

National Snow and Ice Data Center  
*Supporting Cryospheric Research Since 1976*

## Northern Hemisphere Snow Extent from Visible and Passive Microwave Satellite Data



- **Sensors: Visible and Microwave**
- **Temporal coverage: Multi-decadal to snapshots**
- **Spatial resolution: kilometers to meters**
- **Trends in extent and duration**

**R. L. Armstrong, M.J. Brodzik, E. C. Weatherhead, M. H. Savoie**  
**University of Colorado, Boulder, USA**

# *The National Snow and Ice Data Center (NSIDC)*



**The view from NSIDC**

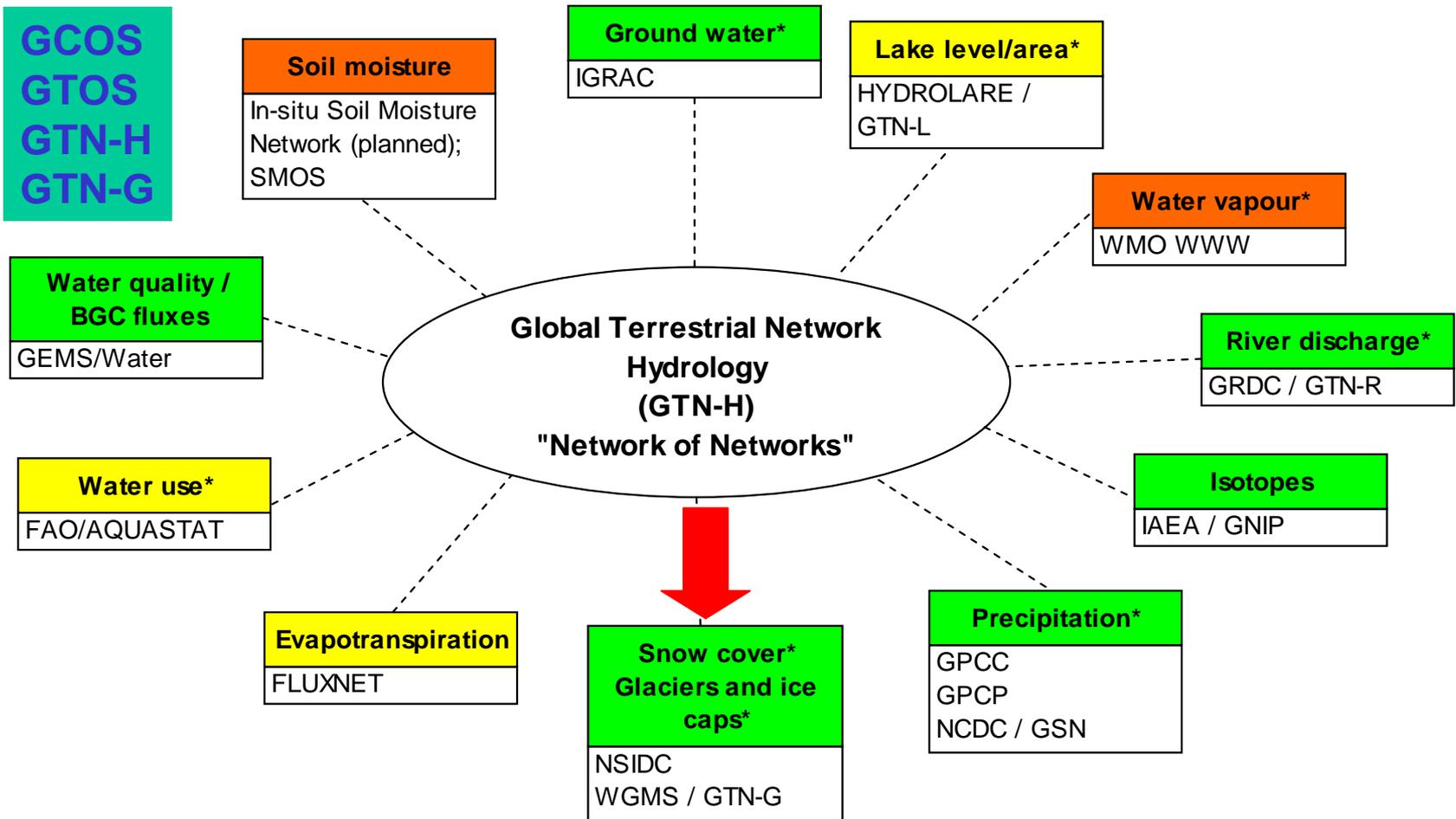
**NSIDC is a Center within the Cooperative Institute for Research in Environmental Sciences (CIRES) at the University of Colorado at Boulder.**

- **Manage and distributes scientific data**
- **Create tools for data access**
- **Support data users**
- **Perform scientific research**
- **Educate the public about the cryosphere.**
  
- **NSIDC's data and research are critical to detecting, monitoring, and analyzing climate change and its impacts. Satellite data, in conjunction with in-situ data, allow NSIDC scientists to monitor changes in the cryosphere, such as:**
  - **recent record minimum sea ice extent in the Arctic**
  - **increasing rate of retreat of mountain glaciers**
  - **reduction in the extent and thickness of permafrost**
  - **decline in the extent of N. Hemisphere snow cover**

# Data at NSIDC & WDC for Glaciology-Boulder

- **All Elements of the Cryosphere**

- Snow cover
- Glaciers
- Permafrost & Seasonally Frozen Ground
- River & Lake Ice
- Ice Sheets & Ice Shelves
- Sea Ice
  
- data catalog - <http://nsidc.org>
  
- **State of the Cryosphere** — provides an overview of the status of snow, ice and global sea level as indicators of climate change. <http://nsidc.org/sotc>



Global network/coverage defined and contact established



Global network/coverage partly existing/identified and/or contact to be improved



No global network/coverage identified

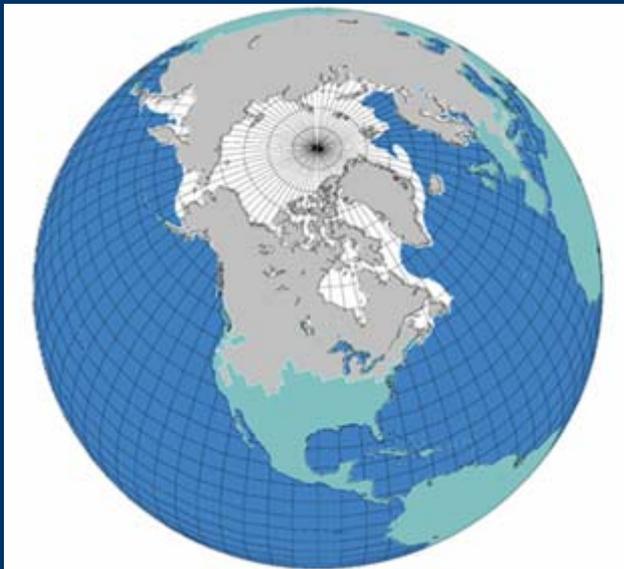
\*

GCOS Essential Climate Variable

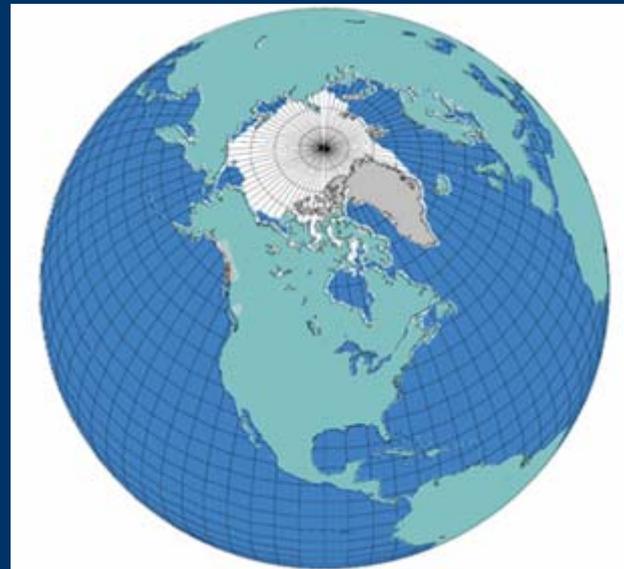
## NSIDC Link to Global Climate Observing System, GTN-H Coordination Panel - Configuration as of September 2007

# Northern Hemisphere Snow-Covered Area

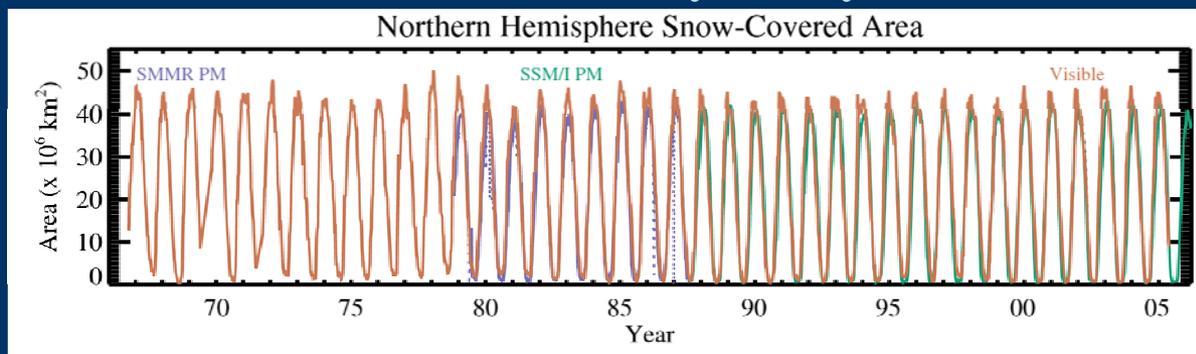
Mean maximum



Mean minimum



## Inter-annual variability—40-year record



# Satellite Remote Sensing of Snow Continental to Hemispheric Scale

## Visible: GOES, AVHRR, MODIS

Higher resolution ( ~ 0.5 km)

