Atmospheric Rivers research in the *Atlantic Ocean*

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Outline

1) North Atlantic Ocean (Overview)

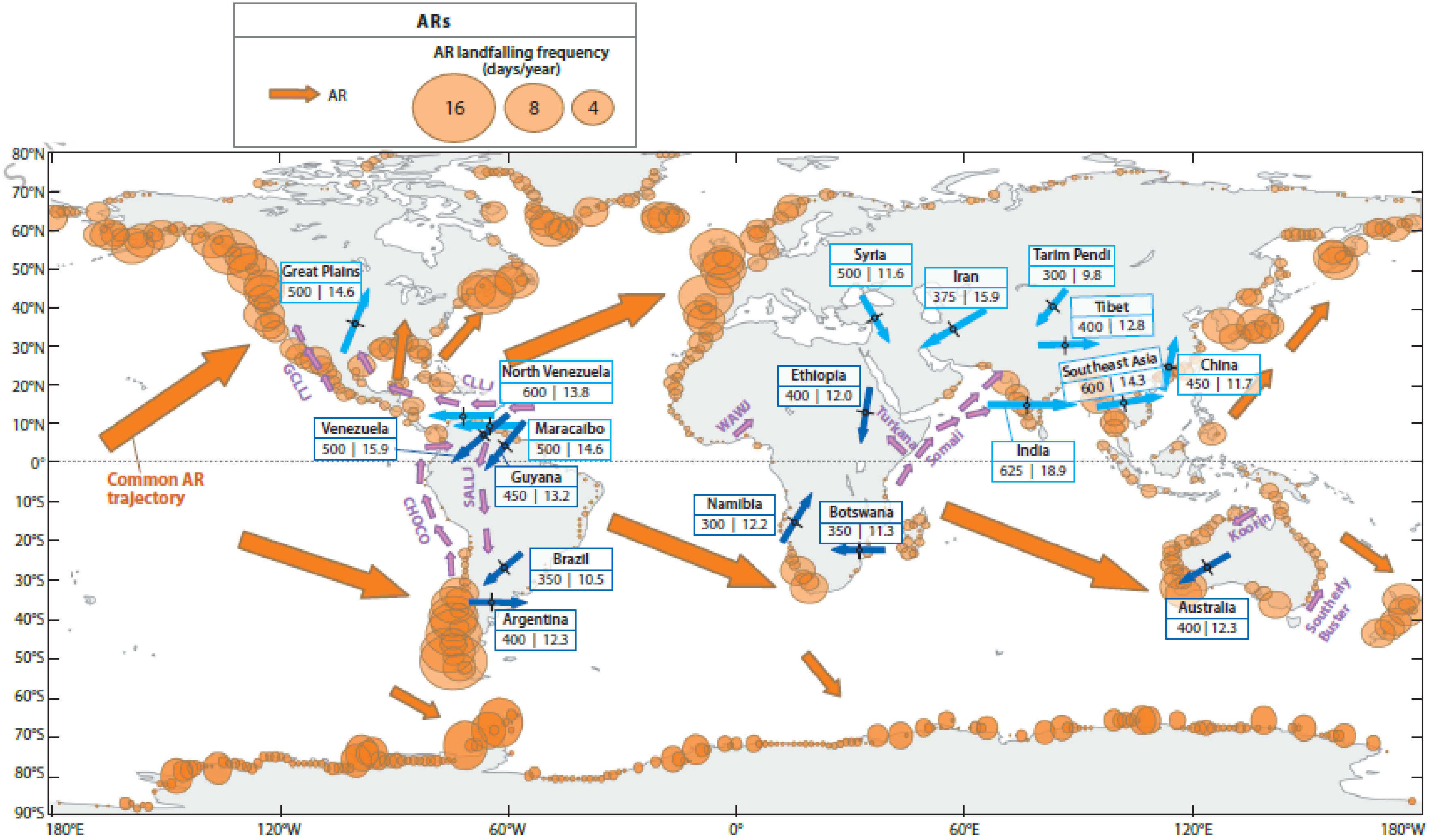
- ARs influence areas in Europe and impacts
- Origin of Moisture Sources of the ARs affecting western Europe
- Future climate scenarios
- ARs Predictability

2) South Atlantic Ocean

- South Africa
- Antarctica (Irina Gorodetskaya)

1) North Atlantic Ocean (Overview)

ARs influence areas in Europe and impacts



ARs climatology provided by Guan and Waliser, 2015.

The global geographical position of **Atmospheric rivers (ARs)** and low-level jets (LLJs).
Gimeno et al. (2016), Annu. Rev. Environ. Resour.

ARs influence areas in Europe and impacts

Average AR fraction in (%) in each month

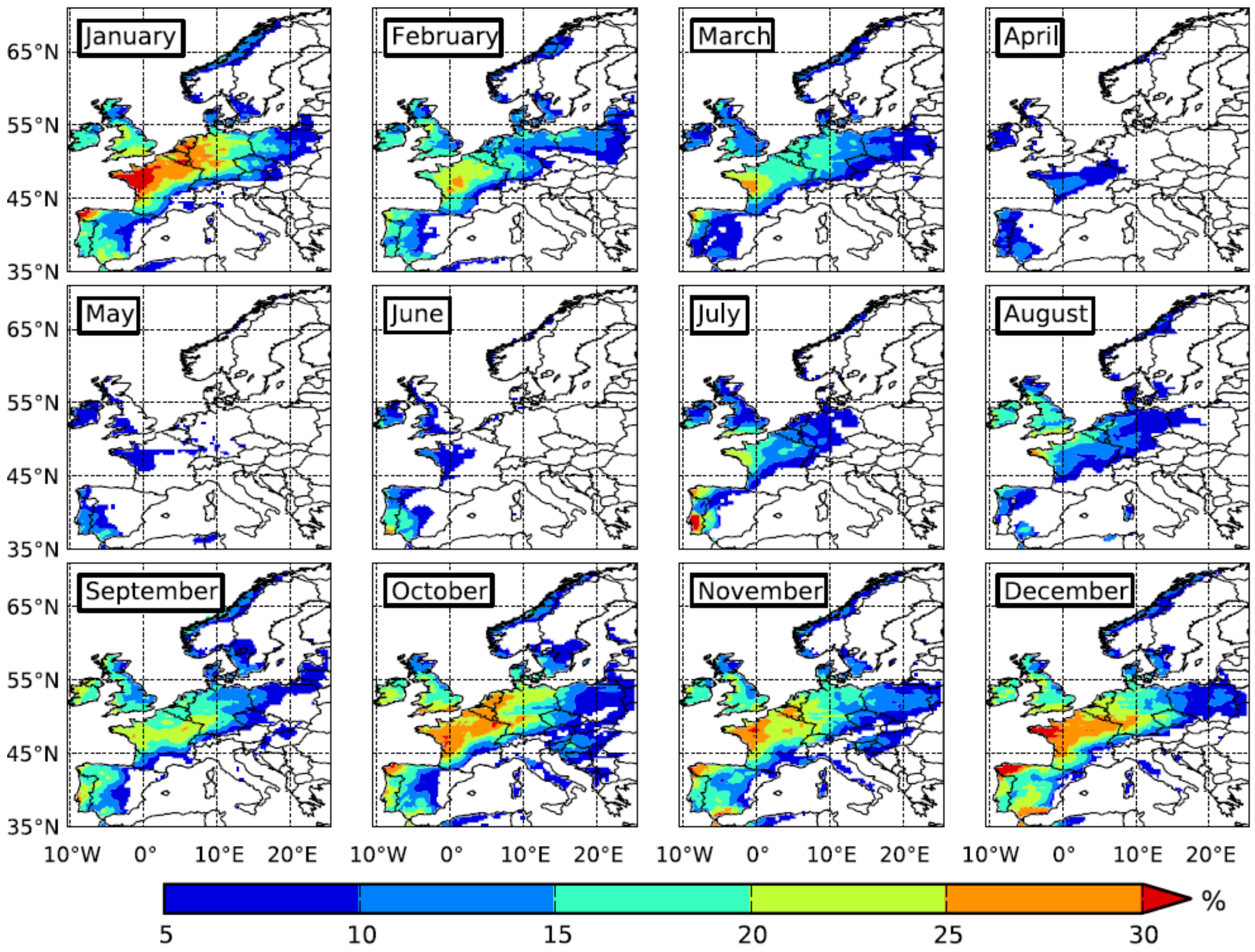
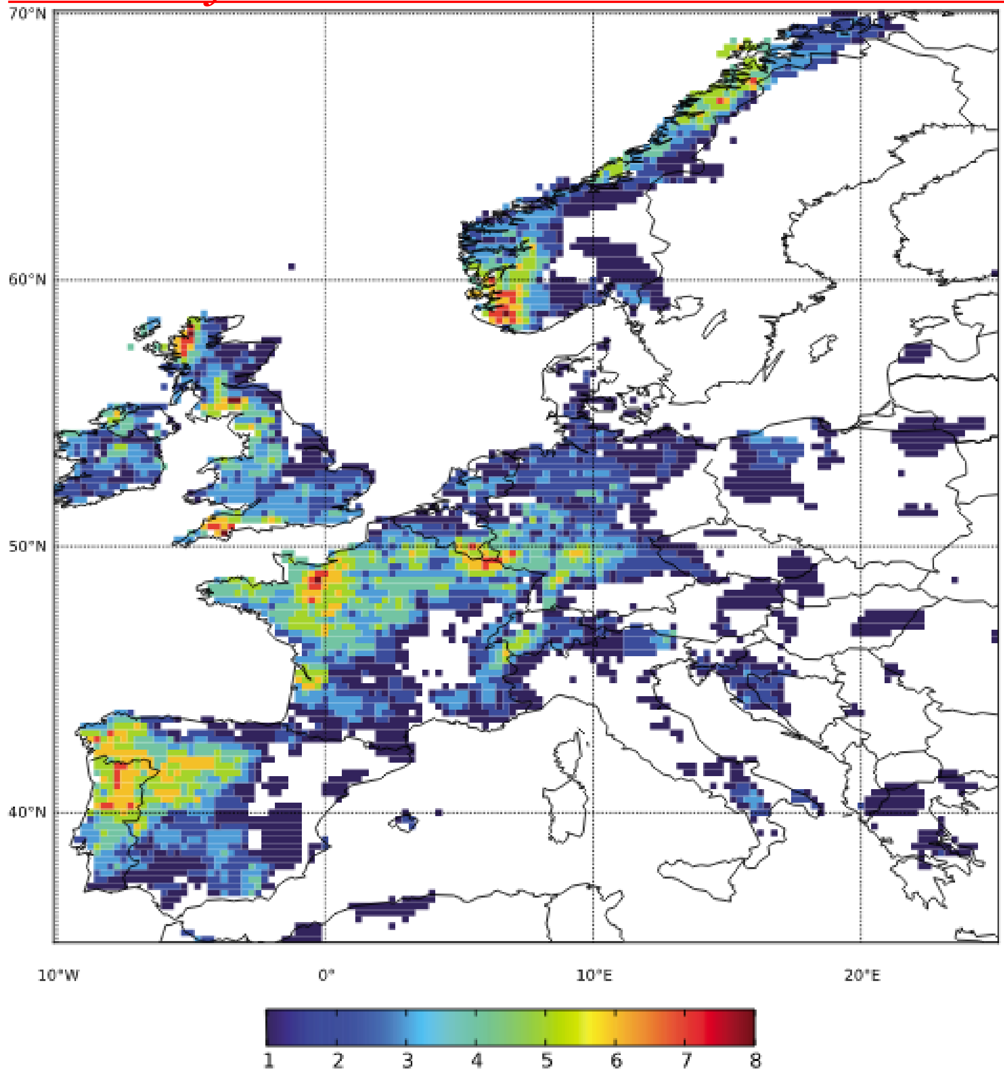


Fig. 2. The average AR fraction (in%) in each month from Europe over the period 1979–2012.

