Snow in Canada’s Numerical Weather Prediction (NWP) Systems

Towards a Polar Snowfall Hydrology Mission
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Snow and Ice in CMC’s NWP Systems

- **SW**: Radiative Transfer in the Atmosphere (in the presence of Clouds)
- **LW**: Grid-Scale Condensation (Microphysics)
- **PBL Clouds**: Deep Convection
- **Snow in Cities**: Shallow Convection
- **Snow on Land and Vegetation**: Frozen Soil
- **Snow on Sea-Ice**: PBL Clouds
- **Snow on Glaciers**: Frozen Soil
Operational Forecasting Suite at the Canadian Meteorological Centre

<table>
<thead>
<tr>
<th>Grid size (km)</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td>Hours</td>
</tr>
<tr>
<td>2</td>
<td>1 day</td>
</tr>
<tr>
<td>15</td>
<td>2 days</td>
</tr>
<tr>
<td>33</td>
<td>10 days</td>
</tr>
<tr>
<td>&gt;200</td>
<td>1 month</td>
</tr>
<tr>
<td>&gt;200</td>
<td>season</td>
</tr>
</tbody>
</table>

Urban* (2.5 km)
Local (15 km)
Regional (33 km)
Global (33 km)
EPS
Seasonal

*) under development (prototype expected in 2007 – but will not be integrated in an everyday manner)
Focus Today: Prediction and Assimilation of Snow on Surface

Atmospheric analyses

Geophysical surface fields

Atmospheric predictions

Observations

Assimilation (or modeling)

Prediction

Initial conditions

PAST

NOW

FUTURE
Data Assimilation of Snow - Current

**ANCILLARY DATA**
(databases for soil texture, vegetation, water/land mask, orography, cities)

**ATMOSPHERIC FORCING**
- Met analyses and forecasts
- $T$, $hu$, winds
- Precipitation
- Radiation

**OFFLINE SNOW MODEL**

Assimilation based on optimal interpolation
Background snow depth is given by a simple off-line snow model
Reports from SYNOP and METAR are used
*(Brasnett, Brown)*

**SNOW OBS**
- Surface stations measurements (snow depth)
Example of Snow Depth Analysis (I)

Global Analysis (33 km)

Valid 5 December 2006
When done on a LAM 2.5-km grid, with adaptation of temperature forcing for the high-resolution orography, the analysis is more realistic in mountainous regions.

(from Amin Erfani)
**Data Assimilation of Snow – In progress**

### Atmospheric Forcing
- Temperature ($T$), humidity ($h$), winds
- Precipitation
- Radiation

### Ancillary Data
- Met analyses and forecasts
- Precip analyses
- Adaptation (downscaling)

### Offline Snow Model
- Background snow depth given by a more complex off-line snow model
- Variational or EKF strategies are examined

### Snow Obs
- Surface measurements (snow depth)
- High-res visible-infrared space-based measurements for snow fractional coverage (e.g., MODIS)
- Lower-res microwave space-based radiometric obs for SWE (e.g., SSM/I, AMSR-E)
- New missions?

**Additional Observations**
- Precip analyses from CaPA
- Space-based remote sensing data will also be used
  
  *Brasnett, Brown*
The Canadian Precipitation Analysis (CaPA)

Correction of a first guess field using a weighted average following:

\[ x_a^j = x_b^j + \sum_{i=1..N} w_{ij} (y_o^i - y_b^i) \]

The background (first guess) is given by our best model products.

The weight matrix is given by

\[ W = (B + O)^{-1} b \]

where \( B \) and \( O \) are the background and observations error covariance matrices, given by

\[ B_{ij} = \sigma_b^2 \times \left( 1 + \frac{r_{ij}}{L} \right) \times \exp \left( -\frac{r_{ij}}{L} \right) \]

\[ O_{ij} = \sigma_o^2 \times \delta_{ij} \]

