

# Objectives and approaches used in moisture transport studies in EPhysLab at the University of Vigo.

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## 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 | Physics | 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.



Dr. Raquel Nieto

P.I.

- Dr. Robert Sorí, Senior Scientist, EPhysLab-UVigo.
- Dr. Milica Stojanovic, Senior Scientist, EPhysLab-UVigo.
- Dr. Jorge Elías-Blanca, Senior Scientist, CUD-UVigo, Marín, Spain.
- Dr. Alterri Pérez-Alarcón, Post-Doc Scientist EPhysLab-UVigo, now at CGUL/IDL, University of Lisbon.
- Dr. José Carlos Fernández-Alvarez, Post-Doc Scientist, Galicia Supercomputing Center (CESGA), Santiago de Compostela, Spain.
- Dr. Luis Gimeno-Sotelo, Post-Doc Student at EPhysLab-UVigo.
- Patricia Coll-Hidalgo, Ph.D. Student at EPhysLab-UVigo.
- Gleisis Álvarez-Socorro, Ph.D. Student at EPhysLab-UVigo.
- Yiyang Wang, Ph.D. Student at EPhysLab-UVigo.
- Jakob Ernst, Ph.D. Student at EPhysLab-UVigo.

### Former Collaborators:

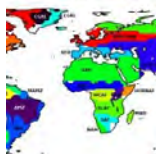
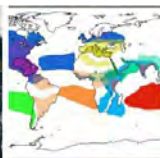
- Dr. Ricardo M. Trigo, Senior Scientist at University of Lisbon, Portugal.
- Dr. Anita Drumond, Senior Post-Doctoral Researcher at USP, Sao Paulo, Brazil.
- Dr. Alexandre Ramos, Senior Scientist at Karlsruhe Institute of Technology (KIT), Germany.
- Dr. Ana M. Durán-Quesada, Senior Scientist at Costa 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 Droughts and extreme precipitation
- 5 Moisture sources in the future



## 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, Vazquez 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., Domínguez, 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 atmospheric moisture transport

### FLEXPART-ERA-I

FLEXPARTv9.0

- 2 million air parcels
- Global simulations
- Period: 1980-2018
- Input H resolution:  $1^{\circ}$
- Input V resolution: 61 levels
- Output: binary files

### FLEXPART-ERA5

FLEXPARTv10.4

- 30 million air parcels
- Global simulations
- Period: 1980-2023
- Input H resolution:  $0.5^{\circ}$
- 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

The moisture transport analysis provided by these datasets have been fully validated.

Fernández-Alvarez, J.C., Vázquez, M., Pérez-Alarcón, A., Nieto, R., Gimeno, L. (2023) Comparison of Moisture Sources and Sinks Estimated with Different Versions of FLEXPART and FLEXPART-WRF Models Forced with ECMWF Reanalysis Data, Journal of Hydrometeorology, <https://doi.org/10.1175/JHM-D-22-0018.1>

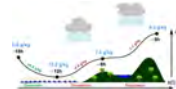
The most up-to-date simulations (FLEXPART-ERA5) are described on Zenodo

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>

## 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 Sodemann et al. (2008)

The precipitation en route is discounted from all previous moisture uptakes

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

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

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

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

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](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](https://doi.org/10.1029/2007JD008503), doi:10.1029/2007JD008503.

## Moisture tracking tools

● TROVA

● LATTIN



### TRAnsport Of water VApour

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 VApour. *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 Atmospheric moisTure and heaT trackINg

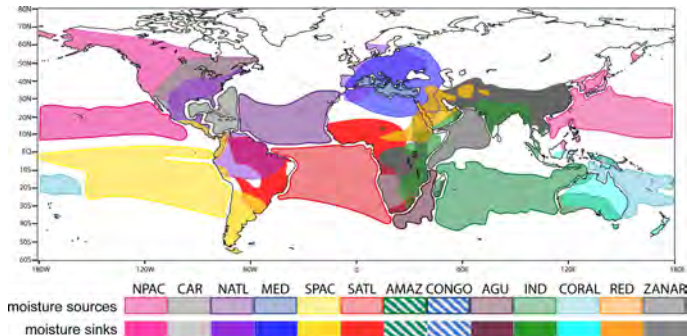
### Tracking approaches

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

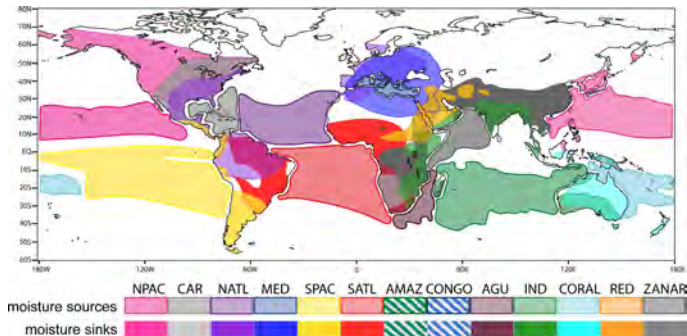
## Primary result



- One of the primary results from EPhsLab studies was identifying the continental sinks based on a forward integration from the main oceanic sources.

