RESUMEN Y PERSPECTIVAS FUTURAS DE LA INVESTIGACIÓN SOBRE EL TRANSPORTE DE HUMEDAD Y CALOR EN EL GRUPO EPHYSLAB DE LA UNIVERSIDAD DE VIGO

Luis Gimeno

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Campus da Auga

EPhysLab

Environmental Physics Laboratory (EPhysLab)

What is EPhysLab?

- It is a multidisciplinary research group of the University of Vigo, established in 2002.
- It is formed of researchers in both **Atmospheric** and Oceanic Physics, and Computer Engineering
- It is a "Competitive Reference Group of the Xunta de Galicia" since 2006.

Environmental I Physics I Laboratory
EPhysLab

The EPhysLab group during the last decades has put its effort and resources to understand better the source-sink moisture relationships around the globe and the meteorological systems involved.

Researchers focussed on the hydrological cycle and atmospheric processes

https://ephyslab.uvigo.es/moisturetransport/index.php/Group

Staff

Dr. Luis Gimeno

P.I.

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- Dr. Milica Stojanovic, Senior Scientist, EPhysLab-UVigo .
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- Gleisis Álvarez-Socorro, Ph.D. Student at EPhysLab-UVigo.
- Yiying Wang, Ph.D. Student at EPhysLab-UVigo.
- Jakob Ernst, Ph.D. Student at EPhysLab-UVigo.

Former Collaborators:

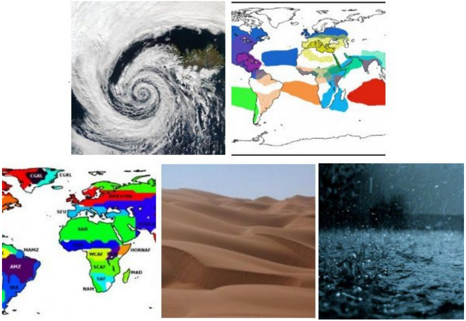
- Dr. Ricardo M. Trigo, Senior Scientist at University of Lisbon, Portugal.
- Dr. Anita Drumond, Senior Post-Doctoral Researcher at USP, Sao Paulo, Brazil.
- Dr. Alexandre Ramos, Senior Scientist at Karlsruhe Institute of Technology (KIT), Germany.
- Dr. Ana M. Durán-Quesada, Senior Scientist at Costa Rica University, Costa Rica.
- Dr. Marta Vázquez, Senior Scientist, EPhysLab-UVigo.

- 3 Senior Researchers
- 3 Postdoc
- 4 PhD Students

Main research topics

https://ephyslab.uvigo.es/moisturetransport/

1. Meteorological systems
2. Global moisture sources
3. Regional moisture sources
4. Drougths and extreme precipitation
5. Moisture sources in the future



Main research topics

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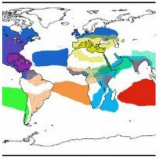
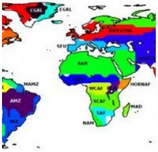



EPhysLab has also led reviews on moisture transport

Gimeno L, Stohl A, Trigo RM, Dominguez F, Yoshimura K, Yu L, Drumond A, Durán-Quesada AM, Nieto R (2012), Oceanic and terrestrial sources of continental precipitation, Rev. Geophys., 50, RG4003, doi:10.1029/2012RG000389

Gimeno L, V´azquez M, Eiras-Barca J, Sorí R, Stojanovic M, Algarra I, Nieto R, Ramos AM, Durán-Quesada AM, Dominguez F (2020) Recent progress on the sources of continental precipitation as revealed by moisture transport analysis, Earth Science Reviews 201 https://doi.org/10.1016/j.earscirev.2019.103070

Gimeno,L., Eiras-Barca, J., Durán-Quesada, A.M., Dom´ınguez, F., van der Ent, R., et al. (2021) The residence time of water vapour in the atmosphere, Nature Reviews Earth & Environment. https://doi.org/10.1038/s43017-021-00181-9

Research topics: Lagrangian models

The trajectory-based (Lagrangian) methods have been widely used in EPhysLab to investigate the atmopsheric moisture transport

FLEXPART-ERA-I

FLEXPARTv9.0

- 2 million air parcels
- Global simulations
- Period: 1980-2018
- Input H resolution: 1^0
- Input V resolution: 61 levels
- Output: binary files

FLEXPART-ERA5

FLEXPARTv10.4

- 30 million air parcels
- Global simulations
- Period: 1980-2023
- Input H resolution: 0.5^0
- Input V resolution: 137 levels
- Output: binary files

FLEXPART-WRF

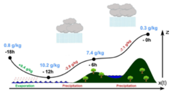
FLEXPART-WRFv3.3.2

- Depending on WRF config
- Regional simulations
- Depending on the study goals
- Input H resolution: WRF
- Input V resolution: WRF
- Output: binary files

Lagrangian moisture tracking approaches

They are based on the Lagrangian water budget equation from Stohl and James (2004,2005)

$$(e - p) = m\frac{dq}{dt} \approx m\frac{\Delta q}{\Delta t}$$



- **From Stohl and James (2004, 2005)**

Considering the $(e - p)$ contribution from all particles at every grid position, the total surface freshwater flux can be computed

$$E - P = \frac{m\sum_{k=1}^{N}(e - p)_k}{A}$$

- $E - P > 0$ Source region
- $E - P < 0$ Sink region

- **From Sodemann et al. (2008)**

The precipitation en route is discounted from all previous moisture uptakes

$$\Delta q_j' = \Delta q_j + \Delta q_i \frac{\Delta q_j}{\sum_{k=t_{end}}^{i-6} \Delta q_k}$$

By amassing the final moisture changes of all the parcels over the area A, the total moisture uptake (MU) was estimated

$$MU = \frac{m\sum_{k=1}^{N}\Delta q_k'}{A}$$

Stohl, A., and P. James (2004). Journal of Hydrometeorology, 5(8), 656–678. https://doi.org/10.1175/1525-7541(2004)005<0656:ALAOTA>2.0.CO;2

Stohl, A., and P. James (2005). Journal of Hydrometeorology, 6(12), 961–984. https://doi.org/10.1175/JHM470.1

Sodemann, H., C. Schwierz, and H. Wernli (2008). Journal of Geophysical Research, 113, D03107, doi:10.1029/2007JD008503.

Moisture tracking tools

- TROVA
- LATTIN

TRansport Of water VApour

TRansport Of water VApor

Tracking approaches

It is developed in Python and Fortran to study moisture sources and sinks

1. Stohl and James (2004, 2005) - forward and backward mode
2. Sodemann et al. (2008) - Modified threshold values

Fernández-Alvarez, J.C.; Pérez-Alarcón, A.; Nieto, R.; Gimeno, L. (2022). TROVA: TRansport Of water VApor. SoftwareX, 20, 101228, https://doi.org/10.1016/j.softx.2022.101228

Moisture tracking tools

- TROVA
- LATTIN

LATTIN
Lagrangian Atmospheric moisTure and heaT trackINg

Lagrangian **A**tmospheric mois**T**ure and hea**T** track**IN**g

Tracking approaches

It is developed in Python and Fortran to study moisture sources and sinks

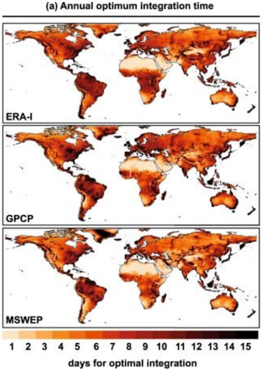
1. Stohl and James (2004, 2005) backward mode
2. Sodemann et al. (2008)
3. Freme and Sodemann (2019)
4. Keune et al. (2022)
5. P´erez-Alarc´on et al. (2022)

It also includes heat tracking approaches

Pérez-Alarcón, A.; Fernández-Alvarez, J.C.; Nieto, R.; Gimeno, L. (2024). LATTIN: A Python-based tool for Lagrangian atmospheric moisture and heat tracking. Software Impacts, 20, 100638. https://doi.org/10.1016/j.simpa.2024.100638

Resulting datasets

- A database of Optimal Integration Times for Lagrangian studies of atmospheric moisture sources and sinks



Nieto, R., Gimeno, L. (2019) A database of optimal integration times for Lagrangian studies of atmospheric moisture sources and sinks. Sci Data 6, 59. https://doi.org/10.1038/s41597-019-0068-8

Resulting datasets

- A database of contributions of major oceanic and terrestrial moisture sources on continental daily extreme precipitation

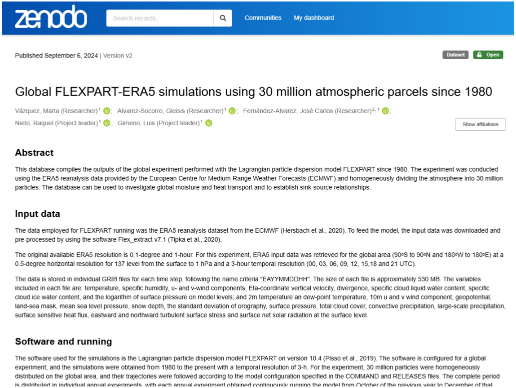
Specifications Table

Subject	Climatology
Specific subject area	Extreme precipitation, moisture transport, climate change
Type of data	NetCDF data files
How data were acquired	Post-processing of the FLEXPART Lagrangian particle dispersion model outputs
data format	analysed
Parameters for data collection	3D (time, longitude, latitude)) ($\|E-P<0\|$) data with 0.5°x0.5° horizontal resolution achieved daily for the period 1980–2018 considering at every grid point only the Peak Precipitation Month.
Description of data collection	The data was obtained by post-processing FLEXPART model global outputs.
Data source location	Institution: University of Vigo City/Town/Region: Ourense Country: Spain Primary data sources: ECMWF ERA-Interim reanalysis data (https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era-interim ↗)
Data accessibility	With the article and in http://dx.doi.org/10.17632/kgvsvx77h8.1 ↗
Related research article	Vázquez M., Nieto R., Liberato M.L.R., Gimeno L. (2020) Atmospheric moisture sources associated with extreme precipitation during the peak precipitation month. Weather and Climate Extremes, 30, 100,289. https://doi.org/10.1016/j.wace.2020.100289 ↗

Vázquez ,M., Nieto, R., Liberato, M.L.R., Gimeno, L. (2021) A data base of contributions of major oceanic and terrestrial moisture sources on continental daily extreme precipitation, Data in Brief, Vol. 35, 106830. https://doi.org/10.1016/j.dib.2021.106830

Resulting datasets

- A database of Global FLEXPART-ERA5 simulations using 30 million atmospheric parcels since 1980



zenodo
Search records... Communities My dashboard

Published September 6, 2024 | Version v2
Dataset Open

Global FLEXPART-ERA5 simulations using 30 million atmospheric parcels since 1980

Vázquez, Marta (Researcher)[1]; Alvarez-Socorro, Gleisis (Researcher)[1]; Fernández-Alvarez, José Carlos (Researcher)[2, 1]; Nieto, Raquel (Project leader)[1]; Gimeno, Luis (Project leader)[1]
Show affiliations

Abstract

This database compiles the outputs of the global experiment performed with the Lagrangian particle dispersion model FLEXPART since 1980. The experiment was conducted using the ERA5 reanalysis data provided by the European Centre for Medium-Range Weather Forecasts (ECMWF) and homogeneously dividing the atmosphere into 30 million particles. The database can be used to investigate global moisture and heat transport and to establish sink-source relationships.

