The impact of snow and soil moisture on atmospheric processes

Michael Brunke, Xubin Zeng, Patrick Broxton, Josh Welty, Nick Dawson

University of Arizona, Tucson, AZ

9 December 2018

ILSTSS2S Workshop

Washington, DC

Motivation

Snow affects weather and climate prediction, but snow initialization and modeling are still deficient.

While snow cover is relatively easy to measure from space, snow water equivalent (SWE) and snow depth are much more challenging to measure from space or to upscale from in situ point measurements to area averages.

SWE measurement is recommended as one of the seven candidates to compete for three NASA Explorer satellite missions in the next decade from the 2017 Decadal Survey (released last Friday).

Washington Post Photo

Daily 4 km SWE over ConUS from Oct 1981- present

a) Input data:

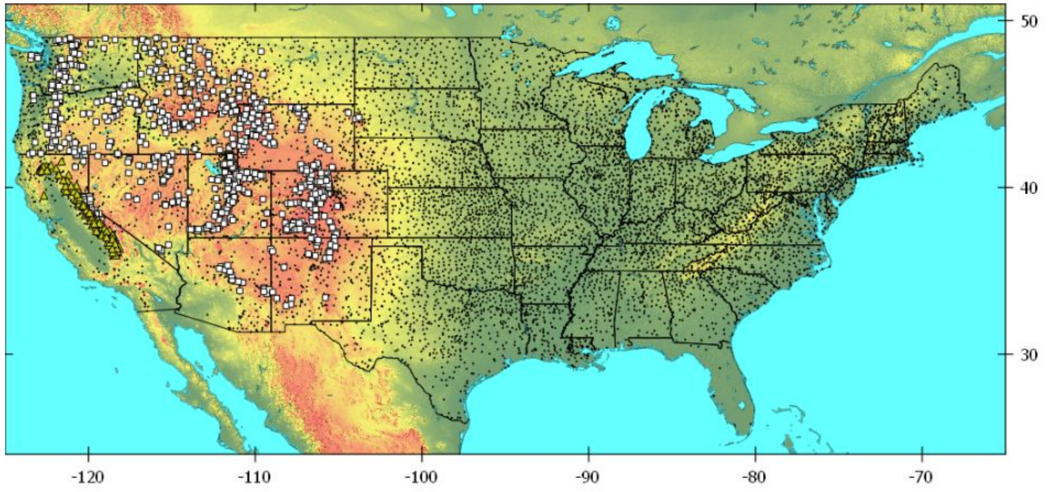
- SNOTEL SWE/snow depth sites, NWS COOP snow depth sites,
- PRISM daily 4 km precipitation and temperature data

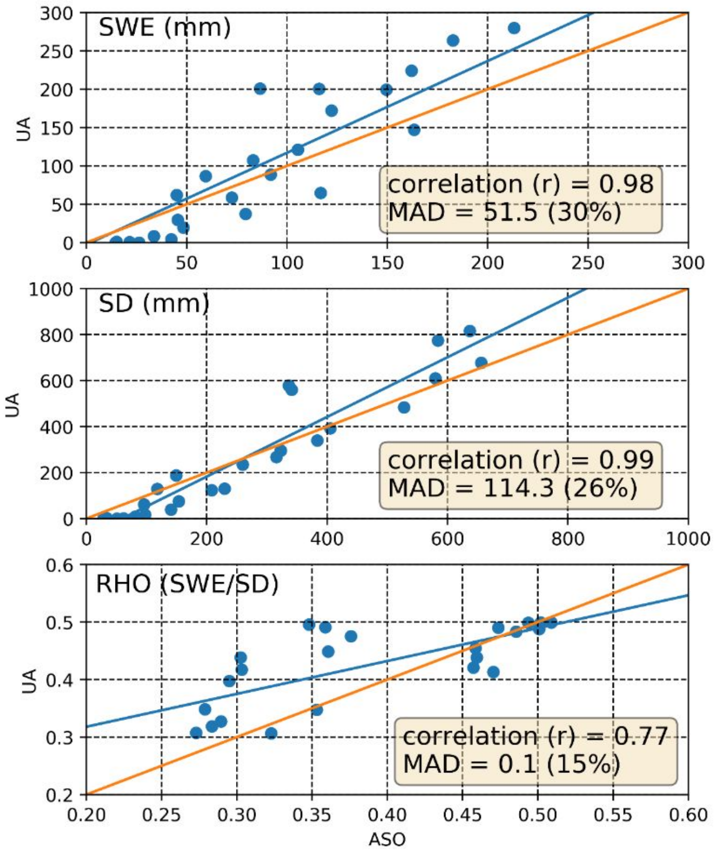
b) Main ideas in data assimilation

- Point-area interpolation (Broxton et al. 2016; Editor's highlight)
- A new snow density model to combine SWE and snow depth measurements (Dawson et al. 2017)

