MERIS US Workshop

Vicarious Calibration Methods and Results

Steven Delwart

Presentation Overview

Recent results

1. CNES methods
   Deserts, Sun Glint, Rayleigh Scattering
2. Inter-sensor Uyuni
3. MOBY-AAOT
4. Vicarious Adjustment methodology

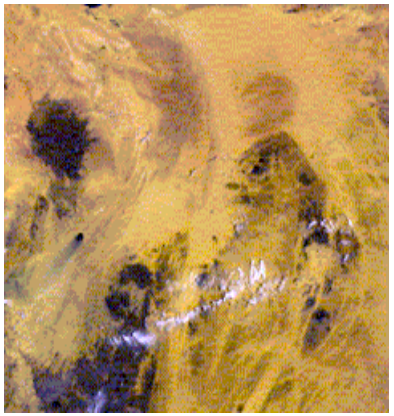
Older results

1. Dark Water
2. SIMBADA Ocean
3. Rail Road Valley Playa
4. Comparison with AATSR
5. Comparison with SCIAMACHY
6. Snow Targets

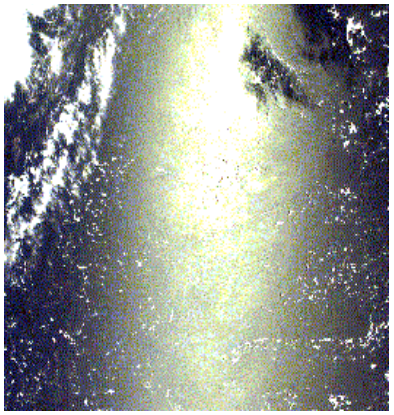
Calibration of MERIS using natural targets

Deserts, Sun Glint, Rayleigh Scattering

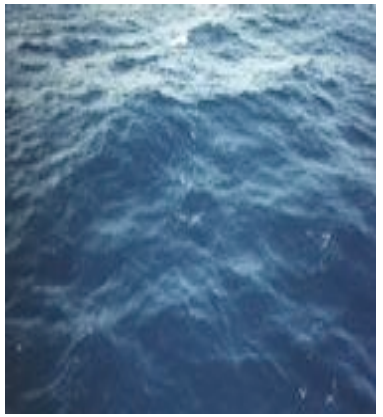
(Claire Tinel, Patrice Henry, Olivier Hagolle - CNES)



Deserts



Sun glint



Rayleigh

These calibration methods are used operationally at CNES
for POLDER 1, 2, 3, VEGETATION 1 and 2,
for SPOT satellites, MERIS, FORMOSAT-2 and KOMPSAT-2

Calibration of MERIS using natural targets

- Definitions
  - Meris on board calibration is the nominal calibration method
  - Meris is calibrated against t.o.a. reflectance

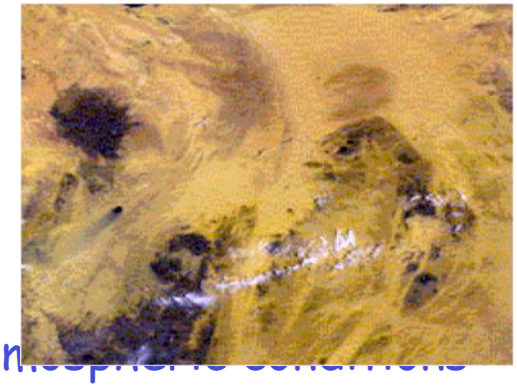
$$DN_k = A_k . \tilde{n}_k . \cos(\grave{e}_s)$$

- k: Spectral band
- DN : Digital Number (Meris Level 0, corrected for instrumental defects)
- r : Reflectance
- A : Sensitivity of instrument for spectral band k

$$\ddot{A}A_k = \frac{A_{k,method}}{A_{k,L1}} = \frac{\tilde{n}_{k,measured(L1)}}{\tilde{n}_{k,predicted}(Method)}$$

Desert Calibration

- Initial objectives :
  - In orbit vicarious calibration to assess :
    - Multiangular calibration (detectors normalization in the f.o.v.)
    - In time calibration monitoring (on-board calibration verification)
    - Intercalibration of sensors

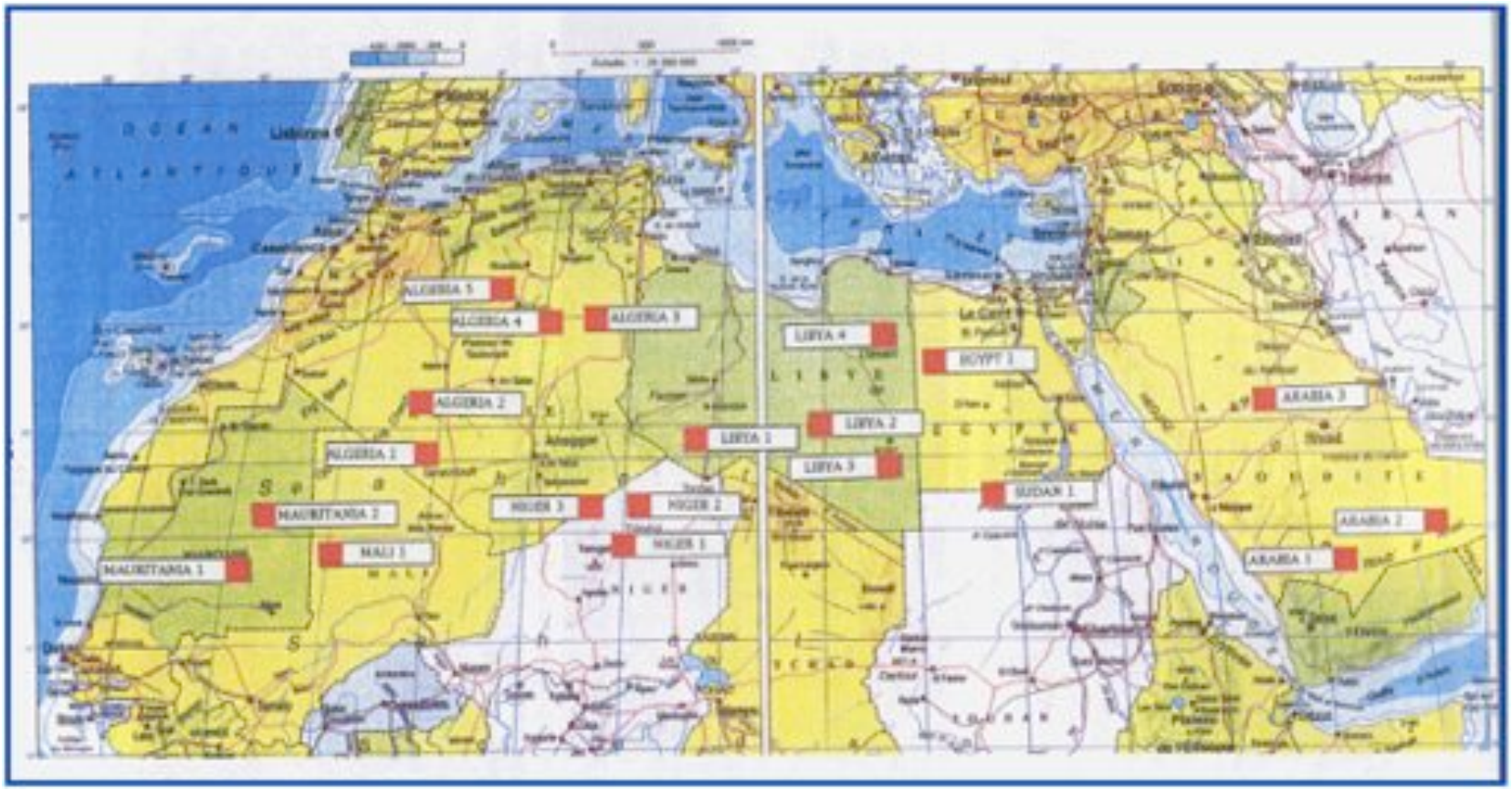


- Main characteristics of the requested sites :
    - Stable in time : no vegetation…
    - Easy to access : low cloud coverage, good atmospheric conditions
    - High reflectance : to reduce the impact of atmospheric effects
    - Low directional effects

⇒ **Choice : Desert sites**

Desert Calibration Sites

- Sites selection :

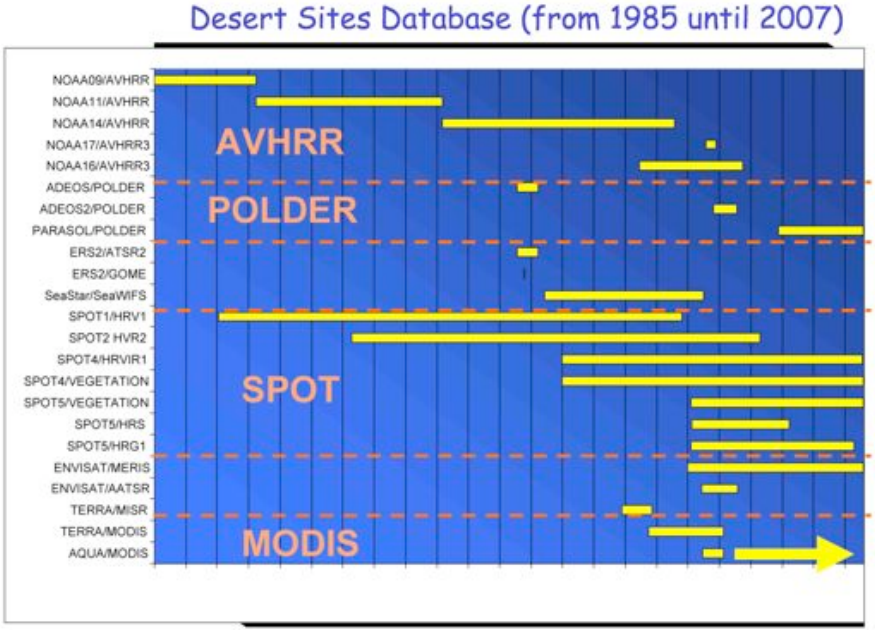


SADE Data Base

- Systematic collect of satellite acquisitior
  Operational monitoring of CNES sensors
  - SPOT(s)/High Resolution
  - SPOT(s)/Vegetation-1&2
  - PARASOL

