NASA Giovanni: A Tool for Visualizing, Analyzing, and Inter-comparing Soil Moisture Data

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Abstract

There are many existing satellite soil moisture algorithms and their derived data products, but there is no simple way for a user to inter-compare the products or analyze them together with other related data. An environment that facilitates such inter-comparison and analysis would be useful for validation of satellite soil moisture retrievals against in situ data and for determining the relationships between different soil moisture products. As part of the NASA Giovanni (**G**eospatial **I**nteractive **O**nline **V**isualization **AN**d a**N**alysis **I**nfrastructure) family of portals, which has provided users worldwide with a simple but powerful way to explore NASA data, a beta prototype Giovanni Inter-comparison of Soil Moisture Products portal has been developed. A number of soil moisture data products are currently included in the prototype portal. More will be added, based on user requirements and feedback and as resources become available. Two application examples for the portal are provided. The NASA Giovanni Soil Moisture portal is versatile and extensible, with many possible uses, for research and applications, as well as for the education community.

Introduction

There are many existing satellite soil moisture algorithms and their derived data products, but there is no simple way for a user to inter-compare the products or analyze them together with other related data (e.g., precipitation). An environment that facilitates such inter-comparison and analysis would be useful for validation of satellite soil moisture retrievals against in situ data and for determining the relationships among different soil moisture products. The latter relationships are particularly important for applications users, for whom the continuity of soil moisture data, from whatever source, is critical. A recent example was provided by the sudden demise of the EOS Aqua AMSR-E (Advanced Microwave Scanning Radiometer-Earth Observing System) sensor and the end of its related soil moisture data production, as well as the end of other soil moisture products that had been based on the AMSR-E data.

For more than 15 years, NASA Giovanni (**G**eospatial **I**nteractive **O**nline **V**isualization **AN**d a**N**alysis **I**nfrastructure) has provided users worldwide with a simple but powerful way to explore (visualize and analyze) the large variety and vast amounts of data (Acker and Leptoukh, 2007; Berrick et al., 2009). These data are from NASA Earth observation sensors, including those on the EOS (Earth Observing System) platforms of Terra, Aqua, and Aura, as well as smaller platforms like TRMM (Tropical Rainfall Measuring Mission); from model data sets, such as GLDAS and NLDAS (Global and North American Land Data Assimilation System, respectively); and from various, separately-funded studies and projects, such as MAIRS (Monsoon Asia Integrated Regional Study). Data available via Giovanni are grouped into "portals." For example, there are four such portals of data from the MAIRS project and 16 portals of data from TRMM, five of which are for inter-comparison.

As part of two NASA-funded projects, with team members who are end users from the NOAA National Weather Service (NWS) and the USDA World Agricultural Outlook Board (WAOB), a number of Level-3 (gridded) soil moisture products have been incorporated into a beta prototype Giovanni portal ("Inter-comparison of Soil Moisture Products"). The purpose of this effort, beyond satisfying the requirements of the projects, is to create an environment, as part of the NASA Giovanni family of portals, that facilitates inter-comparisons and other uses of soil moisture products. (There are other apparently similar systems for exploration of remote sensing data, e.g., LAS (Live Access Server) of the NASA JPL PODAAC (Physical Oceanography DAAC), but a comparison of Giovanni with other systems is beyond the scope of this paper. A compilation of such systems in the NASA data community can be found at https://earthdata.nasa.gov/data/data-tools/data-visualization-analysis-tools.)

The following sections of the paper (1) provide some additional details on Giovanni, (2) describe the data products currently available in the Giovanni Inter-comparison of Soil Moisture Products portal, (3) illustrate the portal's user interface and currently-available services, and (4) give two examples of how the portal might be used for and facilitate hydrologic applications. Evaluation and inter-comparison of soil moisture products and with other data sources are left to the prospective users of the Soil Moisture portal.

NASA Giovanni

Giovanni is a NASA data exploration system that provides a simple and intuitive way to visualize, analyze, and access vast amounts of Earth sciences remote sensing data, without having to download the data, to be familiar with various and often complicated data formats, and to import into other systems or write custom code for basic display and analysis (http://disc.sci.gsfc.nasa.gov/giovanni/overview/index.html). Developed at the NASA Goddard Earth Sciences Data and Information Services Center (GES DISC), with inputs from users both at the Goddard Space Flight Center (GFSC) and from around the world, Giovanni obviates much of the data "pre-work" that users would otherwise need to undertake, thus resulting in weeks to months of time saved. It allows users to rapidly explore data, so that, e.g., spatial-temporal variability, anomalous conditions, and patterns of interest can be directly and quickly observed and analyzed online. Giovanni currently provides 20 some services, such as "Lat-Lon Map, Time-averaged," Latitude-Time Hovmöller Plot," "Correlation Plot," and "Time Series, Area-averaged," different subgroups of which are offered by the various portals. Users of Giovanni have included researchers, modelers, applications users, policy- and decision-makers, those in the education community, and proposal writers. Giovanni has contributed to many users' science research efforts and applications. One metric of this contribution is the number of peer-reviewed publications of research that used Giovanni in some way. Since 2004, there have been 775 such publications (as of 12/13/13).

Giovanni is an evolving system. The earliest portal, before the term "Giovanni" was coined, is the highly popular TOVAS (TRMM Online Visualization and Analysis System) (Zhong et al., 2013). To take advantage of advancing technology and reduce costs in maintaining and extending Giovanni, in response to user-driven and system interoperability requirements, a radical engineering of the underlying infrastructure was undertaken, resulting in "Giovanni, Version 3" (or G3). The Giovanni Inter-comparison of Soil Moisture Products portal is in the G3 family of portals. There is an ongoing effort to develop the next generation of "Giovanni, Version 4" (or G4), designed to be faster, more interactive, and easier to learn.

Soil moisture and related data products in NASA Giovanni

Table 1 lists those soil moisture and related data products that are currently included in the beta prototype Giovanni Inter-comparison of Soil Moisture Products portal. This suite of products will be modified or extended, based on user feedback and availability of resources. The current six Level-3 (gridded) soil moisture products were used or produced as parts of the two previously mentioned projects with NOAA NWS and USDA WAOB.

The LSMEM-TMI product currently in the Giovanni portal is an early limited version, covering 1998 to 2004 (Gao et al., 2006). As part of the NASA Making Earth System Data Records for Use in Research Environments (MEaSUREs) Program, there is an ongoing effort, led by Princeton University, to produce Earth System Data Records (ESDRs) for the global terrestrial water cycle (MacCracken et al., 2013). One of these ESDRs is LSMEM-based soil moisture, using the AMSR-E brightness temperature as input. All of these water cycle ESDRs will be delivered to the GES DISC, at which time the current LSMEM-TMI product in the Giovanni portal will be replaced by the newer LSMEM-AMSR-E ESDR.

The Land Parameter Retrieval Model (LPRM) was originally developed by NASA GSFC and Vrije Universiteit Amsterdam (VUA) (Owe et al., 2008; de Jeu et al., 2008). Subsequent development of the LPRM algorithm has being carried out by VUA, e.g., error estimates (Parinussa et al., 2011), with operational production of the LPRM-AMSR-E data done by the GES DISC. More recent work has focused on replacing the lost AMSR-E/Aqua data stream, by applying LPRM to the TRMM Microwave Imager (TMI) and WindSat brightness temperatures, to generate LPRM-TMI and LPRM-WindSat data, respectively. For the latter, see Parinussa et al., (2012). Current temporal coverage of LPRM-WindSat is limited to that of the input data available from the Naval Research Laboratory (NRL). There is an effort ongoing to fill in the missing time periods. The LPRM-TMI, among all the currently "live" (i.e., forward-processed) retrieved soil moisture products, has the longest temporal coverage (1998-present), although it is relatively limited by the TRMM spatial coverage of 40N – 40S.

The LPRM-RZSM product was produced as part of a separate NASA-funded project, working with the USDA Foreign Agricultural Service (FAS) to improve its soil moisture inputs and, thus, its crop yield forecasts (Bolten et al., 2010). Input to the LPRM-RZSM assimilated product is the LPRM-AMSR-E surface soil moisture.

