Examples of uncertainty characterisation in atmospheric retrievals

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Outline

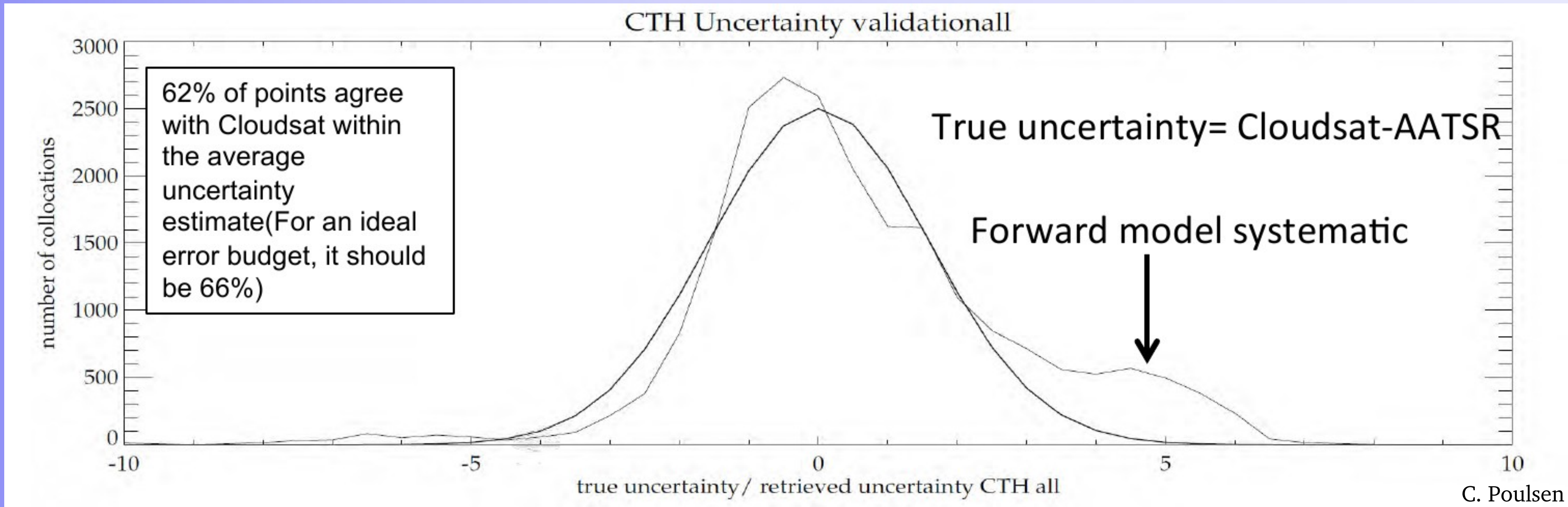
- Representing uncertainty
- Sources of uncertainty
- Estimation of uncertainty
- Discussion

Representing uncertainty

- Uncertainty characterizes the range of values that could be reasonably attributed to a measured quantity. This encapsulates:
  - The accuracy with which a measurement can physically be made;
  - Approximations in the model of the system;
  - The conditions under which the system is observed;
  - Uncertainties in auxiliary information used.

Representing uncertainty

- (My) users generally expect uncertainty to be represented by a single number.
  - Implicitly the standard deviation of a normal distribution about the quoted value.
    - Is a normal distribution appropriate?
    - Is this a sensible means to communicate biases?



