

# Combining Ground-based and Remote-Sensing SNOW Observations within the Model SNOW4

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- **Characteristics and operational service of SNOW4**
- **Interpolation approach for gridding snow observations**
- **Effect of satellite observations on the interpolation product**
- **Summary and outlook**

## Brief profile of SNOW 4

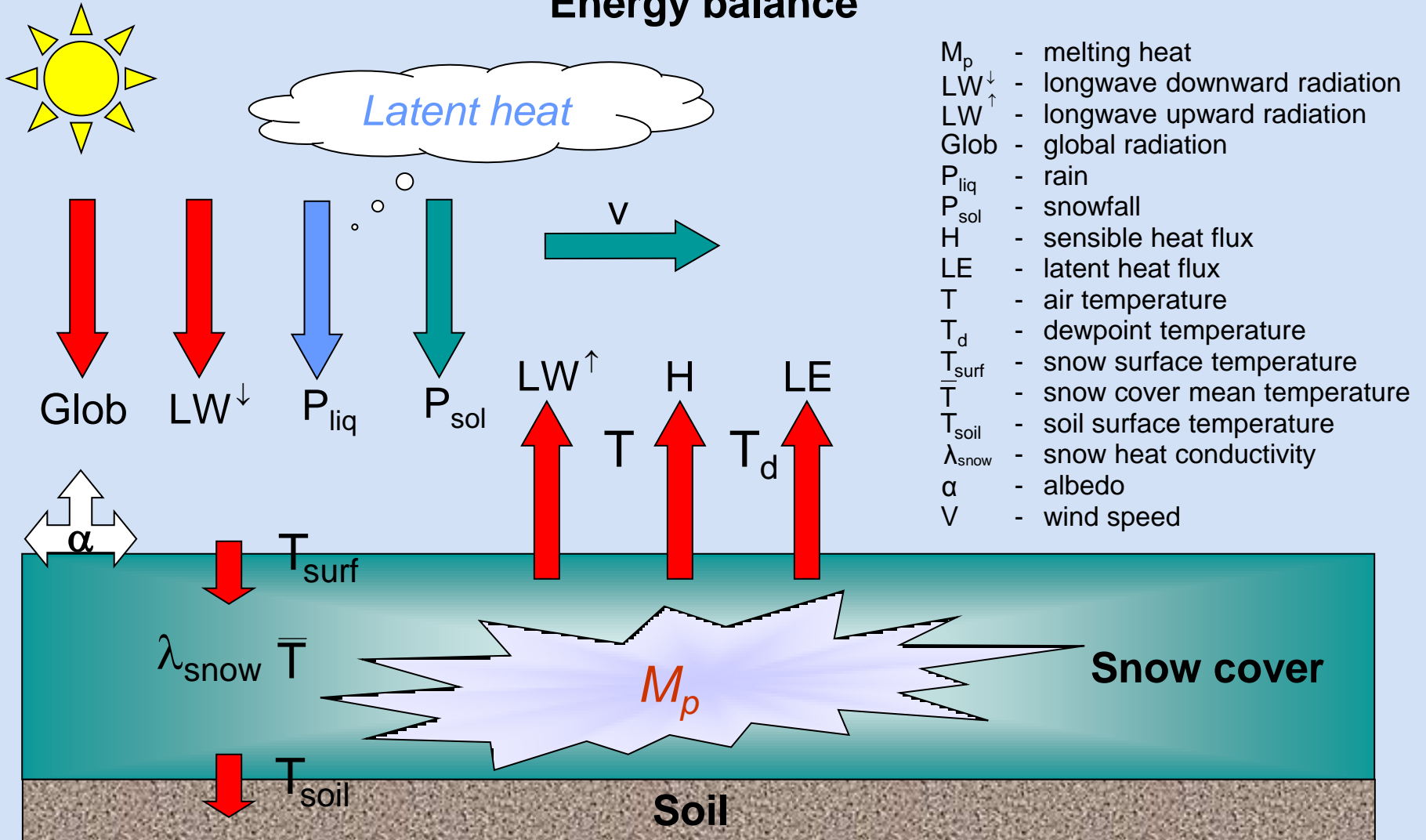
|                           |   |
|---------------------------|---|
| Energy balance quantities | Radiation balances (SW+LW), sensible and latent heat fluxes, latent heat of precipitation                                   |
| Atmospheric processes     | Calculation of sensible and latent heat fluxes considering wind speed, atmospheric stratification and surface roughness     |
| Mass balance model        | Snow compaction algorithm by BERTLE (1966)  |
| Retention concept         | Retention computation and adjustment between modelled and observation-based retention as a function of snow density         |
| Input variables           | Air temperature, water vapour pressure, sunshine duration/shortwave radiation balance and albedo, wind speed, precipitation |
| Target variables          | Melting heat, snow surface temperature, snow cover mean temperature, snow liquid water and ice amount                       |
| <b>Output variables</b>   | <b>Snow water equivalent, precipitation supply</b>  |
| Regionalization approach  | Trend surface analysis + optimal interpolation (analysis part)<br>inverse distance approach (forecast part)                 |

