Improving Supercooled Liquid Water Absorption Models in the Microwave Using Multi-Wavelength Ground-based Observations

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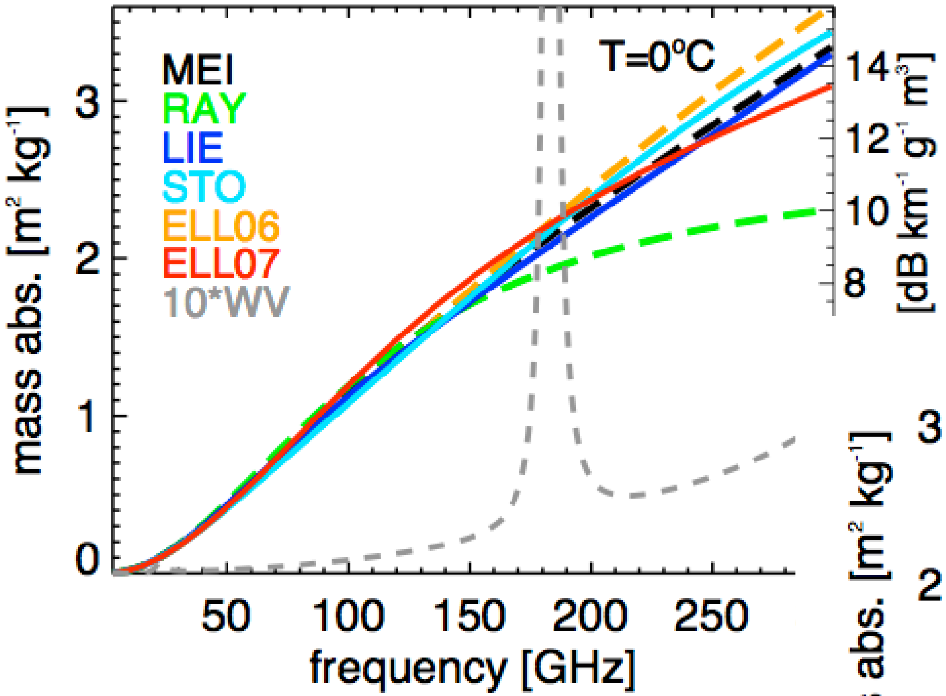
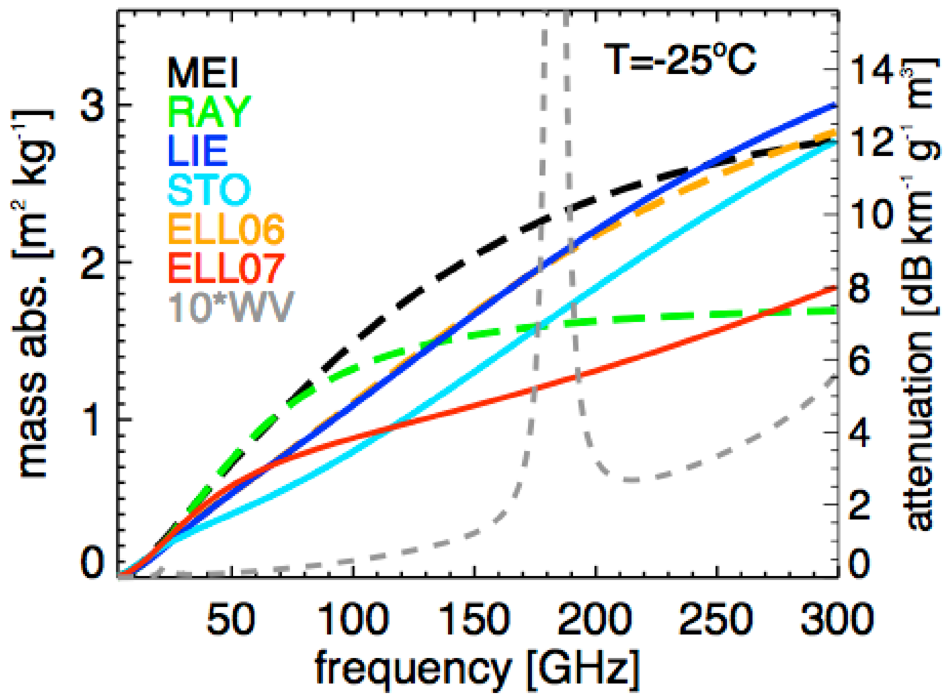
Motivation

- Accurate quantification of liquid water path (LWP) in clouds critical for many atmospheric studies
- Microwave radiometers are the basic observational tools used to measure LWP
- A large fraction of liquid-bearing clouds are supercooled (i.e., $T_{cloud} < 0°C$)
- There are very few laboratory observations of water vapor absorption coefficient in microwave at supercooled temps
- Consequentially, microwave absorption models use semi-empirical models that are fit to warm lab data and extrapolate to supercooled temps
- Translation: a lot of uncertainty in LWP for $T_{cloud} < 0°C$!!

