USFS-NASA Joint Applications Workshop

(April 30 – May 2, 2019, GTAC, Salt Lake City, UT)

Key Opportunity Areas for NASA-Forest Service Collaboration

Executive Summary: In 2019, 107 (82 in-person, 25 remote) U.S. Forest Service, NASA (SMAP, ICESat-2, NISAR, CMS, GEDI), and participants from other entities attended the workshop to increase awareness and understanding of the capabilities of NASA data products, as well as to develop connections and strengthen partnerships between NASA and the Forest Service. One of the workshop objectives was to identify opportunities for collaboration between USFS and NASA. During breakout sessions on (1) soil moisture and hydrology, (2) emissions and flux, and (3) vegetation structure and function, participants discussed key opportunities and challenges around utilizing NASA technology by land management agencies. The bullets below represent high-level key opportunity areas for increased NASA-Forest Service coordination and collaboration to support sustainable natural resource management.

1. **Develop a Strategic Framework for Collaboration and Coordination.** A coordinated approach to prioritizing work between the agencies will result in a more efficient use of resources. Describing connections and assigning contacts for activities such as sharing data, transferring technology, or conducting research will streamline efforts and allow for a better understanding and integration of program needs.
2. **Stand-up Working Groups and Engage in Early Adopter Programs.** Involving land management agencies in the development of requirements for future missions will help meet science and management objectives. Piloting NASA technology on actual land management scenarios and working together iteratively will increase yield tools highly applicable to the needs of land managers.
3. **Develop Needs Requirements, Study Feasibility.** Additional work refining stakeholder needs and clearly outlining barriers to adoption will help determine where to focus resources. Considering stakeholder and science needs from a multi mission perspective will improve outcomes by integrating not only technology, but also ideas and perspectives into the process. Additional workshops and webinars may be needed before the level of technical details are sufficiently translated and understood by both communities.
4. **Tools & Data Integration.** Once technical requirements are clearly defined, understood, and tested, tools for ingesting NASA data into Forest Service models, systems, and workflows will need to be developed. For example, developing methods to integrate multi-sensor data as inputs into fuel models are needed before the technology can be operationalized.

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Panel Discussion Report Out of the Soil Moisture and Hydrology Breakout Panel

Summary: U.S. Forest Service needs consistent and effective forest soil moisture monitoring to support its management decisions that ensure natural resources meet or moving toward desirable conditions. Forest soil moisture monitoring helps USFS monitor and predict droughts in forests and rangelands, predict wildfires, plan for reforestation and promote pre-disturbance resilience and resistance, and improve hydrologic and snowpack modeling for sustainable watershed managements. While NASA Soil Moisture Active Passive (SMAP) provides timely, frequent and high-resolution global soil moisture both for near surface and root-zone, accuracy of soil moisture estimates in forested areas is limited. Currently, the SMAP program is conducting a field experiment to calibrate and validate (cal/val) forest soil moisture estimates. However, the existing sparse forest soil moisture network limits SMAP's capability to improve forest soil moisture estimates. In addition, there are gaps in science and applications of NASA data products preventing the translation of NASA data into USFSs' management tools. It is recommended that USFS and NASA develop a strategic framework for collaboration and coordination to enable uses of NASA data products to support USFS management needs. For example, collaborations between USFS and SMAP to utilize existing forest soil moisture and vegetation water content data and identify where to place additional in-situ sensors could help improve satellite-based forest soil moisture observations. Table 1 provides detailed information regarding USFS decision-support needs, relevant NASA products and tools to support the needs, gaps, and ways to close the gaps.

Table 1. Summary of soil moisture and hydrology information opportunities and challenges resulting from the breakout panel discussion at the 2019 USFS-NASA Joint Applications workshop. Words in *italics* indicate short-term achievable priorities.

