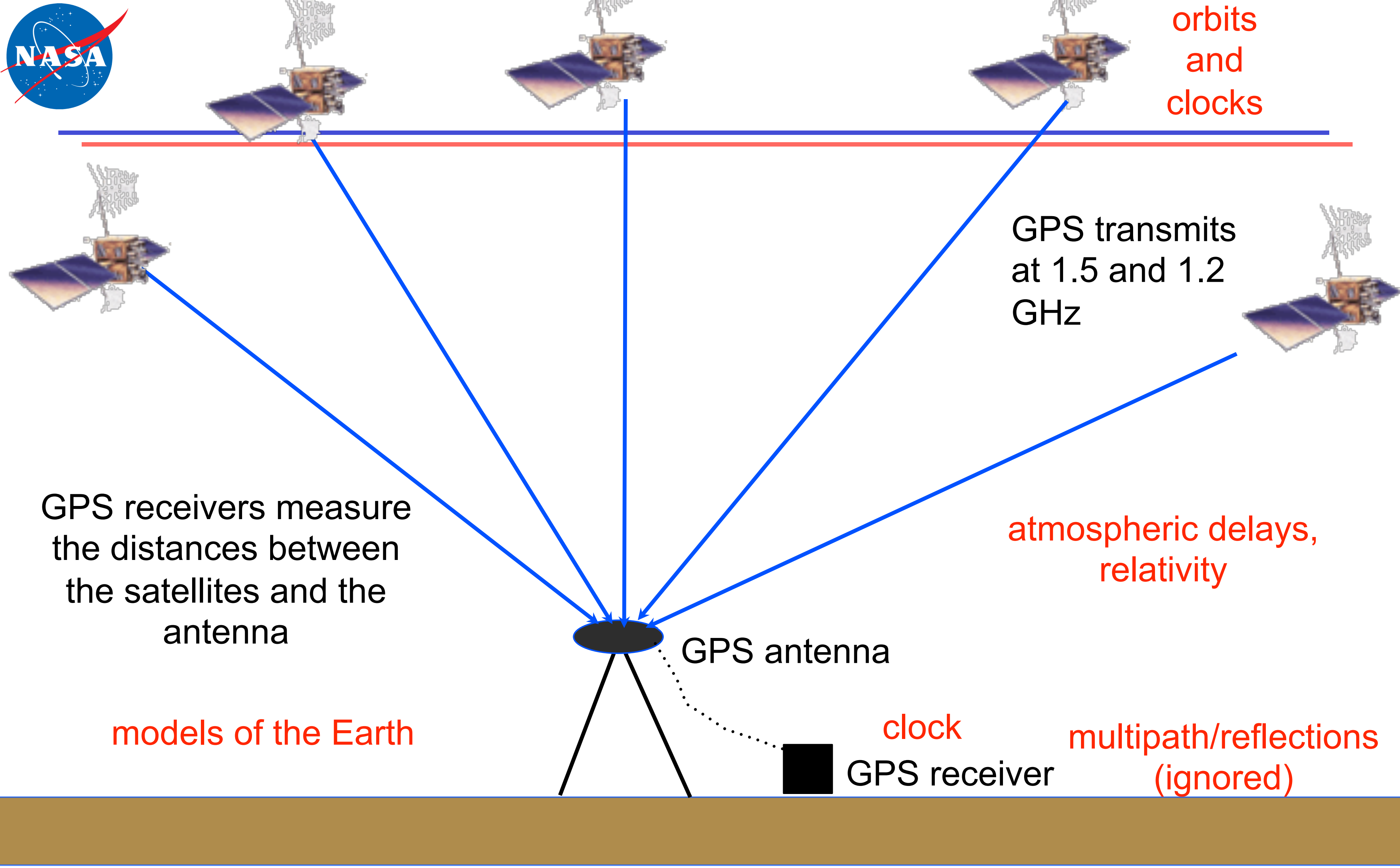
GNSS H_2O: A Global Network of In Situ Hydrologic Sensors Derived from GNSS Data

Susan Owen [1]
Kristine Larson [2], Eric Small [2], Angelyn Moore [1], Sean Hardman [1], Dana Freeborn [1], Cynthia Wong [1]

1. Jet Propulsion Laboratory, California Institute of Technology
2. University of Colorado, Boulder

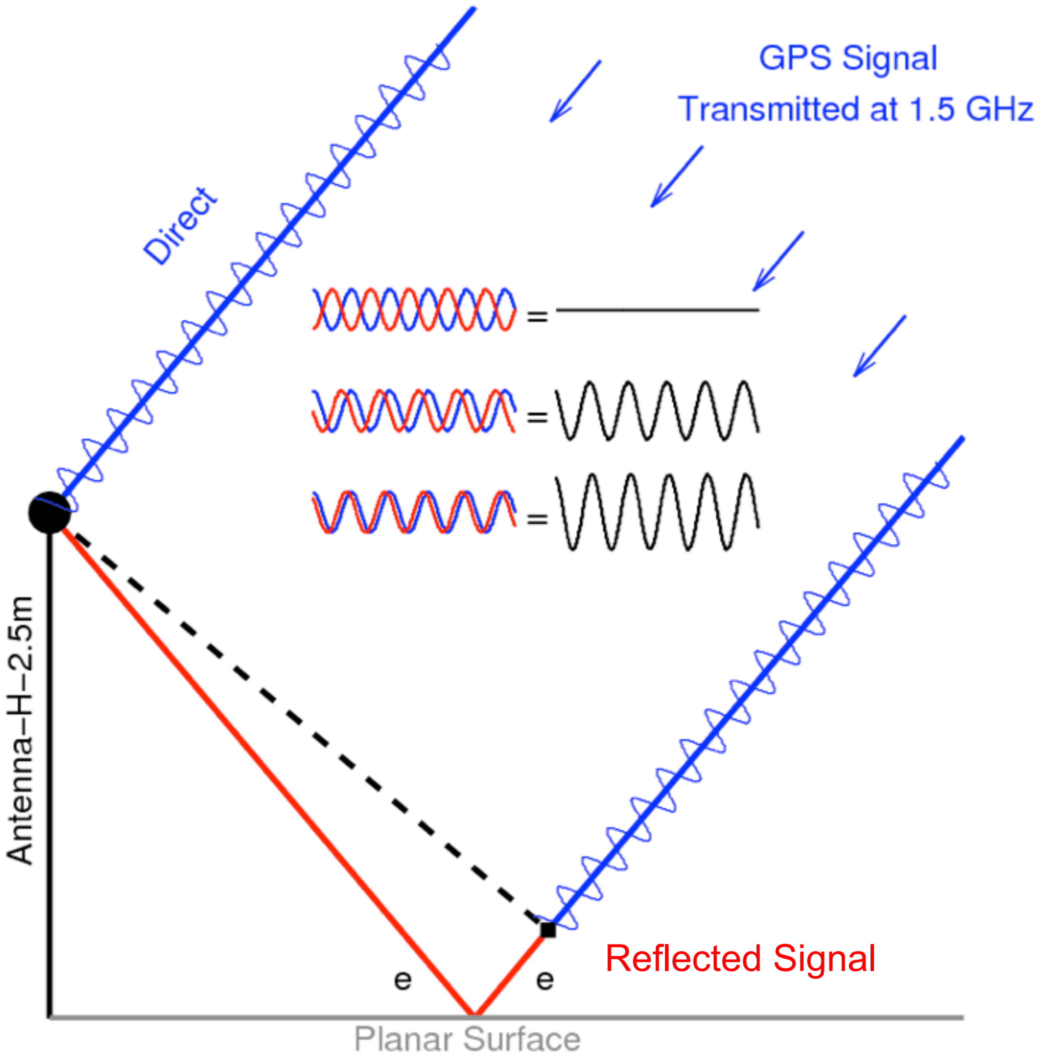
Outline

- GPS and Environmental Signals
- Expanding PBO H_2O to the global GNSS network
- AMIGHO AIST Project
- Current Status



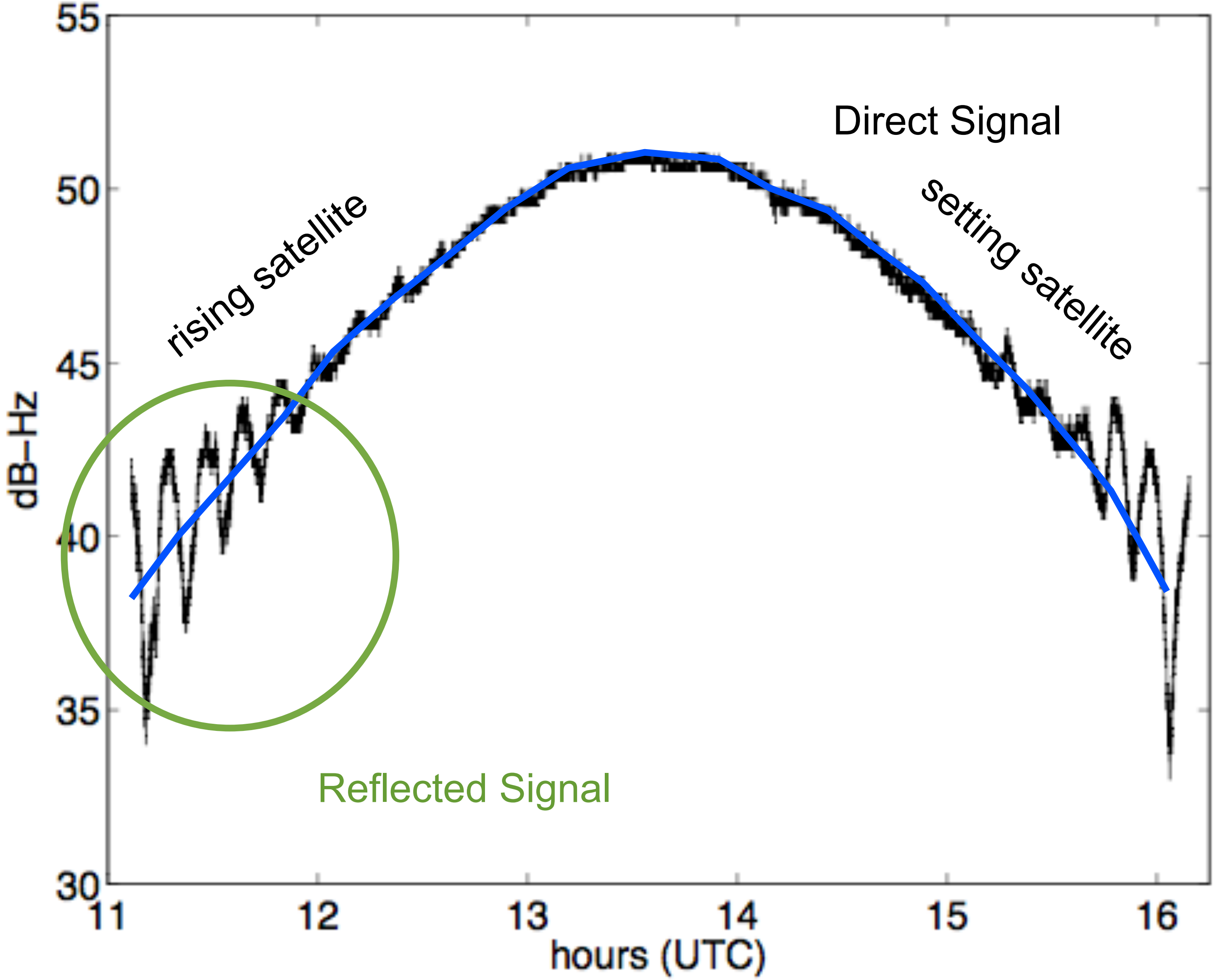
Geodesy: least squares estimation for position of the GPS antenna each day

How do you use a GPS receiver to measure environmental parameters?

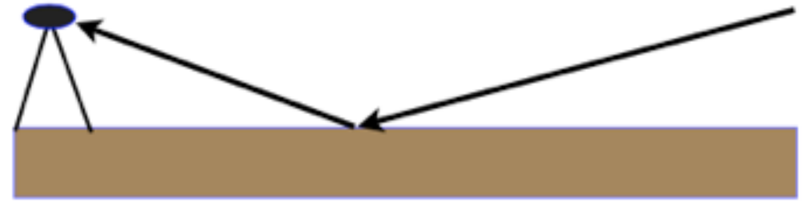


Interference signal provides measurement of surface characteristics that can be converted to snow depth, vegetation water content, and soil moisture.

