Teleconnections and Extreme Ocean States in the Northeast Atlantic Ocean

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1. Introduction

- **A** strong link between low-frequency modes of atmospheric variability and mean significant wave height (Hs), wave period and peak direction during winter and spring in Irish coastal waters was identified by **[1]**.
- **The** influence of the North Atlantic Oscillation (NAO) on extreme sea states was investigated by **[2]**, and how this may change in the future, using an ensemble of WAVEWATCH III **[3]** simulations driven by the EC-Earth global climate model.
- **[2]** showed that the 95th percentile of Hs is strongly positively correlated to the NAO. Projections of Hs extremes are location dependent and under the influence of positive NAO the return levels of Hs may increase, despite the overall decreasing trend in the projections.
- Here we extend the study of **[2]** to include the 3 dominant modes of variability in the North Atlantic region – the NAO, the East Atlantic (EA) and Scandinavian (SCA) Patterns.

2. Experiment Set-up / Validation

- Used EC-EARTH global CMIP5 climate projections run by Met Éireann (3 × historical, 3 × RCP4.5, 3 × RCP8.5) **[4]**.
- Outputs of these simulations used to drive 9 30-year blocks of WAVEWATCH III simulations over the 3-way nested domain shown in **Fig. 1**.
- The years 1980-2009 were chosen for the historical wave simulations and 2070-2099 for the future projections.

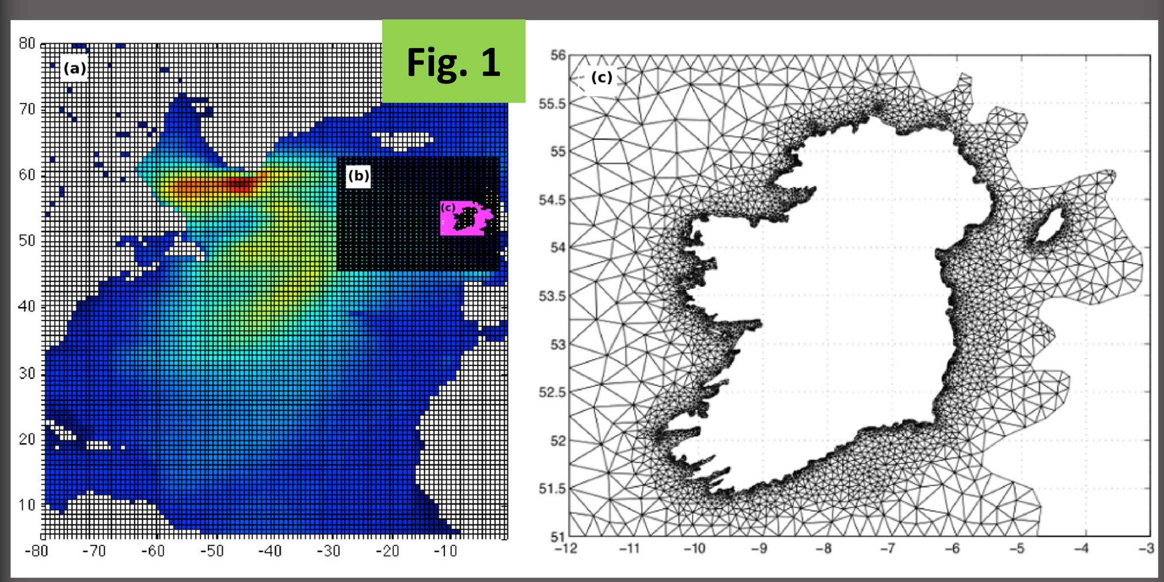

Fig. 1

- We validated the EC-Earth 10 m wind speeds (percentiles) using the ERA-Interim dataset, and the WAVEWATCH III outputs using buoy observations, scatterometer data and a historical simulation driven by ERA-Interim fields. Biases are mostly within 10%.
- The EC-Earth ensemble of projections suggests decreases of up to 14 % in the 95th percentile of 10 m wind speed over the North Atlantic by the end of the century for winter (DJF) under RCP8.5.
- In accordance, WAVEWATCH III suggests decreases in the 95th percentile of Hs of 5-10% around Ireland by the end of the century (**Fig. 2** DJF).

