NWP SAF

Satellite Application Facility for Numerical Weather Prediction

Associate Scientist Mission Report

Document NWPSAF-MO-VS-025

Version 1.9

25 July 2005

Implementation Plan for a NRT global ASCAT soil moisture product for NWP

Part 1: NWP User Community Requirements Summary

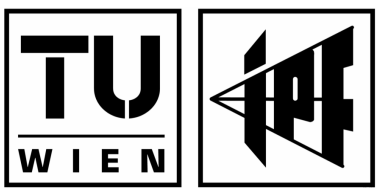
R A Kidd

Institute of Photogrammetry and Remote Sensing, Vienna University of Technology, Austria.

ASCAT Soil Moisture Report Series No. 1

NWP User Community Requirements Summary

VIENNA UNIVERSITY OF TECHNOLOGY
INSTITUTE OF PHOTOGRAMMETRY AND REMOTE SENSING



2005 July 25

Scope of Document

This report integrates the main summaries from the following meetings with NWP groups:

Met Office (United Kingdom)	Meeting 2005 Feb 22
ECMWF (United Kingdom)	Meeting 2005 Feb 23
Météo France (France)	Meeting 2005 Mar 16
KNMI (The Netherlands)	Meeting 2005 Mar 31

These synthesised summaries form a User Requirements Document (URD) that, once reviewed by all meeting participants, completes reporting on work package 1 of this NWP SAF (Numerical Weather Prediction Satellite Application Facility) Associate Scientist Mission.

The present study was funded by the *geoland* project (http://www.gmes-geoland.info) and the NWP SAF (http://www.metoffice.com/research/interproj/nwpsaf).

Status:	Issue 1.9		
Authors:	IPF TU Wien (RAK)		
Circulation:	IPF, NWP SAF		
Amendments:			
Issue	***Date***	***Details***	***Editor***
Issue 1.0	2005 Mar 15	Initial Document.	RAK
Issue 1.1	2005 Mar 15	Included Summaries from MetOffice (UK) and ECMWF– To WW for comments	RAK
Issue 1.2	2005 Apr 8	Structured Document	RAK
Issue 1.3	2005 Apr 18	To KS for comments	RAK
Issue 1.4	2005 Apr 19	Included related documents and edits. To WW/ZB/KS for final comments	RAK
Issue 1.5	2005 Apr 21	Reformatted and included WW comments	RAK
Issue 1.6	2005 May 26	Included edits and applied final formatting	ZB
Issue 1.7	2005 June 27	Included comments from Météo France to finalise report as work package deliverable.	RAK
Issue 1.8	2005 July 25	Included comments from Met Office. Added Section 7, summary of Technology free UR's, summary ranges for global and regional UR's. and Annex 1	RAK
Issue 1.9	2005 Sept 07	Corrected Typo's in Annex 1	RAK

If further corrections are required please contact Richard Kidd. (rk@ipf.tuwien.ac.at).

Contents

Acronym and Abbreviation List

BUFR	Binary Universal Form for the Representation of meteorological data
CEOS	Committee on Earth Observation Satellites
CESBIO	Centre d'Etudes Spatiales de la Biosphère
EARS	EUMETSAT Advanced Retransmission Service
ECMWF	European Centre for Medium-Range Weather Forecasting
ELDAS	European Land Data Assimilation System
ERS	European Remote Sensing Satellite (ESA)
ESTEC	European Space Research and Technology Centre
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
HYDROS	Hydrosphere State Satellite Mission
IPF	Institut für Photogrammetrie und Fernerkundung - Institute of Photogrammetry and Remote Sensing - TU Wien.
KNMI	Koninklijk Nederlands Meteorologisch Instituut
LDAS	Land Data Assimilation System
METOP	Meteorological Operational satellites
NRT	Near Real Time
NWP	Numerical Weather Prediction
PDU	Product Dissemination Unit
RMS	Root Mean Square
SDAS	Scanner for earth's Radiation Budget
SMOS	Soil Moisture and Ocean Salinity
UR	User Requirement
URD	User Requirements Document
WMO	World Meteorological Organisation

1 What Is and Is Not Included in this Document

1.1 What IS included

- The final version of this current draft document provides a common consensus of requirements obtained from meetings with NWP community.
- The user requirements document lays out a wish list of WHAT a global (Section 5) and regional soil (Section 6) moisture product should comprise.
- To furnish background and perspective WHY is also included (Section 4).
- Requirements may be prioritized based upon comments received on the draft versions of this document, along with associated justifications.
- To contextualise these User Requirements in Section 7 they are presented along with a summary of user requirements as already stated by WMO/CEOS and by EUMETSAT, in the context of post-MSG and HSAF activities.

