Lambertian surface scattering at AMSU-B frequencies:

An analysis of airborne microwave data measured over snow-covered surfaces

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Contents

• Two ways to determine effective radiating temperature using three 183 GHz channels.

• Specular versus Lambertian scattering and effects on emissivity retrievals

• Apply to Sea Ice flight data

• Confirmation from 11 other flights

• Impact on NWP assimilation of AMSU-B

• Conclusions
Four ways to estimate surface effective temperature

• (1) Onboard Heimann estimate of surface temperature
  • IR skin surface temperature
  • High temporal resolution (1 or 64 Hz)
• MARSS: $T_{\text{eff}}$ estimated from 183 GHz channels
  • (2) Tech Note 35 (Hewison, 2002)
  • (3) Selbach 2003
  • Each MARSS footprint (nadir every 3 sec)
  • Only uses MARSS data to derive $T_{\text{eff}}$
• (4) Ground measurements of snow temperature
  • Hand measurements: Sparse in space and time
  • Automated: One location but continuous in time
Determining emissivity and effective temperature

- Technote 35 and Selbach methods

- Both require
  - Measurements of $T_{Bn}$ and $T_{Bz}$ on 183 GHz sounding channels (183±1, 183±3 and 183±7 GHz).
  - Measurements of temperature and water vapor profile between the platform and surface.
  - Assume linear emissivity gradient between 175 and 191 GHz
    - $e(183\pm7) \equiv e(183\pm1) \equiv e(183\pm3) \equiv e(183$ GHz)
  - Both use simple clear skies radiative transfer to extrapolate measurements at height to the surface
Technote 35: 183 GHz effective temperature and emissivity

- Uses classical definition of emissivity ((2) below)

\[
T_{\text{eff}} = \frac{T_u (183 \pm 1\text{GHz}) - T_d (183 \pm 1\text{GHz})}{e_s (183\text{GHz})} + T_d (183 \pm 1\text{GHz})
\]  
(1)

\[
e_s (183\text{GHz}) = \frac{T_u (183 \pm 7\text{GHz}) - T_d (183 \pm 7\text{GHz})}{T_{\text{eff}} - T_d (183 \pm 7\text{GHz})}
\]  
(2)

- (1) and (2) combine to form (3)

\[
e_s (183) = \frac{T_u (183 \pm 7) - T_u (183 \pm 1) - T_d (183 \pm 7) + T_d (183 \pm 1)}{T_d (183 \pm 1) - T_d (183 \pm 7)}
\]  
(3)

- Solution of (3) used in (1) to find \(T_{\text{eff}}\)

- Only uses 183±1 and 183±7 GHz channels
Selbach: 183 GHz effective temperature and emissivity

- Uses all three 183 GHz channels.
- Simple clear skies radiative transfer model

\[
T_{Bn} = e_s T_{\text{eff}} \exp(-\tau) - (1-e_s)T_d \exp(-\tau) + T_a
\]

\[
T_d = T_{Bz} \exp(-\tau) + T_a
\]

\[
T_a = (1-\exp(-\tau))T_m
\]

- \(e_s\) and \(T_{\text{eff}}\) -- surface emissivity and effective temperature.
- \(T_{Bzi}\) and \(T_{Bni}\) -- measured zenith and nadir viewing brightness temperatures in channel i.
- \(T_m\) -- mean atmospheric temperature under the aircraft.

\(\forall \tau_i\) is the opacity in channel i. Determined with ARTS using dropsonde profiles.

- Differences between modelled and observed \(T_{Bn}\)'s on the three 183 GHz channels are analytically minimized in cost function.
- Closed form solution: \(T_{\text{eff}}\) and \(e_s\) at 183 GHz
Ice Station off Point Barrow
operated by UAF Geophysical Institute
Visited during 3 flights. B345(5), B348(2), B351(27)
B351: Sea Ice emissivity flight

Low level sector
• 27 runs over fast ice
• Near UAF ice station
• 500’ asl

High level run
• 32,000’ asl
• 3 dropsondes released
• Used to compute absorption
• Coincident with MetOp
B351: Resulting effective temperature time series

- Specular reflection
- Nadir measurements used
- Technote 35 effective temperatures way too warm.
- Other sorties:
  - Same large separation
  - Sometimes roles reversed
- Why the difference?
  - Same parameters used atm. abs. and 183 GHz $T_B$’s
  - Expect much more overlap.

