Metrological approaches to Earth Observation in relation to GCOS requirements

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Essential climate variables (ECVs) measure parameters that quantify the state of the climate system and elucidate processes of change. To understand change in the climate system requires differences in the value of an ECV to be quantified across time at a relevant spatial scale. GCOS requirements are currently inadequate for specifying the “accuracy” & “stability” of ECV products at intermediate spatio-temporal scales important for climate applications.

For robust science, accounting for observational uncertainty is needed. The key uncertainty is often the uncertainty in the comparison of (difference between) two observations aggregated at a certain spatio-temporal scale. A wide range of space-time scales need to be observed for climate science: any combination of space and time resolution for a given ECV may be relevant to different cases.

The uncertainty in a difference is scale dependent. For EO-based ECV products, this scale dependence is never trivial – e.g., when aggregating data to a coarser scale, classic “1-over-root-n” averaging of single-pixel uncertainty estimates will generally give an unrealistic uncertainty estimate – often wildly optimistic. Providing users of climate data records with uncertainty information at the scale of their climate application is a complex challenge, and is essentially not addressed at present.

The complexity arises because different error sources matter on different scales. Random errors average down; bias errors disappear when calculating differences; such errors are not problematic. However, many errors in EO have spatial structure (which may be time-dependent) and temporal correlation. Effects that are negligible in the total uncertainty of a single observation can dominate the uncertainty at a different scale. GCOS requirements take limited account of this by specifying both an “accuracy” requirement (at relatively high resolution) and a “stability” requirement (for the validity of long-term trends).

Limitations of the current status include: satellite providers focus on meeting single-observation accuracy requirements, with limited analysis of the implications of structured errors for climate applications; those deriving ECVs have no means of developing uncertainty estimates for their products across the required range spatio-temporal scales; and the ability to estimate and verify ECV product stability is often minimal.

Metrological analysis of historic Earth Observations can address these limitations, and is being pursued in the project FIDUCEO (www.fiduceo.eu). Metrology is the science of measurement: there is a body of knowledge and practice that can inform EO as an observational science. In a metrological approach, the observing system is analysed and every effect is characterised and propagated to obtain the amplitude, spatio-temporal structure and correlations of the errors it causes, first in the fundamental climate data record (level 1) and in turn in derived geophysical variables (level 2, ECVs). Rigorous analysis of structured errors at level 1 will support ECV producers in developing downstream uncertainty on multiple scales – including the ability to provide traceable, bottom-up estimates of both “GCOS-style” accuracy and stability to assess performance against GCOS requirements.