Supporting climate research and a low carbon future

RadCalNet to PICS an interoperability framework

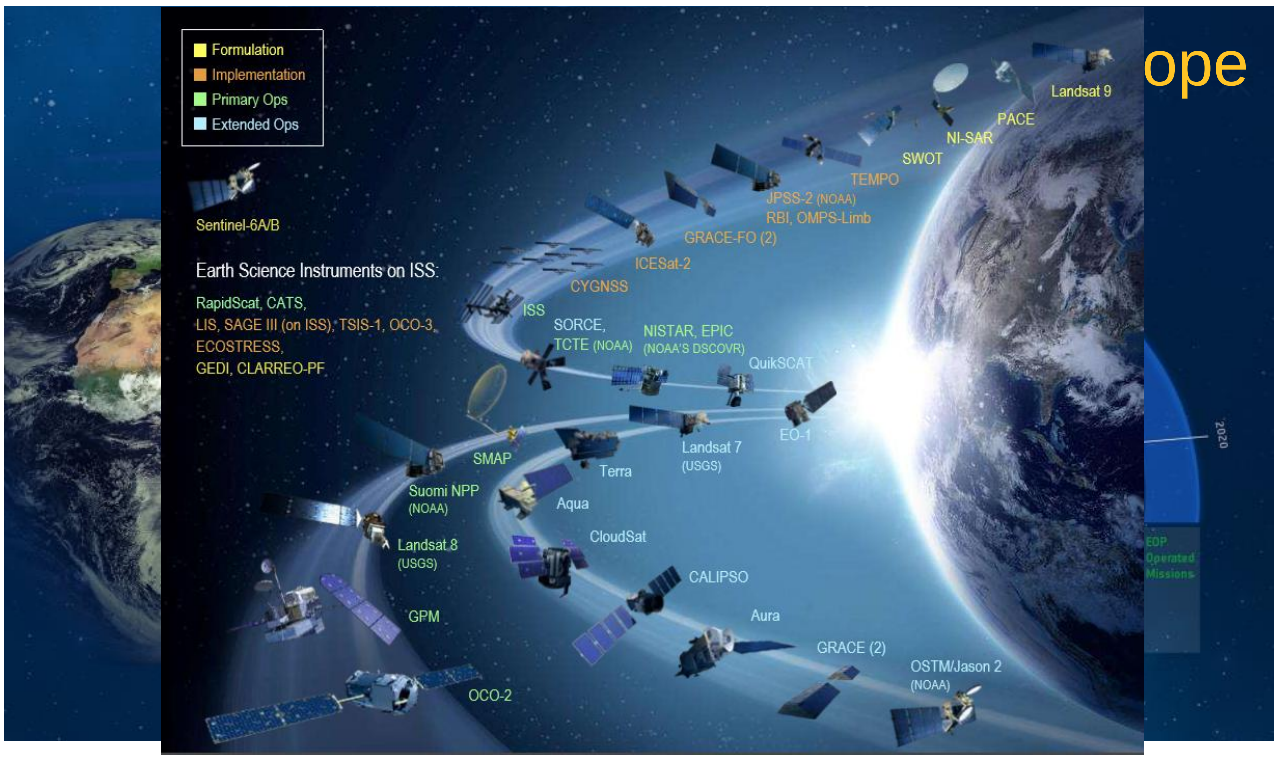
Dr Nigel Fox ++++++++++++++++

Chair CEOS WGCV IVOS

Satellite Data Products:
Knowledge/information

Desire
- Many sensors
- Similar products
- Observations on demand’
  - constellations of nano-sats
- Trustable for decades
- User confidence

Challenges
- Different algorithms
- Limited validation data
- Data similar but different
- Scene/pixel dependent Uc
- Lack of standardisation / interoperability



STEP 1: Interoperability (consistency?) at Leve1 TOA

IVOS: Vision

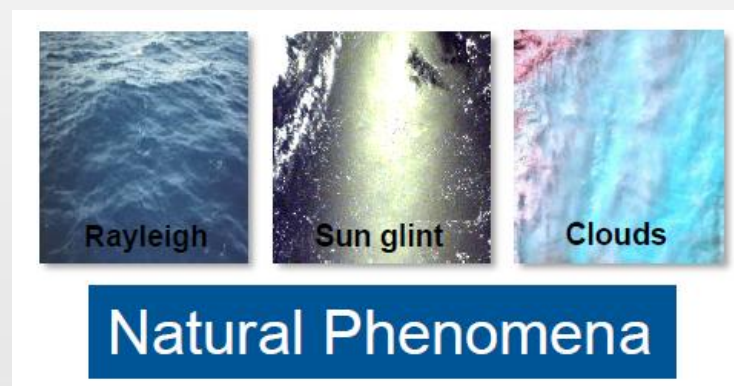
To facilitate the provision of ‘fit for purpose’ information through enabling data interoperability and performance assessment through an ‘operational’ CEOS coordinated & internationally harmonised Cal/Val infrastructure consistent with QA4EO principles.

- ***Pre-flight characterisation & calibration***
- ***Test – sites***
- ***Comparisons***
- ***Agreed methodologies***
- ***Community Good Practices***
- ***Interchangeable/readable formats***
- ***Results/metadata - databases***

Key Infrastructure to be established and maintained independent of sensor specific projects and/or agencies

Post-launch sensor to sensor interoperability of Level 1

- IVOS 27(2015) significant discussion on what to be done & How?
  - Follows similar of many years / many methods / different results
    - o Progress on cataloguing and identifying sub-set of CEOS test-sites
    - o CNES long history and database of results (SADE/Muscle)
    - o GSICS successes on harmonising (meteorological sensors)
    - o Time is right to establish a consensus approach with SI traceability & uncertainty that can provide users with consistent trustable results



Conclusion

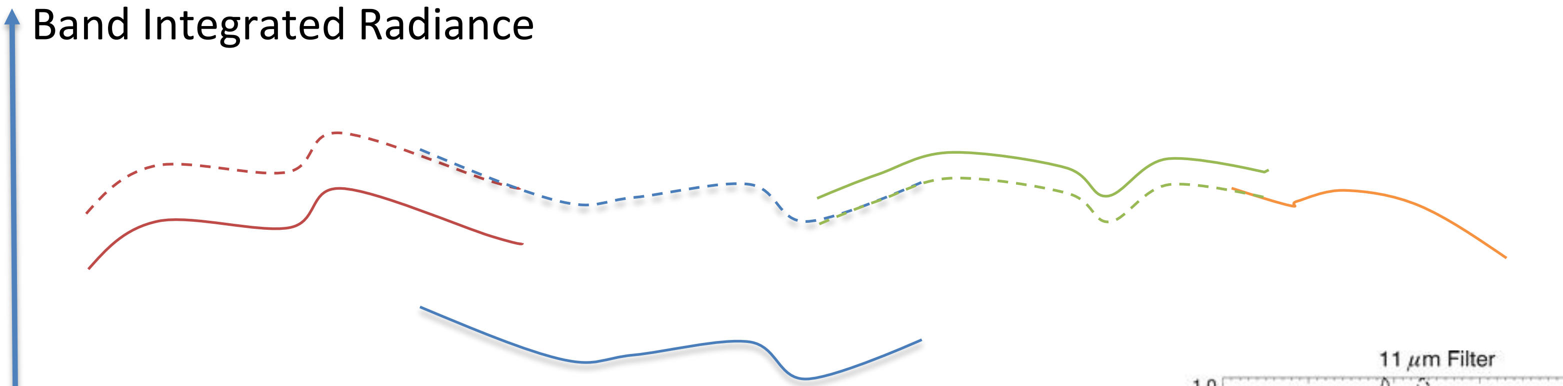
VISION;

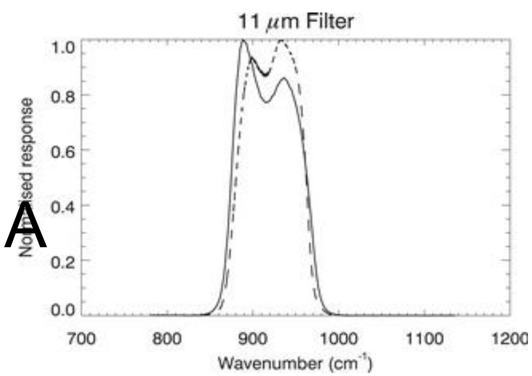
To work towards establishing a community agreed reference (s) (potentially, to reflect different applications/observation characteristics) for level 1 TOA radiances/reflectances and the means of how sensors can and should link to it and subsequently communicate results

- **Objective** is to provide a 'reference' which allows satellite operators and potentially their customers to readily obtain information relating to the radiometric calibration (initially Level 1) of a sensor and its relationship with others in a consistent manner *but interpretation (and any other actions) is responsibility of individual agencies who have appropriate expertise*
- **Users**
  - **satellite operators (public agencies and commercial) – informing them on calibration status**
  - **Users of L1 data products (e.g. L2 data producers, producers of data cubes, climate data records ..) to help obtain consistency across sensors and between bands – over time and for sensor independent products**

Harmonisation not homogenisation

$$R_{\mathrm{E,sensor},i} - R_{\mathrm{E,reference},i} = K_{\mathrm{sensor\text{-}reference},i}$$





Maintain sensor characteristics in viewing ‘reference’ do not force sensor A to appear to be sensor B

Look to consider the measurement equation of sensor and how it interacts

$$R_E = a_0 + \frac{a_1 R_T - a_2 \dot{C}_T^2}{\dot{C}_T} C_E + a_2 C_E^2 + 0$$

NPL National Physical Laboratory

FIduceo

What are the elements of a system to deliver?

- **Understanding user needs and the characteristics of sensors that would use the ‘service’**
  - **who wants it?, why? and what must it be able to do?**

- **A means to formulate a reference (s) and assign its associated uncertainty**
  – **Internationally acceptable standard (proxy for SI)**
    - **Test-site, Reference sensor, virtual sensor, combo….**

- **The means to link sensor measurements to the reference and its associated uncertainty (‘Comparison’)** – **The process**
  Tools to achieve (SBAFs, Ref. Solar Irradiance, Mathematics…),
- **Communication of information (data, results and methods)**
  – **Useability and awareness**

- **Governance, review mechanisms, quality control, maintenance…**
  .- **Community acceptance**

WGCV-IVOS Understanding of user needs and characteristics of sensors that would use such a service

a. Find users for this service (needing interoperability)
   - GEO, CEOS-VCs, WG Climate, WGCV,
   - Operating agencies, Commercial operators

b. Find applications for this service
   - Datacubes
   - Gap filling
   - FCDR and CDR production

c. Understanding what their requirements are
   - How they want to combine sensors, which sensors, what they will use information for
   - Scoping service range: Spectral bands, absolute / relative stability, update frequency, inter-channel
   - [Not geolocation / MTF etc]
   - How they would like to access the information, their involvement as providers (options for types of users)

d. Decide on scope / service requirements (initial / longer term), feasibility

[producing service requirement specification]

CEOS WGCV-IVOS

Development of a means of formulating a reference and its associated uncertainty

a. Define required characteristics of a reference
   - Temporal stability, accessibility to users, political neutrality, dynamic range, wavelength range, spectral resolution, spatial resolution, geographic location

b. List of possible reference approaches and evaluation of these approaches
   - Sites, models, a sensor, a combination of sensors, SI
   - Heritage information

c. Stability of reference due to its formulation / re-realising the reference

d. Traceability of reference
   - Approaches / methods: natural phenomena, PICS, instrumented sites

e. Reference choice (Relative vs absolute radiometry) considering
   - Sensor to sensor (within series, different series) effects
   - Band to band effects
   - Temporal (within orbit, seasonal, diurnal, long-term drift) effects
   - Geographic / geometric sensitivities (e.g. cross swath consistency, inter-scene consistency, geographic representativeness / accessibility of reference)

f. Dynamic range and nonlinearity

g. Combining to a single reference

h. Uncertainty analysis on reference

References?

- A “reliable sensor” (unknown unknowns and potential impact)

  - why do we believe MERIS or MODIS and not OLCI / SLSTR

  - Stable and consistent (yes) – absolute (? Probably)

  - Need to consider if single sensor suddenly changes/dies!

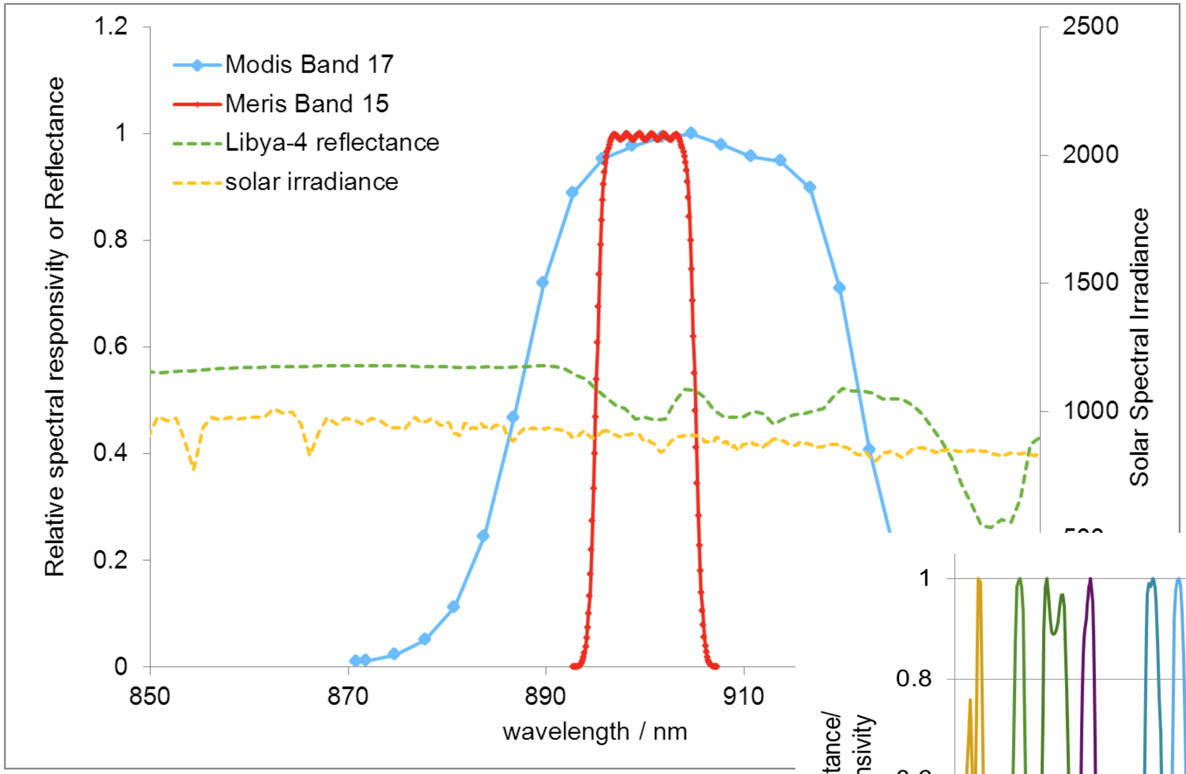
  - Long term long time base invariant reference

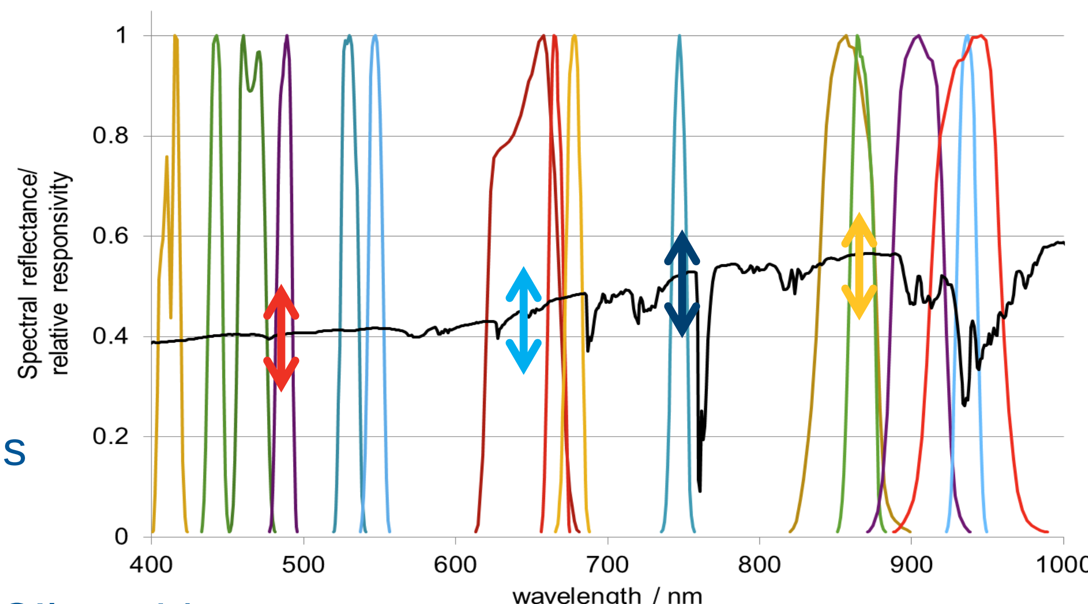
  - Uc propagation

  - Transfer process Uc

  - Spectral mismatch to sensors under test
- SI?
- A virtual ‘average’ satellite based reference?
- Ground measurements?
- Combination of All or some

SBAFs and reference curves



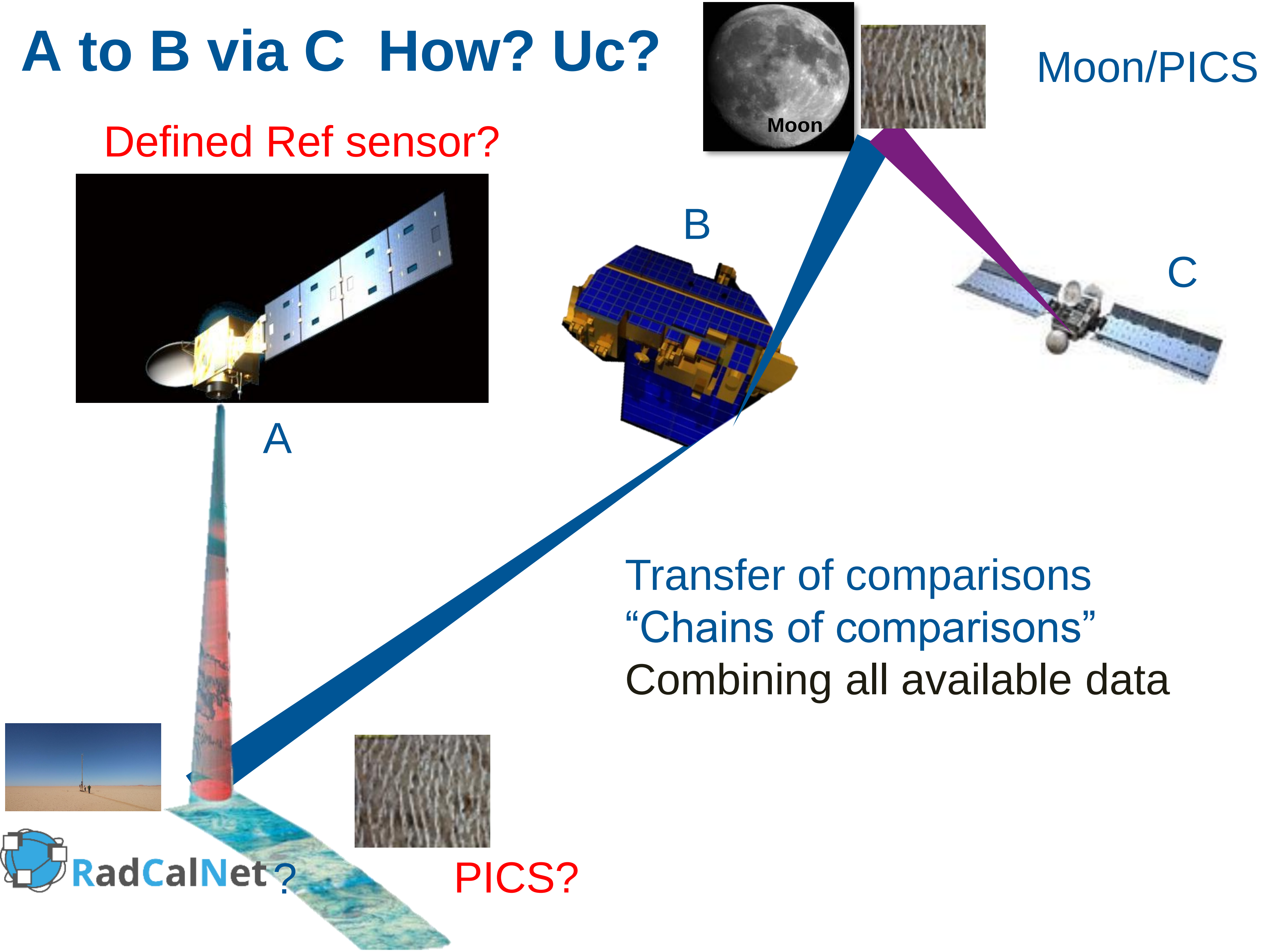


Reference filter based sensor OK?
For similar band sensors

Need to link sensors of different bands or band shapes

NMI community in absence of a 'true SI' would create a 'comparion reference value or curve' from all comparison data weighted by Uc to provide a means to link

A to B via C How? Uc?



Transfer of comparisons
“Chains of comparisons”
Combining all available data

CEOS WGCV-IVOS *Development of a means of linking sensor measurements to this reference (and its associated uncertainty)*

a. **Define required characteristics of linkage approach**
    - **Temporal stability, accessibility to users, political neutrality, dynamic range, wavelength range, spectral resolution, spatial resolution, geographic location**
    - **Approaches / methods: natural phenomena, PICS, instrumented sites**
b. **List of possible linkage approaches and evaluation of these approaches**
c. **Necessary additional information reviewed and agreed**
    - **Reference solar spectra,**
    - **Radiative transfer models and inputs**
d. **Adjusting for different characteristics**
    - **Band convolution techniques**
    - **Temporal interpolation (within orbit, seasonal, diurnal, long-term drift)**
    - **Spatial interpolation and matching**
e. **Uncertainty analysis on linkage**
    - **Ensure traceability is maintained through to sensor**
f. **Operational feedback (defining how data from linkage comes back into system)**

Methods for communicating information and data

a. Information
- The reference and its associated uncertainty
- The way to link to the reference
- Results of comparison to reference (provided by operator/contributing users) [“table”]
- ATBDs, monitoring reports, standards, conventions, file formats

b. Tools
- Software routines? Or algorithms and pseudocode?

c. Communication methods
- Web portal
- Servers – including GSICS?
- Papers and conferences

d. Validation reports / QA / Peer review reports

e. Opportunity for feedback from users

Governance, review mechanisms and quality control (all to be defined!)

a. Scope of implementation

b. Path forward within WGCV

c. Linkage to GSICS

d. Possible means for implementation

e. Possible mechanisms for review, quality control, responsibilities,

f. How open / public is the data, methods etc? Data policy?

Next steps: what do we want to do?

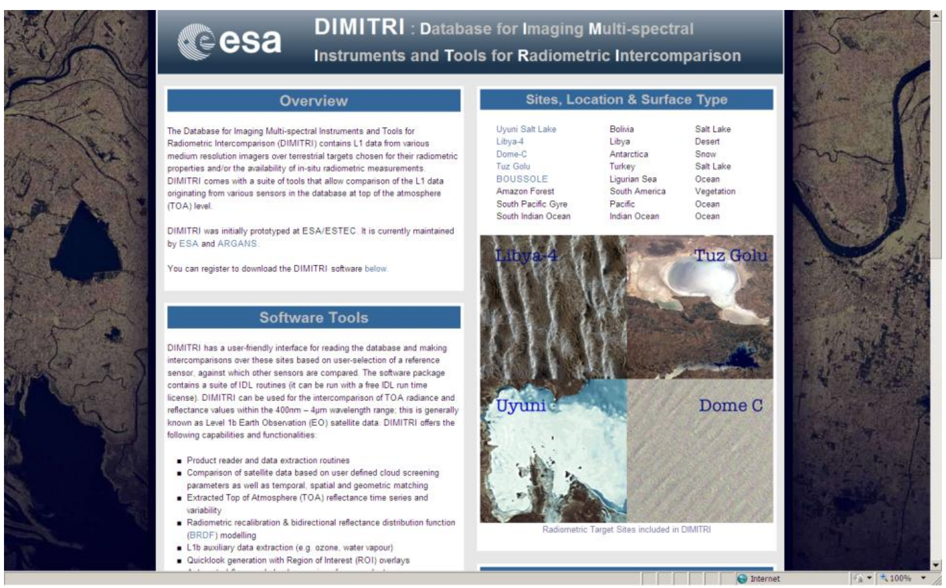
- **As a WGCV IVOS community we share the VISION and wish to pursue (probably with some GSICS technical groups)**
  - **WGCV endorsed initiative with IVOS prototyping**
- **Agree terminology / vocabulary**
  - wider initiative needs WGCV/GSICS/GEO …but IVOS perspective/input
- **Have conversations with users to understand requirements/desires and scope**
  - Probably best done at WGCV level
- **Collect information on existing and future sensor comparisons in common format in a 'restricted' section of Cal/Val portal**
  - Working data-set to identify variances between methods & within methods
  - i.e. summary results (with ref to method etc) from SADE/Muscle, RadCalNet, Bi-laterals, publications etc
- **Continue to develop and evaluate (as community projects) differences between 'methods' for similar activities e.g. Lunar, RadCalNet (BoA & ToA), PICS … -** Ultimately leads to confidence in Uc and potential for SI traceability
- **Consider how best to combine/weight results/information from different methods and assign an Uc (ies) to sensors for particular types of observation**

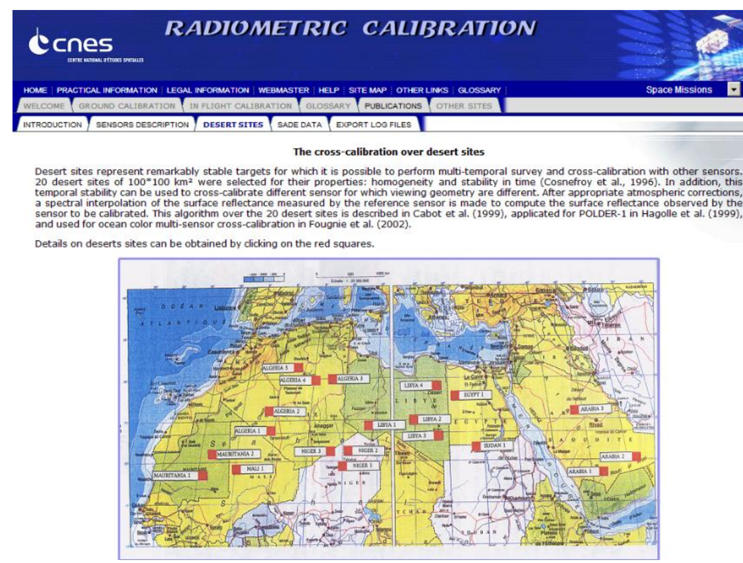
Sharing results – comparing results

- Single repository for comparison results?
- What is needed to be stored?

