The International Detection and Attribution Group IDAG

Final report

(6/2006 to 6/2009, no-cost extended to 7/2011)

This report focuses on the period to 2010 including, after which the new round of the International Detection and Attribution group, led by Claudia Tebaldi, started. In 2011, some final work on report has been done, and outstanding tasks completed. However, most participants are now working on the new grant and hence the citations and work reported is focusing largely on the regular grant period.

Members of the IDAG 2006-2009:

Gabriele Hegerl, PI and coordinator, Duke to 2007 and University of Edinburgh thereafter

Myles Allen (co-coordinator, Oxford University, UK)

Tim Barnett (Scripps Inst Oceanography)

Nathan Gillett (University of East Anglia, UK, later CCCma, of Victoria, Canada)

Phil Jones (University of East Anglia, UK)

David Karoly (co-coordinator, University of Oklahoma, later University of Melbourne, Australia)

Jesse Kenyon (Duke University)

Reto Knutti (ETH Zurich, Switzerland)

Tom Knutson (travel reimbursed, GFDL)

Toru Nozawa (travel reimbursed, Ntl. Inst. for Environmental Studies, Tsukuba, Japan)

Doug Nychka and Claudia Tebaldi (travel reimbursed, NCAR, Boulder)

Benjamin D. Santer (reimbursed for travel, PCMDI)

Richard Smith (Department of Statistics, University of North Carolina, Chapel Hill)

Dáithi Stone (Oxford University, UK, later University of Capetown)

Hans von Storch (GKSS, Geesthacht, Germany)

Peter Stott (reimbursed for travel, Hadley Centre, Reading, UK)

Mike Wehner (reimbursed for travel, Berkely Livermore Laboratory, Berkeley)

Xuebin Zhang (reimbursed for travel, CCRM, Toronto, Canada)

Francis Zwiers (reimbursed for travel, CCCma, Victoria, Canada)

Part 1: Overall summary report

The IDAG group has played a leading role in detection and attribution work for many years, and this funding cycle 2006 on continued and strengthened that role. The funded work led to a large number of publications, many with multiple group members, and shows that the IDAG group is a truly collaborative effort, covering detection and attribution of climate change from large scale temperature changes to changes in regional climate and impacts. The coordination performed by the group stimulated work in individual labs, and increased the reliability of results by exposing them to early critical evaluation within the group, often before they are published, thereby increasing significantly the reliability of the available body of knowledge on attribution and detection. Further, the IDAG is unique in the climate arena in that it is self-organized by the science community itself; the group effectively leverages resources available in a diverse range of institutions.
The information gained by detection and attribution methods can also be used for predictions, and group members have pioneered that application (see below for detail). An example is estimating the equilibrium climate sensitivity, the transient climate response and providing probabilistic regional projections from multimodel ensembles. Detail of the work performed under the IDAG group 2006-2010 (when the new funding cycle started) is given below under the individual tasks. Often, the group work culminated in a joint group report published in a journal (e.g, Barnett et al., 1999; IDAG, 2005). This time, the group instead published several review papers with multiple group members involved (e.g., Stott et al., 2010, Knutti and Hegerl, 2008, Hegerl and Zwiers, 2011, Zhang et al., 2011, Stone et al., 2009, Knutti et al. 2008) which was felt covered the field to an extent that made a further review paper redundant.

The IDAG group also organized **annual, very successful meeting**s held at the Damon room at NCAR in Boulder, Colorado, each year in January/early February for 3 days. The meeting was supported by UCAR (Melanie Whitmire and Tara Torres, who handled travel as well). The meetings were generally very well attended (attendance around 30, including almost full IDAG membership and invited international and local guests, such as senior NCAR and NOAA staff). The meetings really invigorated the research conducted in detection and attribution.

