Convocatorias 2017
Proyectos EXCELENCIA y Proyectos RETOS
AGENCIA ESTATAL DE INVESTIGACIÓN

AVISO IMPORTANTE

En virtud del artículo 16 de la convocatoria **NO SE ACEPTARÁN NI SERÁN SUBSANABLES MEMORIAS CIENTÍFICO-TÉCNICAS** que no se presenten en este formato.

Es obligatorio que la memoria contenga los tres apartados (A, B y C). La parte C de la memoria no podrá exceder de 20 páginas.

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Parte A: RESUMEN DE LA PROPUESTA/SUMMARY OF THE PROPOSAL

INVESTIGADOR PRINCIPAL 1 (Nombre y apellidos)**:**

Omar Bellprat

INVESTIGADOR PRINCIPAL 2 (Nombre y apellidos)**:**

TÍTULO DEL PROYECTO: Predicción y atribución de eventos extremos climáticos

ACRÓNIMO: PANDA

RESUMEN Máximo 3500 caracteres (incluyendo espacios en blanco):

Los eventos climáticos extremos tales como las olas de calor, sequías, inundaciones o estaciones de intensos ciclones tropicales causan grandes impactos en nuestra sociedad. La península ibérica ha experimentado durante este año 2017 una ola de calor agravada por una sequía subsiguiente, que ha llevado a incendios en España y Portugal además de otras pérdidas. Los sistemas de predicción actuales no están todavía preparados para anticipar tales eventos a largo plazo por lo que existe un gran potencial en el uso de sistemas de predicción subestacionales a estacionales para anticiparlos. Esto es particularmente relevante en el actual cambio climático, que está aumentando el número de eventos extremos. Por todo ello, la comprensión del papel del cambio climático en los acontecimientos extremos del pasado es de suma importancia para adaptarse a las futuras condiciones climáticas. El presente proyecto, denominado PANDA, tiene por objeto avanzar y diseñar nuevos sistemas de predicción que permitan predecir los fenómenos climáticos extremos en la escala subestacional a estacional (2) y cuantificar el papel que el cambio climático ha jugado inmediatamente después de que ocurrieran dichos eventos. El Barcelona Supercomputing Center (BSC) es una institución líder a nivel mundial en el desarrollo de sistemas de predicción subestacionales a estacionales y en la configuración de servicios climáticos para el sector público y privado. Su experiencia en combinar el cambio climático a corto plazo y los servicios climáticos brinda una oportunidad única para adaptar nuestra sociedad a futuros eventos climáticos extremos que ocurren en el Mediterráneo y en otras regiones del mundo.

PALABRAS CLAVE: Extremos climáticos, predicción estacionales, impactos socioeconómicos, energía renovable

TITLE OF THE PROJECT: Prediction AND Attribution of extreme climate events

ACRONYM: PANDA

SUMMARY Maximum 3500 characters (including spaces):

Extreme climate events such as heat waves, droughts, flooding or intense tropical cyclones seasons cause large impacts to our society. The Iberian peninsula experienced this year in June (2017) a heatwave which was exacerbated by an ongoing drought, leading fires in Spain and Portugal and many casualties. Today's forecasting systems are not yet prepared to anticipate such long-term events and a huge potential lies in using sub-seasonal-to-seasonal prediction systems to anticipate these. This is particularly relevant under ongoing climate change which is increasing the numbers of climate extremes. Understanding the role of climate change on past extreme events is therefore of paramount importance to adapt to future climate conditions. This new project, named PANDA aims at advancing and designing new forecasting systems that will allow to (1) predict extreme climate events at the sub-seasonal-to-seasonal scale (2) and to quantify the role that climate change has played immediately after these events occurred. The Barcelona Supercomputing Center (BSC) is a world-leading institution in developing sub-seasonal-to-seasonal forecasting systems and shaping climate services for the public and private sector. Its expertise in combining near-term climate change and climate services provides an unique opportunity to adapt our society to future extreme climate events occurring in the Mediterranean and in other regions on the globe.

KEY WORDS: Extreme climate events, sub-seasonal-to-seasonal forecasts, socio-economic impacts, renewable energy

Parte B: INFORMACIÓN ESPECÍFICA DEL EQUIPO

B.1. FINANCIACIÓN PÚBLICA Y PRIVADA (PROYECTOS Y/O CONTRATOS DE I+D+I) DEL EQUIPO DE INVESTIGACIÓN (repita la secuencia tantas veces como se precise hasta un máximo de 10 proyectos y/o contratos).

1. Investigador del equipo de investigación que participa en el proyecto/contrato:
   Omar Bellprat, Louis Philippe Caron
   Referencia del proyecto: EUCLEIA (GA 607085)
   Título: European Climate and weather Events: Interpretation and Attribution
   Investigador principal: Francisco Doblas-Reyes
   Entidad financiadora: FP7
   Duración (fecha inicio - fecha fin, en formato DD/MM/AAAA): 01/01/2014-31/12/2016
   Financiación recibida: 138.282€ (total funding budget 2.990.915,16€)
   Relación con el proyecto que se presenta: EUCLEIA has been the landmark project on attribution of extreme events. PANDA is a natural follow-up initiative from EUCLEIA addressing one of the key remaining challenges highlighted by the advisory panel - the combination of attribution and prediction.
   Estado del proyecto o contrato: finished

2. Investigador del equipo de investigación que participa en el proyecto/contrato:
   Omar Bellprat, Chloé Prodhomme, Louis Philippe Caron
   Referencia del proyecto: SPECS (GA 308378)
   Título: Seasonal-to-decadal climate Prediction for the improvement of European Climate Services
   Investigador principal: Francisco Doblas-Reyes
   Entidad financiadora: FP7
   Duración (fecha inicio - fecha fin, en formato DD/MM/AAAA): 01/11/2012-31/01/2017
   Financiación recibida: 1.615.305,75€ (total budget 8.224.862€)
   Relación con el proyecto que se presenta: SPECS has been the largest initiative so far to improve seasonal-to-decadal prediction and was led by the climate prediction group of BSC (formerly IC3). SPECS had started to analyse the abilities to predict extreme climate events but has as such only made the first step. PANDA is therefore a natural evolution of SPECS.
   Estado del proyecto o contrato: finished

3. Investigador del equipo de investigación que participa en el proyecto/contrato:
   Omar Bellprat
   Referencia del proyecto: VERITAS-CCI
   Título: VERification of high-resolution climate forecasts on Intraseasonal-to-interannual Timescales with Advanced Satellite datasets of the Climate Change Initiative
   Investigador principal: Omar Bellprat
   Entidad financiadora: ESA Living Planet
   Duración (fecha inicio - fecha fin, en formato DD/MM/AAAA): 01/02/2015-01/02/2017
   Financiación recibida: 80.000 €
   Relación con el proyecto que se presenta: VERITAS-CCI explored the use of modern satellite remote sensed data sets in verification of seasonal predictions and the role of observational uncertainties. The project has as such set the ground to establish initialization of prediction experiments using the CCI data as proposed by PANDA.

Estado del proyecto o contrato: finished

4. Investigador del equipo de investigación que participa en el proyecto/contrato:
   Chloé Prodhomme
   Referencia del proyecto: APPLICATE (GA 727862)
   Título: Advanced Prediction in Polar regions and beyond: Modelling, observing system design and LInkages associated with ArctiC ClimATE change.
   Investigador principal: Francisco Doblas-Reyes
   Entidad financiadora: H2020
   Duración (fecha inicio - fecha fin, en formato DD/MM/AAAA): 01/11/2016- 31/10/2020
   Financiación recibida: 677.375€ (total funding 7.999.591,25€)
   Relación con el proyecto que se presenta: APPLICATE studies the impact of climate change on the Arctic system and its impacts on lower latitudes climate. This effort links to the proposed analysis how extreme sea-ice concentration events and the impact low-latitude high-impact events can be predicted as analysed in PANDA WP1.
   Estado del proyecto o contrato: ongoing