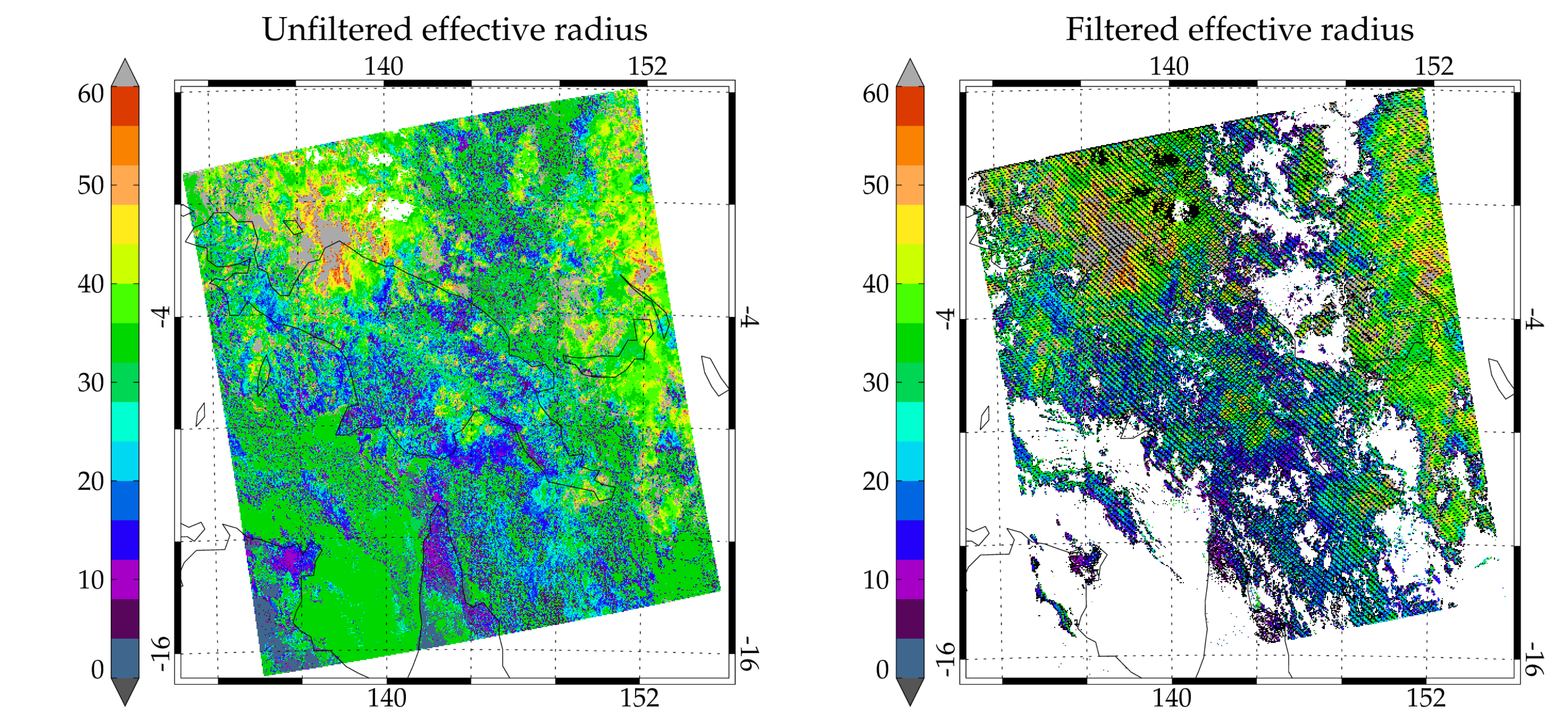
C. Poulsen

Representing uncertainty

- Quality flags are also provided with many products.
  - Describe qualitative difficulties/failures in the retrieval process.
    - e.g. failure to converge, conditions in which the algorithm is known to fail, missing data
  - Can be highly detailed but generally simplified to a few values before publishing.
  - Not strictly an 'uncertainty' but can efficiently convey useful information about the data.

Representing uncertainty

- Data filtering is a common application of quality flags and uncertainty estimates.



Cloud optical thickness retrieved by ORAC from a MODIS scene over Papa New Guinea on 20 June 2006. Note the differing colour bars.
Left: All pixels.
Right: Only pixels which passed all quality flags.

