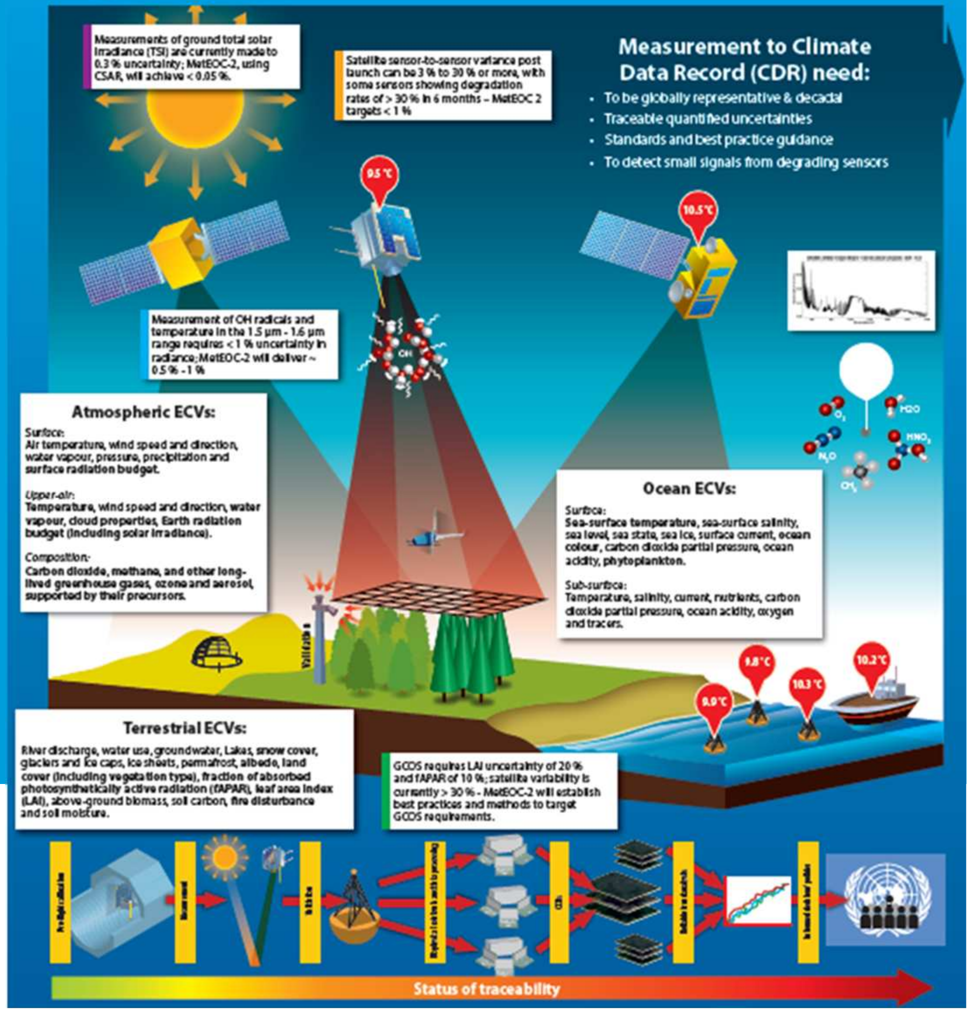
SI traceability for bio-geophysical Variables that constitute ECVs of GCOS



Nigel Fox

Head of Earth Observation, Climate and Optical

Varenna 2016

National Measurement System

What is Earth Observation?

But also In-situ

Remote sensing of the Earth from Space: Utilising full EM spectrum

>100 EO satellites launched in 2000 – 2010 **~900 viewing Earth for defence**

>200 expected to be launched in current decade at a cost of $20B

Operated by > 34 countries **Surface resolutions <1 m**

Life cycle of Wheat

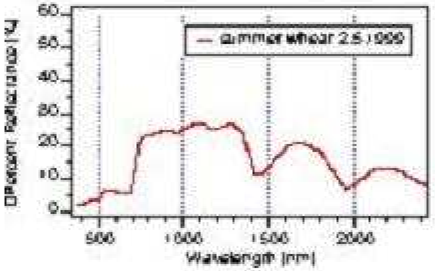
Dep of Geography University of Zurich

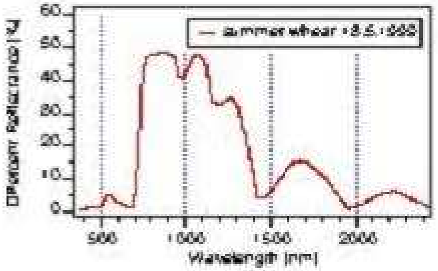
May 2

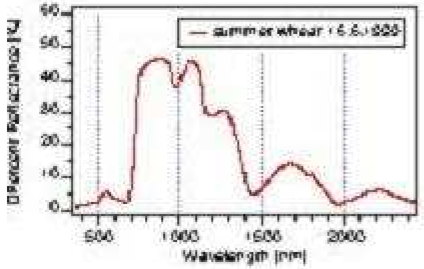
May 18

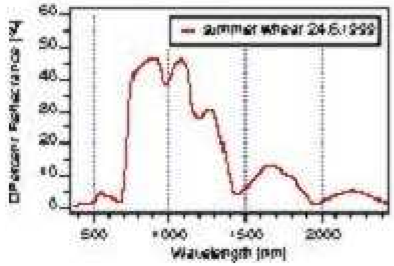
June 16

June 24







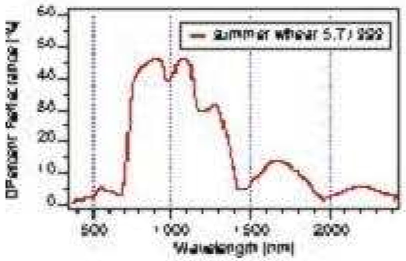


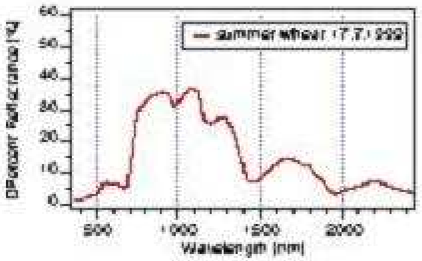
July 5

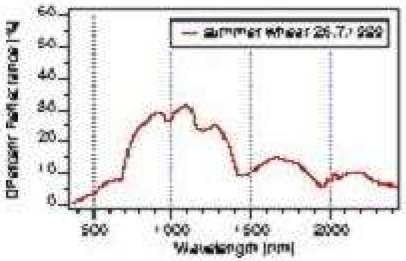
July 17

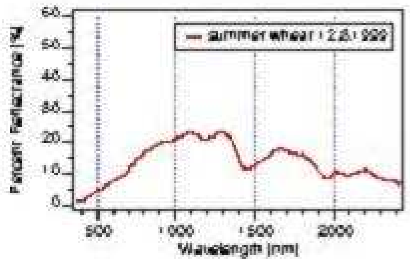
July 26

August 12

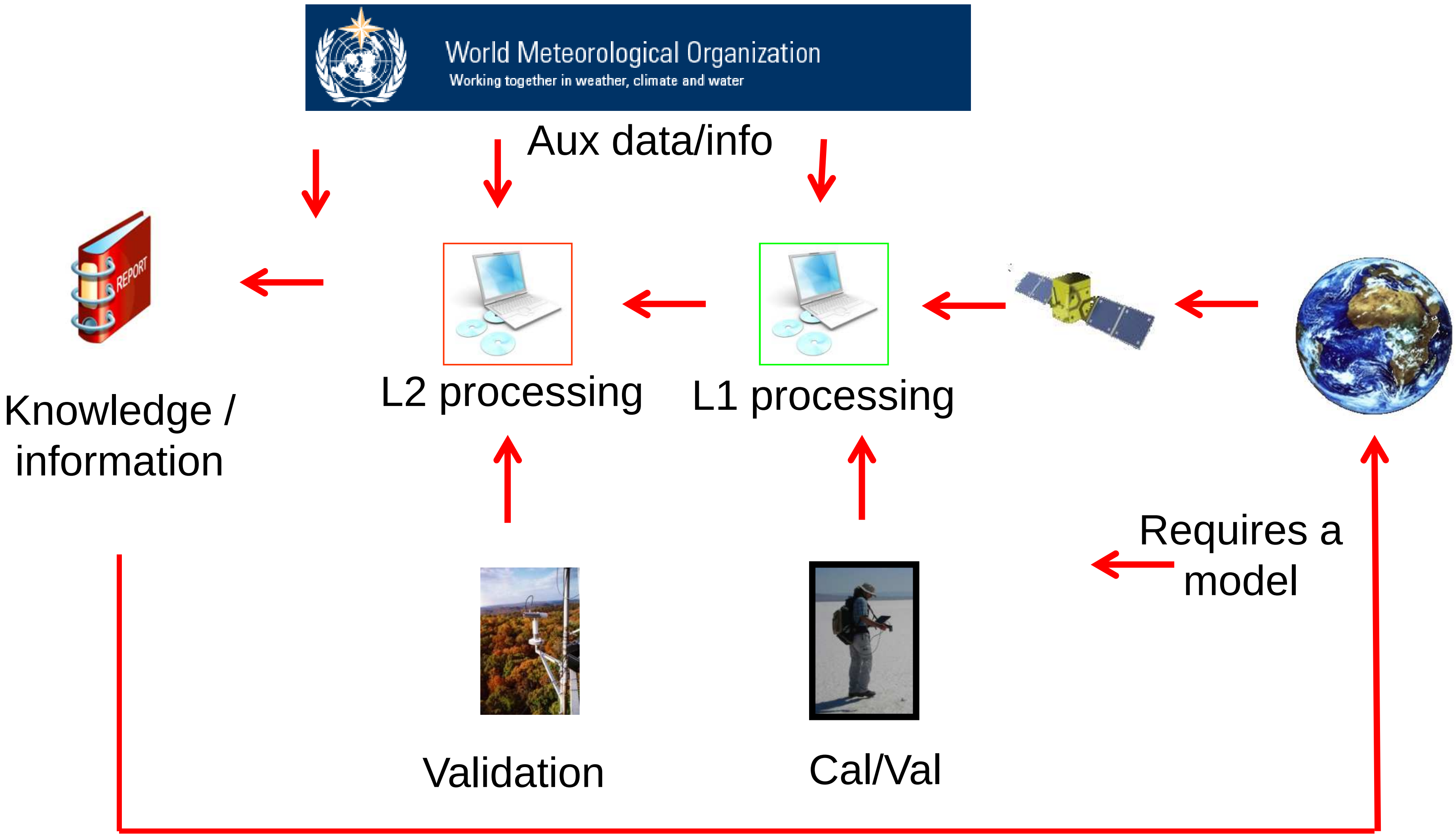






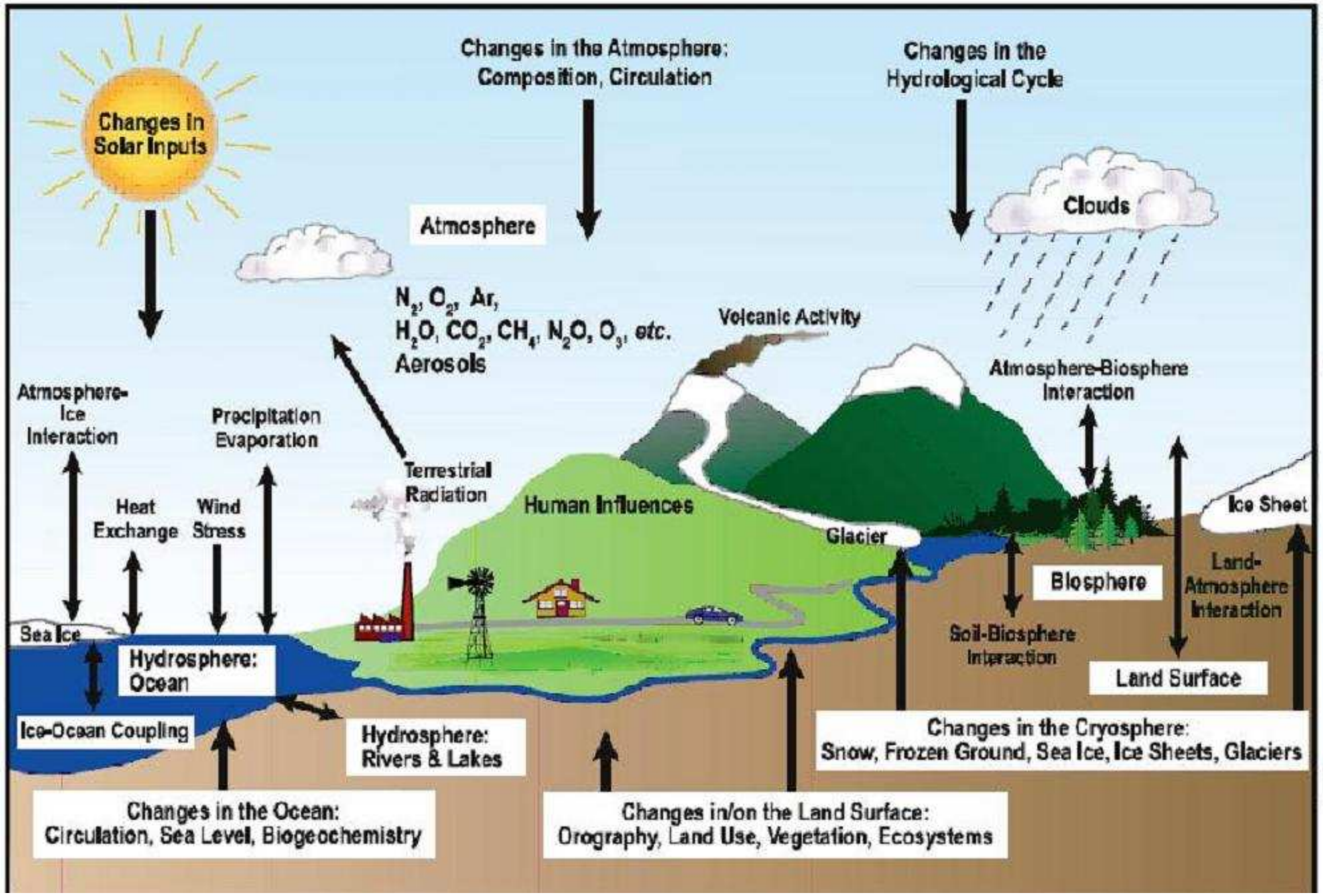


Earth Observation is dependent on models and their uncertainty – often very complex, poorly understood and difficult to robustly validate



Climate Change

Earth System is very complex



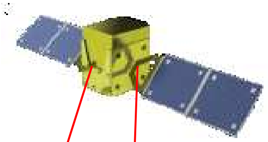
Essential Climate Variables (ECV)

The Global Climate Observing System (GCOS) of UN has defined 50 ECVs that must be observed accurately over the long term to support climate modelling (~2/3 have an optical related measurand)

Mitigating Climate change: Value of Carbon stored in Forests

Discouraging de-forestation of rainforests (UN REDD) & off-setting emissions is leading to trade & an international economic value assigned to carbon

-scale means that the asset can only be properly assessed by satellite (reflectance)



100K hectares – 10M Tonnes of Carbon - $100M

Uncertainty of ± 5% = $5M

in practise Uc ???? 30%, 50%, 100%?