5. Investigador del equipo de investigación que participa en el proyecto/contrato:
   Chloé Prodhomme, Louis Philippe Caron
   Referencia del proyecto: PRIMAVERA (GA 641727)
   Título: PRocess-based climate sIMulation: AdVances in high resolution modelling and European climate Risk Assessment
   Investigador principal: Francisco Doblas-Reyes
   Entidad financiadora: H2020
   Duración (fecha inicio - fecha fin, en formato DD/MM/AAAA): 01/11/2015-31/10/2019
   Financiación recibida: 1.277.425€ (total budget 14.967.970€)
   Relación con el proyecto que se presenta: PRIMAVERA explores the impact of high-resolution global climate modelling in a multi-model perspective. This endeavour is aligned with tasks in PANDA related to high-resolution prediction which are in this proposal extended on the ability to represent extreme climate events
   Estado del proyecto o contrato: ongoing

6. Investigador del equipo de investigación que participa en el proyecto/contrato:
   Chloé Prodhomme
   Referencia del proyecto: IMPREX (GA 641811)
   Título: IMproving PRedictions and management of hydrological Extremes
   Investigador principal: Francisco Doblas-Reyes
   Entidad financiadora: H2020
   Duración (fecha inicio - fecha fin, en formato DD/MM/AAAA): 01/11/2015-31/10/2019
   Financiación recibida: 240.000€ (total funding budget 7.996.850€)
   Relación con el proyecto que se presenta: IMPREX deals with the improved prediction of hydrological extremes over Europe which is such common interests in terms of the role that climate change has played in intensifying past hydrological events.
   Estado del proyecto o contrato: ongoing

7. Investigador del equipo de investigación que participa en el proyecto/contrato:
   Chloé Prodhomme
   Referencia del proyecto: EUPORIAS (GA 308291)

Título: European Provision of Regional Impact Assessment on a Seasonal-to-decadal timescales
Investigador principal: Virginie Guemas
Entidad financiadora: FP7
Duración (fecha inicio - fecha fin, en formato DD/MM/AAAA): 01/11/2012-31/01/2017
Financiación recibida: 697,963€ (total funding budget 8.969.180,25€)
Relación con el proyecto que se presenta: EUPORIAS has been the partner project of SPECS focusing on establishing the user engagement and communication across different public and private sectors.
Estado del proyecto o contrato: finished

8. Investigador del equipo de investigación que participa en el proyecto/contrato:
Louis Philippe Caron
Referencia del proyecto: RESPONS (CGL2014-55764-R)
Título: Regional Seasonal Forecasts and Multi-Annual Predictions of Tropical cyclons
Investigador principal: Louis Philippe Caron
Entidad financiadora: MINECO
Duración (fecha inicio - fecha fin, en formato DD/MM/AAAA): 01/01/2015-30/04/2017
Financiación recibida: 38.720€
Relación con el proyecto que se presenta: Some of the tools developed in RESPONS to estimate hurricane activity from large-scale drivers will be used to estimate hurricane activity in the millennial simulations.
Estado del proyecto o contrato: finished

B.2. RELACIÓN DE LAS PERSONAS NO DOCTORES QUE COMPONEN EL EQUIPO DE TRABAJO (se recuerda que los datos de los doctores del equipo de trabajo y de los componentes del equipo de investigación no se solicitan aquí). Repita la siguiente secuencia tantas veces como precise.

Parte C: DOCUMENTO CIENTÍFICO. Máximo 20 páginas.

C.1. PROPUESTA CIENTÍFICA

General context

Extreme weather and climate events are highly detrimental to our society. They inflict, among natural disasters, the largest damages worldwide. The European Environmental Agency (EEA) estimates that extreme weather and climate events caused 90’000 casualties among EU member states during the period 1980 - 2015. These events were further associated with high losses of EUR 433 Billion over the same period (EEA, 2017). Extreme weather and climate events are therefore of high public concern and there is a strong demand to better understand and anticipate these as reflected in the European Union Horizon 2020 research programme.

Extreme events are commonly distinguished into the two temporal scales of weather and climate. Weather extremes entail short-duration events of hours to a few days such as hail events or winter storms. Climate extremes denote events that last longer than three days up to several months such as *heat and cold waves, droughts, flooding due to persistent rain or intense hurricane season*s. While the prediction of weather extremes is carried out at meteorological centres, no operational systems have been established yet to predict extreme climate events. Various prediction centres worldwide routinely perform and provide long-range forecasts known as seasonal forecasts. However, little efforts have been devoted in these systems to anticipate extreme climate events and a huge potential to serve societal needs remains to be explored (NAS, 2016a).

Predicting extreme climate events is today particularly relevant given that the Earth’s climate is changing. Climate change alters the probabilities that extreme events occur, favouring the occurrence of heat waves but also events associated with heavy precipitation or the absence of it (IPCC et al., 2013). High-impact events are therefore publicly perceived as harbingers of climate change. Whether specific past events are linked to climate change is however unknown in an unequivocal way and their attribution has been a scientific taboo for a long time. Until recently, when a growing number of studies has demonstrated that single events can be attributed to climate change using a probabilistic point of view. Stott et al., (2004) showed for the first time that climate change doubled the probability of the European heat wave in 2003 and demonstrated as such the feasibility of extreme event attribution.

Extreme event attribution to climate change is now a consolidated scientific discipline addressing the strong public demand to understand the human influence on past extreme events. It has however not yet become an operational activity and many methodological grounds remain to be solved. One concern is that event attribution and climate prediction, albeit sharing common methodological approaches and objectives, have lacked interaction in the past. Future operational practices of prediction and event attribution will inevitably have to establish common grounds to maximize the shared resources devoted to these communities and bridging them would enable not only various mutual advances (NAS, 2016b) but also important societal benefits.

PANDA aims at addressing the two research frontiers described above, **to improve the prediction of extreme climate events using sub-seasonal to seasonal (S2S) forecast systems and to bridge the climate prediction and attribution to climate change community**

This proposal is divided in the seven following sections:

1. Prediction and attribution of extreme climate events: state-of-the-art

The prediction of the atmosphere beyond the scales of weather (2 weeks) is possible thanks to slowly varying components of the Earth's system such as sea-surface temperatures (SSTs), sea-ice concentration (SIC), soil moisture, or the stratospheric circulation (Doblas-Reyes et al., 2013). These slowly varying components modulate the atmospheric flow and thereby influence the weather we perceive weeks up to multiple years ahead. The most prominent example is the influence of equatorial Pacific SSTs which vary inter-annually - a phenomenon known as the El Niño Southern Oscillation (ENSO). ENSO modulates the atmosphere through teleconnection patterns over many areas of the globe, favouring for instance during El Niño warm and dry conditions over Indonesia (Trenberth et al., 2002).

Slowly varying climate components and associated global teleconnections modulate the mean climate but also the development of disruptive extreme events (NAS, 2016b). ENSO strongly impacts the frequency of extreme precipitation events over South and North America a season ahead (Grimm and Tedeschi, 2009; Whan and Zwiers, 2017). At the intra-seasonal scale, tropical variability, dominated by the Madden-Julian-Oscillation (MJO), heavily influences tropical and extra-tropical extreme heat and cold events over various global regions (Matsueda and Takaya, 2015). Over the mid-latitudes, heat waves have been shown to be strongly linked to the available levels of soil moisture controlling evaporative capability of the land surface, by members of the PANDA team among others (Fischer et al., 2007; Hirschi et al., 2011, Prodhomme et al., 2016). European events have further been associated with the prevailing flow determined by the North Atlantic Oscillation (NAO) (Scaife et al., 2014).

The correct initialization of the observed climate state (using satellite and in-situ observational networks) in a climate model allows potentially to predict extreme climate events thanks to these slow components of the climate system. Such long-term predictability enables the possibility of early warning systems for disruptive events impacting public and private sectors, particularly at the sub-seasonal-to-seasonal (S2S) time-scale (Vitart et al., 2016). Retrospective predictions of the European heat wave in 2003 or the Russian heat wave in 2010 show that these events could have been anticipated with modern dynamical S2S systems (Weisheimer et al., 2011; Prodhomme et al., 2016) thanks to a correct initialization of land surface conditions, in particular soil moisture, as shown by members of the PANDA team.

Bellprat et al. (2016b), PI of the PANDA project, demonstrated that the extreme cold wave over North America was predictable thanks to memory in the atmospheric flow, SST as well as sea ice (SI) conditions (see figure 1). Caron et al. (2015) show that tropical cyclone activity can potentially be predicted multiple years ahead using global coupled climate models thanks to the initialisation of global SST patterns. Recent studies revealed linkages between Arctic sea-ice conditions and the NAO (García-Serrano et al., 2016) providing additional potential precursors to anticipate extreme events over Europe and North America. This is particularly promising given that state-of-the-art high-resolution climate prediction systems begin to achieve a trustworthy predictive capability regarding the NAO at S2S and even longer scales, as shown by members of the PANDA team among others (Scaife et al., 2014; Prodhomme et al., 2016; Weisheimer et al., 2017).

