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Evaluation of satellite-based snow data for estimating SWE and SCA for water resource applications

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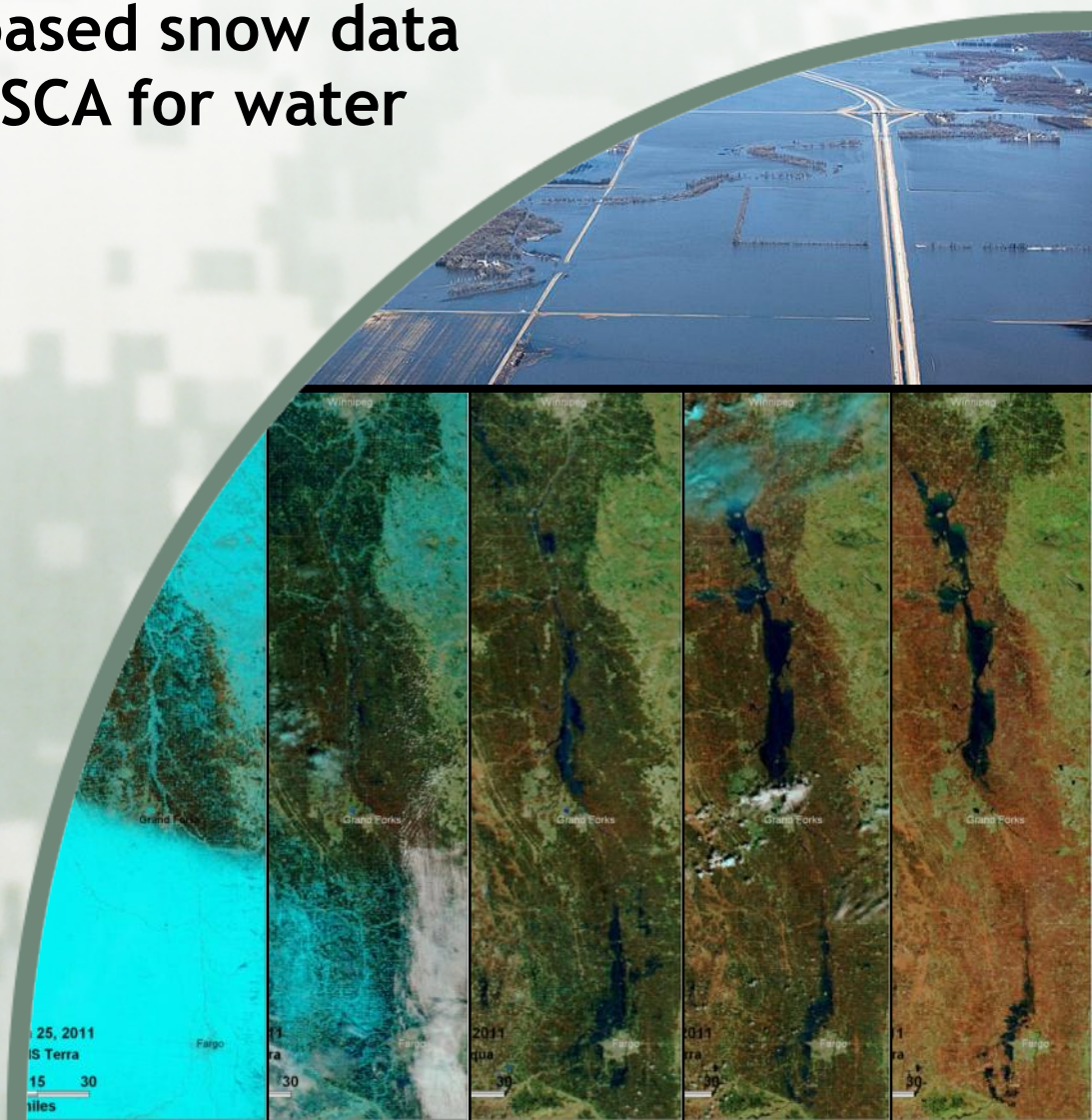

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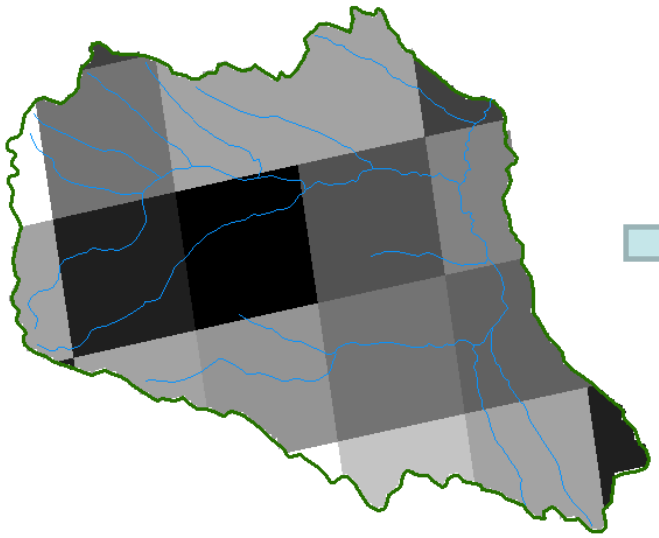
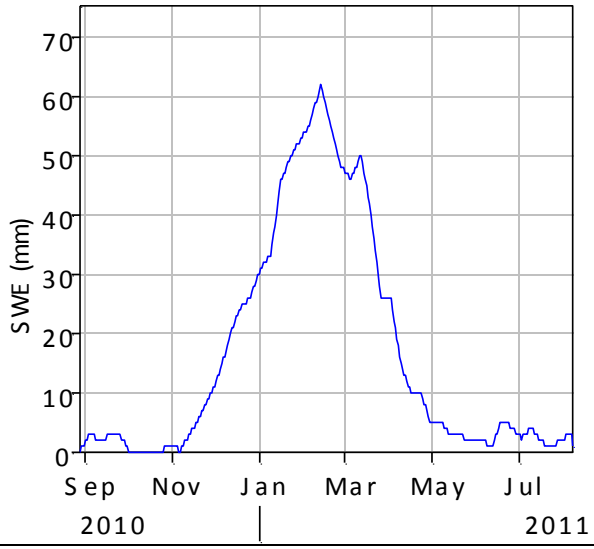
Motivation

Objective: To evaluate satellite SWE products across multiple regions and over time at a watershed scale for use in water resource applications.

