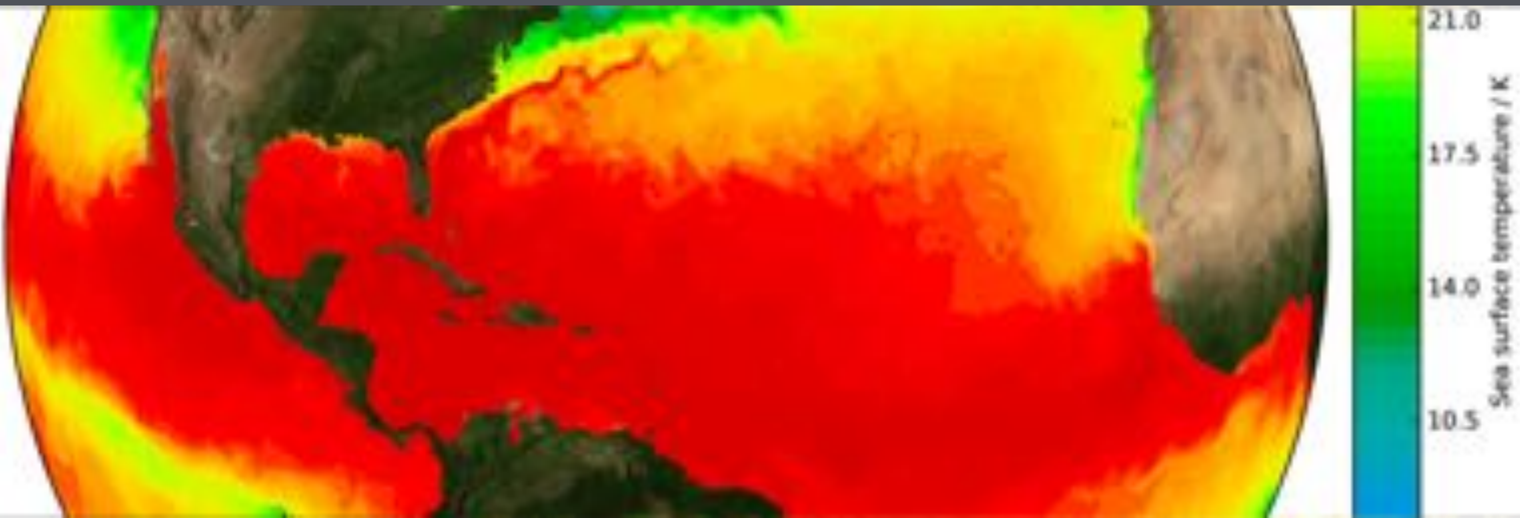
Earth Observation and Space
Department of Meteorology

