Exploring the relationship between the Arctic sea-ice and mid to high latitude circulation anomalies

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1. Background

- There has been a dramatic decrease in annual Arctic sea-ice cover
- For climate change scenarios, sea-ice could play an important role through various feedbacks
- Seasonal predictability in northern Europe could be influenced by Arctic sea-ice

2. The Problem

Sea-ice description in seasonal forecast models

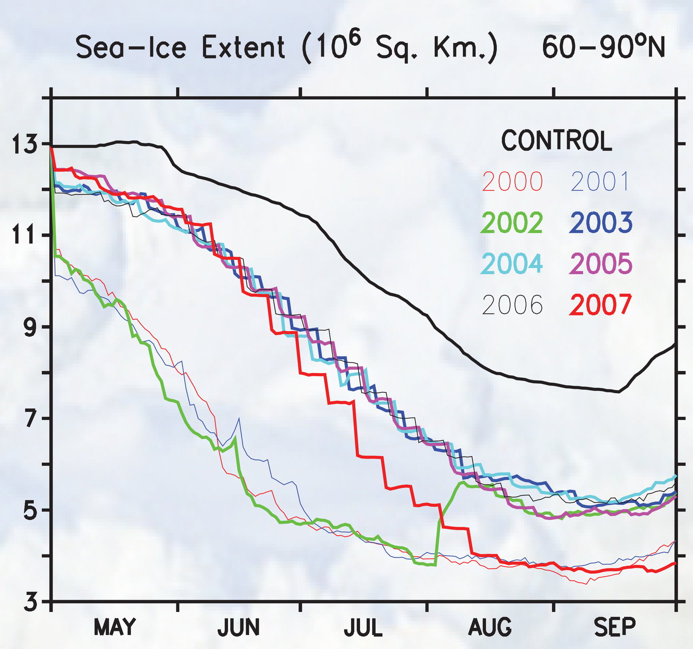
- Sea-ice models do not yet provide sufficiently skillful prediction of actual month-to-month changes in the sea-ice cover.
- Thus, climatological sea-ice used in coupled atmosphere-ocean models (GCMs) for seasonal forecasting.
- All members in ensemble forecasts are constrained by one common solution for surface fluxes in polar regions

3. The Question

- *Does a more realistic sea-ice cover in the models have an effect on the ensemble spread and mean values?*
- *Does Arctic sea-ice impact northern hemisphere high- to mid-latitude storm statistics?*

