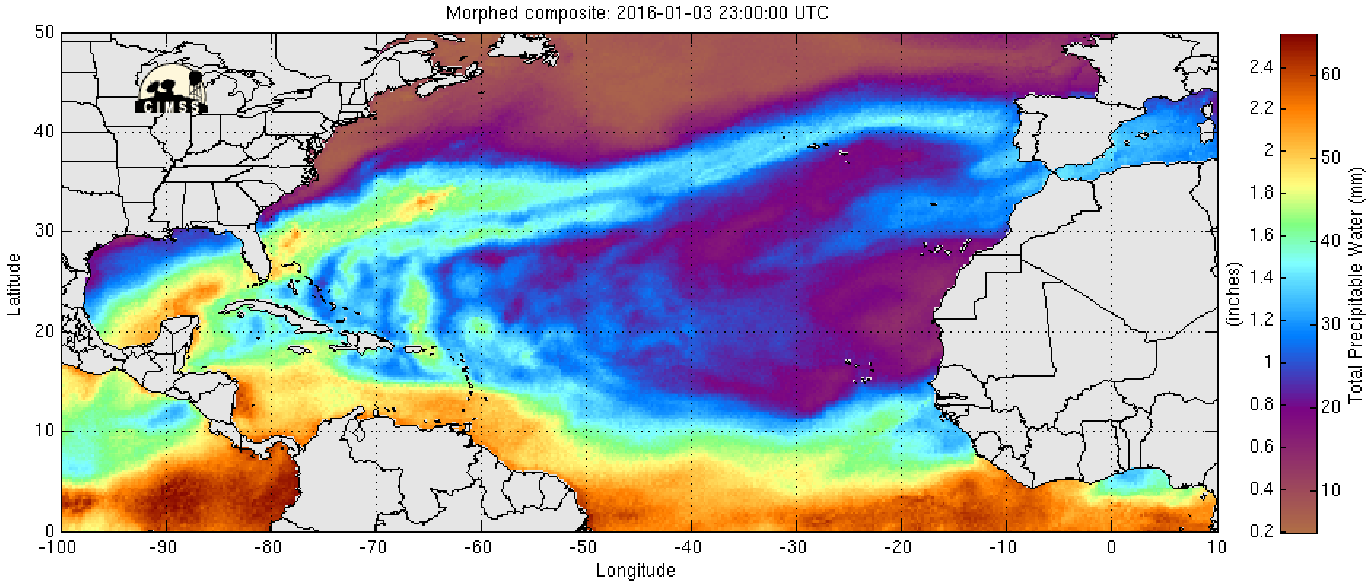
Atmospheric Rivers in Europe: From moisture sources to impacts and future climate scenarios



Alexandre M. Ramos

amramos@fc.ul.pt

Co-Authors

M. L. R. Liberato[(2)], Ricardo Tomé[(1)], Raquel Nieto[(3)], L. Gimeno[(3)], Ricardo M. Trigo[(1)], David Lavers[(4)]

(1) Instituto Dom Luiz (IDL), Universidade de Lisboa, Portugal

(2) Escola de Ciências e Tecnologia, Univ. de Trás-os-Montes e Alto Douro, Portugal

(3) EPhysLab, Facultade de Ciencias, Universidade de Vigo, Spain

(4) European Center for Medium Range Weather Forecasting, Exeter, United Kingdom

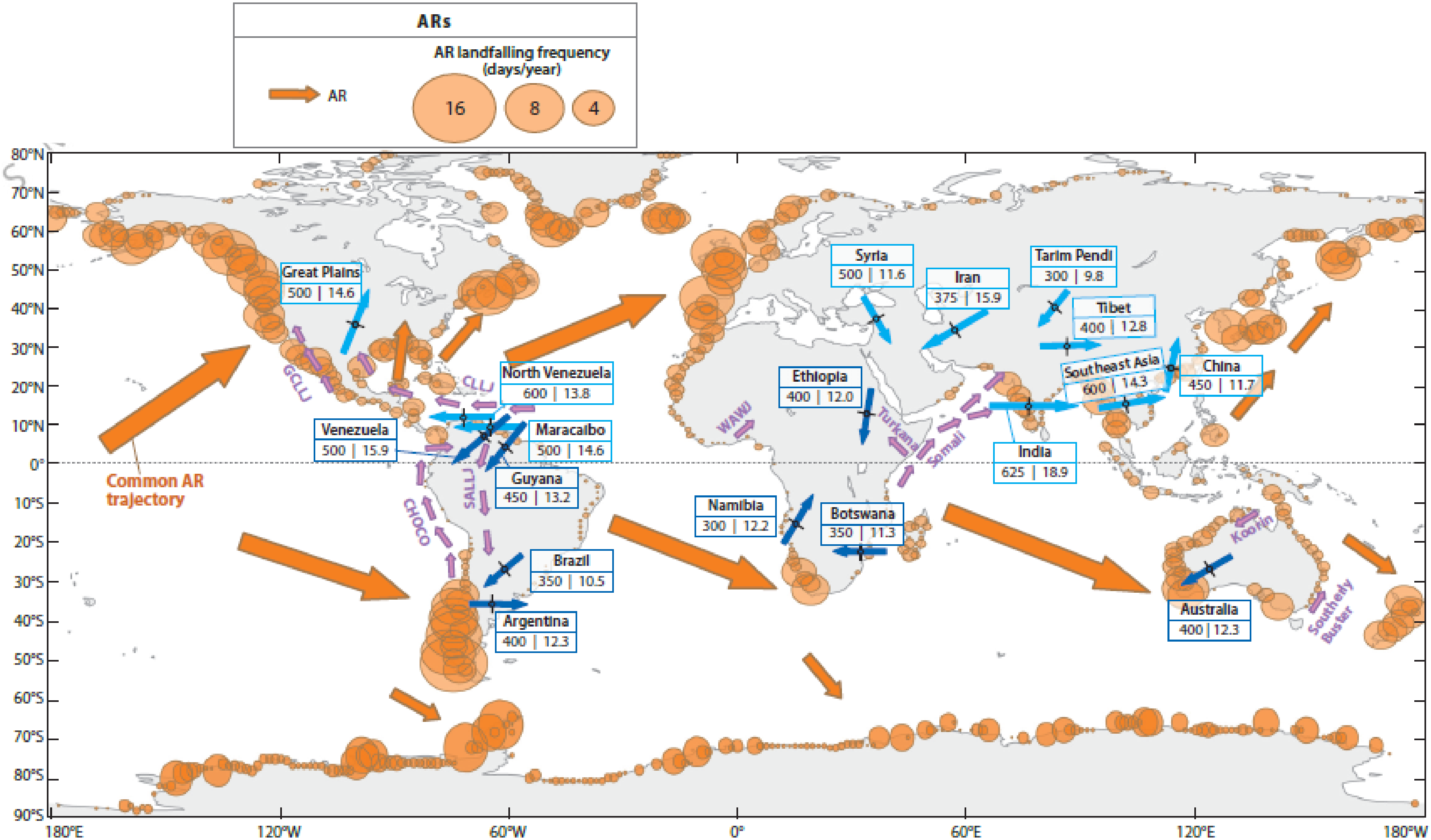
Outline

1) ARs influence areas in Europe and impacts

2) Moisture Sources of the ARs affecting western Europe

3)Projected changes in ARs affecting Europe in CMIP5

1) Atmospheric Rivers – Global Overview



The global geographical position of atmospheric rivers (ARs) and low-level jets (LLJs). ARs climatology provided by Guan and Waliser, 2015.

