European windstorm activity Past, present and future

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Overview

- Introduction
- Storm changes over past 50 to 100 years
- What is causing these changes?
- Future storm activity?
- Applications in insurance?
- References

INTRODUCTION

Introduction

- RMS builds models of insurance risk due to multiple hazards
- European Windstorms is one of the most important
- Insurance companies need to know the risk over the next few years
  - Core uses are for reinsurance pricing and solvency regulations
  - Takes a lot of time and effort for companies to implement new view of hazard climate
  - Therefore companies want stable view of hazard climate over next five to ten years
- We have always used long-term climate as the basis for next few years of windstorm risk
- Researchers have recently gained much knowledge about decadal variations of storm activity
- Should a new view of wind climate include decadal forecast information?

PAST STORM VARIATIONS

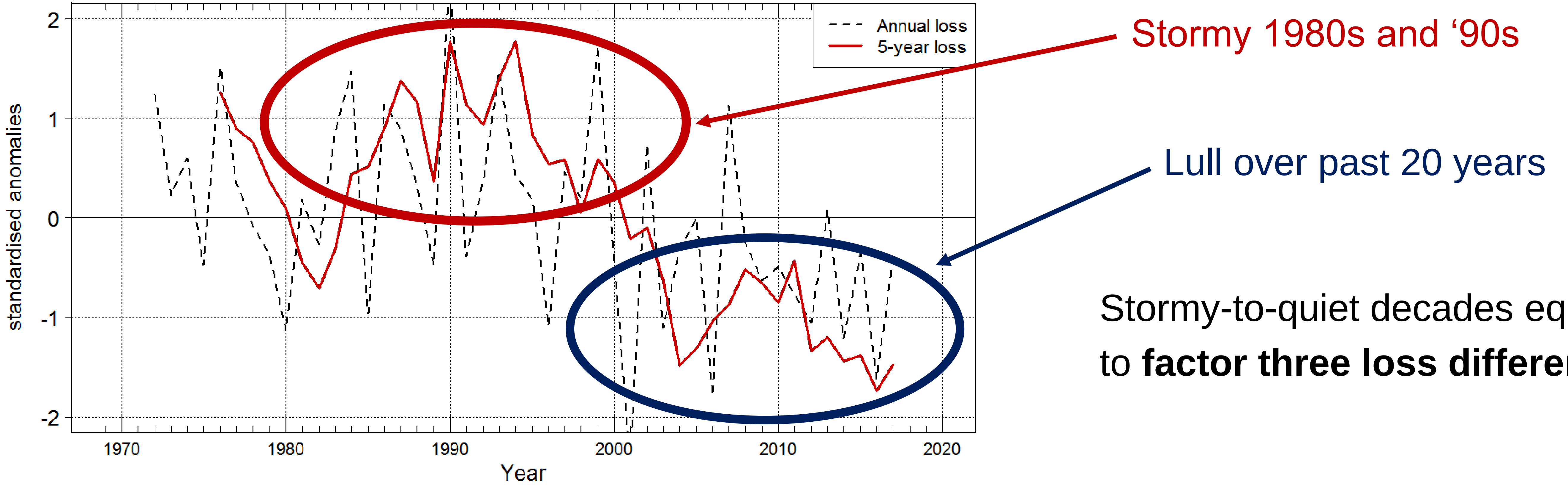
Europe-wide storm activity

- Europe-wide footprints for past storms from RMS
  - Gather all anemometer data, then apply extensive quality control procedures
  - Find max gust per grid-cell per storm
  - Compute loss index per storm based on Klawa and Ulbrich (2003)

$$L = \sum_{i=1}^{N}\left(u_i - u_{i,99}\right)^3 P_i$$

- u_i is wind in i'th cell
- $u_{i,99}$ = 99th percentile of wind in i'th cell
- P_i = population in i'th cell
- N is no. of grid cells in study area

*Timeseries of standardized aggregate **loss** index for main European windstorm countries. Both one-year and five-year running mean losses.*

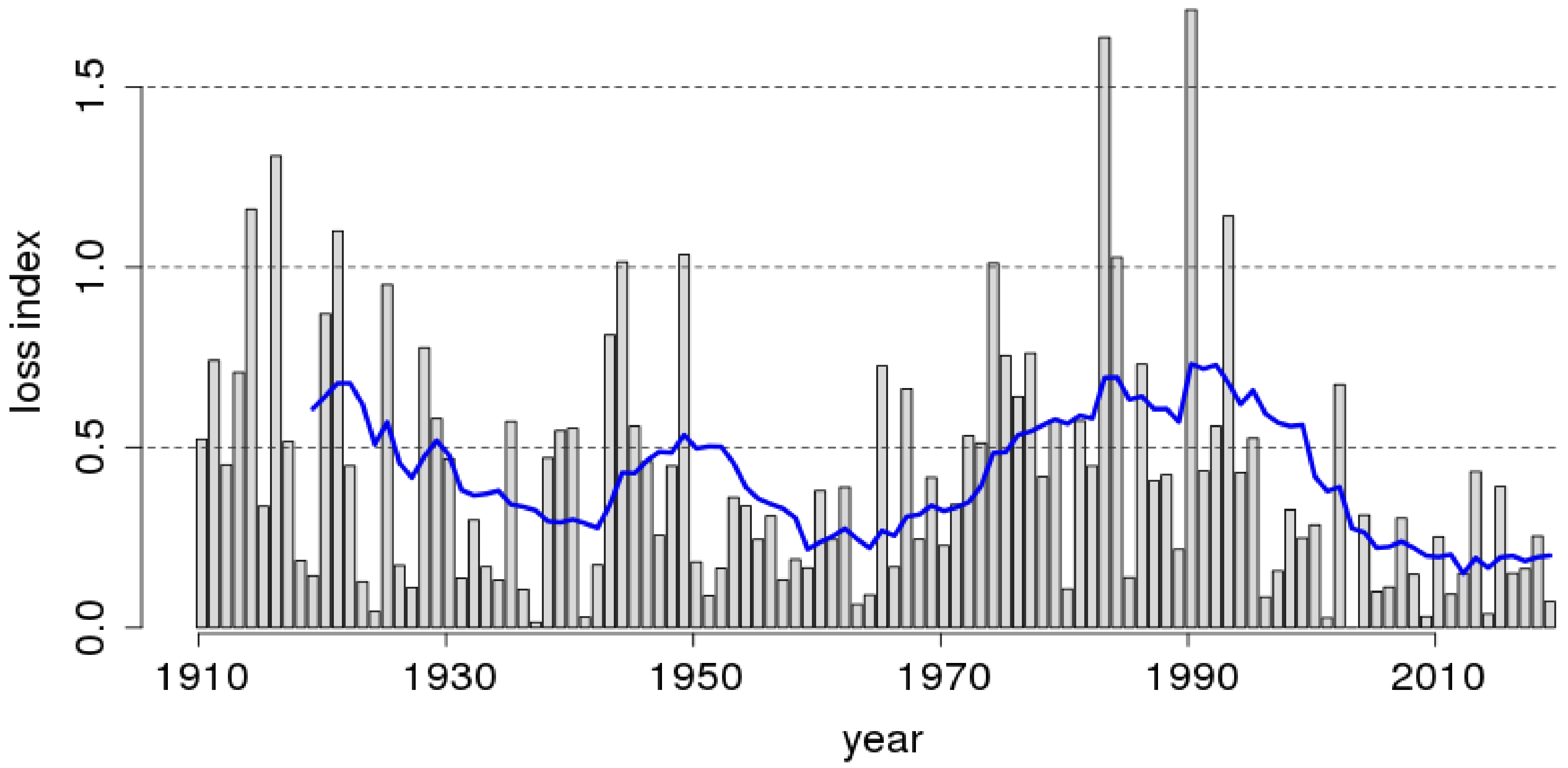


Stormy-to-quiet decades equivalent to **factor three loss difference**

Dutch storm activity

- Cusack (2012) computed losses for 1910-2010 using KNMI wind observations from five Dutch stations
  - Comprehensive quality control, including station metadata (Supp Info of Cusack, 2012)
  - Based on Klawa and Ulbrich (2003) loss index

