Richer characterization of the earth system and its limits

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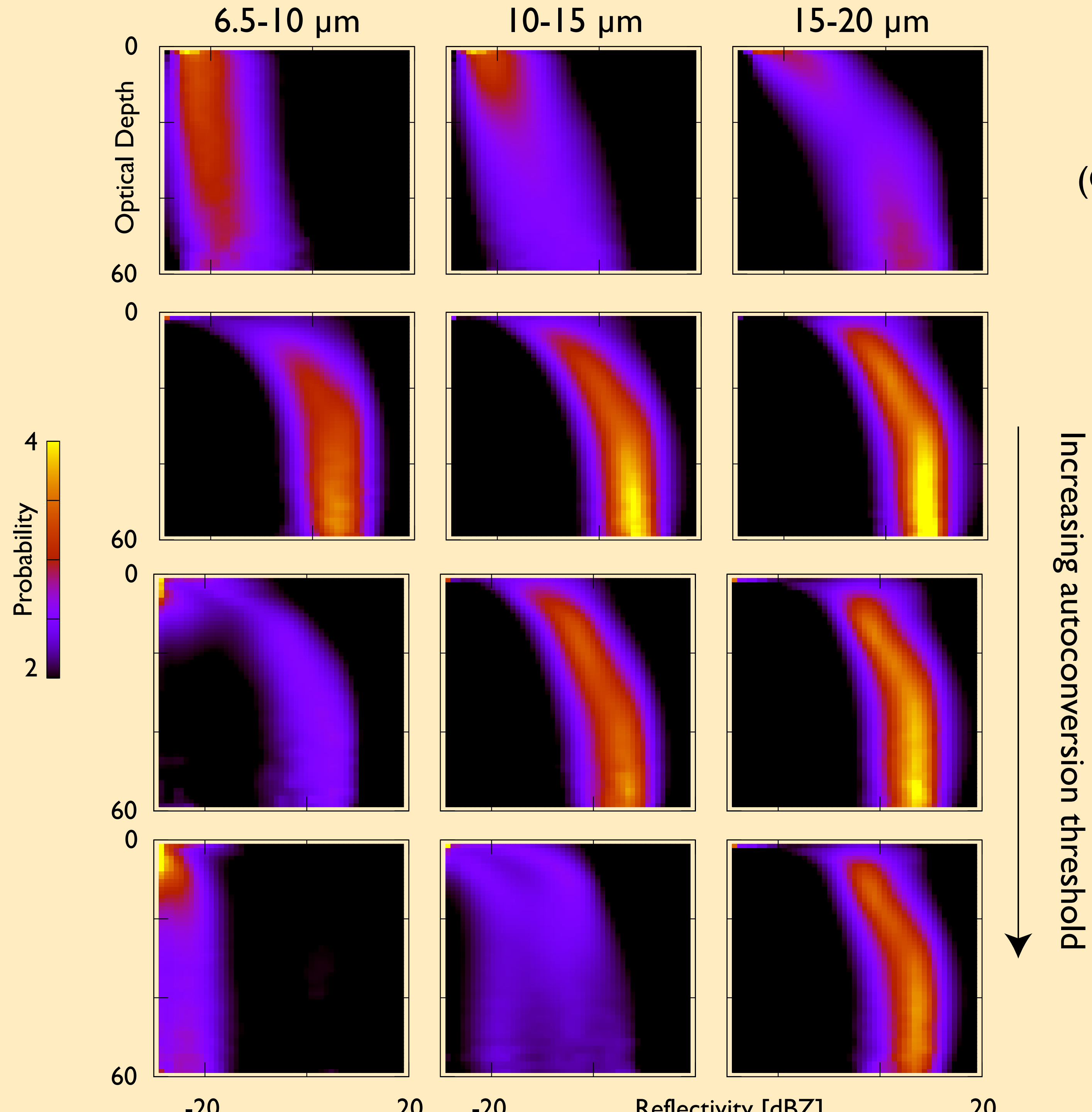
University of Colorado

1. New observations

1. New observations exploiting "new" technology

Increasingly long records from relatively new platforms, esp. active sensors for clouds, and analyses that combine observations provide new opportunities



after Suzuki et. al 2013, 10.1002/grl.50874

1. New observations exploiting "new" technology

Geodetic measurements (gravity, altimetry, radio occultation, VLBI) provide very stable measurements, albeit sparse and quite coarse in space and time

September conference: http://geodesy-for-climate.org

1. New observations targeted at specific phenomena

Space agencies program fund efforts (e.g NASA's MEASURES, ESA's CCI) to make satellite observations more useful for model evaluation.

Some of the most interesting efforts target specific problems e.g. JPL's efforts to characterize various aspects of the cloud boundary layer

- BL water vapor using microwave and near-IR
- cloud LWP from microwave
- BL height from radio occultation
- light rain at surface from CloudSat

1. New observations: increasingly-refined reanalyses

"We are pleased to inform you that today, 6th July 2017, the Copernicus Climate Change Service (C3S), which is operated by ECMWF, has published the first part of the new ERA5 reanalysis product.

This latest development in the ERA series improves on its predecessors by:

Offering a higher horizontal resolution of 31 km and 137 vertical levels from the surface up to 0.01 hPa (around 80 km)

