Development of Integrated Terrestrial Surface Water State Indicators for Climate Assessment

Kyle C. McDonald, Nicholas Steiner,
Marzieh Azarderakhsh, Brian Lamb, Ronny Schroeder,
Balazs Fekete, Charles Vörösmarty

Environmental Crossroads Initiative and CREST Institute
City College of the City University of New York
160 Convent Ave
New York, NY 10031
kmcdonald2@ccny.cuny.edu

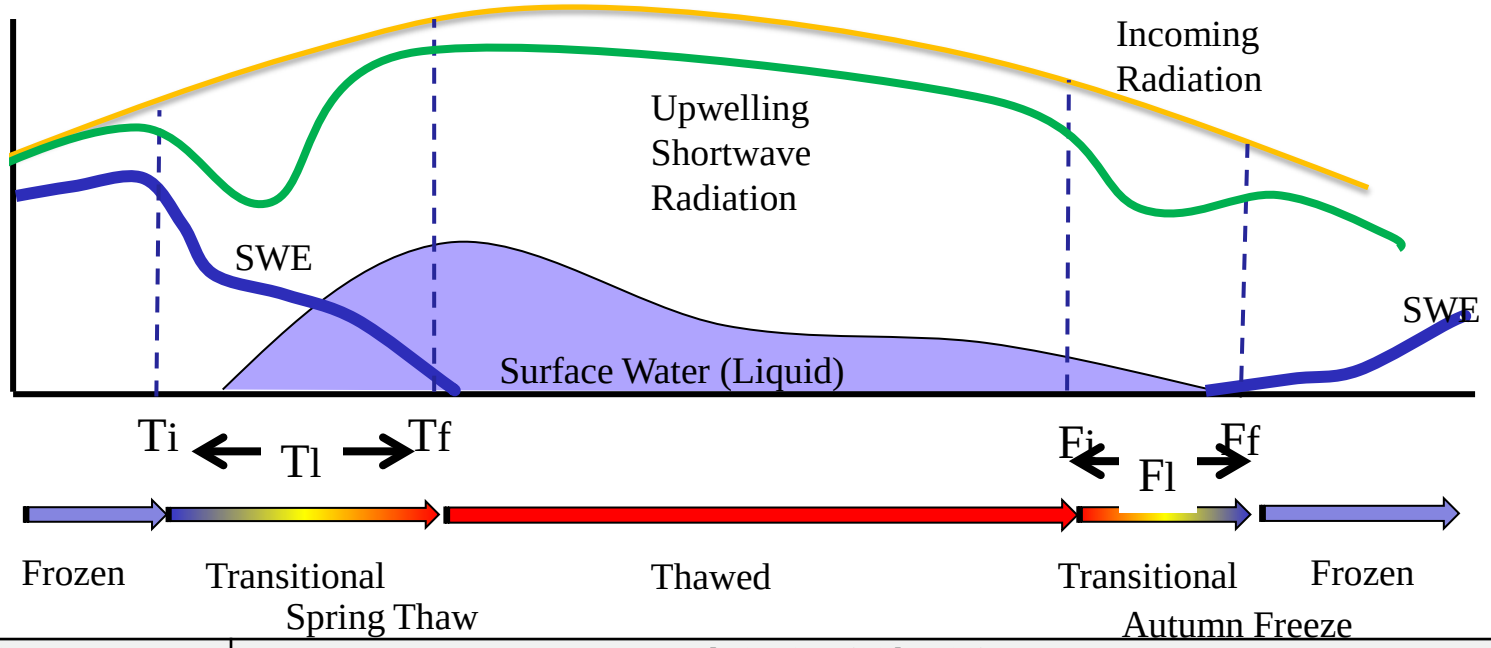
National Climate Assessment Team Meeting
8-9 April 2014
Washington, DC

Development of Integrated Terrestrial Surface Water State Indicators for Climate Assessment

Motivation

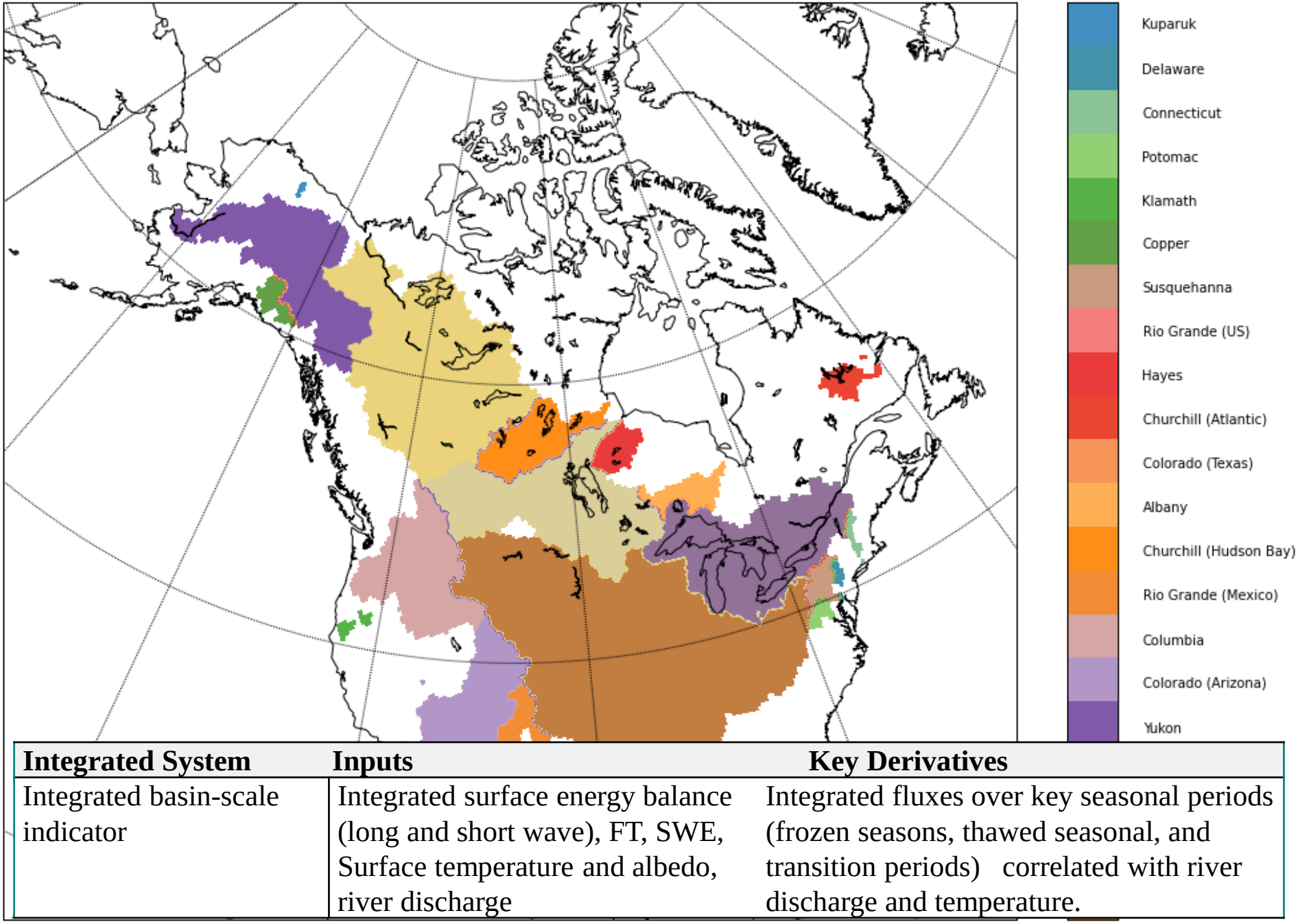
Accurate characterization of seasonal freeze/thaw transition timing coupled with accompanying characterization of snowpack water content, surface inundation, and radiation balance give the potential for an unambiguous indication of climate change.

Integrated Terrestrial Surface Water State Indicators



Indicator	Inputs	Key derivatives (with units)
Freeze/thaw: Growing season length Frozen & non-frozen seasons	Landscape freeze/thaw state	Day of thaw start (Ti) & end (Tf) (day of year) Duration of thaw transition (Tl = Tf – Ti) (days) Day of freeze start (Fi) & end (Ff) (day of year) Duration of freeze transition (Fl = Ff – Fi) (days) Annual max & min thawed and frozen areas (km^2) Potential growing season (days)
Land Surface Inundation	Inundated area fraction (Fw) Fw on days of thaw completion and freeze initiation	Days of max. and min. inundation (day of year) Annual max. and min. inundation area (km^2) Annual integrated inundated area days (days * km^2)
Snow melt duration and melt rate	Freeze/thaw state SWE at time of initial thaw	SWE(Ti)/transition length = SWE/(Tf – Ti) (mm/day)
Hydrology - Radiation Balance	Radiative flux; Freeze/thaw state; SWE	Integrated long and short wave radiative flux (upwelling and downwelling) over key seasonal periods (frozen seasons, thawed seasonal, and transition periods) reported by grid cell and by hydrologic basin.

Major River Basins of North America



Integrated System	Inputs	Key Derivatives
Integrated basin-scale indicator	Integrated surface energy balance (long and short wave), FT, SWE, Surface temperature and albedo, river discharge	Integrated fluxes over key seasonal periods (frozen seasons, thawed seasonal, and transition periods) correlated with river discharge and temperature.

Goals

- Develop a suite of surface hydrologic state indicators
- Investigate trends and anomalies individually
- Identify spatial and temporal relationships between indicators.
- Create a web environment where indicators research is available to the public in a clear, intuitive format.

