Comparisons: The key evidence to demonstrate performance

(Optical space examples)

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+ Cal/Val community

Gdln …..DQK-004: Comparisons (1)

- **Identifies this as primary activity within QA4EO**
  - **when independently carried out against a defined reference, is usually a calibration or consistency check (NOT part of guideline)**
  - **Ideally carried out with peers (one or more)**
  - **Recommends communities identify a few "key comparisons" to test the principle activities/measurements in their field Process adopted at NMIs (see www.bipm.org/mra.html)**
  - **Other comparisons organised as needed**
  - **Can be analysed with respect to a ref lab or standard or to the mean of the participants**

Space examples: Optical sensors

- **All data products must have associated with them a Quality Indicator (QI) based on a documented quantitative assessment of its traceabilty to an agreed reference standard (ideally tied to SI).**

For Guidance:
QA4EO-QAEO-GEN-DQK-002

To establish a QI for a satellite sensor derived data product requires a knowledge of sensor performance and this can best be evaluated through the following guidelines:

Pre-flight:
- **Traceably calibrate all sub-systems**
- **Perform "end to end" system calibration**
- **Maintain witness samples of key components for later testing as necessary**

Post launch: Evaluate sensor performance for following aspects:
- **"Characteristics" compared to pre-flight**
- **Biases to other in-flight sensors"**
- **"Stability" of products (in mission, & link to history and future)**

Can be best achieved through comparison to "CEOS standard" using a "CEOS method"

e.g. LAND imager constellation

Characteristics e.g "Gain"
- On board standard
- CEOS core test site
- Rayleigh scattering
- Clouds
- Moon
- …..

Bias
- SNO
- CEOS core test site
- CEOS invariant standard

Stability
- CEOS invariant standard ("Standard Desserts", Moon)
- CEOS core test site (accuracy)
- On board standard

A QUALITY ASSURANCE FRAMEWORK FOR EARTH OBSERVATION

Comparisons General Requirements: space

- Validate (calibrate) in-flight satellite sensors (absolute and temporal)
- Quantify Biases between sensors
- Establish linkage between data-sets
- Evaluate how to minimise impact of “data gap” non-overlapping sensors

Noting importance of surface Cal/Val data

- Need to establish international reference test sites globally distributed
    - uncertainty achievable
- Equivalence & Variance of characterisation methods
- Traceability of instrumentation

CEOS IVOS "key comparisons"

1. **Sensor measured TOA radiance/reflectance**
   - Using Snow fields of Antarctica - DOME C (Dec 08/Jan 09)
   - Using other Landnet sites (Aug 09 & Aug 10)
   - Compared to ground based measurements (Aug 09 & Aug 10)

2. **Measurement of surface (Ocean/Land) brightness temperature and associated instrumentation** (May 09)

3. **Measurement of Land surface spectral reflectance/radiance – methodologies and associated instrumentation** (Aug 09 & Aug 10)

Organised for open participation and to follow rigour of QA4EO

A QUALITY ASSURANCE FRAMEWORK FOR EARTH OBSERVATION

Comparison planning

- Identify and agree with community Measurands to be tested
- Establish generic methodology for comparison: characteristics of ideal site/artefacts
- Identify pilot (organiser)
- Source of funds (for organisation/analysis) not participation
- Timeline (criticality)
- Invite participants
- Draft protocol
  - Minimise bias to a method
  - Isolate measurand under test
  - Maximise scope of tests
- Agree protocol
- Peer Review of uncertainties (before results)
- Review results
- Publish

	Agree
BLIND	**Plan**
	Draft protocol
	Compare
	Peer review uncertainties (Pre-draft A)
	Participant review Results (Draft A)
	Community Review results (Draft B)
	Publish (Final Report
	Bi-laterals

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Sensor to Sensor TOA radiance: Dome-C

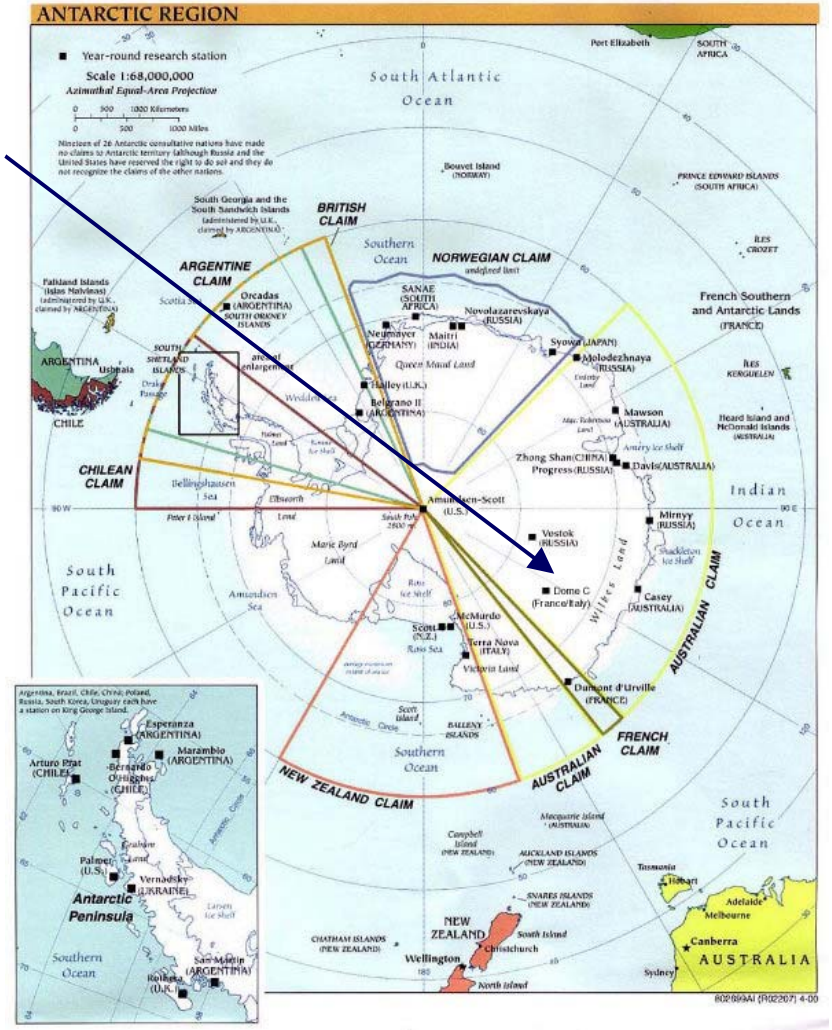
- Concordia Station, located on Dome C, is run jointly by France and Italy.
- During the summer there are about 40 to 50 people on station.
- During winter ~ 13 people on station

- Studied over last decade by CNES, NOAA, RAL, ESA & others.

