Serial clustering of extra-tropical cyclones in a multi-model ensemble of historical and future simulations

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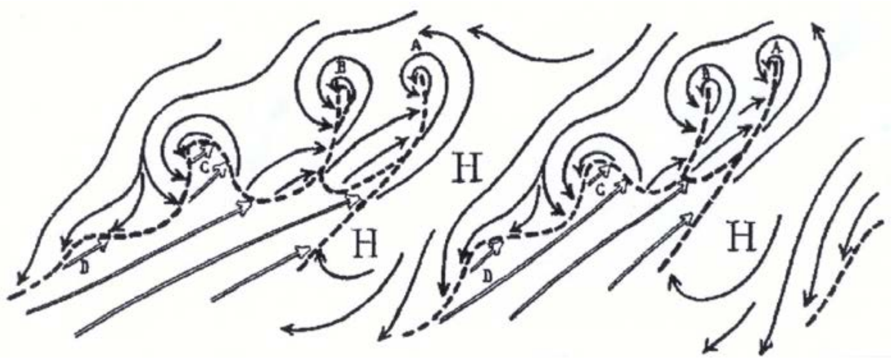
UNIVERSITY OF EXETER
University of Reading

1. Why do hazards cluster?

2. How well do models capture the clustering seen in historical reanalysis tracks?

3. How is clustering projected to change by the CMIP5 models?

4. Can we understand and detect these changes?



5th workshop on European storms, University of Bern, 31 Aug – 2 Sep 2015

Example: European storms in winter 2013/14

Dates	**Notable windstorms**
13-19 Dec 2013	4 Nordic storms: Hilde, Oskari, Ivar, Zaki
5 Dec 2013	Windstorm Xaver (loss E763m)
17 Dec 2013 – 20 Feb 2014	12 major windstorms that included Dirk (23 Dec 2013; loss E420m) and Tini (12 Feb 2014; loss E286m)

Source: www.perils.org/web/news/event-loss.html

Many of the storms also caused a lot of precipitation over Europe leading to some notable flood events:

- UK floods 23 Dec 2013 – 8 Jan 2014 led to losses of £426m (source: ABI);

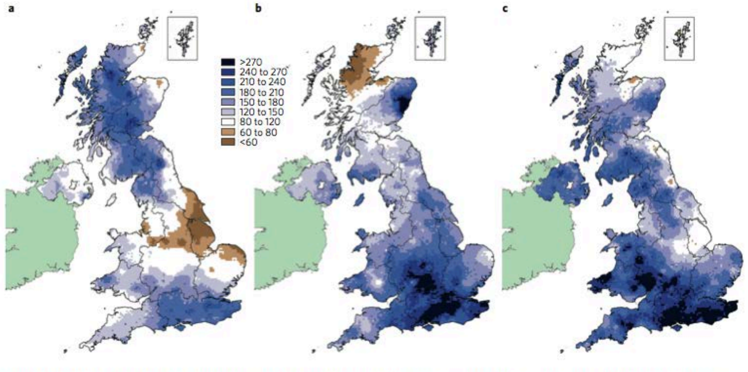


Figure 1 | UK rainfall. a-c, Maps of UK rainfall anomaly as a percentage of 1981-2010 monthly average for December 2013 (**a**), January 2014 (**b**) and February 2014 (**c**).

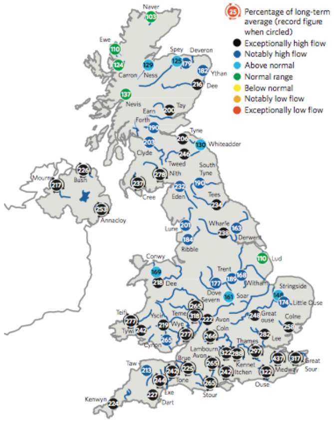


Figure 5 | Monthly river flows for major UK rivers for February 2014. Flows are expressed as a percentage of long-term monthly means (each record at least 30 years).

Source: Huntingford et al. Nature Clim Change 2014.

mirror.co.uk

DAILY Mirror

55P THURSDAY FEBRUARY 13, 2014

MANIAC Joanna Dennehy

I want to kill 9 men

EXCLUSIVE: PAGES 8&9

THERE'S WORSE TO COME

TERROR STORM 3

TERROR STORM 2

TERROR STORM 1

TRIPLE WHAMMY

BY VICKY SMITH

A KILLER storm batters Britain yesterday as two more sweep in to inflict further damage and misery.

Large parts of the country were hit by winds that reached 108mph, sparking travel chaos with trains axed and roads flooded.

One man was electrocuted in Wiltshire by fallen power cables. The storm damage could cost us £15billion. One expert said: "This is an unparalleled natural crisis."

FULL STORY: PAGES 4,5,6&7

» 108mph storm hell... & two more on the way

» Britain in lockdown amid road & rail chaos

» 'Unparalleled natural crisis' will cost us £15bn

Why do hazards cluster?

A. Natural variability

e.g. Homogeneous Poisson process:

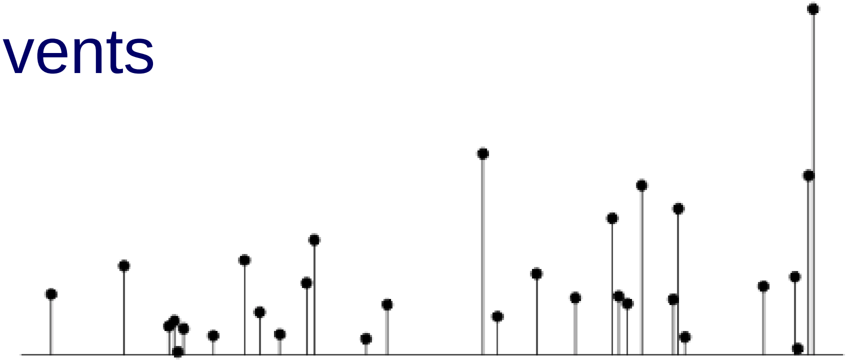
Variance of counts = mean counts

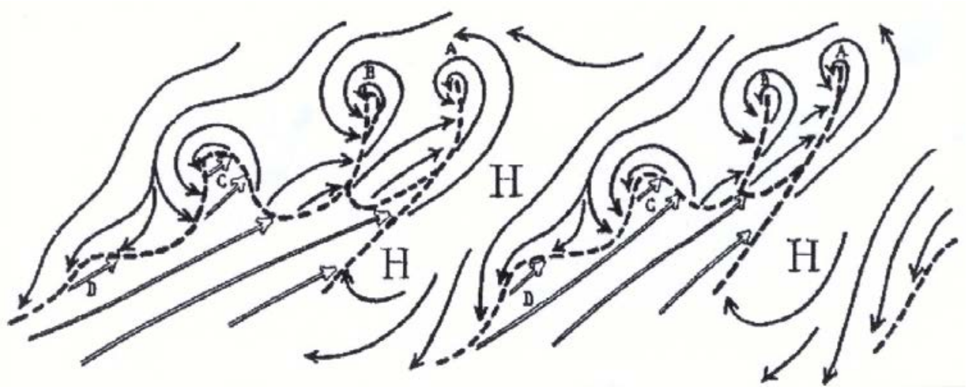
B. Dynamic rates

e.g. Stronger jet in winter → more storms in winter

C: Dependency between nearby events

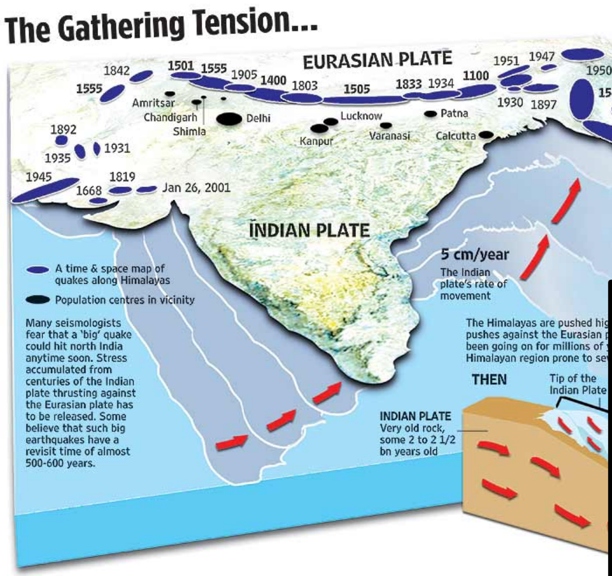
e.g. Secondary cyclogenesis, aftershocks, etc.





Earthquake example:

Perhaps the most timely publication abstract of 2015 ...?