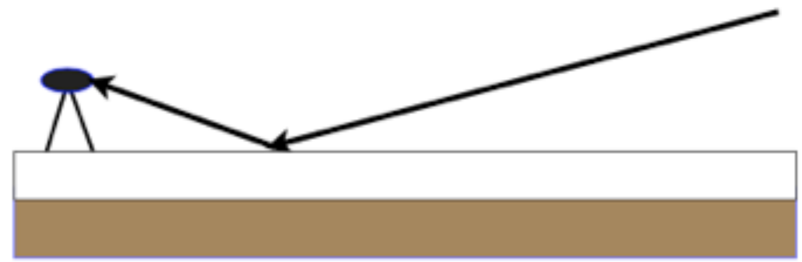
GPS Signal Strength Data



the reflections off bare soil produce this SNR curve

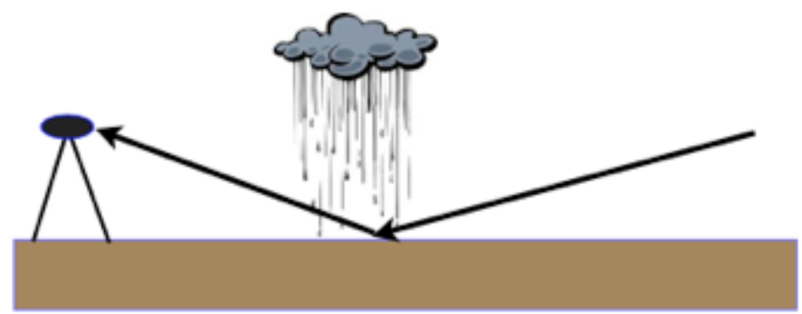


add a snow layer

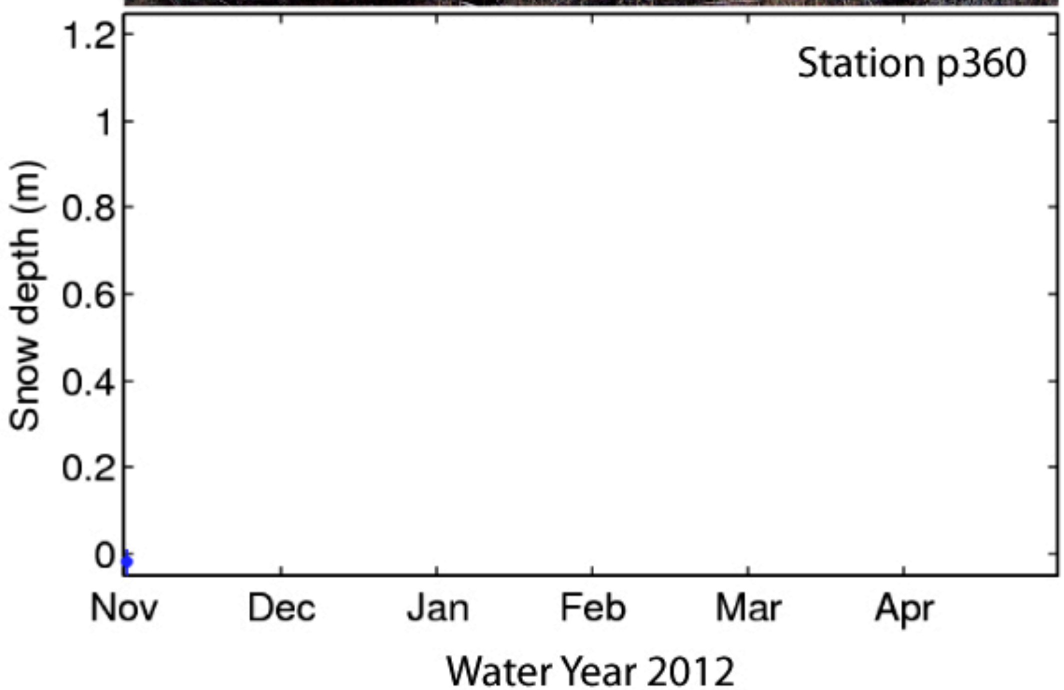


add vegetation

make the soil wet



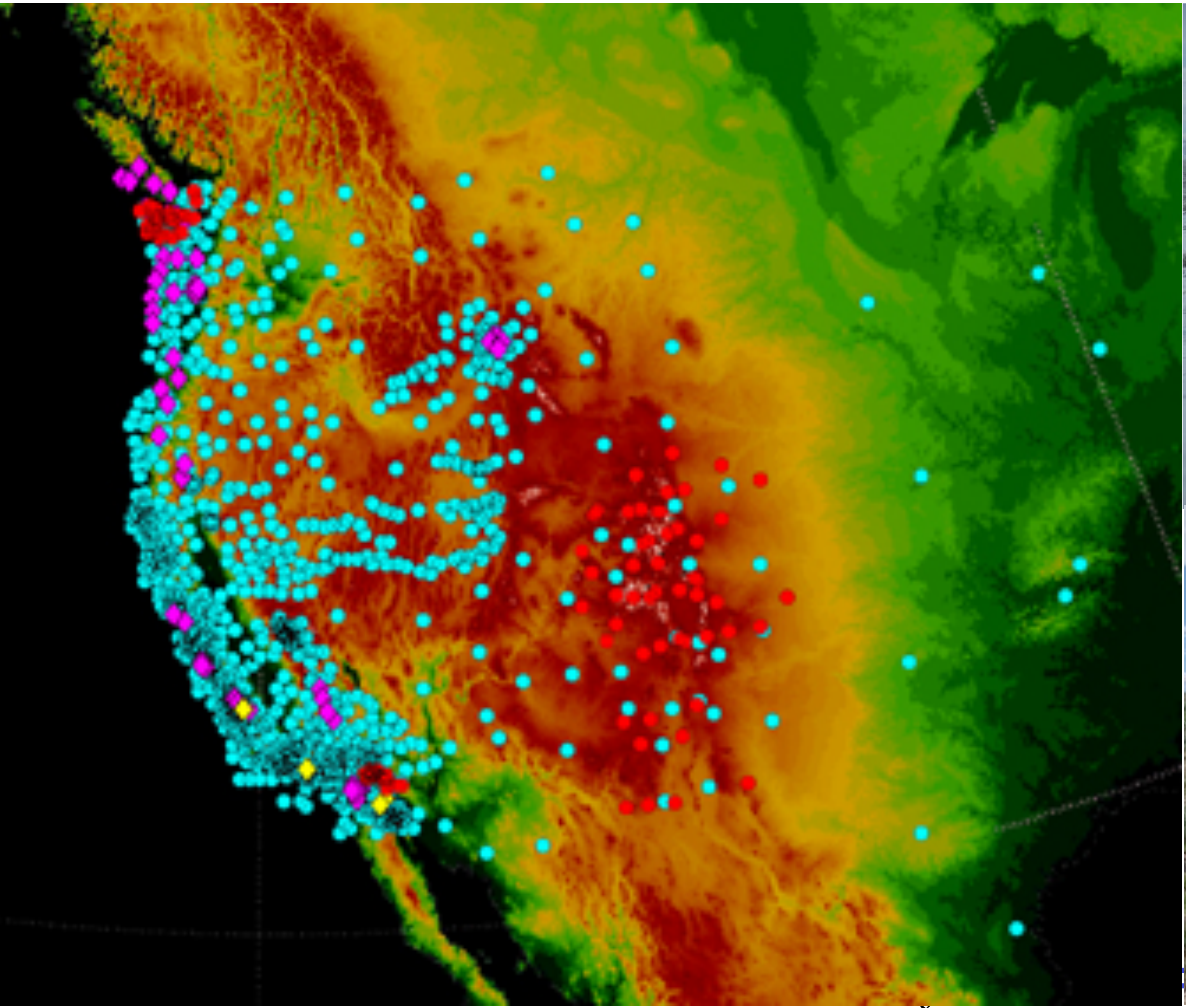
Larson et al., 2008; Larson et al., 2009; Small et al., 2010



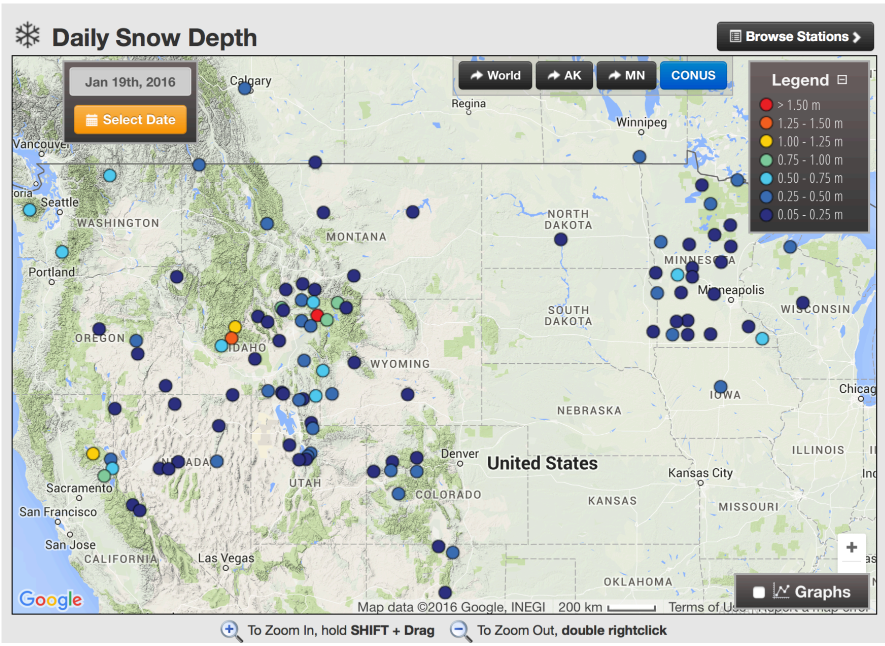
Station p360
Snow depth (m)
1.2
1
0.8
0.6
0.4
0.2
0
Nov
Dec
Jan
Feb
Mar
Apr
Water Year 2012

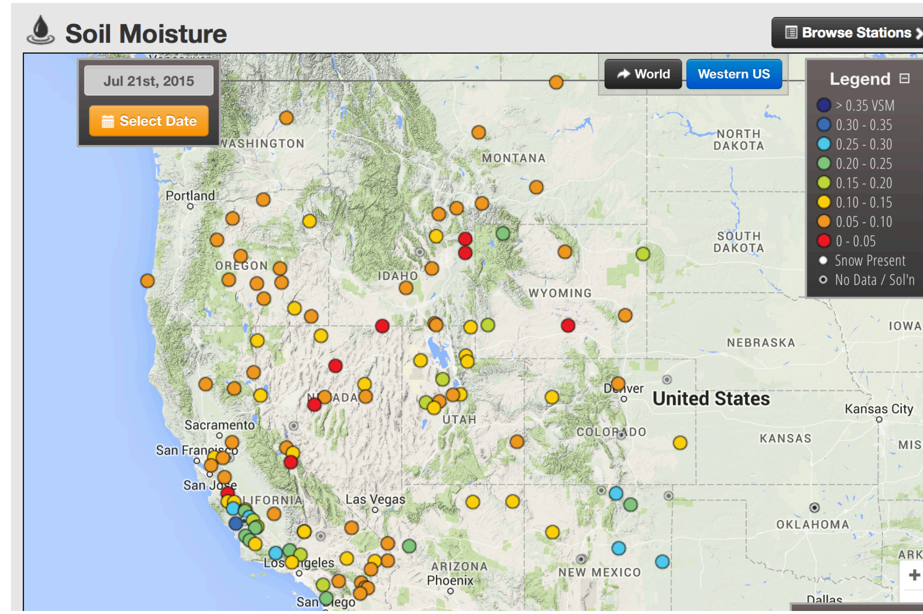
PBO H_2O

Using GPS reflection data from NSF's Plate Boundary Observatory (PBO) to study the water cycle



PBO H_2O



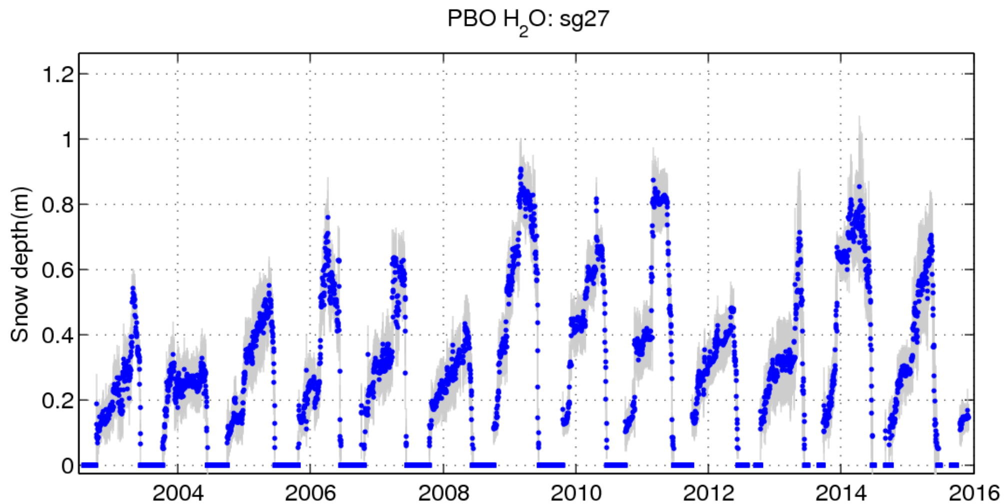


Proto-type GPS reflection system that creates and distributes soil moisture, snow depth/SWE, and vegetation water content products for ~400 sites. 95% of the data used in PBO H_2O comes from a single network, the EarthScope Plate Boundary Observatory.

