Assessing snow extent data sets to inform and improve trace gas retrievals from solar backscatter

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Snow cover is challenging to trace gas retrievals

Retrieved VCD are sensitive to surface reflectance

Snow cover varies with space and time

Existing reflectivity climatologies don’t represent snow well

Snow cover is often mistaken for cloud (and vice versa)

Mistakes in snow attribution cause retrieved NO$_2$ column errors of 20-50%*

*[O’Byrne et al., JGR 2010]*
Snowy scenes often omitted due to potential errors

Greatly reduces number of usable observations

Photo credit: NASA/Goddard Space Flight Center Scientific Visualization Studio
Air Mass Factor: A Large Source of Uncertainty in Trace Gas Retrievals

\[
AMF = \frac{\text{observed slant column}}{\text{vertical column density}} = AMFG \int w(z)S(z)dz
\]

Radiative Transfer Model
Scattering Weights \(w(z)\) function of:
- Viewing geometry
- Clouds, aerosols
- Surface reflectance

\[
w(z) = \frac{-1}{AMFG} \frac{\alpha(z)}{\alpha_e} \frac{\partial \ln I_B}{\partial \tau}
\]

Atmospheric Chemistry Model
NO\(_2\) Shape Factor \(S(z)\)

\[
S(z) = \frac{n(z)}{\Omega_v}
\]
Bright surfaces benefit retrieval sensitivity

Scattering Weight = observed backscattered light sensitivity to NO₂
Bright surfaces benefit retrieval sensitivity

AMF doubles over snow! Means better data quality.
Good snow identification has potential to improve trace gas retrievals
Evaluation of Snow Extent Products

**Canadian Meteorological Centre (CMC)**
- Surface snow depth measurements
- 25 km resolution

**IMS**
- Multiple satellite (Visible & microwave) + ground data + models
- 4 km resolution

**MODIS products**
- VIS-IR radiances. On Aqua and Terra satellites
- 0.05° Resolution

**MAIAC products**
- MODIS radiances
- 1 km resolution

**NISE**
- Microwave (SSM/I)
- 25 km resolution

Compare against >15,000 ground stations from GHCN-D database
### IMS best agrees with observations

<table>
<thead>
<tr>
<th></th>
<th>Accuracy</th>
<th>Precision</th>
<th>Recall</th>
<th>F</th>
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<tbody>
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</table>

- **Accuracy** = \( P(\text{data set is correct}) \)
- **Precision** = \( P(\text{snow in data set is really there}) \)
- **Recall** = \( P(\text{finding snow when it is there}) \)
- **F** = Balances Precision and Recall (best metric for evaluation)

- Tested at different resolutions
  - 4 km (shown here)
  - 25 km
  - Native resolutions
IMS best agrees with observations

<table>
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<th>Spring F</th>
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- Performance of all data sets lower in melting, accumulation season
Spatial structure of IMS Evaluation

- Most errors occur along Pacific coast, or in US South
  - Snow generally thinner and more transient, thus easier to miss
IMS well suited for informing TEMPO

• Satellite-based product for informing satellite observations
  • Snow Depth ≠ Brightness from space

• Multiple observations, different viewing geometries & times
  • Less cloud contamination
Improved data quantity AND quality by including snowy scenes

- Simulated OMI observations of a GEOS-Chem simulation
- Use IMS to identify snow cover
- Use appropriate surface LER
- Either omit or include snowy scenes
Improved data quantity AND quality by including snowy scenes

- Including snowy scenes increases number of observations by factor of 2.1 (assuming clear skies)
- Increases mean AMF x 2.7 in regions with occasional snow cover
  - Higher AMF = better data quality
Summary

• Sensitivity to surface NO$_2$ increases over snow covered scenes
• IMS is the best performing snow extent product over North America and is well suited for informing retrievals from TEMPO
• Observation frequency and retrieval sensitivity increase by more than a factor of two by including observations over snow

Conclusion

Combining daily snow detection from IMS with a climatology of snow reflectance has the potential to greatly improve observation quantity and quality