Modelling serial clustering of European winter windstorms

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Contents

1. Serial Clustering and Motivation
2. Data and Statistical Model
3. Results
   I. Identified large scale drivers
   II. Performance of the statistical model
   III. “Map of drivers” – Spatial distribution of drivers
4. Summary/Outlook
Contents

1. Serial Clustering and Motivation
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3. Results
   I. Identified large scale drivers
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   III. “Map of drivers” – Spatial distribution of drivers
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Serial Clustering of annual windstorm counts

- Key component in understanding inter-annual variability of windstorms
  → Year to year variability

- Common statistical definition:
  → Deviation of windstorm count time series from a Poisson distribution

- How well is a statistical model able to reproduce serial clustering?
  → Application in the actuarial industry
Motivation

Trying to answer two questions:

For a particular region, what are the essential large scale drivers for serial clustering?

Where is the main area of action for the leading large scale drivers with regard to inter-annual variability on grid cell level?

Impact perspective

Statistical model

+ SSTs, QBO...

Physical perspective

Image: Courtesy of NOAA
Definition of Serial Clustering

Quantification of serial clustering through Dispersion score $D$ (Mailier et al., 2006)

$$D = \frac{\sigma^2}{\mu} - 1$$

($\sigma^2$ storm count variance, $\mu$ storm count mean)

Poisson distribution:

- $D < 0$ under-dispersed
- $D = 0$
- $D > 0$ over-dispersed

Clustered time series

Neg. Binomial

Mean = 14.73, Variance = 43.03

Counts

Index
Contents

1. Serial Clustering and Motivation
2. *Data and Statistical Model*
3. Results
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   II. Performance of the statistical model
   III. “Map of drivers” – Spatial distribution of drivers
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Windstorms and large scale drivers

- Objective windstorm tracking algorithm (Kruschke, 2015 and Leckebusch et al. 2008)
- Based on exceedance of 98th percentile
- Tracked in ECMWF ERA 20C (1901-2008)
- Counts per DJF per region
- All drivers were computed using ERA 20C except for QBO (Broennimann et al. 2007)
Modelling serial clustering

Inter-annual variability for a region

1. Serial Clustering statistic $D$

2. Active/Inactive season (AS/IAS) $\mu_r \pm \sigma_r$
Figure: Regions for the 7 different models
Walz et al., 2017 submitted to IJOC

- 7 Regions based on **insurance related regions**
- Potential pool of 20 large-scale drivers

<table>
<thead>
<tr>
<th>Index Name</th>
<th>Long name</th>
</tr>
</thead>
<tbody>
<tr>
<td>QBO30</td>
<td>Quasi-Biennial Oscillation (30 hPa)</td>
</tr>
<tr>
<td>QBO70</td>
<td>Quasi-Biennial Oscillation (70 hPa)</td>
</tr>
<tr>
<td>AMO</td>
<td>Atlantic Meridional Oscillation</td>
</tr>
<tr>
<td>HIS</td>
<td>Horse-Shoe-Index</td>
</tr>
<tr>
<td>SSTS</td>
<td>Southern Box of HSI</td>
</tr>
<tr>
<td>Tdif.Nam</td>
<td>Temperature difference North America – West Atlantic</td>
</tr>
<tr>
<td>W.Atl T</td>
<td>West Atlantic SST</td>
</tr>
<tr>
<td>NINO3.4</td>
<td>Nino 3.4 index</td>
</tr>
<tr>
<td>NAO.Is.Li</td>
<td>Station Based NAO index</td>
</tr>
<tr>
<td>PDO</td>
<td>Pacific Decadal Oscillation</td>
</tr>
<tr>
<td>West Pac</td>
<td>West Pacific Pattern (EOF)</td>
</tr>
<tr>
<td>PNA</td>
<td>Pacific-North American pattern (EOF)</td>
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<tr>
<td>EOF10</td>
<td>West Pacific pattern II (EOF)</td>
</tr>
<tr>
<td>EA.WR</td>
<td>East Atlantic/West Russia pattern (EOF)</td>
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<tr>
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<td>East Atlantic pattern (EOF)</td>
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<tr>
<td>SCA</td>
<td>Scandinavian Pattern (EOF)</td>
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<tr>
<td>TNH</td>
<td>Tropical Northern hemisphere (EOF)</td>
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<tr>
<td>EP.NP</td>
<td>East Pacific/North Pacific pattern (EOF)</td>
</tr>
<tr>
<td>POL</td>
<td>Polar index (POL)</td>
</tr>
<tr>
<td>Sea Ice</td>
<td>Northern Hemispheric sea ice cover</td>
</tr>
</tbody>
</table>
Poisson GLM: European regions

