Using a long-term climate simulation to address future changes in Western Europe precipitation regimes due to global warming

Pedro M Sousa[(1)], Alexandre M Ramos[(1)], Ricardo M Trigo[(1)], Christoph C Raible[(2,3)], M Messmer[(2,3)], Joaquim G Pinto[(4)], Ricardo Tomé[(1)]

(1) Instituto Dom Luiz (IDL), Faculdade de Ciências, Universidade de Lisboa, 1749-016 Lisboa, Portugal (ppsousa@fc.ul.pt) ; (2) Oeschger Centre for Climate Change Research, University of Bern, Bern, Switzerland; (3) Climate and Environmental Physics, University of Bern, Bern, Switzerland; (4) Institute of Meteorology and Climate Research, Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany

The financial support for this work was possible through the following FCT project: HOLMODRIVE - North Atlantic Atmospheric Patterns influence on Western Iberia Climate: From the Lateglacial to the Present [PTDC/CTA-GEO/29029/2017]

SUMMARY

► We analyzed the long-term links between the Integrated Vapor Transport (IVT) and precipitation regime changes in Western Europe

► A clear link with near-surface temperatures is found, being this particularly notable for the Post-Industrial period, and expected to exacerbate further due to Global Warming, to unprecedented levels.

► However, rainfall regime responses are dissimilar for regional domains. While in the UK rainfall increases along with IVT, for Iberia it decreases considerably. Moreover *the relatively steady link at decadal and multi-decadal scales between IVT and precipitation, for UK and Iberia, appears to be lost in Iberia along the 21st century*.

► Taking all the above into account, the combination of the following mechanisms should explain these projections:

1) **Increase in UK precipitation** due to the increase of westerly Circulation Weather Types (CWTs) in Northern Europe combined with enhanced moisture availability in a warmer atmosphere;

2) **Decrease in Iberian precipitation** due to an increase in the frequency of stable CWTs, combined with higher water retaining capacity of a warmer atmosphere, despite enhanced moisture availability.

► We also show how the expansion of the subtropical high pressure belt leads to a poleward shift of moisture corridors and of Atmospheric Rivers in the North Atlantic.

METHODS

► A long-term (850-2100) simulation was performed with the Community Earth System Model (CESM 1.0.1), using a modified reconstruction of total solar irradiance, volcanic forcing and the RCP8.5 forcing scenario (Fig.1);

► IVT fields were computed and compared against precipitation and surface temperature series for the entire domain (Fig.2) and for regional boxes in the UK and Iberia (Figs. 3 and 4) for extended winter (October-March);

► Changes in Circulation Weather Types (CWTs, Fig.5) and large-scale dynamical VS thermodynamical changes in circulation where analyzed (Fig.6);

► These circulation features were compared with frequency and preferred location of Atmospheric Rivers (ARs) and associated moisture corridors, explaining projected regional rainfall changes (Fig.7);

Paper published in Journal of Climate

(Sousa et al., 2020)

DOI: 10.1175/JCLI-D-19-0348.1

1 JANUARY 2020 SOUSA ET AL. 263

North Atlantic Integrated Water Vapor Transport—From 850 to 2100 CE: Impacts on Western European Rainfall

PEDRO M. SOUSA AND ALEXANDRE M. RAMOS

Instituto Dom Luiz, Faculdade de Ciências, Universidade de Lisboa, Lisbon, Portugal

CHRISTOPH C. RAIBLE AND M. MESSMER[a]

Oeschger Centre for Climate Change Research, and Climate and Environmental Physics, University of Bern, Bern, Switzerland

RICARDO TOMÉ

Instituto Dom Luiz, Faculdade de Ciências, Universidade de Lisboa, Lisbon, Portugal

JOAQUIM G. PINTO

Institute of Meteorology and Climate Research, Karlsruhe Institute of Technology, Karlsruhe, Germany

RICARDO M. TRIGO

Instituto Dom Luiz, Faculdade de Ciências, Universidade de Lisboa, Portugal, and Departmento de Meteorologia, Instituto de Geociências, Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brazil

(Manuscript received 17 May 2019, in final form 21 August 2019)

ABSTRACT

Moisture transport over the northeastern Atlantic Ocean is an important process governing precipitation distribution and variability over western Europe. To assess its long-term variability, the vertically integrated horizontal water vapor transport (IVT) from a long-term climate simulation spanning the period 850–2100 CE was used. Results show a steady increase in moisture transport toward western Europe since the late-nineteenth century that is projected to expand during the twenty-first century under the RCP8.5 scenario. The projected IVT for 2070–99 significantly exceeds the range given by interannual–interdecadal variability of the last millennium. Changes in IVT are in line with significant increases in tropospheric moisture content, driven by the concurrent rise in surface temperatures associated with the anthropogenic climate trend. On regional scales, recent and projected precipitation changes over the British Isles follow the global positive IVT trend, whereas a robust precipitation decrease over Iberia is identified in the twenty-first century, particularly during autumn. This indicates a possible extension of stable and dry summer conditions and a decoupling between moisture availability and dynamical forcing. The investigation of circulation features reveals a mean poleward shift of moisture corridors and associated atmospheric rivers. In particular, in Iberia, a significant increase in the frequency of dry weather types is observed, accompanied by a decrease in the frequency of wet types. An opposite response is observed over the British Isles. These changes imply a stronger meridional north–south dipole in terms of pressure and precipitation distributions, enhancing the transport toward central Europe rather than to Iberia.

