Importance of Instrument Calibration, Validation and Inter-Calibration for Demanding Satellite Applications

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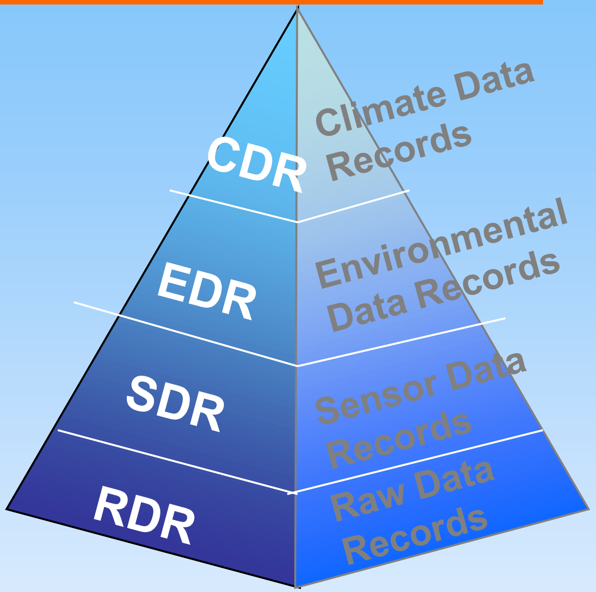
Why Calibration is Critical

- **Calibration:**
  - The process of quantitatively defining the satellite sensor responses to known signal inputs that are traceable to established reference standards, and converting the Earth observation raw signal to Sensor Data Records (SDRs).



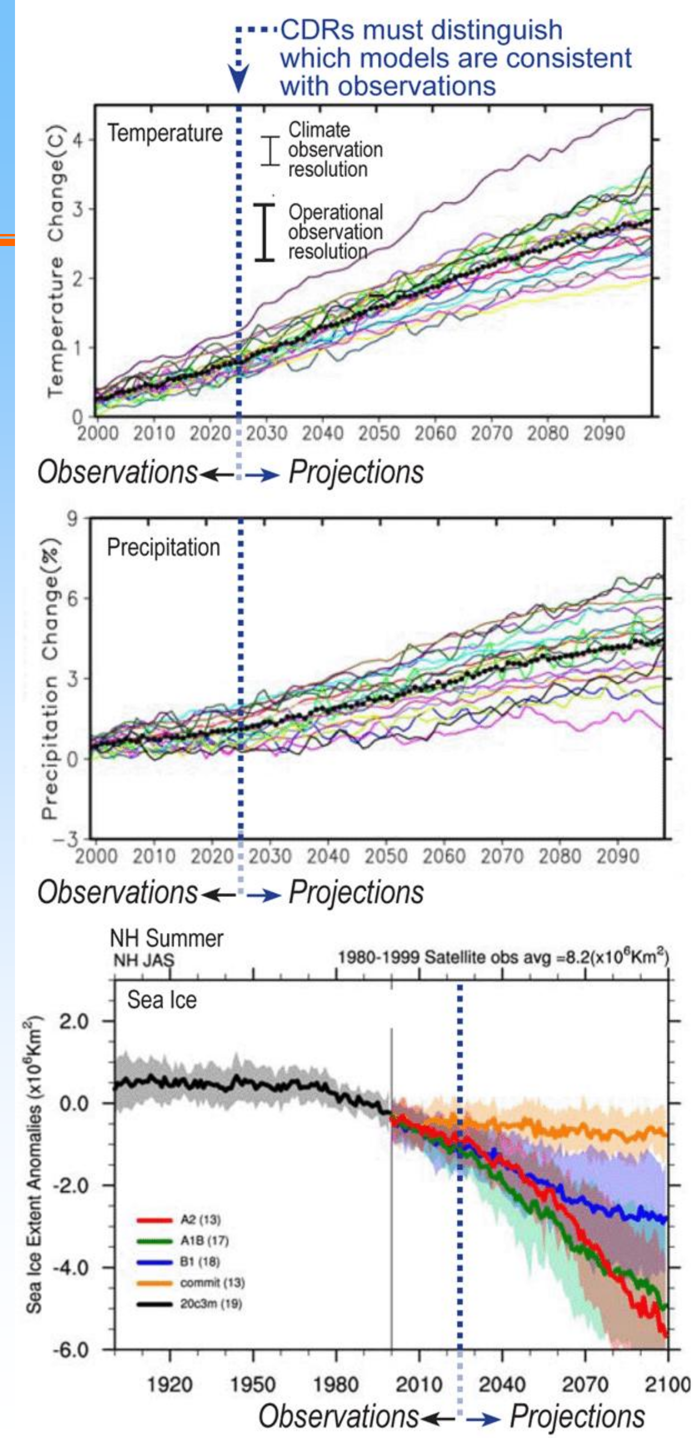
- Calibrated SDRs are the fundamental building blocks for all satellite products, including the radiances for data assimilation in Numerical Weather Prediction (NWP), reanalysis, and fundamental climate data records (FCDRs) for climate change detection.

Calibration is the centerpiece of data quality assurance and is part of the **core competency** of any satellite program

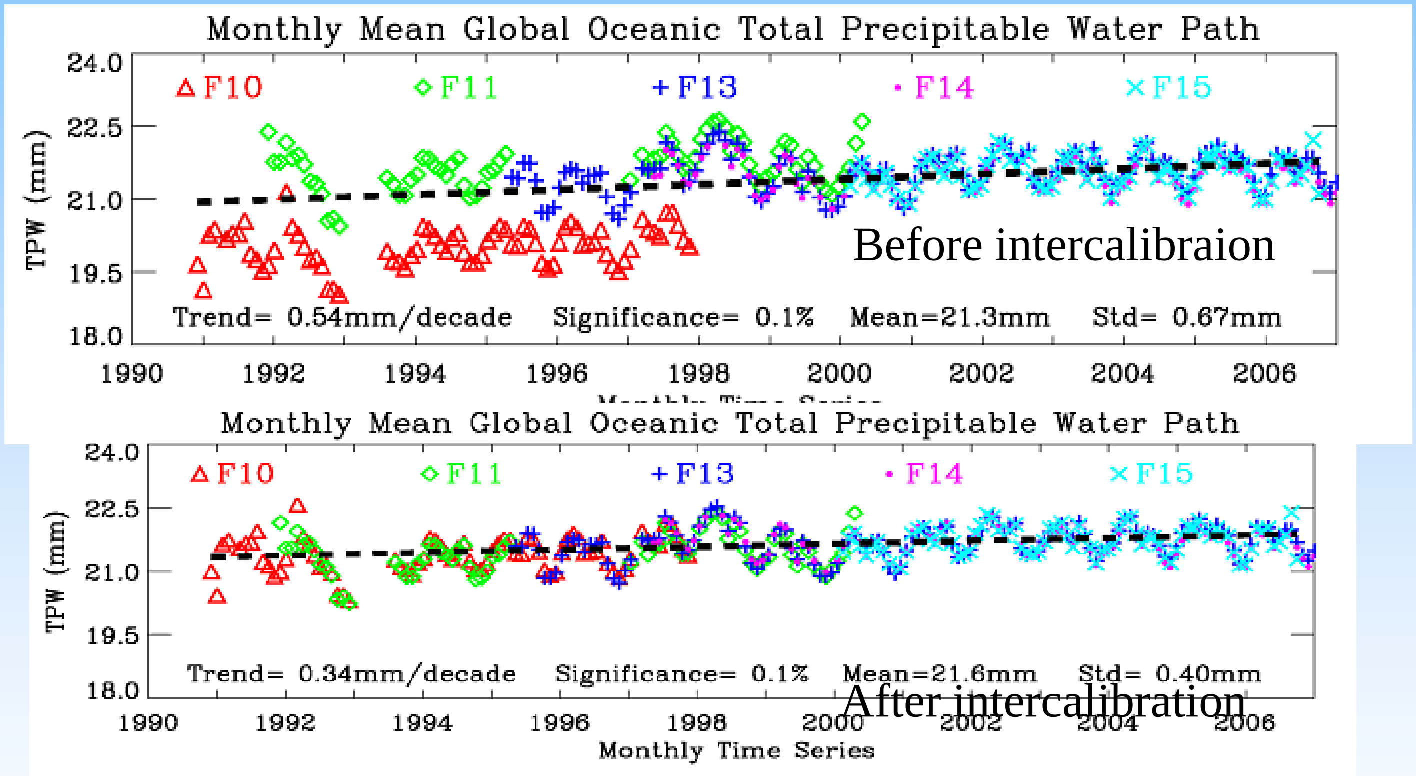
What Climate Trajectory Are We On?

- IPCC model projections for most parameters vary greatly
- Mitigation and adaptation strategies depend on identifying which models are best
- High quality, sustained CDRs are needed to initiate and validate climate model projections

Other uses of CDRs: Detecting, understanding, predicting, and projecting climate change also require long-term records

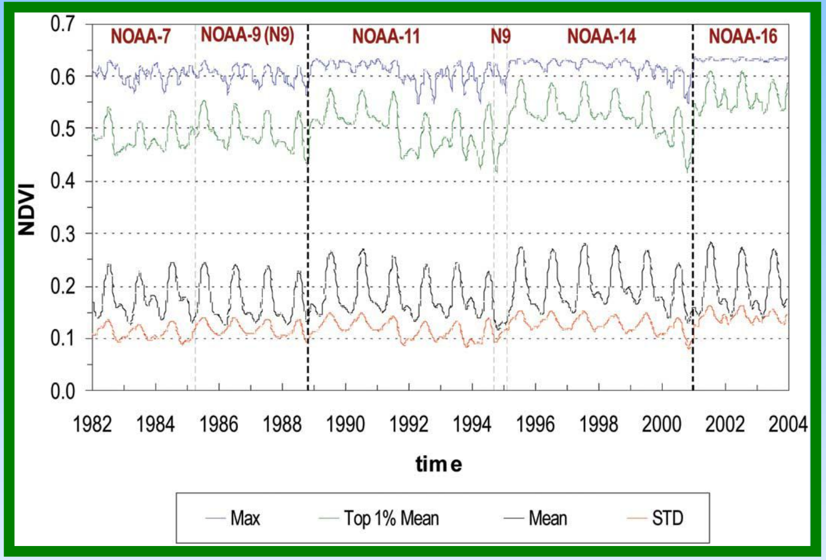


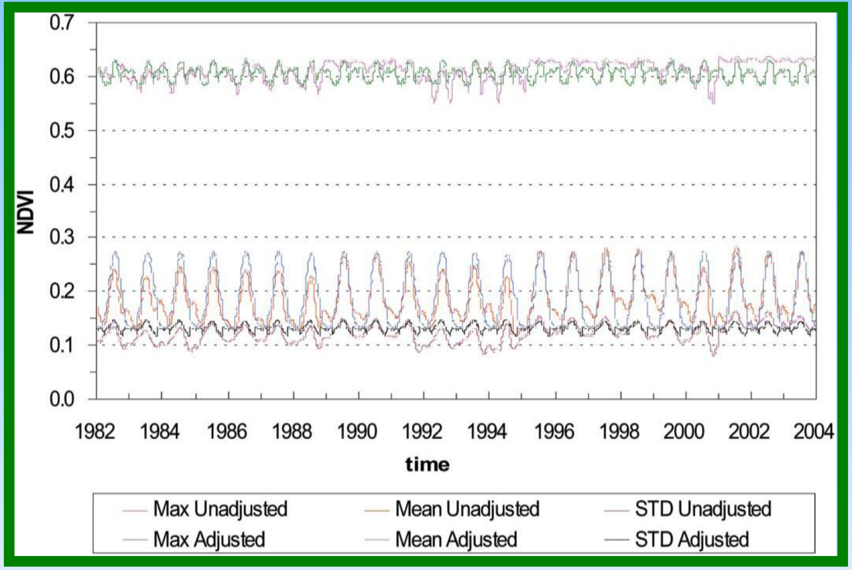
Calibration is Critical for Climate Change Detection