There are other existing and upcoming soil moisture products that could potentially be added to this Giovanni Soil Moisture portal (resources permitting). These include the ongoing missions of (1) the European Space Agency (ESA): Soil Moisture and Ocean Salinity (SMOS), launched in 2009 (Kerr et al., 2001, 2010, 2012), (2) the Japan Aerospace Exploration Agency (JAXA): Advanced Microwave Scanning Radiometer 2 (AMSR2) aboard the Global Change Observation Mission 1st-Water "SHIZUKU" (GCOM-W1), launched in 2012 (Kachi et al., 2008; Oki et al., 2010), and (3) the U.S. Naval Research Laboratory: WindSat, launched in 2003 (Li et al., 2010); the upcoming NASA mission: Soil Moisture Active Passive (SMAP), scheduled for launched in 2014 (Entekhabi et al., 2010); as well as model outputs from the North American Land Data Assimilation System (NLDAS; Mitchell et al., 2004) and the Global Land Data Assimilation System (GLDAS; Rodell et al., 2004).

An initial effort has been made by GES DISC and VUA to test the feasibility of incorporating into the Giovanni portal the soil moisture data from the ESA Water Cycle Multimission Observation Strategy (WACMOS) project (Dorigo et al., 2011; Liu et al., 2011). Although the effort was successful, further work awaits additional resources.

NASA Giovanni Inter-comparison of Soil Moisture portal

Figure 1 shows the user interface of the Giovanni Inter-comparison of Soil Moisture portal. The interface was designed to be simple and intuitive. User selections (e.g., those outlined in red) are spatial region, parameter(s) of interest, temporal range, and Giovanni service (e.g., Lat-Lon Map, Time-averaged). Once the resulting plot is made, additional user preferences can be specified (e.g., color bar, min-max values). Figure 2 shows the resulting soil moisture area maps from the user selections shown in Figure 1.

In addition to Lat-Lon map, Time-averaged, there are currently three other available services (or visualization types) in the Giovanni Soil Moisture portal: (1) Time series, (2) Scatter plot, Time-averaged, and (3) Animation. Other Giovanni services will be added as appropriate and needed, based on user feedback and resources available. Figure 3 shows a scatter plot between LPRM-AMSR-E and LPRM-TMI soil moisture for an area near Austin, Texas. For the same general area, Figure 4 shows three time series plotted together, one of precipitation and two of soil moisture, which can be useful, e.g., to inter-compare the two soil moisture products, in relationship to the precipitation product.

Once the user is satisfied with the plot results, several data format options are available for downloading from all Giovanni portals, including HDF, NetCDF, ASCII, KMZ (Fig. 5). Individual input files and generated output plot files (both data and image) can be downloaded. Information on the lineage (or provenance) of the Giovanni-generated output files is also available, describing all the intermediate steps taken to result in a particular output plot (Fig. 6).

Application of Giovanni Inter-comparison of Soil Moisture portal

Texas drought of 2011

Drought and excessive heat in 2011 created major adverse effects across the U.S. Southern Great Plains, especially Texas and Oklahoma, as shown by the U.S. Drought Monitor (USDM) map of August 30, 2011, in contrast with a more "average" year map of September 1, 2009 (Fig. 7). Total direct losses to crops, livestock, and timber in these areas approached $10 billion. The USDM maps are based on a convergence of multiple sources of evidence. How might surface soil moisture data retrieved from satellites compare with the USDM maps? Figure 8 shows Giovanni-generated area maps of soil moisture, vegetation optical depth, and skin temperature (from the LPRM-AMSR-E product) for Texas and surrounding areas for August 2011 and, for comparison, those for August 2009. Although the overall differences in spatial patterns between the two years are also seen, they are not as contrasted as those in the USDM. Specific features or areas of interest can be quickly identified from these Giovanni outputs, for more detailed analyses.

Land surface models (LSMs) comprise another source of data for comparison with satellite-retrieved data. Figure 9 shows the NLDAS Noah model output for 0-100 cm soil moisture content for a 0.125-deg. grid box over Austin, Texas, for the entire time period of available coverage (so far) and for the year 2011. The extraordinary nature of the 2011 drought in Texas is particularly evident in the context of the historical record (some 34 years so far). In comparison, Figure 10 shows Giovanni-generated area-averaged time series, centered on Austin, Texas, for LPRM-AMSR-E and LPRM-TMI soil moisture data and for EOS Aqua AIRS surface air temperature and LPRM-AMSR-E and LPRM-TMI skin temperature. The trends of both sets of plots are consistent with those of NLDAS Noah, with overall minimum (soil moisture) and maximum (temperature) around August 2011.

Tropical storm Lee

During September 2011, Tropical Storm (TS) Lee, due to its large size and slow forward movement, dumped heavy rainfall over southern Louisiana, Mississippi, Alabama, and the Florida panhandle. The area map of the NLDAS total precipitation, over the period September 2-9 is shown in Figure 11a, with TS Lee's track clearly visible. Figure 11b shows the corresponding area map of the LPRM-AMSR-E soil moisture, averaged over the same time period, resulting in the storm track that is not as distinct. A storm's effect on soil moisture typically has a time lag relative to that on precipitation. Figure 11c shows the same soil moisture data, but averaged with a two-day time lag (i.e., September 4-11). The storm track is somewhat more distinct. Finally, a shorter averaging period after a rain event should show a more distinct soil moisture response. Figure 11d shows the same soil moisture data, but averaged for only the two days after an intense rain event during the storm over Alabama, Georgia, and Tennessee. Now, the effect of TS Lee can be clearly seen. This location is the middle of the three boxed areas shown in Figure 11a. Figure 12 shows, for these three areas, time series of the corresponding NLDAS total precipitation and NLDAS Mosaic 0-10 cm soil moisture content and their relationship to each other, in terms of responses to the storm. Figure 13 shows, for the middle boxed area of Figure 11a, similar time series of TRMM precipitation and LPRM-AMSR-E soil moisture. There are far fewer data points available for these satellite data, but the precipitation peak and slight soil moisture time lag are similar to those shown by the NLDAS data.

Summary

The NASA Giovanni Inter-comparison of Soil Moisture Products portal is versatile and extensible, with many possible uses, for research and applications (e.g., natural disasters, agriculture). It is currently being used by USDA WAOB, as part of one of the projects that supported the portal's development. For the education community, the Giovanni family of portals has been used in classrooms, workshops, and other venues. For example, the current beta prototype of the Soil Moisture portal has already been used in one of VUA's classroom exercises. The portal should also be useful to support upcoming missions, e.g., for pre-launch SMAP activities.

Maintaining continuity of data and minimizing data gaps are important for both research and applications users of satellite mission data. As discussed in an earlier section, to mitigate the loss of the EOS Aqua AMSR-E and keep the data gap to a minimum, the GES DISC and VUA have applied LPRM to brightness temperature data from TMI and WindSat, to produce LPRM-TMI and LPRM-WindSat products, respectively (both Level 2 or swath and Level 3 or gridded). (NB: "Continuity" as used here simply refers to that of temporal coverage provided by Giovanni of some soil moisture data; it does not refer to that of a long time series, i.e., an Earth Science Data Record or ESDR, such as those being produced as part of the ESA WACMOS project.) As previously noted, there is an ongoing effort to extend the coverage of LPRM-WindSat. Also, an effort has just begun to apply the LPRM algorithm to the AMSR2 data from JAXA.

In all these developments, user inputs and feedback are critical (on services, data, and user interface). The Giovanni Inter-comparison of Soil Moisture Products portal, along with all other portals in the Giovanni family, are created, maintained, and enhanced for the many users of NASA data worldwide. To contribute, please check out http://gdata1.sci.gsfc.nasa.gov/daac-bin/G3/gui.cgi?instance_id=soilmoisture_daily. The new version of Giovanni (G4) will feature more interactive data exploration, with order-of-magnitude performance improvement, browserbased interactive plotting, and new services (e.g., seasonal data visualization). An early release of G4 can be accessed at http://giovanni.gsfc.nasa.gov/giovanni/.