Input data

The data employed for FLEXPART running was the ERA5 reanalysis dataset from the ECMWF (Hersbach et al., 2020). To feed the model, the input data was downloaded and pre-processed by using the software Flex_extract v7.1 (Tipka et al., 2020).

The original available ERA5 resolution is 0.1-degree and 1-hour. For this experiment, ERA5 input data was retrieved for the global area (90ºS to 90ºN and 180ºW to 180ºE) at a 0.5-degree horizontal resolution for 137 level from the surface to 1 hPa and a 3-hour temporal resolution (00, 03, 06, 09, 12, 15,18 and 21 UTC).

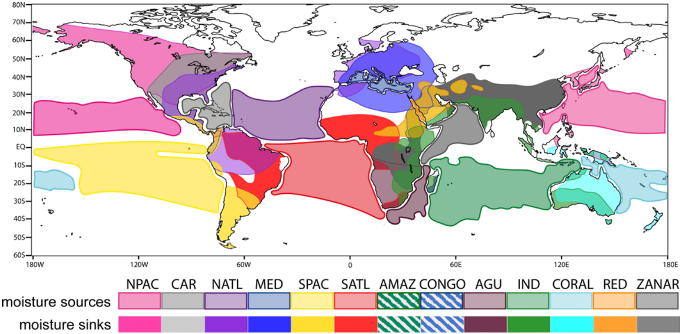
The data is stored in individual GRIB files for each time step, following the name criteria "EAYYMMDDHH". The size of each file is approximately 530 MB. The variables included in each file are: temperature, specific humidity, u- and v-wind components, Eta-coordinate vertical velocity, divergence, specific cloud liquid water content, specific cloud ice water content, and the logarithm of surface pressure on model levels; and 2m temperature an dew-point temperature, 10m u and v wind component, geopotential, land-sea mask, mean sea level pressure, snow depth, the standard deviation of orography, surface pressure, total cloud cover, convective precipitation, large-scale precipitation, surface sensitive heat flux, eastward and northward turbulent surface stress and surface net solar radiation at the surface level.

Software and running

The software used for the simulations is the Lagrangrian particle dispersion model FLEXPART on version 10.4 (Pisso et al., 2019). The software is configured for a global experiment, and the simulations were obtained from 1980 to the present with a temporal resolution of 3-h. For the experiment, 30 million particles were homogeneously distributed on the global area, and their trajectories were followed according to the model configuration specified in the COMMAND and RELEASES files. The complete period is distributed in individual annual experiments, with each annual experiment obtained continuously running the model from October of the previous year to December of that

Vázquez, M., Alvarez-Socorro, G., Fernández-Alvarez, J. C., Nieto, R., & Gimeno, L. (2024). Global FLEXPART-ERA5 simulations using 30 million atmospheric parcels since 1980 [Data set]. Zenodo. https://doi.org/10.5281/zenodo.13682647

Primary result



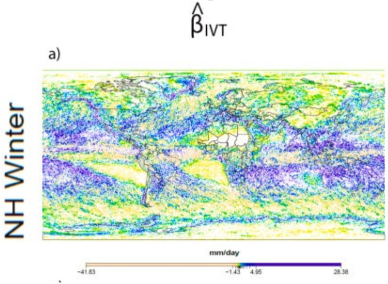
- **This study was highlighted as one of the most important geophysical papers published in 2010 by the AGU (3rd August EOS issue), and a feature paper of EOS was published (Gimeno et al., 2011) by invitation of the editors.**

Gimeno et al. (2011). A Close Look at Oceanic Sources of Continental Precipitation, Eos, 92(23), 193-200

Results

EPhysLab has investigated...

- extreme precipitation events
- occurrence of droughts



Spatial patterns of the significant values of the estimated coefficient that represents the influence of IVT on maximum precipitation according to the GEV analysis (95% confidence level), for Northern Hemisphere Winter (December–February) for the period 1981–2020.

Weather and Climate Extremes 39 (2023) 100536

Contents lists available at ScienceDirect

Weather and Climate Extremes

journal homepage: www.elsevier.com/locate/wace

Where does the link between atmospheric moisture transport and extreme precipitation matter?

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Centro de Investigación Mariña, Universidade de Vigo, Environmental Physics Laboratory (EPhysLab), Ourense, Spain

A R T I C L E I N F O

Keywords:
Extreme precipitation
Moisture transport
Extreme value analysis

A B S T R A C T

Atmospheric moisture transport is the primary component of the atmospheric branch of the water cycle, and its anomalies strongly influence drought and precipitation extremes. We utilised the full geographical and temporal spectrum of the ERA-5 reanalysis data and extreme value theory to identify regions where the atmospheric moisture transport, quantified as local integrated moisture vertical transport (IVT), influences daily extreme precipitation, and where this influence has a relevant dynamic component, which may alter the dependency between IVT and extreme precipitation as temperatures increase with climate change. We showed that this dependency is weak or negligible in tropical regions and strong but nonuniform in extratropical regions. Its influence is much greater in areas where the main moisture transport mechanisms occur, namely, atmospheric rivers, low-level jets, and tropical cyclones. The dynamic component of IVT, linked to wind, is highly consequential in regions with landfalling atmospheric rivers, landfalling tropical cyclones, or moisture-transporting low-level jets.

1. Introduction

Few topics bring as much consensus in the scientific community as the importance of the mechanisms of extreme precipitation and how they are influenced by climate change (Douville et al., 2021; Seneviratne et al., 2021; Caretta and Pörtner, 2022). In fact, extreme precipitation, in addition to being the main cause of floods and their dramatic socio-economic impacts, also arouses an important theoretical interest in relation to the mechanisms causing its intensification in response to a warming climate. Despite limitations in defining extreme precipitation periods and its various behaviours in tropical or extratropical regions (Zhang et al., 2019), a robust signal indicates that extreme precipitation increases globally with temperature, following the thermodynamic constraints imposed by the water-holding capacity of the atmosphere but varying regionally owing to atmospheric dynamical changes (O'Gorman, 2015; Bao et al., 2017).

Depending on the selected temporal and spatial domains, extreme precipitation can be caused by multiple meteorological systems. On the synoptic scale, tropical cyclones and monsoon lows in the tropics and baroclinic systems such as extratropical cyclones, warm conveyor belts, and fronts in the extratropics are the most prominent. The only common factors between these systems are the production of atmospheric instability with strong vertical motion and the potential for intense moisture transport to a region of extreme precipitation (De Vries, 2021). It is very difficult to generate intense precipitation with the sole humidity contained in the atmospheric column; strong and sustained moisture contributions are required from outside regions (Trenberth et al., 2003), in some cases very remote (Insua-Costa et al., 2022). Hence, great importance has been given to the main global mechanisms of moisture transport, namely the atmospheric rivers in the extratropics and the low-level jets (LLJs) in tropical regions (Gimeno et al., 2016).

Among the various methods of quantifying moisture transport (see Gimeno et al., 2012 for a review) the Eulerian scheme based on the integrated moisture vertical transport (IVT) has been the most widespread in extreme precipitation analyses, mainly due to its use in the identification and characterization of the atmospheric rivers (ARs) (Zhu and Newell, 1998; Gimeno et al., 2014; Payne et al., 2020). ARs are organised structures with high IVT that extend thousands of kilometres in length and a few hundred kilometres in width; they are responsible for approximately 90% of the meridional moisture transport from the subtropics to the extratropics (Zhu and Newell, 1998). Many global and regional studies have analysed the link between the current and future frequencies and intensities of ARs and precipitation extremes (e.g., at a global scale (Waliser and Guan, 2017), for the regional-scale current

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Available online 6 December 2022

Gimeno-Sotelo, L., & Gimeno, L. (2023). Where does the link between atmospheric moisture transport and extreme precipitation matter?. Weather and Climate Extremes, 39, 100536.

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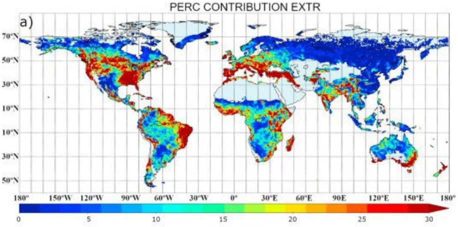

Percentage of contribution from the preferred moisture source for extreme events.

Weather and Climate Extremes 30 (2020) 100289

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Weather and Climate Extremes

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Atmospheric moisture sources associated with extreme precipitation during the peak precipitation month

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ARTICLE INFO

Keywords:
Extreme precipitation
Global moisture sources
Lagrangian analysis

ABSTRACT

Understanding moisture transport is crucial for understanding continental precipitation and extreme precipitation events, which are expected to become substantially more frequent under global warming conditions. In this work, the influence of major global moisture sources on extreme continental precipitation during the peak precipitation month is estimated and compared with climatological patterns. The results show a general change in the pattern of contribution of the primary source of precipitation (the source with the highest contribution) during extreme precipitation events. Most primary sources show a general reduction in their area of influence and a notable reduction in their contribution to the total precipitation.

1. Introduction

Extreme events have been an issue of interest in communities worldwide due to their important socioeconomics impacts. The number of flood events in several regions has risen over recent decades (Paprotny et al., 2018), as have the economic losses associated with these events (EASAC,2018; Willner et al., 2018); these trends are expected to continue in the future (Roudier et al., 2016). The changes observed in extreme events show geographical variability, with observed increases in heavy precipitation events over most continental areas (IPCC et al., 2013). The effects of extreme precipitation events on society are evident and diverse. Although these events can produce natural disasters such as landslides and floods (Tichavský et al., 2019), which have potentially negative implications for crop yields, migration or energy systems (IPCC et al., 2014), several communities are highly dependent on the occurrence of extreme events for their water resources (Paltan et al., 2017). These uneven implications indicate that it is crucial to better understand the factors that influence the occurrence of extreme events to be able to predict them and allow communities to adapt to their possible consequences.

