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# Climate monitoring and attribution

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## 1. Introduction

Over recent years, the Met Office Hadley Centre has made substantial contributions to the evidence basis on climate change. Our global temperature analyses have formed a key part of the evidence underpinning the conclusion from the Fourth Assessment of Working Group I of the IPCC report that “Warming of the climate system is unequivocal”, and we have made important contributions to developing the understanding of past climate changes that have led successive IPCC Assessment reports to strengthen their conclusions on the role of human influence in observed changes.

While, as we concluded in a recent review paper (Stott et al, 2010), the mounting scientific evidence indicates that “there is an increasingly remote possibility that climate is dominated by natural rather than anthropogenic factors”, over the last year there has been a loss of confidence by the public in the scientific basis of climate change. Since the leak of emails from UEA we have played a leading role in helping to rebuild trust in climate science. At the same time the scientific agenda has moved on from determining whether climate is changing to improving our understanding of the rate and manner of change, with a particular emphasis on variability and changes in regional climate and extremes. There are increasing demands for continuous monitoring and attribution of the state of climate to put recent weather events into a longer term context of climate variability and change. As a result the Climate Monitoring and Attribution group has developed its scientific strategy to meet this changing research agenda.

We aim to develop datasets that adequately represent multi-annual and multi-decadal variability and that incorporate quantified uncertainties, and to develop near-real time operational attribution systems that can be used to provide more reliable and robust information following such events as the Moscow heatwave and Pakistan floods of summer 2010. Highlights during the last year have included considerable progress in our development of analyses of marine climate - particularly of ocean temperatures, both at and below the surface - and in our activities delivering updated climate analyses during an extended period of intense media scrutiny. Our engagement in two major meetings on surface temperature datasets and on attribution have helped developed the international research agenda on monitoring and attribution.

## 2. Met Office response to raised public scepticism in climate science following leaked UEA emails

The leak of emails in November 2009, prompted questions in the media about the integrity of the HadCRUT global temperature dataset, a blended combination of the HadSST record of sea surface temperatures and the crutem land near-surface temperature dataset developed at UEA, which we update monthly on our climate dataset website, www.hadobs.org. We responded to concerns about transparency by publicly releasing original monthly mean station data, accompanied by corresponding analyses of global, hemispheric and regional temperatures, and corresponding perl code to generate the global timeseries. Because in the interests of comprehensiveness, many station data going into crutem were not publicly available, and despite the Met Office having written to all National Meteorological Services (NMS) requesting permission to release their station data, explicit permissions from many countries have not been forthcoming. Nevertheless, in our release we showed that there are minimal differences between the original HadCRUT global mean analyses (including all data, both publicly available and not) and analyses including only publicly released station data and that independently derived analyses agree in showing robust global warming signals.

With much greater worldwide attention being paid to the evidence basis for climate, at the end of 2009 we produced a new analysis showing that the first decade of the 21st century was significantly warmer than any other decade in the instrumental record (back to 1850) building on our pioneering work (Brohan et al, 2006) to develop comprehensive estimates of observational uncertainties.

We also played a substantial role in producing the BAMS 2009 state of the climate report, particularly the global chapter (Willett et al, 2010a). We provided a striking innovation this year, which was an analysis of 11 climate indicators (air temperature over land, SSTs, marine air temperature, sea level, ocean heat content, atmospheric humidity, tropospheric temperatures, Arctic sea ice, glacier mass balance, NH Spring snow cover and stratospheric temperatures) which included multiple datasets from different centres (55 in all; Kennedy et al, 2010).

In addition a review of the latest science on attribution was published in March (Stott et al, 2010), providing an update on developments since the IPCC 4th Assessment report of 2007. This paper showed that the fingerprints of human induced climate change could be detected in a wide variety of aspects of the climate system, including not just temperatures at the surface but also free atmosphere temperatures, ocean warming, precipitation, humidity and snow and ice cover. The review showed that at the largest scales, many aspects of climate were changing in a manner consistent with the predicted effects of warming.

All these analyses attracted considerable international media interest. By presenting new scientific evidence in this way, as it became available, rather than defensively responding to allegations, we were able to demonstrate the objectivity and authority of climate science at the Met Office.

## 3. Progress in development of marine datasets

***Ocean temperatures and ice cover at the surface***

We have made improved estimates of uncertainties and biases in historical sea-surface temperature measurements and produced a new version of the Hadley Centre SST data set HadSST3. The new uncertainty estimates are larger than in previous analyses. Biases arise because the methods used to measure sea-surface temperatures have changed over time. This is the first time that an attempt has been made to estimate and adjust for biases in the whole in situ SST record. The bias adjustments change the character of the observed evolution of 20th century climate and reduce the size of the discontinuity in 1945 highlighted in a paper in Nature by Thompson et al. in 2008. The uncertainty in the bias adjustments is comparable to, or greater, than the other uncertainties during the period 1940 to 2006, suggesting that a simple bracketing of all previous analyses of sea-surface temperature change significantly underestimates the inherent uncertainties.