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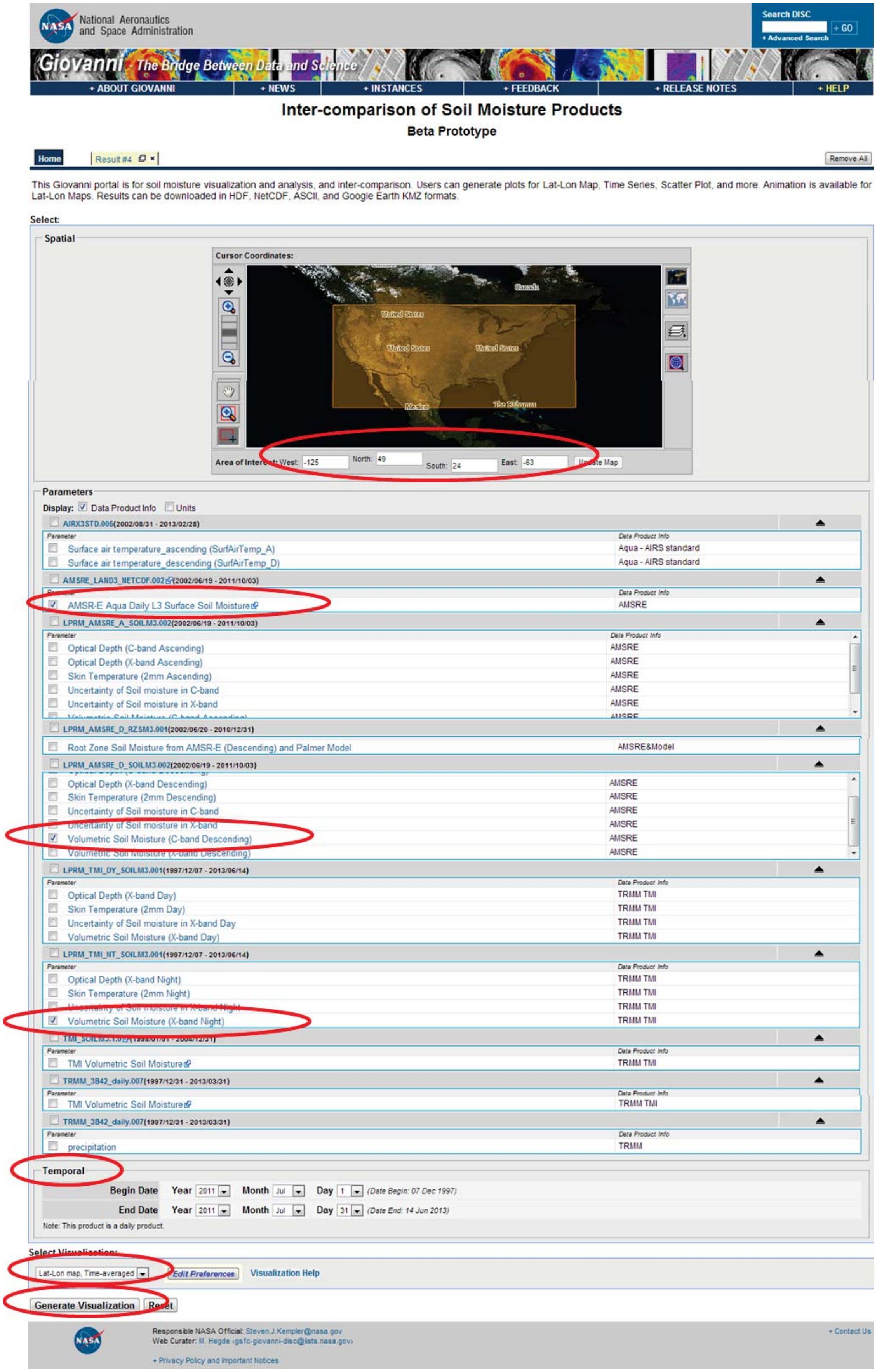
Table 1. Level-3 (gridded) soil moisture and related products currently available in the beta prototype Giovanni portal, "Inter-comparison of Soil Moisture Products."

Soil moisture (SM) and related products	**Spatial Resolution**	**Spatial Coverage**	**Temporal Resolution**	**Temporal Coverage**	**Reference**
EOS[a] Aqua AMSR-E[b] (SM)	¼ deg	Global	Daily	6/2002-10/2011	1
LSMEM[c]-TMI[d] (SM)	1/8 deg	U.S. up to 40N	Daily	1/1998-12/2004	2
LPRM[e]-AMSR-E (SM)	¼ deg	Global	Daily	6/2002-10/2011	3,4
LPRM-TMI (SM)	¼ deg	Global 40N-40S	Daily	1/1998-present	3,4
LPRM-WindSat (SM)	¼ deg	Global	Daily	10/2007-7/2011	5
LPRM-RZSM[f] (AMSR-E)	¼ deg	Global	Daily	6/2002-12/2010	6
TMPA[g] precipitation	¼ deg	Global 50N-50S	Daily	1/1998-present	7
EOS Aqua AIRS[h] surface air temperature	1 deg	Global	Daily	8/2002-present	8

[a]Earth Observing System; [b]Advanced Microwave Scanning Radiometer - Earth Observing System; [c]Land Surface Microwave Emission Model; [d]TRMM Microwave Imager; [e]Land Parameter Retrieval Model; [f]root zone soil moisture; [g]TRMM Multi-satellite Precipitation Analysis; [h]Atmospheric Infrared Sounder. [1](Njoku et al., 2003); [2](Gao et al., 2006); [3](Owe et al., 2008); [4](De Jeu et al., 2008); [5](Parinussa et al., 2012); [6](Bolten et al., 2010); [7](Huffman et al., 2007); [8](Aumann et al., 2003).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+ ABOUT GIOVANNI
+ NEWS
+ INSTANCES
+ FEEDBACK
+ RELEASE NOTES
+ HELP
Inter-comparison of Soil Moisture Products
Beta Prototype
Home
Result #4
Remove All
This Giovanni portal is for soil moisture visualization and analysis, and inter-comparison. Users can generate plots for Lat-Lon Map, Time Series, Scatter Plot, and more. Animation is available for Lat-Lon Maps. Results can be downloaded in HDF, NetCDF, ASCII, and Google Earth KMZ formats.
Select:
Spatial
Cursor Coordinates:
Canada
United States
Mexico
Area of Interest: West: -125 North: 49 South: 24 East: -63 Update Map
Parameters
Display: Data Product Info Units
AIRX3STD.005(2002/08/31 - 2013/02/28)
Parameter
Data Product Info
Surface air temperature_ascending (SurfAirTemp_A)
Aqua - AIRS standard
Surface air temperature_descending (SurfAirTemp_D)
Aqua - AIRS standard
AMSRE_LAND3_NETCDF.002(2002/06/19 - 2011/10/03)
AMSR-E Aqua Daily L3 Surface Soil Moisture
AMSRE
LPRM_AMSRE_A_SOILM3.002(2002/06/19 - 2011/10/03)
Optical Depth (C-band Ascending)
Optical Depth (X-band Ascending)
Skin Temperature (2mm Ascending)
Uncertainty of Soil moisture in C-band
Uncertainty of Soil moisture in X-band
AMSRE
LPRM_AMSRE_D_RZSM3.001(2002/06/20 - 2010/12/31)
Root Zone Soil Moisture from AMSR-E (Descending) and Palmer Model
AMSRE&Model
LPRM_AMSRE_D_SOILM3.002(2002/06/19 - 2011/10/03)
Optical Depth (X-band Descending)
Skin Temperature (2mm Descending)
Uncertainty of Soil moisture in C-band
Uncertainty of Soil moisture in X-band
Volumetric Soil Moisture (C-band Descending)
Volumetric Soil Moisture (X-band Descending)
LPRM_TMI_DY_SOILM3.001(1997/12/07 - 2013/06/14)
Optical Depth (X-band Day)
Skin Temperature (2mm Day)
Uncertainty of Soil moisture in X-band Day
Volumetric Soil Moisture (X-band Day)
TRMM TMI
LPRM_TMI_NT_SOILM3.001(1997/12/07 - 2013/06/14)
Optical Depth (X-band Night)
Skin Temperature (2mm Night)
Uncertainty of Soil moisture in X-band Night
Volumetric Soil Moisture (X-band Night)
TMI Volumetric Soil Moisture
TRMM_3B42_daily.007(1997/12/31 - 2013/03/31)
precipitation
TRMM
Temporal
Begin Date Year 2011 Month Jul Day 1 (Date Begin: 07 Dec 1997)
End Date Year 2011 Month Jul Day 31 (Date End: 14 Jun 2013)
Note: This product is a daily product.
Select Visualization:
Lat-Lon map, Time-averaged
Edit Preferences
Visualization Help
Generate Visualization
Reset
Responsible NASA Official: Steven.J.Kempler@nasa.gov
Web Curator: M. Hegde (gsfc-giovanni-disc@lists.nasa.gov)
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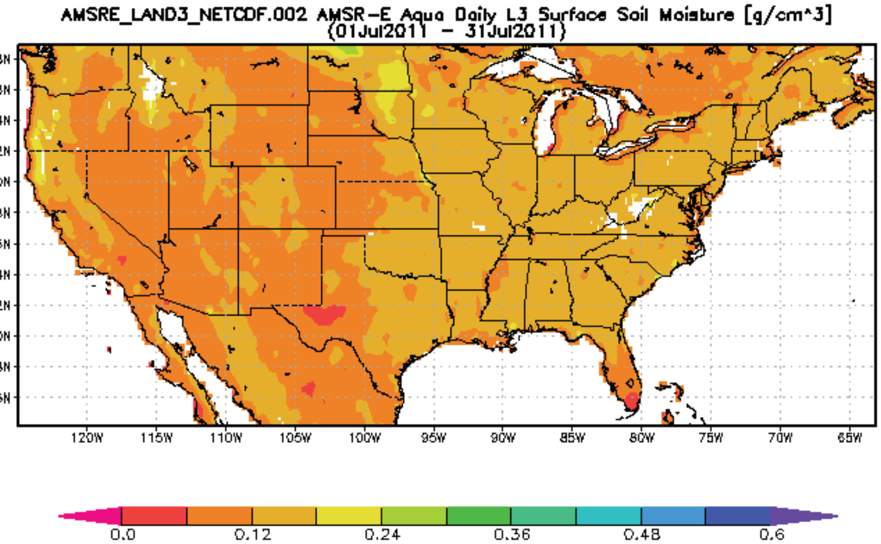
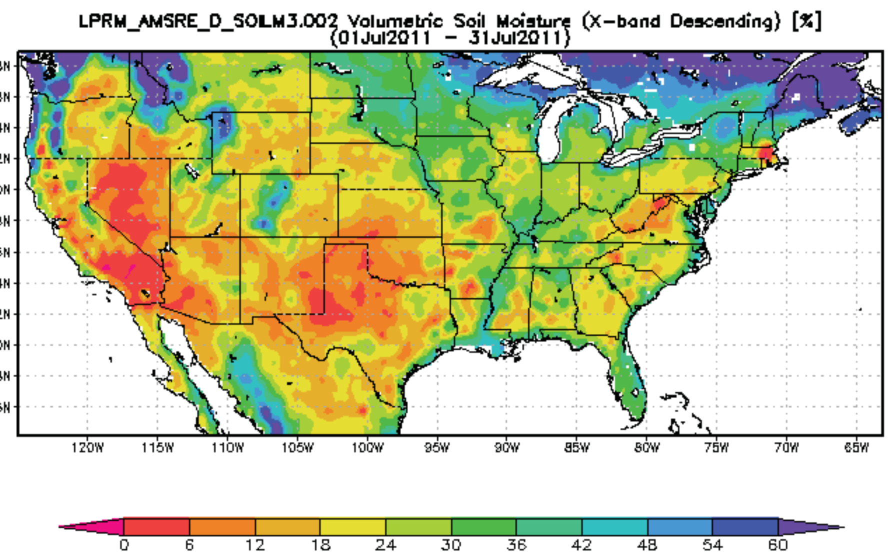
+ Contact Us