Ice station temperature profile implied surface value
• 183 GHz Emissivities calculated with Technote 35 and Selbach methods. Others use Selbach $T_{\text{eff}}$

$$e(\nu) = \frac{T_n(\nu) - T_z(\nu)}{T_{\text{eff}} - T_z(\nu)}$$

• Takes into account
  • The changing path length between the aircraft and the ground
  • The temporal variability in $T_B$’s

• As the two effective temperatures are different so are the emissivities at 183GHz
  • But the two methods use virtually the same information with differing weights.

• Spectra non-monotonic.

• Same signature seen in snow covered land
Assumptions about reflection

- Up to this point all results presented use specular reflection assumption

- Recent literature (Mätzler, 2005; Mätzler and Rosenkranz, 2007) over snow covered surfaces
  - Specularity not a good assumption for near-nadir viewing satellite instruments such as AMSU-A and AMSU-B.
  - Reflection more diffuse in character.

- MARSS scans between 0° and 50° incidence in the upward and downward directions.
  - Near-nadir views overlap with views of other radiometers ARIES and Heimann and the radar altimeter.
  - Diffuse surface scattering characteristic important for retrieving near-nadir emissivities.

- Now demonstrate effect of diffuse surface scattering.
Optically thin channels have $T_{bd}$ that increases with incidence angle.

$T_{MR}$ is the mean atmospheric temperature weighted by the absorption in each layer.

$T_{CMB}$ is the cosmic background radiation.

At high optical depth, $\tau$, $T_{bd}(\theta) = T_{MR}$

$$T_{bd}(\theta) = T_{MR} (1 - \exp(-\tau / \cos \theta)) + T_{CMB} \exp(-\tau / \cos \theta)$$

Elgered (1993)
Calculating surface scattering contribution with MARSS measurements.

\[ T_d(\mu, \phi) = \frac{1}{\varepsilon \pi} \int S(\mu, \phi, \mu_0, \phi_0) T_{bd}(\mu, \phi) d\Omega \]

- MARSS makes six angular measurements of \( T_{bd} \) at 1° to 49° wrt vertical in upward directions.

- Must estimate \( T_d(\mu_0, \phi_0) \) with the limited views provided by MARSS.

- There will be a contribution to \( T_d(\mu_0, \phi_0) \) from outside the scan.

  - Estimated by calculating above over theoretical ‘Tip Curve’ to estimate the proportion of integral outside of MARSS views.

  - \( T_d(\mu_0, \phi_0) \) is then calculated for the MARSS measurements and corrected for partial coverage of sky.

  - These theoretical ‘Tip Curves’ are only valid for homogeneous, clear skies cases.
Resulting emissivity spectra

(a) Specular

(b) Lambertian

- Eq. (16)
- Selbach, Eq. (8)
- TeffTech35, Eq. (3)
Resulting effective temperatures

Ice station temperature profile implied surface value
Strong evidence for diffuse scattering
Confirmation of diffuse scattering with other data

• Analysed nine flights from Feb 2008 CLPX-II campaign (5 over land and 4 over sea ice) and three flights over sea ice from March 2001.

• For all 12 flights:
  • Lambertian emissivities and effective temperatures agree for Selbach and Technote 35 methods within the instrumental error.
  • Specular emissivities disagree to ~0.05 to 0.08
  • Specular effective temps disagree to ~7 to 12 K
Impact on assimilation of AMSU-B over snow in polar regions.

- Assimilation of brightness temperatures under specular surface assumption not good.

- $T_d$ is 15 to 20 K greater than $T_z$ for window channels and at least 30 to 40 K greater for 183±1 GHz.

- Assimilation of AMSU-B when using specular surface assumption introduces large model bias ~10 K. This can be mis-interpreted as emissivity (or observation) error.

- Key to assimilation of surface sensitive channels over polar regions is to use a more realistic surface interaction.

- Observation operator: Down welling component must be modeled at multiple angles and aggregated over $S(\mu, \phi_0, \mu, \phi)$.

- Only then can we hope to parameterize the emissivities and effective temperatures in snow covered areas in terms of physically observable variables.
Conclusions

- Two methods of calculating effective temperature and emissivities at 183 GHz: Selbach and Technote 35.
- Two surface interactions: Specular and Lambertian.
- Two estimates of $T_{\text{eff}}$ and emissivity consistent when surface is Lambertian.
- Strong evidence for diffuse scattering effects.
- Impact on NWP.
References


- Barrow Ice Observatory, http://www.gi.alaska.edu/snowice/sea-lake-ice/index.html