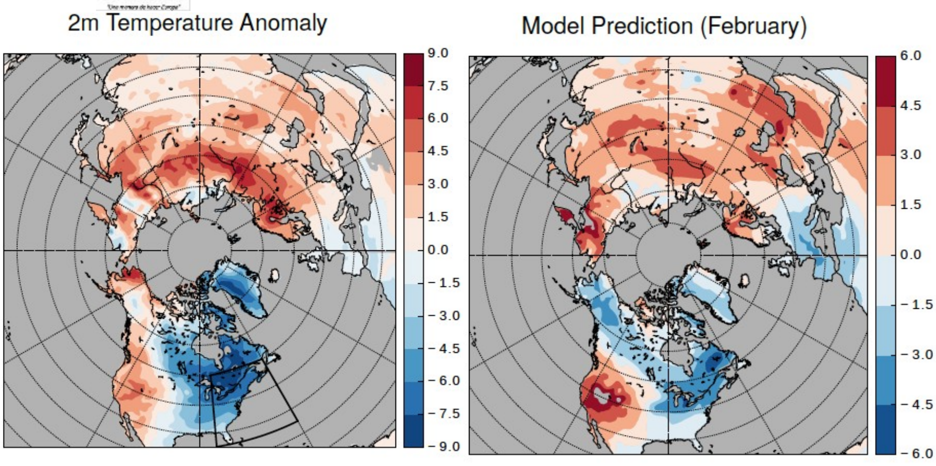

Figure 1: *The extreme cold February over North America in 2015 causing US$ 8 billion losses (from Bellprat et al., 2016b). The left panel shows the extreme cold anomaly observed in the ERA-Interim re-analysis (Dee et al., 2011) and the right panel a retrospective sub-seasonal prediction using the EC-Earth3 climate model simulated at the Barcelona Supercomputing Centre (BSC). The figure shows that the event could have been anticipated using sub-seasonal predictions.*

One natural question at this stage is where the role of climate change comes into play. The Intergovernmental Panel on Climate Change (IPCC, 2013) highlighted in its last Assessment Report that climate change will have a particularly strong influence on extreme events. This is because their rare occurrence can be highly sensitive to changes in the distribution of weather as illustrated in figure 2 (for the case of temperature). As temperatures increase, the whole distribution of temperature is shifted toward higher values and heat waves will become more likely while cold waves frequency decreases (panel a). Climate change also increases the variability in some regions without necessarily modifying the mean state (panel b), favouring the occurrence of both cold and hot seasons. Finally, extreme events may change in a non-symmetric way. For instance, global warming is expected to increase the intensity of tropical cyclones, while at the same time reducing their mean numbers (Kang and Elsner, 2015). Whether climate change was responsible for single past extreme events is often unknown given that it is a slow steady process. However, recent studies have demonstrated that single extreme events can be attributed probabilistically by artificially suppressing the influence of climate change on retrospective climate simulations (Bellprat et al. 2015; Stott et al., 2016). Attribution of past extreme events to climate change provides a powerful tool to communicate the role that climate change is already taking in the development of high impacts events around the globe.

Both operational prediction and attribution of extreme climate events are urgently demanded by public and private sectors to better adapt to the variability of extreme climate events and the impacts of climate change (Sillman et al., 2017). Anticipating and understanding extreme events is for instance of paramount importance for the transition to renewable energy production. Lledó et al., (2017) illustrate the impact of low wind extremes (wind droughts) on wind mill farms and show that prediction and attribution of such extreme climate events are highly valued by the energy producers. Likewise, the prediction of extreme heat or cold events is fundamental for the energy sector in order to anticipate the energy demand (due to cooling or heating) which challenges to supply for current renewable systems (IEA, 2015). Extreme climate events are also of high concern for the reinsurance sector. Reinsurance comes into play when the losses caused by events are so high that insurances can no longer cope with these damages. The impact of Hurricane Katrina on New Orleans and Sandy on New York have caused combined damage reaching close to $200 billions (NOAA, 2014). Being able to predict a potential increased risk of intense hurricane seasons and also to understand how climate change has and will impact the intensity of hurricanes is a priority for reinsurance.

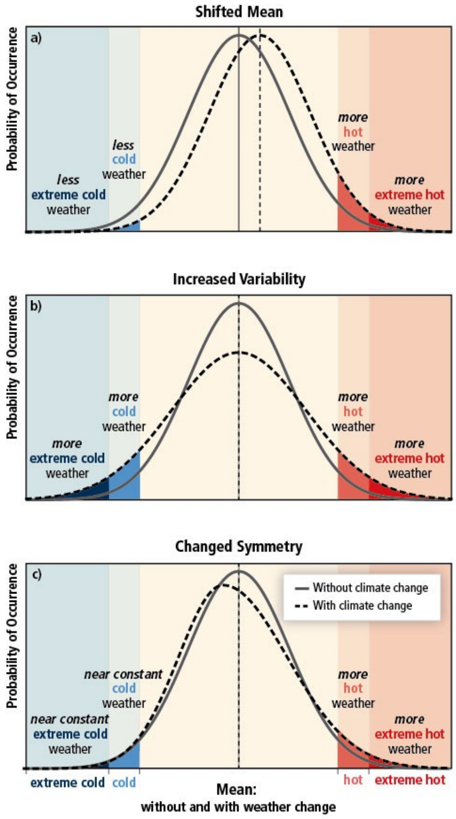

Figure 2: Impact of climate change on extreme cold and hot occurrences due to changes in the distribution of the climate (from IPCC, 2013)

2. Context of the proposal and main issues

Climate prediction skill at sub-seasonal-to-seasonal (S2S) timescales remains limited over many regions and for many types of events, albeit large progress was made over the last years. One of the key challenges is how observations of the climate system can be used to initialize climate models that predict the unknown near-term climate (Doblas-Reyes et al., 2013). This is particularly difficult due to large uncertainties for physical quantities important for the prediction of climate extremes such as soil moisture, sea-ice concentration and sea-surface temperature (Massonnet et al., 2016). These uncertainties are linked to limitations in the current observational networks and a large potential to make progress on this front lies in exploiting data from satellite Earth observation. The European Space Agency (ESA) has launched in the last decade new observational systems that measure unprecedented data of soil moisture (Soil Moisture Ocean Salinity (SMOS) Earth Explorer) and developed within the Climate Change Initiative (CCI) data sets of all these variables which might boost S2S prediction skill.

Another key limitation of current prediction systems is the limited horizontal resolution of global climate models, of typically 80-100 km. Current resolution of operational prediction systems limit the representation of various types of processes linked to extreme climate events such as for instance blocking frequencies over Europe (Jung et al., 2012), the development of tropical cyclones and winter storms (Jung et al., 2012), the prediction skill of ENSO (Prodhomme et al., 2016) and also the prediction of the NAO (Scaife et al., 2014). Recent results further indicate that increasing the horizontal resolution will improve ocean-atmosphere interactions and enable a stronger forcing of the ocean than the community thought was possible (Kirtman, B., personal communication). Pushing the limits of global climate models might hence lead to a new unexplored territory of climate prediction capabilities.