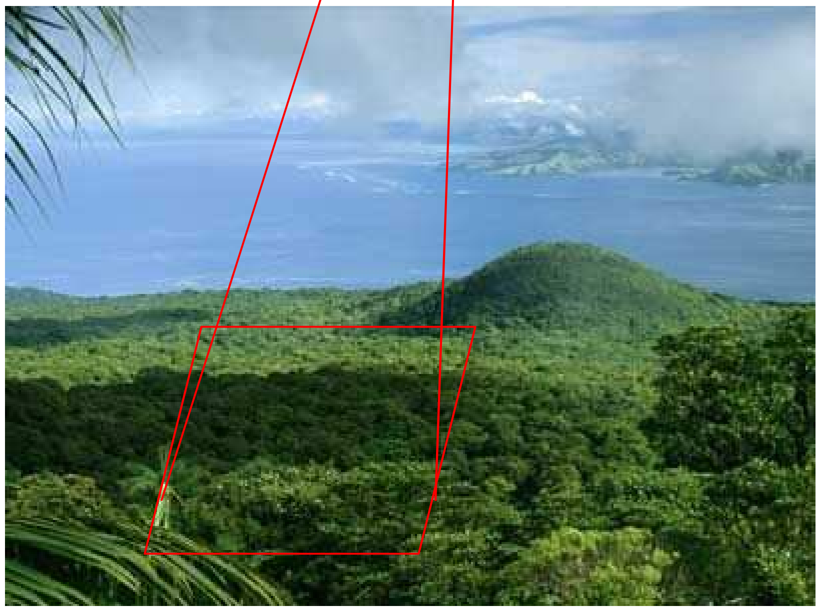
1 Tree = ~ 1 Tonne of Carbon

1 Tonne of Carbon = ~ $10 on market

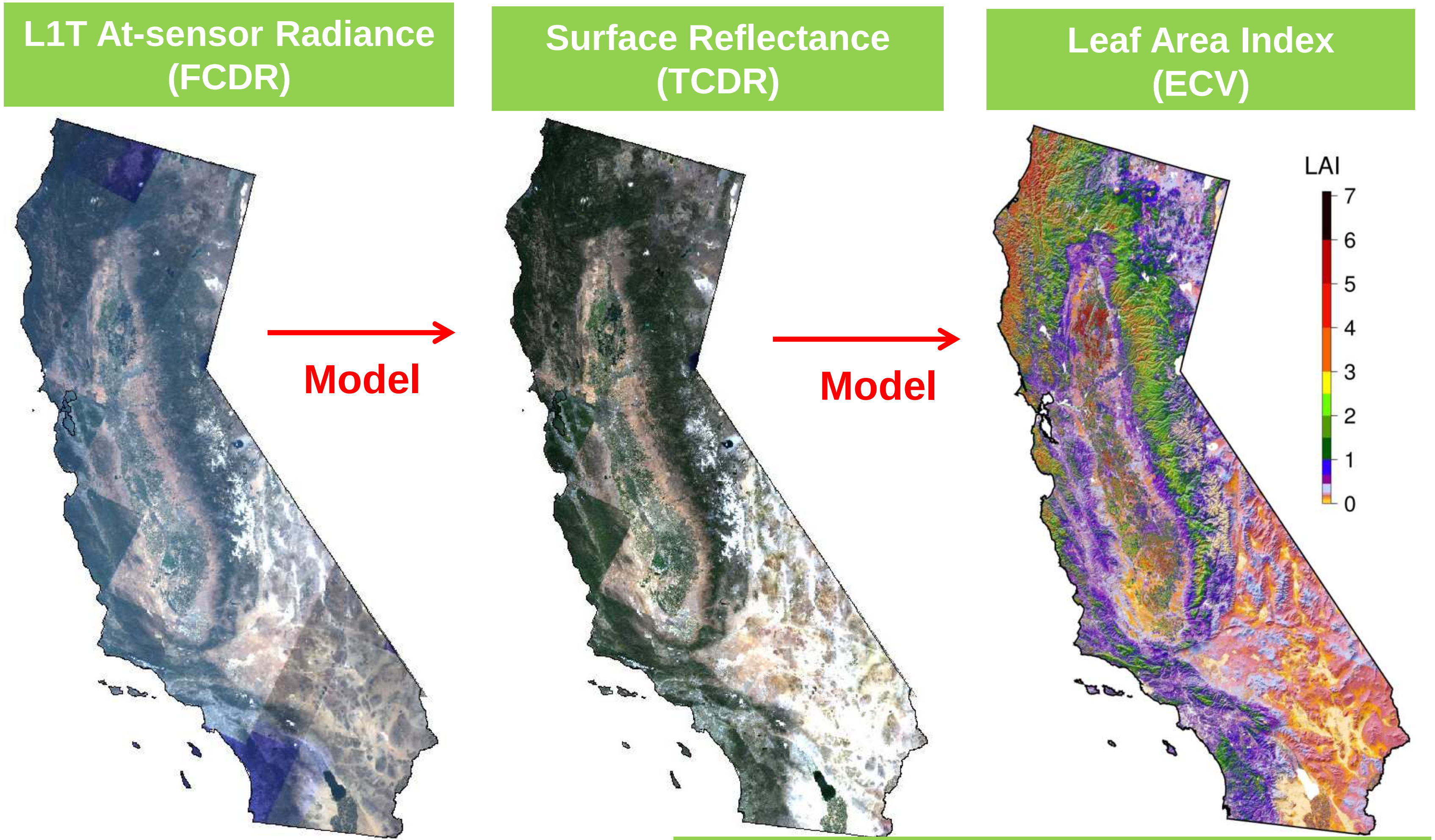
1 hectare = ~100 Trees

Sumatra rain Forest = ~2.5 M Hectares

Value of Carbon = ~$2.5B



Data to Information

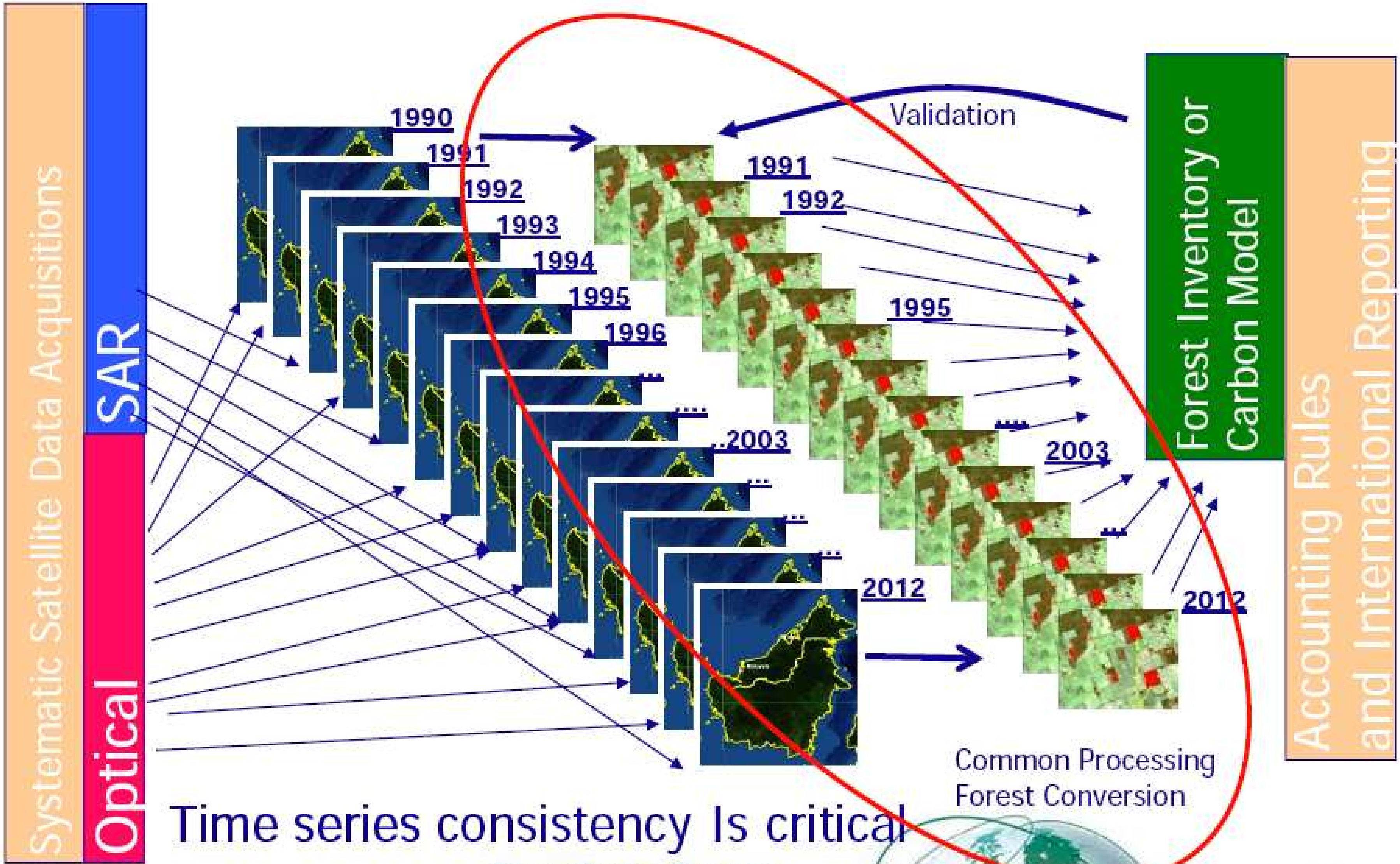


Courtesy Rama Nemani, NASA Ames Research Center

- Ideal to have QI's (uncertainties) for each stage
  - With care for some applications can deal with QI at product level

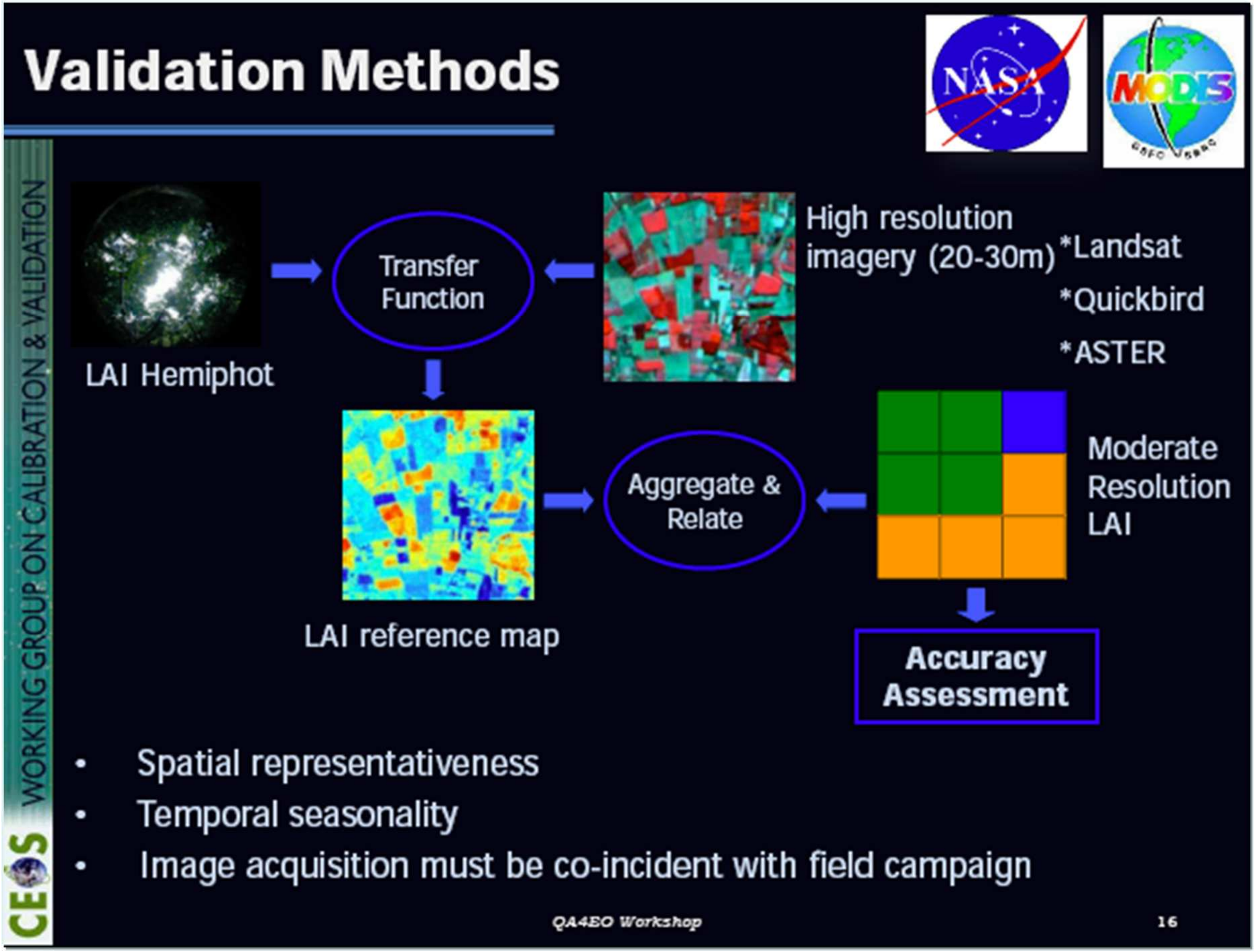
GROUP ON EARTH OBSERVATIONS

Interoperability and complementarity in RS Data Sources



Time series consistency Is critical

Forest Carbon Tracking

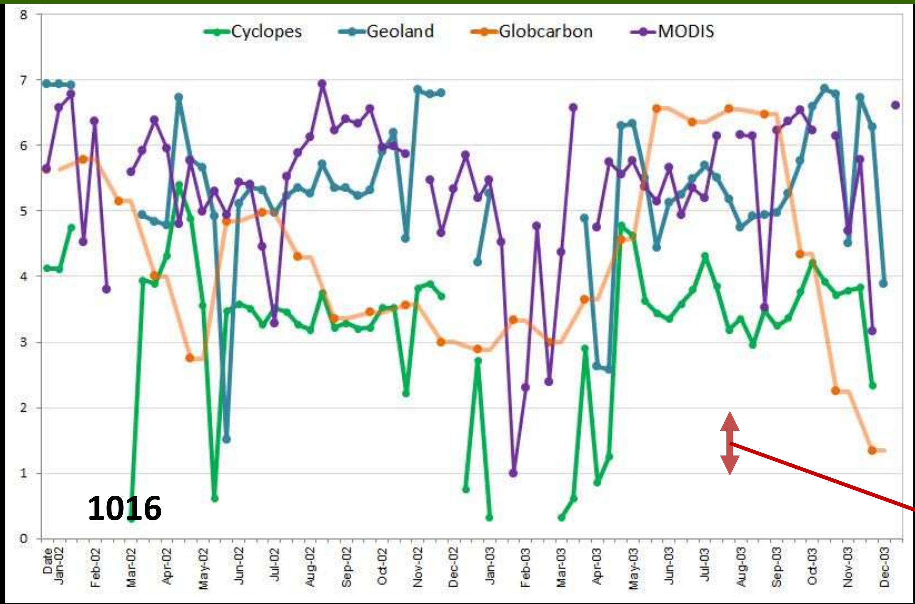


Satellite imagery and representation of reality - Assigning an uncertainty??

- spatial scales

- heterogeneity

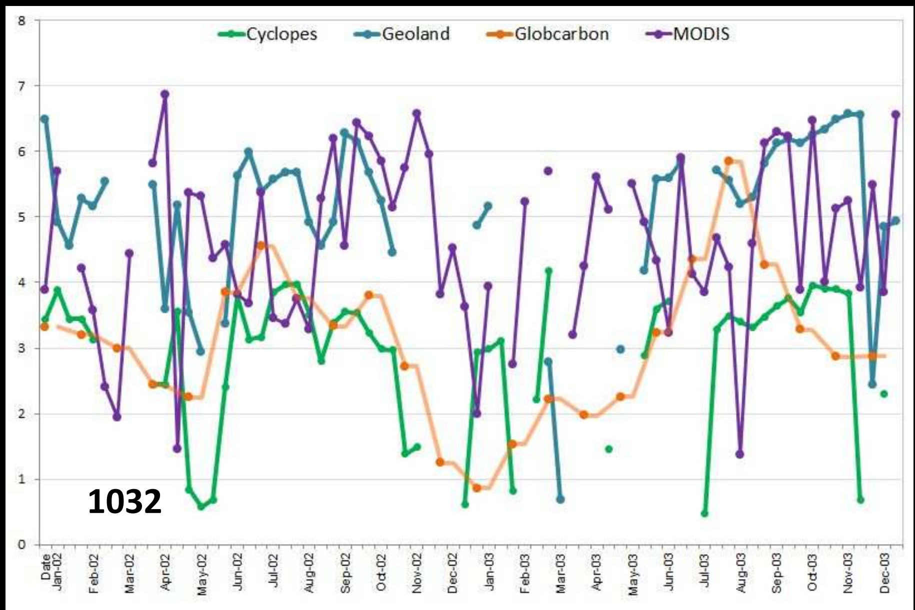
ECV for vegetation: Leaf Area Index (LAI)

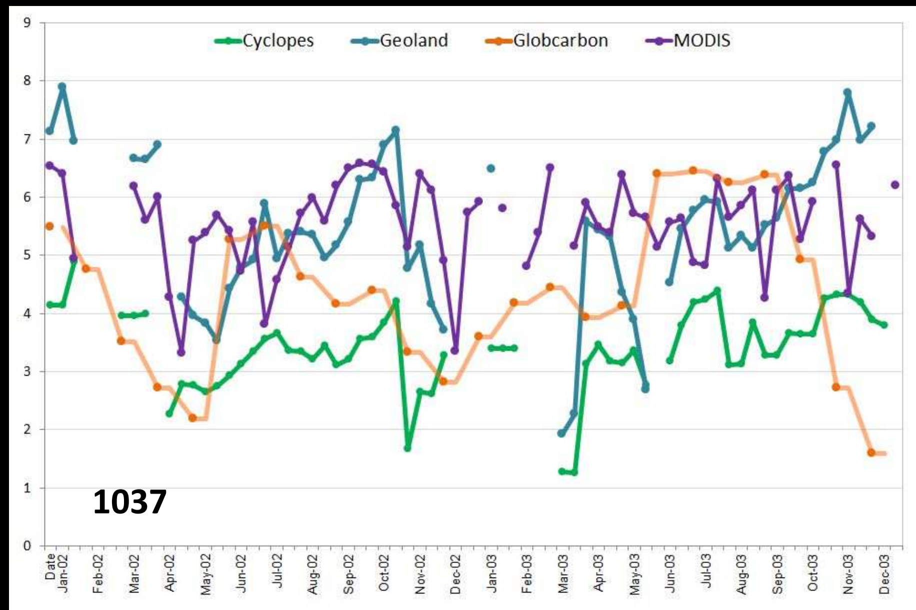


Dimensionless scale. Parameter used as starting point for forest carbon models and carbon cycle

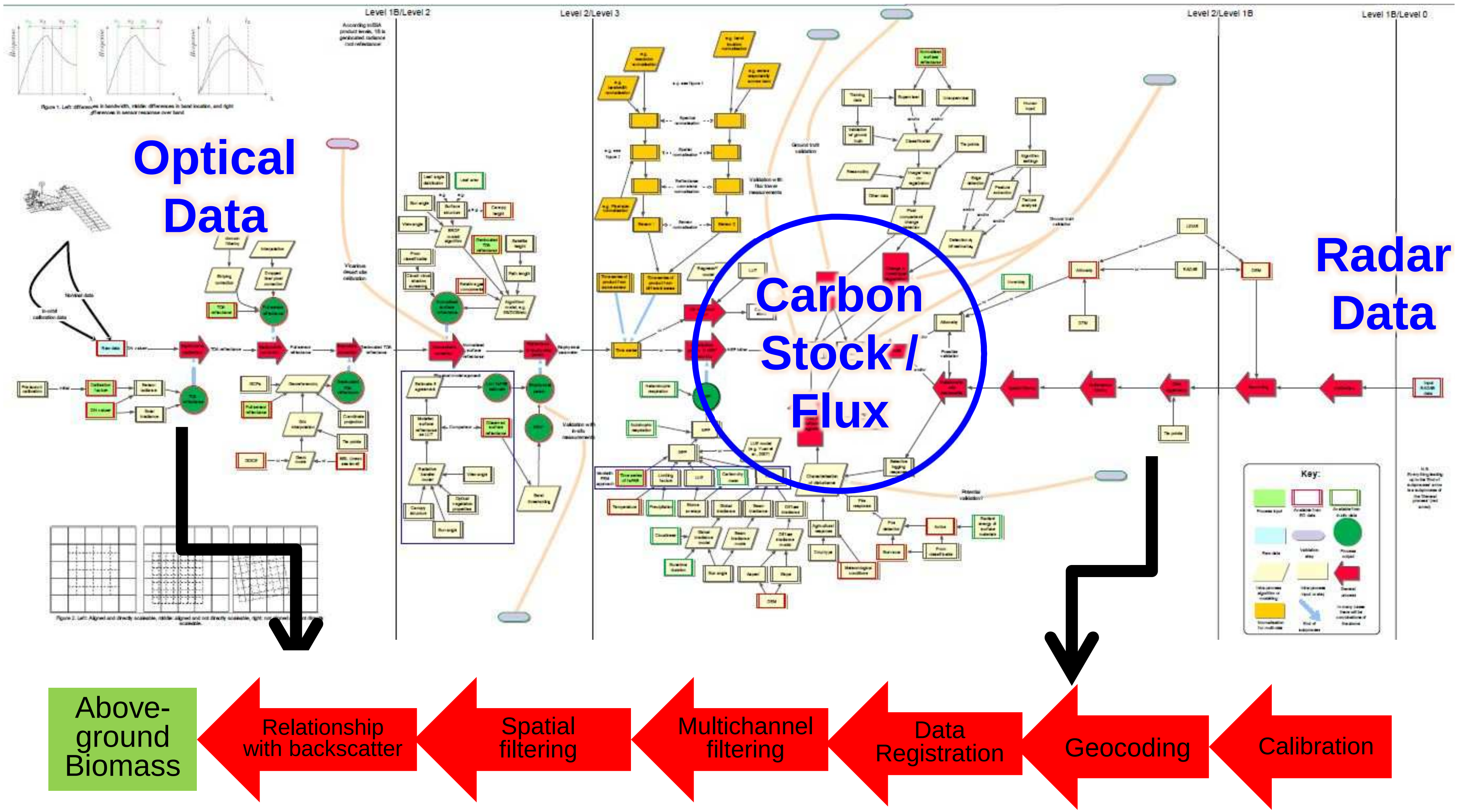
Different models (largely same input data) in different parts of Amazon

- GCOS specifies Uc 0f 0.5 and stability of 0.25!!

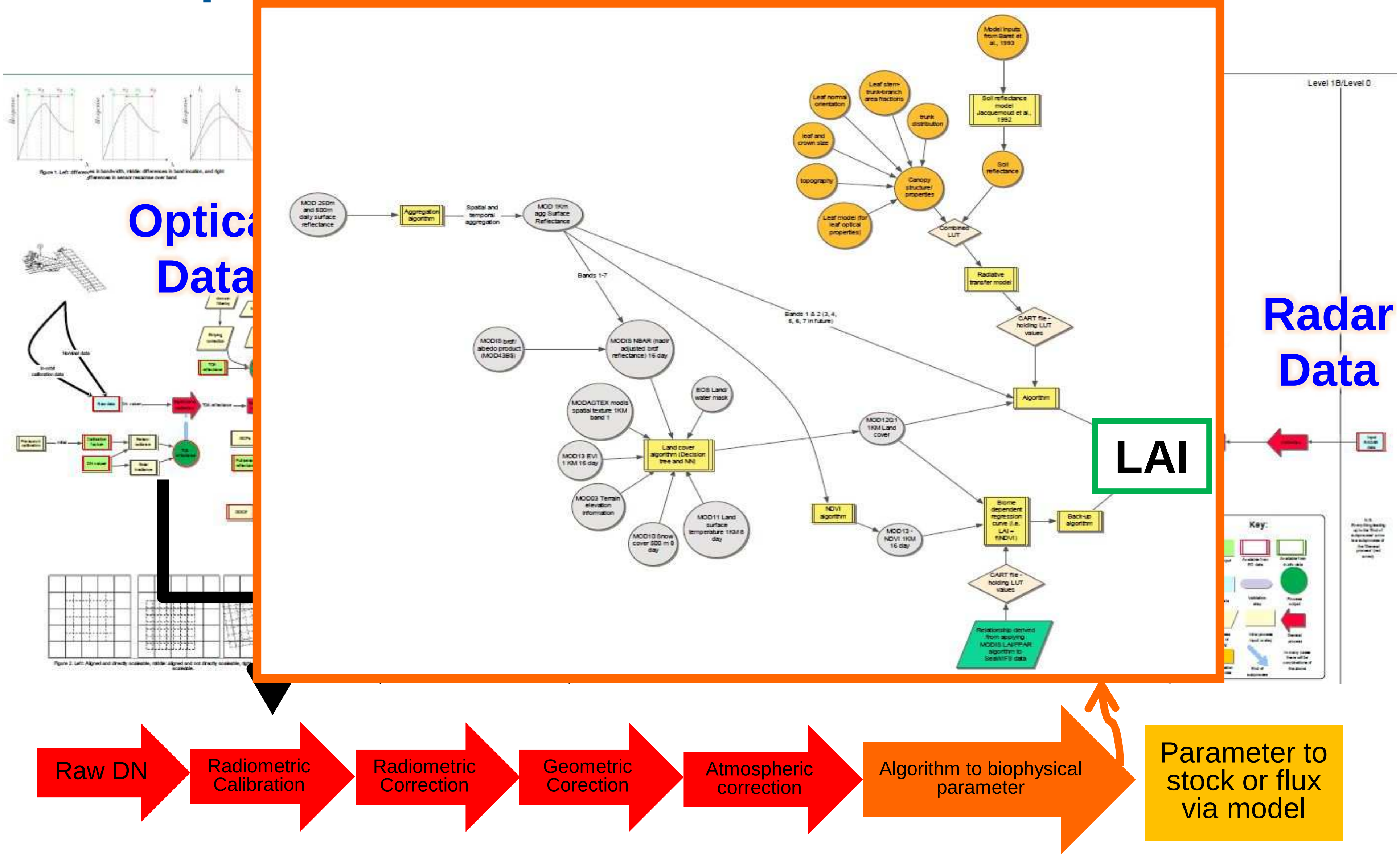




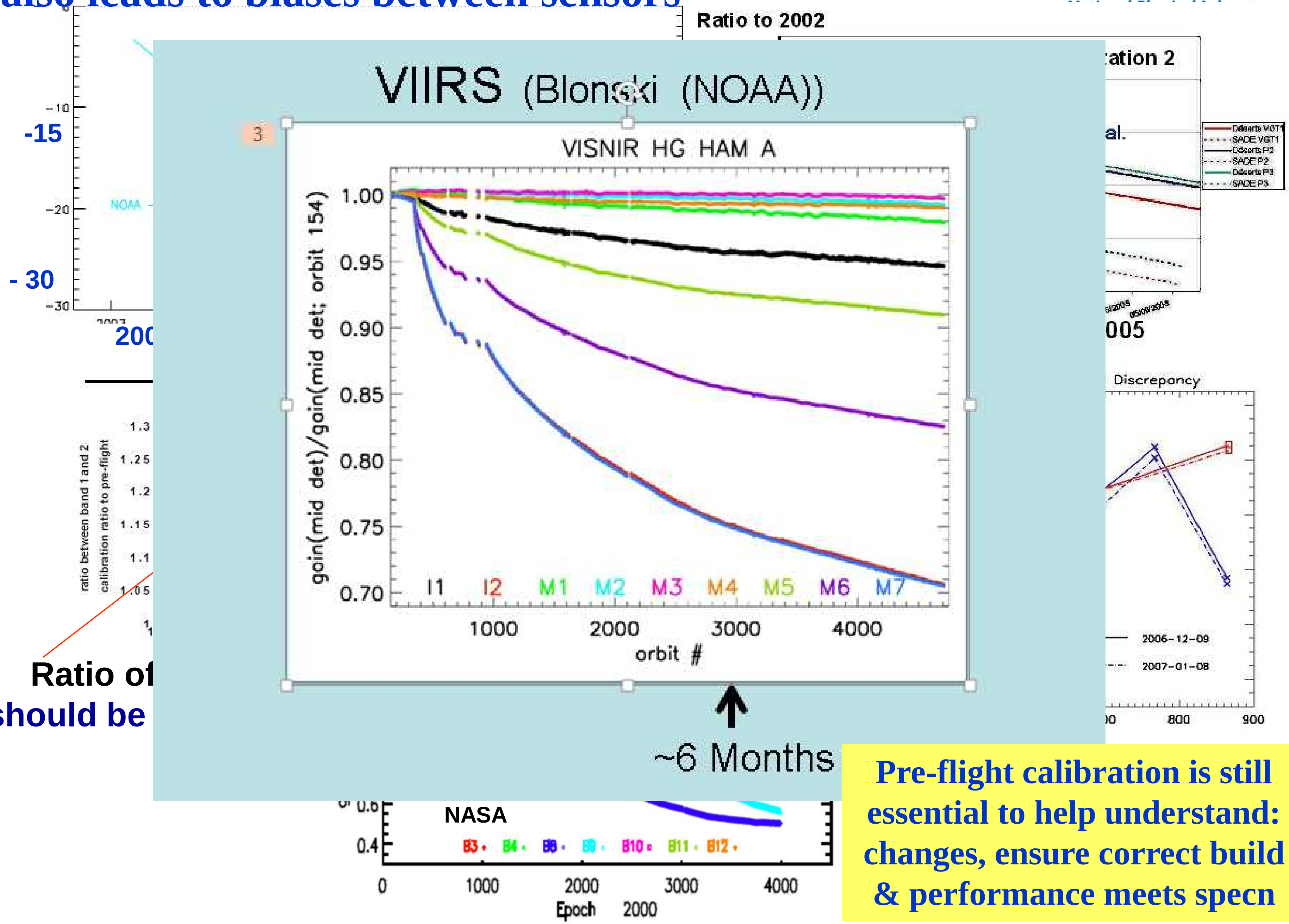
Dependency diagram for estimating carbon from space and propagating uncertainties