1. Introduction

Precipitation variability in western Europe is linked with the intensity and latitudinal location of water vapor transport. In this context, atmospheric rivers (ARs; Zhu and Newell 1998; Neiman et al. 2008; Dettinger et al. 2015), that is, a narrow band or corridor of high vertically integrated horizontal water vapor transport (IVT), gain particular relevance. These structures are responsible

Supplemental information related to this paper is available at the Journals Online website: https://doi.org/10.1175/JCLI-D-19-0348.s1.

[a] Current affiliation: School of Earth Sciences, University of Melbourne, Melbourne, Victoria, Australia.

Corresponding author: Pedro M. Sousa, ppsousa@fc.ul.pt

DOI: 10.1175/JCLI-D-19-0348.1

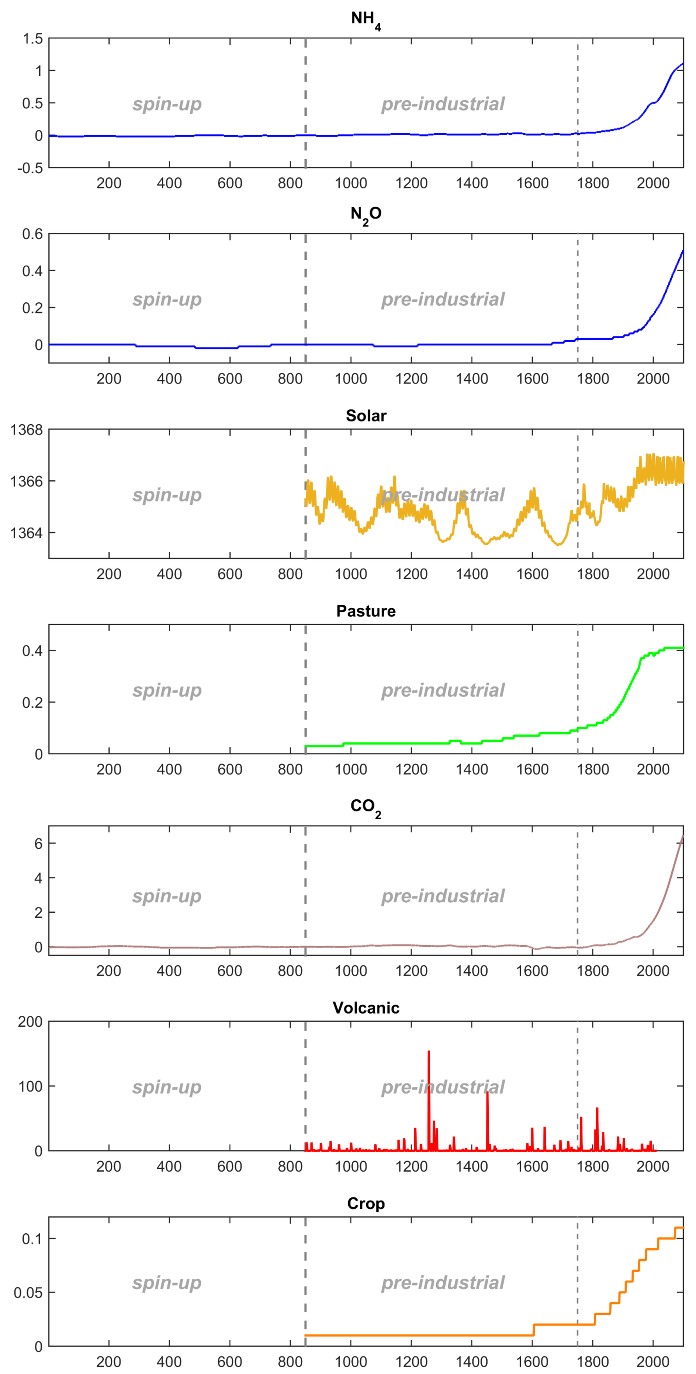
© 2019 American Meteorological Society. For information regarding reuse of this content and general copyright information, consult the AMS Copyright Policy (www.ametsoc.org/PUBSReuseLicenses).

