AGENCIA ESTATAL DE INVESTIGACIÓN - Convocatorias 2018
Proyectos de I+D de GENERACIÓN DE CONOCIMIENTO y Proyectos de I+D+i RETOS INVESTIGACIÓN

AVISO IMPORTANTE - La memoria no podrá exceder de 20 páginas. Para rellenar correctamente esta memoria, lea detenidamente las instrucciones disponibles en la web de la convocatoria. Es obligatorio rellenarla en inglés si se solicita más de 100.000,00 €.

IMPORTANT – The research proposal cannot exceed 20 pages. Instructions to fill this document are available in the website. If the project cost exceeds 100.000,00 €, this document must be filled in English.

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TÍTULO DEL PROYECTO (ACRÓNIMO): Análisis Lagrangiano del Impacto en el Ciclo Hidrológico Global de los Principales Mecanismos de Transporte de Humedad Atmosférica (LAGRIMA)

TITLE OF THE PROJECT (ACRONYM): LAGRangian analysis of the Impact on the global hydrological cycle of the Major Mechanisms of Atmospheric Moisture Transport (LAGRIMA)

1. PROPUESTA CIENTÍFICA - *SCIENTIFIC PROPOSAL*

C.1.1. The outstanding role of major mechanisms of atmospheric moisture transport in the hydrological cycle: Low Level Jets and Atmospheric Rivers:

The **review paper** by Gimeno et al. (2016) in the **Annual Review of Environment and Resources** (ARER) titled "**Major Mechanisms of Atmospheric Moisture Transport and Their Role in Extreme Precipitation Events**" affirms that **the major mechanisms of atmospheric moisture transport** (the nuclei of the atmospheric branch of the hydrological cycle) are **Low Level Jets** (LLJs) and **Atmospheric Rivers** (ARs). Both structures transport the major part of the available moisture in the atmosphere to latitudes further than its origin, and describe the link between evaporation from the ocean/continent and precipitation over the continents (Newman et al., 2012; Arraut et al., 2012; Ralph et al., 2005; Berg et al., 2015). This transport also includes rainfall over the oceans; althougt this component is not always addressed. Thus, moisture transport from sources towards continents/oceans establishes the connection between evaporation and continental/ocean precipitation (or the available moisture). This was also pointed in the review paper by Gimeno et al. (2012), published in the Review of Geophysics, about the origin of continental precipitation on a planetary scale. In a regional analysis, these mechanisms modulate extreme precipitation events, and the intensification (or reduction) of moisture transport modifies precipitation anomalies and the subsequent flooding (or drought). The possible changes in the position and occurrence of LLJs and ARs with their climatological behaviour can alter the precipitation patterns. Based on the indications regarding the lack of specific studies of the impacts and in the graphical summary of the ARER review by Gimeno et al. (2016), **a further analysis of the impacts of these structures is needed to understand the precipitation extremes in terms of atmospheric moisture transport and their evolution over time.**

The factors that need to be taken into account, from the perspective of climate change, are as follows:

- **Atmospheric Rivers** (ARs) are strongly connected with the occurrence of wind and rainfall extremes (e.g. Waliser and Guang, 2017; Ramos et al., 2018). An integral analysis of the ARs linked to moisture transport dynamics is crucial to gaining a deeper understanding of how these systems may be affected in warming scenarios, and of the overall impact on the distribution, intensity, and frequency of extreme events (Ralph et al., 2017).

- The **LLJs** modulate the annual cycle of moisture transport and provide a link to the tropic-extratropic interactions. The role of the LLJs, as moisture conveyors, has a marked response to variability modes associated with increases in SSTs – such as ENSO – which draws attention to the intensification of sensitivity of moisture transport to warming conditions. It is, therefore, important to explore how rises in SST and the associated evaporation may lead this LLJ-moisture transport dynamics to an intensification of the hydrological cycle, and to determine the conditions that constrain these characteristics.

The study in the context of other studies for exploring the sources of moisture:

Different methods – "analytical and box models", "physical water vapour tracers" (isotopes) and "numerical water vapour tracers" (including the Lagrangian and Eulerian approaches) –have been used to establish source-sink relationships for the atmospheric water vapour. A detailed intercomparison of the different methods is given in a paper published in Review of Geophysics by Gimeno et al. (2012). All of these provide useful information for the analysis, where the results depend on the assumptions made, and on the type and accuracy of the data used.

The knowledge of the source-sink moisture relationship is fundamental to understanding the atmospheric branch of the hydrological cycle. To this end, several groups around the world have been studying the transport of moisture using some of the different approaches described previously, and a lot of effort has been put into reproducing this link as well as possible.

There are several groups working on the topic using **Eulerian approaches**. For instance, the group led by Dr. Trenberth in the USA National Centre for Atmospheric Research (NCAR) is a referent in the field. Their studies about moisture transport from ocean to continents in different reanalysis data (Trenberth el al., 2011) showed discrepancies among hydrological cycle components that arise from adding or subtracting moisture. In Europe, the group at Delft University of Technology in the Netherlands, led by Dr. Savenije, has also published a good Eulerian approach to moisture transport (van der Ent et al., 2010). This study makes use of new definitions of moisture recycling to study the complete process of continental moisture feedback, and it demonstrates the important role of global wind patterns, topography, and land cover, in continental moisture recycling patterns and the distribution of global water resources.

Recently, the groups led by Dr. Miguez-Macho and Dr. Dominguez – from Univ. of Santiago de Compostela, Spain, and Univ. of Illinois, USA, respectively – have developed a new Eulerian Tracers Tool coupled to the Weather Research and Forecast (WRF-TT) mesoscale model. With the collaboration of one of the researchers associated with this project (Dr. Eiras-Barca), they have successfully applied WRF-TT to the analysis of moisture fluxes, recycling ratios, and humidity and precipitation sinks for North America (Dominguez et al., 2016; Yang et al., 2017) and the Iberian Peninsula (Eiras-Barca et al., 2017; Insua-Costa et al., 2018). This tool replicates all the equations concerning the advection, convection, turbulence and phase change of the moisture previously evapotranspirated in a certain region of the domain, and labels these cells for analysing the fate of the water.

However, these Eulerian approaches are only able to estimate the ratio between the advected and the recycled moisture, and to calculate moisture transport from prearranged sources or over the sink regions. **They are unable to provide a direct identification of the moisture source regions, which has to be done through very time-consuming computer-based Lagrangian techniques** (as used in this project).

Lagrangian approaches have been utilised abundantly over the past few decades to investigate the changes in the net water vapour along a large number of back trajectories to infer the moisture sources for precipitation falling in a target region. This has been done using FLEXPART (e.g. Stohl and James, 2004, 2005; Stohl et al., 2008; Drumond et al., 2010; Schicket et al., 2009; Durán-Quesada et al., 2012; Wegmann et al., 2015; Ramos et al., 2016), the LAGRANTO model (e.g. Pfahl et al., 2014; Schäfler and Harnisch, 2015), the recently developed "Lagrangian Atmospheric Model" (LAM) (e.g. Haertel et al., 2017), or generic Lagrangian approaches (e.g. Sodemann et al. 2008a, 2008b; Dirmever and Brubaker, 2007). A good intercomparison study between these and other Lagrangian backward mechanisms and procedures can be found in the paper commented by Gimeno et al. (2012) and in Sodemann and Wernli's work (2012).

Our group and others have used these methods to identify and quantify the moisture sources in **different climatic regions**, for instance those that have suffered the longest ***drought periods*** – such as the Sahel (Nieto et al., 2006), the Fertile Crescent (Salah et al., 2018) and different parts of Brazil (Drumond et al., 2008; 2010) – that have suffered. The aim has been to provide historic ***climatic data through ice-cores*** (Sodemann and Stohl, 2009; Nieto et al., 2010), over regions which have an impact on water availability as ***river basins*** (Stohl and James, 2005; Sorí et al., 2017a,b,c; 2018), in regions characterised by ***episodes of intense precipitation*** (e.g. Ciric et al. 2017; Sodeman et al., 2010; Huang et al., 2018; Bohlinger et al., 2017), and over the ***Arctic*** (Vazquez et al., 2016, 2017, 2018; Gimeno et al., 2015; Gimeno-Sotelo et al., 2018; Wegman et al., 2015).

Finding the sources of moisture for all these systems is fundamental to our understanding of them, and continental and oceanic sources have been found to be important in their regional climates and variability.

However, continental regions that have been affected by **monsoonal regimes** deserve special attention, because the most direct connection between moisture transport and precipitation exists. What all of these areas have in common is the large amount of moisture – irrespective of their particular intensity and seasonality – and the dominant sources of monsoonal precipitation, which are the local continental evaporation and the transport of vapour from the adjacent oceanic regions (e.g. Janicot et al., 1998; Taschetto et al., 2010; Vera et al., 2006). This is the case for the **North American Monsoon (NAM)** (Higgings et al, 1997; Dominguez et al, 2008) and the **Southern American Monsoon** (**SAM)** (Vera et al., 2006). Both systems are related with an intensification of summer rainfall, where the presence of strong low-level winds and an intense convergence of moisture are crucial. The supply of moisture from low levels corresponds to the transport of moisture due to **Low Level Jets (LLJs)**, the Great Plains Low Level Jet (GPLLJ) to northern latitudes (Wang et al., 2006, 2007), and the South American Low Level Jet (SALLJ) (Falvey and Garreaud, 2005; Liebmann and Mechoso, 2011) to southern latitudes. In Africa, the **West African Monsoon** does not seem related to a jet at low levels, but the transport of moisture is also relevant throughout the African Easterly Jet (Cadet and Nnoli, 1987), and is a factor in inertial instability (Hagos and Cook, 2007). One of the most studied monsoonal regimes, the **Asian Monsoon** (Wang, 2006), shows variations in the LLJ (including variations in the Somali LLJ over the Arabian Sea) which, along with changes in the SST distribution, are key to the variations in precipitation, and are the basis of ocean-atmosphere coupling during the development of the monsoon. The importance of the moisture evaporated from the Arabian Sea and the South Indian Ocean– as the contributions from the western Pacific Ocean (Lim et al., 2002) – has been determined and recognised (e.g. Ordoñez et al., 2012; Li et al., 2016; Sorí et al., 2017c). The Asian monsoon is strongly connected with the **Australian monsoon** (Gu et al., 2010) since the Indian Ocean is the major source of moisture in both. It develops from December-March and its mature stage is characterised by heavy precipitation caused by moisture transported by low-level westerly winds over northern Australia and the Arafura Sea (McBride 1987; Manton & McBride 1992). In general, **the moisture transported by the LLJ, and their contribution to precipitation over land, may be associated with the onset and demise of the monsoons** (Hung and Yanai, 2004); a crucial issue for the socioeconomic development.