Using a more recent and advanced version of the ECMWF IFS model

Providing hourly estimates of atmospheric variables

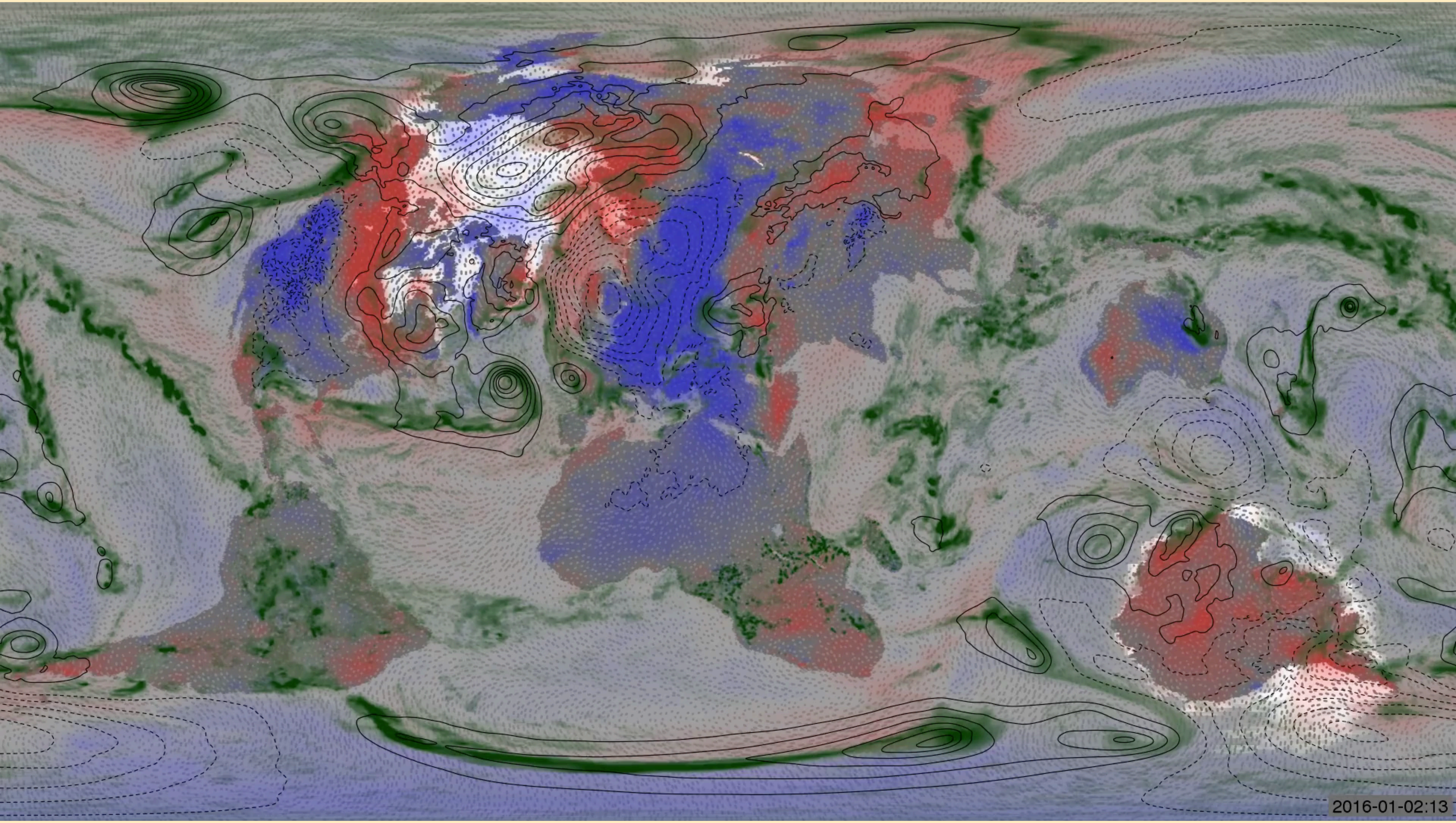
Providing a consistent representation of uncertainties for these variables

Using more satellite observations in the data assimilation

Giving access to all input observations (will be available in a later release)

Please visit http://climate.copernicus.eu/climate-reanalysis …"

1. New observations: increasingly-refined reanalyses



Credit Philip Brohan; https://vimeo.com/191974536

1. New observations: historical reanalyses

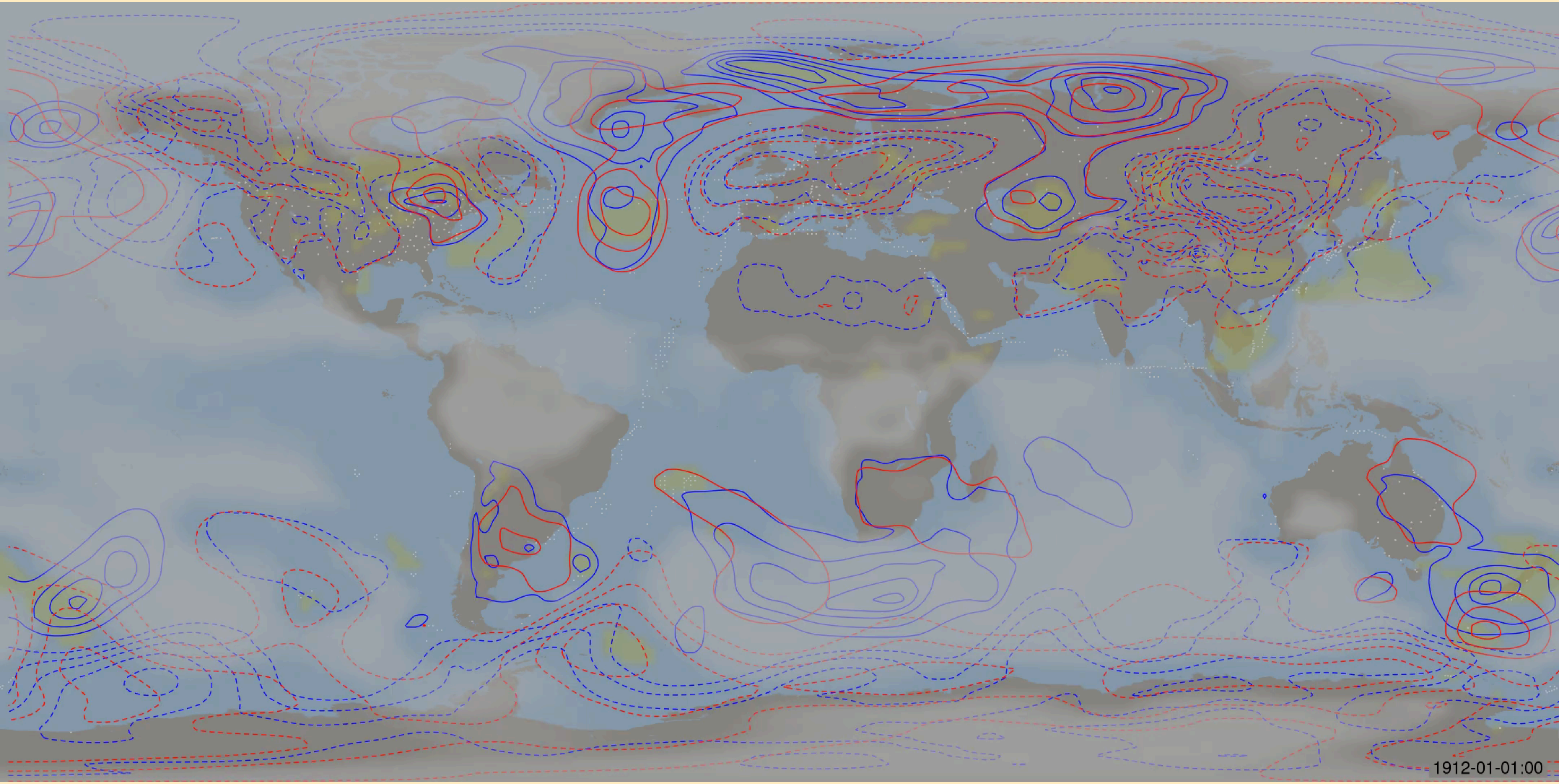
Reanalysis is the result of cycled forecast/assimilation cycles with fixed forecast model and data assimilation system. The observation network evolves over time.

Historical reanalysis a subset of observations available well into the 19th century — mostly surface pressure, but relying on SST fields.

Coverage is not uniform — the fog of ignorance drifts through the analysis.

Historical reanalysis is useful in extending the data record to understand and evaluate modes of variability, extremes, etc.

1. New observations: historical reanalyses



Credit Philip Brohan; https://vimeo.com/109681668

(Re)analysis and retrievals

Retrievals of atmospheric properties
use prior knowledge of the likely state of the state of the atmosphere, to
minimize the difference between between predicted and observed measurements

Meteorological (re)analysis
do exactly this,
balancing a wide range of observations and
using substantially better conditional prior knowledge

Implication: instantaneous estimates of well-observed control variables are likely to be more accurate in reanalysis than in retrievals using the same underlying data.
Differences between data sets do not represent uncertainty.