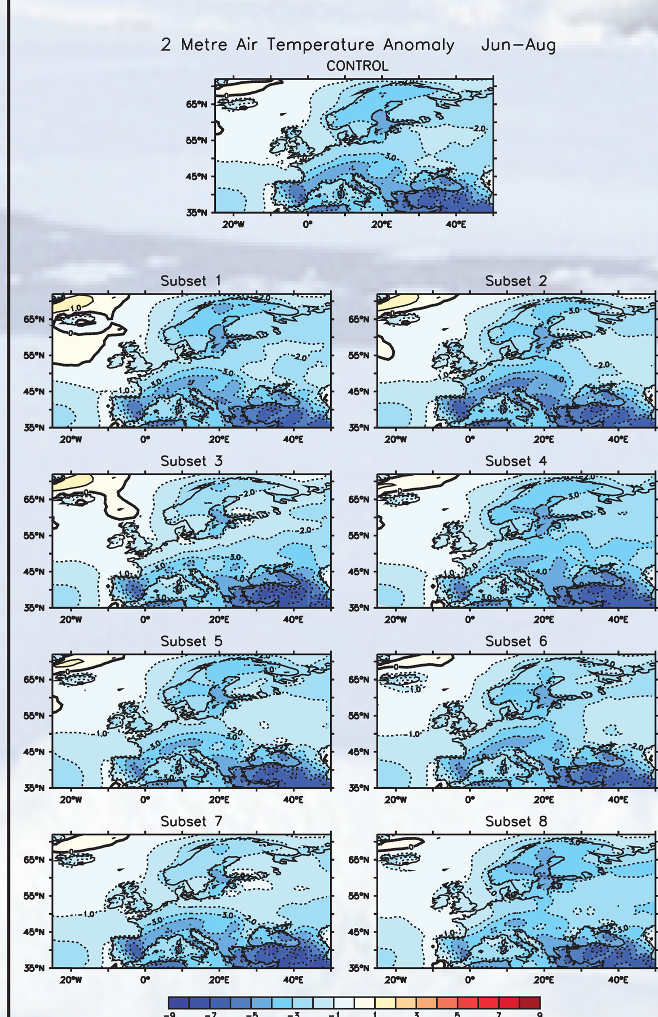
4. Model set-up and Methodology

- ECMWF IFS/HOPE coupled model, Cycle cy31R1, T159L62 resolution
- Eight ensemble integrations ("subsets") of five members each (i.e., N=40 simulations)
- Identical initial conditions (1 May 2007) for all the simulations with SST perturbations applied.
- Sea-ice was prescribed, with each subset subjected to empirical sea-ice observations from the years 2000 to 2007 (see figure), thus preserving the observed seasonal sea-ice evolution
- Control run of 40 ensemble members with 1 May 2007 initial conditions; sea-ice relaxed to climatology over the first month and subsequent sea-ice prescribed from climatology
- Model sea-ice and2m air temperature, T(2m,) are subjected to statistical analyses: Kolmogorov-Smirnov and Student's t- hypothesis tests, analysis of variance (ANOVA), test of field significance (Walker test). Linear factorial regression analysis was used to compare the model response to different sea-ice configurations.
- A chi-squared test was used for assessing the differences in the storm counts. The storm statistics was derived from a calculus-based cyclone identification (CCI) algorithm proposed by Benestad & Chen (2006).

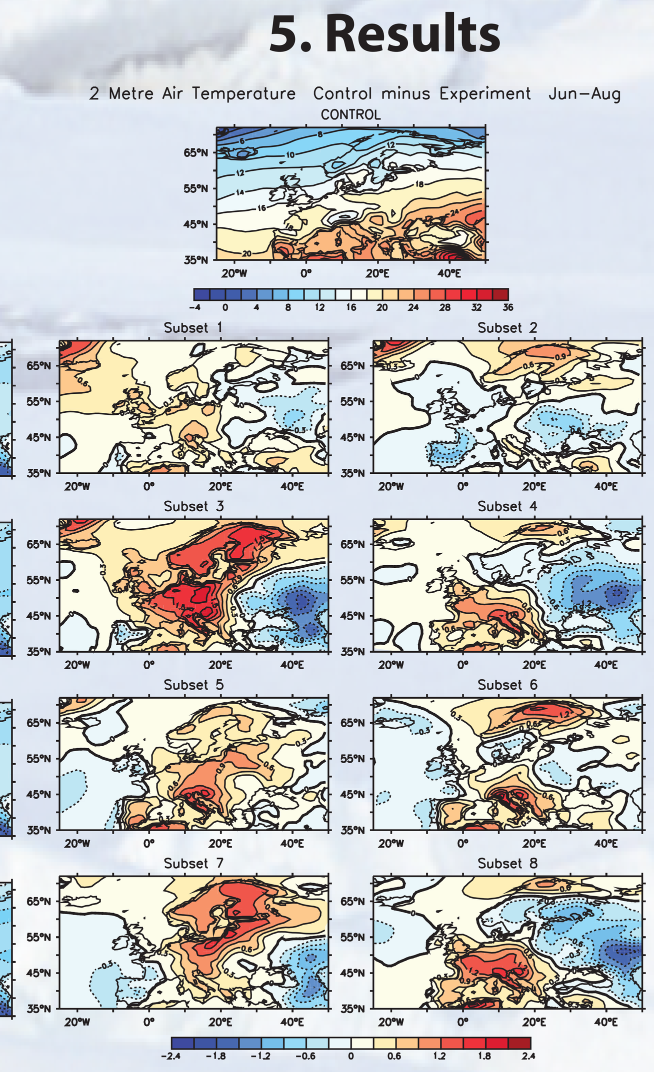


Comparison of sea-ice area prescribed in the different subset experiments and the control simulation

