Barcelona Supercomputing Center
Centro Nacional de Supercomputación

RED ESPAÑOLA DE SUPERCOMPUTACIÓN

AECT-2016-2-0018 Extreme climate event attribution using dynamical seasonal predictions

1. General Information

Activity Id
AECT-2016-2-0018

a) Activity Title
Extreme climate event attribution using dynamical seasonal predictions

b) Area
Astronomy, Space and Earth Sciences

2. Research Project Description

a) Is this a Test Activity?
No

b) Is this a Long Term Activity that will extend over several application periods?
Yes

c) Brief description of the Project
Has climate change been responsible for single past extreme events? This project proposes a novel framework to address this question and an application to the extreme El Niño event of 2015. This activity is tightly linked to the European FP7 project EUCLEIA and to the European Space Agency (ESA) Living Planet Fellowship VERITAS-CCI project.

EUCLEIA (http://eucleia.eu/), a project funded by the European Commission under the 7th framework Programme examines to which degree past extreme climate events (e.g. heat waves or flooding) can be attributed to climate change. How human activity has favoured past extreme event is of high public and private interest, yet formal concepts to answer this question have been lacking in the past. EUCLEIA aims at setting for the first time standards for this raising discipline and is going to present a first prototype for an operational attribution system. Event attribution will as such become an important activity of climate services in future. The Project started on 1st of January 2014 and lasts for 3 years.

VERITAS-CCI is a Fellowship project granted by the European Space Agency (ESA) Climate Change Initiative (CCI, http://cci.esa.int). The project explores new high-quality high-resolution satellite derived

Earth observations for verification of seasonal-to-decadal predictions. These satellite remote sensed (SRS) observations have already played an important role in weather prediction, yet only a moderate one for the evaluation of climate models. Large potential lies thus in exploiting these datasets in verification of climate predictions. Within VERITAS a multitude of climate datasets are used to verify event attribution studies. The project started on 1st of February 2015 and lasts for 2 years.

This project involves extensive modelling using the EC-Earth3 climate model to contribute to both projects. It will in a greater context also contribute to the Grand Challenge on Understanding and Predicting Weather Climate Extremes which has been defined by the World Climate Research Programme. If the approach proves to be successful, it could potentially become an operational standard for climate centres worldwide.

d) Grant References

FP7/2007-2013 607085

e) Brief description of the Project (if this Activity takes place in the context of a Technology or Industrial Project)

f) Specific Activity proposed

Extreme climate events can cause large socio-economical damages as experienced from long-lasting droughts or floods. The vast impact of these events initiates repeatedly a public discussion about the role climate change has played on the occurrence of such an event. So far, a long-standing argument prevailed that an event can not uniquely be attributed to human activity, yet recently adopted approaches demonstrate that one can estimate how climate change has altered the probability that an extreme event occurs (Allen et al., 2003). Estimating the potentially changed probability is important to advance the public perception of how climate change is already affecting our environment.

Conducting an event attribution is a demanding scientific and computational challenge as it requires to disentangle natural drivers from climate change within a complex rare phenomena. A common approach and currently the most adopted strategy is to retrospectively simulate the extreme climate event using ensembles of climate simulations (Pall et al., 2011). In order to disentangle natural causes and those induced by human activity two ensembles are carried out: an ensemble of simulations in a world as we observe it and a composite ensemble in a world that might have been if no climate change would have occurred.

By having a simulated climate in a world with and without climate change, we can compare the probability that the event occurs in the two different conditions. If the event is more likely to occur in the simulations with climate change, we can express a fraction of attributable risk (FAR) by computing the fraction of forecasted probabilities FAR=1-PNAT/PCC in the natural-only world (PNAT) and the world with climate change (PCC). A value of FAR=0.5 would express that the event has become twice as likely under the given circumstances due to human influence. Such a conclusion is a powerful expression of the impact of climate change that can be publicly perceived with little prior knowledge and that can be used in risk models of public sectors dealing with the potential impacts.

Model simulations describing the 'no climate change world' comprise currently either global coupled climate simulations with pre-industrial greenhouse gases (Lewis et al, 2013; King et al., 2014) or atmosphere-only simulations forced by detrended observed sea-surface temperatures (SSTs) (Pall et al., 2011). The latter approach is adopted more frequently since it allows to attribute an event occurred in a specific year under observed conditions of SSTs, which is closer to the notion of event attribution.

However, the former approach has the advantage of considering ocean-atmosphere interactions which are known to be important drivers of extreme events.

This project proposes the development and the proof of the concept of a new event attribution approach that combines the advantages of both approaches. This new approach relies on the framework of coupled seasonal prediction systems (Doblas-Reyes et al., 2013). Instead of prescribing the observed conditions of the ocean surface, the information of the full climate system (deep ocean, atmosphere, land, cryosphere) is provided at the beginning of the simulation. However, there has been no protocol proposed up-to-date to perform a prediction in world without climate change in a coupled (dynamical) prediction as there is no technique available yet to remove the effect of climate change in the full observed coupled system.

