Do Stochastic Parameterizations Modify the Climate Response to External Forcing? An Experiment with EC-Earth.

Virna Loana Meccia[1], Federico Fabiano[1], and Susanna Corti[1]

[1]CNR Institute of Atmospheric Sciences and Climate

November 24, 2022

Abstract

Stochastic physics (SP) schemes provide a more realistic representation of the unresolved scales in global circulation models by improving both mean climate and climate variability. We study the impact of including an SP scheme in the atmospheric component of EC-Earth on the simulated climate. In particular, we analyze the evolution of the sea-ice extent in the Arctic during long-term simulations covering the historical and future periods. The experiments consist of coupled climate simulations in which three ensemble members constitute the control runs (base) and three ensemble members include stochastic physics (stoc). For the latter, the Stochastically Perturbed Parametrization Tendencies (SPPT) scheme is incorporated in the atmospheric component of EC-Earth. The original experiments, that are part of the SPHINX project, span from 1850 to 2100. We have additionally extended each simulation for 60 years; the future scenario corresponds to the CMIP5 RCP8.5 set up. We compare both sets of experiments to investigate the climate response to a perturbed atmosphere. The simulated Arctic sea-ice extent in September and March display an overall decrease. The sea-ice loss results faster in the base experiments than in the stoc ones. The model simulates an abrupt sea-ice loss in March that takes place about 10 years earlier in the base experiments than in the stoc ones. The evolution of the global annual mean surface air temperature differs if the SP is on or off. Curves start separating by the second half of the 20th century; reach the maximum difference in 2100 and become almost indistinguishable around 2110. Our results suggest that the transient climate sensitivity is lower when the SP is on than when it is off during the 21st century. However, the opposite occurs when the Arctic is free of sea ice along the whole year. This behavior might be the consequence of the asymmetric effect of stochastic perturbations on the process of condensation. We are now investigating the differences in the albedo and cloud feedbacks between both sets of experiments and the possible influence of the mean state on the model climate sensitivity.

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Virna Meccia*, Federico Fabiano and Susanna Corti

Institute of Atmospheric Sciences and Climate, National Research Council of Italy

1. Introduction

Stochastic physics schemes (SPS) provide a more realistic representation of the unresolved scales in global circulation models by improving both mean climate and climate variability. We study the impact of including SPS in the atmospheric component of EC-Earth on the simulated climate. In particular, we analyze the evolution of the sea-ice extent in the Arctic during long-term simulations covering the historical and future periods. In light of the results obtained, we further explore the dependence of the transient climate sensitivity on the global mean surface temperature (GSAT) and how it can be modified by the inclusion of SPS.

2. Simulations

- EC-Earth v3.1. IFS T255L91; NEMO ORCA1L46; LIM3; OASIS3.
- Period of simulation: 1850-2100 (original experiments of SPHINX)
  + 2101-2160 (extension of 60 years).
- Forcing: 1850-2005 CMIP5 historical forcing set up;
  2006-2160 CMIP5 RCP8.5 future scenario set up (Fig. 1).
- Experiments[1]: 3 members constitute the control runs (*base*);
  3 members include SPS[2] in the atmosphere (*stoc*).

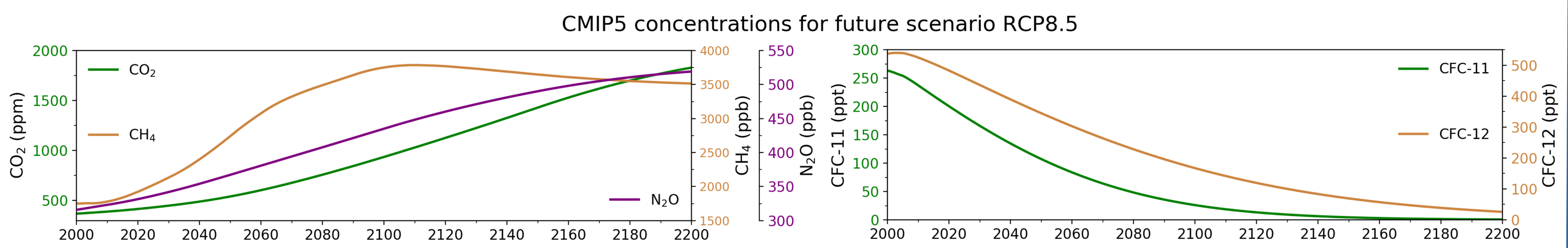

Figure 1. Time series of the RCP8.5 future scenario forcing used in our simulations.

