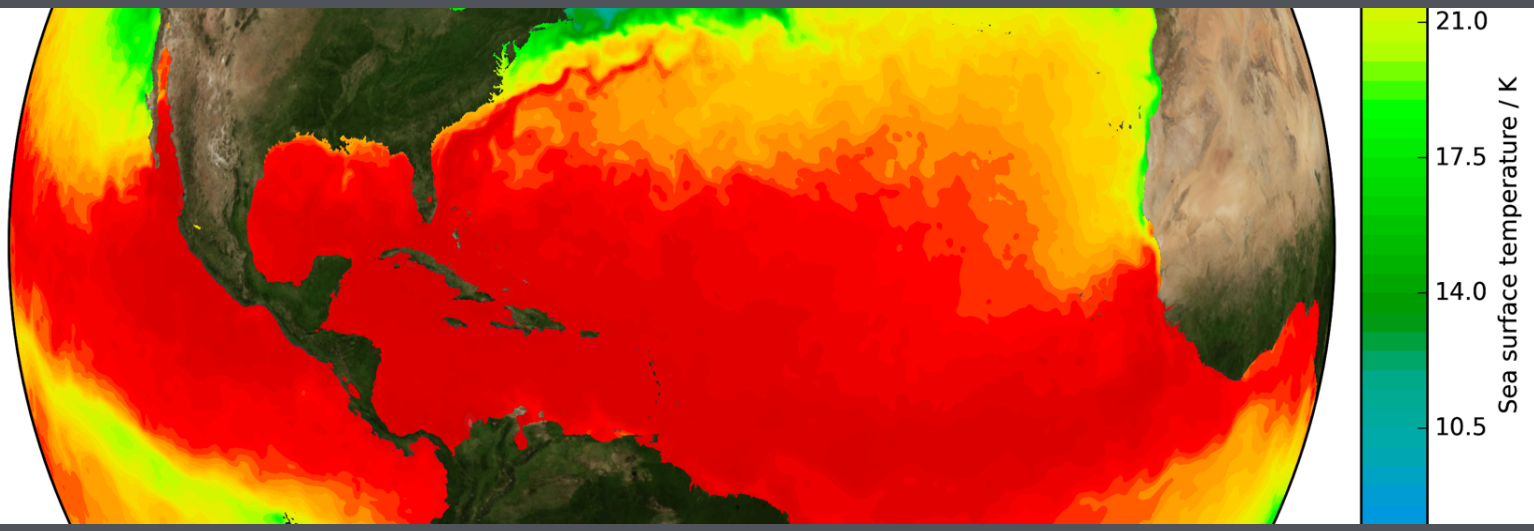
Earth Observation and Space
Department of Meteorology

University of Reading

UNCERTAINTY MODELLING FOR SATELLITE-BASED SST



Chris Merchant, Jon Mittaz*, Claire Bulgin, Owen Embury and Marine Desmons.

Department of Meteorology
University of Reading

*and National Physical Laboratory

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OBJECTIVES FOR UNCERTAINTY

- Satellite datasets should contain sufficient information about uncertainty to
  - distinguish more and less uncertain data
    - per datum
  - propagate uncertainty correctly to higher level datasets
    - such as gridded products and analyses
  - propagate uncertainty to aggregated and derived products
    - products combining datasets

  without over-inflating the data volume

- Give confidence in the uncertainty estimates through validation of them
- Help data users understand and use dataset uncertainties

USER REQ'MTS (SST)

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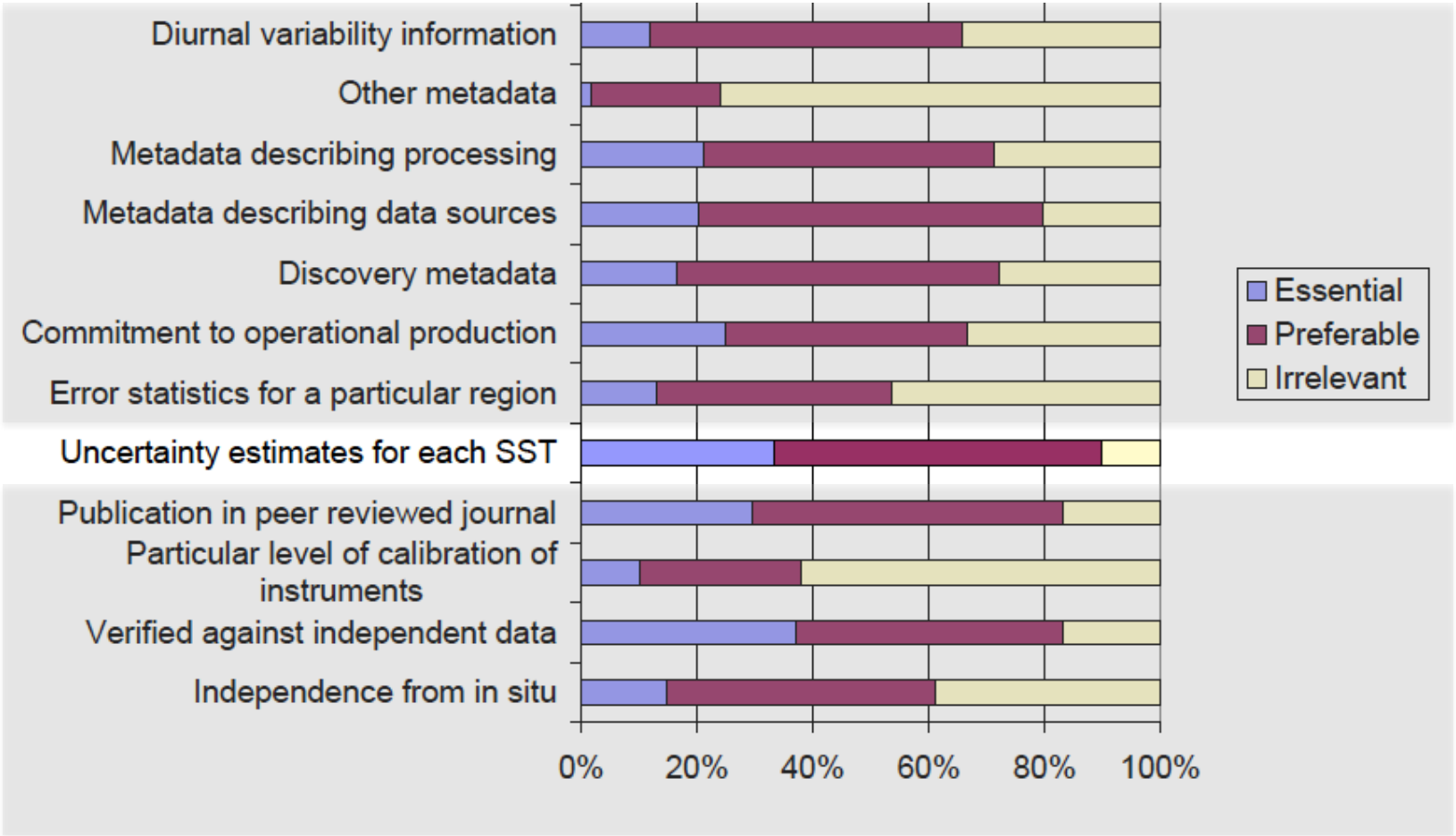
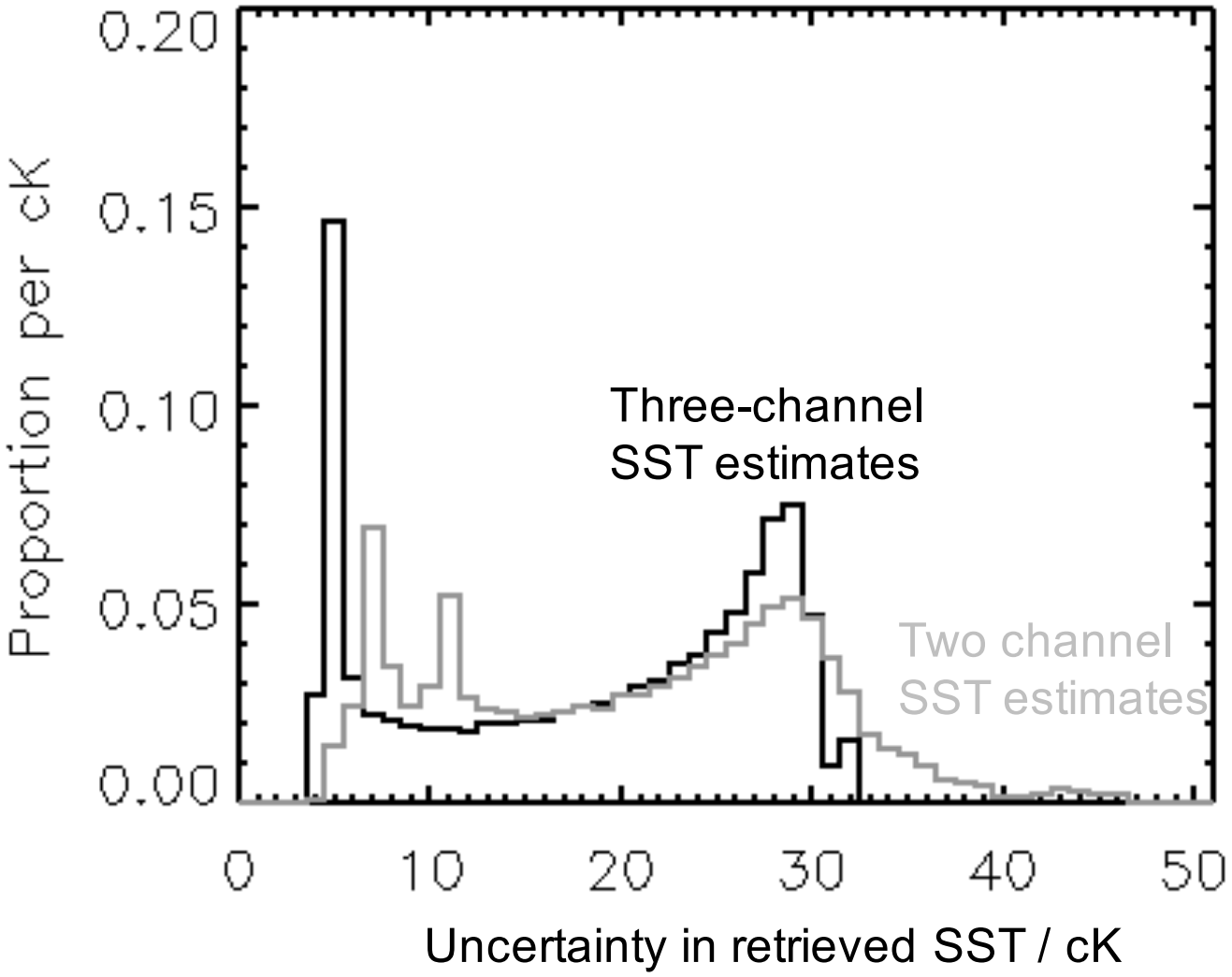


