Towards a Consensus AVHRR Reflectance Calibration

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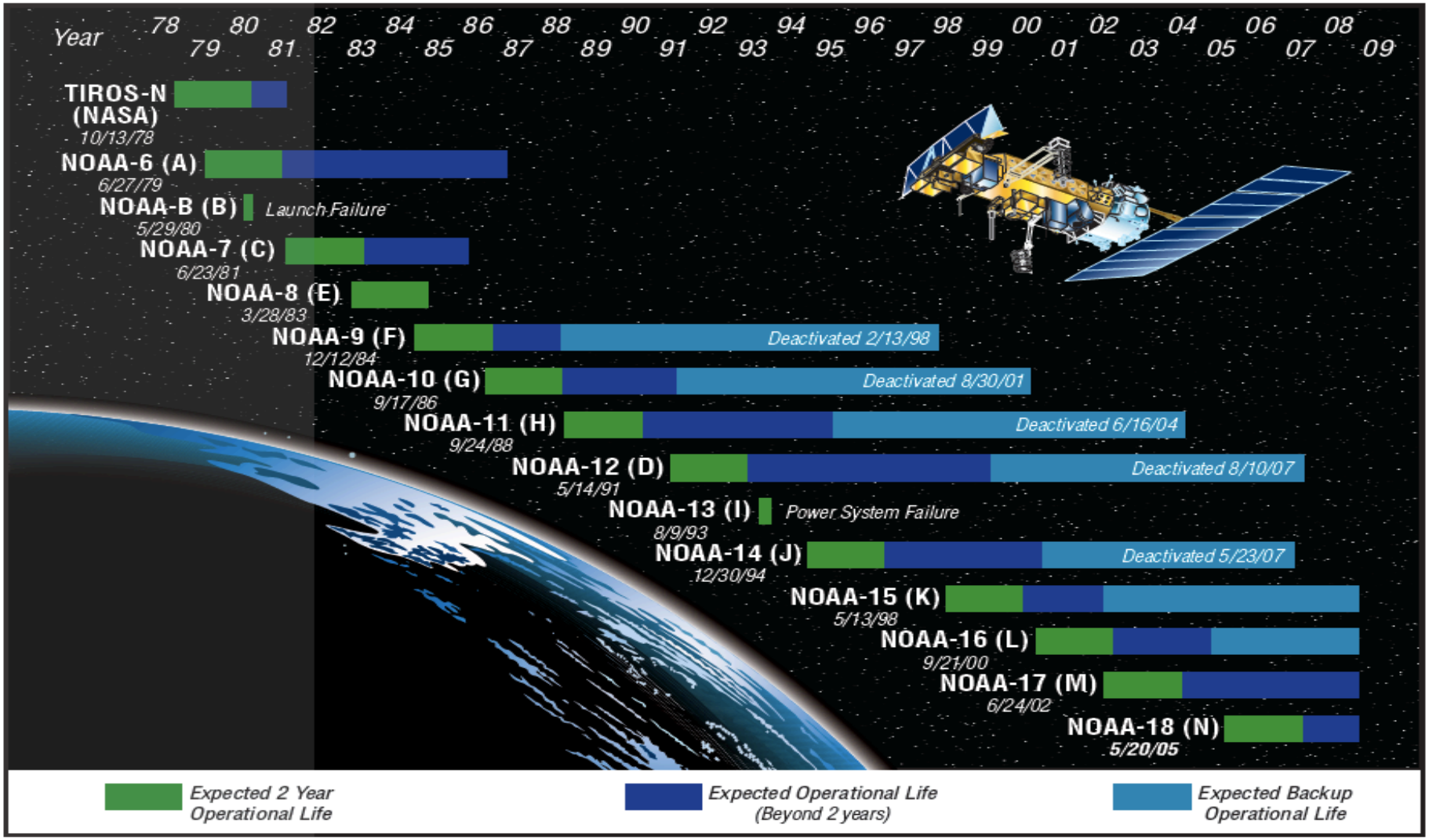
Outline

- **Project Overview and Summary**
- Approach
- Algorithm/Product Maturity
- Outstanding issues, activities, or risks
- Research-to-Operations Results
- Lessons Learned and recommendations

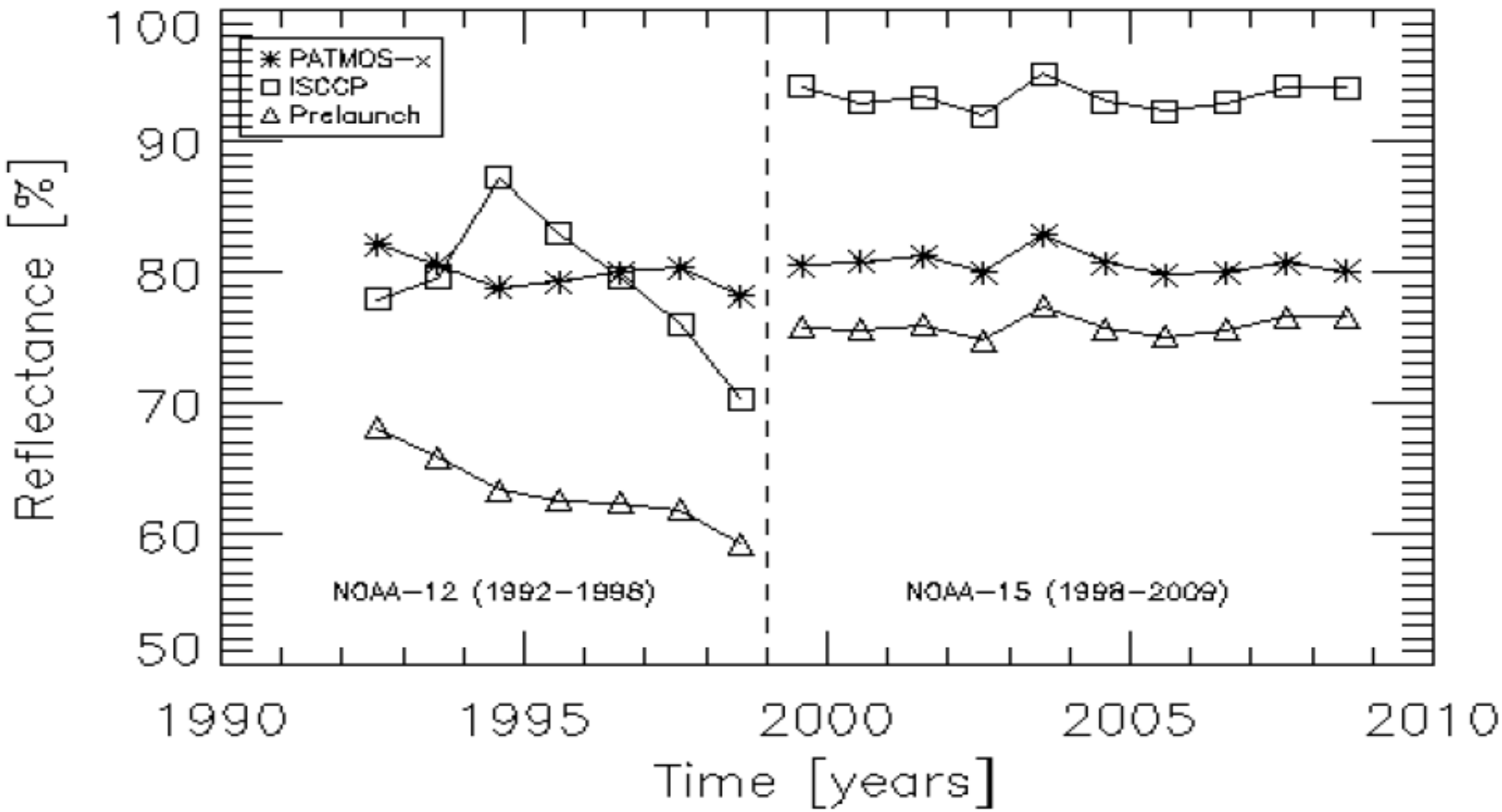
The Challenge: Making consistent climate records from 15 different AVHRR sensors given the lack of any onboard calibration source for the solar reflectance channels.