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

1) Atmospheric Rivers – Impacts

Different areas of study emerge

British Islands

e.g. Lavers et al., 2011, 2012

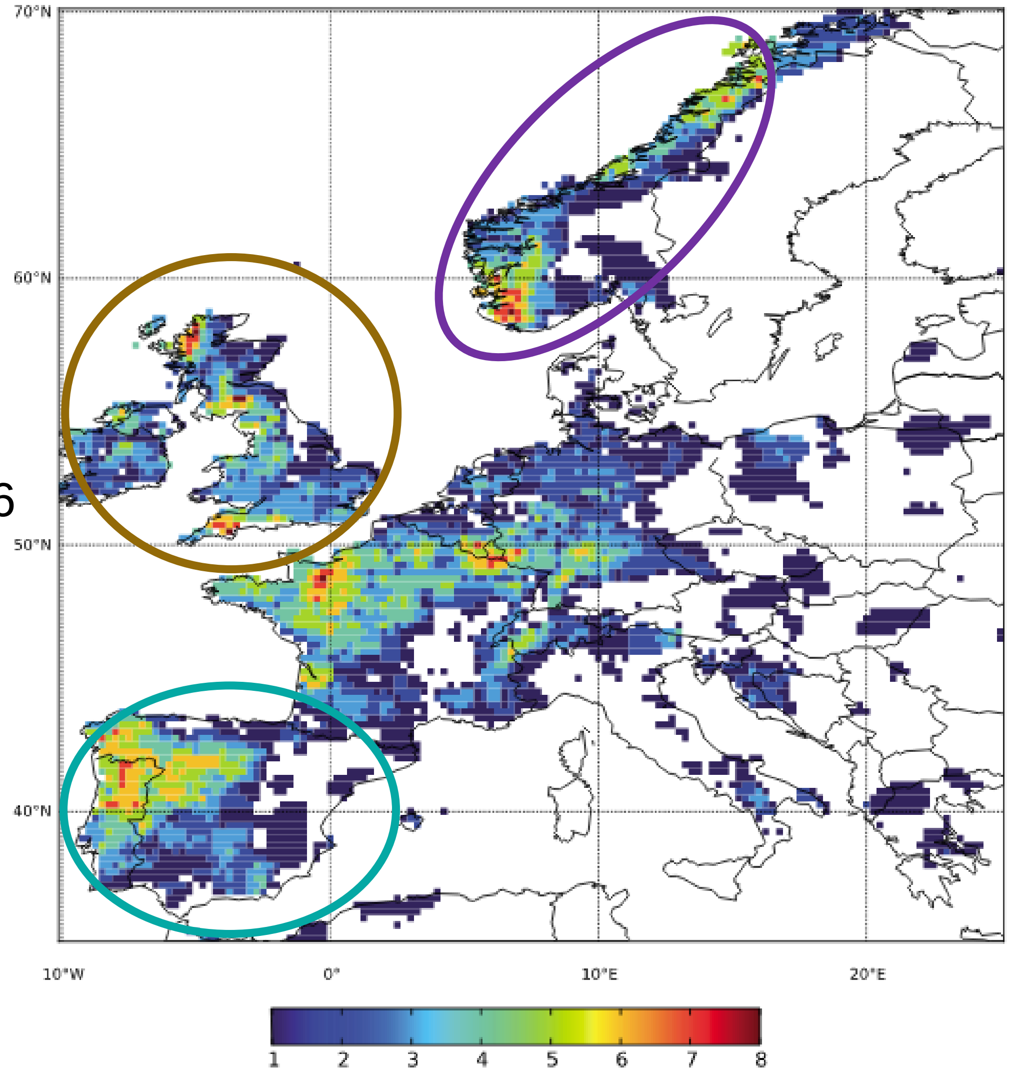
Iberian Peninsula

eg. Ramos et al., 2015, Eiras et al., 2016

Norway

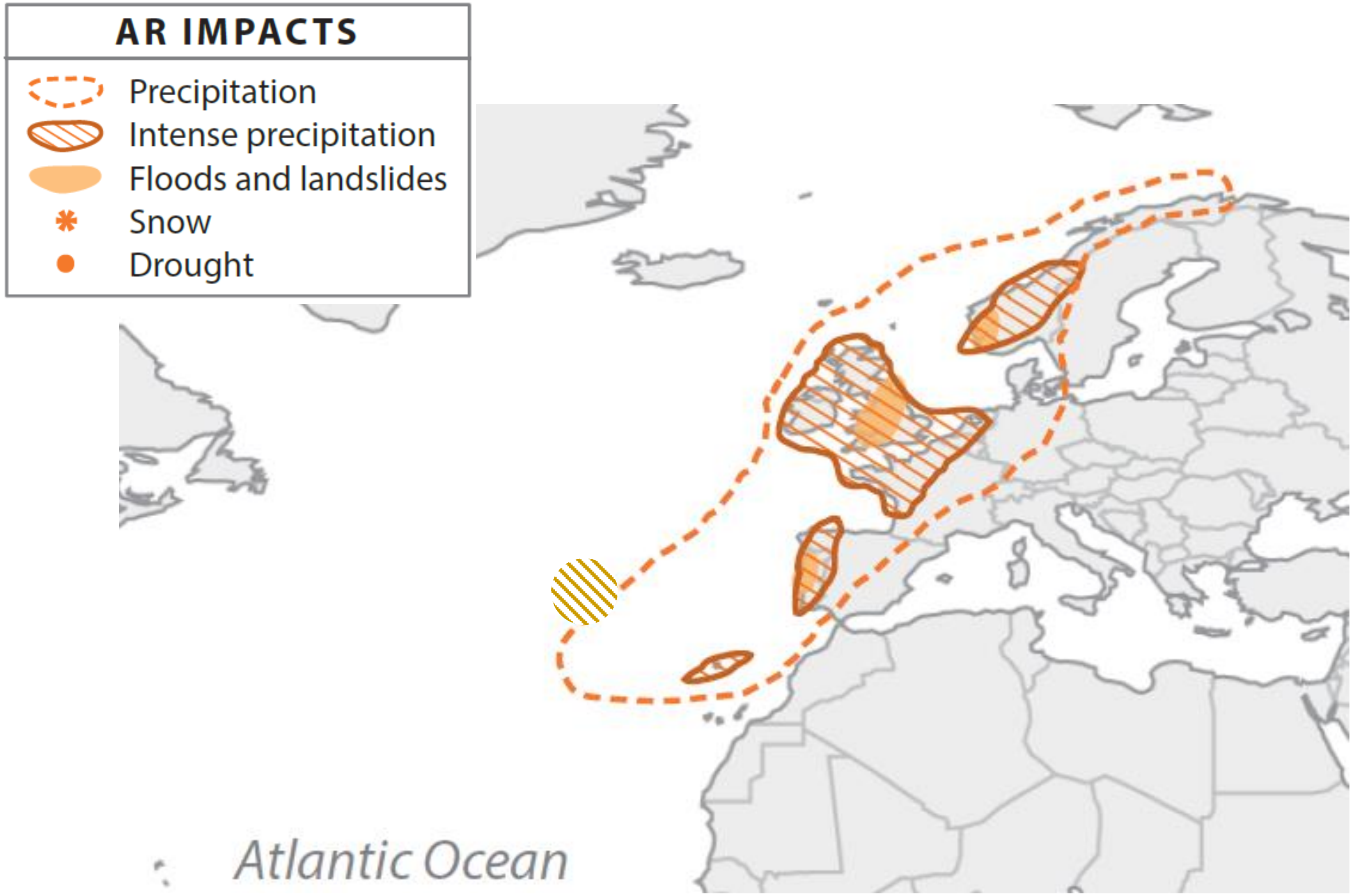
e.g. Sodemann and Stohl, 2013;
Odemark (talk on Monday)

Number of TOP10 Annual Maxima related to ARs



Lavers and Villarini, 2013

1) Atmospheric Rivers – Impacts



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

1) Atmospheric Rivers – Detection

An automated AR detection algorithm based *on the* ***vertically integrated horizontal water vapor transport (IVT)*** to identify the major AR events that affected Europe using the *NCEP/NCAR reanalysis* and *ERA-Interim* (**Lavers et al., 2012**).

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

The algorithm estimates grid points that can be declared as AR grid if the IVT exceeds a threshold, corresponds to the 85th percentile.

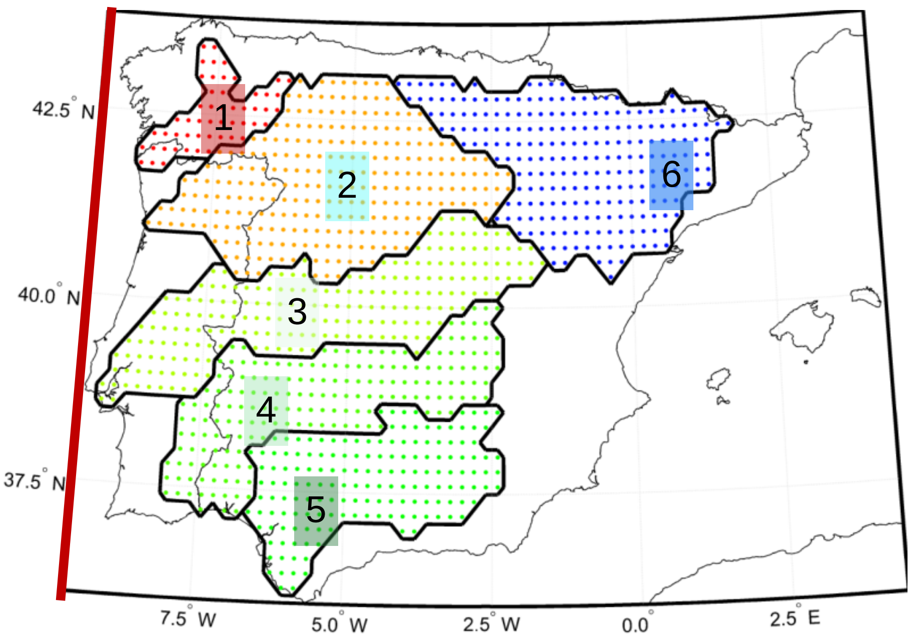
The **AR defines as a contiguous region ~ 2000 km in length with IVT ≥ *threshold***. This is evaluated at every 6 hour time steps.