Using a long-term climate simulation to address future changes in Western Europe precipitation regimes due to global warming

Pedro M Sousa[(1)], Alexandre M Ramos[(1)], Ricardo M Trigo[(1)], Christoph C Raible[(2,3)], M Messmer[(2,3)], Joaquim G Pinto[(4)], Ricardo Tomé[(1)]

(1) Instituto Dom Luiz (IDL), Faculdade de Ciências, Universidade de Lisboa, 1749-016 Lisboa, Portugal (ppsousa@fc.ul.pt) ; (2) Oeschger Centre for Climate Change Research, University of Bern, Bern, Switzerland; (3) Climate and Environmental Physics, University of Bern, Bern, Switzerland; (4) Institute of Meteorology and Climate Research, Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany

The financial support for this work was possible through the following FCT project: HOLMODRIVE - North Atlantic Atmospheric Patterns influence on Western Iberia Climate: From the Lateglacial to the Present [PTDC/CTA-GEO/29029/2017]



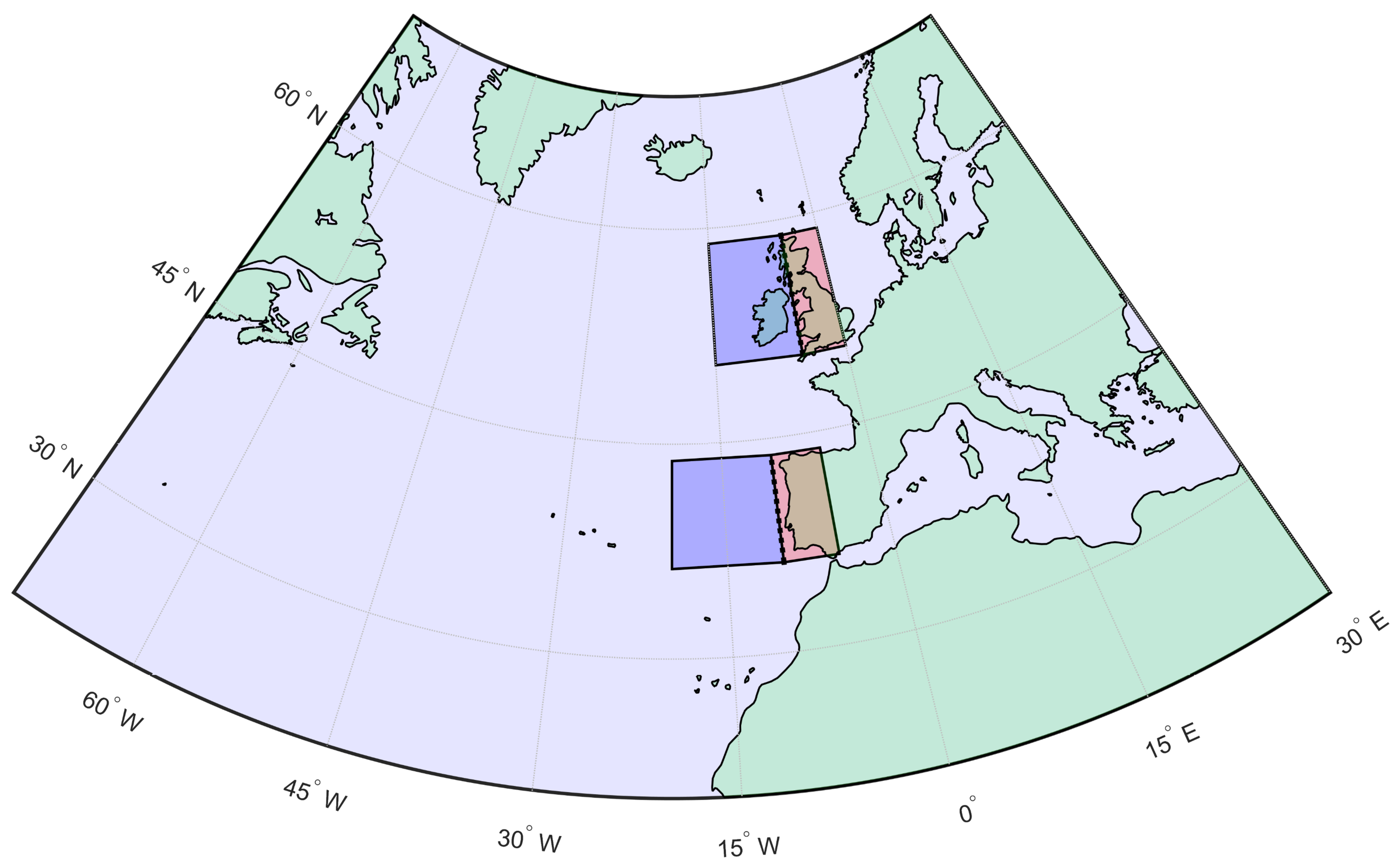
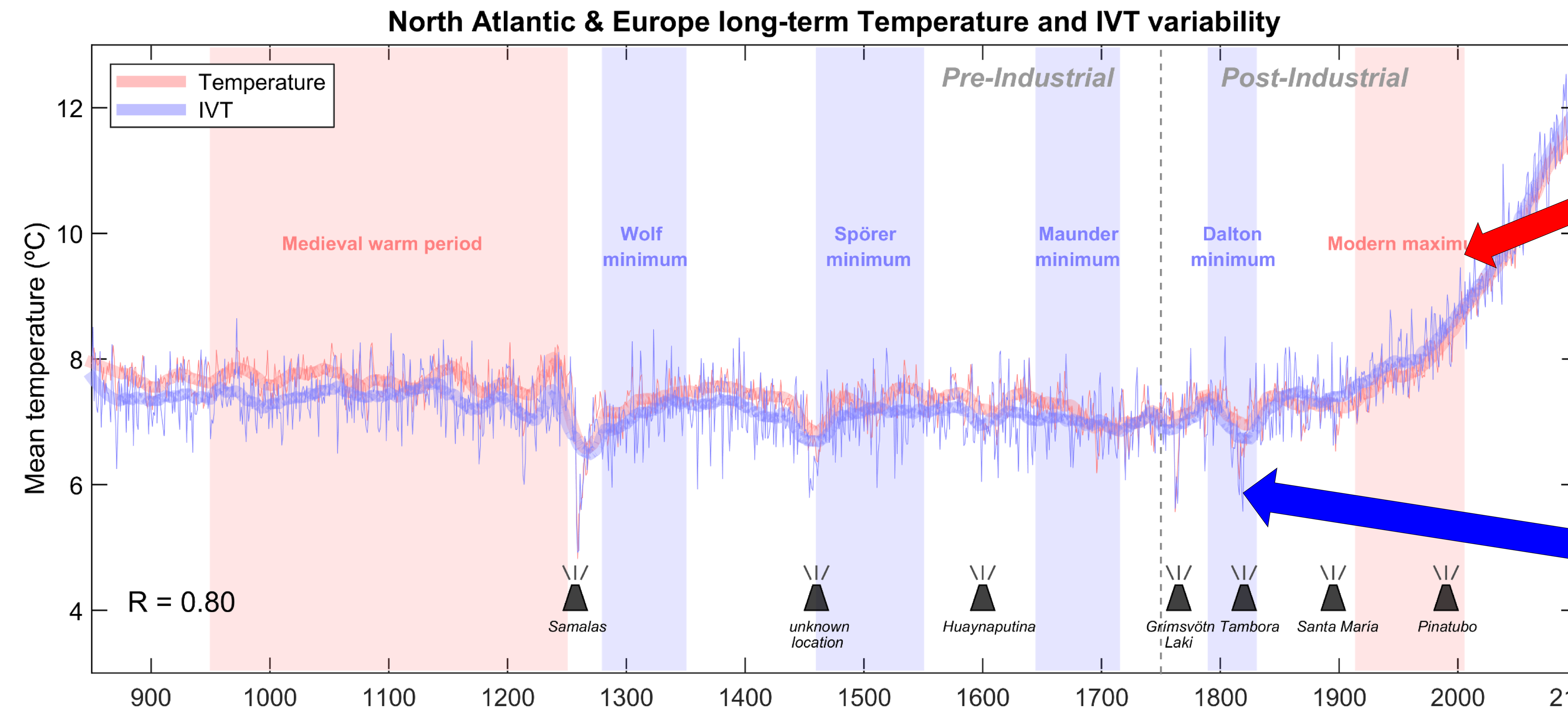


