Bridging the gap between basic soil data and required soil physical parameters for the COSMO soil model TERRA

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and G. Smiatek (IMK-IFU)

Motivation

Global soil properties

- large variability in space
- small temporal variability
- very different physical and chemical properties

Challenge for soil models to capture the main features of the soil at every gridpoint

IFS hydraulic properties

Diffusivity m²/s **Conductivity m/s**

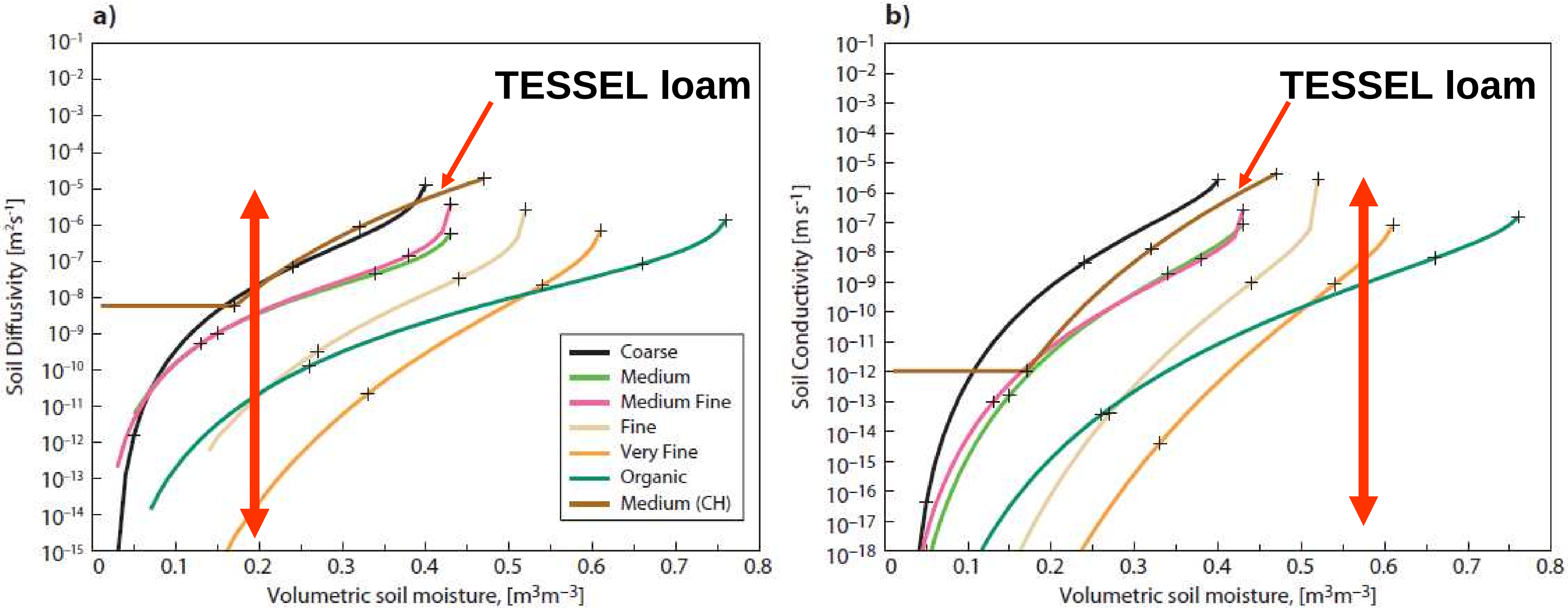

Figure 7.3 *Hydraulic properties of TESSEL and HTESSEL: (a) Diffusivity and (b) conductivity. The (+) symbols on the curves highlight (from high to low values) saturation, field capacity permanent wilting point.*

IFS documentation

Example - IFS

ECMWF Newsletter No. 127 – Spring 2011

METEOROLOGY

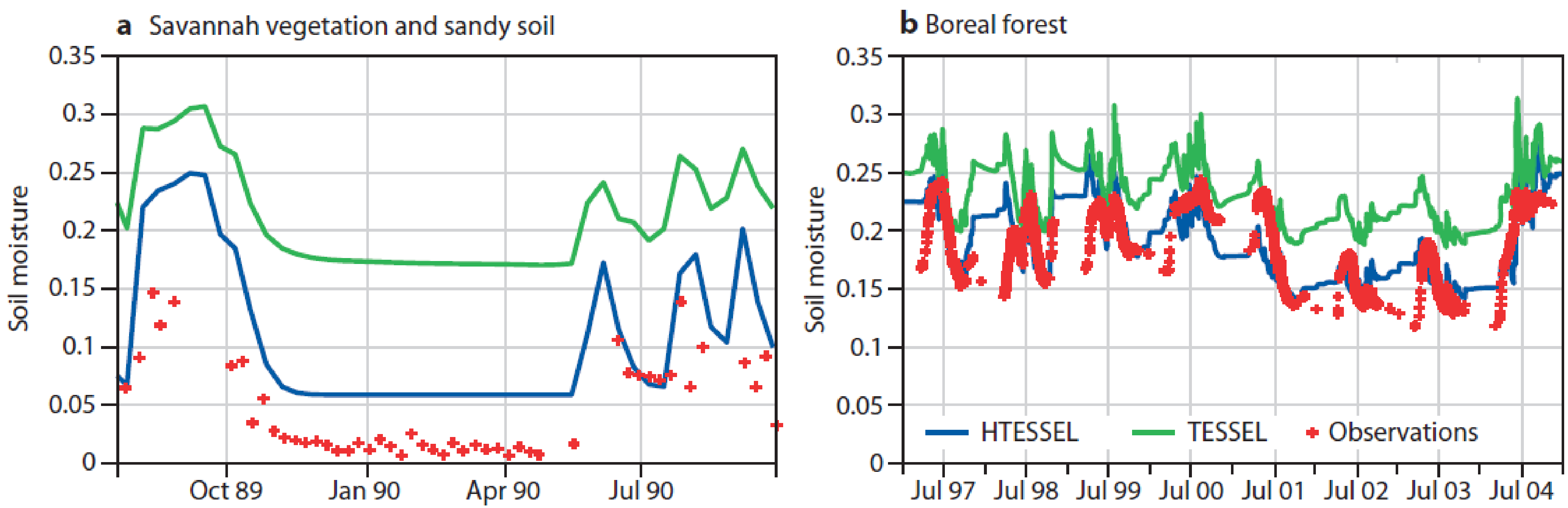

Figure 2 Evolution of soil moisture in TESSEL and HTESSEL in terms of volumetric content (m^3/m^3) compared to observations for two contrasting sites used for field experiments: (a) savannah vegetation and sandy soil (SEBEX, Sahel) and (b) boreal forest (BERMS, Canada).

GIANPAOLO BALSAMO, SOUHAIL BOUSSETTA,
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PEDRO VITERBO, BART VAN DEN HURK

Motivation

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METEOROLOGY

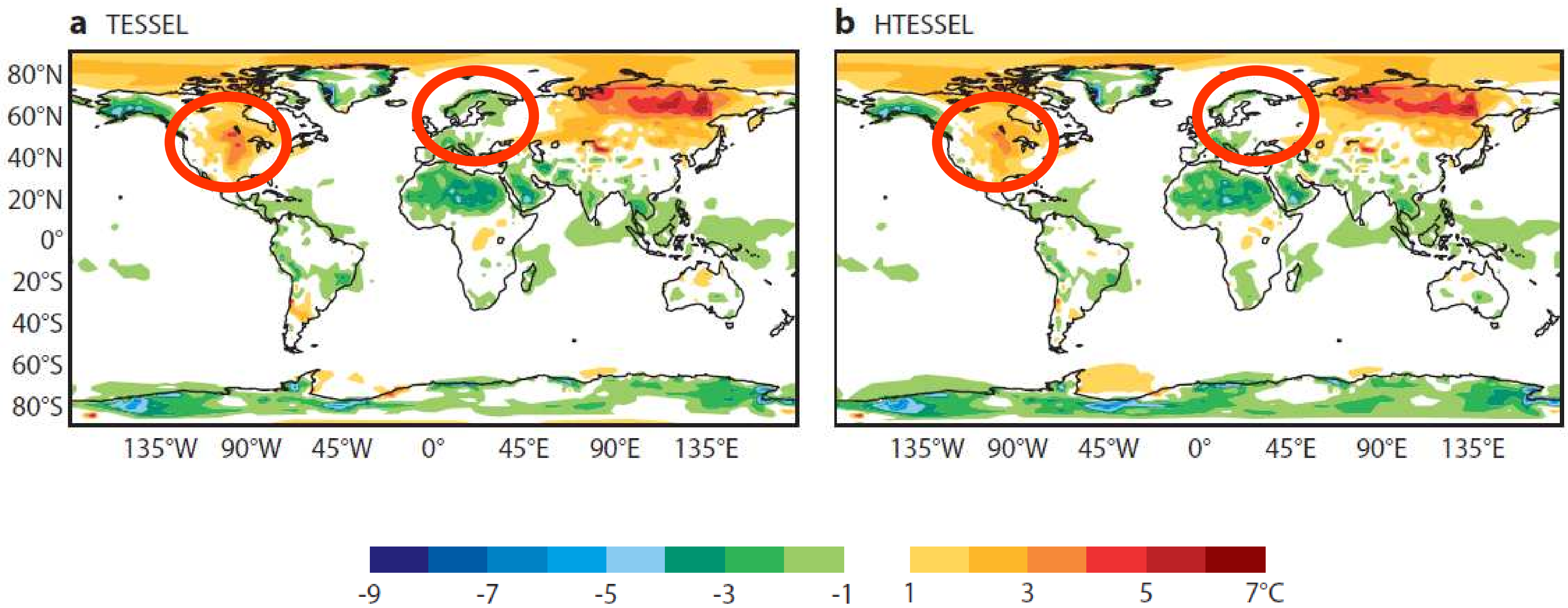

Figure 7 Mean annual 2-metre temperature errors in a long integration compared to ERA-Interim for (a) TESSEL (b) HTESSEL

1 yr, T159 ~125 km, daily specified SST

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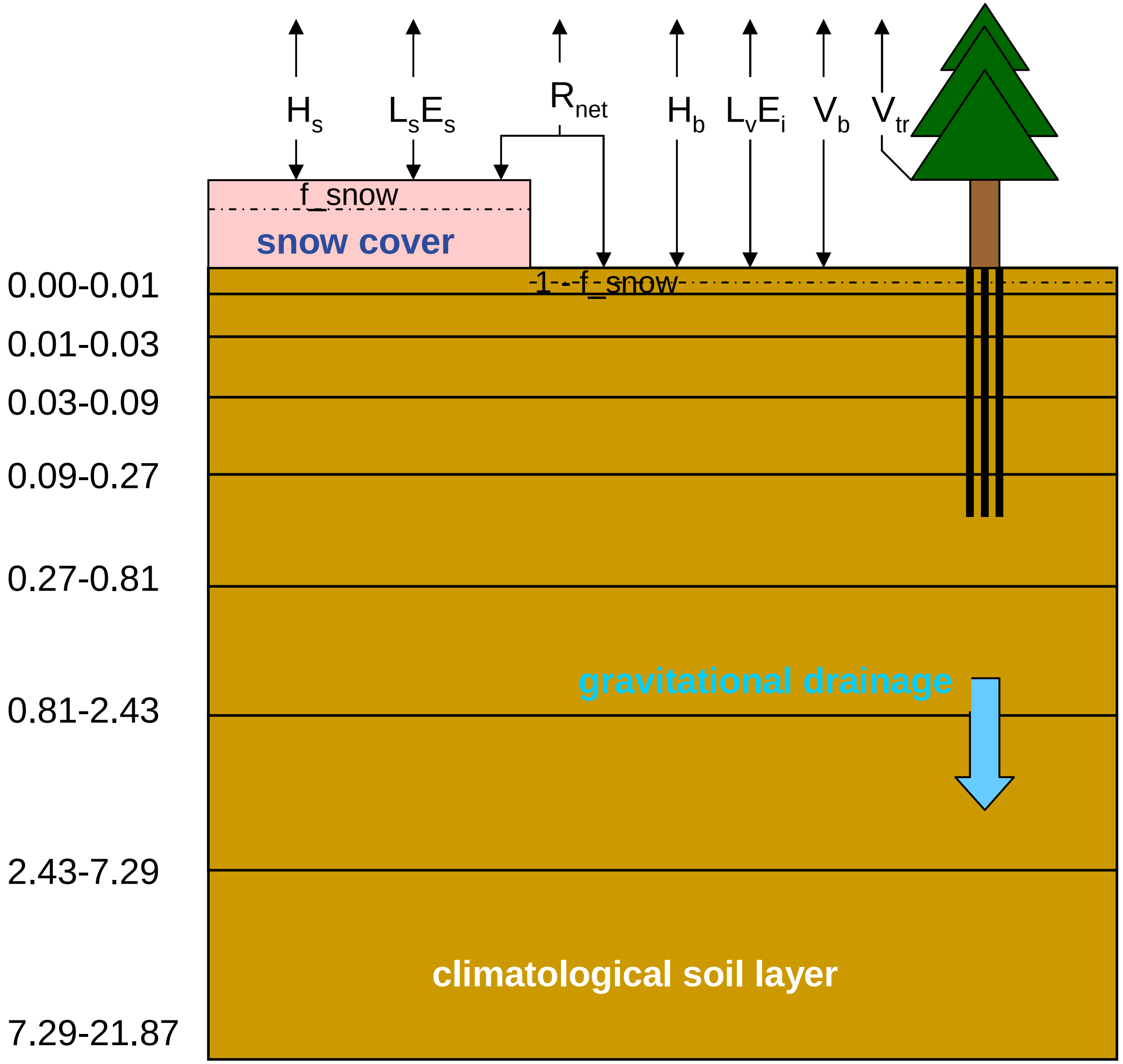
Soil vegetation processes in TERRA