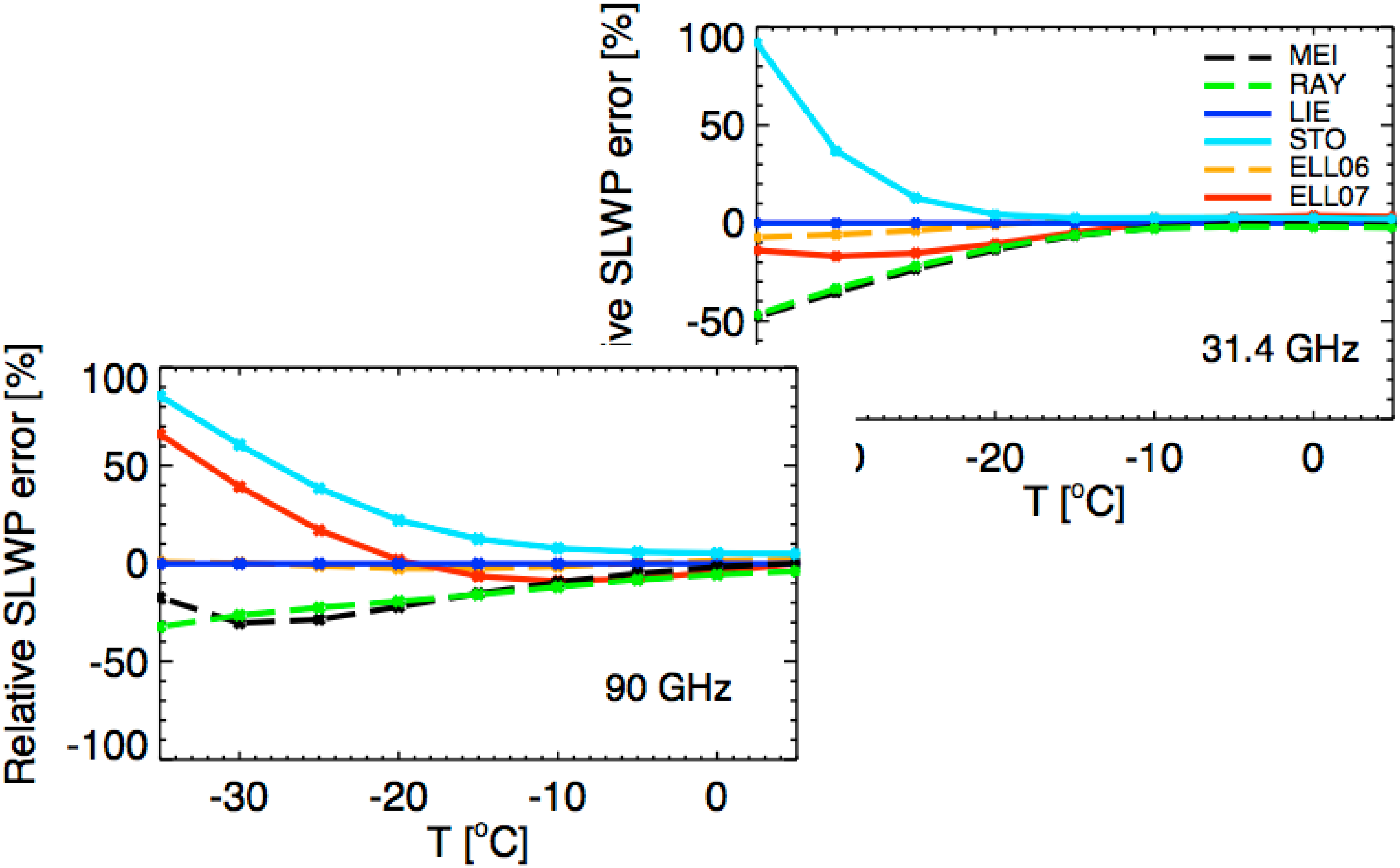
Absorption differences between models





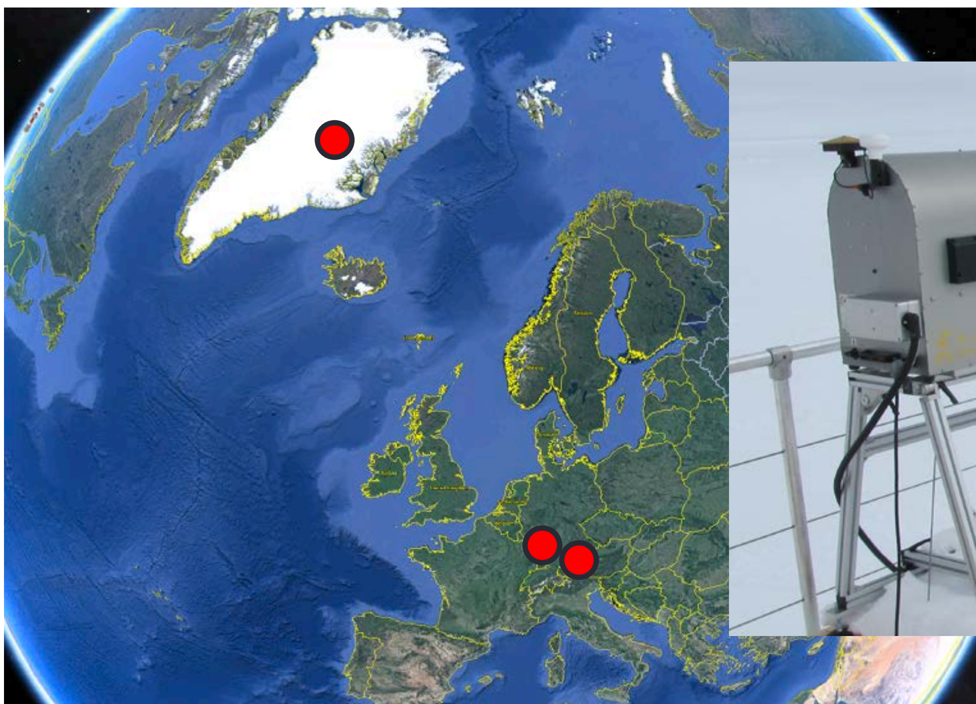
- MEI: Meissner and Wentz (2004)
- RAY: Ray (1972)
- LIE: Liebe et al. (1991, 1993)
- STO: Stogryn et al. (1995)
- ELL06: Ellison (2006)
- ELL07: Ellison (2007)

Impact on retrieved LWP



Datasets used

- AMF Black Forest Deployment
  - 31, 52, 90, 150 GHz; 500 m MSL
- Zugspitze, Germany
  - 31, 52, 90, 150 GHz; 2650 m MSL
- Summit Station, Greenland
  - 31, 52, 90, 150, 225 GHz; 3200 m MSL



MWRs at Summit

Opacity ratios are the key

- The total opacity τ is derived from MWR T_b obs as

$$\tau = \ln\left(\frac{B_\upsilon(T_{MR}) - B_\upsilon(T_c)}{B_\upsilon(T_{MR}) - B_\upsilon(T_b)}\right)$$