For the *stoc* runs, both the Stochastically Perturbed Parameterization Tendencies (SPPT) scheme with multiplicative noise and the Stochastic Kinetic Energy Backscatter (SKEB) scheme are incorporated in IFS.

3. Results

3.1 Arctic sea-ice evolution

The simulated Arctic sea-ice extent in September and March (Fig. 2) display an overall decrease. The sea-ice loss is faster in the *base* experiments than in the *stoc* ones. An Arctic free of sea ice (sea-ice extent < 1×10^6 km^2 for at least 5 consecutive years) in September occurs around 2075 ± 2 (2083 ± 3) for the *base* (*stoc*) experiments (Fig. 2a).

The model simulates an abrupt loss of sea-ice in March (Fig. 2b) in all the experiments. It takes place about 10 years earlier in the *base* experiments than in the *stoc* ones. An Arctic free of sea ice in March occurs around 2151 ± 3 (2153 ± 1) in the *base* (*stoc*) runs.

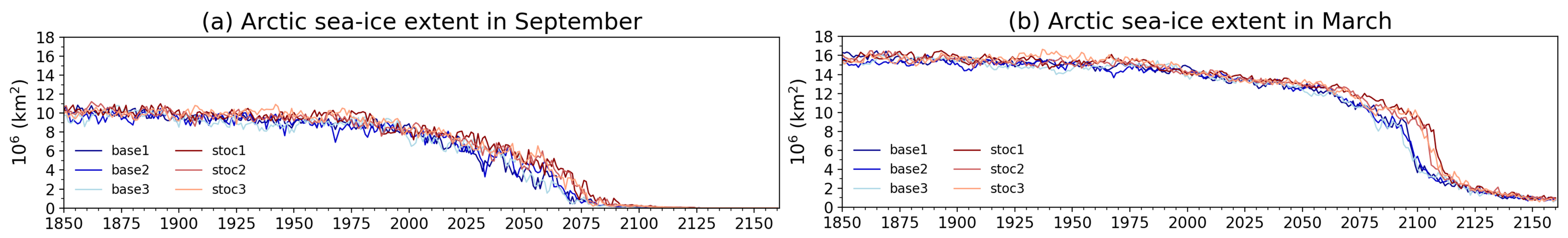

Figure 2: Time series of NH sea-ice extent in (a) September and (b) March. All three ensemble members for the base (stoc) experiments are plotted in blue (red).

The abrupt collapse of winter sea-ice in the Arctic occurs after crossing a threshold value of GSAT which, for the CMIP5 simulations, is only reached under RCP8.5 future scenario[3]. In our experiments, even though the occurrence of the abrupt collapse in *stoc* and *base* is lagged by about 10 years (Fig. 2a), the GSAT that can be considered as the threshold value for the abrupt decline is 17.4 ± 0.35 ºC (Fig. 3).

