Lambertian surface scattering at AMSU-B frequencies:

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

Chawn Harlow, 2nd Workshop on Remote Sensing and Modeling of Land Surface Properties, Toulouse, 09/06/09

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_{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_{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
  - $e(183\pm7) \equiv e(183\pm1) \equiv e(183\pm3) \equiv e(183\text{ GHz})$
- 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)

$$T_{eff} = \frac{T_u(183\pm 1GHz)\quad T_d(183\quad 1GHz)}{e_s(183GHz)} \qquad (1)$$

$$+T_d(183\quad 1GHz)$$

$$e_s(183GHz) = \frac{T_u(183\pm 7GHz)\quad T_d(183\quad 7GHz)}{T_{eff} - T_d(183\quad 7GHz)} \qquad (2)$$

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

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

- Solution of (3) used in (1) to find T_{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

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

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

$T_a=(1-exp(-\tau\ \ ))T_m$

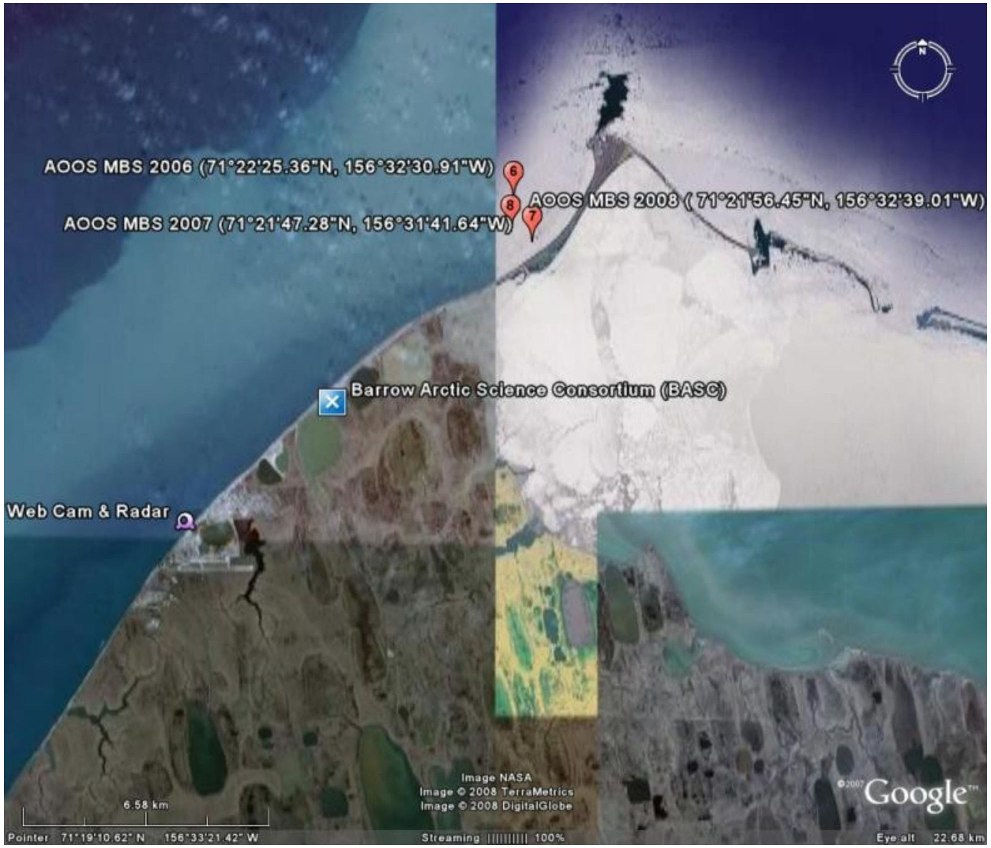
  - e_s and T_{eff} -- surface emissivity and effective temperature.
  - T_{Bzi} and T_{Bni} – measured zenith and nadir viewing brightness temperatures in channel i.
  - T_m -- mean atmospheric temperature under the aircraft.