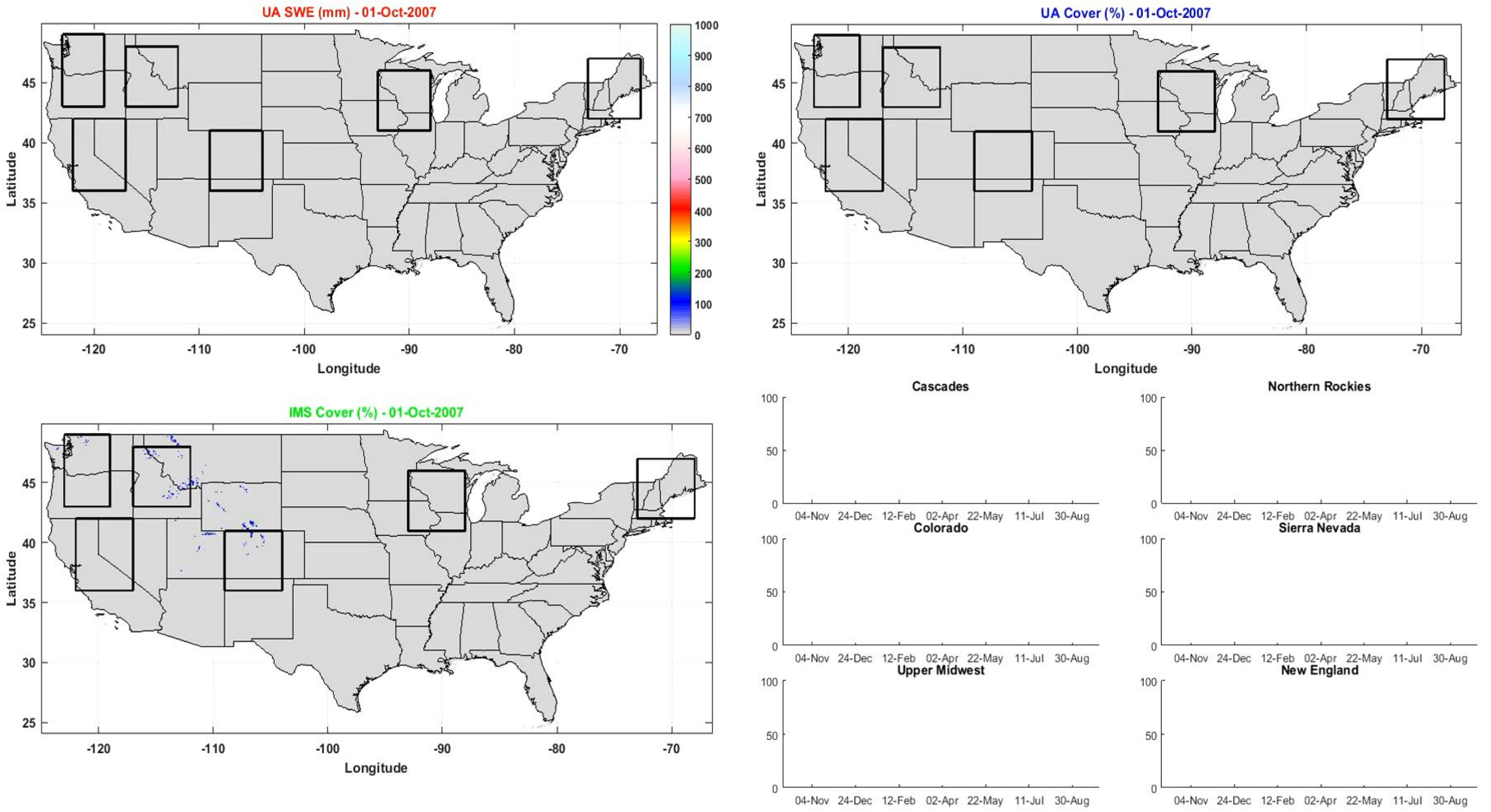
c) Passed four rigorous tests:

- Point-point interpolation test (Broxton et al. 2016)
- Point-pixel interpolation test
- Evaluation using the JPL ASO airborne lidar data (Dawson et al. 2018)
- Evaluation using independent snow cover data



