An examination of the quality of a new snow parameterization scheme combined with the COSMO’s land surface scheme TERRA

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Introduction

The problem is that the modeled by TERRA snow tends to melt earlier and faster than the observed snow.
Snow models description

Implemented processes

- Heat conduction
- Melting when snow surface temperature > 0°C or when soil surface temperature > 0°C
- Heat conduction
- Liquid water transport
- Gravitational compaction + metamorphosis
- Solar radiation penetration

Numerical schemes

1 layer

Arbitrary number of layers; heat conduction: implicit (combined with soil heat conduction), latent heat and solar radiation: source terms
Implemented processes (2)

Heat and water transport

\[
\rho_{sn} c_{sn} \frac{\partial T_{sn}}{\partial t} = \frac{\partial}{\partial z} \lambda_{sn} \frac{\partial T_{sn}}{\partial z} + \mathcal{L}_i (R(z) - M(z))
\]

\[
\rho_{sn} \frac{\partial w_{sn}}{\partial t} (z) = \rho_w (M(z) - R(z) - q(z))
\]

\(T_{sn}\) - snow temperature, \(w_{sn}\) - snow liquid water content, \(\lambda_{sn}\) - snow heat conductivity, \(\rho_{sn}\) - snow density, \(c_{sn}\) - snow specific heat content, \(\mathcal{L}_i\) - latent heat for freezing/melting, \(M\) - melting rate, \(R\) - refreezing rate, \(q\) - infiltration rate due to gravity

Water percolation:

\[q = h \cdot \left( \frac{w_{sn}}{\Pi - w_{hc}} \right)^3 \]

\(h\) - snow hydraulic conductivity, \(w_{hc}\) - snow water holding capacity, \(\Pi\) - snow porosity
Gravitational compaction and metamorphosis

\[ \frac{1}{\rho_{sn}(t)} \frac{d\rho_{sn}}{dt} = \frac{1}{\eta(t)} [\sigma_m(t) + \sigma_g(t)] \]

Where

- \( \sigma_g(t) = \int \rho_{sn}(t) gz \) describes the gravity effect
- \( \sigma_m(t) \) describes the snow metamorphosis, = 75 Pa
- \( \eta(t) \) - the snow compaction viscosity

Solar radiation penetration

\[ S(z) = S_0 e^{-\beta z} \]
## Results discussion (1)

<table>
<thead>
<tr>
<th></th>
<th>Correlation coefficient between time series of observed and simulated SWE (N = 221, p&lt;0.0001)</th>
<th>Mean error (± standard deviation) in the time of the snow complete ablation (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TERRA</td>
<td>0.70</td>
<td>-17 (±7)</td>
</tr>
<tr>
<td>TERRA + new snow</td>
<td>0.90</td>
<td>-7 (±5)</td>
</tr>
</tbody>
</table>
Results discussion: snow water-equivalent depth, Valdai, 1966-1972
Continue: snow water-equivalent depth, 1972 - 1978
Continue: snow water-equivalent depth, 1978 - 1983

[Graph showing snow water-equivalent depth from 1978 to 1983 with different lines representing TERRA ctrl, TERRA + new snow, and observed values.]
Results discussion (2): snow density $\rightarrow$ snow height

**Snow density**

- **Observed**
- **TERRA**
- **TERRA + new snow**

**Snow height**

- **Observed**
- **TERRA**
- **TERRA + new snow**
Continue: snow density → snow height
Results discussion (3): parameterizations related to snow-albedo feedbacks

Besides the processes which relate to liquid water treatment, there are various possibilities to describe:

- dependence of *snow cover fraction* (∝ of weighted grid albedo) on snow depth, snow “age”, or decreasing of
- dependence of *snow albedo* on: snow temperature, or … etc.

- *fresh snow albedo* (now 0.7, possibly too low)

**Question**: Maybe it will be enough to replace current dependencies with other ones without introducing of liquid water content? –

Parameterization of *snow cover fraction*:

can reveal an effect in 3d-experiments,

but in 1d-stand alone simulations the strength of *snow cover fraction*-albedo feedback is damped through the prescribed air temperature at 2m.
Results discussion (3): parameterizations related to snow-albedo feedbacks

Reference version:

<table>
<thead>
<tr>
<th></th>
<th>fresh snow albedo = 0.7</th>
<th>fresh snow albedo = 0.85</th>
</tr>
</thead>
<tbody>
<tr>
<td>albedo depends on</td>
<td>r = 0.70</td>
<td>r = 0.89</td>
</tr>
<tr>
<td>snow age</td>
<td>σ = 28.9 mm</td>
<td>σ = 18.9 mm</td>
</tr>
<tr>
<td>albedo depends on</td>
<td>r = 0.61</td>
<td>r = 0.81</td>
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<tr>
<td>snow temperature</td>
<td>σ = 32.6 mm</td>
<td>σ = 25.6 mm</td>
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</tbody>
</table>

“new snow” version:

<table>
<thead>
<tr>
<th></th>
<th>fresh snow albedo = 0.7</th>
<th>fresh snow albedo = 0.85</th>
</tr>
</thead>
<tbody>
<tr>
<td>age</td>
<td>r = 0.89</td>
<td></td>
</tr>
<tr>
<td></td>
<td>σ = 24.7</td>
<td></td>
</tr>
<tr>
<td>temp.</td>
<td></td>
<td>r = 0.90</td>
</tr>
<tr>
<td></td>
<td></td>
<td>σ = 24.3</td>
</tr>
</tbody>
</table>

Answer: no
(liquid water is needed)
Results discussion (3):

…but:

2 layers are enough!

Computational costs:

+5% of TERRA
Results discussion (4): hydrological outflow

Mean (for 18 years) seasonal cycle of run-off at Valdai

- observed
- TERRA
- TERRA + new snow

mm/month

months
Summary

• A new, more physically based parameterization of snow is suggested and implemented into TERRA. As the main component, this scheme includes description of the water phase transitions within snowpack.

• By means of the Valdai long-term data an comparison with the current snow model incorporated in COSMO is done. The new scheme represents the snow evolution more realistically, particularly during melting period.

• The new snow scheme essentially improves the simulated runoff.
Outlook

• Near future:
  3-d experiments, test cases (verification of SWE, surface and 2m temperatures, hydrological outflow (?)

• After:
  investigation of a possibility to account for a sub-grid variability of snow height and melting rates
Thank you for your attention!