Research Focus

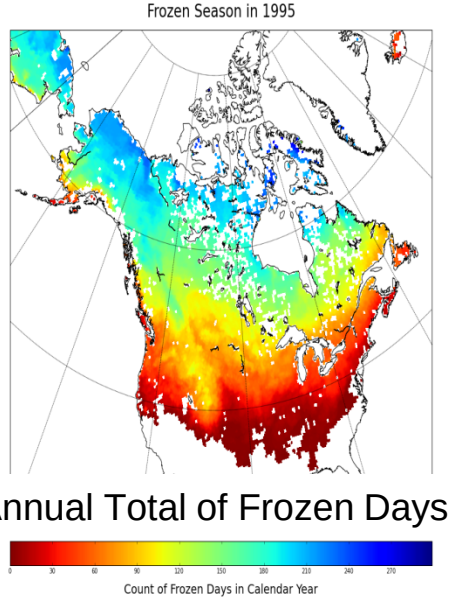
- Investigate indices related to:
  - Landscape freeze/thaw state (FT)
  - Snow water equivalent (SWE)
  - Surface inundation fraction (Fw)
  - Radiative flux
  - River discharge

- Focus on the northern hemisphere & major river basins of North America
  - Pixel-scale assessment for individual data fields
  - Basin-scale assessment for integrative analyses

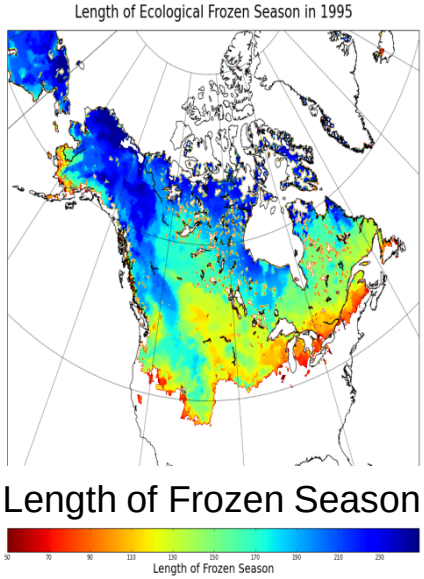
Surface Hydrologic State Indicators Enlisted Source Datasets

Variable	Source Dataset	Start Date	End Date
Freeze-Thaw	SSMI/SMMR Freeze-Thaw	1979	2013
Inundation	Active/Passive Microwave	1992	2013
Snow	GlobSnow	1980	2014
Energy balance	GEWEX SRB	1984	2008
Discharge*	USGS River Discharge	1950	2014
	*** Discharge temporal coverage varies with river basin**		

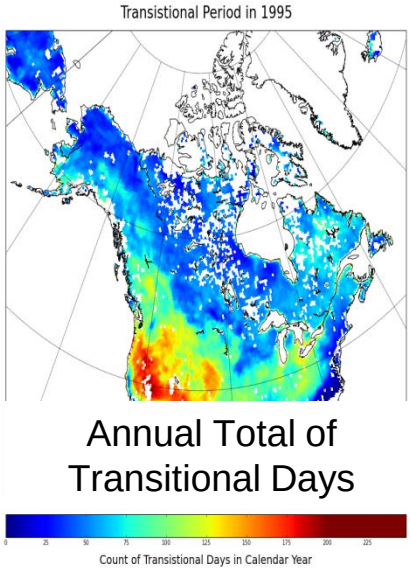
Surface Freeze/Thaw State Indicators



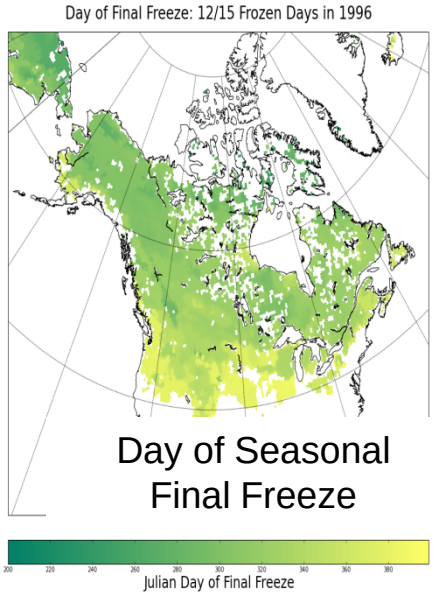
Annual Total of Frozen Days



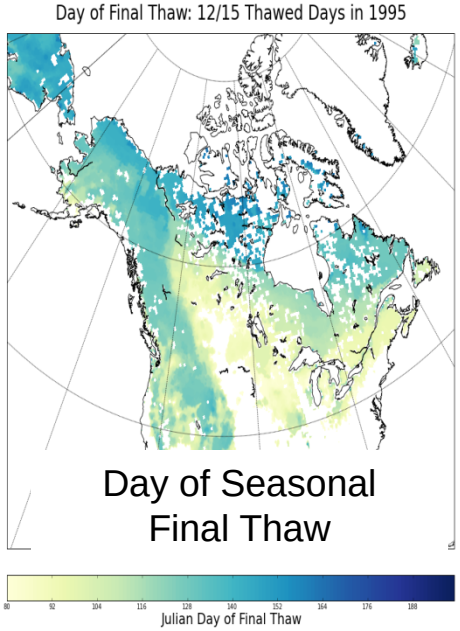
Length of Frozen Season



Annual Total of Transitional Days



Day of Seasonal Final Freeze

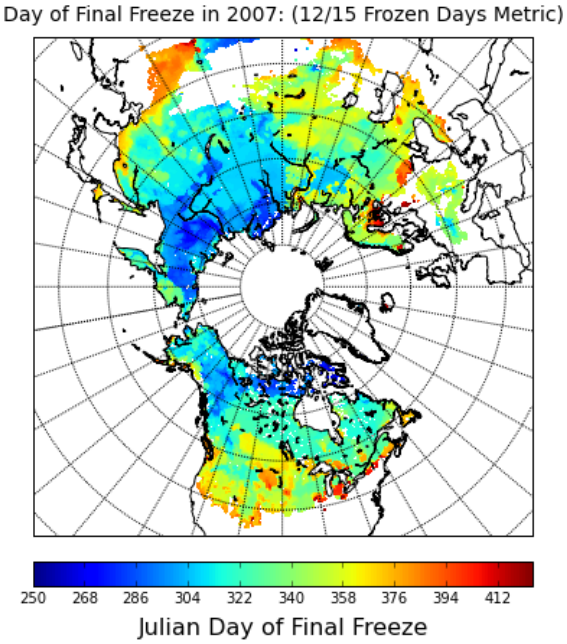


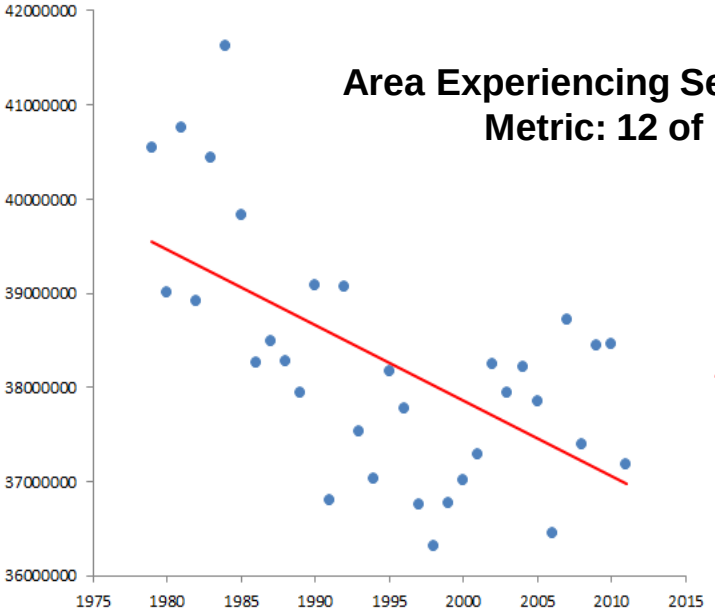
Day of Seasonal Final Thaw

Indicators derived from Freeze/Thaw state:

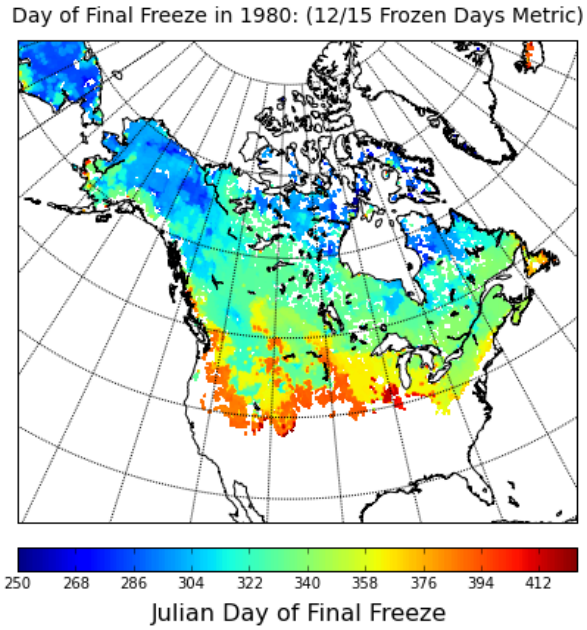
- Day of thaw start
- Day of thaw end
- Duration of thaw transition
- Day of freeze start
- Day of freeze end
- Day of freeze transition
- Potential Growing Season (Ecological Non-Frozen Season)
- Frozen Season (Count of frozen days)
- Seasonal final freeze
- Seasonal final thaw