Watershed analysis:

- Allow independent comparison of watershed SWE volumes to discharge
- Eliminates need to reproject or re-grid



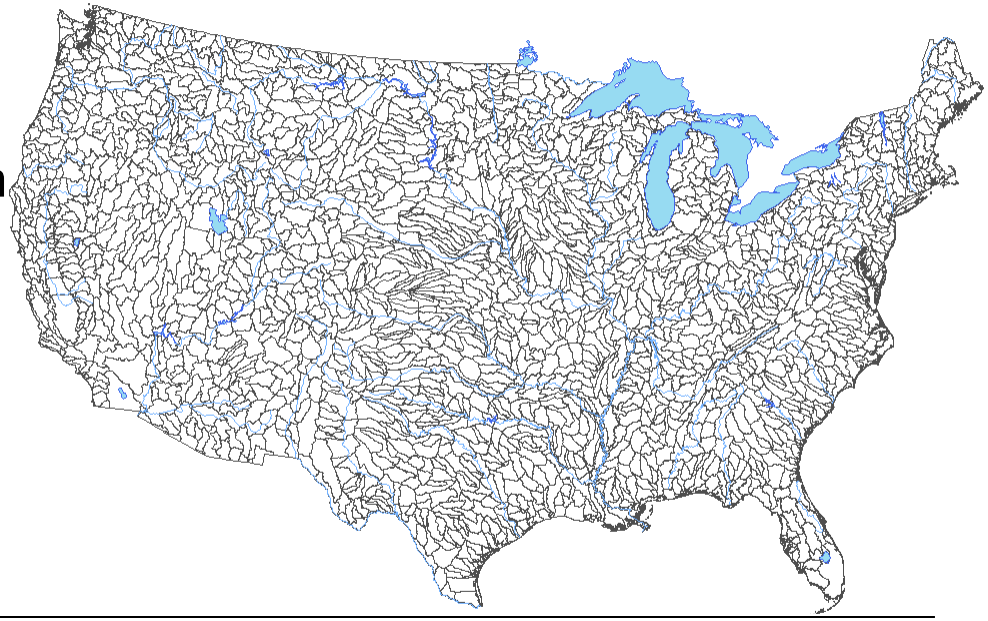


Methodology

National comparison

- Compared SWE estimates by 2100 HUC8 watersheds across the U.S.
  - SNODAS, AMSR-E and SSM/I
  - 2004 – 2011
  - Statistical comparison of peak SWE and temporal trends
  - Analyzed by elevation and forest cover

- Statistics:
  - Average, Maximum, Minimum
  - Difference in annual max
  - Correlation
  - Spearman's rank-order
  - Nash-Sutcliffe efficiency



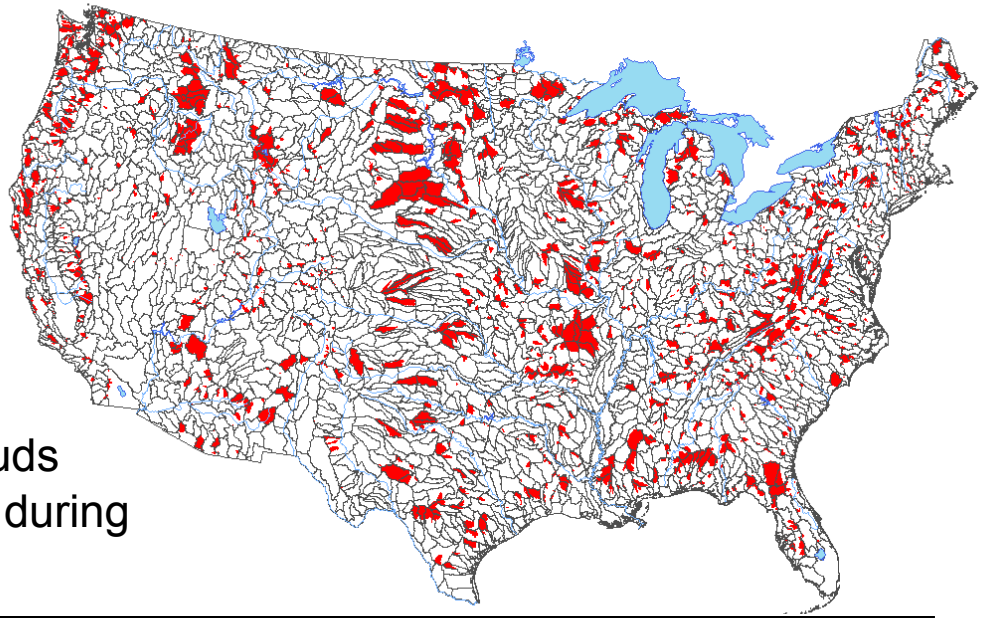
Methodology

Regional comparison:

- Water balance analysis
  - Hydro-Climatic Data Network (HCDN) reference basin dataset used to identify watersheds with minimal human impacts.

$$R = SWE_{max} + P - ET - GW \pm \Delta SM$$

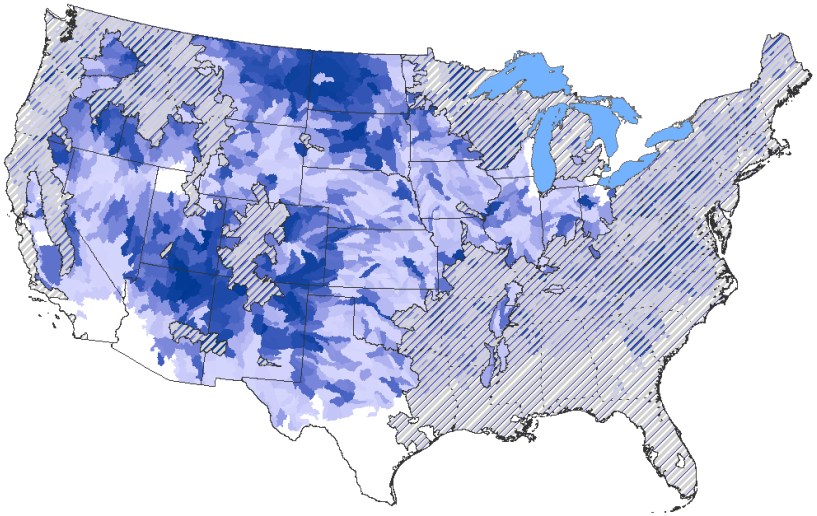
  - Where SWE_{max} is max annual
  - R, P and ET are the total volumes, March – June
  - GW is the loss to deep groundwater
  - ΔSM is the change in soil moisture over analysis period



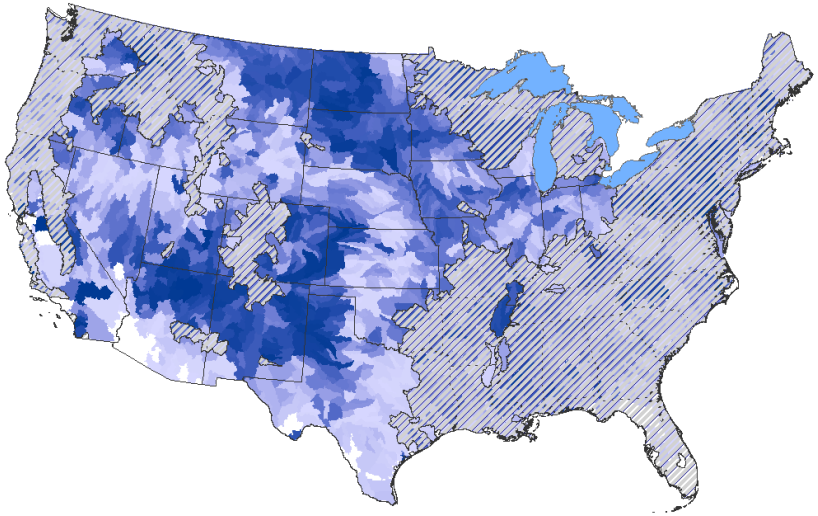
- Snow Extent analysis
  - MOD10A1, processed to filter clouds
  - Compared total basin SE to SWE during melt period

National Comparison results
Passive microwave and SNODAS SWE by HUC8

SNODAS - AMSR-E



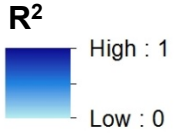
SNODAS - SSM/I



Correlations of annual maximum SWE for each HUC8. Hatched area shows regions with >20% forest fraction or > 200 mm annual maximum SWE.