University of Reading

UNCERTAINTY IN CLIMATE DATA RECORDS FROM SATELLITE OBS'NS



Christopher Merchant
Department of Meteorology
University of Reading

National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL

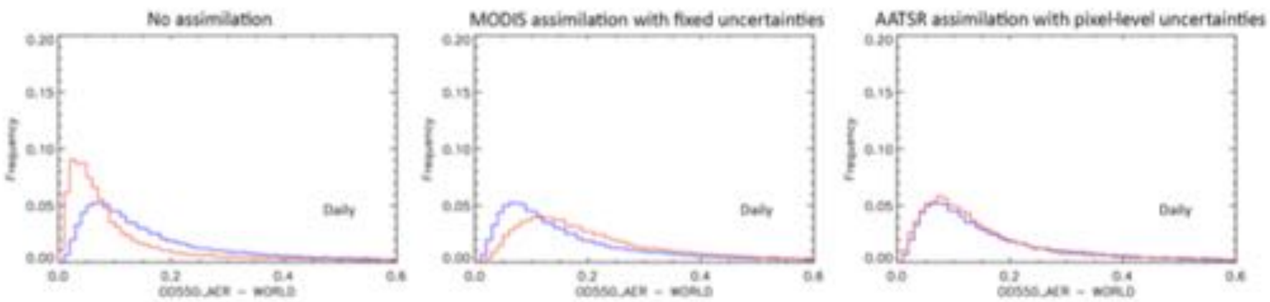
UK SPACE AGENCY

MOTIVATIONS FOR UNCERTAINTY INFORMATION IN CDRS

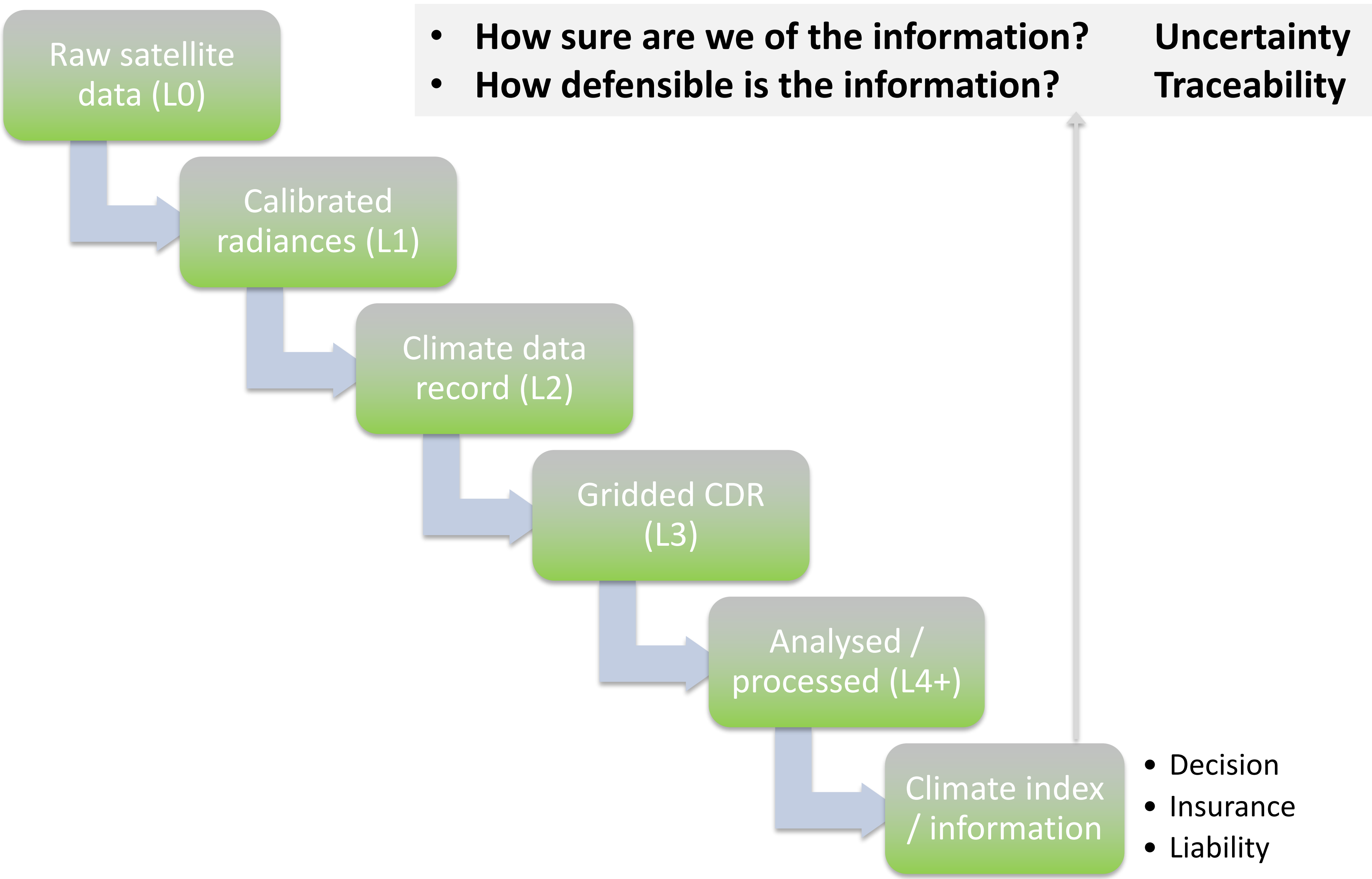
University of Reading

- Uncertainty estimation is fundamental to any measurement science

- Information about observational uncertainty in CDRs is needed in science
  - to quantify the confidence in inferences about changes in the Earth system (do we really know what we think we know?)
  - to support further propagation of uncertainty to higher-level studies
  - for informed model evaluation
  - as an element of observation error covariance in assimilation



- Requirements in society
  - to inform users (decision makers etc) about the data they are using



University of Reading

FIduceo

Cross-ECV efforts in CCI

Earth System Science Data
The Data Publishing Journal

Earth Syst. Sci. Data, 9, 511-527, 2017
https://doi.org/10.5194/essd-9-511-2017

Volume 9, issue 2

Article | Peer review | Metrics | Related articles

Review article

25 Jul 2017

Uncertainty information in climate data records from Earth observation

Christopher J. Merchant[1,2], Frank Paul[3], Thomas Popp[4], Michael Ablain[5], Sophie Bontemps[6], Pierre Defourny[6], Rainer Hollmann[7], Thomas Lavergne[8], Alexandra Laeng[9], Gerrit de Leeuw[10], Jonathan Mittaz[1,11], Caroline Poulsen[12], Adam C. Povey[13], Max Reuter[14], Shubha Sathyendranath[15], Stein Sandven[16], Viktoria F. Sofieva[10], and Wolfgang Wagner[17]
[1]Department of Meteorology, University of Reading, Reading RG6 6AL, UK
[2]National Centre for Earth Observation, University of Reading, Reading RG6 6AL, UK
[3]Department of Geography, University of Zurich, Winterthurerstr. 190, 8057 Zurich, Switzerland
[4]Deutsches Zentrum für Luft-und Raumfahrt e. V., Deutsches Fernerkundungsdatenzentrum, 82234 Oberpfaffenhofen, Germany
[5]Collecte Localisation Satellites, 11 Rue Hermès, 31520 Ramonville-Saint-Agne, France
[6]Earth and Life Institute, Université catholique de Louvain, 1348 Louvain-la-Neuve, Belgium
[7]Deutscher Wetterdienst, Frankfurterstr. 135, 63500 Offenbach, Germany
[8]Norwegian Meteorological Institute, 0313 Oslo, Norway
[9]Karlsrhue Institute for Technology, Institut für Meteorologie und Klimaforschung, 76021 Karlsruhe, Germany
[10]Finnish Meteorological Institute, 00101 Helsinki, Finland
[11]National Physical Laboratory, Teddington TW11 0LW, UK
[12]Science and Technology Facilities Council, Rutherford Appleton Laboratory, Didcot OX11 0QX, UK
[13]National Centre for Earth Observation, University of Oxford, Oxford OX1 3PU, UK
[14]Institute of Environmental Physics, University of Bremen, 28359 Bremen, Germany
[15]Plymouth Marine Laboratory, Prospect Place, Plymouth PL1 3DH, UK
[16]Nansen Environmental and Remote Sensing Center, Thormohlensgate 47, 5006 Bergen, Norway
[17]Department of Geodesy and Geoinformation, Vienna University of Technology, 1040 Wien, Austria

Received: 21 Feb 2017 – Discussion started: 28 Feb 2017
Revised: 19 Jun 2017 – Accepted: 19 Jun 2017 – Published: 25 Jul 2017