The effects of global warming have modified global rainfall patterns. However, the changed in observed and expected precipitation show high geographical and temporal variability (Adler et al., 2018; Nguyen et al., 2018; Pendergrass et al., 2017). Associated with higher temperatures, the water holding capacity of the atmosphere increases according to the Clausius-Clapeyron (C–C) relationship, in which the expected increase in water holding capacity is 7% per degree temperature increase (Trenberth et al., 2003). Therefore, an intensification of precipitation is expected. A global mean precipitation pattern cannot be estimated by scaling the C–C relationship; however, extreme precipitation events have a more consistent global relationship (Held and Soden, 2006; Trenberth, 2011). Both observed and predicted extreme events increase under global warming more than mean precipitation (e.g., Myhre et al., 2019; Donat et al., 2016; Papalexiou and Montanari, 2019). For example, according to Myhre et al. (2019), the occurrence of extreme precipitation events would double for each degree of temperature increase if historical trends continue. In general, this behaviour could be caused by the fraction of water vapor converted into rain during such events. During extreme precipitation events, most of the water vapor is precipitated out and, due to the higher moisture availability predicted by the C–C relationship, the upper percentile precipitation is expected to scale with temperature (Allen and Ingram 2002; Pall et al., 2007). However, important latitudinal differences in the response of extreme precipitation events to global warming were observed. These discrepancies are mostly derived from a dynamical contribution (O'Gorman and Schneider, 2009), as vertical motion is significantly relevant to the occurrence of extreme events (Duffy et al., 2020; Li and O'Gorman, 2020).

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Results

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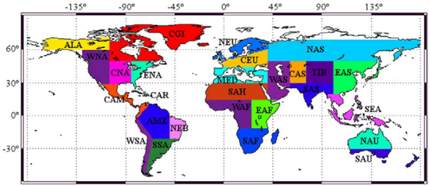

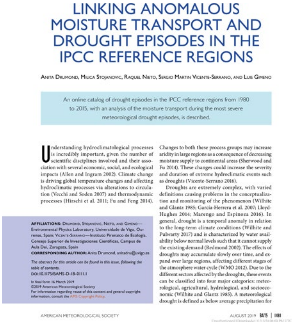

LINKING ANOMALOUS MOISTURE TRANSPORT AND DROUGHT EPISODES IN THE IPCC REFERENCE REGIONS

Anita Drumond, Milica Stojanovic, Raquel Nieto, Sergio Martin Vicente-Serrano, and Luis Gimeno

An online catalog of drought episodes in the IPCC reference regions from 1980 to 2015, with an analysis of the moisture transport during the most severe meteorological drought episodes, is described.

Understanding hydroclimatological processes is incredibly important, given the number of scientific disciplines involved and their association with several economic, social, and ecological impacts (Allen and Ingram 2002). Climate change is driving global temperature changes and affecting hydroclimatic processes via alterations to circulation (Vecchi and Soden 2007) and thermodynamic processes (Hirschi et al. 2011; Fu and Feng 2014). Changes to both these process groups may increase aridity in large regions as a consequence of decreasing moisture supply to continental areas (Sherwood and Fu 2014). These changes could increase the severity and duration of extreme hydroclimatic events such as droughts (Vicente-Serrano 2016).

Droughts are extremely complex, with varied definitions causing problems in the conceptualization and monitoring of the phenomenon (Wilhite and Glantz 1985; Garcia-Herrera et al. 2007; Lloyd-Hughes 2014; Marengo and Espinoza 2016). In general, drought is a temporal anomaly in relation to the long-term climate conditions (Wilhite and Pulwarty 2017) and is characterized by water availability below normal levels such that it cannot supply the existing demand (Redmond 2002). The effects of droughts may accumulate slowly over time, and expand over large regions, affecting different stages of the atmosphere water cycle (WMO 2012). Due to the different sectors affected by the droughts, these events can be classified into four major categories: meteorological, agricultural, hydrological, and socioeconomic (Wilhite and Glantz 1985). A meteorological drought is defined as below average precipitation for

AFFILIATIONS: Drumond, Stojanovic, Nieto, and Gimeno—Environmental Physics Laboratory, Universidade de Vigo, Ourense, Spain; Vicente-Serrano—Instituto Pirenaico de Ecología, Consejo Superior de Investigaciones Cientificas, Campus de Aula Dei, Zaragoza, Spain
CORRESPONDING AUTHOR: Anita Drumond, anitadru@uvigo.es

The abstract for this article can be found in this issue, following the table of contents.
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Drumond, A., Stojanovic, M., Nieto, R., Vicente-Serrano, S.M., Gimeno, L. (2019) Linking Anomalous Moisture Transport and Drought Episodes in the IPCC Reference Regions, Bulletin of the American Meteorological Society, 10(8), 1481–1498. https://doi.org/10.1175/BAMS-D-18-0111.1

Results

EPhysLab has investigated...

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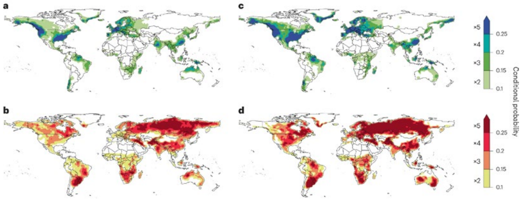
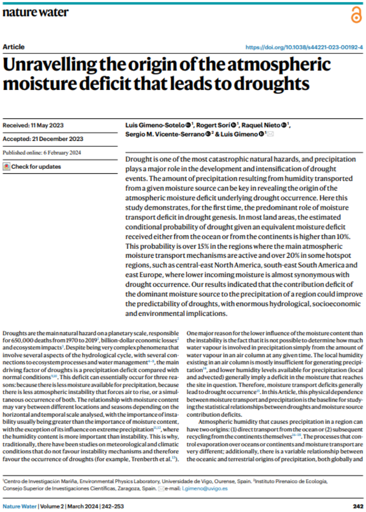
- occurrence of droughts





nature water

Article

https://doi.org/10.1038/s44221-023-00192-4

Unravelling the origin of the atmospheric moisture deficit that leads to droughts

Received: 11 May 2023

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Luis Gimeno-Sotelo[1], Rogert Sorí[1], Raquel Nieto[1], Sergio M. Vicente-Serrano[2] & Luis Gimeno[1]

Drought is one of the most catastrophic natural hazards, and precipitation plays a major role in the development and intensification of drought events. The amount of precipitation resulting from humidity transported from a given moisture source can be key in revealing the origin of the atmospheric moisture deficit underlying drought occurrence. Here this study demonstrates, for the first time, the predominant role of moisture transport deficit in drought genesis. In most land areas, the estimated conditional probability of drought given an equivalent moisture deficit received either from the ocean or from the continents is higher than 10%. This probability is over 15% in the regions where the main atmospheric moisture transport mechanisms are active and over 20% in some hotspot regions, such as central-east North America, south-east South America and east Europe, where lower incoming moisture is almost synonymous with drought occurrence. Our results indicated that the contribution deficit of the dominant moisture source to the precipitation of a region could improve the predictability of droughts, with enormous hydrological, socioeconomic and environmental implications.

Droughts are the main natural hazard on a planetary scale, responsible for 650,000 deaths from 1970 to 2019[1], billion-dollar economic losses[2] and ecosystem impacts[3]. Despite being very complex phenomena that involve several aspects of the hydrological cycle, with several connections to ecosystem processes and water management[4–8], the main driving factor of droughts is a precipitation deficit compared with normal conditions[9,10]. This deficit can essentially occur for three reasons: because there is less moisture available for precipitation, because there is less atmospheric instability that forces air to rise, or a simultaneous occurrence of both. The relationship with moisture content may vary between different locations and seasons depending on the horizontal and temporal scale analysed, with the importance of instability usually being greater than the importance of moisture content, with the exception of its influence on extreme precipitation[11,12], where the humidity content is more important than instability. This is why, traditionally, there have been studies on meteorological and climatic conditions that do not favour instability mechanisms and therefore favour the occurrence of droughts (for example, Trenberth et al.[13]).

One major reason for the lower influence of the moisture content than the instability is the fact that it is not possible to determine how much water vapour is involved in precipitation simply from the amount of water vapour in an air column at any given time. The local humidity existing in an air column is mostly insufficient for generating precipitation[14], and lower humidity levels available for precipitation (local and advected) generally imply a deficit in the moisture that reaches the site in question. Therefore, moisture transport deficits generally lead to drought occurrence[15]. In this Article, this physical dependence between moisture transport and precipitation is the baseline for studying the statistical relationships between droughts and moisture source contribution deficits.

Atmospheric humidity that causes precipitation in a region can have two origins: (1) direct transport from the ocean or (2) subsequent recycling from the continents themselves[16–18]. The processes that control evaporation over oceans or continents and moisture transport are very different; additionally, there is a variable relationship between the oceanic and terrestrial origins of precipitation, both globally and

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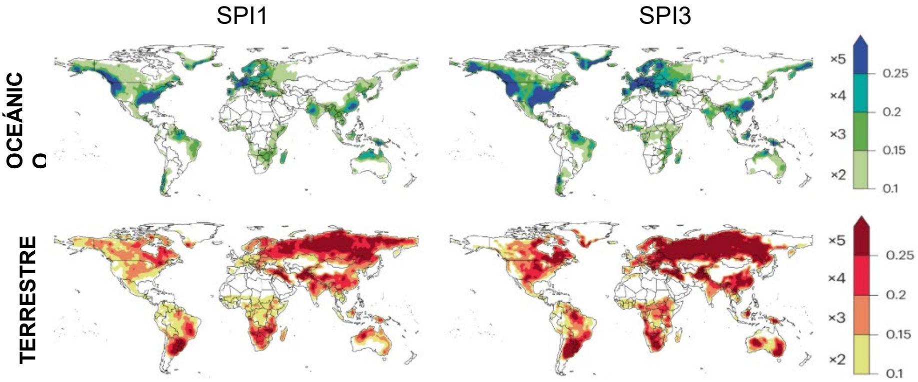
Gimeno-Sotelo, L., Sorí, R., Nieto, R. Vicente-Serrano S. and Gimeno L. Unravelling the origin of the atmospheric moisture deficit that leads to droughts. Nat Water 2, 242–253 (2024). https://doi.org/10.1038/s44221-023-00192-4

La importancia de los déficits de transporte de humedad en la ocurrencia de sequías meteorológicas

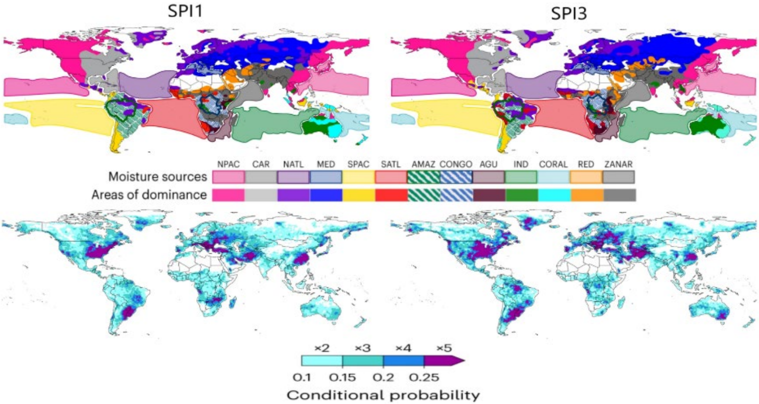
Probabilidades condicionales de ocurrencia de sequía dados déficits de contribución a la precipitación de orígenes oceánico y terrestre