● A time & space map of quakes along Himalayas

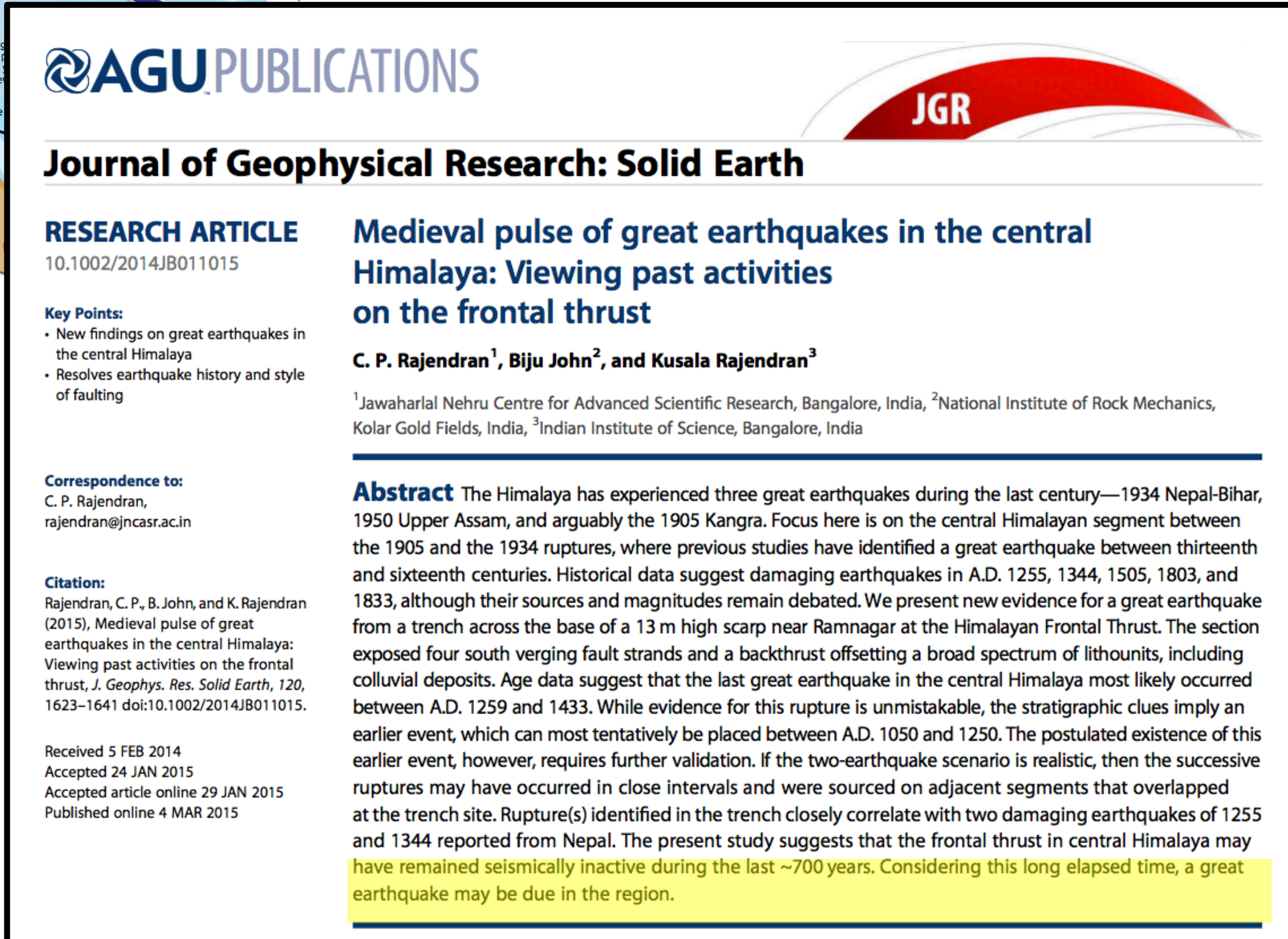
● Population centres in vicinity

Many seismologists fear that a 'big' quake could hit north India anytime soon. Stress accumulated from centuries of the Indian plate thrusting against the Eurasian plate has to be released. Some believe that such big earthquakes have a revisit time of almost 500-600 years.

The Himalayas are pushed hig
pushes against the Eurasian p
been going on for millions of y
Himalayan region prone to se

SIKKIM EARTHQUAKE

Sikkim, which lies in high-risk zone IV, has experienced 18 earthquakes of magnitude five or greater intensity in the last 35 years, all within 100 km of the epicentre of the September 18 quake. The largest of these was a 6.1 earthquake in November 1980.



AGU PUBLICATIONS

JGR

Journal of Geophysical Research: Solid Earth

RESEARCH ARTICLE

10.1002/2014JB011015

Medieval pulse of great earthquakes in the central Himalaya: Viewing past activities on the frontal thrust

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Key Points:
- New findings on great earthquakes in the central Himalaya
- Resolves earthquake history and style of faulting

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Citation:
Rajendran, C. P., B. John, and K. Rajendran (2015), Medieval pulse of great earthquakes in the central Himalaya: Viewing past activities on the frontal thrust, *J. Geophys. Res. Solid Earth*, *120*, 1623–1641 doi:10.1002/2014JB011015.

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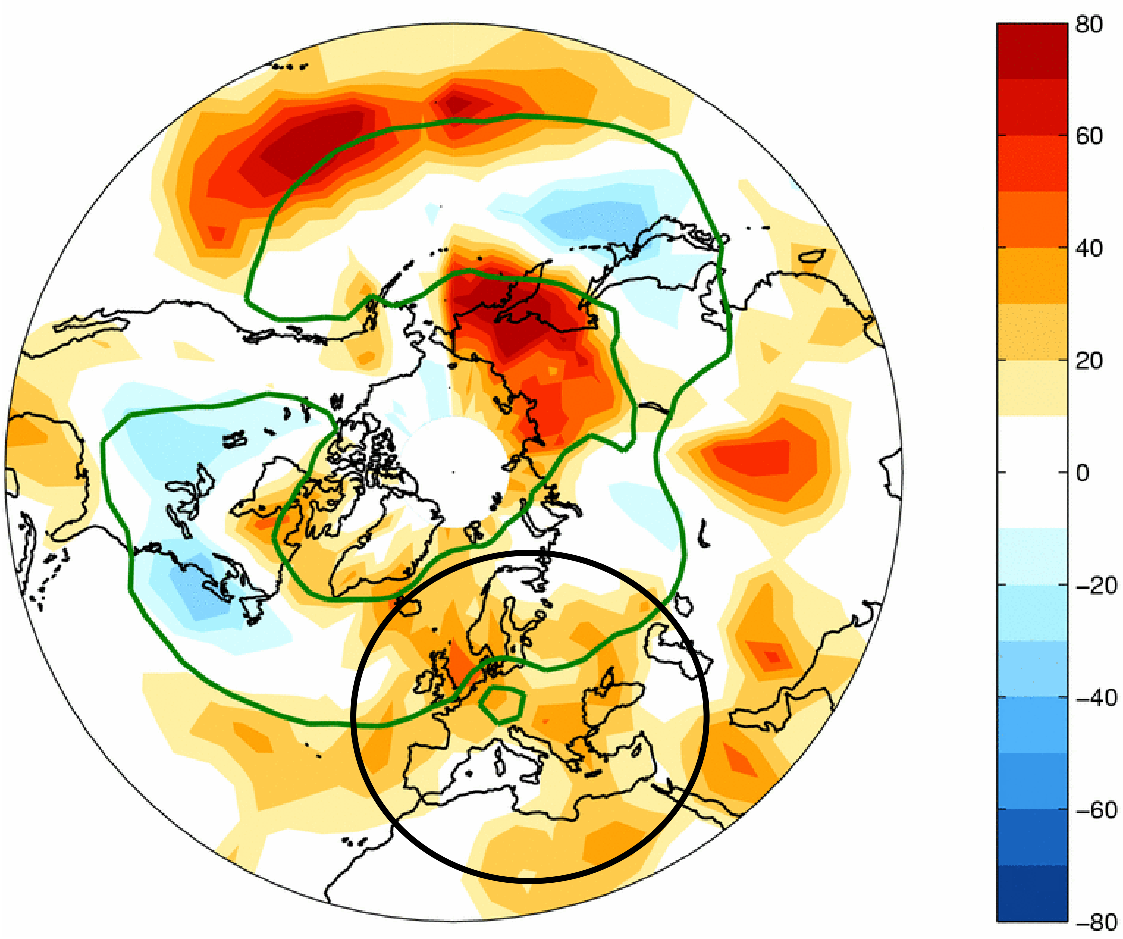
Abstract The Himalaya has experienced three great earthquakes during the last century—1934 Nepal-Bihar, 1950 Upper Assam, and arguably the 1905 Kangra. Focus here is on the central Himalayan segment between the 1905 and the 1934 ruptures, where previous studies have identified a great earthquake between thirteenth and sixteenth centuries. Historical data suggest damaging earthquakes in A.D. 1255, 1344, 1505, 1803, and 1833, although their sources and magnitudes remain debated. We present new evidence for a great earthquake from a trench across the base of a 13 m high scarp near Ramnagar at the Himalayan Frontal Thrust. The section exposed four south verging fault strands and a backthrust offsetting a broad spectrum of lithounits, including colluvial deposits. Age data suggest that the last great earthquake in the central Himalaya most likely occurred between A.D. 1259 and 1433. While evidence for this rupture is unmistakable, the stratigraphic clues imply an earlier event, which can most tentatively be placed between A.D. 1050 and 1250. The postulated existence of this earlier event, however, requires further validation. If the two-earthquake scenario is realistic, then the successive ruptures may have occurred in close intervals and were sourced on adjacent segments that overlapped at the trench site. Rupture(s) identified in the trench closely correlate with two damaging earthquakes of 1255 and 1344 reported from Nepal. The present study suggests that the frontal thrust in central Himalaya may have remained seismically inactive during the last ~700 years. Considering this long elapsed time, a great earthquake may be due in the region.

