Supporting climate research and a low carbon future

Workshop on Uncertainties in Remote Sensing (summary)

Dr Nigel Fox

Organising Committee

- Philippe Goryl - ESA
- Nigel Fox - NPL
- Chris Merchant - U of Reading
- Gareth Davies - Serco
- Fabrizio Niro - Serco
- Georgia Doxani - Serco

Dates 24-25th October

Approximately 50 attendees!

Objectives

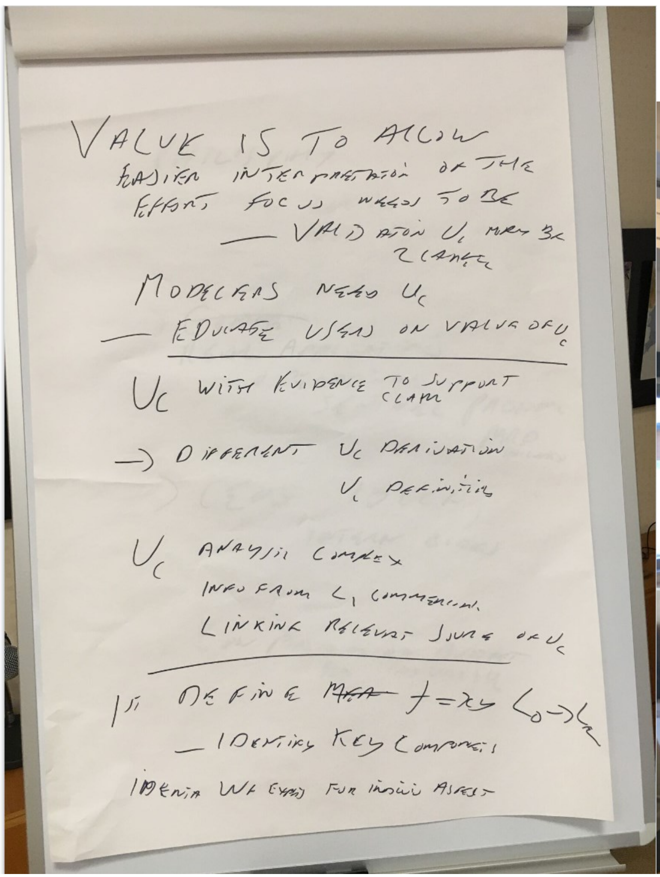
The Quality Assurance Framework for Earth Observation (QA4EO) states "that all EO data and derived products have associated with them a documented and fully traceable quality indicator (QI)". In remote sensing, provision of uncertainty information is a fundamental aspect of indicating data quality: an uncertainty associated with a measurement is needed to allow proper interpretation and further application of data, both in scientific and decision-making contexts.

The objectives of this workshop are to:

- make a status on the 'state of the art' in Uncertainties in Remote Sensing,
- present the theory of uncertainties in remote sensing,
- discuss the meaning and the differences among different methodologies,
- illustrate with current examples and discuss the limitations and the evolution,
- discuss the validation of uncertainties,
- get recommendations and discuss a roadmap for implementation in "operational" missions.

Meeting Format

- Invited presentations to scope a theme or topic
- Facilitated discussion sessions
- 'Break out' groups with seed questions



Topics/Case studies Day 1

Theory		
09:15 – 11:15	Metrology Theory on Uncertainties Uncertainty for RS in FIDUCEO FIDUCEO example Wider considerations	Nigel Fox, NPL Sam Hunt, NPL Chris Merchant, Reading Jon Mittaz, Reading & NPL Chris Merchant, Reading
11:15 - 12:00	Discussion	ALL
12:00 - 13:30	Lunch break	
Examples I		
13:30 – 14:00	Radiometric Uncertainties Tool for S2 - RUT	Javier Gorroño, NPL
14:00 – 14:30	• Toward uncertainties for OLCI TOA radiances • L2 uncertainties in MERIS/S3-OLCI ocean processing	Ludovic Bourg, Nicolas Lamquin, ACRI
14:30 – 15:00	Ocean colour uncertainties: status and evolution	Constant Mazeran, Solvo
15:00 - 15:30	Coffee break	
15:30 - 16:00	Example of FAPAR in MERIS/OLCI	Nadine Gobron, JRC
16:00 – 16:30	Uncertainty framework for burnt area products (CCI project)	James Brennan, UCL
16:30 - 17:00	Example of Neural Network uncertainties	Roland Doerffer, Carsten Brockmann, Brockmann Consult

