Convocatorias 2015
Proyectos EXCELENCIA y Proyectos RETOS
Dirección General de Investigación Científica y Técnica
Subdirección General de Proyectos de Investigación

AVISO IMPORTANTE

En virtud del artículo 11 de la convocatoria **NO SE ACEPTARÁN NI SERÁN SUBSANABLES MEMORIAS CIENTÍFICO-TÉCNICAS** que no se presenten en este formato.

La parte C de la memoria no podrá exceder de 20 páginas.

Lea detenidamente las instrucciones para rellenar correctamente esta memoria, disponibles en la web de la convocatoria.

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

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

Dr Virginie Guemas

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

TÍTULO DEL PROYECTO: Hiatus en temperatura de superficie del siglo XXI: Investigación, Atribución, comprensión Teórica y experimentos Únicos de Sensibilidad

ACRÓNIMO: HIATUS

RESUMEN Máximo 3500 caracteres (incluyendo espacios en blanco):

Producir predicciones climáticas interanuales a decadales fiables constituye un reto social con numerosas aplicaciones socioeconómicas (agricultura, energía, salud, recursos hídricos, seguros). El clima es, por ejemplo, uno de los factores clave que influyen en la producción de la uva y del vino por afectar a la idoneidad de ciertas variedades de uva en una región en particular, así como el tipo y la calidad del vino producido, lo que constituirá la aplicación principal de este proyecto. Aceptar el reto de predecir el clima a escala interanual a decadal se apoya tanto en la previsibilidad de la variabilidad del clima generado internamente como en la estimación de la rapidez del calentamiento global forzado externamente. Mientras la mayoría de las oscilaciones climáticas alrededor de la tendencia al calentamiento durante los últimos 50 años están relativamente bien entendidas, el siglo XXI ha estado marcado por una pausa intrigante del calentamiento global de la superficie a pesar de una acumulación sostenida de los gases de efecto invernadero en la atmósfera. Este fenómeno, conocido como hiatus, ha provocado un intenso debate científico sobre sus causas y ha llamado la atención considerablemente en los medios. El equipo aplicante ha logrado recientemente una identificación robusta de la absorción de calor por el océano como una causa mayor del hiatus - estudio publicado en Nature Climate Change - a través de la explotación de predicciones climáticas retrospectivas certeras del hiatus con hasta 5 años de antelación. Sin embargo, estas predicciones climáticas retrospectivas no fueron totalmente exploradas para comprender los mecanismos completos que condujeron al hiatus, lo que implica que parte de la señal de esa pausa no fue capturada. El proyecto HIATUS propone una investigación más profunda de estas simulaciones y de predicciones climáticas similares generadas con una versión del sistema de predicción del clima más reciente. Balances

regionales completos de calor, análisis dinámicos exhaustivos y experimentos de sensibilidad a la reducción de información, están planeados combinados con una validación usando nuevas fuentes de datos observacionales. Otras hipótesis sugeridas en la literatura, como el papel de los aerosoles estratosféricos, serán además exploradas para explicar la parte de la señal del hiatus no capturada por otros procesos. El conocimiento adquirido durante el proyecto HIATUS nos permitirá determinar si se debe esperar que la desaceleración del calentamiento global experimentada en los últimos quince años siga en la próxima década o si deberíamos observar un efecto rebote con un calentamiento global intensificado. Por último, el impacto de la variabilidad de la temperatura decenal sobre el rendimiento agrícola en los últimos 50 años y en la próxima década se estimará, con un enfoque en el sector vitivinícola, explotando la información climática más fiable que surja del proyecto HIATUS. Este proyecto se llevará a cabo con el Laboratoire d'Etudes en Géophysique et Océanographie Spatiales (LEGOS, Toulouse, France), el Mediterranean Institute of Oceanography (MIO, Toulon, France), la Universidad Complutense de Madrid (UCM, Madrid) y la Universidad Politécnica de Madrid (UPM, Madrid).

PALABRAS CLAVE: calentamiento global, absorción oceánica de calor, aerosol estratosférico, predicción climática decadal, producción vitivinícola.

TITLE OF THE PROJECT: XXIst century surface temperature Hiatus: Investigation, Attribution, Thorough Understanding and Sensitivity experiments

ACRONYM: HIATUS

SUMMARY Maximum 3500 characters (including spaces):

Producing trustworthy interannual to decadal climate predictions constitutes a societal challenge with numerous socio-economic applications (agriculture, energy, health, water resources, insurance). Climate is, for example, one of the key factors that influences grape and wine production affecting the suitability of certain grape varieties to a particular region as well as the type and quality of the wine produced, which will be the main application of the results of this project. Taking up the challenge of predicting the climate on interannual to decadal timescales relies on both the predictability of the internally generated climate variability and the externally forced rate of global warming. Whereas most of the climate oscillations around the long-term warming trend over the last 50 years are relatively well understood, the XXIst century has been marked by an intriguing pause of the near surface global warming despite a sustained buildup of atmospheric greenhouse gas levels. This so-called hiatus has triggered an intense scientific debate on its causes and has drawn considerable media attention. The applying team has recently achieved a robust identification of the enhanced ocean heat absorption as a main cause for the recent hiatus, published in Nature Climate Change, through the exploitation of successful retrospective climate predictions of the hiatus until 5 years ahead. However, these retrospective climate predictions were not fully explored to understand the complete mechanisms leading to the recent hiatus, and as a result part of the recent hiatus signal was not captured. The HIATUS project proposes a deeper investigation of these simulations and similar climate predictions generated with a newer model version. Complete regional heat budgets, thorough dynamical analyses and information-denial sensitivity experiments are planned, combined with a validation against innovative observational data sources. Other hypotheses suggested in the literature, such as the role of stratospheric aerosol concentrations, will additionally be explored to explain the uncaptured part of the hiatus signal. The knowledge gathered during the HIATUS project will allow us to determine whether the global warming slowdown experienced in the last fifteen years should be expected to last in the coming decade or whether we should observe a rebound effect with an intensified global warming. Finally, the

impact of decadal temperature variability on agriculture yield over the last 50 years and the coming decade will be estimated, with a focus on the wine sector, exploiting the most reliable climate information that can be provided within the HIATUS project. This project will be carried out with the Laboratoire d'Etudes en Géophysique et Océanographie Spatiales (LEGOS, Toulouse, France), the Mediterranean Institute of Oceanography (MIO, Toulon, France), the Universidad Complutense de Madrid (UCM, Madrid) and the Universidad Politécnica de Madrid (UPM, Madrid).

KEY WORDS: global warming, ocean heat uptake, stratospheric aerosol, decadal climate prediction, wine production.

Parte B: INFORMACIÓN ESPECÍFICA DEL EQUIPO

B.1. RELACIÓN DE LAS PERSONAS NO DOCTORES QUE COMPONEN EL EQUIPO DE TRABAJO (se recuerda que los doctores del equipo de trabajo y los componentes del equipo de investigación no se solicitan aquí porque deberán incluirse en la aplicación informática de solicitud). Repita la siguiente secuencia tantas veces como precise.

1. **Nombre y apellidos:** Oriol Mula-Valls
   Titulación: ingeniero
   Tipo de contrato: técnico
   Duración del contrato: indefinido

B.2. 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:** Virginie Guemas
   Referencia del proyecto: Acuerdo de subvención nº 641727
   Título: PRIMAVERA : PRocess-based climate sIMulation: AdVances in high resolution modelling and European climate Risk Assessment
   Investigador principal: Francisco Doblas-Reyes
   Entidad financiadora: European Commission under the Horizon 2020 Programme
   Duración: 01/11/2015-31/10/2019
   Financiación recibida: 1277425,00 euros
   Relación con el proyecto que se presenta: está algo relacionado
   Estado del proyecto o contrato: concedido

2. **Investigador del equipo de investigación que participa en el proyecto/contrato:** Isadora Christel Jiménez
   Referencia del proyecto: Acuerdo de subvención nº 641811
   Título: IMPREX : IMproving PRedictions and management of hydrological Extremes
   Investigador principal: Francisco Doblas-Reyes
   Entidad financiadora: European Commission under the Horizon 2020 Programme
   Duración: 01/10/2015-30/09/2019
   Financiación recibida: 240000,00 euros
   Relación con el proyecto que se presenta: està algo relacionado
   Estado del proyecto o contrato: concedido

