Trends in Wave Height and its Relation to Cyclone Activity in the NE Atlantic

-

Winter season (DJF) of 1959-2002

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Motivation

Investigate trends in winter season statistics of Hs and its relation to:

- *NAO – North Atlantic Oscillation*
- *Cyclone activity*

=> which is the more “robust” wave-predictor in the sense of climate projections?

Data and methodology

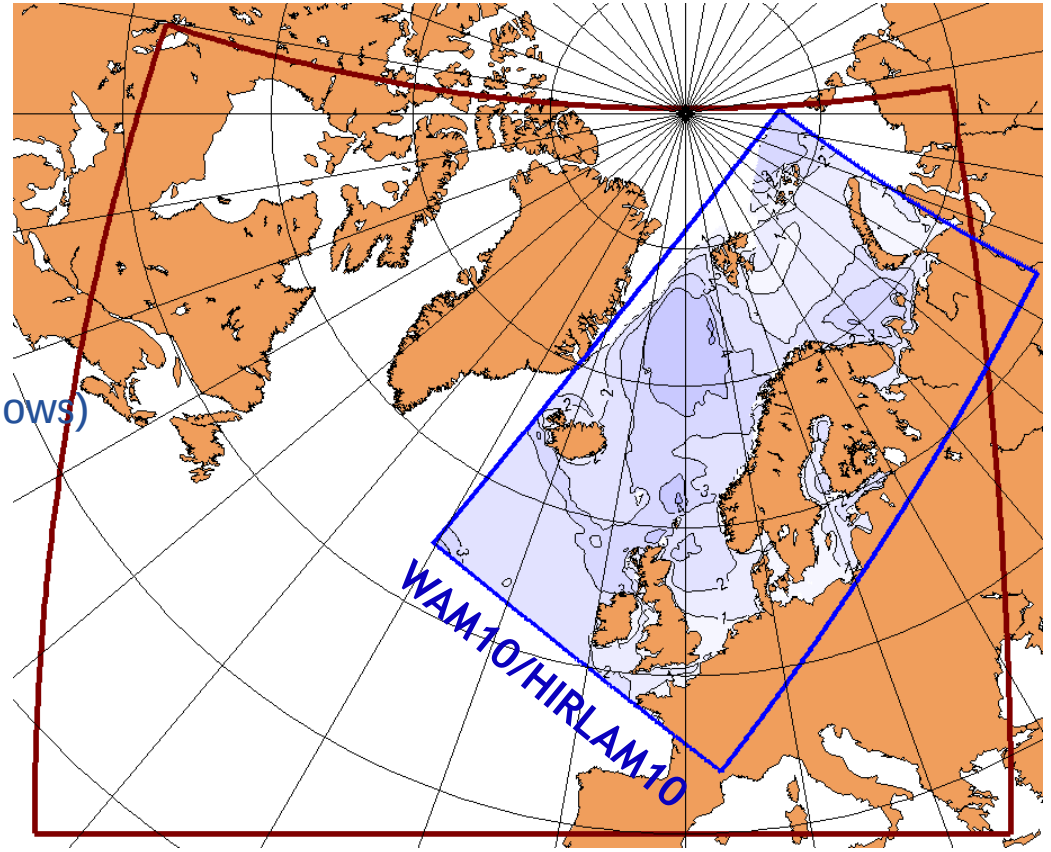
- Use two (three) corresponding data bases:
  - *NORA10:*
    - Hs statistics (mean, p90, p99, max)
  - *ERA-40:*
    - Cyclone tracks
  - NAO index - difference in normalized pressure between Iceland and the Azores
- Trend analysis:
  - Based on Kendall's rank correlation & Mann Kendall significance test
- Trend and correlation maps

Summary of conclusions

- Trends in Hs:
  - Overall a 0-0.75 % increase per year
  - Only decrease is found in max Hs in the N-Norwegian Sea (~-0.25 %)
  - Significance is mainly obtained in the North Sea, SW Baltic Sea and W-N of the British Isles
- Trends in cyclone activity:
  - corresponds with Hs, but are locally higher: < 1.5 %
- NAO is found superior to cyclone activity as a predictor for seasonal Hs

NORA10 – NOrwegian ReAnalysis 10 km

- Nested model:
  - WAM50/ERA40
  - WAM10/HIRLAM10
- Digital filter between ERA40/HIRLAM10
  - Maintain large-scale features
  - Resolve mesoscale features (polar lows)
- Ice edge updated weekly
- Output:
  - 248 x 400 grid points
  - 10 km resolution
  - 3-hourly data (Sep. 1957-2010)



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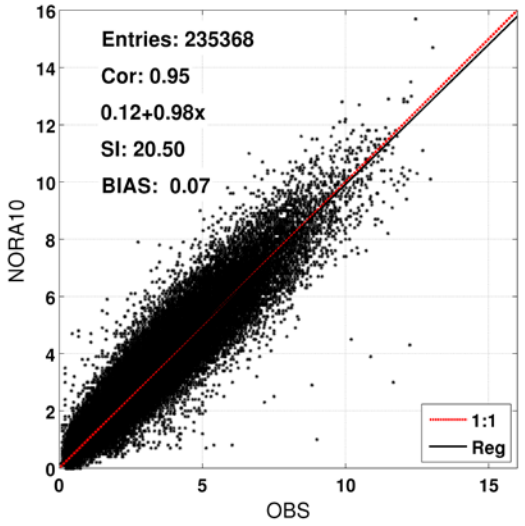
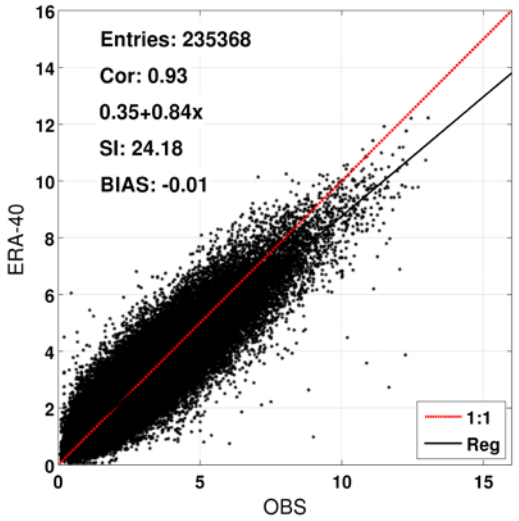


NORA10



ERA-40

Extracting cyclone tracks from ERA-40

- Relative vorticity field at 850 hPa
- Threshold: $10^{-5}\ s^{-1}$
- Local extremes are identified and linked together between consecutive time steps
- Cyclone lifespan shorter than 1 day is removed
- Time step: 6 hours
- Main synoptic features of ERA-40 should correspond very well with NORA10

$$\xi = \frac{\partial v_r}{\partial x} - \frac{\partial u_r}{\partial y}$$

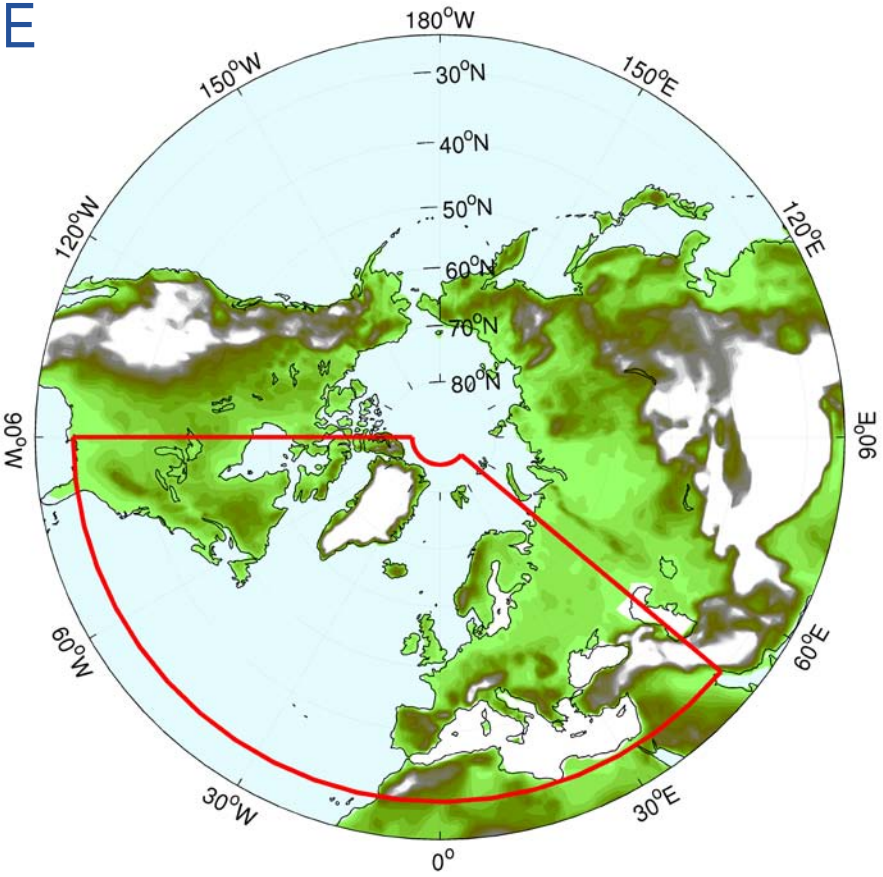
Big thanks to Professor Asgeir Sorteberg, University of Bergen, Norway

Sorteberg, A., and J. E. Walsh (2008), Seasonal cyclone variability at 70N and its impact on moisture transport into the Arctic, Tellus, Ser. A, 60, 570–586.

