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Earth System
Dynamics
Discussions

Interactive comment on "A dynamical and thermodynamic mechanism to explain heavy snowfalls in current and future climate over Italy during cold spells" *by* Miriam D'Errico et al.

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Anonymous Referee #1

GENERAL COMMENTS This paper first uses reanalysis data to document the large-scale circulation conditions that have led to heavy snowfall events together with low temperatures in Italy between the years 1954 and 2018. After this, an intermediate complexity climate model (PlaSim) is used to explore how the occurrence of such events might change in a warmer future climate. The paper has its positive aspects but also severe limitations. To start with the former, it includes a valuable compilation of 32 major snowfall / cold spell events that have affected Italy since the mid-20th cen-

tury. The analysis of the corresponding circulation anomalies in the NCEP reanalysis also makes good sense. Furthermore, the paper is written in good English.

We thank the reviewer for the appreciation of our work. Indeed the reconstruction of the 32 major snowfall events via multiple sources is an achievement of this work on its own as we wanted to investigate the compound aspects of cold and snowy spells over large populated areas of Italy.

On the other hand, there are many problems in the PlaSim simulations and in the interpretation of their results. The first is, obviously, the coarse (2.8âŮę× 2.8âŮę) resolution of the model. Simulations at such a resolution give very little direct information on snowfall in Italy. In the control simulation, the (country mean) snow water equivalent anomalies in the identified extreme cases are of the order of 2 mm, which is at least an order of magnitude smaller than the observed local snowfalls. Therefore, in practice, the analysis mainly gives information on the atmospheric circulation events that resemble the circulation during the observed snowfall extremes.

We agree with the comment of the referee, which is also reflected by the other reviewer about the inadequacy of PlaSim in reproducing physical quantities such as snowfall. We will change the point of the view of the manuscript and focus the results obtained with PlaSim on the analogues of the circulation fields associated with the events detected in the reanalysis. Our study therefore provides a procedure to evaluate the role of atmospheric circulation in the occurrence of those compound events. The manuscript will then have the following key points:
1) Detection of compound snowy and cold events over Italy in documentary sources.
2) Assessment of the existence of common circulation patterns for such events.
3) Detection of Analogues in climate simulations in present and future climate conditions and consideration about the associated temperature, snow depth and pressure fields.

A second important problem is that the severity of the cold spells is only analysed based on the magnitude of the 850 hPa cold anomalies relative to the climatological mean values. These anomalies are found to (more or less) retain their earlier magnitude, leading to the suggestion that such events in the future will be no less severe than those observed this far. Yet the warmer mean climate in these simulations also means that the actual temperatures during the cold spells will become higher. In the RCP8.5 scenario, this change is large enough to nearly eliminate all snowfall in Italy. Thus, a cold anomaly with the same magnitude will not have the same effects in a warmer climate. In addition to the simulation based on the RCP8.5 forcing scenario, the study uses another simulation in which the sea surface temperature (SST) has been uniformly increased by 4 K, without changing the atmospheric composition. Such a simulation may be useful for process studies but does not represent a plausible future. Increasing the SST without increasing atmospheric greenhouse gas concentrations creates an artificial energy source at the sea surface, which distorts the dynamics of the climate system. The finding that the simulated snowfall extremes increase under such conditions is therefore difficult to interpret.

Following the suggestion of the reviewer, in the version of the manuscript we will also display the changes in the identified observables for all winter days and for the days corresponding to analogues of NCEP reanalyses. This figure is reported here as Figure A1. It suggests indeed the need to rephrase some statements of the manuscript and to clearly state the thermodynamic limitations of our study, namely that:
A warmer mean climate in RCP8.5 simulation implies that temperatures during cold spells will be way higher and that snowfall will possibly disappear.
Snowfall in Italy is almost eliminated in the RCP8.5 scenarios.
The +4K SST is an idealized simulation, taken from AMIP runs, that we use to push to an extreme set-up in order to observe clear thermodynamic changes in PlaSim. We will stress furthermore that this simulation is just used to understand the possible thermodynamic feedback of warmer Mediterranean sea dur-

ing events whose atmospheric circulation matches cold and snowy spells. The comments of both the referees made us rethink to the conclusions that can be drawn from this analysis: the fact that the convection potential is enhanced with warmer seas can i) produce snowfalls in some cases where the temperatures remain below the melting threshold ii) transform the snowy events in events where large amounts of convective precipitation falls on the ground in liquid or mixed phase, with important consequences for hydrology and winter tourism.

Aside from these scientific issues, the selection of figures requires consideration. For example, Figure 8 is hardly at all discussed in the text, suggesting that it is redundant. Figure 4 is also a candidate for deletion (see comment 17 below). On the other hand, to aid the reader to assess how severe the simulated future cold spells are, figures and/or other information on the average winter warming would be needed.

