Combining Ray-matching (SNO) with Invariant Target Methods for GSICS GEO-LEO Inter-Calibration

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Outline of Presentation

- Introduction
- Strategy for Inter-Calibration of Solar-band Channels
  - Reference Instrument
  - Combining Invariant Targets & Direct comparison of ray-matched collocations
  - Deep Convective Cloud
  - Liquid Water Cloud
  - Deserts and Bright Land Surfaces
  - Rayleigh Scattering
  - Sun Glint
  - Moon
  - Stars
  - Ray-Matched Collocations
- Future
  - Combination, Monitoring, Correction for GEO imagers
  - Extension to other instruments

Global Space-based Inter-Calibration System

- What is GSICS?
  - Global Space-based Inter-Calibration System
  - Initiative of CGMS and WMO
  - An effort to produce consistent, well-calibrated data from the international constellation of operational meteorological satellites

- What are the basic strategies of GSICS?
  - Best practices/requirements for prelaunch characterisation (with CEOS WGCV)
  - Improve on-orbit calibration by developing an integrated inter-calibration system
    - Initially by LEO-GEO Inter-satellite/ inter-sensor calibration

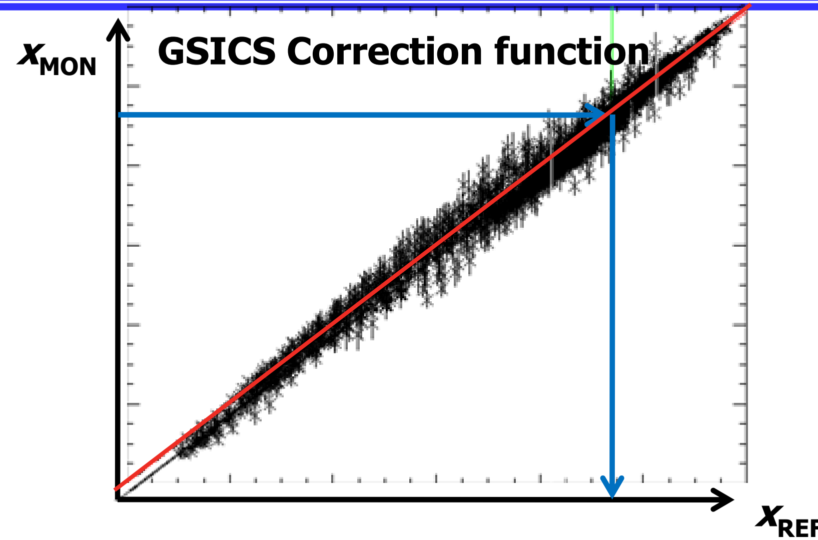
- This will allow us to:
  - Improve consistency between instruments
  - Produce less bias in Level 1 and 2 products
  - Retrospectively re-calibrate archive data
  - Better specify future instruments

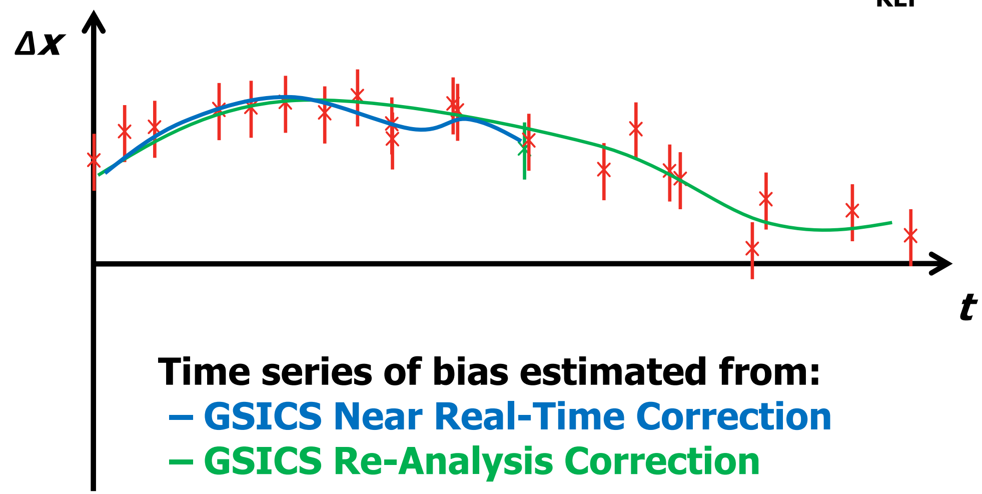
GSICS
Global Space-based
Inter-Calibration System

EUMETSAT | CNES | JMA
NOAA | CMA | KMA
ISRO | NASA | WMO
NIST | JAXA

GSICS Products for GEO IR

- GSICS Monitoring
- GSICS Corrections
  - Near Real-Time & Re-Analysis
- for Monitored instrument
  - IR channels of GEO imagers
- against reference instrument
  - IASI and AIRS (hyperspectral)
- by direct comparison
  - of collocated radiances
- Typical Corrections ~1K
  - For GEO IR channels