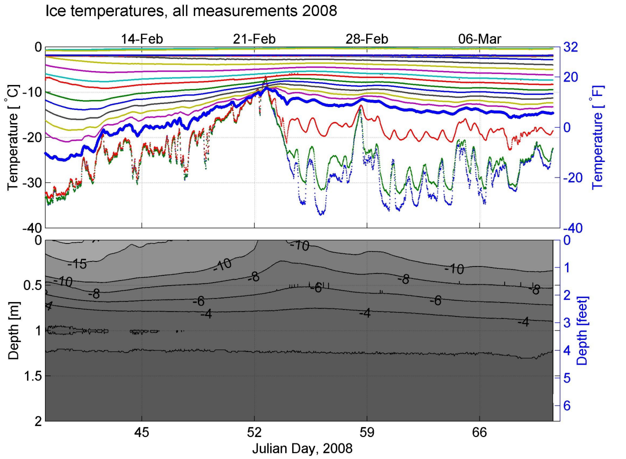
∀ τ_i is the opacity in channel i. Determined with ARTS using dropsonde profiles.

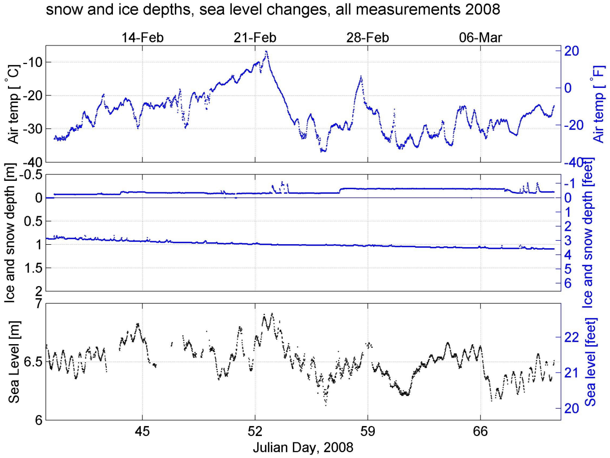
- Differences between modelled and observed T_{Bn}'s on the three 183 GHz channels are analytically minimized in cost function.
  - Closed form solution: T_{eff} and e_s at 183 GHz