Reanalyzes or Model output

• Wind components (**u and v**)   Specific humidity (**q**)

1) Atmospheric Rivers – Iberian Peninsula

Ranked extreme precipitation days tanking into account **intensity** of precipitation and **area affected**

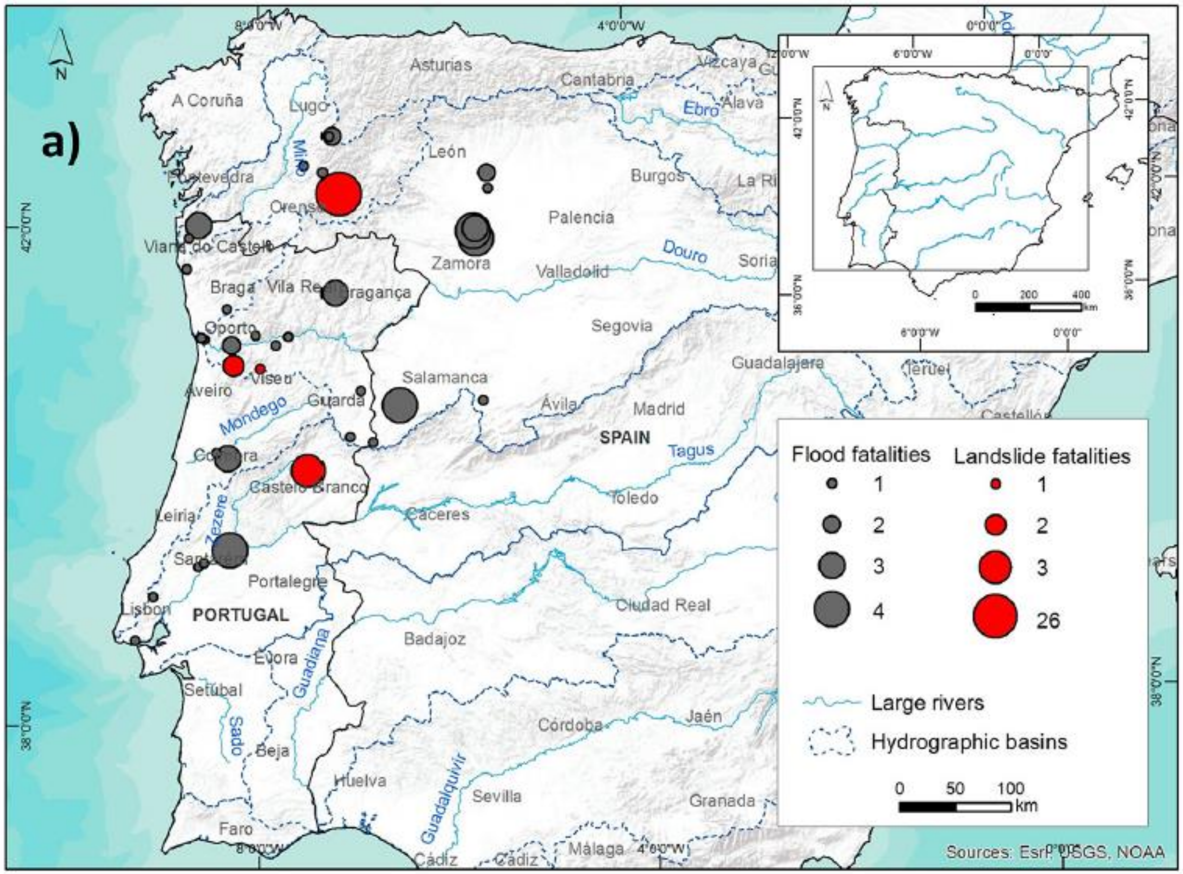


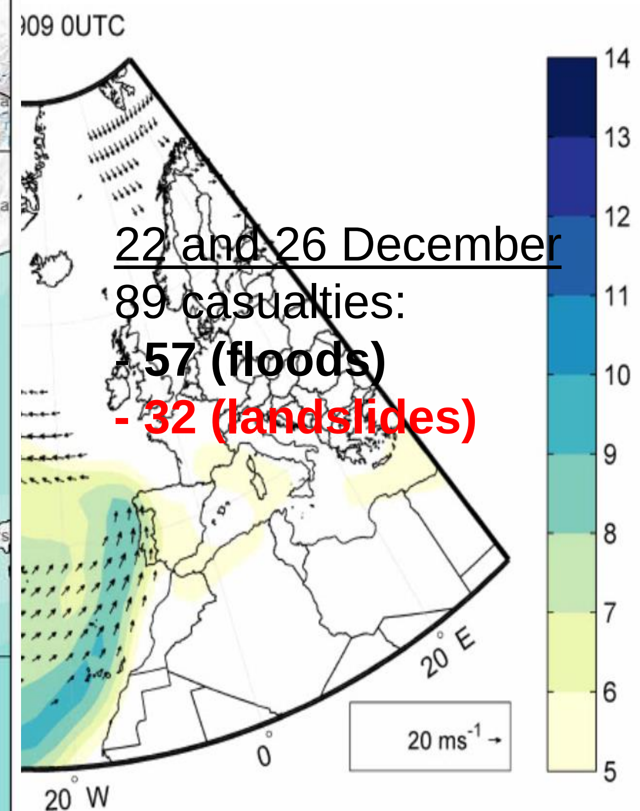
Extended winter months – 1950-2012

Ramos et al., 2014 , Atmos Science Letters

1) Atmospheric Rivers – Dec. 1909 historical case

Largest floods in Duero river





22 and 26 December

89 casualties:

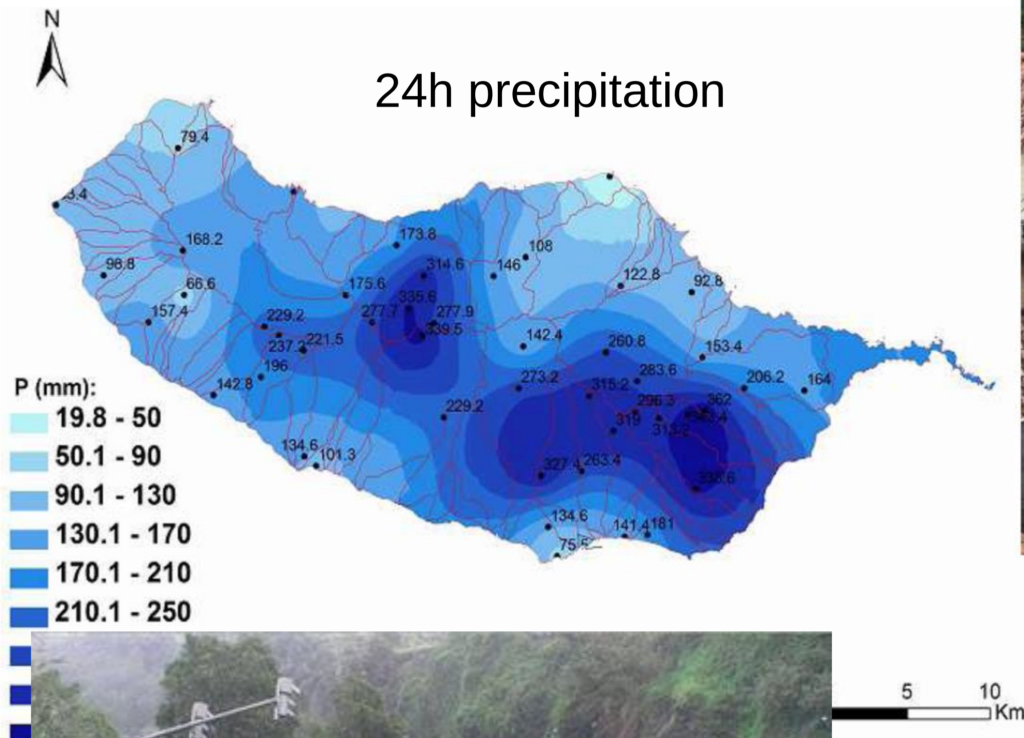
- 57 (floods)

- 32 (landslides)

Pereira et al., 2016, Nat. Hazards Earth Syst. Sci

1) Atmospheric Rivers – Madeira 2010

Flash Flood Event in Madeira 20 February 2010

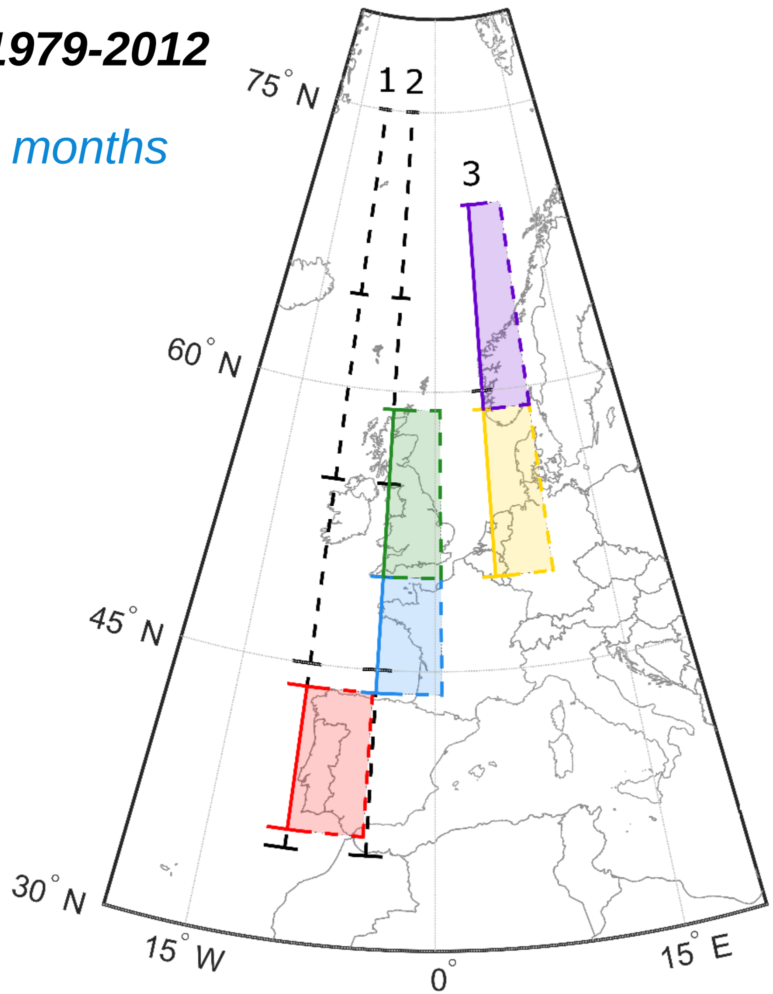


2) Atmospheric Rivers – Moisture Sources

Use the detection algorithm to **3 reference meridians** (1, 2, 3)
Ultimate Goal have 5 ARs domains (*will be used also in Future Scenarios*)

