Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Simulation of Snow Cover Evolution by means of the model SNOW4

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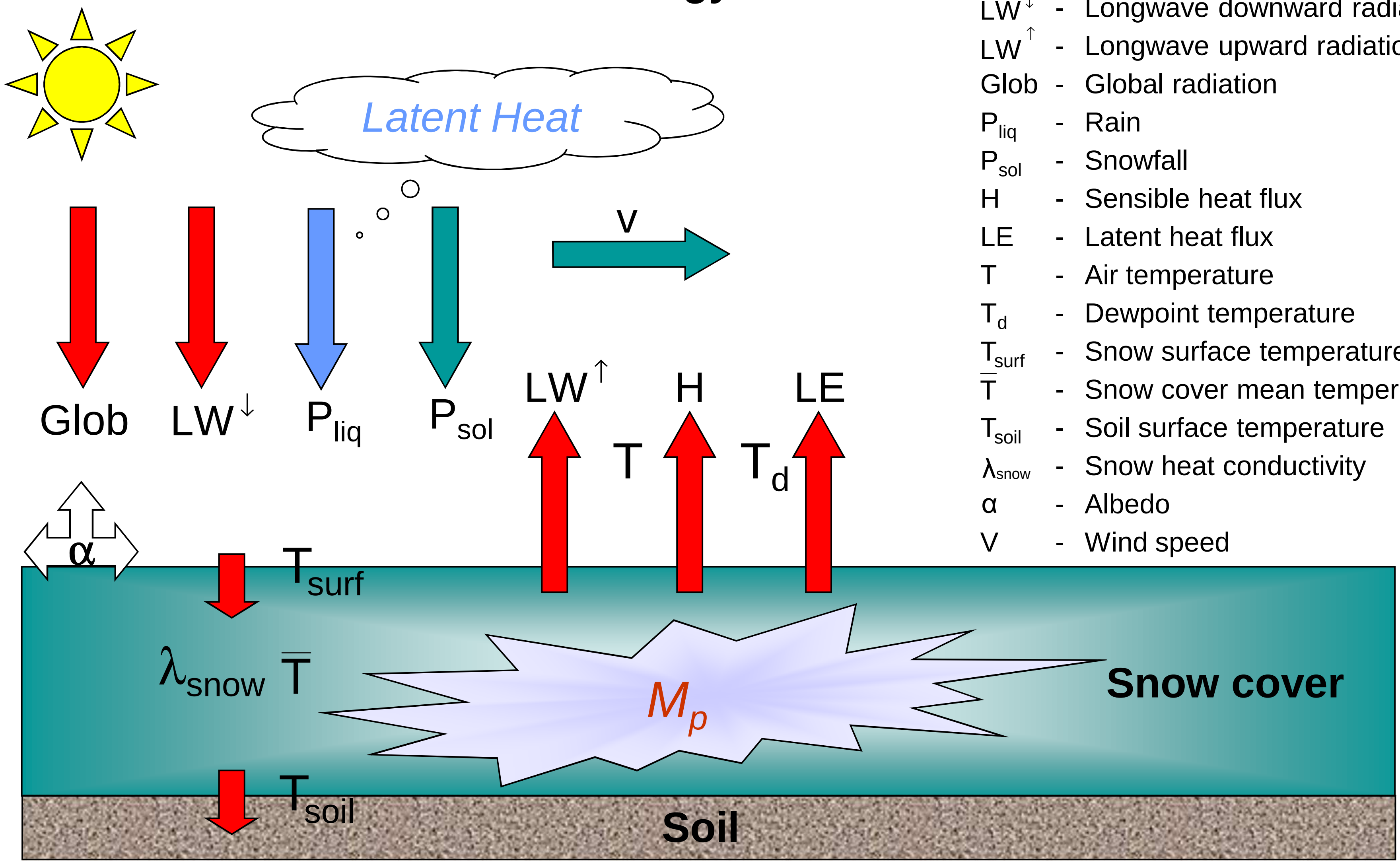
Outline

- Model Physics
- Modules & Model Configuration
- Input Data & Computing Time
- Model Evaluation
- Summary & Outlook

Model Physics

Energy Balance



- M_p - Melting heat
- $LW^{\downarrow}$ - Longwave downward radiation
- $LW^{\uparrow}$ - Longwave upward radiation
- Glob - Global radiation
- P_{liq} - Rain
- P_{sol} - Snowfall
- H - Sensible heat flux
- LE - Latent heat flux
- T - Air temperature
- T_d - Dewpoint temperature
- T_{surf} - Snow surface temperature
- $\overline{T}$ - Snow cover mean temperature
- T_{soil} - Soil surface temperature
- λ_{snow} - Snow heat conductivity
- α - Albedo
- V - Wind speed

Snow Surface Energy Balance Equation

$$\underbrace{M_p}_{\text{meltingheat}} = \underbrace{\lambda_{snow}\cdot\frac{T_{surf}-\overline{T}}{D_{n_1}} + \lambda_{snow}\cdot\left(T_{soil}-\overline{T}\right)\cdot\left(\frac{1}{D_{n_2}} - \frac{1}{\max\left(0.04\text{m}, D_{n_2}/2\right)}\right)}_{\text{snow heat conduction}}$$

$$- \underbrace{(H+LE)}_{\text{sensible \& latent heat flux}} + \underbrace{LW^{\downarrow} - LW^{\uparrow}}_{\text{longwave radiation balance}} + \underbrace{Glob}_{\text{shortwave radiation balance}}$$

$$- \left[\underbrace{P_{liq}^{corr}\cdot c_w\cdot\left(T_{liq}-T_{surf}\right)}_{\text{internal heat of rain}} + \underbrace{P_{sol}^{corr}\cdot c_{ice}\cdot\left(T_{soil}-T_{surf}\right)}_{\text{internal heat of snowfall}}\right.$$

$$\left. - \underbrace{\left((c_w - c_{ice})\cdot\frac{\Delta P_{liq}}{\Delta t}\cdot T_{surf} + L_{melt}\cdot\frac{\Delta P_{liq}}{\Delta t}\right)}_{\text{conversion heat rain}\rightarrow\text{snow}}\right]$$

$$D_{n_1} = \frac{1}{\sqrt{2}}\cdot\left(\frac{\lambda_{snow}\cdot 24\,h}{P_d\cdot c_{ice}\cdot\pi}\right)^{1/2}$$

