Data Products

OVERVIEW

The Global Positioning System continuously transmits L-band signals (wavelengths of 19 and 24.4 cm) to support real-time navigation users. These same signals are being tracked by networks of high-precision GPS instruments that were installed by geophysicists and geodesists to measure plate tectonics. These networks exist at both the global and regional scale and data are freely available. One of the error sources for geodetic and geophysical users of GPS data is reflected signals. The GPS Reflections Research Group uses the reflected signals captured by these GPS networks to measure environmental parameters, including near-surface soil moisture, snow cover, and vegetation. For most sites the footprint of the method is ~20 meter in radius, which complements small-scale *in situ* sensors and large-scale satellite methods.

Updated snow depth, soil moisture, and vegetation data products using GPS reflections are posted every morning. The full period of record is available for download in a csv format. Efforts have been made to ensure that the products available through the PBO H2O Data Portal are of high quality, but inconsistencies and erroneous data may pass through our analysis system without being identified. Please contact the data products manager (gps.reflections@gmail.com) if you uncover problems with the data.

We are currently focusing on data from the NSF EarthScope Plate Boundary Observatory. This facility is operated by UNAVCO. The PBO network is comprised of 1100 GPS receivers; nearly all are located in the western United States. Raw GPS RINEX files, metadata, and positioning products are available from the UNAVCO archive.

-The GPS Reflections Research Group
Kristine M. Larson and Eric E. Small
October 27, 2015

1. DOWNLOADS

Our water cycle products are updated every day. A cdv file is created for each site. These files are zipped together, and this updated zipped file is what is made available at our web portal, http://xenon.colorado.edu/portal, or directly at the pho_h2o.zip file.

If you want to download this file every day, you can use this csh command: wget http://xenon.colorado.edu/downloads/pbo_h2o.zip

Three metadata lists are provided in the zip file to allow people to use specific products (these lists have latitutde,longitude,and ellipsoidal height in them). The files are called snow_metadata.csv, smc_metadata.csv, and veg_metadata.csv.

2. SNOW DEPTH PRODUCT

Snow depth is estimated through a calculation of the relative change of the effective multipath reflector height with respect to a snow free surface. Our ability to measure the location of the reflecting surface has a precision of a few cm.

Snow depth is currently being reported with a time resolution of one day. This snow depth value is the average of all available satellite tracks. The uncertainty reported represents a rms scatter of those satellite tracks. Given that snow depth does vary azimuthally (and thus will be different for different satellite tracks), some of the error reported for daily snow depth represents true variability rather than measurement error. We can provide snow depth values for individual satellite tracks to interested researchers. Poor precision may also indicate that snow fell that day. If there is only a single satellite retrieval at a site, the error has been set to 5 cm.
You can download all snow results, look at individual stations, or use the dynamic snow map capability.
We have compiled and animated results from past snow years. These gifs are available here.

We use the L2C GPS SNR data to estimate snow depth. At our request, UNAVCO turned on L2C tracking at a few sites in fall 2009 and 2010. The greater PBO network only became L2C-enabled in July, 2011. For this reason, the number of sites reporting snow depth increased dramatically from less than 10 in 2010 to nearly 100 in 2012. Please refer to Larson et al. (2009) and Larson and Nievinski (2013) for further details about the methodologies to estimate snow depth from GPS data.

3. SNOW WATER EQUIVALENT

We provide SWE estimates with error for all GPS sites. For most sites SWE estimates are modeled on (1) the time series of daily snow depth observations, and (2) snow depth and density observations taken from nearby (within 70 km) SNOTEL stations. The snow density model used to convert these required data to SWE estimates is described in McCreight and Small (2014). The model estimates daily density which is multiplied by observed depth to give daily SWE.

The SWE errors are a (vector sum) combination of the depth and density errors (though they are not truly independent), as described by McCreight et al. (2014). The density errors (not provided) are a function of day of year at each GPS site. Density errors are estimated using a process of leave-one-out cross validation, also described by McCreight et al. (2014). Essentially, when more than one SNOTEL location is used to model density at a GPS, each of these SNOTEL are in-turn treated as if it were the GPS antenna and its density estimated using the remaining SNOTEL sites. The modeled density errors (modeled-observed) are then gathered from all these individually-left-out SNOTEL sites by day of year and their standard deviation on each day is used to describe the uncertainty in the corresponding density model estimate at the GPS antenna. When only one SNOTEL is available for estimating density at a GPS antenna it is not possible to estimate the errors in this way and no error is provided.