# SNOW model region

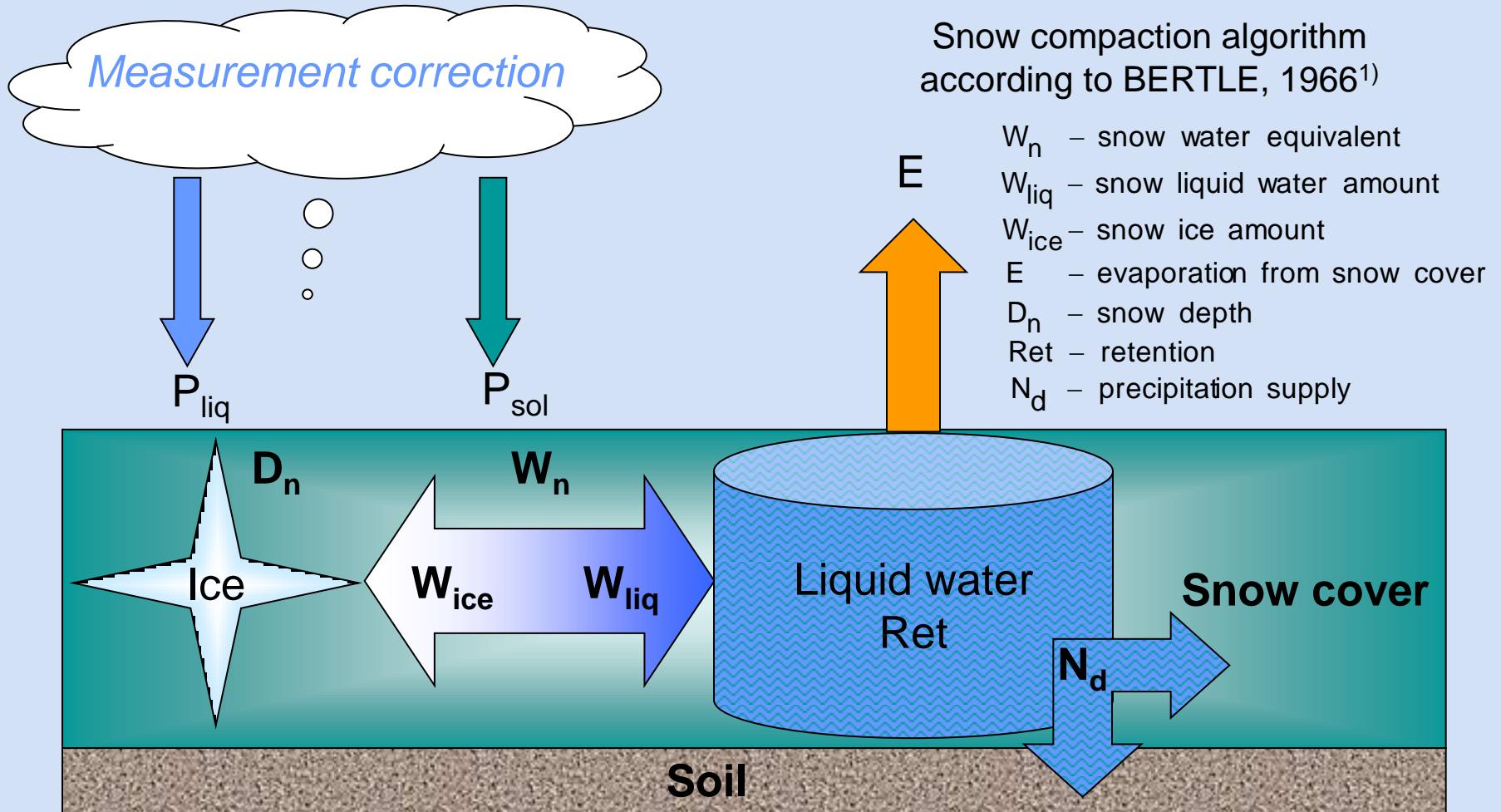


**Covering (almost) the catchments of all rivers draining from Germany (except Danube)**

# Energy balance



## Mass balance



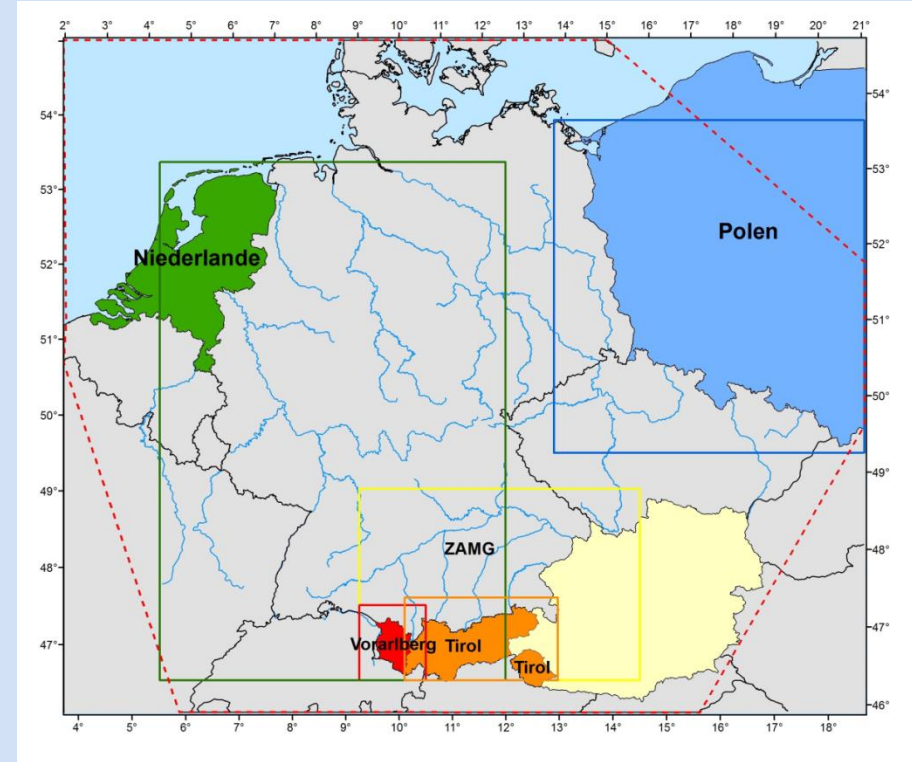
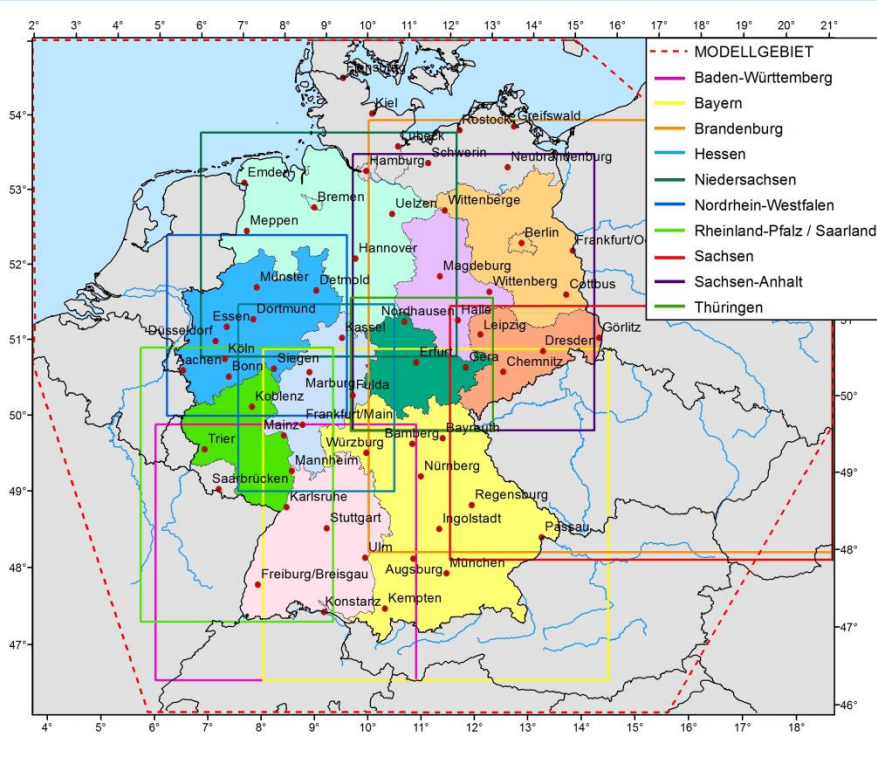
<sup>1)</sup> Bertle, F.A., 1966: Effect of snow compaction on runoff from rain on snow. United States Department of the Interior, Bureau of Reclamation: Water Resources Technical Publication, Engineering Monograph No. 35.



## Operational Model Configuration

|                                 |   |
|---------------------------------|---|
| Model region                    | Rectangular window covering Germany (1250 x 1050 km <sup>2</sup> )                          |
| Grid size                       | 1 x 1 km <sup>2</sup>   |
| Time step                       | 1 h   |
| Operational frequency           | 4 runs each day, every six hours (forecast times: 0, 6, 12, 18 UTC)<br>from October to June |
| Analysis (initialisation) phase | Forecast time – 30 h  |
| Forecast phase                  | Forecast time + 72 h (ICON-EU-driven)   |

