COST ES1404

Working Group 3

Snow models for NWP application

Motivation

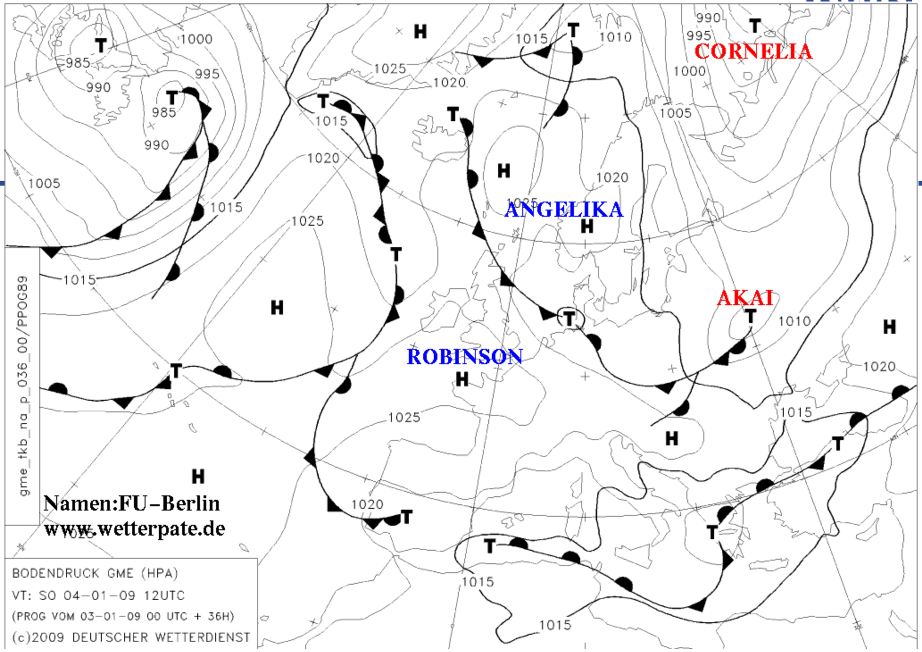
Case Study
Stable boundary layer over snow
Observatory Lindenberg
Januar 2009

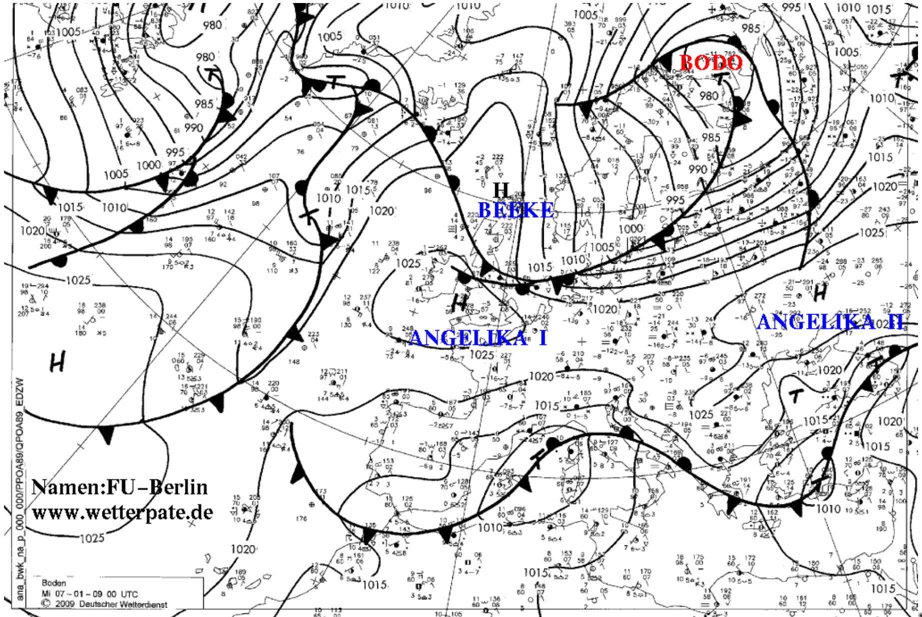
Foto: G. Hollaz, DWD, 2009

C. Becker, DWD
02/03 2009

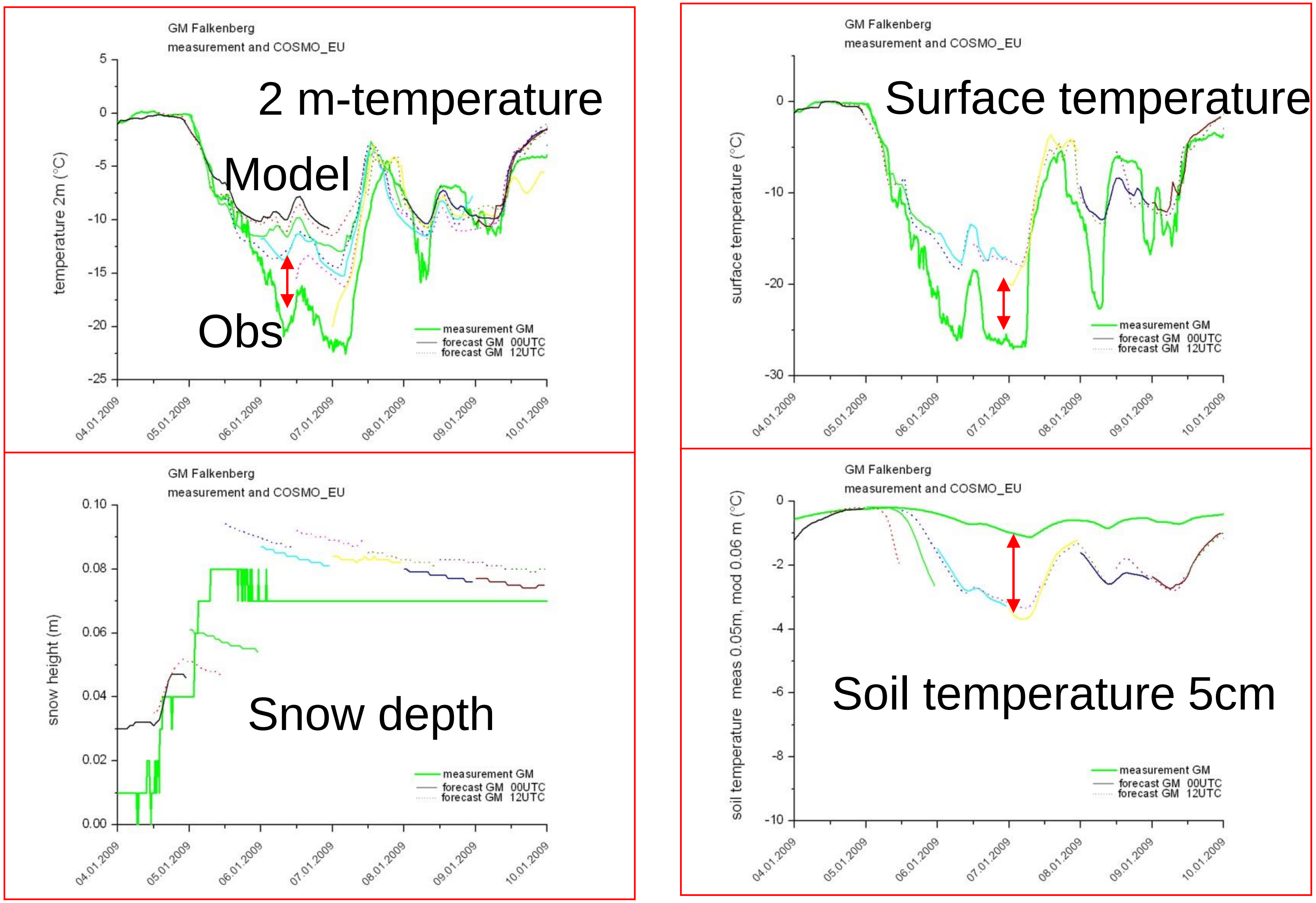
Synoptical Situation 2009 Jan 04-07

- 04.01. Frontal system with heavy snow fall, polar cold air approached
- 05.01. Strong cooling due to advection of cold air, development of a stable boundary layer
- 06.01. Decrease of geostrophic wind,BL decoupling, warming
- 07.01 Advection of warm air, low clouds

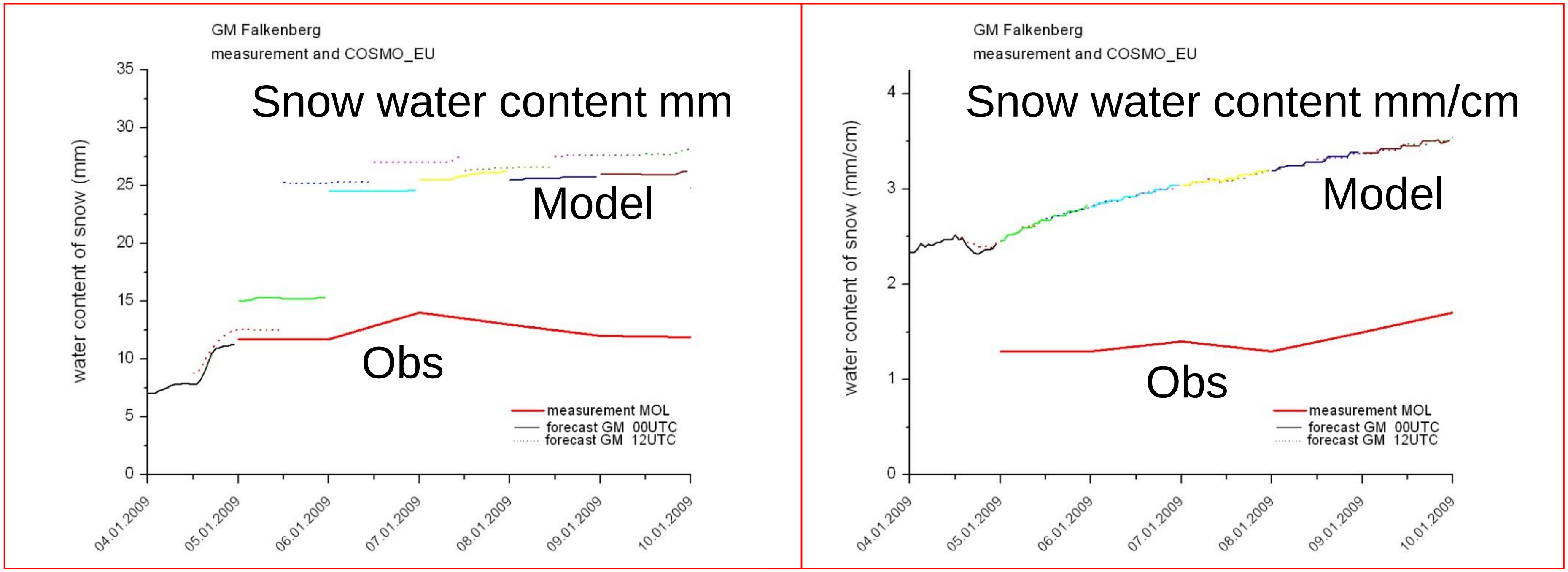




Temperature error

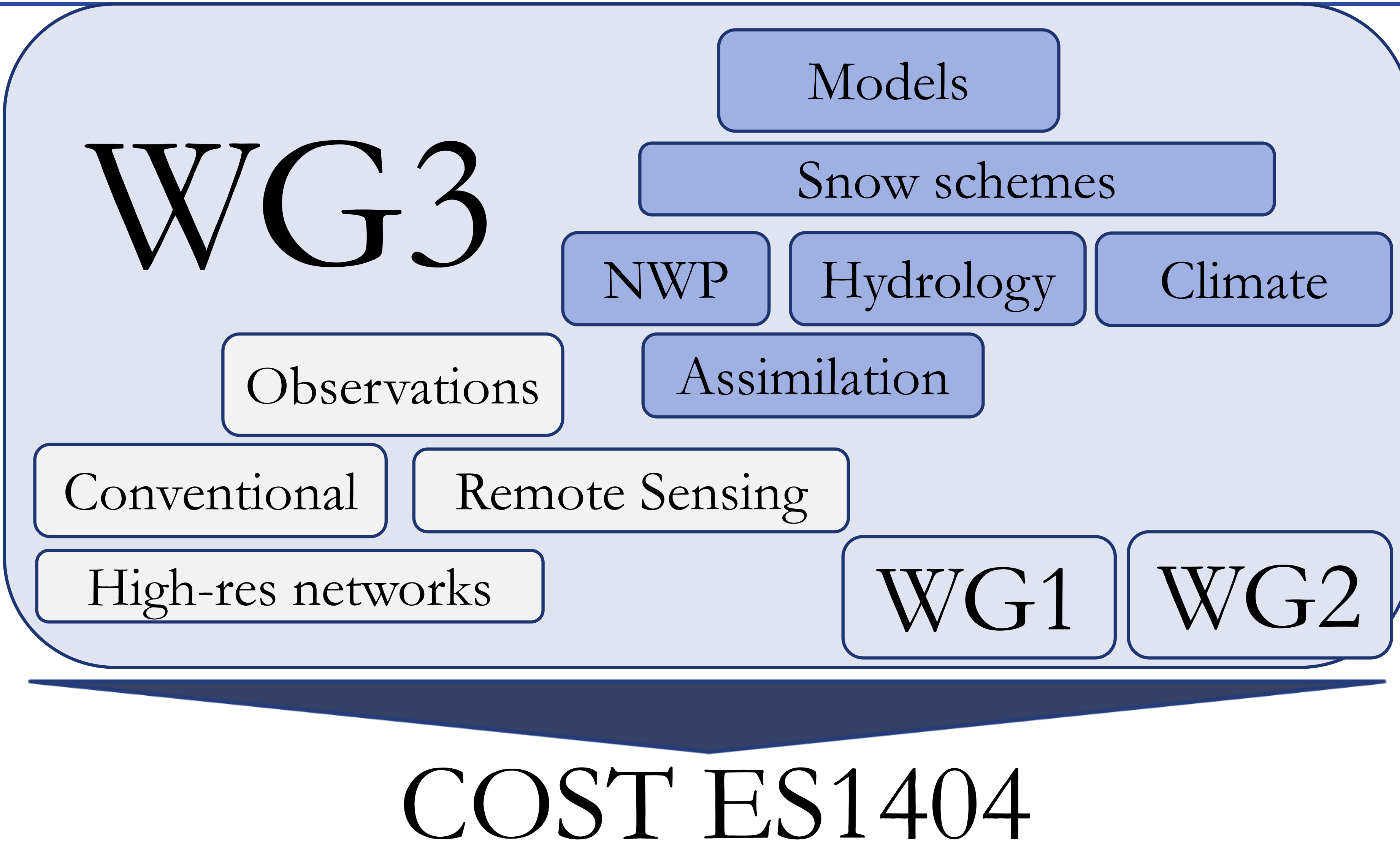


Impact of snow properties



Problem: Overestimation of SWE, wrong snow density and weak decoupling of the atmosphere from the soil

Structure


Models
Snow schemes
WG3
NWP
Hydrology
Climate
Observations
Assimilation
Conventional
Remote Sensing
High-res networks
WG1
WG2
COST ES1404

Tasks

- A critical review of *snow models* utilizing physical snow *parameters* as input and used as parametrization schemes or for downstream applications (CROCUS, Snowpack, …) will be included.

Preparing a questionnaire, using existing model intercomparison experience (e.g. SNOWMIP2), investigating interoperability of snow models with data assimilation, consider model sophistication.

Models

Snow schemes

CROCUS | TERRA | JULES | Snowpack | SnowGrid

- Treatment of snow processes (metamorphism, liquid water)
- Considered complexity (one-layer, multi-layer schemes)
- Grid-scale and subgrid-scale features (snow tiles)
- Interaction with other land-surface properties (e.g. vegetation)

Main effects

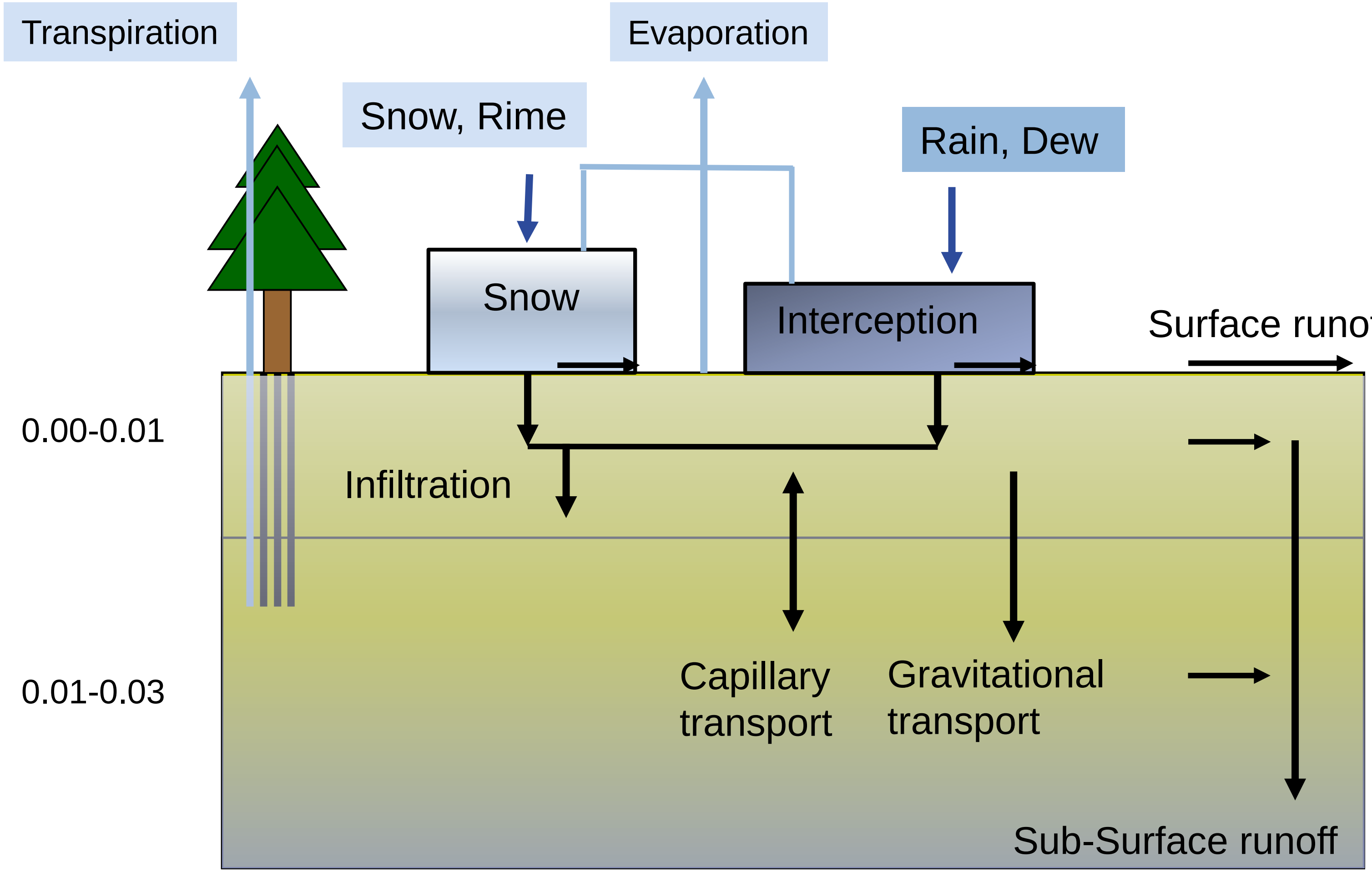
- Insulation effect: Decoupling of soil from atmosphere (30%-90% of the snow mantle is air)
- Albedo Effect: Higher albedo than any other natural surface (0.4-0.85 for bare ground/low vegetation, 0.2-0.33 for snow in forests)
- Snow melting prevents rise of surface temperature above 0°C for a long period in spring – impact on hydrological cycle and energy budget at surface

G. Balsamo, 2007

Snow Model

- One layer – prognostic variables : snow temperature, snow water equivalent, snow density, snow albedo
- Multi-layer – Vertical profiles in snow pack; considers equations for the snow albedo, snow temperature, density, *total* water content and content of *liquid* water. Therefore phase transitions in the snow pack are included.