Dependency diagram for estimating carbon from space and propagating uncertainties



All SR optical sensors drift from pre-flight calibrations – also leads to biases between sensors



Pre-flight calibration is still essential to help understand: changes, ensure correct build & performance meets specn

CEOS WGCV:IVOS “instrumented sites” (LandNet)

Reference stds for radiometric gain (land imagers)

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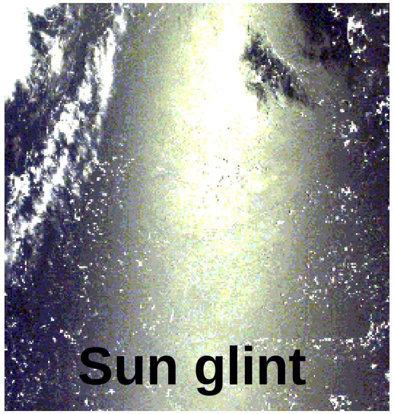
Ideally Need Ten! **Five if fully automated**

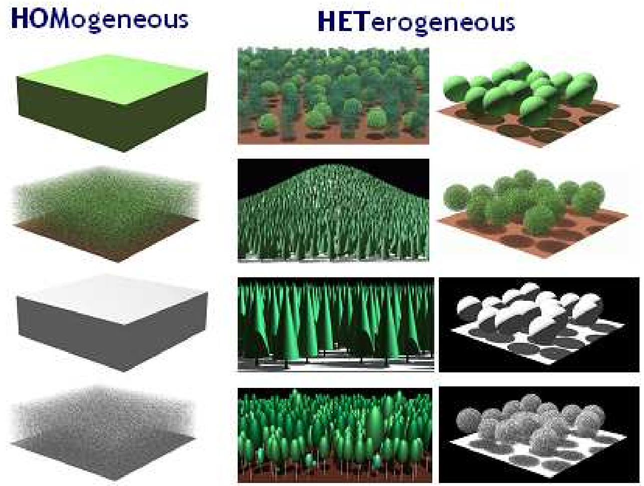
- Spatially uniform, bright, large (pixels from 10’s to 100’s m)
- Standardised procedures to aid characterisation (and for new sites)
- Comparisons of “field measurement” instruments & techniques to ensure consistency and “traceability”

CEOS WGCV IVOS: "stability" Reference standards:

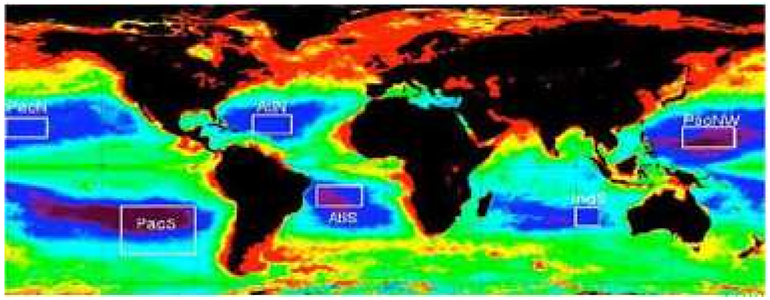
inaccessible for direct surface measurements but temporally stable

“intrinsic standards” (methods) & transient stds





Radiation Transfer model intercomparison (RAMI) of JRC

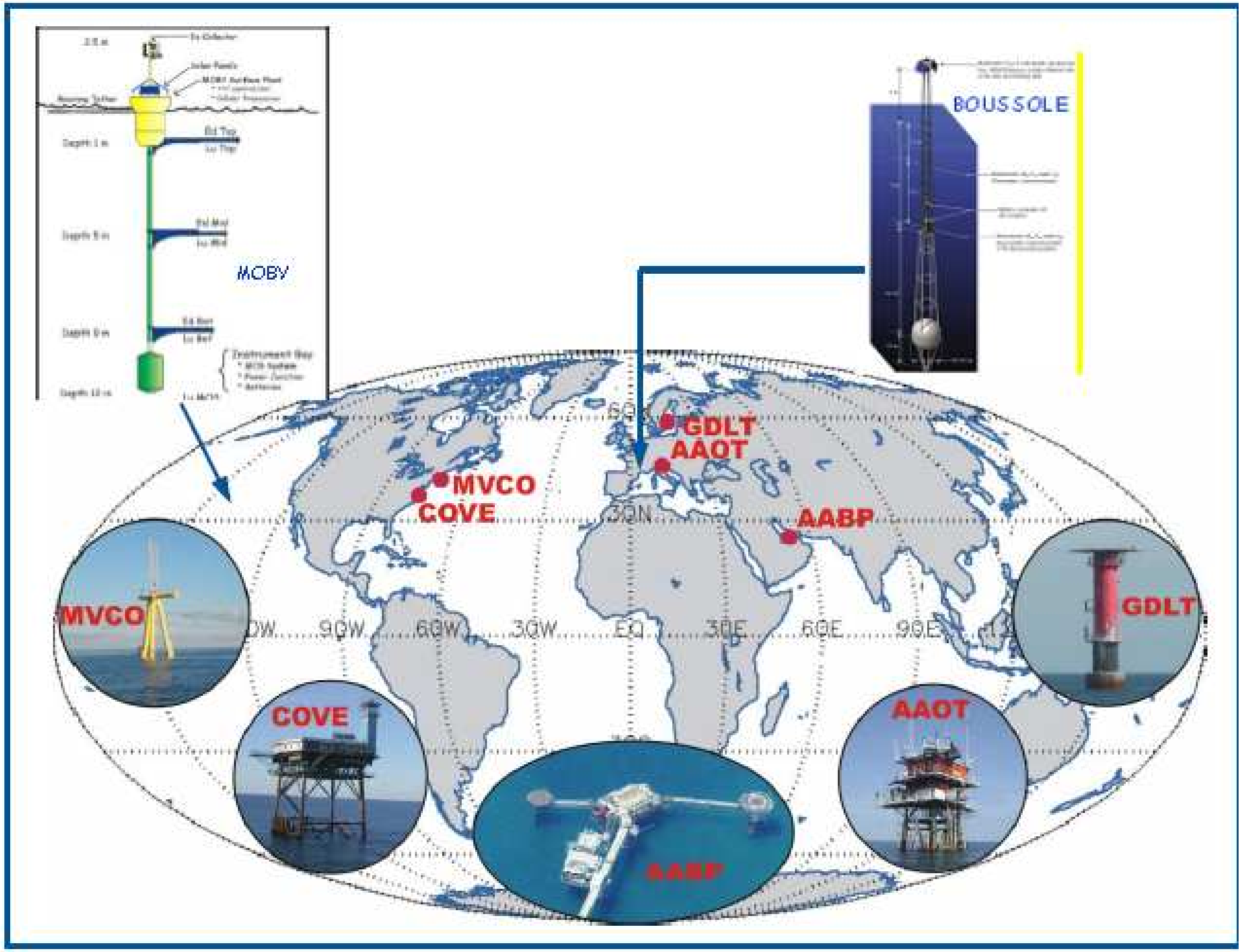


Rayleigh Calibration Sites – Choice of oligotrophic areas with 2 years of SeaWiFS data made in 2001 with ACRI and LOV (CLIMZOO zones)

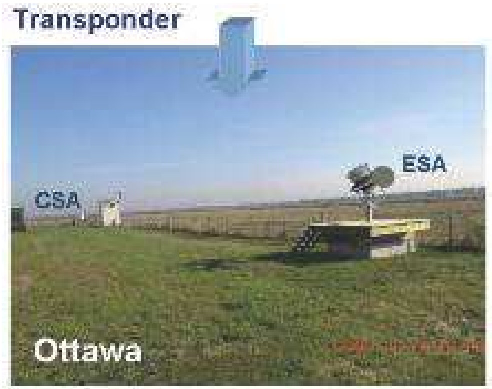
Ocean buoys & ships

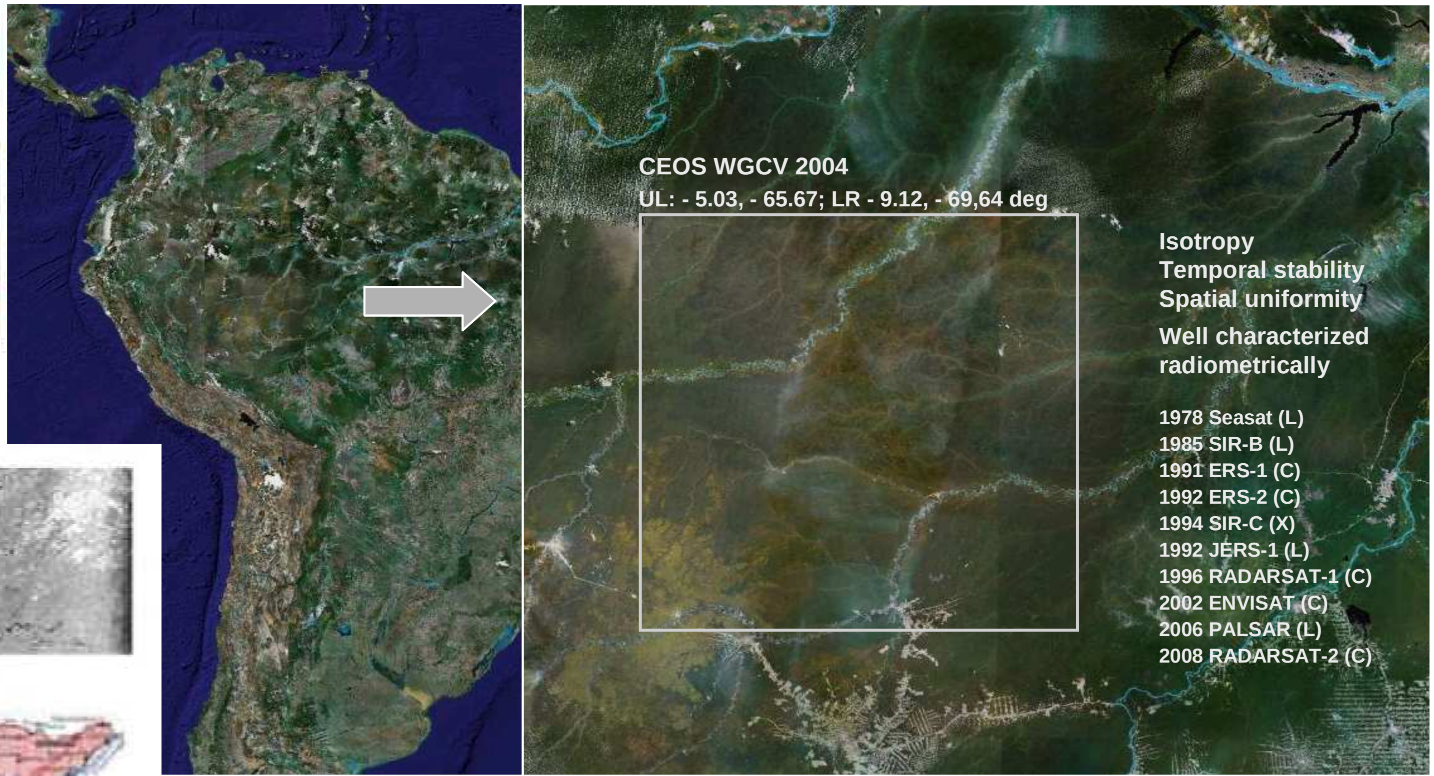
“test data sets” to evaluate models, algorithms and software

Ocean Colour system calibration/validation



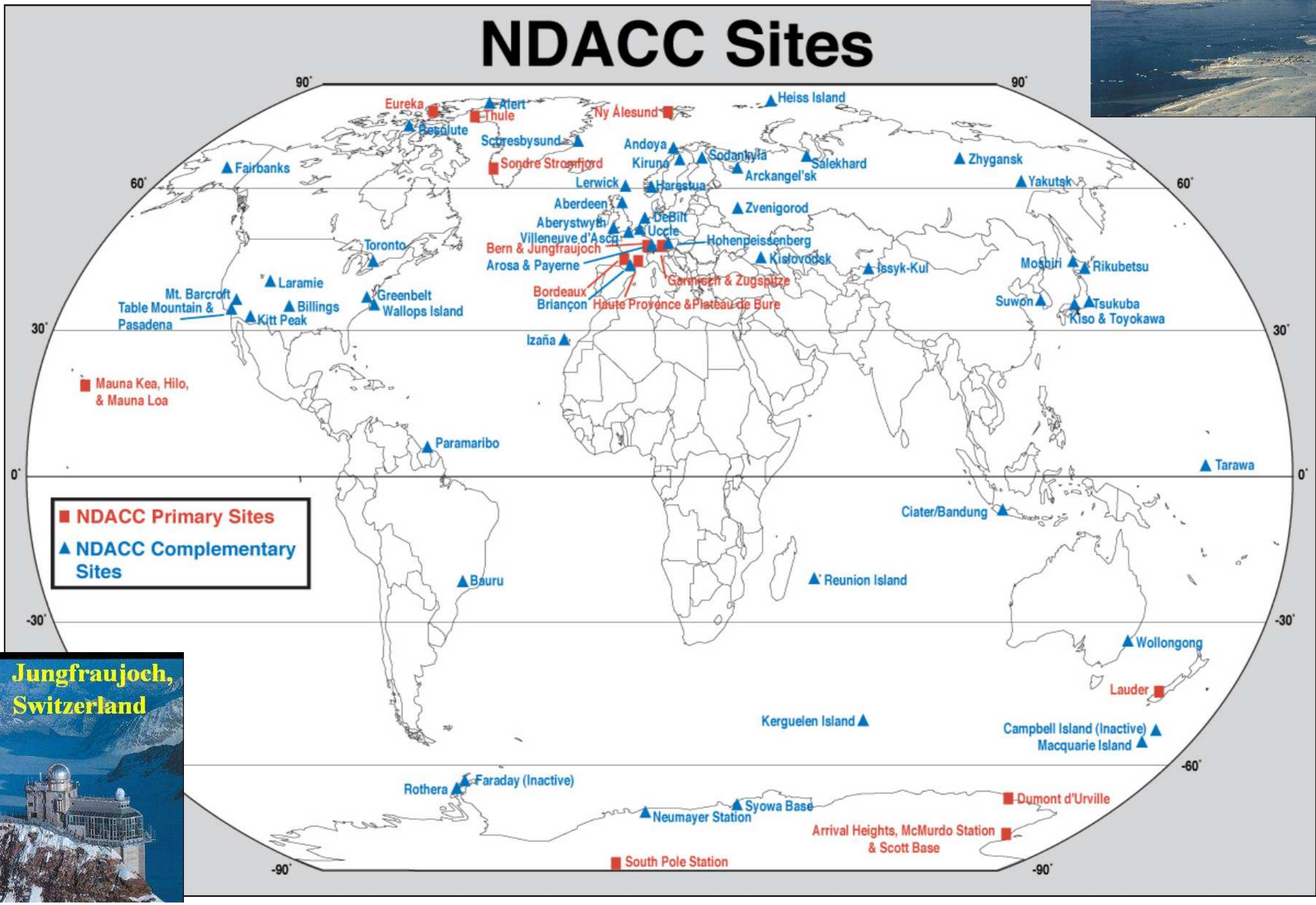
Reference standards for SAR (Synthetic Aperture Radar)imagers



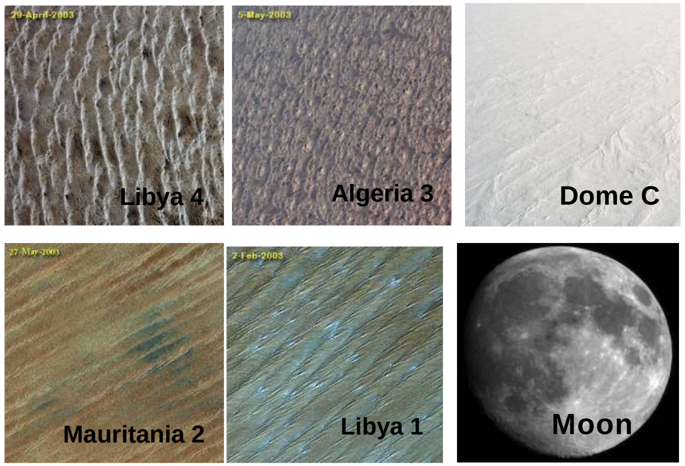


Combinations of Natural and man-made standards

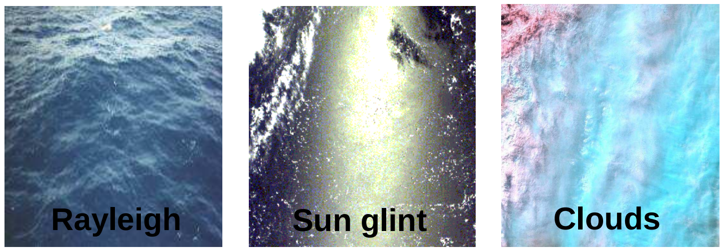
Atmospheric composition: Reference standard sites (core instruments and procedures)