  Calibration monitoring and intercalibrati
  (through cooperation agreements v
  - High resolution : Formosat-2 (Taiwar
  - Medium resolution : MERIS (ESA), M

  Archive of POLDER1&2, SeaWiFS, AVHI



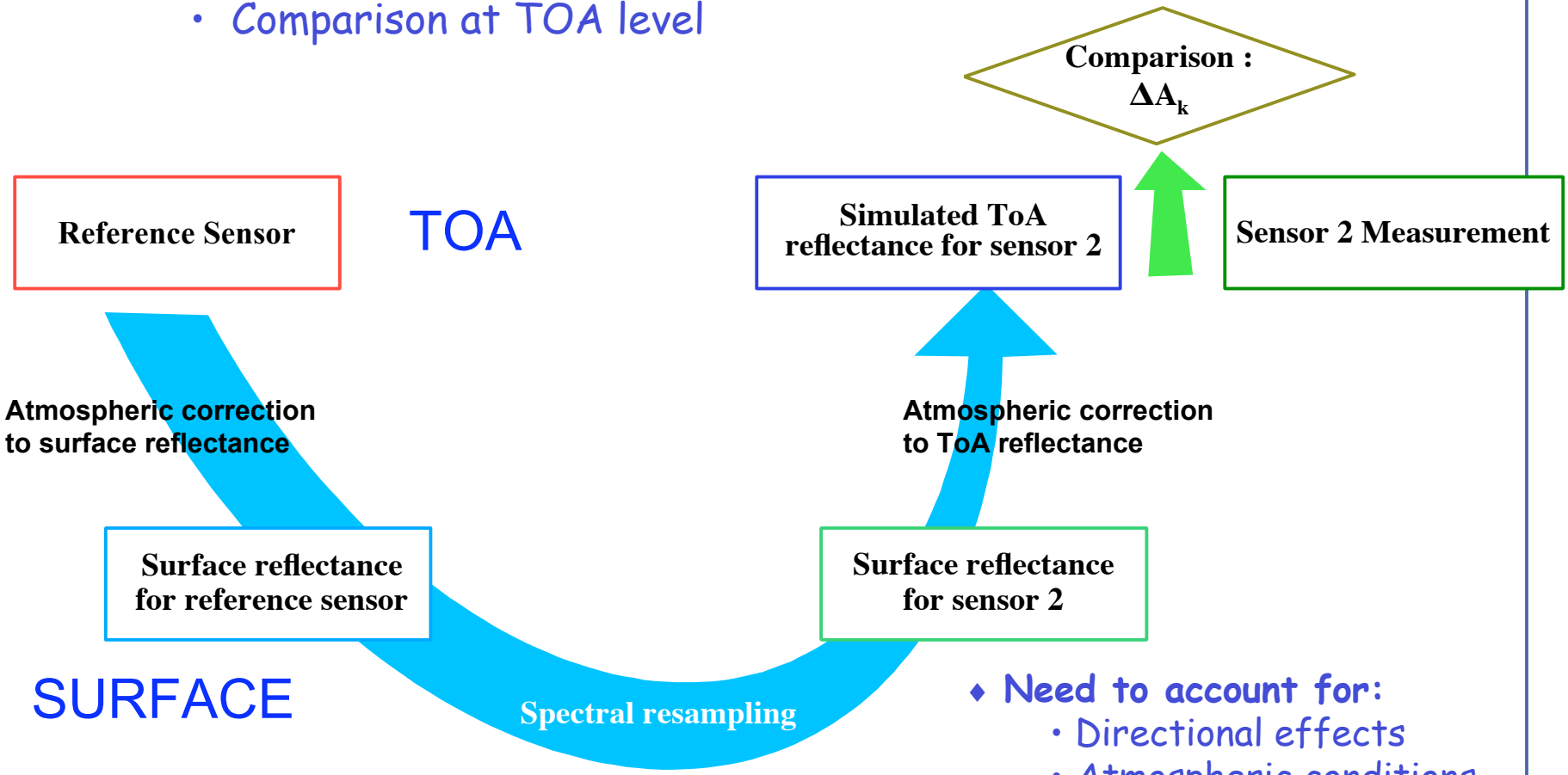
- Storage in a data base :
  - SADE data base : "Structure d'Accueil de Données d'Etalonnage" (***Calibration Data Repository)***
  - Easy data management
  - Link between satellite measurements and calibration results (traceability)

- Nota : the SADE data base also includes calibration measurements over ocean, sun glint, clouds and snow covered sites.

Desert Calibration

Method

- Compare two sensors :
  - One sensor as reference
  - Comparison at TOA level

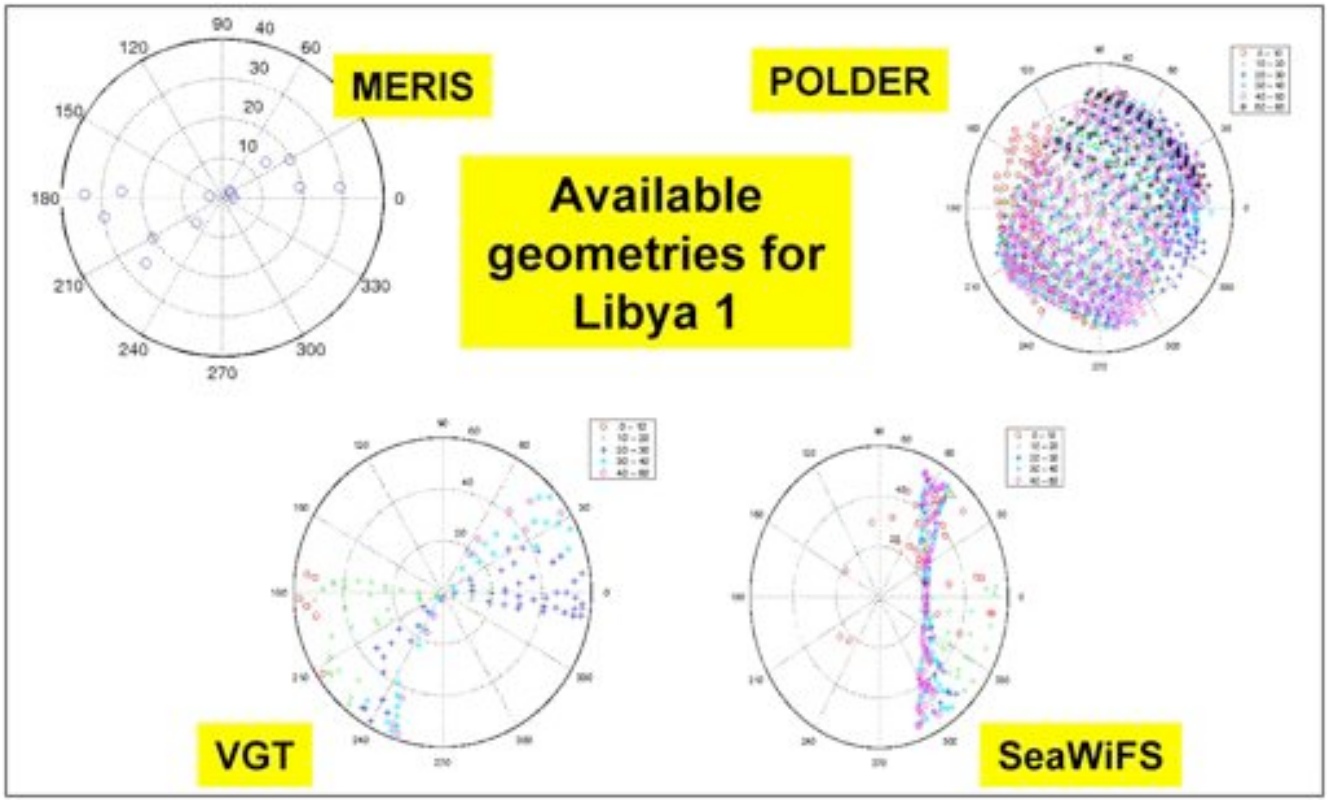


- Need to account for:
  - Directional effects
  - Atmospheric conditions
  - Spectral discrepancies

Desert Calibration

Geometry

- Directional effects :
  - Direct comparison of measurements in the same geometry **(qs, qv, f)**
  - Use of reciprocity principle to extend field of matching geometries