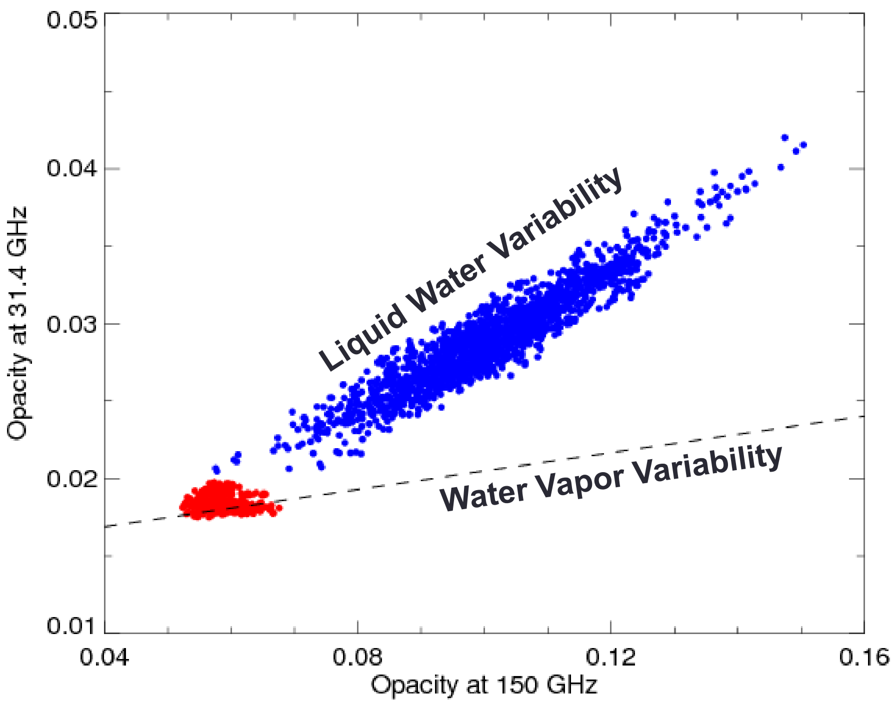
- The total opacity is $\tau = \tau_{dry} + \tau_{wv} + \tau_{liq}$
- Mätzler et al. (2010) presented a method to separate τ_{liq} from τ_{dry} and τ_{wv} using the temporal variability of the liquid
- Assuming cloud temp is fixed for a given cloud, then

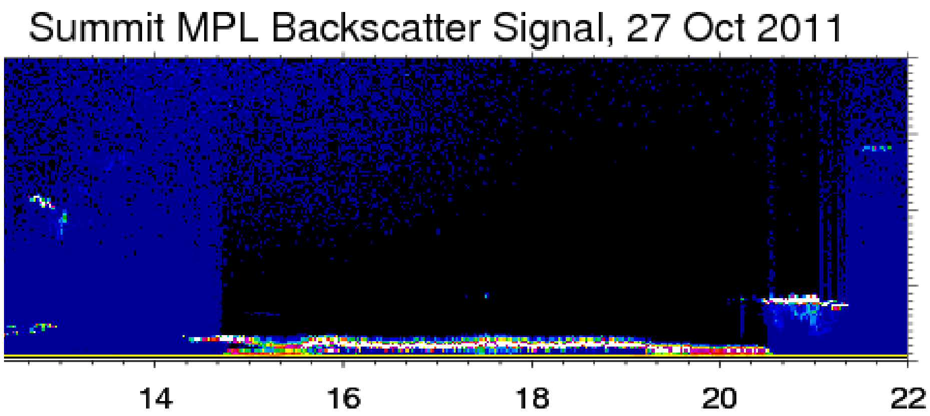
$$\Delta\tau_{liq}(\upsilon, T_{cld}) = \Delta LWP \; \alpha_{liq}(\upsilon, T_{cld})$$

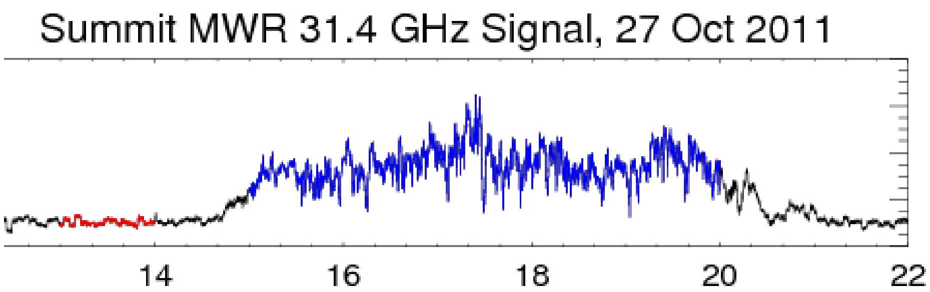
- Thus, the ratio of the fast opacity changes btwn two freqs is

