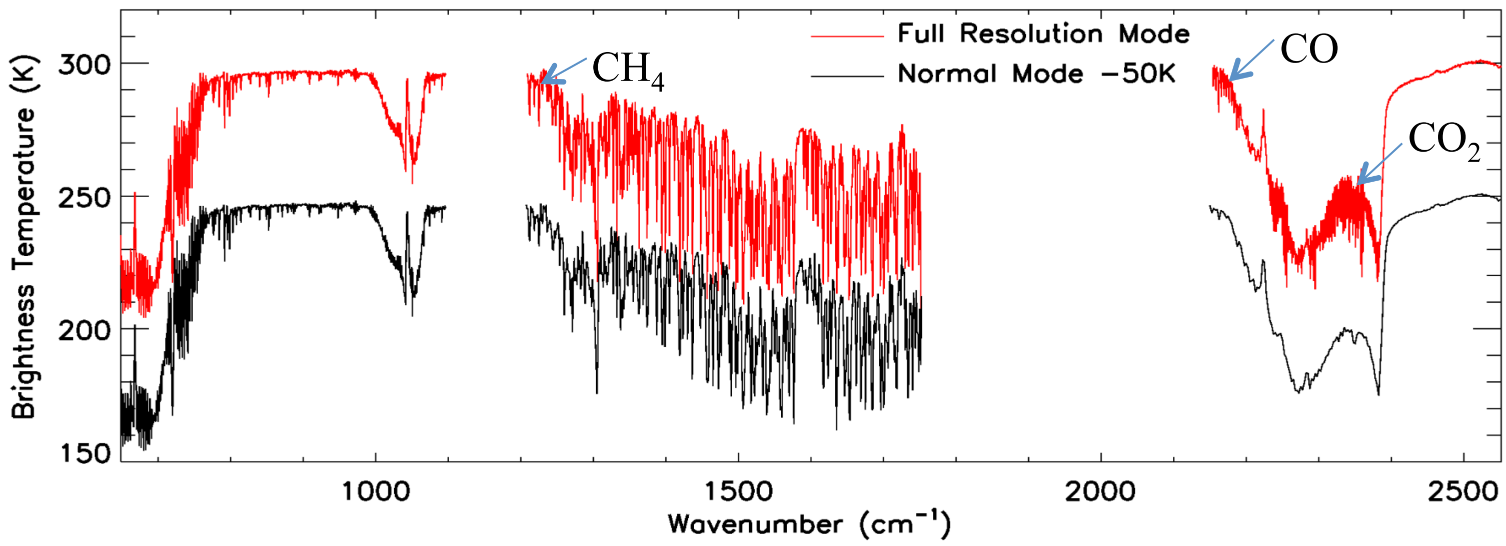
# CrIS SDR Algorithm Change from SNPP to J1



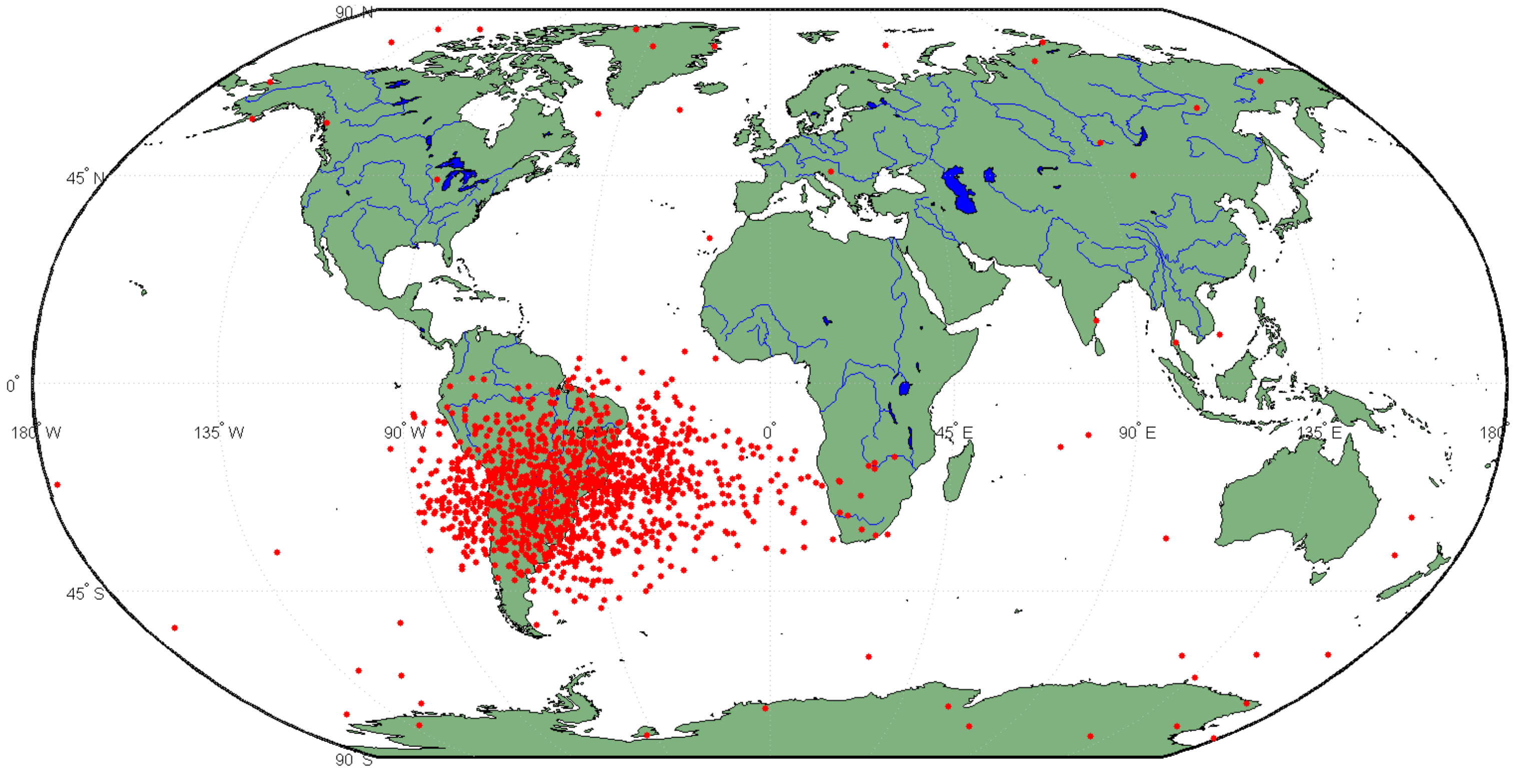
# SNPP CrIS Full Spectral Resolution SDR

| Frequency Band | Spectral Range ($cm^{-1}$) | Number of Channel | Spectral Resolution ($cm^{-1}$) |
|---|---|---|---|
| LWIR | 650 to 1095 | 713 (713) | 0.625 (0.625) |
| MWIR | 1210 to 1750 | 865 (433) | 0.625 (1.25) |
| SWIR | 2155 to 2550 | 633 (159) | 0.625 (2.5) |

Red: Full resolution mode



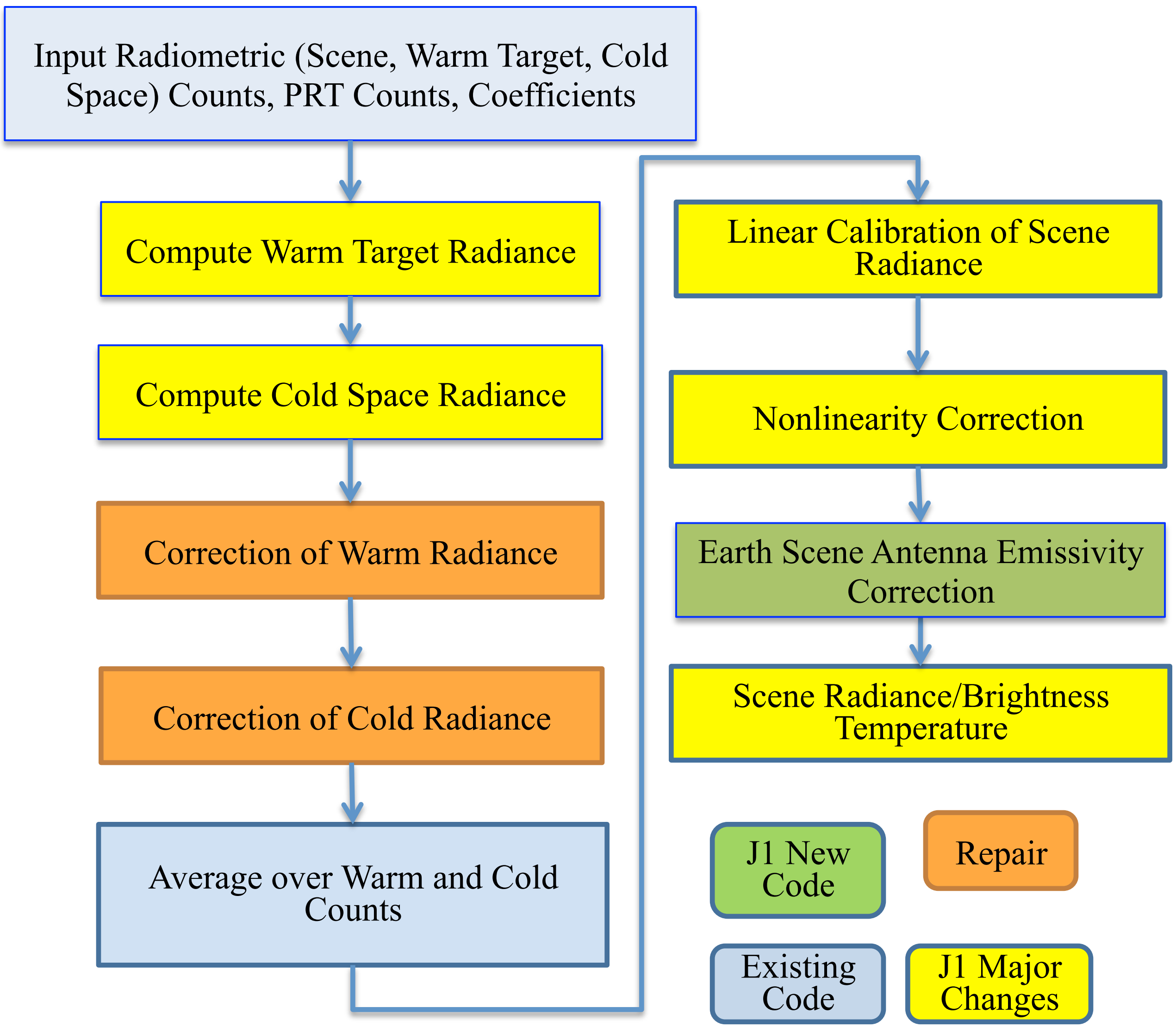
# An issue never been considered in the current SDR data product: SNPP FSR SW ICT scene impulse noise event 2014-12-04 to 2015-06-05




Only the impulse noise events on ICT scenes are plotted here:
Total number of event: 1325
If impulse hits ES, DS and ICT scenes randomly, the estimated events of all SW scenes should be 1325*17 = 22525 in 6 months, i.e. 123 per day.
Low resolution data is impacted as well.