Gridding cyclone tracks

- Focus area: 30N-85N & 90W-50E
- 1°x 1° grid
- Cyclone activity within 5°x 5°
  - Counts
  - Cyclone Activity Index – CAI (intensity, number, residence)

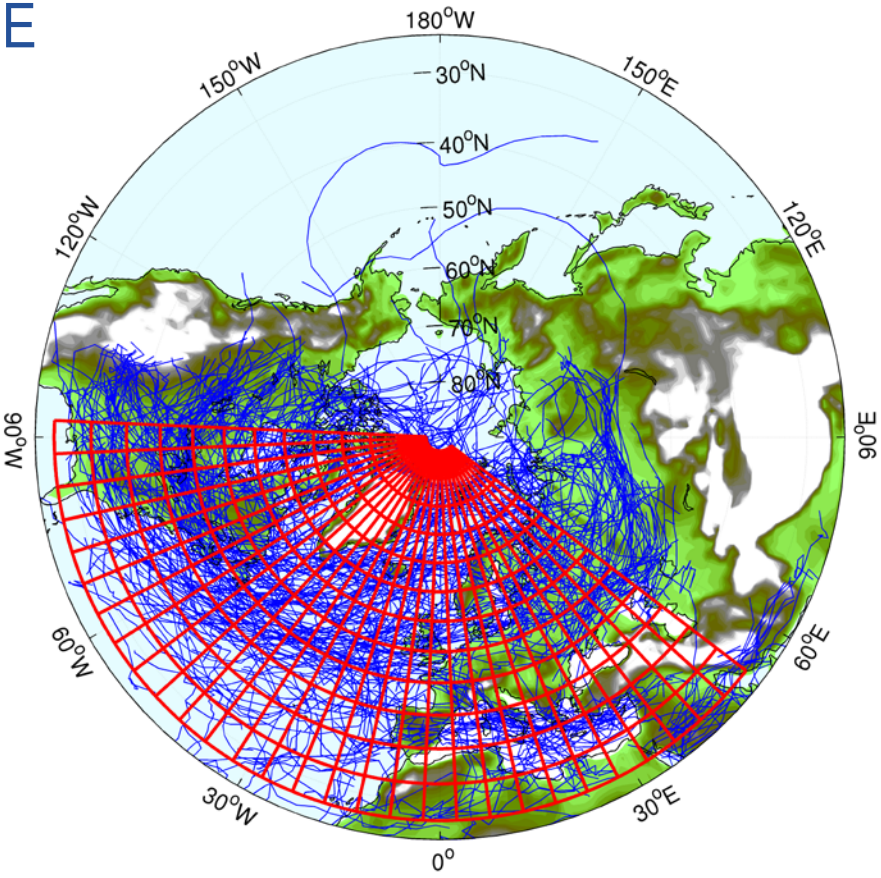
$$CAI = \sum_{i=1}^{n} \xi_{i,\varphi\pm2.5^{\circ}/\lambda\pm2.5^{\circ}}$$



Gridding cyclone tracks

- Focus area: 30N-85N & 90W-50E
- 1°x 1° grid
- Cyclone activity within 5°x 5°
  - Counts
  - Cyclone Activity Index – CAI (strength, number, residence)

$$CAI = \sum_{i=1}^{n} \xi_{i,\varphi\pm2.5^{\circ}/\lambda\pm2.5^{\circ}}$$



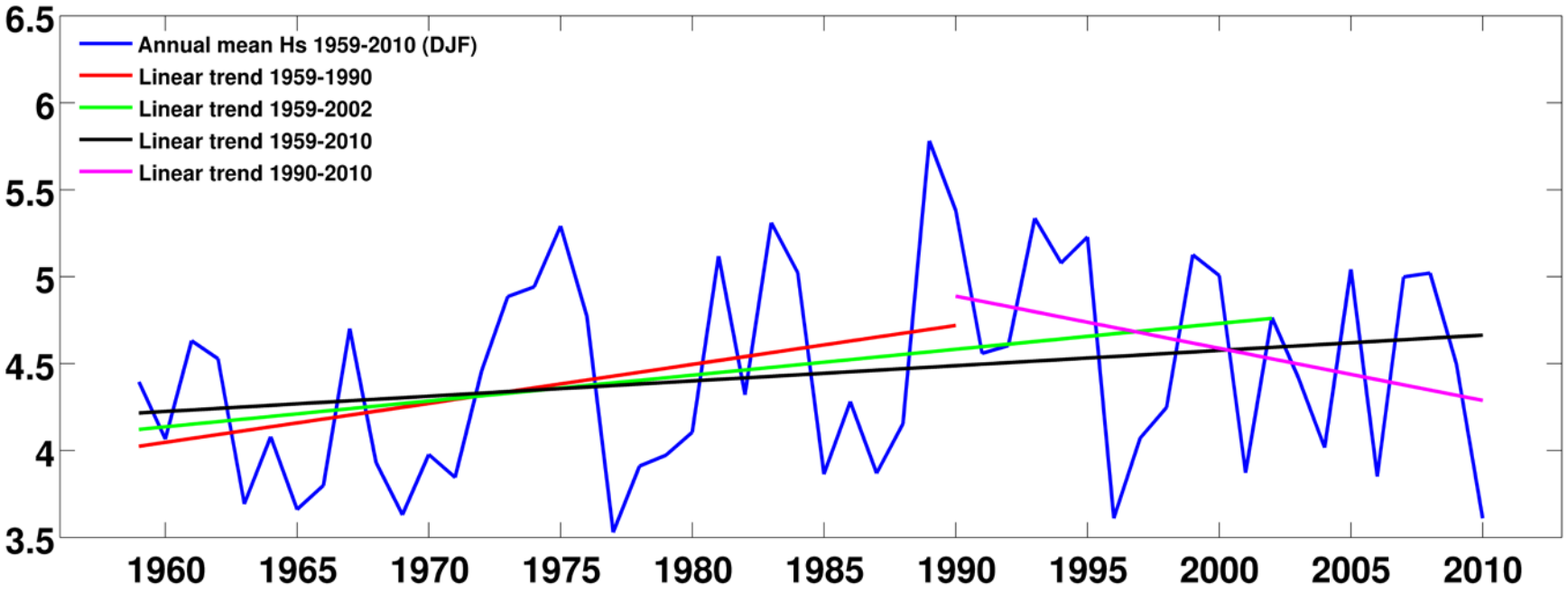
Cyclone tracks: 1995-1997

Trend analysis

- Trend
  - We assume a fit to a linear model: $Y(t) = a + bt + e$
  - Follow Sen (1968), based on Kendall's rank correlation, to obtain an estimate of b (non-parametric approach)

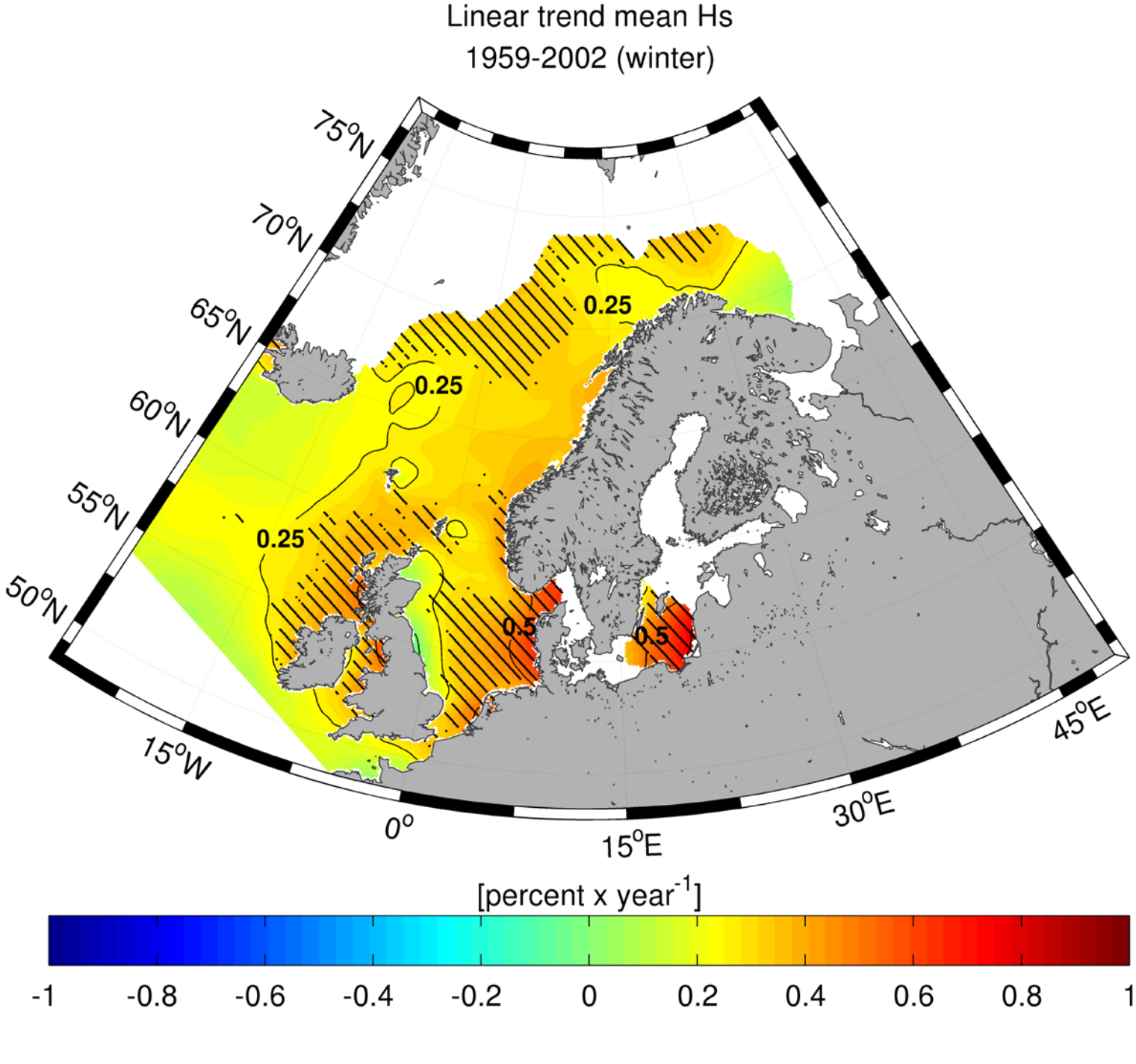
$$b = median\left(\frac{X_j - X_i}{j - i}\right) \quad \forall\, i < j$$