Topics/Case studies Day 2

09:00-09:30	Sea Surface Temperature	Claire Bulgin, University of Reading
09:30-10:00	Uncertainties in Sentinel-3 Sea and Land Surface Temperature Radiometer Thermal Infrared Calibration	Dave Smith, STFC
10:00-10:30	Surface Reflectance	Eric Vermote, NASA
10:30-11:00	Coffee break	
11:00-11:30	Status of uncertainties in Aerosol_cci	Thomas Popp, DLR
11:30-12:00	Role of data assimilation diagnostics in uncertainty estimation for microwave satellite observations	Heather Lawrence, ECMWF
12:00-13:00	Discussion	ALL
13:00-14:00	Lunch break	
Validation		
14:00-14:30	Land Products Validation	Joanne Nightingale, NPL
14:30-15:00	GAIA CLIM experience: The importance of in situ and matching process uncertainty estimation in the context of validating satellite data and satellite data uncertainties	Tijl Verhoelst, BIRA
15:00-15:30	Validation of uncertainties (Discussion)	Prompter slides from Gary Corlett (10 mins)
15:30-15:45	Demonstration of "virtual observatory" tool	Tijl Verhoelst, BIRA

Principles of Metrology and their applicability to Earth Observation

Nigel Fox, Emma Woolliams, Sam Hunt, Jon Mittaz (NPL)
Chris Merchant, Jon Mittaz (U o Reading)

FIDUCEO has received funding from the European Union's Horizon 2020 Programme for Research and Innovation, under Grant Agreement no. 638822

What is Traceability?

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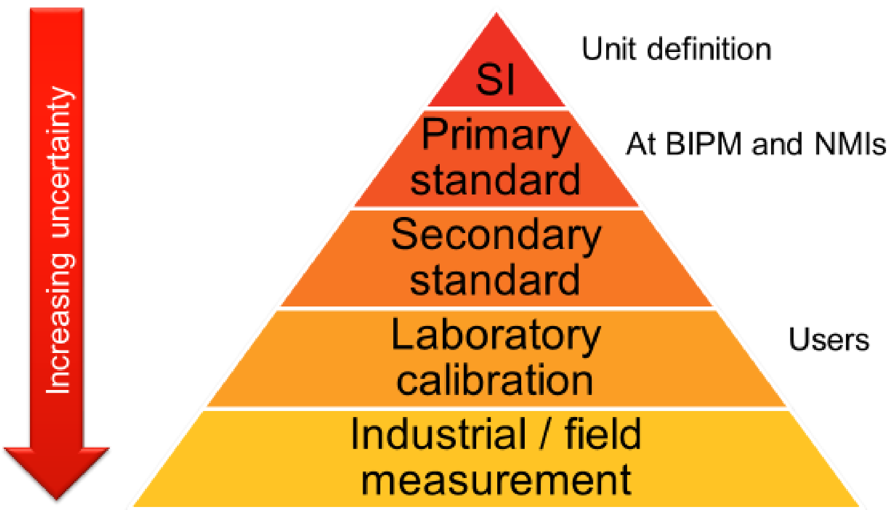
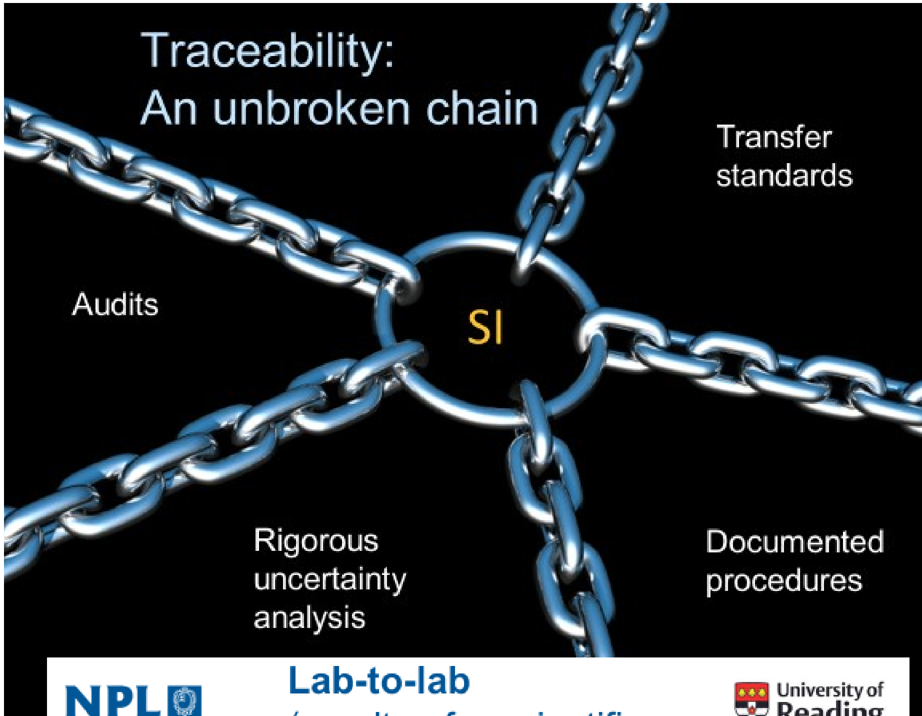
Traceability