Conclusions:

- Best comparison in areas with < 20% forest cover with an average annual maximum SWE < 200 mm
- Good agreement in the northern Great Plains and southern Rockies regions



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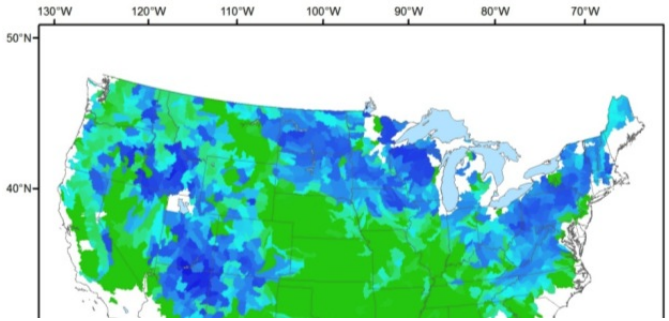
Comparison of passive microwave and SNODAS SWE by HUC8

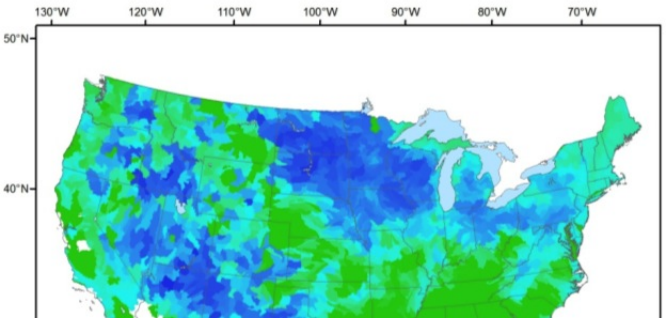
- Nash-Sutcliffe Efficiency measure:

$$E = 1 - \frac{\sum_{t=1}^{T} \left(Q_o^t - Q_m^t\right)^2}{\sum_{t=1}^{T} \left(Q_o^t - \overline{Q_o}\right)^2}$$

SNODAS - AMSR-E

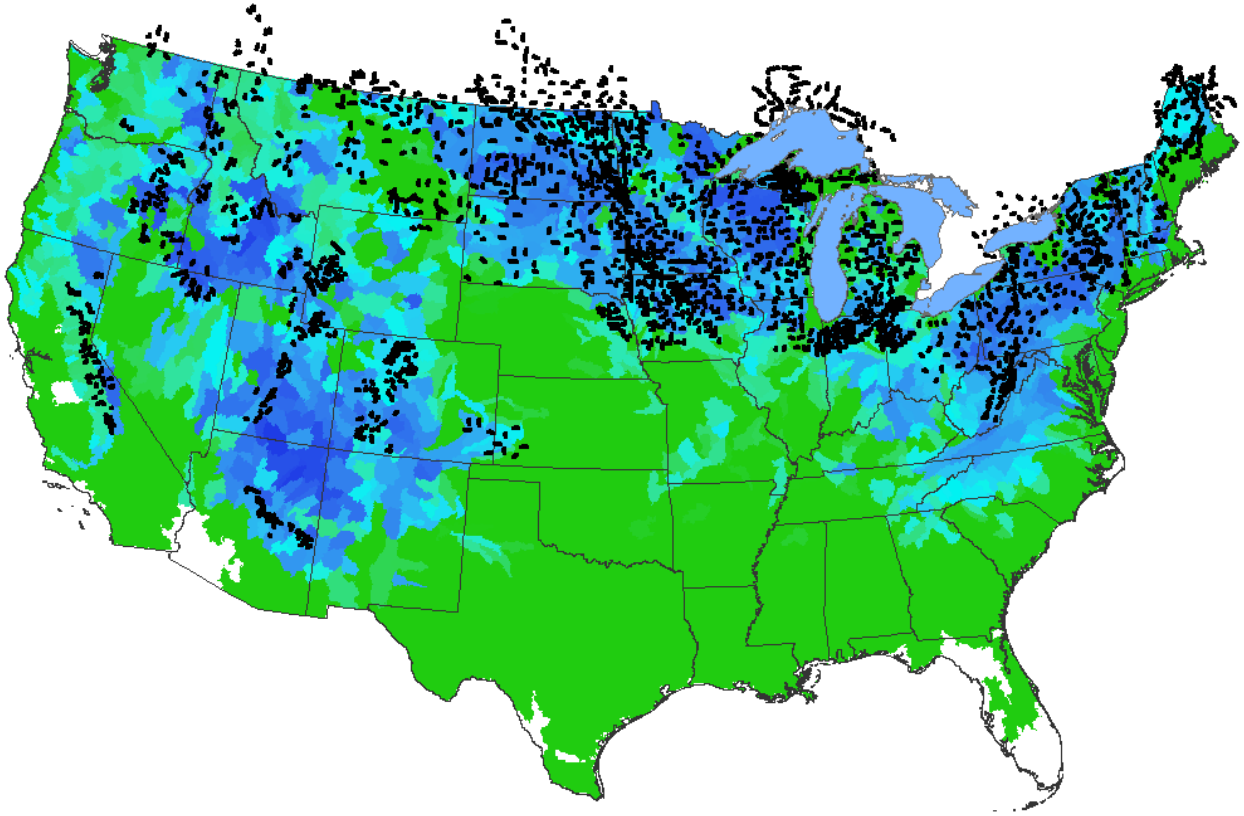


SNODAS - SSM/I



- Comparison of weekly time series show good agreement even in regions where passive microwave data does not capture the magnitude of SWE
- Regional Analyses:
  - Great Plains region, differences between SNODAS and passive microwave
  - New England, differences in passive microwave algorithms

Differences in Central Plains



SNODAS – AMSR-E Nash-Sutcliffe results overlaid with NOHRSC gamma flight lines

- Lack of observations in the Central Plains region is a likely reason for the differences between the SNODAS data and the passive microwave
- Significant interest in Plains snow due to recent snowmelt driven flood events.