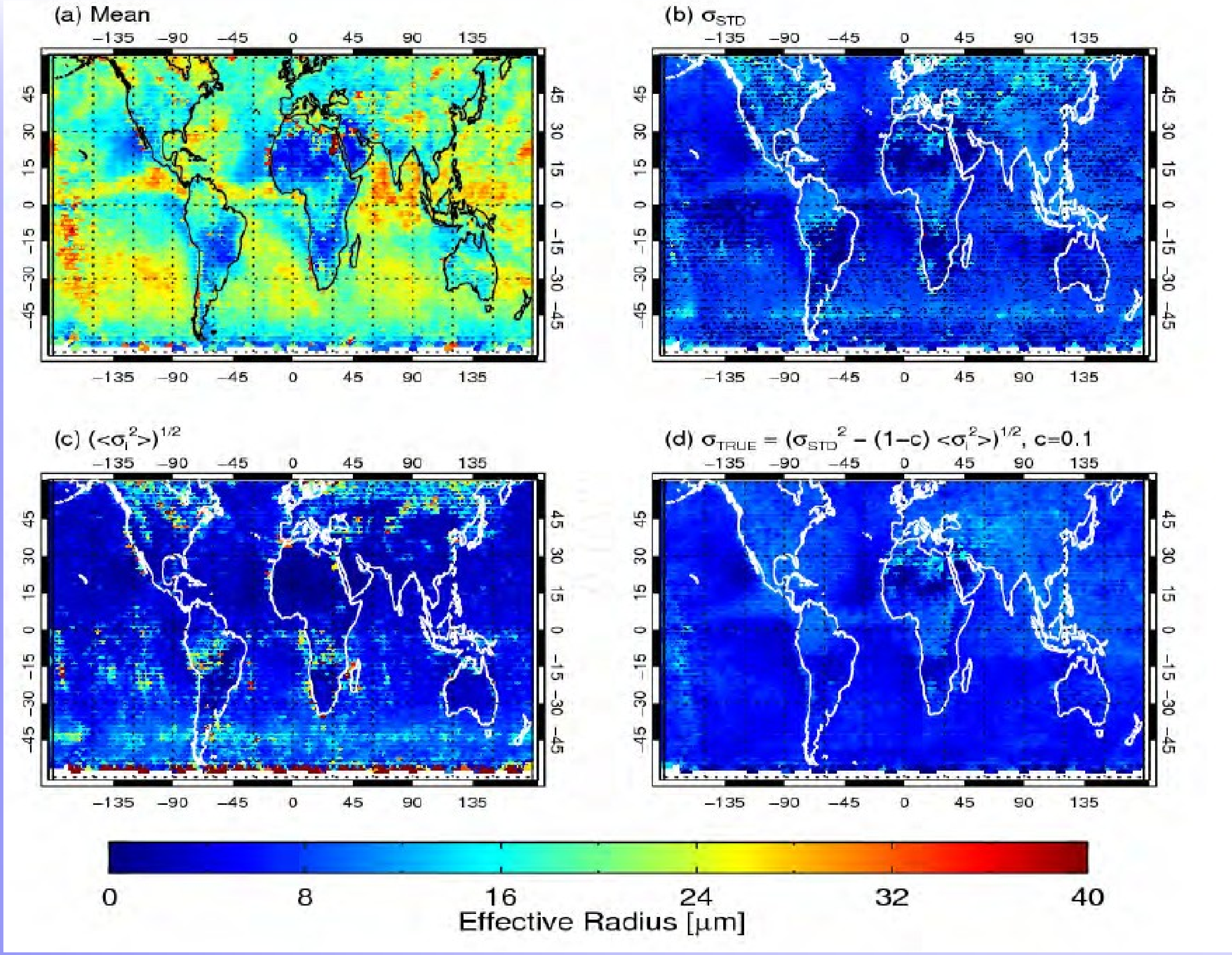
Sources of uncertainty

- Random
  - Measurement noise
  - Propagated noise from auxiliary information
- Systematic
  - Approximations in the forward model
  - Circumstances not represented in the forward model
- Some mixture of the two
  - Instrument calibration
  - Look-up table interpolation

Sources of uncertainty

- Representivity
  - Most important for Level 3 products.
    - Precisely how to propagate uncertainties into Level 3 is an open question for many products.
    - Spatial and temporal correlations of errors mostly neglected (as poorly constrained).
  - Highly dependent on variable considered and the current state as natural variability can be relatively more important.
  - Relevant to intercomparision of ground and satellite-based observations.
    - Differing spatial/temporal coverage.