Figure 4 will be replaced by that presented at the end of this answer (Figure A1).

In conclusion, large improvements are still needed in this paper.

SPECIFIC COMMENTS L131. What is the length of the cold spells and their analogues? Does it vary from case to case, and if so, how is the length determined?

For each cold-spell we have taken the 32 days documented in the appendix as the ones for the analogous search. Then, for each of those days, we have taken the best analogues and performed a lagged analysis in time. So the analysis is based on a single day. The lag extends back in the past and forward in the future from this day. We will further specify this in the new version of the manuscript.

L156-157. How much does the average winter T850 in Europe / in Italy increase relative to CTRL in RCP8.5 and 4SST?

To answer this question, we have produced Figure A1 at the end of this review. It will substitute with Figure 4 in the previous version of the manuscript. Indeed the RCP8.5 scenario is about 10 degrees warmer in winter, over Italy, than the

CTRL scenario. Interestingly, the 4SST scenario produces about the same temperatures as the CTRL scenario. This explains why in the RCP8.5 scenario we barely observe snowfalls while we do observe it for the 4SST one.

L163-168 and Fig. 8. If there is nothing more to say about Fig. 8, the figure and this paragraph can be deleted. To me there are two main messages: (i) the zero-lag correlations between the observed events are not very strong (âĹij0.3) suggesting that there is actually quite a lot of case-to-case variability, and (ii) the correlations in PlaSim are stronger, indicating that there is less case-to-case variation in the model.

We will rephrase the manuscript accordingly.

L179-181. Although the anomalies remain similar, the absolute temperatures must be higher (how much higher?) in RCP8.5 and 4SST than in CTRL. I don't see anything particularly counterintuitive in your results.

The new boxplot figure at the end of the end of the review shows that indeed for the RCP8.5 scenario, the temperature is about 10 degrees higher than in CTRL.

L179-181. Are these differences in the average magnitude of the cold anomaly statistically significant in comparison with the inter-event variability?

Figure A1 clearly shows that: analogues of cold spells yield significantly lower temperature and geopotential height and higher Snow Depth amounts than the statistics for all winter days.

L181. Warmer mean temperatures are expected, but not necessarily smaller warm or cold anomalies (the latter depends on location and season).

We agree with the reviewer. This sentence will be rephrased.

L193-194. Is this really cooler than in CTRL in terms of the absolute temperature?

We will correct the sentence as: "This effect is amplified by a warmer ocean in the case of 4K-SST simulation causing cold spells with temperatures and snow-

fall comparable to those observed in the CTRL scenario"

L196-197. There is nothing about the lapse rate in Eq. (1). Delta_T is the temperature tendency caused by the parameterized condensation of water vapour.

The distribution of temperature Tcl in the cloud is found by first lifting the air dry adiabatically and corrected due to condensation of water vapor. The temperature tendency $(\Delta T)_{cl}$ is the temperature difference between the environmental heating and cloud temperature of each cloud layer $(T_{cl} - T_e)$.
Cumulus clouds are assumed to exist only if the environmental air with temperature Te is unstable stratified with regard to the rising cloud parcel: $(T_{cl}) > (T_e)$. The top of the cloud σ_{Top} is then defined as $\sigma_{Top} = \sigma_{l+1/2}$ if $(T_{cl})_l < (T_e)_l$ and $(T_{cl})_{l+1} > (T_e)_{l+1}$. The final temperature $\partial T/\partial t$ which appears in the diabatic leap frog time step is given by $(\Delta T)cl/2\Delta t$, where $2\Delta t$ is the leap frog time step of the model. The convective precipitation rate $P_c[m/s]$ of each cloud layer is

$$P_c = \frac{c_p \Delta p}{Lg\rho_{\mathrm{H_2O}}} \frac{(\Delta T)^{cl}}{2\Delta t} \tag{1}$$

whereΔp is the pressure thickness of the layer and ρ_{H_2O} is the density of water. Note that in the previous expression, the larger the convection, the more negative is the P_c value because of the definition of $(\Delta T)_{cl}$ which is itself negative.

L197-199. If the colour scale in Fig. 11 is correct, then there is less convective precipitation over the northern parts of the Mediterranean (including surroundings of Italy) although more in the south.

We will rephrase this sentence to make it clearer to the readers.

L211-212. Although a similar frequency of the analogue events (in terms of the SLP and T850 anomalies) occurs, the absolute values of T850 during these events are higher. Therefore, the sentence (This means that . . .) is misleading.

We will rephrase this sentence "This means that the chance of cold event hap-

pening in this region does not decrease under anthropogenic forcing." as: "This means that, in an RCP8.5 warmer climate, geopotential patterns similar to those leading to historical cold spells will be observed with the same frequency and lead to relatively lower temperature than average winter days. However, the large increase of mean temperature in the RCP8.5 scenarios will prevent snowfall precipitation during most of those events".