- used for comparison but largely informal and few sensors

- Ground- BRF data based on Hudson & Warren

Photo courtesy Stephen Hudson, Univ. of Washington



Altitude 3250 m, 10,600 feet
Max Temp -18°C on summer afternoons

Comparison planning: Dome C

- Formal invitation to participate circulated to all CEOS agencies
  - Request for acquisitions over DOME-C and associated sites during Dec 08 – Jan 09
  - Also for sensor characteristics e.g. spectral response and uncertainty
  - Observation conditions and any "constants" used e.g. solar irradiance spectrum

- All data to be analysed and compared relative to a "comparison mean" using common methodology

- NOAA analyse Medium/large resolution & NPL (ESA) high resolution + some medium for linkage

- Analysis protocol drafted based on expertise of RAL, CNES, NOAA
  - pre-analysis of sensitivity to meteo conditions and angles based on actual data sets

- Following initial comparison, data sets to be available to community via portal for cal studies

Participating Sensors

Medium/Large	High
ASTER	AVNIR-2
AATSR	Landsat
AVHRR	Spot
CERES	Vegetation
MERIS	CHRIS / Proba
MISR	DMC (suite of satellites)
MODIS	Hyperion
	CBERS-2B

Analysis procedure

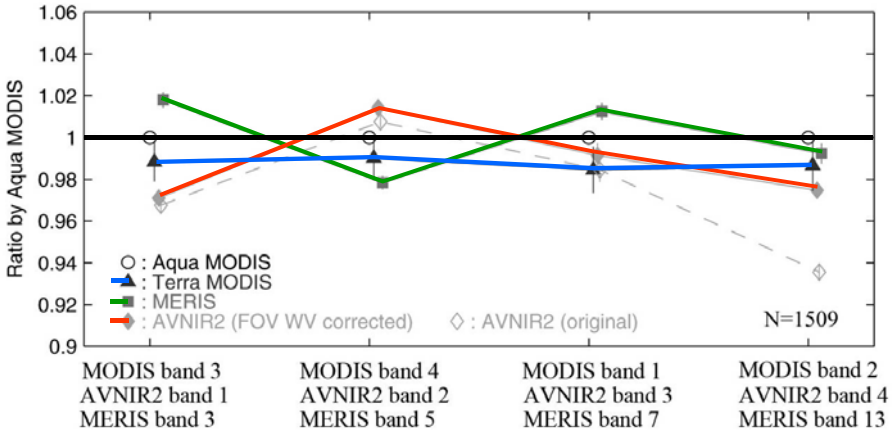
- **Observations by different sensors on different days and times**
  - **Meteorology – atmospheric correction, clouds**
  - **Solar illumination and sensor view angle / surface BRDF**
  - **Sensor spectral bands**

- **Correct to standardised conditions (Nadir)**
- **BRDF can be large effect in some spectral bands**
- **Sensors linked via a ground projected relative snow reflectance curve**

Independent analysis also possible

Dome-C observation in Dec. 2008 (2/2)

Results over Dome-C in Dec 2008.



Aqua Band	*3*	*4*	*1*	*2*
AVNIR-2	0.971	1.014	0.991	0.975
MERIS	1.018	0.978	1.012	0.992
Terra	0.988	0.990	0.985	0.987

Please see details:
H. Murakami, T. Tadono, H. Imai, J. Nieke, and M. Shimada, "Improvement of AVNIR-2 radiometric calibration by comparison of cross-calibration and on-board lamp calibration", *IEEE Trans. Geosci. Remote Sens.*, 2009 (Accepted). (TGRS ALOS special issue)


Improvement of AVNIR-2 Radiometric Calibration by Comparison of Cross-Calibration and Onboard Lamp Calibration

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CEOS Infrared spectral emitted radiance (brightness T comparison)

April/May 2009 key sponsors: ESA and NASA (+ participants)
Hosts: University of Miami & NPL (pilot/coordinator: NPL)

Scope:

- Compare IR radiometers used to measure brightness temp
  - Laboratory (ideal) and "as used" ocean viewing
- Compare reference BBs used by participants to calibrate radiometers

N.b. instrumentation both commercial and research

Objectives:

- Establish degree of equivalence between participants
- Ensure robust traceability to SI (via NIST and NPL)
- Establish protocols to facilitate future comparisons

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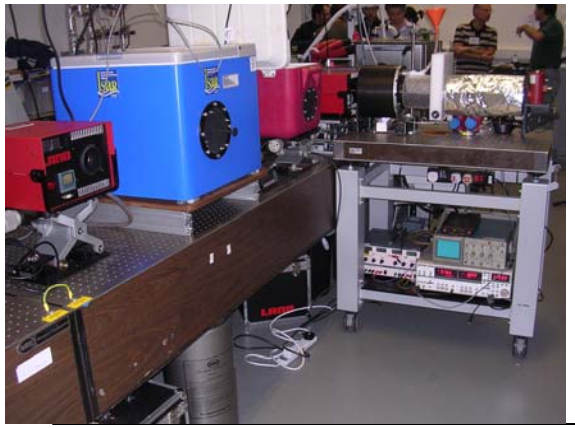
Methodology:

- 1/ Compare black bodies to a reference standard black body using SI traceable and characterised radiometer (AMBER NPL and TXR NIST)
- 2/ Compare radiometers to a reference standard black body
- 3/ Compare radiometers to a common view of the Ocean

Task 1 and 2 (lab based) to be carried out in UK (NPL) and USA (Miami) linked by common radiometers.



30 radiometers (lab)

13 Radiometers (Ocean)

5 black bodies

9 participants plus NPL and NIST for traceability

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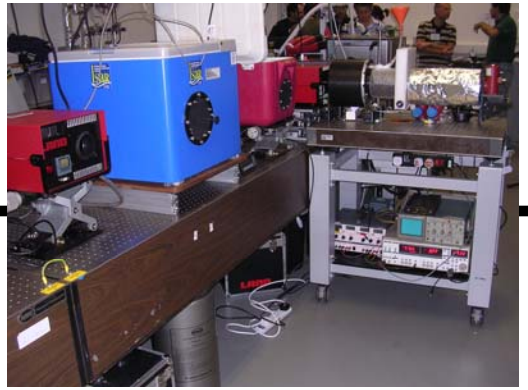

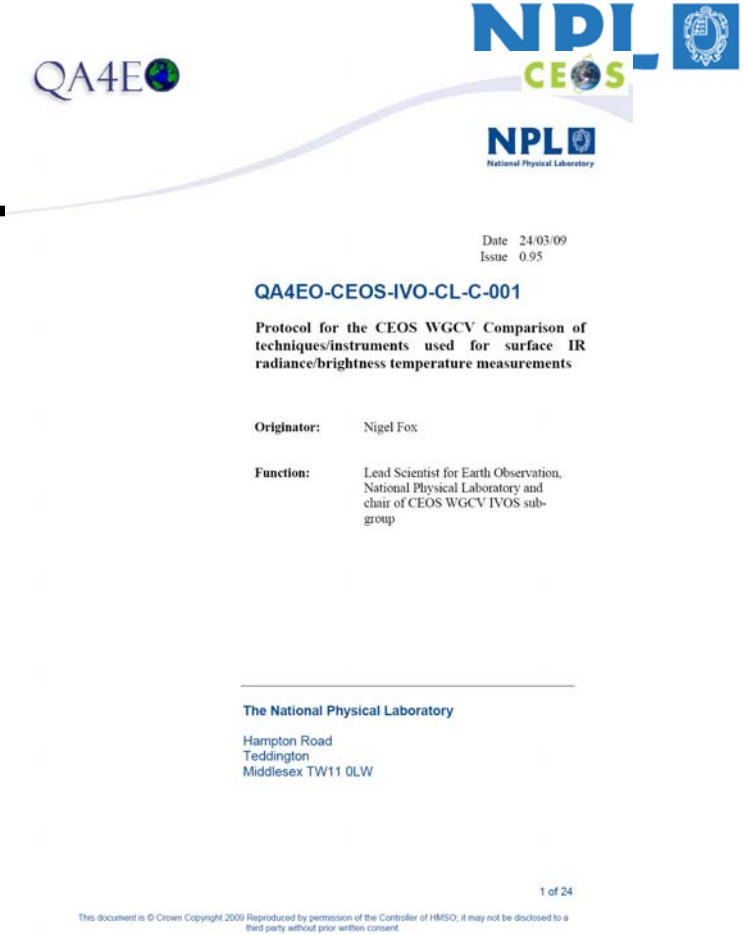

- Lab based temps from 10 to 30 ºC (nominal)
- Link between UK and US via radiometers
- China participate at NPL June 2 (visa difficulties for US)
- Still awaiting some data and uncertainties