User requirements survey by UKMO in SST CCI

sst cci

Uncertainty varies. This should matter to some users



DEFINITIONS

- Error
  - Concept: How wrong is the measured value?
  - Number: Measured value minus true value
  - We don't know the error, but we should estimate its probability distribution
- Uncertainty
  - Concept: To what degree is the measured value in doubt?
  - Number: e.g., "standard uncertainty" is the SD of the (estimated) error distribution

- Random errors
  - Unpredictable in sign and magnitude
  - Cannot correct
- Systematic errors
  - Predictable in principle, if we had the understanding
  - Not just bias
  - Can learn to correct (and remove)
- Structured random errors
  - (Predictable relationship of error in measured values) x (Random magnitude)
  - Errors are correlated (but, not "correlated uncertainty")

I PLEAD GUILTY

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- I have been on a learning journey – and have published confusing terms along the way!
  - All these terms refer to the same component of uncertainty in satellite SST images
  - "Symmetric pseudo-random error"
    - ATBD for Sentinel 3 SLSTR
    - Focus on how errors affect validation statistics
  - "Synoptically correlated uncertainty"
    - SST CCI ATBD and Product Specification
    - Focus on the origin in synoptic variability of atmosphere
  - "Uncertainty from spatio-temporally correlated effects"
    - Focus on general statistical nature of effect
- It is worth adopting (and extending) the language of measurement experts

GUM IS RECOMMENDED

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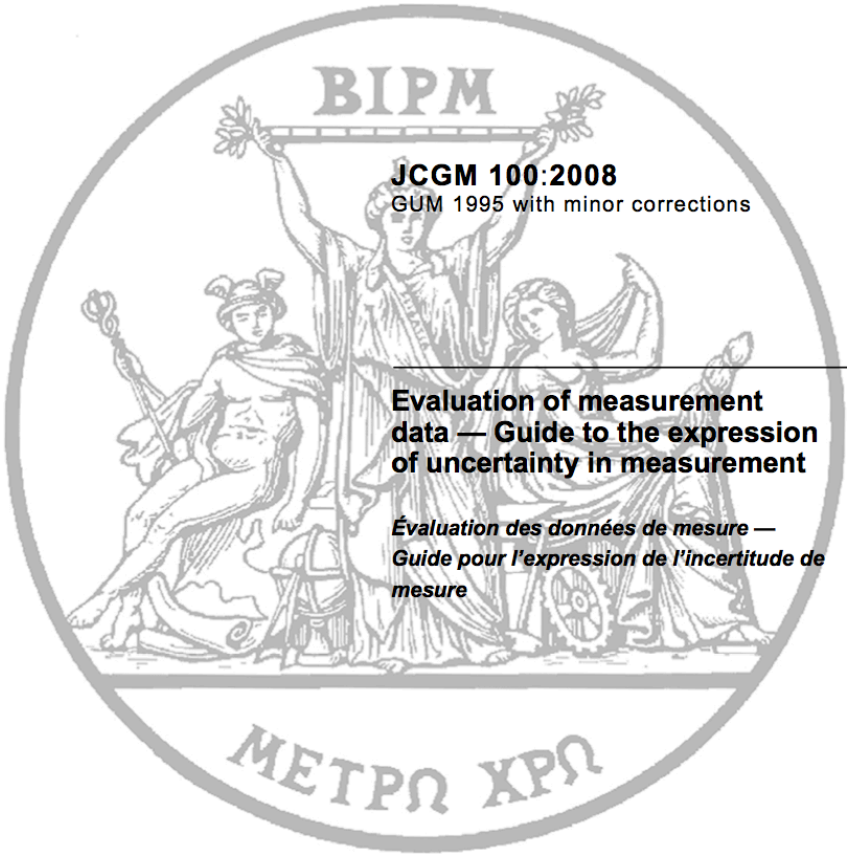
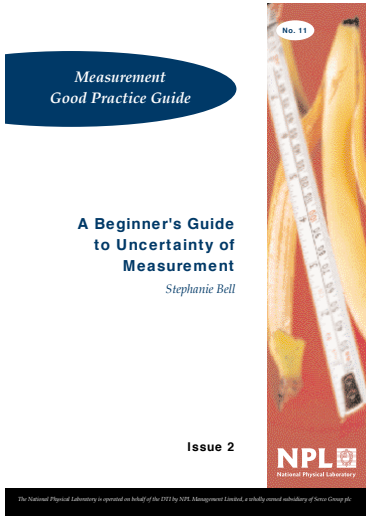


www.bipm.org/en/publications/guides/gum.html



UNCERTAINTY CASCADE

detector, amplifier, digitisation, non-linearity …

L0

↓

radiance calibration, geolocation …

L1b

↓

retrieval ambiguity, geophysical definition …

L2

↓

spatio-temporal sampling, correlated errors …

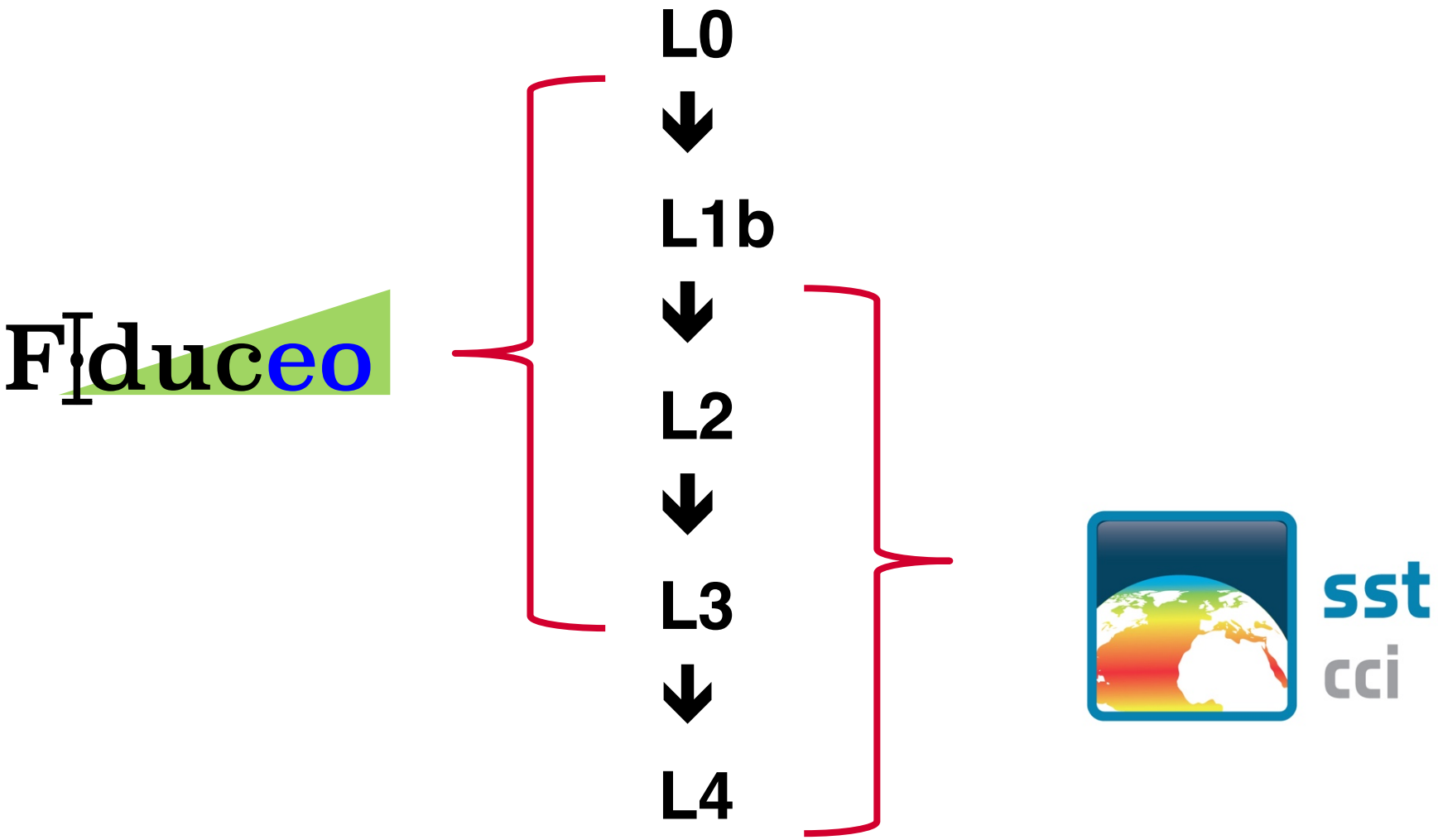
L3

↓

extra-/interpolation, smoothing

L4

UNCERTAINTY CASCADE



FIDUCEO

- **Key idea**: develop a widely applicable basis for the **metrology of Earth observation** including historical satellite missions

- The **motivation** is to establish "uncertainty-quantified" evidence base for long-term climate and environmental change from EO systems

