Climate Dynamics
Summer Semester 2019

UNIVERSITÄT LEIPZIG

Homework 7
Due 19 June 2019

Problem 1 Arctic Oscillation (courtesy Tom Goren)

The Arctic Oscillation (AO) refers to an opposing pattern of pressure between the Arctic and the midlatitudes: If the atmospheric pressure is high in the Arctic, it tends to be low in the midlatitudes. In such cases the AO is in its negative phase. In the positive phase, the pattern is reversed. The phase has an important effect on weather in northern locations.

Your task is to identify the AO pattern in the atmospheric pressure field. In order to do so you need to use empirical orthogonal function (EOF) analysis. EOF is a statistical method used to emphasize variation and bring out strong patterns in a dataset. It is often used in climate studies to study spatial patterns of variability and how they change with time. The method is described in Appendix B of Peixoto and Oort. Many analysis packages provide a function to perform EOF analysis.

(a) The AO is most pronounced in the 1000 hPa geopotential height. Reanalysis of the 1000 hPa geopotential (not geopotential height!) for the winter months (DJFM) of the years 1979–2015 is available in `/home_local/tgoren/ex5/1000_geop_DJFM.nc`. Average the data for each year and then apply the EOF method on the data north of 20°N. In order to ensure an equal area weighting, weight the data by $\sqrt{\cos\phi}$. Don't forget that the input to the EOF analysis is the pressure anomaly. Plot the first EOF and describe how wind direction, storm tracks, and jet stream curvature and strength in the upper atmosphere relate to the pattern that you see.

(b) Plot the time series of the AO index. Based on your conclusions from part (a), under which AO phase (positive/negative) you would expect to have warmer/colder winters in northern Europe and the US?

(c) Use the 1000 hPa temperature in `/home_local/tgoren/ex5/1000_temp_DJFM.nc` to plot the difference in the temperature between positive and negative AO index years for grid points north of 20°N. Explain the geographical patterns that you see with respect to the AO phase.

Problem 2 Sea ice area and internal variability

A widely held opinion about projections of Arctic sea ice area (or extent) is exemplified by the following quote from AR5 (Sec. 12.4.6; emphasis mine):

> A frequent criticism of the CMIP3 models is that, as a group, they strongly underestimate the rapid decline in summer Arctic sea ice extent observed during the past few decades (e.g., Stroeve et al., 2007; Winton, 2011), **which suggests that the CMIP3 projections of summer Arctic sea ice areal coverage might be too conservative**. As shown in Section 9.4.3 and Figure 12.28b, the magnitude of the CMIP5 multi-model mean trend in September Arctic sea ice extent over the satellite era is more consistent with, but still underestimates, the observed one (see also Massonnet et al., 2012; Stroeve et al., 2012; Wang and Overland, 2012; Overland and Wang, 2013).

(a) Is the underestimate of the historical sea ice extent in AR5 Fig. 12.28b conclusive proof that the climate models participating in CMIP5 are too conservative in their sea ice estimates? What else could be causing the disagreement? Formulate a hypothesis on the origin of the disagreement that you could test if you had an ensemble of model runs, all with the same model physics but all with slightly different initial conditions to allow you to sample different realizations of the chaotic system (an "initial condition ensemble").

(b) Here, serendipitously, is an initial condition ensemble consisting of 40 runs: the CESM Large Ensemble (Kay et al. 2015; the CESM Large Ensemble Community Project and supercomputing resources provided by NSF/CISL/Yellowstone are gratefully acknowledged). You can find the sea ice fractional area files from the CESM Large Ensemble, along with the satellite record of September sea ice area from NSIDC (Sea Ice Index product version 3), in `/home_local/jmuelmenstaedt/cesm_le`. If you plot time series of the modeled September sea ice area, does the model appear incapable of simulating the observed time series? Is the historical realization of the sea ice loss a particularly likely or unlikely outcome? Does this mean we can stop worrying about Arctic sea ice loss? *Note: you may consider using `cdo fldsum` to calculate the sea ice area.*

(c) AR5 chose to address the suspected "conservative" model projections by selecting the "subset of models that most closely reproduce the climatological mean state and 1979 to 2012 trend of the Arctic sea ice" (AR5 Fig. SPM.7; "SPM" is the Summary for Policymakers, presumably the most widely read part of the report) and then estimating, e.g., the first occurrence of ice-free summers (defined as a sea ice extent of less than 10^6 km^2) based on only those models. But if the models represent the ice loss correctly, doesn't this extra selection bias the result? Select the subset of CESM Large Ensemble runs that most closely reproduce historical sea ice area record. Does this subset predict ice-free Septembers significantly sooner than the full ensemble? *Note: for computational simplicity, use sea ice area rather instead of extent, but keep the 10^6 km^2 threshold; see this document for an explanation of the difference.*

Note: you are walking in the footsteps of Jahn et al. (2016); feel free to use the paper as a resource if you get stuck, but keep in mind that you'll have more fun if you rediscover these results for yourself.