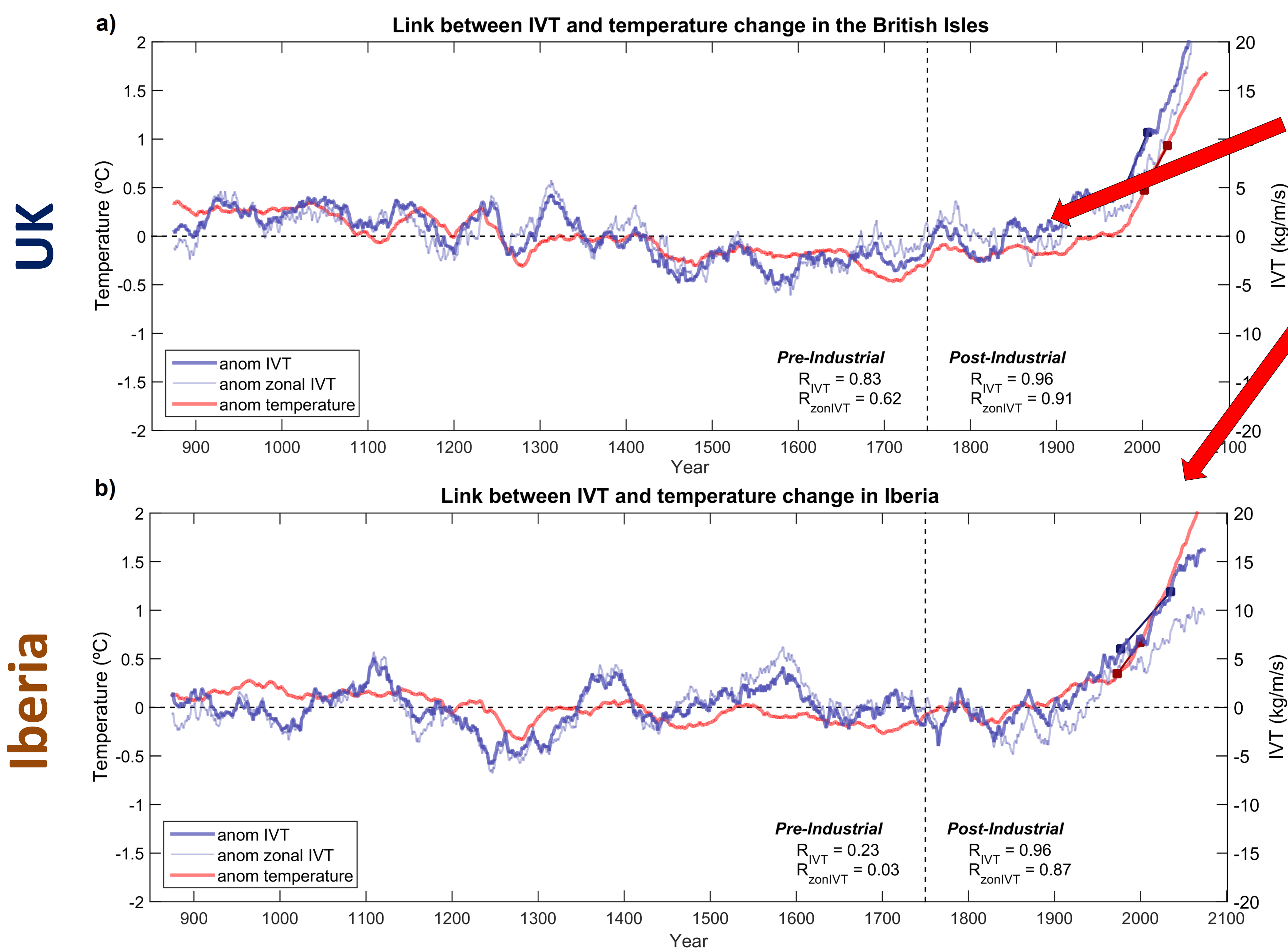
Fig.1 – **Left**: Prescribed forcing mechanisms for the transient simulation using CESM during the 850-2100 CE period. Note the spin-up forcing period for the greenhouse gases prior to 850.; **Right**: Regional boxes (UK and Iberia) considered in this work. Mean surface temperature and IVT fields were computed for the blue boxes and precipitation for the red boxes.



