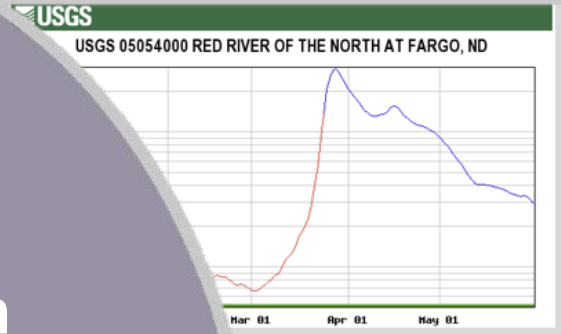
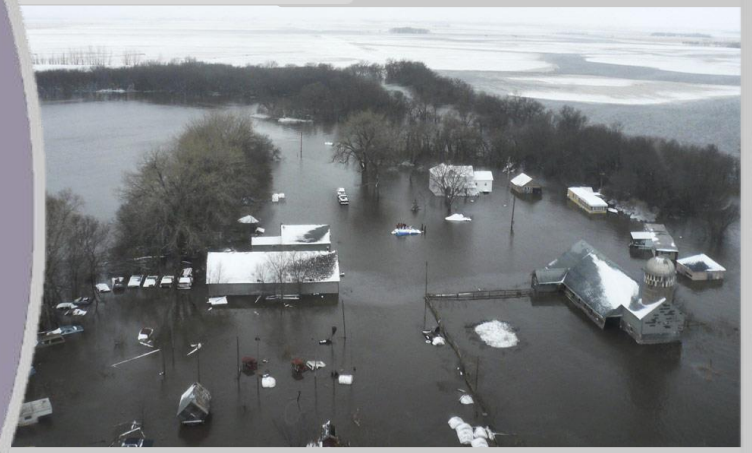
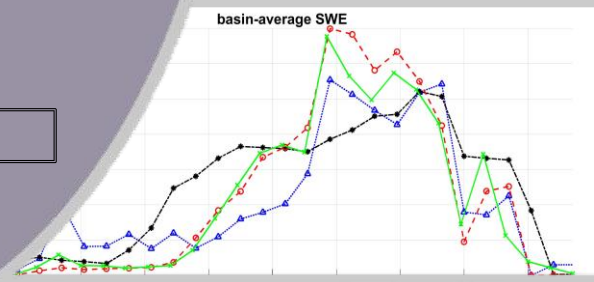
Investigating the 2009 Red River of the North snowmelt flood with Enhanced Resolution Passive Microwave Data

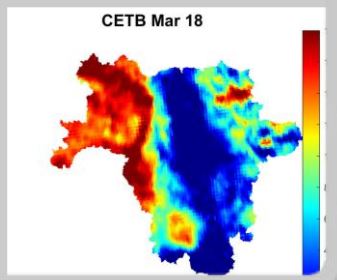
Marissa Torres, Marina Reilly-Collette (ERB, FTG), Carrie Vuyovich (RS/GIS)

Ron Liston Seminar
CRREL
1 August 2018









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US Army Corps of Engineers

ERDC ENGINEER RESEARCH & DEVELOPMENT CENTER

DISCOVER | DEVELOP | DELIVER

Outline

- Problem
- Objective
- Approach
- Definitions
- Study Area
- Results
- Conclusion
- Next steps
- Acknowledgements

nohrsc.noaa.gov/snowsurvey

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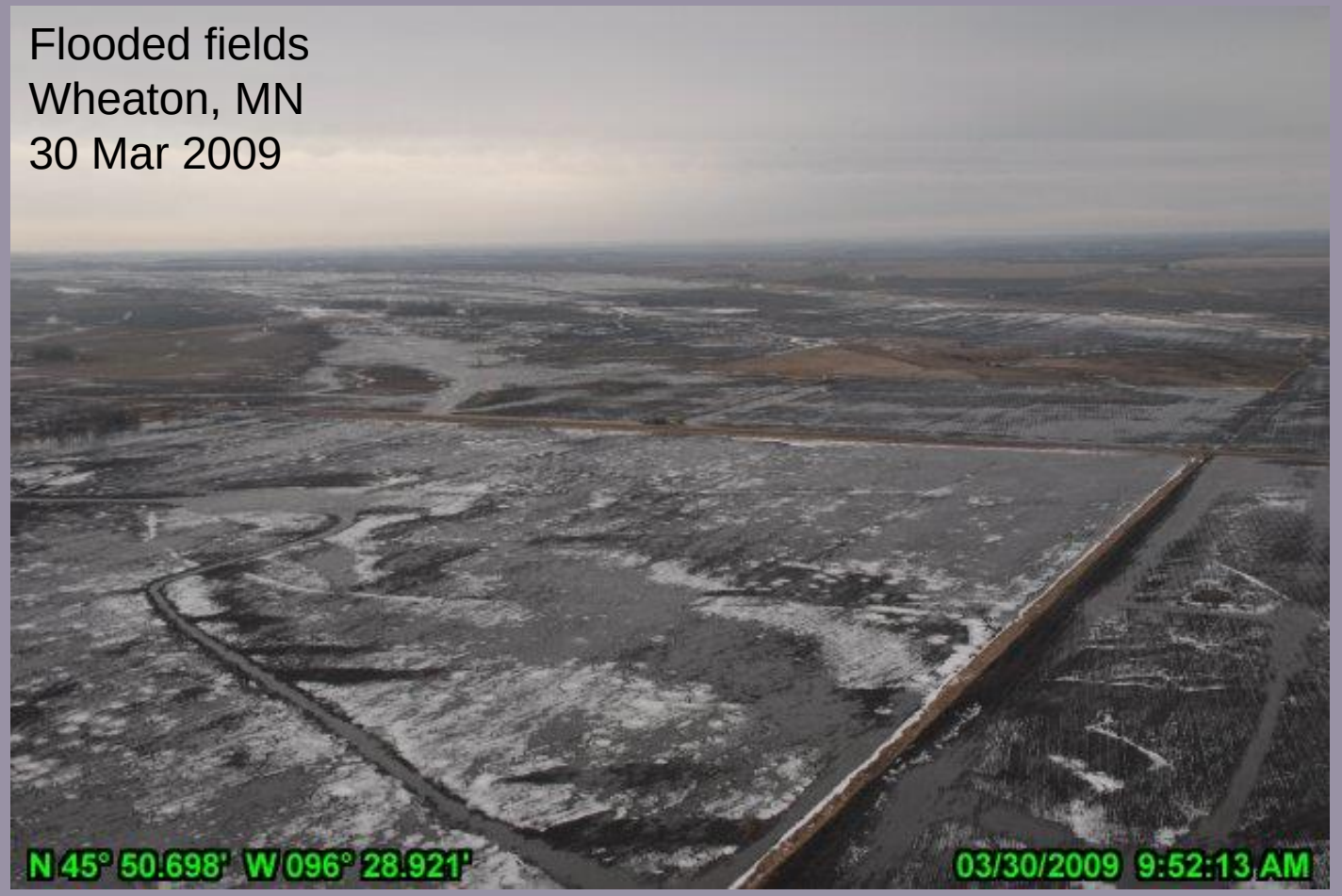
Problem

- **Severe flooding in areas with snow melt runoff timed with precipitation in the spring**
- **Predicting snow melt runoff in the RRN basin is difficult**
- **Accurate high resolution spatial estimates of snow ripening/melt are not available**



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Objective

- **Investigate capability of Calibrated Enhanced Brightness Temperature (CETB) satellite data to detect snowpack ripening and melt runoff**
- **Aim to improve stream flow estimation capability**

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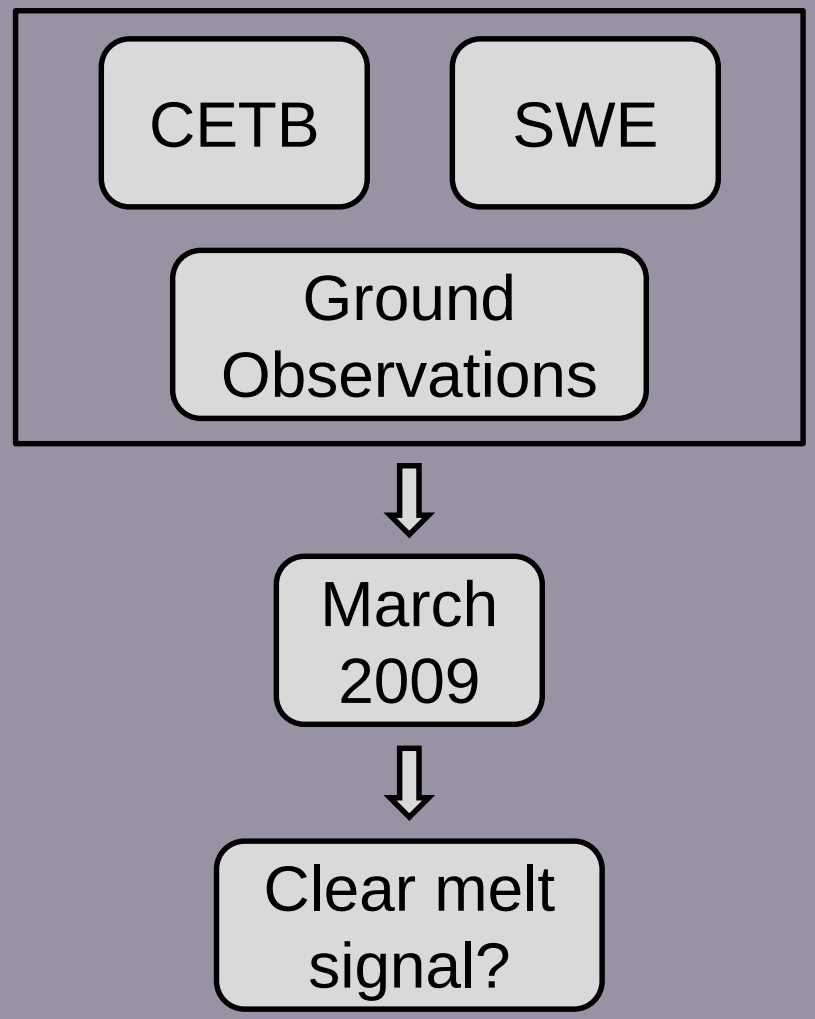
Approach

- **Compute SWE from Calibrated Enhanced Brightness Temperature (CETB)**
- **Compare CETB data with coarser resolution microwave SWE products and modeled SWE**
- **Evaluate progression of March 2009 snow ripening and melt event**
- **Examine data to determine if melt signals can be detected**



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Data

Observations

- Climate Data Online (CDO)
  - NOAA Daily Summaries: Precipitation, Snowfall
- Integrated Surface Dataset (ISD)
  - NOAA hourly time series: Precipitation
- North Dakota Agricultural Weather Network (NDAWN)
  - NDSU hourly time series: Temperature (air, soil), Precipitation
- USGS Stream Gauges – discharge

Parameter-elevation Relationships on Independent Slopes Model (PRISM)

- Oregon State daily grids: Temperature, Precipitation CONUS 4 km

Moderate Resolution Imaging Spectro-radiometer (MODIS)

- *NASA Snow cover (MOD10A1): Global 1 km*
  - *Temporal filtering to remove clouds*

Snow Water Equivalent (SWE)

- Snow Data Assimilation System (SNODAS)
  - NOAA: CONUS 1 km
- Advanced Microwave Scanning Radiometer for EOS (AMSR-E)
  - NASA: Global 25 km
- Special Sensor Microwave Imager (SSM/I)
  - DMSP: Global 25 km
- Calibrated Enhanced Brightness Temperature (CETB)
  - NASA: Global 3.125 km

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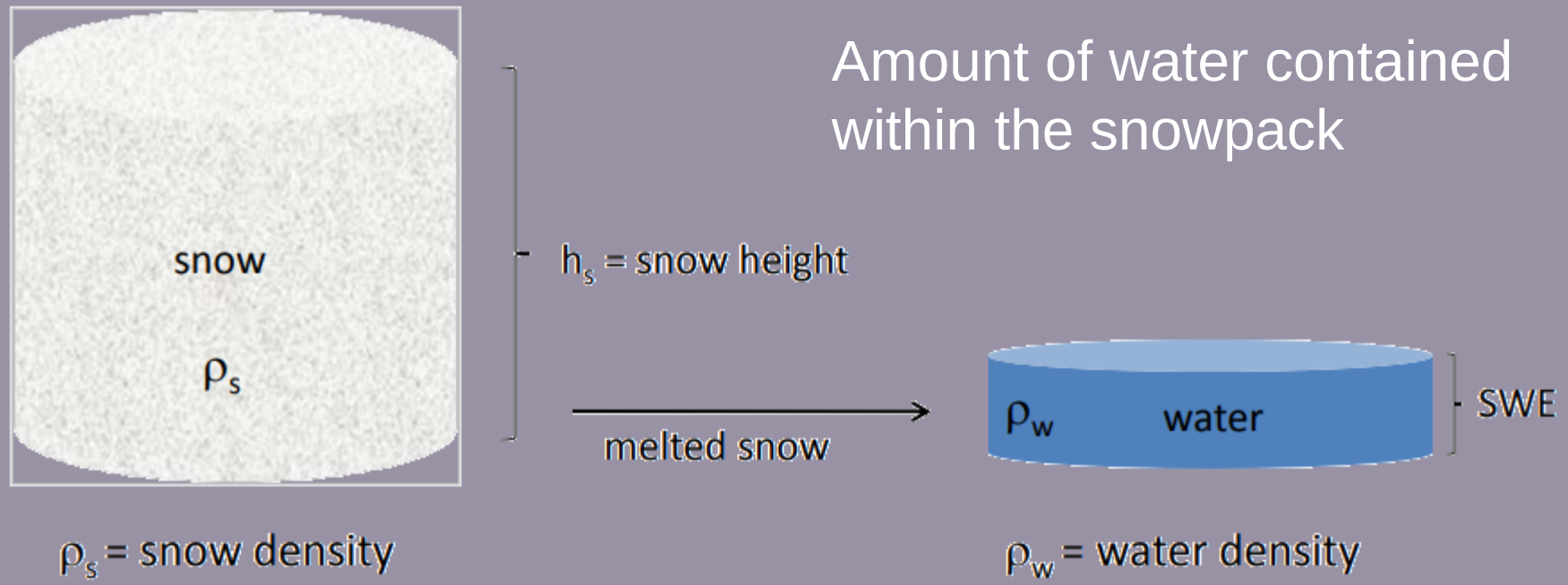
Definitions

- **Snow Water Equivalent (SWE)**
- **Passive microwave remote sensing**
- **Brightness temperature (T_B)**



Amount of water contained within the snowpack

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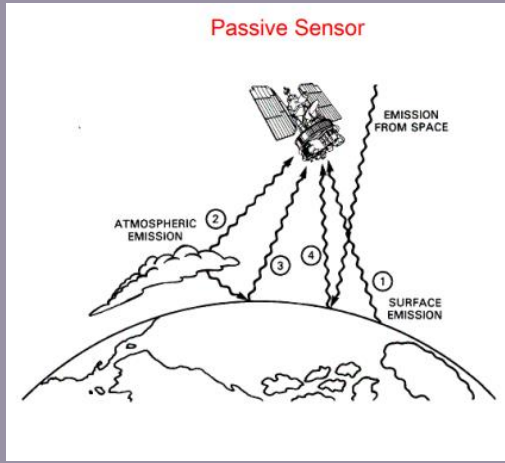
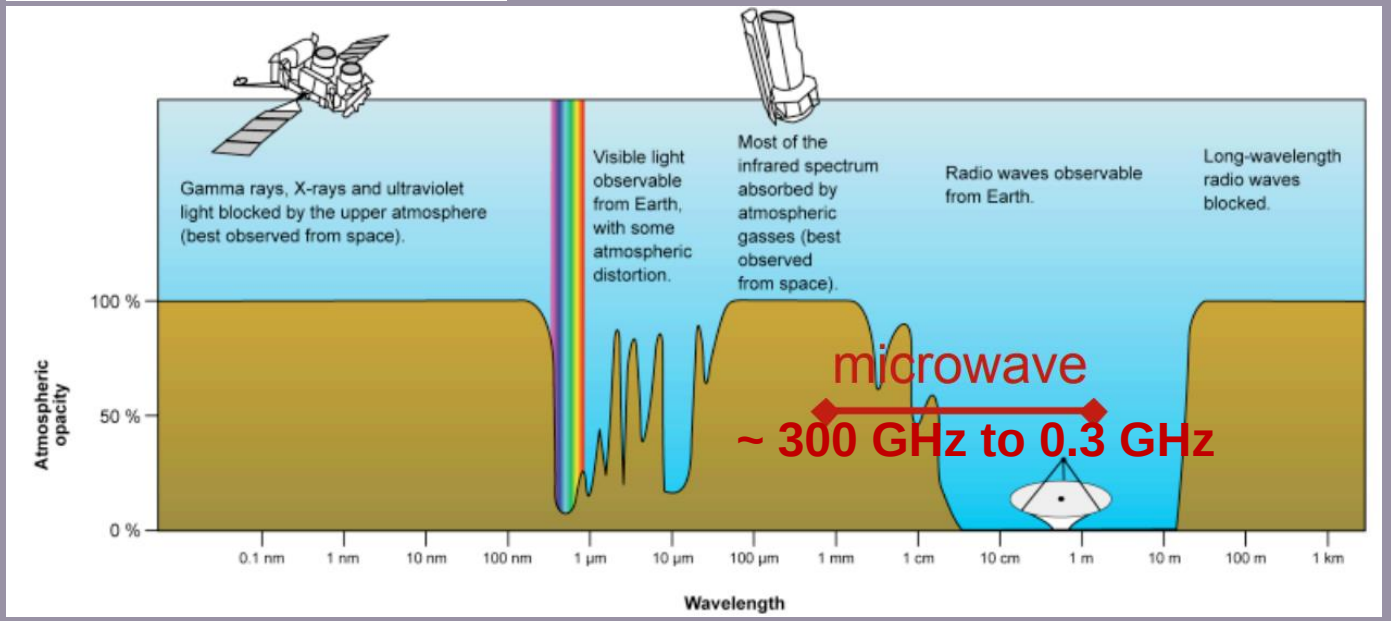
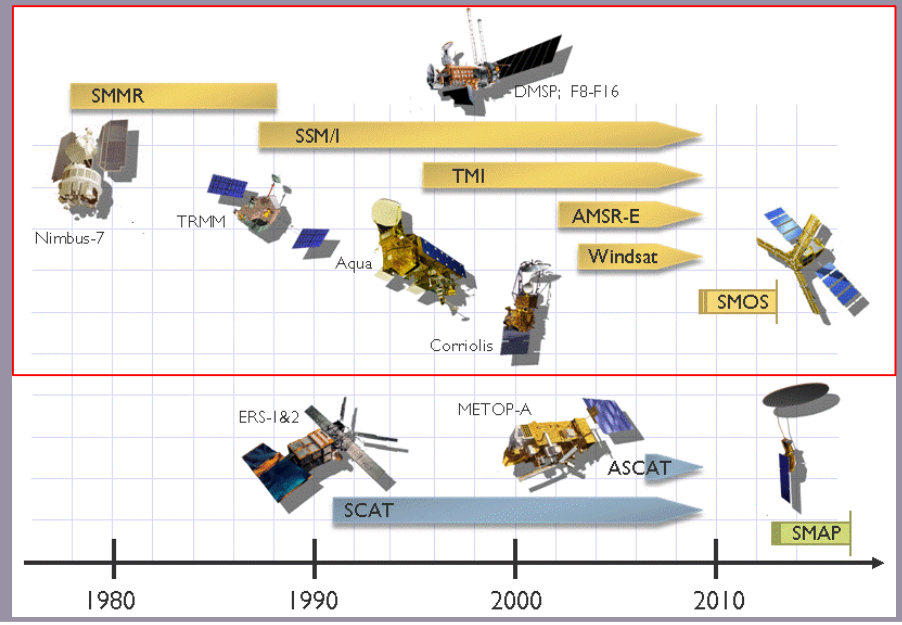
geol.wwu.edu

Passive microwave remote sensing

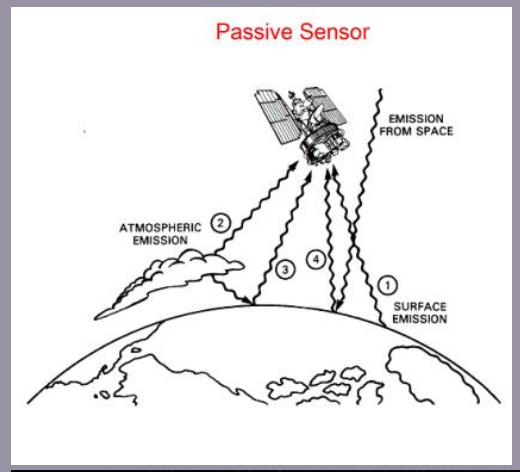


- Low energy (large pixel size)
- Unaffected by cloud cover and day/night
- Daily measurement of passive microwave signals since 1987
- Periodic gaps of spatial coverage due to orbit





Passive microwave remote sensing



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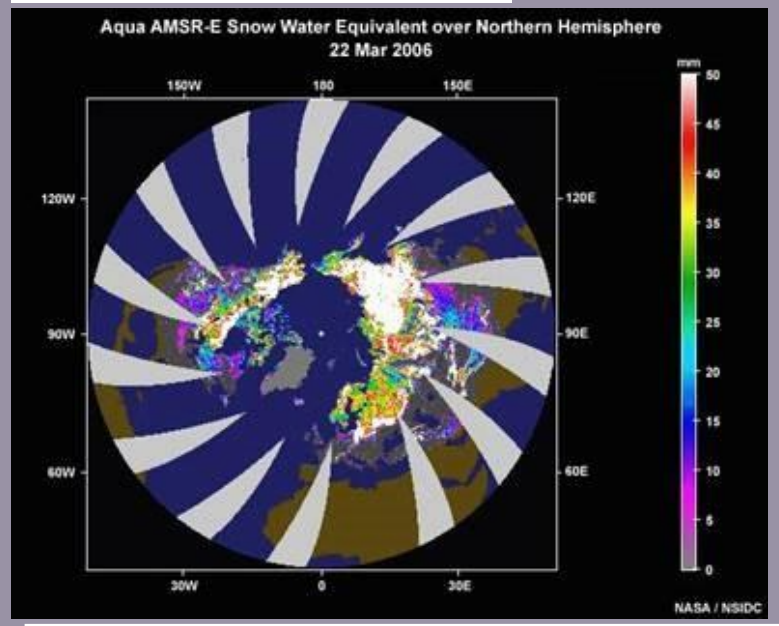
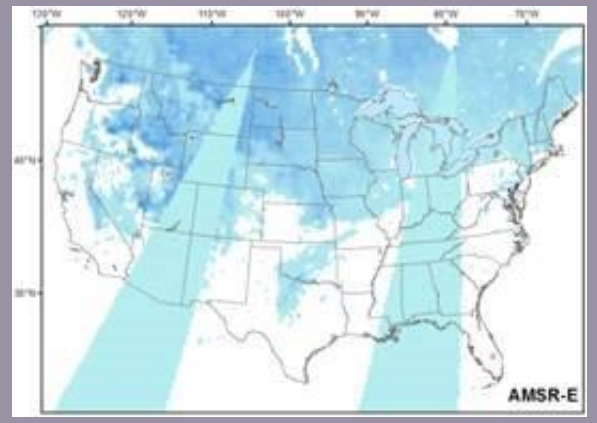
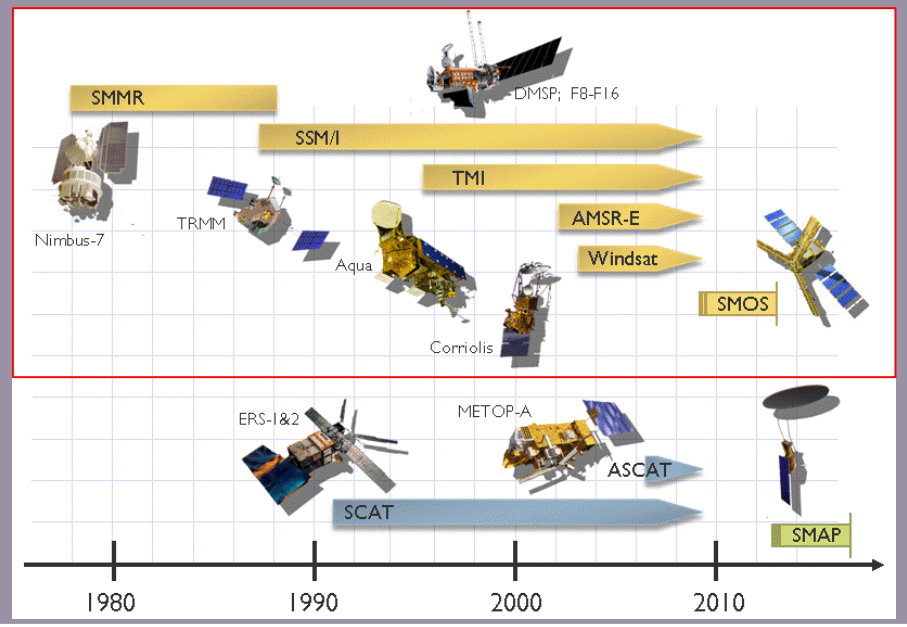