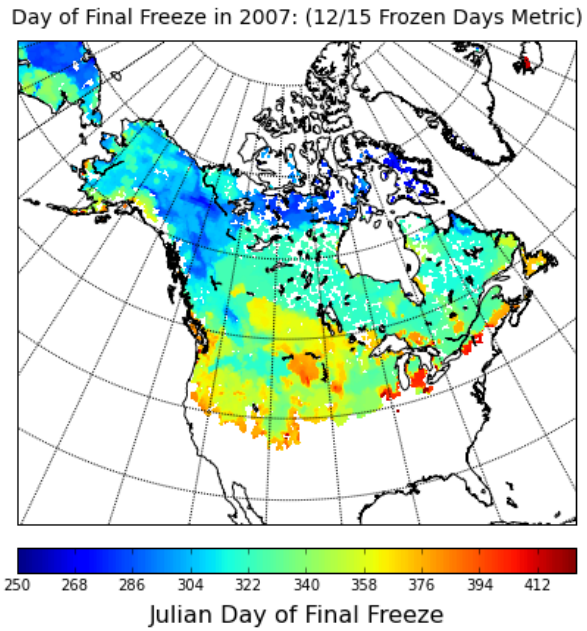
Day of Seasonal Freeze



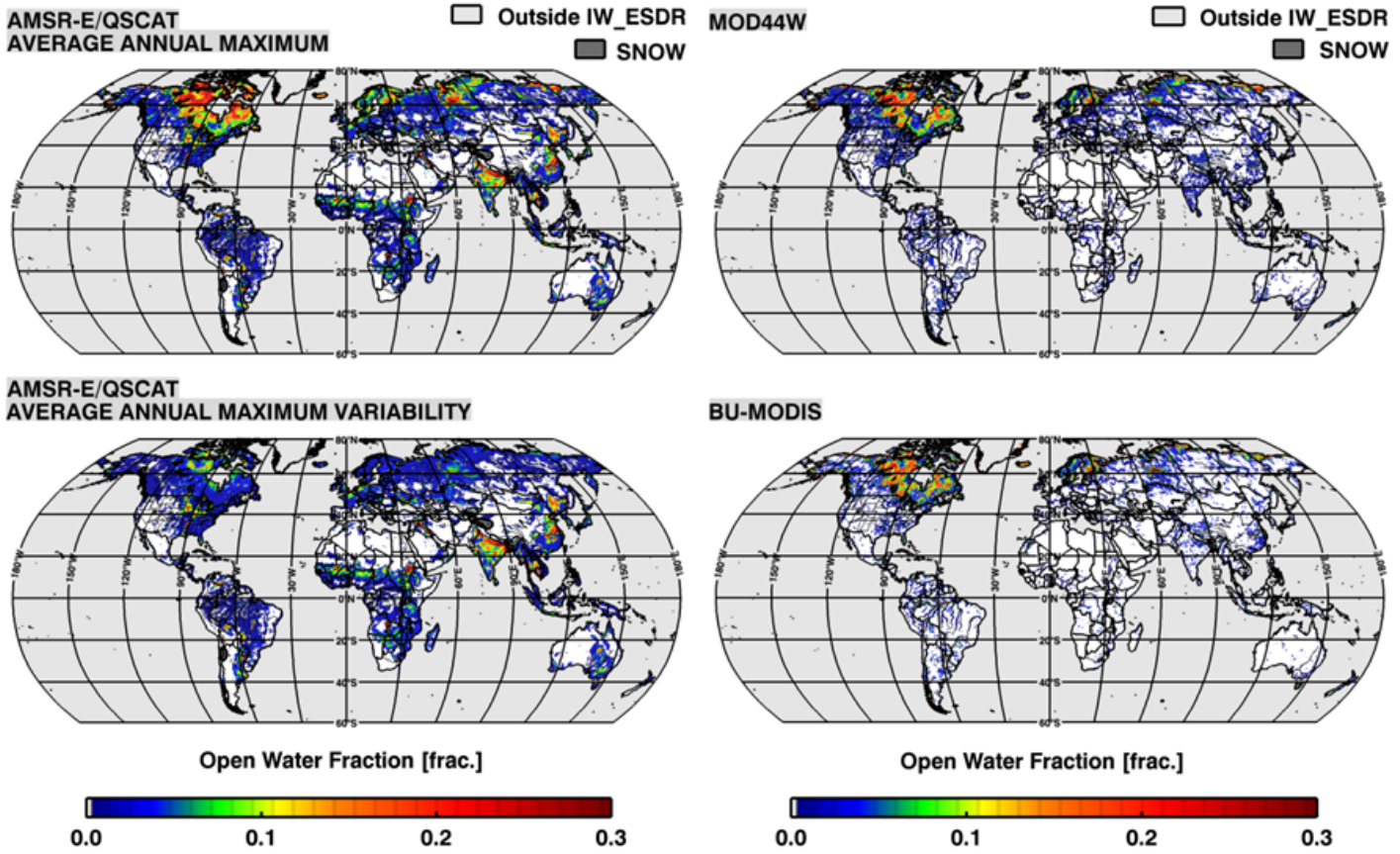


Area Experiencing Seasonal Freeze
Metric: 12 of 15 days frozen

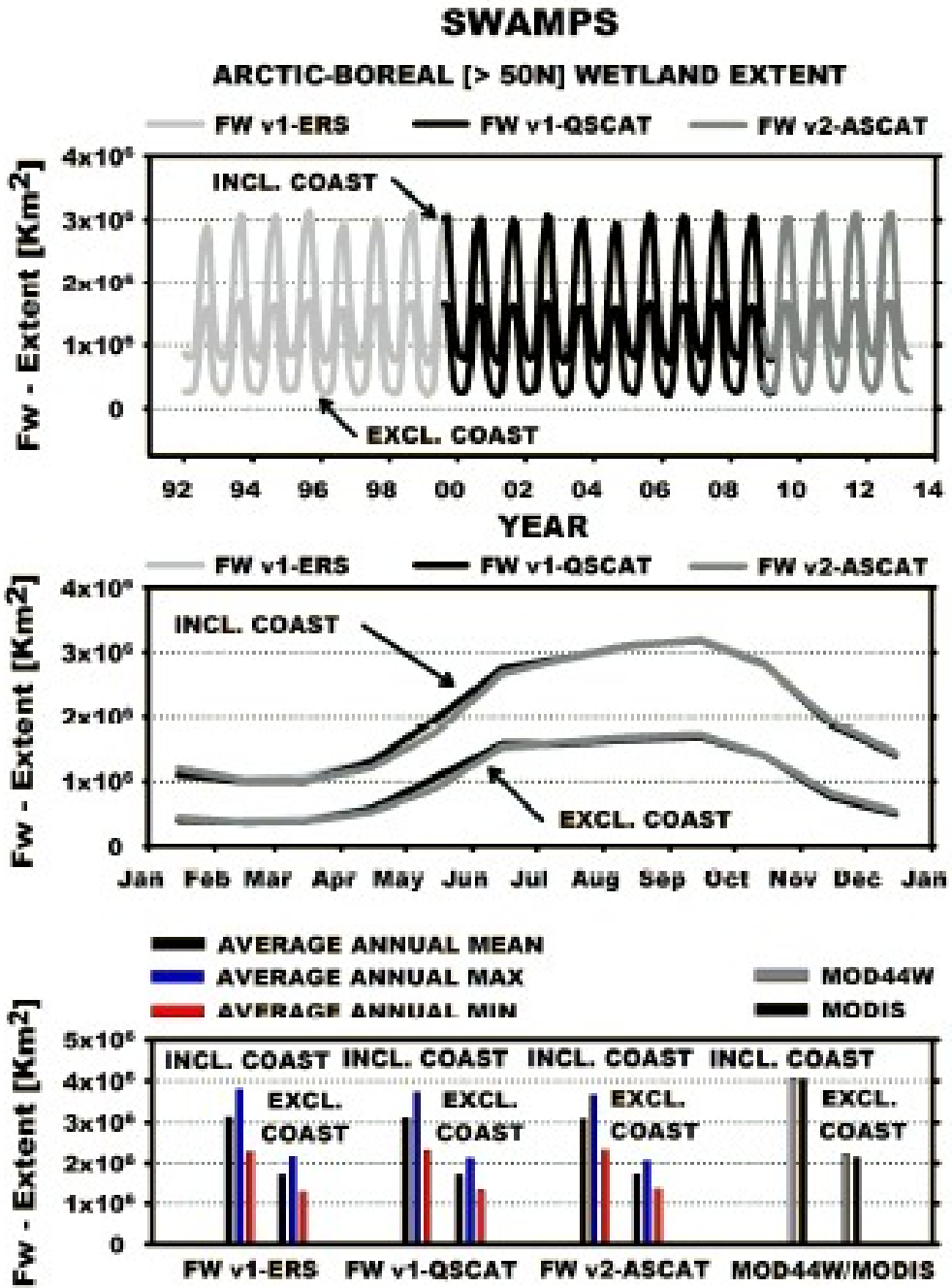




Inundated Area from Active/Passive Microwave 1992-2013



Average annual maximum extent (top left) and average annual maximum variability (bottom left) as obtained from 7+ years of the Fw dataset. For comparison, the static high-resolution 250 m land-water mask from MODIS-SRTM (MOD44W) (top right) and the Boston University MOD12Q1 V004 (BU-MODIS) permanent open water and wetland distribution map (bottom right) are shown (Schroeder et al. 2014)



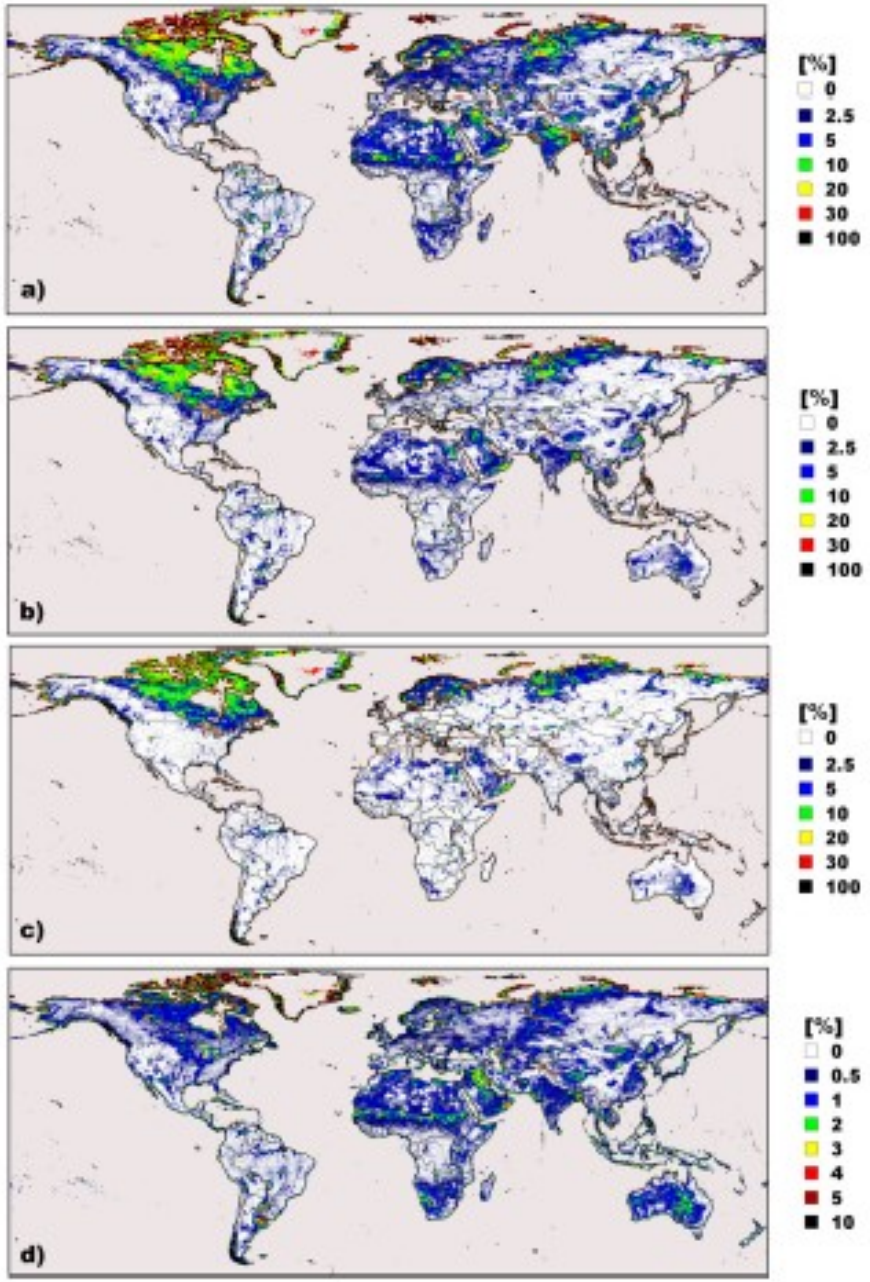
Seasonal progression of surface inundation (FW) extent for high latitudes

Derived from monthly average FW

1992-2013

Global Fw Distribution (from monthly means)

FW V1-ERS, V1-QSCAT (1992-2008)