$$D_{n_2} = \max\left(D_{n_1}, D_{n}/2\right)$$

P_{liq}^{corr} – Corrected rain

P_{lsol}^{corr} – Corrected snowfall

T_{liq} – Temperature of rain

c_w – Heat capacity of water

c_{ice} – Heat capacity of ice

Δt – Time step

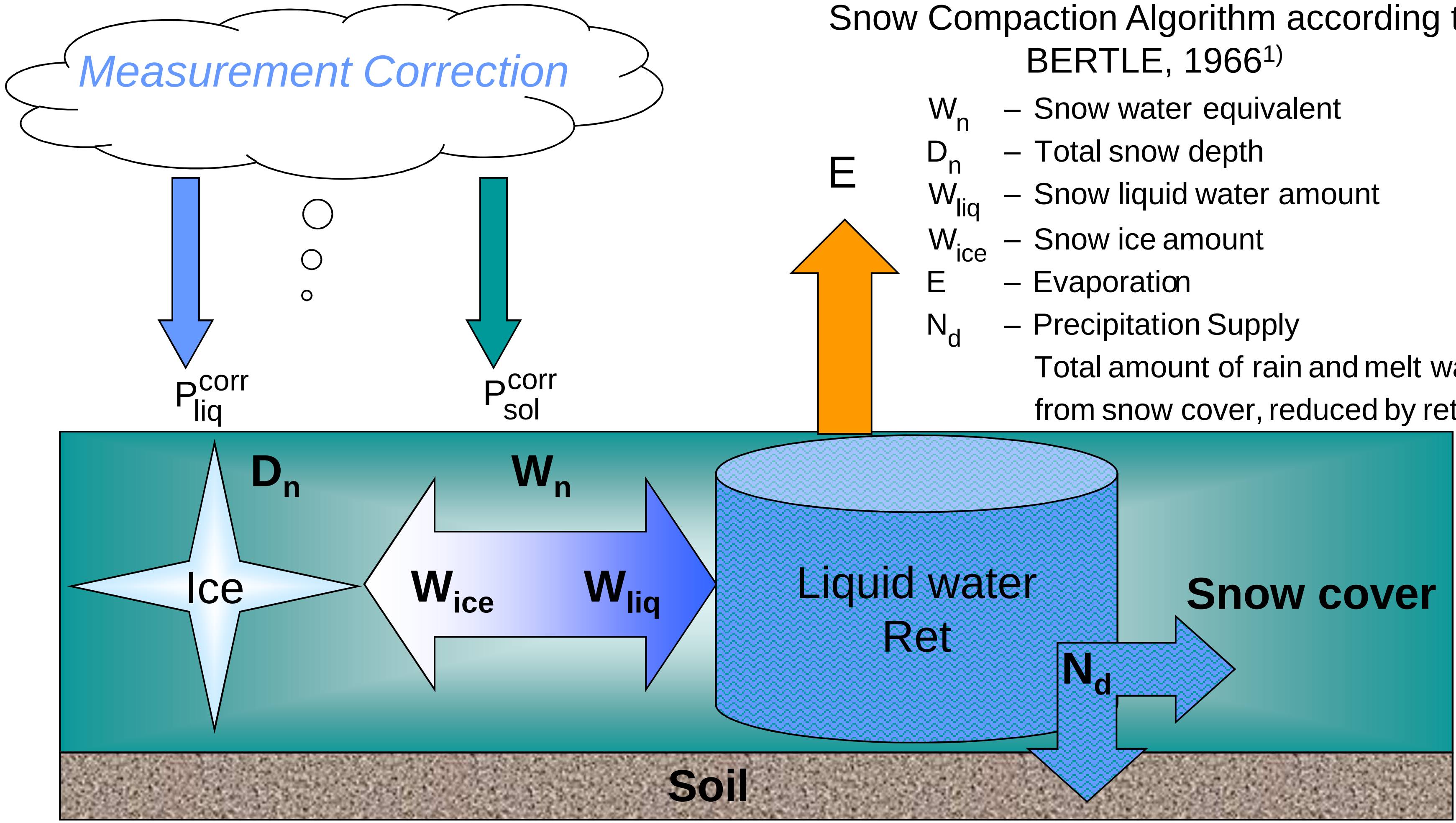
$\frac{\Delta P_{liq}}{\Delta t}$ – Change of rain per time step

L_{melt} – Specific heat of melting

$$P_d = \frac{W_n}{D_n}$$

Mass Balance

Snow Compaction Algorithm according to BERTLE, 1966[1)]



- W_n – Snow water equivalent
- D_n – Total snow depth
- W_{liq} – Snow liquid water amount
- W_{ice} – Snow ice amount
- E – Evaporation
- N_d – Precipitation Supply
  Total amount of rain and melt water from snow cover, reduced by retention

1) Bertle, F.A., 1966: Effect of Snow Compaction on Runoff From Rain on Snow. United States Department of the Interior, Bureau of Reclamation: Water Resources Technical Publication, Engineering Monograph No. 35.

Basic Mass Balance Equations - Time Integration - 1

$$W_{n_{t+\Delta t}} = W_{n_t} + P_{liq}^{corr} + P_{sol}^{corr}$$

$$W_{n,dry_{t+\Delta t}} = W_{n,dry_t} + P_{sol}^{corr} - \underbrace{\frac{M_p \cdot \Delta t}{L_{melt}}}_{\text{melting amount}} - E_{t+\Delta t}$$

$$D_{n,dry_{t+\Delta t}} = \frac{W_{n,dry_{t+\Delta t}}}{\rho_{n,dry}}$$

$$\rho_{n,dry} = 0.11 \cdot 10^3 \frac{kg}{m^3}$$

$$D_{n_{t+\Delta t}} = \left(c_1 - c_2 \cdot \frac{W_{n_{t+\Delta t}}}{W_{n,dry_{t+\Delta t}}} \right) \cdot D_{n,dry_{t+\Delta t}}$$

$$\rho_{n_{t+\Delta t}} = \frac{W_{n_{t+\Delta t}}}{D_{n_{t+\Delta t}}}$$

$t+\Delta t$	– New (actual) time step
t	– Prevoious time step
$W_{n,dry}$	– Dry snow water equivalent
$D_{n,dry}$	– Dry snow depth
$\rho_{n,dry}$	– Density of dry snow
c_1	– Bertle algorithm constant
c_2	– Bertle algorithm constant; $c_2 = c_1 - 1$