Abstract. The question of how to derive and present uncertainty information in climate data records (CDRs) has received sustained attention within the European Space Agency Climate Change Initiative (CCI), a programme to generate CDRs addressing a range of essential climate variables (ECVs) from satellite data. Here, we review the nature, mathematics, practicalities, and communication of uncertainty information in CDRs from Earth observations. This review paper argues that CDRs derived from satellite-based Earth observation (EO) should include rigorous uncertainty information to support the application of the data in contexts such as policy, climate modelling, and numerical weather prediction reanalysis. Uncertainty, error, and quality are distinct concepts, and the case is made that CDR products should follow international metrological norms for presenting quantified uncertainty. As a baseline for good practice, total standard uncertainty should be quantified per datum in a CDR, meaning that uncertainty estimates should clearly discriminate more and less certain data. In this case, flags for data quality should not duplicate uncertainty information, but instead describe complementary information (such as the confidence in the uncertainty estimate provided or indicators of conditions violating the retrieval assumptions). The paper discusses the many sources of error in CDRs, noting that different errors may be correlated across a wide range of timescales and space scales. Error effects that contribute negligibly to the total uncertainty in a single-satellite measurement can be the dominant sources of uncertainty in a CDR on the large space scales and long timescales that are highly relevant for some climate applications. For this reason, identifying and characterizing the relevant sources of uncertainty for CDRs is particularly challenging. The characterization of uncertainty caused by a given

Earth Syst. Sci. Data, 9, 511-527, 2017
https://doi.org/10.5194/essd-9-511-2017

Uncertainty recomendations for CDRs

- **Provide uncertainty estimates**
- Follow metrological conventions
- Give u per datum if necessary
- Uncertain ≠ Bad quality
- Explain the uncertainty info
- Give advice to users on usage
- Validate the uncertainties
- Error correlation matters

- DOI 10.5194/essd-9-511-2017

- Put uncertainty information in the dataset, rather than expect users to hunt the literature for values
- Information should be quantitative
  - standard uncertainty
  - standard fractional uncertainty
  - error covariance matrices
  - confidence intervals
  - probability of mis-classification
  - variability across repeat evaluations …

- Numerical data by default should be associated with an estimate of **standard uncertainty**

Uncertainty recomendations for CDRs

- Provide uncertainty estimates
- **Follow metrological conventions**
- Give u per datum if necessary
- Uncertain ≠ Bad quality
- Explain the uncertainty info
- Give advice to users on usage
- Validate the uncertainties
- Error correlation matters
- Don't re-invent what the measurement science community spent decades deliberating about
- **Nomenclature** for unambiguous communication
  - Measurand, effects, error, uncertainty, …
- Tried-and-tested **methodologies** for estimating uncertainty

- DOI 10.5194/essd-9-511-2017

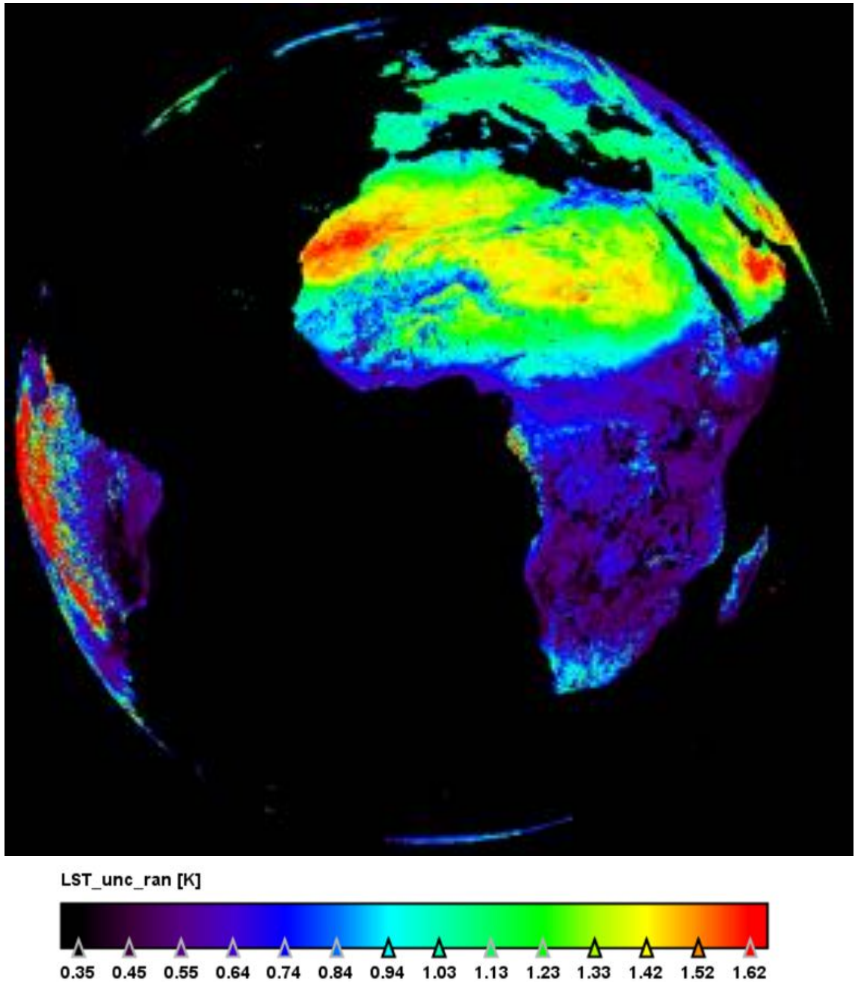
Uncertainty recomendations for CDRs

- Provide uncertainty estimates
- Follow metrological conventions
- **Give uncertainty per datum if necessary**
- Uncertain ≠ Bad quality
- Explain the uncertainty info
- Give advice to users on usage
- Validate the uncertainties
- Error correlation matters