3. **Investigador del equipo de investigación que participa en el proyecto/contrato:** Virginie Guemas and Neven Fuckar
   Referencia del proyecto: Acuerdo de subvención nº 308378
   Título: SPECS : Seasonal-to-decadal climate Prediction for the improvement of European Climate Services
   Investigador principal: Francisco Doblas-Reyes
   Entidad financiadora: European Commission under the Seventh Framework Programme (FP7)
   Duración: 01/11/2012-31/01/2017
   Financiación recibida: 1615305,00 euros
   Relación con el proyecto que se presenta: está muy relacionado
   Estado del proyecto o contrato: concedido

4. **Investigador del equipo de investigación que participa en el proyecto/contrato:** Virginie Guemas
   Referencia del proyecto: Acuerdo de subvención nº 603521
   Título: PREFACE : Enhancing prediction of tropical Atlantic climate and its impacts
   Investigador principal: Francisco Doblas-Reyes

Entidad financiadora: European Commission under the Seventh Framework Programme (FP7)
Duración: 01/11/2013-31/01/2017
Financiación recibida: 266569,00 euros
Relación con el proyecto que se presenta: está algo relacionado
Estado del proyecto o contrato: concedido

5. **Investigador del equipo de investigación que participa en el proyecto/contrato:** Virginie Guemas
Referencia del proyecto: Acuerdo de subvención nº 308291
Título: EUPORIAS : European Provision of Regional Impact Assessment on a Seasonal-to-decadal timescales
Investigador principal: Francisco Doblas-Reyes
Entidad financiadora: European Commission under the Seventh Framework Programme (FP7)
Duración: 01/11/2012-31/01/2017
Financiación recibida: 571212,50€
Relación con el proyecto que se presenta: está algo relacionado
Estado del proyecto o contrato: concedido

6. **Investigador del equipo de investigación que participa en el proyecto/contrato:** Virginie Guemas
Referencia del proyecto: Acuerdo de subvención nº 607085
Título: EUCLEIA : European Climate and weather Events: Interpretation and Attribution
Investigador principal: Francisco Doblas-Reyes
Entidad financiadora: European Commission under the the Seventh Framework Programme (FP7)
Duración: 01/01/2014-31/12/2016
Financiación recibida: 138282,00€
Relación con el proyecto que se presenta: está algo relacionado
Estado del proyecto o contrato: concedido

7. **Investigador del equipo de investigación que participa en el proyecto/contrato:** Virginie Guemas
Referencia del proyecto: Acuerdo de subvención nº 282378
Título: DENFREE: Dengue research Framework for Resisting Epidemics in Europe
Investigador principal: Francisco Doblas-Reyes
Entidad financiadora: European Commission under the the Seventh Framework Programme (FP7)
Duración: 01/01/2012-31/12/2016
Financiación recibida: 409304,50€
Relación con el proyecto que se presenta: está algo relacionado
Estado del proyecto o contrato: concedido

8. **Investigador del equipo de investigación que participa en el proyecto/contrato:** Virginie Guemas
Referencia del proyecto: Acuerdo de subvención nº312979
Título: IS-ENES2 : Infrastructure for the European Network for Earth System modelling
Investigador principal: Francisco Doblas-Reyes
Entidad financiadora: European Commission under the FP7 framework
Duración: 01/04/2013-31/03/2017
Financiación recibida: 57420,00€
Relación con el proyecto que se presenta: está algo relacionado
Estado del proyecto o contrato: concedido

9. **Investigador del equipo de investigación que participa en el proyecto/contrato:** Virginie Guemas
Referencia del proyecto:
Título: POLARIS: Prévisibilité saisOnnière de L'ARctIque avec des Systèmes climatiques

Investigador principal: Virginie Guemas
Entidad financiadora: Agence Nationale de la Recherche (ANR, France)
Duración: 01/01/2016-31/12/2019
Financiación recibida: 0 euros
Relación con el proyecto que se presenta: está poco relacionado
Estado del proyecto o contrato: pendiente de resolución

10. **Investigador del equipo de investigación que participa en el proyecto/contrato:** Virginie Guemas
Referencia del proyecto:
Título: Climate modelling User group: CMUG phase 2/Cloud-ECV in phase 1 - Cross-assessment of SST, SI, ocean colour and sea-level data for seasonal and decadal predictions and CCI4MIP simulations
Investigador principal: Virginie Guemas
Entidad financiadora: European Space Agency
Duración: no determinada
Financiación recibida: 92126,75 euros
Relación con el proyecto que se presenta: está algo relacionado
Estado del proyecto o contrato: pendiente de resolución

Parte C: DOCUMENTO CIENTÍFICO. Máximo 20 páginas.

C.1. PROPUESTA CIENTÍFICA

1. Los antecedentes y estado actual de los conocimientos científico-técnicos de la materia específica del proyecto, incluyendo, en su caso, los resultados previos del equipo de investigación y la relación, si la hubiera, entre el grupo solicitante y otros grupos de investigación nacionales y extranjeros. Si el proyecto aborda un tema nuevo, deben indicarse los antecedentes y contribuciones previas del equipo de investigación que justifiquen su capacidad para llevarlo a cabo.

The Global Framework for Climate Services (GFCS), created under the governance of the World Meteorological Organisation (WMO), has illustrated the increasing need for actionable regional climate information for the next decade for economic, industrial and political planning, as well as to provide critical support in areas such as agricultural planning, food security and disaster preparedness. Providing climate information a few years in advance requires predicting both the radiatively forced climate change and the superimposed internal climate variability (Hawkins and Sutton, 2009). The superimposition of these two sources is illustrated in Figure 1, which shows the evolution of the observed global mean temperature from 1970 onward (Morice et al, 2012): the long-term warming trend, which is mainly attributed to the increasing greenhouse gas concentration, is modulated on interannual to decadal timescales by warm and cold periods.

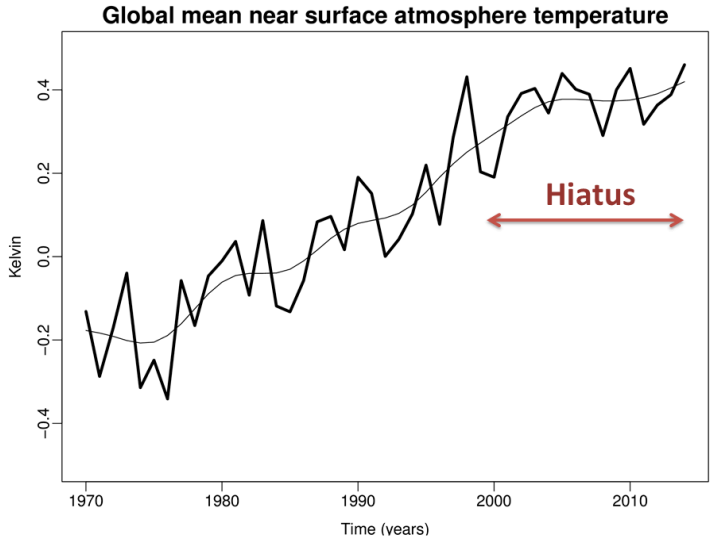

Figure 1: Global mean temperature anomaly relative to the 1971-2000 period. Bold line: Annual mean HadCRUT4 (Morice et al, 2012) observations. Thin line: Smoothed HadCRUT4 observations filtered to remove variability on timescales of less than a decade, computed by application of a 21-point binomial filter to the annual time series.