Clouds and darkness obscure surface

Limited to surface characteristics

## Microwave: SMMR, SSM/I, AMSR-E

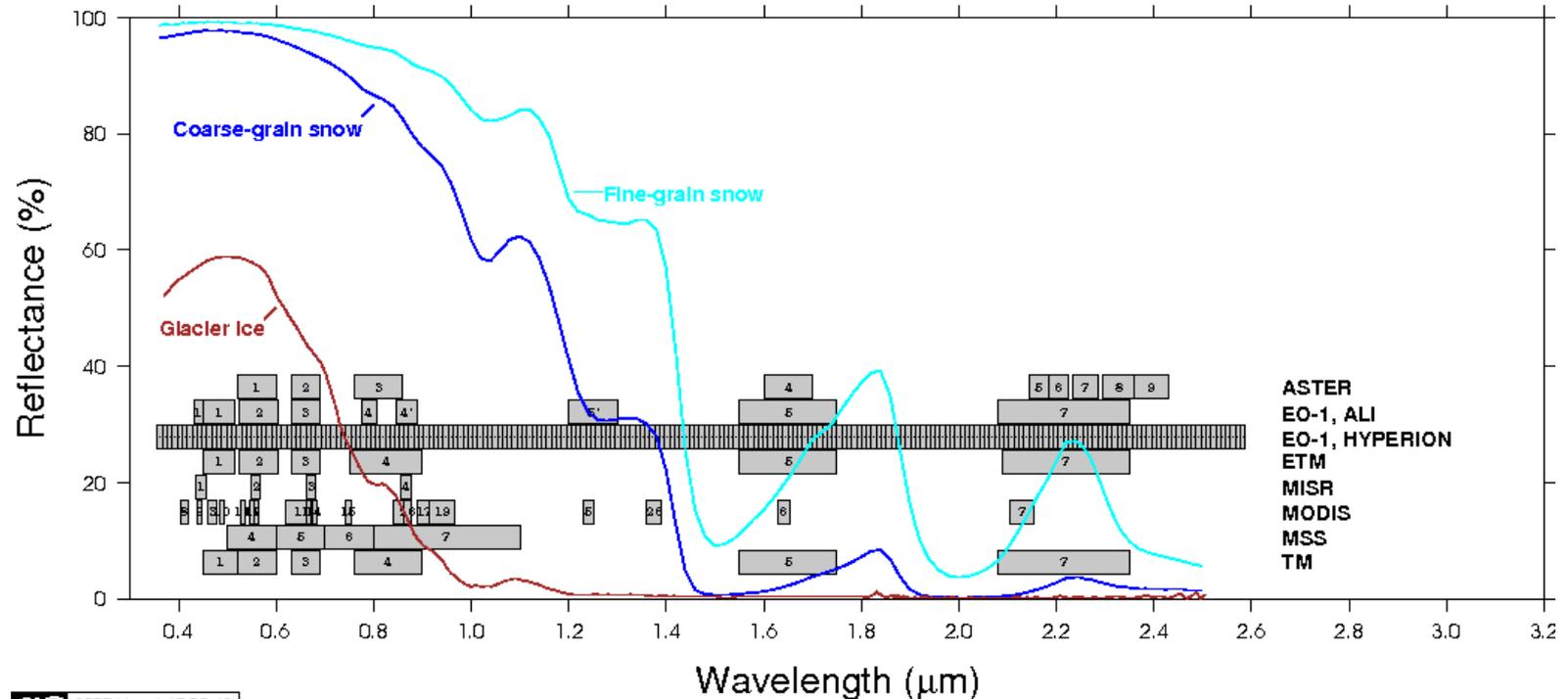
Lower resolution (~ 10-25 km)

All weather & day/night

Sub-surface characteristics (mass)

# Visible Remote Sensing of Snow

## Pass bands for selected instruments



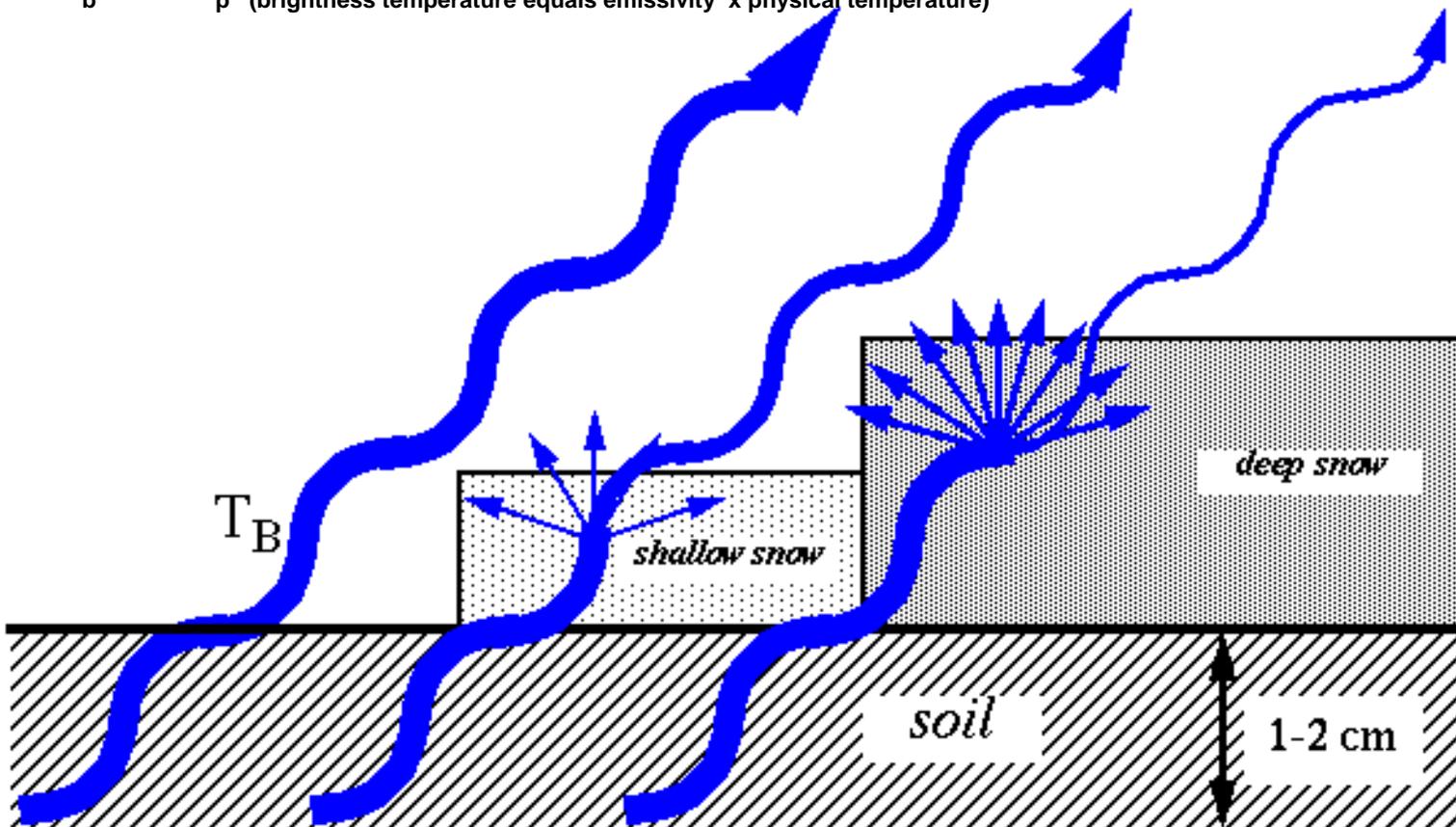
GM 2007 Mar 1 17:00:42 Raup

**Early remote sensing of snow based on manual interpretation of magnitude of reflectance and manual distinction between snow and cloud. More recent methods involve automated algorithms based on the spectral signature of snow and ice.**

# Passive Microwave Remote Sensing of Snow

- Radiation emitted from the soil is scattered by the snow cover
- Scattering increases in proportion to amount (mass) of snow
- Spectral signature: brightness temperature decrease, negative spectral gradient, polarization difference

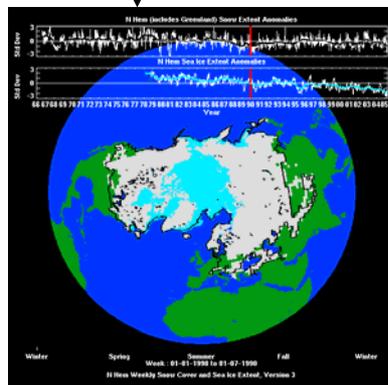
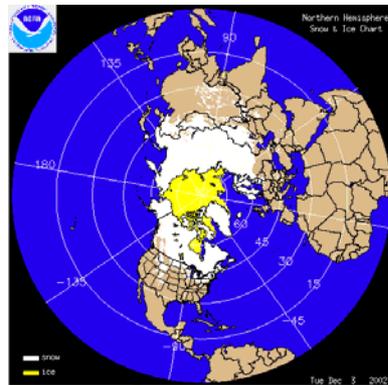
$$T_b = \epsilon * T_p \text{ (brightness temperature equals emissivity x physical temperature)}$$



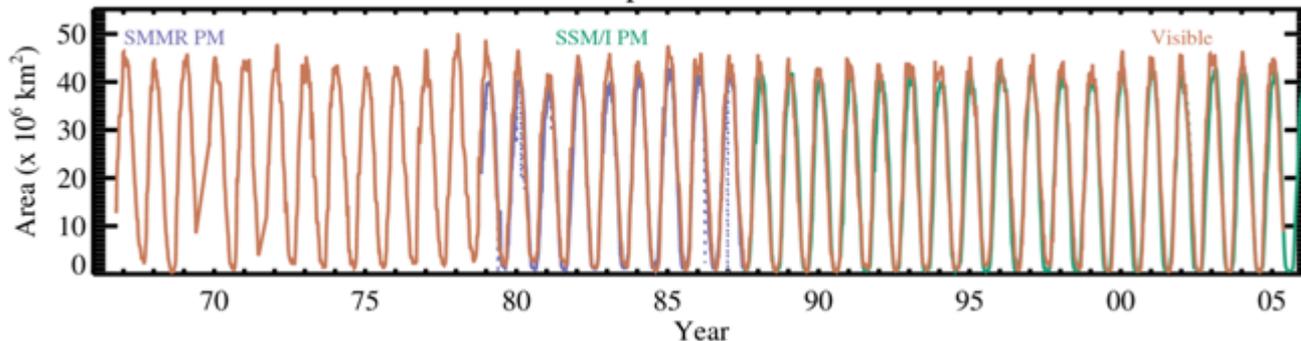
“Visible”-  
derived  
snow data

NOAA weekly  
snow charts,  
(1966-2007) +  
Robinson QC,  
regridded to...

...Northern  
Hemisphere 25  
km EASE-Grid,  
aggregated into  
monthly average  
snow-covered  
area.



Northern Hemisphere Snow-Covered Area

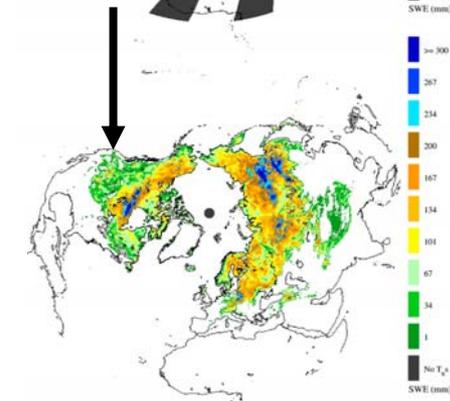
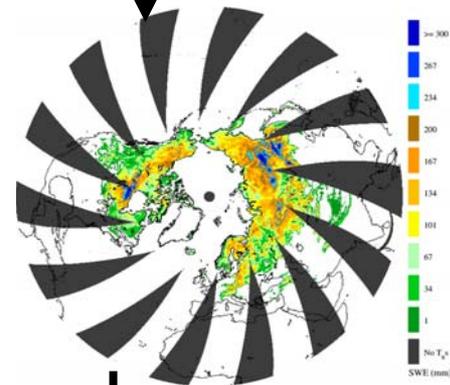
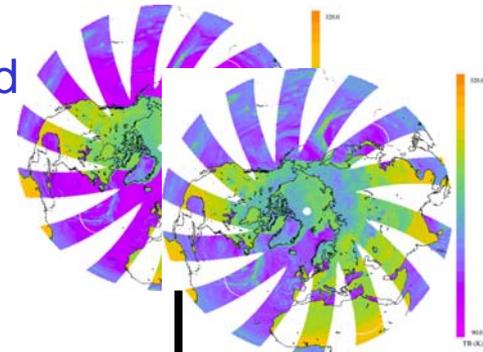


Microwave-derived  
snow data

EASE-Grid daily  
SMMR-SSM/I -  
AMSR-E TBs  
(1978-2007)...

...to derive daily  
SWE...

...combined into  
weekly maximum  
SWE maps, and  
monthly average  
SCA.

