Centre for Climate Change Economics and Policy

Signal, insight and noise: contrasting the decision relevance of climate models with climate science

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I. Introduction:

It is often said that, as the Earth warms, the impacts of climate change will become more apparent as the "signal will come out of the noise". The extent to which this vague, intuitively appealing claim may prove relevant to decisions makers and scientists is considered, with a focus on hydrology. While one might argue that local temperatures might eventually be observed to increase almost everywhere as a planet warms, and hence the "signal" from changes in the local climate distribution will come out of the "noise" of natural variability, similar arguments flounder for other high impact variables. Contrasting the behaviours within CMIP3 climate model output archives shows that the concept of "signal" and "noise" in precipitation is challenging to grasp firmly. Methodologies to determine when quantitative analysis of model output might be considered fit for purpose is discussed. Do today's models provide decision relevant information on precipitation in a 2x CO_2 world beyond that available 50 or 80 years ago? To what extent is it only our insight which has increased, not our quantitative grasp of expected impacts? And in any case, what can we do today to increase our confidence in attribution and detection tomorrow?

These questions are important; due to the complexity of the Earth System and the relatively short duration of high resolution observations, new "records" would be expected in future observations even in a stationary climate. A clear case can be made that a wide-spread increase in annually averaged temperature significantly greater than historically quantified internal variability is a response to new forcing. In many other fields, specifying before the fact how the signal will come out of the noise, indeed specifying what the signal is exactly (intensity, frequency, variability, ...) will significantly increase our confidence in both detection and attribution. This is particularly the case for precipitation. In section II we illustrate how scientific insight contributes to this task. In sections III and IV we question whether or not models are up to this task. It appears likely that they are not, suggesting more emphasis be placed on climate science relative to climate modelling.

II. Insight:

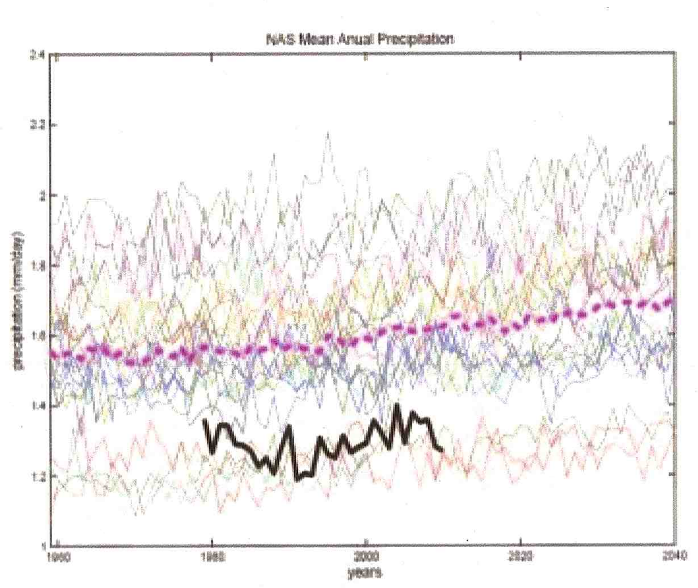
Precipitation (hail, rainfall, snowfall, and other forms) forms as water vapour condenses, usually in rising air (over mountains, as warm or cold fronts, local convection, etc.). Precipitation depends on temperature and the weather situation, and changes if any of these aspects alter precipitation. Warming due to greenhouse effect increases evaporation when surface moisture is available (as over the oceans and wet surfaces). A basic thermodynamic law (Clausius-Clayperon) determines that the water holding capacity of the atmosphere increases by about 7% /℃. Uncertain observations suggest that relative humidity has remained constant from the surface through the troposphere; consequently according to the Clausius-Clayperon law, it is expected that the amount of water vapour in the atmosphere should have increased due to higher temperatures, leading to a general increase in precipitation intensity and the risk of heavy rain and snow events.

Using these basic physical arguments, we can argue that in a warmer climate the risk of drought will increase where it is not raining, and the risk of floods will increase where it is raining. But where and when these events occur will vary depending on changes in the atmospheric circulation patterns determined by , for instance, El Niño or the North Atlantic Oscillation; these changes are not completely understood and/or very hard to predict . A recent example of this high variability is given y the fact that in the European summer of 2002 there were wide spread floods, followed by a record breaking heat wave in 2003.[1]

III. Projections:

Confidence in climate models was considered higher "*at hemispheric to continental projections than at regional scales where confidence remains low*" in the AR2 [2], while in 2007 "*... considerable confidence that climate models provide credible quantitative estimates of future climate change, particularly at continental scales and above ....Nevertheless, models still show significant errors. Although these are generally greater at smaller scales, important large-scale problems also remain...*" [3. In the first and second assessment reports, mean precipitation was projected to increase at high northern latitudes in winter. The third report projected an increase of tropical precipitation mostly over ocean areas and a decrease of subtropical precipitation. And the fourth report added as robust findings increases at high latitudes as a consequence of a general intensification of the hydrological cycle, and globally averaged mean water vapour, evaporation and precipitation. How can we best make these projections more discriminating?

