On detection of climate change

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This note attempts to clarify what is meant by (statistical) detection of climate change, and discusses some recent developments. Trends in 20th century climate are less significant than originally thought.

Definitions

Climate, *change* and *detection* are three poorly defined concepts. No wonder there is a lot of confusion about *climate change detection*.

Let's first consider *climate change*. It is worthwhile to distinguish

- The intuitive, existential meaning. Climate change is perceived as a lasting change in typical weather conditions (dry, wet, cold, warm).
- The meaning given by the Framework Conference on Climate Change (UNFCCC): a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods[1].
- The meaning used by IPCC: Climate change refers to a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer[2].

These are three very different meanings. Particularly troubling is the inconsistency between the use of climate change by IPCC ('a change, whatever the cause') and UNFCCC ('a change attributed to human activity'). In this note I will use the IPCC definition.

The IPCC definition raises two new questions: 1. What is climate? 2. How does one actually detect a change? The UNFCC definition raises a third question: 3. How does one attribute a perceived change to a 'cause'?

What is climate?

This is another important semantic issue. The World Meteorological Organisation defined climate as a 'sample statistic of weather' (e.g. the average weather over the period 1961–1990).

As a physicist, I would avoid the word *climate*, but instead define the *climate system*, by specifying its spatial domain and by enumerating the variables under consideration. This also comes with a number of problems because many choices are possible, and in practice the number of variables to be included is very large (think e.g. of different species of bottom microbes or oceanic phytoplankton, all relevant for the carbon cycle!). As a result the frequently used distinction between 'internal variability' and 'forced variability' is a model concept, rather than something with an objective meaning. As such it is an artefact of how we choose to delineate the model. As an example, think of variations originating in the interaction of the land surface and the atmosphere. In a model

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[1] See article 1.2 in http://unfccc.int/essential_background/convention/background/items/2536.php
[2] See http://www.ipcc.ch/pdf/glossary/ar4-wg1.pdf

considering the land surface as an external field this would be a forced variation, whereas in models with a dynamical land-surface they would be internal. In a very broad definition of the earth system one could even consider humans as internal to the climate system, so that anthropogenic climate change would become an internal change (as compared to change induced by, say, cosmic radiation).

Statisticians aim at a deeper statistical and scientific insight by considering climate to be the process that generates weather (Stephenson, 2012), and by making additional assumptions which allow them to estimate probability distributions. This involves problems such as making statistical judgements about similarity and independence/exchangeability of weather over neighbouring times.

One approach is to consider physical climate models as stochastic models. This allows the translation of assumed input probability distributions for initial conditions or model parameters into pdfs for output quantities. However, the interpretation of these probabilities is not without problems (Stephenson et al, 2012).

What is climate change detection?

Unfortunately, IPCC is not consistent in its definition of the concept of detection. I quote from AR5

> 'Detection of change is defined as the process of demonstrating that climate or a system affected by climate has changed in some defined statistical sense without providing a reason for that change [A]. An identified change is detected in observations if its likelihood of occurrence by chance due to internal variability alone is determined to be small [B].' (Hegerl et al., 2010).

The first sentence [A] is the official IPCC definition, which I will use. The second sentence links variability with a physical cause ('not internal variability'), which is at variance with [A]. An additional problem is that the concept of internal variability is not well-defined, as discussed above.

IPCC is also not consistent in the use of the word detection when (frequently) speaking of "detection of anthropogenic influence" where one would expect to read "attribution of anthropogenic influence".

According to the official IPCC definition [A] climate change detection is a purely statistical approach. In this approach, one considers time series of observed values of climate variables. In a typical detection study one assumes that the signal is a superposition of a stochastic signal of a particular type (say AR(1) or LTP[3]) and a trend[4]. If the probability that the trend is zero is found to be small one has detected a change.

In my opinion detection studies have limited meaning, because finding a trend in this way just shows that the series cannot be described by the assumed stochastic Ansatz . Of course, the fact that a variation occurs is interesting in itself, because it has a direct impact on the environment.

[3] The definitions are given in the guest blog by Armin Bunde on http://www.climatedialogue.org/long-term-persistence-and-trend-significance/ .