**CrIS RDR data needs to be reprocessed in considering ICT impulse issue.**

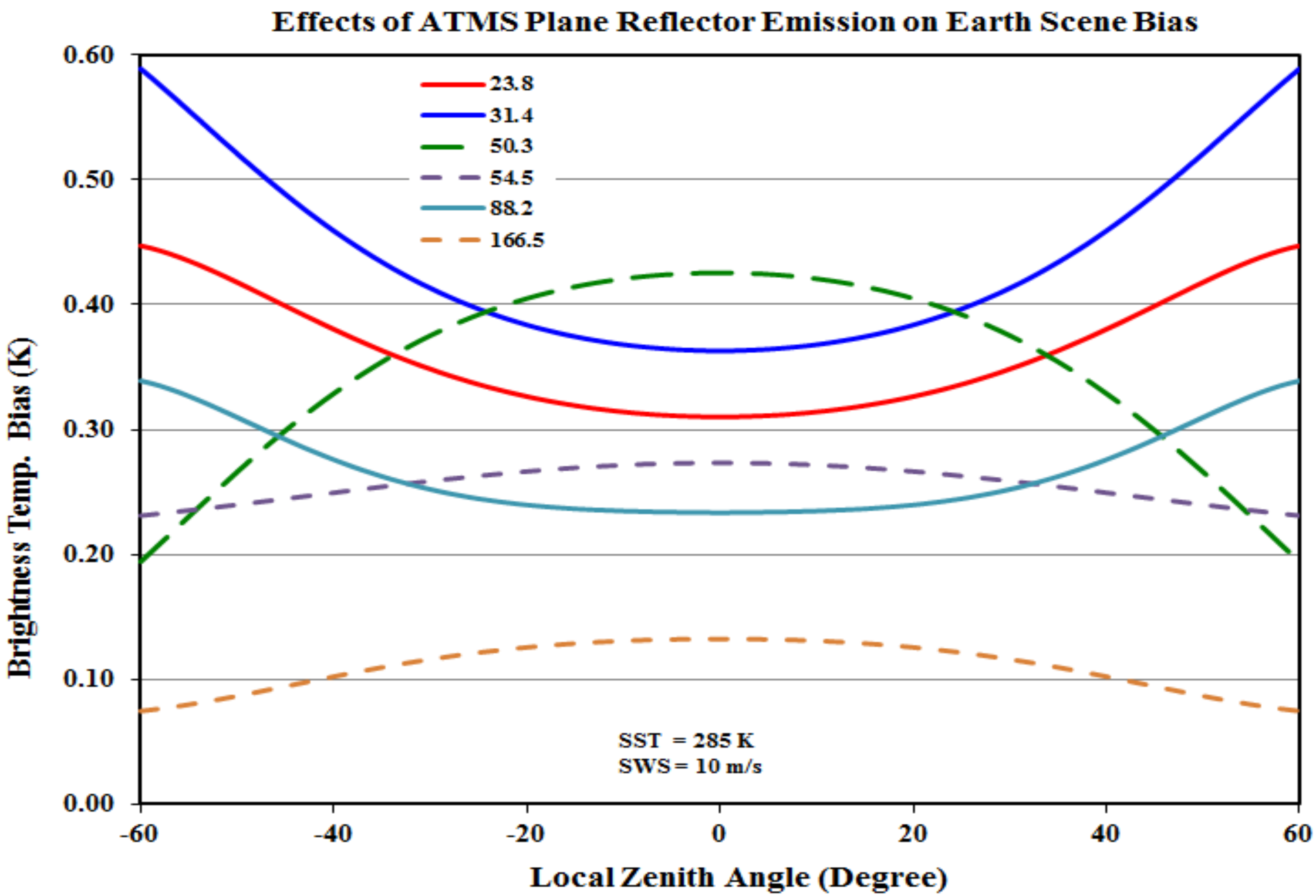
# ATMS SDR Algorithm Change from SNPP to JPSS



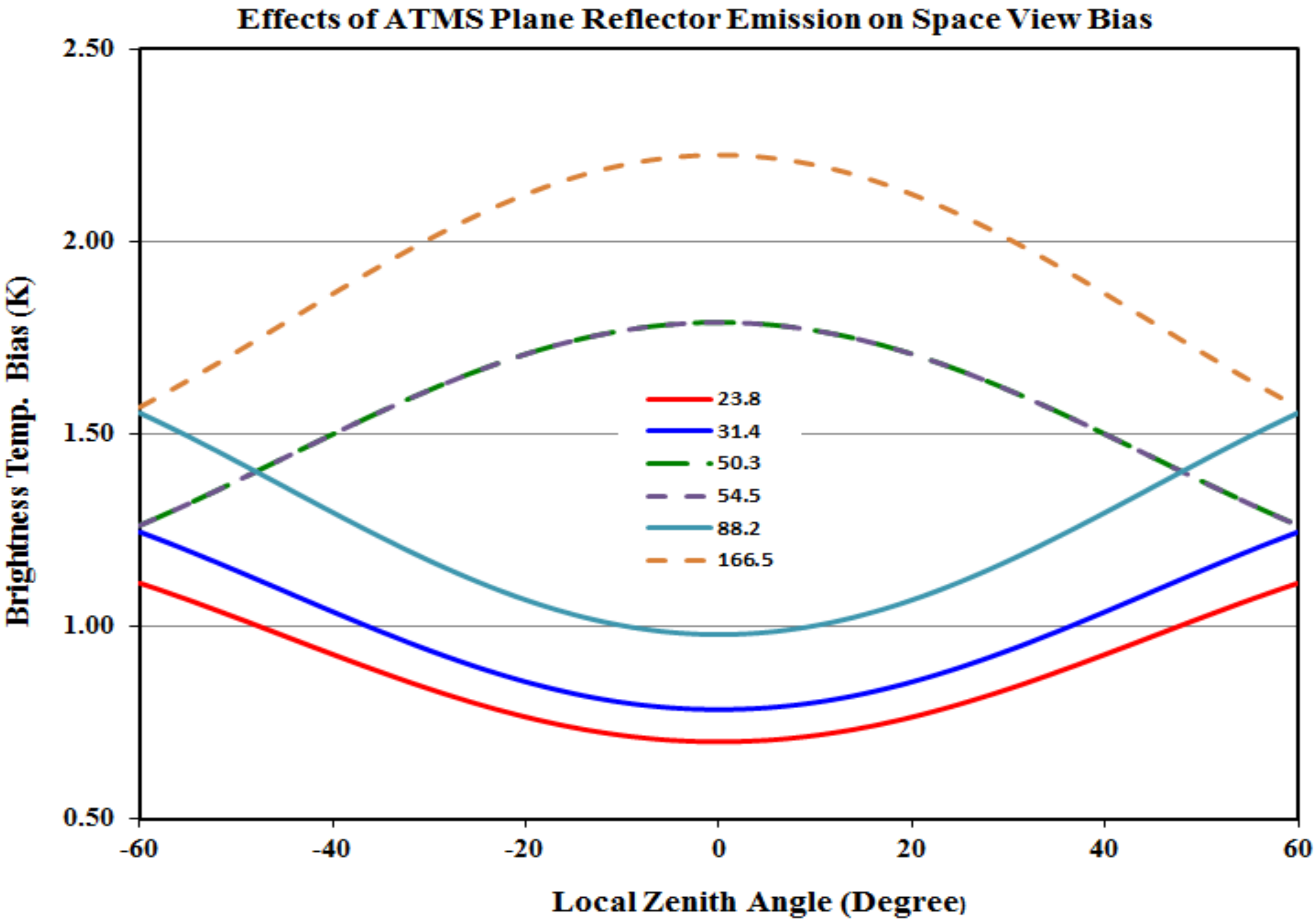

## Major Changes:

- Radiance based calibration
- Model based lunar contamination correction
- Updated parameterized nonlinearity correction
- Model based antenna reflector emissivity correction

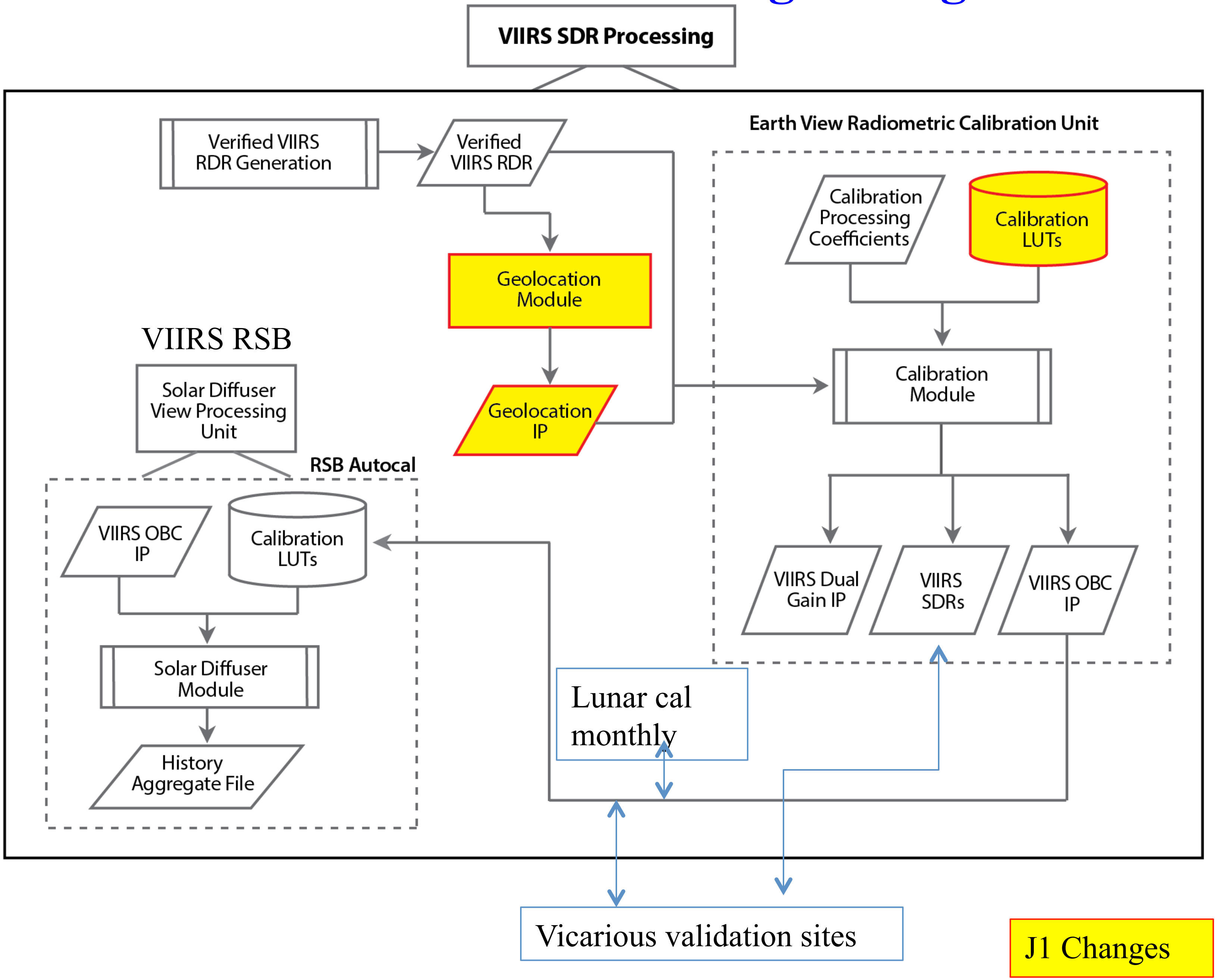
# The Reflector-Emission Bias for Earth Scenes