Basic Mass Balance Equations - Time Integration - 2

Formation of N_d: $\rho_n > \rho_{n,crit}$

$$N_{d_{t+\Delta t}} = W_{n_{t+\Delta t}} - \rho_{n,crit} \cdot D_{n,crit}$$

$$D_{n,crit} = \left(c_1 - c_2 \cdot \frac{W_{n,crit_{t+\Delta t}}}{W_{n,dry_{t+\Delta t}}} \right) \cdot D_{n,dry_{t+\Delta t}}$$

$$W_{n,crit_{t+\Delta t}} = \frac{W_{n,dry_{t+\Delta t}} \cdot c_1}{\frac{\rho_{n,dry}}{\rho_{n,crit}} + c_2}$$

$$\rho_{n,crit} = 0.4 \cdot 10^{-3} \frac{kg}{m^3}$$

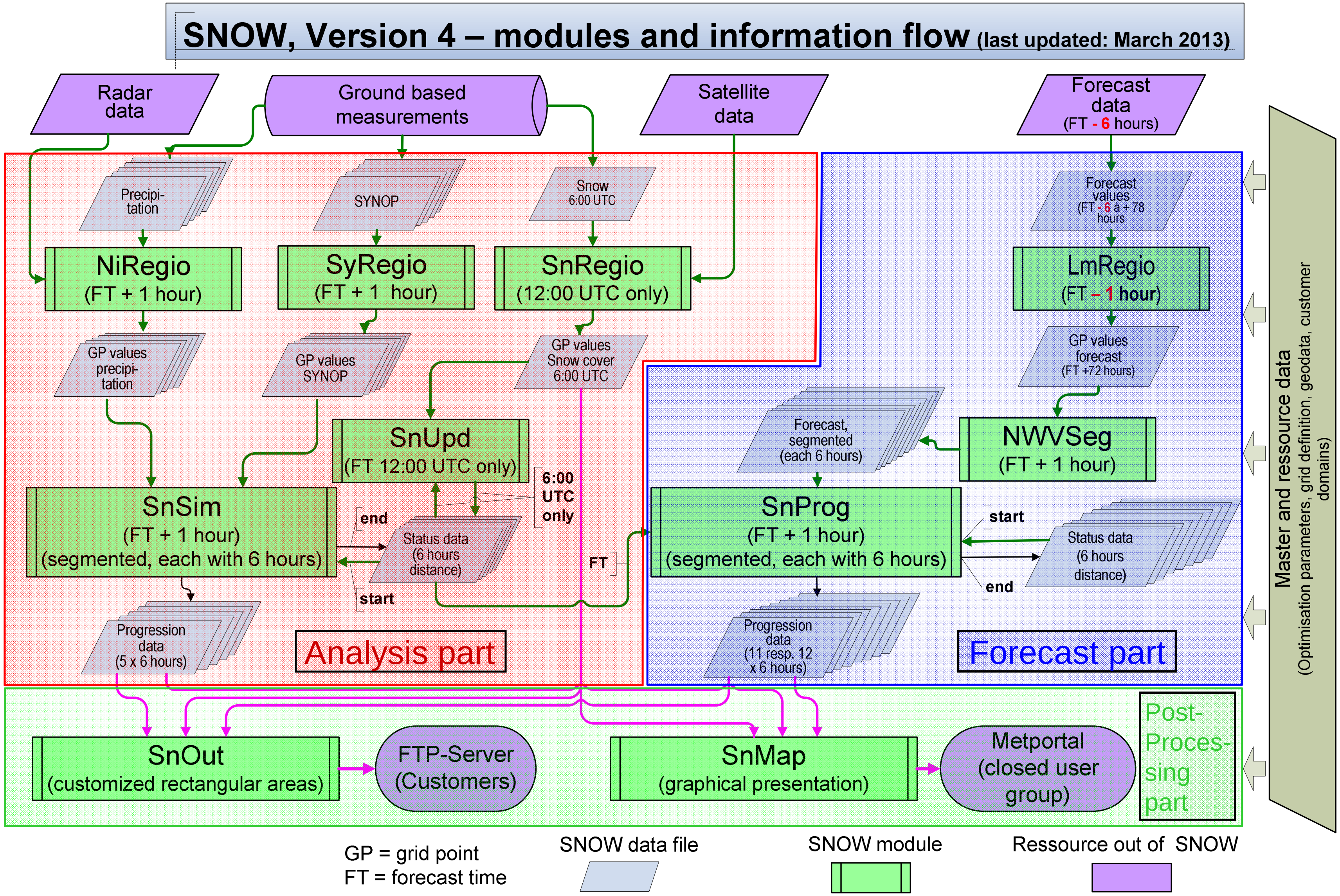
$$W^{updated}_{n_{t+\Delta t}} = W_{n_{t+\Delta t}} - N_{d_{t+\Delta t}}$$

$$D^{updated}_{n_{t+\Delta t}} = D_{n,crit}$$

$$\rho^{updated}_{n_{t+\Delta t}} = \rho_{n,crit}$$

$\rho_{n,crit}$ – Water saturation density of snow
$D_{n,crit}$ – Snow depth at water saturation
$W_{n,crit}$ – Water equivalent of snow at saturation