Great Plains Regional Analysis

Objective: Evaluate SWE estimates from the 3 datasets (SNODAS, AMSR-E and SSM/I) through water budget analysis in selected Great Plains basins.

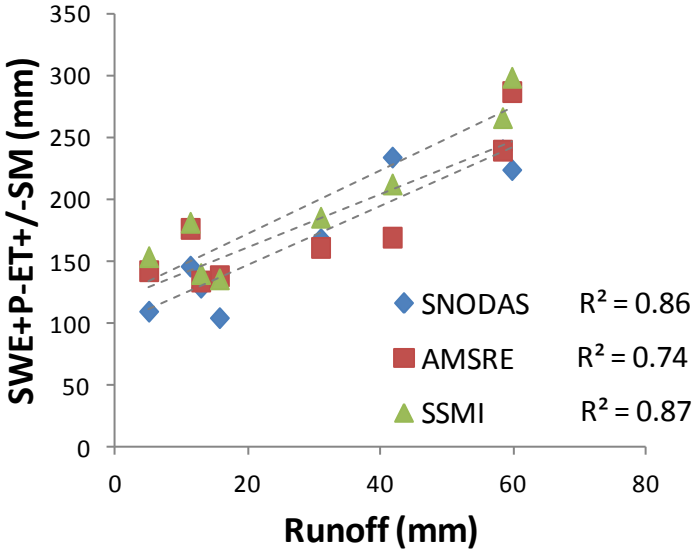
Basin Selection:

- Half of basins within the northern plains region of good agreement, and half in Central Plains region of disagreement between SNODAS and passive microwave.

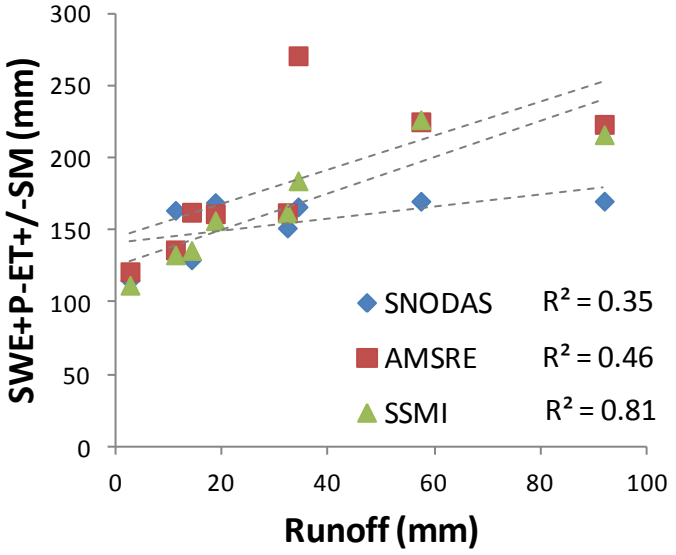
1. Sheyenne River near Cooperstown, ND
2. Cannonball River at Breien, ND
3. Moreau River near Whitehorse, SD
4. Bad River near Ft. Pierre, SD
5. Cheyenne River at Spencer, WY
6. White River near Interior, SD
7. White River near Oacoma, SD
8. Ponca Creek near Verdel, NE
9. South Loup River at St. Michael, NE