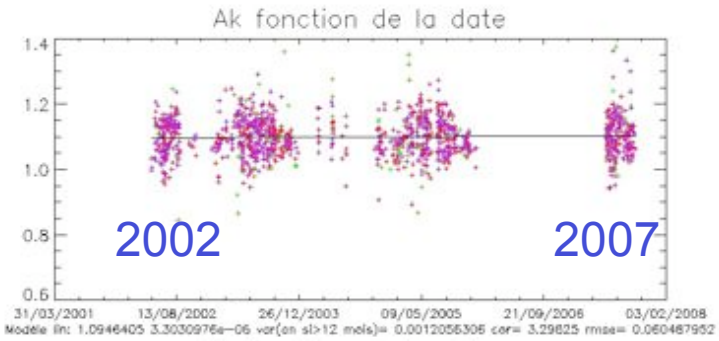
Desert Calibration

Processing

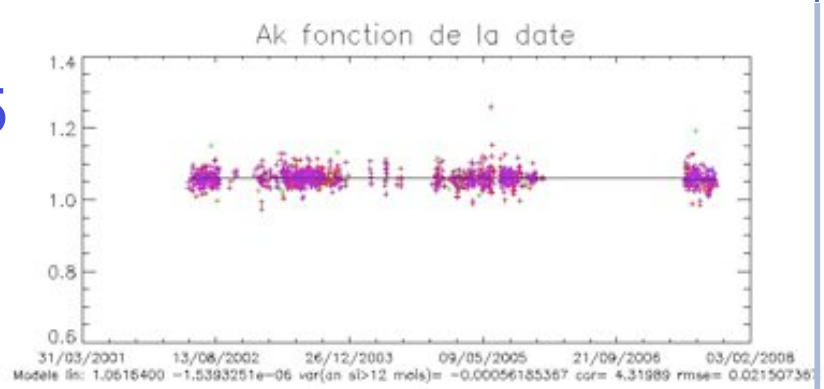
- Atmospheric correction :
  - Atmospheric correction performed using SMAC and meteo data :
    - Rayleigh scattering correction
    - Water vapour
    - Ozone
    - Other contributors : CO2, CO, NO2, CH4 (climatologies)
  - Problem : aerosol correction…
    - Aerosol optical thickness t =0.2
    - Statistically solved through the use of a lot of data:
      no significant bias, but dispersion for short wavelengths

POLDER Comparison

490



865



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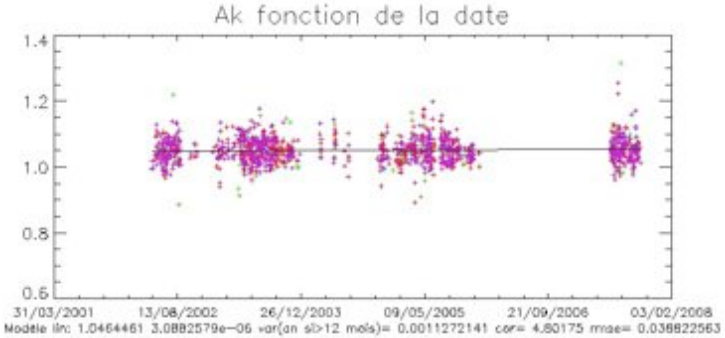

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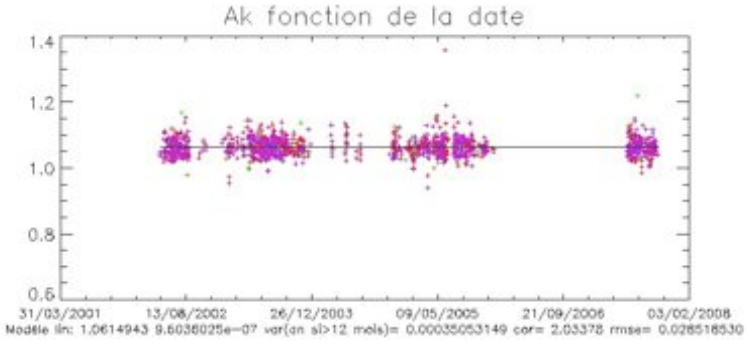


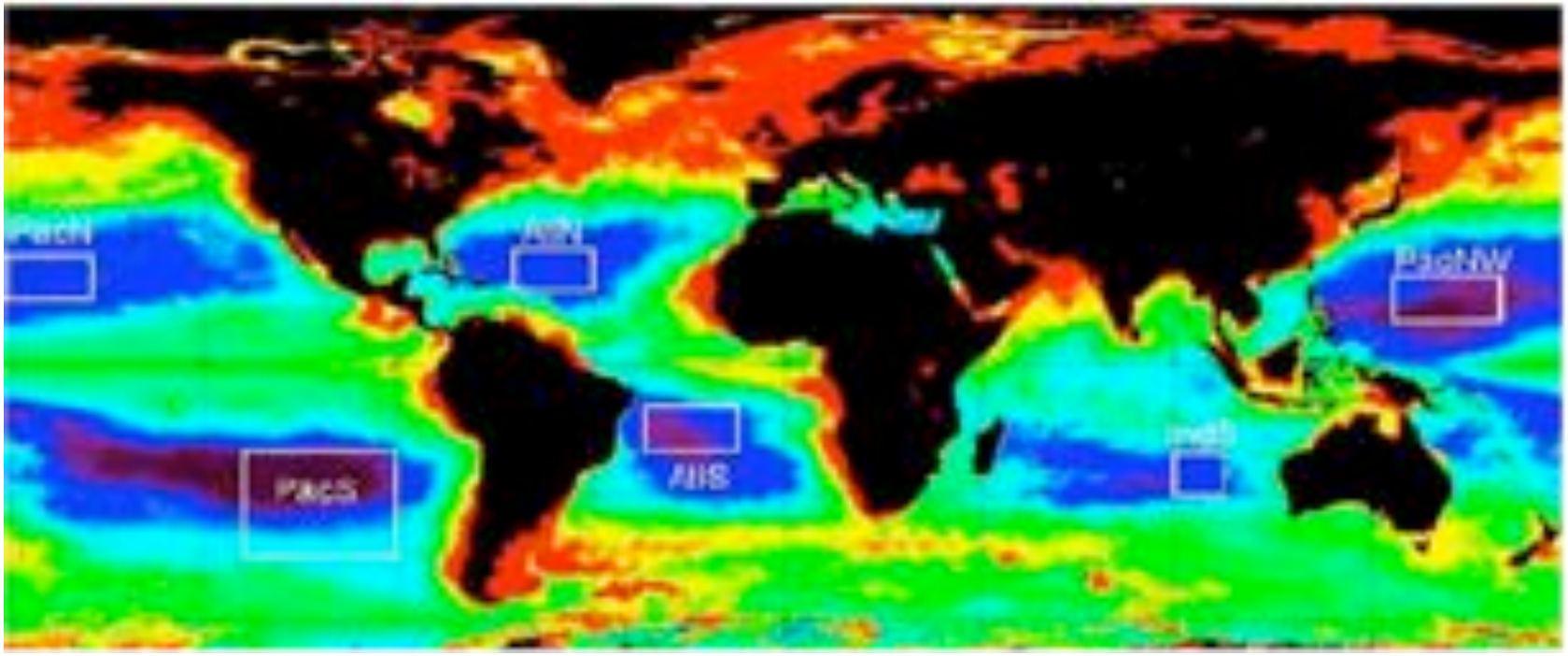
Cross-calibration with PARASOL as a function of time (20 sites)

No significant variation with time

Rayleigh Calibration

- Observe the atmosphere over ocean (dark)
- Absolute calibration of bands < 700 nm
- Rayleigh scattering : > 80% of signal
- TOA reflectance well predicted using:
  - Successive Orders of Scattering
  - Smile effect correction
- Main error sources
  - ocean surface reflectance :
    - predicted using climatology derived from SeaWiF
    - only over very stable oceanic zones (oligotrophic zones)
  - aerosols : estimated using 865 nm band
    - Only optical thickness < 0.1 are kept
- Accuracy : 4 to 5% (3s) – 2 to 3 % (RMS)