Overdispersion in monthly storm counts



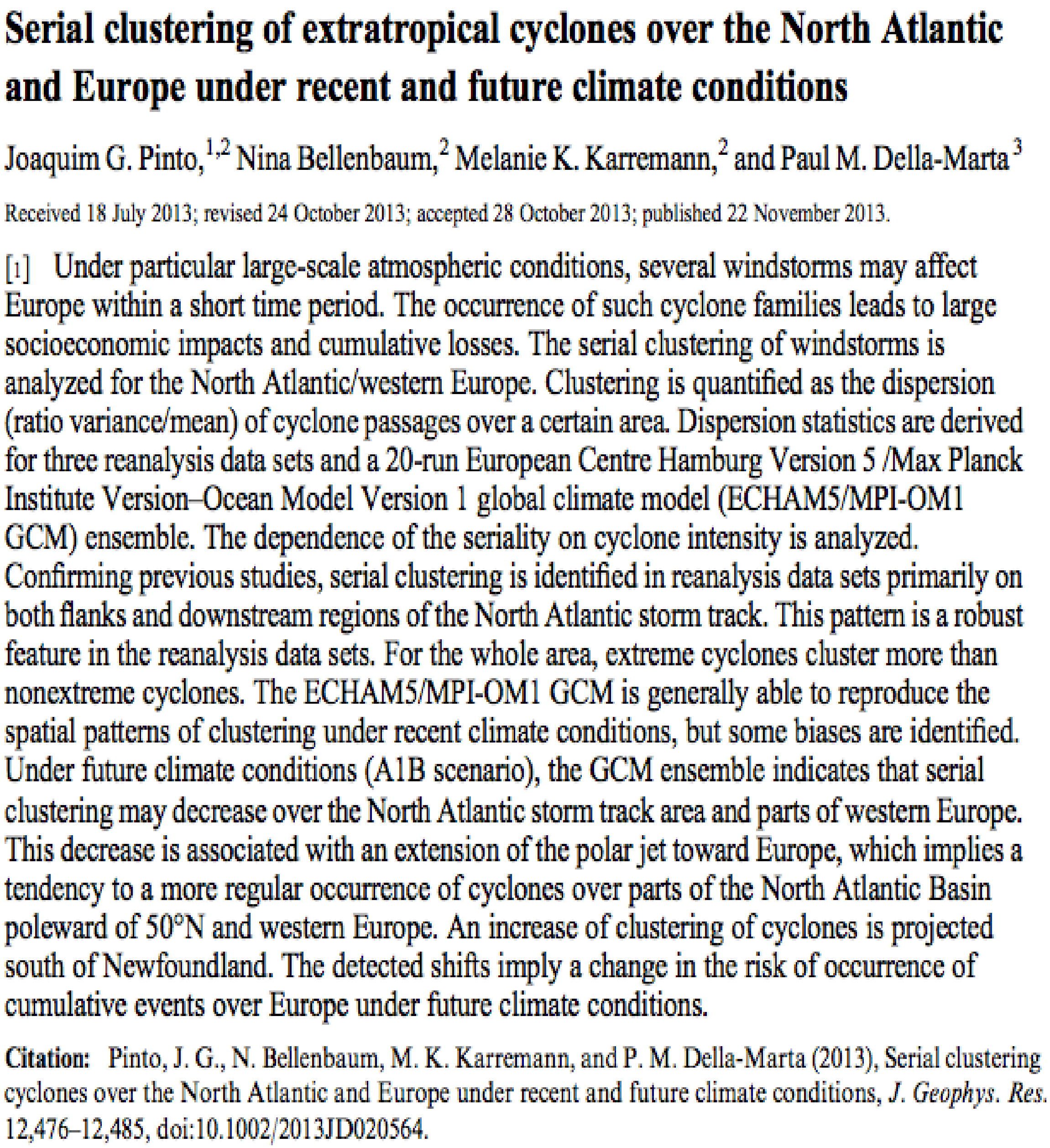
$$\frac{s_n^2}{\bar{n}} - 1$$

Units: %

→ More variance in counts than expected for Poisson with constant mean
→ Substantial clustering over western Europe.

Mailier, P.J., Stephenson, D.B., Ferro, C.A.T. and Hodges, K.I. (2006):
Serial clustering of extratropical cyclones, Monthly Weather Review, 134, pp 2224-2240

How will clustering of windstorms change?



Serial clustering of extratropical cyclones over the North Atlantic and Europe under recent and future climate conditions

Joaquim G. Pinto,[1,2] Nina Bellenbaum,[2] Melanie K. Karremann,[2] and Paul M. Della-Marta[3]

Received 18 July 2013; revised 24 October 2013; accepted 28 October 2013; published 22 November 2013.

[1] Under particular large-scale atmospheric conditions, several windstorms may affect Europe within a short time period. The occurrence of such cyclone families leads to large socioeconomic impacts and cumulative losses. The serial clustering of windstorms is analyzed for the North Atlantic/western Europe. Clustering is quantified as the dispersion (ratio variance/mean) of cyclone passages over a certain area. Dispersion statistics are derived for three reanalysis data sets and a 20-run European Centre Hamburg Version 5 /Max Planck Institute Version–Ocean Model Version 1 global climate model (ECHAM5/MPI-OM1 GCM) ensemble. The dependence of the seriality on cyclone intensity is analyzed. Confirming previous studies, serial clustering is identified in reanalysis data sets primarily on both flanks and downstream regions of the North Atlantic storm track. This pattern is a robust feature in the reanalysis data sets. For the whole area, extreme cyclones cluster more than nonextreme cyclones. The ECHAM5/MPI-OM1 GCM is generally able to reproduce the spatial patterns of clustering under recent climate conditions, but some biases are identified. Under future climate conditions (A1B scenario), the GCM ensemble indicates that serial clustering may decrease over the North Atlantic storm track area and parts of western Europe. This decrease is associated with an extension of the polar jet toward Europe, which implies a tendency to a more regular occurrence of cyclones over parts of the North Atlantic Basin poleward of 50°N and western Europe. An increase of clustering of cyclones is projected south of Newfoundland. The detected shifts imply a change in the risk of occurrence of cumulative events over Europe under future climate conditions.

Citation: Pinto, J. G., N. Bellenbaum, M. K. Karremann, and P. M. Della-Marta (2013), Serial clustering cyclones over the North Atlantic and Europe under recent and future climate conditions, *J. Geophys. Res.* 12,476–12,485, doi:10.1002/2013JD020564.

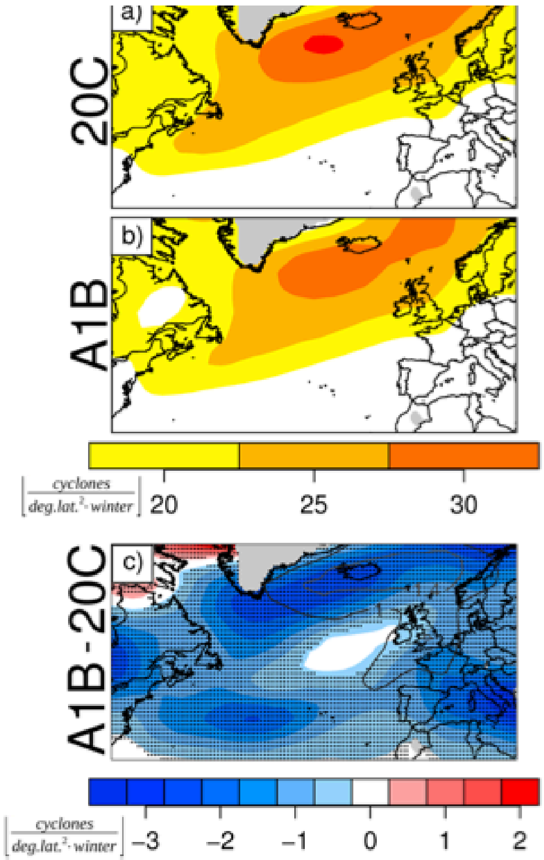


Figure 4. (a) Cyclone track density for ECHAM5 GCM ensemble average for winter season (December–February) for the period 1960–2000 (20C, 20 simulations). Values given in cyclone days per winter per (degree latitude)^2. (b) Same as Figure 4a but for the ECHAM5 GCM ensemble average for the period 2060–2100 (A1B, 20 simulations). (c) Changes in cyclone track density between Figures 4b and 4a. Blue (red) values correspond to a reduction (enhancement) of cyclone track density. Values in areas with orography above 1500 m are suppressed. Significant changes at the 5% level of significance (Student's *t* test) are areas with black stipplings. Gray isolines in Figure 4c delimit areas where spread between the GCM is large (standard deviation).

Future decrease in European clustering

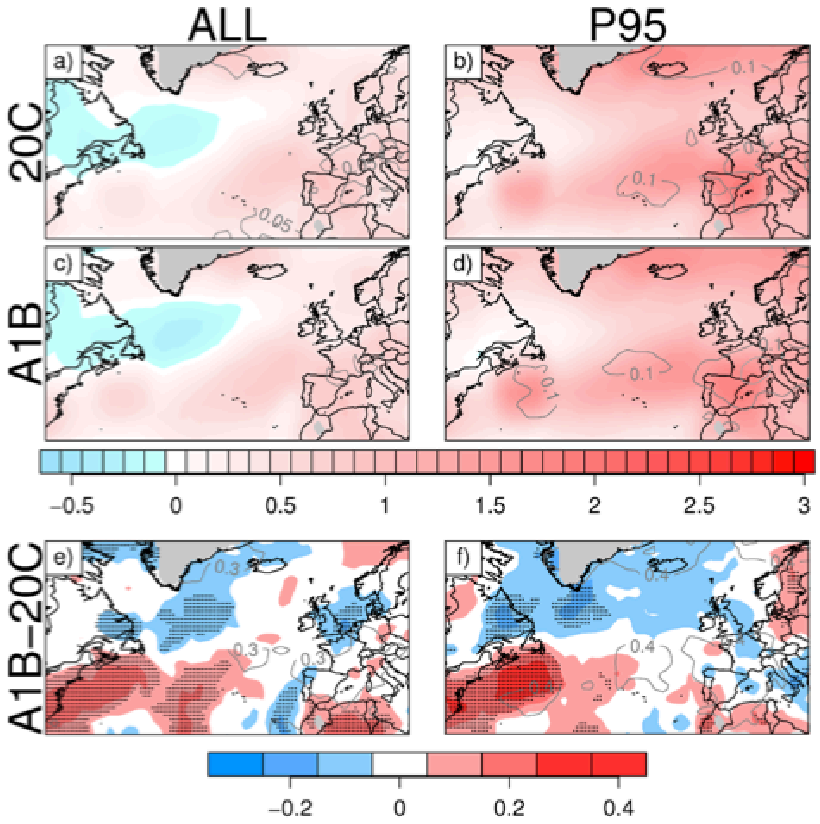


Figure 5. (a) Estimated dispersion statistic (Ψ) of winter cyclone transits (December–February) for ECHAM5 GCM ensemble average for the period 1960–2000 (20C, 20 simulations). (b) Same as Figure 5a but for cyclones with minimum core pressure exceeding the 95th percentile. (c) Same as Figure 5a but for the ECHAM5 GCM ensemble average for the period 2060–2100 (A1B, 20 simulations). (d) Same as Figure 5c but for cyclones with minimum core pressure exceeding the 95th percentile. Blue values correspond to an underdispersive process (Ψ < 0; regular), white values to a random process (Ψ = 0), and red values to an overdispersive process (Ψ > 0; clustering). (e) Changes in Ψ between Figures 5c and 5a. Colored areas indicate decreases (blue) or increases (red) of Ψ, statistically significant changes at the 5% level of significance (Student's *t* test) are marked with black dots. Gray isolines delimit areas where the spread between the GCM ensemble runs is high. (f) Same as Figure 5e but changes between Figures 5d and 5b.