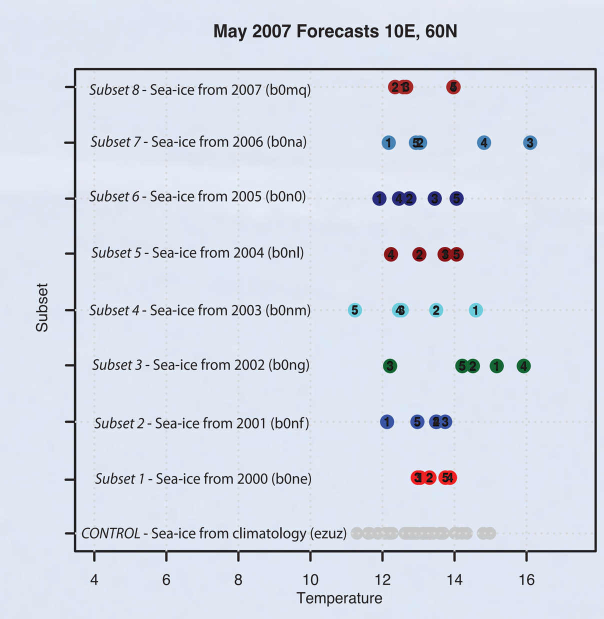
5. Results



June- August ensemble mean T(2m) anomalies with respect to ERA40 climatology for the control and the subset simulations



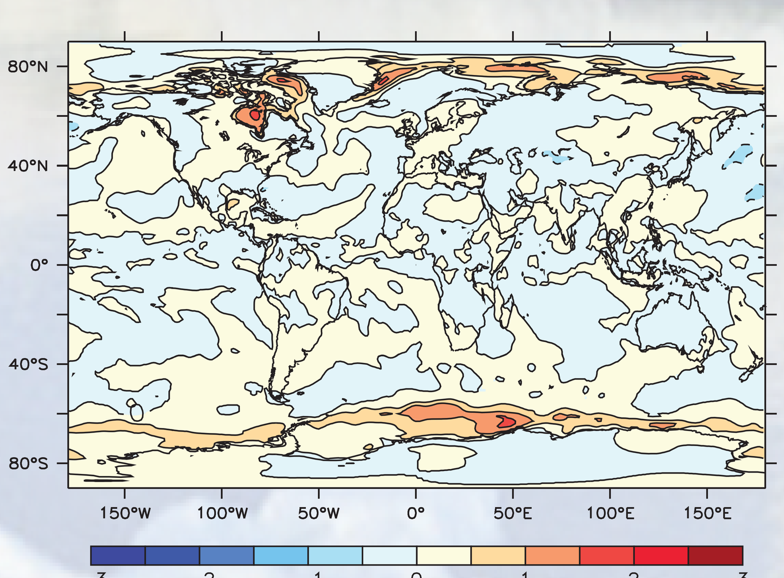
June-August ensemble mean T(2m) from the control simulation and its difference from the subset simulations



June–August mean 2m air temperature interpolated to 10E/60N (near Oslo) for the control and the subsets. The model experiment identifier on the ECMWF MARS archive are in parentheses.

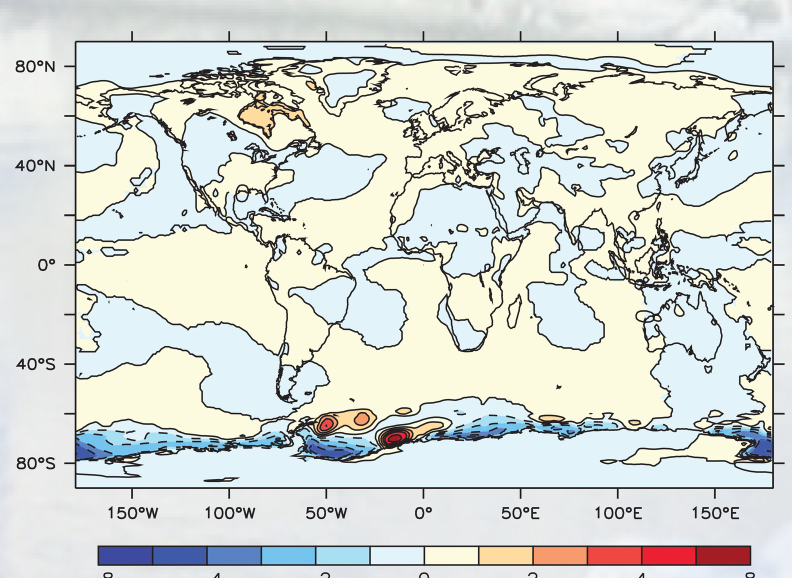
- There is no systematic pattern whereby a specific SST perturbation gives lower or higher temperature than others.
- Depending on sea-ice conditions, the different integrations follow different trajectories
- Thus, the sea-ice affects the way the different SST-perturbations lead to different solutions in a more convoluted manner.
- Anomalies exhibit some robust features with respect to the prescribed sea-ice boudary conditions, notably the cold anomalies over Turkey, along the northern coast of the Mediterranean, parts of Spain, and the Baltic sea.
- There are nevertheless fairly pronounced differences between each subset that can be attributed to the different sea-ice conditions: 2002 and 2006 sea-ice conditions were associated with warm anomalies simulated over most of northern Europe, and Fennoscandia in particular.