USFS decision-support need and how is USFS meeting this need now?	What are relevant NASA product(s) and tool(s) to address the need?	How could these NASA product(s) and tool(s) improve USFS decision-making?	What are barrier(s) and gap(s) for NASA product/tool integration? (e.g., resolution, errors)	What are way(s) to close the gap(s)? (please rank by priority)
General themes:	• SMAP • NISAR	• More efficient decision making	• Lack of in-situ measurements (cal/val data)	• *Develop a Strategic Framework for*

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	• Soil moisture visualizer • MODIS • Landsat • ECOSTRESS • GOES • VIIRS • LIS	• Appropriate information reduces the level of risk • Improve ability to better predict and plan for medium (3-5 yrs) to long term (10-20 yrs) change (i.e. improving parametrization in existing or future models) • Improve landscape level data consistency across all forests and for "all lands approach" • Improve data sources and tools for broad level climate change indicators (e.g., USGCRP indicators, Forest Service Broader-Scale Monitoring Strategies)	• Differing perspectives on uncertainty and what are acceptable levels of risk • Translating NASA data into FS management tools: ○ Gap between science and applications ○ "Pixels scare people" (FS GIS community more experienced working with vector data; majority of FS GIS data is vector) ○ Tool box is already "stuffed" • Communication: ○ Managers understanding of data availability, uses, limitations, scale, and uncertainty. ○ Data producer's understanding of management capabilities and limitations for user of	*Collaboration and Coordination:* ○ *Use an all-lands approach and include all land management agencies in the strategic framework. Bring land use managers across agencies together to identify common priorities.* ○ *Develop a list of FS-NASA joint efforts already underway.* ○ *Describe connections between R&D and NASA. The R&D branch is the most appropriate place to engage NASA at the tactical level.* ○ *Internally, do more to connect R&D staff with NFS managers (e.g., the Be Smart program).* ○ *Develop strategy for USFS Earth*

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			remote sensed soil moisture information. • Spatial resolution of NASA data: ○ NASA makes measurements from a difficult vantage point (mostly space) so that it is a synoptic context picture; and cannot replace the project or plot scale observers. Instead, show added-value of synoptic information to site-specific applications (in both NASA & USFS). ○ Contrast the above with the way Forest Service managers generally thinks of scale requirements: project level: 1m - 30m; mid-scale: 30m - 100m; Broad-scale: >100 m	*Observation (EO) integration and outlook.* • *Develop Needs Requirements, Study Feasibility:* ○ *Broadly synthesize needs, requirements, gaps, and barriers to adoption within the USFS that are clearly defined, accepted, and stated.* ○ *Identify and prioritize issues of common interest and capability between USFS and NASA. Continue to engage in ongoing discussions about what is needed versus what is possible.* • *Stand-up Working Groups and engage in Early Adopter Programs:*

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			○ NASA data can address the temporal and temporal change issues, but are limited to spatial scales in the km range.	○ *Ensure FS requirements are captured in Traceability Matrices and participate on Decadal Survey Workgroups (application community requirements for future missions). Work with NASA iteratively on workgroups and early adopter programs* ○ *Form focused Working Groups that have the correct expertise and current working knowledge of existing tools. Meet on telecons regularly.* ○ *Designate a Working Group Liaison for every FS-NASA priority.*

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				• Tools & Data Integration ○ Build tools for ingesting NASA data into USFS models, systems, and workflows where feasible. ○ Invest in open technologies that are interoperable with existing data and methods. ○ Provide incentives to citizen scientists to participate in data collection (via schools, towns, states). ○ Develop tools and use-cases for synoptic information. • Launch Pilots and Case Studies: ○ Ensure inputs from regions and forests (in addition to R&D and WO) are included when

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				designing case studies/ proof of concept studies. ○ Prioritize pilot studies/management applications where the risk to management is high and there is a need across land ownerships ○ Show a success-story or two (case study). Take a regional or specific example, pair NASA & USFS enthusiastic individuals, and show it can be done. Both members of pair need to do the technical work.
Forest soil moisture monitoring: • Soil inventories • Soil probes (somewhat	• Large-scale frequent mapping of soil moisture at various spatial scales is available from various NASA soil moisture products:	• Improve plant stress early warning • Improve modelling surface soil moisture to predict soil moisture at deeper layers	• Lack of forest soil moisture in situ sensors • SMAP performance in complex terrain	• Sharing validation resources for forest soil moisture and vegetation water content (e.g., share data collected at USFS

