Euroclivar/DETR workshop of Attribution and Detection: Attribution beyond Discernible – Workshop Aims February 9, 1998

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1 Introduction

In this position paper we present the aims of the workshop and pose some questions which we like the workshop to address. By doing this we hope to encourage all participants to think about their answers to some of the questions prior to the workshop. We also encourage all participants to consider which areas need highest priority in order to have results results included in the IPCC 2000 report.

In the 1995 IPCC report(Houghton *et al*, 1996) the claim was made "That the balance of evidence suggests a discernible human influence on climate". The aim of the workshop is to consider the "end-to-end" attribution process and to answer the following questions.

1. Does the balance of evidence still support a discernible human influence on climate?

2. If, so can we quantify the anthropogenic contribution to observed climate change ?

3. What does successfully detecting climate change and attributing it to anthropogenic effects tell us about future climate change?

4. What are the main sources of uncertainty in the detection and attribution of climate change? What can be done to reduce these uncertainties and in what order of priority should it be done?

5. What other important research questions need to be answered in respect of attribution by the next IPCC report?

6. What specific recommendations can be made for the implementation of CLIVAR in europe?

By the "End-to-End" attribution process we mean:

1. Identification and quantification of climatic forcings; both natural and anthropogenic over at least the last 50 years.

2. Computing responses to these forcings using a credible model of climate.

3. Creation of appropriate observational datasets.

4. Comparison of the model responses to those forcings with observations to attribute some, all, or none of the observed climate change to those forcings.

2 Detection and Attribution

The climate system, which we define as the atmosphere-ocean-ice-land-surface, exhibits variability on many space and time scales. Some of this variability is due to the interactions between and within the various components of the system. The El-Niño/Southern Oscillation is an example of this type of variability. Some of the variability is due to a response to changes in forcing external to the system. For example there have been changes in concentrations of atmospheric carbon dioxide over the the twentieth century which may be responsible for the climate warming observed over the last 30 years.

The detection of climate change is defined here as showing that some climate change is outside the bounds of possible internal climate variability. By internal climate variability we mean the variability that the atmosphere-ocean-ice-land system would show in the case of constant forcing external to the system. Note that this internal variability cannot be directly measured on all space and time scales as the natural climate system will have had, at the very least, changes in natural forcings. An example of detection would be to show that the global mean temperature of the 1990s is unusually warm.

Note that Santer *et al* (1996a) define detection as being outside the range of natural variability i.e. internal variability plus naturally forced variability.

The global mean temperature has risen by approximately 0.6K since the beginning of the centuryParker *et al* (1994). The question is whether this can be attributed to:

- decadal to century internal variation of the climate system,
- a slow change in natural forcing,
- an anthropogenic change.

The concept of "attribution" is used rather than that of "cause" because this is more appropriate for a complex system. Attribution is not a unique relation. It is possible that a particular change can be attributed to different forcings. An example of a unique attribution would be the statement that the warm 1990s can be attributed to solar activity and not to other known forcings.

Of the two activities detection is by far the easiest. It requires rejection of only one hypothesis – that of internal variability. Several studies have already claimed to have detected climate change (e.g. Stouffer *et al* (1994); Hegerl *et al* (1996); Santer *et al* (1996b)) subject to the very important caveat that the model simulated internal variability is correct.

The method commonly used to detect and attribute climate change is termed fingerprinting. In this method an expected signal of climate change ("fingerprint"), due to some forcing, is compared with observations of climate change. If the match is better than expected by chance then detection is claimed. If no other "plausible" cause could lead to such a signal then the climate change is attributed to that forcing. In our view a fingerprinting strategy has four components (Fig. 1):

1. Fingerprints of possible climate changes. In most recent studies these are generated by forcing climate models with estimates of change in different forcing agents.
2. Observations.
3. Methods of comparison between the fingerprints and the observations.
4. Estimates of internal variability.

Attribution can never be final because that would require consideration of all possible forcing of climate. This is by definition impossible as there are an infinite number of possible forcings of climate. In practice we restrict ourselves to the more limited set of forcings considered "plausible".