  SBAF and other corrections?

  Determined biases?





Potential Database entry

Participating Institution:	RAL Space

Band Name	Sensor under test		Sensor secondary band		Reference TOA Reflectance Factor	
	Nominal Band Centre (nm)	Nominal Bandwidth (nm)	Secondary band Centre for band to band comp (nm)	Nominal bandwidth of secondary band (nm)	Mean	Std Dev
V555	555	20				

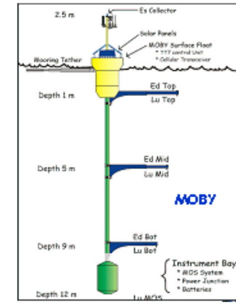
Ratio Sensor/Reference		Number of Samples	Measurement Uncertainties	
Mean	Std Dev		Type A (statistical/ random)	Type B (non-statistical e.g. absolute caln)

Site identifier: name, nominal location	
Site Latitude:	
Site Longitude:	
Procedure Reference:	
Sensor Being Compared:	AATSR
Sensor L1b Processing Version:	AATSR/6.01
Reference sensor:	MERIS
Reference sensor processing version:	
For other reference (origin of comparison values) e.g. ground measured reflectances	
Nominal at sensor solar irradiance:	
Special characteristic of comparison (e.g. non nadir)	
Date Range of Measurements:	02-Nov-08

Sensor/Reference		Number of Samples	Measurement Uncertainties	
an	Std Dev		Type A (statistical/ random)	Type B (non-statistical e.g. absolute caln)
276	0.0072	42	0.001110984	
192	0.0075	42	0.001157275	
258	0.0077	42	0.001188136	

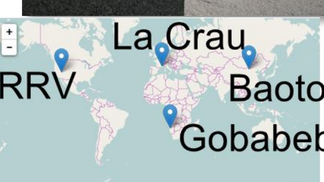
Achieving SI Traceable Cal infrastructure /methods

PICS

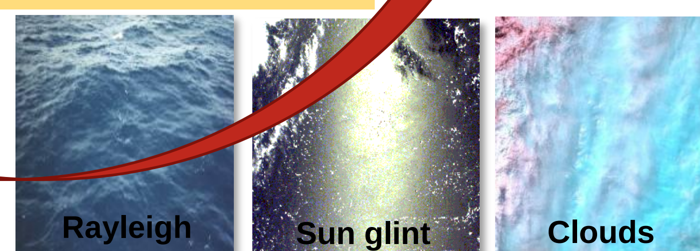


Combine information weighted by Uc for particular sensor and application

Ocean Colour



RadCalNet



Natural Phenomena

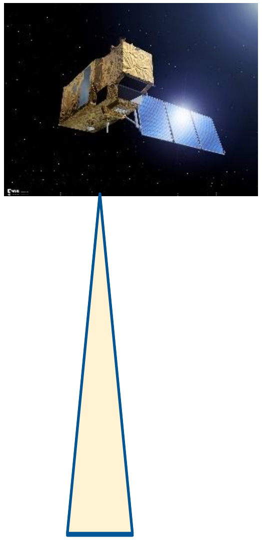
Summary of this part

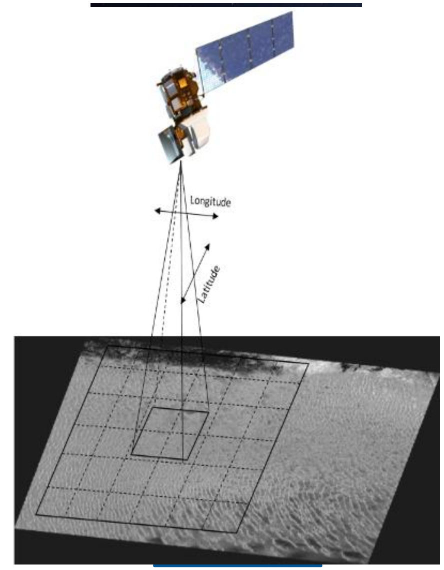
- Must have comprehensive Pre-flight to understand the sensor
- Ideally have on-board systems on some sensors to as a minimum allow in-orbit studies

Need for some means to consistently evaluate and communicate 'differences' between sensor L1 for user community.

- Could be based on consistency if we are very very careful
  - Ideally SI traceable for robustness in long term
- What to use is still 'Open'
- Need to continue strategy to evaluate and improve different vicarious Cal/Val and comparison methods
  - Linking between sensors with different bands
- As a starting point, for at least Europe, collect results of comparisons to facilitate analysis studies.
  - Assess how to weight and combine results? And assign Uc

What can we do now?





RadCalNet

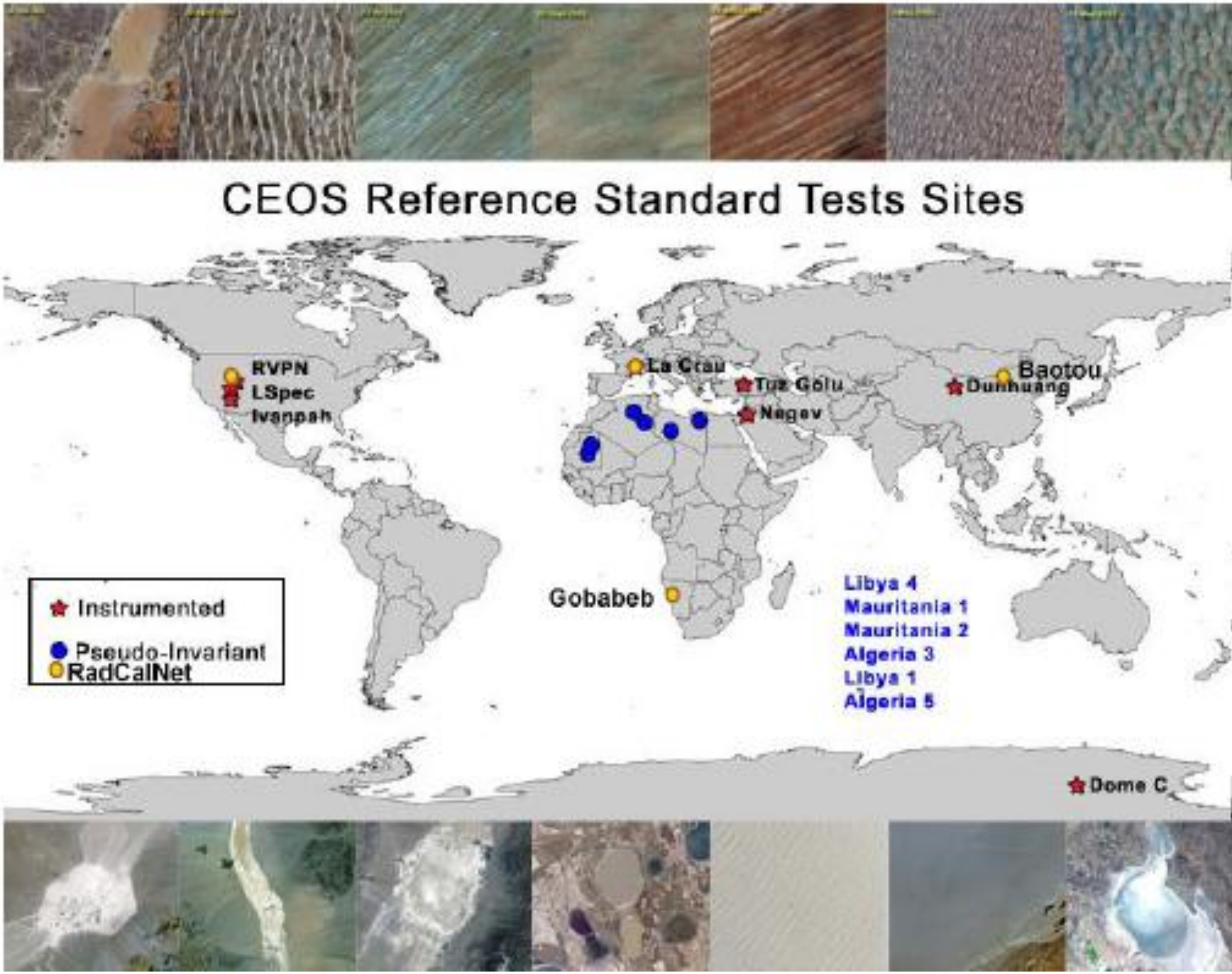
SI

CEOS

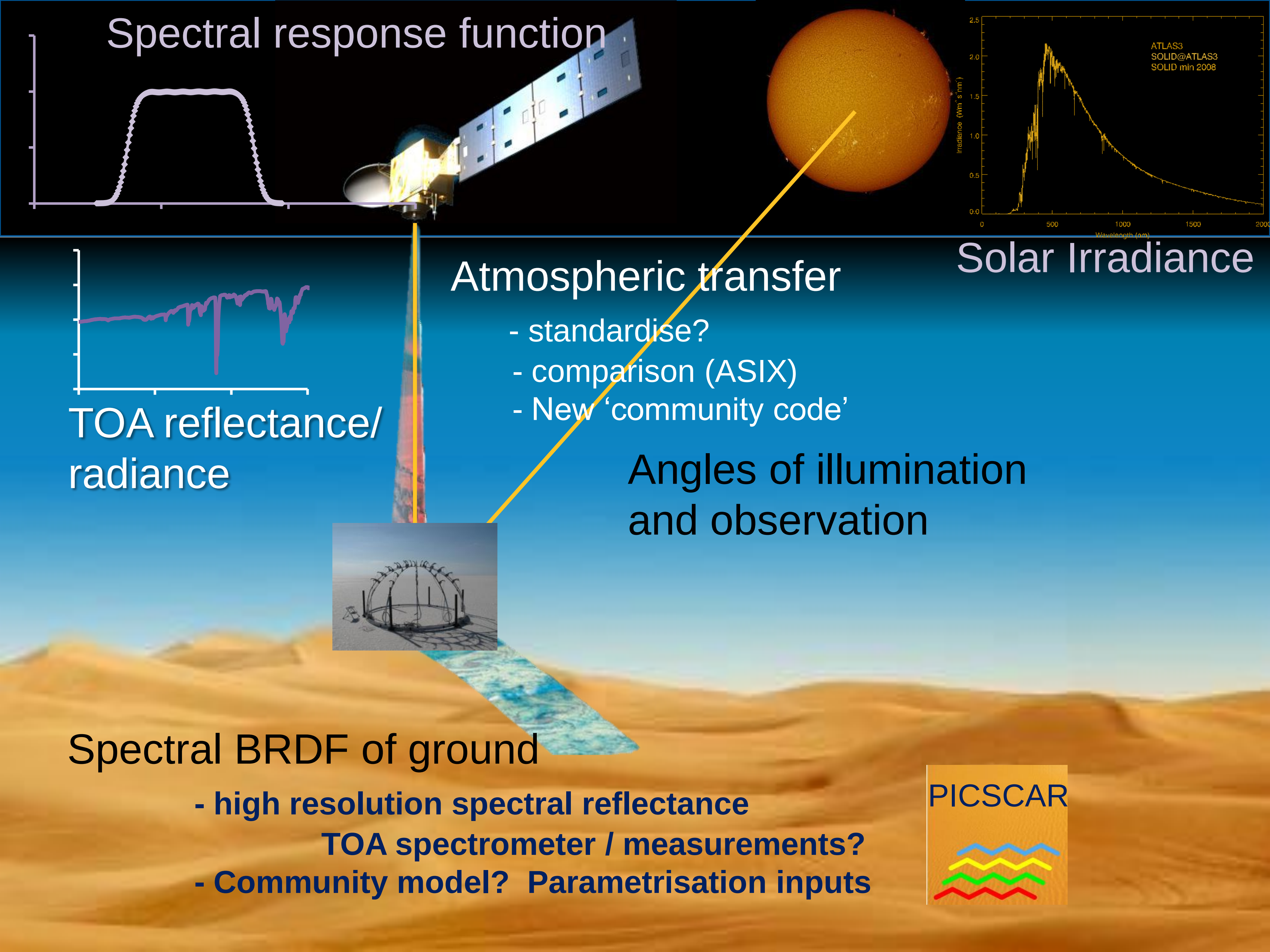
PICS

Priority sites for cross-comparison of L1

NPL National Physical Laboratory | Centre for Carbon Measurement

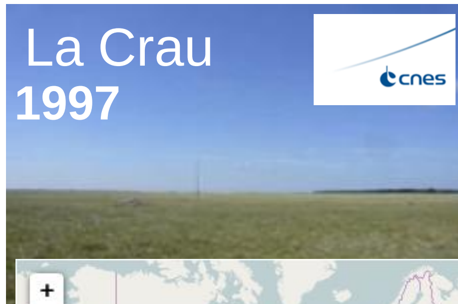


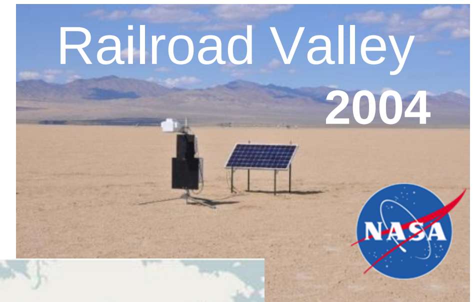
RadCalNet

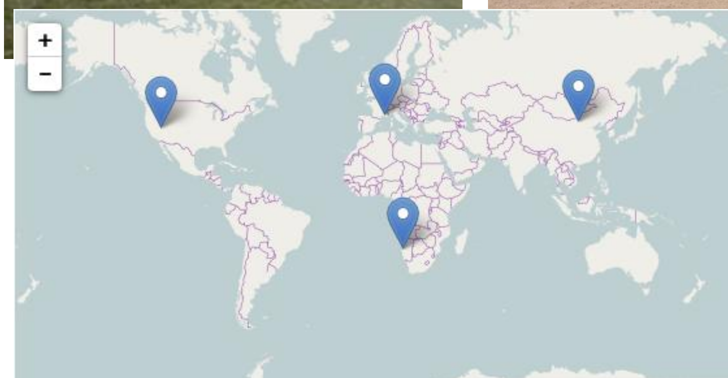

Spectral response function
ATLAS3
SOLID@ATLAS3
SOLID min 2008
Solar Irradiance
Atmospheric transfer
- standardise?
- comparison (ASIX)
- New ‘community code’
TOA reflectance/
radiance
Angles of illumination
and observation
Spectral BRDF of ground
- high resolution spectral reflectance
TOA spectrometer / measurements?
- Community model? Parametrisation inputs
PICSCAR

What is RadCalNet

TOA nadir-view hyperspectral (400 - 2350 nm) reflectance every 30 minutes (9:00 -15:00 LT) - Individual site measurements documented and traceable







Site Characterisation

Site permanent monitoring (radiometry and atmosphere/weather)

Modelling of TOA nadir-view reflectance

Who is involved in establishing RadCalNet?

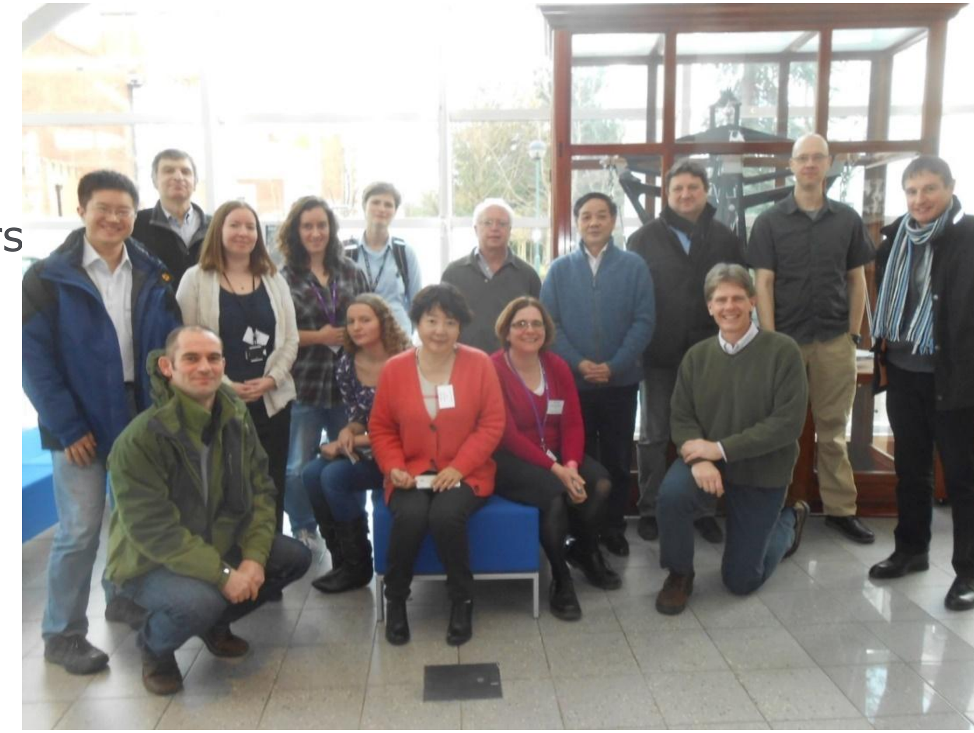
-Initiated in IVOS sub-group 2014 (evolving from Landnet and original concept GIANTS (Teillet 1999)

- **Key objectives:**
- More consistent sites - more data points for users
- Member sites must **operationally** deliver hyperspectral surface reflectance data
- Sites must provide documented evidence of **traceability and Uncertainty**
- Data and info open access at a portal

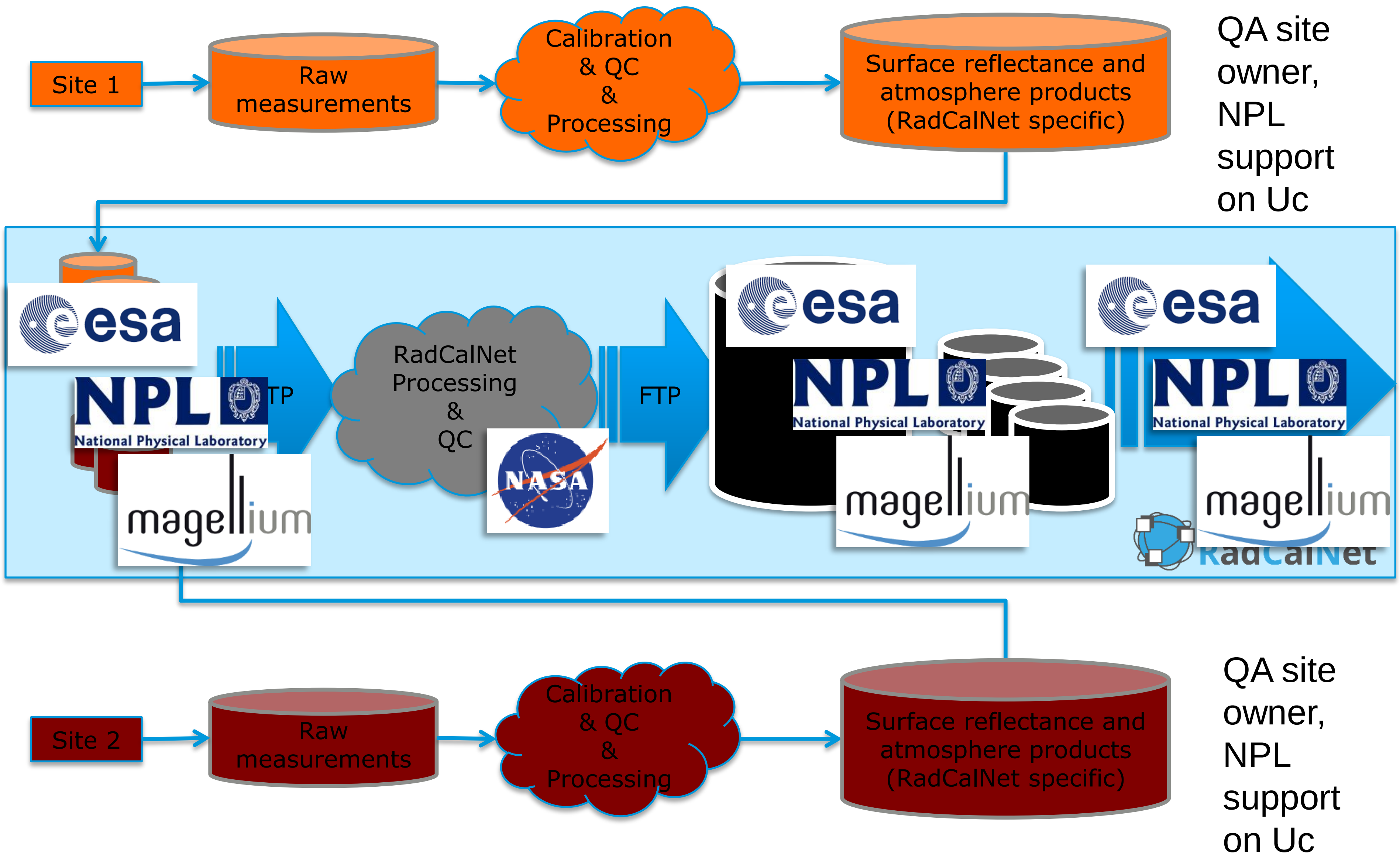
- WG formed under CEOS WGCV to prototype concept (3 sites + 1) under Chair of Marc Bouvet ESA target of 2 yrs

RadCalNet WG members at 3rd meeting (NPL, UK)

- **AOE (China)** (C. Li, L. Ma, L. Tang, N. Wang)
- **CNES** (P. Henry, A. Meygret)
- **ESA** (M. Bouvet, P. Goryl) supported by Magellium (B. Berthelot)
- **NASA** (K. Thome, B. Wenny) and University of Arizona (J. Czapla-Myers)
- **NPL** (N. Fox, E. Woolliams)

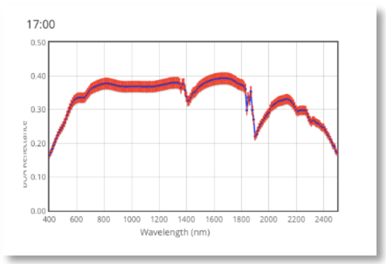


The data circulation

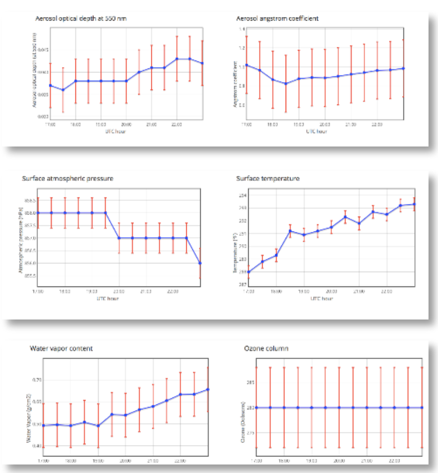


The RadCalNet processing

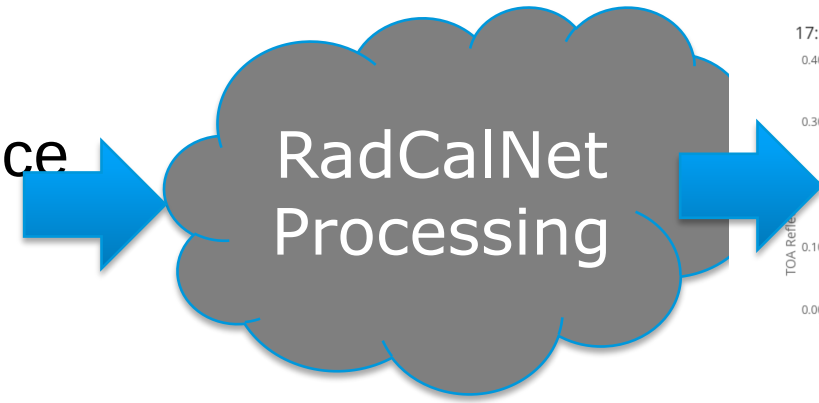
- MODTRAN 5 (assume lambertian surface)
- On-going work by K. Thome / B. Wenny to **propagate the surface / atmosphere uncertainties to TOA uncertainties** via pre-computed LUT from Montecarlo MODTRAN runs

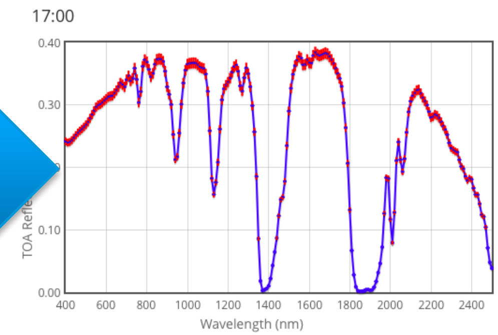


Surface reflectance



Atmospheric measurements





TOA reflectance

www.RadCalNet.org

RadCalNet

radcalnet.org/#!