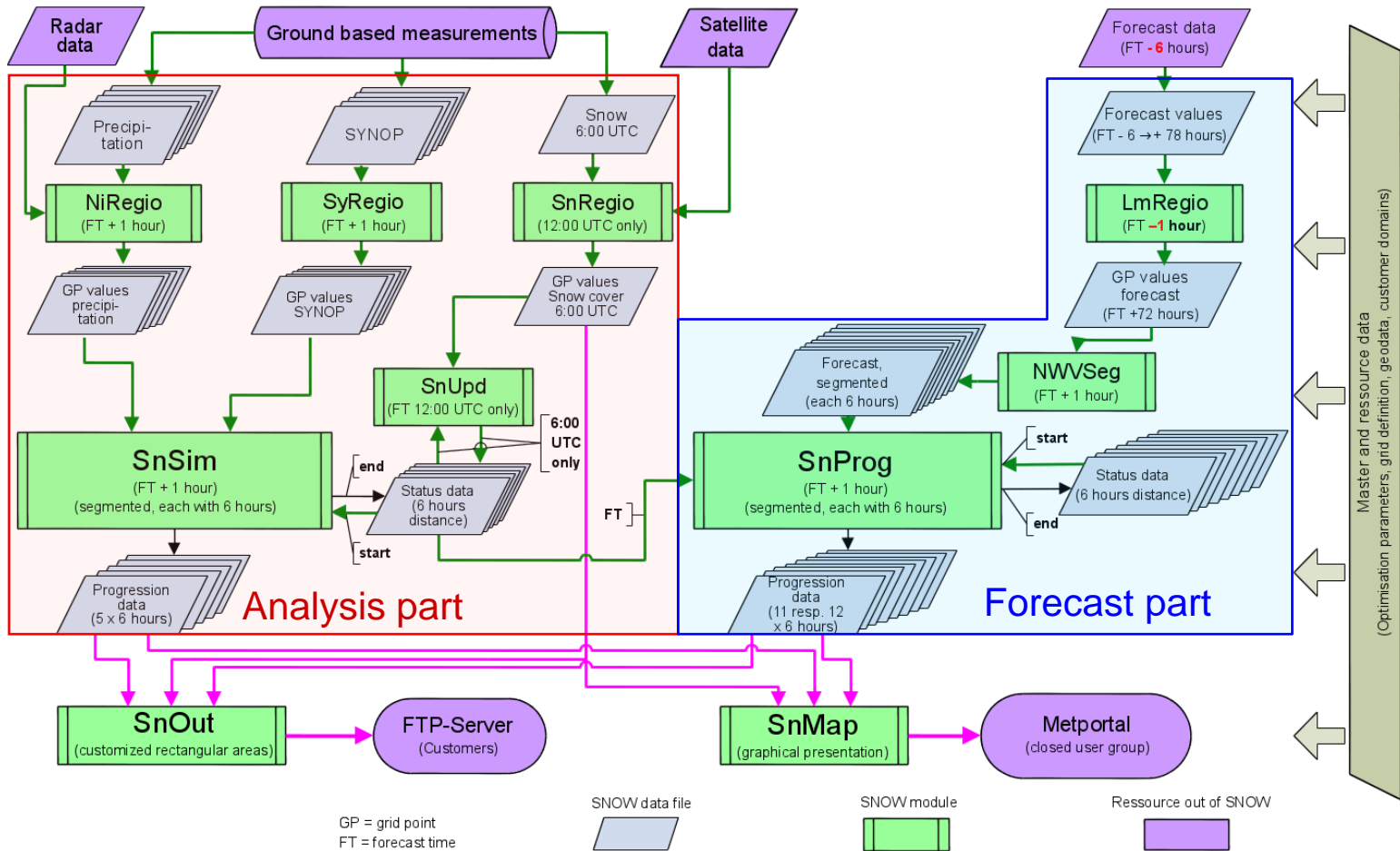
# Characteristics and operational service of SNOW4



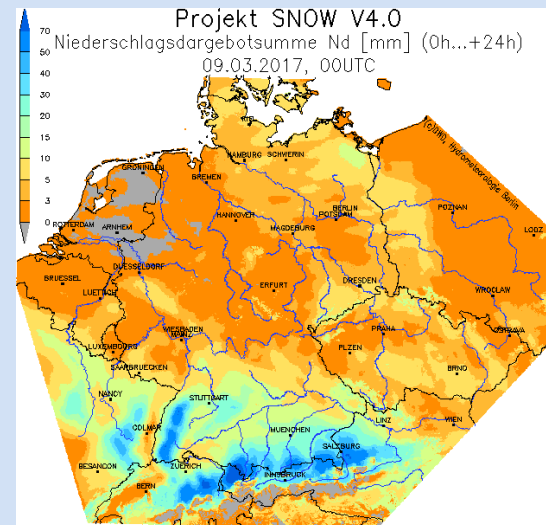
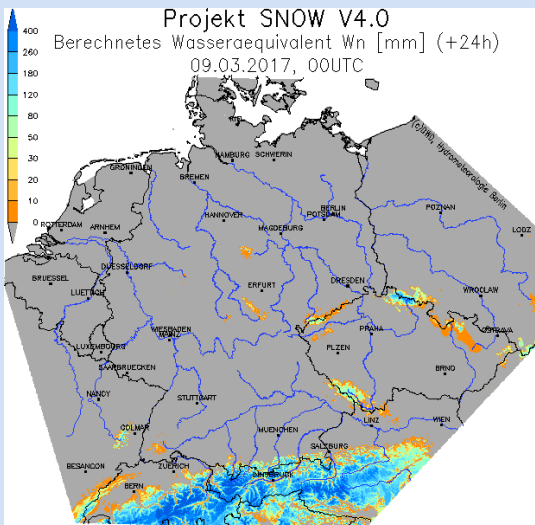
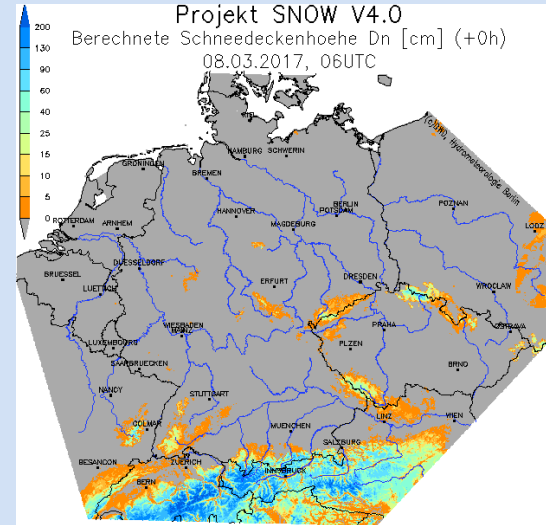
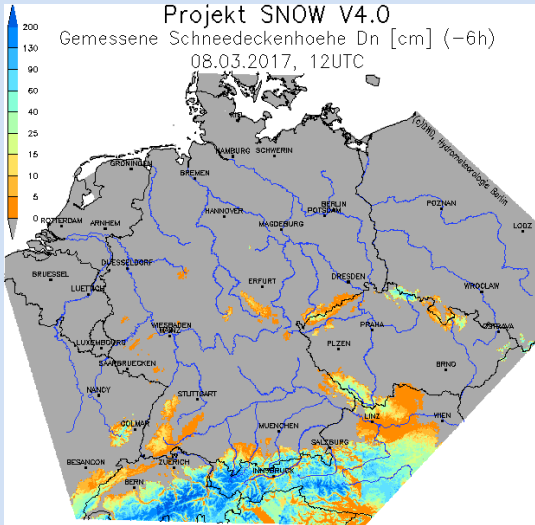
# Characteristics and operational service of SNOW4