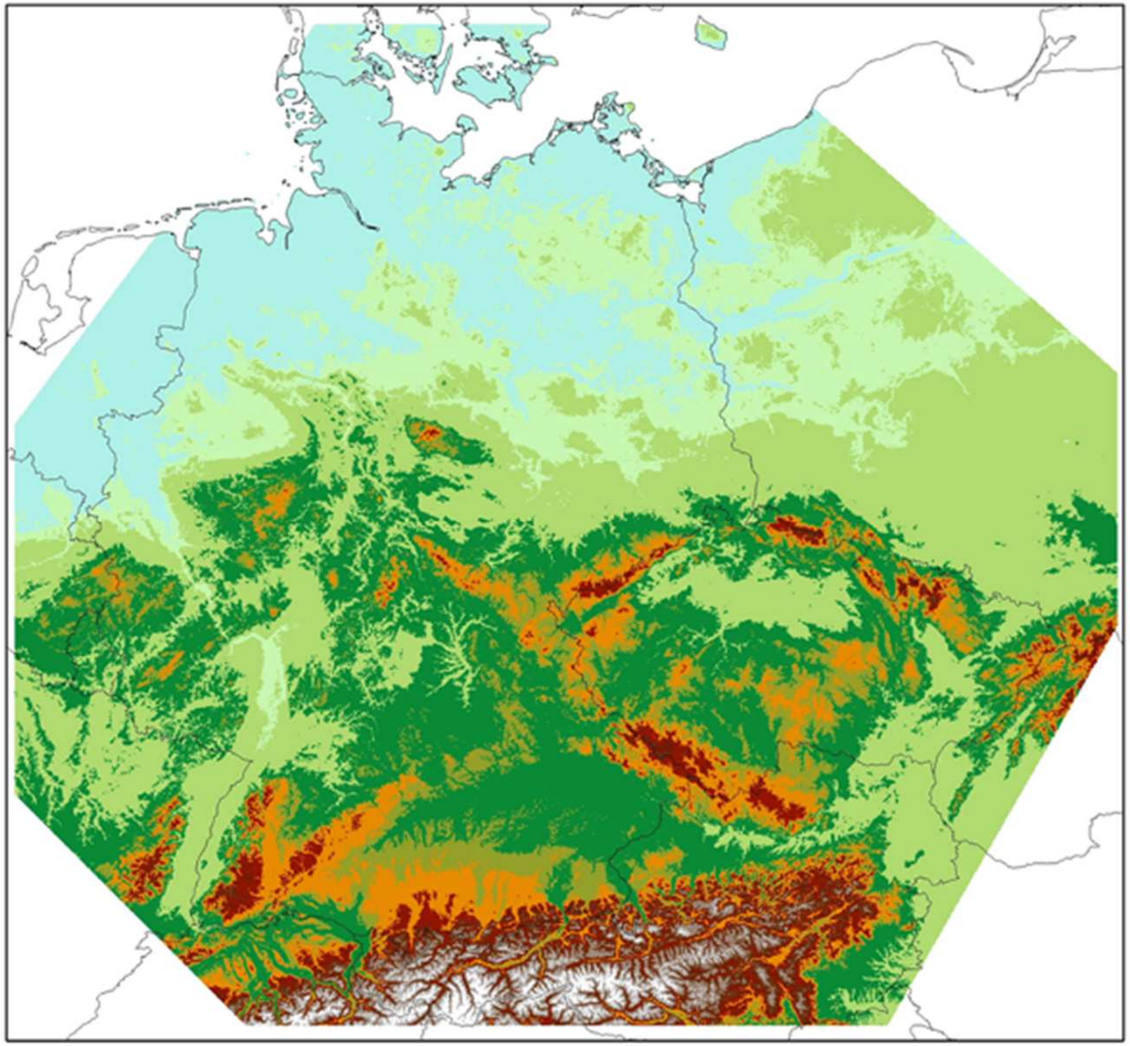
Modules & Model Configuration



Operational Model Configuration

Model region	Octagon covering Germany and adjacent catchments of rivers passing through Germany (1100 x 1000 km)
Grid size	1 x 1 km^2
Time step	1 h
Operational frequency	4 runs each day, six-hourly cycle (Forecast time: 0, 6, 12, 18 UTC)
Analysis (Initialisation) period	Forecast time – 30 h
Forecast period	Forecast time + 72 h

Modules & Model Configuration



Model Area SNOW 4

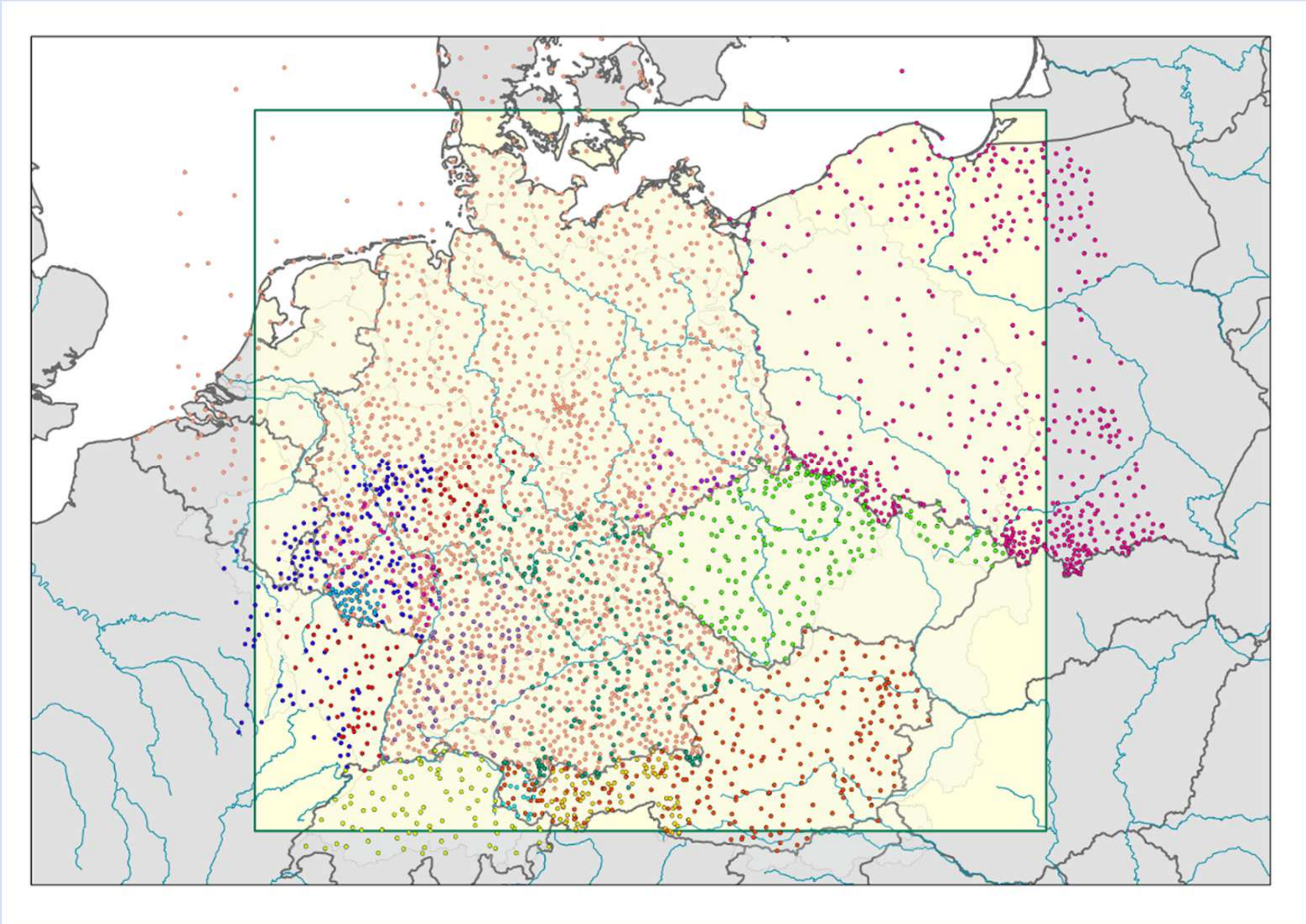
Current Region
1100 x 1000 km^2

Next Version
(scheduled:
Winter 2014/15)
1250 x 1050 km^2

Extension by 150 km to the West and 50 km to the South to cover entirely the Rhine and Meuse catchments