History and accomplishments of the IDAG group

The IDAG group has been very strongly involved and leading in detection and attribution. Early results from the group contributed to the IPCC Second Assessment Report (SAR; IPCC 1996) that found a “discernible” human influence on climate. Additional results were reported by Barnett et al. (1999) and contributed to the IPCC Third Assessment Report (TAR; IPCC 2001), which concluded that “most of the observed warming over the last 50 years is likely to have been due to the increase in greenhouse gas concentrations.” The evidence has continued to accumulate since the TAR. The IDAG group published a review paper (IDAG, 2005), which reviewed the further evidence and open questions on the detection of climate change since the TAR. Group members were heavily involved in the Fourth Asssessment. G. Hegerl and F. Zwiers were Coordinating Lead Authors (CLAs), and N. Gillett and P. Stott were Lead Authors of chapter 9, “Understanding and attributing climate change”. P. Jones was a CLA of chapter 3 (Observations: Surface and Atmospheric Climate Change), while Reto Knutti was lead author of chapter 10 (Global climate projections). Myles Allen was a review editor (RE) of chapter 10, and David Karoly of chapter 9. Nearly all other group members are contributing authors to the IPCC effort. In the upcoming Fifth Assessment Report, IDAG members are again involved as lead authors and coordinating lead authors (Peter Stott, CLA Chapter 10, Gabi Hegerl, Myles Allen, Nathan Gillett, LA chapter 10, Francis Zwiers, RE Chapter 11, Reto Knutti, CLA Chapter 12, Claudia Tebaldi, Michael Wehner, LA Chapter 12, Dáithi Stone, LA Chapter 18). Zhang is involved in the upcoming IPCC SREX report on changes in climate extremes.

Group members were also strongly involved with the CCSP effort. Santer was a Coordinating Lead Author for chapter 5 of the CCSP report on satellite trends, Jones and Smith were involved in an NRC review panel of it. Zwiers, Hegerl, Smith, Wehner and Knutson served as lead authors for the CCSP report on extreme events, and Hegerl and Karoly as Lead Authors of the report on reanalyses and attribution of recent climate change.

Several members of the group are also involved in the CCl/CLIVAR Expert Team on Climate Change Detection, Monitoring and Indices.

Many members of the group are also involved in research relevant for impacts of climate change (e.g., Gillett et al. 2004a). Karoly published in this area, and served as a Lead author of a chapter from Working Group 2 on impacts of climate change. Barnett and Santer played leading roles in a detection and attribution (D&A) study of changes in key parameters of the hydrological cycle in the western U.S., while Nychka led a project whose aims include assessment of regional changes and providing scenarios for impact research. Von Storch has led many projects on role of forcing and variability in Northern Europe and the Baltic. Knutson is co-chair of a WMO Expert Team on Climate Change Impacts on Tropical Cyclones and thus represents a valuable link into the tropical cyclone community.

Part 2: Detailed workplan report

This part of the report links outcomes to tasks from the proposal and provides the basis for the short overall report.

Task 1) Quantify and reduce uncertainty in global climate change projections using climate observations

Subtask 1.1) Assess the implications of new datasets and observations for existing estimates of attributable surface warming

A number of papers have been submitted by group members re-doing detection and attribution work for global scales, and this work has been one of the key inputs to the IPCC AR4 detection conclusions and subsequent work investigating it, and since then in the update on detection and attribution published in WIRES (see Huntingford et al., 2006; Stott et al., 2010). The Oxford group has used further available historical simulations forced with natural forcings only to update global and regional attribution results and to address the question of how the current climate differs from one in which human activities had never affected the climate (Stone et al., 2009).

A large number of simulations with different historical forcing scenarios produced by the NIES group have been used to update a check on the additivity of responses to different forcings, expanding to further forcings including specific aerosols and to regional scales (Shiogama et al., near submission), and simulations with black carbon show

The inclusion of error uncertainty estimates in observational datasets will enable more rigorous attribution of climate change. HadCRUT3 is the first climate quality dataset to incorporate comprehensive uncertainty estimates on all space scales; the effects of observational biases have now been fully incorporated into an optimal detection analysis of past surface temperature changes. These results show that attribution estimates on global scales are relatively little affected but that in some regions, including Africa and South America land regions and some SST regions, accounting for observational uncertainties increases the spread of possible temperature changes attributable to greenhouse gases and other anthropogenic forcing factors (Jones et al, 2011 In prep). Also, an inhomogeneity in the mid-20th century surface temperature record has been detected, including IDAG members, and the dataset is presently being updated, but isn't ready yet for applying the detection and attribution code (Thompson et al., 2008). A paper published in *Climate Dynamics* by Christidis et al (2009b) develops a methodology for taking account of model uncertainty in mean and extreme temperature changes at regional scales; and that methodology is further applied in Christidis et al (2011b).