External parameter – model configuration

Parameter / Model	Orography	Land-use Vegetation	Soil
COSMO-DE	● (green)	● (green)	● (red)
COSMO-EU	● (green)	● (green)	● (red)
GME/ICON	● (green)	● (green)	● (green)

● (green) resolution of raw data set higher than target model grid

● (red) resolution of raw data set lower than target model grid

Soil data sets

FAO Digital Soil Map of the World (DSMW): Resolution 0.083°

Options:

- **Textures, e.g. coarse, medium, fine – 9 TERRA soiltypes**
- **135 soil units – Pedotransfer functions for physical soil parameters**

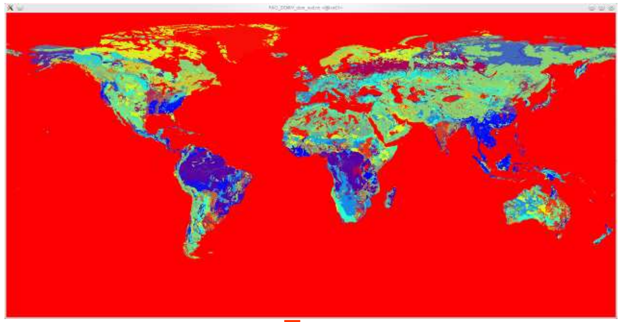
Harmonized World Soil Database (HWSD): Resolution 0.0083°

Options:

- **Textures, e.g. coarse, medium, fine – 9 TERRA soiltypes**
- **16102 soil units – Pedotransfer functions for physical soil parameters**

Retrieval of TERRA soil properties Option I

Soil data set



Soil textures

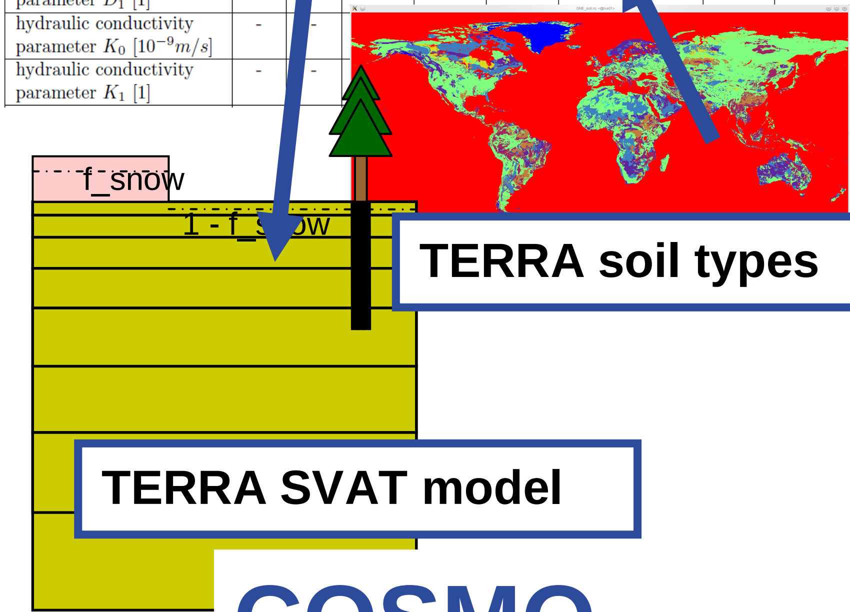
TERRA soil types

EXTPAR

int_2_lm

soil type	1 ice	2 rock	3 sand	4 sandy loam	5 loam	6 loamy clay	7 clay	8 peat
volume of voids w_{PV} [1]	-	-	0.364	0.445	0.455	0.475	0.507	0 .863
field capacity w_{FC} [1]								
permanent wilting point w_{PWP} [1]								
air dryness point w_{ADP} [1]								
hydraulic diffusivity parameter D_0 $[10^{-9} m^2/s]$	-	-	18400	3460	3570	1180	442	106
hydraulic diffusivity parameter D_1 [1]	-	-	-8.45	-9.47	-7.44	-7.76	-6.74	-5.97
hydraulic conductivity parameter K_0 $[10^{-9} m/s]$	-	-						
hydraulic conductivity parameter K_1 [1]	-	-						

TERRA look-up table physical properties



TERRA soil types

TERRA SVAT model

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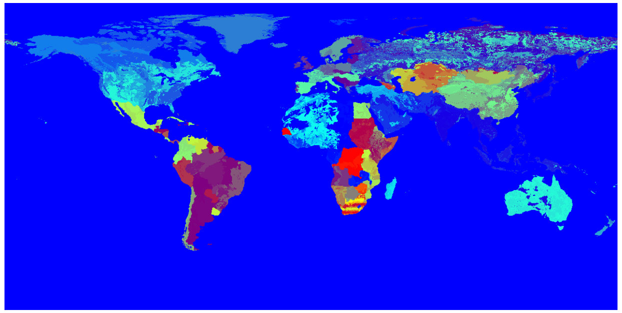
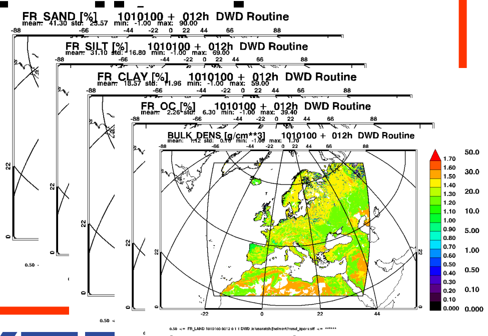
Retrieval of TERRA soil properties Option II