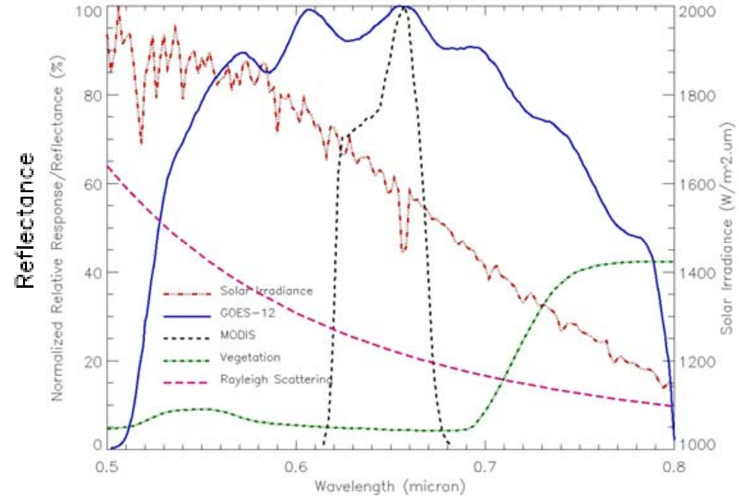




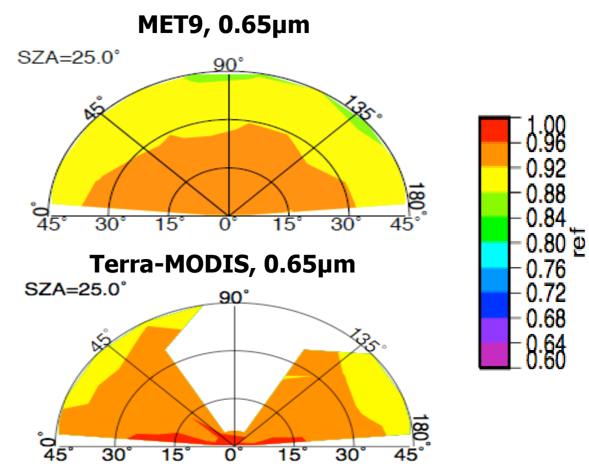
GSICS Global Space-based Inter-Calibration System

Extension to Solar-band Channels

- Choice of Reference
  - No suitable hyperspectral instrument
  - Until CLARREO/TRUTHS
  - Use MODIS as inter-cal reference
    - Need spectral corrections
  - Use GOME2 to research anomalies
- Direct comparisons possible
  - Limited by solar & viewing geometry
  - Need to account for different SRFs
- Supplement with invariant targets
  - Build up BRDF of scene
  - Compare observed BRDF with reference BRDF



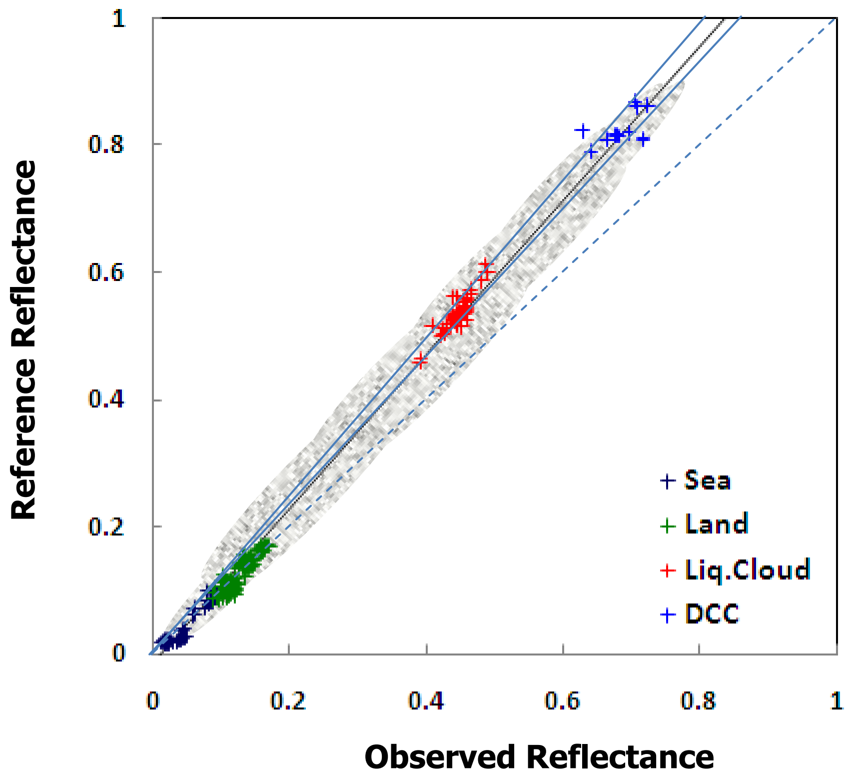
Spectral Response Functions (SRFs) of GOES and MODIS channels, compared to radiance/reflectance of 3 scenes



Bi-Directional Reflectance Functions (BRDFs) derived from Meteosat & MODIS observations of Deep Convective Clouds

Combination of Methods

- Combining results from
  - Direct Ray-matched Comparison
  - Different Invariant Targets
- Spans observational range
  - of Reflectance/Radiance
- Combine in linear regression
  - Weighted by methods' uncertainty
  - Similar concept used to MSG VIS
- Automatic, routine processing
  - Provide daily/monthly cal updates
- Error budget for each method
  - Also assess: Independence, Stability, Availability, Latency and Cost

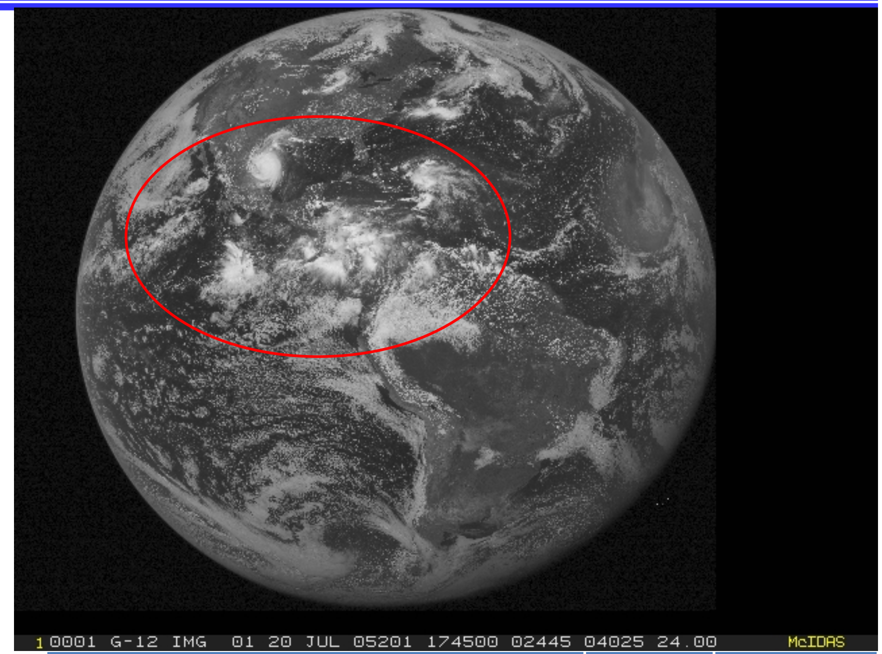


Comparison of Reflectance from Monitored Instrument and Reference for 4 different invariant targets Plus direct ray-matched comparisons (grey cloud)