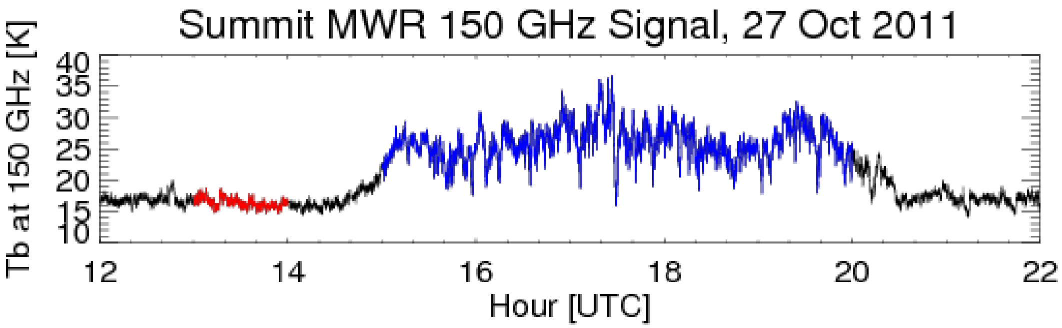
$$\gamma_{\upsilon 1,\upsilon 2} = \frac{\Delta\tau_{liq}(\upsilon_1, T_{cld})}{\Delta\tau_{liq}(\upsilon_2, T_{cld})} = \frac{\alpha_{liq}(\upsilon_1)}{\alpha_{liq}(\upsilon_2)}$$