Gimeno-Sotelo, L., Sorí, R., Nieto, R., Vicente-Serrano, S. M., & Gimeno, L. (2024). Unravelling the origin of the atmospheric moisture deficit that leads to droughts. *Nature Water*, 2, 242-253. https://doi.org/10.1038/s44221-023-00192-4

La importancia de los déficits de transporte de humedad en la ocurrencia de sequías meteorológicas

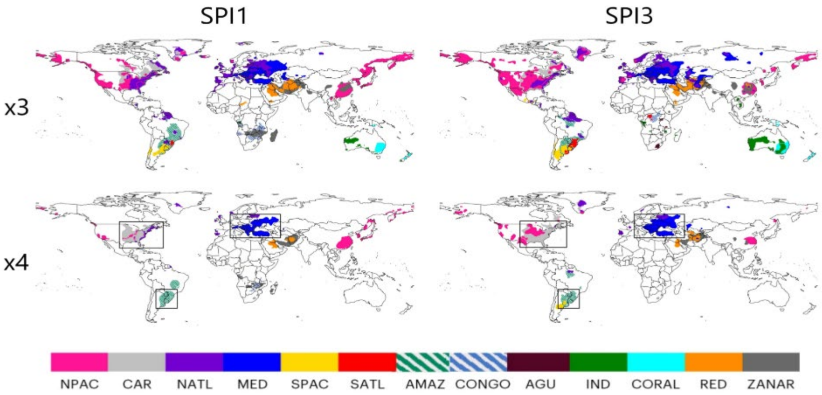
Áreas de dominancia para la ocurrencia de sequías meteorológicas de las principales fuentes de humedad del planeta



Gimeno-Sotelo, L., Sorí, R., Nieto, R., Vicente-Serrano, S. M., & Gimeno, L. (2024). Unravelling the origin of the atmospheric moisture deficit that leads to droughts. *Nature Water*, 2, 242-253. https://doi.org/10.1038/s44221-023-00192-4

La importancia de los déficits de transporte de humedad en la ocurrencia de sequías meteorológicas

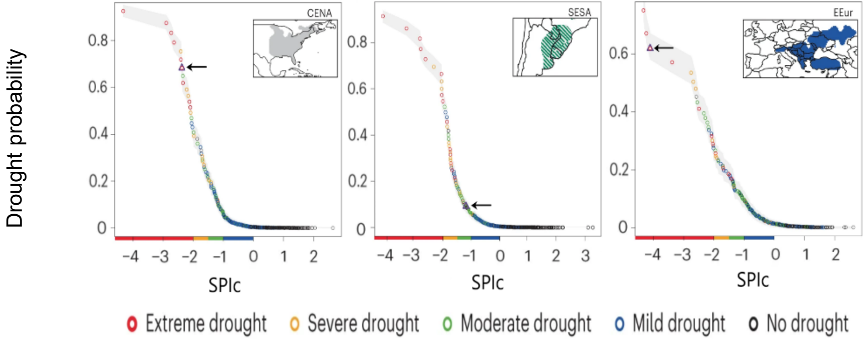
Zonas de alta probabilidad de sequía asociada a déficits de contribución a la precipitación de las principales fuentes de humedad del planeta



Gimeno-Sotelo, L., Sorí, R., Nieto, R., Vicente-Serrano, S. M., & Gimeno, L. (2024). Unravelling the origin of the atmospheric moisture deficit that leads to droughts. *Nature Water*, 2, 242-253. https://doi.org/10.1038/s44221-023-00192-4

La importancia de los déficits de transporte de humedad en la ocurrencia de sequías meteorológicas

Potencial del transporte de humedad en la predictibilidad de sequías

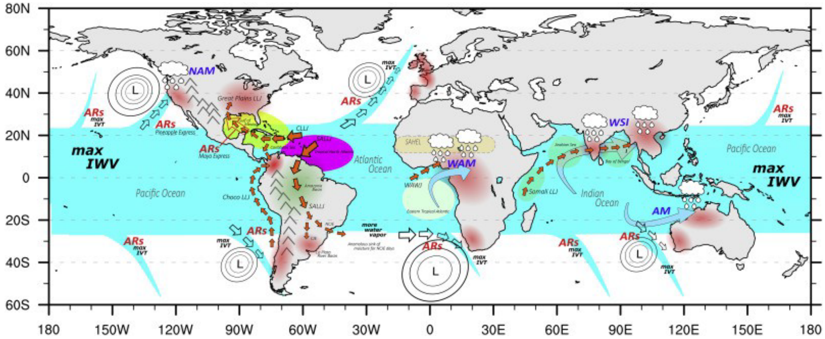


Peak of a well-known drought event: 05/1988 for CENA, 07/1988 for SESA and 11/2011 for EEur

Gimeno-Sotelo, L., Sorí, R., Nieto, R., Vicente-Serrano, S. M., & Gimeno, L. (2024). Unravelling the origin of the atmospheric moisture deficit that leads to droughts. *Nature Water*, 2, 242-253. https://doi.org/10.1038/s44221-023-00192-4

Weather Systems

EPhysLab has also investigated the moisture transport mechanisms associated with different weather systems



Major mechanisms of moisture transport at the global scale [from Gimeno et al. (2020)]

- Atmospheric rivers
- Low Level jets
- Tropical Cyclones
- Monsoons
- Extratropical and Subtropical cyclones

Gimeno et al. (2020) Recent progress on the sources of continental precipitation as revealed by moisture transport analysis, Earth Science Reviews 201 https://doi.org/10.1016/j.earscirev.2019.103070

The list of articles related with these studies can be found at

https://ephyslab.uvigo.es/moisturetransport/index.php/Meteorological_systems

Moisture Transport: from Evaporation to Precipitation

Home | Group | Publications | Research topics | Data, Catalogs & Software | Computing Resources | Links | News & Press

Meteorological systems

- Related Research Project: LAGRangian analysis of the Impact on the global hydrological cycle of the Major Mechanisms of Atmospheric Moisture Transport (LAGRIMA)

Atmospheric Rivers (ARs), **Low-Level Jets** (LLJs), **Cyclones (tropical, extratropical and subtropical)** and **monsoonal regimes** are the major mechanisms in the atmospheric moisture transport, carring large amounts of moisture from certain regions of the planet to others.

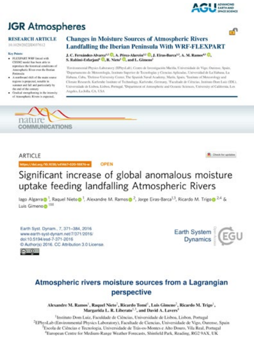
In order to understand these mechanisms as well as their impact in the sink regions, which is particularly important for the further analysis of climate change scenarios, the correct identification of moisture sources is essential.

Mainly, but not exclusively, the Lagrangian model FLEXPART, in its different versions, will be used for the identification and further analysis of moisture sources related to these mechanisms.

Below, you can find some works (not all) published by our group for different mechanisms (complete list in Publications).

> Atmospheric Rivers (ARs) | Low-Level Jets (LLJs)
>
> Tropical Cyclones (TCs) | Extratropical and Subtropical cyclones
>
> Monsoons

Weather Systems and Mechanisms: Atmospheric Rivers


JGR Atmospheres

RESEARCH ARTICLE

Changes in Moisture Sources of Atmospheric Rivers Landfalling the Iberian Peninsula With WRF-FLEXPART

nature COMMUNICATIONS

ARTICLE

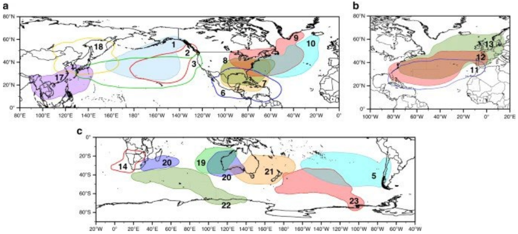
Significant increase of global anomalous moisture uptake feeding landfalling Atmospheric Rivers

Earth Syst. Dynam., 7, 371–384, 2016

Earth System Dynamics

Atmospheric rivers moisture sources from a Lagrangian perspective

1. Fernández-Alvarez et al. (2023)
2. Algarra et al., (2020)
3. Ramos et al., (2016)



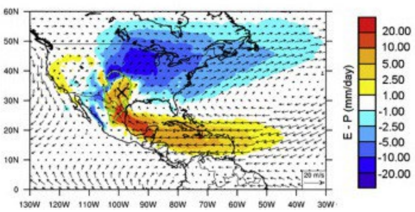
Fernández-Alvarez, J.C., Pérez-Alarcón, A., Eiras-Barca, J., Ramos, A.M., Rahimi-Esfarjani, S., Nieto, R., Gimeno, L. (2023). Changes in moisture sources of atmospheric rivers landfalling the Iberian Peninsula with WRF-Flexpart, Journal of Geophysical Research: Atmospheres, doi: 10.1029/2022JD037612

Algarra, I., Nieto, R., Ramos, A.M., Eiras-Barca, J., Trigo, R.M., Gimeno, L. (2020). Significant increase of global anomalous moisture uptake feeding landfalling Atmospheric Rivers, Nature Communications 11, 5082, https://doi.org/10.1038/s41467-020-18876-w

Ramos, A.M., Nieto, R., Tomée, R., Gimeno, L., Trigo, R.M., Liberato, M.L.R., Lavers, D.A. (2016) Atmospheric rivers moisture sources from a Lagrangian perspective, Earth System Dynamics, 7, 371-384

Weather Systems and Mechanisms: Nocturnal Low Level Jets

- Algarra et al. (2019)



Atmospheric Research 229 (2019) 39–59

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Invited review article

Global climatology of nocturnal low-level jets and associated moisture sources and sinks

Iago Algarra[a,*], Jorge Eiras-Barca[a,b], Raquel Nieto[a], Luis Gimeno[a]

[a] EPhysLab (Environmental Physics Laboratory), CIM-UVigo, Universidade de Vigo, Ourense, Spain
[b] Department of Atmospheric Sciences, University of Illinois at Urbana-Champaign, Urbana, IL, United States

ABSTRACT

Low-level jets (LLJs) are defined as regions of anomalously high wind speeds occurring within the first kilometre of the troposphere. They are filamentous structures that are usually strongly related to moisture transport. This study analysed the moisture transport associated with LLJs, and the role of LLJs in precipitation events that occasionally lead to extreme precipitation and major floods. A daily climatology dataset of nocturnal LLJs was developed and moisture transport was studied by analysing the source and sink regions. A nocturnal LLJ index based on the vertical structure of temporal wind variations was applied, and a total of 33 nocturnal LLJs were identified and characterised. The FLEXPART Lagrangian model was then used to simulate jet behaviour and to identify major source and sink regions during the period from 1980 to 2016. Differences between days with LLJs and days with no LLJs were subsequently calculated for each LLJ on a global scale with respect to moisture transport for the sources and sinks of moisture. Finally, each LLJ was analysed in terms of its associated socioeconomic impact and relationship with water scarcity.