The role of ocean surface conditions relates to the challenges in attribution of extreme climate events to climate change. Currently, typical event attribution techniques compare climate model experiments where the influence of climate change is included or artificially suppressed (Stott et al., 2016). This is commonly done using large ensembles of atmosphere-only simulations which are forced by observed marine boundary conditions of SSTs and sea-ice. The impact of climate change is discerned by comparing an ensemble forced with observed conditions and one counterfactual where the climate change signal is statistically removed in these marine boundary conditions (Stott et al., 2016). This approach ensures that natural modes of variability such as ENSO are retained in both ensembles. An important drawback is that ocean-atmosphere coupling processes are suppressed, potentially leading to unreliable simulation of extreme event probabilities (Bellprat and Doblas-Reyes, 2016). The prescription of marine boundary conditions also requires to have the past observed state which is not immediately distributed by institutes collecting observations (for technical reasons) and delays the attribution process that is often desired in the aftermath of an event by the public and media. Using the climate prediction perspective a new event attribution system could be defined where the effect of climate change is removed from the whole coupled initial state. Such an approach would ensure a strong interaction of the climate prediction and event attribution as has been called for (NAS, 2016b)

Irrespective of the methodology, the attribution of extreme events to climate change requires the understanding of how climate change is thought to impact certain extreme events. This understanding is advanced for events related to temperatures extremes (see figure 2) and also considerable understanding has recently been achieved for events associated with heavy precipitation (Fischer and Knutti, 2016). For certain kind of events such as tropical cyclones (TC) the role of climate change remains substantially obscured. The primary energy source for a TC is the evaporation from the ocean surface. With the warming of oceans due to global warming, the threat posed by these storms is expected to grow not only in North and Latin America, but also in Europe (Haarsma et al., 2016). Already, an upward trend in the intensity of the strongest storms has been detected (Elsner et al, 2008) and the geographical regions supporting cyclogenesis have been measured to be migrating poleward, away from the tropics towards the extra-tropics (Kossin et al., 2014). However, beside an increase in surface wind and precipitation, the impact of climate change on tropical cyclone activity remains uncertain, in particular with respect to their geographical distribution across basins and their size.

Finally, a large gap remains before transforming climate prediction and attribution of extreme climate events into actionable information. Results from the EUPORIAS project (http://www.euporias.eu/) showed that an effective way to explore the value of prediction in decision-making is by studying past high impacts events. Studying the ability to anticipate a past event and attribute it to its to principal drivers is an effective way to communicate the use of operational system in future decision making.

3. Groups working on climate prediction and attribution of extreme events

The Earth Science Department of the Barcelona Supercomputing Centre (BSC) is an international reference in climate prediction and has coordinated the European project SPECS (Seasonal to Decadal climate Predictions for the improvement of the European Climate Services, http://www.specs-fp7.eu/) which has been the largest European effort to date to advance regional climate prediction. It has as such become a leading institution in European climate prediction in coordinating work together with the UK Met Office (Adam Scaife), the KNMI (Netherlands, Bart van der Hurk), ECMWF (UK, Antje Weisheimer, Tim Palmer), Météo-France (Michel Déqué) and SMHI (Sweden, Colin Jones). BSC is further co-coordinating the MEDSCOPE (MEDiterranean Services Chain based On climate PrEdictions) European project which aims at improving climate prediction capability over western Europe.

BSC has also been a partner in the EUropean CLimate and weather Events: Interpretation and Attribution (EUCLEIA) Project which has been the world-leading initiative in setting the landmarks for extreme event attribution (let by Peter Stott, UK Met Office). BSC and the Principal Investigator of PANDA works in strong collaboration with institutes leading research on the impact of climate change on extreme events: the University of Oxford (Frederike Otto, Myles Allen), the Swiss Federal Institute of Technology (ETH, Sonia Seneviratne, Erich Fischer), the Institut Pierre Simon Laplace (IPSL, Robert Vautard), and the UK MetOffice (Peter Stott, Nikos Christidis). The BSC has in addition since 2013 contributed with at least one publication every year in the highly recognised annual special report on explaining past extreme events from a climate perspective in the Bulletin of the American Meteorological Society (BAMS) (Guemas, et al., 2014, Massonnet et al., 2015, Bellprat et al., 2016b, Fuckar et al., 2016).

A network of European and international collaborators will support the science and the dissemination of PANDA. These include European researcher at the scientific forefront of climate extremes and their prediction: Erich Fischer (ETH Zurich) and Antje Weisheimer (Univ. of Oxford and ECMWF) as well as a representative of the reinsurance sector which is has strong interest in anticipating extreme climate events: Andreas Weigel (SwissRe). Further international collaborators will support the challenge of understanding the role of climate change on tropical cyclones: Mathieu Boudreault (Univ. Québec à Montréal), David Carozza (Univ. Québec à Montréal), Fabrice Chauvin (Météo-France), and Kevin Walsh (Univ. Melbourne).

4. Description of the objectives

The prediction and attribution of extreme climate events is still at an early stage and a large potential lies in improving these systems. The objectives of PANDA are two-fold: (1) to improve the predictability of extreme climate events by using new satellite remote sensing data for the initialization of climate models, increasing the resolution of global climate models and improving the understanding of the mechanisms responsible for predictability of extreme climate events and (2) to improve the understanding of how climate change impacts extreme events and providing a new framework for operational extreme event attribution that allows to attribute extreme events immediately after the occurrence of an event.

PANDA is structured into two work packages (WP), **improving the prediction** of extreme climate events (WP1) and **understanding the role of climate change** on past and future extreme events (WP2). The analysis relies on large ensemble experiments using global climate models experiments carried out in the framework of the H2020 initiatives **MEDSCOPE** (advancing climate prediction and climate services), **PRIMAVERA** (exploring the benefits of high-resolution global climate modelling), **APPLICATE** (understanding the role of Arctic climate and their mid-latitude linkages), and the ESA Climate Modelling User Group **CMUG** (using satellite Earth observation in climate modelling). The community Earth System model **EC-Earth** (https://www.ec-earth.org/, Hazeleger et al., 2013) is the working horse at BSC to address the associated research questions. BSC is a core member of the EC-Earth consortium and contributes fundamentally to the High-Performance Computing (HPC) capabilities of the model as required for an endeavour. PANDA aims at addressing the "Reto: Acción sobre el cambio climático y eficiencia en la utilización de recursos y materias primas", by enhancing the predictive capability of high-impact events and understanding the role of climate change. This project is also fully in line with the objectives from the Scientific and Technological Spanish strategy of "generating cutting-edge knowledge", and with the priority axis of "knowledge transfer" (Table 1).

PANDA will be carried out within the Climate Prediction Group (CPG, led by Virginie Guemas), involving Omar Bellprat (PI of the project, expert in seasonal prediction and attribution of extreme climate events), Louis-Philippe Caron (expert in tropical cyclone variability and predictability), Chloé Prodhomme (expert in seasonal prediction of heat waves and high-resolution modelling), and Alasdair Hunter (expert in the impact of climate change on extremes). The seasonal prediction and attribution of extreme events is one of the principal research areas https://www.bsc.es/es/research-development/research areas/climate-prediction/seasonal-prediction-and-attribution-extreme) of the Earth Science Department at BSC led by the PI of PANDA.

5. Research methodology, approach and work plan

A large set of global climate model experiments will be performed in PANDA. Investigations of the predictability of extreme climate events (WP1) will rely on retrospective sub-seasonal-to-seasonal predictions (hereafter termed hindcasts) with EC-Earth3. The hindcasts will cover the satellite era starting in 1979 until present, corresponding to the period where the ERA-Interim atmospheric re-analysis (Dee et al., 2011) is available. ERA-Interim will be used to initialize the model together with the ocean re-analysis ORA-S4 (Balmaseda et al., 2013) to predict four consecutive months of the summer (starting in May) and winter (starting in November) season using 10 ensemble members each. In addition to these hindcasts, predictions starting at different dates and larger ensembles will assess the predictability of specific events, the past European heatwaves in 2003, 2010, 2016, or the wind droughts over Europe and North America in 2016 and 2015, respectively. The role of land-surface (soil moisture and snow) and sea-ice conditions will be investigated using new satellite observations from the Climate Change Initiative (CCI) to initialize the model. Furthermore, hindcasts with increased model resolution will test the impact of the resolution on extreme event predictability. We define in this project sub-seasonal-to-seasonal (S2S) predictions seasonal predictions which are evaluated are evaluated at a monthly basis and also seasonal averages.

The role of climate change on past and future extreme events (WP2) will rely on historical simulations and future projections with EC-Earth3 contributing to **CMIP6 HighResMIP** (Haarsma et al. 2016) and **PRIMAVERA** project, as well as WP1 climate predictions focusing on specific events. In addition to the experiments carried out in PANDA, existing repositories of multi-model ensembles will be used, such as the WMO S2S database (Vitart et al. 2016), the North American Multi-model Ensemble (NMME, Kirtman et al., 2014) or the EUROpean Seasonal-to-Interannual Prediction (EUROSIP) multi-model. As S2S system we refer in this project to sub-seasonal analysis of classical seasonal prediction systems.