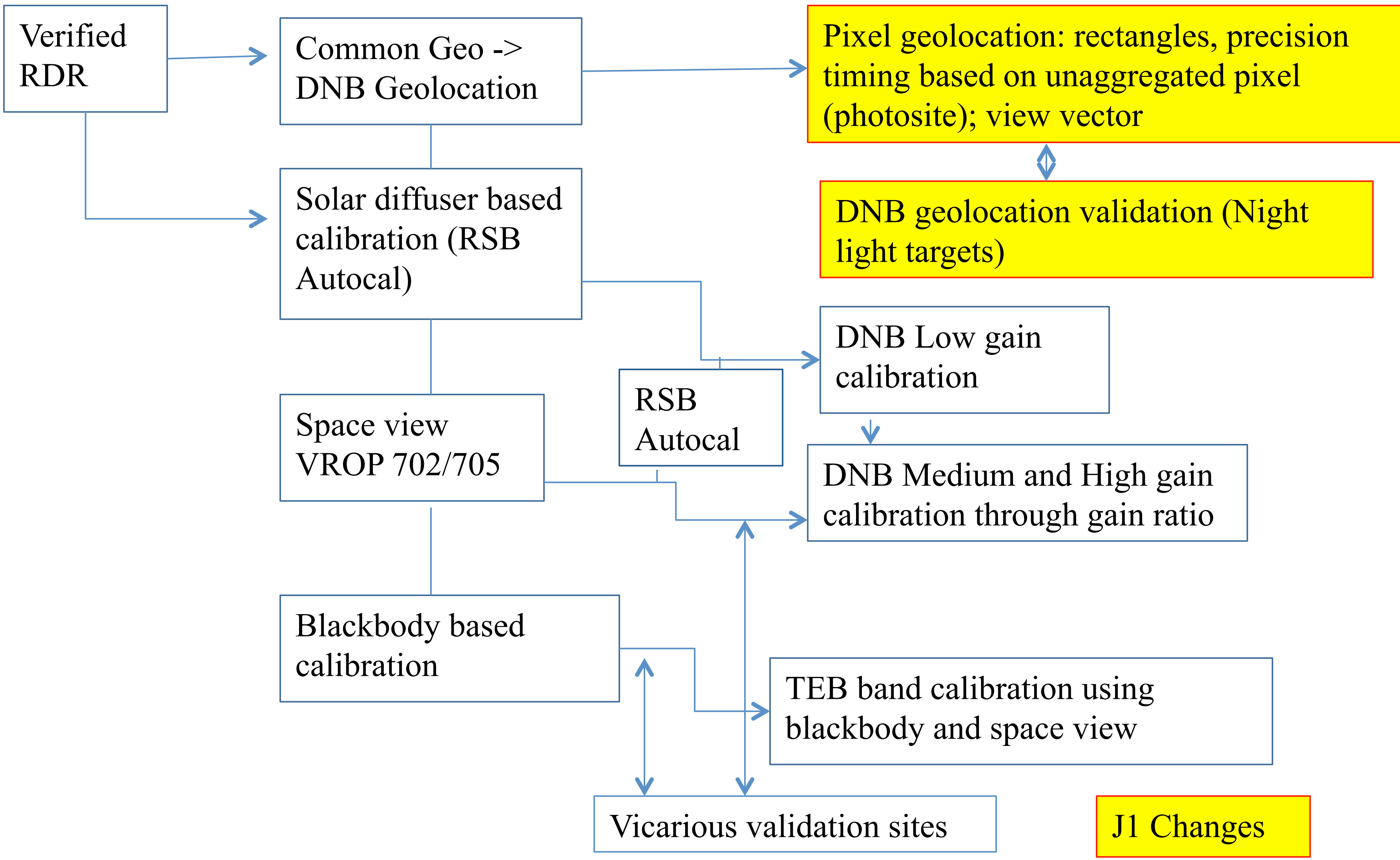
# The Reflector-Emission Bias for Space View



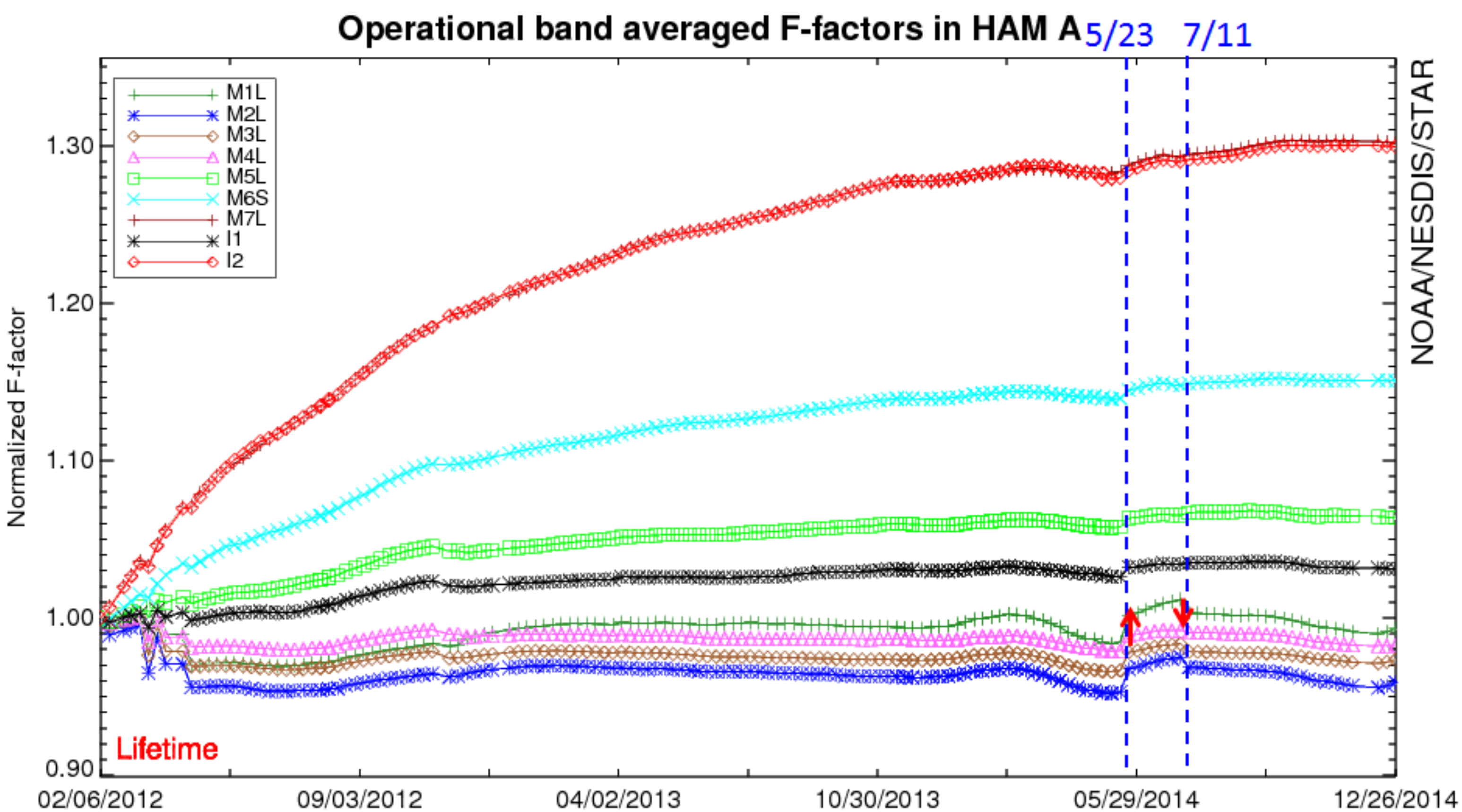
# VIIRS SDR Processing Changes



# VIIRS DNB and TEB Calibration



# VIIRS Reflective Solar Band (RSB)
# F /H Factor LUTs

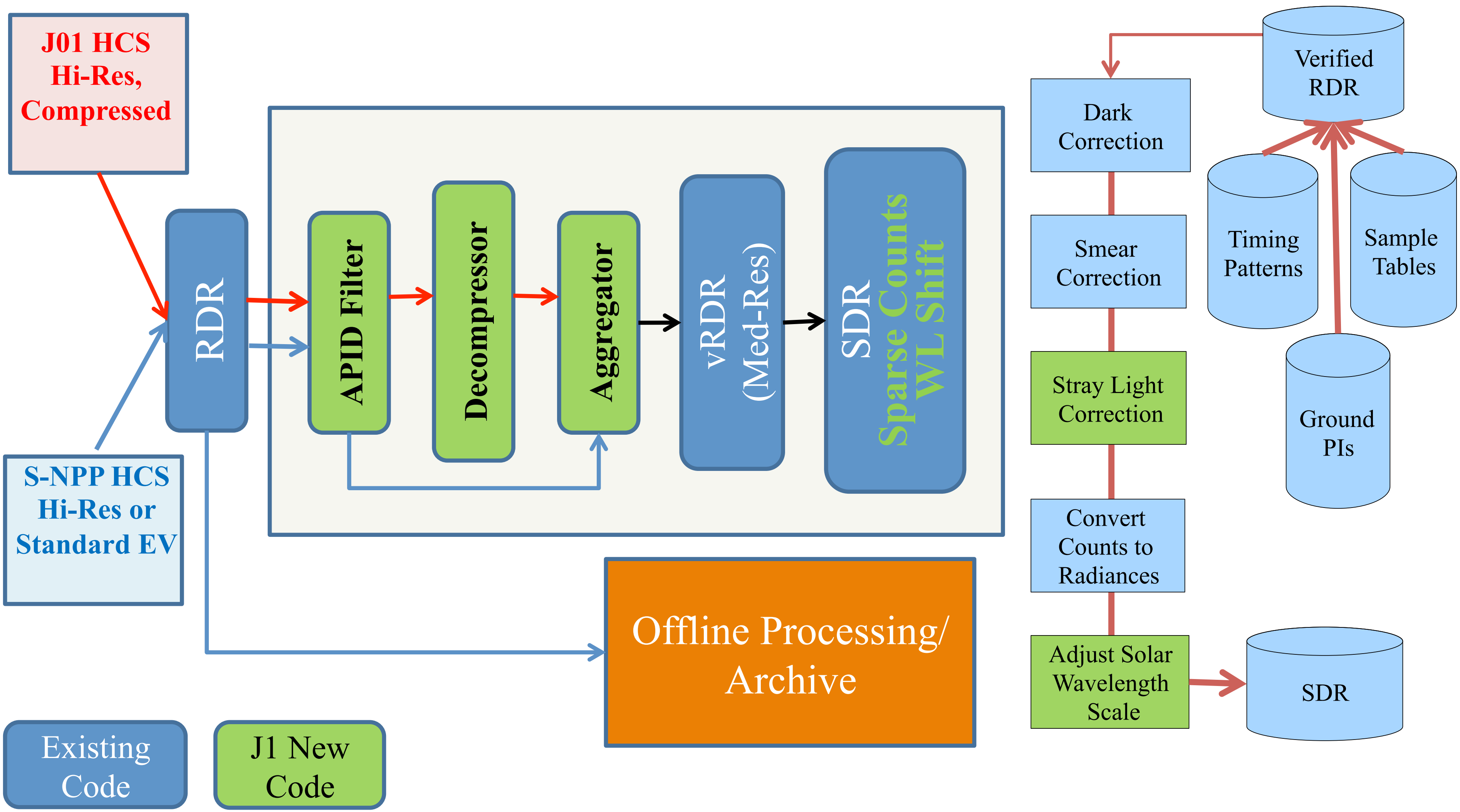



- The H-factor is directly related to the F-factor.
- The changes in the H-factors affect the reflectance in short wavelength bands in M1 to M4 (up to 1.5% jump).

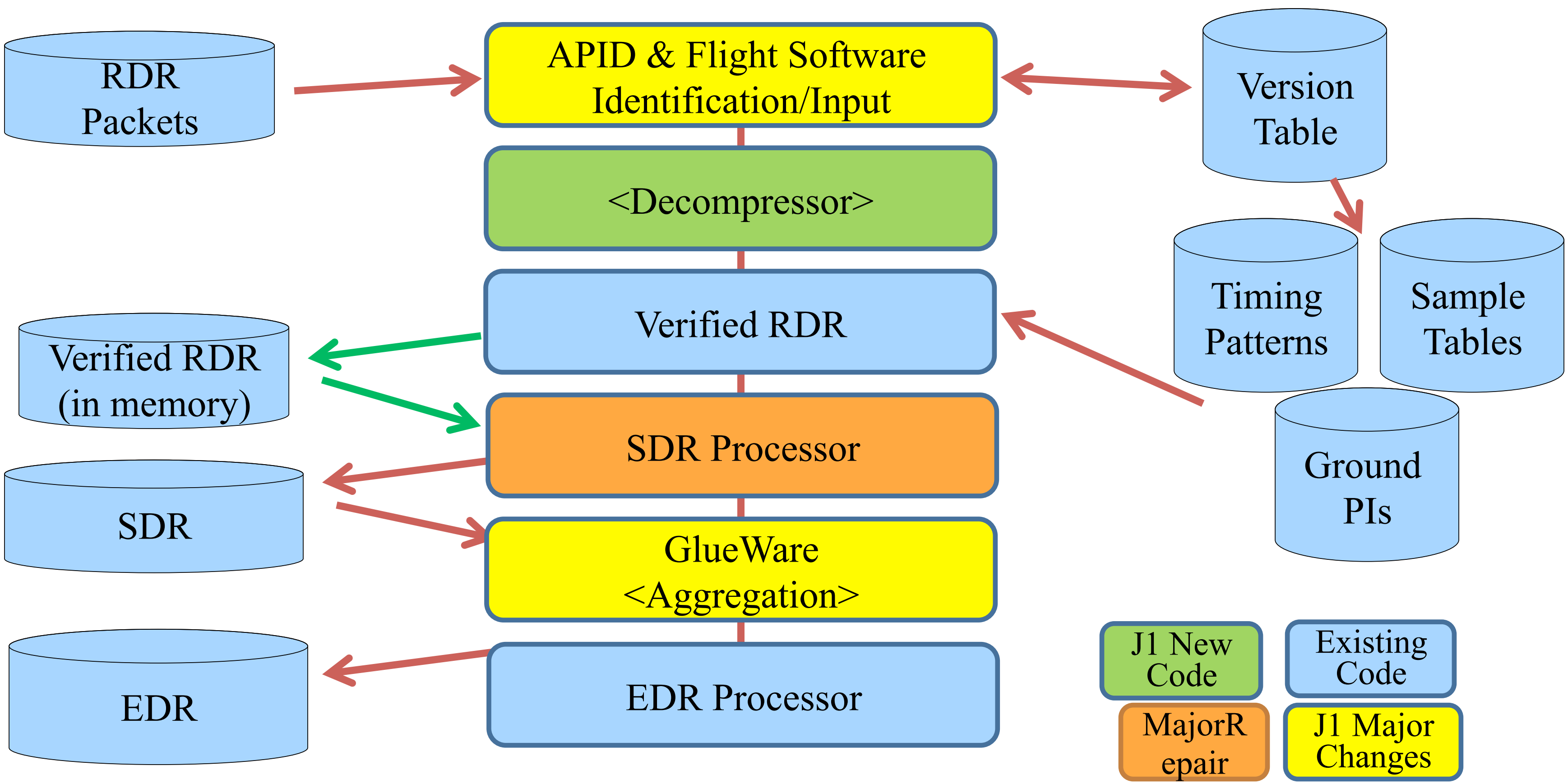
# JPSS-1 OMPS SDR Algorithm Change Summary