1.2 What is NOT included

- The user requirements document does not present, or propose solutions, for the provision of the soil moisture product; these will be addressed in the final report of this NWP Associate Scientist Mission.

2 Related Documents

To understand the current state of the art concerning user requirements for soil moisture products, to initiate discussions, and to assist in formulating this user requirement document the following documents were also sourced:

Entekhabi, D. et al, (2004), *The Hydrosphere State (Hydros) Satellite Mission: An Earth System Pathfinder for Global Mapping of Soil Moisture and Land Freeze/Thaw.* IEEE Transactions on Geoscience and Remote Sensing, vol. 42, No. 10, October 2004, pp. 2184-2195

Soil moisture retrieval by a future space-borne Earth observation mission, ESTEC contract number 14662/00/NL/DC University of Reading, Reading, UK, Feb 2004.

Kerr, Yann H. (2005), *Mission Objectives and Scientific Requirements of the Soil Moisture and Ocean Salinity (SMOS) Mission*, Version 5, CESBIO
http://www.cesbio.ups-tlse.fr/us/indexsmos.html,
http://esamultimedia.esa.int/docs/SMOS_MRD_V5.pdf

van den Hurk, Bart (ed.) (2005), *User Requirements Document from "Annexes ELDAS final report,* Project ID EVG2-2001-00013", 12 April 2005, KNMI, The Netherlands
http://www.knmi.nl/samenw/eldas

Beck, R., P. Campling, J. DeBelder, B. van den Hurk, K. Scipal, W. Wagner (2003), *CLIMSCAT - Service definition for ERS Scatterometer Derived Soil Moisture Information for Climate Modeling and Numerical Weather Forecasting*, Final Report, ESA Data User Programme 2001, Frascati, Italy, March 2003, 59 p

Eyre, J., Thépaut, J., N,. Joiner, J., Riishojgaard L., P., Gérard, F., *Position Paper: Requirements for observations for global NWP.* Version 2.1 8th January 2002, http://www.eumetsat.int/

Gustafsson, N., Capaldo, M., Orfila Estrada, B., Quiby, J., *Position Paper: Requirements for observations for Regional NWP.* 18th October 2001, http://www.eumetsat.int/

Summary Report of the SAF Hydrology Framework Working Group, ref: EUM/PPS/REP/04/0002
http://www.eumetsat.int/en/area4/saf/internet/main_safs/hwm/main_hwmsaf.html/

3 NWP User Community Meetings and List of Participants

Met Office (United Kingdom), 2005 Feb 22

Sean Milton
Clive Wilson
Roy Kershaw
Adrian Lock
Bruce Macpherson
Clive Jones
Rebecca Quaggin
John Eyre
Roger Saunders
Dave Offiler
Simon Keogh

ECMWF (United Kingdom), 2005 Feb 23

Adrian Simmons
Philippe Bougeault
Pedro Viterbo
Matthias Drusch
Erik Andersson
Hans Hersbach

Météo France (France), 2005 Mar 16

Florence Rabier
Francois Bouyssel
Jean-Christophe Calvet

KMNI (The Netherlands), 2005 Mar 31

Ad Stoffelen
Bart van den Hurk
Marcos Portabella
Paul de Valk
Anton Verhoef
Jeroen Verspeek
Han The *(not present – input by e-mail)*

IPF Participants

Wolfgang Wagner
Richard Kidd
Zoltan Bartalis

4 Summary of Discussions

To initiate discussions the following 7 points (see sub-section headings) requiring clarification were identified by IPF. Each point has been specifically addressed to each NWP group as detailed in Section 3. Discussion relating to each point is reported within these following sub sections; specific comments are preceded by author.

4.1 Product Type

[Met Office], [ECMWF], [Météo France], [KNMI] Preference is for "raw" data, i.e. something that is as close as possible to the actual parameter (observable) as observed by satellite and unmodified by profiling algorithms. The preference is for surface soil moisture (m_s) product.