- Now extended up to 2019



Timeseries of annual storm loss in the Netherlands, with 10-year running means

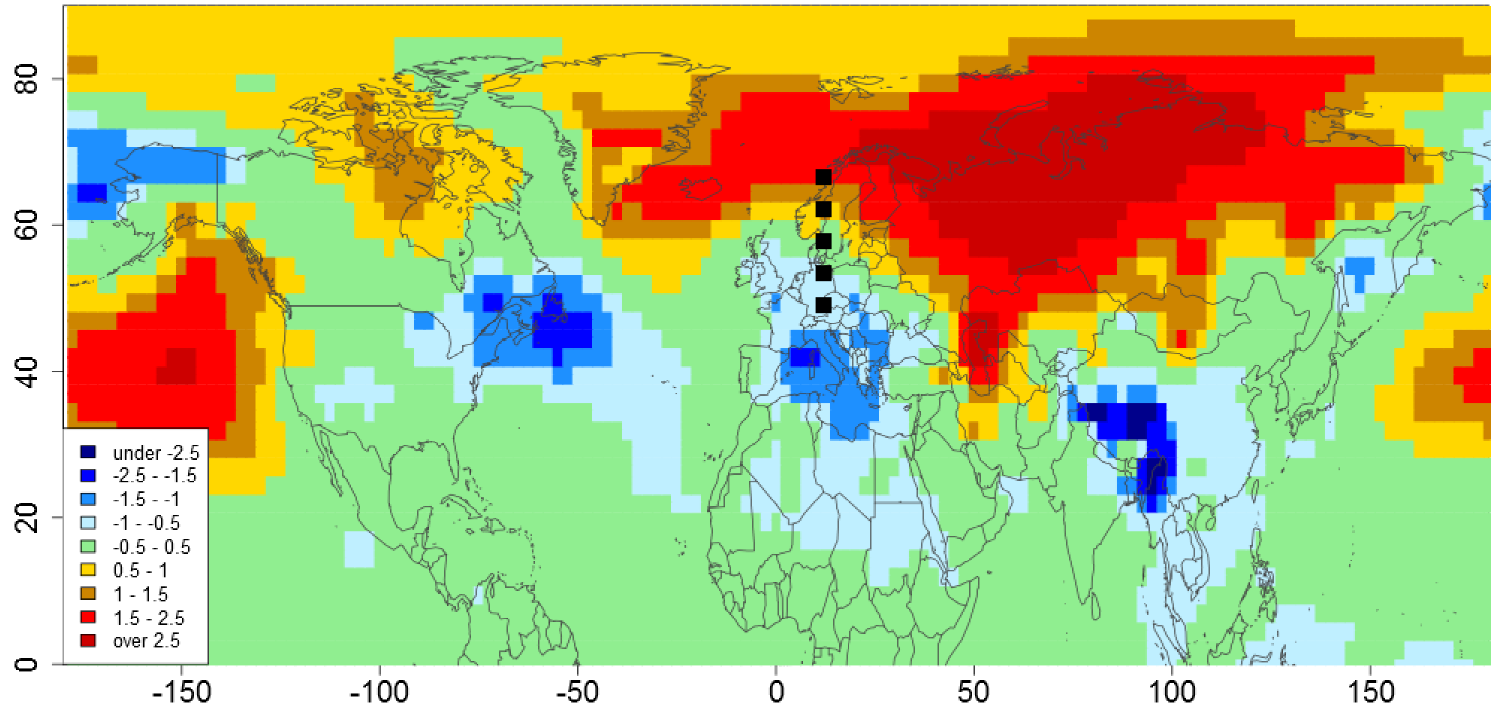
- **Pronounced decadal variations of loss over past 110 years**

- Similar signals as Europe-wide dataset
  - Stormier 1980s/'90s
  - Lull in new millennium

Atmosphere reanalyses

- Artificial trends in storm climate in reanalyses (e.g. Krueger et al., 2013)
- Use north-south mean sea-level pressure (pmsl) gradient at about 10°E as proxy of Europe-wide storminess (black dashed line in plot)
  - Assume % change in extreme storm winds similar to % change in mean wind
  - Reasonable, since both connected to eddy-driven jet
- 2.5 hPa change in gradient between active and quiet periods
- Mean climate gradient is 15 hPa
- **NB**: 10% higher gusts $\Rightarrow$ double storm loss
- Reanalyses suggest large reduction in losses from 1980s/'90s to present day

Difference in winter (Dec-Feb) mean sea-level pressure between (2000–2018) and (1972–1999). Data from NCEP Reanalyses 1.



Key Points

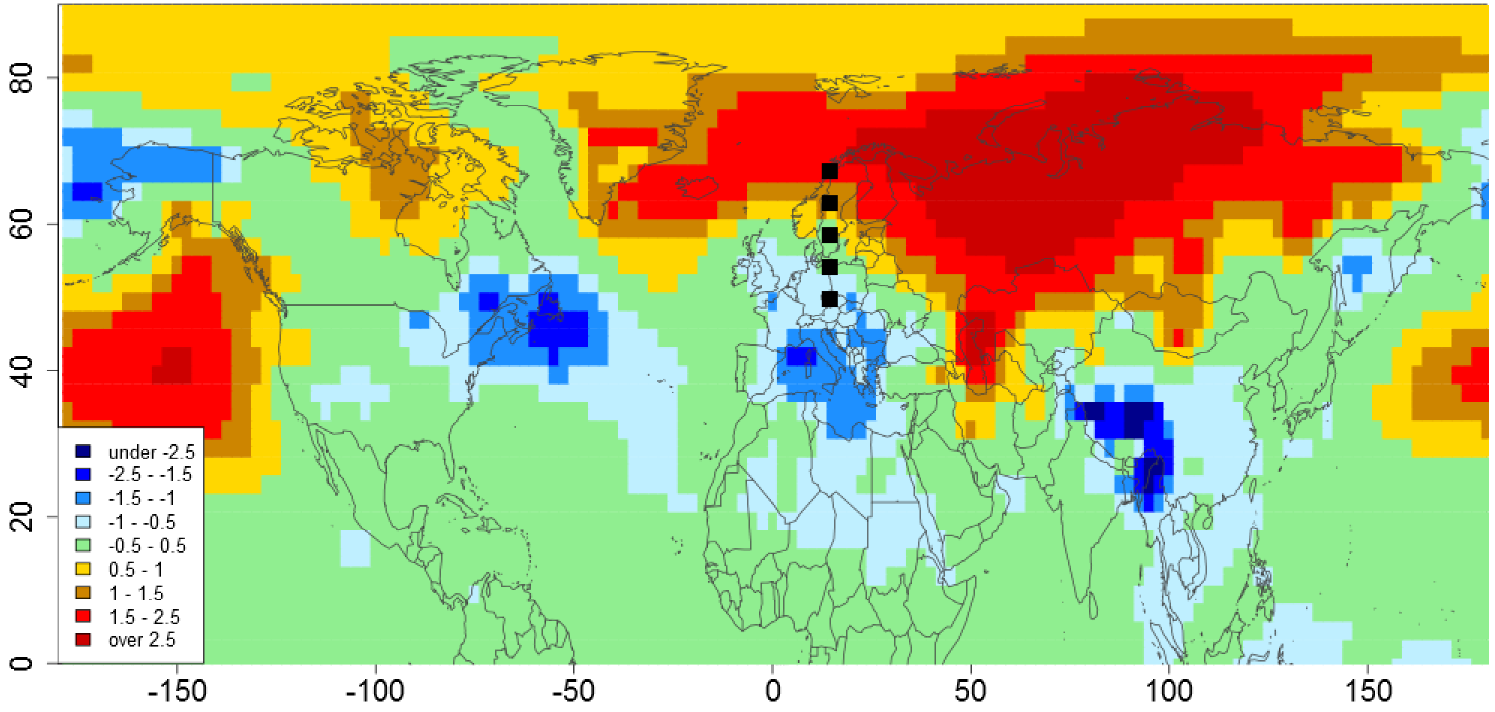
- Factor **three** loss decline from stormy 1980s/90s to lull in past two decades
  - Regional variability within EU (not shown)
- All three independent datasets show a decline to modern-day lull
  - Observed gusts at stations around EU (various national met. centres)
  - Extended wind records from KNMI
  - Mean sea-level pressure from weather reanalyses
- Dutch records contain decadal-scale variability throughout past 110 years
- *What do we know about the drivers of storm variability at decadal timescales?*