TERRA – Water budget



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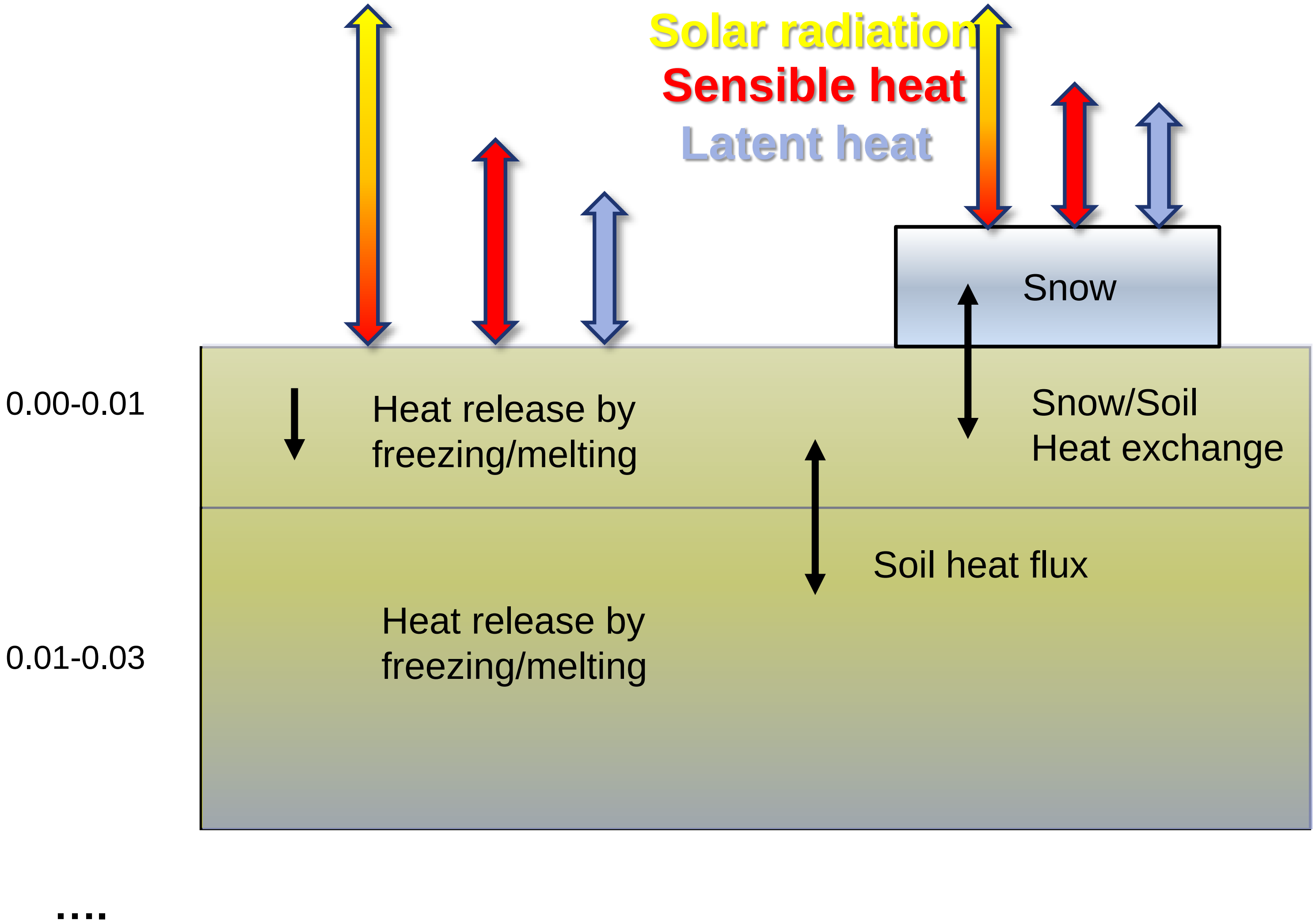
TERRA – Energy budget



Snow processes

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

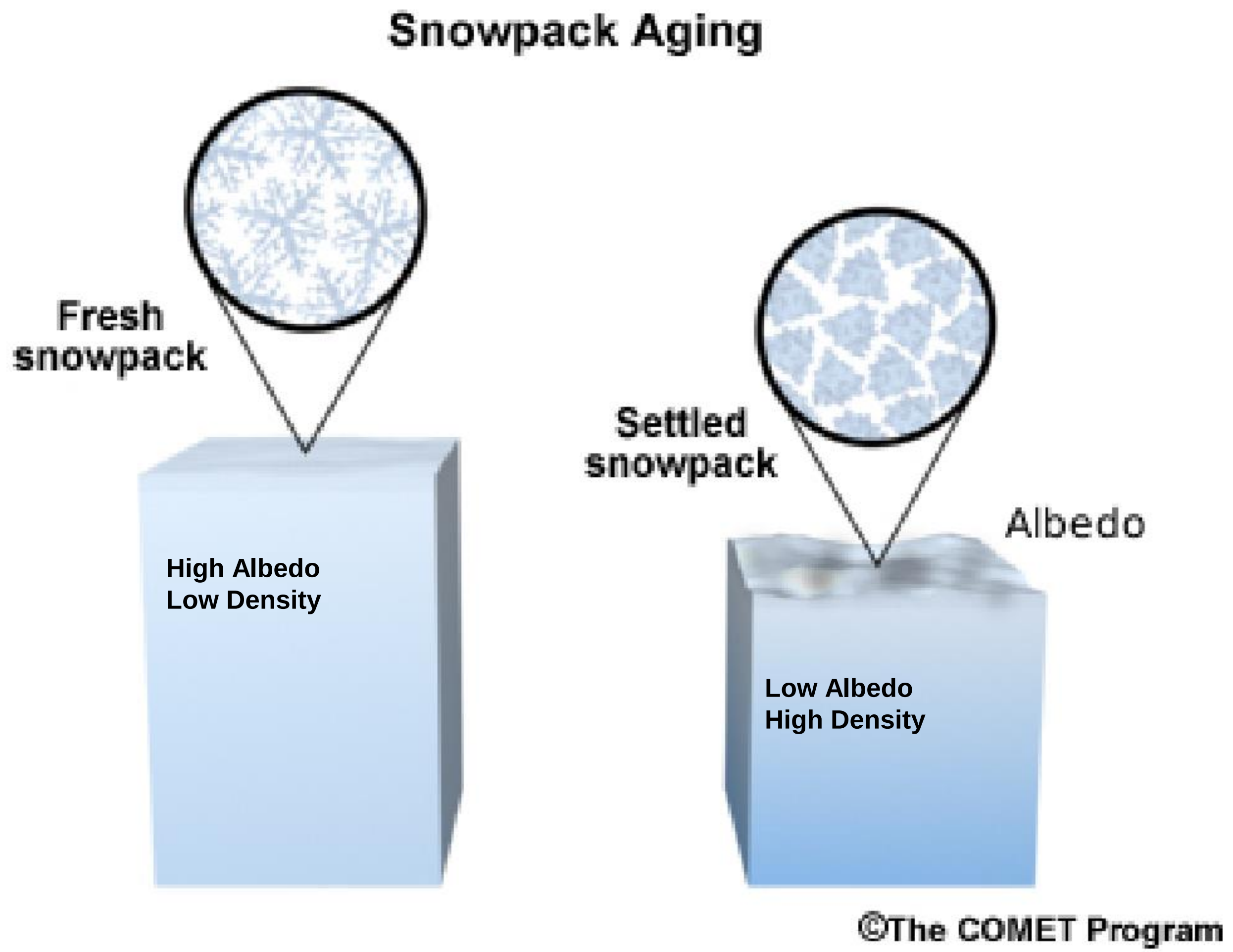
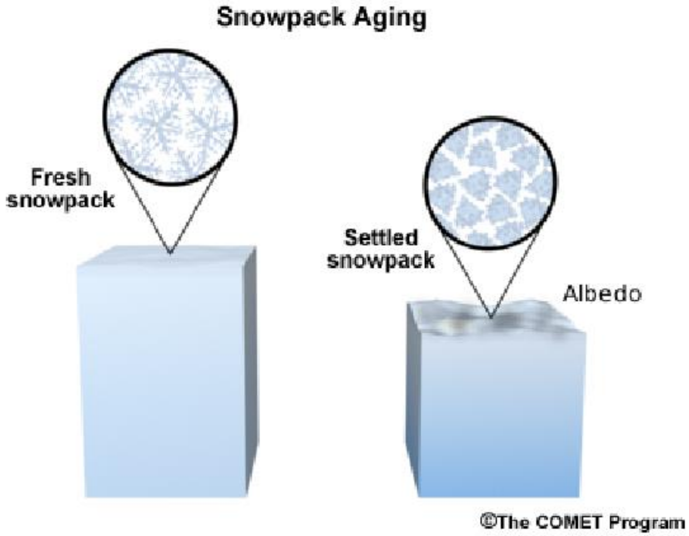


Figure: Snow Processes (COMET® Website at http://meted.ucar.edu/)

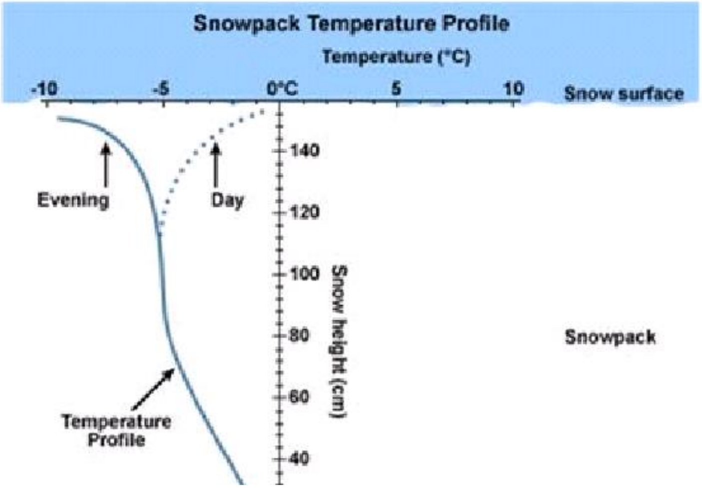
Snow processes



- Prognostic Snow Density
  - Exponential relaxation ($\rho_{min} = 50$ kg/m^3, $\rho_{max} = 400$ kg/m^3)
  - Snow Ageing: Increasing Compactness
  - Fresh Snow: Decreasing Snow Density
- Time-dependent Snow Albedo
  - Constant relaxation ($\alpha_{max} = 0.85$, $\alpha_{min} = 0.5$)
  - Regeneration by falling snow

Snow processes

Heatflux through the snow pack: $$G_{snow} = k_s \frac{T_{snow,sfc} - T_{sfc}}{\Delta z_{snow}}$$



- Heat transfer within Snow Layer: Considering
  - Soil Surface Temperature
  - Snow Surface Temperature
- Impact on Infiltration and Runoff (frozen/unfrozen soil)

Thermal snow processes

$$\frac{\partial T_{snow}}{\partial t} = \frac{1}{(\rho c \Delta z)_{snow}} \left(G_{snow,sfc} - G_{snow} + G_{melt} \right)$$

Evolution of the snow temperature

$$G_{snow} = \lambda_{snow} \frac{T_{snow,sfc} - T_{sfc}}{\Delta z_{snow}}$$

Heatflux through the snow

$$\lambda_{snow} = \lambda_{ice} \frac{\rho_{snow}}{\rho_w}^{1.88}$$

$$G_{sfc} = (1 - f_{snow}) \cdot \left(c_p \hat{H}^3_{sfc} + L(F^3_{q^v})_{sfc} + Q_{rad,net} \right) + f_{snow} \cdot G_{snow}$$

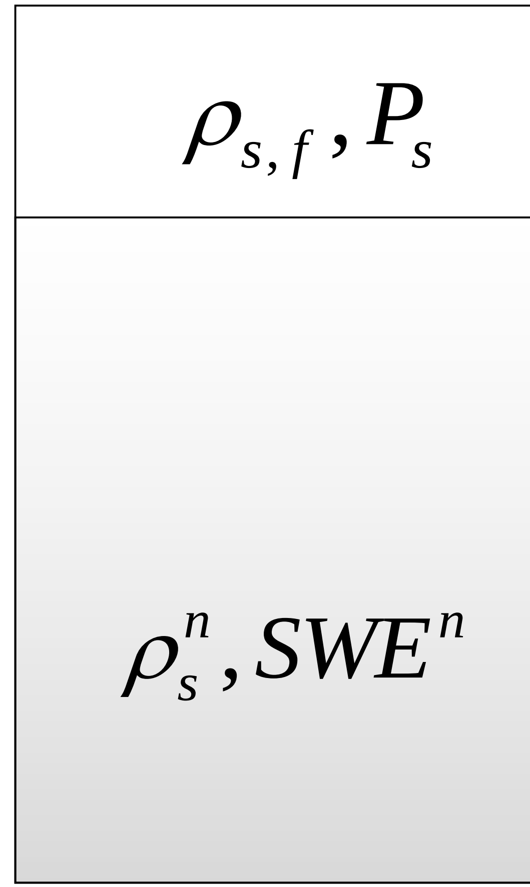
Surface forcing

Snow depth, Snow density

$$h_s = \frac{\rho_w SWE}{\rho_s^n(t) f}$$

$$\lambda_s = 2.22 \left(\frac{\rho_s^n}{\rho_w} \right)^{1.88}$$

$$\rho_s^{n+1} = \frac{\rho_s^n(t) SWE^n + \rho_{s,f}(T) P_s}{SWE^n + P_s}$$



Snow albedo

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

ROUTI EXP

```
Csalb_snow_min = 0.400 0.500   ! snow for forest free surfaces
Csalb_snow_max = 0.700 0.850   ! snow for forest free surfaces
Csalb_snow_fe  = 0.200 0.270   ! snow with evergreen forest
Csalb_snow_fd  = 0.200 0.320   ! snow with deciduous forest
```

TABLE 1. Mean values of Northern Hemisphere 5-yr (2000–04) broadband surface albedo (in presence of snow) aggregated by high vegetation type (adapted from Moody et al. 2007).

Vegetation type	Albedo
Evergreen needleleaf trees	0.27
Deciduous needleleaf trees	0.33
Deciduous broadleaf trees	0.31
Evergreen broadleaf trees	0.38
Mixed forest–woodland	0.29
Interrupted forest	0.29

Dutra et al., 2010

Snow cover fraction

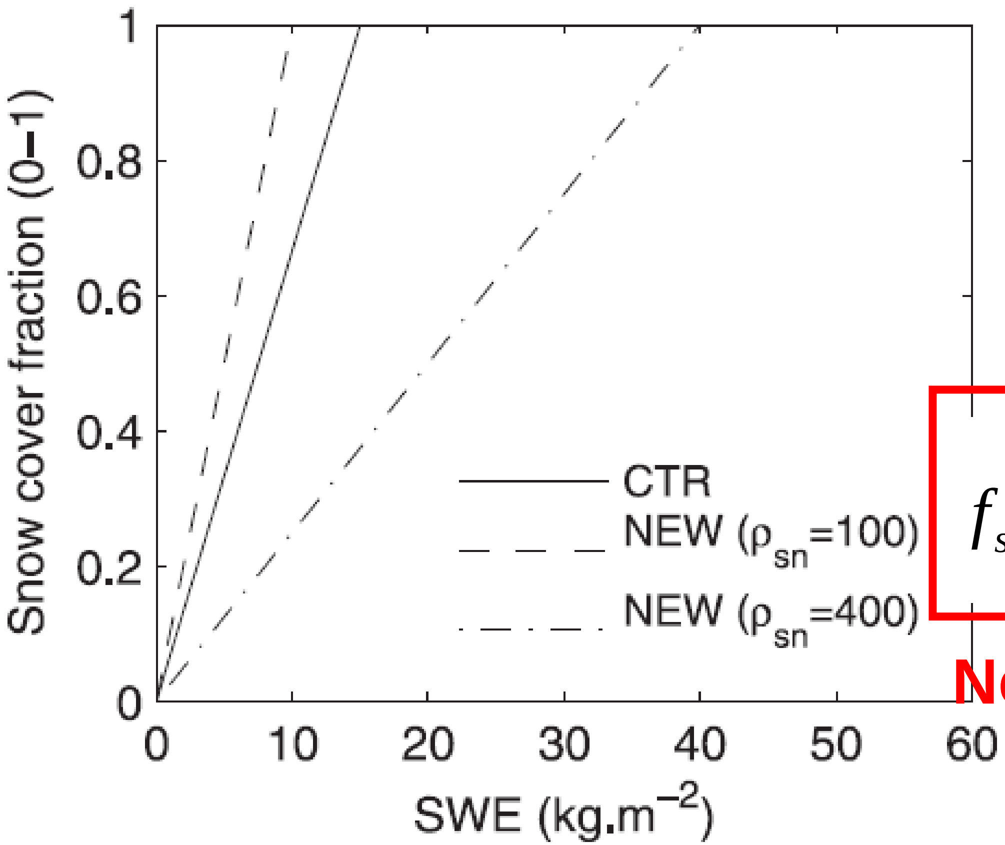


FIG. 2. Snow cover fraction as function of SWE as in the original HTESSEL snow scheme [solid line, Eq. (A2)], and new [Eq. (8)] for snow densities of 100 (dashed line) and 400 (dashed dotted line) kg m^{-3}.