For example, cold periods were observed after the volcanic eruptions of El Chichón and Pinatubo in 1982 and 1991 respectively, which led to an increase in stratospheric aerosol concentration during the next few years, thus reducing the solar energy that reaches the Earth's surface (Robock, 2000). Cold and warm events were also associated respectively with La Niña events in 1974-1976 and with El Niño events in 1972-1973, 1982-83 and 1997-98, for example, the dominant mode of internal variability in the tropical Pacific with worldwide teleconnections and fingerprints (Diaz et al, 2002). Whereas most of the climate oscillations around the long-term warming trend over the last 40 years are relatively well understood, the XXIst century has been marked by an intriguing pause of the near surface global warming (Figure 1; Easterling and Wehner, 2009; IPCC, 2013) despite a sustained buildup of atmospheric greenhouse gas levels. This so-called hiatus has triggered an intense scientific debate on its causes and has drawn considerable media attention (Nature Climate Change special edition, March 2014). A deep understanding of the mechanisms responsible for this past hiatus, only partially understood so far as explained below in more detail, is

essential to reach confidence in the climate predictions for the next decade. Climate is furthermore one of the key factors that influences grape and wine production (Fraga et al, 2014), affecting the suitability of certain grape varieties to a particular region as well as the type and quality of the wine produced (Gladstones, 1992). Temperature seems to have the most profound effect on viticulture as the temperature during the winter dormancy affects the budding for the following growing season (Jones et al, 2005), beginning in spring following consistent daytime temperatures of 10º Celsius (Winkler et al, 1974). Prolonged high temperature and/or frosts outside of the usual winter period can have a negative impact on the yield and quality of the grapes as well as the wine they produce. Future temperature variability means that growers will have to adapt to climate change using various strategies (IPCC, 2013). The ability to reliably and accurately anticipate temperature changes over the coming years is essential to develop optimal strategies: user decisions such as which grape variety to choose, how irrigation systems need to be adapted, and which regions to plant are all influenced by future changes in climatic conditions. The questions that the HIATUS project will address therefore are:

1. What are the mechanisms behind the global warming slowdown observed in the last 15 years and their regional fingerprints?
2. Is this slowdown expected to last in the coming decade or could a rebound effect with an intensified global warming occur?
3. What has been and will be the impact of decadal temperature variability on agriculture yield, with a focus on the wine sector?

Changes in the Earth's radiative budget through changes in the solar activity (Hansen et al, 2011), the stratospheric water vapour (Solomon et al, 2010), the stratospheric (Solomon et al, 2011; Fyfe et al, 2013; Santer et al, 2014) and the tropospheric aerosols (Kaufmann et al, 2011) have been hypothesized to cancel out, at least partially, the greenhouse effect during the past hiatus. Internal climate system variability has also been suggested to be a main contributor via an increased ocean heat uptake (OHU) that would have compensated for the Earth's total (top-of-atmosphere) heat storage (Meehl et al, 2011; Katsman and van Oldenborgh 2011; Guemas et al, 2013; Watanabe et al, 2013; England et al, 2014). More details about these different hypotheses are provided below:

*[Hypothesis 1 - H1] Solar cycle minimum: The solar activity and the associated energy that reaches the Earth exhibit a cycle with an approximate 11-year period (Hathaway, 2010). A maximum occurred in 2001 whereas the subsequent minimum peaking in 2008 was particularly deep and long with a particularly weak maximum afterwards in 2014. This anomalously low input solar energy could have contributed to a deficit of the top-of-atmosphere (TOA) net budget by about 0.1 W.m-2 during the last decade (Hansen et al, 2011; Kaufmann et al, 2011), which should be compared with the approximate net TOA budget of 0.5 W.m-2 (Loeb et al, 2012; Trenberth and Fasullo, 2009).

*[H2] Stratospheric water vapour: According to satellite data, the tropical stratospheric water vapour concentration dropped in the early 2000s (Solomon et al, 2010), triggered by a decrease in sea surface temperature (SST) and in deep convection reaching the tropopause and injecting water vapour into the stratosphere. The water vapour, being a greenhouse gas, would have caused a deficit of the TOA net budget by about 0.1 W.m-2 in 2001-2005 (Solomon et al, 2010). However, since this decrease in TOA net budget constitutes a response to a decreased tropical SST associated with the hiatus, this mechanism appears to be a consequence of the hiatus occurring at the Earth's surface rather than its triggering mechanism.

*[H3] Stratospheric aerosols: Between major volcanic eruptions such as those of El Chichón and Pinatubo, the stratospheric aerosol concentration is substantially lower than during these eruptions and referred to as the "background stratospheric aerosol concentration". This background concentration is made of tropospheric aerosols reaching the tropopause and entering the stratosphere thanks to the occurrence of deep convection as well as of minor tropical volcanic eruptions that could inject part of their aerosols up into the stratosphere (Solomon et al, 2011). The climate change projections and predictions

performed within the framework of the Coupled Model Intercomparison Project Fifth Phase (CMIP5; Taylor et al, 2005) used the Amman et al (2003) or the Sato et al (1993) stratospheric aerosol datasets, which both considered the background aerosol concentration to be null during the last fifteen years. The dataset by Vernier et al (2011) shows that this concentration was not zero but rather causing a deficit of the TOA net budget by about 0.1 W.m-2 (Solomon et al, 2011; Fyfe et al, 2013; Santer et al, 2014). This estimation could be even higher considering the impact of recent small eruptions on stratospheric aerosol load (Ridley et al, 2014).

*[H4] Tropospheric aerosols: Chinese coal consumption more than doubled from 2003 to 2007 (the previous doubling took 22 years, 1980-2002). In this four-year period, Chinese coal consumption accounted for 77% of the 26% rise in global coal consumption (EIA, 2008) whereas global coal consumption increased only by 27% in the twenty two years between 1980 and 2002 (EIA, 2008). The associated rapid rise in tropospheric sulphate aerosol concentrations, which tend to reflect solar energy, was not accounted for in the climate change projections and predictions performed within the framework of the CMIP5 project (Taylor et al 2005). According to Kaufmann et al (2011), this additional tropospheric aerosol concentration would have contributed to a 0.06 W.m-2 deficit of the TOA net budget.

*[H5] Ocean heat uptake (OHU): Despite a reduced TOA net budget due to H1-H4 compensating partially for the greenhouse effect, recent satellite data showed that the net input TOA energy remained in the [0.5-1] W.m-2 interval during the past decade (Trenberth et al, 2009; Loeb et al, 2012). An increase in OHU below the upper ocean layers has been suggested to overcompensate for the TOA imbalance (Meehl et al, 2011; Katsman and van Oldenborgh, 2011), therefore allowing the lower atmosphere temperature to remain stationary. These studies were based on an ensemble of climate change projections in which the TOA net budget remained around 1 W.m-2. Several hiatus periods occurred in these projections in which enhanced OHU in the Atlantic Ocean linked to a weakening of the Atlantic meridional overturning streamfunction and in the tropical Pacific linked to the strengthening of the subtropical overturning cells was the main mechanism explaining these hiatus periods. A robust identification of the enhanced ocean heat absorption as a main cause for the recent hiatus has been achieved only recently, by the HIATUS team, through the analysis of successful retrospective climate predictions of the hiatus up to 5 years ahead (Guemas et al, 2013, thereafter G13). Indeed, sensitivity experiments in which only changes in the Earth's radiative forcings were accounted for did not capture the global warming slowdown. A particularly remarkable result from this study is that the retrospective climate predictions did not only capture the observed global mean temperature anomalies before and during the hiatus, which could have been argued to be a simple persistence of the observed initial states of the climate predictions (Meehl and Teng, 2012), but they also captured the observed tendency in global mean temperature along the predictions. This demonstrated the ability of the forecast system to capture the mechanisms leading to the global warming slowdown with a proper initialization of the internal climate system variability. Most of the TOA excess input energy was found to be absorbed in the top 700m of the ocean at the onset of the warming slowdown, 65% of it in the tropical Pacific and Atlantic oceans (G13).

The HIATUS project will build on this experience from the applying team. The climate predictions produced in G13 were not fully explored to extract the complete mechanisms leading to the recent hiatus. A deeper investigation of these simulations and of similar climate predictions generated with a newer model version is proposed within HIATUS. Furthermore, part of the recent hiatus signal was not captured in G13 climate predictions. Sensitivity experiments to the solar cycle activity did not show any significant surface signal (G13). However, the role of tropospheric and stratospheric aerosol concentrations using the newly released datasets has not been explored yet. Finally, the consequences of the hiatus of the last fifteen years for the climate of the next decade and for socio-economic activities, in particular for the wine production, were not explored in G13 and will be during the HIATUS project. This project will be carried out with the following no-cost partners:

1. LEGOS (Laboratoire d'Etudes en Géophysique et Océanographie Spatiales, Toulouse, France, http://www.legos.obs-mip.fr/) and the MIO (Mediterranean Institute of Oceanography, Toulon, France, https://www.mio.univ-amu.fr/). The expertise of our collaborators (Benoit Meyssignac, Alexandre Ganachaud, Karina Von Schuckmann, Remy Roca) on sea level measurements can be exploited to estimate the regional ocean heat storage, in particular in the deep ocean where classical networks of thermometers and bathythermographs do not provide any information. Climate predictions generated for G13 and within HIATUS with a newer model version will be compared with these data to further investigate the mechanisms behind the enhanced OHU.