Measure of overdispersion:

$$\phi = \frac{VarN}{\overline{N}} - 1$$

=0 Poisson with fixed rate
>0 Clustering
<0 regular process

→ Overdispersion projected to decrease over Europe from about 0.5 to 0.3

This raised some questions …

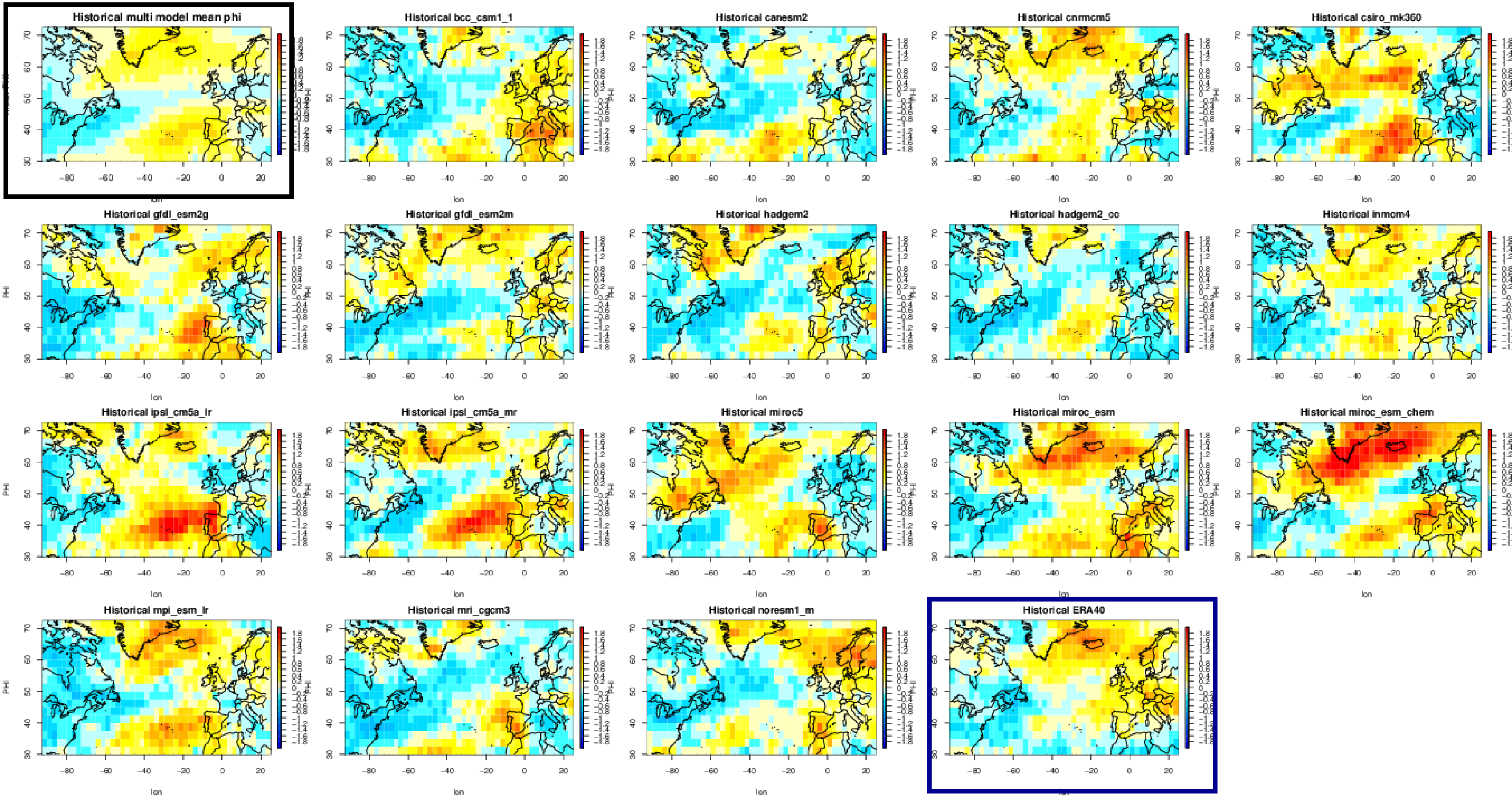
- How well do other climate models represent clustering?
- Do other climate models show similar changes in clustering?
- Can we understand these changes physically? (e.g. in terms of how storms are related to climate modes such as the North Atlantic Oscillation).
- How well could we detect such a change in clustering in future observations of storm counts?

T. Economou, D.B. Stephenson, J. Pinto, L.C. Shaffrey, G. Zappa, 2015:*Serial clustering of extratropical cyclones in historical and future CMIP5 model simulations*, Quarterly Journal of Royal Meteorological Society (in press)

How well do climate models represent clustering?