Protocol:

- defined methods
- Example uncertainties
- Requirements

Uncertainty table in protocol: radiometer

Parameter	Type A Uncertainty in Value / %	Type B Uncertainty in Value / (appropriate units)	Uncertainty in Brightness temperature K
Repeatability of measurement	0.12K / 0.040%		0.12K
Reproducibility of measurement	0.06K / 0.020%		0.06K
Linearity of radiometer		0.10K	0.10K
Primary calibration		0.20K	0.20K
Drift since calibration		-	-
RMS total	0.13K / 0.045%	0.22K	0.26K

During "pre-phase A all participants check own and others uncertainties.

Allows any debate before seeing results

Few provided this level of detail

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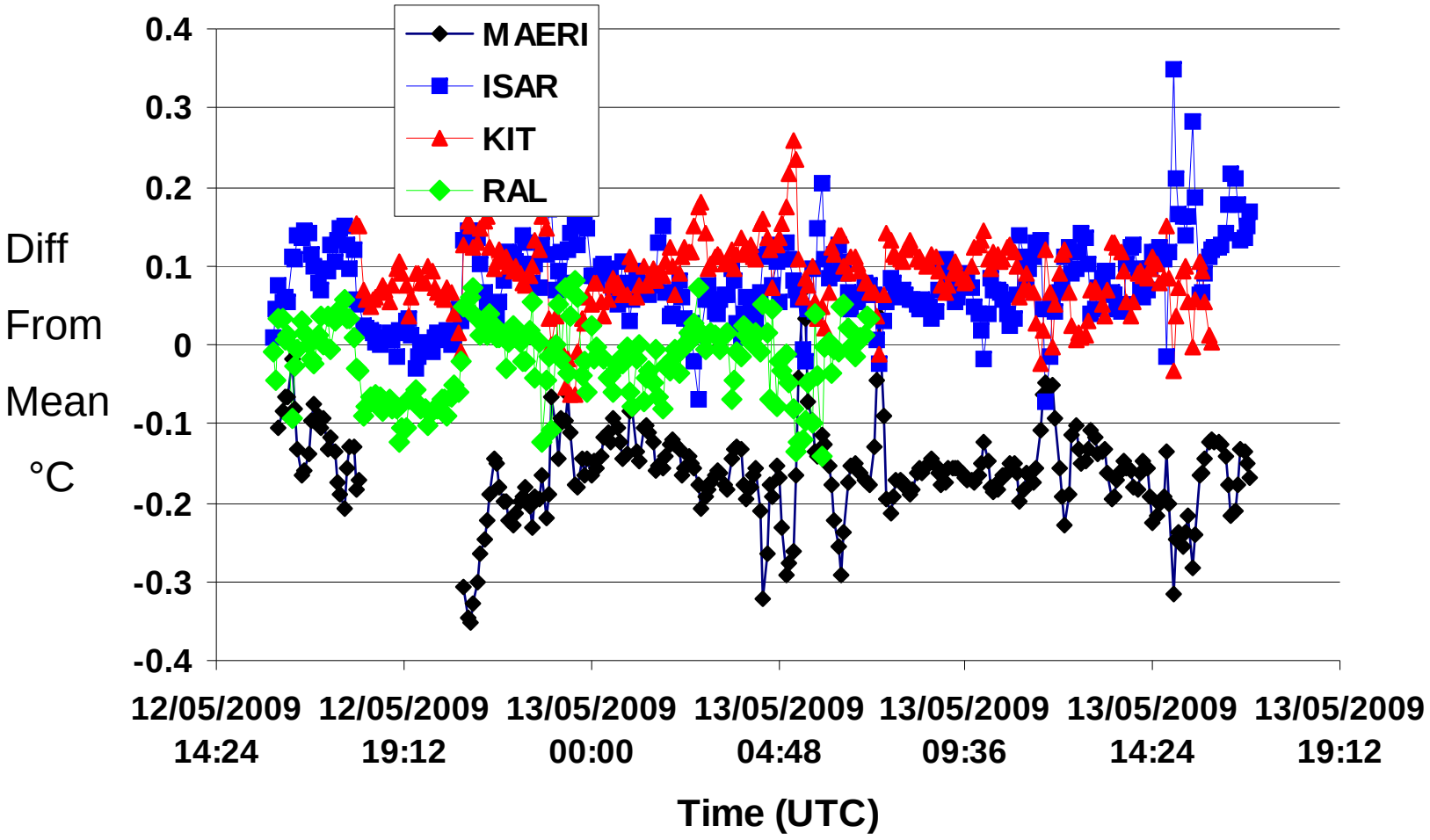
Continuous SST measurements normalised to Mean