Input Data & Computing Time

Maximum number of real-time station observations for the SNOW4 analysis part

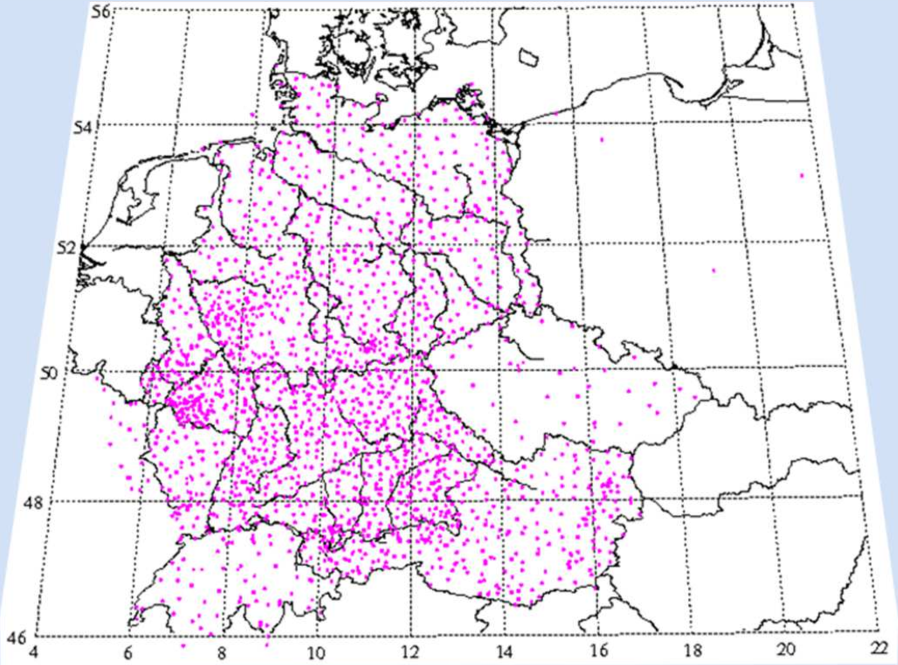


Maximum number of real-time station observations for the SNOW4 analysis part

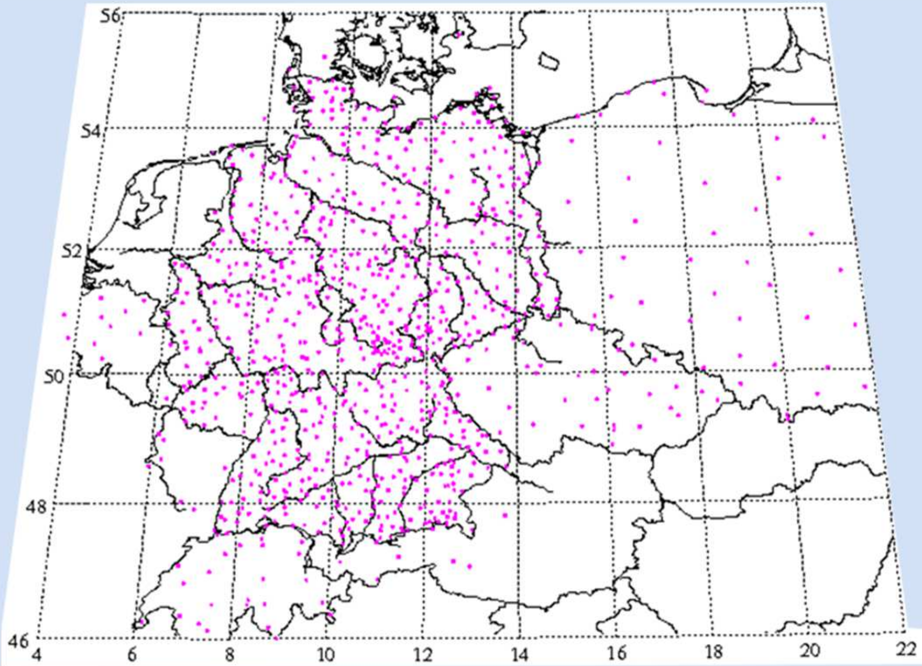
	Synop Data		Snow Data	
Country	T, T_d, S_d, V	P	D_n	R_n
Germany	710	1565	1650	585
Austria	245	350	110	7
France	55	55	5	-
Czech Republic	120	180	90	90
Swiss	70	65	65	-
Polen	55 (without S_d)	155	55	45
Total number neighbouring countries	**545**	**805**	**320**	**142**
Total number	**1255**	**2370**	**1975**	**730**

Snapshot:
Number of station observations available for the SNOW analysis
26.11.2009, 06:00 UTC

Precipitation (1992 stations)

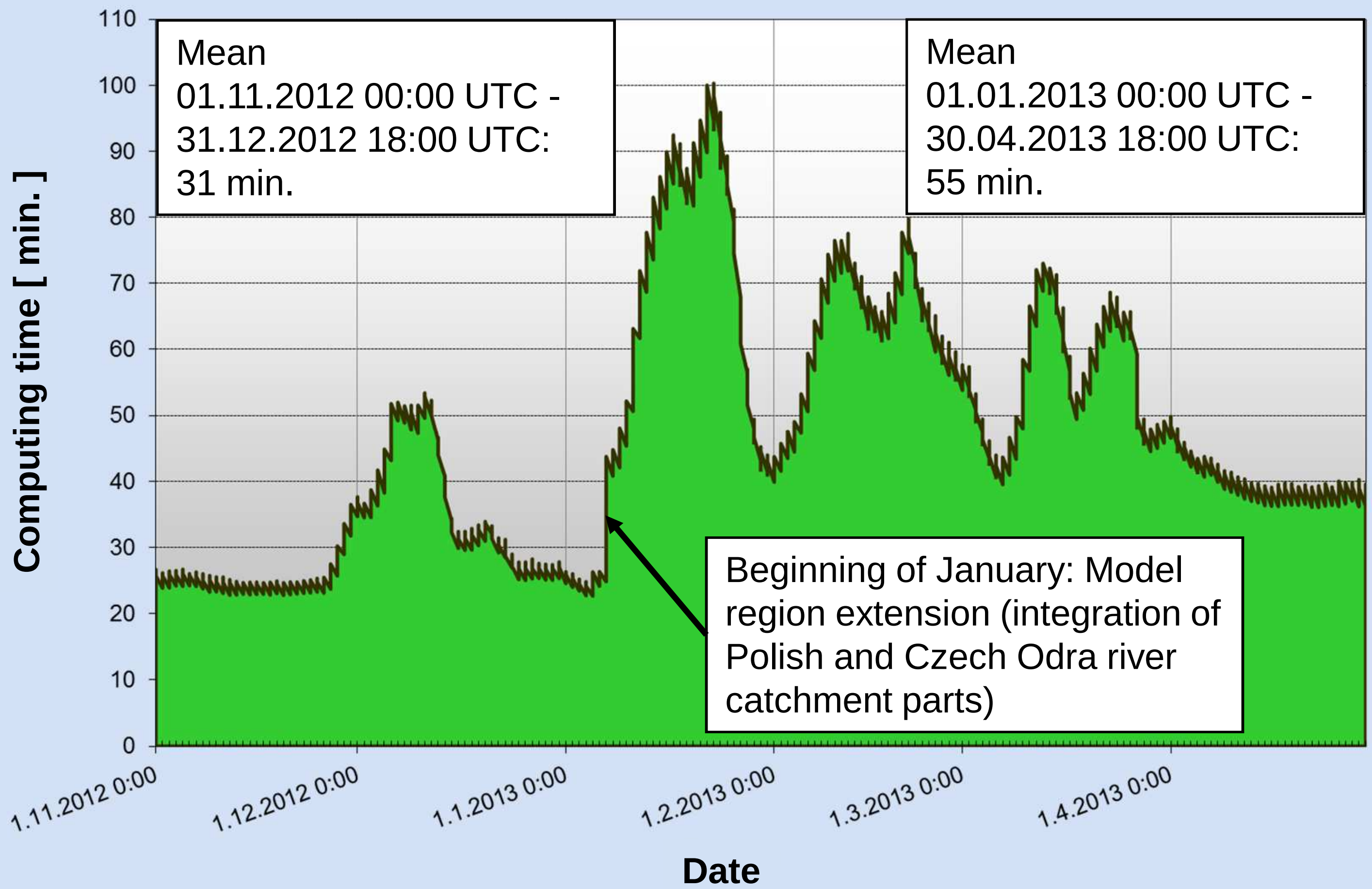


Snow depth (919 stations)

