Influence of geomagnetic activity on the wintertime electricity consumption in Finland via Northern Annular Mode

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1. Introduction

Prevailing weather conditions and especially temperatures are known to have a huge effect on electricity consumption in different European countries (Bessec & Fouquau, 2008; Pilli-Sihvola et al. 2010). In winter much of electricity is used for heating purposes in countries that have cold winter temperatures, including Finland (see Figs 1 and 2).

It is also known that energetic particle precipitation (EPP), associated with increased geomagnetic activity produces ozone-depleting odd hydrogen (HOx) and nitrogen oxides (NOx). Ozone depletion leads to cooling of the lower polar stratosphere and associated strengthening of the stratospheric polar vortex (e.g., Salminen et al., 2019).

Variations of the polar vortex can be seen down at the surface in Northern Annular Mode (NAM). Stronger polar vortex leads to more positive NAM → warm and wet winter weather in Northern Europe (see Fig. 4).

The EPP effect on the vortex and ground climate is more efficient during the negative QBO phase (e.g., Salminen et al., 2019). It has been suggested that during easterly QBO more planetary waves are directed to higher latitudes (Holton-Tan effect) thereby intensifying wave-mean-flow interactions, which amplify EPP-related changes in atmospheric winds (e.g., Asikainen et al., 2020; Salminen et al., 2022).

Here we investigate how the influence of geomagnetic activity (proxy for EPP) on Northern Annular Mode can be seen in the wintertime electricity consumption in Finland.

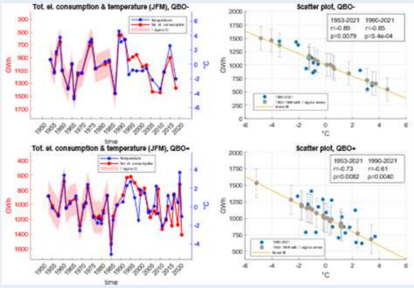

Figure 1. The total electricity consumption related to surface temperatures in Finland. Time series and scatter plots in different QBO-phases.

2. Data and Methods

We used the following datasets:
- NCEP/NCAR Reanalysis for temperature and geopotential height
- International Service of Geomagnetic Indices (ISGI) for geomagnetic aa-index
- Statistics of Finland (Tilastokeskus) for the total electricity consumption
- Free University of Berlin (FuB) QBO data

Trend removal for temperature and total electricity consumption data:
- We remove a linear trend from temperature data from each calendar month separately.
- From total electricity consumption we remove a smooth trend by using LOESS method. A span value of 0.2 (fraction of data points included in smoothing) was chosen because it gives the best correlation between Jan-Mar (JFM) averages of the total electricity consumption and surface temperature in Finland (r=-0.72).

Reconstruction of the total electricity consumption:
- We also reconstruct representative monthly total electricity consumption values for 1953-1989 by linear regression with surface temperature data over Finland. We note that errors of the reconstruction are smaller during winter (high correlation) while for summer months the reconstruction does not give reliable estimates.

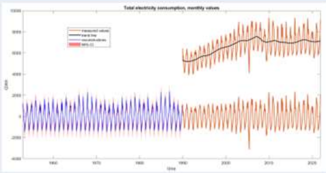

Figure 2. Monthly total electricity consumption in Finland. Trend line (black) is removed from the data. Reconstructed values (1959-1989) are represented in blue color with 95% confidence intervals.

Northern Annular Mode (NAM) index:
- We calculate the NAM index as the leading principal component of the monthly geopotential height anomalies.
- NAM explains around 20-30 % of the total variance in geopotential height during northern winter.
- Positive (negative) NAM → lower (higher) than average air pressure on the pole → stronger (weaker) westerly winds → warm and wet (cold and dry) winter weather in Northern Europe

Quasi-biennial oscillation (QBO):
- Roughly 28-month oscillation of equatorial stratospheric zonal winds between easterly (negative) and westerly (positive) phases
- We consider here the monthly QBO at 30 hPa pressure level.

Estimation of correlations and errors for reconstructed electricity data:
- When calculating correlations involving reconstructed electricity consumption we take into account the uncertainty of the reconstructed points.
- We add a random set of residuals for the reconstructed values in a Monte Carlo simulation (10 000 repetitions) and calculate the correlation as mean value of repetitions.
- P-values are estimated by shifting these total electricity consumption data series randomly in a similar Monte Carlo simulation and estimating the fraction of correlations larger than the observed correlation.