Era- Interim – 1979-2012

Extended winter months



Final ARs domains
1) Iberian Peninsula
9.75ºW; 36ºN – 43.75ºN
2) France
4.5ºW; 43.75ºN – 50ºN
3) UK
4.5ºW; 50ºN-59ºN
4) Southern Scandinavia & Netherlands
5.25ºE; 50ºN-59ºN
5) Northern Scandinavia
5.25ºE; 59ºN – 70ºN

Ramos et al., 2016, Earth System Dynamics

2) Atmospheric Rivers – Moisture Sources

5 domains ARs landfall were analyzed regarding the *moisture sources*

Method:

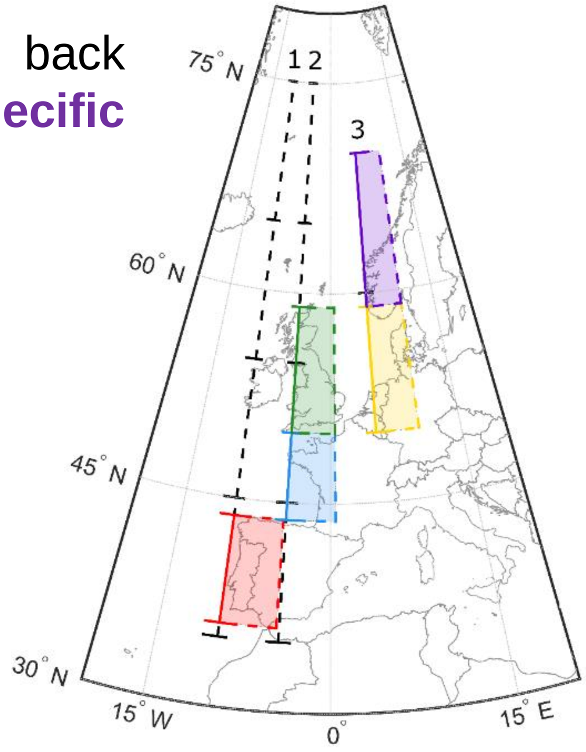
Lagrangian Model – FLEXPART   ERA-Interim 1979-2012   Extended winter months

For the particles arriving to each domain a 10-days back trajectory was analyzed taking into account changes in **specific humidity:**

For an individual particle: $$e - p = m\frac{dq}{dt},$$

(e-p) can be inferred as the freshwater flux in the parcel (difference of evaporation and precipitation).

The moisture changes (e-p) of all of the particles in an atmospheric column over a specified area (A) gives the surface freshwater flux **(E-P),** where E is the evaporation rate per unit area, P is the precipitation rate per unit area



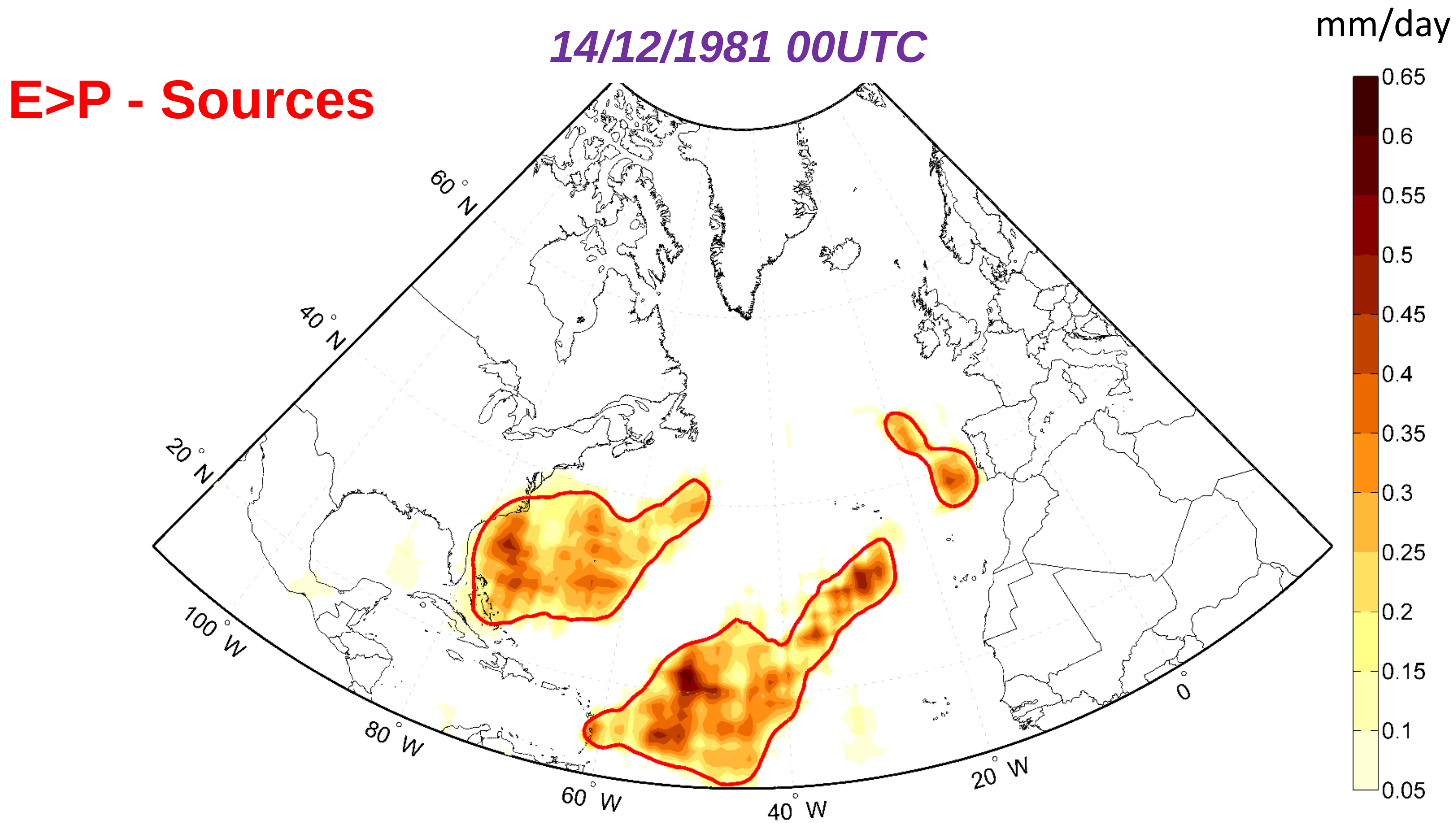
E-P >0 areas of moisture source

E-P < 0 areas of moisture sink

Ramos et al., 2016, Earth System Dynamics

2) Atmospheric Rivers – Moisture Sources

Example AR that makes landfall Iberian Peninsula



Anomalous moisture sources for a **particular case** (with respect to the climatology)

Ramos et al., 2016, Earth System Dynamics

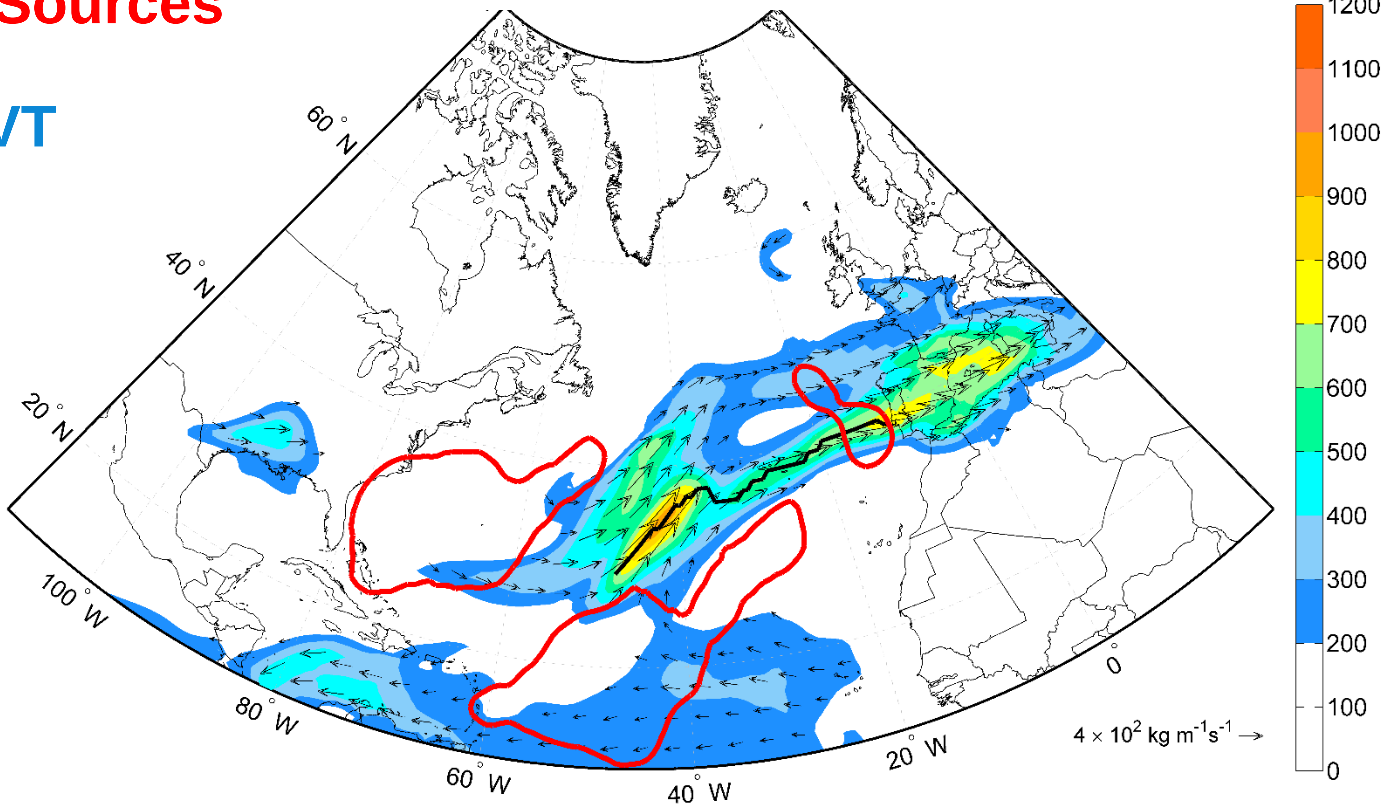
2) Atmospheric Rivers – Moisture Sources