We propose for this purpose to generate a world without climate change by simulating the past century with pre-industrial atmosphericconditions such that no change in the external forcings of climate takes place. In order to represent the observed climate variability, the model is relaxed (constrained) to the observed atmospheric circulation that has been recorded for the last century. The atmospheric circulation is the main driver of the ocean circulation (Deser et al., 2010) which would hence adapt to its forcing. However, the temperatures would no longer increase (note that the internal variability is thereafter mainly determined by the ocean state while the information from the atmospheric conditions are lost within a few weeks). Also no a-posteriori correction of the observed sea surface temperatures or the cryosphere are necessary in contrast to e.g. Pall et al., (2011). Based on this retrospective simulation and a simulation where the anthropogenic contribution to the atmospheric composition is allowed to increase, we can perform an event attribution using a coupled ocean-atmosphere system.

The new dynamical event attribution system will be applied to the extreme El Niño event which occurred in 2015 as a case study of theconcept. The El Niño has reached last year similar levels as the historic event in 1997/98 and strongly impacted climatic conditions world-wide, leading to the strongest coral bleaching event ever observed. Strong El Niño conditions have further recently been shown to increase as a consequence ofglobal warming (Cai et al., 2014). The strong El Niño event which occurred last year might hence have already been favored by ongoing warming conditions. None of the event attributions systems currently developed would be able to address this question taking into account the conditions that prevailed in the year 2015. This approach proposed here has never been tested before and could become, if successful, an operational standard for climate centres worldwide.

The proposed project will cover two consecutive phases.

Phase 1: Proof of the concept

The first phase will provide the proof of the concept that the observed interannual variability of the climate system can be reproduced by relaxing a coupled climate model to the observed atmospheric circulation. The global climate model EC-Earth3 (Hazeleger et al., 2011) will be used for the entire activity. This has not been demonstrated so far and therefore requires a test-bed using different configurations. The proposal is to generate a control model world using fixed conditions of the present day climate by simulating 60 years of repetitively the conditions observed during the year 2000. After omitting the first 30 years for spin-up, ten simulations using different initial conditions chosen a few years apart in this control will relax the atmospheric flow to a different section of the control simulation using different strength of the relaxation time-scale. These set of simulations will allow to investigate if the rest of the climate system, particularly the surface ocean flow, adapts to the one in the control simulation and which is the optimal strength of the relaxation. The 10 relaxations simulations will run in parallel with a high amount of cores (~500 cores) such that the experiments can successfully finish within the first period. The experiments will run using jobs covering one year for the control simulation

(60 jobs) and the jobs of four months (because of memory constraints) for the relaxation simulation (900 jobs). The model runs for 2 hours and 3 hours respectively for one year for the control and relaxation runs which corresponds to 1'000 and and 1'500 CPUhs. For a total number of 360 years, this phase 1 will require a total of 510'000 CPU-hours plus a buffer of 5% in case of crash/bugs.

Phase 2: Application to El Niño 2015

If the approach proves to be successful, it will be applied to the case study of the extreme El Niño 2015. This will consist in simulating two historical simulations of the past century (1900 until present): one with observed changes in the climate system and one without human intervention. Both simulations will be relaxed to observed atmospheric circulation from the newly released ERA-20C re-analysis (Stickler et al., 2014) such that they share the observed interannual variability of the past century. The second phase will consist of a case study to test the approach. Using the two historical simulations as initial conditions, seasonal predictions (4 month-long simulations) with large ensemble size (150 members) will simulate the El Niño of 2015 under observed and no-climate change conditions. A large ensemble size is crucial in order to capture accurately rare events (tails of the distribution). The seasonal predictions will allow to evaluate whether and if so, to which extent, human intervention has contributed to the development of the strong El Niño and its impacts. The second phase will require 200 model years in relaxation mode for the historical simulations (600 jobs) and total of 200 model years for the El Niño prediction (300 ensemble members for each of the two experiments simulating 4 months). The prediction simulations require the same amount of resources as the control simulations (1,000 CPUhs for one year). The total cost of the second phase will amount to 500'000 CPU-hours plus a buffer of 5% in case of crash/bugs.

