GLOBAL FREEZE/THAW PRODUCT FROM L-BAND RADIOMETER DATA

Xiaolan Xu[1], Youngwook Kim[2], John Kimball[2], Chris Derksen[3], R. Scott Dunbar[1], Andreas Colliander[1]

[1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA
[2]Numerical Terradynamic Simulation Group, University of Montana, Missoula, MT, USA
[3]Climate Research Division, Environment Canada, Toronto, ON, Canada

ABSTRACT

The NASA Soil Moisture Active Passive (SMAP) mission has been successfully operated for almost three years. The SMAP freeze/thaw algorithm is based on a seasonal threshold approach. It's important to have a stable and self-consistent freeze and thaw reference that can be applied for multi-year dataset. The three-year long radiometer datasets allow us to reassess the criteria of reference setup and evaluate its stability. In this paper, we first refined the freeze reference requirements and compare three different methods of setting up the thaw reference to minimize the false flags. The original freeze/thaw products is in the polar grid and only cover the region north of 45° N latitude. The limitation is due to lack of enough freezing days in the lower latitude, where the freezing reference cannot be generated. To extend the freeze/thaw product to global region, we combine the single channel algorithm in the lower latitude and southern atmosphere. The global results have been validated through WMO air temperature.

Index Terms— freeze/thaw; SMAP; radiometer

1. INTRODUCTION

The terrestrial cryosphere comprises cold areas of Earth's land surface where water is either permanently or seasonally frozen. This includes most regions north of 45°N latitude and most areas with elevation greater than 1000 meters. Within the terrestrial cryosphere, spatial patterns and timing of landscape freeze/thaw state transitions are highly variable with measurable impacts to climate, hydrological, ecological and biogeochemical processes [1,2,3,4]. Satellite-borne microwave remote sensing has unique capabilities that allow near real-time monitoring of freeze/thaw state, without many of the limitations of optical-infrared sensors such as solar illumination or atmospheric conditions. The primary science objectives for SMAP directly relevant to the freeze/thaw product include linking terrestrial water, energy and carbon cycle processes, quantifying the net carbon flux in boreal landscapes and reducing uncertainties regarding the so-called missing carbon sink on land. The current standard and enhanced freeze/thaw products only provide the freeze/thaw status for north of 45°N latitude. In this paper, we extended the algorithm to global region and provide an opportunity to compare with other hemispheric F/T datasets such as SMOS, Aquarius, AMSR2 and land surface mode estimates.

2. SMAP FREEZE/THAW GLOBAL COMBINED ALGORITHMS

The SMAP freeze/thaw algorithm is based on a seasonal threshold approach [5,6]. The seasonal threshold (baseline) algorithm examines the time series progression of the remote sensing signature relative to signatures acquired during seasonal reference frozen and thawed states. The global combined algorithms are using normalized polarization ration as an indicator for higher latitude and vertical polarization brightness temperature for lower latitude and southern atmosphere.

In the last few years, we've been demonstrated that the normalized polarization ratio is a good indicator the soil freeze and thaw states for the higher latitude.

$$NPR = \frac{TBV-TBH}{TBV+TBH} \qquad (1)$$

Decreases and increases in NPR are associated with landscape freezing and thawing transitions, respectively. The decrease in NPR under frozen conditions is a result of small increases in the V-pol brightness temperature combined with larger increases at H-pol [7][8]. Various studies have shown the NPR to be preferred over other approaches as it minimizes sensitivity to physical temperature and outperforms other L-band brightness temperature based approaches [9][10].

A seasonal scale factor Δ(t) is defined for an observation acquired at time t as:

$$\Delta t = \frac{NPR(t)-NPR(fr)}{NPR(th)-NPR(fr)} \qquad (2)$$

where NPR(t) is the normalized polarization ratio calculated at time t, for which a freeze/thaw classification is sought, and NPR(th) and NPR(fr) are normalized polarization ratios corresponding to respective frozen and thawed reference states. Originally, the 20 highest (lowest) NPR values from summer (July/August) and winter (January/February) were retained and averaged to create respective thaw and freeze references. However, for lower latitude, in winter, there are only a few days of freezing and cannot meet 20 days requirement for setting up freeze reference. In figure 1, the light green area is the region where the freezing period is long enough to perform threshold method using NPR as an indicator. The boundary is set up by the freezing reference.