NOAA-N' launched in 2009 and METOP-A launched in 2006. METOP programs ends in 2020.



Motivation

•AVHRR Prelaunch is typically inadequate (no onboard calibration).
•Existing long-term AVHRR reflectance calibration parameter data sets contain some large artifacts that need to be addressed for CDR generation.
• Time series below show a region over Greenland from NOAA-12 and NOAA-15.



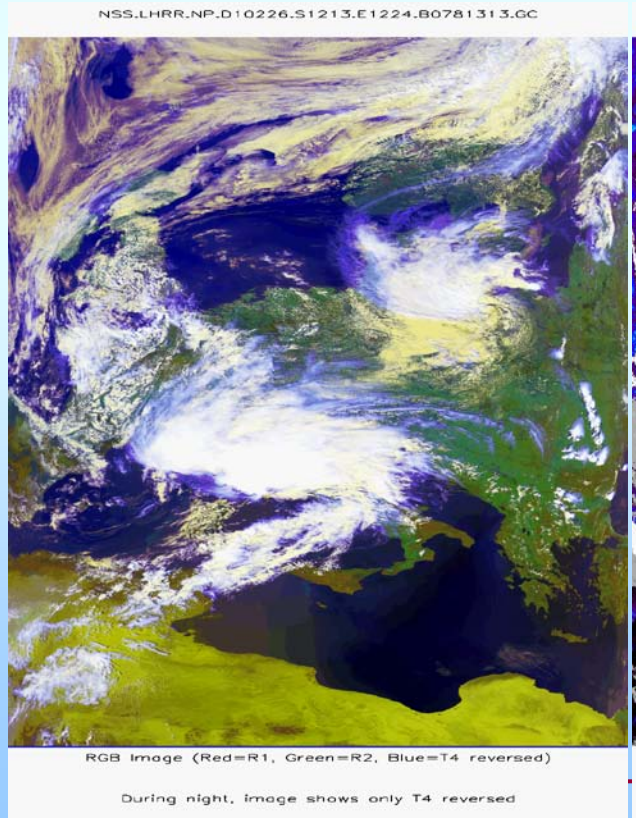
AVHRR's Remote Sensing Capabilities Impacted by the Reflectance Calibration

- Reflectances at 0.63, 0.86 and 1.6 μm
- Vegetation index
- Aerosol optical thickness
- Cloud properties
- Solar flux at the surface.
- Surface temperature.

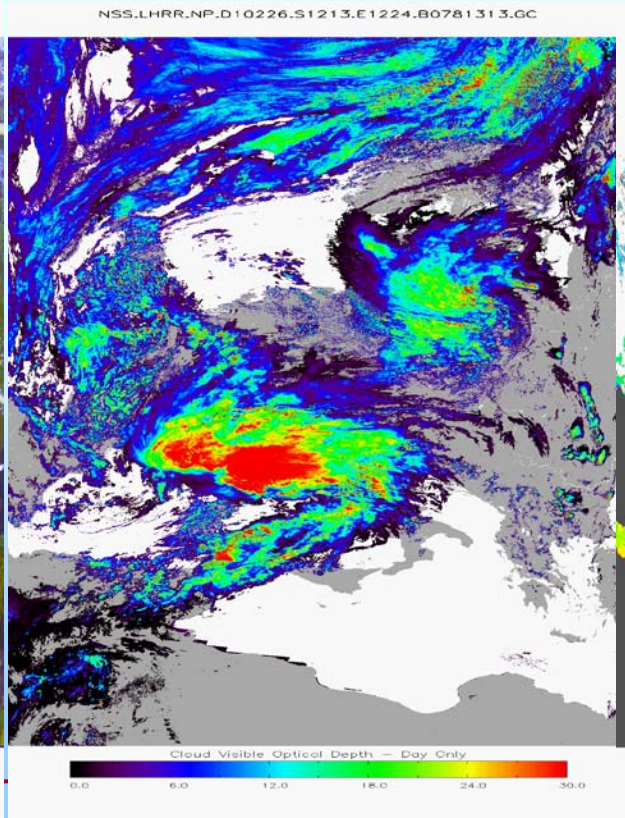
All of these are critical climate records that are at times and locations only provided by the AVHRR

Example AVHRR Images from NOAA-18 LAC over Europe (August 13, 2010)