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cost prohibitive) • Some (not many) forest soil monitoring networks • Remote sensors (e.g., experimental use in R5 for 'data driven' opening and closing of ATV trails)	○ Satellite-based: SMAP (current); AMSRE (historical), ○ Model-based: NLDAS, MERRA2, etc. ○ Vegetation water content can also be inferred indirectly through SMAP's vegetation opacity parameter	• Improve consistency of soil moisture information across scales (reconciling project/plot/sub-watershed scale with watershed (>HUC 12) and Region)		experimental forests for cal/val) • Need a national survey and assessment of where forest soil moisture in situ sensors are available in order to better define gaps and needs. • Explore how modeling /stats can show us where to place additional sensors. • Tap into the wealth of underutilized georeferenced soil information (e.g., NASA's data set includes over 50,000 soil pedon samples that are to protocol; soil moisture, soil temperature, soil carbon, texture etc. are available for validation. Another 30,000 points probably exist that are not in the database. • Provide funding to an adequate number of

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				forest soil moisture in situ sensors. • Equip RAWS stations with soil moisture sensors. • Develop forested validation sites for soil moisture (more than a dozen or 50 in situ stations within 40 km so that the replicability of SMAP data to USFS applications is quantitatively known).
Soil mapping/ inventory: • Resource photography interpretation • Field data collection • NRM database • NRCS maps	• SMAP	• Additional parameters and data to integrate into mapping workflows		
Soil carbon:	• SMAP		• Lack of soil carbon and carbon flux info in different environments/land use categories	

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Wildfire prediction:	• SMAP • NISAR	• Inform spatial variability in fire behavior modeling • NASA data can provide reliable estimates of fuel load and wetness conditions.		• Pursue value case study with fire and reverse engineering exercise to improve risk scenario analysis • USFS does not use SMAP or any remote soil moisture product in fire danger rating. Could be an easy feasibility study to set up to test added value of SMAP data for this application
Pre-disturbance resilience and resistance: • Forest level expertise • National Insect and Disease Risk Map • Hazardous Fuel Models (FAM) • Existing Vegetation maps • Climate Change Vulnerability Assessments	• SMAP • NISAR • MODIS • Landsat • ECOSTRESS • GOES • VIIRS • LIS	• Early stress detection • Additional information on tree canopy water content and change to aid models • Utility of microwave VOD from SMAP as a new indicator of vegetation water relations, phenology, and health		• "SMAP is working on an algorithm to retrieve vegetation water content in physical unit (kg/m2) using passive microwave observations. The resulting parameter will be a direct indicator of vegetation/forest health and vitality."

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• NRM database				
Rangeland monitoring: • Drought indicators • Local expertise • Productivity data	• SMAP • MODIS • Landsat • ECOSTRESS • GOES • VIIRS	• Better early warning indicators		
Hydrologic and Snowpack modeling: Fine scale DEMs (e.g., topographic wetness index), SNOTEL network, vegetation maps, USGS stream gauges, NHD, VIC, WaSSI, NRM database	• SMAP • NISAR • MODIS • Landsat • ECOSTRESS • GOES • VIIRS • LIS	• Improve water supply maximization strategies • Better infiltration capacity information to improve understanding of watershed runoff • Contribution of improved LAI models: temporally specific; overstory vs understory • Operationalized production of a periodically updated overstory LAI map at high resolution		• Model LAI using FIA plot data combined with LiDAR and Landsat data (then used in distributed hydrological models)

Panel Discussion Report Out of the Emissions and Flux Breakout Panel

Table 2. Summary of emissions and flux information opportunities and challenges resulting from the breakout panel discussion at the 2019 USFS-NASA Joint Applications workshop.

