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EUropean CLimate and weather Events: Interpretation and Attribution

Deliverable D8.1

A HadGEM3-A based operational attribution system

Deliverable Title	*A HadGEM3-A based operational attribution system*	
Brief Description	*A prototype attribution system based on ensembles generated with the HadGEM3-A model has been developed by upgrading the model to high resolution. The upgrade has led to a state-of-the-art system that simulates the global climate on 85 vertical levels and resolves horizontal spatial scales as small as ~60km. Multi-decadal simulations were produced to facilitate a detailed evaluation of the system and the delivery of the first attribution studies. The system is now ready for integration into an operational framework.*	
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Contributors	*Andrew Ciavarella, Met Office* *Nikolaos Christidis, Met Office* *Peter A Stott, Met Office*	
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0.1	15/12/2015	AC	First draft
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Table of Contents

List of Figures

1. Executive Summary

The Met Office operational system for the attribution of extreme weather and climate events is based on the global atmospheric component of the Unified Model at a resolution already used operationally for seasonal forecasting. By running pairs of large ensemble experiments modelling a recent period both with and without anthropogenic forcings the system can be used to determine the changing likelihood of extreme events under climate change. By providing the atmospheric model with observed sea surface temperature and sea ice boundary conditions as well as initialisation of the atmospheric state the system can be used to ascertain the likelihood of events unfolding under the same conditions as those in which a real event occurred in the recent past.

The system described here is an upgrade of the previously existing Met Office system[1] based on the Hadley Centre climate model HadGEM3-A to higher resolution and to include an improved forcings set consistent with the CMIP5[2] generation models. Increased resolution through finer horizontal grid sizes as well as more vertical levels for a better resolved stratosphere improves modelling of synoptic scale features that should contribute to improved representation of extreme events. The system also benefits from running the latest operational dynamical core and land-surface scheme. Model validation experiments have been produced. Apart from the experiment with all historical forcings, a second experiment with natural forcings only has been carried out, so that attribution analyses can also be performed. As part of the prototype attribution service EUCLEIA aims to deliver, the new system will be utilised within an operational setup to provide regular attribution assessments.

2. Project Objectives

With this deliverable, the project has contributed to the achievement of the following objectives (DOW, Section B1.1):

No.	Objective	Yes	No
1	Derive the requirements that targeted user groups (including regional stakeholders, re-insurance Companies, general public/media) have from attribution products and demonstrate the value to these users of the attribution products developed under EUCLEIA.		×
2	Develop experimental designs and clear ways of framing attribution studies in such a way that attribution products provide a fair reflection of current evidence on attributable risk.	×	
3	Develop the methodology for representing the level of confidence in attribution results so that attribution products can be trusted to inform decision making.		×

4	Demonstrate the utility of the attribution system on a set of test cases of European weather extremes.	×	
5	Produce traceable and consistent attribution assessments on European climate and weather extremes on a range of timescales; on a fast-track basis in the immediate aftermath of extreme events, on a seasonal basis to our stakeholder groups, and annually to the BAMS attribution supplement.	×	

3. Detailed Report

3.1 Upgraded HadGEM3-A based system: model description, forcing and ensemble generation

The difference between the two sets of experiments, one with both natural and anthropogenic external climate forcings present (ALL) and the other with only natural (NAT), arises through the prescription of lower boundary conditions, green house gas (GHG) and ozone concentrations, aerosol emissions and land use. The core atmospheric model, land model, initial conditions and stochastic ensemble generation are identical.

Scientific configurations of Met Office global coupled and atmospheric models are described by their Global Coupled (GC) and Global Atmospheric (GA) number, which can encompass many Unified Model (UM) code versions. The new system was developed using the GA6 atmospheric science package at code version UM8.5. GC2 and GA6 science are currently operational across Met Office NWP and climate systems. A detailed description of the GA6 atmosphere is in preparation but the associated coupled model description is available[3] as well as that for recent versions of the atmosphere[4].

Two significant upgrades to the previous HadGEM3-A based system are to the non-hydrostatic dynamical core of the model and the resolution. GA6 uses the ENDGame dynamical core[5] while the previous version of our model used New Dynamics[6], which also brings notable improvements in numerical stability. Resolution has increased from N96 L38 to N216 L85. This refers to a horizontal latitude/longitude grid that is 2N cells East-West by 1.5N cells North-South where N = 216, i.e. 432 by 324 cells, 0.83˚×0.56˚ angular resolution equivalent to around 60km at mid-latitudes. There are 85 vertical levels: 50 tropospheric and 35 stratospheric.