Regression provides inter-calibration function

Deep Convective Cloud Method

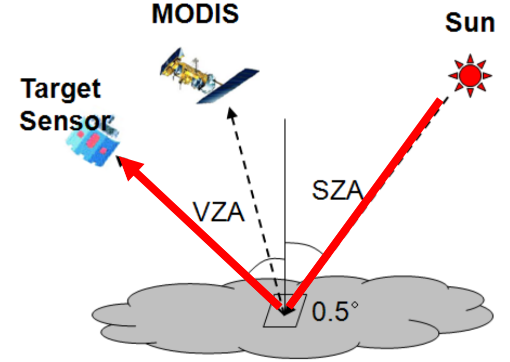
- PI: Dave Doelling (NASA)
- Overshooting cloud tops
  - Uniform reflectance
  - Reliably modelled
- Main issues:
  - identification of DCC targets according to chosen thresholds of infrared radiance
  - viewing and solar geometry
  - scene variance
  - Seasonal/geographic changes in DCCs
  - validation of their BRDF
  - weak SRF dependence
  - Impact of ice particles shape
  - choice of PDF metric (mode, median, ...).



Reflectance Error Budget	VIS	SWIR
Temporal Variability	?%	?%
Geometric Variability	?%	?%
Atmospheric Variability	?%	?%
Spectral Variability	?%	?%
Total (rms)	**?%**	**?%**

Liquid Water Cloud Method

- PI: B.J. Sohn (SNU), Arata Okuyama (JMA)
- Coincident and collocated MODIS cloud products are used to describe water cloud properties in RTM, from which TOA radiances of target sensor can be simulated
- Main Issues:
  - accuracy of radiative transfer model (particularly associated with 3D effects)
  - uncertainty in MODIS cloud parameters (COT for VIS band, r_e for NIR band)
  - weak SRF dependence

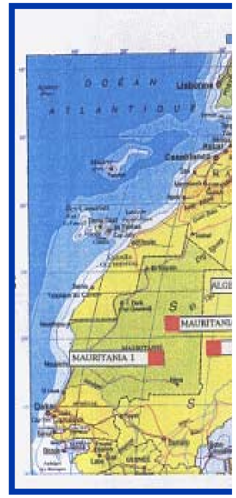


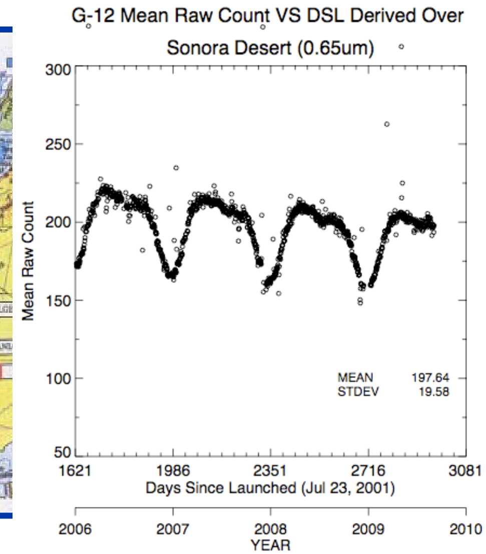
Collocated MODIS cloud parameters (COT, r_e, cloud phase, cloud altitude)

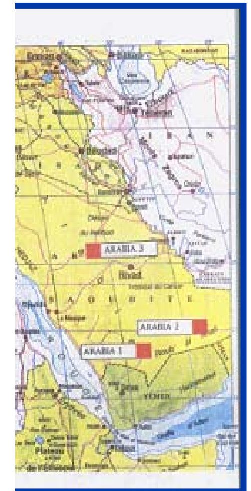
Reflectance Error Budget	VIS	SWIR
Ocean reflectance: 0.05±0.02	0.3%	0.05%
Atmospheric profile: TRO and MLS	1%	0.9%
Ozone profile only: TRO±10%	0.5%	0%
Cloud optical thickness: 30±3 (10%)	4%	0.9%
Cloud particle radius: 20±2μm (10%)	0.8%	6%
Boundary layer AOT: 0.5±0.25	0.9%	0.4%
Stratospheric AOT: 0.02±0.02	0.4%	0.5%
Total (rms)	**4.35%**	**6.17%**

Desert and Bright Land Surfaces

- PI: Patrice Henry (CNES)
- Identify land targets with constant reflectance
  - Deserts, salt flats, glaciers
- Main Issues
  - global distribution of targets
  - characterising their spectral variation and BRDF
  - strong season variation
  - necessitating time series of ≥3 years
  - knowledge of atmospheric (particularly humidity and aerosol)







Reflectance Error Budget	VIS	SWIR
Temporal Variability	?%	?%
Geometric Variability	?%	?%
Atmospheric Variability	?%	?%
Spectral Variability	?%	?%
Total (rms)	**?%**	**?%**

Rayleigh Scattering Method

- PI: Patrice Henry (CNES)
- Observe the atmosphere above ocean surface (= dark surface)
- Contributions to the TOA signal:
  - Rayleigh molecular scattering : accurately computed (SOS code)
  - Ocean surface : from climatology
  - Aerosols : rejection threshold + corr.
- Main Issues
  - Low reflectance scene
  - Confirmation of clear sky
  - Variable aerosol contribution
  - Atmospheric correction
  - SRF correction