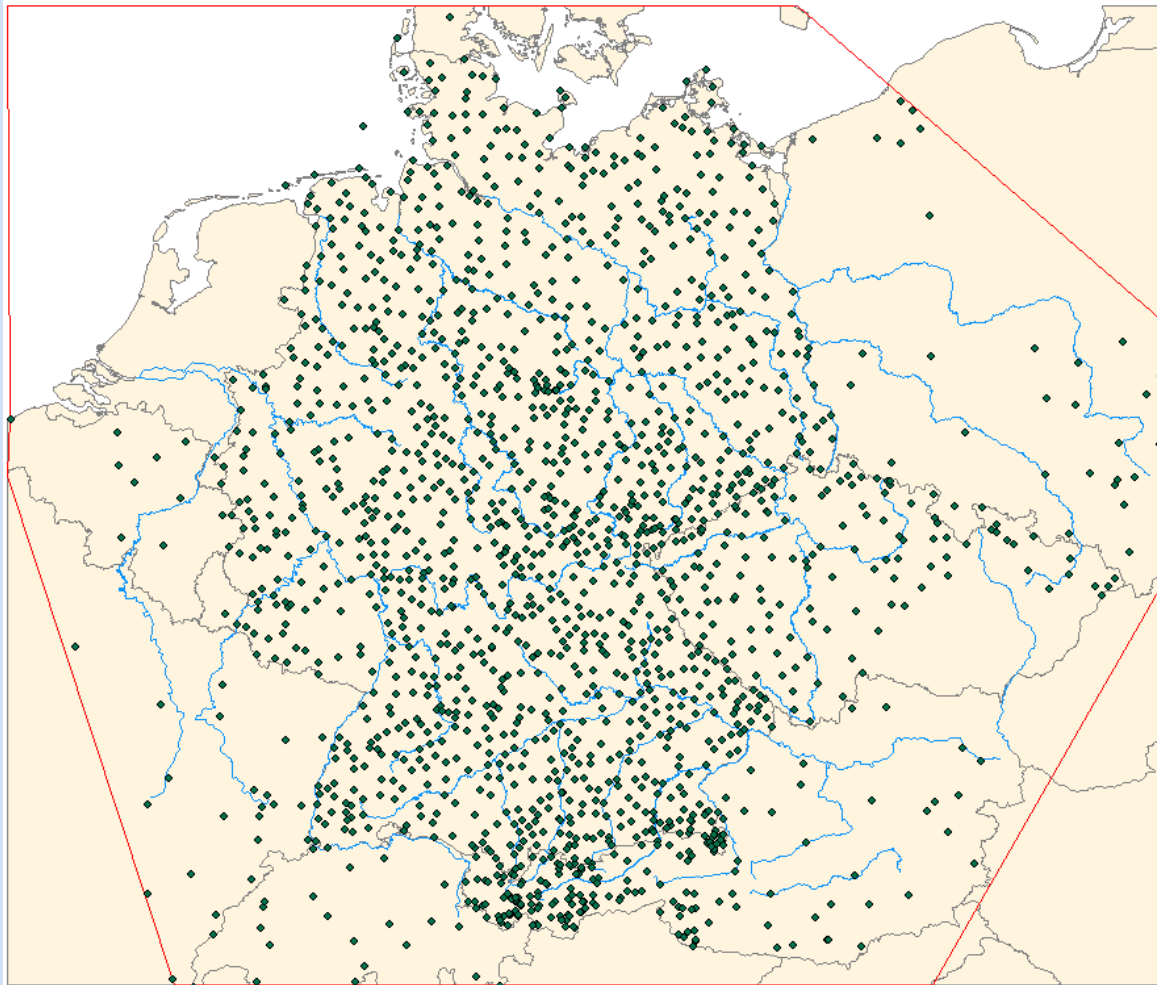
**SNOW, Version 4 – Modules and Data Flow** (last updated: May 2016)



# Characteristics and operational service of SNOW4



## Model region and snow observations



**Maximum real-time  
available snow  
observations:**

- Stations DWD: 1725
- others: 670

**Effectively available  
observations for the  
specific example  
23th January 2017:**

**1768 (altogether)**

- **Characteristics and operational service of SNOW4**
- **Interpolation approach for gridding snow observations**
- **Impact of satellite observations on the interpolation**
- **Summary and outlook**

## I – Data evaluation and outlier tests

- **Global data checks:**
  - **Plausibility check of the range of values for snow depth and (specific) snow water equivalent**
  - **Completion of stations with missing data for the actual day by data from the two preceding days (if available) using a global trend**
  - **Plausibility check of snow coverage by means of a varying elevation threshold  $H_t$  (maximum: summer, minimum: winter) and by using an also varying temperature threshold  $T_t$  (maximum: winter, minimum: summer) at the same time**
- **Local data checks:**
  - **Repeated definition of boxes of changing size until a certain number of valid ground observations between a previously defined minimum and maximum (number of stations) is contained**
  - **Elevation-based regression and splitting of ground observations into background part and anomaly**
  - **Outlier test (Dixon test) on anomalies**