PICS



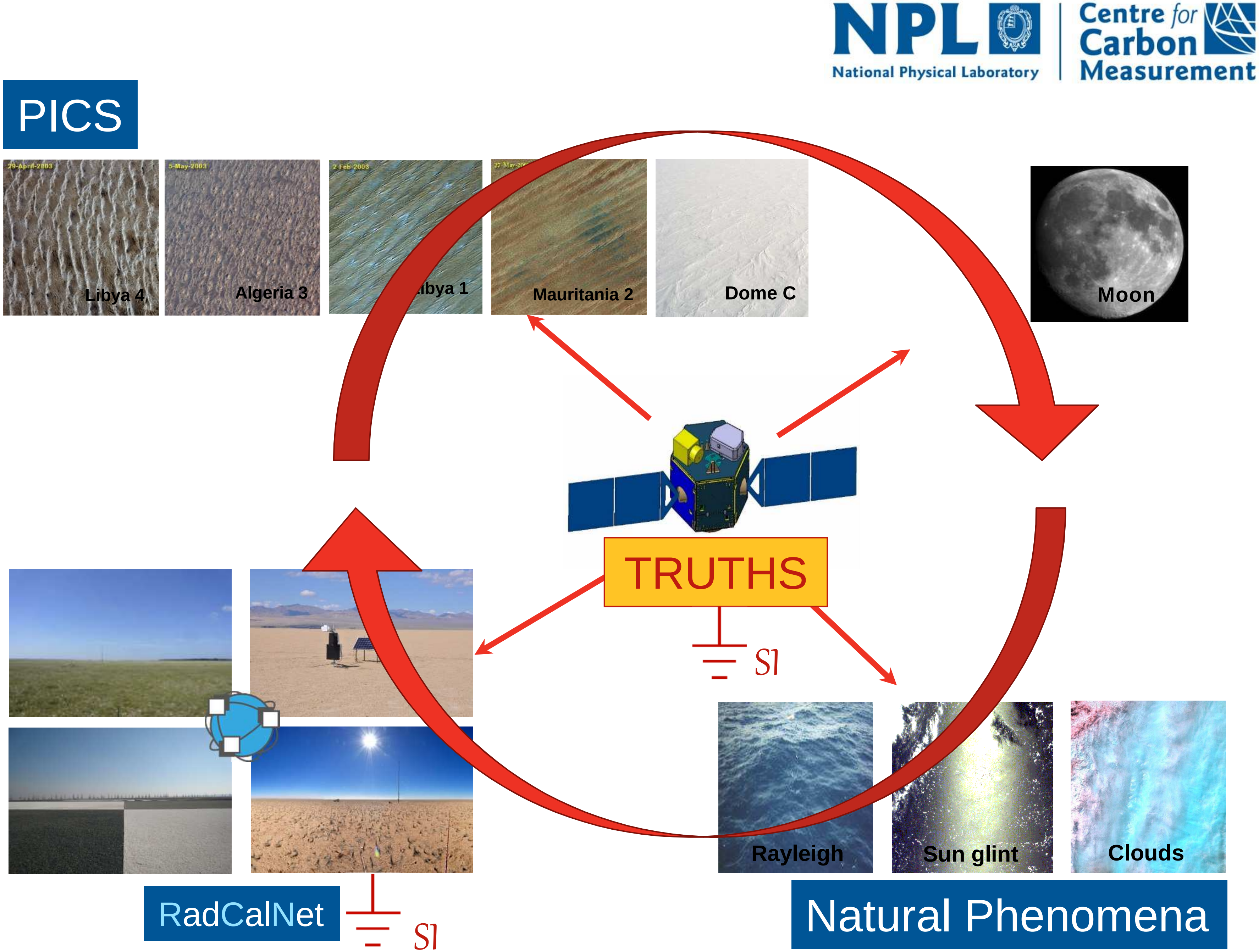
RadCalNet



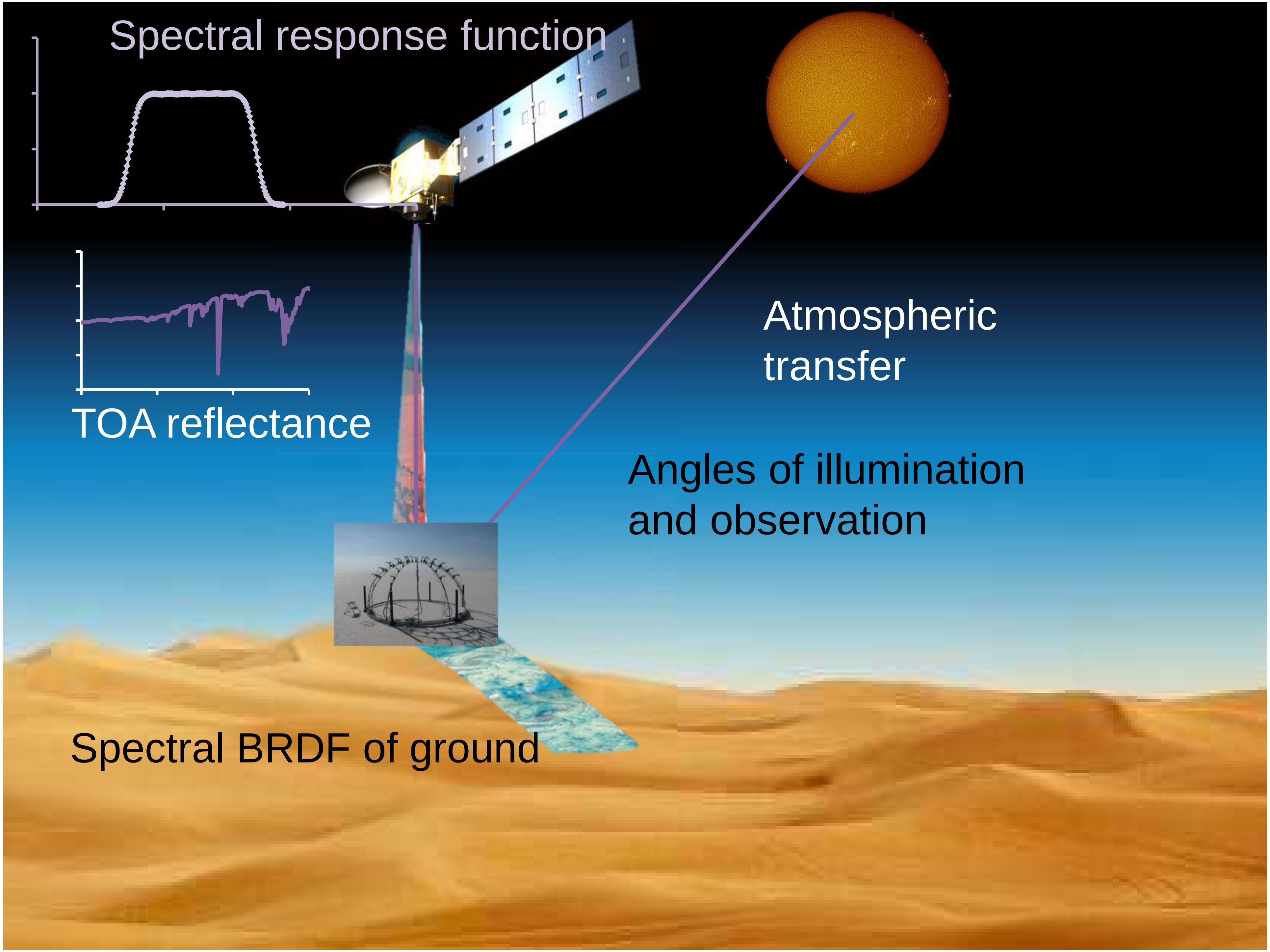
Natural Phenomena

Asking the questions:

- What are intersensor biases?
- What is long-term stability?
- What is the difference to truth?
- Are the sites ‘representative’
- What are interband differences?
- TOA and BOA



NPL National Physical Laboratory
Centre for Carbon Measurement
PICS
Libya 4
Algeria 3
ibya 1
Mauritania 2
Dome C
Moon
TRUTHS
SI
RadCalNet
SI
Rayleigh
Sun glint
Clouds
Natural Phenomena


Spectral response function
TOA reflectance
Atmospheric transfer
Angles of illumination and observation
Spectral BRDF of ground

Characterisation to enable SI traceability has its challenges!

NPL National Physical Laboratory

- Reflectance measured over large areas in short time as illumination source (sun) angle moves
- (Laboratory instruments/concepts need to be adapted to the field
- Suffer Extremes of temperature/environment
- Atmosphere well-characterised & no clouds
- Uncertainty (for climate) factor 5 to 10 too high

Multi-angular reflectance

"Ghost-Busters"

Good Exercise

Also the oceans

"Colour" ↑

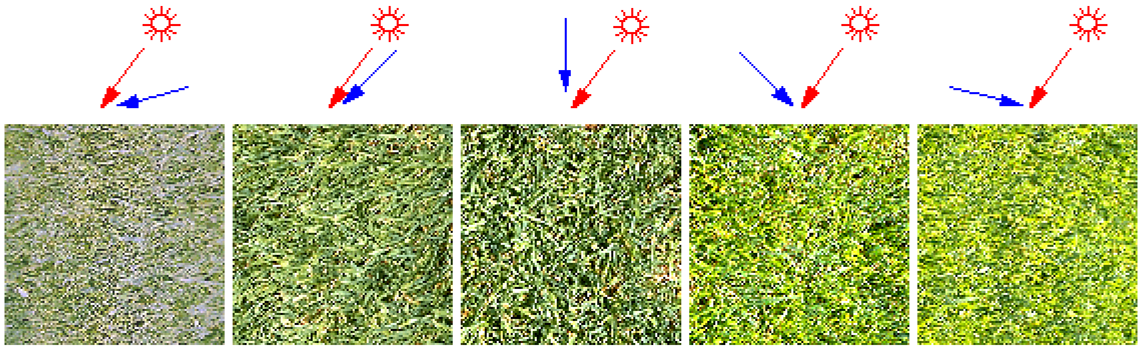
&

Temperature

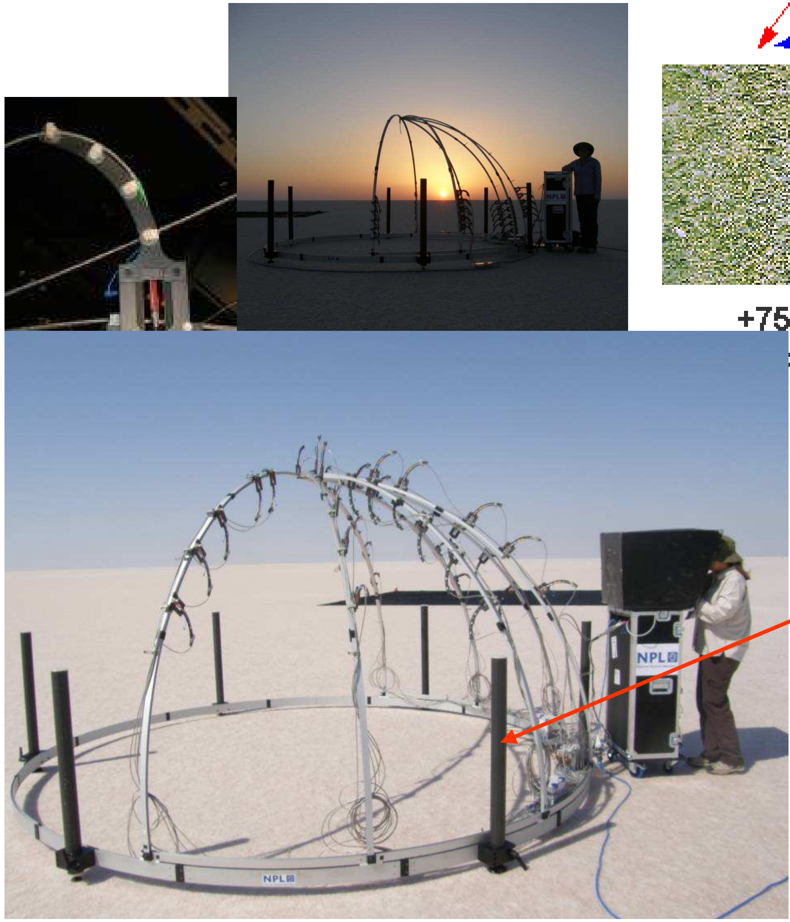
←

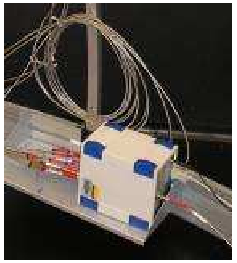
A surprise for the "locals"

Sensors view the Earth at multi-angles & illumination

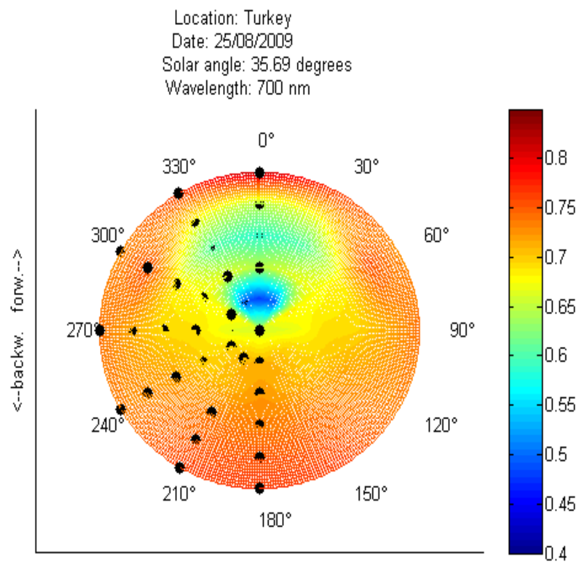


+75° atter)	+45° (backscatter)	0° (nadir)	-45° (forward scatter)	-75° (forward scatter)





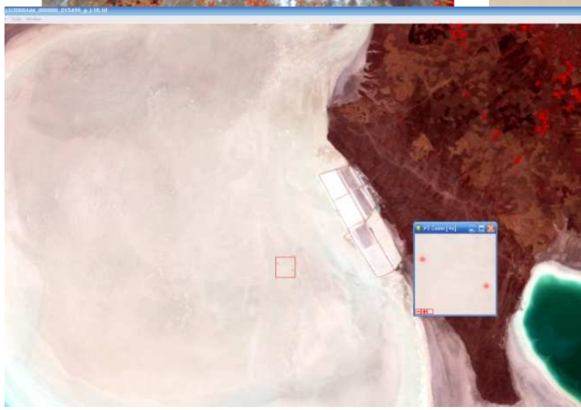
Legs allow structure to stand above vegetation (1 m) and slopes

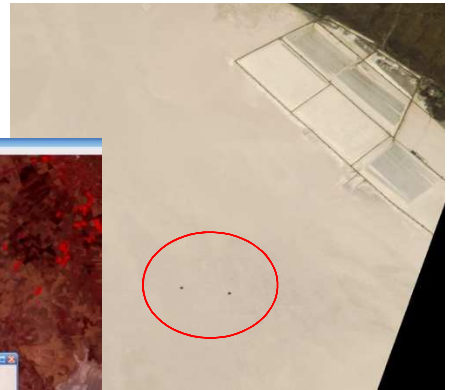


NPL Gonio-Radiometric Absolute Spectrometer System (**GRASS**), measurements of both surface BRDF, but also angular sky radiance.

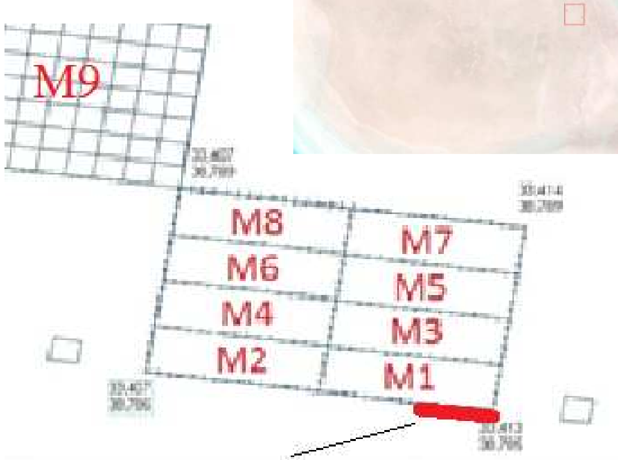
Tuz Golu test site:
Land surface reflectance

~2000 sq km
of salt





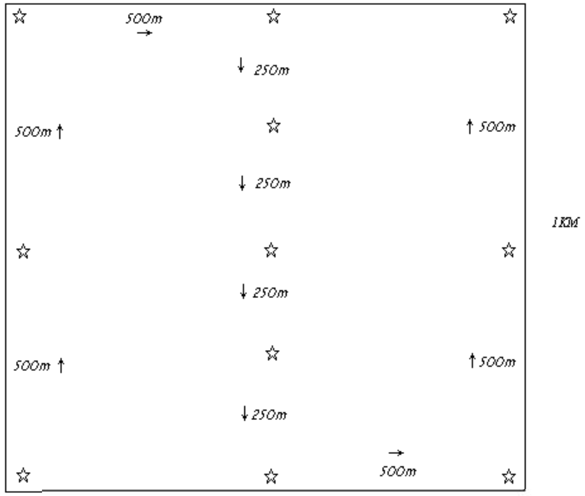
~50 m sq
of black
plastic

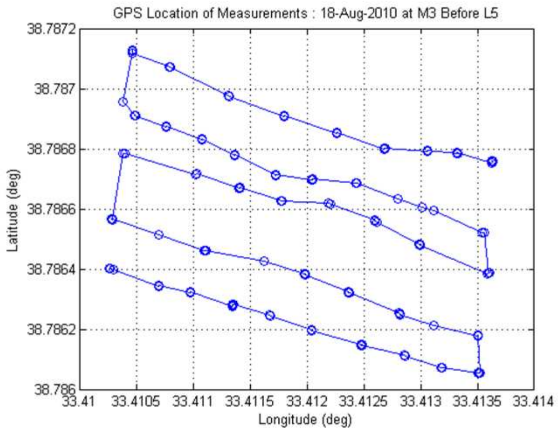


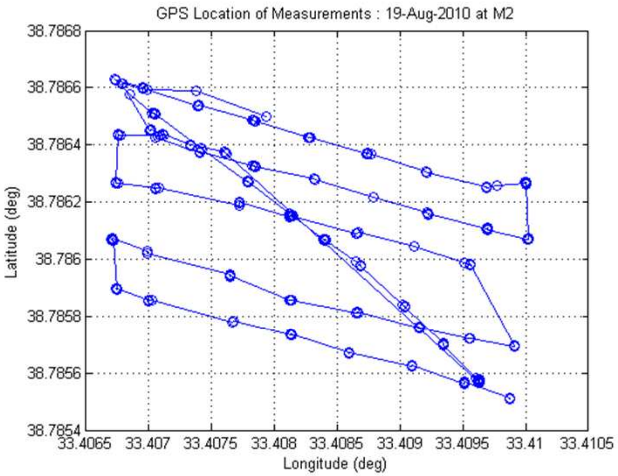
Targets (M1 to M8)
100 x 300 m

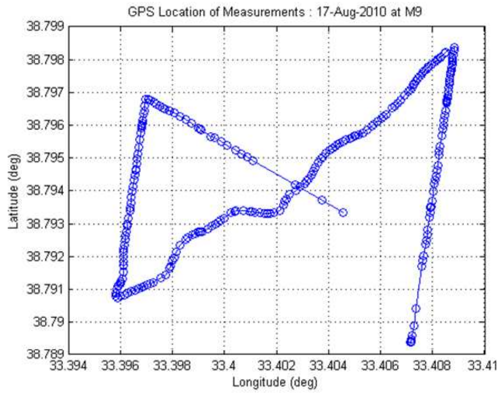
M9 1 x 1 km

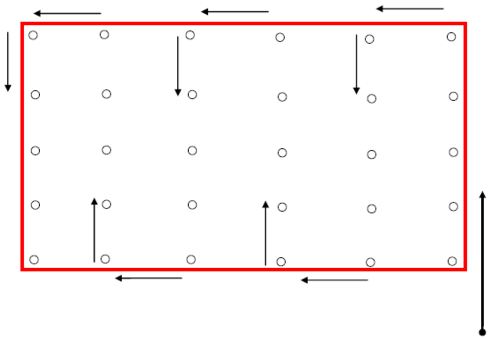
NMIs can help optimise sampling – time vs representativeness & and how to assign uncertainty to a sensor (large footprint) viewing at top of atmosphere