Lavers and Villarini, 2015

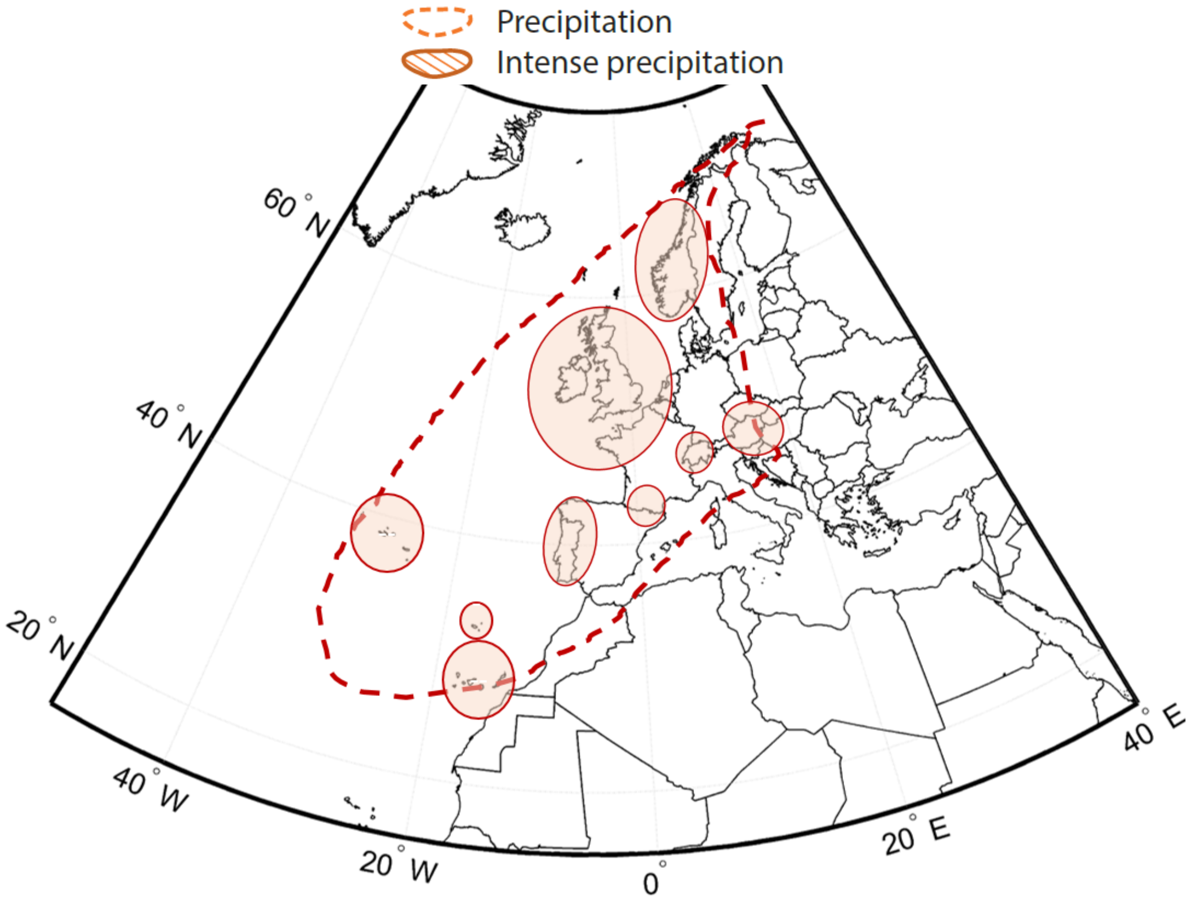
Number of TOP10 Annual Maxima related to ARs



Lavers and Villarini, 2013

ARs influence areas in Western Europe and impacts

Studies dealing with **climatologies of ARs** and impacts or ARs case studies



Updated from Gimeno et al., 2016, Annu. Rev. Environ. Resour.

Some examples (not exhaustive list):

- Stohl et al. (2008) (*Norway*)
- Lavers et al. (2012) (*UK*)
- Trapero et al. (2013) (*Eastern Pyrenees*)
- Rössler et al. (2014) (*Alps*)
- Trigo et al. (2014) (*Portugal*)
- **Ramos et al. (2015)** (*Iberian Peninsula*)
- Couto et al. (2015) (*Madeira Island*)
- **Lavers and Villarini (2015) (*Europe*)**
- Eiras-Barca et al. (2016) (*Iberian Peninsula*)
- **Brands et al. (2016) (*Europe*)**
- Ciric et al. (2017) (*Danube River Basin*)
- Ramos et al. (submitted) (*Macaronesia Islands*)

Origin of Moisture Sources of the ARs affecting western Europe

According to Dacre et al. (2015), water vapor in the warm sector of the cyclone, rather than long-distance transport of water vapor from the subtropics, is responsible for the generation of ARs

However

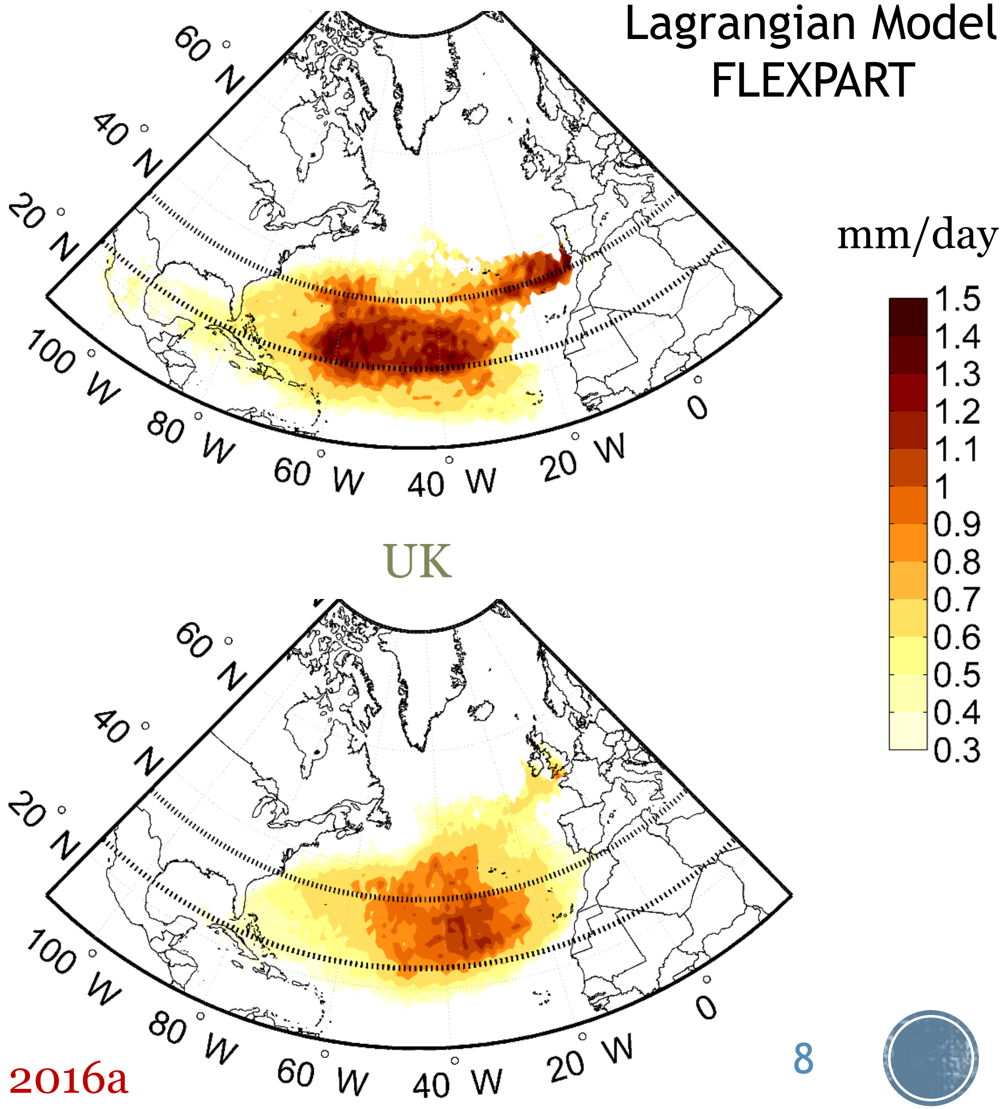
The **moistures sources** and **transport of atmospheric water vapor** during different ARs events that strike Europe were analyzed by Sodemann and Stohl (2013); Garaboa-Paz et al. (2015); Ramos et al. (2016a), **from a Lagrangian perspective.**

It was shown that the poleward transport of tropical moisture combined with mid-latitude moisture sources and convergence along the AR paths are responsible for the generation and evolution of ARs in the North Atlantic Ocean.

Eiras-Barca et al. (2017) using WRF-tracers tool for two case studies also confirm these results.

