SMAP Freeze/Thaw and Carbon Cycle Science Activities

John Kimball[1,2]

[1]Numerical Terradynamic Simulation Group, University of Montana, USA.

[2]Flathead Lake Biological Station, Division of Biological Sciences, Univ. MT.

In collaboration with: Steve Running (NTSG) and Kyle McDonald (NASA JPL).

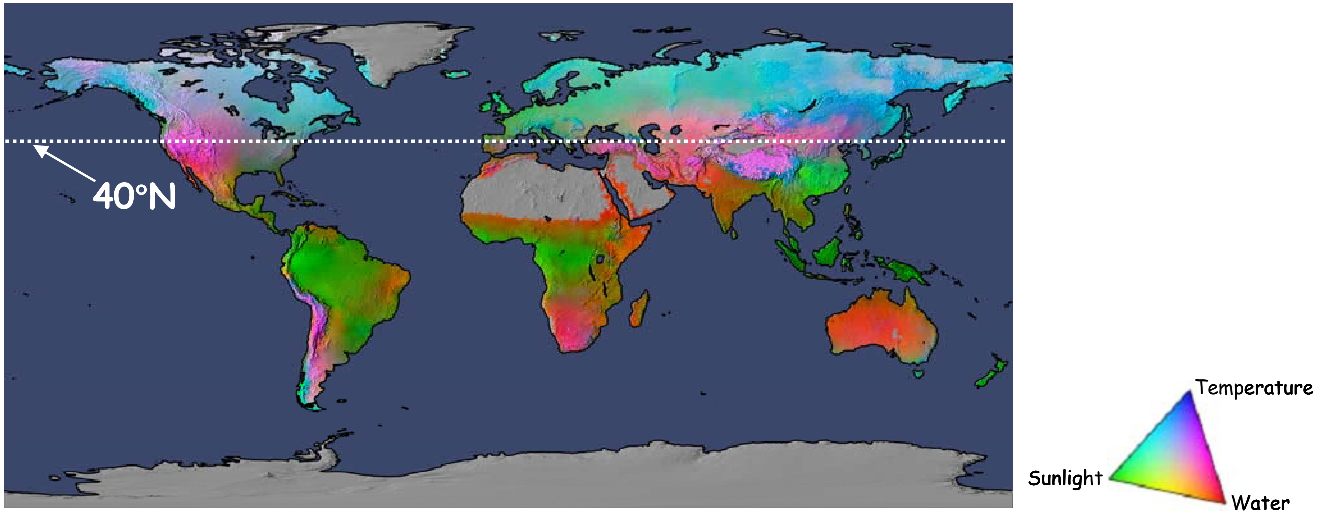
SMAP Freeze/Thaw Science Goal: To quantify the nature, extent, timing and duration of landscape seasonal freeze/thaw state transitions for improved understanding of ecosystem processes.

- Domain: Areas of the terrestrial biosphere where low temperatures constrain land-atmosphere water, energy and carbon exchange.

- Critical: Areas above 40 degrees N latitude or 1000m elevation where cold temperatures are a major constraint to vegetation productivity and land-atmosphere carbon exchange.

- Beneficial: Global, wall-to-wall coverage including all frost affected land.

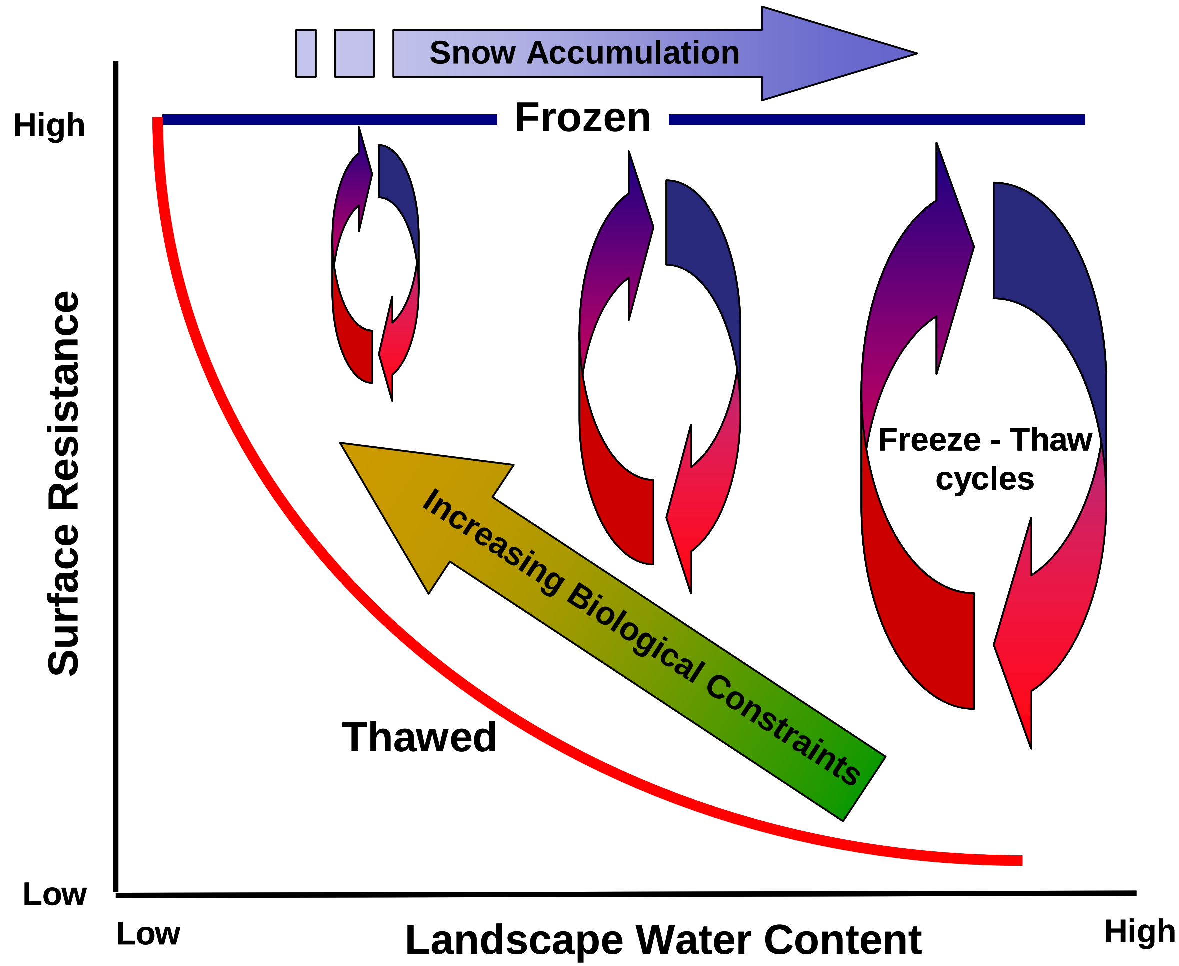
Potential Climate Limitations to Land-Atmosphere Water, Energy and Carbon Exchange