- Project runs March 2015 to February 2019

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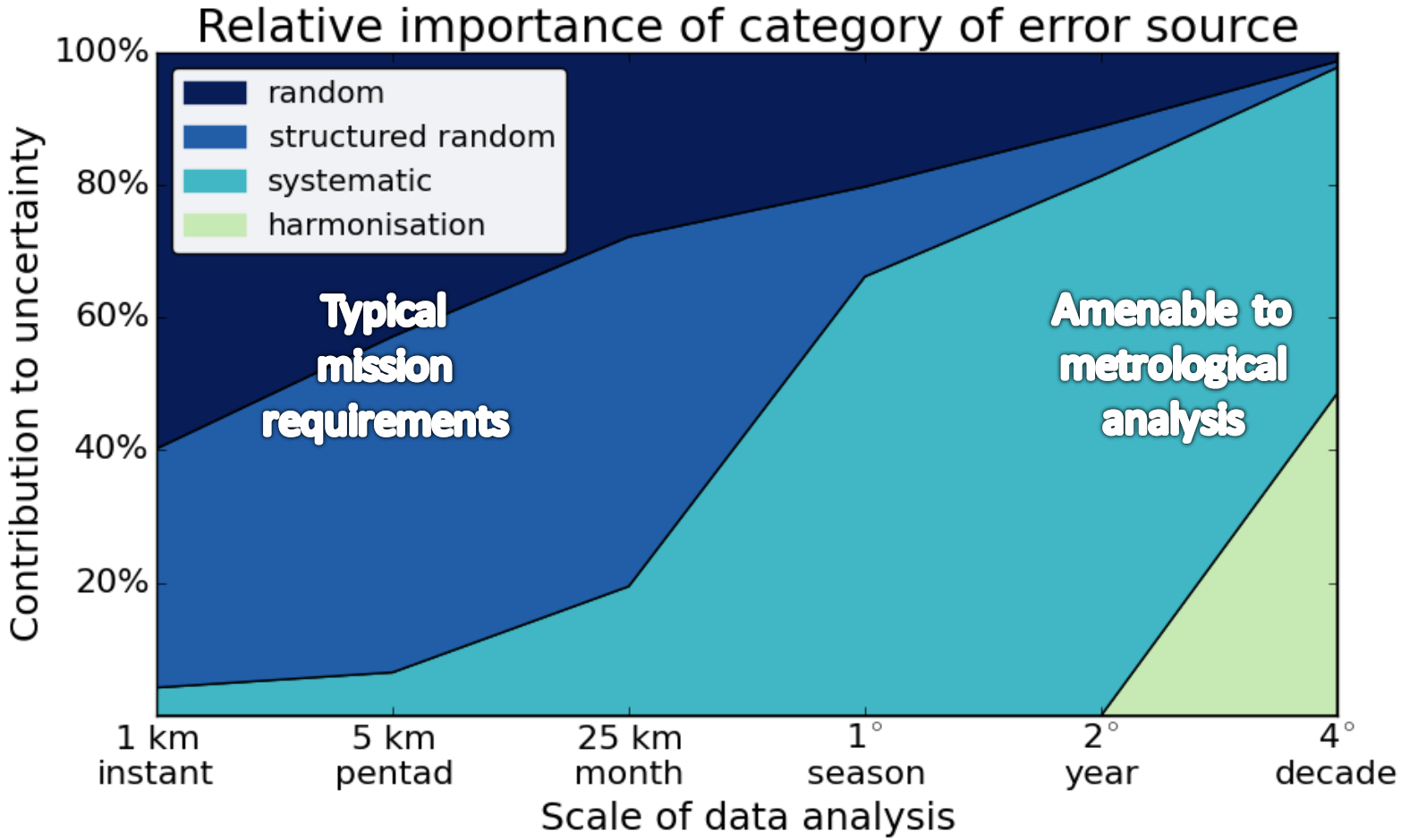
Why a **metrological** approach?
Why consider **all** sources of uncertainty?



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

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

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FIDUCEO FCDRs (Yr 1 & 2)

DATASET	NATURE	POSSIBLE USES
AVHRR FCDR	Harmonised infra-red radiances and best available reflectance radiances, 1982 - 2016	SST, LSWT, aerosol, LST, phenology, cloud properties, surface reflectance …
HIRS FCDR	Harmonised infra-red radiances, 1982 - 2016	Atmospheric humidity, NWP re-analysis, stratospheric aerosol …
MW Sounder FCDR	Harmonised microwave BTs for AMSU-B and equivalent channels, 1992 – 2016	Atmospheric humidity, NWP re-analysis …
Meteosat VIS FCDR	Improved visible spectral response functions and reflectance 1982 to 2016	Albedo, aerosol, NWP re-analysis, cloud, wind motion vectors,…

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FIDUCEO CDRs (Yr 3 & 4)

DATASET	NATURE	USE
Surface Temperature CDRs	**Ensemble SST and lake surface water temperature**	Climate science … model evaluation, re-analysis, derived/synthesis products ..
UTH CDR	From HIRS and MW, 1992 - 2016	Sensitive climate change metric, re-analysis …
Albedo and aerosol CDRs	From M5 – 7 (1995 – 2006)	Climate forcing and change, health …
Aerosol CDR	2002-2012 aerosol for Europe and Africa from AVHRR	Climate forcing and change, health …

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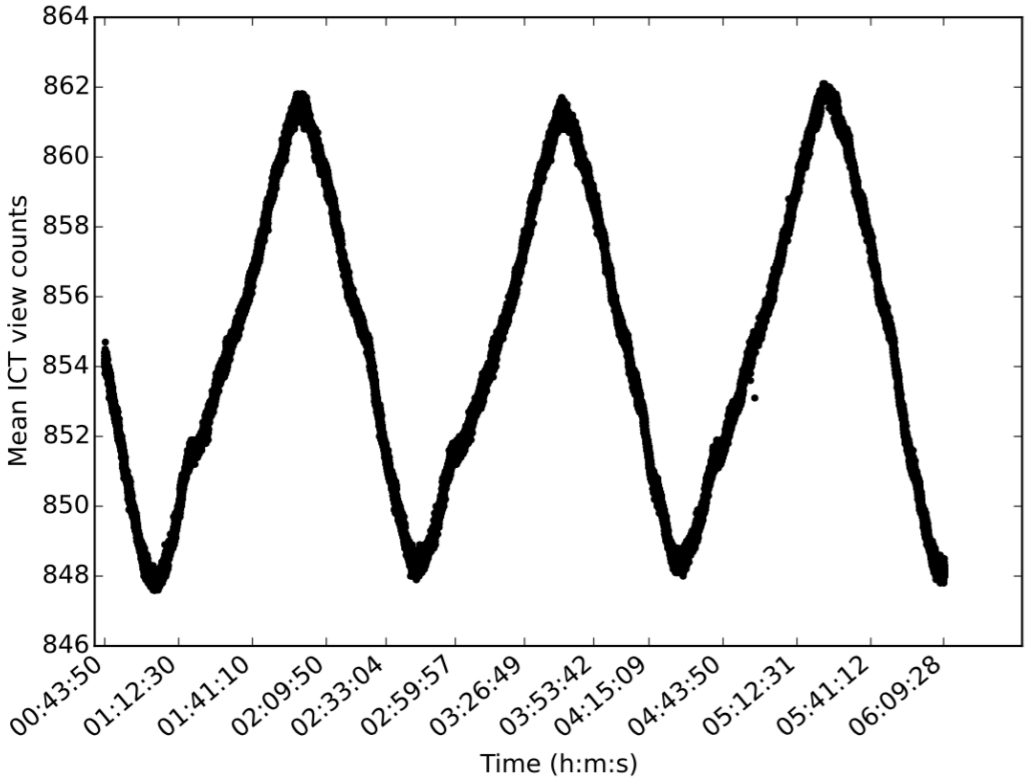
Example: AVHRR noise effects

Generally quoted as “0.12 K” NEDT

Can look at NEDT on internal calibration target (ICT)

Counts standard deviation

But non-stationary



Three orbits of AVHRR ICT counts, NOAA-19

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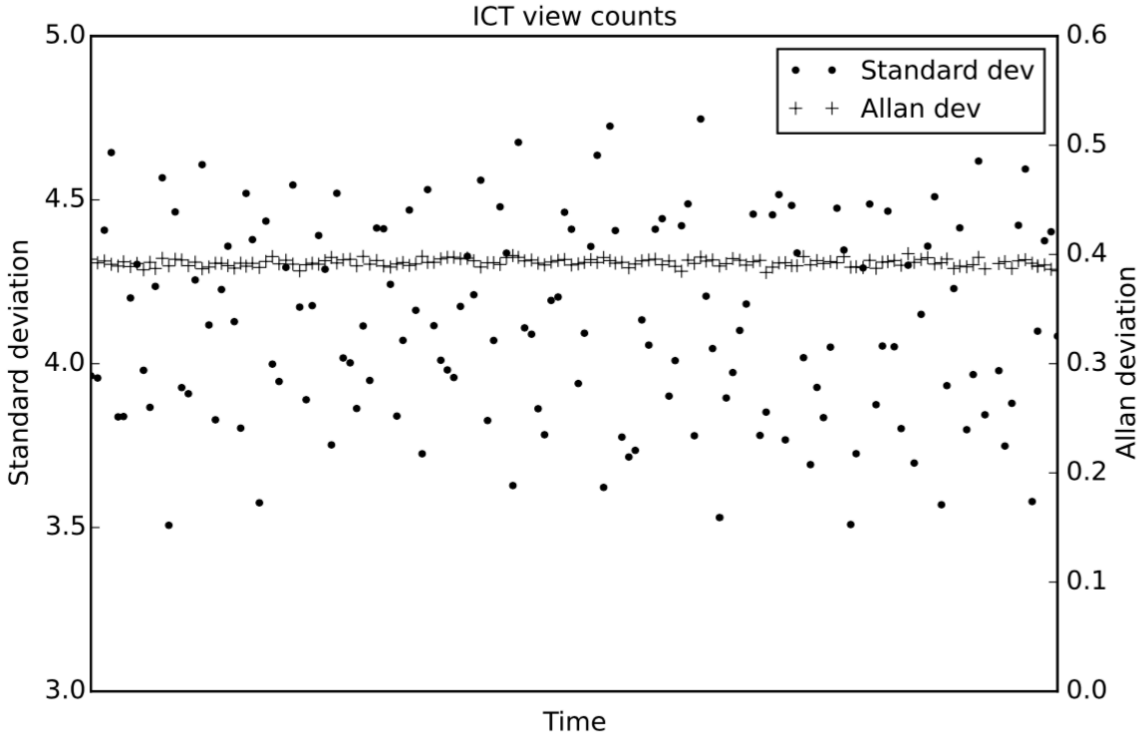
Example: AVHRR noise effects

Generally quoted as “0.12 K” NEDT

Metrologists use “Allan variances” to analyse noise in non-stationary series

True NEDT ~O(0.05 K)