Anomalous Uptake of Moisture

Iberian Peninsula

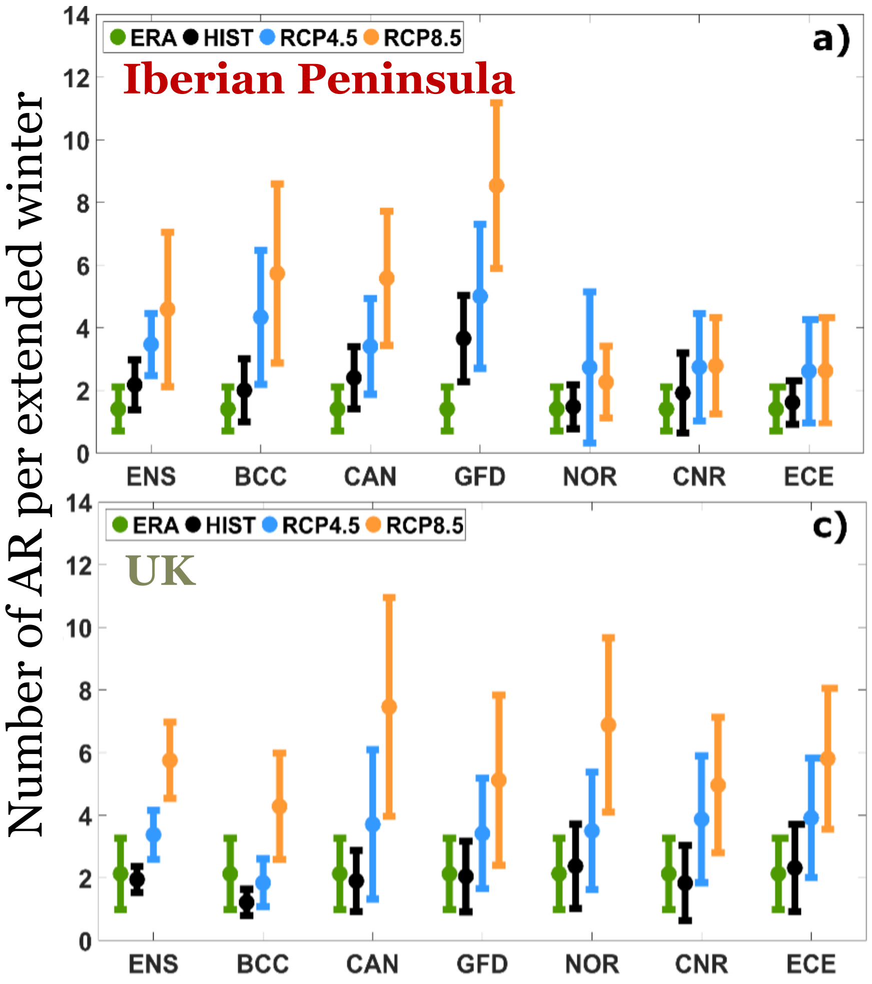


Ramos et al., 2016a

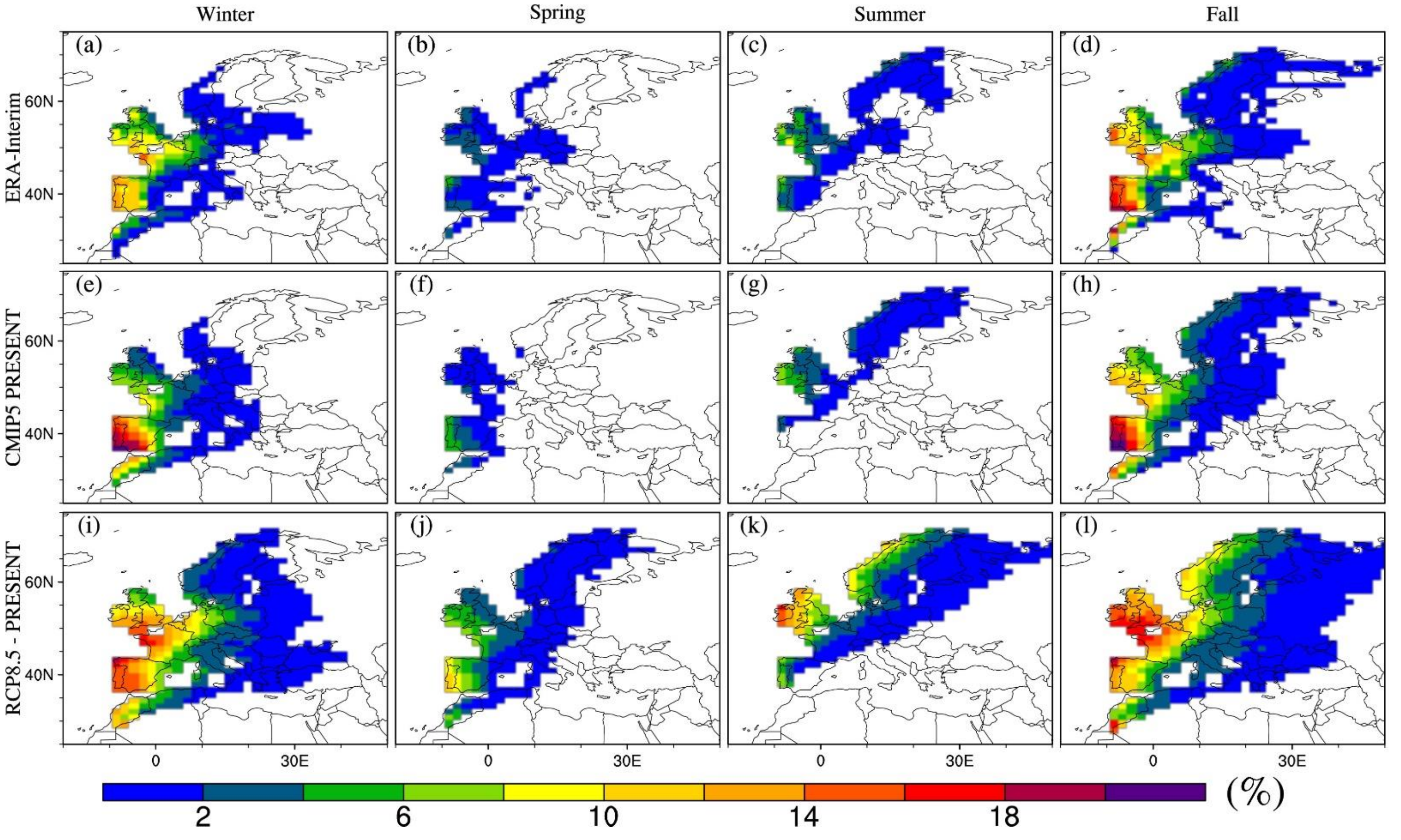
Future Climate Scenarios

Since ARs frequently lead to heavy precipitation in Europe it is also import to understand how they change in future climate scenarios and possible impacts.

- Lavers et al. (2013) (UK)
- Gao et al. (2016) (Europe)
- Shields et al. (2016) (UK)



Ramos et al. (2016b)



The fractional contribution of AR-induced precipitation to the total precipitation in each season. Gao et al. (2016)

ARs Predictability

- Using **the Extreme Forecast Index (EFI) from the ECMWF** for the **integrated water vapor transport (IVT)** **and** **precipitation** **for the ability to discriminate** **extreme precipitation (> 99th percentile).**

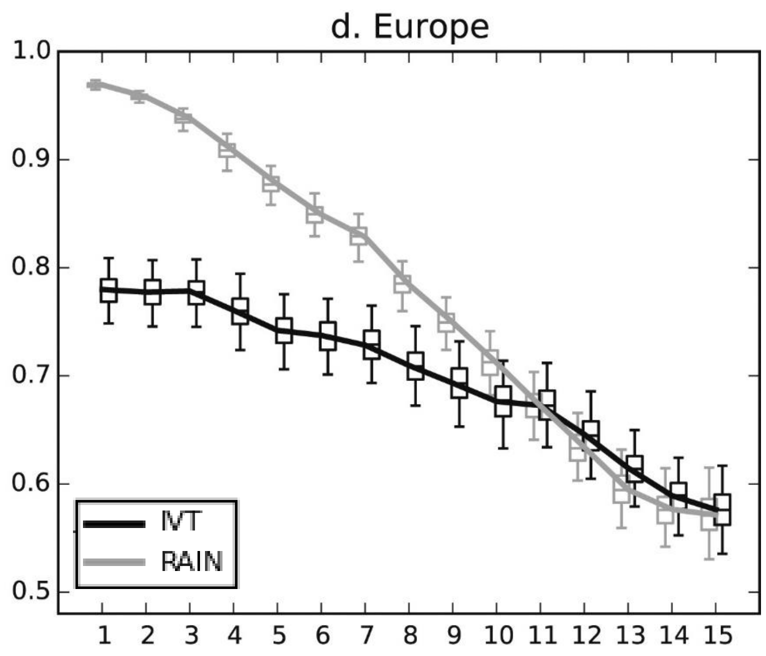
Extreme Forecast Index (EFI) - ECMWF

- **Extreme Forecast Index (EFI)** is designed to measure how extreme a given ensemble forecast is.
- EFI is a measure of the difference between the ensemble forecast distribution and a reference distribution - **model climate (M-climate)**.
- EFI delivers model-climate-related information, therefore it can be used as an “alarm bell” for extreme weather situations over any area without defining different space- and time-dependent thresholds.

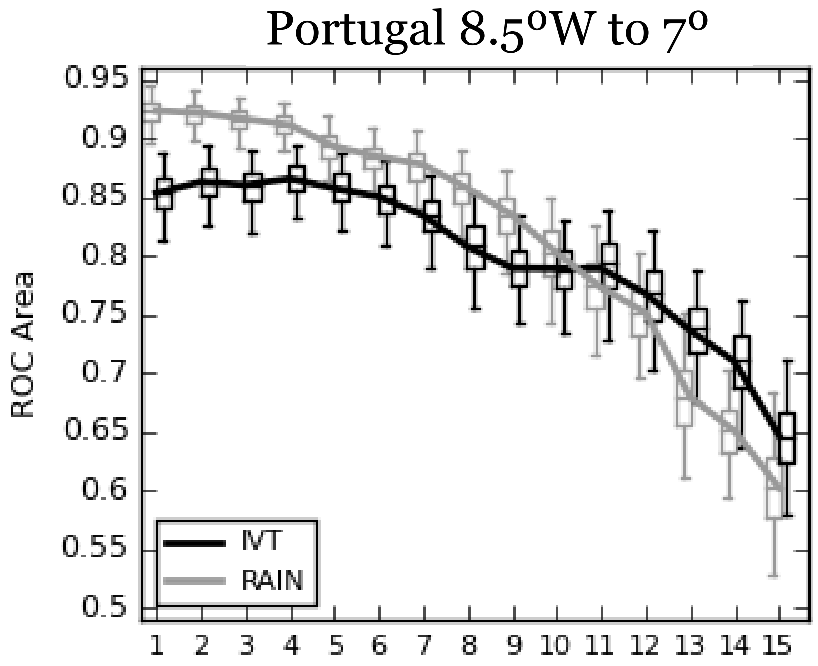
ARs Predictability

- Using **the Extreme Forecast Index (EFI) from the ECMWF** for the **integrated water vapor transport (IVT)** and **precipitation** **for the ability to discriminate** **extreme precipitation (> 99th percentile).**

ROC Areas



Lavers et al., 2017



Lavers et al., 2018

ROC Area: Hit Rate vs False Alarm Rate

Probably the EFI of the IVT will be operational later this year at the ECMWF.

ARs Predictability

Forecasting the ARs as an object also using the **integrated water vapor transport (IVT)**

21 – Nov – 2015

50 Ensemble members ECMWF

Talk on WEDNESDAY

North Atlantic Remarks

- In Europe, since 2008 there have been several papers investigating the impacts of ARs and their relationship with the major large-scale atmospheric patterns, which has increased the understanding of this phenomenon.
- However, there are lack of studies in the North Atlantic basin and Western Europe that use “real” observations of ARs from aircraft dropsonde data or Doppler wind profilers like there is in the Pacific Basin. Despite this some scatter measurements have already been done.
- I believe future work in North Atlantic Ocean and Europe will be focus on:
  - ❑ Sensitivity analysis to different cloud microphysics parametrization and importance of high resolution (<3km) convection-permitting modeling using mesoscale numerical weather models during ARs events;
  - ❑ Analysis of precipitation isotopes during ARs events;
  - ❑ Using tools like WRF tracers and lagrangian models like FLEXPART to study in detailed the origin of moisture and it´s transport by the ARs;
  - ❑ Continue to study the ARs Predictability;
  - ❑ Analysis of Long term simulation of Coupled Climate Models like EC-Earth and/or Community Earth System Model in past, present and future climates.

