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

U. Böhm, G. Schneider, R. Müller
(DWD)
• 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

<table>
<thead>
<tr>
<th>Energy balance quantities</th>
<th>Radiation balances (SW+LW), sensible and latent heat fluxes, latent heat of precipitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atmospheric processes</td>
<td>Calculation of sensible and latent heat fluxes considering wind speed, atmospheric stratification and surface roughness</td>
</tr>
<tr>
<td>Mass balance model</td>
<td>Snow compaction algorithm by BERTLE (1966)</td>
</tr>
<tr>
<td>Retention concept</td>
<td>Retention computation and adjustment between modelled and observation-based retention as a function of snow density</td>
</tr>
<tr>
<td>Input variables</td>
<td>Air temperature, water vapour pressure, sunshine duration/shortwave radiation balance and albedo, wind speed, precipitation</td>
</tr>
<tr>
<td>Target variables</td>
<td>Melting heat, snow surface temperature, snow cover mean temperature, snow liquid water and ice amount</td>
</tr>
<tr>
<td>Output variables</td>
<td><strong>Snow water equivalent, precipitation supply</strong></td>
</tr>
<tr>
<td>Regionalization approach</td>
<td>Trend surface analysis + optimal interpolation (analysis part) inverse distance approach (forecast part)</td>
</tr>
</tbody>
</table>
Characteristics and operational service of SNOW4

SNOW model region

Covering (almost) the catchments of all rivers draining from Germany (except Danube)
Characteristics and operational service of SNOW4

Energy balance

- $M_p$: melting heat
- $LW^{-}$: longwave downward radiation
- $LW^{+}$: longwave upward radiation
- $\text{Glob}$: global radiation
- $P_{\text{liq}}$: rain
- $P_{\text{sol}}$: snowfall
- $H$: sensible heat flux
- $LE$: latent heat flux
- $T$: air temperature
- $T_d$: dewpoint temperature
- $T_{\text{surf}}$: snow surface temperature
- $\overline{T}$: snow cover mean temperature
- $T_{\text{soil}}$: soil surface temperature
- $\lambda_{\text{snow}}$: snow heat conductivity
- $\alpha$: albedo
- $V$: wind speed

- $\lambda_{\text{snow}}$: snow heat conductivity
- $T_{\text{surf}}$: snow surface temperature
- $T_{\text{soil}}$: soil surface temperature

Workshop on snow data assimilation, Offenbach, 08/09.02.2017
Characteristics and operational service of SNOW4

Mass balance

Snow compaction algorithm according to BERTLE, 1966

\[ W_n \] – snow water equivalent
\[ W_{liq} \] – snow liquid water amount
\[ W_{ice} \] – snow ice amount
\[ E \] – evaporation from snow cover
\[ D_n \] – snow depth
\[ Ret \] – retention
\[ N_d \] – precipitation supply

### Operational Model Configuration

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model region</td>
<td>Rectangular window covering Germany (1250 x 1050 km²)</td>
</tr>
<tr>
<td>Grid size</td>
<td>1 x 1 km²</td>
</tr>
<tr>
<td>Time step</td>
<td>1 h</td>
</tr>
<tr>
<td>Operational frequency</td>
<td>4 runs each day, every six hours (forecast times: 0, 6, 12, 18 UTC) from October to June</td>
</tr>
<tr>
<td>Analysis (initialisation) phase</td>
<td>Forecast time – 30 h</td>
</tr>
<tr>
<td>Forecast phase</td>
<td>Forecast time + 72 h (ICON-EU-driven)</td>
</tr>
</tbody>
</table>
Characteristics and operational service of SNOW4
Characteristics and operational service of SNOW4

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

Analysis part

Forecast part

SNOW data assimilation, Offenbach, 08/09.02.2017
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 $k$:
  
  $\mathbf{RK}[0][k] = 1$
  $\mathbf{RK}[1][k] = u[k]$ (grid index in x-direction of station $k$)
  $\mathbf{RK}[2][k] = v[k]$ (grid index in y-direction of station $k$)
  $\mathbf{RK}[3][k] = \text{Height}[k]$