Social pressures notwithstanding.

What (re)analysis doesn't provide

A forecast/analysis system is designed to produce the best short-term weather forecasts by way of instantaneous estimates of atmospheric state.

In consequence

energy and mass budgets are not closed

observations inform only parts of the state vector

small scales are not well-constrained; sub-grid information is purely model

the observing system changes over time, causing spurious secular changes

models are subject to error, especially where observations aren't informative

So there are plenty of aspects of the earth system where we rely on more direct observations

(Re)analysis as observation

"It is tempting to think that what justifies warnings about reanalysis datasets is the fact that they are determined in part by NWP forecasts. There is some truth in this, but it is not reliance on these forecasts per se—the results of theory-based calculation—that should prompt concern; after all, many trusted observations and measurements also are produced with the help of theory-based calculations. The real issue is that the errors and uncertainties associated with NWP forecasts, and with some other aspects of the reanalysis process, are only partially understood, leaving it unclear just how accurate we can expect many reanalysis results to be."

Wendy Parker
Reanalysis and Observations: What's the difference?
https://doi.org/10.1175/BAMS-D-14-00226.1

1. New observations: increasingly-refined reanalyses

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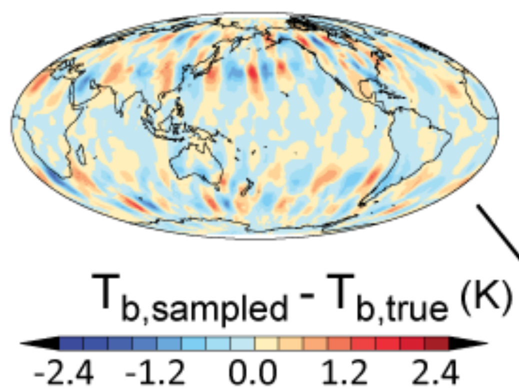
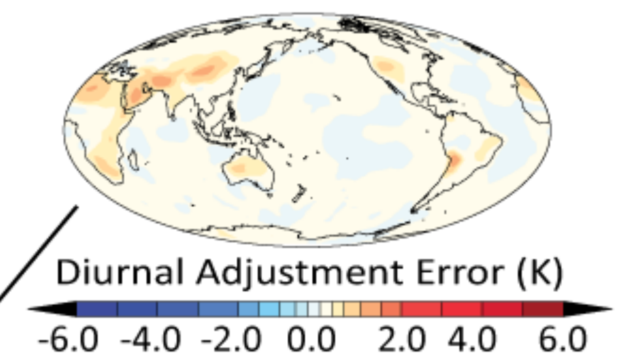
2. Observational uncertainty in full detail (c.f. Ben Santer's talk)

Monte-Carlo Method

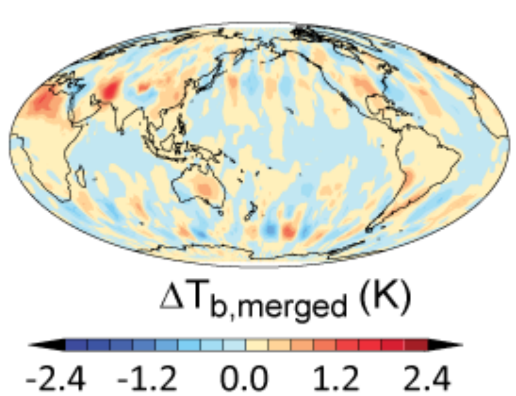
Take a series of instances of the estimated sampling uncertainty.....



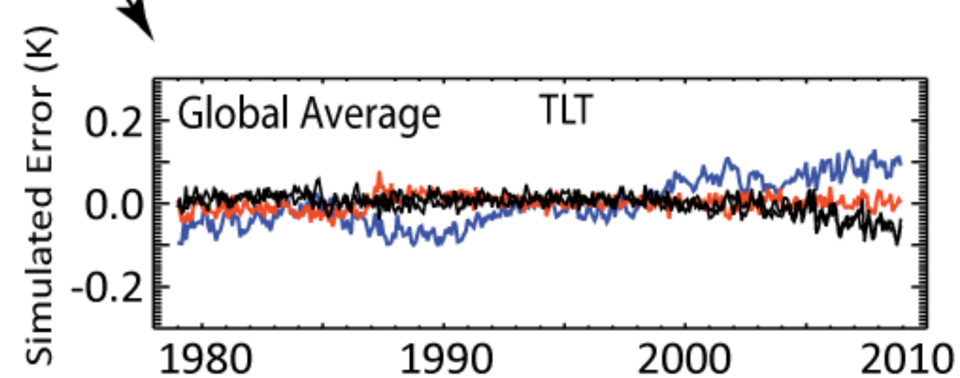
and an instance of the estimated uncertainty in each monthly diurnal adjustment....



....which are added together to make a combined uncertainty instance for each satellite and month. Uncertainty from each satellite are then combined into a single dataset using the same merging system as the actual measurements to obtain an instance of the estimated uncertainty.