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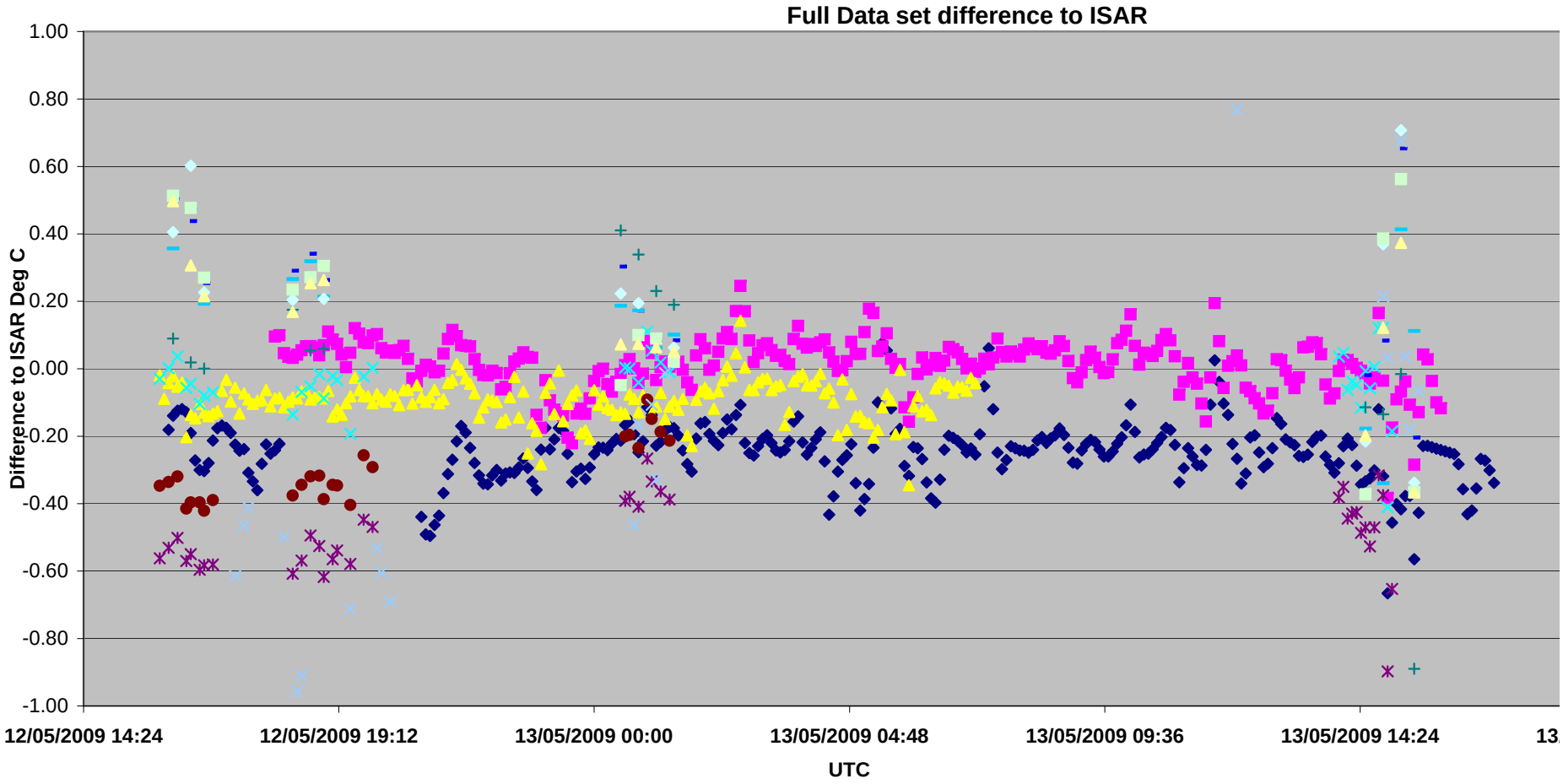
All data normalised to ISAR radiometer



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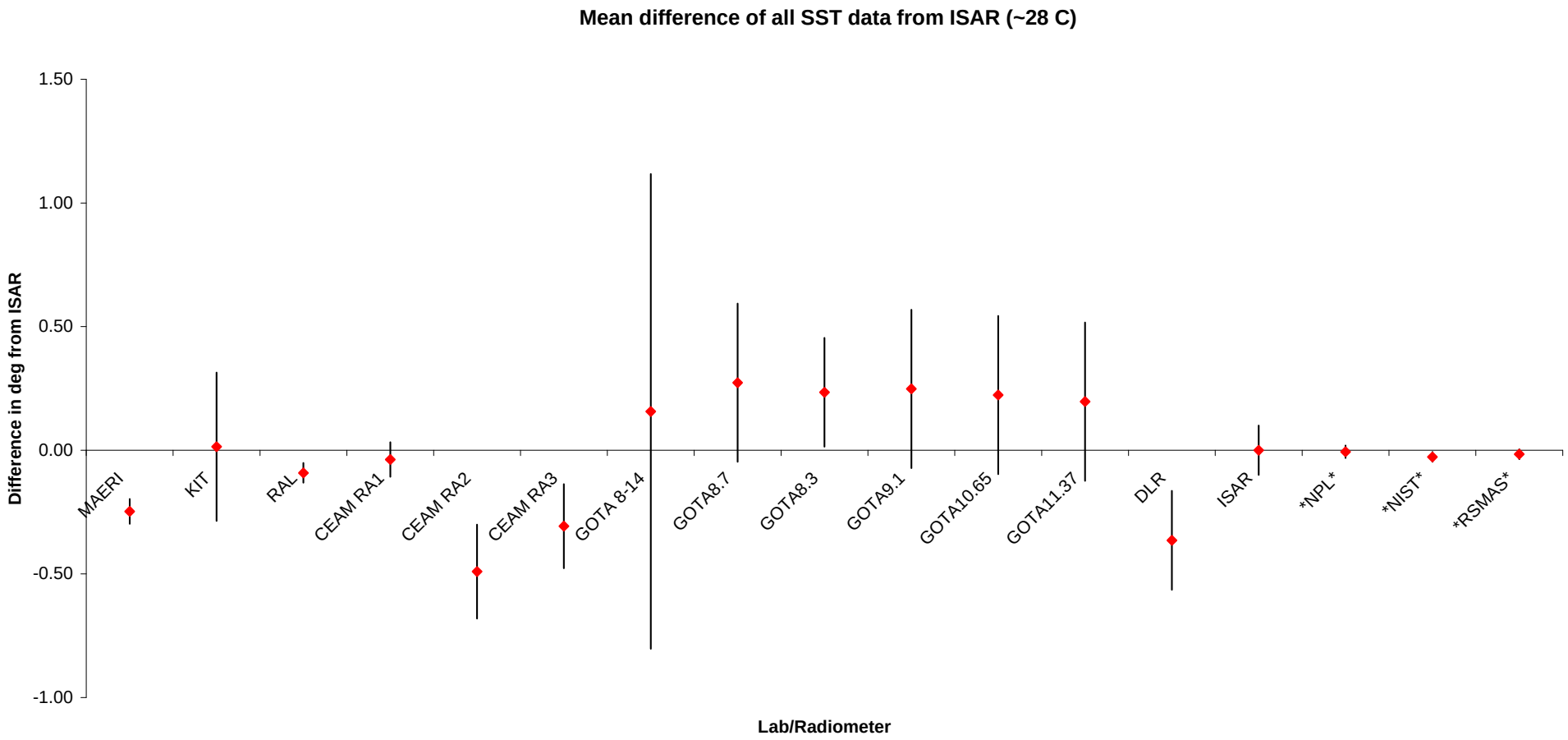
Mean diff of all SST data from ISAR ~ 28 °C (+reference Lab BB data)