USFS Decision-Support Needs	How is USFS meeting this need now?	What are relevant NASA product(s) and tool(s) to address the need?	How could these NASA product(s) and tool(s) improve USFS decision-making?	What are barrier(s) and gap(s) for NASA product/tool integration? (e.g. resolution, errors)	What are way(s) to close the gap(s)? (please rank by priority)
Reporting a Map (which forest monitoring map is better for a country) – under USFS International Programs (SilvaCarbon).	Using Guidance (in a Box) that Grant mentioned; they follow the IPCC good practice guidelines and REDD+ requirements.	ICESat-2, GEDI, Airborne LiDAR, and data sets that are consistent, institutionalized, and at the country-scale.	They can help countries decide which map to use; they are helpful because the data is consistent and institutionalize.	Too many maps out there, which one to choose? Andrew Lister mentioned that we should not push a science product that is not compatible with the country's institutional readiness. Sassan brought up the issue of limited funding for a just a couple of years, which leaves no room to interact with potential users for a long time, thus affecting the integration of products.	Develop workshops and roadmaps to understand what stakeholders really need/want; and make sure that they understand the science and uncertainty metrics.
The USFS Air Resource and Management (ARM)	By other means besides remote sensing. They use	Engagement with the Air Quality & Health Working Group from	They can help in source apportionment,	Lack of engagement between USFS and NASA personnel	More engagement between USFS and

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Program identified several data needs, among those, monitoring for Regional Haze, and criteria pollutants or aerosol fine particulates. They needed in 10-100m grid cells horizontally; 100 m – 1 km vertical resolution; they need to know where the pollutants are coming from?; hourly to daily measurements; 1 to 10 years of data; aerosol size and composition; and the data should be easy to access.	little remote sensing data.	Goddard Applied Sciences, and connect with Stephanie Uz, who should provide guidance on relevant NASA air quality products (e.g. MODIS instrument onboard NASA's Terra and Aqua satellites provides near daily observations of aerosols over global land and ocean surfaces with moderate spatial resolution; others that can help include MISR, OMI, VIIRS, POLDER, and CALIPSO)	and to interpret events intercepted by IMPROVE monitors, among other uses.		NASA scientists and program managers
Does NASA have data to track algal blooms in lakes that we could use as an early	By other means besides remote sensing. They use little remote sensing data.	MODIS. For more information contact Stephanize Uz at NASA GSFC, or Rick Stumpf from NOAA.		Lack of engagement between USFS and NASA personnel	More engagement between USFS and NASA scientists and program managers

USFS Decision-Support Needs	How is USFS meeting this need now?	What are relevant NASA product(s) and tool(s) to address the need?	How could these NASA product(s) and tool(s) improve USFS decision-making?	What are barrier(s) and gap(s) for NASA product/tool integration? (e.g. resolution, errors)	What are way(s) to close the gap(s)? (please rank by priority)
warning for lake eutrophication? Does NASA have a means to monitor deposition of nitrogen and/or sulfur containing pollutants?		Yes, the Aura Ozone monitoring Instrument and NO2			
Data Needs for NEPA AQ Analyses for Energy and Minerals Projects: criteria pollutants, methane, CO2 at project level	By other means besides remote sensing. They use little remote sensing data.	See Riley Duren's (NASA JPL) CMS Project: Prototype Methane Monitoring System for California. A dataset has been archived: "Sources of Methane Emissions (Vista-LA), South Coast Air Basin, California, USA." See also Daniel Jacob's (Harvard University) CMS Projects, and engagement with EDF.	Could use remote sensing to look for methane leaks and determine compliance with lease conditions	Resolution. Most of the products from Daniel Jacob are not for project level analysis.	Higher-resolution products, collaborations with organizations like Environmental Defense Fund (EDF), who are working on launching MethaneSAT.
Predictors or imputation modeling at continental scales, and repeated height	Model-assisted and model-based inference may use data in "stages"		Could help with their customers' needs for wall-to-		Bridge the gaps between the sensed landscape and the