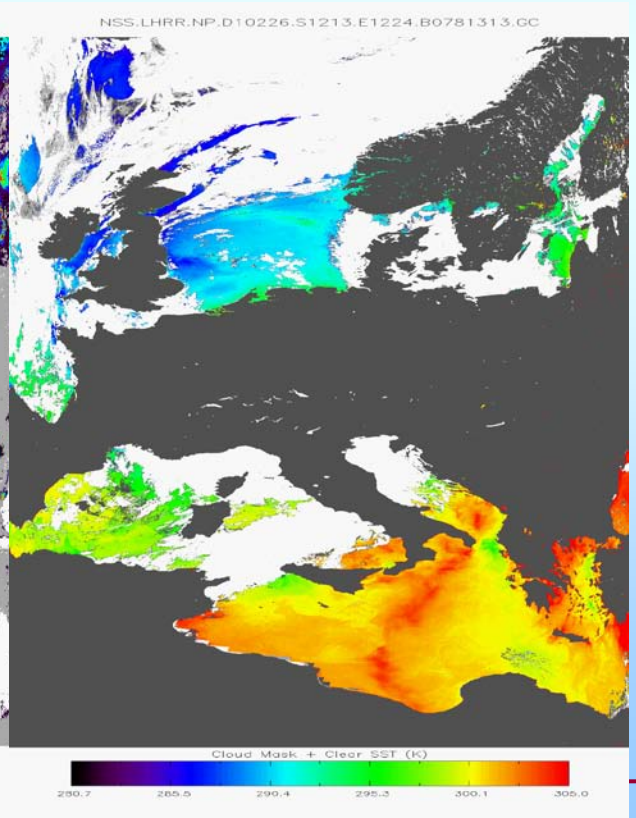
False Color Image (0.63, 0.86, 11 μm)



Cloud Optical Thickness (0.63 μm)



Clouds + Sea Surface Temperature (K)



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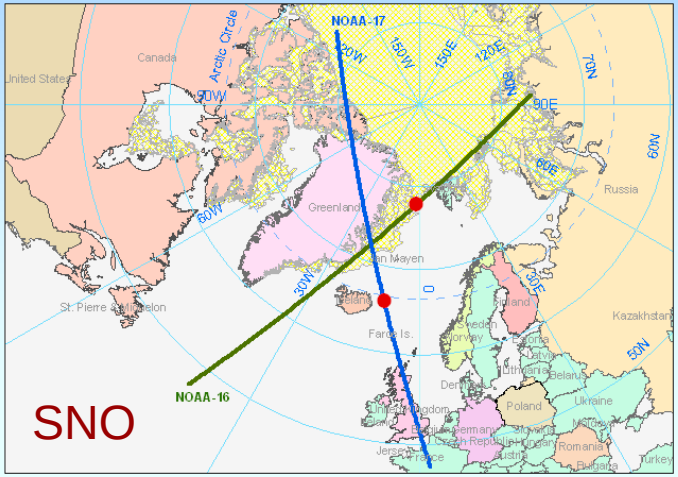
AVHRR Reflectance Calibration Methodology

Our new PATMOS-x AVHRR reflectance calibration is based on 4 different sources of data. All absolute values derive from MODIS. Method has been applied to all sensors.

1. MODIS to AVHRR SNO (2000-2009)
2. AVHRR to AVHRR SNO (1980-2009)
3. Libyan Desert MODIS-derived Reference
4. DOME-C MODIS-derived Reference



Images courtesy of CEOS and STAR websites

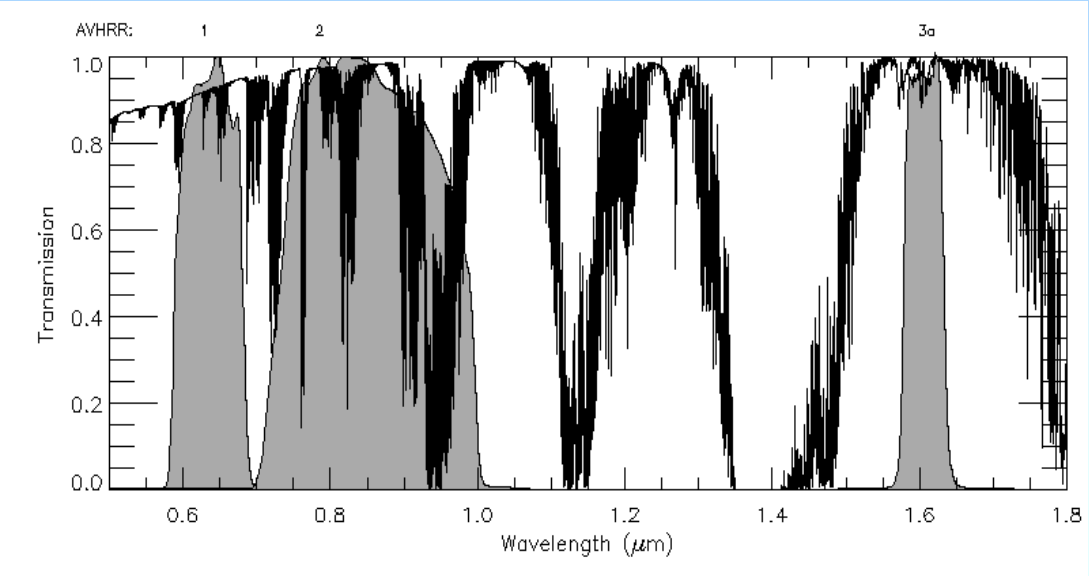
Accounting for Spectral Response Differences

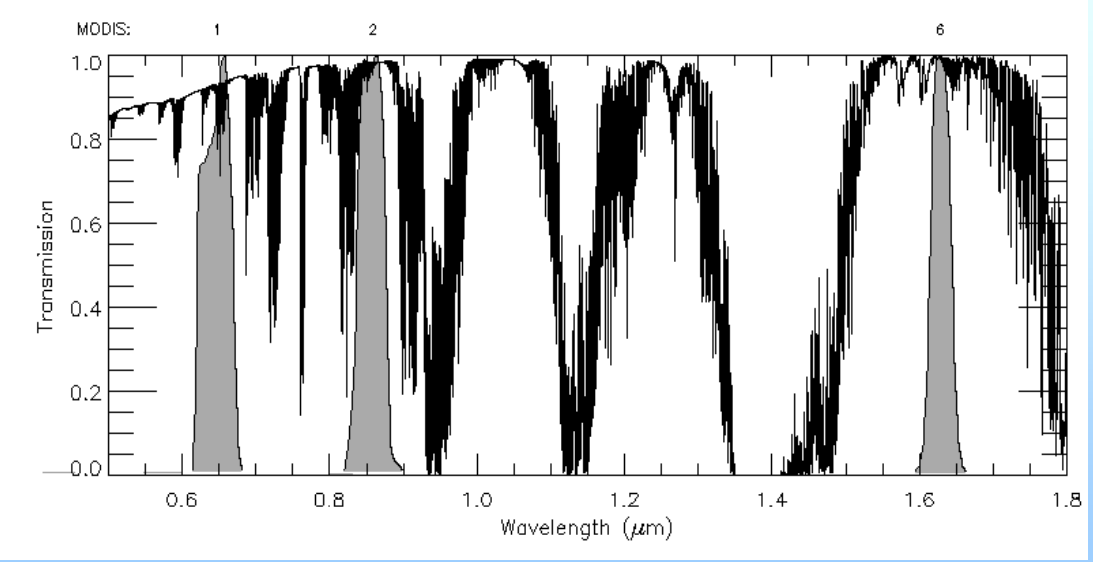
- AVHRR spectral band passes are wider than their analogs on MODIS.