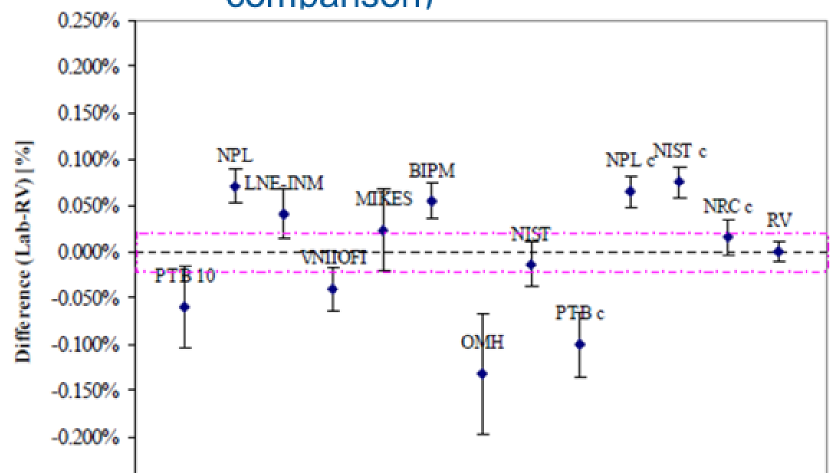


Documented evidence of degree of consistency with international std & Uc budget

i.e.COMPARISONS

Lab-to-lab

(results of a scientific comparison)



Operational framework:
Principles and scope (space example)

All activities which contribute to the delivery of an end product derived from an input measurand