Dutra et al., 2010

$$f_s = \frac{SWE}{0.015m}$$

$$f_s = \frac{SWE\left[kg/m^2\right] / \rho_{snow}\left[kg/m^3\right]}{0.15m}$$

New approach

Snow aging

Temporal evolution of snow albedo

$$\alpha_s = \alpha_{s,\max} S_{age} + \alpha_{s,\min}(1 - S_{age})$$

New approach

$$S_{age}^{old} = \left\langle \begin{array}{ll} \dfrac{\Delta t}{12.5d} & \\ (1 - e^{-\frac{\Delta t}{4d}}) & T_{snow} \geq -2°C \vee P_{rain} > 0 \end{array} \right.$$

$$S_{age}^{new} = \frac{\Delta t P_{snow}}{10mm/d}$$

$$S_{age}^{old} = \frac{\Delta t}{28d}$$

$$S_{age}^{new} = \frac{\Delta t P_{snow}}{5mm/d}$$

Aging function S

T_2M Verification

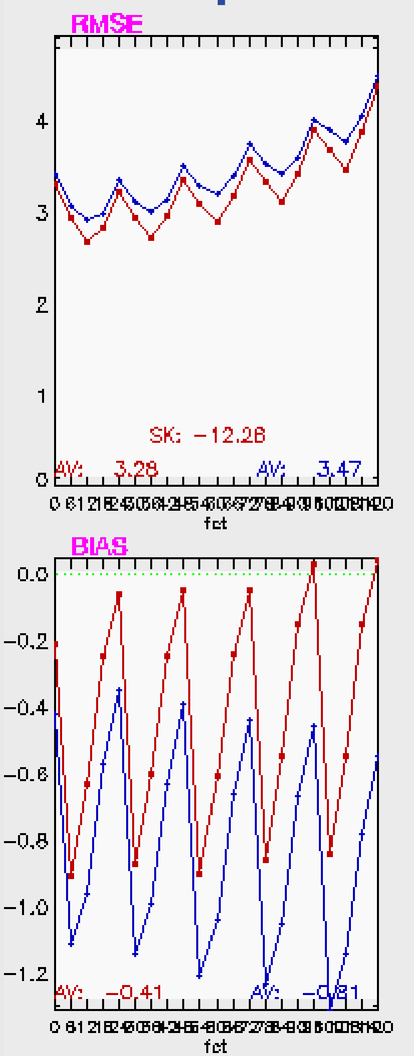
Routi

2011020200 - 2011030100

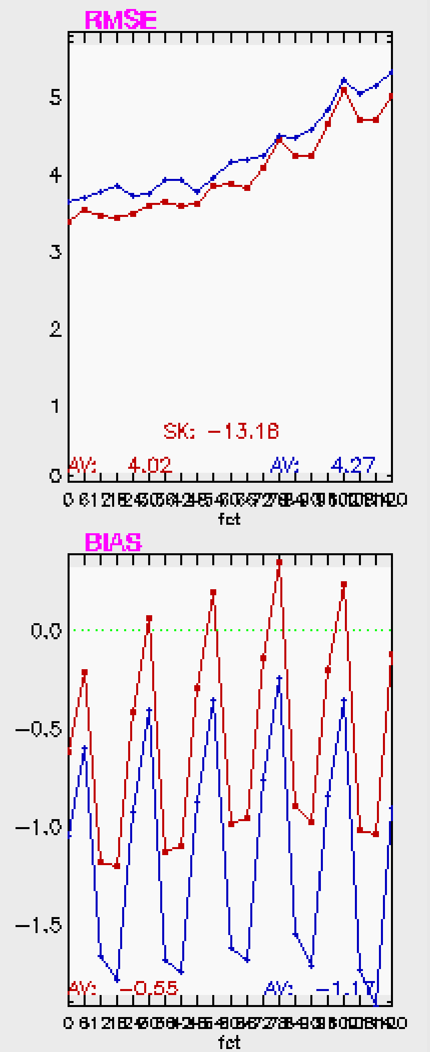
8101

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Europa

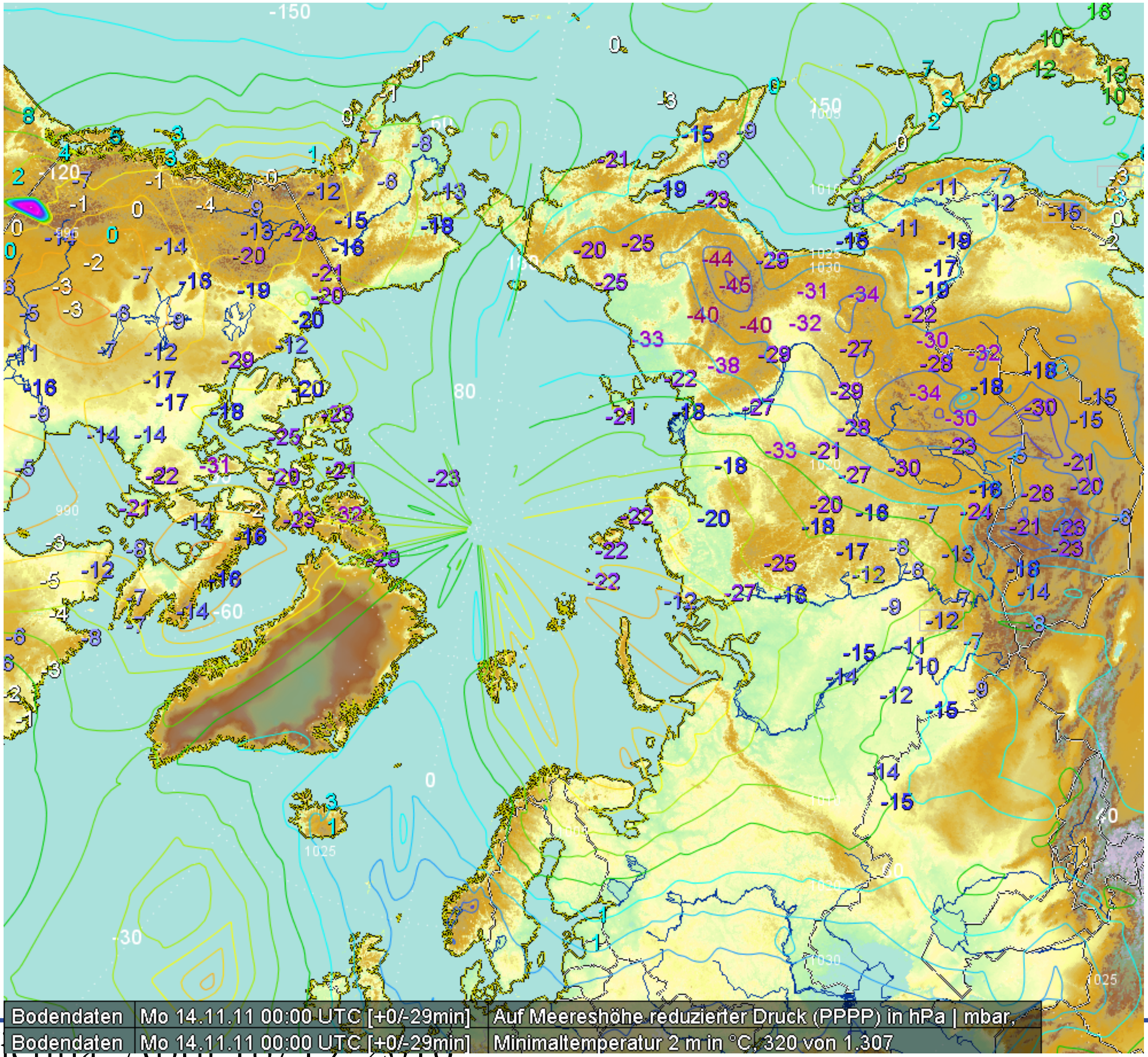


North Amerika



Snow density aging

Deutscher Wetterdienst
Wetter und Klima aus einer Hand



Snow density aging EXP8483

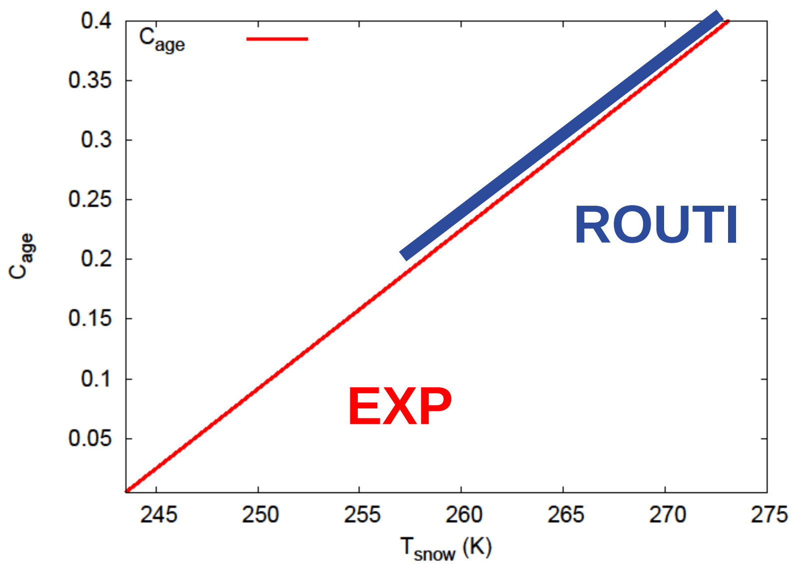
$$\rho_{snow,age} = \rho_{snow,\max} + (\rho^{n}{}_{snow} - \rho_{snow,\max})\exp^{-\frac{C_{age}\Delta t}{\tau_\rho}}$$

$$\rho_{snow,\max} = 400\frac{kg}{m^3}$$

$$\tau_\rho = 86400s$$

Temperature dependence of aging function C follows:

$$C_{age} = f(T_{snow})$$

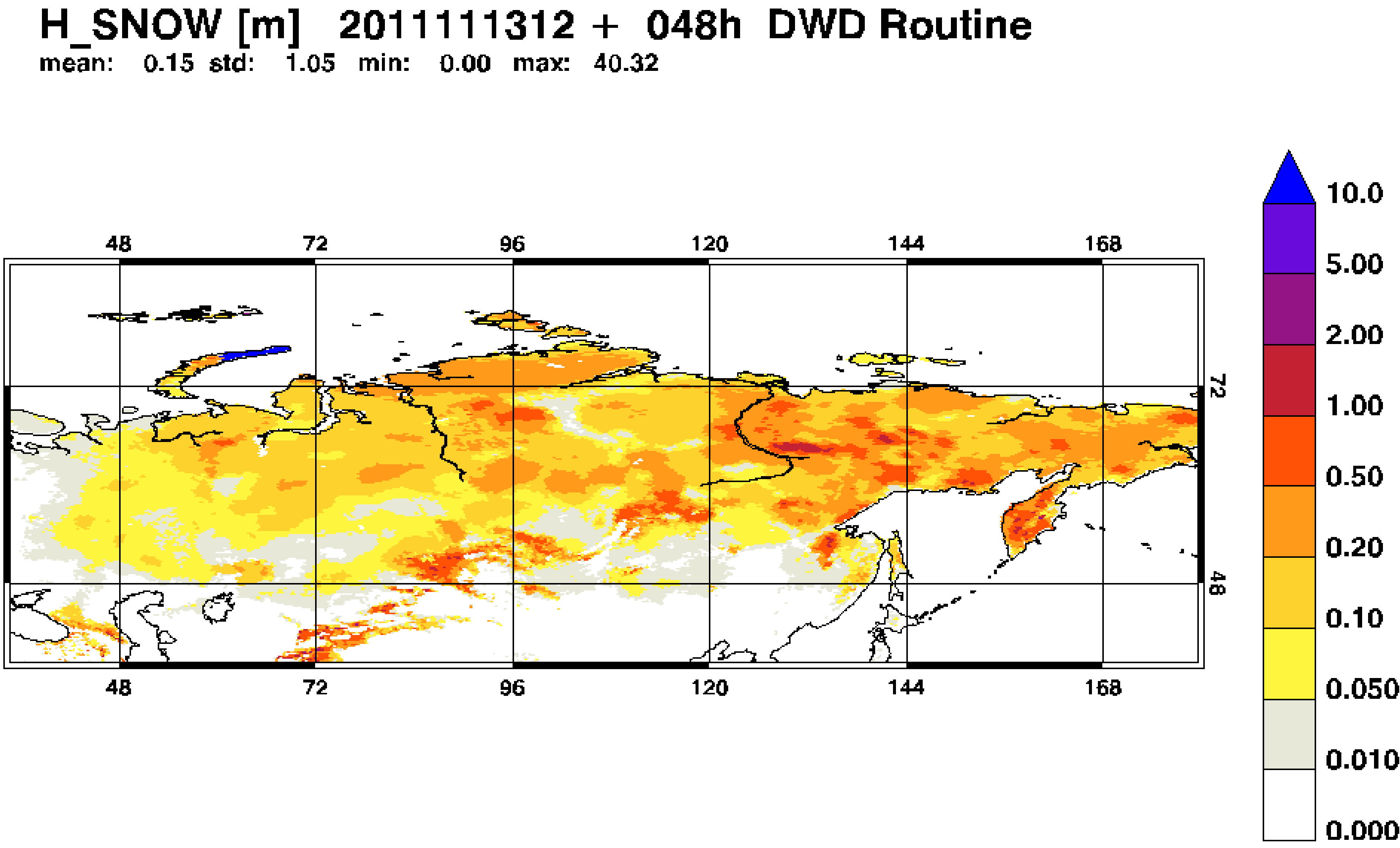


ROUTI: Lower limit of C_age = 0.2

EXP : Extend the lower limit of C_age = 0.005

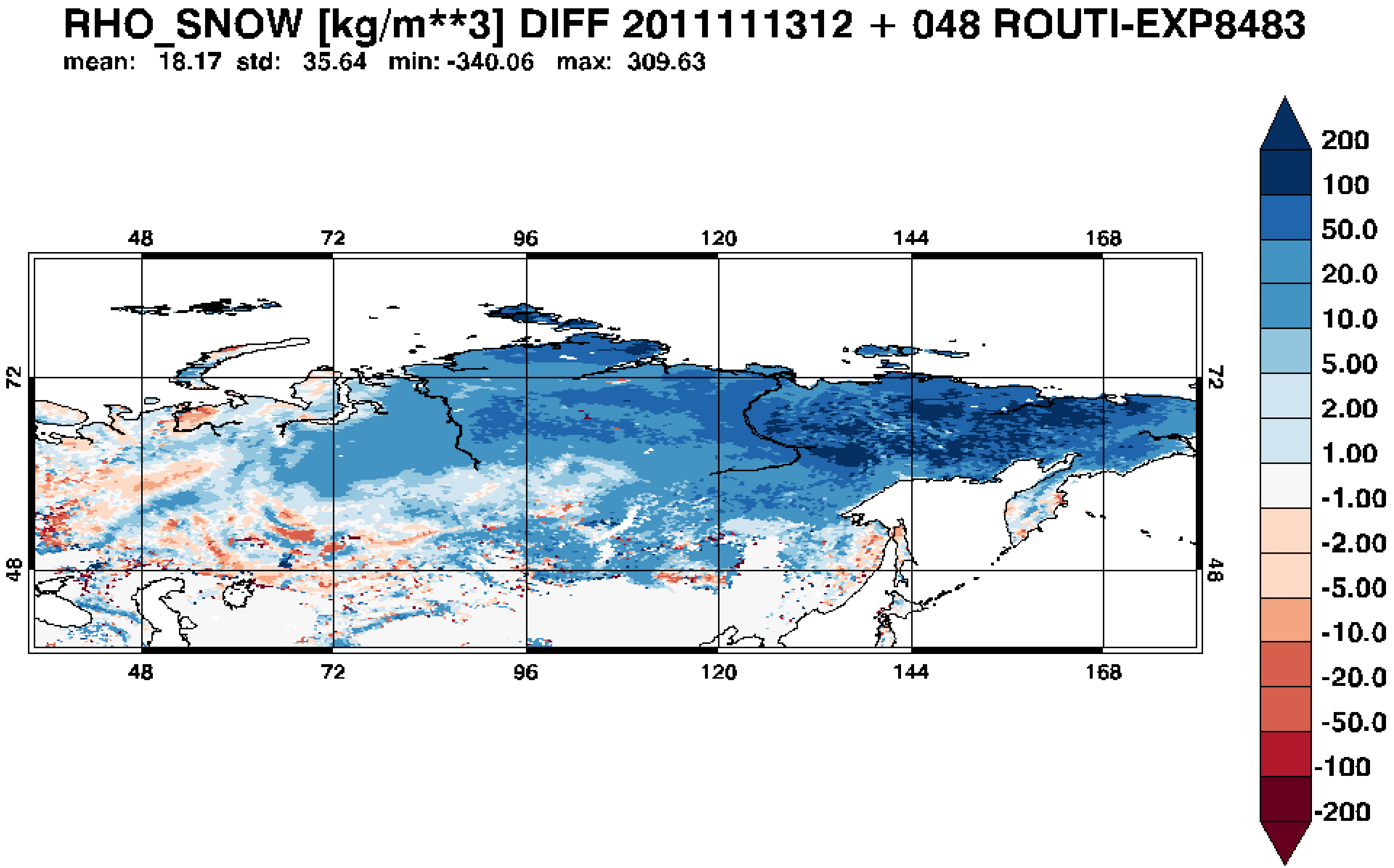
Case study: 2011111312+048h

Deutscher Wetterdienst
Wetter und Klima aus einer Hand



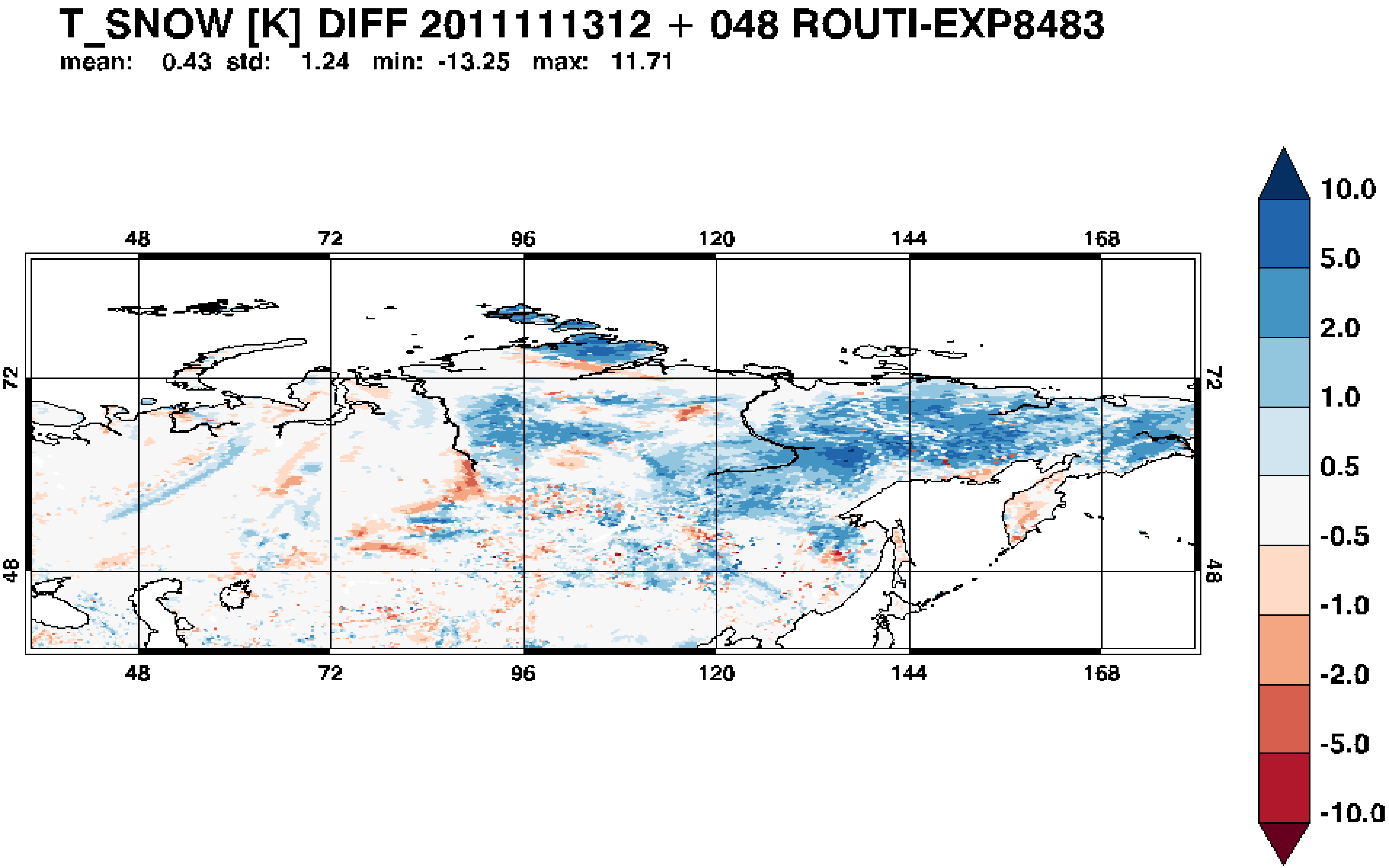
Case study: 2011111312+048h

Deutscher Wetterdienst
Wetter und Klima aus einer Hand



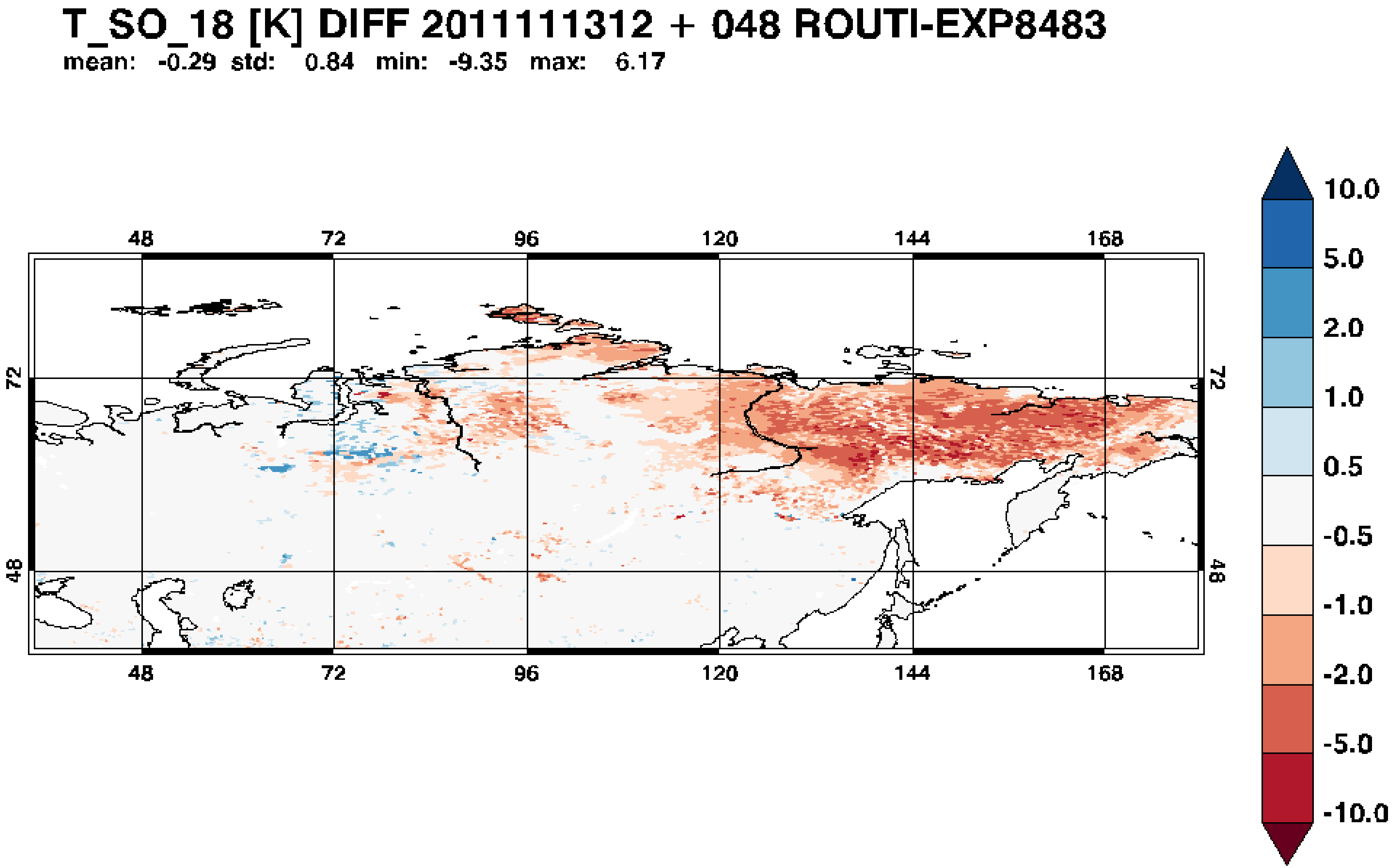
Case study: 2011111312+048h

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

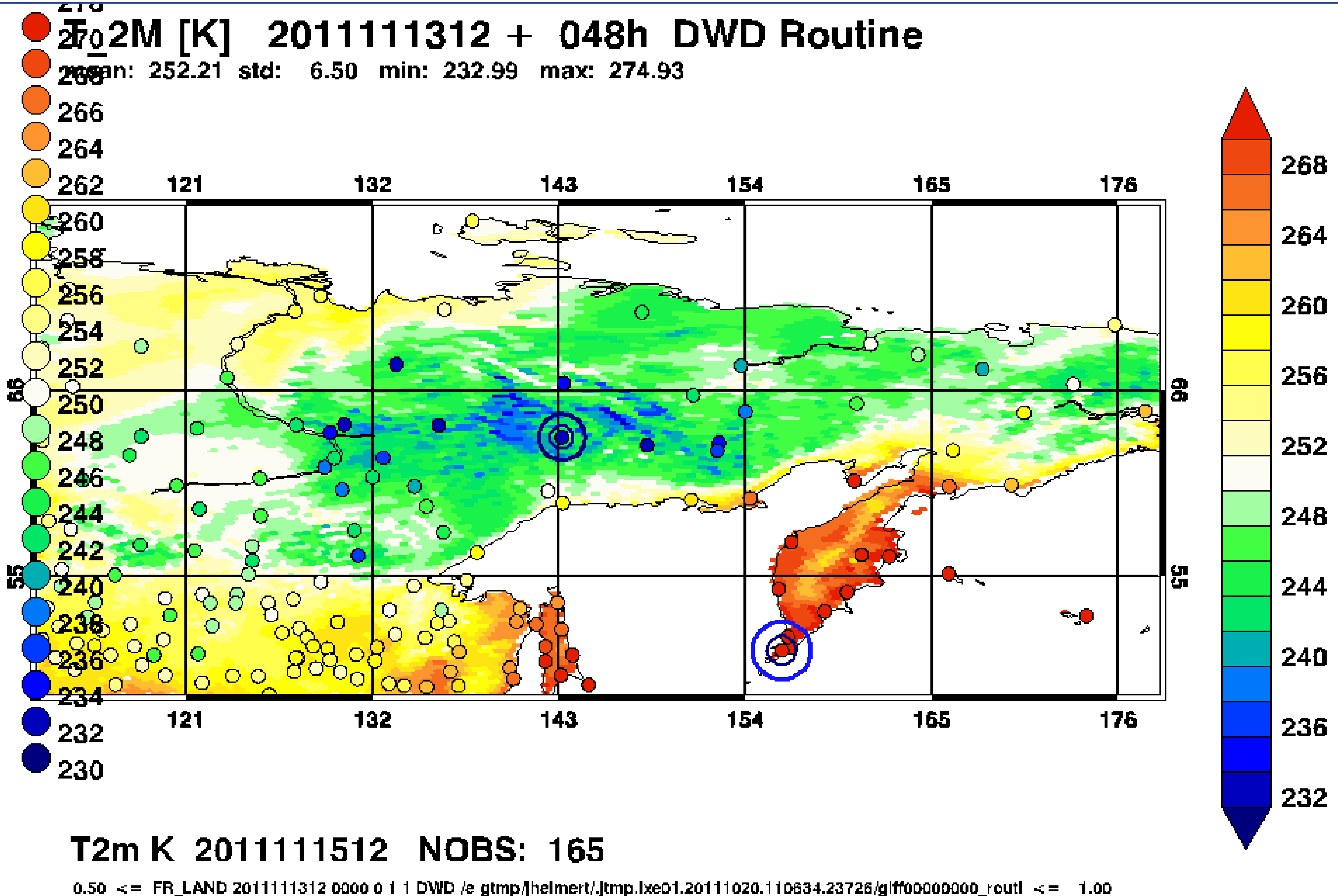


Case study: 2011111312+048h

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

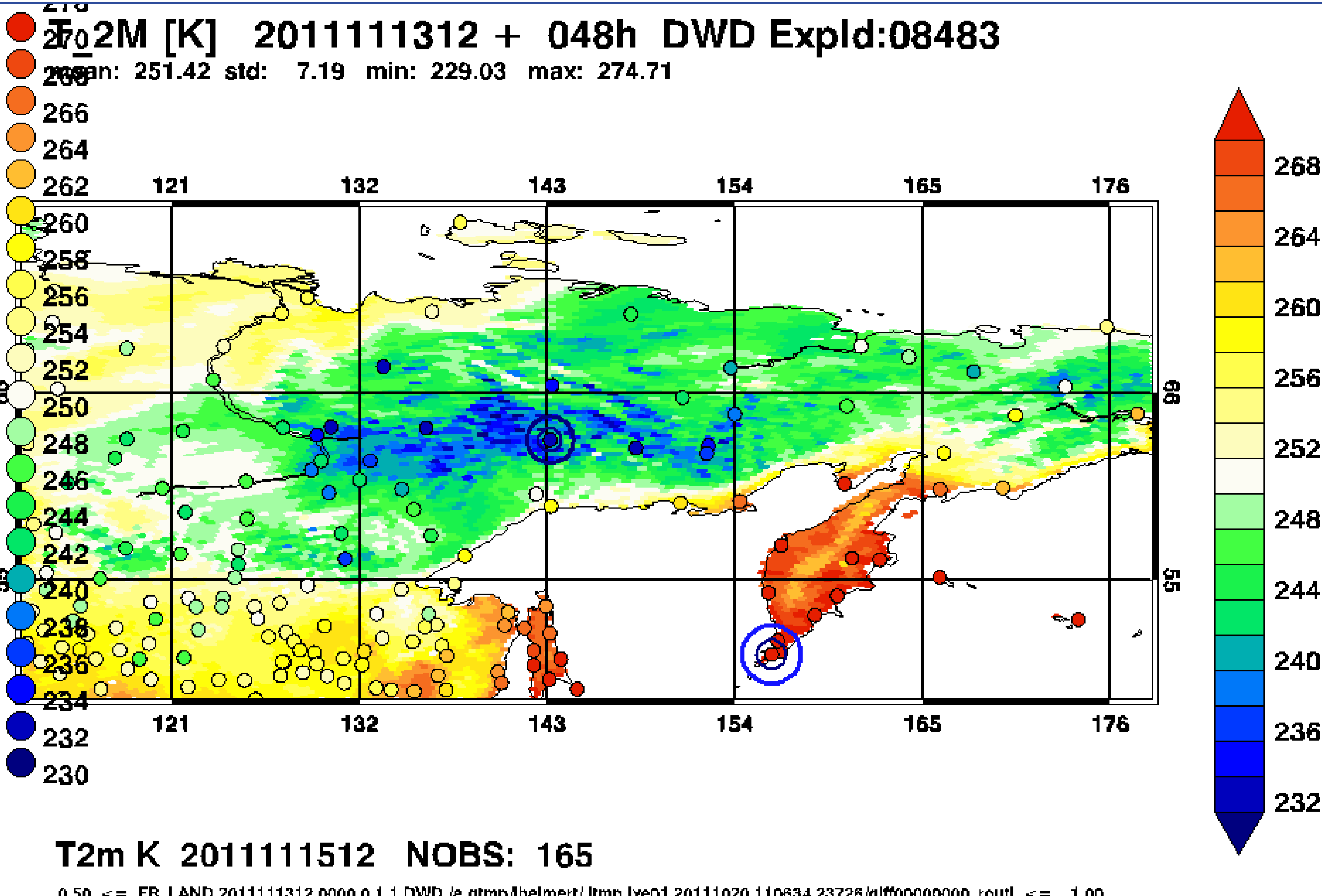


Case study: 2011111312+048h



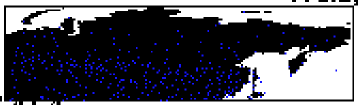
Case study: 2011111312+048h

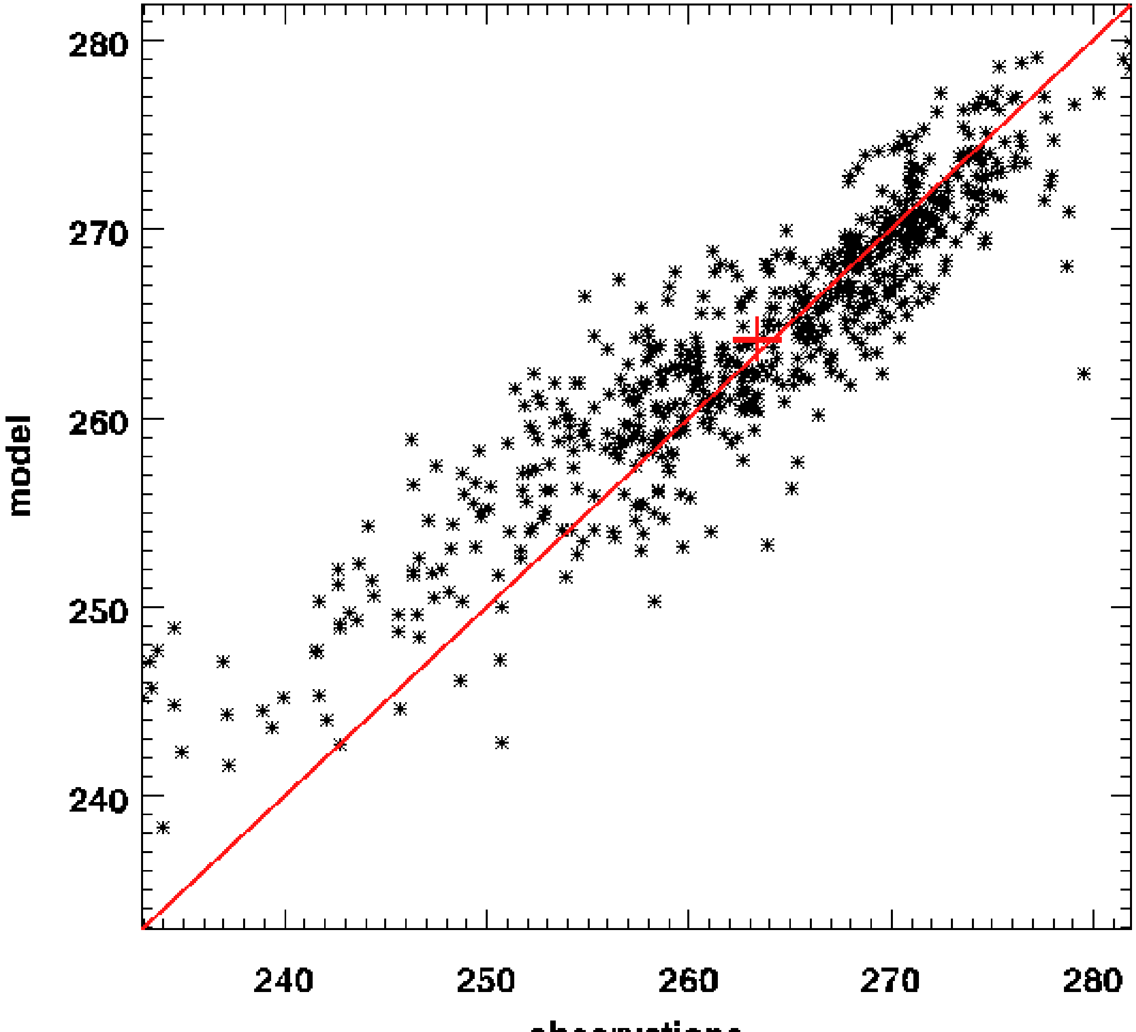
Deutscher Wetterdienst
Wetter und Klima aus einer Hand