Soil data set

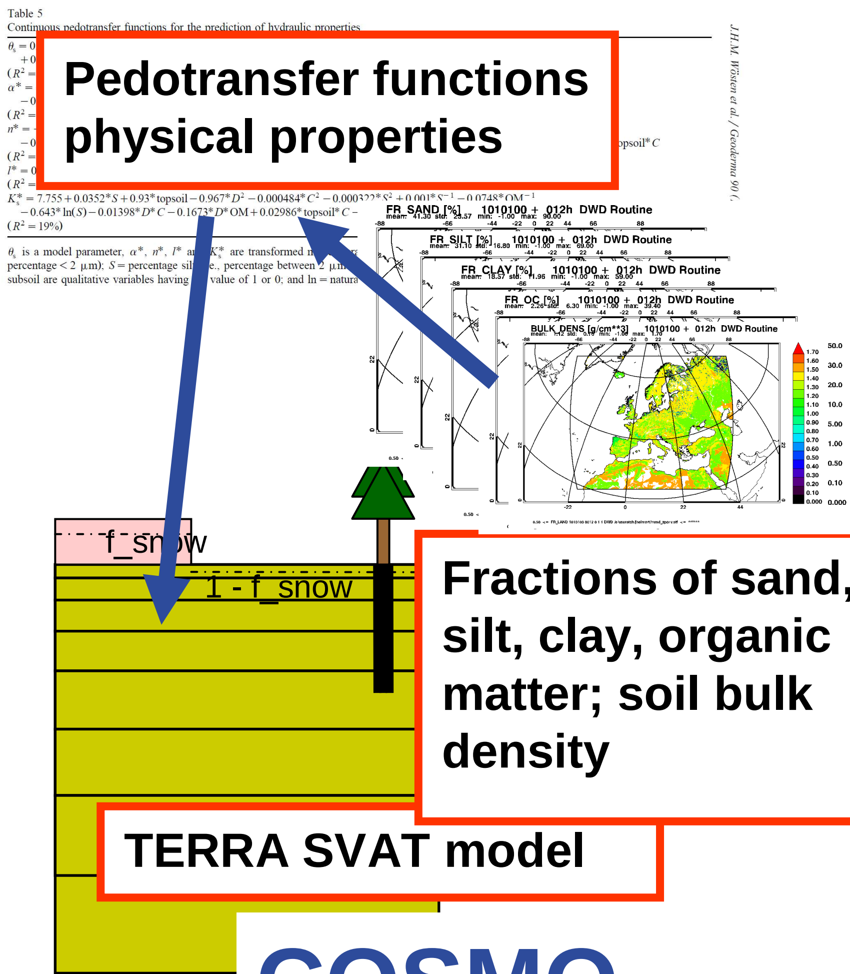


Fractions of sand, silt, clay, organic matter; soil bulk density



EXTPAR

int_2_lm

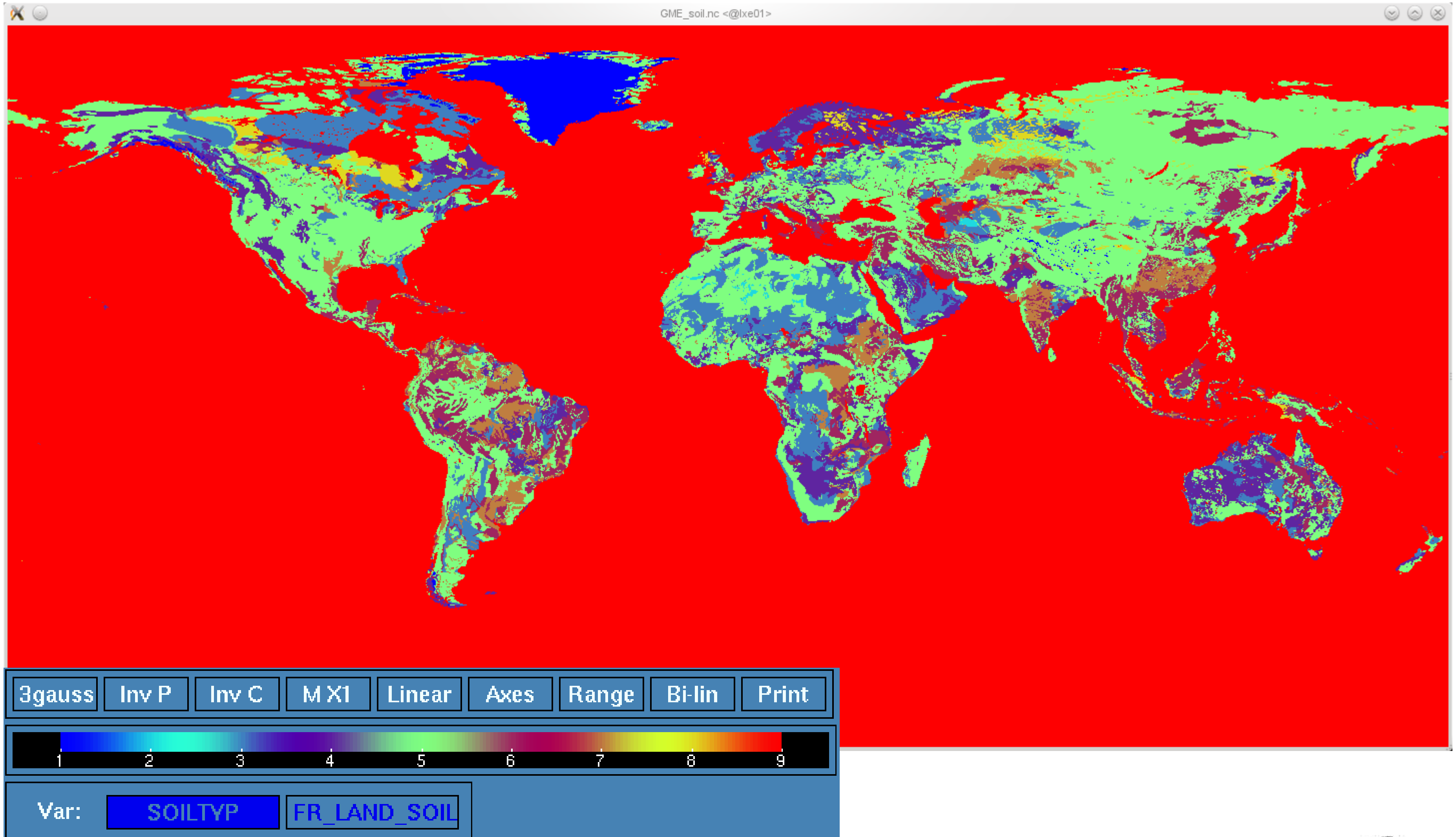


Fractions of sand, silt, clay, organic matter; soil bulk density

TERRA SVAT model

COSMO

FAO-DSMW – Option I



Soil properties – Option I

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

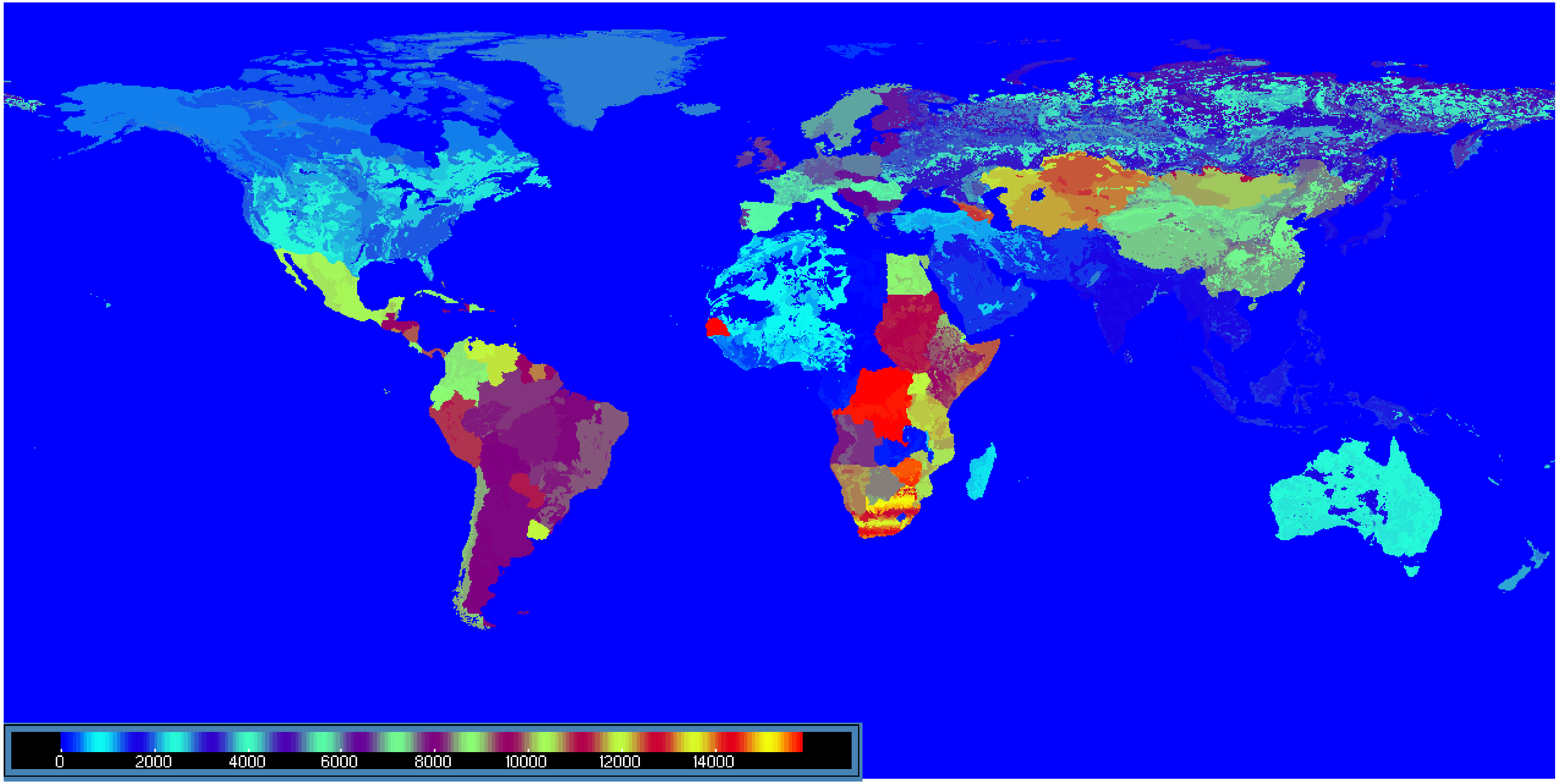
soil type	1 ice	2 rock	3 sand	4 sandy loam	5 loam	6 loamy clay	7 clay	8 peat
volume of voids w_{PV} [1]	-	-	0.364	0.445	0.455	0.475	0.507	0 .863
field capacity w_{FC} [1]	-	-	0.196	0.260	0.340	0.370	0.463	0.763
permanent wilting point w_{PWP} [1]	-	-	0.042	0.100	0.110	0.185	0.257	0.265
air dryness point w_{ADP} [1]	-	-	0.012	0.030	0.035	0.060	0.065	0.098
hydraulic diffusivity parameter D_0 $[10^{-9} m^2/s]$	-	-	18400	3460	3570	1180	442	106
hydraulic diffusivity parameter D_1 [1]	-	-	-8.45	-9.47	-7.44	-7.76	-6.74	-5.97
hydraulic conductivity parameter K_0 $[10^{-9} m/s]$	-	-	47900	9430	5310	764	17	58
hydraulic conductivity parameter K_1 [1]	-	-	-19.27	-20.86	-19.66	-18.52	-16.32	-16.48

Soil properties – Option I

COSMO parameterisations based on soil type:

- Soil hydraulic transport – Rijtema scheme
- Soil heat transport
- Bare soil evaporation (BATS - Dickinson)
- Bare soil albedo

HWSD: Soil Units – Option II



HWSD: Soil Units – Option II

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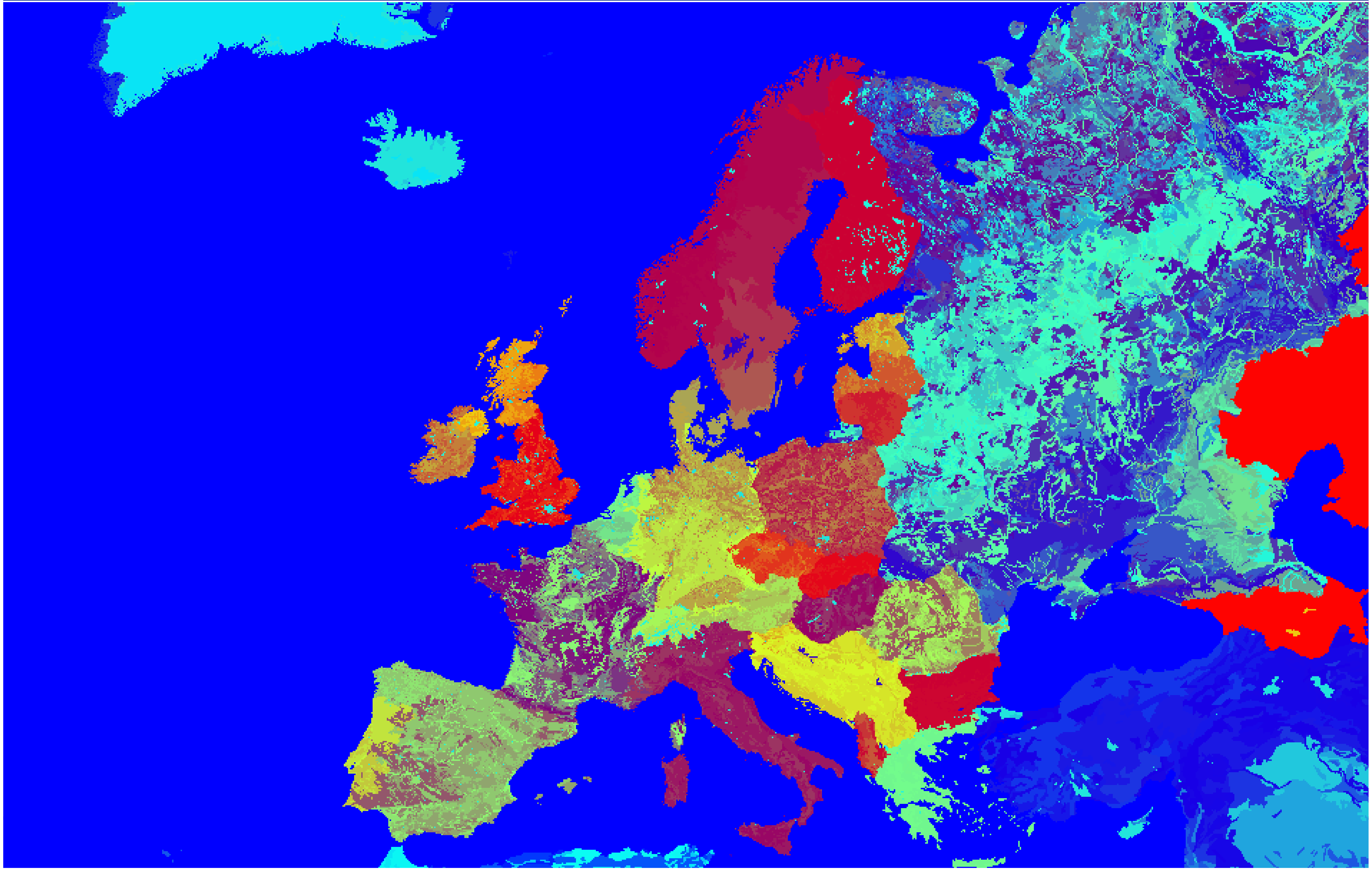


Soil properties – Option II

COSMO parameterisations based on fractions of soil components :

- Soil water freezing
- Soil hydraulic transport – van Genuchten scheme
- Soil heat transport – Peters-Lidard scheme
- Bare soil evaporation - Noilhan and Platon
- Bare soil albedo – MODIS background albedo

Soil properties – Option II

Pedotransfer functions

- based on soil bulk density and contents of clay, silt, organic matter
- first, consider topsoil dataset (0-30cm)

Table 5
Continuous pedotransfer functions for the prediction of hydraulic properties

$$\theta_s = 0.7919 + 0.001691{*}C - 0.29619{*}D - 0.000001491{*}S^2 + 0.0000821{*}\mathrm{OM}^2 + 0.02427{*}C^{-1} + 0.01113{*}S^{-1} + 0.01472{*}\ln(S) - 0.0000733{*}\mathrm{OM}{*}C - 0.000619{*}D{*}C - 0.001183{*}D{*}\mathrm{OM} - 0.0001664{*}\mathrm{topsoil}{*}S$$

$(R^2 = 76\%)$

$$\alpha^* = -14.96 + 0.03135{*}C + 0.0351{*}S + 0.646{*}\mathrm{OM} + 15.29{*}D - 0.192{*}\mathrm{topsoil} - 4.671{*}D^2 - 0.000781{*}C^2 - 0.00687{*}\mathrm{OM}^2 + 0.0449{*}\mathrm{OM}^{-1} + 0.0663{*}\ln(S) + 0.1482{*}\ln(\mathrm{OM}) - 0.04546{*}D{*}S - 0.4852{*}D{*}\mathrm{OM} + 0.00673{*}\mathrm{topsoil}{*}C$$

$(R^2 = 20\%)$

$$n^* = -25.23 - 0.02195{*}C + 0.0074{*}S - 0.1940{*}\mathrm{OM} + 45.5{*}D - 7.24{*}D^2 + 0.0003658{*}C^2 + 0.002885{*}\mathrm{OM}^2 - 12.81{*}D^{-1} - 0.1524{*}S^{-1} - 0.01958{*}\mathrm{OM}^{-1} - 0.2876{*}\ln(S) - 0.0709{*}\ln(\mathrm{OM}) - 44.6{*}\ln(D) - 0.02264{*}D{*}C + 0.0896{*}D{*}\mathrm{OM} + 0.00718{*}\mathrm{topsoil}{*}C$$

$(R^2 = 54\%)$

$$l^* = 0.0202 + 0.0006193{*}C^2 - 0.001136{*}\mathrm{OM}^2 - 0.2316{*}\ln(\mathrm{OM}) - 0.03544{*}D{*}C + 0.00283{*}D{*}S + 0.0488{*}D{*}\mathrm{OM}$$

$(R^2 = 12\%)$

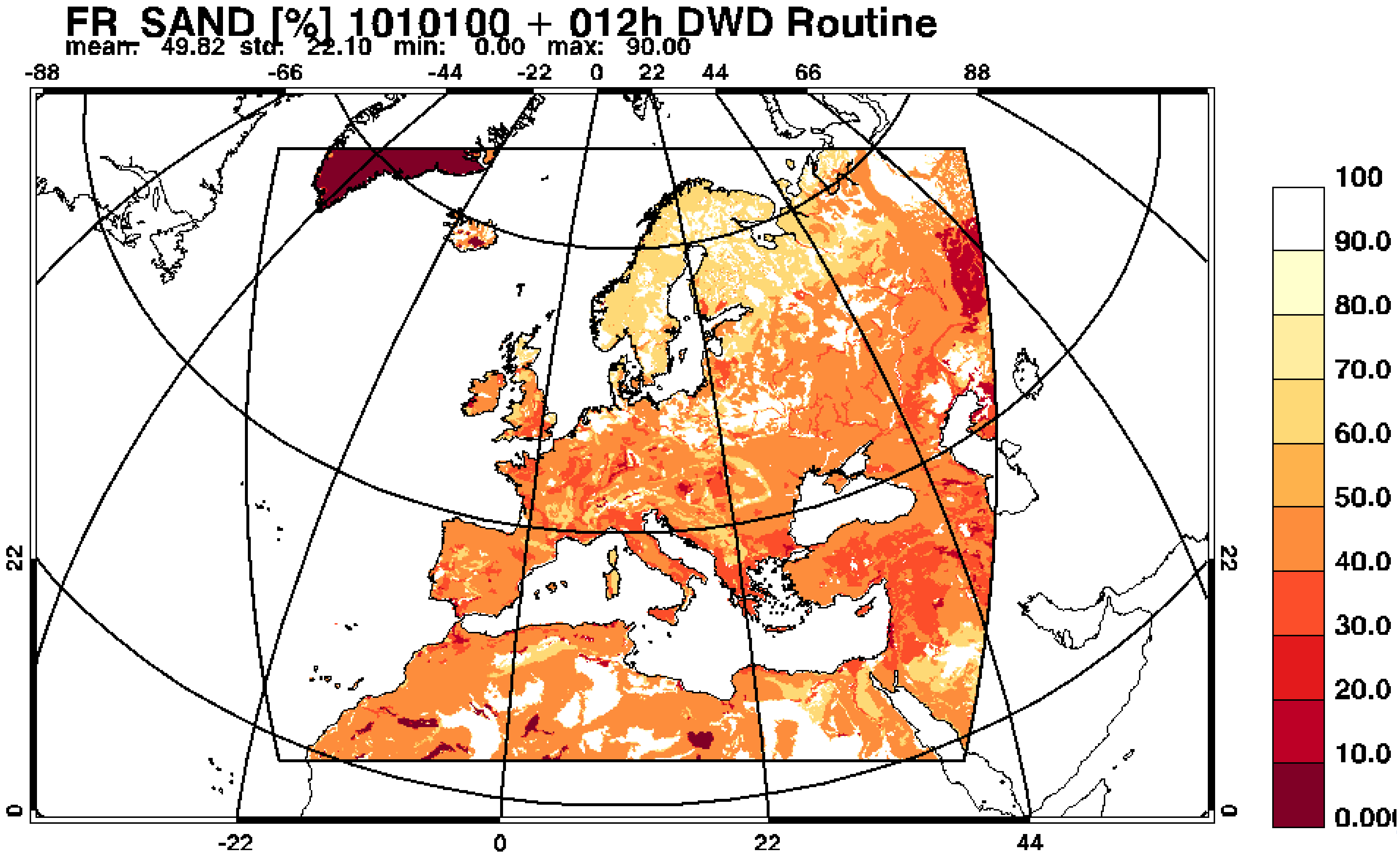
$$K_s^* = 7.755 + 0.0352{*}S + 0.93{*}\mathrm{topsoil} - 0.967{*}D^2 - 0.000484{*}C^2 - 0.000322{*}S^2 + 0.001{*}S^{-1} - 0.0748{*}\mathrm{OM}^{-1} - 0.643{*}\ln(S) - 0.01398{*}D{*}C - 0.1673{*}D{*}\mathrm{OM} + 0.02986{*}\mathrm{topsoil}{*}C - 0.03305{*}\mathrm{topsoil}{*}S$$