2. UCM (Universidad Complutense de Madrid, Madrid, Spain, https://www.ucm.es/). The expertise of our collaborators (Maria Belén Rodríguez de Fonseca, Elsa Mohino Harris, Teresa Losada) on the tropical Atlantic and Pacific variability, El Niño, their modulation on decadal to multidecadal timescales and their teleconnections with continental changes are an important asset for the investigation of the mechanisms behind the recent hiatus proposed within the HIATUS project since these regions correspond to those where most of the OHU took place according to G13. Predictions produced within HIATUS will be provided to UCM while sensitivity experiments in the Atlantic Ocean produced by UCM will be exchanged with IC3.

3. UPM (Universidad Politécnica de Madrid). The expertise of our collaborators (Margarita Ruiz Ramos, Inés Mínguez) on the determination of agricultural yield depending on climate conditions will be exploited for predicting the yield of the next decade, based on climate predictions integrating the knowledge gathered during the HIATUS project.

At the Spanish level, the applying team stands as the national reference on the global warming hiatus of the last fifteen years, mainly thanks to the G13 article in a high impact journal which, according to the report from the communication team of our institute, was mentioned in more than 8000 articles in the international (New York Times, ABC Sciences, Le Figaro ...), national (La Vanguardia, El Periodico ...) and local media. At the international level, the list of groups working on this topic with which the applying team has on-going collaborations, and with which there will be scientific exchanges on the HIATUS project is:

1. The Large-Scale Meteorology and Climate Group of the French National Meteorological Research Centre (http://www.cnrm.meteo.fr/), where Virginie Guemas is part-time visitor, especially with Hervé Douville and Aurore Voldoire, who investigated the enhanced OHU theory to explain the hiatus with a different climate model than the one used by the applying team (Douville et al, 2015).

2. The Climate Modelling and Global Change team from the Centre Européen de Recherches et de Formation Avancée en Calcul Scientifique (France; http://www.cerfacs.fr/3-25708-Home.php), in particular with Christophe Cassou, who leads the project "*Mechanisms for climate Oscillations and Retroactions at Decadal tImesCale: Uncertainties and Sensitivity*" (MORDICUS), where the applying team is a partner, focused on decadal to multidecadal variability and predicting the climate of the next decade.

3. The Department of Meteorology of the Reading University (UK; http://www.reading.ac.uk/meteorology/), especially with Jon Robson and Rowan Sutton who coordinate the investigations of the recent hiatus within the SPECS project funded by the European Commission and led by the applying team.

4. The European Centre for Medium Range Weather Forecasts (ECMWF, UK; http://www.ecmwf.int), especially with Magdalena Balmaseda, who estimated the deep ocean heat storage during the hiatus (Balmaseda et al, 2013).

5. The Climate Research Seismology and Oceanographic Research group of the Dutch Weather Service (KNMI, The Netherlands; http://www.knmi.nl/), in particular with Geert Jan van Oldenborgh who was one of the first suggesting the OHU as a main cause for the hiatus (Katsman and van Oldenborgh, 2011) and with which the applying team has close collaboration via the EC-Earth consortium.

6. The VARCLIM team from the Oceanography and Climate Laboratory (France, https://www.locean-ipsl.upmc.fr), especially with Juliette Mignot and Eric Guilyardi, with which the CFU organizes meetings every six months to exchange on research progress on various topics.

The HIATUS project proposed here will stand as the Spanish contribution to the internationally coordinated *Decadal Climate Prediction Project*, as part of the Coupled Model Intercomparison Phase 6 (CMIP6), which will feed the preparation of the Intergovernmental Panel on Climate Change (IPCC) sixth report. It will also contribute to the *Decadal climate variability and predictability* and the *Consistency between planetary energy balance and ocean heat storage* research foci of the World Climate Research Programme CLIVAR (Climate and Ocean Variability Predictability and Change) project. The PI is the first member ever of the CLIVAR Scientific Steering Group from a Spanish institution.

References (for this section and all sections of part C1):

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2. La hipótesis de partida y los objetivos generales perseguidos, así como la adecuación del proyecto a la Estrategia Española de Ciencia y Tecnología y de Innovación y, en su caso, a Horizonte 2020 (H2020) o a cualquier otra estrategia nacional o internacional de I+D+i. Si la memoria se presenta a la convocatoria de RETOS, deberá identificarse el reto cuyo estudio se pretende abordar y la relevancia social o económica prevista.

Despite a sustained production of anthropogenic greenhouse gases, the Earth's mean near-surface temperature paused its rise during the 2000-2015 period. Understanding this pause is crucial to provide trustworthy climate predictions for the coming decade and predictions of the associated socio-economic impacts. The CFU's investigation is the only Spanish contribution, to the best of our knowledge, to the provision of climate information in the near term at both the global and regional scales. The general objectives of HIATUS are:

1. to investigate the mechanisms behind the global warming slowdown observed in the last 15 years,
2. to provide a trustworthy prediction of the climate of the next decade, integrating the knowledge gathered during the HIATUS project,
3. to provide an assessment of the impact of temperature variability over the past and the next decades on agriculture yield, with a focus on the wine sector.

These objectives complement those of the H2020 PRIMAVERA and IMPREX projects in which the applying team is participating and the submitted H2020 "*European coordination of climate services activities, 2nd part*" (ECOMS2) coordinating and support action proposal. HIATUS aims at addressing the "Reto: Acción sobre el cambio climático y eficiencia en la utilización de recursos y materias primas", by providing the best possible estimate of the climate conditions to be expected in the next decade, as well as its potential socioeconomic impacts in terms of agricultural yield. 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).

3. Los objetivos específicos, enumerándolos brevemente, con claridad, precisión y de manera realista (acorde con la duración prevista del proyecto). En los proyectos con dos investigadores principales, deberá indicarse expresamente de qué objetivos específicos se hará responsable cada uno de ellos.

The specific objectives that the HIATUS project will tackle are:

1. to generate new climate predictions and sensitivity experiments similar to those published in G13 but with a newer model version to assess whether the hiatus signal is better captured (part of the hiatus signal remained uncaptured in G13) and to ensure that there is a Spanish contribution to the decadal prediction component of CMIP6 [M1-M18]
2. to exploit further the G13 predictions and those produced within the HIATUS project to investigate the mechanisms behind the enhanced OHU during the hiatus, by confronting the model data to innovative observational data sources [M7-M30]
3. to produce original sensitivity experiments and exploit those produced by collaborators to confirm the mechanisms behind the enhanced OHU extracted from the comparison with observational data [M19-M30]
4. to assess the contributions of stratospheric aerosols to the hiatus signal [M13-M24]
5. to produce an exceptionally large ensemble of climate predictions for the next decade sampling all the known sources of uncertainty and integrating all the knowledge generated during the HIATUS project [M25-M36]
6. to develop a climate service targeted to the needs of wine producers, based on the best possible climate information generated during the HIATUS project [M1-M36].

4. El detalle de la metodología propuesta, incluyendo la viabilidad metodológica de las tareas. Si fuera necesario, también se incluirá una evaluación crítica de las posibles dificultades de un objetivo específico y un plan de contingencia para resolverlas.

Our six objectives will be tackled in six different work packages (WP) whose interactions are summarized in Figure 2, together with the interactions with our external partners.