Case study: 2011111312+048h

Model field : T_2M [K] 2011111312 + 048h DWD Routine
Observations: T2m K 2011111512 n= 654





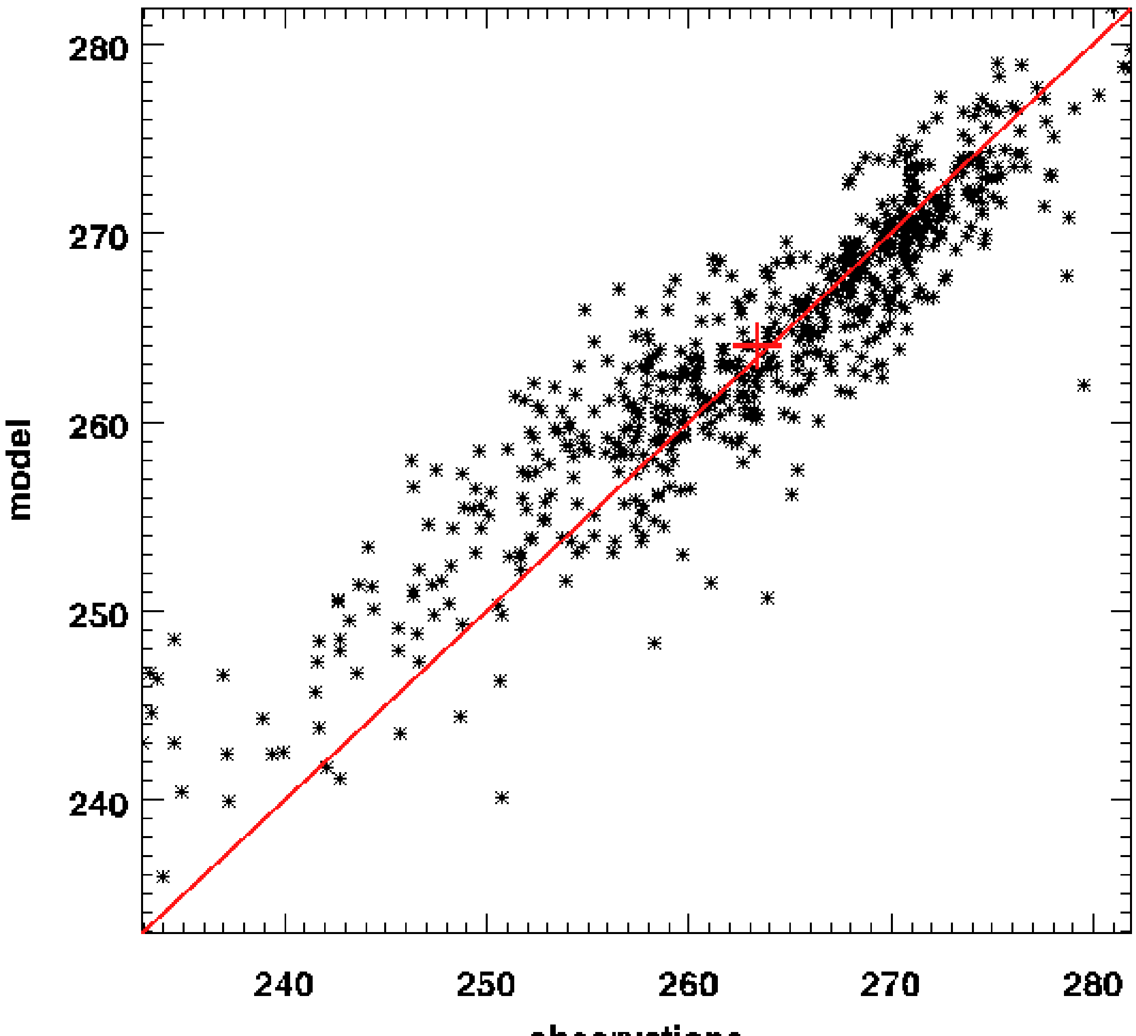
mean values

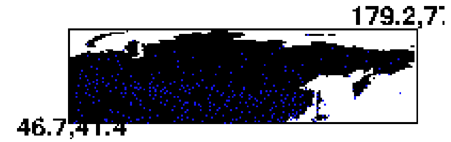
observations	:	263.41
model	:	264.16
bias	:	-0.75

Case study: 2011111312+048h

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Model field : T_2M [K] 2011111312 + 048h DWD ExpId:08483
Observations: T2m K 2011111512 n= 654