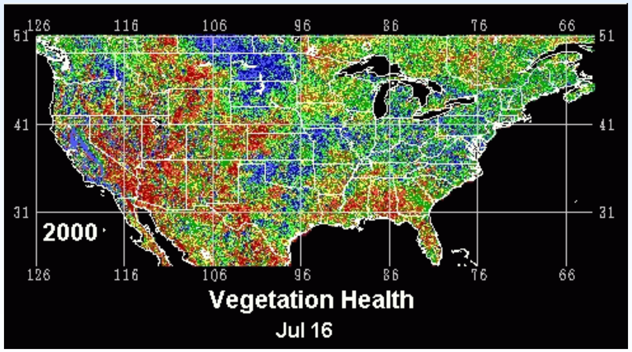


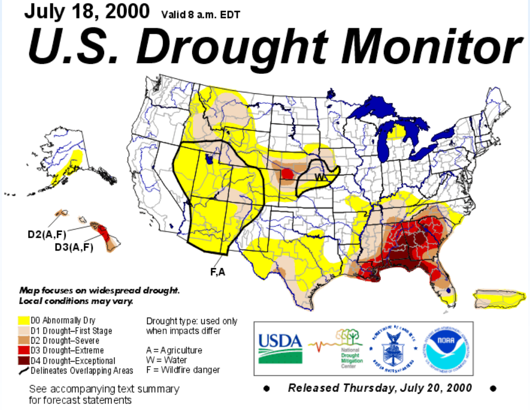
Trend of global oceanic total precipitable water decreases from 0.54 mm/decade to 0.34 mm/decade after intercalibrations! Calibration uncertainties translate to uncertainties in climate change detection

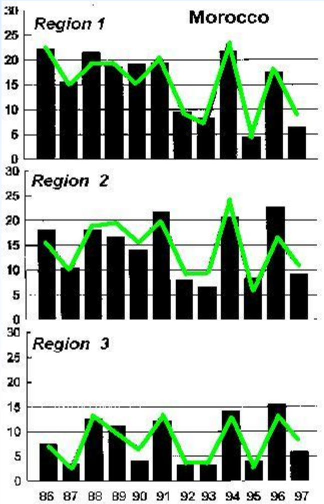
Intercalibration of AVHRR NDVI











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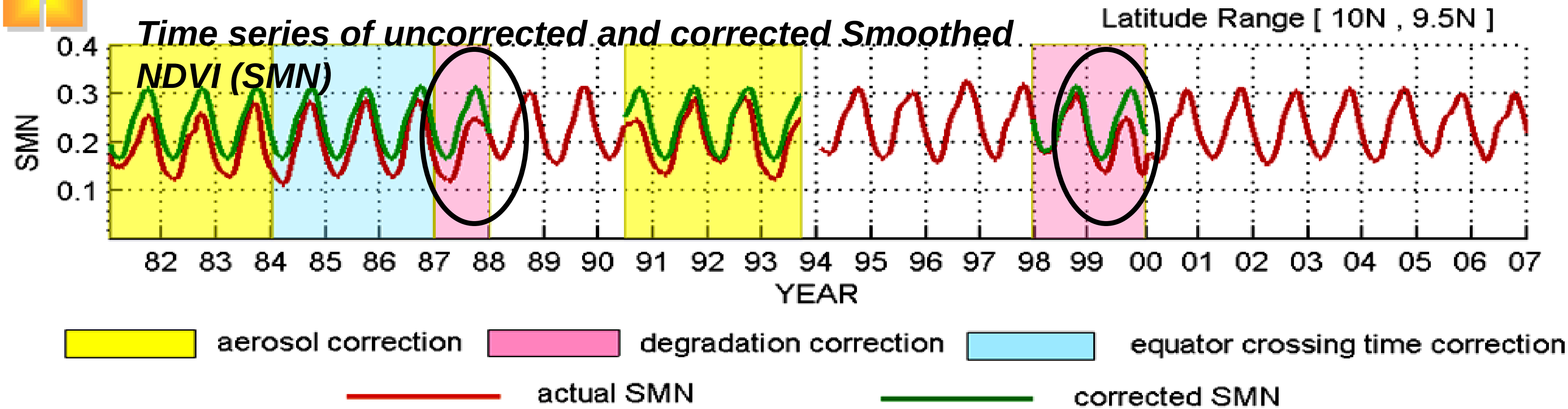
Climate Trends and Analyses

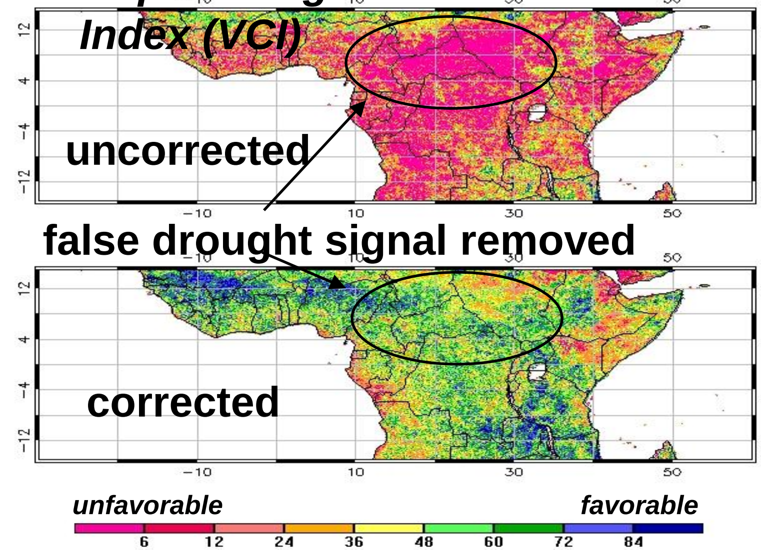
Vegetation

Time series of uncorrected and corrected Smoothed NDVI (SMN)



- **The current NDVI time series have not been corrected for the effect of volcanic aerosol (El Chichon and Mt. Pinatubo) and satellite orbital drift.**
- **A statistical method was applied to correct these errors.**
- **The NDVI correction allows for improved applications such as vegetation health, fire risk, malaria risk, and agricultural yield**

Maps of Vegetation Condition Index (VCI)



Significance: Provides improved dataset and more consistent time series for climate and environmental applications.

Do we Care about Satellite Biases in NWP?

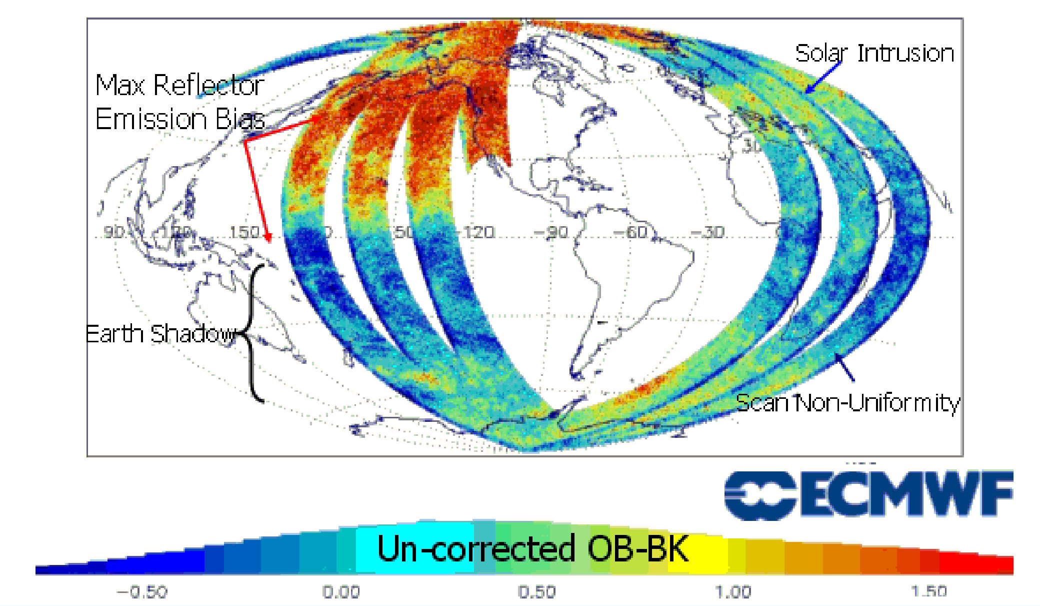
After McNally, Bell, et al. ECMWF, 2005 & 2009

Yes! Because:

1) We wish to understand the **origin** of the bias and ideally correct instrument / RT / NWP model **at source**

2) I*n principle* **we do not wish to apply a correction to unbiased satellite data if it is the NWP model which is biased**. Doing so is likely to:

- **Re-enforce the model bias** and degrade the analysis fit to other observations
- Produce a **biased analysis** (bad for re-analysis / climate applications)

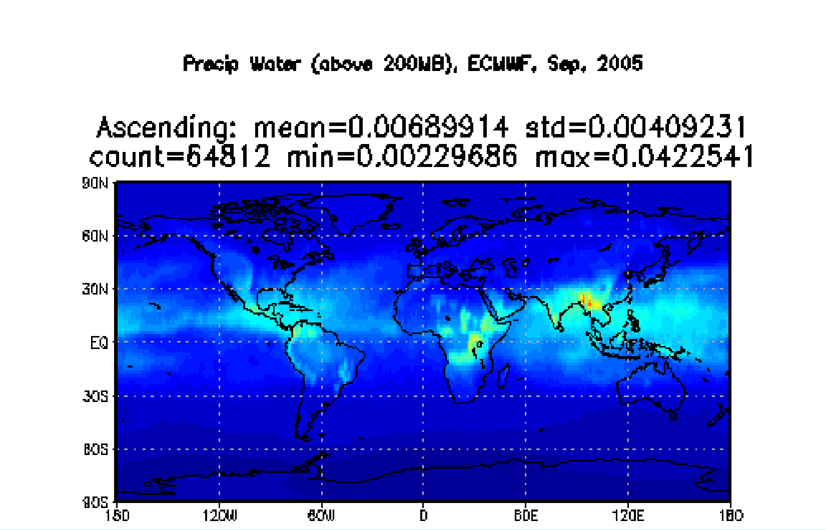


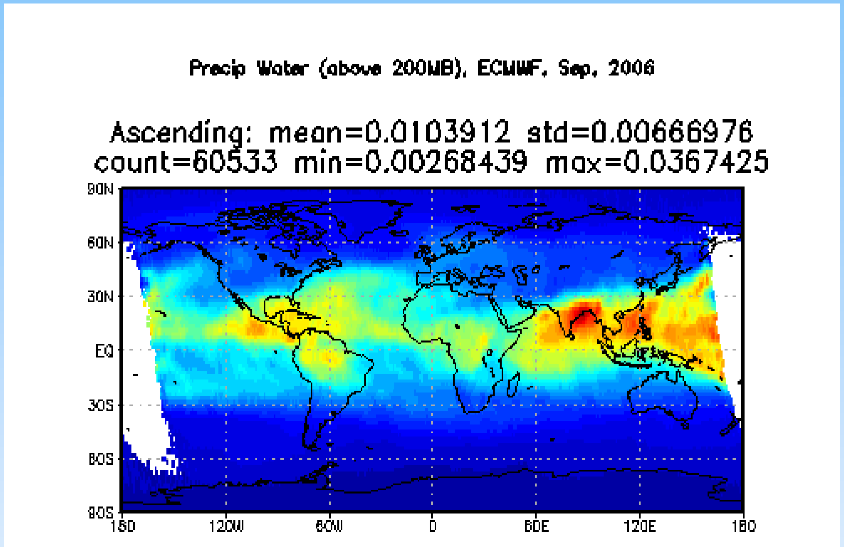
SSMIS calibration biases cause regional weather patterns

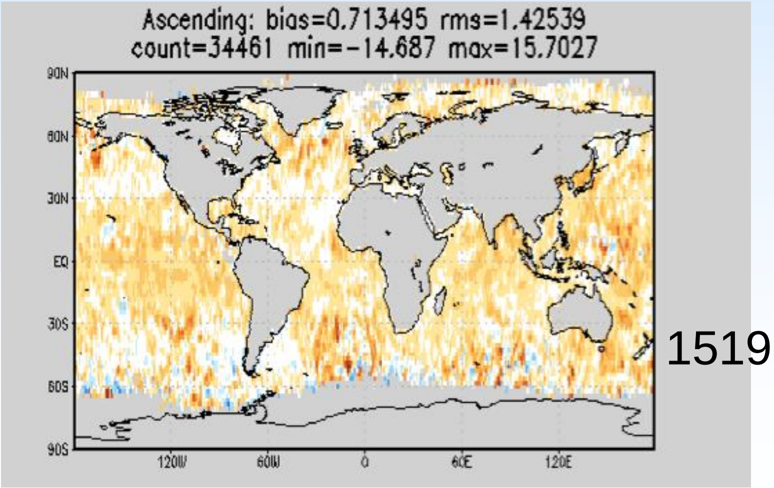
More accurate satellite observations will facilitate discovery of model errors and their correction. Additional gains in forecast accuracy can be expected.