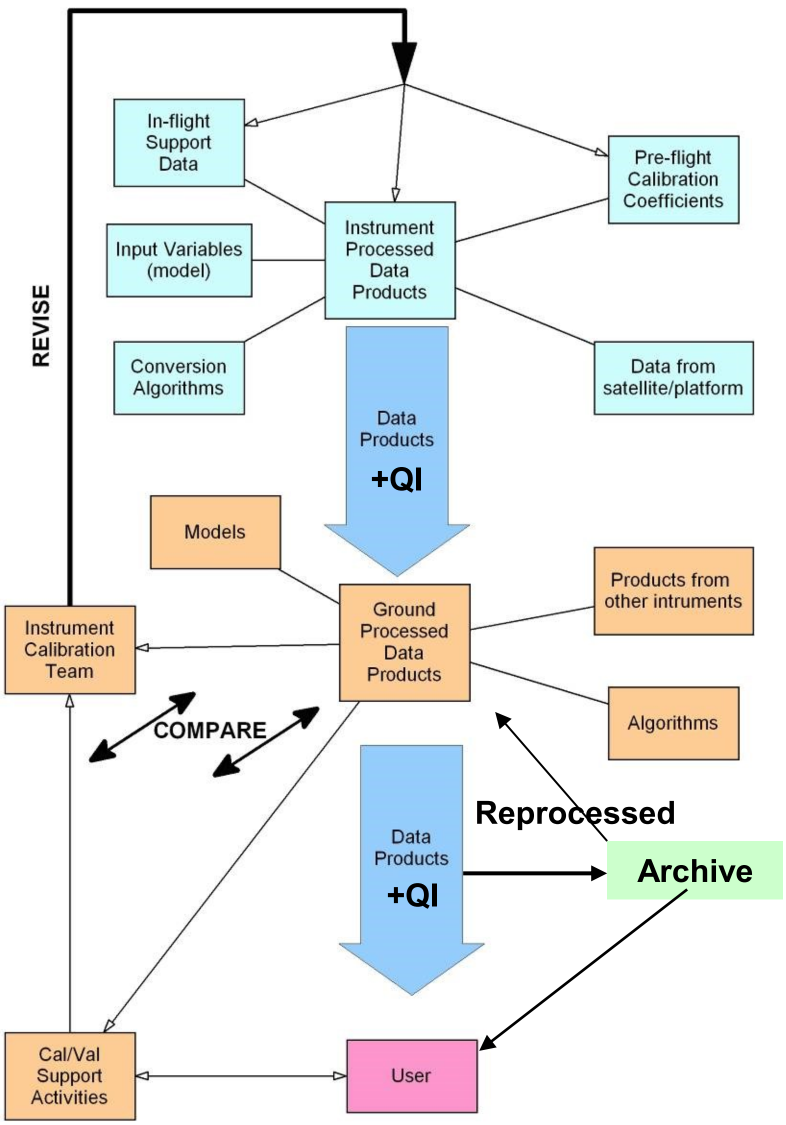
Pre-Flight

- Requirement/Design Specification
- Instrument build: characterisation/calibration
- Data processing: algorithms, ref/support data,

Post-Launch

- Instrument performance
- Output data quality characteristics:
    - accuracy
    - equivalence to others (sensors/in-situ)
- Processing – high level products
- Data distribution/archive …

Collection – Processing – Validation - Delivery



Fiducial Reference measurments (FRMs)

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What are Fiducial Reference Measurements?

"The suite of independent ground measurements that provide the maximum return on investment for a satellite mission by delivering, to users, the required confidence in data products, in the form of independent validation results and satellite measurement uncertainty estimation, over the entire end-to-end duration of a satellite mission" (Sentinel-3 Validation Team)

An FRM must:

- Have documented evidence of its degree of consistency for its traceability to SI through the results of round robin inter-comparisons and calibrations using formal metrology standards
- Be independent from the satellite geophysical retrieval process
- Have a detailed uncertainty budget for the instrumentation and measurement process for the range of conditions it is used over.
- Adhere to community agreed measurement protocols, and management practises.

& have Uc levels fit for the application they are used for

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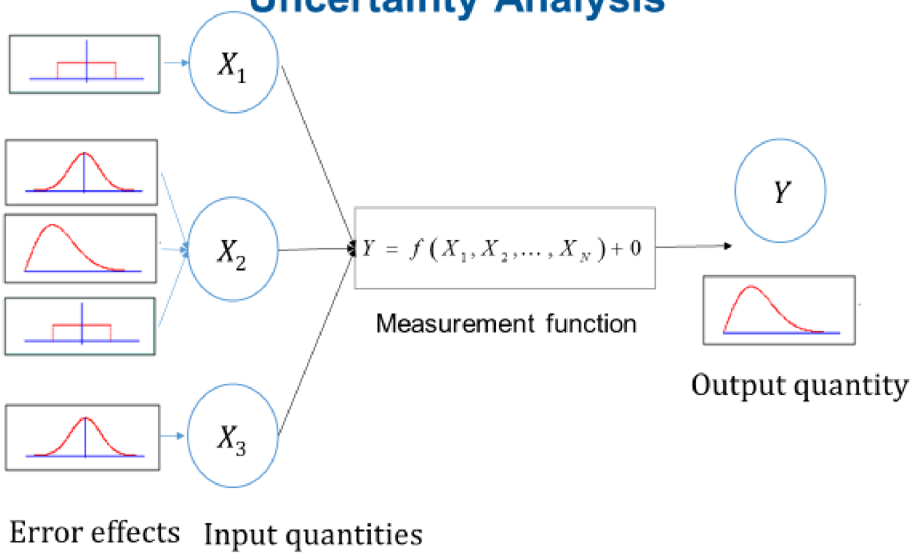
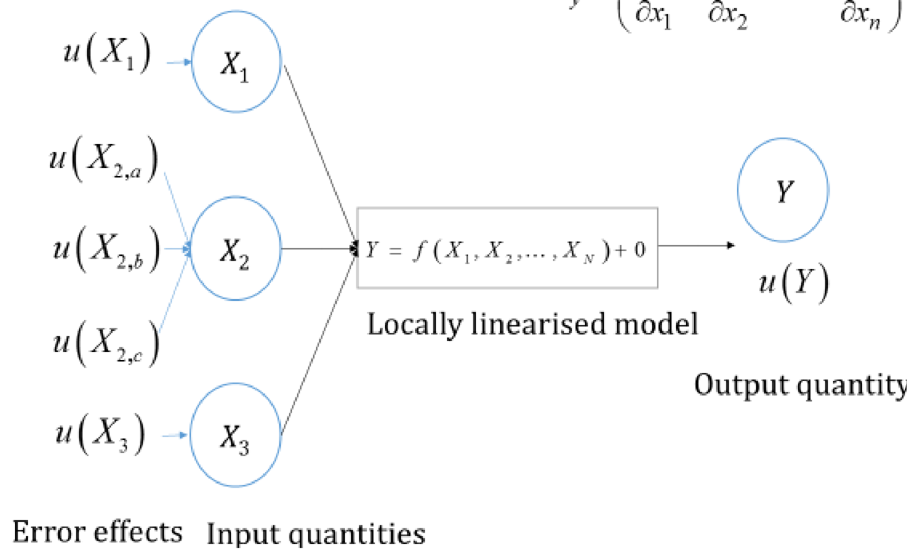
Principle of Uncertainty Analysis