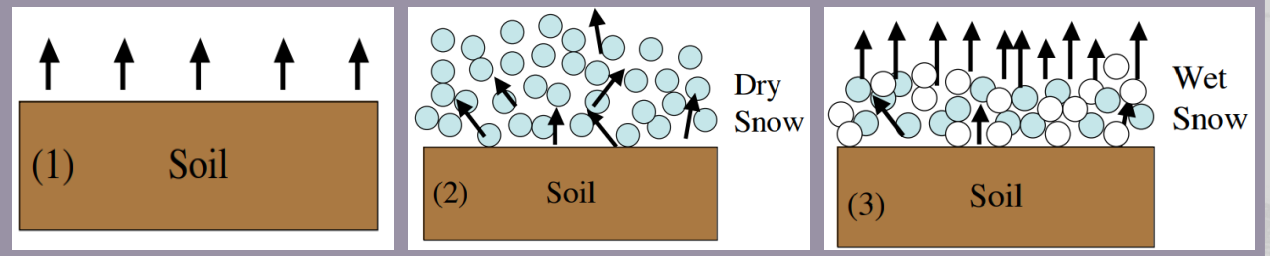


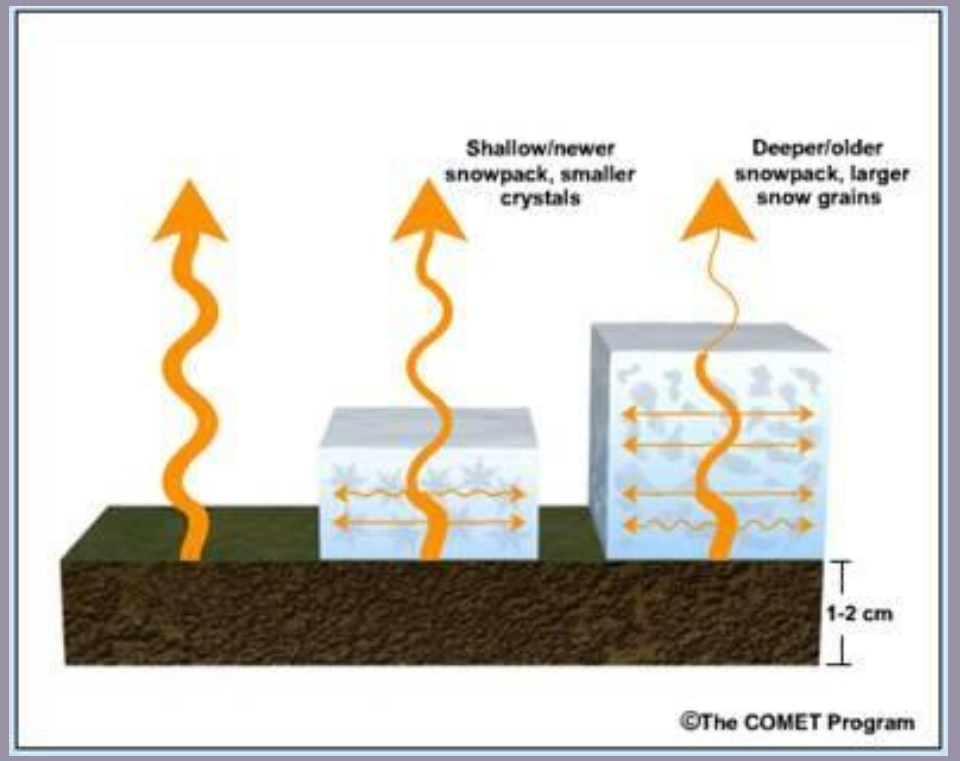


Brightness Temperature (T_B)

- Scattering of signal when wavelength is on the order of snow grain size
- SWE is proportional to the difference between two frequencies – one that scatters and one that doesn't
- Any liquid water in snow eliminates scattering of signal and SWE estimate goes to zero

Snow emissivity





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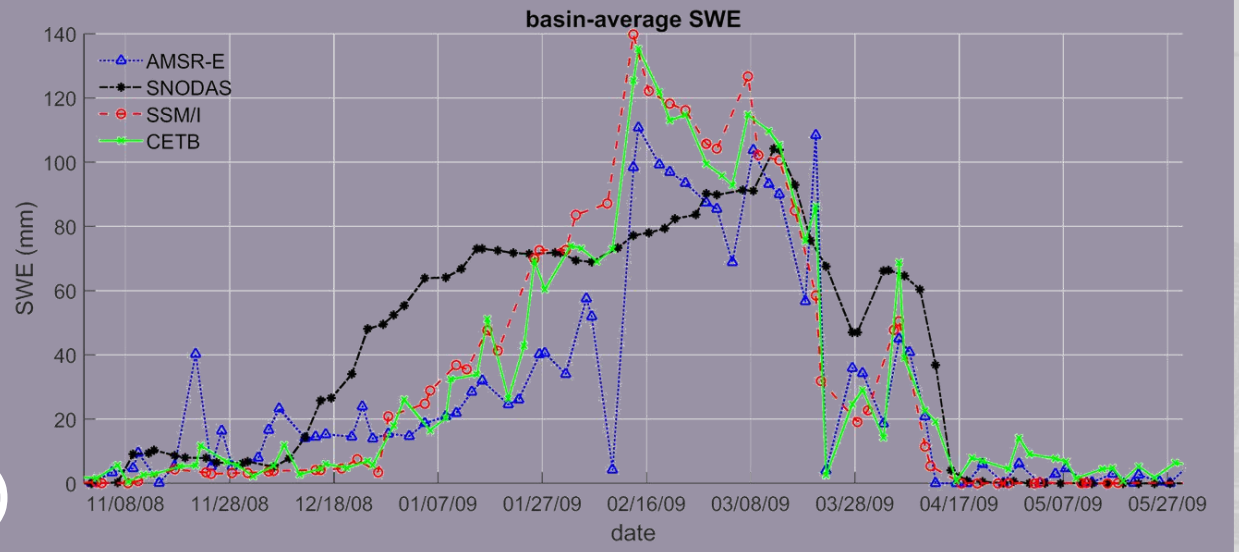
Calibrated Enhanced Brightness Temperature

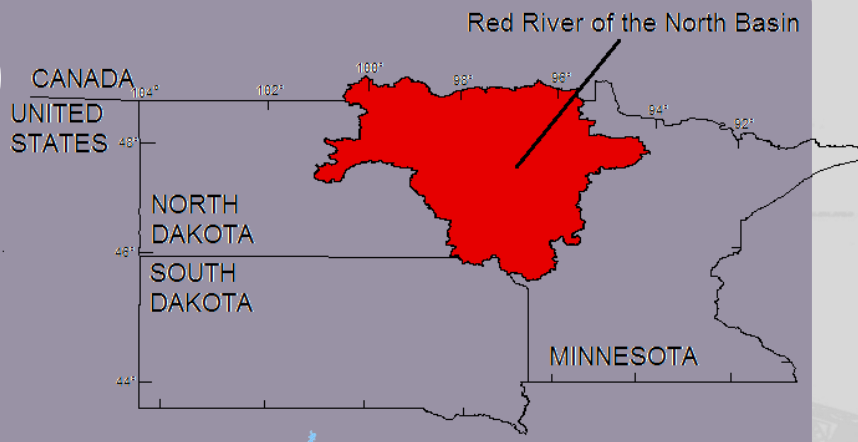
- NASA MEaSUREs CETB Microwave Daily EASE-Grid 2.0 Brightness Temperature ESDR
- Long-term record of higher-resolution passive microwave data than previously available
- AMSR-E: 36 GHz (3.125km), 18 GHz (6.25km)
- Compute SWE using empirical algorithm (Chang 1987, Armstrong & Brodzik, 2001)
- Evaluate 2009 event for melt signals in the microwave data (indicated by sharp decreases in SWE data; (Schroeder, 2018))



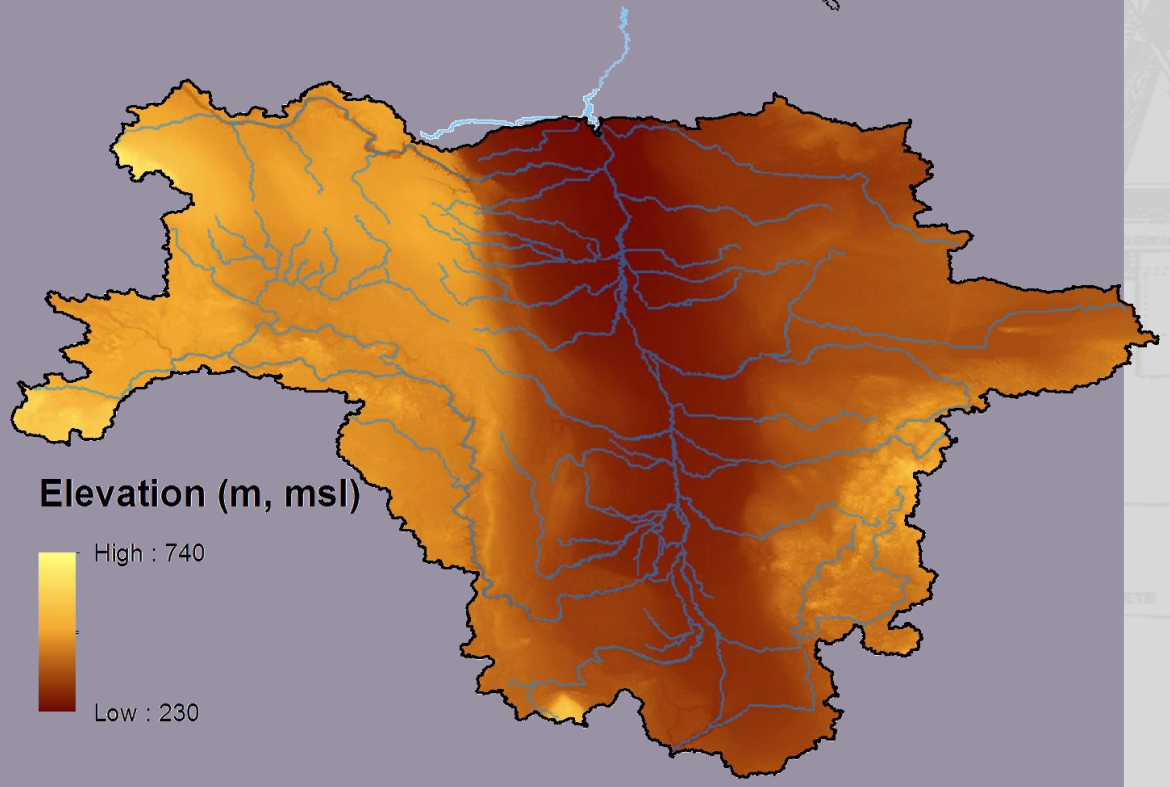
$$SWE\ (mm) = 4.77 * (T_{B18H} - T_{B37H} - 5)$$

Armstrong & Brodzik, Recent Northern Hemisphere Snow Extent. Geophysical Research Letters, VOL.28, NO.19, Pages 3673-3676, Oct 1, 2001.
Chang, A. T. C., J. L. Foster, and Dorothy K. Hall. 1987. Nimbus-7 Derived Global Snow Cover Parameters. *Annals of Glaciology* 9: 39-44.
Schroeder, R., S. Kraatz, J. M. Jacobs, C. M. Vuyovich, C. Olheiser, B. Connelly, M. M. DeWeese. 2018. Detection of snowmelt signals for improving snowmelt flood forecast in the Red River basin of the North. *75th Eastern Snow Conference,* June 5-8, College Park, MD.

Study Area: Red River of the North (US)



- Riverine flooding is difficult to predict due to complex hydrological processes
  - Red River flows north
  - Ice jams
  - Flat – slope of ½ ft per mile
- NWS River Forecast Center (RFC) uses Community Hydrologic Prediction System (CHPS) model to predict flooding



Schwert, D.P., 2003. A geologist's perspective on the Red River of the North: history, geography, and planning/management issues. Proceedings 1st International Water Conferences, Red River Basin Institute, Moorhead, MN.
River Keepers, 2015. Red River Geography. Fargo, ND.

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March 2009 Flood Event

- **Combination of:**
  - **Above normal precipitation in Fall 2008 – soil moisture maxed out**
  - **Record snow fall in Winter 2008 – 2009**
  - **Rainfall and warming temperatures in late March 2009**
- **Areas remained flooded for two months after Mar ‘09**
- **55M USD in damage**

25 March 2009
Fargo, ND
(US Coast Guard, Lt. Brendan Evans)

26 March 2009
Fargo, ND
(Carolyn Kaster)

Archive.boston.com/bigpicture/2009/03/red_river_flooding

Macek-Rowland, K.M., and Gross, T.A., 2011, 2009 Spring floods in North Dakota, western Minnesota, and northeastern South Dakota: U.S. Geological Survey Scientific Investigations Report 2010–5225, 41 p.
National Weather Service (NWS), 2010. Flood Damages Suffered in the United States During Water Year 2009. Annual Flood Loss Summary Reports. National Oceanic and Atmospheric Administration (NOAA).

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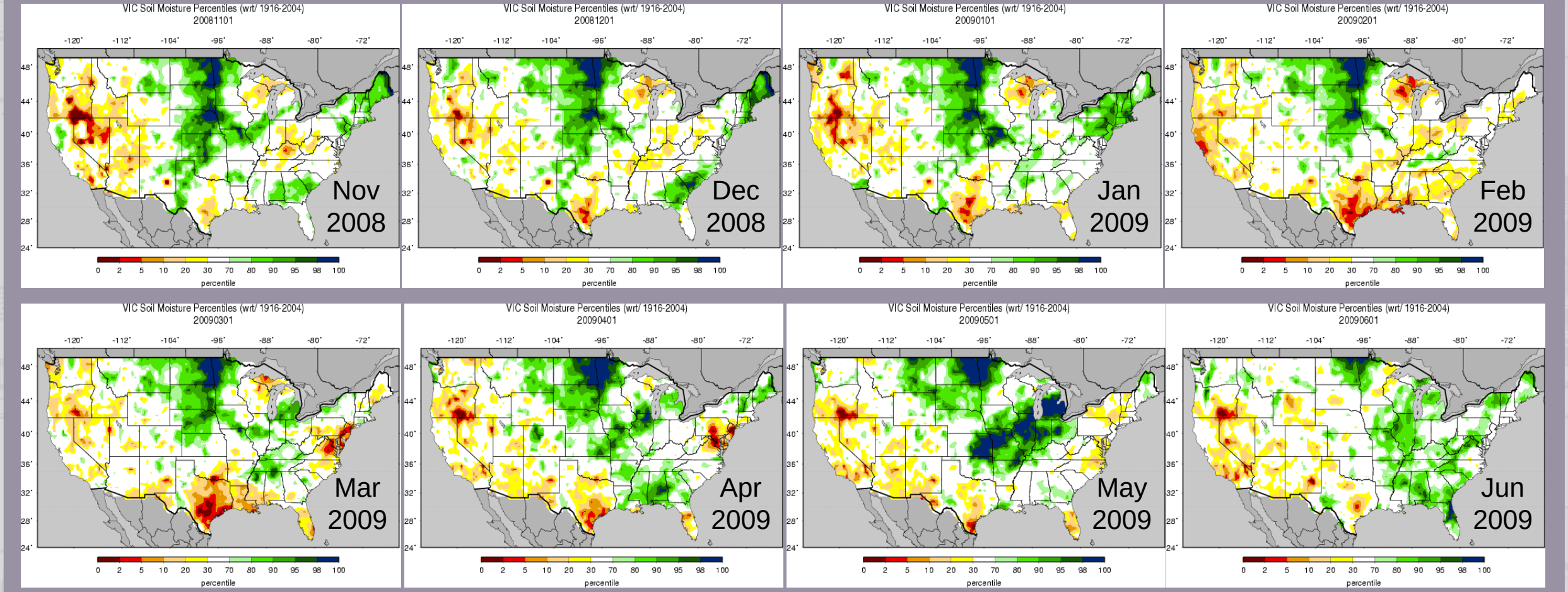
March 2009 Flood Event



Variable Infiltration Capacity (VIC) Soil Moisture

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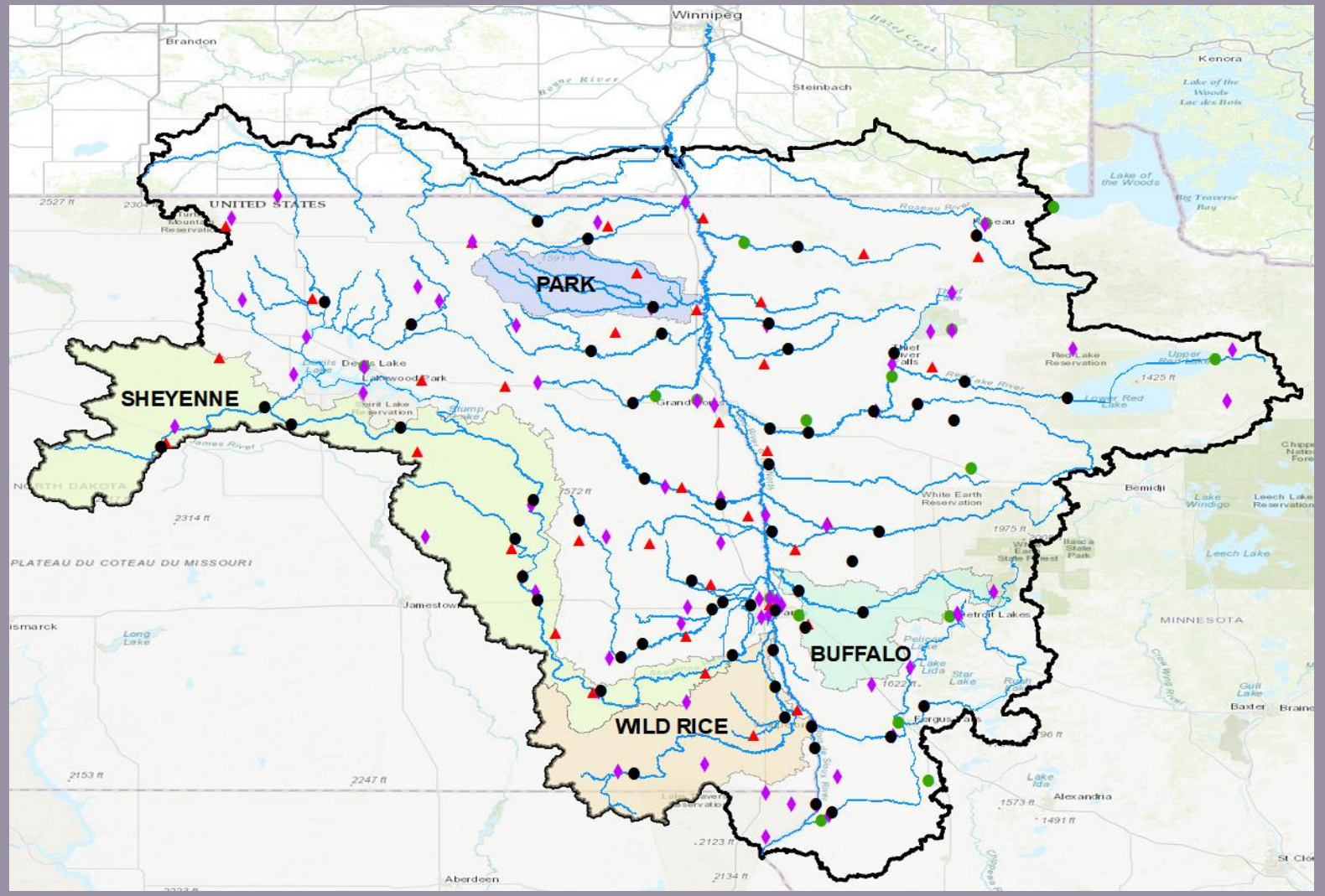
www.hydro.washington.edu/forecast/monitor/outlook/index.shtml

Observation locations

Legend

- NDAWN (*temp – air, soil*)
- ISD (*precip*)
- CDO (*precip, snowfall*)
- USGS (*discharge*)

- **36 NDAWN stations**
- **17 ISD stations**
- **65 CDO stations**
- **51 USGS gauges**



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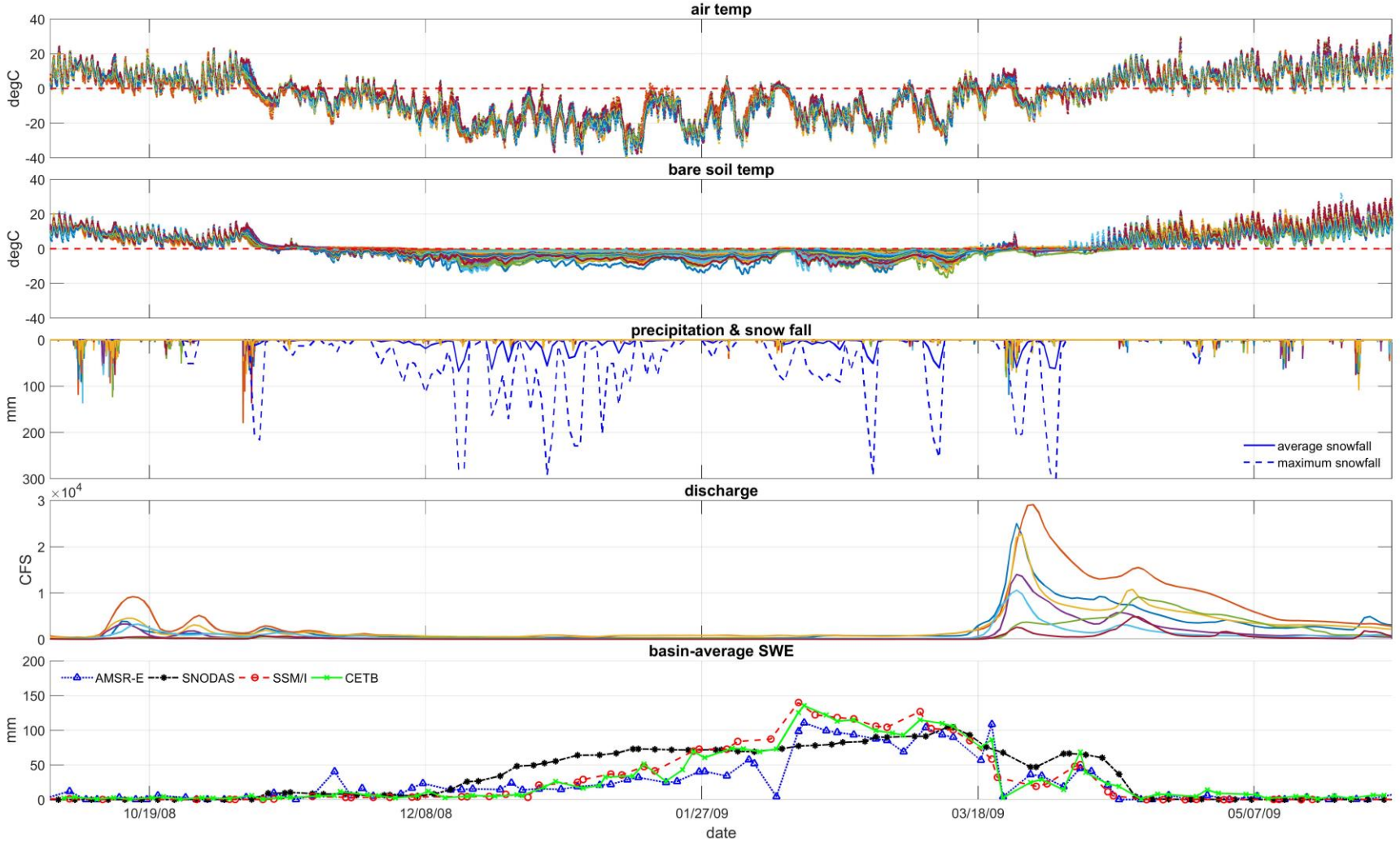
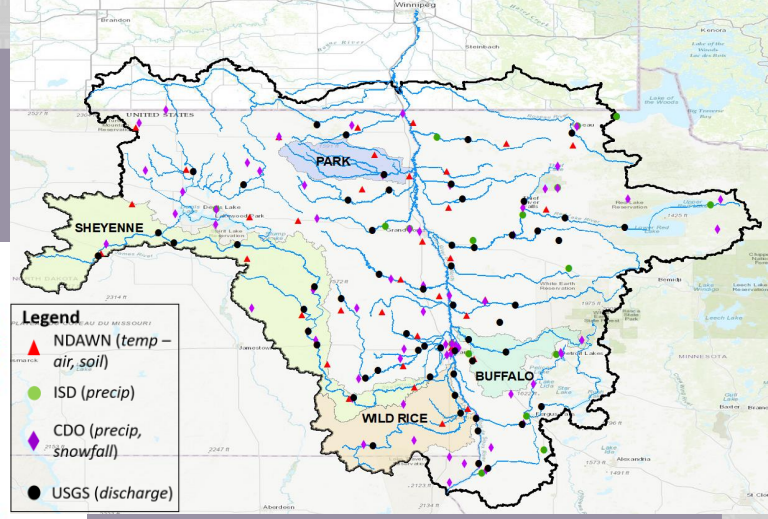
Results