DECADAL DRIVERS

Background information

- Most published research articles show change in average pmsl
- Use info from slide 8 to relate pmsl gradient to storminess
  - Use change in north-south pmsl gradient at about 10°E to represent Europe-wide storminess
  - Weakening by about 2.5 hPa can explain much of observed loss change from 1980s/90s to 21st century lull (although method assumes change in gusts in proportion to change in geostrophic wind → not proven)

Difference in winter (Dec-Feb) mean sea-level pressure between (2000–2018) and (1972–1999). Data from NCEP Reanalyses 1



Introduction to drivers

- Researchers have identified two main drivers of storminess at decadal-to-multidecadal timescales

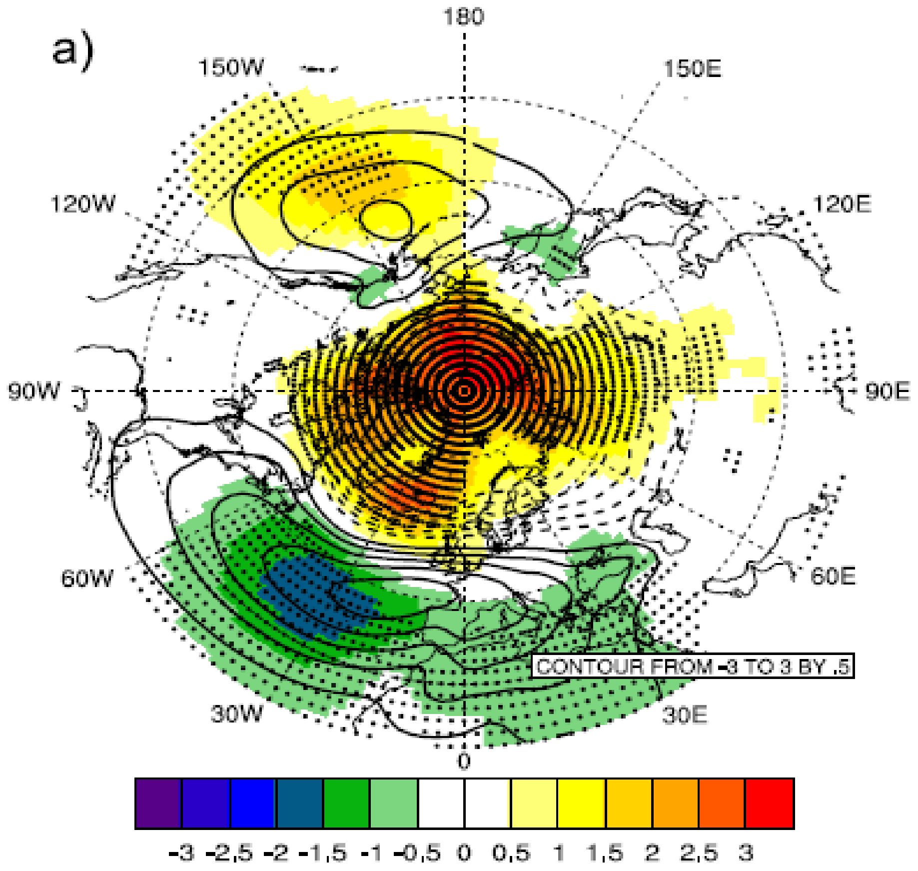
1. North Atlantic Ocean heat anomalies
2. Arctic heat anomalies

- Anthropogenic forcing? Has the right timescale, but not identified as key driver (yet)
  - Discussed later, in Uncertainties in outlook

North Atlantic Ocean: *empirical* studies

- Peings and Magnusdottir (2014) split North Atlantic into warm and cold SST periods, 1901 to 2010
- Then plotted difference in pmsl between warm and cold SST periods
  - SST from HadISST, pmsl from 20CR

Change in surface pressure in December to March for (warm-cold) multidecadal periods in the North Atlantic, Figure 2 of Peings and Magnusdottir (2014)



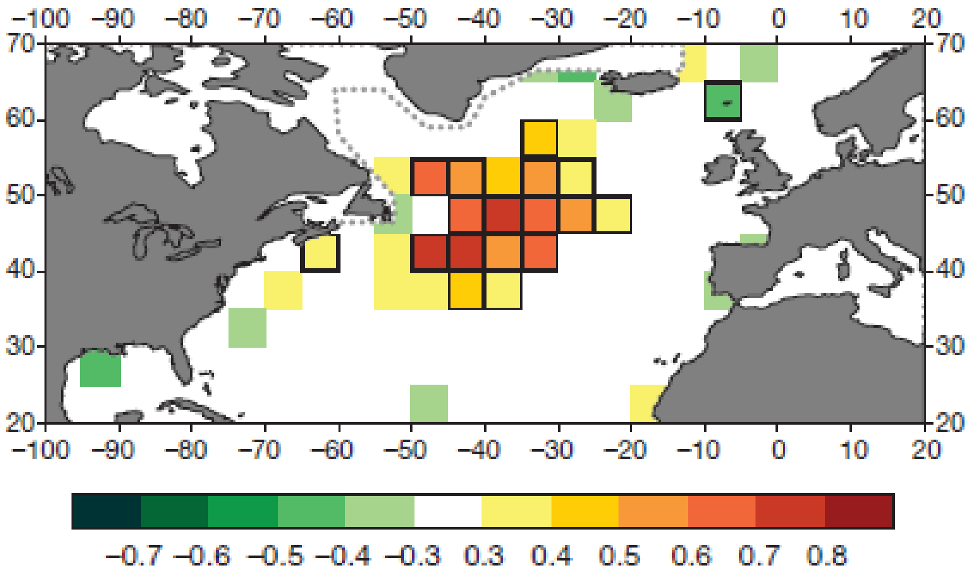
- pmsl changes the most over central Atlantic
  - Projects quite strongly onto NAO
- Smaller change over central Europe, ~1 to 1.5 hPa
- *Warm Atlantic = easterly anomaly over Europe*

A link from North Atlantic SST to European winds

North Atlantic Ocean: *process-based* studies

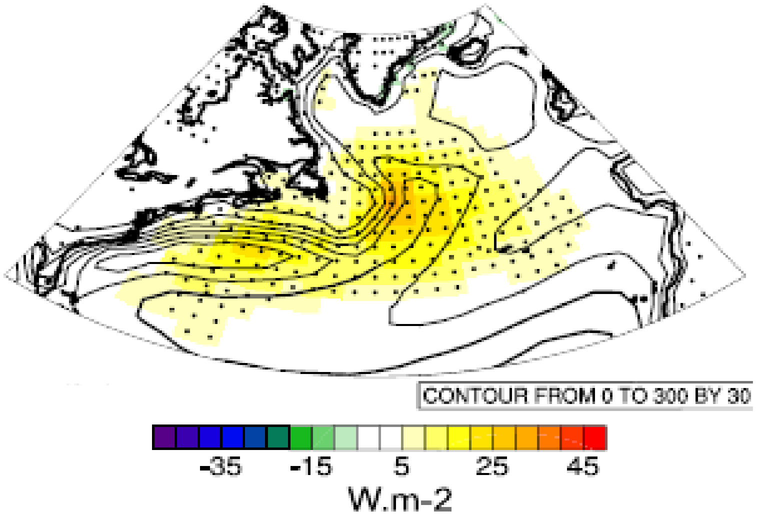
- Gulev et al. (2013) studied SST and surface heat fluxes
- Found *positive* correlation at decadal scales
- Indicates ocean forcing of atmosphere
- Key region in central northern North Atlantic, off Newfoundland
  - Where storm track moves over ocean

Observed correlation of low-pass filtered surface latent heat fluxes and sea surface temperatures in the period 1880–2007, Figure 1b of Gulev et al. (2013).