The land surface and hydrology schemes are also upgraded from the previous system, which used the MOSES-II model, to JULES (Joint UK Land Environment Simulator[7]), a community land surface model. This handles fluxes of heat, moisture and gases between the atmosphere and land, surface hydrology as well as deep soil processes through 4 sub-surface layers. The land surface is described by 9 “tile” types given as fractions of each grid cell: Broad leaf trees, Needle leaf trees, C3 (temperate) grasses, C4 (tropical) grasses, Shrubs, Urban, Inland water, Bare soil and Ice.

Horizontal boundary conditions at the bottom of the atmosphere are given by series of Sea Surface Temperatures (SST) and Sea Ice (SIC) fields. The ALL experiments takes these from observed values (HadISST) while for the NAT experiments an estimate of the change due to anthropogenic influence is removed from the observations[1]. These are prescribed as monthly data using the AMIPII method[8], involving pre-processing to avoid reduction of variance in monthly and seasonal means that result when the model interpolates to daily values at run time.

Well-mixed GHG concentrations are prescribed as series of annual values obtained from the RCP Scenario Data Group[9] which are historical values up to 2005 and following the RCP4.5 scenario[10] beyond 2005. Five gases are prescribed: CO_2, CH_4, NO_x, and two sets of fluorocarbon equivalents, CFC12 equivalent and HFC134-A equivalents. Estimates of these concentrations during the historical period have not changed from those supplied to the original HadGEM3-A system.

Aerosol emissions, handled by the CLASSIC scheme, are prescribed via UM ancillary files as CMIP5 recommended monthly values. The list of aerosol types and specific radiative effects included within the model remain unchanged from the previous system but the data sets have been updated. Anthropogenic precursor gases and aerosol emissions of the following types are included, with the indicated radiative effects (in short wave (SW) and long wave (LW) radiation) and references for the source data:

1. Sulphates: high and low level SO2 + surface dimethyl sulphide[11]

   Direct (SW + LW) + 1st (SW + LW) and 2nd indirect radiative effects

2. Soot[12]

   Direct (SW + LW) radiative effects

3. Organic Carbon Fossil Fuels (OCFF)[12]

   Direct (SW + LW) + 1st indirect (SW + LW) and 2nd indirect radiative effects

4. Biomass[13]

   Direct (SW + LW) + 1st (SW and/or LW) and 2nd indirect radiative effects

Additionally, mineral dust and sea salt are modelled interactively at run time while biogenic aerosols are included via a 12-month climatology.

Ozone[14] is prescribed as monthly 2-dimensional fields of zonal mean values across the 85 model levels. The values are historical up to 2005 and follow RCP4.5 thereafter.

Land use forcing is prescribed once per decade as annual fields of tile type fractions described above. The model interpolates in time between these fields and subjects five of them (the vegetation "functional types") to monthly modulation within JULES. This forcing is much improved from the data supplied to the previous system. The source is the ISAM-HYDE dataset[15], which is the HYDE3.1 dataset[16] harmonized with satellite-derived (MODIS) estimates.

The ISAM-HYDE source data consists of fractions of 28 land surface types. Prior to run time these are mapped via 18 IGBP types to the 9 MOSES-II types used by the JULES model using a modified routine produced by Margriet Groenedijk. The values prescribed at 2020 are a repeat of those at 2010 so (annually averaged) land use forcing is constant between these dates.

Natural forcings due to solar variability and aerosols from volcanic activity are included via branch modifications to the UM code itself, feeding times series data to the radiation scheme. Total solar irradiance is partitioned into 6 short-wave spectral bands and supplied as monthly global mean values. The data[17] is that used to force the HadGEM2-ES CMIP5 historical simulations. Volcanic stratospheric aerosol optical depth is supplied as monthly mean values for 4 equal area latitudinal bands and the data[18] is also that supplied to the HadGEM2-ES CMIP5 historical simulations.

Stochastic physics ensembles are generated through the simultaneous operation of two schemes, Random Parameters (RP) and Stochastic Kinetic Energy Backscatter II (SKEB II), originally developed for and still used by the Met Office Global and Regional Ensemble Prediction System (MOGREPS). The schemes are designed to represent model uncertainty and are used in our system to generate ensembles of atmospheric states reasonably obtainable under given forcing conditions with likelihood equal to the deterministic solution.

RP varies the values of a set of parameters mainly related to parameterised convection within some range every 3 hours throughout the run such that we avoid introducing a bias into the climate of a member with respect to the best estimate values. SKEB II estimates numerical dissipation of kinetic energy and reintroduces this back into the mean flow. The random number seeding of both stochastic schemes is controlled by the initial choice of single integer parameter uniquely defining an ensemble member.

Indexing of ensemble members follows the CMIP5 syntax[19] of "r", "i" and "p" numbers. Stochastic physics at the Met Office has previously been disseminated as a form of "perturbed physics" and as such the indexing of the ensemble members with this system is "r1i1p*x*" where $x = 1, ..., n$, with n being the size of the ensemble.