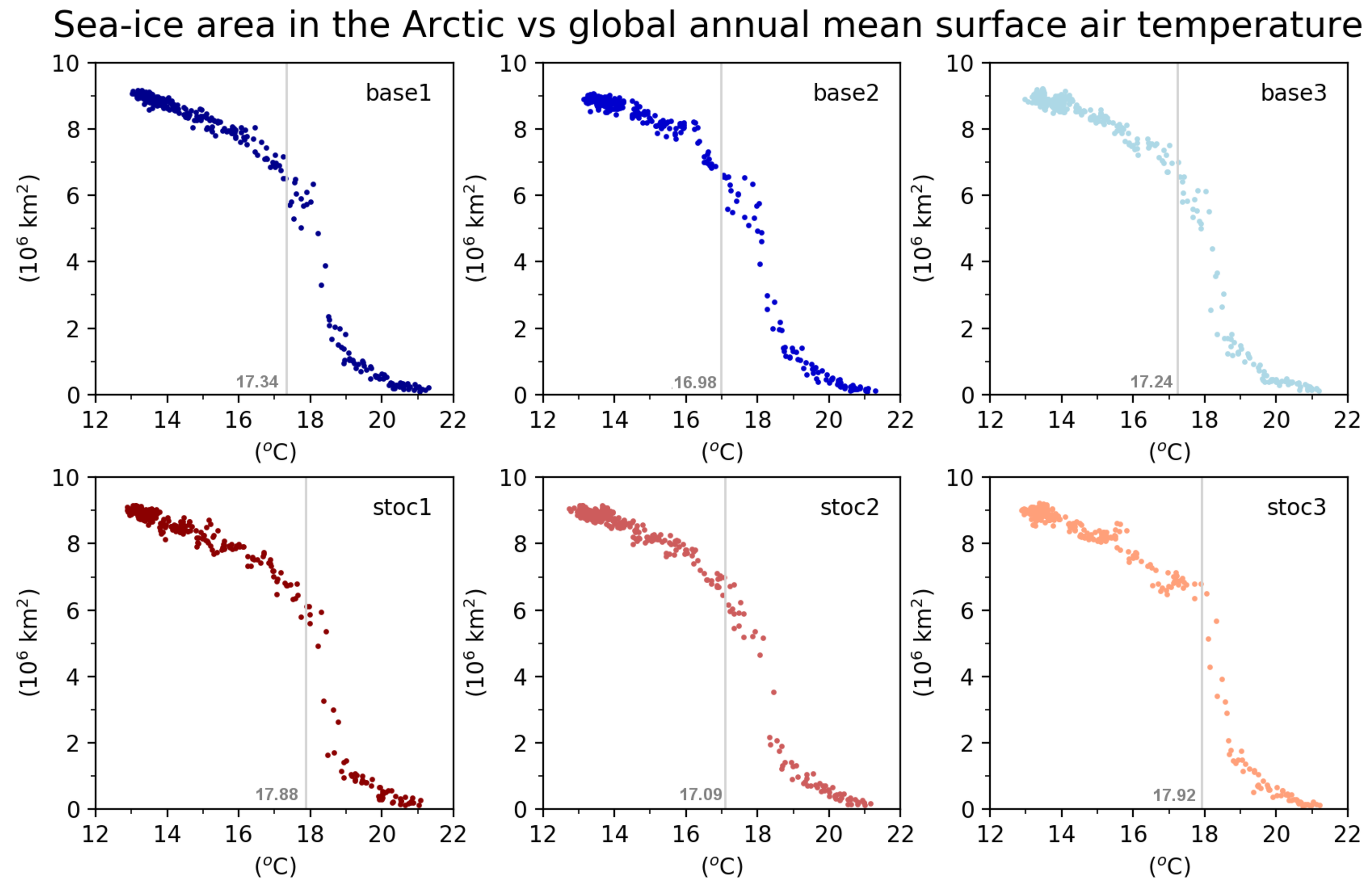

Figure 3: Sea-ice area in the Arctic vs GSAT for each experiment. Each dot represents a seasonal average over March-April-May (MAM) of one year. The threshold temperature value for the abrupt decline of winter sea ice is highlighted in gray.

3.2 Global temperature

The evolution of the global annual mean surface air temperature (Fig. 4a) is similar among the ensemble members but differs if the SPS are on or off. The difference between the two sets of experiments reaches the maximum value around 2100 when the GSAT change is larger in the *base* experiments. Quite unexpectedly, after the year 2100, the opposite occurs: global temperature increases faster in the *stoc* runs (Fig. 4).

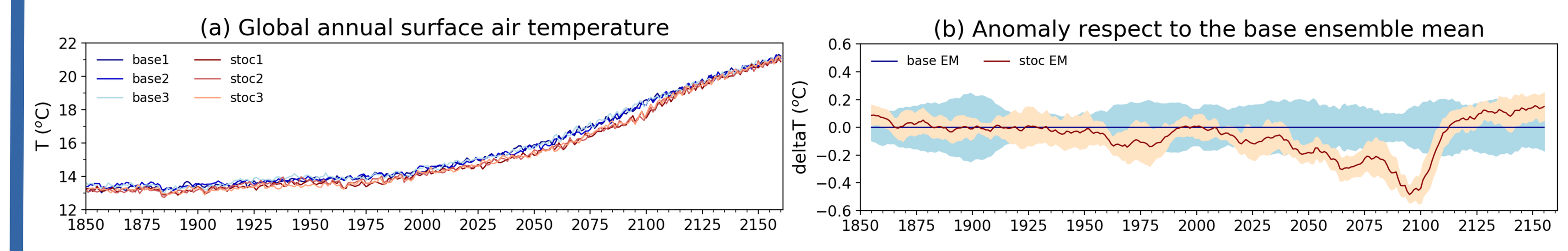

Figure 4: (a) GSAT (ºC) for each ensemble member and (b) difference respect to the base ensemble mean of the GSAT increment (ºC). 10-yr moving averaged ensemble means and the ensemble members' spread are plotted in (b).

4. Discussion and conclusion

The transient climate sensitivity is lower when the SPS are on than when they are off only during the 21st century. This has been associated to a different amount of low-level clouds cover (LCC) between the *base* and *stoc* runs[4] (Fig. 5a). However, we found that the opposite occurs after 2100 and it seems to be associated to the high-level clouds cover (HCC, Fig. 5b). In a warmer climate, the model produces more HCC when SPS are activated (positive feedback) giving rise to a larger cloud radiative forcing when compared to the *base* runs. The global surface relative humidity increases with warming (Fig. 5c) so, it is possible that once a certain critical threshold of relative humidity is achieved, the stochastic perturbations might favour condensation (Fig. 5d). Such a tipping point occurs at about 75% relative humidity and will be investigated in a forthcoming study.