Oct 2008 – May 2009

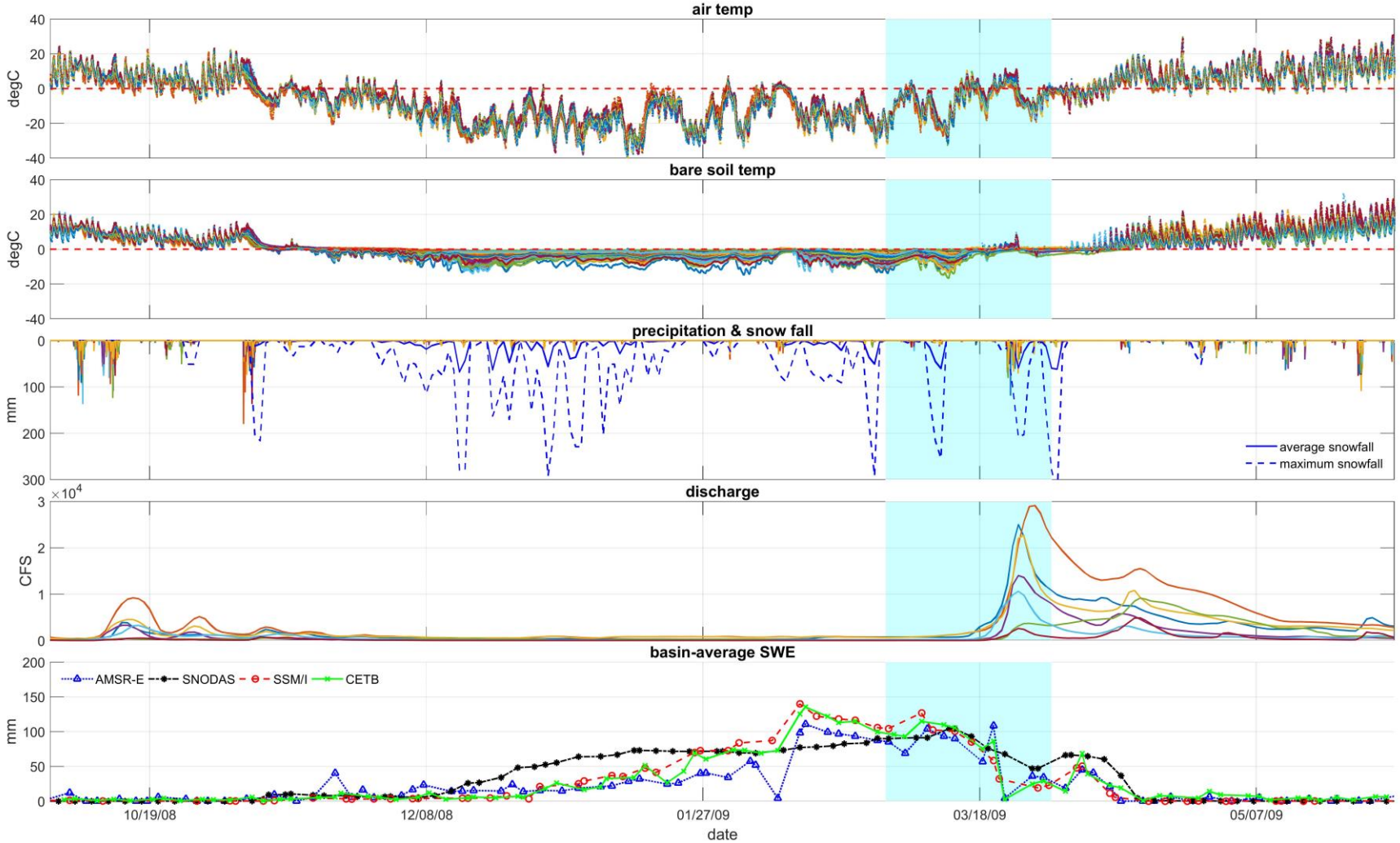


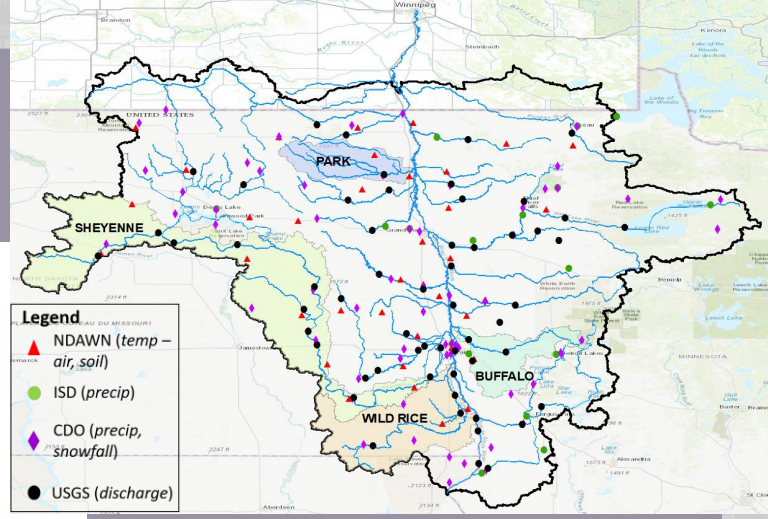


- 36 NDAWN stations
- 17 ISD stations
- 65 CDO stations
- 51 USGS gauges

Results

March 2009





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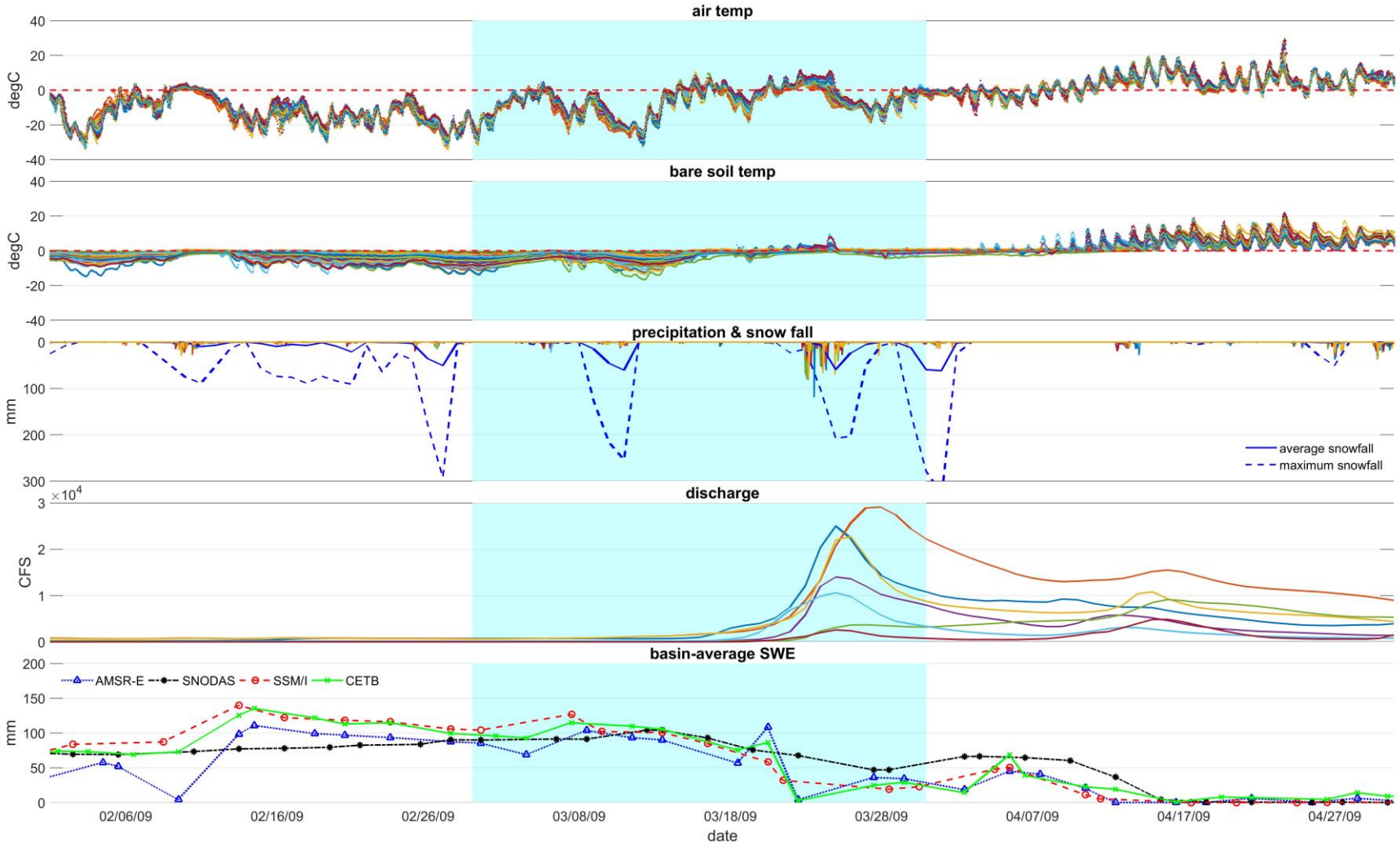
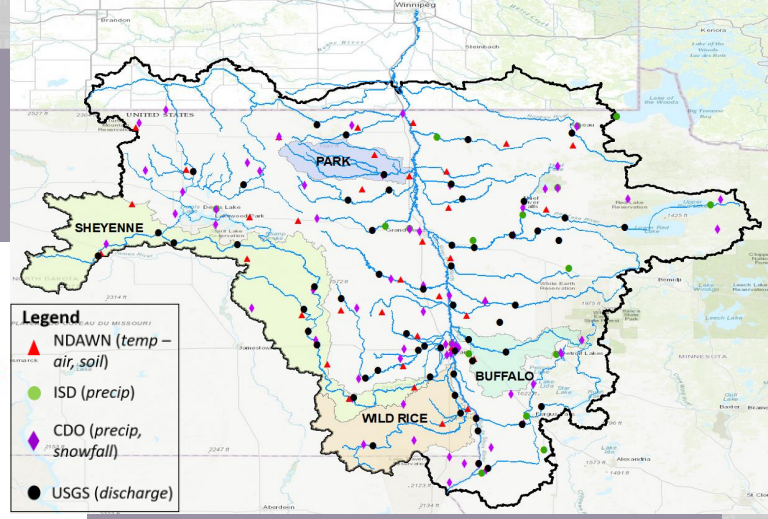
Results

Feb 2009 – Apr 2009





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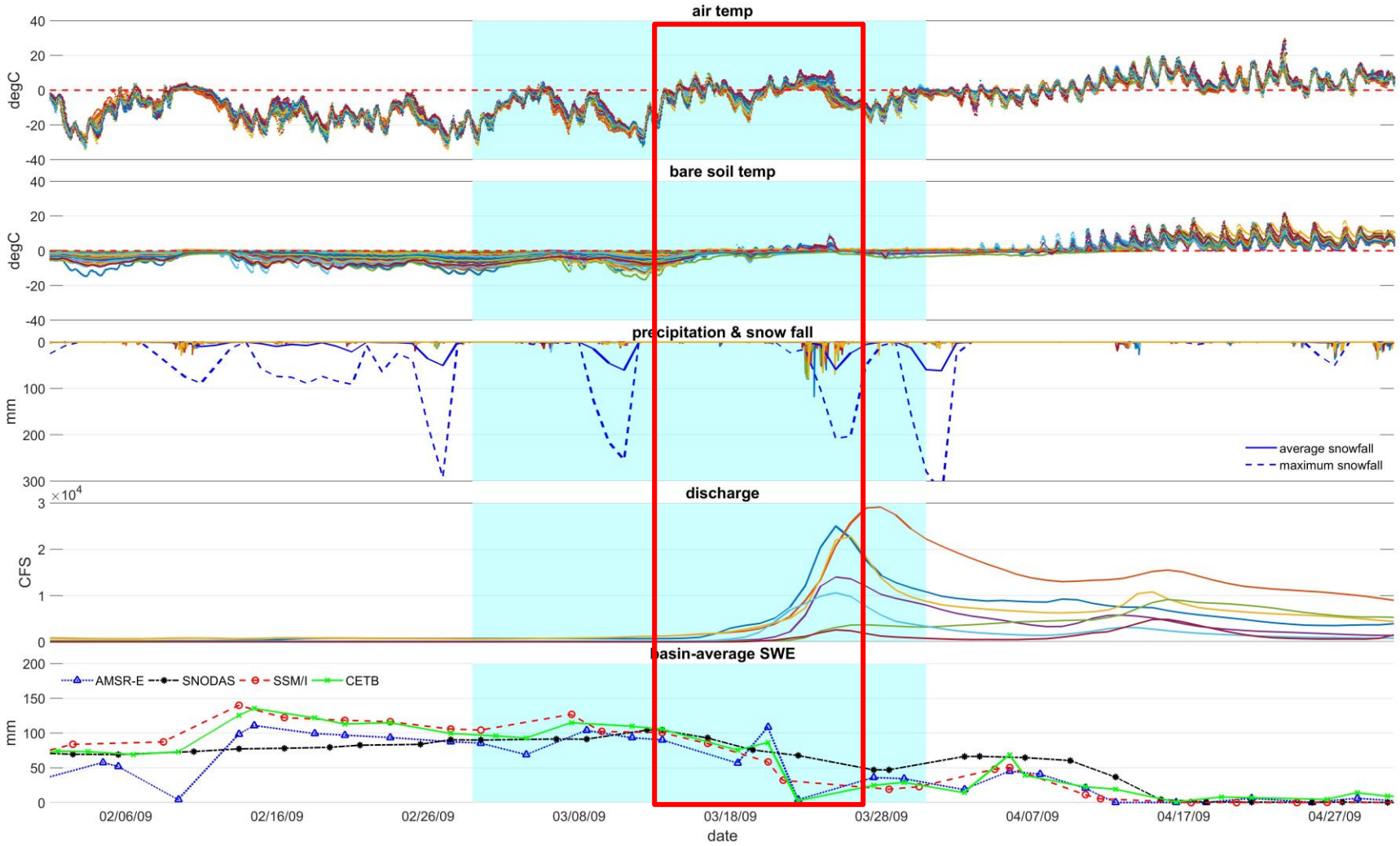

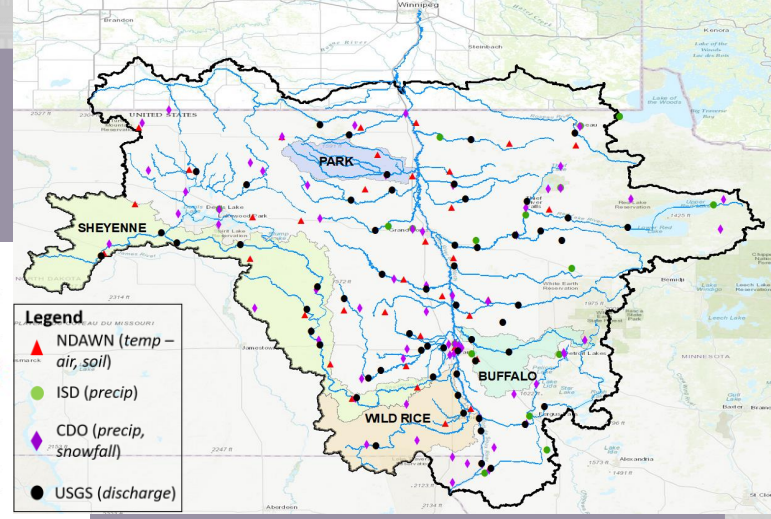

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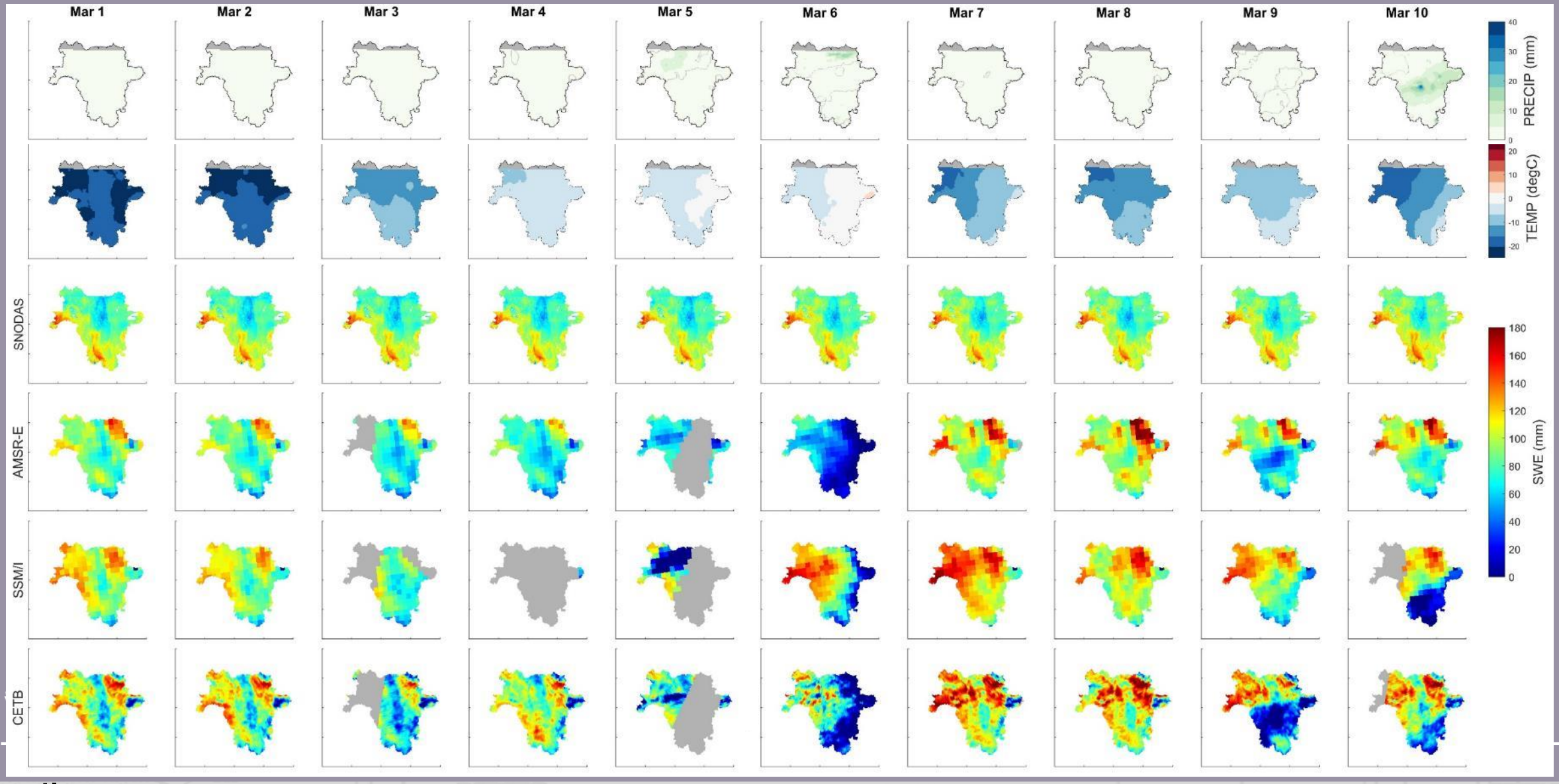
Sharp decrease in SWE

Increase in discharge

Above zero air & soil temperature

Results



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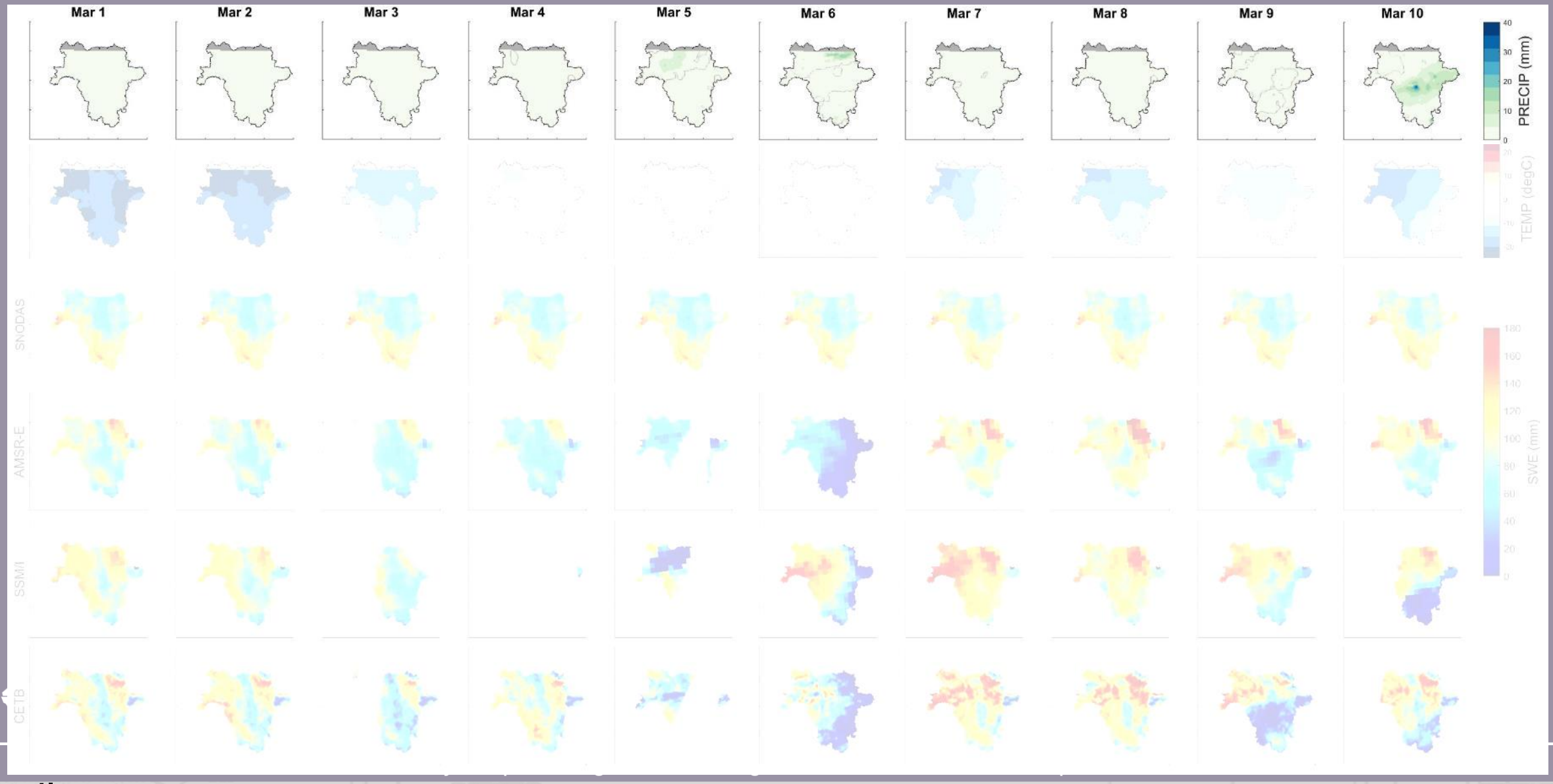