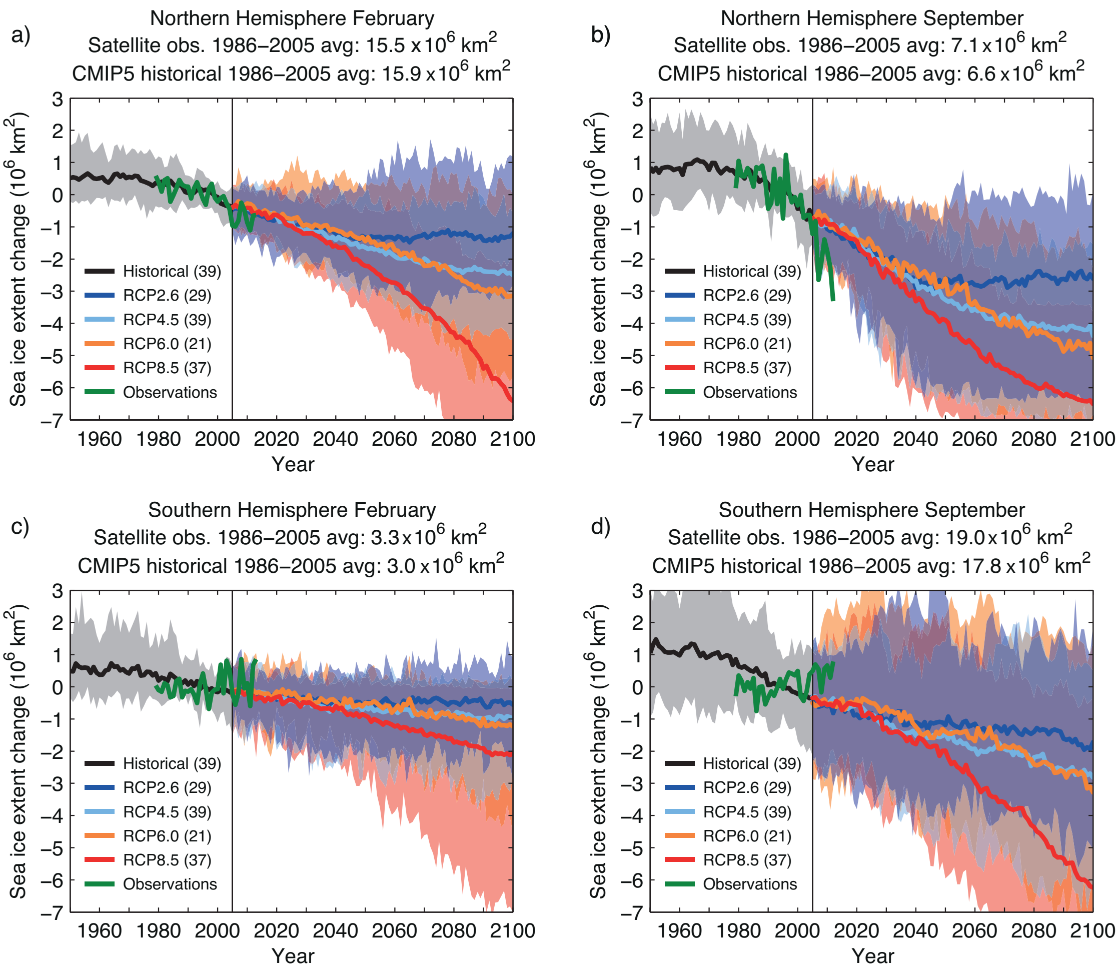

Figure 12.28 | Changes in sea ice extent as simulated by CMIP5 models over the second half of the 20th century and the whole 21st century under RCP2.6, RCP4.5, RCP6.0 and RCP8.5 for (a) Northern Hemisphere February, (b) Northern Hemisphere September, (c) Southern Hemisphere February and (d) Southern Hemisphere September. The solid curves show the multi-model means and the shading denotes the 5 to 95% range of the ensemble. The vertical line marks the end of CMIP5 historical climate change simulations. One ensemble member per model is taken into account in the analysis. Sea ice extent is defined as the total ocean area where sea ice concentration exceeds 15% and is calculated on the original model grids. Changes are relative to the reference period 1986–2005. The number of models available for each RCP is given in the legend. Also plotted (solid green curves) are the satellite data of Comiso and Nishio (2008, updated 2012) over 1979–2012.