Figure 1. User interface of the Giovanni Inter-comparison of Soil Moisture portal. Red ovals are example user selections (i.e., Spatial: 125W-63W, 24N-49N (U.S.); Parameter: Soil moisture (3 products); Temporal: July 1-31, 2011; Visualization: Lat-Lon map, Time-averaged) that result in the area maps shown in Fig. 2.


AMSRE_LAND3_NETCDF.002 AMSR-E Aqua Daily L3 Surface Soil Moisture [g/cm^3]
(01Jul2011 - 31Jul2011)
48N 46N 44N 42N 40N 38N 36N 34N 32N 30N 28N 26N
120W 115W 110W 105W 100W 95W 90W 85W 80W 75W 70W 65W
0.0 0.12 0.24 0.36 0.48 0.6


LPRM_AMSRE_D_SOILM3.002 Volumetric Soil Moisture (X-band Descending) [%]
(01Jul2011 - 31Jul2011)
48N 46N 44N 42N 40N 38N 36N 34N 32N 30N 28N 26N
120W 115W 110W 105W 100W 95W 90W 85W 80W 75W 70W 65W
0 6 12 18 24 30 36 42 48 54 60

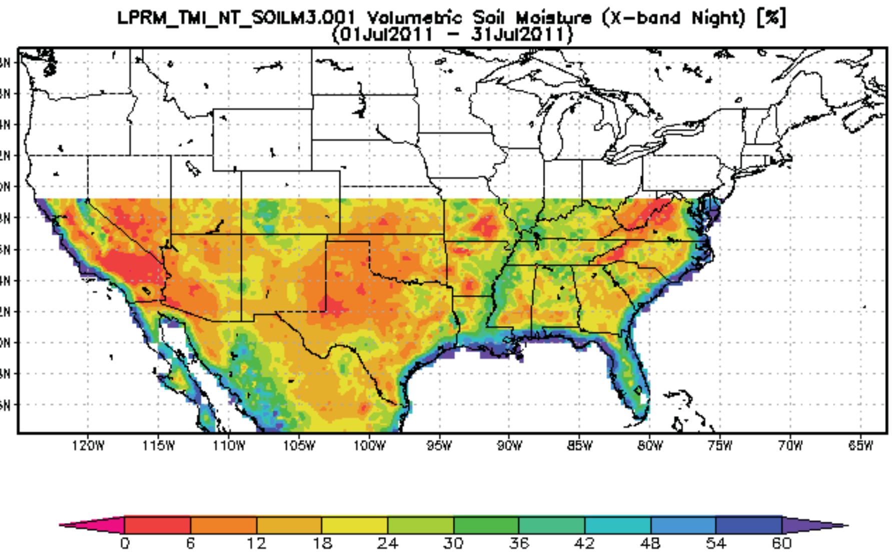


Figure 2. Giovanni Inter-comparison of Soil Moisture portal outputs: Area maps ("Lat-Lon map, Time-averaged") of soil moisture from (top to bottom) EOS Aqua AMSR-E, LPRM-AMSR-E, and LPRM-TMI (See Table 1), for the U.S. and July 1-31, 2011.

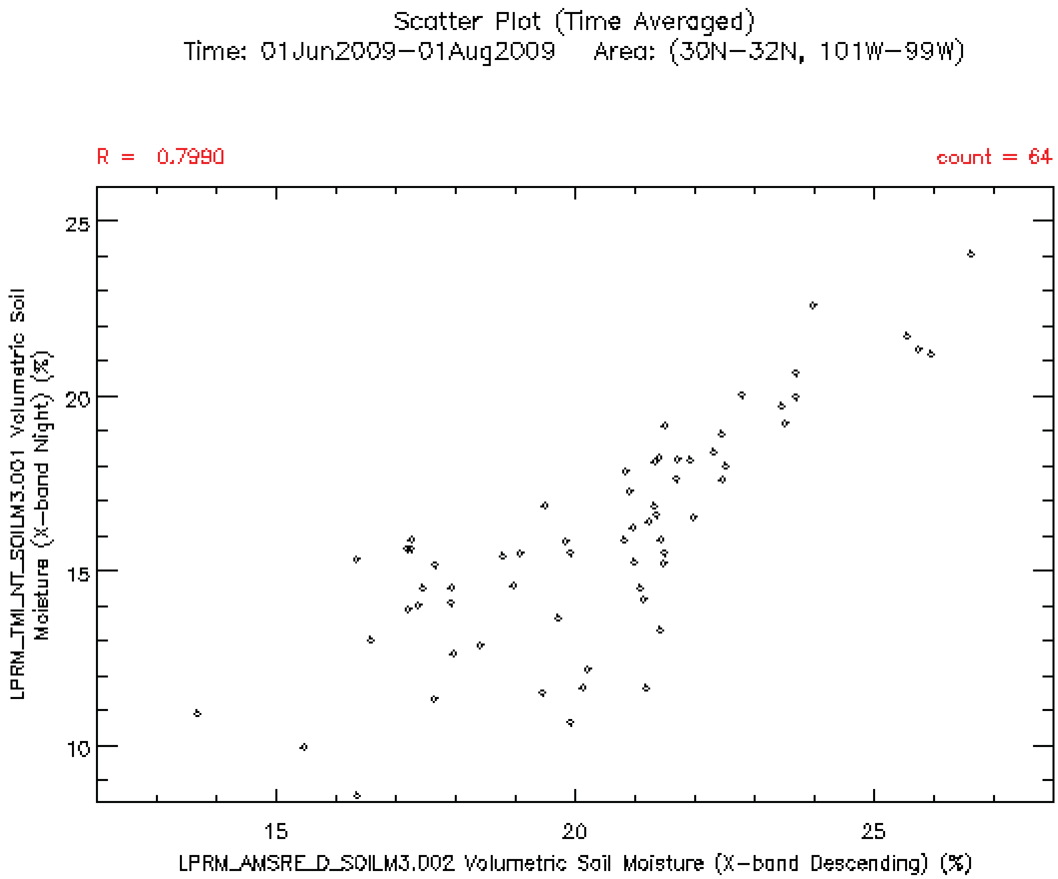


Figure 3. Scatter plot between LPRM-AMSR-E and LPRM-TMI soil moisture, for an area near Austin, Texas and June 1 to August 1, 2009.