Gimeno, L., Drumond, A., Nieto, R., Trigo, R.M., Stohl, A. (2010) On the origin of continental precipitation, *Geophysical Research Letters*, 37. <https://doi.org/10.1029/2010GL043712>

## Primary result

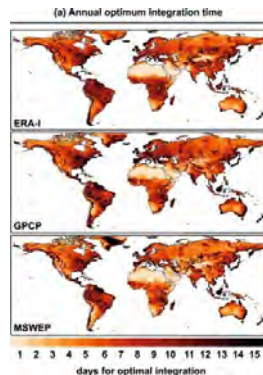


- This study was highlighted as one of the most important geophysical papers published in 2010 by the AGU (3rd August EOS issue), and a feature paper of EOS was published (Gimeno et al., 2011) by invitation of the editors.

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

## 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

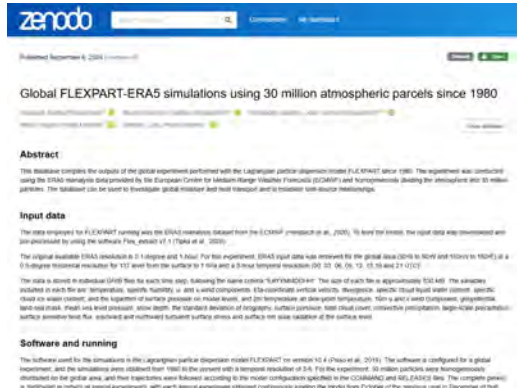
Specifications Table

|                                       |                                                                                                                                                                                                                                                                                                                     |
|---------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Subject</b>                        | Climatology                                                                                                                                                                                                                                                                                                         |
| <b>Specific subject area</b>          | Extreme precipitation, moisture transport, climate change                                                                                                                                                                                                                                                           |
| <b>Type of data</b>                   | NetCDF data files                                                                                                                                                                                                                                                                                                   |
| <b>How data were acquired</b>         | Post-processing of the FLEXPART Lagrangian particle dispersion model outputs                                                                                                                                                                                                                                        |
| <b>data format</b>                    | analysed                                                                                                                                                                                                                                                                                                            |
| <b>Parameters for data collection</b> | 3D (time, longitude, latitude) ( $R - P < 0$ ) data with 0.5°x0.5° horizontal resolution archived daily for the period 1980–2018 considering at every grid point only the Peak Precipitation Month.                                                                                                                 |
| <b>Description of data collection</b> | The data was obtained by post-processing FLEXPART model global outputs.                                                                                                                                                                                                                                             |
| <b>Data source location</b>           | Institution: University of Vigo<br>City/Town/Region: Ourense<br>Country: Spain<br>Primary data sources: ECMWF ERA-Interim reanalysis data<br>( <a href="https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era-4000m">https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era-4000m</a> ») |
| <b>Data accessibility</b>             | With the article and in <a href="http://dx.doi.org/10.17632/jgsvvc77h8.1">http://dx.doi.org/10.17632/jgsvvc77h8.1</a> »                                                                                                                                                                                             |
| <b>Related research article</b>       | Vázquez M., Nieto R., Liberato M.L.R., Gimeno L. (2021) Atmospheric moisture sources associated with extreme precipitation during the peak precipitation month. Weather and Climate Extremes, 30, 100289.<br><a href="https://doi.org/10.1016/j.wace.2020.100289">https://doi.org/10.1016/j.wace.2020.100289</a> »  |

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



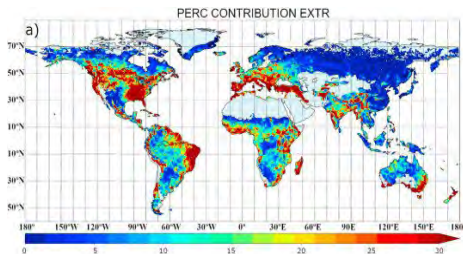
Vázquez, M., Alvarez-Socorro, G., Fernández-Alvarez, J. C., Nieto, R., & Gimeno, L. (2024). Global FLEXPART-ERA5 simulations using 30 million atmospheric parcels since 1980 [Data set]. Zenodo. <https://doi.org/10.5281/zenodo.13682647>

## Results

EPHysLab has investigated...

● extreme precipitation events

● occurrence of droughts



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



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

Maria Vázquez<sup>a,b,\*</sup>, Rafael Nieto<sup>c</sup>, Margoth L.R. Liberato<sup>b,c</sup>, Luis Gimeno<sup>c</sup>

<sup>a</sup> Environmental Physics Laboratory (EPHysLab), IANIGLA, Universidad de San Carlos, 5400, San

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**ABSTRACT**

**Keywords:**

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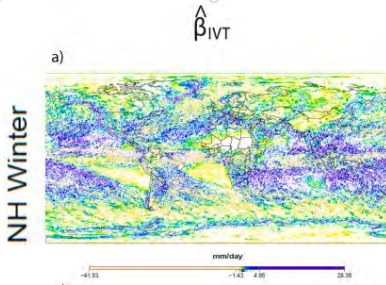
Moisture sources

Global warming

Climate change

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.

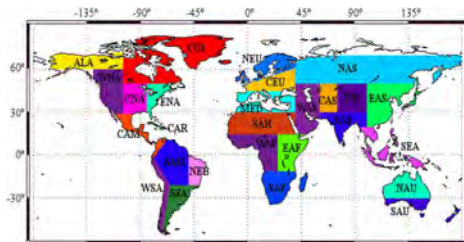
Gimeno-Sotelo, L., & Gimeno, L. (2023). Where does the link between atmospheric moisture transport and extreme precipitation matter?. *Weather and Climate Extremes*, 39, 100536.