## II – Indicator approach for using satellite snow coverage data

**Consistency check between the (merged) indicator array and the values of the valid surface observations**

### III – Interpolation approach

#### Initial Trend Surface Analysis (equivalent to Universal Kriging):

- Re-definition of a box around a grid cell of concern for interpolation containing the nearest 15 to 30 ground stations with valid data
- Each observation  $z$  is decomposed into a background  $z_b$  and an anomaly  $z_a$  value:
- Setting up the matrix of regressors for all stations  $k$ :
  - $RK[0][k]=1$
  - $RK[1][k]=u[k]$  (grid index in x-direction of station  $k$ )
  - $RK[2][k]=v[k]$  (grid index in y-direction of station  $k$ )
  - $RK[3][k]=Height[k]$
- Calculation of covariance matrix  $\mathbf{C} = \mathbf{RK} * \mathbf{RK}^T$
- Calculation of  $\vec{Y} = \mathbf{RK} * \vec{D}$ , with  $\vec{D}$  = vector of station observations
- Cholesky-decomposition of covariance matrix  $\mathbf{C}$
- Solution of the system of equations  $\mathbf{C} * \vec{B} = \vec{Y}$ , where  $\vec{B}$  is the vector of solutions
- Computation of the background value for each station observation  $k$ :
  - $z_b[k] = \vec{B}[0] + \vec{B}[1] * u[k] + \vec{B}[2] * v[k] + \vec{B}[3] * Height[k]$
- In the same way, computation of background array for the grid point of concern
- If this approach fails,  $z_b = \text{mean}(\text{observations})$ , equivalent to **Ordinary Kriging**

### III – Interpolation approach cont.

#### Basic approach of the actual gridding algorithm: Optimal Interpolation acc. to Gandin <sup>1)</sup>

- For two stations with indices i,j computation of a squared distance function (with elevation):
- $D_{[j]}[i] = (\text{abs}(u[i] - u[j]))^2 + (\text{abs}(v[i] - v[j]))^2 + (\text{abs}(\text{Height}[i] - \text{Height}[j]))^2 * \text{CorHGew}^2$  and
- $D[i][j] = D[j][i]$
- Computation of the correlation function matrix using a hyperbolic approach:

$$R_{ss}[i][j] = \frac{1}{1+p \cdot D[i][j]} \quad \text{with } p - \text{empirical parameter}$$

- In addition, a “nugget effect” is considered by elements of the principal diagonal of  $R_{ss}[i][i]$
- Cholesky-decomposition of correlation matrix  $R_{ss}$
- Computation of the vector of station – grid point correlation  $\vec{r}_{sg}$  for each station k with:
- $\vec{D}_{sg}[k] = \text{abs}((i\text{Col}[k] - i)^2 + (i\text{Row}[k] - j)^2) + ((\text{Height}[k] - \text{Height}[i][j]) * f\text{KorHGew})^2$
- and computation of the related correlation function vector:

$$\vec{r}_{sg}[k] = \frac{1}{1+p \cdot \vec{D}_{sg}[k]}$$

- Formulation of the linear equation system  $R_{ss} \mathbf{w} = \vec{r}_{sg}$
- The solution vector  $\mathbf{w}$  contains the interpolation weights, normalized to a total of 1 and used to calculate  $z_a$

<sup>1)</sup> GANDIN, L.S.: “Ob’ektivnyj analiz meteorologičeskikh polej”, Leningrad (1963)

## IV – Further use of indicator mask

- **during interpolation:**  
use of the indicator array to check, if at least one snow-covered grid point exist within an interpolation box;  
otherwise no interpolation is performed
- **after interpolation:**  
use of the indicator array for winsorization of the interpolated/gridded data:  
in case of snow coverage setting of the minimum snow depth to the lowest possible value according to the chosen accuracy

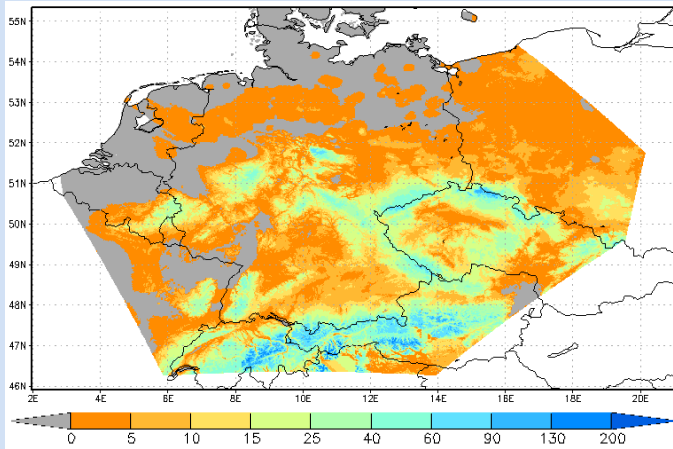
## V – Adjusting the gridded data to the observations

- before interpolation  
the elevation of a SNOW4 grid point may optionally be replaced by the station, if there exist a station in the concerned grid box (configured)
- after interpolation  
at grid points, where station observations exist, gridded data may be replaced by the observed values (configured)