Bias correcting good data results in degraded analysis fields

Water vapor is near doubled after AIRS radiances are bias corrected







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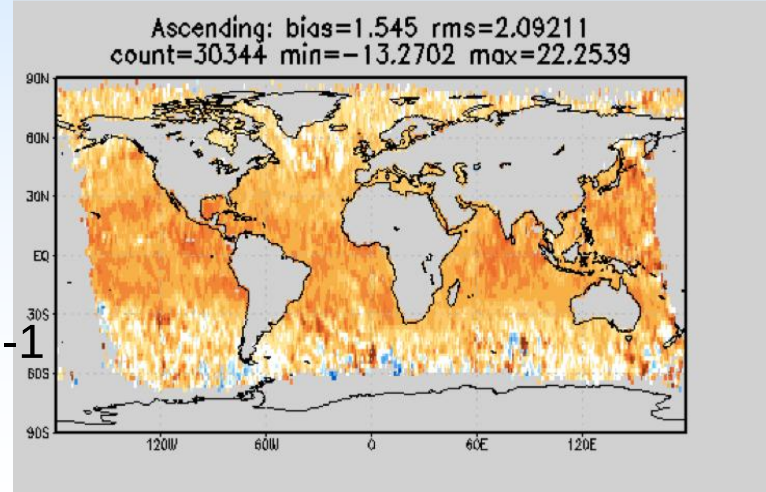

Motivation

- Demanding applications require well calibrated and intercalibrated measurements
  - Climate Data Records
  - Radiance Assimilation in Numerical Weather Prediction
  - Data Fusion
- Growing Global Earth Observing System of System (GEOSS)

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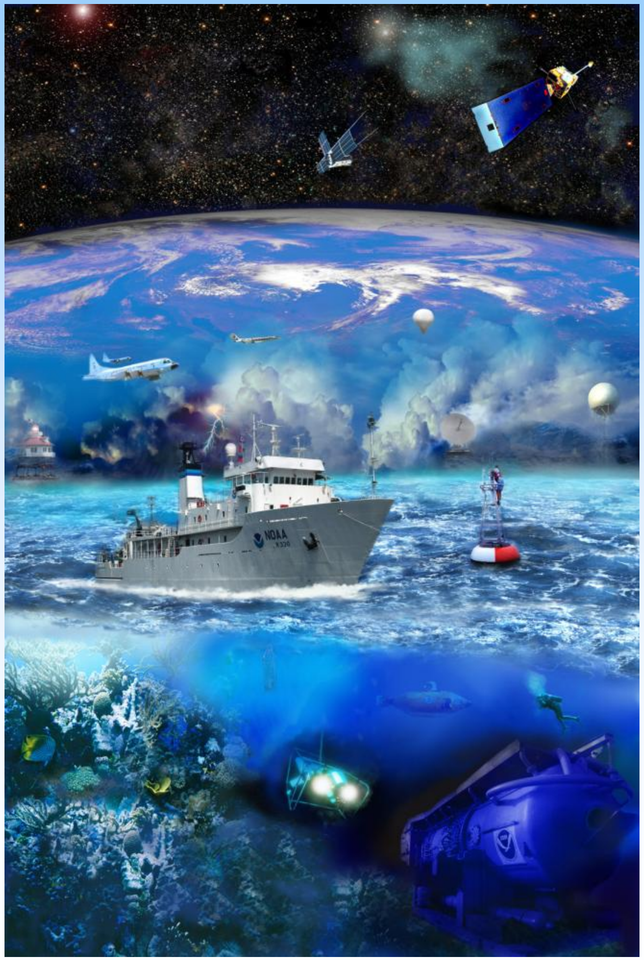
What is GEOSS?

Global Earth Observing System of Systems

- GEOSS is a distributed system of systems built on current international cooperation among existing Earth observing and data management systems

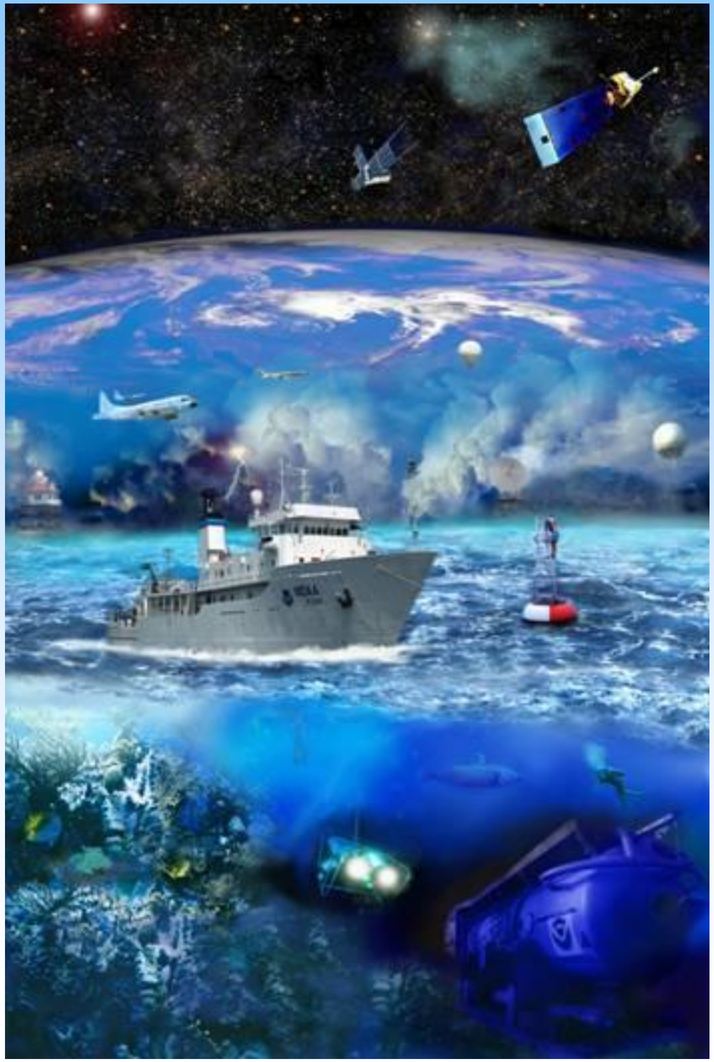
- GEOSS enables the collection and distribution of accurate, reliable Earth Observation data, information, products, and services in an end-to-end process



The Global Framework

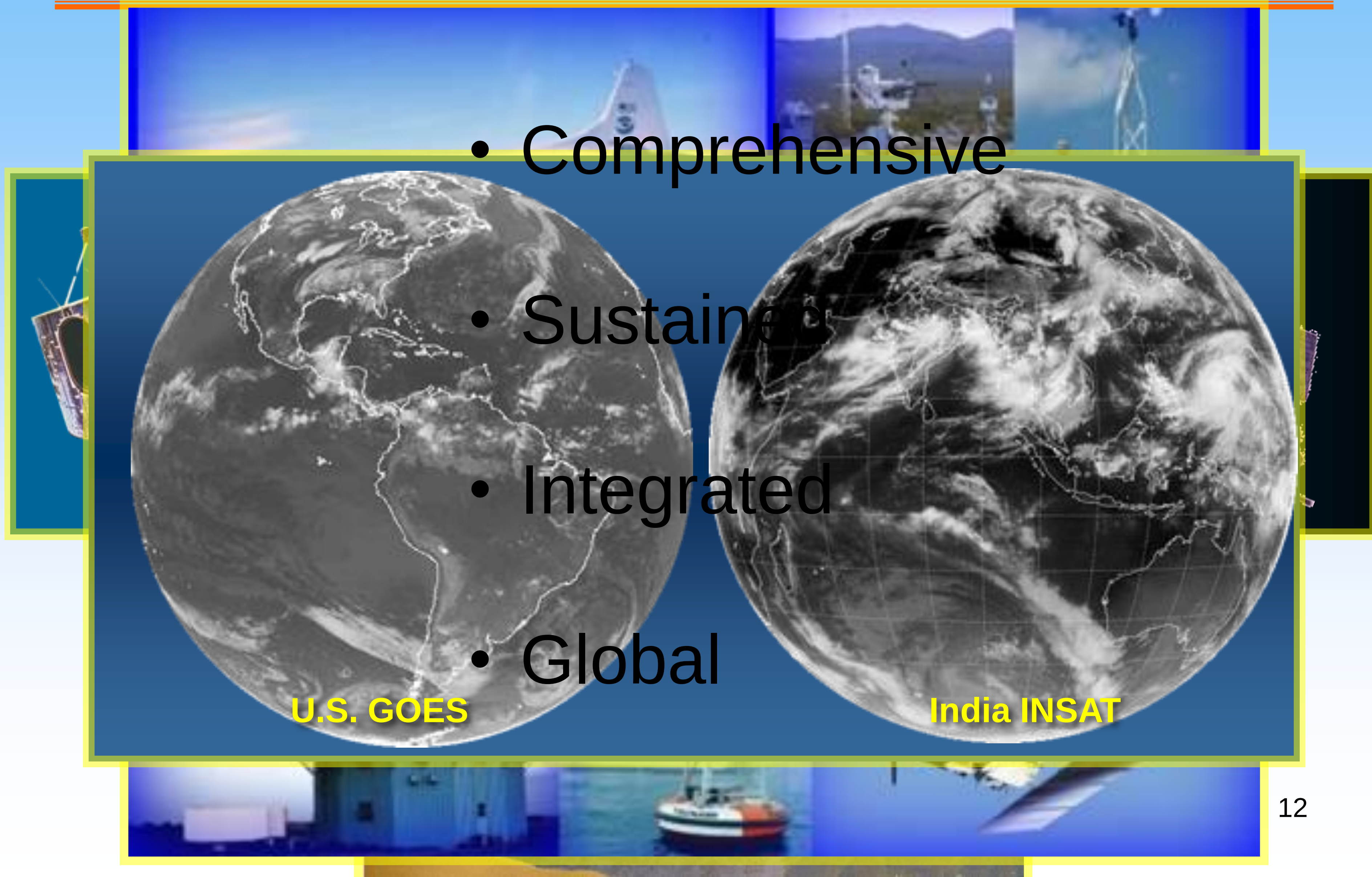
A distributed system of systems

- Improves coordination of strategies and observation systems
- Links all platforms: in situ, aircraft, and satellite networks
- Identifies gaps in our global capacity
- Facilitates exchange of data and information
- Improves decision-makers' abilities to address pressing policy issues