Opacity changes example from Summit

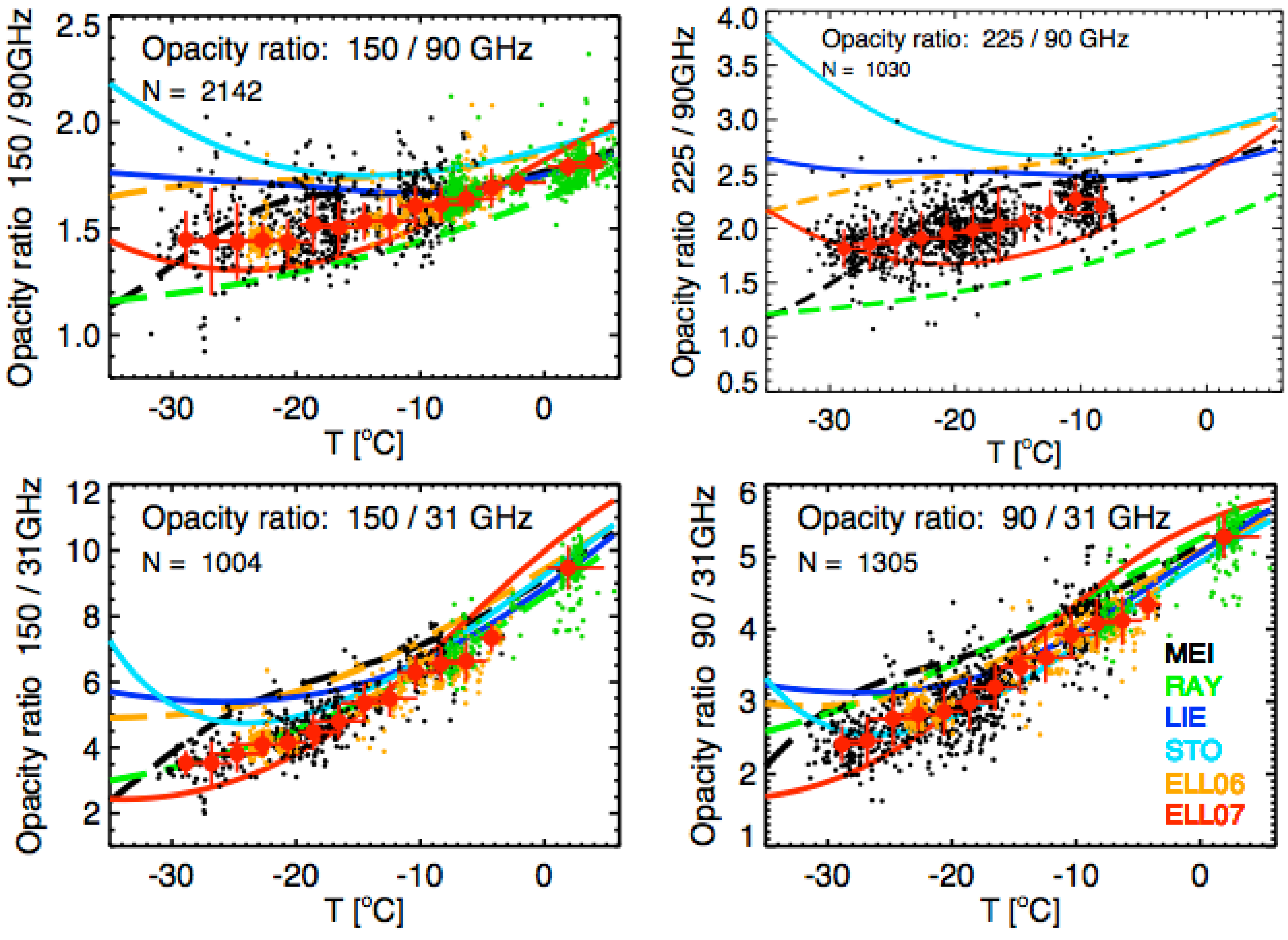