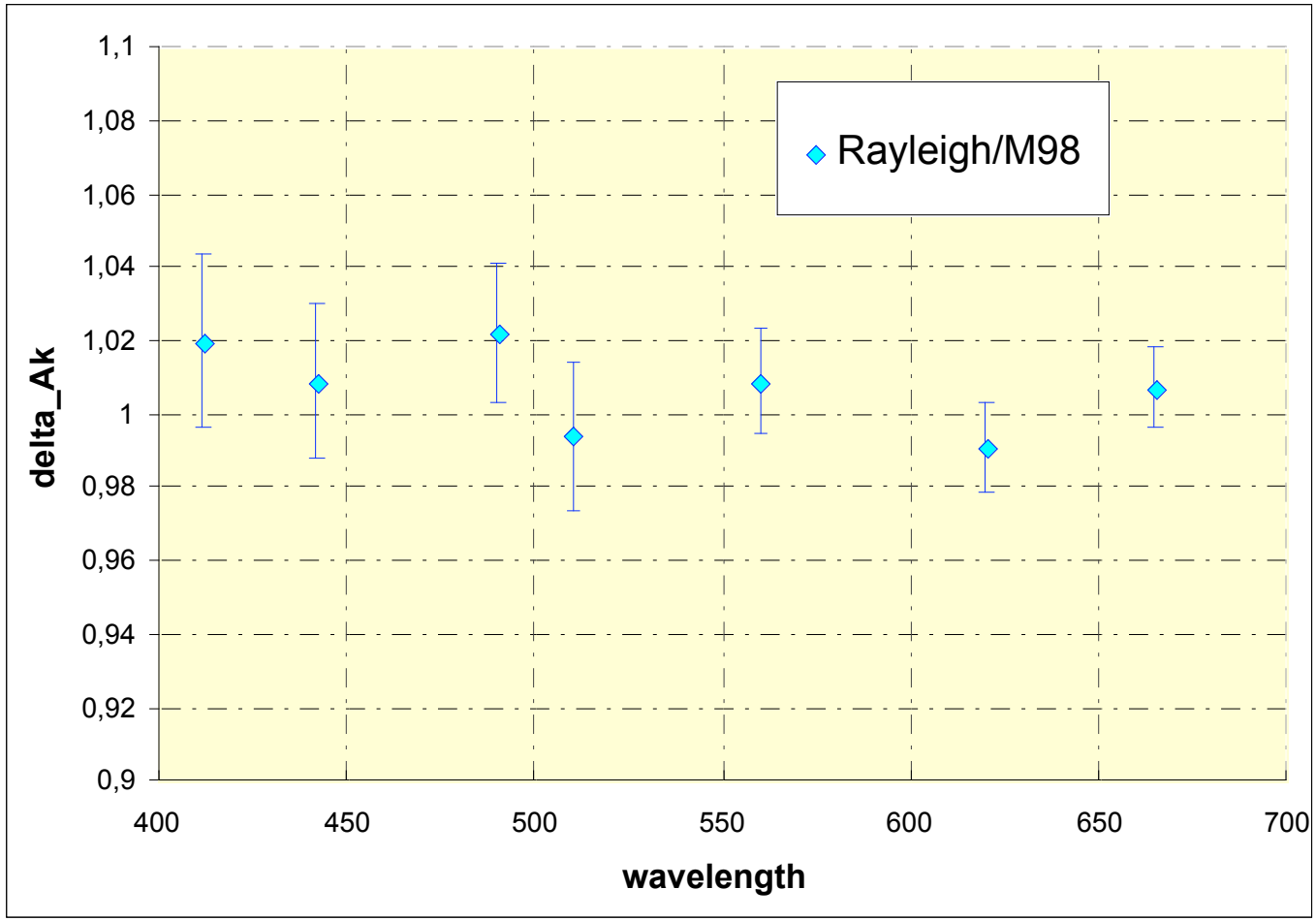
Rayleigh Calibration Sites



Choice of oligotrophic areas with 2 years of SeaWiFS data made in 2001 with ACRI and LOV (CLIMZOO zones)

Rayleigh Calibration

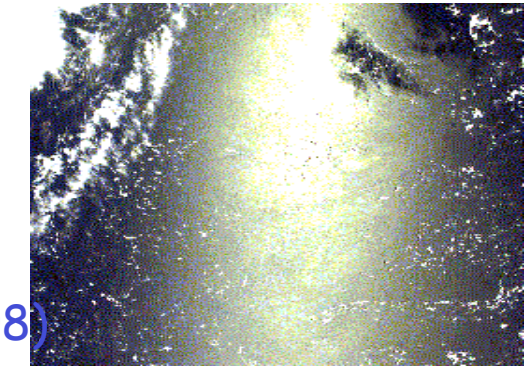
Results



No discrepancy greater than 2.5%

Calibration of MERIS using natural targets

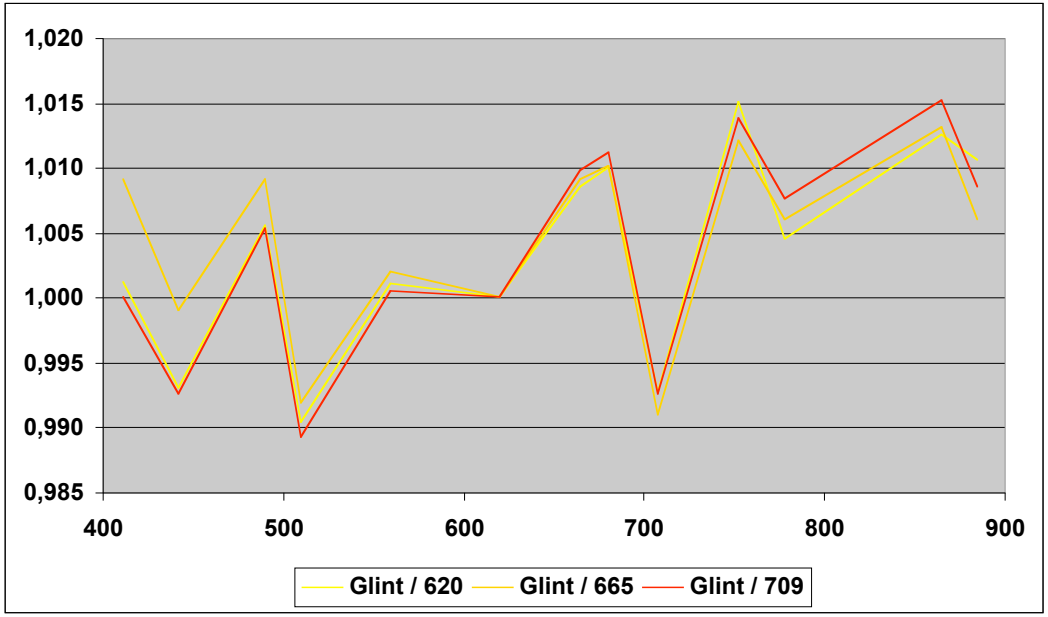
- Sun glint calibration
  - observe the white reflection of the sun over the ocean surface
  - interband calibration w.r.t. a reference spectral band
  - TOA reflectance predicted using SOS code



  - Main error sources
    - Reference band calibration errors
    - ocean surface : SeaWiFS climatology
    - aerosols : fixed model used (M98, AOT :0.08)
      - daily SeaWiFS aerosol product used to discard cases when aerosol properties differ from reference model
- Accuracy : 3 to 4.5% (3s) - 1.5 to 2% (RMS)

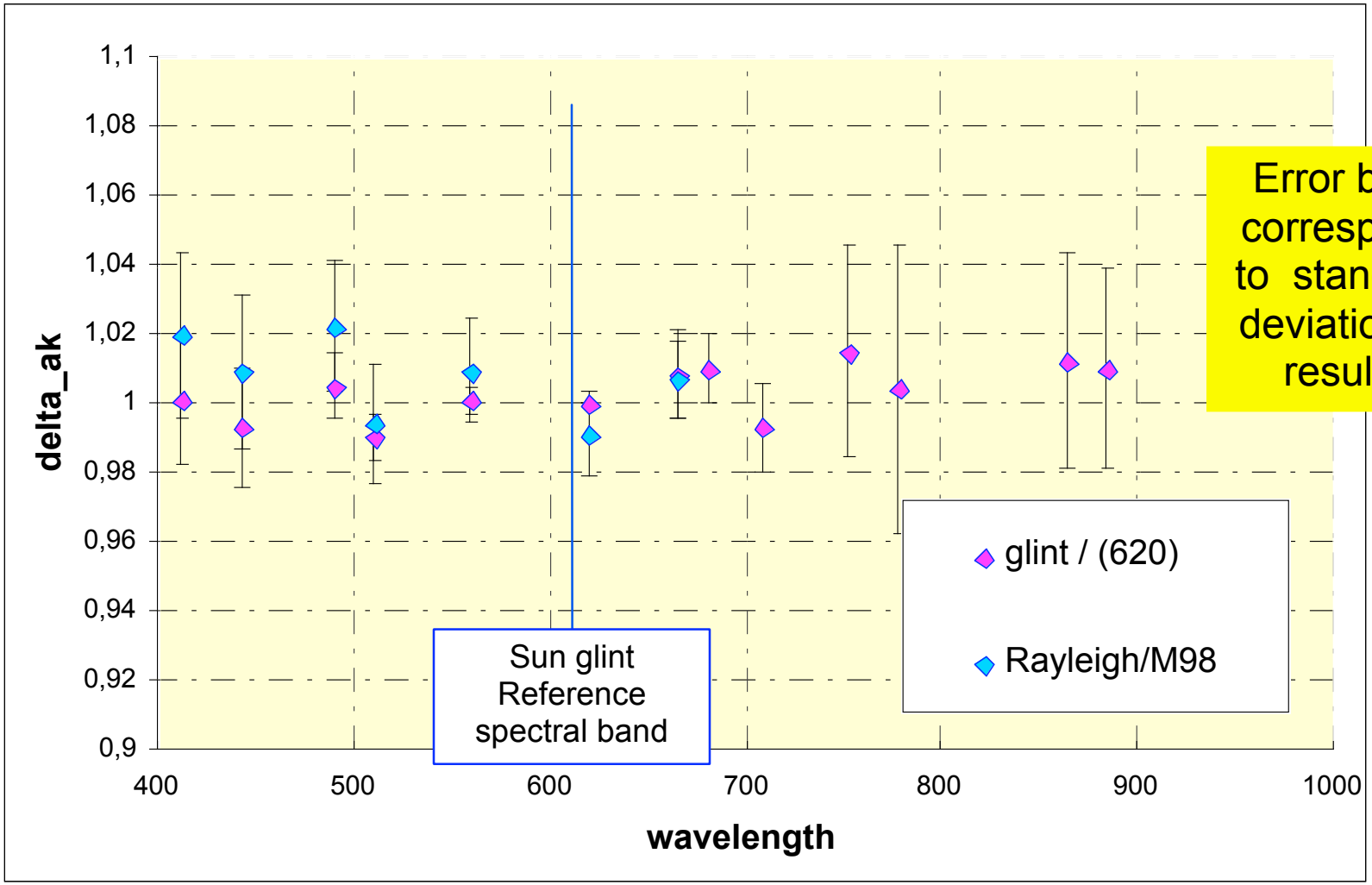
Sun Glint Calibration Results

Band	Ref Band 620		Ref Band 708	
	ΔA_k	σ	ΔA_k	σ
412	1.001	0.019	1.007	0.022
442	0.993	0.017	1.000	0.020
490	1.005	0.010	1.013	0.016
510	0.990	0.007	0.997	0.130
560	1.001	0.004	1.008	0.013
620	-	-	1.007	0.011
665	1.008	0.013	1.017	0.008
681	1.010	0.010	1.019	0.008
708	0.993	0.013	-	-
753	1.015	0.031	1.021	0.026
778	1.004	0.042	1.015	0.021
865	1.012	0.031	1.023	0.016
885	1.010	0.029	1.016	0.024