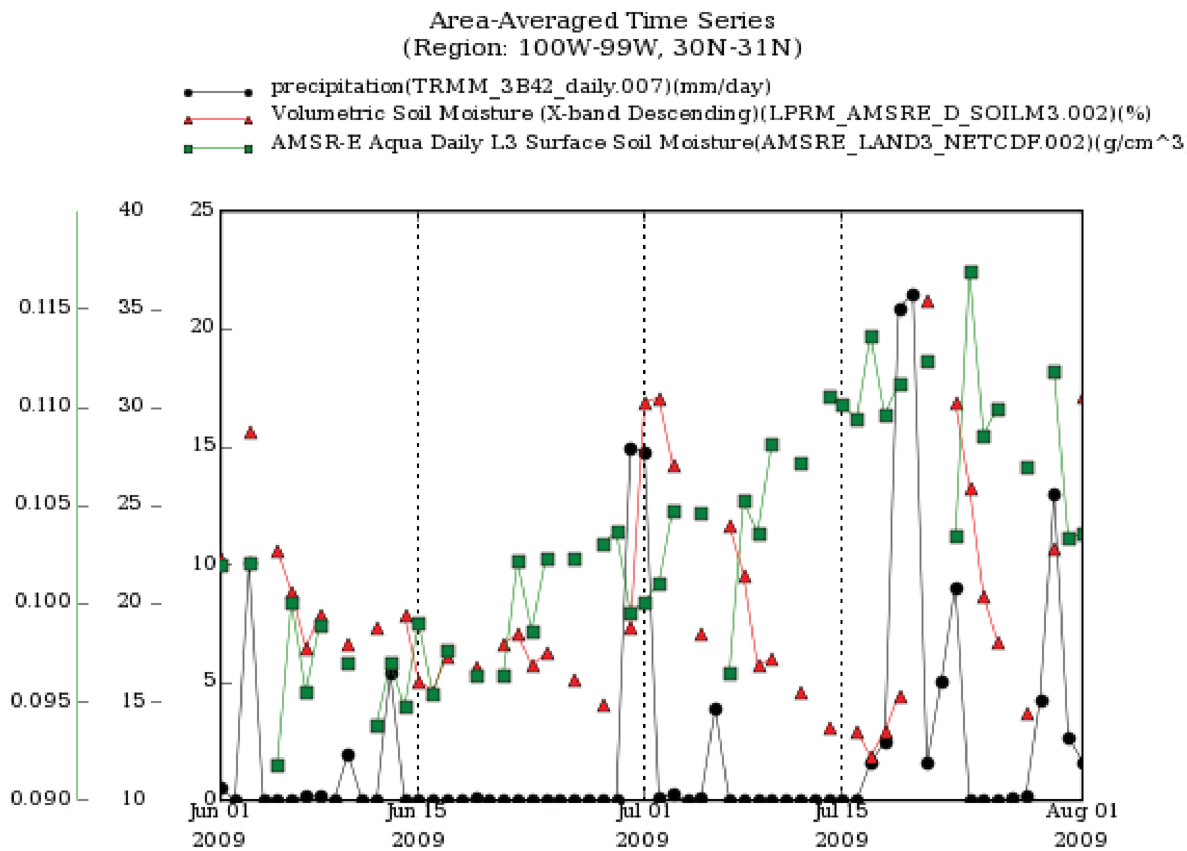


Figure 4. Time series, area-averaged, of TRMM precipitation and LPRM-AMSR-E and EOS Aqua AMSR-E soil moisture, for an area near Austin, Texas and June 1 to August 1, 2009.

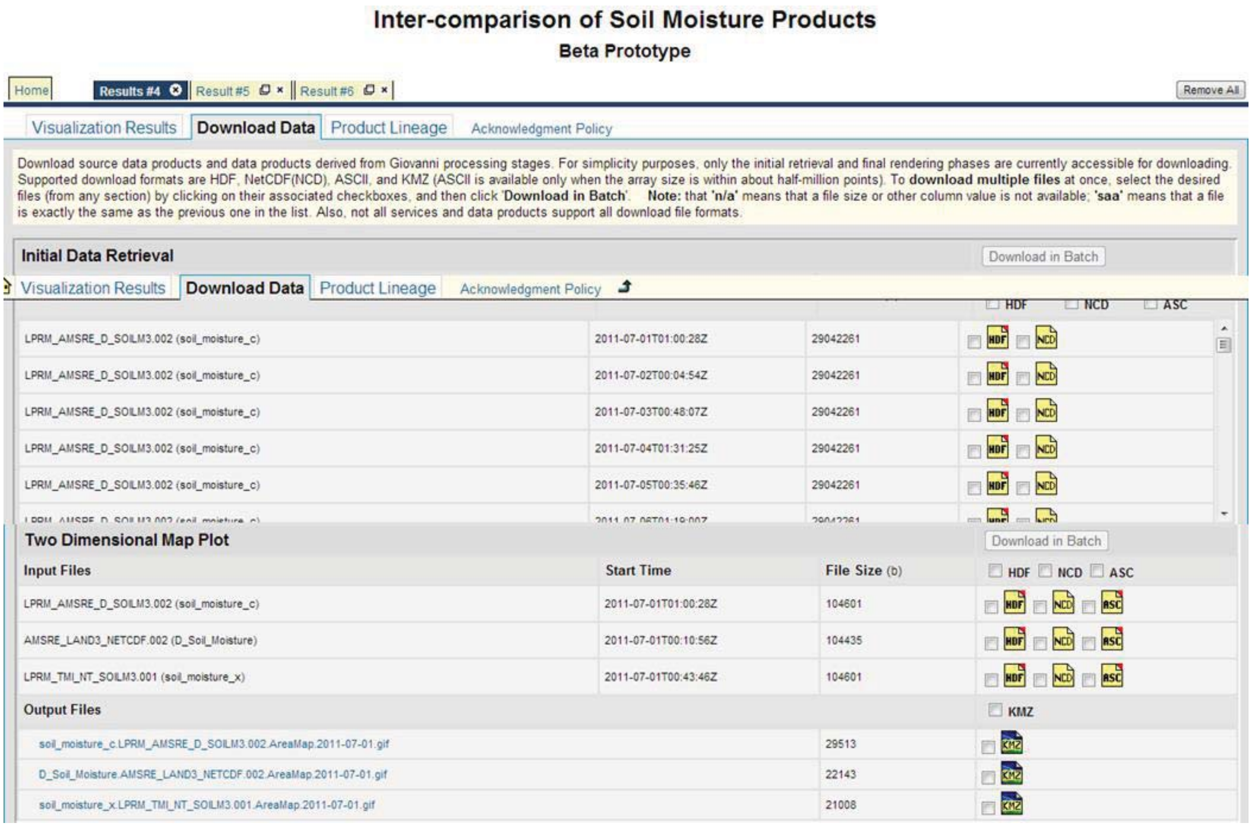


Figure 5. “Download Data” tab in Giovanni portals provides data format options for downloading individual input files and generated output plot files (both data and image).