Rayleigh

Ocean

Aerosols

Reflectance Error Budget	VIS	SWIR
Surface Pressure: 10hPa	0.8%	1.2%
Wind Speed: 2m/s	1.0%	1.0%
Calibration at 865nm: 3%	1.4%	1.4%
Aerosol Model: 50%	0.3%	0.5%
Gas Amount: 20%	0.7%	4.0%
Marine Reflectance	0.3%	3.0%
Total (rms)	**2.1%**	**6.2%**

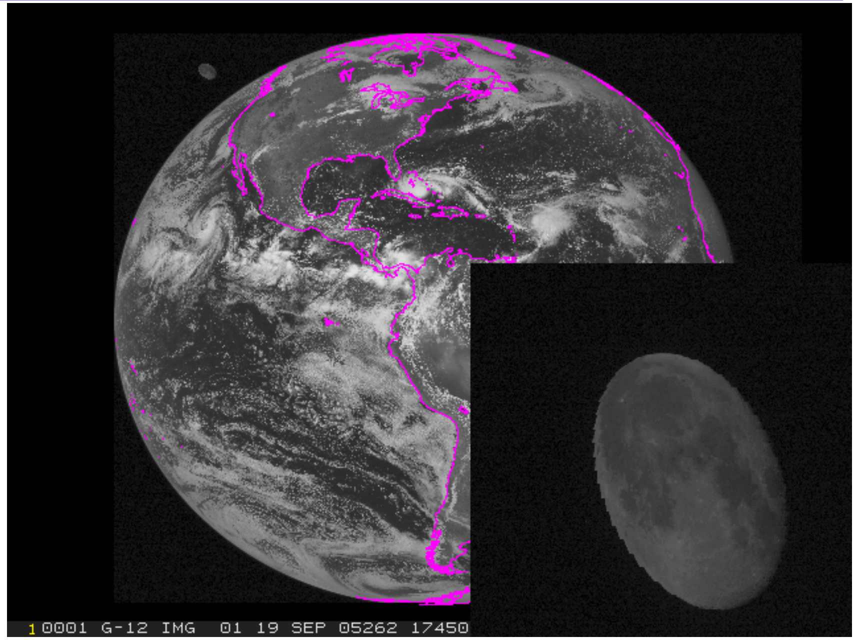
Sun Glint Method

- PI: Andy Heidinger (NOAA)
- Observe the "white" reflection of the sun over the ocean surface
- Inter-calibration of blue to SWIR bands with a reference band (usually red)
  - **application requires multiple channels in the solar band to provide a relative calibration**
- Main Issues
  - confirmation of clear sky
  - atmospheric correction
  - SRF correction
  - sea state assessment <5m/s
  - Possible saturation
  - extreme sensitivity to SRF errors

Reflectance Error Budget	VIS	SWIR
Rayleigh Scattering	?%	?%
Surface Wind Speed	?%	?%
Aerosol	?%	?%
Gaseous absorption	?%	?%
Total (rms)	**~2%**	**?%**

Moon Method

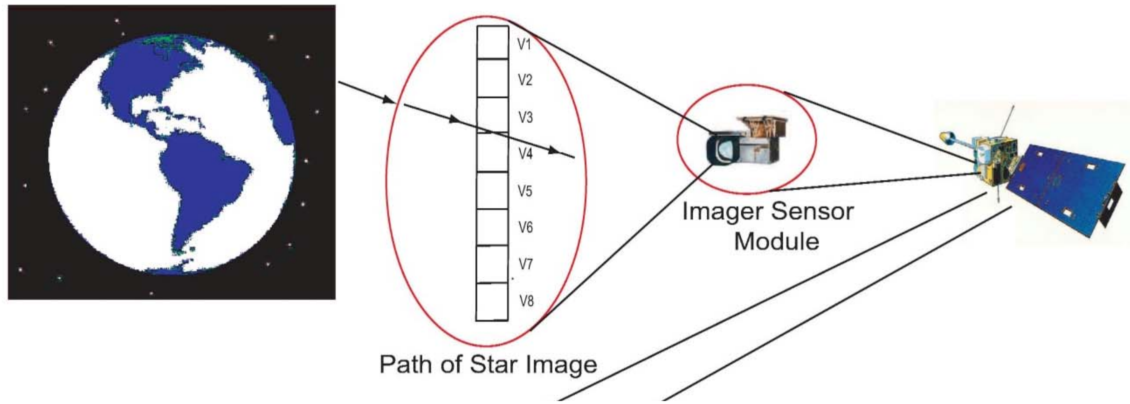
- Moon – PI: Fred Wu (NOAA)
- Nearly ideal target
  - Highly stable
  - No atmosphere
  - Independent of Earth
  - Absolute calibration reference
  - Not very bright
- Main Issues
  - Rely on lunar irradiance model (ROLO)
  - Stray light (MTF, diffraction)
  - Requires accurate navigation
  - Instrument noise
  - Infrequently observed



Reflectance Error Budget	VIS	SWIR
Obs. Freq.	?%	?%
Lunar Irrad. Model	1%	?%
Stray Light	2%	?%
Instr. Noise	2%	?%
Total (rms)	**3%**	**?%**