Comparison of sun glint results using different reference bands

Rayleigh / Sun Glint



Still no discrepancy greater than 2.5%

Calibration of MERIS using natural targets

- Conclusions
  - MERIS instrument seems well calibrated
  - Rayleigh + glint + deserts
    - measurements agree with MERIS level 1 calibration (within 2 %)
      - Very good agreement between Rayleigh and sun glint calibration methods
      - no significant degradation with time
      - thanks to :
        - » MERIS calibration device
        - » MERIS good spectral calibration
  - Simultaneous validation of :
    - MERIS calibration
    - CNES calibration methods
- Perspective
  - Multitemporal calibration monitoring of 412 and 443 nm bands
  - MERIS/MODIS intercalibration over deserts

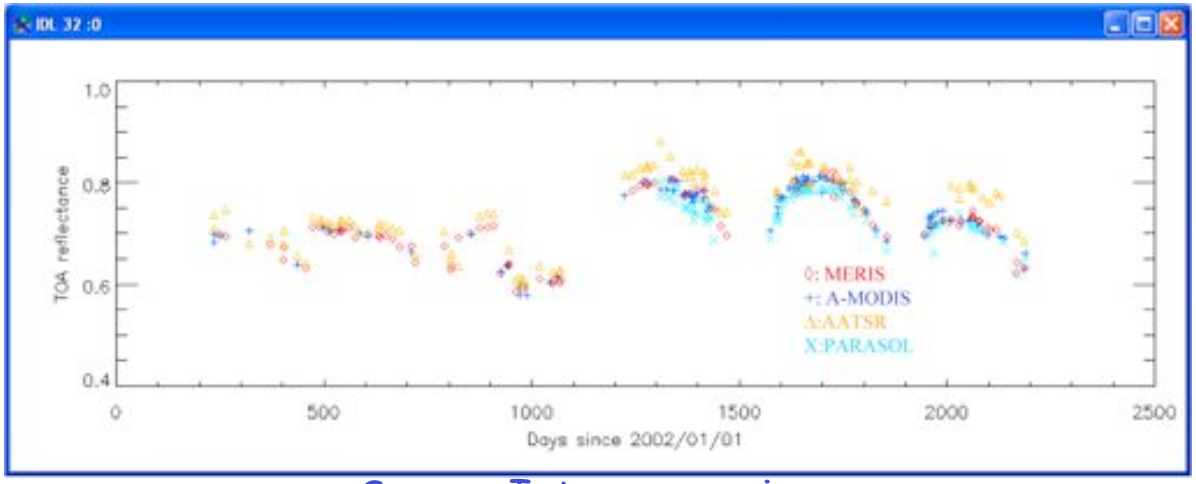
Inter-sensor at Uyuni

Data Selection Criteria: Reciprocal and identical doublets are kept if from the same day or differing by one day

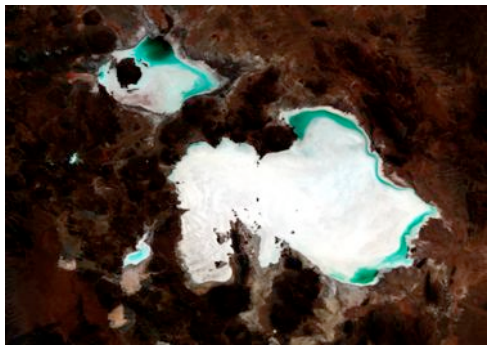
Geometric selection criteria

10 deg > √ [(SZA(i)- SZA(j))^2+ (VZA(i)- VZA(j))^2+ 1/4x(abs(RAA(i))- abs(RAA(j)))^2]

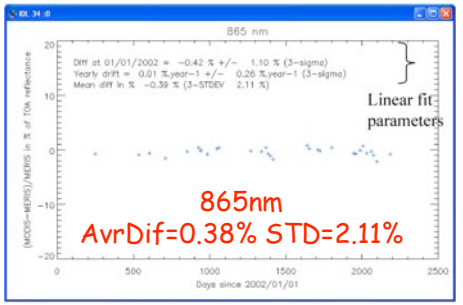
(Equvalent to a difference of 5 deg for VZA & SZA and ±10 for RAA.)

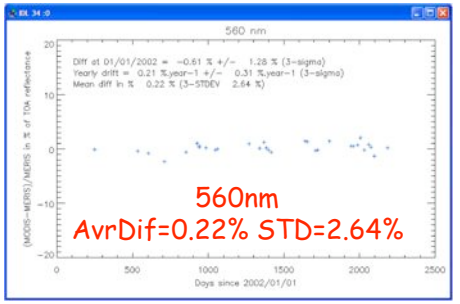


Sensor Intercomparison
MERIS, MODIS, AATSR, PARASOL



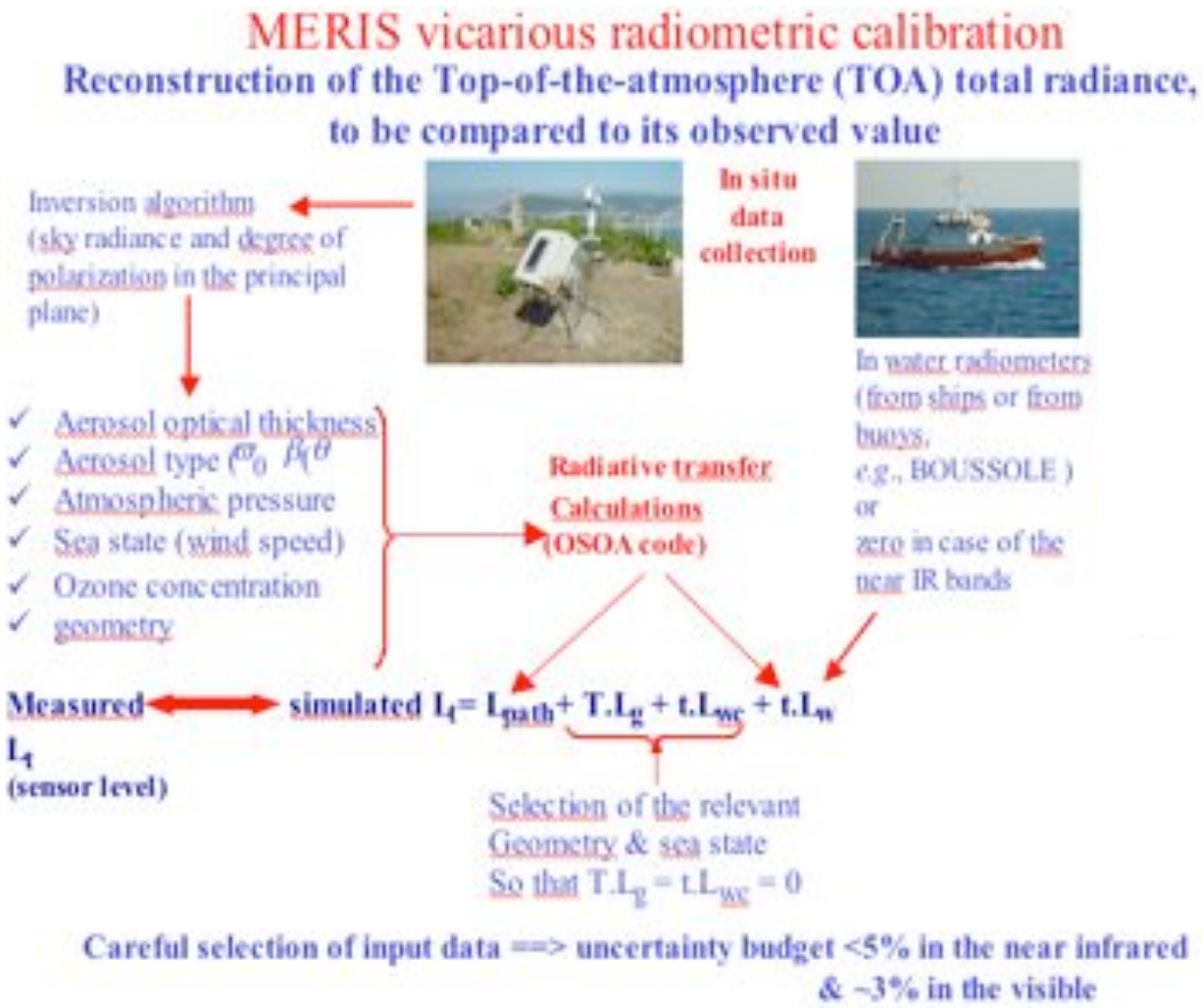
Salar de Uyuni (Bolivia)





MODIS vs MERIS
Very good agreement

LISE Analysis
Moby, AAOT



Aerosol	[nm]	412	443	490	520
Venise AAOT					
IOPA	Slope	0.972	0.970	0.953	0.965
	R^2	0.98	0.97	0.93	0.92
Junge	Slope	1.019	1.018	1.004	1.016
	R^2	0.80	0.90	0.86	0.85
SAM	Slope	0.996	0.994	0.979	0.991
	R^2	0.90	0.90	0.84	0.83
MOBY					
IOPA	Slope	0.957	0.951	0.927	0.910
	R^2	0.87	0.79	0.56	0.27
Junge	Slope	0.972	0.967	0.946	0.930
	R^2	0.84	0.76	0.51	0.21
SAM	Slope	0.961	0.954	0.930	0.912
	R^2	0.83	0.74	0.48	0.16

Good agreement in the blue, questionable in the NIR do to dominant backscattering geometry available from Moby.