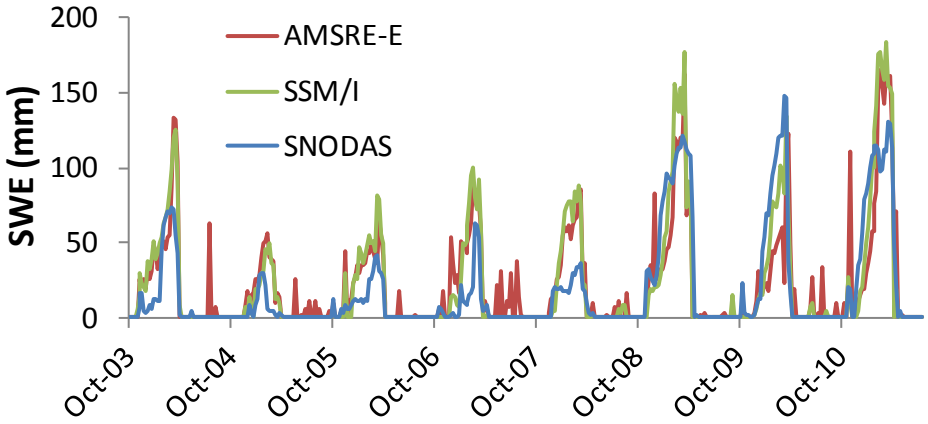
Example Results

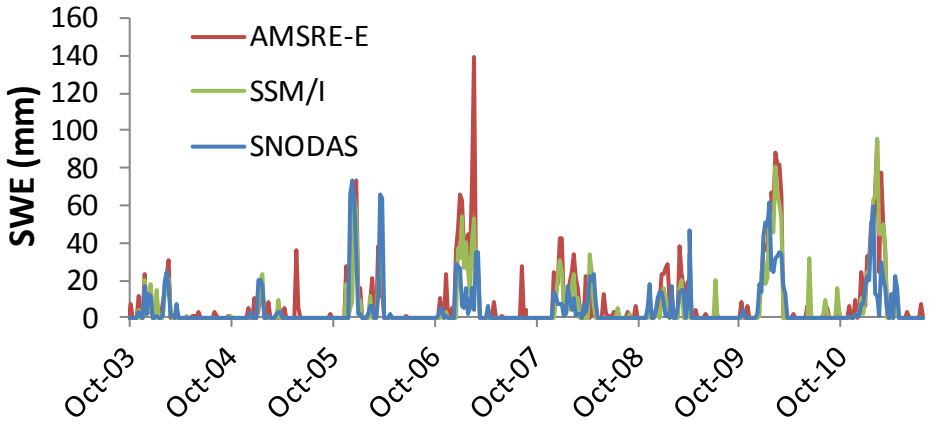
Sheyenne River at Cooperstown, ND



Ponca Creek at Verdel, NE







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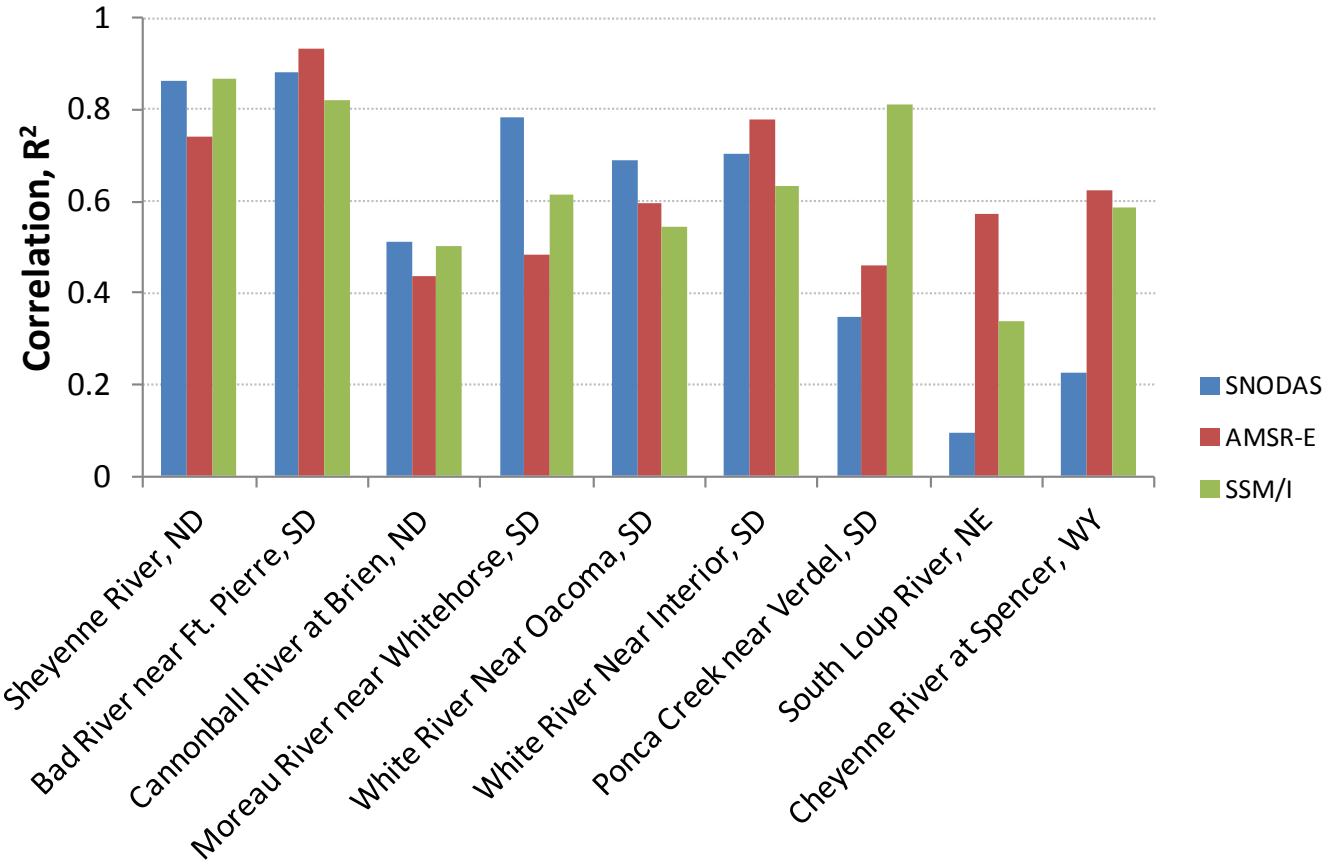
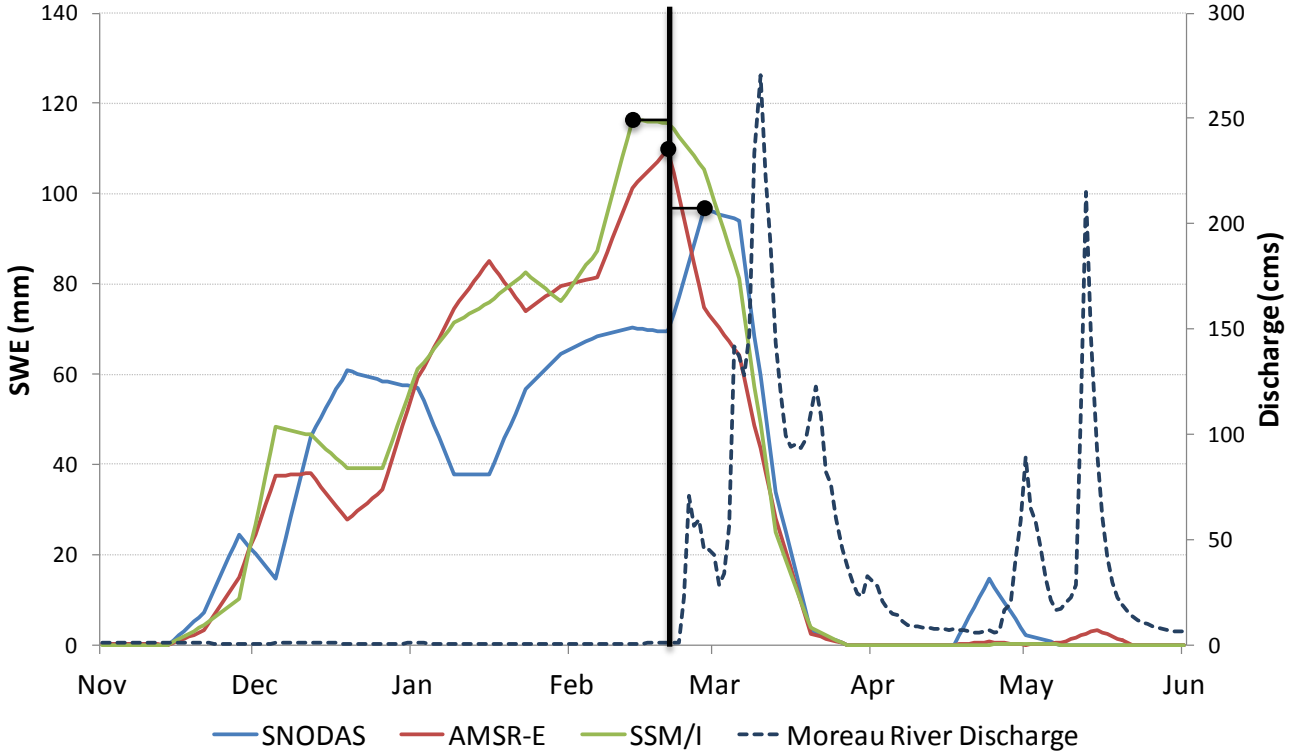
Results


Correlation, R²
1
0.8
0.6
0.4
0.2
0
Sheyenne River, ND
Bad River near Ft. Pierre, SD
Cannonball River at Brien, ND
Moreau River near Whitehorse, SD
White River Near Oacoma, SD
White River Near Interior, SD
Ponca Creek near Verdel, SD
South Loup River, NE
Cheyenne River at Spencer, WY
SNODAS
AMSR-E
SSM/I