If there are no nearby SNOTEL sites, the model from the Sturm paper is used:
Sturm, M., B. Taras, G. E. Liston, C. Derksen, T. Jonas, and J. Lea (2010), Estimating Snow Water Equivalent Using Snow Depth Data and Climate Classes, J. Hydrometeorol., 11(6), 1380–1394, doi:10.1175/2010JHM1202.1.

4. SOIL MOISTURE PRODUCT

The ground reflected multipath at a given site modulates the Signal-to-Noise Ratio (SNR) observations

according to the following simple relationship:

$$SNR = A\ \cos\left(\frac{4\pi h}{\lambda}\sin(E)+\phi\right)$$

Where *A* is the multipath amplitude, *h* is the height of the antenna phase center above the ground, lambda is the GPS wavelength, *E* is the satellite elevation angle, and phi is a phase offset.

Near surface soil moisture is reported as volumetric soil moisture (VSM). In release 1.0, soil moisture values are based on fluctuations in phi, where VSM = VSM_min + 0.0148*phi. The minimum soil moisture value (VSM_min) is determined for each site based on the residual moisture content in the STATSGO dataset. The linear relationship is based on forward modeling done in Chew et al. (2014).

Each daily VSM value is based on the average for 8 or more satellite tracks. GPS data contaminated by snow have been removed. We are currently working on:

1. A vegetation model to improve soil moisture retrievals.
2. Definition of the standard error for the daily retrieval.
3. Validation of the GPS technique by comparison with other soil moisture sensors.

We use the L2C signal for soil moisture studies. For this reason (see discussion above in the snow section), few results are available before June 2011. Further details regarding the retrieval of soil moisture content from GPS data, and its comparison to in-situ samples of volumetric water content can be found in Larson et al. (2008) and Larson et al. (2010).

We are collaborating with the SMAP validation team.

Release 2.0 of the soil moisture product was made on 2014 April 1. This version includes ~50 more stations and uses a vegetation model. Release 2.5 included more than 130 sites, and uses the vegetation model described by Chew et al. (2015). On October 28, 2015, we improved the data leveling algorithm.

5. VEGETATION PRODUCT

Changes in vegetation are quantified through changes in the GPS engineering metric mp1rms (Estey and Meertens, 1999). This metric is computed on a daily basis. It represents an average scattering statistic for all GPS satellites, not just those transmitting the L2C frequency. For this reason we are able to present results for most sites starting on January 1, 2007. Data have been evaluated for contamination by snow and rain; *a quality flag* is provided to indicate when our vegetation products should be used. As our algorithms for detecting these effects improve, we will release new vegetation products.

We have normalized the mp1rms GPS engineering data, and provide this in the column designated **NMRI (Normalized Microwave Reflection Index).** Defining the raw mp1rms data as *GPS*, and the mean value of data in top 5th percentile as GPS_{max}

$$NMRI = \frac{-(GPS - GPS_{max})}{GPS_{max}}$$

For an overview of the release 1.0 and 2.0 GPS NMRI vegetation index, see Larson and Small (2014).. Release 3.0 of the vegetation index, including ~200 more stations, should be available in summer 2014.

6. LOADING PRODUCT

Water loading for the GPS stations (Li and vanDam, 2015) is determined by convolving Greens functions with surface mass from the North American Land Data Assimilation System (NLDAS). The NLDAS snow water equivalent and soil moisture are provided at monthly periods with spatial sampling every 0.25 degree of latitude and longitude. Snow and soil moisture is masked out in ice-covered regions. See also information provided at UCAR.

This water loading product will be updated twice per year. The north, east, and vertical load time series begin in 2000 and ends in early 2014. Plots of the vertical loads and detrended position time series from the Nevada Geodetic Laboratory are provided on the portal. However, the position data themselves must be downloaded from Nevada Reno.

7. ANCILLARY DATA

Approximately 100 PBO sites have Vaisala WXT520 Sensors. These instruments are maintained by UNAVCO, and the data are archived at UNAVCO. We have computed maximum, minimum, and daily average temperatures, and daily precipitation and provide these with our water cycle products when they are available. However, we cannot vouch for the accuracy of these data. Questions about the accuracy of these data should be sent to UNAVCO.