2) South Atlantic Ocean

Motivation

- The **southwest region of South Africa** is the only part of the country that receives most of its rainfall during the austral winter months (May-September).

- Located within this region is the city of Cape Town, the **2nd largest metropolitan municipality** in South Africa with around 3.7 million inhabitants, which is completely reliant on the **winter rainfall as a primary water source**.

- Poor winter rainfall can often have **dire consequences within the city of Cape Town** and surrounds, particularly when it occurs over successive years, resulting in severe water restrictions being put in place (e.g. 2003-2004 and **2015-2017**).

Objectives

- The aim is provide some insight into the location and frequency of ARs in a relatively poorly studied region, the South Atlantic.
- Secondly, to better understand the role that such phenomena play in winter rainfall, including extreme rainfall events, across the winter rainfall region of South Africa.
- Moisture sources analyses on the ARs that strike South Africa

The influence of Atmospheric Rivers over the South Atlantic on Winter Rainfall in South Africa

R. C. Blamey[2]

Alexandre M. Ramos[1], R. M. Trigo[1], R. Tomé[1] & C. J. C. Reason[2]

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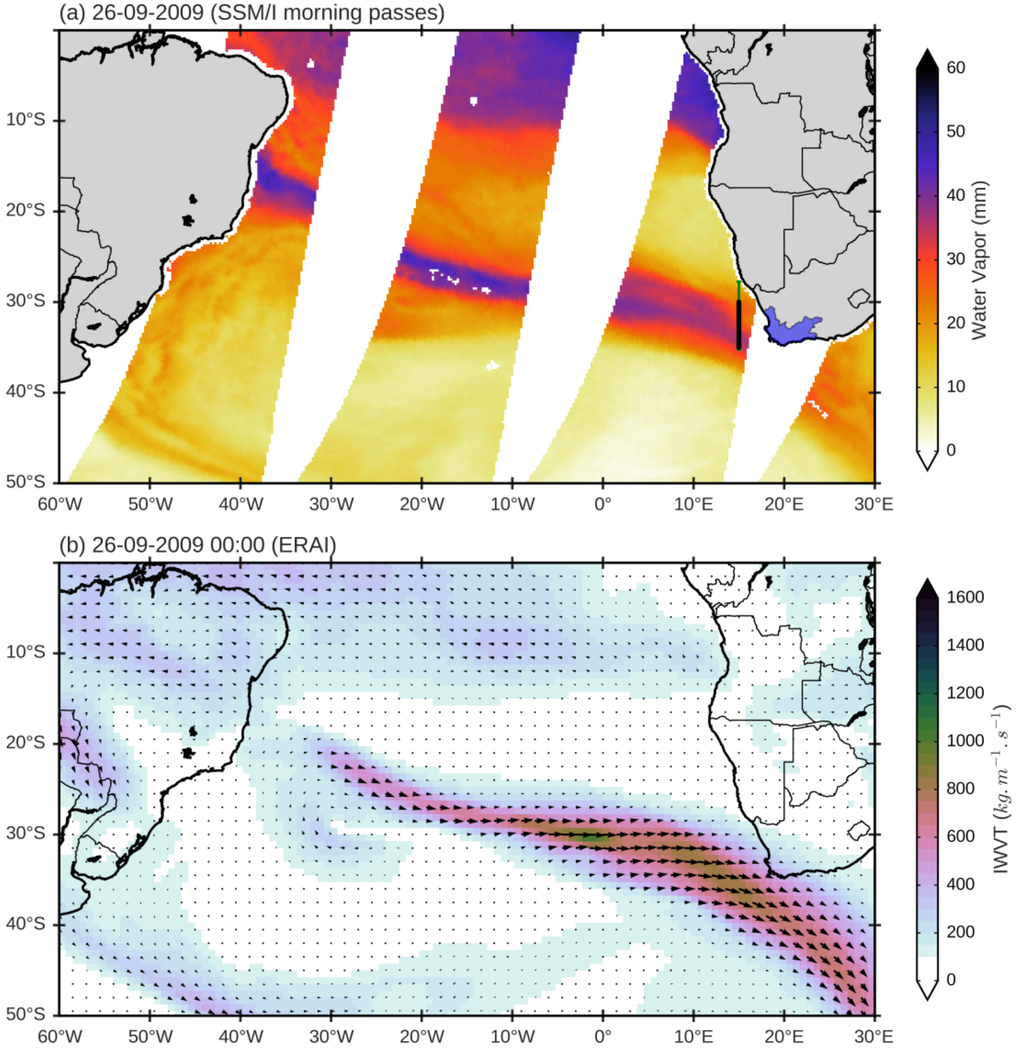
More Information:

Blamey *et al*. 2018: *J. Hydrometeor.* 19, *127-142*

Influence of the Atmospheric Rivers in South Africa

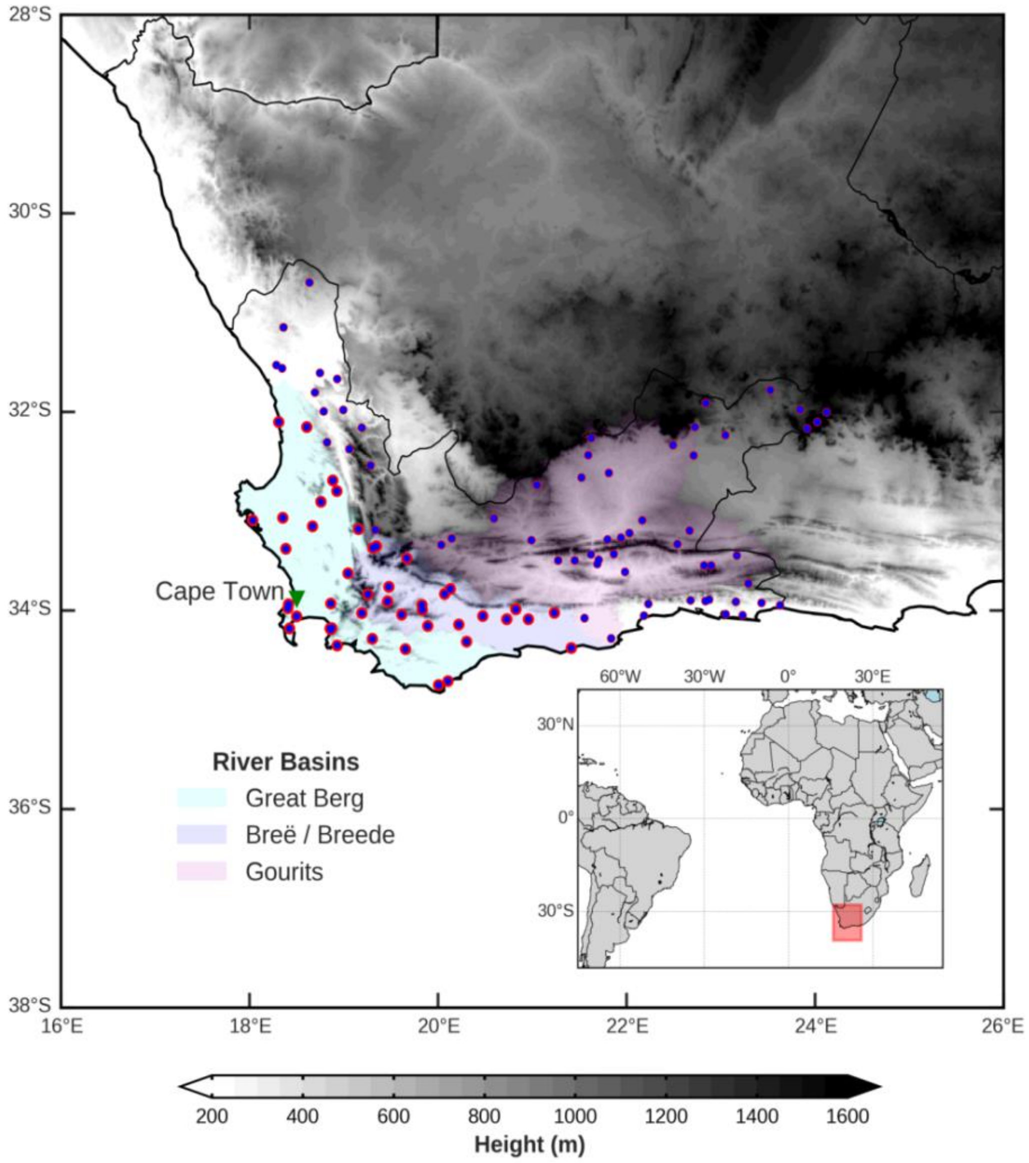
Data and Methods

- Integrated water vapor transport (IVT) from reanalysis products for AR identification.
- **ERA-Interim** reanalysis data (0.75°) and **NCEP-NCAR** reanalysis (2.5°) from 1979-2014
- AR detection methodology used by Lavers et al. (2012) and Ramos et al. (2015) – IVT 85th percentile and around exceeding 2000 km in length
- Only for systems occurring during the austral winter months (May – September)



Influence of the Atmospheric Rivers in South Africa

Data and Methods



Daily rainfall data over South Africa were provided by the South African Weather Service (SAWS) for the period May 1979 to September 2014

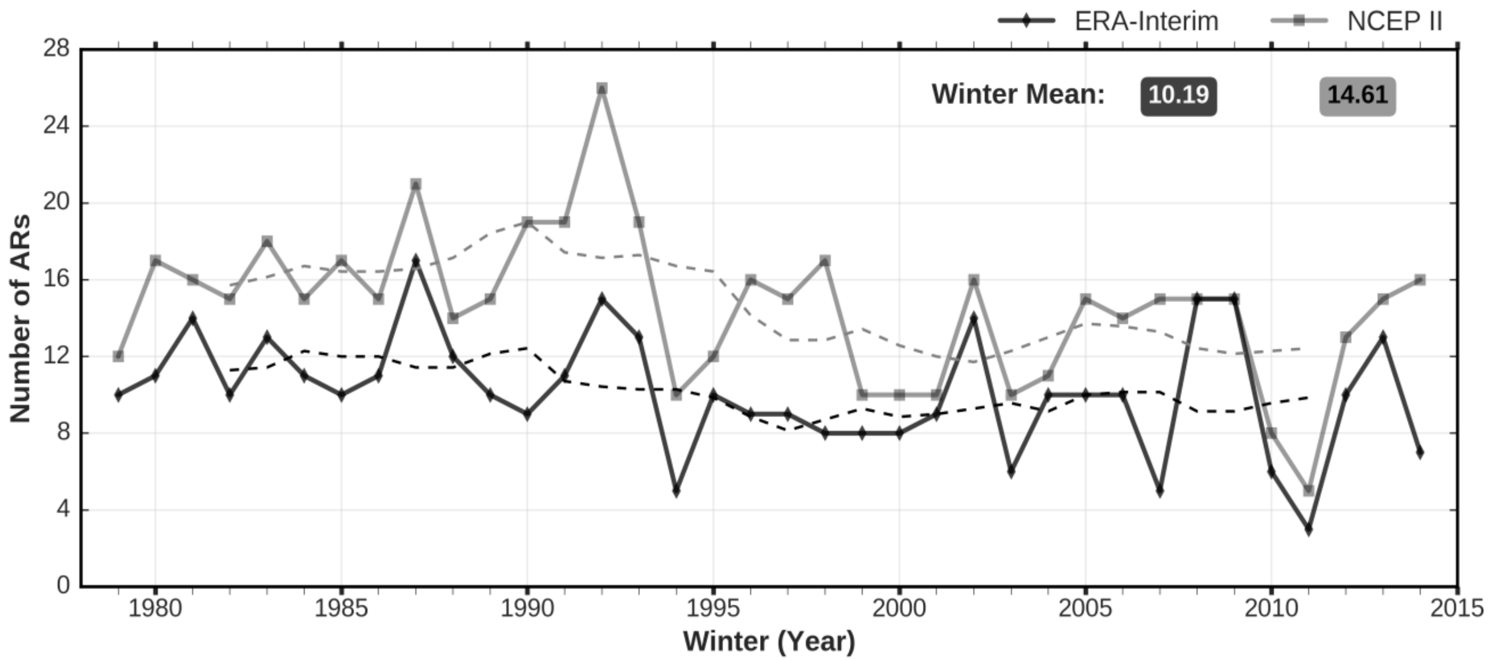
Only **45 of stations** were retained for the analysis covering the two main river catchments

The **ranking of daily extremes** is based on a method that has been adapted from Ramos et al. (2014).

