Satellite Enhanced Snowmelt Flood Forecasting in the Red River of the North

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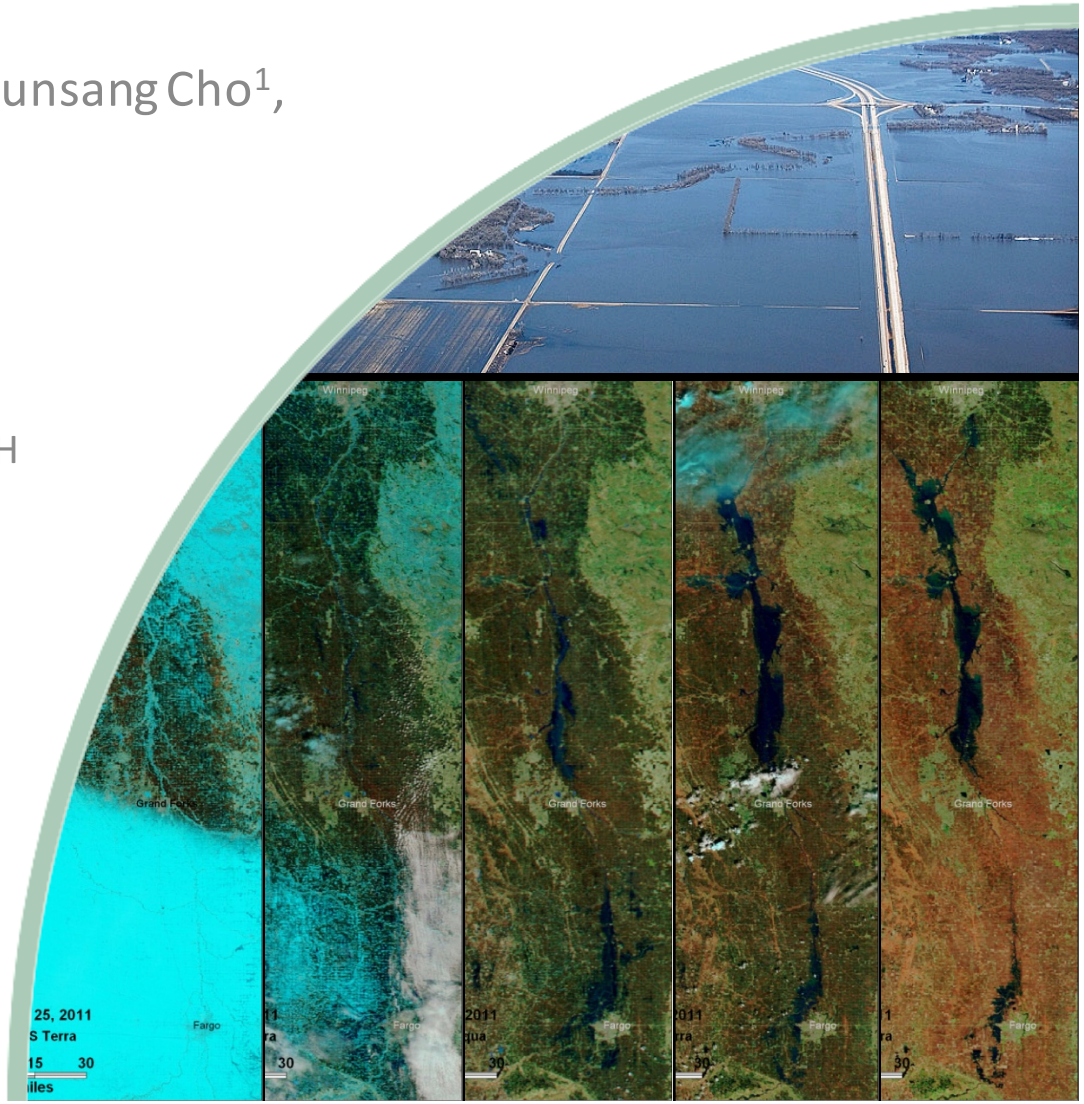

NASA Applied Sciences
Water Resources Team Meeting
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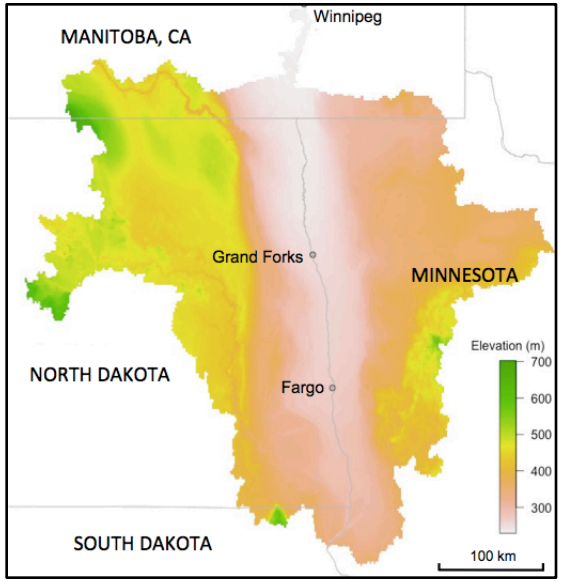
University of New Hampshire

Red River Basin



- Red River Basin (RRB) experiences frequent floods, largely related to annual spring snowmelt
- In recent decades, flood peaks have been increasing

River Discharge at Fargo, ND

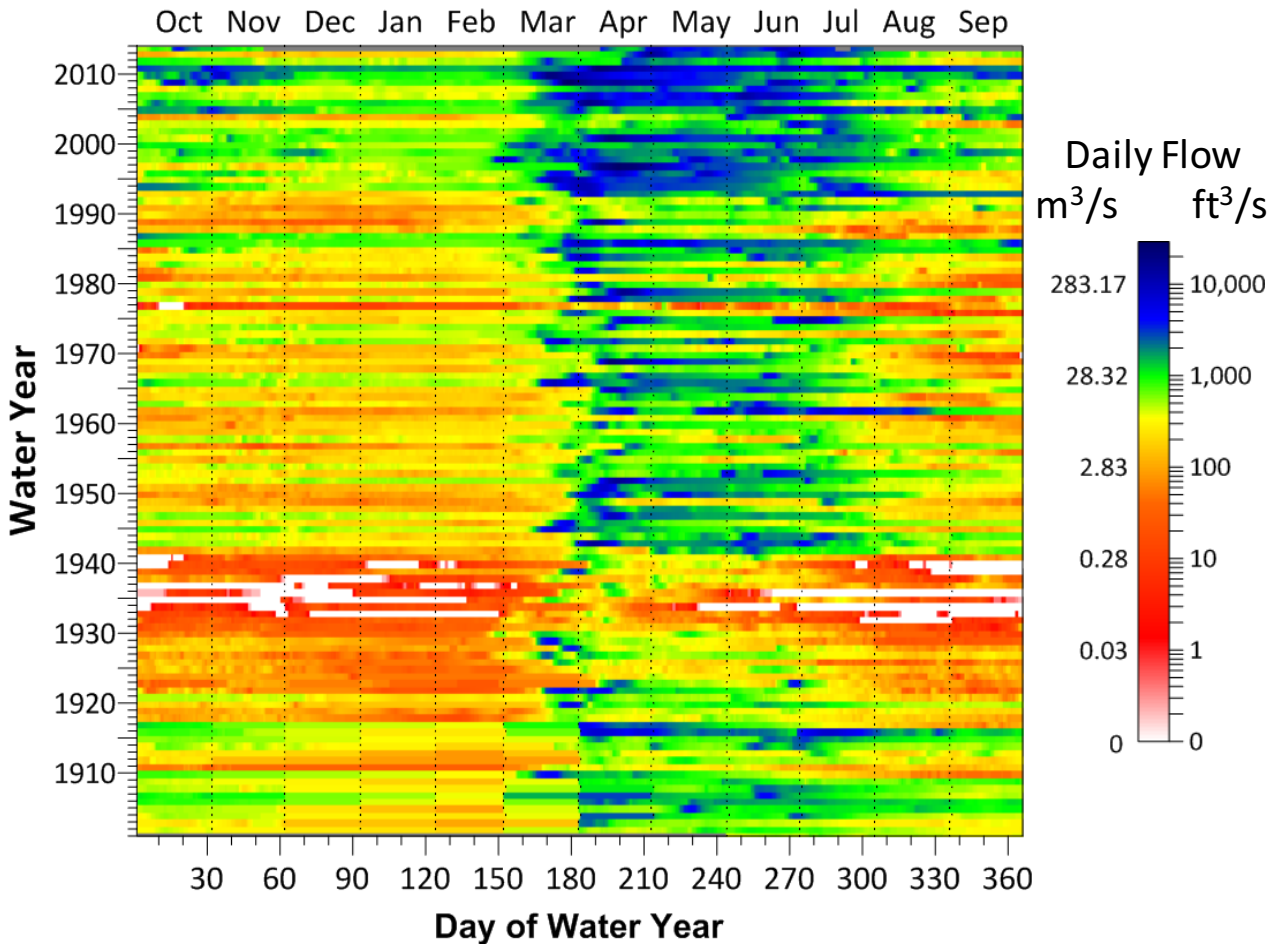
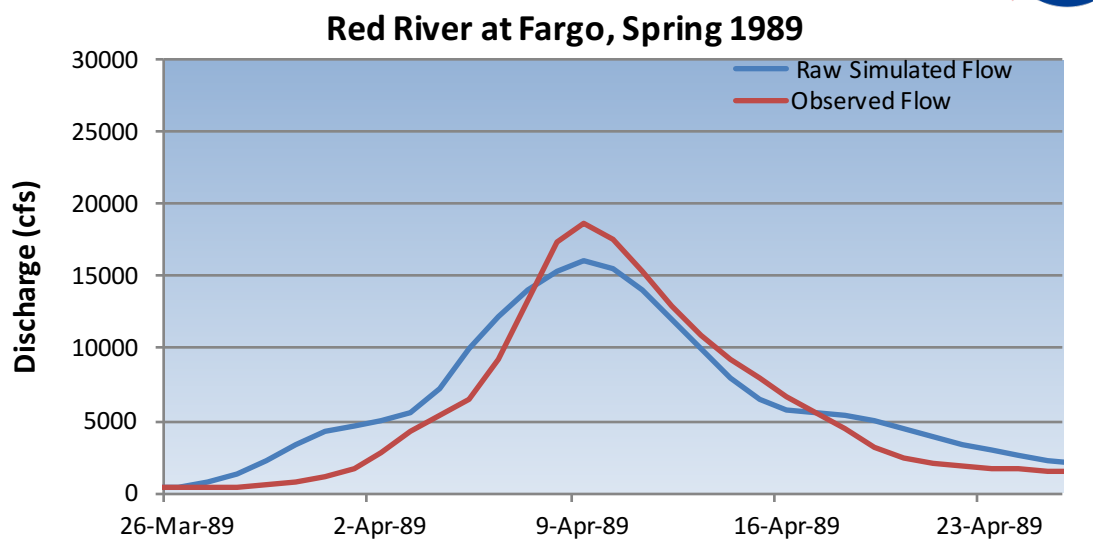