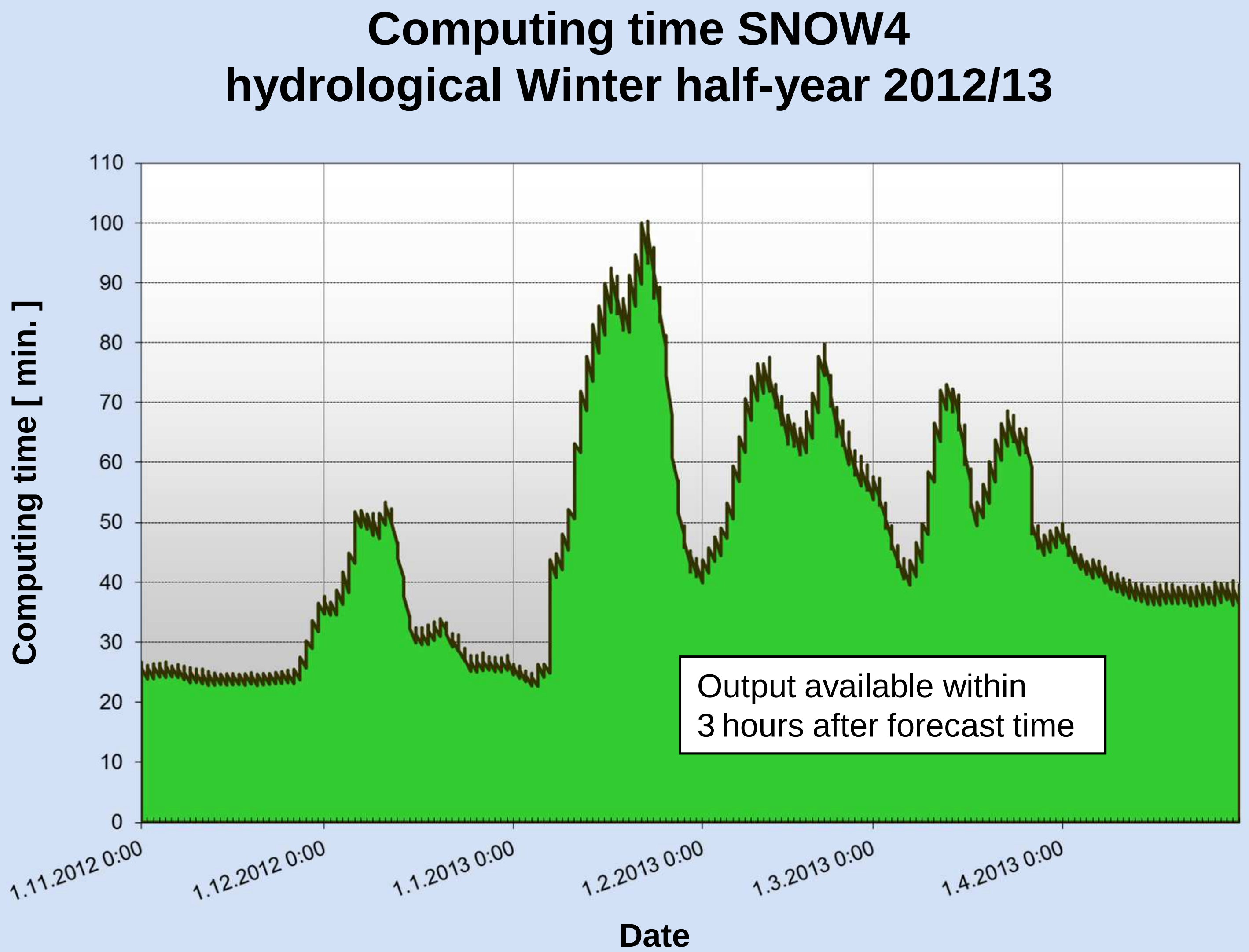


The number of really available station observations may considerably vary from day to day depending on the specific parameter.

Computing time SNOW4
hydrological Winter half-year 2012/13



Input Data & Computing Time



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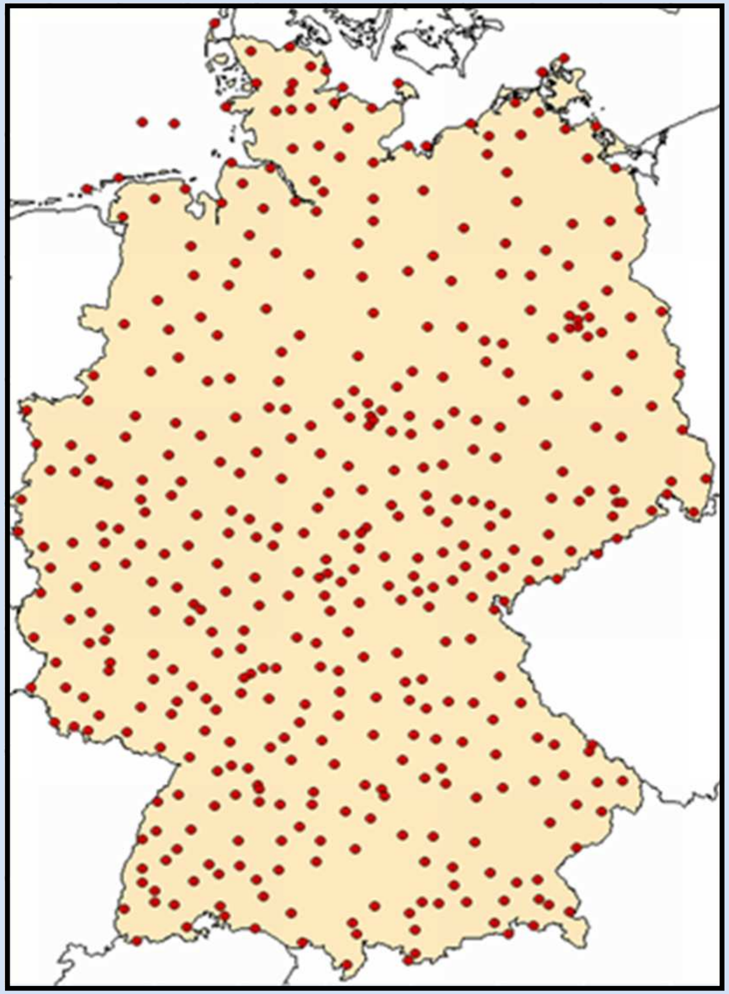
– Snow water equivalent –