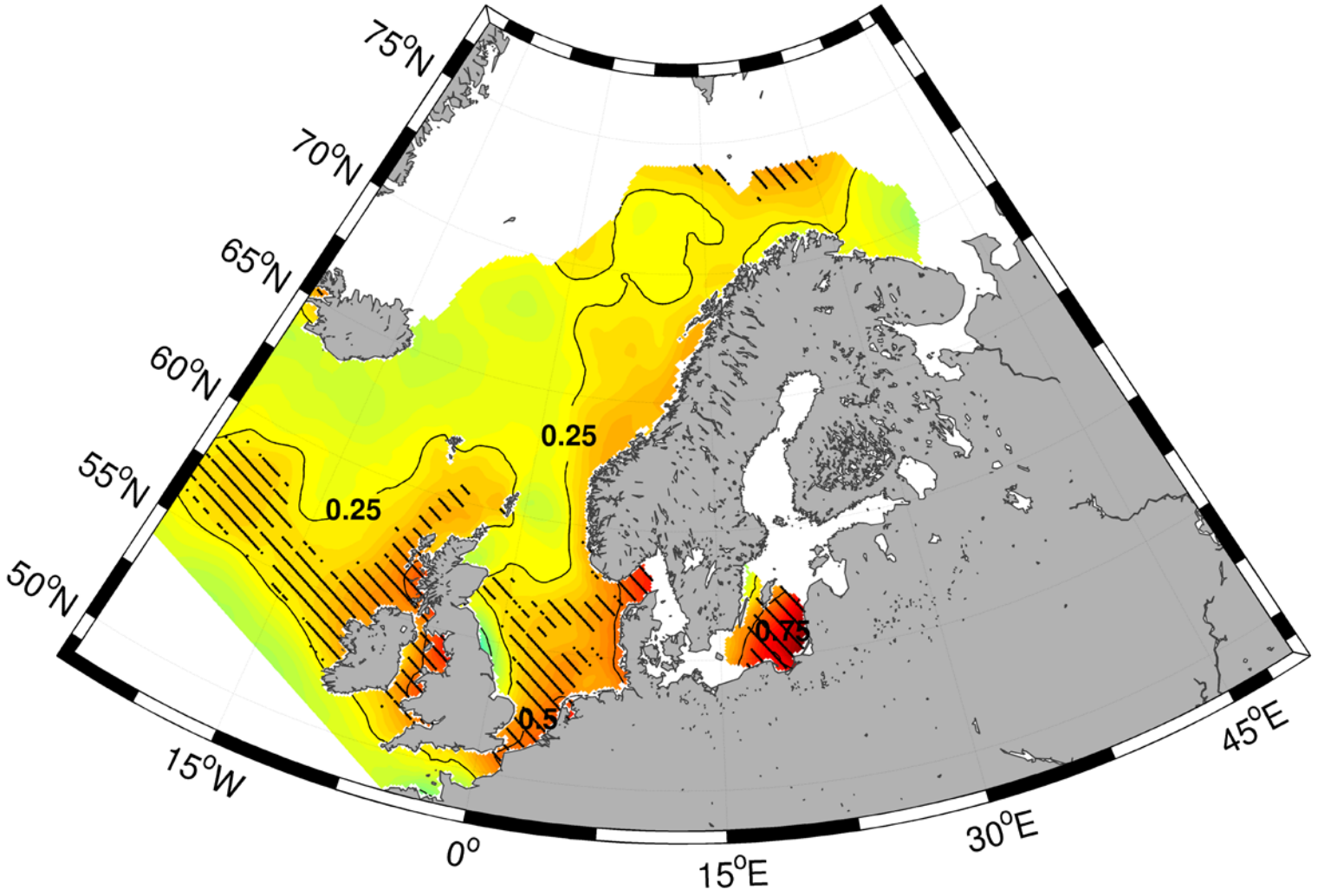
- Significance test:
  - Follow Yue *et al* (2002), Wang and Swail (2002) among others
  - Trend-free pre-whitening procedure to remove the first autoregressive process AR(1)
  - Perform the Mann Kendall Test (α=0.05)