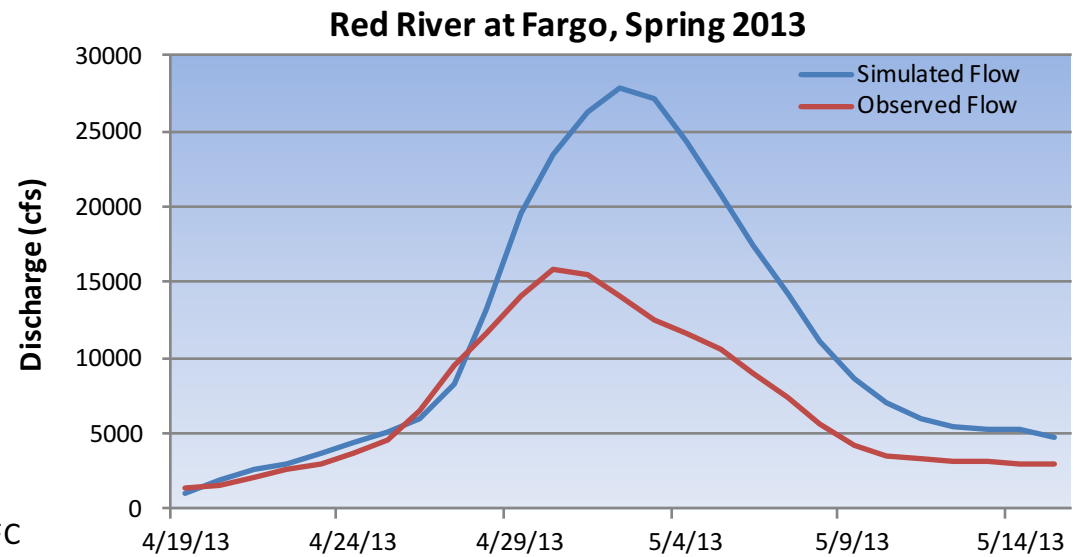
Figure courtesy of Richard Koehler, NOAA NWS

See also: R. M. Hirsch & K. R. Ryberg (2011): "Has the magnitude of floods across the USA changed with global CO2 levels?", Hydrological Sciences Journal, DOI:10.1080/02626667.2011.621895

Flood Forecasting Challenges

- Lack of snow depth and snow equivalent water measurements
- Sparse in situ soil moisture measurements of state variables compared to other regions
- Lack of understanding of snowmelt processes and soil infiltration during soil freeze and thaw





Figures courtesy of Pedro Restrepo, NOAA NCRFC

Project Objective:

Enhance the NOAA National Weather Service (NWS) North Central River Forecast Center's (NCRFC) snowmelt flood prediction capacity in the RRB using remote sensing estimates to constrain snowmelt flood drivers (especially snow and soil moisture)

Primary Stakeholder: NCRFC

Data Sources

Product	Instrument/Source	Platform/Agency	Spatial Resolution	Temporal Resolution
SWE	SSM/I & SSMIS	DMSP	25 km	Twice daily
SWE	AMSR-E	Aqua	25 km	Twice daily
SWE	AMSR-2	GCOM-W1	25 km	Twice daily
SCA	MODIS	Terra/Aqua	500 m	Daily
SWE/snow depth	SNODAS Model	NOHRSC	1 km	Daily
SWE/snow depth	Ground Observations	NDSU, USACE, SCAN, NWS, CoCoRaHS,	Point	Varies
SWE	Gamma Radiation Surveys	NOHRSC	~ 2 mi^2	Varies
Soil Moisture	AMSR-E	Aqua	25 km	Twice daily
Soil Moisture	AMSR-2	GCOM-W1	25 km	Twice daily
Soil Moisture	SMOS	Proteus	~25 km	2-3 day
Soil Moisture	SMAP	SMAP	36 km	2-3-day
Soil Moisture	ECV	ESA CCI	25 km	Daily
Freeze/Thaw	SMAP	SMAP	36 km	2-3-day