Substantial studies on the moisture for these monsoonal regions, that use the Eulerian and/or Lagrangian approaches, permit the characterisation of their sources and the related precipitation. However, **there are currently no studies that specifically link the moisture transported at lower latitudes by the LLJs, related to the precipitation variability, with the changes in position and/or intensity of the LLJs.**

On the other hand, **Atmospheric Rivers** (ARs), as commented previously, are one of the major mechanisms responsible for the transport of higher amounts of water from the tropics through to the mid-latitudes, towards higher latitudes, providing 95% of the meridional water vapour flux north of the 35º latitude. Over the last decade, **many studies have been carried out on Atmospheric Rivers (ARs)** in relation to intense precipitations. However, studies dealing with moisture sources from a Lagrangian point of view along the paths of ARs are scarce, and have only been developed for selected case studies in the US (e.g. Moore et al., 2012; Ryoo et al., 2015; Rutz et al., 2015), Europe (Stohl et al., 2008; Liberato et al., 2013; Sodemann and Stohl, 2013; Ramos et al., 2016), and western South Africa (Ramos et al., 2018). However, **there is a need for a complete analysis of the anomalous moisture transported by the ARs at global scale over regions of high AR activity, as well as the global identification of the sources.**

Research CHALLENGES for the next three years:

Most of these studies have been limited to the effects of the changes in position and intensity of the sources in the distribution of continental precipitation linked to each source, the role of the main or local modes of climate variability (in both the sources and their associated precipitations over the sinks), and the variability of droughts associated with moisture sources.

Nevertheless, **what remains to be addressed** **-** which is crucial to the understanding of the atmospheric branch of the hydrological cycle **-** is:

Challenge 1. The role of the major mechanisms of atmospheric moisture transport in the hydrological cycle.

To account for this:

In this project, we focus on the two **major mechanisms of atmospheric moisture transport**, LLJs and ARs, and **try to establish their roles in extreme hydro meteorological events** (droughts and flooding) **at the global scale**, paying special attention to:

(a) the intensification (or reduction) of moisture transport caused by each, together with their roles in rainfall anomalies and flooding (drought);

(b) changes in the position and occurrence of the LLJs and ARs, and the associated rainfall response and/or flooding and drought.

The major part of these studies, along with hundreds of publications over the past decade, have used Lagrangian approaches. However, the results derived from these approaches are very sensitive to the integration time of the trajectories used in the analyses. The most widely used integration time is that derived from the average residence time of water vapour in the atmosphere, normally considered to be around 10 days (Numaguti, 1999). However, a more accurate time is needed for obtaining the best results. During 2016, two articles discussed the suitability of this time value, one of which (Läderach & Sodemann, 2016) indicated a shorter time (4 - 5 days), while the other obtained a residence time of around 8.5 days (van der Ent & Tuinenburg, 2017). The use of different time periods to find sources and sinks of moisture could alter the initial results, the subsequent analyses and the interpretations. It is, therefore, necessary to **estimate the optimal integration time for** these **Lagrangian methods** for estimating sources and sinks.

For this reason, in this project, we propose a different way for approaching this problem. We will try:

Challenge 2. To find the "optimal time for the integration" in the Lagrangian analysis for the best estimation of moisture sources and sinks.

This would not only be for those regions impacted by LLJs and ARs (the aim of this project), but for all the continental areas around the world (to serve as a guide for researchers who use Lagrangian models).

To account for this end:

we propose a method that uses three state-of-the-art reanalyses for estimating the optimal integration time by comparing estimates of precipitation obtained for different times – using the Lagrangian approach – thereby providing a gridded database of optimal integration times per month.

WE PROPOSE TO RESPOND TO THE FOLLOWING SCIENTIFIC QUESTIONS:

1. Is it possible to define a useful reference time for the analysis of moisture transport for precipitation using Lagrangian approaches that permits a comparison between different latitudinal regions as areas with maximum LLJ and AR occurrence?
2. How much moisture is being transported by LLJs and ARs?
3. Have their regions of moisture sources and sinks been stationary along the years, or have they changed over the last decades? Is there any correlation between the amount of contribution and the average location?
4. How do the changes in intensity (more or less evaporation) and position of the sources affect the distribution of precipitation in the sinks of both systems?
5. Which are the anomalous sources of moisture to LLJs and ARs?
6. Are these anomalies affected by changes in the characteristics of the LLJs and ARs?
7. Are the impacts, in terms of precipitation or droughts, related to the intensity (or changes) of LLJs and ARs?
8. How do drought and/or changes in the use of land affect the moisture transport by the LLJs?
9. Are LLJs and ARs linked in terms of moisture transport?

C.2 SCIENTIFIC BACKGROUND:

C.2.1 On the main meteorological structures, on a planetary scale, transporting moisture for precipitation: Low Level Jets (LLJs) and Atmospheric Rivers (ARs)

As we commented previously, there are two meteorological structures responsible for most of the moisture transport on a global scale: one is particularly important in tropical and subtropical regions – the Low Level Jets (LLJ) – and the other is important in extratropical ones – the so-called Atmospheric Rivers (ARs).

Low Level Jets (LLJs): LLJs, defined in the lower levels of the troposphere, are very localised phenomena (in space and time), and are outlined by maximum wind values within the first km of height (Blackadar, 1957; Bonner, 1968; Nicholson, 2016). They show a daily cycle with maximum intensity at night (NLLJs), triggered mainly by the decoupling of the Planetary Boundary Layer. Although LLJs are present all year round, they are especially marked in the warm season (Bonner, 1968). A summary of the geographical position of the LLJs is displayed in Figure C.2.1.a.

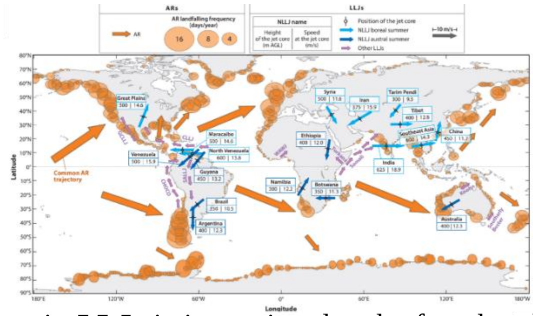

Figure C.2.1.a

The climatological interest in **LLJs** is increasing due the fact that they are understood as **the main meteorological structure of moisture transport in tropical and subtropical regions** (Gimeno et al., 2016). The bulk of the moisture contained in the atmosphere is concentrated in the lower troposphere, and nearly half of the inter-hemispheric mass transport occurs through LLJs (Bunker, 1965). These strong currents also play an important role in the global and local heat, angular momentum, and kinetic energy budgets (Krishnamurti, 1961; Bordi, 2007). Since **LLJs are clearly associated with precipitation patterns** (Amador 1998; Pan et al., 2004; Amador 2008; Gimeno et al., 2016), changes under different scenarios of global warming may substantially modify the global hydrological cycle.

The particular dependency of the hydrological cycle on changes in the behaviour of LLJs is the reason why, in the last decades, many researchers have focused on the close relationship between LLJs and rainfall. Gimeno et al. (2016) and Monaghan et al. (2010) have highlighted this fact. Both studies have investigated areas where droughts or floods are likely to occur in the absence or presence of LLJs and they have found that the precipitations are, in several cases, due to a mesoscale ascending motion which often occurs near the LLJ's exit region (Monaghan et al., 2010), when they find upward terrains or fronts. It is, however important to point out, that this connection between NLJJs and rainfall is not so clear for all the regions.

Despite this interest, the scarcity of studies that identify LLJs in a more accurate way, is a particular challenge. A remarkable exception, with great data collection campaigns and several papers, is the Great Plains LLJ (GPLLJ, e.g. Bonner, 1968; Whiteman et al., 1997; Hoecker Jr. 1963). Its presence is associated with an increase in precipitation in the eastern USA (Higgins et al., 1996; Mo et al., 2004). In addition, the South America LLJ (SALLJ) is another well-documented system flowing parallel to the east of the Andes (Marego et al., 2004; Vera et al., 2006), and contributing to the moisture reaching the La Plata basin, and transporting humidity from the Amazon basin (Vera et al., 2006; van der Ent et al., 2010). Therefore, changes in land use, as in the case of the Amazon, modify the evaporation rate, thus affecting the atmospheric humidity that reaches the sinks. Xavier et al. (2017) studied the role of the monsoon LLJs over India as well as its influence on extreme rainfall, and Bunker (1965) and Findlater (1966) studied, for first time, the Somali Jet (SJ) in eastern Africa (a flow that crosses the equator south to north). Based on previously local studies, Stensrud (1996) and Higgins et al. (1996) summarised the several possible regions where LLJ takes place on a global scale, and their general characteristics. These areas are displayed in the Figure C.2.1.a.