# Results

EPHysLab has investigated...

- extreme precipitation events
- occurrence of droughts



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

Araceli Drumond, Mica Stojanovic, Raquel Nieto, Sergio Martín Vicente-Serrano, and Lluís Gimeno

An online catalog of drought episodes in the IPCC reference regions from 1960 to 2015, with an analysis of the moisture transport during the most severe meteorological drought episodes, is described.

Understanding hydroclimatic processes is incredibly important: great the number of scientific disciplines involved and their associations 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 (Vellinga and Stouffer 2002) and thermodynamic processes (Held et al. 2011; Fu and Peng 2014).

Changes in both these process groups may increase aridity in large regions as a consequence of decreasing moisture supply to continental areas (Stouffer and Fu 2014). These changes could increase the severity and duration of extreme hydroclimatic events such as droughts (Vicente-Serrano 2014).

Droughts are extremely complex, with several definitions causing problems in the conceptualization and monitoring of the phenomenon (Wilhite and Glantz 1983; Gochis et al. 2007; Elmer-Hughes 2014; Murguía and Espinosa 2014). 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 (Dekkers 2002). The effects of droughts may accumulate slowly over time, and expand over large regions, affecting different stages in the atmospheric water cycle (Vellinga 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

**APPROXIMATE DATES:** December, 2016; 15, 2017; and December, 2018.  
**ENVIRONMENTAL PAPER CATEGORIES:** Letters to the Editor, Open Access, Special Issue, and Special Issue.  
**ENVIRONMENTAL PAPER CATEGORIES:** Letters to the Editor, Open Access, Special Issue, and Special Issue.  
**ENVIRONMENTAL PAPER CATEGORIES:** Letters to the Editor, Open Access, Special Issue, and Special Issue.

**COMING SOON:** The Journal of Climate, Volume 31, Number 1, January 2018.

The Journal of Climate, Volume 31, Number 1, January 2018. The Journal of Climate, Volume 31, Number 1, January 2018. The Journal of Climate, Volume 31, Number 1, January 2018.

AMERICAN METEOROLOGICAL SOCIETY

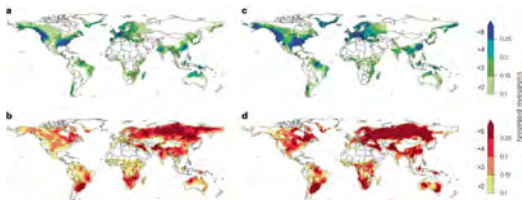
15 JULY 2018

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...

- extreme precipitation events
- 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

Luis Gimeno-Sotelo<sup>1</sup>, Rogert Sorf<sup>2</sup>, Raquel Nieto<sup>2</sup>,

Sergio M. Vicente-Serrano<sup>2</sup> & Luis Gimeno<sup>2</sup>

Accepted: 21 December 2023

Published online: 4 February 2024

Check for updates

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 hot/arid 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 error minus hydrological, socioeconomic and environmental implications.

Droughts are the most natural hazard on a planetary scale, responsible for 600,000 deaths from 2010 to 2019, billion-dollar economic losses and ecosystem impairment<sup>1,2</sup>. Drought being very complex phenomenon that involves several aspects of the hydrological cycle, with several co-relevant factors require processes and water management<sup>3</sup>. The main driving factor of droughts is a precipitation deficit compared with normal conditions<sup>4</sup>. 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 moisture content usually being greater than the importance of moisture content, with the exception of its influence on convective precipitation<sup>5</sup>, 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 (low humidity and therefore, favour the occurrence of droughts (for example, Trenberth et al.<sup>6</sup>).

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<sup>7</sup>, 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 deficit is generally linked to drought occurrence<sup>8</sup>. In this article, the relationship between between moisture transport and precipitation is the baseline for studying the statistical relationship between rainfall and moisture source (river, ocean, deficit).

Atmospheric humidity that causes precipitation in a region can have two origins: (1) direct transport from the ocean or (2) subsequent transport from the continents. The generalised case of evaporation over oceans or continents and moisture transport are very different, additionally, there is a vast relationship between the oceanic and continental origins of precipitation, both globally and

Centro de Investigación Marítima, Environmental Physics Laboratory, Universidad de Vigo, Ourense, Spain; Instituto Península de Estudios, Consejo Superior de Investigaciones Científicas, Zaragoza, Spain; <sup>✉</sup> Luis Gimeno [l.gimeno@uvigo.es](mailto:l.gimeno@uvigo.es)

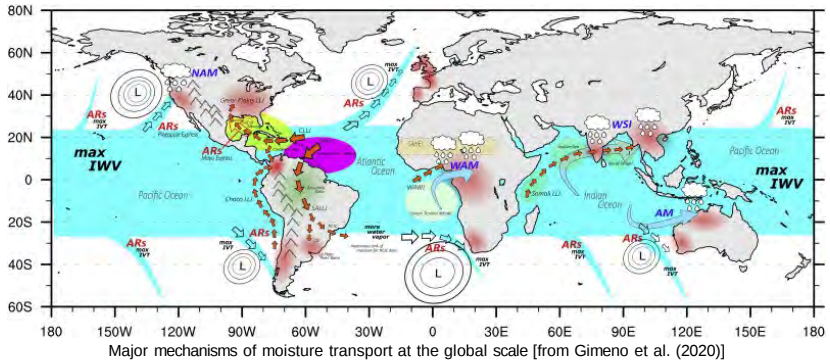
Nature Water | Volume 2 | March 2024 | 242–253

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Gimeno-Sotelo, L., Sorf, 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>

# Weather Systems

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



- 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](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 five 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, carrying 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.