We have downloaded hourly NLDAS modeled data for temperature and precipitation (0.125 degree, NLDAS-2 data for North America (NLDAS_FORA0125_H.002) from the Goddard Earth Science Data and Information Services Center (GES DISC)) for each of our sites. We have computed daily values (maximum, minimum, and average temperature, and precipitation) for each of these quantities. We currently update the NLDAS files daily with a 8 day lag. Please refer to the North American Land Data Assimilation System Phase 2 (NLDAS-2) Products README Document for further information.

We have downloaded NDVI (MOD13 16-day 250m MODIS) and GPP (1km, MODIS, 8 day) products for each PBO site. They have been minimally edited, i.e. negative NDVI values have been set to zero and some snow clearing has been done. These data are available in the csv archive file along with our water cycle products.

For each station website, we have provided a digital elevation model (raw DEM data available upon request), NLDAS cumulative precipitation plot, a google maps link, a photograph, and a link to the official PBO website for this station hosted by UNAVCO.

8. PRODUCT RELEASE VERSION

Product Version 1.0

- Snow Depth (meters)
- NMRI (normalized)
- Volumetric Soil Moisture Percentage, 100*cm3 cm-3

Product Version 1.1

- Snow Depth and Snow Water Equivalent (meters)
- NMRI (normalized)
- Volumetric Soil Moisture (cm3 cm-3)
- GLDAS Water Loading

Product Version 2.0

- Snow Depth and Snow Water Equivalent (m)
- NMRI (normalized)
- Volumetric Soil Moisture (cm3 cm-3) with vegetation corrections.
- GLDAS Water Loading

Product Version 2.5

- New retrieval algorithm for volumetric soil moisture.
- Bias (2cm) removed from snow depth retrievals.
- No change to vegetation products.
- Oct 28, 2015, updated soil moisture leveling code.

Station Information

1. AIRPORT
This field holds a 1 (TRUE) or 0 (FALSE) depending on whether the station in question is located at an airport.
[UNITS: *none*, FIELD: *One digit integer*]

This information was determined by using Google maps.

2. COUNTRY
This field holds the country name where the station is located.
[UNITS: *none*, FIELD: *text*]

This information was provided by http://pbo.unavco.org.

3. ELEVATION
This field holds the station elevation.
[UNITS: *m*, FIELD: *Decimal with one degree of precision*]

This information was provided by http://pbo.unavco.org.

4. ELEVATION MASK END
This field holds the end value of the recommended station elevation mask.
[UNITS: *degrees*, FIELD: *Decimal with zero degrees of precision*]

This value is determined by the GPS reflections group.

5. ELEVATION MASK START
This field holds the start value of the recommended station elevation mask.
[UNITS: *degrees*, FIELD: *Decimal with zero degrees of precision*]

This value is determined by the GPS reflections group.

6. ESTABLISHED DATE
This field holds the year that the station was established.
[UNITS: *year*, FIELD: *Four character text*]

This value is provided by UNAVCO.

7. GRAZING
This field holds a 1 (TRUE) or 0 (FALSE) depending on whether the station in question is located on grazing land.
[UNITS: *none*, FIELD: *One digit integer*]

Aerial and satellite imagery were manually referenced to create this designation

8. IN SITU SM
This field holds a 1 (TRUE) or 0 (FALSE) depending on whether soil moisture has been manually sampled at the station.
[UNITS: *none*, FIELD: *One digit integer*]

This value is determined by the GPS reflections group.

9. IN SITU SM DATE
This field holds the date that soil moisture was first manually measured at the station.
[UNITS: *yyyy/mm/dd*, FIELD: *Ten character text*]

10. IN SITU VEG
This field holds a 1 (TRUE) or 0 (FALSE) depending on whether vegetation water content has been sampled at the station.
[UNITS: *none*, FIELD: *One digit integer*]

11. IN SITU VEG DATE
This field holds the date that vegetation water content was first manually measured at the station.
[UNITS: *yyyy/mm/dd*, FIELD: *Ten character text*]

12. L2C DATE RECENT
This field holds the most recent L2C date for the station.
[UNITS: *yyyy/mm/dd*, FIELD: *Ten character text*]

This value was calculated by the GPS reflections group.

13. L2C DATE START
This field holds the date that L2C was turned on at the station.
[UNITS: *yyyy/mm/dd*, FIELD: *Ten character text*]

This information was provided by the UNAVCO archive.

14. LAND CLASS
This field holds a categorical descriptor for the landcover classification of the station in question.
[UNITS: *none*, FIELD: *Text*]

This information was determined by evaluation of photographs and MODIS land cover classifications.