RadCalNet   CEOS Committee on Earth Observation Satellites   Sign In

Welcome to the Radiometric Calibration Network portal

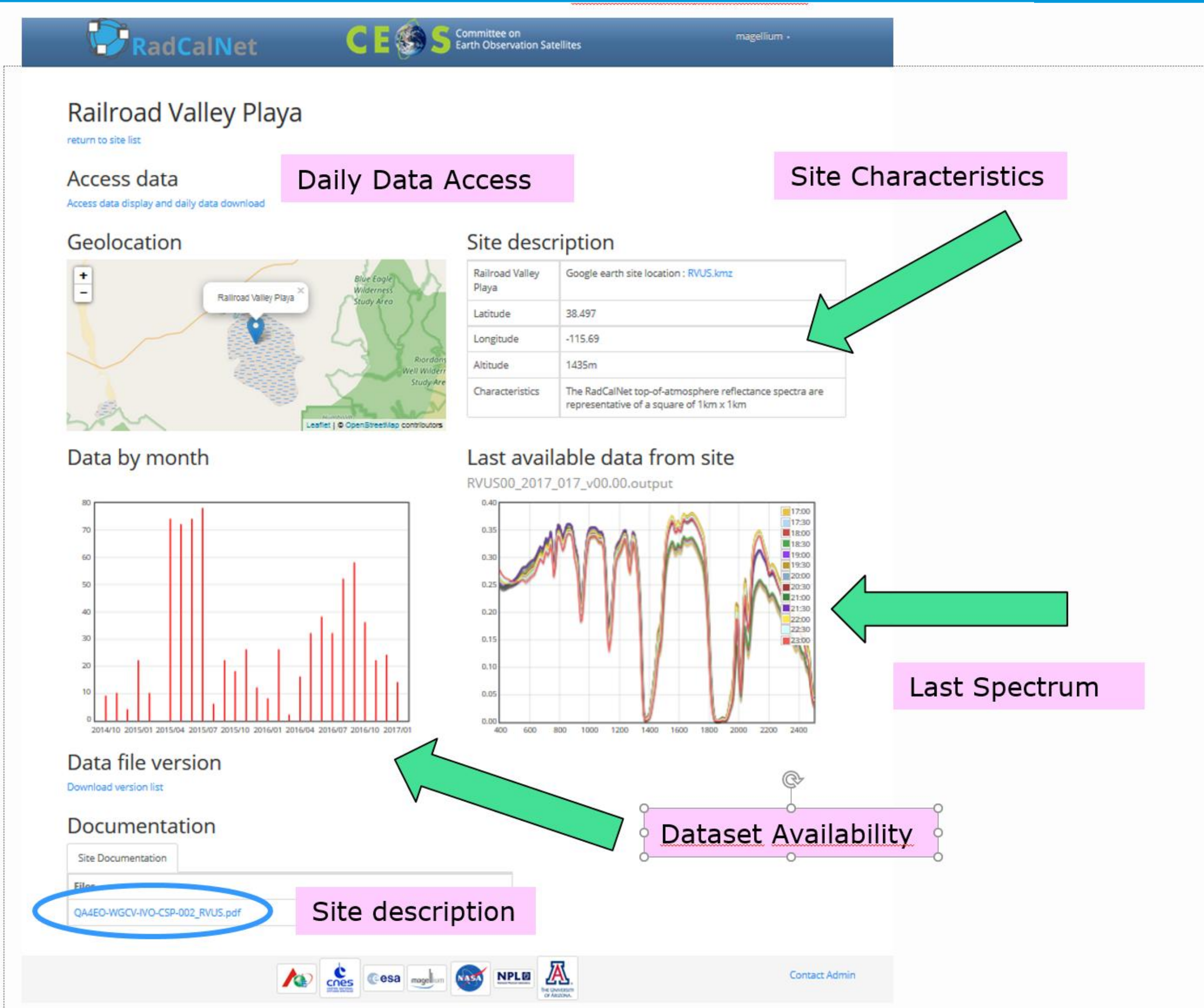
RadCalNet is a CEOS WGCV initiative to provide satellite operators with SI-traceable Top-of-Atmosphere (TOA) spectrally-resolved reflectances to aid in the post-launch radiometric calibration and validation of optical imaging sensors from a coordinated network of instrumented land-based test sites. The free and open access service provides a continuously updated archive of TOA reflectances and associated uncertainties at 10 nm intervals spanning the spectral range 380 nm to 2500 nm at 30 minute intervals* from each of its member sites together with some tools to aid in its use. Each individual site is well characterised and equipped with ground monitoring instrumentation to provide continuous measurements of both surface reflectance and local environmental/atmospheric conditions to facilitate the derivation of TOA reflectance values. Each member site takes responsibility for its own quality assurance but is subject to peer review and rigorous comparison to ensure site-to-site consistency and SI traceability. TOA reflectances provided on this portal are processed from the individual sites using a common method through a central processing system.

*Only data meeting RadCalNet defined minimum QA will be made available, and each data set is associated with its own specific uncertainty budget.

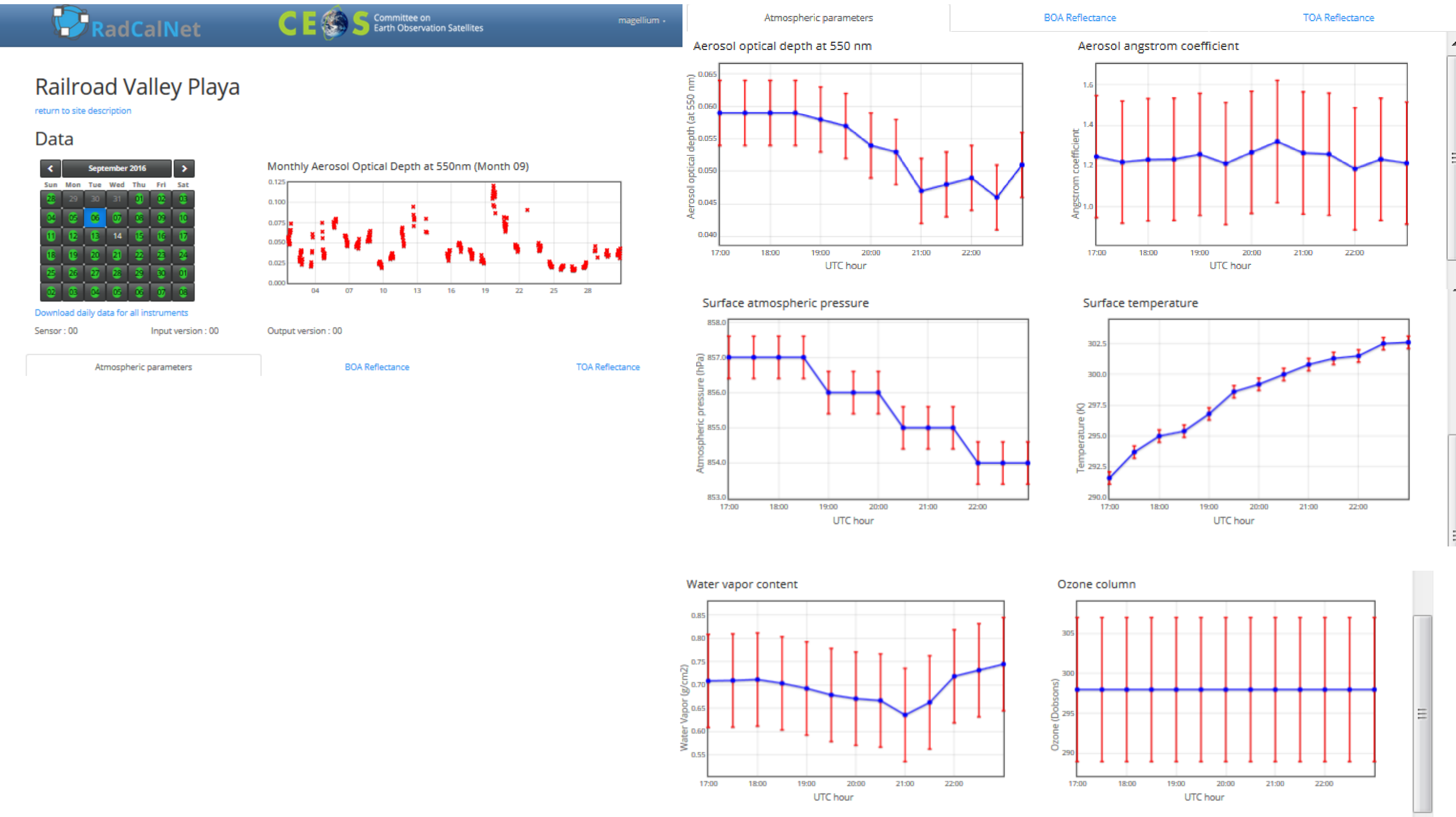
cnes esa magellium NASA

Contact Admin

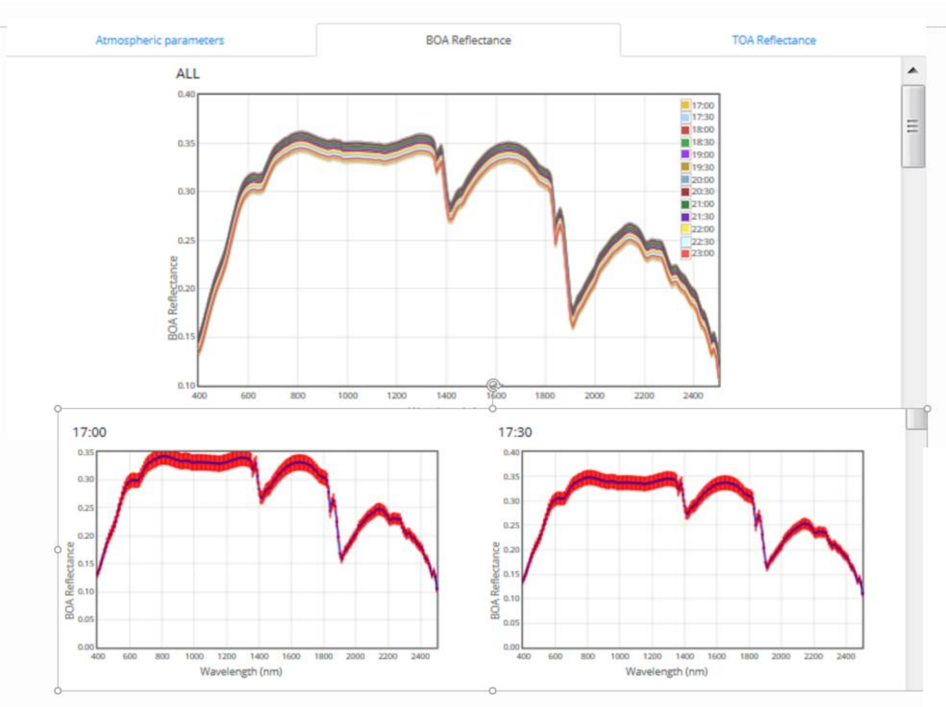
Portal Content



Site environmental characteristics

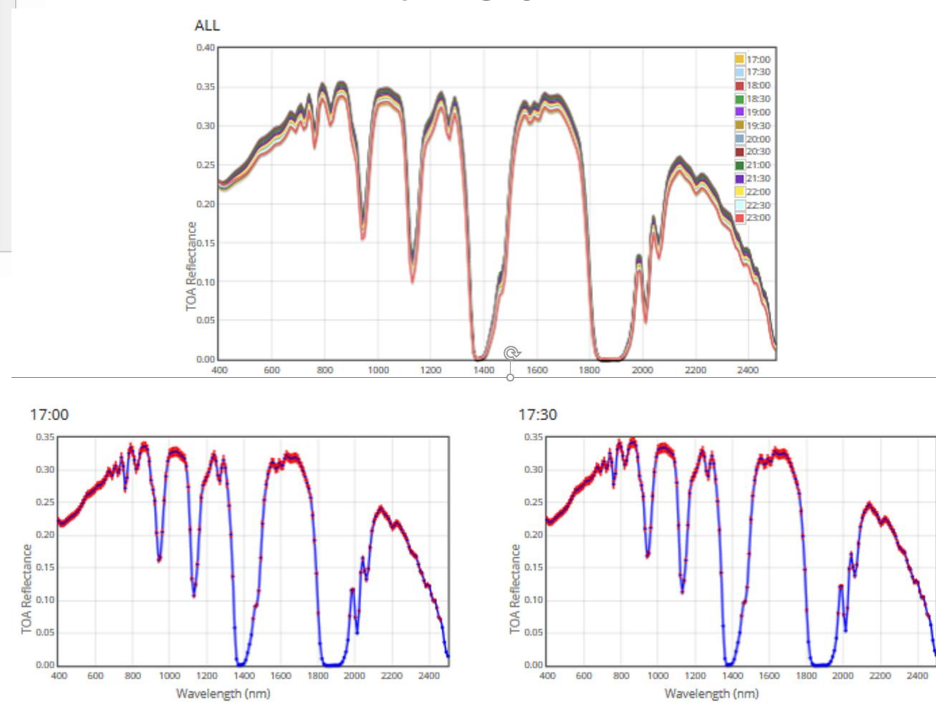


Site reflectance



BoA reflectance
With Uc

ToA reflectance
With Uc

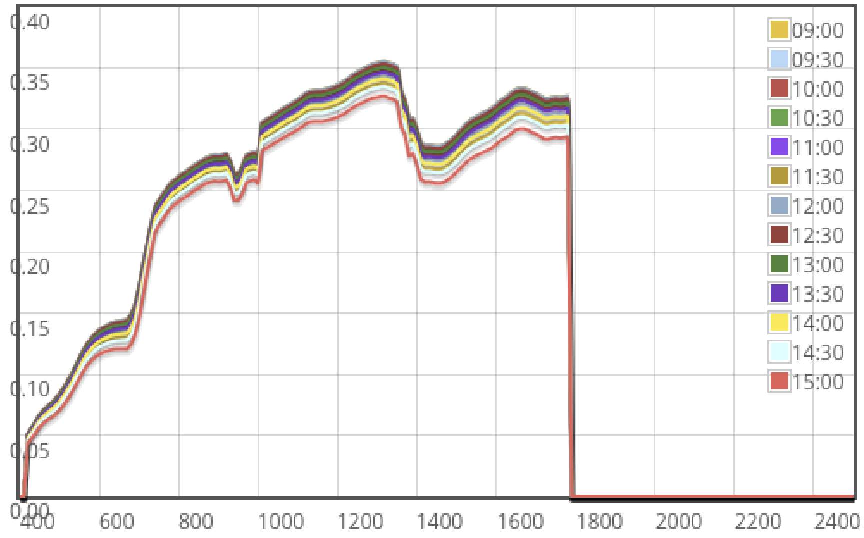


RadCalNet input data

RadCalNet inputs are:

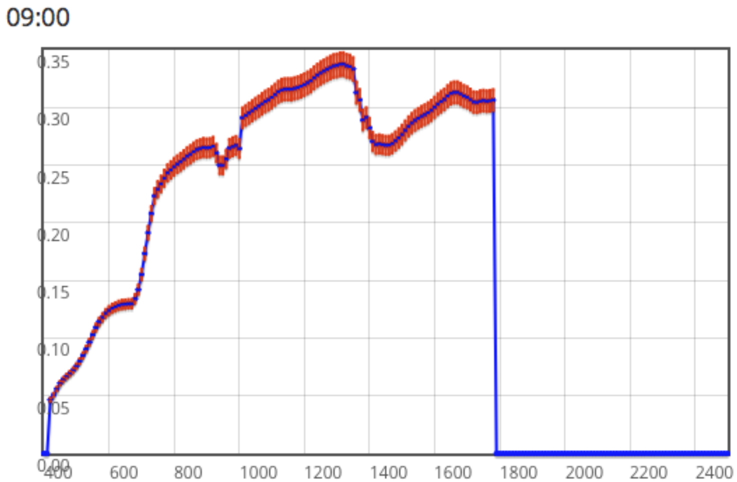
1. The surface reflectance:

- 30 minute intervals
- 9 am to 3 pm local standard time
- Nadir view only
- 10-nm intervals from 400 to 2500 nm (=goal) or at least between 400 nm and 1000 nm + uncertainty

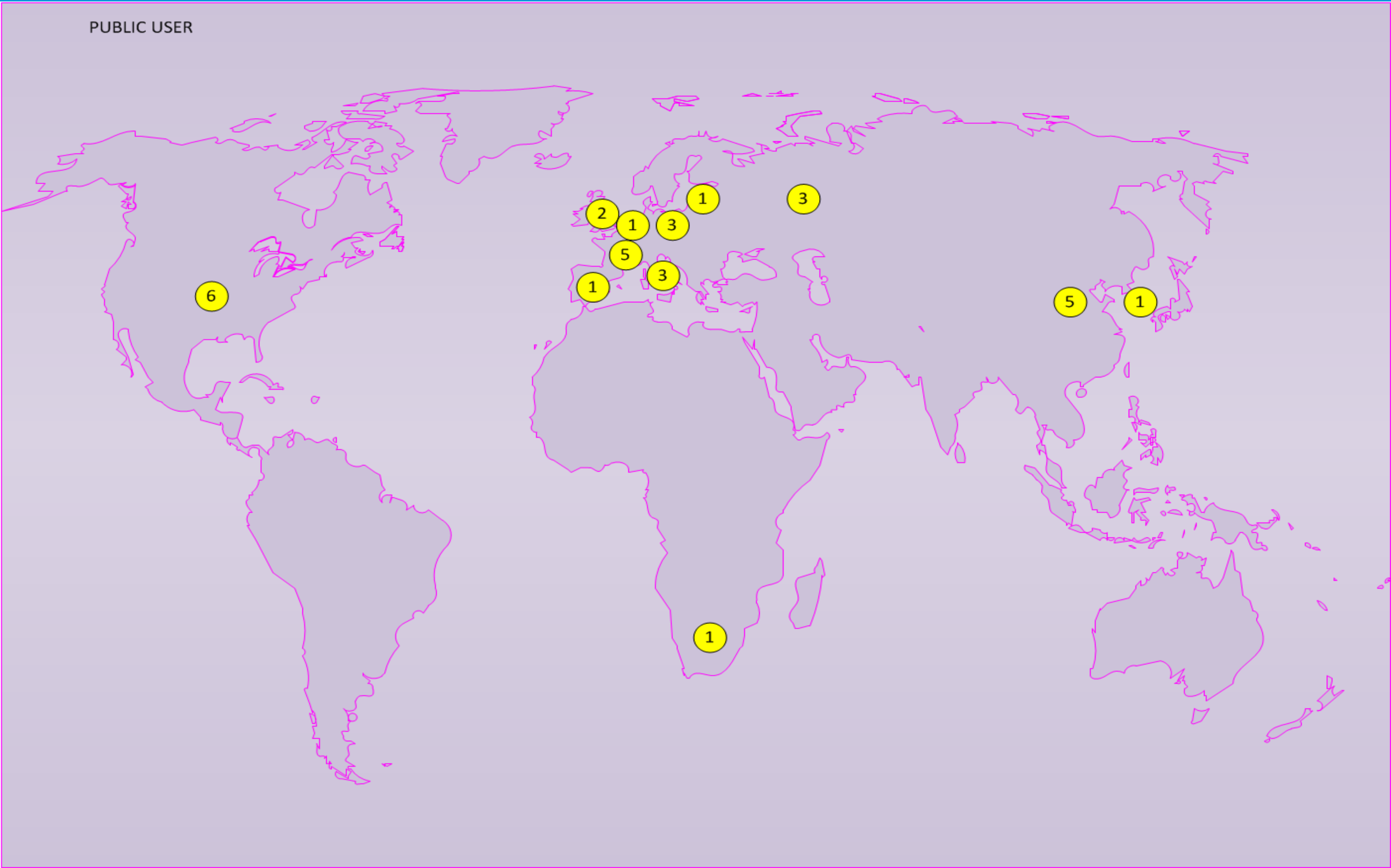


2. Concomitant atmosphere data for the TOA propagation:

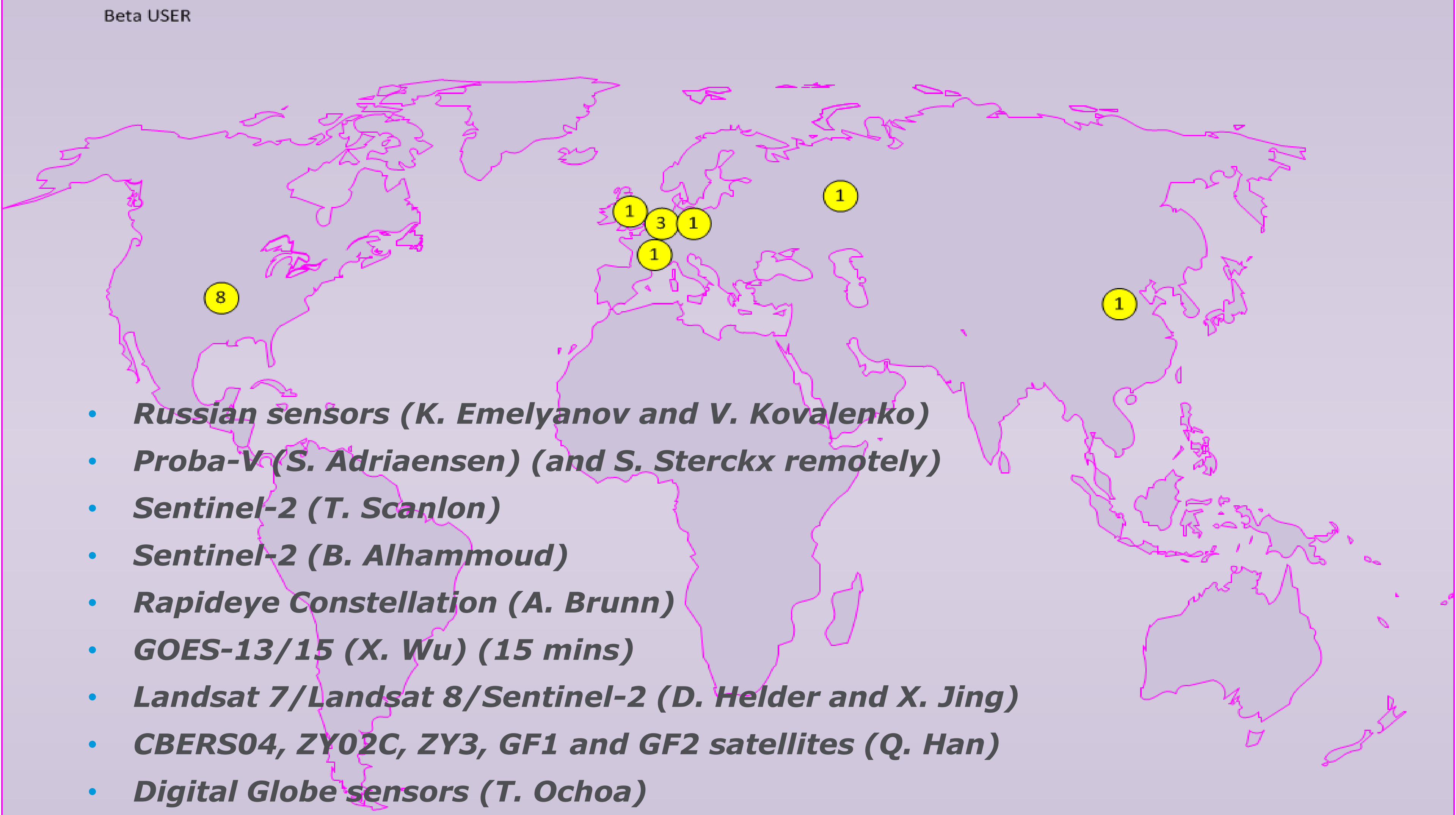
- Pressure + uncertainty
- Temperature + uncertainty
- Total column water vapour + uncertainty
- Total column ozone + uncertainty
- Aerosol optical thickness + uncertainty
- Aerosol Angstrom exponent + uncertainty
- Aerosol Type (following MODTRAN options)



Candidate public user



Current beta users



- *Russian sensors (K. Emelyanov and V. Kovalenko)*
- *Proba-V (S. Adriaensen) (and S. Sterckx remotely)*
- *Sentinel-2 (T. Scanlon)*
- *Sentinel-2 (B. Alhammoud)*
- *Rapideye Constellation (A. Brunn)*
- *GOES-13/15 (X. Wu) (15 mins)*
- *Landsat 7/Landsat 8/Sentinel-2 (D. Helder and X. Jing)*
- *CBERS04, ZY02C, ZY3, GF1 and GF2 satellites (Q. Han)*
- *Digital Globe sensors (T. Ochoa)*
- *Dove Constellation (N. Wilson)*

Beta Users Workshop Summary

RadCalNet

General comments:

- Comparison of sensor observations to RadCalNet TOA simulations at RVUS and LCFR point towards consistency across the two sites and with space sensors radiometry levels.
- Beta users generally expressed their interest in using RadCalNet data to support their sensor in-flight radiometric performance assessment
- Overall satisfied by the portal functionalities and documentation

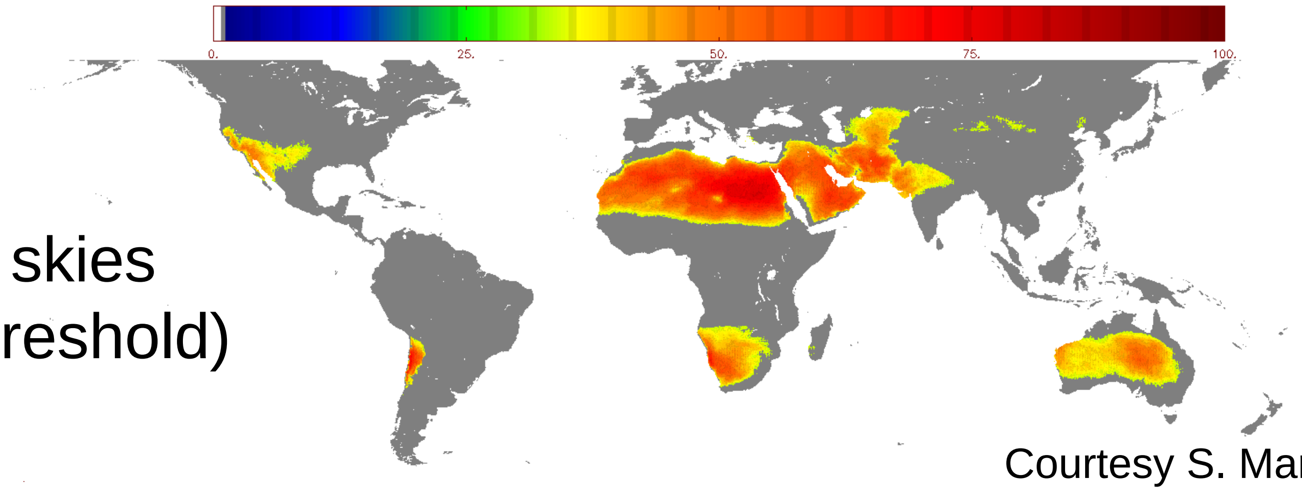
A fourth site: ESA/CNES

RadCalNet

Site identification

Based on a methodology developed through a CNES contract with MAGELLIUM (France)