4.2 Product Geometry

[Met Office], [ECMWF], [Météo France], [KNMI] Preference is for provision of data in orbital geometry, or orbital data. Should be either as a subset of IPF's Geodetic Grid, or based on parameters interpolated from Geodetic Grid to Orbit Nodes.

[Met Office], [ECMWF] Product should be in what ever format is provided by EUMETSAT (PDU: Product Data Units). The most important data that should be delivered is a vector, or array, of [Lat, Long, Time, m_s] at the best possible observable scale.

4.3 Product Timeliness and Cycle

[Met Office] has a preference for real time (NRT) data. Product should be delivered within the timeframe stated by EUMETSAT for their level 2 products (180 min). An ultimate goal could be to match the same processing times as stated for KNMI. KNMI can produce an orbit of wind vectors (from ERS Scat) within 10 minutes after reception of level 1b data from EUMETSAT.

[ECMWF] Product should be delivered within 8 hours to fit into SDAS – Soil Moisture Data Assimilation System.

[Météo France] has a global model with a data assimilation cut-off time of 6 h and a regional model with 2 h. Ideally products should be delivered within 2 hours to be easily assimilated in land surface analy-

sis. If not possible, a timeliness of 8 hours would be still acceptable, but not later

[KNMI] There is a 3 hour window for data assimilation.

[Met Office] Product cycle should be similar to EUMETSAT data broadcast over EUMETCast, preferably on an orbit basis, whenever product is available.

[ECMWF] Product cycle should be at least 3 days, but preferably daily, to take into consideration the surface soil moisture and links with memory effects of subsequent soil layers.

[KNMI] Product cycle was not explicitly stated, but as an example vegetation (LAI) products are foreseen (2007) to be provided on a 14 day cycle. This 14 day product cycle is inferred to be an upper limit.

[KNMI], [Météo France] Regional product also of interest within similar timeframe to that as specified within EUMETSAT Advanced Retransmission Service (EARS). The question is if this makes sense given the limited temporal coverage of the ASCAT (14 ascending and 14 descending passes per day, see Figure 1).

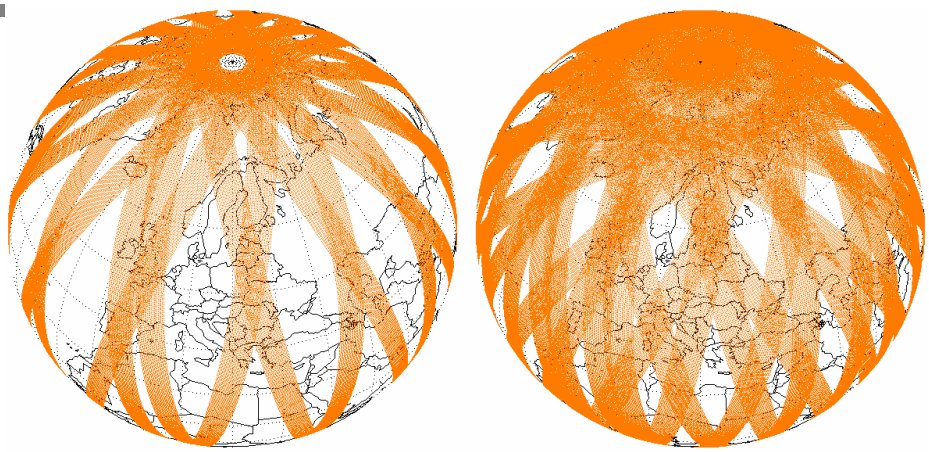


Figure 1.

Comparison between a typical 1-day coverage of the ERS Scatterometer operated continuously (left) and the equivalent coverage of the ASCAT scatterometer.

4.4 Accuracy Requirements

[Met Office] group have not arrived at a common consensus concerning accuracy. For example there is confusion as to why the unit for soil moisture is set to g/kg as now used by WMO. It is suggested that Volumetric Soil Moisture is required at an accuracy of 0.5% to 2% as this relates to an equivalence of 10% difference in evapotranspiration. A 10% difference in evapotranspiration is crucial as this is the difference between the critical point and the wilting point for a plant when considering saturated soil state as 100%.

[ECMWF] Accuracy requirements can only be specified once an assessment and evaluation of the use of the soil moisture product within (offline) forecast has been carried out.

[Météo France] As for SMOS the accuracy goal should be 4 % volumetric soil moisture. Given that no soil moisture information exists to date it is possible that even less accurate products could prove useful.