$(R^2 = 19\%)$

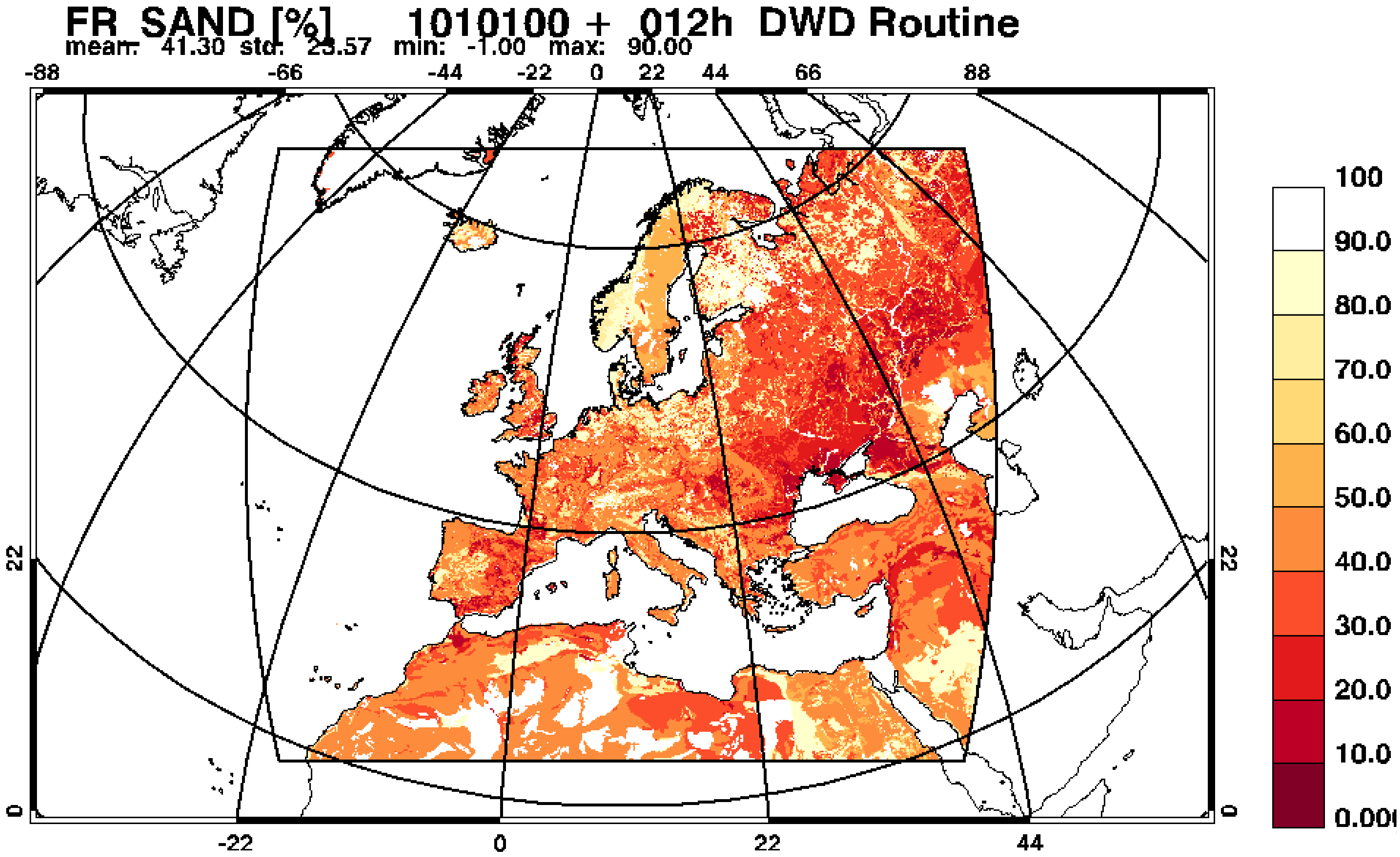
θ_s is a model parameter, α^*, n^*, l^* and K_s^* are transformed model parameters in the Mualem-van Genuchten equations; C = percentage clay (i.e., percentage < 2 μm); S = percentage silt (i.e., percentage between 2 μm and 50 μm); OM = percentage organic matter; D = bulk density; topsoil and subsoil are qualitative variables having the value of 1 or 0; and ln = natural logarithm.