Although knowledge about the LLJs has increased over the last few years, the transport of moisture associated with LLJs has been classically addressed, making use of Eulerian approaches (e.g. Marengo et al., 2004), along with some Lagrangian analyses related to monsoons. Besides the lack of long-term observations, lack of data at high temporal and spatial resolution presents challenges to the study being carried out from a global perspective. In particular, **no research has evaluated the global sources and sinks from a Lagrangian perspective**. Thus, the later methodology, proposed in this project, will be used for the first time to these meteorological systems, which would enable a fine LLJ characterisation by identifying them as coherent structures with defined sources and sinks of moisture. Once the trajectories are selected, it would allow the characterisation of the LLJs' dynamic and thermodynamic characteristics in a much accurate manner than Eulerian approaches. Besides, the total precipitation associated with LLJs is still not well quantified and is likely larger than what it is currently considered to be (Gimeno et al., 2016). **Up until now, there has never been a complete characterisation of LLJs by the Lagrangian methods, and the transported moisture has never been analysed.**

A detailed study of the source and sink regions of each LLJ will help to understand the impact of these mechanisms on the hydrological cycle within the context of climate change in which an intensification of the same is foreseen (Gimeno et al., 2010, 2012, 2013). The knowledge of moisture transport linked to LLJ will help to optimise the monitoring of rainfall and will improve the water resources. Taking measures and adopting adaptation strategies will also improve regional impacts.

Atmospheric Rivers (ARs):

Atmospheric Rivers (ARs) are one of the major mechanisms responsible for the transport of large amounts of water along relatively narrow streams from the tropics through to the mid-latitudes, towards higher latitudes. Newell et al. (1992) labelled them as "atmospheric rivers" due to their capability of carrying water comparable to the Amazon River stream flow. These structures provide for most of the long distance moisture transport, accounting for 95% of the meridional water vapour flux at 35º latitude (e.g. Zhu and Newell, 1998; Ralph et al., 2004). Their characteristic dimensions are: (1) integrated water vapour (IWV) concentration of 2 or more cm; (2) wind speeds greater than 12.5 m/s in the first 2 km; and (3) a shape that is long and narrow, no more than 400–500 km wide, and extending for thousands of km, sometimes across entire ocean basins (a complete review in Gimeno et al. (2014)). Higher amounts of moisture associated with ARs are usually located within the warm sector of extratropical cyclones, ahead of the cold front. ARs continually form, move, and evolve in the mid-latitude storm tracks, releasing substantial amounts of latent and sensible heat and water directly into the middle latitudes (Stohl et al., 2008; Ralph et al., 2011). They have been related to explosive cyclogenesis (Eiras-Barca et al. 2017) and the incidence of extreme precipitation and flooding in different regions all over the planet.

In the recent years, there has been a growing number of studies that have explored their physical characteristics and effects, focused mostly on extreme precipitation over both coasts of North America (e.g. Neiman et al., 2008; Ralph et al., 2016; Hatchett et al., 2017), Europe (Trigo et al., 2014; Ramos et al., 2015; Pereira et al., 2016), and South Africa (Blamey et al., 2018). A huge effort has been made in the last decade to better understand ARs by doing reconnaissance campaigns, mainly in the west coast of the USA. Aircraft observations (Ralph et al., 2005) or the CalWater campaign (2014-15), led by NOAA, allowed us to understand their offshore dynamics and aerosol transports (https://www.esrl.noaa.gov/psd/calwater/index.html). The Center for Western Weather & Water Extremes (CW3E) at Scripps Institution of Oceanography led two campaigns (http://cw3e.ucsd.edu/arrecon_overview/), three missions in 2016 and six in 2018. These campaigns will improve predictions of landfalling ARs, and provide data to be used in studies to further understand the dynamics and processes that are the main drivers of key AR characteristics (strength, position, length, orientation, and duration). In addition, there is an international effort to understand and quantify uncertainties about the detection/tracking methodologies (Shields et al., 2018) in re-analysis models, because their climatological characteristics are strongly dependent on the method used. The precipitation attributable to ARs is perhaps most strongly affected, and this has significant implications for our understanding of how ARs contribute to regional hydroclimate now and in the future. Another widespread mechanism for measuring the moisture along ARs is through microwave remote sensing from polar satellites (e.g. Matrosov, 2013). The Special Sensor Microwave Imager (SSM/I) provides frequent global measurements of IWV (from 1998) with an adequate spatiotemporal coverage, which works very well over oceans. CloudSat and Aqua satellites (A-Train satellite constellation (http://atrain.nasa.gov/)) incorporate instrumentations, which measure different characteristics of water.

Understanding the location of moisture sources, the means of transport of this moisture and the continental rainfall regimes remain one of the important areas of climate research particularly so within the current climate change paradigm. However, to the best of our knowledge, studies dealing with moisture sources from a **Lagrangian point of view** along the paths of ARs are scarce and have only been developed for selected case studies. For instance, in **North America**, Moore et al. (2012), Ryoo et al. (2015) and Rutz et al. (2015) have used different Lagrangian methodologies to link precipitation with ARs in several regions. In **Europe**, Stohl et al. (2008) investigated the AR-linked remote moisture sources forming precipitations in Norway over a five-year period. In their investigations of moisture sources for precipitation over Lisbon in the 20th century, Liberato et al. (2013) found that the heaviest precipitation events were located over large regions of the tropical-subtropical North Atlantic Ocean. Moreover, Sodemann and Stohl (2013) analysed the origins of moisture and meridional transport in ARs and their association with multiple cyclones in December 2006. Recently Ramos et al. (2016; 2018) analysed the major climatological areas for the anomalous moisture uptake for ARs that reached western Europe and western South Africa, showing that the (sub)tropical Atlantic Ocean is reinforced as a source during the occurrence of ARs, together with mid-latitude anomaly sources at some locations closer to AR landfalls. From the South African study (Ramos et al., 2018) emerges another important connection: that the Amazon moisture source detected is linked with a particular phase of the SALLJ (No Choco Jet events), which transports moisture to the western and central South Atlantic basin, that is a moisture source for the ARs that reach South Africa.

The Lagrangian approach addressed in this project could be used to primordially identify the anomalous sources of moisture that fed ARs, following the methodology used in Ramos et al. (2016; 2018) and developed by Raquel Nieto. **A complete analysis of the anomalous moisture transported by the ARs on a global scale over the regions of high AR activity, as well as, the global identification of sources is still needed today**.

In this research project, we will also trace this anomalous moisture that triggers precipitation inlands, where water is needed to supply ecosystems and human socio-economic activities.

C.2.1.2 Impacts

Both ARs and LLJs are major mechanisms in the poleward moisture transport in the troposphere. A better knowledge of the specificities of the advective processes as well as the accurate identification of moisture sources and sinks associated with these phenomena will increase our global understanding of extreme events related to flooding and droughts worldwide.

The review paper of Gimeno et al. (2016) shows a map (Figure C.2.1.2) that summaries the general **impacts of extremes linked to LLJs and ARs in terms of precipitation**, intense precipitation, floods and landslides, snow, **and droughts**, based on several regional papers. All these hydrological impacts occur over the sinks of moisture of the LLJs regions. **In this project, we will be able to define – for the first time and with the highest precision – these impacted areas and we will analyse them in terms of extreme events.**

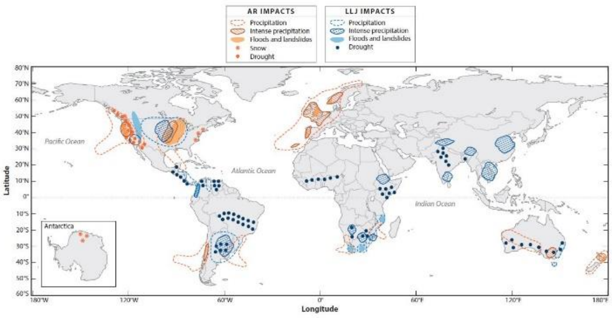

Figure C.2.1.2

Intense precipitations, floods or droughts are some of the most outstanding **MAIN IMPACTS ASSOCIATED WITH LLJ** (Fig. C.2.1.2). In **North America**, where the GPLLJ plays a critical role in the hydrological cycle, at least one-third of the moisture that penetrates into the continental areas in May and June is carried by the LLJs, and it has been extensively linked to precipitations (Helfand and Schubert, 1995). Extreme rainfall events are related to an increase in moisture transport convergence (Mo et al., 1995; Arritt et al., 1997). In **Central and South America**, the Caribbean LLJ (CLLJ) modulates the climate during summer when the jet is intensified, and it is responsible for the maximum precipitation over Caribbean areas when it converges with the Choco jet and a reduction in precipitation in the case of divergence (Amador, 2008). During the wet season, the moisture is exported from the Amazon basin and is transported via the SALLJ east of the Andes, contributing to precipitation over southern Amazonia and the La Plata River Basin (Marengo, 2005; Drumond et al., 2014). Thus, changes in land use – particularly the deforestation that has been affecting the Amazon basin over the past few decades – alter the rate of evapotranspiration, and affect the water cycle (Marengo, 2006; Zemp et al., 2014). The reduction in the regional moisture available from the tropical North Atlantic supply may have important consequences for the stability of the Amazonian rainforests and also for other southern regions that depend on the Amazon rainforest as a moisture source. In **Africa**, LLJs are common features in desert regions and their impact is mainly associated with the transport of large amounts of the mineral dust emission. Over the Sahelian region, a decrease in the moisture transported by a weak West African westerly jet (WAWJ) leads to droughts (Pu and Cook, 2012). The climate in **India and Southern Asia** is strongly influenced by monsoon regimes. A decrease in the strength of the LLJs has been shown to favour drought conditions (Joseph and Simon, 2005). Finally, the **Australia** region is also influenced by a monsoon regime, which occurs from November to April, and is responsible for approximately 90% of the total annual precipitation in the North (Pope et al., 2009). The primary source of moisture and extreme rainfall over southern Australia comes from synoptic systems (as cut-off lows) during wintertime, associated with LLJs that transport moisture from the Coral Sea (Qi et al., 1999).