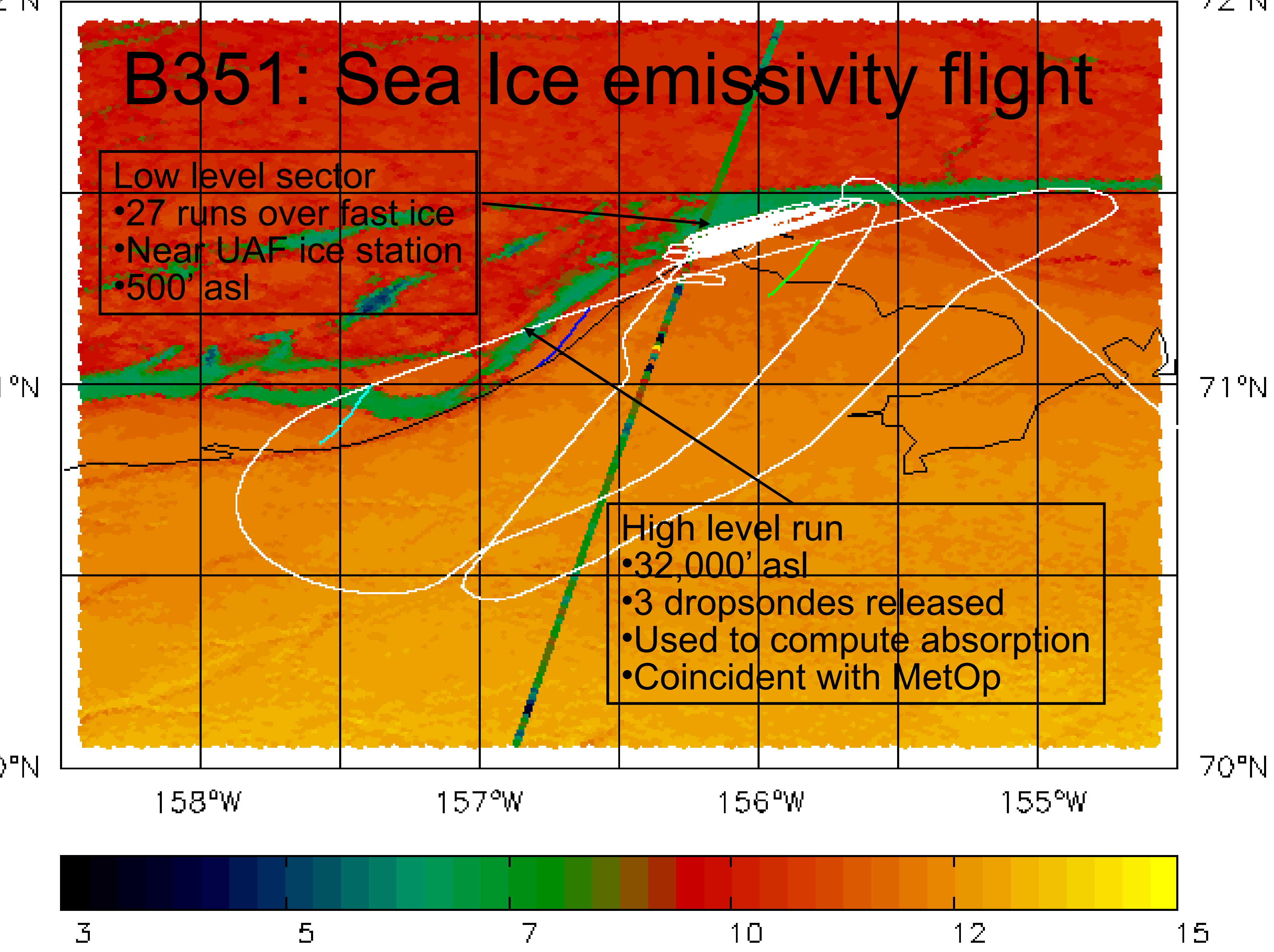
Ice Station off Point Barrow

operated by UAF Geophysical Institue
Visited during 3 flights. B345(5),B348(2),B351(27)