J.H.M. Wösten et al. / Geoderma 90 (1999) 169–185

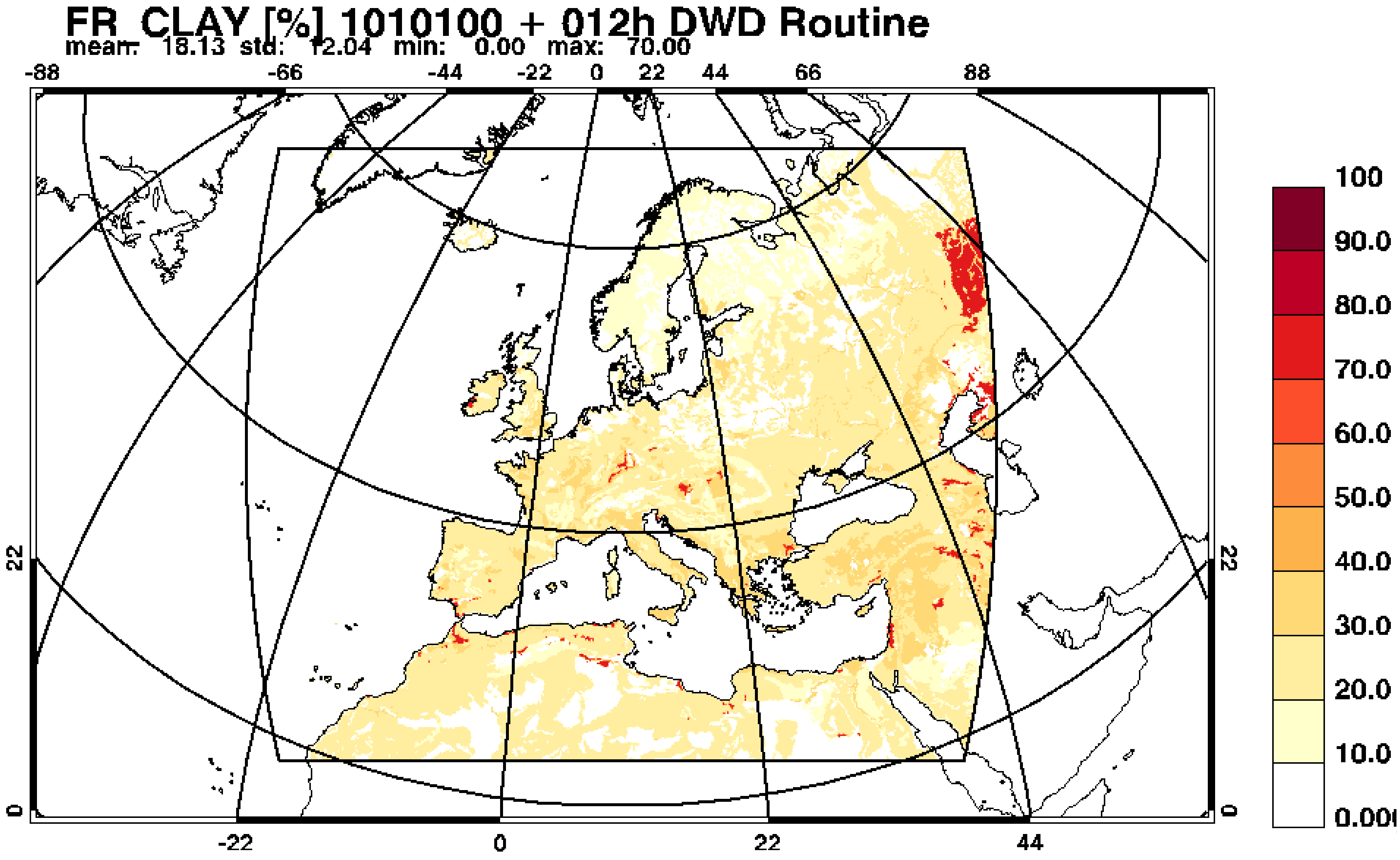
FAO – sand fraction



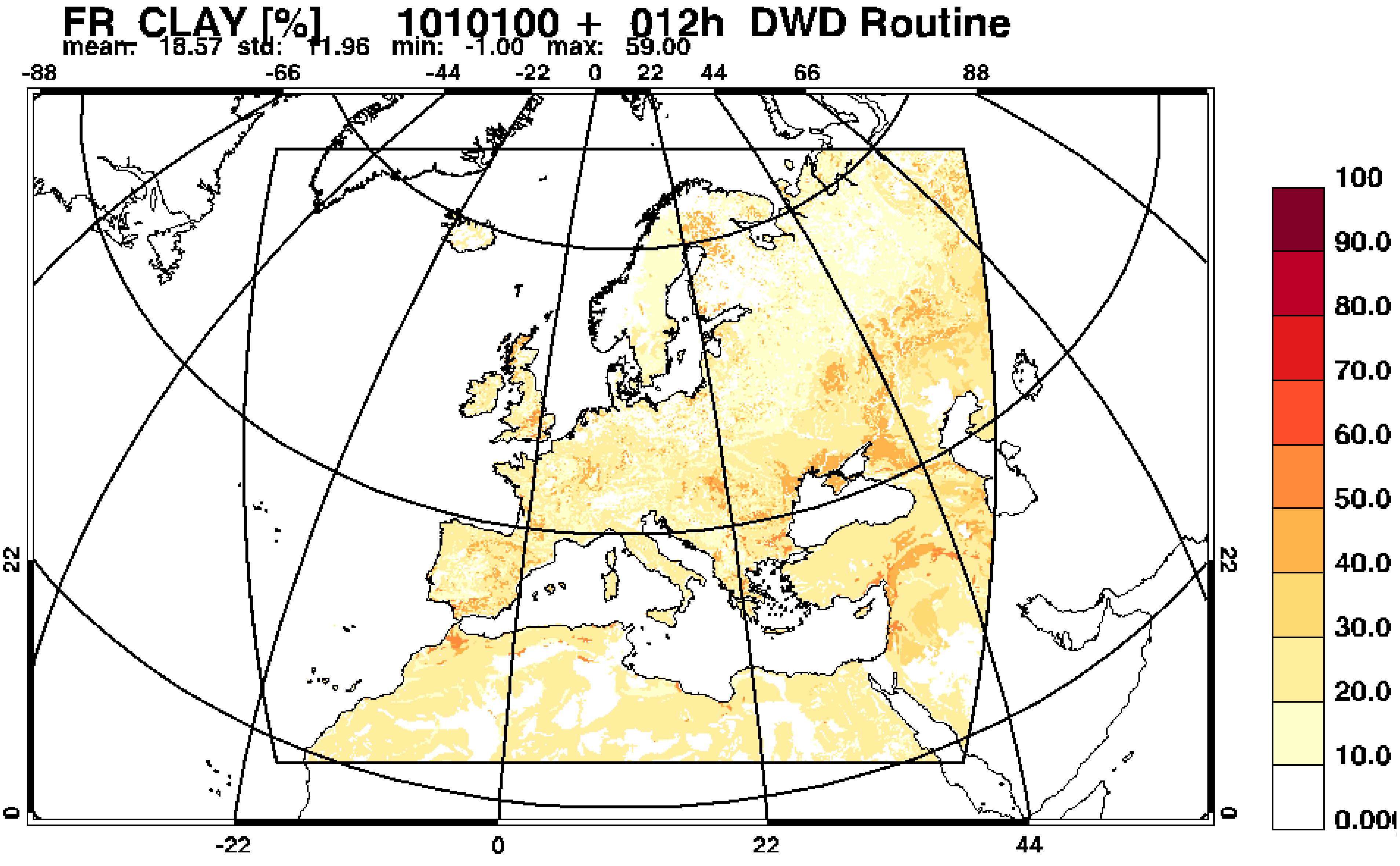
HWSD – sand fraction



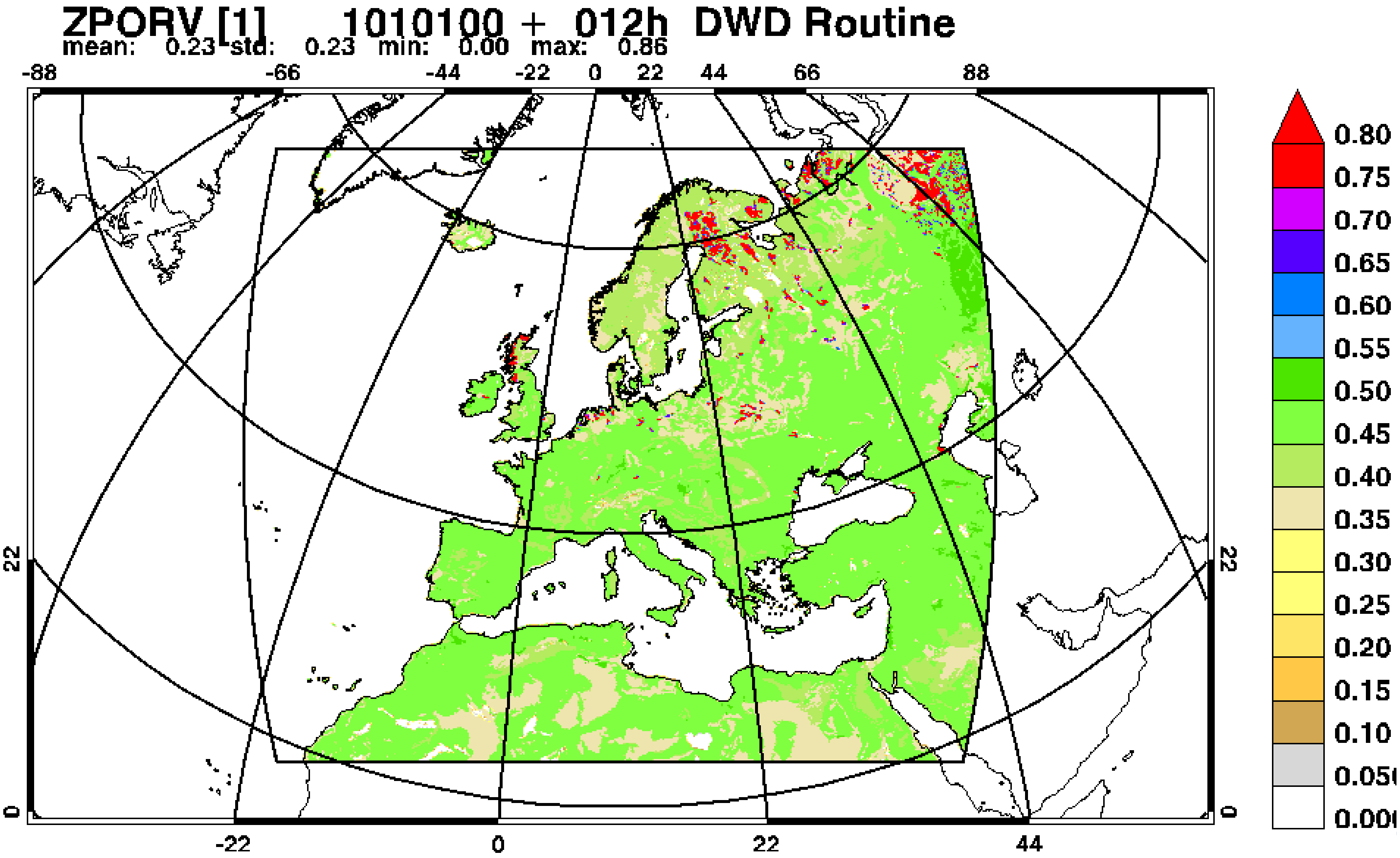
FAO – clay fraction



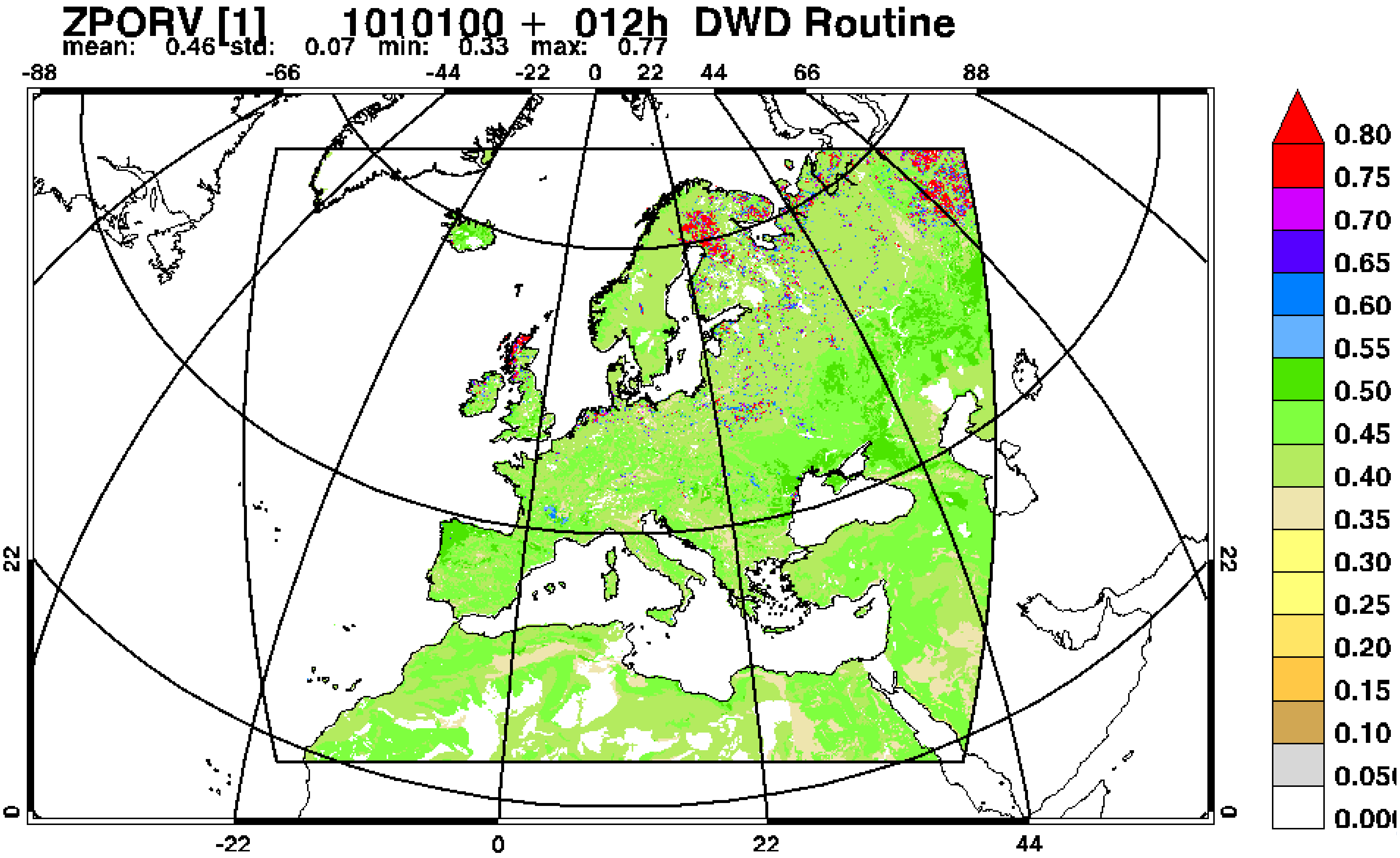
HWSD – clay fraction



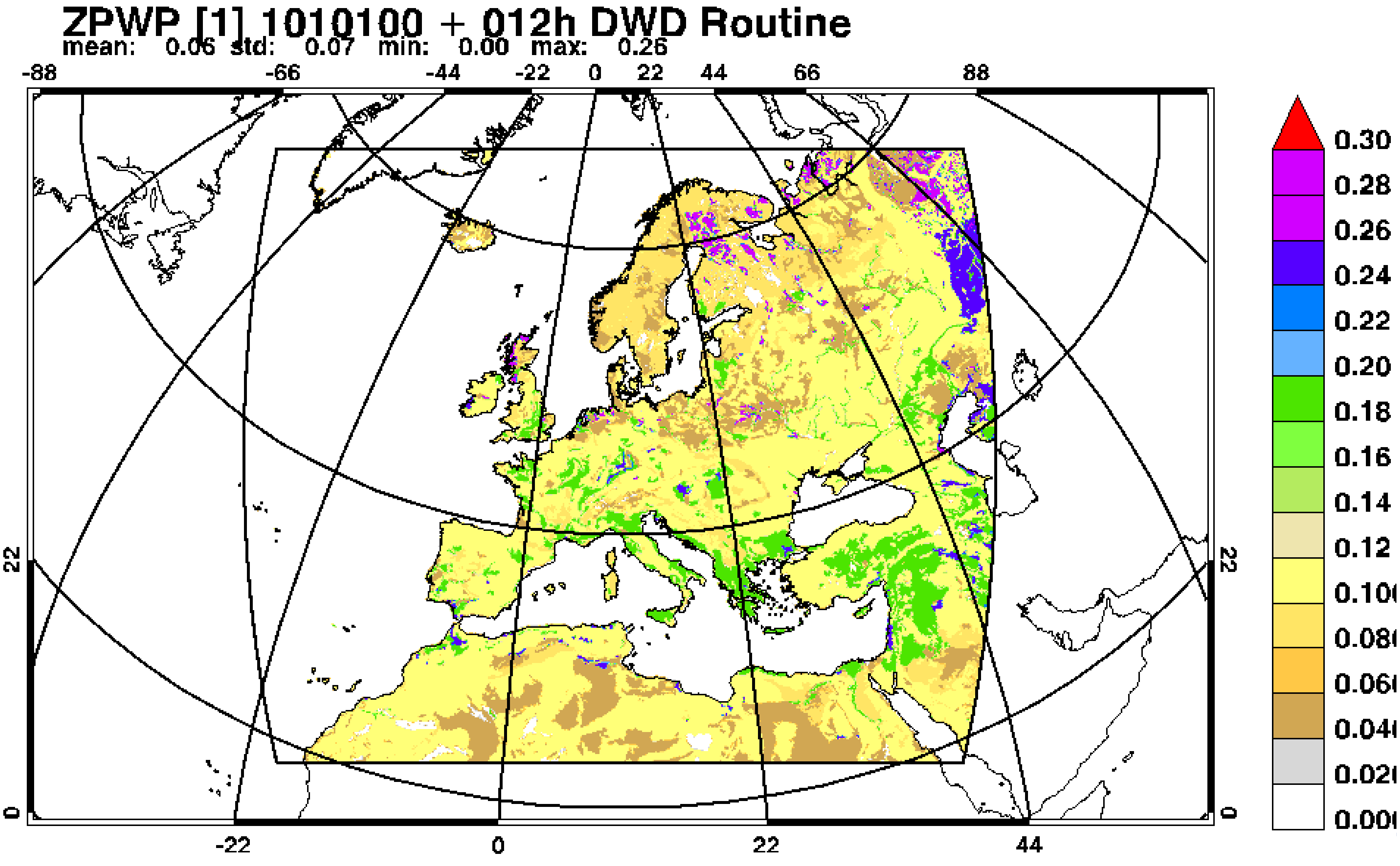
FAO – pore volume



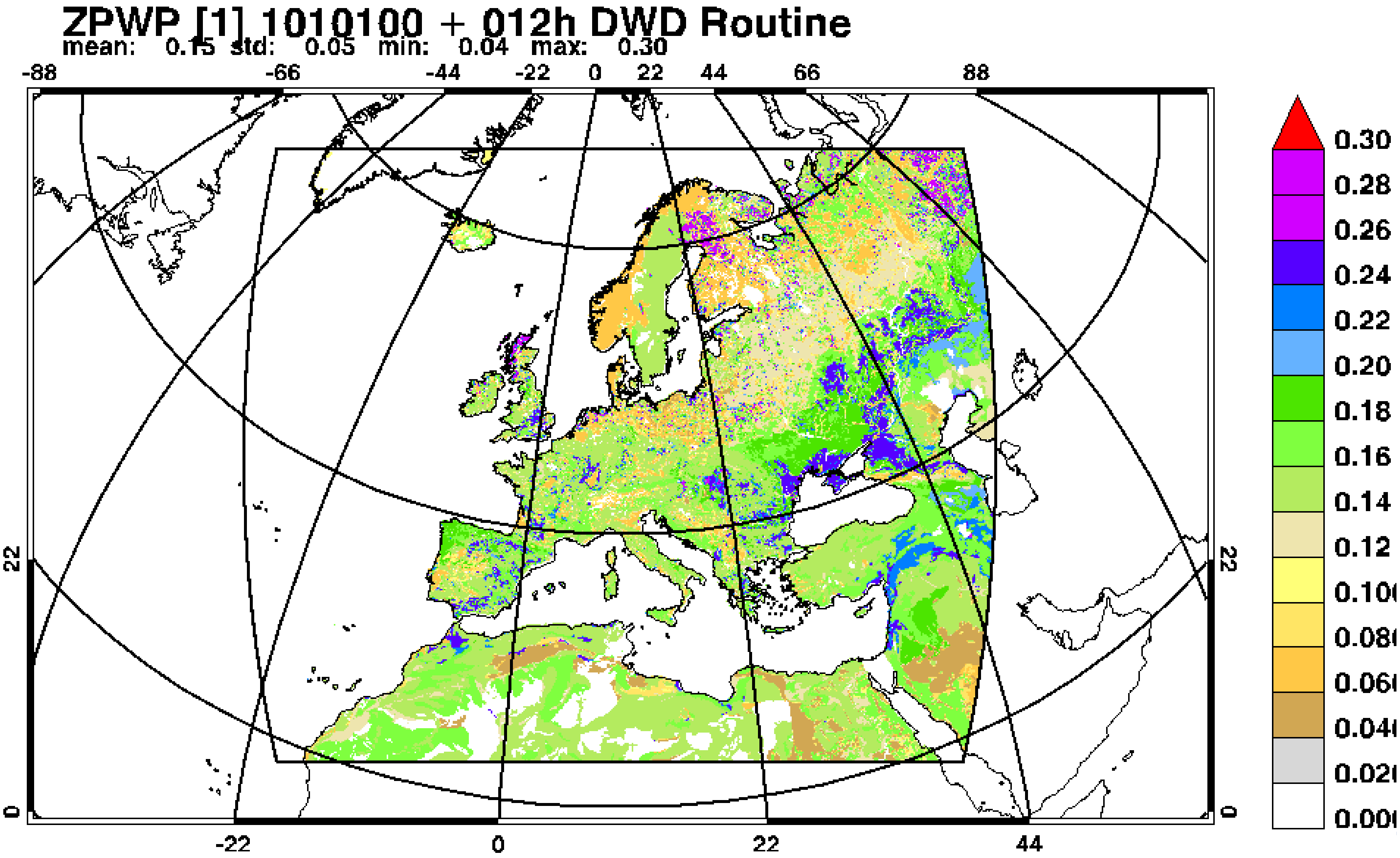
HWSD – pore volume



FAO – plant wilting point



HWSD – plant wilting point



FAO – hydraul. conductivity

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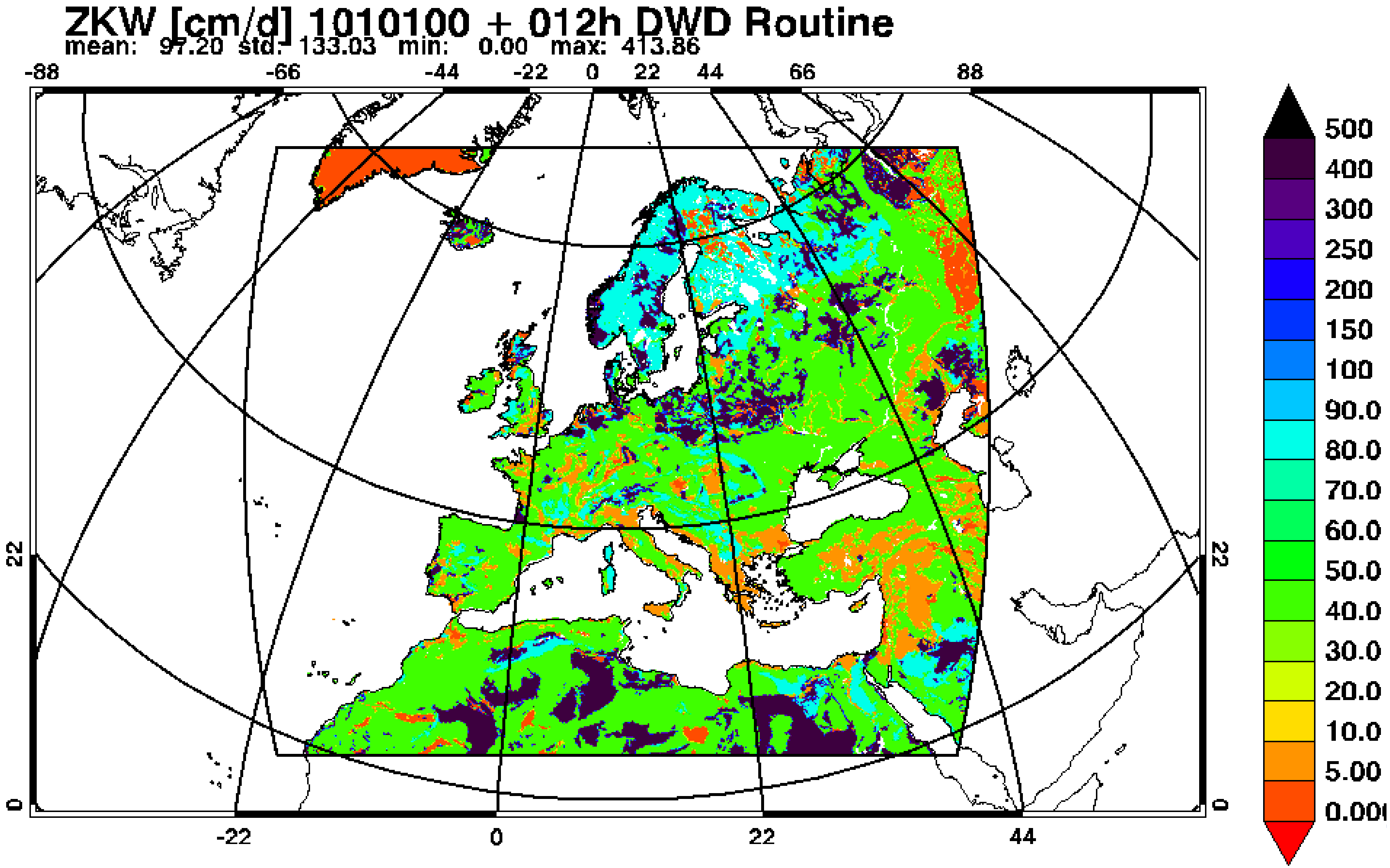