The use of Lagrangian analysis has proven to be an accurate tool (Gimeno et al., 2016) in the identification of **IMPACTS ASSOCIATED TO ARs**. In these terms, ARs have been linked to most of the extreme precipitations observed in many parts of the world: in **Western Europe** – where ARs are responsible for approximately 20%-30% of total precipitation – and in **North America** – where they have been strongly linked to extreme floods in coastal and inland locations playing a critical role in water resources. However, the focus on ARs in terms of extreme precipitation and droughts is gaining importance in other parts of the world such as **Africa** (e.g. Hart et al., 2010), **Central and South America** (e.g. Guan et al., 2015), **Australia** – where ARs are anomalies associated with cut-off low systems – (Reboita et al., 2010) or even the **Antarctic regions** (Gorodetskaya et al., 2010). Moreover, extreme precipitation associated with ARs in these regions will increase since ARs are expected to become stronger and more frequent in the future (e.g. Lavers et al., 2013; Warnet et al., 2015).

Given that there will be a likely rise in extreme events, associated with water availability and transport by LLJs (e.g. Cook et al., 2008; Harding et al., 2014) or ARs (e.g. Gao et al., 2014; Jongman et al., 2014; Ramos et al., 2016b) under different global warming scenarios in different regions of the world (e.g. Forzieri et al., 2013; Masih et al., 2014, Roudier et al., 2016), **a precise identification of moisture source/sink regions will provide reliable insight** for future works related to the projection of changes linked to the referred climate change scenarios. Specific analyses of shifts related to water vapour transport cannot be made since sources and sinks of moisture associated with ARs and LLJs have not yet been accurately identified. This project will make relevant contribution in this regard.

C.2.2 On the link between Low Level Jets (LLJs) and Atmospheric Rivers (ARs):

Given what has been said on the project so far, **LLJs and ARs** mostly occur at different latitudes, at tropical ones in the former case and in the mid and higher latitudes the in latter one. However, one may ask if **they could be connected in terms of moisture transport.**

Focusing on the South Atlantic Ocean Basin and its continental margins, both meteorological structures play an important role in moisture transport: the ARs' impact in South Africa produces heavy rainfall (Blamey et al., 2018), and the SALLJ dominates the climate over South America (Gimeno et al., 2012, Marengo et al., 2004). The SALLJ presents variations along the year in its direction and intensity, so the sinks of moisture could change in function of the LLJ configuration or intensity (Salio and Nicolini, 2006; Ramos et al., 2018). During austral summer, when the LLJs are stronger, the sinks are southernmost, but during austral winter the wind maxima associated with the LLJs do not cross 25ºS, and the flow turns more zonally to the east. Under this particular condition, Ramos et al. (2018) found that it is possible that moisture coming from the Amazonian region will be available to be transported by the ARs to South Africa due the fact that their anomalous source of moisture is located in the same region over the ocean where the SALLJ leaves its moisture (see Figure C.2.2). Previously, teleconnections were found between South America and South Africa during austral summer (Grimm and Reason, 2015), whereas the austral winter rainfall, restricted to the extreme southwestern part of South Africa, is poorly understood.

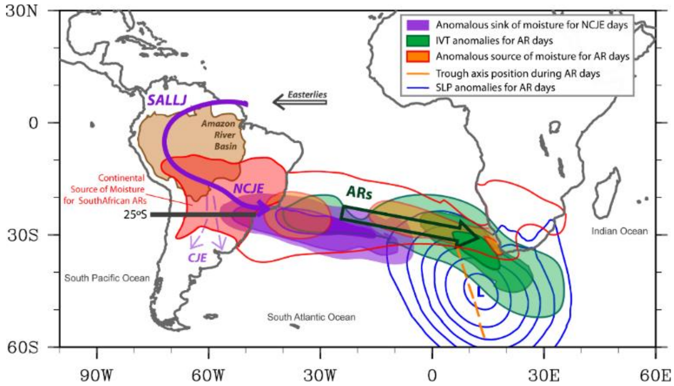

Figure C.2.2

Zhang and Villarini (2018) have attempted to find a relationship between the northern Pacific Ocean borders from a different perspective, and in a recent paper, they have shown that the Pacific-Japan teleconnections/patterns and the East Asian subtropical jet exhibit the strongest linkage with the total frequency of landfalling ARs that affect the western United States much more strongly than the other potential climate modes previously considered.

To the best of our knowledge, apart from the recent work of Ramos et al. (2018), in which the project team performed a high participation calculation for the LLJ and the anomalous sources of moisture for ARs, **no previous work has considered the link between the two major mechanisms of moisture transport** – ARs and LLJ – **across the ocean basins**. Therefore, one of the aims of this project is to **provide a comprehensive link between the two major mechanisms of moisture transport and to put them into a larger context of moisture availability and transport between continents**.

C.2.3 Critical analysis of the residence time of atmospheric vapour:

One of the key variables for understanding the global hydrological cycle is the **residence time of water vapour in the atmosphere**. Classical methods, based on dividing the atmospheric reservoir into the incoming and the outgoing flux, estimate this time to be 8 - 10 days (Chow et al., 1988). This variable has an enormous space-time variability with marked seasonality, displaying very strong changes with latitude and orography, and is very dependent on weather conditions – being very brief when local or mesoscale meteorological systems occur and quite high in the upper troposphere where few precipitating systems occur. By finding W/P, and W/E ratios (where W is the water in the local atmospheric column, P the precipitation and E evaporation), Trenberth (1998) found residence times close to 9 days. Using moisture-tracking models (semi-Lagrangian (Bosilovich and Schubert, 2002) or Eulerian (Yoshimura et al., 2004)), the residence time ranged between 7 days (spring) and 9 days (summer) – values close to classic studies. Using age tracers in a global circulation model, Numaguti (1999) found residence times to be around 10 days. This last study has been often used as a reference in scientific literature. In recent times, two different studies used two completely different techniques, and clearly divergent results were obtained. Thus, using the average times for the duration of the humidity phase gain by atmospheric particles in a Lagrangian method, Läderach and Sodemann (2016) obtained times as short as 4 - 5 days, half that usually obtained in previous studies. In response to this article, van der Ent and Tuinenburg (2017) used two different atmospheric moisture-tracking models (WAM-2layers and 3D-T) to obtain a residence time of around 8.5 days. For a complete review of the methods and results, please see van der Ent and Tuinenburg (2017), but this paragraph suffices in indicating that the residence time was not, until recently, a very controversial variable in scientific terms.

The value of residence time is not only of theoretical interest in the study of the hydrological cycle, but many estimates of other characteristics of the hydrological cycle also depend on it. An example of this, and what we are concerned with in this project, is the estimation of sources and sinks of moisture for different regions of the globe at several latitudes and longitudes, taking into account the seasonal changes.

Lagrangian methods for estimating water vapour sources and sinks have been widely used over the last decade (hundreds of works) because they are able to capture moisture sources and sinks with a reasonable degree of accuracy, and the great majority of these works have used Numaguti's (1999) 10 days as the integration time. It goes without saying that the results of these studies (sources and sinks) are highly sensitive to the time used in the integration. They identify sources closer to the target region when short times are used, and are much more remote with longer periods. Although these Lagrangian techniques are based on the estimation of the E-P balance, they have also been used extensively, with great success, in dozens of papers for estimating the precipitation from the humidity coming from source to the target regions (Gimeno et al. (2010, 2013) for a global analysis; Gimeno-Sotelo et al. (2018), Salah et al. (2018) or Sorí et al. (2017) for regional studies for very different latitudes).

One of the objectives of this project – prior to the calculation and analysis of the sources and sinks of moisture related to LLJs and ARs – is to propose a different orientation to this scientific problem: to **find the "optimal time for the integration" in the Lagrangian approaches for the best estimation of moisture sources and sinks**. The objective will not be to seek the residence time of water vapour, but whether the determined values can approach this time, though not with the same classical concept.

C.3. Objectives, activities and general methods linked to activities:

THE GENERAL OBJECTIVE OF THIS PROJECT is to determine the link between the main atmospheric structures for moisture transport – LLJs and ARS – and extreme events, with the overall assumption that there exists a link between the evaporation in moisture source regions and the precipitation in moisture sink regions that impacts extreme events.

Specific objectives are:

1. To identify the "optimum" time period for simulating the atmospheric transport of moisture – through a Lagrangian method – for all continental areas, with the aim of improving the impact in terms of precipitation of the LLJs and ARs.
2. To identify the main meteorological structures (the LLJs and ARs) that transport moisture on a planetary scale, by using objective multi-methodologies to find the main regions of occurrence (those areas around the world where each system occurs more frequently).
3. To analyse the climatological moisture sources and sinks (from a Lagrangian perspective) for areas affected by LLJs and ARs, and the behaviour of these sources and sinks under different intensities of both mechanisms.
4. To analyse changes in evaporation over moisture sources and changes in precipitation over the sinks.
5. To analyse the effects of changes in land use.
6. To look for links between changes and extreme events in precipitation (floods or droughts).
7. To characterise, as well as we can, the LLJs and ARs using other tools, such as the Eulerian tracers, vertical profile soundings, and satellite data.
8. To look for link a between LLJs and ARs in terms of moisture transport.

ACTIVITY 1 (A1) → Identification of the **"optimum" lifetime of atmospheric water vapour** that reaches the continental areas at a global scale for the best precipitation adjust between the reanalysis precipitation data and those modelled by the FLEXPART model.

Finding the most accurate results for continental precipitation, using precipitation data and FLEXPART, is necessary for minimising the possible errors due to the medium lifetime applied to identifying the sources of moisture that run in the backward mode in the model. This activity will permit the best approximation for the sources' definition.

Methodology: To implement our Lagrangian moisture transport approach, we use data from the European Centre for Medium-Range Weather Forecasts (ECMWF) Interim Re-Analysis (ERA-Interim) (Dee et al., 2011). This reanalysis (the most appropriate for representing the hydrological cycle (Lorenz and Kunstmann, 2012)), covers the period from January 1979 to the present, and contains data at 6-h intervals with a spatial resolution of 1°x1° in latitude and longitude for 61 vertical levels (1000 to 0.1 hPa).