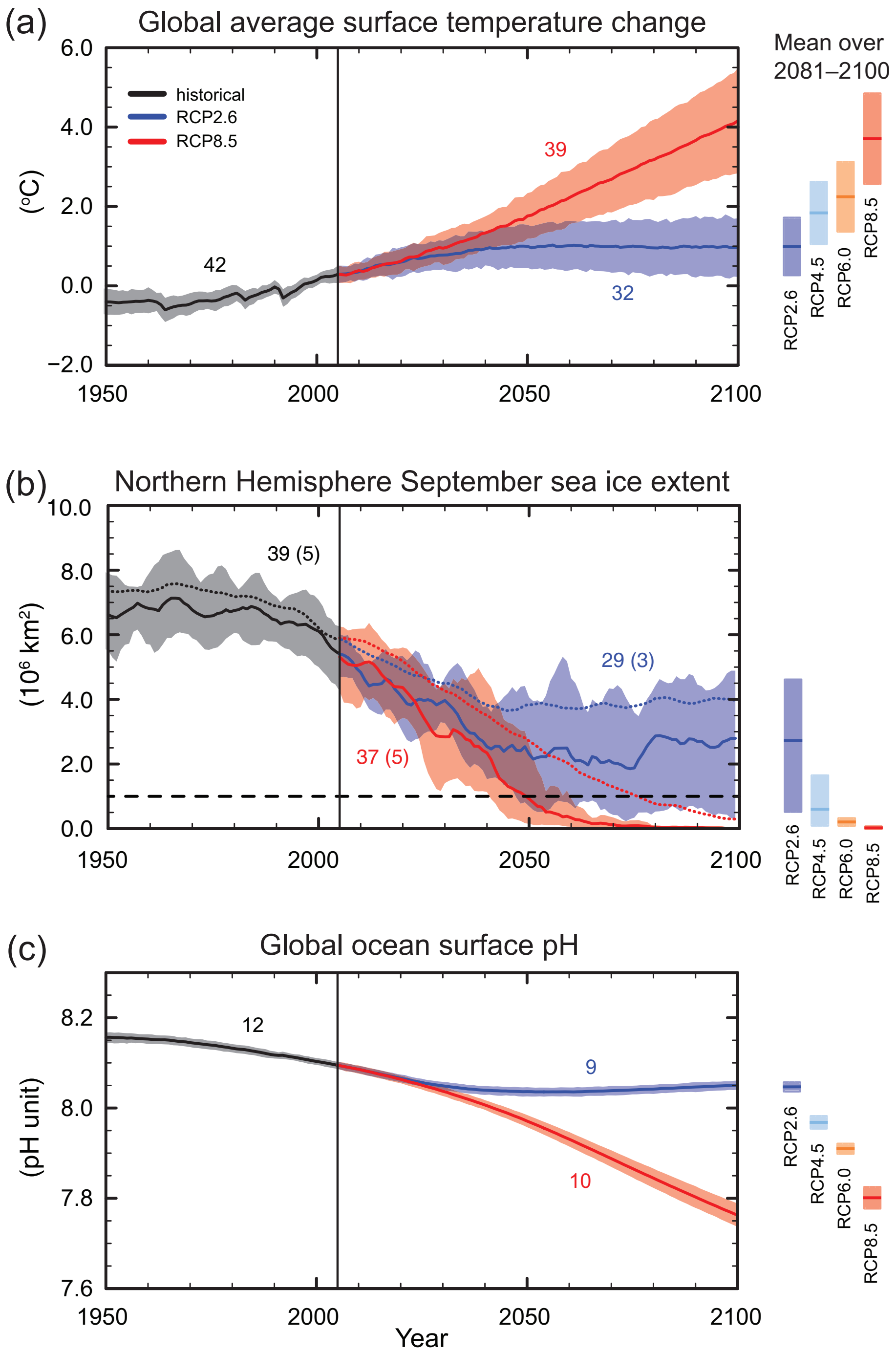

Figure SPM.7 | CMIP5 multi-model simulated time series from 1950 to 2100 for (a) change in global annual mean surface temperature relative to 1986–2005, (b) Northern Hemisphere September sea ice extent (5-year running mean), and (c) global mean ocean surface pH. Time series of projections and a measure of uncertainty (shading) are shown for scenarios RCP2.6 (blue) and RCP8.5 (red). Black (grey shading) is the modelled historical evolution using historical reconstructed forcings. The mean and associated uncertainties averaged over 2081–2100 are given for all RCP scenarios as colored vertical bars. The numbers of CMIP5 models used to calculate the multi-model mean is indicated. For sea ice extent (b), the projected mean and uncertainty (minimum-maximum range) of the subset of models that most closely reproduce the climatological mean state and 1979 to 2012 trend of the Arctic sea ice is given (number of models given in brackets). For completeness, the CMIP5 multi-model mean is also indicated with dotted lines. The dashed line represents nearly ice-free conditions (i.e., when sea ice extent is less than 10^6 km² for at least five consecutive years). For further technical details see the Technical Summary Supplementary Material {Figures 6.28, 12.5, and 12.28–12.31; Figures TS.15, TS.17, and TS.20}