Star Method

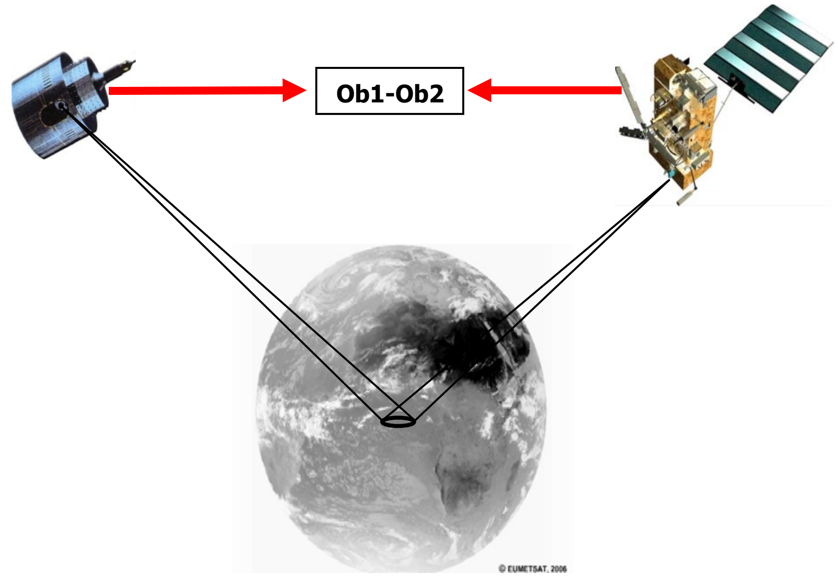
- Stars – PI: Fred Wu (NOAA)
- Highly stable invariant target
  - Highly stable
  - No atmosphere
  - Independent of Earth
  - Plenty measurements
  - Relative calibration (so far)
  - Additional pre-amplifier
  - Only for certain GEO
- Main Issues
  - Instr. Noise – low signal
  - Point source – radiance vs. irradiance
  - Intensity is coupled with instr. op. env.
  - Observation gap (~2 month/year)
  - Need several years' obs -> latency



Reflectance Error Budget	VIS	SWIR
Instr. Noise	>10 %	?%
Intra-Annual Variation	%	?%
Point Spread Function	?%	?%
Stray light	?%	?%
Total (rms)	**?%**	**?%**

Ray-Matching Method

- PI: Dave Doelling (NASA)
- Regress ray-matched coincident and collocated reflectances from GEO and reference
  - Traceability to reference
  - Monitor gain over time
  - Apply correction factor to take out spectral differences
- Main Issues
  - Collocation criteria
  - Accounting for SRF differences between the instruments
  - Choice of reference instrument

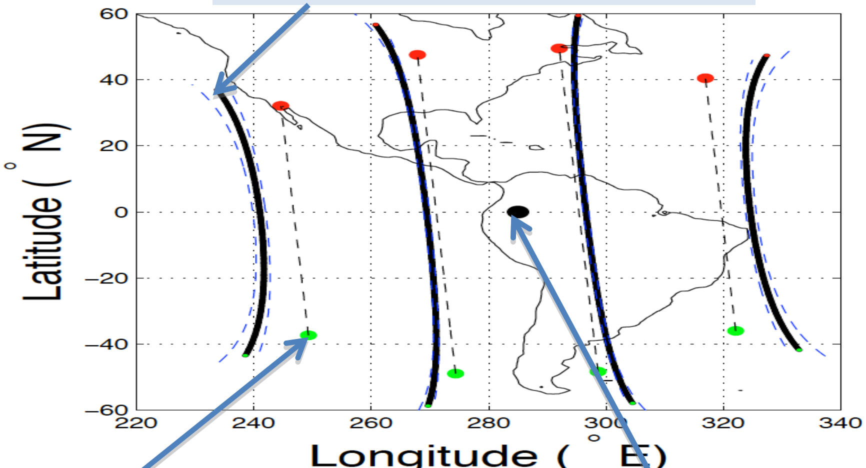


Reflectance Error Budget	VIS	SWIR
Spatial Variability	?%	?%
Temporal Variability	?%	?%
Spectral Variability	?%	?%
Geometric Variability	?%	?%
Total (rms)	**?%**	**?%**

GEO to MODIS Cross-Calibration Method

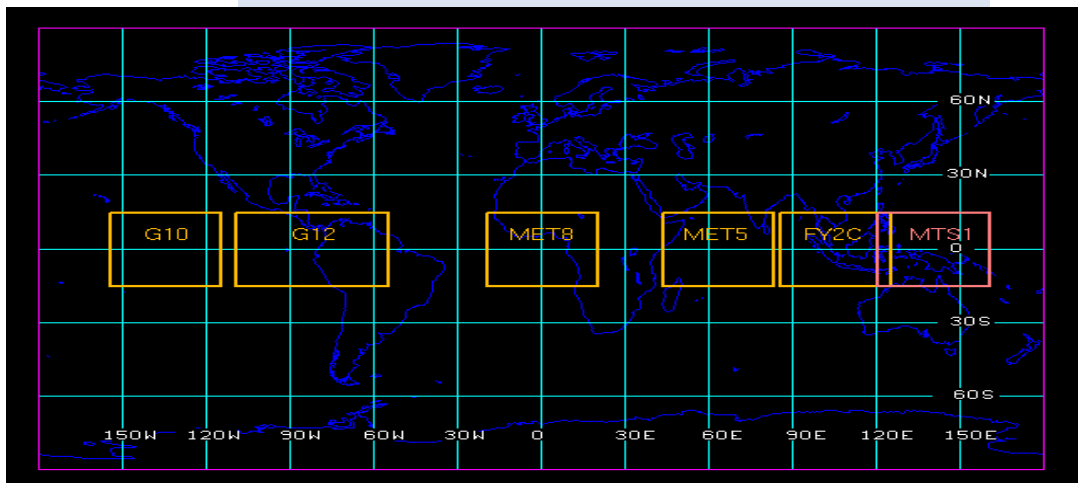
- Ray-match coincident GEO counts (proportional to radiance) and MODIS radiances
  - Use monthly 0.5°x0.5° lat/lon grid to mitigate navigation and time matching errors
  - Use MODIS as reference since GEOs have no onboard calibration
  - Normalize solar constants and SZA, obtain MODIS equivalent radiance
- Perform monthly GEO/MODIS regressions of the gridded radiances, and derive monthly gains
- Compute timeline trends from the monthly gains