By "plausible", we mean the use of forcings for which we have creditable quantitative estimates and whose magnitude is believed to be large enough to have an impact on the climate system. This is clearly a matter of subjective judgment. We exclude factors which are highly speculative (for example interstellar dust or an impact with a large meteor). As we learn more about the climate system we will change our mind as to what is (or is not) "plausible".

To date there have been very few studies which have attributed recent climate change to human activities largely because they have not considered possible natural forcings. Hegerl *et al* (1997) considered two anthropogenic forcings (greenhouse gases and sulphate aerosols) and one possible solar forcing and found, at least, for the most recent period that anthropogenic forcings were responsible for the recently observed climate change.

3 Fingerprints of climate change

In this section we suggest a set of "plausible" forcings and ask some questions about them before turning to the models used to derive the forcings.

3a Agents of climate change

We suggest that the following are currently "plausible" agents of climate change.

- Anthropogenic greenhouse gases (could be considered individually or collectively)
- Anthropogenically generated tropospheric aerosols such as sulphate aerosols and soots through both direct and indirect means.
- Stratospheric ozone changes.
- Tropospheric ozone changes.
- Land use.
- Naturally generated changes in aerosols.
- Solar irradiance. Possible amplification will be considered separately.
- Volcanic aerosols both directly and via their possible effects on stratospheric ozone.

- Changes in the atmosphere due to solar changes. i.e. cloud changes or stratospheric ozone changes induced by changes in the UV flux.

Are there any other "plausible" forcings? Should some of the above be removed?

Now and in the next few years we will not be able to consider all these forcings simultaneously either because we do not have the computer time to carry out experiments with all possible combinations or because a linear analysis would become degenerate. Therefore some methodology needs to be developed to determine which forcings we consider.

With the exception of greenhouse gases there is, at present, very little confidence in the amplitude of the climatic forcings due to the above agents. Again with the exception of greenhouse gases most of the forcings, at least to the level necessary to introduce them into AOGCMs, have been derived using other models. The workshop will consider how to improve confidence in the forcings used to drive models in order to extract their fingerprints.

For each forcing agent the following questions need to be answered:

- What are the temporal and spatial variations of the forcing?
- What are the main sources of uncertainty?
- What needs to be done to reduce the uncertainties?

Considering all the "plausible" forcings which ones should receive greatest priority. To date greatest priority has been given to greenhouse gases, then to sulphate aerosols, stratospheric ozone changes and solar forcing changes. Should these relative levels of priorities stay constant or should different priorities be introduced?

3b Modeling the climatic response to forcing changes

The first component in the fingerprinting strategy is to compare model fingerprints with observations. What effect does model error have on the comparison? For example if the coupled model used has too long an ocean lag in response to forcing then forcings with a short timescales such as solar forcing may be damped strongly.

What kind of simulations should be used to detect and attribute climate change? Equilibrium simulations have the advantage of low noise but the disadvantage is that they contain no transient information. Signals of late 21st century climate change have high signal to noise ratio but the spatial and temporal patterns may be significantly different from those of the 20th century. Transient simulations of the 20th century have a more accurate representation of the forcing but ensembles may be needed to increase the signal to noise ratio.

What are the key characteristics in the model response to changes in forcing ?

On the basis of studies to date the main factors appear to be:

- The land/sea contrast especially in the transient response.
- The climate sensitivity (K/Wm^{-2}) by which we mean the global temperature change to a global scale forcing. In practice this is normally obtained from simulations with doubled CO_2 concentrations. For more localised forcings this may not be appropriate.
- The lag timescale as set up by the ocean.

Some more questions about climate models.

1. How well do we know the water vapor feedback?
2. To what extent do cloud feedbacks affect fingerprints?
3. Could the total model uncertainty be partitioned amongst different processes such as, for example, the water vapor feedback, cloud changes and ice feedbacks
4. Is the response to two forcings the sum of the individual responses? i.e. is the response to greenhouse gases and sulphate aerosols close to the response to greenhouse gases alone added to the response to sulphate aerosols alone.
5. Are non-linear dynamical responses represented well enough in existing climate models?