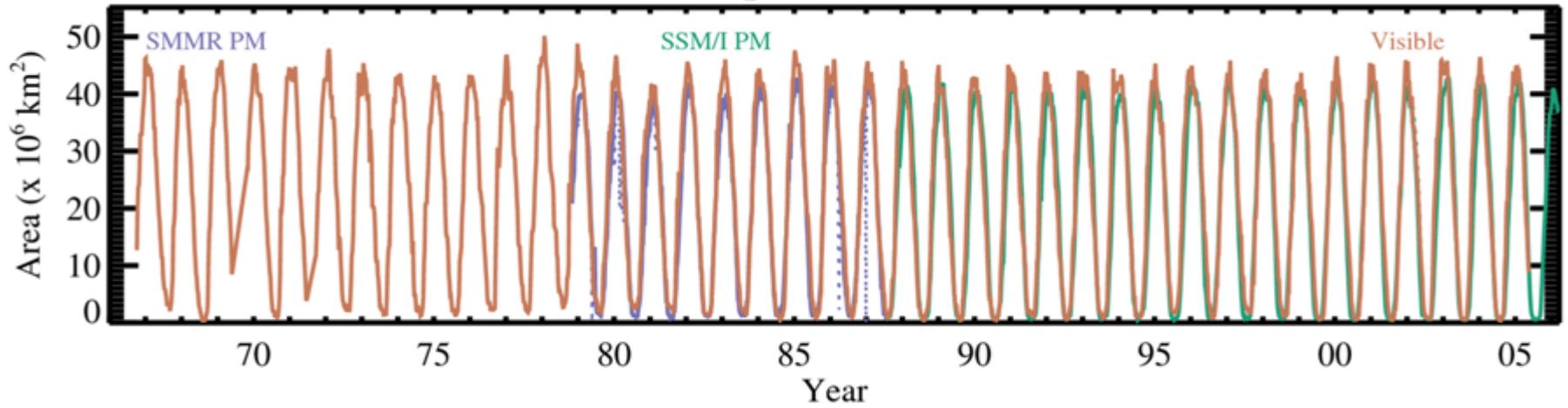


nsidc.org

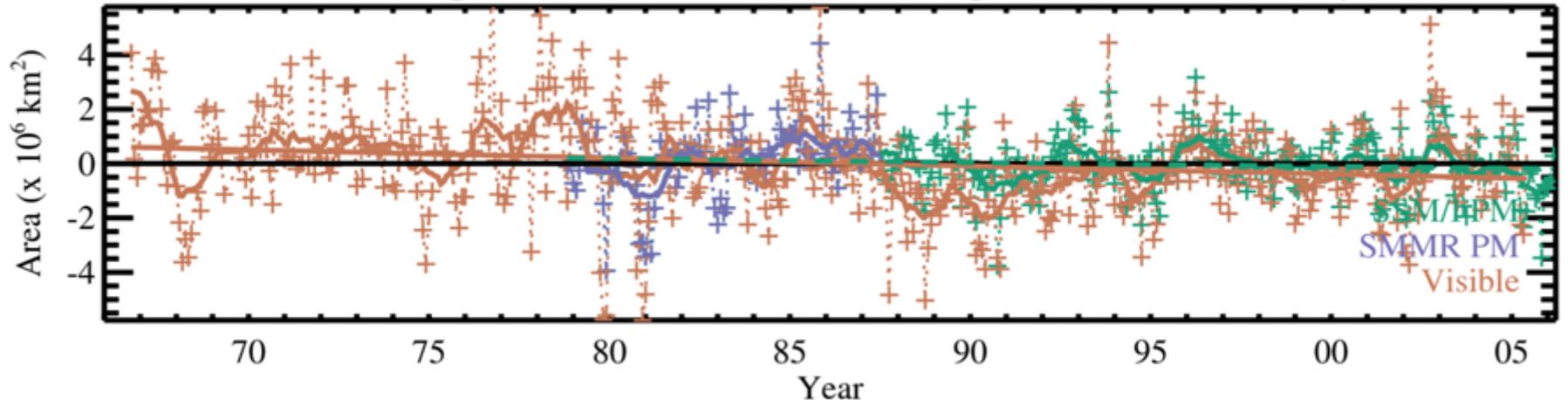
# Snow-covered Area (SCA) Time Series

## Visible (1966-2006) vs. Passive Microwave (1978-2006)

### Northern Hemisphere Snow-Covered Area

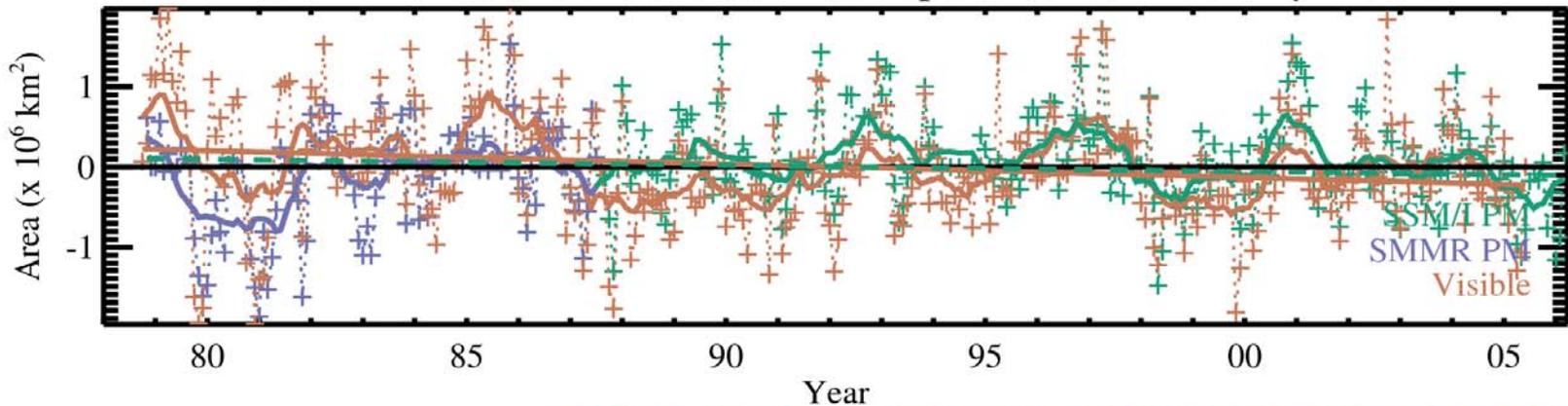


### Northern Hemisphere Snow-Covered Area Departures from Monthly Means



**Visible – 1.4%/decade\***      Trend fit: ( $\phi = 0.51^*$ ), ( $-1.330 \pm 0.569\%/decade^*$ ), required yrs > 25  
**Microwave – 0.7%/decade**      Trend fit: ( $\phi = 0.48^*$ ), ( $-0.697 \pm 0.640\%/decade$ ), required yrs > 50

## North America Snow-Covered Area Departures from Monthly Means



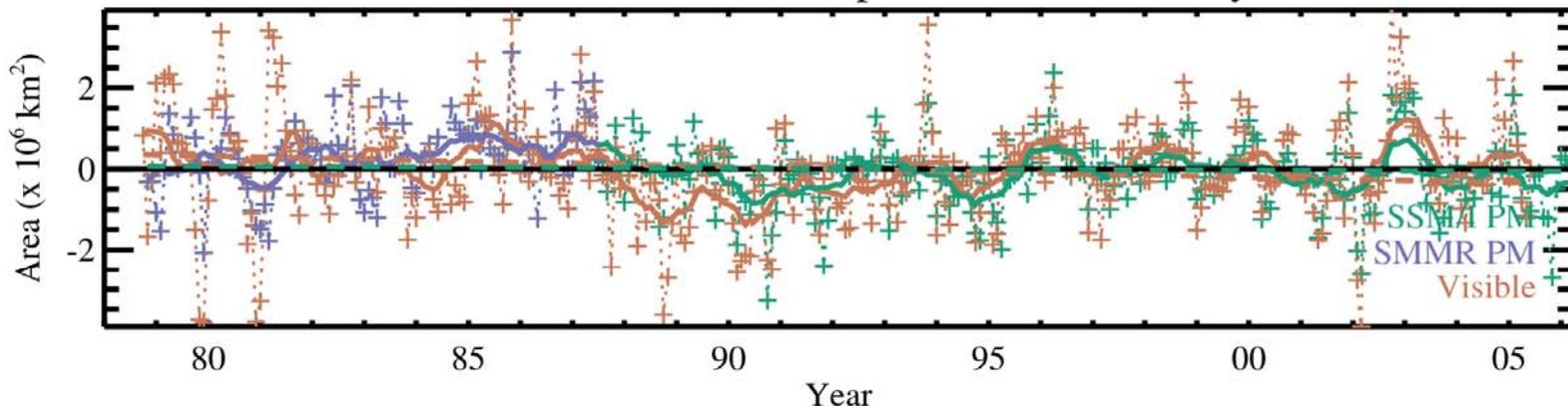
**Visible** – 2.1%/decade\*

**Microwave** – 1.2%/decade

Trend fit: ( $\phi = 0.51^*$ ), ( $-2.118 \pm 1.137\%/decade^*$ ), required yrs > 25

Trend fit: ( $\phi = 0.55^*$ ), ( $-1.213 \pm 1.215\%/decade$ ), required yrs > 50

## Eurasia Snow-Covered Area Departures from Monthly Means



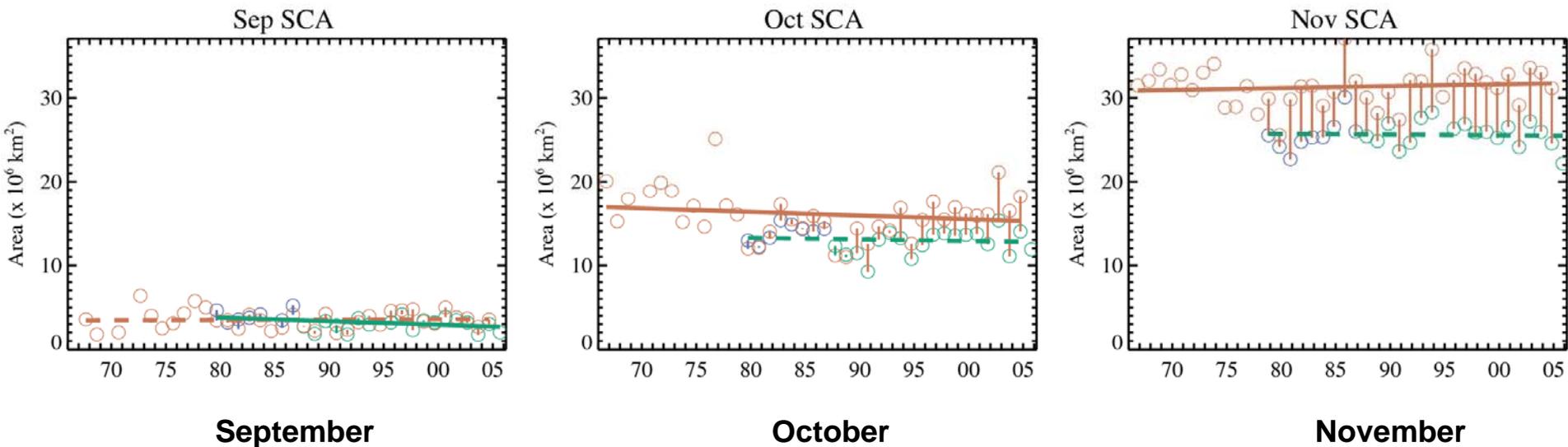
**Visible** – 1.8%/decade

**Microwave** – 0.3%/decade

Trend fit: ( $\phi = 0.53^*$ ), ( $-1.861 \pm 1.177\%/decade$ ), required yrs > 25