Aerosol	[nm]	753	778	865
Venise AAOT				
IOPA	Slope	0.870	0.880	0.876
	R^2	0.89	0.88	0.86
Junge	Slope	0.910	0.900	0.879
	R^2	0.86	0.87	0.87
SAM	Slope	0.865	0.852	0.825
	R^2	0.81	0.80	0.80
MOBY				
IOPA	Slope	0.660	0.635	0.566
	R^2	-2.51	-2.46	-2.00
Junge	Slope	0.681	0.654	0.570
	R^2	-2.00	-1.99	-1.75
SAM	Slope	0.961	0.954	0.930
	R^2	-3.11	-3.21	-3.08

Older Vicarious Results

Older results

- Dark Water
- SIMBADA Ocean
- Rail Road Valley Playa
- Comparison with AATSR
- Comparison with SCIAMACHY
- Snow Targets

Dark Water (LISE)

METHODOLOGY

-We use PPL radiance measurements instead of only AOT

-Method reported in *Santer & Martiny* (AO, fev2003) :
Computation of phase function as follows:

1- Correction of PPL measurements using the f corrective factor (correction for multiple scattering effects) :

$$f = \left(\frac{L^{(1)}}{L}\right)_{theo} \approx \left(\frac{L^{(1)}}{L}\right)_{mes}$$

- Order 0, f simulated with Junge Power Law as input of RTC (SOS)
- Iterations stop when f converges at 0.5%

2- Approximation of primary scattering :

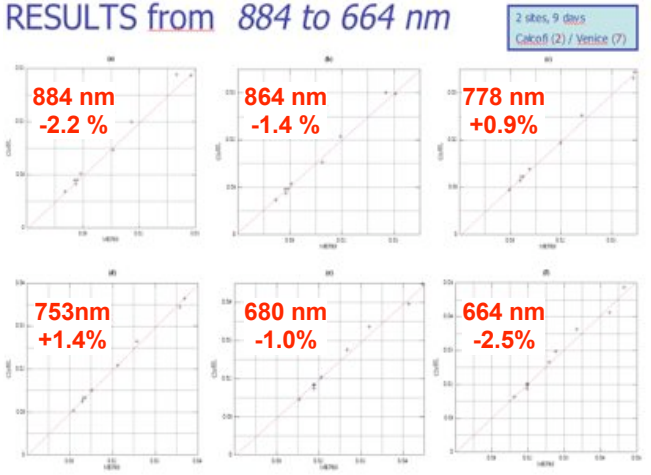
(SOS)

$$P(\Theta) = 4L^{(1)}_{mes} \exp\left(\frac{\tau}{\mu}\right)\left[1-\exp\left(-\tau\left(\frac{1}{\mu_o}-\frac{1}{\mu}\right)\right)\right]^{-1}\left[\frac{\mu_o}{\mu-\mu_o}\right]^{-1}$$

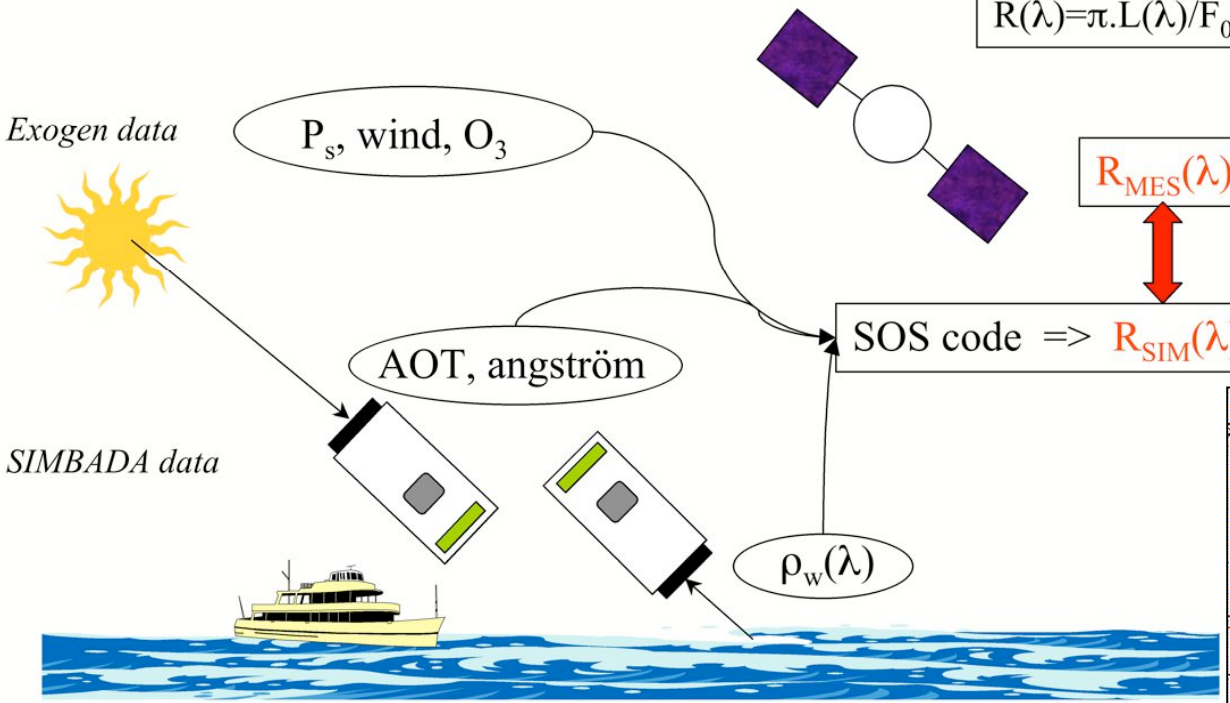
Total Phase Function *
Total Single scattering albedo

(SOS) → **Simulated MERIS Radiances**

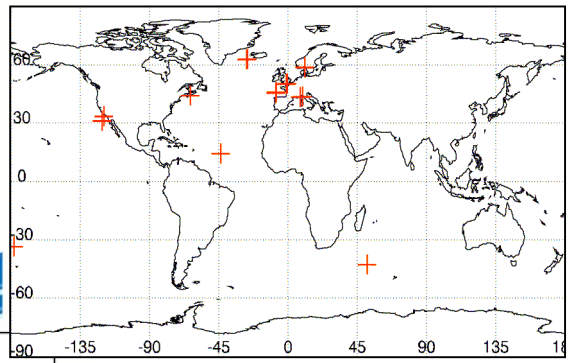
RESULTS from *884 to 664 nm*



SIMBADA (LOA)



bands	Ak(mean)
412	0.991
443	0.987
490	0.991
510	0.996
560	0.988
620	0.992



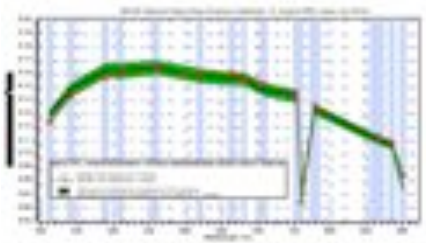
- Successive Order of Scattering (SOS) code from LOA/CNES
- Threshold :
  - AOT(865 nm) < 0.15
  - Measurement within +/- 3 hours from satellite overpass
  - No case 2 waters (high reflectance at 560 nm)

- 23 independant pixels from 14 scenes
- AOT max : 0.15
- Within 3 hours from satellite overpass
- Case 2 waters rejected

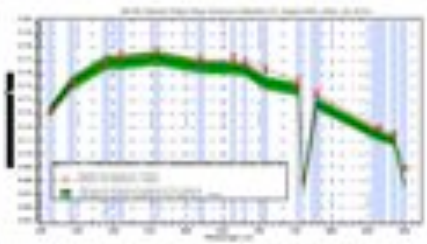
Rail Road Valley Playa

Collaboration RSL & UofA

MERIS	Center	(%)	(%)	(%)	(%)	(%)	(%)	(%)
1	412.545	-4.481	-0.604	-6.614	-10.879	3.080	-0.330	0.565
2	442.401	-5.193	-0.844	-3.141	-7.658	2.825	0.782	0.138
3	489.744	-4.861	-0.335	-1.267	-5.069	1.024	-0.541	-0.221
4	509.700	-2.037	2.356	1.147	-1.624	2.221	1.161	1.834
5	559.634	-1.727	2.543	1.530	0.054	0.832	0.449	2.080
6	616.620	-0.881	3.035	1.325	0.634	0.471	0.353	2.491
7	664.640	0.398	4.028	1.805	1.317	0.912	3.252	5.444
8	680.902	-0.123	3.442	0.674	0.298	-0.020	1.337	3.984
9	708.426	2.480	5.884	3.657	3.282	2.287	2.486	1.460
10	753.472	0.573	3.856	0.218	0.097	-0.387	-0.955	2.238
12	778.498	1.820	5.011	0.941	1.195	0.492	-0.097	3.388
13	864.833	1.622	4.512	-0.026	0.550	0.321	-0.364	3.096
14	884.849	1.619	4.465	-0.436	-0.083	-0.324	-0.950	2.253
Mean diff (%)	All Bands	**1.820**	**2.140**	**1.752**	**2.518**	**1.169**	**1.004**	**2.246**



August 12, 2002



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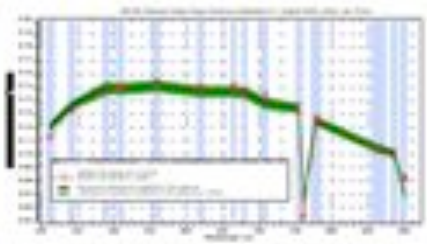