Propagation of Uncertainty

$$u^2(y) = C_y U_x C_y^\top$$

$$C_y = \left(\frac{\partial f}{\partial x_1} \quad \frac{\partial f}{\partial x_2} \quad \cdots \quad \frac{\partial f}{\partial x_n} \right)$$



GUM: Law of Propagation of Uncertainties

Algebraic form

$$u_c^2(y) = \sum_{i=1}^{n} \left(\frac{\partial f}{\partial x_i} \right)^2 u^2(x_i) + 2 \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \frac{\partial f}{\partial x_i} \frac{\partial f}{\partial x_j} u(x_i, x_j)$$

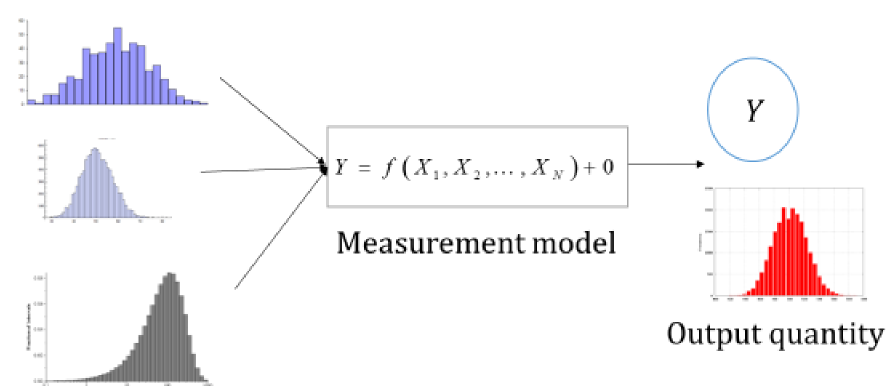
Matrix form

$$u^2(y) = C_y U_x C_y^\top$$

$$C_y = \left(\frac{\partial f}{\partial x_1} \quad \frac{\partial f}{\partial x_2} \quad \cdots \quad \frac{\partial f}{\partial x_n} \right)$$