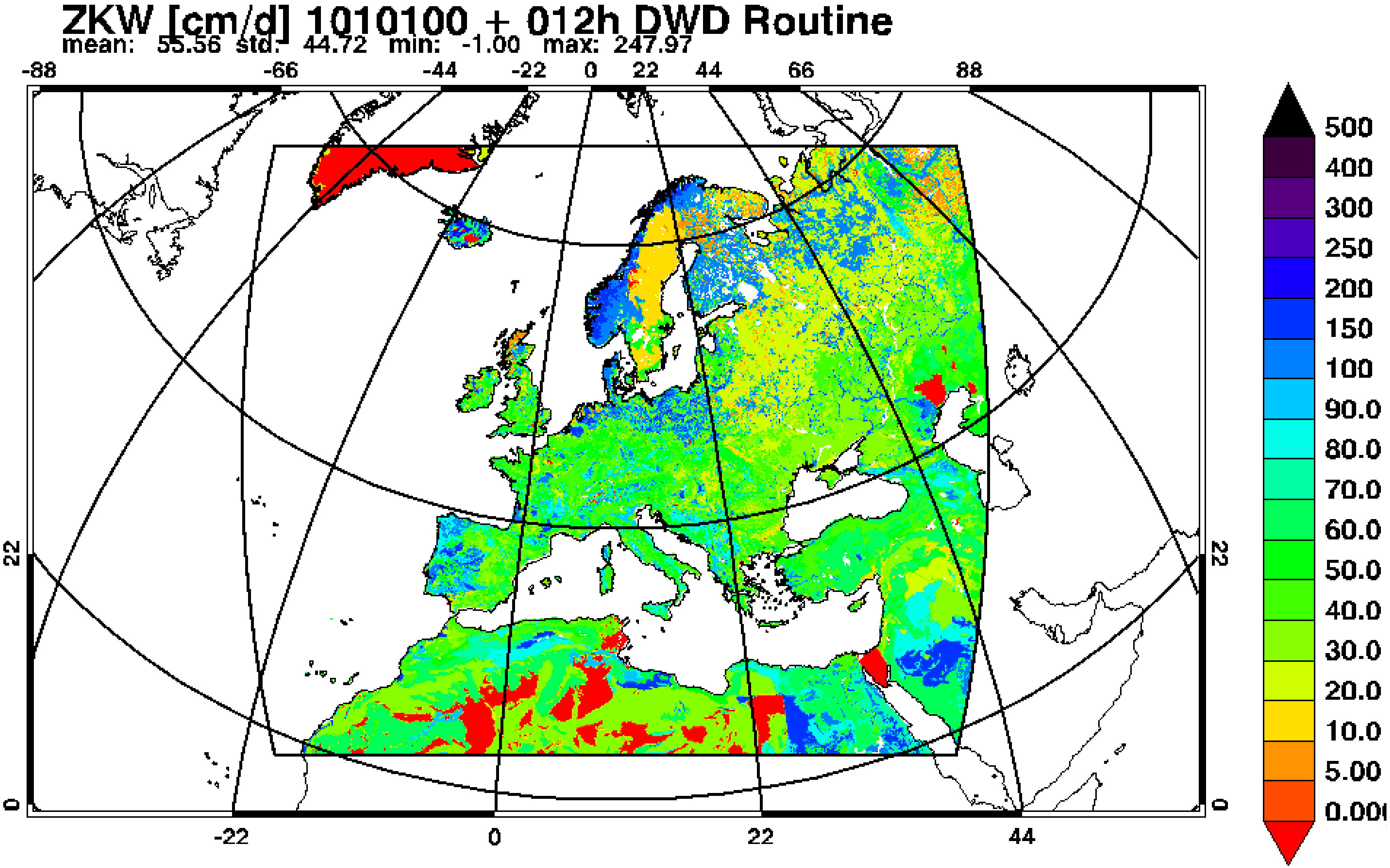
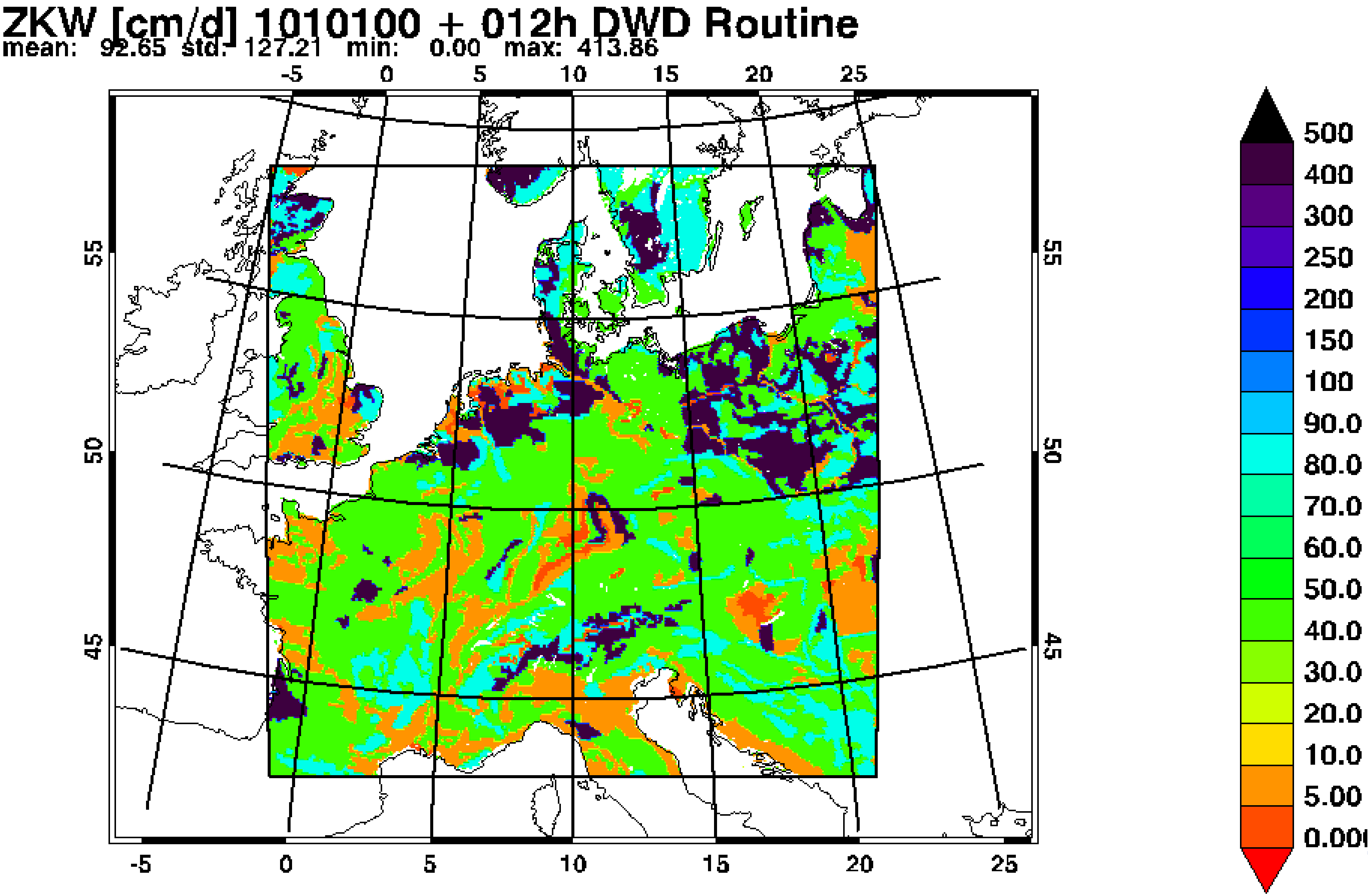


HWSD – hydraul. conductivity



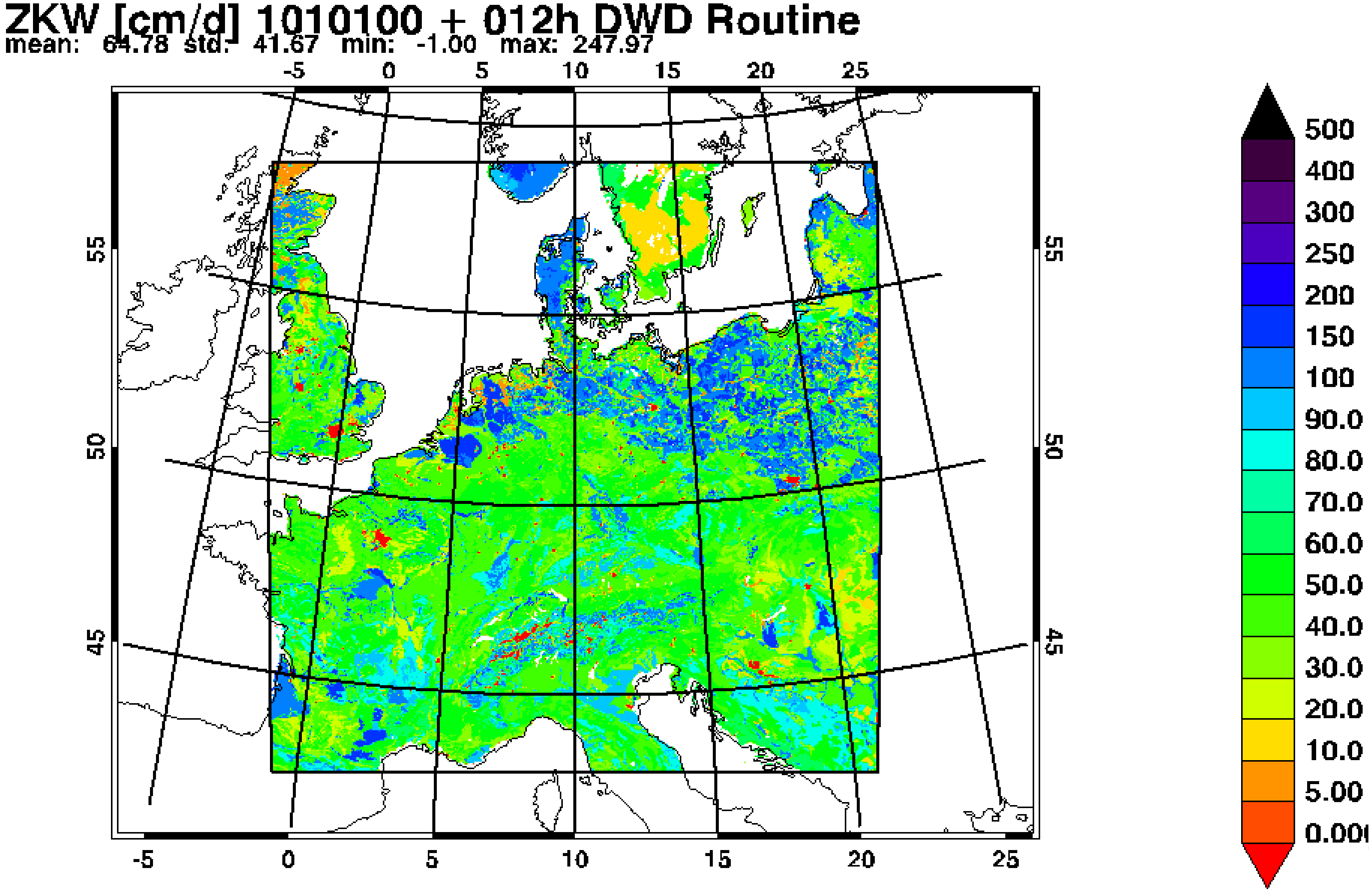
FAO – hydraul. conductivity

model resolution: 2.8 km



HWSD – hydraul. conductivity

model resolution: 2.8 km



Conclusions

Benefits of the new approach for soil data in TERRA

- increase horizontal heterogeneity of soils in the model domain

- independend of underlying soil data base – allows use of other data sets

- reliable way to retrieve physical soil parameters

- comparable to other global NWP models (IFS, UM)