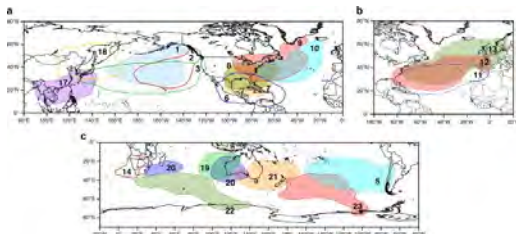
Mainly, but not exclusively, the Lagrangian model FLEXPART, in its different versions, will be used for the identification and further analysis of moisture sources related to these mechanisms.

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

- 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

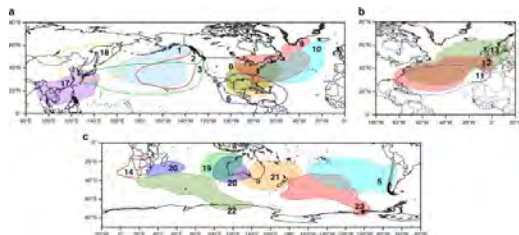
Algarra, I., Nieto, R., Ramos, A.M., Eiras-Barca, J., Trigo, R.M., Gimeno, L. (2020). Significant increase of global anomalous moisture uptake feeding landfalling Atmospheric Rivers, *Nature Communications* 11, 5082, <https://doi.org/10.1038/s41467-020-18876-w>

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: Atmospheric Rivers



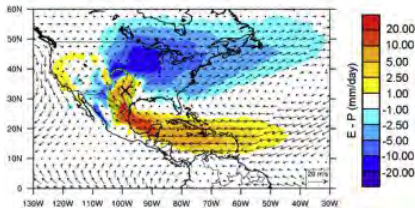
- ① Fernández-Alvarez et al. (2023)
- ② Algarra et al., (2020)
- ③ Ramos et al., (2016)



## Key Points

- 1 It is projected a northward shift of the main moisture source regions for AR in the IP in summer and fall, being particularly noticeable by the end of the 21st century.
- 2 It is found an enhanced evapotranspiration rates in association with landfalling atmospheric river events.
- 3 The major climatological areas for the anomalous moisture uptake extend along the subtropical North Atlantic, from the Florida Peninsula to each sink region.

- Algarra et al. (2019)



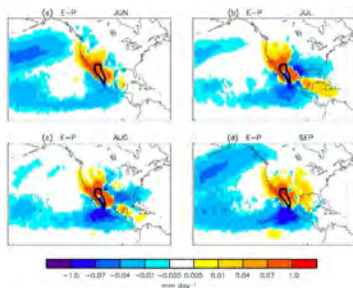
## Key Points

- 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.

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

# Weather Systems and Mechanisms: Monsoons

## Ordoñez et al. (2019)



## Key Points

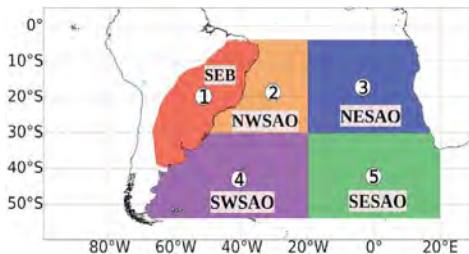
- During the wet season, the western North American monsoon region itself is on average the main evaporative source, followed by the Gulf of California.
- Moisture transport from the Caribbean Sea and the Gulf of Mexico is found to influence regional-scale rainfall during the monsoon peak



Ordóñez et al. (2019) Climatological moisture sources for the Western North American Monsoon through a Lagrangian approach: their influence on precipitation intensity, Earth System Dynamics 10, 59-72, doi: <https://doi.org/10.5194/esd-10-59-2019>

# Weather Systems and Mechanisms: Subtropical Cyclones

These studies are focused on the South Atlantic basin



## Key Points

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

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

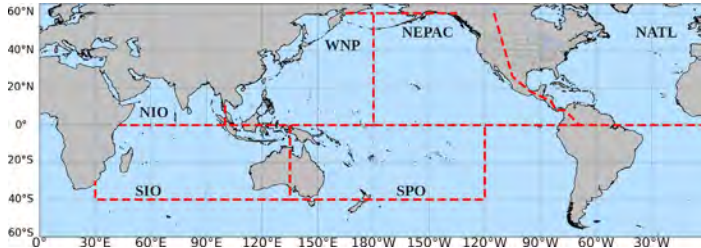
The northwestern SAO is the principal moisture source for SCs, with a quasi-constant contribution along the year.

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

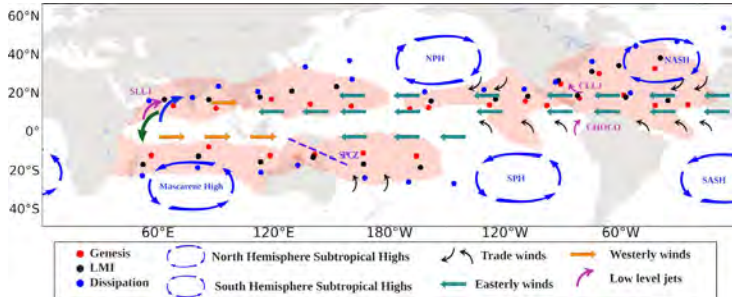
## Weather Systems and Mechanisms: Tropical Cyclones

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



# Weather Systems and Mechanisms: Tropical Cyclones

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



Schematic representation of moisture sources and transport mechanisms

## Key Points

The moisture transport is controlled by the characteristic of the atmospheric circulation in each basin.