Nemani, R.R., et al., 2003. *Science*, 300, 1560-1563.

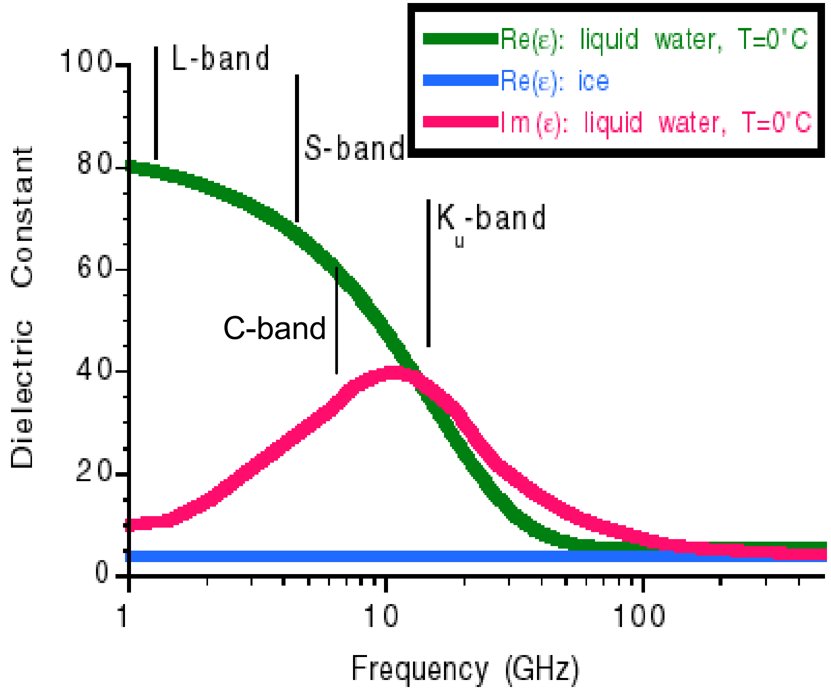
Terrestrial Water Mobility Constraints to Ecosystem Processes

Conceptual relationship between landscape water content and associated environmental constraints to ecosystem processes including land-atmosphere carbon, water and energy exchange and vegetation productivity. **The SMAP mission will provide a direct measure of changes in landscape water content and freeze/thaw status for monitoring terrestrial water mobility controls on ecosystem processes.**

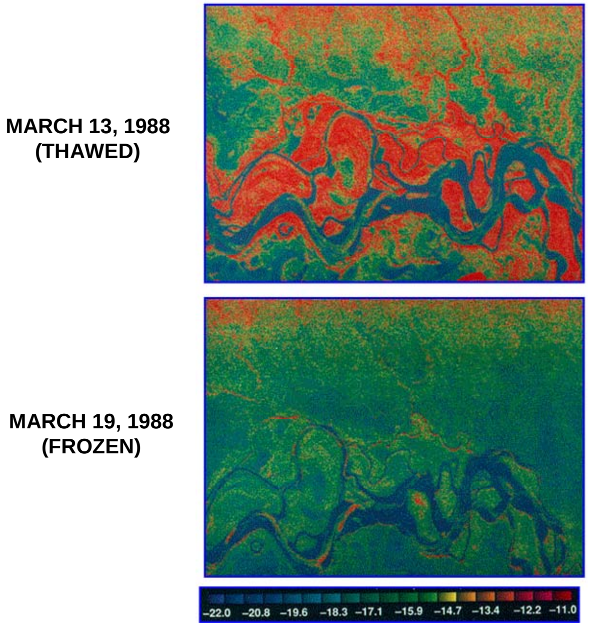


Source: Running, S.W., and J.S. Kimball, 2005. Satellite-based analysis of ecological controls for land-surface evaporation resistance. Encyclopedia of Hydrological Sciences. Part 9, Ecological and Hydrological Interactions. DOI: 10.1002/0470848944.hsal10.