Ice temperatures, all measurements 2008


snow and ice depths, sea level changes, all measurements 2008



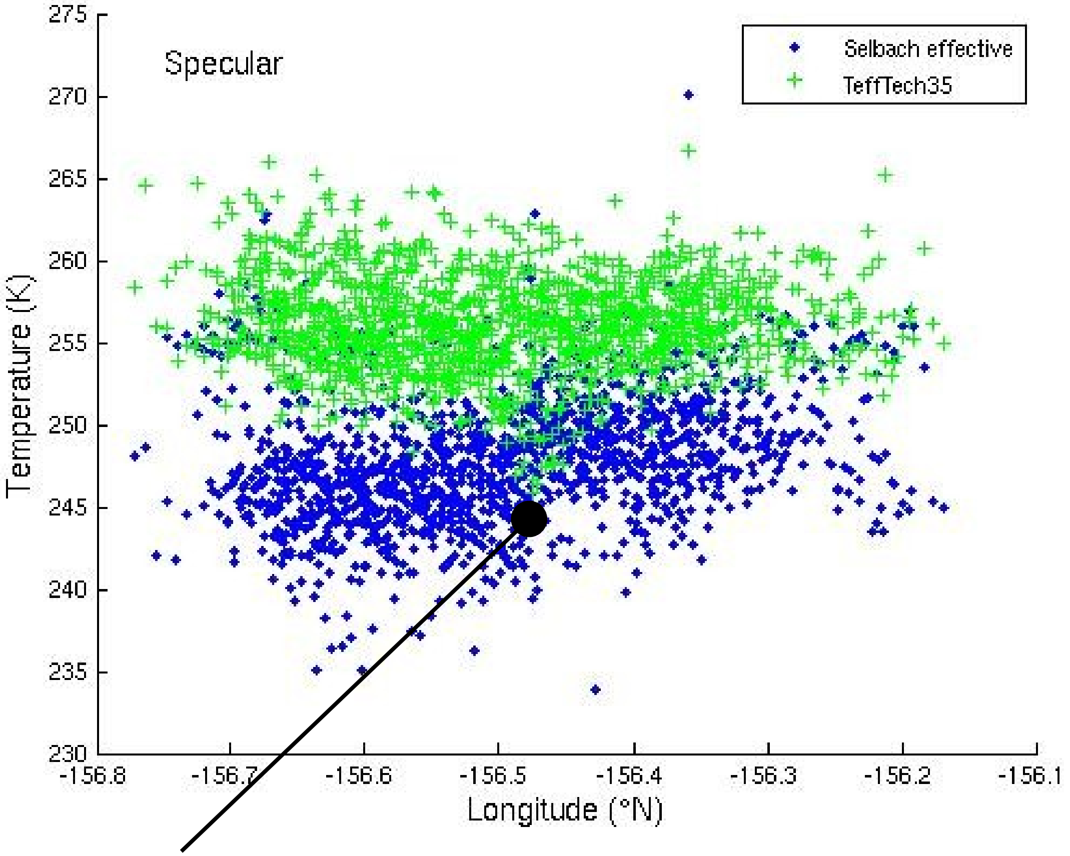
B351: Sea Ice emissivity flight

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.



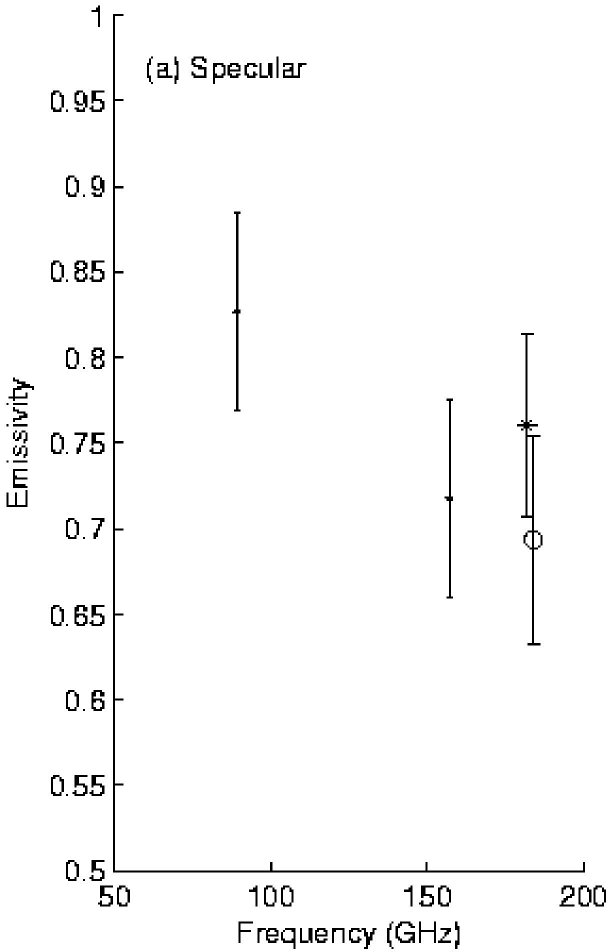
Ice station temperature profile implied surface value

Resulting sea ice emissivity spectra

- 183 GHz Emissivities calculated with Technote 35 and Selbach methods. Others use Selbach T_{eff}