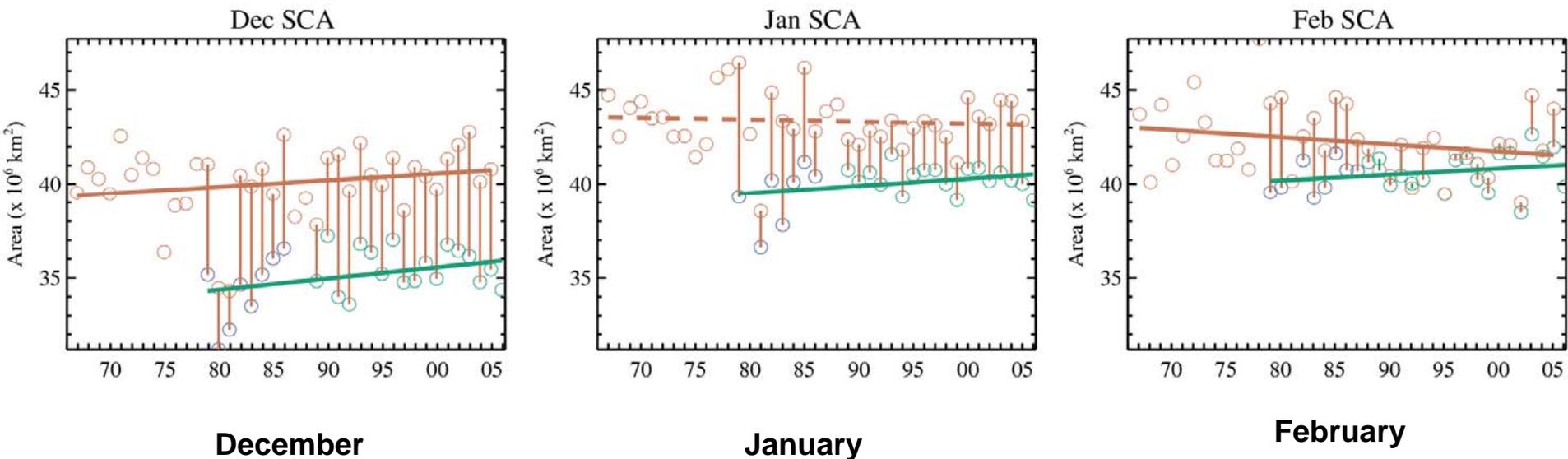
Trend fit: ( $\phi = 0.49^*$ ), ( $-0.338 \pm 0.741\%/decade$ ), required yrs > 75

# Visible vs. Passive Microwave SCA: Autumn



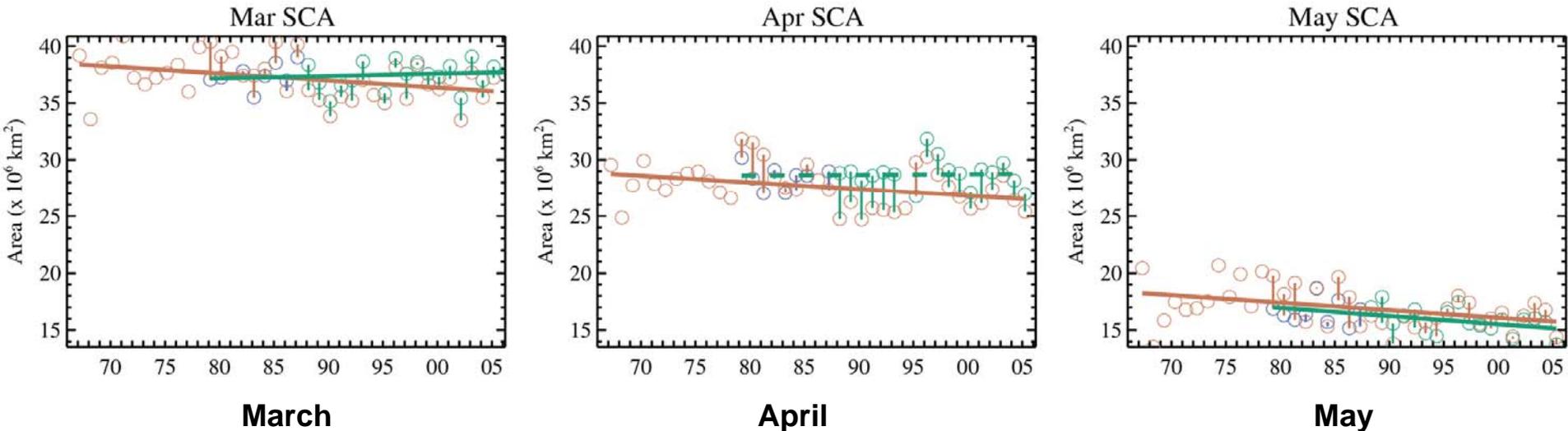
Monthly hemispheric SCA time series, solid line = significant (90%) trend, vertical lines connect sensor data points for given year (red = visible, green = microwave)  
October shows a slight decreasing trend while November shows a slight increase for the visible.

# Visible vs. Passive Microwave SCA: Winter



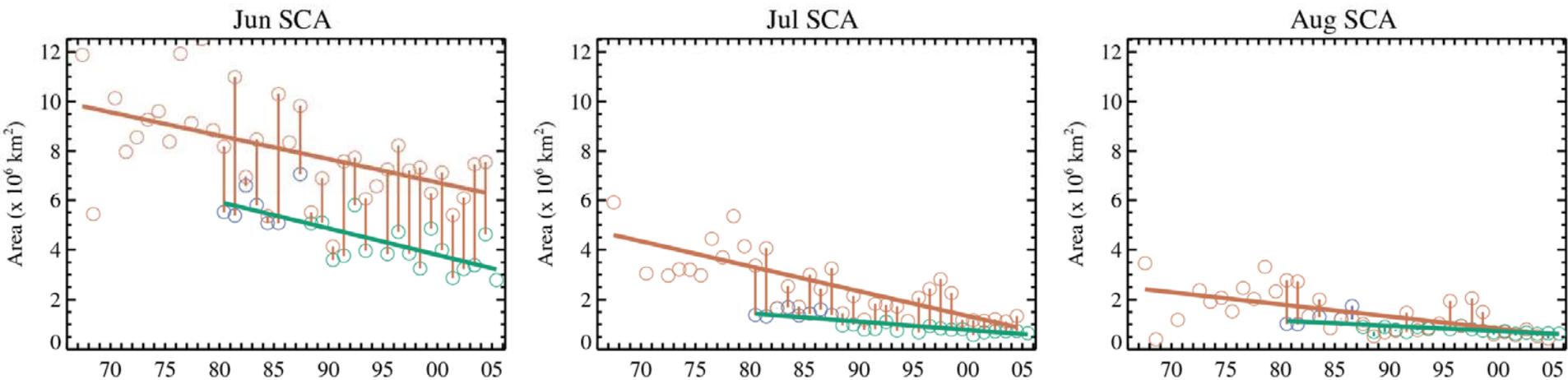
**Both SCA trends are positive in December, PM remains so, while visible SCA trends change to negative by February. (red = visible, green = microwave)**

# Visible vs. Passive Microwave SCA: Spring



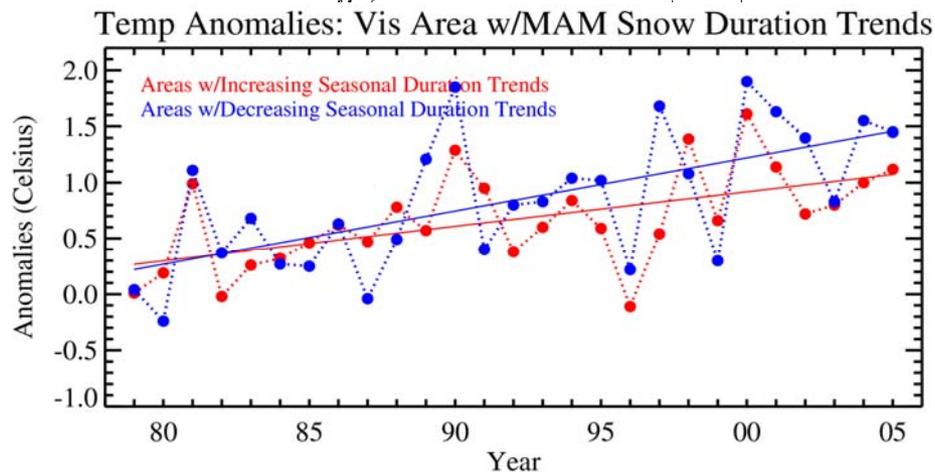
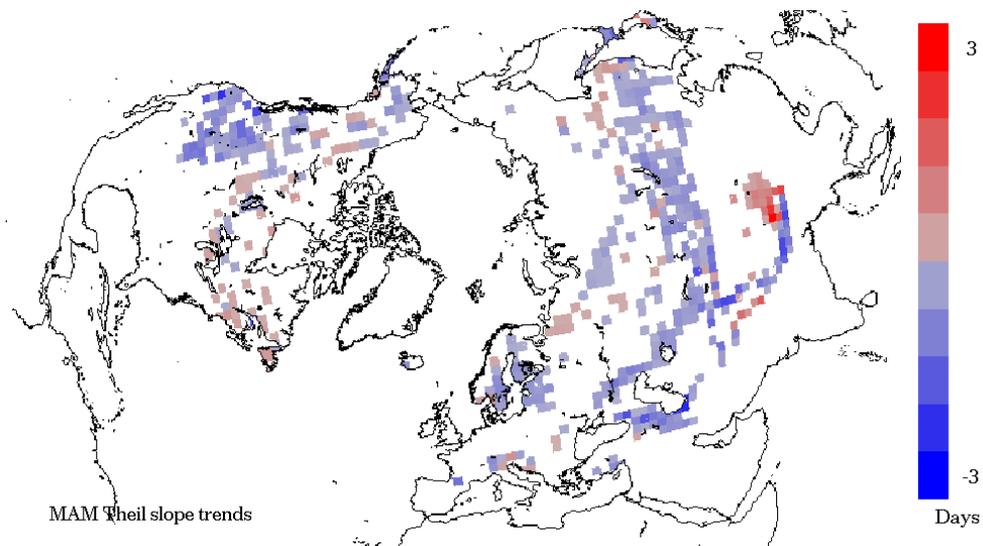
Visible data show significant decreasing trends in all months, with PM shifting from positive in March to negative by May. (red = visible, green = microwave)