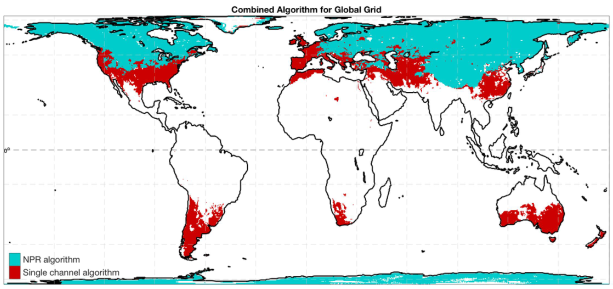

Figure 1. Combined algorithm map.

For thaw reference, we reassess three methods to reduce the summer false flag. A) thaw reference is generated from highest 20 NPR value from summer period (July to August) B) highest 20 NPR value from the whole year C) average two months (July and August) NPR value. In table 1, we demonstrate the error estimate of false freeze and false thaw error for three methods. The false thaw error is defined as below:

i. False Thaw: NPR algorithm predicts thaw, while GMAO model surface temperature is less than -5C

ii. False Freeze: NPR algorithm predicts freezing, while GMAP model surface temperature is greater than 5C.

Overall, the NPR averaging over two months gives the best performance for both AM and PM.

Table 1. F/T false flag error estimate for three thawing references.

AM	H20(summer)	H20(year)	Avg(summer)
	False T False F	False T False F	False T False F
NPR with weekly AMSR-mask	1.11% 3%	2.55% 2.2%	1.98% 1.56%
PM	**H20(summer)**	**H20(year)**	**Avg(summer)**
	False T False F	False T False F	False T False F
NPR with weekly AMSR-mask	1.45% 2.36%	2.57% 1.54%	2.15% 1.3%

For lower latitude, we use the single channel algorithm using vertical polarization brightness temperature. The single channel algorithm has been successfully used in AMSR2 freeze/thaw products. In the single channel algorithm, we define freeze/thaw as,

$$\text{FT status} = \begin{cases} \text{Non-frozen}, & \text{if } T_b > \text{threshold} \\ \text{Frozen}, & \text{if } T_b \leq \text{threshold} \end{cases} \quad (3)$$

The threshold has been determined on a grid cell by cell basis. In figure 2, we plot an example over Alaska area. We sort out a year of brightness temperature data and modeled surface air temperature and fitted them in linear relationship. The brightness temperature value that crosses the 0C surface air temperature is the threshold. In figure 1, the red region shows the single channel applied area.

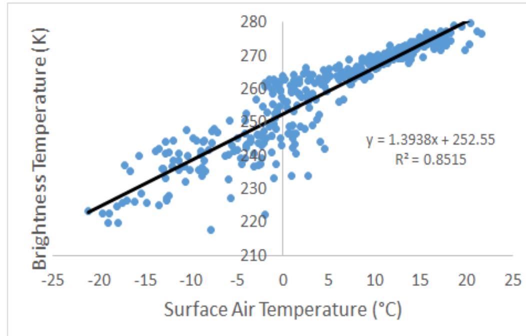

Figure 2. Brightness temperature vs. Surface air temperature for determining the threshold of the single channel algorithm.

3. VALIDATION

The combined global freeze/thaw products were validated using core sites and WMO station networks. The number of core sites available for validation of SMAP FT products is limited in number, but they yield important insights into the behavior of NPR time series. In figure 3, the time series NPR signals was plot in the black line. The upper dash line is the average thaw reference from three years and lower dash line is the average freezing reference. The blue color block is the freeing period while the red block shows the thaw period. In the lower panel, we plot the surface temperature estimated from GMAO run. The two methods match each other very well.

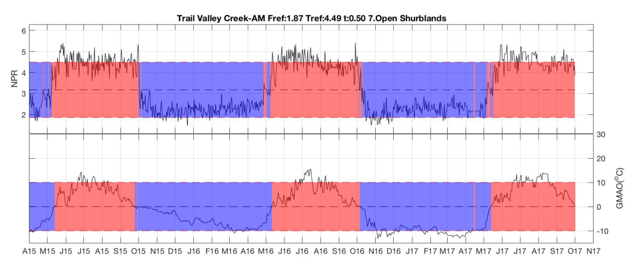

Figure 3. NPR derived F/T vs. GMAO air temperature derived F/T.

To better evaluate the dataset globally, we also compare the SMAP derived freeze/thaw with the WMO air temperature in figure 4. The overall accuracy for global and high northern latitude is all above 80%.