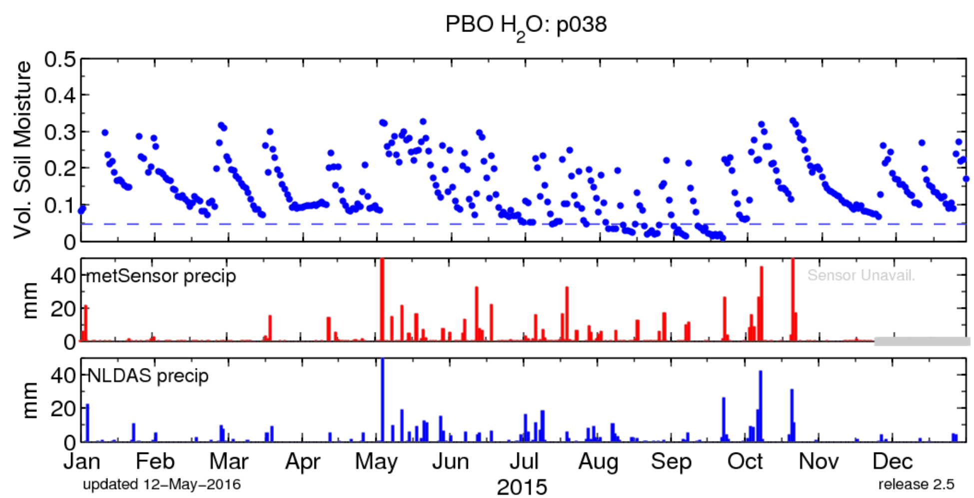
http://xenon.colorado.edu/portal

Earth Science Technology Office

Motivation for GNSS H_2O: New Climate Records



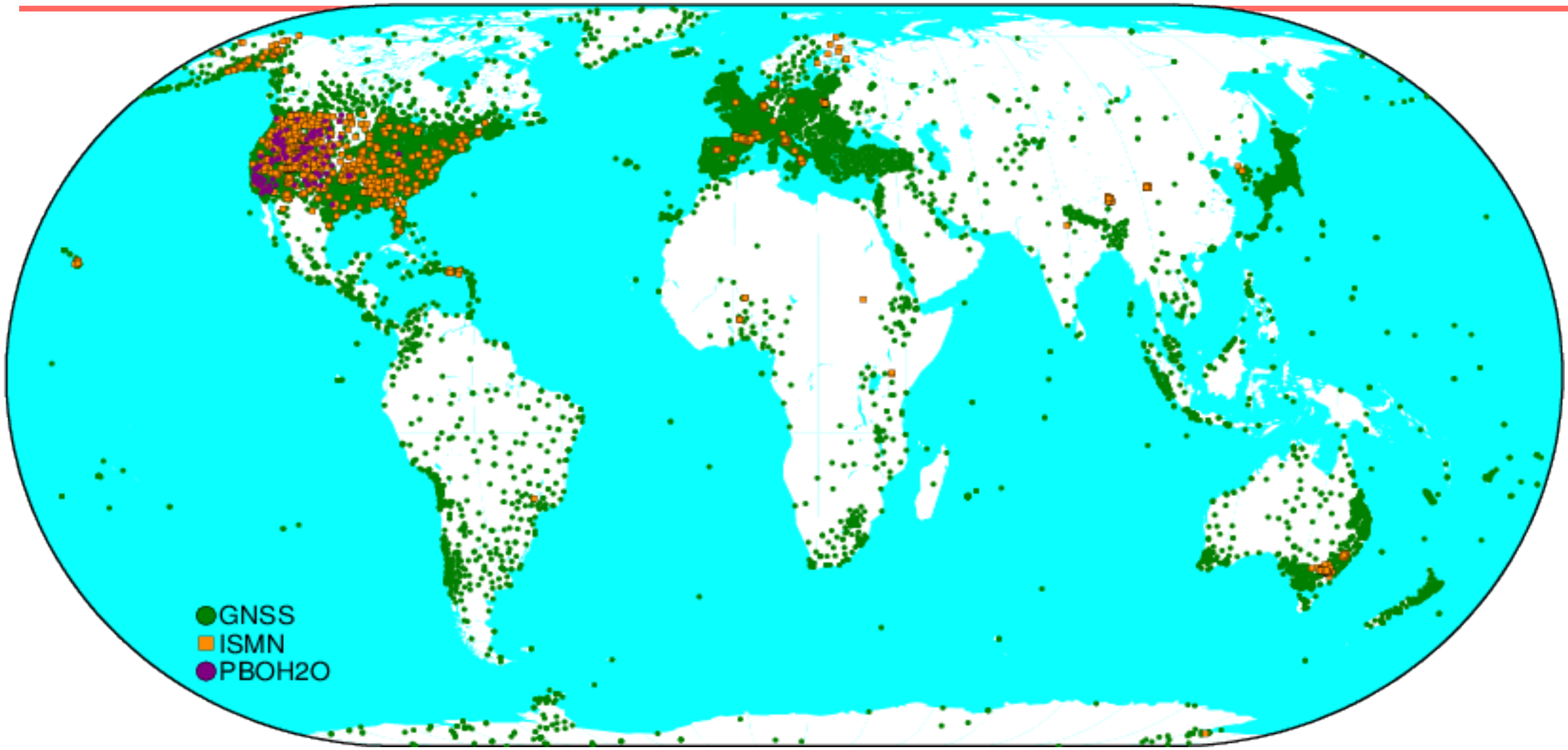
Snow Depth



Soil Moisture

Goal: provide access to thousands of inexpensive GNSS environmental sensors on a global scale, providing long time-scale records for climate studies.

GNSS H_2O & AMIGHO



International Soil Moisture Network

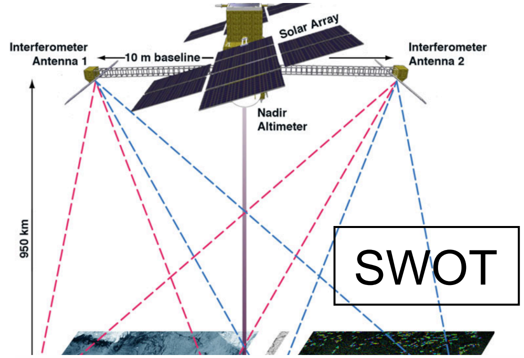
Public GNSS sites

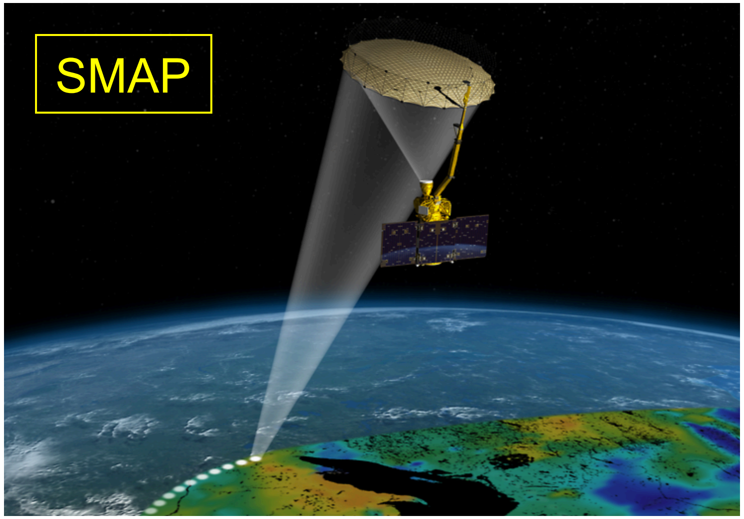
PBO H2O pilot project

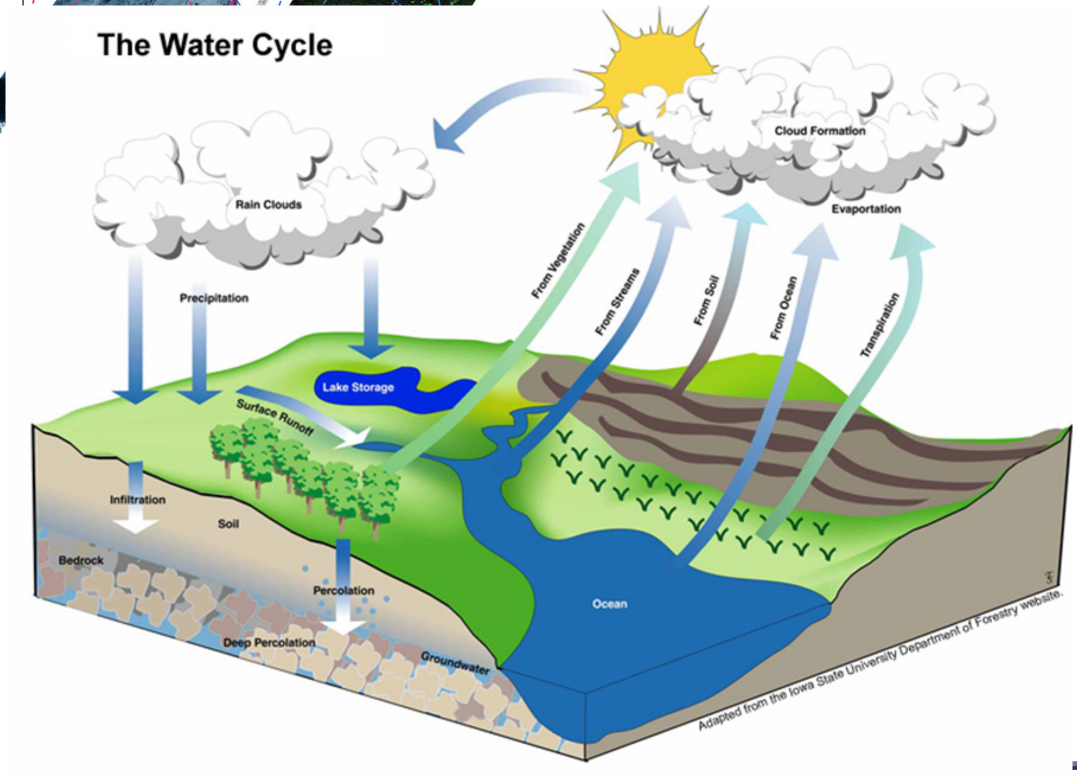
- Enable operators of GNSS networks to provide current and past data to the GNSS H2O system.
- Develop a system to automatically ingest GNSS observations and related metadata to produce data products.
- Enable understanding of GNSS water products through a portal which supports:
  - Visualization.
  - Data mining.
  - Data sharing.

ESTO Earth Science Technology Office

Motivation: Satellite Validation Data







Approach

- Leverage the prototype GNSS hydrologic products system (PBO H_2O) developed using NSF and NASA science funding and operated by the University of Colorado Boulder
  - Heterogeneous code, difficult to expand to new networks
- Leverage Apache OODT for extensibility
  - Design for expansion to global GNSS networks and continued long-term operations
- Develop new technology to automatically ingest new networks
  - Station Evaluator
- Develop automated Apache OODT configuration mechanisms

AMIGHO – Automated Metadata Ingestion for GNSS Hydrology with OODT

What is Apache OODT?

- Apache Object-Oriented Data Technology (OODT) is a standards-based, open source, data-grid middleware developed at JPL that serves as the backbone for many JPL, NASA and non-NASA science data systems.

- An adaptable framework for ingestion, management, processing and distribution of science data.