The data set will be presented as a set of ~100 interchangeable realisations which together span the range of uncertainty. The aim is to make it much easier for users to incorporate our estimates of observational uncertainties in their analyses. e.g. in detection and attribution studies. HadSST3 will be blended with an update of the CRUTEM land temperature data set to provide an improved estimate of global temperature: HadCRUT4.

The analysis currently stops in 2006 because after this date, the call signs of ships were no longer reported with their meteorological observations for security and commercial reasons. Call signs were used to connect the observations to additional information about the ships in our database in order to estimate the biases and uncertainties. In order to bring the data set up to date we will have to find some way around this problem, which might result in a lower quality estimate of global and regional averages than would be available if the information were openly reported.

HadSST3 will be appropriate for many climate applications, but some e.g. reanalyses, like the new ERA-CLIM project, and atmosphere-only climate simulations, need information about sea-surface temperature everywhere, even where we have no observations. We are now developing HadISST2, in which complete global sea-surface temperature fields have been reconstructed since

1850 by including satellite measurements and using a statistical technique, which exploits connections between sea-surface temperature anomalies in different locations. The technique we have used is a significant advance on that used in the current, extensively used, HadISST1. As for HadSST3, we will produce a number of interchangeable realisations, spanning the range of uncertainty in the analysis allowing ensembles of atmospheric simulations or Reanalyses to be produced.

In addition to sea-surface temperature, HadISST includes information on sea ice cover. Our sea ice analysis for HadISST2 has been completely reassessed based on new data sources and new approaches for homogenisation of the record. In particular, for the first time, we will include *in situ* observations of Southern Ocean ice edge for the late-1920s to 1950s, which we are turning into estimates of ice extent.

***Ocean temperatures below the surface***

Parallel work has been undertaken on our analyses of ocean temperature at depth. These are used *inter alia* to provide a basis from which seasonal-to-decadal climate predictions are made and to monitor changes in the heat content of the ocean. We have implemented a range of adjustments for biases in ocean temperature measurements in our database, EN3, to provide an ensemble of ocean temperature data sets. This ensemble was used recently in a Nature paper by Lyman et al (2010) to help to quantify uncertainties in records of ocean heat content.

We aim to bring our surface and sub-surface ocean temperature databases together to provide an integrated picture of ocean temperature variability and change, free from the artificial discontinuities which arise from mixing measurements taken by varied instrumentation.

## 3. Development of datasets for monitoring and attributing extremes

***Surface temperature workshop 7-9 September, 2010***

Following a UK Met Office proposal to the WMO Commission on Climatology for a new international effort to develop temperature datasets at daily and sub-daily timescales with sufficient quality control and homogenization as well as meeting increasingly rigorous demands for traceability and transparency, an international workshop on surface temperature was held at the Met Office from 7-9 September 2010. Climate scientists, metrologists, statisticians, software engineers and economists were present. The meeting agreed that there should be a single global databank for land meteorological data, like already exists for marine data (ICOADS (http://icoads.noaa.gov/). From this databank there should be multiple data products created by independent teams to meet different user needs and to investigate structural uncertainty in dataset construction. The meeting also discussed the requirement for an agreed consistent benchmarking and assessment procedure. It was agreed that a key requirement in creating a suite of temperature products fit for the 21st Century was strong adherence to an ideal of openness and transparency. However it was also recognized that current data policy in many countries restricts free access to much data and that many barriers need to be overcome in obtaining such data. Greater effort will be required ascertaining provenance of data with a consequent substantial additional overhead in resourcing. The meeting discussed the governance of such an initiative and agreed that an ad-hoc structure should be set up until the initiative can be adopted under WMO structures.

***Quality control***

An unglamorous but essential task in the construction of datasets for climate monitoring is appropriate quality control. Despite advances in automation, manual quality control cannot be eliminated. Institutes can be inter-dependent; for example NOAA NCDC depend for the integrity of their land temperature datasets on manual checking carried out at the Met Office. The two part-time members of Met Office staff who carried out manual quality control on UK and global data will both soon have retired and consideration will need to be given as to how to resource any replacement.

***Development of temperature and humidity dataset***
We have continued our research into the quality-control and homogenization of hourly temperature and humidity data for use in analysis of extremes. The global humidity dataset, HadCRUH, has contributed to our understanding of trends and variability in atmospheric humidity and suggests that there has been a reduction in relative humidity in recent years over some land areas (Willett et al, 2010b; Simmons, 2010).

***Engagement in European activities***
The surface temperature workshop endorsed the importance of building on existing efforts to improve observational information for climate services. We play an active role in a number of important ongoing initiatives. These include the European Climate Assessment and Dataset (ECA&D) which prepares information on changes in weather and climate extremes to which the National Climate Information Centre (NCIC, part of the Climate Monitoring and Attribution group) supplies UK temperature and rainfall for 100 sites and pressure, humidity, snow depth, and sunshine for 22 sites (http://ecam.knmi.nl). We form part of EUMETGRID whose aim is to establish European gridded datasets with high spatial (preferably 1x1 km) and temporal (at least daily) resolutions. And we are partners in EURO4M, an FP7 project to develop climate monitoring services for Europe. The Met Office is contributing regional reanalyses, data rescue through the Atmospheric Circulation Reconstructions over the Earth (ACRE) a project led from the Met Office, and to the development of Climate Information Bulletins to monitor extreme events.