L-Band Sensitivity to Landscape Freeze-Thaw State Change



Bonanza Creek, AK

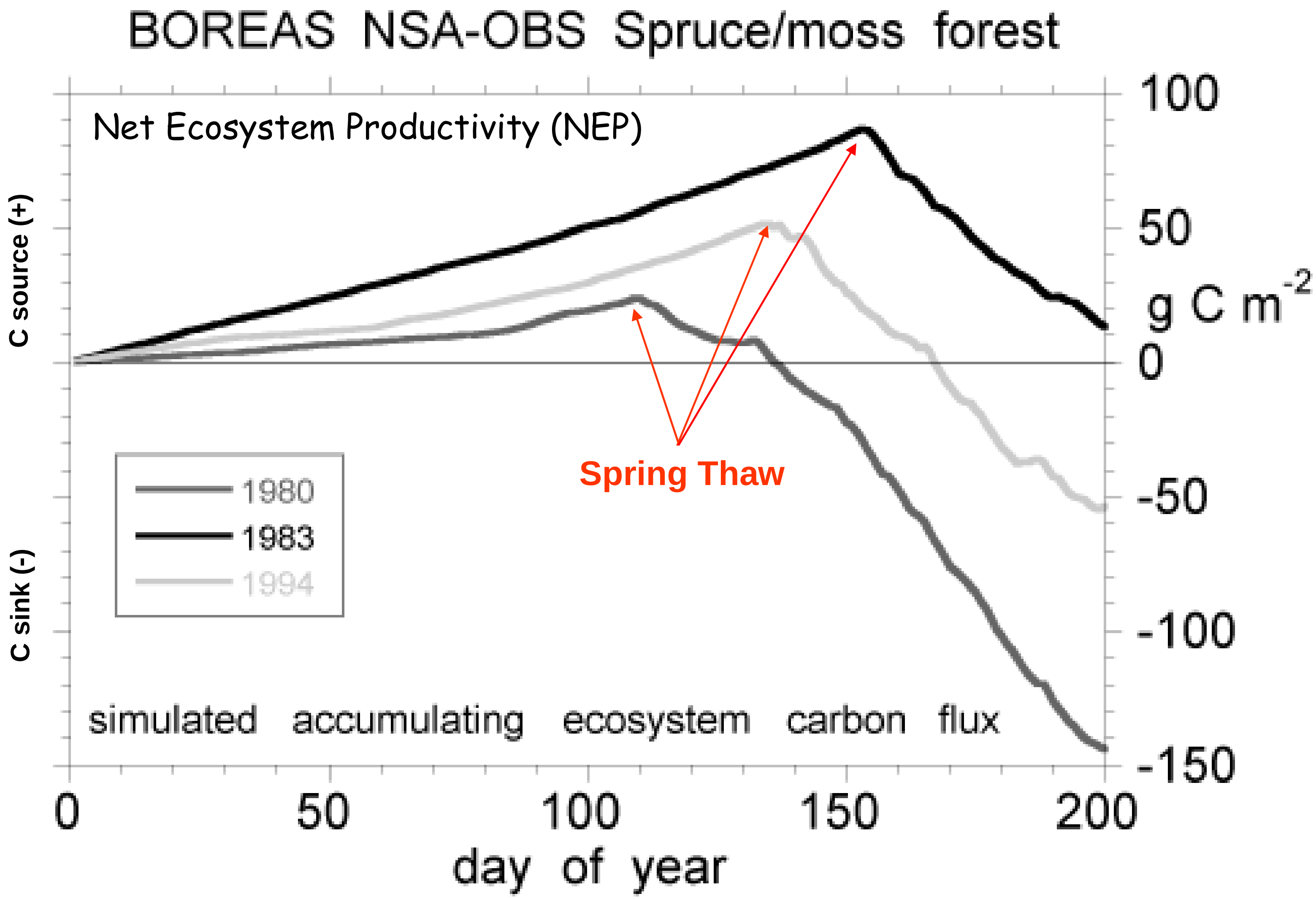


AIRSAR L-band

Way, J.B. et al., 1994. Trans. Geosci. Rem. Sens. 32, 2.

The basis of the radar remote sensing based freeze-thaw measurement is the large shift in dielectric constant and associated backscatter as the landscape shifts between predominantly frozen and thawed conditions. The top-left figure shows the dielectric constant of liquid water and ice as a function of frequency across the microwave spectrum; the Dielectric constant of liquid water varies with frequency, whereas that of pure ice is constant (Ulaby, et al., 1986, p. 848; Kraszewski, 1996). The top-right figure shows the large L-band dB shift during a freeze-thaw transition event as captured from multi-temporal AIRSAR acquisitions.