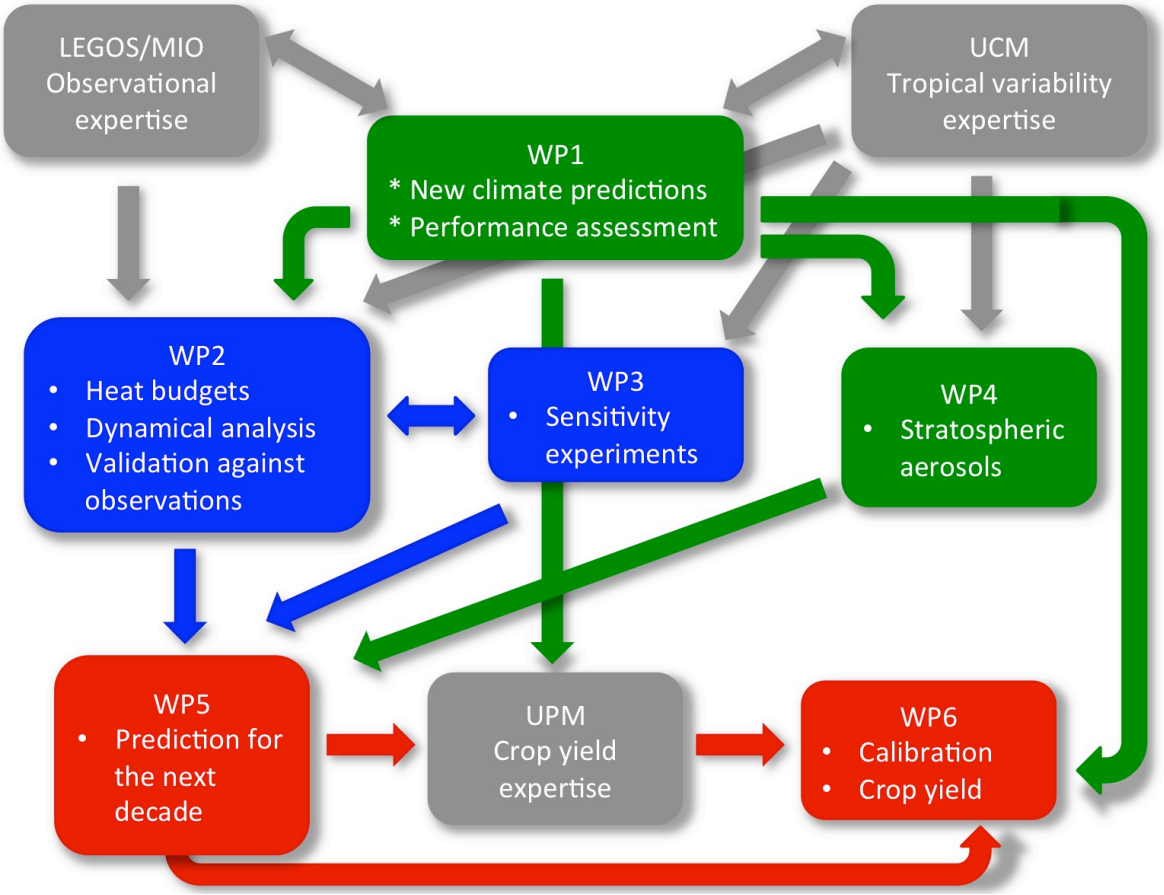

Figure 2: Interactions between the different work packages of the HIATUS project (in colour), and between the HIATUS team and external partners (in grey). Green, blue and red colours differentiate the WPs on which will focus the three postdocs needed for the HIATUS project (see Section C.1.7).

WP1: EC-Earth3 retrospective climate prediction exercise to capture the hiatus (M1-M18)

Participants: Virginie Guemas (IC3) 10%
Postdoc 1 (IC3) 50%
Postdoc 2 (IC3) 10%
Muhammad Asif (IC3) 30%
Oriol Mula-Valls (IC3) 10%

The ability to predict retrospectively the hiatus of the last fifteen years will be assessed in a newer version of the dynamical forecast system used in G13, EC-Earth3. To be able to calibrate (i.e. bias correct) the climate predictions over the last fifteen years and exploit them for process analysis, it is necessary to perform a full retrospective prediction exercise from 1960 to 2015, i.e. the same period as used in G13 extended to present. Ten-member predictions will be initialised every year on 1st November and extended initially eight years into the future. The atmospheric initial conditions will come from ERA40 (before 1979) and ERA-interim (after 1979) reanalysis of the ECMWF, the ocean ones from the NEMOVAR-ORAS4 ocean reanalysis of the ECMWF, and the sea ice ones from an in-house sea ice reanalysis produced within the framework of the MINECO-funded PICA-ICE project (CGL2012-31987). Following the CMIP5 experimental setup, observed external radiative forcings will be used until 2005 and the RCP4.5 scenario will be used afterwards. Diagnostics of the Earth's heat budget will be coded jointly with the LEGOS/MIO collaborators while diagnostics on the atmosphere and ocean dynamics will benefit from the collaboration with UCM prior to running the experiments so that these diagnostics are computed online reducing the data traffic. The ability to capture the hiatus with EC-Earth2.3 in G13 was limited to 5 years into the future. If better performance is obtained with EC-

Earth3, we will extend the forecast length from 8 years into the future up to 10 or 15 years. The sensitivity to the initialisation start date will be assessed by running additional 10-member predictions initialised every year on 1st February, 1st May and 1st August and extended eight months into the future. Finally, to assess the role of initialisation from observational data on the ability to capture the hiatus of the last fifteen years, 10-member historical simulations will be also run with EC-Earth3 initialised in 1850 from a pre-industrial control simulation and extended until 2030 using the exact same external radiative forcings as used for the climate predictions. In these sensitivity experiments, the internal variability will not be in phase with the observed one. Preliminary analysis of these experiments will include reproducing the diagnostics implemented in G13 and comparing the performance of EC-Earth3 with those of EC-Earth2.3, namely assessing: 1. how close predicted anomalies in global mean surface temperature are from their observed counterpart, 2. how close the trends along the predictions are from the observed trends for surface temperature (i.e to which extent the forecast system is able to capture the mechanisms leading to the hiatus), 3. to which extent the predicted global OHU compensate for the TOA energy input to the climate system and how much of the hiatus can be explained by enhanced OHU. The outputs from these experiments will be shared with the LEGOS/MIO, the UCM and the UPM to enhance the collaboration beyond HIATUS.

Milestones: S1.1 [M6] Ensemble of historical simulations performed
S1.2 [M12] Full set of retrospective climate predictions performed
S1.3 [M18] Analyses of G13 reproduced on WP1 predictions

WP2: Potential mechanisms for increased OHU in G13/WP1 forecasts (M7 - M30)

Participants: Virginie Guemas (IC3) 20%
Neven Fuckar (IC3) 40%
Postdoc 2 (IC3) 40%
Oriol Mula-Valls (IC3) 5%

Refined analyses will be performed on both the G13 and WP1 retrospective climate predictions to understand the potential mechanisms by which the ocean could have increased its heat storage in the last fifteen years and in which regions. Detailed heat budget analyses will be performed in each basin, separating the tropical, mid-latitudes and high latitudes regions and the ocean mixed layer, the upper ocean (down to 500m) below the mixed layer, the intermediate ocean (500m-1km) and the deep ocean (below 1km) in the simulations. These heat budgets will be validated, whenever and wherever possible, against the most recent observational data such as the EN4 temperature and salinity profiles (Good et al, 2013), as well as estimates by the LEGOS/MIO of the vertically integrated ocean heat content obtained from sea level budget analysis including thermosteric sea level measurements and ocean mass variation measurements. Once the regions responsible for most of the increased total OHU identified, analyses of the ocean dynamics and the role of coupling with the atmosphere will be conducted in the simulations over these regions to extract potential mechanisms behind this increased total OHU beyond the mechanisms already suggested in the literature explaining only part of the signal. In particular, changes in the strength of the ocean gyres, overturning circulation and the main currents in each ocean basin will be diagnosed as well as changes in the surface large-scale atmospheric circulation, convective activity and meridional cells in the simulations. The conclusions will be validated against observational data whenever possible. Analyses of the changes in the Atlantic and Pacific El Niño variability in the last fifteen years with respect to previous periods performed by the UCM team as well as their impact on continental areas will also contribute to the objectives of WP2.

Milestones: S2.1 [M18] Detailed regional heat budgets validated against observational data
S2.2 [M30] Assessment of dynamical changes responsible for the OHU

Deliverables: D2.1 [M24] Publication(s) submitted on the identification of the regions playing a key role in the increased OHU during the hiatus

WP3: Robust identification of OHU mechanisms through sensitivity experiments (M19 - M30)

Participants: Virginie Guemas (IC3) 20%
Neven Fuckar (IC3) 30%
Postdoc 2 (IC3) 40%
Muhammad Asif (IC3) 5%

The analyses from WP2 will be complemented by sensitivity experiments to validate further the mechanisms suggested in WP2. These sensitivity experiments will be based on the experimental protocol used by England et al (2014) and Douville et al (2015) to investigate the mechanisms explaining the increased OHU in the tropical Pacific in the past decade. These two studies used regional constraints on wind stress or surface temperature toward observational datasets in historical experiments to capture the hiatus uncaptured by similar historical experiments but without observational constraints. Here, we will perform sensitivity experiments to our WP1 or G13 successful retrospective climate predictions by applying regional constraints toward an earlier simulated period (for example, 1970-1985) to assess whether the constrained variable was key in the ability to capture the recent hiatus. A larger set of dynamical and thermodynamical variables (temperature, salinity, wind, precipitation, currents,…) will be considered to perform a robust identification of the mechanisms responsible for the increased total OHU. The constraints will be applied by nudging or replacement, depending on the variable considered, following the expertise of the UCM.