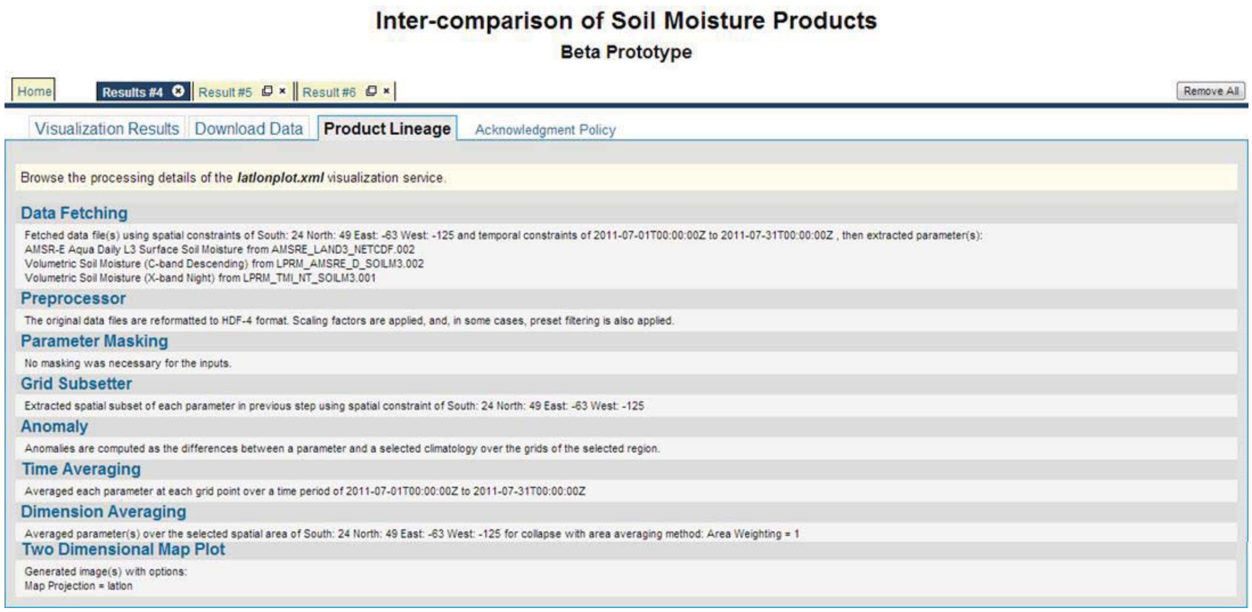


Figure 6. "Product Lineage" tab in Giovanni portals provides information on the lineage (or provenance) of the Giovanni-generated output files, describing all the intermediate steps taken to result in a particular output plot.

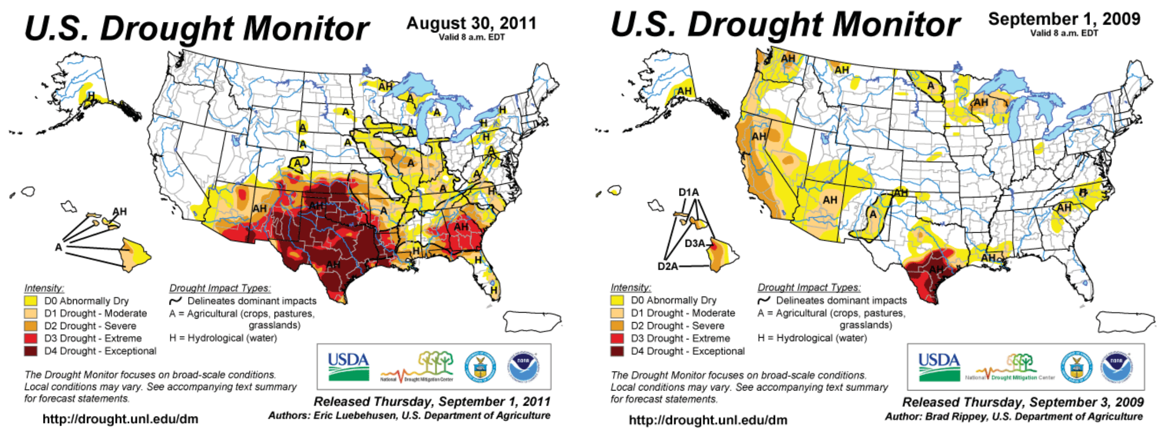
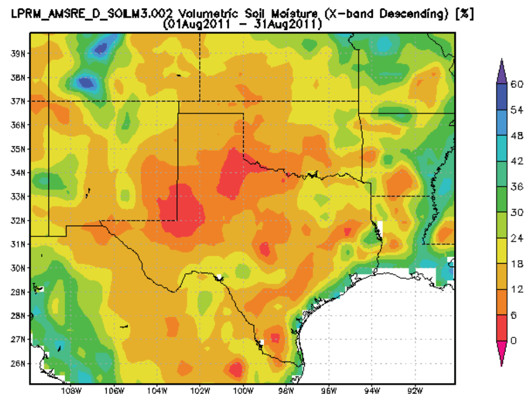
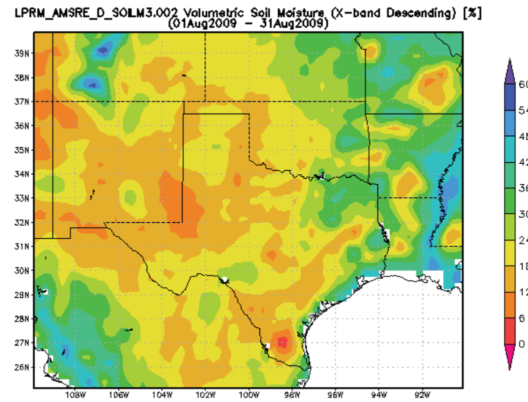


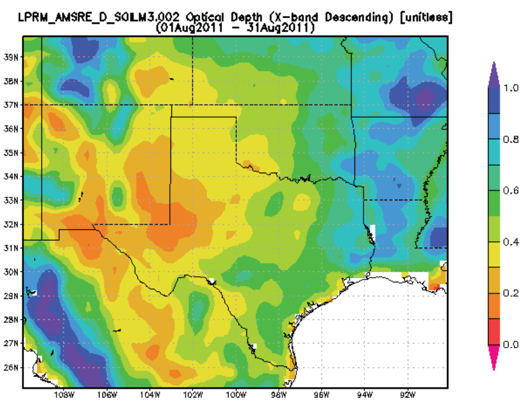
Figure 7. U.S. Drought Monitor map of August 30, 2011, showing most of Texas in “Exceptional Drought,” compared with a similar map for September 1, 2009, a more “average” year.


LPRM_AMSRE_D_SOILM3.002 Volumetric Soil Moisture (X-band Descending) [%]
(01Aug2011 – 31Aug2011)
60
54
48
42
36
30
24
18
12
6
0

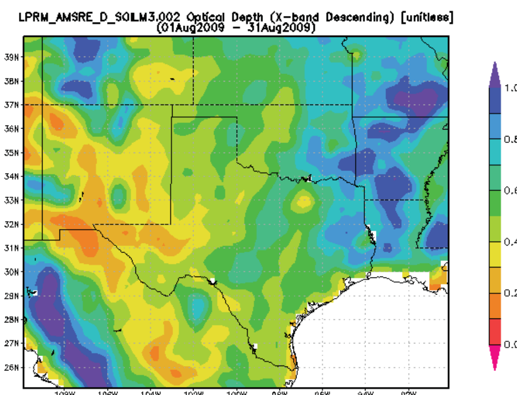
a


LPRM_AMSRE_D_SOILM3.002 Volumetric Soil Moisture (X-band Descending) [%]
(01Aug2009 – 31Aug2009)
60
54
48
42
36
30
24
18
12
6
0

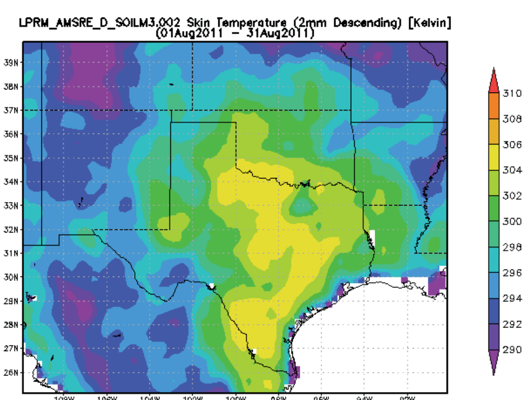
b


LPRM_AMSRE_D_SOILM3.002 Optical Depth (X-band Descending) [unitless]
(01Aug2011 – 31Aug2011)
1.0
0.8
0.6
0.4
0.2
0.0

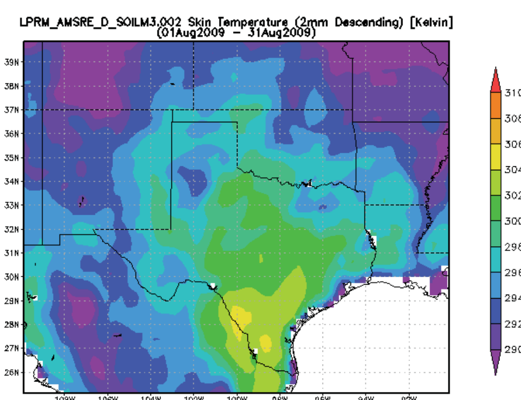
c


LPRM_AMSRE_D_SOILM3.002 Optical Depth (X-band Descending) [unitless]
(01Aug2009 – 31Aug2009)
1.0
0.8
0.6
0.4
0.2
0.0

d


LPRM_AMSRE_D_SOILM3.002 Skin Temperature (2mm Descending) [Kelvin]
(01Aug2011 – 31Aug2011)
310
308
306
304
302
300
298
296
294
292
290

e


LPRM_AMSRE_D_SOILM3.002 Skin Temperature (2mm Descending) [Kelvin]
(01Aug2009 – 31Aug2009)
310
308
306
304
302
300
298
296
294
292
290

f

Figure 8. Giovanni-generated area maps of soil moisture (a,b), vegetation optical depth (c,d), and skin temperature (e,f) from the LPRM-AMSR-E product, for Texas and surrounding areas for August 2011 and August 2009.