- Peings and Magnusdottir (2014) studied climate model simulations
- Warmer North Atlantic = more latent heat in Gulev’s key area

⇒ **Decadal scale: ocean forcing atmosphere, in observations and models**

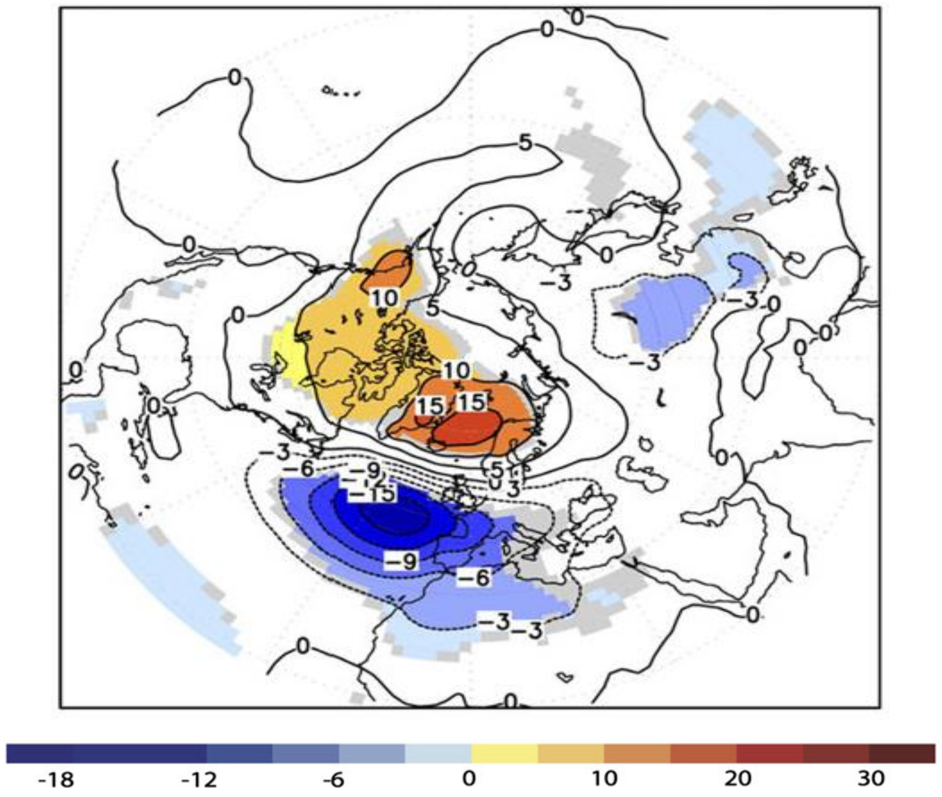


Modeled change in latent heat flux in December–March due to (warm minus cold) North Atlantic experiments, Figure 4c of Peings and Magnusdottir (2014).

North Atlantic Ocean: *climate model* results

- Initial modelling results of North Atlantic Ocean forcing were mixed
  - Some had signal, some did not (e.g. Figure 6 of Hodson et al. 2010)
- Insight from Scaife et al. (2012) on modelling mid-lat winter
  - *Climate models need high top to better simulate mid-lat winter*
- Omrani et al. (2014) high-top model has big signal of ocean forcing
  - Larger impacts over ocean, and 75% of recent Europe decadal signal too
- Their result consistent with empirical and process-based studies
- Significant uncertainties remain:
  - Just one model; idealised test with Atlantic-only anomalies

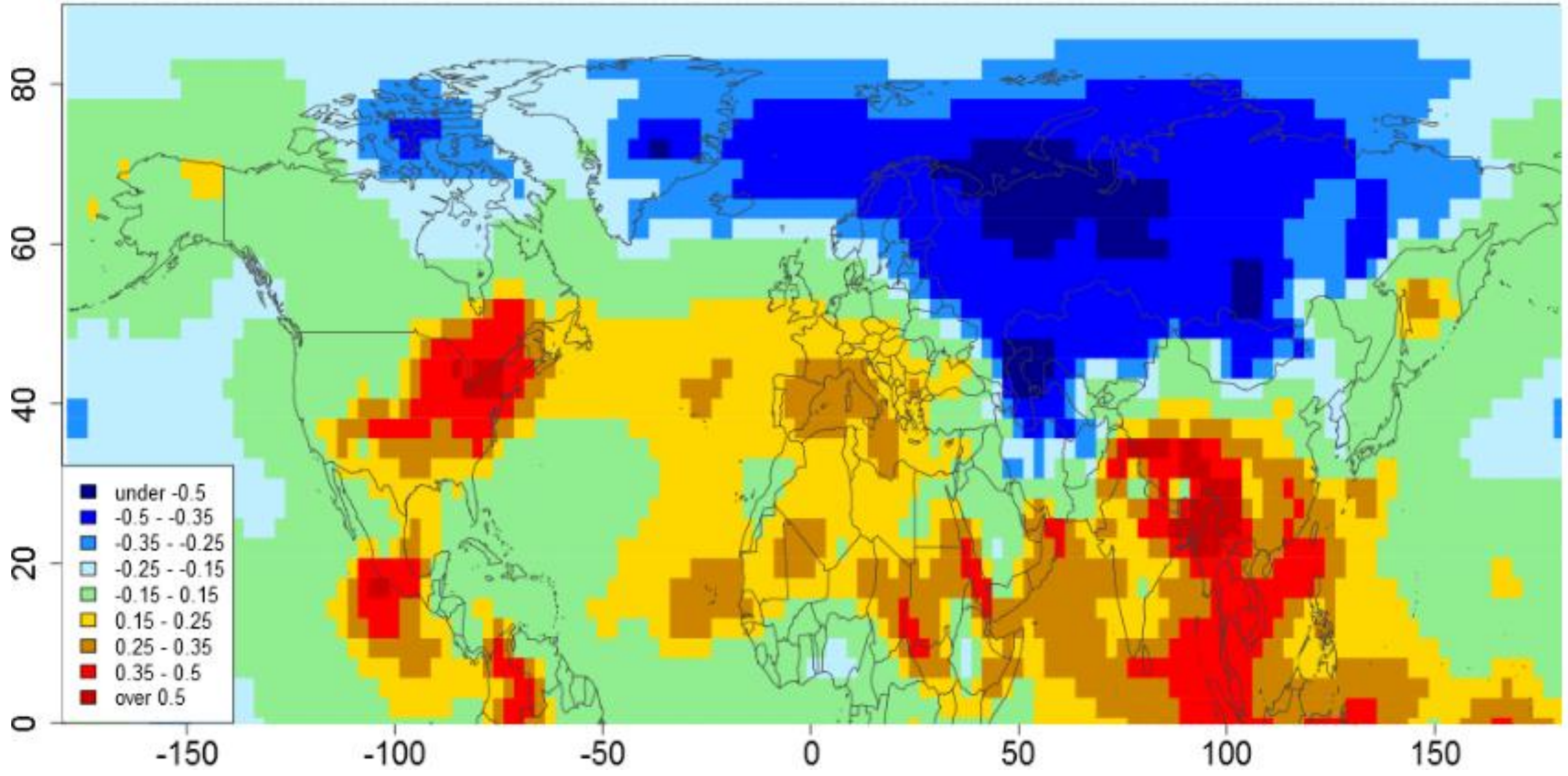
Modeled winter (Jan-Mar) change in geopotential heights at 1000 hPa between the 1950s and 1961–90 reference period, Figure 4a of Omrani et al. (2014).