The method is used to characterize and rank each winter day, taking into account the severity of the rainfall anomaly and its spatial extent.

Influence of the Atmospheric Rivers in South Africa

Results: *AR Climatology*

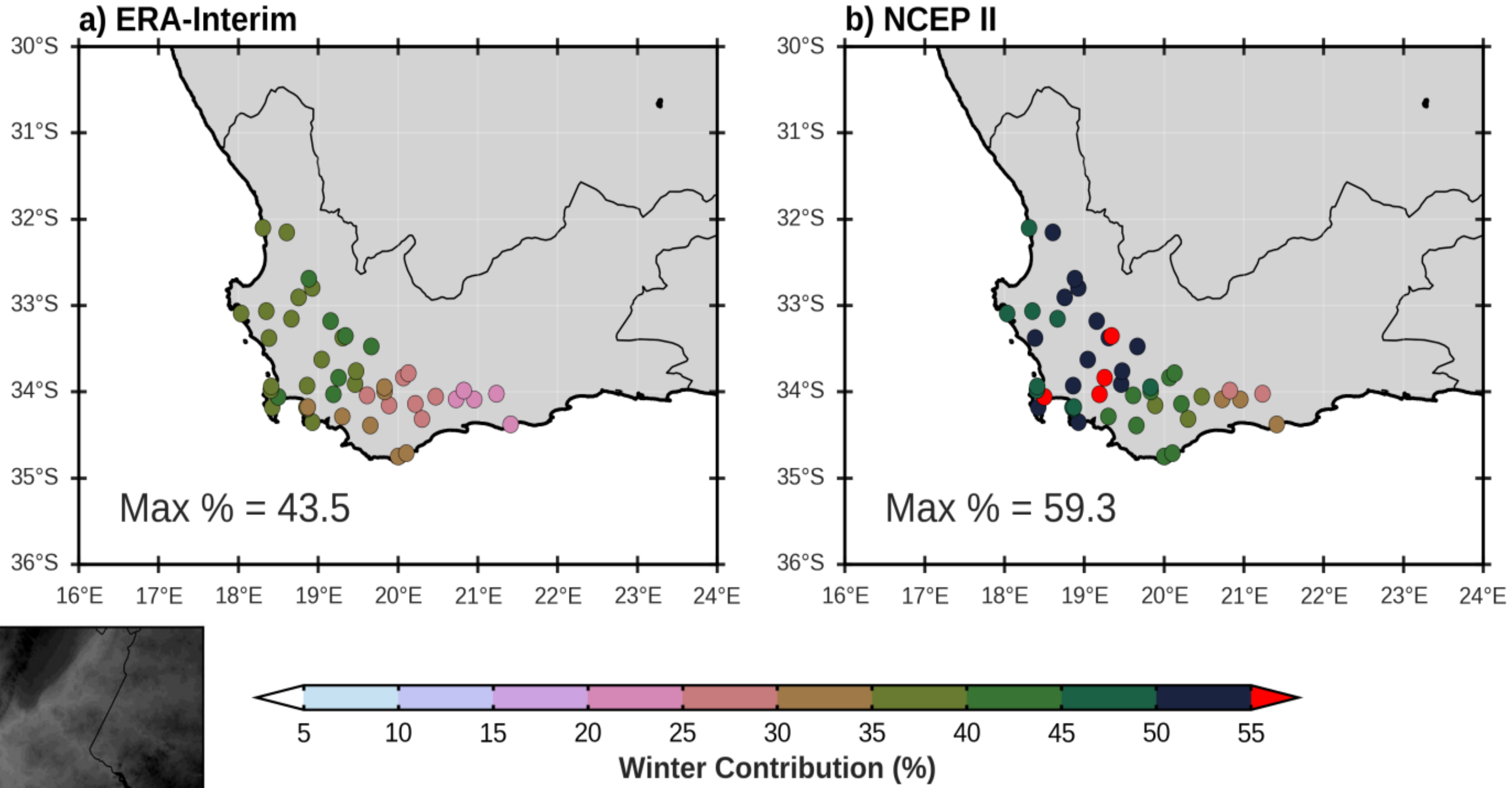


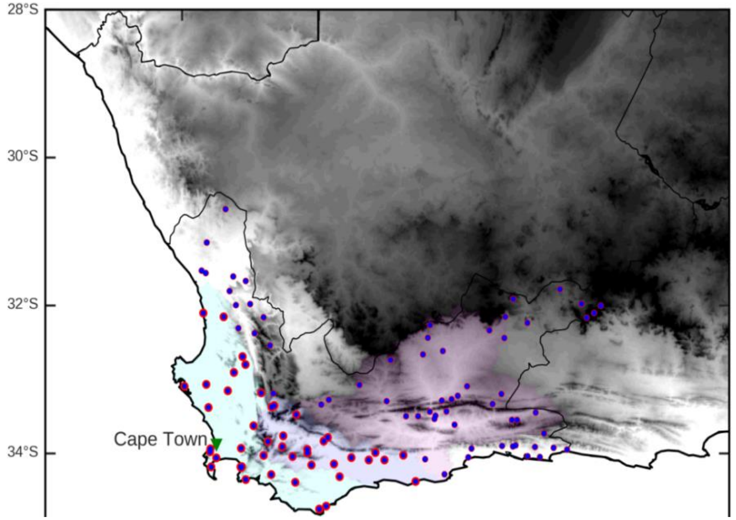
Persistent ARs – at least 3 consecutive time steps

Influence of the Atmospheric Rivers in South Africa

Results: ARs Winter Rainfall Contribution

(May-September)





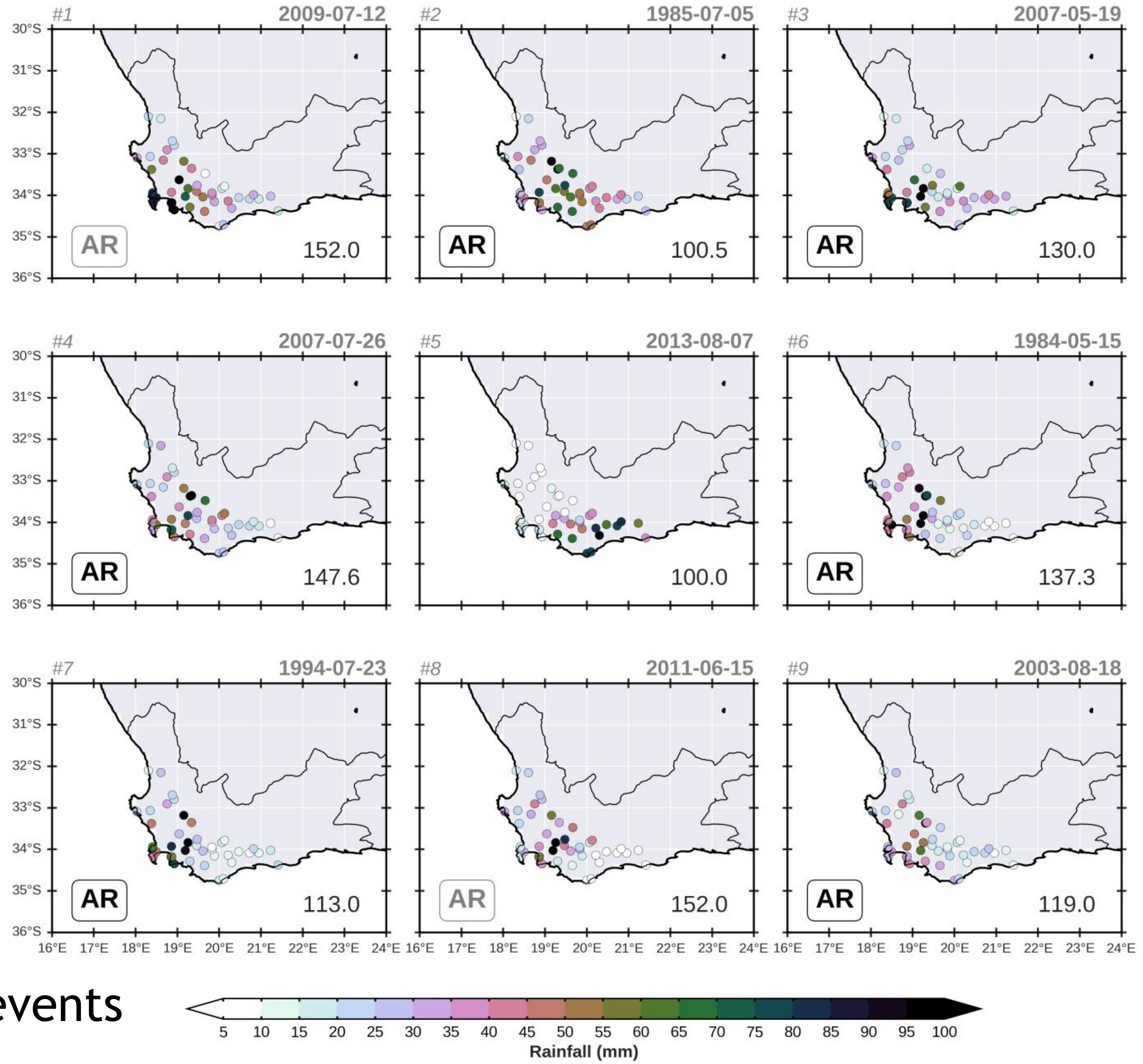
Influence of the Atmospheric Rivers in South Africa

Results: *Extreme Events*

Extreme daily rainfall events

8 out of top 9 events associated with ARs, but only 6 of these have an AR in both ERA and NCEP

Around **70% of the top 50** daily winter rainfall extremes the winter rainfall region were found in some way **linked to ARs**



Top #9 events

From Amazonia to southern Africa: Atmospheric moisture transport through Low Level Jets and Atmospheric Rivers

Alexandre M. Ramos[1], R.C. Blamey[2], I. Algarra[3], R. Nieto[3], L. Gimeno[3], R. Tomé[1], C.J.C. Reason[2], R.M. Trigo[1]