- potential to improve model forecasts in some regions

External parameter – model configuration

Parameter / Model	Orography	Land-use Vegetation	Soil
COSMO-DE	●	●	●
COSMO-EU	●	●	●
GME/ICON	●	●	●

- ● (green) resolution of raw data set higher than target model grid
- ● (red) resolution of raw data set lower than target model grid

Last, but not least ...

New namelist parameter

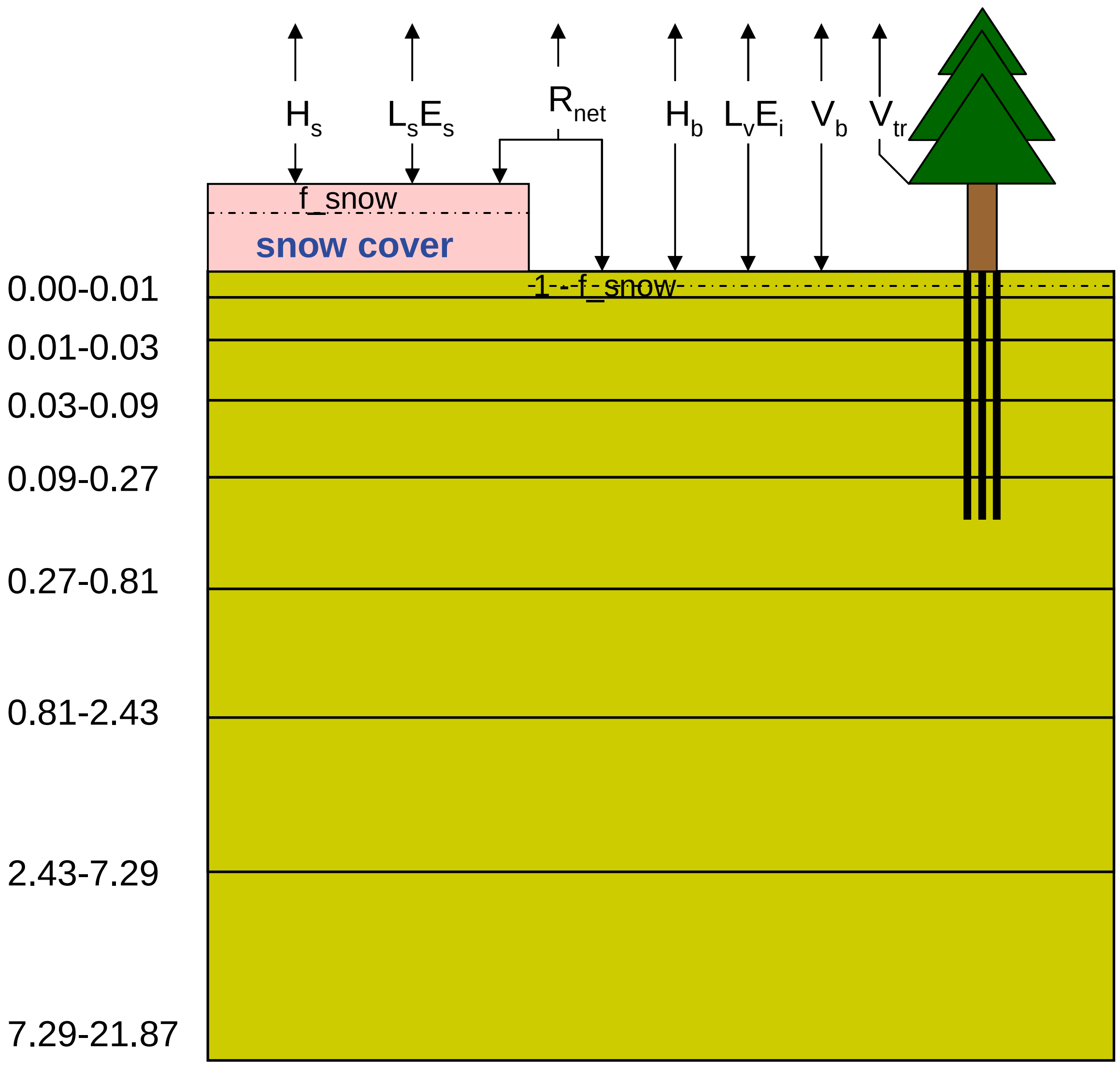
`itype_soil = 1.OR.2`

`itype_soil = 2` replacement for

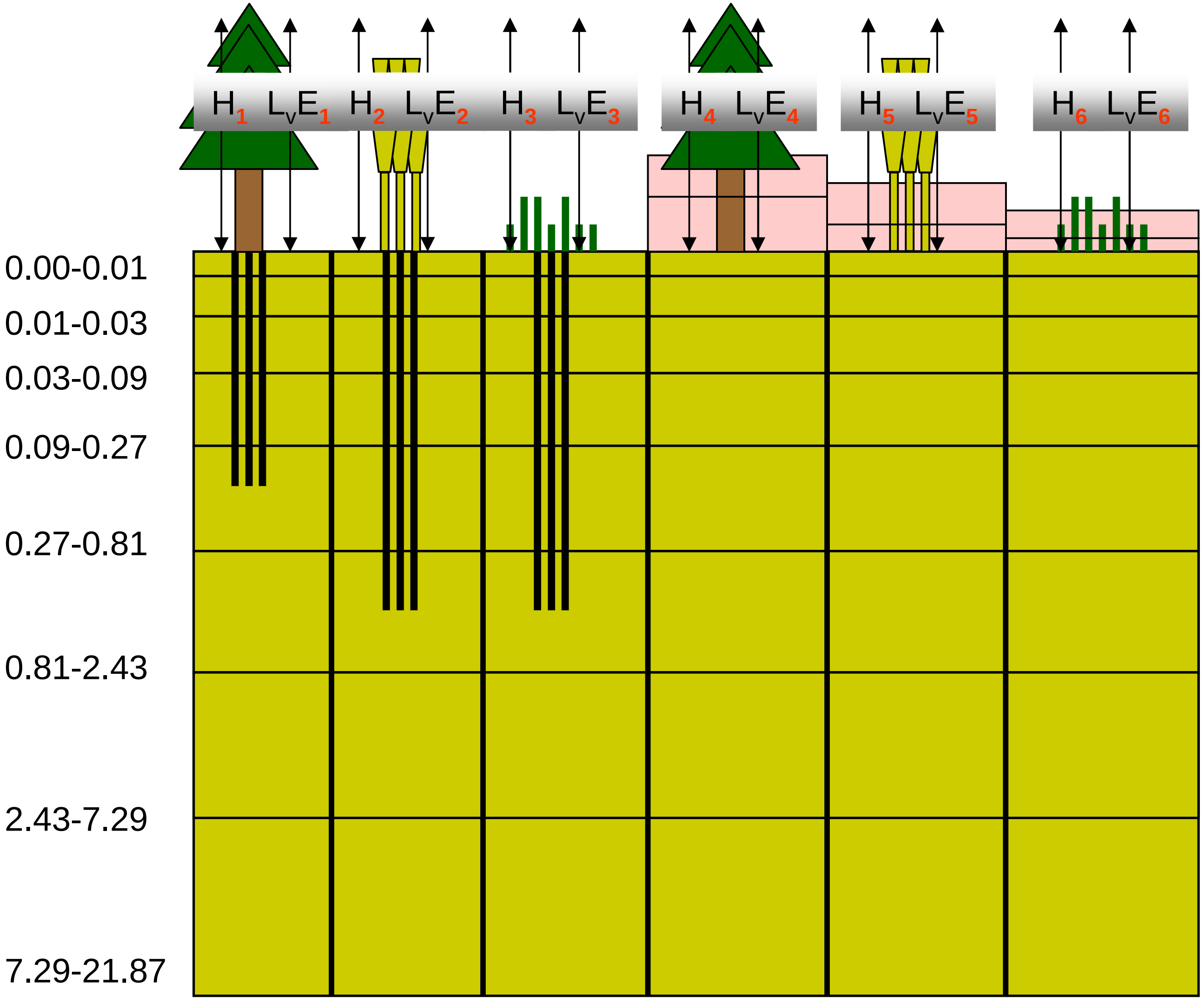
`itype_evsl = 3`
`itype_heatcond = 2`
`itype_albedo = 3`

Thank you

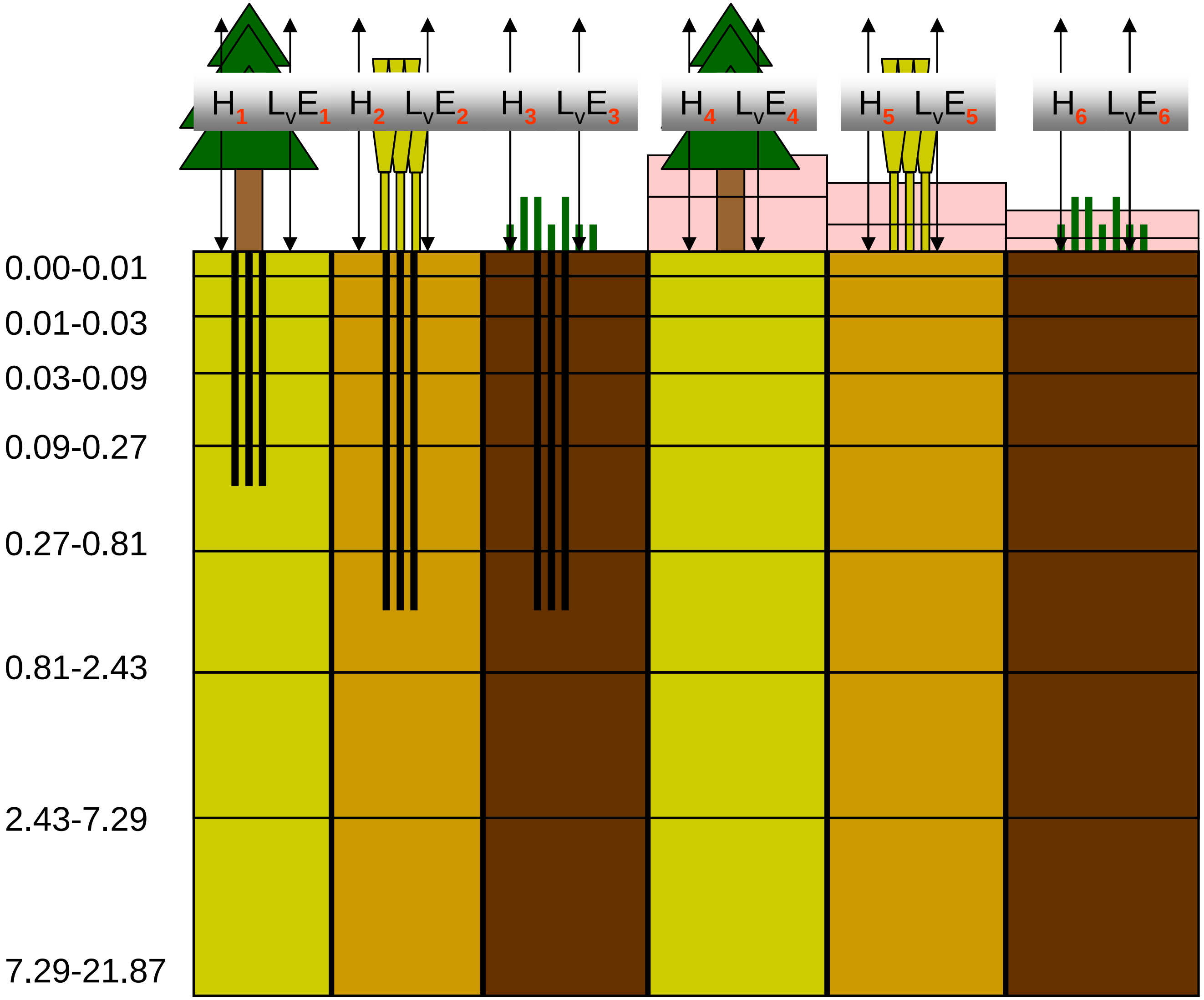
TERRA no-Tiles



TERRA Tiles


H1 LvE1
H2 LvE2
H3 LvE3
H4 LvE4
H5 LvE5
H6 LvE6
0.00-0.01
0.01-0.03
0.03-0.09
0.09-0.27
0.27-0.81
0.81-2.43
2.43-7.29
7.29-21.87