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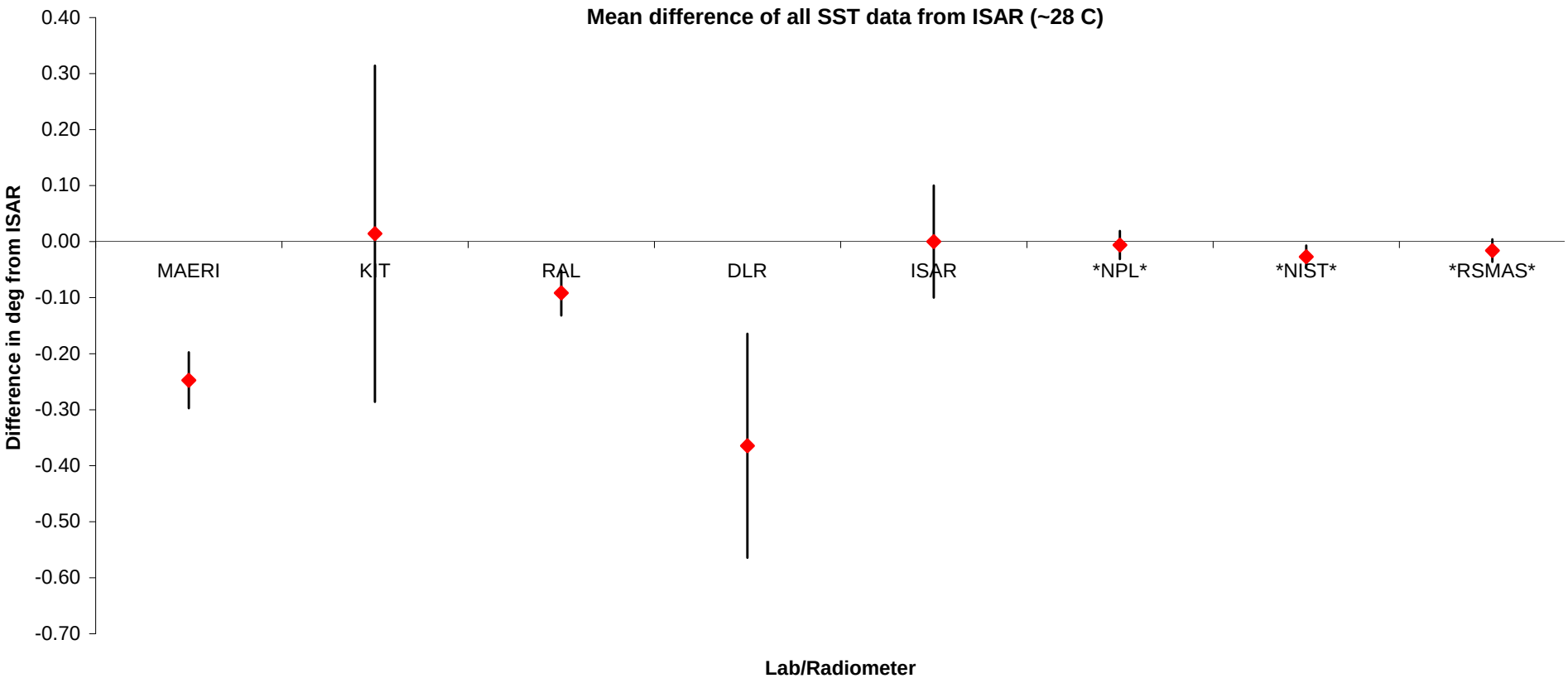
SST instruments difference to ISAR



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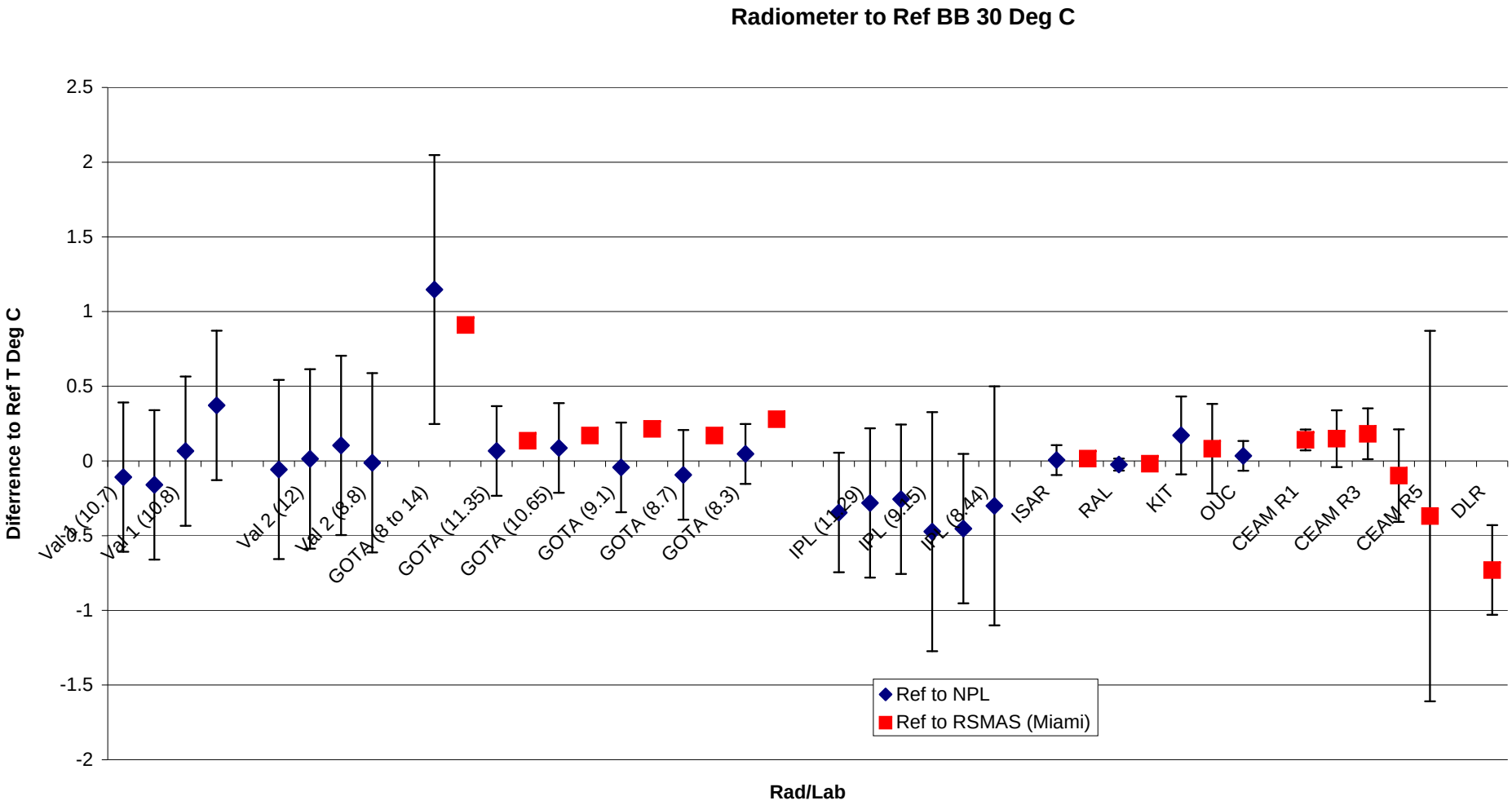
Radiometers to Ref BB at 30 °C