Primary Drivers of Spring Snowmelt Flooding in the Red River Basin

1. Snowpack (quantity and coverage)

   SSM/I, AMSR-E, AMSR2, MODIS

2. Antecedent soil moisture content

   SMAP, SMOS, AMSR2, AMSR-E, ECV

3. Soil freeze/thaw state (infiltration vs. runoff)

   SMAP

4. Melt onset timing

   SSM/I, AMSR-E, AMSR2, MODIS

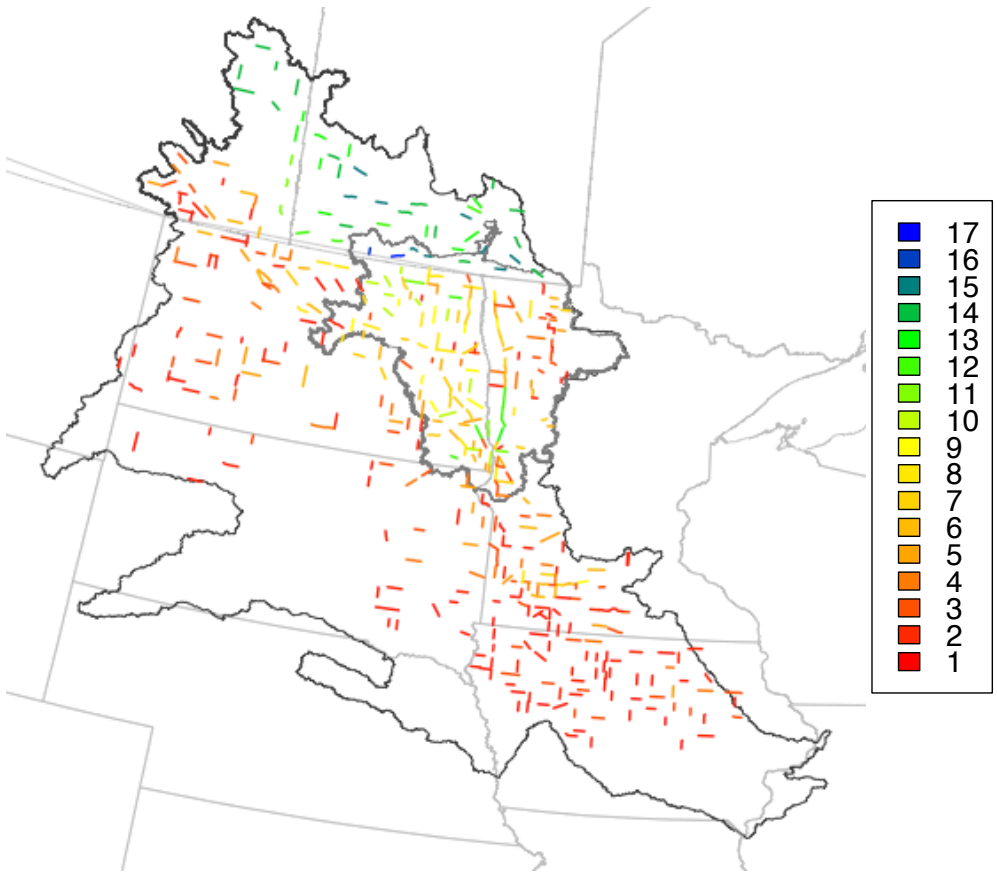
5. Spatial distribution of melting

   MODIS

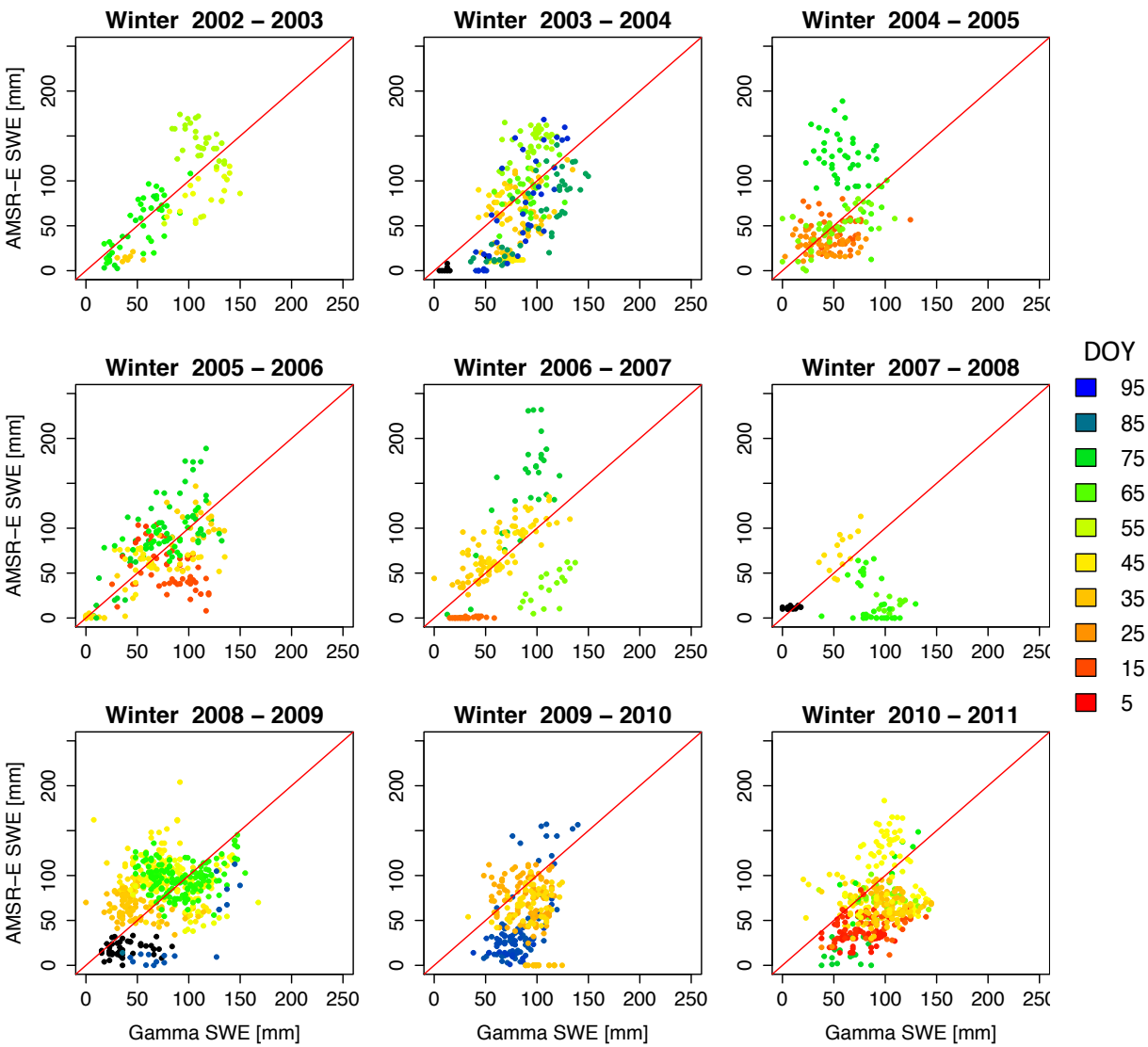
Retrospective: Evaluation of Passive Microwave SWE using NOAA NOHRSC Airborne Gamma Radiation SWE

- Each flight line approx. 16 km long, 300 m wide (150 m alt.)
- Natural terrestrial gamma radiation emitted by radioisotopes in soil (~0-20 cm depth)
- Water mass (any phase) blocks the signal
- Difference between radiation detected over bare ground (fall) and over snow (winter) allows SWE estimation

Number of Observations per Flight Line:
Fall 2002-Fall 2011



Comparison of Airborne Gamma and AMSR-E SWE

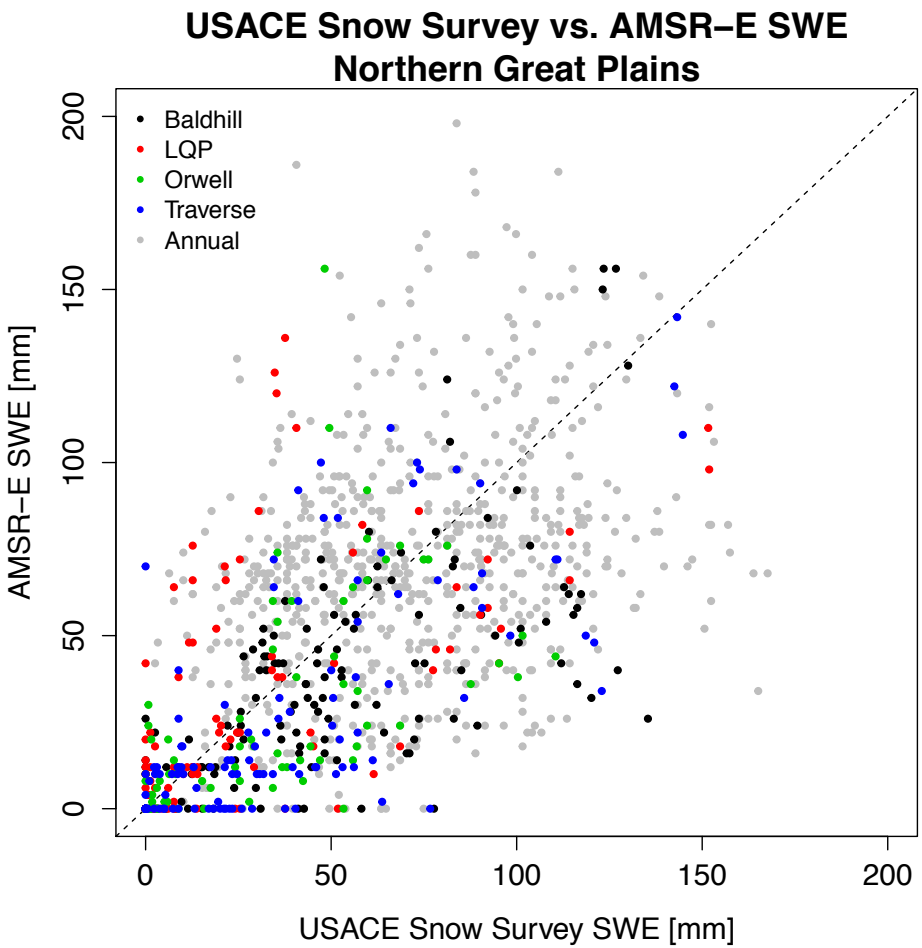


- Weighted average AMSR-E SWE found for each gamma flight line

RMSE	41.9 mm
R^2	0.14
Mean Difference	-9.4 mm
% Difference	-12.1 %

- AMSR-E SWE increases with DOY beyond what would be expected, given gamma SWE
  - Grain size/density effect?
- Low AMSR-E values
  - Likely liquid water microwave absorption
- Changes in soil water