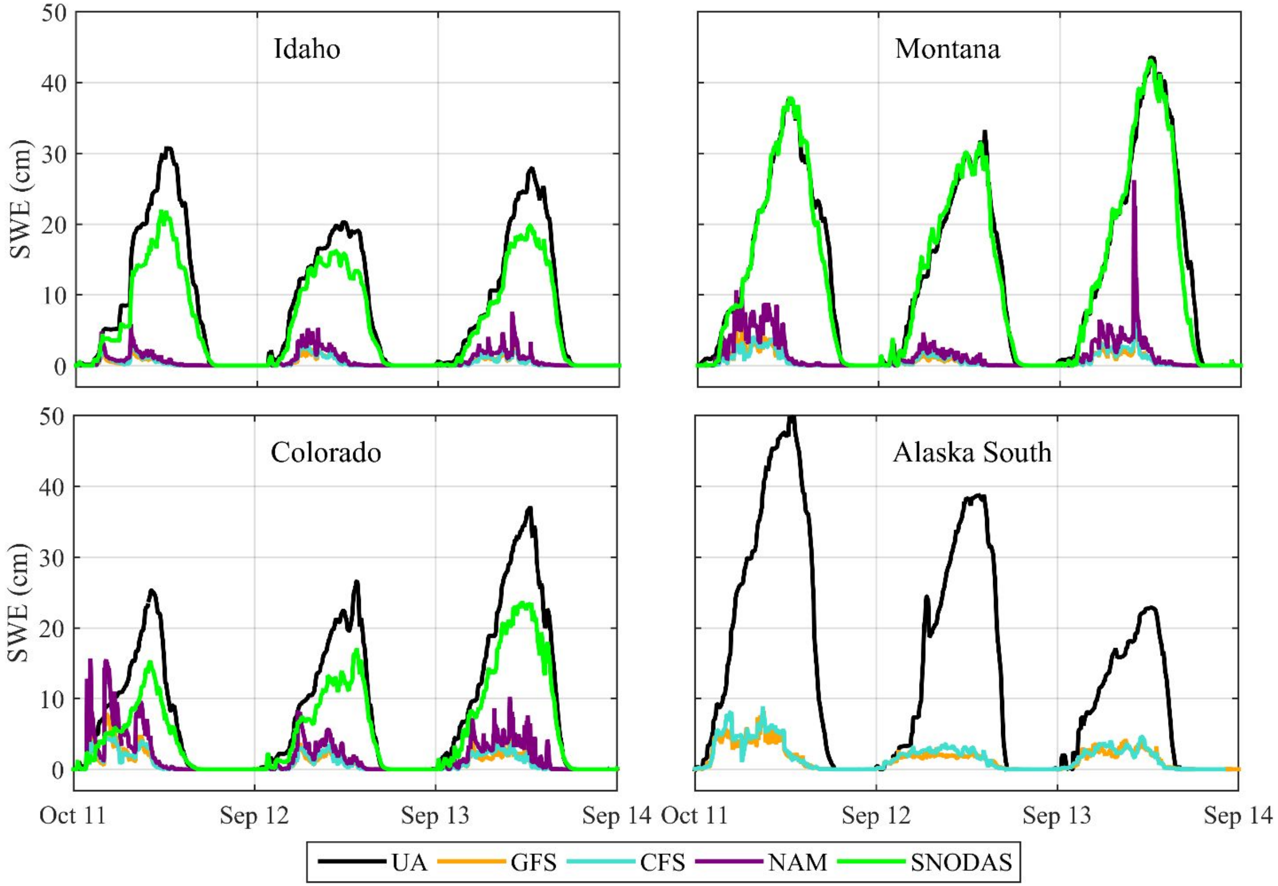


Test #4: Compare daily UA snow cover (SWE > 3 mm) with NOAA IMS product (Dawson et al. 2018)



Overall, UA and IMS snow cover data agree with each other very well, though some inconsistencies in areas with shallow snow / near edges

Q: How good are NCEP SWE initializations?

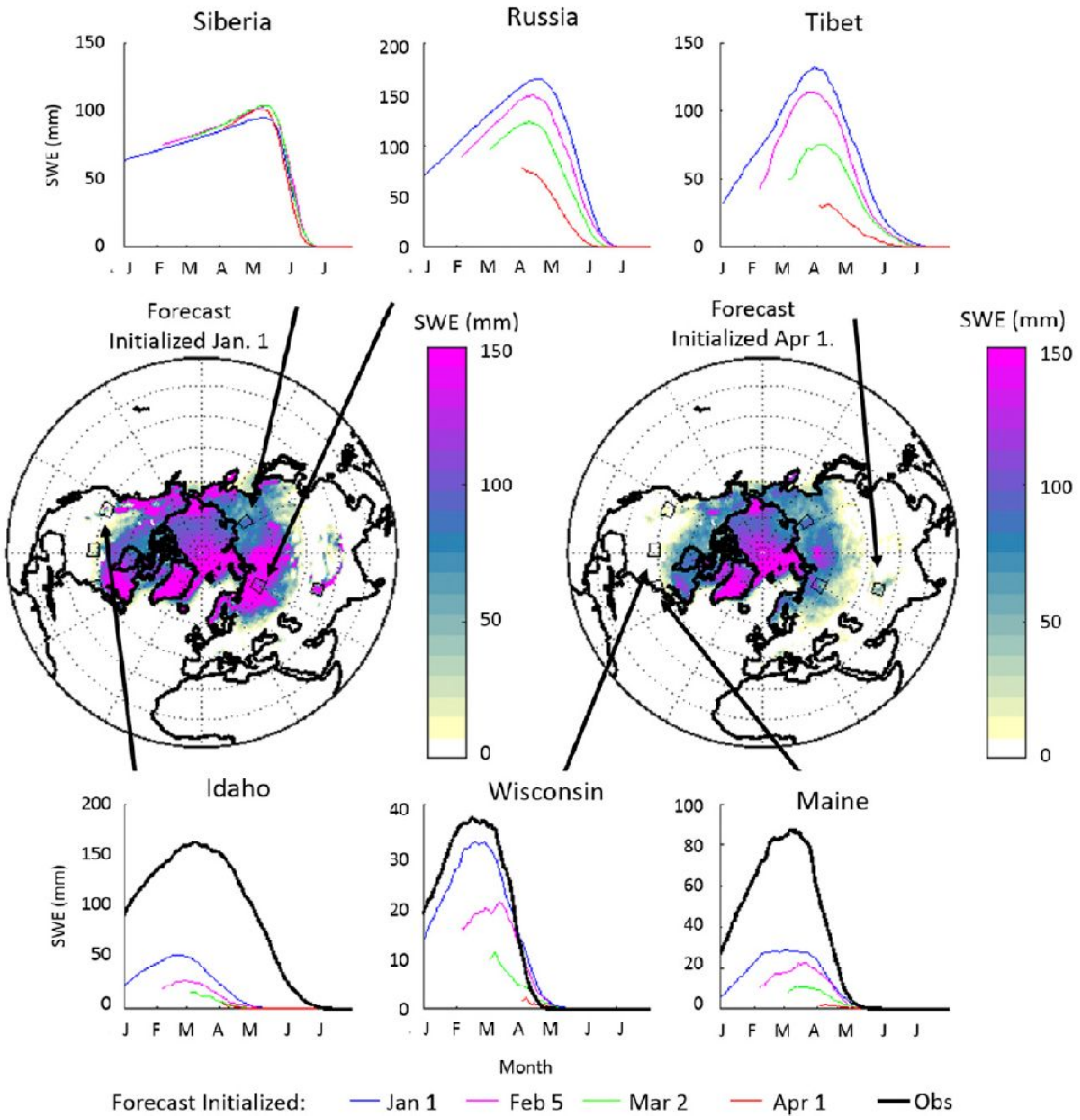


Deficiency: SWE initialization for GFS, CFS, and NAM is too low

Reason: based on the poor AFWA snow depth analysis and use of constant snow density or very simple treatment