Significant increase since the Industrial era, and projected to exacerbate during the 21st century

Largest Pre-Industrial changes related to major volcanic eruptions

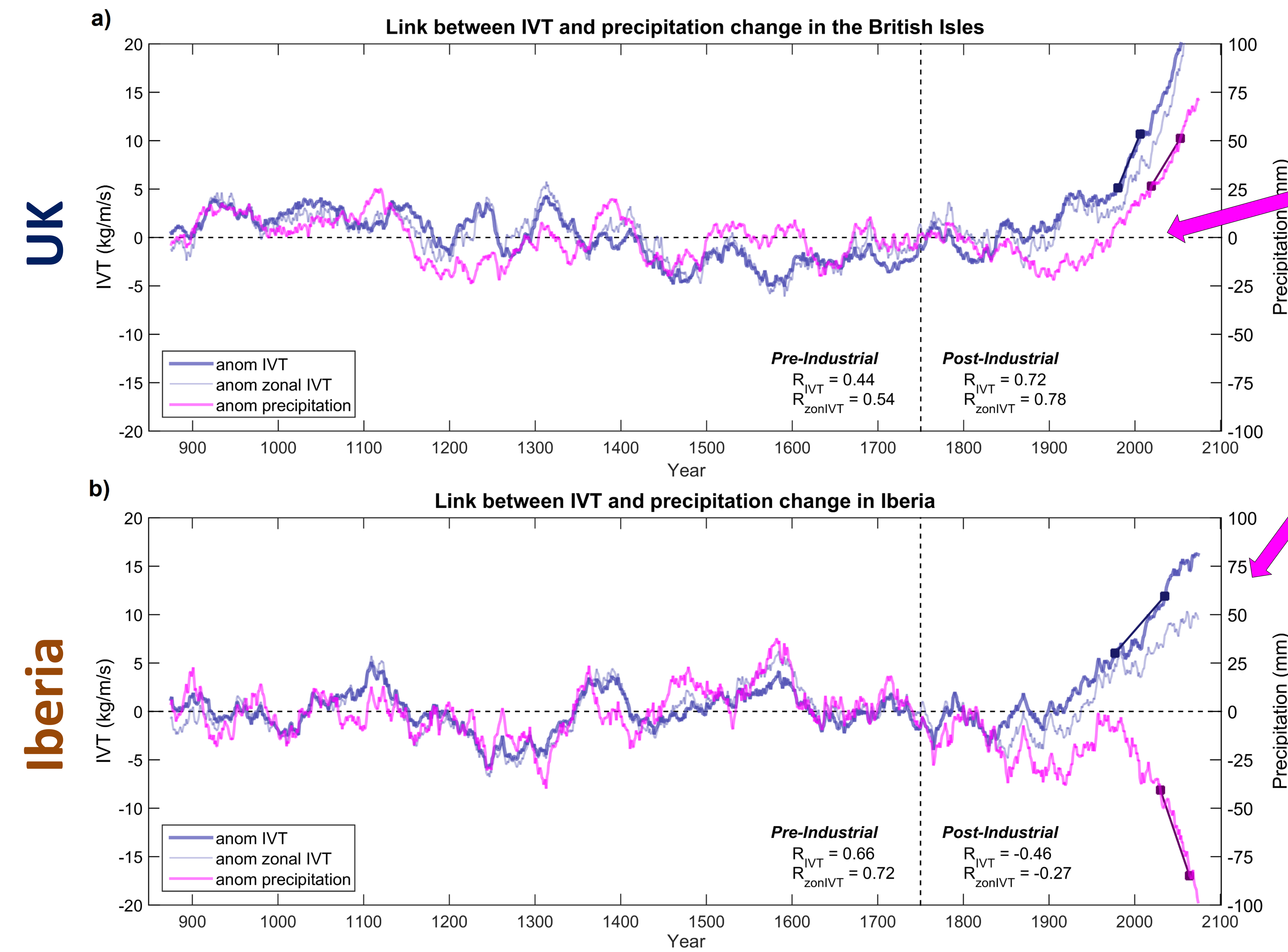
Fig.2 – Long-term variability of mean extended winter (October-March) temperature (red) and IVT (blue) for the domain presented in Fig.1 - thicker lines are the 30-year smoothed series. Major eruptions are represented in the bottom section of the figure, and light red/blue shadings denote warm/cold eras.