- Ch2 (0.86 μm) on AVHRR encompasses much more water vapor absorption than does MODIS.

- We employ physical corrections based on water vapor profiles from NWP Reanalysis coupled with MODTRAN4 calculations.

- Correction also employed for Rayleigh scattering and surface reflectance.





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v. June 2010

CDR Maturity Matrix

Level	Sensor Use	Code Stability	Metadata & QA	Documentation	Validation	Public Release	Science & Applications	IV&V
1	Research Mission	Significant changes likely	Incomplete	Draft ATBD	Minimal	Limited data availability to develop familiarity	Little or none	
2	Research Mission	Some changes expected	Research grade (extensive)	ATBD Version 1+	Uncertainty estimated for select locations/times	Data available but of unknown accuracy; caveats required for use.	Limited or ongoing	ATBD Review
3	Research Missions	Minimal changes expected	Research grade (extensive); Meets international standards	Public ATBD; Peer-reviewed algorithm and product descriptions	Uncertainty estimated over widely distribute times/location by multiple investigators; Differences understood.	Data available but of unknown accuracy; caveats required for use.	Provisionally used in applications and assessments demonstrating positive value.	NOAA Operations Review
4	Operational Mission	Minimal changes expected	Stable, Allows provenance tracking and reproducibility; Meets international standards	Public ATBD; Draft Operational Algorithm Description (OAD); Peer-reviewed algorithm and product descriptions	Uncertainty estimated over widely distribute times/location by multiple investigators; Differences understood.	Source code released; Data available but of unknown accuracy; caveats required for use.	Provisionally used in applications and assessments demonstrating positive value.	
5	All relevant research and operational missions; unified and coherent record demonstrated across different sensors	Stable and reproducible	Stable, Allows provenance tracking and reproducibility; Meeting international standards	Public ATBD, Operational Algorithm Description (OAD) and Validation Plan; Peer-reviewed algorithm, product and validation articles	Consistent uncertainties estimated over most environmental conditions by multiple investigators	Source code portable and released; Multi-mission record is publicly available with associated uncertainty estimate	Used in various published applications and assessments by different investigators	CDR Certification Review
6	All relevant research and operational missions; unified and coherent record over complete series; record is considered scientifically irrefutable following extensive scrutiny	Stable and reproducible; homogeneous and published error budget	Stable, Allows provenance tracking and reproducibility; Meeting international standards	Product, algorithm, validation, processing and metadata described in peer-reviewed literature	Observation strategy designed to reveal systematic errors through independent cross-checks, open inspection, and continuous interrogation	Source code portable and released; Multi-mission record is publicly available from Long-Term archive	Used in various published applications and assessments by different investigators	

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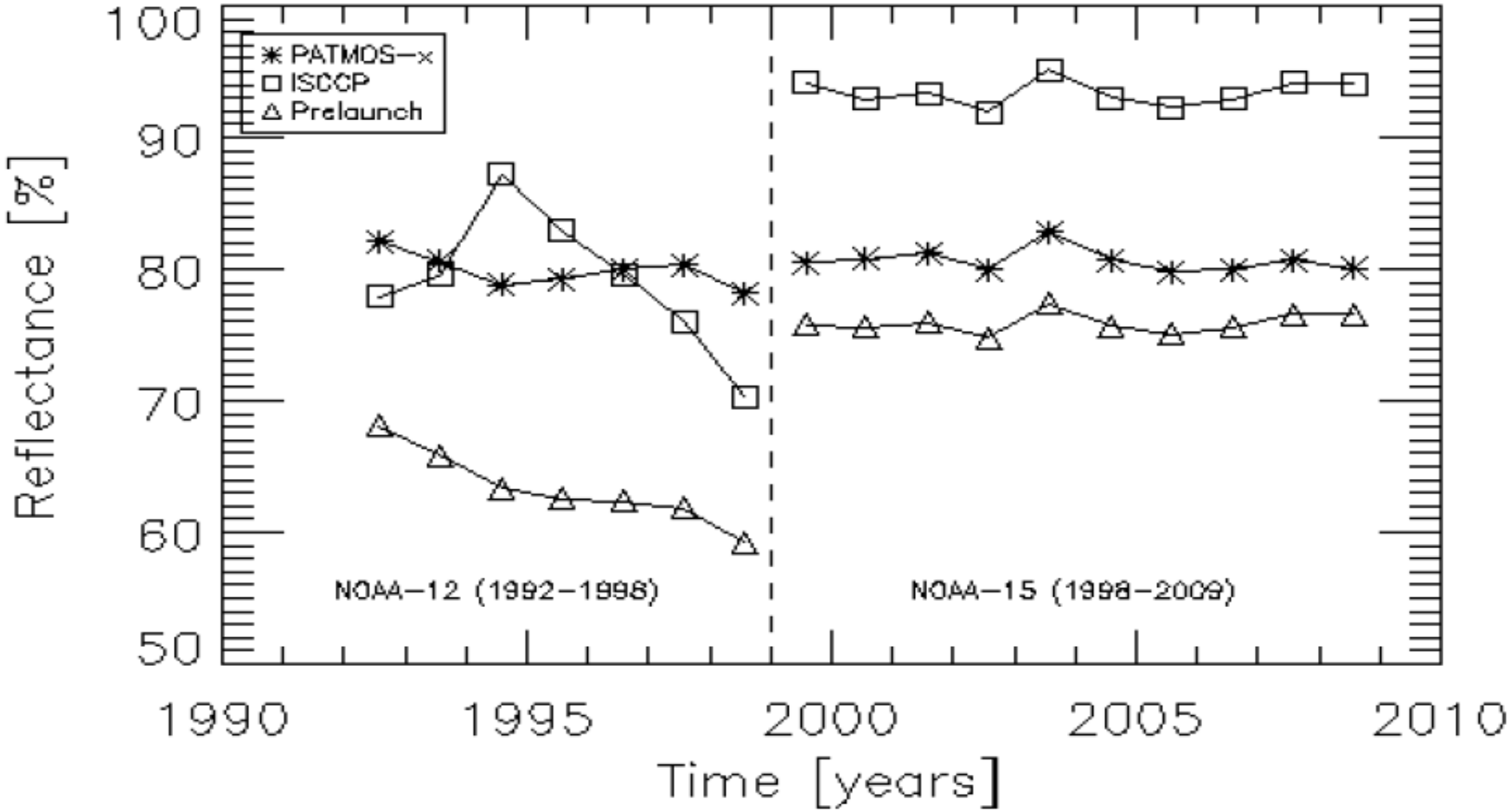
Research- to- Operations Results