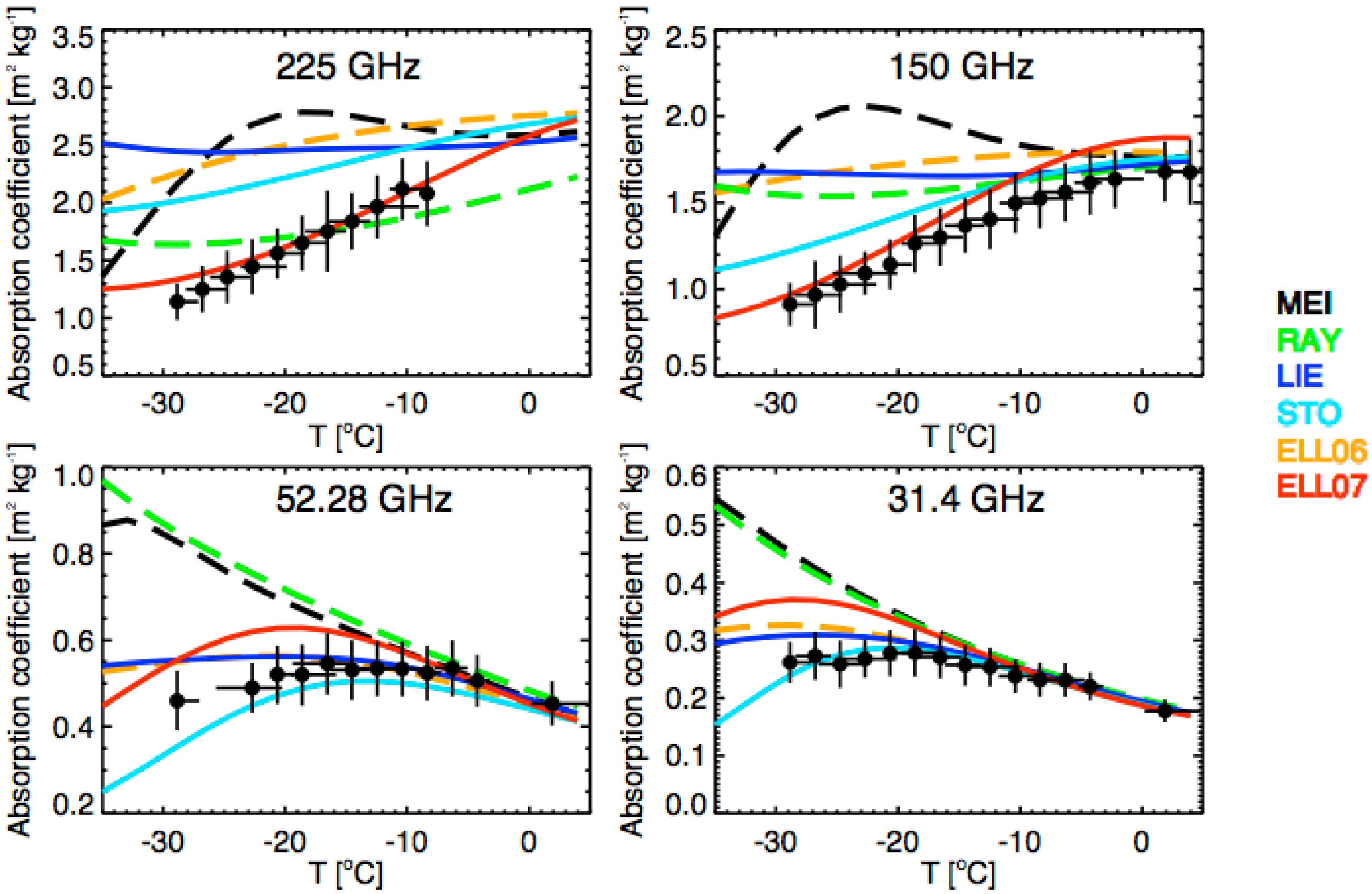




Opacity ratios: Models vs. Obs