- Calculation of covariance matrix $\mathbf{C} = \mathbf{RK} \times \mathbf{RK}^T$
- Calculation of $\mathbf{Y} = \mathbf{RK} \times \mathbf{D}$, with $\mathbf{D}$ = vector of station observations
- Cholesky-decomposition of covariance matrix $\mathbf{C}$
- Solution of the system of equations $\mathbf{C} \times \mathbf{B} = \mathbf{Y}$, where $\mathbf{B}$ is the vector of solutions
- Computation of the background value for each station observation $k$:
  
  $z_b[k] = \mathbf{B}[0] + \mathbf{B}[1] \times u[k] + \mathbf{B}[2] \times v[k] + \mathbf{B}[3] \times \text{Height}[k]$

- In the same way, computation of background array for the grid point of concern
- If this approach fails, $z_b = \text{mean(observations)}$, equivalent to Ordinary Kriging
III – Interpolation approach cont.

Basic approach of the actual gridding algorithm: Optimal Interpolation acc. to Gandin

1) For two stations with indices i,j computation of a squared distance function (with elevation):
   \[ D[i][j] = (\text{abs}(u[i] - u[j])^2 + (\text{abs}(v[i] - v[j])^2 + (\text{abs}(\text{Height}[i] - \text{Height}[j])^2) \times \text{CorHGew}^2 \text{ and} \]
   \[ D[j][i] = D[i][j] \]

2) Computation of the correlation function matrix using a hyperbolic approach:
   \[ R_{ss}[i][j] = \frac{1}{1 + p \cdot D[i][j]} \]
   with \( p \) – empirical parameter

3) In addition, a “nugget effect” is considered by elements of the principal diagonal of \( R_{ss}[i][i] \)
4) Cholesky-decomposition of correlation matrix \( R_{ss} \)
5) Computation of the vector of station – grid point correlation \( \mathbf{r}_{sg} \) for each station k with:
   \[ \mathbf{D}_{sg}[k] = \text{abs}( (iCol[k] - i)^2 + (iRow[k] - j)^2 ) + ((Height[k] - Height[i][j]) \times fKorHGew )^2 \]
6) and computation of the related correlation function vector:
   \[ \mathbf{r}_{sg}[k] = \frac{1}{1 + p \cdot \mathbf{D}_{sg}[k]} \]
7) Formulation of the linear equation system \( R_{ss} \mathbf{w} = \mathbf{r}_{sg} \)
8) The solution vector \( \mathbf{w} \) contains the interpolation weights, normalized to a total of 1 and used to calculate \( z_a \)

1) GANDIN, L.S.: “Ob’ektivnyj analiz meteorologičeskij 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)
• Characteristics and operational service of SNOW4

• Interpolation approach for gridding snow observations

• Impact of satellite observations on the interpolation

• Summary and outlook
Impact of satellite observations on the interpolation

**Interpolation result – 23.01.2017 - I**

**Gridded snow depth without Land-SAF**

**Land SAF snow coverage 22.01.2017**

**Gridded snow depth with Land SAF**

**Difference with – without Land SAF**

- Water (5)
- No snow (2)
- No data (0)
- Snow cover (4)
Comparison of snow coverage in satellite products – 23.01.2017

Snow mask Land-SAF

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

Snow mask IMS

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

Difference IMS – Land-SAF
Impact of satellite observations on the interpolation

Interpolation result – 23.01.2017 - II

Gridded snow depth without IMS

Gridded snow depth with IMS

Difference with – without IMS

Difference with – without Land SAF

Workshop on snow data assimilation, Offenbach, 08/09.02.2017
• Characteristics and operational service of SNOW4
• Interpolation approach for gridding snow observations
• Impact of satellite observations on the interpolation
• Summary and outlook
• 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?)
Thank you for your attention!