# Visible vs. Passive Microwave SCA: Summer



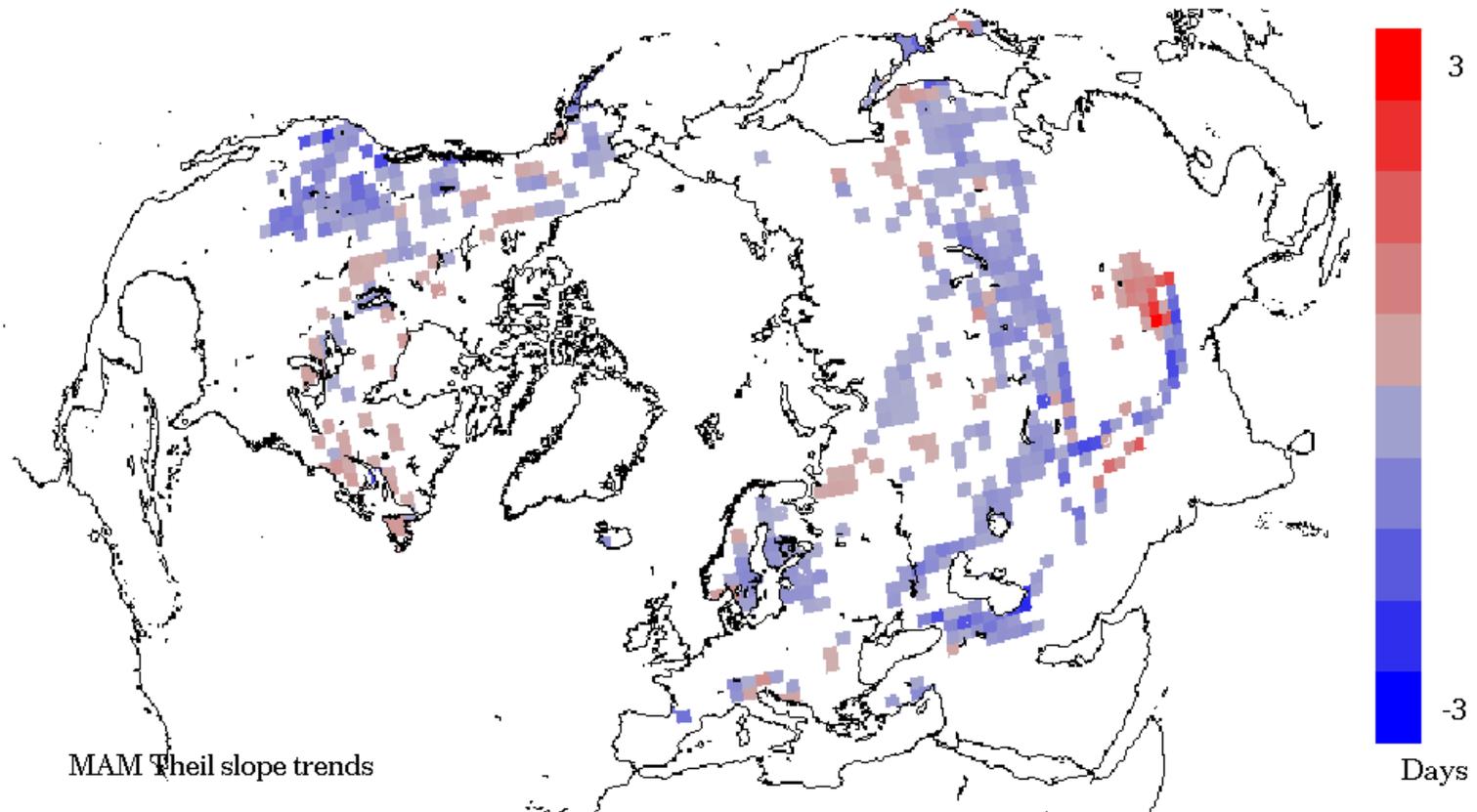
**Very little seasonal snow during Northern Hemisphere summer. SCA trends in both data sets are significant and decreasing in all months. (red = visible, green = microwave)**

# Spring Duration of Snow Cover (Visible Data) vs. Surface Temperature Anomalies 1978-2006



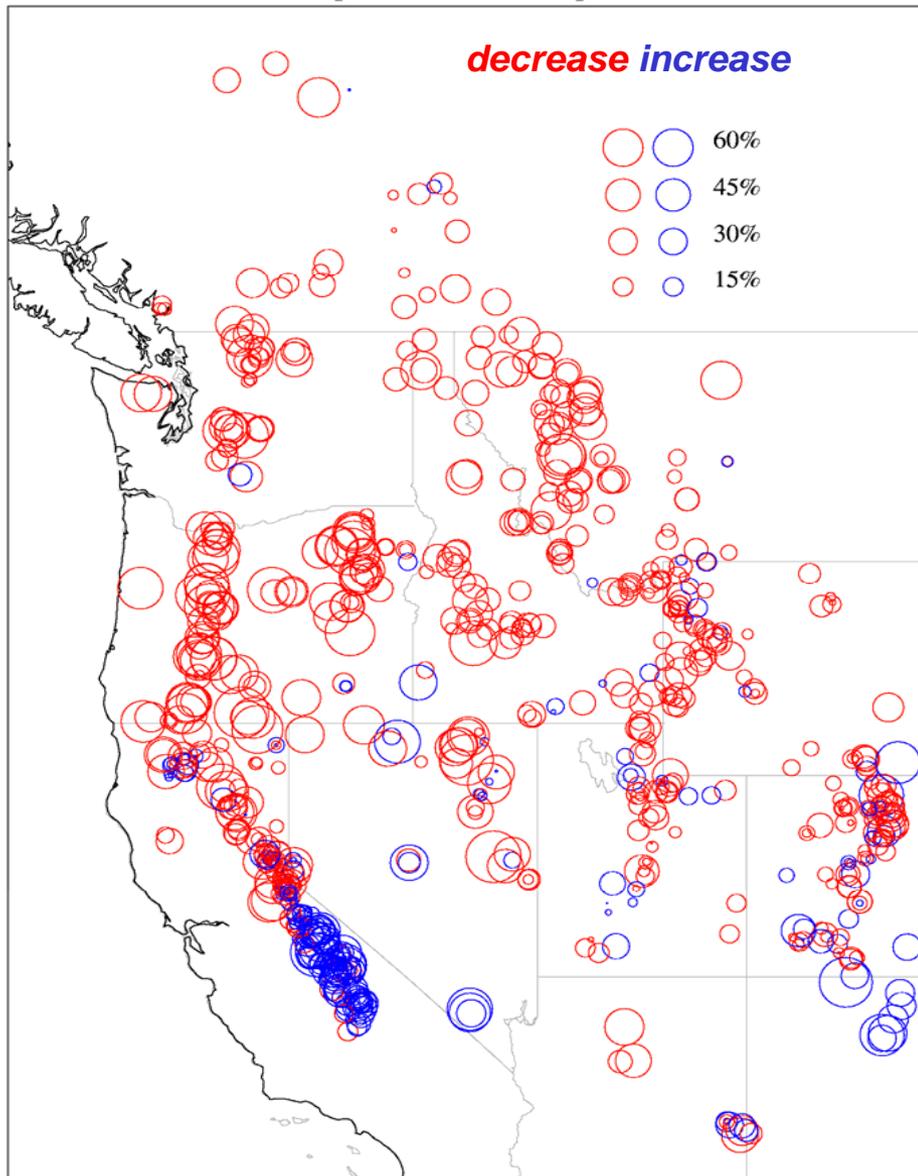
**Upper:** Regions of increasing (red) and decreasing (blue) snow duration trends greater than zero.  
**Lower:** Temperature trends (NASA GISS) corresponding to the locations of increase or decrease. While both regions show increase, the temperature trend magnitudes are greater in the areas with decreasing snow duration.

# Spring Duration of Snow Cover Trends Derived from Visible Satellite Data 1978-2006



**Decreases in the Western US of up to 3 days per decade  
(preliminary results, Armstrong and Brodzik, NSIDC)**

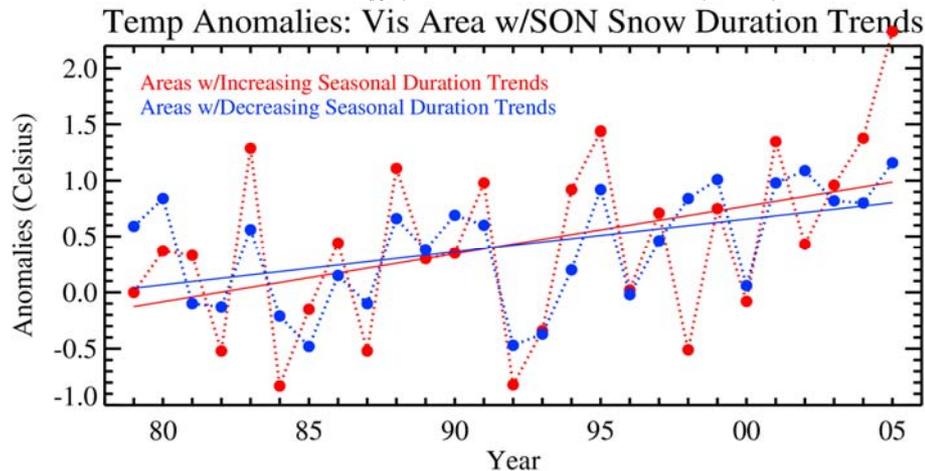
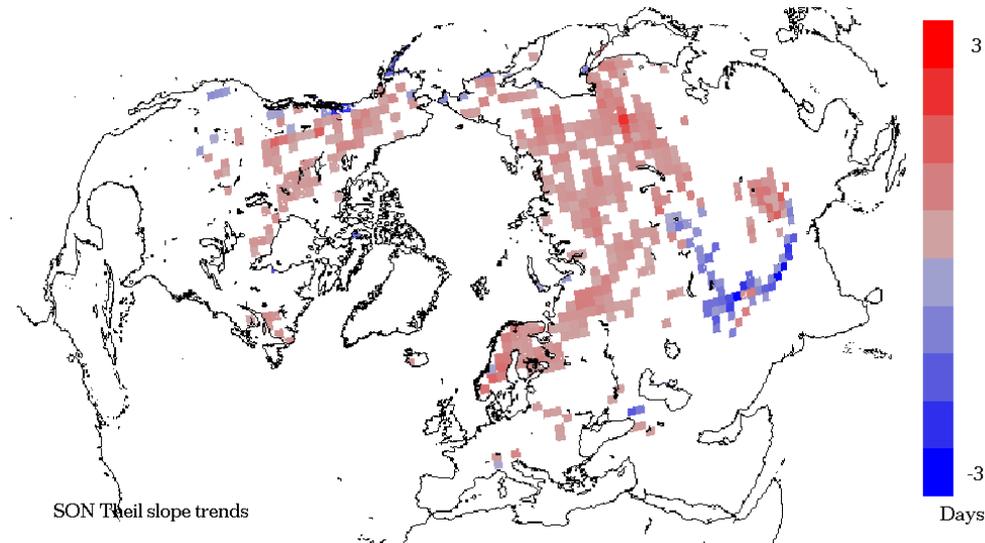
Relative trend in Apr 1 snow water equivalent, 1950-2000