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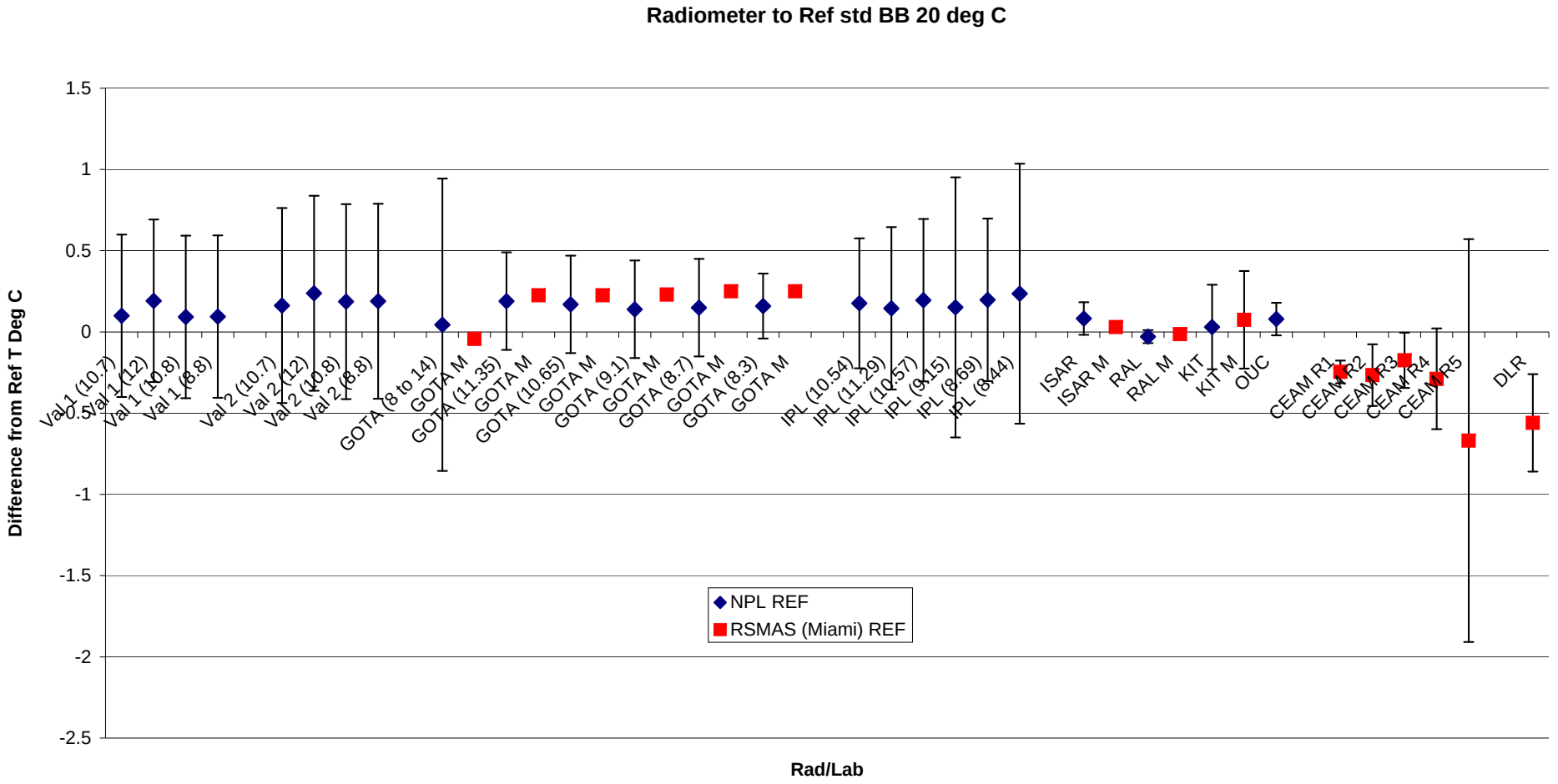
Radiometers to Ref BB at 20 °C



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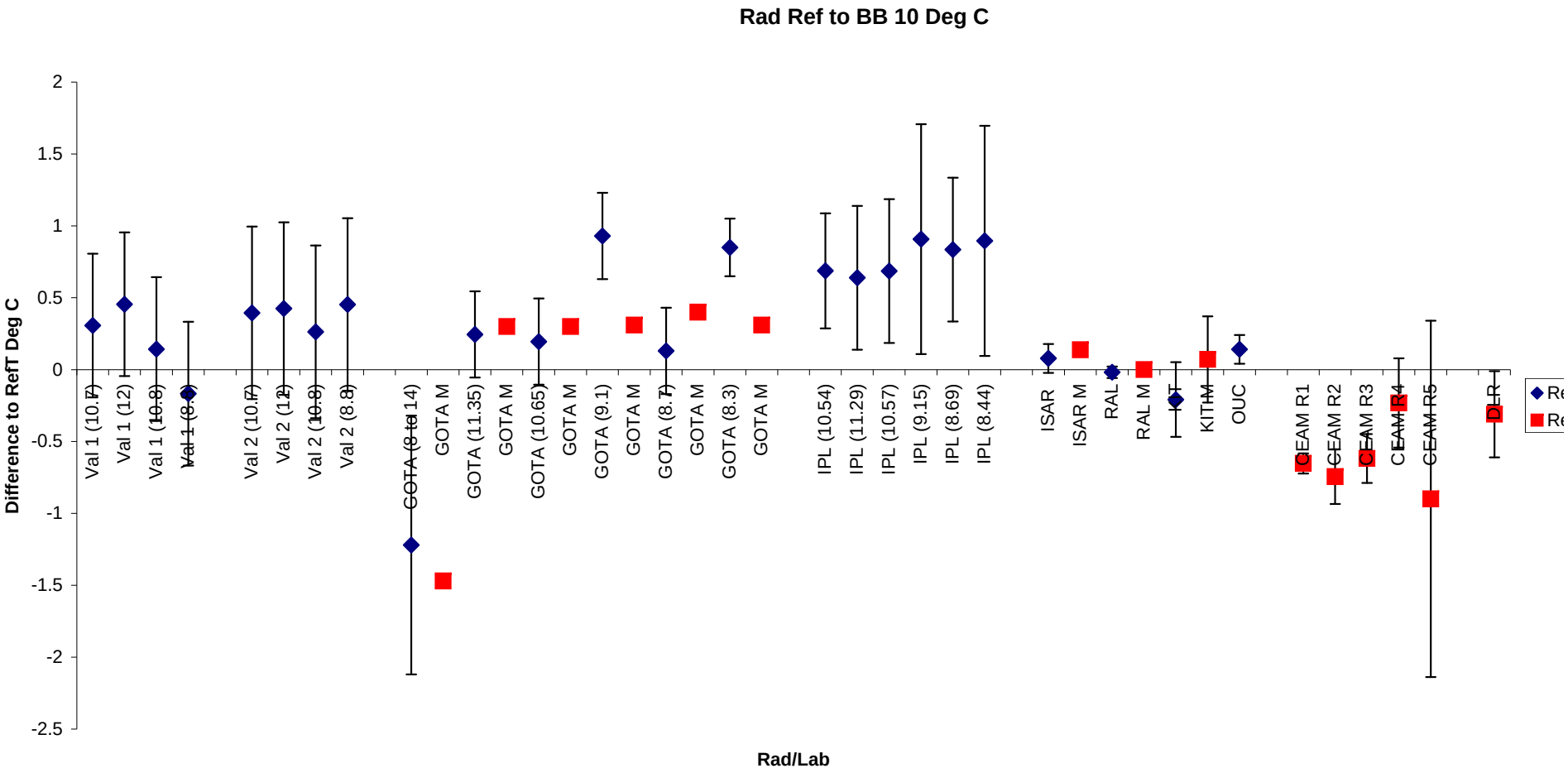
Radiometers to Ref BB at 10 °C



Issues

- **Obtaining resource for joint common activities highly challenging**
- **VISAs**
- **Obtaining results and descriptions quickly**
- **Uncertainties and their meaning and getting detailed breakdowns**
- **Cancellations!**
- **Number of radiometers per participant**

Positives

- Seen as important by community
- Excellent learning opportunity
- Clear knowledge of bias and traceability

Next steps:

- Complete analysis
- Publish results
- Compare with previous and consider timescale for repeats
- Assess need for any variation on type of measurements

CEOS WGCV pilot comparison of techniques/instruments used for vicarious calibration of Land surface imaging through a ground reference standard test site August 2009, Turkey

Nigel Fox, Irina Behnert, National Physical Laboratory, UK
Selime Gürol, TÜBİTAK UZAY, Turkey

CEOS comparison of Land surface reflectance:
Vicarious calibration/Validation

Requirement for activity (priority of need for comparison):