Example AR that make landfall Iberian Peninsula

E>P - Sources

IVT

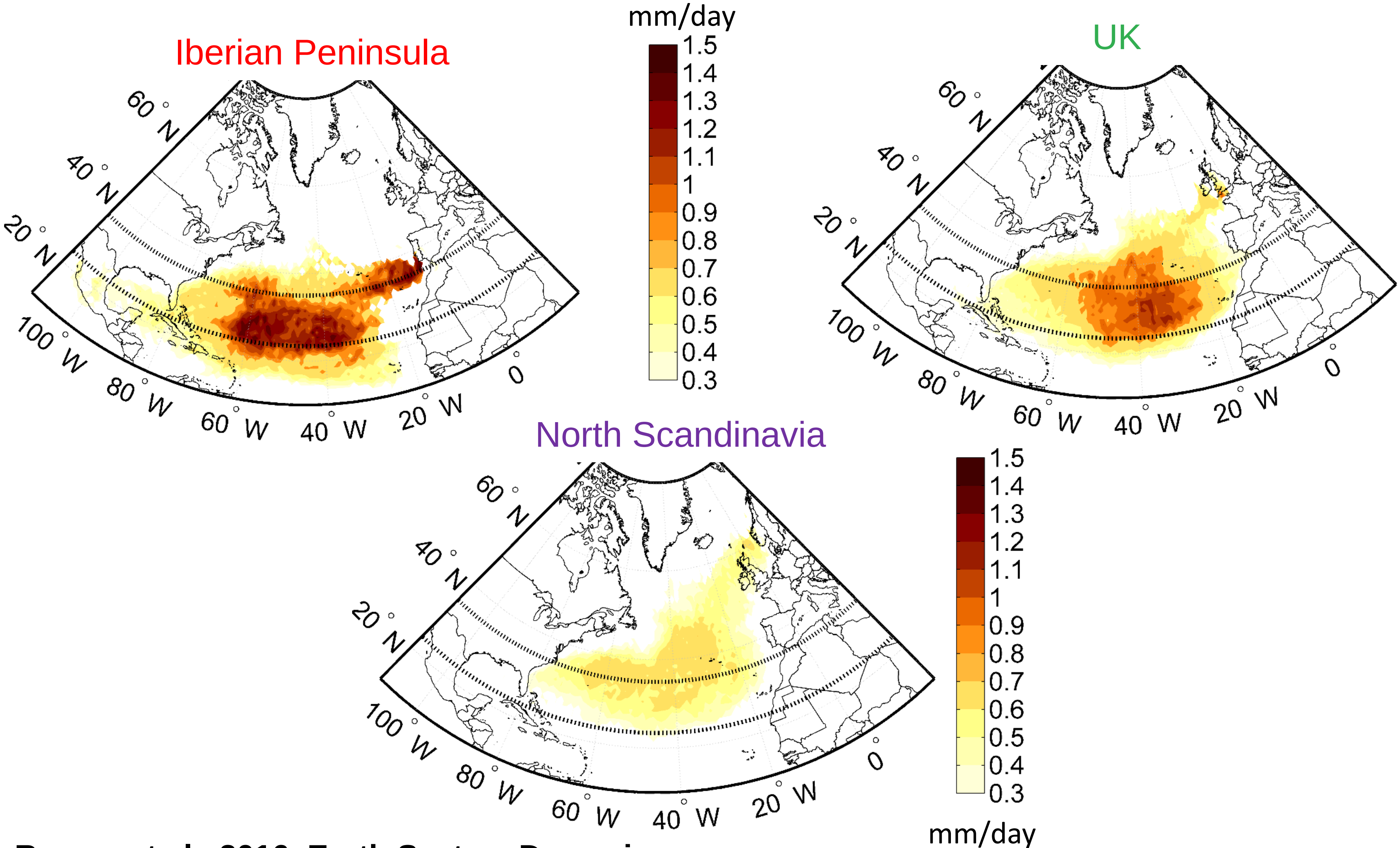
14/12/1981 00UTC



Ramos et al., 2016, Earth System Dynamics

2) Atmospheric Rivers – Moisture Sources

*Moisture Sources **Anomalies** for **all the ARs** found in different domains*



Ramos et al., 2016, Earth System Dynamics

3) Atmospheric Rivers – Future Scenarios

Extended winter months

RCP4.5 and RCP8.5 Climate Change Scenarios

Climate Models

<table>
<tr><th></th><th>Resolution</th><th>Consecutive grid points</th><th>Minimum Length</th><th>Past Present Climate</th><th>RCP4.5 RCP8.5</th></tr>
<tr><td>ERA-Interim (ERA)</td><td>0.75 x 0.75</td><td>36</td><td>1728</td><td>1980-2005</td><td>-</td></tr>
<tr><td>BCC-CSM (BCC)</td><td>~2.812 x ~2.812</td><td>10</td><td>1800</td><td rowspan="5">1980-2005</td><td rowspan="5">2074-2099</td></tr>
<tr><td>CAN-ESM (CAN)</td><td>~2.812 x ~2.812</td><td>10</td><td>1800</td></tr>
<tr><td>GFDL-ESM2G (GFD)</td><td>2.5 x 2.5</td><td>11</td><td>1760</td></tr>
<tr><td>NOR-ESM1 (NOR)</td><td>2.5 x 2.5</td><td>11</td><td>1760</td></tr>
<tr><td>CNRM-CM5 (CNR)</td><td>~1.406 x ~1.406</td><td>19</td><td>1710</td></tr>
<tr><td>EC-Earth (ECE)</td><td>1.125 x 1.125</td><td>24</td><td>1728</td><td>1850-2009</td><td>2006-2099</td></tr>
</table>

High temporal resolution 6h

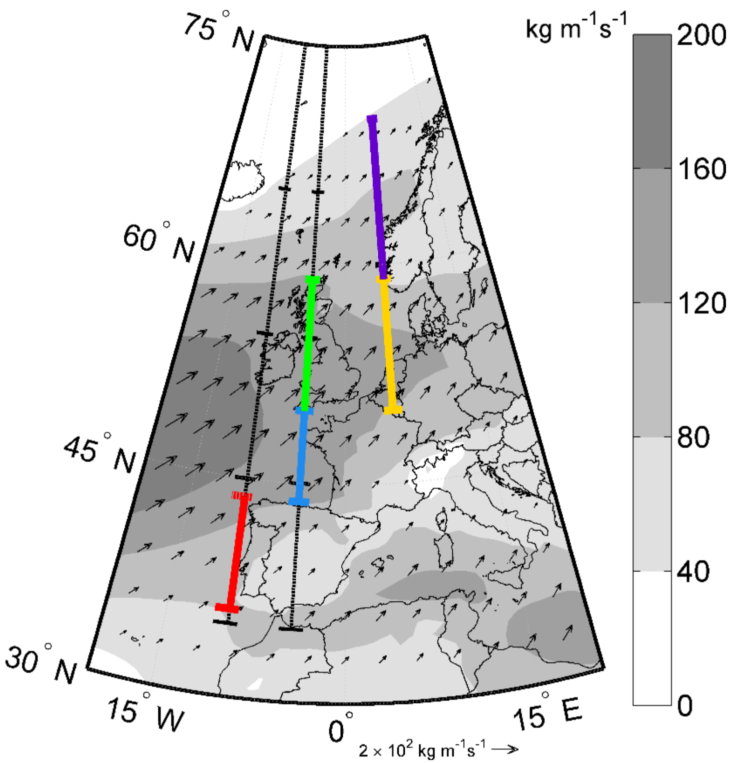
Model levels between 1000 hPa to 300 hPa

Same methodology as before (IVT) and same domains

Ramos et al., 2016, Geo Res Lett (under review)