Average Annual Maximum

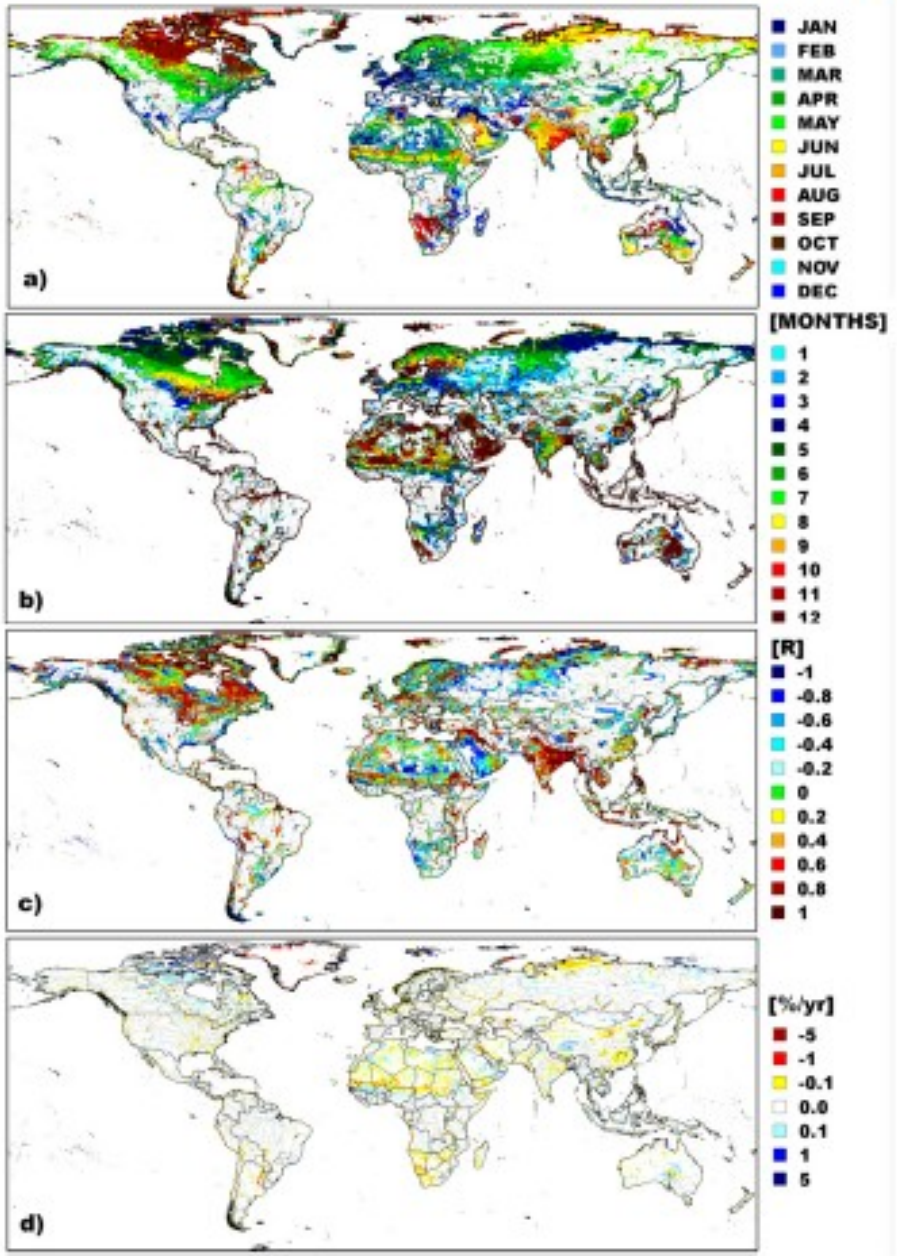
Average Annual Mean

Average Annual Minimum

Variability of the Annual Mean (StdDev)

Global Fw (from monthly means, Fw > 1%)

FW V1-ERS, V1-QSCAT (1992-2008)