[1] *Instituto Dom Luiz (IDL), Faculdade de Ciências, Universidade de Lisboa,* ***Portugal***

[2] *Department of Oceanography, University of Cape Town, Private Bag X3, Rondebosch, 7701,* ***South Africa***

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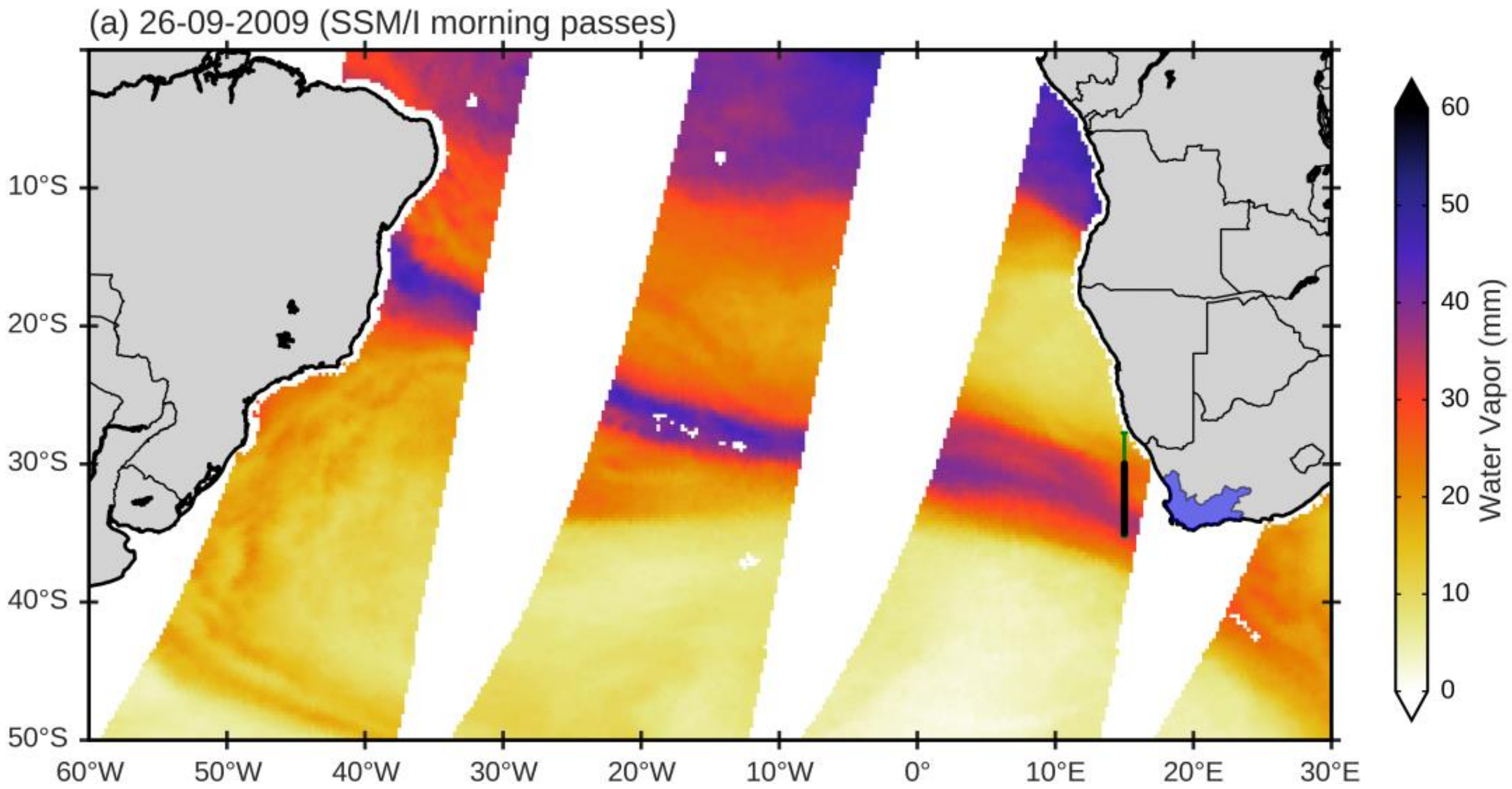
More Information:

Ramos et al. 2018: Annals NYAS (in revision)

From Amazonia to southern Africa

Results: *Moisture Sources*



Ramos *et al*. 2018: *Annals NYAS* (*in revision*)

From Amazonia to southern Africa

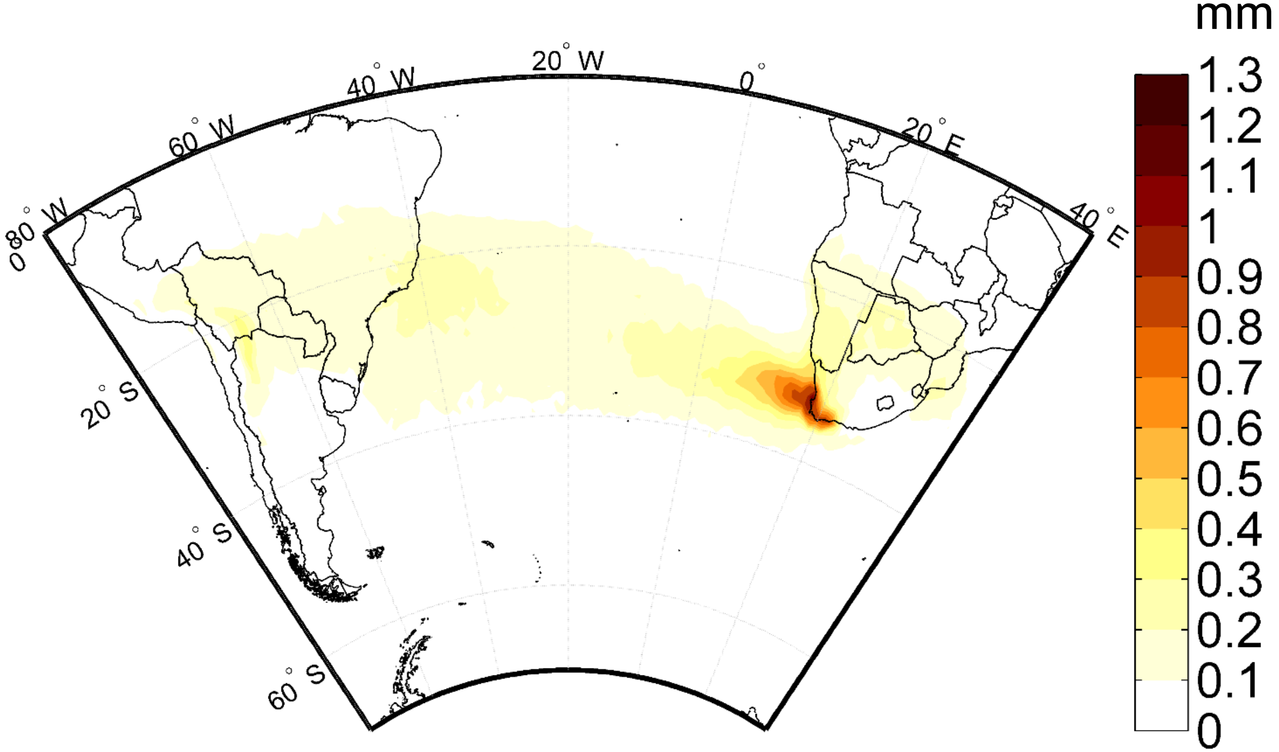
Results: Moisture Sources

Lagrangian Model – FLEXPART
Global Simulation – Era-Interim 1979-2014

For the ARs days (particles) arriving to western South Africa, a 10-days back trajectory was analyzed taking into account changes in specific humidity (E-P)

Anomalous Uptake of Moisture

[ARs days E-P] - [Climatology of E-P]



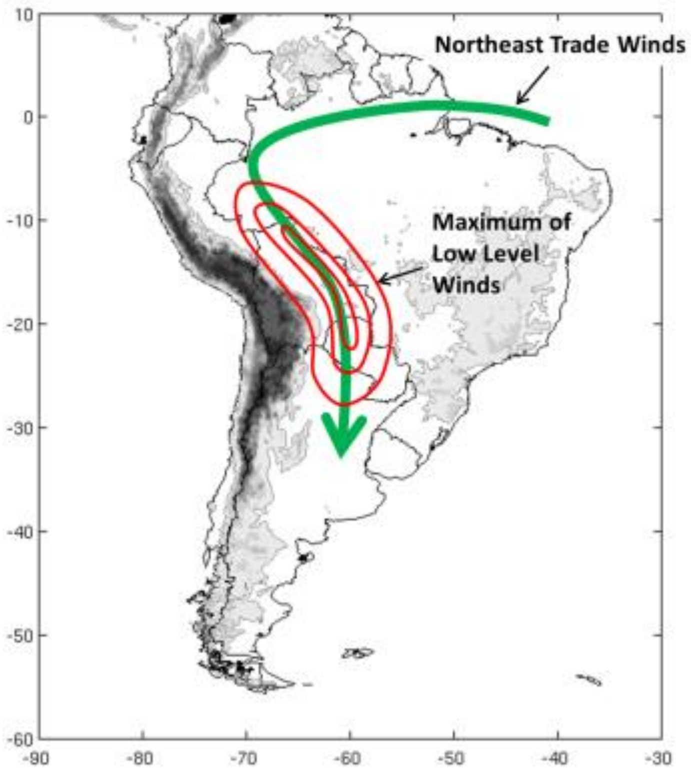
Ramos *et al*. 2018: *Annals NYAS (in revision)*

From Amazonia to southern Africa

Results: *South America Low Level Jet*

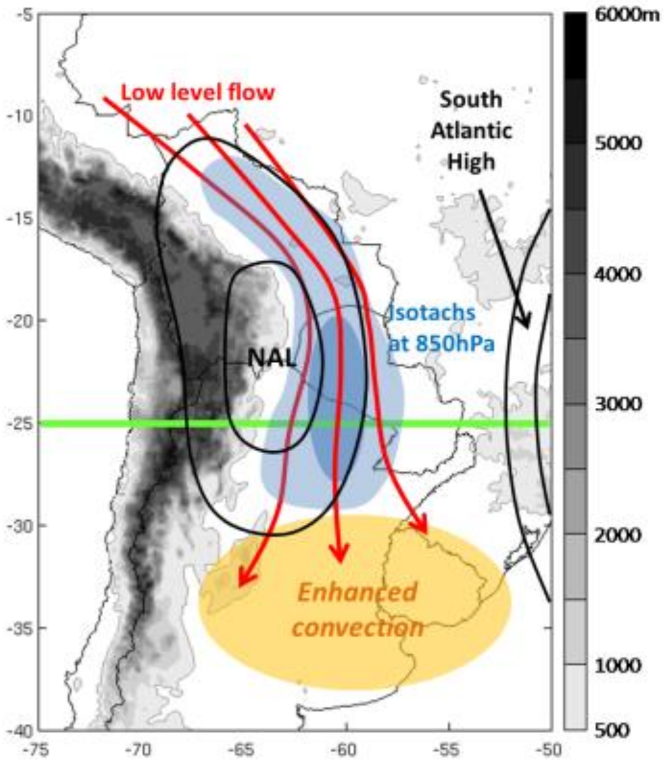
There are different configurations of SALLJ