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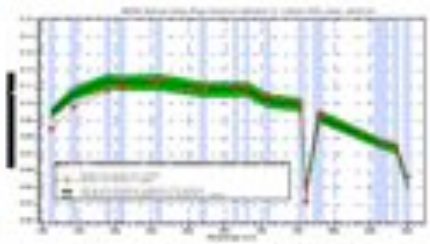
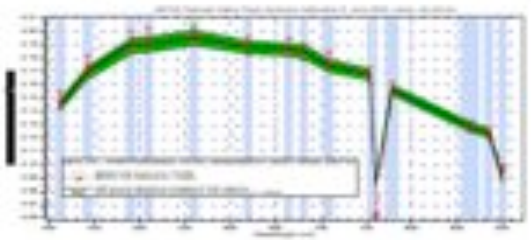
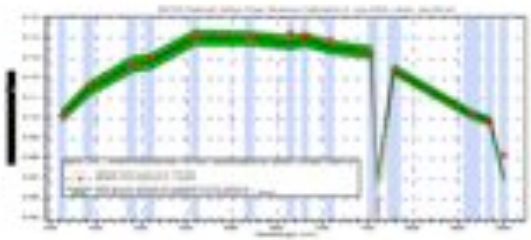


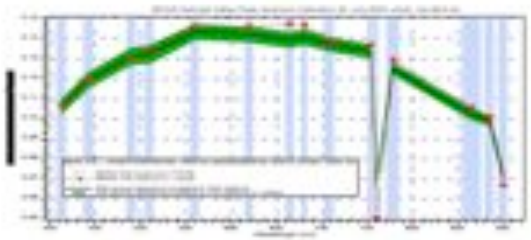
October 21, 2002



June 6, 2003



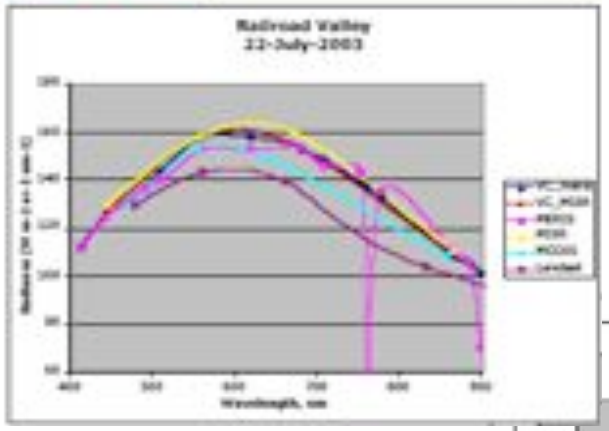
July 9, 2003



July 22, 2003

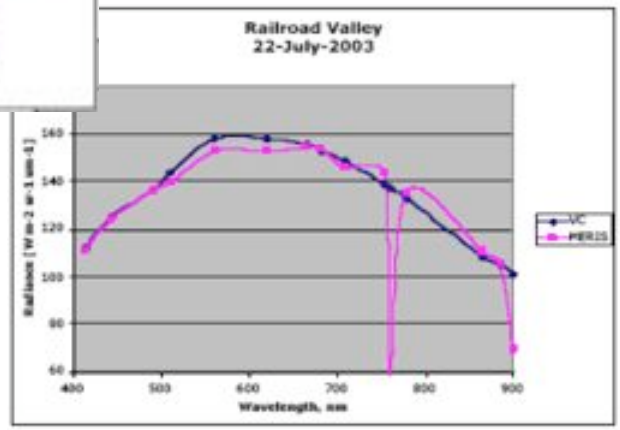
Rail Road Valley Playa

Collaboration JPL & UofA



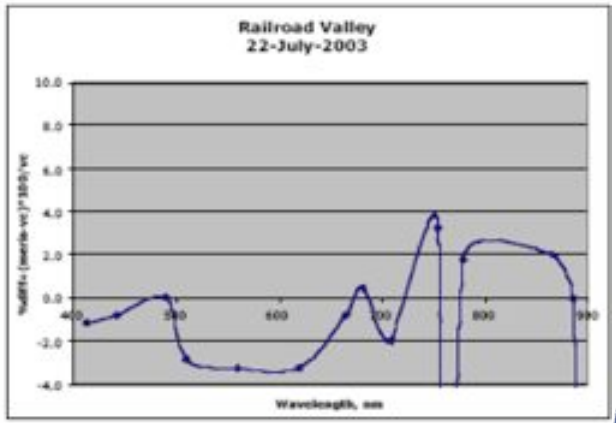
MISR/ MERIS measured radiances agree to within +/- 3%

MERIS data confirm that VC scale is consistent, band-to-band, with AirMISR, MODIS band-relative scale

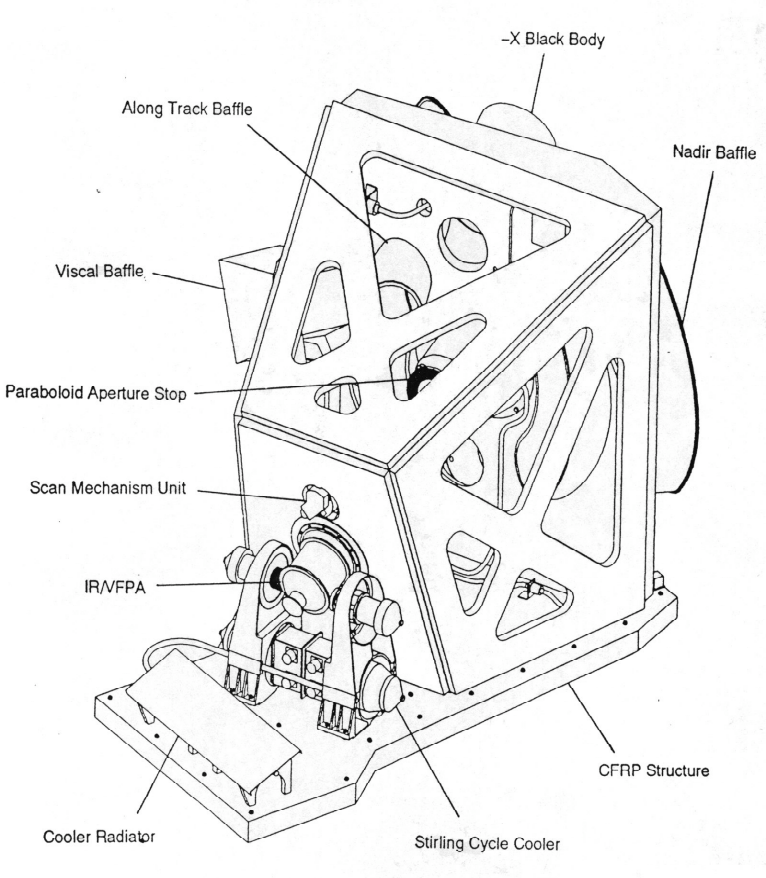


MERIS radiances include 1.04 adjustment due to Terra/ Envisat time difference.

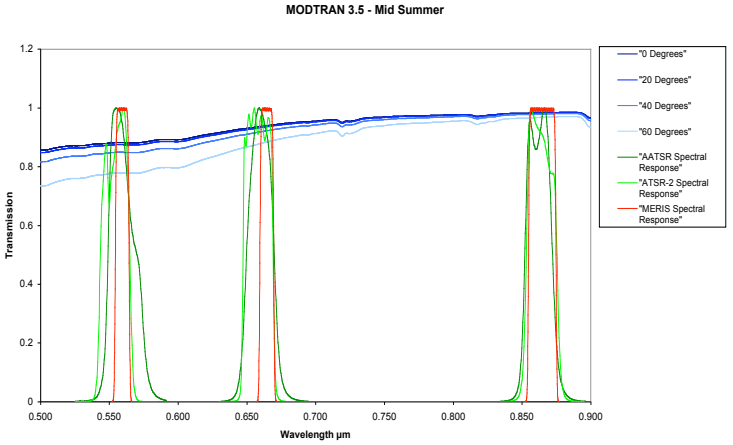
Agreement with VC computed radiances is generally within 4%.



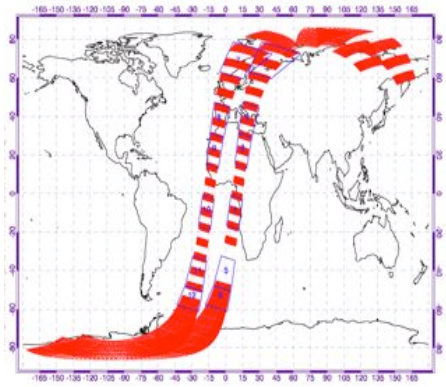
Comparison with AATSR

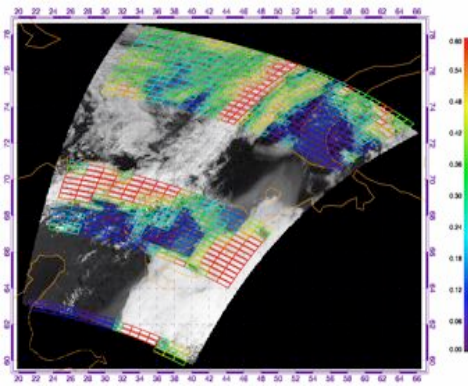


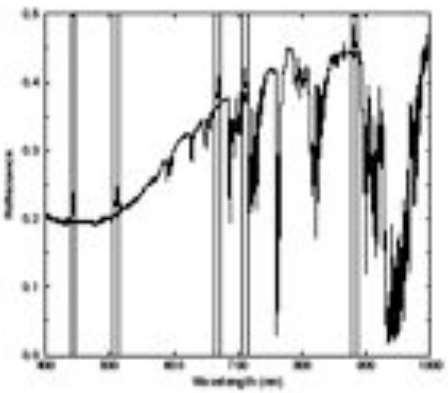
Surface	560 nm	670 nm	870 nm
Deserts (Smith)	1.041	1.001	1.037
Greenland (Smith)	1.034	1.012	1.037
Clouds (Poulsen)	1.047	1.026	1.054
Longyeardyen	1.026	1.024	1.038
Barrows	1.024	1.001	1.023