To compare the monthly precipitation estimated by the Lagrangian approach to the gridded data, we will need to use data derived from other databases, such as GPCP and/or MSWEP, in addition to the ERA-Interim monthly precipitation. All the data will be downscaled to 0.25 degrees using linear interpolations, and will be aggregated over monthly intervals for the common period 1980 - 2015.

Sequence of steps for calculating the optimal integration times and quality control:

Estimation of a first approximation of the gridded precipitation calculated by the Lagrangian method (PLi) for multiple integration times: After dividing the world into two large sources – the entire continental area and the entire oceanic one – FLEXPART is run in the forward mode from these two global sources, taking only the negative E-P values for calculating the contribution of moisture sources to precipitation (PL). In this way, and for each 0.25° grid element, we have two values of PL, one corresponding to the terrestrial source (PLT) and the other corresponding to the oceanic source (PLO). This calculation will be done for different integration times, from day 1 to day 15 (i = 1,.., 15). We, thus, obtain the contribution of the oceanic and terrestrial sources to the precipitation for a range of integration days in each element of the grid, PLOi and PLTi. From the sum of these two quantities, we will obtain a first approximation to the precipitation calculated by the Lagrangian methods (PLi) for each integration time and grid element.

Comparison of PLi with precipitation from various reanalyses and choice of optimal integration time: For each grid element and integration time, the PLi is compared with the precipitation obtained from different reanalyses of precipitation (ERA-Interim, GPCP and/or MSWEP), and the integration time is chosen for each grid element where the difference between these two values is as small as possible. The annual and monthly maps for the optimum integration time, hereafter PLopt, will be presented. A comparison could be made between the results of the average residence times of water vapour in Läderach and Sodemann (2016) and in van der Ent and Tuinenburg (2017).

Quality control of results: we will use different procedures: a) spatial correlations of PLopt with P for each month for the whole set of 36 years; b) maps of the Root Mean Square Error (RMSE) and the Mean Absolute Error (MAE), two widely used indicators of performance validation in many fields (Chai and Draxler, 2014); c) ratio of PLTopt to PLopt, to give an idea of the recycling, and to allow a comparison to the previous studies, but with different methodologies (Dirmeyer et al., 2014; van der Ent et al., 2010).

Tasks 1.: **Task 1.1** Calculation of the moisture contribution to precipitation over the continents by grid for different integration times, from day i=1 to i=15, from the oceanic and terrestrial sources.// **Task 1.2** Finding the best precipitation pattern (minimum differences) using different reanalysis data for different integration times at each grid point.// **Task 1.3** Find the "optimum" lifetime for the moisture transport calculation for the FLEXPART model, based on the best precipitation pattern.// **Task 1.4** Comparison to other studies related to water vapour residence time and recycling.// **Task 1.5** Quality control: spatial correlations, maps of RMSE and MAE, and PLTopt/ PLopt ratio.// **Task 1.6** Construct a freely available repository including the monthly optimal integration time.

ACTIVITY 2 (A2) → Objective identification of LLJs and ARs, and their target regions:

The first step is to identify regions and times where LLJs and ARs occur. To do this, we will use a multi-objective identification algorithm based on reanalysis data for both, and will impose selected main physical characteristics of their conceptual models. Dynamic data and moisture data will be (mainly) collected from the ERA-Interim reanalysis.

Methodology (diagnosis) could be performed as follows:

A2.1. Detection of LLJs and regions of maximum occurrence:

Studies about LLJs are habitually focused on the analysis of their vertical structure (field campaigns), or aim to find the associated precipitations in North or South America (as commented before). There are, however, only a handful of studies about other continents – Africa (Zhang et al. 2006), India (Joseph and Sijikumar, 2004), and western Pacific (Miller and Fritsch, 1991). But, there are few studies focused on an objective global scale detection of LLJs. Rife et al. (2010) identified 21 continental LLJs during the central summer months of each hemisphere (January and July, when they show maximum intensity), based on the criteria described by Whiteman et al. (1997). They used an objective method based on an index definition of the vertical structure of the wind variation (using mesoscale reanalysis for 1985-2005). They reported a pair of new LLJs (Tarim-Pendi and Ethiopia LLJs), but they obviated others that clearly appeared in subjective studies.

One of the goals of this project is to use an **objective-methodology** to identify the **locations of the LLJs around the world**, and to proceed with a **characterisation of their structure, both horizontally and vertically, as well as their time evolution**. To do this, climatology will be developed for every LLJ detected, not only during the hemispheric summer, but for all the areas reported by the objective approach.

A complete, comprehensive map of LLJs over continent will be presented for the first time.

LLJ index: We will employ 6-h ERA-Interim reanalysis data (Dee et al., 2011) from the ECMWF with a 0.25º horizontal resolution from 1980 - 2018, longer than the period used in Rife et al. (2010). The LLJs are mainly associated with the warm season, so we will initially focus on the summer months to detect the main areas of occurrence. However, the study will be extended to the remaining months to evaluate monthly and seasonal variability. Because the jet core is located within the first km of the troposphere, it is necessary to take into account the elevation of land, and so sigma coordinates will be used.

The LLJ index (ILLJ) is based on the work of Rife et al. (2010), and is a function that describes the relationship between the difference of surface and high level winds, and the diurnal variation of the wind. The index was calculated daily at each grid point, with the proviso that the following two criteria had to be satisfied simultaneously: (i) the wind near the LLJ core level (500 m AGL, sigma level 53) had to be stronger at local midnight than at local noon, and (ii) the wind speed at the LLJ core had to be more intense than at higher levels (4 km AGL, sigma level 42). The index is defined as follows:

$$ILLJ = \lambda\varphi\sqrt{[(u_{00}^{L1} - u_{00}^{L2}) - (u_{12}^{L1} - u_{12}^{L2})]^2 + [(v_{00}^{L1} - v_{00}^{L2}) - (v_{12}^{L1} - v_{12}^{L2})]^2}$$

$$\lambda = \begin{cases} 0, & ws_{00}^{l1} \le ws_{12}^{l1} \\ 1, & ws_{00}^{l1} > ws_{12}^{l1} \end{cases} \qquad \varphi = \begin{cases} 0, & ws_{00}^{l1} \le ws_{00}^{l2} \\ 1, & ws_{00}^{l1} > ws_{00}^{l2} \end{cases}$$

where u and v are the zonal and meridional wind components; L1 and L2 represents the winds at 53 and 42 sigma levels respectively, the numbers 00 and 12 refer to the local midnight and the local noon, and λ and φ are two binary elements that take into account the temporal variations of the wind and its vertical shear.

To select the area around the different positions of the LLJs (to carry out the posterior Lagrangian analysis) a threshold will be imposed on the index. We will select, for instance, the area within the 75%, 80%, 90% 95% of the maximum value of the index for each individual LLJ, to capture the main region where it occurs.

A2.2. Detection of ARs and regions of maximum occurrence: The first step is to identify those regions where ARs occur. To do this, we will use an objective identification algorithm based on data from the reanalysis data, and impose selected main physical characteristics of the conceptual model of AR. Dynamic data (winds, geopotential, and height) and moisture data will be collected from the ERA-Interim reanalysis for 1980 to 2018.

The ARs identification will be principally done using one of the two usual approaches. It will be based on the use of the vertically integrated horizontal water vapour transport (**IVT**) between the lower and upper troposphere, following an adapted methodology used by Ramos et al. (2015) based on Lavers et al. (2012) and Lavers and Villarini (2013). The IVT was computed between the 1000 to 300 hPa levels:

$$IVT = \sqrt{\left(\frac{1}{g}\int_{1000\,hPa}^{300\,hPa} qu\,dp\right)^2 + \left(\frac{1}{g}\int_{1000\,hPa}^{300\,hPa} qv\,dp\right)^2}$$

where q is the layer-averaged specific humidity in kg/kg, u and v are the layer-averaged zonal and meridional winds, measured in m/s, g is the acceleration due to gravity, and dp is the pressure difference between two adjacent pressure levels. In view of the previous studies, the 85th percentile of the maximum IVT distribution would be enough to detect the most intense ARs. According to Ramos et al. (2015), additional conditions will be imposed. We will use the global ARTMIP project database (Shields et al., 2018) and the one widely used by Guan and Waliser (2015), to check ours. However, there are some caveats in the Guan and Waliser (2015) database. One example is the high frequency of ARs in the tropics, probably due to a misidentification of the ARs with other tropical moisture transport features like LLJ, or even monsoons. In addition, it the overestimation of the ARs is clearly visible in areas of occurrence of LLJs in different regions of the world (Gimeno et al., 2016).

To select the areas of maximum AR occurrence (to carry out the posterior Lagrangian analysis) a threshold will be imposed on the number of ARs along the world's coasts, to retain the main affected areas (75th, 80th, 90th, 95th percentiles).

Tasks 2.: Task 2.1 Collection of the appropriate reanalysis data.// **Task 2.2** Implementation and checking of the diagnosis algorithm.// **Task 2.3** Identification of target regions for AR and checking with previous climatology.// **Task 2.4** Identification of target regions for LLJ and checking with previous climatology.// **Task 2.5.** Elucidate problems where both systems were detected in previous works.// **Task 2.6.** Compose a final database and maps for ARs and LLJs.

***ACTIVITY 3 (A3) → Detection of the climatological moisture sources and sinks for LLJs and ARs*:**

After A2, the associated moisture transport to the LLJs and ARs will be studied, **detecting** their climatological **sources and sinks of moisture** using a **Lagrangian methodology**, which integrates E-P during the "optimum" lifetime for the atmospheric water vapour over the target areas calculated in Activity 1.