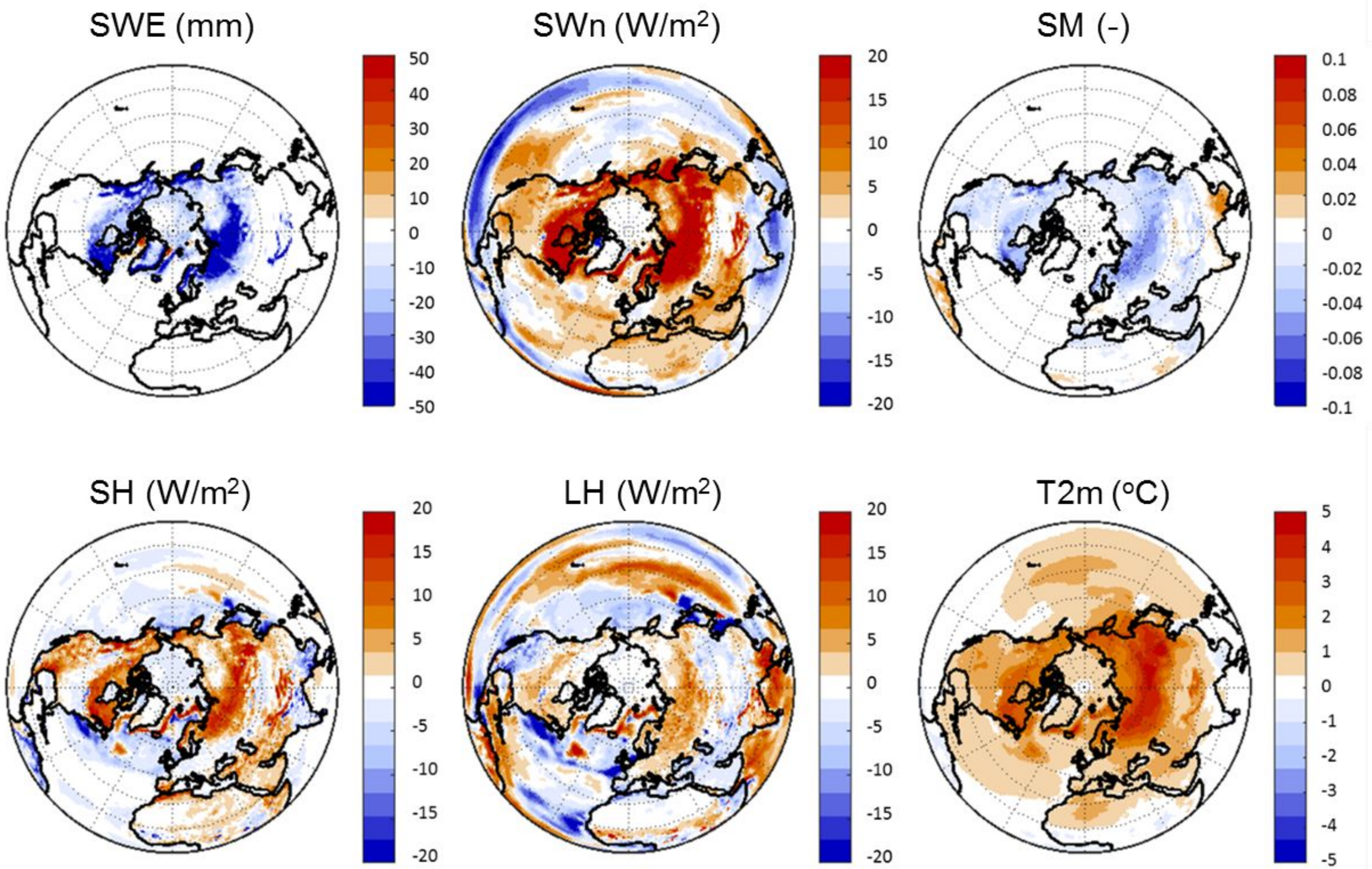
Dawson et al. (2016)

How does poor CFS SWE initialization affect SWE forecasts?