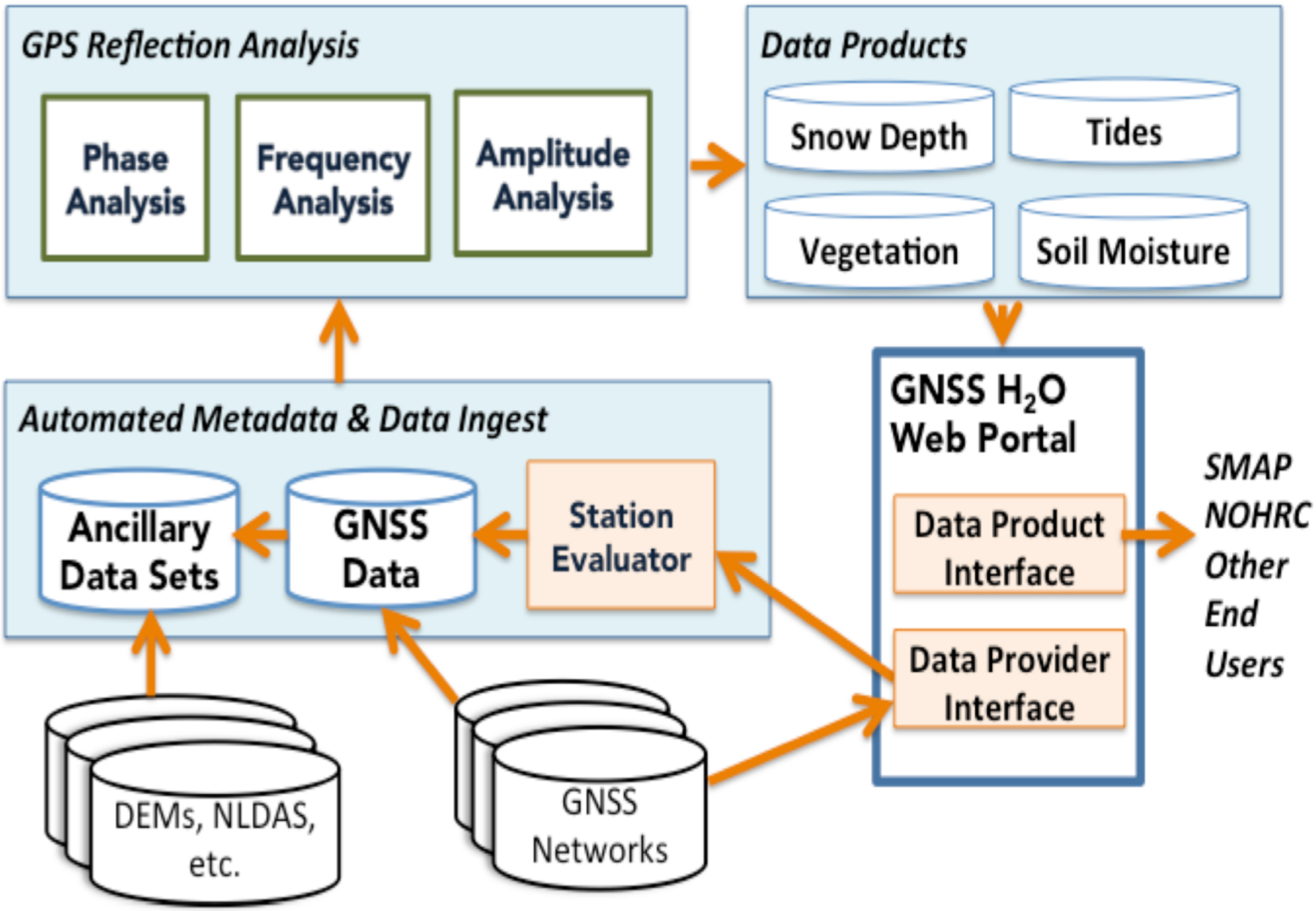
- Designed to enable reproducible pipelines - uses structured XML-based capturing of the processing pipeline that can be understood and modified to create, edit, manage and provision workflow and task execution.

- AMIGHO – will extend Apache OODT with autoconfiguration capability when adding new data sets

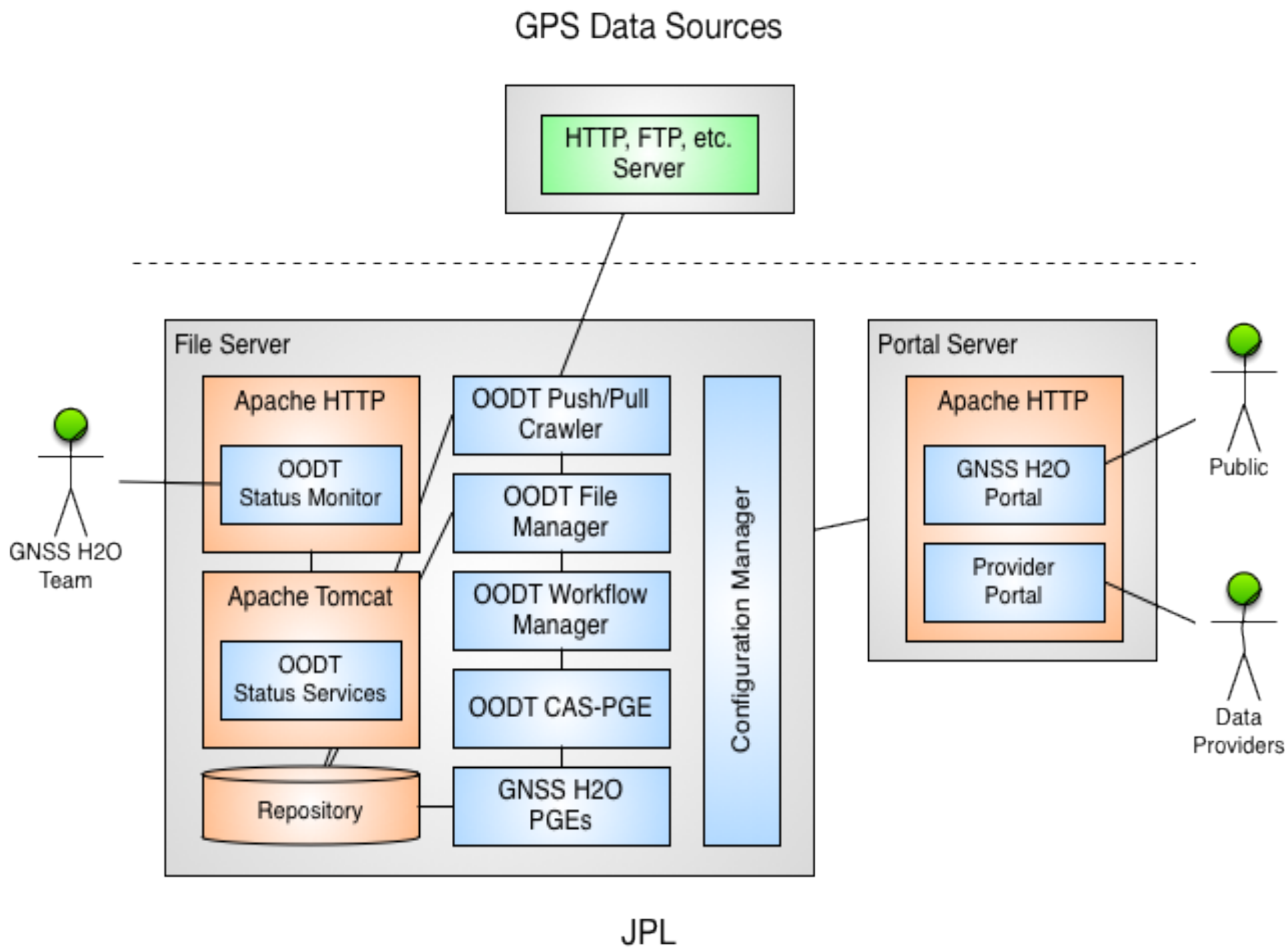
AMIGHO Tasks

- Year 1 Tasks
  - Implement GNSS Hydrology System using Apache OODT framework using existing algorithms.
    - Migrate existing PBO H2O
    - Re-implement ingest, analysis processes.
    - Re-implement data product production.
  - Identify new GNSS Networks for Ingestion
  - Design Automated Metadata Ingest & Configuration Technology
    - Design Station Evaluator
- Year 2 Tasks
  - Implement Automated Metadata Ingest & Configuration Technology
  - Demonstrate System with new GNSS networks
  - Develop New User Interface Tool

Operational Concept for GNSS H_2O



GNSS H_2O Deployment Architecture

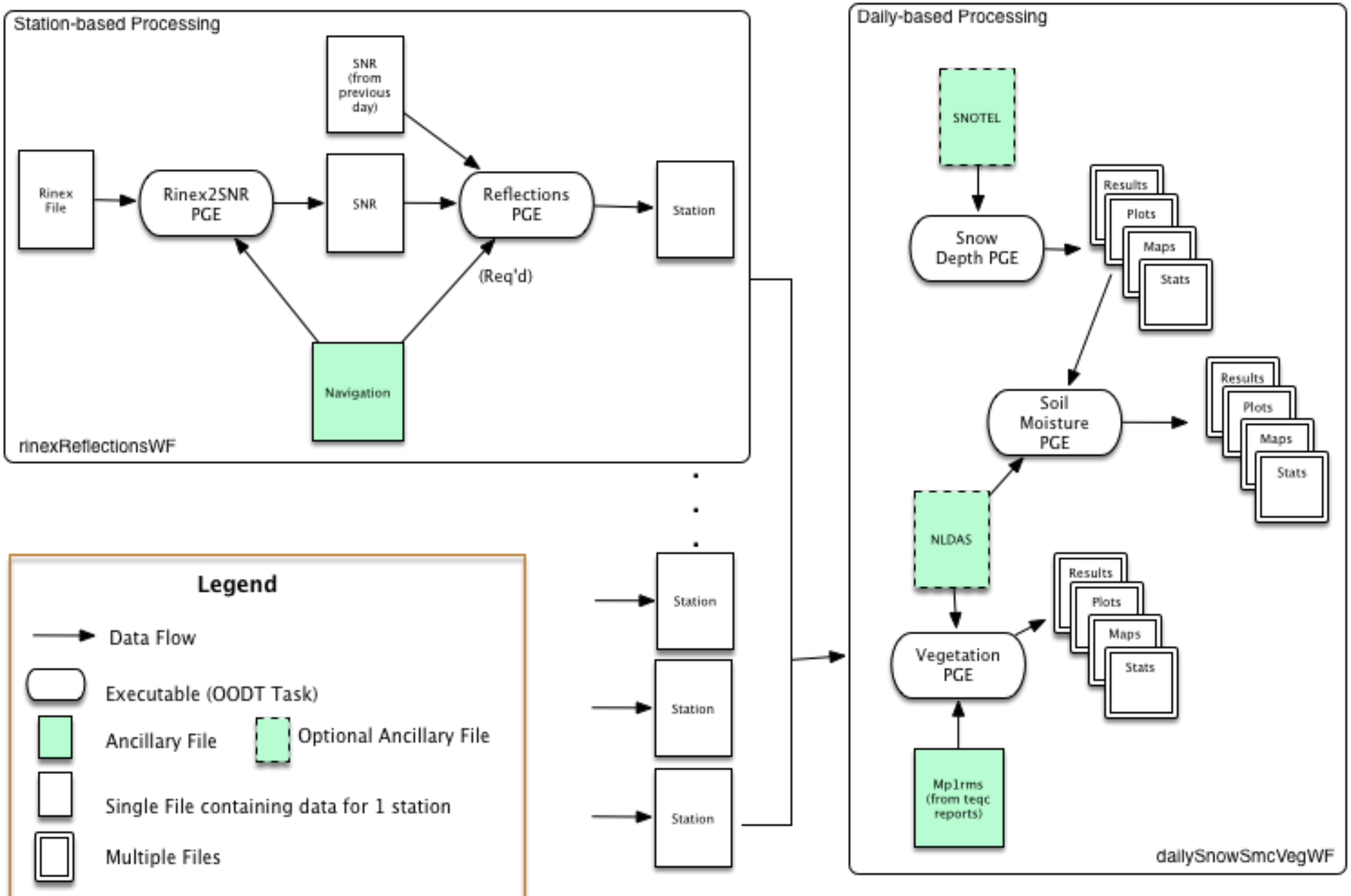


Task 1: Infusion of OODT into GNSS Hydrology System

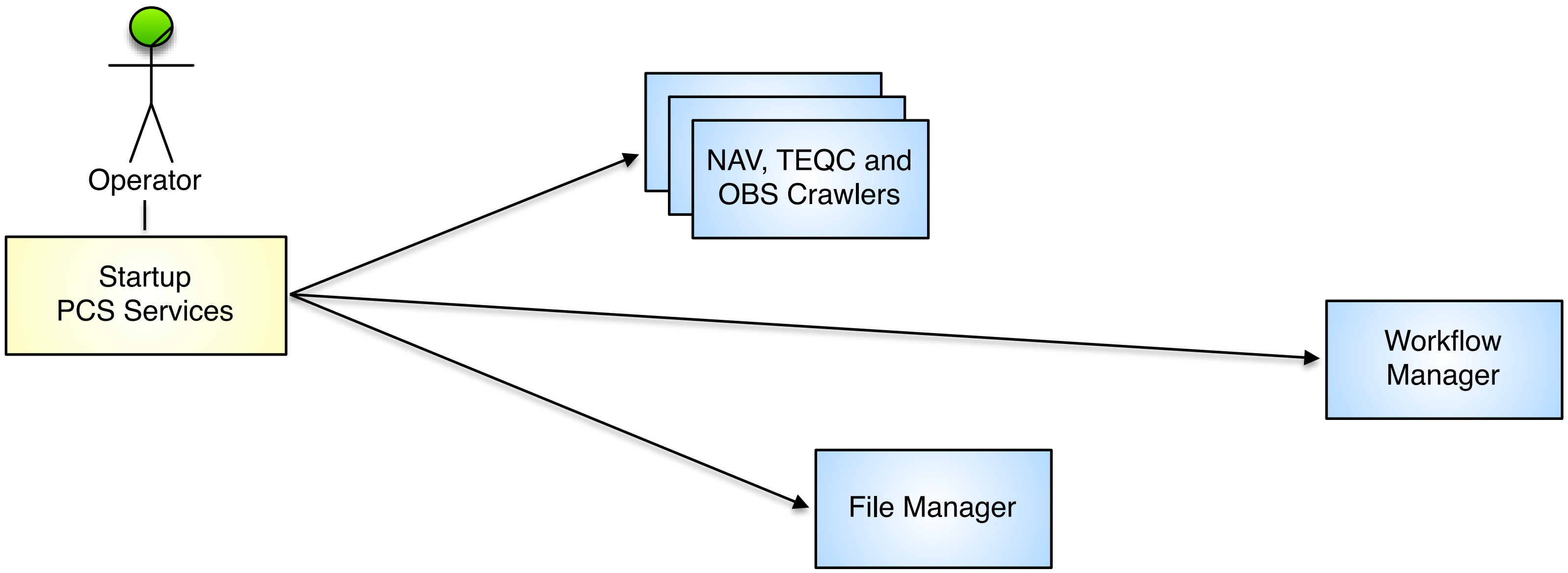
- Transfer PBO-H_20 code to JPL, understand and analyze the PBO-H_2O system
  - 68,000 lines of code, 9 different languages
- Streamline the CU PGE code where needed for extending to new GNSS networks.
- Design and develop GNSS-H_2O system using OODT
- Test, demonstrate and verify the GNSS-H_2O system