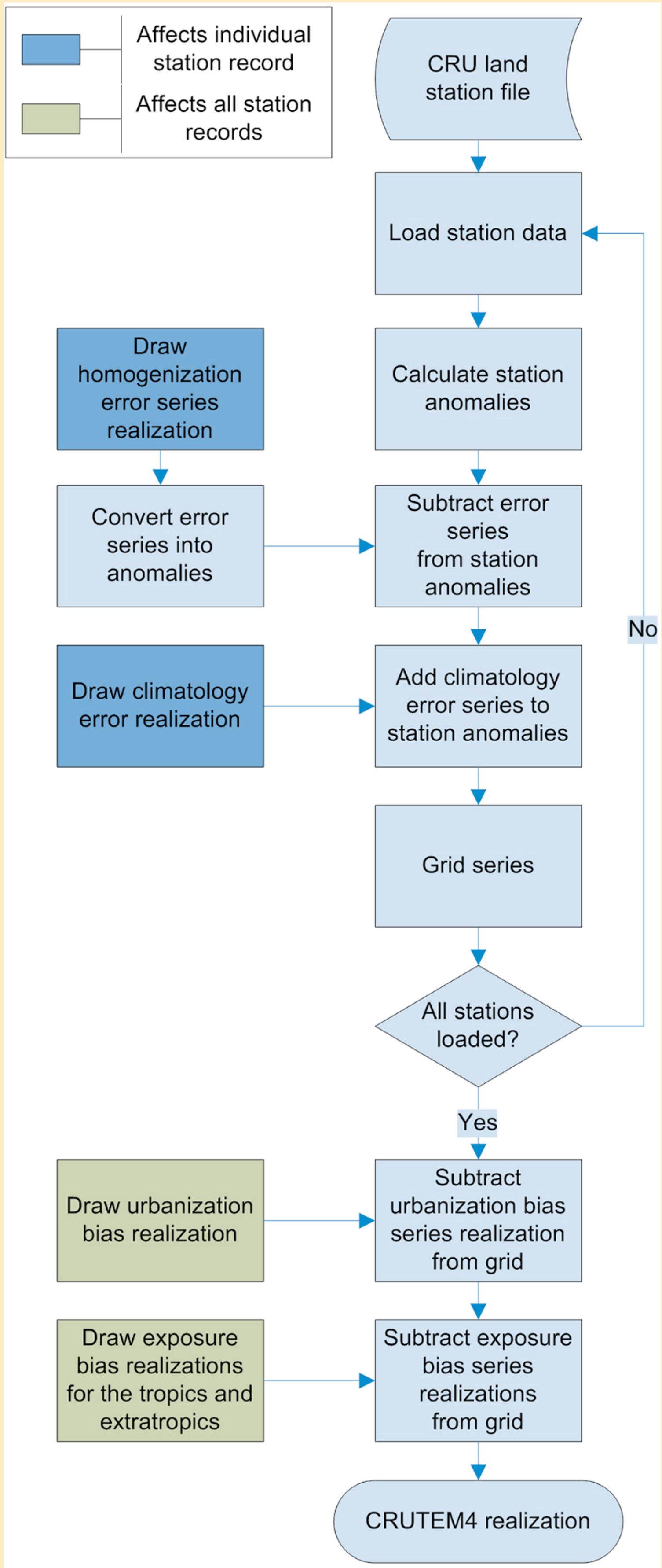


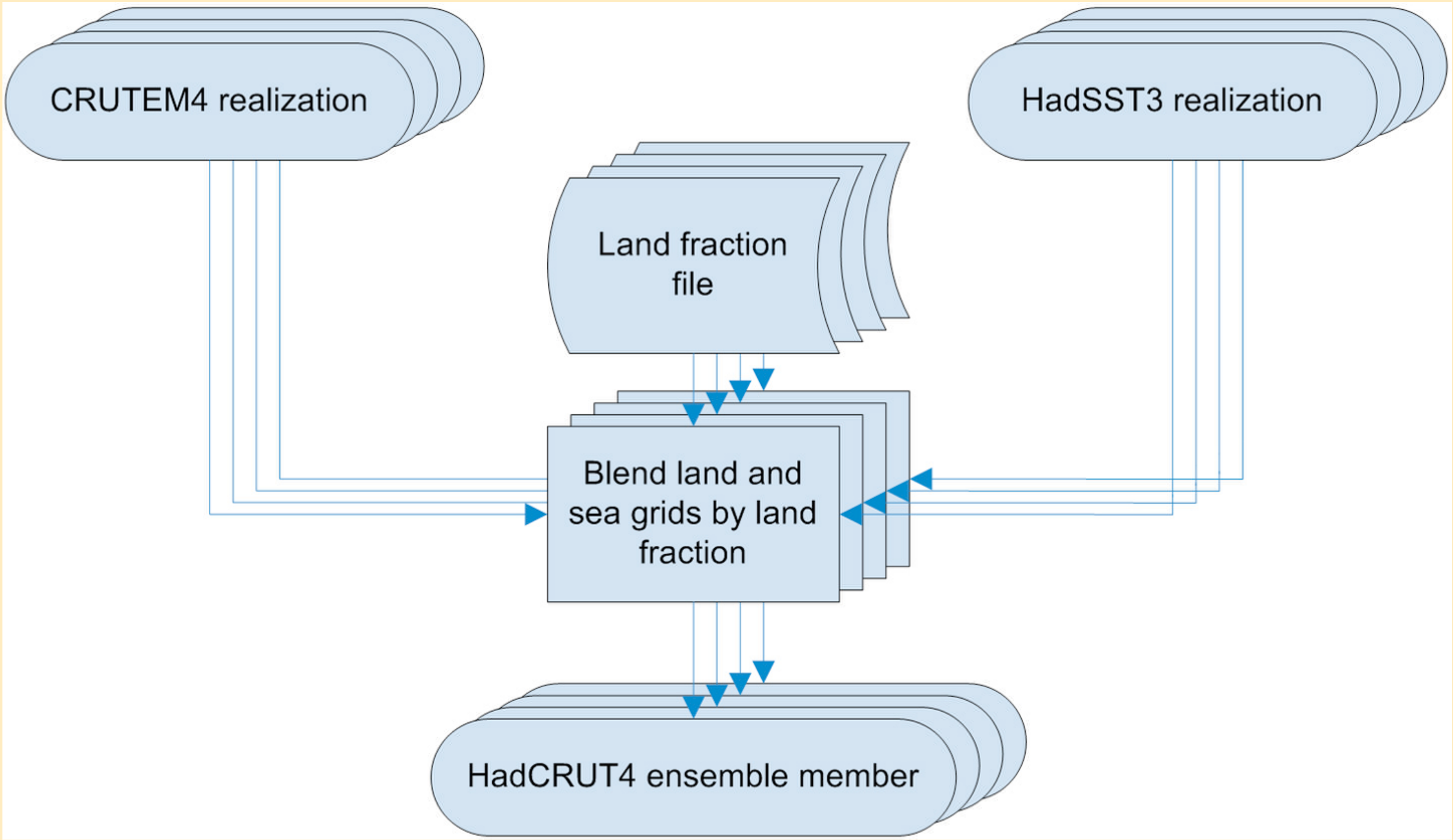
Map of an instance of simulated errors for a single month.



Time series of 3 instances of the globally averaged errors. 400 such instances were generated in total.

2. Observational uncertainty in full detail: HadCRUT4





Morice et al. 2012, 10.1029/2011JD017187

2. Observational uncertainty: individual measurements

MODIS cloud optical property retrievals use lookup-table Jacobians, i.e.

$$S_{\mathrm{Ret}} = (K^T S_y^{-1} K)^{-1} + \sum_i (K^{-1} K_{b_i}) S_{b_i} (K^{-1} K_{b_i})^T$$

to treat uncertainties in measurement *y* and model *b* (with *i* = surface albedo; atmospheric correction, esp. *q*, O_3; cloud particle distribution width; emission components for $R_{3.7}$)

Optimal estimation uses simplifying assumptions and other prior information to estimate a Gaussian distribution for each retrieval (mean, variance)

Monte Carlo Markov Chain relaxes most assumptions made by OE and provides less constrained estimates of the retrieval distribution, at the cost of much more computation

2. Observational uncertainty, structural and sampling errors

Every observation has a model attached to it. Most models used in remote sensing make strong assumptions e.g. 1-dimensional radiative transfer, sub-footprint homogeneity, vertical homogeneity.

Measurement proxies ("satellite simulators") address only some of these issues

The assumptions go hand-in-hand with limited information. Where the assumptions hold retrievals can be accurate; where they don't retrievals are in error.

Hobson's choice: how to trade off sampling biases and retrieval accuracy?

(Models will not, in general, have the same sampling biases.)