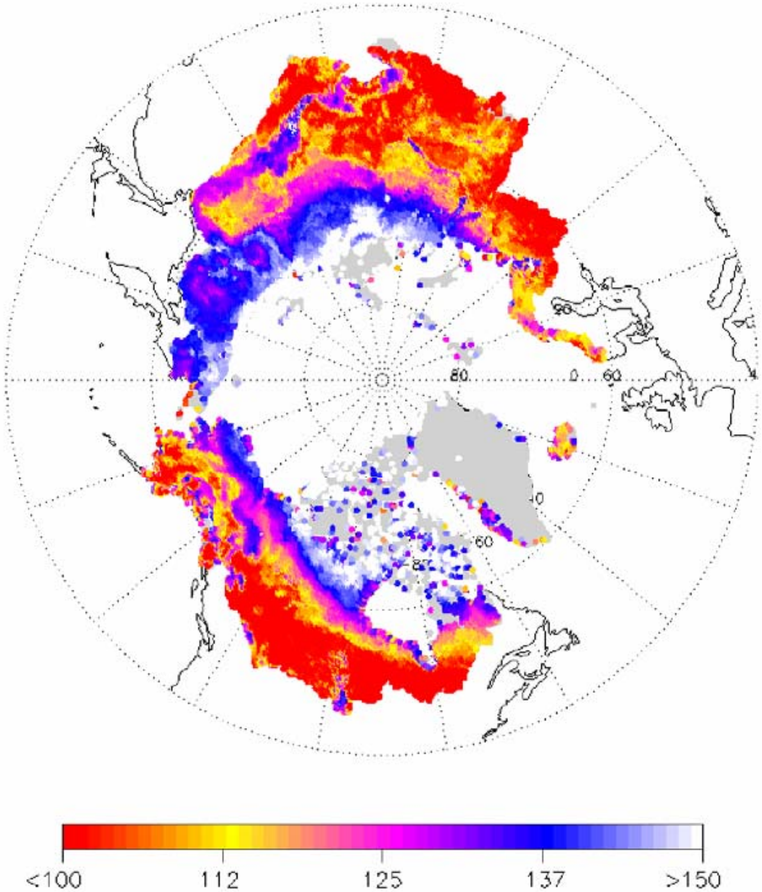
Importance of Spring Thaw Timing in Determining NEP



Frolking, S., et al. 1996. Global Change Biol. 2, 343-366.

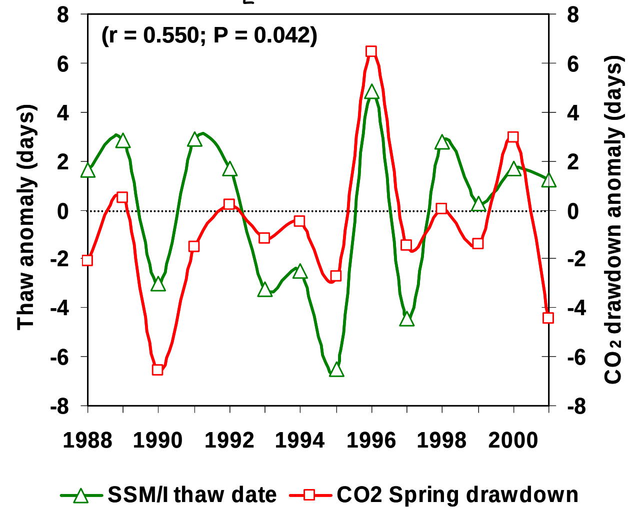
Satellite Detection of Pan-Arctic Growing Season Onset

Mean Growing Season Onset
(SSM/I, 1988-2002)



Primary thaw day (DOY)

SSM/I Thaw Date vs Spring Atmosphere CO_2 Anomalies



Map (**left**) of the average (1988-2002) timing of growing season onset as derived from temporal classification of daily Tb measurements from the SSM/I, excluding non-vegetated areas (in grey). The thaw signal coincides with the seasonal relaxation of low temperature constraints to boreal-arctic NPP and the spring drawdown of atmospheric CO_2 as reported by NOAA CMDL northern (>50°N) monitoring stations (**above**); negative anomalies denote both earlier thaws and CO_2 drawdown while positive values denote the opposite response. **SMAP will provide enhanced L-band spectral sensitivity and more than 8-fold increase in spatial resolution for improved detection and monitoring of landscape freeze-thaw processes**.

Source: McDonald, K.C., J.S. Kimball, E. Njoku, R. Zimmermann, and M. Zhao, 2004. Variability in springtime thaw in the terrestrial high latitudes: Monitoring a major control on the biospheric assimilation of atmospheric CO_2 with spaceborne microwave remote sensing. *Earth Interactions* 8(20), 1-23.