Milestones: S3.1 [M24] Sensitivity experiments to oceanic quantities performed
S3.2 [M30] Sensitivity experiments to atmospheric quantities performed

Deliverables: D3.1 [M30] Publication(s) submitted on the dynamical changes responsible for the increased OHU during the hiatus

WP4: Role of stratospheric aerosols (M13-M24)

Participants: Virginie Guemas (IC3) 20%
Neven Fuckar (IC3) 20%
Postdoc 1 (IC3) 40%
Muhammad Asif (IC3) 15%
Oriol Mula-Valls (IC3) 10%

Part of the hiatus signal remained uncaptured with the G13 retrospective climate predictions and we expect a similar result with the WP1 predictions. These experiments both use the CMIP5 external radiative forcings that, as explained in the introduction, underestimate the background stratospheric aerosols related to minor volcanic eruptions and transport from the troposphere to the stratosphere. Under WP4, a set of retrospective climate predictions will be run replacing the CMIP5 stratospheric sulphate aerosol specification by the dataset from Ridley et al (2014), the rest of the experimental setup being exactly the same as used to produce WP1 retrospective climate predictions except that only start dates from 1990 to present will be run in WP4. Indeed, the updated stratospheric aerosol datasets used in WP4 only show differences with previous datasets during the last fifteen years. A 10-member historical simulation will also be run replacing the stratospheric aerosol datasets used for CMIP5 by the same updated dataset as used in WP4 climate predictions. The sensitivity experiments performed under WP4 will allow assessing the role of stratospheric aerosols on the recent hiatus by comparing experiments using different forcing datasets, but also assessing the interactions between the aerosol composition changes and the internal climate variability by comparing historical simulations and climate predictions. There are also evidences suggesting that stratospheric aerosols could have an impact on rainfall over continental regions like the Sahel (Haywood et al, 2013). We will analyse the simulations performed in WP4 to test the extent to which the stratospheric aerosols might have contributed to the Sahel rainfall recovery observed since the 1990s.

Milestones: S4.1 [M18] Sensitivity experiments to the stratospheric aerosols performed

Deliverables: D4.1 [M24] Publication submitted on the role of stratospheric aerosols on the hiatus

WP5: Integration of the HIATUS knowledge into a 2018-2028 climate prediction (M25-M36)

Participants: Virginie Guemas (IC3) 10%
Neven Fuckar (IC3) 10%
Isadora Christel Jimenez (IC3) 20%
Postdoc 1 (IC3) 10%
Postdoc 2 (IC3) 10%
Postdoc 3 (IC3) 20%
Oriol Mula-Valls (IC3) 5%

A trustworthy climate prediction for the next decade should properly account for the background stratospheric aerosols and potential volcanic eruptions that could occur in the next decade, and for the current state of internal climate variability and its possible evolution. Under WP5, several 10-member climate predictions for the next decade will be generated with EC-Earth3 using the same sources of initial conditions as used under WP1 and using: 1. the four different scenarios proposed by Solomon et al (2013) and Fyfe et al (2013) to extend Ridley et al. (2014) background stratospheric aerosol concentration dataset into the future, 2. a scenario in which a Pinatubo-like eruption would occur in the next years. These would make an ensemble comprising a total of 50 members of climate prediction for the next decade. All these predictions would account for the evolution of the internal climate variability as seen by the EC-Earth3 dynamical forecast system, i.e. an imperfect evolution due to biases and misrepresented processes. Relying on the deep analyses performed under WP2 and WP3 and the best possible knowledge about biases and misrepresented processes in EC-Earth3 obtained from these analyses, the 50 members will be corrected to obtain the best possible estimate of the climate for the near future.

Milestone: S5.1 [M33] 50-member climate prediction with EC-Earth3 performed

Deliverable: D5.1 [M36] Publication submitted on the range of possibilities for the climate of the next decade

WP6: Climate service for the agriculture sector: wine yields (M1-M36)

Participants: Virginie Guemas (IC3) 20%
Isadora Christel Jimenez (IC3) 80%
Postdoc 3 (IC3) 80%
Oriol Mula-Valls (IC3) 20%

WP6 will use the results coming from WP1 and WP5 to make a full evaluation of the impact of temperature variability on viticulture over the past and future decades respectively. Due to their inherent uncertain nature, probabilistic climate predictions are difficult to access and poorly understood, and therefore underutilised by end user groups. Therefore, the overall aim of this WP is to develop a climate service for the wine sector to bridge this communications gap and to ensure that research reaches the industry and society in a timely and usable manner. This will be carried out using a process known as co-production (Cash et al., 2006), involving both users from the wine sector (Bodegas Torres, SOGRAPE Vinhos S.A., ...) and climate scientists. The first objective is to understand the specific needs of end users in the wine sector, such as their spatial and temporal regions of interest, as well as relevant temperature indices and thresholds. This information will be communicated to WP1 and WP5. A second objective will be to calibrate the predictions coming from these WPs to offer the most comprehensive and reliable set of probabilistic climate information alongside their full verifications for the end users. The third objective will be to co-develop user-tailored decision-support materials and tools in order to communicate the results so that they can be

applied to key decision-making processes. This will include factsheets, case studies and articles tailored to the wine sector. The factsheets will consist of two-pages that summarise the impact of temperature on wine yields over past and future, and the role of probabilistic predictions to minimise identified risks, describing the information and the meaning of a prediction. Additional fact-sheets will explain how end users can apply information from probabilistic climate predictions in decision-making processes by describing the temperature prediction quality assessment and its interpretation. Finally, the economic costs and benefits of using a probabilistic approach over a deterministic one for viticulture management will be summarised. This evaluation will be based on the interest-related loss or gain of the two different forecast approaches, and their respective profit/loss impact on decision making processes. The methodology used will be adapted from the weather roulette approach (Hagedorn and Smith, 2009). Case studies from the past will be analysed to demonstrate the role of climate predictions to anticipate key events that have impacted wine yields over the past decades. Articles on climate uncertainty and the impact of climate information to anticipate impacts to wine yields will be prepared for technical journals, to communicate the objectives and outcomes of the climate service for agriculture to targeted media. Finally, focused interviews at the end of the project will be carried out with end users to test the usefulness and usability of the climate service for agriculture in their practices. Interviews will be designed and tested to favour the co-production and evaluate the efficiency of the communication of the climate predictions. The interview will cover key “communication modes” of the predictions, such as their visualisation, value assessment and interpretation, by which the usefulness and usability of the scientific information, support materials and tools are determined. Possible improvements to refine the communication of the climate predictions and service will be made. Finally, we will benefit from the UPM expertise to evaluate the crop yields predictability associated to the climate data obtained from WP1 over the last 50 years. The WP5 outputs will be used to estimate the crop yields for the next decade. This pioneering approach will allow designing the tools and methods to transfer the decadal climate forecast outputs to useful and usable climate information for farmers in the wine sector.

Milestone: S6.1 [M6] Undertake and document user needs to feed back to WP1 and WP5.

Deliverable: D6.1 [M36] Delivery of a prototype climate service for agriculture, with a focus on the wine production sector.

5. La descripción de los medios materiales, infraestructuras y equipamientos singulares a disposición del proyecto que permitan abordar la metodología propuesta.