Attributes of an Integrated Global Observing System

- Comprehensive
- Sustained
- Integrated
- Global



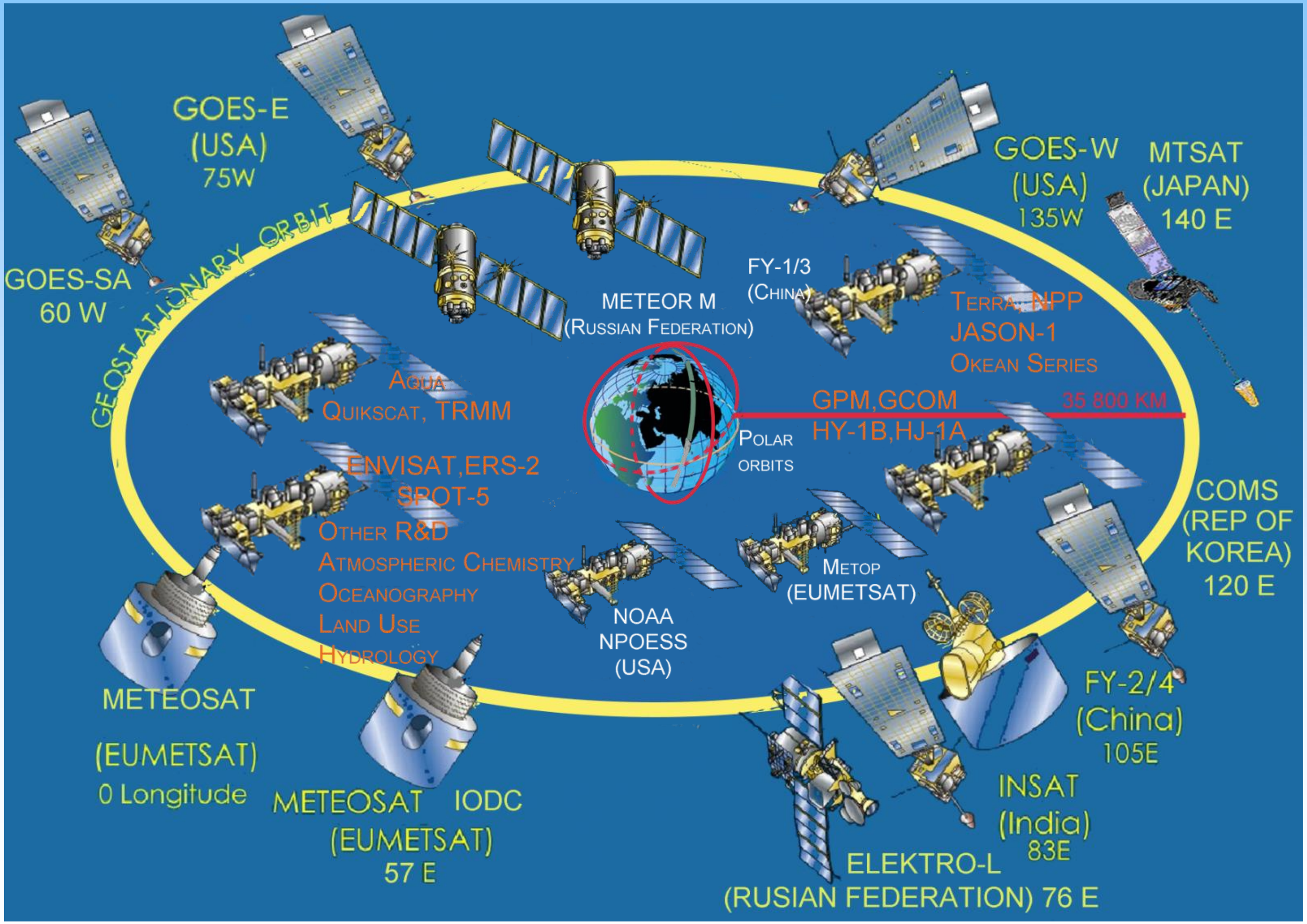
Nine Societal Benefits

- Improve Weather Forecasting
- Reduce Loss of Life and Property from Disasters
- Protect and Monitor Our Ocean Resource
- Understand, Assess, Predict, Mitigate and Adapt to Climate Variability and Change
- Support Sustainable Agriculture and Forestry and Combat Land Degradation
- Understand the Effect of Environmental Factors on Human Health and Well-Being
- Develop the Capacity to Make Ecological Forecasts
- Protect and Monitor Water Resources
- Monitor and Manage Energy Resources

Science Requirements for GEOSS to meet the 9 societal benefits:

- Sensor characterization & Satellite Intercalibration
- Data Fusion & Integrated Products, including CDRs
- Data Assimilation & Modeling

Space-Based component of the Global Observing System (GOS)

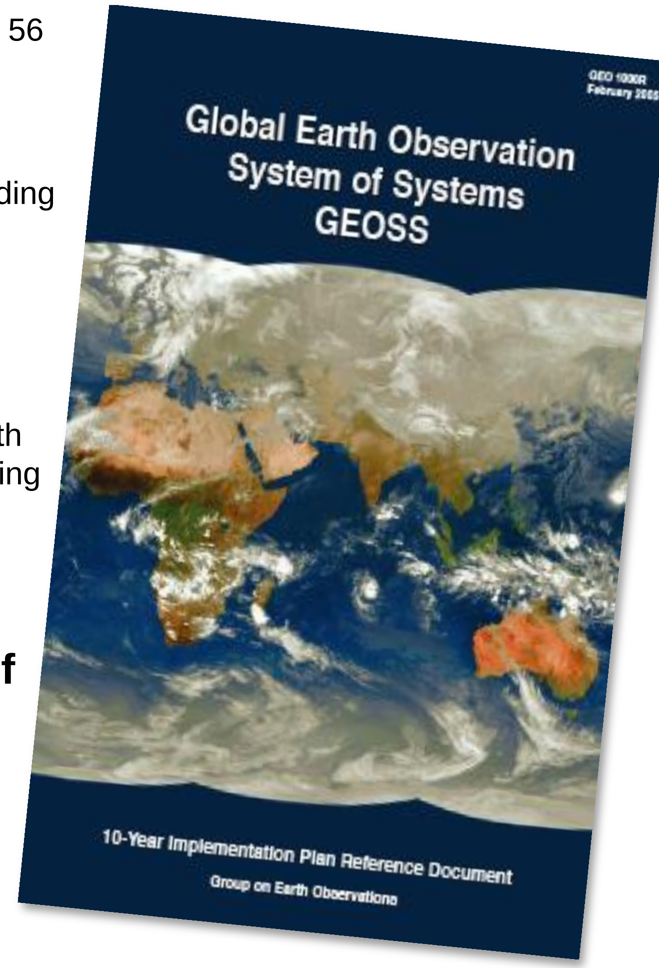


Players

- The intergovernmental *Group on Earth Observations* (GEO) is leading a worldwide effort to build a Global Earth Observation System of Systems (GEOSS)
- Satellite component is addressed by the Committee on Earth Observation Satellites (CEOS)
- CEOS includes space /satellite agencies and WMO
- Two key international cal/val programs
  - CEOS Working Group on Cal/Val (WGCV)
  - WMO GSICS

International Earth Observation Coordination

- **Group on Earth Observations (GEO)**
  - Membership consists of 76 countries and the European Commission, over 56 participating organizations and observers
- **U.S. Group on Earth Observations (USGEO)**
  - 25 participating U.S. Government Department and Agency members including two White House offices
  - Standing subcommittee of the National Science and Technology Council Committee on Environment and Natural Resources
- **Committee on Earth Observation Satellites (CEOS)**
  - 27 members (Space Agencies), 21 Associates (UN Agencies, Agencies with space programs in conceptual design phase and/or Agencies with supporting ground facilities)
  - CEOS serves as the “space arm” of GEO, implementing high priority GEO actions requiring space-based Earth observation
- **Unifying Principle: Global Earth Observation System of Systems (GEOSS)**
  - Coordinating strategies and observation systems
  - Linking platforms: *in situ*, aircraft, and satellite networks
  - Identifying gaps in our global capacity
  - Facilitating exchange of data and information
  - Improving decision makers’ abilities to address pressing policy issues



CEOS/WGCV

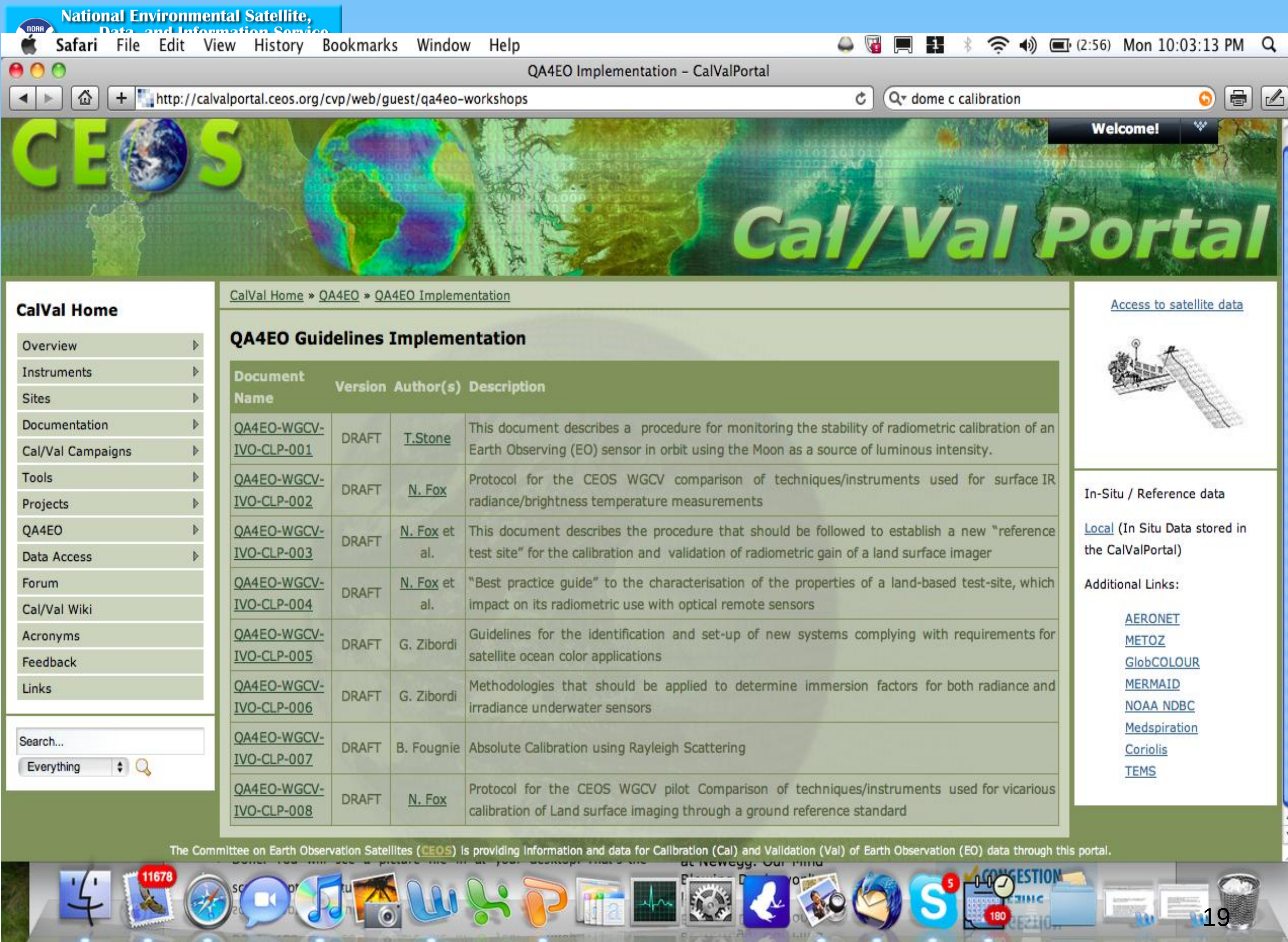
Background

- The Working Group on Calibration and Validation (WGCV) was originally established in 1984. This resulted from the recognition by CEOS that calibration and validation activities should play a key role in all satellite Earth Observation missions to ensure the clear and quantitative understanding of the data they generate.

  - Calibration: The process of quantitatively defining the system responses to known, controlled signal inputs.

  - Validation: The process of assessing, by independent means, the quality of the data products derived from the system outputs.

- In the GEOSS era, CEOS has become the space segment of GEOSS in support of GEO. WGCV is actively engaged in both GEO and CEOS tasks.



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QA4EO Implementation – CalValPortal

http://calvalportal.ceos.org/cvp/web/guest/qa4eo-workshops

dome c calibration

CEOS Cal/Val Portal

Welcome!

CalVal Home » QA4EO » QA4EO Implementation

QA4EO Guidelines Implementation

Document Name	Version	Author(s)	Description
QA4EO-WGCV-IVO-CLP-001	DRAFT	T.Stone	This document describes a procedure for monitoring the stability of radiometric calibration of an Earth Observing (EO) sensor in orbit using the Moon as a source of luminous intensity.
QA4EO-WGCV-IVO-CLP-002	DRAFT	N. Fox	Protocol for the CEOS WGCV comparison of techniques/instruments used for surface IR radiance/brightness temperature measurements
QA4EO-WGCV-IVO-CLP-003	DRAFT	N. Fox et al.	This document describes the procedure that should be followed to establish a new "reference test site" for the calibration and validation of radiometric gain of a land surface imager
QA4EO-WGCV-IVO-CLP-004	DRAFT	N. Fox et al.	"Best practice guide" to the characterisation of the properties of a land-based test-site, which impact on its radiometric use with optical remote sensors
QA4EO-WGCV-IVO-CLP-005	DRAFT	G. Zibordi	Guidelines for the identification and set-up of new systems complying with requirements for satellite ocean color applications
QA4EO-WGCV-IVO-CLP-006	DRAFT	G. Zibordi	Methodologies that should be applied to determine immersion factors for both radiance and irradiance underwater sensors
QA4EO-WGCV-IVO-CLP-007	DRAFT	B. Fougnie	Absolute Calibration using Rayleigh Scattering
QA4EO-WGCV-IVO-CLP-008	DRAFT	N. Fox	Protocol for the CEOS WGCV pilot Comparison of techniques/instruments used for vicarious calibration of Land surface imaging through a ground reference standard

CalVal Home

- Overview
- Instruments
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- Documentation
- Cal/Val Campaigns
- Tools
- Projects
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- Acronyms
- Feedback
- Links

Search...