SALLJ



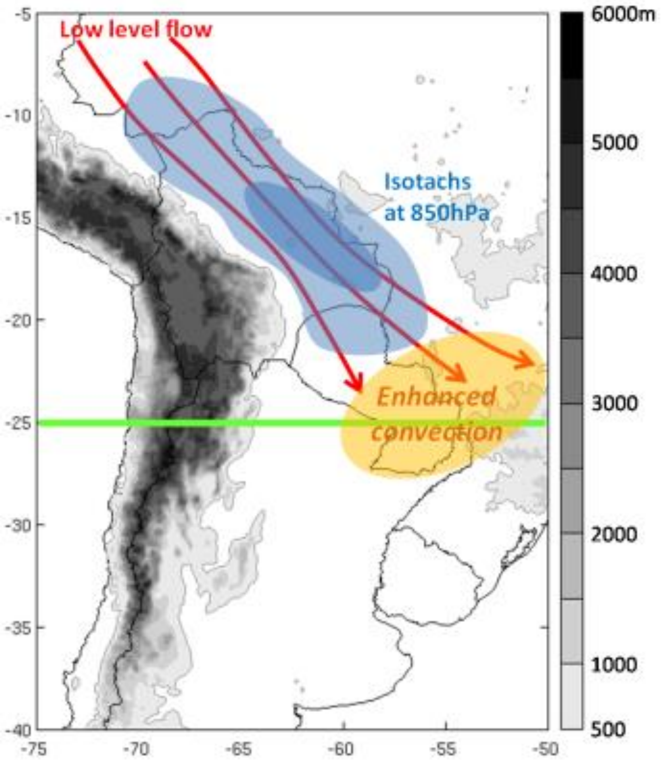
Is a northerly wind with a maximum (between 10ºS and 20ºS located immediately to the east of the Andes.

Chaco Jet Event (CJE)



This event occurs when the SALLJ's wind maximum penetrates south of 25°S

No Chaco Jet Event (NCJE)

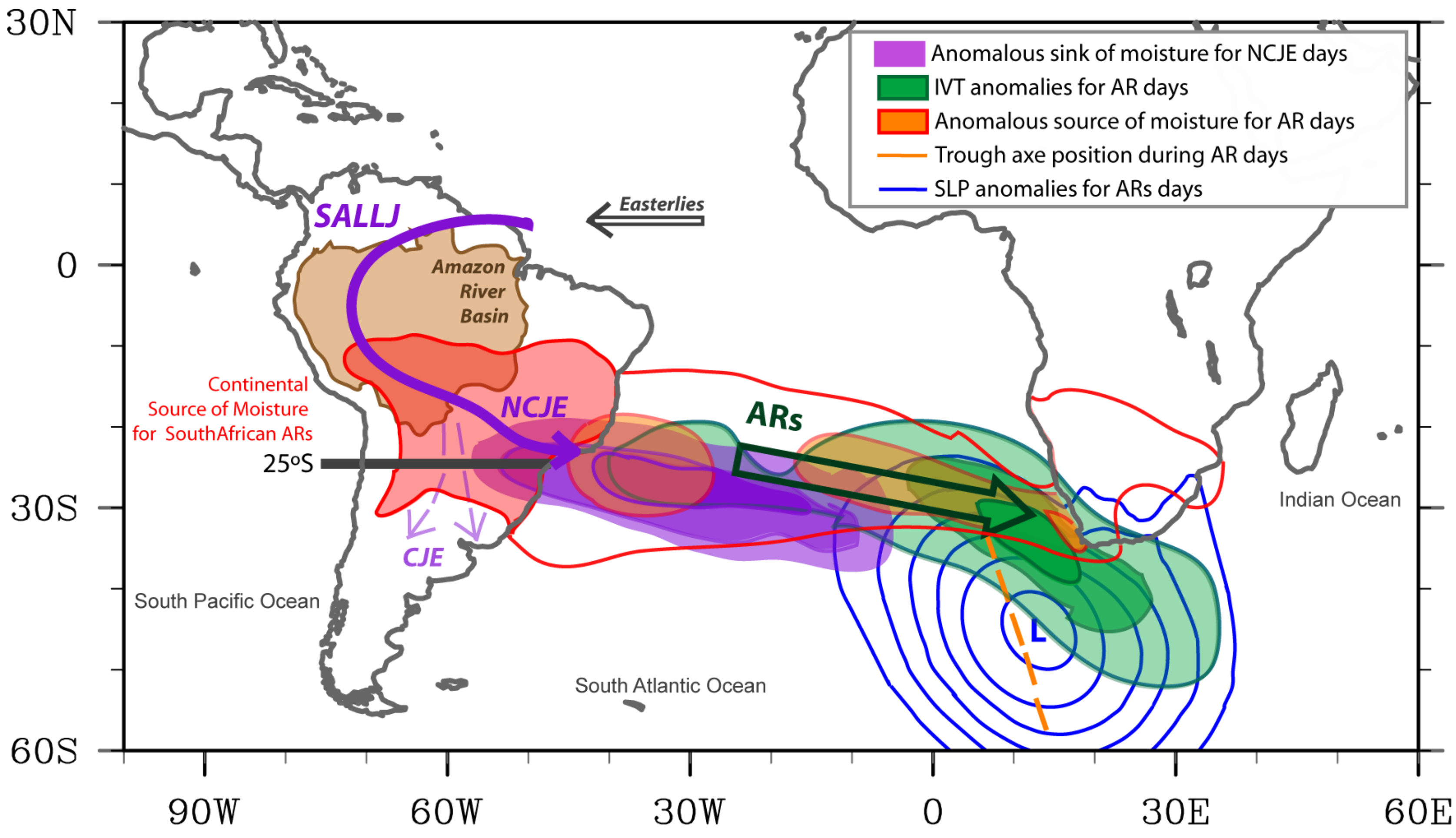


Is similar to that of the CJEs, but the wind maxima do not penetrate south of 25°S

http://www.eumetrain.org/satmanu/CMs/Sallj/navmenu.php?page=2.0.0

From Amazonia to southern Africa

Results: Conceptual model



Ramos *et al*. 2018: *Annals NYAS* (*in revision*)

Atmospheric Rivers in South Africa

Take away messages

i) Results of AR for the South Atlantic support similar investigations on ARs in the North Atlantic and North Pacific.

ii) ARs found to play a vital role in the regional hydrological cycle, resulting in moisture availability for rainfall (sometimes extreme daily rainfall) in the southwestern Cape.

iii) Again highlighting the influence the choice of reanalysis can have on AR identification as previously been documented by others

iv) ARs could potentially be a link between South American climate and African climate variability, which has not been well documented.

More Information:

Blamey *et al*. 2018: *J. Hydrometeor.* 19, *127-142* | Ramos *et al*. 2018: *Annals NYAS* (*in revision*)

Antarctica

Work by *Irina Gorodetskaya*

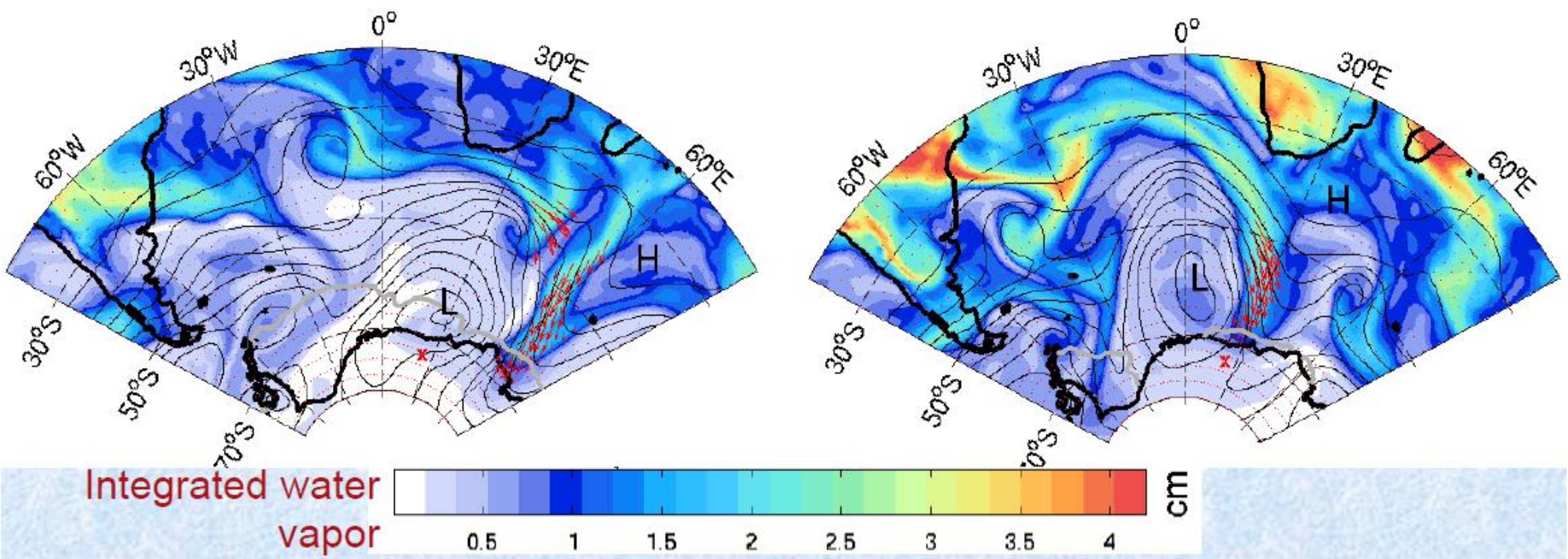
She was part of the Antarctic Circumnavigation Expedition (ACE) organized by Swiss Polar Research Institute onboard Akademik Tryoshnikov in 2017.

Latest work

Characteristics of enhanced moisture transport towards Antarctica from radiosonde measurements at coastal stations and over Southern Ocean

Atmospheric rivers identified using a new definition adapted for Antarctica

19 May 2009 15 Feb 2011



Colors = integrated (900-300hPa) water vapour
Red arrows = total integrated moisture transport within ARs
black contours = 500 hPa geopotential height

➤ *Gorodetskaya et al "The role of atmospheric rivers in anomalous snow accumulation in East Antarctica, GRL (2014)*

Acknowledgments

The financial support for attending this conference was possible through FCT project UID/GEO/50019/2013 - Instituto Dom Luiz (IDL).

I would like to thank Marty Ralph for the additional support for attending this conference.