Ray-matches radiances



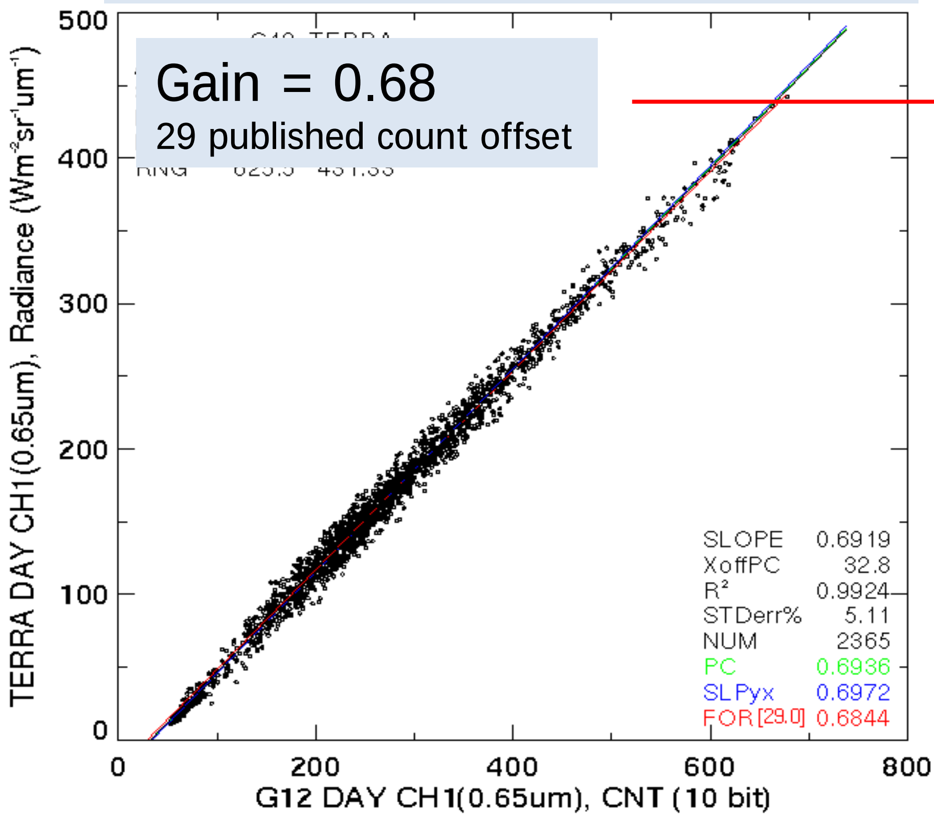
LEO satellite **GEO satellite**

LEO/GEO Ray-matching domains

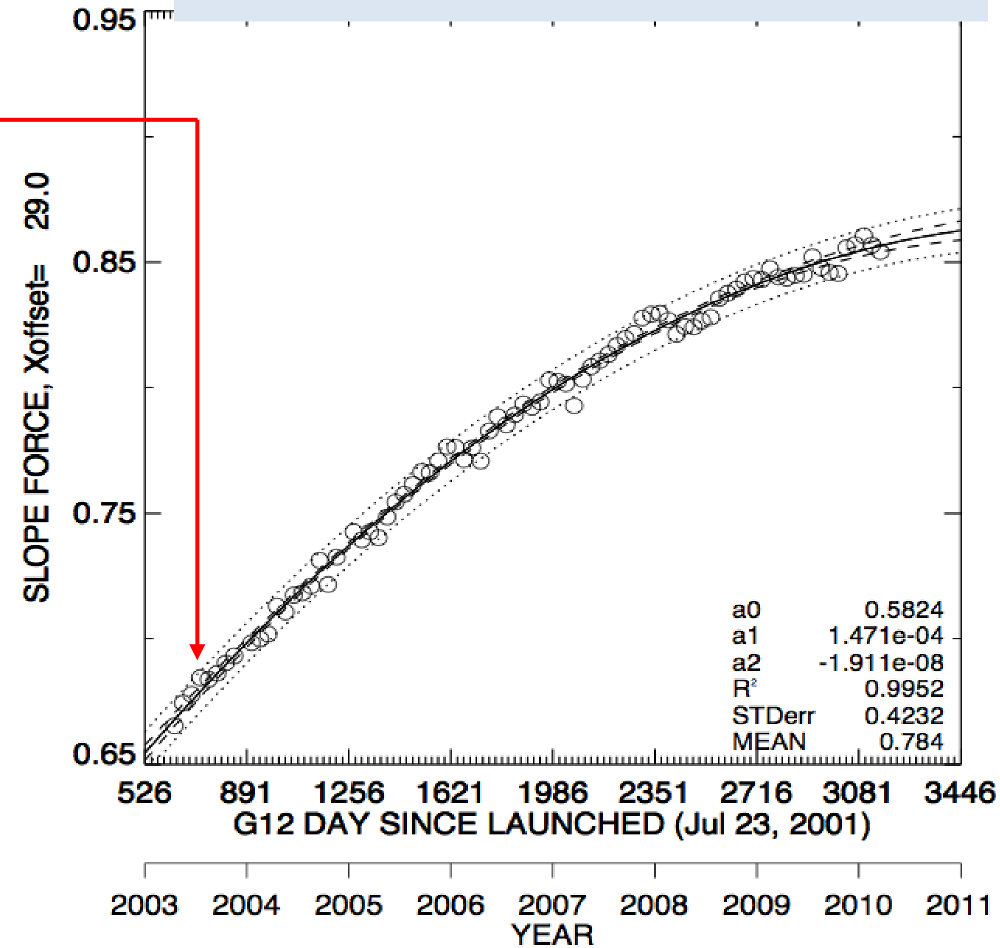


Ray-Matching of LEO-MODIS and GEO

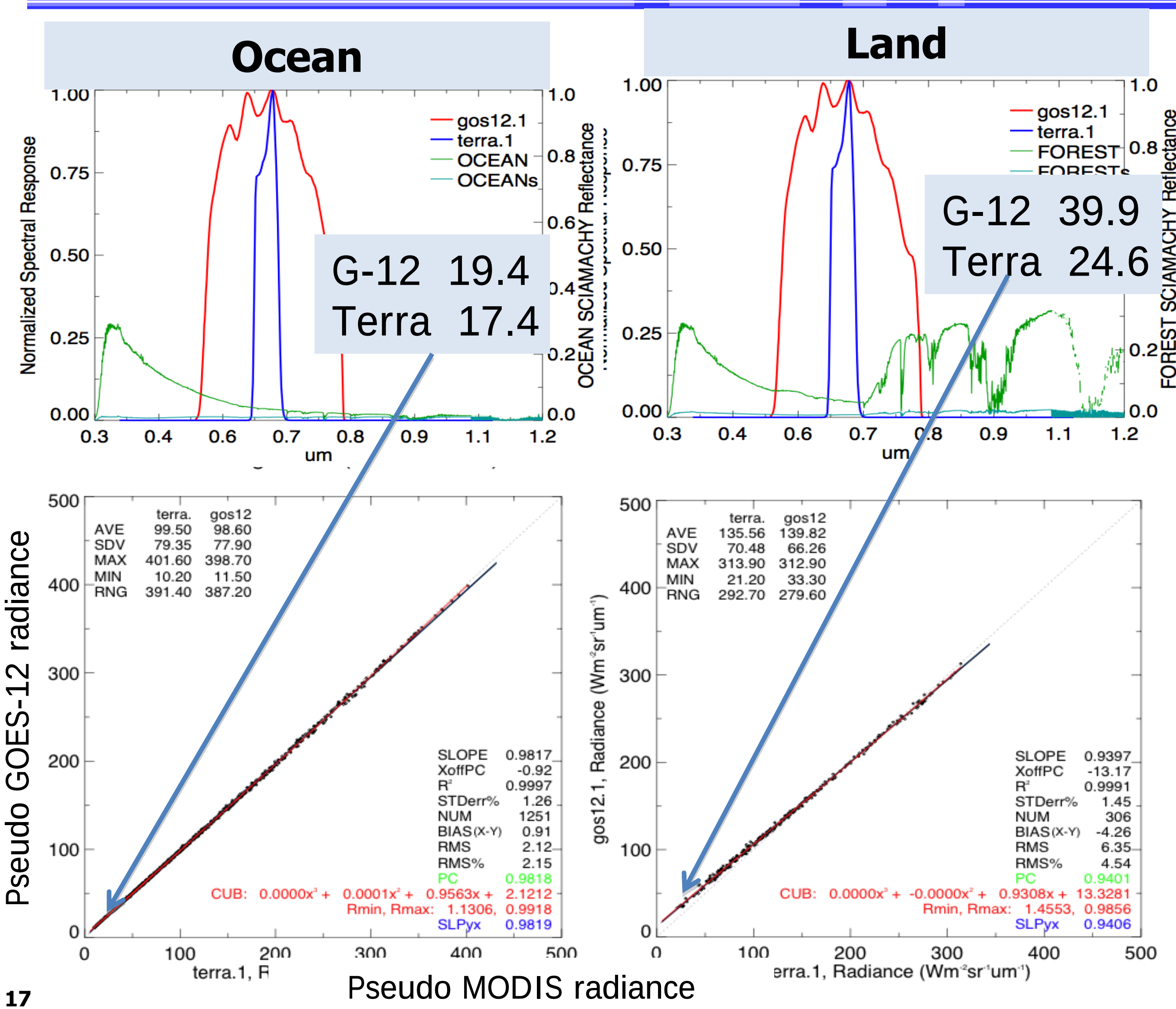
GOES-12/Terra-MODIS July 2003



GOES-12 gain based on Terra-MODIS



Use SCIAMACHY for spectral correction

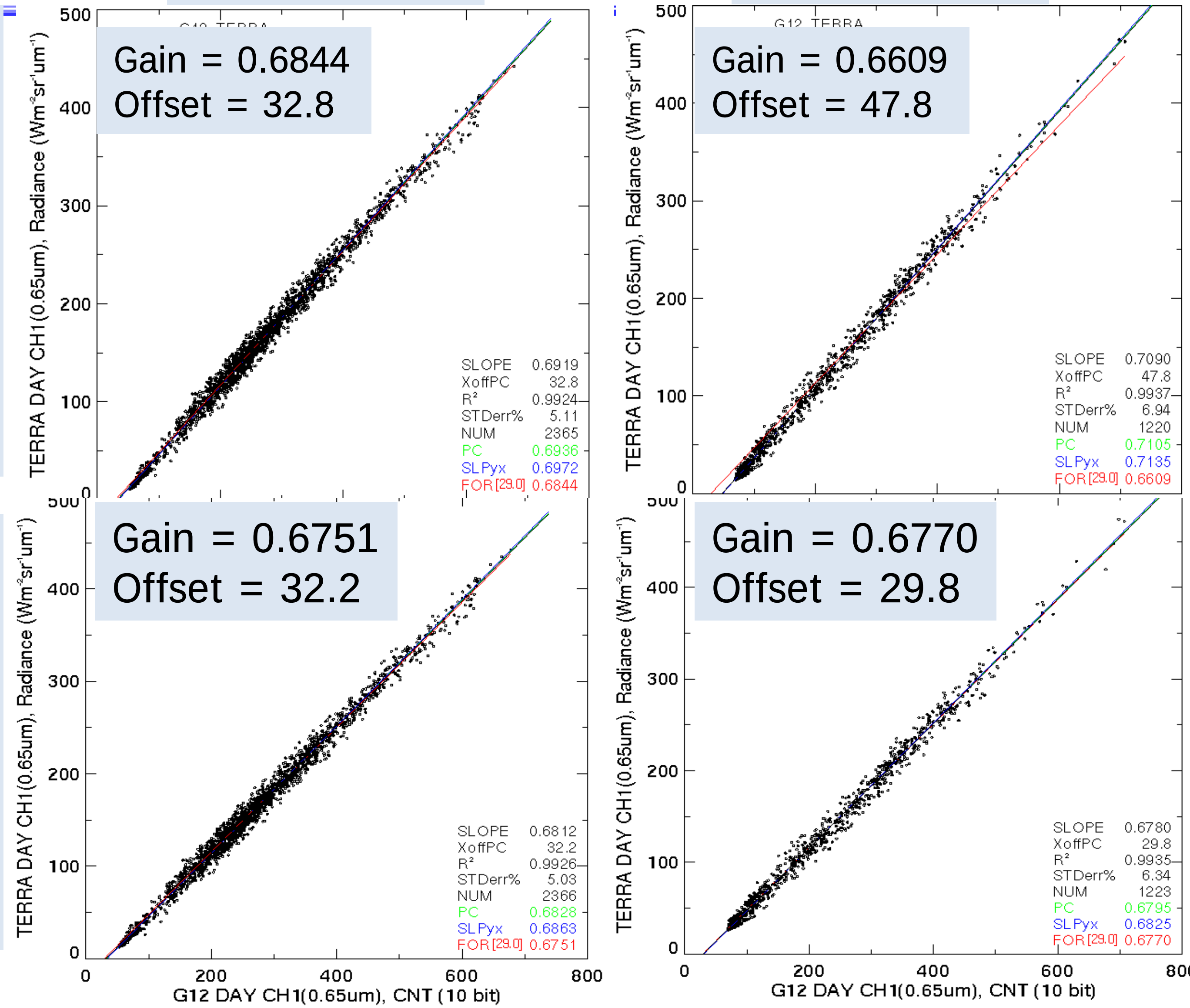


- Compute pseudo GOES-12 and Terra-MODIS from a single SCIAMACHY footprint spectra
- Example to the left is for clear-sky ocean and land
- Note the radiance difference from GOES-12 and MODIS

- Compute pseudo GOES-12 and MODIS radiances for all SCIAMACHY footprints that fall in the GEO equatorial domain
- A cubic regression works for most geo-types
- Apply the SCIAMACHY spectral correction to ray-matches over ocean and land
- The technique is validated if the same overall calibration coefficients are derived

Spectral Correction Validation

	Ocean	Land
Before Spectral Correction	Gain = 0.6844, Offset = 32.8	Gain = 0.6609, Offset = 47.8
After Spectral Correction	Gain = 0.6751, Offset = 32.2	Gain = 0.6770, Offset = 29.8



- GOES-12/Terra-MODIS, July 2003
- Before correction land-ocean difference gain = 3% Offset = Δ 15 counts