Allen, M., 2003: Liability for climate change. Nature, 421, 891-892.
Deser, C., Alexander M.A., Xie S-P., Phillips A. S. 2010: Sea Surface Temperature Variability: Patterns and Mechanisms. Annual Review of Marine Science. 2:115-143.
Doblas-Reyes FJ, García-Serrano J, Lienert F, et al., 2013: Seasonal climate predictability and forecasting: Status and prospects. Wiley Interdiscip Rev Clim Chang 4:245268.
Hazeleger W, Wang X, Severijns C, et al., 2011: EC-Earth: description and validation of a new seamless earth system prediction model. Clim. Dyn. 39:26112629.
Pall, P., T. Aina, D. A. Stone, P. A. Stott, T. Nozawa, A. G. J. Hilberts, D. Lohmann, and M. R. Allen, 2011: Anthropogenic greenhouse gas contribution to flood risk in England and Wales in autumn 2000. Nature 470, 382-385.
Stickler, A., S. Brönnimann, M. A. Valente, J. Bethke, A. Sterin, S. Jourdain, E. Roucaute, M. V Vasquez, D. A. Reyes, R. Allan, and D. Dee, 2014: ERA-CLIM: Historical Surface and Upper-Air Data for Future Reanalyses. Bull. Amer Meteor. Soc., 95(9), 1419-1430.

g) Computational algorithms and codes outline

EC-Earth3 comprises three major components: IFS, NEMO and OASIS3. It is essential to configure and build separate executable for each one of them. IFS and NEMO fully support a parallel environment, while OASIS3 supports a pseudo-parallel environment. OASIS3 requires Cray pointers. For IFS there is a possibility to activate an OpenMP switch but in this case the implemented MPI should be thread-safe. IFS generates the output in GRIB format and NEMO in NetCDF, while OASIS3 does not generate any output. At the end of a simulation the three components always generate restarts separately (IFS in binary, and NEMO and OASIS3 in NetCDF format).

For configuring and building the model executable, GNU make 3.81 or 3.81+, FORTRAN 77/90/95 complaint compiler with preprocessing capabilities and NetCDF4 deployed with HDF5 and SZIP are needed. A newly designed tool for automatic build configuration called "ec-conf" can be used. This useful tool requires Python 2.4.3 or 2.4.3+ (although it does not work yet with Python 3.0+). For NEMO useful tool requires Python 2.4.3 or 2.4.3+ (although it does not work yet with Python 3.0+). For NEMO, the FCM bash and perl mechanism is essential, as it is the I/O GRIB_API 1.9.9 or 1.9.9+ and GRIBEX 370 mechanism that are needed for IFS. To test the model with the run scripts, GNU date (64-bit) is also required.

EC-Earth3 supports several configurations that have already been tested on various super-computing platforms, Marenostrum3 among them.In this activity we will use the configuration of T255-ORCA1 which corresponds to a spatial resolution of 80 km in the atmosphere and 100 km in the ocean. In order to store sources and initial data, the experiments require at least ~100 GB of disk space for each release. Currently, four releases of EC-Earth3 are available, v3.0, v3.0.1, v3.1 and v3.2. This activity is planned to be carried out with the latest version, v3.2.

In the context of the experiments planned that will use the T255-ORCA1 configuration, a benchmarking performed previously suggests that, taking into account the average load of the Marenostrum queues, optimum performance is obtained when using 496 cores, respectively. This is a configuration that runs faster than previous experiments at Marenostrum but still remains scalable for this resolution. This configuration generates 2 GB of output per month of simulation. This particular application will require large amount of atmospheric circulation data of the 19th century at a 6-hourly basis which will require a total amount of 8 TB of disk space.

3. Software and Numerical Libraries

Software components that the project team requires for the activity.

a) Applications + Libraries

BLAS, HDF5, LAPACK, NETCDF, SCALAPACK, UDUNITS

b) Compilers and Development Tools

GCC, INTEL, MVAPICH2

c) Utilities + Parallel Debuggers and Performance Analysis Tools

CMAKE, PYTHON, NCVIEW, AUTOCONF

d) Other requested software

GRIB_API, GRIBEX, NCO and CDFTOOLS

e) Proprietary software

4. Research Team Description

a) Personal Data

Name of Team Leader Omar Bellprat Vilanova
Institution Barcelona Supercomputing Centre
e-mail omar.bellprat@bsc.es
Phone +34 934 13 77 16

b) The employment contract of the activity leader with the research organisation is valid at least 3 months after the end of the allocation period.

Yes

c) Curriculum Vitae of the Team Leader

Curriculum Vitae of the Team Leader:

The scientist responsible of this proposal is a PostDoctoral research fellow within the Earth Science department led by Prof. Doblas-Reyes of the Barcelona Supercomputing Centre.

Omar Bellprat has obtained his PhD in 2013 at the Institute for Atmospheric and Climate Science at Federal Institute of Technology (ETH) in Zurich, Switzerland (ranked 10th best university world-wide and 5th in Evironmental System Science). The PhD was awarded with a medal for outstanding PhD thesis by ETH Zurich. His work involved extensive Earth system modelling generating large model ensembles to explore and constrain uncertainties in physical model schemes. Within this project, a new model calibration scheme for computationally demanding models has been developed which has become operational at the Federal Office of Meteorology, Switzerland.