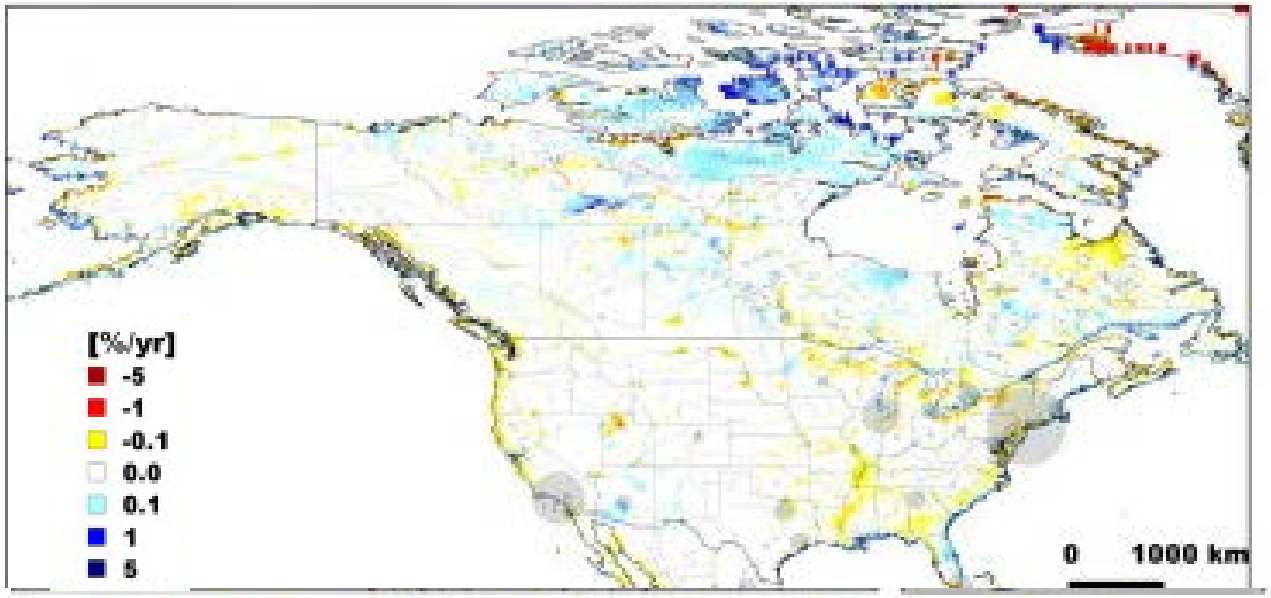
Month of Maximum Fw

Fw Duration

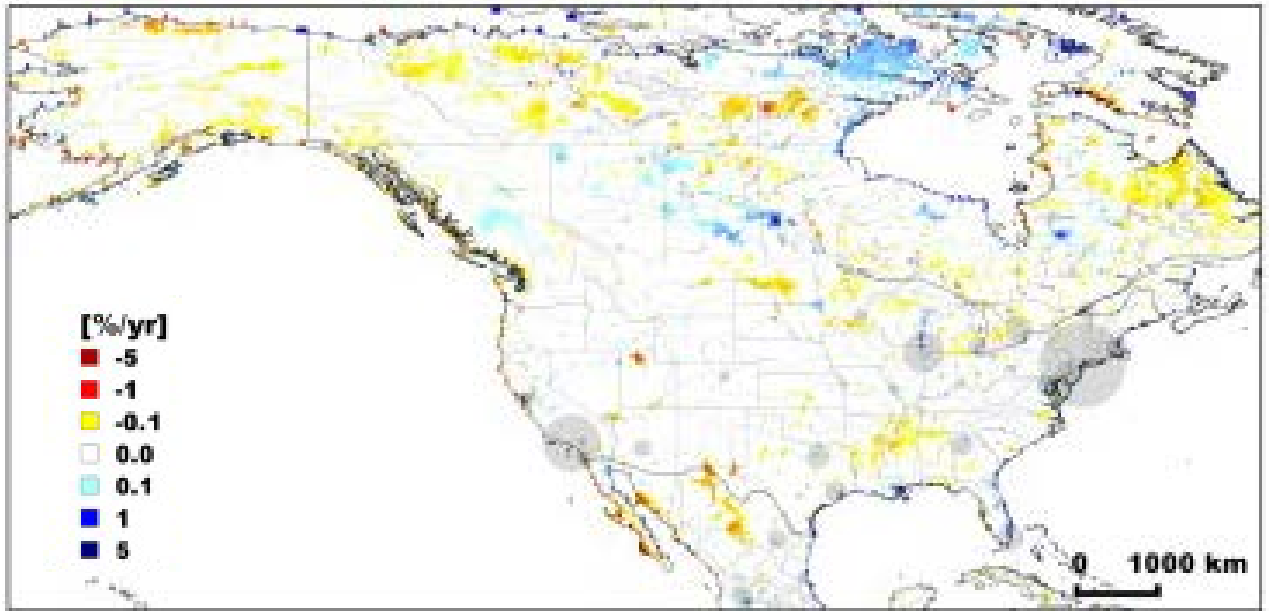
Correlation Precipitation/Fw

Trend of Annual Means

Annual Trends in Surface Inundation



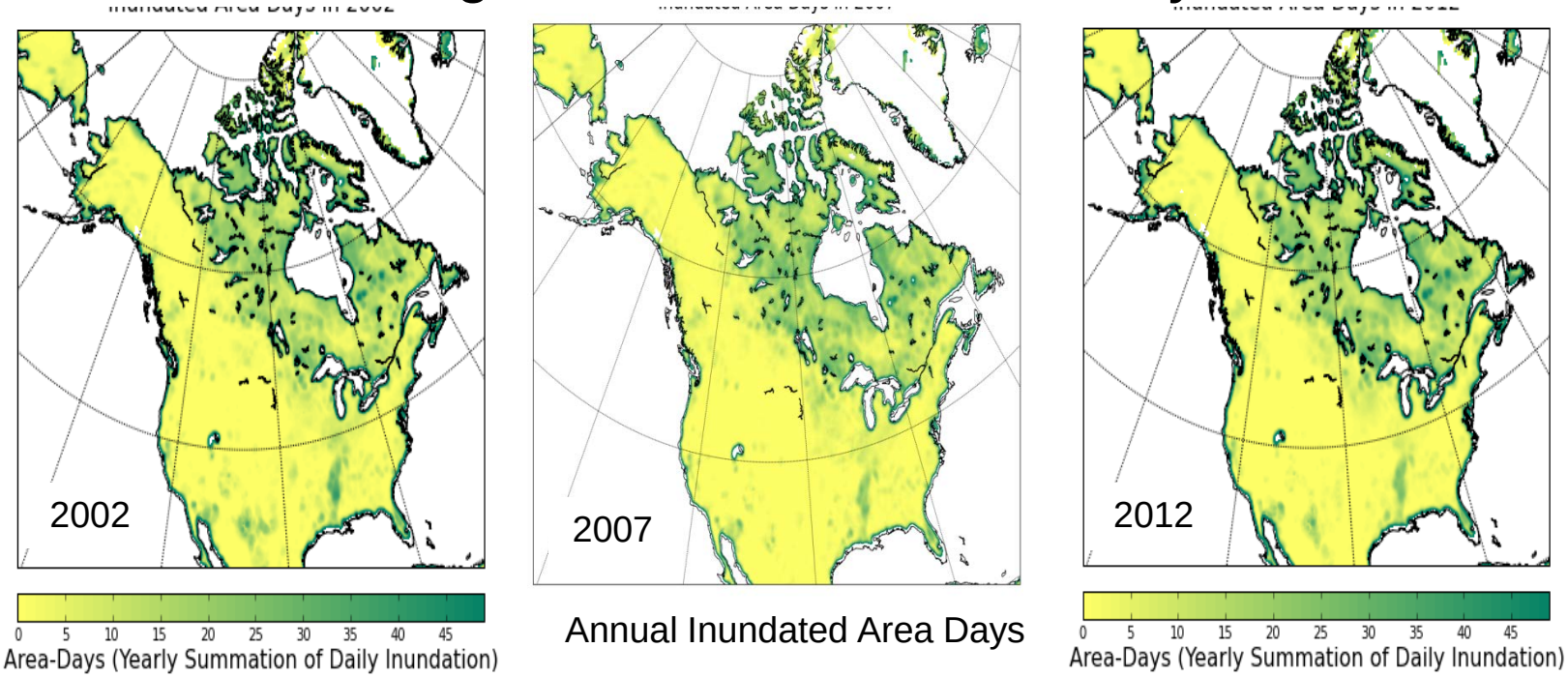
1992 - 2008



2000 - 2008

Surface Inundation Indicators

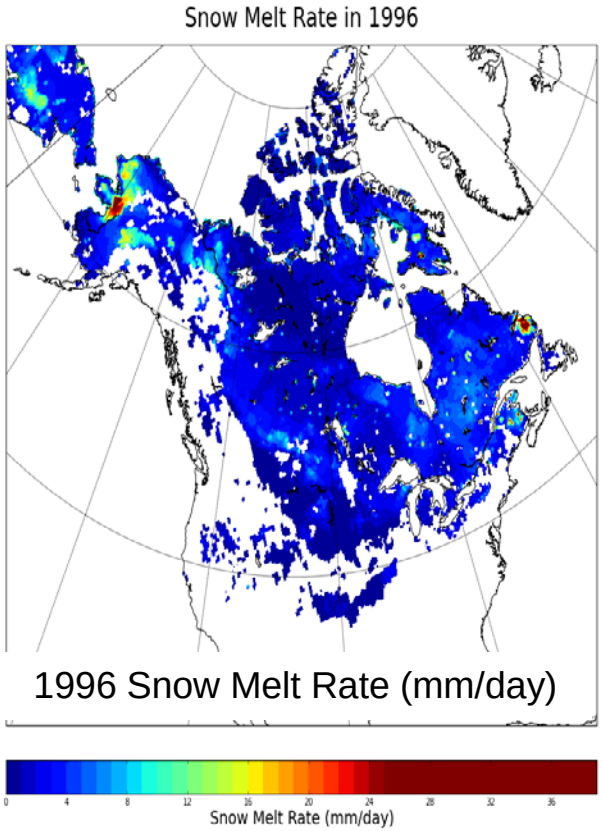
Integrated Inundated Area Days

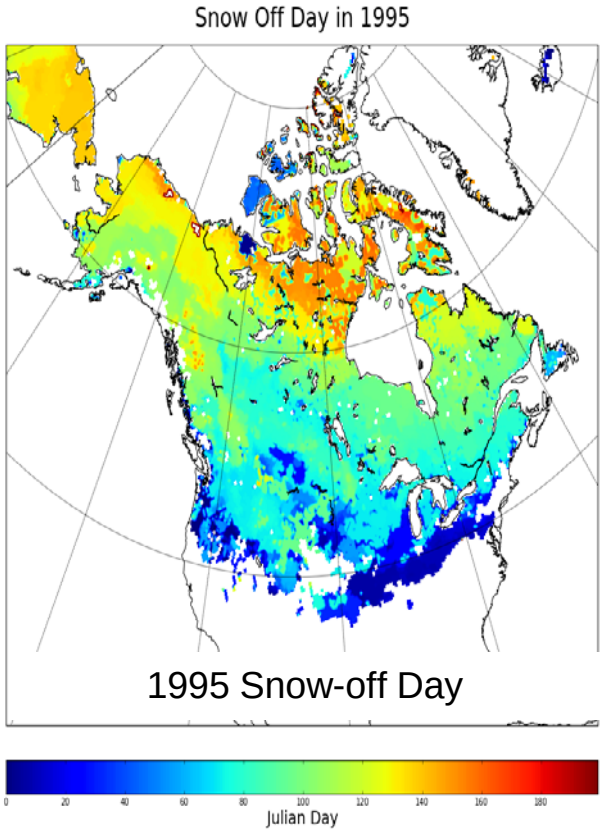


Indicators Derived from Surface Inundation:

- Day of min inundation
- Day of max inundation
- Annual max inundated area
- Annual min inundated area
- Integrated inundated area days (Shown above)

Snow State Indicators

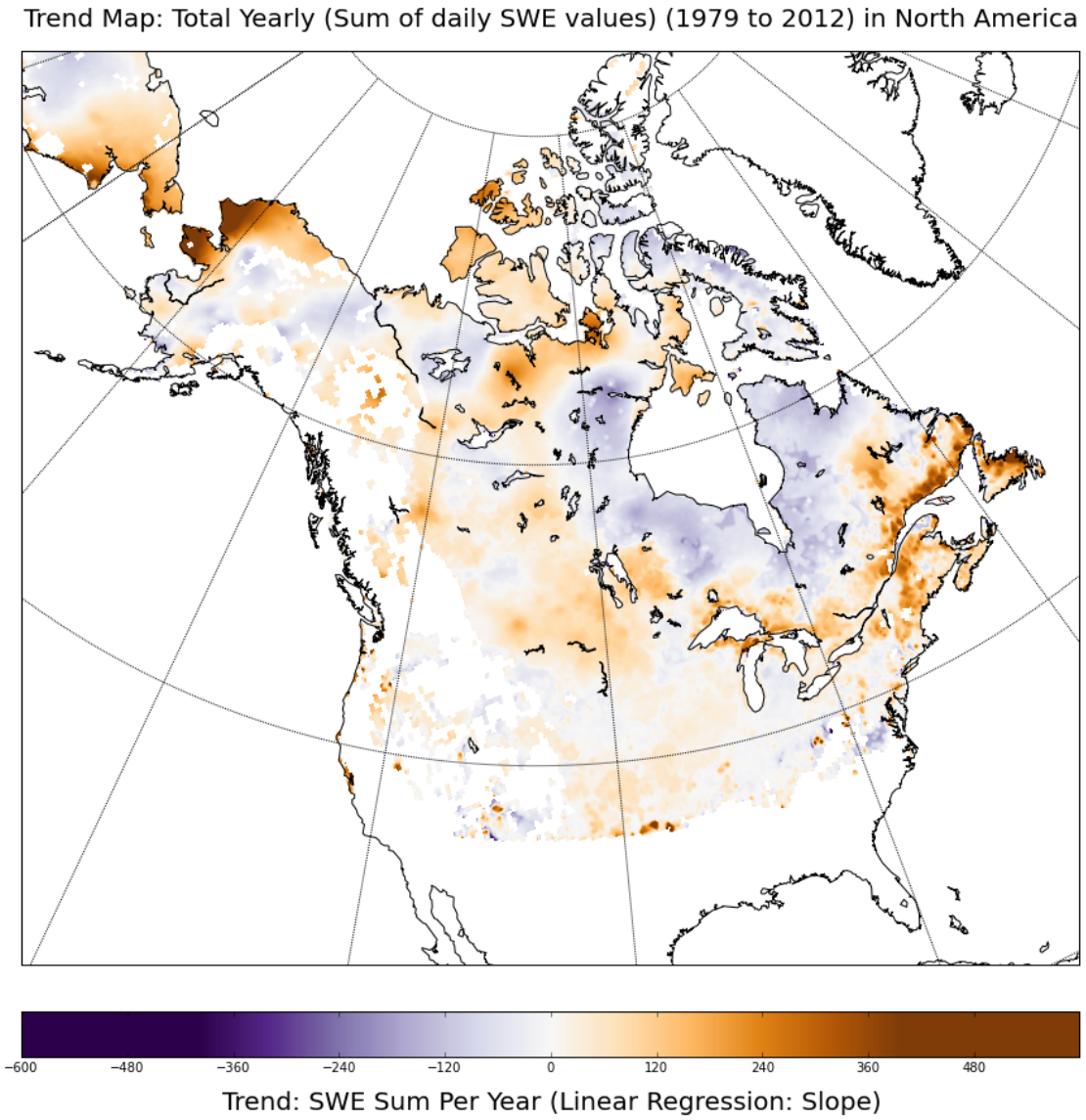




Indicators Derived from Snow Properties:

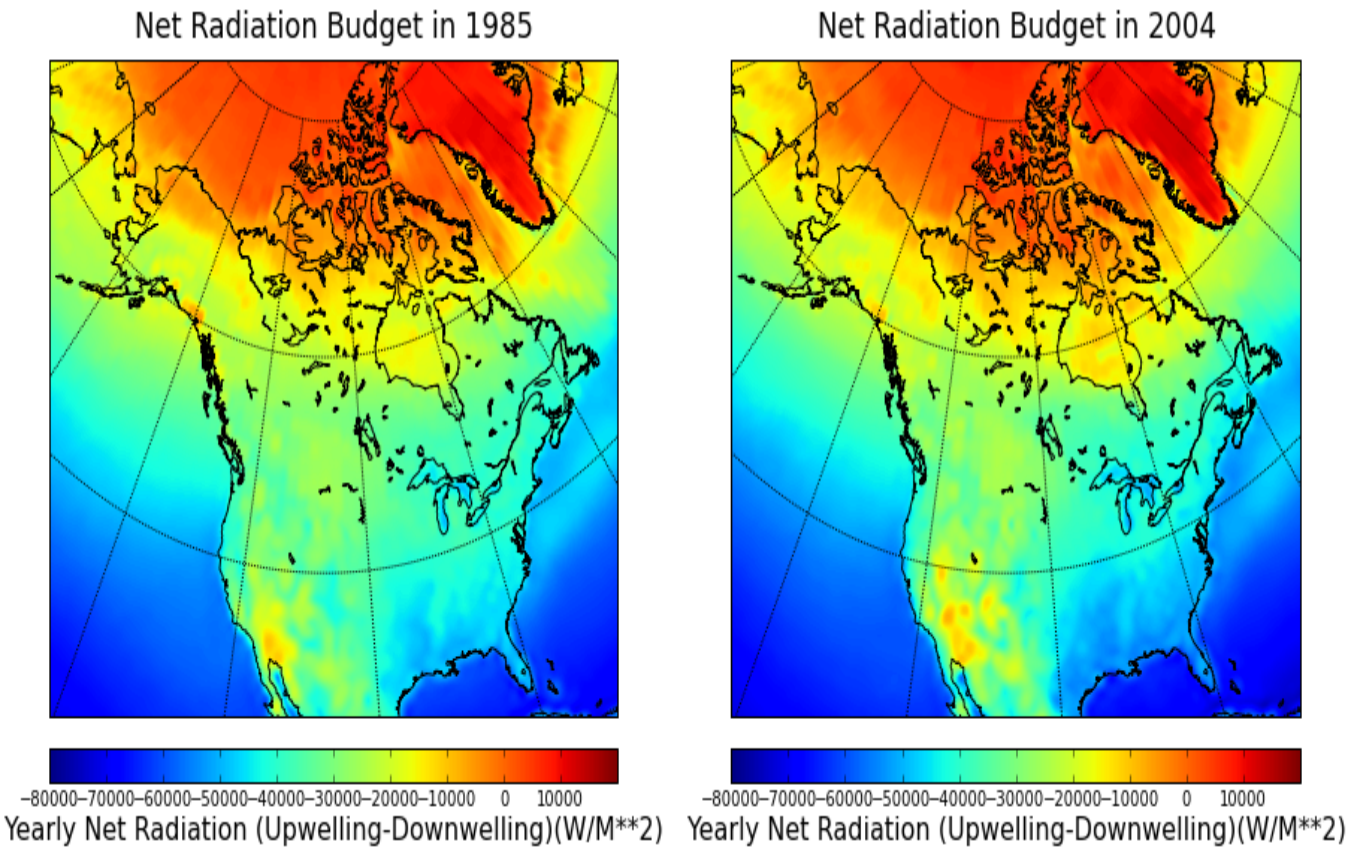
- Snow melt rate
- Snow free season
- Snow off day