Everything

Access to satellite data

In-Situ / Reference data

Local (In Situ Data stored in the CalValPortal)

Additional Links:

- AERONET
- METOZ
- GlobCOLOUR
- MERMAID
- NOAA NDBC
- Medspiration
- Coriolis
- TEMS

The Committee on Earth Observation Satellites (CEOS) is providing information and data for Calibration (Cal) and Validation (Val) of Earth Observation (EO) data through this portal.

What is GSICS?

- Global Space-based Inter-Calibration System (GSICS)
- Goal - Enhance calibration and validation of satellite observations and to intercalibrate critical components global observing system
- Part of WMO Space Programme
  - GSICS Implementation Plan and Program formally endorsed at CGMS 34 (11/06)

GSICS Mission

- To provide sustained calibration and validation of satellite observations
- To intercalibrate critical components of the global observing system to climate quality benchmark observations and/or reference sites
- To provide corrected observations and/or correction algorithms to the user community for current and historical data

Or in technical terms:

- Quantify the differences – magnitude and uncertainty
- Correct the differences – physical basis and empirical removal
- Diagnose the differences – root cause analysis

Organizations contributing to GSICS

- NOAA
- NIST
- NASA
- EUMETSAT
- CNES
- CMA
- JMA
- KMA
- WMO

- Official observers:
  - JAXA
  - ESA

GSICS current focus is on the intercalibration of operational satellites, and makes use of key research instruments such as AIRS and MODIS to intercalibration the operational instruments

Building Blocks for Satellite Intercalibration

- Collocation
  - Determination and distribution of locations for simultaneous observations by different sensors (space-based and in-situ)
  - Collocation with benchmark measurements
- Data collection
  - Archive, metadata - easily accessible
- Coordinated operational data analyses
  - Processing centers for assembling collocated data
  - Expert teams
- Assessments
  - communication including recommendations
  - Vicarious coefficient updates for “drifting” sensors

Other key building blocks for accurate measurements and intercalibration

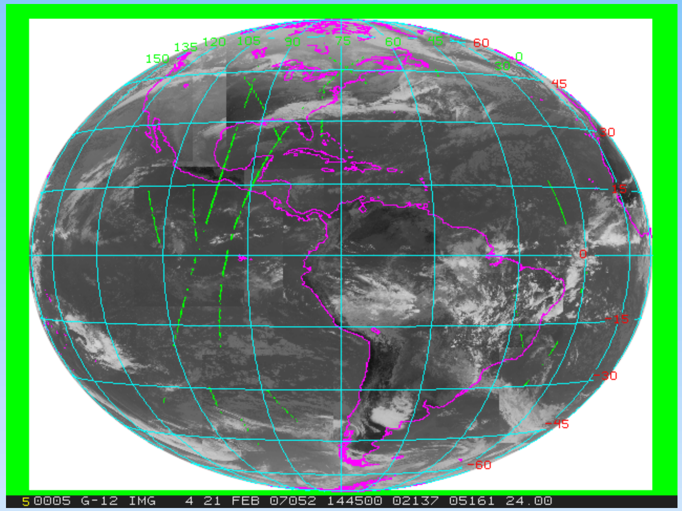
- Extensive pre-launch characterization of all instruments traceable to SI standards
- Benchmark instruments in space with appropriate accuracy, spectral coverage and resolution to act as a standard for inter-calibration
- Independent observations (calibration/validation sites – ground based, aircraft)

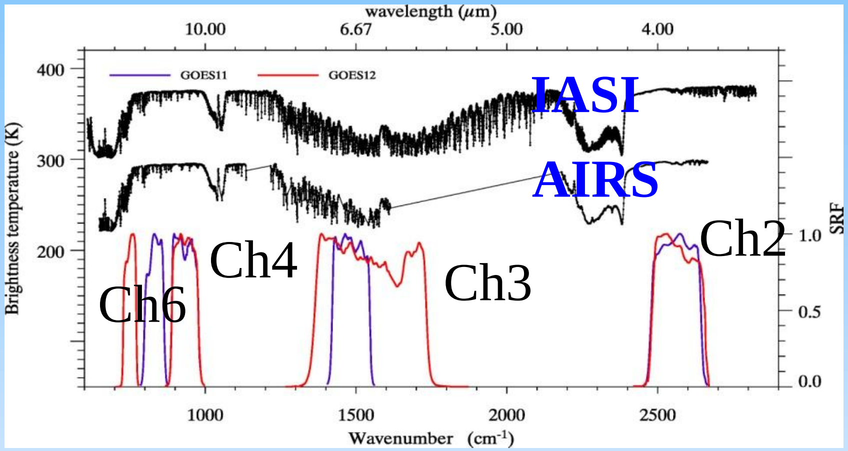
Current focus of GSICS

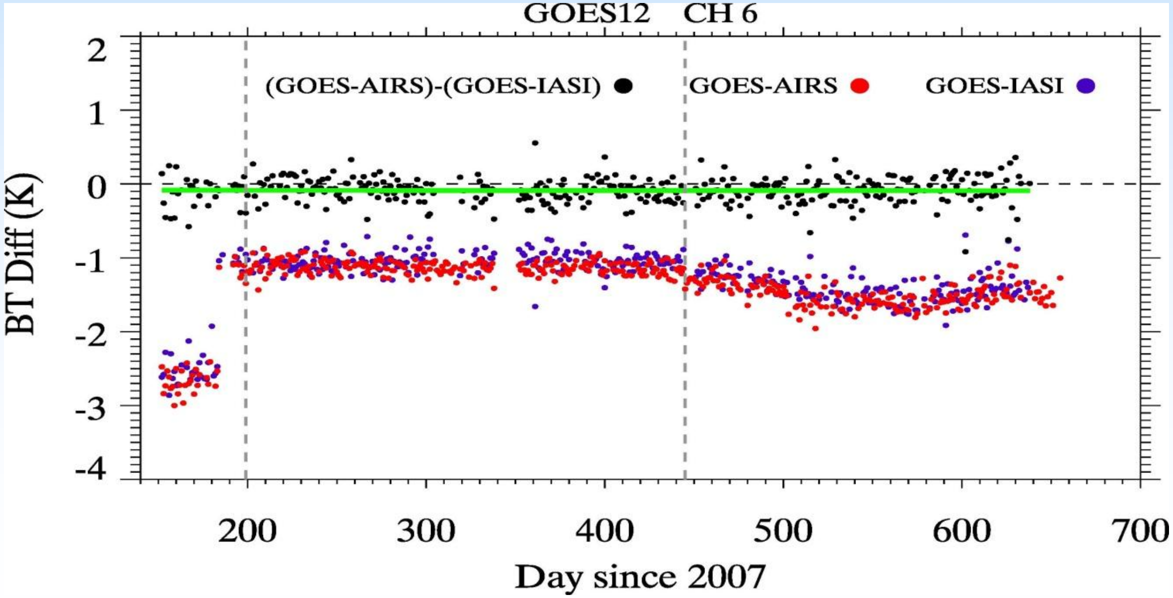
- Interagency collaboration on algorithms (GRWG) and data (GDWG)
- Product acceptance and documentation requirements, metadata standards, data formats, website standards
- Routine intercalibration of all operational GEO imagers using IASI and AIRS
  - Infrared and visible channels
- Intercalibration of LEO instruments (NOAA, CNES, CMA, EUMETSAT)
  - HIRS, SSMI, AMSU, MHS, AVHRR, AIRS, IASI, FY3,
  - GOME-2, OMI, SBUV
- Traceability
  - Campaigns
  - Key collocation datasets
  - Requirements for pre-launch calibration
- Root causes and corrections

GSICS

Coordinated international program for sustained operational implementation of satellite intercalibration and characterisation