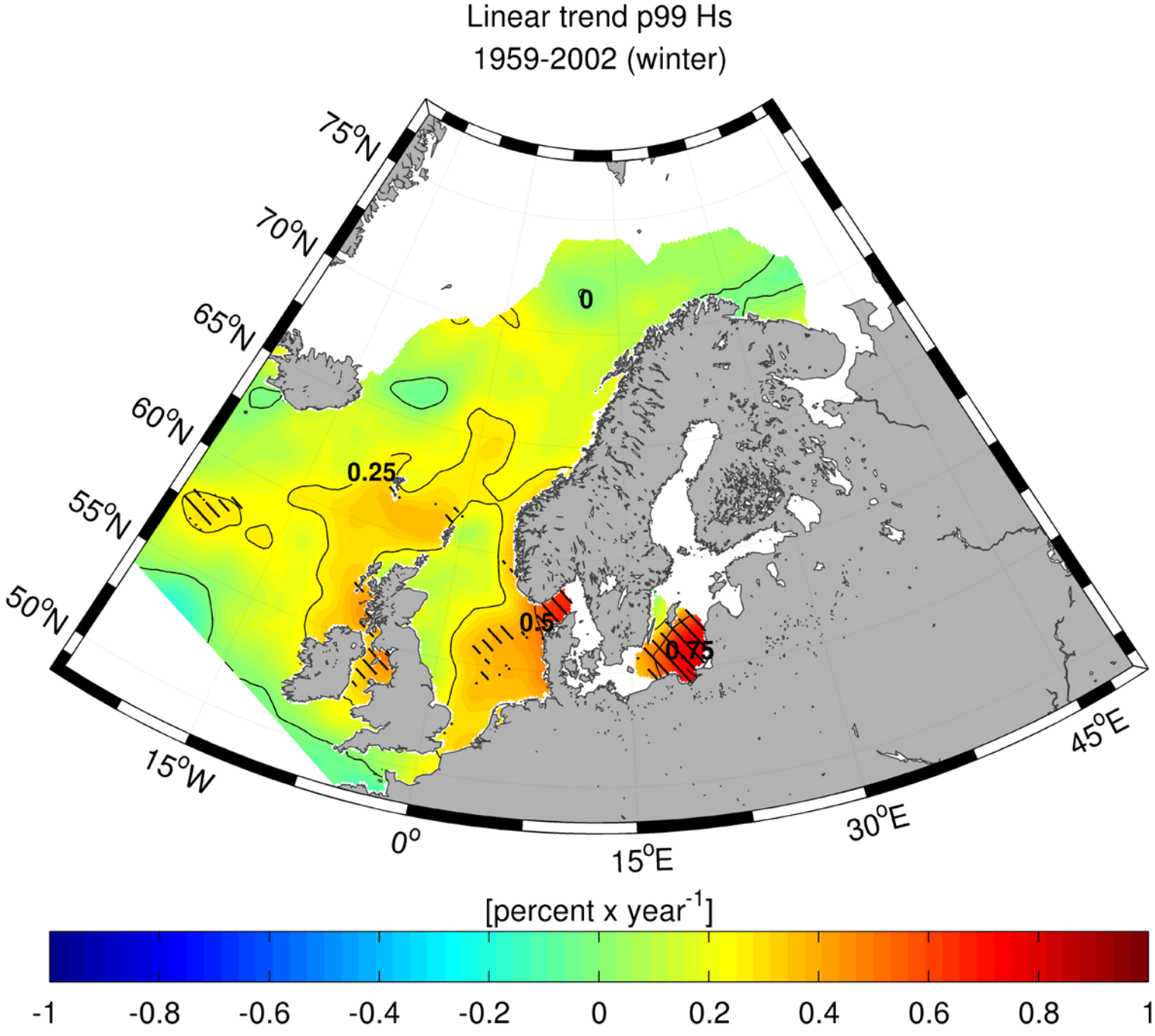


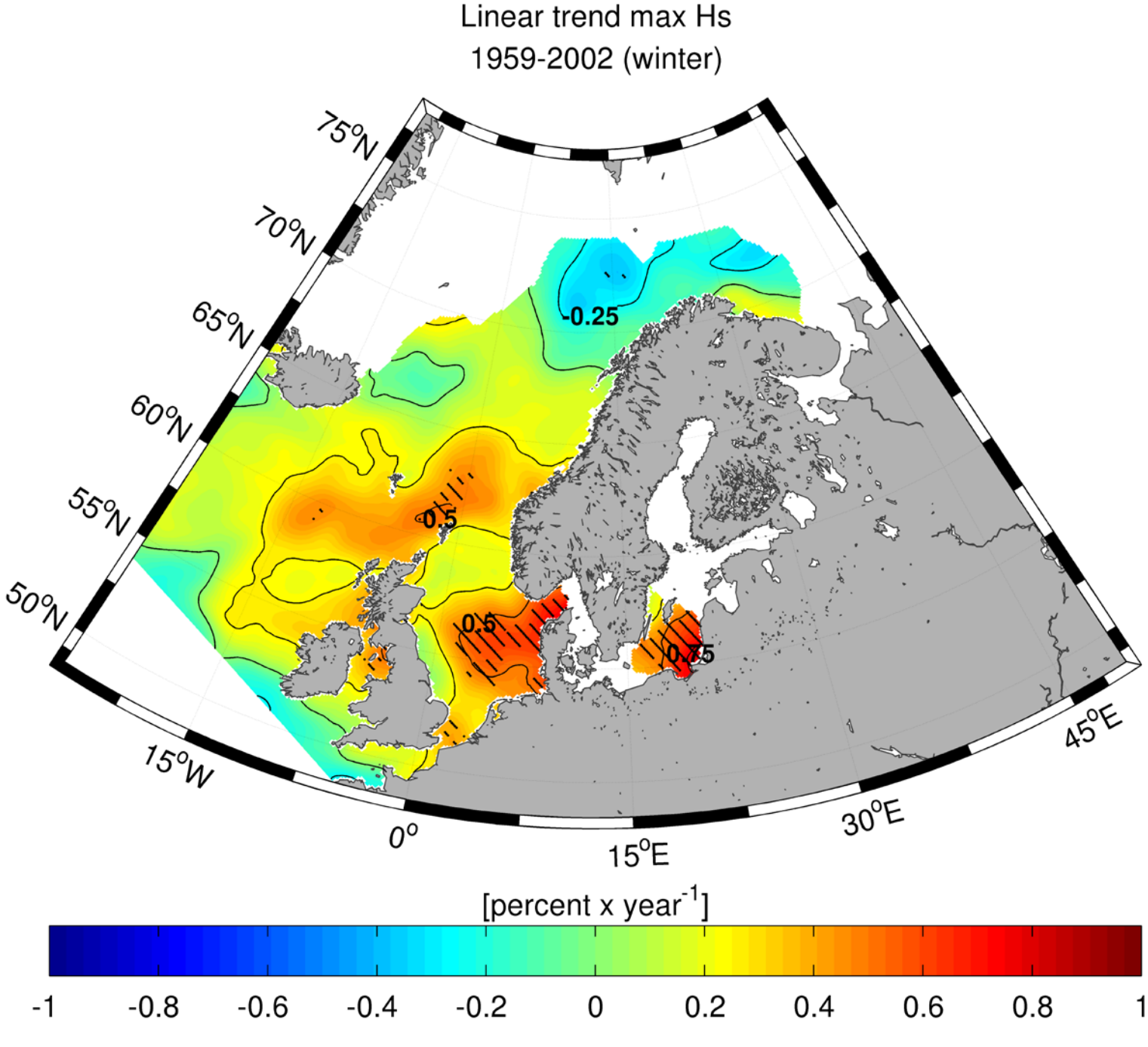
Mean Hs at 58.20N 11.49W

Trends in Significant Wave Height

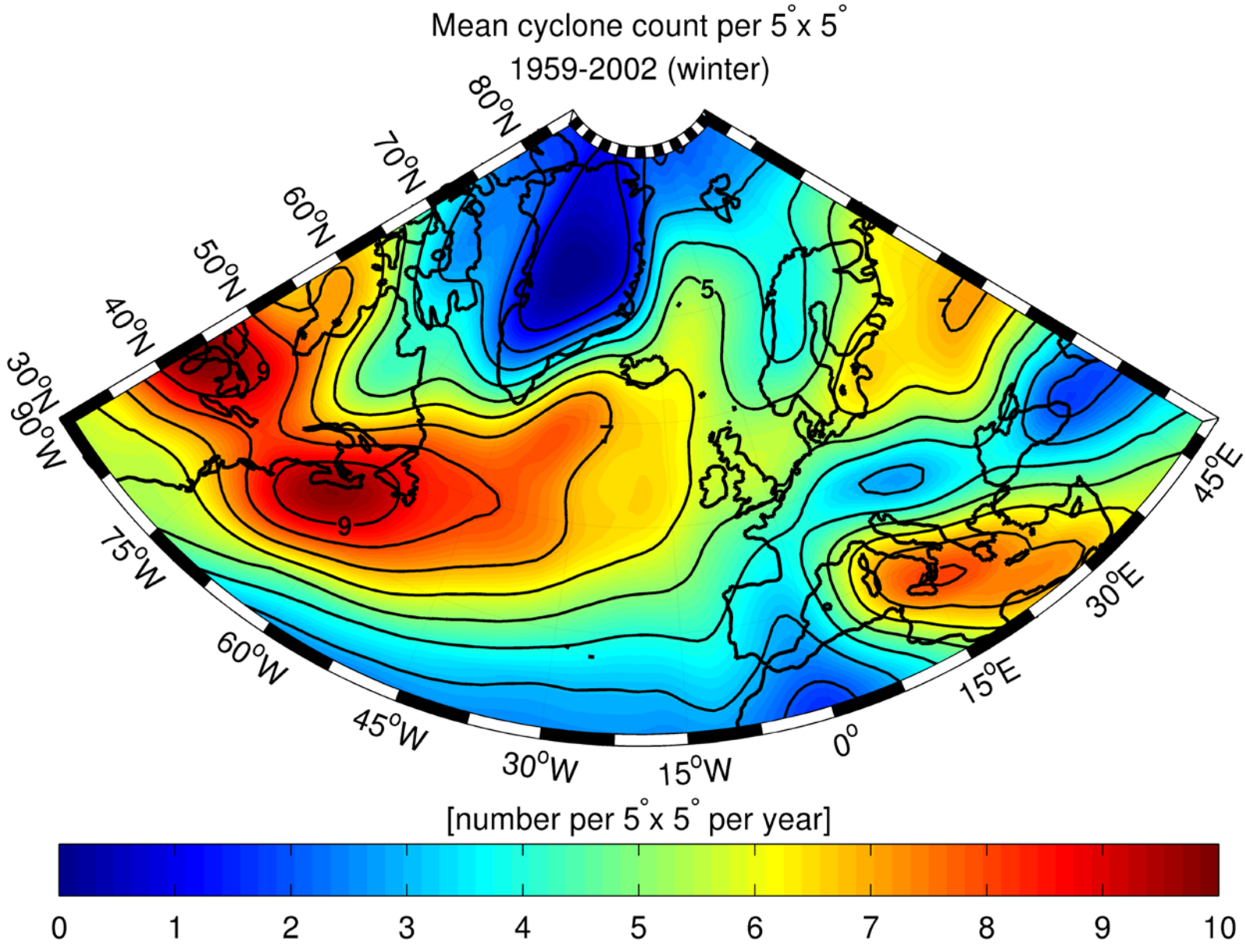

Linear trend mean Hs
1959-2002 (winter)
75°N
70°N
65°N
60°N
55°N
50°N
15°W
0°
15°E
30°E
45°E
0.25
0.25
0.25
0.5
0.5
[percent x year-1]
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1

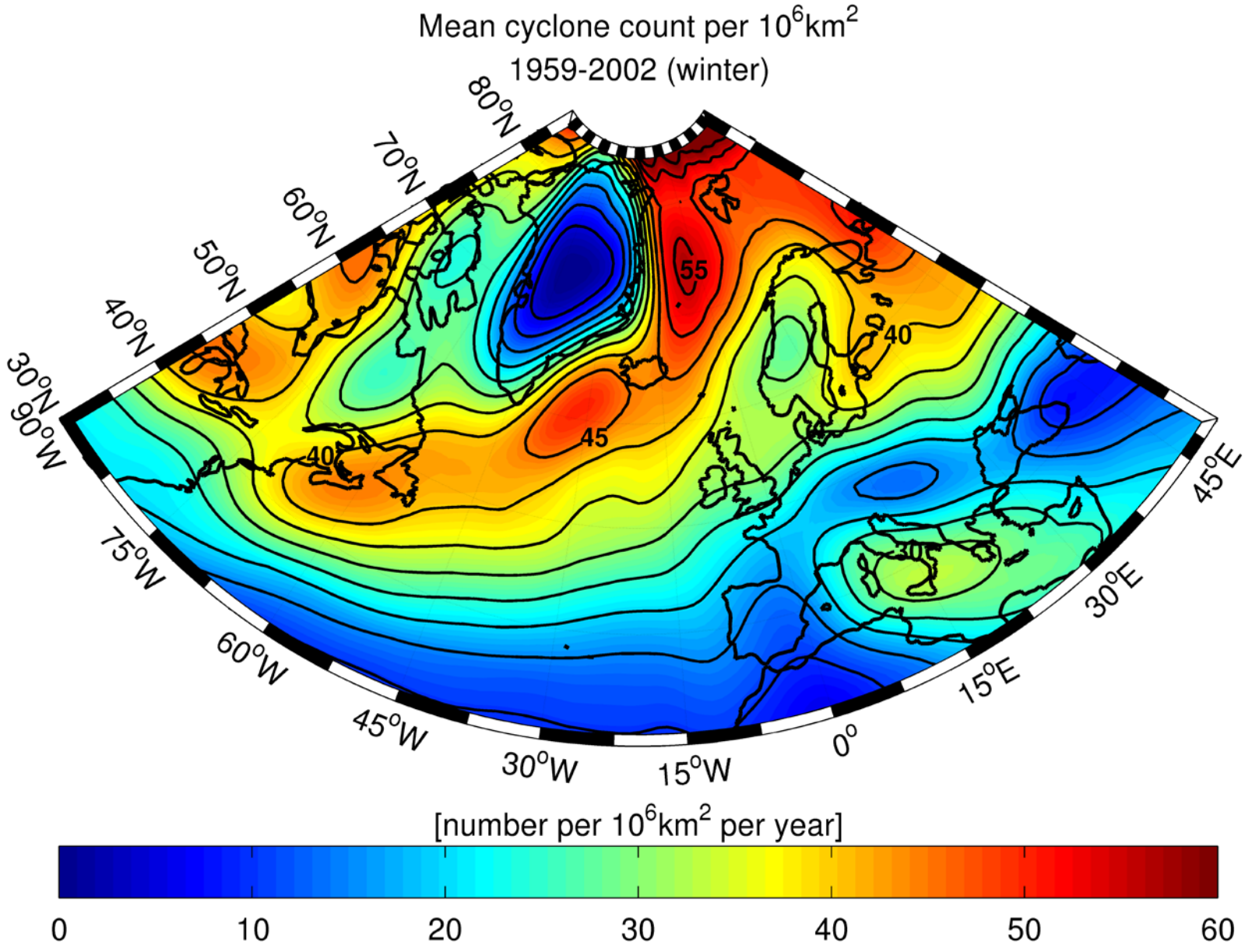

Linear trend p90 Hs
1959-2002 (winter)
75°N
70°N
65°N
60°N
55°N
50°N
15°W
0°
15°E
30°E
45°E
0.25
0.25
0.5
0.5
[percent x year-1]
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1