Counts standard deviation, calculated two ways

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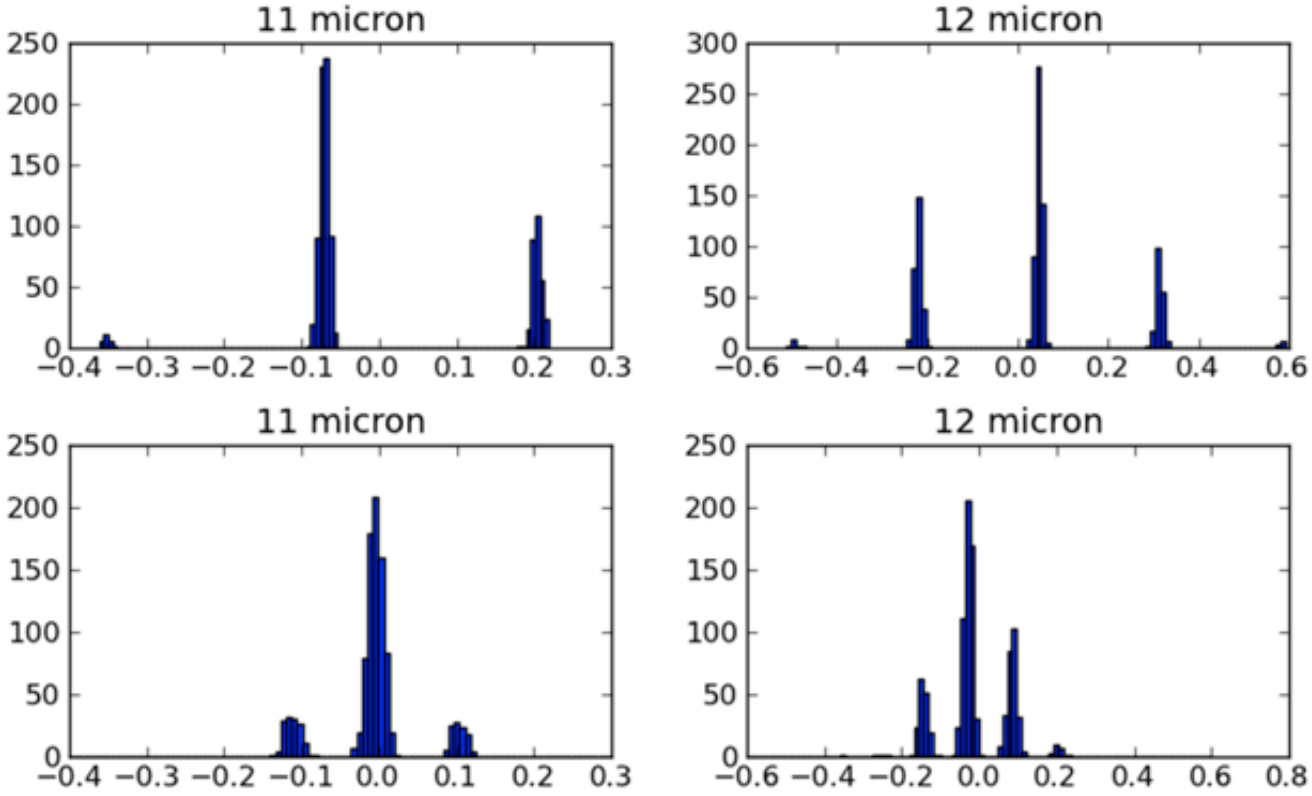
Error PDFs for random effects

230K

300K



Accounts for: (1) noise and digitization in pixel (random)
(2) noise/digitization in calibration (structured random)

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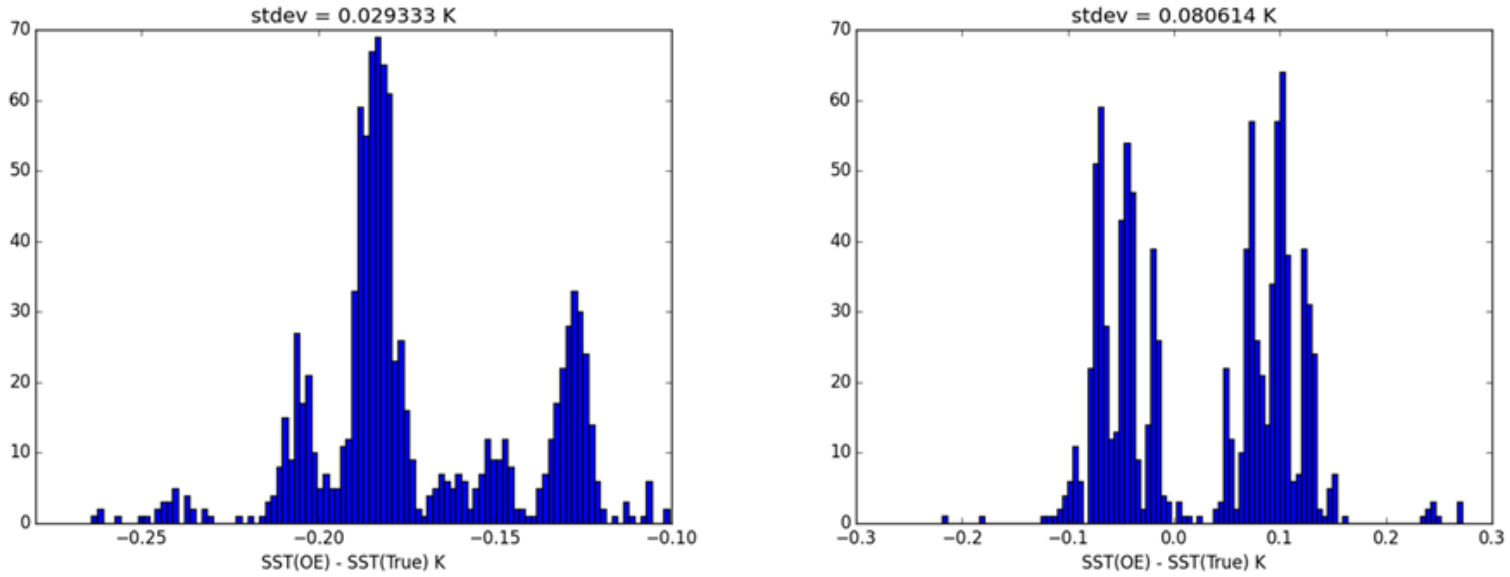
Propagation to SST Error PDFs

Monte-Carlo simulation for individual SST retrievals



Highly non-Gaussian error distribution

Spread is dominated by propagation of random effect from L1

Non-zero mean dominated by SST retrieval effects (new in L2)

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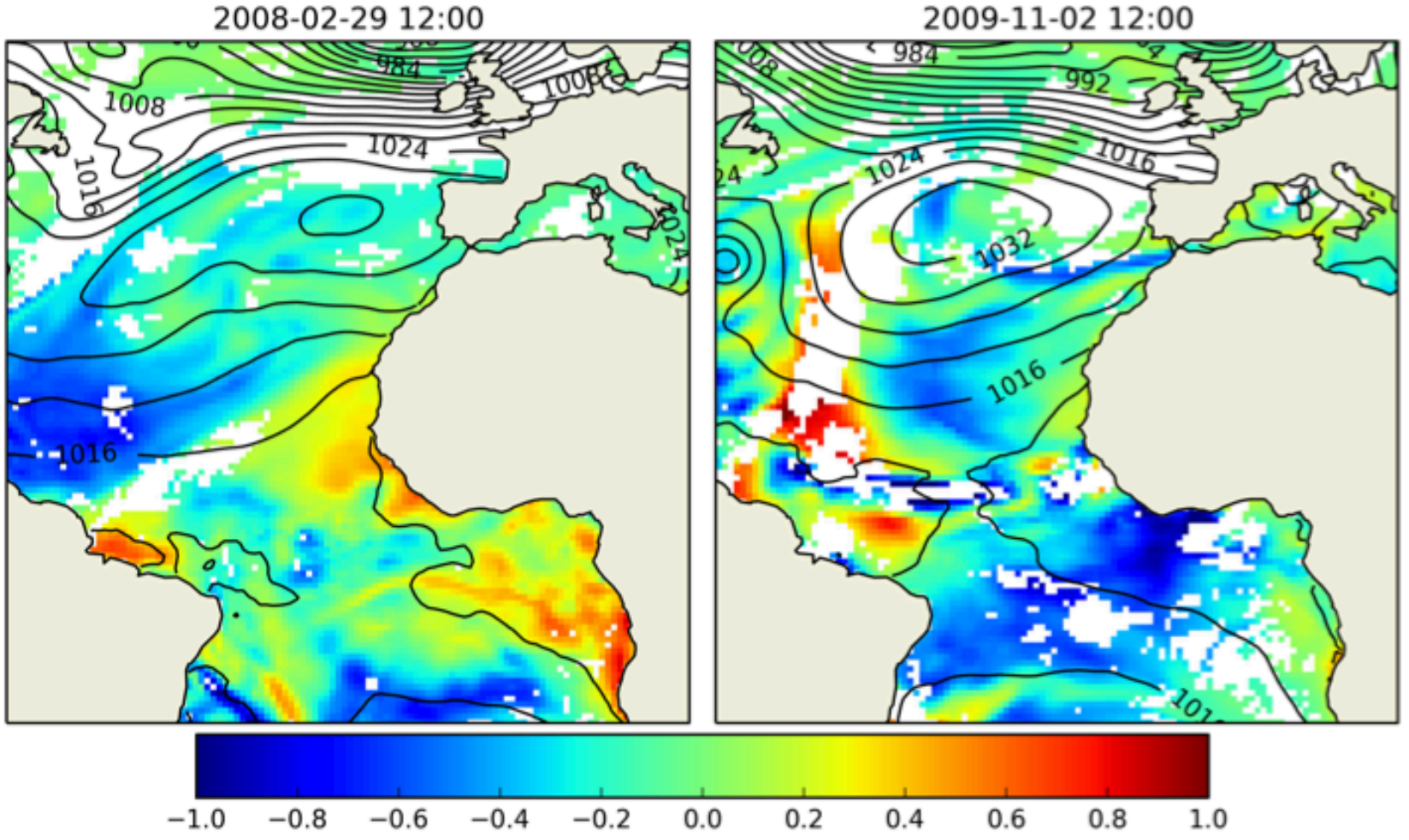
Simulation of retrieval error