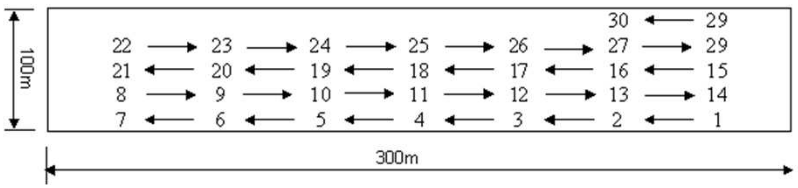


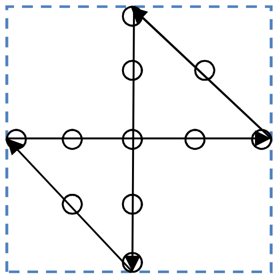












Laboratory & In-field panel calibration

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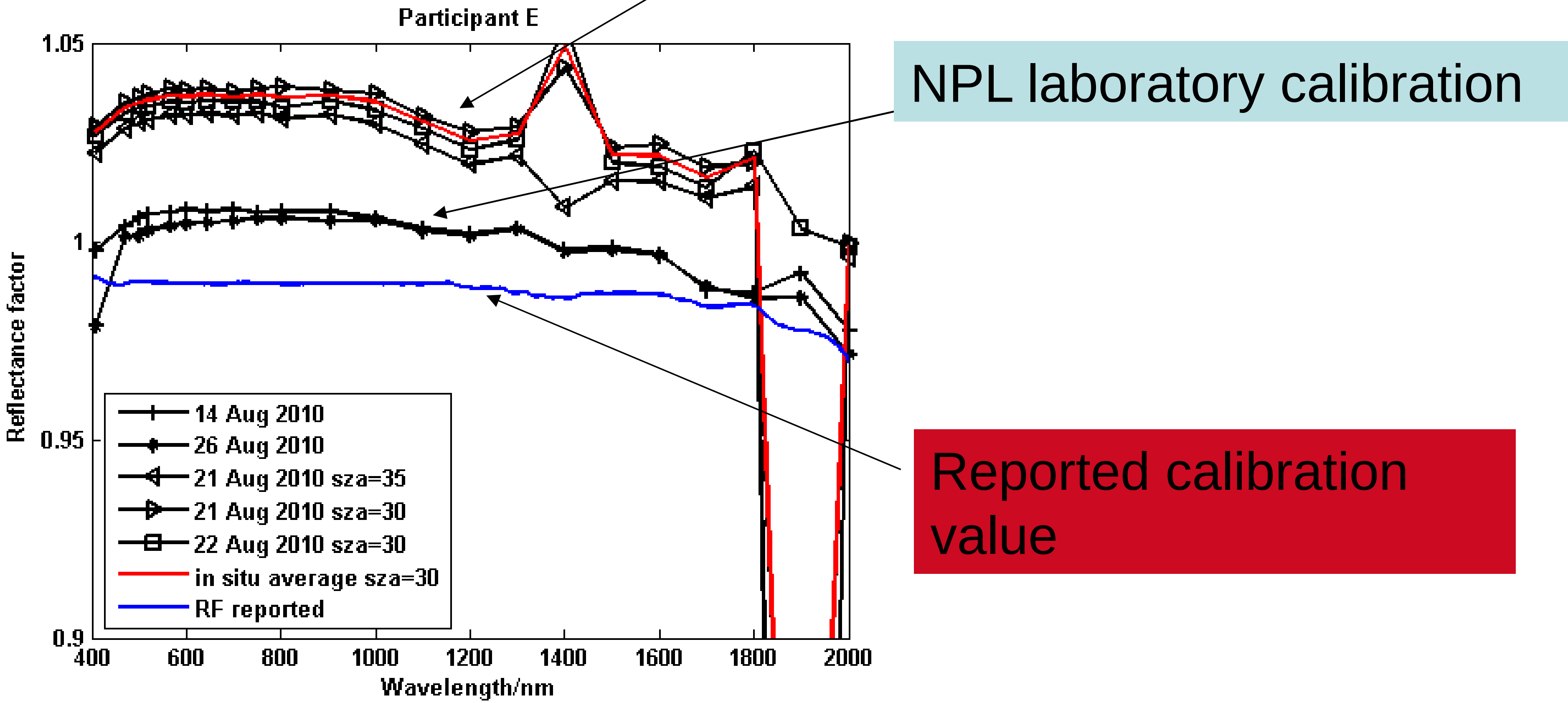
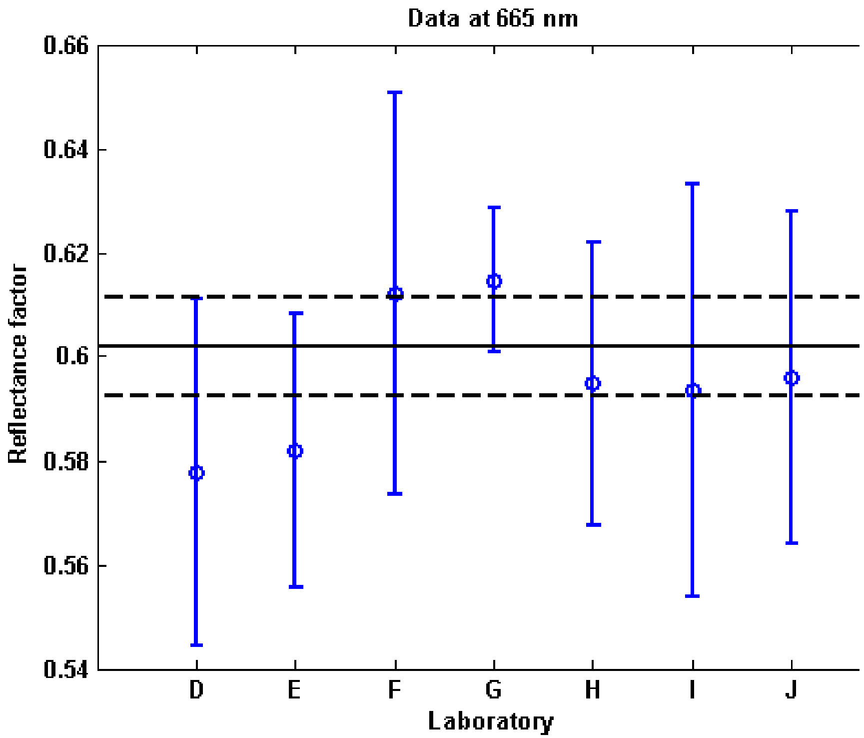


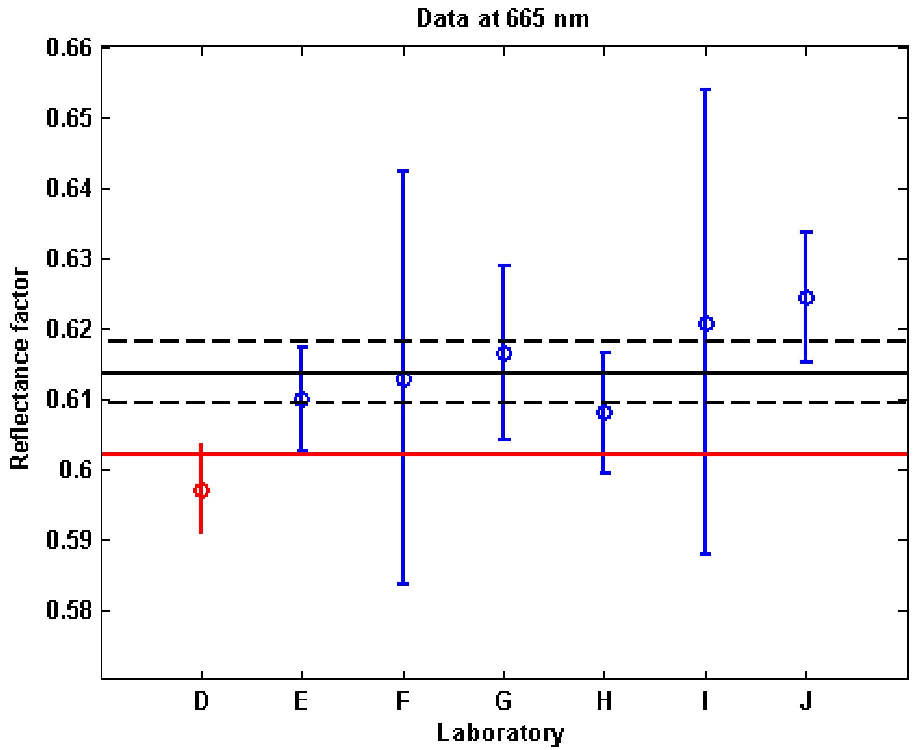
Land surface reflectance:

Site reflectance from different participants

- Reasonably good consistency between participants
- Site calibrated to ~ 1 to 2 %

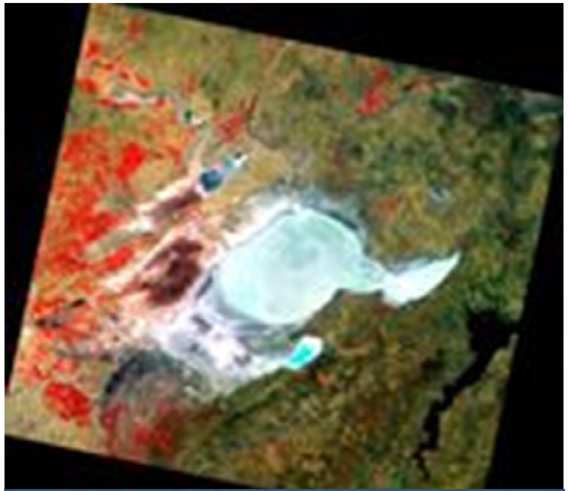


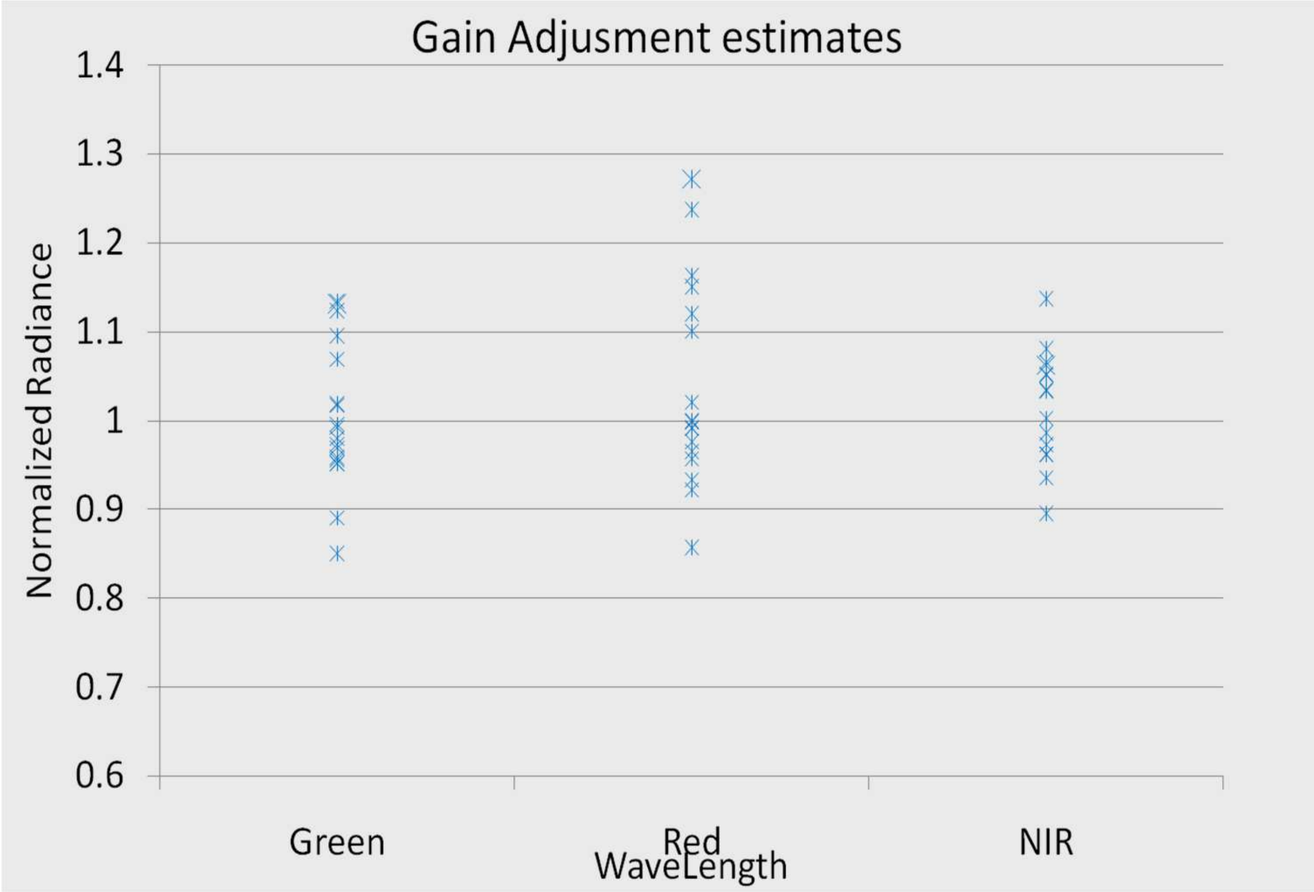
Comparison of results as supplied inc biases and uncertainties from primary calibrations of reference panels.



Comparison of methodologies – type B uncertainties are not considered nor is the uncertainty from the NPL reference panel – tougher test.

Satellite to Satellite ToA reflectance comparison



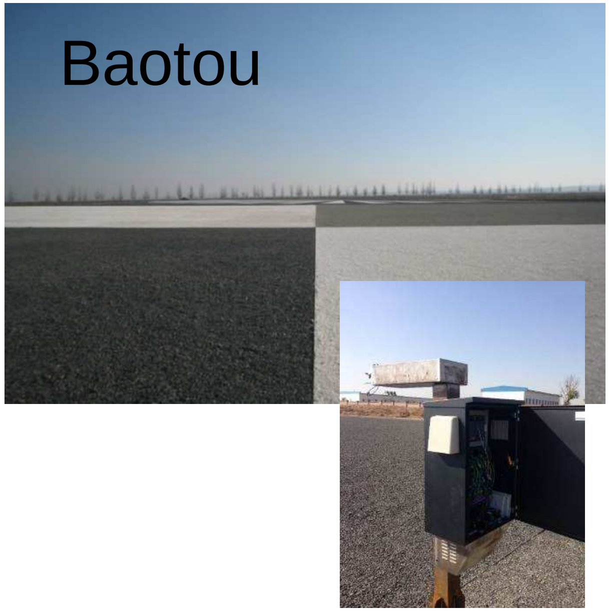


Individual sensors claimed uncertainties ~ 5 % to meet operational needs e.g. Forests, Land cover …

Climate requires <0.5%!

The sites

3 sites operational, one being established



RadCalNet

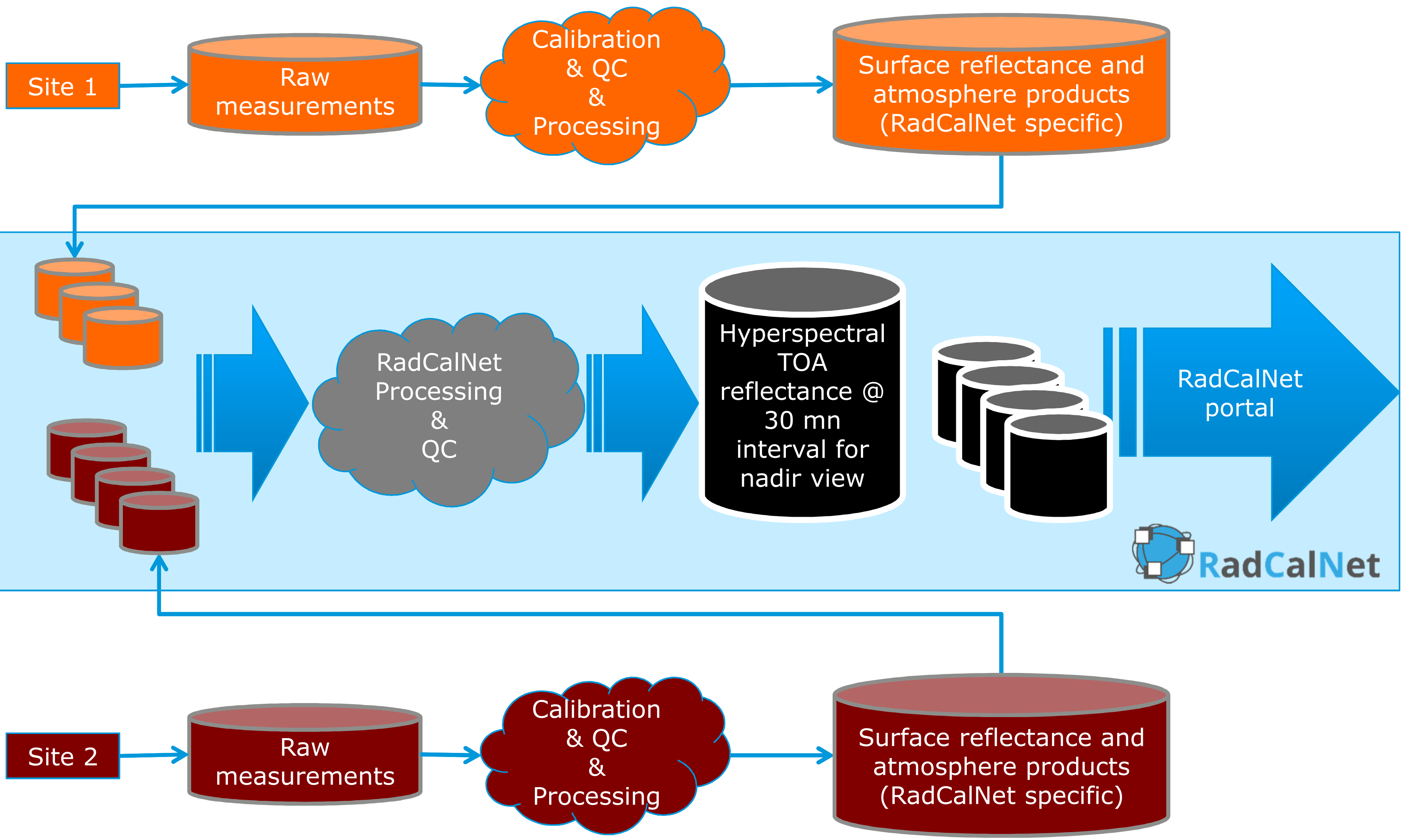
TOA nadir-view hyperspectral reflectance every 5 minutes
Individual site measurements documented and traceable

Site Characterisation

Modelling of TOA nadir-view reflectance

Site permanent monitoring (radiometry and atmosphere/weather)

The shared vision of RadCalNet

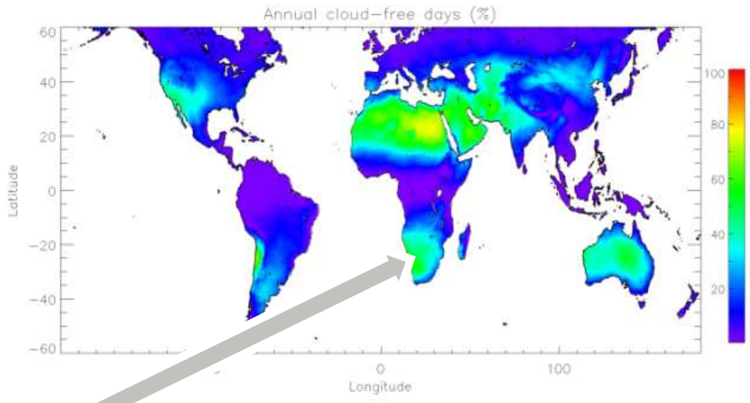


Global search for a new site

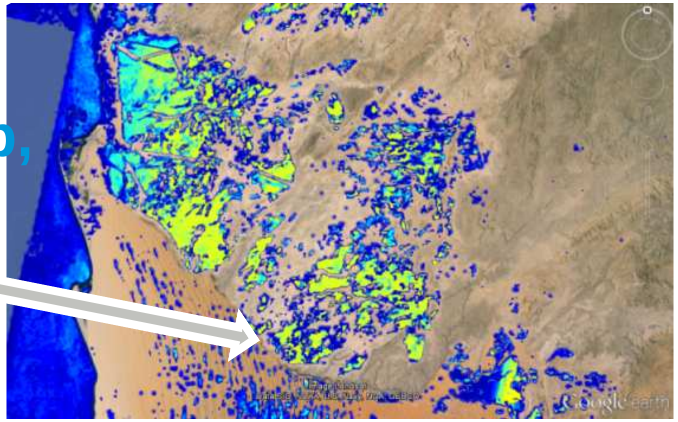
look for a new site (ESA+CNES) as part of RadCalNet (Radiometric Calibration Network) supported by NPL

Criteria for <u>global</u> analysis:

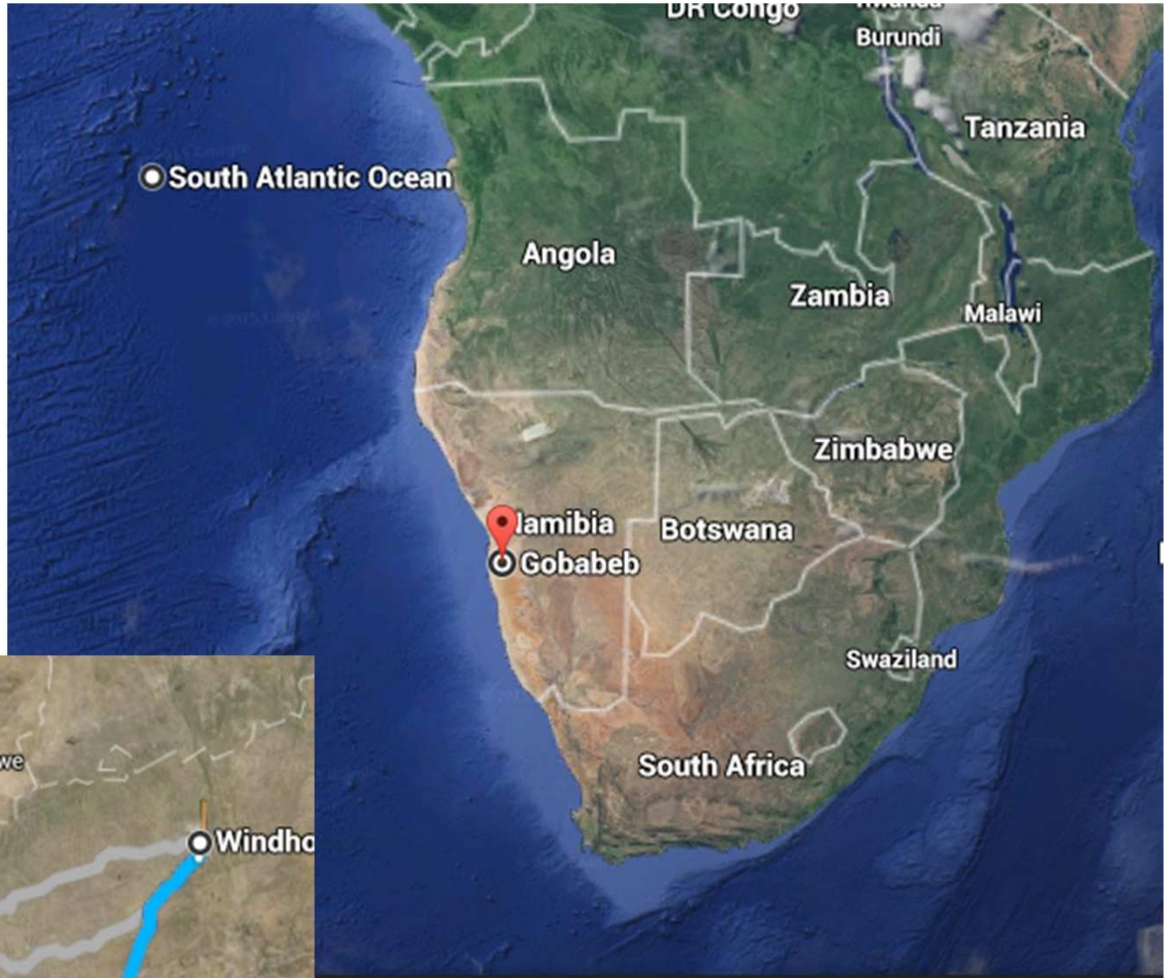
- Low Cloud coverage
- High Spatial homogeneity at several scales (10s of meters to 100s of meters)
- Stability (no vegetation)
- Low Atmospheric changes (atmospheric particles, water wapor…)
- Practicaliaties (Access, communication)