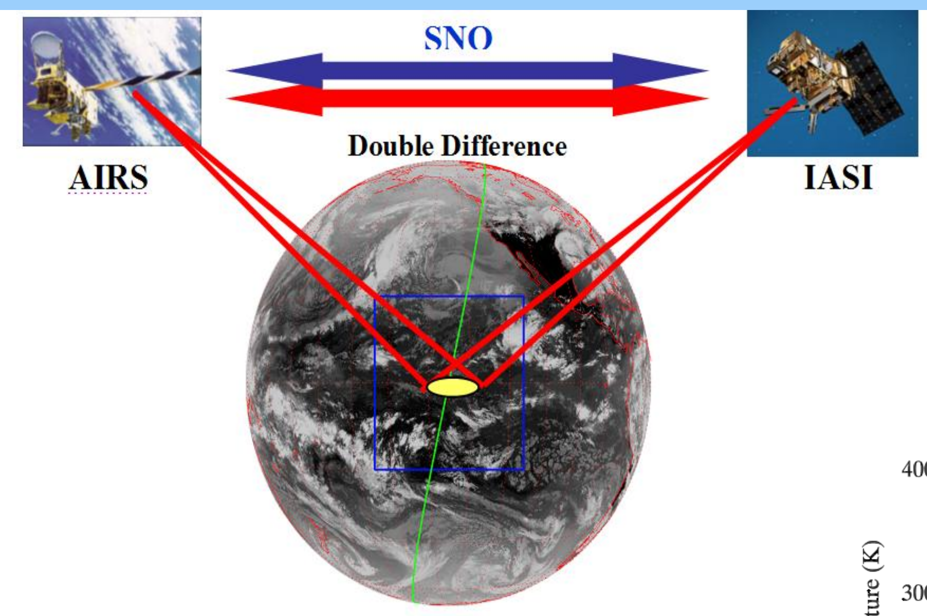


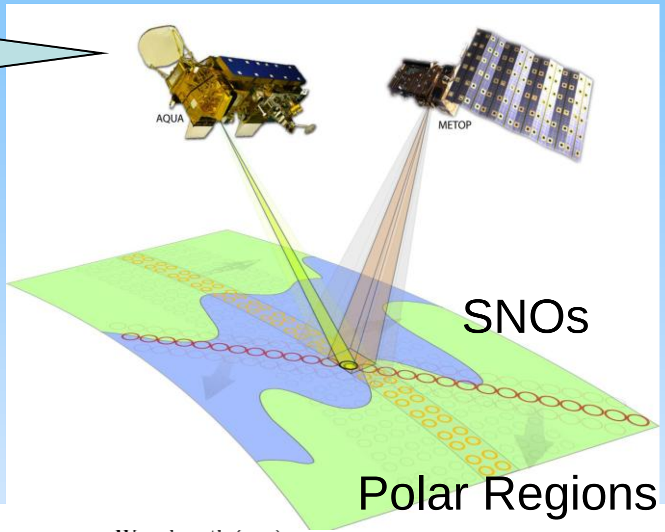


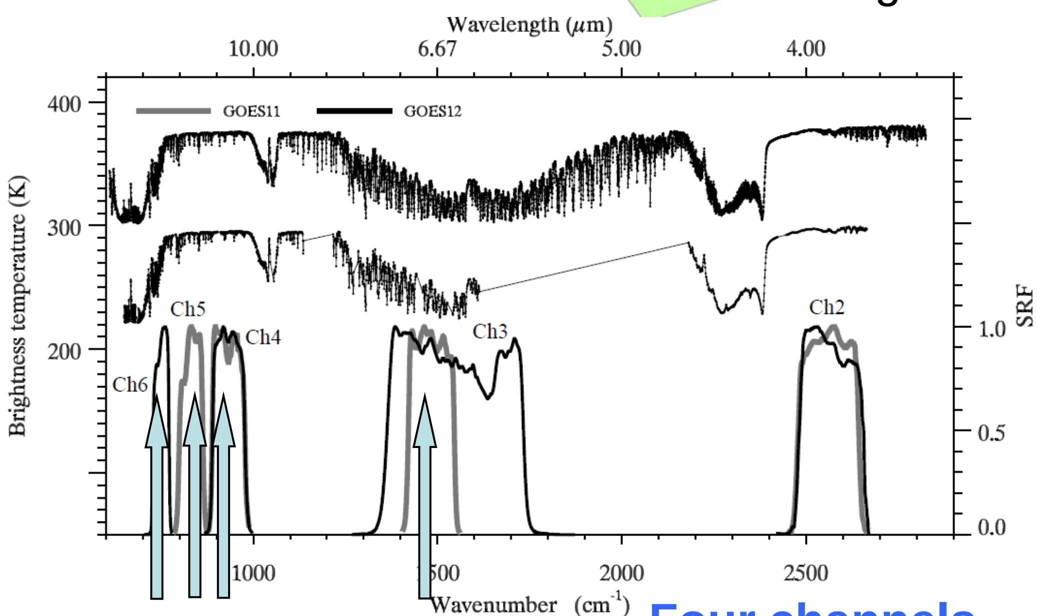


Web Accessible

Double Difference versus SNOs





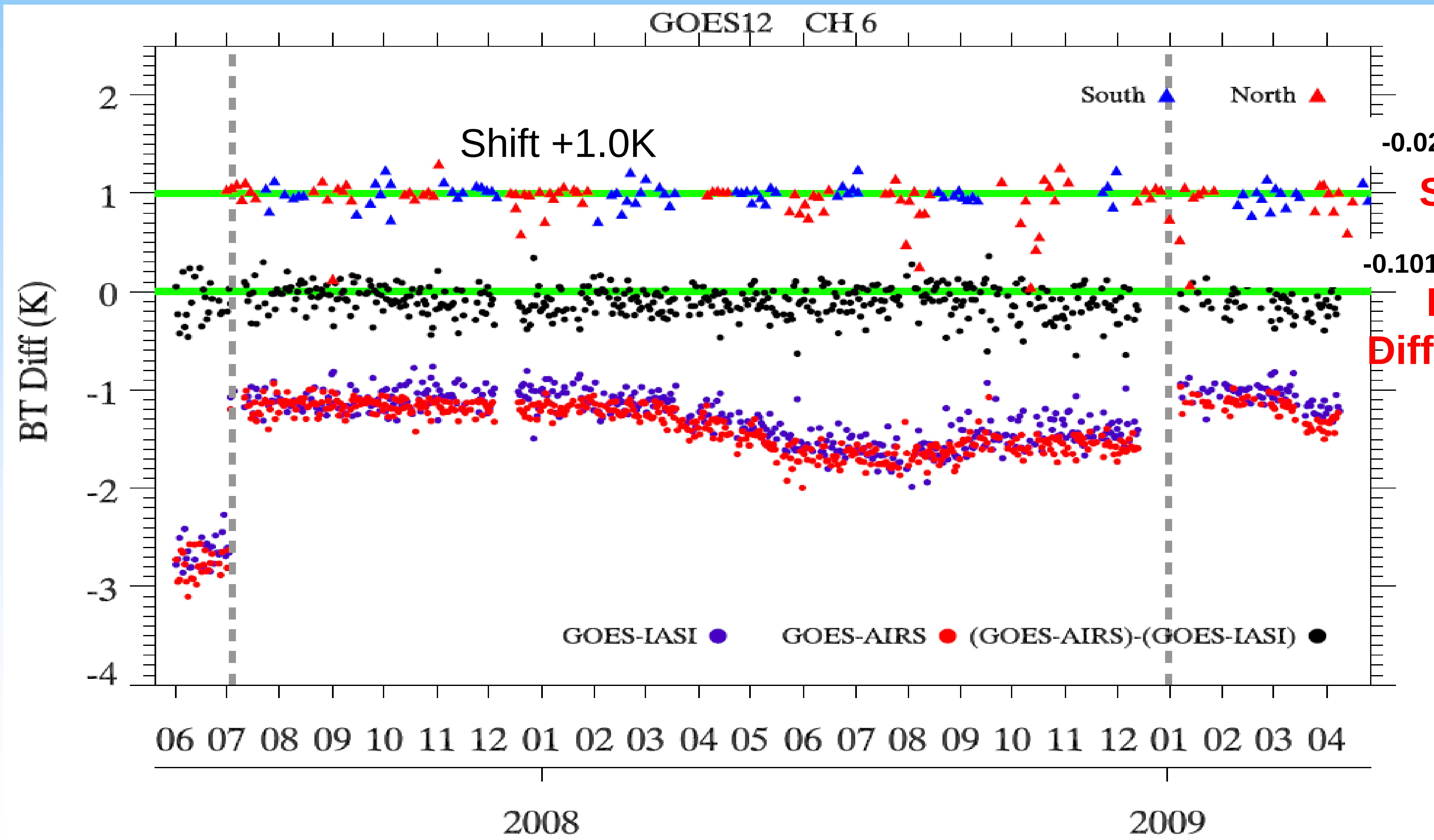


Four channels

1) Indirect vs. Direct comparison

01/29/2010

Double Difference vs. SNO



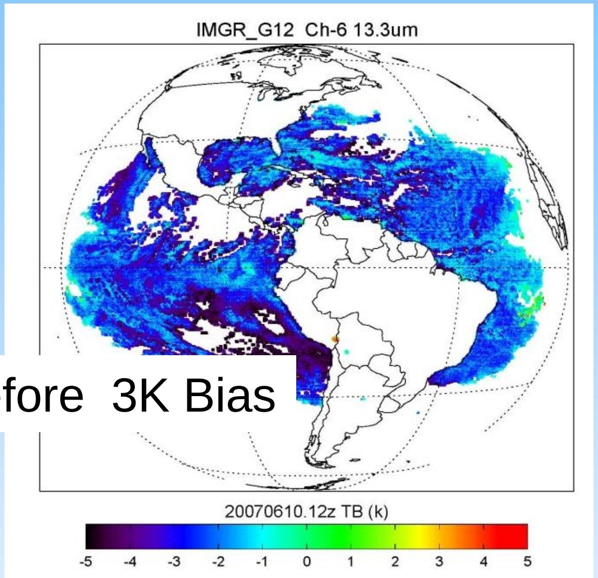
-0.027±0.199 K

SNO

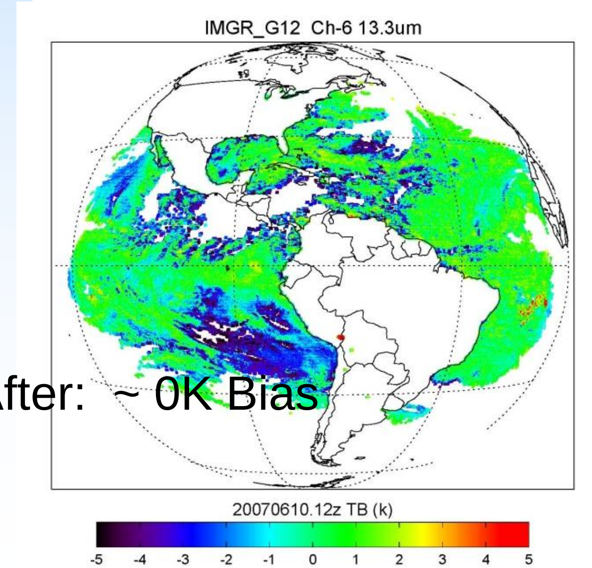
-0.101 ±0.150 K

Double Difference

GSICS Correction Algorithm for Geostationary Infrared Imagers



Before 3K Bias



After: ~ 0K Bias

The first major deliverable to the user community is the GSICS correction algorithm for geostationary satellites.

The user applies the correction to the original data using GSICS provided software and coefficients.

The correction adjusts the GOES data to be consistent with IASI and AIRS.

The figures to the left show the difference between observed and calculated brightness temperatures (from NCEP analysis) correction, respectively.

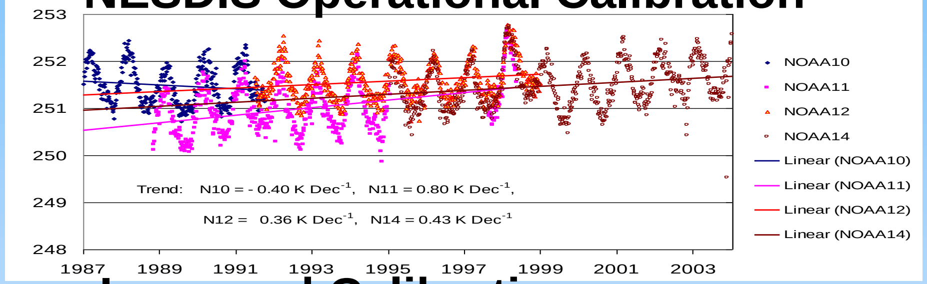
The bias is reduced from 3 K to nearly zero.

Other Examples

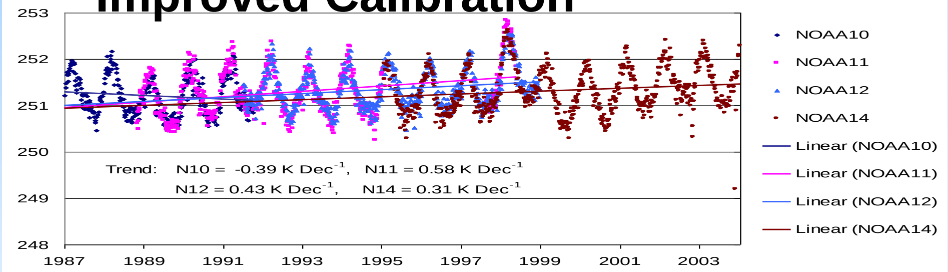
Satellite Intercalibration improves MSU time series

Simultaneous Nadir Overpass (SNO)