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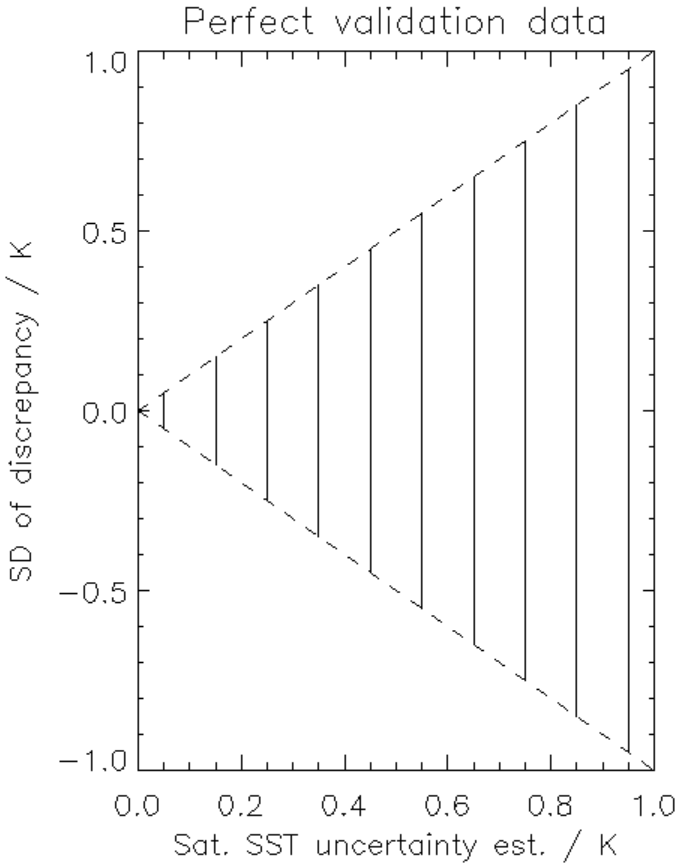
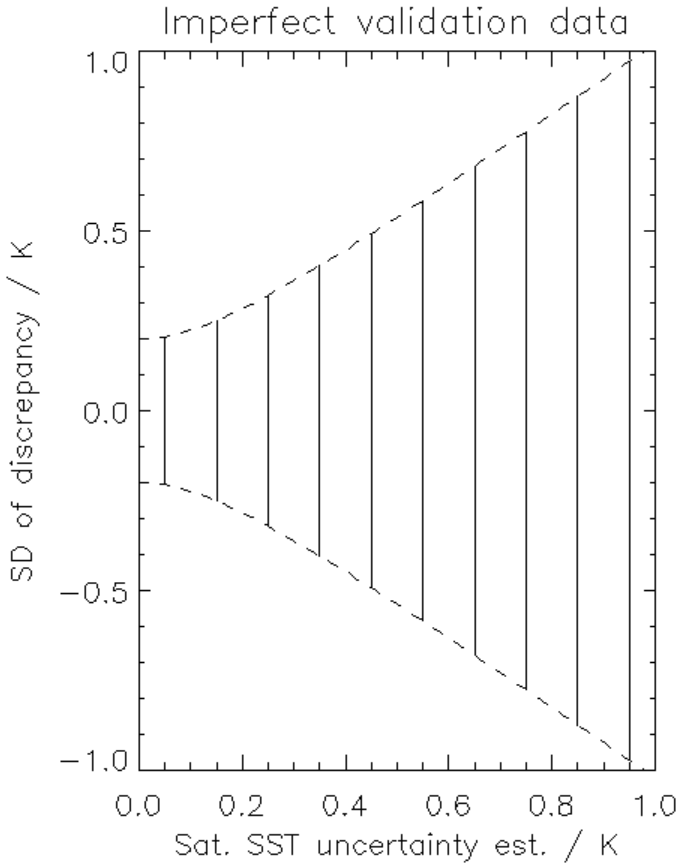
How to validate uncertainty?

Given drifter calibration uncertainty ~0.2 K





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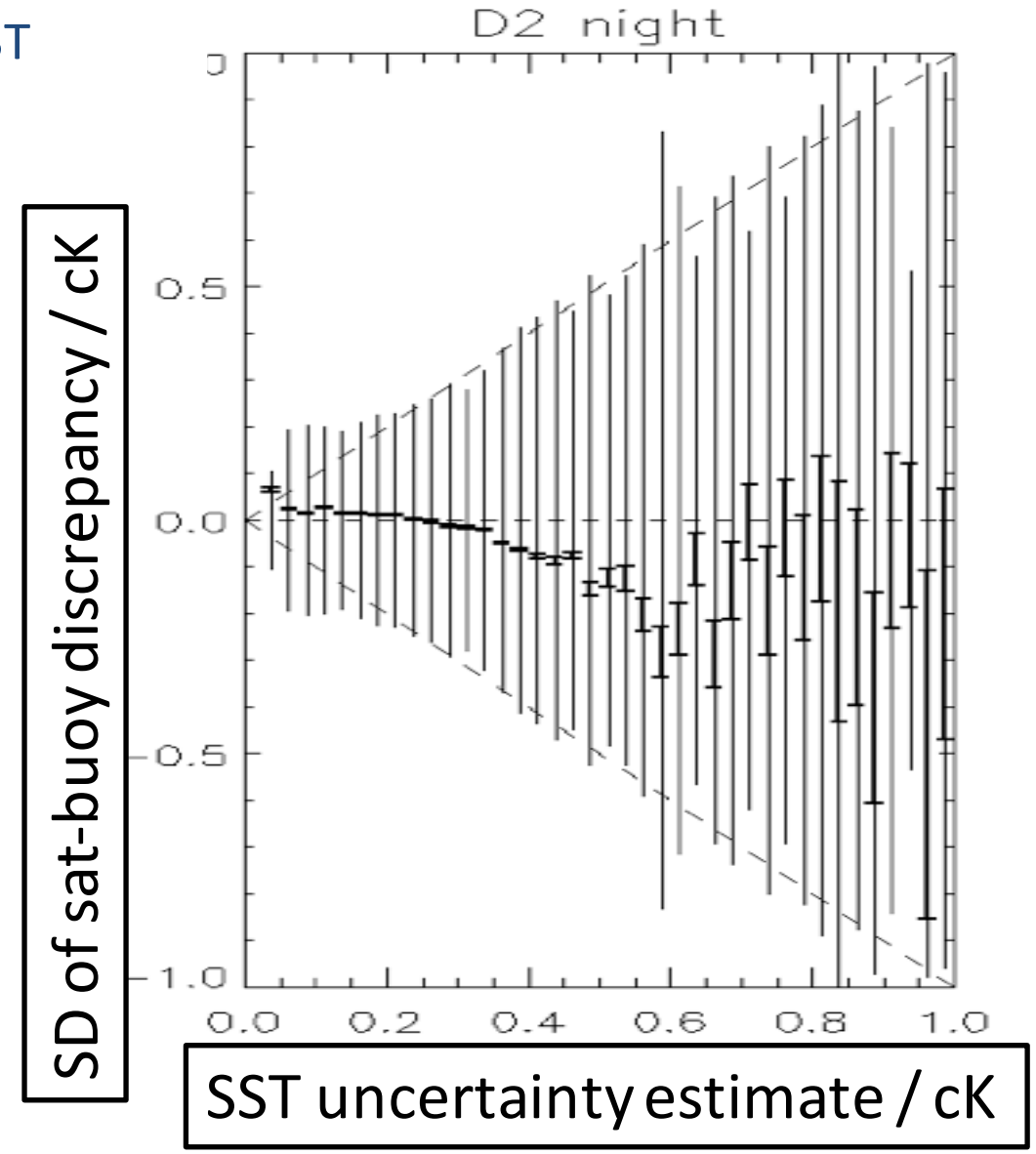
AATSR D2 SST
based on
coefficients
0.1 deg cells



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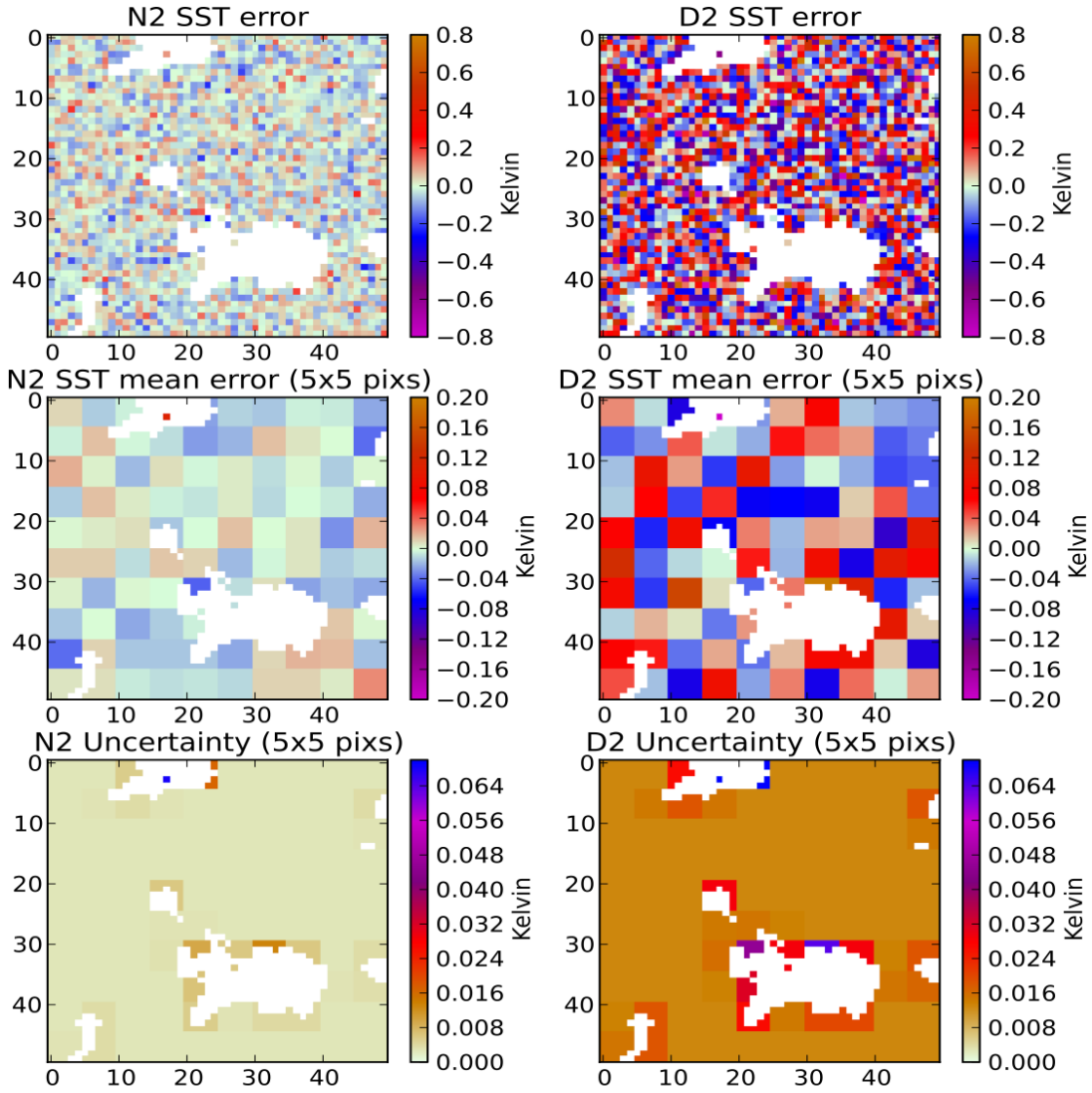
ARC SST