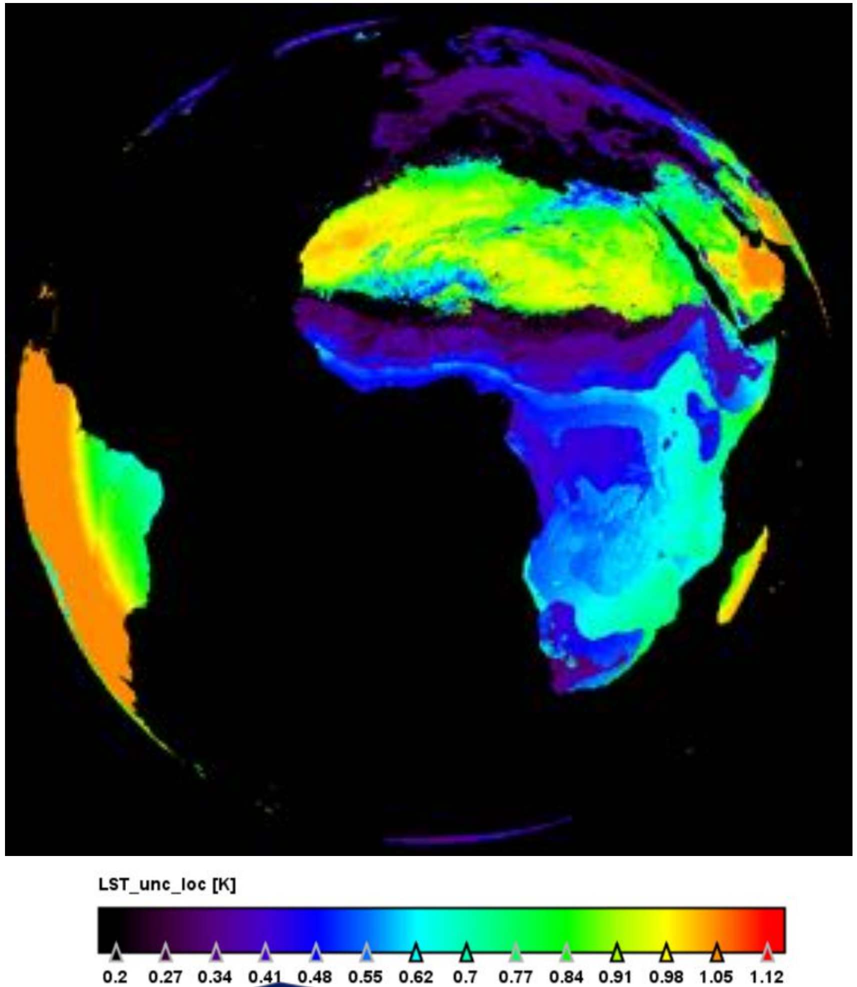
- DOI 10.5194/essd-9-511-2017

Land Surface Temperature Uncertainties

Random (Radiance and Emissivity)



Locally correlated (Atmosphere & Em.)



UNIVERSITY OF LEICESTER University of Reading National Centre for Earth Observation NATURAL ENVIRONMENT RESEARCH COUNCIL GLOBTEMPERATURE EUSTACE

Uncertainty recomendations for CDRs

- Provide uncertainty estimates
- Follow metrological conventions
- Give u per datum if necessary
- **Uncertain ≠ Bad quality**
- Explain the uncertainty info
- Give advice to users on usage
- Validate the uncertainties
- Error correlation matters

- Given per datum uncertainty estimates, a highly uncertain estimate is not poor quality …
- … **iff** that uncertainty is confidently estimated and is provided to the user

- DOI 10.5194/essd-9-511-2017

esa cci

esa University of Reading University of Leicester National Oceanography Centre NATURAL ENVIRONMENT RESEARCH COUNCIL Met Office Norwegian Meteorological Institute METEO FRANCE Toujours un temps d'avance DMI Brockmann Consult Space ConneXions

Uncertainty recomendations for CDRs

- Provide uncertainty estimates
- Follow metrological conventions
- Give u per datum if necessary
- Uncertain ≠ Bad quality
- **Explain the uncertainty info**
- **Give advice to users on usage**
- Validate the uncertainties
- Error correlation matters

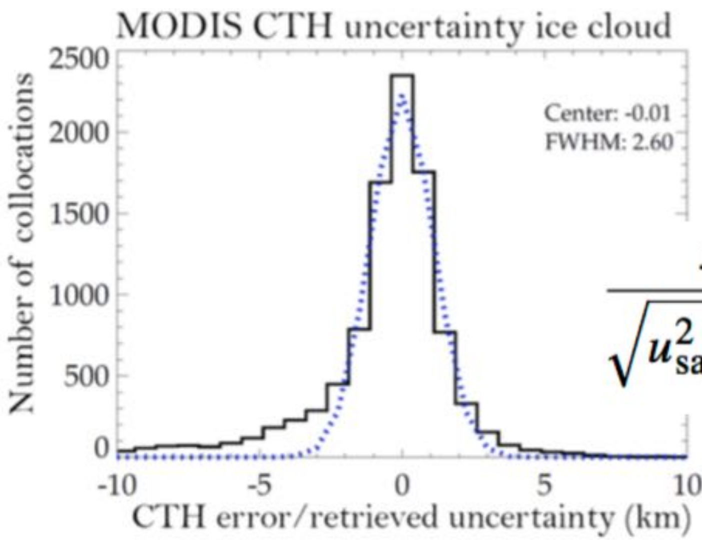
- Not only the definition of the uncertainty information, but examples of how you recommend users to exploit the information

- DOI 10.5194/essd-9-511-2017

Uncertainty recomendations for CDRs

- Provide uncertainty estimates
- Follow metrological conventions
- Give u per datum if necessary
- Uncertain ≠ Bad quality
- Explain the uncertainty info
- Give advice to users on usage
- **Validate the uncertainties**
- Error correlation matters