Concurrent increases between IVT and near-surface temperature also observed regionally

Signals are emerging or have already emerged (when compared to Pre-Industrial) in terms of IVT and temperature

Fig.3 – Long-term variability of the IVT and temperature anomalies in the UK and Iberia. Straight thick lines represent the estimated period of emergence of the signals, by considering the exceedance of the maximum pre-industrial variability (and two-fold).



Opposite responses in rainfall, with increase in the UK and decrease in Iberia

Signals are still starting to emerge, in terms of rainfall

Fig.4 – Same as Fig.3, but for IVT and precipitation series.

Using a long-term climate simulation to address future changes in Western Europe precipitation regimes due to global warming

Pedro M Sousa[(1)], Alexandre M Ramos[(1)], Ricardo M Trigo[(1)], Christoph C Raible[(2,3)], M Messmer[(2,3)], Joaquim G Pinto[(4)], Ricardo Tomé[(1)]

(1) Instituto Dom Luiz (IDL), Faculdade de Ciências, Universidade de Lisboa, 1749-016 Lisboa, Portugal (ppsousa@fc.ul.pt) ; (2) Oeschger Centre for Climate Change Research, University of Bern, Bern, Switzerland; (3) Climate and Environmental Physics, University of Bern, Bern, Switzerland; (4) Institute of Meteorology and Climate Research, Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany

The financial support for this work was possible through the following FCT project: HOLMODRIVE - North Atlantic Atmospheric Patterns influence on Western Iberia Climate: From the Lateglacial to the Present [PTDC/CTA-GEO/29029/2017]