Fiduceo

Noise propagation to L3 Gridded Products



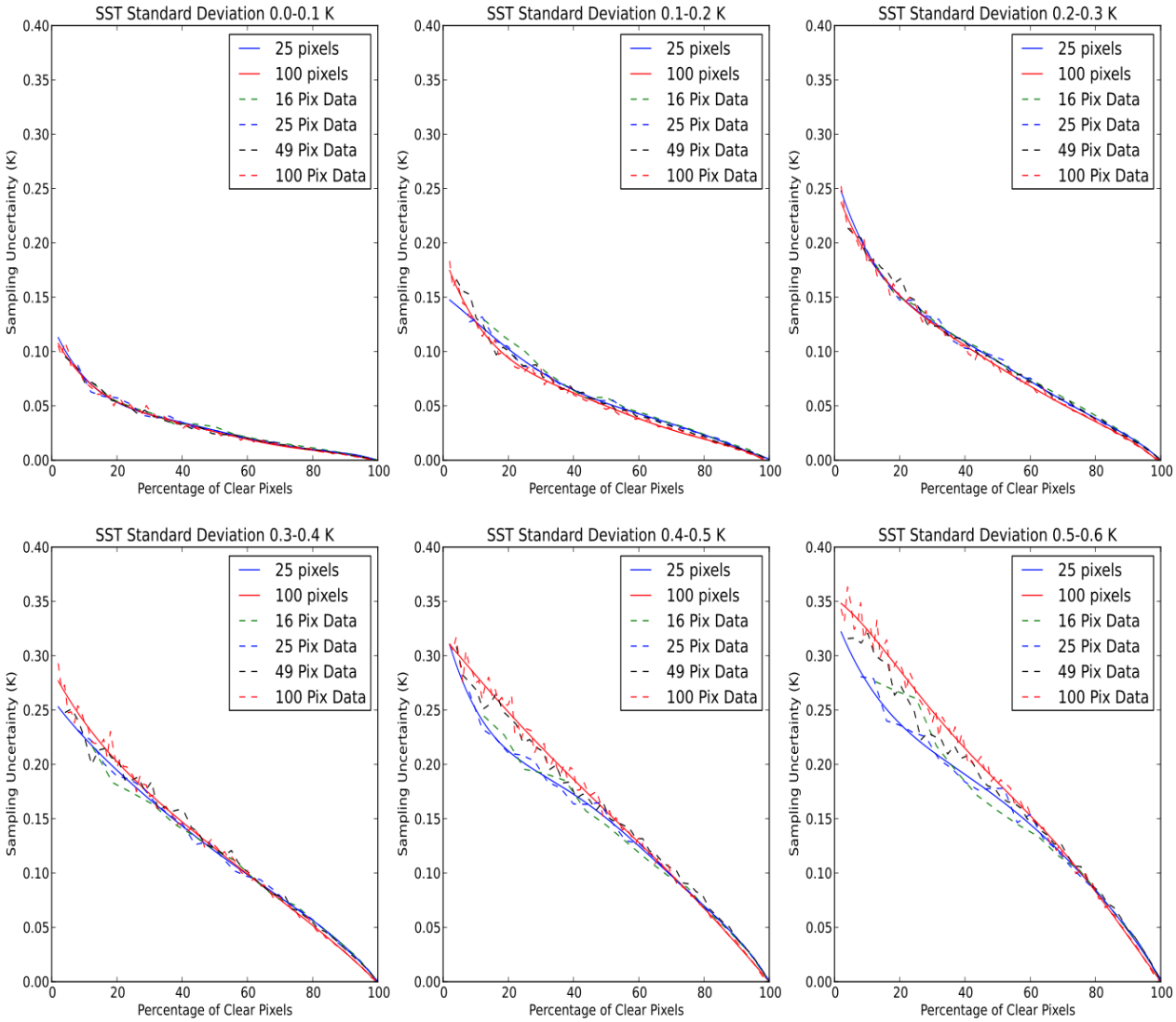
Many SST users want data at 0.05 degrees or coarser so we generate gridded products:

- Uncertainty from random effects reduces as $1/\sqrt{n}$.

Bulgin et al., 2016, RSE.

10.1016/j.rse.2016.02.022

Sampling Uncertainty in L3 Products



- Sampling uncertainties are introduced where the gridded domain is not fully observed (eg. partially cloud covered).
- These uncertainties can be modeled as a function of domain size, clear sky percentage and SST variability.

How these uncertainties are communicated in SST CCI products

Name	Long Name	Type
20030904091826-ESACCI-L3U_GHR...	20030904091826-ESACCI-L3U_GHRSST-SSTskin-AATSR-LT-v02.0-fv0...	Local File
adjustment_uncertainty	Time and depth adjustment uncertainty	[lon][lat]
l2p_flags	L2P flags	[lon][lat]
large_scale_correlated_uncertainty	Uncertainty from errors likely to be correlated over large scales	[lon][lat]
lat	Latitude	—
lat_bnds	Latitude cell boundaries	—
lon	Longitude	—
lon_bnds	Longitude cell boundaries	—
quality_level	quality level of SST pixel	[lon][lat]
sea_surface_temperature	sea surface skin temperature	[lon][lat]
sea_surface_temperature_depth	sea surface temperature at 0.2 m	[lon][lat]
sses_bias	SSES bias estimate	[lon][lat]
sses_standard_deviation	SSES standard deviation	[lon][lat]
sst_depth_total_uncertainty	Total uncertainty in sea surface temperature depth	[lon][lat]
sst_dtime	time difference from reference time	[lon][lat]
synoptically_correlated_uncertainty	Uncertainty from errors likely to be correlated over synoptic scales	[lon][lat]
time	reference time of sst file	—
time_bnds	Time cell boundaries	—
uncorrelated_uncertainty	Uncertainty from errors unlikely to be correlated between SSTs	[lon][lat]
wind_speed	10m wind speed	[lon][lat]

How these uncertainties are communicated in SST CCI products

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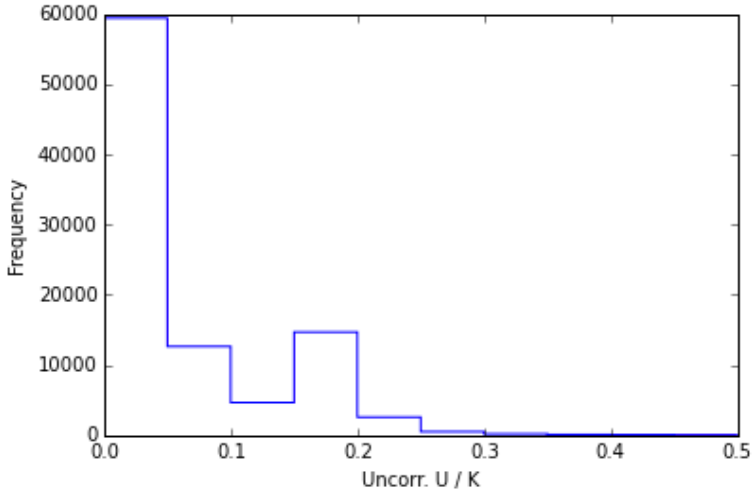
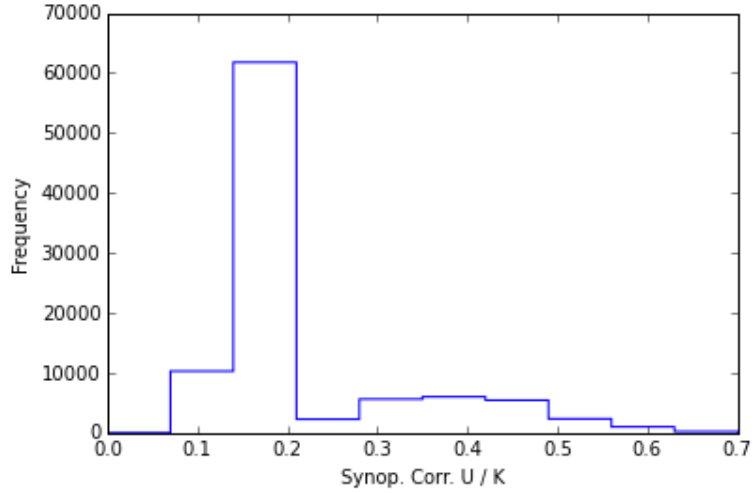
‘Noise’ in SST (uncorrelated)



Limitations of algorithm (synop. corr.)