- Validation is sometimes used to generate uncertainty estimates, which is not what is meant here
- Where we model and provide quantitative uncertainty, those numbers should also be validated



$$\frac{x_{sat} - x_{ref}}{\sqrt{u_{sat}^2 + u_{ref}^2 + u_{mis}^2}}$$

cloud cci

- DOI 10.5194/essd-9-511-2017

esa cci

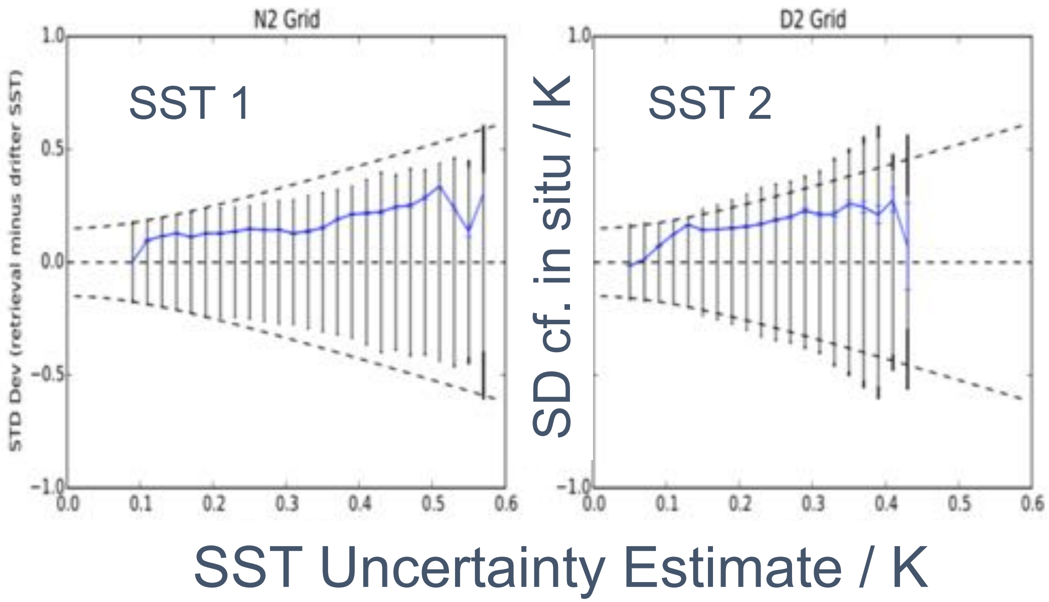
esa | University of Reading | University of Leicester | National Oceanography Centre NATURAL ENVIRONMENT RESEARCH COUNCIL | Met Office | Norwegian Meteorological Institute | METEO FRANCE Toujours un temps d'avance | DMI | Brockmann Consult | Space ConneXions

Uncertainty recomendations for CDRs

- Provide uncertainty estimates
- Follow metrological conventions
- Give u per datum if necessary
- Uncertain ≠ Bad quality
- Explain the uncertainty info
- Give advice to users on usage
- **Validate the uncertainties**
- Error correlation matters

- DOI 10.5194/essd-9-511-2017

- Validation is sometimes used to generate uncertainty estimates, which is not what is meant here
- Where we model and provide quantitative uncertainty, those numbers should also be validated