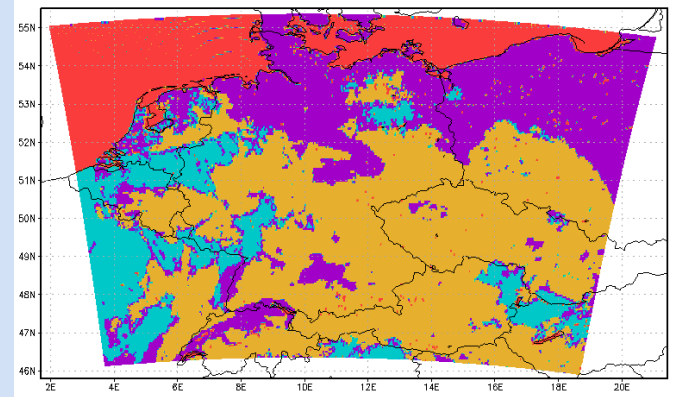
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## Interpolation result – 23.01.2017 - I

Gridded snow depth without Land-SAF

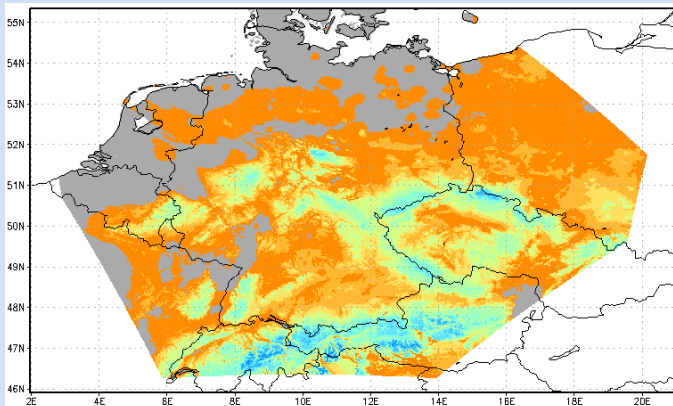


Land SAF snow coverage 22.01.2017

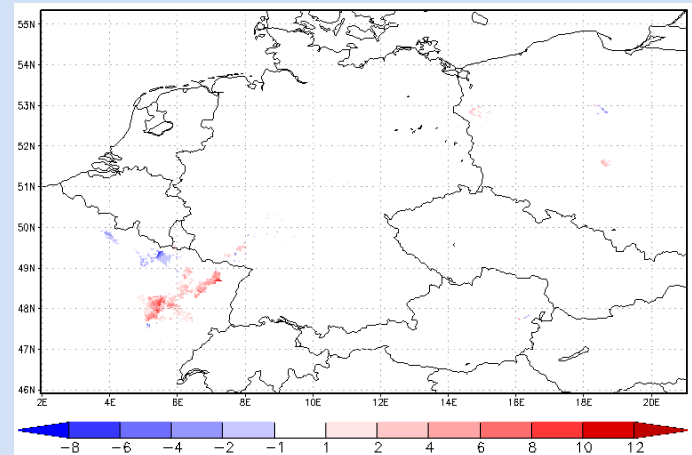


- - Water (5)
- - No snow (2)
- - No data (0)
- - Snow cover (4)

Gridded snow depth with Land SAF

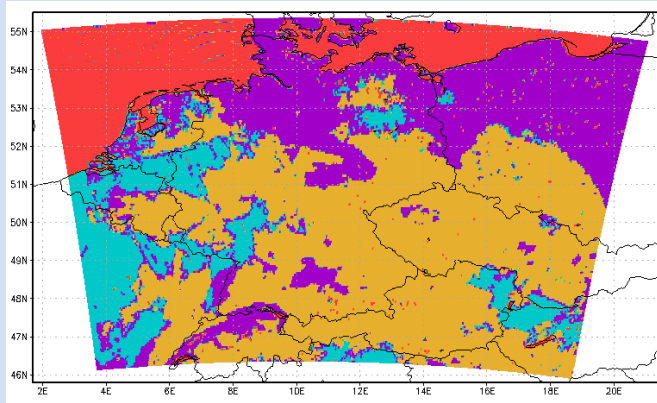


Difference with – without Land SAF



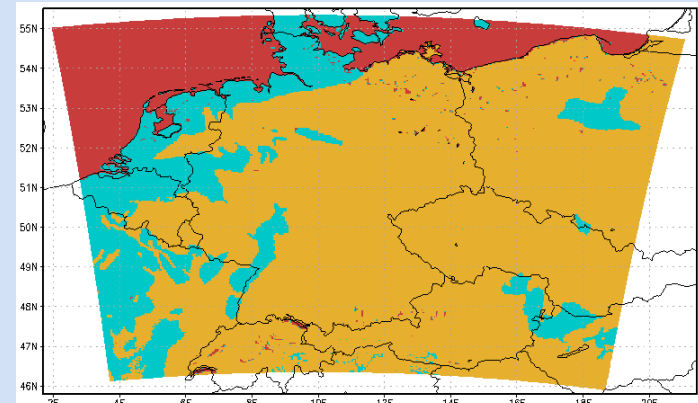
# Comparison of snow coverage in satellite products – 23.01.2017

Snow mask Land-SAF



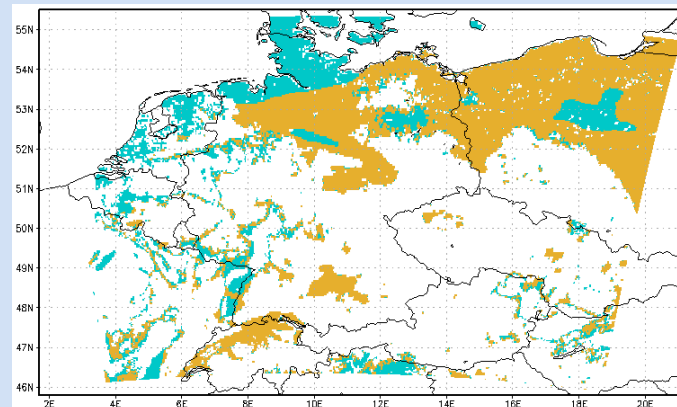
- Water (5)
- No snow (2)
- No data (0)
- Snow cover (4)