Earth Science Technology Office

PGE Processing Flow

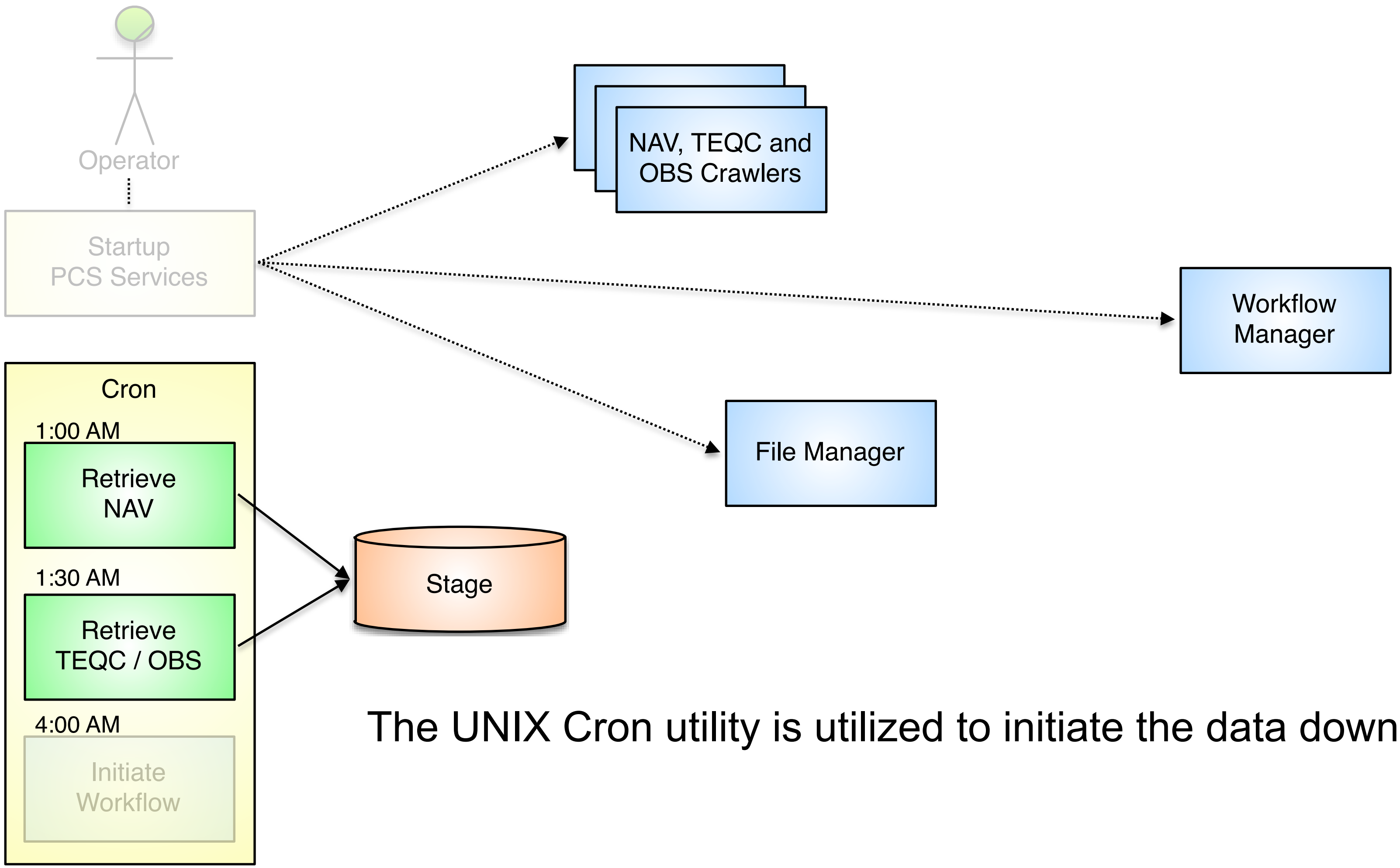


Animated GNSS-H_2O Demonstration



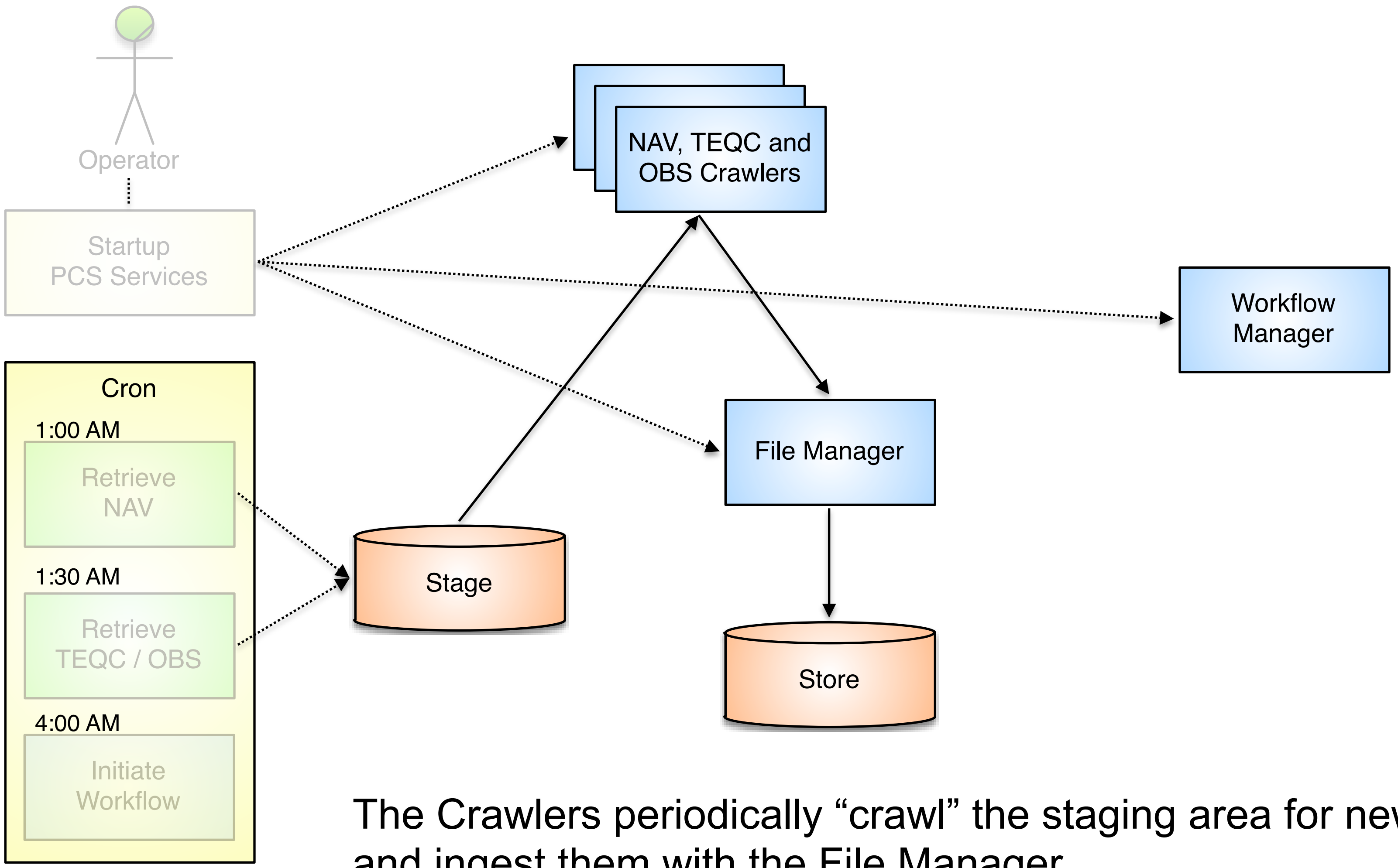
The Operator starts up the PCS (OODT) Services, which includes the Crawlers, File Manager and Workflow Manager.

Animated GNSS-H_2O Demonstration



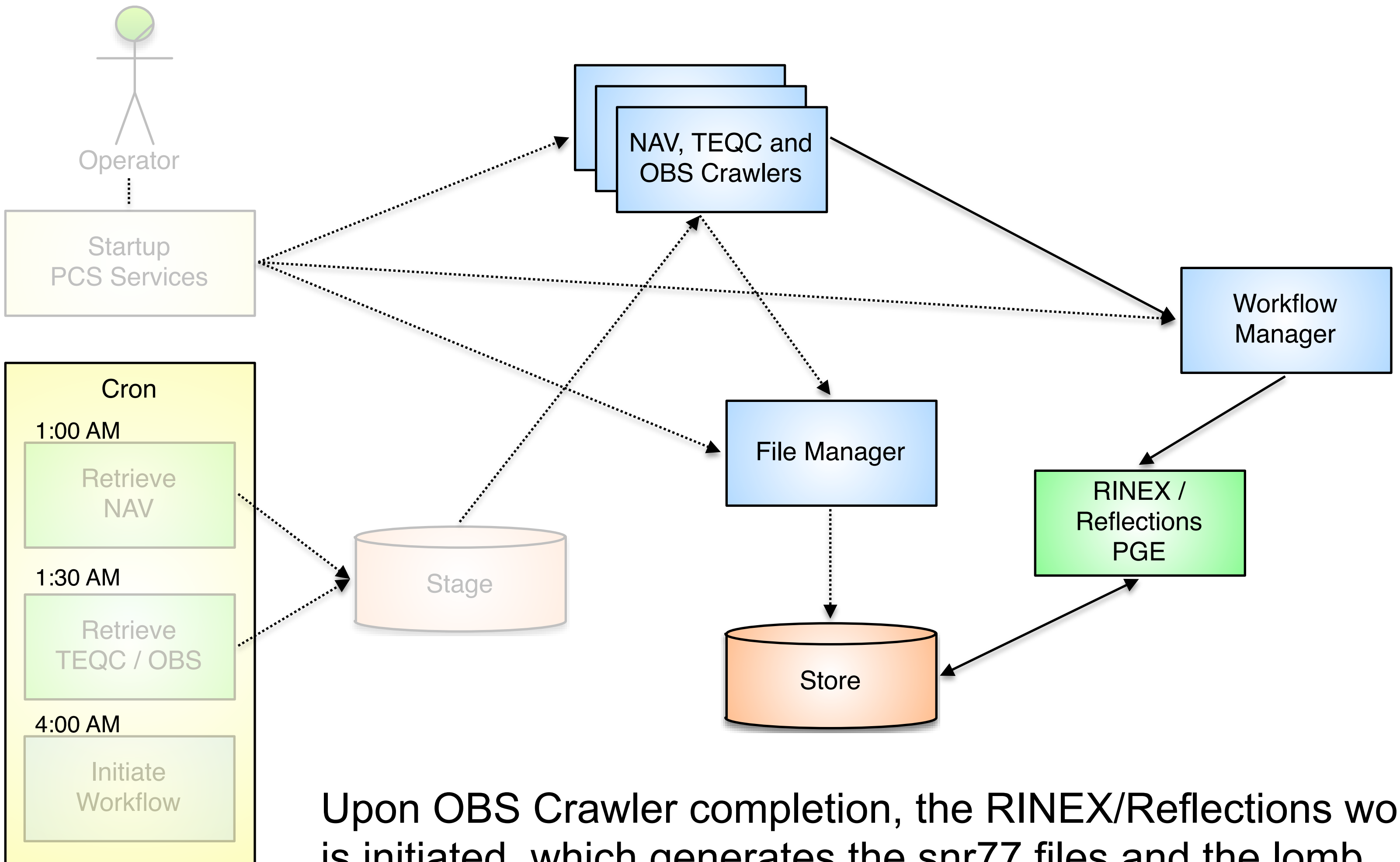
The UNIX Cron utility is utilized to initiate the data download.