⇒ *Research suggests North Atlantic forcing accounts for more than half of recent multidecadal decline in storms*

Sea-ice forcing: *empirical* studies

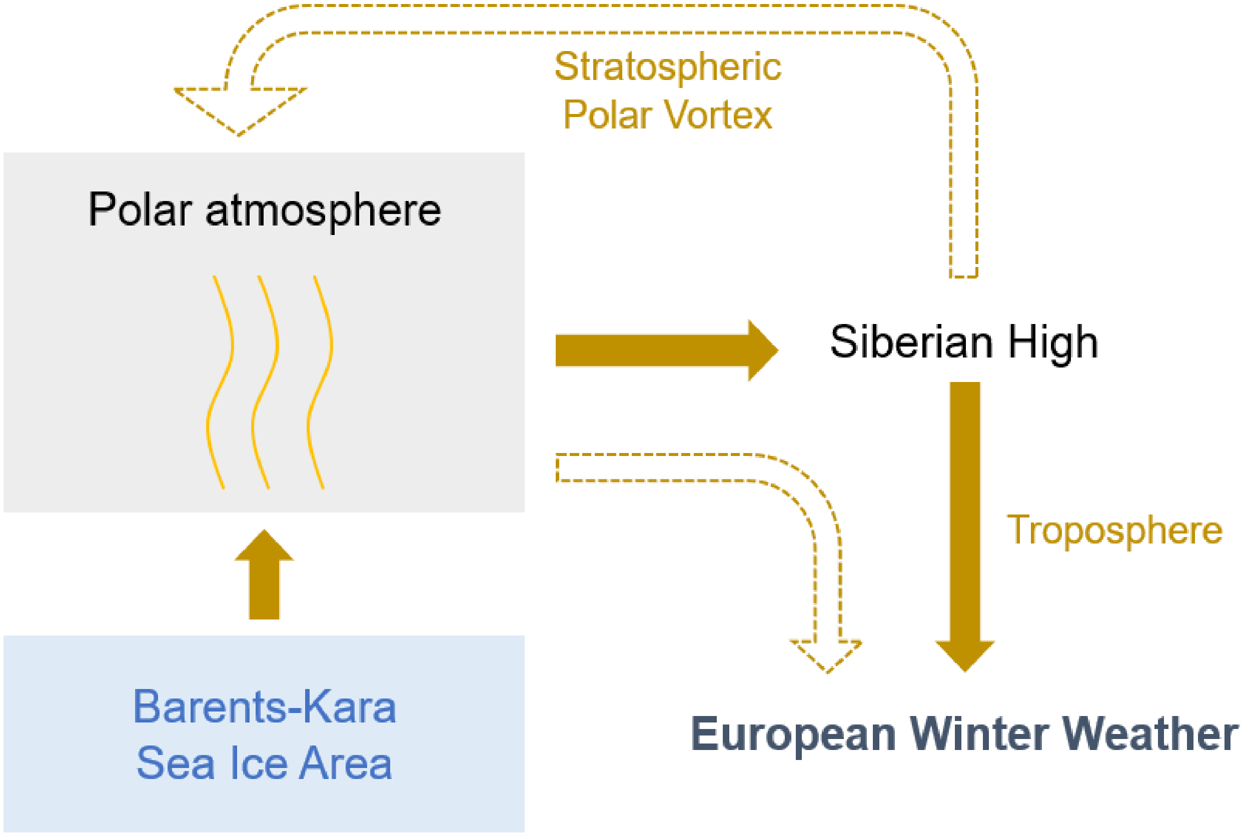
- Several studies highlight strong empirical relation between Arctic sea-ice and pmsl anomalies
- Over Europe, circulation anomalies closely tied to Barents+Kara sea-ice
- Map shows correlation between autumn sea-ice in Barents+Kara Seas with winter pmsl
- Less BK sea-ice $\Rightarrow$ stronger Siberian High $\Rightarrow$ weaker westerlies over Europe



Correlation in 1979–2018 between Barents and Kara sea-ice anomalies in autumn (September–November, from NSIDC) with gridded mean sea-level pressure in the following winter (December–February, from NCEP-NCAR Reanalyses-1).

Sea-ice forcing: *process-based* studies

- Cohen et al. (2020) review of process-based studies
- They suggest the most robust process is:
  1. Warmer Arctic, and sea-ice loss
  2. Newly-opened sea warms air above
  3. Westerlies weaken over northwest Eurasia…
  4. Northwestern expansion of Siberian High
  5. Local stronger Siberian High has two pathways to Europe:
     - Directly inhibits storms from moving into Europe
       - E.g. Rogers (1997)
     - Indirectly reduces storminess by weakening polar vortex
       - E.g. Jaiser et al. (2016)
- Observational studies support this causal chain



A schematic of the process linking Barents and Kara sea-ice to European winter climate

Sea-ice forcing: *climate model* results

- Vast amount of research has defined a set of new climate model requirements:
  1. High-top models: needed for polar vortex simulation (e.g. Omrani et al., 2014; Zhang et al., 2018)
  2. Sea-ice decline: regionality and seasonality important (e.g. Screen, 2017)
  3. Ocean changes accompanying sea-ice change can amplify signal by about 30% (e.g. Deser et al., 2015)
  4. Simulation years: natural internal variability is large in high-latitude winters
  5. Interactive ozone chemistry can improve polar vortex simulation (Romanowsky et al., 2019)

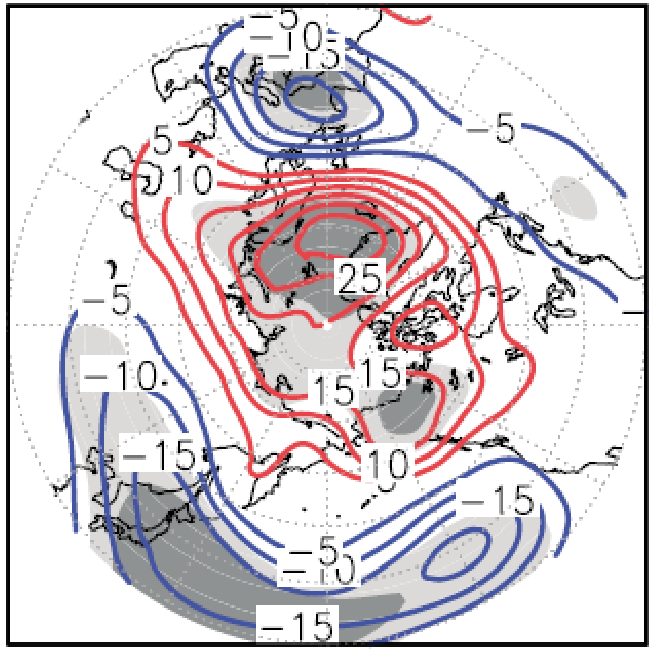
⇒ *Experimental details require scrutiny*