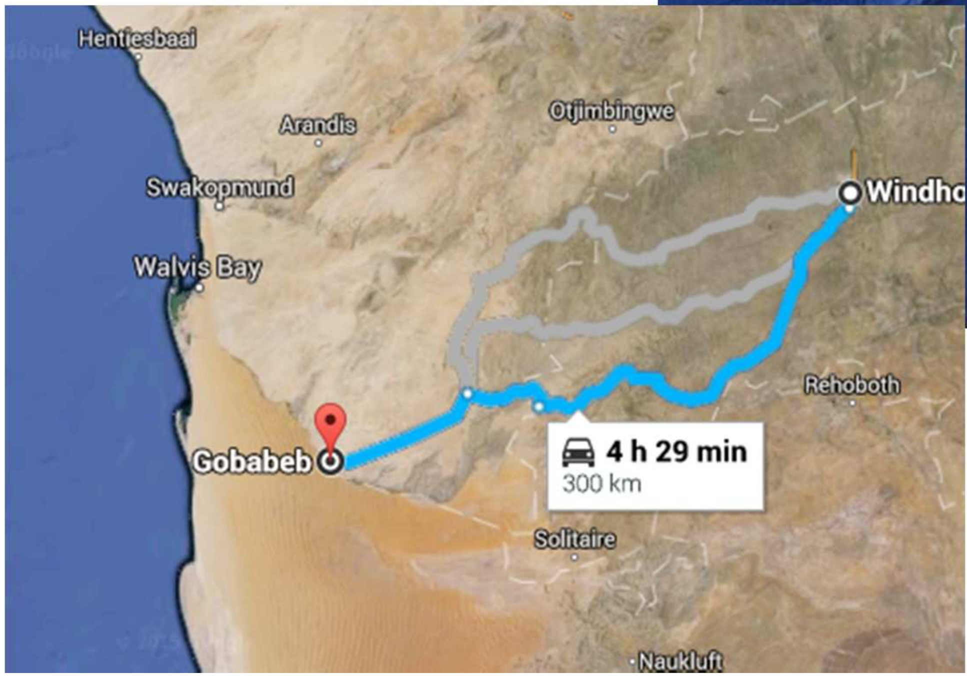


Area of Gobabeb, Namibia



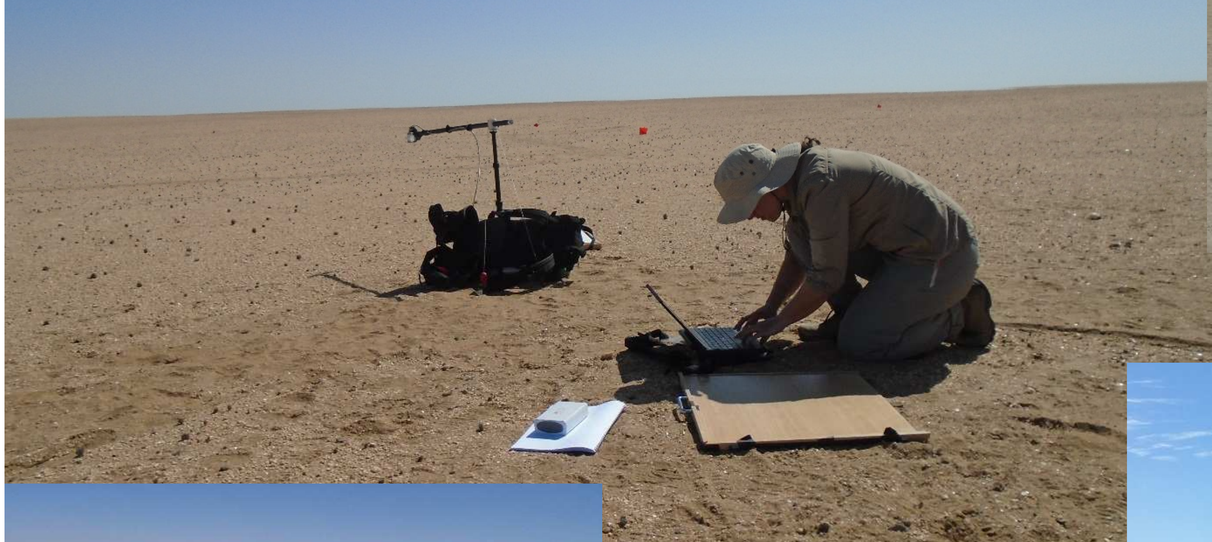
Gobabeb Site

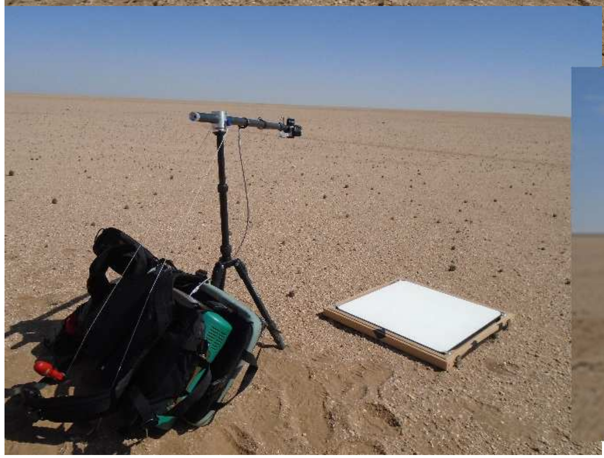




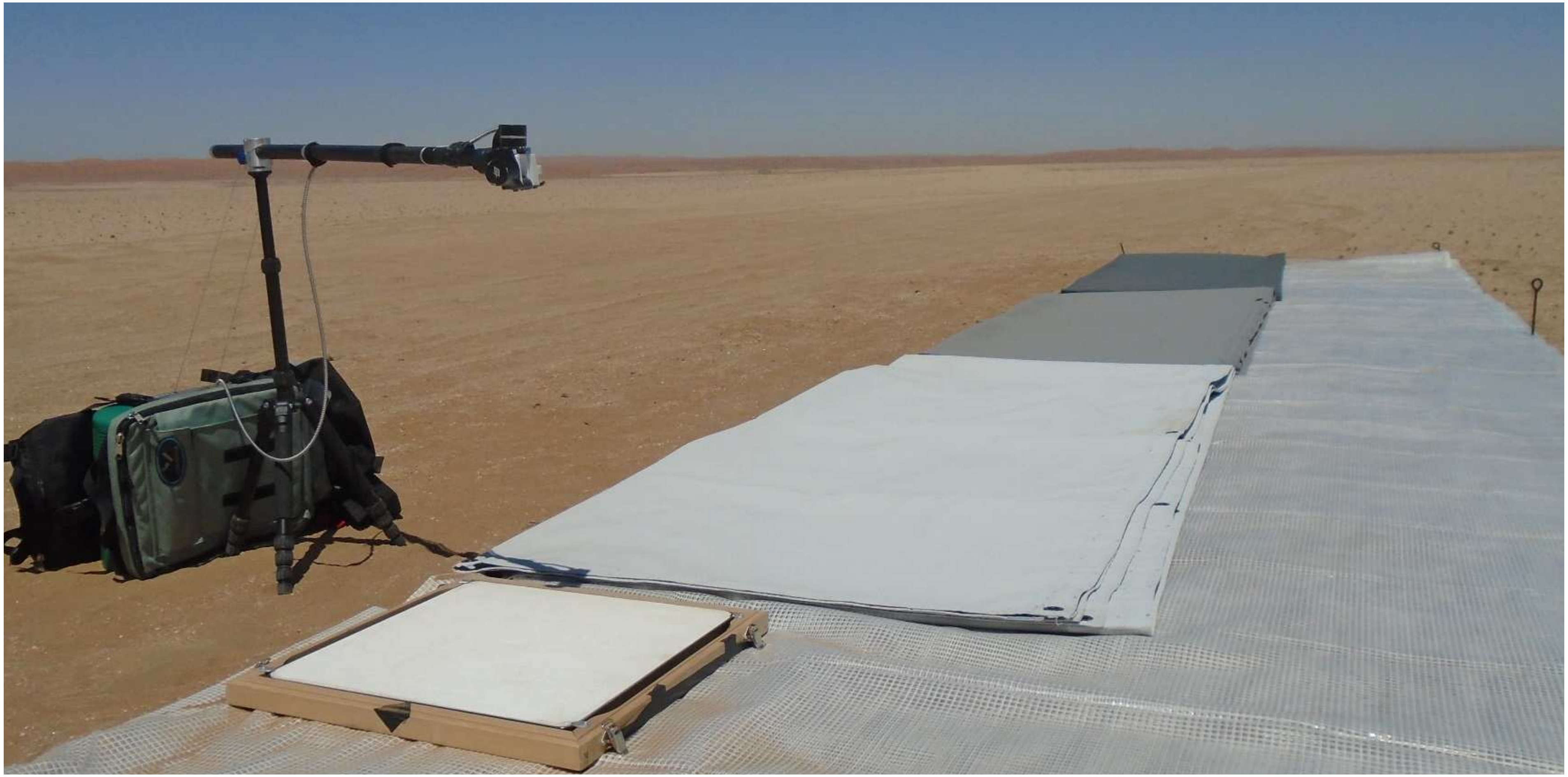
Site Characterisation

- Hyperspectral measurements
- BRF in some cases

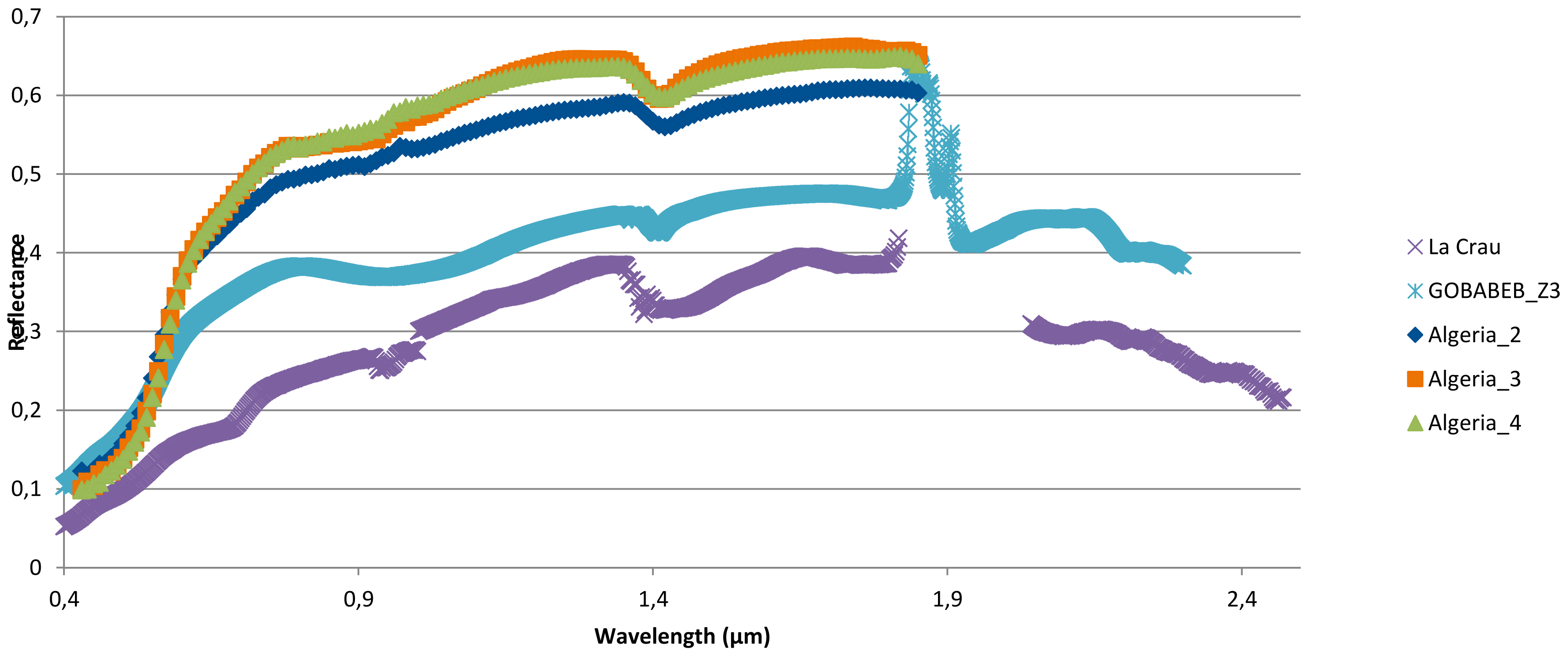




Tarpaulins as ref standards to include ‘sampling’ in Gobabeb



Site reflectance compared to other sites

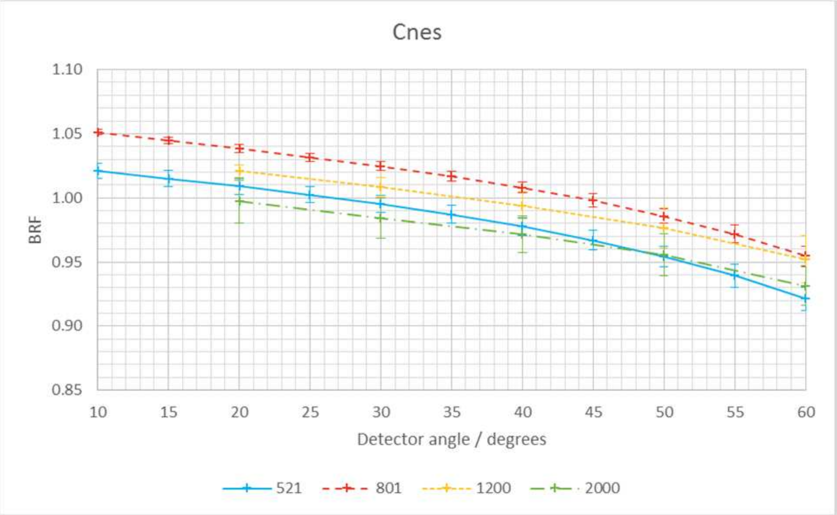


Spectralon panel reflectance monitoring

Spectralon reflectance is modeled as

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

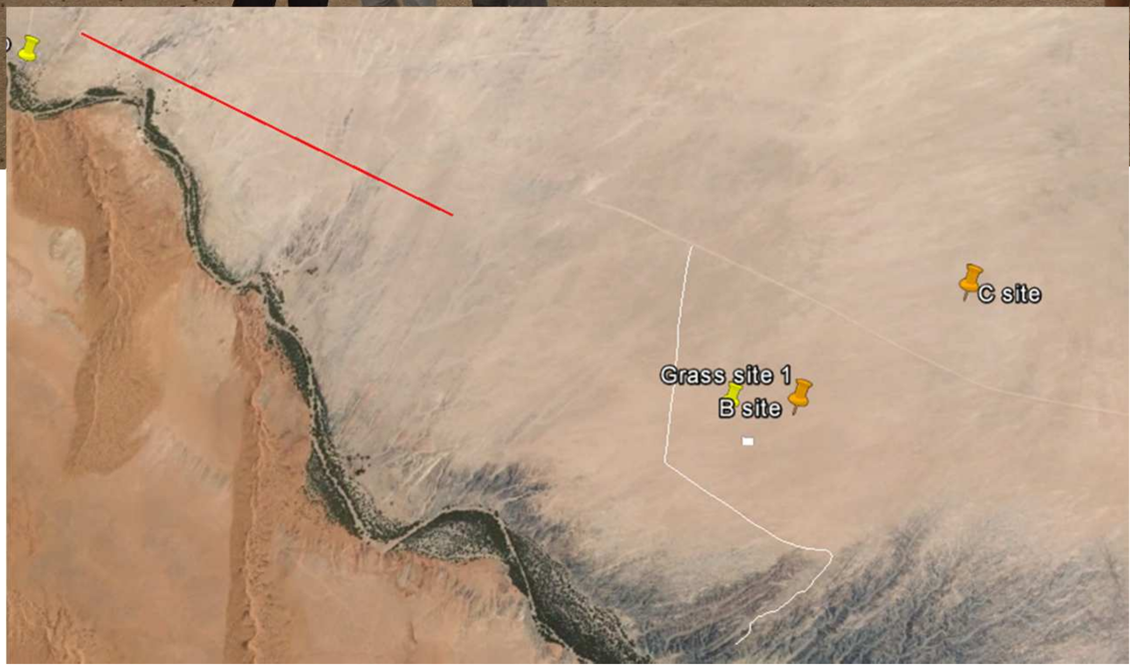
- **Direct and diffuse irradiances (E_{dir}, E_{dif}) given by 6S for each measurement**
- **Directionnal and hemispheric reflectance (ρ_{direct}, $\rho_{diffuse}$) measured in the lab (NPL)**
- **Day-to-day variations (comparison to « super reference » + cleaning) -> dimming factor $f(t)$**



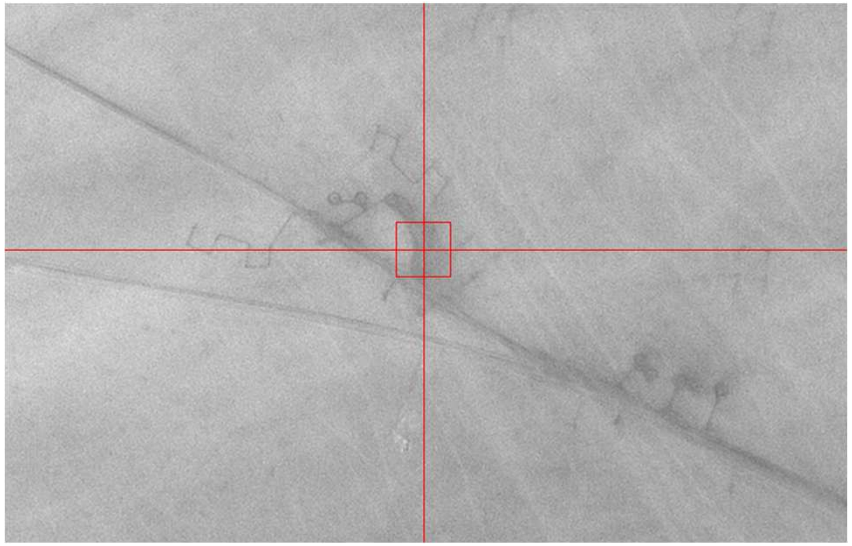
Spectralon BRDF measured in the lab (NPL) – *NPL*