Measurement Requirements to Satisfy Freeze/Thaw Science Objectives

- Acquisition of surface freeze/thaw state measurements over land areas where these factors are primary environmental controls on land-atmosphere exchanges of water, energy and carbon;

- Freeze/thaw status of the aggregate vegetation-soil layer determined sufficiently to characterize the low-temperature constraint on vegetation net primary productivity and surface-atmosphere CO_2 exchange;

- Minimum spatial resolution ≤3 km and a mean temporal sampling of 2 days or better;

- Freeze/thaw measurement accuracy sufficient to resolve the temporal dynamics of net ecosystem carbon exchange to within 0.05 tons C ha^{-1} (or 3%) over a ~100-day growing season.

Heritage Datasets for SMAP Freeze/Thaw Science and Algorithm Assessment

Sensor	Bands/ Polarization	Grid Resolution	Repeat	Data Duration	Coverage
L-band Active/Passive Data Sets					
ALOS PALSAR (SAR)	L (1.27GHz) Multi-polarization	6.5m-50m	Monthly [‡]	2006 - present	Local-Global
JERS (SAR)	L (1.25 GHz)/ HH	12.5m & 100m	44-day [†]	1992-1998	Regional- Continental
SMOS (Radiometer)	L (1.4GHz) H and V	40km	10-day [†]	2008 (planned)	Global
AIRSAR (SAR)	P, L, C (0.45, 1.26, 5.31 GHz)	12.5m	Periodic Opportunities	Multi-season Winter 1988-Summer 1993, Autumn 2004	Local sites in Alaska
Other Active/Passive Data Sets					
AMSR-E (Radiometer)	C (6.9 GHz) H and V	50km	8-day [†]	2002-present	Global
SSM/I (Radiometer)	Ka (19GHz) H	25km	Daily	1988-present	Global
SeaWinds (Scatterometer)	Ku (13.4GHz) HH, VV	25km	Daily	1999-present	Global
ERS-1/2 (SAR)	C (5.3 GHz)/ VV	100m	3-35day [†]	1991-2002	Regional
Envisat (SAR)	C (5.33GHz) Multi-polarization	100m	35-day [†]	2002-present	Regional
RADARSAT (SAR)	C (5.3GHz)/ HH	100m	24-day [†]	1995-present	Regional-Continental
SMMR (Radiometer)	Ka (18GHz) H	25km	3-4 day	1979-1987	Global
NSCAT (Scatterometer)	Ku (14GHz) HH,VV	25km	Daily	1997	Global

[‡] PALSAR ScanSAR mode has 46-day exact repeat orbit with 17-day sub-cycles.

[†] Orbit repeat cycles are based on orbit geometry for exact recurrent observations. Higher revisit rates allow increased imaing opportunities at high latitides.

Verification of F/T Temporal Accuracy Requirements

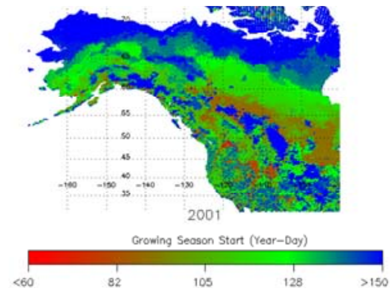
Major findings:

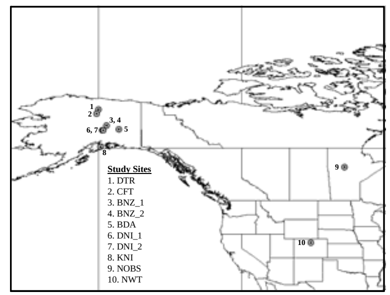
• Growing season initiation coincides with snowmelt and rise in surface (≤20cm) soil T to +/-1°C.

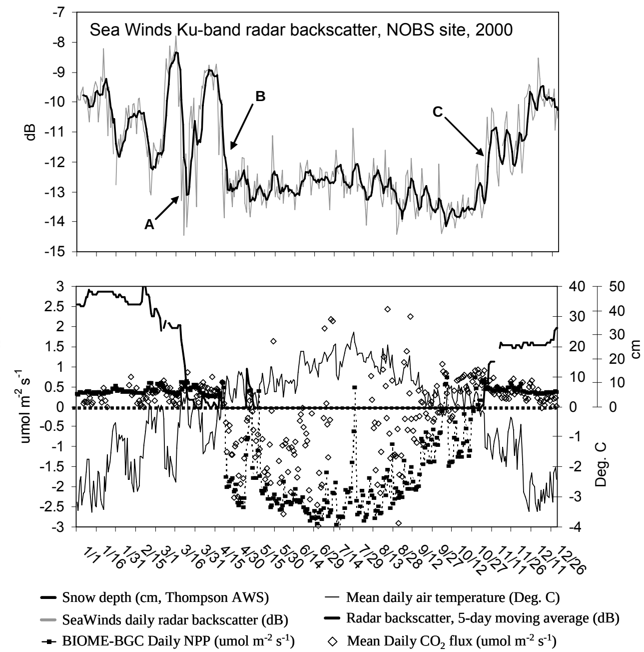
• Boreal sites sequester ~ 1% (+/- 0.4%) of annual NPP on a daily basis immediately following growing season initiation; in Fall carbon is sequestered at ~0.3% (+/- 0.2%) per day prior to growing season termination.

• Any error in determining the timing of growing season initiation has a threefold greater impact relative to annual NPP than a similar error in determining the end of the growing season.