Omar Bellprat works since 2014 with Prof. Doblas-Reyes and the climate prediction group on attribution of extreme climate events in the FP7 EUCLEIA project. During this period he has also become a postdoctoral fellow of the European Space Agency (ESA) and PI of the project VERITAS-CCI. Omar Bellprat is author and co-author of more than ten published and accepted papers in international peer-reviewed journals and is collaborating with a multitude of international climate centers world-wide. He has been invited speaker at five different institutes, has attended large number of conferences, and lectured at the Basque Centre for Climate Change summer school in 2015. Omar Bellprat has also successfully been granted computational resources at the Argonne National Laboratory in 2015.

d) Names of other researchers involved in this activity

Virginie Guemas (virginie.guemas@bsc.es)
Francisco Doblas-Reyes (francisco.doblas-reyes@bsc.es)
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Valentina Viscardi (valentina.viscardi@bsc.es)
Mario Acosta (mario.acosta@bsc.es)

e) Relevant publications

Bellprat O. and F. Doblas-Reyes (2016). Attribution of extreme weather and climate events overestimated by unreliable climate simulations. Geophysical Research Letters, 0.1002/2015GL067189

Bellprat O., Lott, F. C., Gulizia, C., Parker, H. R., Pampuch, L. A, Pinto, I., Ciavarella, A., P. A. Stott (2015).

Unusual past dry and wet rainy seasons over Southern Africa and South America from a climate perspective, Weather and Climate Extremes, Volume 9, September 2015, Pages 36-46

F. Massonnet, V. Guemas, N. S. Fučkar, and F. J. Doblas-Reyes (2015). The 2014 high record of Antarctic sea-ice extent [inExplaining Extreme Events of 2014 from a Climate Perspective]. Bull. Amer. Meteor. Soc., 96 (12), S163S166.

Guemas V., F.J. Doblas-Reyes, I. Andreu-Burillo and M. Asif (2013). Retrospective prediction of the global warming slowdown in the past decade. Nature Climate Change, 3, 649-653, doi:10.1038/nclimate1863

Guemas V., Doblas-Reyes F., Germe A., Chevallier M., and D. Salas y Mélia,(2013). September 2012 Arctic sea-ice minimum: Discriminating between sea-ice memory, the august 2012 extreme storm, and prevailing warm conditions [inExplaining Extreme Events of 2014 from a Climate Perspective]. Bull. Amer. Meteor. Soc., 94 (9), S20S22.

5. Resources

a) Estimated resources required for the Activity for the current Application Period

Requested machine	MareNostrum 3 ((IBM System X iDataplex with Infiniband / >40000 cores)
Interprocess communication	Null

Typical Job Run				
Number of processors needed for eachjob		500.00		
Estimated number of jobs to submit		900.00		
Average job durations (hours) per job		1.00		
Total memory used by the job (GBytes)		65.00		
Largest Job Run				
Number of processors needed for eachjob		500.00		
Estimated number of jobs to submit		60.00		
Average job durations (hours) per job		2.00		
Total memory used by the job (GBytes)		65.00		
Total disk space (Gigabytes)	**Minimum**	1000.00	**Desirable**	2000.00
Total scratch space (Gigabytes)	**Minimum**	8000.00	**Desirable**	10000.00
Total tape space (Gigabytes)	**Minimum**	0.00	**Desirable**	0.00
Total Requested time (Thousands of hours)		536.00		

If this activity is asking for more than 2Million CPU hours, you need to justify the amount of resources requested for the activity (max 1000 characters)

INFORMATION: The estimated cost of the requested hours, considering only the electricity cost, is 6126.48 euros.

The required resources have to be executed in the selected machines, the other architectures do not fit the requirements to execute the proposal.
** this option implies that if no hours in this machine/these machines are available, the acces committee will reject the full application

b) Estimate of the total resources that the Activity will require until it is completed (including the present and all the following Application Periods)

Number of application periods expected to complete this Activity

2

Total Requested Time (thousands of hours) expected to complete this Activity

1061.00

6. Abstract for publication

This project proposes to investigate a novel approach to identify to which extent the human activity influences the occurrences of extreme climate events. The results are expected to improve our understanding on optimal methodologies to detect the human influence on single extreme events and might lead to an operational standard for climate centres world wide. The approach will be applied to the extreme El Niño event which occurred in 2015 and which impacted socio-economic sectors and which could potentially to a high-impact publication. This project will contribute to the Grand Challenge on Understanding and Predicting Weather Climate Extremes from the World Climate Research Programme (WCRP) as well as the EUCLEIA european project and the VERITAS fellowship objectives.

7. Contact with CURES during last year

Information about the RES Users Committee (CURES).

a) User has contacted the CURES during last year

No

b) If not, indicate why you have not contacted the CURES

Because I have not needed it.