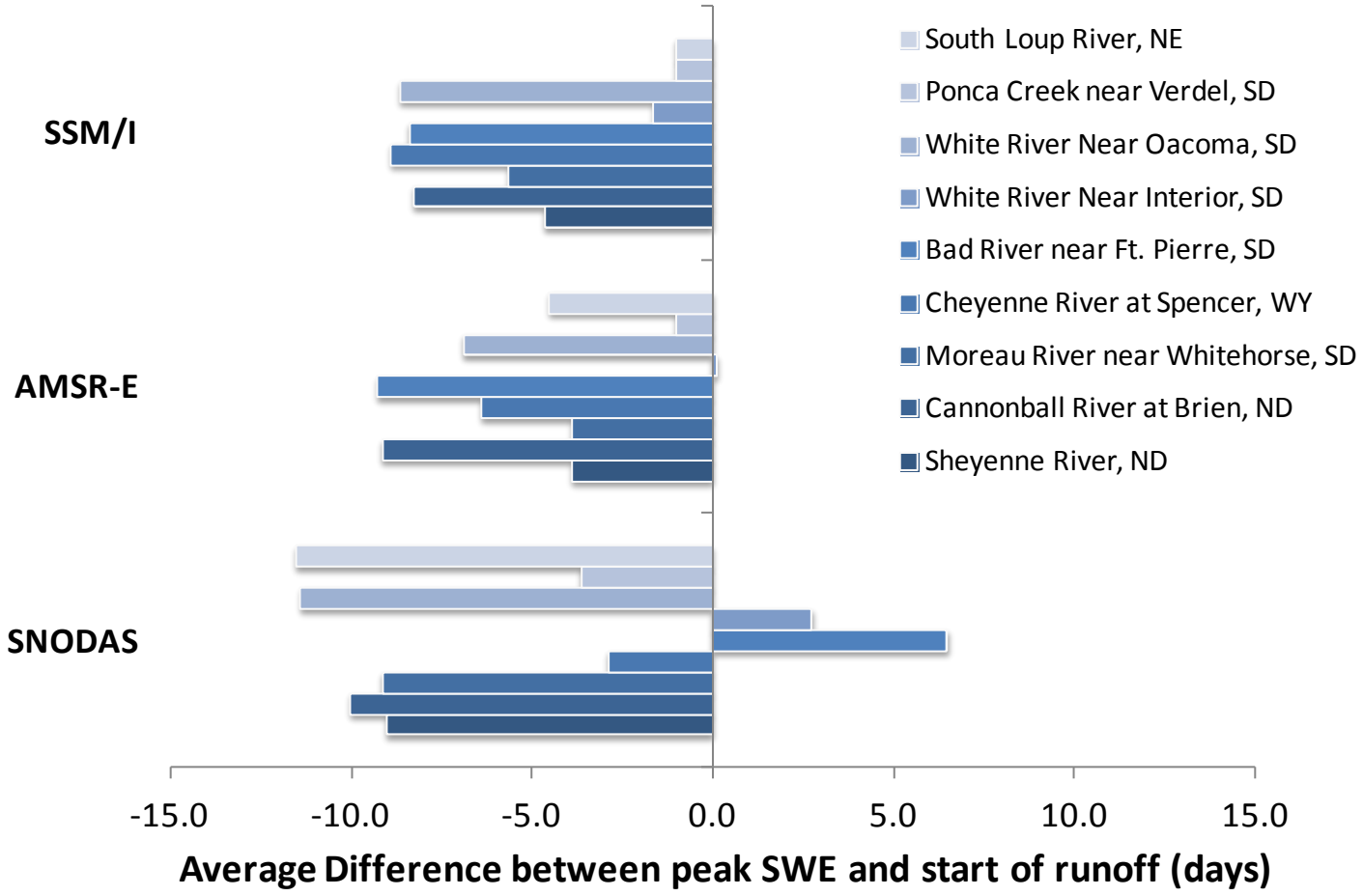
Timing of snowmelt



Winter snowpack and spring runoff for the 2008-09 water year in the Moreau River basin, SD.

Timing of Spring runoff typically corresponds to onset of snowmelt.
Method: calculated timing difference between start of spring runoff and peak SWE

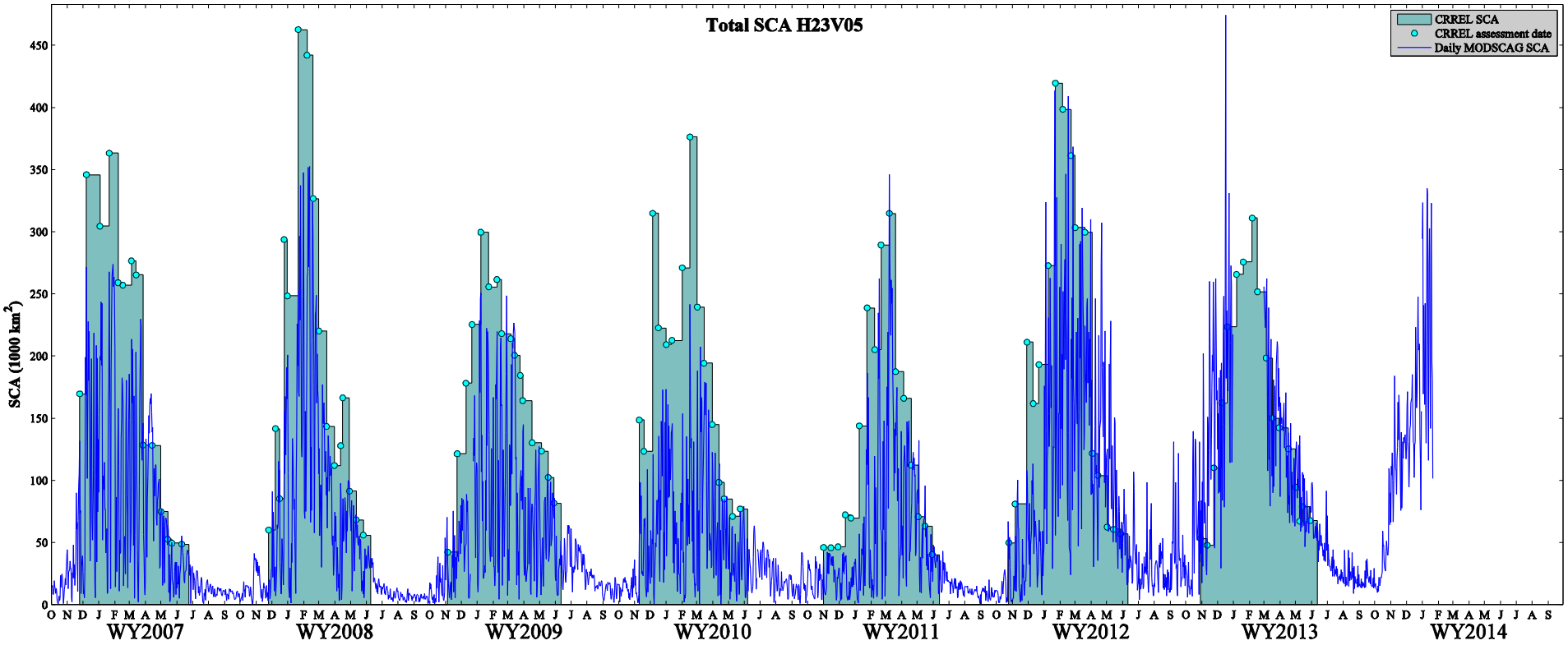
Results


SSM/I
AMSR-E
SNODAS
South Loup River, NE
Ponca Creek near Verdel, SD
White River Near Oacoma, SD
White River Near Interior, SD
Bad River near Ft. Pierre, SD
Cheyenne River at Spencer, WY
Moreau River near Whitehorse, SD
Cannonball River at Brien, ND
Sheyenne River, ND
-15.0
-10.0
-5.0
0.0
5.0
10.0
15.0
Average Difference between peak SWE and start of runoff (days)