TERRA Tiles


H1 LvE1
H2 LvE2
H3 LvE3
H4 LvE4
H5 LvE5
H6 LvE6
0.00-0.01
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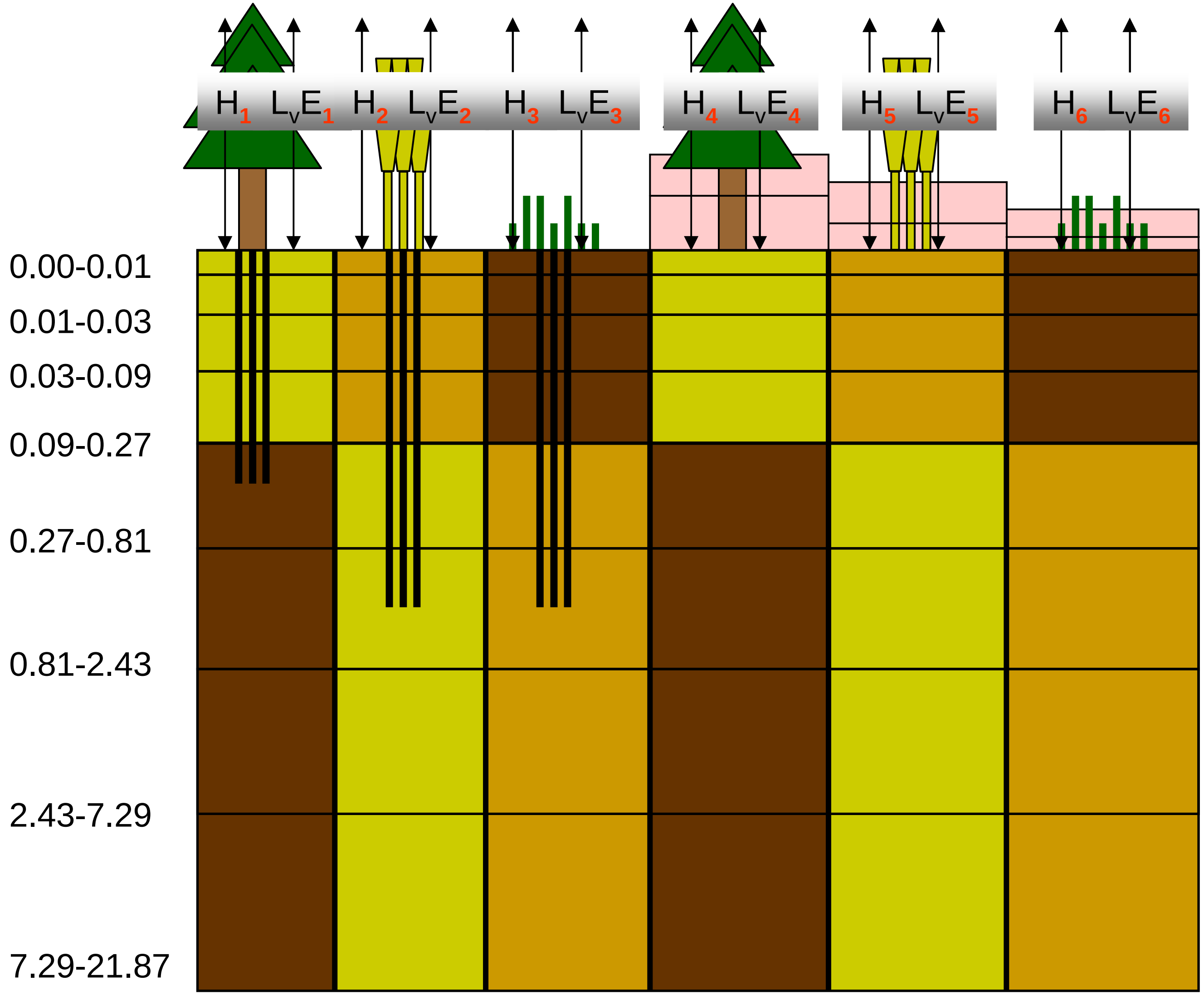
TERRA Tiles


H1 LvE1
H2 LvE2
H3 LvE3
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0.00-0.01
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0.09-0.27
0.27-0.81
0.81-2.43
2.43-7.29
7.29-21.87

Soil water transport
Rijtema model in TERRA

$$\frac{\partial w_l}{\partial t} = \frac{1}{\rho_w} \frac{\partial F}{\partial z}$$

soil water change

$$F = -\rho_w \left[- D_w(w_l) \frac{\partial w_l}{\partial z} + K_w(w_l) \right]$$

soil water flux, Richards equation

$$D_w(w_l) = D_0 \;\; exp \;\; \left[D_1(w_{PV} - \bar{w}_l)/(w_{PV} - w_{ADP}) \right]$$

soil water diffusivity, Rijtema (1969)

$$K_w(w_l) = K_0 \;\; exp \;\; \left[K_1(w_{PV} - \bar{w}_l)/(w_{PV} - w_{ADP}) \right]$$

soil water conductivity, Rijtema (1969)

Soil water transport
van Genuchten **model**

$$\frac{\partial w_l}{\partial t} = \frac{1}{\rho_w}\frac{\partial F}{\partial z} \qquad F = -\rho_w\left[-D_w(w_l)\frac{\partial w_l}{\partial z} + K_w(w_l)\right]$$

soil water change **soil water flux, Richards equation**

$$D = \frac{(1-m)\cdot K_S}{\alpha\cdot m\cdot(\theta_S - \theta_r)}\cdot\theta^{\left(\frac{1}{2}-\frac{1}{m}\right)}\cdot \left[\left(1-\theta^{\frac{1}{m}}\right)^{-m} + \left(1-\theta^{\frac{1}{m}}\right)^{m} - 2\right]$$

$$\theta = \frac{\theta - \theta_r}{\theta_s - \theta_r}$$

$$\theta = \theta_r + \frac{\theta_s - \theta_r}{[1+(\alpha\cdot h)^n]^m}$$

$$K_r = \frac{\{1-(\alpha\cdot h)^{n-1}\cdot[1+(\alpha\cdot h)^n]^{-m}\}^2}{[1+(\alpha\cdot h)^n]^{\frac{m}{2}}} \qquad \left(m = 1 - \frac{1}{n}\right) \qquad K_r = \frac{K}{K_s}$$

Soil water transport
van Genuchten **model**

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$$\frac{\partial w_l}{\partial t} = \frac{1}{\rho_w}\frac{\partial F}{\partial z}$$

soil water change

$$F = -\rho_w\Big[-D_w(w_l)\frac{\partial w_l}{\partial z} + K_w(w_l)\Big]$$

soil water flux, Richards equation

Determination of required soil parameters

$$\theta_r \quad \theta_s \quad \alpha \quad n \quad K_s$$

Soil properties – Option 1

J.H.M. Wösten et al. / Geoderma 90 (1999) 169–185

Table 4
Mualem-van Genuchten parameters for the fits on the geometric mean curves

	θ_r	θ_s	α	n	m	l	K_s
Topsoils							
Coarse	0.025	0.403	0.0383	1.3774	0.2740	1.2500	60.000
Medium	0.010	0.439	0.0314	1.1804	0.1528	−2.3421	12.061
Mediumfine	0.010	0.430	0.0083	1.2539	0.2025	−0.5884	2.272
Fine	0.010	0.520	0.0367	1.1012	0.0919	−1.9772	24.800
Very Fine	0.010	0.614	0.0265	1.1033	0.0936	2.5000	15.000
Subsoils							
Coarse	0.025	0.366	0.0430	1.5206	0.3424	1.2500	70.000
Medium	0.010	0.392	0.0249	1.1689	0.1445	−0.7437	10.755
Mediumfine	0.010	0.412	0.0082	1.2179	0.1789	0.5000	4.000
Fine	0.010	0.481	0.0198	1.0861	0.0793	−3.7124	8.500
Very Fine	0.010	0.538	0.0168	1.0730	0.0680	0.0001	8.235
Organic[a]	0.010	0.766	0.0130	1.2039	0.1694	0.4000	8.000

[a] Within the organic soils no distinction is made in topsoils and subsoils.

Hydraulic properties

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Diffusivity m^2/s Conductivity m/s

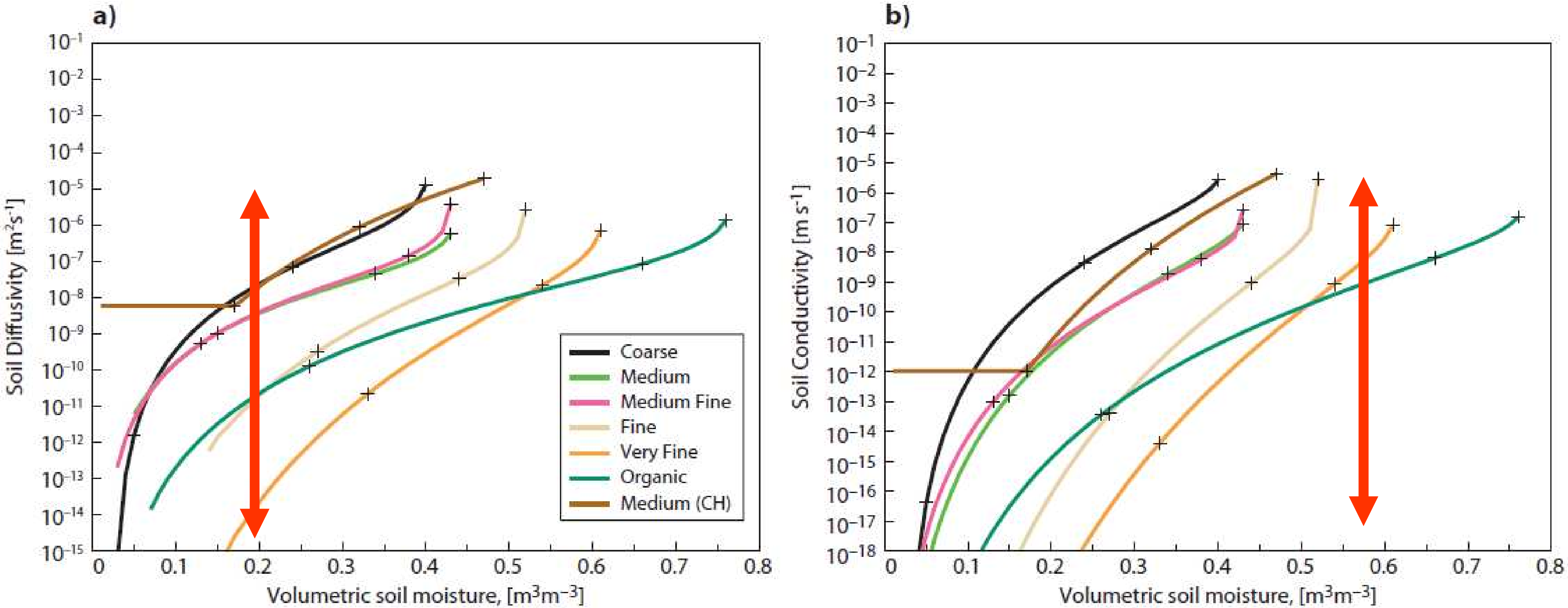
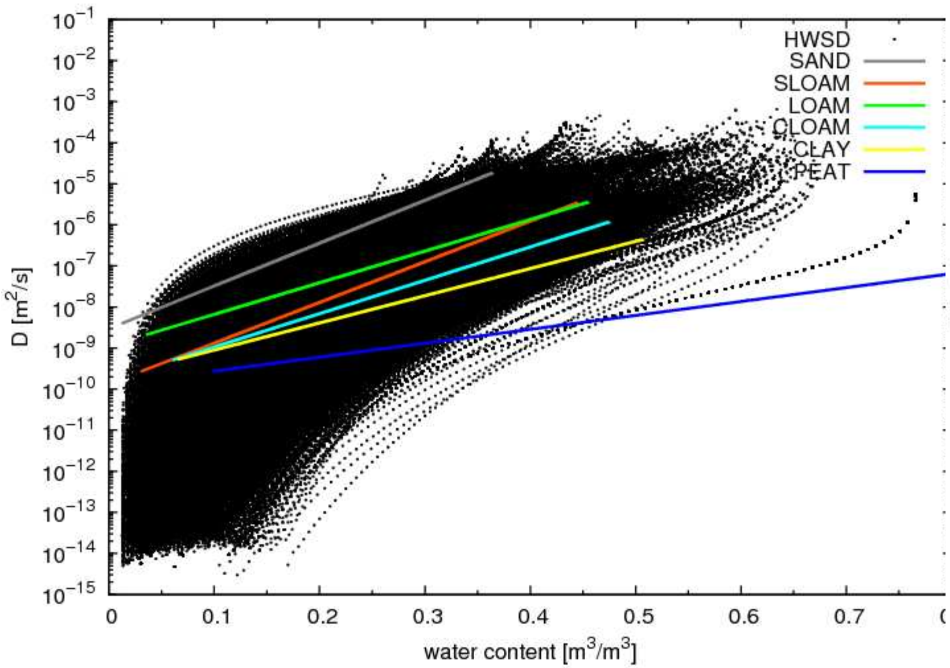


Figure 7.3 *Hydraulic properties of TESSEL and HTESSEL: (a) Diffusivity and (b) conductivity. The (+) symbols on the curves highlight (from high to low values) saturation, field capacity permanent wilting point.*

IFS documentation

Hydraulic properties

Diffusivity m^2/s



Conductivity m/s