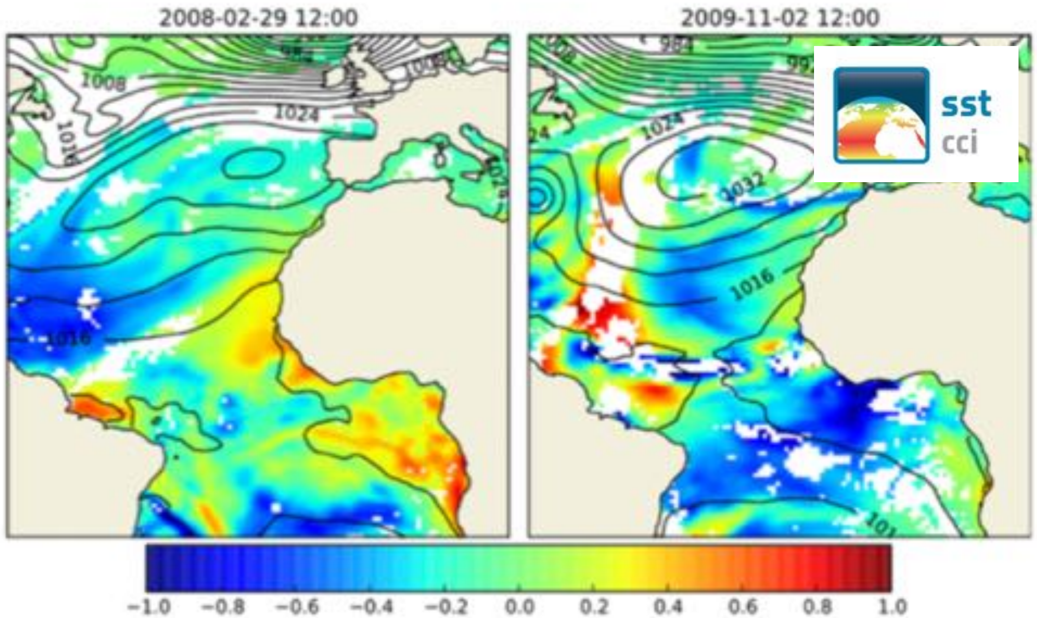


Uncertainty recomendations for CDRs

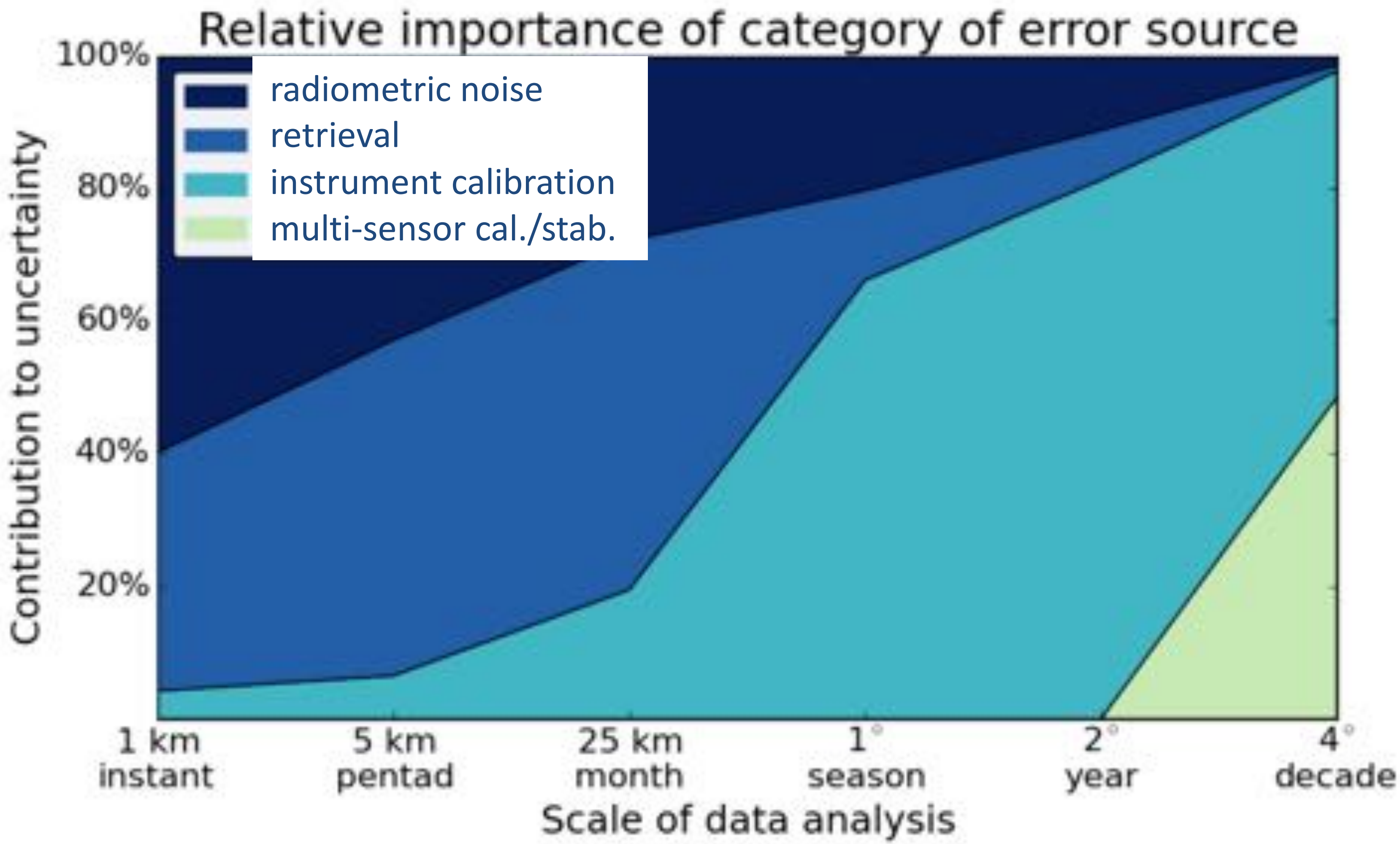
- Provide uncertainty estimates
- Follow metrological conventions
- Give u per datum if necessary
- Uncertain ≠ Bad quality
- Explain the uncertainty info
- Give advice to users on usage
- Validate the uncertainties
- **Error correlation matters**

- DOI 10.5194/essd-9-511-2017

- Where CDR products are generated on different scales (e.g., full res and gridded variants) consistent uncertainty information can only be propagated if error correlation is accounted for



Dominant effects depend on scale (eg SST)



If you compare two measurements on different space-time scales the dominant sources of uncertainty in that difference change.