A. M. Ramos is supported by a FCT post-doctoral grant (FCT/DFRH/ SFRH/BPD/84328/2012).

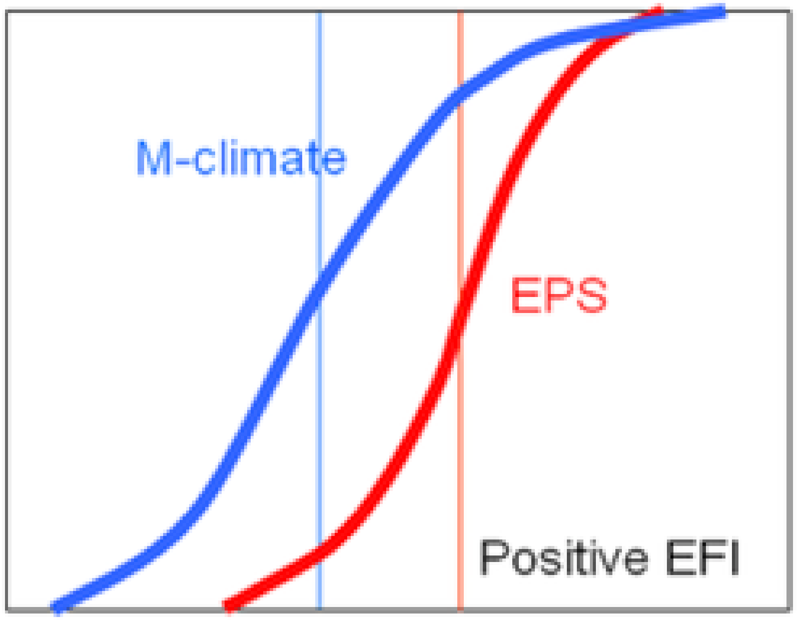
Thank you very much for your attention!

1) Atmospheric Rivers – Extreme Forecast Index (EFI)

Extreme Forecast Index (EFI) - ECMWF

$$EFI = \frac{2}{\pi}\int_0^1 \frac{p - F_f(p)}{\sqrt{p(1-p)}} dp$$

where Ff(p) denotes the proportion of EPS (ensemble prediction system) members lying below the p quantile of the climate record. The EFI is computed for many weather parameters, for different forecast ranges and accumulation periods.



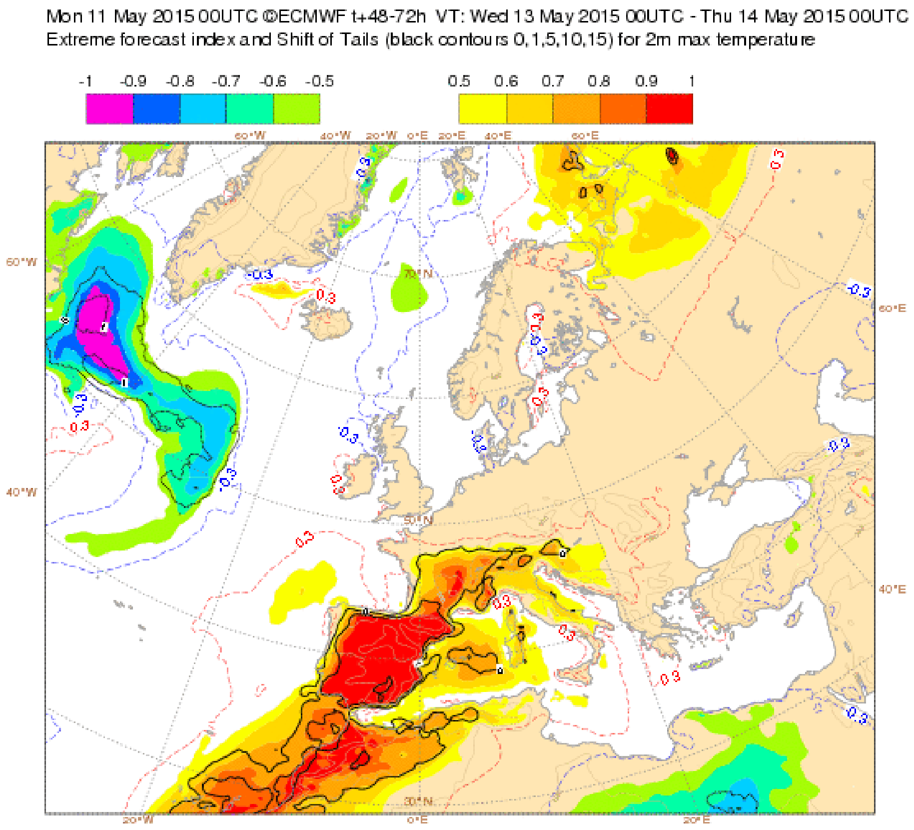
1) Atmospheric Rivers – Extreme Forecast Index (EFI)

Example for Temperature - mid-May 2015 Spain and Portugal experienced a heatwave

On the 13 May several stations in southern Spain broke their May record (including Madrid, Seville, Granada and Cordoba).

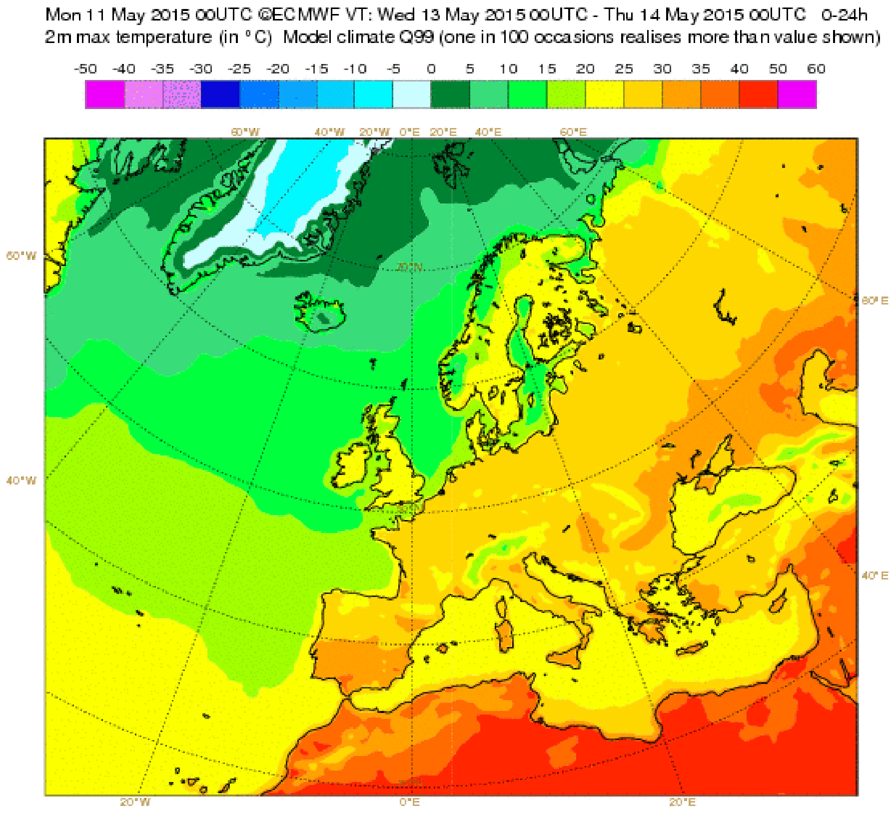
EFI FORECAST 11/5/2015 00UTC

VT: 13/5/2015-14/5/2015



2m max Temp FORECAST 11/5/2015 00UTC

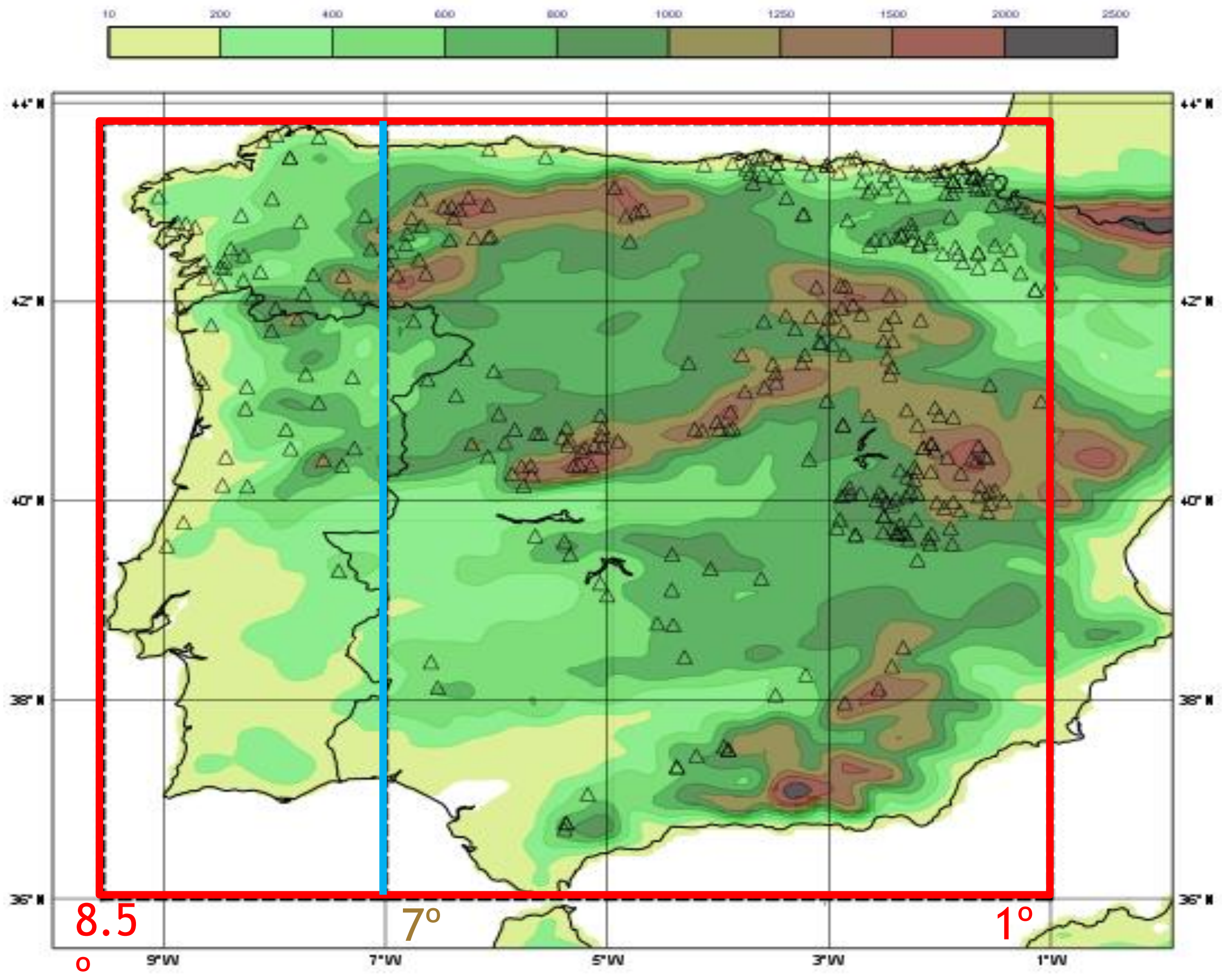
VT: 13/5/2015-14/5/2015



https://software.ecmwf.int/wiki/display/FCST/201505+-+Heatwave+-+Spain%2C+Portugal

1) Atmospheric Rivers – Extreme Forecast Index (EFI)

2 areas of study - 8.5º till 7ºW and 1ºW



EFI from :

- Precipitation
- IVT

2015/16; 2016/17 winters

Daily precipitation
AEMET
IPMA

EFI computed based on :
51 members (out to 15 days) from the ECMWF Integrated Forecasting System