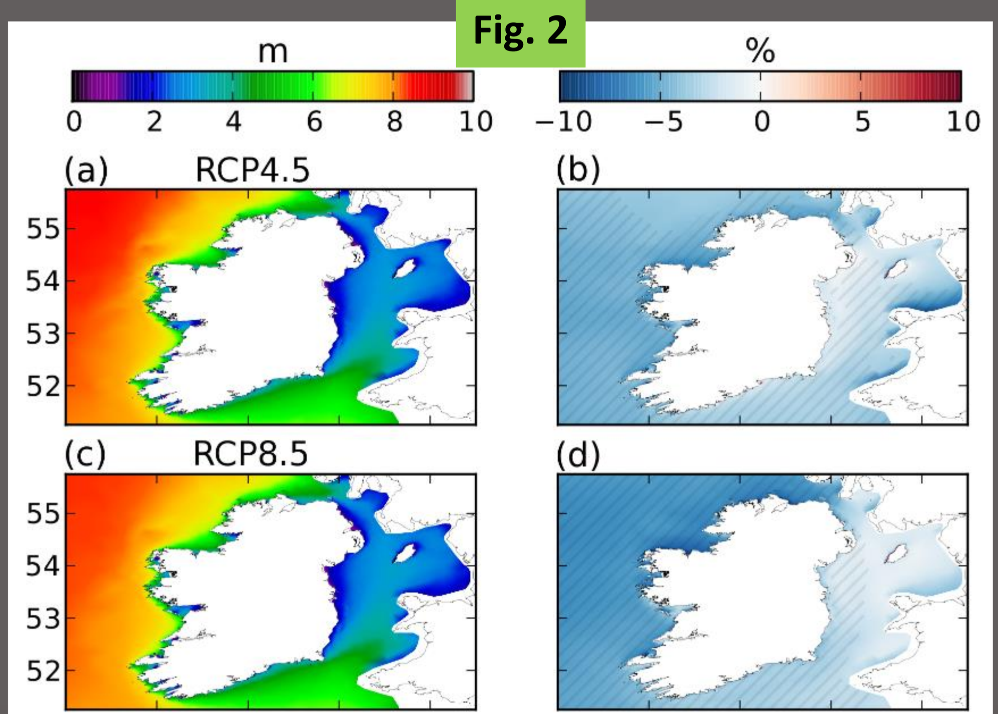

Fig. 2

3. Atmospheric Teleconnections

- The NAO is the leading mode of atmospheric variability in the North Atlantic region and is manifested as a meridional dipole anomaly in MSLP with centres of action over Iceland and the Azores **[5]**.
- A station-based calculation of the NAO index was used in **[2]**. Disadvantages of this method are that it is fixed in space and shows low signal-to-noise ratios.
- Alternative method of deriving the NAO index: calculating the principal component (PC) time series of the leading empirical orthogonal function (EOF) of gridded MSLP **[6].**
- Second mode of atmospheric variability is the East Atlantic (EA) pattern **[7]** which usually has a centre of action in the Atlantic Ocean west of Ireland. This mode is defined as the second leading EOF of gridded MSLP.
- The Scandinavian Pattern (SCA) is the third leading mode of winter MSLP variability.
- In this study the first 3 modes of MSLP variability were calculated for the following North Atlantic area 20-90°N 80°W-40°E using a 3-member ensemble of historical and RCP4.5/8.5 projection EC-Earth data for the months of December to March.
- EOFs 1-3, expressed as a covariance between the PC time series and the MSLP anomalies at each grid point, are shown in **Fig. 3**.
- EOFs 1-3 are usually considered to be the NAO, EA and SCA modes of atmospheric variability. EOFs are shown for ERA-Interim data, RCP4.5 member 3 (me43) and RCP8.5 member 2 (me82).
- In our calculations the NAO accounted for 35-46% of the variability, the EA accounted for 15-20% and the SCA accounted for 10-15%.