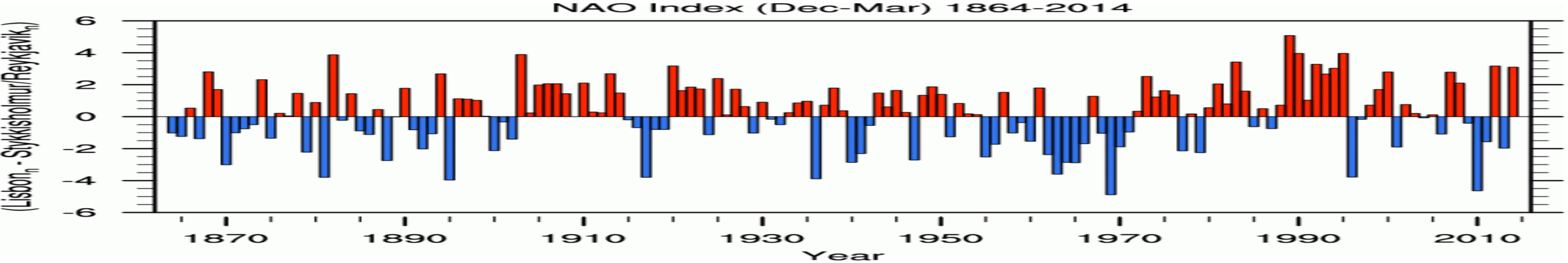
Historical overdispersion 1975-2005

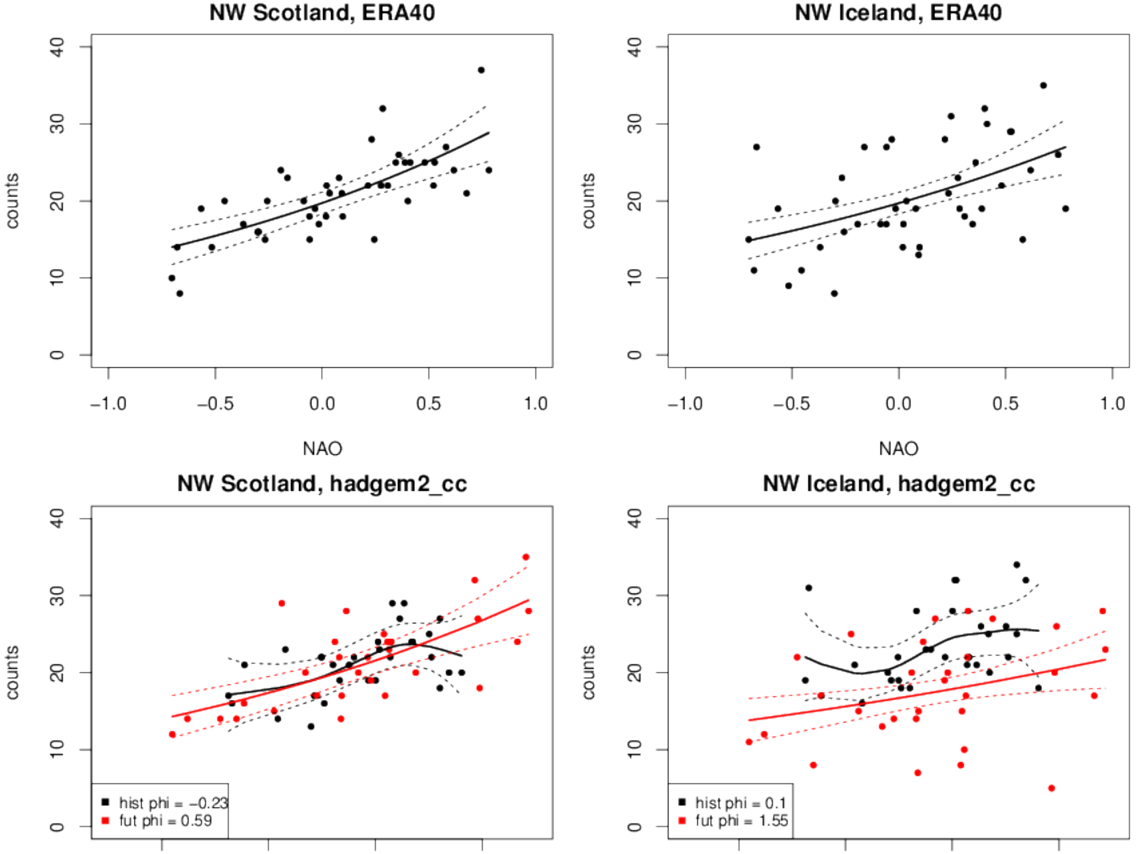
Var(counts)/Mean(counts)-1

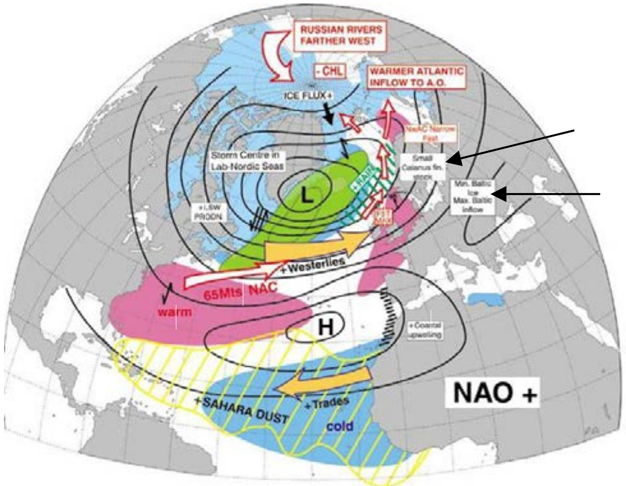


→ Models qualitatively capture the gross features seen in observations

Monthly rate dependence on NAO: historical and future

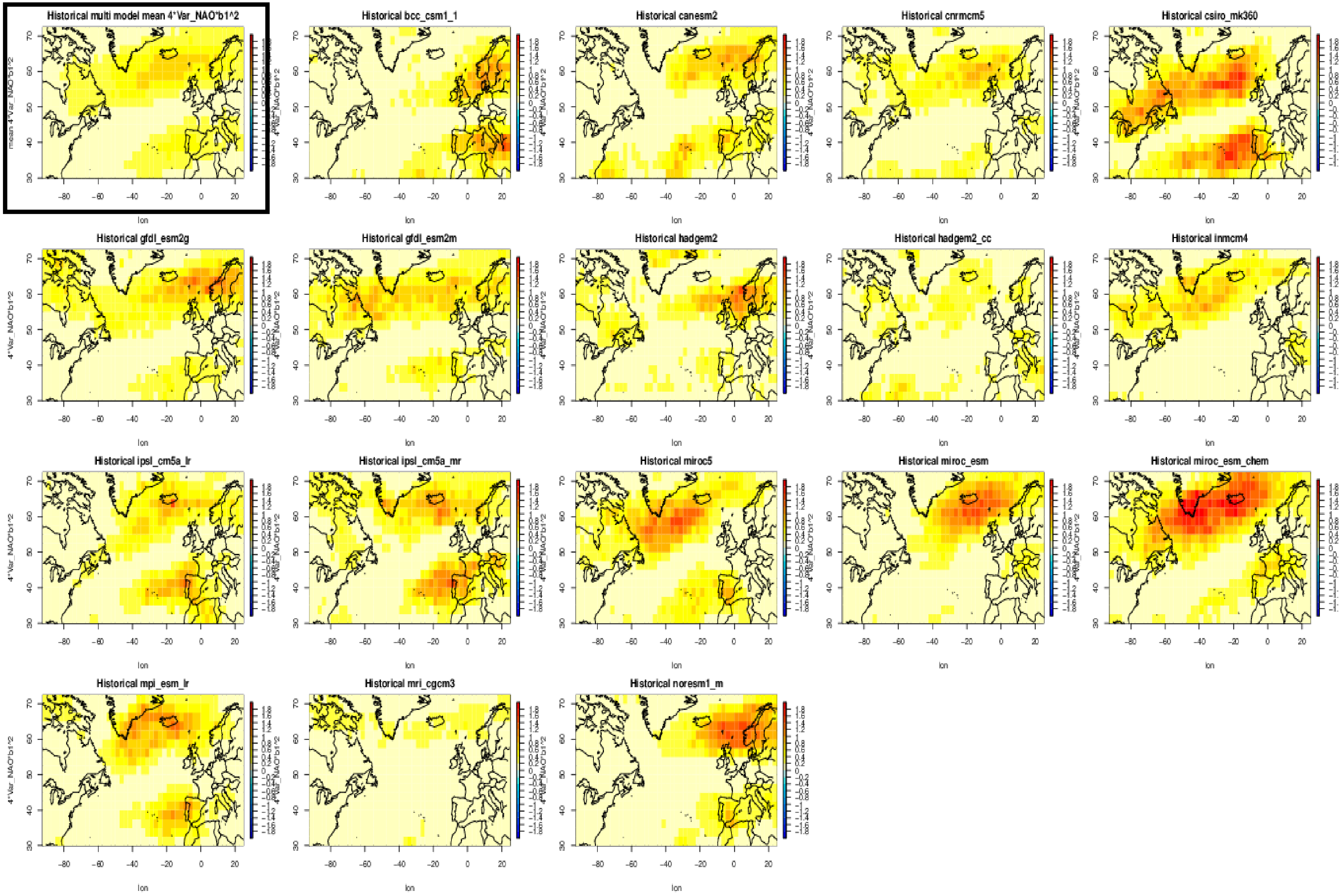






→ Counts depend on NAO and this relationship doesn't appear to change

Historical overdispersion accounted for by NAO



→ NAO accounts for a sizeable proportion of the overdispersion

Projected changes in NAO, NAM and SAM

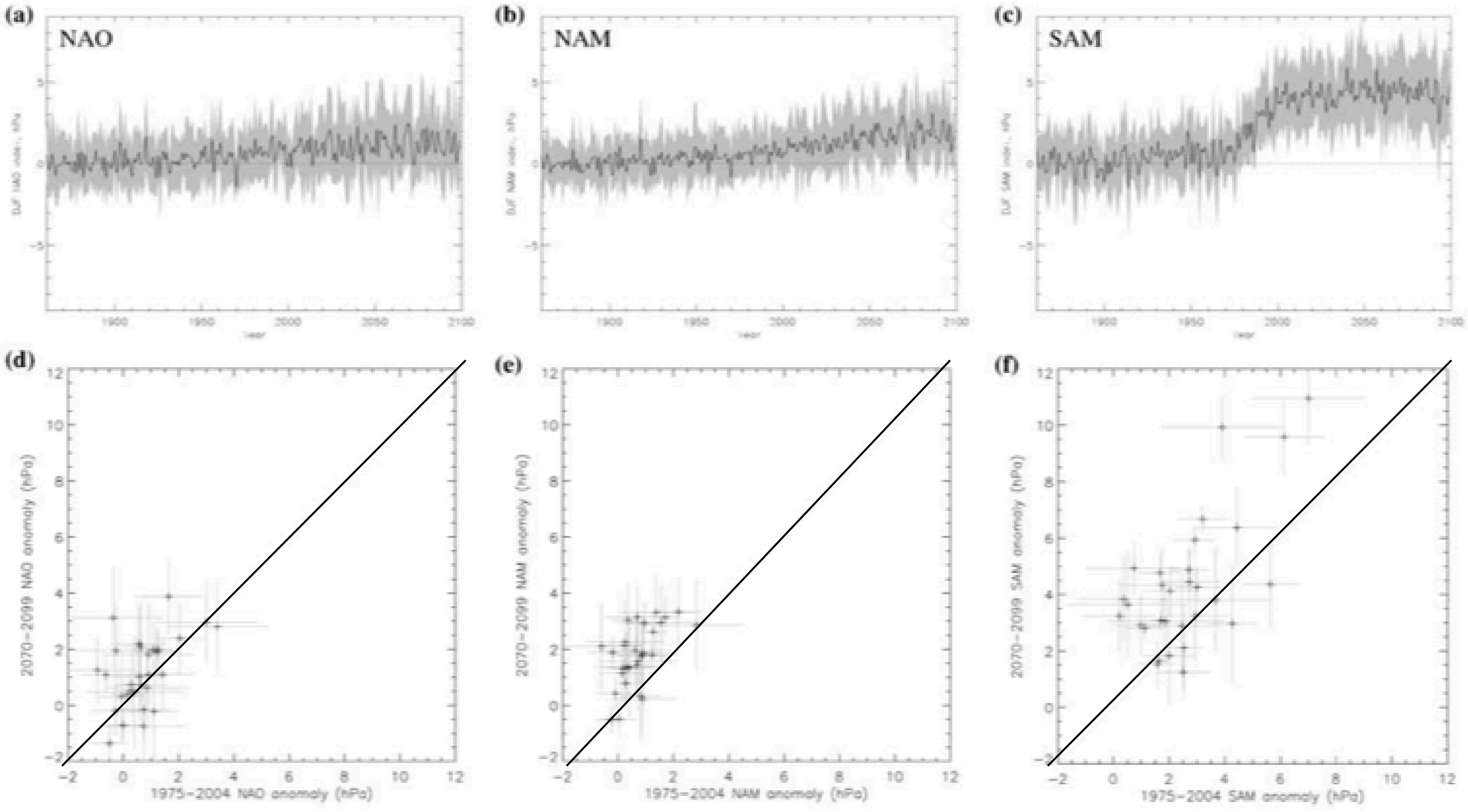
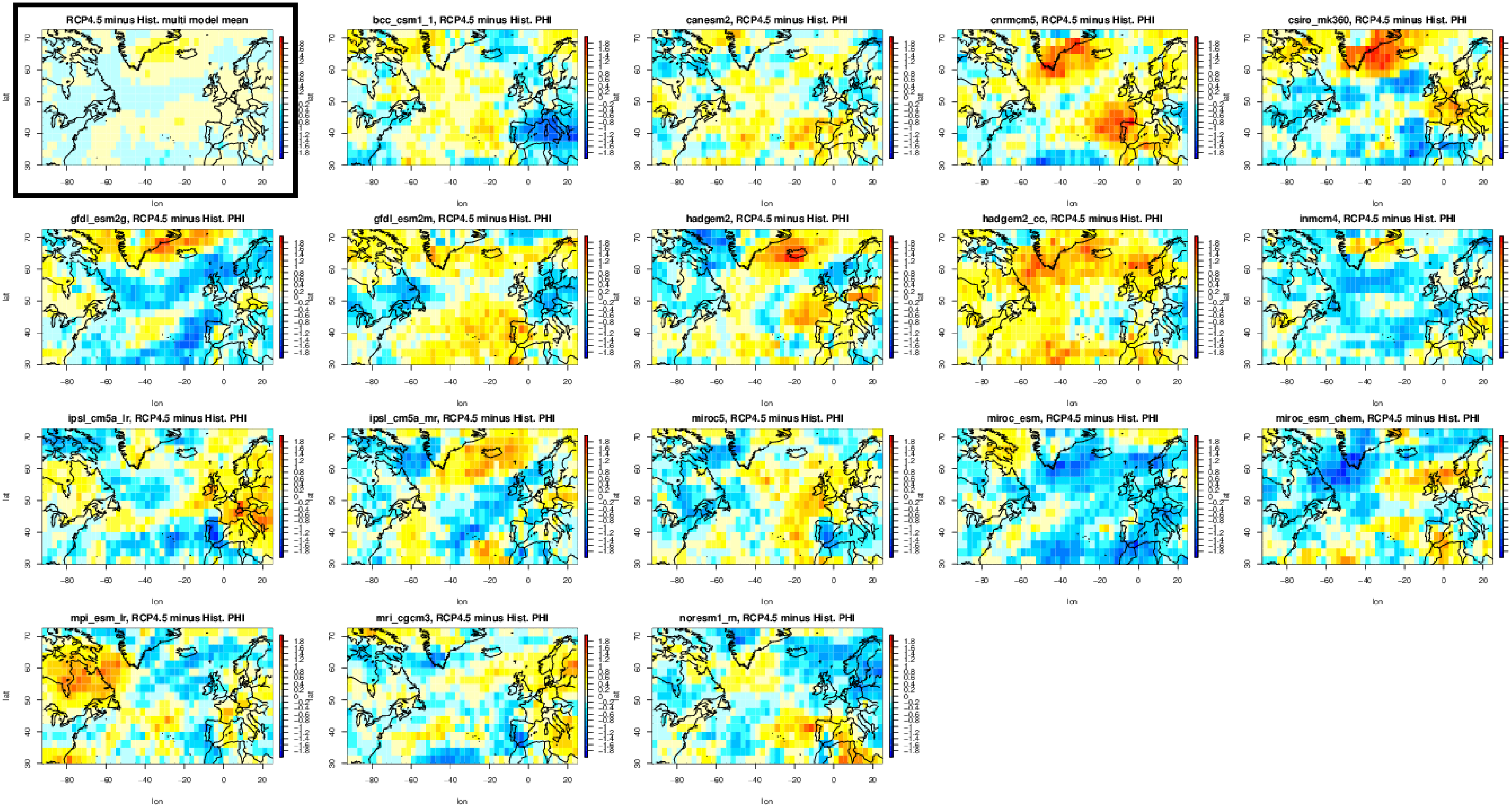