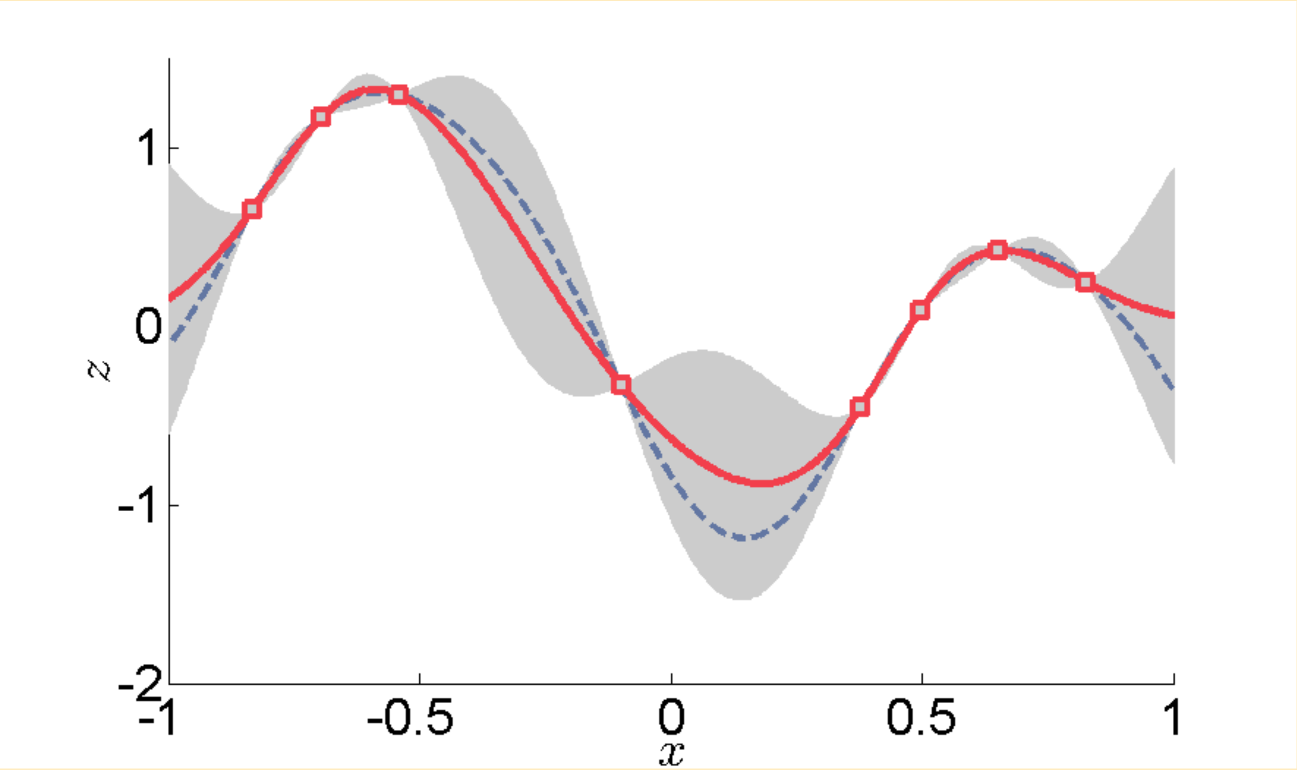
2. Observational uncertainty and change of support

MODIS:

> "We estimate the uncertainty in the mean of τ and r_e from pixel-level uncertainties by assuming that errors are perfectly correlated within each grid cell on a given day but perfectly uncorrelated from day to day."

This is a model for the uncertainty of aggregates in space and time, but it's limited.

The statisticians are busy with this problem. The basic idea is to use observations and uncertainties to build a statistical model for the true distribution and its uncertainty, which can be interrogated in time and parameter or geographic space. This remains far from our main stream.



2. Observational uncertainty and secular change

Temporal stability is hard.

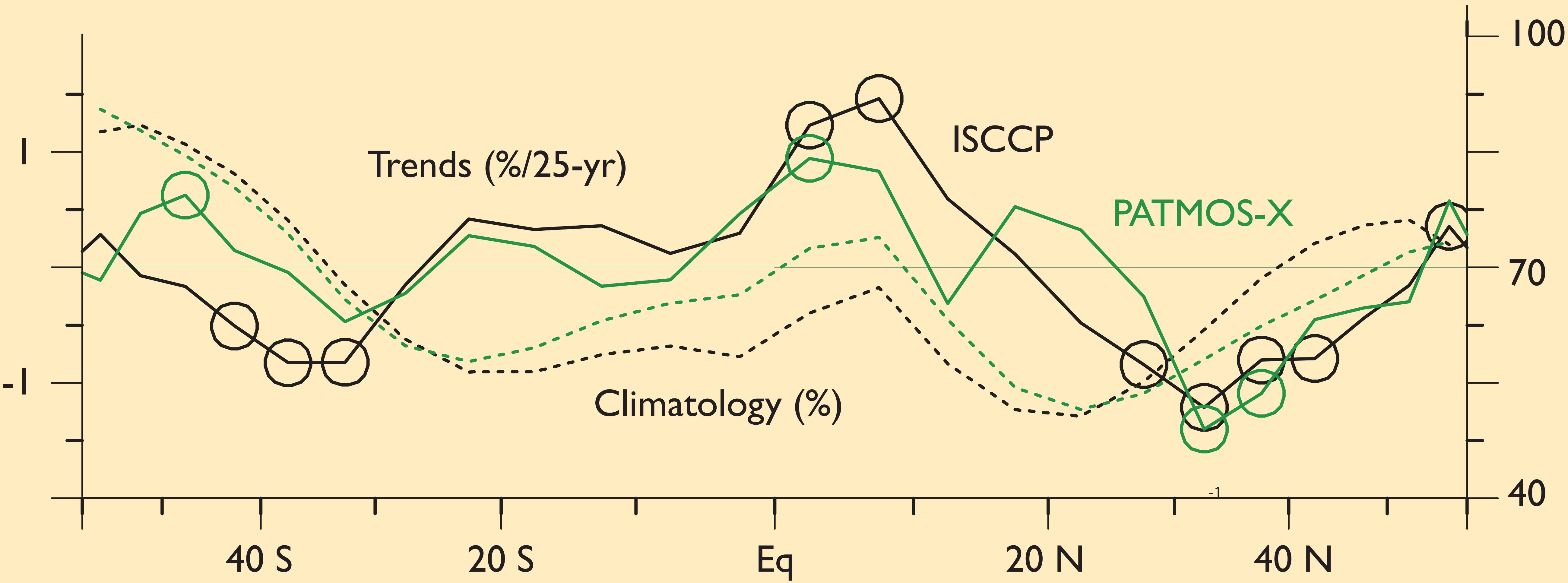
> “Global mean sea level (GMSL) has been rising at a faster rate during the satellite altimetry period (1993–2014) than previous decades… However, the accelerations observed over century and longer periods[2] have not been clearly detected in altimeter data spanning the past two decades. Here we show that the rise, from the sum of all observed contributions to GMSL … is in approximate agreement with observed increase in GMSL rise… from satellite observations that have been adjusted for small systematic drift, particularly affecting the first decade of satellite observations.”

