# The WindSat Global Surface Soil Moisture Data Set

Version 1

January 29, 2008

### Introduction

The WindSat instrument is a spaceborne polarimetric microwave radiometer launched by Naval Research Laboratory (NRL) under the sponsorship of the U.S. Navy and the National Polar-orbiting Operational Environmental Satellite System (NPOESS) in 2003 (Gaiser et al., 2004). The first release of WindSat land data products includes the daily global data of the surface soil moisture, land classification and the observation time. The vegetation water content and land surface temperature data will be included in the next release following completion of the preliminary validation. Meanwhile the vegetation data are available through special request for validation purpose. Preview images of daily global soil moisture are also included in the data set. The goal of this data release is to explore the utility of passive microwave land data products, encourage collaborations among data developers and data users, expand the ongoing WindSat data evaluation and improvements, and seek user feedback for the risk reduction of the future NPOESS MIS (Microwave Imager/Sounder) mission. Therefore your communications with us on data assessment and research and applications using this data set will be greatly appreciated.

# WindSat Land Algorithm and Data Validation/Performance

The WindSat soil moisture retrievals are based on a multi-channel maximum-likelihood algorithm using 10 to 37 GHz channels (Li et al., 2008). The surface parameters considered by the algorithm include soil moisture, vegetation water content, land surface temperature, surface types, precipitation and snow cover. The algorithm outputs are validated against multi-scale data including soil moisture climatology, ground in-situ network data, precipitation patterns, and vegetation data from AVHRR sensors. Some of the validation results are summarized below.

Figure 1 shows composite WindSat global surface soil moisture retrievals for the period of 20-29 September 2003. Overall, the soil moisture retrievals are very consistent with global dry/wet patterns of climate regimes. All the deserts and arid regions were captured well by the retrievals. High soil moisture was found in the typically wet regions in high latitude, stretching from Europe to Asia. In the United States, there are two distinct patterns of continental climate: the humid East and the arid West. The climate transition zone is around 100° west longitude line extending through the Great Plains from North Dakota to Texas. Such a pattern of dry in the west and wet in the east is clearly depicted by soil moisture retrievals. The retrievals exhibit is a distinct and sharp boundary, which agrees with the strong west-to-east soil moisture gradient near this boundary that is predicted by the NASA Catchment Land Surface Model (CLSM) (Koster et al., 2000a, b).



Figure 1. Global soil moisture retrievals for 20 – 29 September 2003.

The quantitative algorithm validation is based on soil moisture data of top 5 cm soil layer acquired using dense in-situ network during the Soil Moisture Experiment (SMEX) over the United States by USDA (Jackson et al., 2005) The SMEX data available to us cover the summer months in three years: 2003 in Oklahoma, 2004 in Arizona, and 2005 in Iowa. Despite the relatively short temporal coverage in the summer, these three experiment sites provided diverse vegetation covers (rangeland, winter wheat, sparse shrubland, agricultural

domain with corn and soybean) and extreme wet and dry soil conditions. Figure 2 plots the area-averaged insitu soil moisture data against the WindSat retrievals for all three SMEX field experiments. Data from different experiments are separated using different plotting symbols. In general, the WindSat retrieved soil moisture retrievals agree very well with the in-situ data from all the SMEX sites with an uncertainty of about 4% and bias of 0.4%. The retrieved soil moisture is also highly correlated with in-situ data with a correlation coefficient of 0.89.



Figure 2. WindSat soil moisture validation against SMEX data.



Figure 3. WindSat soil moisture validation against CEOP Mongolia data.

During the Coordinated Enhanced Observing Period (CEOP), soil moisture data were collected over Mongolia using an in-situ network by JAXA (Kaihotsu, 2005). Since the network is located in the cold region and the WindSat snow cover data have yet to be validated, we only used summer 2003 data for this soil moisture validation. Since the network is relatively sparse, no spatial averaging was performed on the point measurements of each station. Therefore the WindSat data were compared against in-situ data from each individual station. Figure 3 compares WindSat retrievals against four in-situ stations. Of 16 total stations, four stations did not pass the quality control procedure, two did not pass consistency check, and similar results are obtained for rest of the stations. These validation results are also quite consistent with the SMEX validation results.