Figure 14.26: Summary of multi-model ensemble simulations of wintertime mean NAO, NAM and SAM sea-level pressure indices for historical and RCP4.5 scenarios produced by 30 climate models participating in CMIP5. Panels a-c) show time series of the ensemble mean (black line) and inter-quartile range (grey shading) of the mean index for each model. Panels d-f) show scatter plots of individual model 2070–2099 time means versus 1975–2004 time means (black crosses) together with (–2,+2) standard error bars. The NAO index is defined here as the difference of regional averages: (90°W–60°E, 20°N–55°N) minus (90°W–60°E, 55°N–90N) (Stephenson and Pavan, 2003). The NAM and SAM are defined as zonal indices: NAM as the difference in zonal mean SLP at 35°N and 65°N (Li and Wang, 2003) and SAM as the difference in zonal mean SLP at 40°S and 65°S (Gong and Wang, 1999). All indices have been centered to have zero time mean from 1861–1900. Comparison of simulated and observed trends from 1961–2011 is shown in Figure 10.11.

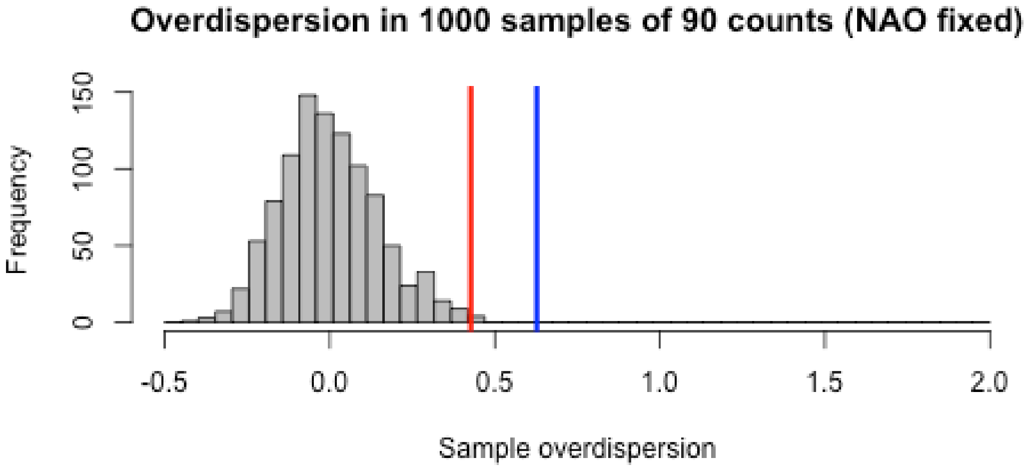
Projected changes in clustering

Change in overdispersion: 2069-99 minus1975-2005
RCP4.5 scenario



- → Noisey with not much agreement between model responses
- → Multi-model mean shows similar response to Pinto et al. (2013)

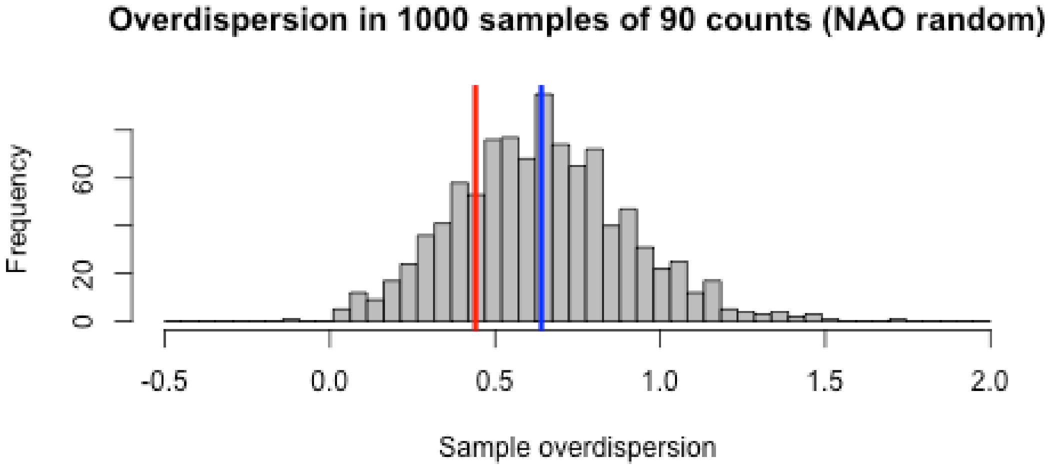
Natural variability in the overdispersion statistic


Overdispersion in 1000 samples of 90 counts (NAO fixed)

Toy model simulation:

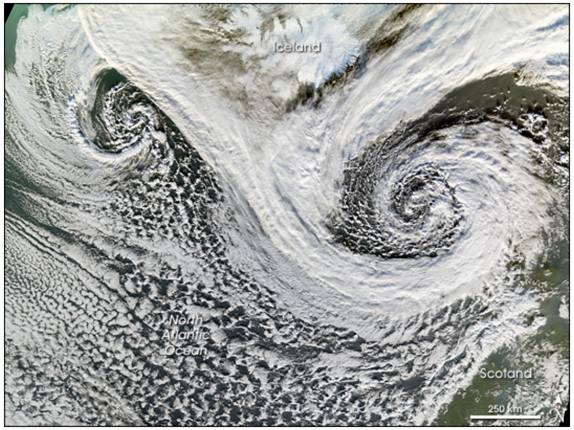
Frequency distribution of sample overdispersion in 1000 simulations of 30 winters.

Mean rate of 20 counts/month
Overdispersion of 0.63


Overdispersion in 1000 samples of 90 counts (NAO random)

- → Unlikely to detect the decrease due to large natural variability in counts
- → Large amount of uncertainty even if NAO fixed (e.g. historical period)

Summary



- CMIP5 models qualitatively capture the historical clustering pattern;

- Much of the overdispersion in this pattern around the edges of the storm track is related to modulation of storm counts by varying NAO;

- Individual model projections differ substantially from one another but the multi-model mean resembles Pinto et al.;

- The climate change signal in clustering is small:
  - Only small projected changes in mean and variance of NAO;
  - Changes compensate: increase in mean and variance of NAO

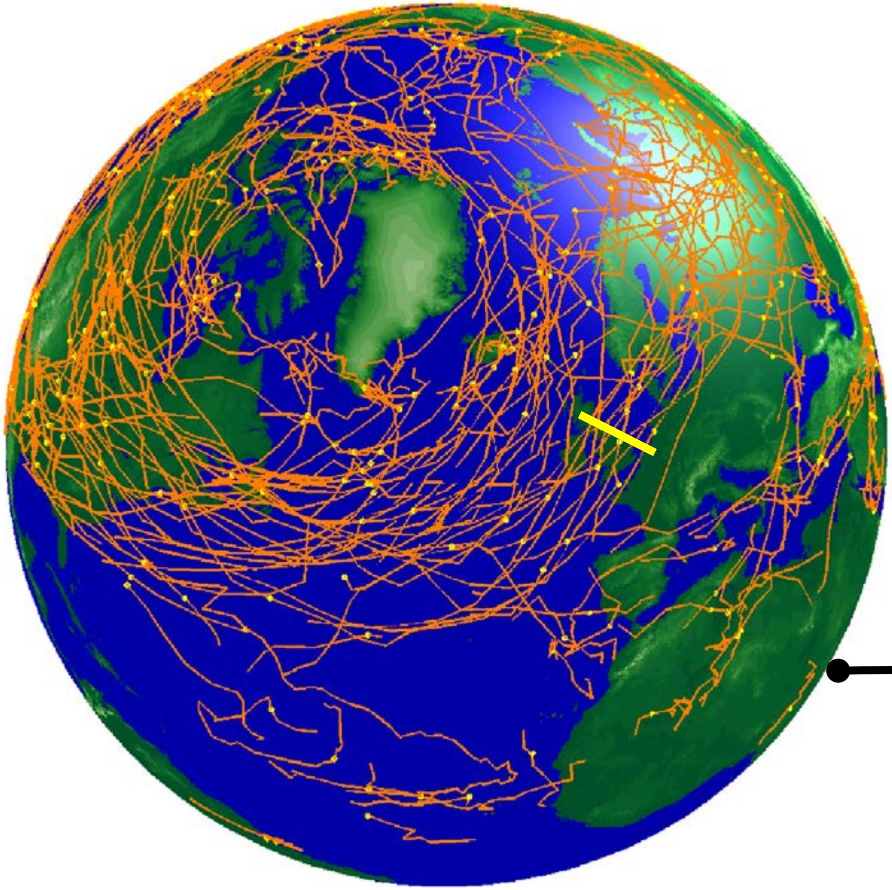
- The climate change signal is obscured by natural variability (of future NAO AND storm counts). Therefore, future observations are unlikely to resemble the multi-mean response.

Additional slides for questions etc. ...