Hurricanes category 1 and 2 gained more moisture to produce precipitation than in any other stage of development.

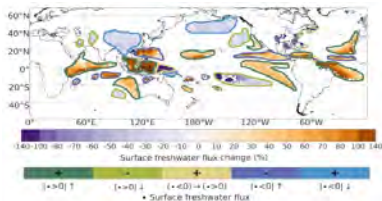
RI TCs gained more moisture from local sources than those undergoing slow intensification (SI). Total MU was approximately three times higher during RI than SI.

Tropical cyclones gained the highest amount of moisture from sources within 3–5° from their pathways (NATL basin).

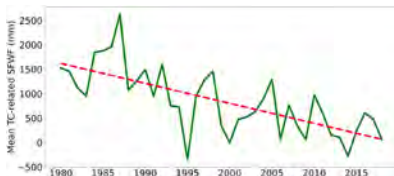
The moisture was predominately originated from the south and southwest sectors during PRE-extratropical transition (ET) and from the southwest-west during POST-ET in the NATL basin

# 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 ( $p < 0.05$ )

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>



**INTRODUCTION**

Tropical cyclones (TCs) are critical for transferring moisture from the tropics to subtropical and high-latitude<sup>1,2</sup> and from the ocean to land<sup>3</sup>. Monthly influencing weather patterns in tropical and subtropical regions worldwide by off-land playing a crucial role in the atmospheric branch of the global hydrological cycle<sup>4,5</sup>. While relevant in these roles, the contribution of TCs to global water cycle transport from tropical to subtropical regions across the mid-latitude globally is substantially smaller than that of atmospheric waves<sup>6</sup>. Nevertheless, intense convection actively during TCs reduces a vast amount of water vapor that is redistributed across the atmosphere and can produce notable precipitation shifts to terrestrial regions<sup>7,8</sup>, providing moisture to areas that may experience dry conditions<sup>9</sup>. Moreover, impacts of TCs are associated with substantial environmental fluctuations as well as socio-economic and human losses caused by extreme compound events such as strong winds, heavy rainfall, storm surge, flash flooding and landslides<sup>10</sup>.

Atmospheric moisture availability is crucial for TC genesis and evolution<sup>11</sup>. Natural variability and decadal-scale studies have demonstrated that an increase (decrease) in mid-latitude mean water content enhances (reduces) TC susceptibility<sup>12,13</sup>. Furthermore, understanding the range of moisture for precipitation associated with TCs is key to significantly improving the analysis and projecting the often intense associated impacts. Recently, Wang et al.<sup>14</sup> (2022) revealed that precipitation moisture was predominantly higher (lower) than the TC, implying that large-scale atmospheric circulation patterns in each region alter the moisture transport to land.

Improving our knowledge of moisture transport is crucial for investigating extreme precipitation<sup>15,16</sup>. Atmospheric moisture transport caused by changes in large-scale circulation is a key factor in long-term change in extreme precipitation<sup>17</sup>. Thus, TCs contribute significantly to intense moisture transport. Because moisture and heat flows from the ocean sea surface are the primary

precipitation from TCs<sup>18</sup>, previous studies have been largely focused on the TC water budget<sup>19–21</sup>, the range of responses for TC precipitation<sup>22–24</sup>, the contribution of TCs to monthly and annual precipitation totals in tropical and subtropical latitudes<sup>25</sup> or the TC-related moisture transport<sup>26</sup>. For example, moisture convergence is the main contributor to TC rainfall<sup>27–29</sup>. TCs are responsible for approximately 10% of the net surface moisture fluxes towards South America<sup>30</sup> and their precipitation represent a significant fraction of the annual precipitation totals in regional, continental and even global scale<sup>31</sup>. Additionally, part of the moisture gained by TCs from the ocean evaporation is brought about by the storm itself<sup>32</sup> as TCs in regional and global hydrological cycles. Extreme precipitation and moisture fluxes are positively correlated<sup>33</sup>. On this basis, the updated pattern of atmospheric moisture convergence tends to agree with the regions of atmospheric cyclonic circulation in the tropical hemisphere: Pacific (tropics)<sup>34</sup>, to Atlantic, a climatological pattern of vertically integrated mean moisture transport from the Atlantic to the Pacific<sup>35</sup> and the Atlantic to the Pacific<sup>36</sup> around the equator. The critical role of atmospheric moisture flux from the Atlantic Ocean in producing extreme rainfall in North and South America<sup>37</sup>.

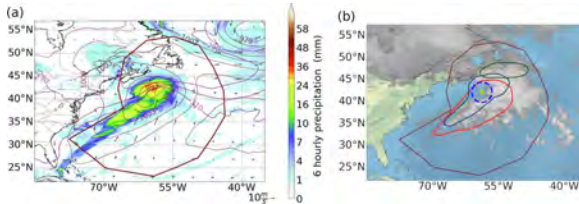
Based on these previous studies and large-scale water and energy budgets, it remains unclear what happens with atmospheric moisture fluxes as TCs intensify, which would impact the moisture transport that precipitation during TCs and the subsequent impact of the atmospheric moisture fluxes on the land to global warming. Thus, the knowledge gap and the potential increase in atmospheric moisture content of TCs (7–15% per °C) in response to surface warming on the basis of the Clausius-Clapeyron equation<sup>38,39</sup> against further enhancement of the precipitation

Supplementary Information: The Supplementary Information for this article is available online. It includes a detailed description of the data sources, the methods used for the analysis, and the results of the simulations. The Supplementary Information is available as a separate document, which can be accessed by clicking on the 'Supplementary Information' link in the top right corner of the article page.