[4] Sometimes, incorrectly and confusingly called external or deterministic or even anthropogenic trend.

At the basis of statistical studies is the separation of a stochastic signal and a trend. From a physical point of view, this is hard to justify, because, in a finite record, there is no difference between a trend and a slow stochastic variation.

Attribution vs detection

Statistical detection studies do not provide information on the cause of a detected change. In contrast, attribution studies are able to attribute causes to observed variations by using a physical model. Unavoidably, attribution of a particular variation to a particular cause will be conditional to the assumption that the model is accurate enough. Scientists having confidence in physical models will tend to attach more value to attribution studies, because they provide more information and there is no need for making ad hoc assumption about the statistical nature of climate series. Scientists with little confidence in climate models will attach importance to detection studies because they do not depend on a physical model.

What statistical model is most appropriate for climate data?

Demetri Koutsoyiannis argues that LTP as a measure of variability and change is a fundamental property of climate time series. His belief is based on the analysis of observed and reconstructed time series. He also gave an elegant derivation based on the principle of extremal entropy production (Koutsoyiannis, 2011). However, it should be noted that the validity of this principle is not generally accepted (Verkleij and Koutsoyiannis, private communication).

Armin Bunde takes a more pragmatic view. He noted that observed and reconstructed time series are better described with LTP than with e.g. AR(1), but he also acknowledges that LTP cannot be used to give a full characterization of the climate system.

Personally, I find it hard to believe that a simple stochastic characterization of climate time series has fundamental significance.

Are observed trends significant?

Many studies have used AR(1) to compute the significance of trends in 100-year temperature records. IPCC, in its Fourth Assessment Report, gives an overview of relevant studies, for example in table 3.3 [Linear trends in hemispheric and global combined land-surface air temperatures and SST]. From this table one would conclude that the trends are highly significant. By assuming AR(1) one neglects long term correlations. [*to be updated with AR5 information*]

Armin Bunde has been studying LTP for many years (Kantelhard et al, 2001; Lennartz and Bunde, 2011). Already in 2001 he and his collaborators applied detrended fluctuation analysis to study long-range correlations. A more recent paper (Lennartz and Bunde, 2011) analysed various global and local climate data and discussed the different results for the significance of the observed trends. Assuming LTP the trend in the global sea surface temperature, which increased in the past 100 year by about 0.6 degree, was found not to be significant. A significant warming trend was obtained for the land surface, but with a much lower significance then obtained by IPCC from the false assumption of AR1.

In discussions Bunde makes an additional working hypothesis, namely that "anthropogenic influences make the trend, and all natural forcings mainly contribute to LTP". In my opinion this assumption would need justification. If it were correct one could conclude that anthropogenic trends are smaller than thought. But this conclusion hinges on the working hypothesis, which lies outside the domain of statistical testing.

Markonis and Koutsoyiannis (2013), in a sequel to earlier work (see e.g. Koutsoyiannis and Montanari, 2007), analysed observational times series spanning time scales from 1 month to 50 million years. This confirmed long term persistence. On the basis of these studies Koutsoyiannis is doubtful about the significance of trends in the 20th century.

Relevance and interpretation

One should always be aware that statistical detection studies are based on assumptions, some of which are hard to justify.

A physical interpretation of the outcome of statistical studies requires additional assumptions.

My best intuitive summary of the situation is

- Climate varies on all time scales, which is reflected in long term persistence.
- In a finite record it is impossible to distinguish a trend from a slow stochastic variation.
- Without additional physical model information it is impossible to distinguish trends arising from, say, varying solar forcing, slow oscillations in the (deep) ocean circulation and anthropogenic causes.

Conclusions

1. LTP gives a better description of climate records than AR(1).
2. The old trend estimations of the IPCC based on the false assumption of AR1 process strongly overestimate the significance of trends.
3. Assuming LTP the trend in the global sea surface temperature, which increased in the past 100 years by about 0.6 degree, is not significant.
4. The interpretation of these findings requires additional assumptions.
5. There is a considerable semantic confusion from sloppy use of concepts like internal/external/ natural/anthropogenic and detection/attribution. This obscures discussions on the interpretation of statistical detection studies.

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