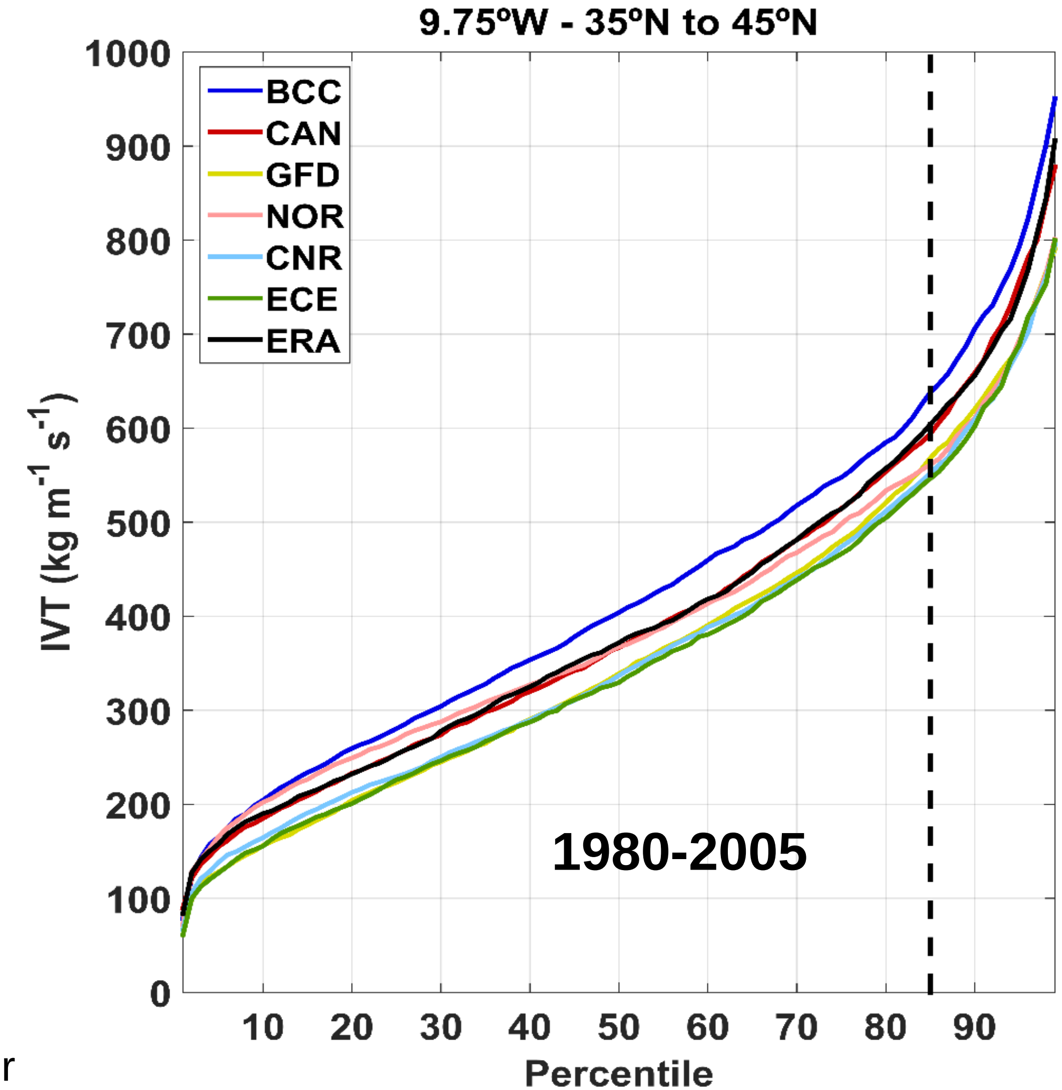
3) Atmospheric Rivers – Future Scenarios