[KNMI] It is not meaningful to provide a single accuracy value for the complete product. Priority is for provision of meaningful and precise flags. This will allow KNMI to assess and evaluate influence of use of soil moisture product.

4.5 Accuracy Indicators and Error Estimation

[Met Office], [ECMWF], [Météo France], [KNMI] All data should be provided with as many relevant, meaningful, and inventive, flags as possible, to allow groups to understand the limitations of the data, and to [Météo France] reflect the current state of knowledge about the quality of the products. [ECMWF] A potential flag, in the form of a continuous function, could be the difference between wet and dry reference, also [Météo France] snow and frozen surfaces should be indicated since models are not good enough to reliably exclude such observations. [KNMI] vegetation correction parameters or spatial distribution of dry/wet reference should be included.

[KNMI] The most straightforward way to understand and to obtain a measure of accuracy for the soil moisture product is also to provide the anomaly of soil moisture from its climatological mean.

[KNMI] In conjunction to any error estimation a validation of the product is also suggested via comparison and consistency monitoring with other land surface schemes. Time series of soil moisture product maps should be kept and checked for consistency monitoring. Time derivative quality parameters could then be added (drying/moistening). Since these are associated with rain/no rain events, NWP modellers could use it and validate against their own scheme.

[KNMI], [ECMWF] To advance product understanding, and validation, prior to the operational availability of METOP data would like to receive IPF's scattering data base parameters.

4.6 Uncertainties

[Met Office], [ECMWF] Product that has areas with producer's uncertainties should be processed and delivered with appropriate flags. Prefer to have well defined, appropriate flags that clearly describe producers' confidence in the product. It is important to assimilate data of good quality.

4.7 Delivery Format

[Met Office], [ECMWF], [Météo France], [KNMI] Preference would be for same format as on EUMETCast, preferably in BUFR, although [ECMWF] other delivery formats and methods such as ftp, GTS, can be considered. [Météo France] problems have been encountered for MODIS winds, which are received with ftp.

[Met Office], [ECMWF] Overall want to have well described data, preferably in BUFR format.

[KNMI] Due to administrative and standardisation (WMO) requirements it may be advisable to initially work with the soil moisture product in a standard scientific format, such as hierarchical data format (HDF), letting the final product distributor (EUMETSAT) to be concerned with modification and acceptance of new BUFR definition.

5 User Requirements for Global Soil Moisture Product (UR G)

For user requirements where a consensus has been reached each requirement is defined as a single value. For all other instances, the discussion with user community has been summarised and is presented as a range of acceptable values for each requirement. For clarification, the initial 7 discussion points in section 4 have been expanded to nine user requirements (UR) for the global soil moisture product. A user requirement concerning uncertainties (discussion point 4.6) is not necessary.

A general observation from all meetings is that user requirements can only clearly be stated once the NWP group has a good understanding and feel for the data, which, in turn, can only be achieved by a cycle of provision, use and assessment of the data by the group.

The following user requirements are provided to initiate this cycle and to establish a baseline. Final user requirements will be clarified after a number of iterations of this data provision cycle.

5.1 Product Type

UR G1: Surface soil moisture (m_s) product

5.2 Product Geometry

UR G2: Product to be provided in orbit geometry

5.3 Product Timeliness

UR G3: Product will be delivered within the 180 min timeframe, from sensing, as stated by EUMETSAT for their level 2 products

5.4 Product Cycle

UR G4: When ever a complete product is available, or latest within the range of 1 to 3 days

5.5 Accuracy Requirements

UR G5: Goal should be 4 % volumetric soil moisture.

5.6 Accuracy Indicators

UR G6.1: Provision of anomaly of soil moisture from its climatological mean

UR G6.2: Indication of snow and frozen surfaces

UR G6.3: Inclusion of wet/dry reference range

5.7 Error Estimation

UR G7: Estimation of errors should be provided in relevant units, relating to dynamic ranges, and numerical precision of product

5.8 Delivery Format

UR G8: Product to be delivered in WMO BUFR format

5.9 Delivery Method

UR G9: Product to be delivered via EUMETCast

6 User Requirements for Regional Soil Moisture Product (UR R)

Interest for a regional soil moisture product was expressed, but needs further clarification. It appears that the regional product is of interest for nowcasting and flood monitoring. User requirements are as for global soil moisture product, with amendments to product timeliness (User Requirement 3).