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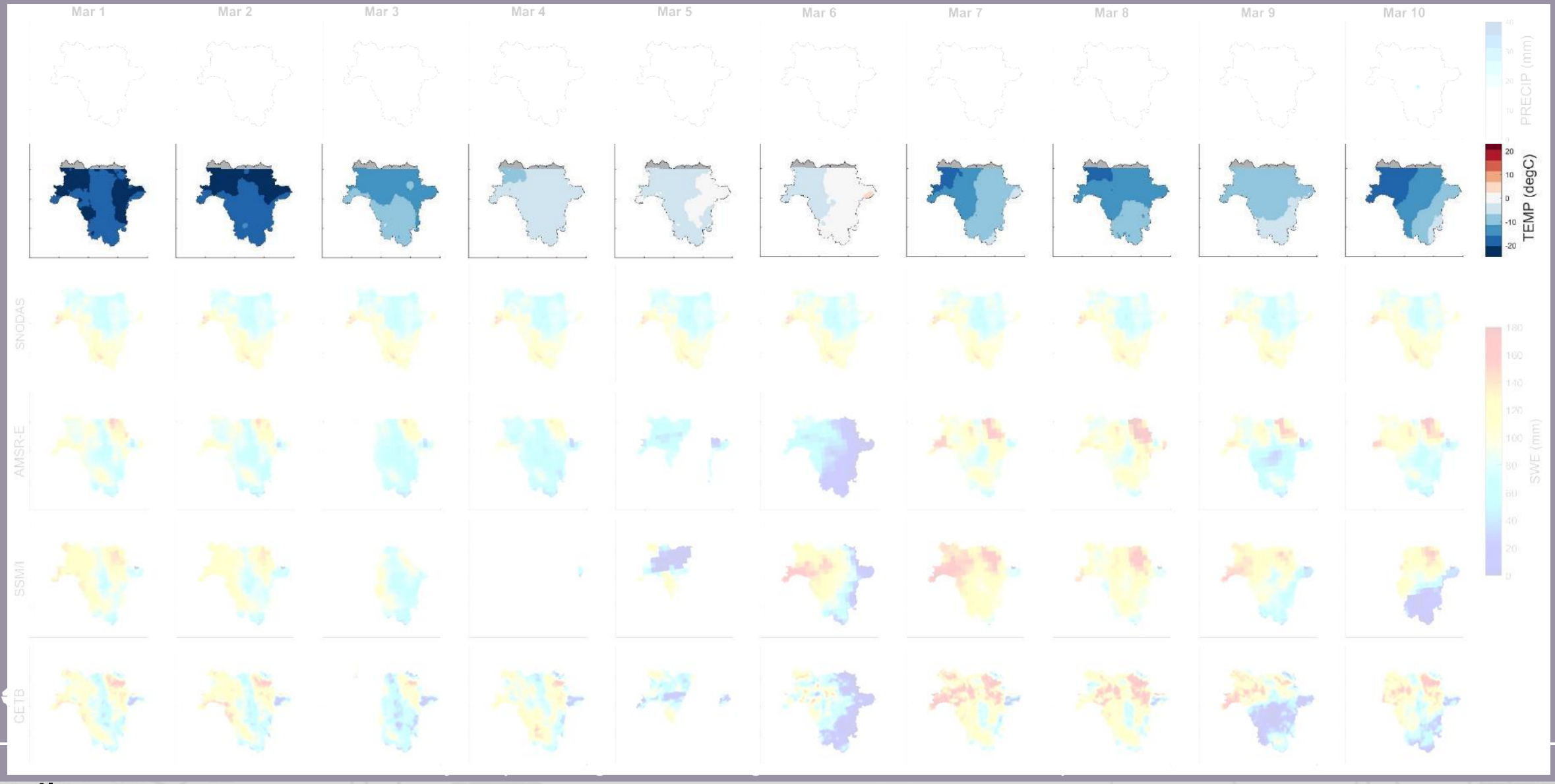

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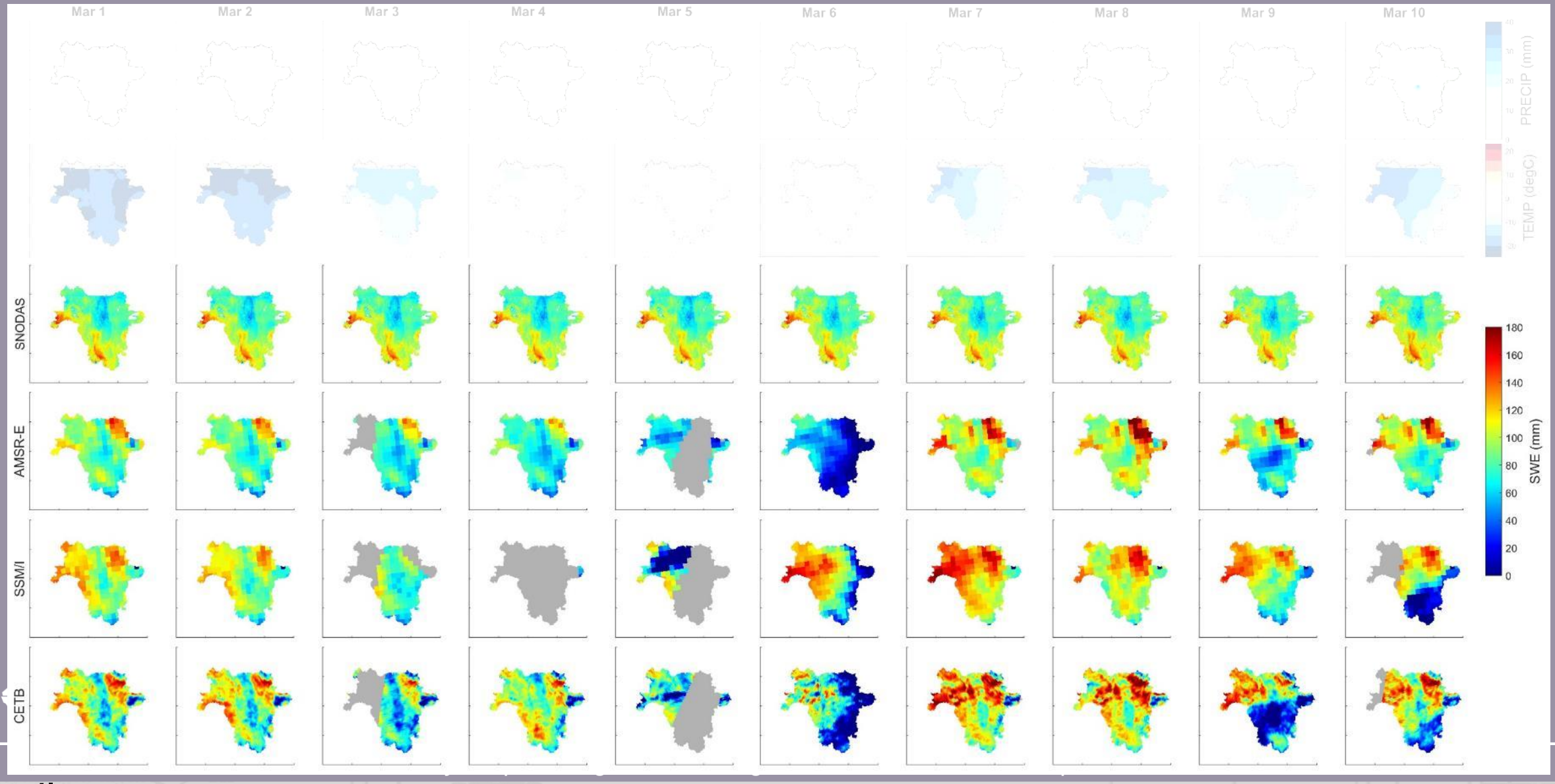

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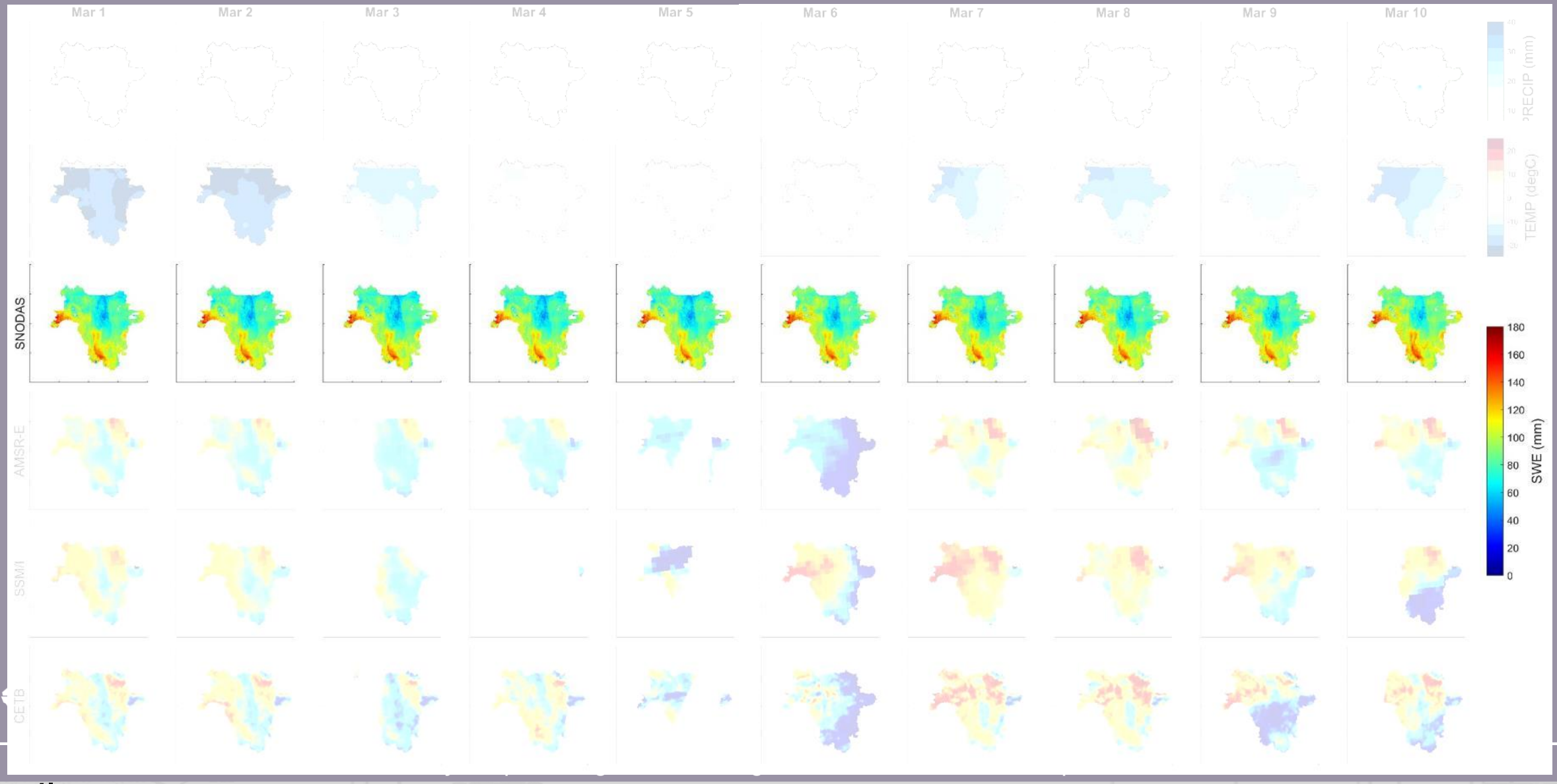

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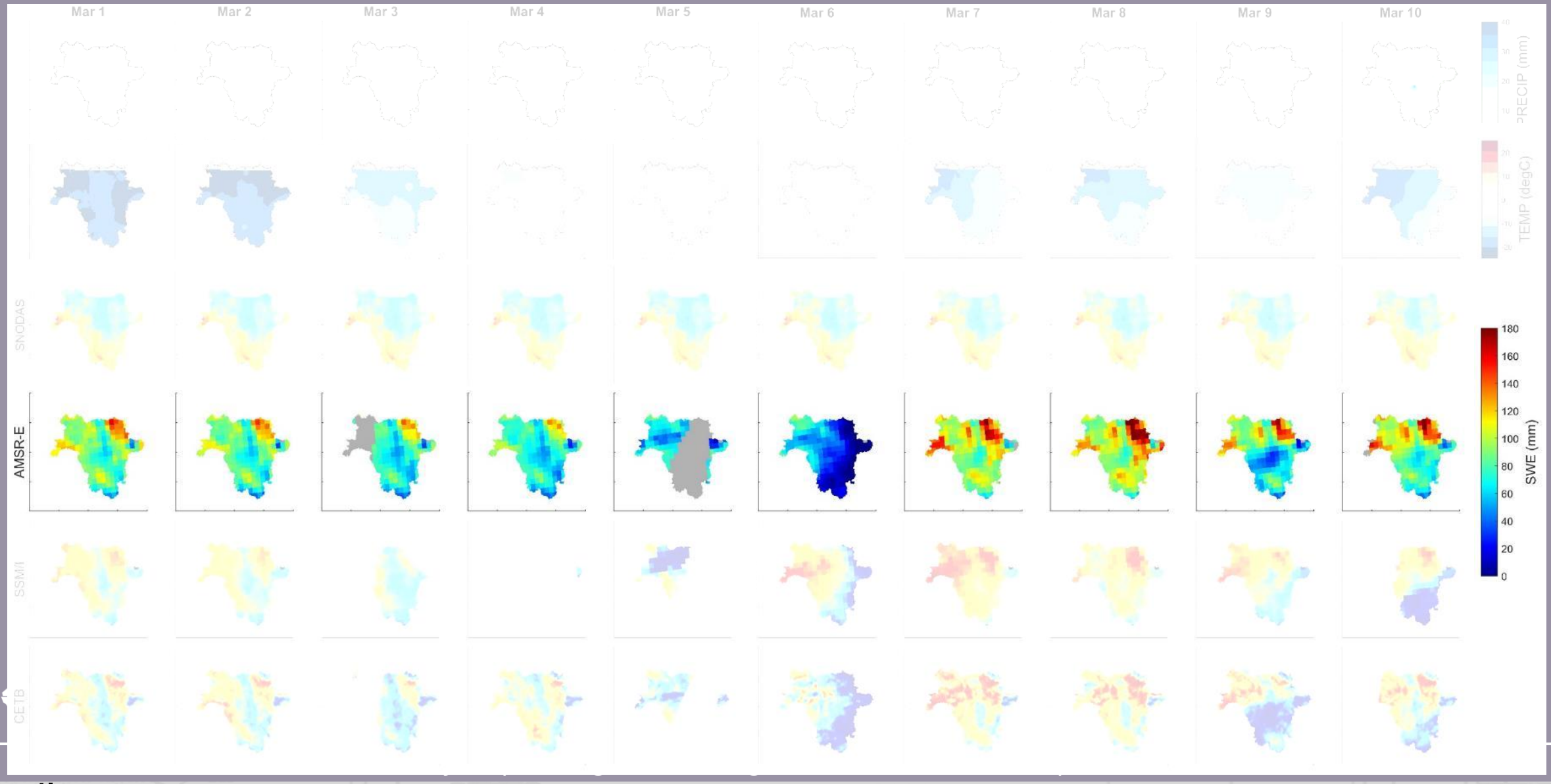
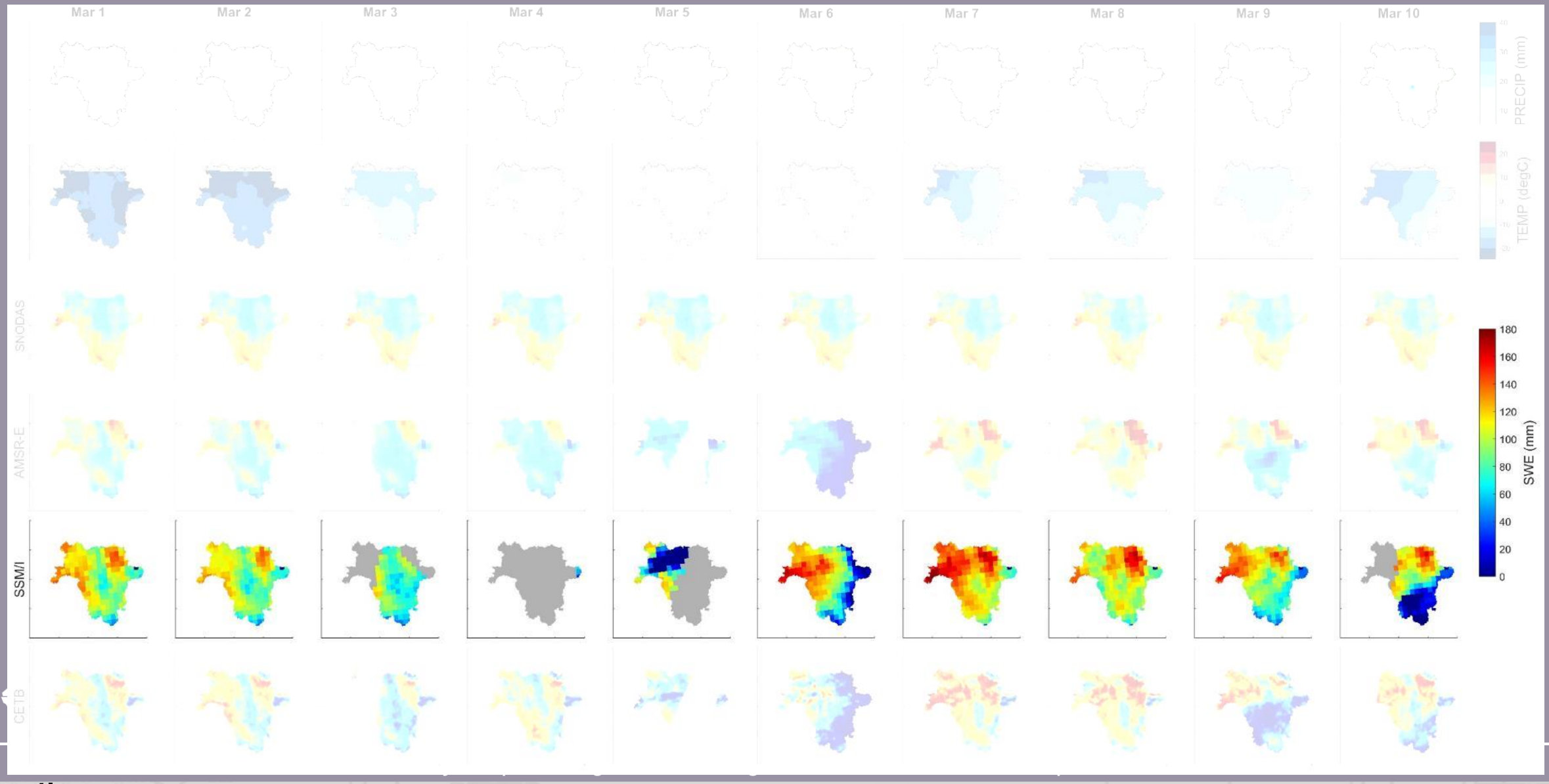

Mar 1
Mar 2
Mar 3
Mar 4
Mar 5
Mar 6
Mar 7
Mar 8
Mar 9
Mar 10
PRECIP (mm)
TEMP (degC)
SNODAS
AMSR-E
SSM/I
CETB
SWE (mm)
180
160
140
120
100
80
60
40
20
0

Results



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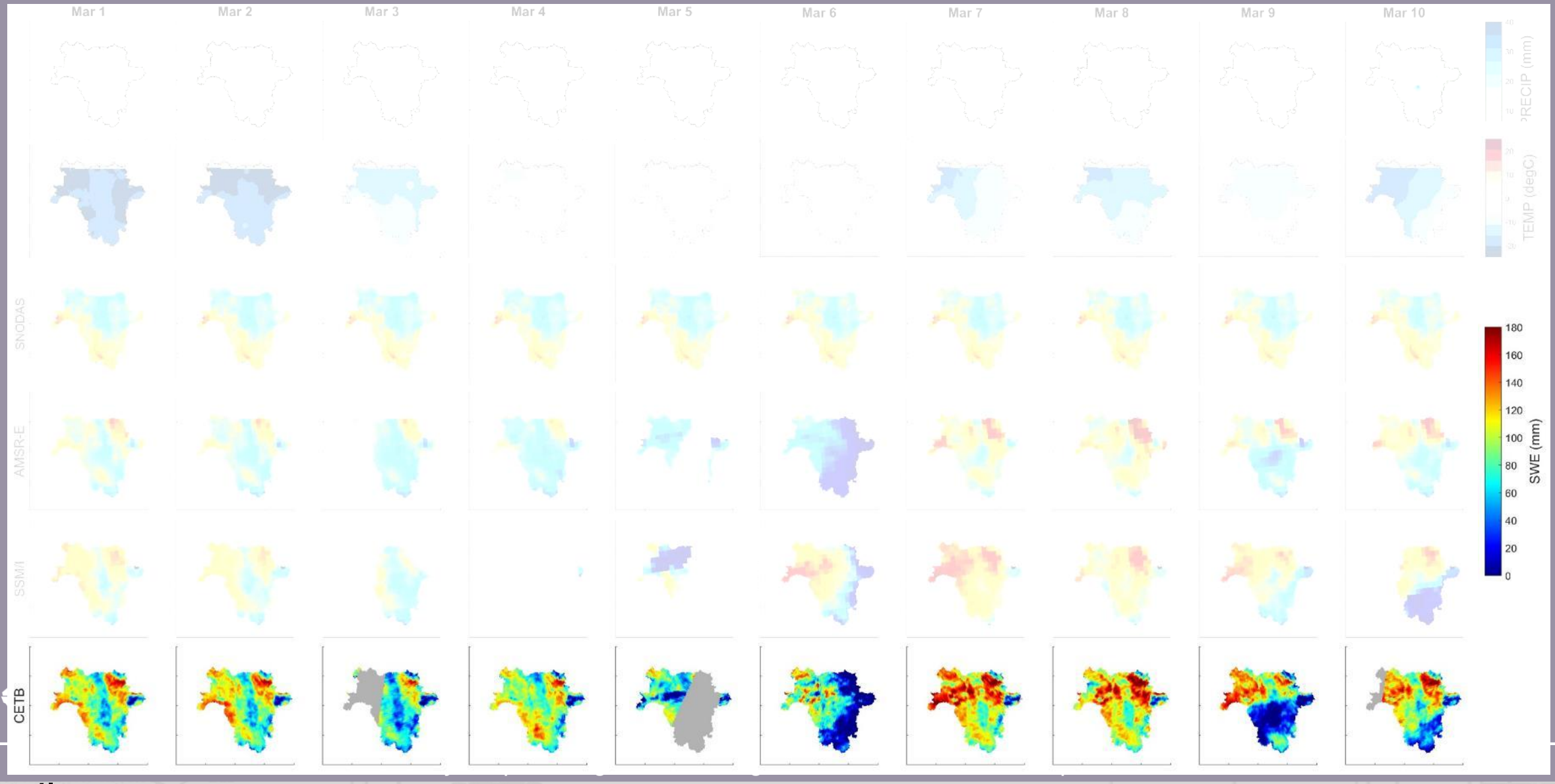