Linear trend p99 Hs
1959-2002 (winter)
75°N
70°N
65°N
60°N
55°N
50°N
15°W
0°
15°E
30°E
45°E
0
0.25
0.5
0.75
[percent x year-1]
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1

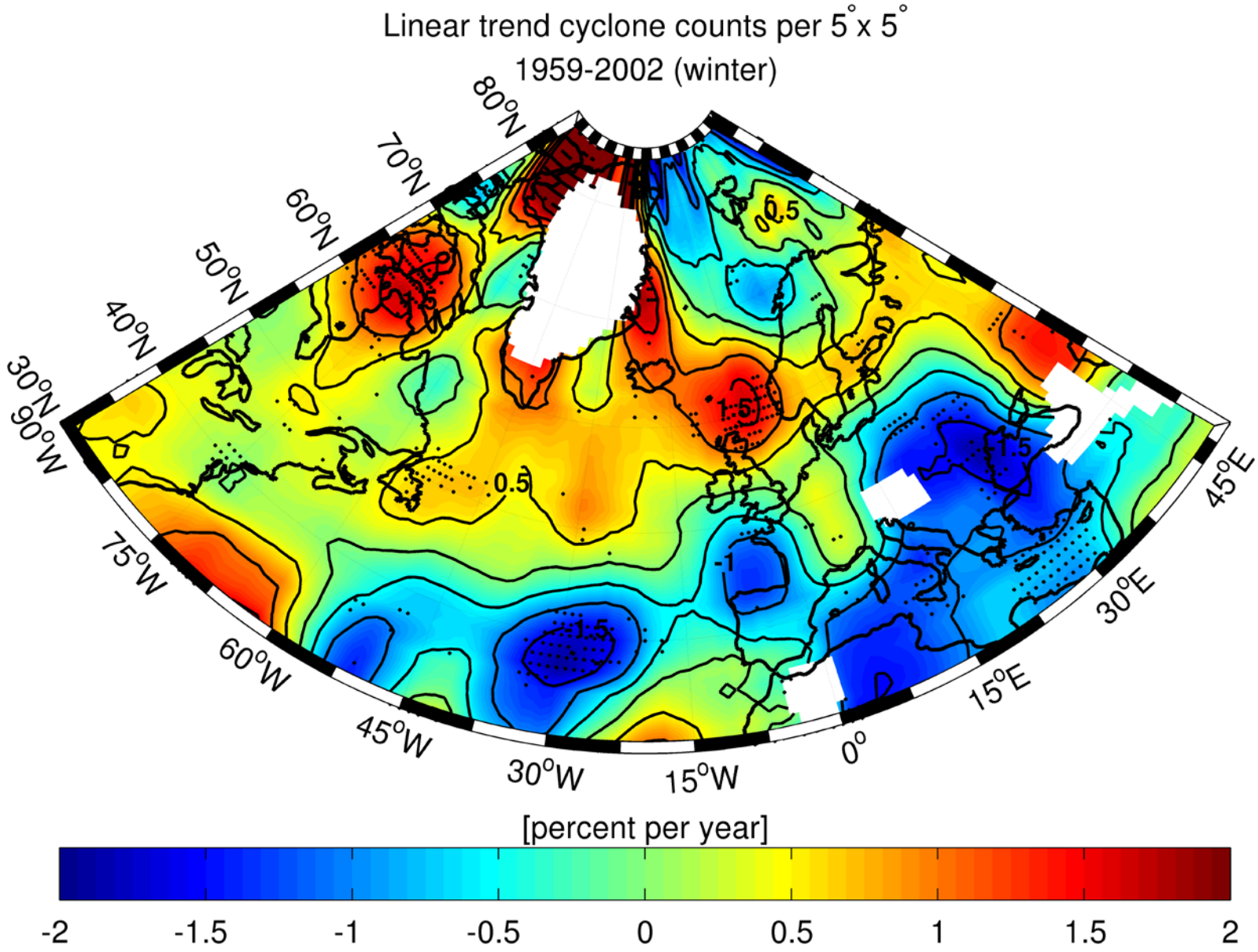

Linear trend max Hs
1959-2002 (winter)
75°N
70°N
65°N
60°N
55°N
50°N
15°W
0°
15°E
30°E
45°E
-0.25
0.5
0.5
0.75
[percent x year-1]
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1

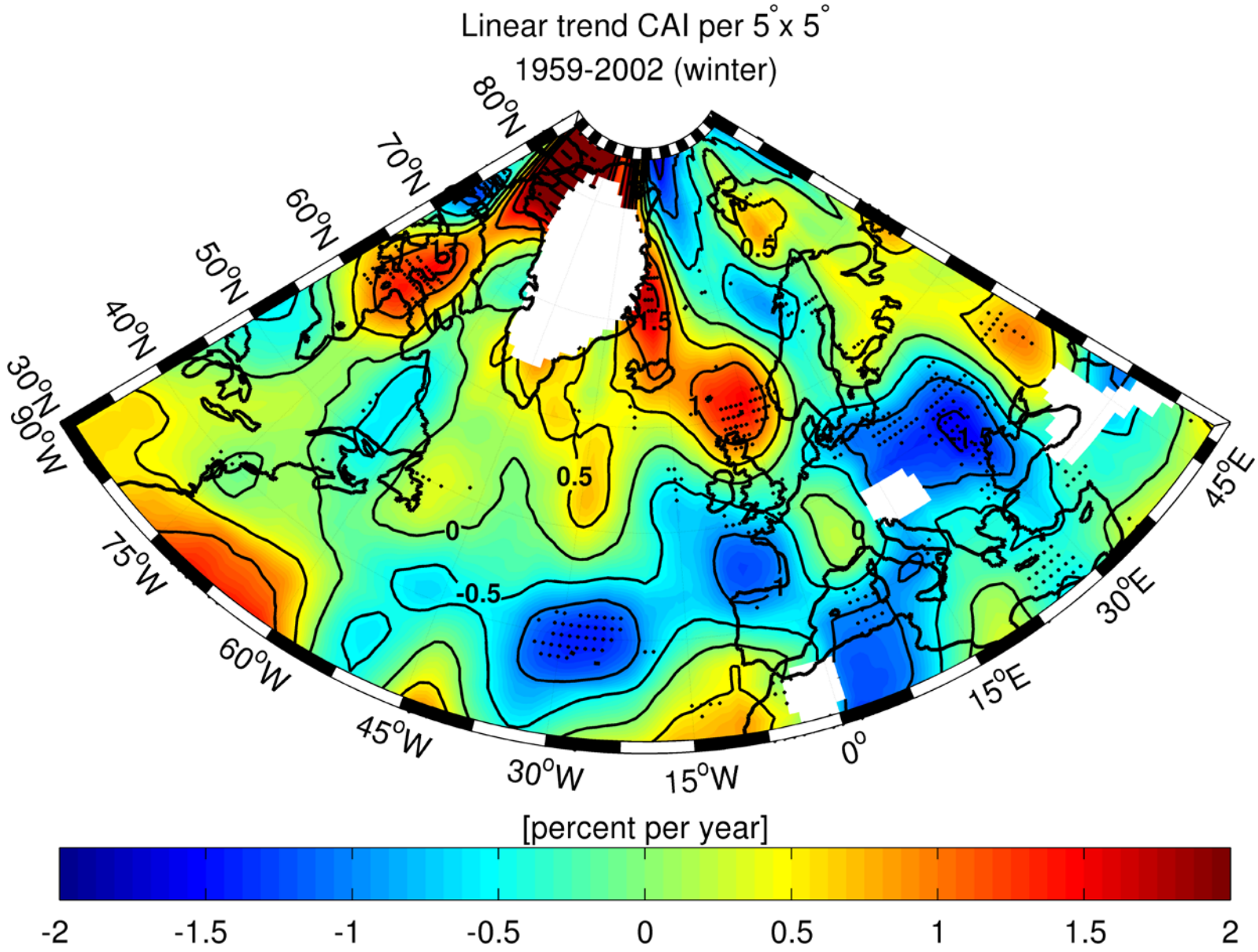
Cyclone climate


Mean cyclone count per 5° x 5°
1959-2002 (winter)
80°N
70°N
60°N
50°N
40°N
30°N
90°W
75°W
60°W
45°W
30°W
15°W
0°
15°E
30°E
45°E
5
7
9
[number per 5° x 5° per year]
0
1
2
3
4
5
6
7
8
9
10