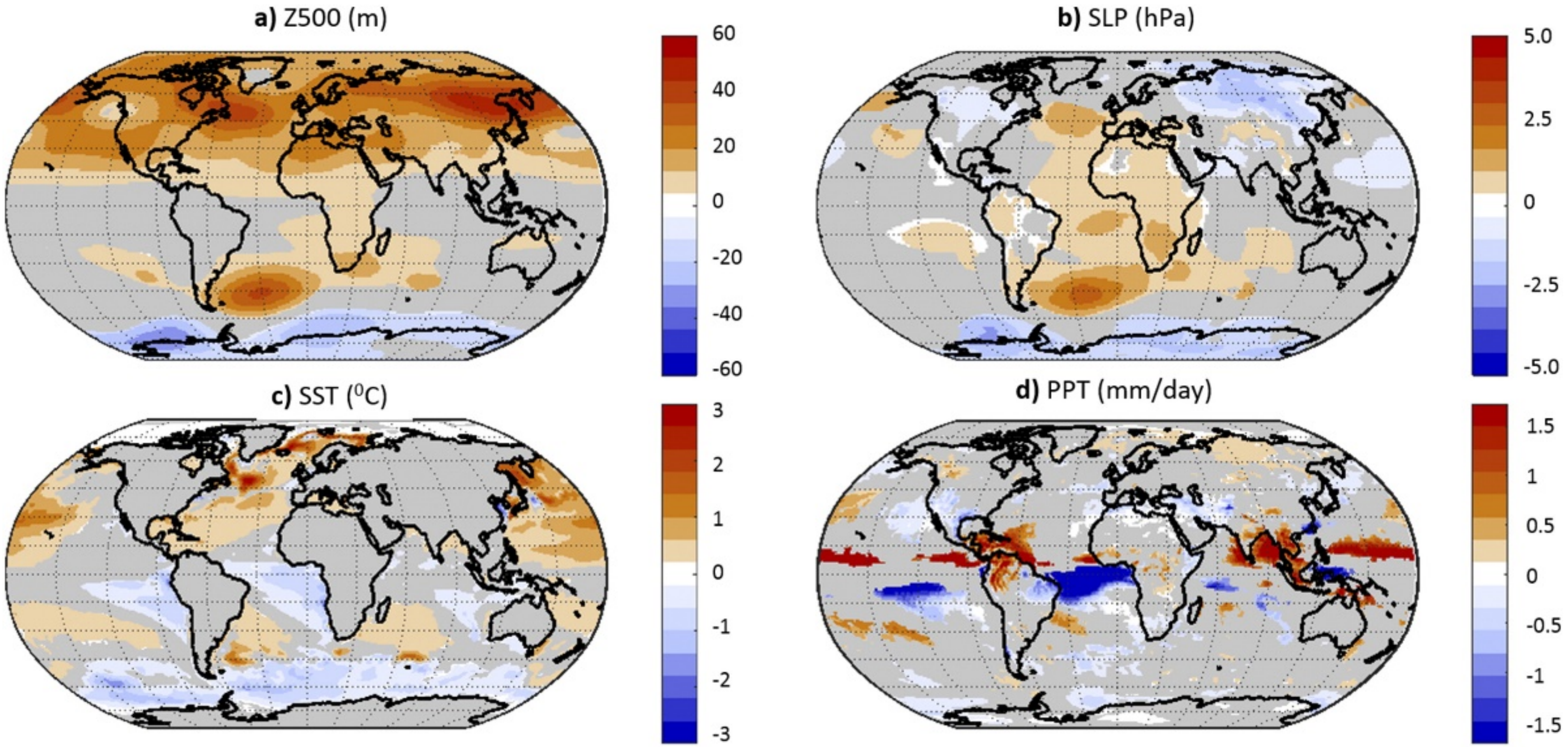
Q: How does this affect other model forecast quantities during spring-summer transition?

Broxton et al. (2017)



Apr 1st minus Jan 1st forecast of model quantities for Apr-Jun averaged from 1982-2009.

Forecasts made later in the season have less SWE, more net solar radiation (SWn), less soil moisture (SM), more sensible heat (SH), and higher T_{2M}. Latent heat (LH) change is more complicated.

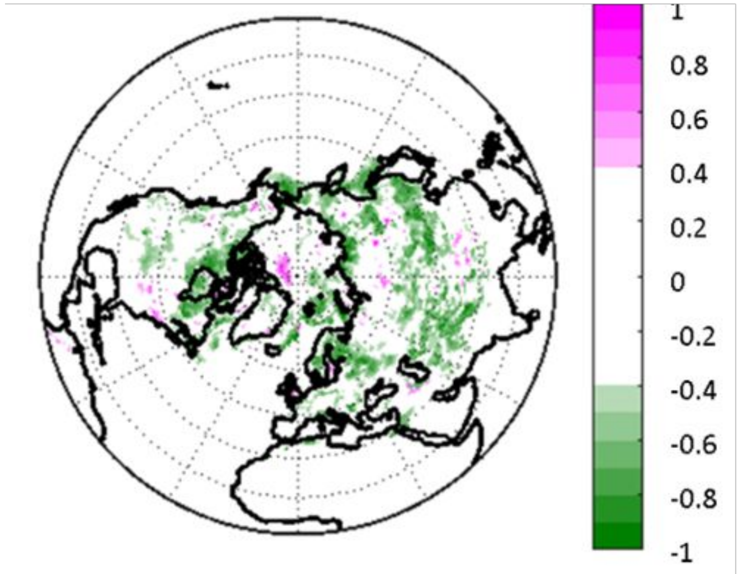


1 Apr minus 1 Jan forecast of model quantities for Apr-Jun averaged from 1982-2009.

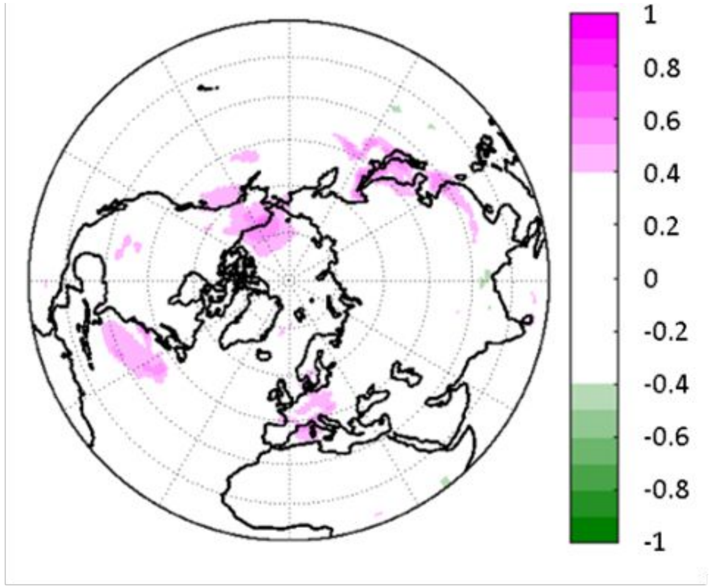
Reasons for these differences:

- Land state (primarily SWE) on 1 April
- Ocean state on 1 April - most important (conventional view)?
- Atmospheric state on 1 April