- After correction Gain = 0.3% Offset = Δ 2.4 counts and closer to 29

GSICS Global Space-based Inter-Calibration System

Future

- Review Assessments and Error Budgets
  - Select best mix of methods for each monitored instrument
  - Derive relative weights of each method
- Develop GSICS Monitoring
  - Provide web pages to monitor calibration relative to reference
- Develop GSICS Corrections
  - Functions to correct calibration to be consistent with reference
  - For Near Real-Time and Re-Analysis applications
- Aim to have monitoring and corrections for Vis channels of GEO imagers
  - As Demonstration products by end 2011
- Then extend methodology to other sensors on LEO satellites
  - AVHRR, AATSR, etc...
- Extend to CLARREO/TRUTHS
  - Transfer absolute calibration traceable to SI standards
- Step towards GSICS aim to develop integrated on-orbit inter-calibration system
  - For our constellation of operational weather satellites

GSICS
Global Space-based Inter-Calibration System

Thank You

Any Questions?

Time Line for GSICS GEO-LEO Products

Class	#	GPRC	Monitored Instrument	Ref	Product	Date Range	2010 Q1	2010 Q2	2010 Q3	2010 Q4	2011 Q1	2011 Q2	2011 Q3	2011 Q4	2012 Q1	2012 Q2	2012 Q3	2012 Q4
GEO-LEO IR	GL01	EUMETSAT	Meteosat9	IASI	NRTC	2008-05/		Demo				PreOp		Op				