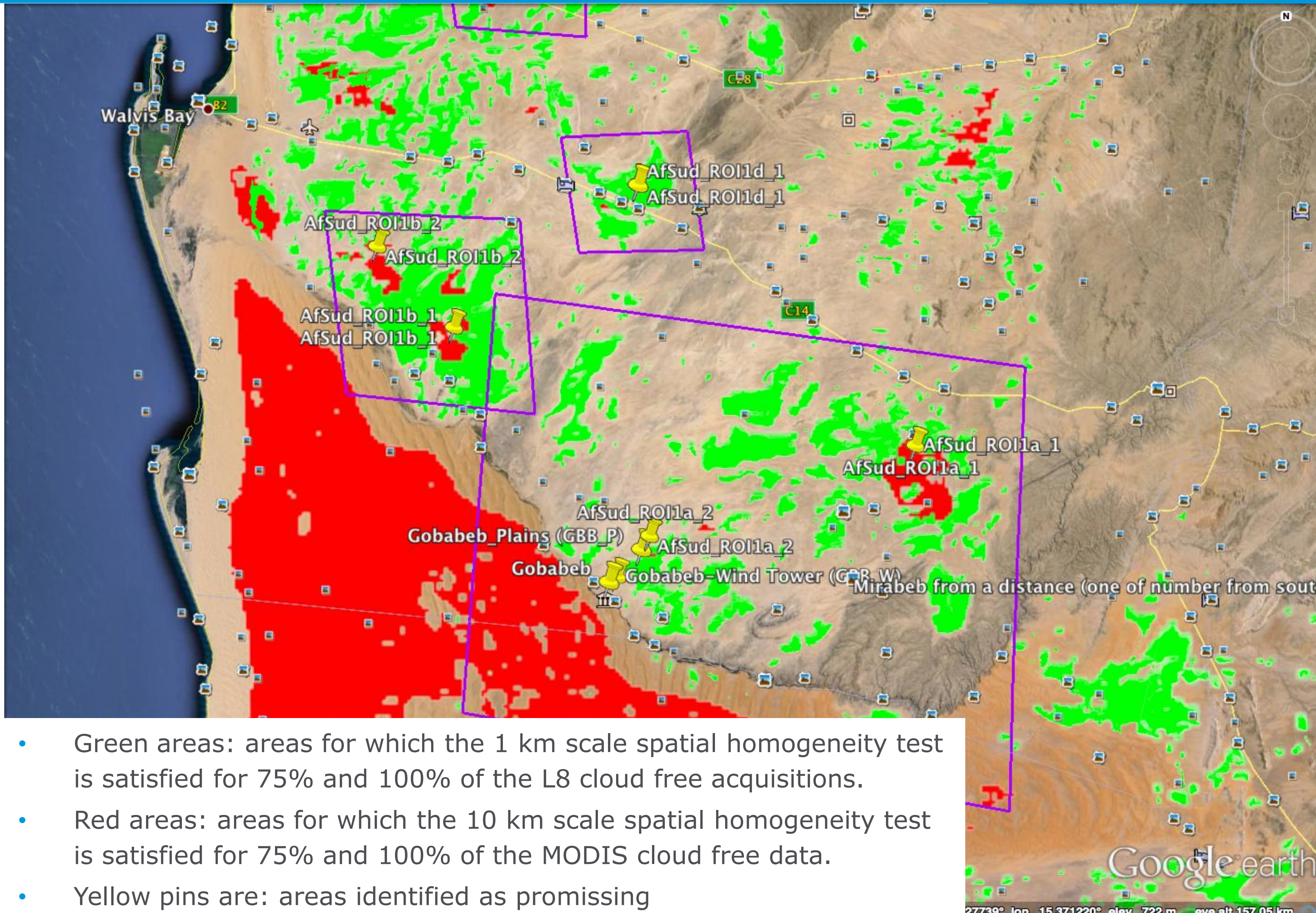
- At least 30 % of clear sky days (based on ECMWF data)
  - ✓ Terrain slope < 2 % within 10 km x 10 km (SRTM DEM)
  - ✓ Spatial homogeneity within 10 km x 10 km < ~ 3 % (based on MODIS
  - ✓ White sky albedo data in NIR)
  - ✓ Additionally, other parameters were collected: aerosol load, altitude
  - ✓ Regionally then, spatial homogeneity within 1 km x 1 km < ~ 3 % (based on 1 year of L8)



% clear skies
(30% threshold)

Courtesy S. Marcq (CNES)

The sites: a fourth site



- Green areas: areas for which the 1 km scale spatial homogeneity test is satisfied for 75% and 100% of the L8 cloud free acquisitions.
- Red areas: areas for which the 10 km scale spatial homogeneity test is satisfied for 75% and 100% of the MODIS cloud free data.
- Yellow pins are: areas identified as promising

Gobabeb

Gobabeb (Namibian desert)

- 51 % of clear days
- 85% of days with AOT < 0.2
- Altitude 470 m
- Cover type: sparse dry grass and gravel/sand

Gobabeb Site

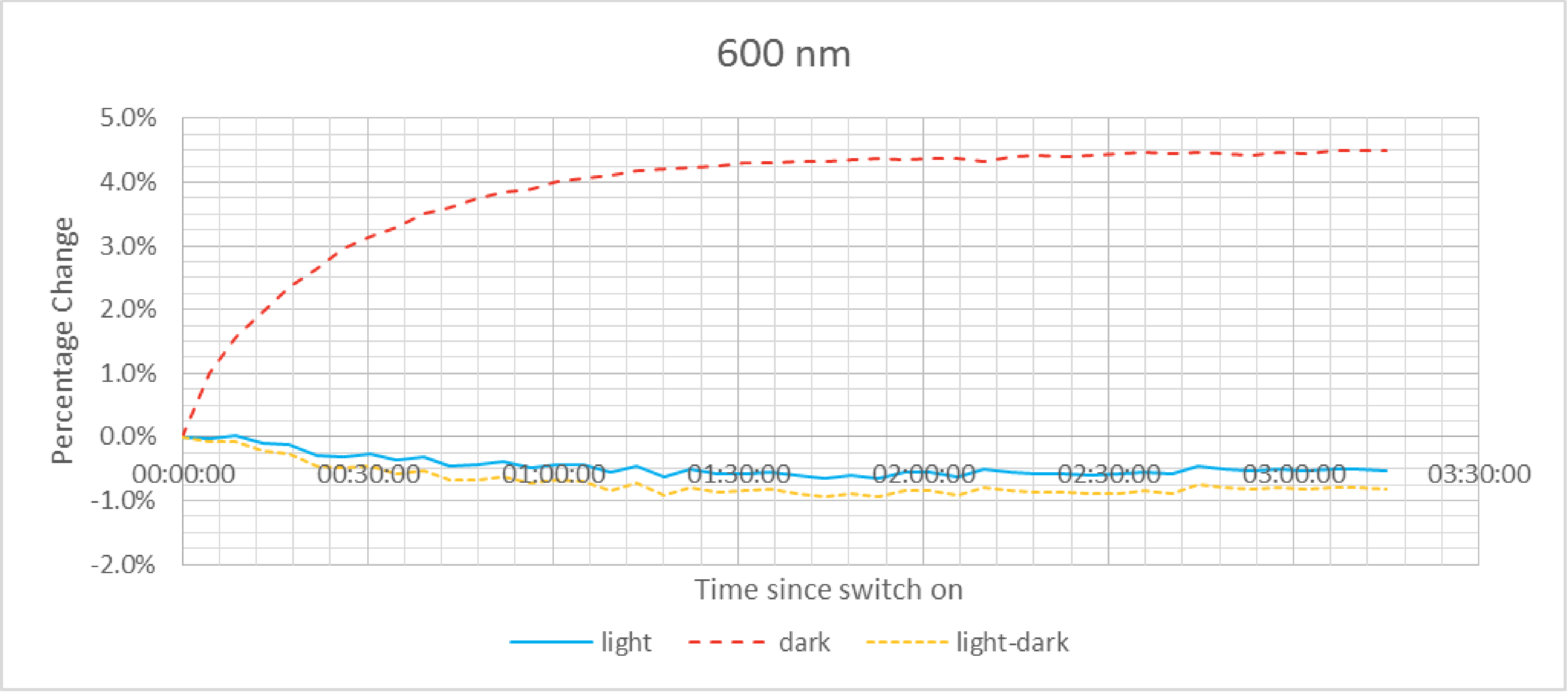
- near Gobabeb Research and Training Centre, Namib Desert
- area selection was based on a number of criteria e.g. spatial homogeneity, flatness, atmosphere, cloud levels, accessibility, GSM coverage

A Meygret, S Marcq, S Lacherade
CNES
C Greenwell, A Bialek, M Lamare
NPL

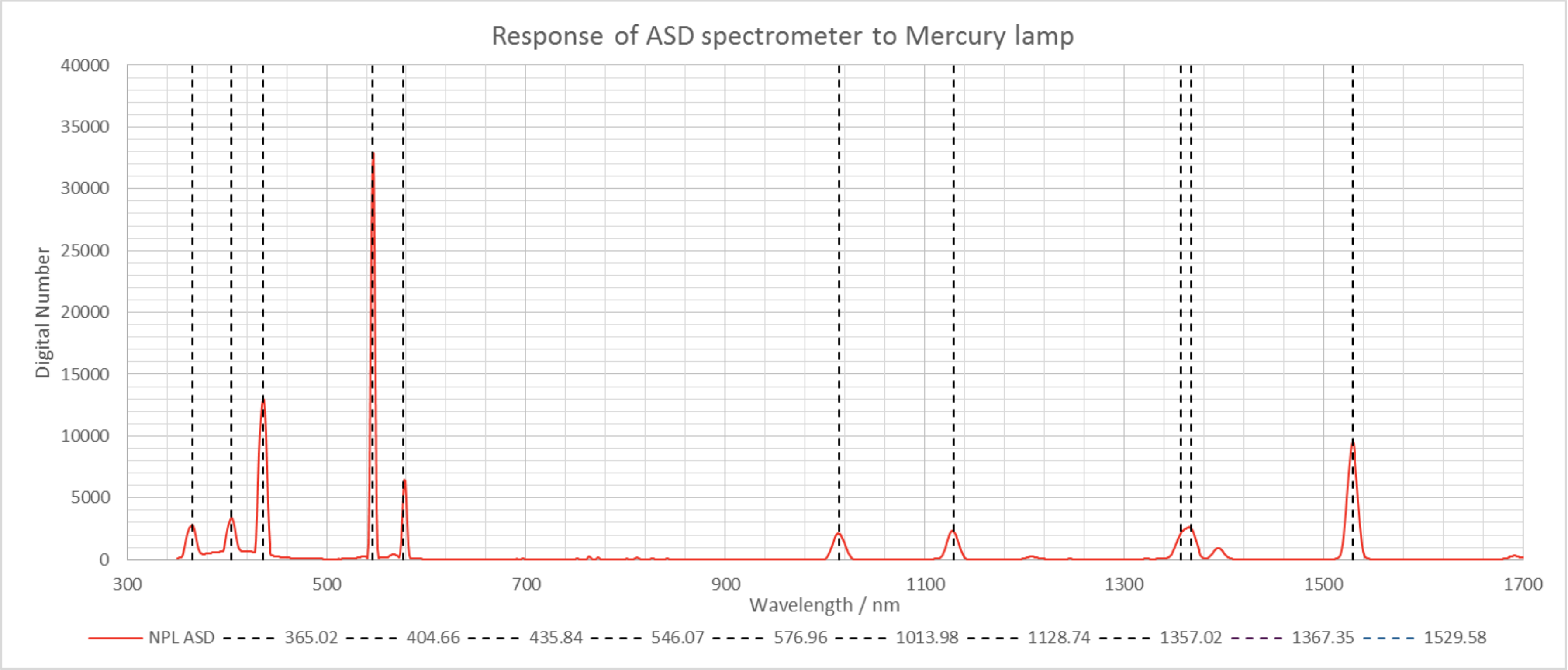
Preparation of Field Campaign Instruments – ASD Spectrometer

1. Stability
2. Wavelength check
3. Temperature sensitivity

Preparation of Field Campaign Instruments – ASD Spectrometer

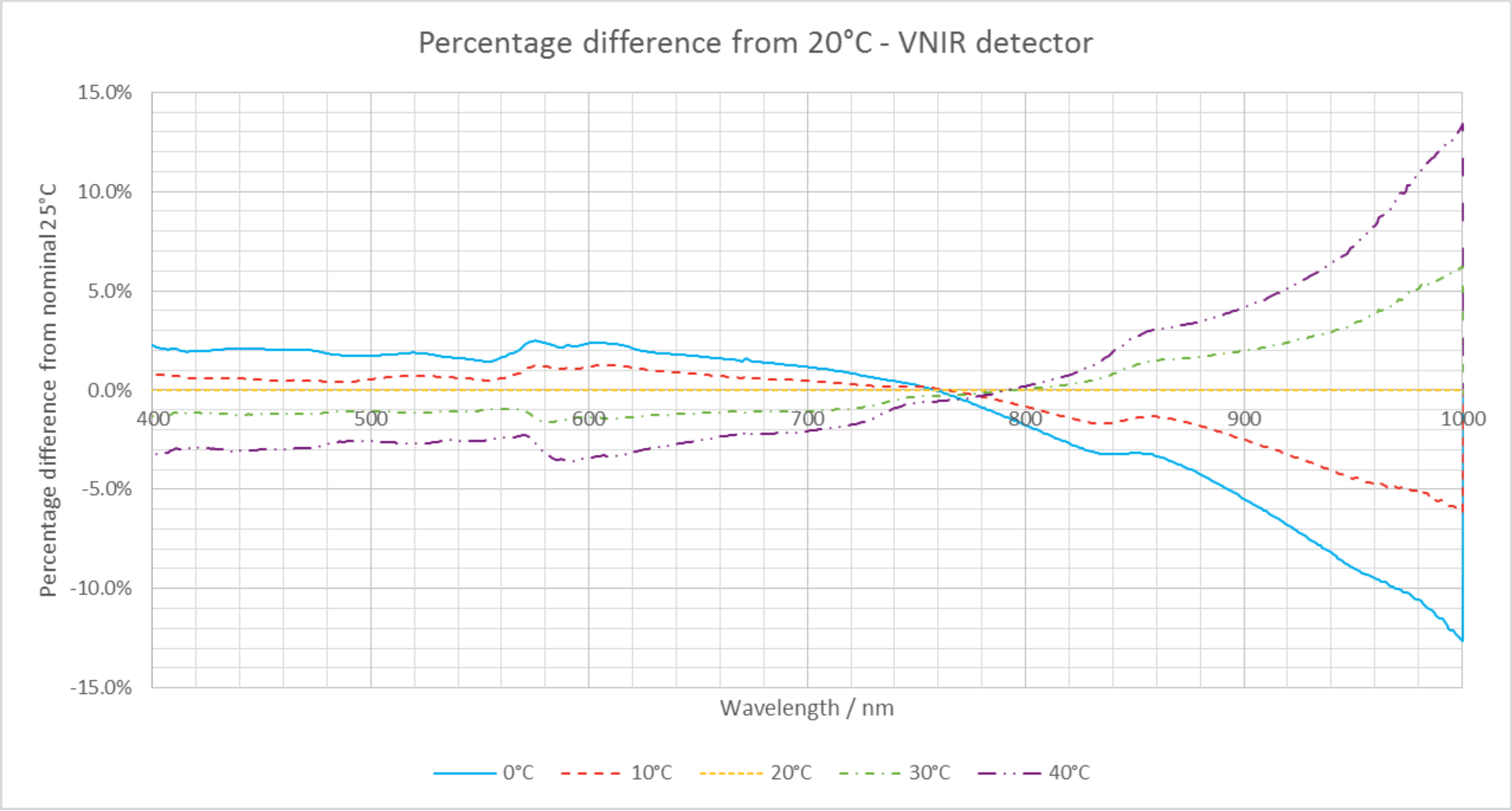


Preparation of Field Campaign Instruments – ASD Spectrometer



Preparation of Field Campaign Instruments – ASD Spectrometer

NPL National Physical Laboratory | Centre for Carbon Measurement



Characterization
ASD – Surface reflectance

$$\rho_t = \frac{L_t}{L_{ref}} \rho_{ref}$$

ASD measurements

Characterized by NPL in the lab…

…but the wind is getting it dirty faster than expected

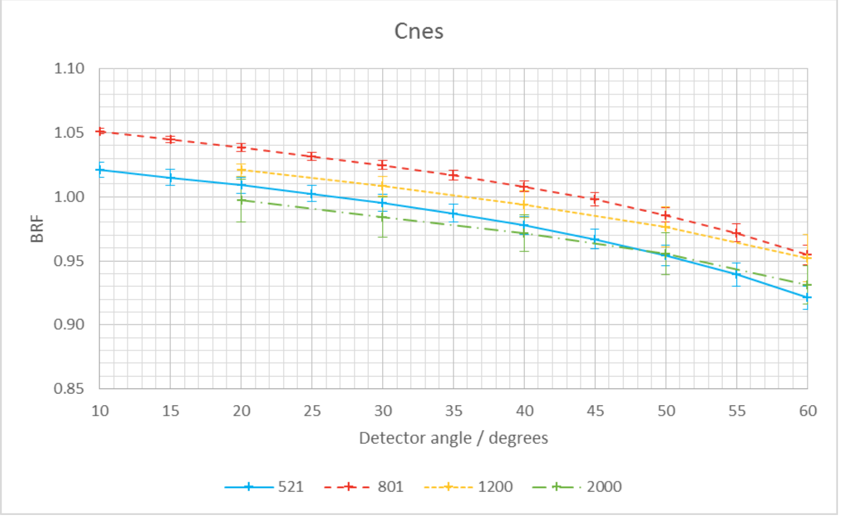
-> needs to be monitored

Spectralon panel reflectance monitoring

Spectralon reflectance is modeled as

$$\rho_{spec}(\theta_s, t) = f(t)\,\frac{\left(\rho_{direct}(\theta_s) \times E_{dir}(t) + \rho_{hemispheric} \times E_{dif}(t)\right)}{E_{dir}(t) + E_{dif}(t)}$$

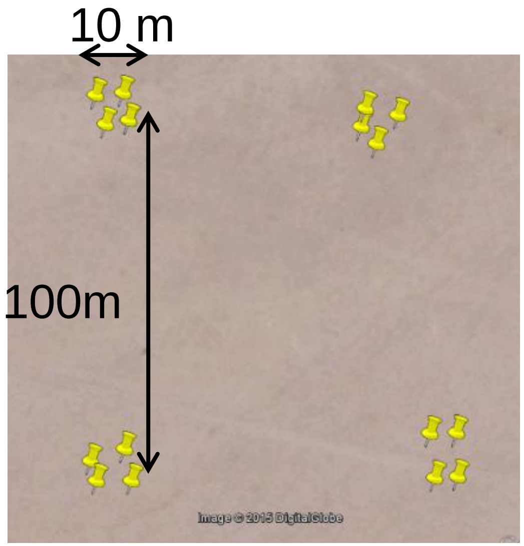
- Direct and diffuse irradiances (E_{dir}, E_{dif}) given by 6S for each measurement
- Directionnal and hemispheric reflectance (ρ_{direct}, $\rho_{diffuse}$) measured in the lab (NPL)
- Day-to-day variations (comparison to « super reference » + cleaning) -> dimming factor $f(t)$

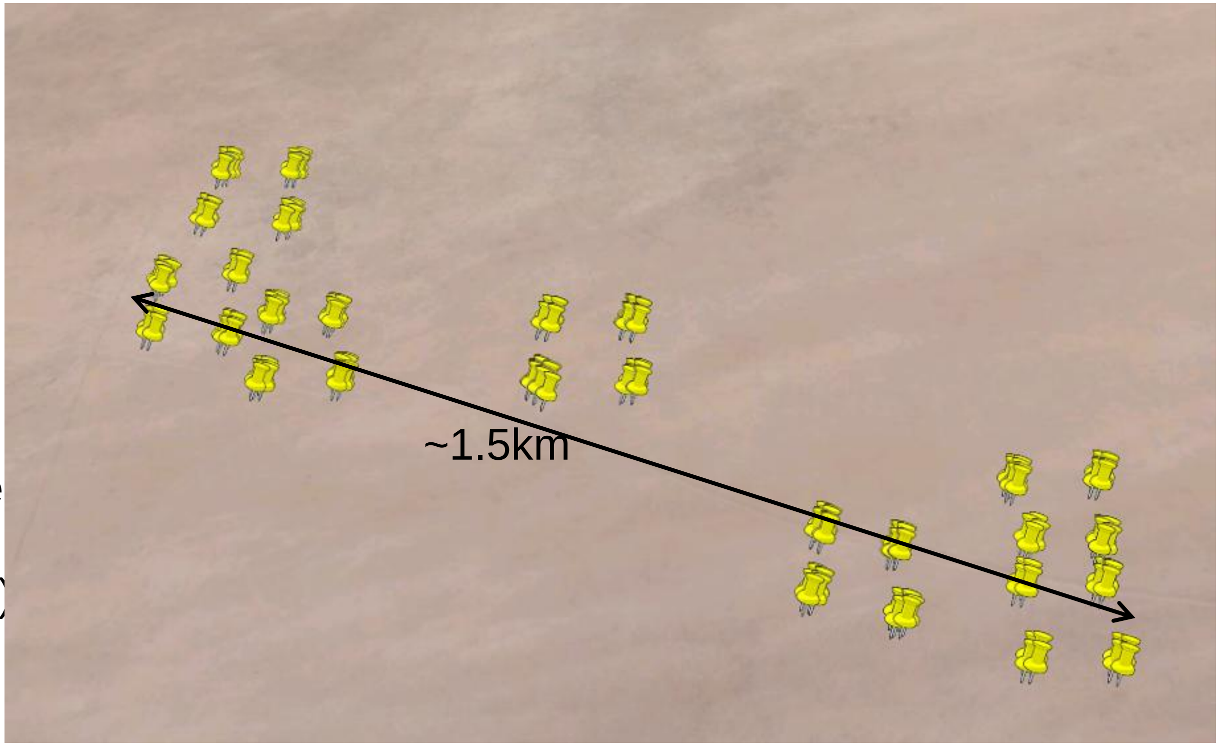


Spectralon BRDF measured in the lab (NPL) – *NPL*

Day-to-day monitoring using a super reference

Surface reflectance protocol





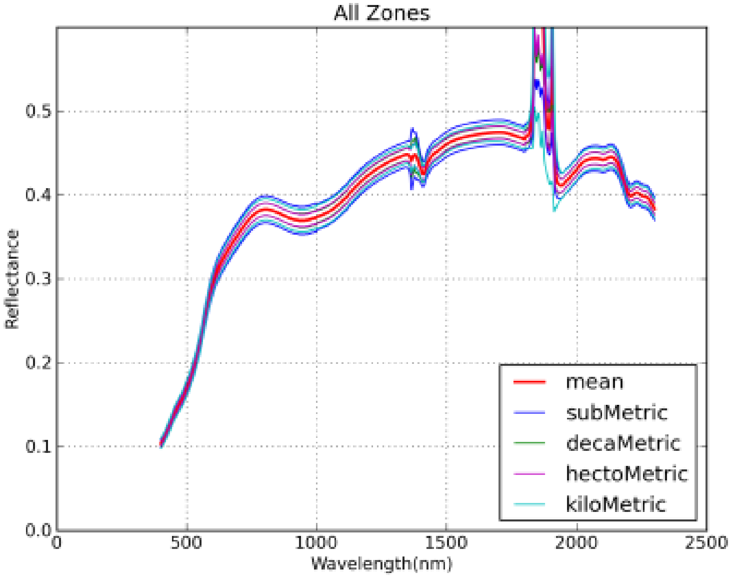
16 x 2 x 7 = 224 series = 2240 points

Characterize surface reflectance
different resolutions:

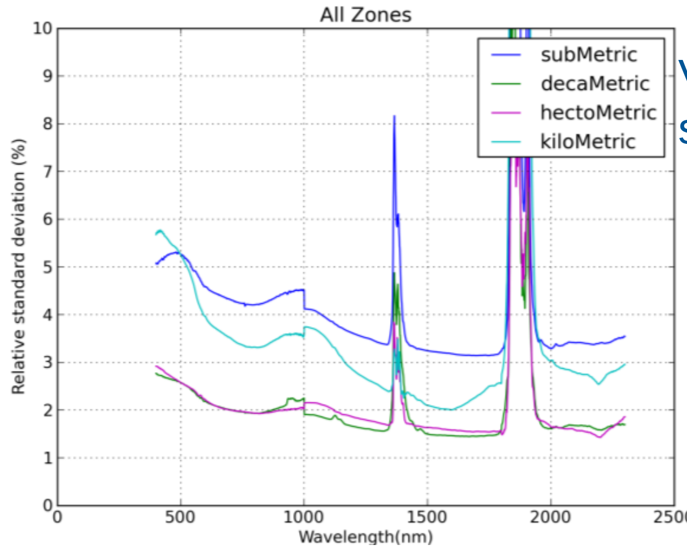
- < 1m (ASD + CIMEL footprint)
- 10m (CIMEL surface)
- 100m (potential sensors to calibrate)

+ 2 loops: account for BRDF (sun related)