L215-217. Overinterpretation of a very subtle difference. Even if the difference were larger, why would the decrease in the frequency of good circulation anomalies in 4K-SST indicate that dynamic processes are more favoured than thermodynamic processes?

We see the point of the reviewer. We will replace "are more favored" with "concur" .

L222-224. The 4K-SST increase without increasing greenhouse gases is not a physically consistent possibility in the real world.

As we stressed in a previous answer, we will stress that we have used the 4SST only to study lake effect snow and that it is not physically consistent with the real world.

Figure 7d. The values of T850 in CTRL (particularly) in Italy seem surprisingly high compared with those in NCEP (Fig. 5b), RCP8.5 and 4SST (Figs. 7e-f). Are they correct? In particular, given the 8 K increase in the global mean temperature in RCP8.5 (Fig. 4), a much larger difference between CTRL and RCP8.5 would be expected.

Let us say that many climate simulations have an offset with respect observations and Plasim does not make exceptions for that. We will further underline it in the new version of the manuscript. However, we checked that FIgure 7 is correct and coherent with new Figure A1.

COMMENTS ON PRESENTATION

L29. Dynamics of compound extreme cold and snowy events?
L35. the Great Lakes
L89. deteriorates the realism of the resulting climate?
L117. Figure 4 seems unnecessary. Just mention how much the global mean temperature increases in your RCP8.5 simulation and how much it increases in the CMIP5 simulations by the end of the century. C4
L125. +3.5 K . . . under which scenario?
L139. western half of Eurasia
L164. at time lags up to +/- 60 days
L207. SLP, not SPL 22. L254. main characteristics 23. Table 1. Write T850 and Z850 (rather than a) and b)) directly in the table

Technical corrections will be implemented in the new version of the paper.

Please find figure A1 in attachment:
Figure A1: Boxplots of the spatial average over Italy of SLP (hPa) (a), T850 (°C) (b), Geopotential Height HGT (dam) (c) and Snow depth (Kg/m2) (d) for all winter days (grey) and for the analogues of cold spells (blue).

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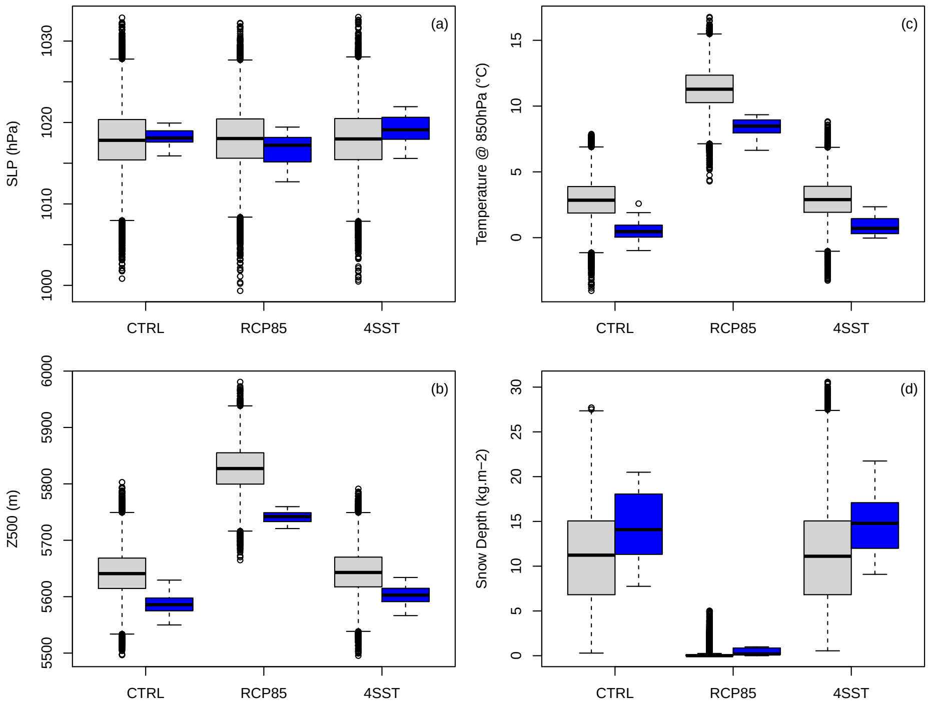
(a)
SLP (hPa)
1000
1010
1020
1030
(c)
Temperature @ 850hPa (°C)
0
5
10
15
(b)
Z500 (m)
5500
5600
5700
5800
5900
6000
(d)
Snow Depth (kg.m−2)
0
5
10
15
20
25
30
CTRL
RCP85
4SST

Fig. 1.