- Decompression Subroutine
  - A new subroutine to decompress Flight Software 6.0 compressed data. Decompression will effectively double our data rate from the instrument to the ground.
- Small FOV SDR processing to the OMPS Nadir Profiler and Nadir Mapper
- Aggregator Subroutines
  - A new subroutine for the Nadir Mapper to aggregate small Field-of-View data into standard FOVs prior to SDR processing.
  - A new component of the Nadir Profiler "glueware" to aggregate small SDR FOV measurements into standard FOVs.
- Model Based Wavelength Shift is developed
  - A branch of the code to compute model estimates of the wavelength shifts.
- Filling of Sparse Spectral Counts
  - A branch of the wavelength scale adjustment code to interpolate and extrapolate counts for unmeasured rows using the relative solar irradiance values. This allows continued use of the current stray light correction procedure.

# JPSS-1 OMPS NM SDR Change Overview
# Four Algorithm Changes

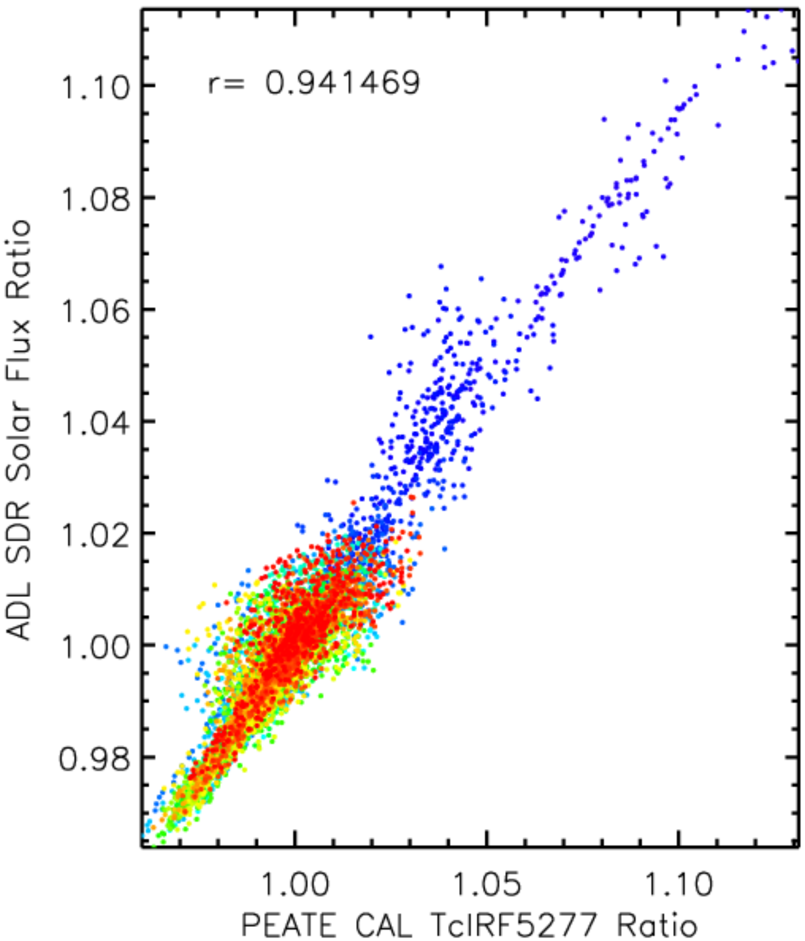


# JPSS-1 OMPS NP SDR Change Overview
# Three Algorithm Changes

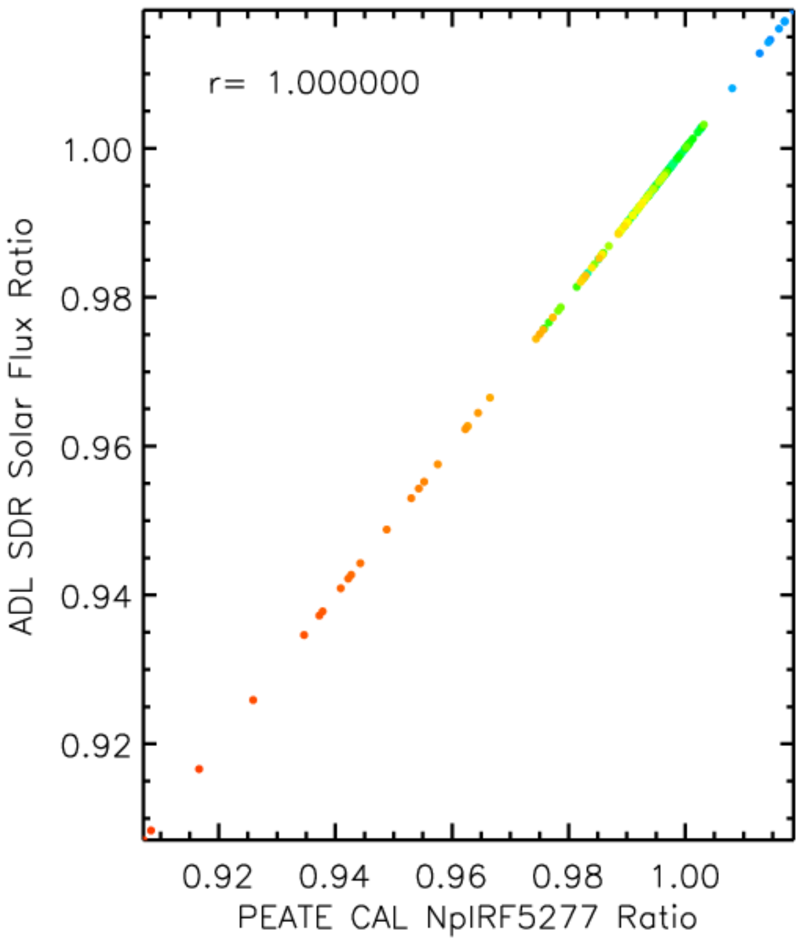


# IDPS OMPS NM/NP Solar Flux Compared with NASA PEATE (CAL IRF5277)

NM



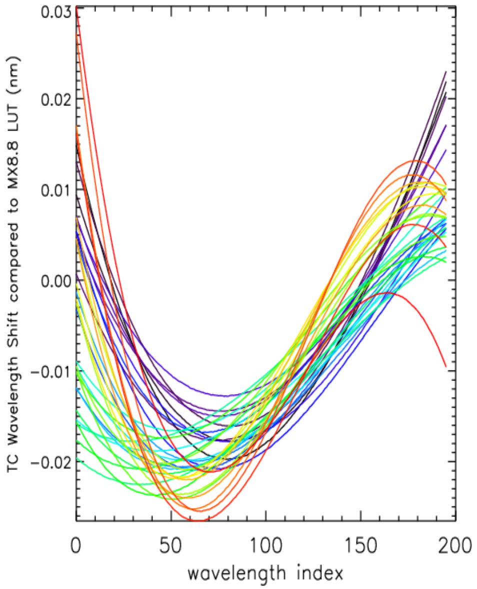

NP



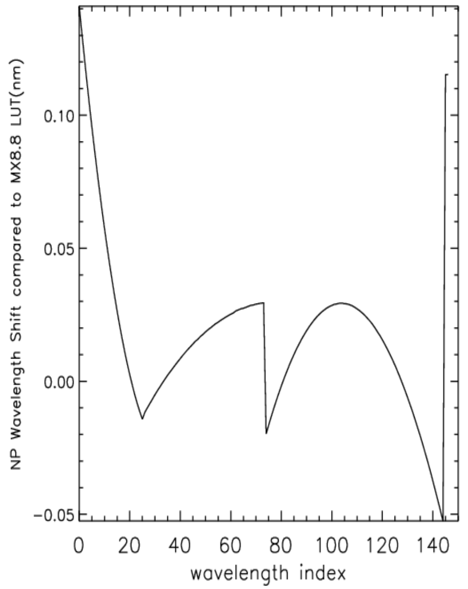

The discrepancy of NM solar flux derived from IDPS and NASA PEATE still remains obvious and varies with angle.

# Influence of TC/NM and NP Wavelength Shifts on Ozone Profile EDR

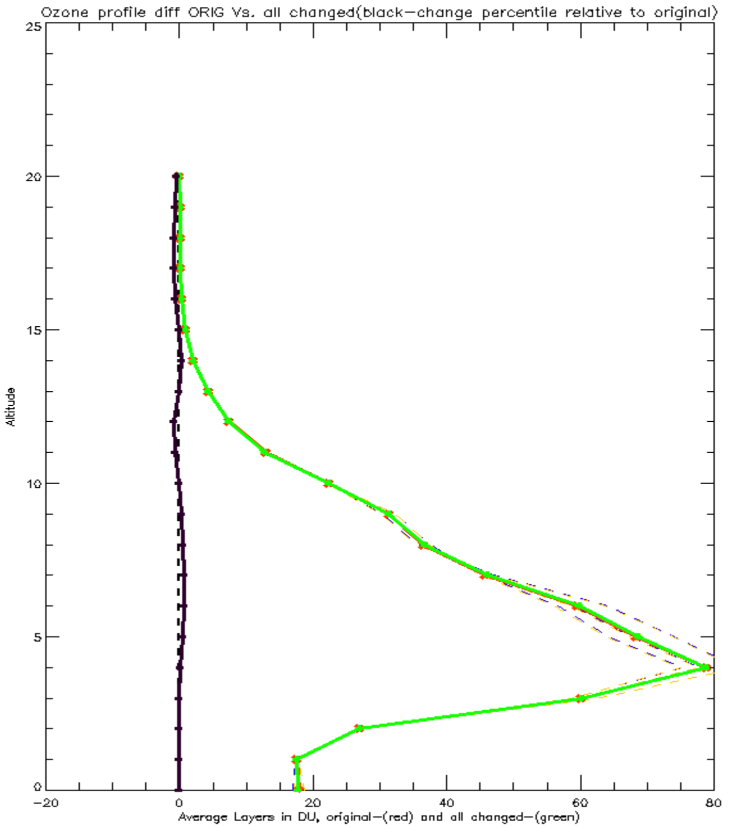
**TC/NM**




**NP**




**Ozone Profile**




- TC wavelength shift is less than 0.03nm.
- 35 colorful lines represent 35 macropixels.
- NP wavelength shift is in the range of -0.05nm to 0.14nm.
- Ozone vertical profile changes caused by TC and NP wavelength shifts are small but cant be neglected.