6. Spread and Location



Logarithm of ratio of standard devaition of June-August T (2m) from the subset experiments combined to that of the control

- Greater range of scatter in the high latitudes

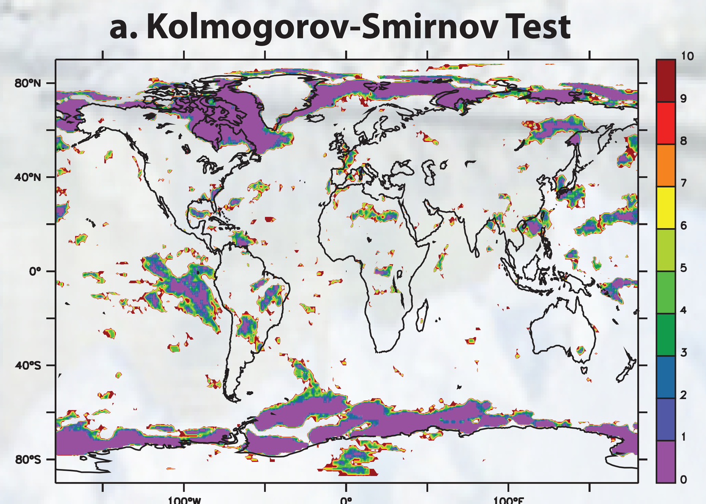


June-August ensemble mean difference between T (2m) from the subset experiments combined and the control simulation

- Largest differences over regions with sea-ice

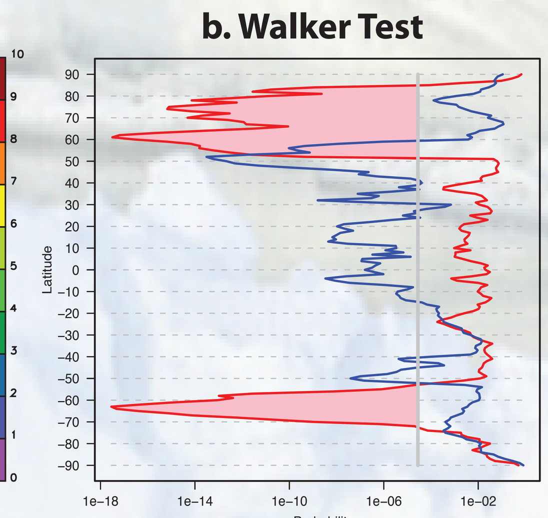
7. Statistical Distributions

a. Kolmogorov-Smirnov Test



K-S test probability values between T (2m) values from the subset experiments combined and the control simulation

b. Walker Test



Latitudinal profiles of the minimum p-value (p_1) from the Walker test associated with sea-ice (red) and SST perturbations in the initial conditions (blue). The pink regions mark the latitudes where $p_1 < p_{walker}$