- Stepwise AIC approach for driver selection for every region
- $\chi^2$ –test to test for significance of drivers
- Poisson GLM:

$$y(t) \sim \text{Poisson}(\lambda(t))$$

$$\log(\lambda(t)) = \beta_0 + \beta_1 x_1(t) + \sum_{i=2}^{N} \beta_i x_i(t)$$

Annual storm counts

- Linear time trend
- Selected driver time series
5 predominant drivers identified by AIC are examined on grid cell level

- Poisson model for 1x1 degree grid cell
- Identifying the driver that explains most variability per grid cell

→ Spatial distribution of most important drivers of inter-annual variability
Contents

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Identified large scale drivers

Table: Identified large scale drivers per region and observed and modelled Dispersion score

<table>
<thead>
<tr>
<th>Selected large scale drivers</th>
<th>BI Region 1</th>
<th>C.Eur Region 2</th>
<th>BI/C.Eur Region 3</th>
<th>Scand Region 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>NAO stat</td>
<td>SCA</td>
<td>SCA</td>
<td>SCA</td>
<td>SCA</td>
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<tr>
<td>SCA Tdif.Nam</td>
<td>Tdif.Nam</td>
<td>NAO stat</td>
<td>West Atl. T</td>
<td></td>
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<tr>
<td>EA POL</td>
<td>QBO30</td>
<td>Tdif.Nam</td>
<td>W.Atl.T</td>
<td></td>
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<tr>
<td></td>
<td>EA</td>
<td>EOF 10</td>
<td>West Pac</td>
<td></td>
</tr>
<tr>
<td></td>
<td>EA.WR</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dispersion score D model</td>
<td>1.14</td>
<td>0.12</td>
<td>0.60</td>
<td>1.54</td>
</tr>
<tr>
<td>Dispersion score D observed</td>
<td>1.94</td>
<td>0.85</td>
<td>1.35</td>
<td>2.67</td>
</tr>
</tbody>
</table>

- SCA, NAO and EA appear as key drivers
- Tdif.Nam (Wild et al., 2016) and W.Atl.T also explain variance
- Modelled Dispersion score generally too small
Qualitative performance of statistical model

Figure: Windstorm frequency per year for the British Isles from 1901-2008. Circles indicate active/inactive seasons. Walz et al., 2017 submitted to IJOC

- Significant trend in observations (cf. Befort et al., 2016)
- Satisfactorily performance of predicting annual storm count
# Quantitative performance of the Poisson model

**Table: Cross validated skill scores for the developed statistical model**

<table>
<thead>
<tr>
<th>Region</th>
<th>Hit rate active</th>
<th>Hit rate inactive</th>
<th>D bias Model-Obs</th>
<th>Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>British Isles</td>
<td>78.9%</td>
<td>61.1%</td>
<td>-0.80</td>
<td>0.84</td>
</tr>
<tr>
<td>Central Europe</td>
<td>71.1%</td>
<td>50.0%</td>
<td>-0.73</td>
<td>0.72</td>
</tr>
<tr>
<td>BI+C.Europe</td>
<td>71.1%</td>
<td>65.5%</td>
<td>-0.75</td>
<td>0.81</td>
</tr>
<tr>
<td>Scandinavia</td>
<td>75.0%</td>
<td>64.3%</td>
<td>-1.13</td>
<td>0.82</td>
</tr>
</tbody>
</table>

- Underestimation of $D \rightarrow$ underestimation of inter-annual variability by model
Large scale driver on grid cell level – Map of drivers

Figure: Left: Most dominant pattern explaining the inter-annual variability of windstorm. Right: Explained deviance of the Poisson regression. Walz et al., 2017 submitted to IJOC
Large scale driver on grid cell level

Figure: Significant Poisson GLM regression coefficients for the dominant selected large scale drivers

Walz et al., 2017 submitted to IJOC

- Prominent NAO pattern
- SCA as main driver for Central Europe
- POL for Scandinavia
Contents

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Summary/Outlook

- Statistical model to estimate seasonal clustering and also active/inactive seasons
- Identified drivers entail SCA, NAO, W.Atl.T
- “Map of drivers”:
  - SCA is dominant driver for windstorms in Central Europe
  - NAO for Brit. Isles and NA
- Statistical model with time lag → SON indices
- Interactions between drivers in statistical model
References