The knowledge of the sources and sinks of moisture for each LLJ and for the major areas where ARs occur, and which were detected in the A2, will allow us to identify the regions in which both mechanisms uptake moisture, and those regions where they cause precipitation (regions that act as sinks). **In this project, we will be able to define, with the highest precision, those areas that act as sources and sinks of moisture (and their anomalies). This global analysis has not been performed comprehensively to date.**

Method: THE LAGRANGIAN APPROACH: The analysis used is based on the Lagrangian particle dispersion model FLEXPART (Stohl and James, 2004), using data from 1980 to 2018, obtained from the ERA-Interim reanalysis of the ECMWF (Dee et al., 2011), the state of the art reanalysis in terms of the hydrological cycle (Trenberth et al., 2011; Lorenz and Kunstmann, 2012). Using a 1º horizontal resolution and 61 vertical levels, the model tracks atmospheric moisture along trajectories. A 3-D wind field moves a large number of so-called particles (air parcels) resulting from a homogeneous division of the atmosphere. The specific humidity (q) and the position (latitude, longitude and altitude) of all the particles are recorded every six hours. We are, therefore, able to calculate increases (e) and decreases (p) in moisture along every trajectory, at each time step, by variations in (q) with respect to time: $e\text{-}p = m\, dq/dt$. The quantity (E-P) is calculated for a given area of interest by adding (e-p) for all the particles over a defined grid column of the atmosphere, where E and P are the rates of evaporation and precipitation, respectively. The particles are tracked backwards or forwards from a specific area to estimate the sources and sinks of moisture, respectively, and a database is created with values of E-P averaged and integrated over several days of transport. The main sources and sinks of moisture for the target area (in terms of when and where the air masses that reach the target area acquire or lose moisture) are shown through the analysis of the integrated (E-P) field. The Lagrangian methods for estimating water vapour sources and sinks have become very important in the recent years because of the reliability of the technique (see Gimeno et al. (2012) for a review on advantages/disadvantages of different techniques for estimating moisture sources).

Tasks 3.: Task 3.1 Identification of the climatological moisture sources and sinks for LLJs generating E-P fields. // **Task 3.2** As T3.1 but for ARs

ACTIVITY 4 (A4) → Analysis of the anomalies over climatological sources and sinks of moisture:

Figure C2.1.2 summarises the general impacts of extremes linked to LLJs and ARs in terms of precipitation, precipitation, floods, snow, and drought. All these hydrological impacts occur over the moisture sinks of both systems. **In this project, we will be able to define extreme events (anomalies) with the highest precision over the areas affected by LLJs and ARs that have not been done to date.**

Methodology:

For LLJs: In order to better characterise the sinks of moisture (and also the sources for LLJs), we will analyse the daily effect of the LLJs using the index intensity (from Activity 2). For every LLJ region we will compute the moisture sources and sinks for different LLJ intensities – for instance **between days with and without LLJ to detect the most affected areas by these systems**. We will also analyse the differences in the behaviour between those days with the highest LLJs and those with the lowest ones (using 95^{th} and 10^{th} percentiles), to see if the intensity of the LLJs could affect the area of the sink and the precipitation pattern over it.

For ARs: for anomalous moisture quantification for ARs, we will follow our methodology published by Ramos et al (2017; 2018). It used FLEXPART outputs and took into account only positive values of e-p along the particles' backward trajectories from areas where there were ARs landfilling. The values are added over a grid.

All along this activity, a set of statistical standard tools will be used, including sophisticated time series analyses, correlations, and composite analyses, to reach the most robust conclusions.

Tasks 4: Task 4.1 Identification of anomalies of moisture over sources and sinks for LLJs. // **Task 4.2** Identification of the oceanic areas where the ARs takes anomalous moisture, and the anomalies of moisture over the sinks. // **Task 4.3** Application of several statistical tools to the analysis of the behaviour of the anomalies.

ACTIVITY 5 (A5) -> Analysis of the advective transport of moisture through the WRF-Tracers Tool

The moisture sources for the LLJs and ARs will be accurately identified after Activities 3 and 4. These "source regions" will be set as the moisture tracers' masks in the innovative Eulerian 3D tracers tool coupled to the Weather Research and Forecast (WRF) mesoscale model (WRF-TT, Eiras-Barca et al., 2017; Insua-Costa et al., 2018). This procedure ensures that a series of the most important events for the LLJs and ARs are analysed in detail. Selecting the most significant events for all the AR-regions and LLJs, WRF-TT will allow a thorough analysis of the advective processes, the vertical distribution of the moisture, and phase changes. Furthermore, the ratio between the precipitation originated at the mask source and the total precipitation will be obtained for each event, strengthening the results obtained by the Lagrangian models. Figure C.3.A5 displays an example of this procedure using WRF-TT. Figure C.3.A5 a shows an example plot for the total precipitable water in 7th June 1992: passing through a sentinel wall located at the northern edge of the source region previously identified by the FLEXPART model in a Great Plains LLJ case-study. Figures C.3.A5 b and c display the vertical distribution of the water vapour content and water vapour flux.

Tasks 5: **Task 5.1** Implementation of tracer masks using source regions obtained in A3.// **Task 5.2** Objective selection of relevant events for each LLJ and AR regions detected.// **Task 5.3** WRF-TT simulations.// **Task 5.4** Detailed analysis of the results and comparison with expected sink regions.

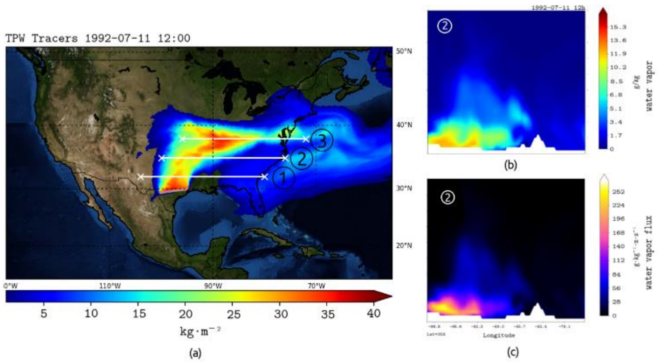

Figure C.3.A5: Example of a GPLLJ case-study analysed with WRF-TT. a) Vertically integrated total precipitable water in kg·m-2. Vertical cross-sections of water vapour and water vapour flux in b (g/kg) and c (g·kg-1·m-1·s-1), respectively**.**

ACTIVITY 6 (A6) -> Additional characterisation for the identified ARs and LLJs, and their sources and sinks of moisture:

Datasets obtained from the Integrated Global **Radiosonde** Archive (IGRA, Ferreira et al., 2018) as well as the vertically integrated vapour data obtained from **CloudSat observations** (Stephens et al., 2002) will be used as supplements to the reanalysis data in the characterisation of the analysed events. The characterisation, which is based on a "multi-tool" procedure, will ensure the accurate identification of ARs and LLJs involved in the project. In addition, **satellite data** could be used to compose the moisture structure as data from the Special Sensor Microwave Imager (SSM/i) when available. This imagery works very well over oceans and its spatial-temporal coverage became adequate at around 1998. We will also use the **regional reanalysed datasets** over the main detected occurrence areas, to characterise the system as best as possible: as NARR for the USA, APHODITE for Asia, etc.…

We will also analyse the **anomalies of evaporation over the sources of moisture, and precipitation** over the sinks. Variations in the evaporation in the source and sink regions will be analysed through two datasets considered the "state of the art": **OAFLUX** for the oceanic evaporation (Yu and Wheeler, 2007) and **GLEAM** (Global Land Evaporation: the Amsterdam Methodology) (Miralles et al., 2011) for the land evaporation.

An interesting twist on this analysis is how to reconcile the increase in water vapour content due to enhanced evaporation with the different rainfall conditions, and the role of evaporative cooling over the tropical oceans to explain large-scale rainfall dynamics. This is a rather interesting issue for the LLJs.

Tasks 6: Task 6.1 Use of satellite data as a complement for the ARs and LLJs characterisation// **Task 6.2** Use of several precipitation data for achieving the best analysis over the sinks of ARs and LLJs// **Task 6.3** Analysis of evaporation anomalies over the sources of moisture for ARs and LLJs using OAFLUX and GLEAM datasets. **Task 6.4** Finding relationships between changes in evaporation and precipitation

ACTIVITY 7 (A7) → Analysis of extremes: Droughts and extreme precipitation over the sinks of moisture for LLJs and ARs

Many indices have been developed and used by meteorologists and climatologists around the world ranging from simple indices such as the percentage of normal precipitation and precipitation percentiles, to more complicated examples (WMO, 2012).

Selection of outstanding drought periods: Normal **drought indices** are quantitative measurements that characterise drought levels by assimilating data from one or several variables (indicators) such as precipitation and/or evapotranspiration into a single numerical value (Zargar et al., 2011). In this project, we will primordially use SPEI (Vicente-Serrano et al., 2010), but we will check the analyses with SPI (McKee et al., 1993) and/or PDSI (Palmer 1965; Alley, W.M., 1984) if necessary. The **Standardised Precipitation-Evapotranspiration Index (SPEI)** will be used to identify dry conditions in the sinks, detected for LLJs and ARs in Activity 3. Dry episodes begin when the SPEI falls below zero, reaching a value of -1 or less, and end when the SPEI returns to positive values. Several indicators were calculated for such episodes, including the duration and the severity computed as the absolute value of the sum of all the SPEI values during the episode. To compute SPEI we will use the monthly precipitation and potential evapotranspiration from the CRU data.

Selection of outstanding extreme precipitation events: Following, for instance, the ranking method developed by Ramos et al. (2014; 2017) using daily ERA-Interim precipitation data, we will rank extreme precipitation events with different durations (1, 3, 5, 7 and 10 days) over every moisture sink (for LLJs and ARs) to analyse only the most intense wet-spell events (in terms of moisture availability).

Analysis of sinks of moisture for outstanding drought periods and extreme precipitation events:

The anomalies of moisture transport will be calculated for the highest events from Task 6.3 by comparing sinks in these periods or events with the climatology.