Snow Water Equivalent Metric: Yearly Sums



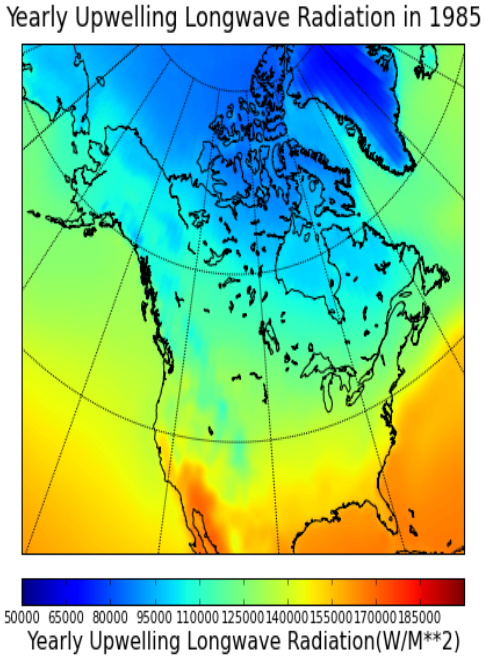
- Based on GlobSnow
- Summation of daily SWE values over a given year
- Combined metric for amount of yearly snow & length of snow cover

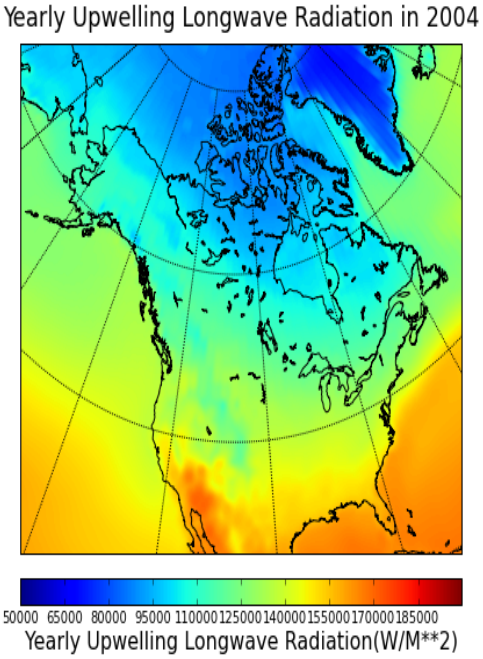
Radiation Balance

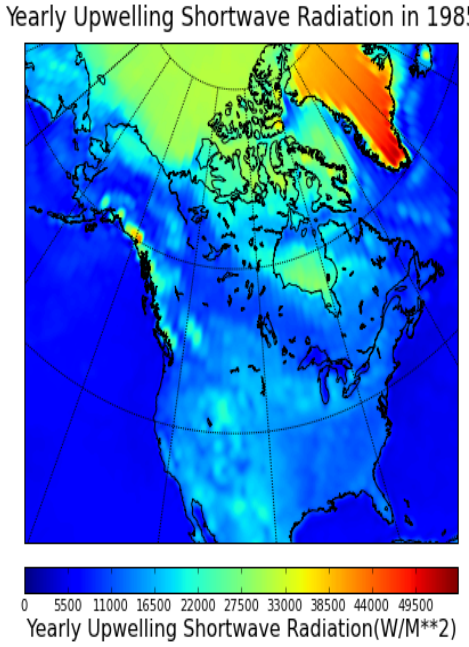


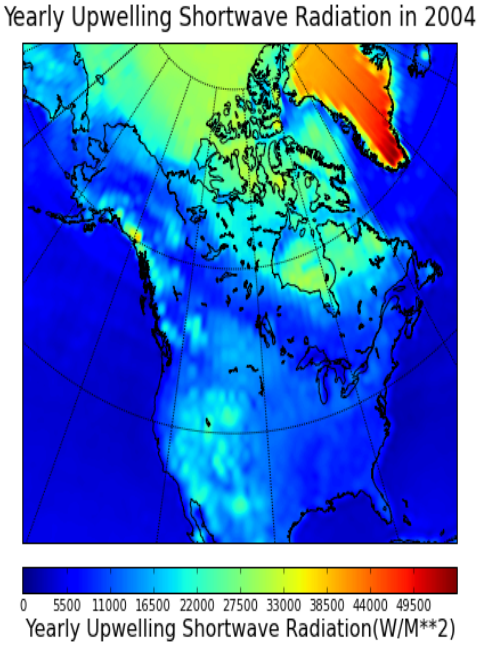
Metrics from radiation balance

- Net radiation balance
- Shortwave upwelling radiation
- Longwave upwelling Radiation
- Metrics still being explored and derived