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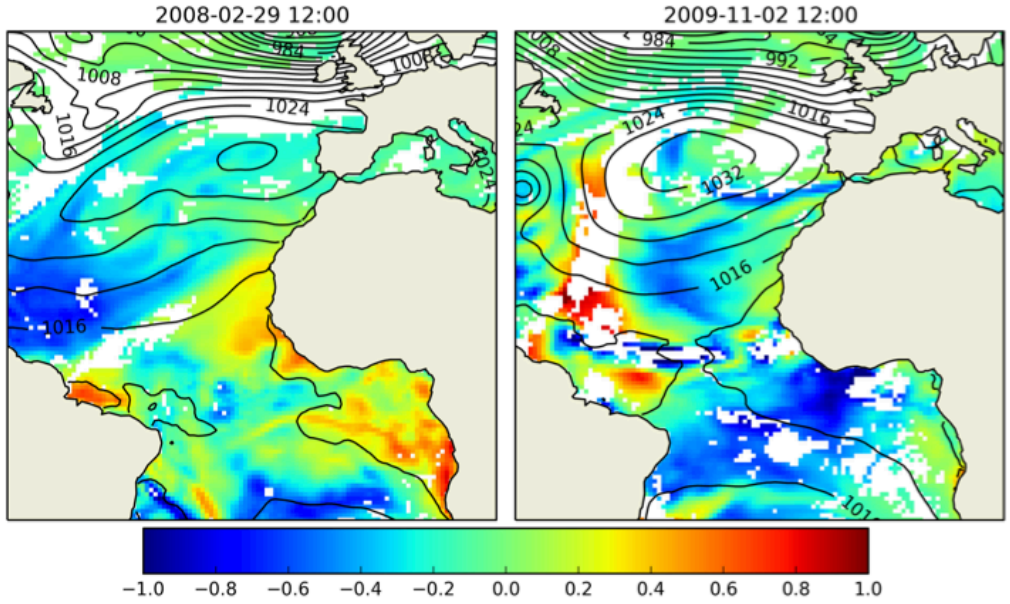

How these uncertainties are communicated in SST CCI products

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lat	Latitude	—
lat_bnds	Latitude cell boundaries	—
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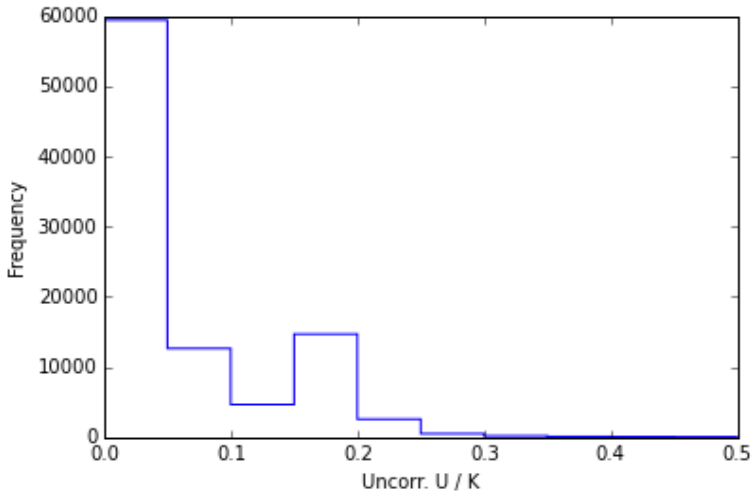
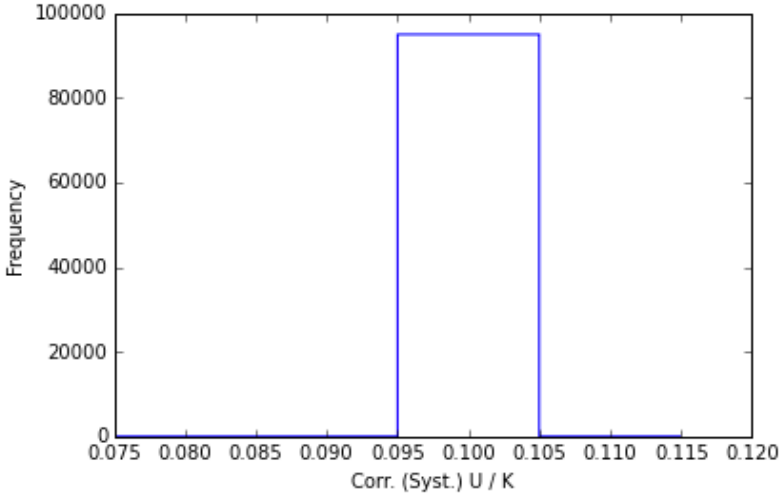
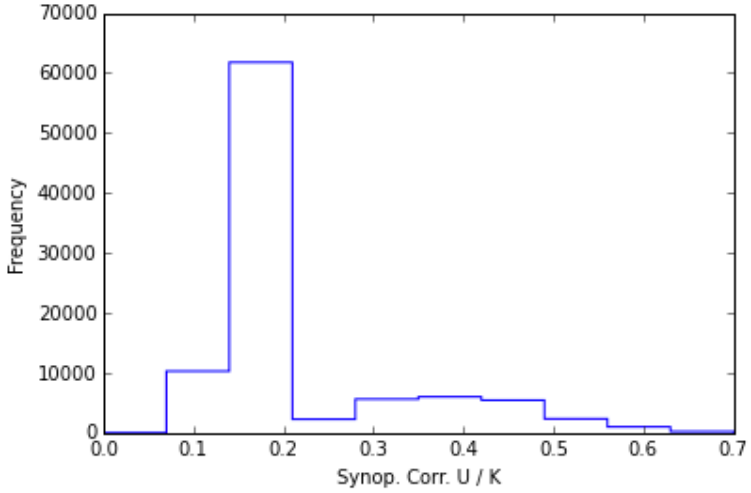
‘Noise’ in SST (uncorrelated)



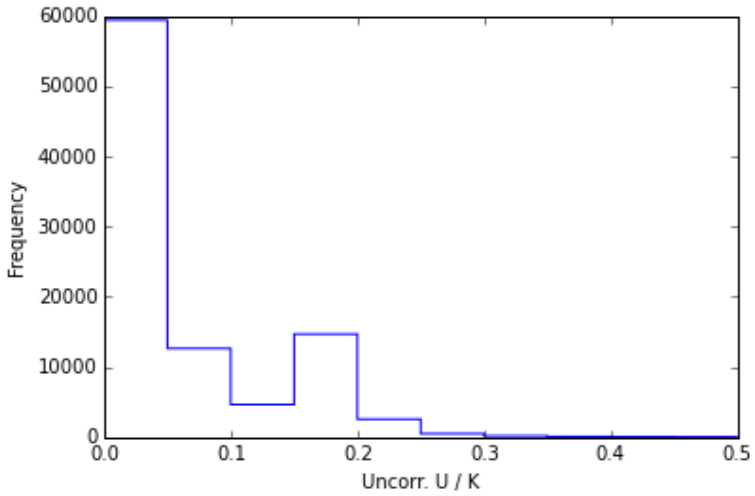
Systematic (large scale correlated)



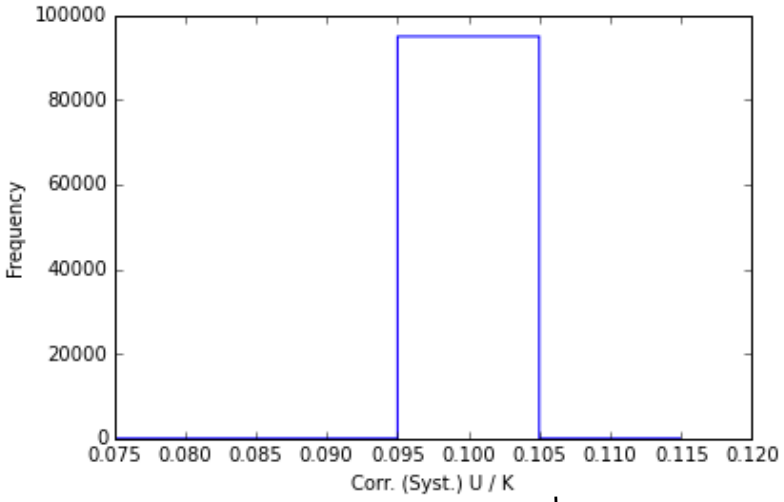
Limitations of algorithm (synop. corr.)



‘Noise’ in SST (uncorrelated)



Systematic (large scale correlated)



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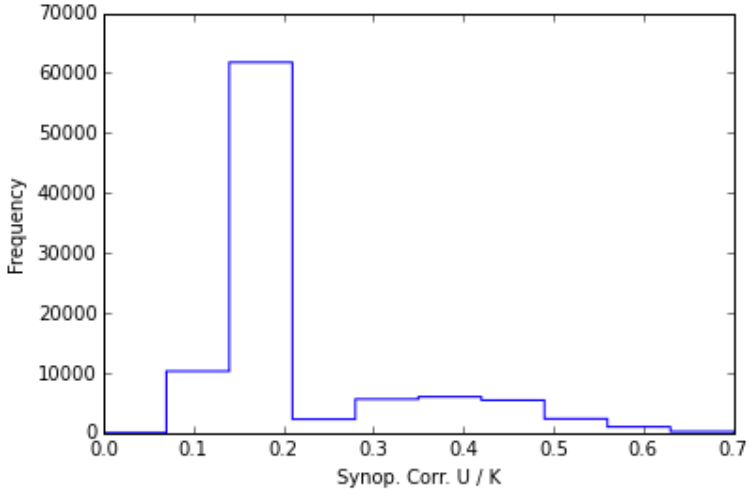
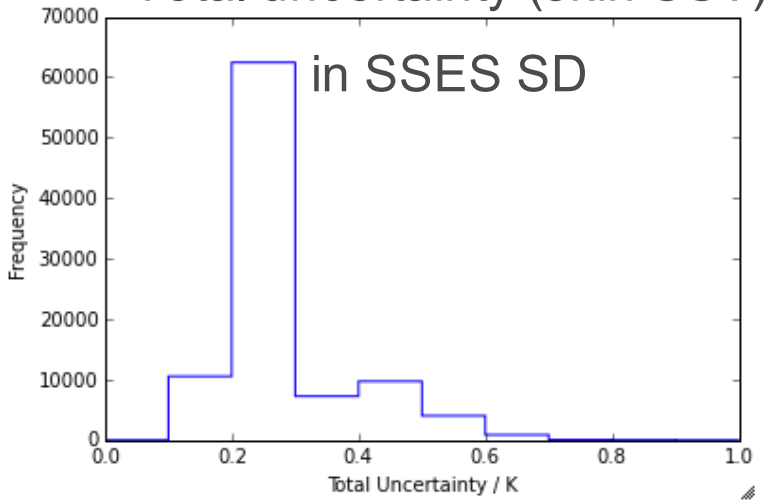