Chen et. al 2017
The increasing rate of global mean sea-level rise during 1993–2014
doi:10.1038/nclimate3325

2. Observational uncertainty and secular change

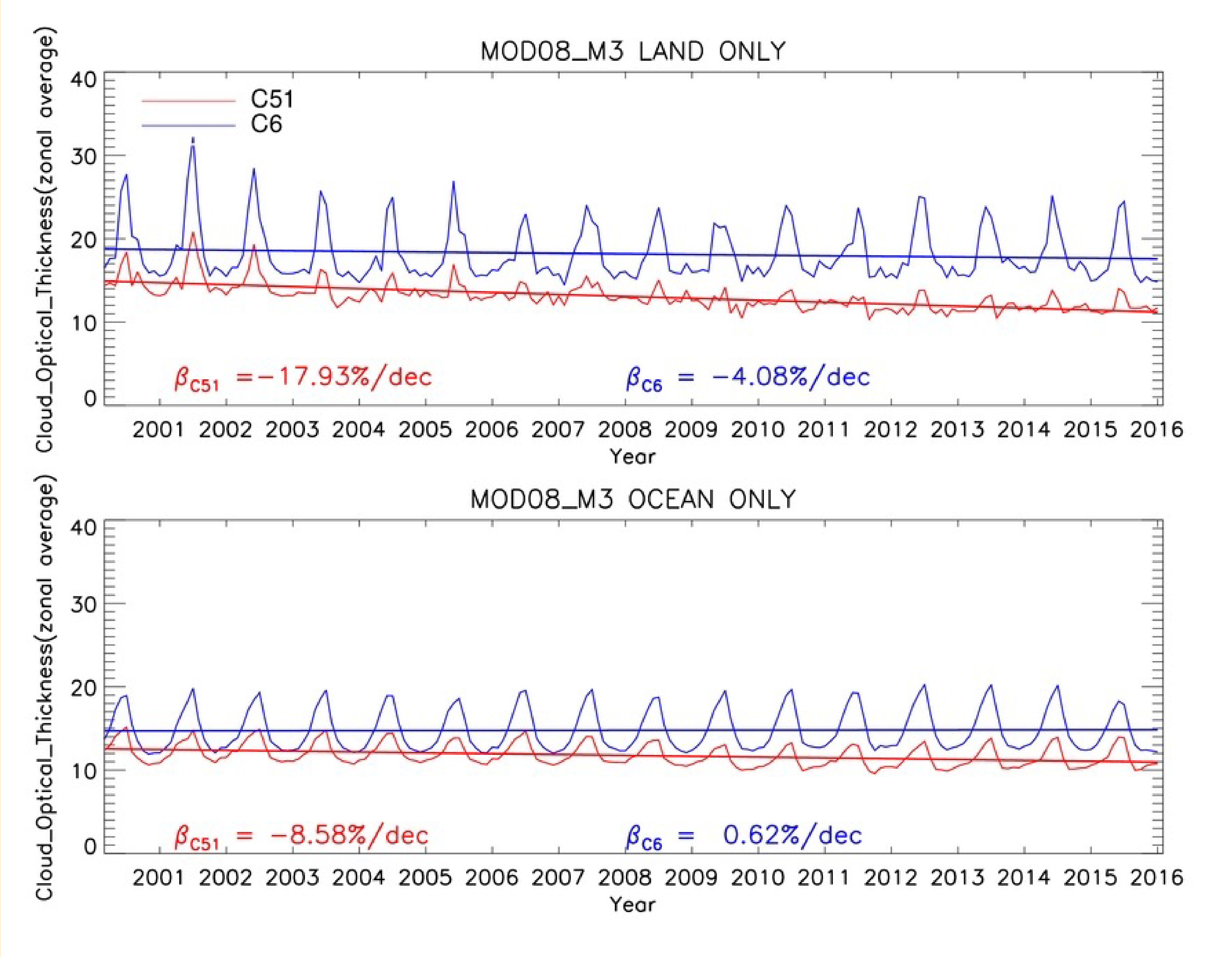
Temporal stability is hard.

Our two longest observing systems disagree with respect to trends in important ways even when adjusted as well as we know how…



after Norris et al. 2016, 10.1038/nature18273

… while trends from single instruments are subject to sensor drift.



Credit Steven Platnick, NASA/GSFC

Comments

Routine model evaluation is a natural extension of the increasing transparency of climate model (thanks to CMIP, PCMDI, ESGF, …). Still, interesting opportunities come from focused questions which may innovative use of models and/or observations.

The observational community is moving towards better characterizations of uncertainty in space and time. Conceptual challenges remain in understanding the uncertainties in

- model failure
- change of support
- secular changes

3. Model evaluation and constraints on forcing

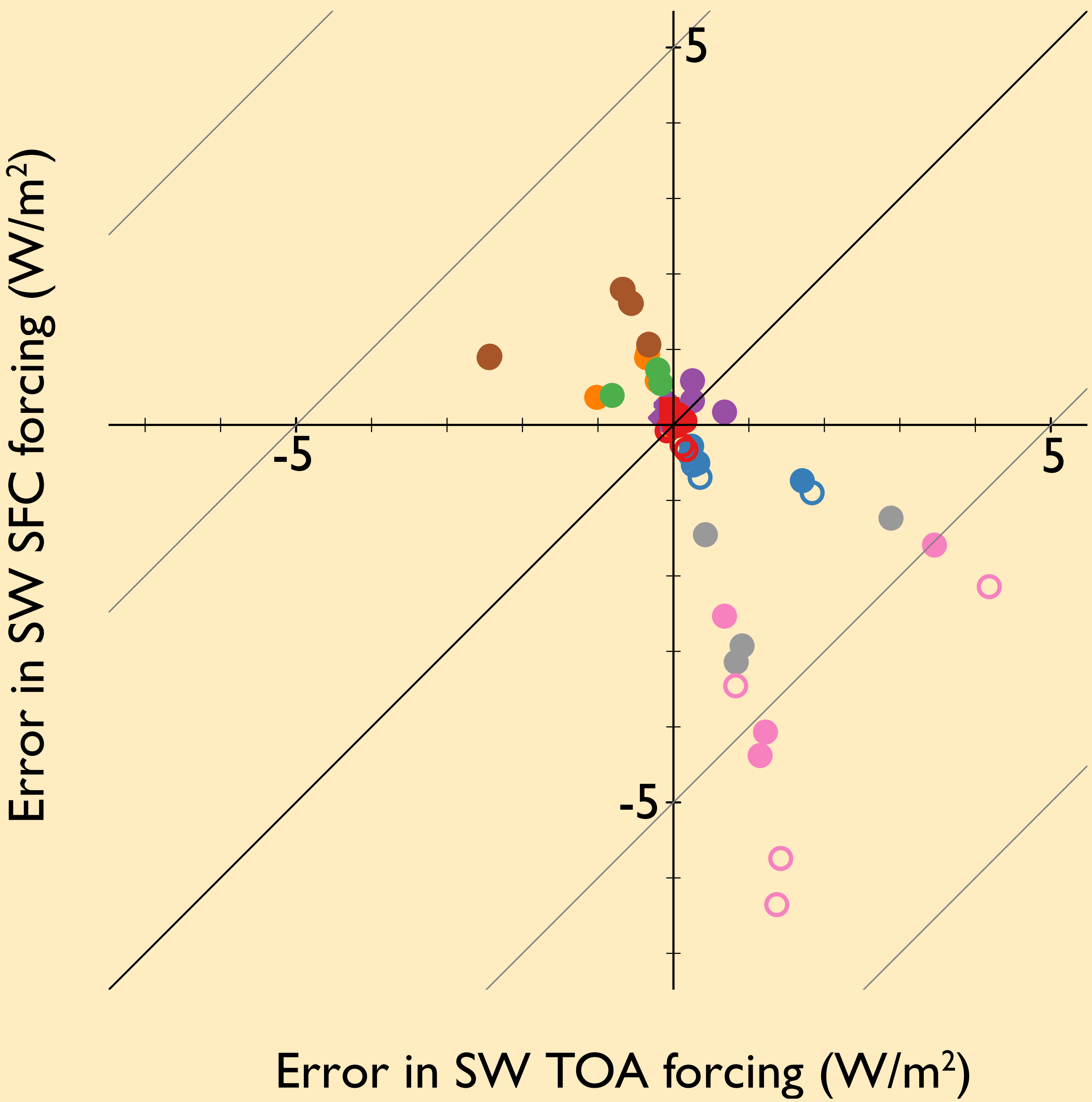
Forcing and response are not independent in climate models.