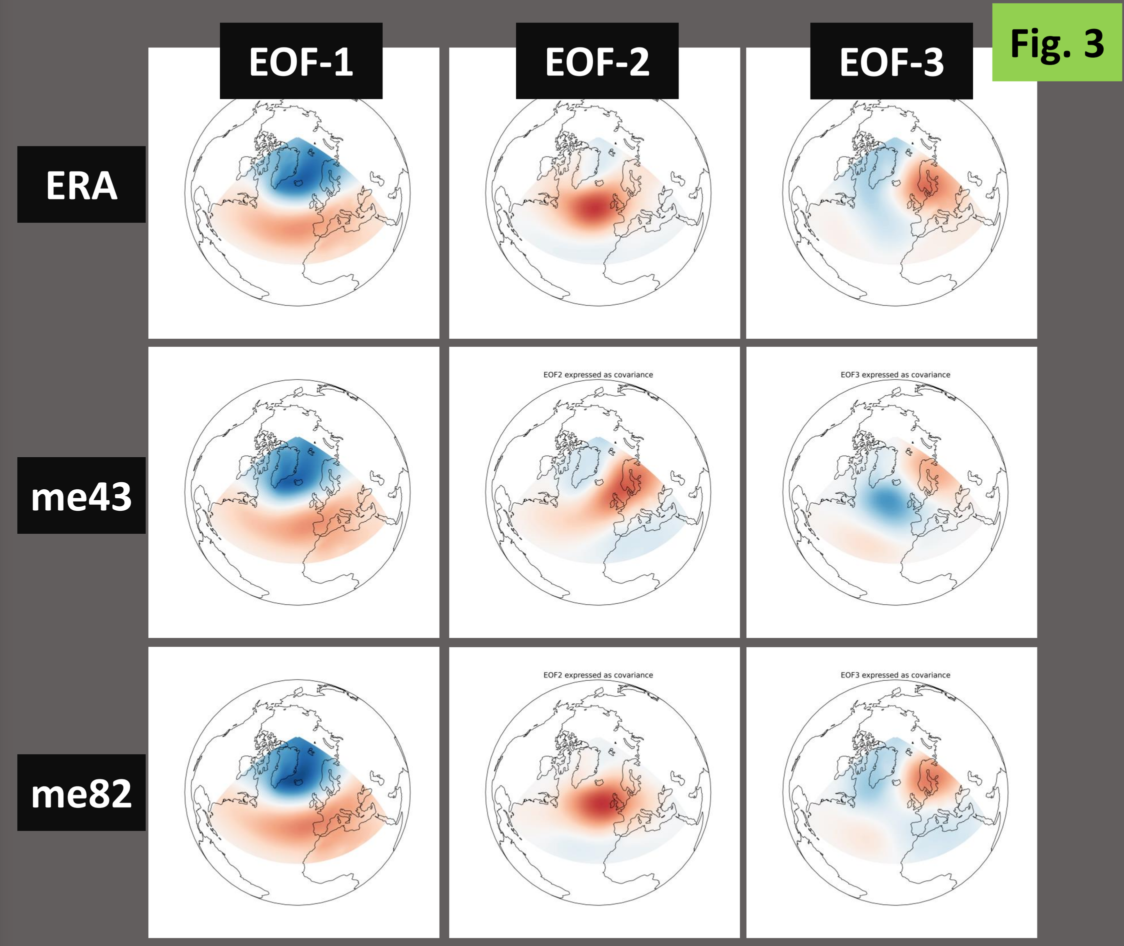

Fig. 3

- In most of the EC-Earth runs the positive centre in EOF-2 (the EA) is shifted eastwards e.g. see me43 above.

4. NAO, EA, SCA vs Hs

- As in **[2]**, **but with minor differences,** the 95th percentile of Hs and the PC of the NAO show a positive correlation, with large areas west of Ireland where it is over +0.7.
- **Fig. 4** and **5** show the Spearman correlation coefficient between the PC of EA and the PC of SCA respectively and the 95th percentile of Hs for DJFM. (a)-(c) historical period 3 x ensemble members; (d)-(f) future period under RCP4.5 and similarly (g)-(i) is for RCP8.5.