- Will show results from four studies more closely matching model requirements

Sea-ice forcing: *climate model* results

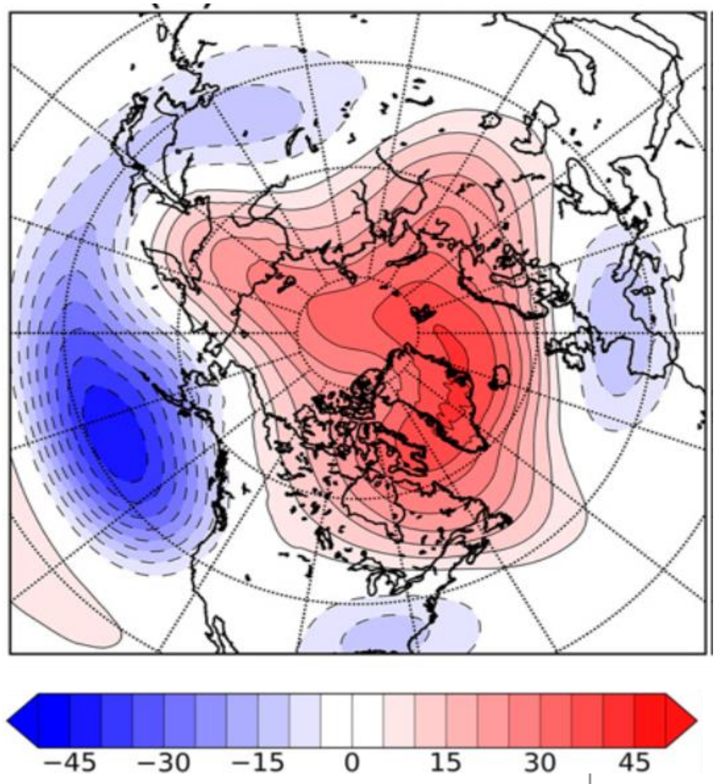
- **Nakamura et al. (2015)**
  - High-top model; historical sea-ice test; 60-year simulations; no ocean feedback
  - Plot shows change in geopotential height at 500 hPa (m) between (2005-09) and (1979-83) mean sea-ice extents

  ⇒ Change in north-south gradient in Europe similar to observed



- **Blackport and Kushner (2016)**
  - Intermediate-top model; 300-year simulations; tested a 50% larger sea-ice decline than history; no ocean feedback
  - Plot: change in geopotential height at 500 hPa (m) due to their sea-ice decline

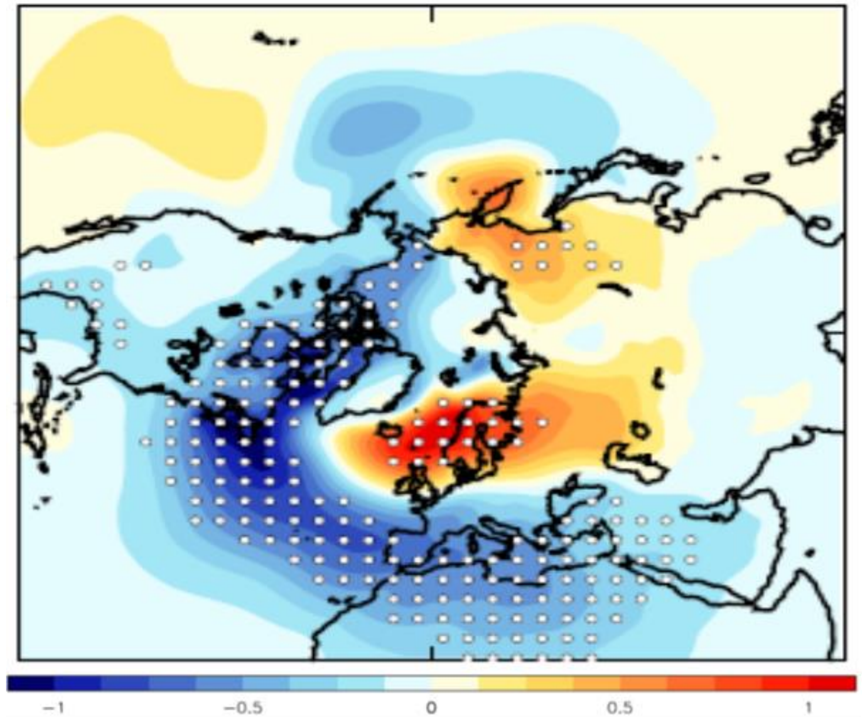
  ⇒ Slightly smaller change in north-south gradient in Europe than observed
    - After scaling sea-ice decline to observed change over past 30 years



Sea-ice forcing: *climate model* results

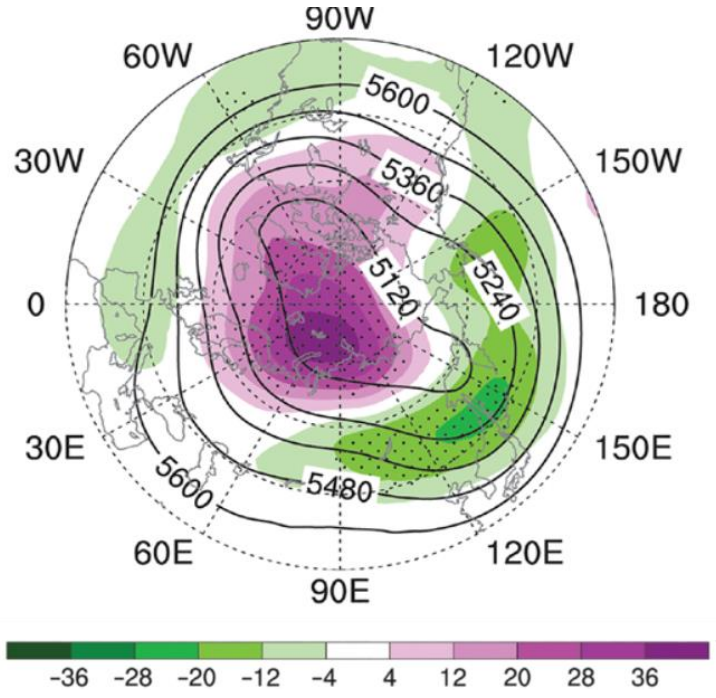
- **Smith et al. (2017)**
  - High-top model; sea-ice declines similar to past 30 years; 300-year simulations; with ocean feedback
  - Plot shows change in pmsl (hPa) for (low – high) sea-ice extents

  ⇒ Change in north-south gradient in Europe slightly more than half of observed recent multidecadal decline



- **Zhang et al. (2018)**
  - High-top model; 50-year simulations; sea-ice decline similar to past 30 years; no ocean feedback
  - Plot shows change in geop ht at 500 hPa (m) due to their sea-ice decline

  ⇒ Change in north-south gradient in Europe similar to observed



Sea-ice forcing: *climate model* results

- There are many other studies of sea-ice decline
- In general, they use older climate models, most commonly ***not*** high-top
- Or the sea-ice perturbation is not like history – in terms of regional amplitude or seasonality
- *Please share if you know others as good as the four on previous slides?*

⇒ **Sea-ice explains more than half of recent multidecadal decline in European storminess**

Combined impacts of ocean and sea-ice?