# Trends in Measured April 1 snow water equivalent (SWE), 1950-2000

Data from Phil Mote, UW/CIG

# Autumn Duration of Snow Cover (Visible Data) vs. Surface Temperature Anomalies 1978-2006



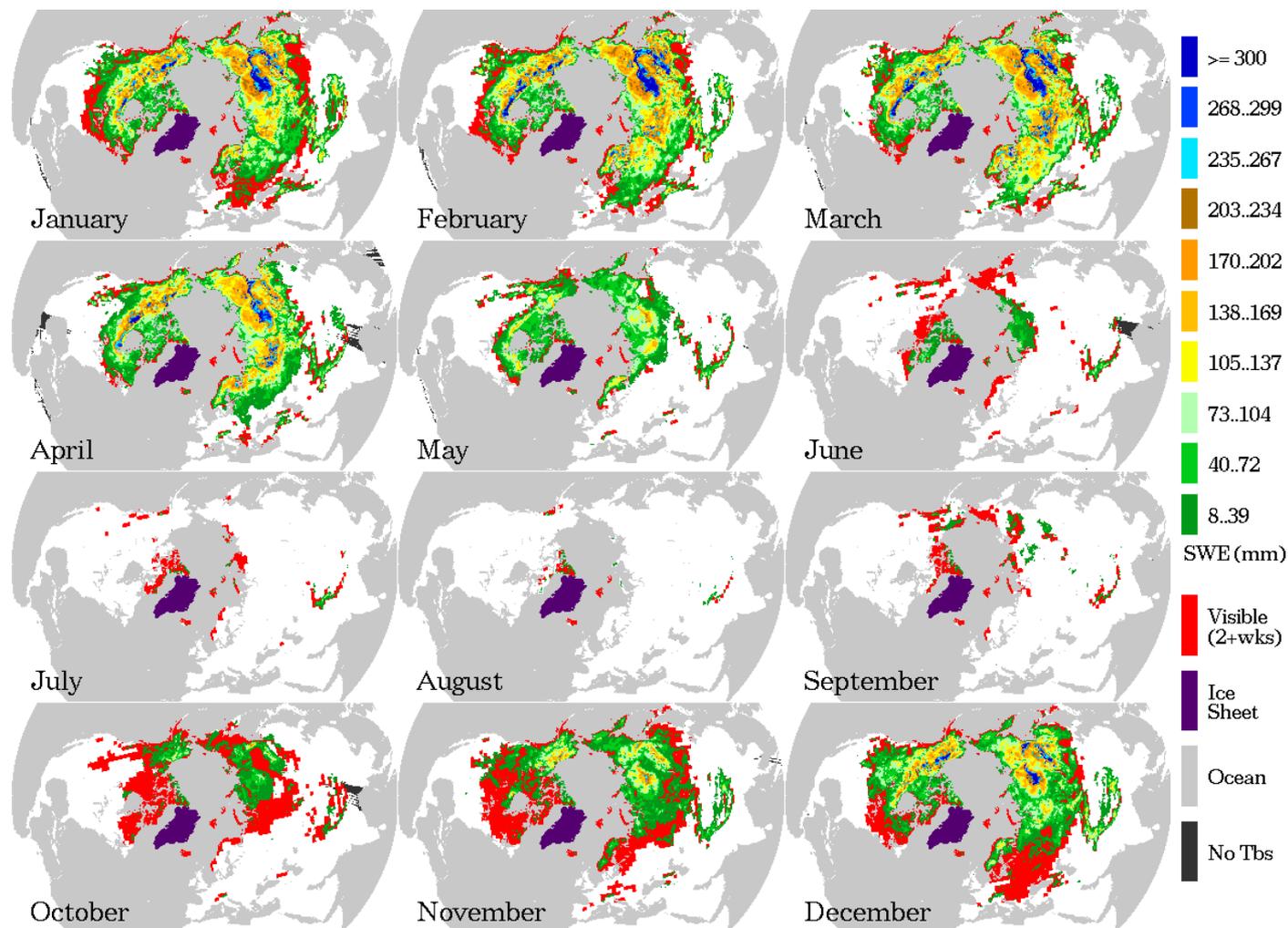
**Upper:** Regions of increasing (red) and decreasing (blue) snow duration trends greater than zero.  
**Lower:** Temperature trends corresponding to the locations of increase or decrease. (temperatures may be increasing but it is still cold enough for the precipitation to be falling as snow)



# Conclusions

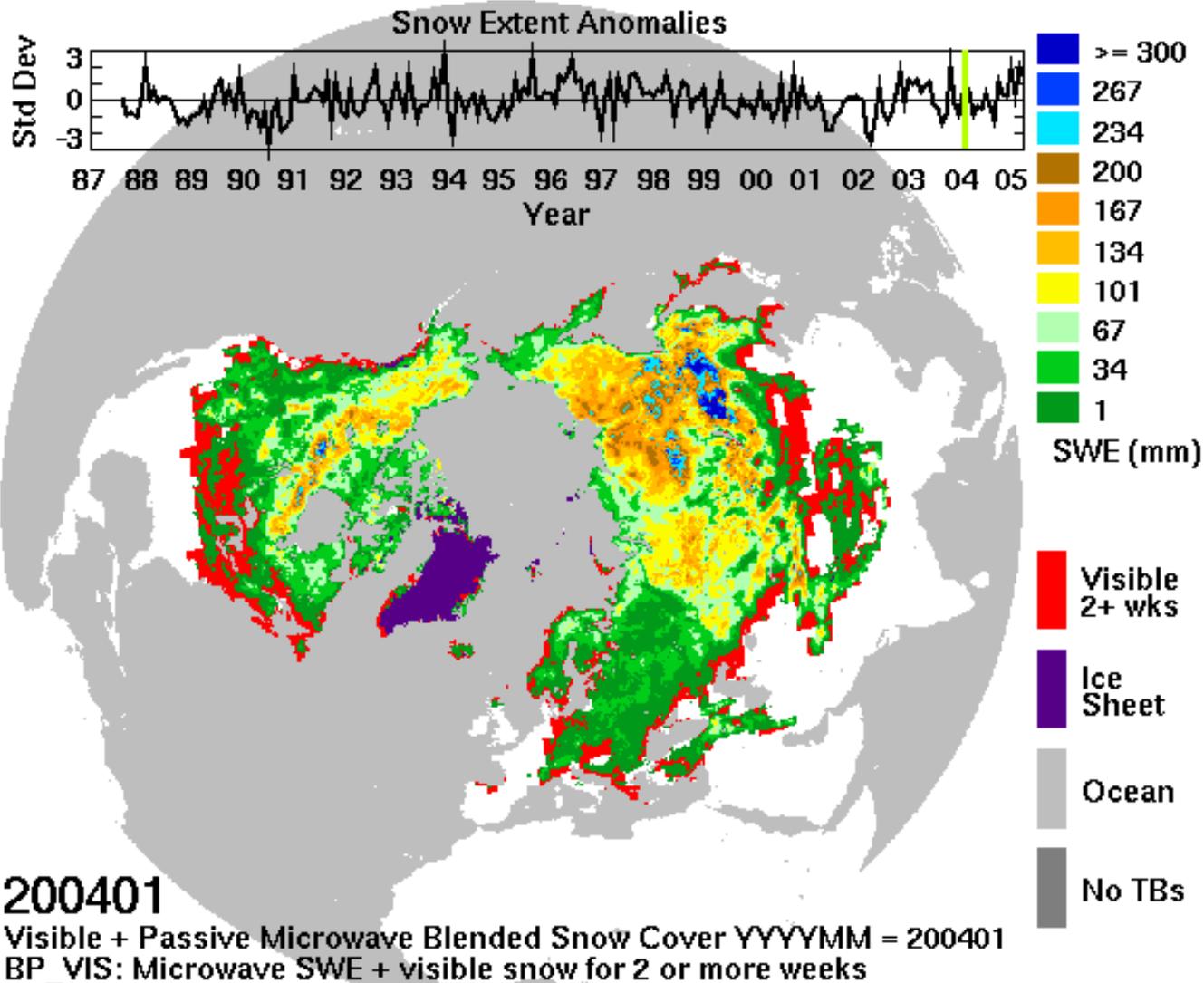
- **We are seeing changes in snow cover over the last several decades from both data sets, although the message is mixed: fall/winter trends don't agree, but decreasing trends are consistent in spring/summer months.**
- **The strongest seasonal signal occurs during May to August, when both data sets indicate significant decreasing trends.**
- **Areas with decreasing spring season snow cover show greatest positive temperature anomalies.**
- **Next version of climatologies will include an improved SMMR-SSM/I cross-calibration, Tibet plateau atmospheric correction.**

# Combine visible and microwave – monthly climatologies



**Mean monthly snow extent and SWE for 1978-2007  
from a blend of passive microwave (SMMR &  
SSM/I) and **visible (NOAA)** 25 x 25 km**

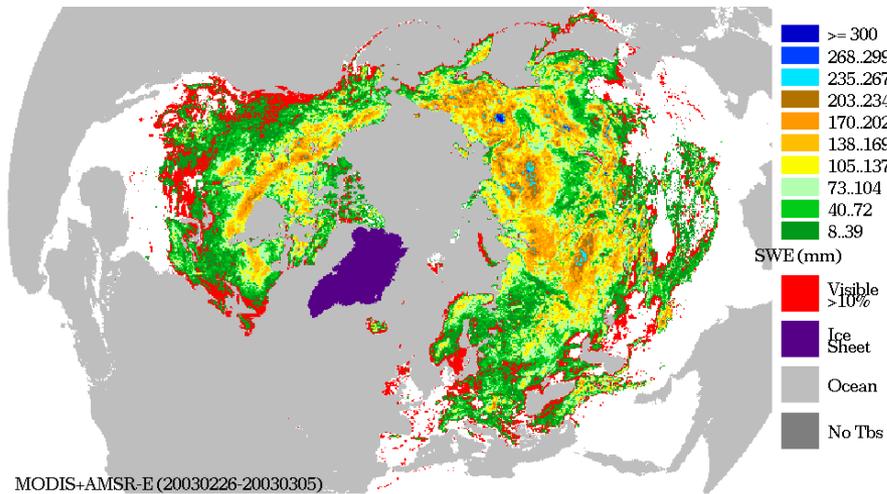
# NSIDC Global Monthly EASE-Grid Snow Water Equivalent Climatology (browse image)



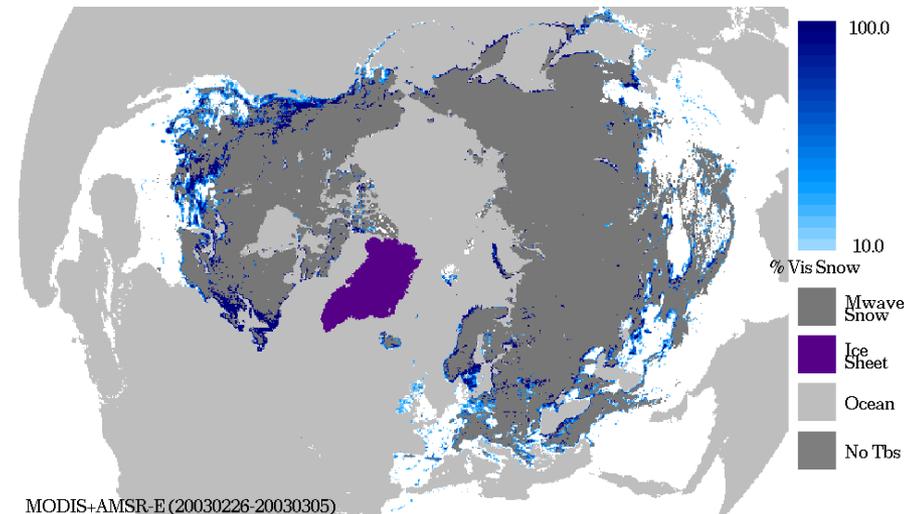
Combines visible (NOAA) and passive microwave (SMMR.SSM/I) 1978 – 2007 (25 x 25 km)

# New Product – Increased Spatial Resolution

NSIDC Global **Daily Snow Extent and Snow Water Equivalent** Derived From NASA EOS AMSR-E (passive microwave) and MODIS (optical) Satellite Data – June 2002 to present.