Great Plains Snow Extent Analysis

Objective: Compare basin SWE estimates to total basin SE during melt period

Method: Produce daily cloud-free snow extent image and calculate total SE over each basin



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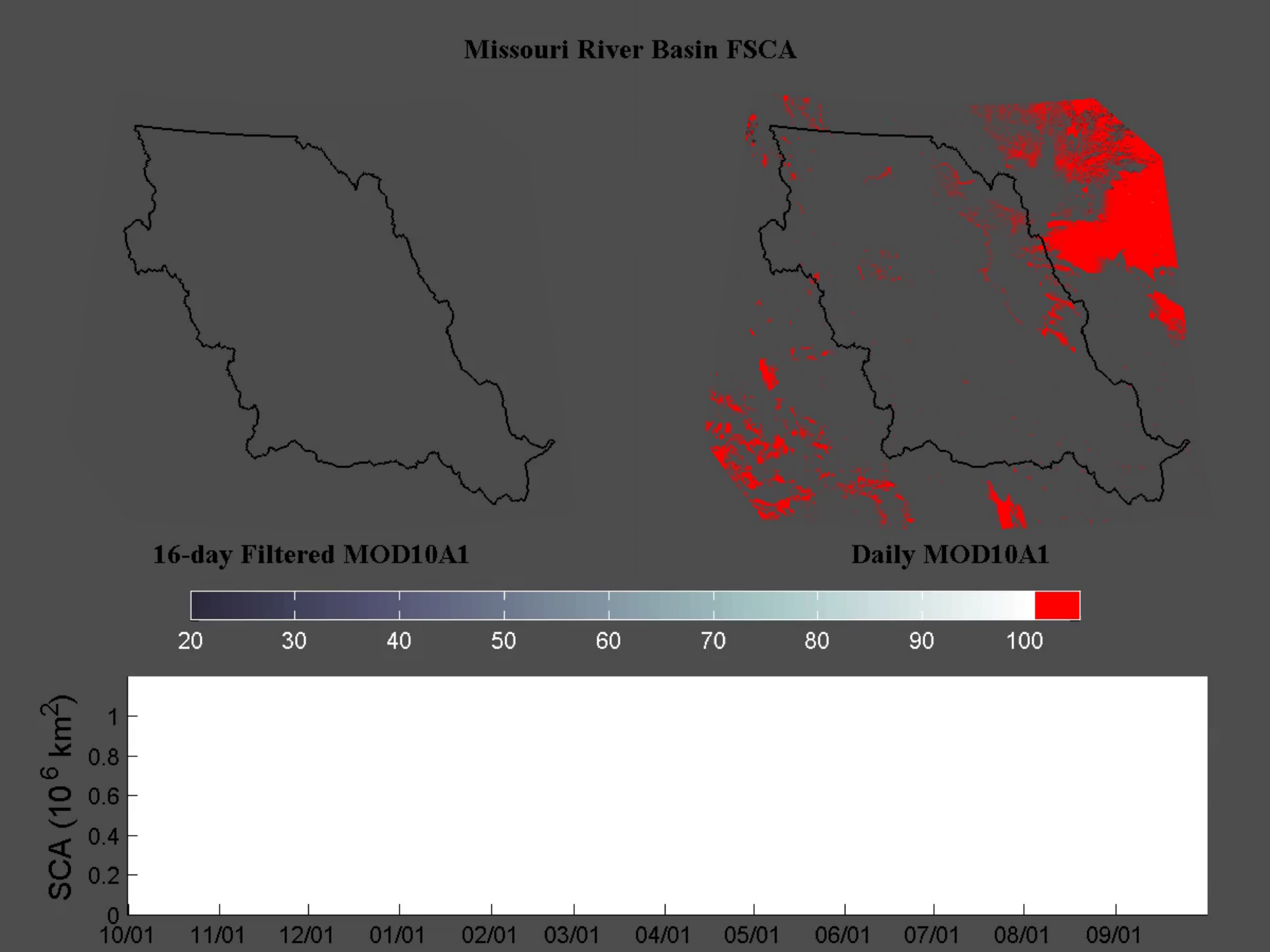
Our Solution

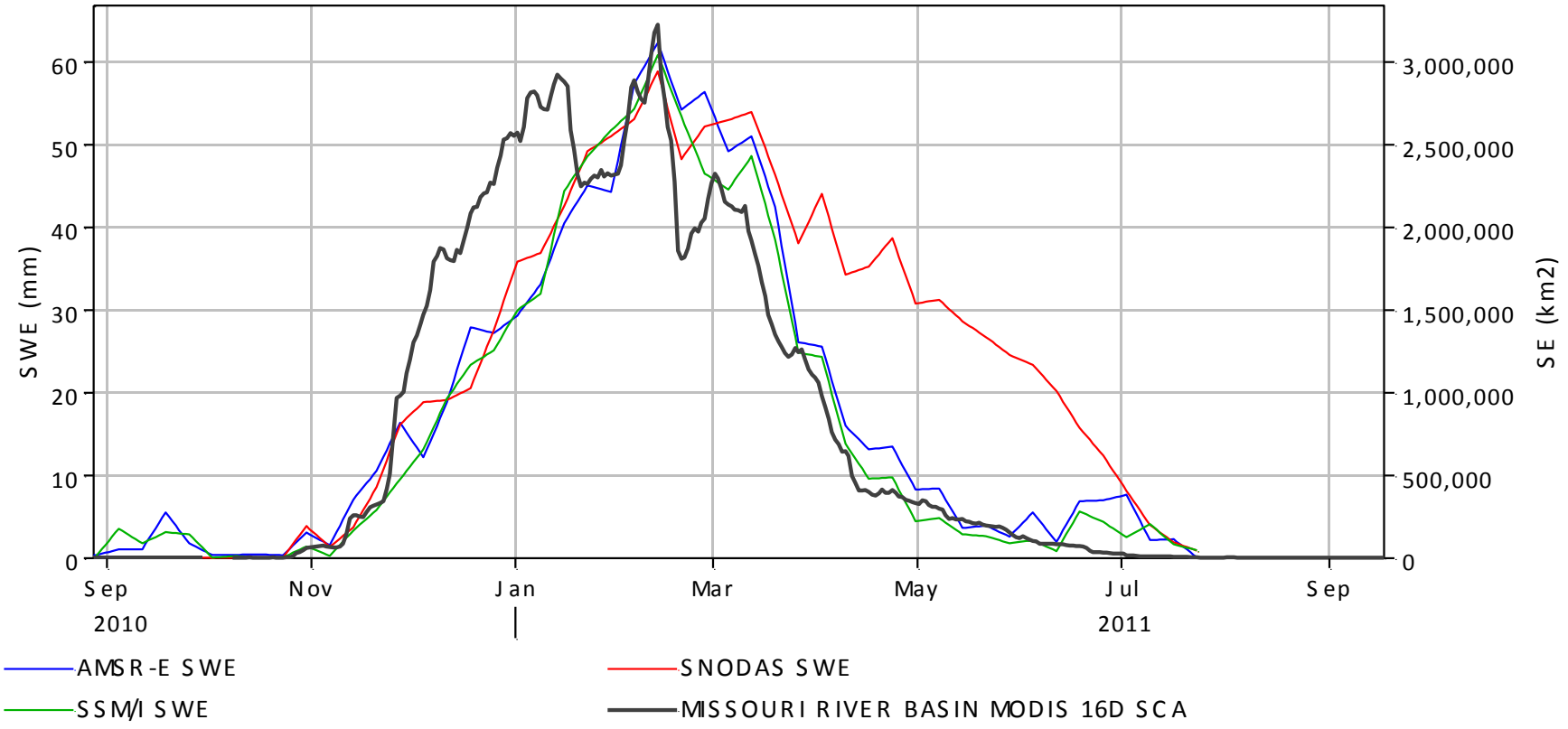
- Use **16 days** of SCA data (1 scene per day) and exclude FSC < 20%