- What is the deliverable?
  - From the ARC project, our deliverable is the set of reflectance calibrations that have been published and submitted to GSICS.
  - From the Fy2010 SDS support, our deliverable is a data set containing the AVHRR reflectance FCDRs and other supporting variables.
- What are your post-award plans with continuing this work, or not?
  - We intend to continue update the calibration for 2010.
  - We intend to continue to evolve the PATMOS-x cloud parameters into TCDRs for the CDR program.
  - We also intend to expand PATMOS-x to include HIRS information to mitigate some of weaknesses inherent in any AVHRR-based cloud CDR time-series and a definitive POES TCDR data set for clouds.

Research- to- Operations Results

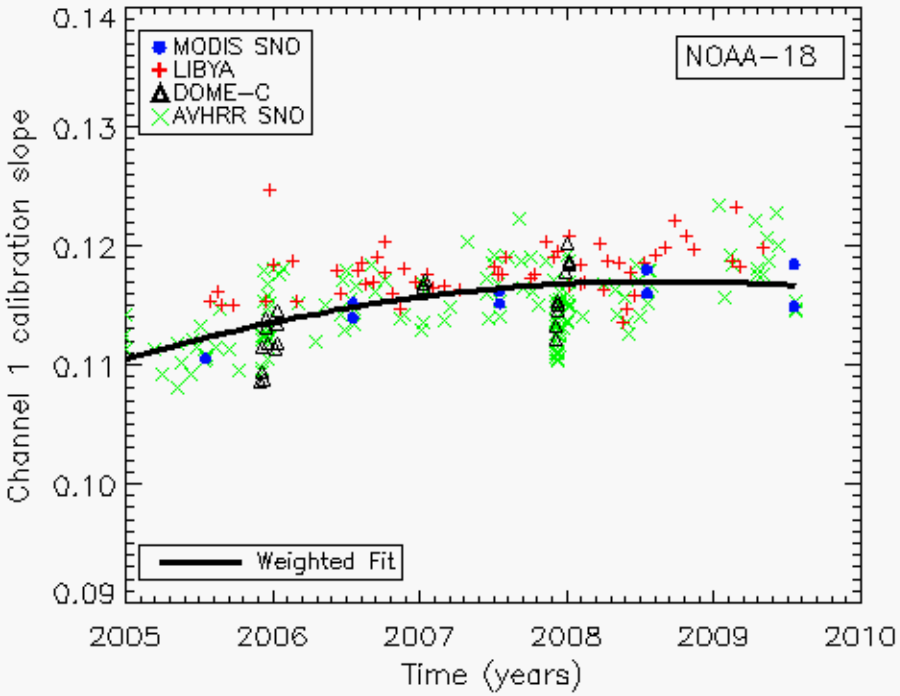
- NOAA points-of-contact or collaborators, as applicable
  - A. Heidinger is the current lead of the CDR Cloud Team.
  - Ken Knapp is our NCDC CDR Cloud Team Liason
  - Dan Wunder and Phil Jones are heavily involved in the current deliverable.
  - Gilberto Vincente is the collaborator on the operational version of these projects, which will continue to run through METOP.
  - Tom Zhao (NCDC) is a collaborator who does aerosol remote sensing
  - The CIMSS (a NOAA CI), is comprised of Mike Foster, Andi Walther and William Straka.

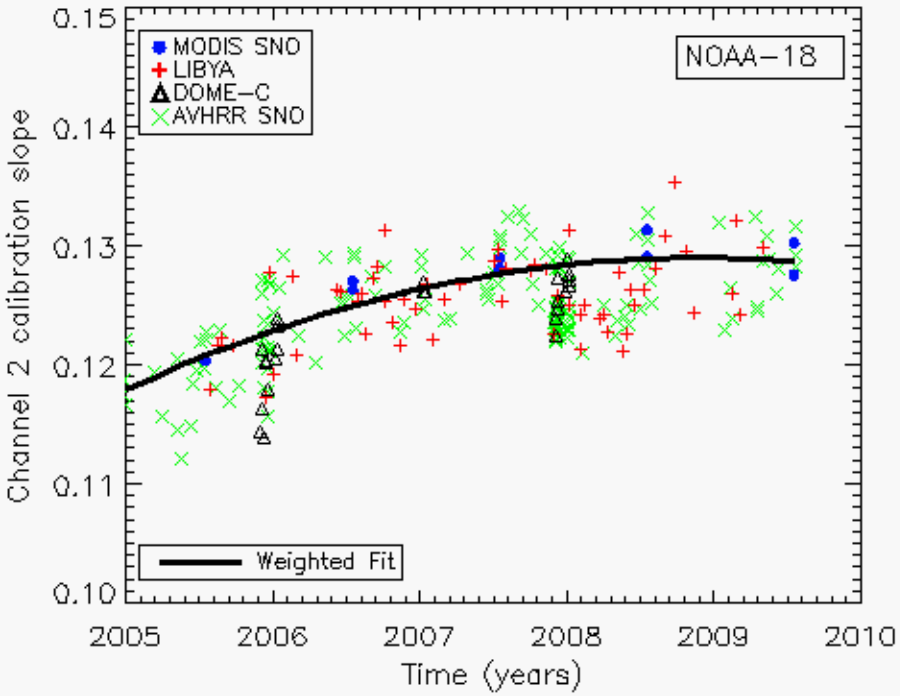
Results


PATMOS−x
ISCCP
Prelaunch
NOAA−12 (1992−1998)
NOAA−15 (1998−2009)
Reflectance [%]
Time [years]
100
90
80
70
60
50
1990
1995
2000
2005
2010

Combining All this Data into one Calibration

Example Sensor : NOAA-18 2005-2010





Blue Points – Calibration slopes generated from MODIS to AVHRR simultaneous nadir overpasses.
Black Points – Calibration slopes generated from AVHRR observations of DOME-C (Antarctica) using a MODIS-derived reflectance model.
Red Points – Calibration slopes generated from AVHRR observations of the Libyan Desert using a MODIS-derived reflectance model.
Green Points – Calibrations slopes from other AVHRR sensors transferred using AVHRR to AVHRR simultaneous nadir overpasses.