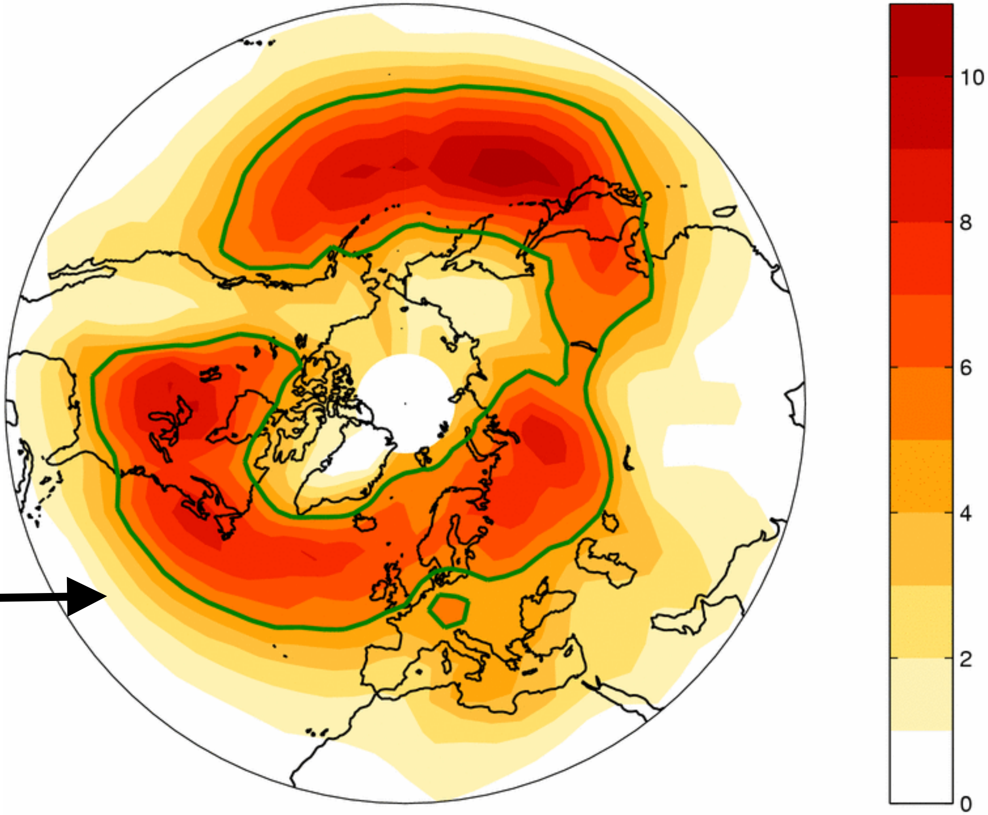
Storm tracking

- Objectively track every wintertime (1 Oct – 31 Mar) storm feature in 6 hourly data
- Count storms that pass 10° north/south of each location
- Record the 6-hourly precipitation and wind speeds as they pass the barrier

Storm tracks of Dec 1989-Feb1990



Mean transit counts (per month)



How well do climate models simulate storm tracks?

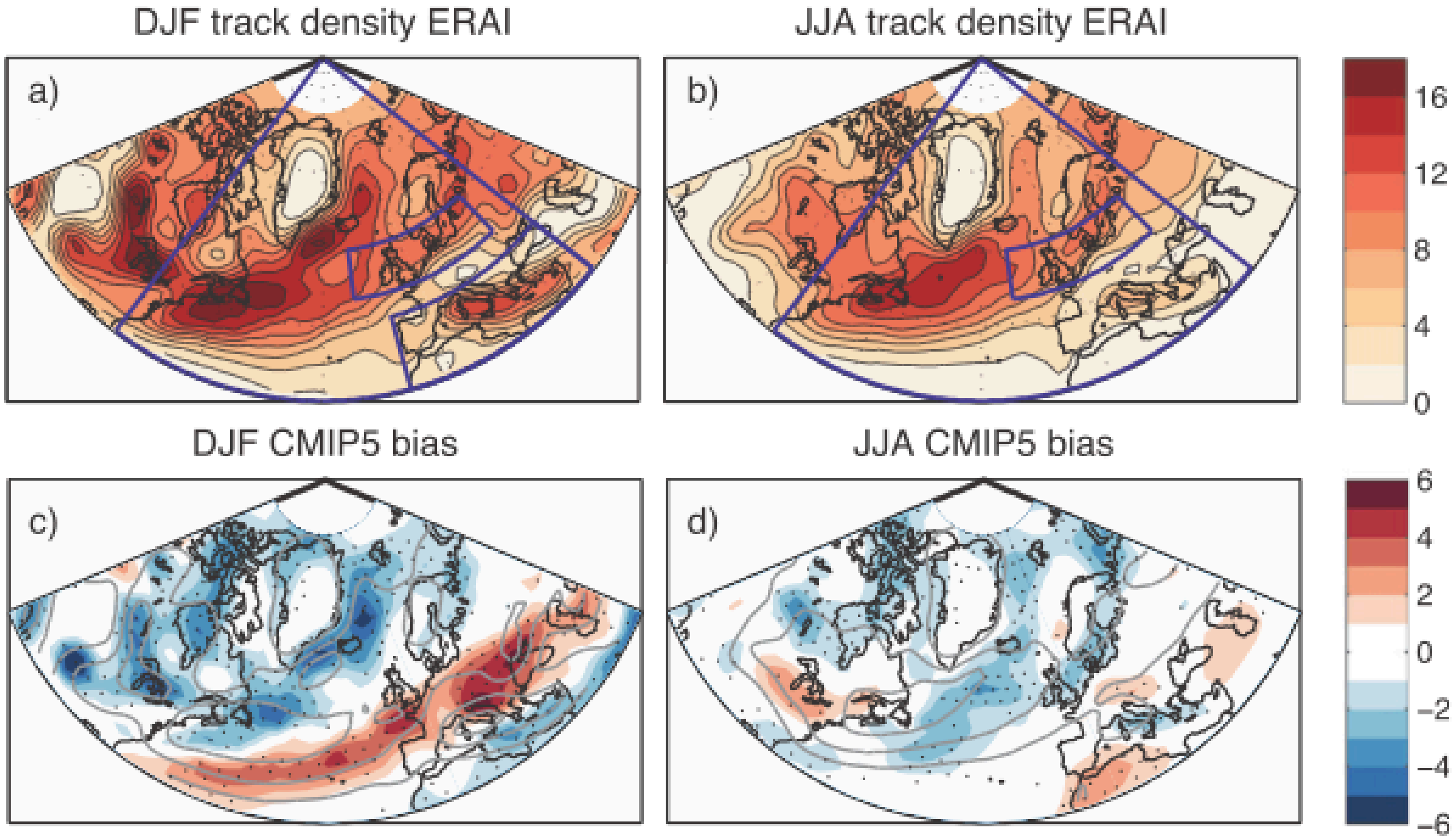
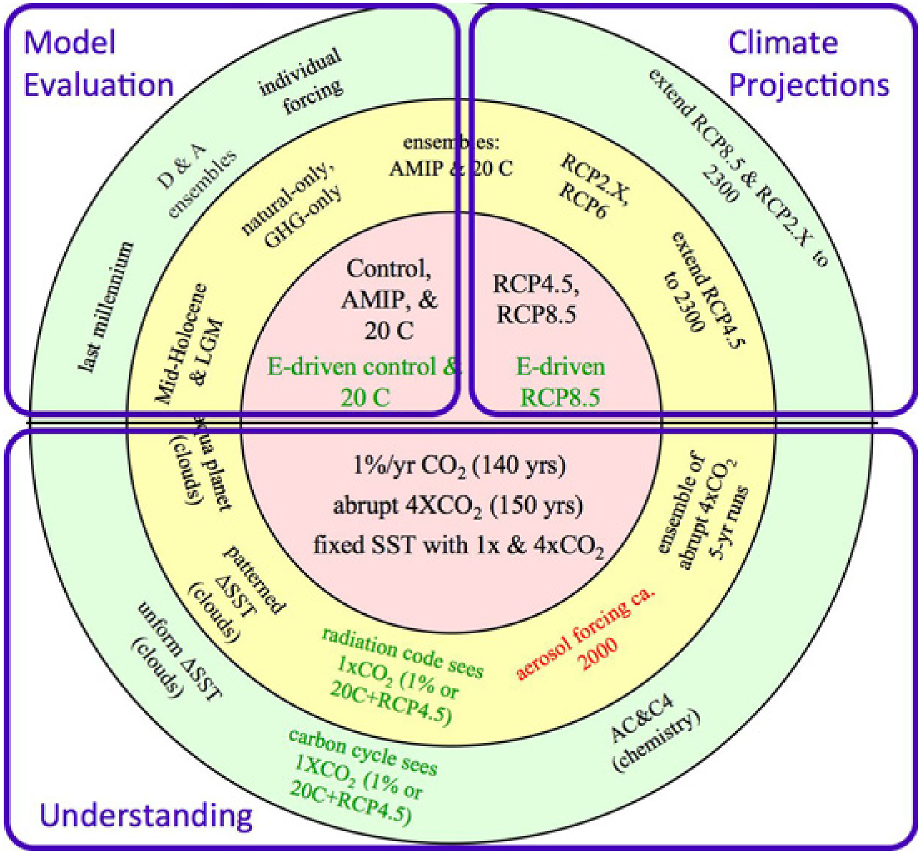


FIG. 1. (a),(b) Track density in ERA-Interim (1980–2009) and (c),(d) mean track density bias of CMIP5 models in the HIST simulations relative to ERA-Interim, for (left) DJF and (right) JJA. Units are in number of cyclones per month per unit area, where unit area is equivalent to a 5° spherical cap. In (a),(b), the large blue circular sector defines the region of the North Atlantic and European cyclones. The small boxes define the Mediterranean [in (a) only] and central European area of interests. In (c),(d), stippling shows where more than 80% of the models have a bias of the same sign, and the contours show the CMIP5-averaged track density with isolines every four cyclones per month per unit area.