Subtask 1.2) Assess the evidence for anthropogenic and natural influence on global precipitation and circulation

This work package has been very successful, with two publications published in Nature (Zhang et al., 2007; Willet et al., 2007) and two in PNAS (Santer et al., 2007, 2009) showing that anthropogenic changes in precipitation and water vapour have been detected, thus producing a compelling case that anthropogenic forcing has already

impacted the water cycle. Min et al. (*Science,* 2008) also showed that there is detectable human influence on high latitude precipitation and that external influence, probably anthropogenic, has influenced the probability of heavy precipitation (Min et al., (*Nature*, 2011)). Furthermore, Gillett and Stott (2009) have updated the detection of changes in sea level pressure (SLP) to seasonal resolution and show that externally-forced SLP trends are observed in all four seasons, with simulated and observed decreases in SLP at high latitudes and increases elsewhere. Wang et al (2008) showed that external influence can be detected on extratropical storminess and wave height.

Subtask 1.3) Assess the implications of past changes in temperature and ocean heat content for global transient and equilibrium climate change

The IDAG group has been heavily involved in characterizing and resolving the difference between interdecadal variability in global ocean heat content (Achuta-Rao et al., 2007), which is now resolved as largely a data problem. There is also a very active strand of IDAG work on transient climate response and equilibrium climate sensitivity.

A review paper has been produced on probabilistic projections and transient climate response (Knutti et al., 2008), which discusses different methods to arrive at probabilistic projections of global temperature changes and suggests how to estimate such projections in a way consistent with most methods. Stott et al. (2008) apply detection and attribution results towards predicting the near-term and overcoming aerosol uncertainty; and a further publication discusses the constraint on the transient climate response arising from ocean heat uptake data, showing that the uncertainties in atmospheric feedbacks demonstrate the overall uncertainty on the transient climate response (Knutti and Tomassini, 2008). Matthews et al. (2009) and Allen et al. (2009) used observations to constrain estimates of the ratio of global warming to cumulative carbon emissions. Knutti and Hegerl (2008) reviewed, in *Nature Geoscience*, the work on climate sensitivity at the time of AR4 and after.

Subtask 1.4) Application of detection and attribution results to provide objective measures of climate model performance and reliability (Richard Smith /Peter Stott)

A publication discussing the relationship between climate model performance in 20th century simulations and climate sensitivity has been published in a nature discussion forum (Forster et al., 2007). Furthermore, Smith et al. (2009) investigates the uncertainty in climate models applying a hierarchal Bayesian model in order to estimate probability distributions of the signal of temperature change at regional scales making use of multi-model ensembles. The approach accounts for models' possible systematic biases. It also accounts for differential precision in simulating current average temperature over the region of interest. This is estimated either as originating from each model's overall (over all regions of the globe) differential skills, or in the overall (over all models) challenge posed by a specific region to the simulation of its climate, or as the effect of an interaction between model- and region-specific precisions. The result is a probabilistic characterization of many parameters of interest, among which the main foci are regional signals of temperature changes. Santer et al. (2009) explore the implications of model quality differences for detection and attribution results, and show that the identification of anthropogenic climate change in observed water vapor fields is relatively insensitive to

such quality differences. Easterling and Wehner (2009) and Santer et al. (2011) address the issue of why there has been relatively muted warming since 1998, and show that because of the large influence of interannual variability on decadal trends, current models are capable of simulating such “muted warming” behavior even under anthropogenic forcing.