Large scale model projections are broadly consistent; more precise claims regarding the future from either the models or the science would aid attribution and detection. Where are such claims most likely to be found?



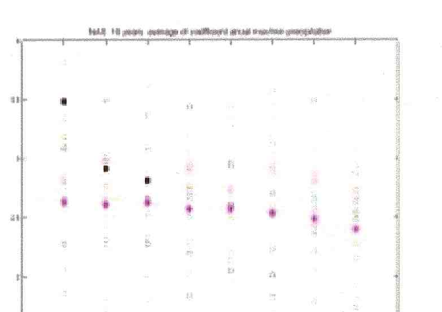
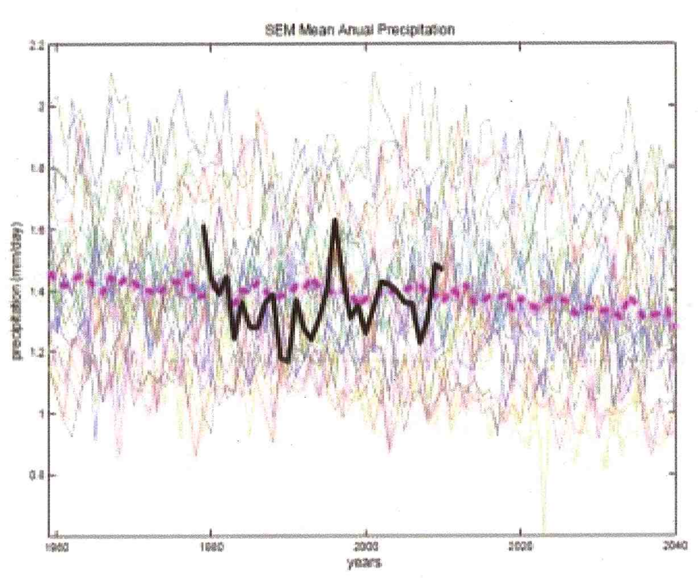


Fig. 2: Northern Asia (NAS) annual mean precipitation (left) and ratio of max to min precipitation in any given year averaged over a decade (top). Colours:CMIP3 models, black: observations, magenta: ensemble mean.



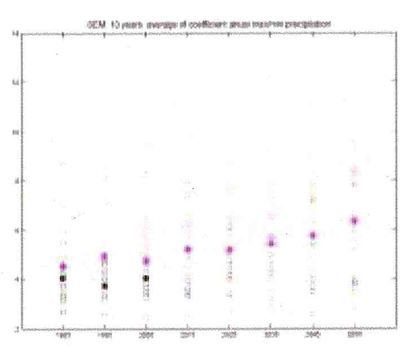


Fig. 3:same as figure 2 for Mediterranean region (SEM)

IV. Biases, changes and missing feedbacks.

Consider precipitation model data at scales considered to be robust (continental and sub-continental), we ask whether biases in the model simulations do matter in terms of attribution and detections, and if it is sensible in the context of impacts studies to treat biases some statistical methodology, implicitly assuming that even if models have biases, simulated changes are robust.

The left panels of figure 1 illustrate the seasonal biases (top) for 1961-1990 and changes (bottom) from 2071-2100 to 1961-1990, for the models reported in the third AR (figs 10.2 and 10.5 in [4]). The right hand panels show biases (top) and changes (bottom) from 24 models reported in the 4AR [3].

We notice that:

- Model biases have increased since the third AR in spite of model improvements.
- Biases are generally larger than simulated changes and would stimulate significant (false) feedbacks in vegetation, surface albedo, etc.
- In some cases the biases are so large that, if the precipitation of the region was to change by that magnitude, the region would correspond to a different climate type. For instance, a reduction in the annual Central America (CAM) precipitation by about 60% would take it from its current value , approximately 1200mm/y to about 480mm/y which is currently typical of the Mediterranean region (SEM). Might a negative bias in precipitation artificially increase the number of heat waves projected?
- What hard falsifiable predictions do projections claim to make, conditional on concentration pathways?