1. Introduction

Low-level jets (LLJs) are common global meteorological phenomena and they are considered a major global mechanism of moisture transport, together with atmospheric rivers. As such, they are receiving an increasing attention in analyses of local precipitation in the regions in which they occur (Gimeno et al., 2016). In fact, LLJs generally occur in specific regions of the world, and tend to be semi-stationary seasonal events. Simplistically, they can be defined as filamentous regions or corridors of anomalously high wind speeds that are located within the first kilometre of the troposphere (Jiang et al., 2006; Nicholson, 2016). Several dynamic conditions are responsible for triggering and maintaining the structures of these LLJs, which can be essentially summarised as follows: (i) thermal gradients generated by topography, (ii) oscillations of the Planetary Boundary Layer (PBL), and (iii) characteristics of the Earth's surface. As an example, the Intra-Americas low-level jet (IALLJ) shows clear seasonal behaviour in response to thermal contrasts during the summer season (Amador, 2008). During the boreal summer, the IALLJ is divided into two branches: one that moves to the north, and another that crosses Central America and reaches the Pacific Ocean. However, in winter, one branch of the IALLJ turns to the south after crossing the Isthmus of Panama. Although LLJ systems occur throughout the year, they tend to be more strongly associated with the warm season (Bonner, 1968), and are more stable during the night (Blackadar, 1957). For these two reasons, this study focuses on nocturnal LLJs that begin to develop after sunset, reach a maximum at midnight, dissipate with the onset of daytime convective mixing, and are assumed to be caused by the nocturnal decoupling of the PBL (e.g. Jiang et al., 2007).

An initial theory on the development of LLJs was presented in a seminal paper by Blackadar (1957), who proposed that LLJs are the result of inertial oscillation of the ageostrophic wind triggered by a sudden decay of turbulence in the boundary layer after sunset, due to radiative cooling of the land's surface. However, this theory cannot explain the occurrence of certain LLJ structures, such as the Great Plains LLJ (GPLLJ). A subsequent theory proposed by Holton (1967) emphasised the importance of the role of thermal forcing in the diurnal oscillation of the boundary layer wind (as a consequence of sloping terrain), which affects the strength of LLJs. More recently, although the formation of these structures and their dominant mechanism are not yet well understood, a combination of the Blackadar mechanism and the thermal wind balance produced by sloping terrain are assumed to lead to the generation of these nocturnal LLJs (Parish and Oolman, 2010; Shapiro et al., 2016; Parish, 2017). For example, Wexler (1961) proposed that the origin of the GPLLJ is related to blocking of the easterly trade winds by the Rocky Mountains, and topography is thus an important trigger for the formation of such LLJ structures. Terrain characteristics can significantly deviate the direction of the wind at low levels and canalise it. Another example of this is the South American LLJ (SALLJ), whose flow intensifies when channelled through the

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Available online 24 June 2019

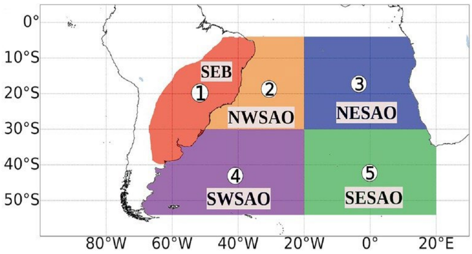
Algarra, I., Eiras-Barca, J., Nieto, R., Gimeno, L. (2019) Global climatology of nocturnal low-level jets and associated moisture sources and sinks, Atmospheric Research 229, 39-59. doi:10.1016/j.atmosres.2019.06.016

Key Points

- It is provided the location of the main moisture sinks and sources associated with each LLJ.
- Changes between days of jet and no-jet are reported geographically in terms of evaporation and precipitation.
- A brief appointment is done in terms of water scarcity and the association with the LLJs occurrence.

Weather Systems and Mechanisms: Subtropical Cyclones

These studies are focused on the South Atlantic basin

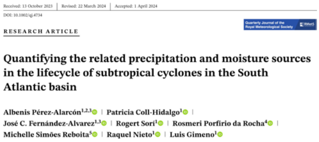



Received: 29 November 2022 | Revised: 31 January 2023 | Accepted: 8 March 2023 | Published on: 13 April 2023
DOI: 10.1002/qj.4452
Quarterly Journal of the Royal Meteorological Society RMetS

RESEARCH ARTICLE

The rare case of Hurricane *Catarina* (2004) over the South Atlantic Ocean: The origin of its precipitation through a Lagrangian approach

Albenis Pérez-Alarcón[1,2] | Patricia Coll-Hidalgo[1,3] | José C. Fernández-Alvarez[1,2] | Ricardo M. Trigo[4,5] | Raquel Nieto[1] | Luis Gimeno[1]


Received: 13 October 2023 | Revised: 22 March 2024 | Accepted: 1 April 2024
DOI: 10.1002/qj.4734
Quarterly Journal of the Royal Meteorological Society RMetS

RESEARCH ARTICLE

Quantifying the related precipitation and moisture sources in the lifecycle of subtropical cyclones in the South Atlantic basin

Albenis Pérez-Alarcón[1,2,3] | Patricia Coll-Hidalgo[1] | José C. Fernández-Alvarez[1,3] | Rogert Sorí[1] | Rosmeri Porfírio da Rocha[4] | Michelle Simões Reboita[5] | Raquel Nieto[1] | Luis Gimeno[1]

Key Points

The analysis highlights the role of external sources in moisture support.

~42 %–47 % of the moisture that reached the SCs precipitates

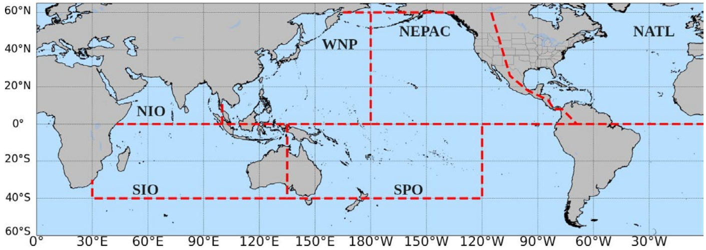
The northwestern SAO is the principal moisture source for SCs, with a quasi-constant contribution along the year.

Pérez-Alarcón, A. et al. (2023). The rare case of Hurricane Catarina (2004) over the South Atlantic Ocean: The origin of its precipitation through a Lagrangian approach. Q. J. R. Meteorol. Soc., 149 (752), 1038–1055. doi:10.1002/qj.4452

Pérez-Alarcón, A. et al. (2024). Quantifying the related precipitation and moisture sources in the lifecycle of subtropical cyclones in the South Atlantic basin. Q. J. R. Meteorol. Soc., 150(762), 2765–2782. doi:10.1002/qj.4734

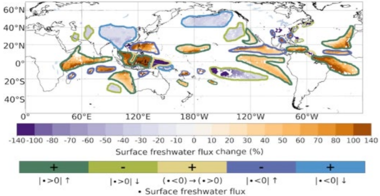
Weather Systems and Mechanisms: Tropical Cyclones

Moisture sources for tropical cyclones has been investigated in each of the ocean basins

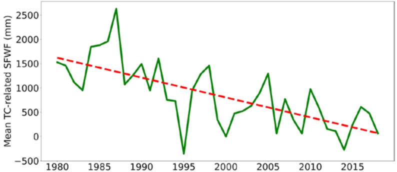


Weather Systems and Mechanisms: Tropical Cyclones

Impacts of tropical cyclones on the global water budget



Surface freshwater fluxes anomalies in (%) during TCs.



Annual global TC-related surface freshwater flux (SFWF) and the dashed red line shows its statistically significant (p<0.05)

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ARTICLE OPEN

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Impacts of tropical cyclones on the global water budget

Albenis Pérez-Alarcón[1,2], Patricia Coll-Hidalgo[1], José C. Fernández-Alvarez[1,2], Ricardo M. Trigo[3,4], Raquel Nieto[1] and Luis Gimeno[1]✉

Tropical cyclones (TCs) require substantial amounts of moisture for their genesis and development, acting as important moisture drivers from the ocean to land and from tropical to subtropical and extratropical regions. Quantifying anomalous moisture transport related to TCs is crucial for understanding long-term TC-induced changes in the global hydrological cycle. Our results highlight that, in terms of the global water budget, TCs enhance moisture transport from evaporative regions and precipitation over sink regions, leading to predominantly anomalous positive surface freshwater flux areas over the tropics and more regionally concentrated negative areas over the Intertropical Convergence Zone. Furthermore, we detected seasonal variability in the impact of TC on the hydrological cycle, which is closely related to the annual and seasonal TC frequency. Our analysis also revealed a global statistically significant drop (~40 mm year^{-1}) in TC-induced surface freshwater fluxes from 1980 to 2018 in response to the increasing sea surface temperature and slightly decrease in global TC frequency and lifetime in the last two decades. These findings have important implications for predicting the impacts of TCs on the hydrological cycle under global warming conditions.

npj Climate and Atmospheric Science (2023)6:212 ; https://doi.org/10.1038/s41612-023-00546-5

INTRODUCTION

Tropical cyclones (TCs) are critical for transferring moisture from the tropics to mid-latitudes and high latitudes[1,2] and from the ocean to land[3,4], thereby influencing weather patterns in tropical and subtropical regions worldwide [e.g. ref. [5]] and playing a crucial role in the atmospheric branch of the global hydrological cycle[3,4,6,7]. While relevant in these roles, the contribution of TCs to poleward water vapour transport from tropical to extratropical regions across the mid-latitudes globally is substantially smaller than that of atmospheric rivers[8]. Nonetheless, intense convective activity during TCs induces a vast amount of water vapour that is redistributed across the atmosphere and can produce notable precipitation totals in terrestrial regions[6,7], providing moisture to areas that may experience dry conditions[9]. However, impacts of TCs are associated with substantial environmental disturbances as well as socioeconomic and human losses caused by extreme compound events, such as strong winds, heavy rainfall, storm surges, flash flooding, and landslide[10,11].

Atmospheric moisture availability is crucial for TC genesis and development[12]. Indeed, modelling and theoretical studies have demonstrated that an increase (decrease) in mid-level water vapour content enhances (inhibits) TC intensification[13,14]. Furthermore, understanding the origin of moisture for precipitation produced by TCs is key to significantly assisting in risk analysis and mitigating the often strong associated impacts. Recently, Pérez-Alarcón et al.[15–17] revealed that precipitating moisture was predominantly highest from sources close to the TC positions. Likewise, large-scale atmospheric circulation patterns in each region drove the moisture towards the TC locations.