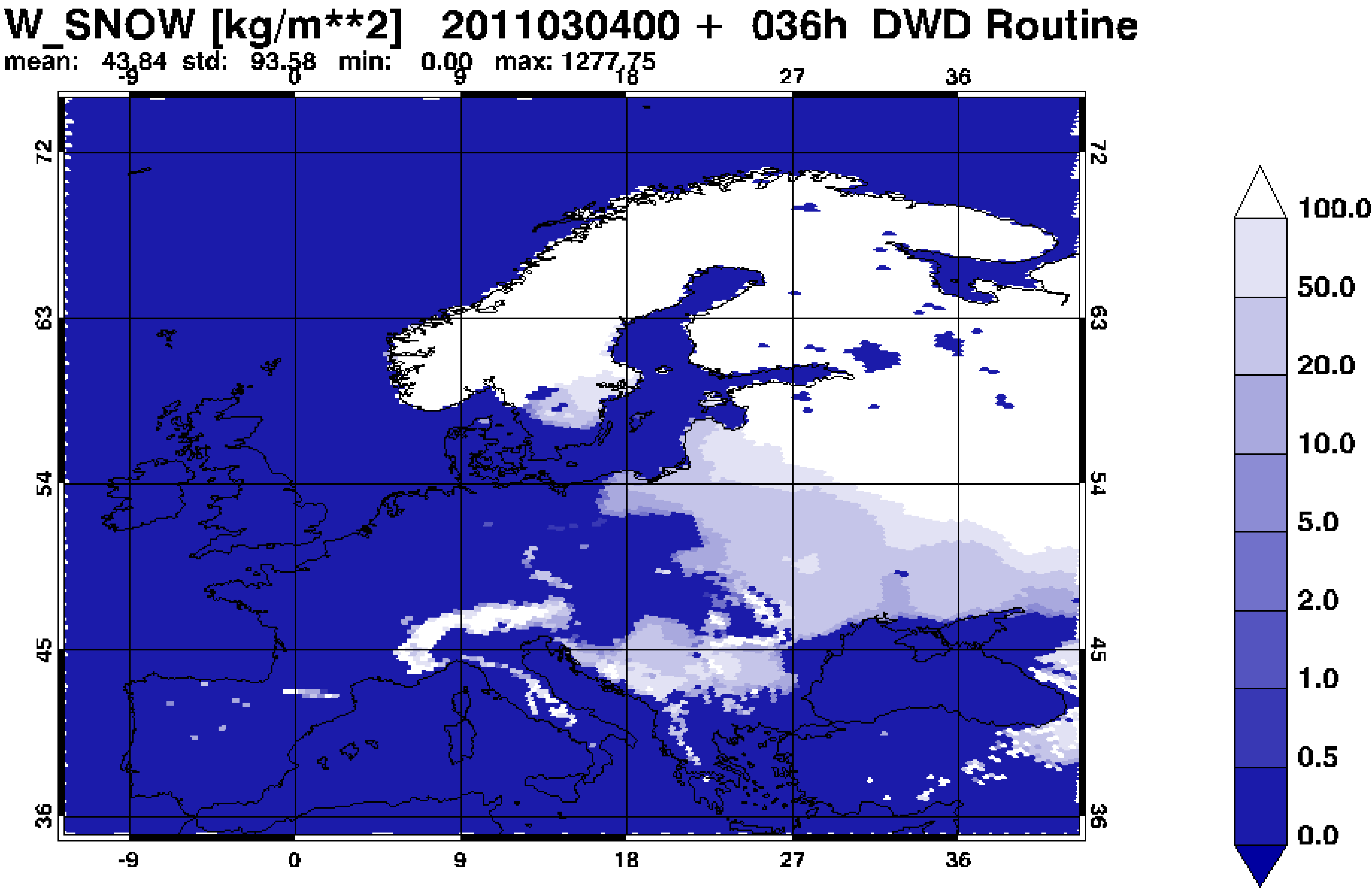


mean values

observations	:	263.41
model	:	264.01
bias	:	-0.60

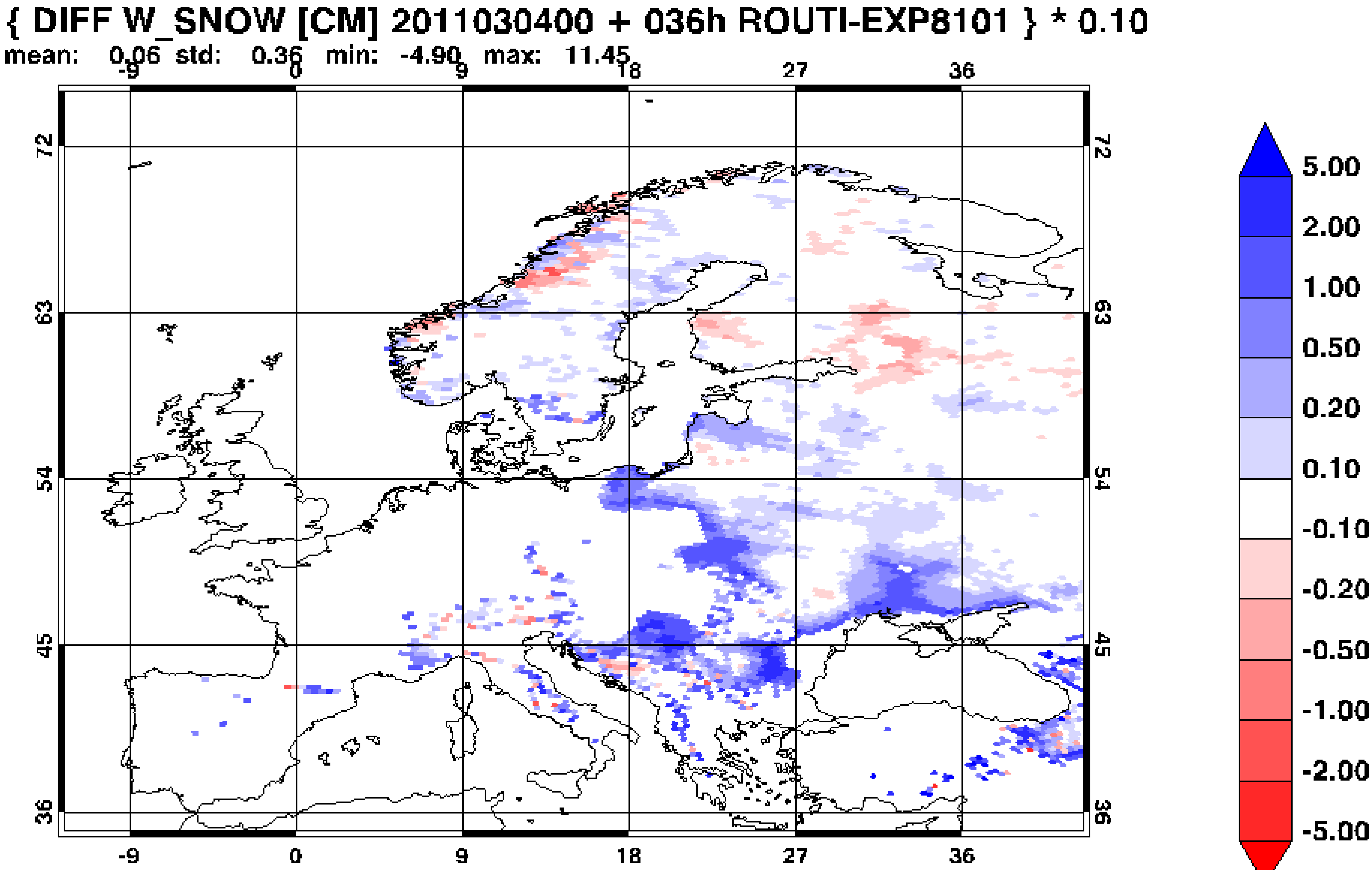
Case study 05.03.11 12 UTC

Deutscher Wetterdienst
Wetter und Klima aus einer Hand



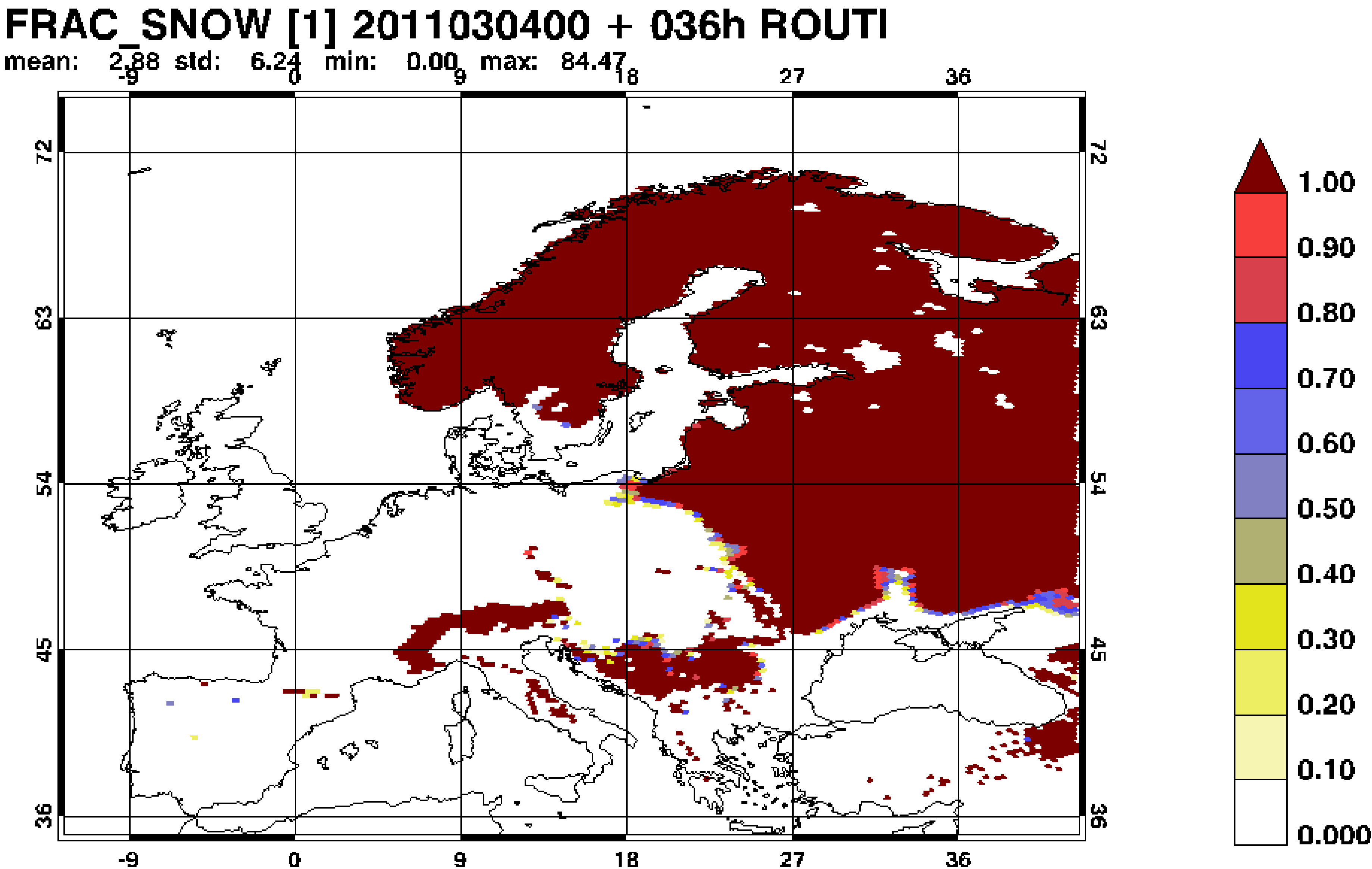
W_SNOW DIFF

Deutscher Wetterdienst
Wetter und Klima aus einer Hand



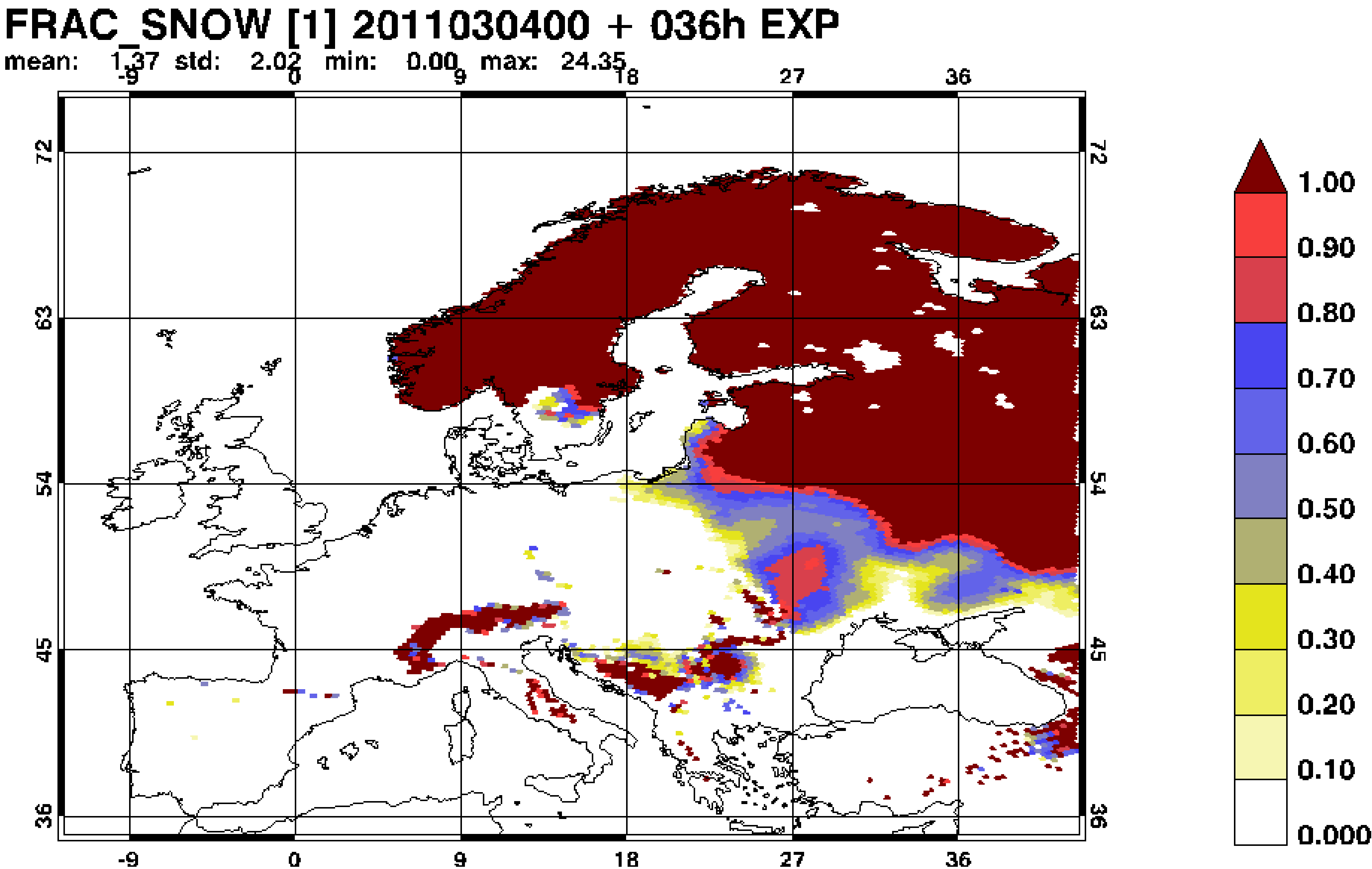
Snow Fraction ROUTI

Deutscher Wetterdienst
Wetter und Klima aus einer Hand



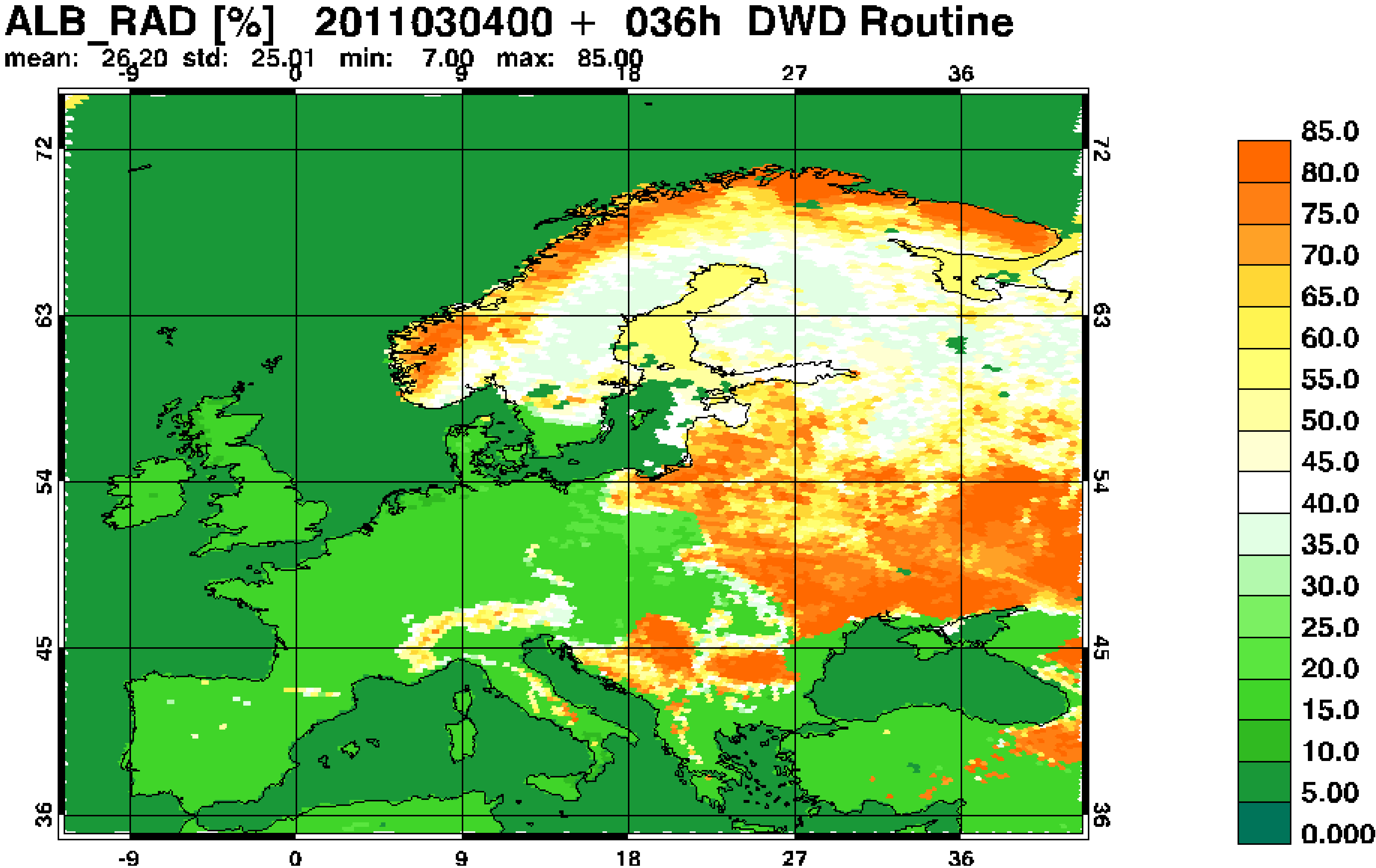
Snow Fraction EXP

Deutscher Wetterdienst
Wetter und Klima aus einer Hand



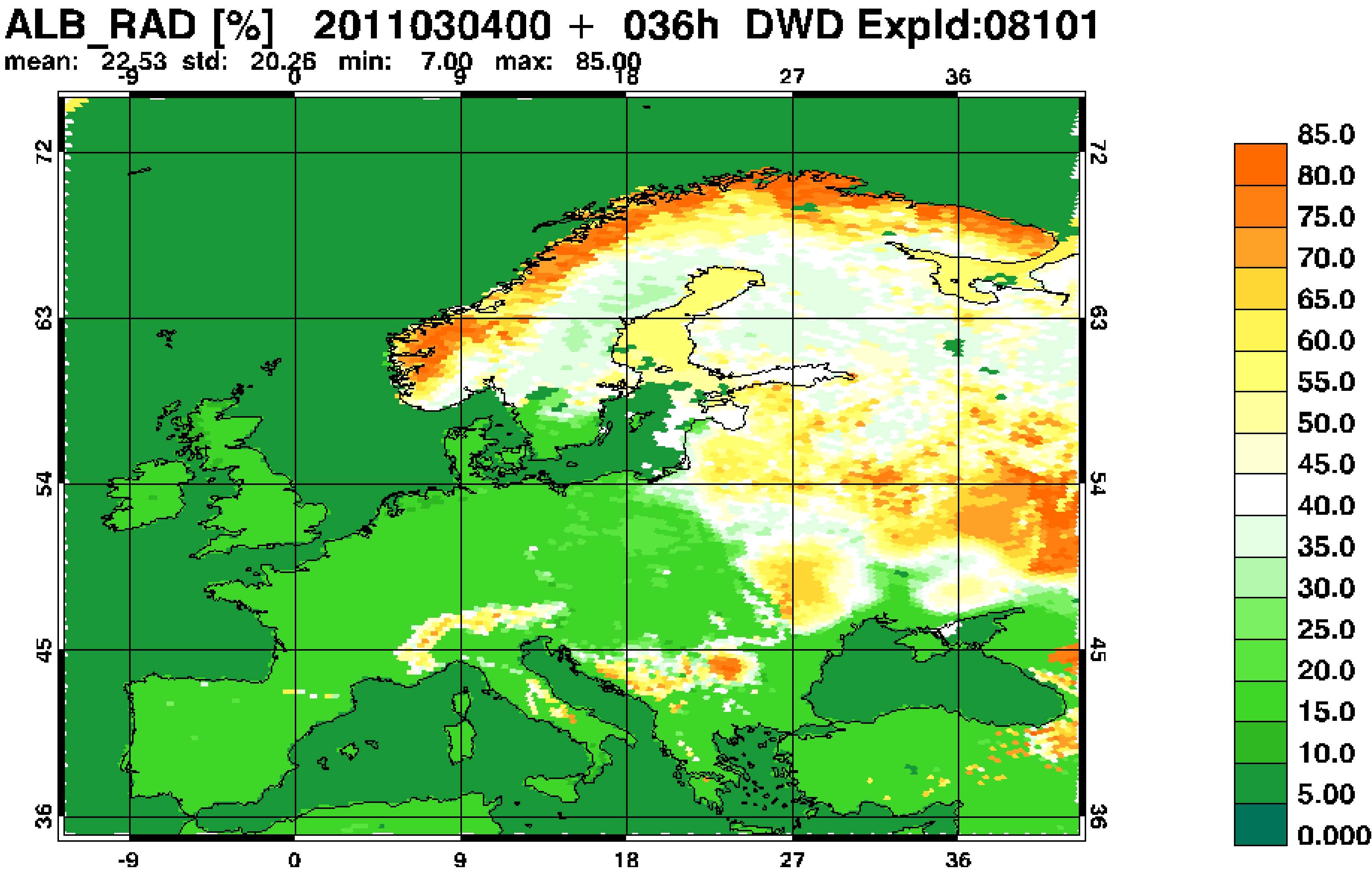
Albedo ROUTI

Deutscher Wetterdienst
Wetter und Klima aus einer Hand



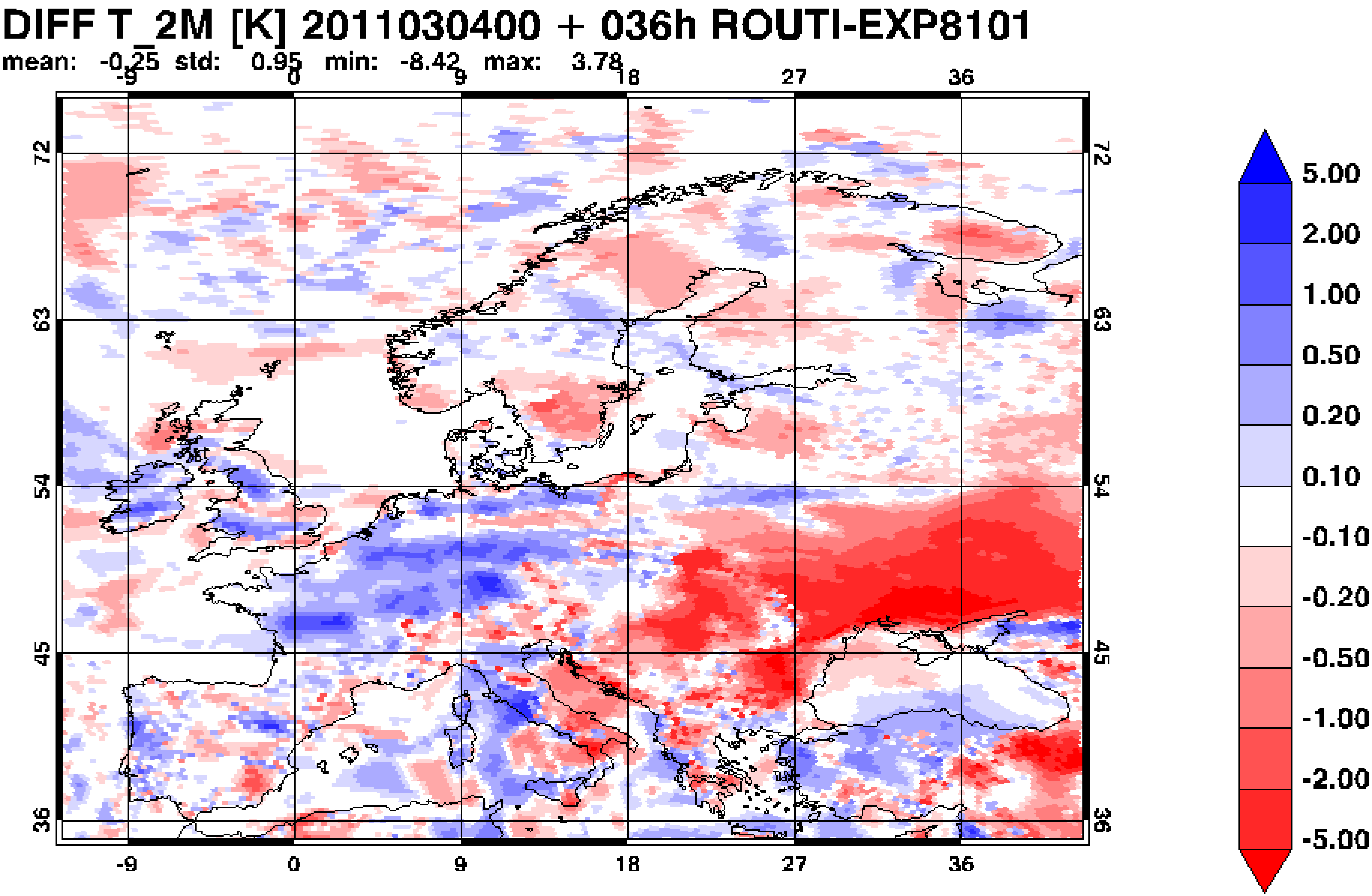
Albedo EXP

Deutscher Wetterdienst
Wetter und Klima aus einer Hand



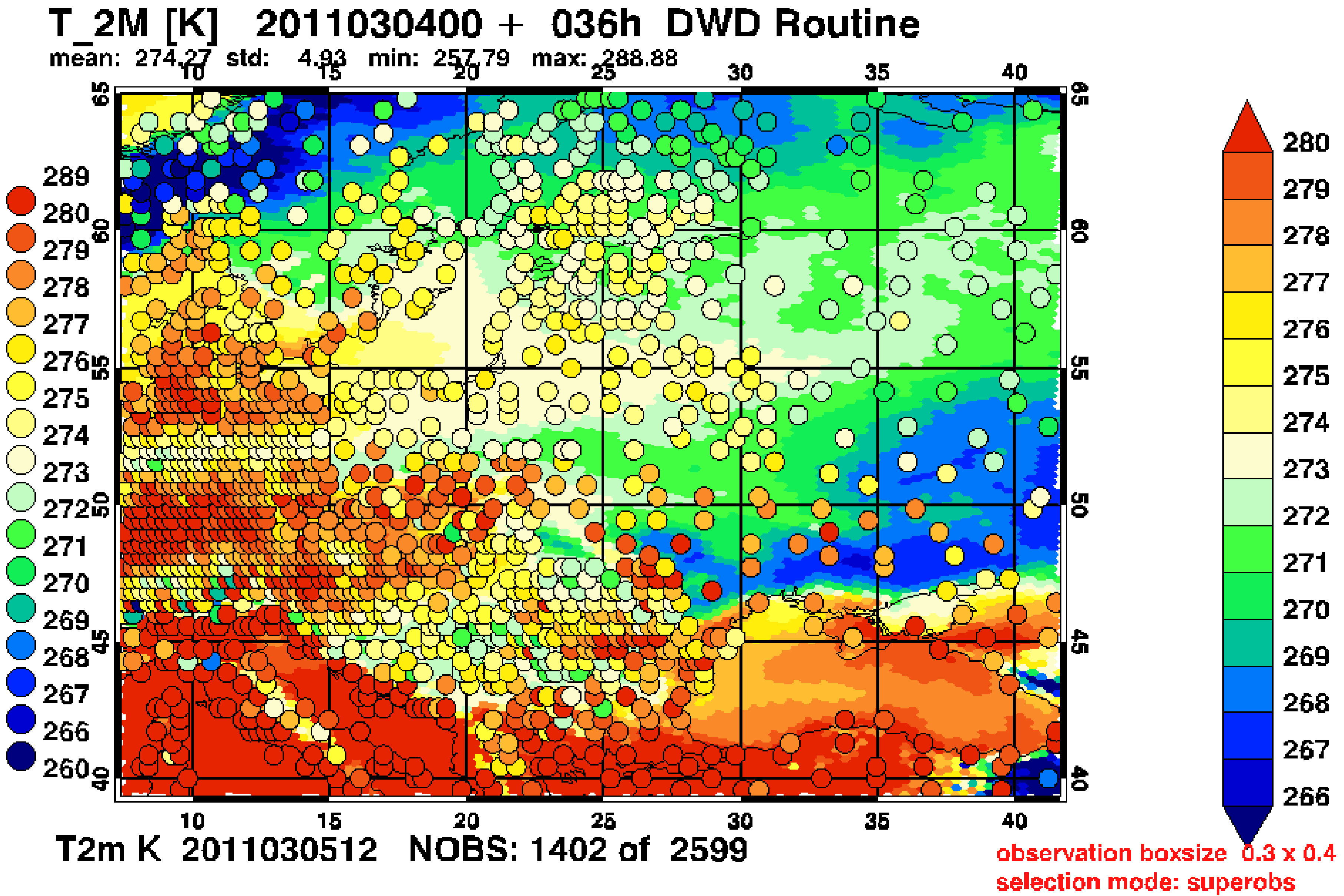
T_2M DIFF

Deutscher Wetterdienst
Wetter und Klima aus einer Hand



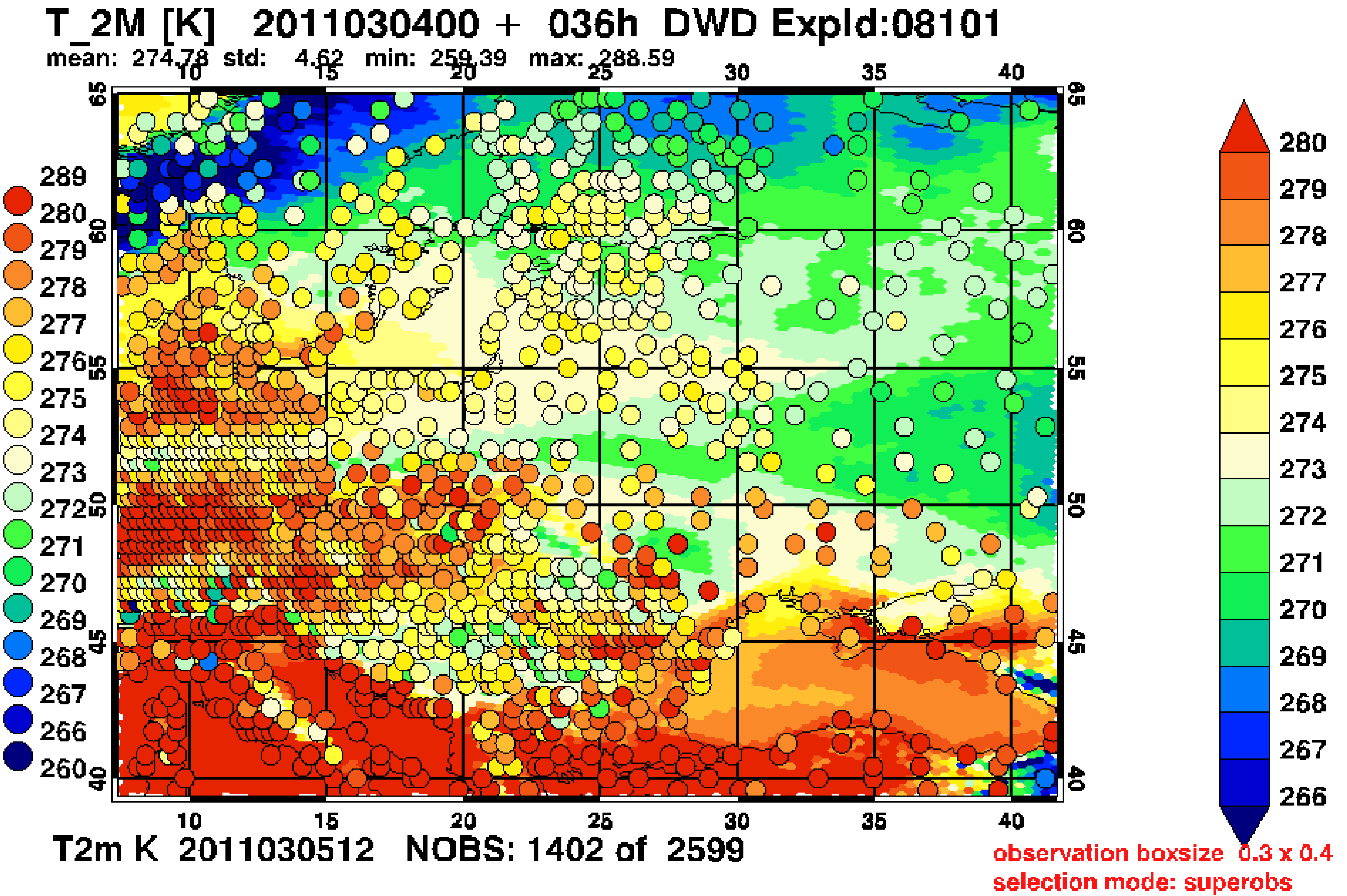
T_2M OBS with GME ROUTI