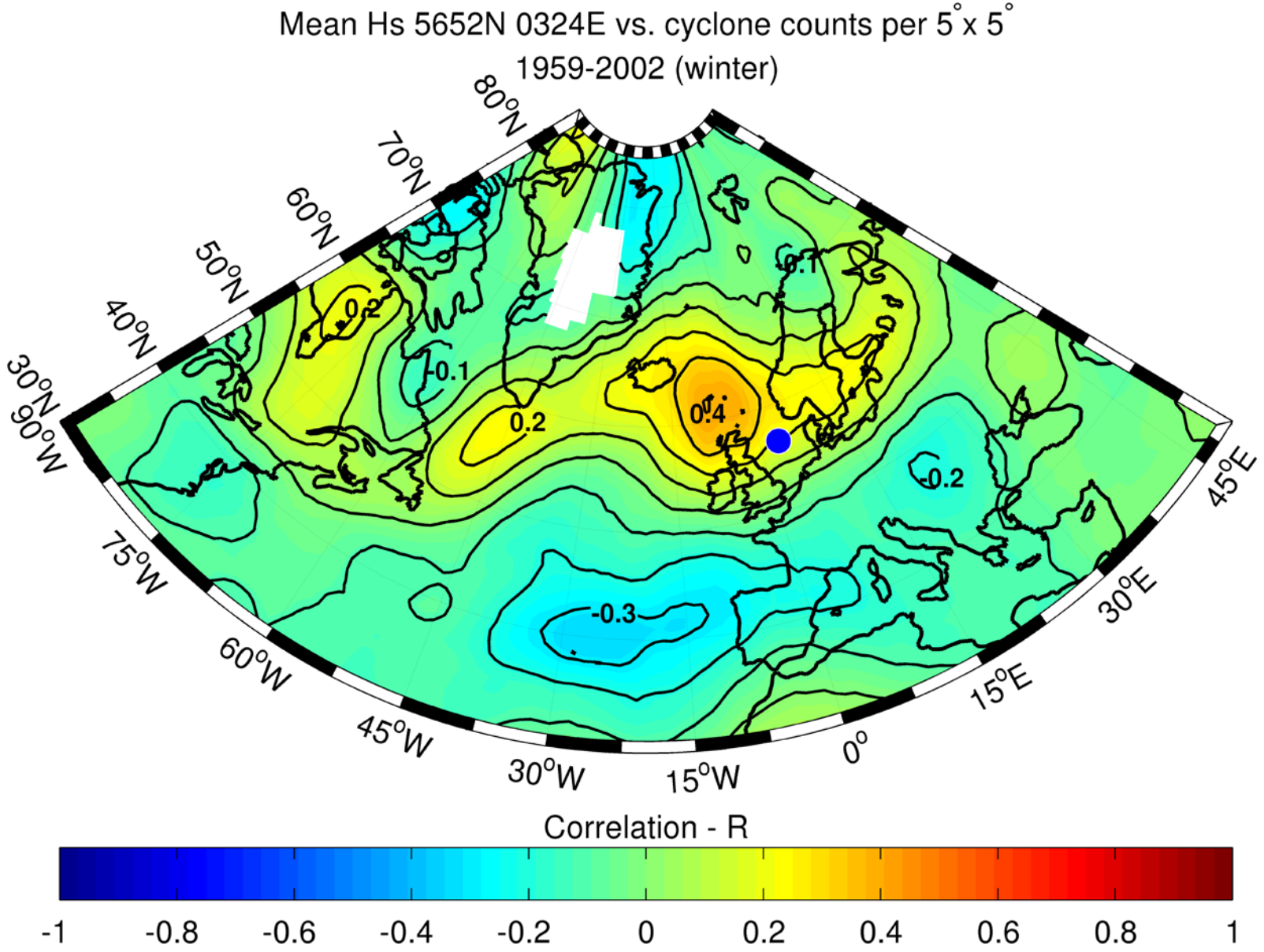

Mean cyclone count per 10^6km^2
1959-2002 (winter)
80°N
70°N
60°N
50°N
40°N
30°N
90°W
75°W
60°W
45°W
30°W
15°W
0°
15°E
30°E
45°E
55
45
40
40
30
[number per 10^6km^2 per year]
0
10
20
30
40
50
60

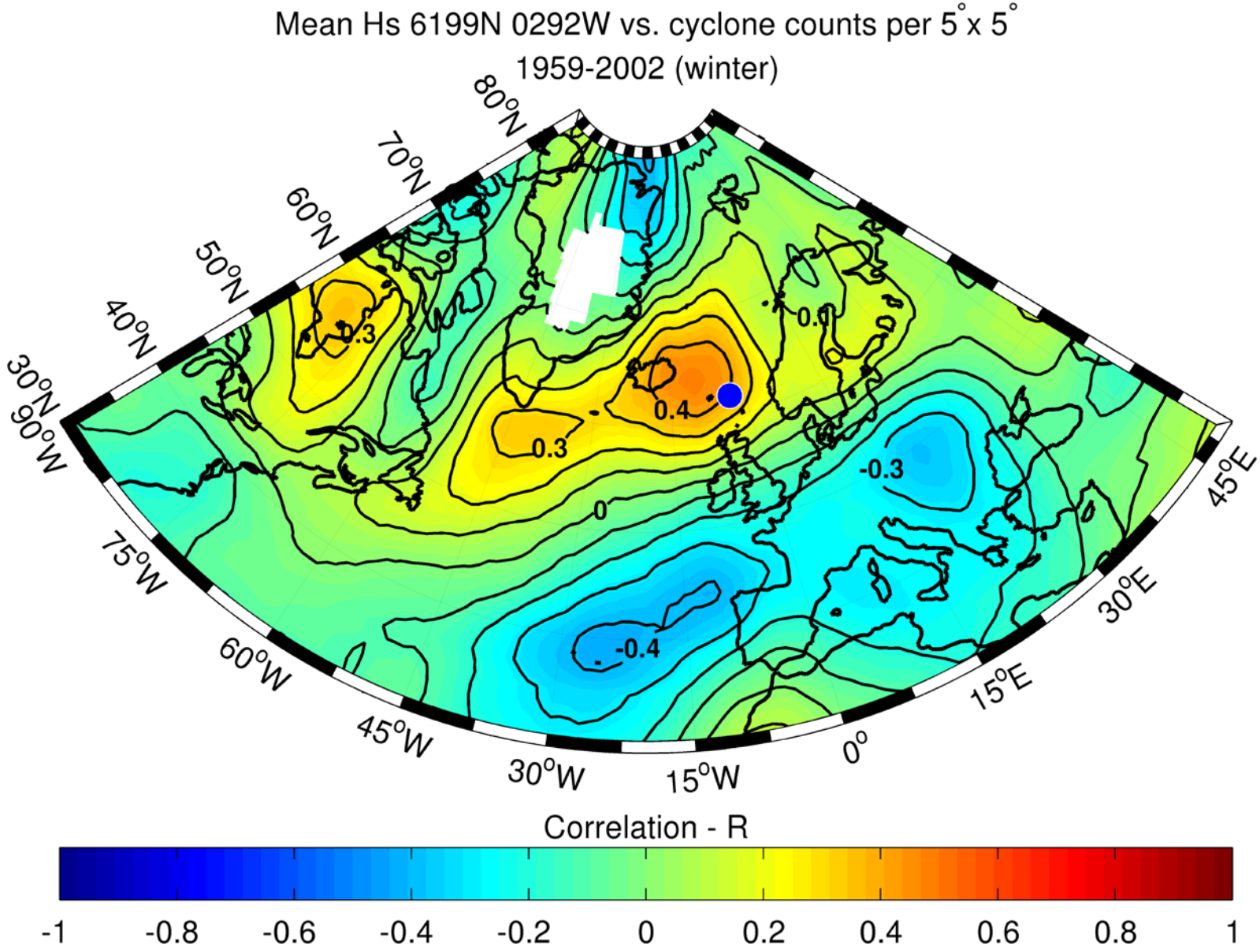
Cyclone trends

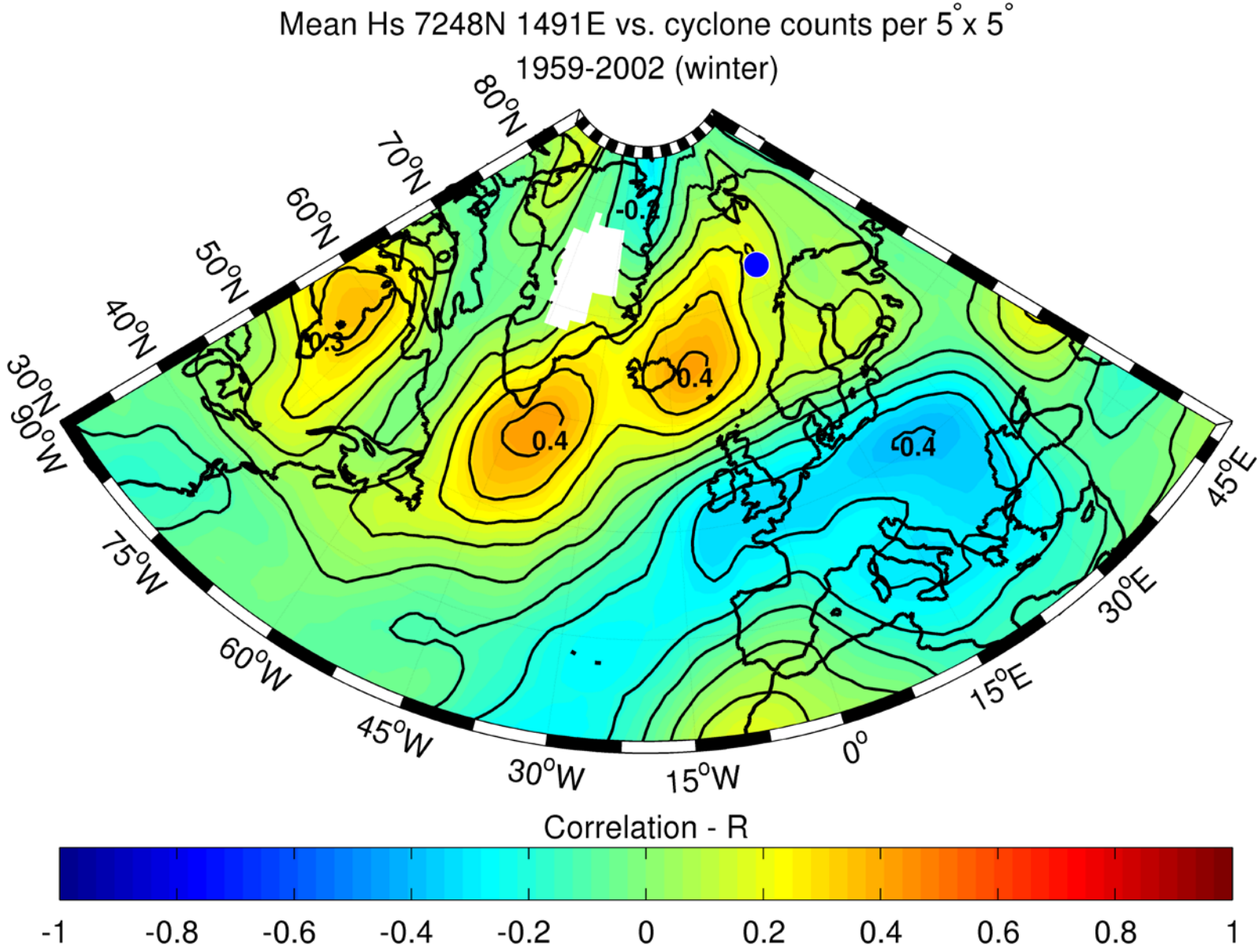

Linear trend cyclone counts per 5°x 5°
1959-2002 (winter)
80°N
70°N
60°N
50°N
40°N
30°N
90°W
75°W
60°W
45°W
30°W
15°W
0°
15°E
30°E
45°E
0.5
1.5
-1
[percent per year]
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2