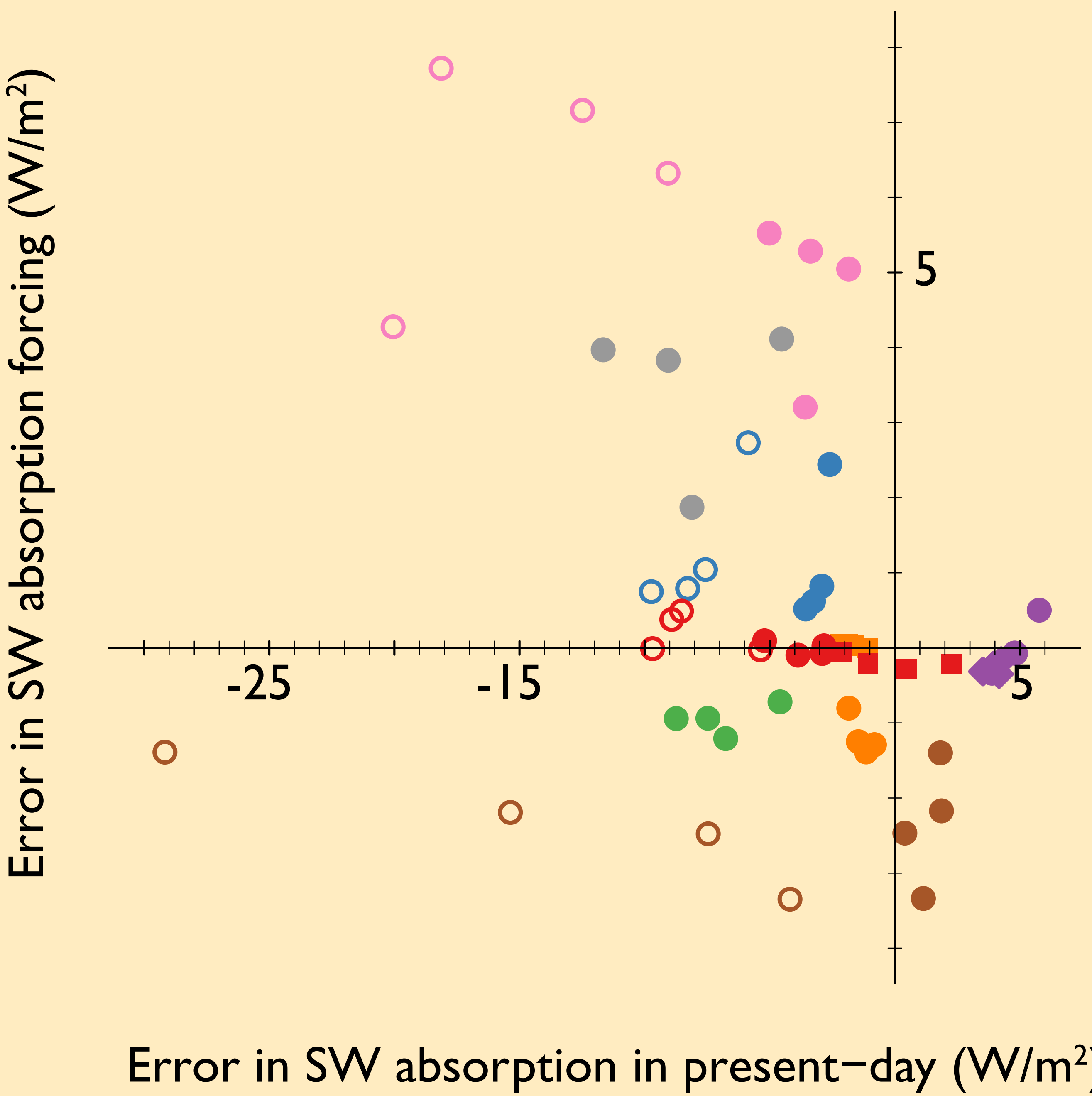
In the present paradigm any effective radiative forcing is considered equally valid. Do we believe this?

Radiative forcing can't be observed directly, but we have strong bridges to observations.

RFMIP will document effective radiative forcing at present day and through the historical period. We are also assessing the accuracy of (some aspects of) forcing calculations.