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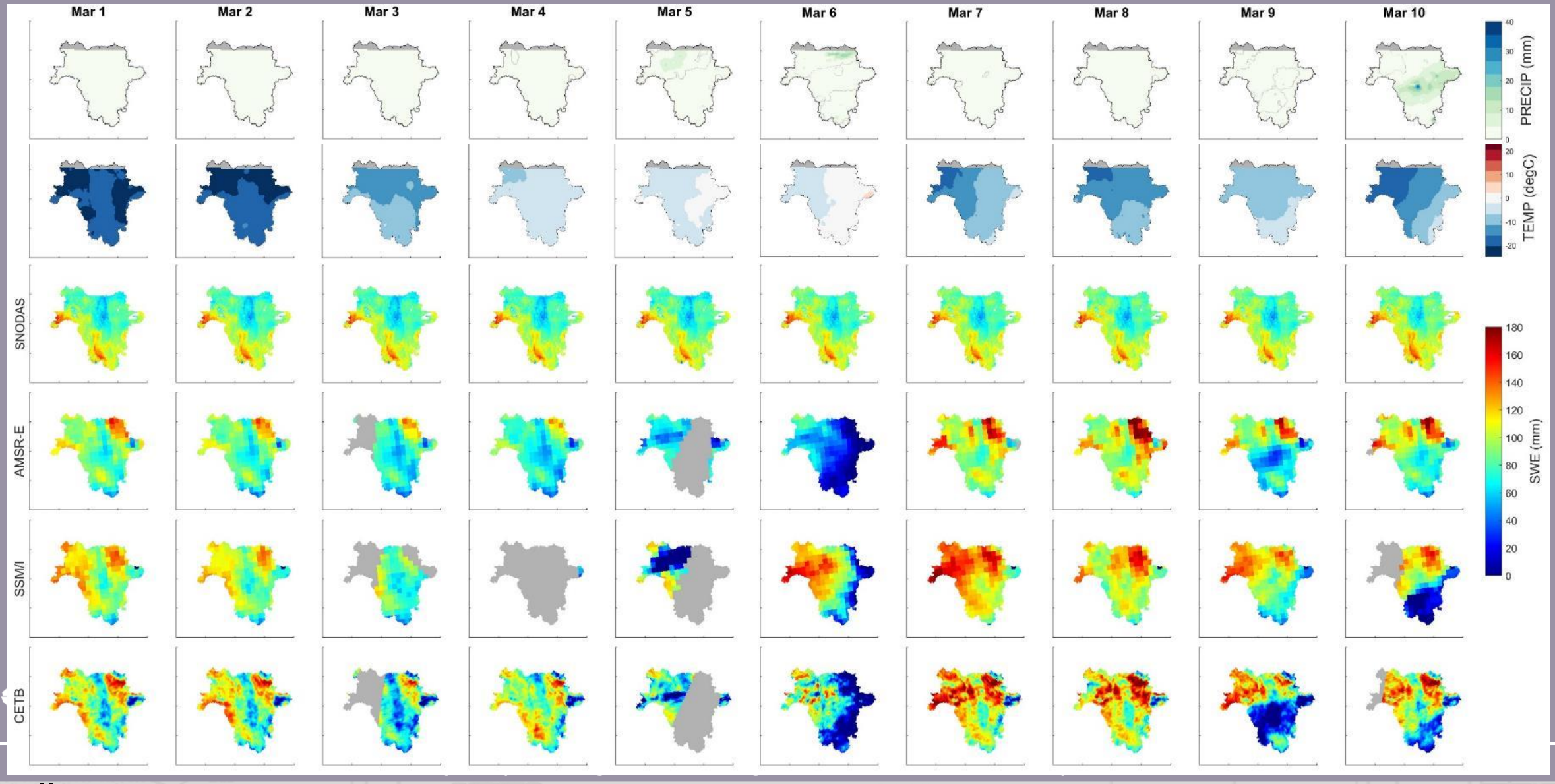

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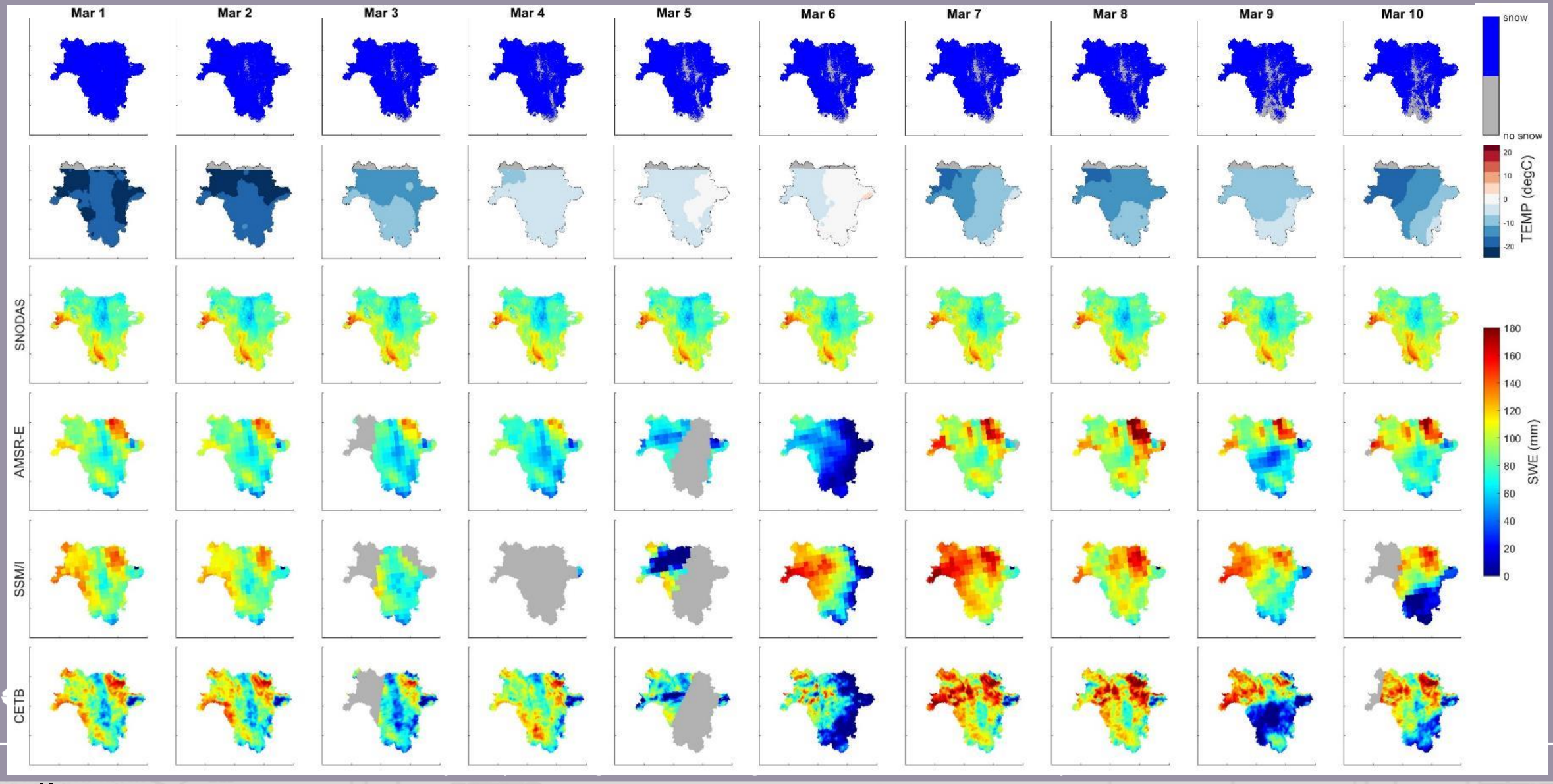

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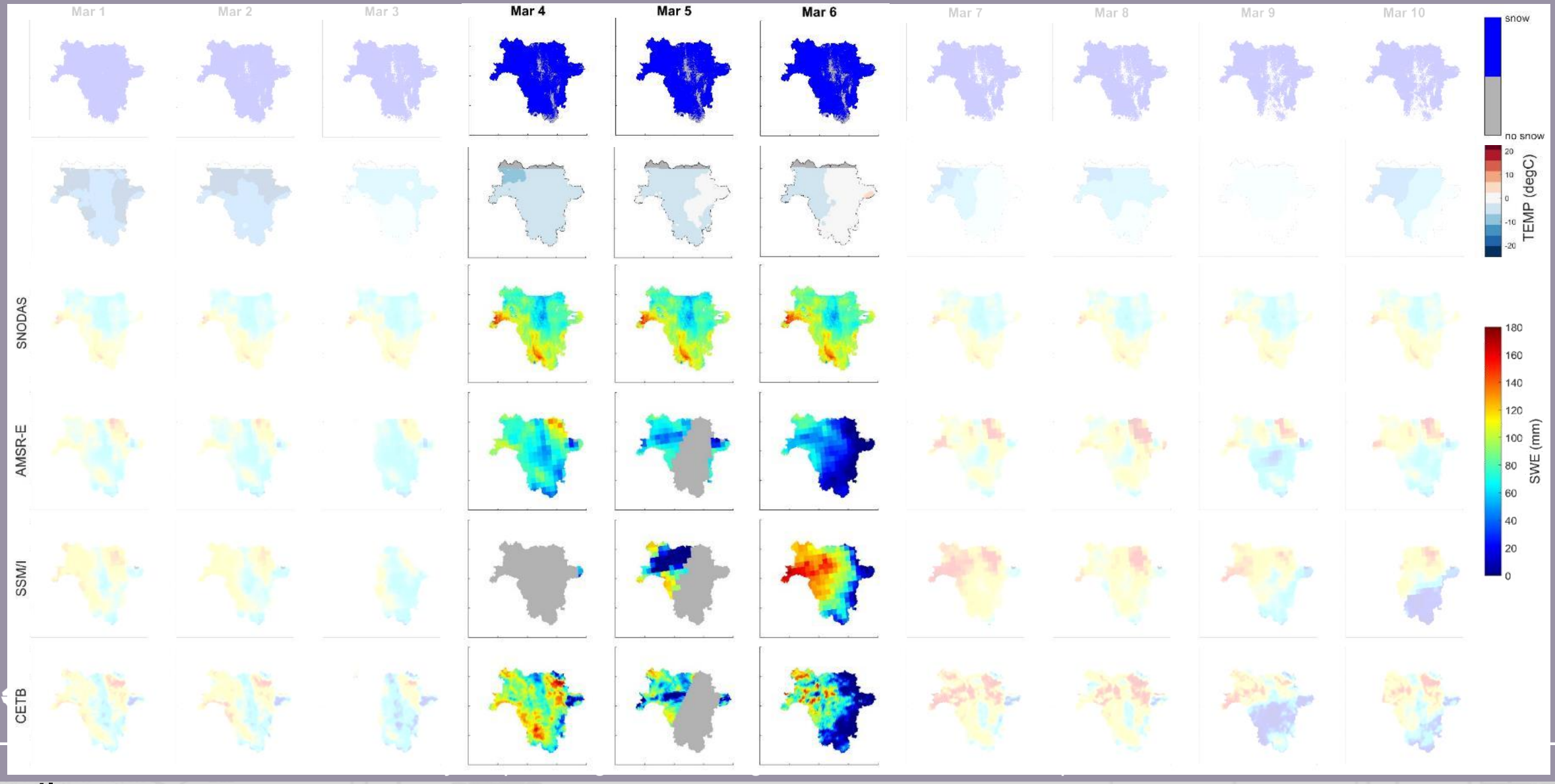

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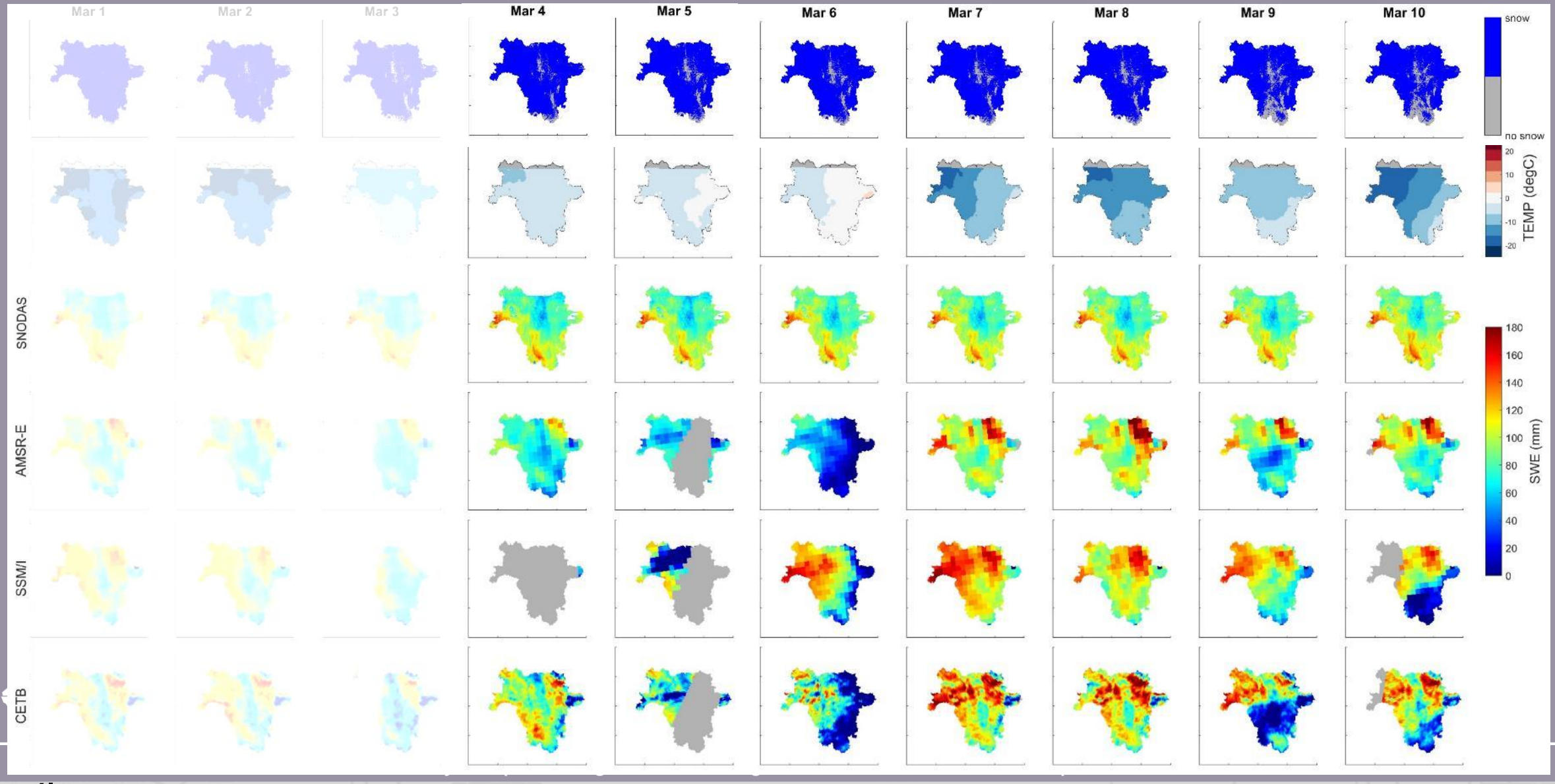

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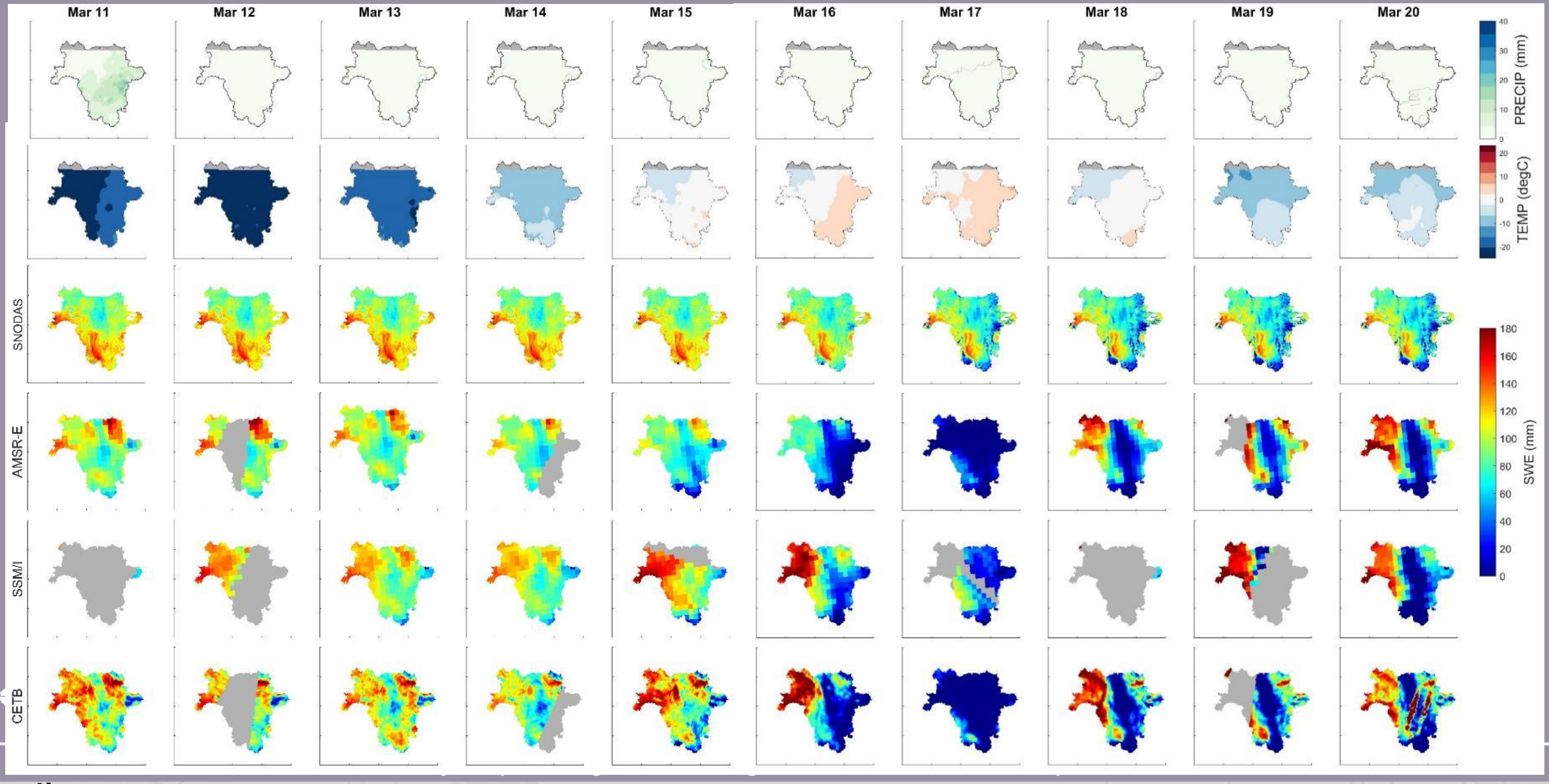

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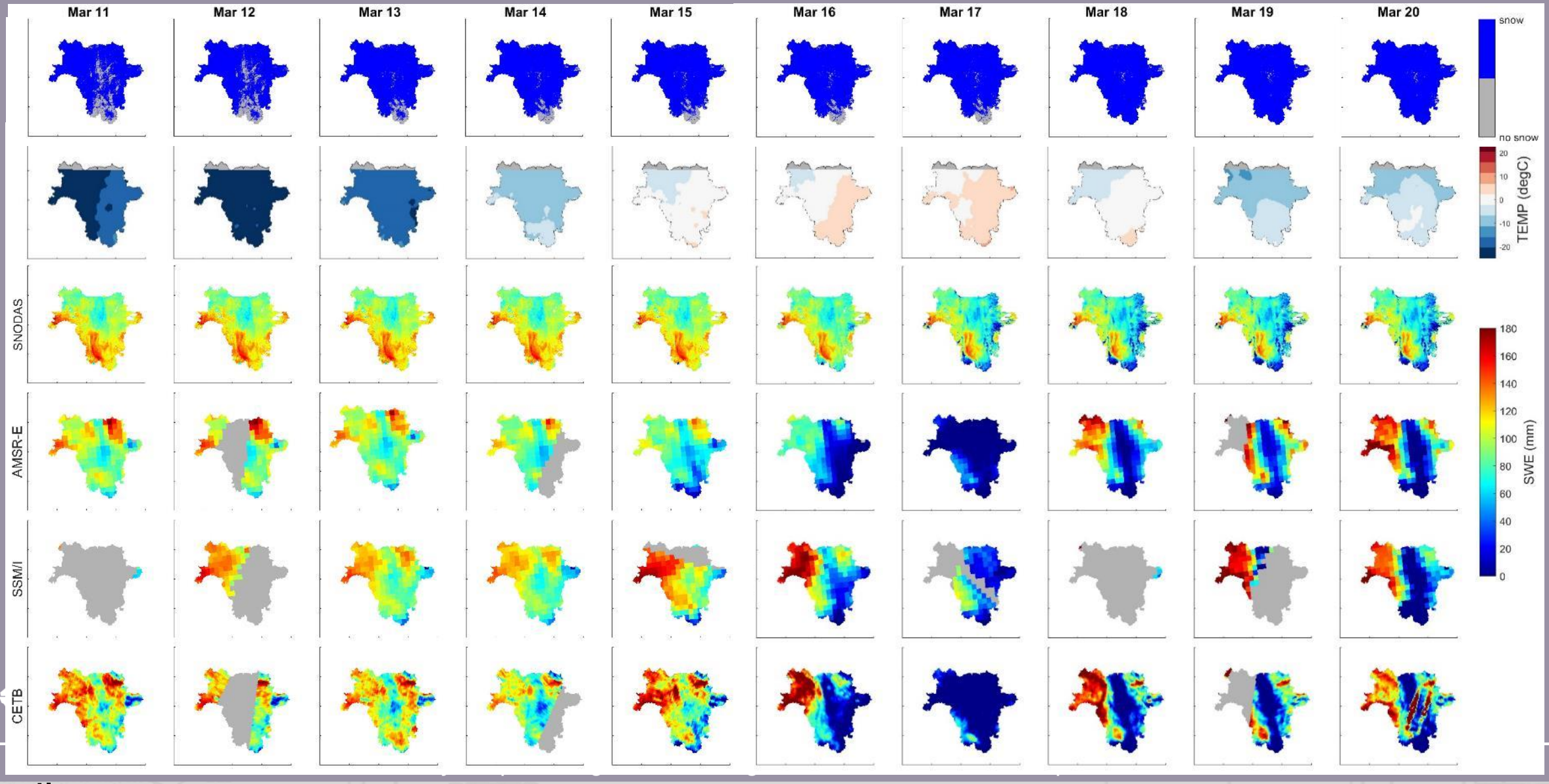