The most recent climate model data

Coupled Model Intercomparison Project Phase 5 (CMIP5)

Climate projections from more than 20 modelling centres around the world



- High frequency (6 hourly) model output is available at 100-500km spatial resolution.
- CMIP5 is the first opportunity to evaluate a large ensemble of models using a tracking technique
- Changes in the number and in the intensity of cyclones can now be comprehensively assessed

ipcc

INTERGOVERNMENTAL PANEL ON climate change

Working Group I (WG I) – The Physical Science Basis

All data freely available from:
http://cmip-pcmdi.llnl.gov/cmip5

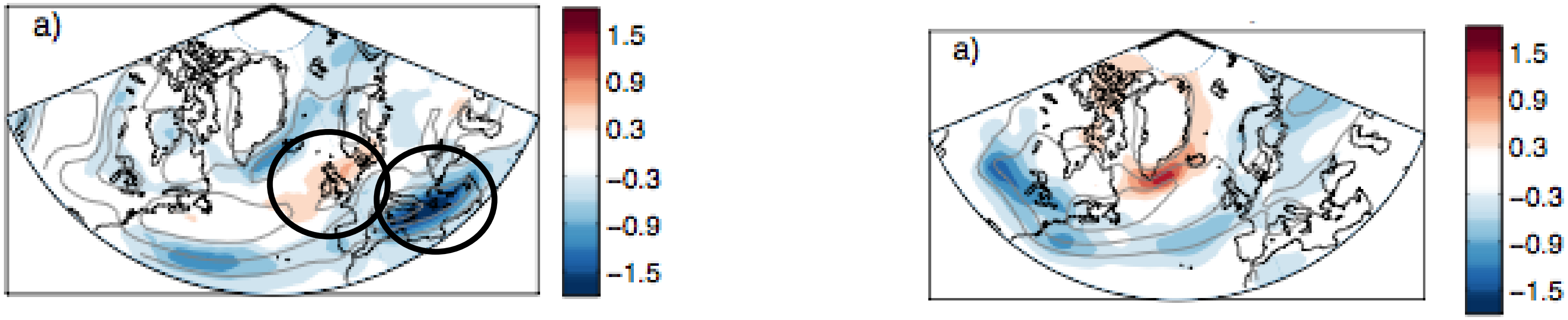
Projected future change under RCP4.5 scenario

Difference in time means over 2070-99 and 1976-2005

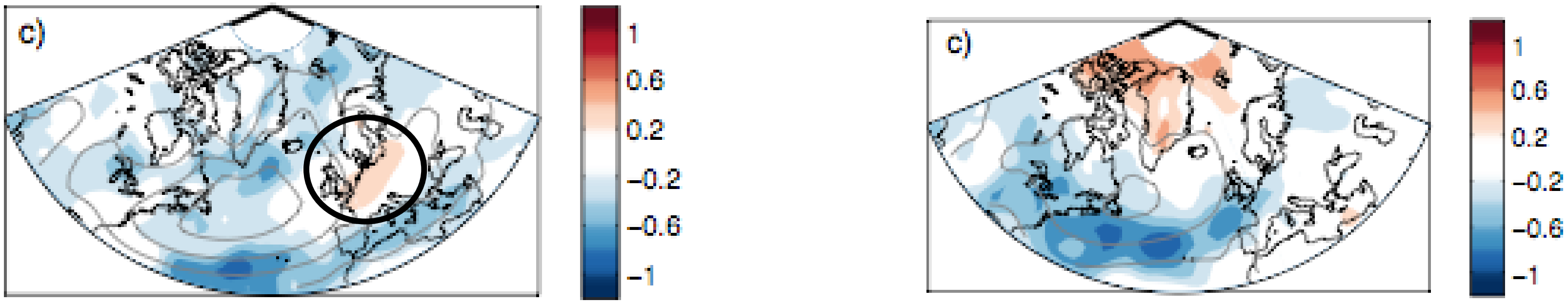
Winter (DJF)

Summer (JJA)

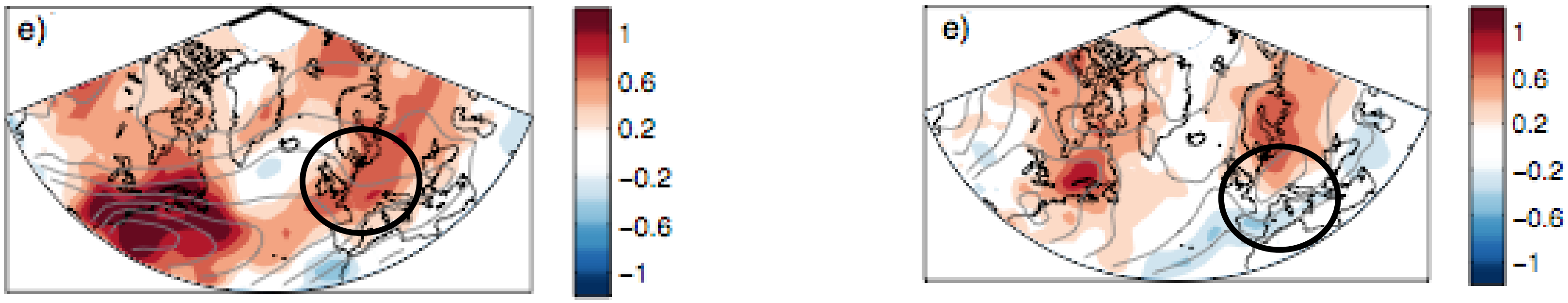
Track density (no. of storms/month)



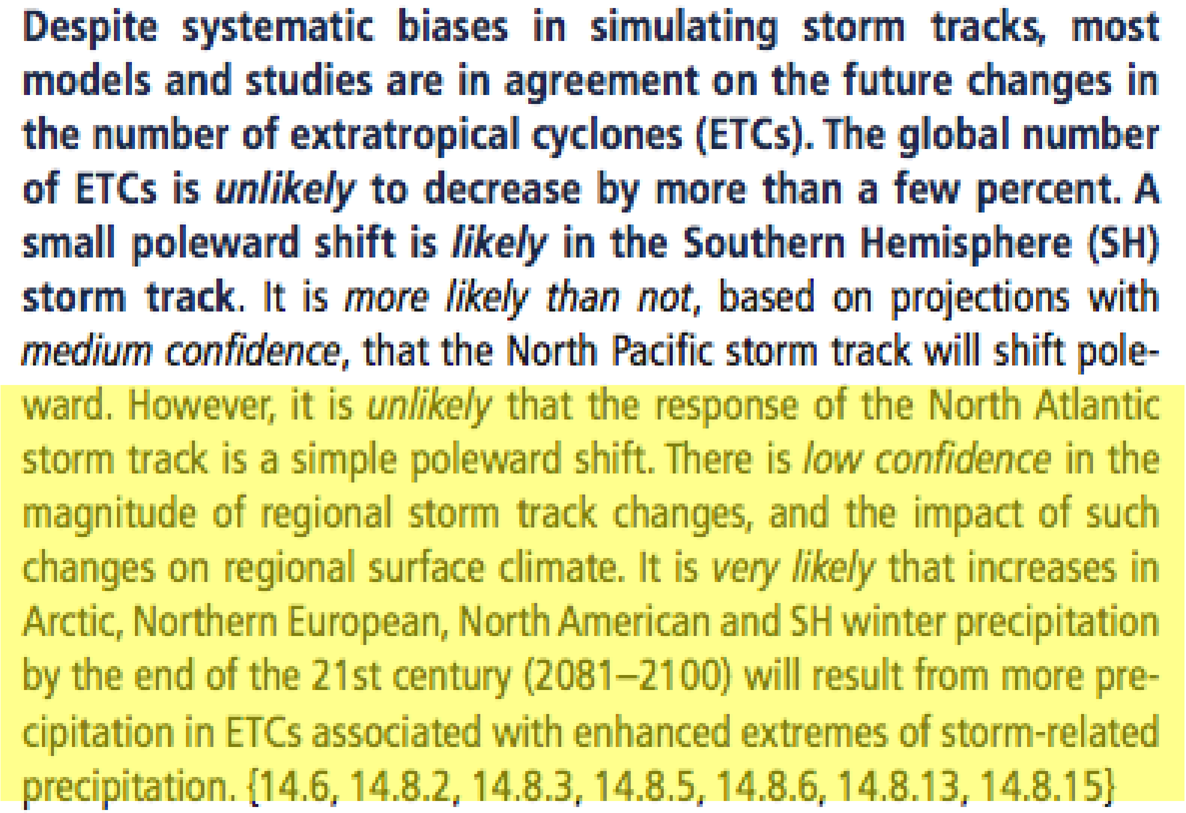
Wind speed intensity (m/s)



Precipitation intensity (mm/day)



IPCC assessment of storm tracks



Despite systematic biases in simulating storm tracks, most models and studies are in agreement on the future changes in the number of extratropical cyclones (ETCs). The global number of ETCs is *unlikely* to decrease by more than a few percent. A small poleward shift is *likely* in the Southern Hemisphere (SH) storm track. It is *more likely than not*, based on projections with *medium confidence*, that the North Pacific storm track will shift poleward. However, it is *unlikely* that the response of the North Atlantic storm track is a simple poleward shift. There is *low confidence* in the magnitude of regional storm track changes, and the impact of such changes on regional surface climate. It is *very likely* that increases in Arctic, Northern European, North American and SH winter precipitation by the end of the 21st century (2081–2100) will result from more precipitation in ETCs associated with enhanced extremes of storm-related precipitation. {14.6, 14.8.2, 14.8.3, 14.8.5, 14.8.6, 14.8.13, 14.8.15}

IPCC uncertainty language

Confidence obtained by multiple lines of evidence that agree.

- *High confidence*
    - *Very likely* $p>0.9$
    - *Likely* $p>2/3$
    - *Unlikely* $p<1/3$

- *Medium confidence*

- *Low confidence*

- Zappa, G., Shaffrey, L., Hodges, K, Sansom, P.G, and D.B. Stephenson, (2012): A multi-model assessment of future projections of North Atlantic and European extratropical cyclones in the CMIP5 climate models. J. Climate, 26, 5846-5862.

- Sansom, P. G., D. B. Stephenson, C.A.T. Ferro, G. Zappa, and L.C. Shaffrey, (2013): Simple uncertainty frameworks for selecting weighting schemes and interpreting multi-model ensemble climate change experiments, Journal of Climate, 26, 4017-4037.

Analogy with UK buses ...

Is this because bus drivers really
love each other?

More to do with rate of arrival depending
on time varying background traffic flow.