Iberian Peninsula – IVT distribution



Extended winter months

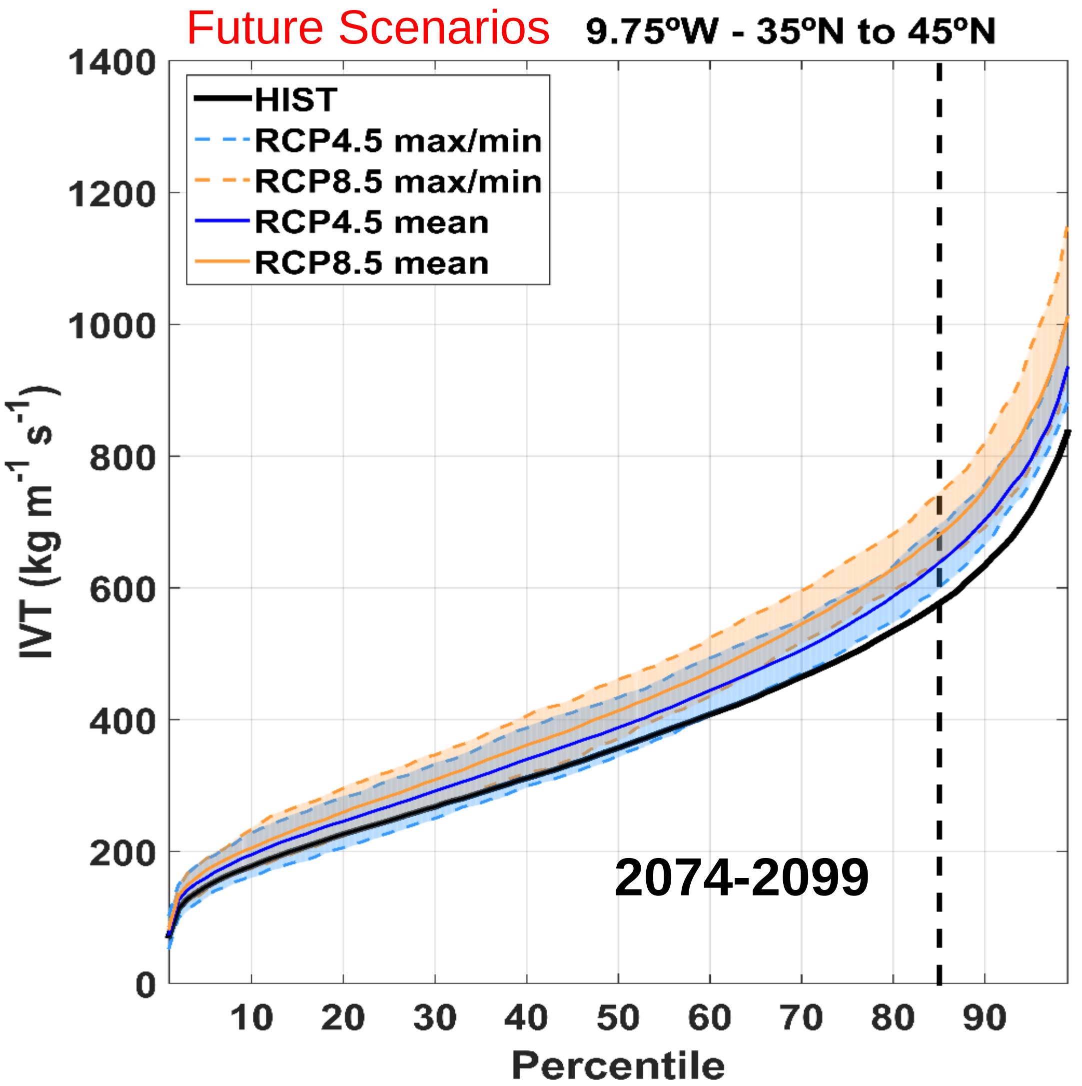
Comparison for present climate



Ramos et al., 2016, Geo Res Lett (under

3) Atmospheric Rivers – Future Scenarios

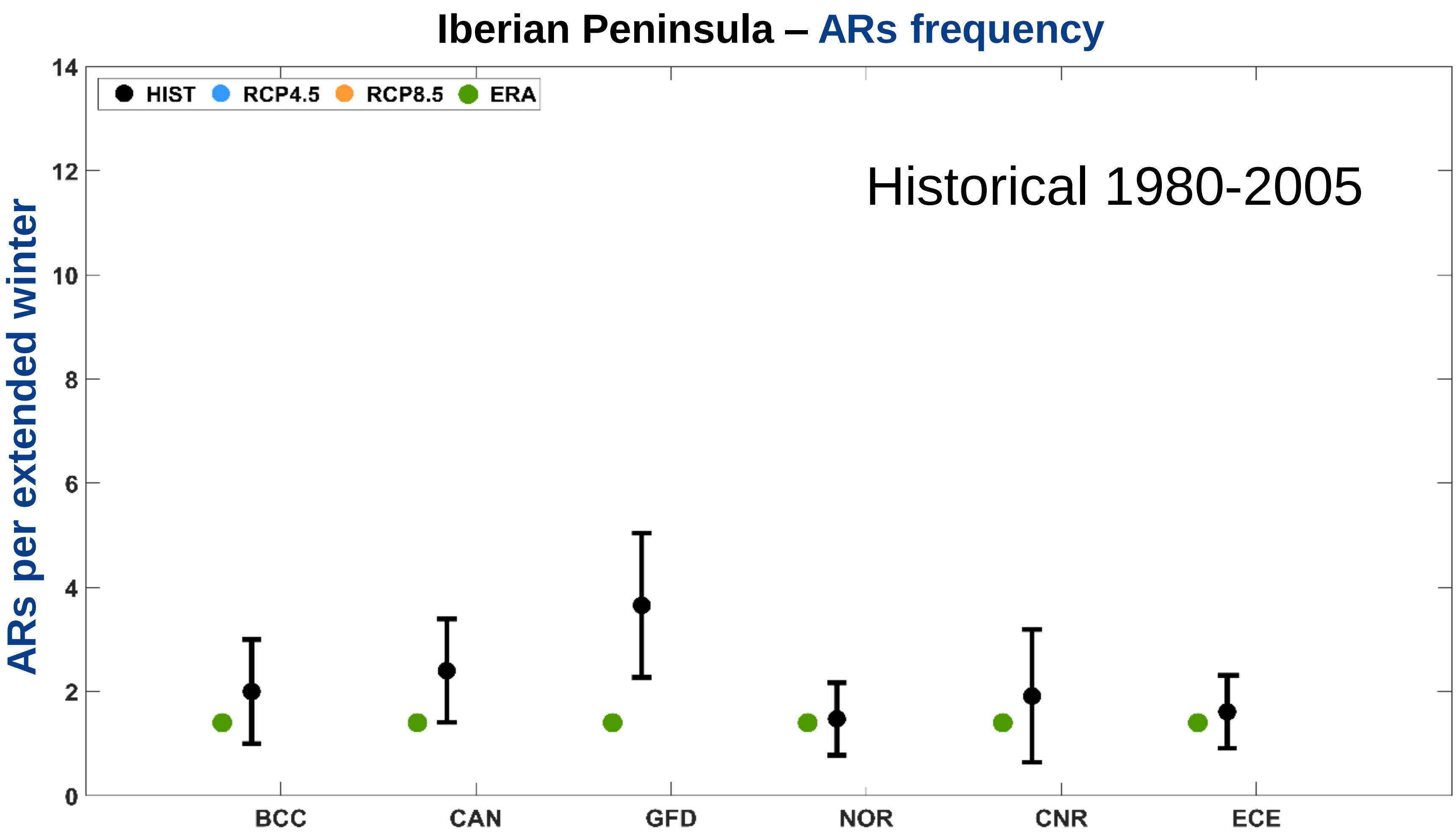
Iberian Peninsula – IVT distribution



Extended winter months

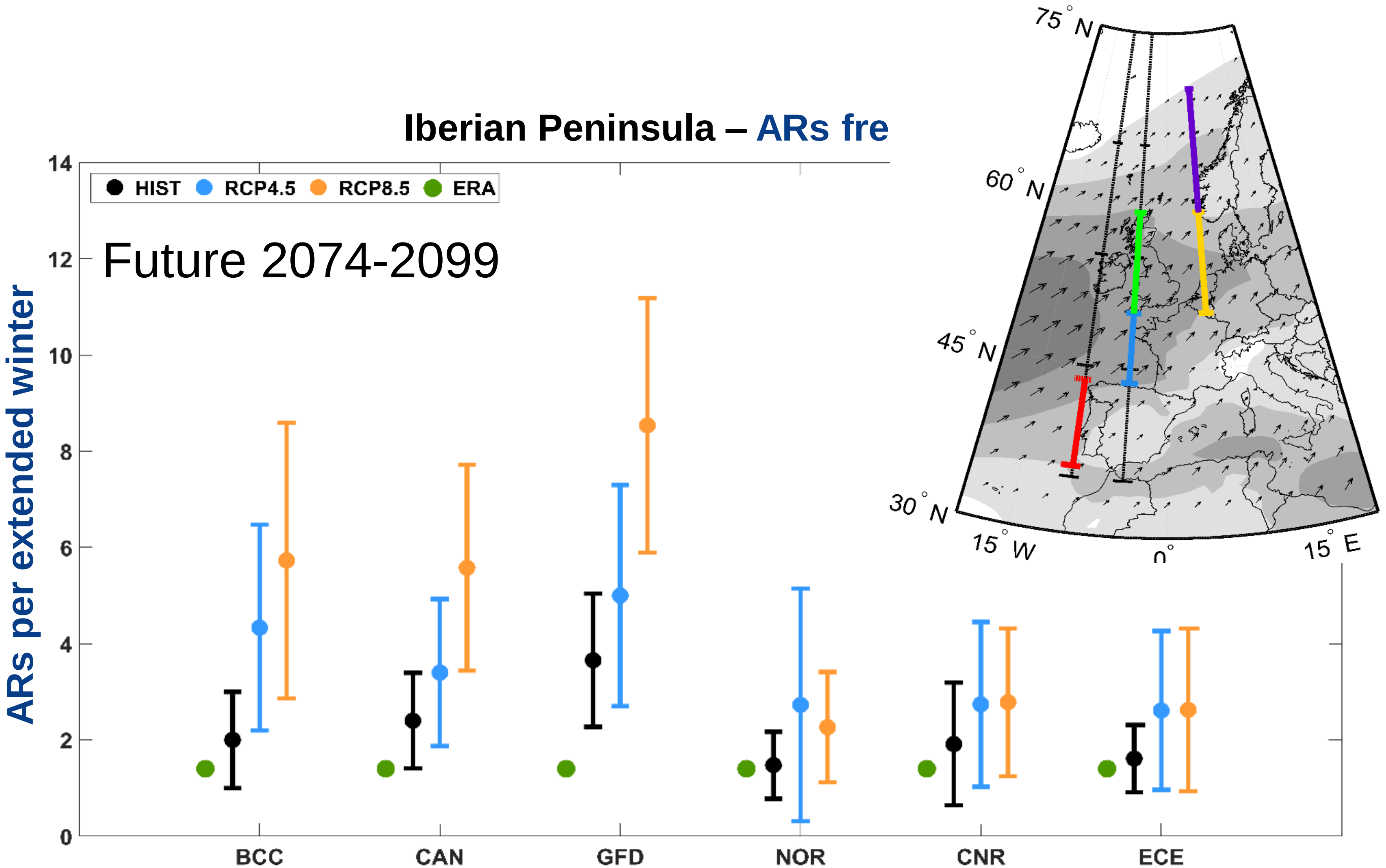
Ramos et al., 2016, Geo Res Lett (under review)

3) Atmospheric Rivers – Future Scenarios



Ramos et al., 2016, Geo Res Lett (under review)

3) Atmospheric Rivers – Future Scenarios



Ramos et al., 2016, Geo Res Lett (under review)

Conclusions

- ARs have different areas of influence in Europe **with major socio-economic impacts** in all the western facade;

- **Anomalous moisture uptake** extend along the **subtropical North Atlantic**, from the Florida Peninsula (northward of 20ºN) to each sink region.

- Anomalous advection of moisture linked to ARs **from subtropical ocean areas but also the existence of a tropical source**, together with midlatitude anomaly sources at some locations closer to AR landfalls.

- The **frequency and intensity** of ARs increases along the European Coast in both RCP scenarios, particularly for RCP8.5; The increase in the number of ARs is robust and is **projected to double on average** in the northern domains compared to the historical period

Ramos et al., 2014 , Atmos Science Letters
Ramos et al., 2015, J. Hydrometeorology
Gimeno et al., 2016, Annu. Rev. Environ. Resou
Ramos et al., 2016, Earth System Dynamics
Pereira et al., 2016, Nat. Hazards Earth Syst. Sci
Ramos et al., 2016, Geo Res Lett (under review)

amramos@fc.ul.pt

Thank you for your attention!

Acknowledgments

- **Alexandre M. Ramos** was supported through a postdoctoral grant (SFRH/BPD/84328/2012) from the FCT.
- The LUSO- AMERICAN Development foundation supported **A.M.Ramo**s through a travel Grant for attending to the *2016 International Atmospheric Rivers Conference*
- Additional financial support for attending 2016 International Atmospheric Rivers Conference was possible through FCT project UID/GEO/50019/2013 - Instituto Dom Luiz