Subtask 1.5) Review paper on activities in Task 1

A publication is in preparation by Myles Allen et al. However, the review paper by Stott et al. (2010) and Stone et al. (2009) also address large-scale climate change, Knutti et al. (2008) have reviewed the uncertainty in the transient response, Knutti and Hegerl (2008) have reviewed estimates of climate sensitivity, and Hegerl and Zwiers (2011) discussed the use of models in detection and attribution in a WIRES review paper. In addition, Zhang et al (2011) review the current status of research in indices of extremes in another WIRES review paper. In conclusion, a range of high-level review papers originated from the group, concluding this task.

Task 2) Quantify and reduce uncertainty in projections of impact-relevant climate variables including regional changes and extremes (David Karoly)

Subtask 2.1) Assess contribution of external influences on climate to changes in regional temperatures and precipitation, their extremes and impacts related to these changes.

Group members showed that many observed climate changes on regional and continental scales that are relevant for impacts have been influenced by anthropogenic forcing. Examples include Central European temperature and precipitation (Bhend et al., 2009), high latitude precipitation (Min et al., 2008a) and New Zealand temperatures (Dean and Stott, 2009). Hegerl et al. (2011, in work partly performed under the old grant) showed that European seasonal temperatures have been influenced by anthropogenic forcing even prior to the late 20th century. For some regions, the anthropogenic component is partly masked by changes in circulation. For example, a focussed study on the polar regions has found a component attributable to anthropogenic activities in both Arctic and Antarctic temperatures (Gillett et al., 2008), and Dean and Stott (2009) find a significant human influence on New Zealand temperatures once the effects of circulation variability are taken into account. The analysis of Dean and Stott (2009) highlights the effect of circulation variability which can act to either mask or accelerate human-induced warming in a particular region.

Group members also demonstrated a forced change in worldwide intense precipitation (Min et al., Nature, 2011), heat waves and temperature extremes and their impacts (Meehl et al., 2007; Christidis et al., 2009a; Christidis et al., 2011a; Zwiers et al., 2011; Stott et al., 2011) as well as their connection to precipitation (Kenyon and Hegerl, 2008, 2010; Zhang et al., 2008) and connections between regional changes in extreme temperature and the water cycle (Portmann et al., 2009). Group members also published a formal detection and attribution study linking human influence to observed reductions in Arctic sea-ice extent (Min et al., 2008b). Results indicate that anthropogenic changes are emerging in temperature extremes, although some aspects of changes, such as the lack of

increase in hot extremes in daily max temperatures appear unusual relative to model projections and correlate to wet regions, the publication speculates it might be associated with changes in biogenic aerosols.

Members have also been looking at how regional temperatures have differed from a world in which human activities had never affected the climate, often in collaboration with other members, and finding a detectable difference in average temperatures in most regions and in unusually warm hot seasons in extratropical regions (Stone et al., 2008, 2008a, near submission). The Oxford group estimated the anthropogenic contribution to risk in intense precipitation in the UK and finds a likely, although model dependent, contribution of greenhouse gas forcing to very intense autumn precipitation, but a robust anthropogenic contribution appears to be found in runoff (Pall et al., *Nature*, 2011). Results from such methods can be used to estimate contribution of anthropogenic climate change to damaging events (Allen et al., 2007). The group in Victoria also analyzed changes in climate associated with different vegetation classes (Dang et al., 2007).

An analysis by Jones et al, J. Geophys. Res. (2008) has examined hot summers throughout the Northern hemisphere and detected the dominant influence of human influence on almost every region, which has led to hot summers which were infrequent 20-40 years ago now being much more common. In conclusion, very many high level publications of group members individually and in collaboration have resulted from this task.