The following sections describe the methodology planned to successfully implement the two work packages of PANDA. A Gantt chart describing the timeline for the different tasks that will be performed over the three years of the project appear at the end of this section.

Work Package 1: Prediction of extreme climate events

Months 1-36

Chloé Prodhomme (BSC) 100%
Omar Bellprat (BSC) 50%
Alasdair Hunter (BSC) 25%
Postdoc1 100%

Task 1.1. Heat waves and droughts and the role of land-atmosphere coupling
Chloe Prodhomme (50%), Alasdair Hunter (15%), Omar Bellprat (5%)

Heat waves and droughts have a strong impact on society as can be felt in the present summer of 2017. They increase human mortality (Ballester et al. 2011) and cause large economical losses, through agricultural damages, cattle loss, water scarcity, forest fires among others. In order to better mitigate the impact of heatwaves and droughts, it is essential to have in place early warning systems and thus to have prediction of heat waves a few month ahead (Lowe et al. 2016). Up to now the capability of seasonal forecasts to predict heat waves has been scarcely investigated (Weisheimer et al. 2011; Prodhomme et al. 2016). Several studies have shown that a proper representation of the soil moisture state at the beginning of the forecast strongly enhance the prediction performance for warm extremes (Prodhomme et al. 2016; Ardilouze et al. 2017). Winter heat waves could also have strong consequences on economics through their impact on crop (Ceglar et al. 2016) and large snow deficit in the skiing resorts. Anomalous snow cover plays a large role on the winter climate, such as on the occurrence of cold spells (Cattiaux et al. 2010). This task will investigate the impact of land-atmosphere coupling, soil moisture memory and snow cover on seasonal forecasts of European heat waves and droughts both in winter and summer. Ad-hoc metrics and indices will be developed to this purpose, such as odds-ratios of the Standardized Precipitation Index (SPI, Hirschi et al., 211). Several case studies will be carried out, such as the prediction of the 2003 and 2010 summer heat waves and the 2016 and 2017 warm early winter associated with large snow deficit over the Alps. For these events, we will analyse their characteristics, the associated anomalous atmospheric circulation and its potential drivers, such as SSTs, soil moisture and snow cover anomalies using new satellite data from the Climate Change Initiative (CCI). These data have not been used up-to date to initialize climate predictions and a large potential lies in exploiting their added value given their unprecedented quality (Massonnet et al., 2016). The predictability of these events will also be investigated in state-of-the-art operational or real-time climate prediction systems. In addition, sensitivity experiments will be realized to better understand the land contribution to heat waves, for example comparing seasonal forecasts initializing or not the land surface from observational data and leaving the land surface free to evolve or constrained to a climatology during the forecasts.

Task 1.2 Arctic sea-ice extremes and impacts mid-latitude events
Postdoc1 (50%) Omar Bellprat (20%)

The Arctic climate is changing at unprecedented pace. This and last year Arctic sea-ice cover has repeatedly broke many low monthly records, closely monitored since the dawn of modern satellite era in the late 1970s, which are attributable to the influence of anthropogenic climate change (Fuckar et al., 2016). The reduction of Arctic sea-ice extent, age and thickness has enormous impacts on local ecosystems and socio-economic activities such as fishing, shipping, and management of mineral resources (Guemas et al., 2015). Being able to predict future long-term sea-ice loss, as well as sea-ice interannual variability and associated extreme is therefore of high public interest. This concern of many stakeholders is further substantiated by recent findings showing that reduced sea-ice cover impacts the atmospheric circulation and as such also mid-latitude climate and extremes (Francis and Skific, 2015). Various studies showed that surface heating of the Arctic seas can impact the climate through tropospheric and stratospheric pathways, influencing remote climate several months ahead (Garcia-Serrano et al., 2016). For example, anomalously warm surface air in the Barents and Kara Seas during the sea-ice growth season has been associated with below average wintertime temperature conditions over Eurasia, while anomalously warm conditions over the East Siberian and Chukchi Seas are possibly linked to cold winters in eastern North America (Kug et al., 2015). A proper observation-based initialization of sea-ice conditions might therefore improve the prediction of sub-seasonal-to-seasonal Northern Hemisphere climate and the associated extreme events (Cohen et al., 2014).
This task will investigate the ability of a state-of-the-art coupled climate model to predict extreme Arctic sea-ice conditions and their impact on the mid-latitude climate with a focus on Europe. The ability to predict past extreme sea-ice events will be analysed with seasonal hindcasts that initialize the Arctic sea-ice cover from recent sea-ice reanalysis developed at BSC which assimilates modern satellite sea-ice concentration using an Ensemble Kalman Filter (EnKF) approach. The predictions using the improved Arctic sea-ice conditions will be compared to former hindcasts which did not use sea ice data assimilation (Guemas et al., 2016) in order to identify the added value of assimilated satellite data. These improved retrospective predictions will in addition be analysed in terms of the ability to predict the NAO (Scaife et al., 2014) and to predict specific extreme events such as the extreme dry winter in Europe in 2015/2016 and its connection to the historical low sea-ice concentration during the same months.

Task 1.3 Impact of high-resolution modelling
Chloe Prodhomme (50%) Omar Bellprat (10%)

One of the key limiting factors of current climate prediction systems is the limited horizontal resolution which impacts the accuracy with which the global climate system is simulated. Recent advances in increasing the horizontal resolution of climate models demonstrated improved representation of important processes relevant for the prediction of extreme events such as blocking frequencies, the prediction of ENSO and the NAO (Scaife et al., 2014).

However, little efforts have been made up to date to assess whether increasing model resolution in global climate models improves the prediction of extreme climate events such as heat or cold waves and persistent precipitation (Prodhomme et al., 2016). The role of the horizontal resolution might also be particularly relevant for regional scale processes such as land-atmosphere coupling that strongly impact the development of heat waves (link with Task 1.1)

In this task, we propose to study the impact of resolution on the S2S prediction skill in a set of high resolution retrospective S2S predictions using EC-Earth with a resolution of 25 km in the ocean and 40 km in the atmosphere, globally. This implies a four-fold and a two-fold increase in the resolution of the ocean and the atmosphere, respectively, in comparison to standard resolution experiments which will be run in the other Tasks. Such a high resolution allows to resolve meso-scale ocean eddies and therefore improved tropical and extra-tropical forcing of the ocean which can improve the forecasting skill. This setup will be similar to the one of Prodhomme et al. (2016) but with an updated model version and with the prescription of land-surface parameters relevant for the prediction of heat waves. The tasks will as such also examine whether high-resolution modelling is required to fully harvest the benefits of land surface initialization on climate forecast quality (link with Task 1.1)

Task 1.4 Prediction of wind droughts for the renewable energy sector
Postdoc 1 (50%), Alasdair Hunter (10%), Omar Bellprat (15%)

The prediction of the climate is not only relevant for temperature and precipitation extremes but also for other geophysical variables that can impact human activity. One sector which is thought to become highly vulnerable to climatic extremes in the years to come is the renewable energy sector (IEA, 2015). Climate extremes not only impact the energy demand due to heating or cooling needs but can also directly impact the energy production for instance due to extreme low wind conditions (wind droughts) that drop the electricity production of wind farms (Lledó, 2017). With ongoing efforts to decarbonize the energy sector the share of renewable energy in the electricity system is growing fast, and with more energy production depending on atmospheric conditions the impacts of extreme events are becoming more relevant. Sub-seasonal-to-seasonal predictions have recently been shown to provide useful information on potential wind energy production which the industry is not currently making use of (Torralba, et al., 2017). However, recent wind droughts such as the one that occurred over Europe in 2016 or over North America early 2015 have made the sector aware of the impacts associated with these extremes, leading to an increased interest to anticipate such episodes and better understand what caused them.

One effective way to demonstrate the use of S2S predictions for the private sector and foster its uptake is to focus on case studies (Troccoli et al. 2017). In this task, we therefore will evaluate whether the wind droughts which occurred in Europe in 2016 and North America 2015 could have been predicted using S2S prediction system carried out in PANDA and other operational systems. Further sensitivity experiments will be carried out to understand what their causes have been. Bellprat et al., (2016) show that the large-scale atmospheric flow prevailing over North America in 2015 was predictable at least one month ahead and that tropical anomalous sea-surface temperatures contributed in establishing and sustaining anomalous meandering of the jet-stream. These anomalous conditions might have been responsible for the wind droughts observed in the western coast of North America leading to large losses in energy production. Likewise, similar forcings might have contributed to the wind droughts in the European winter of 2016 which remain poorly understood. This task will lead help to prepare for future extreme events and such make renewable energy sector more resilient to wind extremes.