6.1 Product Type

UR R1: Surface soil moisture (m_s) product

6.2 Product Geometry

UR R2: Product to be provided in orbit geometry

6.3 Product Timeliness

UR R3: Within 30 minutes

6.4 Product Cycle

UR R4: Whenever a complete product is available

6.5 Accuracy Requirements

UR R5: Goal should be 4 % volumetric soil moisture.

6.6 Accuracy Indicators

UR R6.1: Provision of anomaly of soil moisture from its climatological mean

UR R6.2: Indication of snow and frozen surfaces

UR R6.3: Inclusion of wet/dry reference range

6.7 Error Estimation

UR R7: Estimation of errors should be provided in relevant units, relating to dynamic ranges, and numerical precision of product

6.8 Delivery Format

UR R8: Product to be delivered in WMO BUFR format

6.9 Delivery Method

UR R9: Product to be delivered via EUMETCast

7 User requirement comparison

The aim of this section is to allow readers to easily compare user requirements for NWP soil moisture product obtained from this study with published user requirements. The following section presents the "technology free" user requirements for Global NWP soil moisture products (summarised and mapped from Section 5) and Regional NWP soil moisture products (from Section 6), along with currently published user requirements from EUMETSAT and WMO/CEOS.

User requirements previously published by EUMETSAT have been extracted from two EUMETSAT position papers which addressed requirements of observations in medium (2001-2015) and long term (2015-2025) perspective for Global (Eyre, 2002) and Regional (Gustaffsson, 2001) NWP. User requirements from WMO have been sourced from the Summary Report of the SAF Hydrology Framework Working Group.

Table 1 details requirements for global and regional NWP defined in terms of horizontal resolution (dx), vertical resolution (dz), and accuracy. Table 2 details requirements for global and regional NWP defined in terms of frequency, (temporal resolution, dt), timeliness (delay).

As noted (Eyre, 2002) the requirements for accuracy are stated in terms of r.m.s. error. This is a simplification, since there will, in general, be requirements on bias, both absolute and relative. Since accuracy requirements are presented both in terms of g/Kg, as used by WMO, and in terms of percentage volumetric soil moisture, a note on their cross-conversion is given in Annex 1.

Performance requirements are presented for each of the following levels:

- An "optimum" (*Opt.*) or a "maximum" performance level;
- A "threshold" (*Thr.*) or "minimum", performance level;
- A "breakthrough" (*Br.*) performance level.

The "maximum" requirement is the value which, if exceeded, does not yield significant improvements in performance for the application in question. Therefore, the cost of improving the observations beyond this requirement would not be matched by a significantly increased benefit. Maximum requirements are likely to evolve; as applications progress, they develop a capacity to make use of better observations

The "minimum" or "threshold" requirement is the value below which the observation does not yield any significant benefit for the application in question. As a system that meets only minimum require-

ments is unlikely to be cost-effective, it should not be used as a minimum target level for an acceptable system.

The "breakthrough" level represents the value that would need to be attained to provide a significant benefit for the application, compared with current performance.

In both tables missing values, i.e. performance levels for which a value has not been explicitly stated, or mapped, are represented as "-".

Table 1

Summary for Observation requirements of soil moisture for horizontal (dx), vertical resolution (dz) and accuracy (RMS)

	dx (km)			**dz (layers)**			RMS **(g/kg)**		
Source	Opt.	Br.	Thr.	Opt.	Br.	Thr.	Opt.	Br.	Thr.
Global NWP									
WMO	15	-	250	-	-	-	10	-	50
EUMETSAT	5	100	250	-	-	-	5	20	20
NWP	-	-	-	-	-	-	$^{\Psi}$2%	4%	$^{\#}$10%
Regional NWP									
WMO	5	-	250	-	-	-	10	-	50
EUMETSAT	1	10	50	2	-	5	10	20	50
NWP	-	-	-	-	-	-	$^{\Psi}$2%	4%	$^{\#}$10%

$^{\Psi}$ *Values suffixed with % are stated in percentage volumetric soil moisture, not g/kg.*

$^{\#}$ *Value is set to 10% as "given that no soil moisture information exists to date it is possible that even less accurate products (<4%) could prove useful"(section 4.4)*

Values for accuracy stated in g/kg cannot be directly compared with values given in percentage volumetric soil moisture unless the bulk soil density is considered. Bulk soil density varies depending upon the soil type being considered but is generally within the range of 1100 to 1600 kg m^{-3}. From (7) in Annex 1 an RMS accuracy of 10 g/kg relates to percentage volumetric soil moisture value in the range of 1.1% to 1.6%.