Animated GNSS-H_2O Demonstration



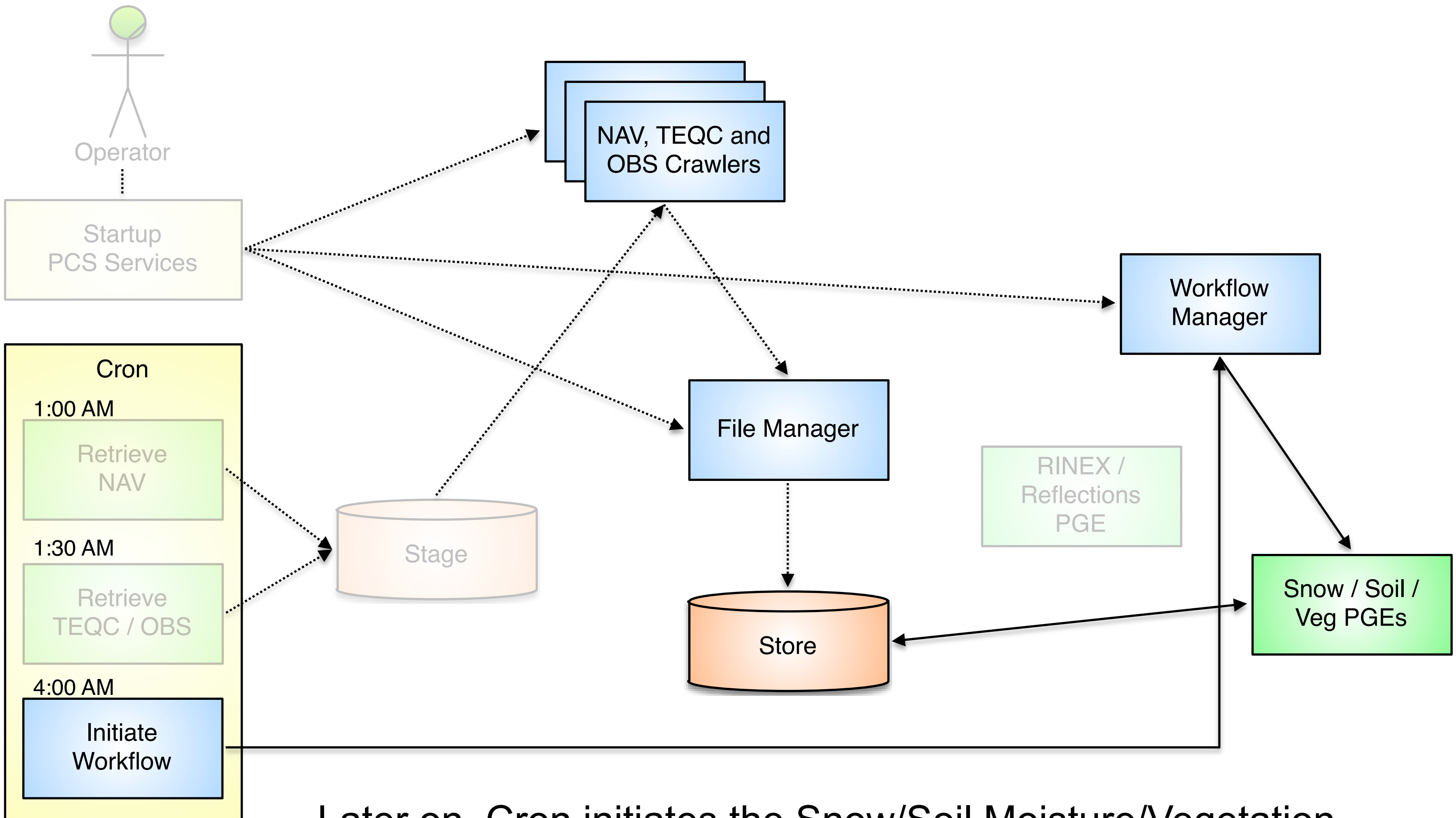
The Crawlers periodically “crawl” the staging area for new files and ingest them with the File Manager.

Animated GNSS-H_2O Demonstration



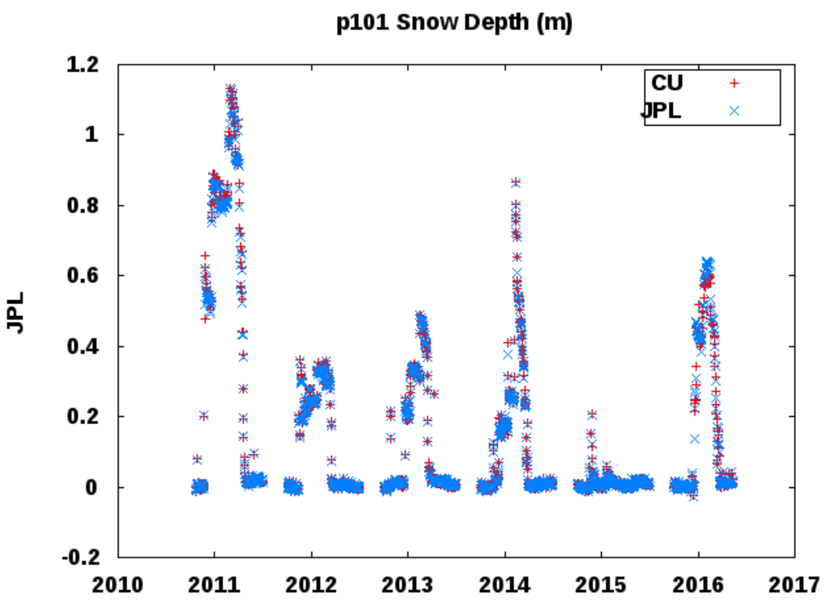
Upon OBS Crawler completion, the RINEX/Reflections workflow is initiated, which generates the snr77 files and the lomb scargle/least squares solutions for snow and soil moisture.

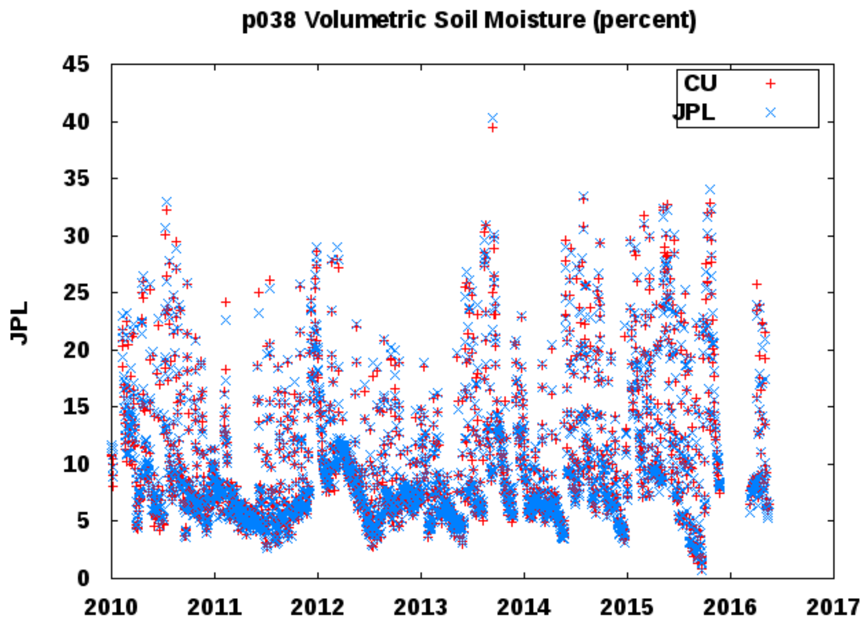
Animated GNSS-H_2O Demonstration

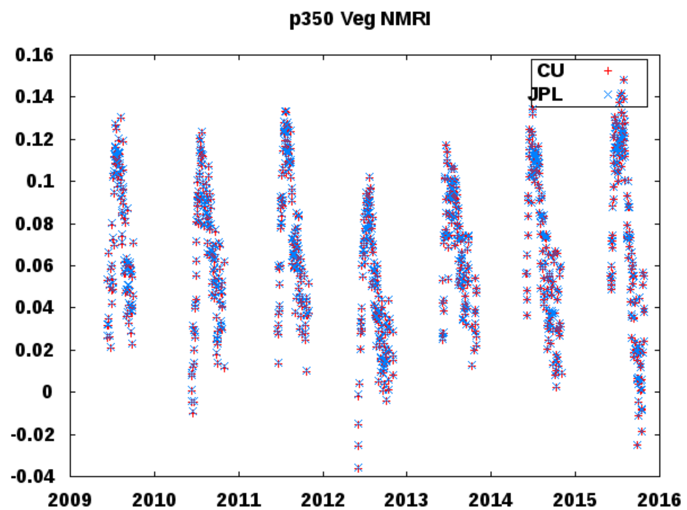


Later on, Cron initiates the Snow/Soil Moisture/Vegetation workflow, which generates the final products.

Sample Validation Time Series

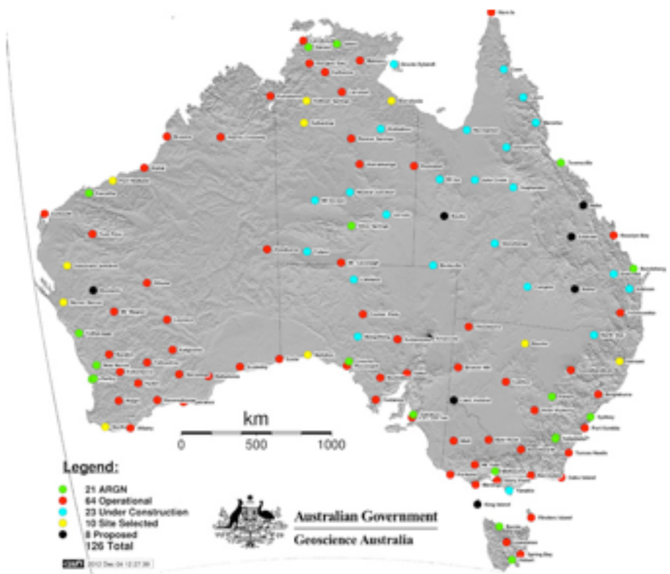






Earth Science Technology Office

Task 2: Identify New Networks



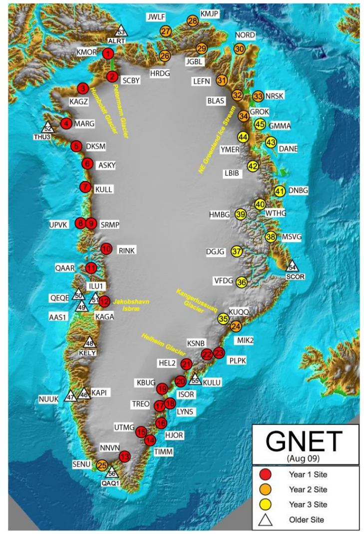
Australia

Nepal

Goals:

- Test ingestion and processing data from multiple GNSS networks.
- Allow later integration of new signals from the Russian, Chinese, and European constellations.
- Emphasize networks from the southern hemisphere and other regions with limited soil moisture, snow depth, and vegetation networks.

Task 2. Identifying New Networks



The global GNSS network consists of more than 12,000 stations operated by hundreds of different agencies at a variety of scales (global, regional).

No one archive has all GNSS data. Data formats are well defined, but require that operators use special options when making those data files to be useful for reflection applications.

We need a metadata system that operates in both directions – ingesting data from these networks and communicating to those operators what is needed for a proper GNSS reflection site.