*Blended snow product prototypes, SWE (mm) from AMSR-E with additional snow extent from MODIS in red (Feb 26 – Mar 5, 2003).*



*AMSR-E snow extent in grey, with percent of additional area that MODIS classifies as snow in blues.*

**Spatial Resoluton: MODIS = 500m, AMSR-E = ~ 10 km, final product resolution tbd.**

**Temporal Resolution: Daily**

**Availability: NSIDC User Services – [nsidc@nsidc.org](mailto:nsidc@nsidc.org)**

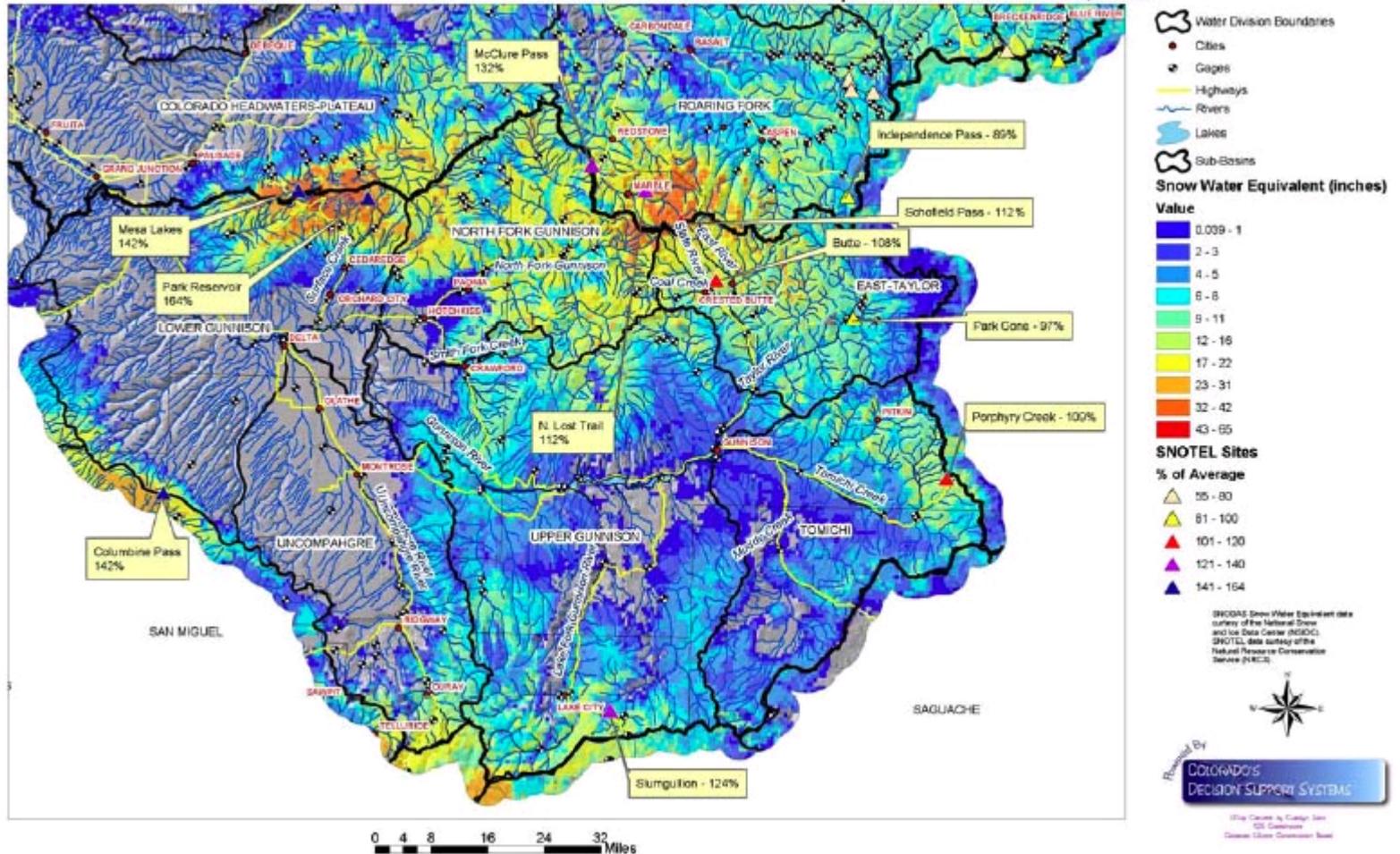
# NOHRSC Snow Data Assimilation System (SNODAS)

## --- Data Products at NSIDC

A physically based, spatially distributed energy- and mass-balance snow model designed to **integrate snow data from satellite, airborne platforms, and ground stations with model estimates of snow cover** (Carroll et al., 2001). Also includes procedures to ingest and downscale output from Numerical Weather Prediction (NWP) models; NSIDC archives eight of the variables:

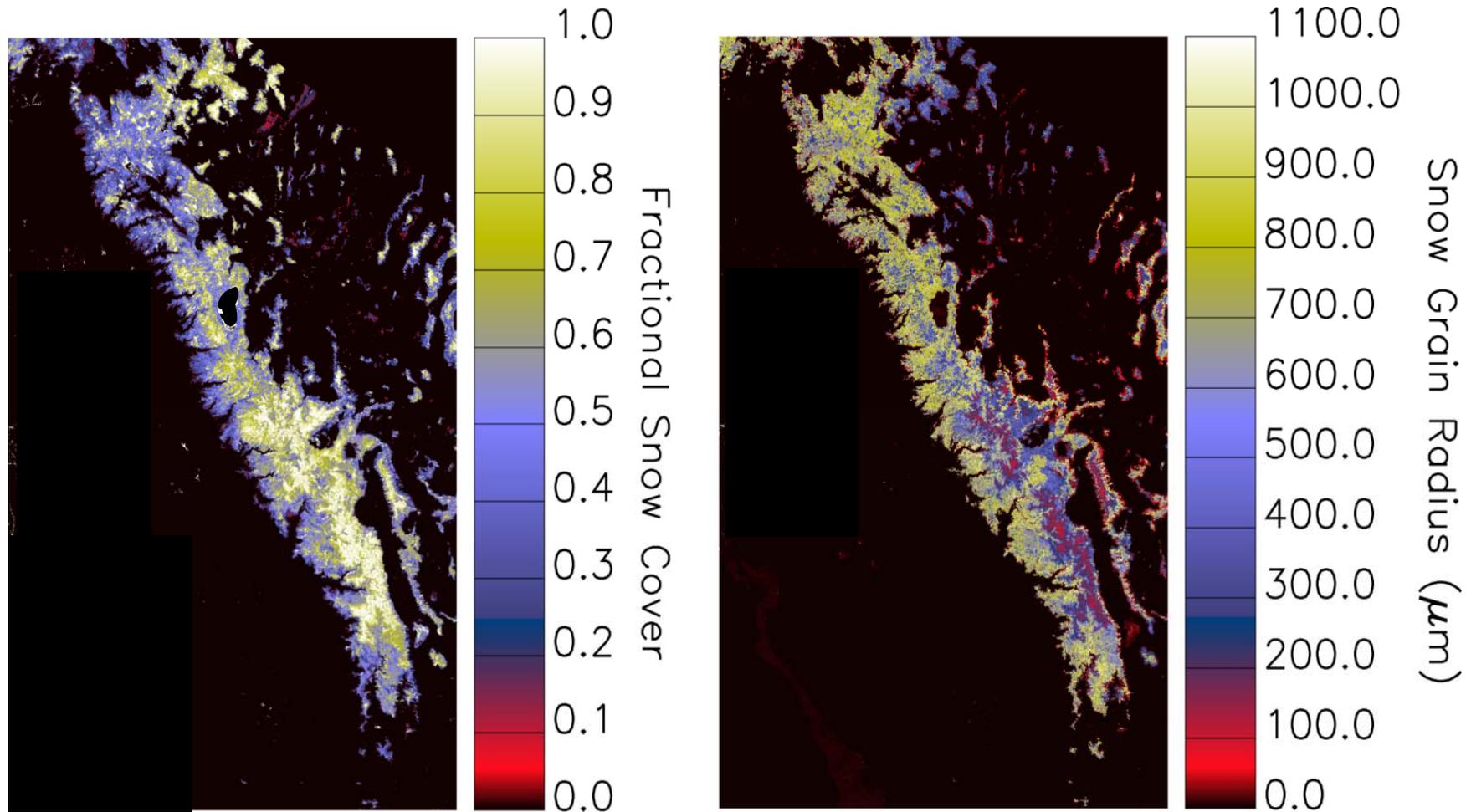
- Snow water equivalent (SWE); liquid and solid water in the pack
- Snow depth
- Snow melt runoff at the base of snow pack
- Sublimation from the snow pack
- Sublimation of blowing snow
- Solid precipitation
- Liquid precipitation
- Snow pack average temperature

## Gunnison Basin SNOTEL & SNODAS Snow Water Equivalent - March 14, 2005



**Figure 1. SNODAS fields can be imported into GIS, as illustrated in this view of SWE in the Gunnison Basin. Figure courtesy of Joe Busto of the Colorado Water Conservation Board**

# MODSCAG – MODIS snow covered-area and grain size, percent w/in 500 m grid cell --- T. Painter



**MODSCAG is a multiple endmember spectral mixture analysis** combined with radiative transfer directional reflectance: spectrally unmixes allowing number of endmembers and the endmembers themselves to vary on pixel by pixel basis

# MODIS Snow Products at NSIDC

Short Name	Long Name	Spatial Type
M*D10_L2	5-Min L2 Swath 500m (snow cover & fractional snow cover)	Swath product
M*D10A1	Daily L3 Global 500m Grid (snow, fractional snow, & albedo)	Tiled Sinusoidal Grid
M*D10A2	8-Day L3 Global 500m Grid (maximum snow extent)	Tiled Sinusoidal Grid
M*D10C1	Daily L3 Global 0.05Deg CMG (percent snow cover)	Climate Modeling Grid
M*D10C2	8-Day L3 Global 0.05Deg CMG (percent snow cover)	Climate Modeling Grid
M*D10CM	Monthly L3 Global 0.05Deg CMG (percent snow cover)	Climate Modeling Grid