3. Results

The geomagnetic activity (aa-index) and NAM are related to surface temperature

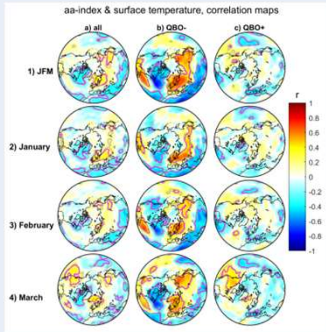

Figure 3. Correlation maps between the aa-index and surface temperature at latitudes 20-90˚ N. 1953-2021. QBO is taken from February. Gray (pink) contours indicate 95% (99%) significance

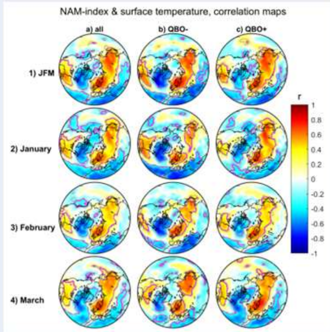

Figure 4. Correlation maps between the NAM-index and surface temperature at latitudes 20-90˚ N. 1953-2021. QBO is taken from February.

The geomagnetic activity correlates positively with NAM and produces a NAM-like temperature pattern, which has a strong impact in Scandinavia and Finland.

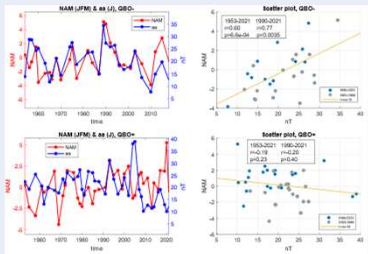

Figure 5. NAM correlates with aa-index during negative QBO-phase when studying the JFM-averages. Better correlation is obtained when only data from 1990-2021 is used.

NAM strongly influences the total electricity consumption in Finland.

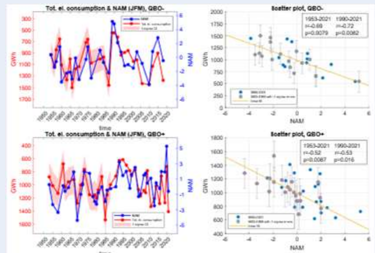

Figure 6. NAM correlates with the total electricity consumption in Finland a bit better during QBO-negative winters.

Geomagnetic activity correlates with total electricity consumption in Finland.

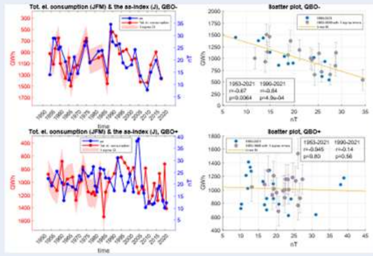

Figure 7. Geomagnetic activity (aa-index) correlates with the total electricity consumption in Finland. A good response is obtained only during QBO-negative winters.

Table 1. Correlations between aa-index and the total electricity consumption in different winter months. QBO is taken from February and aa from previous or same month as indicated in table.

Calendar month	All winters	QBO-	QBO+
December 1953-2021 (aa Nov)	r=-0.20 (p=0.11)	r=-0.23 (p=0.21)	r=-0.20 (p=0.25)
December 1990-2021	r=-0.31 (p=0.089)	r=-0.37 (p=0.26)	r=-0.29 (p=0.22)
January 1953-2021 (aa Jan)	r=-0.26 (p=0.029)	r=-0.45 (p=0.021)	r=-0.13 (p=0.46)
January 1990-2021	r=-0.39 (p=0.027)	r=-0.61 (p=0.033)	r=-0.30 (p=0.19)
February 1953-2021 (aa Jan)	r=-0.23 (p=0.067)	r=-0.64 (p=0.0075)	r=0.094 (p=0.54)
February 1990-2021	r=-0.24 (p=0.18)	r=-0.75 (p=0.0048)	r=0.0037 (p=0.99)
March 1953-2021 (aa Feb)	r=-0.33 (p=0.0077)	r=-0.53 (p=0.0090)	r=-0.088 (p=0.61)
March 1990-2021	r=-0.43 (p=0.015)	r=-0.59 (p=0.044)	r=-0.22 (p=0.36)

4. Conclusions

- High geomagnetic activity (high EPP) → stronger polar vortex and more positive NAM during easterly QBO → warmer winter temperatures in Finland → decreased wintertime electricity consumption in Finland
- Low geomagnetic activity (low EPP) → weaker polar vortex and negative NAM during easterly QBO → colder winter temperatures → increased wintertime electricity consumption in Finland
- Thus, the polar vortex works as a link transmitting the EPP effects down to the surface level when the QBO phase is favorable (easterly)
- The effect of geomagnetic activity explains around 45-70% of the variation in Finland´s wintertime total electricity consumption in easterly QBO phase

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