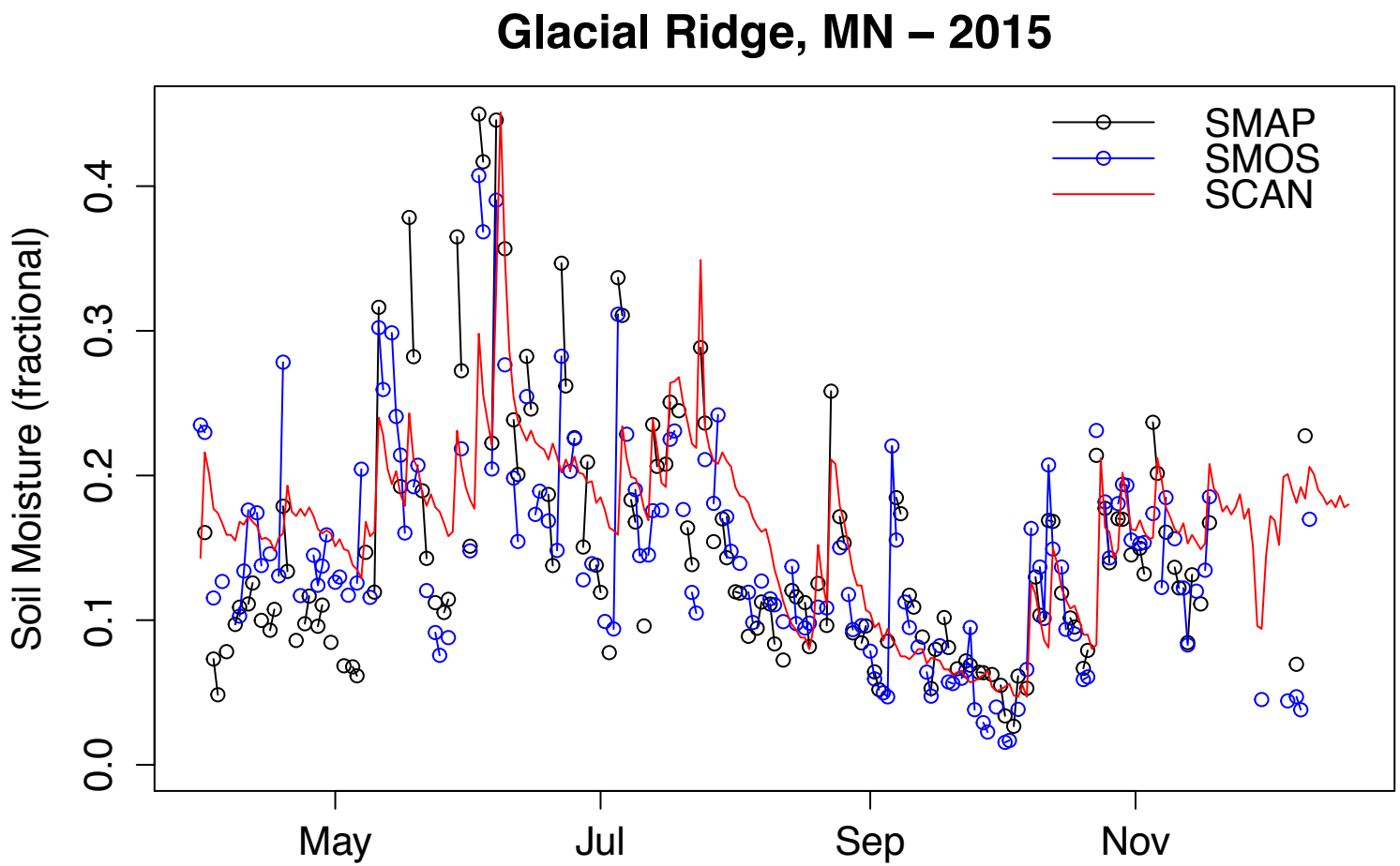
Retrospective: Evaluation of AMSR-E SWE using USACE Ground Survey SWE



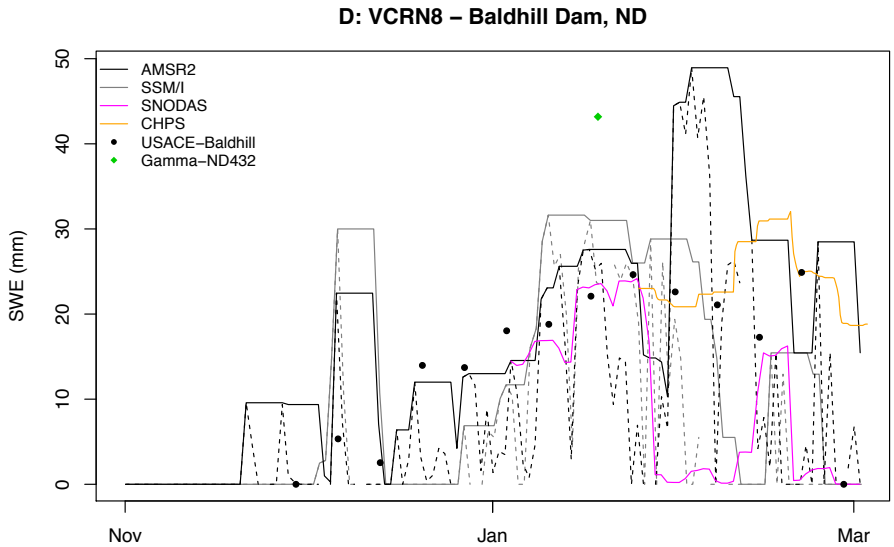
RMSE	34.7 mm
R^2	0.36
Mean Difference	-3.8 mm
% Difference	-6.6 %

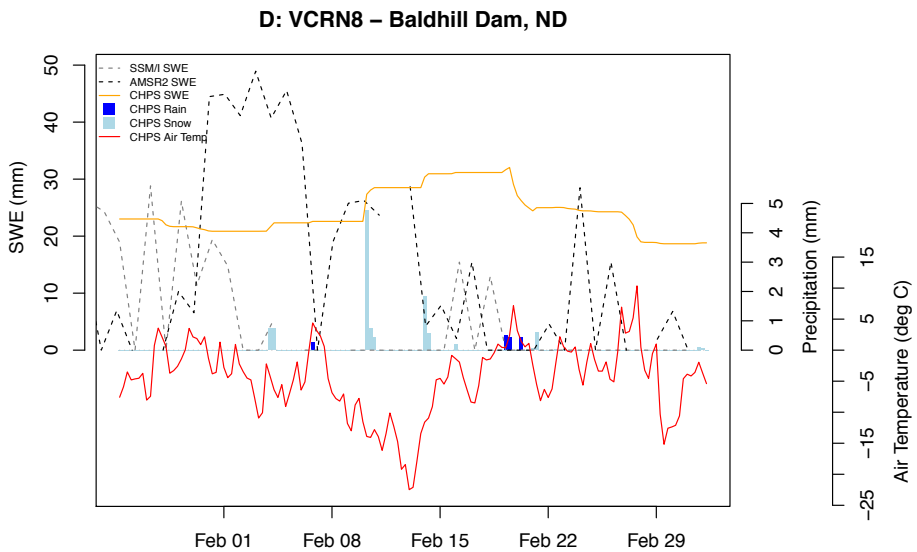
- Large variance but low bias
  - Scale mismatch between point data and 25 km resolution pixels