- Process-based analysis support a strong connection between these two main drivers
  - Atlantic Ocean inflow modulates sea-ice extents in the Barents and Kara Seas
  - From analysis of climate models (e.g. Mahajan et al., 2011)
  - And observational datasets (e.g. Årthun et al., 2012)
  - Connection is two-way: changes in sea-ice affecting AMOC/THC (Sévellec et al., 2017)
- Causal chain:
  - Cooler northern Atlantic drives more storm genesis, and cooler water inflow causes more sea-ice in the Atlantic sector
  - Extra sea-ice weakens Siberian High, and makes it more likely for the storm track to go through Europe
  - This linkage between northern ocean and sea-ice observed over past 100 years
- No climate model results quantifying how the two processes combine

⇒ No destructive interference: combined signal no smaller than larger of two individual signals

Key Points

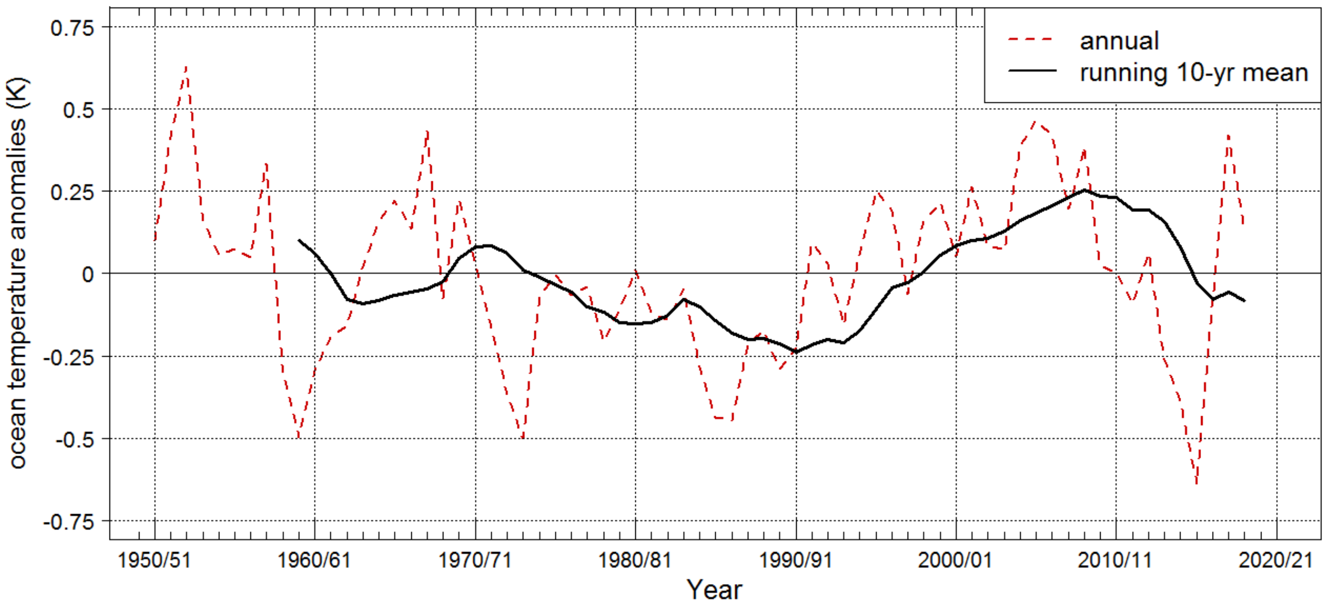
- Heat anomalies in North Atlantic Ocean and Arctic drive multidecadal storm activity
- Likely to explain **more than one half** of decline from stormy 1980s and '90s to the 21st century lull
  - From observational studies of physical processes and pathways
  - Supported by experiments with better climate model configurations
- *What does this mean for European windstorm climate over the next few years?*

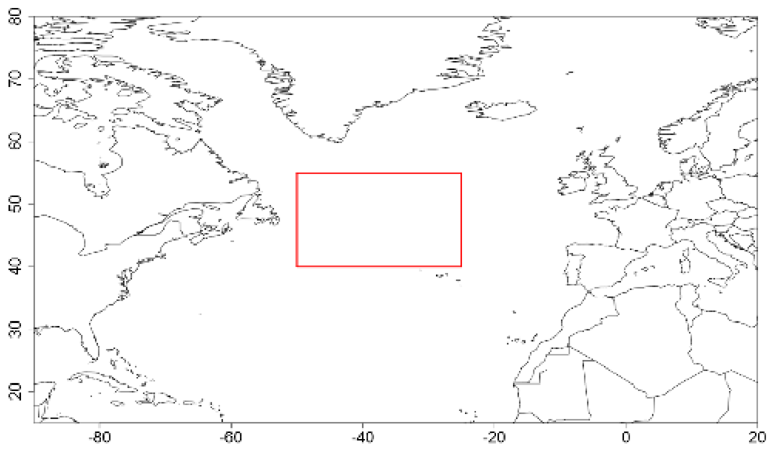
FUTURE STORM ACTIVITY?

North Atlantic Ocean Outlook (1/2)

- Key region (central northern Atlantic) has been cooling recently
  - Driving raised storminess in North Atlantic, but RMS windstorm dataset indicates no similar signal over Europe
- Will cooling continue?
- Encouraging skill of climate models (Yeager et al. 2012; Hermanson et al. 2014) to predict North Atlantic SST
- *But no available forecasts for the key area in central northern Atlantic over next 5-10 years…*

Timeseries of mean temperature anomaly in the top 400 m of the ocean in November to April (left plot), for the region off Newfoundland indicated by red box in the plot on right. Ocean temperatures from EN4 were linearly de-trended to remove global warming signal, because storm track forcing depends more on north-south gradients of temperature, rather than absolute values in a single region

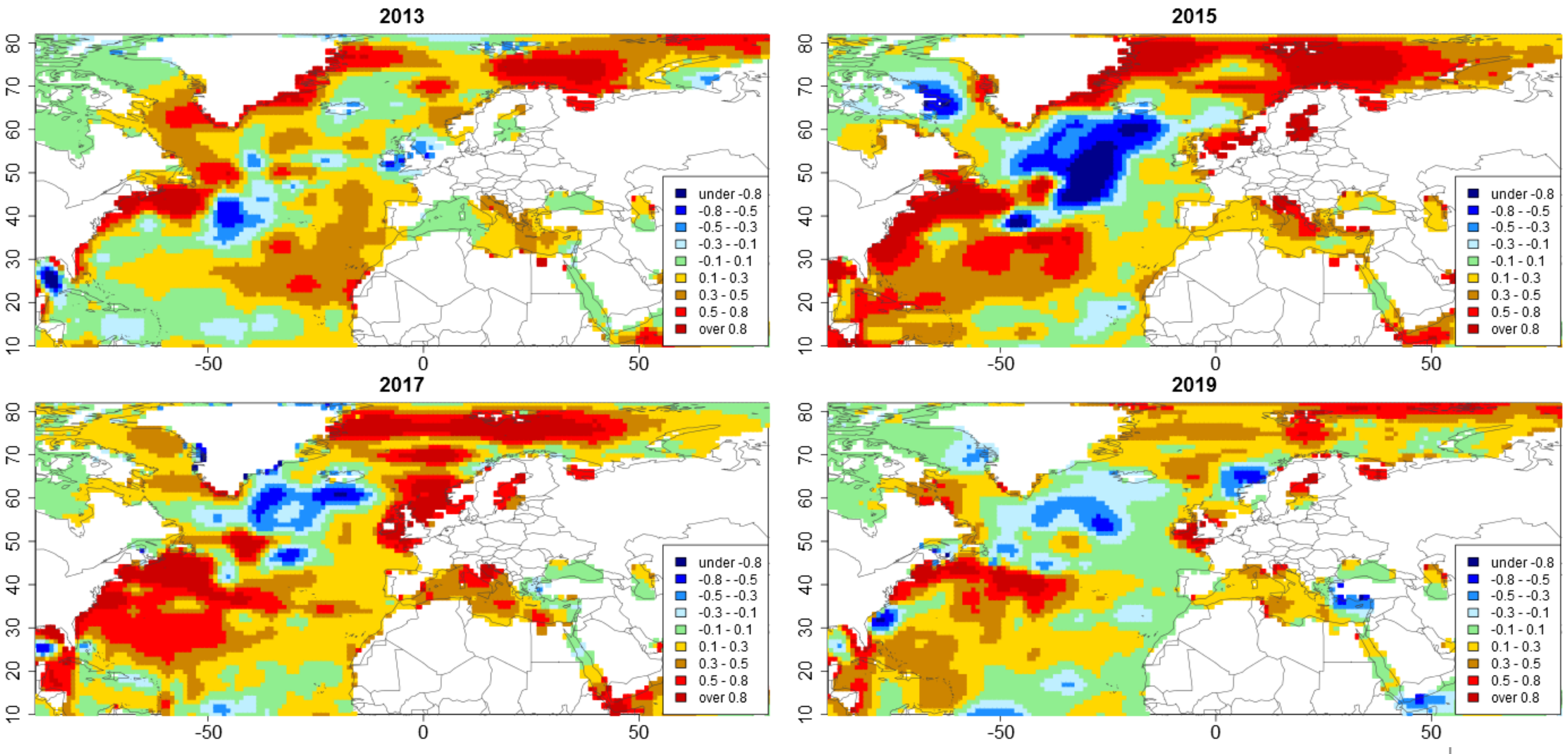




North Atlantic Ocean Outlook (2/2)