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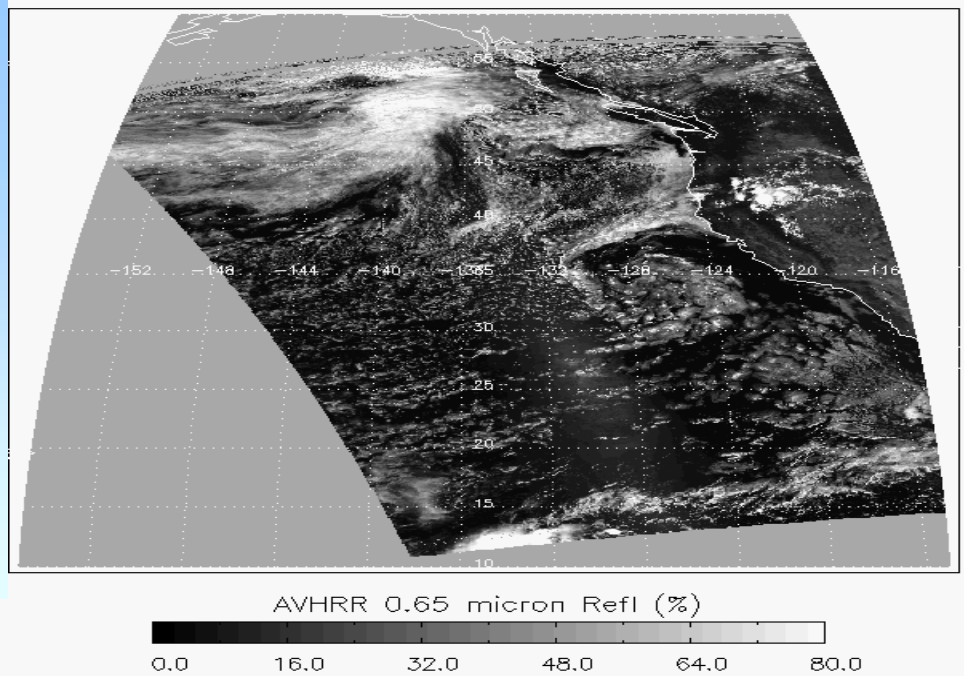
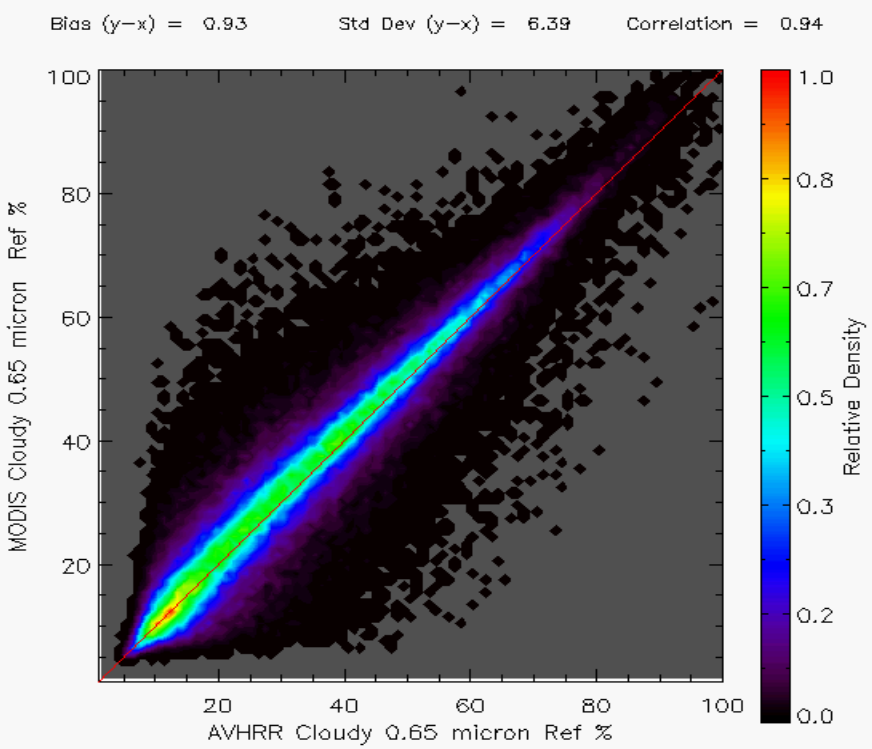
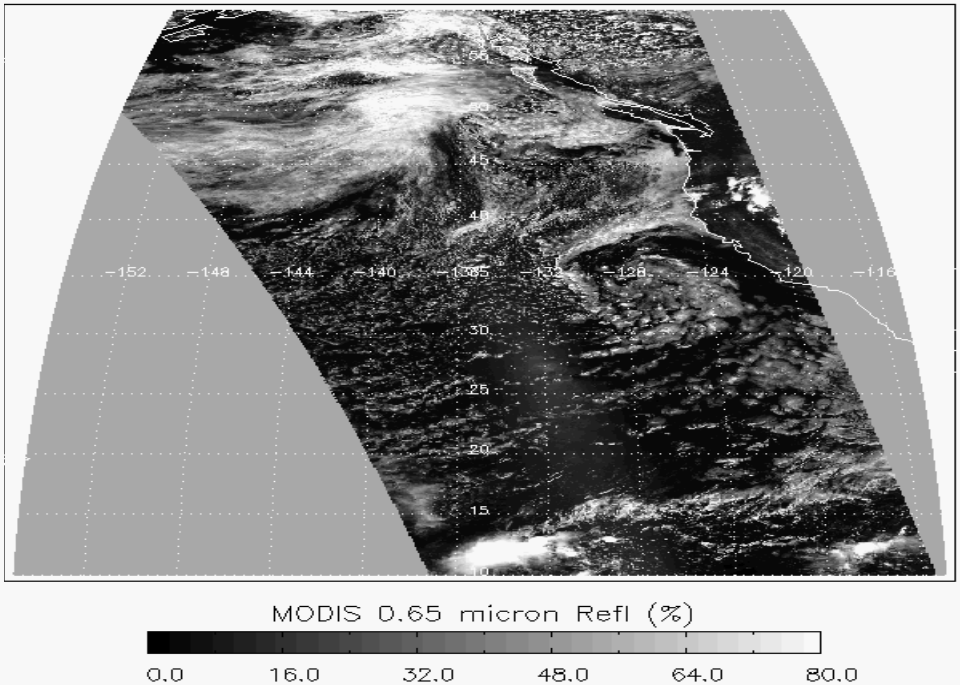
Comparison to MODIS during Simultaneous Off-Nadir Overpasses

- At all latitudes, polar orbits can view the same scenes simultaneously at different angles.
- Shown below is a scene off the Coast of California where AQUA/MODIS and NOAA-18/AVHRR were separated in time by less than 2 minutes.
- Scatterplot of the 0.63 μm reflectances verifies performance of the calibration derived from the high-latitude SNO's and other sources.