Day-to-day monitoring using a super reference

Mast location



Surface degradation

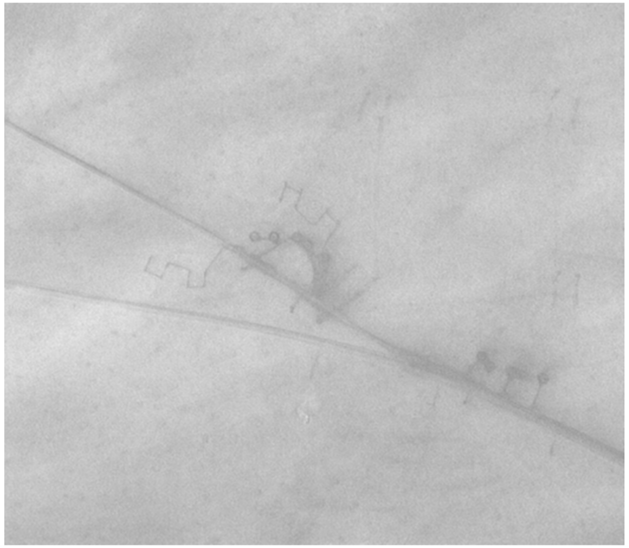


Impact of the characterization campaign

Monitoring using PLEIADES 70cm resolution imagery

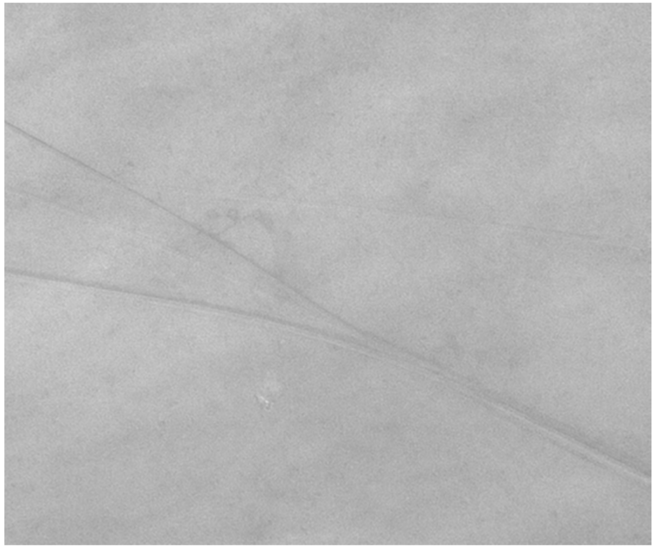
Before
Sept 9th 2015

Right After
Dec. 18th 2015



Footprints Impact: ~6%

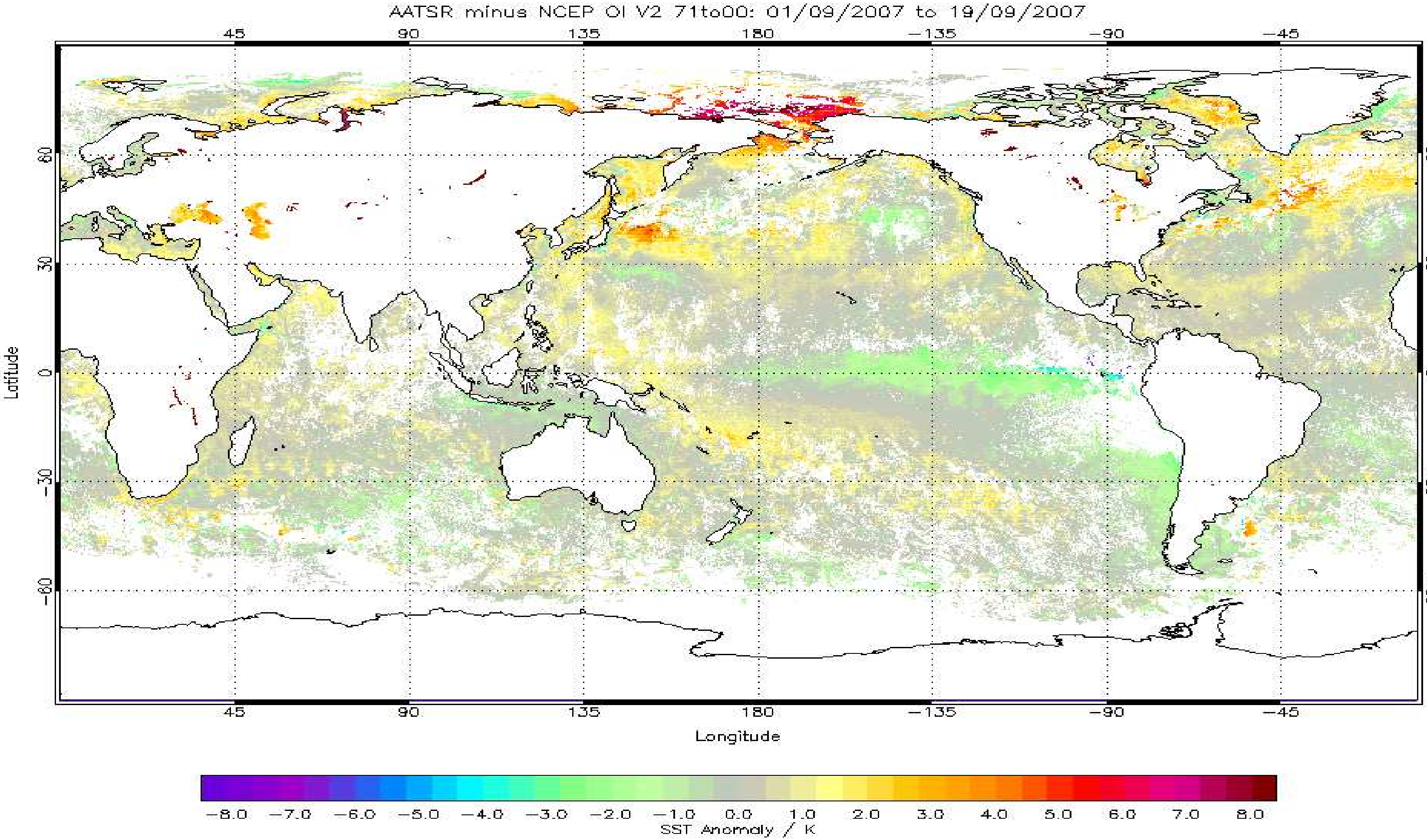
Now
April 27th 2016



Footprints Impact: ~2%

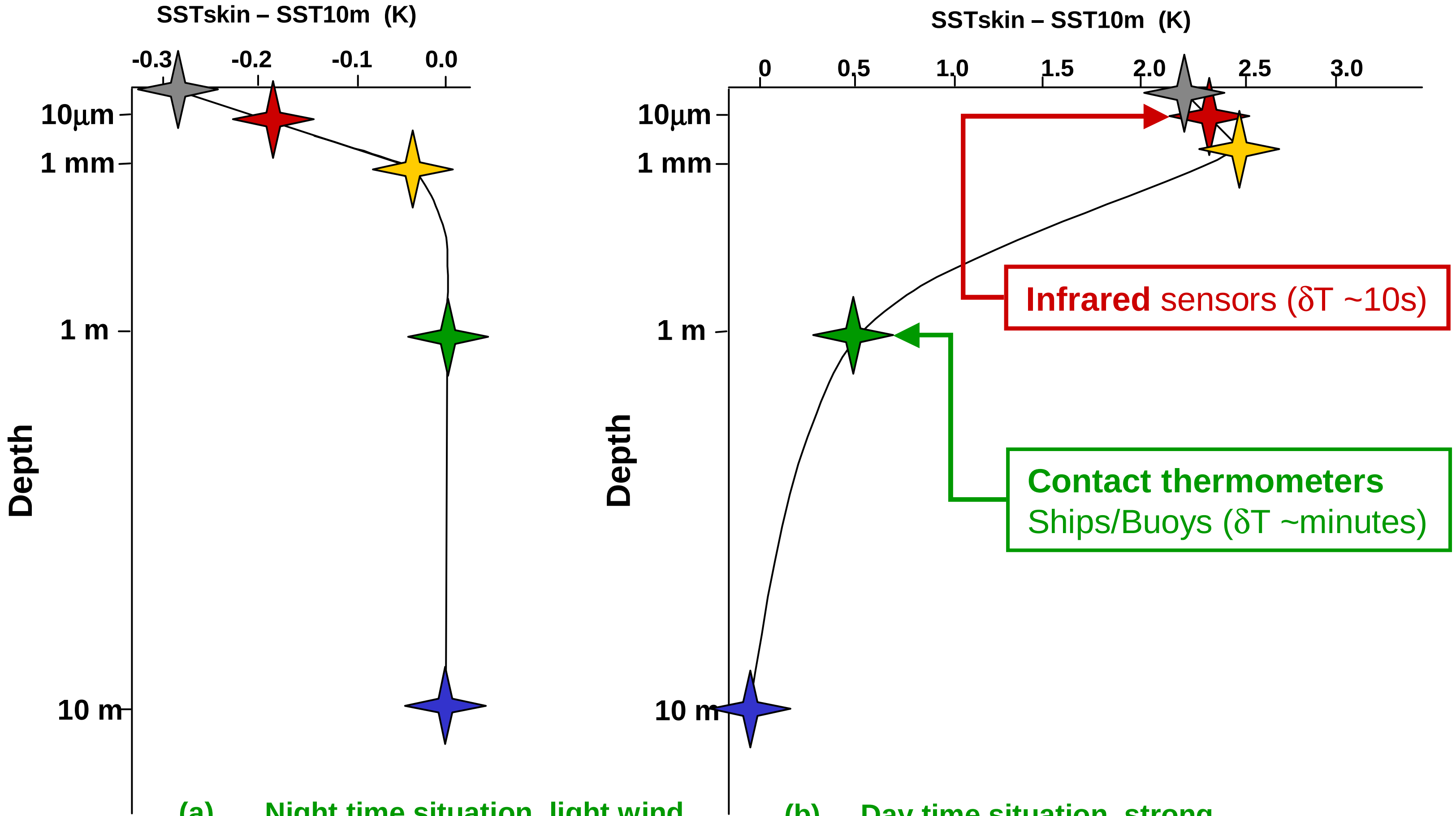
Limited impact and fading away…

Why do we validate SSTs? (Sea Surface Temp)



To debate with the modellers!

Definitions of SST



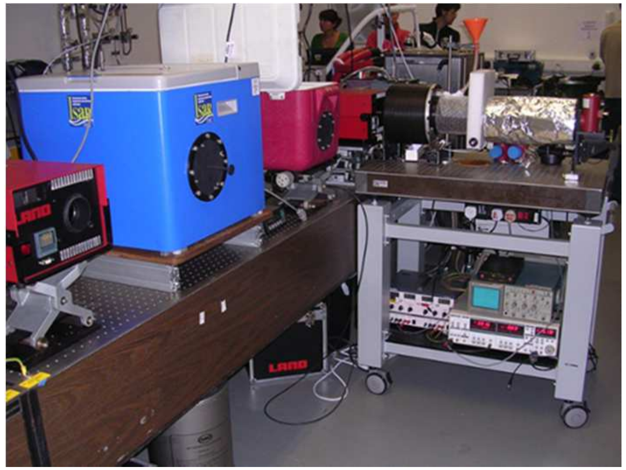
(a) Night time situation, light wind
AATSR 3 channel

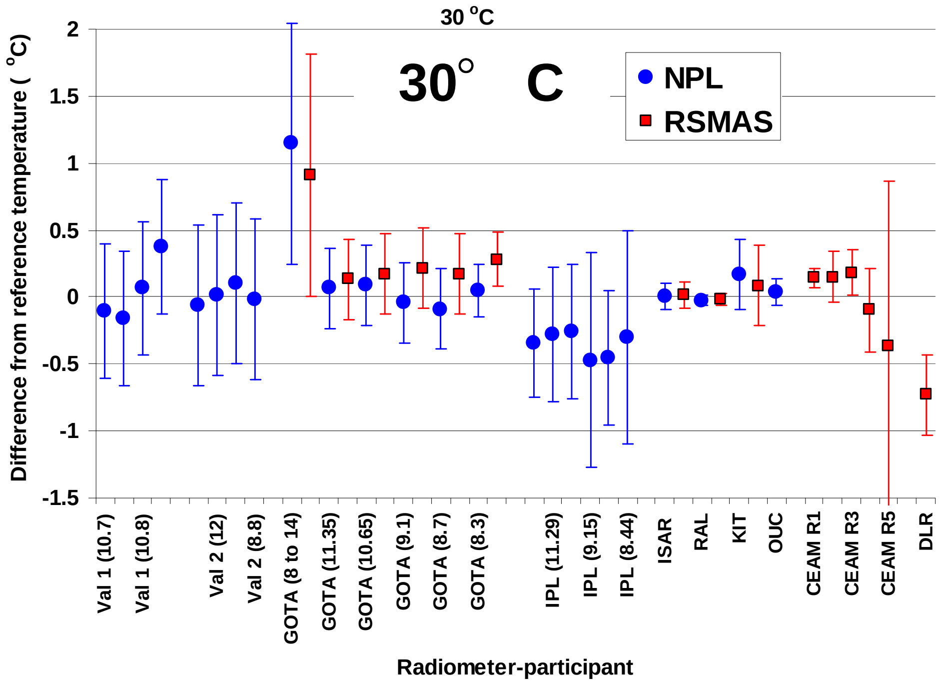
(b) Day time situation, strong solar radiation and light winds
AATSR 2-channel

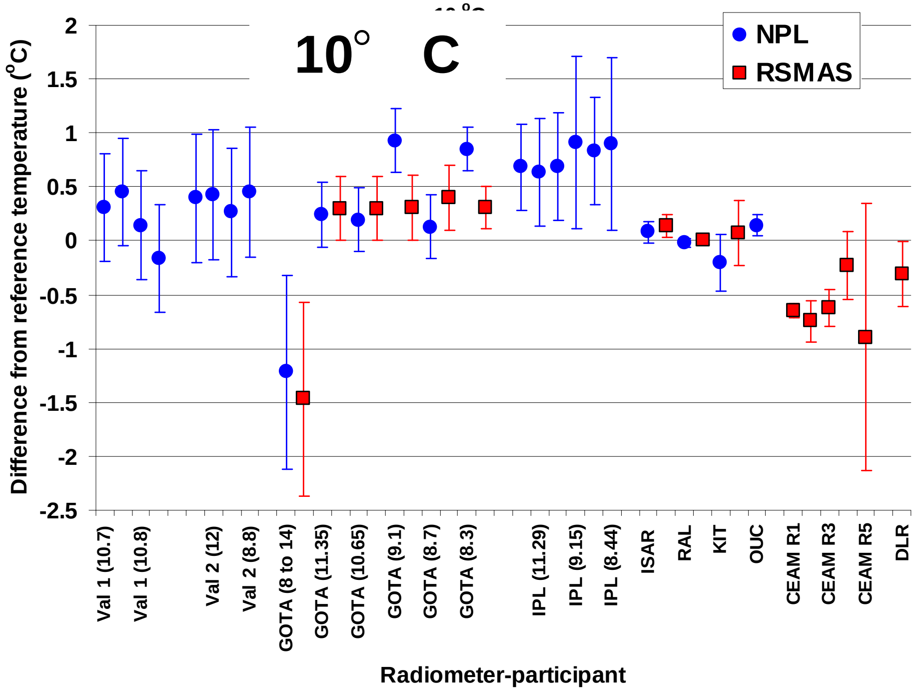
From Craig Donlon (Met Office)

Results of radiometers to a “standard black body” in Lab (NPL and RSMAS) (2010)

- Excellent agreement near ambient but increased variance between participants at cooler temperatures
- Results in UK and US consistent showing stability of radiometers and also agreement between NPL and NIST







2016: 18 participants 30 radiometers

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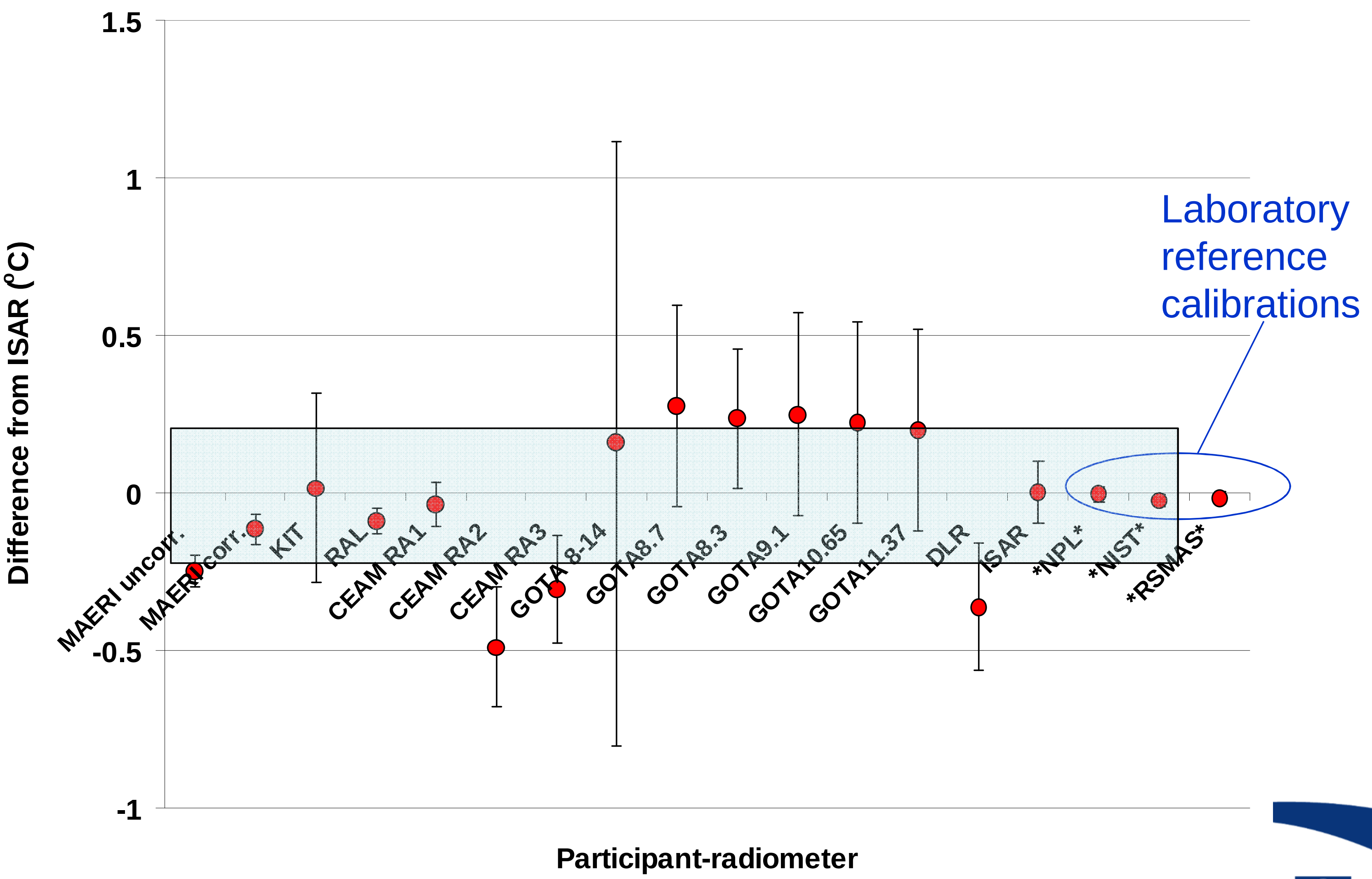
Differences to “selected radiometer” (ISAR) for simultaneous measurements of Ocean (nominal 28 ° C)



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Water Surface Temp (near NPL) (Jun/Jul 2016)

National Physical Laboratory

The floating platform from which WST measurements are due to take place is in the middle of the Wraysbury reservoir. The depth of the reservoir is 20 m.

fiducial reference temperature measurements

LST measurements @ NPL (impact of environment e.g. sky in context of ε) July 2016

Planned LST measurement targets

- The following "targets" are being planned (on the advice of KIT):
- Short green grass (high emissivity at 10 µm).
- Short dry grass (low emissivity at 10 µm).
- Sand / gravel with different SiO_2 contents and grain sizes
- "Dark soil".
- Tarmac.

fiducial reference temperature measurements

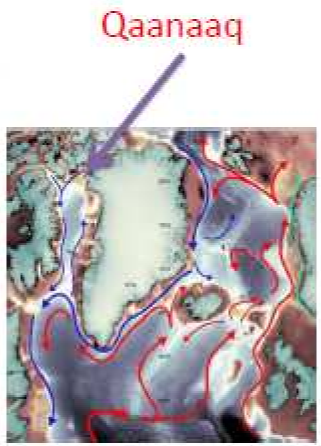
esa

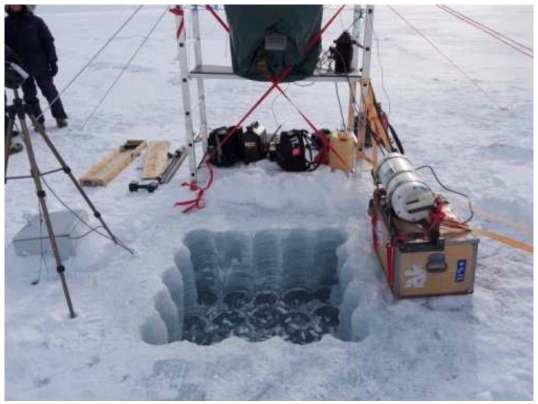
IST 'pilot' comparison (April 2016)

The aim with this study is to evaluate potential variances (non-equivalences) in FRM of TIR radiometers under high latitude sea ice field conditions.