Surface reflectance results

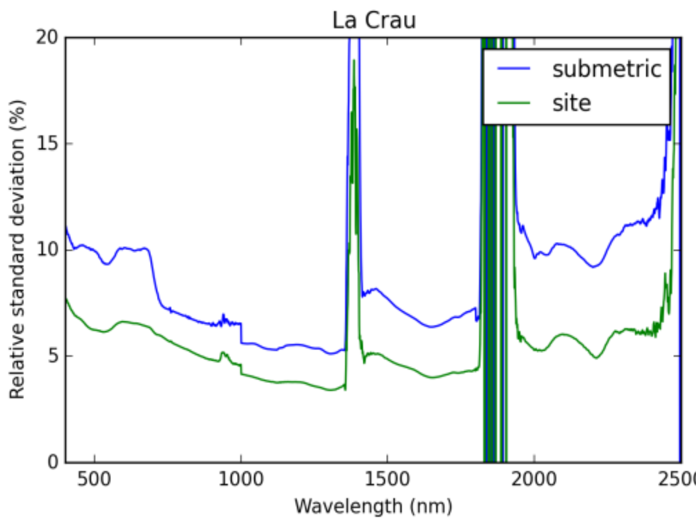


Absolute Reflectance value



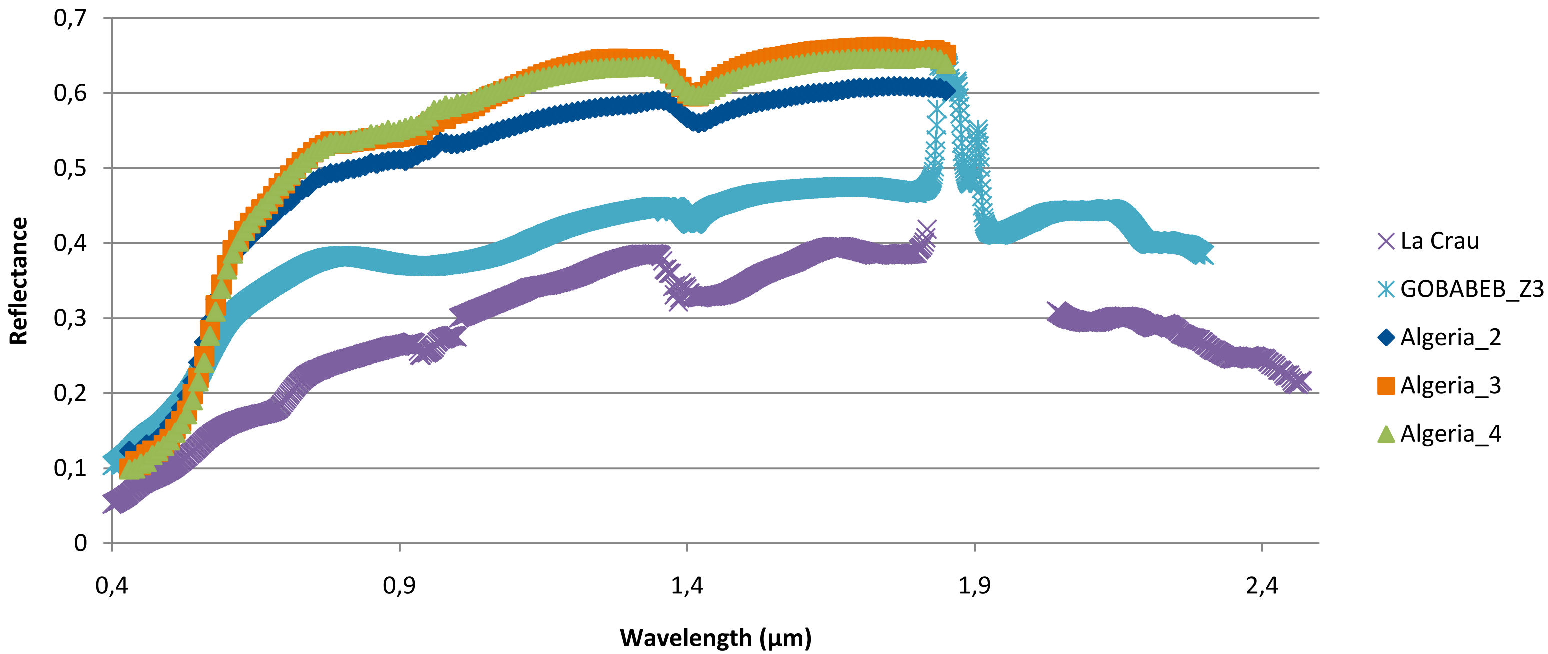
Variability at different scales

Note that kilometric variability is not representative (BRDF + poor correction of Spectralon Variation)



Gobabeb site is much more homogeneous than La Crau

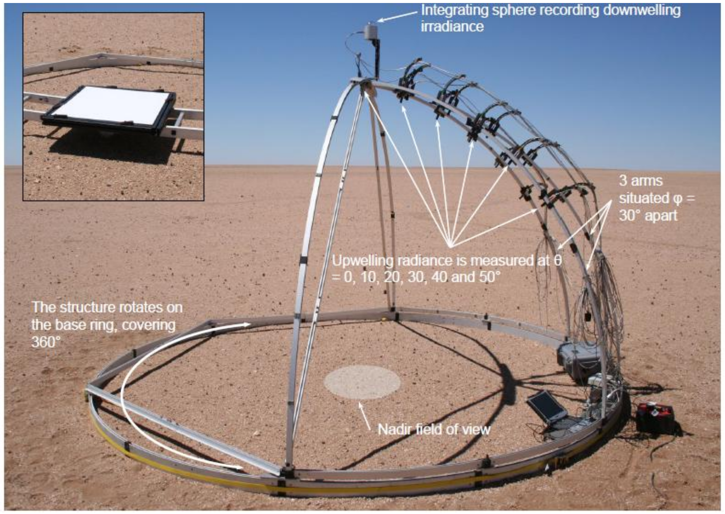
Surface reflectance results: Comparison with other sites

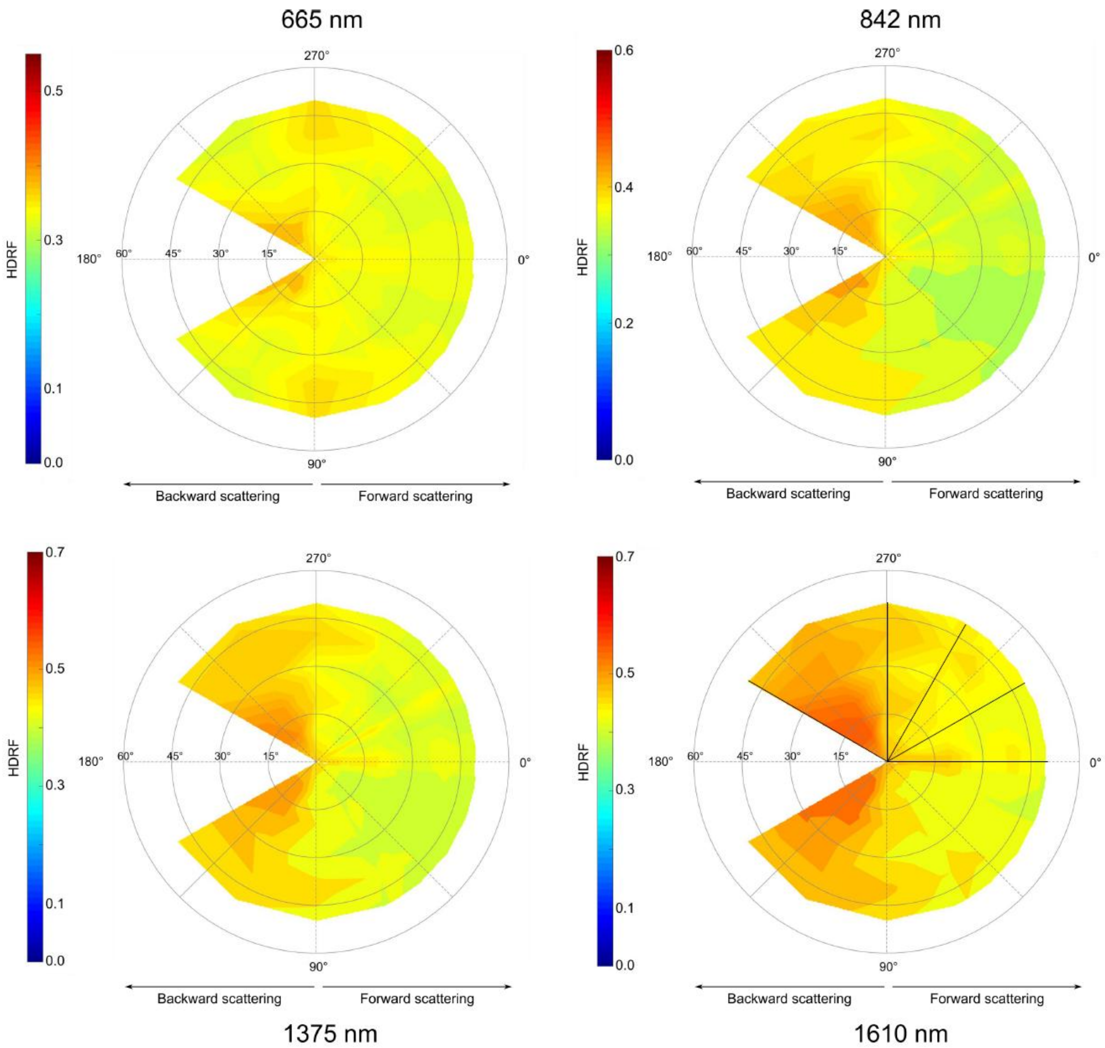


La Crau, Gobabeb reflectance acquired by CNES (in-situ)
Algeria spectra acquired by ONERA based on samples

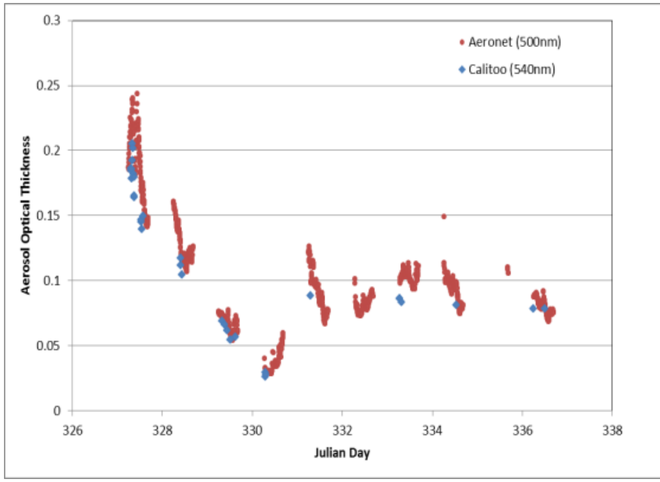
Characterization
GRASS – directional reflectance

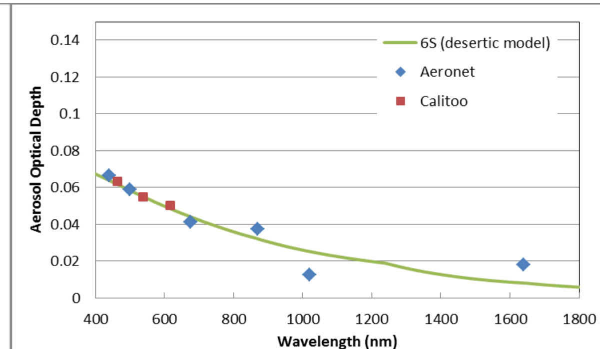
HDRF results from the Gonio RAdiometric Spectrometer System (GRASS – NPL)





Characterization
CIMEL – Aerosols

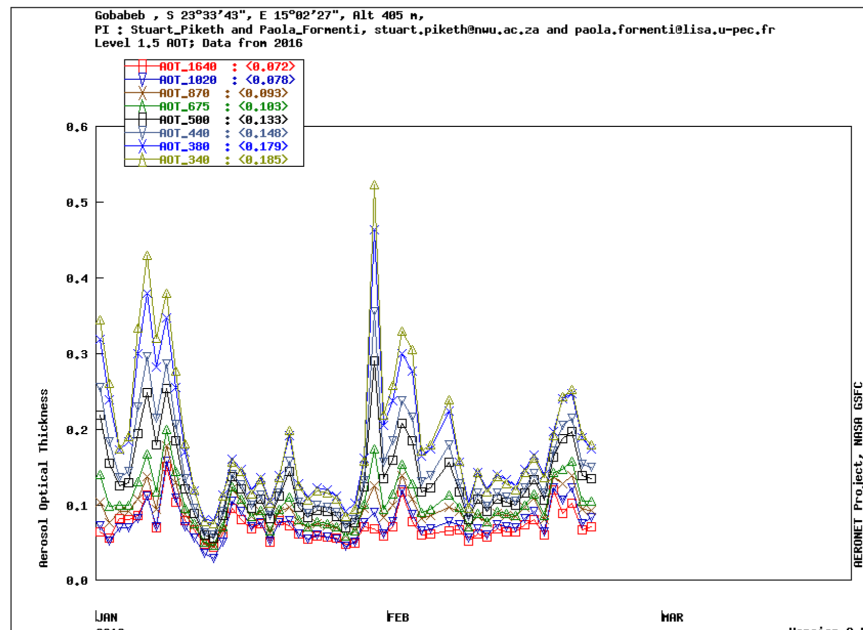




Use of the Gobabeb AERONET station (7km away) AOT

-> Consistency between station and place of measurements confirmed by Calitoo (handheld sunphotometer)

-> Relatively low AOT most of the time

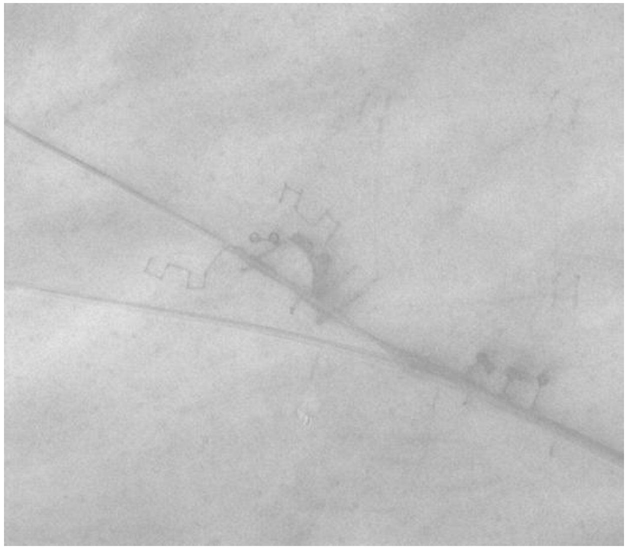


Impact of the characterization campaign

Monitoring using PLEIADES 70cm resolution imagery

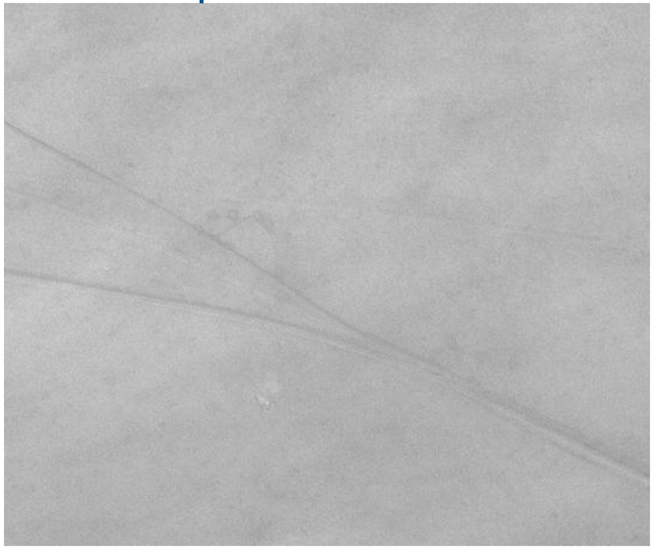
Before

Right After
Dec. 18th 2015



Footprints Impact: ~6%

Now
April 27th 2016

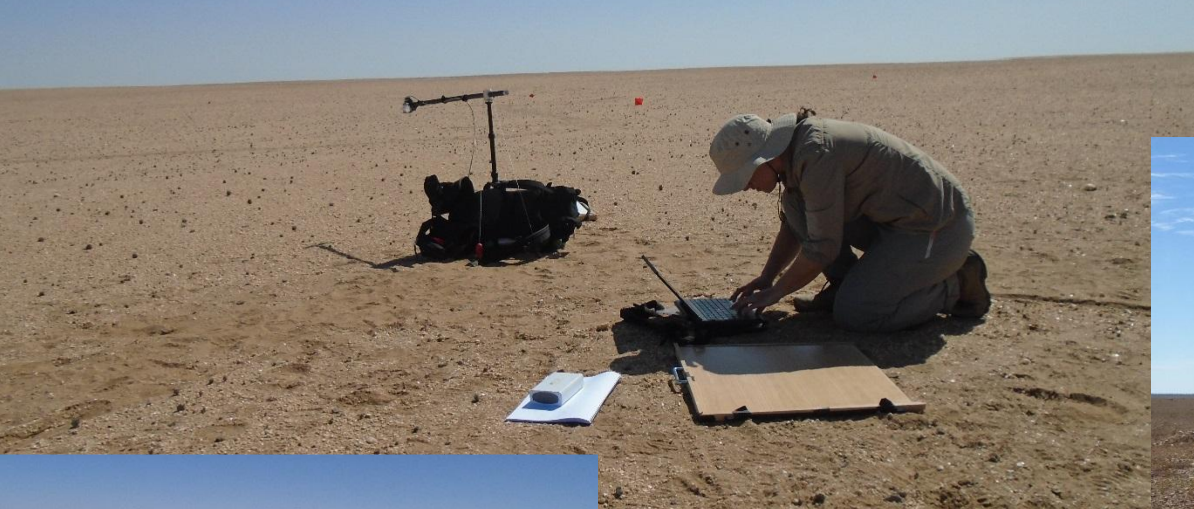


Footprints Impact: ~2%

Limited impact and fading away…

Site Characterisation: Gobabeb, Namibia

- Hyperspectral measurements
- BRF in some cases
- To determine overall site characteristics

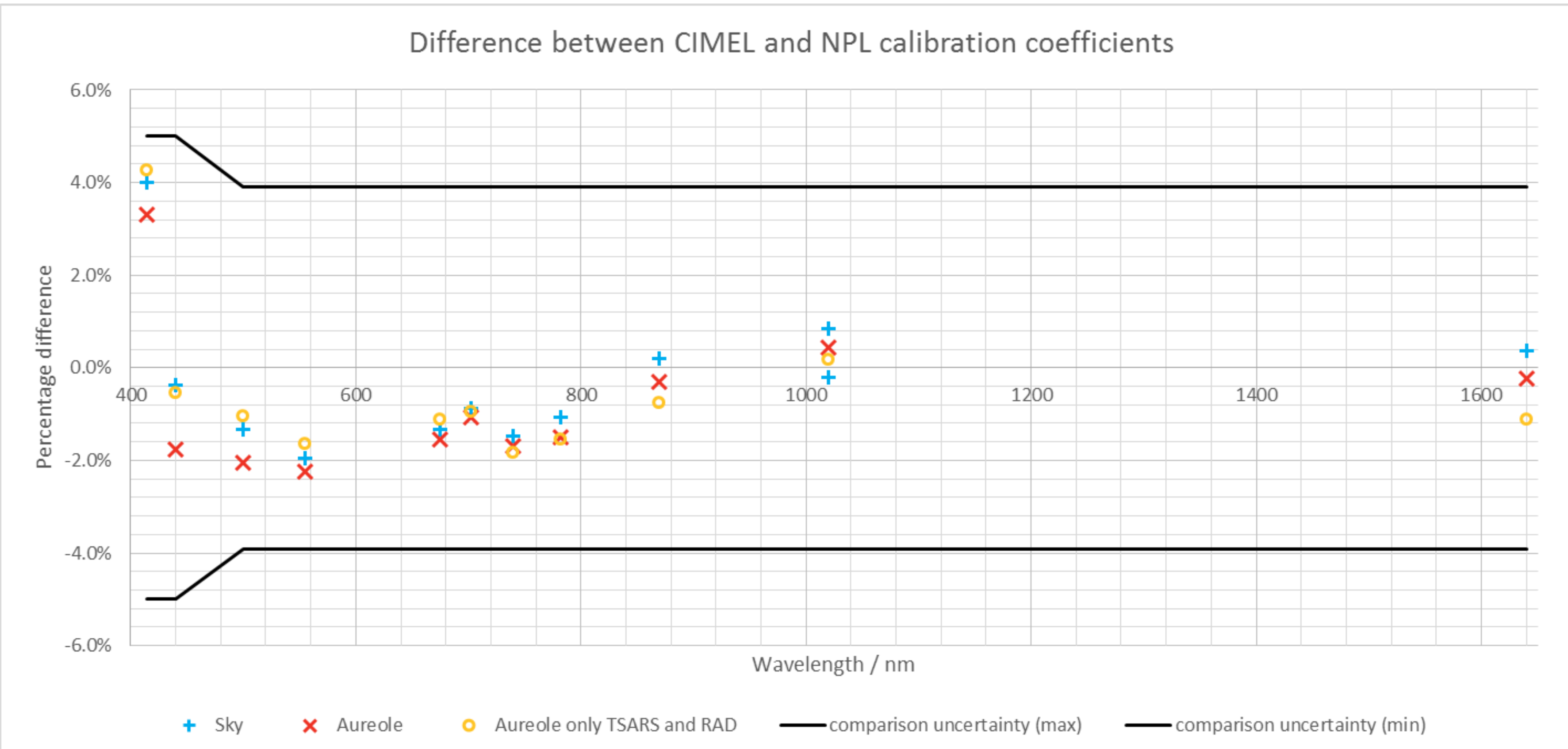


Preparation of Permanent Instruments – CIMEL Sun Photometer

1. Stability test
2. Spectral response
3. Temperature sensitivity
4. Absolute calibration

Preparation of Permanent Instruments – CIMEL Sun Photometer

4. Absolute calibration



Gobabeb (RadCalNet 4): NOW Operational

NPL National Physical Laboratory | Centre for Carbon Measurement

- Reflectance
- Cloud camera
- Meteorological

Delivering data: since end of July 2017

- Processing checks in progress

cnes

RadCalNet

- NEED TO ENSURE Consistency
- SI Traceability
- Validation/evidence of reliability of Uncertainty budget

Ground Comparisons at RadCalNet Sites Railroad Valley March 2017

T. Scanlon, C. Greenwell, N. Anderson, J. Czapla-Myers

(1) National Physical Laboratory, Teddington, UK
(2) University of Arizona, Tucson, USA

Railroad Valley

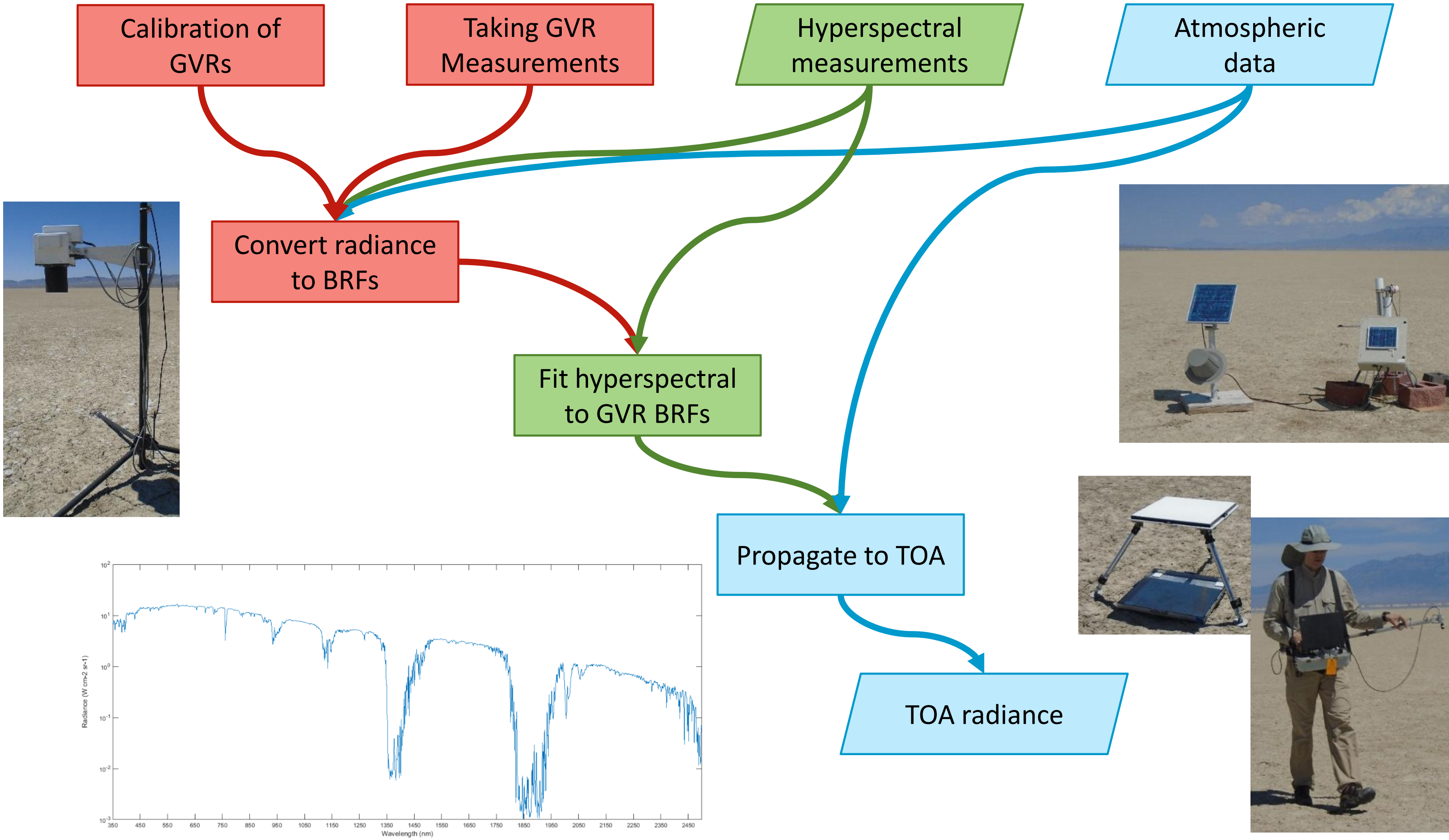
Site:

- Spatially homogenous – to 2 % reflectance
- Many clear days per year
- Large area - ~10 km square

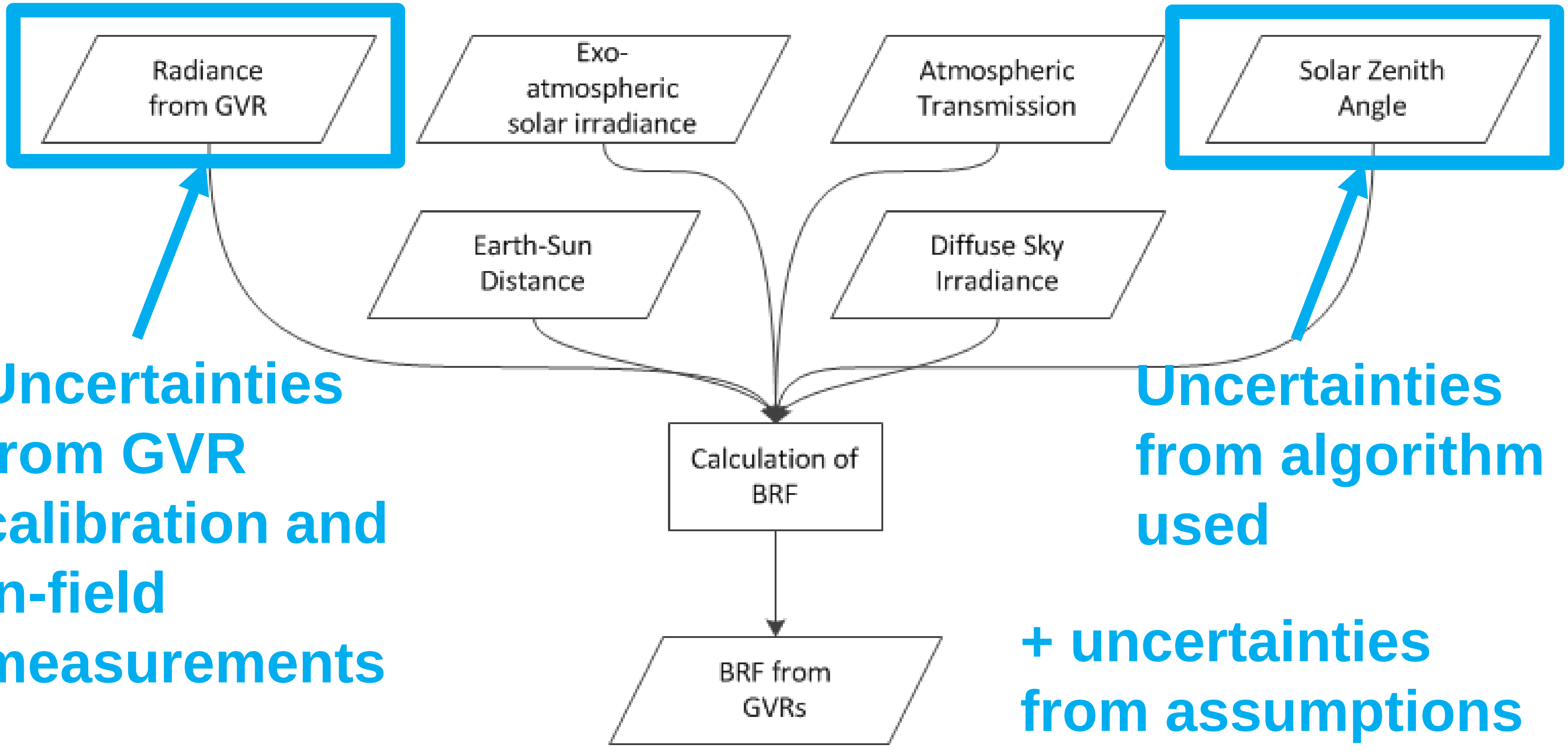
In-situ Measurements:

- Ground Viewing Radiometers (GVRs) obtain radiance of the ground every 2 minutes.
- Atmospheric monitoring (CIMEL and met station) used in RT code.