(Fortin, Mahfouf, Brasnett, Gagnon)
# Snow Models in CMC’s NWP Systems

<table>
<thead>
<tr>
<th>Component</th>
<th>Model Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soils and vegetation</td>
<td>ISBA, CLASS, Force-Restore</td>
</tr>
<tr>
<td>Water</td>
<td>Simple scheme with constant surface temperature (Lake model eventually?)</td>
</tr>
<tr>
<td>Urban covers</td>
<td>TEB</td>
</tr>
<tr>
<td>Glaciers</td>
<td>Force-restore scheme (with snow), module from CLASS</td>
</tr>
<tr>
<td>Sea ice</td>
<td>3-layer model with snow on top</td>
</tr>
<tr>
<td>Snow</td>
<td>Very simple schemes over glaciers and sea ice; one layer model in ISBA, CLASS, slightly more complex in TEB</td>
</tr>
</tbody>
</table>
Snow Modeling in ISBA

• Single layer model
• Force-restore approach for temperatures
• Water balance for snow mass
• Prognostic equations for:
  • Snow mass
  • Surface and snow pack temperatures
  • Snow density
  • Snow albedo
  • Liquid water in snowpack
• Includes:
  • Refreezing in the snow pack
  • Melting due to rain
  • Snow coverage fractions (bare soil, vegetation)

(Bélair et al., 2003)
More Complex Surface Models
Example: SNThERM (Jordan)
Surface Snow Prediction System

**INITIAL SURFACE CONDITIONS**
- Temperatures
- SWE
- Snow albedo
- Snow density
- Liquid water content in snow

**ATMOSPHERIC FORCING**
- Near-surface air characteristics (temperature, humidity, winds)
- Surface pressure
- Incident radiation (solar and infrared)
- Precipitation (rain and snow)

**LAND SURFACE CHARACTERISTICS**
- Topography
- Land/water fractions
- Soil texture
- Land use / Land cover

**DOWNSCALING MODELS**
- **Low res forcing**
- **High res forcing**

**SNOW MODEL(S)**
- ISBA
- CLASS
- Others (SNThERM)
External Land Surface Systems

Grid size

- Global (33 km)
- Regional (15 km)
- Local (2.5 km)
- Urban (200 m)

1 day
2 days
10 days

External Surface Model

With horizontal resolution as high as that of surface databases (e.g., 200 m)

Cost of the external surface modeling system is much less than an integration of the full atmospheric model.
Downscaling: Impact on Surface Snow

15 km (GEM)

1 km (MEC)

(Valid 0000 UTC 1 December 2006)
Special Project for VAN 2010 Olympics

Topography and the Vancouver urban area

Topography from SRTM (30 m)

Urban LULC from Lemonsu et al. (2007)

Computational grid: 1400 x 1800 (100 m)
Snow in NWP: Last Few Comments

• Blowing snow is being included in the atmospheric model, but it may be difficult to include blowing snow in an external land surface system.

• Verification: more is needed (including space-based remote sensing).

• Remote-sensing of snowfall could be used in precipitation analysis (not much else information in northern regions) – Important to have a good idea of the observation errors.

• Remote sensing of surface snow conditions (again, need good estimate of the observation errors):
  • Snow coverage
  • SWE
  • Snow albedo

• Temporal resolution: would be nice to have information daily.

• Spatial resolution: at least of the order of the regional model grid-size (~10-20 km).
Thank you …
Statistical Adaptation for Local Prediction

**INITIALIZATION / ASSIMILATION**

- **OBS FORCING**
  - Precip
  - Tair, qair
  - Wind
  - Cloud cover

- **OBS SURFACE VARIABLES**
  - Tsnow
  - Snow depth
  - Soil moisture
  - Tsurf

**FORECAST**

- **LAM1 km for day 1**
- **Reg for day 2**
- **Glb after**

**LAND SURFACE MODEL + VAR ASSIMILATION**

- **Assimilation window**

- **Initial Conditions**

- **Past**

- **Now**

- **Future**
Snow Modeling in CLASS
(Similar in ISBA)

\[ \alpha_{\text{snow}} = f(t, T_{\text{snow}}) \]

\[ \rho_{\text{snow}} = f(\rho_{\text{fall}}, t, z_{\text{snow}}, T_{\text{snow}}, \text{refreeze}) \]

variable snowfall density
\[ \rho_{\text{fall}} = f(T_{\text{air}}) \]

canopy interception sublimation and unloading

variable surface albedo
\[ \alpha_{\text{snow}} = f(t, T_{\text{snow}}) \]

snow-covered fraction
\[ f_{\text{snow}} = f(z_{\text{snow}}) \]

sublimation and condensation

melt, runoff, refreeze

Layer 1

(from Ross Brown)