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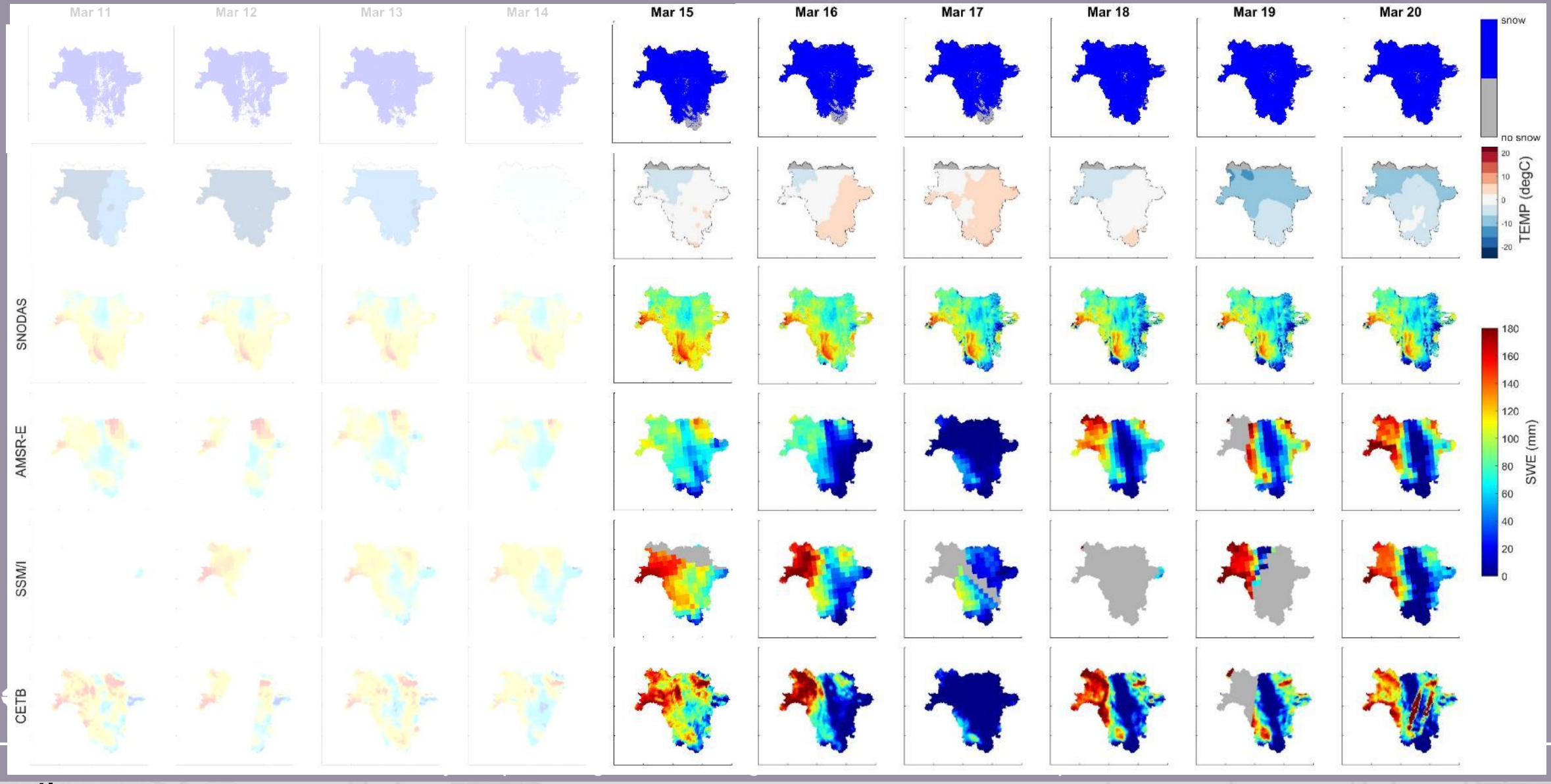
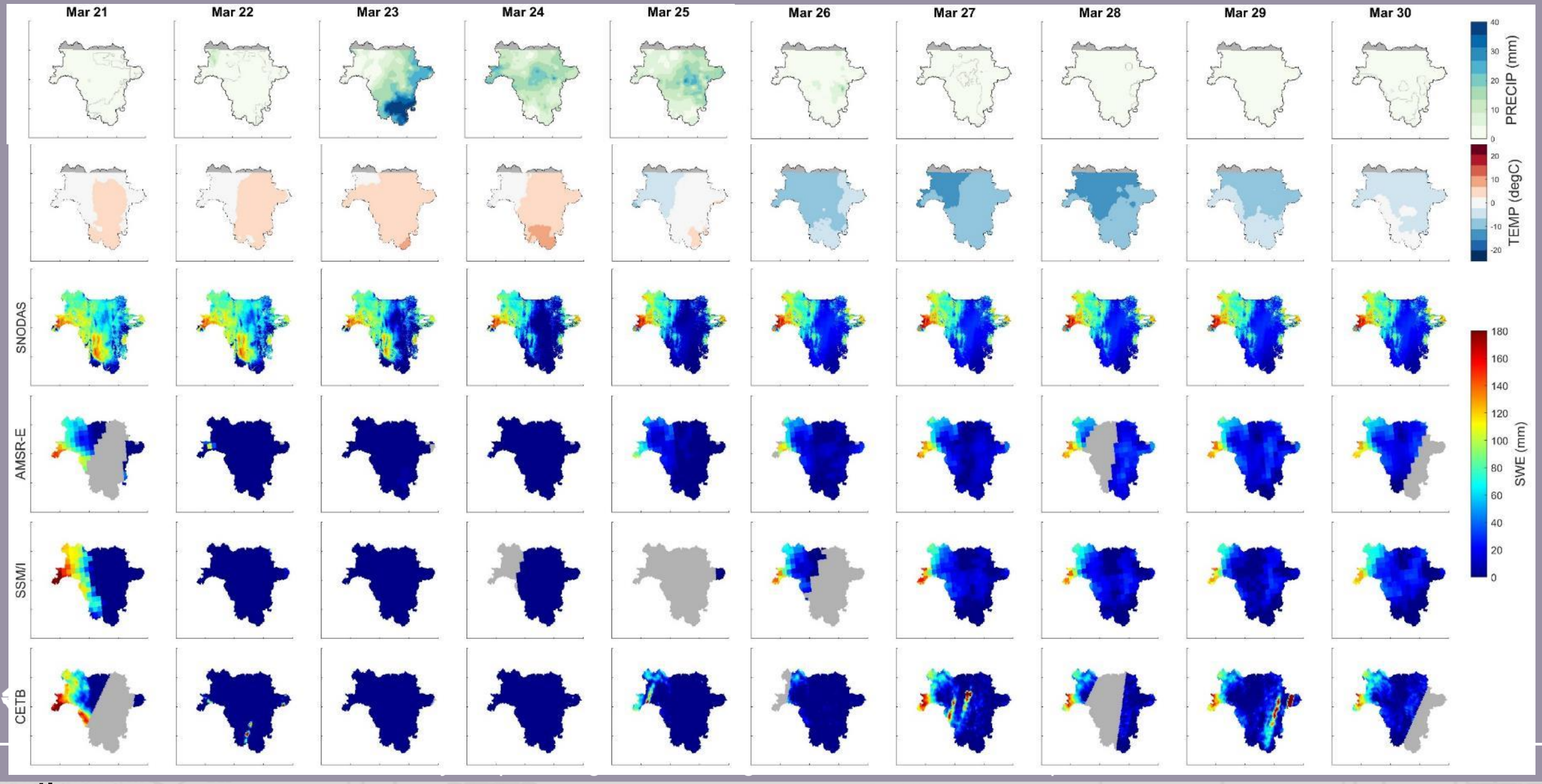


