Experimental approaches to uncertainty: Communicating the unquantifiable

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Representing uncertainty

a) Typical understanding of uncertainty as the width of the distribution of error around the measurand. This is generally accurate for random errors.

b) The 'uncertainty' of a systematic error can be more complex as the distribution of error is asymmetric with non-zero mean.
Classifying sources of error

- Intrinsic sources of error
  - Measurement
    - Statistical variation in measurand or detector
    - e.g. dark current, radiometric calibration
  - Parameter
    - Uncertainty in auxiliary information used
    - e.g. spectroscopic data, meteorological profiles
  - Both also known as “parametric errors”
- Generally well-represented by traditional techniques for calculating uncertainty.
Classifying sources of error

- Structural errors, resulting from choices made in the measurement and analysis systems
  - Approximation
    - Simplifications and approximations in calculations
    - e.g. using a LUT or plane-parallel atmosphere
  - System
    - Physically meaningful assumptions
    - e.g. choice of aerosol optical model
  - Resolution
    - Finite sampling of a constantly varying system
    - e.g. fair-weather bias, MODIS “bow-tie effect”

- Potentially non-linear and circumstantial. Thus, the source of error affects how it needs to be reported to users.
Communicating with scientific community

Pre-Launch

Instrument Description
Description of the instrument and its principles of operation.

Calibration
Prelaunch characterisation of instrument radiometric response referenced to international standard.

Post launch evaluation of instrument performance against onboard reference and/or vicarious targets.

Algorithm Development Cycle

Post-Launch

Validation
Characterisation of the retrieved geophysical quantities over observation space.
A description of the uncertainty as a function of state and its stability over time.

Algorithm Description
Description of how measurements are converted into geophysical quantities.
Quantification of the uncertainty budget.
Evaluation of theoretical performance for reference atmospheric states.

Application
Use of geophysical results to characterise or describe the state of the atmosphere or processes within it.
Communicating with users

• Important to clarify the difference between what is measured and what the user wants to know.
  – For example, satellites only sample one time of day but users may need observations at other times.
    • For SST, in situ observations indicate the diurnal cycle is somewhat predictable so empirical corrections may be useful.
    • For cloud, data indicates the diurnal cycle is highly circumstantial so a single observation is not representative of an entire day.

• A quantity can be adjusted to meet a user's needs but
  – The transformation will introduce additional uncertainty and
  – The new quantity may not meet other user's needs.

• We prefer to report only the measured value and provide secondary support (i.e. communication) to produce transformations as needed.
Communicating with users

• Many satellite products require significant assumptions to constrain their analysis.
  – Some simplify the problem, introducing approximation errors
    • e.g. neglecting multiple scattering
  – Others are physical constraints, introducing system errors
    • e.g. classifying land type into finite, idealised categories
  – In either case, it isn't obvious how to quantify the uncertainty
Ensemble techniques

- Ensemble techniques can better communicate uncertainties resulting from such errors.
  - A “multi-model” ensemble of analyses with differing assumptions and approximations.
  - A “multi-run” ensemble of analyses with different constraints.

![Liquid cloud effective radius](image1)
![Ice cloud effective radius](image2)
![Optimal phase](image3)

*Experimental approaches to uncertainty*
System maturity

- Designed for judging the suitability of an algorithm for operational use and it's uptake by the community.
- Does not measure the science value, i.e. if the product extracts all the information available or addresses the needs of users.
- We are concerned that using these to publicly evaluate products could mistake data with a short/long heritage as in/accurate.

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Summary

- Uncertainty must represent the non-linear and circumstantial nature of errors often dominant in satellite products.

- Communication of uncertainty to users should be tailored to
  - The data available to calculate and validate the uncertainty,
  - The underlying cause of the error, and
  - A broad range of users' needs.

- As the distribution of these errors is not always well understood, data producers must engage in a dialogue with data users to work towards useful estimates.
  - This can include ensemble techniques, quality assurance, qualitative descriptions.
  - This is complimented, not replaced, by validation activities.
This discussion paper is/has been under review for the journal Atmospheric Measurement Techniques (AMT). Please refer to the corresponding final paper in AMT if available.

Known and unknown unknowns: the application of ensemble techniques to uncertainty estimation in satellite remote sensing data

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Uncertainty

- Uncertainty is a vital component of data as it provides
  - a means of efficiently and consistently communicating the strengths and limitations of data to users, and
  - a metric with which to compare different data sets.

- Uncertainty should be
  - **Universal**: calculated in a manner applicable to all data;
  - **Internally consistent**: derived from the same information as the data and not draw on external validation data;
  - **Transferable**: of use to users for various purposes.
Ensemble Techniques

- Consider estimating the volume of a bucket, knowing only its mass.
- Shape is assumed but different assumptions produce different errors.
- The magnitude of error due to that assumption depends on the underlying state and other parameters of the retrieval.