"d" in dSWE and other quantities represents the 1 Apr minus 1 Jan forecast difference



Temporal correlation (from 1982-2009) between dSWE on Apr 1st and Apr-Jun dT2m (grid-to-grid);

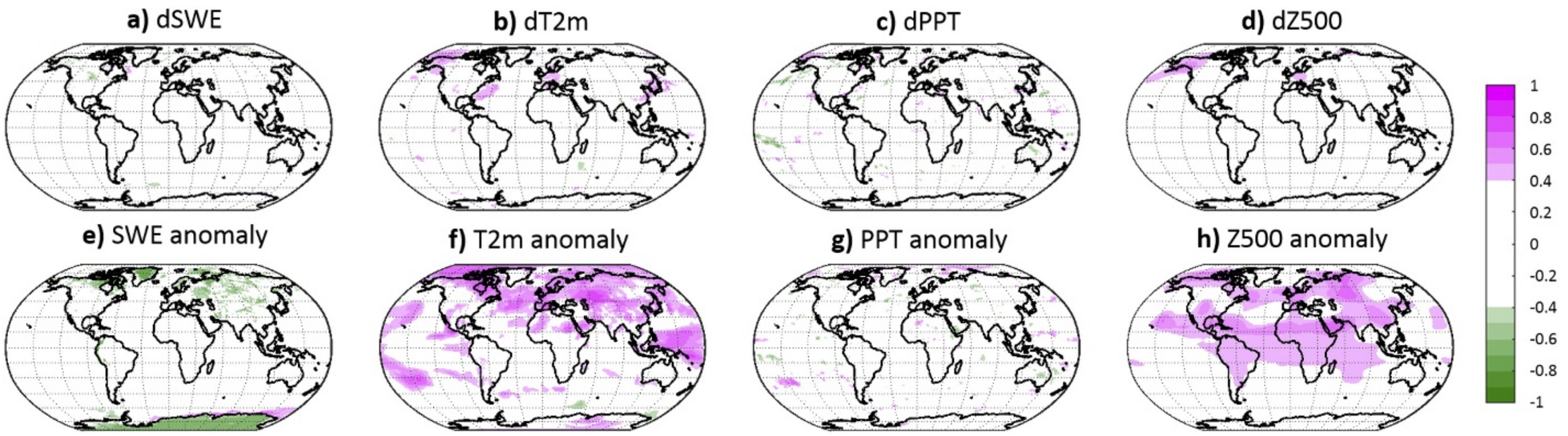


correlation between Apr-Jun dSST (over oceans north of 30°N) and Apr-Jun dT2m

Over Land, SWE affects other variables (e.g. T_{2M}) more strongly than do SSTs, whose influence is mostly felt on the edges of continents

Why is SST state on 1 Apr not important here, while SST is regarded as the most important in seasonal forecasting in conventional view?

Top row: Temporal correlation between Apr-Jun dSST (North of 30^{o}N) and Apr-Jun quantities



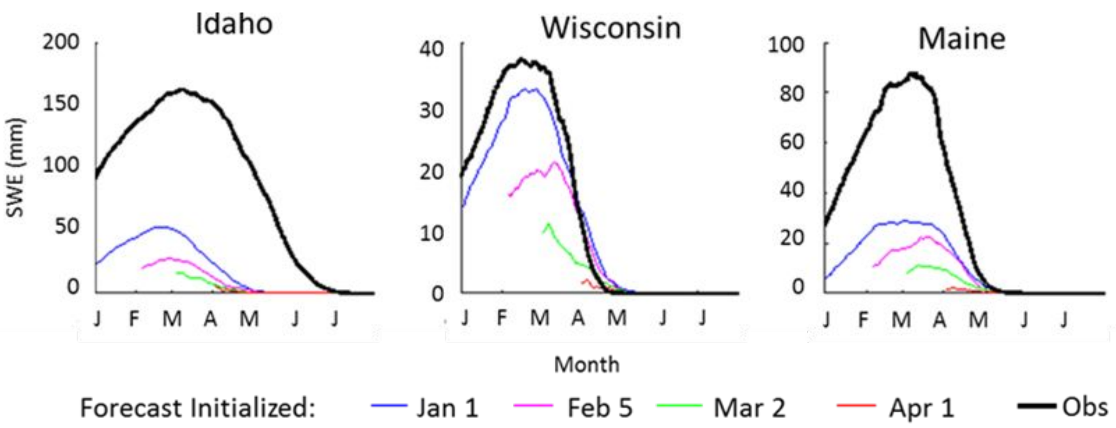
Bottom row: Correlation between Apr-Jun SST anomalies from 1982-2009 climatology (North of 30^{o}N) and Apr-Jun anomalies based on the 1 Apr forecasts.

How does SWE initialization bias affect T2m prediction?

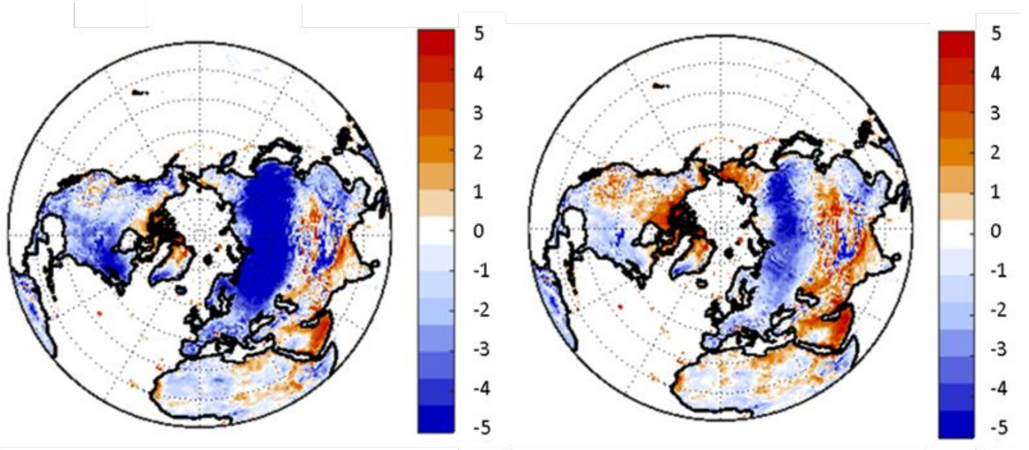
Earlier forecasts of SWE are more realistic (but still too little snow)