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

- 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

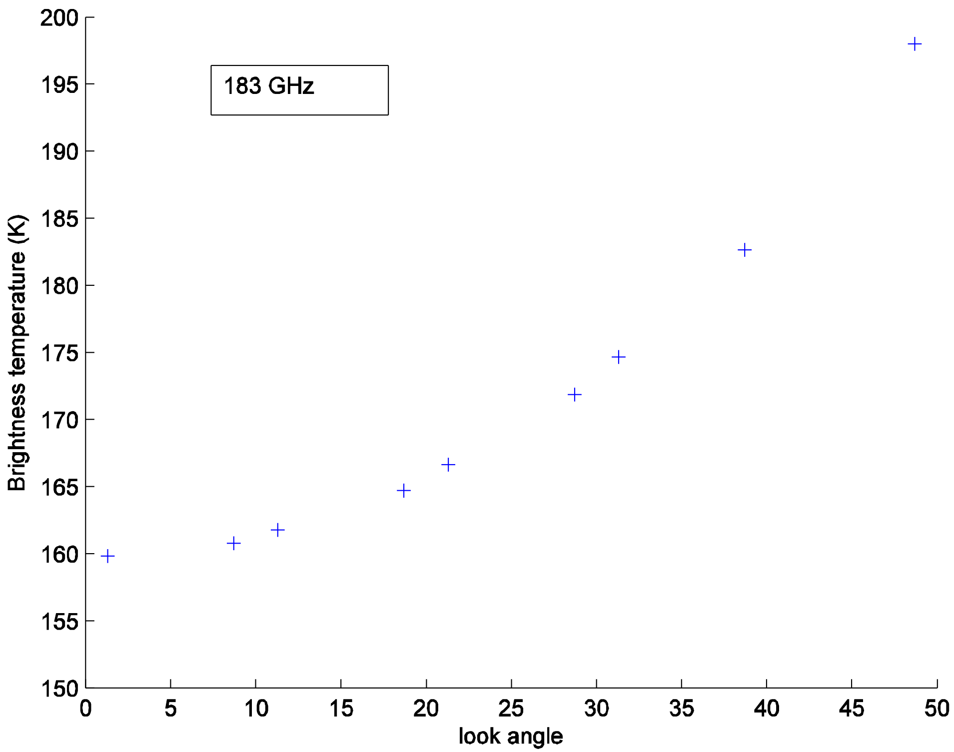


Assumptions about reflection

- 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.

MARSS Tip Curve

- 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, τ , $T_{bd}(\theta\ ) = T_{MR}$



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

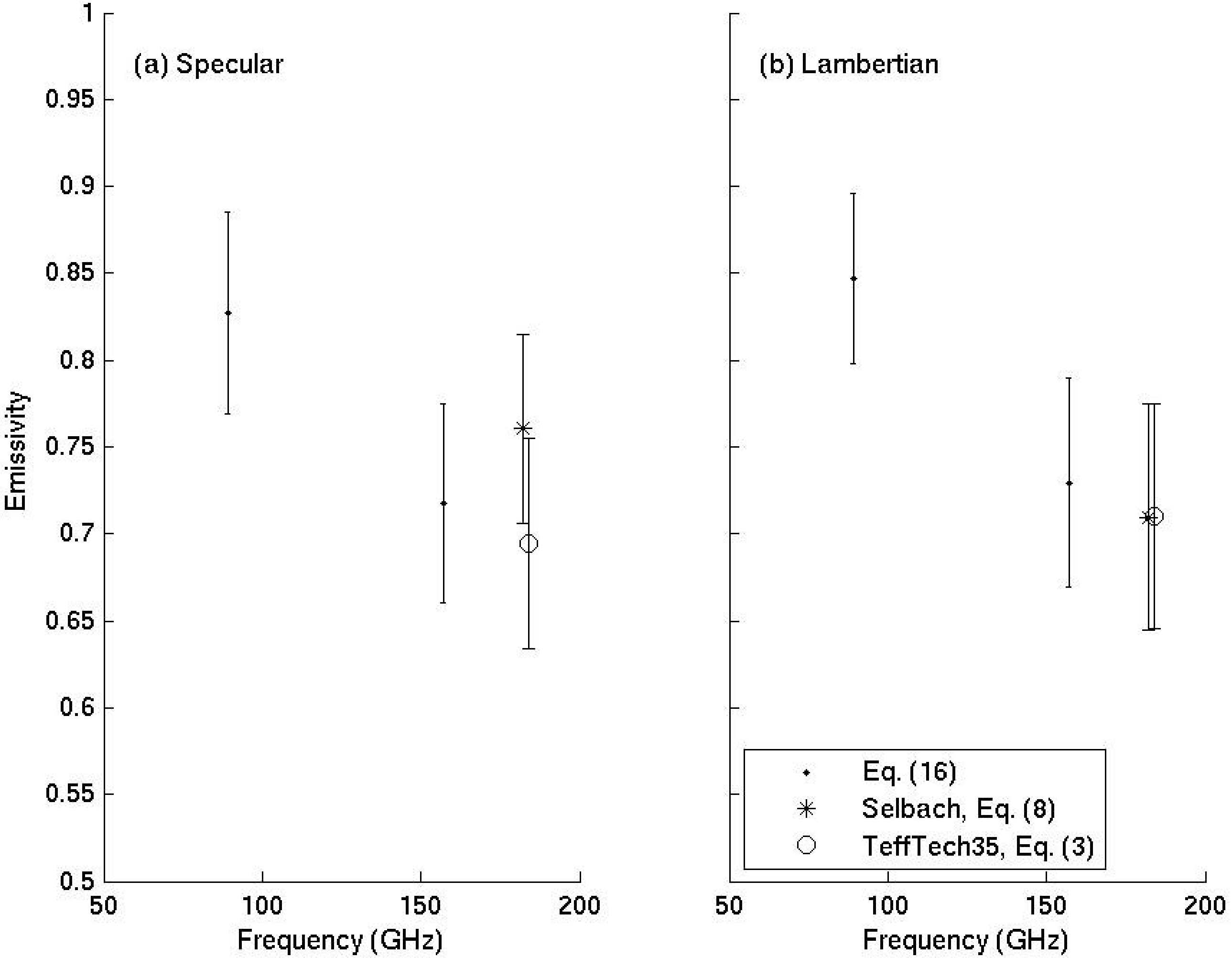
Elgered (1993)