Improving our knowledge of moisture transport is crucial for investigating extreme precipitation events[18,19]. Anomalous moisture transport caused by changes in large-scale circulation is a key factor in long-term changes in extreme precipitation[20]. Thus, TCs contribute significantly to onshore moisture transport. Because moisture and heat fluxes from the warm sea surface are the principal fuels for TCs[13], previous studies have been mainly focused on the TC water budget[21–26], the origin of moisture for TCs precipitation[15–17,27], the contribution of TCs to monthly and annual precipitation totals in tropical and subtropical latitudes[6,7] or the TC-related onshore moisture transport[3,4]. For example, moisture convergence is the main contributor to TC rainfall[24,26]; TCs are responsible for approximately 14–19% of the net onshore moisture driven towards North America[3] and their precipitation represents a significant fraction of the annual precipitation totals at regional, continental and even global scales[4,6]. Additionally, part of the moisture gained by TCs from the ocean evaporation is brought about by the storm itself[22], so TCs can induce anomalous moisture fluxes towards their locations. However, few studies [e.g. refs. [28–31]] have investigated anomalies in moisture transport by TCs, which are necessary to understand the role of TCs in regional and global hydrological cycles. Extreme precipitation and moisture flux are positively correlated[3]. On this basis, the spatial pattern of anomalous moisture convergence tends to agree with the regions of anomalous cyclonic circulation in the tropical northeastern Pacific Ocean[28]. In particular, a climatological analysis of vertically integrated water vapour transport from hurricanes Matthew (2016) and Florence (2018) revealed the critical role of anomalous moisture flow from the Atlantic Ocean in producing extreme rainfall in North and South Carolina[30].

Based on these previous studies and large-scale water and energy budgets, it remains unclear what happens with atmospheric moisture before it arrives at TC locations, which areas experience more evaporation than precipitation during TCs and vice versa, and whether the long-term tendencies of these anomalous moisture fluxes are linked to global warming. Therefore, this knowledge gap and the projected increase in atmospheric water vapour content at a rate of ~6–7% per degree of sea surface warming (on the basis of the Clausius–Clapeyron equation)[32–34] warrant further examination of the anomalous

[1]Centro de Investigación Mariña, Universidade de Vigo, Environmental Physics Laboratory (EPhysLab), Campus As Lagoas s/n, 32004 Ourense, Spain. [2]Departamento de Meteorología, Instituto Superior de Tecnologías y Ciencias Aplicadas, Universidad de La Habana, 10400 La Habana, Cuba. [3]Instituto Dom Luiz (IDL), Faculdade de Ciências, Universidade de Lisboa, Lisbon, Portugal. [4]Departamento de Meteorologia, Universidade Federal do Rio de Janeiro, Rio de Janeiro 21941-919, Brazil. ✉email: l.gimeno@uvigo.es

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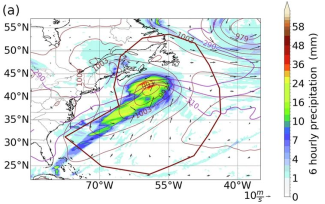
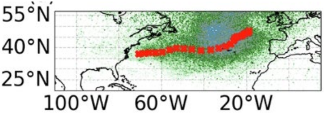
Pérez-Alarcón, A., Coll-Hidalgo, P., Fernández-Alvarez, J.C. et al. Impacts of tropical cyclones on the global water budget. npj Clim Atmos Sci 6, 212 (2023). https://doi.org/10.1038/s41612-023-00546-5

Weather Systems and Mechanisms: ExtraTropical cyclones

Moisture sources for extratropical cyclones has been investigated in the North Atlantic ocean basin



ETC shape modelling for the EC02902 case on February 8, 2002, at 1200 UTC over the North Atlantic (NATL) basin.



Moisture uptake for a radius target region over the entire lifecycle,ranging from March 21 at 0600 UTC to March 27 at 0000UTC

Coll-Hidalgo, P., Gimeno-Sotelo, L., Fernández-Alvárez, J.C. Nieto, R. and Gimeno, L.. North Atlantic Extratropical Cyclone Tracks and Lagrangian-Derived Moisture Uptake Dataset. Sci Data 11, 1258 (2024). https://doi.org/10.1038/s41597-024-04091-5

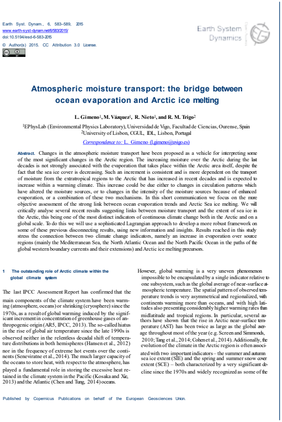
Key Points

In this study, we present a database for North Atlantic ETC tracks and a Lagrangian-Derived Moisture Uptake Dataset, both of which are derived from dynamically downscaled ERA5 reanalysis data. We provide moisture parameters such as the total moisture uptake and its vertical distribution by layer, and shapefiles of ETC structures, to facilitate further studies in this area. Our data have been thoroughly validated to ensure that the storm tracks and their characteristics are accurately represented in the model without distortion. Additionally, we conduct a series of experiments to demonstrate the rigour and quality of the methods employed to generate the data.

Other results from EPhysLab

Several regional studies have also been performed.

- **Polar Regions**
- River basins
- Moisture sources for Continental Climate Regions
- Ecoregions



Earth Syst. Dynam., 6, 583–589, 2015
www.earth-syst-dynam.net/6/583/2015/
doi:10.5194/esd-6-583-2015

Earth System Dynamics

Atmospheric moisture transport: the bridge between ocean evaporation and Arctic ice melting

L. Gimeno[1], M. Vázquez[1], R. Nieto[1], and R. M. Trigo[2]
[1]EPhysLab (Environmental Physics Laboratory), Universidad de Vigo, Facultad de Ciencias, Ourense, Spain
[2]University of Lisbon, CGUL, IDL, Lisbon, Portugal
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Abstract. Changes in the atmospheric moisture transport have been proposed as a vehicle for interpreting some of the most significant changes in the Arctic region. The increasing moisture over the Arctic during the last decades is not strongly associated with the evaporation that takes place within the Arctic area itself, despite the fact that the sea ice cover is decreasing. Such an increment is consistent and is more dependent on the transport of moisture from the extratropical regions to the Arctic that has increased in recent decades and is expected to increase within a warming climate. This increase could be due either to changes in circulation patterns which have altered the moisture sources, or to changes in the intensity of the moisture sources because of enhanced evaporation, or a combination of these two mechanisms. In this short communication we focus on the more objective assessment of the strong link between ocean evaporation trends and Arctic Sea ice melting. We will critically analyse several recent results suggesting links between moisture transport and the extent of sea ice in the Arctic, this being one of the most distinct indicators of continuous climate change both in the Arctic and on a global scale. To do this we will use a sophisticated Lagrangian approach to develop a more robust framework on some of these previous disconnecting results, using new information and insights. Results reached in this study stress the connection between two climate change indicators, namely an increase in evaporation over source regions (mainly the Mediterranean Sea, the North Atlantic Ocean and the North Pacific Ocean in the paths of the global western boundary currents and their extensions) and Arctic ice melting precursors.

1 The outstanding role of Arctic climate within the global climate system

The last IPCC Assessment Report has confirmed that the main components of the climate system have been warming (atmosphere, oceans) or shrinking (cryosphere) since the 1970s, as a result of global warming induced by the significant increment in concentration of greenhouse gases of anthropogenic origin (AR5, IPCC, 2013). The so-called hiatus in the rise of global air temperature since the late 1990s is observed neither in the relentless decadal shift of temperature distributions in both hemispheres (Hansen et al., 2012) nor in the frequency of extreme hot events over the continents (Seneviratne et al., 2014). The much larger capacity of the oceans to store heat, with respect to the atmosphere, has played a fundamental role in storing the excessive heat retained in the climate system in the Pacific (Kosaka and Xie, 2013) and the Atlantic (Chen and Tung, 2014) oceans.

However, global warming is a very uneven phenomenon impossible to be encapsulated by a single indicator relative to one subsystem, such as the global average of near-surface atmospheric temperature. The spatial pattern of observed temperature trends is very asymmetrical and regionalized, with continents warming more than oceans, and with high latitudes also presenting considerably higher warming rates than midlatitude and tropical regions. In particular, several authors have shown that the rise in Arctic near-surface temperature (AST) has been twice as large as the global average throughout most of the year (e.g. Screen and Simmonds, 2010; Tang et al., 2014; Cohen et al., 2014). Additionally, the evolution of the climate in the Arctic region is often associated with two important indicators – the summer and autumn sea ice extent (SIE) and the spring and summer snow cover extent (SCE) – both characterized by a very significant decline since the 1970s and widely recognized as some of the

Published by Copernicus Publications on behalf of the European Geosciences Union.

Gimeno et al. (2015) Atmospheric moisture transport: the bridge between ocean evaporation and Arctic ice melting, Earth System Dynamics, 2, 583-589. doi:10.5194/esd-6-583-2015

Other results from EPhysLab

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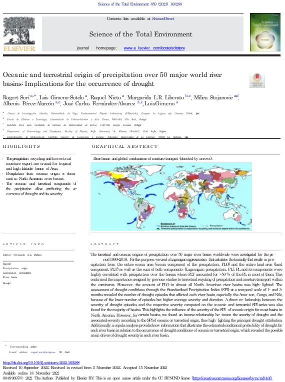
Science of the Total Environment 859 (2023) 160288

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.e lsevier. com/locate/scitotenv

Oceanic and terrestrial origin of precipitation over 50 major world river basins: Implications for the occurrence of drought

Rogert Sorí[a,*], Luis Gimeno-Sotelo[a], Raquel Nieto[a], Margarida L.R. Liberato[b,c], Milica Stojanovic[a,d], Albenis Pérez-Alarcón[a,e], José Carlos Fernández-Alvarez[a,e], Luis Gimeno[a]

HIGHLIGHTS

- The precipitation recycling and terrestrial moisture export are crucial for tropical and high latitudes basins of Asia.
- Precipitation from oceanic origin is dominant in North American river basins.
- The oceanic and terrestrial components of the precipitation allow attributing the occurrence of drought and its severity.

GRAPHICAL ABSTRACT

River basins and global mechanisms of moisture transport (denoted by arrows).