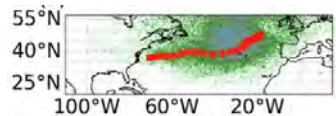
Published in partnership with the International Geosphere and Biosphere Programme (IGBP)

## 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 0000 UTC

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 System  
Dynamics

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

L. Gimeno<sup>1</sup>, M. Vinyar<sup>2</sup>, R. Nieto<sup>3</sup>, and R. M. Trigo<sup>4</sup>

<sup>1</sup>EPhysLab (Environment Physics Laboratory), Universidad de Válg, Facultad de Ciencias, Oviedo, Spain

<sup>2</sup>University of Lisbon, UGEL, EA, Lisbon, Portugal

<sup>3</sup>Correspondence to: L. Gimeno (lgimeno@uvigo.es)

**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 enough associated with the evaporation that takes place within the Arctic sea itself, despite the fact that the sea ice cover is decreasing. Such an increase 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 little 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 in 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 coastal regions (mainly the Mediterranean Sea, the North Atlantic Ocean and the North Pacific Ocean) on the path of the global western boundary currents and their extension) and Arctic ice melting processes.

#### 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, ocean) or diminishing (cryosphere) since the 1970s, as a result of global warming induced by the significant increments concentration of greenhouse gases of anthropogenic origin (AR5, IPCC, 2013). The ice-retreat has been the size of global air temperature since the late 19th century is observed neither in the relatively decadal shift of temperature distributions in both hemispheres (Hansen et al., 2012) nor in the frequency of extreme hot events over the continents (Gouveias et al., 2014). The much larger capacity of the oceans to store heat, with respect to the atmosphere, has played a fundamental role in ensuring the excessive heat contained in the climate system in the Pacific (Kouskoushi et al., 2013) and the Atlantic (Chen and Tang, 2013) Oceans.

However, global warming is a very common phenomenon impossible to be encapsulated by a single indicator relative to our subsystem, such as the global average of near-surface atmospheric temperature. The spatial pattern of observed temperature trends is very asymmetrical and regionalized, with continuous warming more than 10°C with high latitudes also presenting considerably higher warming rates than mid-latitude and tropical regions. In particular, several authors have shown that the rise in Arctic near-surface temperature (NSST) has been the largest in the global average throughout most of the year (e.g. Screen and Solomon, 2010; Tang et al., 2014; Cohen et al., 2014). Additionally, the evaluation of the climate in the Arctic region is closely 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

Several regional studies have also been performed.

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



Sotí 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](https://doi.org/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

**Moisture Sources for Continental Climatic Regions (CCRs)**

### Items

- Identification of the moisture sources
- Evaluation of the importance of the source throughout the so-days of moisture transport
- Monthly cycle of the contribution of the moisture sources to the precipitation on the CCR
- Interannual (seasonal) interannuality of the contribution of the moisture sources to the precipitation on the CCR
- Evaluation of the role of main teleconnection patterns
- Identification of hot spots in the regions where influenced by future climate changes in evaporation minus precipitation
- Reference plots
- Contact: [mielke@unipon.es](mailto:mielke@unipon.es)

### Moisture Sources for Continental Climatic Regions (CCRs)

This web provides a catalog of moisture sources for two sets of continental climatic regions (CCRs) based on the Lagrangian particle dispersion model FLEXPART using data from 1980 to 2012 obtained from the ERA-Interim reanalysis of the ECMWF:

- one based on 35 regions with similarities not only in terms of mean climate (temp-rain) but also in terms of projected changes in precipitation (aridity-wetness) (ARID/GENUINE FUTURE CHANGE) defined by Malvesto and Kienast (2006), and hereinafter named MORA
- other widely used in IPCC reports which represents 20 different climatic regions (HOMOGENEOUS CURRENT CLIMATE) defined by Giorgi and Marinuzzi (2000), and hereinafter referred as GCR

[Click to select the CCRs with ARID/GENUINE FUTURE CHANGE \(MORA\)](#)

[Click to select the CCRs under HOMOGENEOUS CURRENT CLIMATE \(GCR\)](#)

The catalog contains the characteristics of all the major sources of moisture for each CCR, and the analysis of their interannual variability and the role of the main climate variability modes, including the El Niño–Southern Oscillation (ENSO) and the Northern Annular Mode (NAM) / Southern Annular Mode (SAM).

The estimation of the influence of those oceanic regions that will see the greatest increases in evaporation rate in future years is also analyzed.

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

Several regional studies have also been performed.

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



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

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

Received: 3 May 2023  
 Accepted: 19 September 2023

José C. Fernández-Alvarez<sup>1,2</sup>, Alberto Pérez-Alarcón<sup>1,2</sup>, Jorge Eiras-Barca<sup>1</sup>,  
 Soledad Rahimi<sup>1,2</sup>, Raquel Nieto<sup>1,2</sup> & Luis Gimeno<sup>1,2</sup>

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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 teleconnections—can also be studied in detail. By the end of the century, moisture from the NATL will increase precipitation over northern North America by virtue of advection and on the British Isles by vortex. Moreover, 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 eastern Europe and Africa. Precipitation recycling over the Iberian Peninsula will decrease in all seasons except summer. By end-century, climate change, as simulated by CESM2, thus modifies atmospheric moisture transport, affecting regional hydrological cycles.