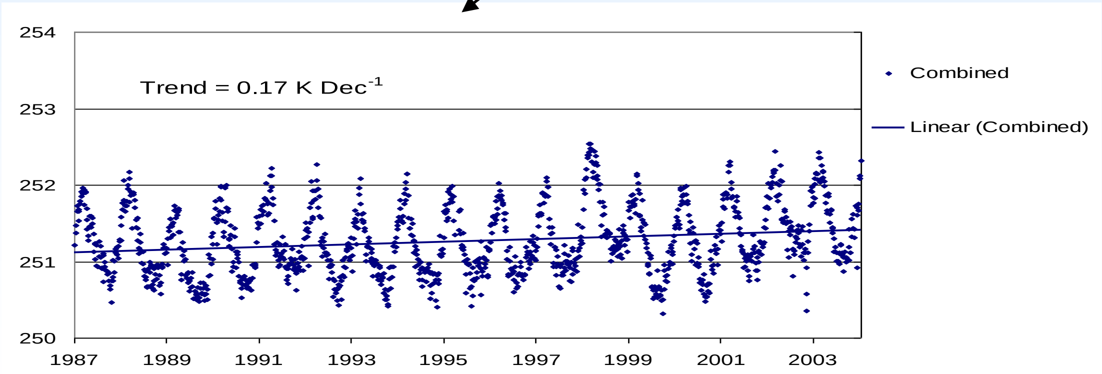
NESDIS Operational Calibration



Improved Calibration



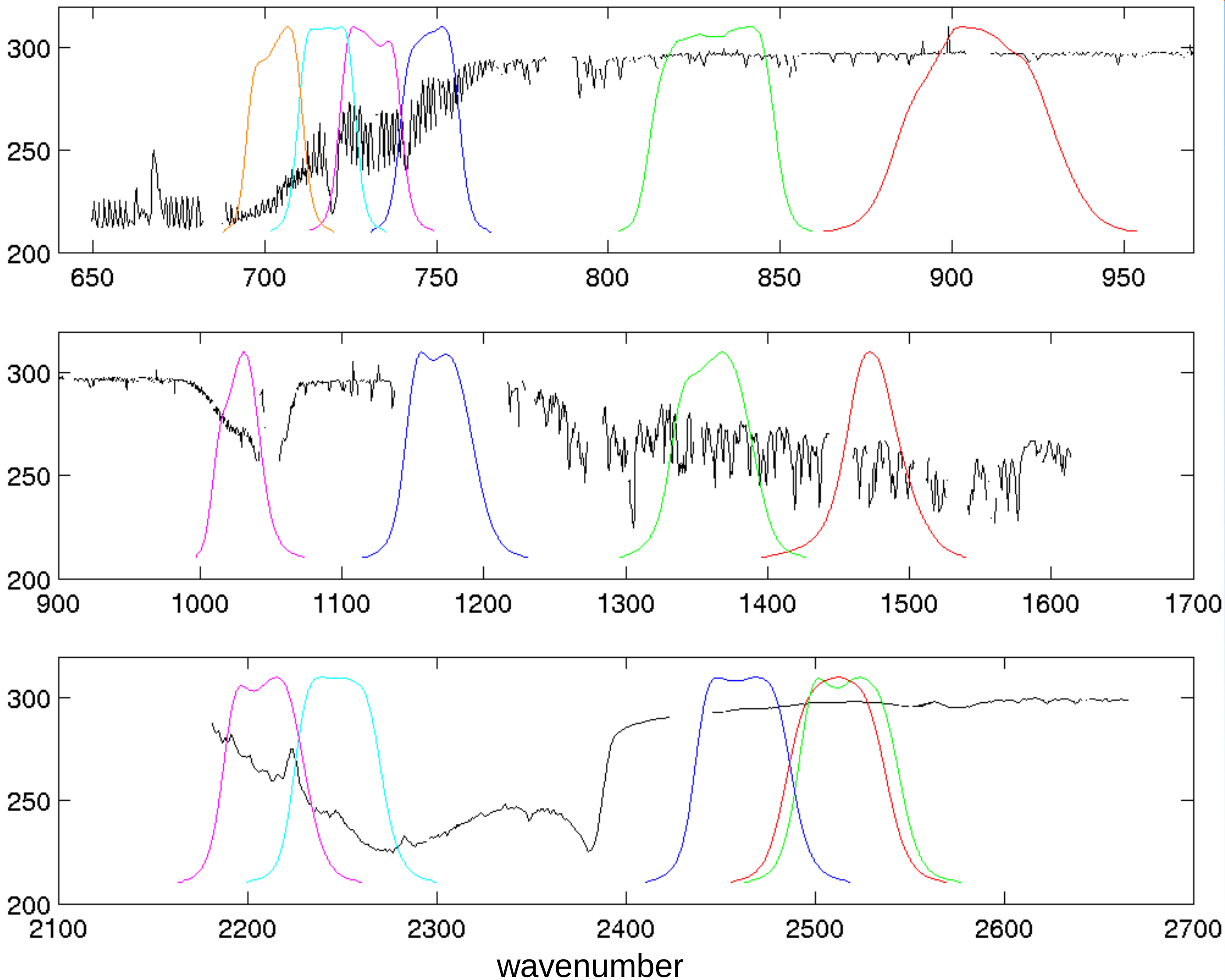
Improved calibrated radiances using SNO- improved differences between sensors by order of magnitude.



Trends for nonlinear calibration algorithm using SNO cross calibration

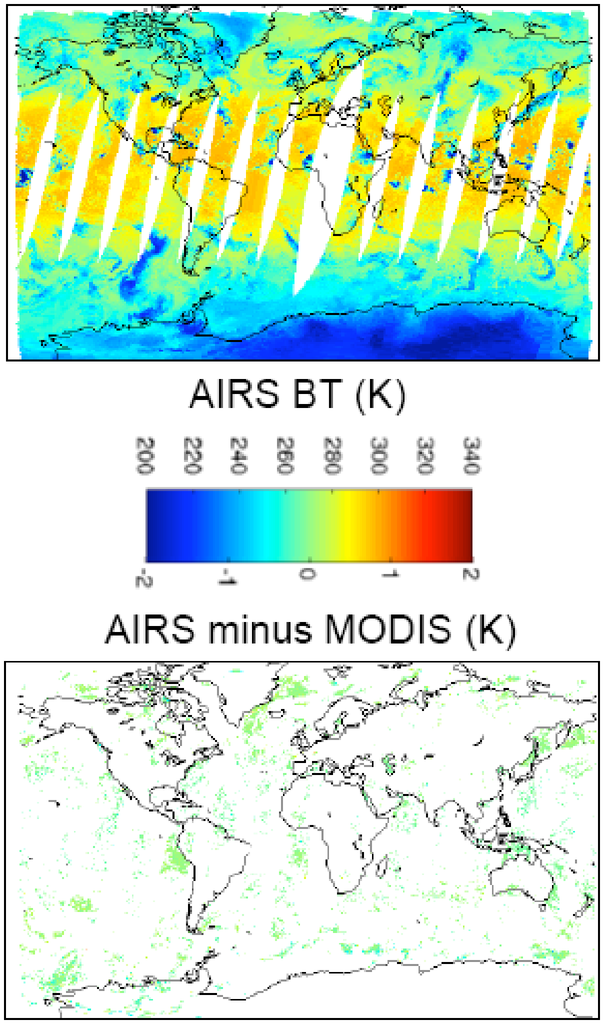
0.20 K Decade^{-1}

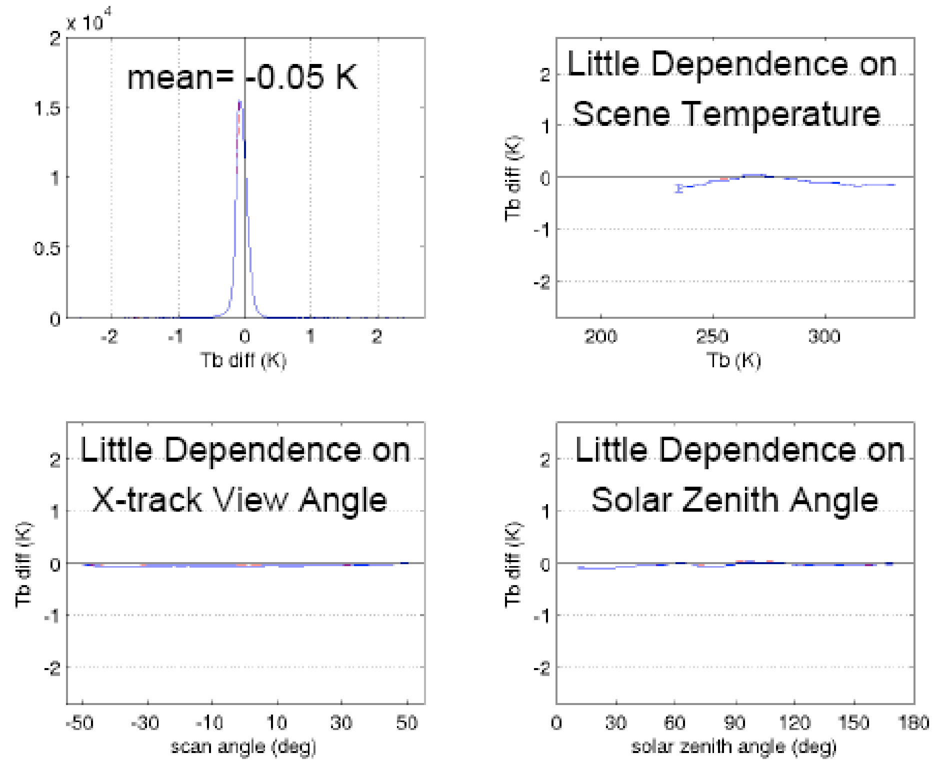
AIRS spectrum and Aqua MODIS Band Spectral Response Functions (SSEC)



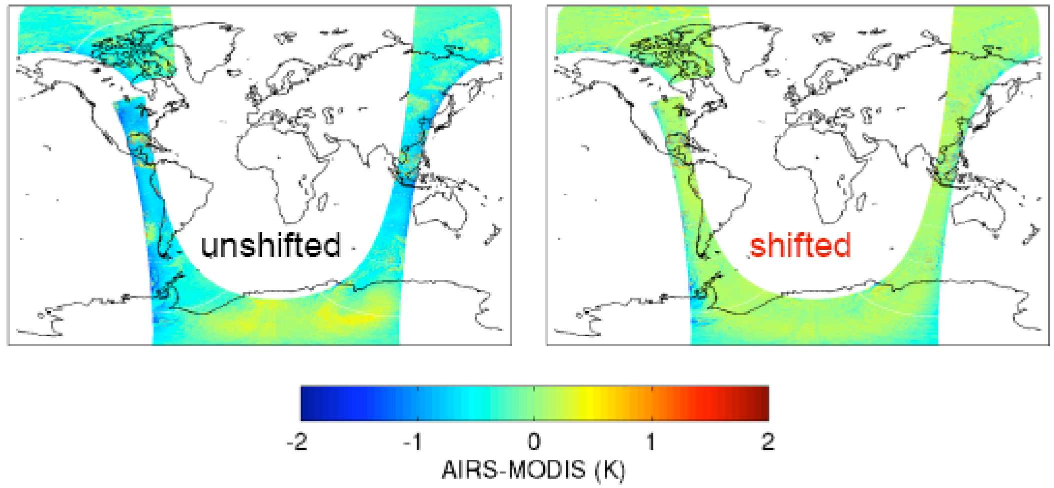
MODIS Band / wavelength(µm)	
36	14.2
35	13.9
34	13.7
33	13.4
32	12.0
31	11.0
30	11.0
29	9.7
28	7.3
27	6.8
25	4.5
24	4.4
23	4.1
22	4.0
21	4.0

Example comparisons for band 22 (4.0 μm) on 6 Sept 2002.

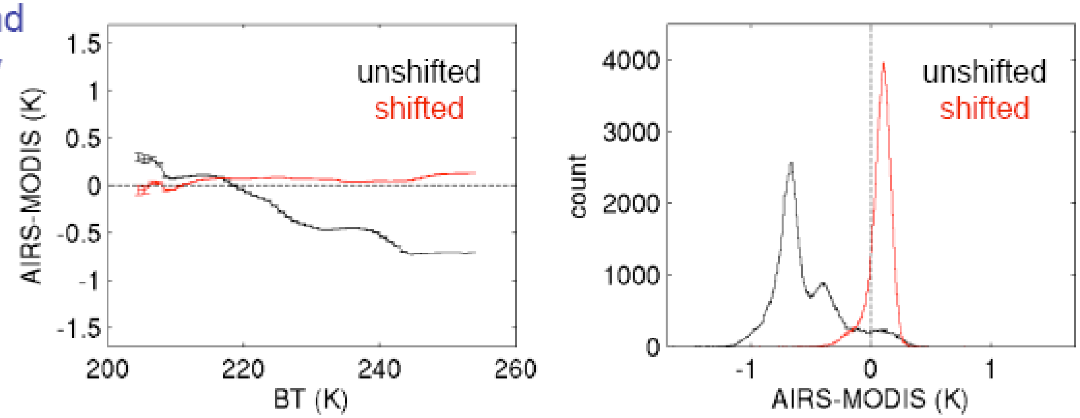




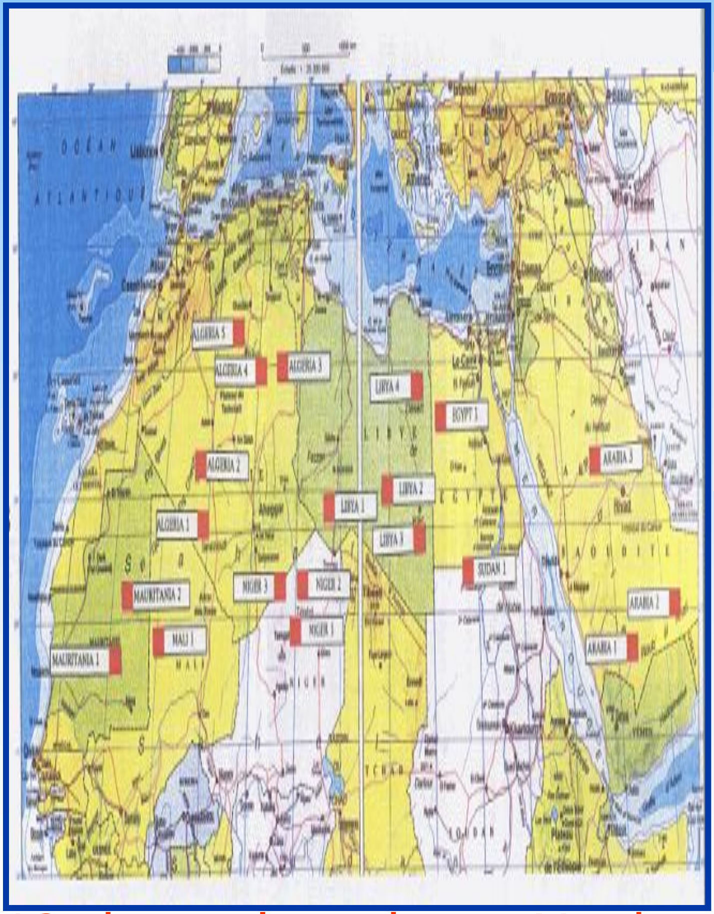
Band 35 (13.9 μm) brightness temperature differences for one orbit of data on 6 Sept 2002 using (1) the nominal MODIS SRF and (2) the MODIS SRF shifted by +0.8 cm^{-1}.