ARTICLE INFO

Editor: Fernando A.L. Pacheco

Keywords:
Precipitation origin
Lagrangian precipitation
River basins
Drought

ABSTRACT

The terrestrial and oceanic origins of precipitation over 50 major river basins worldwide were investigated for the period 1980–2018. For this purpose, we used a Lagrangian approximation that calculates the humidity that results in precipitation from the entire ocean area (ocean component of the precipitation, PLO) and the entire land area (land component, PLT) as well as the sum of both components (Lagrangian precipitation, PL). PL and its components were highly correlated with precipitation over the basins, where PLT accounted for >50 % of the PL in most of them. This confirmed the importance assigned by previous studies to terrestrial recycling of precipitation and moisture transport within the continents. However, the amount of PLO in almost all North American river basins was highlighted. The assessment of drought conditions through the Standardized Precipitation Index (SPI) at a temporal scale of 1- and 3-months revealed the number of drought episodes that affected each river basin, especially the Amazon, Congo, and Nile, because of the lower number of episodes but higher average severity and duration. A direct relationship between the severity of drought episodes and the respective severity computed on the oceanic and terrestrial SPI series was also found for the majority of basins. This highlights the influence of the severity of the SPI of oceanic origin for most basins in North America. However, for certain basins, we found an inverse relationship between the severity of drought and the associated severity according to the SPI of oceanic or terrestrial origin, thus highlighting the principal drought attribution. Additionally, a copula analysis provided new information that illustrates the estimated conditional probability of drought for each river basin in relation to the occurrence of drought conditions of oceanic or terrestrial origin, which revealed the possible main driver of drought severity in each river basin.

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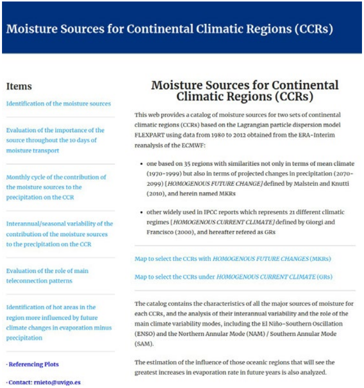
Sorí et al. (2023) Oceanic and terrestrial origin of precipitation over 50 major world river basins: Implications for the occurrence of drought, Science of The Total Environment, Vol. 859, Part 2; DOI: 10.1016/j.scitotenv.2022.160288

Other results from EPhysLab

Several regional studies have also been performed.

- Polar Regions
- River basins
- Moisture sources for Continental Climate Regions
- Ecoregions



Nieto et al. (2014), A catalog of moisture sources for continental climatic regions, Water Resour. Res., 50, 5322–5328, doi:10.1002/2013WR013901.

Other results from EPhysLab

Several regional studies have also been performed.

- Polar Regions
- River basins
- Moisture sources for Continental Climate Regions
- Ecoregions

remote sensing MDPI

Article

Vegetation Greenness Sensitivity to Precipitation and Its Oceanic and Terrestrial Component in Selected Biomes and Ecoregions of the World

Milica Stojanovic [1,2,*], Rogert Sori [1], Guergana Guerova [2], Marta Vázquez [1], Raquel Nieto [1] and Luis Gimeno [1]

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Abstract: In this study, we conducted a global assessment of the sensitivity of vegetation greenness (VGS) to precipitation and to the estimated Lagrangian precipitation time series of oceanic (PLO) and terrestrial (PLT) origin. The study was carried out for terrestrial ecosystems consisting of 9 biomes and 139 ecoregions during the period of 2001–2018. This analysis aimed to diagnose the vegetative response of vegetation to the dominant component of precipitation, which is of particular interest considering the hydroclimatic characteristics of each ecoregion, climate variability, and changes in the origin of precipitation that may occur in the context of climate change. The enhanced vegetation index (EVI) was used as an indicator of vegetation greenness. Without consideration of semi-arid and arid regions and removing the role of temperature and radiation, the results show the maximum VGS to precipitation in boreal high-latitude ecoregions that belong to boreal forest/taiga: temperate grasslands, savannas, and shrublands. Few ecoregions, mainly in the Amazon basin, show a negative sensitivity. We also found that vegetation greenness is generally more sensitive to the component that contributes the least to precipitation and is less stable throughout the year. Therefore, most vegetation greenness in Europe is sensitive to changes in PLT and less to PLO. In contrast, the boreal forest/taiga in northeast Asia and North America is more sensitive to changes in PLO. Finally, in most South American and African ecoregions, where PLT is crucial, the vegetation is more sensitive to PLO, whereas the contrast occurs in the northern and eastern ecoregions of Australia.

Keywords: vegetation sensitivity; precipitation; PLO; PLT

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Citation: Stojanovic, M.; Sori, R.; Guerova, G.; Vázquez, M.; Nieto, R.; Gimeno, L. Vegetation Greenness Sensitivity to Precipitation and Its Oceanic and Terrestrial Component in Selected Biomes and Ecoregions of the World. *Remote Sens.* **2023**, 15, 4706. https://doi.org/10.3390/rs15194706

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Published: 26 September 2023

1. Introduction

Covering approximately three-fourths of the land surface, vegetation represents a principal part of land ecosystems [1] and plays an important role in land–atmosphere interactions [2,3]. Additionally, vegetation in terrestrial ecosystems affords a broad range of ecosystem goods and services (e.g., water balance and carbon cycle) [4]. Thus, many researchers have focused their studies on the estimation of vegetation feedback to fluctuations in specific climatic variables [5,6], revealing that climate change has seriously affected the distribution and variety of vegetation [7,8]. Vegetation is a crucial element in the terrestrial ecosystem functionality and is highly dependent on climatic conditions. Vegetation changes have been particularly linked with variations in temperature and precipitation [9–11]. Because precipitation has a crucial role in water accessibility, it is considered a meteorological variable that primarily controls vegetation structure and dynamics. It is responsible for vegetation greenness and growth in arid and semi-arid ecosystems where the lack of precipitation suppresses the grow of plants [12–15].

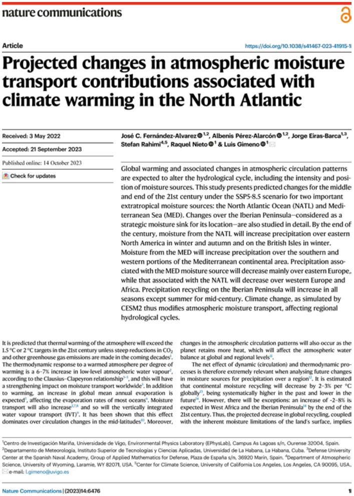
Remote Sens. **2023**, 15, 4706. https://doi.org/10.3390/rs15194706 https://www.mdpi.com/journal/remotesensing

Stojanovic et al. (2023) Vegetation Greenness Sensitivity to Precipitation and Its Oceanic and Terrestrial Component in Selected Biomes and Ecoregions of the World, Remote Sensing, 15 (19), 4706. https://doi.org/10.3390/rs15194706

Moisture sources in the future

Investigating future changes in moisture sources contributions has been addressed for the first time in EPhysLab

Moisture sources in the future



nature communications

Article https://doi.org/10.1038/s41467-023-41915-1

Projected changes in atmospheric moisture transport contributions associated with climate warming in the North Atlantic

Received: 3 May 2022

Accepted: 21 September 2023

Published online: 14 October 2023

Check for updates

José C. Fernández-Alvarez[1,2], Albenis Pérez-Alarcón[1,2], Jorge Eiras-Barca[1,3], Stefan Rahimi[4,5], Raquel Nieto[1] & Luis Gimeno[1]

Global warming and associated changes in atmospheric circulation patterns are expected to alter the hydrological cycle, including the intensity and position of moisture sources. This study presents predicted changes for the middle and end of the 21st century under the SSP5-8.5 scenario for two important extratropical moisture sources: the North Atlantic Ocean (NATL) and Mediterranean Sea (MED). Changes over the Iberian Peninsula—considered as a strategic moisture sink for its location—are also studied in detail. By the end of the century, moisture from the NATL will increase precipitation over eastern North America in winter and autumn and on the British Isles in winter. Moisture from the MED will increase precipitation over the southern and western portions of the Mediterranean continental area. Precipitation associated with the MED moisture source will decrease mainly over eastern Europe, while that associated with the NATL will decrease over western Europe and Africa. Precipitation recycling on the Iberian Peninsula will increase in all seasons except summer for mid-century. Climate change, as simulated by CESM2 thus modifies atmospheric moisture transport, affecting regional hydrological cycles.

It is predicted that thermal warming of the atmosphere will exceed the 1.5 °C or 2 °C targets in the 21st century unless steep reductions in CO_2 and other greenhouse gas emissions are made in the coming decades[1]. The thermodynamic response to a warmed atmosphere per degree of warming is a 6–7% increase in low-level atmospheric water vapour[2], according to the Clausius–Clapeyron relationship[3–5], and this will have a strengthening impact on moisture transport worldwide[5]. In addition to warming, an increase in global mean annual evaporation is expected[5], affecting the evaporation rates of most oceans[6]. Moisture transport will also increase[2,7,8] and so will the vertically integrated water vapour transport (IVT)[9]. It has been shown that this effect dominates over circulation changes in the mid-latitudes[10]. Moreover, changes in the atmospheric circulation patterns will also occur as the planet retains more heat, which will affect the atmospheric water balance at global and regional levels[11].

The net effect of dynamic (circulation) and thermodynamic processes is therefore extremely relevant when analysing future changes in moisture sources for precipitation over a region[12]. It is estimated that continental moisture recycling will decrease by 2–3% per °C globally[13], being systematically higher in the past and lower in the future[14]. However, there will be exceptions: an increase of ~2–8% is expected in West Africa and the Iberian Peninsula[14] by the end of the 21st century. Thus, the projected decrease in global recycling, coupled with the inherent moisture limitations of the land's surface, implies

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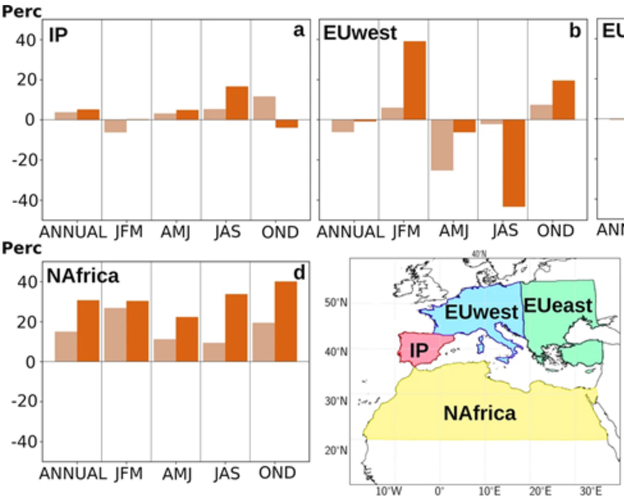
Nature Communications | (2023)14:6476 1

Investigating future changes in moisture sources contributions has been addressed for the first time in EPhysLab

- FLEXPART-WRF has been used to simulate future changes in moisture transport contributions in the North Atlantic in the context of global warning

Fernández-Alvarez, J.C.; Pérez-Alarcón, A.; Eiras-Barca,J.; Rahimi, S.; Nieto, R.; Gimeno, L. (2023). Projected changes in atmospheric moisture transport contributions associated with climate warming in the North Atlantic. Nature Communications volume, 14, 6476. https://doi.org/10.1038/s41467-023-41915-1

Moisture sources in the future



Description of bars colours

Projected changes for the mid-of-century period (2036-2065):

SSP5-8.5

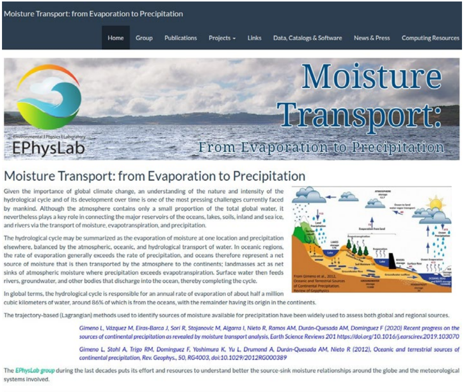
Projected changes for the end-of-century period (2071-2100):

SSP5-8.5

EPysLab in numbers

Scientific results linked to moisture transport

- Doctoral Thesis: 11
- Master Thesis: 3
- Publications: 161


Moisture Transport: from Evaporation to Precipitation

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Moisture Transport: from Evaporation to Precipitation

Given the importance of global climate change, an understanding of the nature and intensity of the hydrological cycle and of its development over time is one of the most pressing challenges currently faced by mankind. Although the atmosphere contains only a small proportion of the total global water, it nevertheless plays a key role in connecting the major reservoirs of the oceans, lakes, soils, inland and sea ice, and rivers via the transport of moisture, evapotranspiration, and precipitation.