It is predicted that climate warming of the atmosphere will alter the hydrological cycle, affecting the evaporation rates of the oceans and the atmosphere, and the 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 teleconnections—can also be studied in detail. By the end of the century, moisture from the NATL will increase precipitation over northern North America by virtue of advection and on the British Isles by vortex. Moreover, 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 eastern Europe and Africa. Precipitation recycling over the Iberian Peninsula will decrease in all seasons except summer. By end-century, climate change, as simulated by CESM2, thus modifies atmospheric moisture transport, affecting regional hydrological cycles.

Changes in the atmospheric circulation patterns will also act on the global moisture source, which will affect the atmospheric moisture source in global and regional scales. The net effect of atmospheric circulation and thermodynamic processes is therefore extremely relevant when analyzing future changes in moisture sources for precipitation over a region. It is estimated that moisture from the NATL will increase by 2–3% per °C globally, being consistently higher in the pole and lower in the equator. Moreover, there will be a decrease in precipitation of 2–3% in the equator in West Africa and the Iberian Peninsula. By the end of the 21st century, the projected decrease in precipitation over the equator will also decrease moisture from the pole's surface moisture

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 1Instituto de Investigación en Recursos Cinegéticos (IREC), Consejo Superior de Investigaciones Científicas (CSIC), Universidad de Castilla-La Mancha, 13005, Toledo, Spain  
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 e-mail: jca@maia.uma.es

Nature Communications | (2023) 14:10000

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 warming

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

Earth Systems and Environment  
https://doi.org/10.1007/s41748-024-00532-8

## ORIGINAL ARTICLE

### Future Changes in the Contribution of Gulf of Mexico-Caribbean Sea Moisture Source: Impacts on Regional Precipitation Patterns

José C. Fernández-Alvarez<sup>1,2,3,4</sup> · Gleison Alvarez Socorro<sup>5</sup> · Ana María Durán Quesada<sup>6</sup> · Raquel Nieto<sup>1,2</sup> · Luis Gimeno<sup>1,2</sup>

Received: 3 July 2024 / Revised: 12 November 2024 / Accepted: 20 November 2024  
© The Author(s) 2024

#### Abstract

Central America (CA) and the eastern United States (US) is a region with a significant contribution from the Gulf of Mexico-Caribbean Sea (GM-CS) moisture source. In the context of climate change, sink patterns associated with this source may change implying significant changes in this region. Hence, this study determined future changes in the contributions to precipitation (PCs) associated with GM-CS. So, a dynamic downscaling methodology was considered using the regional climate model WRF-ARW and FLEXPART-WRF, forced with the CESM2 climate model. Specifically, a decrease in the GM-CS contribution in the CA region was projected for all seasons considered, showing a southward shift in the contribution pattern. Additionally, the sink pattern was projected to increase, but the area was projected to decrease, mainly by the end of the century, except in the autumn. In addition, for the southeastern US region, an increase in PCs in spring and autumn was projected for end-century, but a decrease in PCs by more than 40% in the summer months was projected. However, for the northeastern US, changes in PCs were amplified for both the mid- and end-century relative to the southeastern US region, with an increase projected for most periods, except for a slight decrease in the summer of 10%.

**Keywords** Climate Models · Dynamic Downscaling · Future Changes · Moisture Source · Precipitation

#### 1 Introduction

The Central America (CA) region and eastern United States (US) are limited to the east by the Gulf of Mexico, Caribbean Sea, and western Atlantic Ocean, which are in direct contact with the Atlantic Warm Pool (Wang and Fu, 2006a, b). This region is highly vulnerable to droughts and heavy precipitation events linked to tropical cyclones and

convective development (Maxwell et al., 2012; Durán Quesada et al., 2020). The occurrence of precipitation extremes is highly relevant for the region, as these events severely affect regional socioeconomic development (Masson-Delmotte, 2021) and biodiversity (Adams, 1999). Precipitation extremes have been highlighted as one of the main causes of climate change in this region (Haber et al., 2023). Advancing the current understanding of the factors that dominate precipitation variability and changes allows for improved risk assessment under present climatic conditions and evaluation of the impacts of the likely increase in precipitation extremes under a warming climate (Carr and Ummenhofer, 2023).

According to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2023), if society does not reduce CO<sub>2</sub> emissions, the mean temperature could increase by more than 2 °C by the end of the century in the most extreme scenario. As a result, based on the Clausius-Clapeyron relationship, atmospheric water vapor could increase by approximately 4–7% per degree (Trenberth et al., 2003; O'Gorman and Mo, 2019). In addition, increases in the global annual average evaporation

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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 warming

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# Moisture sources in the future

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ORIGINAL ARTICLE

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## Projected changes in moisture sources and sinks affecting the US East Coast and the Caribbean Sea

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### Abstract

This study uses a combination of the FLEXPART Lagrangian dispersion model with the Weather Research and Forecasting (WRF) mesoscale Eulerian model (FLEXPART-WRF) to analyze the expected mid- to late century changes in the moisture sources and sinks of the North American East Coast (ENAC) and the Gulf of Mexico (GM), as well as their most relevant along moisture transport events: atmospheric rivers (ARs) and low level jets of the Great Plains (GPLL) and the Caribbean (CLL). Both the ENAC and GM are expected to increase in importance as moisture source regions over the century, both overall and in their contributions to the ARs and both LLJs. A notable increase in the intensity of the GPLL and CLL moisture sources is also observed. All of these behaviors are neither spatially nor temporally homogeneous and need to be analyzed in a seasonal context. Likewise, the most relevant signs of change are also observed all observed by the end of the century. Other noteworthy behaviors are also observed, including an increase in humidity associated with landfalling atmospheric river events in the winter months, or a notable latitudinal shift of the CLL's area of influence. These findings are best understood within the context of an observed increase in both continental precipitation and sea surface temperature.