Earth Science Technology Office

Identify New Networks

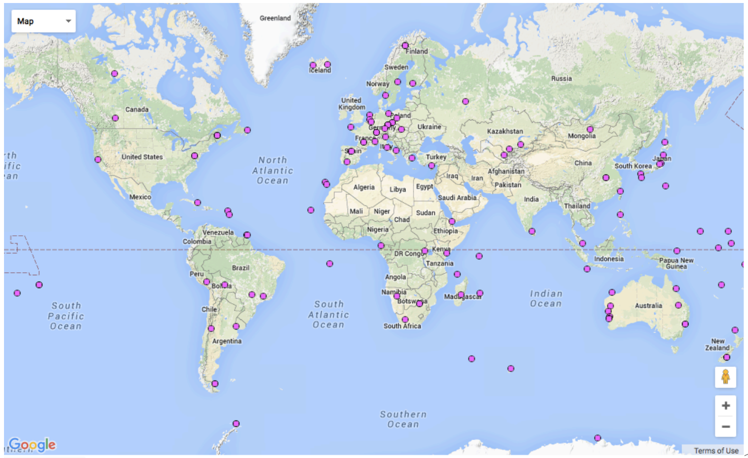
- GPS/GNSS receivers record data in various binary formats.
- Station managers convert data to an internationally accepted, ascii (receiver independent, RINEX) format for public access.
- Reflection studies often require observables stored in the binary file, but not always archived in RINEX files.

We have three options:

1. Whenever possible, use existing archived RINEX (version 2) ascii files
2. Request network managers provide binary files
3. Request network managers provide reflections compliant ascii files (RINEX version 3)

We have identified a source (MGEX) of RINEX version 3 GNSS data that is reflections compliant. Using the gfzrnx converter, we can create RINEX version 2 and use this in the GNSS H_2O software, without the need for any special data access.

The IGS (International GNSS Service) Multi-GNSS Experiment (MGEX) network archives data from ~120 sites operated by about 30 agencies.



Task 3: Design Automated Metadata Ingestion

Goals:

- Define a standard set of metadata for describing a GNSS station, its data, and the site's reflection qualities.
- Design a web-based interface for submitting this metadata to the system.
  - To be utilized by GNSS Network Managers as well as the system operator.
- Design and develop the automatic configuration layer for OODT.
  - Determine the suitability of a station's reflection data for generating hydrologic products.
  - Evaluate and modify the configuration of the OODT components accordingly in real-time.

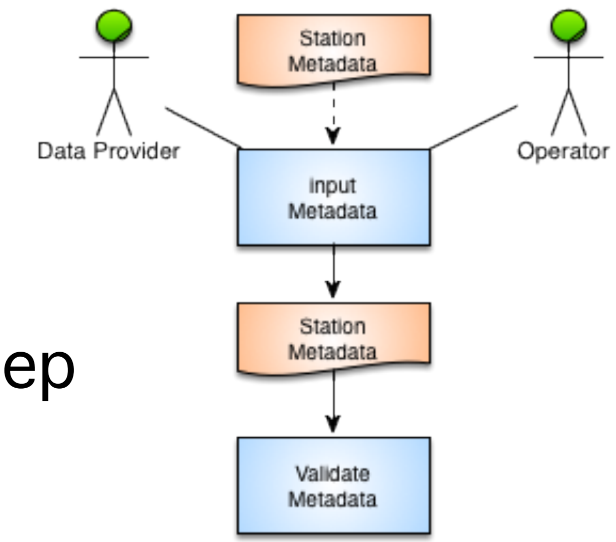
ESTO Earth Science Technology Office

Task 3: Design Automated Metadata Ingestion

- Accept station metadata from the provider
- Store the metadata in a central database
- Evaluate the location of the station for suitability in the data system
- Evaluate the data from the station to further determine its suitability
- Configure the OODT components to retrieve data from this new source and process it with the other station data in the data system

Accept Metadata

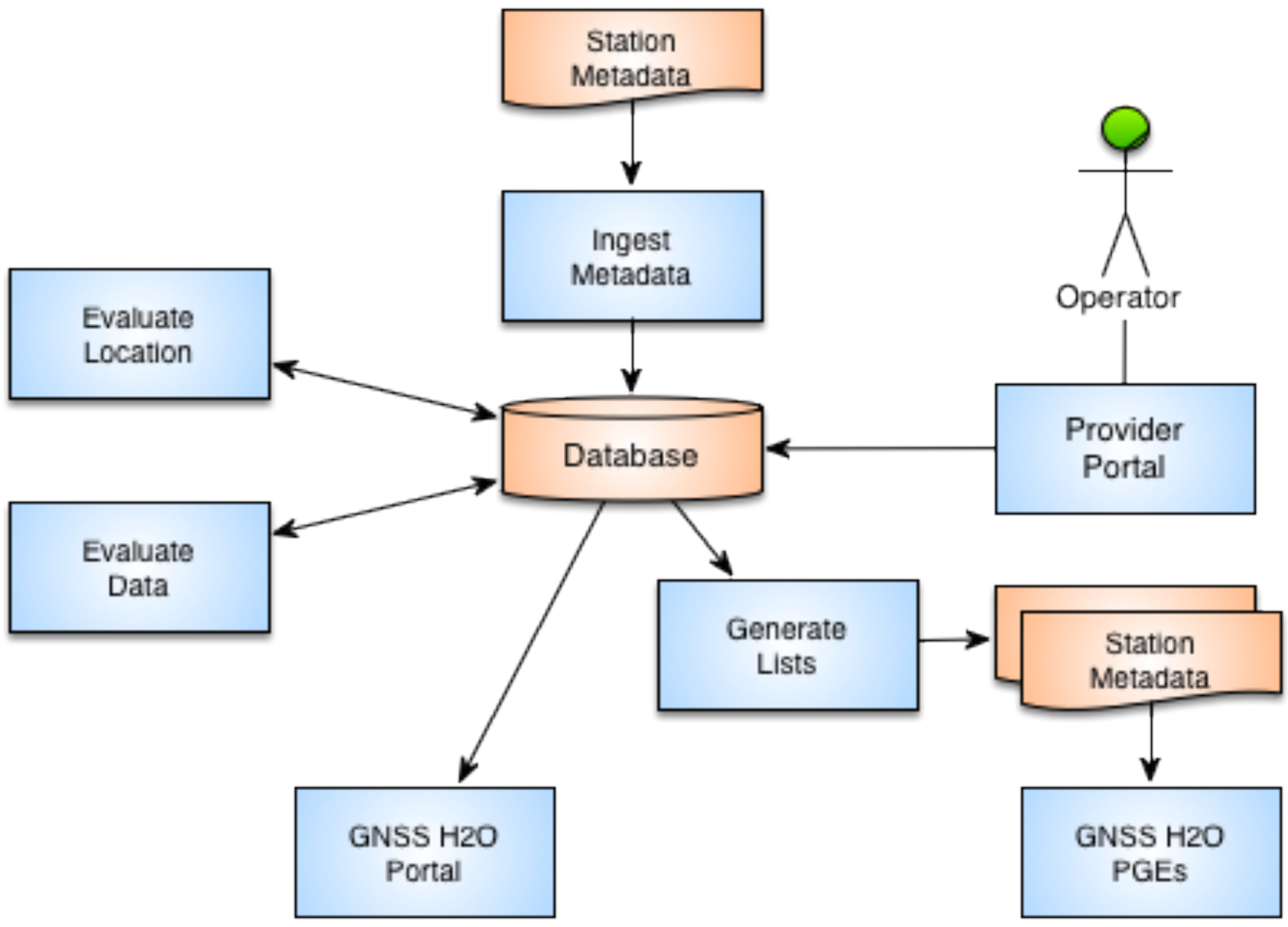
- Provide an interface for data providers and operators enabling submission of metadata
- Provide a mechanism to receive metadata in bulk
- Required attributes for a GPS station:
  - Identifier and Name
  - Latitude, Longitude and Elevation
  - Data Access URL and Data Type
  - Submitter Name and Email Address
- Validate the provided metadata prior to moving onto the next step



Store Metadata

- The inherited PBO-H_2O system stores metadata in multiple repositories (e,g,. databases, lists, etc.)
- In order to streamline the GNSS-H_2O data system, a single database will be designed and populated with metadata from all stations
- In order to minimize impact on the processing scripts, the various input lists will be maintained.
- The difference being that these lists will be generated from the single database.

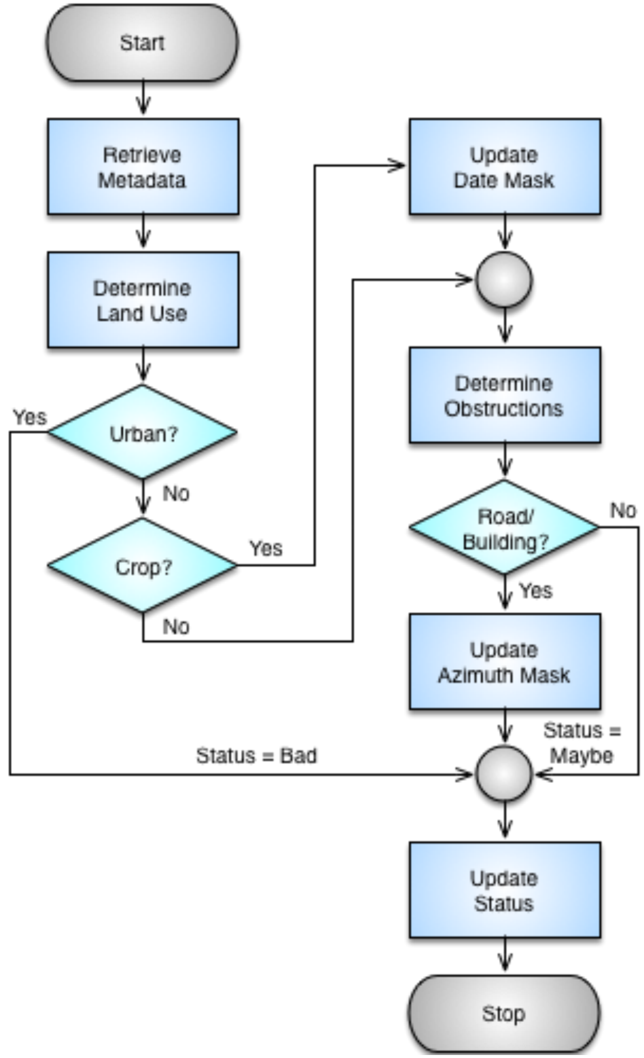
Metadata Storage Flow



Evaluate Location

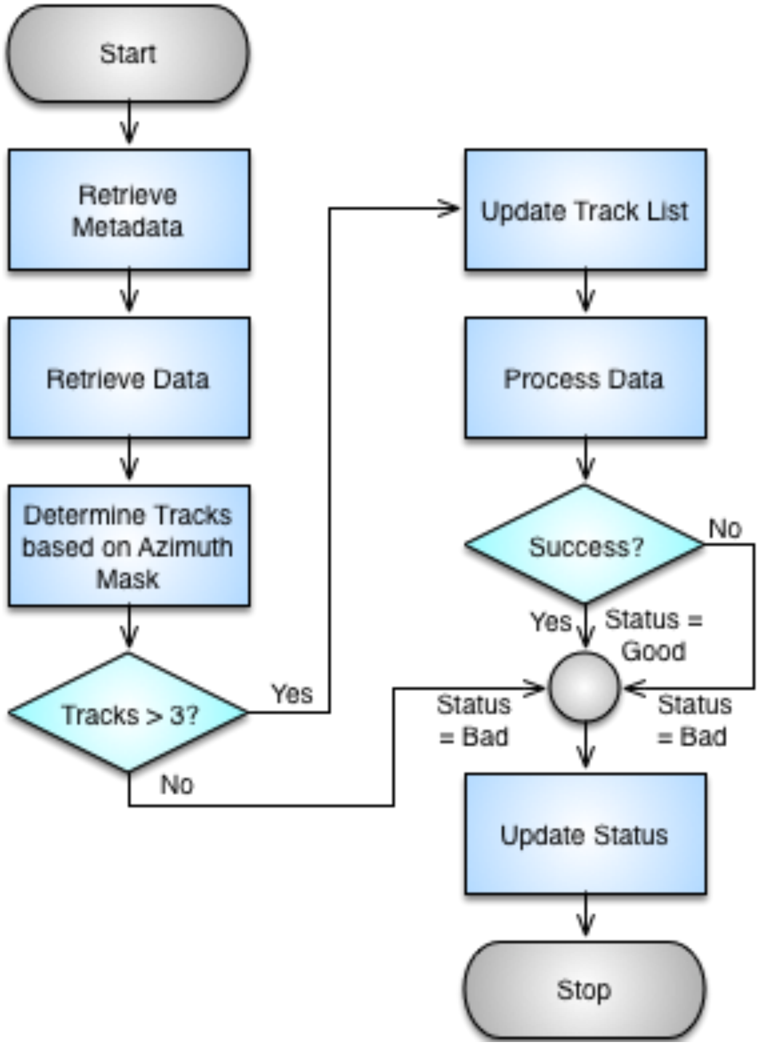
- Determine characteristics of the station location based on one or more sources
  - Query-able services
  - Satellite-based static maps

