How are CFS seasonal forecasts affected by poor snow initialization?

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Introduction

- Seasonal forecasts made using the Climate Forecast System (CFSv2) are initialized with too little SWE (Dawson et al., 2016), which tends to not accumulate enough and melt too early (Fig. 1)
- As a result, there are mismatches between forecasts made earlier vs. later in the winter; earlier forecasts have more SWE and later forecasts have less SWE
- This influences other forecast variables as well because SWE strongly affects the surface energy balance
- Here, we use 28 years of CFS retrospective forecasts (CFS-RR) to investigate **how much these other forecast variables are affected by having too little SWE during the spring-summer transition**
- We also compare the forecast data to observation-based datasets of SWE over the Conterminous US (Broxton et al 2016) and global corrected temperature (Wang and Zeng, 2013) to assess the quality of CFS forecasts

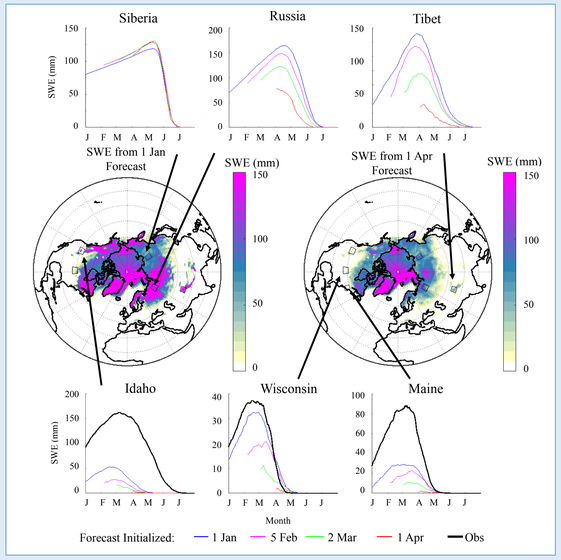
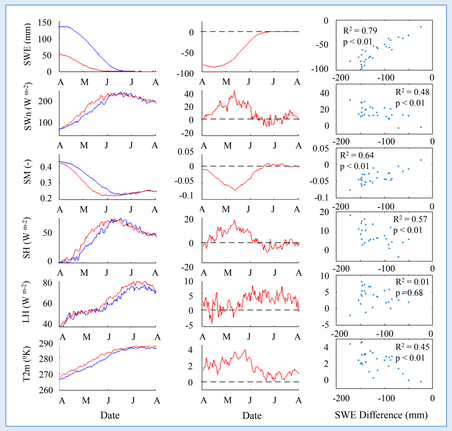


Figure 1: Maps) 1 Apr SWE based on forecasts initialized on 1 Jan and 1 Apr; **Line graphs**) Seasonal progression of SWE for selected areas based on 1 Jan, 5 Feb, 2 Mar, and 1 Apr forecasts. Solid black lines show observed SWE (from Broxton et al., 2016)

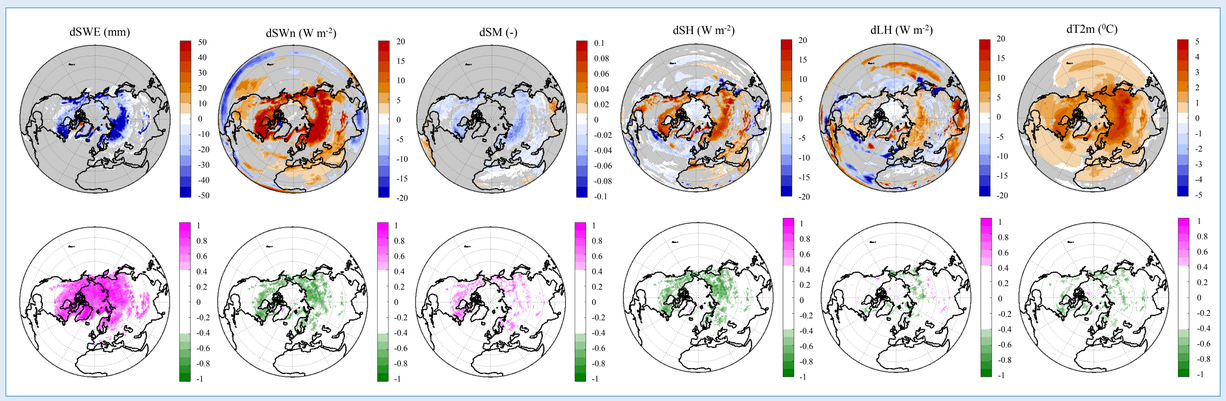
Influence of too little SWE on model energy balance variables