Slide Courtesy of Zhihua Zhang

# STAR Interests in Exploring the CDRs from Operational Satellite Missions

- *40 years (1978-2018) of microwave sounding data records – C. Zou*
- *AVHRR Pathfinder Atmospheres-Extended (PATMOS-X) – A. Heidinger*
- *AMSU window channel FCDR and TCDR – R. Ferraro*
- *40 years of ozone products from SBUV2, OMI and OMPS – L. Flynn*
- *A long-term sea ice product from satellites – J. Key*
- AVHRR and VIIRS vegetation health and drought products – F. Kogan
- VIIRS ocean color EDR reprocessing – M. Wang
- ACSPO AVHRR and VIIRS SST reanalysis – A. Ignatov
- 5 km Global Blend SST analysis – E. Maturi
- Sea level height budget analysis – L. Miller

Highlighted projects are being funded through NCEI CDR program

# Available MSU/AMSU/SSU FCDR and TCDR Products

<table>
<tr><th></th><th>MSU, 9 satellites<br>1978-2006</th><th>AMSU, 6 satellites<br>1998-present</th><th>SSU, 7 satellites<br>1978-2006</th></tr>
<tr><td>Radiance FCDR</td><td>Completed;<br>Transitioned to NCEI</td><td>Completed;<br>Transitioned to NCEI</td><td>Completed;<br>Archived at STAR</td></tr>
<tr><td>Layer Temperature TCDR from Single Instrument</td><td>Completed;<br>Transitioned to NCEI</td><td>Completed;<br>To be transitioned to NCEI in FY2016</td><td>Completed;<br>Archived at STAR</td></tr>
<tr><td rowspan="2">Merged Layer Temperature TCDR from Different Instruments</td><td colspan="2">MSU/AMSU Merging Completed;<br>Transitioned to NCEI</td><td></td></tr>
<tr><td></td><td colspan="2">Still Working on SSU/AMSU Merging;<br>To be Completed in FY2016</td></tr>
</table>

*Cheng-zhi Zou*

# Funding Source, Users and Applications, Future Plan

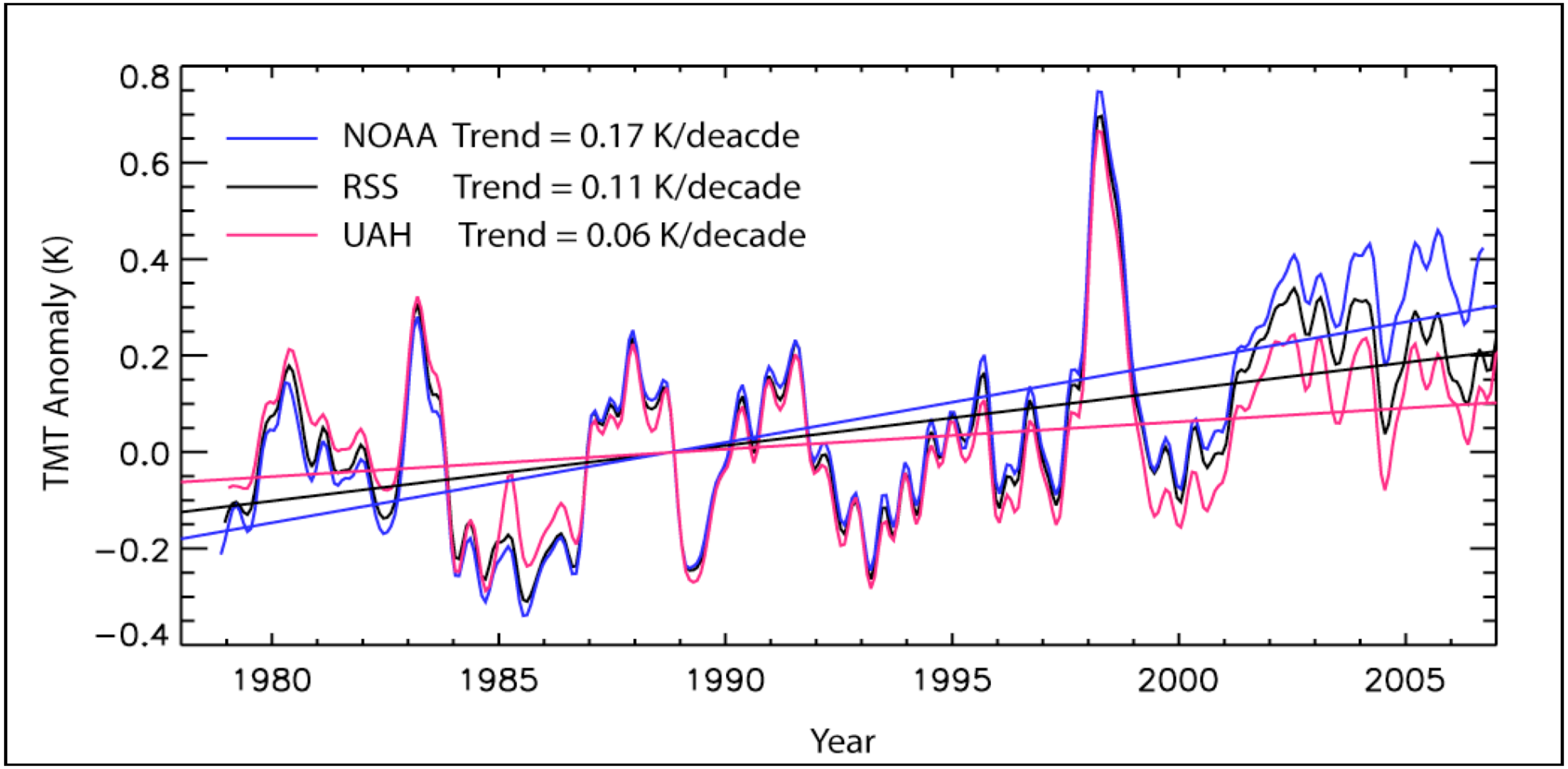
- NCEI CDR Program for Product Transition from STAR to NCEI
- STAR leveraged funding for FCDR/TCDR development
- FCDR users: Climate reanalysis development
  Consistent retrievals for climate quality dataset
- TCDR users include: IPCC
  NCEI annual climate assessment
  WCRP/SPARC
  Academics
- Future plans: To inter-calibrated ATMS with AMSU-A for consistent AMSU/ATMS radiance FCDR

  To merge ATMS with AMSU to develop MSU/AMSU/SSU/ATMS layer temperature TCDR from 1978 to present and beyond

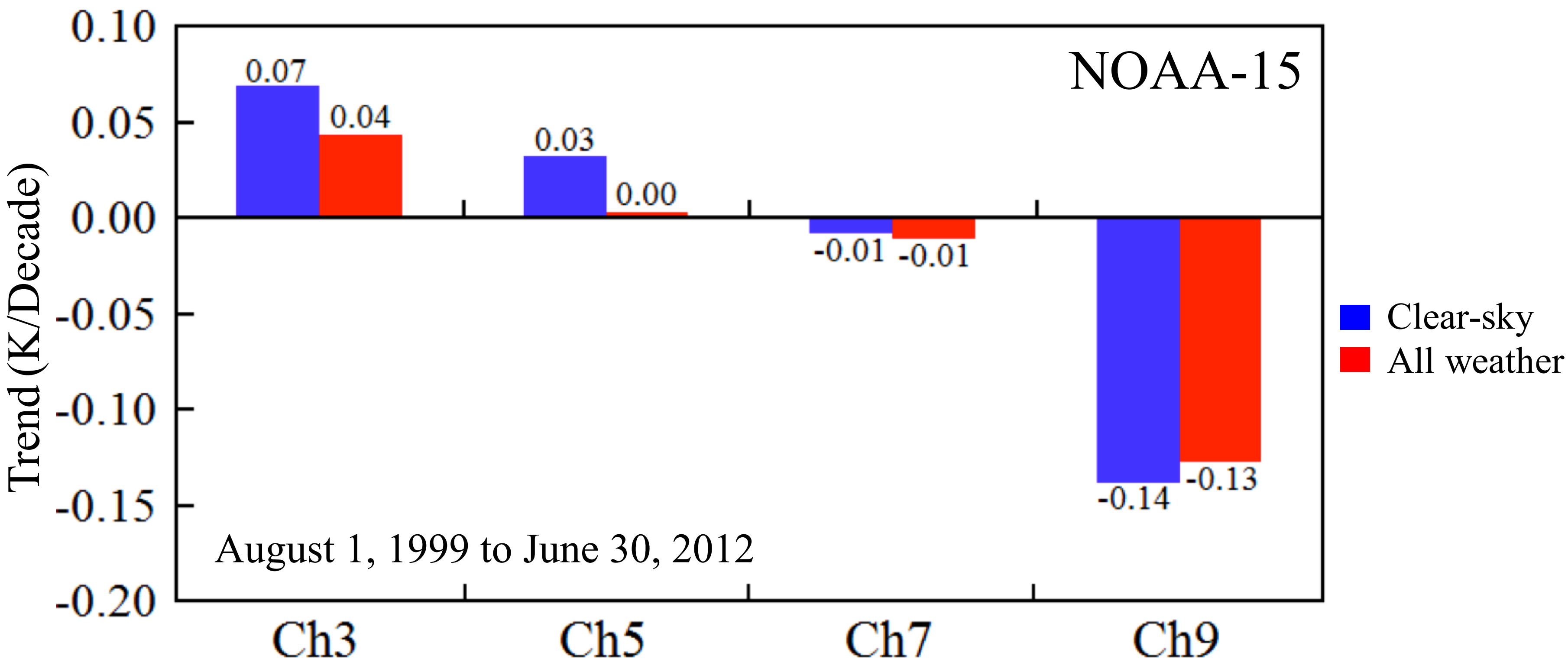
*Cheng-zhi Zou*

# Three MSU Groups Derived Different Global Tropospheric Temperature Trend

Example: Middle Tropospheric Temperature.