- Update metadata about the station in the database accordingly



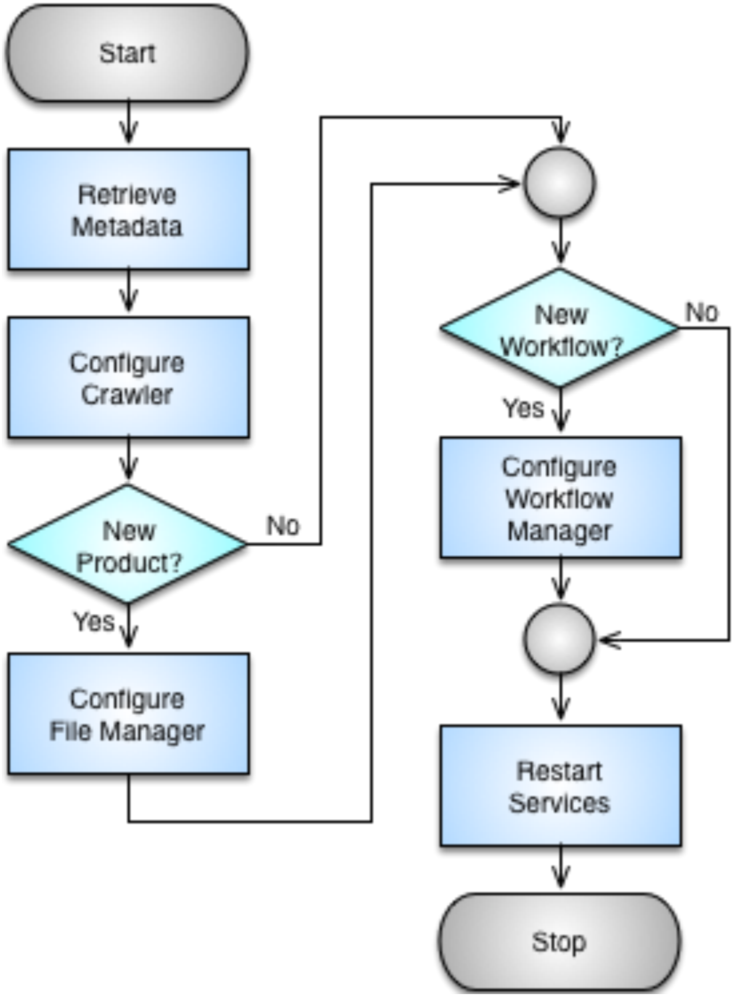
Evaluate Data

- Determine available data for a station based on the azimuth mask
- Minimum number of tracks
- Process data to determine quality

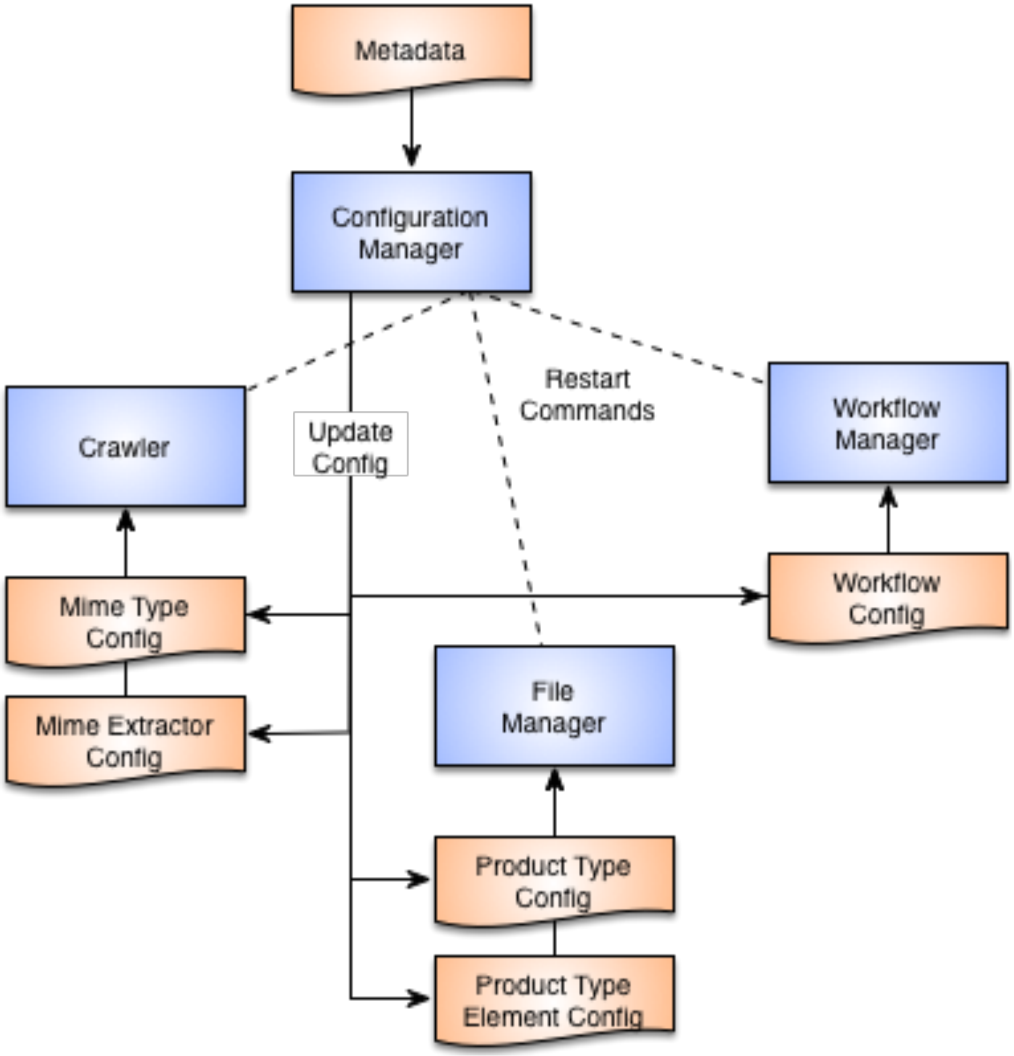


Configure OODT

- Focus on configuration of the primary components utilized by GNSS-H_2O
- Develop generic metadata structure
- Develop handlers to update specific configuration files
- Enable shutdown and restart actions



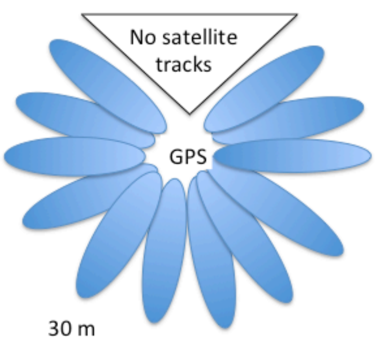
Configure OODT Architecture



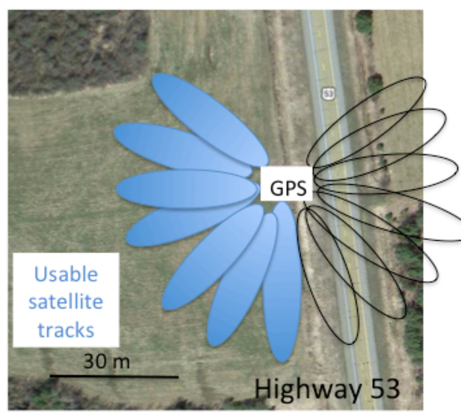
Station Evaluator

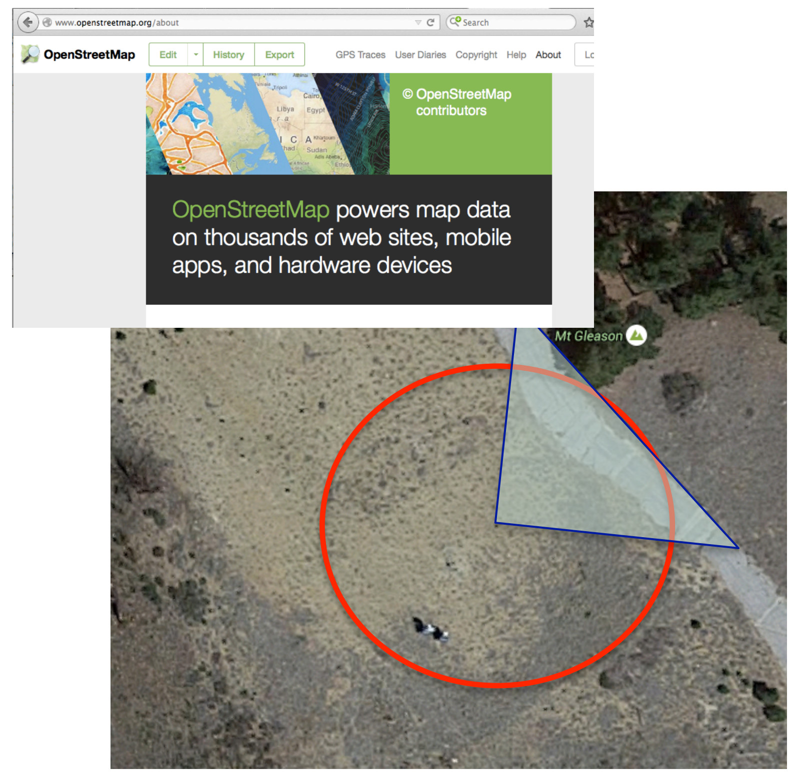
- Need to identify useable satellite tracks (soil, not roads)
- OpenStreetMap, using its Overpass API, can be queried for paved roads and parking lots within a lat/lon box . The response, in JavaScript Object Notation (JSON) format, can be parsed to determine the distance and bearing from the center of the box to the contained roads.

Theoretical GNSS Site



Ashland, Minnesota



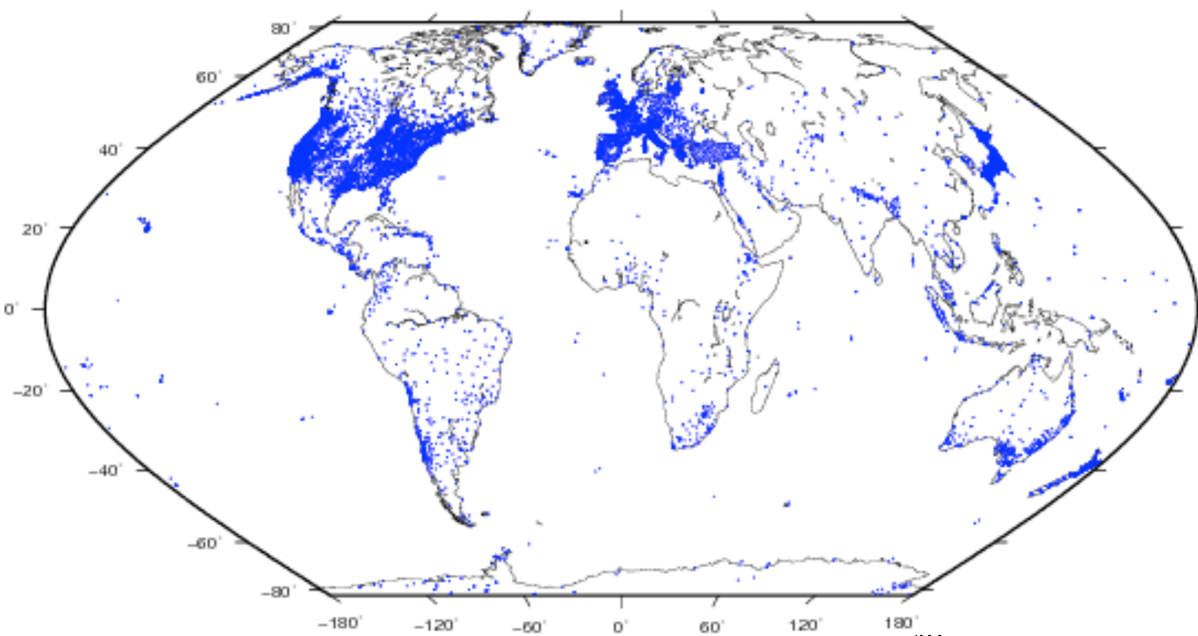


AMIGHO Tasks

- Year 1 Tasks
  - Implement GNSS Hydrology System using Apache OODT framework using existing algorithms.
    - Migrate existing PBO H2O
    - Re-implement ingest, analysis processes.
    - Re-implement data product production.
  - Identify new GNSS Networks for Ingestion
  - Design Automated Metadata Ingest & Configuration Technology
    - Design Station Evaluator
- **Year 2 Tasks**
  - Implement Automated Metadata Ingest & Configuration Technology
  - Demonstrate System with new GNSS networks
  - Develop New User Interface Tool

Summary

- PBO H_2O is already one of the largest soil moisture networks in the world; it also provides snow depth (170) and vegetation (370) information in near real time.
- GNSS H_2O will provide a global dataset of *in situ* climate data and satellite validation data.
- GNSS H_2O will expand PBO H_2O, professionalizing the code so that it can operated with many networks and users and automating the addition of new networks.



Funding for developing the GNSS H_2O comes from NASA AIST. PBO H_2O was developed with assistance from NSF and NASA.