Railroad Valley RadCaTS: Processing Scheme



Railroad Valley RadCaTS: Identifying uncertainties



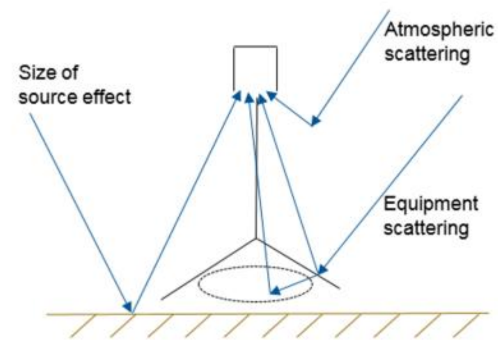
Uncertainties from GVR calibration and in-field measurements

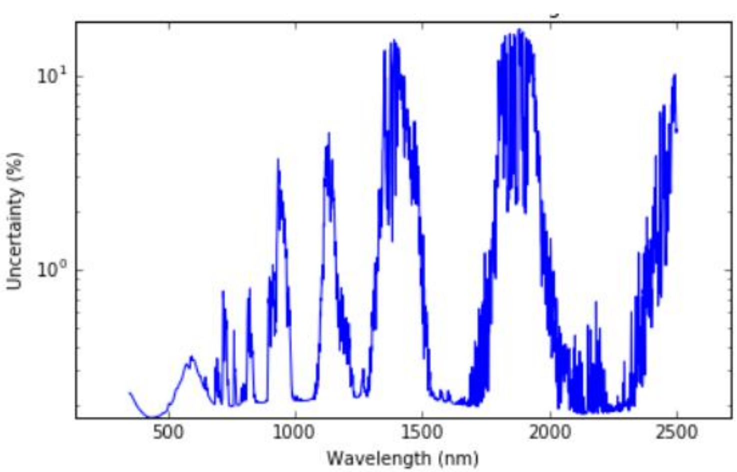
Uncertainties from algorithm used

+ uncertainties from assumptions

Railroad Valley RadCaTS: Uncertainty Analysis

GVR Channels (Central Wavelength (nm))[1] Uncertainty Contributor (%)	C1 400	C2 450	C3 500	C4 550	C5 650	C6 850	C7 1000	C8 1550
Calibration of the GVRs, $u_{C_{GVR}}$	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
In-field Measurements, $u_{V_{GVR}}$								
Noise on GVR Measurements	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Temporary Degradation	0.91	0.79	0.71	0.64	0.53	0.40	0.35	0.23
Stray Light	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Solar Irradiance Model, u_{E_0}	5.27	3.02	2.36	2.72	3.26	3.13	2.91	3.79
Solar Zenith Angle, u_θ	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79
Atmospheric Transmission, u_{τ_A}	1.39	1.23	1.11	1.01	0.86	0.65	0.55	0.36
Diffuse Sky Irradiance, $u_{E_{sky}}$	3.39	3.00	2.68	2.44	2.10	1.67	1.36	0.93
Spatial Representativeness	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Total, u_ρ	7.89	5.47	4.84	4.88	5.24	4.75	4.46	5.24





L8 Band (Central Wavelength (nm))	Uncertainty Contributor Surface	Atmosphere	Total (%) Total
B1 Coastal (440)	2.35	0.22	2.36
B2 Blue (480)	2.33	0.18	2.34
B3 Green (560)	2.38	0.27	2.40
B4 Red (655)	2.33	0.20	2.34
B5 NIR (865)	2.82	0.19	2.82
B6 SWIR 1 (1610)	2.37	0.21	2.38
B7 SWIR 2 (2200)	3.54	0.23	3.54
B8 Pan (590)	2.48	0.27	2.49
B9 Cirrus (1370)	0.73	6.84	6.88

Comparisons: Evidence of Uc

- Compare with someone else
  - Compare results, uncertainties and uncertainty budgets
  - Helps quantify ‘known unknowns’
  - Helps identify ‘unknown unknowns’

$$E_N = \frac{|E_1 - E_2|}{\sqrt{{U_1}^2 + {U_2}^2}}$$

E is measurement result
U is associated expanded uncertainty

$E_N < 1.0$ indicates results agree with each other within the limits expected based on their associated uncertainties

Compare RadCalNet sites: at TOA via satellite & ideally at BoA via a travelling reference standard

Equivalence equation becomes…due to process of comparison

$$E_N = \frac{|E_1 - E_2|}{\sqrt{{U_1}^2 + {U_2}^2}}$$

$$E_N = \frac{|E_1 - E_2|}{\sqrt{{U_1}^2 + {U_2}^2 \boxed{+{U_c}^2}}}$$

Comparison Uncertainty

What should a field comparison instrument do?

- Intention is to send transfer radiometers between sites
- They must therefore be robust and reliable: able to hold calibration when shipped or carried
- They must be comparable with installed equipment, e.g. matched channels

Comparison Instruments

A transfer radiometer must ***perform better than a given system under test***.

Potential metrics defined by University of Arizona and NASA for filter radiometers:

SNR > 1000	Linearity error < 0.25 %	Spatial stray light < 1 %
Long-term (months) repeatability variation < 2 %	Dark current variation < 0.001 x expected signal	Spectral stray light < 0.5 %

RadCalNet Comparison Instruments

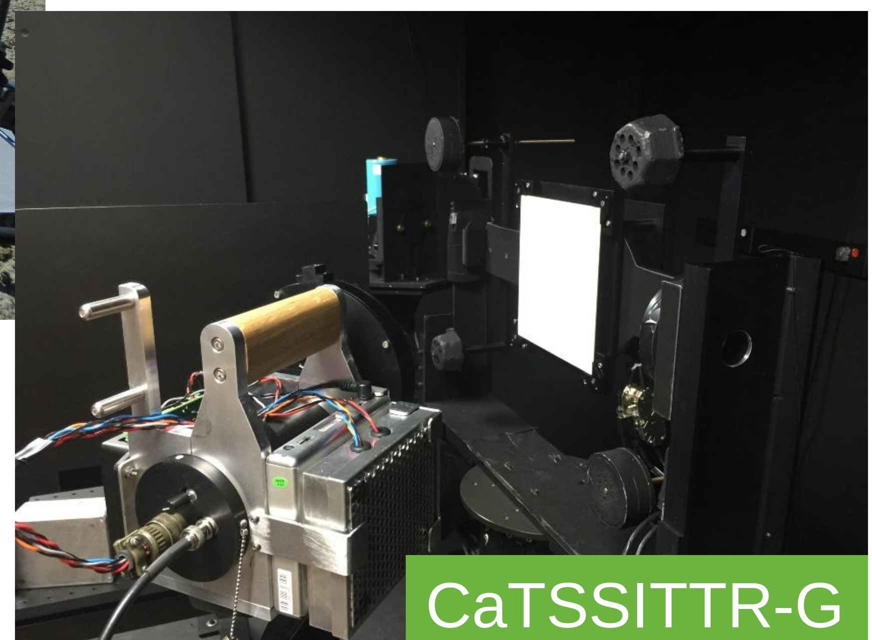
National Physical Laboratory

ARIZONA

MuSTR

- Produced for NASA GSFC by UoA
- Filter radiometer
- 7 VIS channels
- Operated with ipod

- Produced for NPL by CMI
- Spectrometer
- VIS and SWIR
- Operated with tablet

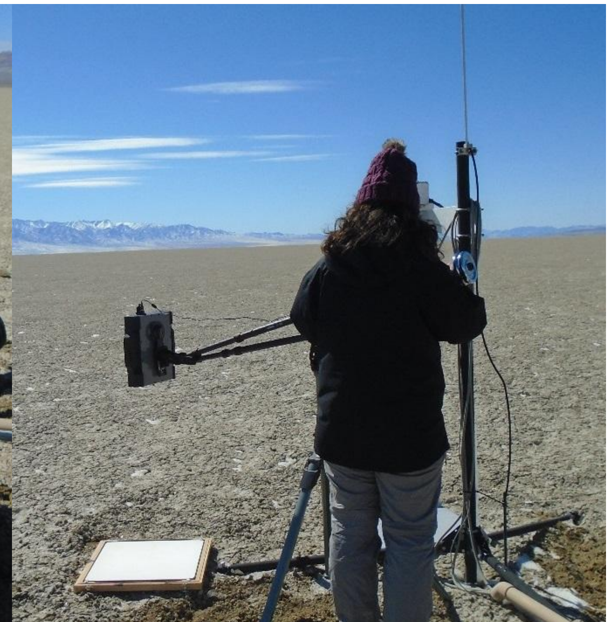


CaTSSITTR-G

Field Comparisons
5^{th} / 6^{th} / 7^{th} March 2017

5^{th}: Dust
6^{th}: Ice
7^{th}: Clouds
☹

RRV – March 2017 – Day 1
ASD vs. MuSTR and GVRs



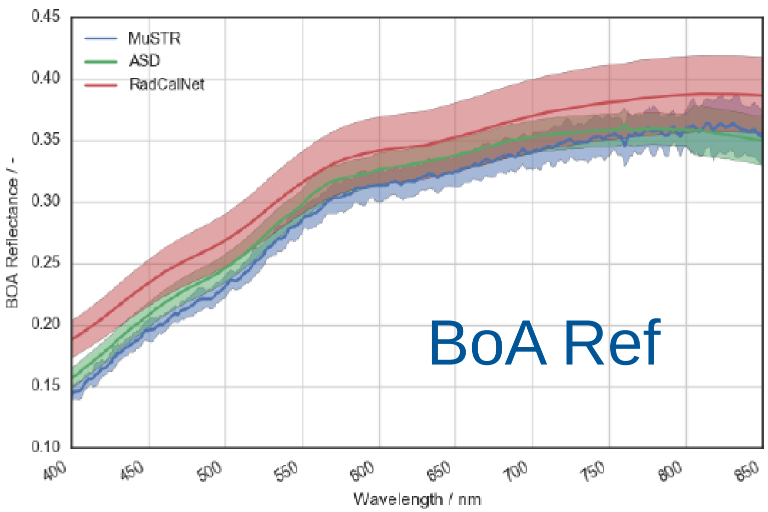
Method:

Near coincident measurements.

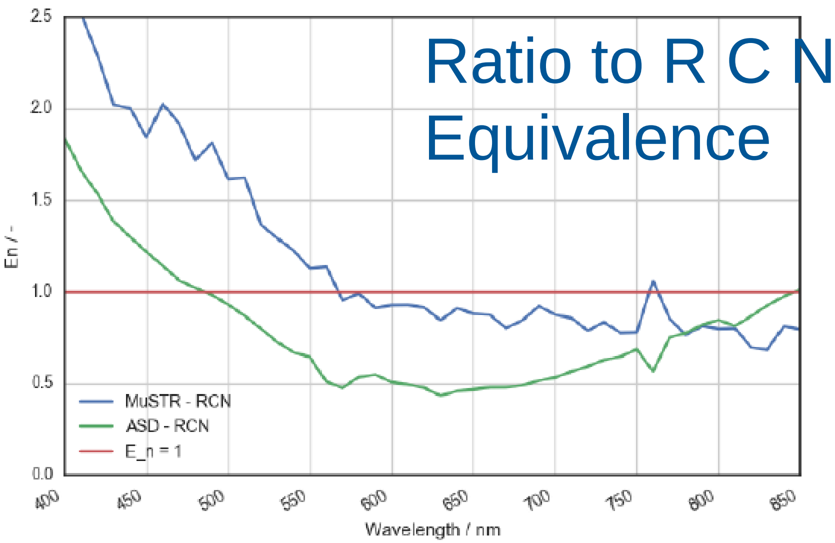
All relative to NPL ASD measurements.

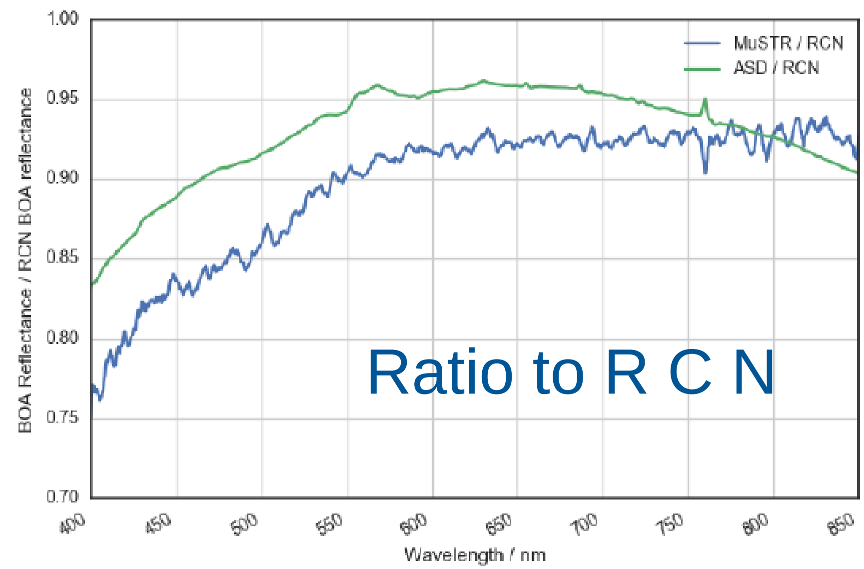
RRV Site comparison

National Physical Laboratory



Uncertainty Contributor	Instrument	400 nm	500 nm	600 nm	700 nm	800 nm
Absolute Calibration						
Reference Panel	MuSTR	2.18 %	1.94 %	1.76 %	1.78 %	1.76 %
	ASD	2.18 %	1.94 %	1.76 %	1.78 %	1.76 %
Field Uncertainties						
Reproducibility	MuSTR	0.76 %	2.87 %	1.33 %	2.60 %	2.05 %
	ASD	1.20 %	0.31 %	1.05 %	1.78 %	2.30 %
Repeatability - Ground	MuSTR	3.32 %	3.04 %	3.68 %	3.58 %	3.56 %
	ASD	4.58 %	4.02 %	3.55 %	3.00 %	2.68 %
Repeatability - Panel	MuSTR	0.86 %	0.28 %	0.72 %	0.63 %	1.11 %
	ASD	1.28 %	1.14 %	0.94 %	0.93 %	0.99 %
Combined Uncertainties	MuSTR	4.09 %	3.98 %	4.21 %	4.31 %	4.29 %
	ASD	5.26 %	4.61 %	4.12 %	3.75 %	3.60 %
	RadCalNet	7.98 %	7.97 %	8.03 %	8.00 %	8.01 %





Tucson – March 2017
ASD vs. MuSTR and CaTSSITTR

Comparison Uncertainty Measurement Protocol

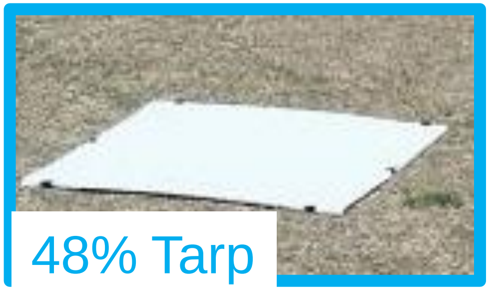
$u_{spatial}$ Differences between ground measured

$u_{temporal}$ Temporal difference between ground measured

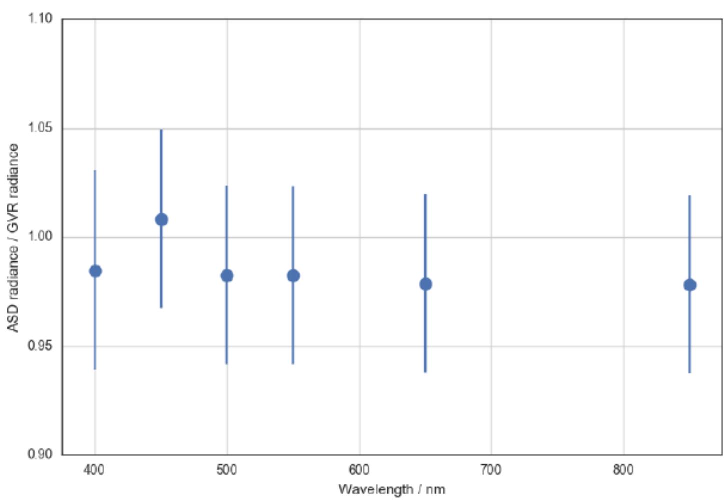
u_{view} Differences in viewing angles

Tucson Comparisons
9th March 2017
ASD vs. MuSTR and CaTSSITTR using Tarp

Reflectance

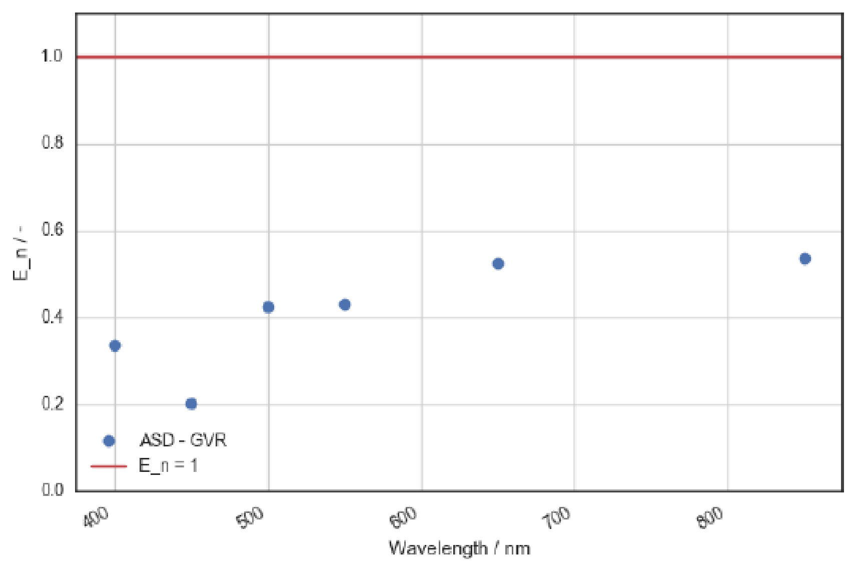


CW (nm)	400	450	500	550	650	850	1000
ASD	0.256	0.474	0.468	0.469	0.475	0.483	0.488
MUSTR	0.266	0.484	0.485	0.496	0.509	0.563	0.578
CaTSSITTR-G	0.269	0.505	0.500	0.501	0.506	0.501	0.509



ASD/GVR

Radiance



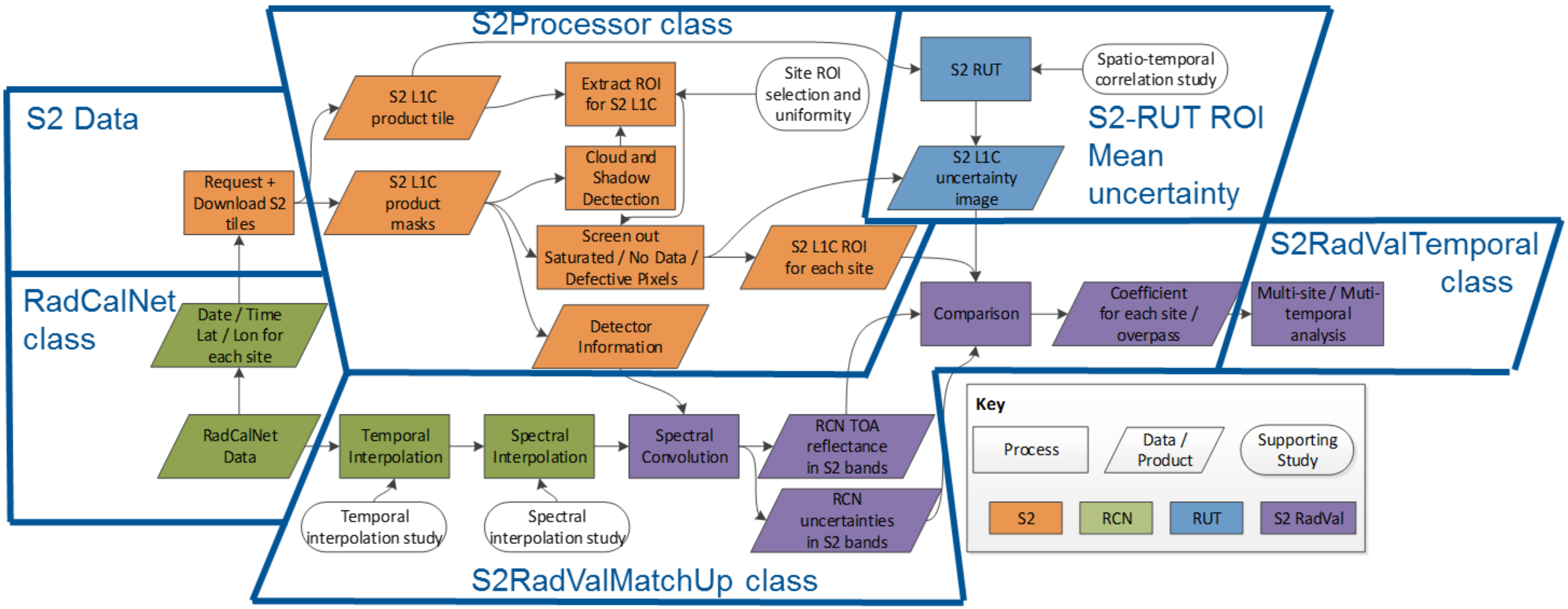
Equivalence

Linking Sentinel-2 MSI and Sentinel-3 OLCI using RadCalNet

Andrew Banks, Javier Gorroño, Sam Hunt, Tracy Scanlon, Emma Woolliams and Nigel Fox

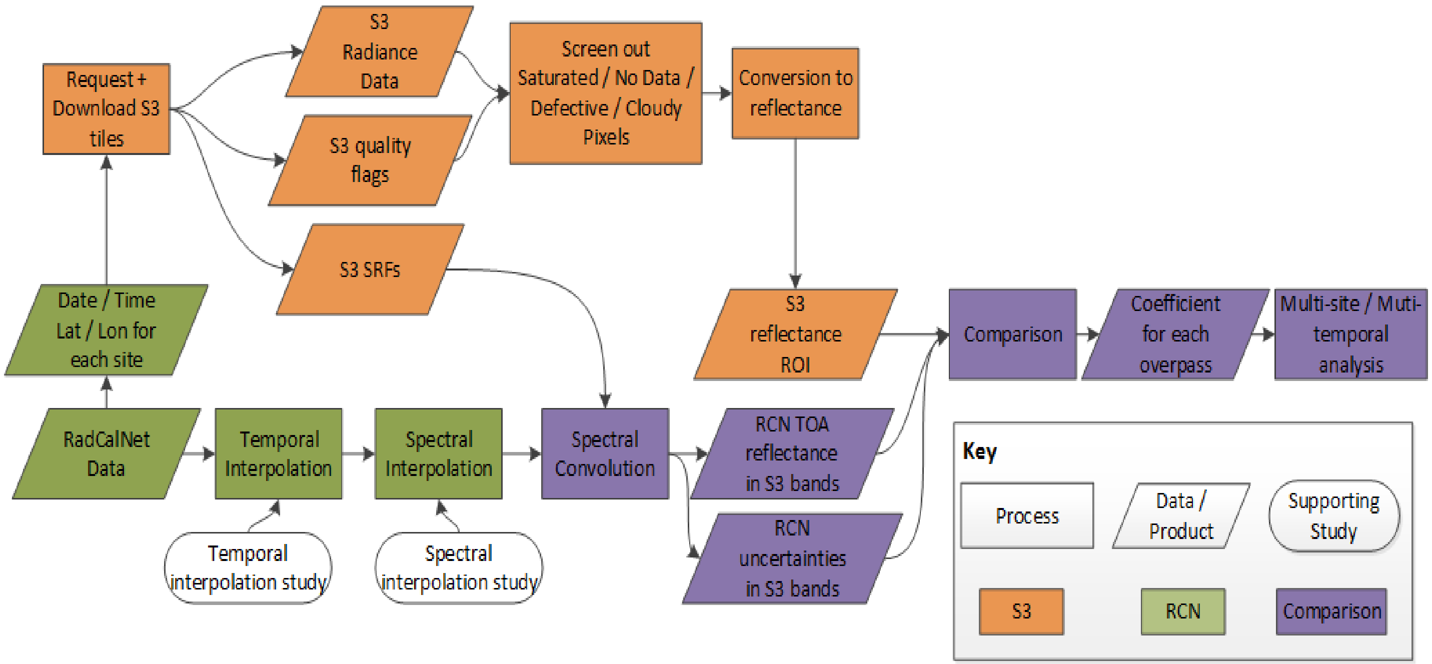
National Physical Laboratory, Teddington, UK

Define process and algorithm (S2 – MSI)



- The software is implemented using SNAP libraries
- Easily adapted as a RadCalNet plug-in processor for S2TBX
- Full documentation of the software. A table of variables has been created for each class.