4 Observations

The most important component of the fingerprinting strategy is the observed datasets which we use to compare "fingerprints" of climate change with reality. Attribution and detection studies to date have focused on surface temperature and, with reasonable success, on temperature changes in the free atmosphere. Mean sea level pressure and precipitation, maximum temperature and minimum temperature measurements exist going back to at least 1900. The workshop will consider if there is much to be gained by use of either of these datasets. The workshop should also consider if there are other datasets that could be used for detection and attribution studies.

- What remaining biases exist in the observational datasets. i.e. is there a land/sea bias in the surface temperature record which changes with time?

- What are the error characteristics of the observational datasets and are they important compared to natural climate variability?

- What are the main deficiencies with current data used in detection and attribution? e.g. how large are the corrections that need to be applied to the radiosonde temperature data to correct for changes in measuring instruments.

25 years of radio-sonde data were used in a pioneering study by Santer *et al* (1996b) to detect climate change. The MSU-2R record spans 18 years. The workshop should consider whether this is long enough for it and other satellite records be used to detect let alone attribute climate change. However questions remain about the reliability and homogeneity of the MSU-2R record over the 1979–1997 period (e.g. Hurrell and Trenberth (1996)).

- What do the satellite records tell us about changes in the climate system. e.g.. for the MSU-2R record how much, if any, contamination is there from surface emissivity?

- What are the implications of the apparent disagreement between the MSU-2R/radiosonde temperatures and surface temperatures ?

- What are the temporal and spatial error characteristics of satellite records?

- How homogeneous are they compared to the surface record?

- What is the minimum record length of a satellite record for it to be useful in detection and attribution studies?

5 Comparison between observations and fingerprints

There are several techniques used to compare observations with model "fingerprints". Some researchers have used correlation techniques to show increasing agreement between model predicted fingerprints of climate change and observations to claim to have detected climate change (and presumably attributed it to anthropogenic effects). Other researches have used "optimal detection" techniques. This section of the workshop will aim to consider the following questions:

- How does the technique use information about natural variability?
- Is natural variability simulated and sampled well enough to use optimal detection techniques? If it isn't what effect does this have on the technique?
- How would we tell if the natural variability is both simulated and sampled well enough?
- Do the advantages of more complex techniques make up for the difficulty of explaining to non-specialists how they work?
- What assumptions are made and how sensitive is the technique to those assumptions?
- Is there a best technique to use or does it depend on application.
- What techniques should be used for non-normal distributions such as rainfall distributions.
- Is there a place for simpler methods?

6 Quantification of internal climate variability

All existing claims of detection and attribution rely, in our view, rather uncomfortably on the use of coupled models to provide estimates of internal climate variability. How well existing models do in simulating internal variability is a difficult question to answer. The best way forward appears to be to compare model natural variability with proxy records. In a pioneering study Barnett *et al* (1996) showed that there were deficiencies in the simulation of variability in two coupled AOGCMs compared with estimated from proxy data. Such results could cast doubt on the detection claim. However such comparisons tend to focus on very small scales. Stott and Tett (1997) showed that model variability was too weak on scales below 2000 km.

Some (Hegerl *et al*, 1996) studies have removed model predicted patterns of climate change from the observations and used the residual change from the observational record as an estimate of internal climate variability. Allen and Tett (1998) suggested that the residuals between the observations and best fit model predicted climate changes should be internal natural variability.

- Could proxy data be used to help to detect climate change (i.e. Briffa *et al* (1995)).
- Do proxy/paleo data provide more reliable estimates of climate variability than model simulations.
- How would the effects of natural forcing changes be considered in any analysis of proxy/paleo data.
- Is the "climate noise" that is computed by removing model predicted patterns of climate change adequate to use for detection studies?
- If an optimal detection strategy is followed then the residuals should look like "climate noise" (Allen and Tett, 1998). Does this offer a way forward? Are there better techniques than a simple check on the residuals?

7 Other Issues

What happens if climate variability changes as the climate changes? For example if ENSO changes then climate variability would also change.

Existing studies essentially use linear statistical techniques. If climate change includes changes in regime population or other highly non-linear processes how could it be detected? Is it sufficiently important to worry about?

In this note the definitions of detection and attribution rely on estimates of natural internal variability. Are these definitions of detection and attribution used useful ? Are there better definitions which rely less on estimated internal variability ?