KEYWORDS  
CHIM, FLEXPART-WRF, moisture sources, moisture sinks

### INTRODUCTION

In the current context of climate change and global warming, water resources will play a crucial role in the development and sustainability of societies in the medium term.<sup>1</sup> Excessive or extreme precipitation events can cause serious damage to infrastructure and human life, in short supply. They can limit development and cause long periods of drought at the expense of human life. Therefore, the scientific community considers it crucial to correctly understand the expected evolution of the meteorological phenomena involved in precipitation,

as well as the processes of reevaporation that lead to rainfall.<sup>2–4</sup>

In recent years, several studies have been carried out to understand the evolution of moisture sources and sinks in different regions, both of which are fundamental components of the transport processes that modulate the precipitation regime. These studies have their efforts on the detection of the signals of change expected in the medium and long term, using model-based methodologies based on projections subject to different possible scenarios. In this respect, the combined work of many authors leads to a number of conclusions:

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Eiras-Barca, J., Fernández-Alvarez, J. C., Alvarez-Socorro, G., Rahimi-Esfarjani, S., Carrasco-Pena, P., Nieto, R., & Gimeno, L. (2025). Projected changes in moisture sources and sinks affecting the US East Coast and the Caribbean Sea. *Ann NY Acad Sci.*, 1–19.  
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## Moisture sources in the future

### Key Points

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.

The Gulf of Mexico- Caribbean Sea (GM\_CS) is expected to increase in importance as moisture source regions over the century for Eastern North America, both overall and in their contributions to the ARs and both LLJs. A notable increase in the intensity of the GPLLJ and CLLJ moisture sources is also observed.

A decrease in the GM\_CS contribution in the Centro America region was projected for all seasons considered, showing a southward shift in the contribution pattern.

# 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

**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 facing 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 into 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 oceans 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 from fields, rivers, groundwater, and other bodies that discharge into the ocean, thereby completing the cycle.

In global terms, the hydrological cycle is responsible for an annual rate of evaporation of about half a million cubic kilometers of water, around 60% of which is from the oceans, with the remainder having its origins 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.

Grimm, L., Vilaguer, M., Esteban, J., Solé, R., Sempere, M., Aguirre, J., Nieto, R., Roman, A.M., Durán-Quesada, A.M., Dominguez, F. (2020) Recent progress on the sources of continental precipitation as revealed by moisture transport analysis. *Earth Science Reviews* 201 (104):104-106. doi:10.1016/j.earscirev.2019.103307

Grimm, L., Solé, R., Vilaguer, M., Dominguez, F., Sempere, M., Nieto, R., Roman, A., Durán-Quesada, A.M., Nieto, R. (2022). Oceanic and terrestrial sources of continental precipitation. *Rev. Geophys.*, 60, 100003. doi:10.1029/2021RG000739

The [EPysLab group](https://epyslab.uvigo.es) 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://epyslab.uvigo.es/moisturetransport/>

## Current research topics

- Changes in the moisture sources' contribution to tropical cyclones, droughts, and extreme precipitation in the European and American regions under global warming.
- Quantifying the moisture transport anomalies during compound drought and heat wave events in the Iberian Peninsula
- Deficit of moisture transport and its linkages with droughts in the Central and South America and Caribbean regions.
- Moisture transport and associated mechanisms for extreme precipitation events in South America.
- Impacts of moisture transport on major continental floods.
- Continuous improvements of LATTIN's features and capabilities

## 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, Innovación 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 Economía y Competitividad. (Grant: RTI2018-095772-B-I00), Spain
- Moisture Transport (TRAMO). Funded by Ministerio de Economía 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)

EPhysLab is contributing to the **"Moisture tracking intercomparison project"**.

**Lorentz center**

**Moisture Tracking Intercomparison**  
*Time to Address the Uncertainty*

Workshop @Snelius 27 - 31 May 2024, Leiden, the Netherlands

**Scientific Organizers**

- Imme Benedict, Wageningen University and Research
- Chris Weijenborg, Wageningen University and Research
- Rens van der Eide, Delft University of Technology
- Jessica Keutler, European Centre for Medium Range Weather Forecast
- Gerbrand Koren, Utrecht University

**Topics**

- Best Practices of Data Sharing
- Comparing of Moisture Source Result from Different models
- Understanding Differences and (Dis)Advantages of Tracking Models
- Discussing the Research Agenda

**Lorentz center**

[www.lorentzcenter.nl](http://www.lorentzcenter.nl)

# Objectives and approaches used in moisture transport studies in EPhyLab at the University of Vigo.

Environmental Physics Laboratory, Centro de Investigación Mariña, Universidade de Vigo, Spain