## 4. Attribution of climate-related events

The recent extreme weather around the world this summer, including the Moscow heatwave and the Pakistan floods, and the particularly cold and snowy winters in the UK and parts of the US, have provided another pertinent reminder of the demand for reliable information that will put such events into the context of longer term climate variability and change. Local communities and stakeholders need to know whether they need to adapt to an increasing frequency of such extreme weather events in future. Poor adaptation decisions and damage to the credibility of climate science could result from misattribution of such events, a common problem at present, when reliable and robust information is lacking in the immediate aftermath of such events. Therefore the Met Office, in collaboration with academic partners in the UK and internationally, is in the process of develop operational systems that would calculate the changed risk of such events attributable to particular causes. We have shown that it is possible to apply the attributable risk concept to the extreme European summer temperatures of 2003 (Stott et al, 2004), where we concluded that human influence had very likely more than doubled the probability of such an event. We are now working to extend this concept to a wider variety of extreme weather events. For events such as the Pakistan floods considerable further research will be required in order to determine the relative roles of circulation changes and thermodynamic changes on the changing probability of extreme rainfall events and the links to flooding and other impacts. For other events there is considerable scope to provide better information in the shorter term. A key requirement is to quantify the reliability of assessments so that we can provide robust information where we have high confidence in the results and provide suitable advice when current robust information is lacking.

***International Group on Attribution of Climate-related Events (ACE)***
The first full meeting of the International Group on Attribution of Climate-related Events (ACE) was held in Colorado on 17-18 August, 2010 with contributors from the Met Office, NOAA, NCAR, the University of Cape Town, as well as communications professionals and experts on impacts. The meeting agreed that a comprehensive and authoritative attribution activity will demand the enhanced collaboration and coordination of numerous partners, especially in the context of providing decision-imperative information on plausible causes for evolving climate conditions that is

regularly updated. The underpinning of a strong and sustained research enterprise to provide the best possible operational systems for attribution was emphasized. The workshop agreed that an effective attribution service must be timely if it is to be relevant to decision making, and to fill the void that could be easily filled by speculations. There was also concurrence that an attribution service activity must be scientifically sound and authoritative if the public and decision makers are to correctly understand the causes of extreme climate events, draw the proper inference from such events, and appreciate the context of their occurrence in a changing climate.

***Met Office research***

We have enhanced our capability to provide updated information on regional temperatures shortly following the season in question. Our new analysis (Christidis et al, 2010) uses the two coupled climate models which have multi-initial condition member ensembles with different forcing combinations (to distinguish between the current world which is influenced by both anthropogenic and natural forcings, and the world that might have been had there been only natural forcings from solar variability and explosive volcanic eruptions) that have been run up to and beyond the present day; HadGEM1 and MIROC. (We have now repeated such experiments with HadGEM2-ES and a call has gone out for other climate modeling centres to do likewise in time for AR5; at present the standard experimental design is to stop at 2005). This study finds that there have been large shifts in European seasonal temperature distributions between the current world and the world that might have been. It is extremely likely (probability greater than 95%) that the probability of recent warm seasons has more than doubled under the influence of human activity in spring and autumn, while for summer it is extremely likely that the probability has at least quadrupled. With this system we are in a position to provide assessments of the likely change in probability attributable to human influence of exceeding particular European temperature thresholds as soon as observations become available. The approach is being extended to sub-continental scale regions worldwide.

In parallel to coupled modelling approaches we are developing experimental designs that use atmosphere only models forced by observed SSTs to generate statistics of the probability of exceeding extreme thresholds and compare with alternative SSTs with the anthropogenic contribution to those SSTs subtracted. Recent work has applied this approach to the autumn 2000 UK flooding event (Pall et al, 2010). The model results indicate that $20^{th}$ century anthropogenic greenhouse gas emissions significantly (at the 10% level) increased England and Wales flood risk in autumn 2000. The results come from a robust increase in atmospheric moisture, which translate into a significantly increased flood risk.

Among the issues that need to be addressed following this study are improved strategies for validating and calibrating such model ensembles and an optimisation of ensembles size. An outcome of the ACE meeting in Colorado was to initiate a coordinated set of model experiments to evaluate model uncertainty and to compare with observational statistics. We will be contributing 50 member ensembles of HadGAM3 (25 member current world and 25 member world that might have been) for a range of years. By using the same model as used for seasonal forecasting we aim to benefit from validation undertaken as part of seasonal forecasting. Once such a system becomes operational we would envisage running such ensembles every month or season with the most recently updated SSTs.

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