Sources of uncertainty



Sources of uncertainty

- Most satellite remote sensing retrievals require some manner of cloud filtering.
  - Cloud contamination will clearly introduce error into a retrieval.
    - Not generally clear if this is a random or systematic.
    - Frequently assumed (and described) to be a bias.
  - Excessive cloud clearing will clearly bias an averaged product against high radiance situations.
    - If one could quantify what was being unduly cleared, it wouldn't have been cleared in the first place.
  - Radiative impacts known to extend well beyond cloud edges.
- Very few retrievals contain any explicit estimation of these uncertainties.

Estimation of uncertainty

- Jacobian error propagation
  - Basically the standard propagation of uncertainties taught to undergraduates.
  - Provides an analytic, numeric estimate of uncertainty.
  - Assumes errors are Gaussian.
  - Only appropriate for errors which are well characterised. Cannot sensibly account for “known unknowns”.
- Monte Carlo estimation
  - Brute force technique.

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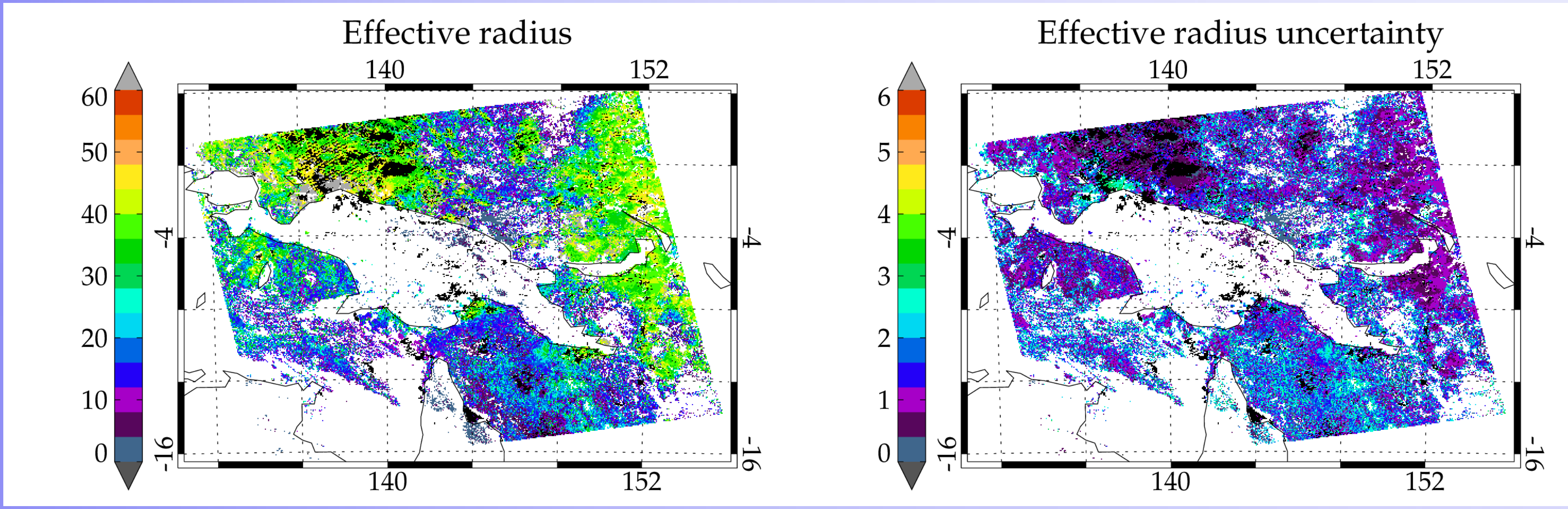
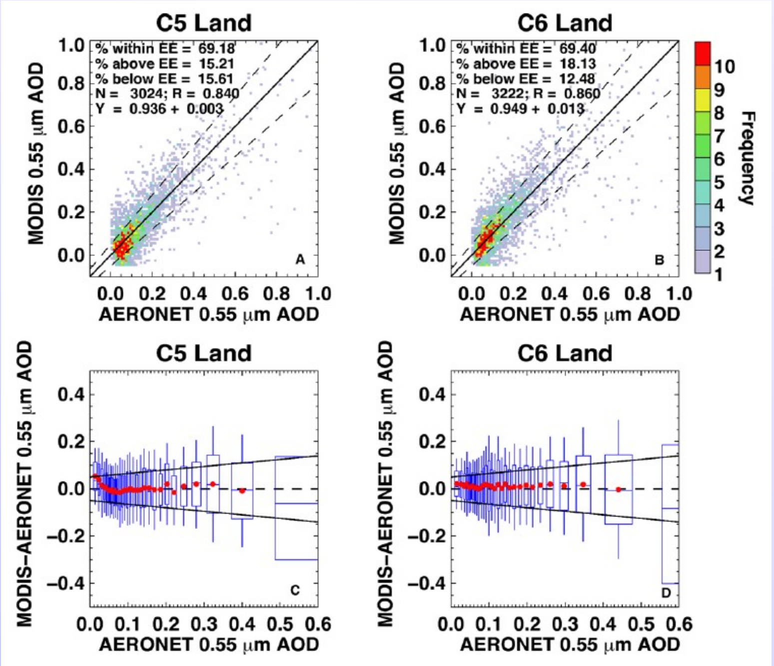