Reference: 439 stations measuring daily snow water equivalent in Germany



Model Evaluation

Valididation period 01.09.2012 - 31.05.2013

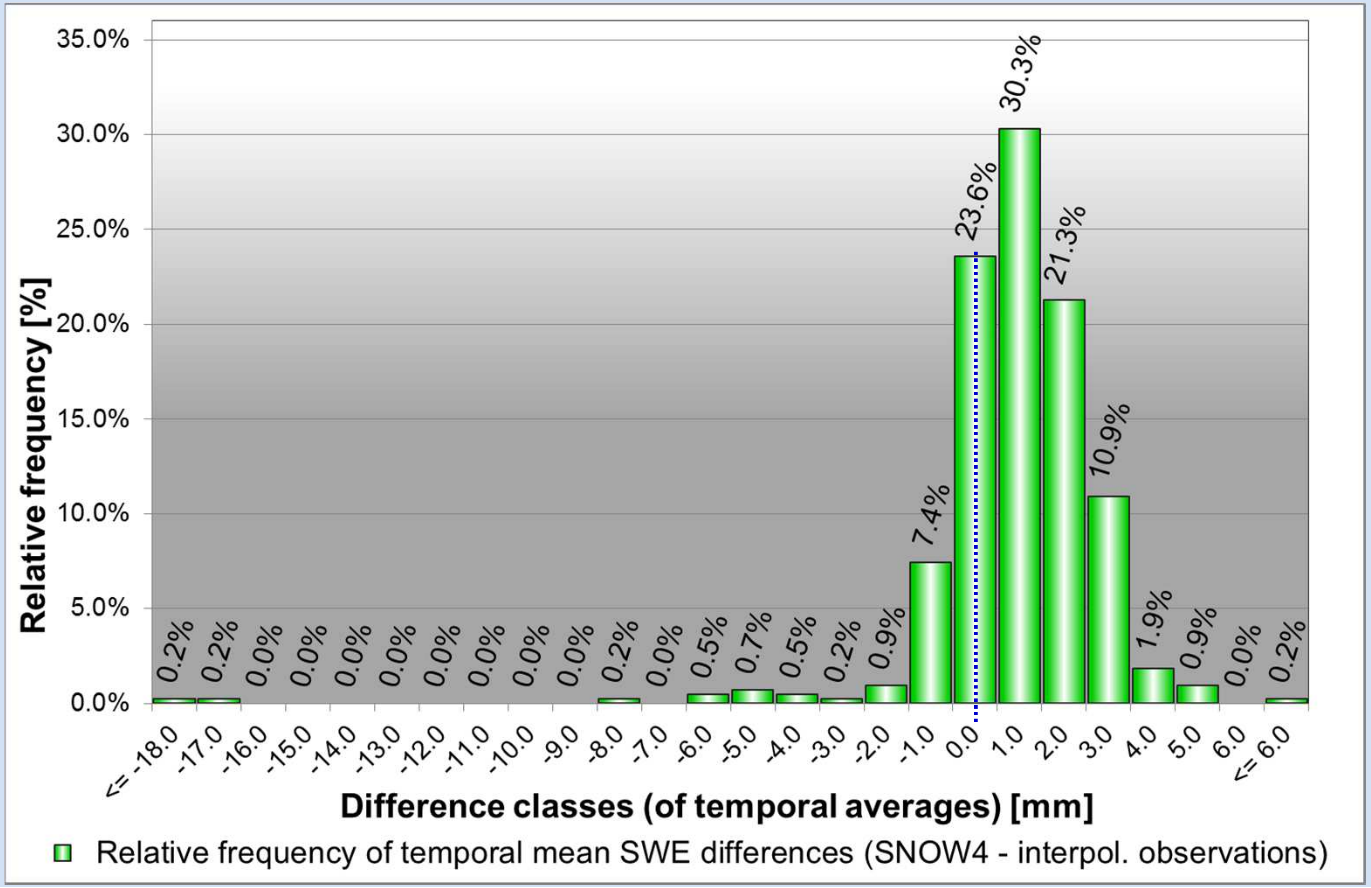
Winter 2012 / 2013	≥ 10 Stations with snow (476 dates)			≥ 25 Stations with snow (372 dates)		
	N stations	μ	rmse	N stations	μ	rmse
Primary statistics of interp. observations [mm]	240	34.0	σ = 72.4	281	26.6	σ = 60.2
Snow water equivalent (W_n) differences [mm]						
Observations - interpol. observations	64	0.1	0.7	77	0.1	0.9
SNOW 4 - interpol. observations	240	-0.1	11.2	281	0.2	8.4
COSMO-EU - interpol. observations	240	-10.1	63.7	281	-1.1	52.3
Relative snow water equivalent (Wn) differences [% related to the mean μ of the primary statistics]						
SNOW 4 - interpol. observations	-	-0.4	33.0	-	0.9	31.7
COSMO-EU - interpol. observations	-	-29.8	187.3	-	-4.0	196.6

Model Evaluation

Relative frequency of W_n differences SNOW4 – interpolated observations in grid boxes with reference observation stations