Inferring Inter-Satellite Calibration Stability via Analysis of CDR Time Series.

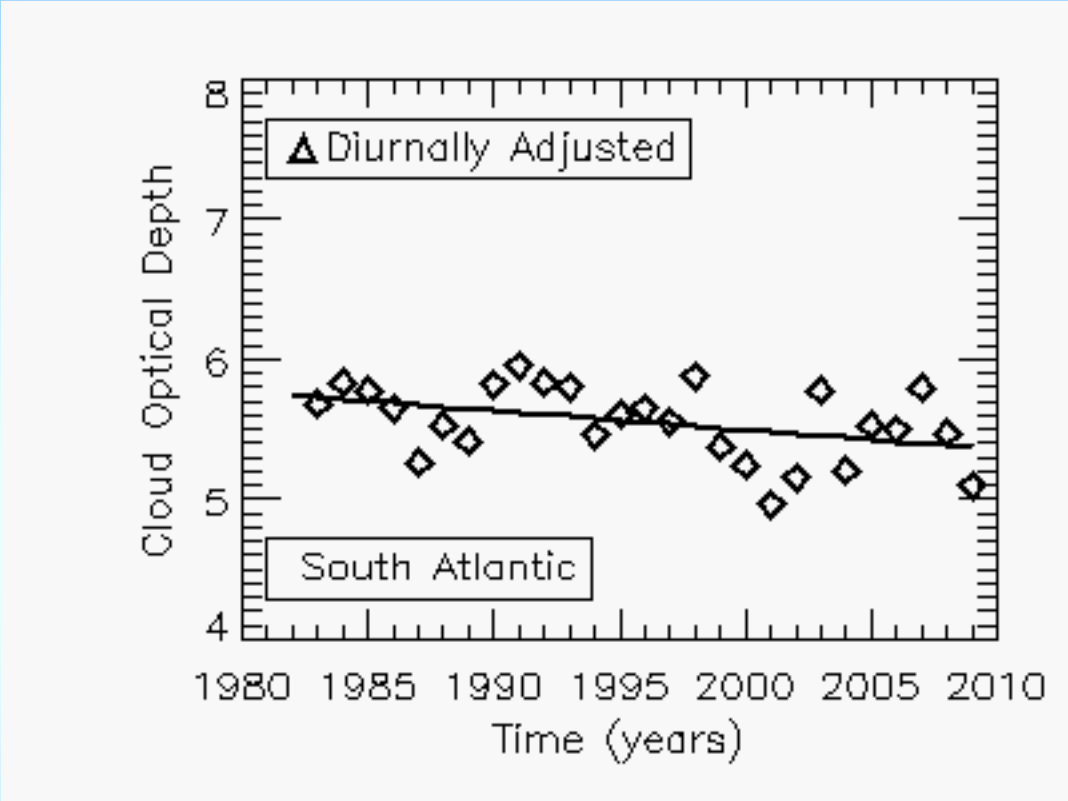
- While direct comparisons can be made to MODIS during the EOS era, other techniques are needed to verify calibration before 2000.

- Here we analyze time-series of cloud optical depth from the stratus-dominated South Atlantic.

- Assuming cloud optical depth is stable, we can ask: *What amount of yearly calibration error would be required to account for the observed time-series variability?*

- Answer: When averaged by satellite, the *inferred inter-satellite calibration error is less than 2%.*

- Caveat: This analysis would not detect any systematic bias.



Sat #	N-7	N-9	N-11	N-14	N-16	N-18
Cal Err. %	0.7	-1.8	1.5	0.3	-1.9	1.2

Using Earth Targets for Verification of Inter-satellite Consistency

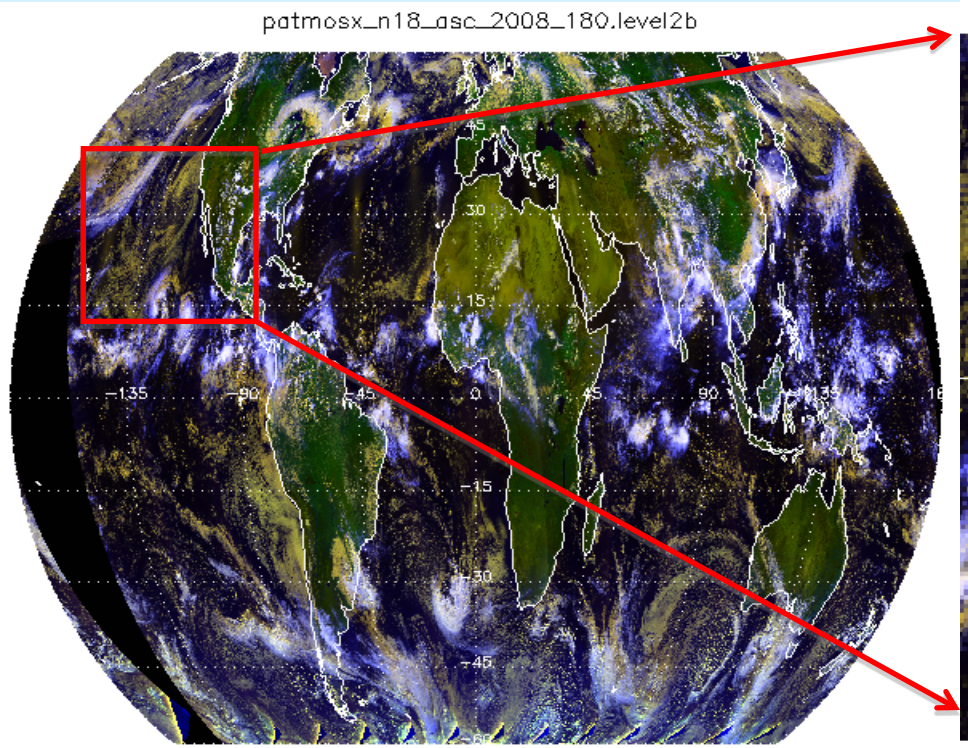
- We can also verify inter-satellite calibration accuracy by comparing reflectance time-series over stable earth scenes.
- Here we show the stats for the DOME-C site. Note, all sensors view this site.
- Results show a each sensor is consistent +/- 1.5% of the period mean.