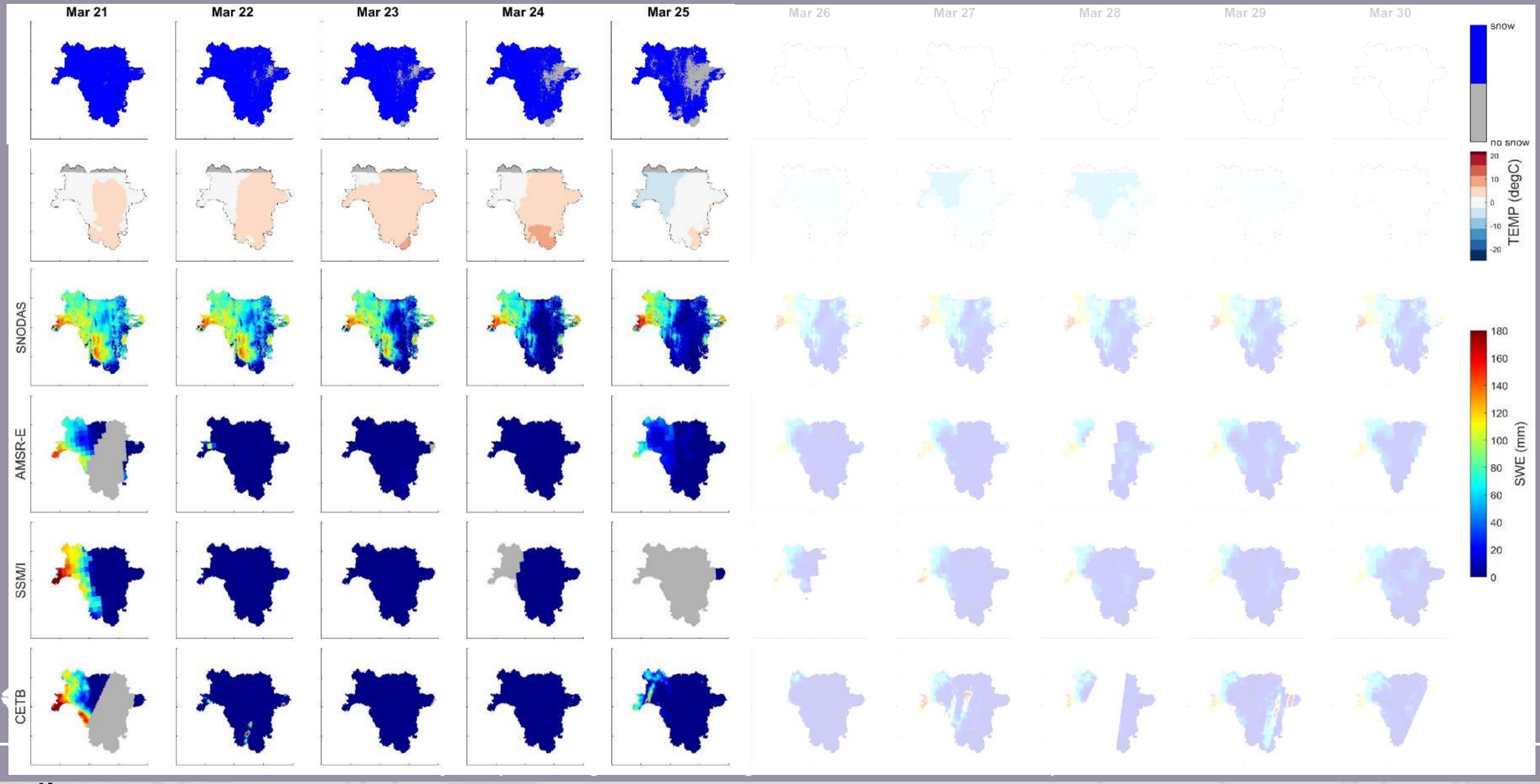
File Name

Results



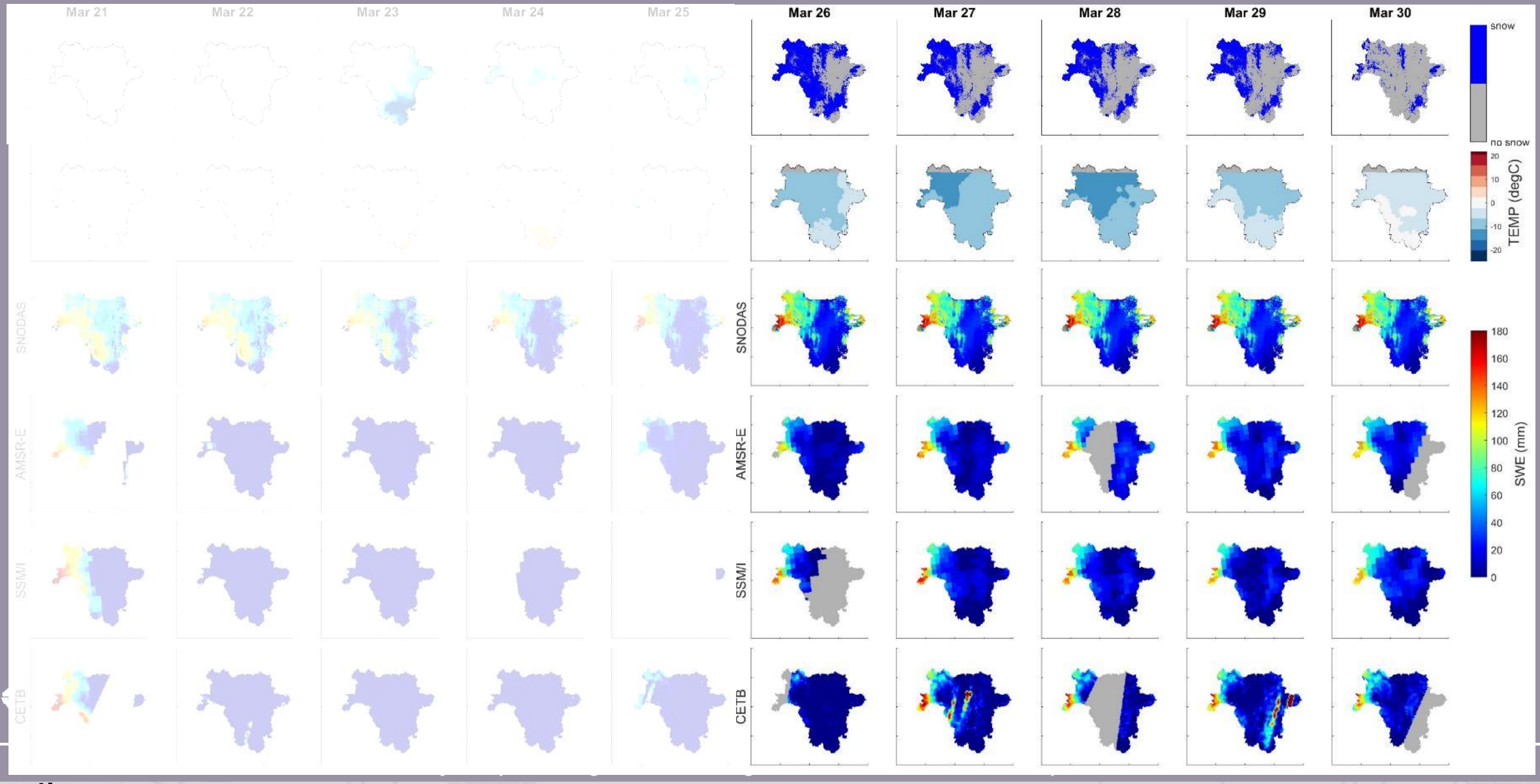
File Name

Results



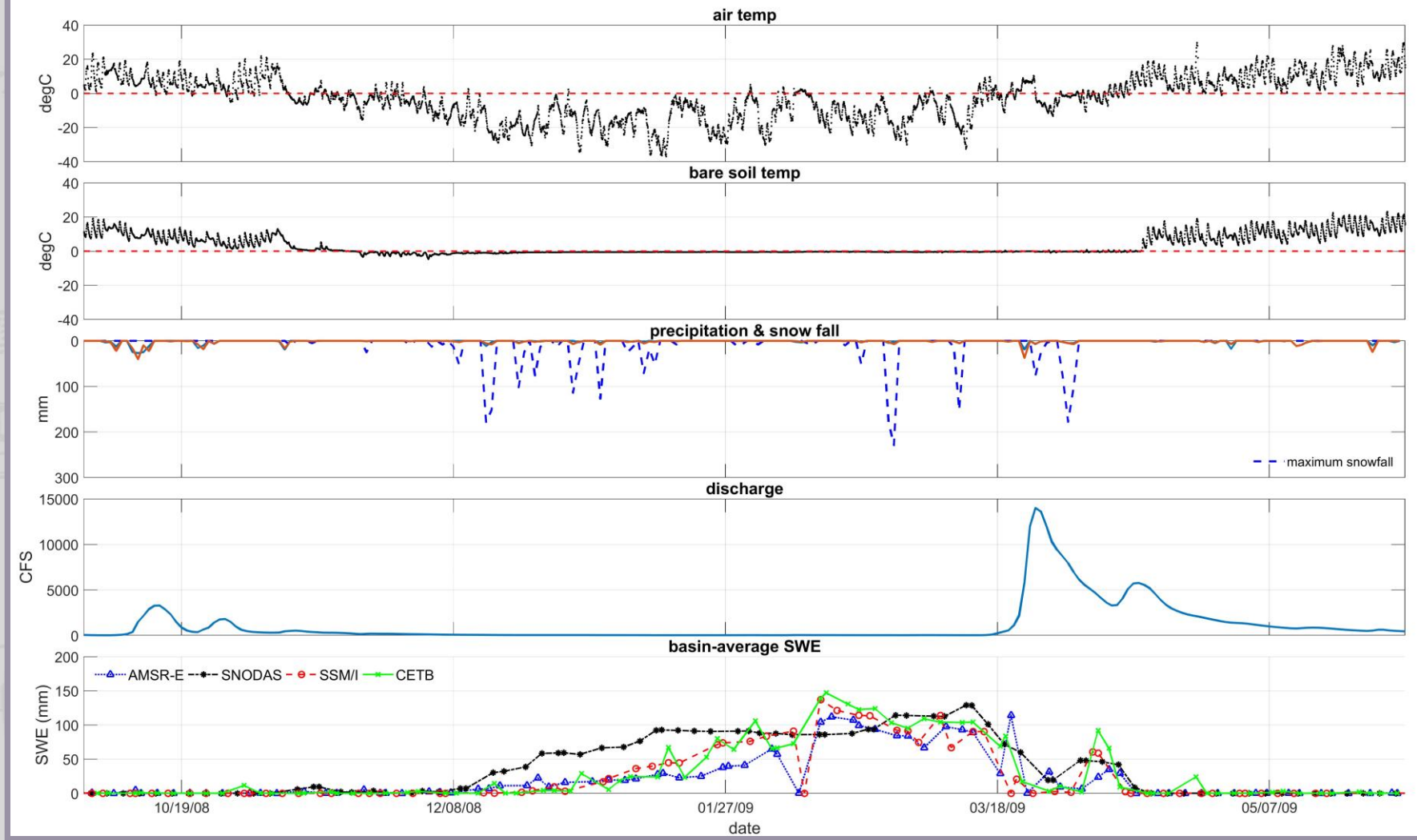
File Name

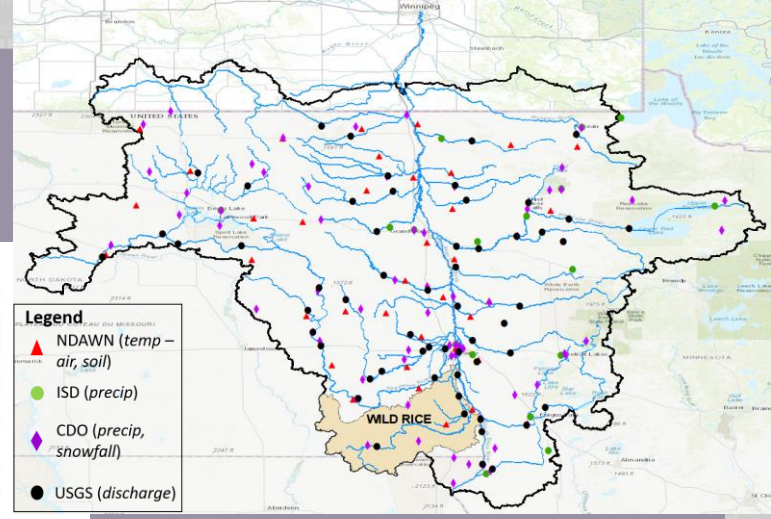
Results



File Name

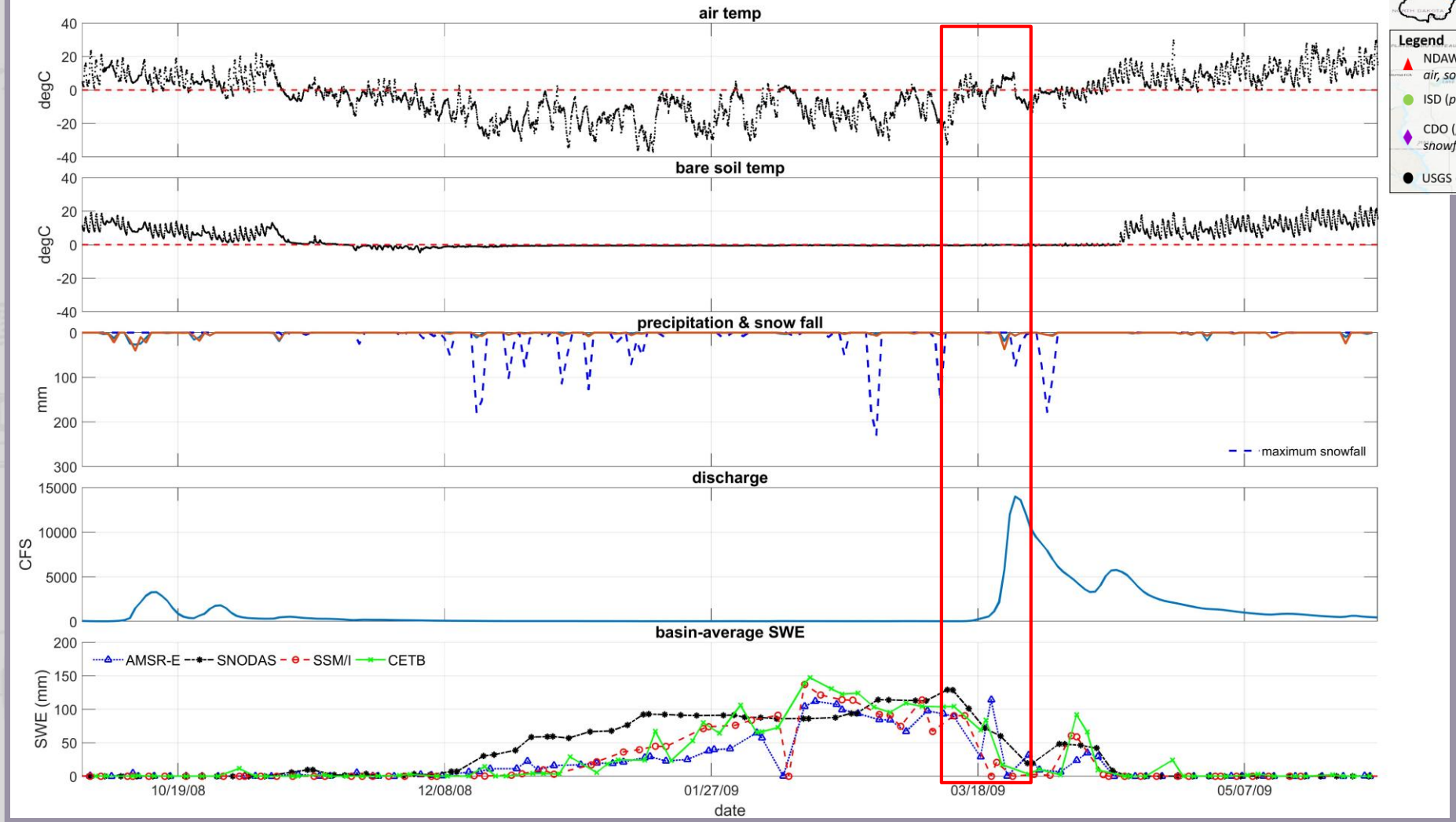
Results – Wild Rice

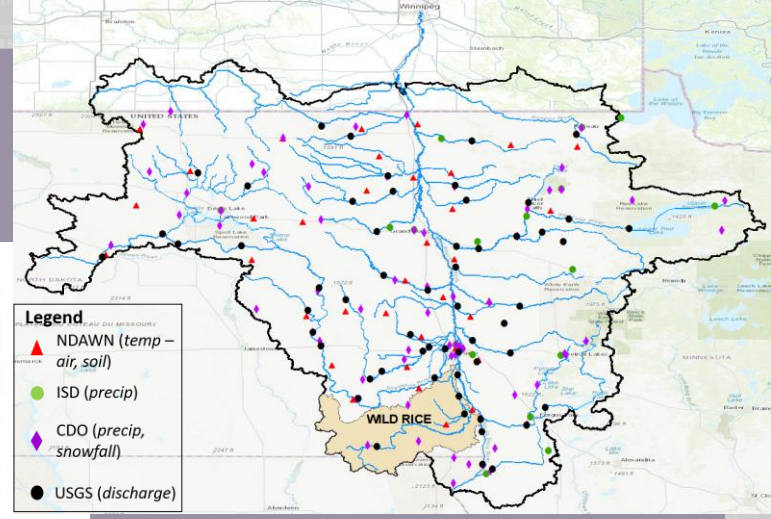




- 1 NDAWN station
- 0 ISD stations
- 2 CDO stations
- 3 USGS gauges

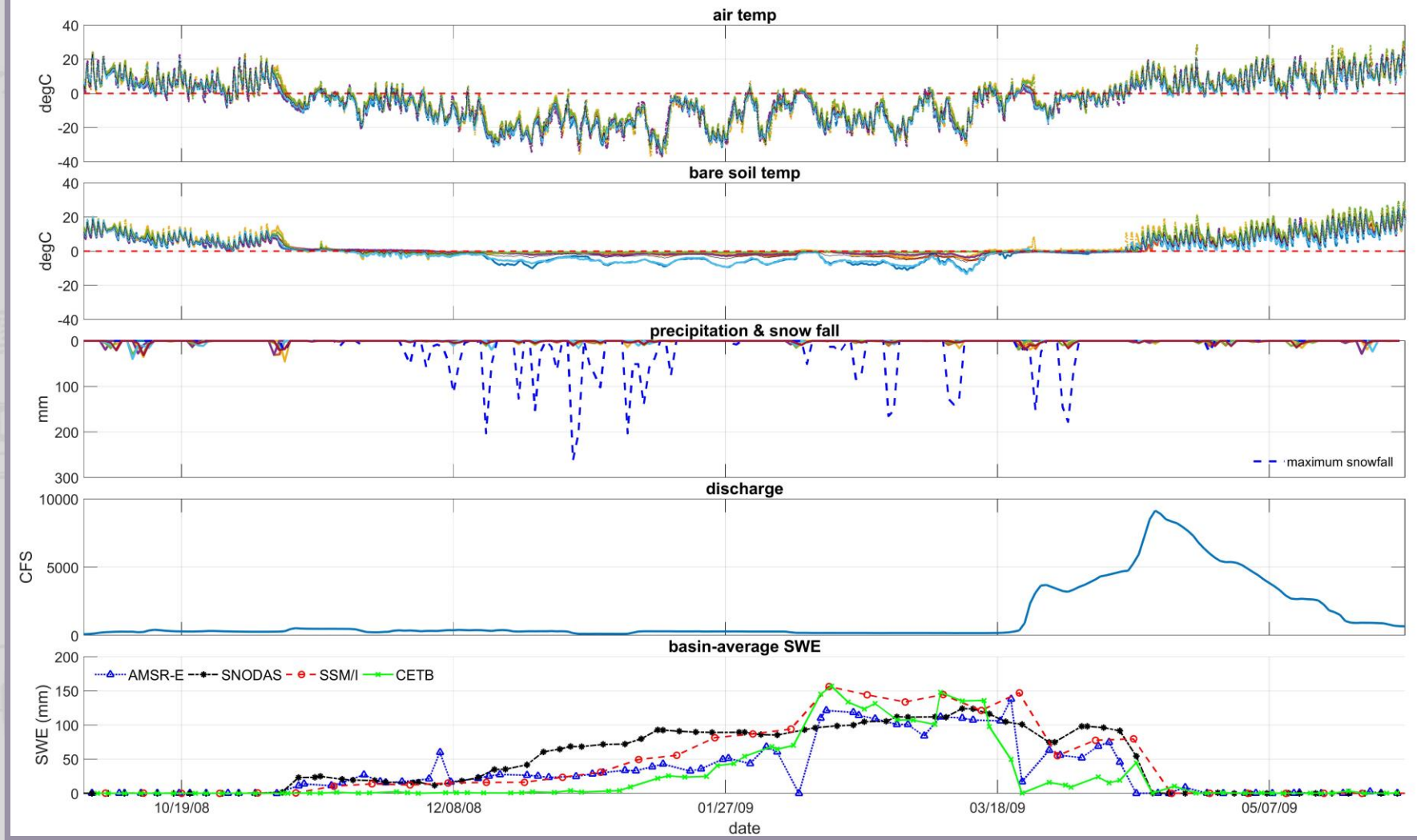
Results – Wild Rice

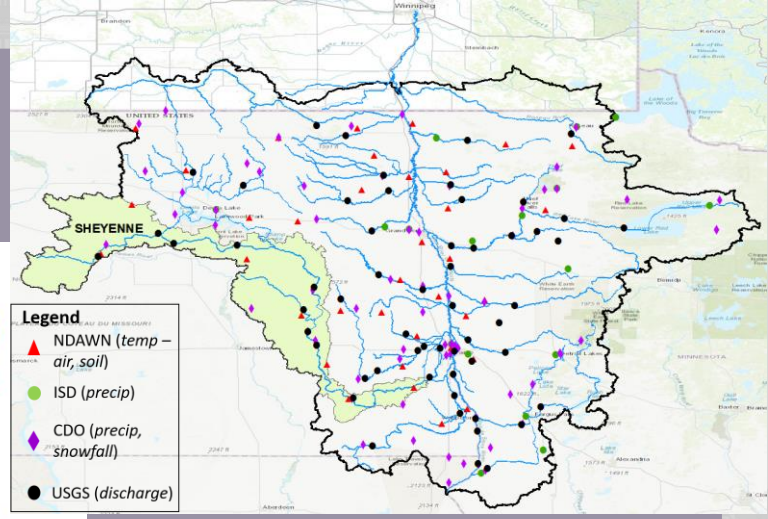




- 1 NDAWN station
- 0 ISD stations
- 2 CDO stations
- 3 USGS gauges

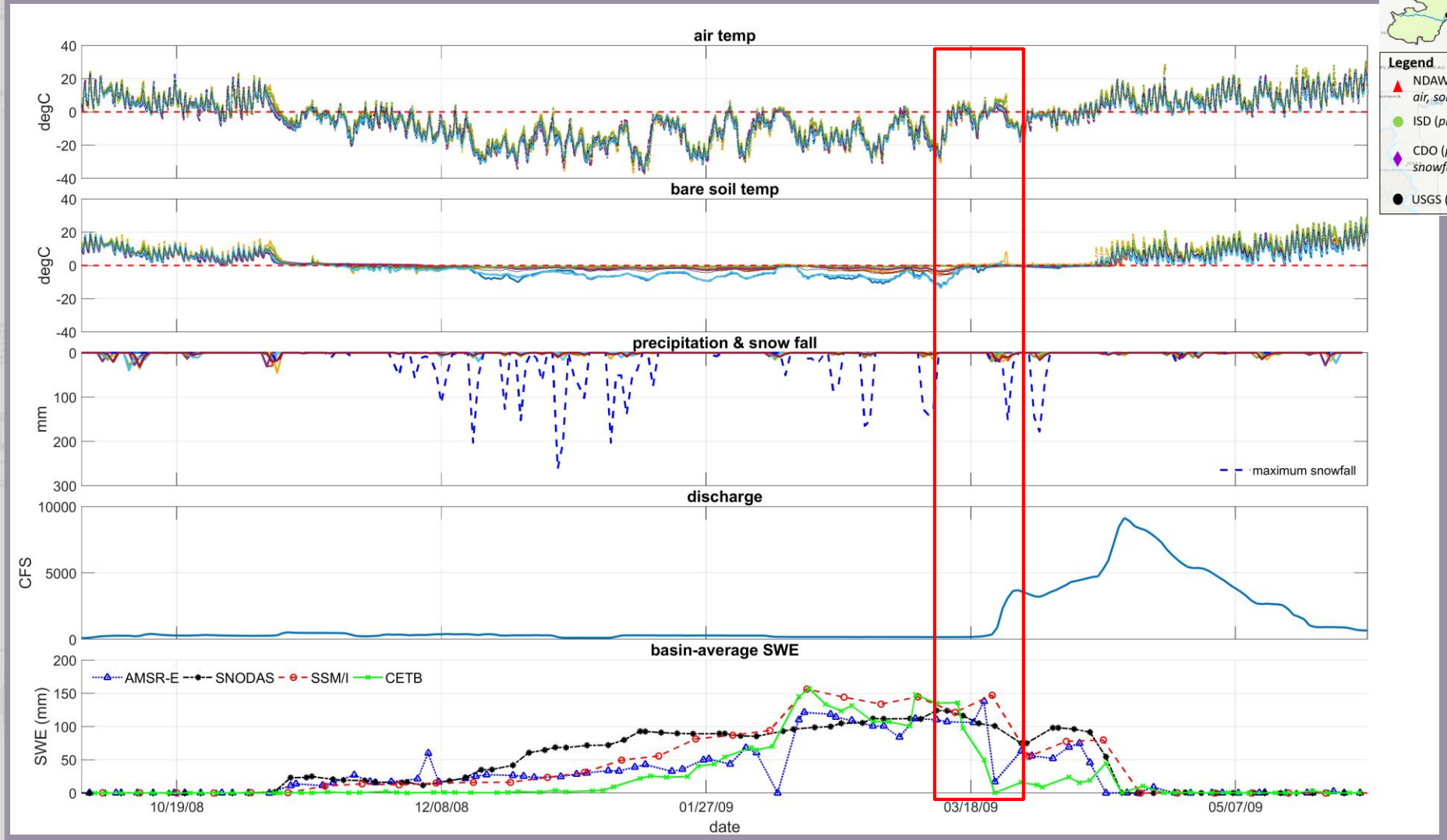
Results – Sheyenne

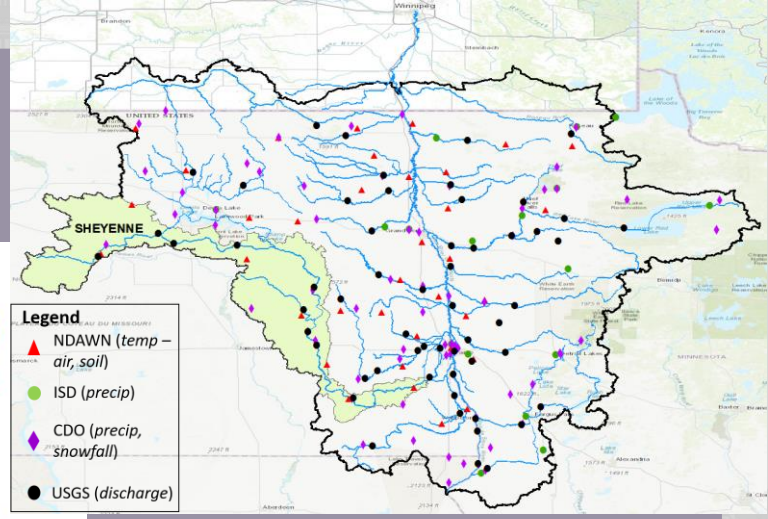




- 6 NDAWN stations
- 0 ISD stations
- 7 CDO stations
- 8 USGS gauges

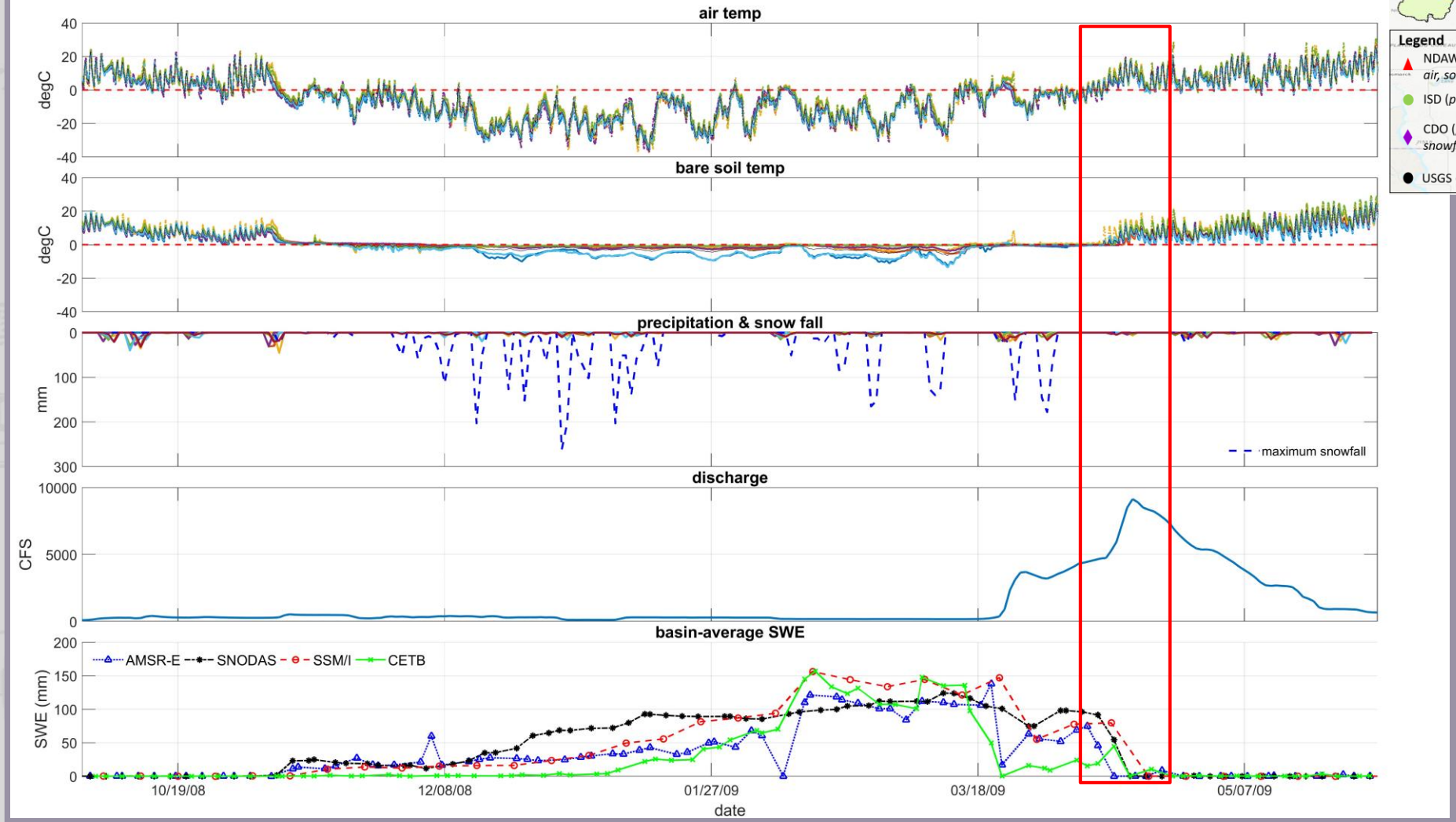
Results – Sheyenne

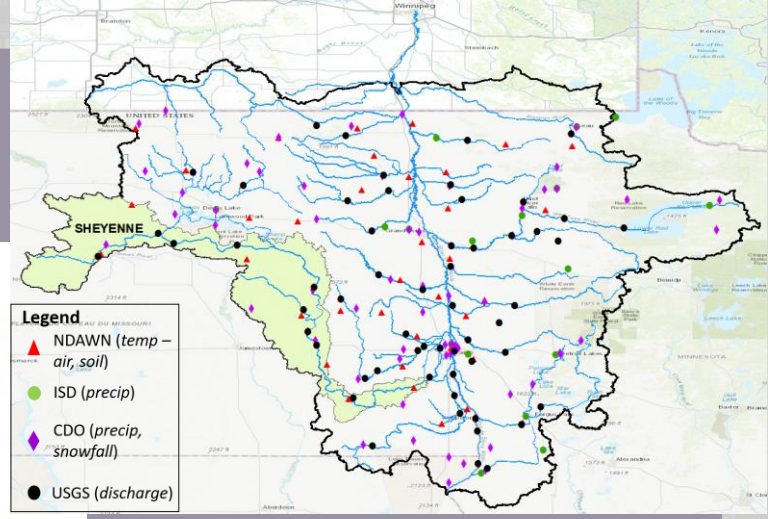




- 6 NDAWN stations
- 0 ISD stations
- 7 CDO stations
- 8 USGS gauges

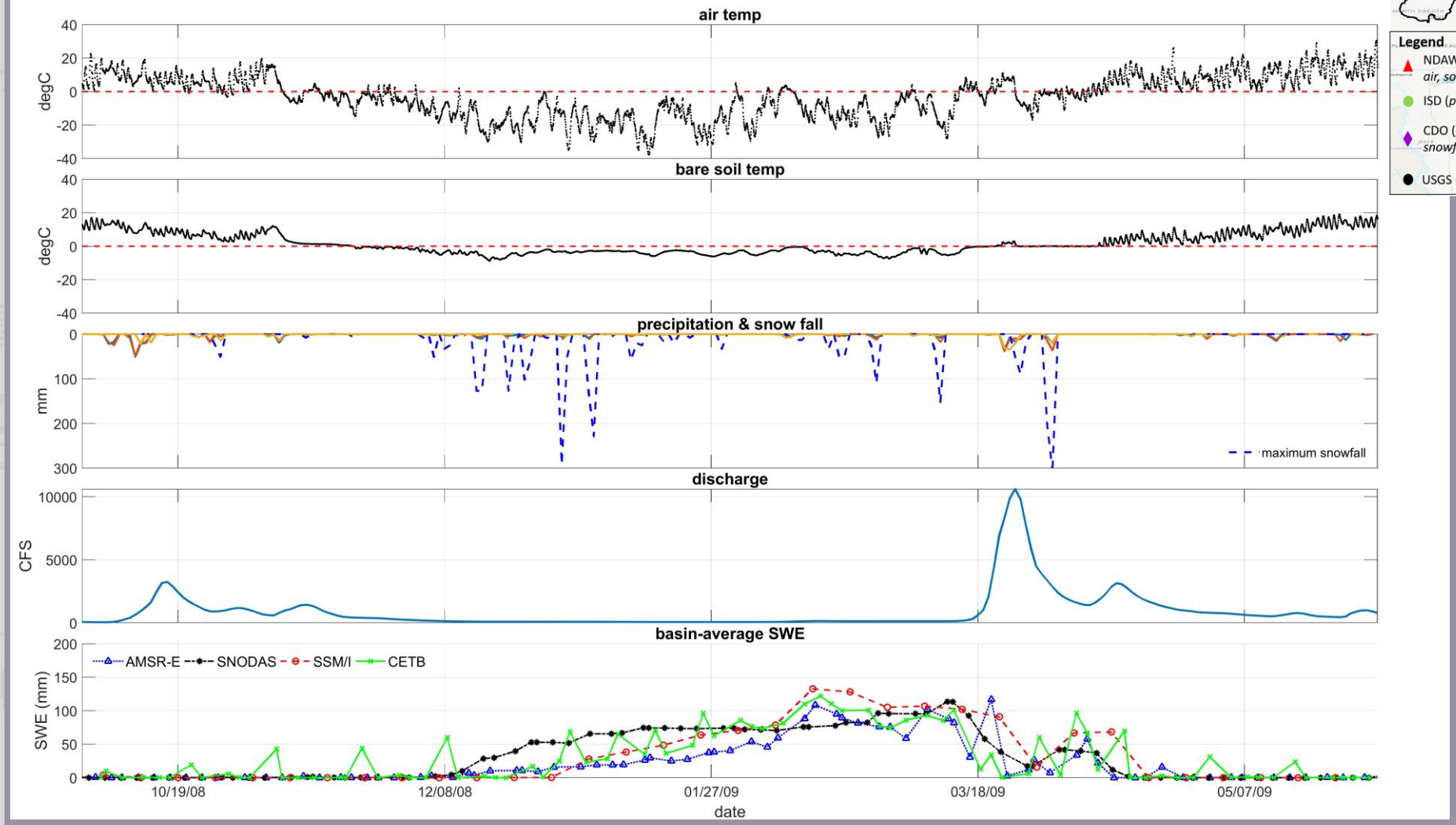
Results – Sheyenne

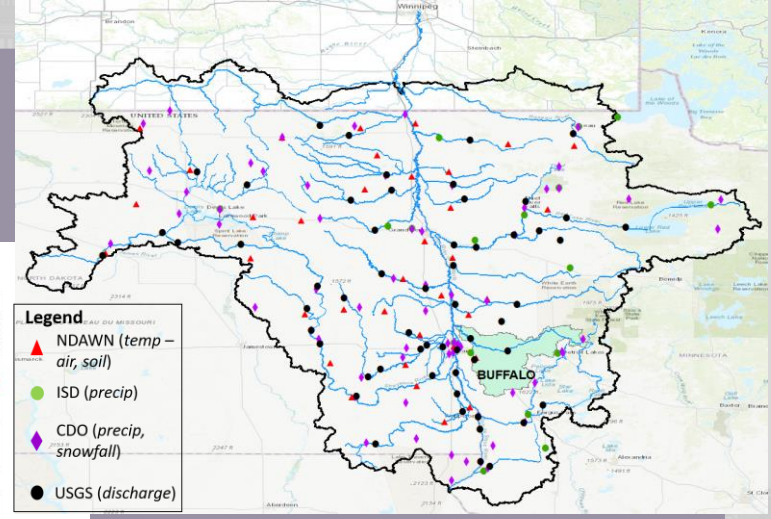




- 6 NDAWN stations
- 0 ISD stations
- 7 CDO stations
- 8 USGS gauges

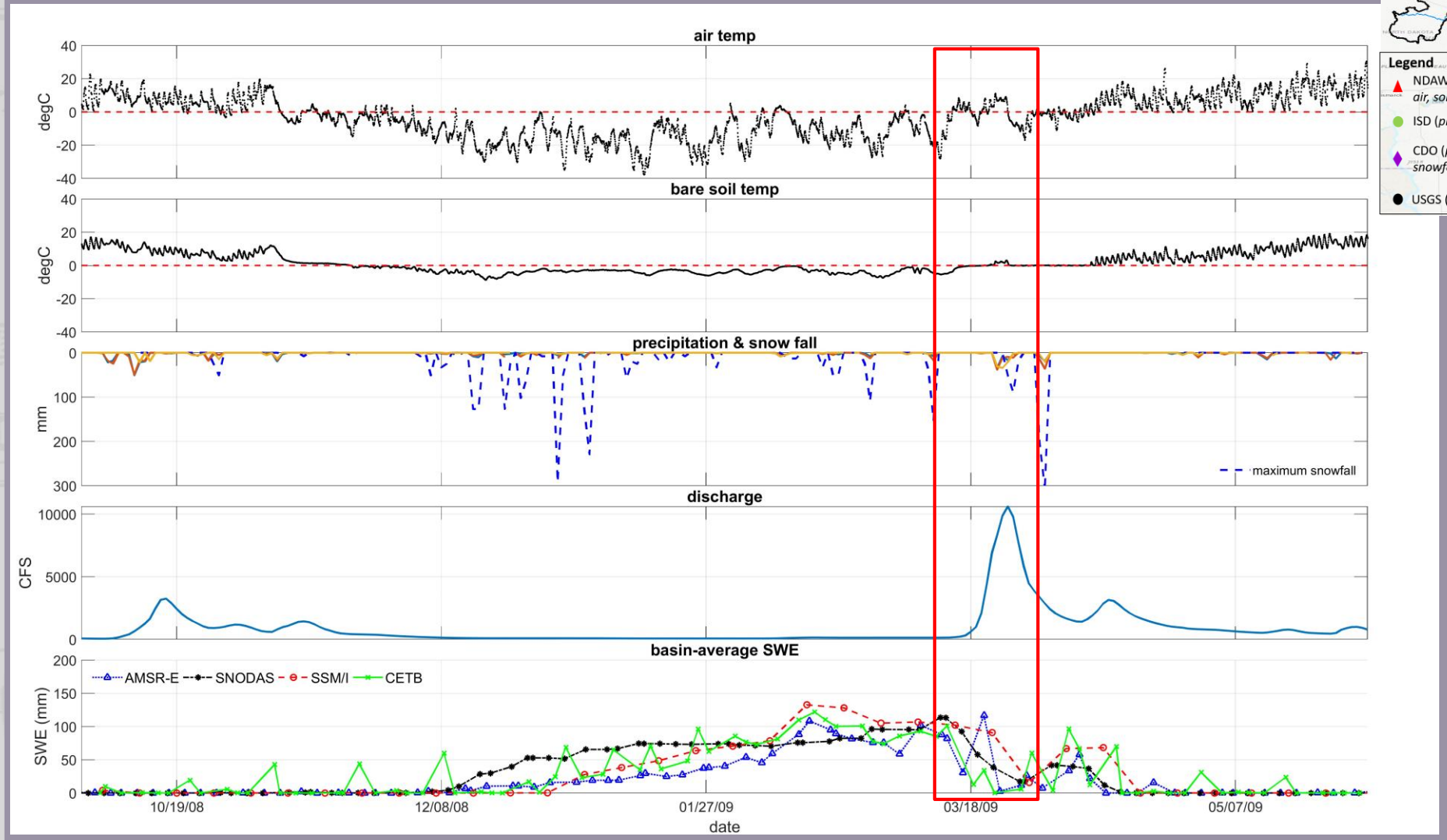
Results – Buffalo

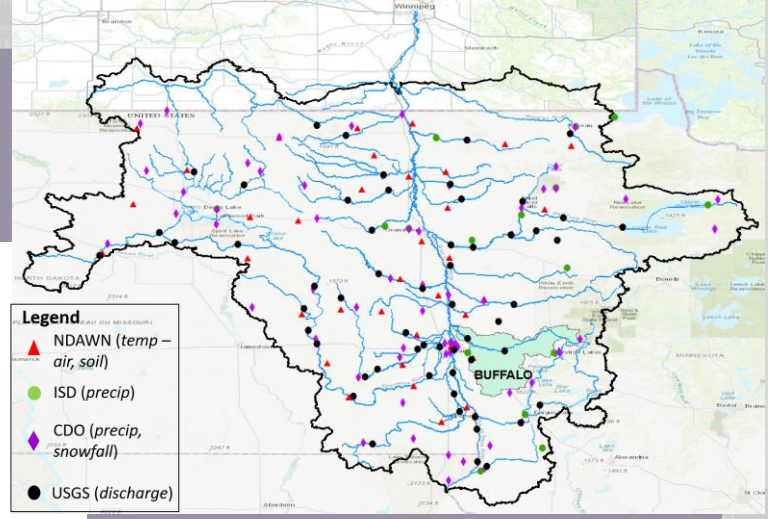




- 1 NDAWN station
- 0 ISD stations
- 3 CDO stations (adjacent)
- 3 USGS gauges

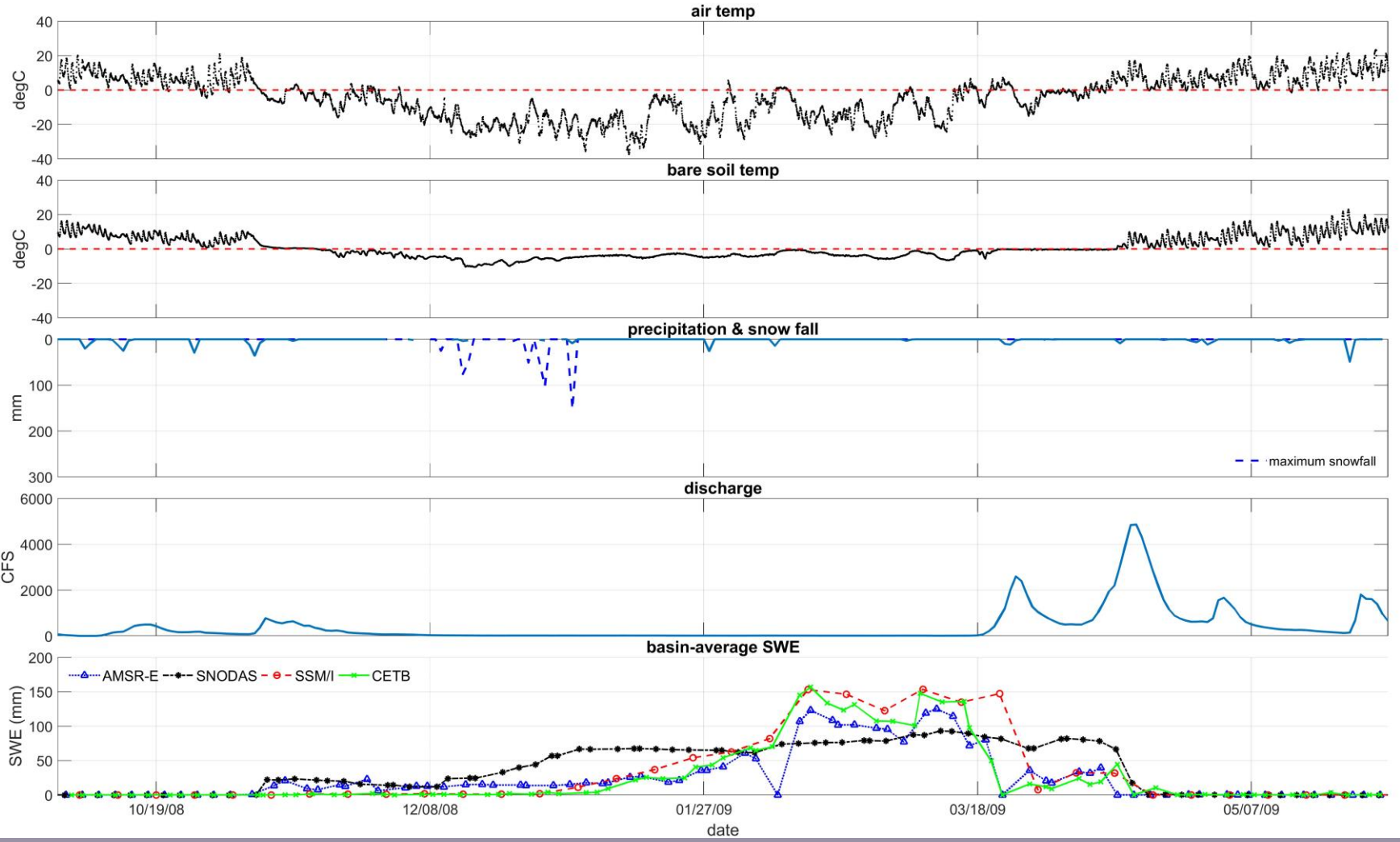
Results – Buffalo

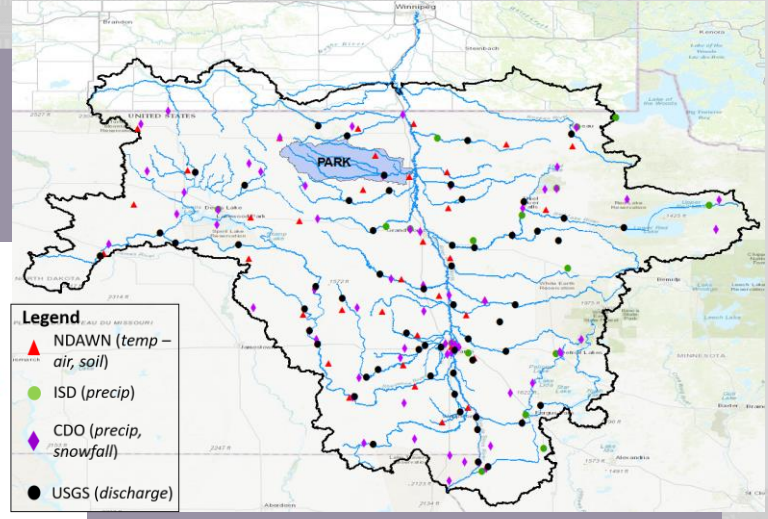




- 1 NDAWN station
- 0 ISD stations
- 3 CDO stations (adjacent)
- 3 USGS gauges