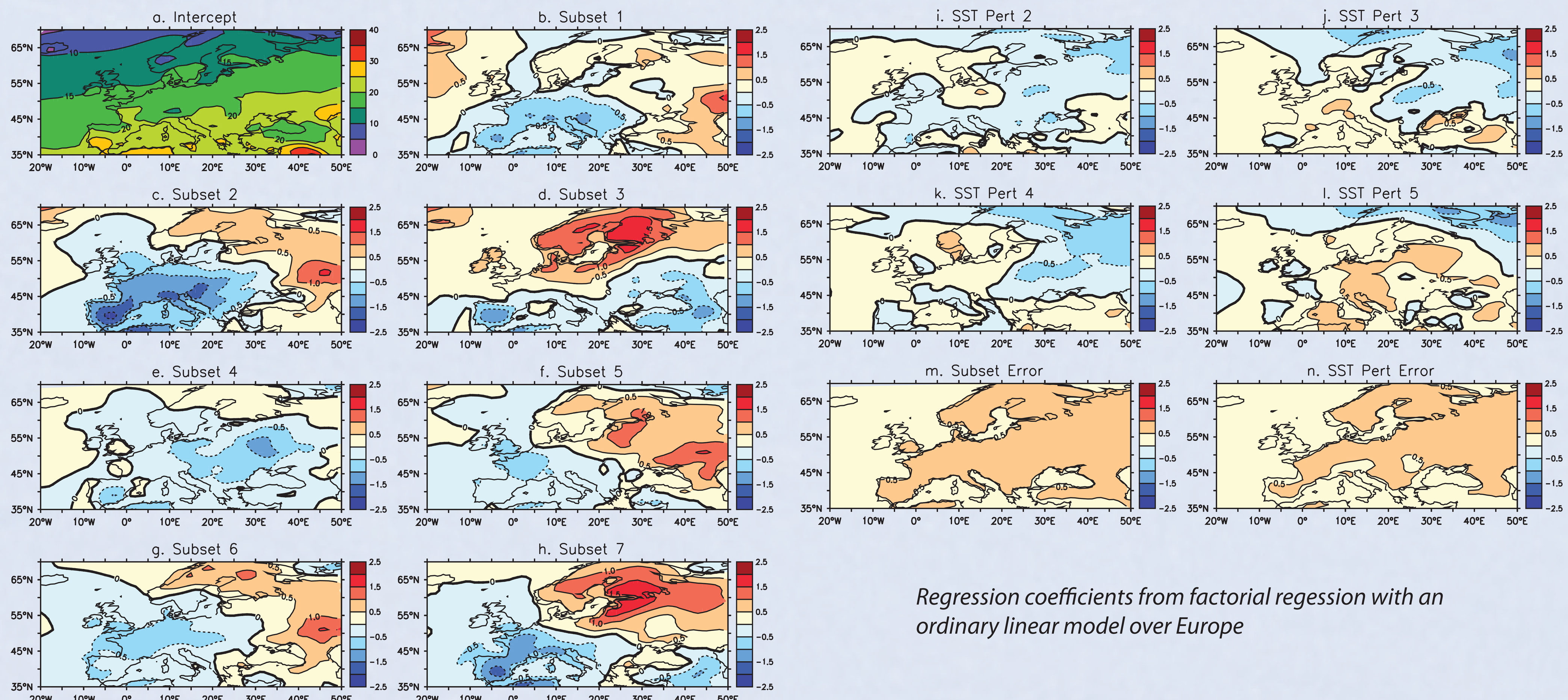
$p_{walker} = 1-(1-\alpha_{global})^{1/K}$

$\alpha_{global} = 0.01$ *is the level of global significance* $K = 360$

- Expectedly, lowest p-values (greatest probability that the T(2m) really responds to the sea-ice cover) are found in the polar regions near the ice edge.
- Results from Walker test suggests that the p-value associated with sea-ice from is statistically significant at the 1%-level in upper mid- to lower high- latitudes.