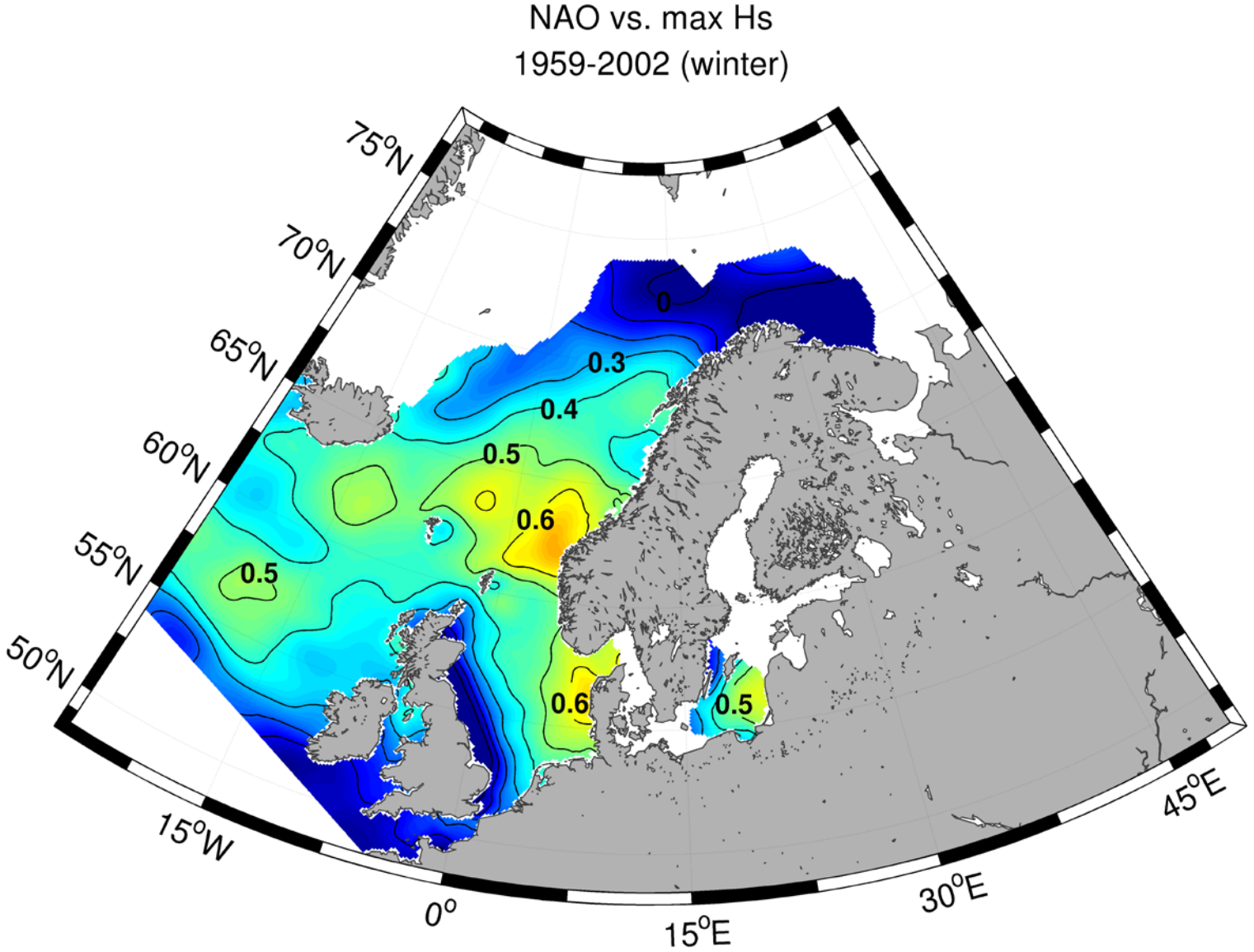

Linear trend CAI per 5° x 5°
1959-2002 (winter)
80°N
70°N
60°N
50°N
40°N
30°N
90°W
75°W
60°W
45°W
30°W
15°W
0°
15°E
30°E
45°E
0.5
1.5
1
0
-0.5
[percent per year]
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2