Deutscher Wetterdienst
Wetter und Klima aus einer Hand



T_2M OBS wih GME EXP

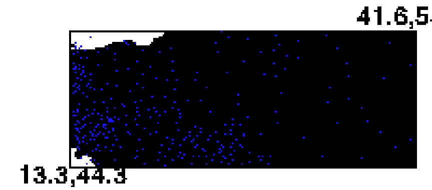
Deutscher Wetterdienst
Wetter und Klima aus einer Hand

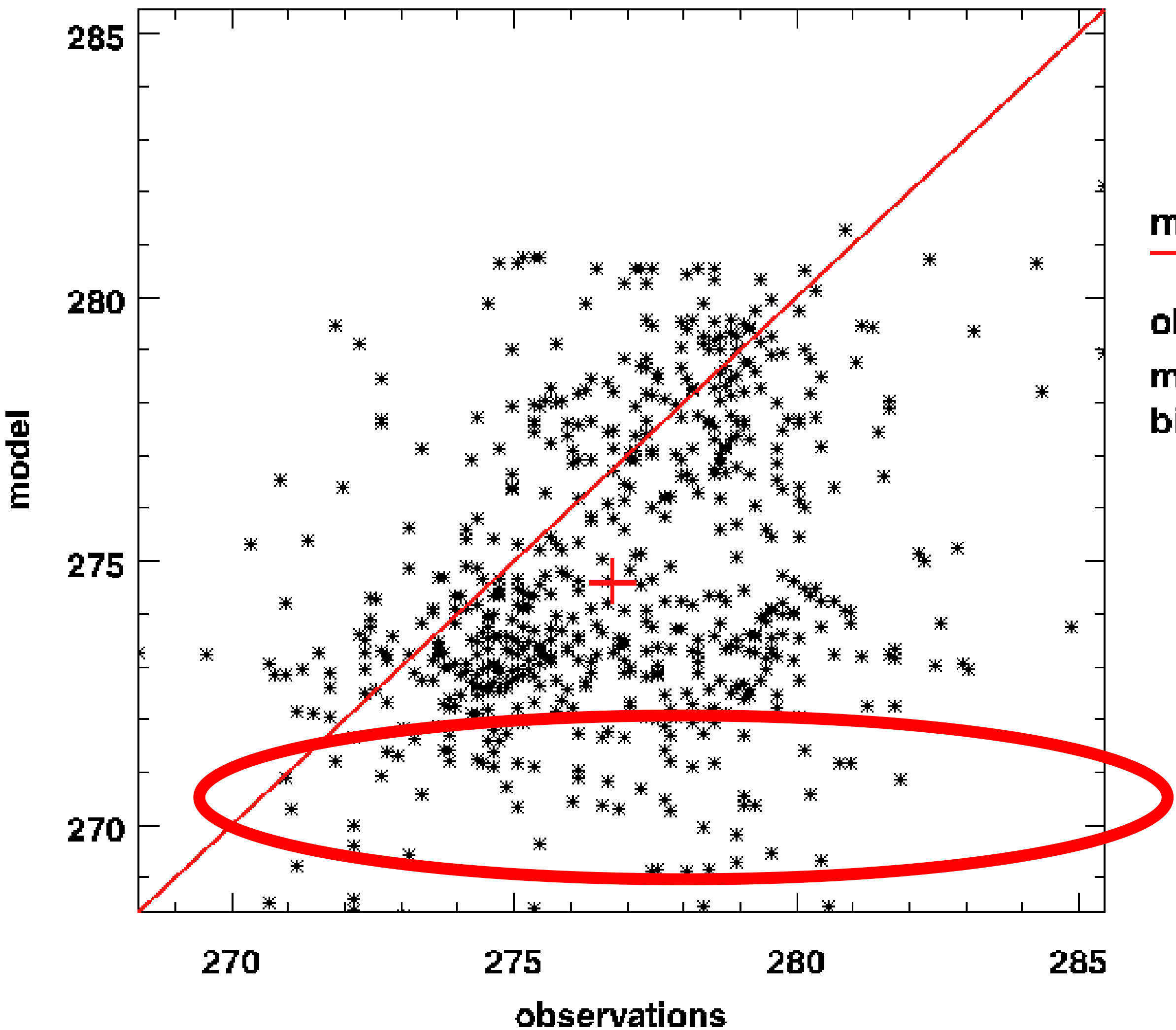


T2M OBS ROUTI

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Model field : T_2M [K] 2011030400 + 036h DWD Routine
Observations: T2m K 2011030512 n= 711

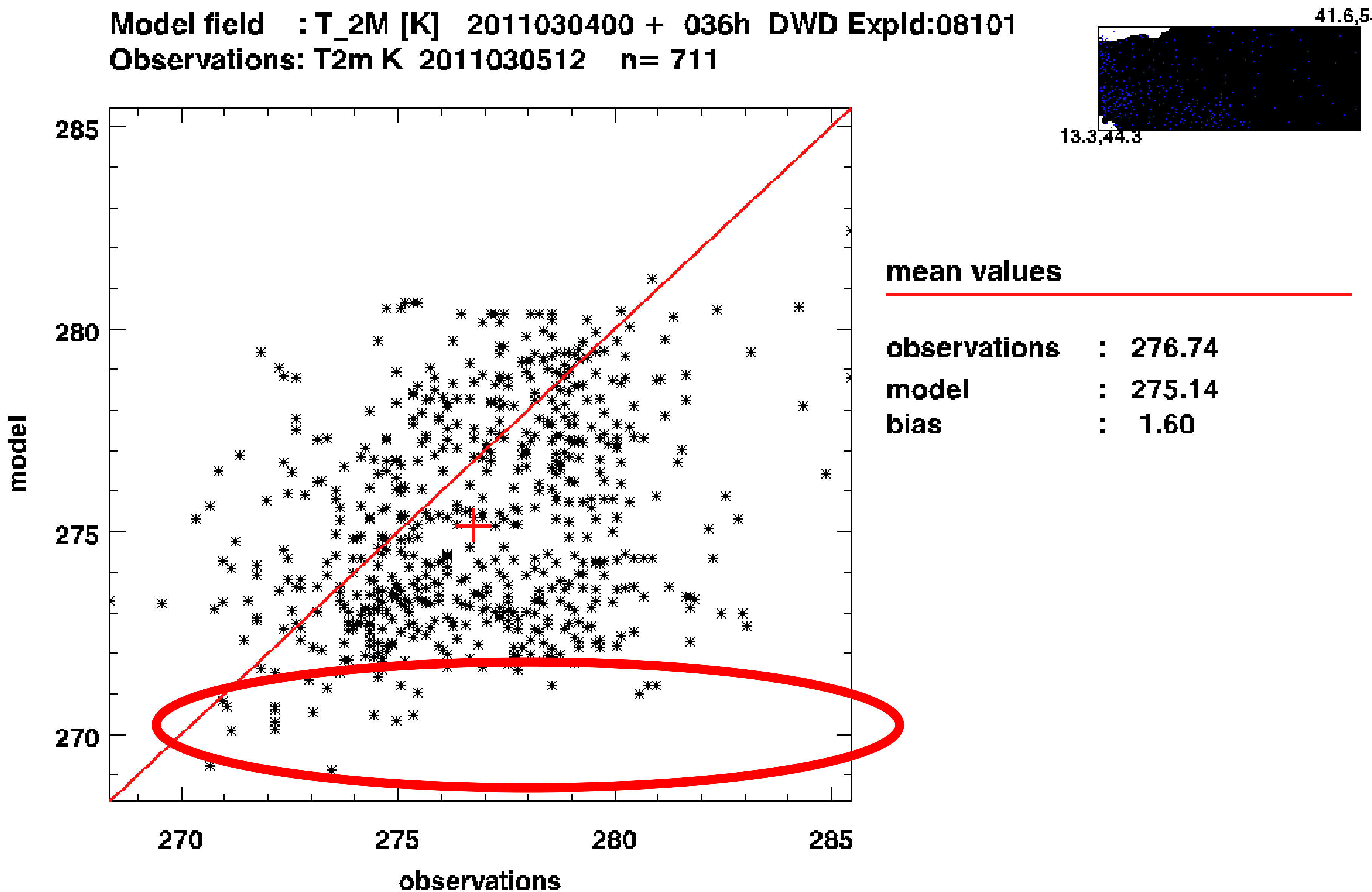




mean values

observations : 276.74
model : 274.60
bias : 2.15

T_2M OBS EXP



mean values

observations	:	276.74
model	:	275.14
bias	:	1.60

Snow fraction

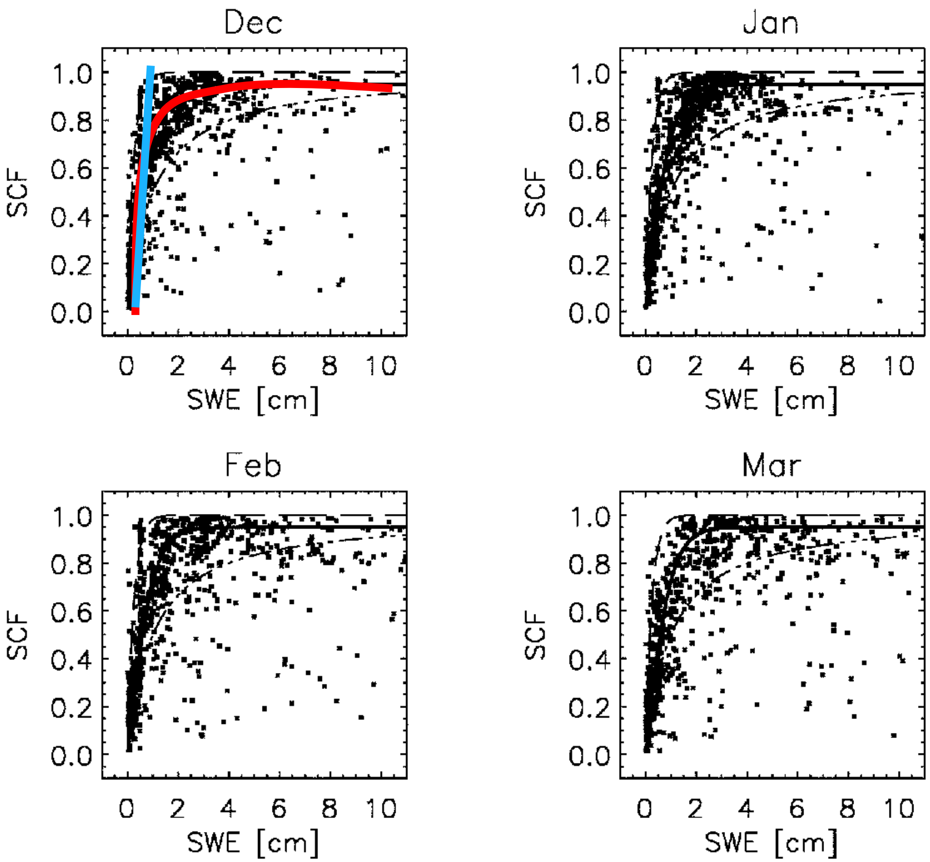


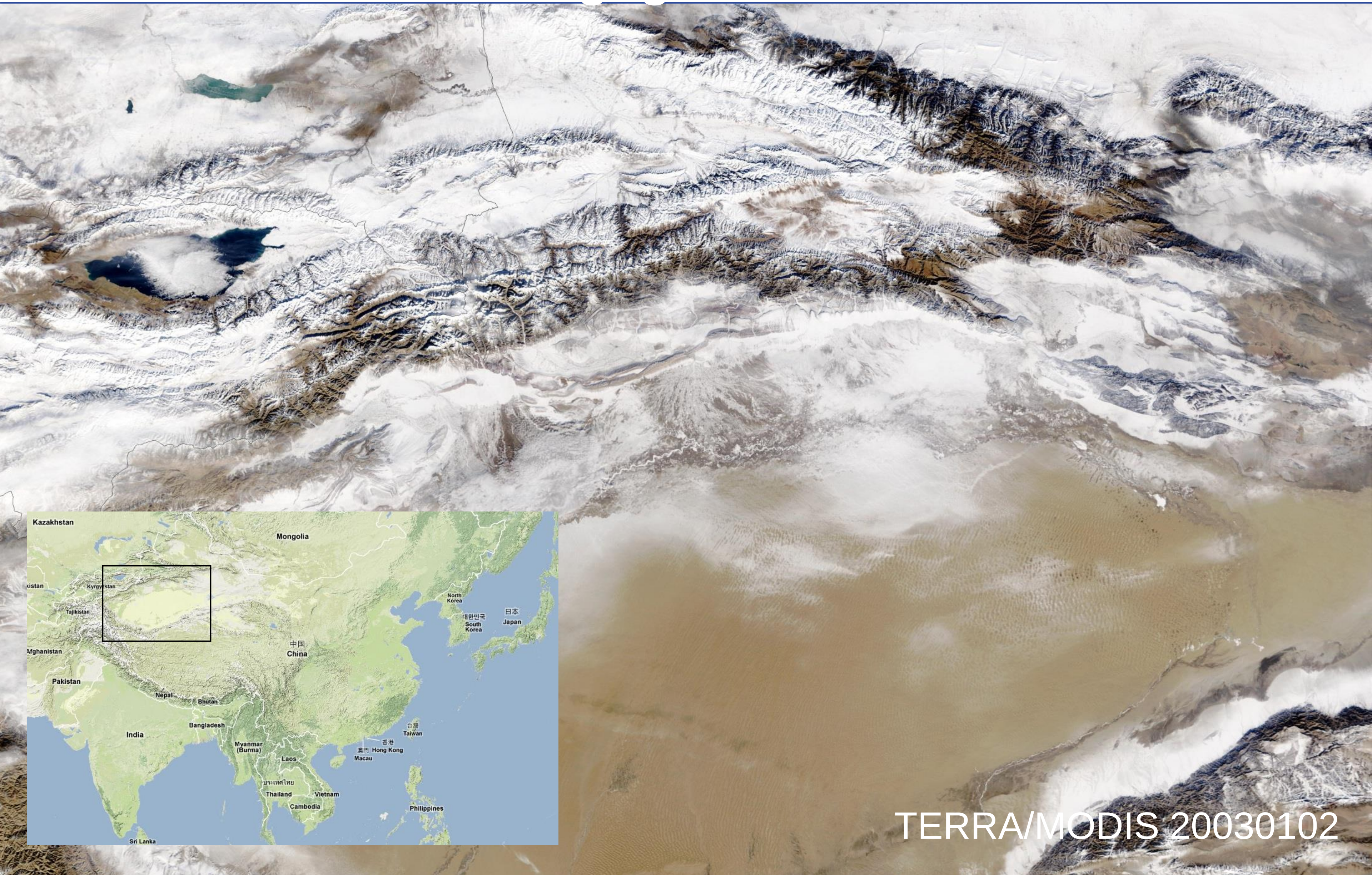
Fig. 3 SCF as a function of SWE in flat, non-forested T106 grid cells. SWE interpolated from USAF snow depth climatology; SCF from NOAA data (1973–1996). Curves are displayed for the new parametrization (*solid thick line*, Eq. 6), "Europa-Modell" (EM, *long-dashed*) and ECHAM (*dash-dotted*, Eq. 2)