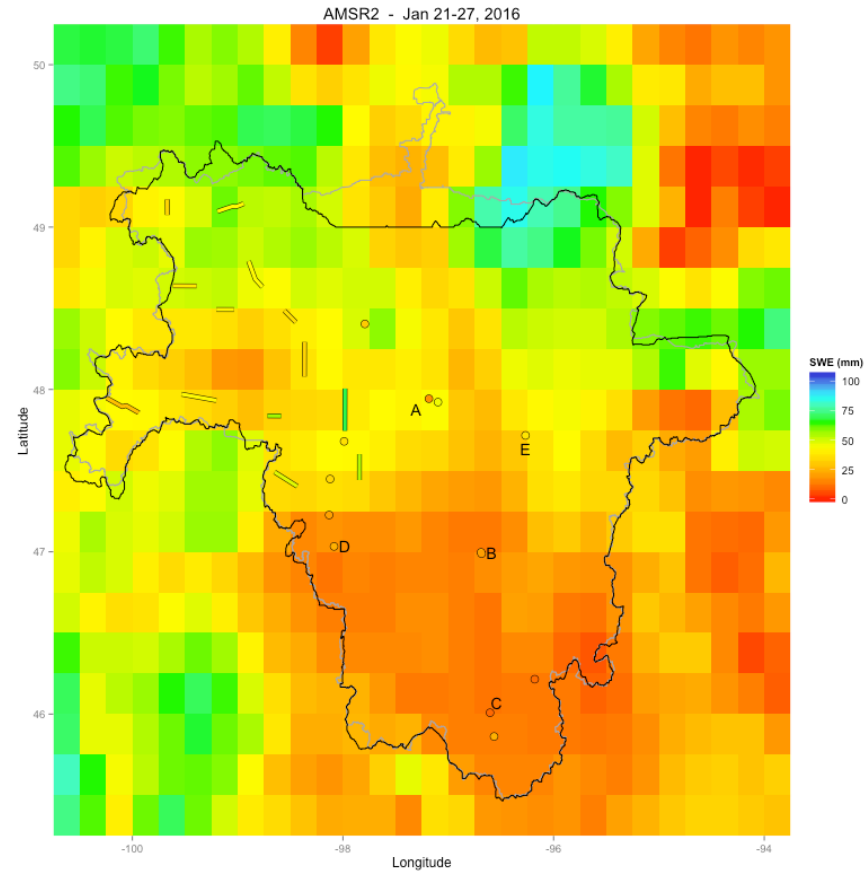
Winter 2015/16: Antecedent Moisture



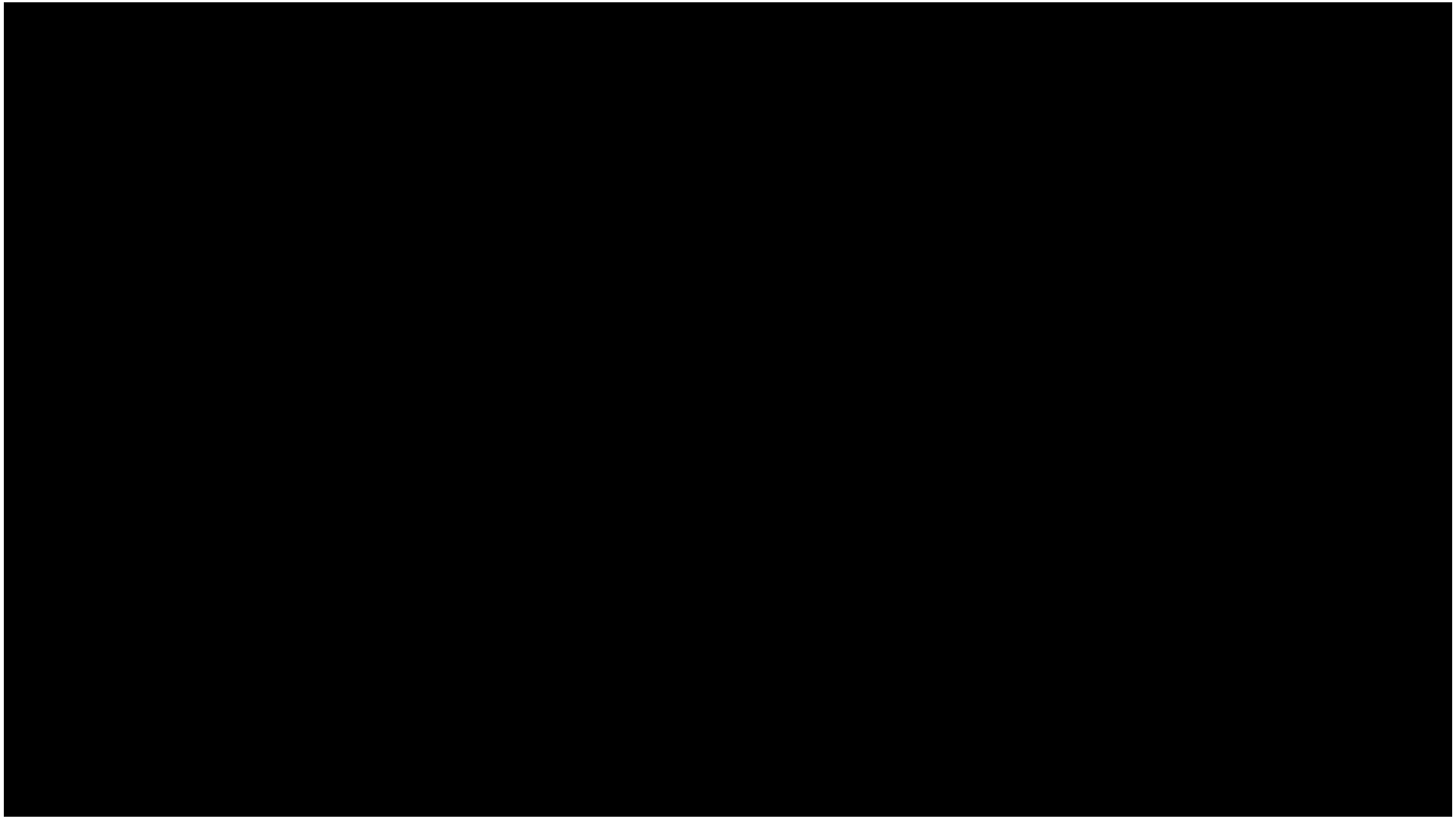
Winter 2015/16: Weekly Snow Products







Rainfall/Melt Effect on Satellite SWE

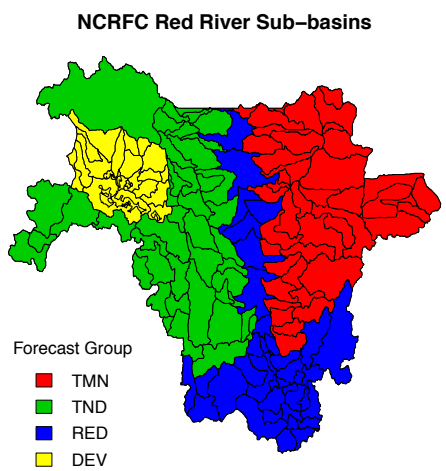


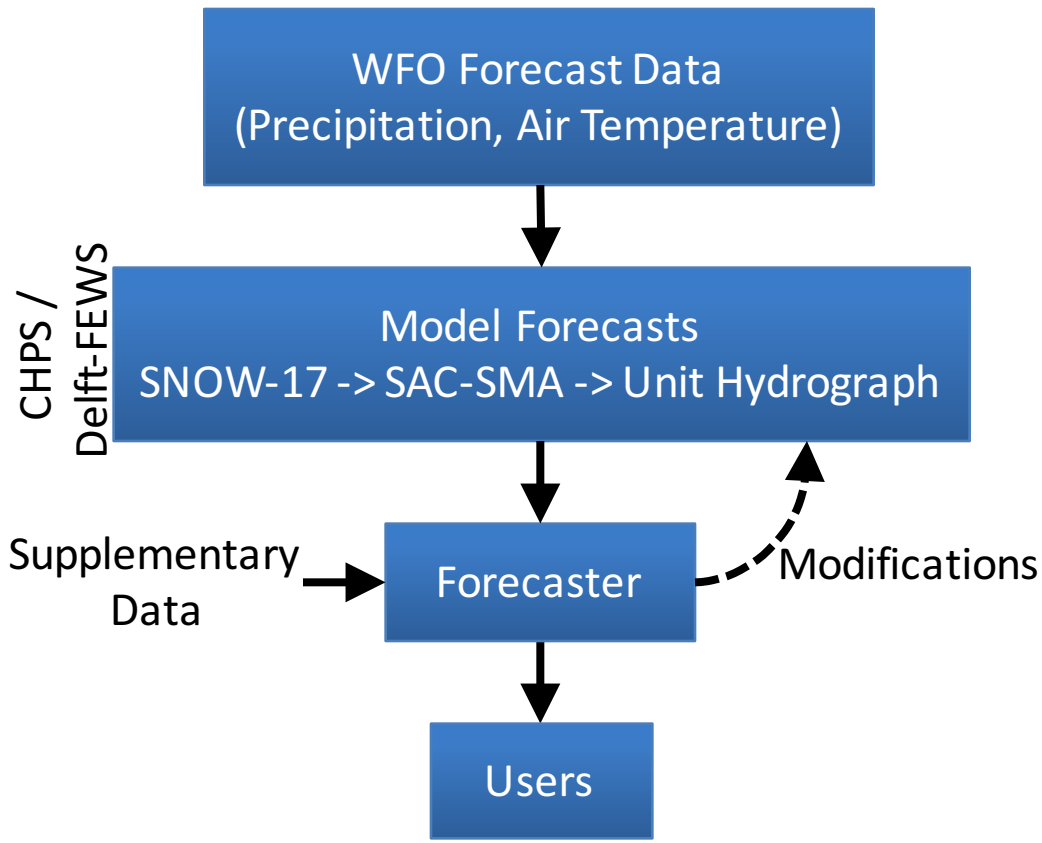
Moving Forward: Collaboration

- Currently, 3 NASA-funded projects studying RRB using remote sensing
  - Surface water ponding (Andy Wood, NCAR)
  - GRACE + LSM (Matt Rodell, NASA GSFC)
  - SWE & Soil Moisture (Jennifer Jacobs, UNH)
- Sum of the whole likely greater than sum of the parts
  - Improve moisture partitioning estimates
- Work with Pedro Restrepo (NCRFC) to assimilate information from all 3 projects into CHPS flow forecasting system (SNOW-17 and SAC-SMA models)
  - Test at sub-basin(s) within the RRB
  - Retrospective analysis: winter 2008/9, winter 2012/13
  - Recalibrate model, compare to current