Subtask 2.2) Assess contribution of external influences on climate to changes in tropical and extra-tropical storminess and wave heights

The anthropogenic contribution to SST changes in cyclogenesis region has been estimated and found to be significant and robust to using hurricane season SSTs rather than annual SSTs, the greenhouse gas induced change can be separated from those caused by other forcings (Gillett et al., 2008; Santer et al., 2006). Also, group members participated in the CCSP report on changes in climate extremes (Karl, Meehl et al.) with a detailed section on changes in tropical cyclones. Furthermore, Knutson and collaborators have shown that climate models are beginning to be able to simulate hurricane changes and discuss observational estimates of changes in cyclone activity (Knutson et al. 2007, 2008; Vecchi and Knutson, 2008; Bender et al., 2010), and that some of the simulated changes indicate decreases in the frequency of cyclones under 21rst century conditions. Knutson led a WMO expert team review and assessment of tropical cyclones and climate change (Knutson et al. 2010) which concluded that it remains uncertain whether any changes in tropical cyclone metrics exceed the variability expected from natural causes. Zahn and Storch (2008) investigated changes in North Atlantic Polar lows and found Strong inter-annual variability, while frequency remains on a similar level (no systematic trend for North Atlantic Polar Lows), while Wang et al. showed that wave heights and storminess in Northern Oceans seem to show significant and detectable changes. For synoptic storms in the NE Atlantic, there was a strong increase in 1970-1990, but after 1995 a decline (following NAO).

Subtask 2.3) Assess the implications of observed climate and climate change for probabilistic future regional climate projections (Claudia Tebaldi / Doug Nychka, Myles Allen, Francis Zwiers)
A review on the use of multi-model ensemble simulations has been published (Tebaldi and Knutti, 2007), and a Bayesian approach to jointly estimate trends in current and future temperature and precipitation projections at regional scales has been developed and submitted for publication (Tebaldi and Sanso, 2008; Furrer et al., 2007). Several papers have addressed the questioin of how performance on present day climate relates to future projections (Jun et al., 2008a, b, Knutti et al. 2010, Knutti 2010. The key role of the IDAG group on the use of multimodel ensembles has been recognized by very high IDAG participation in a recent IPCC meeting on multimodel ensembles Reto Knutti has led the writing of the IPCC Good Practice Guidance Paper on Assessing and Combining Multi Model Climate Projections. The use of multi-model ensembles to arrive at probabilistic projections has been discussed in Smith et al. (2009), and the combination of a variety of methods to arrive at probabilistic projections has been published in Knutti et al., 2008. Hence, the group arguably plays a leading role in the topic of using multi-model ensembles in order to derive probabilistic projections.

Subtask 2.4): *Detection and Attribution of hydrological change in the western U.S.* (*Barnett / Santer*)
Attribution work has been performed on elements of W US hydrological cycle, including snowpack and hydrological variables shows that these show already anthropogenic changes, which has been published in high-impact journals (Barnett et al., 2008, 2009, Barnett and Pierce, 2008, 2009). Much of the changes can be explained by changes in regional temperature (Bonfils et al., 2008).

Subtask 2.5) Assess implications of past climate events for potential early warning systems for sudden climate change (*Phil Jones*)
Jones et al. (2006) show that a very rapid climate variation occurred in Europe during the period 1730 to 1745. Work on the use of the RAPID array to find an early warning signal for sudden transition in the AMOC is ongoing (e.g., Tett and Hegerl).

Subtask 2.6) Review paper on activities in Task 2
This task has been completed very successfully, with a review paper by Peter Stott and many group members in WIRES (Stott et al., 2010), which was very well received, being selected as part of a Climate Change Master Class edition of the journal. The effect of climate change on impacts has also been discussed by group members. Rosenzweig et al., 2007 showed that the changes in impacts correspond to changes expected with warming, a result that led to a discussion in the literature about methods (Zwiers and Hegerl, 2007) and to many IDAG group members being heavily involved in an IPCC guidance paper on detection and attribution that also addresses how to attribute impacts to a changing climate and to radiative forcing (Hegerl et al., 2010).

Stone et al. (2009) reviews methods for the attribution of changes in nonmeteorological quantities, such as hydrological and ecological measures, and of changes in the risk of extreme weather events to anthropogenic emissions. It suggests approaches for tackling these two problems.

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