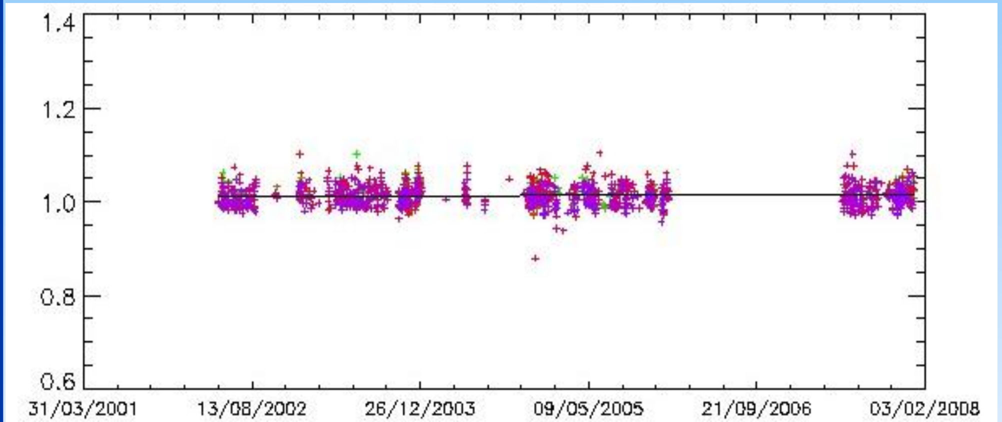
MODIS SRF out-of-band response also currently being investigated.



CNES SADE Data Base is critical for assessing stability of visible/near infrared reference instruments for intercalibration

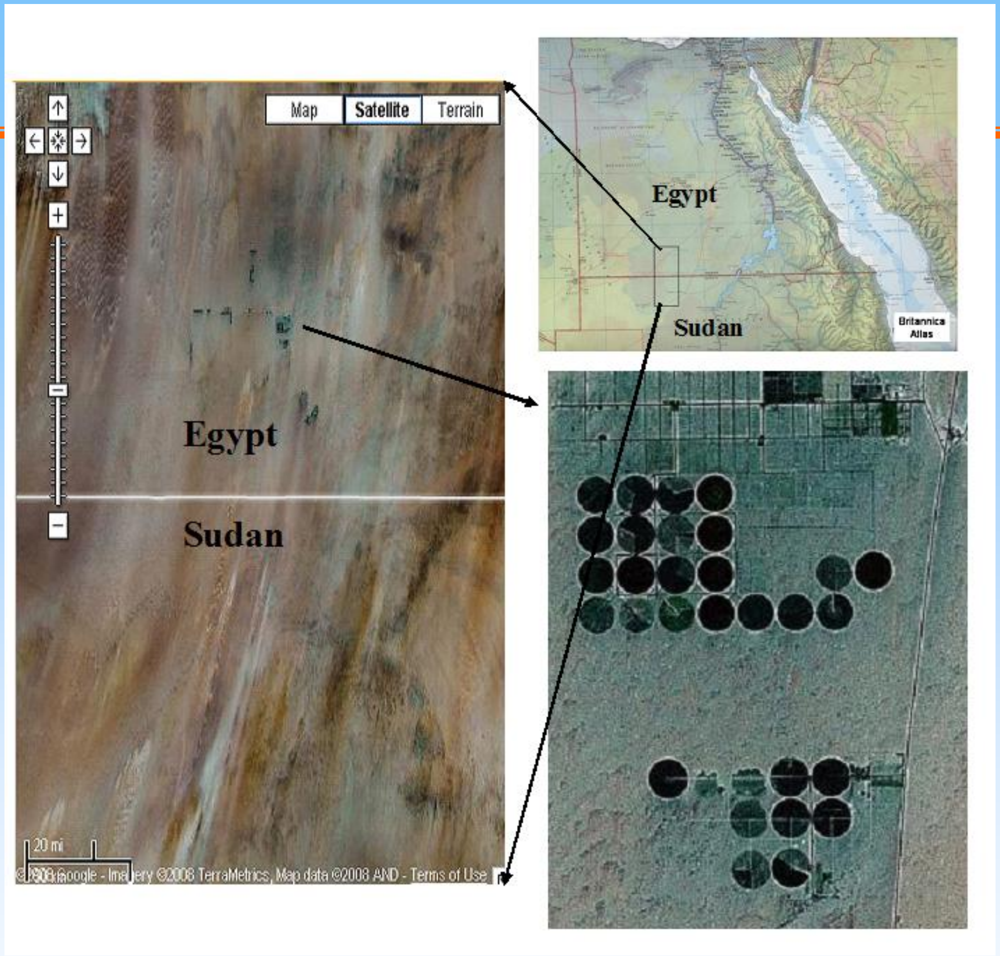


- 19 sites selected over North Africa and Arabia



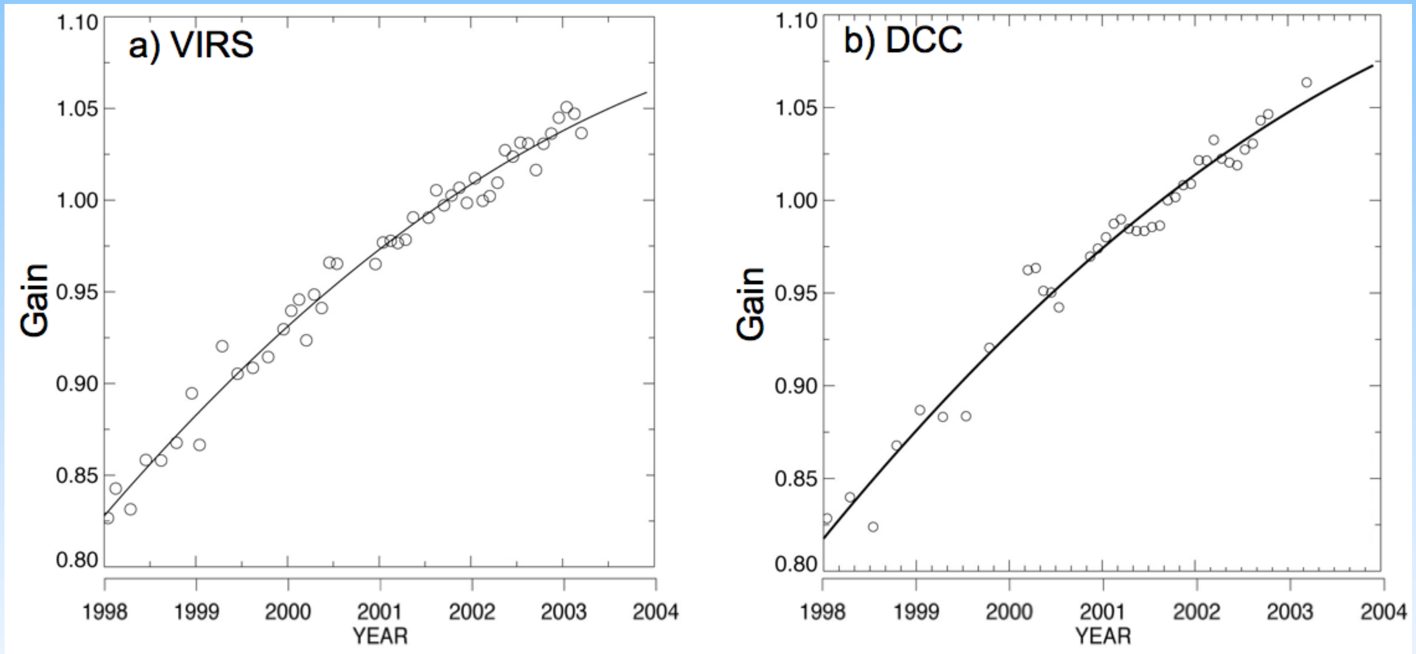
Time series of the ratio of the ESA MERIS to NASA MODIS 0.665 micron visible channel reflectance from observations at 19 desert sites in North Africa and Saudi Arabia.

The results show very good agreement and stability between the two sensors



The Libyan Desert. Google map images with TerraMetrics show the irrigation vegetation growth inside the calibration target (circle spots in the lower-right). The left image is the MODIS RGB image with 1km spatial resolution. The lower-right image is the Landsat-7 ETM 30m spatial resolution measurement.

Use of Deep Convective Clouds to calibrated Visible and NIR channels



Monitoring of the GOES-8 visible (0.63µm) channel using the DCC and LEO/GEO inter-calibration methods.

The left panel (a) shows the GOES-8 visible gain during 1998 through 2003, based on the inter-calibration VIRS and GOES-8. The right panel (b) shows the relative DCC calibration, normalized to the VIRS/GOES-8 gain on January 2001, based on the degradation of the DCC visible digital counts over time.
A 2nd order regression is also plotted for each method. Note the excellent agreement between the two calibration methods.

Integrated Cal/Val System Architecture

Calibration Opportunity Prediction

Data Acquisition Scheduler

Calibration Opportunity Register (CORE)

Raw Data Acquisition for Calibration Analyses

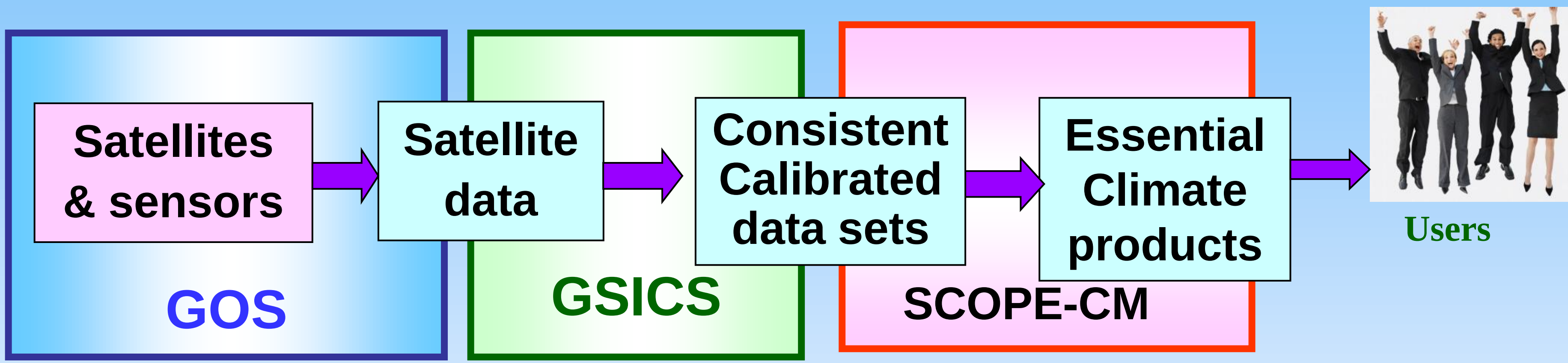
Stored Raw Data for Calibration Analyses

- SNO/ SCO Rad. Bias and Spectral Analysis
- Calibration Parameter Noise/ Stability Monitoring
- RTM Model Rad. at Calibration Reference Sites
- Inter-sensor Bias and Spectral Analysis
- Earth & Lunar Calibration
- Geolocation Assessment (Coastlines, etc.)

Assessment Reports and Calibration Updates

SCOPE-CM to maximize data usage

Sustained and Coordinated Processing of Environmental Satellite Data



- Regional/Specialized Satellite Centres
  - Address the requirements of GCOS in a cost-effective, coordinated manner, capitalising upon the existing expertise and infrastructures.
  - Continuous and sustained provision of high-quality ECVs
  - GSICS enables the generation of Fundamental Climate Data records and provides the basis for sustained climate monitoring and the generation of ECV satellite products.

National Environmental Satellite, Data, and Information Service

Establishing A National Calibration Center (NCC)

Vision
Mission
& Strategy

Vision

Establish long-term stewardship and an independent technical authoritative source for satellite instrument calibration to ensure confidence in the accuracy, consistency, interoperability, and quality of satellite observations

Mission

Reduce satellite measurement uncertainties to meet environmental and climate change detection requirements, and ensure high quality data for NWP and other operational environmental applications

Technical Strategy

Leverage complementary expertise from key agencies/labs to develop, maintain, and promote the use of calibration standards and best practices to make satellite observations consistent, intercomparable, and traceable to national/international standards.

Enable required measurement accuracy and climate change detection from satellites, and ensure high-quality satellite data for all applications