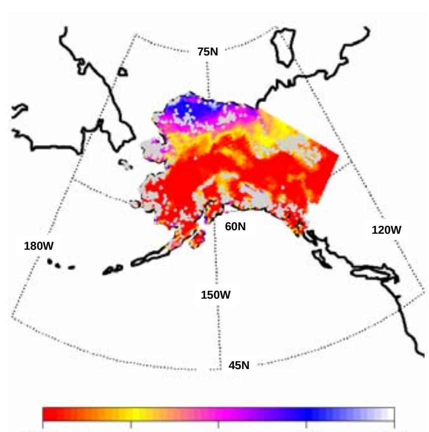
Satellite (SeaWinds) Derived Growing Season Onset for 2001



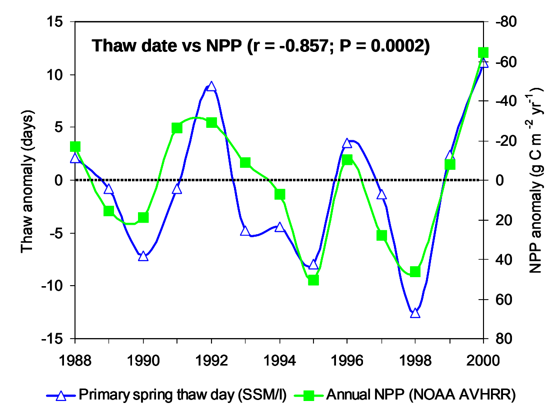




Satellite Detection of Spring Thaw Impacts to NPP



Primary Thaw Day (SSM/I, 2000)



Sources:
Kimball, J.S. et al. 2006. *Earth Int.* 10(21), 1-22.
Kimball, J.S. et al. 2004. *Rem. Sens. Environ.* 90, 243-258.

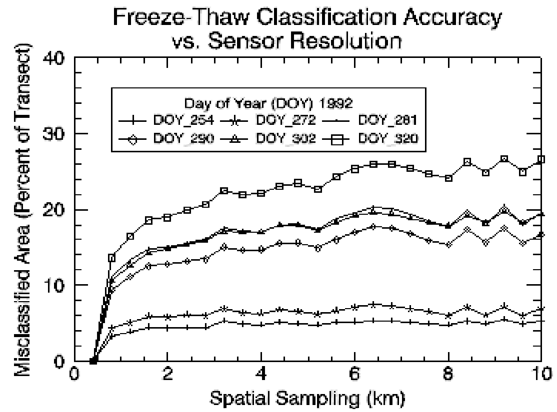
Verification of F/T Spatial Accuracy Requirements from Regional Experiment Data

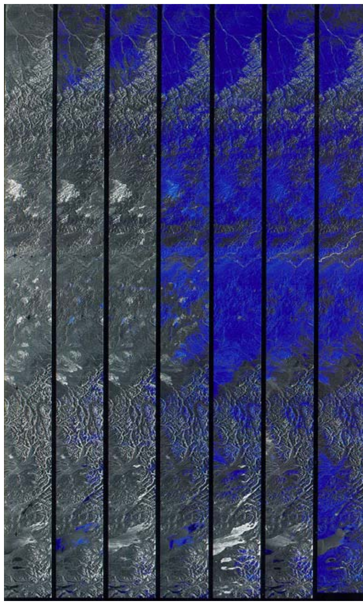
- Classification error increases rapidly as spatial resolution approaches scale of landscape F/T spatial heterogeneity.

- F/T spatial heterogeneity varies by region and on a seasonal basis; heterogeneity is maximized during spring/fall transitions, in complex land cover and terrain, and along lower elevations and latitudinal boundaries.

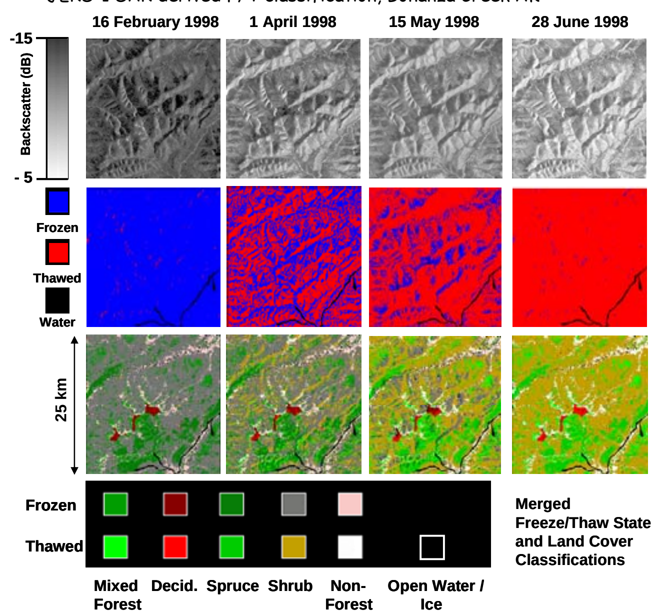
- Classification accuracy drops off rapidly with decreasing spatial resolution during F/T transitions when landscape heterogeneity is maximized.