Milestones WP1:
MS1.1 - Climate predictions initialized from CCI data carried out (M12)
MS1.2 - Sensitivity experiments to land initial conditions carried out (M18)
MS1.3 - Climate prediction assimilating sea ice data in their initial conditions (M12)
MS1.4 - High resolution climate predictions carried out (M24)

Deliverable WP1:
D1.1 - Article on the role of land surface on heat waves (M24)

D1.2 - Article on the role of Arctic sea ice on the mid-latitude climate (M24)
D1.3 - Technical memorandum on the role of high resolution on climate prediction skill (M36)
D1.4 - Article on the European 2016 and North American 2015 wind drought (M36)

<u>Work Package 2: Extreme climate events and climate change</u>
Months 1-36
Louis-Philippe Caron (BSC) 100%
Omar Bellprat (BSC) 50%
Alasdair Hunter (BSC) 25%
Postdoc 2 (BSC) 100%

Task 2.1. An initialized coupled event attribution approach
Postdoc 2 (50%), Alasdair Hunter (15%), Omar Bellprat (20%)

Disentangling the role of global warming on past extreme events from natural drivers studied in WP1 is a challenge. The most commonly adopted strategy is to retrospectively simulate an extreme event using two ensemble experiments: one consisting of simulations including all radiative forcings as observed (including anthropogenic greenhouse gases) and a counterfactual ensemble in a world that might have been if no climate change would have occurred (including only natural radiative forcings) (Stott et al., 2016). Current event attribution methodologies use predominantly atmosphere-only simulations that are forced by SSTs and sea-ice in which the climate change signal can be suppressed (Folland et al., 2015, Massey et al., 2015). This is a different approach than S2S prediction but pursues a similar objective.

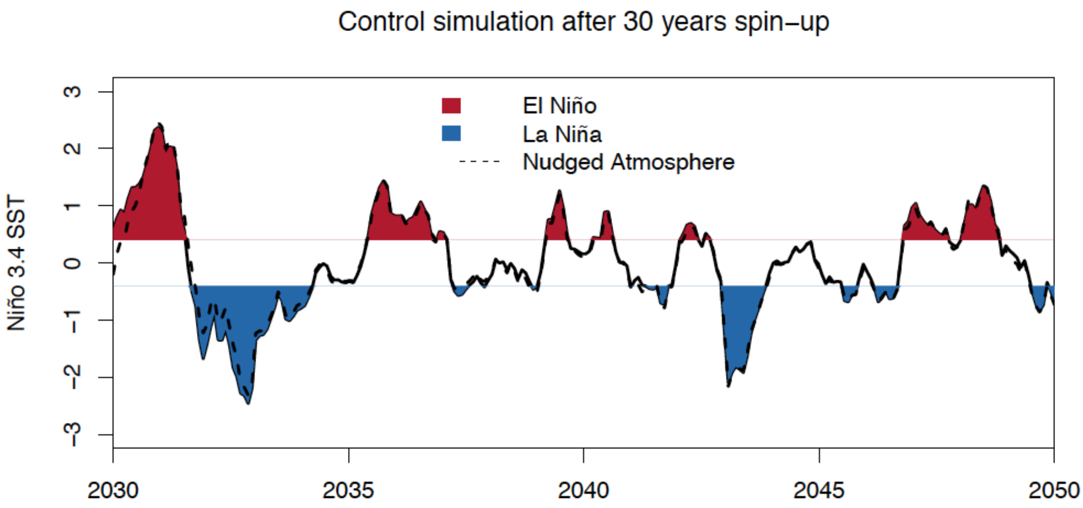

Figure 3: *Proof-of-the-concept for coupled event attribution. The figure shows tropical SST variability in a control simulation using EC-Earth3 indicating El Niño and La Niña states which develop at an interannual basis. A second experiment, initialized from from a different ocean state, is relaxed to the atmospheric circulation of the control simulation leading to indistinguishable variability of SSTs. Using this approach a simulation nudging the observed circulation of the past century but with pre-industrial conditions of greenhouse gases will provide a coupled initial state where no climate change occurred.*

In this task, we propose to develop and test a novel approach that allows to attribute extreme events using coupled simulations as in S2S predictions. This methodology would bridge the two activities and *allow to simultaneously predict and attribute extreme events in a forecasting* context. Extreme events could hence be attributed before they even occur. This has advantages to previous approaches which require to simulate the event retrospectively and which rely on simulations that do not account for atmosphere-ocean interactions. We propose for this purpose to generate initial coupled climate conditions in which the effects of climate change have been removed. This can be done by relaxing the model atmospheric circulation in a coupled model towards the observed re-analysis while keeping radiative forcings at pre-industrial levels. The atmospheric circulation is the main driver of the ocean circulation (Deser et al., 2010) which hence adapts this forcing. This strategy has recently proved efficient in EC-Earth3 as shown in figure 3. Temperatures would no longer increase and also no a-posteriori correction of the observed SSTs, the cryosphere or soil moisture are necessary in contrast to current approaches. As a comparison, a simpler approach will be tested which removes the climate change response as simulated by the CMIP5 integrations directly from the re-analysis without physically consistent relaxation. These new coupled event attribution approach will be compared to the current quasi-operational event attribution systems in the collaboration with the University of Oxford (weather@home).

Task 2.2. Attribution of the extreme el Niño 2016
Postdoc 2 (50%), Alasdair Hunter (10%), Omar Bellprat (20%)

The attribution approach proposed in task 2.1. will pave the way to attribute extreme events which are inherently coupled such as an extreme El Niño event. This is currently not possible using state-of-the-art attribution methodologies. The El Niño which occurred in 2015/2016 caused enormous impacts world-wide such as irreversible coral bleaching, exacerbated energy consumption, agricultural losses and human discomfort (Thirumalai et al., 2017). Such a strong a El Niño has not been observed since 1997/98 and recent studies indicate that strong El Niño events might become more intense as a consequence of global warming (Cai et al., 2014). The strong El Niño event which occurred last year might hence have already been favored by ongoing warming conditions.
In this task, we will apply the coupled attribution methodology developed under Task 1.1 to the 2015/2016 El Niño event as a demonstrator of the novel approach. 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. 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.

Task 2.3. Changes in hurricane activity
Louis-Philippe Caron (50%), Omar Bellprat (10%)

One of the limitation in regards to investigating the impact of climate change on tropical cyclone activity is the coarse resolution of climate models. Tropical cyclone are, comparatively speaking, relatively small atmospheric phenomena (~100 km). Climate models are capable of producing tropical cyclone-like disturbances, forming in some of the same basins where cyclones are generally observed and at the same period of the year, but these storms are typically much larger and much weaker than real tropical cyclones. Increasing the model resolution has been shown to produce significant improvement in the simulation of tropical cyclone activity (Caron et al., 2011). Here, we propose to investigate the impact of anthropogenic climate change on hurricane activity by comparing tropical cyclone activity in present and future climate conditions using the latest version of EC-Earth (v3.2), ran in coupled mode at high resolution (~25 km in both the atmosphere and the ocean). To that end, we will run a continuous 100-year climate simulation covering the 1950-2050 period, using a high-end emission scenario of the Shared Socio-Economic Pathways. A similar experiment will be performed by our French collaborator at CRNM with the ARPEGE model and analysed in parallel to the simulation performed with EC-Earth. Detecting and tracking tropical cyclones require a software than can identify the storms in the climate output and provide information as to their physical characteristics (e.g. intensity of the surface winds). As such, in parallel to the climate integration, we will proceed to install a tropical cyclone tracker (a few such softwares are available, so it is not necessary to develop a new one). We will install the GFDL vortex tracker system, as it provides some information on the size of the storms, information that is not usually provided by the trackers. Beside comparing the number and the intensity of the tropical cyclones, this tool will allow us to compare the size of the storms between future and present climate (something that has not been explored before). And it is well known that the destructiveness of the storms is linked to both to their intensity and their size: a combination of these two metrics provides a much more accurate picture of the potential destructiveness of a cyclone than the intensity alone. A good example of that is hurricane Sandy, which was a fairly weak, but very large, storm when it made landfall in 2012.