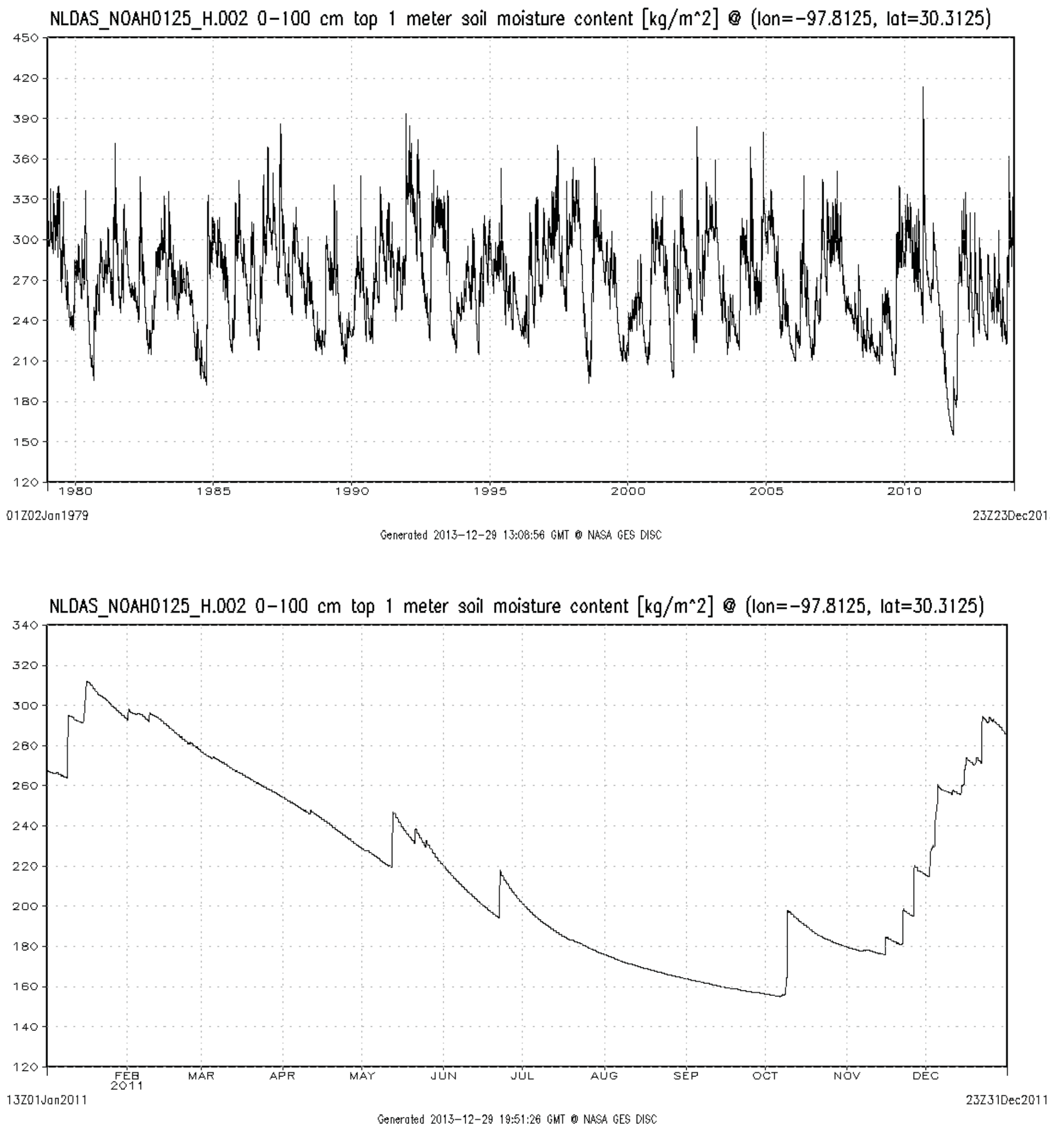


Figure 9. NLDAS Noah model output for 0-100 cm soil moisture content for a 0.125-deg. grid box over Austin, Texas, for the entire time period of available coverage (so far) (top) and for the year 2011 (bottom).

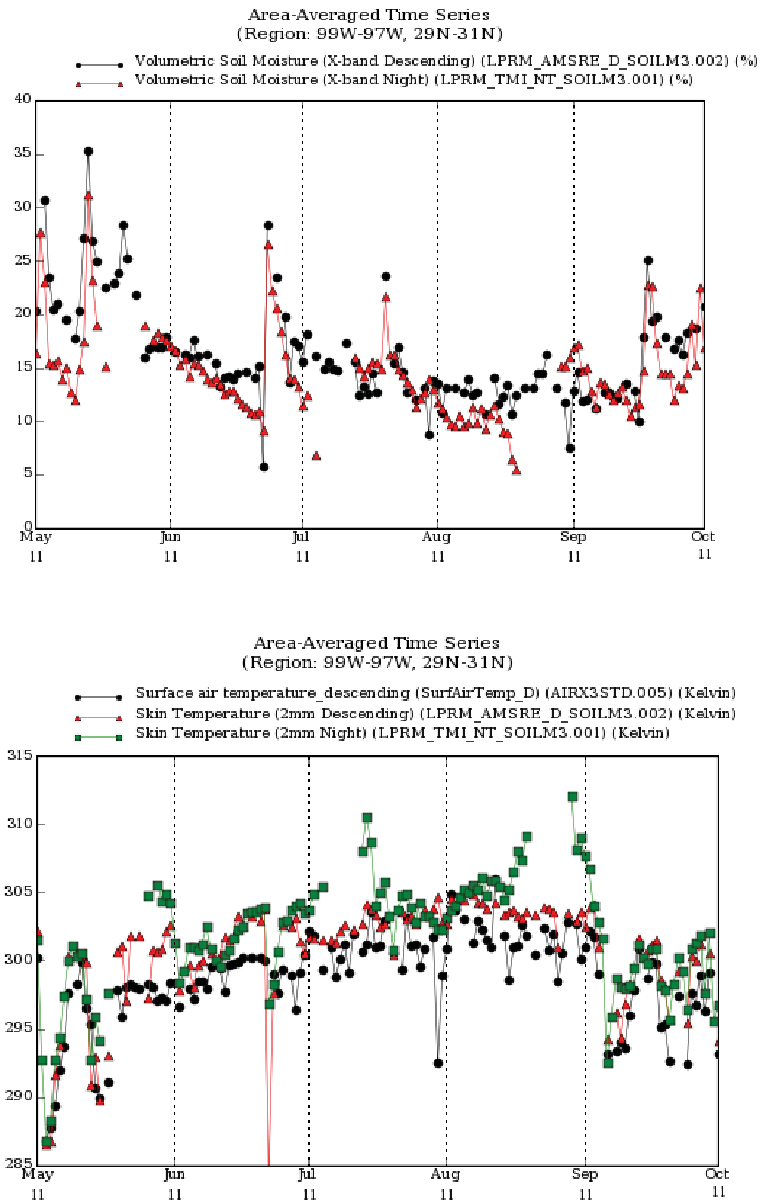


Figure 10. Giovanni-generated time series, area-averaged, centered on Austin, Texas, for soil moisture from LPRM-AMSR-E and LPRM-TMI (top) and surface temperature from EOS Aqua AIRS (surface air temperature) and LPRM-AMSR-E and LPRM-TMI (skin temperature) (bottom), covering a time period from May 1 to October 1, 2011.