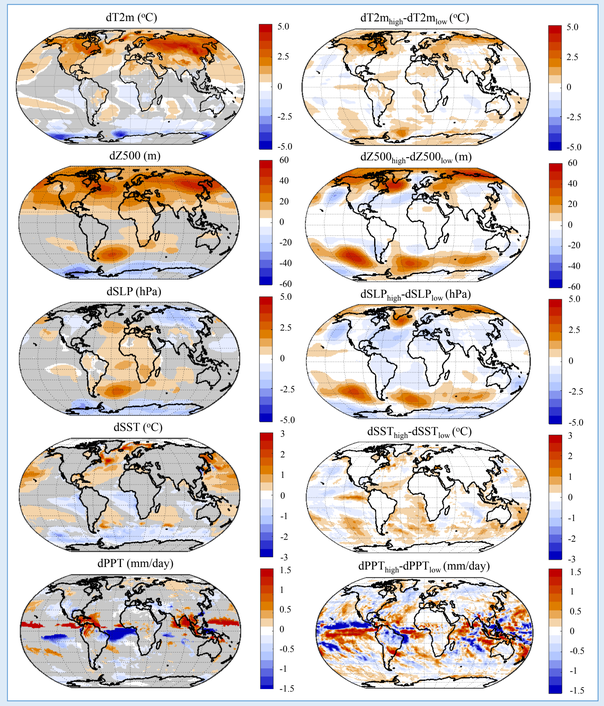
- Too little SWE in later CFS-RR forecasts most strongly affects variables related to the surface energy balance; 1 Apr forecasts generally have less SWE, more net shortwave radiation (SWn), lower soil moisture (SM), higher sensible heat flux (SH), higher latent heat flux (LH), and higher 2-meter temperatures (T2m) during the spring-summer transition (Apr-Jun) than 1 Jan forecasts (Figs. 2 and 3)
- There is significant correlation between the difference between 1 Apr SWE from the two forecasts (dSWE on 1 Apr) and the difference between Apr-Jun forecast quantities from the two forecasts (Apr-Jun dX) (Figs. 2 and 3)

Figure 2: **Left column)** Seasonal progression of quantities from 1 Jan (blue) and 1 Apr (red) forecasts for the box over northwest Russia in Fig. 1; **Middle column)** Difference between the forecasts; **Right column)** Scatterplots between dSWE on 1 Apr and Apr-Jun dX

Figure 3: **Top row)** Maps of Apr-Jun dX (grey shows where this difference is not statistically significant using a difference of means test with $p < 0.01$); **Bottom row)** Interannual correlations between dSWE on 1 Apr and Apr-Jun dX (areas where $p > 0.035$ are white).