The comparisons of soil moisture retrievals and precipitation patterns offer an indirect, qualitative but multi-scale way to validate soil moisture retrievals (McCabe et al., 2005). As an example, at the synoptic scale, the hot and dry July and August 2003 resulted in extreme short-term drought conditions in 109-year record from western Great Lakes to northern Rockies and Great Plains, including Nebraska, Kansas, and Oklahoma (<u>http://www.ncdc.noaa.gov/oa/climate/research/monitoring.html</u>). On 11 September 2003, a very heavy rain band was formed across northern and central plains (Minnesota, Nebraska,

and Kansas), which lasted for many hours and created saturated conditions on the ground. Figure 4(a) shows the 24-hour rainfall total for 11 September. The rain band location is illustrated well on the image. By the morning of 12 September, the rain started to move to the east of Mississippi river and then diminished, as shown in Figure 4(b). The WindSat morning pass on 12 September has a swath lined up well with the rain band on the previous day and captures the wet event under rain-free conditions. Figure 4(c) and (d) depict the Windsat soil moisture retrievals over the similar region on September 6 and 12, respectively. Figure 4(c) shows mostly very dry conditions prior to the rain event and Figure 4(d) the very wet conditions after the rain. Not only are the WindSat soil moisture data able to capture these two extreme dry and wet conditions well, demonstrating sufficient retrieval sensitivity, but the spatial patterns of rainfall and soil moisture also show strong correlations. The location of the patterns almost overlaps with each other, despite of the qualitative nature of such comparison. The results suggest that WindSat soil moisture data can capture the hydrological processes at the synoptic scale.



Figure 4. Comparisons of precipitation with soil moisture retrievals before and after the rain event. The precipitation images are provided by Dr. Andy Jones/CIRA, Colorado State University.

### Caveat

Developing a globally validated passive microwave land product is a significant challenge to the research community. While the high quality in-situ observations over diverse climate regimes are essential to develop the global validation, many microwave phenomena and signatures have yet to be explored. Some examples of remaining algorithm issues include, but are not limited to:

- (1) Topographic surface roughness and mountainous terrain effects have yet to be determined and removed (Njoku and Chan, 2006; Shi et al., 2006).
- (2) Heterogeneity of land cover is not considered.
- (3) The cloud effect is not considered, which can result in significant retrieval errors for heavy cloud conditions.
- (4) Volume scattering at the very low soil moisture conditions (Lu et al., 2005). The volume scattering signature is especially pronounced over the sandy desert, which may result in abnormally higher soil moisture retrievals.
- (5) Precipitation detection algorithm has yet to be validated quantitatively. The rain contamination effects through outside the antenna beamwidth or sidelobe have yet to be determined and removed.
- (6) Vegetation impact at high biomass is not yet been evaluated. The algorithm is validated only for low to moderate vegetation. The detailed algorithm performance as a function of vegetation water content has yet to be determined.
- (7) The Radio Frequency Interference (RFI) at 10 GHz (Li et al., 2006) is detected and the contaminated data removed. The impact of undetected small RFI is unknown at this moment.
- (8) Effects associated with freeze/thaw, dew deposition and rain water interception have not been accounted for.

Therefore, caution is recommended when dealing with the extreme dry/wet, vegetation, land surface temperature, and atmospheric conditions.

### Data Format

The WindSat land data products use binary data format. The brightness temperatures of 50 km spatial resolution are first resampled to a global cylindrical EASE-Grid of 25 km resolution (true at 30° latitude) with the grid size of 1383 columns by 586 rows. During the resampling to EASE-grid, the swath was trimmed to remove the edge effect due partial blockage of antenna beams by the calibration targets. Small but non-negligible biases for all the channels are removed based on the brightness temperature calibration over the ocean scene. Detailed information about EASE-Grid can be found at <a href="http://nsidc.org/data/ease/index.html">http://nsidc.org/data/ease/index.html</a>. IDL tools are included in this data release, including programs for the conversions between geographic coordinates and EASE-grid coordinates. The data fields are summarized in the following table. A sample IDL program is also provided to read all the data fields.

Field Name	Data Type	Data Range	Description	Flag Value
Time	Float 64		The number of	-999
			seconds since	
			January 1, 2000	
			<u>noon</u> GMT	
Soil Moisture	Float 32	$0.0 - 0.5 \text{ cm}^3/\text{cm}^3$	Volumetric soil	-999
			moisture	
Land Surface	Float 32	$1 - 60 ^{\circ}\text{C}$		-999
Temperature				
Vegetation	Float32	$0 - 15 \text{ kg/m}^2$	Vegetation	-999
			water content	
Surface Type	Integer 16		Surface	-999
	_		classification	

The surface type has integer value as follows,

Surface Type	value
Water body/ocean	0
Permanent ice sheet	10
Mountainous terrain	20
Snow Cover	30
Frozen Ground	40
Precipitation	50
10 GHz RFI	60
Dense vegetation	70
Moderate vegetation	80
Low vegetation	90

The daily composite data are organized according to observation date. Each data parameter is in a separate file with the following naming convention,

#### dyyyymmddGEZ25av\_pass.pp#

Where d field is the date (yyyymmdd), GEZ25av indicate the data points are defined on global 25 km resolution EASE-grid, pass indicates ascending or descending pass ('a' or 'd', respectively), pp is the land parameter, and # is the version number. For the pp field, sm is soil moisture; ts is the land surface temperature; cls is the land type; tm is the observation time. Currently, only the data of descending orbit are processed. Descending orbits have early morning passes when the differences between effective land surface and vegetation temperatures are at the daily minimum. This simplifies the modeling and retrieval algorithms. We expect larger retrieval errors for the afternoon passes when the surface and vegetation temperatures differ significantly. We do plan to process the ascending orbit data and examine their retrieval performance in the near future.