This option will be conducted as four main tasks:

- *Plan and arrange a FICE with focus upon FRM for Ice surface temperature*
- *Conduct an IST FICE in Qaanaaq, Greenland with at least 2 independent FRM TIR radiometers*
- *Process the field campaign data with focus upon SI traceability*
- *Report the results in a technical report/publication*





fiducial reference temperature measurements

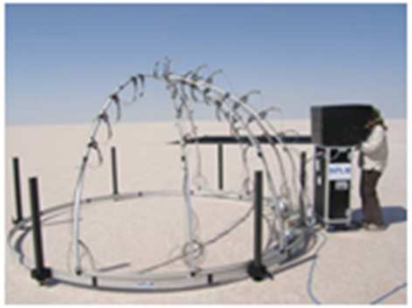
Traceability and Validation of Bio-physical products

National Physical Laboratory

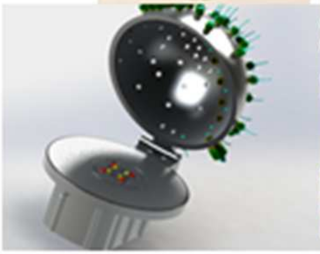
Metrology for Earth Observation and Climate

Field Gonio-meter for spectral reflectance (BRF) of individual leafs

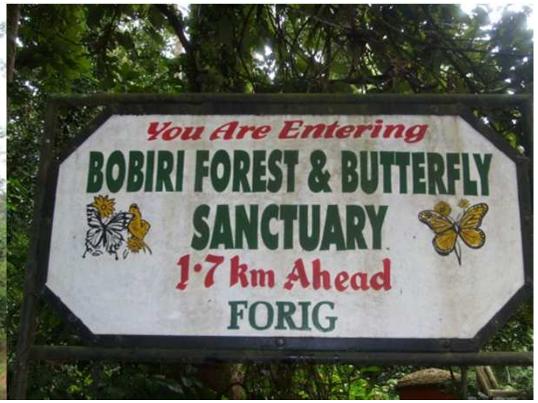
(JRC, INRIM, NPL)



GRASS ~ 2 m diameter

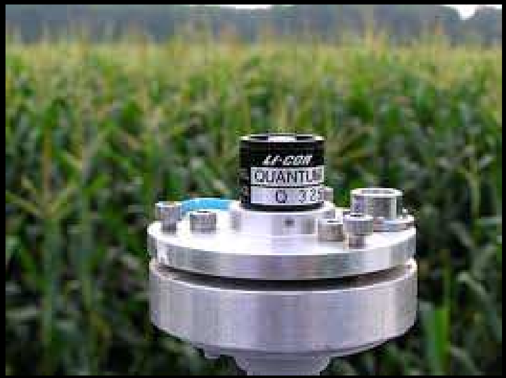


To ~ 20 cm diameter

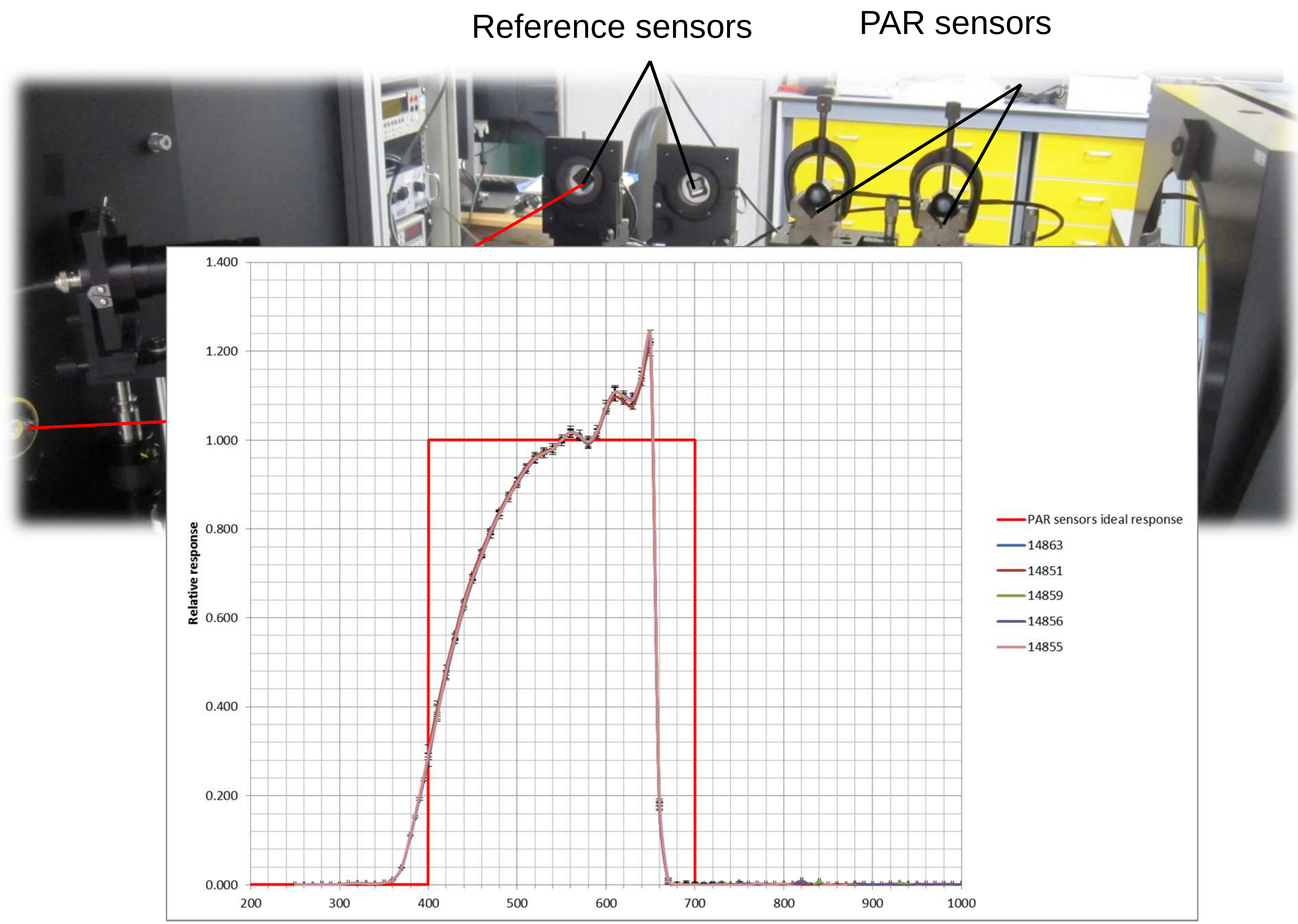


Validation Needs…

- Rigorous calibration of sensors in the laboratory (PAR, LAI)
- Spectral, angular and environmental information



Spectral responsivity



Constructing a large area virtual validation forest stand from terrestrial LiDAR

K. Calders, A. Burt, N.Origo, M. Disney, J. Nightingale,
P. Raumonen, P. Lewis, J. Brennan

Outline

1. Data collection within the MetEOC2 project: sampling large areas with TLS ➔ new opportunities

2. Building a 3D virtual reference site from TLS data ➔ a "virtual laboratory" as QA framework for other sensors & end-to-end traceability

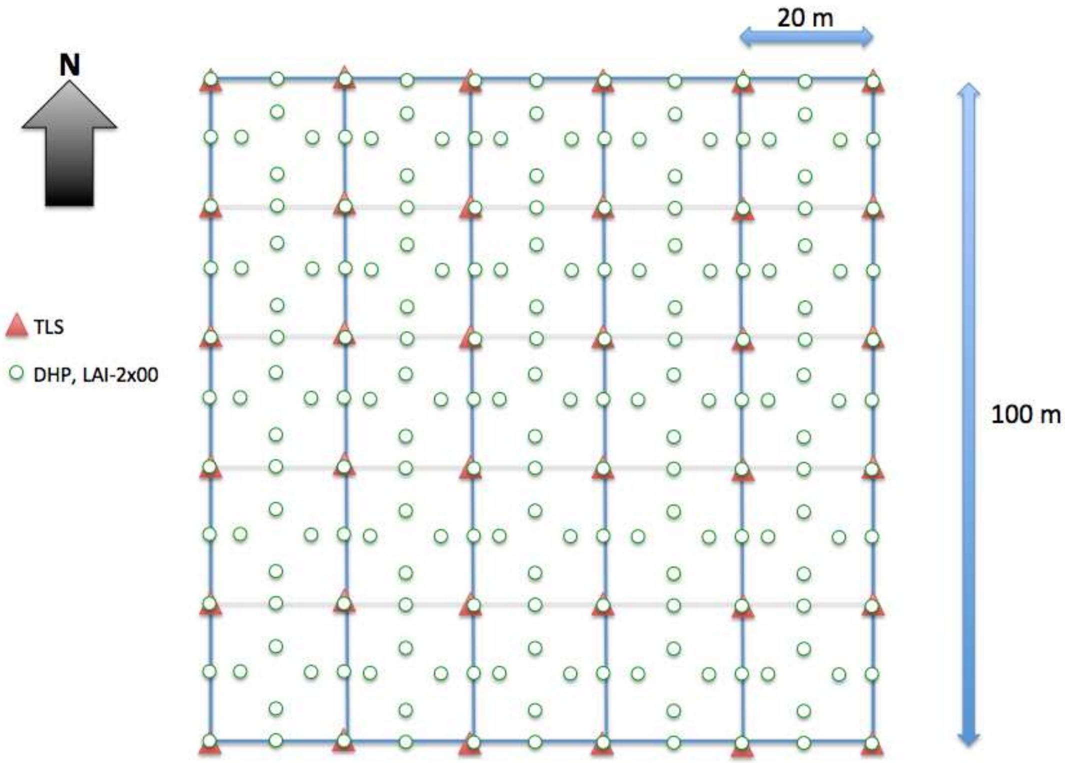
Methods

6ha (200 m x 300 m) study site in Wytham Woods, UK

Methods

Sampling designs:

- TLS: every 20 m (total: 176 scan locations)
- Optical sensors: site-wide coverage with VALERI design (total: 1800 sample locations)



Data collection

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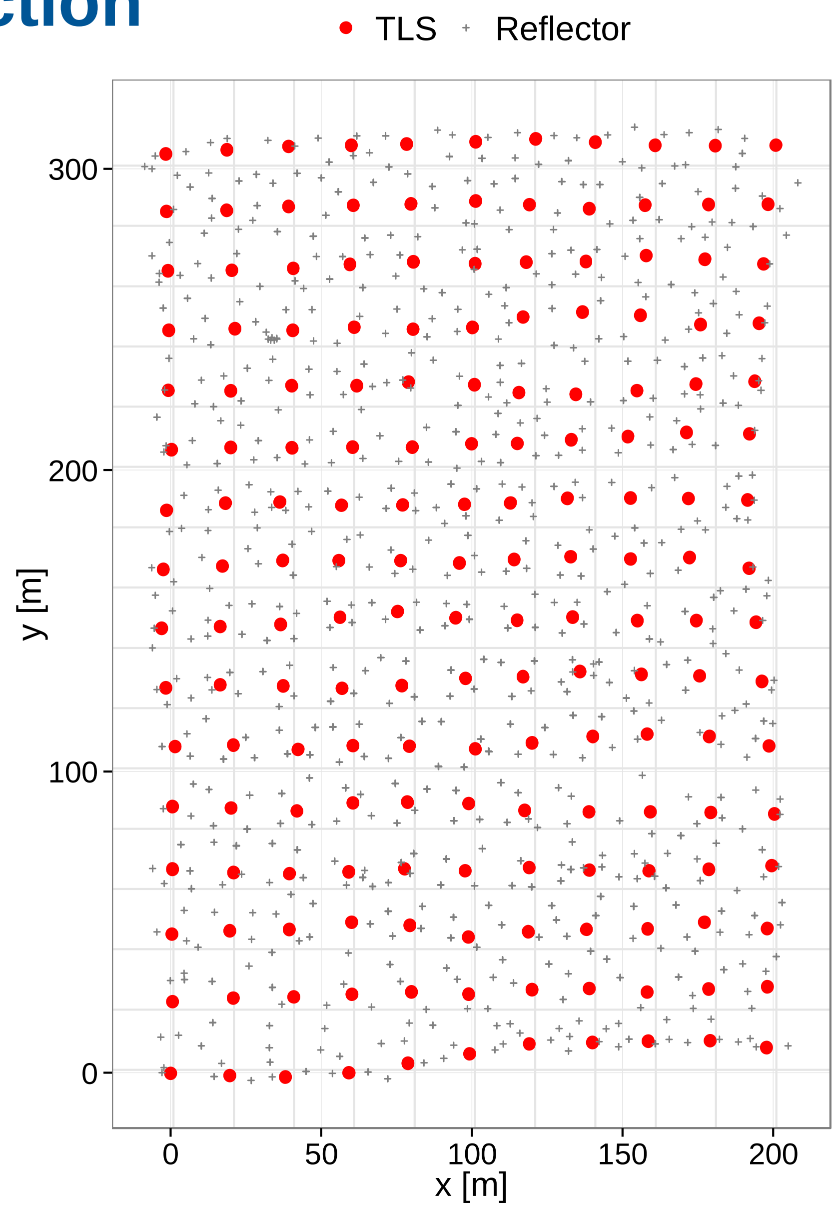
Data collection

TLS registration:



Data collection

Building a virtual forest

NPL
National Physical Laboratory

QSM
Quantitative Structure Models

Animation by M. Åkerblom (TUT)

Bobiri Forest Reserve, Ghana

- Forestry Research Institute of Ghana (FORIG), Council for Scientific and Industrial Research (CSIR)
- Located at Fumesua near Kumasi in the Ashanti Region
- Humid tropical rainforest
- Permanent carbon monitoring / leaf trait research site for GEM, Global Ecosystem Monitoring network, University of Oxford



Assigning uncertainty

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typical Quality metrics
(provided per image)

- Cloud cover ~30 %
- ToA reflectance
  @ 450 nm = 5%

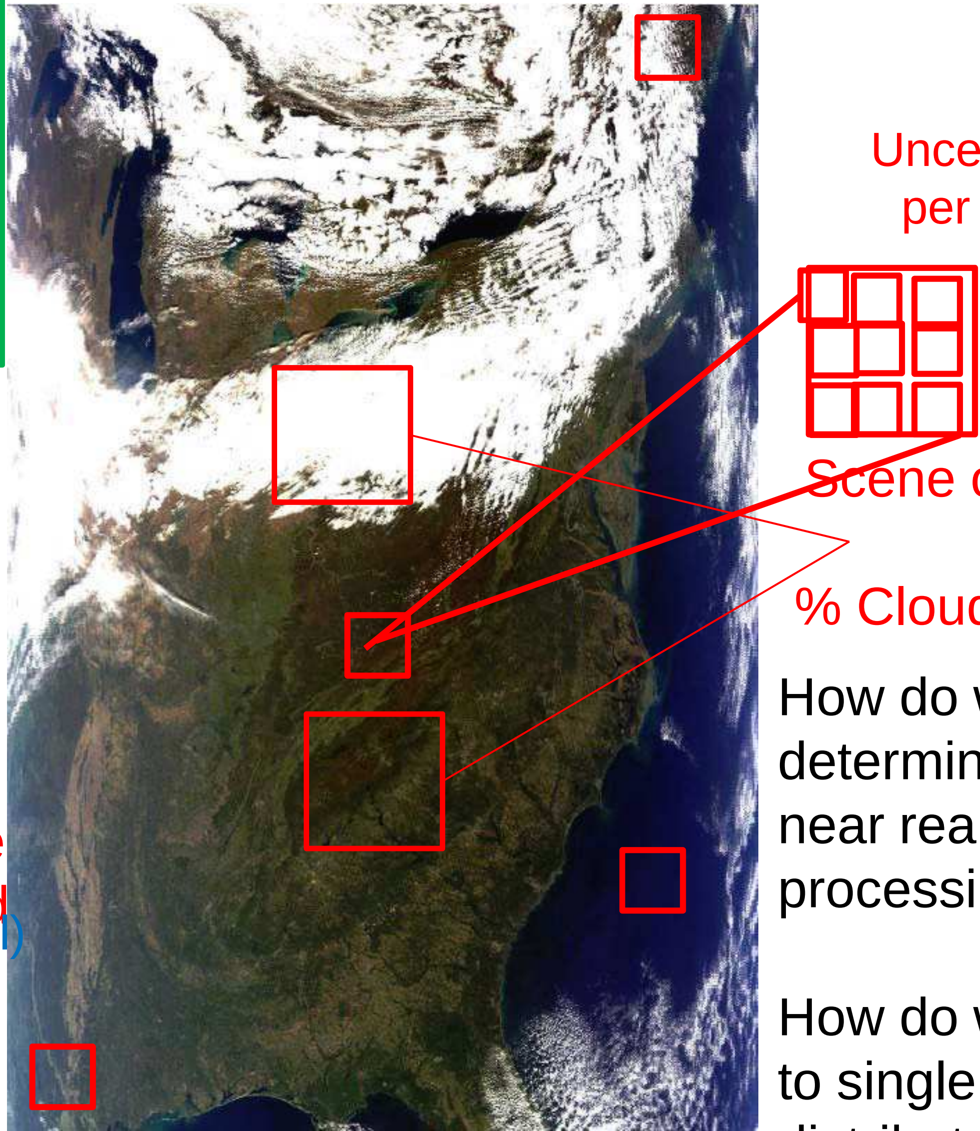
BoA Reflectance what Is the accuracy?

ToA Reflectance Is the accuracy the same?

Sensor variation
Mixed scene dynamic range
Signal - noise– Ocean/ Land
Cloud shading/shadowing

Sensor variation
Mixed scene dynamic range
Signal - noise– Ocean/ Land
Cloud shading

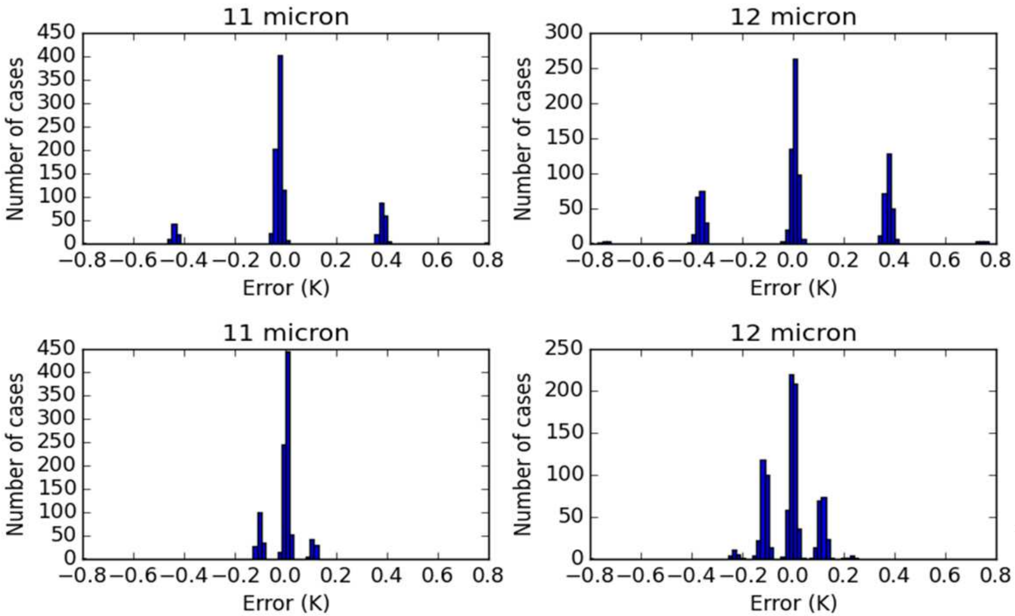
Atmospheric correction
- Model (Land/ocean/coastal)
- Input parameters
  - Real time
  - Typical
  - Uncertainties?



How do we determine U_i in near real-time processing?

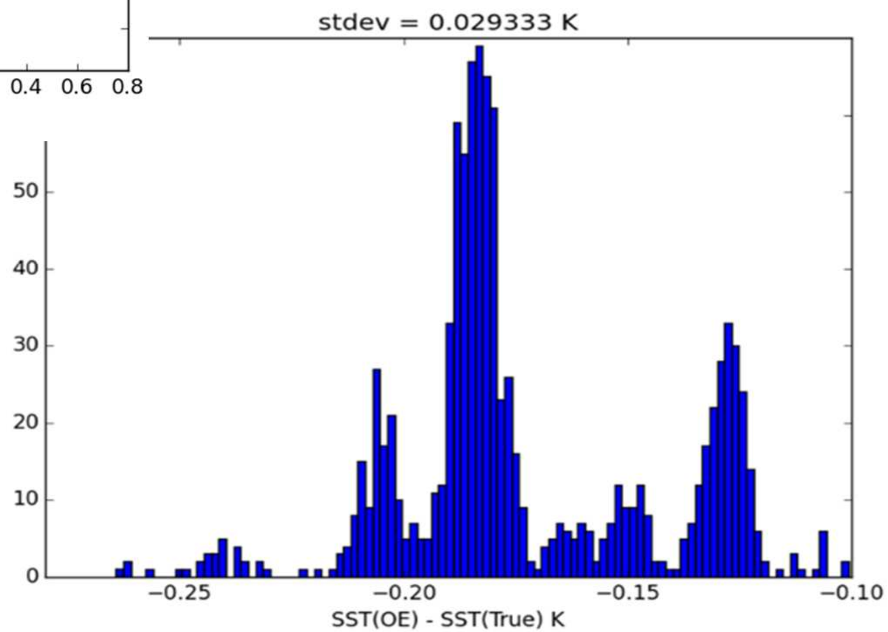
How do we assign to single pixels & distribute?

Monte Carlo Example: The importance of digitisation



Brightness temperature PDFs show impact of digitisation

BT digitisation translates into complex SST residuals



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Conclusion

- Although at TOA the measurand of satellites tends to be a conventional SI quantity: e.g. radiance, reflectance, transmittance….
- It is often not the parameter of real interest, and if not originating from TOA requires some retrieval/correction process
- Satellite measurements always needs some post launch validation (calibration) tied to the parameter and sampled to be representative.
- Scaling is always an issue
- Traceability at TOA without an SI standard in space is challenging
    - Traceability at BOA??
- But traceability is started to be asked for by community and funding agencies (ESA, EU) with full understanding of meaning