3.2 Model validation experiments

In order to validate the model a pair of 15 member ensemble simulations (ALL and NAT) were produced spanning the period 1960 – 2013 (54 complete years). From these we may assess forecast reliability of the modelled event statistics.

All 30 runs shared identical initialisation of the atmospheric state from ERA-40 reanalysis at 0000Z on 1st December 1959, giving the experimental period one month's spin-down. We were able to secure the use of 60 priority nodes on the Met Office IBM supercomputer for much of the duration of the experiments, which were completed between July 2014 and May 2015.

A set of diagnostic outputs[20] pre-agreed with EUCLEIA project partners was stored to the MASS archive with full atmospheric dumps also archived once per model year. Validation diagnostics were output as a mixture of monthly, daily, 6 hourly and 3 hourly mean values at a mixture of different levels. By working closely with the CR IT Applications team all diagnostics were subsequently converted from pp to NetCDF4 format and transferred to the JASMIN collaboration space[21] and BADC. There is a total of 36T of validation data across both experiments.

At run time the simulations were monitored by use of procedures that extracted and plotted monthly mean fields of near surface air temperature, precipitation and total soil moisture for the globe and for the northern and southern hemispheres.

3.3 Operational attribution

Attribution experiments with the earlier version of the HadGEM3-A system had been carried out on an annual basis to investigate specific weather and climate extremes in each year and contribute studies to the special supplement of BAMS on extreme events[22]. With the new upgraded system EUCLEIA aims to move from a research to an operational framework that will enable a systematic examination of different types of extremes, in different locations and on a regular basis. Such an operational system would provide a wealth of information to meet the needs of different stakeholder groups. Moreover, this information would become available in a timely manner. For example, a system that operates on a seasonal cycle (Figure 1) will be able to provide formal attribution assessments of interesting (e.g. high-impact) events within about 3 months after they occur. As the system employs a well-established, peer-reviewed methodology and is built on a model that has been extensively evaluated, it is expected to provide reliable quantitative estimates of the anthropogenic influence on extremes, which are in high demand in the aftermath of catastrophic events. It is envisaged that by the end of EUCLEIA a prototype system similar to the one illustrated in Figure 1 will be in place and will become a key component of a further developing climate service for Europe.

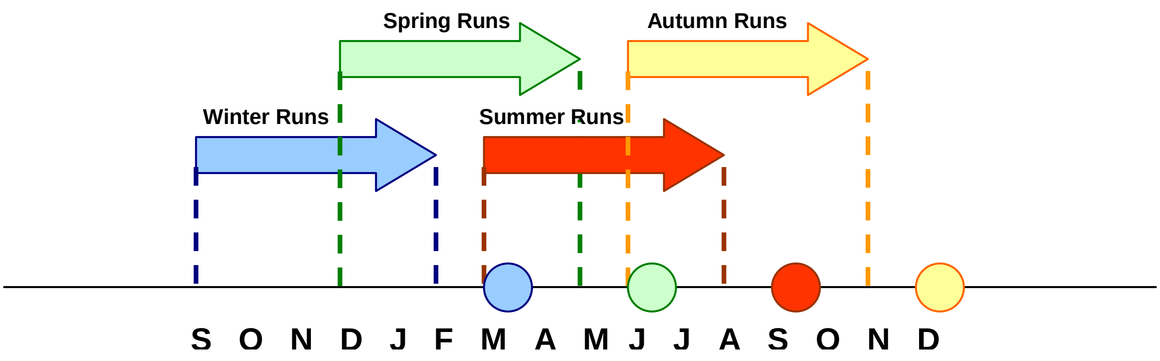

Figure 1. An illustration of operational attribution runs for each season in the year. The arrows represent the period covered by the runs and the circles mark the point in real time when the runs will be carried out. The seasons are with reference to the Northern Hemisphere

3.4 References

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4. Lessons Learnt

Experience with the older version of the attribution system has been valuable in the upgrade of the model and the experimental setup. Dissemination of the model output among partners was found to be efficient via JASMIN, though the transfer of the data was relatively slow. Main challenges in the upgrade of the system were the replacement of the Met Office supercomputer and changes in the model's user interface. These changes, however, are expected to improve the efficiency of the experimental work in the long run.

5. Links Built

Links with WP3 & WP4: The new system provides attribution information communicated to stakeholders. Stakeholder requirements also determine what information is more useful.

Links with WP5: Research carried out by WP5 guides the setup and design of attribution experiments with the new system.

Links with WP6: Multi-decadal simulations produced with the new system are used by WP6 for model evaluation.

Links with WP7: The new attribution system provides simulations for case studies of different extremes carried out by WP7.