- Evaluate SCA on a per-pixel basis using only cloud-free pixels
  - If the **two most recent** values are snow, output **snow**
  - If either is no snow, output **no snow**
  - If there are no cloud-free days, output **cloud**

- Mask output based on historical SCA and surface water


Missouri River Basin FSCA
16-day Filtered MOD10A1
Daily MOD10A1
20
30
40
50
60
70
80
90
100
SCA (10^6 km^2)
0
0.2
0.4
0.6
0.8
1
10/01
11/01
12/01
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01

Great Plains Snow Extent Analysis

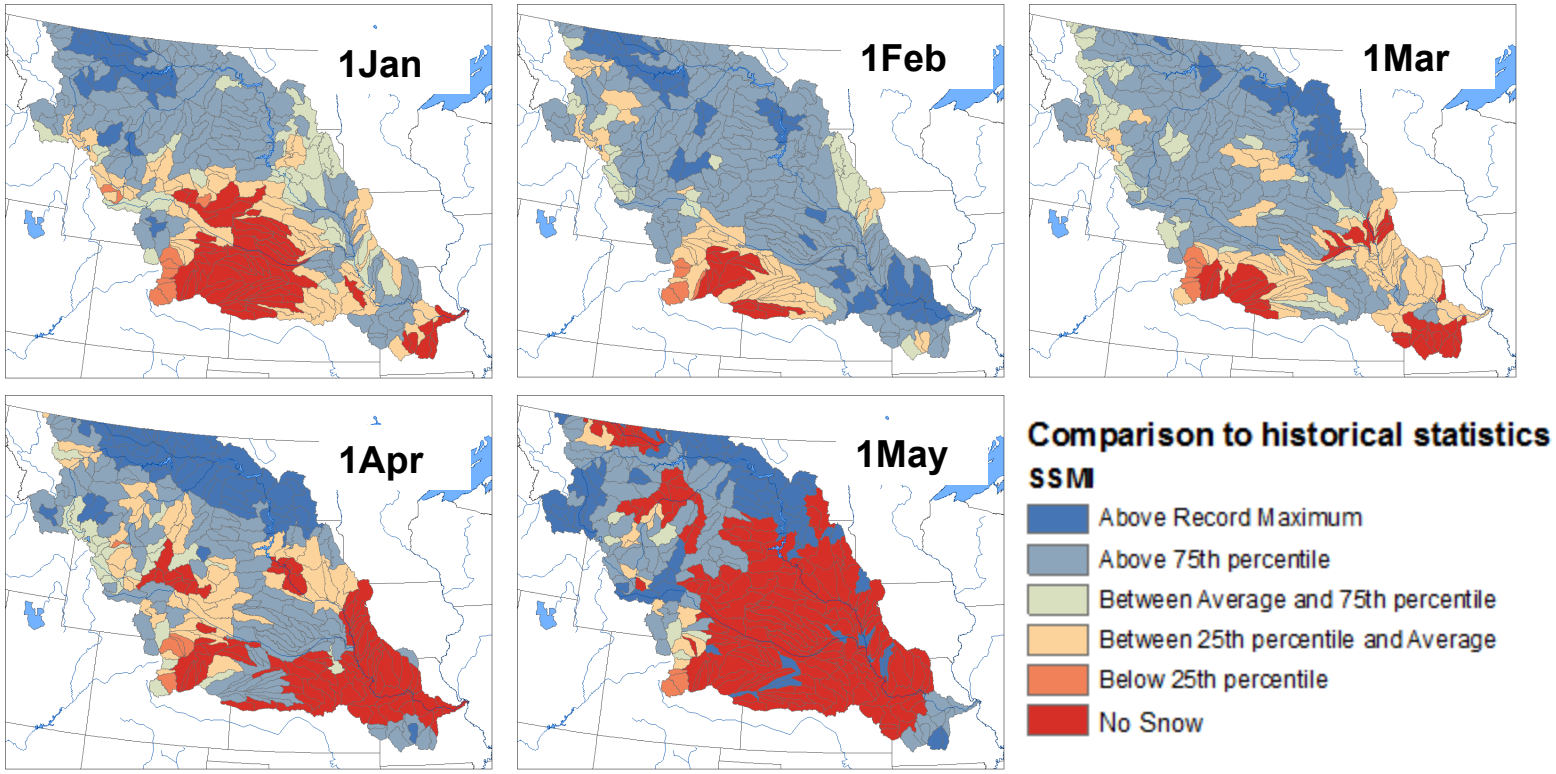


Great Plains Snow Extent Analysis

Basin	AMSR-E	SSM/I	SNODAS
Sheyenne River near Cooperstown, ND	0.69	0.74	0.55
Cannonball River at Breien, ND	0.58	0.59	0.61
Moreau River near Whitehorse, SD	0.36	0.36	0.25
Bad River near Ft. Pierre, SD	0.38	0.46	0.25
Cheyenne River at Spencer, WY	0.24	0.28	0.06
White River near Interior, SD	0.50	0.56	0.36
White River near Oacoma, SD	0.29	0.35	0.11
Ponca Creek near Verdel, NE	0.24	0.34	0.26
South Loup River at St. Michael, NE	0.33	0.46	0.25
Entire Missouri River Basin	**0.79**	**0.73**	**0.48**

R^2, total basin SWE and SE during melt period, 2004-2011.

2011 Missouri River Flood



SSM/I SWE on 1st of each month in 2011, compared to historical statistics, 1987-2010.