NCRFC River Flow Forecasting

- Community Hydrologic Prediction System (CHPS)
  - Lumped model (i.e. sub-basin average)
  - Operates from a "warm state"
  - Sub-basins forecasted upstream-to-downstream





Questions?

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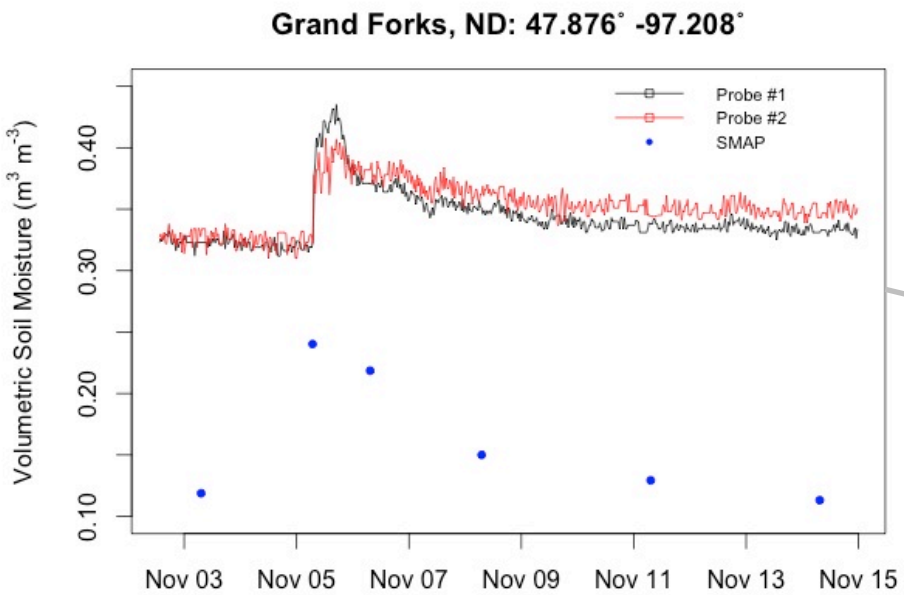
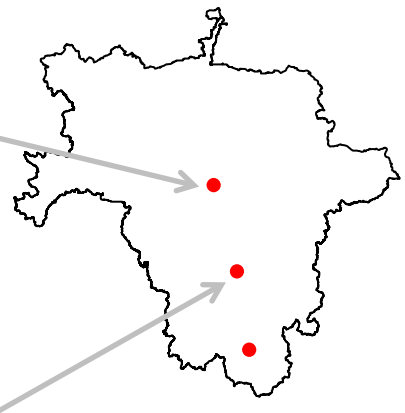
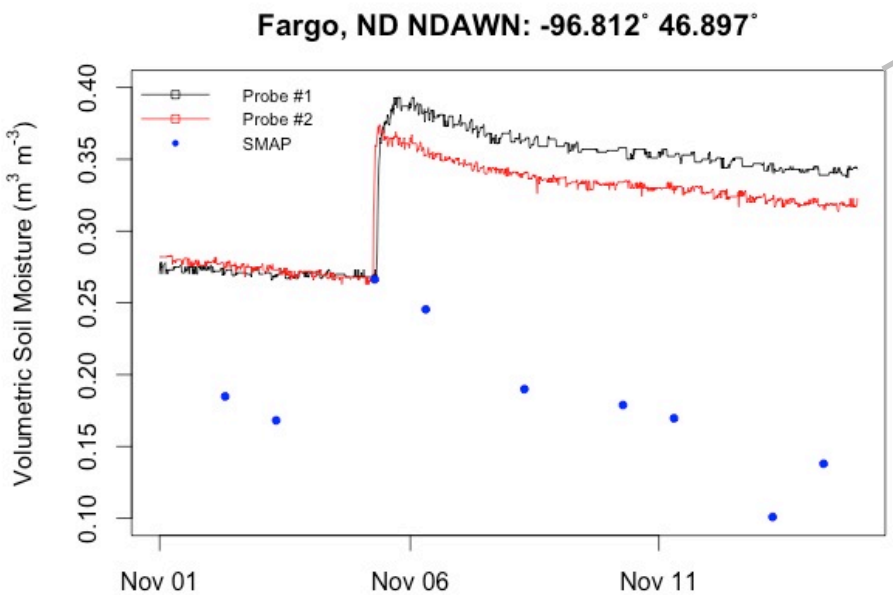
SMAP vs. In Situ Soil Moisture – Clay Soil