Tasks 7: Task 7.1 Calculation of drought indicators and catalogue of episodes for LLJs and ARs sink areas.// **Task 7.2** Calculation of extreme precipitation and catalogue of events for LLJs and ARs sink areas.// **Task 7.3** Detail analysis of daily mean and anomalies of the precipitation values from reanalysis data for a set of the events over the sinks.// **Task 7.4** Analysis of anomalies of moisture transport for drought periods for LLJs and ARs.// **Task 7.5** As T7.4, but for extreme precipitation events.// **Task 7.6** Analysis of the links of anomalies of moisture transport for drought periods and extreme precipitation events with anomalous intensity in the moisture source regions, and in extreme values of the LLJ index (from A2).

ACTIVITY 8 (A8) Detection of areas where LLJs and ARs are connected by moisture transport:

As it was comment in C2.2 the LLJs moisture sinks and the ARs anomalous sources could be connected over the oceans (or over continents), and this fact has not yet been studied.

Methodology: after the anomalous sources of moisture for ARs are identified (A4) we will check if they coincide with those areas that are moisture sinks for the LLJs. The link could be delayed; so we will check several lags (from 1 to 15 days) in the relationship. Also, variations in intensity of the LLJs could affect the position of their sinks.

Tasks 8: Task 8.1 Calculation of moisture sinks as functions of LLJ intensity.// **Task 8.2** Check connected areas for different lags for ARs sources of moisture and LLJs sinks

ACTIVITY 9 (A9) Dissemination of results: **DIFFUSION TASKS: Task D.1** Elaboration and maintenance of a project web page// **Task D.2** Presentation of results in international conferences// **Task D.3** Publication of results in SCI journals// **Task D.4** Writing of partial reports// **Task D.5** Writing of the final report. **EDUCATIONAL TASKS: Task E.1** Supervision of the PhD work linked to the project, **Task E.2** Elaboration of didactic material from the results of the project.

C.4 TEAM MEMBERS & WORKING PLAN:

The team is multidisciplinary (Meteorology, Hydrology and Oceanography) composed of two leading professors (PIs): **Raquel Nieto**, RN, and **Luis Gimeno**, LG; and six researchers who are added in the working plan: two postdoctoral researchers, **Marta Vázquez** (MV) and **Jorge Eiras-Barca** (JEB), and two pre-doctoral students, **Rogert Sorí** (RS) and **Iago Algarra** (IA), all of whom belong to the UVigo [JEB comes from Univ. Santiago Compostela] with extensive research experience, having published over 180 papers in SCI journals in the last 15 years, including invited papers on the topic (see page 20). The team will have the support of international experts in different themes related to the project: two meteorologist and climatologist, **Ana María Durán-Quesada** (AMDQ, from Univ. Costa Rica) and **Alexandre M. Ramos** (AMR, from the Univ. Lisbon), who are experts in tropical dynamics and moisture transport and in extreme events and AR, respectively, and they will help in the working plan.

Furthermore, two hydrologists, *Dr. Diego Miralles* at the University of Ghent, who developed the "state of the art" terrestrial evaporation data (GLEAM) with keynote publications in Nature Geosciences, Nature Climate Change and Nature Communications, with an active ERC grant about world droughts concatenation, and *Dr. Francina Dominguez* at Univ. Illinois (USA) who developed a tracer tool and is the author of several studies about regional impact of LLJs and ARs in North America, will be involved in the FPI stays. The group is complemented with the collaboration of several excellent centres for a better understanding of regional impacts. These will act as collaborative researchers (letters of interest are presented in this proposal): *University of Sao Paulo* and the Brazilian National Centre for Monitoring and Early Warning of Natural Disasters (*CEMADEN*) in Brazil, with long tradition in Amazonian studies and climatic impacts, the *National Colombian University*, one the world's references in LLJs analysis, the Centre of Excellence for Climate Extremes of *University of New South Wales*, Australia, expert in the Pacific climate implications, and the *University of Cape Town* in South Africa, which is involved in southern hemisphere climate diagnosis. All of these form a part of our Collaborating International Group (CIG) and have sent **letters of interest "AVAILABLE IF REQUESTED BY THE COMMISSION"**.

The project will be developed in three years with an 8 – 12 month period dedicated to each activity.

	Involved People and **resposible scientist**
1	**RN,**LG,MV,RS,T
2	**LG,**RN,IA,JE,AR,T
3	**RN,**LG,MV,RS,IA,AM,T
4	**RN,**LG,MV,RS,IA,AM,AR
5	**LG,**RN,JE,IA,Pd,T,CIG
6	**RN,**LG,JE,MV,RS,Pd,T
7	**LG,**RN,MV,RS,AR,T,CIG
8	**RN,**LG,IA,JE,T,CIG
9	**All**

LG: L. Gimeno; RN: R. Nieto; JE: J. Eiras; MV: M. Vázquez; RS: R. Sorí; IA: I. Algarra; AM: Ana M Durán-Quesada; AR: A..Ramos; T: Technical staff; Pd:postdoc //CIG:Colaborating Internat.Groups

Expertise and complementarity of the research team: **Role (and need) of the people to contract: Postdoc:** The implementation of additional tools in the Lagrangian methods as those related to tracers (A5) and the different configurations of the models for gaining a better response in the regional dynamic, requires a postdoc who has an in-depth knowledge of the topic. They will also have expertise in the areas outlined in A6. // **Technical staff:** Software adaptation and the management of sophisticated visualisation tools require qualified and dedicated personnel. Articles in multidisciplinary journals require the use of very high level figures. The use of these high level outputs will be one of the strong points of a successful submission.

Links with international initiatives, and priorities in RETOs: The proposal is included in the Spanish Science Strategic Plan inside the RETO devoted to Climate Change (5th point) with special relevance to the domain of Environmental Sciences and Technology, in Climate and Atmosphere. The project is also linked to the European Commission's Horizon 2020 objectives, mainly to the action called "Climate and Environment Action, Resource Efficiency and Raw Materials" and the challenge of "protection and sustainable management of natural resources and ecosystems".

Our project is also framed within the granted consortium to create climatic data records of atmospheric water vapour from satellite observations funded by ESA (http://cci.esa.int/watervapour).

EPhysLab Computational Cluster: Our cluster is used by more than 50 users among which are Physics researchers, who specialise in earth sciences, from around the world. The analysis of atmospheric and oceanic databases requires a large capacity of computation and storage. In addition, numerous atmospheric, hydraulic and oceanic models are implemented, such as **FLEXPART**, **WRF**, Delft3D, Mohid, DualSPHysics and Iber. The cluster is composed of 10 nodes of 146 cores each, 14 GPUs cards and a 400 TB storage capacity. The emergence of increasingly higher resolution databases and the use of increasingly complex models require constant updating of the hardware infrastructure to adapt to new demands. The continuous advances in hardware offers new products with greater energy efficiency, which allows the computational capacity to be increased without the need to expand the associated infrastructure. In addition, the Supercomputing Centre of Galicia (CESGA) is available for long-term computations, given its great use. **EPhysLab Data Available:** - Different datasets of precipitation (GPCP, MWEP, ERA-Interim, CRU, CHIRPS) and evaporation (GLEAM, OAFLUX, ERA-Interim). Multiple variables from ERA-Interim (u, v, q, T, IVT, etc), - IGRA radiosondes, - CouldSat data, - Era-interim fields to constrain FLEXPART runs, - Out puts of FLEXPART v9.0. **Period:** the major current climate datasets cover the study period 1980 - 2018, or a subset of it.

2. IMPACTO ESPERADO DE LOS RESULTADOS - *EXPECTED RESULTS IMPACT*

Given the importance of the atmospheric branch of the hydrological cycle and its evident implications for climate, ARs and LLJs - as the major mechanisms for moisture transport - are considered as a hotspot in climate studies at present and should continue to do so in the future. The consequences of changes in atmospheric circulation associated with ARs and LLJs and the related meteorological and climatic events are a particular challenge, being a subject of singular scientific and socioeconomic importance. Although a moderate degree of uncertainty is involved, the results will, without doubt, be useful to the scientific community. Thus, the plan is to publish the results in top impact journals in the fields of hydrology, meteorology, or climate research, such as WRR, Climate Change, GRL, J. Climate, or JGR. The most relevant and impactful results could be also published in multidisciplinary journals with the highest impact, such as Nature or Science. We will attend several international congresses: such as the annual meeting of the AGU, EGU, or the AMS to share our results internationally.

3. CAPACIDAD FORMATIVA - *TRAINING CAPACITY*

The FPI fellow will join the **Doctorate Program on Water, Sustainability and Development** (https://www.uvigo.gal/cursos/es/doctorado-del-agua/informacion/), an international PhD program linked to the **Campus of International Excellence of Water at Ourense**, coordinated by the UVigo, whose partners are the Polytechnic Institute of Porto (IPP) and the Univ. de Trás-os-Montes e Alto-Douro (UTAD) in Portugal. This program has a high-level training scheme and includes methodological courses by distinguished foreign researchers, and theoretical and practical training. The Program has three thematic research blocks: WATER, SUSTAINABILITY and DEVELOPMENT. The FPI´s line will be "**Sustainability"** on **"Climate change and water resources"**. The topic of this project and the FPI research lines are, therefore, clearly framed in the PhD Program described. In this PhD Program, the candidates must meet certain training requirements to complete a total of 500 h of work in different training activities, which can be carried out at UVigo, or at external Universities or Research Centres. The **TRAINING ACTIVITIES** which the FPI could attend are as follows (without being definitive): **1.- Water PhD Program Training activities related to the project topic:** -Fundamentals of the hydrological cycle, -Research methods in the diagnosis and modelling of the hydrological cycle. **2.- Scientific computer courses** [Python, by the Galicia Supercomputing Centre, R course by Univ. Zaragoza-CSIC, IDL course by the EPhysLab, UVigo], **3.- UVigo International Doctoral School courses:** www.uvigo.gal/uvigo_gl/centros/vigo/eido/actividades_formativas/, **5.-International Schools and Seminars** [among others, e.g. Specialised course on Earth System Physics (ESP) of the ICTP in Trieste, Italy; COPERNICUS workshops (Europe's eyes on Earth); Summer Schools by the Bolin Centre], **6.- International congresses** (one or two per year, EGU, AGU, EMS, Hymex).