Calculating surface scattering contribution with MARSS measurements.

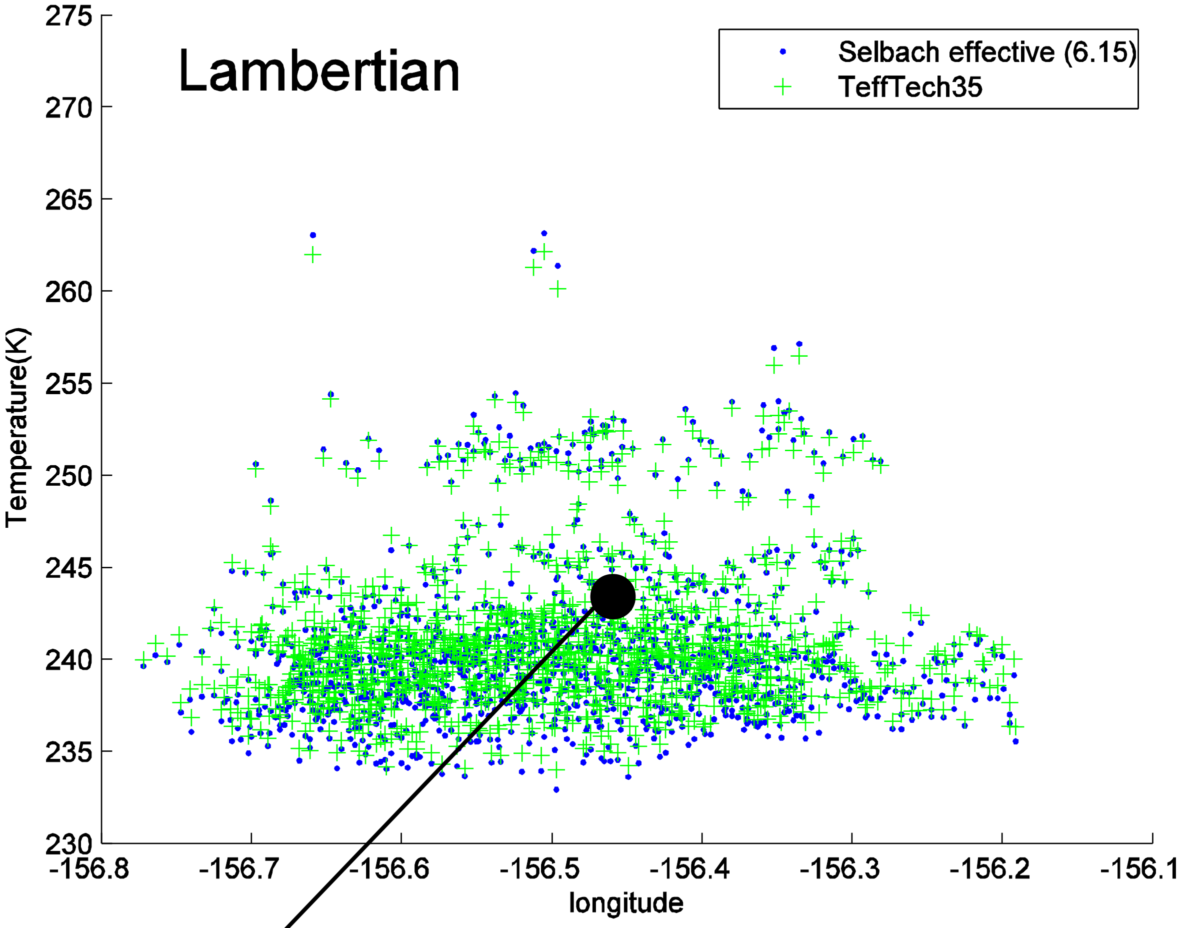
$$T_d(\mu_0,\phi_0) = \frac{1}{4\pi\ \mu_0}\int_{2\pi} S(\mu_0,\phi_0,\mu,\phi)T_{bd}(\mu,\phi)d\Omega$$