- **Need to validate radiometric performance of satellite sensors (gain), also pixel to pixel variation and in-flight degradation**
- **Evaluate biases between in-flight sensors**
  - **Allow harmonised data sets**
- **Provide linkage to future generation of sensors**
- **Traceably "calibrate" in flight performance**
  - **Dependent on achievable uncertainties**

Methodology to achieve:

- **Use "CEOS" reference standard test site**
  - **Have identified set of 8**
- **Ground Characterised site**
  - **Field team**
  - **Stability monitoring**

Issues: need for comparisons

- Need to know characteristics of site – independent of measurement team
  - At least know potential variability due to measurement technique
    - Noting "local expertise"
  - Instrumentation used is reliable and repeatable
    - Traceably calibrated
    - Consistent (or known differences) method of use
  - Harmonisation of site evaluation, mapping strategy (best practise) can it be "standardised"
- Use of site for satellite sensor characterisation, cross-comparison and interoperability
  - Scaling/mapping of ground measurements to satellites
  - Spectral matching of sensors
  - Encouragement/Coordination of sensor observations
  - Analysis and presentation of results
    - Minimising debate
    - Efficiently
    - Transparently

Work plan for comparison: agreed at IVOS and CEOS WGCV 2008

Decide on candidate site

- CEOS core test site
- Ideally (high and Medium res imagers)
- Site owner willingness
- Resourcing
- Added value of activity

Tuz Golu proposed and accepted with financial support from ESA with NPL as pilot

- **3 phases (3 yrs):**
  - Site initial evaluation/strategy/protocol development (2008)
  - Pilot comparison EU invitees only to test methodology/logistics etc (2009)
  - CEOS comparison all agencies invited (2010)

Comparison Objectives

1. Evaluate differences in field instrument primary calibrations
   - a/. Reference standards used and traceability (based on "Laboratory" information)
   - b/. On-site calibrations/validations
2. Evaluate differences in methods for characterising and assigning "radiometric value" to a site, for multiple view angles
   - a/. Small area for high-resolution imagers
   - b/. Large area for medium-resolution imagers
3. Establish formal traceability of Tuz Gölü reference site based on an evaluation of all comparison results.
4. Establish "best practice" guidance for above and/or knowledge of variance between methodologies.
5. A multi-sensor (satellite and aircraft) comparison linked to the ground calibration derived from the multi-team comparison.
6. Identify the minimum and ideal specifications for characterisation/instrumentation for a CEOS "reference standard"

Additional Objectives

Establish new reference test site for the vicarious calibration,

3 hours flight from Europe

Pilot for CEOS comparison

Pilot for network of sites/operational calibration

Evaluate state-of-the-art in cal/val (variance)

Momentum for QA4EO and IVOS

Tuz Golu, Turkey
38 50º N, 33 20º E
Surface: 324 km^2

CEOS Pilot comparison August 2009

National Physical Laboratory (NPL), UK – Pilot
Space Technologies Institute (TU), Turkey – Host

Participants:
French Aerospace Research Center (CNES/ONERA), France
German Aerospace Center (DLR), Germany
Space Technologies Institute (TU), Turkey

Site selection:

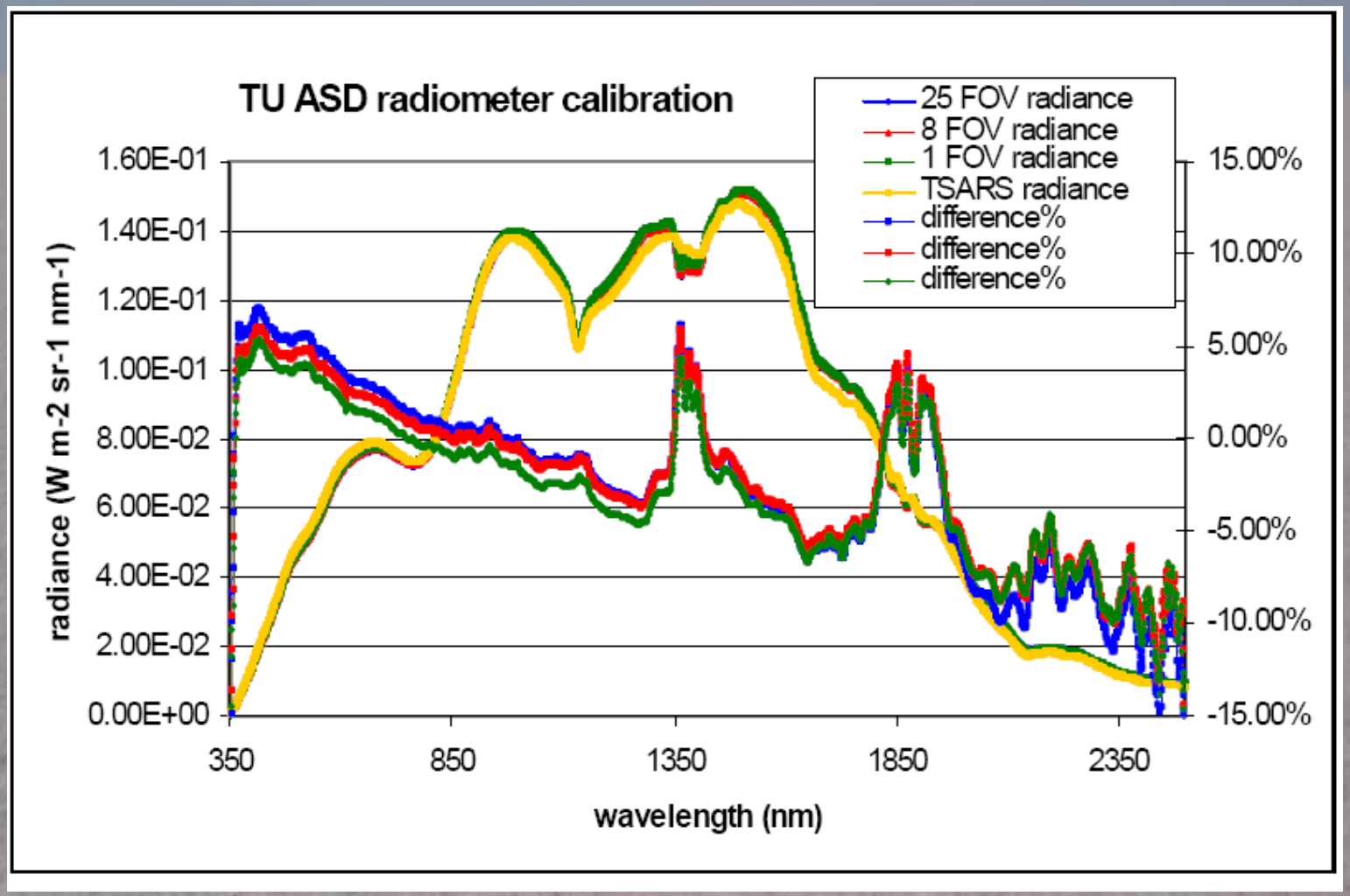
1. TU and NPL select areas with adequate spatial uniformity in July 2009, using high-resolution satellite data
2. in-situ TU visits for BRF characterisation at different angles and to plan access
3. 2 Tarpaulins 50m*50m to mark the corners of the high resolution site
4. 1 km*1 km test site and 3 overlapping targets 100 m*300 m
5. Marker flags to identify sites for participants