Example file name: d20030808GEZ25av\_d.sm1

The temporal coverage of this release contains data for July/August/September for three years from 2003 to 2005. They are stored in appropriate year and month subdirectories. The daily global quick look soil moisture images are created as JPEG images during the archive process. They are also available in this data release.

# Data Access and Tool

The WindSat land data products are available from the Center for Spatial Information Science and Systems (CSISS), George Mason University. The first release of WindSat land data products includes the daily global data of the surface soil moisture, land classification and the observation time. The vegetation water content and land surface temperature data will be included in the next release following completion of the preliminary validation.

The entire archive of data and browse files can be accessed through the File Transfer Protocol (FTP) or the CSISS interface <u>http://laits.gmu.edu:8099/windsat/search.jsp</u>. Registration is recommended so that we can inform you of the future data releases. Please email <u>windsat\_land@nrl.navy.mil</u> to register.

The EASE-Grid Geolocation Tools can be found at <u>http://nsidc.org/data/ease/tools.html</u>. The computer programs and ancillary data can be extracted from the "Ml\_geolocation" tar file.

# Contact

## Investigators

Li Li Naval Research Laboratory Code 7223, Bldg 2/220 4555 Overlook Avenue, S.W. Washington DC 20375 Phone: 202-767-0849 Fax: 202-767-9194 E-mail: li.li@nrl.navy.mil

Peter Gaiser Naval Research Laboratory Code 7220 4555 Overlook Avenue, S.W. Washington DC 20375 Phone: 202-767-8253 Fax: 202-767-7885 E-mail: peter.gaiser@nrl.navy.mil

#### **Technical Contact**

Peisheng Zhao, PhD Research Assistant Professor Center for Spatial Information Science and Systems (CSISS) George Mason University Fairfax, Virginia Phone: 301-220-1536 Fax: 301-345-5492 E-mail: pzhao@gmu.edu

#### Acknowledgement

We would like to thank Dr. Tom Jackson of USDA, Professor Ichirow Kaihotsu of Hiroshima University, and Dr. Jean-Christophe Calvet of METEO-FRANCE/CNRM for providing their in-situ data. The WindSat soil moisture data are produced by NRL as part of the risk reduction effort for the NPOESS Microwave Imager Sounder (MIS) mission and ongoing research into further applications of WindSat polarimetric microwave radiometer data. The George Mason University, Fairfax, Virginia provided data archival and distribution through its Center for Spatial Information Science and Systems (CSISS). Support from the NPOESS Integrated Program Office (IPO) and the Office of Naval Research (ONR) are gratefully acknowledged.

## Reference

Gaiser, P.W.; St Germain, K.M.; Twarog, E.M.; Poe, G.A.; Purdy, W.; Richardson, D.; Grossman, W.; Jones, W.L.; Spencer, D.; Golba, G.; Cleveland, J.; Choy, L.; Bevilacqua, R.M.; Chang, P.S, "The WindSat spaceborne polarimetric microwave radiometer: Sensor description and early orbit performance," IEEE Trans. Geosci. Remote Sens., vol. 42, pp. 2347–2361, 2004.

Jackson, T.J.; Bindlish, R.; Gasiewski, A.J.; Stankov, B.; Klein, M.; Njoku, E.G.; Bosch, D.; Coleman, T.L.; Laymon, C.A.; Starks, P., "Polarimetric Scannung Radiometer C- and X-band microwave observations during SMEX03," IEEE Trans. Geosci. Remote Sens., vol. 43, pp. 2418–2430, 2005.

Kaihostu, I., "Current status of ground observations in Mongolia," Joint AMSR Science Team Meeting, 13-15 September 2005, University of Hawaii at Manoa, Honolulu, HI

Koster, R. D.; Suarez, M. J.; Ducharne, A.; Stieglitz, M.; and Kumar, P., A catchment-based approach to modeling land surface processes in a general circulation model: 1. Model structure. J Geophys. Res., Vol. 105, No. D20, 24,809-24822, 2000a.

Koster, R. D.; Suarez, M. J.; Ducharne, A.; Stieglitz, M.; and Kumar, P., A catchment-based approach to modeling land surface processes in a general circulation model: 2. Parameter estimation and model demonstration. J Geophys. Res., Vol. 105, No. D20, 24,823-24838, 2000b.