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products to incorporate into these models	across spatial and temporal resolutions		wall products over time		full raster mesh used for mapping
Shrub Biomass. Shrub species represent a significant component of aboveground carbon stocks in interior AK, but FIA is not funded to establish field plots in "non-forest" conditions, such as shrubs.	It is not currently, and Alaska was included in the U.S. National Forest Inventory just recently.	**G-LiHT**: Goddard's LiDAR, Hyperspectral, & Thermal Imager NASA CMS-funded project proposes to measure shrub biomass on a representative set of plots, develop G-LiHT-field relationships, and then estimate shrub biomass over entire inventory unit.	It could help in acquiring high-resolution airborne remote sensing data for highly-complex and remote areas, where otherwise it would be too costly. Including large shrubs as tree tally species would likely add several million acres to FIA inventory.		
Other data needs identified by Hans Andersen from USFS are: forest type/species-level & mortality information, and uncertainties in carbon emissions		Readily-available frequent radar imaging (NISAR), and accessible satellite lidar (ICESat-2) for forest monitoring			Frequently collected, and easily-available L-band radar from NISAR will likely be a game changer; continued development of methods to integrate multi-sensor data (ICESat-2, NISAR, G-

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from wildfire in boreal forests					LiHT, etc. & field data)
In general, George Hurtt indicated that there is a need to move from considering stakeholder and science needs separately to consider them jointly, moving to co-production. There is a need for more data and models, with very high resolution, accurate, transparent, easy to use, and repeatable.		Huge potential in new missions, such as GEDI		Considering science needs and capabilities separately.	Move to co-production, into considering the stakeholder and science needs jointly

Panel Discussion Report Out of the Vegetation Structure and Function Breakout Panel

Summary: During this session, we broke into four groups and rotated amongst topics such that each group discussed the following four topics:

USFS management issues
1. Silviculture: NEPA and management planning including harvest areas
2. Fire & fuels: Modeling fire behavior and effects, fuel treatments
3. Range management: Change over time including biomass, pinyon/juniper encroachment
4. Wildlife habitat: Habitat modeling with vegetation lifeform (forest/woodland, shrubland, herbaceous) and multi-layer cover

The following questions were used for prompts
1. What Forest Service information needs do NASA's existing products address?
2. What are the remaining data/knowledge gaps?
3. What are the biggest technical challenges around this topic that data and tools could fill?
4. How can we best fill the gaps?
5. What recent discoveries have you made on the topic that could help fill data and knowledge gaps?
6. How would you prioritize what needs to be done next?
7. What level of error/uncertainty is acceptable?

Each group then reported out on one of four topics in Table 3. Two recurring USFS needs that were discussed amongst all four topics was the ability to quantify the vegetation understory, and the ability to quantify the vertical and horizontal complexity of the vegetation. There was also ensuing conversation about the need for translation between USFS and NASA and in particular a sensitivity to NASA vs USFS terminology; and secondly tech transfer and specifically that NASA products needs to be ready to go into USFS models (i.e. fuel models) as inputs. The group also felt that more Involvement by USFS before NASA missions will help with adoption and use of NASA data.

Table 3. Summary of vegetation structure and function information opportunities and challenges resulting from the breakout panel discussion at the 2019 USFS-NASA Joint Applications workshop.

USDA Forest Service Needs	NASA product(s) and tool(s) to address the need	Example(s) of where the product(s)/tool(s) match the need	Barrier(s) and Gap(s) e.g., resolution, errors	Way(s) to close the gap(s)—please rank by priority
Silviculture: NEPA and management planning including harvest areas				
Disturbance + Recovery	SMAP, ICESat-2	Disturbance products are available but not recovery	Need a time sequence, spectral information	
Tree species, stocking, crown bulk density	Future hyperspectral (SBG)	Forest density / canopy cover needs to be tied to specific species (e.g. stocking normalizes density to species); need phenology	Legacy of Landsat under delivering is an issue; species is very important, separating trees from shrubs	Sentinel (10 m large improvement over 30 m but need additional R&D for applicability), time series; SBG
Height	Airborne lidar, GEDI, ICESat-2	Airborne lidar already used but not regularly repeated	Could learn to accept GEDI as a sampling mission	SAR? Probably skills needed make this difficult to adopt; complexity also difficult to explain to managers
Separating trees from shrubs	Airborne lidar	Understory estimates	Availability of data	
Fire & fuels: Modeling fire behavior and effects, fuel treatments				
Improved estimates of where the fuels are	Mid-regional level land cover mapping		Need model ready products	
Utility in LandFIRE but needs to be updated more regularly	30 km to 1 km	LandFIRE, mid-level data already available	Increased temporal resolution	
a) Crown b) Bulk density c) CBH		Need model level inputs that are easily ingested		