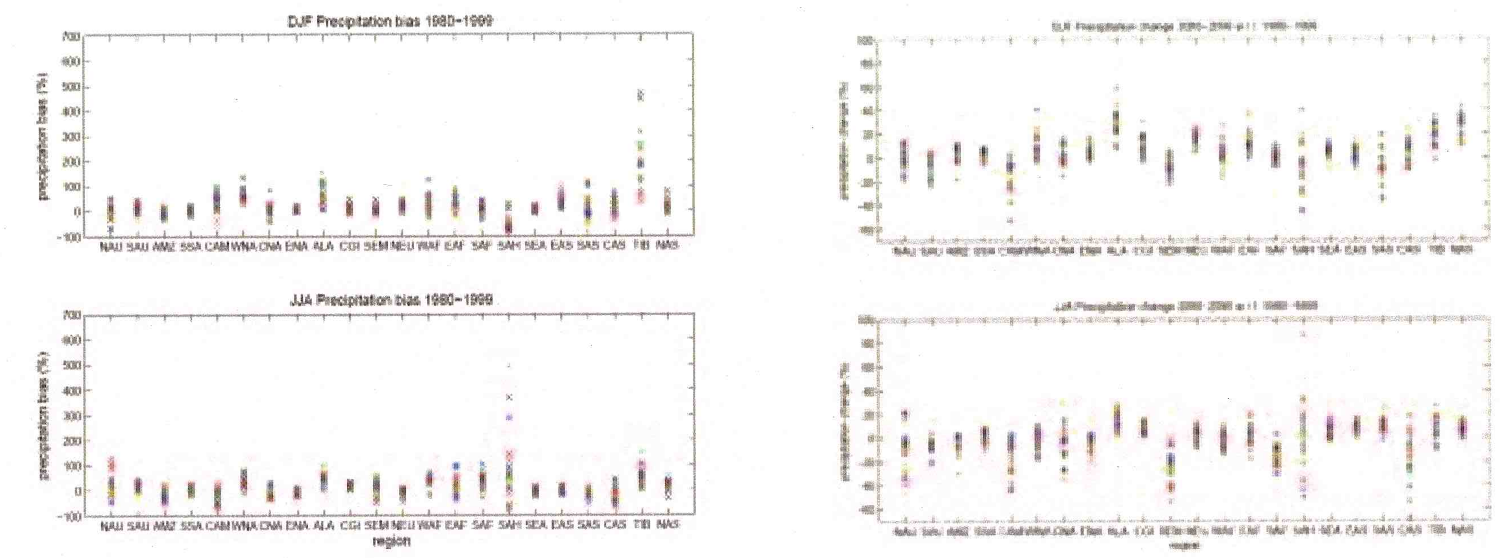


Figure 1: precipitation biases (left) and changes (right) for the fourth AR models.

V. Signal and noise:

The identification of "signal" and "noise" is not always as clear cut as it is in the case of establishing a change in the annual average temperature. In cases where one expects the particular variable to trend in a particular direction, detecting a signal is a straightforward affair where the prior distribution of internal variability is known.

This is not always straightforward even for local variables like temperature and sea level, statistically we expect a wide variety of "records" can be set in every year even in a stationary climate; establishing (much less attributing) a true change in the climatological distribution is greatly eased by stating, in advance, precisely which records are likely to be broken in a given scenario.

The situation is much more complicated in the cases of precipitation (fig 2), storminess and flooding. Anthropogenic climate change is not expected to provide such a linear "trend emerging from variability" for these phenomena as it is for large-scale temperature change. Particular changes in frequency or changes in intensity; changes in clustering or changes in extremes due to coincident events may be determined using physics based models driven by particular changes in atmospheric constituents. It is important to identify which particular changes are expected before the event, if one is to have confidence in the mechanism and the attribution. Such insights can come wither via simulation models or via physical argument.

Conclusions: If current models have insufficient fidelity to predict the types of changes expected in particular regions of the planet, then clear physical arguments of an "if, then" type (projections via insight) can provide an important foundation for the detection and attribution of climate change. While arguments have been formulated for over 80 years, a clear discussion of where insight is believed to outperform quantitative forecasting would be of value in advancing science based decision making.

The general credibility of science is enhanced when relatively precise statements can be made before the details of the experiment are known. In large complex systems, many results may be "consistent with the changes expected" given a theory, but to be persuasive (much less to claim statistical significance) fairly precise, falsifiable expectations need to be stated before the "evidence" is observed. While we question whether climate science might play a larger role in this task than climate modelling, we stress the need to maintain the credibility of science even if doing so weakens some (current) cases for detection and attribution.

References:

Data: Observations: CPC Merged Analysis of Precipitation (CMAP) product (Xie and Arkin, 1997); Models: CMIP3 project.

[1] Trenberth et al (2007) Chapter 3 in [3]

[2] Houghton et al (1996) "Climate Change 1995: The Science of Climate Change",Cambridge University Press, Cambridge, UK

[3] Solomon, Qin et al (2007) "Climate Change 2007: the Physical Science Basis", Cambridge University Press, Cambridge, UK.

[4] Giorgi et al (2001) Chapter 10 in "Climate Change 2001: the Scientific Basis", Houghton et al eds, Cambridge University Press, Cambridge, UK.

[5] Smith LA & A Lopez (2012) Clarifying the roles of science and modelling in climate change attribution and detection. (in preparation)

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