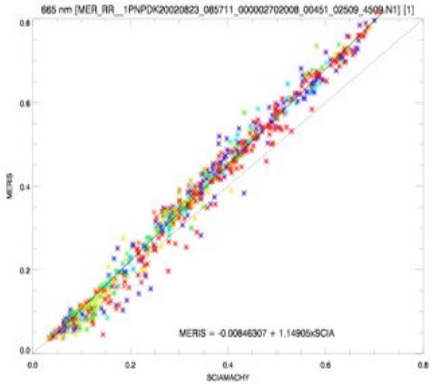


Comparison with SCIAMACHY

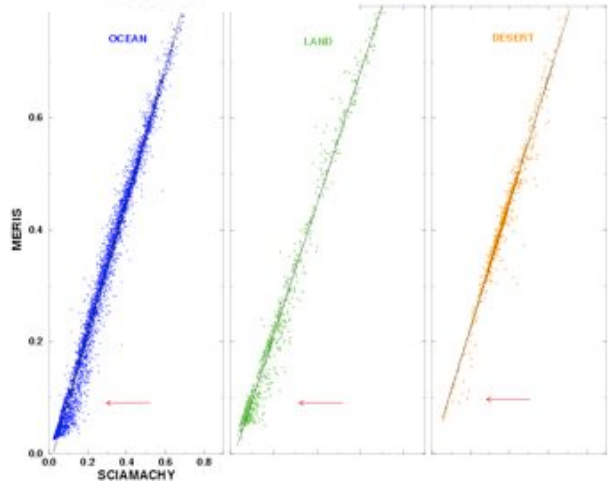






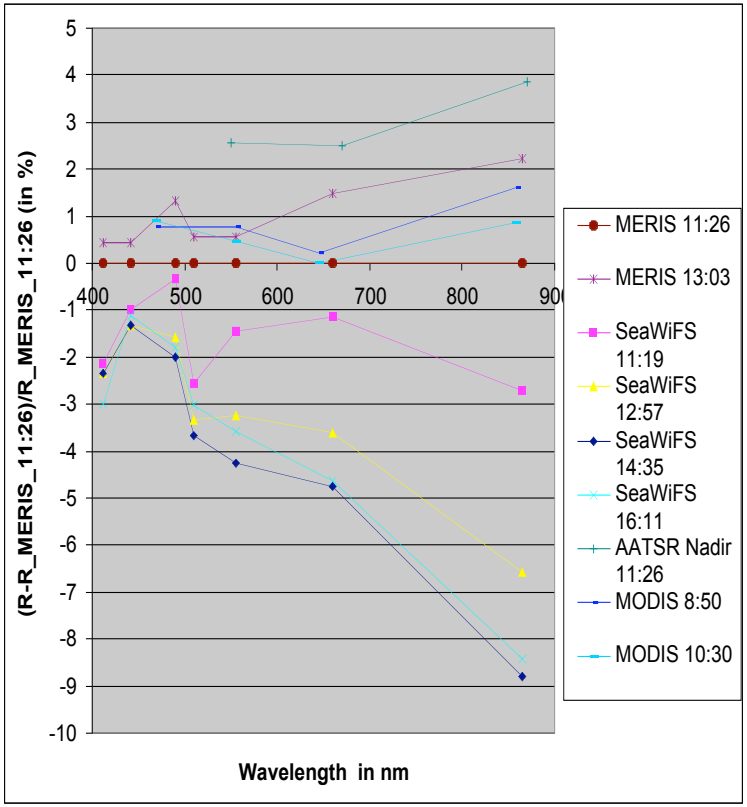


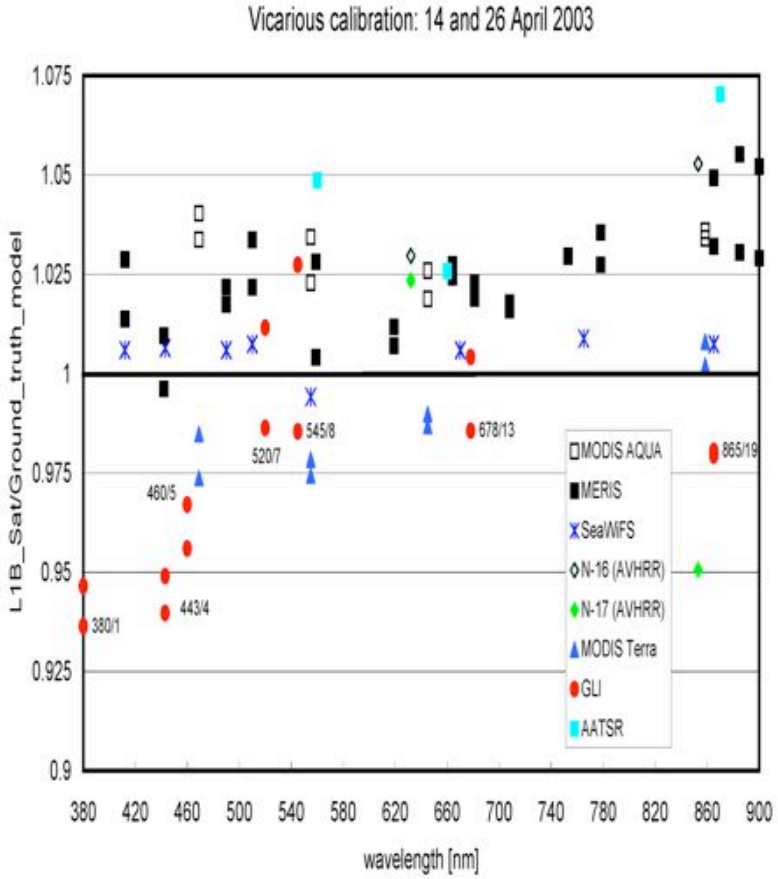
Slope	1.18	1.17	1.19	1.21	1.25
	1.15	1.16	1.17	1.19	1.20
	1.10	1.09	1.12	1.12	1.15
Offset	-0.026	-0.023	-0.024	-0.023	-0.027
	-0.022	-0.022	-0.023	-0.020	-0.012
	-0.004	0.000	0.002	0.010	0.013
Corr.	0.993	0.992	0.990	0.989	0.988
	0.990	0.988	0.990	0.988	0.987
	0.988	0.985	0.985	0.980	0.976



- Given the current state of knowledge, we (KNMI) propose that it is the reflectance data of SCIAMACHY instead of MERIS, that should be corrected.

Snow Targets





Longyearbyne (ESA)

Barrows (JAXA)

Vicarious Adjustment Principle

- Based on the work currently lead at NASA for SeaWiFS and MODIS vicarious calibration, see Franz et al. 2007, Bailey et al. 2007.

- Consists in computing averaged multiplicative gains to correct the "TOA signal", thanks to a DB of reference in-situ signals:
  - → « TOA signal » = Level 2 reflectance pre-corrected for smile, gaseous absorption, glint, *i.e.* just before the Atmospheric Correction algorithm.
  - → $rho_{gc}^{new}(l)=rho_{gc}(l)*G(l)$ for l in the VIS and NIR

- Two-step approach separating the NIR and VIS channels, avoiding an iterative procedure within the Atmospheric Correction algorithm:
  1. First adjust two bands in the NIR with $G(l_{NIR})$
  2. Then, assuming a perfect AC, adjust the VIS with $G(l_{VIS})$

- The methodology fully imbricates the sensor response and the processing:
  - → The gains need to be updated each time a change occurs in the processing (LUTs, algorithm, L1b calibration, etc.)
  - → a strong effort of traceability in the gain computation, with respect to all other processing parameters, should be maintained.

Vicarious Gain Computation

- Computation starts from the decomposition

$$r_{gc}(l) = r_{path}(l) + t_d(l) r_w(l)$$

- Knowing the true (or targetted) signal through in-situ measurements, individual gains are computed matchups per matchups by

$$g_i(l) = [r^t_{path}(l) + t^t_d(l) r^t_w(l)] / [r_{path}(l) + t_d(l) r_w(l)]$$

- Averaged gains are finally deduced by $G(l)$=Mean $g_i(l)$

- In the NIR, two assumptions:
  - the water-leaving reflectance is truly negligible: $r_w(l_{NIR})=0$
  - the most NIR band (865 nm for MERIS) is perfectly calibrated : $g_i(865)=1$
- Thus one has

$$r^t_{gc}(865) = r_{gc}(865) = r_{path}(865)$$
$$r^t_{gc}(775) = g(775) * r_{gc}(775) = r^t_{path}(775).$$

- DB : oligotrophic sites ($\rightarrow r_w=0$) + homogeneity in space and time ($\rightarrow$ alpha)
- In the VIS, once the NIR is calibrated, gains are computed thanks to

$$r^t_{path}(l_{VIS}) = r_{path}(l_{VIS}) \quad \text{and} \quad t^t_d(l_{VIS}) = t_d(l_{VIS})$$
$$r^t_w(l_{VIS}) = r_w^{\text{in-situ}}(l_{VIS})$$