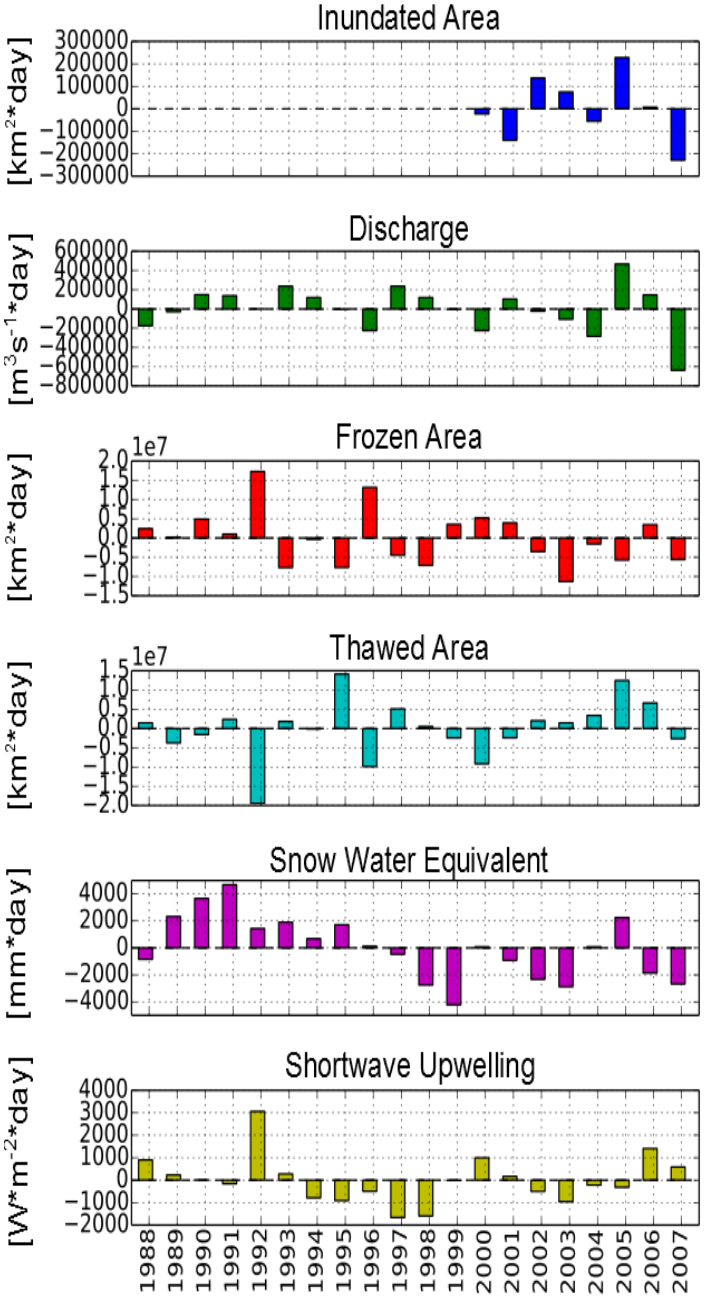




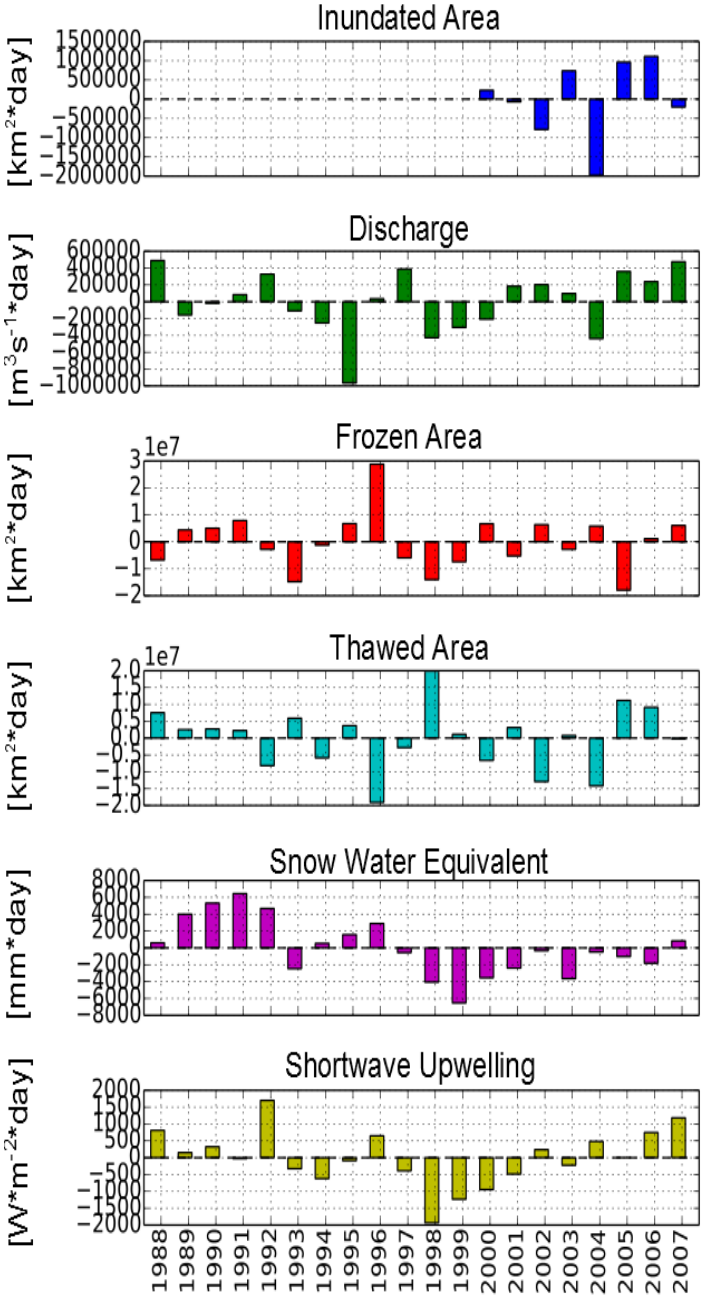
Radiation Balance

- Heat transport
- Surface temperature
- Surface albedo

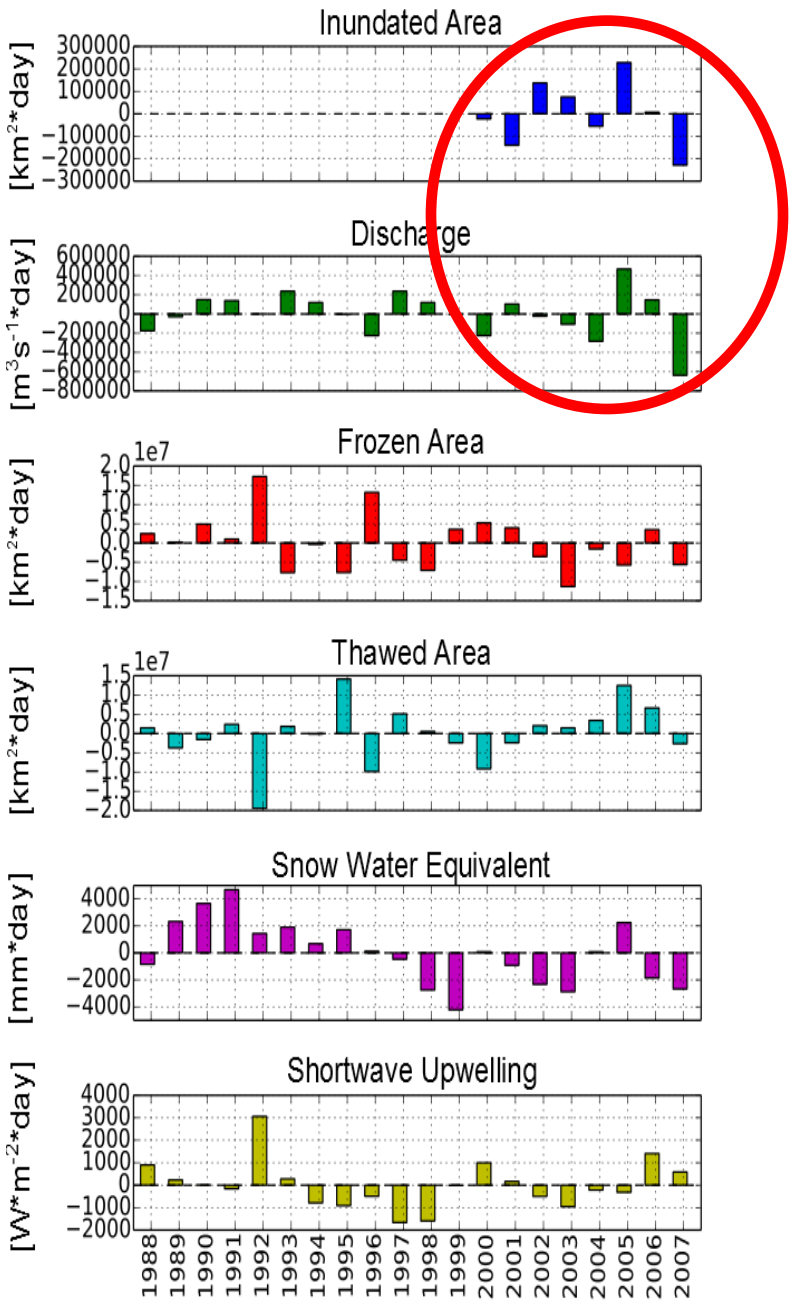
Yukon Basin Anomalies [1988-2008]



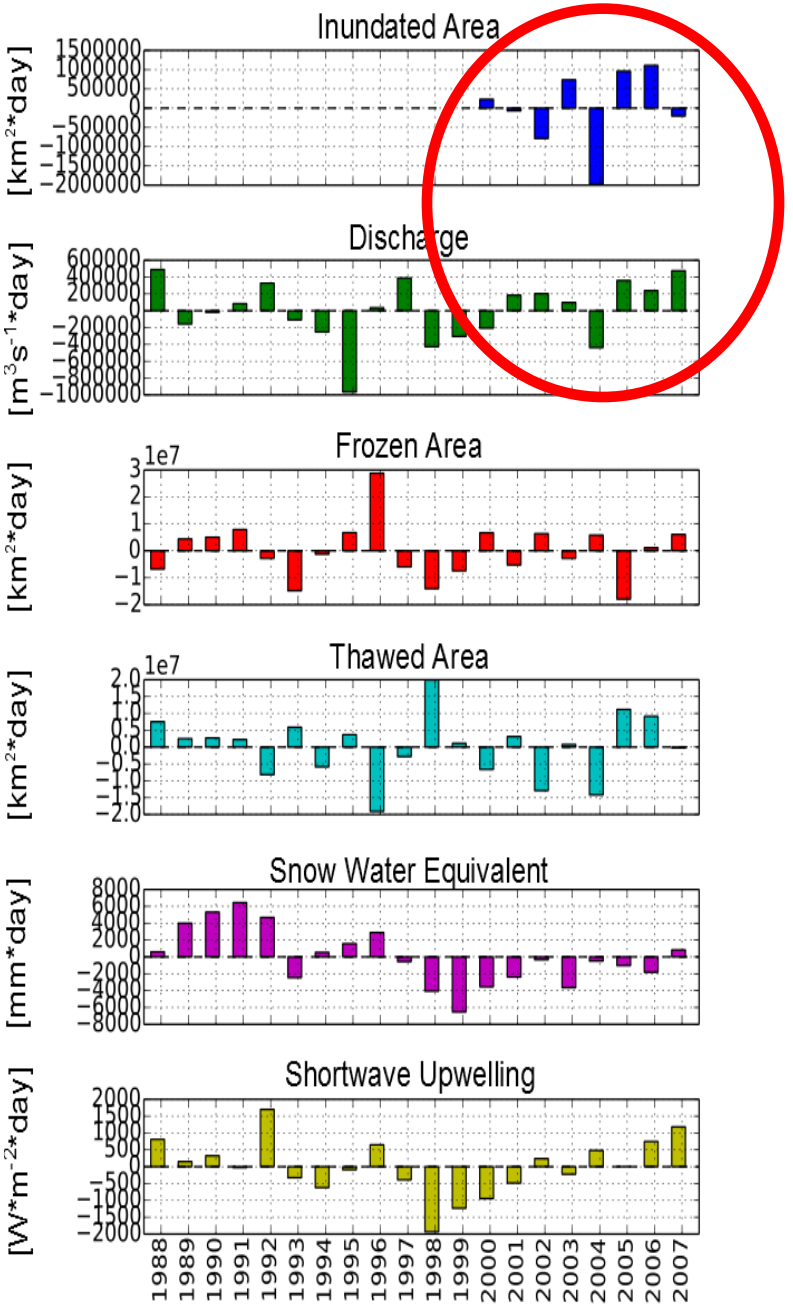
Mackenzie Basin Anomalies [1988-2008]



Yukon Basin Anomalies [1988-2008]



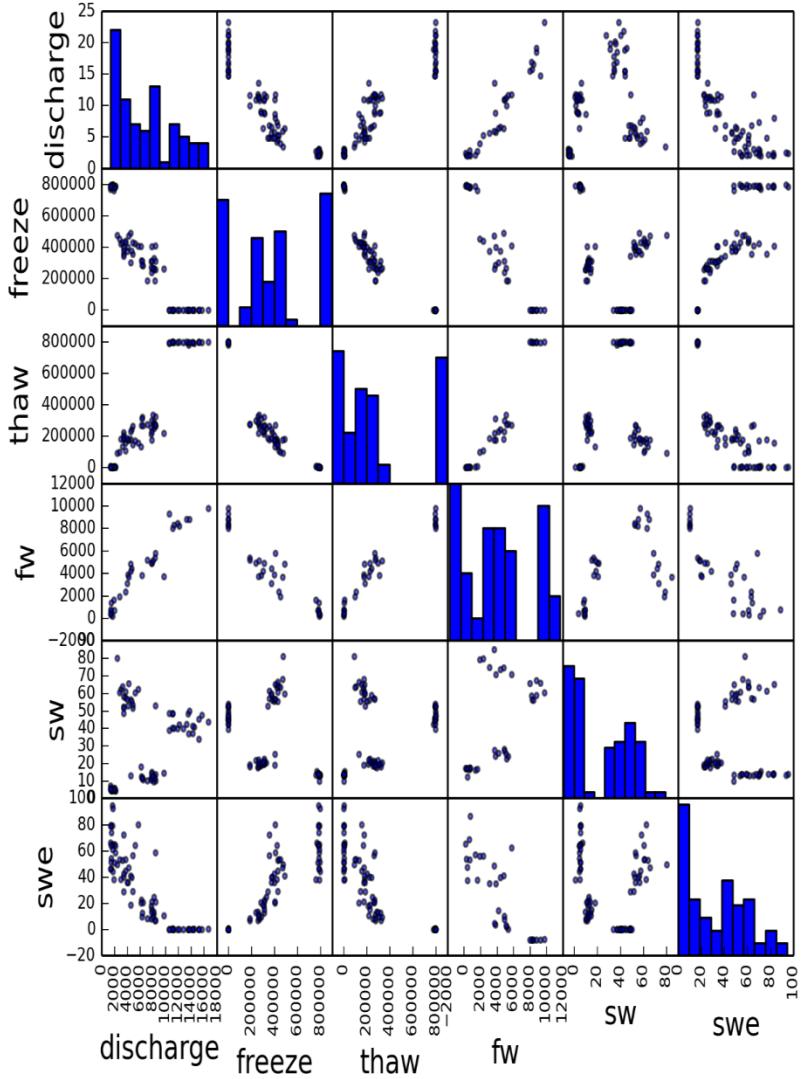
Mackenzie Basin Anomalies [1988-2008]



Yukon Seasonal Aggregate Correlation Analysis [1988-2008]

Yukon Basin						
	discharge	freeze	thaw	fw	sw	swe
discharge	1.00	-0.92	0.94	0.95	0.30	-0.84
freeze	-0.92	1.00	-0.92	-0.95	-0.50	0.87
thaw	0.94	-0.92	1.00	0.96	0.41	-0.81
fw	0.95	-0.95	0.96	1.00	0.52	-0.82
sw	0.30	-0.50	0.41	0.52	1.00	-0.16
swe	-0.84	0.87	-0.81	-0.82	-0.16	1.00