- Smeed et al. (2018) report on 15% reduction of AMOC since 2008
- Gastineau and Frankignoul (2012) find this cools northern Atlantic in models
- But warmer Gulf Stream (see maps) suggests increased heat advection into key area

Anomalies of the annual mean temperatures over the top 600 m of the ocean in recent years, with respect to 1950–2019 climatology. Ocean temperatures from EN4, provisional values used for December 2019. Values are plotted where ocean is deeper than 100 m



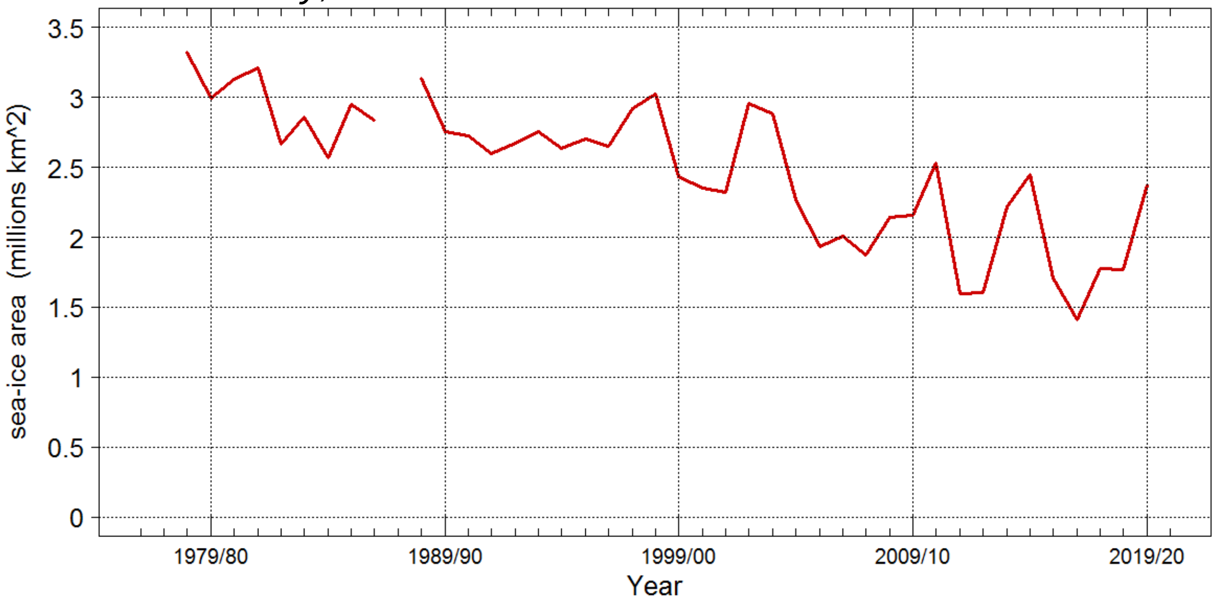
- Overall, weaker AMOC suggests key ocean area remains cool
- With significant uncertainty
- ***Decadal model forecasts would be useful here***

Barents and Kara Sea-ice Outlook

- Two main drivers of BK sea-ice extents

1. Anthropogenic:
   - Greenhouse gases cause amplified warming at high latitudes
   - IPCC : very likely to continue to shrink through 21st century
   - This forcing is on longer timescales, and alters other drivers

The sum of sea-ice area in Barents and Kara Seas for December and January, from NSIDC



2. Advection of North Atlantic ocean heat anomalies
   - Process found in observations (Årthun et al., 2017) and models (Yeager et al., 2015)
   - Recent cooling in northern Atlantic suggests this forcing on BK sea-ice is active
   - Expectation for northern Atlantic to remain cool…
   - Figure S10 of Yeager et al. (2015) – decadal forecasts indicate slight upward trend in Barents sector sea-ice

⇒ Slight reversal of multidecadal BK sea-ice decline over the next few years

Uncertainties (1/2)

- Uncertain predictions of future state of the two storm drivers:
  - Will warm Gulf Stream anomalies overcome a slower AMOC to warm the central northern Atlantic?
  - Is the current stormier North Atlantic driving a stronger AMOC, but not yet distinguishable from noise?
  - Will the unexplained 6-year cycle in winter sea-ice in previous slide cause a flip back to reduced sea-ice?

- Anthropogenic forcing
  - On long timescales, it's a battle between two large opposing forces
  - Tropical upper troposphere warming increasing storminess
  - Arctic sea-ice melt weakening westerlies, reducing storminess
  - IPCC: "*Substantial uncertainty and thus low confidence remains in projecting changes in northern hemisphere storm tracks, especially for the North Atlantic basin*"
  - Further, could the transient response include imbalances between the two big opposing forcings of storminess?

Uncertainties (2/2)

- An explosive, sulphur-rich volcanic eruption in the tropics could significantly alter European windstorm risk over the following few years (e.g. Fischer et al., 2007)
- Natural variability, with no known link to decadal drivers, could overwhelm all forcings?
- Uncertainty in method: we use time-mean pmsl gradients to inform on changes in peak gusts
  - Peak gust is a combination of geostrophic, and ageostrophic mesoscale components
  - Foregoing analysis assumes ageostrophic part changes in proportion with the geostrophic part

$\Rightarrow$ There are many sources of uncertainty in forecasts for next ten years

Key Points

- Cooler northern Atlantic could be key influence over next few years
  - ⇒ More storminess, especially over North Atlantic
  - ⇒ Less ocean heat into Barents Sea, slight increase in sea-ice, then storm-track favours path through Europe

- Overall, the forecast suggests raised storm losses in Europe compared to past 10 years

- But there are many uncertainties
  - Evolution of the two main drivers is uncertain
  - Other processes may become more prominent in next ten years
    - E.g. major volcanic eruption, anthropogenic effects (esp. tropical heating), natural internal variability

APPLICATIONS IN INSURANCE?

Defining hazard climate for insurance companies

- Translating climate model skill to new view of hazard climate has some challenges
- We know a view of hazard climate covering next 5 to 10 years is more practicable for insurance
- What about regionality?
  - Recent multidecadal signal has regionality, larger amplitude changes in northwest Europe etc
  - Problem: regional storm information from climate model forecasts is more uncertain
    - Large internal variability + model biases in communicating signals from remote areas (e.g. Smith et al., 2017)
  - Should we use forecasts of key drivers, then a simpler stats model to relate this to European regional signals?
- Incomplete information in forecast creates uncertainty:
  - Forecast refers to a mean storminess change; insurance companies need to know full pdf
- Reliability is important for insurance (avoid insolvencies etc); how to manage forecast uncertainty?
- Keen to get the views of insurance companies, researchers, decadal forecasting groups

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