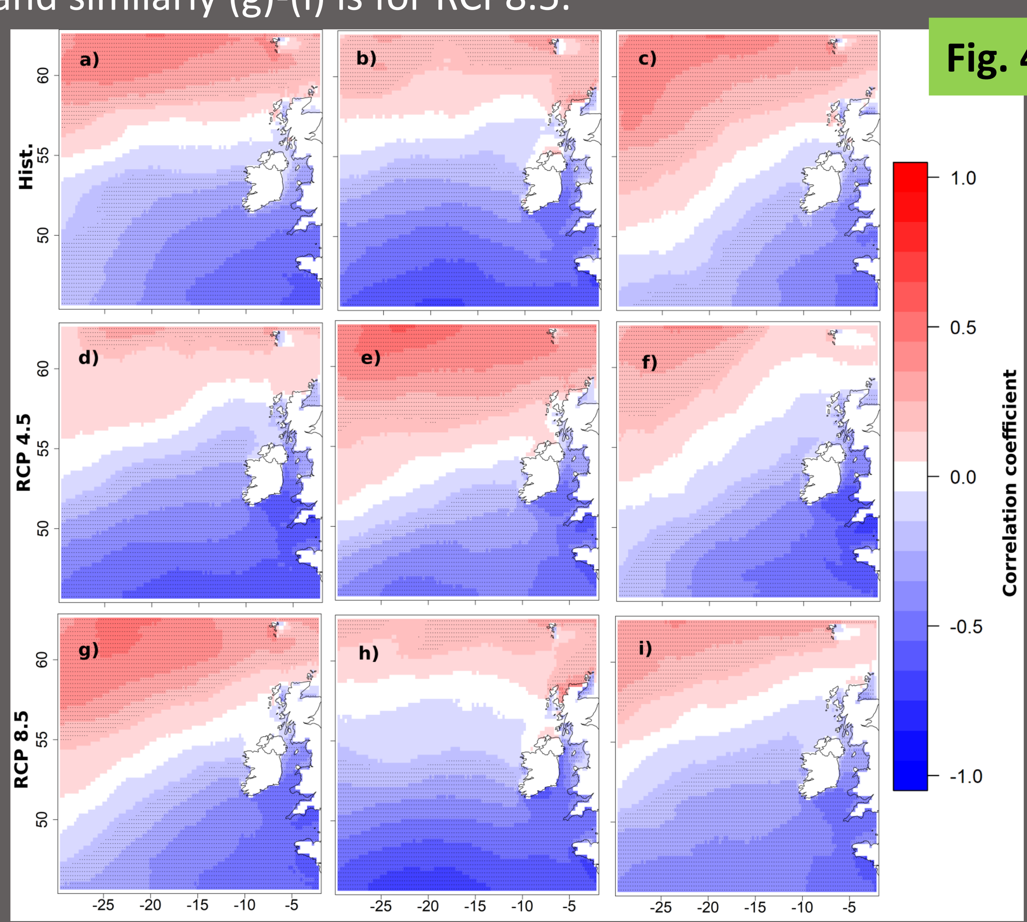

Fig. 4

- Correlations statistically significant at the 0.05 level are dotted. Areas to the north of Ireland tend to mostly show a positive correlation between the PC of EA and 95th percentile of Hs while around Ireland and to the south of the country, correlations are negative. Correlations of both sign increase further away from Ireland. Correlations are mostly statistically insignificant around the north coast of Ireland.