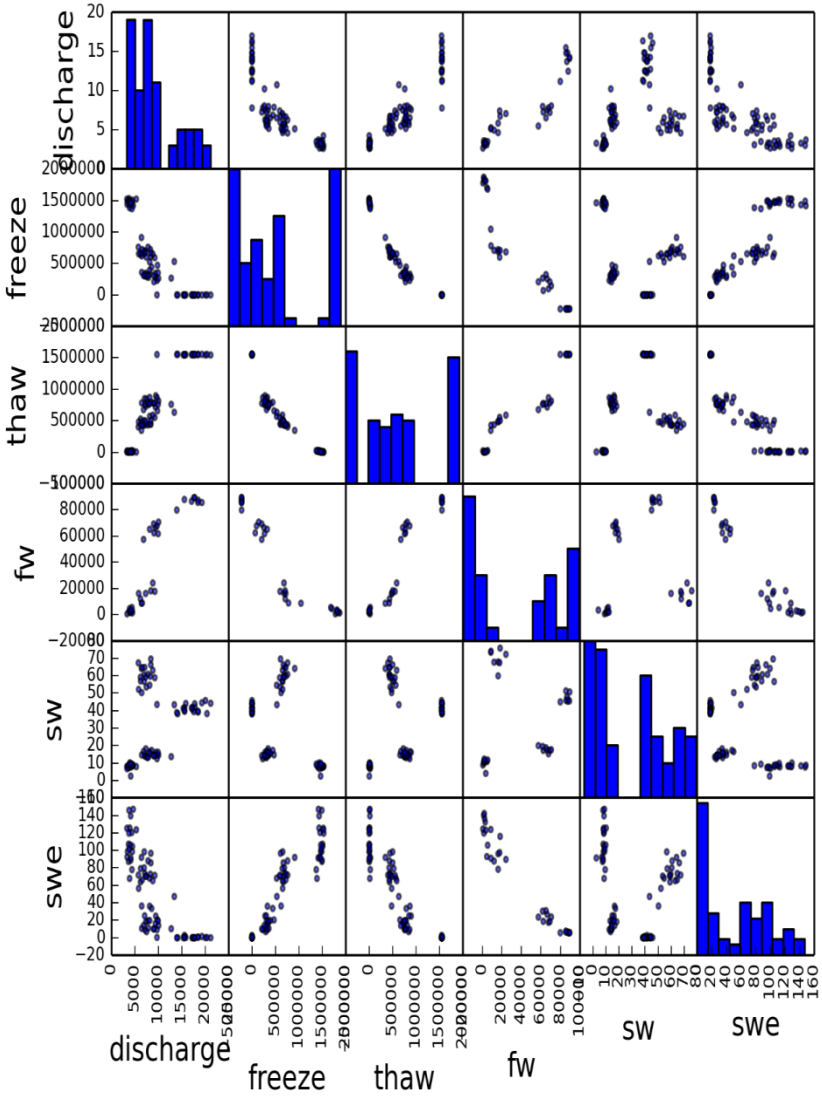
Pearson's R



Mackenzie Seasonal Aggregate Correlation Analysis [1988-2008]

Mackenzie Basin						
	discharge	freeze	thaw	fw	sw	swe
discharge	1.00	-0.83	0.93	0.89	0.38	-0.77
freeze	-0.83	1.00	-0.94	-0.92	-0.43	0.92
thaw	0.93	-0.94	1.00	0.94	0.37	-0.89
fw	0.89	-0.92	0.94	1.00	0.09	-0.97
sw	0.38	-0.43	0.37	0.09	1.00	-0.17
swe	-0.77	0.92	-0.89	-0.97	-0.17	1.00

Pearson's R

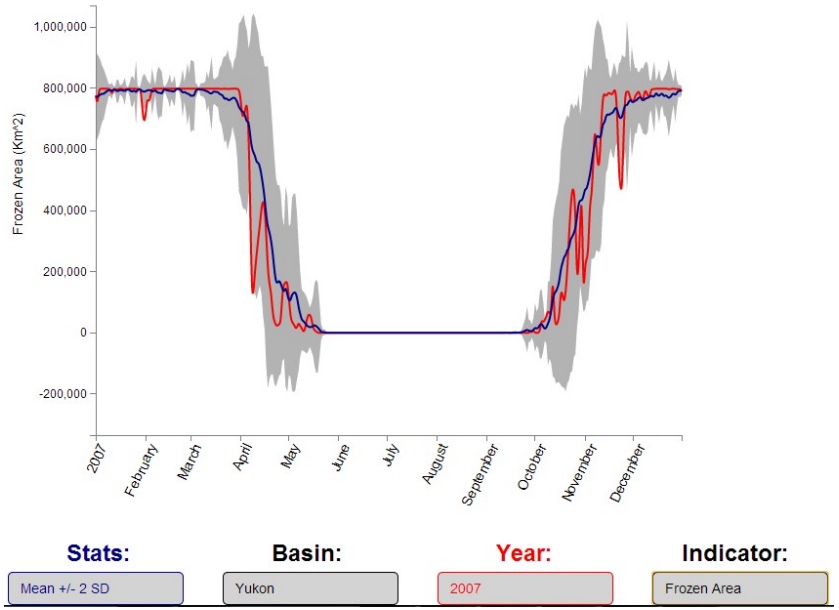


Web Tool Development

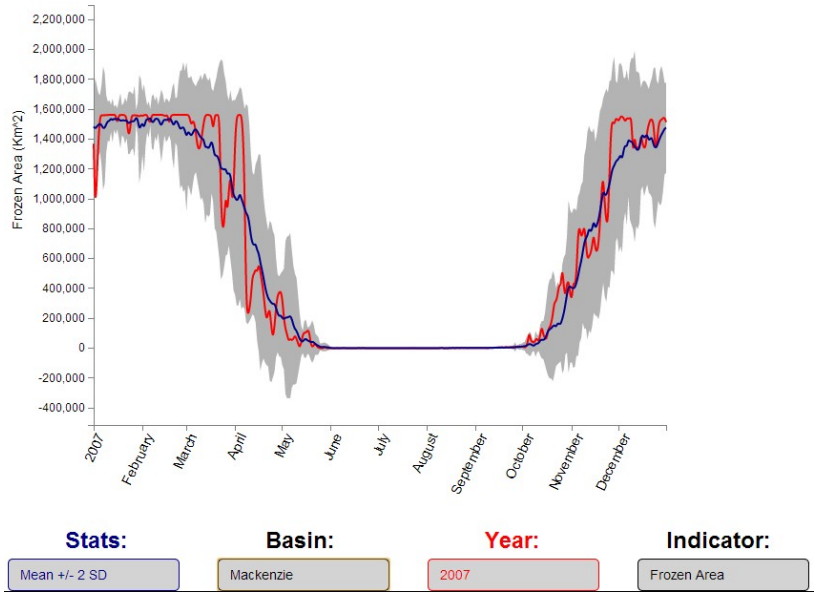
- Webpage is currently under development
- A JavaScript/HTML charting tool has been developed for displaying indicators in a web portal
- This charting tool allows the user to select the following: type of indicator, river basin, year, and indicator climatology statistics (mean and SD)

Web Tool Development

Basin-scale Examination of Indicators



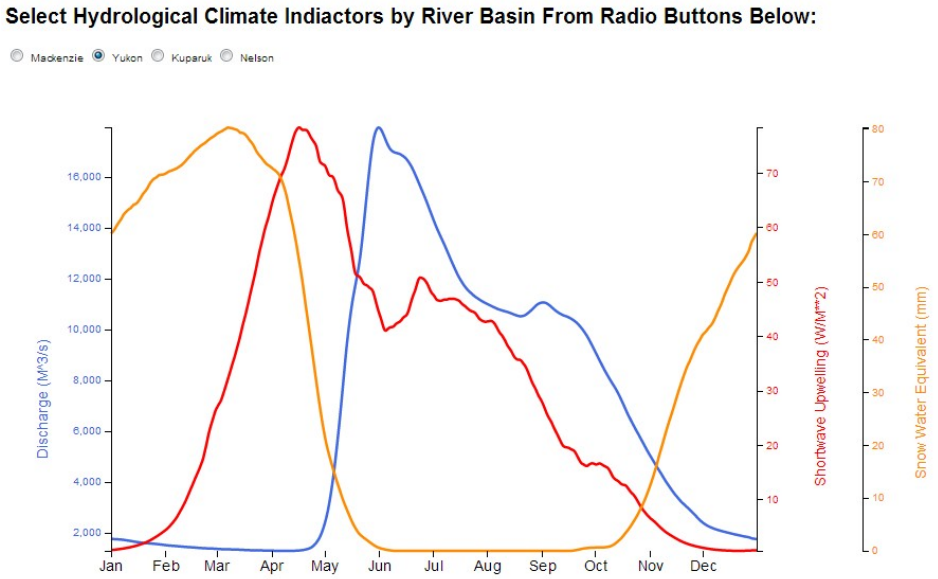
Yukon Basin Frozen Area 2007



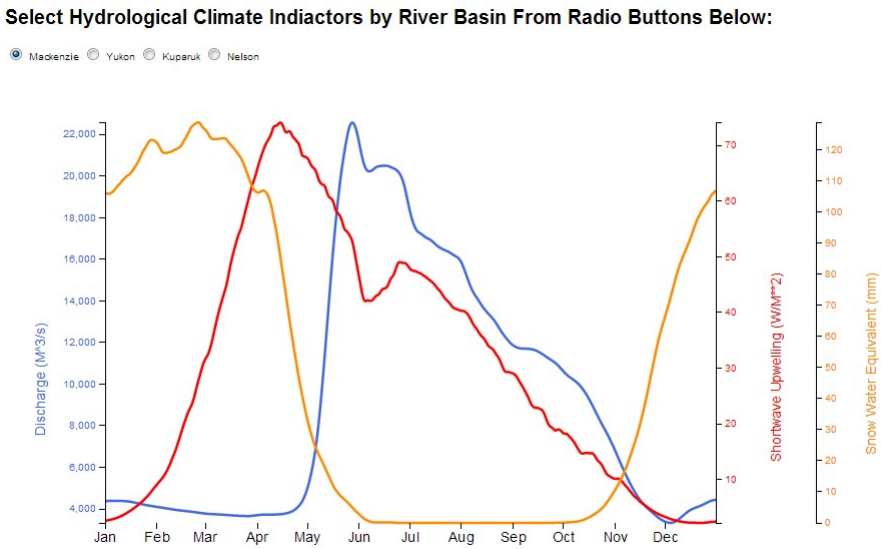
Mackenzie Basin Frozen Area 2007

Web Tool Development

Basin-scale Examination of Indicators



Yukon Basin Multiple Indicators



Mackenzie Basin Frozen Area

Indicators Displayed:

- Discharge
- SWE
- Shortwave Upwelling Radiation

Next Steps:

- Complete integrative analysis of surface hydrology indicators and metrics
- Define functional dependencies between these indicators and assess how they may be changing across years
    - Potentially indicative of system state changes
    - Examine correlation to positive and negative phases in ENSO, AO, NAO, and PDO
- Mature web portal
- Operationalization of dataset generation
- Develop user community
- Synthesis with other indicators