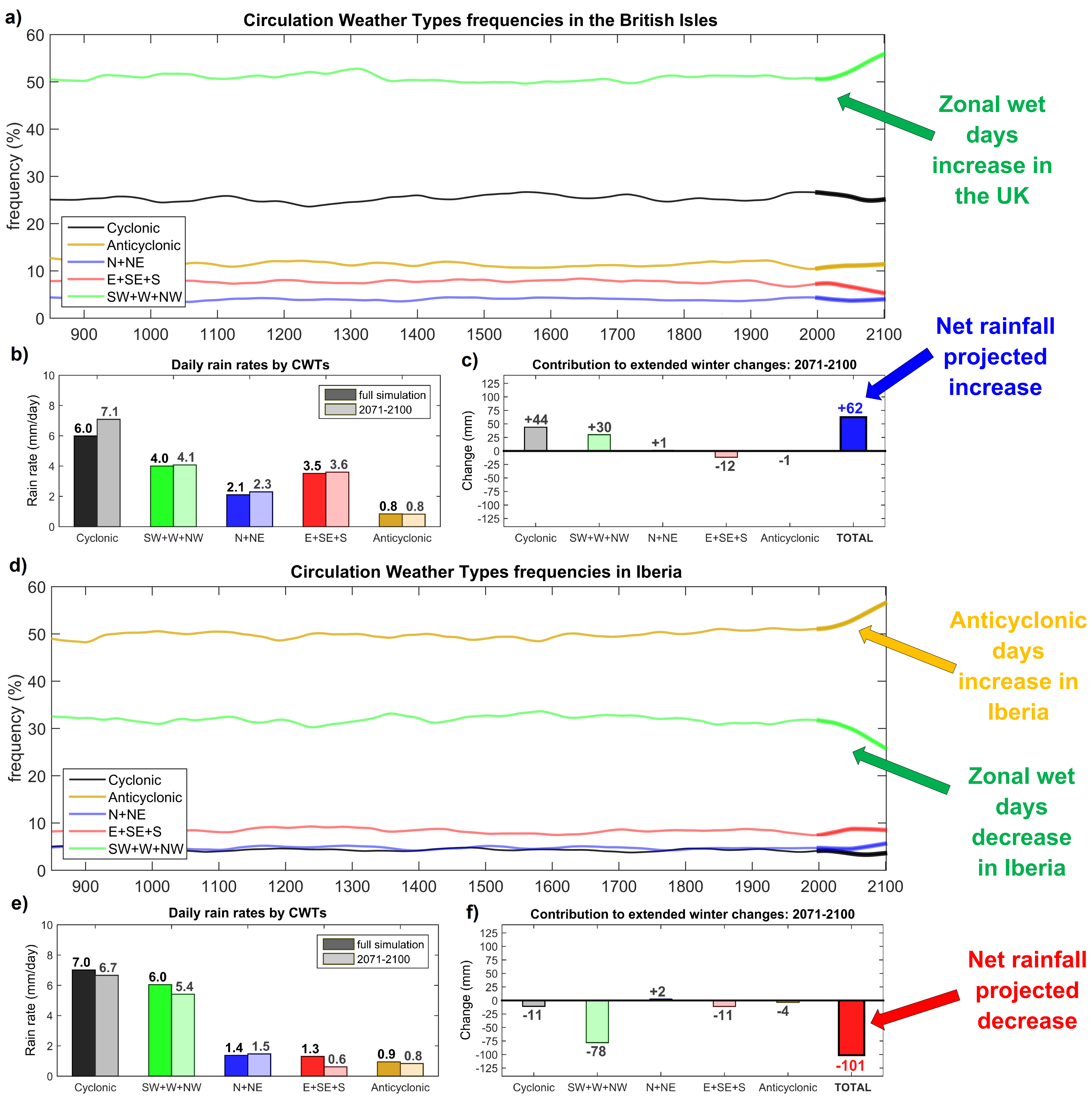


Fig.5 a) Changes in the frequency of Circulation Weather Types (CWTs) for the British Isles during extended winter months (October-March) throughout the long-simulation period. Directional weather types are grouped according to typical coherent surface responses. The thicker curves highlight changes occurring during the 21st century. A 30-year running mean has been applied to the series. b) Daily precipitation (mm per day) associated to each group of CWTs: darker bars refer to the 1981-2010 climatology, and lighter bars to the 2070-2099 projected climatology. c) Changes (2070-2099 minus 1981-2010) in total extended winter precipitation associated to each group of CWTs, and the overall net change (TOTAL). d), e) and f): Same as a), b) and c), but for Iberia.