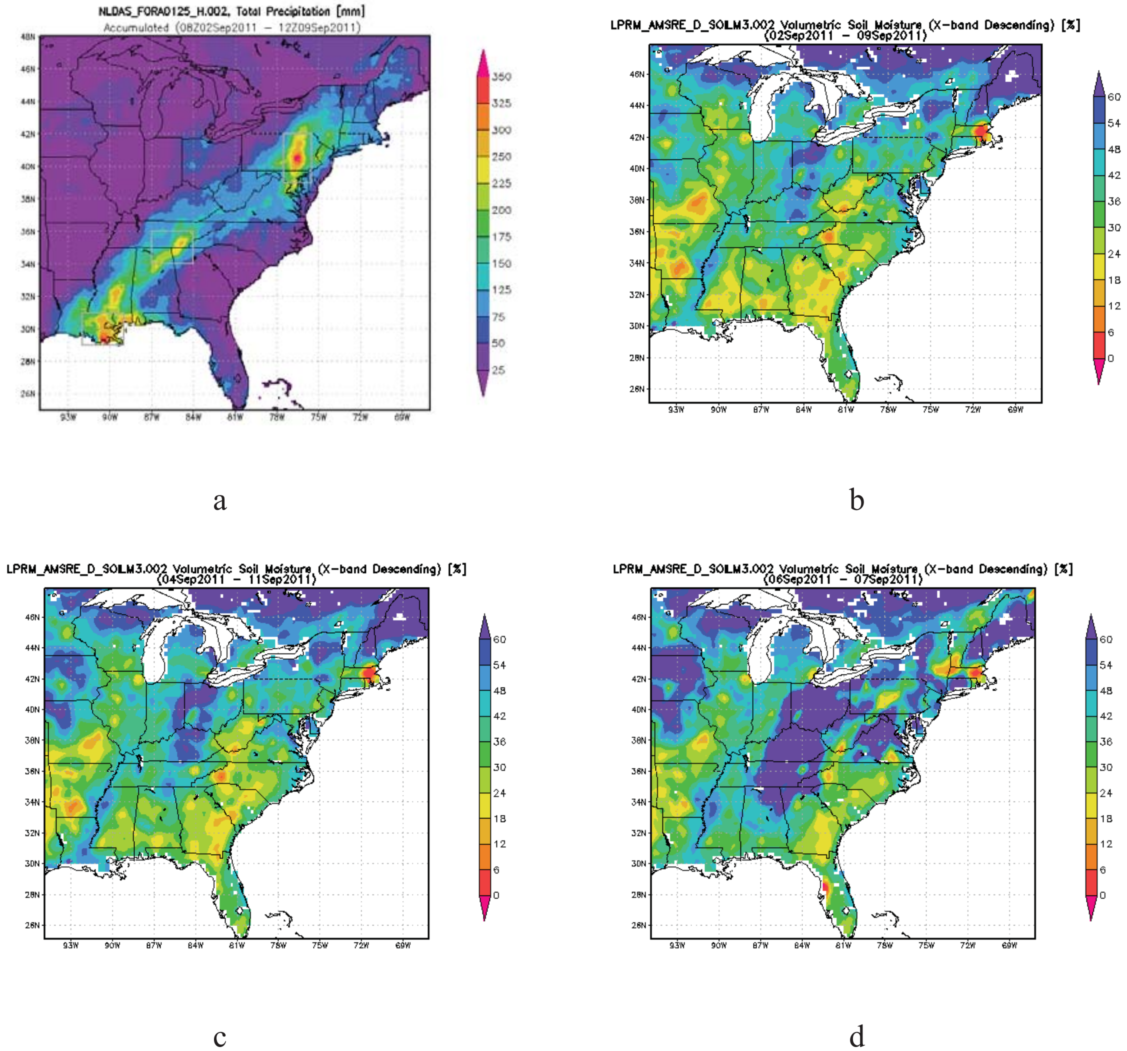


Figure 11. The track and effect of Tropical Storm Lee, September 2-9, 2011, shown by Giovanni-generated area maps of (a) NLDAS total precipitation; (b) LPRM-AMSR-E averaged soil moisture, over the same time period; (c) averaged soil moisture, with a two-day time lag (i.e., September 4-11); and (d) averaged soil moisture, for the two days after an intense rain event over Alabama, Georgia, and Tennessee.

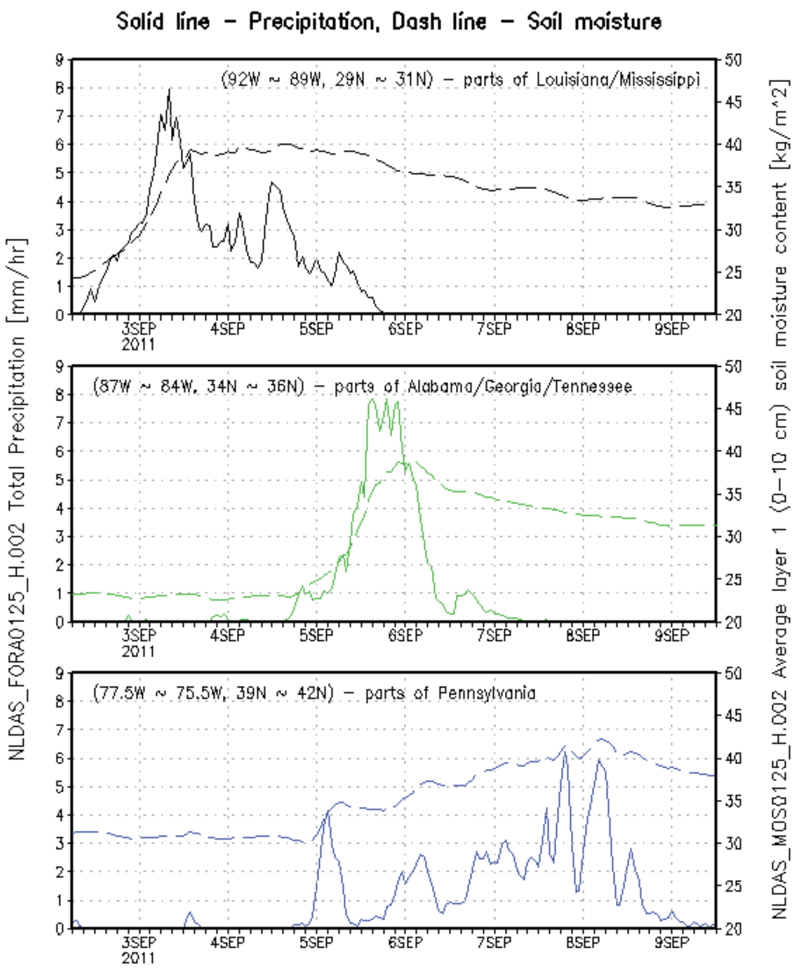


Figure 12. Time series of NLDAS total precipitation and NLDAS Mosaic 0-10 cm soil moisture content for the three boxed areas shown in Fig. 11a.

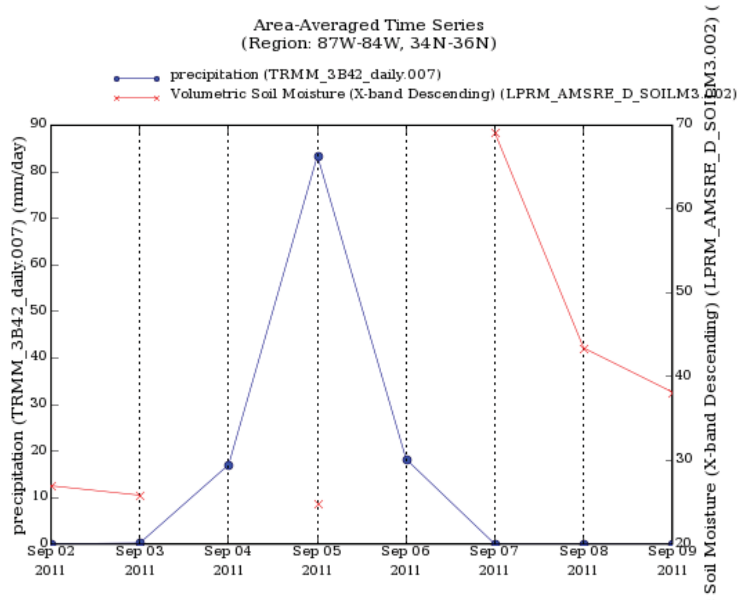


Figure 13. Time series of TRMM precipitation and LPRM-AMSR-E soil moisture, for the same middle boxed area of Fig. 11a, showing a similar precipitation peak and slight soil moisture time lag as those shown by the NLDAS data (compare middle plot of Fig. 12).