ERS-1 (C-band) Alaska
Latitudinal transect





JERS-1 SAR derived F/T classification, Bonanza Creek AK



Source: McDonald, K.C, and J.S. Kimball, 2005. Hydrological application of remote sensing: Freeze-thaw states using both active and passive microwave sensors. Encyclopedia of Hydrological Sciences. DOI: 10.1002/0470848944.hsa059a.

Current Baseline and Optional Freeze/Thaw Algorithms

Seasonal threshold Approach (Baseline Algorithm):

$$\Delta(t) = \frac{\sigma(t) - \sigma_{fr}}{\sigma_{th} - \sigma_{fr}}$$

$\Delta(t) > T$ Thawed

$\Delta(t) \leq T$ Frozen

Seasonal threshold Approach (Enhanced Baseline Algorithm):

$$\Delta(t) = \sigma(t) - \left\{ \sigma_{fr} + \left(\sigma_{th} - \sigma_{fr} \right) T \right\}$$

$\Delta(t) > 0$ Thawed

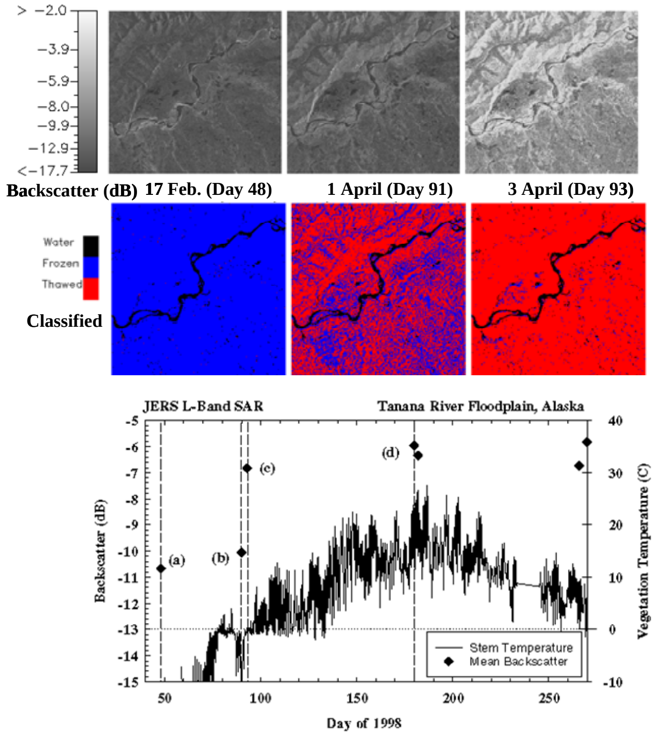
$\Delta(t) \leq 0$ Frozen

Source: McDonald, K.C, and J.S. Kimball, 2005. Hydrological application of remote sensing: Freeze-thaw states using both active and passive microwave sensors. Encyclopedia of Hydrological Sciences. DOI: 10.1002/0470848944.hsa059a.

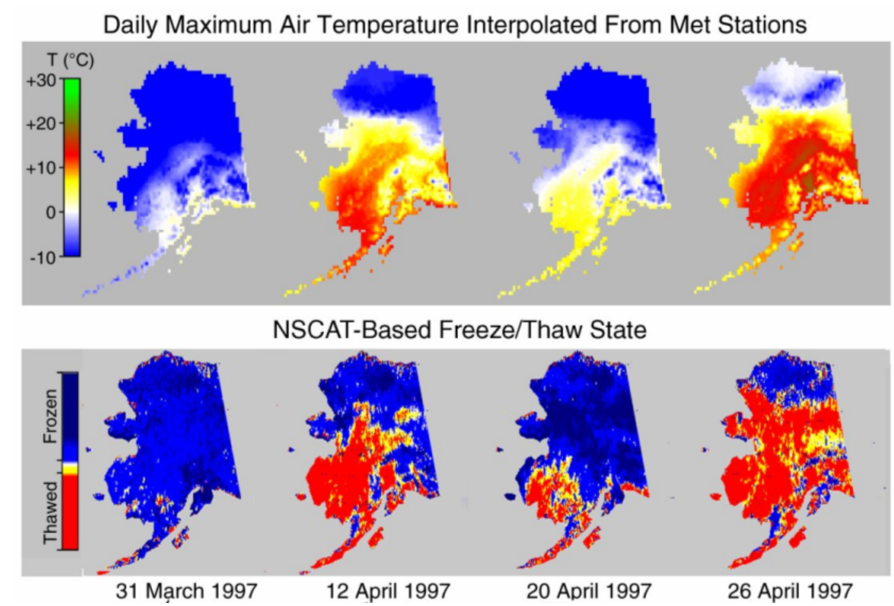
Seasonal Threshold Approach: Time-Series Classification of Frozen Area for Alaska