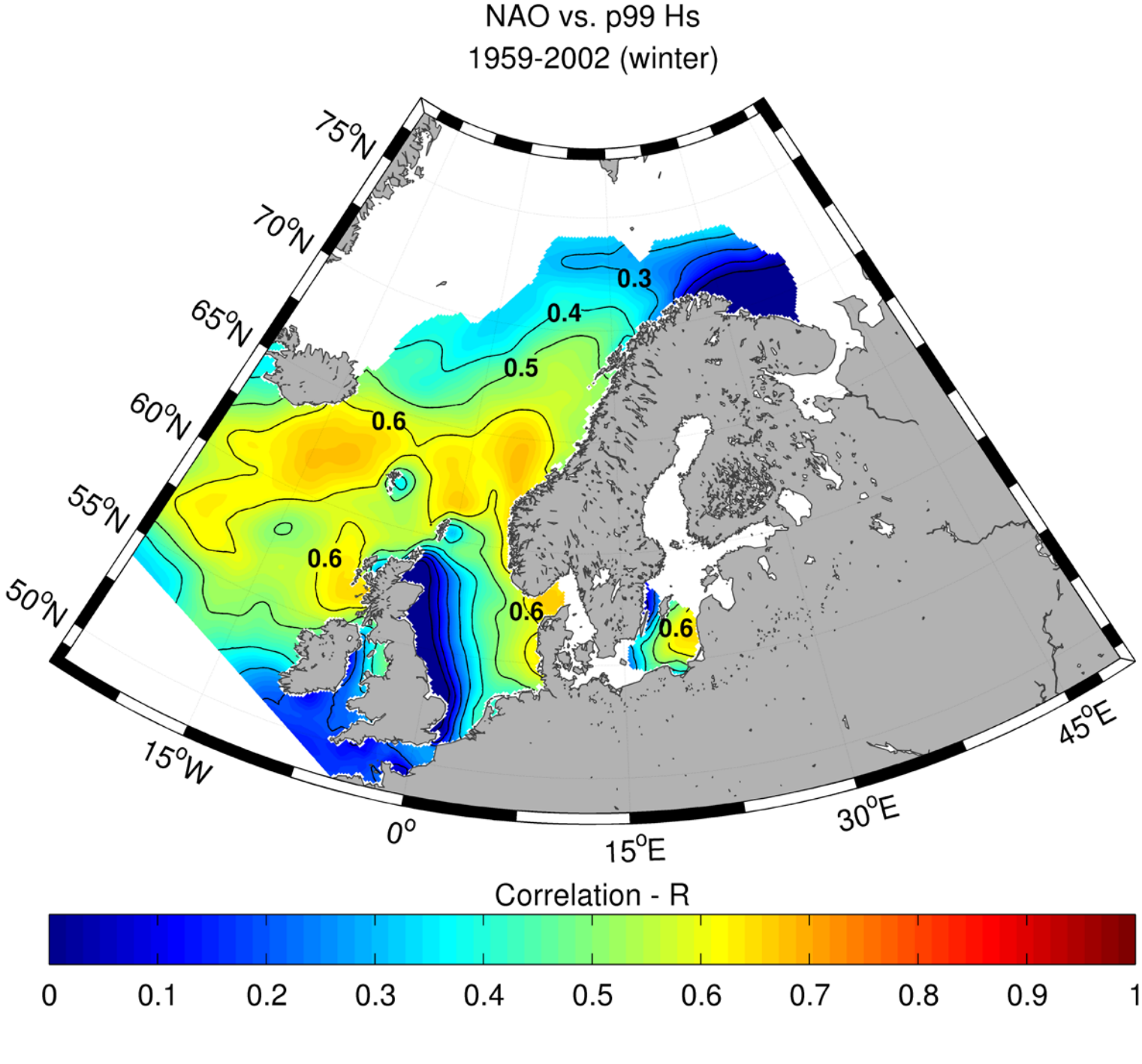
Correlation with NAO

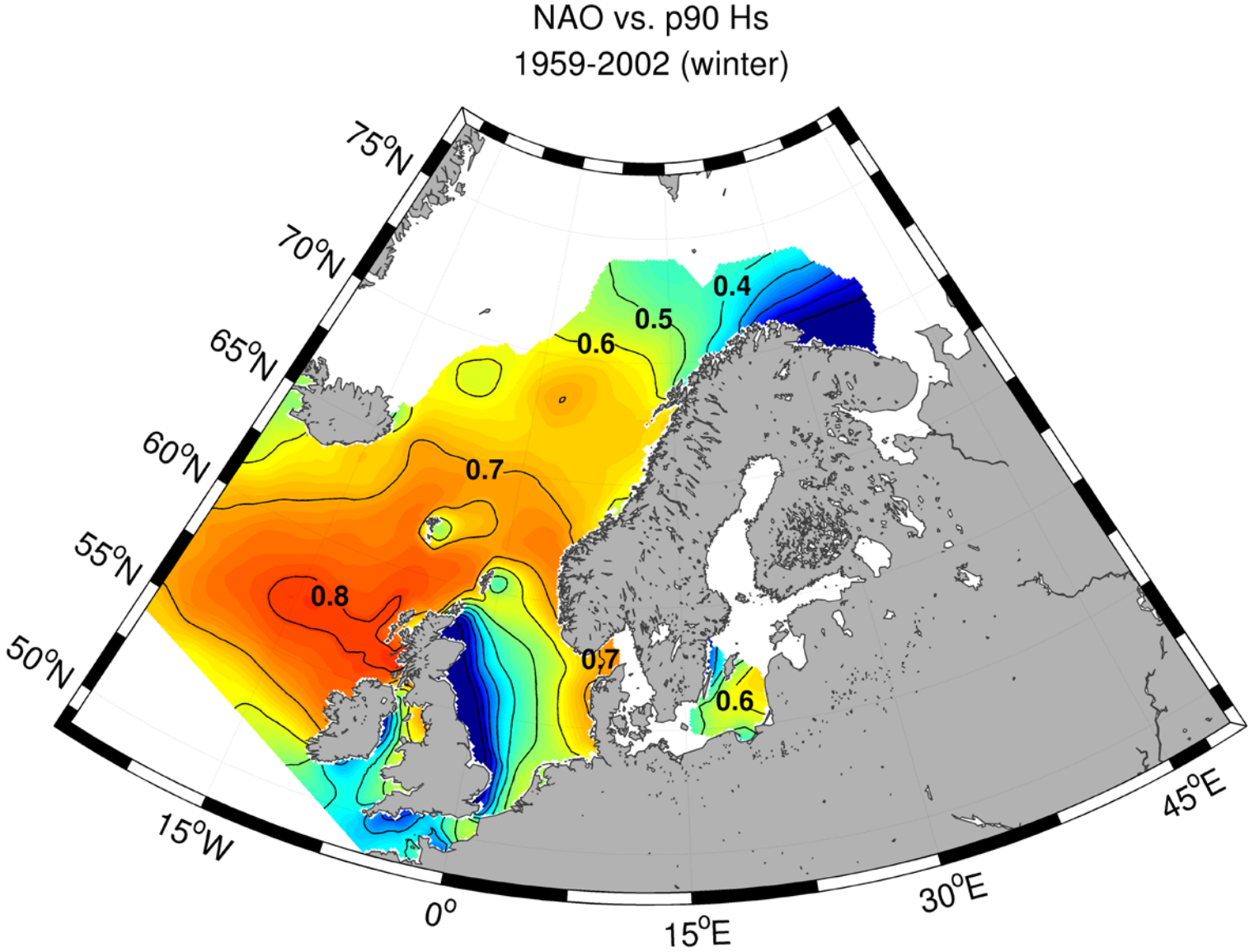

Mean Hs 5652N 0324E vs. cyclone counts per 5° x 5°
1959-2002 (winter)
80°N
70°N
60°N
50°N
40°N
30°N
90°W
75°W
60°W
45°W
30°W
15°W
0°
15°E
30°E
45°E
0.2
0.4
-0.1
-0.2
-0.3
Correlation - R
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1

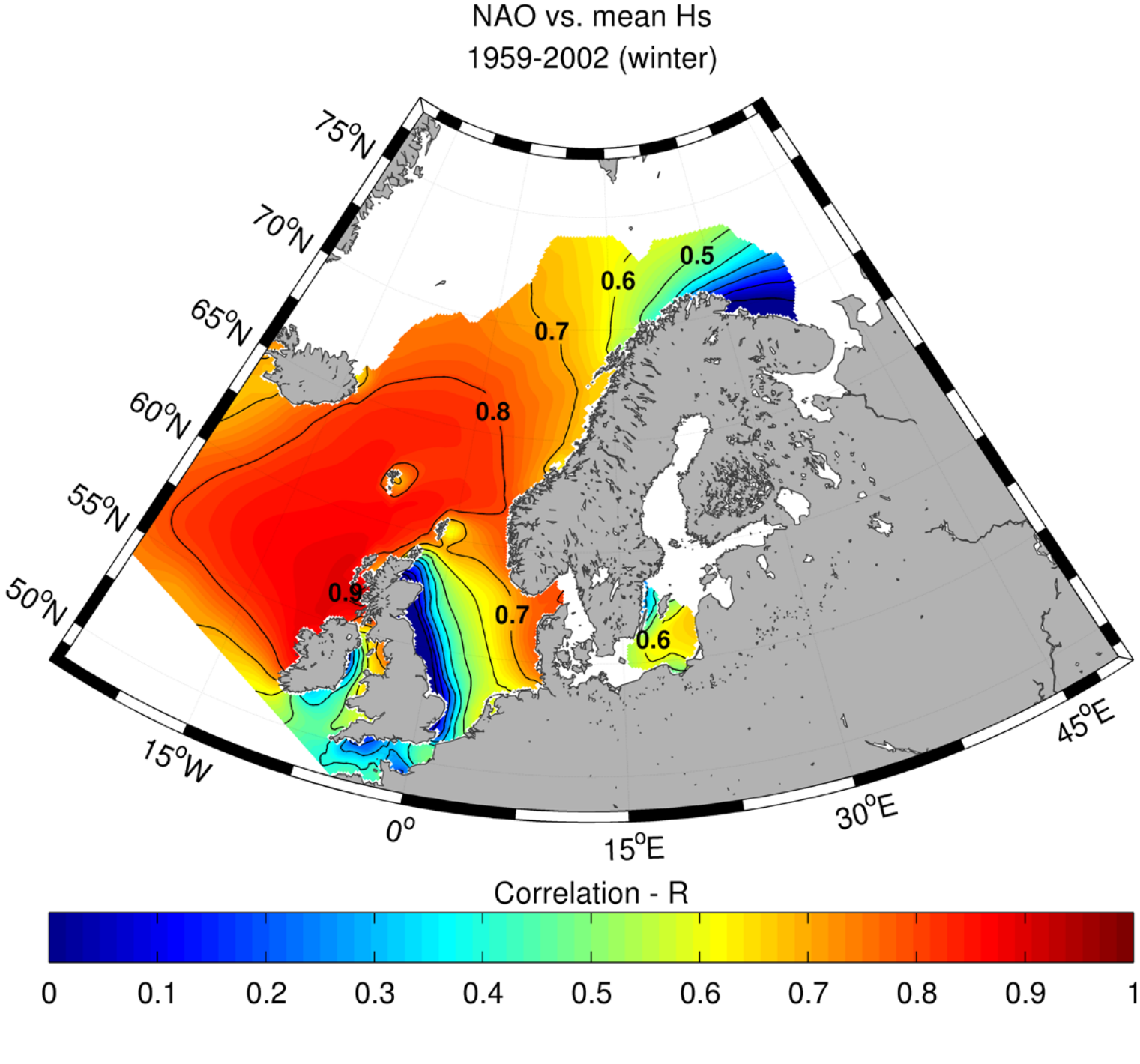

Mean Hs 6199N 0292W vs. cyclone counts per 5° x 5°
1959-2002 (winter)
80°N
70°N
60°N
50°N
40°N
30°N
90°W
75°W
60°W
45°W
30°W
15°W
0°
15°E
30°E
45°E
0.3
0.4
0.3
0
-0.3
-0.4
Correlation - R
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1


Mean Hs 7248N 1491E vs. cyclone counts per 5° x 5°
1959-2002 (winter)
80°N
70°N
60°N
50°N
40°N
30°N
90°W
75°W
60°W
45°W
30°W
15°W
0°
15°E
30°E
45°E
-0.2
0.3
0.4
0.4
0.4
Correlation - R
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1


NAO vs. max Hs
1959-2002 (winter)
75°N
70°N
65°N
60°N
55°N
50°N
15°W
0°
15°E
30°E
45°E
0
0.3
0.4
0.5
0.6
0.5
0.6
0.5
Correlation - R
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1


NAO vs. p99 Hs
1959-2002 (winter)
75°N
70°N
65°N
60°N
55°N
50°N
15°W
0°
15°E
30°E
45°E
0.3
0.4
0.5
0.6
0.6
0.6
0.6
Correlation - R
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1


NAO vs. p90 Hs
1959-2002 (winter)
75°N
70°N
65°N
60°N
55°N
50°N
15°W
0°
15°E
30°E
45°E
0.4
0.5
0.6
0.7
0.8
0.7
0.6
Correlation - R
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1


NAO vs. mean Hs
1959-2002 (winter)
75°N
70°N
65°N
60°N
55°N
50°N
15°W
0°
15°E
30°E
45°E
0.5
0.6
0.7
0.8
0.9
0.7
0.6
Correlation - R
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

Concluding remarks

- Mainly positive trends in Hs and cyclone activity in the NE-Atlantic over the period 1959-2002 (DJF)
- NAO is a very robust predicator for mean wave conditions
- Cyclone activity does not show the same correlations

Future work

- Extend analysis to 2010
- Cyclone data:
  - Cyclone activity within a radius of the grid point
  - Cyclone intensity - CAI/counts
  - Cluster analysis for highest Hs events
  - Linear interpolation to get 1 hr data
- Investigate running fetch / cyclone speed
- Influence of ice extend
- Separate swell/wind sea

References

Sen, P. K., 1968: Estimates of the regression coefficient based on Kendall's tau. *Journal of the American Statistical Association* **63**, 1379–1389.

Yue, S., Pilon, P., Phinney, B. and Cavadias, G., 2002: The influence of autocorrelation on the ability to detect trend in hydrological series. *Hydrological processes,* **16**, 1807-1829.

Wang, X. L., and Swail, V. R., 2001: Changes of Extreme Wave Height in Northern Hemisphere Oceans and Realated Atmospheric Circulation Regimes. *Journal of Climate*, **14,** 2204-2221.

Thank you!