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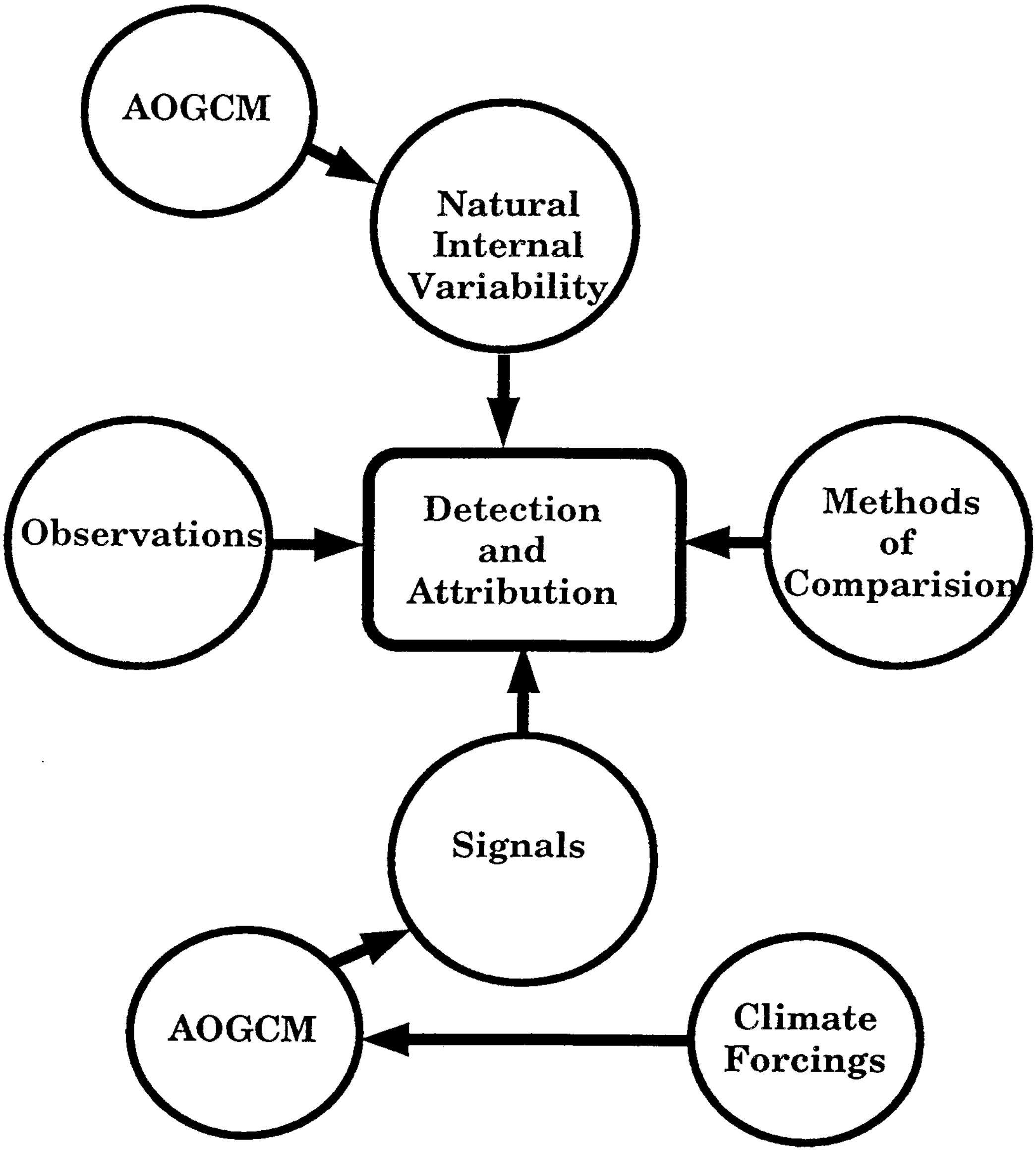

Figure 1: Four Components of Detection and Attribution.
Inner ring shows four requirements for detection and attribution. Outer rings shows how AOGCMs can be used to provide some of the requirements.