The HIATUS project will be carried out within the Climate Forecasting Unit (CFU) of the Institut Català de Ciències del Clima (IC3). The CFU undertakes innovative, challenging research that ensures the development of top-notch climate services. The unit has been a pioneer in the field, participating in the first European projects aimed at addressing the problems associated with co-development of climate information. More specifically, the CFU undertakes research for the development and assessment of dynamical and statistical methods for the prediction of global and regional climate on time scales ranging from a few weeks to several years. Sources of predictability and processes at the origin of model error play a major role in the assessment. The formulation of the predictions includes the development and implementation of techniques to statistically downscale, calibrate and combine dynamical ensembles and simple statistical forecasts to satisfy specific user needs. The CFU is composed by a core team of 1 senior scientist, Prof. Doblas-Reyes, 1 junior scientist, Virginie Guemas, 8 postdocs, 1 PhD student, 2 master students, 1 project manager, 4 climate services officers, 5 software engineers, 1 system administrator and 1 secretary. 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 CFU can run state-of-art seasonal-to-decadal ensemble climate prediction system.

Local HPC: The continuous increase of computing needs of the scientific community motivated the deployment of a High Performance Computing (HPC) cluster at IC3. The IC3 cluster is made of 48 homogeneous server blades. Each server blade has two "quadcore" processors, 48 GB main memory, 146 GB disk space and fast network interconnect (Infiniband). In order to share data (model code, input data and output data) among computing nodes, there is an I/O node which comprises 48 disks of 1TB each. In short, the computing cluster has 384 cores, 8.81 TB memory (RAM) and 55 TB of shared disk capacity. Moreover, the cluster has 97.2 TB tape backup capacity. The IC3 computing cluster is installed within a CPD of 17 m2.

Competitive computing resources obtained to date: Thanks to many national and international partnerships with high-performance computing centers, the CFU 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). The remaining resources are obtained from the IC3 cluster, which provides around 10% of the total computing time used.

Local Storage: A local data storage with 1.5 PB of capacity with high availability and replication is also available, as well as a set of associated computing nodes for post-processing (fat nodes). The local storage hosts at this stage a unique set of global climate predictions performed by IC3 in research mode and operationally by global producing centres around the world. A comprehensive dataset including observations and re-analyses is also available to the CFU members. All these datasets are kept up to date.

Fat nodes: One computing node to postprocess model outputs and preprocess initial conditions to perform climate simulations is available. It has 12 cores and 256 GB memory (RAM). It is accessible through ssh and can be used through schedulers that have been fine tuned for the kind of work the CFU carries out. Another computing node will be required to increase the postprocessing capacity for the project which will cost around **7838.68 euros**.

Desktops: All scientists have desktops with multi-core processors that are available through the local network and share exactly the same software and environment, offering a seamless environment to perform all sorts of diagnostics that do not require the large memory of the fat nodes.

Equipment - consumables: To store all the climate simulation outputs that will be produced during HIATUS, the storage system of the department will have to be expanded. For the amount of data that the project is expected to generate, we need around 0.5PB of raw space. That will require the acquisition of 3 disk cabinets (1 head node + 2 JBODs which cost about 21.000 euros) and 126 4TB disks (which cost about 27720 euros). This makes a total of **48720 euros**.

Publications: One publication, at least, is expected to describe the results for each of the following questions: 1. Which were the regions playing a key role in the increased ocean heat uptake during the past hiatus? 2. What are the dynamical changes responsible for this increased ocean heat uptake? 3. What was the contribution from the stratospheric aerosols to the past hiatus? 4. What is the range of possibilities for the climate of the next decade? 5. What is the impact of temperature on crop yield in the wine sector over the last 60 years, and what is the skill of hindcasts to represent this change? 6. What is the expected impact of

temperature on crop yield in the wine sector over the next decade? This makes a total of six publications at an average cost of 2,000 euros, i.e. a total of about **12000 euros**.

Travels: About 2 travels per year are planned for each one of the scientists involved in the project and one travel per year for each engineer to attend summer schools or international workshops or conferences such as the European Geosciences Union Annual Meeting or others more focused on climate variability and predictability on decadal timescales, the Earth's heat budget, or the aerosols ... that might be organised at a later stage, international meetings of the EC-Earth consortium, or to visit collaborators of the HIATUS project. This makes a total of about 40 travels for the whole duration of the HIATUS project and for the whole team with a total cost of about **50820 euros**.

Invitation of our collaborators: Each one of our collaborators at LEGOS/MIO, UCM or UPM will be invited for a one-week stay at least once during the HIATUS project to visit IC3. This makes a total of about 8 travels at an average cost of 1000 euros, i.e. a total of **8000 euros**

6. Un cronograma claro y preciso de las fases e hitos previstos en relación con los objetivos planteados en la propuesta.

	M3	M6	M9	M12	M15	M18	M21	M24	M27	M30	M33	M36
WP1												
WP2												
WP3												
WP4												
WP5												
WP6												
Milestones		S1.1 S6.1		S1.2		S1.3 S2.1 S4.1		S3.1		S2.2 S3.2	S5.1	
Deliverables								D2.1 D4.1		D3.1		D5.1 D6.1

Figure 3: Gantt chart of the HIATUS project. Each column spans a three-month period with its last month indicated in the top row. For instance, M3 corresponds to the first three months of HIATUS.

7. Si se solicita ayuda para la contratación de personal, justificación de su necesidad y descripción de las tareas que vaya a desarrollar.

Postdoc1 (36PM): Given the large amount of experiments that are expected to be produced, sufficient workforce beyond what the research group can provide is essential to the success of the project. The post-doctoral researcher requested will be the main person in charge of the generation of the decadal prediction experiments under WP1 and WP4. He/she will be leading the comparison of the decadal predictions and historical simulations performed under WP1 to assess the role of external radiative forcings in the hiatus, to which extent our climate predictions capture the mechanisms leading to the hiatus and how much of the hiatus signal can be explained by an increased OHU. This post-doctoral researcher will furthermore lead the analyses of the role of stratospheric aerosols on the hiatus. Finally, thanks to the experience he/she will have gained during the first two years of the HIATUS project, he/she will be able to add an important contribution to the correction of the climate predictions for the near future planned under WP5.

Postdoc2 (36PM): Given the large amount of data to be thoroughly analysed during this project, a substantial increase in the human resources of the research group is highly desirable. The post-doctoral researcher requested will contribute to the generation of the decadal prediction experiments under WP1 and he/she will lead the deep analysis planned under WP2, namely the identification of the regions playing a key role in the increased OHU

and the dynamical changes that could have caused this increased OHU. He/she will furthermore perform a large part of the sensitivity experiments planned under WP3 for a robust extraction of the main mechanisms responsible for the increased OHU and the recent hiatus. Finally, thanks to the experience he/she will have gained during the first two years of the HIATUS project, he/she will be able to add an important contribution to the correction of the climate predictions for the near future.

Postdoc3 (36PM): A dedicated position is required to facilitate and manage the interaction with the end users in WP6. He/she will spend time to understand the needs and expectations of both the climate science and its application in a decision-making context. He/she will also design and coordinate the development of the climate service for agriculture, through assessing its usefulness and usability in practice. This will require establishing collaborations with experts in communications, visualisations and social science. He/she will also be responsible for the dissemination of the project outcomes to a wider community in the agricultural sector, and for the completion of WP6 deliverables and milestones.

C.2. IMPACTO ESPERADO DE LOS RESULTADOS

1. Descripción del impacto científico-técnico social y/o económico que se espera de los resultados del proyecto, tanto a nivel nacional como internacional.

The HIATUS project will stand as the Spanish contribution to the international coordinated *Decadal Climate Prediction Project*, as part of the Coupled Model Intercomparison Phase 6 (CMIP6). It will also contribute to the *Decadal climate variability and predictability* and the *Consistency between planetary energy balance and ocean heat storage* research foci of CLIVAR, closely monitored by Virginie Guemas, member of the CLIVAR Scientific Steering Group. Given the substantial interest of the large public for the reasons behind the global warming slowdown in the last decade, as seen by the large success of the G13 article with more than 8000 citations in articles in the international (New York Times, ABC Sciences, Le Figaro ...), national (La Vanguardia, El Periodico ...) and local media, we expect even a larger enthusiasm for the results of the HIATUS project of larger scope and challenging objectives. The climate information that HIATUS plan to provide for the next decade will be of substantial socio-economic interests for applications such as in the energy or health sectors. Applications in the agriculture sector will be directly tackled by the HIATUS project which will provide an assessment of the impact of temperature variability on wine crop yields over the next decade. The spanish wine-makers *Sogrape Vinhos* and *Bodegas Torres* are enthusiastically supporting the HIATUS project, expecting that our scientific community will be able to provide climate information directly usable by them, which has not the been the case up to now. The interest of these private companies on our investigations may be representative of a large part of wine producers, in Spain and in the whole Europe.