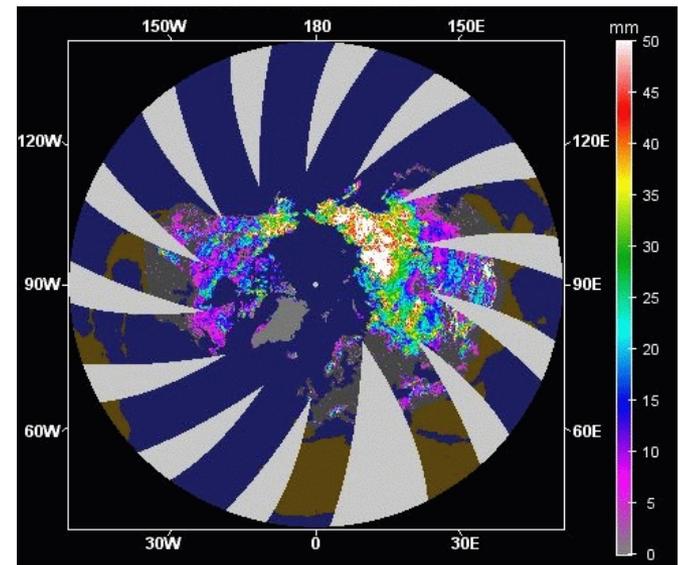
\* = O for Terra, Y for Aqua

# *NASA EOS - AMSR-E Products: Snow*

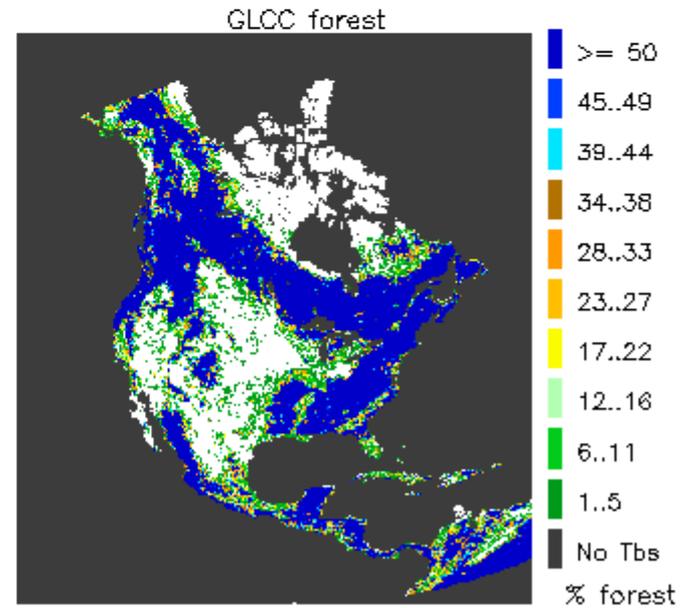
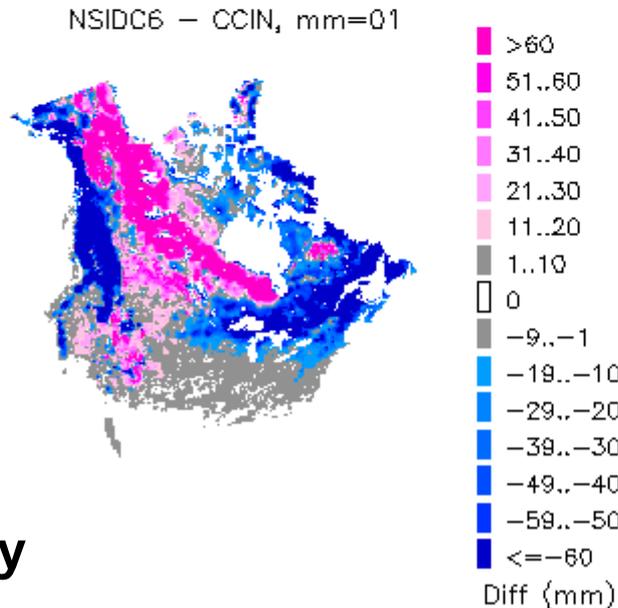
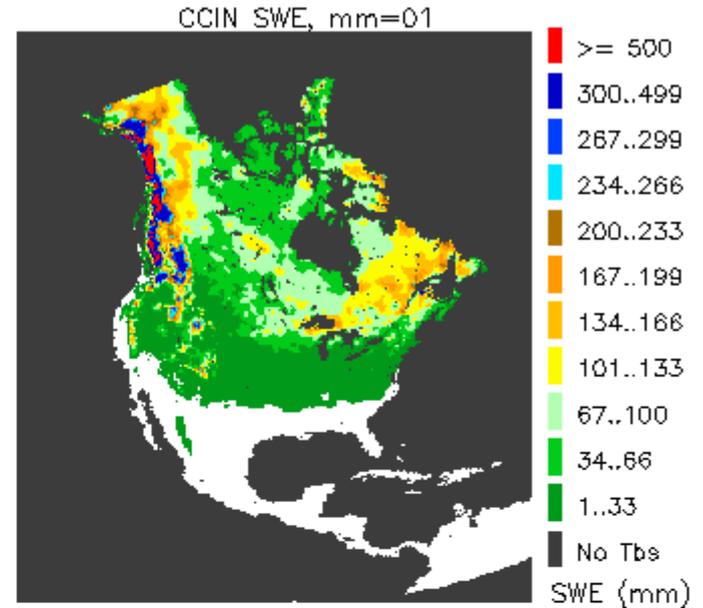
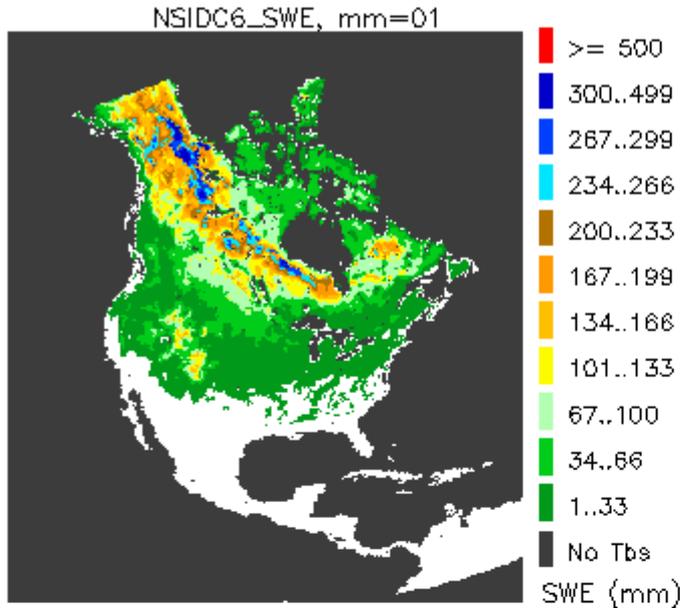
## **Daily, 5-Day, & Monthly Level-3 SWE**

- Temporal coverage: 18 June 2002 - Present
- Spatial coverage: Northern & Southern Hemisphere
- Spatial resolution: 10 - 25 km
- Grid: EASE-Grid
- Parameters: SWE (mm), QA flags
- Documentation & Data Access:  
[http://nsidc.org/data/ae\\_ocean.html](http://nsidc.org/data/ae_ocean.html)

**Northern Hemisphere SWE  
for 22 December 2006**



# Comparison of Monthly SWE Derived from SSM/I and the CCIN Gridded North American Data Set (Brown, Brasnett and Robinson, 2003)



January

Armstrong and Brun

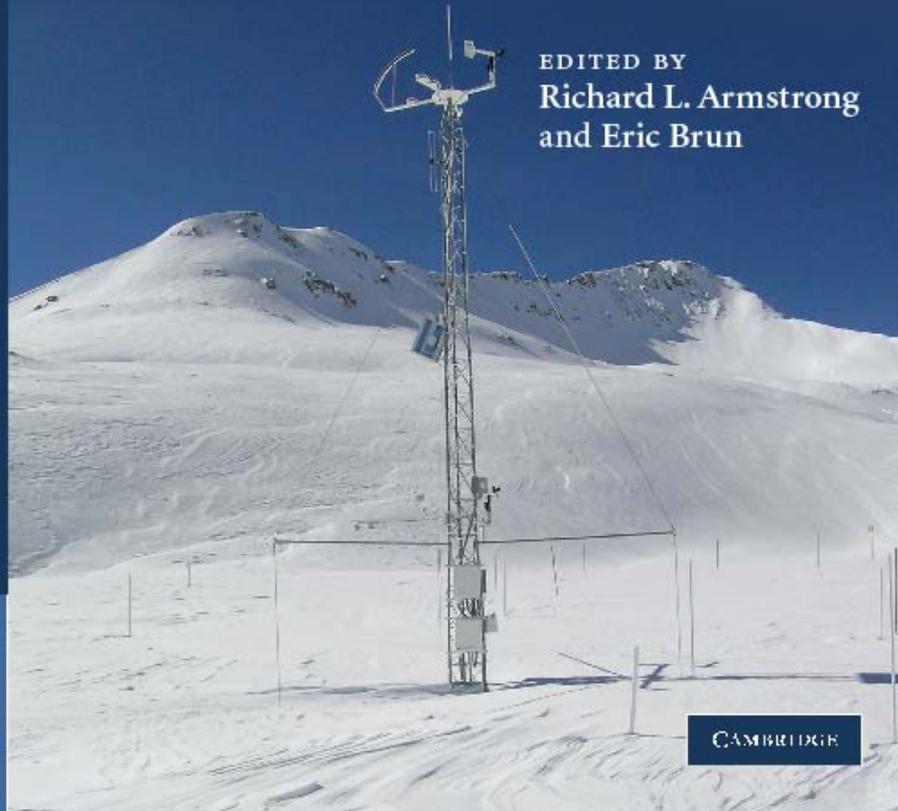
Snow and Climate

CAMBRIDGE

# Snow and Climate

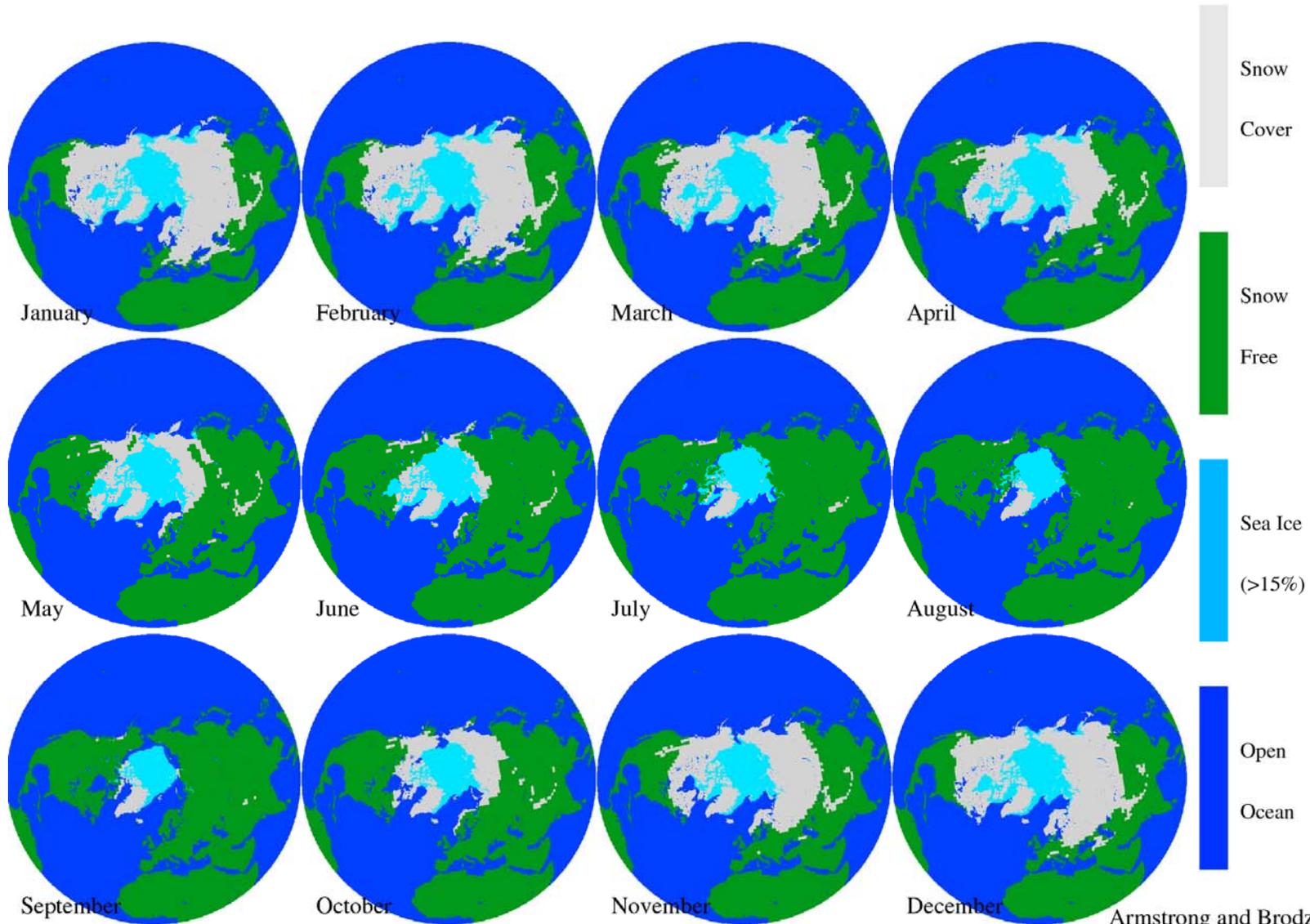
Physical Processes, Surface Energy Exchange and Modelling

EDITED BY  
Richard L. Armstrong  
and Eric Brun



CAMBRIDGE

# Average Snow Cover (1966-2007) & Sea Ice Extent (1978-2007)



Armstrong and Brodzik, NSIDC