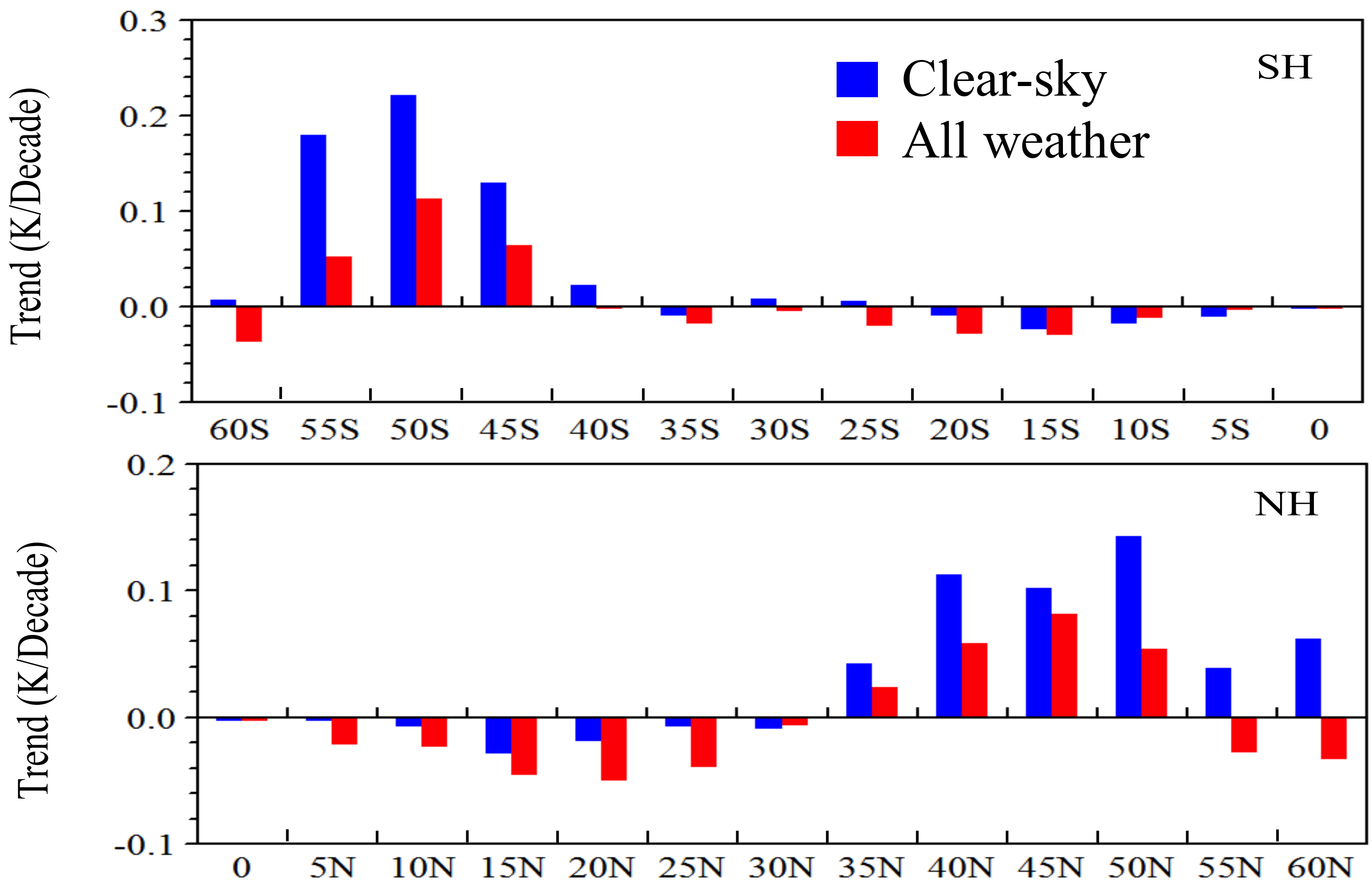


# Impact of Clouds on AMSU-Derived Global Warming



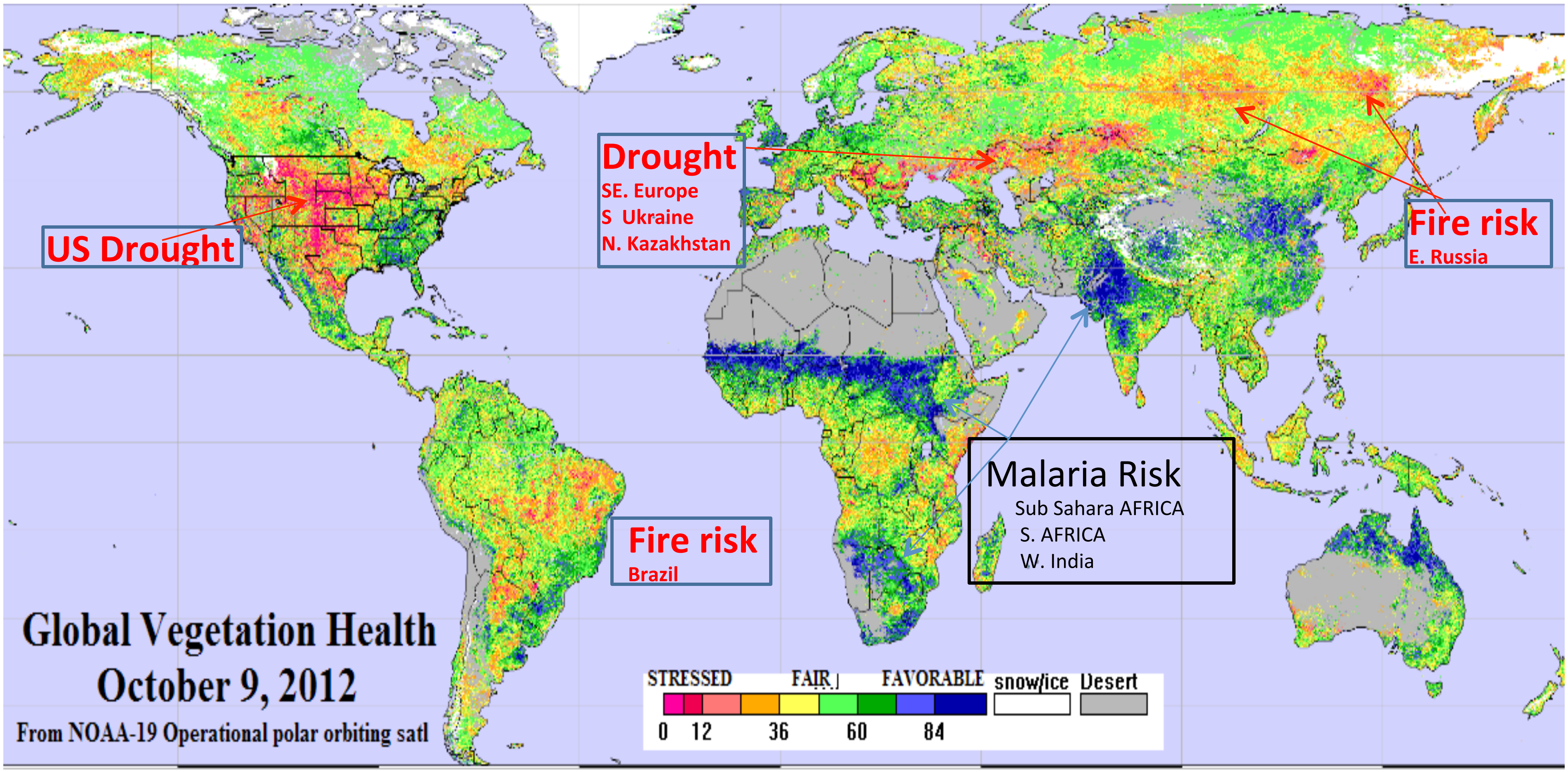

**When the cloud effect is eliminated, the global temperature trend for both channels 3 and 5 is increased by 43%.**

# Cloud Impacts on MSU/AMSU Channel 5 Derived Trends in South and North Hemispheres



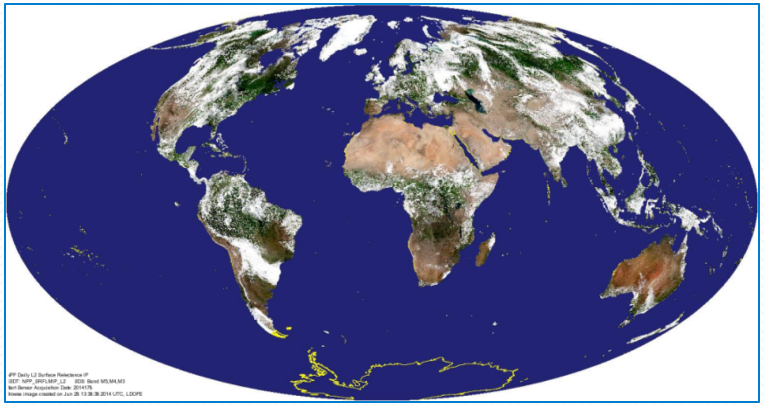
# 2012 Global Vegetation Health

From AVHRR/NOAA-19 Operational Polar Orbiting Satellite

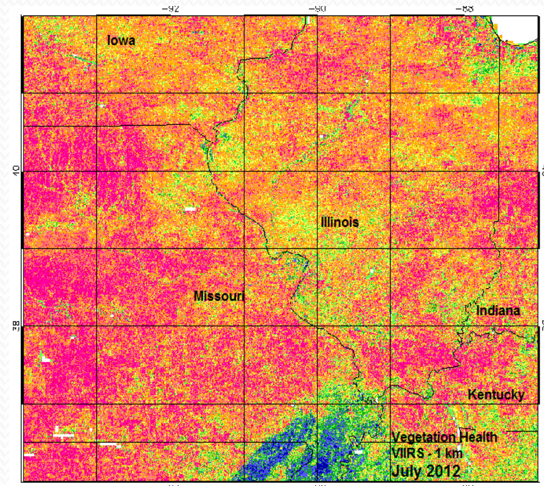



*Slide courtesy of Felix Kogan*

# Principal VIIRS Land Products

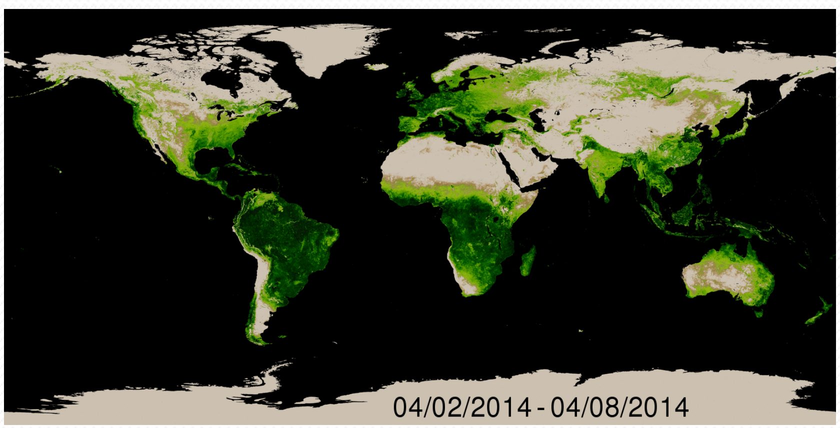


***Surface reflectance: extended to all atmospheric conditions***

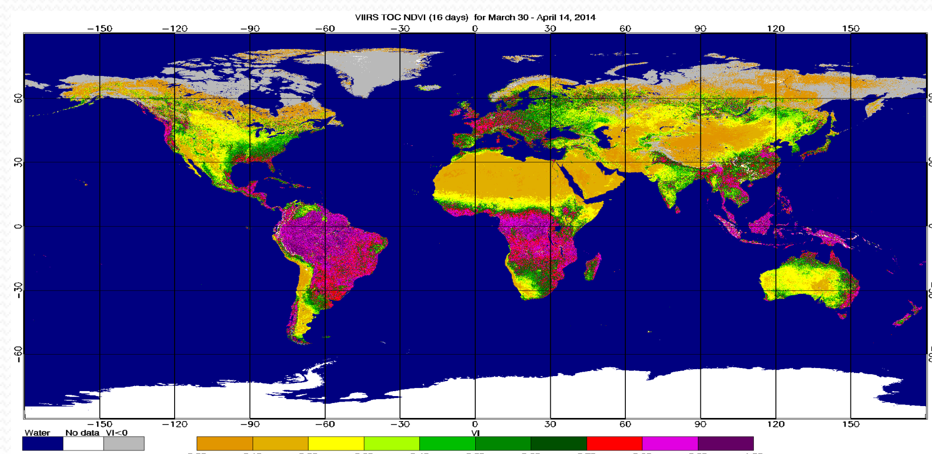



***Vegetation Health: long-term continuity, drought monitoring***

***Vegetation indices: extended to suite of top-of-atmosphere and top-of-canopy variables***




***Green Vegetation Fraction: critical input to NCEP Land modeling suite***




Ivan Csiszar, F. Kogan, and Bob Yu

# VIIRS Ocean Color EDR Reprocessing

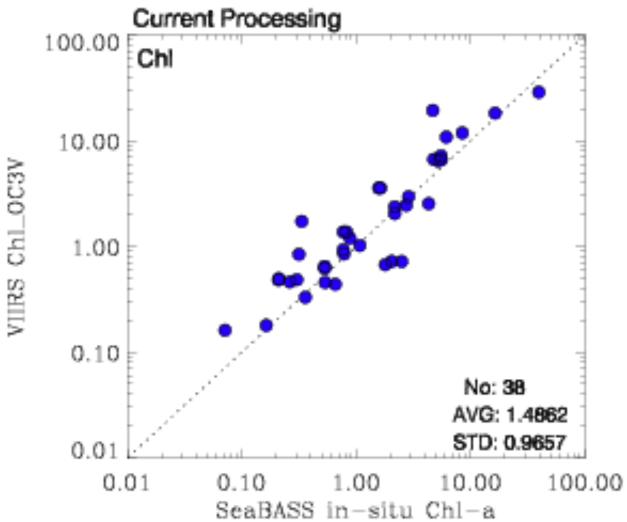
**Users require science quality time series** Ocean Color data (i.e. NMFS, NOS, OAR, NWS, and outside NOAA agencies, academics, etc.)