Later T_{2m} forecasts are more realistic, despite having less realistic SWE

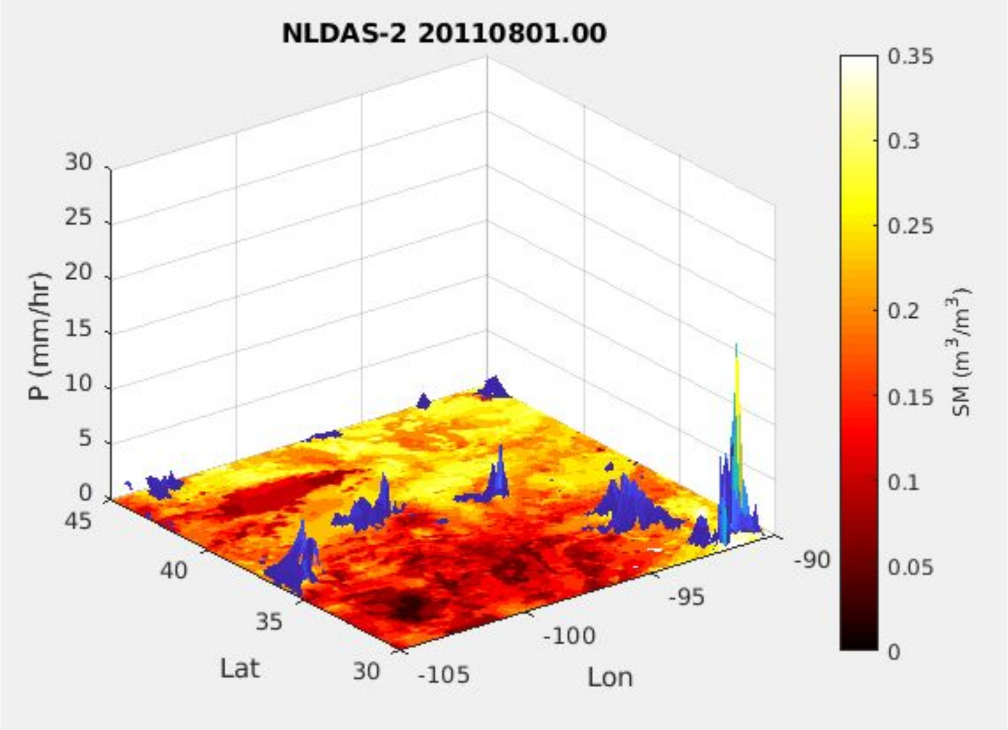
Point: More realistic SWE from Jan 1st forecast would lead to greater T_{2m} cold bias, because of the CFS model deficiencies (e.g., radiative transfer, PBL turbulence, land model)



Forecast SWE from different initialization times for three areas compared with our SWE data (Obs)



Left: Apr-Jun T_{2m} difference between CFS and Obs (Wang and Zeng 2013) (forecasted from Jan 1^{st}); Right: diff between CFS and Obs (from Apr 1^{st})



NLDAS-2 SM and P
Aug. 1-10, 2011

Does soil moisture affect warm season precipitation over the SGP?

Reference: Welty and Zeng (2018)

- UA News Release on 8/8/2018: Does rain follow the plow?
- DOE Office of Science web site: University research highlight
- DOE ARM: Newsletter article

THE UNIVERSITY OF ARIZONA

SM-P Correlations under Different Dynamic Regimes (from NASA MERRA-2)