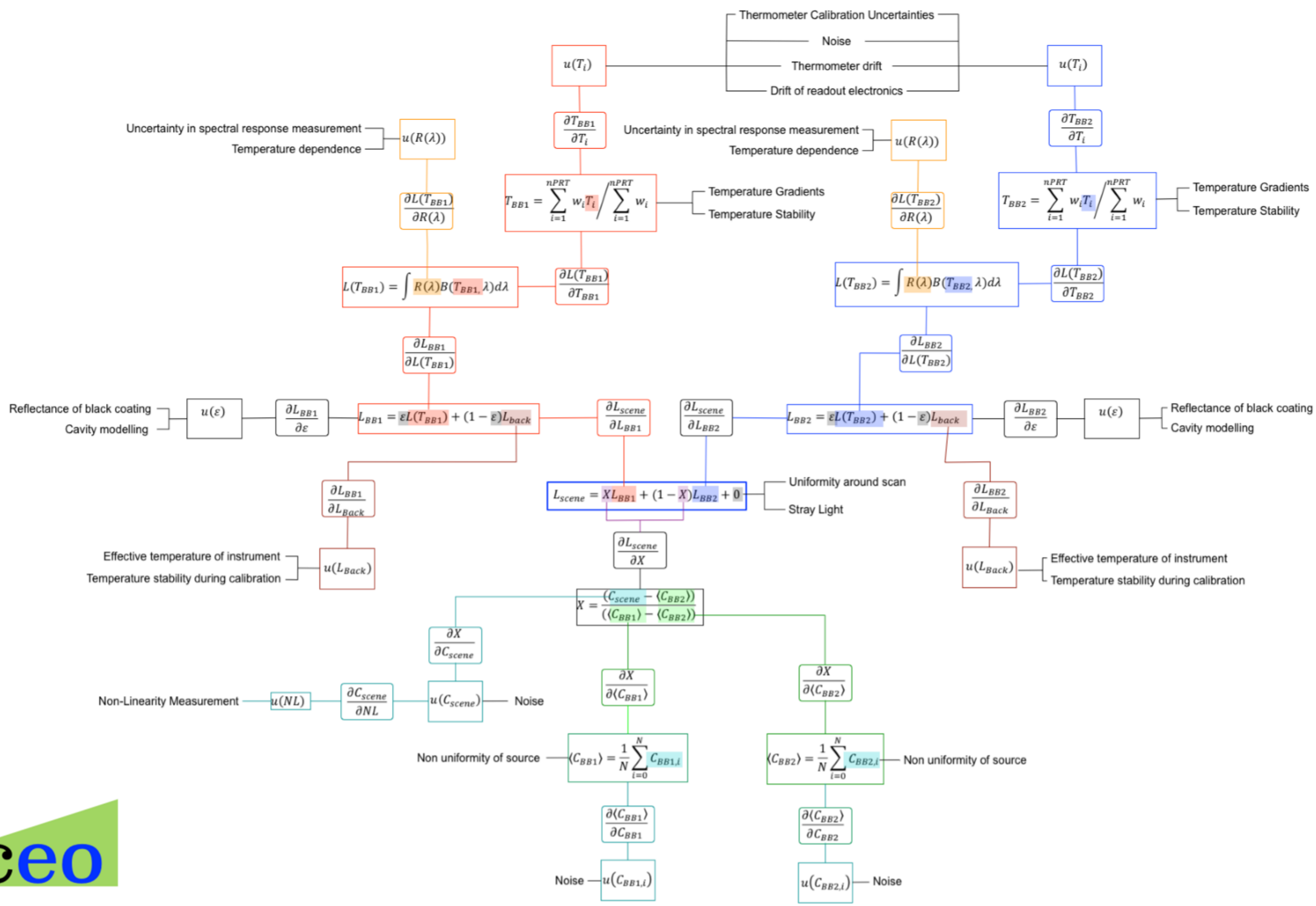
$$U_E = \begin{array}{c} \\ 1 \\ 2 \\ \vdots \\ n \end{array} \begin{array}{c} \begin{array}{cccc} 1 & 2 & \cdots & n \end{array} \\ \begin{bmatrix} u^2(E_1) & u(E_1, E_2) & \cdots & u(E_1, E_n) \\ u(E_2, E_1) & u^2(E_2) & \cdots & u(E_2, E_n) \\ \vdots & \vdots & \ddots & \vdots \\ u(E_n, E_1) & u(E_n, E_2) & \cdots & u^2(E_n) \end{bmatrix} \end{array}$$

Monte Carlo Approach



Fiduceo principles to assess and evaluate all Uc

SLSTR IR Traceability Tree



Evolve good practice towards …

Good practice	Apply to
Level 1 radiance provided with uncertainty estimates per datum.	Key heritage sensor series. Planned missions.
Multi-mission series should be harmonised.	Key heritage sensor series. Planned missions.
Propagate radiance uncertainties to inform level 2 (swath) and 3 (gridded) geophysical data.	Climate data records (CDRs) and environmental data records.
Propagate CDR uncertainty to higher-levels.	Climate information derived (in part) from CDRs
Decision makers and other users access and trust information on uncertainty.	Presentation of climate information in climate services.