15. LATITUDE
This field holds the station latitude.
[UNITS: *decimal degrees*, FIELD: *Decimal with twelve degrees of precision*]

This information was provided by http://pbo.unavco.org.

16. LONGITUDE
This field holds the station longitude.
[UNITS: *decimal degrees*, FIELD: *Decimal with twelve degrees of precision*]

This information was provided by http://pbo.unavco.org.

17. MET
This field holds a 1 (TRUE) or 0 (FALSE) depending on whether the station in question has meteorological sensors.
[UNITS: *none*, FIELD: *One digit integer*]

This information was provided by http://pbo.unavco.org.

18. MP1
This field holds a categorical descriptor for the MP1 Status of the station in question.
[UNITS: *none*, FIELD: *Text*]

This value is determined by the GPS reflections group.

19. MP1 MEAN
This field holds the average MP1 value for the station.
[UNITS: *none*, FIELD: *Decimal with three degrees of precision*]

This information was calculated by the GPS Reflections team. Typically it is based on a five year average after snow-contaminated data have been removed.

20. NDVI CORR
This field holds a value representing the station correlation to NDVI.
[UNITS: *none*, FIELD: *Decimal with two degrees of precision*]

This value was calculated from a comparison of five years of NDVI data and MP1rms data made by the GPS reflections team. Both time series were cleared for snow. Correlations were calculated for lags between 0 to 5 weeks, and the best correlation is reported.

21. NDVI HIGH
This field holds the maximum observed normalized difference vegetation index (NDVI) value for the station in question.
[UNITS: *none*, FIELD: *Decimal with three degrees of precision*]

This information was calculated by the GPS Reflections group, reporting the average of the 95th percentile.

22. NDVI LOW
This field holds the minimum observed normalized difference vegetation index (NDVI) value for the station in question.
[UNITS: *none*, FIELD: *Decimal with three degrees of precision*]

This information was calculated by the GPS Reflections group, reporting the average of the 5th percentile.

23. PBO
This field holds a 1 (TRUE) or 0 (FALSE) depending on whether the station in a Plate Boundary Observatory (PBO) site.
[UNITS: *none*, FIELD: *One digit integer*]

This information was provided by http://pbo.unavco.org.

24. PRECIP
This field holds the annual precipitation at the station.
[UNITS: *mm*, FIELD: *Decimal with one degree of precision*]

PRISM.

25. REFLECTOR HEIGHT
This field holds the nominal reflector height for the station.
[UNITS: *m*, FIELD: *Decimal with three degrees of precision*]

This information was calculated by the GPS reflections group.

26. SAMPLING RATE
This field holds the current sampling rate for the station.
[UNITS: *sec*, FIELD: *Two digit integer*]

This information was provided by http://pbo.unavco.org.

27. SENSING AREA SNOW
This field holds the snow depth sensing footprint for the station.
[UNITS: m^2, FIELD: *Decimal with one degree of precision*]

This information is not currently available.

28. SENSING AREA VEG
This field holds the vegetation water content sensing footprint for the station.
[UNITS: m^2, FIELD: *Decimal with one degree of precision*]

This information is not currently available.

29. SITE ID
This field holds the four-character station ID.
[UNITS: *none*, FIELD: *Four character lowercase text*]

This information was provided by http://pbo.unavco.org.

30. SITE NAME
This field holds the ten-character longform station name.
[UNITS: *none*, FIELD: *Ten character uppercase text*]

This information was provided by http://pbo.unavco.org.

31. SM PRODUCT
This field holds a 1 (TRUE) or 0 (FALSE) depending on whether the station produces a soil moisture product.
[UNITS: *none*, FIELD: *One digit integer*]

32. SNOTEL
This field holds a 1 (TRUE) or 0 (FALSE) depending on whether the station in question is co-located with a SNOTEL station.
[UNITS: *none*, FIELD: *One digit integer*]

The GPS reflections group calculated which GPS sites were within 25 km of SNOTEL sites.

33. SNOTEL DISTANCE
This field holds the distance between the co-located SNOTEL station and the station in question.
[UNITS: *km*, FIELD: *Decimal with one degree of precision*]

This distance was calculated by the GPS reflections group based on station locations provided by SNOTEL.

34. SNOTEL ELEVATION
This field holds the elevation of the co-located SNOTEL station.
[UNITS: *m*, FIELD: *Decimal with one degree of precision*]

This information was provided by SNOTEL.

