Advances in the assimilation of MW sounding data over snow and sea-ice

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Background: Impact from denying polar observations: Z 500

- **Summer**: Largest impact from MW radiances
- **Winter**: Poorer impact from MW radiances
  - Attributed to poorer use of surface-sensitive sounding radiances over snow and sea-ice (e.g., poorer forward modelling, issues in forecast model, background error modelling etc)
- See *Lawrence et al, QJRMS, 2019*
Background: How do we treat surface characteristics for MW sounders over snow and sea-ice?

- Use **effective skin temperature and emissivity; specular assumption**.

  - **Skin temperature:**
    - Model surface temperature used as background
    - For AMSU-A and ATMS: Retrieved as sink variable during the assimilation, separately for each FOV

  - **Emissivity:**
    - Retrieved prior to assimilation from an otherwise not assimilated window channel (e.g., Karbou et al 2006)

<table>
<thead>
<tr>
<th>Assimilated sounding channels</th>
<th>Emissivity channel</th>
</tr>
</thead>
<tbody>
<tr>
<td>50-60 GHz band</td>
<td>50.3 GHz</td>
</tr>
<tr>
<td>183 GHz band</td>
<td>150/165 GHz over snow, sea-ice</td>
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- **Investigated here:**
  - What biases are arising from using the specular assumption?
  - What is the role of the skin temperature estimate?
Lambertian effects over snow and sea-ice for 183 GHz channels

- Assuming Lambertian reflection leads to better simulations over snow and sea-ice for 183 GHz channels.
- Parameterisation available in RTTOV for clear-sky simulations (not yet for RTTOV-SCATT).

(ATMS data before screening, Jan 2020, Arctic)
Lambertian effects over snow and sea-ice for 50-60 GHz channels?

- Situation less clear for 50 GHz, particularly over sea-ice
- Partial-Lambertian behaviour and seasonal variations?
- Mixed with poor skin-temperature estimate?

(ATMS data before screening, Jan 2020, Arctic)
Assimilation experiments with Lambertian reflection over snow/sea-ice

- **Control**: Full observing system, specular assumption used over land/snow/sea-ice throughout
- **Lamb**: As Control, but using:
  - Lambertian reflection over snow and sea-ice for 183 GHz channels on ATMS
  - Semi-Lambertian reflection over snow and sea-ice for 50 GHz channels on ATMS and AMSU-A
- **Periods**:
  - 20 June – 30 Sept 2019;
  - 1 Dec 2019 – 31 March 2020
- **12-h 4D-Var; T CO 399 model resolution (~25 km)**
Forecast impact from Lambertian surface treatment

Normalised difference in RMSE of vector wind, verified against own analyses

20 June – 30 Sept 2019

Dec 2019 – March 2020

Lamb better than Control

Lamb worse than Control
Advancing the treatment of skin temperature

• Over snow and sea-ice, the model surface temperature is likely to be a poor effective skin temperature at MW frequencies, due to neglected penetration depth.

• **Experimental new approach:**
  – Retrieve an effective skin-temperature field (instead of separate values for each FOV):
    • “Augmented control variable”: Hourly skin-temperature fields, with separate fields for MW and IR instruments
  – Skin-temperature background errors include spatial and temporal correlations
  – The new skin-temperature field is constrained simultaneously by all instruments affected
  – See Massart et al (2021), GMDD

  – In addition, **address skin-temperature biases** by **persisting the increments** for the MW skin temperature fields (using the result from 24 h prior as background).

• Preliminary additional experiment:
  – **Lamb+TskinACV**: As Lambertian experiment, but applying the new skin temperature approach for all surfaces and to all instruments assimilated in clear-sky (for MW: AMSU-A and ATMS only).
Preliminary results from the new skin-temperature treatment

- Large difference between retrieved skin-temperature and model surface temperature over snow and sea-ice.
- Reduced biases in background departures for surface-sensitive channels.
- Further increase in the number of observations passing quality control, primarily for the 50-GHz channels.

Mean difference between retrieved skin-temperature field and model surface-temperature field [K] in Lambert+TskinACV experiment; 11-31 Dec 2019

Difference in the number of used observations Lamb+TskinACV vs Lamb

NOAA-20 ATMS, 11-31 Dec 2019
Preliminary results from using the new skin-temperature treatment and Lambertian reflection

- Large reductions in stdev(o-b) from Lambertian surface treatment and new skin-temperature approach
  - Skin-temperature impact larger for 50-GHz channels
  - Lambertian effect larger for 183-GHz channels

Normalised differences in standard deviation [%], NOAA-20 ATMS, 11-31 Dec 2019, all data

Lamb vs Control

Lamb+TskinACV vs Lamb
Summary and conclusions

• Two potential sources of bias in the forward modelling of surface-sensitive MW sounding radiances over snow and sea-ice have been explored:
  – Assuming (part-)Lambertian rather than specular reflection leads to better background departures, particularly for 183-GHz channels
  – The use of the model surface temperature as effective skin temperature appears to significantly contribute to the biases, particularly for the 50-GHz channels

• Ways to address these biases have been investigated:
  – Assuming Lambertian reflection in the assimilation leads to an increase in the number of observations passing quality control (esp for 183 GHz), and neutral-to-positive forecast impact
  – Addressing skin-temperature biases via an augmented control variable framework allows further increases in the data usage for 50-GHz channels, with promising benefits in departure statistics
    • Further experimentation is required to assess the overall performance of the new skin-temperature approach

• So far only considered instruments assimilated in clear-sky conditions – further work is required to adapt these methods in the all-sky framework.

• Possibilities to address some of the issues through better radiative transfer of the surface contribution and atmosphere-surface interaction in the future?