Estimation of uncertainties

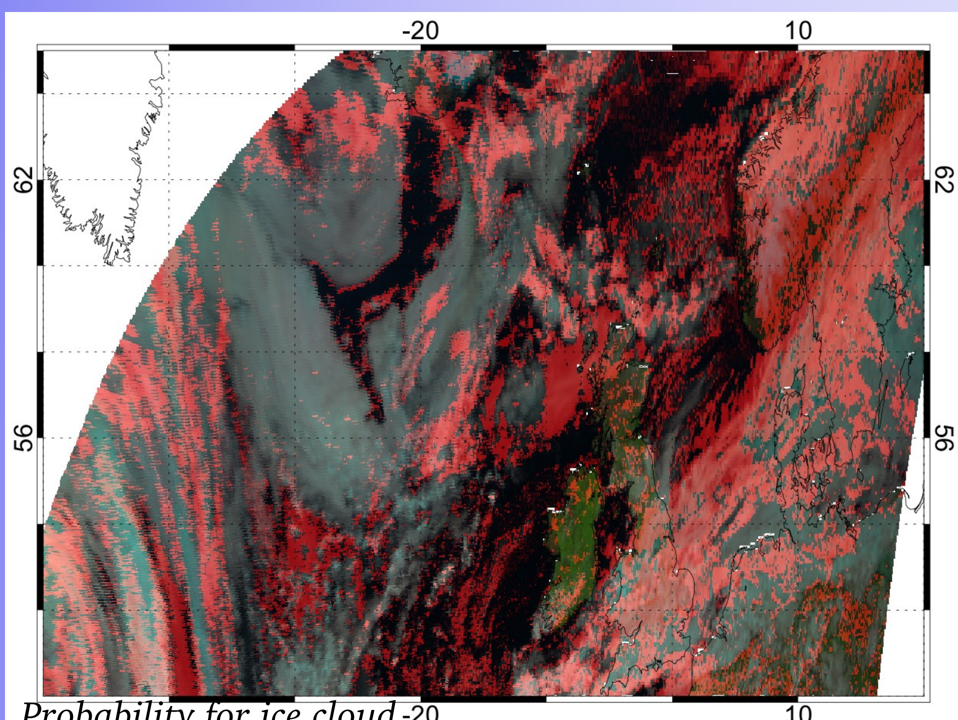
- “Expected error” envelopes
  - Prevalent in aerosol optical depth retrievals.
  - Compare retrieval to the 'true value'. The envelope is defined to enclose 66% of the observed errors.
  - Can be stratified by conditions, assumptions, etc.
  - Does not provide pixel-level uncertainties.
  - Disconnects local and global sources of uncertainty, complica-ting the merging of data sets.
  - Compatible with GCOS.