	Mean	Stand. Dev.	Count
period	83.77	1.81	370
noaa-7	83.27	1.69	33
noaa-9	82.35	1.20	40
noaa-10	82.68	0.67	3
noaa-11	84.41	1.94	64
noaa-12	83.43	1.05	4
noaa-14	84.66	1.44	69
noaa-15	83.23	2.18	55
noaa-16	83.64	1.72	47
noaa-17	83.88	1.36	13
noaa-18	84.04	1.33	42

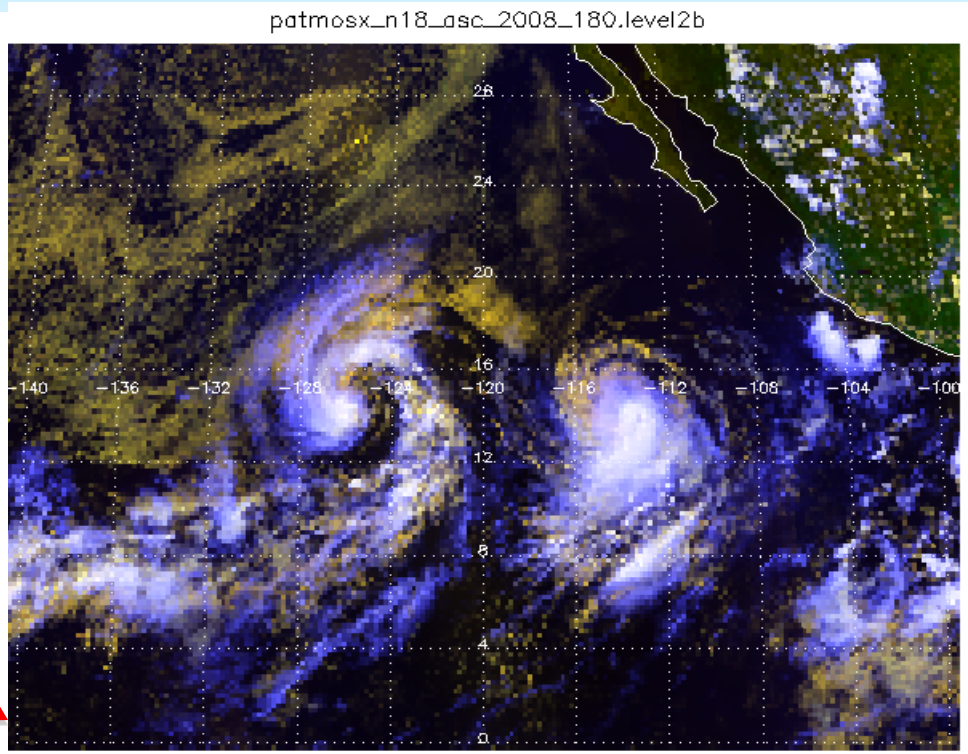
DOME-C December Statistics (Channel-1 Only)

FCDR Deliverable Example.

- As part of our Fy2010 SDS project, we are delivering AVHRR reflectance FCDR's
- These include the 0.63, 0.86 and 1.6 μm reflectances from the new ARC calibration.
- The data is provided on a 0.1 degree equal-angle grid and referred to as (level-2b).
- Other parameters include angles, land masks, meta-data and other non-FCDRs
- Final contents of data will be determined by NCDC.
- Images below show an example false color image using this data.



False Color Image
Red=0.63μm, Green = 0.86μm, Blue = 11μm (reversed)



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References

HEIDINGER, A.K., STRAKA III, W.C., MOLLING, C.C., SULLIVAN, J.T. and WU, X., 2010, Deriving an inter-sensor consistent calibration for the AVHRR solar reflectance data record. *International Journal of Remote Sensing*

MOLLING, C.C., HEIDINGER, A.K., STRAKA III, W.C. and WU, X., 2009, Calibrations for AVHRR channels 1 and 2: review and path toward consensus. *International Journal of Remote Sensing.*

HEIDINGER, A.K., CAO, C. and SULLIVAN, J.T., 2002, Using moderate resolution imaging spectrometer (MODIS) to calibrate advanced very high resolution radiometer reflectance channels. *Journal of Geophysical Research, 107, pp. 11.1-11.9.*

HEIDINGER, A.K., SULLIVAN, J.T. and RAO, C.R.N., 2003, Calibration of visible and near-infrared channels of the NOAA-12 AVHRR using time series of observations over deserts. *International Journal of Remote Sensing*

Extra slides

Algorithm/Product Maturity

- Sensor Use (4): All relevant research and operational missions; unified and coherent record demonstrated across different sensors.
  - *This calibration is the first to cover all AVHRR sensors (1978-2010).*
- Algorithm Stability (4): Minimal changes expected.
  - *Values need to be update each year for current sensors*
- Metadata Q&A (3) : Research grade (extensive); Meets international standards
  - *PATMOS-x includes all viewing angles and scan line quality flags that indicate some conditions that impact the accuracy of the reflectance including stray-light and moon contamination. Our cal. data has passed GSICS meta-data specs.*
- Documentation (3): Public ATBD; Peer-reviewed algorithm and product descriptions
  - *We do not have an OAD but have written an ATBD for GSICS which may provide much of the same functionality. Calibration is published.*

Algorithm/Product Maturity

- Validation(3): Uncertainty estimated over widely distribute times/location by multiple investigators; Differences understood.
  - *PATMOS-x validation has occurred via direct comparison to MODIS during periods of near nadir overpasses that occur at latitudes are not in the calibration data. In addition, PATMOS-x TCDRs of cloud and aerosol optical thickness and NDVI have been validated for temporal and inter-satellite stability.*
- Public Release(4):Source code released;
  Data available but of unknown accuracy; caveats required for use.
  - *Yes all data is available via publication and by GSICS. PATMOS-x code is public.*
- Science and Applications (4): Provisionally used in applications and assessments demonstrating positive value.
  - *These calibration data have been tested and are being used by SMHI, KNMI, ISCCP and Prof Wunderle at University of Bern. All have given positive feedback and no issues yet exist that warrant a regeneration of the data.*
- *IV&V (2): ATBD Review*
  - *ATBD has been submitted to and reviewed by GSICS. Calibration is*