Comparison 1: Cross-comparison of all instrumentation (identify and removal of biases from subsequent comparisons)

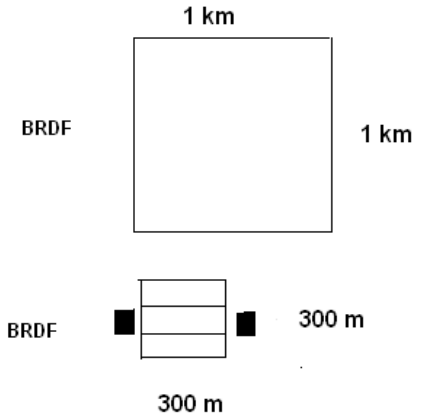
- All radiometers characterised using TSARS,
NPL standard radiance source at TU Laboratory, Ankara

- Nadir and 30º measurements of a Lambertian panel diffuser,
NPL reflectance reference standard in Sun and all participant panels

Example of potential issues of manufacturer calibrations



Protocol comparison 2: site characterisation



- Radiance/reflectance measurements at nadir, by each participant using own panel for 100m*300m targets & 1000*1000m site (by rotation on different days)

- All participants characterise the same target at the same time (sun angle) but on different days using their own method & sampling strategy

- All results will be considered blind to all participants only the pilot will have access.

- Participants results will be provided as "site values" for surface and as TOA for nominated satellites with uncertainty budgets.

- BRDF measurements (NPL) taken near M1, sampled near 1000m*1000m site

- Final day participants agree common methodology and all characterise one site at the same time

Infrastructure is crucial

3 Analytical Spectral Device (CNES/ONERA, DLR, TU)
1 aircraft (Hymap DLR)
BRDF (NPL)
Cimel Sunphotometer (TU, CNES)
Automatic weather station : T, P, RH%, Wind speed/direction (TU)
Differential GPS (TU)

Comparison 3: sensor to sensor using site and ground to sensor.

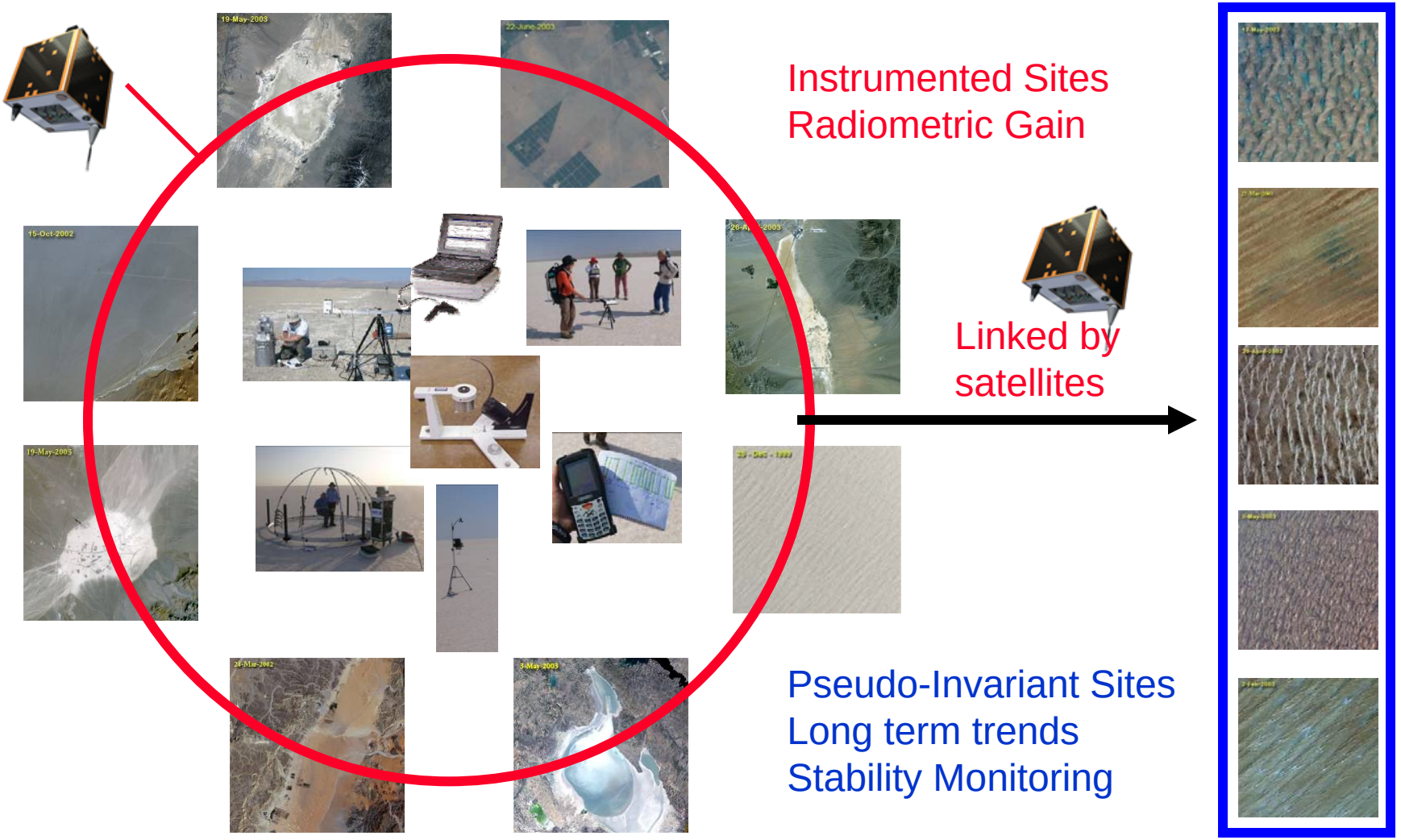
Example Satellite overpasses 22-29 August 2009

	Scheduled (GMT)	Satellite view zenith
UK-DMC	6:15 – 6:28	11-12
Nigeriasat1	6:18 – 6:31	5 -12
PROBA	7:38 – 7:49	7.6 – 15.9
ENVISAT	8:10 – 8:22	4 – 14
SPOT 5	8:27 – 8:31	9 – 15
SPOT4	8:33 – 8:37	1 – 4
LANDSAT5	8:09 – 8:22	7.1 – 13.7
Terra	8:32 – 8:50	4 – 16.5
ALOS	8:37 – 8:54	12 – 17

ANALYSIS: Timeline

PHASE 3: ANALYSIS AND REPORTS	
Participants send all data and reports to pilot	Sep-09
Pilot sends measurement reports of all participants and uncertainty statements to all participants (pre-draft)	Oct-09
Pilot sends relative data to each participant and reported values to participants for checking	Oct-09
Participants return to pilot with comments	Nov-09
Participants respond to comments on uncertainty statements	Nov-09
Revisions to pre-draft closed	Dec-09
Draft B distributed	Jan-10
Comments on draft due	Jan-10
Final Report published	Jan-10

Operational “calibration service”



QA4EO
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Summary

- **New comparisons ideally piloted first**
- **Need clear agreed protocols**
- **For full community inclusion – need Resource – Sharing**
- **“Pilots” ideally independent**
- **Maximise number of activities in each comparison**
- **Establish regularity (not isolated one-off)**
  - If possible automate
- **Are NOT optional**
- **Number and topic selected with care**