USDA Forest Service Needs	NASA product(s) and tool(s) to address the need	Example(s) of where the product(s)/tool(s) match the need	Barrier(s) and Gap(s) e.g., resolution, errors	Way(s) to close the gap(s)—please rank by priority
d) Understory fuels across landscapes				
Wildlife habitat: Habitat modeling with vegetation lifeform (forest/woodland, shrubland, herbaceous) and multi-layer cover				
Strata and layers (horizontal and vertical), including snags, understory		Structural mapping has happened in forests but not shrublands	60% accuracy acceptable; 80% outstanding	Improve with lidar data
Mesic / ephemeral areas	Significant gaps now	Not many examples	Need high temporal resolution	Could use SMAP plus a high resolution product?
Landcover change, tracking change near real time (this is prioritization)	Currently have Landsat but need higher temporal resolution in some ecosystems where phenology is driver			
Tracking snow cover under forested canopy	Have MODIS and Landsat snow covered pixels	lidar	Need higher resolution for snow cover extent but also snow depth from lidar	
Climate and topographic information, adaptatio to climate change	NLCD	Rates of change	Need more frequent products for assessing rates of change	
Range management: Change over time including biomass, pinyon/juniper encroachment				
Invasive species mapping	MODIS at very coarse scales	MODIS at very coarse scales - phenology	Need project level data at finer spatial scales	ICESat-2 & GEDI might not have height resolution needed; future SBG

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				(hyperspectral) mission
Soil stability and bare ground	This provides inverse (eg veg cover)	Need high temporal frequency due to phenology/changes	Need project level data at finer spatial and temporal scales; need consistent records	Sentinel, future SBG, possibly SAR, SMAP associated with bare ground
Disturbance & recovery	Landsat, MODIS	Landsat, Wildfire, structural, and drought recovery	Need project level data at finer spatial and temporal scales	ICESat-2 & GEDI might not have height resolution needed, possibly SAR

Annex: List of Acronyms

CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation
CBH	Canopy Base Height
CMS	Carbon Monitoring System
DEM	Digital Elevation Model
ICESat-2	Ice, Cloud, and land Elevation Satellite-2
EDF	Environmental Defense Fund
FAM	USFS Fire and Aviation Management (staff area)
FIA	USFS Forest Inventory and Analysis (program)
GEDI	Global Ecosystem Dynamics Investigation
G-LIGHT	Goddard LiDAR, Hyperspectral, & Thermal Imager
GOES	Geostationary Operational Environmental Satellite
LAI	Leaf Area Index
LandFIRE	Landscape Fire and Resource Management Planning Tools
LIDAR	Light Detection and Ranging
LIS	Land Information System
MDZ	Moisture Difference Z-Score (dataset)
MERRA2	Modern-Era Retrospective analysis for Research and Applications, Version 2
MISR	Multi-angle Imaging SpectroRadiometer
MODIS	Moderate Resolution Imaging Spectroradiometer
NASA	National Aeronautics and Space Administration
NEPA	National Environmental Policy Act
NISAR	NASA-ISRO SAR Mission
NLCD	National Land Cover Database
NLDAS	North American Land Data Assimilation System
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
OMI	Ozone Monitoring Instrument
PDSI	Palmer Drought Severity Index
POLDER	Polarization and Directionality of Earth's Reflectances
RAWS	Remote Automated Weather Stations
R&D	Research and Development
REDD+	Reducing Emissions from Deforestation and Forest Degradation
SAR	Synthetic-aperture radar
SBG	Surface Biology and Geology
SMAP	Soil Moisture Active Passive
SNOTEL	Snow Telemetry
SPI	Standardized Precipitation Index
USFS	U.S. Forest Service
VIIRS	Visible Infrared Imaging Radiometer Suite