8. Factorial Regression

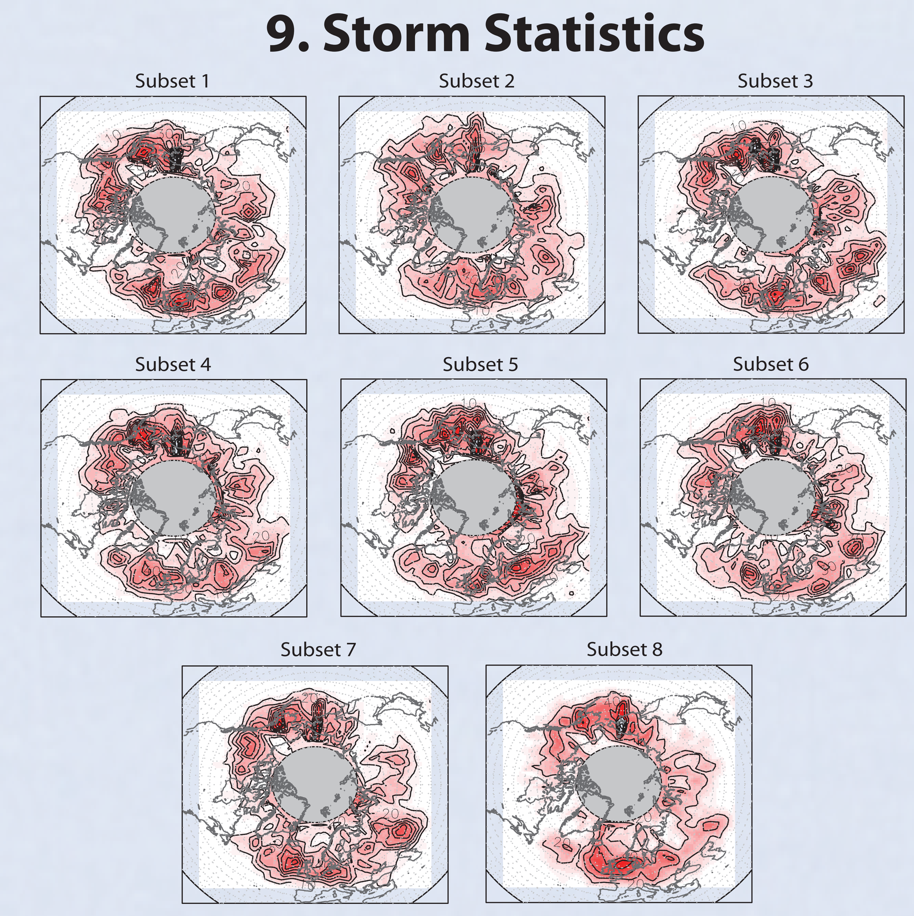
- Used to compare the sensitivity of T(2m) to sea-ice and SST perturbations respectively, with 7 degrees of freedom for sea-ice conditions and 4 for SST perturbations



Regression coefficients from factorial regression with an ordinary linear model over Europe

- Factorial regression does not try to determine the degree to which the outcome varies with the degree of sea-ice or SST change, but instead examines whether a different set-up (sea-ice or SST-perturbation category) has a predictable effect on the results.
- Regression coefficients for sea-ice are associated with greater magnitudes that those for SST perturbations and the standard errors for both - implies that the systematic effect from sea-ice boundary conditions is more compared to the effect of SST perturbations

9. Storm Statistics



Density of storm occurrence over the northern hemisphere high latitudes estimated from CCI data

- Cyclone statistics (Benestad & Chen, 2006) derived for the different experiments suggests only minor variations in summer, but are more discernible in winter (not shown).
- A Chi-squared test applied to the storm count at all grid boxes suggested that these were not merely statistical fluctuations. Such storm systems have an impact on the local temperature and precipitation.

10. Conclusions

- Sea ice has an influence on the T(2m) response in the mid-latitudes (50N–80N & 60S–80N), but the number of simulations were too low to derive results that were statistical significant at the 5% level.
- One explanation for stronger regression coefficients for the sea-ice than SST-perturbation may be that the sea-ice conditions were prescribed throughout the entire integration while the SST-perturbations were only applied to the initial state.
- Thus, a non-linear chaotic response involving folding in phase-space would make the response unpredictable and difficult to identify with normal statistical analysis. However, more direct and clear-cut effects of sea-ice are local.
- Sea-ice also has an influence (albeit weak)on high latitude storm statistics

Further Information:

The SPAR (Seasonal Predictability over the Arctic Region - Role of Boundary conditions) Project *http://spar.met.no* . The SPAR project is funded by the Norwegian Research Council.

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Benestad & Chen (2006) The use of a Calculus-based Cyclone Identification method for generating storm statistics, Tellus A, 58A, 473-486, doi:10.1111/j.1600-0870.2006.00191.x