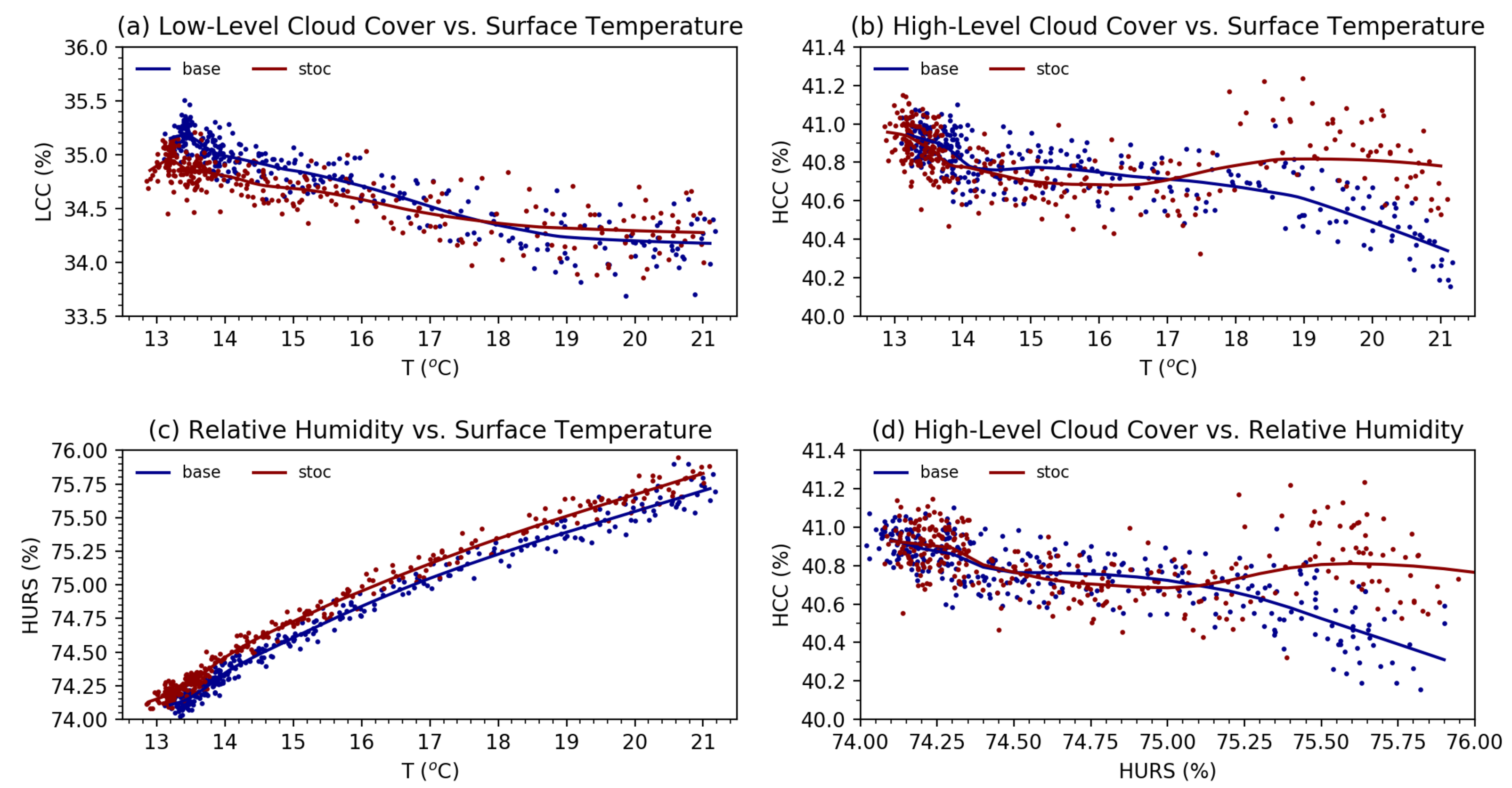

Figure 5: Globally averaged (a) LCC; (b) HCC and (c) surface relative humidity versus the GSAT and (d) HCC versus surface relative humidity for the ensemble mean of the base (blue) and stoc (red) experiments. Solid lines are the results of a non-parametric regression method (LOESS).

Contact: v.meccia@isac.cnr.it

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