The hydrological cycle may be summarized as the evaporation of moisture at one location and precipitation elsewhere, balanced by the atmospheric, oceanic, and hydrological transport of water. In oceanic regions, the rate of evaporation generally exceeds the rate of precipitation, and oceans therefore represent a net source of moisture that is then transported by the atmosphere to the continents; landmasses act as net sinks of atmospheric moisture where precipitation exceeds evapotranspiration. Surface water then feeds rivers, groundwater, and other bodies that discharge into the ocean, thereby completing the cycle.

From Gimeno et al., 2012, Oceanic and Terrestrial Sources of Continental Precipitation. Review of Geophysics

In global terms, the hydrological cycle is responsible for an annual rate of evaporation of about half a million cubic kilometers of water, around 86% of which is from the oceans, with the remainder having its origin in the continents.

The trajectory-based (Lagrangian) methods used to identify sources of moisture available for precipitation have been widely used to assess both global and regional sources.

Gimeno L, Vázquez M, Eiras-Barca J, Sori R, Stojanovic M, Algarra I, Nieto R, Ramos AM, Durán-Quesada AM, Dominguez F (2020) Recent progress on the sources of continental precipitation as revealed by moisture transport analysis, Earth Science Reviews 201 https://doi.org/10.1016/j.earscirev.2019.103070

Gimeno L, Stohl A, Trigo RM, Dominguez F, Yoshimura K, Yu L, Drumond A, Durán-Quesada AM, Nieto R (2012), Oceanic and terrestrial sources of continental precipitation, Rev. Geophys., 50, RG4003, doi:10.1029/2012RG000389

The EPhysLab group during the last decades puts its effort and resources to understand better the source-sink moisture relationships around the globe and the meteorological systems involved.

https://ephyslab.uvigo.es/moisturetransport/

Research Projects

All of the EPhysLab studies has been associated with research projects

- **Present and future climate humidity transport over Central and South America: Mechanisms, extremes and attribution of changes. Funded by Xunta de Galicia (Grant: ED431F-2024/03), Spain**
- **High-resolution assessment of North Atlantic moisture transport in current climate and CMIP-6 future projections. Funded by Ministerio de Ciencia, Innovaci´on y Universidades (Grant: PID2021-122314OB-I00), Spain**
- LAGRangian analysis of the Impact on the global hydrological cycle of the Major Mechanisms of Atmospheric Moisture Transport (LAGRIMA). Funded by Ministerio de Econom´ıa y Competitividad. (Grant: RTI2018-095772-B-I00), Spain
- Moisture Tranport (TRAMO). Funded by Ministerio de Econom´ıa y Competitividad. Spain.
- Droughts and Moisture Transport (SETH)
- Moisture Sources for Continental Climatic Regions (CCRs)
- Atmospheric moisture transport, the bridge between ocean evaporation and Arctic Sea ice melting (EVOCAR)

Análisis lagrangiano de transporte de calor

Identificación Lagrangiana de las fuentes de calor sensible

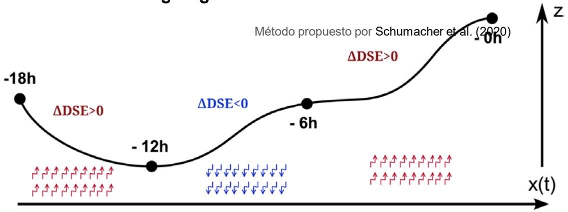


Figura. Representación esquemática tridimensional de la trayectoria de una partícula atmosférica. DSE: Energía estática seca

- Las parcelas de aire que residen en la capa límite (PBL) en la región de interés fueron seguidas hacia atrás en el tiempo hasta 10 días.
- Las fuentes de calor sensibles se identifican entonces cuando la energía estática seca (DSE) de la parcela aumenta en más de 1 kJ en un intervalo de tiempo de 6 horas dentro de la PBL a lo largo de su trayectoria.
- Como las pérdidas de calor (es decir, enfriamiento) pueden ocurrir antes de que la parcela llegue a la región objetivo, descontamos proporcionalmente la pérdida a todo el calentamiento anterior.

La distribución espacial de las fuentes de calor sensible se estima finalmente como:

$$SHF = \frac{m\sum_{k=1}^{N} \triangle DSE_k}{A}$$

Análisis lagrangiano de anomalías de temperatura particionadas por procesos físicos

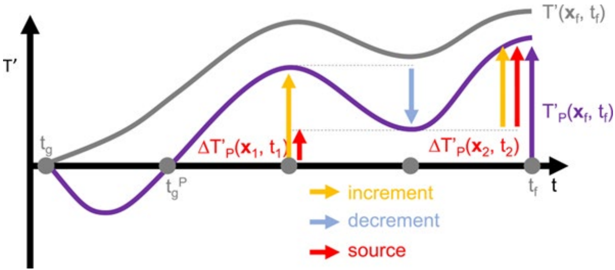
Para determinar las fuentes de las anomalías de temperatura se define (T’) como desviaciones de la temperatura respecto a la climatología de temperatura Para la identificación de la fuente T’ se utilizarán las trayectorias del FLEX-ERA5 y FLEXPART-WRF con las diferentes bases de datos. Los campos de T’ podrían descomponerse e interpolarse a las posiciones de las trayectorias, y las cantidades derivadas evaluarse como en Röthlisberger & Papritz (2023) y Papritz & Röthlisberger (2023). El cambio de T’ en la trayectoria de una partícula entre las posiciones de trayectoria xg en el tiempo tg y x en el tiempo t se define como sigue:

$$\boldsymbol{T'(x,t) - T'(x_g,t_g) = -\int_{t_g^{sea}}^{t} \frac{\partial \underline{T}}{\partial t} d\tau - \int_{t_g^{adv}}^{t} v * \nabla_h(\underline{T}) d\tau + \int_{t_g^{adi}}^{t} \left[\frac{\kappa T}{p} - \frac{\partial \underline{T}}{\partial p}\right] \omega d\tau + \int_{t_g^{dia}}^{t} \left(\frac{p}{p_0}\right)^{\kappa} \frac{D\theta}{Dt} d\tau}$$

donde v y ω son las componentes horizontal y vertical del viento, respectivamente, T la climatología de la temperatura, ∇h el gradiente horizontal, κ la constante de Poisson, p la presión (p_0 = 1000 hPa), y θ la temperatura potencial.

Análisis lagrangiano de anomalías de temperatura particionadas por procesos físicos

En la ecuación, los términos de izquierda a derecha representan T’ determinada por cambios temporales en la climatología, incluyendo el ciclo diario y la estacionalidad (primer término, ⟦T'⟧_sea), la advección horizontal asociada a los gradientes climatológicos de T (advección, segundo término, ⟦T' ⟧_adv), la expansión y compresión adiabática (adiabática, tercer término, ⟦T'⟧_adi) y el calentamiento o enfriamiento diabático (diabático, cuarto término, ⟦T'⟧_dia)



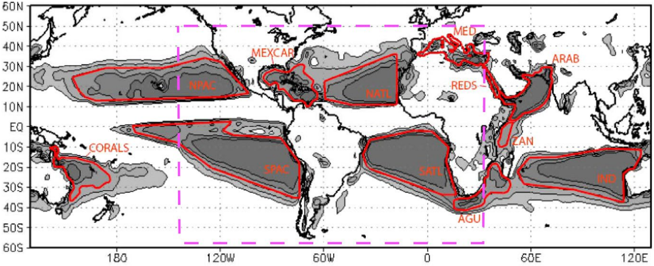
Increments and decrements are shown by orange and blue arrows, respectively. Two sources, ΔTP’(x1,t1) and ΔTP’(x2,t2) (red arrows), contribute to TP’(xf,tf) (purple arrow). From [Papritz & Röthlisberger (2023)](#)

Proyecto: Present and future climate humidity transport over Central and South America: Mechanisms, extremes and attribution of changes

Se realizará la reducción de escala dinámica utilizando el modelo WRF v4.2, con datos de entrada del reanálisis ERA5 para el periodo histórico y un ensemble de salidas de GCM CMIP6 para tres conjuntos de simulaciones, un período histórico (1985-2014) y mediados y finales del siglo (2041-2070 y 2071-2100) utilizando un dominio con 20 km de resolución.

Se implementará FLEXPART-WRF para el análisis del transporte de humedad.

Dominio de modelización



1. *Se investigarán las fuentes de humedad, histórico vs futuro.*
2. *Los cambios en los mecanismos de transporte, histórico vs futuro*
3. *Eventos de sequía, histórico vs futuro*
4. *Role del transporte de humedad en la atribución de estos eventos.*

RESUMEN Y PERSPECTIVAS FUTURAS DE LA INVESTIGACIÓN SOBRE EL TRANSPORTE DE HUMEDAD Y CALOR EN EL GRUPO EPHYSLAB DE LA UNIVERSIDAD DE VIGO

Luis Gimeno

The authors acknoledge the support from
EXMERISK PROJECT (TED2021-129152B-C43)
MCIN/AEI y Unión Europea NextGenerationEU/ PRTR)

MINISTERIO DE CIENCIA E INNOVACIÓN
Financiado por la Unión Europea NextGenerationEU
Plan de Recuperación, Transformación y Resiliencia
AGENCIA ESTATAL DE INVESTIGACIÓN
Campus da Auga
EPhysLab