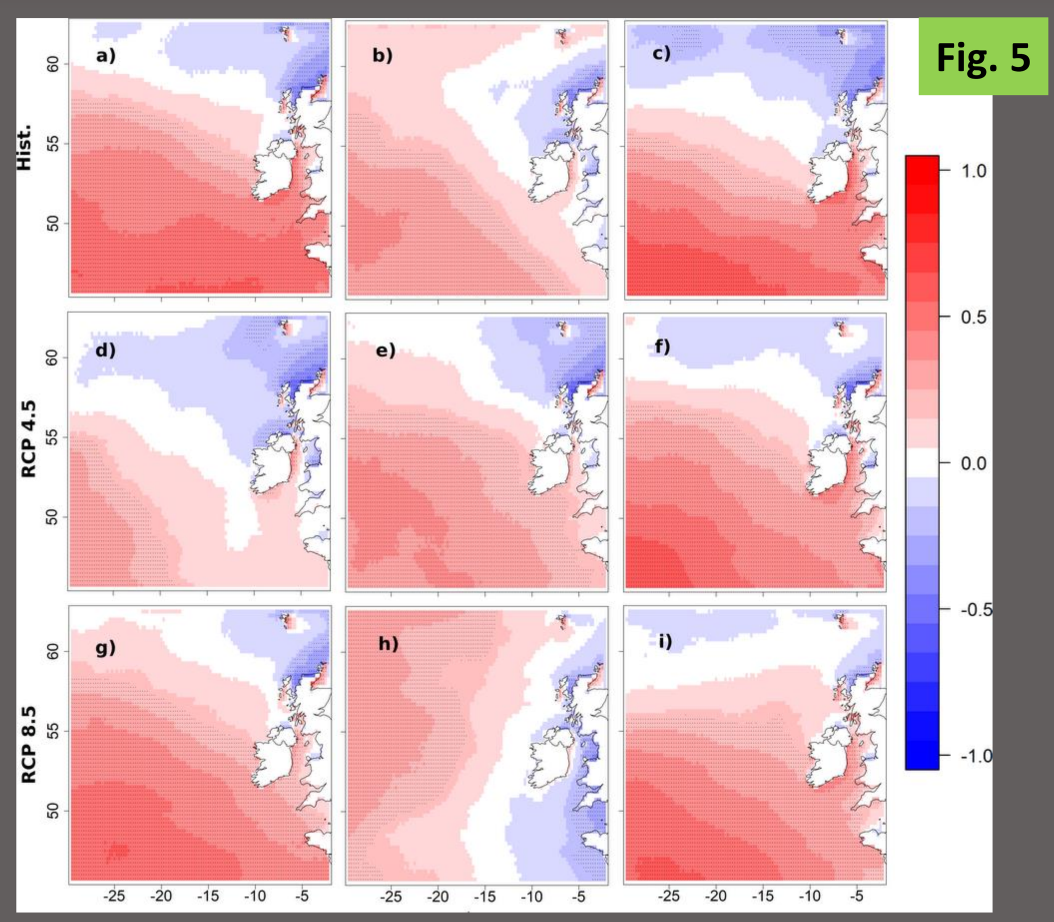

Fig. 5

- Again statistically significant correlations at the 0.05 level are dotted. In general the sign of the correlation switches from being negatively correlated to the NE of Ireland to positively correlated to the SW, with the correlation increasing in the SW direction.
- For the most part the correlations around Ireland are small and often not statistically significant.

5. NAO, EA, SCA vs Hs extremes

- The Generalised Extreme Value (GEV) distribution was fitted to the significant wave height maxima of the DJFM months **[8]**.

$$G(z) = \exp\left(-\left[1+\xi\left(\frac{z-\mu}{\sigma}\right)\right]^{-1/\xi}\right)$$

- The three PCs were added as covariates to the location parameter: i.e $\mu(t) = \mu 0 + \mu 1 \times PC1(t) + \mu 2 \times PC2(t) + \mu 3 \times PC3(t)$. The scale, σ, and shape, ξ, were kept constant.
- With the parameter values, we may obtain N-year return levels, zN, such that G(zN) = 1 – 1/N. Using the above distribution function yields

$$z_N = \mu - \frac{\sigma}{\xi}\left(1-\left[-\log\left(1-1/N\right)\right]^{-\xi}\right)$$

- From the above, we can see that any increase (decrease) in µ will result in higher (lower) return levels of extremes, if other parameters remain constant. **[2]** already studied the effect of the NAO.
- **Fig. 6** and **7** show µ2 and µ3, the effects from PC2 and PC3, respectively. Considerable spatial dependence is evident, with areas of both increase and decrease in extremes visible, consistent with **Fig. 4** and **5** and previous studies **[9, 10]**.