Define process and algorithm (S3-OLCI)



Uncertainty Contributors S2 Example (S3 similar)

u_{S2MSI}	S2-MSI uncertainties
u_{RCN}	RadCalNet uncertainties
$u_{spatial}$	Difference between the RadCalNet site and the area used for S2
u_{interp_t}	Temporal interpolation of RadCalNet data
u_{interp_s}	Spectral interpolation of RadCalNet data
u_{view}	Viewing angle differences between overpass and RadCalNet data
$u_{convolve}$	Spectral convolution of the data

RadCalNet Data Fields

RadCalNet class Fields	Description
Header Data	
`site`	Site name
`lat`	Site latitude
`lon`	Site longitude
`alt`	Site altitude
Time Data	
`year`	Year of data collection
`doy_utc`	UTC day of data collection
`utc_time`	UTC time of data collection
`doy_local`	Local day of data collection
`local_time`	Local time of data collection
`datetime_utc`	UTC timestamp object handler
`datetime_local`	Local timestamp object handler

RadCalNet class Fields	Description
Atmospheric Data	
`pressure`	Surface atmospheric pressure [mbars]
`temp`	Surface temperature [°C]
`wv`	Water vapour [g/cm]
`ozone`	Ozone [dobsons]
`aod`	Aerosol Optical Depth @550 nm
`angstrom`	Aerosol Angstrom coefficient
`type_scene`	Type of aerosol D=Desert, M= Marine, etc.
TOA Reflectance Data	
`toa_ref`	13 sets of TOA reflectance at 30 min intervals from 9:00-15:00 local time in 10 nm intervals, 400-2500 nm

- The processor successfully parses all the info including uncertainty

RadCalNet uncertainties

The RadCalNet product contains the uncertainty information.

RadCalNet class Fields	Description
Atmospheric Data Uncertainty	
`unc_pressure`	Surface atmospheric pressure [mbars]
`unc_temp`	Surface temperature [°C]
`unc_wv`	Water vapour [g/cm]
`unc_ozone`	Ozone [dobsons]
`unc_aod`	Aerosol Optical Depth @550 nm
`unc_angstrom`	Aerosol Angstrom coefficient
TOA Reflectance Data Uncertainty	
`unc_toa_ref`	13 sets of TOA reflectance at 30 min intervals from 9:00-15:00 local time in 10 nm intervals, 400-2500 nm

For the spectral and temporal interpolation, we will assume that the major contributors are correlated and systematic (i.e. uncertainty constant over interpolation)

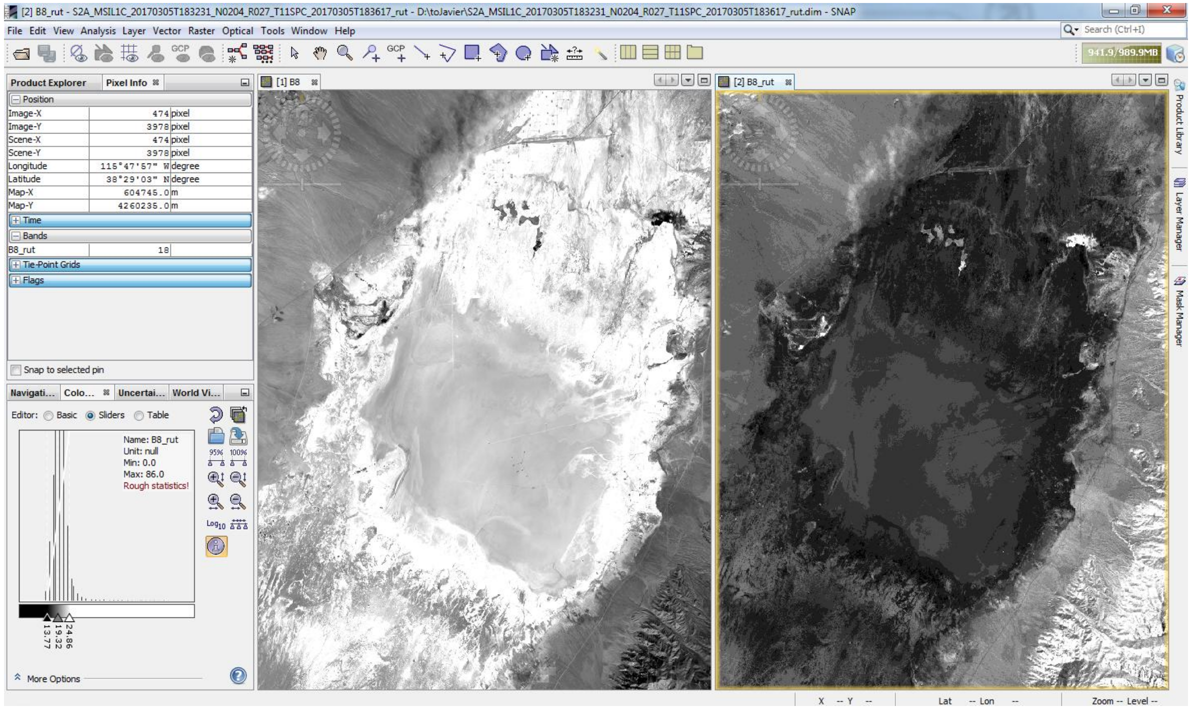
NPL National Physical Laboratory | esa European Space Agency

Pixel mean ROI unc.: simplified method

- Preliminary results of ROI mean uncertainty (k=1) at RRVP for 5th March 2017

B1	B2	B3	B4	B5	B6	B7	B8	B8A	B11	B12
1.8%	1.8%	1.7%	1.4%	1.3%	1.2%	1.3%	1.2%	1.4%	1.7%	1.8%

- S2-RUT→ calculate per-pixel uncertainty
- …but we want the ROI mean uncertainty. Not a pixel mean or the standard deviation of the mean!
- Simple approach→ use the select/deselect uncertainty contributors option of RUT to simulate which are the uncertainty contributions that will not be minimised.

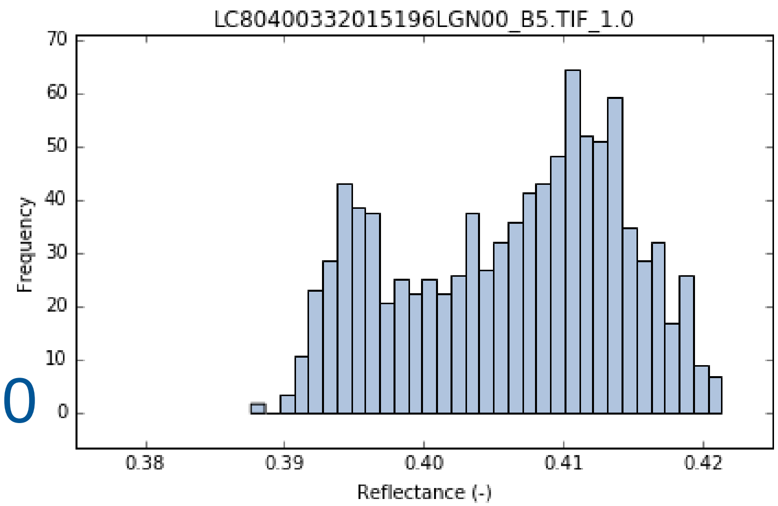


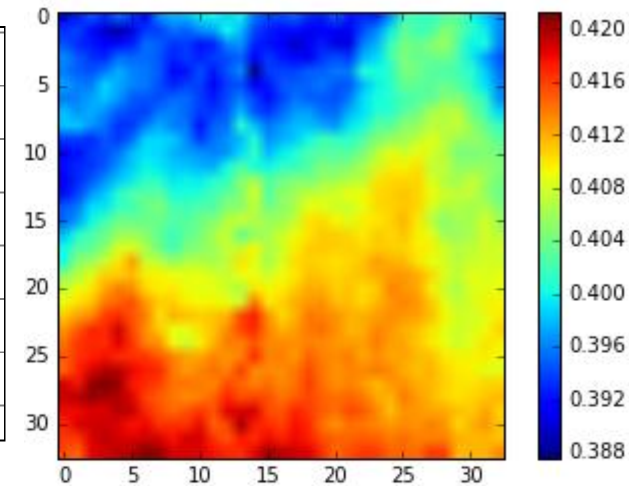
RadCalNet Site Area: Railroad Valley

NPL National Physical Laboratory | Centre for Carbon Measurement

1 km

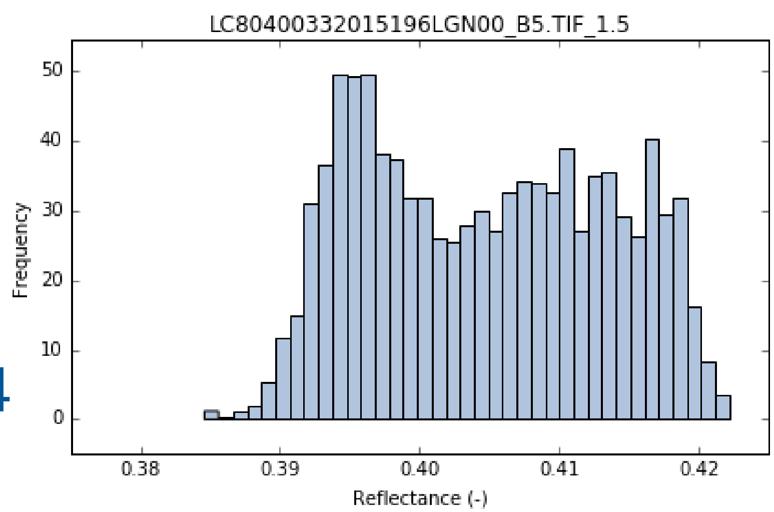
μ = 0.4062
σ = 0.0079
kurt = -1.0553
skew = -0.2760

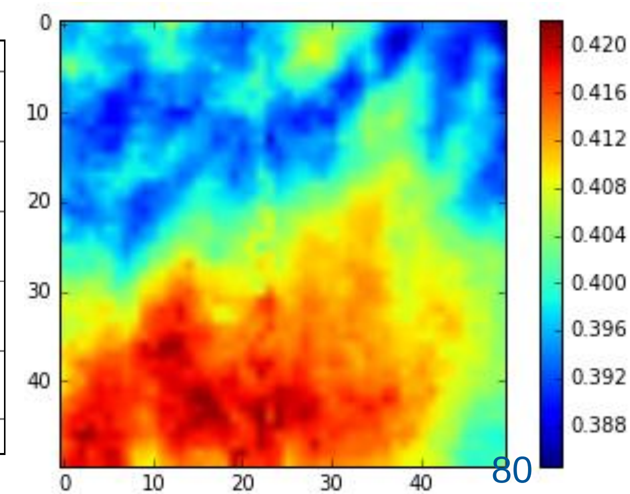




1.5 km

μ = 0.4047
σ = 0.0087
kurt = -1.2215
skew = 0.0804





Difference between the RadCalNet site and the area used for S2

Example: Gobabeb instrument sub-samples the up-welling radiance of an area of ~34.6m (10m pole at max zenith angle of 60º) fitted to a Roujean BRDF model (Meygret et al 2011).

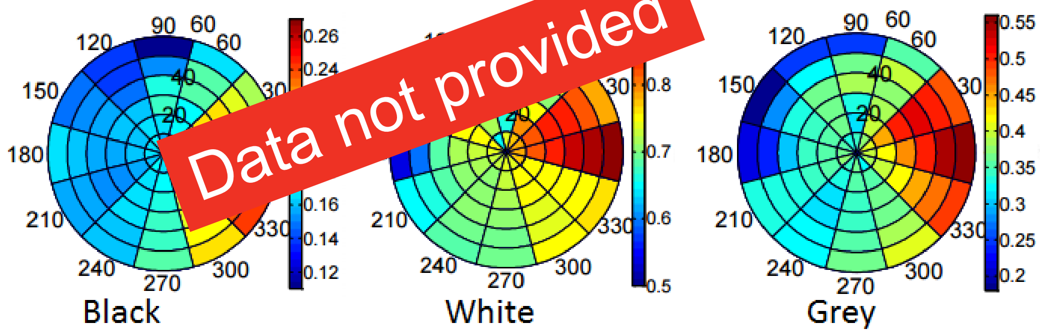
$$\rho_k(\theta_s, \theta_v, \Delta\varphi) = \frac{\pi . L_k^{\uparrow}(\theta_s, \theta_v, \Delta\varphi)}{\phi_{total,k}^{\downarrow}}$$

What does the RadCalNet surface area represents vs. the selected S2 ROI?

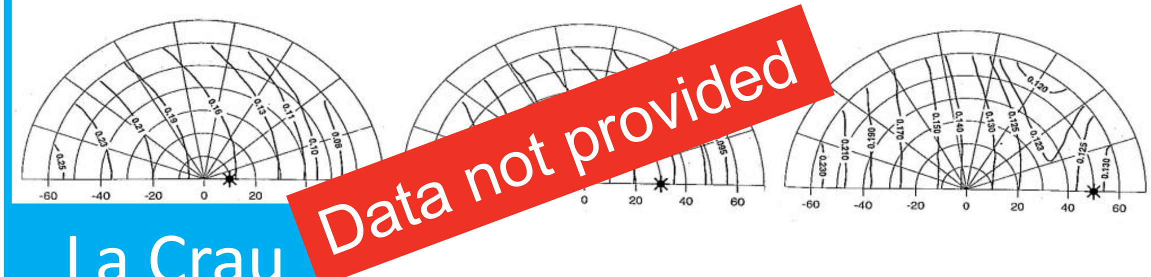
Viewing Angles

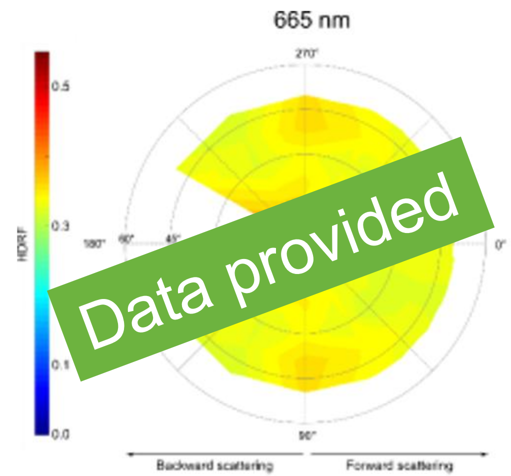
- RadCalNet provides nadir only.
- Each RadCalNet site is nominally Lambertian, however available data shows some BRDF effects.

Baotou



La Crau

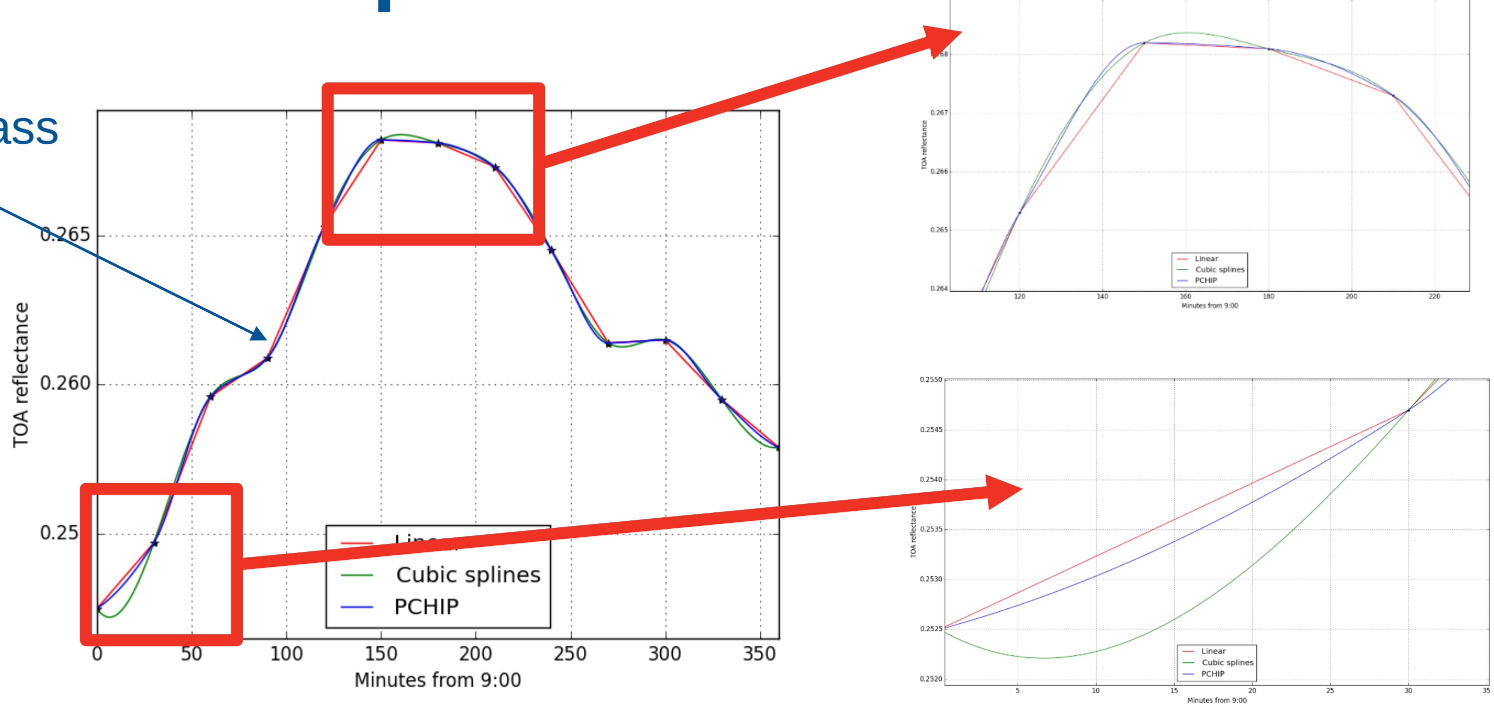




Gobabeb

Temporal Interpolation

S2 ~18:30
UTC overpass



Data provided for Railroad Valley ONLY

Railroad Valley RadCalNet Data

- Nearest-Neighbour interpolation:

  30 min changes up to 2 % (e.g. near the S2 overpass)

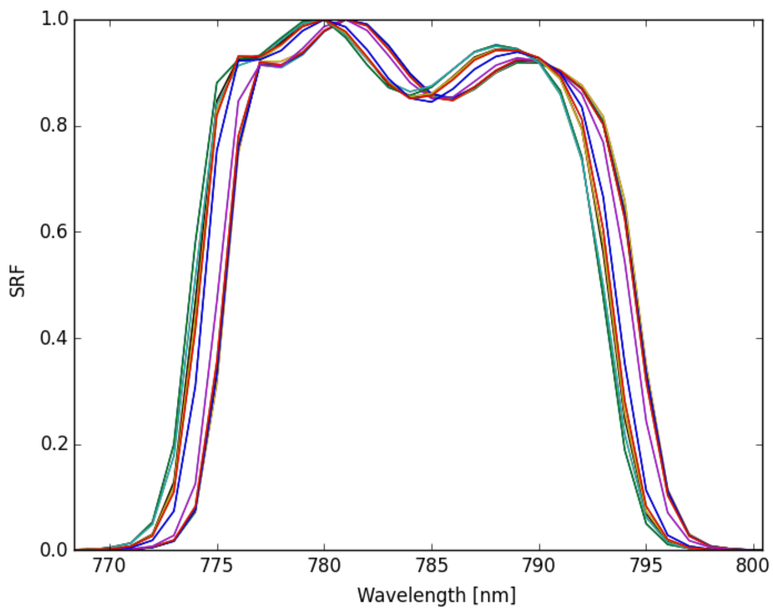
- Linear / PCHIP / Spline:

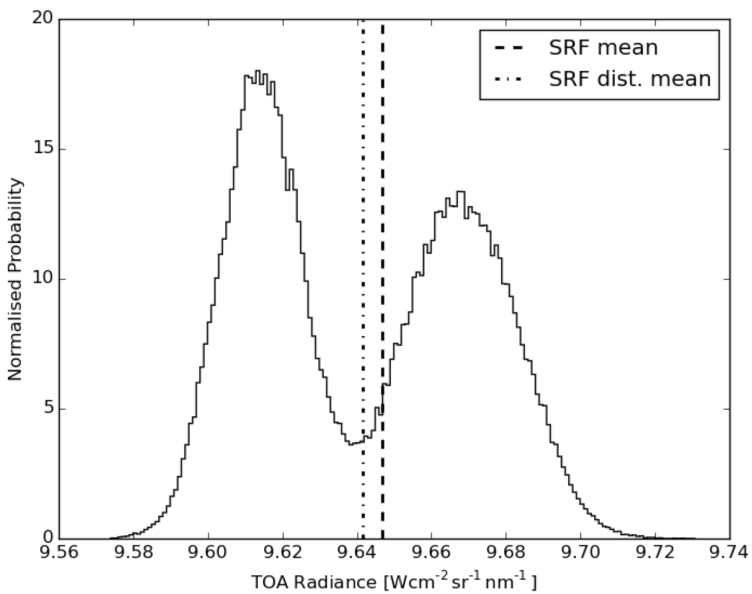
  differences up to 0.4 % in potential S2 window overpass (unstable situations)

Spectral Convolution

- The convolution will need to consider the impact of the spectral non-uniformity of the detectors

$$\rho_{\mathrm{RCN}}^{\mathrm{TOA}}(b) = \frac{\int SRF_{S2}(\lambda)\rho_{RCN}^{TOA}(\lambda)\,d\lambda}{\int SRF_{S2}(\lambda)\,d\lambda}$$





$u_{convolve}$

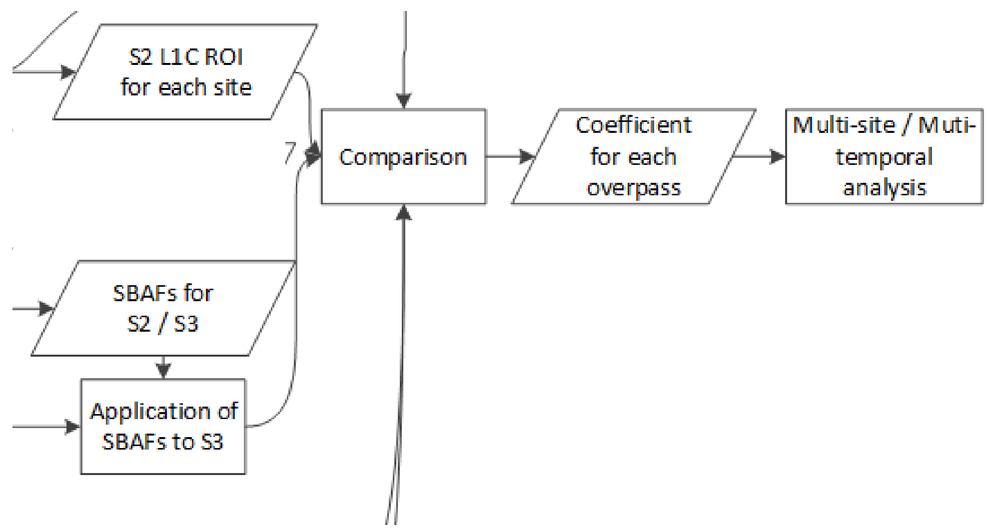
Spectral convolution of the data

u_{SRF_λ}	Wavelength knowledge of S2 SRF
u_{SRF}	Magnitude knowledge of S2-MSI SRF
u_{SRF_detec}	Difference between S2-MSI SRF for each detector vs published data
u_{SRF_interp}	Interpolation to SRF resolution from interpolated data

RadCalNet to Sentinel-3 OLCI using Sentinel-2 MSI as Transfer Radiometer

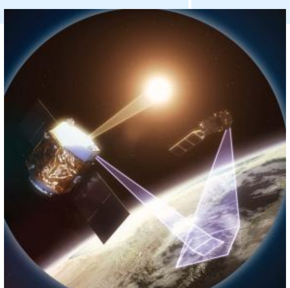
$$\Delta A_{\mathrm{XCAL}}(b) = \frac{\boxed{\Delta A_{\mathrm{RCN}}}(b)\,\rho_{\mathrm{S2}}^{\mathrm{TOA}}(b)}{\rho_{\mathrm{S3}}^{\mathrm{TOA}}(b)}$$

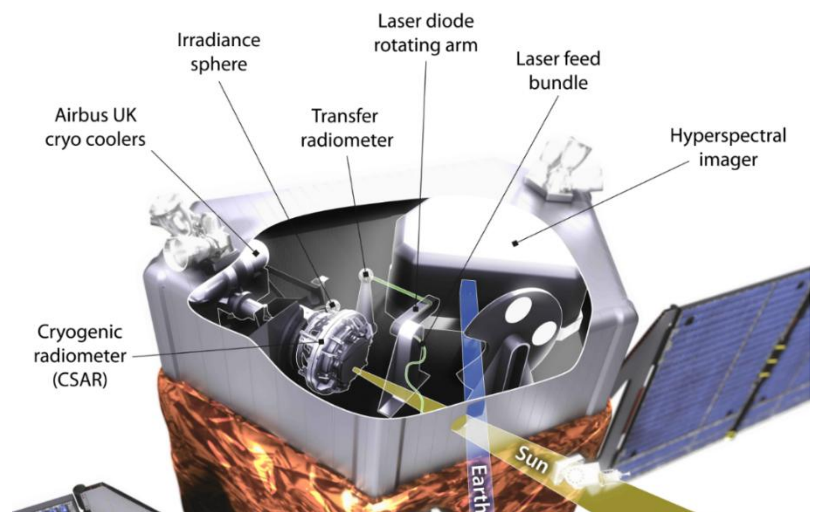
From RadCalNet method. Need to determine if this should be a “lifetime” coefficient or updated for each available comparison to RadCalNet sites.