Influence of too little SWE on other forecast quantities



- Other variables in CFS-RR also show large differences between the 1 Apr and 1 Jan forecasts; these differences aren't localized to grid cells over the snow (Fig. 4)
- Like T2m, the change in 500 mbar geopotential heights between the two forecasts (Apr-Jun dZ500) is also significantly correlated with dSWE on 1 Apr; other variables are not as strongly influenced by dSWE on 1 Apr (Table 1)
- Apr-Jun SSTs in the Northern Hemisphere and PPT in the tropics show large differences between the forecasts, but these are poorly related to differences in SWE (Broxton et al, 2017)
- dSWE much more strongly affects dT2m over land than does dSST

Table 1: Average correlation coefficients between dSWE and dX for all northern hemisphere land areas, over North America, and over Eurasia. Correlations with $p > 0.35$ are shown in grey

	Entire Northern Hemisphere	North America	Eurasia
dT2m	-0.77	-0.51	-0.58
dZ500	-0.62	-0.35	-0.48
dP_0	0.29	0.13	0.35
dPPT	0.10	0.33	-0.03

Figure 4: Left column) Maps of Apr-Jun dX (grey shows where this difference is not statistically significant using a difference of means test with $p < 0.01$); **Right column)** Composite differences of Apr-Jun dX for the 5 years with the highest dSWE on 1 Apr minus the 5 years with the lowest dSWE on 1 Apr.

How does snow initialization affect the quality of CFS forecasts?

- Later predictions of SWE (e.g. those made on 1 Apr) in CFS-RR are worse than earlier predictions of SWE (e.g. those made on 1 Jan) (Fig. 1)
- Later forecasts of T2m show much less bias than earlier forecasts (Fig. 5, top)
- Forecast skill of T2m also increases between the two forecasts (Fig. 5, bottom)
- This suggests that CFS deficiencies in atmospheric processes (e.g. radiative transfer, turbulence) provide compensating errors for the initialized shallow snow packs (e.g. those in later forecasts)

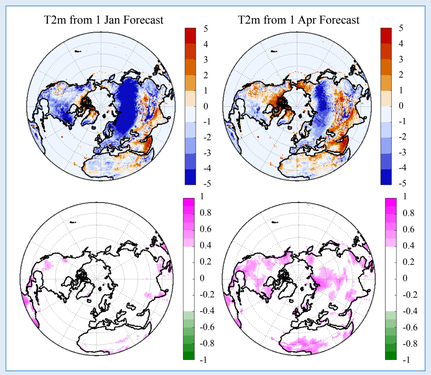


Figure 5: Top-left) Apr-Jun T2m from 1 Jan CFS-RR forecasts minus that from Wang and Zeng, 2013; **Top-right)** Same except using the 1 Apr forecasts; **Bottom-left)** Interannual correlation between Apr-Jun T2m from the 1 Jan CFS-RR forecasts and the Wang and Zeng, 2013 data; **Bottom-right)** Same except using the 1 Apr forecasts

Conclusions

- Springtime SWE in CFS-RR forecasts made later in the winter is worse than in forecasts made earlier in the winter, yet later temperature forecasts show less of a cold bias and higher skill
- This study highlights the need to improve atmospheric processes in CFS (e.g., radiative transfer, turbulence) that would cause cold biases when a realistic amount of snow is on the ground
- It also highlights the major role of snowpack in seasonal prediction during the spring-summer transition due to its influence on T2m

Acknowledgements

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References

Broxton, P. D., X. Zeng, N. Dawson, 2017: The impact of too little initialized SWE on CFS seasonal forecasts, *J. Climate*, in review.

Broxton, P. D., X. Zeng, N. Dawson, 2016: Why Do Global Reanalyses and Land Data Assimilation Products Underestimate Snow Water Equivalent? *J. Hydrometeor.*, 17(11), 2743-2761, doi: 10.1175/JHM-D-16-0056.1.

Dawson, N., P. D. Broxton, X. Zeng, M. Leuthold, P. Holbrook, 2016: An Evaluation of Snow Initializations for NCEP Global and Regional Forecasting Models. *J. Hydrometeor.*, 17(6), 1885-1901, doi: 10.1175/JHM-D-15-0227.1.

Wang, A. X. Zeng, 2013: Development of global hourly 0.5° land surface air temperature datasets. *J. Climate*, 26 (19), 7676-7691, doi: 10.1175/JCLI-D-12-00682.1.