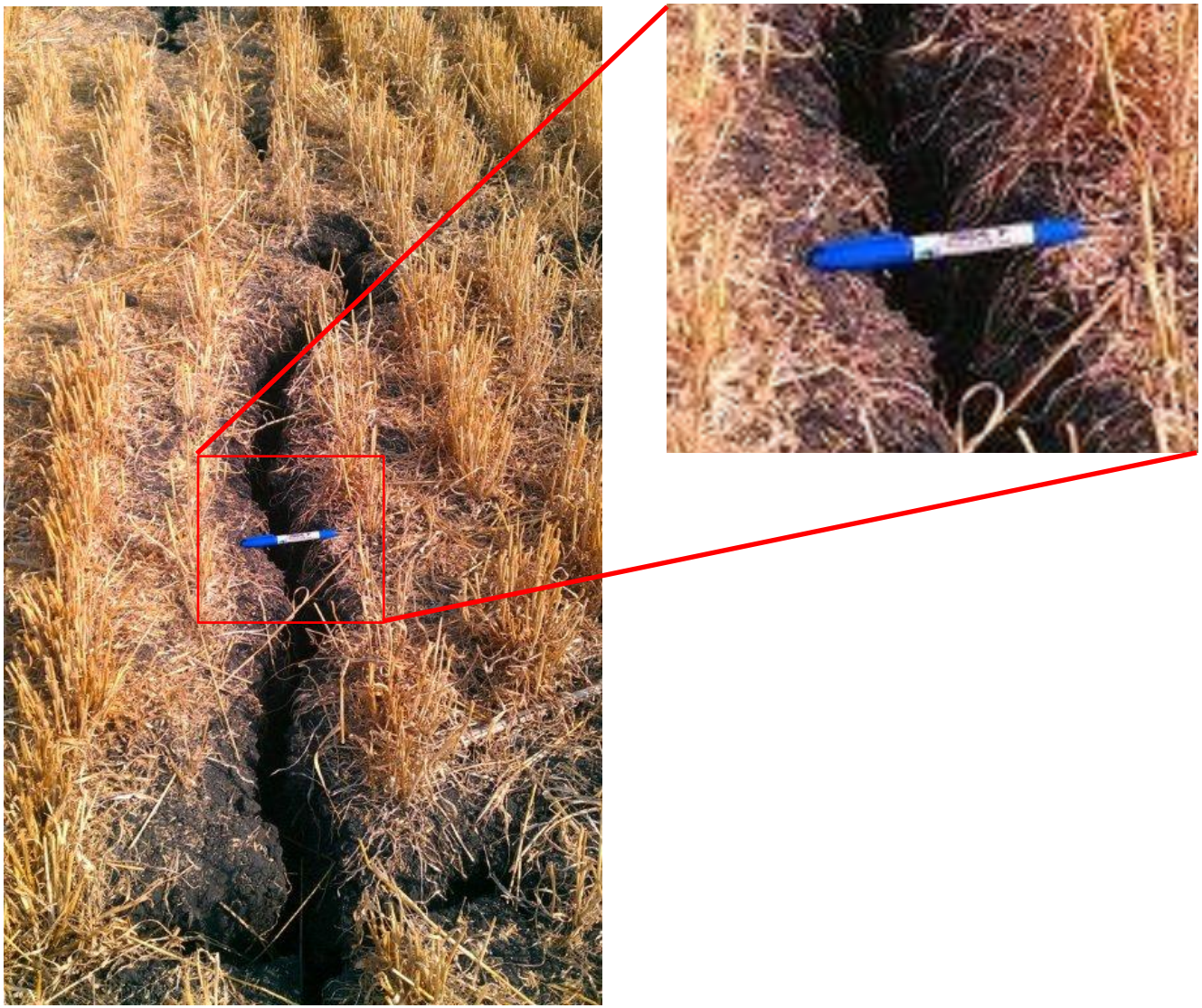




In situ soil moisture courtesy of Xinhua Jia, NDSU

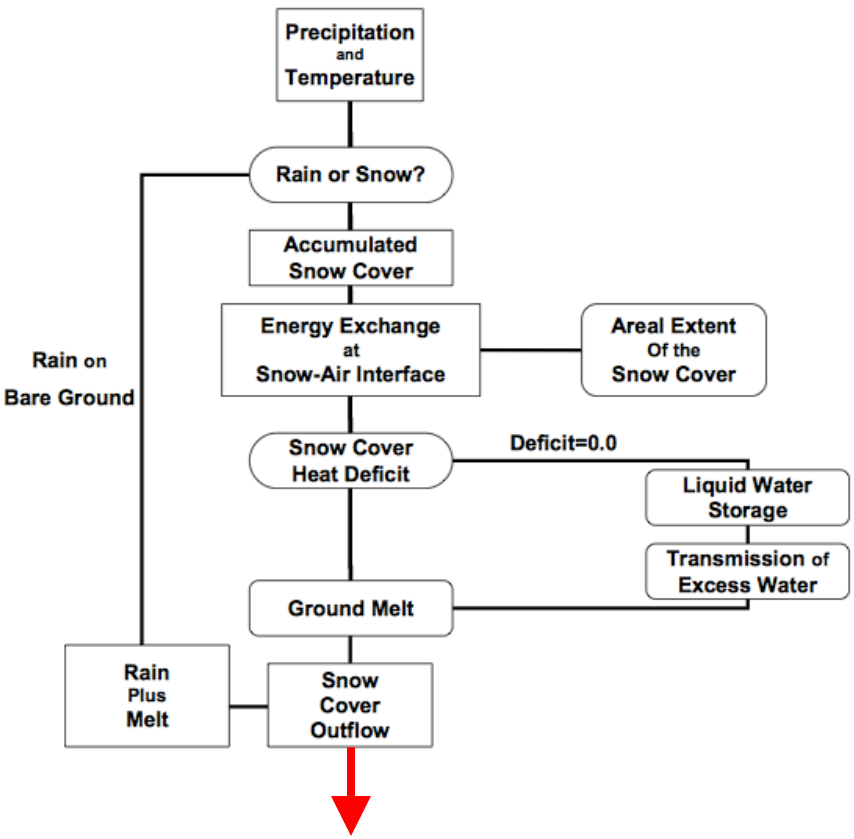


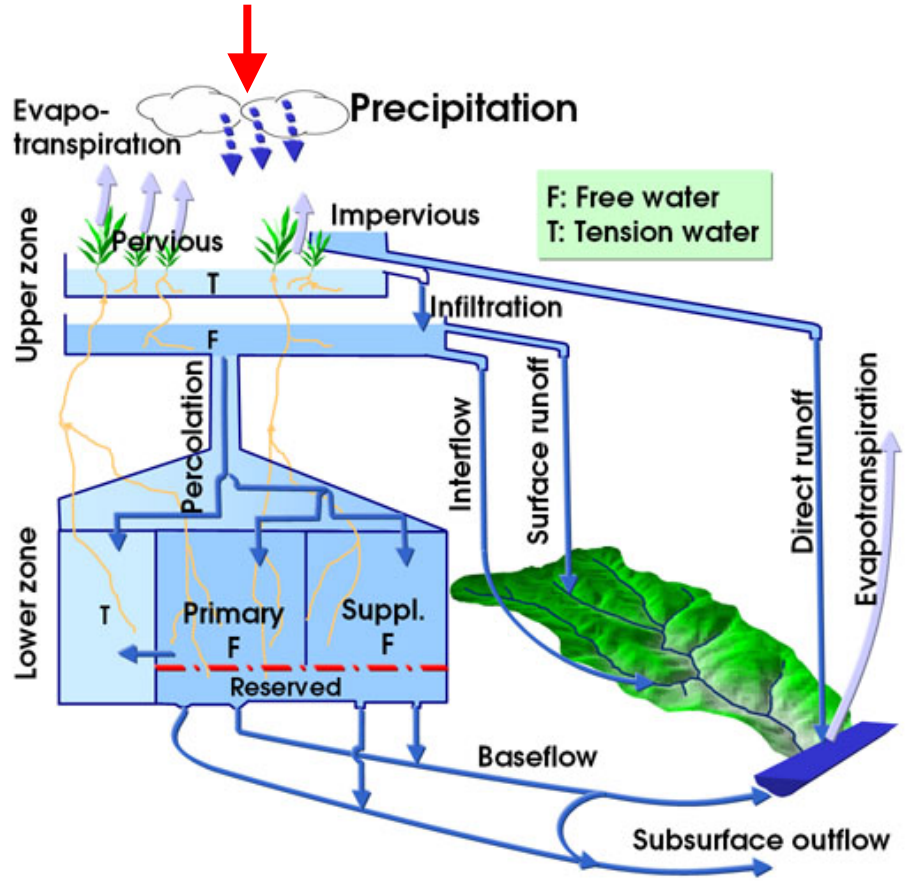
Fargo Clay Soil

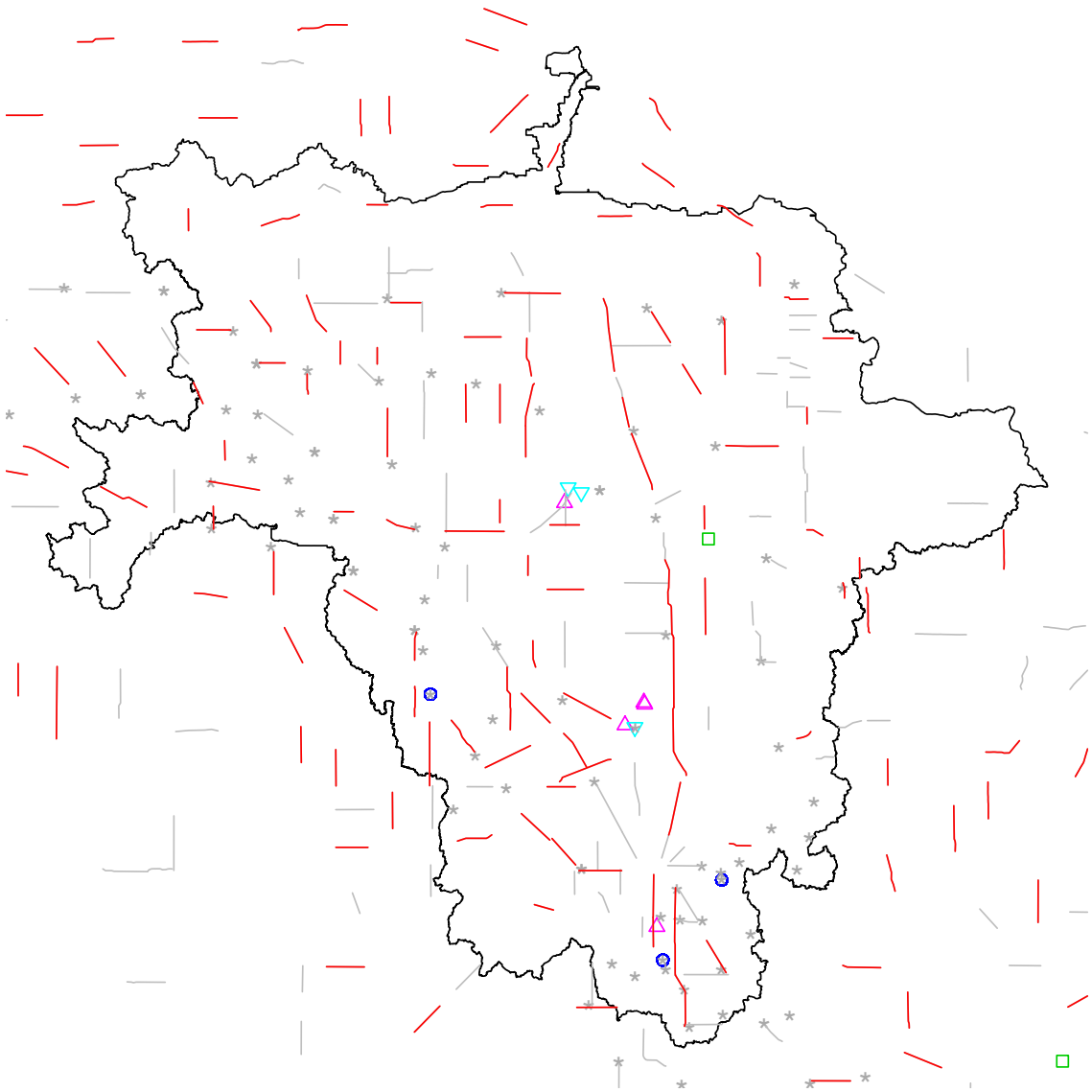


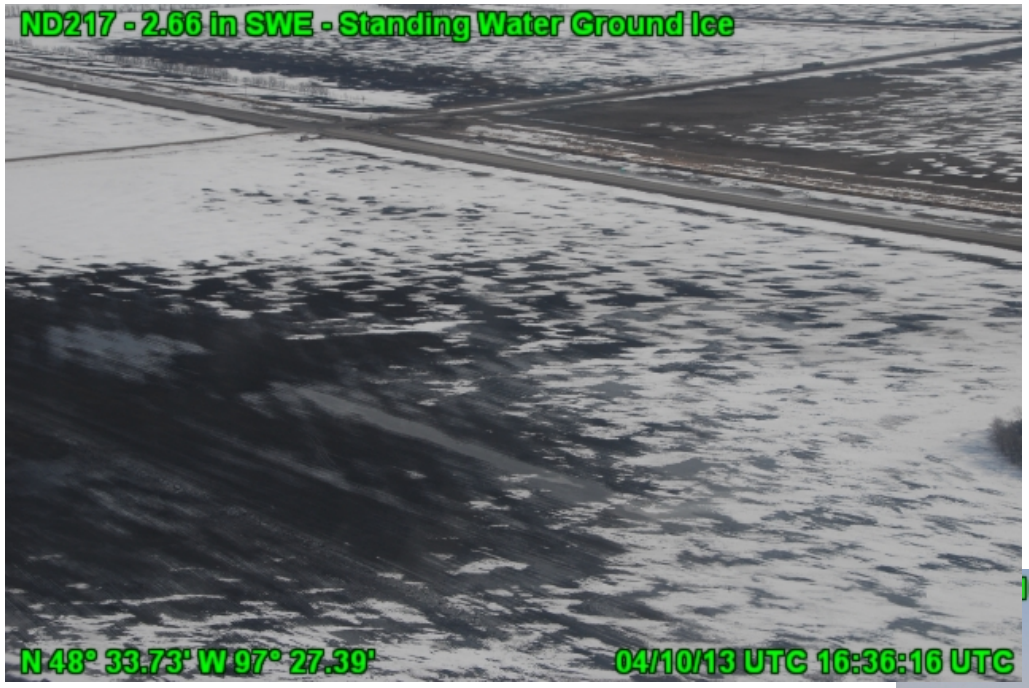
Left: Courtesy Prof. David Hopkins, NDSU (via Pedro Restrepo, NCRFC)
Photo by John Nowatski
South of Red River Valley Fairgrounds
August 22, 2013

SNOW-17 → SAC-SMA

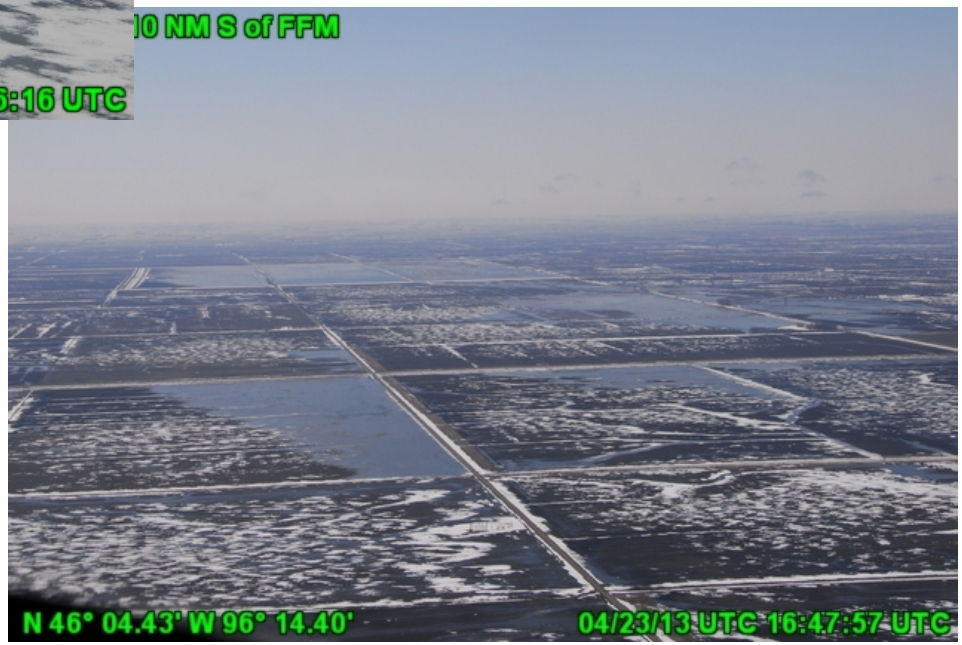


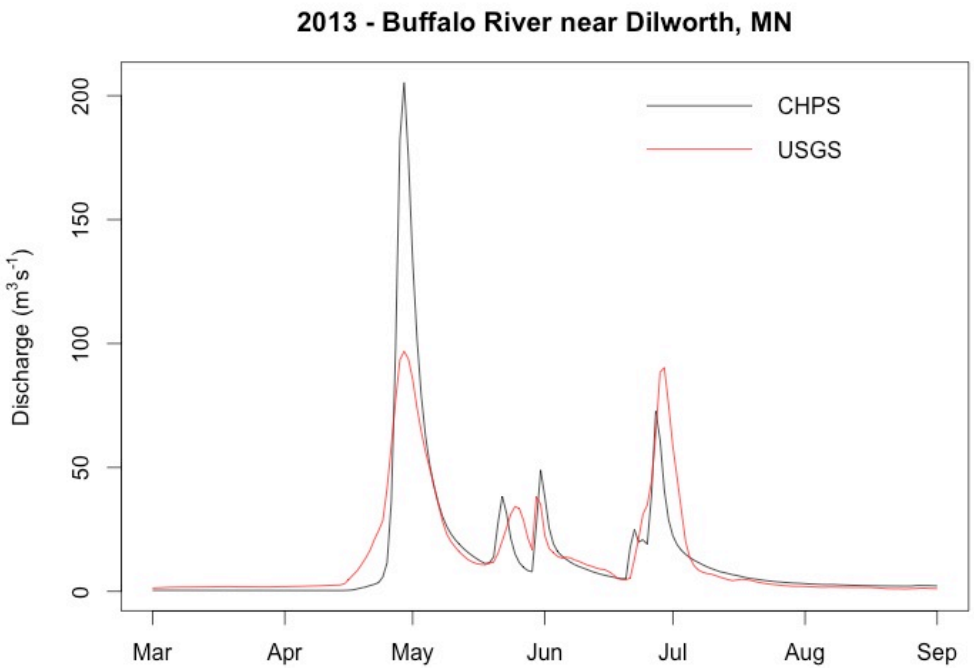






Aerial photos courtesy of NOAA NOHRSC




2013 - Buffalo River near Dilworth, MN
CHPS
USGS
Discharge (m3s-1)
0
50
100
150
200
Mar
Apr
May
Jun
Jul
Aug
Sep

Conclusions

- **Goal: Enhance the NCRFC flood prediction capacity in the Red River Basin using satellite observations**

- Currently used observations lack sufficient spatial and temporal coverage to inform river flow forecasting
- Passive microwave SWE requires additional translation/processing for end user applications
  - Liquid water hinders accurate retrieval
  - Potential grain size/density affects on signal
  - Provides different information than currently used observations
- Satellite soil moisture quality appears to be adequate
  - Absolute magnitude unimportant: only temporal evolution of wet/dry matters
- Communication with NCRFC: you can hear a whole lot by listening