FCT
Fundação para a Ciência e a Tecnologia
MINISTÉRIO DA EDUCAÇÃO E CIÊNCIA

INSTITUTO DOM LUIZ

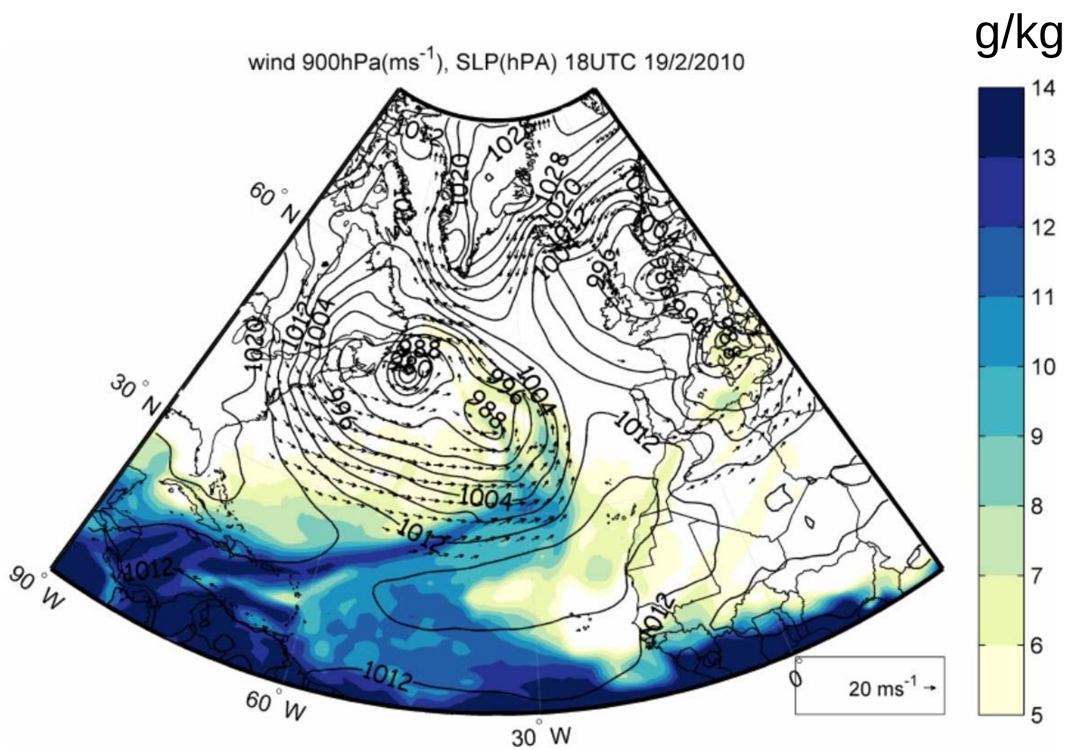
LUSO-AMERICAN DEVELOPMENT foundation

Supplementary Slides

1) Atmospheric Rivers – Madeira 2010

Flash Flood Event in Madeira 20 February 2010

45 fatalities, 6 missed people



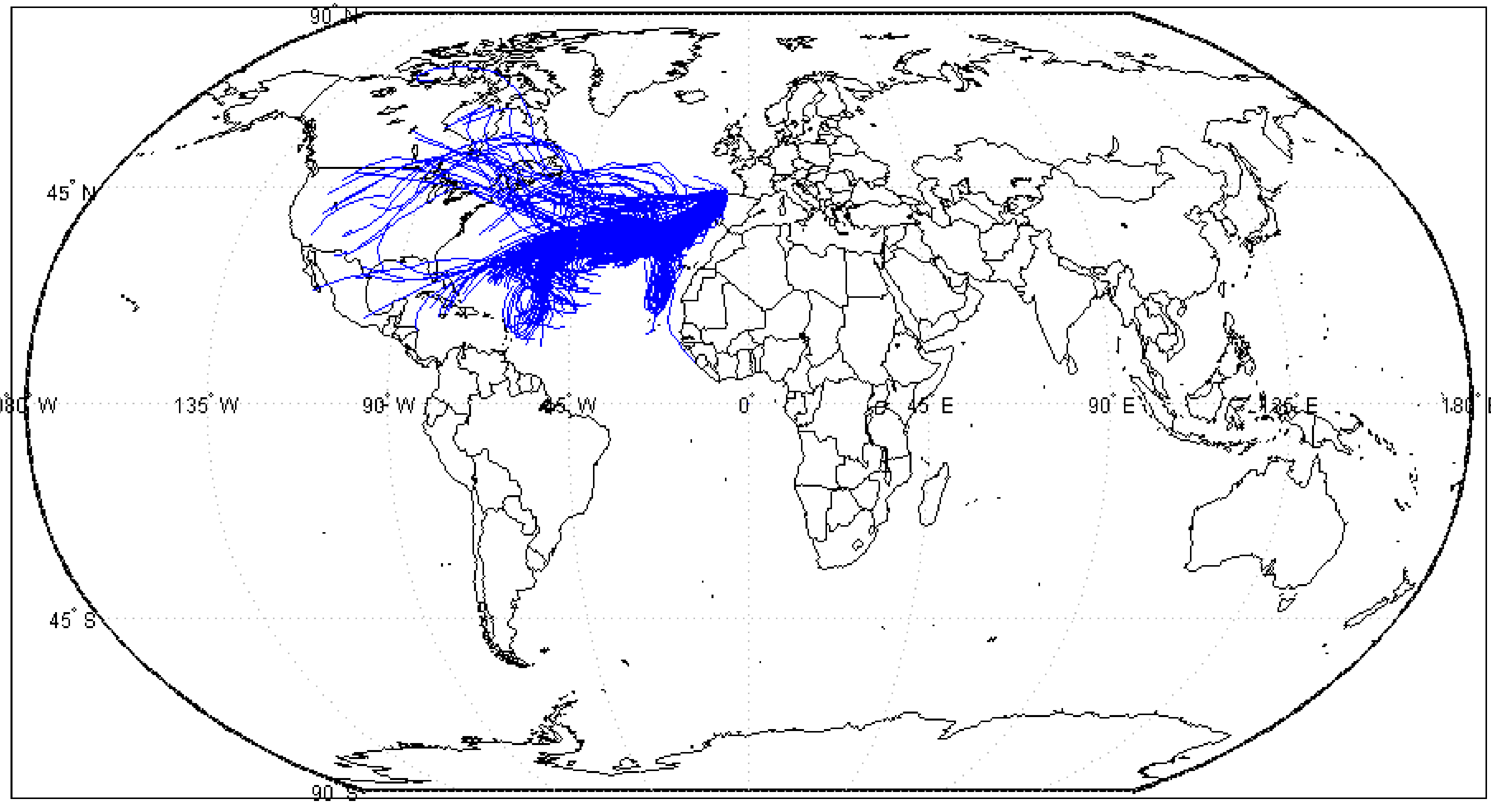
ERA-Interim – 0,75º resolution

Specific humidity 900hPa (g/kg) , wind 900hPa (m/s) and SLP (hPa)

2) Atmospheric Rivers – Moisture Sources

Lagrangian Model – FLEXPART

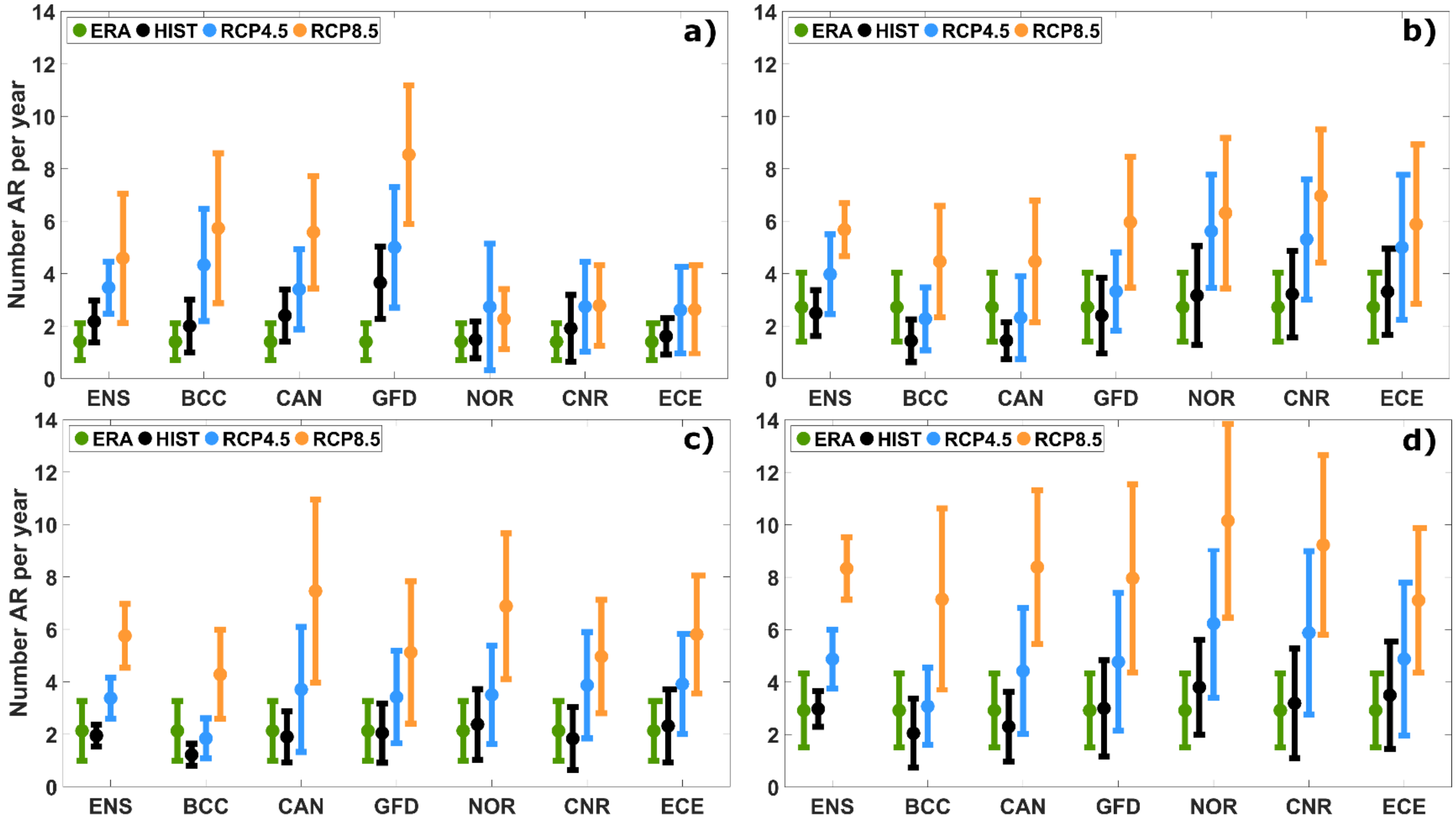
ERA-Interim 1979-2012

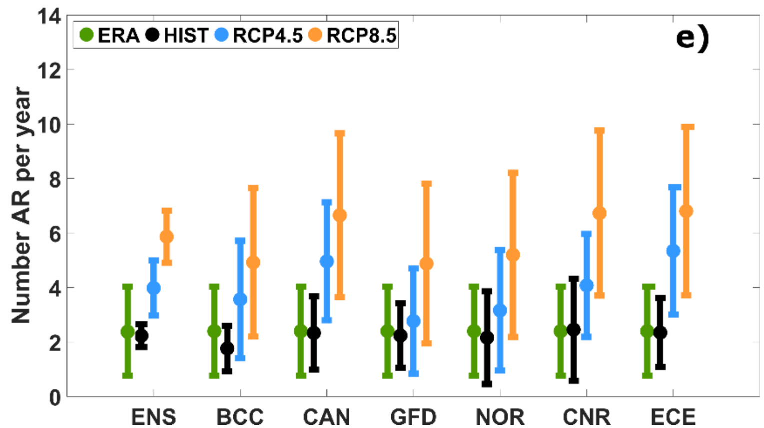


For the particles arriving to each domain a 10-days backtrajectory was analyzed t
account changes in **specific humidity**

Ramos et al., 2016

3) Atmospheric Rivers – Future Scenarios





a) Iberian Peninsula
b) France
c) UK
d) S.Scandinavia & Netherlands
e) North Scandinavia