Temporal averages over all dates of the period 01.09.2012 – 31.05.2013

if there are ≥ 25 stations with snow cover



Model Evaluation

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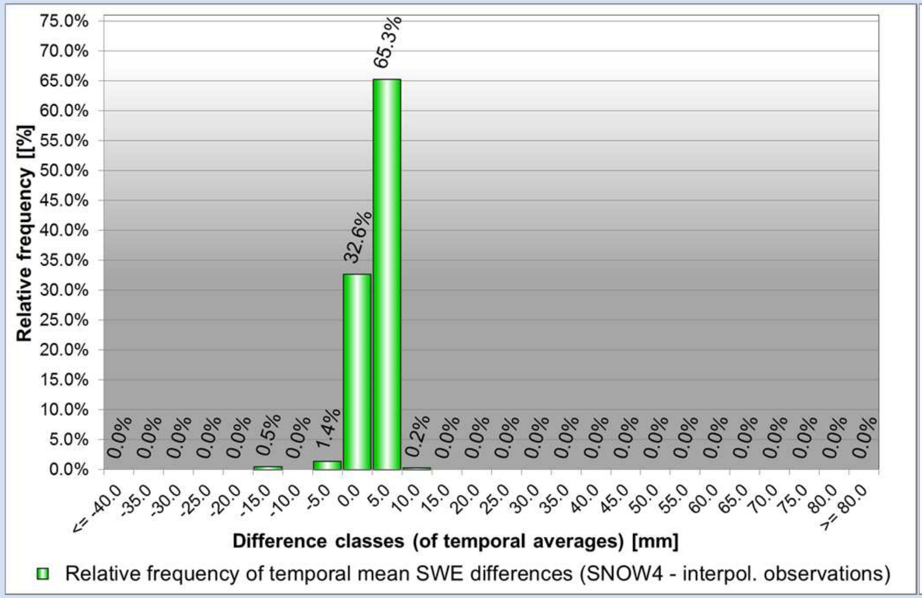
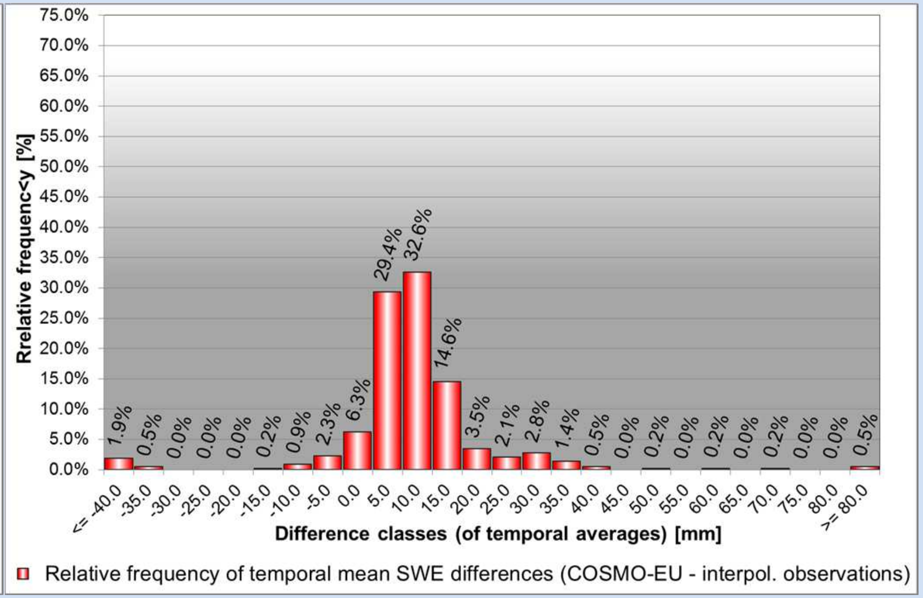
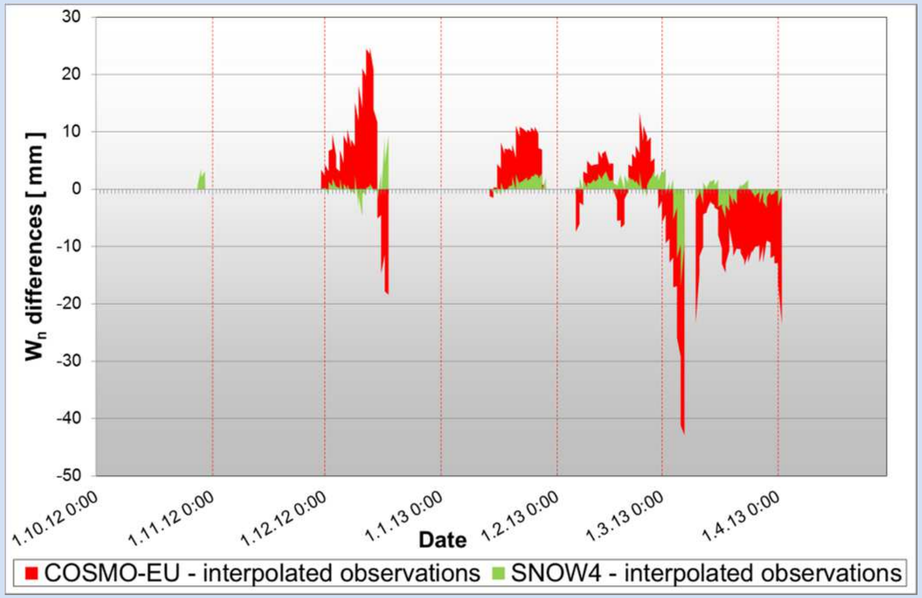


SNOW4 – interpolated observations

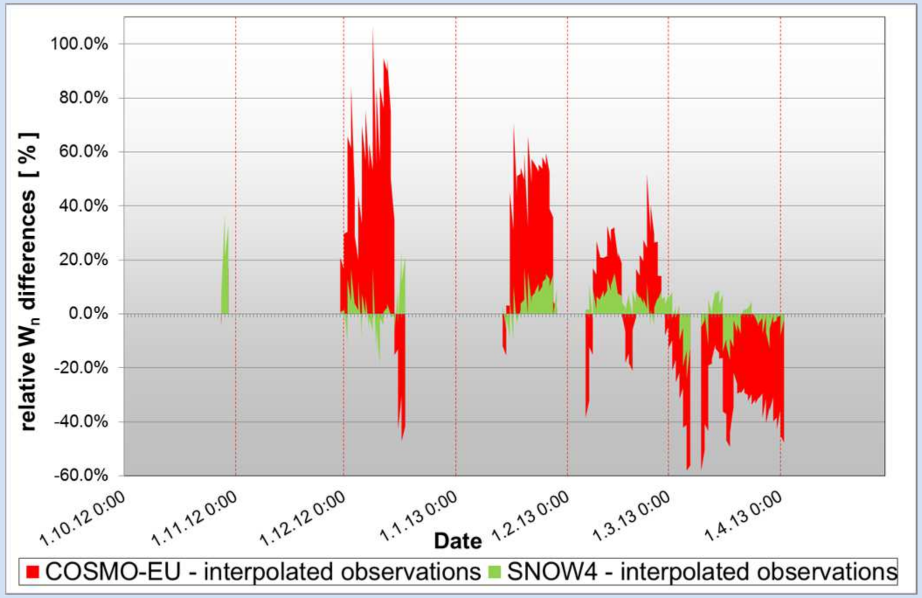


COSMO-EU – interpolated observations

Temporal evolution of W_n differences for the period 01.10.2012 – 30.04.2013 – Dates with ≥ 25 snow-covered rid boxes only –



Mean SNOW4 – interpolated observations: 0.4 mm
Mean COSMO-EU – interpolated observations: -29.8 mm



Mean SNOW4 – interpolated observations: 0.9 %
Mean COSMO-EU – interpolated observations : - 4.0 %

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Summary

SNOW4:

- bridges the gap between meteorological and flood forecasting
- physically describes the snow cover accumulation and ablation
- computes precipitation supply at high spatial and temporal resolution ($1km^2$, 1h)
- provides customers with region-specific actual forecasts every 6 hours
- continuous validation gave evidence of its performance and its added value (both in terms mean and RMSE)
- specific situations indicated needs for model enhancements (higher-level warm air advection, thawing over frozen soil, ..)

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Outlook

- Implementation of a local (instead of global) model analysis phase adjustment module
- Model region enlargement to the West and to the South to entirely cove the Rhine and Meuse river catchments
- Model physics enhancements (soil heat flux, solid/liquid precipitation)
- Adjustment of internal spatially-explicit parameters (daily → hourly)

Thank You for Your Attention