35. SNOTEL ID
This field holds the SNOTEL ID for the co-located SNOTEL station.
[UNITS: *none*, FIELD: *Text*]

This information was provided by SNOTEL.

36. SNOWPACK
This field holds a 1 (TRUE) or 0 (FALSE) depending on whether the station accumulates a significant snowpack.
[UNITS: *none*, FIELD: *One digit integer*]

37. SNOW PRODUCT
This field holds a 1 (TRUE) or 0 (FALSE) depending on whether the station produces a snow depth product.
[UNITS: *none*, FIELD: *One digit integer*]

38. SNR
This field holds a categorical descriptor for the SNR Status of the station in question.
[UNITS: *none*, FIELD: *Text*]

This information was provided by http://pbo.unavco.org.

39. SOIL TYPE
This field holds a categorical descriptor for the soil type of the station in question.
[UNITS: *none*, FIELD: *Text*]

This information is currently not available.

40. STATE
This field holds the two-character abbreviation for the state where the station is located.
[UNITS: *none*, FIELD: *Two character text*]
Special Note: CN/CS = CA North/South

This information was provided by http://pbo.unavco.org.

41. SWE
This field holds modeled annual snow water equivalent (SWE) at the station.

[UNITS: *mm*, FIELD: *Decimal with one degree of precision*]

Armstrong, R.L., M.J. Brodzik, K. Knowles, and M. Savoie, Global monthly EASE-Grid snow water equivalent climatology. Boulder, CO: National Snow and Ice Data Center. Digital media. Available at http://nsidc.org/data/nsidc-0271.html, *2005.*

42. TEMP CORR

This field holds a value representing the correlation between MP1RMS to NLDAS average temperature.
[UNITS: *none*, FIELD: *Decimal with two degrees of precision*]

This information was calculated by the GPS reflections group.

43. TEMP MAX

This field holds a maximum annual air temperature value for the station in question.
[UNITS: *degC*, FIELD: *Decimal with one degree of precision*]

This information is calculated from NLDAS temperature data.

44. TEMP MEAN

This field holds a mean annual air temperature value for the station in question.
[UNITS: *degC*, FIELD: *Decimal with one degree of precision*]

This information is calculated from NLDAS temperature data.

45. TEMP MIN

This field holds a minimum annual air temperature value for the station in question.
[UNITS: *degC*, FIELD: *Decimal with one degree of precision*]

This information is calculated from NLDAS temperature data.

46. THETA RES

This field holds the theta res value for the station.
[UNITS: *none*, FIELD: *Decimal with four degrees of precision*]

This value was calculated with Rosetta using input data from STATSGO

47. THETA RES UNCERTAINTY

This field holds the theta res uncertainty value for the station.
[UNITS: *none*, FIELD: *Decimal with four degrees of precision*]

This value was calculated with Rosetta using input data from STATSGO

48. THETA SAT

This field holds the theta sat value for the station.
[UNITS: *none*, FIELD: *Decimal with four degrees of precision*]

This value was calculated with Rosetta using input data from STATSGO

49. THETA SAT UNCERTAINTY

This field holds the theta sat uncertainty value for the station.
[UNITS: *none*, FIELD: *Decimal with four degrees of precision*]

This value was calculated with Rosetta using input data from STATSGO

50. VEG PRODUCT

This field holds a 1 (TRUE) or 0 (FALSE) depending on whether the station produces a vegetation water content product.
[UNITS: *none*, FIELD: *One digit integer*]

Data Portal Citation

To cite data from the PBO H_2O data portal, please reference the URL *<http://xenon.colorado.edu/portal>* and include the following publications within the reference list:

Soil Moisture:
Larson, K.M., E.E. Small, E. Gutmann, A. Bilich, J. Braun, V. Zavorotny, Use of GPS receivers as a soil moisture network for water cycle studies, Geophys. Res. Lett., 35, L24405, doi:10.1029/2008GL036013, 2008.

Snow Depth:
Larson, K.M., E. Gutmann, V. Zavorotny, J. Braun, M. Williams, and F. Nievinski, Can We Measure Snow Depth with GPS Receivers?,Geophys. Res. Lett., 36, L17502, doi:10.1029/2009GL039430, 2009.

Vegetation:
Small, E.E., K.M. Larson, and J. J. Braun, Sensing Vegetation Growth Using Reflected GPS Signals, Geophys. Res. Lett. 37, L12401, doi:10.1029/2010GL042951, 2010.

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