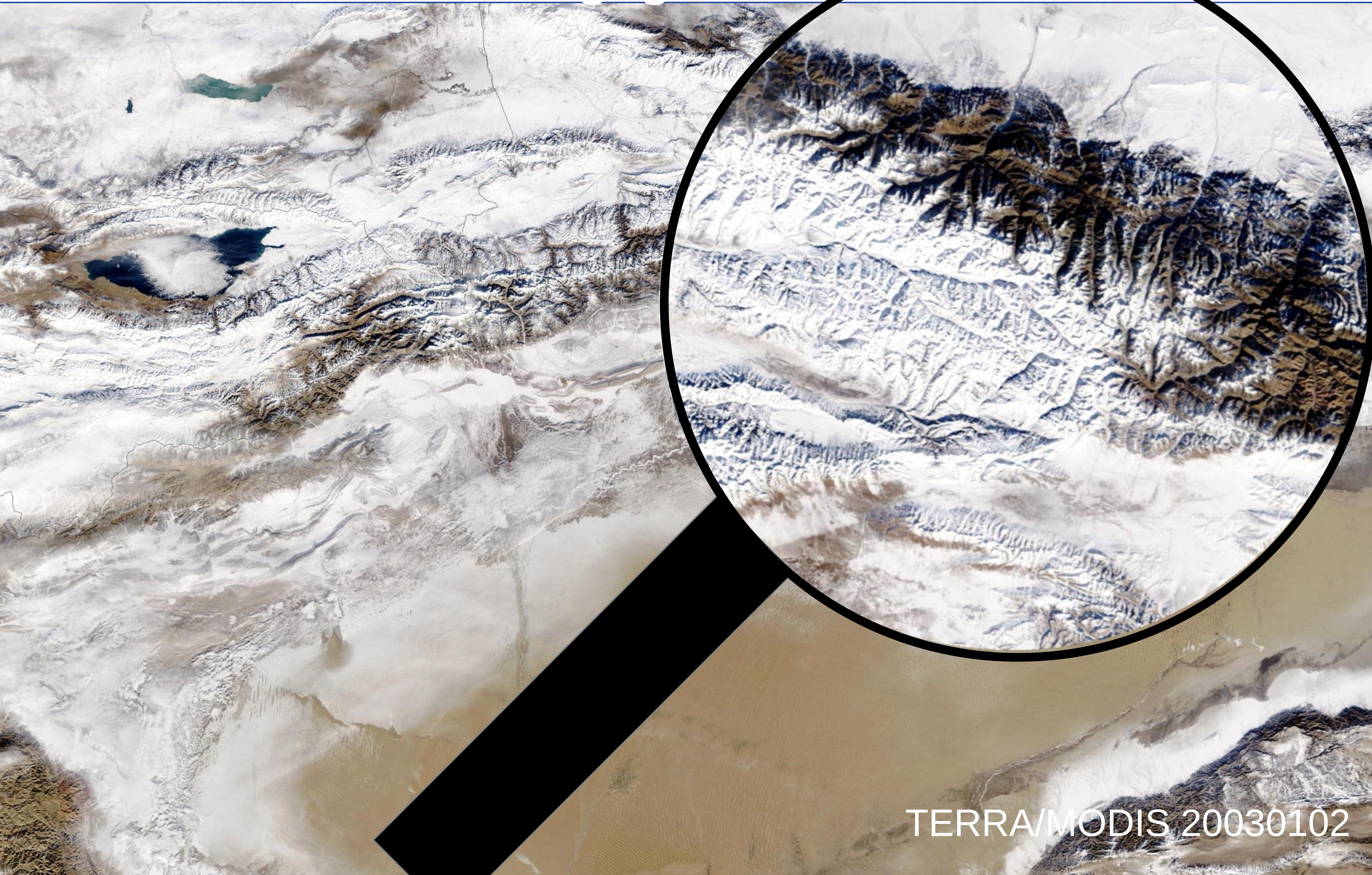
$$f_s = \frac{SWE}{0.015m}$$

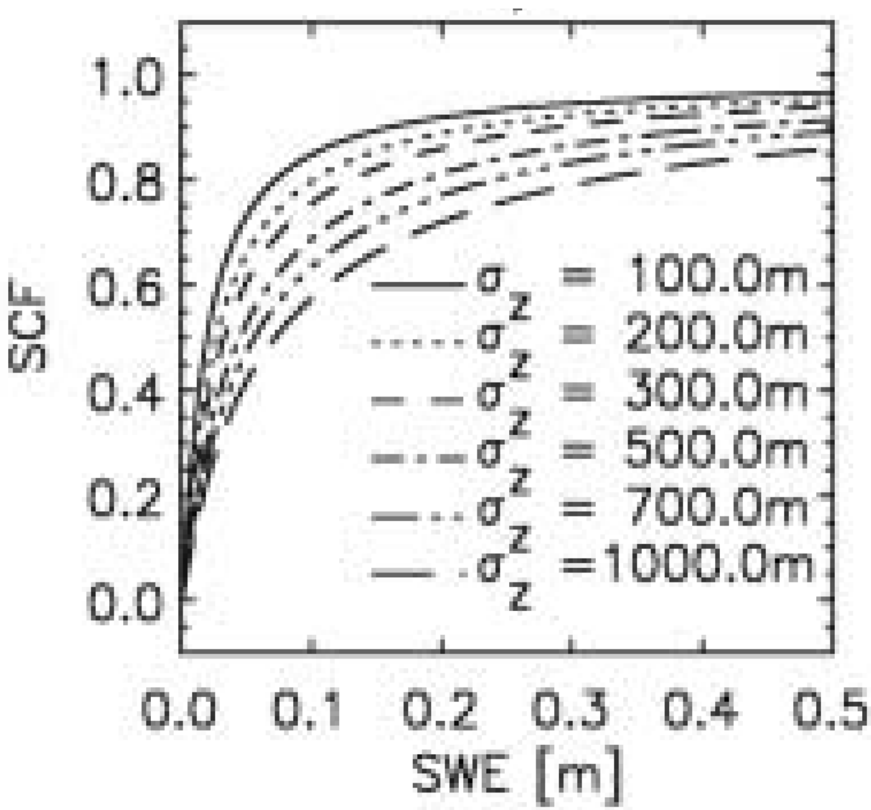
$$f_s = b\tanh(aSWE)$$

$$a = 100m^{-1} \quad b = 0.95$$

Roesch et al., 2001


Kazakhstan
Mongolia
Kyrgyzstan
Tajikistan
Afghanistan
Pakistan
Nepal
Bhutan
India
Bangladesh
Myanmar (Burma)
Laos
Thailand
Vietnam
Cambodia
Sri Lanka
中国
China
North Korea
대한민국
South Korea
日本
Japan
台灣
Taiwan
香港
Hong Kong
澳門
Macau
Philippines
TERRA/MODIS 20030102


TERRA/MODIS 20030102



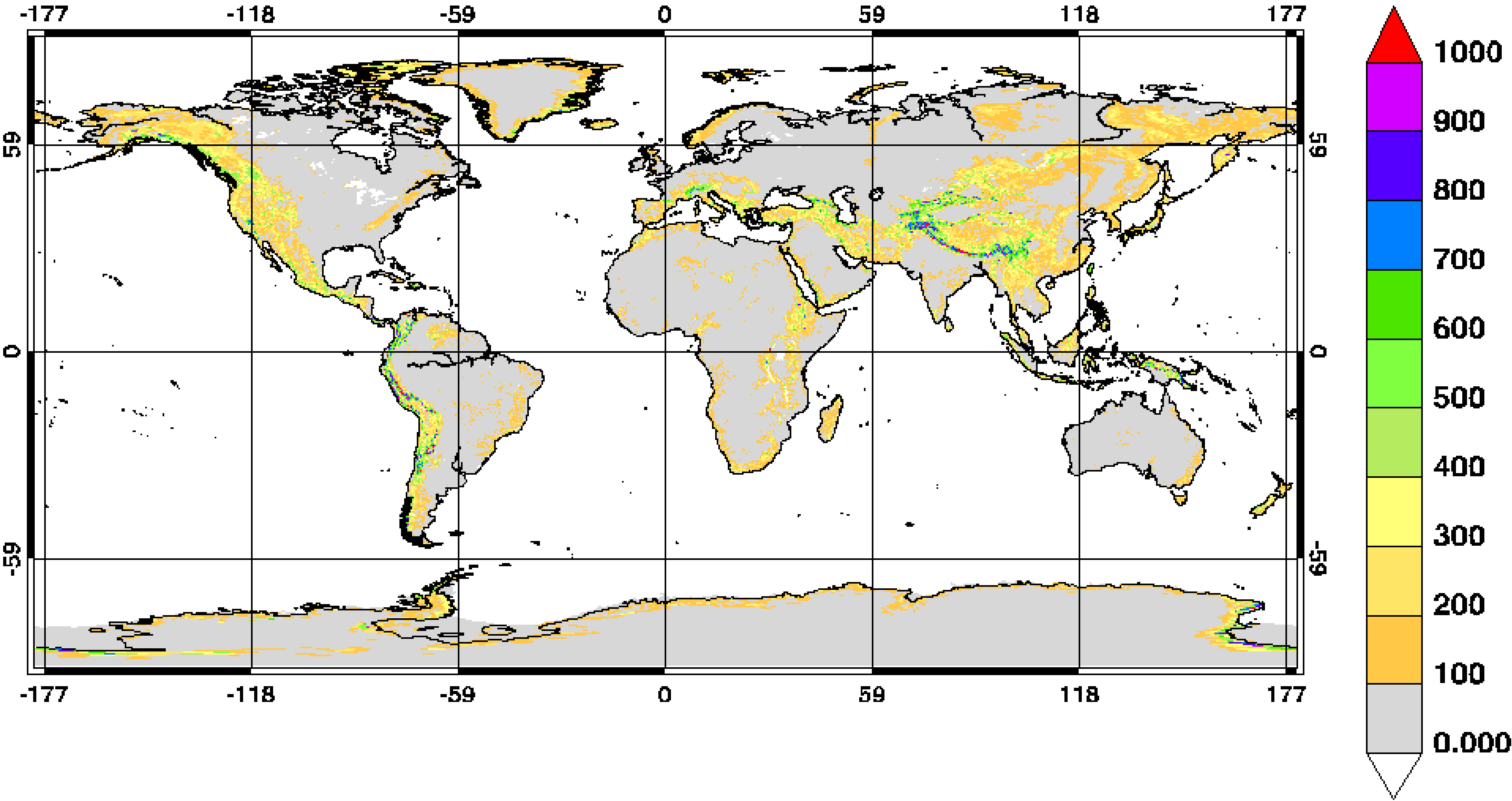
- Decrease of SCF in alpine regions
- Aim: More realistic albedo
- Impact factors: thermal exposition, avalanches
- Consideration of subgrid orography (Douville et al., 1995)

$$f_s = b\tanh(aSWE_n)\sqrt{\frac{1000SWE}{1000SWE+\varepsilon+0.15\sigma_z}}$$

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

SSO_STDH [m] 1010100 + 000h DWD Routine

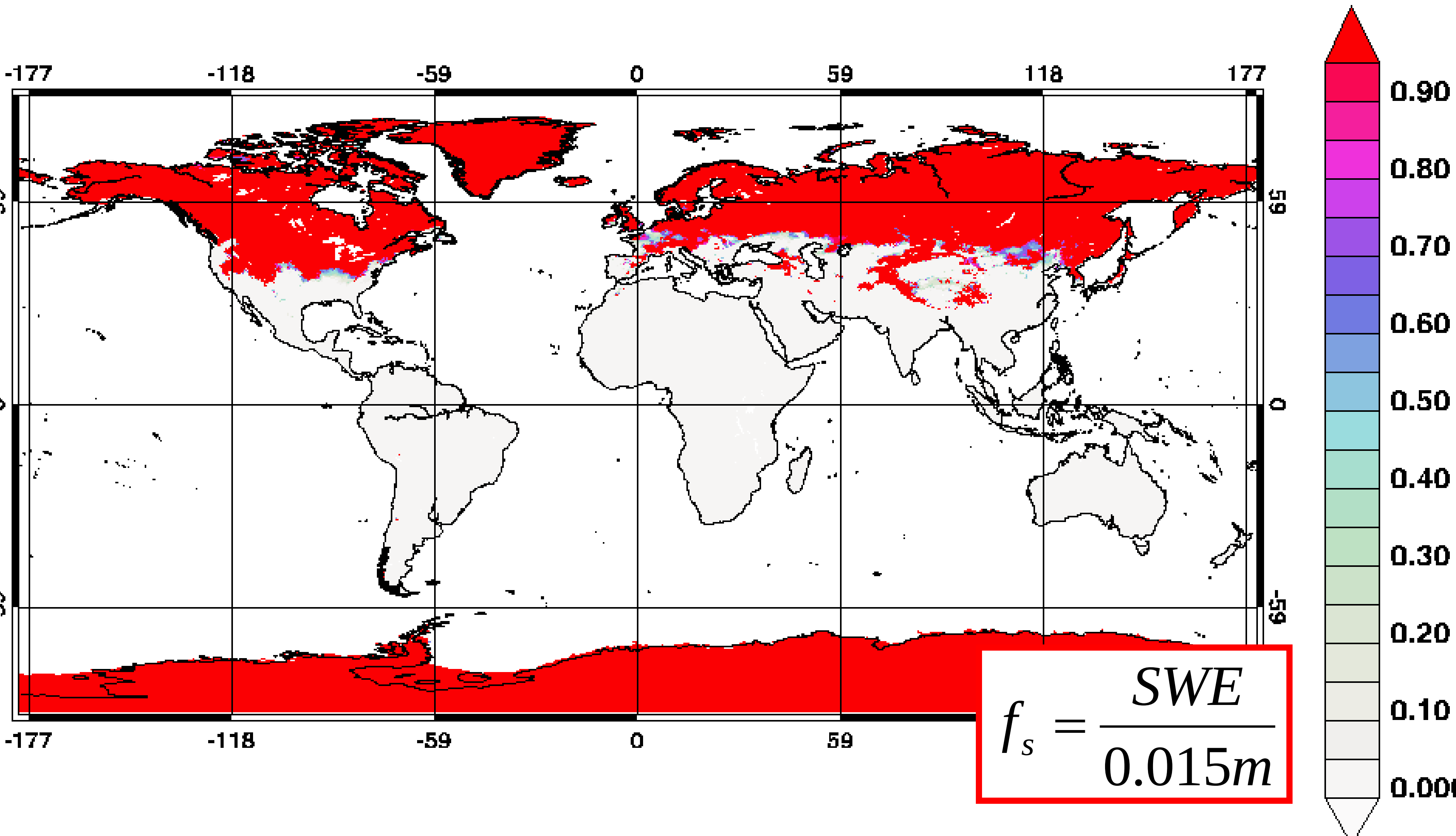
mean: 104.77 std: 138.71 min: 0.00 max: 1457.16



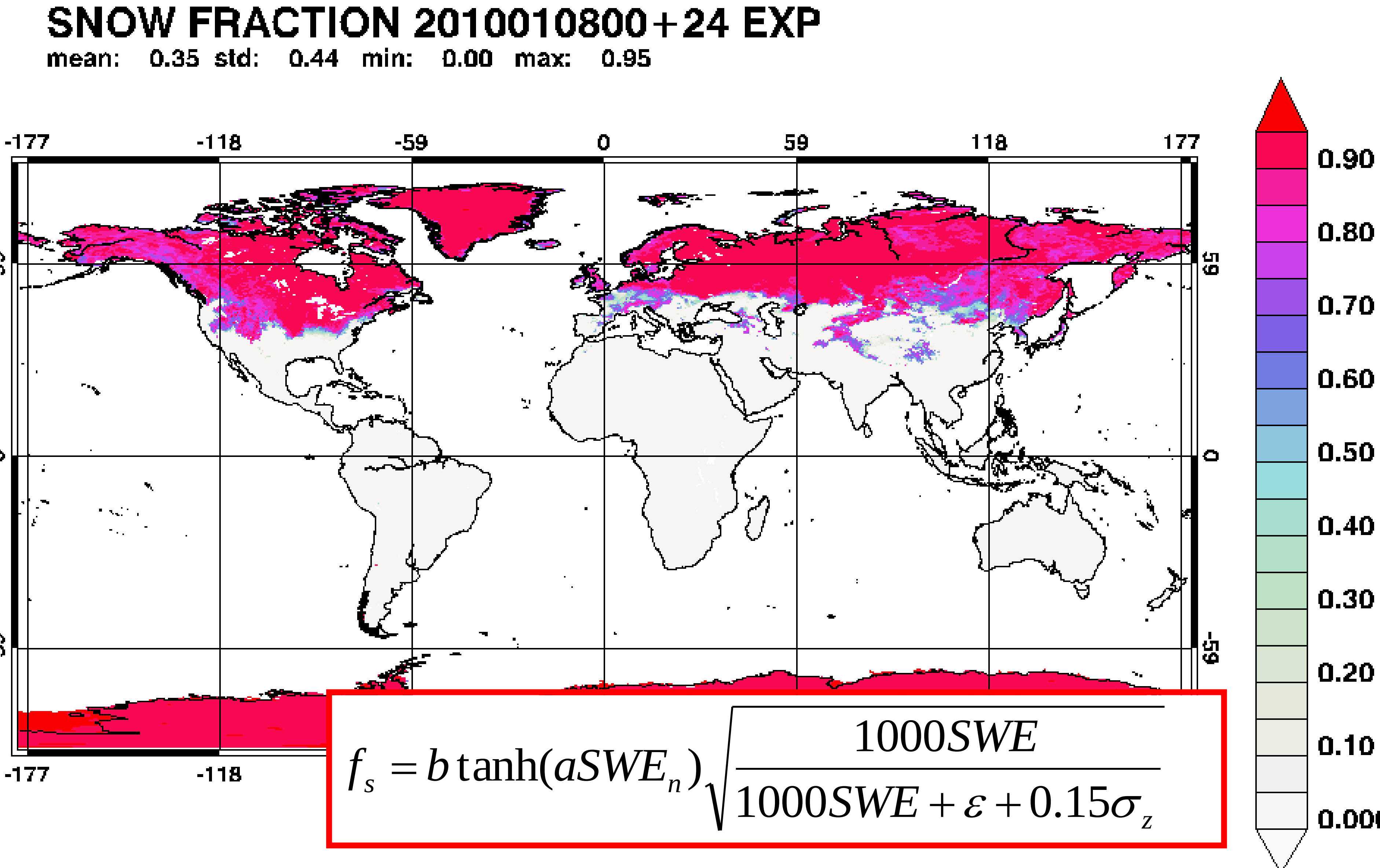
Deutscher Wetterdienst
Wetter und Klima aus einer Hand

SNOW FRACTION 2010010800+24 ROUTI

mean: 115.75 std: 327.28 min: 0.00 max: 1068.33



$$f_s = \frac{SWE}{0.015m}$$



$$f_s = b\tanh(aSWE_n)\sqrt{\frac{1000SWE}{1000SWE+\varepsilon+0.15\sigma_z}}$$

Summary

- Snow model treatment in WG 3 of COST 1404
- Case study of wrong model forecast due to wrong snow properties
- Important snow parameters in NWP snow models (depth, density, (SWE), albedo)
- Impact studies of different approaches
- Aim: Exchange of useful parameter setups for NWP models