JERS-1 L-band Freeze-Thaw Classification

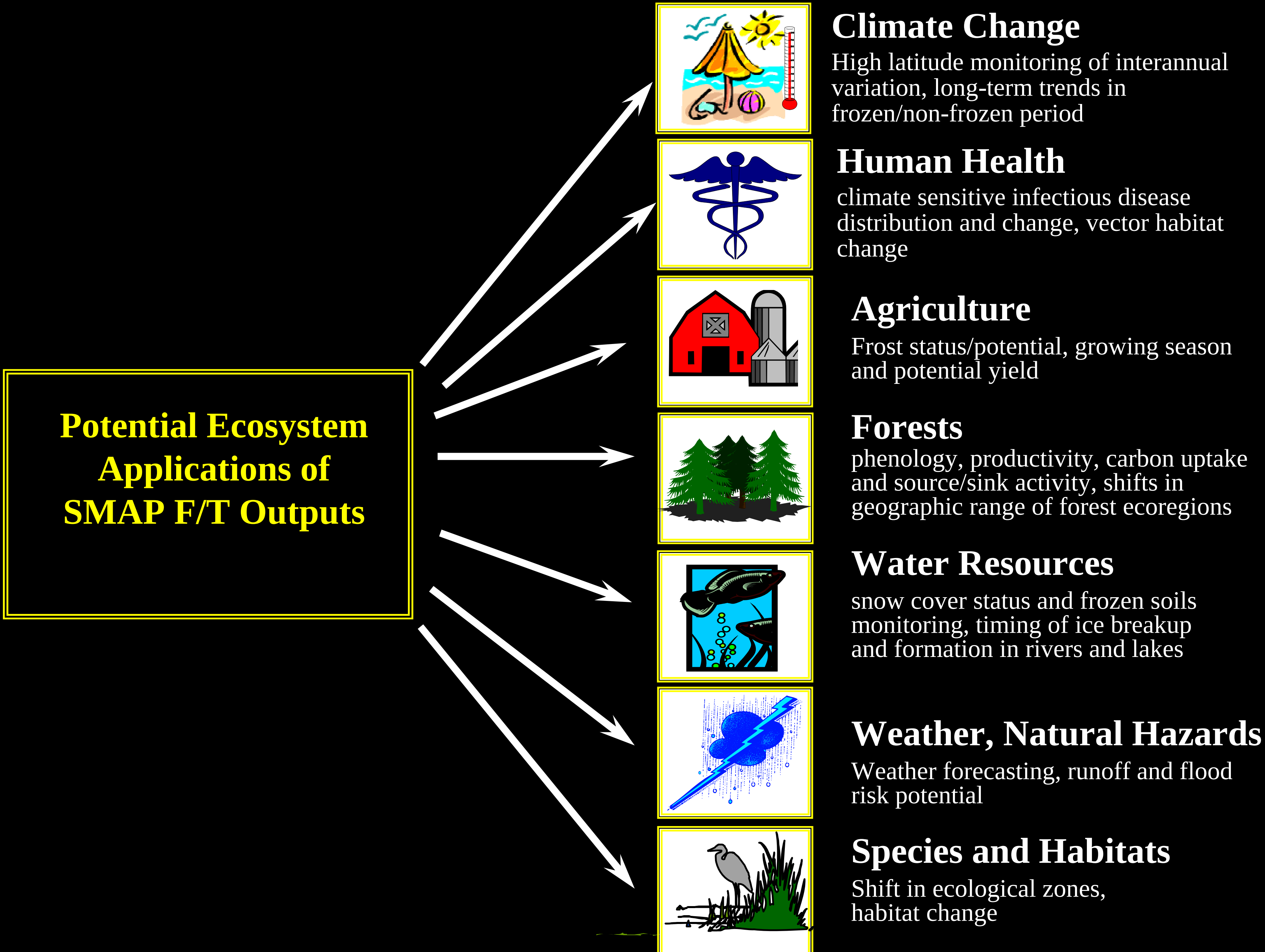
Bonanza Creek-Alaska



AK Daily Frozen Area Classification from NSCAT



Source: Kimball, J.S., K. McDonald, et al., 2001. *Rem. Sens. Environ.* 75, 113-126.


Potential Ecosystem Applications of SMAP F/T Outputs
Climate Change
High latitude monitoring of interannual variation, long-term trends in frozen/non-frozen period
Human Health
climate sensitive infectious disease distribution and change, vector habitat change
Agriculture
Frost status/potential, growing season and potential yield
Forests
phenology, productivity, carbon uptake and source/sink activity, shifts in geographic range of forest ecoregions
Water Resources
snow cover status and frozen soils monitoring, timing of ice breakup and formation in rivers and lakes
Weather, Natural Hazards
Weather forecasting, runoff and flood risk potential
Species and Habitats
Shift in ecological zones, habitat change

SMAP Freeze/Thaw Science Summary

- The SMAP mission will quantify the nature, extent, timing and duration of landscape seasonal freeze/thaw state transitions for improved understanding of ecosystem processes.

- The physical basis, algorithms and ecological importance of the F/T measurement are well established from a wide range of field measurement, airborne and satellite active/passive microwave remote sensing, and from plot to regional, continental and global scales;

- SMAP will provide enhanced L-band spectral sensitivity, and relatively fine spatial and temporal scales for improved detection and monitoring of landscape F/T and associated biophysical processes.

- The F/T measurement spans a diverse range of potential applications, including climate change detection, weather forecasting, forest and agricultural productivity, water resources, and disease vector monitoring.