Snow mask IMS



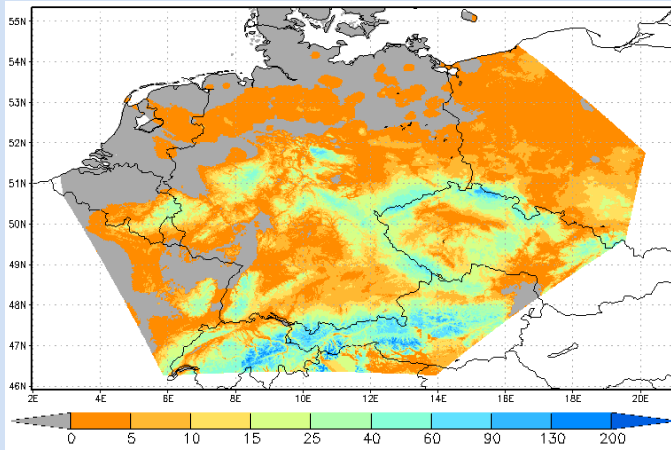
- Water (1)
- No snow (2)
- No data (0)
- Snow cover (4)

Difference IMS – Land-SAF

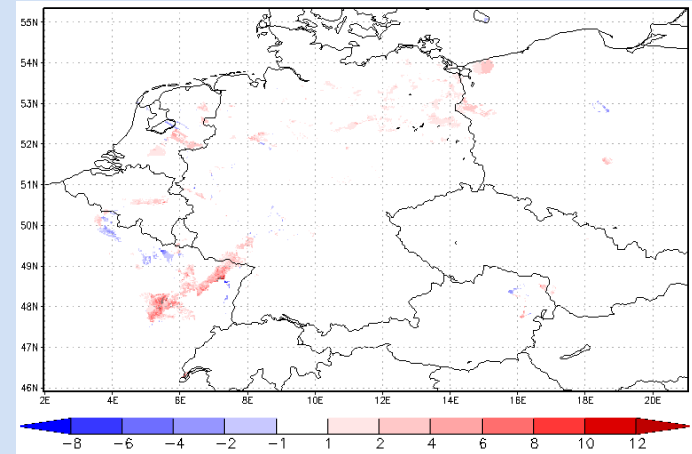


# Interpolation result – 23.01.2017 - II

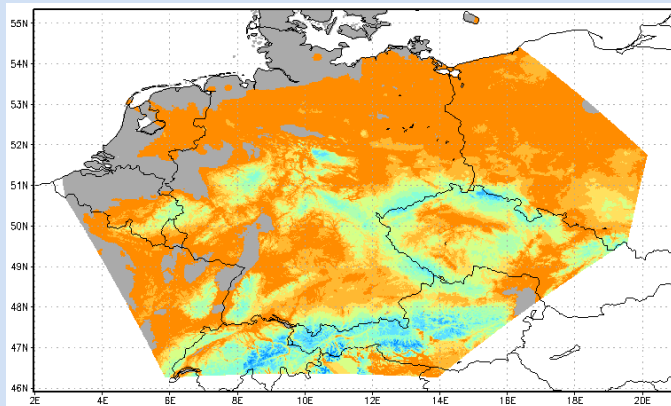
## Gridded snow depth without IMS



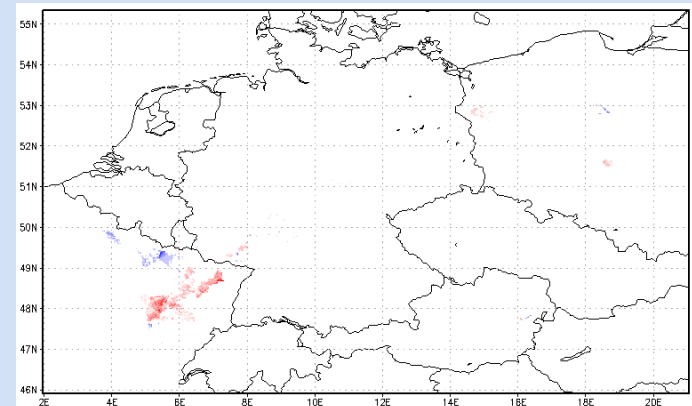
## Difference with – without IMS



## Gridded snow depth with IMS




## Difference with – without Land SAF



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- Use of satellite observations as a supplementary source of information has impact on the result of the gridding algorithm of ground observations, validation still to be done
- IMS data provide an added value compared to Land SAF data in terms of coverage due to a multi-sensor approach
- For operational use in SNOW4, a selection-based approach will be implemented (use of IMS product, if available, otherwise, use of LAND SAF product)
- A remaining problem is the frequency of data provision and how to update IMS sub-daily (cloud-based product? NDVI?)

A photograph of a weather station in winter. The ground is covered in snow. In the center, there is a large, snow-covered evergreen tree. To the left, there is a white weather shelter on a tripod stand. In the background, there are more trees and a building. The sky is overcast.

Thank you for your  
attention!