University of Reading

See blog article http://www.fiduceo.eu/node/237

FIduceo

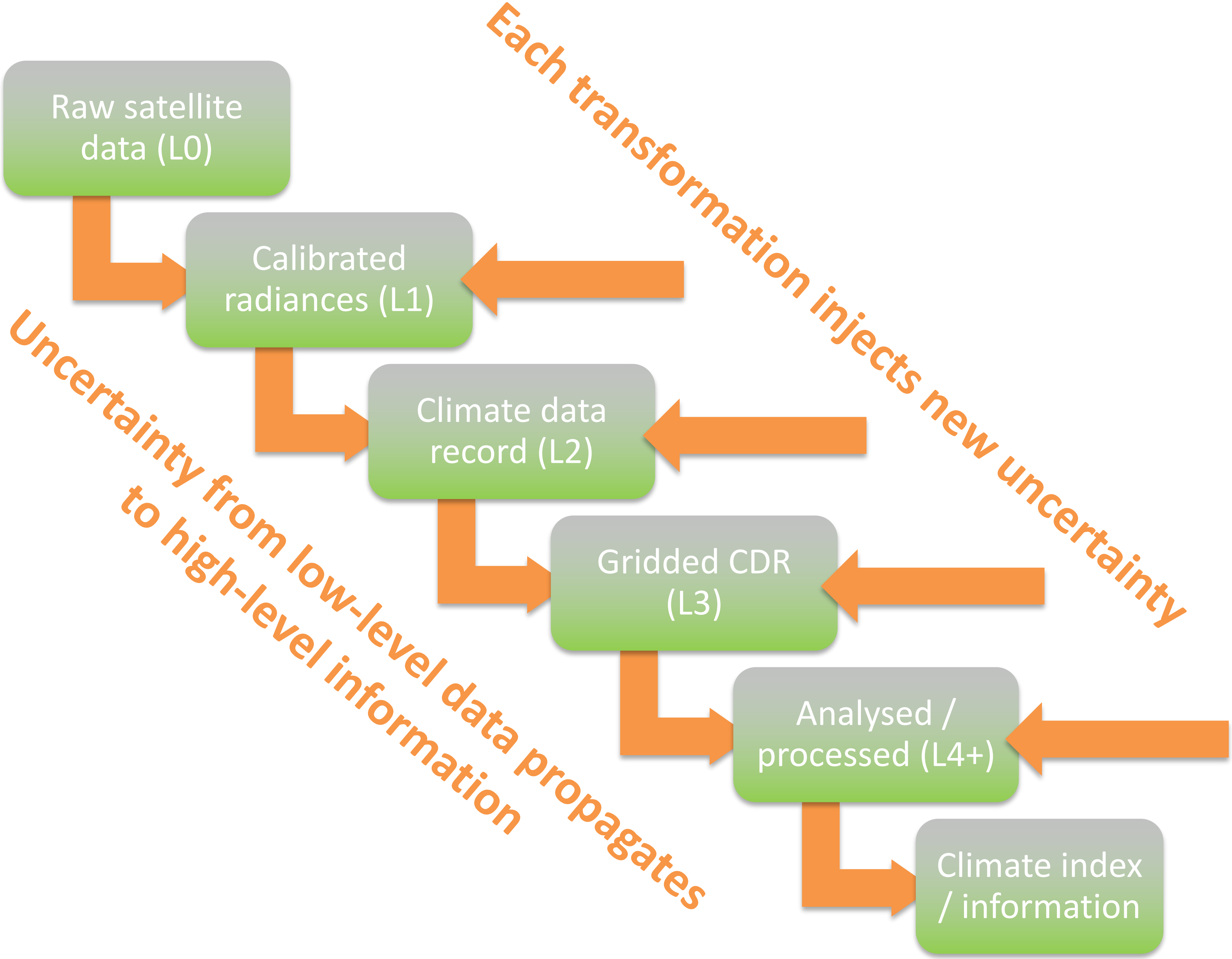
OBSTACLES TO PROVIDING UNCERTAINTY INFORMATION

- Lack of expertise, confusion about uncertainty concepts, unawareness of best practice
- Adopt, extend and communicate the concepts from laboratory metrology
- Need "EO metrology"

- Resources, since uncertainty estimation roughly doubles the effort of creating data
- Funding aspect
- Tools, guidelines, precedents

- Scepticism that user communities will use the information
- Trail-blazing that demonstrates value

- And …



University of Reading

Fiduceo

FIDUCEO

- **Fidelity and Uncertainty in Climate data records from Earth observation**
- **Ambition**: develop a widely applicable **metrology of Earth observation (EO)**
- **Motivation:** establish **defensible**, **uncertainty-quantified evidence (CDRs)** for climate and environmental change from space assets
- **Limitation of the status quo:** the level-1/radiance/FCDR uncertainty is not characterised, and **therefore cannot be propagated to the CDR**

More info, blog etc at: www.fiduceo.eu

University of Reading

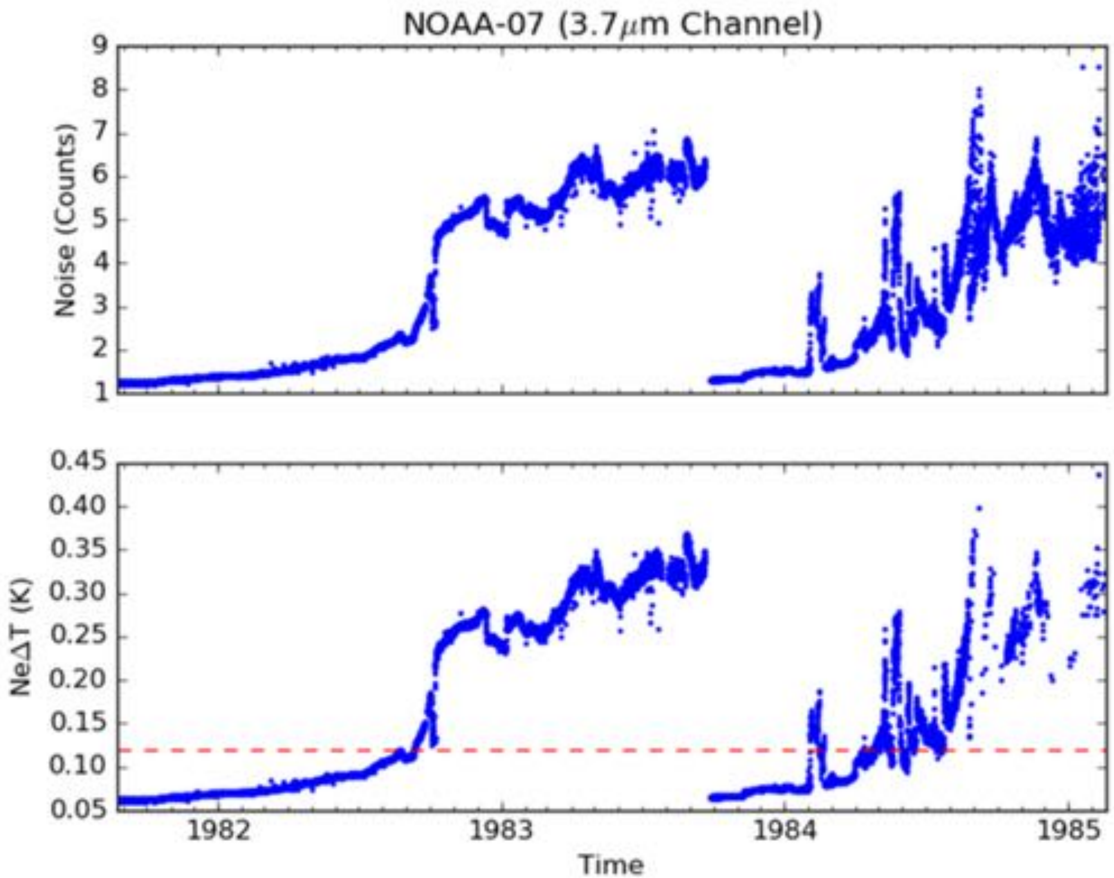
Fiduceo

Quantifying radiance uncertainty

- Understand the **measurement equation** (the calculation of the radiance in the product)
- Quantify the **sources of error** (effects)
- Quantify each effect’s **magnitude** and **error structures**
- Propagate to get radiance **uncertainty**