Total uncertainty (skin SST) in SSES SD



How these uncertainties are communicated in SST CCI products

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adjustment_uncertainty	Time and depth adjustment uncertainty	[lon][lat]
l2p_flags	L2P flags	[lon][lat]
large_scale_correlated_uncertainty	Uncertainty from errors likely to be correlated over large scales	[lon][lat]
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lat_bnds	Latitude cell boundaries	—
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lon_bnds	Longitude cell boundaries	—
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synoptically_correlated_uncertainty	Uncertainty from errors likely to be correlated over synoptic scales	[lon][lat]
time	reference time of sst file	—
time_bnds	Time cell boundaries	—
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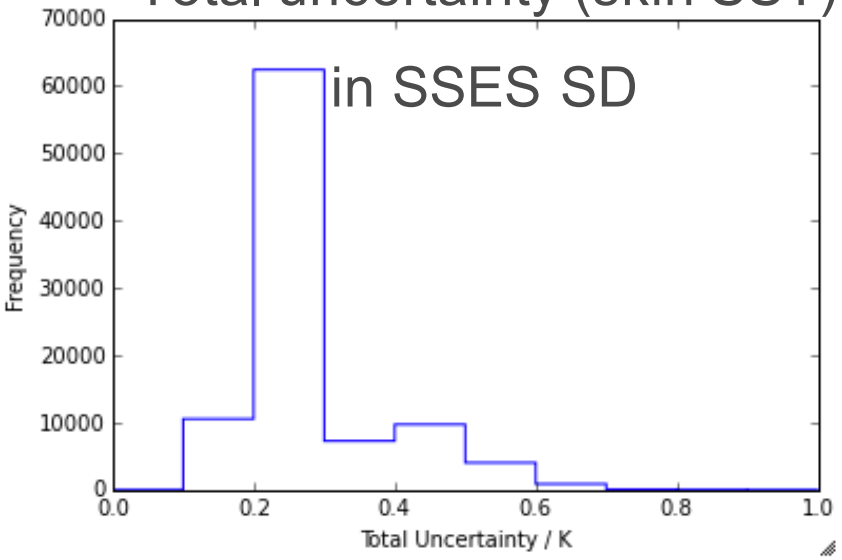
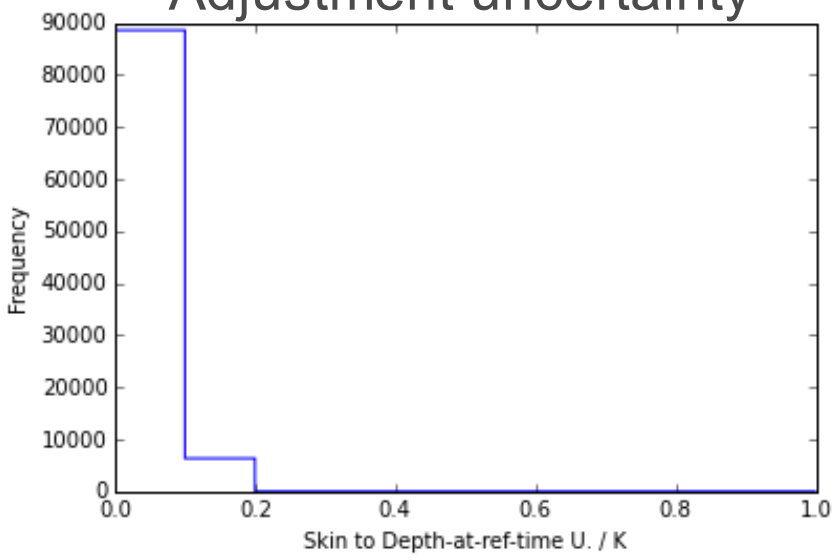
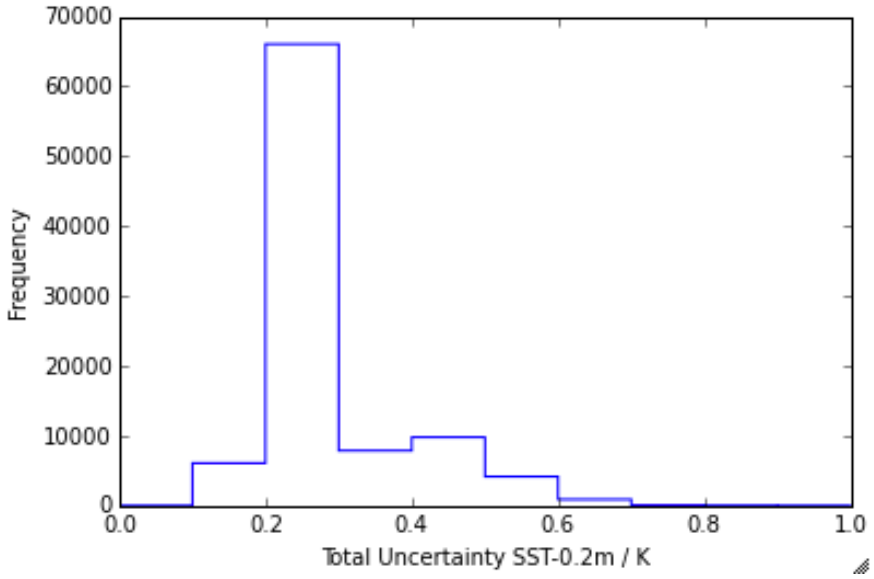
Total uncertainty (skin SST) in SSES SD



Adjustment uncertainty





Total uncertainty in $SST_{0.2\ m}$

How these uncertainties are communicated in SST CCI products

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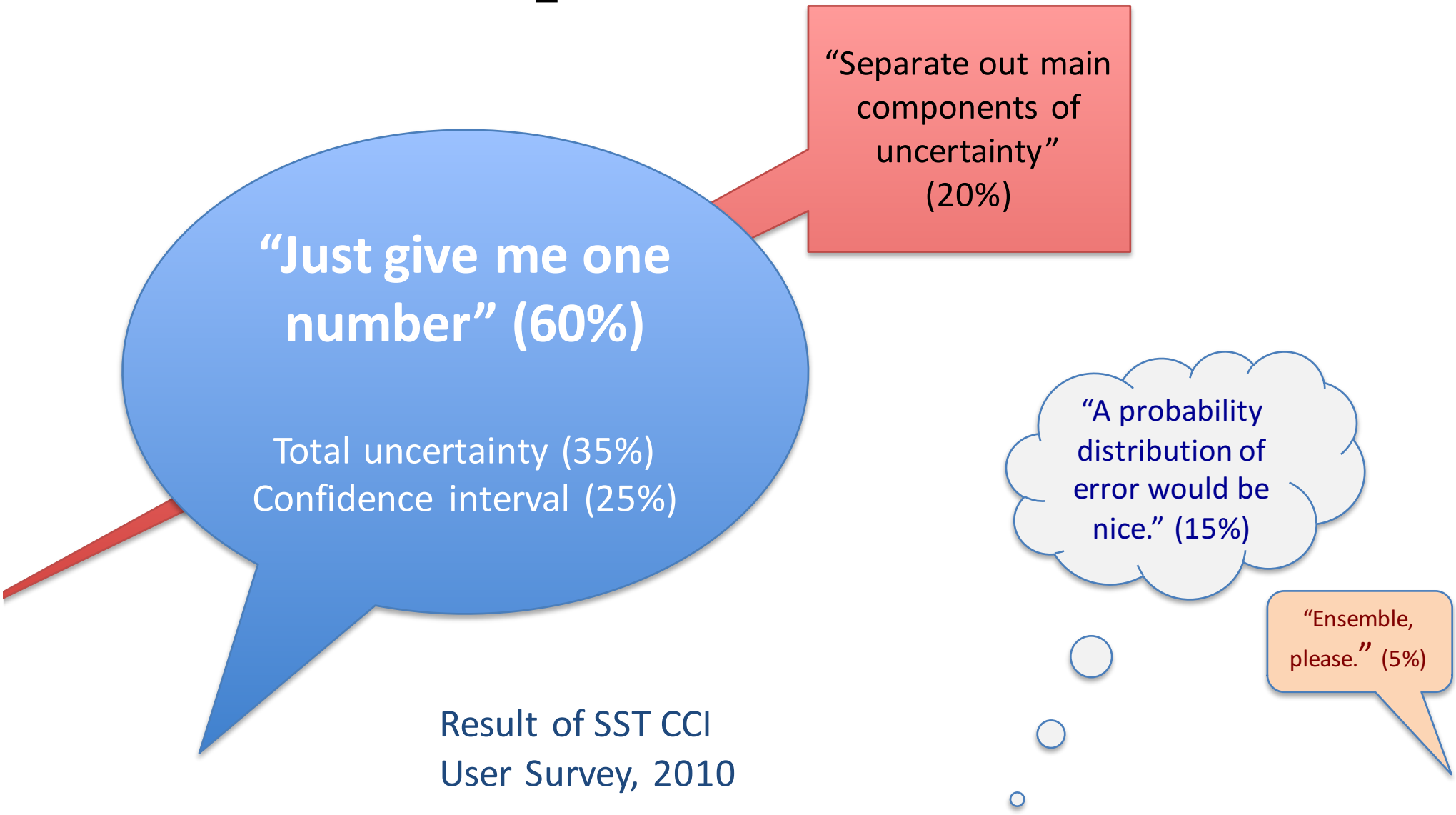
wind_speed	10m wind speed	[lon][lat]

How should uncertainty be presented?



Result of SST CCI User Survey, 2010

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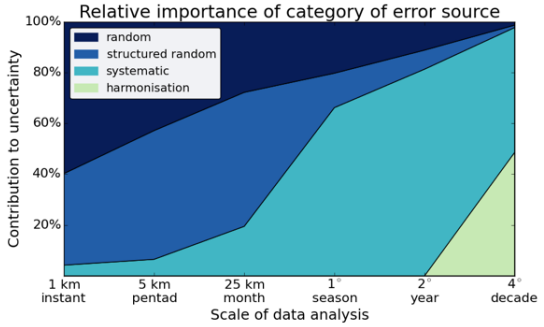
How should uncertainty be presented?

Significant request from major users at SST CCI user consultation in 2014 (after discussing uncertainty concepts and issues for two days)

"Ensemble, please."



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CONCLUSIONS

- Worthwhile to work with metrologists and their defined language for uncertainty in measurement
  - needs some extension: FIDUCEO vocabulary
- Some errors are random or systematic, but structured random errors can't be ignored
  - correlated effects are complex to propagate across scales
  - "slow" effects are most readily captured and understood via ensemble products?
- Uncertainty-quantified Climate Data Record
  - Uncertainty information in product that (i) discriminates more and less certain data, (ii) is validated as being realistic in magnitude and structure, (iii) is traceable back to FCDR uncertainty information (also traceable)
- Still working on
  - Uncertainty propagation across scales
  - Validation of uncertainty – including correlation structures
  - Standardisation of uncertainty in data structures
  - Satellite-based ensemble SST products