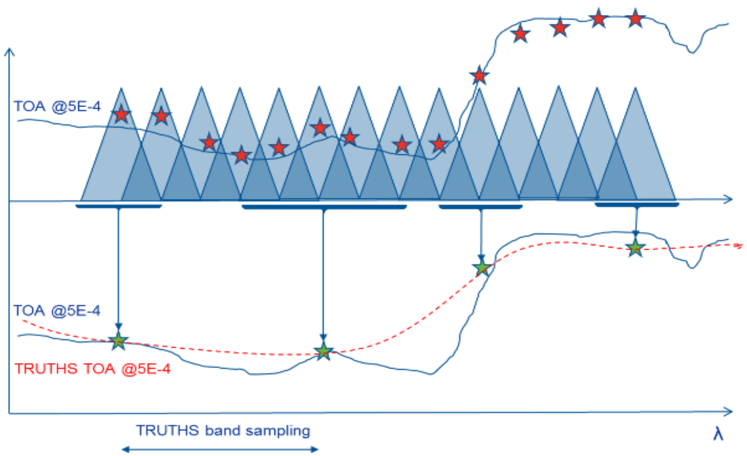
TRUTHS: What is it? A proposed small satellite mission, to establish ‘fiducial’ data sets of Level 1 spectrally resolved (Ir) radiance (solar reflective) of unprecedented (~10X improvement) SI traceable accuracy to enable:

Parameter	Spectral range /µm	Spectral resolution / nm	GIFOV / m	SNR	Sampling	Uncertainty / % (2σ)
Earth Spectral Radiance	0.32 - 2.45	~5 to 10	~50 250	~300 (Vis-NIR) >2000 Blue	Global nadir 100 km swath + multi-angle	0.3
Lunar Spectral Irradiance	0.32 - 2.45	5 - 10	NA	>300	Weekly (libration sampled)	0.3
Total Solar Irradiance (TSI)	0.2 - 35	NA	NA	>500	Daily	0.02
Solar Spectral Irradiance (SSI)	~0.30 - 2.45	2 to 10	NA	>300	Daily	0.3



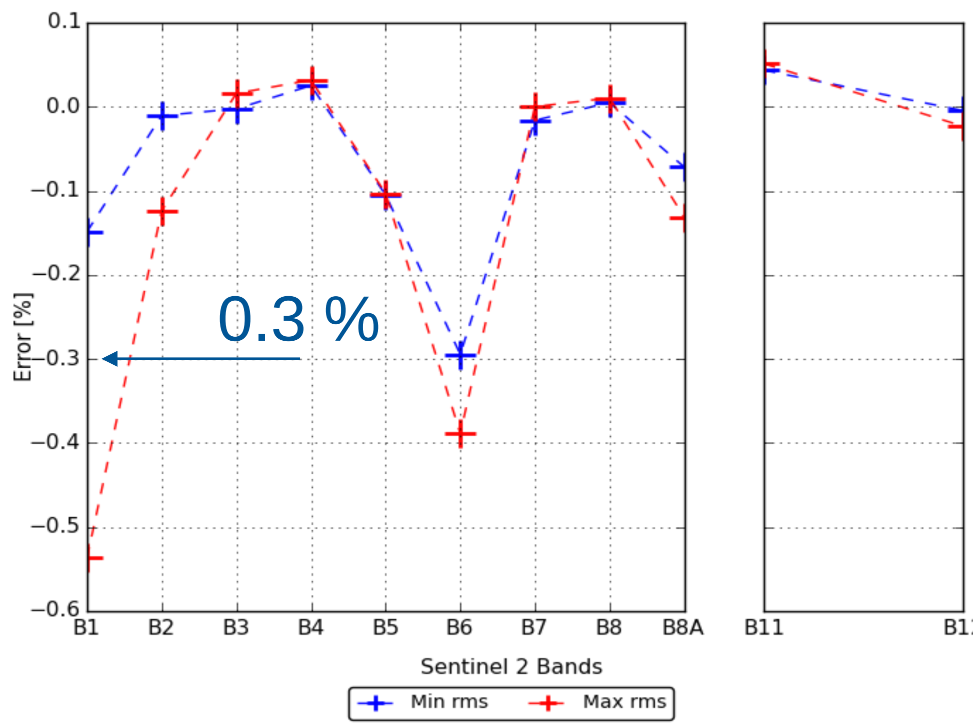


Spectral dimension



Sentinel 2 – TRUTHS comparison

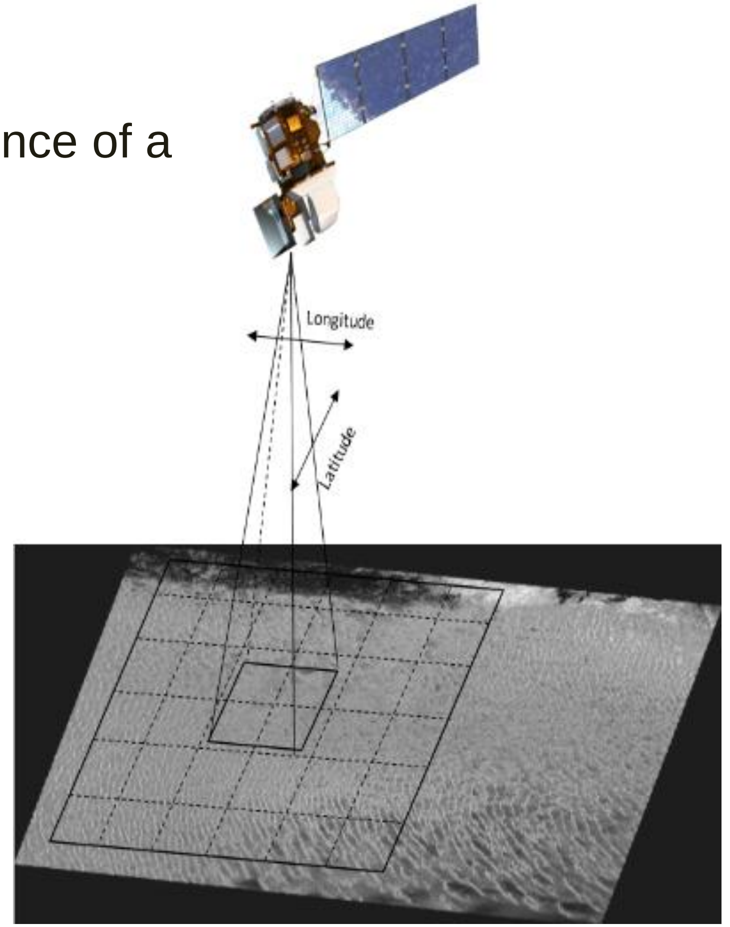
Maximum error introduced by spectral interpolation (red and blue lines depend on starting wavelength)



ISPRS Journal of Photogrammetry and Remote Sensing
Gorrono et al. 2017
Funded by CEOI

Spatial dimension: methodology: how sensitive to geo position and knowledge

Objective:
Study the TOA radiometric uncertainty as a consequence of a geolocation uncertainty at a single overpass



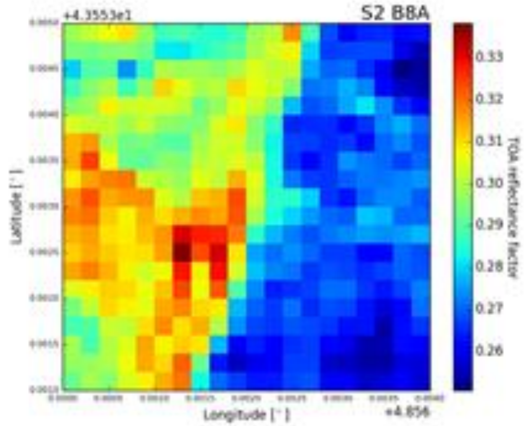
Methodology
1) Select a ROI
2) Create an error image by shifting the ROI over an enlarged area
3) Calculate the std. growing from the centre to produce a relationship of TOA reflectance uncertainty with geoposition knowledge
4) Validate by comparing L8 OLI to S2 MSI

<0.1 % for Libya 4
0.1 % - 0.5 % for La Crau

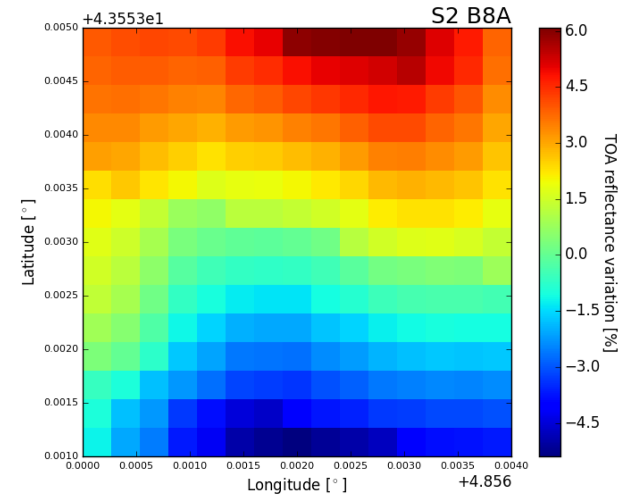
(40 m geometric knowledge)

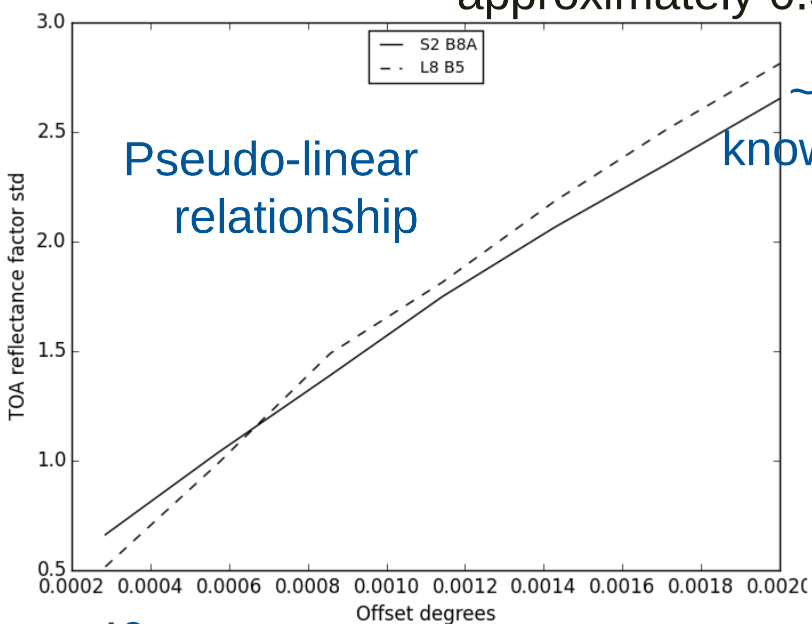
Spatial dimension: La Crau

Step 1. La Crau 400 × 400 m^2 area centred at 43.556º N 4.858º E
(TOA reflectance factor)



Step 2. Error map of approximately 0.32 × 0.44 km^2





Pseudo-linear relationship

~400 m knowledge

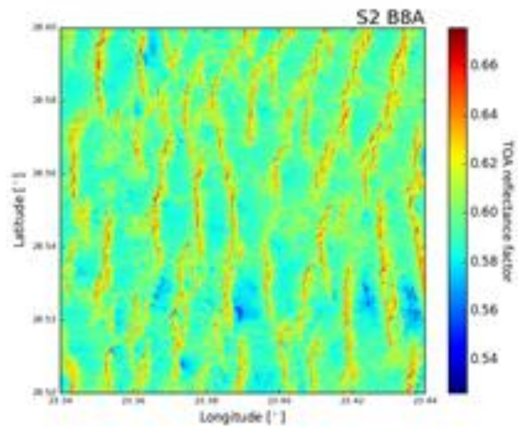
~40 m knowledge

Step 3. Std growing from the centre offset vs TOA reflectance std

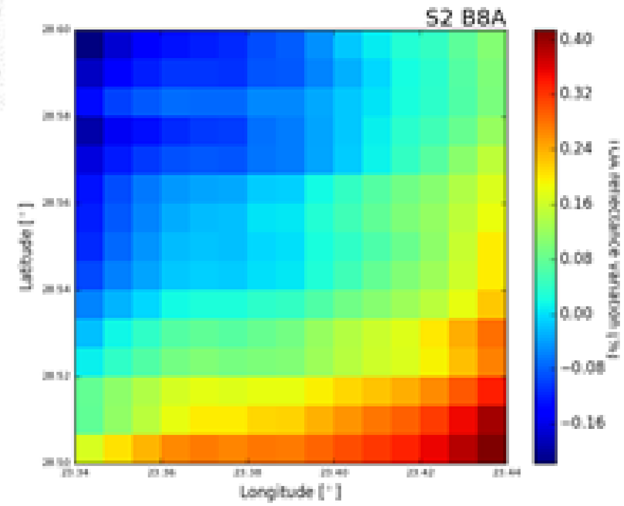
Step 4. Comparison for L8 OLI ans S2 MSI

Spatial dimension: Libya-4

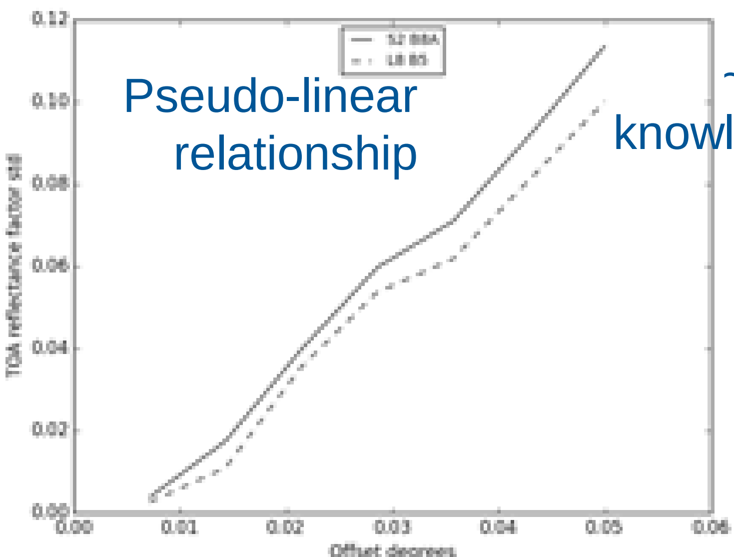
Step 1. 28.55º N 23.39º E with a size of 20 km x 20 km (TOA reflectance factor)



Step 2. Error map of approximately 10 × 10 km^2



Step 3. Std growing from the centre offset vs TOA reflectance std



Pseudo-linear relationship

~5km knowledge

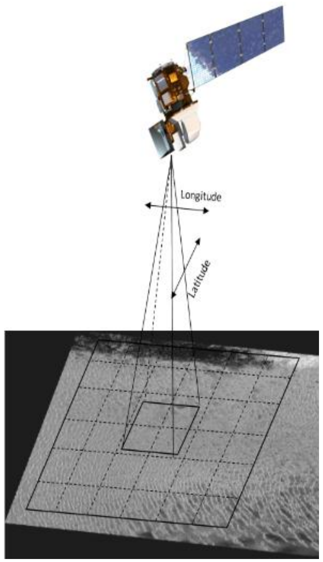
~500 m knowledge

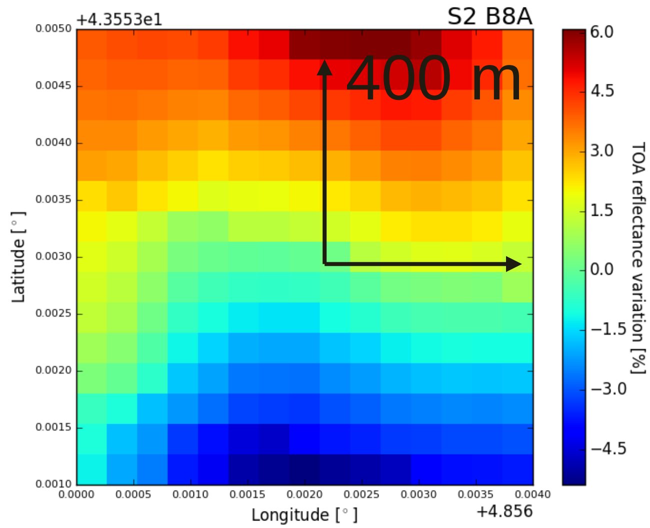
Step 4. Comparison for L8 OLI and S2 MSI

Spatial dimension

NPL National Physical Laboratory | Centre for Carbon Measurement

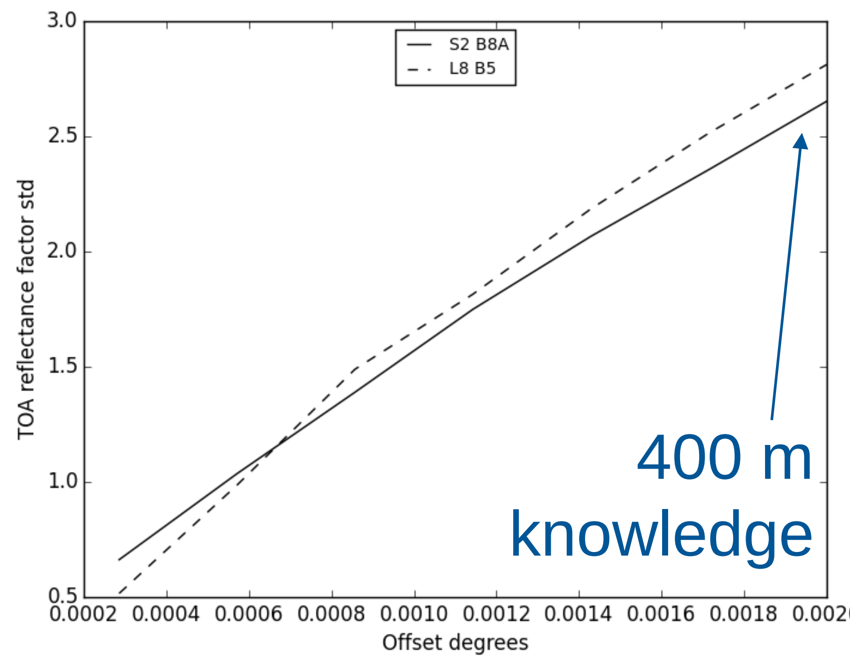
How sensitive is comparison to geolocation accuracy?





<0.1 % for Libya 4
0.1 % - 0.5 % for La Crau

(40 m geometric knowledge)



Submitted to ISPRS Journal of Photogrammetry and Remote Sensing
Gorrono et al. 2017

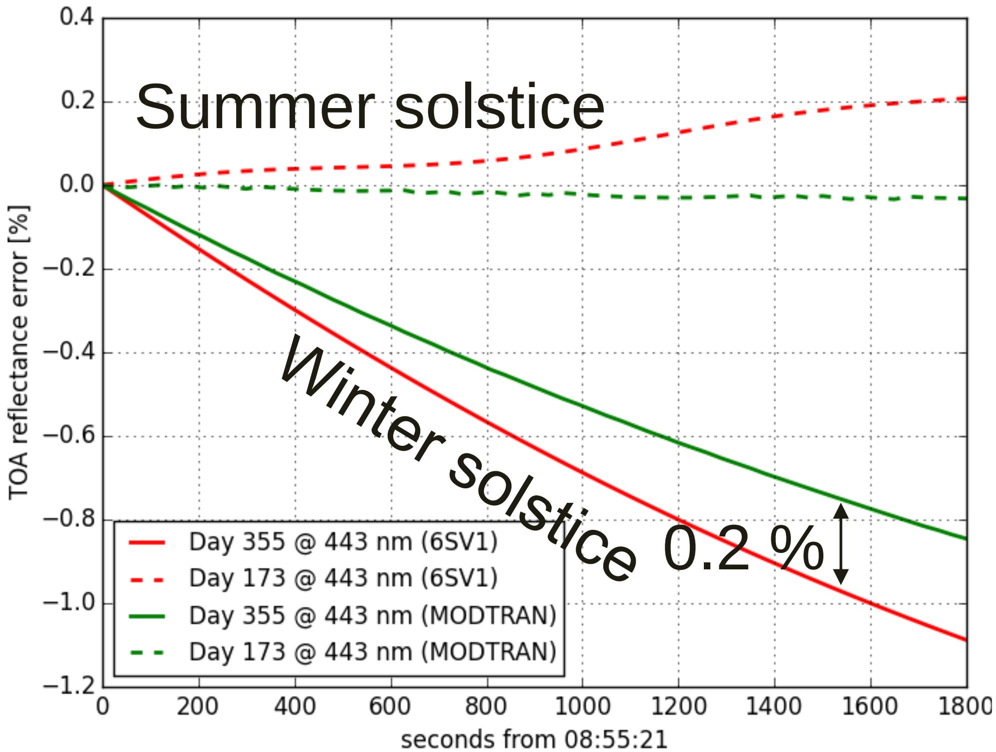
Funded by CEOI

Centre for EO Instrumentation

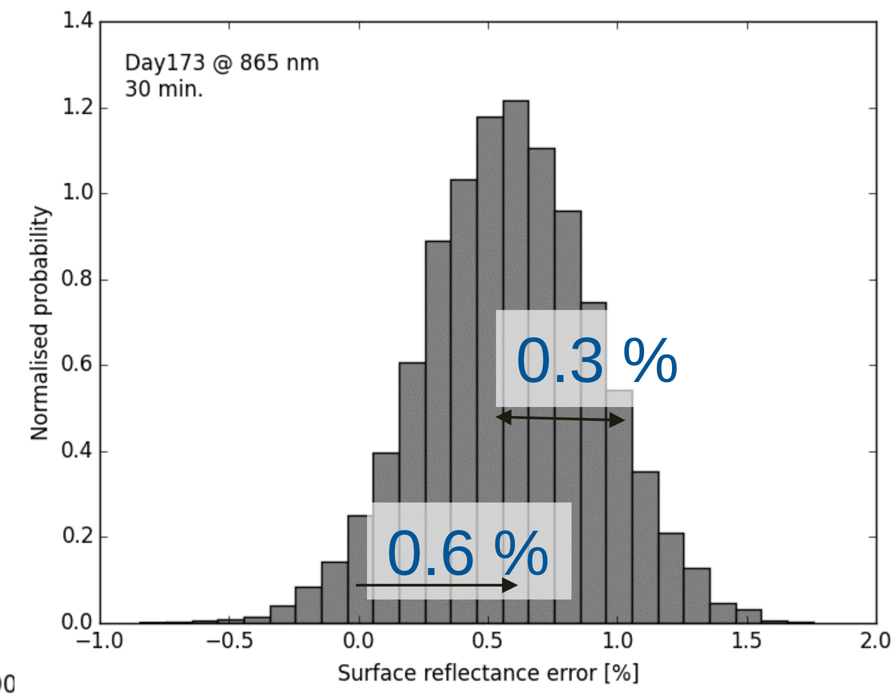
Temporal dimension

Effect of changes in water vapour, aerosols, surface BRF, SZA

Atmosphere dominant (443 nm)



Surface dominant (865 nm)



Centre for EO Instrumentation

ISPRS Journal of Photogrammetry and Remote Sensing Gorrono et al. 2017

Uncertainty budget for TRUTHS – satellite comparisons

(single overpass – reduces for multiple overpasses)

Uncertainty	Best S2 bands	Worst S2 bands
Spectral resolution TRUTHS	0.1 %	0.6 %
Spectral accuracy TRUTHS	0.1 %	0.2 %
Spatial co-alignment mismatch	0.1 % (Libya) 0.12 % (La Crau)	0.1 % (Libya) 0.5 % (La Crau)
30 minute time difference (atmospheric effects)	0.1 % (if corrected) 0.3 % (if atmosphere not known)	0.1 % (if corrected) 2 % (if atmosphere not known)
30 minute time difference (surface BRF)	0.2 %	0.4 %
Combined with reasonable corrections	**0.4 % - 0.5 %**	**0.7 %**

CONCLUSION

PICS

CEOS WGCV working towards a holistic solution

- SI traceable sensor
- linking sensor
- RadCalNet
- PICSCAR
- Moon
- DCC etc

Need database of results

Standardised or traceable (with Uc) tools

RT code, Solar spectrum, Spectral convolution ….

Challenge not yet resolved but strategy is defined