Magnitude of uncertainty

- Even the noise at the counts level can be surprisingly complex

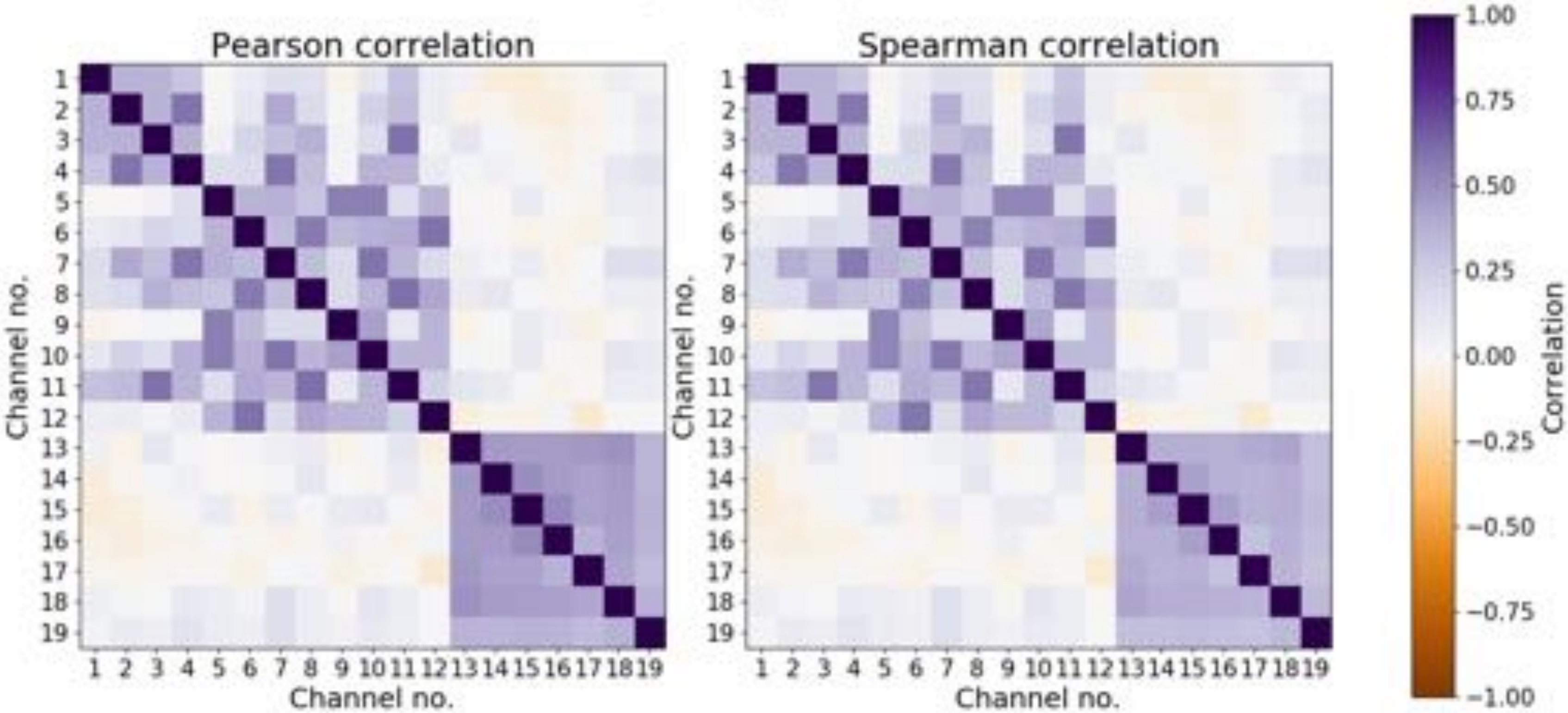


University of Reading

FIduceo

Correlated effects

- For some HIRS, strong correlations in noise between channels



University of Reading

Fiduceo

UNCERTAINTY QUANTIFICATION

University of Reading

- Radiance (reflectance, brightness temperature,…) uncertainty quantification should include:
  - Standard uncertainty estimates
    - Per datum or parameterised if highly variable
    - In components with different spatial correlation structures if necessary, along with correlation information
    - In FIDUCEO, 3-component model (independent, structured and common components)
  - Cross-channel error correlation matrix
    - For geophysical propagation, assimilation etc

THAT WOULD LET L1 USERS …

University of Reading

- Propagate radiance uncertainty to L2 CDR
  - Geophysical quantities on satellite projection with U
  - Accounting for error covariance (avoid underestimate)
- Quantify spatio-temporal error correlations at L2 CDR
  - Necessary to propagate uncertainty consistently to L3+ CDRs, and climate indices from space data
- Work with (F)CDR users (modellers, etc) to exploit uncertainty for
  - Model evaluation, assimilation, index information …

Brief conclusions

- Recommendations on uncertainty in CDRs can be articulated that are widely applicable (CCI)
- One of the barriers is lack of uncertainty information at FCDR level
- But that also can (and should) be addressed, in my view (FIDUCEO)