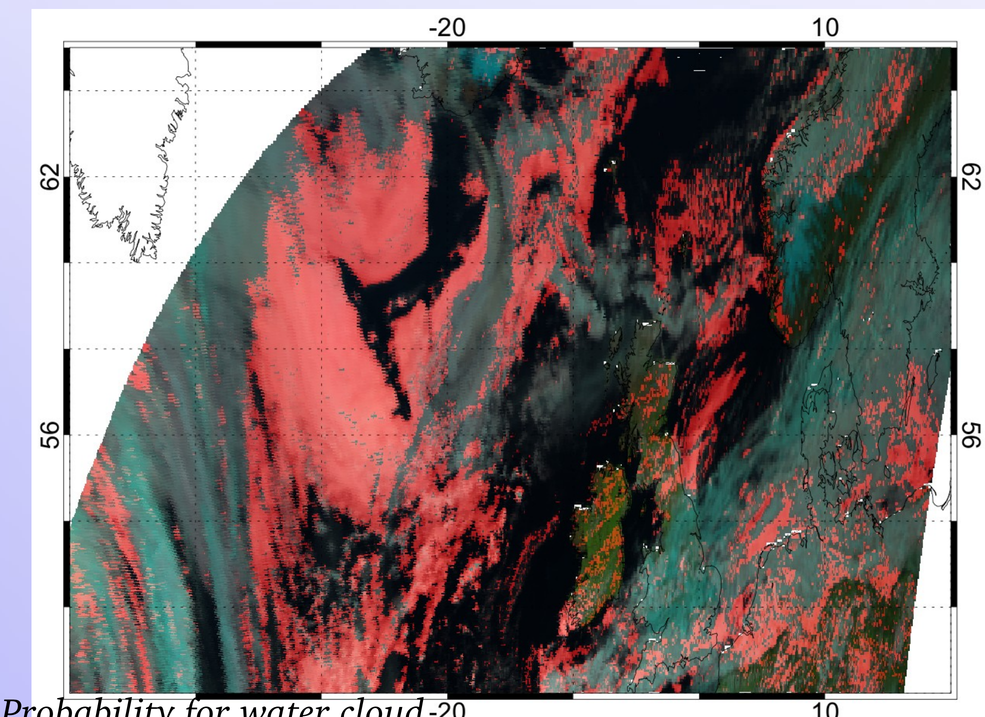
Levy et al., AMT 6, p.2989 (2013). doi: 10.5194/amt-6-2989-2013

Estimation of uncertainties

- Classification
    - Products such as land surface and aerosol typing return a classification rather than a number.
    - Frequent use of Bayesian probabilities.



Probability for ice cloud



Probability for water cloud

Estimation of uncertainties

- Classification
  - Products such as land surface and aerosol typing return a classification rather than a number.
  - Frequent use of Bayesian probabilities.
  - Here, uncertainty describes the confidence in the identification.
  - Important to include a classification for “We don't know”.
  - When classification impacts later analysis (as for aerosol type), it is not yet agreed how to evaluate uncertainties.

Communicating uncertainty

- A user's requirements are practically unique.
  - Uncertainty estimates are required for data assimilation but can be a nuisance for multi-decadal analysis.
  - Estimates of both random and systematic uncertainties are necessary.
- Exercises such as this meeting are important in allowing data producers to cater their outputs to a wide range of users.
- Though dissatisfying, it is not practical wrong to overestimate uncertainty.

Communicating uncertainty

- The basis with which you describe the system will fundamentally limit what you can and cannot say about that system.
- Ideally, uncertainty assess the likely distribution of error in a measurement from only the information used to calculate it. For poorly constrained problems, validation contributes to the estimation.
    - Where no validation available, best understanding prevails.
- Regardless, there remain “unknown unknowns”
    - Effects too poorly understood to quantify.
    - Variables without validation data.

Looking forward

- There are significant uncertainties in the uncertainty of many retrievals. None the less, an estimate of uncertainty is required by users and for validation.
- Need to start with what can currently be achieved and iterate with users until we have usable uncertainty products.
  - Concentrate on how best to communicate where the algorithm is known to fail.
- Must improve reputation of remote sensing data among users. Providing validated pixel-level uncertainties and continuing the conversation about how to improve them should help.

Questions or comments?

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