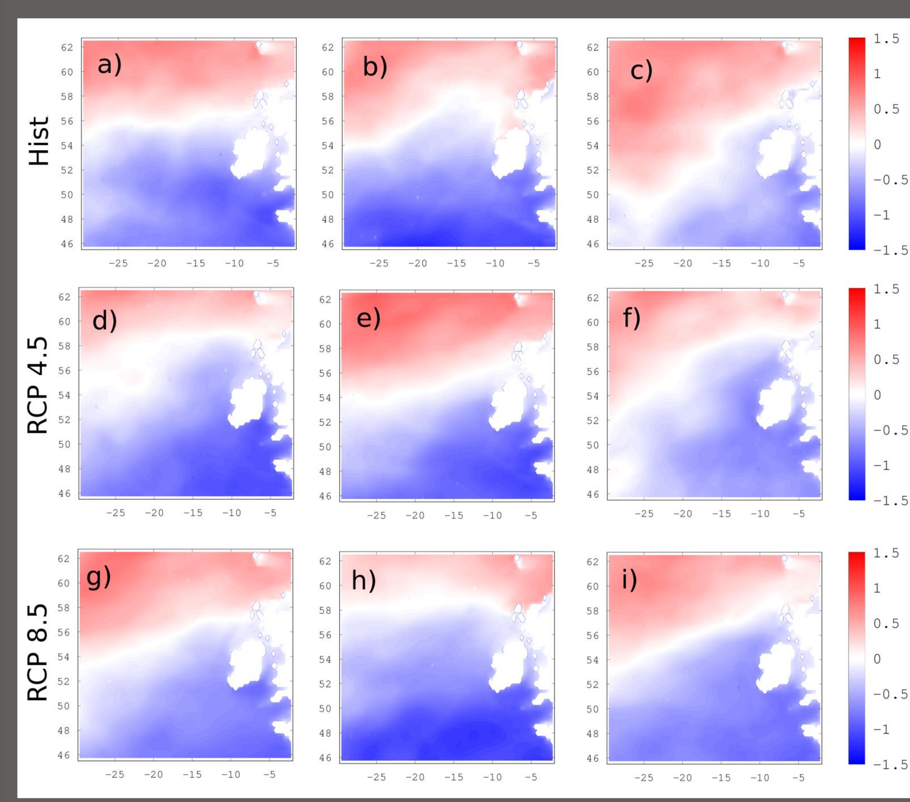

Fig. 6 (PC2)

(a)-(c) historical period 3 x ensemble members; (d)-(f) future period under RCP4.5 and similarly (g)-(i) is for RCP8.5.

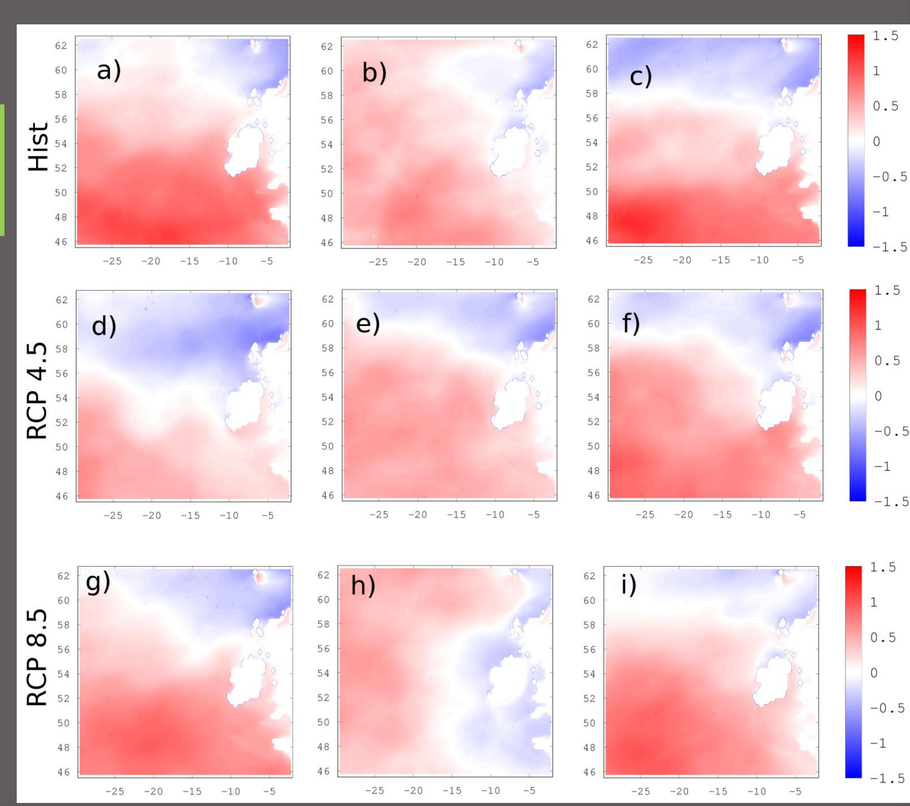

Fig. 7 (PC3)

References: **[1]** Gallagher et al., Ocean Dynamics, 2014; **[2]** Gleeson et al., ASR, 2017; **[3]** Tolman, WAVEWATCH III, 2014; **[4]** van Vuuren et al., 2011; **[5]** Hurrell, Science, 1995; **[6]** Moore, et al., J. Climate, 2013; **[7]** Wallace & Gutzler, Mon. Weather Rev., 1981; **[8]** Coles, Springer, 2001.; **[9]** Izaguirre et al., Geophy. Res. Let., 2011; **[10]** Trigo et al., Ann. N.Y. Acad. Sci., 2008.