			Meteosat8	IASI	NRTC	2008-05/			Demo				PreOp		Op			
			Meteosat7	IASI	NRTC	2008-05/			Demo				PreOp		Op			
			Meteosat7-9	IASI	RAC	2008-05/			Demo				PreOp		Op			
			Meteosat7-9	IASI	BiasMon	2008-05/			In Developmer		Demo				PreOp		Op	
			Meteosat2-9	HIRS	RAC	1977-??/					In Development				Demo			
	GL02	JMA	MTSAT1R-2	AIRS +IASI	RAC	2009-??/		Demo				PreOp		Op				
			MTSAT1R-2		BiasMon			In Development			Demo				PreOp		Op	
	GL03	NOAA	GOES11-12 Imager	AIRS +IASI	NRTC +RAC	??		Demo				PreOp		Op				
		CMA	FY2C-E	AIRS +IASI	??	2008-??/												
		KMA	COMS	??	??	2010-??/												
GEO-LEO Solar		Various	Current GEOs	MODIS	NRTC +RAC	2000-??/	In Development					Demo				PreOp		Op
					BiasMon											PreOp		Op

GSICS Global Space-based Inter-Calibration System

Time Line for GSICS LEO-LEO Products

Class	#	GPRC	Monitored Instrument	Ref	Product	Date Range	2010 Q1	Q2	Q3	Q4	2011 Q1	Q2	Q3	Q4	2012 Q1	Q2	Q3	Q4
LEO-LEO Microwave		NOAA	NOAA14-19/AMSU		??	??	In Development											
		NOAA	DMSP14-19/SSMI		??	??	In Development											
		GPM X-Cal	Various	TMI	??	??	In Development											
LEO-LEO Solar	LL01	NOAA	TIROSN->/AVHRR		Cal	1980/?				Demo				PreOp		Op		
LEO-LEO IR			(A)ATSR		??	??												
		EUMETSAT	MetopA/HIRS	IASI	BiasMon+	2007/?	In Development											