3. Model evaluation and strong constraints on forcing

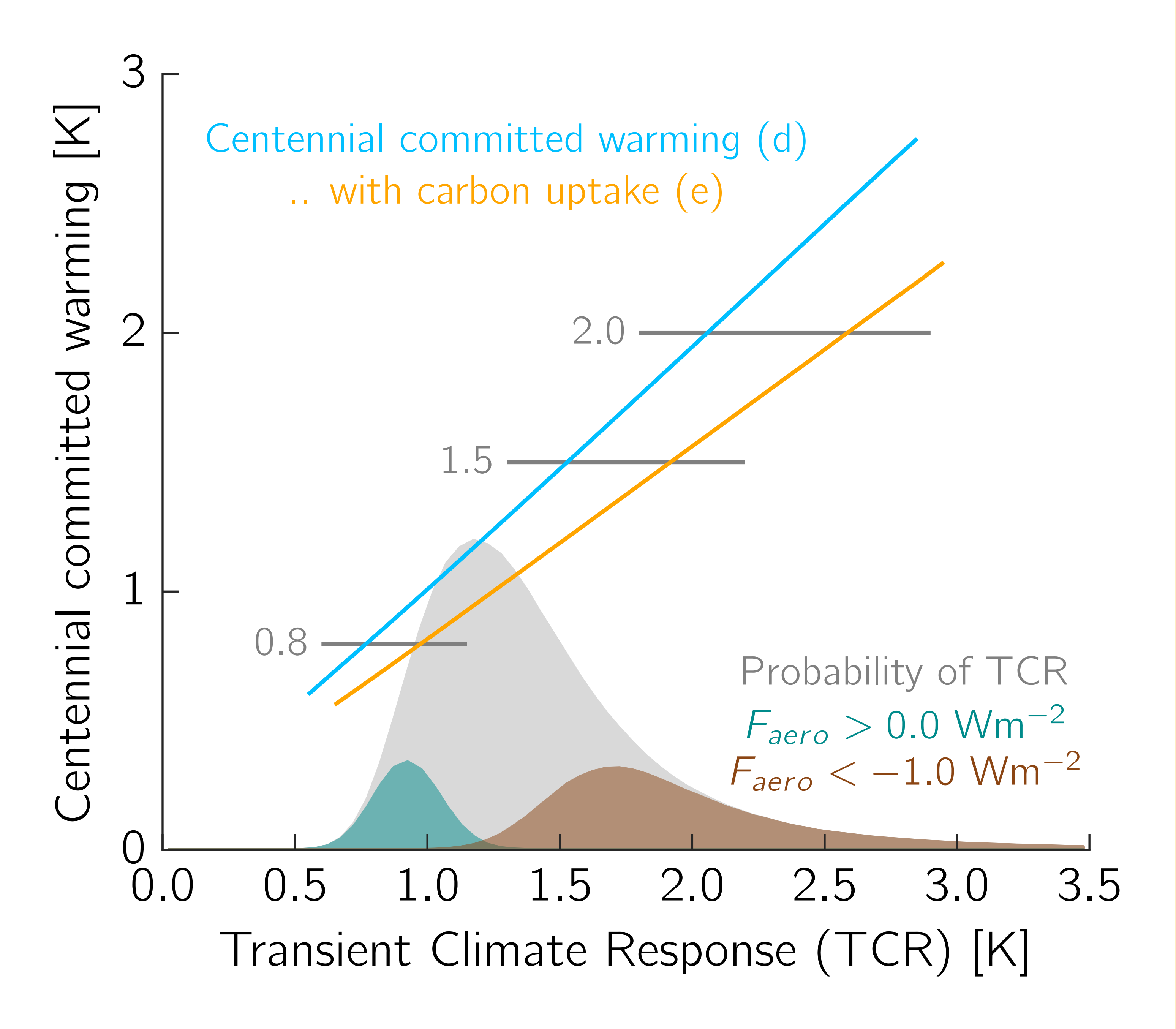




after Pincus et al., 2015, 10.1002/2015GL064291

3. Model evaluation and weak constraints on forcing

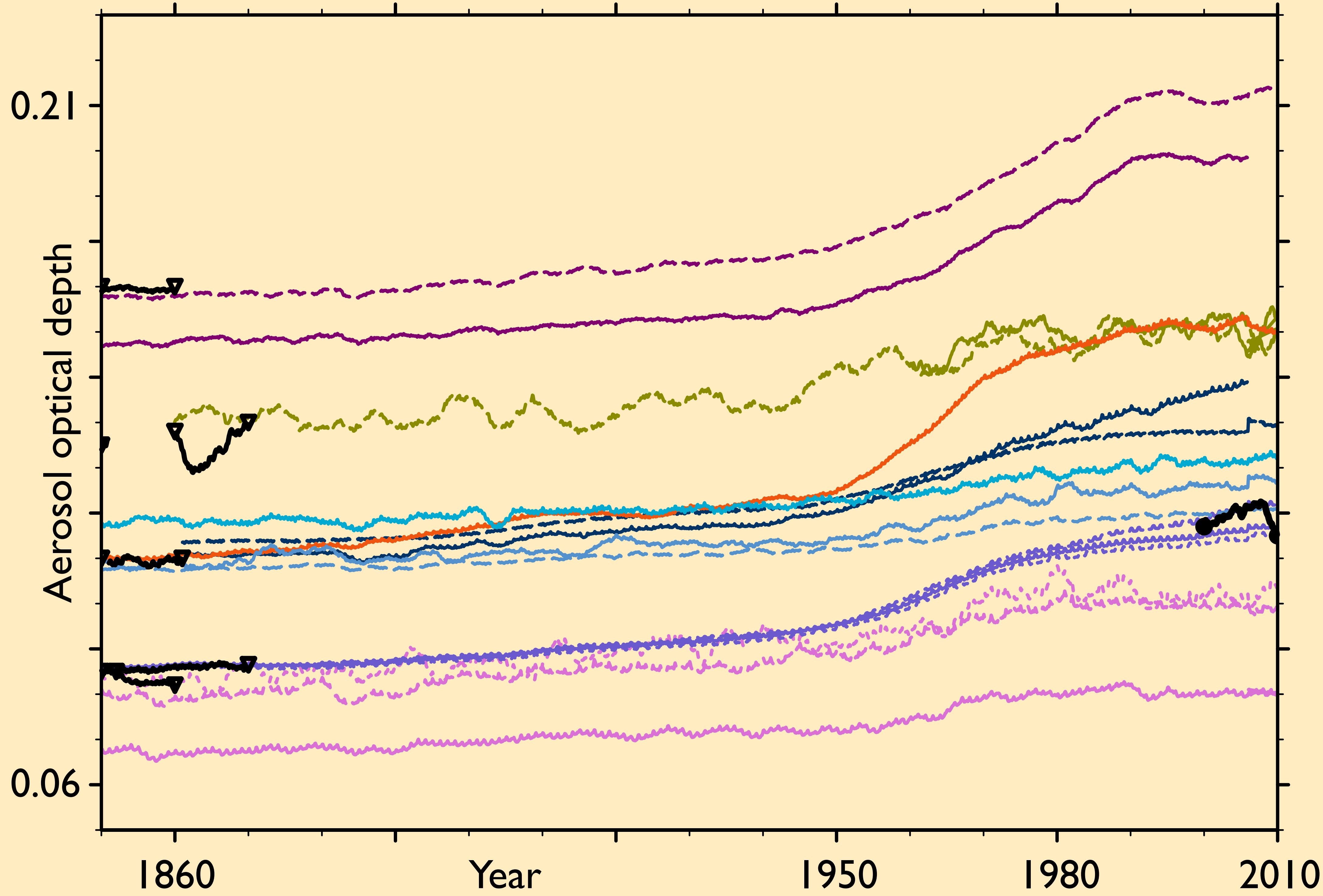
Uncertainty (really, model disagreement) about aerosol effective radiative forcing dominates the uncertainty in many applications, even through the forcing itself is roughly a third of the greenhouse gas forcing.



Mauritsen and Pincus 2017, 10.1038/nclimate3357

3. Model evaluation and weak constraints on forcing

That uncertainty is driven largely by enormous variability in aerosol burdens



Shindell et al. 2013, doi:10.5194/acp-13-2939-2013

3. Model evaluation and weak constraints on forcing

To get forcing right we'll need process understanding…

"As Johannes [Quaas] says, one challenge of the evaluation is that the parameters that matters in evaluating the state and the perturbation (forcing) are not necessarily the same."

Email from Nicolas Bellouin, 24 July 2017