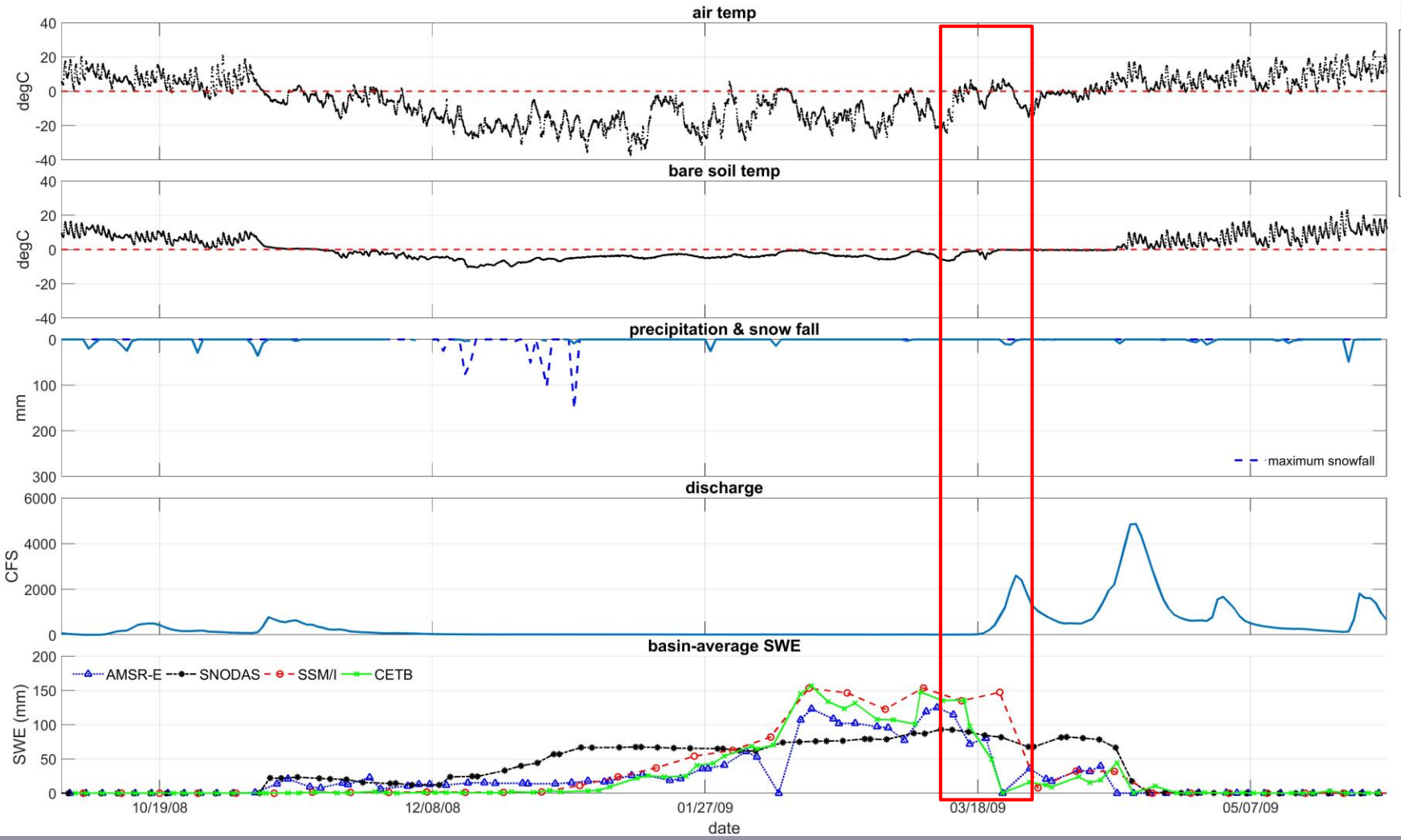
Results – Park River

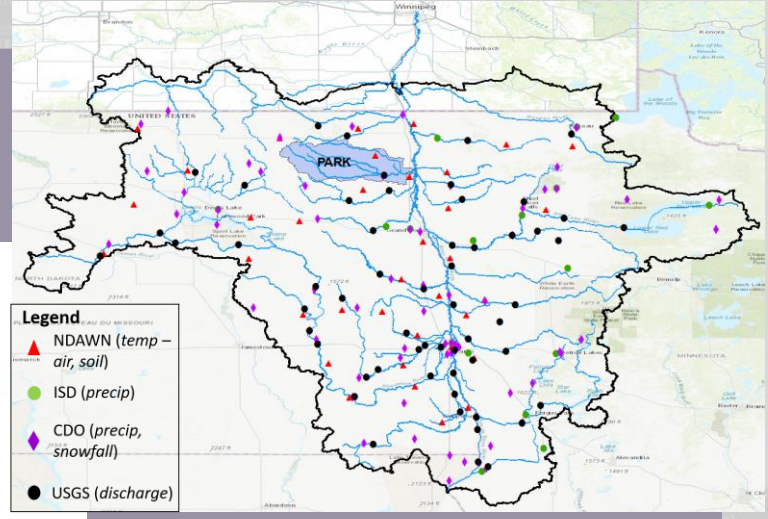




- 1 NDAWN station
- 0 ISD stations
- 1 CDO stations
- 1 USGS gauge

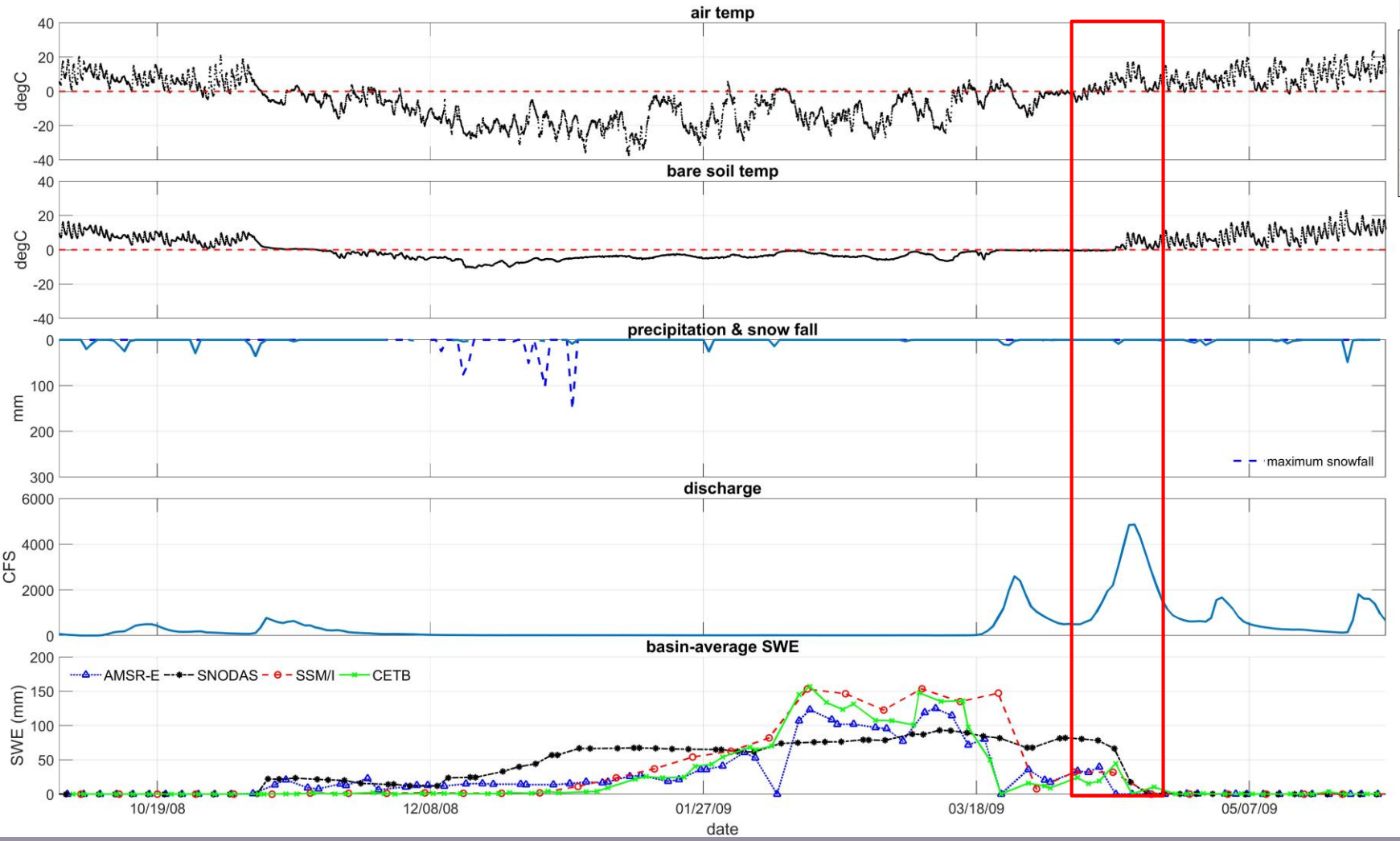
Results – Park River

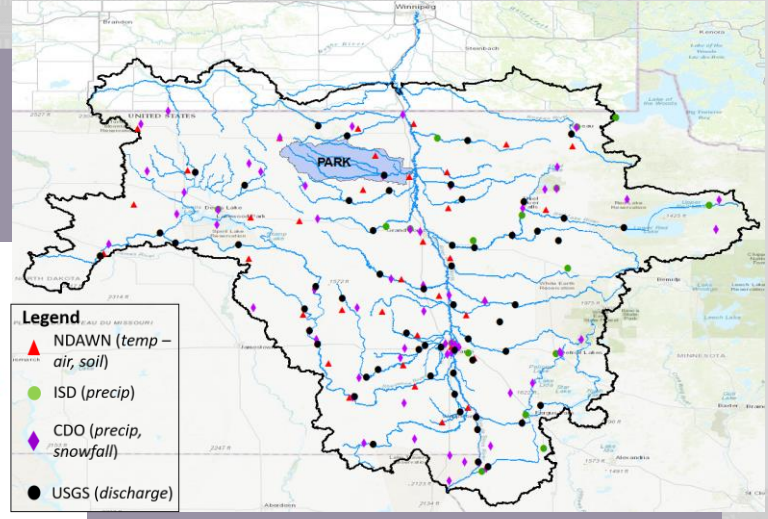




- 1 NDAWN station
- 0 ISD stations
- 1 CDO stations
- 1 USGS gauge

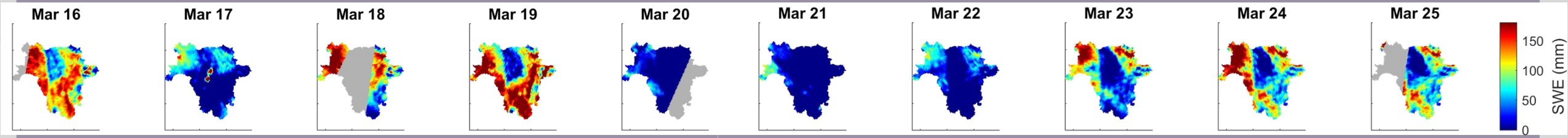
Results – Park River

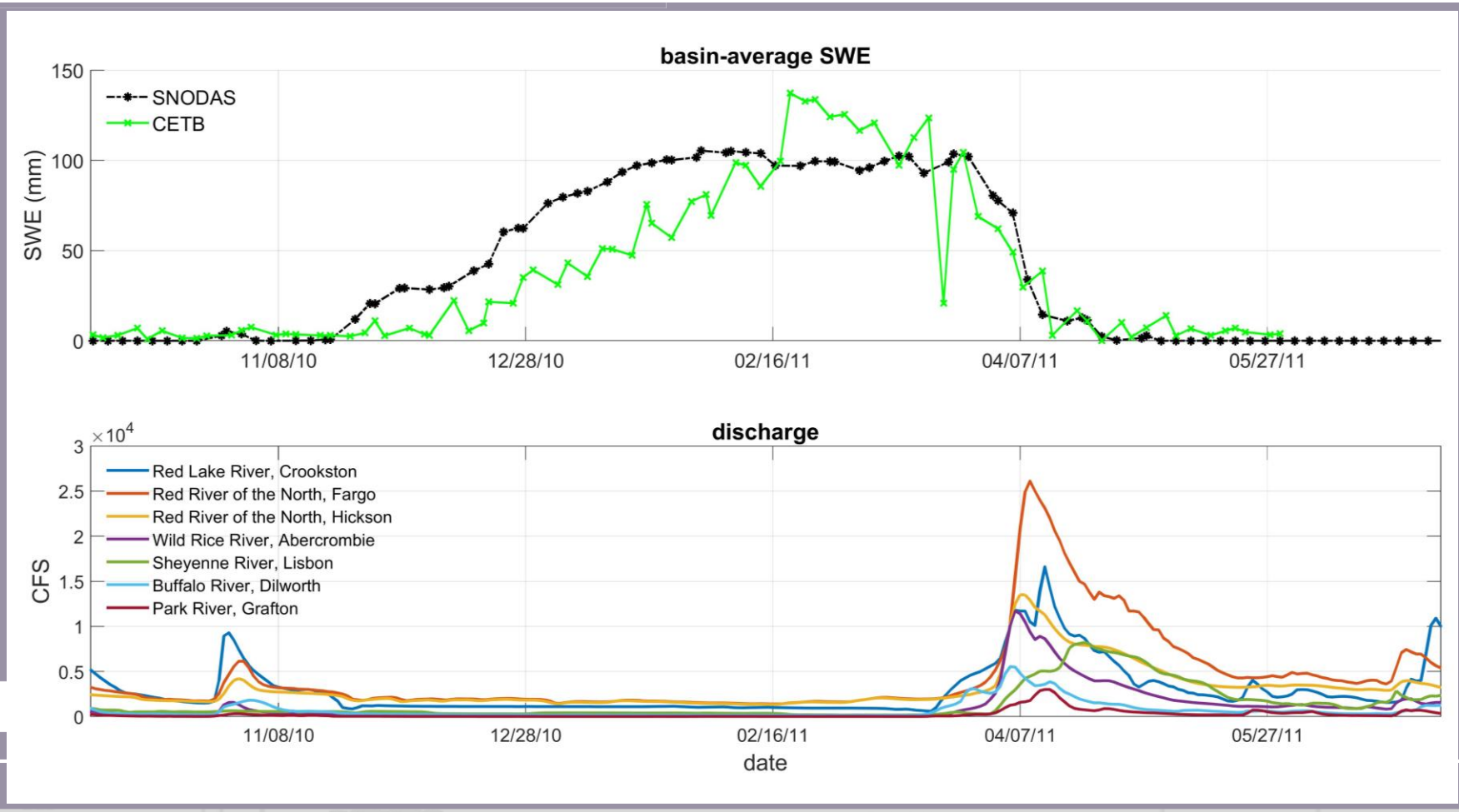




- 1 NDAWN station
- 0 ISD stations
- 1 CDO stations
- 1 USGS gauge

April 2011 Flood Event



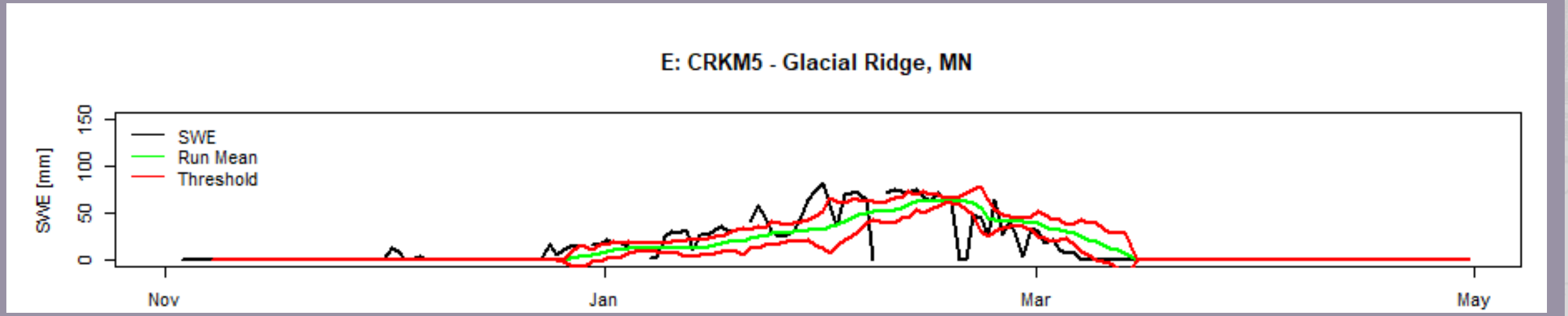


Conclusion

- Spatial relationship between air temperature and passive microwave SWE estimates
- Microwave signal response to wet snow corresponds to timing of discharge increase
- Although shallow and flat, the RRN ripening pattern shows a melt signal along the main stem first, and later at higher elevations
- CETB seems to show higher resolution reasonable estimate of melt signal

Next steps

- **SWE melt algorithm (Schroeder, 2018)**
- **Look closer at MODIS SCA, SNODAS snow melt**
- **Initialize hydrologic model with CETB data**



Schroeder, R., S. Kraatz, J. M. Jacobs, C. M. Vuyovich, C. Olheiser, B. Connelly, M. M. DeWeese. 2018. Detection of snowmelt signals for improving snowmelt flood forecast in the Red River basin of the North. *75th Eastern Snow Conference,* June 5-8, College Park, MD.

Acknowledgements

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