SEED Questions

- Q1 What degree of need for improved, transparent uncertainty information is recognised amongst users/product/service developers?
- Q2 What are benefits and challenges to applying EO-metrology principles to L1 and L2?
- Q3 Is the current approach to instrument uncertainty characterisation and pre-flight cal/val adequate (from point of view of ultimate users of L1 and derived data)? If no, what problems are caused?
- Q4 What should next case studies be for L1?
- Q5 What priority case studies should we address next for L1 to L2+ ?

SEED Questions

- Q6 What additional information from instrument dev and pre-flight cal should be made available to users and how?
- Q7 How could we build the core principles of providing uncertainty into the development of phase of new missions?
- Q8 Are there additional steps that can be built into in-flight operational missions to validate and test performance?
- Q9 What activities/strategies do we need to consider to validate Uc of L1 and L2 products and ensure their interoperability?
- Q10 Is targeted training on Uc analysis needed, and how to develop this?

What degree of need for improved, transparent uncertainty information is recognised amongst users/product/service developers?

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PERCEPTION SIGNIFICANT NEED NOT ALWAYS RECOGNISED

- Service providers are seeing customers needing and expecting some level of confidence
- Need case study examples with evidence of benefit
- Show criticality of Cal/Val and Uc to product users
- Educate users and service developers of what the info provides and what current info does not
  - Users prefer good data rather than Uc
- Modellers need to recognise value of Uc
- Added Reliability from correlation info
- Need closer link between cal community and user community
- Validation measurements need to have Uc on them also
- Philosophy of technology driven rather than application driven has limited emphasis
- Need to have default location for Uc in metadata
- Clear definitions and consistent use of terminology
  - -error, Uc, traceability

What are benefits and challenges to applying EO-metrology principles to L1 and L2?

- For radiometric like Quantities: Albedo, SST, ‘relatively’ easy,
  - how does geometric impact though?
- For biophysical paratmeters e.g. Chlorophyll, LAI, land cover- harder
- Benefits – gives consistency/comparability between products
- Challenges – completeness of information, setting appropriate limitations, nature of assumptions

Is the current approach to instrument uncertainty characterisation and pre-flight Cal/Val adequate (from point of view of ultimate users of L1 and derived data)? If no, what problems are caused?

- Not complete
- Information not always provided on how test was done and what basis of evidence
- Often carried out to an engineering spec rather than an uncertainty

What should the next case study (Fidcueo like) be for L1

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- OLCI, optical sensors, sentinel 3, altimetry FDR, SAR (big q, what is the need?), active and passive missions for soil moisture, AMSU-A, VIIRS
- Case studies for true uncertainty based on instrument characterisation vs “supplier” uncertainty
- new post launch methods to verify error models e.g. Moon to examine stray light; how to understand U after cross-calibration?
- Stray light in OLCI.
- Compare against approaches of different agencies – eg MODIS.
- Education, tools, examples of complex effects worked out
- Geometric uncertainty, resampling, geolocation, fov weighting and impact
- Practicalities for U dissemination in face of data volume – standards for on-the-fly calculation where possible

What priority case studies should we address next for L1 to L2+ (L3, L4)..

- Case studies on: non-normal error distributions, Uc model for cloud and other masks, cloud shadow, adjacency

- Multi-mission uncertainty / stability ;

- how to validate test cases (eg fine resolution to inform low res)

- Priority products for Uc development: surface reflectance, ocean colour, **classification products** , wind stress (ASCAT) – any ECV – atmospheric reflection, land ST, snow water equivalent, soil moisture, SAR (noise level reached)

- **Propagation:** to level 4, from few validation sites to global scale, methods and tools,

    - comparisons of propagation by different methods (gum, MC, NN; perhaps on aerosol?)

- Uncertainty when using NWP (need covariances); from RT models too; independent validation protocols

What additional information from instrument dev and pre-flight cal should be made available to users and how? (only for expert users!?)