Task 2.4. Extreme 2005 hurricane season: a climate perspective
Louis-Philippe Caron (50%), Omar Bellprat (10%)

Natural hazard managers and policymakers need the best possible information regarding the recurrence intervals of hazards such as tropical cyclones. From what we know it is clear that there must be an upper limit on the yearly incidence of tropical cyclones due to limits to the energy available for their formation and intensification. This limit has not yet been quantified or justified by either theory or numerical simulation, however. Establishment of a practical upper limit would establish a baseline for the worst-case scenario of seasonal tropical cyclone occurrence, which would then be useful information for risk assessment. Here, we investigate whether the extreme level of tropical cyclone occurrence in 2005 in the North Atlantic is close to the maximum possible or whether it is possible for the current climate to generate a more extreme tropical cyclone season in this region?
We will analyze two very long (millennial) climate model simulations of the current climate to understand whether the favourable climate conditions of 2005 for tropical cyclones in the North Atlantic are ever equalled or exceeded over a longer period of time than the available observations. The climate model simulations in question are two 1,000 year control simulations from the CSIRO model and the EC-Earth model. Both are coupled ocean-atmosphere models and so generate their own climate variability and appear to have a good simulation of the climate variables relevant to tropical cyclone formation. Favorable climate conditions for tropical cyclone formation can be deduced from the construction of cyclone genesis parameters (GP), which provide information on how favorable to tropical cyclone formation the ocean-atmosphere system is (different GP will be considered as defined in Emanuel, et al., 2004; Tippett et al., 2011; Bruyere and Holland, 2012). Further simulations using the higher-resolution Japanese MRI-AGCM 100 member ensemble (Mizuta et al. 2012) will be used to evaluate the envelope of possible realisations of the 2005 SST conditions might lead to different atmospheric states. From the analysis of the 1000-year control simulations, if there are past atmospheric conditions that are outside of this envelope, this would provide further justification for concluding that 2005 was not the most favorable possible tropical cyclone season in the Atlantic, which would then indicate that further risk management measures might have to be put into place in this region beyond those needed for a possible repetition of the 2005 hurricane hazard.

Milestones WP2:
MS2.1 - Historical simulations with and without anthropogenic effect (M24)
MS2.4 - 1950-2050 high resolution simulation ready (M24)
MS2.3 - Hurricane tracker installed and adapted to BSC infrastructure (M18)
MS2.2 - Long pre-industrial control simulations downloaded (M3)

Deliverable WP2:
D2.1 - Article on coupled event attribution and the extreme 2015/2016 El Niño (M36)
D2.2 - Article on the role of climate change on tropical cyclone activity (M36)
D2.3 - Article on the 2005 tropical cyclone activity in context (M18)

6. Planning

	Year 1				Year 2				Year 3			
Month	M3	M6	M9	M12	M15	M18	M21	M24	M27	M30	M33	M36
WP1	T 1.1: Heat waves and land-surface coupling											
	T 1.2: Arctic sea-ice extremes and mid-latitudes											
					T1.3: Role of resolution in sub-seasonal-to-seasonal predictions							
					T1.4: Prediction of wind droughts for renewable energy							
WP2	T 2.1: A coupled event attribution approach											
							T 2.1: Attribution of the extreme El Niño					
	T 2.3: Extreme 2005 hurricane season											
				T 2.4: Changes in hurricane activity								
Milestones				M1.1 M1.3 M2.2		M1.2		M1.4 M2.1 M2.3				M1.3 M1.4 M2.1 M2.4
Deliverables								D1.1 D1.2 D2.2 D2.3				D1.3 D1.4 D2.1

Gantt chart of the PANDA project: *Each column spans a three-month period with its last month indicated in the second row. T denotes the different tasks of the WPs.*

7. Detail of the workforce needed

The two-postdoctoral scientists are requested to carry out successfully this ambitious project. They will be co-supervised by Omar Bellprat, Louis-Philippe Caron and Chloe Prodhomme, three experienced and renowned scientists with experience in mentoring students, and which were each awarded the highly competitive Juan de la Cierva fellowship.

Postdoc 1 (24 PM) will work on improving the prediction of extreme climate events as described in WP1. He will specifically be responsible to carry out the high-resolution hindcast required for tasks 1.3 and carry out the core analysis on analysing the impact of horizontal resolution on extreme climate events. This will particularly involve the understanding how the resolution impacts atmospheric circulation patterns frequently associated with extreme events (e.g. blocking). The Postdoc will further carry out the two case studies on the North American and European wind drought extremes determining the causes for the anomalous circulation regimes as defined in task 1.4

Postdoc 2 (24 PM) will work on establishing the proposed event attribution approach as described in WP2. He will specifically carry out the historical climate simulations which are relaxed to the atmospheric circulation as reconstructed by the re-analysis of the 19th century. The Postdoc will consequently apply the approach to the extreme El Niño which occured in 2015/2016 as demonstrator of the methodology and compare the system to current systems that carry out extreme event attribution at a semi-operational basis: The weather@home network at the University of Oxford and the HadGEM3-A system at the UK Met Office.

8. Services and infrastructure available and needed for PANDA

The PANDA project will be carried out within the climate prediction group (CPG) of the Earth Sciences Department at the Barcelona Supercomputing Center (BSC). The CPG undertakes innovative, challenging research that ensures the development of high quality climate services. The Climate Prediction group aims at developing regional and global climate prediction capability for time scales ranging from a few weeks to a few decades into the future (sub-seasonal to decadal climate prediction). This objective relies on expanding our understanding of the climate processes through a deep analysis of the strengths and weaknesses of state-of-the-art climate forecast systems in comparison with the most up-to-date observational datasets, and on exploiting these detailed analyses to refine the representation of climate processes in our climate forecast systems and as well as their initialization. It is composed by 14 research scientists and 3 students. It receives IT support from the Computational Earth Sciences group in the department. The software engineers work on supercomputing over different platforms. They have a highly qualified technical expertise to deal with complex parallelized codes such as the ones that will be used within this proposal. Besides, the members of the unit work with freely available software developing post-processing and diagnostic tools that are openly shared under GNU licenses with the rest of the community, strengthening the efficiency and impact of the work developed. They also maintain a common data repository competitive with what is available in the leading climate research institutions to ensure that the research carried out makes use of the latest, highest quality observational datasets. Thanks to the host infrastructures (detailed below) and unique human resources (with a ratio of one technician for every two researchers), the climate prediction group can run state-of-art sub-seasonal-to seasonal ensemble climate prediction system.

Local HPC Marenostrum4 and other IT infrastructure: BSC operates since beginning of July the new HPC system Marenostrum4 (MN4) replacing the former system Marenostrum3 (MN3). MN4 has a capacity of 11 Petaflops/s and which as such be 10 times faster than MN3 but it will require only 30% more energy. The HPC contains 3400 compute nodes with Intel Xeon processors disseminated in 48 racks. A central memory of 390 Terabytes ensures the operation of memory intensive applications such as the global climate models EC-Earth. MN4 has recently been ranked the 13th largest HPC system on the globe. The Earth Science department has already successfully ported climate model EC-Earth to MN4 and found a 40% increase in efficiency in comparison to MN3 using the same number of cores. The Earth Science Department operates separately from MN4 a data storage system and three fat nodes with a total of 64 computing nodes to store and analyse climate model data output.

Competitive computing resources obtained to date: Competitive computing resources obtained to date: Thanks to many national and international partnerships with high-performance computing centers, the climate prediction group is able to run state-of-the art climate models with a large number of ensemble members. Available computing time worth more than 1 million euros per year just in electricity costs have been obtained on the following institutions and programs: 1) Red Española de Supercomputación (RES); 2) PRACE Tier 0 and 1 (using platforms in Sweden, Spain and the UK); 3) European Centre for Medium-Range Weather Forecasts (ECMWF); 4) INCITE (US DoE's program, offering computing time on Titan), 5) RIKKEN (the K-computer), 6) MIRA.

Equipment (consumables): The experiments carried out and retrieved for PANDA will require additional data storage on the local data storage totalling 80 TB raw space. This demand will require the acquisition of 1 JBOD disk cabinets which cost about 6.000 euros and 20 4TB disks which cost 220 euros each. This makes a total of **10’400 euros**. 2 additional desktops will be purchased for the two post-doctoral scientists for a total cost of **3’000 euros** and 2 laptops will also be purchased for the international exchange in Europe with the University of Oxford, MétéoFrance and ETH Zurich leading to a total cost of **1’600 euros**.