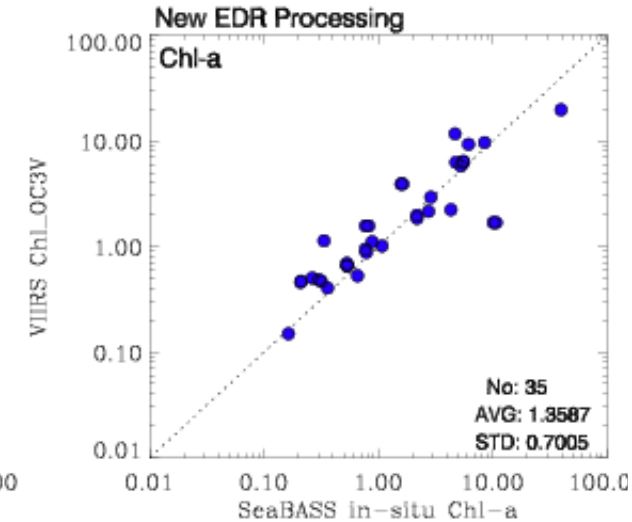
***The VIIRS Ocean Color EDR team is currently reprocessing mission-long, "Science Quality" VIIRS ocean color data.***

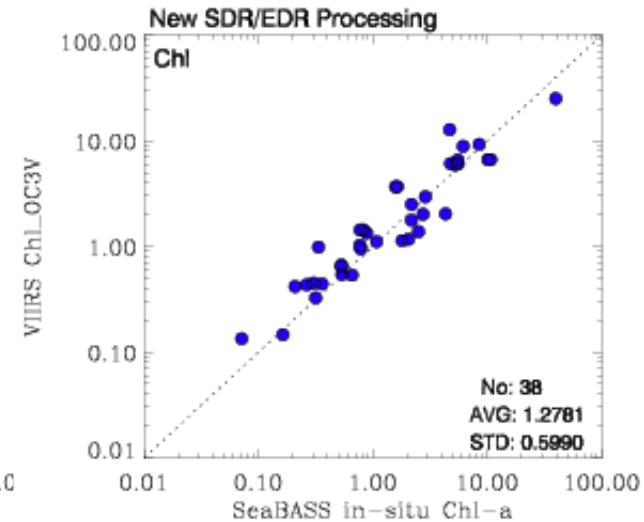
| Attribute | Near-Real Time | Science Quality Delayed Mode |
|---|---|---|
| *Latency:* | Best effort, as soon as possible (~12-24h) | Best effort, ~1-2 week delay |
| *SDR:* | IDPS Operational SDR | OC-improved IDPS SDR |
| *Ancillary Data:* | Global Forecast System (GFS) Model | Science quality (assimilated; GDAS) from NCEP |
| *Spatial Coverage:* | May be gaps due to various issues | Complete global coverage |
| *Processed by:* | CoastWatch, transferring to OSPO | NOAA/STAR |
| *Distributed by:* | CoastWatch | CoastWatch, NCEI |
| *Archive Plans:* | TBD | Yes, NCEI |
| *Reprocessing:* | No | Yes, ~2-3 years or as needed |

*Menghua Wang*

# Matchup Comparison of SeaBASS Chl-a




| | Ratio of OC3V/Chl | | | OC3V vs Chl | | | log(OC3V) vs log(Chl) | | | No |
|---|---|---|---|---|---|---|---|---|---|---|
| | AVG | MED | STD | Slope | Intcpt | $R^2$ | Slope | Intcpt | $R^2$ | |
| Current Data Processing | 1.4862 | 1.2273 | 0.966 | 0.812 | 1.225 | 0.78 | 0.866 | 0.112 | 0.81 | 38 |
| New EDR Processing (2015-03-19) | 1.3587 | 1.2210 | 0.701 | 0.487 | 1.391 | 0.66 | 0.743 | 0.102 | 0.77 | 35 |
| New SDR/EDR Processing (2015-02-26) | 1.2781 | 1.1933 | 0.599 | 0.652 | 1.099 | 0.83 | 0.857 | 0.085 | 0.89 | 38 |

**Improved** with new MSL12 and new SDR/MSL12.
Accuracy for Chl-a is within ~30% for Chl-a of 0.1 to ~30 mg $m^{-3}$.

*Menghua Wang*

# Summary and Conclusions

- STAR calval teams provide critical supports to JPSS and GOES-R programs, and are also essential to NOAA CDR program
- Innovative calval sciences are developed for better characterization of instrument noises and product accuracies
- A mission life cycle reprocessing is being explored at both SDR and EDR levels through JPSS CalVal program funded to STAR
- STAR is responsible for WMO GSICS coordination, and provides the cross-calibration of operational and research instruments and develops the SDR data consistency across all the missions
- STAR ICVS is monitoring and trending all the instrument performance in orbits and also accumulating the critical metadata for CDR generations
- STAR satellite CDR projects have been funded by NCEI CDR program and the data sets have been delivered to NCEI for general dissemination and archival
- Many peer review and highly influential papers were published by STAR scientists. The CDR data sets developed by STAR are cited in nature and science papers and are being used in NWP reanalysis

# Backup Slides from STAR CDR PIs

# AVHRR Pathfinder Atmospheres Extended (PATMOS-x)

- **History**
  - PATMOS developed by NESDIS/ORA in 1990's as part of NASA/NOAA Pathfinder
  - PATMOS was only afternoon AVHRR's and included cloud fraction, OLR and aerosol over ocean. Ended in 2000.
  - PATMOS-x included all AVHRRs (morning, mid-morning, afternoon) from 1979 to 2015.
- **PATMOS-x CDR Products**
  - Spatial Resolution = 0.1$^{o}$. Temporal resolution = 2 – 6 times per day.
  - Fundamental
    - Solar-reflectance channels calibrated with PATMOS-x coefficients (in GSICS)
    - Thermal channels calibrated with original Pathfinder approach.
  - Thematic
    - Cloud properties: Amount, Cloud Water Path, Height, Temperature, Pressure, Emissivity, Optical Depth, Particle Size.
    - Surface properties: Land Surface Temperature, NDVI
    - Radiation: Outgoing Longwave Radiation (OLR)
- **Major Funding Sources**
  - ORA AVHRR Pilot Project (2004-2006)
  - NCDC SDS Project (2008-2010)
  - NCDC CDR Project (2010-2015)

*Andy Heidinger*

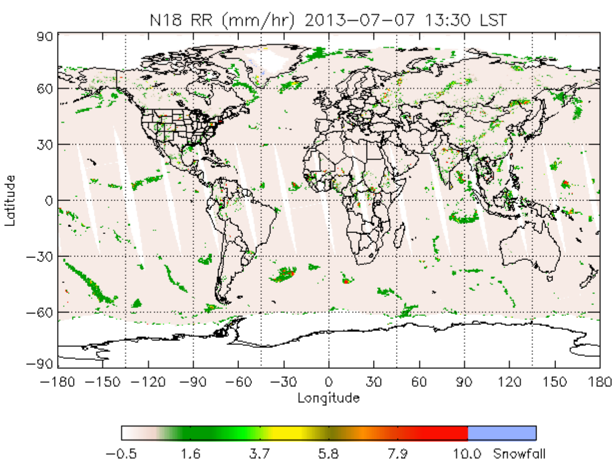
# Pathfinder Atmospheres Extended (PATMOS-x)

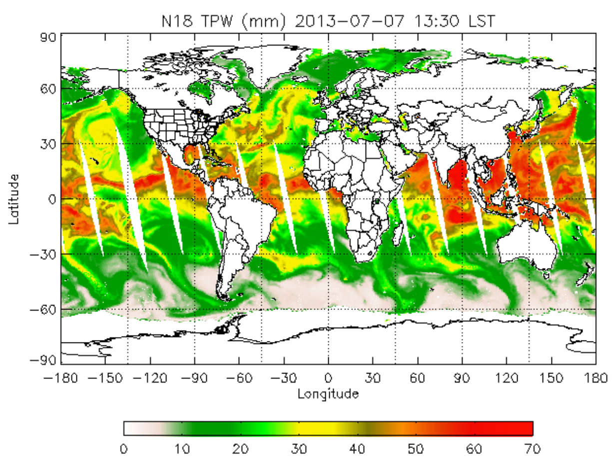
- **Users and Applications**
  - Solar-reflectance calibration is used by EUMETSAT CM-SAF
  - PATMOS-x FCDR used by the NCDC Aerosol CDR project
  - PATMOS-x participated in GEWEX Cloud Climatology Assessment
  - PATMOS-x calibration submitted to and accepted into GSICS.
  - 23 articles with PATMOS-x in the title (Google Scholar).
  - Over 300 articles with reference to PATMOS-x data and methods.
  - PATMOS-x analysis appears in BAMS State of Climate 2008-2014
- **Plans or Recommendations for Future Work**
  - PATMOS-x AVHRR being modified to use HIRS data with support from NCDC.
    - This will give a spectral baseline of 0.65, 0.86, 1.6, 3.75, 6.7, 8.5, 11, 12 and 13.3 microns.
    - ***This baseline can extend far into the future on MODIS and VIIRS/CrIS.***
  - PATMOS-x can also process data from many other instruments. We would like specifically to make an hourly GOES I-M and GOES NOP version of PATMOS-x.
  - VIIRS version of PATMOS-x is being explored.

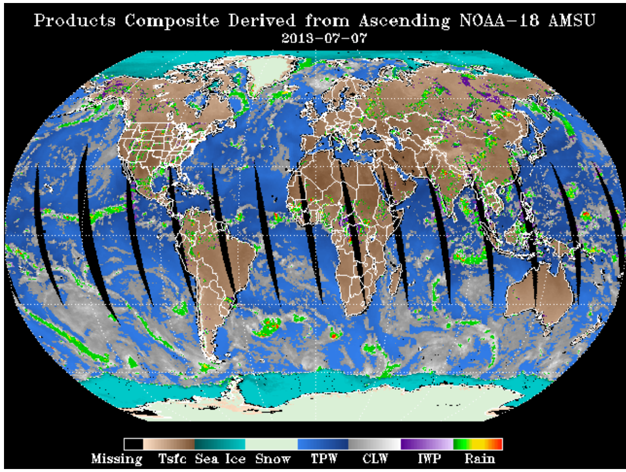
*Andy Heidinger*

# AMSU FCDR's and TCDR's for Hydrological Applications

- FCDR: AMSU-A: 23.8, 31.4, 50.3, 89.0 GHz, AMSU-B/MHS: 89, 150/157; 183±1, 183±3, 183±7/190 GHz
- TCDR's for hydrological products (12 products)
  - Rain rate (and snowfall detection), total precipitable water, cloud liquid water, ice water path, sea ice concentration, snow cover, snow water equivalent, land surface temperature, land surface emissivity 23, 31 and 50 GHz.
- Satellites: NOAA-15,16,17,18,19 & MetOp-A
- Period; 2000-2016