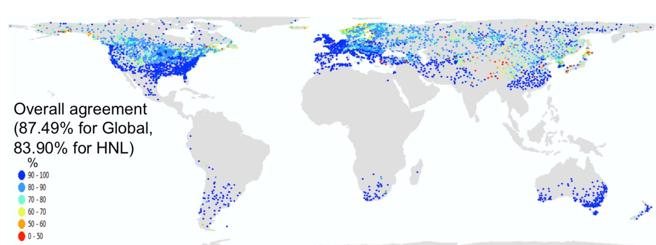

Figure 4. WMO station distribution with overall agreement.

In figure 5, we plot a snapshot freeze/thaw prediction for four seasons.

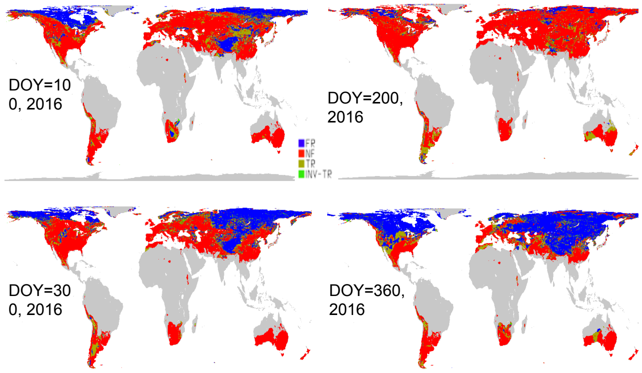

Figure 5. Snapshot of the four season freeze/thaw over 2016.

6. ACKNOWLEDGMENT

The research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

7. REFERENCES

[1] Entekhabi, D., S. Yueh, P. O'Neill, K. Kellogg et al., SMAP Handbook, JPL Publication JPL 400-1567, Jet Propulsion Laboratory, Pasadena, California, 182 pages, July, 2014.

[2] Y. Kim, J. S. Kimball, K. Zhang, and K. C. McDonald, "Satellite detection of increasing Northern Hemisphere non-frozen seasons from 1979 to 2008: Implications for regional vegetation growth," *Remote Sensing of Environment*, vol. 121, pp. 472-487, 2012.

[3] Y. Kim, J. Kimball, K. Didan, and G. Henebry, "Response of vegetation growth and productivity to spring climate indicators in the conterminous United States derived from satellite remote sensing data fusion," *Agricultural and Forest Meteorology*, vol. 194, pp. 132-143, 2014.

[4] K. C. McDonald, J. S. Kimball, E. Njoku, R. Zimmermann, and M. Zhao, "Variability in springtime thaw in the terrestrial high latitudes: Monitoring a major control on the biospheric assimilation of atmospheric CO2 with spaceborne microwave remote sensing," *Earth Interactions*, vol. 8, pp. 1-23, 2004.

[5] R. S. Dunbar, X. Xu, A. Colliander, K. McDonald, E. Podest, E. Njoku, J. Kimball, Y. Kim, and C. Derksen, "Soil Moisture Active Passive (SMAP) L3 Radar Freeze/Thaw (Active) Algorithm Theoretical Basis Document" Release v3.2, *Jet Propulsion Laboratory Technical Document*, 56 Pages.

[6] X. Xu, C. Derksen, S. Yueh, R. S. Dunbar, and A. Colliander, "Freeze/thaw detection and validation using Aquarius' L-band backscattering data", *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, 9 (4), 1370-1381.

[7] Derksen, C., Xu, X., Dunbar, R. S., Colliander, A., Kim, Y., Kimball, J. S., ... & Marsh, P. (2017). Retrieving landscape freeze/thaw state from Soil Moisture Active Passive (SMAP) radar and radiometer measurements. Remote Sensing of Environment, 194, 48-62.

[8] A. Roy, A. Royer, C. Derksen, L. Brucker, A. Langlois, A. Mialon and Y. Kerr, "Evaluation of spaceborne L-band radiometer measurements for terrestrial freeze/thaw retrievals in Canada", *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, 10.1109/JSTARS.2015.2476358, in press.

[9] Rautiainen, K., J. Lemmetyinen, M. Schwank, A. Kontu, C. Ménard, C. Mätzler, M. Drusch, A. Wiesmann, J. Ikonen, and J. Pulliainen, "Detection of soil freezing from L-band passive microwave observations", Remote Sensing of Environment, 147, 206–218, 2014.

[10] Rautiainen, K., T. Parkkinen, J. Lemmetyinen, M. Schwank, A. Wiesmann, J. Ikonen, C. Derksen, S. Davydov, A. Davydova, J. Boike, M. Langer, M. Drusch and J. Pulliainen, "SMOS prototype algorithm for detecting autumn soil freezing", Remote Sensing of Environment, 180, 346–360, 2016.