Publications: As described in the workplan, we foresee six articles, three of which on improving the predictions of extreme climate events and three articles on coupled event attribution and the influence of climate change on tropical cycles. With an average cost of 2000 euros per publications, that makes an approximate budget for publication of about **12.000 euros**

Travels and invitation of collaborators: Several travels are planned for the scientists involved in PANDA (4 core members + 2 postdoctoral scientists), to attend any conference that would be organized on prediction or attribution of extreme events.The main conferences interesting fot the project would be the following: - The European Geosciences Union General Assembly (EGU) in Austria. - The American Geophysical Union annula meeting in the USA. - The International Detection and Attribution Group" (IDAG) meeting (venue to be confirmed) - The Interational meeting of statistical climatology (IMSC) (venue to be confirmed) - The AMS Conference on hurricane and tropical meteorology in the USA - The Hurricane and Climate Change Summit, Greece. That makes a total of about **18.000 euros**. Each of the European collaborators (E. Fischer, A. Weisheimer, A. Weigel, F. Chauvin) will be further invited to stay at BSC for a one-week and one of the North American collaborators (M. Brodault) for two weeks leading to a total cost of **9.425 euros.**

C.2. IMPACTO ESPERADO DE LOS RESULTADOS

International research activities

Project PANDA targets one of the most pressing questions in climate science - a how can our society adapt to current and future extreme climate events. Climate variability and change is felt most intensively through the occurrence of extreme events. Improving the prediction and understanding of extreme events is therefore now one of the highest priority set by international climate panels. PANDA contributes as such to two grand-challenges defined by the World Climate Research Programme (WCRP): weather and climate extremes and regional near-term climate prediction. Furthermore, the combination of these two aspects is one of CLIVAR’s Research Focus: Understanding and Prediction of Weather and Climate Extreme Events. The research questions in PANDA are also aligned with international activities on early-warning systems within the United Nations (UN) Sendai framework for Disaster Risk Reduction (DDR).

Operationalisation through European Union climate services

Results obtained on predicting and attributing extreme climate events will contribute to the European Union Copernicus Climate Change Service (C3S). Seasonal prediction is one of the three pillars of C3S and BSC is leading its quality assurance project within C3S (QA4Seas). Advancing the C3S seasonal forecast systems to predict extreme climate events is going to be the next great challenge. The contribution of PANDA could therefore lead to the development of early warning systems for European climate extremes such as heat waves and cold spells which is fundamental information for the renewable energy and insurance sector. C3S is further planning to establish an operational event attribution service in with several European institutions involved including BSC. The proposal of a coupled event attribution approach within the seasonal prediction would allow expanding the development of an attribution system that combines seasonal prediction and attribution of extreme events. This is seen as the ultimate objective of event attribution as described in the support letter of the leading scientist in the field.

International collaboration and dissemination

The project will be carried out in collaboration with world-leading institutions in the field prediction and of attribution (ETH Zurich, Univ. Oxford, MétéoFrance) with members of both WCRP grand-challenges and a member of CLIVAR. The collaboration with the reinsurance sector (SwissRe) and the renewable wind energy sector (Nnergix) will ensure links outside academia. The results obtained in PANDA are expected to lead to six scientific publications in first quartile impact journals and dissemination leaflets for the wind energy sector and reinsurance sector. The results will be further disseminated using the BSC climate services that are continuously developing. This will lead for instance to direct interaction with partners from the local and international wind energy sector interested in the case studies wind droughts. Further dissemination will be achieved through the BSC climate services portal where we will illustrate the degree to which past extreme events could have been anticipated and the role played by climate change in these events. This work will represent the first steps towards operationalizing extreme climate event prediction and attribution based on sub-seasonal-to-seasonal forecasting systems. The results and practice will feed to national (AEMET) and international operational centers (C3S) able to provide long-lead prediction of heat and cold waves, prolonged precipitation and wind droughts for both Spanish and European society.

C.3. CAPACIDAD FORMATIVA DEL EQUIPO SOLICITANTE

Not applicable

C.4. IMPLICACIONES ÉTICAS Y/O DE BIOSEGURIDAD

Nothing to declare.

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To Whom It May Concern:

10 July 2017

Re: **Prediction and Attribution of Extreme Climate Events (PANDA)**

I am delighted to support and participate in the proposed PANDA project, allowing us to build up our collaboration with Omar Bellpratt and the Barcelona Supercomputing Centre initiated under the FP7 EUCLEIA project. Predicting and understanding extreme weather events and trends in extreme weather risk remains one of the highest-impact applications of climate science, central to the development of climate services. Proper attribution of meteorological hazards is essential to the correct interpretation of trends in weather-related losses, and the purely empirical approaches traditionally used by the insurance industry break down when trends are non-linear, multiple drivers are involved, and the climate is changing faster than return-times of of interest. All of these challenges apply to European weather risk at present, particularly in the Mediterranean region where the impacts of anthropogenic climate change are felt earliest. A new challenge following the Paris Climate Change Agreement is to contribute to the proposed periodic stocktake process, which is likely eventually to include an assessment of observed impacts of anthropogenic climate change.

The physically-based approach to modelling meteorological hazards using high-resolution coupled atmosphere-ocean models is clearly the way forward, and this project will be using world-class modelling tools and supercomputing infrastructure. I anticipate the meteorological event-sets that PANDA will generate will be a fertile resource themselves. We in Oxford would be delighted to contribute coordinated ensemble experiments using the climateprediction.net/weatherathome distributed computing system (which uses a very different design, based on a nested regional model driven with observed and counterfactual ("natural") sea surface temperatures) for a systematic comparison of results with Omar Bellpratt's simulations. This would also be a welcome opportunity, at essentially zero cost, to promote the use of distributed computing to understand extreme weather risk among the Spanish public and provide members of the public, students and schoolchildren to participate directly in extreme weather research.

I have long believed that the fully coupled "counterfactual seasonal forecast" proposed (WP2) by the Principal Investigator, Omar Bellpratt, represents the most robust and physically justifiable approach to the attribution problem, and I am delighted that a major modelling and seasonal forecasting centre is finally taking up the challenge. The prescribed-sea-surface-temperature experiments that formed the backbone of the EUCLEIA and now the EUPHEME project must ultimately be superseded by a fully coupled design. Hence the PANDA project promises to be pioneering one of the central components of climate services over the coming decade.

Yours sincerely,

Myles Allen, Principal Investigator, climate*prediction*.net

Nnergix
Energy Forecasting Services
Joan Miquel Anglès
Business Development Manager

Dr. Omar Bellprat
Lead researcher for Seasonal prediction and attribution of extreme events
in the Earth Siciences Department,Barcelona Supercomputing Center
Barcelona, Spain

Date: June 28th, 2017

Letter of support for the Prediction AND Attribution of Extreme Climate Events (PANDA) project

Nnergix is a data mining and energy forecasting service designed by renewable energy industry professionals. It is obvious that our company is paying a lot of attention to the development of climate services in Europe, following with attention the investigations of climate centres involved in this research activity. From an operational point of view, BSC clearly appears as the unique group in Spain that is likely to provide seasonal forecasts in an operational way. We are expecting the possibility to improve our forecast energy products thanks to the development of seasonal predictions and the assessment of extreme events. For this reason, I would like to offer my enthusiastic support for the Omar Bellprat proposal “*Prediction AND Attribution of Extreme Climate Events*” (PANDA). Omar Bellprat will provide a substantial effort to increase the performances of European climate forecast systems.

Three main reasons encourage me to support his project: (1) BSC is highly active in the development of climate services, by being involved in several European projects devoted to the valorisation of climate research for applications in the energy sector. Based at BSC, Omar Bellprat will efficiently share its results with the other European climate centres; (2) I hope its research activities to contribute to the improvement of the forecasts quality in Europe; (3) the BSC climate services team will support Omar Bellprat to reach practical applications of its research trough an improvement of the climate forecast systems and its dissemination to the users of seasonal forecasts.

I would be happy to collaborate more with Omar Bellprat in the future, hoping to reinforce the links between public and private groups facing together the challenging issue of energy management.

Yours sincerely,

Nnergix
Energy Forecasting Service