Li, L.; Gaiser, P.W.; Bettenhausen, M.H.; Johnston, W., "WindSat radio-frequency interference signature and its identification over land and ocean," IEEE Trans. Geosci. Remote Sens., vol. 44, pp. 530 - 539, 2006.

Li, L.; Gaiser, P.W.; Bevilacqua, R.; "WindSat Global Soil Moisture Retrieval and Validation," to be submitted to IEEE Trans. Geosci. Remote Sens., 2008

Lu, H.; Koike, T.;, Fujii, H.; Hirose, H.; Tamagawa, K., "A radiative transfer model and an algorithm for soil moisture including very dry conditions," in Proc. IEEE International Geoscience and Remote Sensing Symposium, 2005.

McCabe, M.F.; Gao, H.; and Wood E.F., "Initial soil moisture retrievals from AMSR-E: Multiscale comparison using in situ data and rainfall patterns over Iowa," Geophysical Research Letters, vol. 32, L06403, dio:10.1029/2004GL021222, 2005.

Njoku, E.G.; and S.K. Chan, "Vegetation and surface roughness effects on AMSR-E land observations," Remote Sensing of Environment, vol. 100, pp. 190-199, 2006.

Shi, J.; Njoku, E., Jackson, T., O'Neill, P., "Evaluation of Potential Error Sources for Soil Moisture Retrieval from Satellite Microwave Radiometer," in Proc. IEEE International Geoscience and Remote Sensing Symposium, 2006.

Appendix A: A sample IDL program to read land EDR.

```
FUNCTION read_wsat_opt_ledr1_gez25, file, mv, ts, tm, scls
;
;input: file - file name of the soil moisture data
;outpour: mv - soil moisture
; ts - land surface temperature
; tm - WindSat time
; scls - surface class
;
;
if(file eq ") then return, -1
files = findfile(file,COUNT=ct)
if(ct le 0) then begin
; print, 'WindSat data not found:', file
return, -1
endif
```

```
nx=1383L

ny=586L

mv = fltarr(nx,ny) - 999.

ts = fltarr(nx,ny) - 999.

tm = dblarr(nx,ny) - 999.

scls = intarr(nx,ny) - 999

slen = strlen(file)

file2 = strmid(file, 0, slen-3)+'ts1'

file3 = strmid(file, 0, slen-3)+'tm1'

file4 = strmid(file, 0, slen-3)+'cls1'
```

lun = 10 openr,lun,file readu, lun, mv close,lun free\_lun,lun

openr,lun,file2 readu, lun,ts close,lun free\_lun,lun openr,lun,file3 readu, lun,tm close,lun free\_lun,lun

openr,lun,file4 readu, lun, scls close,lun free\_lun,lun

return, 0

end

Appendix B: Sample IDL programs for the conversions between geographic coordinates and EASE-grid coordinates.

FUNCTION ease\_convert, lat, lon, r, s

; ; status = ease\_convert (lat, lon, r, s) ;

; if ((lat lt -86.72) or (lat gt 86.72)) then return, -1 if ((lat lt -90.0) or (lat gt 90.0)) then return, -1 if ((lon lt -180.0) or (lon gt 180.0)) then return, -1

```
pi = 3.141592653589793

re = 6371.228; Earth radius (km)

cell = 25.067525; Nominal cell size (km)

cols = 1383; Number of columns

rows = 586; Number of rows

r0 = (cols-1)/2.; Map origin (column)

s0 = (rows-1)/2.; Map origin (row)

ctrue = 0.866025403;! cos(TRUE*pi/180.)

r = r0 + (re/cell)*(lon*pi/180.)*ctrue

s = s0 - (re/cell)*sin(lat*pi/180.)/ctrue

return, 0
```

end

```
;-----

FUNCTION ease_inverse, r, s, lat, lon

;

; status = ease_inverse (r, s, lat, lon)

;
```

if ((r lt -0.5) or (r gt 1382.5)) then return, -1 if ((s lt -0.5) or (s gt 585.5)) then return, -1

```
\begin{array}{l} pi = 3.141592653589793 \ ;!!3.14159\\ re = 6371.228 \qquad ; Earth radius \ (km)\\ cell = 25.067525 \qquad ; Nominal cell size \ (km)\\ cols = 1383 \qquad ; Number \ of \ columns\\ rows = 586 \qquad ; Number \ of \ rows\\ r0 = (cols-1)/2. \qquad ; Map \ origin \ (column) \end{array}
```

```
s0 = (rows-1)/2.; Map origin (row)
```

```
ctrue = 0.866025403 ;!!cos(TRUE*pi/180.)
lon = ((r-r0)/((re/cell)*ctrue))*180./pi
lat = asin(-(s-s0)*ctrue/(re/cell))*180./pi
```

return, 0

end