7.- International Research Stays (one per year): The structure of the project, with several foreign research centres involved, will facilitate the stays. The FPI is intended to carry out his/her PhD work linked transversely to all project activities, which would imply a comprehensive and multidisciplinary training. For this purpose, one of the proposed mechanisms could be chosen, such as the LLJs and the modifications in the transport of humidity linked to the change of land-use over the source regions if they take place on mainland. Two or three international stays are planned, of around two months each, with:

- **Dr. Francina Domínguez** at **Illinois University (USA)**: Hydroclimatologist. Her work is focused on land-atmosphere interactions. The research by the FPI will be focused on understanding the role of LLJs in moisture transport from the Amazon to southern latitudes and how it is affected by deforestation, or changes in land-use, and the consequences in the precipitation patterns over the climatological sinks of moisture. Personal web: https://www.atmos.illinois.edu/people/francina/home.
- **Dr. Diego Miralles** at **Ghent University (Belgium):** Hydroclimatologist. His work strives towards the general understanding of the dynamics of the global water cycle and the impact of climate change

on hydrology. At this moment he has an ERC grant to investigate: "Do droughts self-propagate and self-intensity?" The FPI will focus on understanding the role of LLJs in these processes of drought concatenation. How could anomalies in moisture transport by the LLJs from their sources affect areas of intense droughts? and how do these changes affect other regions? Personal web: https://www.ugent.be/bw/dfwm/en/research/lhwm/staff/diego.htm

- **Dr. Ana María Durán Quesada** at **University of Costa Rica (Costa Rica)**: Climatologist. Her work focuses on the understanding of the role surface processes in modulating the thermodynamic profiles that control the energy transfer between the surface and the atmosphere, as a key process to understanding climatic variability and change. The research by the FPI will focus on understanding the role of LLJ-associated moist flow, interaction with complex surfaces and the role of the surface conditions in this interaction to lead either drier or wetter conditions, combining modelling, observations and physical proxies. Personal web: https://www.cigefi.ucr.ac.cr/biosphere/duran.htm

The decompensation in the project-time and the scholarship would allow him/her to incorporate much of the software and data already processed, which would be an advance for his/her PhD work and would also allow him/her to have a period after the project where the work could be expanded to analyses that arise in the development of the project and that may not be described in this project. Thus, the **FPI student** could have a **work plan** like the one detailed below (in big lines and open to certain modifications) to analyse the LLJs as a mechanism of moisture transport, and to carry out an in-depth study of its variations and climatic consequences.

PhDs carried out or in progress, and a brief description their scientific/professional development: **[8]** M. Vázquez, 2018. "Oceanic Sources of precipitation: New research goals and directions from a Lagrangian approach" by L. Gimeno & R. Nieto. UVigo Postdoc// **[7]** AP. Ferreira, 2018. "Water vapour stratification and dynamical warming behind the sharpness of the Earth's mid-latitude tropopause" by L. Gimeno & J.H. Castanheira. UVigo Postdoc// **[6]** R. Castillo, 2015. "Fuentes globales de humedad: caracterización y estudio de su variabilidad" by R. Nieto & L. Gimeno. Associate professor Univ. Costa Rica// **[5]** MM Gómez. 2014, "Análisis de las fuentes de humedad en la cuenca Mediterránea en el periodo 1980-2000" by L. Gimeno & R. García-Herrera. Meteorologist Eltiempo.es// **[4]** AM Durán-Quesada, 2012, "Sources of moisture for Central America based on a Lagrangian approach: variability, contributions to precipitation and transport mechanisms" by L. Gimeno & J. Amador. International PhD. Full professor Univ. Costa Rica// **[3]** AM. Ramos, 2012, "Improving circulation weather type classification using a 3D framework: relationship with climate variability and projections for future climates" by L. Gimeno & N. Lorenzo. International PhD. Senior Postdoc Researcher Univ. Lisbon// **[2]** J. Hidalgo, 2008, "An observational, numerical and theoretical approach to the daytime Urban-breeze circulation in inland cities" by L. Gimeno & V. Masson. European PhD. Senior Researcher CNRS, France// **[1]** M. Tesouro, 2008, "Análise climática do modelo conceptual de desenvolvemento en aire frío" by L. Gimeno & P. Ribera. Meteorologist MeteoGalicia.

PhD in course: **[1]** R. Sorí, 22 Oct 2018, "Atmospheric moisture transport and extremes in major river basins" by Gimeno&Nieto. International PhD. Predoc by Xunta Galicia (equivalent FPI)// **[2]** M. Stojanovic, Dec 2018, "The role of Atmospheric moisture transport in major drought episodes" by Gimeno &Drumond. Predoc by Erasmus-Mundus "GreenTech"// **[3]** D. Ciric, Dec 2018, "Atmospheric moisture transport in major extreme precipitation episodes" by Gimeno&Nieto. Predoc by Erasmus-Mundus "GreenTech"// **[4]** S. Salvador, June 2019, by Gimeno&Sanz-Larruga. International PhD. Predoc by Xunta Galicia (equivalent FPI)// **[5]** I. Algarra, 2021 by Gimeno& Nieto. International PhD. FPI// **[6]** C. Salvador, 2021 by Nieto&Linares. International PhD. UVigo Predoc.

C.1.2. Contribution of EPhysLab Group to the knowledge on the topic:

EPhysLab (the candidates are members of the team) has applied the 3D **Lagrangian transport model FLEXPART** by the diagnostic scheme of Stohl and James (2004, 2005) to identify which continental regions are affected by the moisture transport from the major oceanic sources (e.g. Gimeno et al., 2010, 2011, 2012, 2013). The original study published in **Geophysical Research Letters** entitled **"On the origin of continental precipitation"** (Gimeno et al., 2010) **was highlighted** as one of the most important geophysical papers published in 2010 by the AGU (3rd August EOS issue), and a feature paper of **EOS was published** (Gimeno et al., 2011) **by invitation of the editors**. The relevance of the topic has resulted in the elaboration of three other scientific publications: 1) a chapter in the **"Encyclopedia of Sustainability Science and Technology"** **invited by the Editor-in-Chief of Springer** about "Ocean evaporation & precipitation", 2) **a review paper in the Review of Geophysics "Oceanic and Terrestrial Sources of Continental Precipitation"** (Gimeno et al., 2012), and 3) we were **invited** to write a **review** for **Annual Review of Environmental and Resources** on **"Major**

Mechanisms of Atmospheric Moisture Transport and Their Role in Extreme Precipitation Events" (Gimeno et al., 2016). During our last project, we put light on the role of anomalous moisture transport to the Arctic and the related extreme meteorological events, such as Arctic ice-melting and snow cover, that had been poorly explored through Lagrangian approaches previously. One of the results was published in **Environmental Research Letters**, **"Arctic moisture source for Eurasian snow cover variations in autumn"** by Wegmann et al. (2015), and it was **highlighted** both by the journal and **by Nature**.

One IP of this project, **Raquel Nieto**, won the **"2011 EGU Atmospheric Sciences Outstanding Young Scientists Award"** that recognises her "**outstanding contribution to the understanding of the moisture sources and precipitation in the atmospheric system"** (https://www.egu.eu/awards-medals/division-outstanding-ecs-award/2011/raquel-nieto/).

We have **organised** (as chairs) two **international conferences** related to the topic: 1) the **8th EGU Leonardo Topical Conference Series on the Hydrological Cycle** that is the forum that EGU provides for scientific discussions focused on specific topics around the Hydrological Cycle. In 2016 it was devoted to the Atmospheric Branch of the Hydrological Cycle under the title "**From evaporation to precipitation: the atmospheric moisture transport**" in Ourense, Spain, October, with more than 100 participants from over 20 countries (http://ephyslab.uvigo.es/eguleonardo2016/); and 2) the **1st Internat. Electronic Conference on the Hydrological Cycle**, November 2017 supported by the MDPI group (https://sciforum.net/conference/CHyCle-2017). L. Gimeno was also co-chair of a **2018 EGU session**.

In addition, we are editing two **Special Issues**: 1) in **Earth System Dynamics** the interactive open-access journal of the EGU [https://www.earth-syst-dynam.net/special_issue867.html], and 2) in **Water** that is a peer-reviewed open access journal by the MDPI editorial group in the section of Hydrology [http://www.mdpi.com/journal/water/special_issues/ChyCle2017]

In **our group's previous three projects** – TRAMO, SETH and EVOCAR – we have shed light on crucial aspects of the atmospheric branch of the hydrological cycle. The results are available on the EPhysLab web (more than 70 SCI papers): http://ephyslab.uvigo.es/moisturetransport/index.php/Publications

The first project (**TRAMO**, CGL2012-35485, 2013-2015) was aimed at investigating whether moisture source regions have been stationary over the years, or if they have changed over this period. And if the possible changes in the intensity (more evaporation) and position of the sources have affected the distribution of continental precipitation, the role of the main modes of climate variability in the variability of the moisture regions, and the supply of moisture from the warm pools. We also analysed if the oceanic sources of moisture could change in a warming climate in the future. The second one (**SETH**, CGL2014-60849-JIN, 2015-2018) was focused on the anomalous moisture transport during the occurrence of the most important drought episodes observed worldwide in the last 30 years. Through a Lagrangian method, we investigated the role of the areas affected as a receptor/source of moisture during the drought episodes, identified and characterised through the SPEI index. **EVOCAR's** (CGL2015-65141-R, 2016-2018) main objective was to find out if there is a significant link between evaporation and sea ice melting through atmospheric moisture transport, assuming that there is a link between the two climate change hotspots through the chain of events related to (1) trends in evaporation in moisture source regions, (2) trends in atmospheric transport from these regions to ice-melting precursors regions and (3) trends in ice-melting.

4. IMPLICACIONES ÉTICAS Y/O DE BIOSEGURIDAD - *ETHICAL AND/OR BIOSAFETY IMPLICATIONS*

No.

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