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- What can be built into mission requirements for Uc provision?;
- Identify measurement equation and requirement to do traceability tree/document like FIDUCEO – this NOT being confidential into mission req docs and instrument supplier provided docs
- Transparent methodology-
  - maintained, independently assessed if confidential aspects such as proprietary models
- Key L0 data replicated/summarised in L1 for future re-calibration
- Reference data set updated and archived
- Well defined measurands eg reflectance. Minimise changes between missions in series
- Uncertainty budget adequate to compute Uc for L1 in flight per datum
  – maintained, updated
- Enough info for L2+ to maintain their traceability
  – e.g., measurement equ, sensitivity, correlations
- One stop shop for Uc info and uncertainty budget of instrument
  – give access to data, not only buried in docs & maintained/updated with archive
- Simplified, open-access sensor simulators usable by L1+ users

How could we build the core principles of providing uncertainty into the development of phase of new missions?

- Inform mission requirements around uncertainty info/budget provision ;
  - recognise some extra cost,
  - convince member states/agencies
  - expose results of eg sensitivity analyses
- Make our Uc info needs clear and justified eg to ESA and Copernicus
  – all public missions
- Build uncertainty tree into development and communicate state of knowledge
- Distinguish the engineering budget from the uncertainty budget and provide also the latter

Are there additional steps that can be built into in-flight operational missions to validate and test performance?

- Activities such as in flight diffuser characterisation
- Use of international reference sites and sensor-to-sensor using defined protocol, standardised validation protocols and ground measurement protocols (sensors, placing, etc), support understanding of mismatch uncertainties (scaling, spectral, spatial) at such sites
- Establish Standards in space
- Reference sites (FRM) for the long term, multi-instrument networks (super testsites), comprehensive characterisation
- Dedicated campaigns – more needed in some cases ; optimise distributions of measurements globally, consider trade-offs
- Support interactions of data producers and validation scientists to feedback insights to products

What activities/strategies do we need to consider to validate Uc of L1 and L2 products and ensure their interoperability?

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- Uncertainty validation- can validate results, assumptions and inputs
- Colocation uncertainty: for validation of Uc this is generally needed, estimate mismatch starting from measurement equation considerations
- FRM generally address L2, (arguably RADCALNET is L1).
  - L1 validation: model involved (RT and sensor)
  – a generic solution would be efficient
  - FRM-like networks need to support estimation of mis-match uncertainty in order to validate uncertainty as well as data (tools?)
  - forward modelling of FRM measurements/context (3D land models)
- Integration of L1 and L2 experts
- Need methods to deal with sparse reference networks ; often had detail over few well studied scene types, question of dealing with representativeness
- Non-gaussian: more required to understand this case
- Multi-instrument methods (triple colocations, and beyond) ; round robin exercises
- Common meaning(s) for Uc and product definitions- need to be transparent ;
- strategy to make Uc ïnteroperable across multiple sensors

Is targeted training on Uc analysis needed, and how to develop this?

- YES
- Regular dedicated workshops of data producers, metrologists and users
- example use cases of U in data documentation, online, new docs where needed
- Promotion at conferences etc
- Get training into universities
- ESA LPP and other big events, IGARRS etc

Recommendations /Conclusions

- Interest in improving availability and use of U, supported by an engaged community
- Need U principles more widely embedded in agency and community practice
- Need more fora to bring several communities together including instrument manufacturers, range of contexts and foci, across levels
- Uncertainty info reqs need to be embedded at high levels of mission and system requirements
- Involves definition of practicalities about how mission will deliver U to users
- Precedent of Sentinel 3 MRD – partly driven by Dat Assim community
- Need methods to invert from user requirements back to radiance error covariance, and methods to ensure that user requirements on uncertainty are well founded
- Need to find ways to raise profile of these issues

Recommendations/ conclusions

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- Demonstrations of users benefitting from U information,
  - links of user and mission requirements need to be more obvious
  - e.g. Dat Assim use case
- Uncertainty analysis as a way of identifying priorities and investment, and driving improvements in products
- What does absence of U prevent?
  - Relatively clear for climate - societal impacts in future.
  - Soil moisture, precip.- for use in satellite-indexed insurance of drought etc.
  - Providing U helps users avoid misuse of data (and wasted science!), and increases dialogue
- Develop tools, methods/guidance for uncertainty tree etc to lower the level of expertise required to exploit
- Areas needing theoretical advances:
  - uncertainty associated with classification including cloud masks, categorical variables (eg burnt pixels), Neural Networks

Need to classify recommendations by whom they are addressed to

What Next?

- A LOT TO DO!!!!!

But

- Community is engaged,
- Applications and Services need solution

Develop case studies to show benefit and strategy to move forwards.