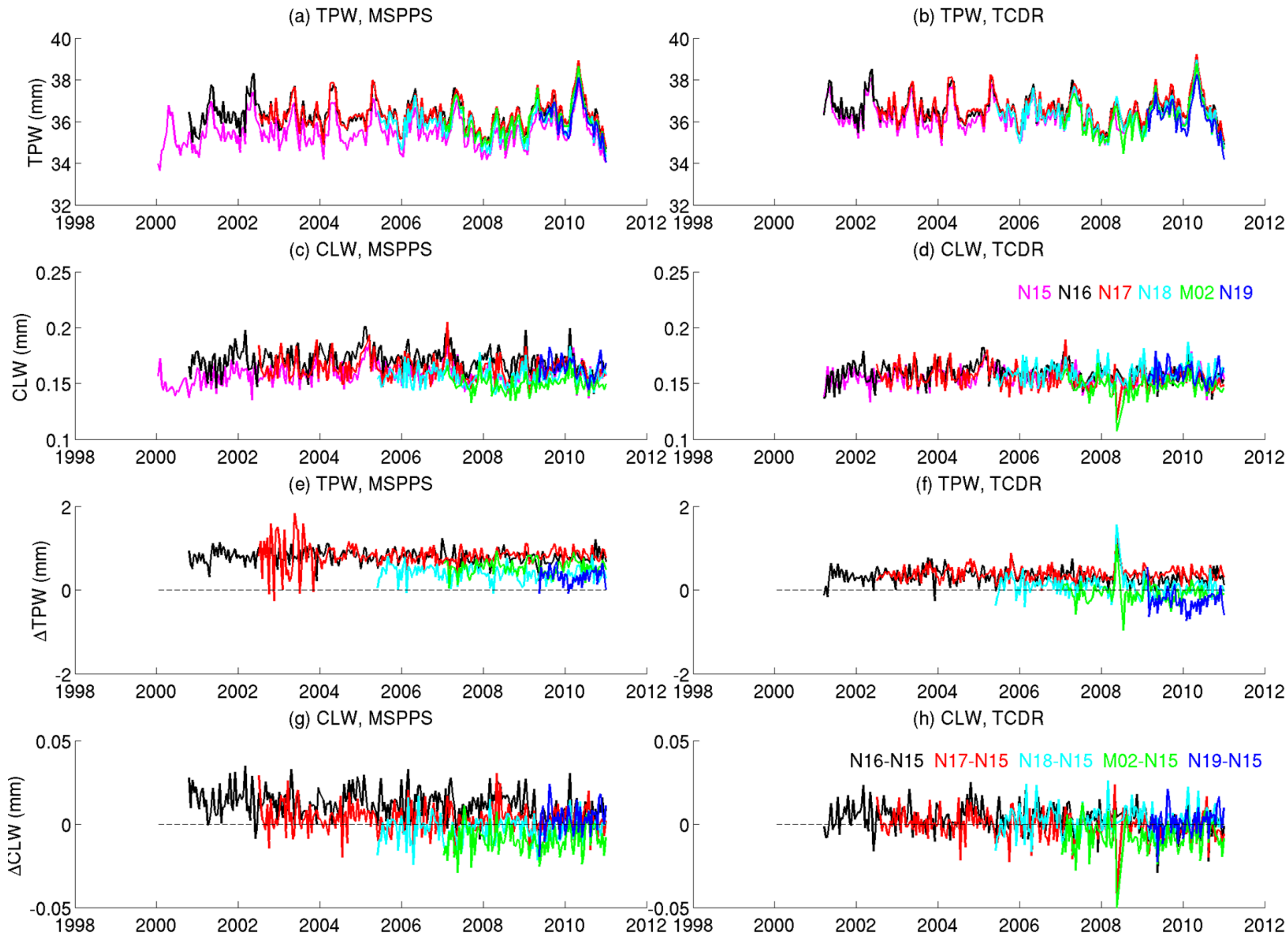




*Ralph Ferraro*

# Impact of Inter-Calibration on TCDR's

BEFORE




AFTER

*Ralph Ferraro*

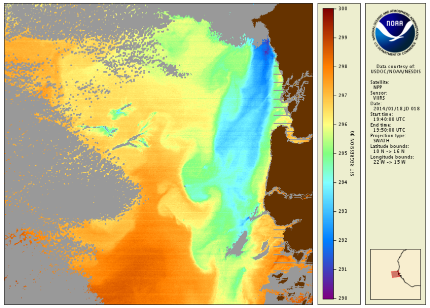
# ACSPO VIIRS SST Reanalysis ("RAN1") and ACSPO AVHRR GAC RAN1 (2002-pr)

**Users require science quality time series** SST data (i.e. NMFS, NOS, OAR, NESDIS (STAR and NCEI), NWS NCEP, GHRSST, UK Met office, Canada Met Office, BoM of Australia, Japanese Met Agency, and other agencies, academics, etc.).

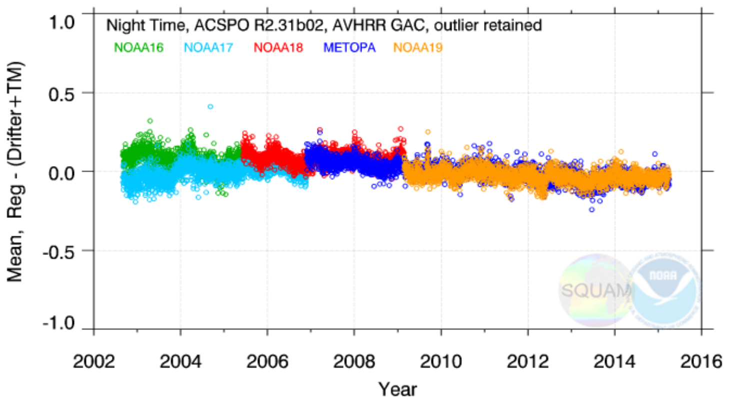
## ACSPO VIIRS SST Reanalysis ("RAN1")

- In partnership with Univ. of Wisconsin – Madison, Space Science and Engineering Center (SSEC)
- RAN infrastructure has been set up and tested at UW/SSEC, including the following codes
- Validation and monitoring is an integral part of RAN
    - www.star.nesdis.noaa.gov/sod/sst/iquam/
    - www.star.nesdis.noaa.gov/sod/sst/squam/
    - www.star.nesdis.noaa.gov/sod/sst/micros/
- ACSPO VIIRS RAN1 L2 and L3U data from Jan 2012-pr will be archived w/PO.DAAC and NCEI
- NOAA CoastWatch will also serve reprocessed data to users

Example S-NPP VIIRS SST image produced by the NOAA ACSPO system



## ACSPO AVHRR GAC RAN1 (2002-pr)



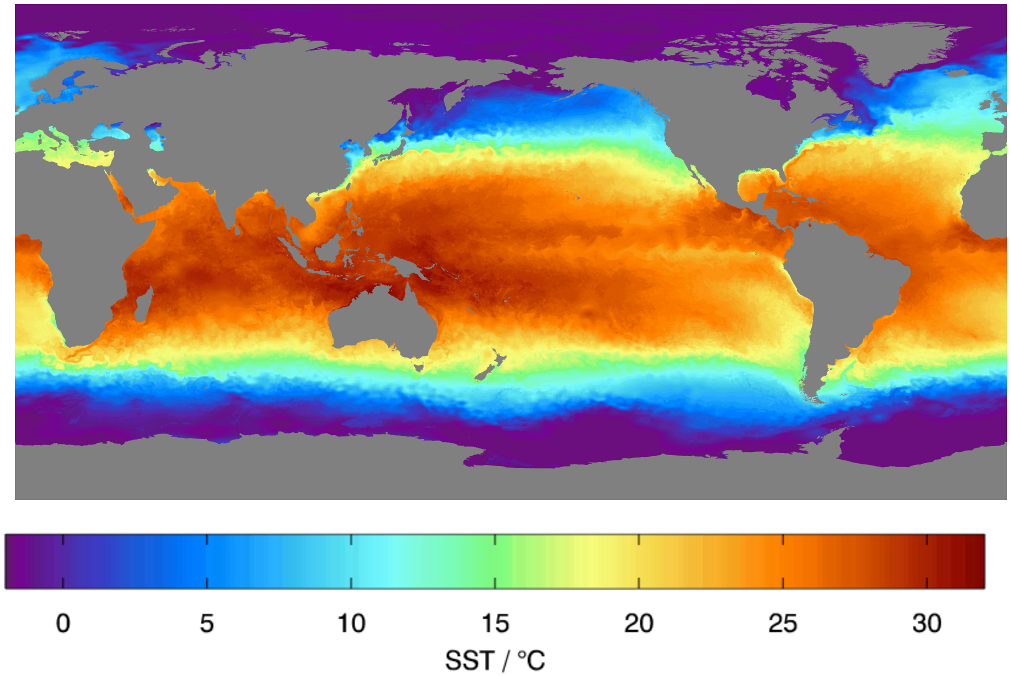

- Unstable sensors/periods excluded = 5 AVHRRs reprocessed
- 2 platforms at a time: One mid-AM (N17, Metop-A) and one PM (N16/18/19)
- L2/L3U will be archived with PO.DAAC & NCEI
- Will be tested in NOAA geo-polar blended and other L4 analyses (2015/16)
- RAN2 (~2017) will reprocess 1994-pr; RAN3: 1981-pr

*Alexander Ignatov*

# 5 km Global Blended SST Analysis Reprocessing

These 5-km blended SST analyses are produced daily from 24 hours of polar and geostationary sea surface temperature satellite retrievals:

- •S-NPP
- •Metop-B,
- •GOES-E/W
- •Meteosat-10
- •MTSAT-2 (will be replaced by Himawari-8 in November 2015.)



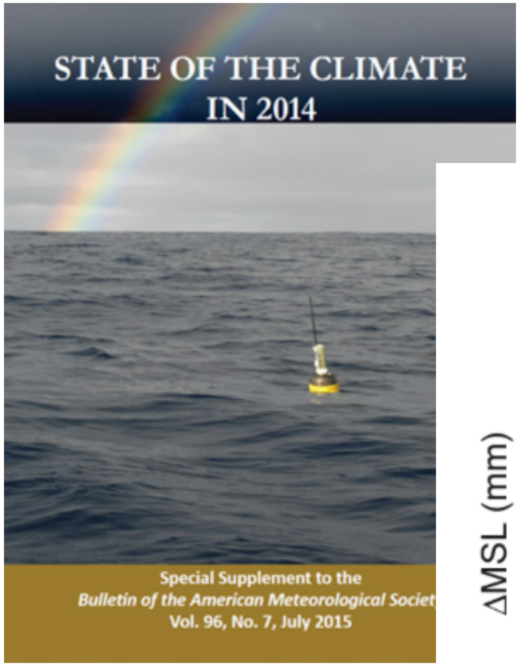

**PHASE I 2004 to present**
**September 2015**

**PHASE II 1994 to 2004**
**September 2016**

**Coral Reef Watch** will generate a new climatology for their bleaching alert and monitoring products for the coral reefs around the globe.

*Eileen Maturi*

# Closing the Global Sea Level Budget




*NOAA/STAR analysis shows 2/3 of recent sea level increase is due to mass (ice melt), 1/3 due to steric (ocean heating).*

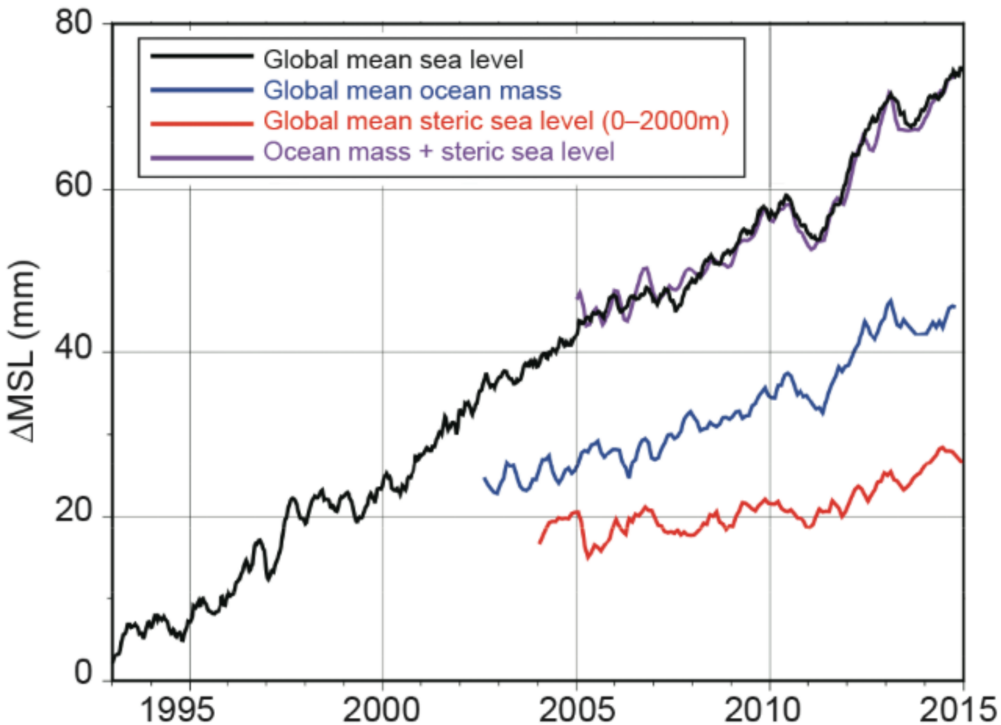



**FIG. 3.27. Comparisons of global mean sea level from NOAA/NESDIS/STAR, global mean ocean mass from GRACE, and steric (density) sea level from Argo, with seasonal variations removed and 60-day smoothing applied.**

*Laury Miller and Eric Leuliette*