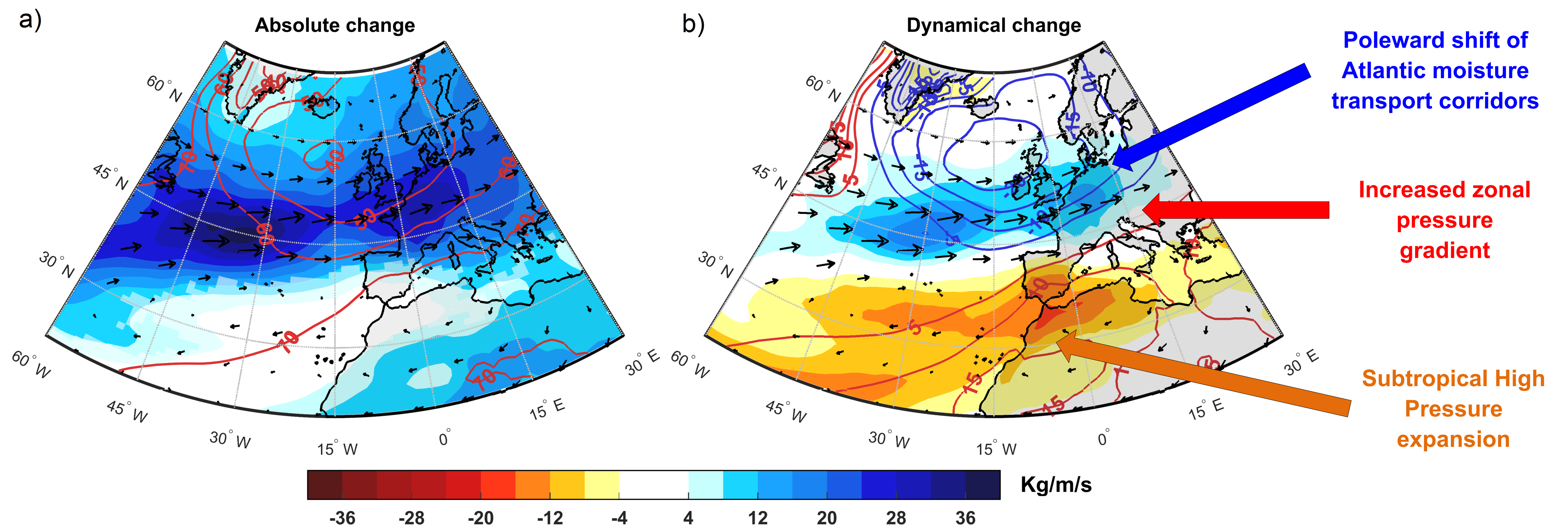


Fig.6 – Projected changes in IVT (shading, in kg/m/s) and 1000-500 hPa geopotential **height** thickness (red/blue contours, dam) during extended winter (2070-2099 minus 1981-2010). Arrows represent the change in the IVT direction and magnitude. a) Projected absolute changes, with transparent shading denoting areas where changes are not significant. b) Changes attributable to dynamical modifications, i.e., after removing the moisture increase associated to the warming signal.

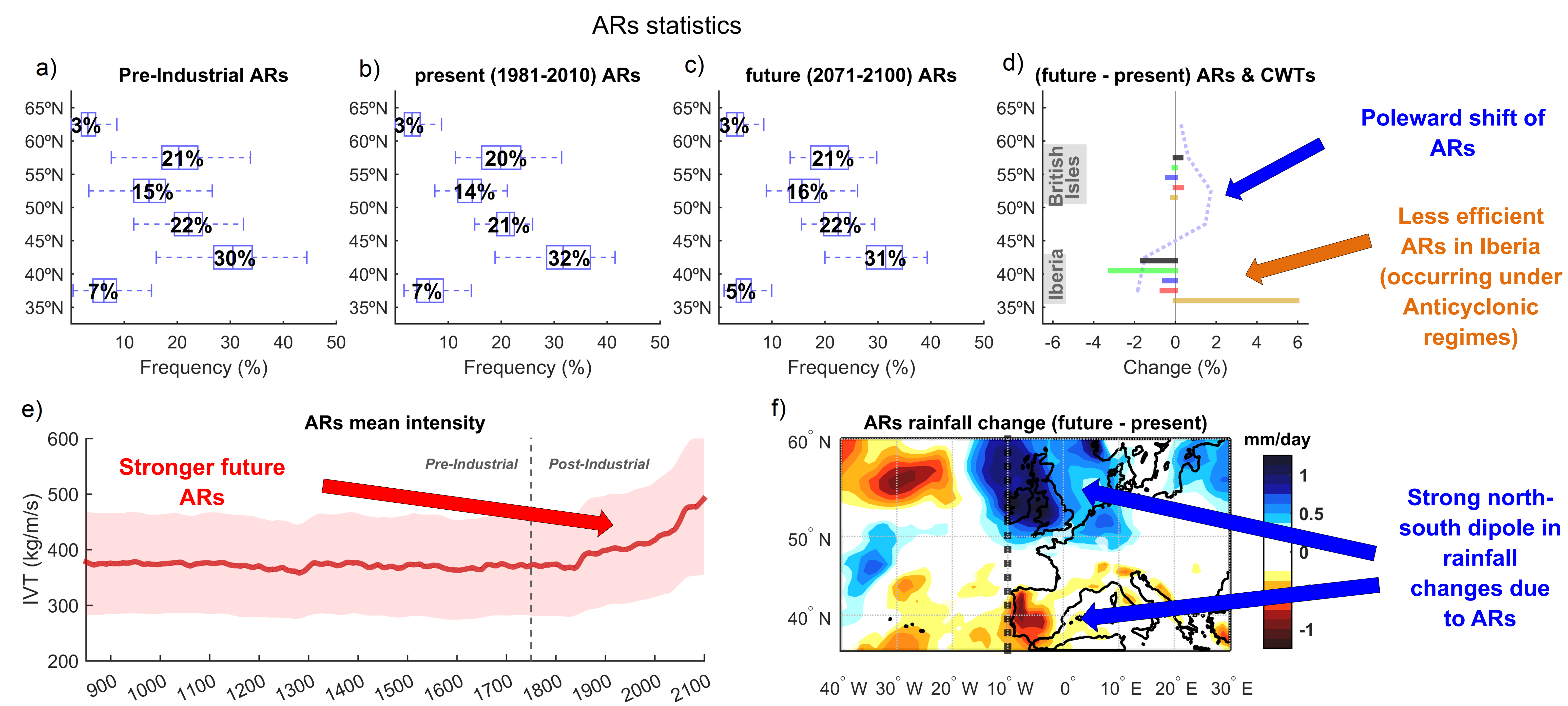


Fig.7 – Statistics for ARs in the North Atlantic crossing the 10°W meridian during extended winter. a), b) and c) Boxplots for the frequency of occurrence of ARs in 5º latitudinal windows, for the pre-industrial, present and future climates, respectively. d) Dashed line shows the difference between c) and b), and bars represent future changes in CWTs during ARs for each regional box - shaded areas highlight the latitudes where the British Isles and Iberia are located. e) Mean intensity of ARs crossing the 10°W meridian throughout the entire simulation. The envelope corresponds to 1std. f) Spatial changes in mean daily precipitation during days with ARs.