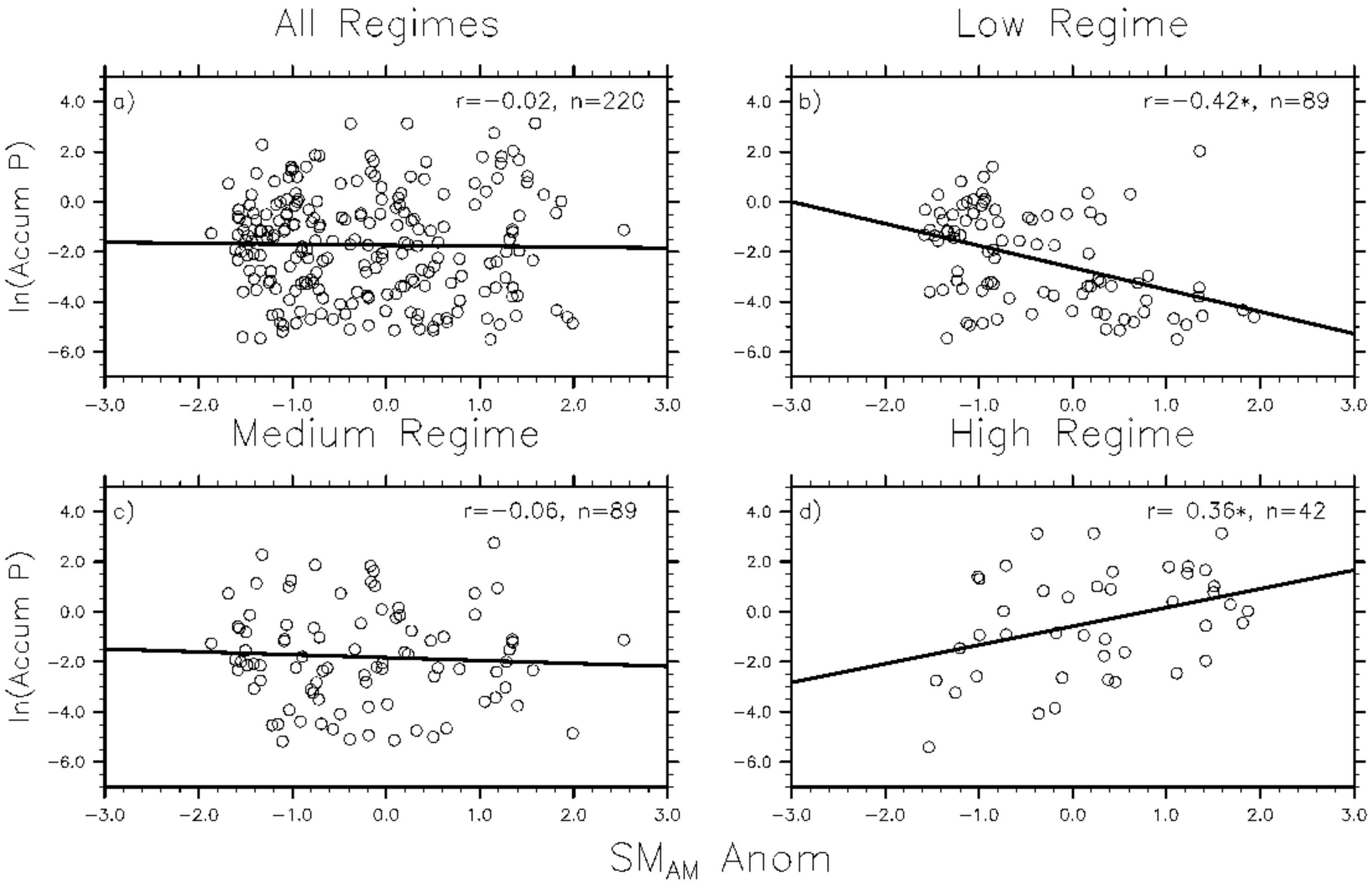


Figure 2. Relationship between the logarithm of precipitation accumulations (mm) from 1100–2300 CST and antecedent standardized soil moisture anomalies from 0700–1100 CST over stations across the SGP domain for a) all APEs, b) low dynamic regime APEs, c) medium regime APEs, and d) high regime APEs. Correlation coefficients (r) significant at $p < 0.05$ are marked with an asterisk, and n refers to the number of days.

- Negative (positive) correlation between seasonal standardized anomaly of morning SM with afternoon P accumulation under low (high) regime
- When all afternoon P days taken as a whole, no statistically significant relationship between SM and P

THE UNIVERSITY OF ARIZONA

Physical Pathways

- Under low regime:
  - positive correlations for soil T, 2m T, 2m Q, CAPE, and PBLHd/LCLd
  - negative correlation for SM
- Under high regime:
  - positive correlation for EF, SM

Table 1
Relationship Between Variables and Accumulated Precipitation Across Regimes

P vs.	All	Low	Medium	High
Morning SM Anomaly	−0.02	−0.42*	−0.06	0.36*
Morning SM	0.11	−0.21	0.09	0.34*
Soil T	0.21*	0.38*	0.25*	−0.01
Q	0.27*	0.39*	0.23*	0.08
RH	0.04	−0.02	0.06	0.02
T	0.20*	0.33*	0.17*	0.04
Net Radiation	0.09	0.16	−0.05	0.15
CTP	−0.07	0.13	0.04	−0.23
HI_{low}	−0.04	−0.23*	−0.10	0.16
CAPE	0.21*	0.30*	0.16	0.07
PBLHd/LCLd	0.14*	0.31*	0.09	−0.03
EF	0.08	−0.07	−0.02	0.36*

Note. Correlation coefficients between the logarithm of precipitation accumulations (mm) from 1100–2300 CST and various quantities for APEs for all, low, medium, and high dynamic regimes. The meaning of variables is provided in the text. CAPE, CTP, and HI_{low} are computed from the ~0600 CST sounding, and the PBLHd and LCLd are calculated as the respective differences between ~0600 and ~1200 CST soundings (to capture the diurnal growth of each). Other variables are averaged from 0700–1100 CST. Correlation coefficients significant ($p < 0.05$) are marked with an asterisk.

*CTP: Convective Triggering Potential
*HI_{low}: Low-level Humidity Index

THE UNIVERSITY OF ARIZONA

Conclusions

- The effect of morning soil moisture on subsequent afternoon precipitation depends on the dynamic regime.
- NCEP global (CFS, GFS) and regional (NAM) operational model snow initialization substantially underestimates SWE.
- SWE on Apr 1 is much more strongly correlated to the CFS Apr-Jun forecasts of T_{2m}, soil moisture, 500 mb geopotential height over mid- and high-latitudes than SST is, suggesting the major role of snowpack in seasonal prediction during the spring-summer transition over snowy regions.
- More realistic SWE from Jan 1st forecast would lead to greater T2m cold bias in Apr-Jun, suggesting that CFS needs to improve both SWE initialization and model parameterizations (e.g., radiative transfer, PBL turbulence, land processes).
- Based on this and other studies, a community effort is emerging to coordinate international studies to further quantify the role of snowpack in subseasonal to seasonal (S2S) forecasting, as part of the GEWEX activities.