2. El plan de difusión e internacionalización en su caso de los resultados.

To respond to the demand of the large public on information about the global warming slowdown and the climate to be expected in the next decade, we will organize at least two presentations intended to non-specialists, as already done by CFU in the past. A web page intended to non-specialists will also be setup on our website to present the main results of the HIATUS project. This web page will contain material targeting different audiences, from the general public to climate scientists, explaining the differences between the forced and natural climate variability and how this affects both people's lives and society. It is the first time such a web site will be set up and for this reason, both English and Spanish will be used.

At least six manuscripts will be submitted to international journals, as indicated in section C.1.5, of high-impact whenever possible. The results of the project will be of the research type and, hence, will not be the subject of commercial use. Instead, the results will be widely presented in scientific conferences, in courses and at the CLIVAR meetings. Frequent video-conferences will be organized with our national and international collaborators.

3. Si se considera que puede haber transferencia de resultados, se deberán identificar los resultados potencialmente transferibles y detallar el plan previsto para la transferencia de los mismos.

Any result with potential operational use and the associated technical know-how will be transferred to both the Agencia Española de Meteorología (AEMET) and the ECMWF. The project deliverables will be shared with the AEMET, which is the natural user of the climate forecast information at the Spanish level, to keep them informed about the progress of this sort of predictions. Being the body with competence on operational climate forecasting and a natural user of the Spanish climate research, AEMET will benefit from and take over the technological developments carried out throughout this project to improve climate prediction capability. The entire WP6 on climate services is additionally devoted to transfer of results toward private companies, i.e. transfer of climate information tailored to their specific needs. One main ilustration of this challenging issue is ilustrated by our contact with *Sogrape Vinhos* and *Bodegas Torres*. Looking at our scientific results, these companies will give us feedbacks very helpful to design climate information products shaped for wine-growers.

C.3. CAPACIDAD FORMATIVA DEL EQUIPO SOLICITANTE

1. El plan de formación previsto en el contexto del proyecto solicitado.

While most previous studies have focused on the mechanisms for the ocean heat uptake increase in the Pacific in the last decade (England et al, 2014; Douville et al, 2015), very little is known about the behaviour of the Atlantic Ocean although its ocean thermohaline circulation is suspected to have played a key role as well (Meehl et al, 2011; Katsman and Van Oldenborgh, 2011). We consider here a PhD project, complementary to the HIATUS project, that focus on the interannual to decadal variability and predictability of the North Atlantic thermohaline circulation and sea surface temperatures (SST), arising from both the internal variability of the climate system and from the external radiative forcings, over the last 60 years. A number of mechanisms for predictability of the North Atlantic Ocean dynamics and SSTs have been suggested (Cassou et al, 2007; Sutton and Allen, 1997; Delworth and Greatbach 2000; Persechino et al, 2012) and the predictability limit for the ocean thermohaline circulation has been estimated to reach between 5 and 20 years depending on the model and variable considered (Collins et al, 2006; Msadek et al, 2010). Despite a consensus on the potential predictability of the North Atlantic thermohaline circulation and SSTs, such consensus is not found regarding the mechanisms leading to this predictability and little is known about the reasons behind their predictability limit. This PhD project therefore aims at furthering our understanding of the mechanisms driving the interannual to decadal variability and predictability of the North Atlantic thermohaline circulation and SSTs and at extending their predictability limit through the following three objectives:

1. To assess the robustness of previously published mechanisms to explain the interannual variability and predictability of the North Atlantic thermohaline circulation and SSTs using the most recent observational datasets and idealized multi-model experiments produced within the framework of the APPOSITE NERC-funded project (http://arp.arctic.ac.uk/projects/arctic-predictability-and-prediction-seasonal-inte/)
2. To assess to which extent those mechanisms are captured by the EC-Earth coupled climate model in historical and present-day control simulations and their sensitivity to some parameterizations such as the ocean mixing and diffusion or the surface ocean-atmosphere heat fluxes, as well as their sensitivity to the specification of the atmospheric aerosol concentration.
3. To assess the ability of EC-Earth to predict the North Atlantic SSTs and thermohaline circulation with a focus on selected major events and to investigate the causes for the predictability limit of those major events.

These analyses will contribute to WP2 and WP3 of the HIATUS project. They will also ensure the Spanish contribution to the *Decadal Climate Prediction Project*, as part of CMIP6, and to the *Decadal climate variability and predictability* research foci of CLIVAR.

The PhD advisor will be Dr Virginie Guemas, the head of the Polar Climate Prediction research line at CFU and PI of HIATUS, who is an expert on seasonal to decadal climate prediction with a special emphasis on the recent global warming slowdown and the Arctic sea ice prediction. She has been PI of the 3-year MINECO-funded PICA-ICE project focused on the Arctic climate (2012-2015). She is member of the WCRP CLIVAR Scientific Steering Group, has contributed to the IPCC (Fifth Assessment Report) and is participating in several FP7 and H2020 projects; she has so far supervised 1 PhD student who defended in March 2015, has given several lectures at the university and has solid experience in coaching MsC/PhD students.

References unlisted in section C.1.1:

Collins M et al. (2006) Interannual to decadal climate predictability in the North Atlantic: A multimodel-ensemble study. J. Clim., 19, 1195-1203.

Cassou C, Deser C, Alexander MA (2007) Investigating the impact of reemerging sea surface temperature anomalies on the winter atmospheric circulation over the North Atlantic. J. Clim., 20, 3510-3526.

Delworth TL, Greatbatch RJ (2000) Multidecadal thermohaline circulation variability driven by atmospheric surface flux forcing. J. Clim., 13, 1481-1495.

Msadek R, Dixon KW, Delworth TL, Hurlin W (2010) Assessing the predictability of the Atlantic meridional overturning circulation and associated fingerprints. Geophys. Res. Lett., 37, L19608, doi:10.1029/2010GL044517.

Persechino A et al. (2012) Decadal-timescale changes of the Atlantic overturning circulation and climate in a coupled climate model with a hybrid-coordinate ocean component. Clim. Dyn., 39 (3-4), 1021-1042, doi:10.1007/s00382-012-1432-y.

Sutton RT, Allen MR (1997) Decadal predictability of North Atlantic sea surface temperature and climate. Nature, 388, 563-56.

2. Relación de tesis realizadas o en curso (últimos 10 años) con indicación del nombre del doctorando, el título de tesis y la fecha de obtención del grado de doctor o de la fecha prevista de lectura de tesis.

Since its creation in 2009, the CFU, in which the HIATUS project will be carried out, has mentored 5 PhD students:

1. Danila Volpi (January 2011 - March 2015) has defended her PhD entitled “Benefits and drawbacks of different initialization techniques in global dynamical climate predictions” on 27 March 2015 at the University of Reading. Virginie Guemas was her PhD advisor.
2. Luis Ricardo Lage Rodriguez (January 2010 - present) is currently writing his PhD entitled : “Improvement of seasonal climate prediction over the Mediterranean region” with a defense planned for fall 2015. His obtention of a permanent position in Brazil in Spring 2014 has delayed the writing and defense of his PhD that he is currently finishing on his spare time.
3. Aida Pintó (September 2012 - summer 2014) dropped her PhD entitled “Prediction of climatic extreme events at seasonal and decadal time scales” to carry out a career in fashion and as a professional athlete for triathlon.
4. Verónica Torralba Fernández (October 2013 - present) is currently carrying out her PhD on climate services for the renewable energy sector.
5. Oriol Tintó (June 2015 - present) is currently beginning his PhD on the efficiency of climate models.

3. Breve descripción del desarrollo científico o profesional de los doctores egresados del equipo de investigación.

1. Danila Volpi currently has 3 articles accepted, 4 submitted and 1 in preparation. She will be working as a post-doctoral researcher on the FP7 PREFACE project at CFU in the next few months until she finds a suitable post-doctoral position for her scientific background in a foreign institute.
2. Luis Ricardo Lage Rodrigues currently has a permanent position as a research assistant at the Center for Earth System Sciences (CCST) from the Brazilian National Institute for Space Research (INPE) on the validation of climate models.
3. Aida Pinto works now in the consultancy sector and is, in parallel, a professional athlete for triathlon.

C.4. IMPLICACIONES ÉTICAS Y/O DE BIOSEGURIDAD

Nothing to declare.