- 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

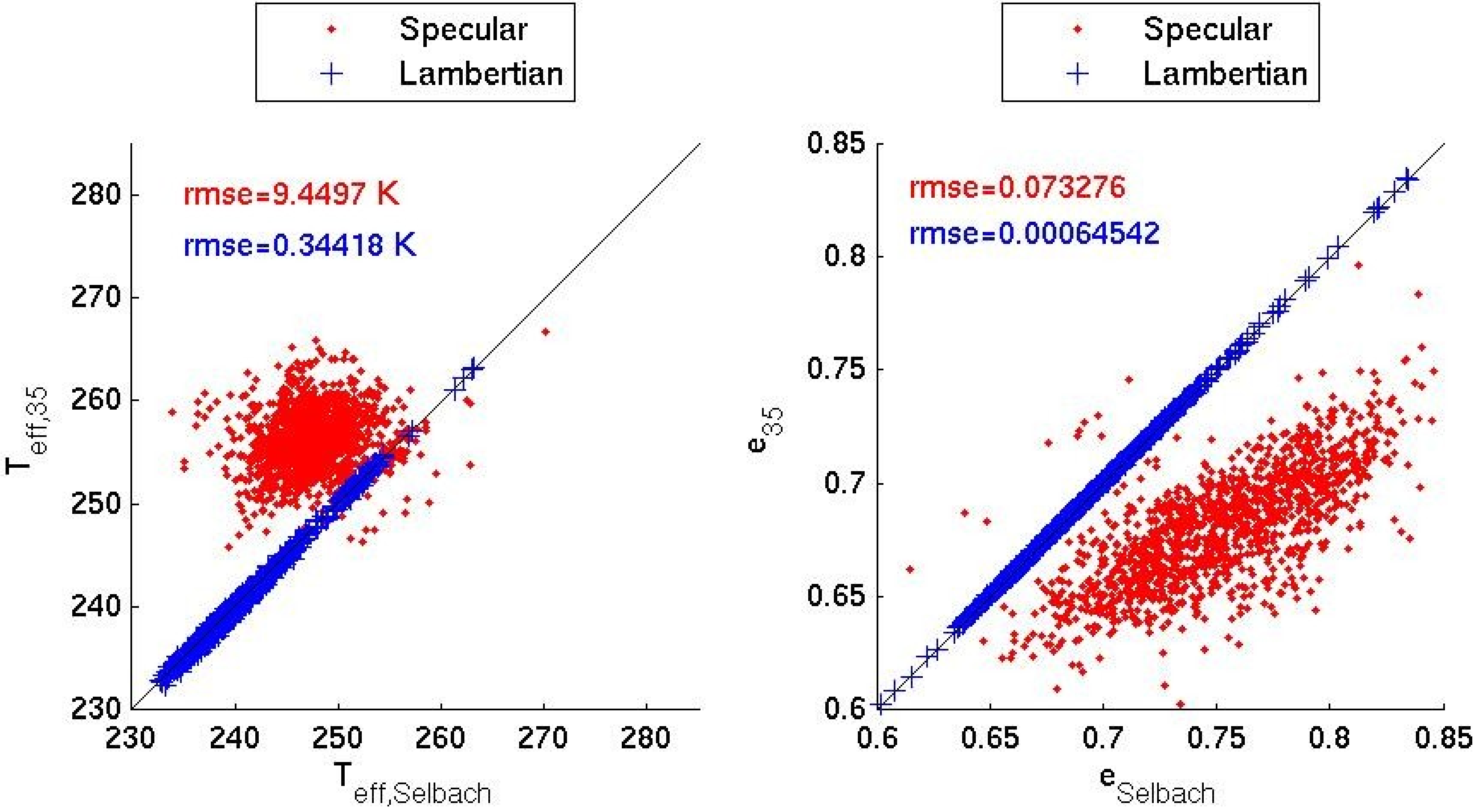


Resulting effective temperatures



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:

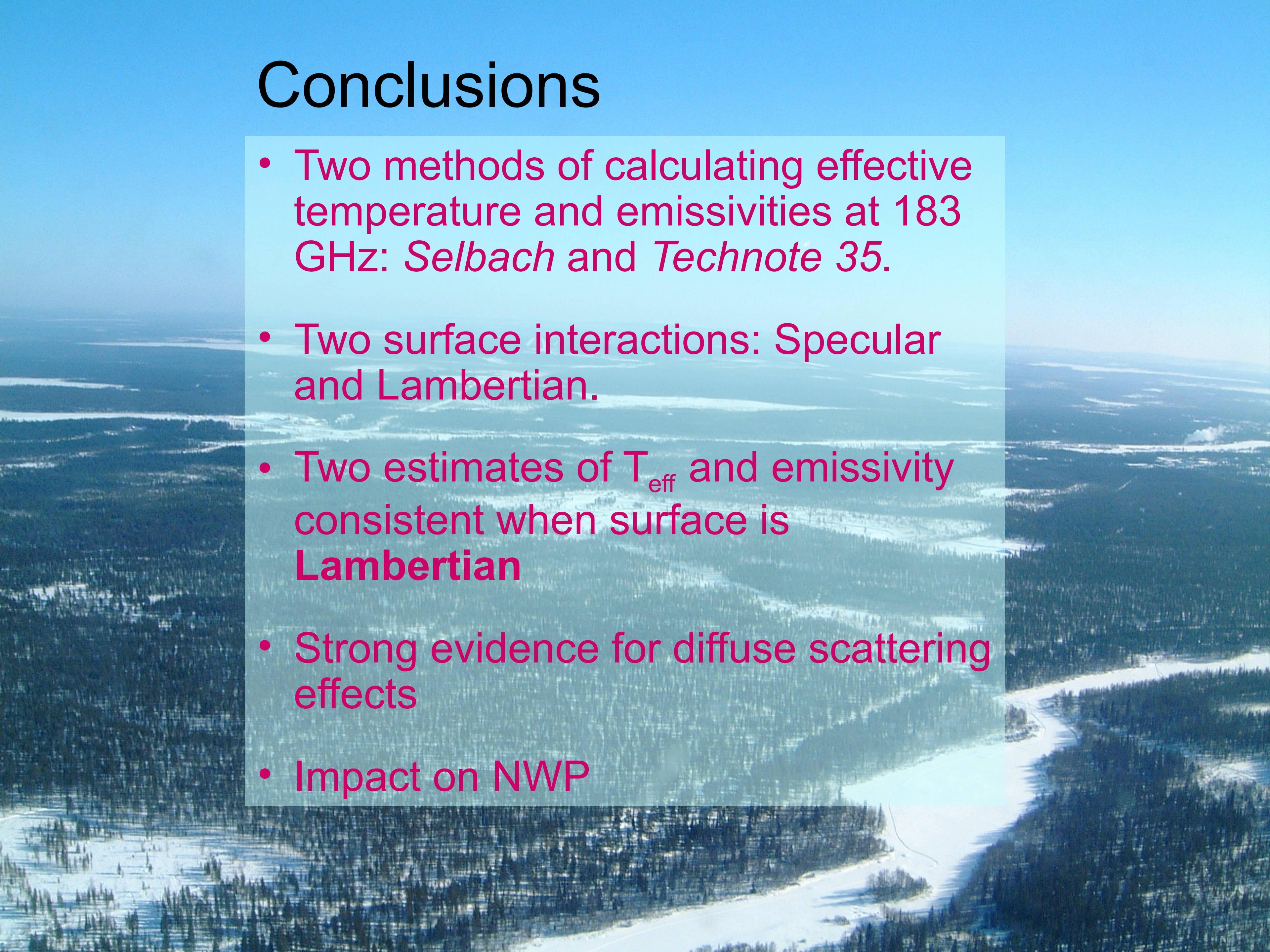
    - Lambertian emissivities and effective temperatures agree for Selbach and Technote 35 methods within the instrumental error.

    - 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 $S(\mu_0,\phi_0,\mu,\phi)$
- 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_{eff} and emissivity consistent when surface is **Lambertian**
- Strong evidence for diffuse scattering effects
- Impact on NWP

References

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