Table 2

Summary for Observation requirements of soil moisture for frequency (dt)and timeliness (δ)

	dt (hours)			**δ (hours)**		
Source	Opt.	Br.	Thr.	Opt.	Br.	Thr.
Global NWP						
WMO	24	-	168	6	-	24
EUMETSAT	3	24	120	3	-	120
NWP	24	72	336	3	6	8
Regional NWP						
WMO	24	-	168	168	-	168
EUMETSAT	1	6	24	-	-	-
NWP	-	*	-	0.5	2	8

**Whenever regional product is available*

As can be seen in the above tables, and supported by a general observation from all meetings made in the scope of this study, there is a wide inconsistency in values attributed to user requirements.

User requirements can only clearly be stated once the NWP group has a good understanding and feel for the data, which, in turn, can only be achieved by a cycle of provision, use and assessment of the data.

Annex 1: Notes on conversion between percentage (g kg^{-1}) soil moisture and percentage volumetric soil moisture

The wetness, or relative water content, of the soil can be expressed in various ways: relative to the mass of solids, relative to the total mass, relative to the volume of the solids, relative to the total volume and relative to the volume of pores (Hillel, D., 1982). The conversion between the two most commonly used, Mass Wetness (gravimetric water content) and Volume Wetness (volumetric water content, or volume fraction of soil water) are presented.

Mass Wetness w (gravimetric water content, kg kg^{-1})

This is the mass of water M_w relative to the mass of dry soil particles M_s

$$w = \frac{M_w}{M_s} \tag{1}$$

Volume Wetness θ (volume fraction of water)

Water content in a soil can also be expressed as the volume fraction of water in bulk soil; volume of water V_w, relative to total volume V_t

$$\theta = \frac{V_w}{V_t} \tag{2}$$

In order to convert between gravimetric to volume water contents the dry bulk densities of soil, ρ_b, needs to be known. Bulk Density of soil is the mass of soil divided by the total, or bulk volume of the soil (kg m^{-3})

$$\rho_b = \frac{M_s}{V_t}$$

Re-arranged

$$V_t = \frac{M_s}{\rho_b} \tag{3}$$

Average dry bulk densities ρ_b found in surface soils are (Koorevaar, P., 1983);

- 1600 kg m^{-3} for sandy soils
- 1100 kg m^{-3} for clay soils
- 1100 kg m^{-3} for loamy soils
- 250 kg m^{-3} for peat soils

The density of water ρ_w naturally varies with temperature, but is generally approximated to be 1000.0kg m^{-3} (1000.0 kg m^{-3} at 4°C)

$\rho_w = 1000$ kg m^{-3}

The mass of water, M_w is simply calculated

$$M_w = \rho_w \cdot V_w \tag{4}$$

(3) and (4) in (2)

$$\theta = \rho_b \frac{V_w}{M_s} = \frac{\rho_b}{\rho_w} \frac{M_w}{M_s} \tag{5}$$

(1) in (5)

$$\theta = \frac{\rho_b}{\rho_w} w \tag{6}$$

In (6) volumetric soil moisture is now expressed in terms of mass wetness and bulk soil density.

Example: Considering a value of mass wetness of 10g kg^{-1} (10.10^{-3} kg kg^{-1}), knowing ρ_w, and leaving aside peat soils the volumetric soil moisture can be approximated from (6)

$\theta \approx [1.1..to.1.6] \cdot w$ (kg kg^{-1})

θ (10 g kg^{-1}) ≈ [1.1 to 1.6] 10.10^{-3} (kg kg^{-1})
θ (10 g kg^{-1}) ≈ 0.011 to 0.016 (m^3 m^{-3})

Then

θ (10 g kg^{-1}) ≈1.1% to 1.6% (7)

References:

Koorevaar,P., Menelik , G., Dirksen, C. (1983), *Elements of Soil Physics*, Developments in Soil Science, 13, ELSEVIER

Hillel, D., (1982), *Introduction to Soil Physics*, Academic Press.