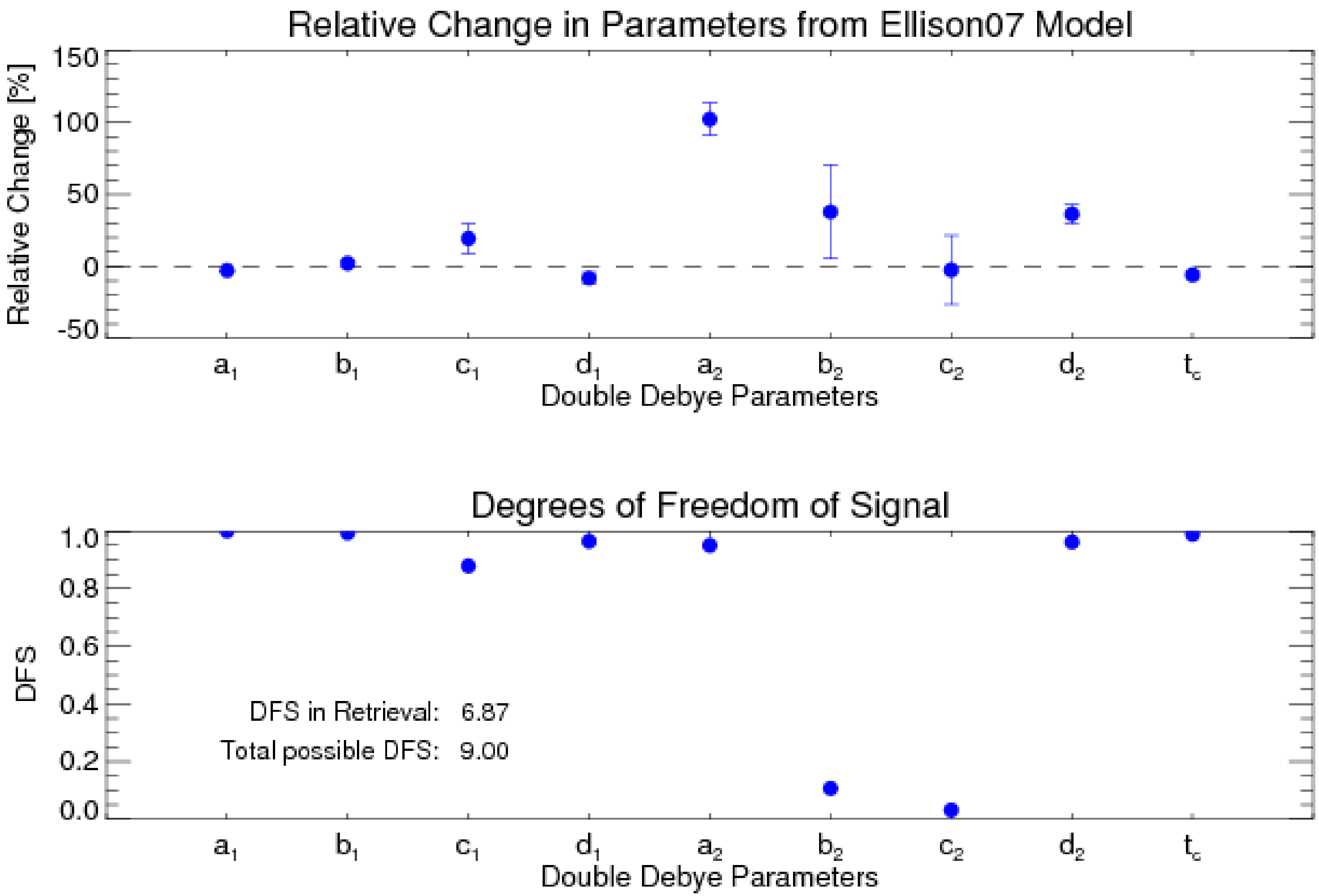
Absorption coefficient: Models vs. Obs



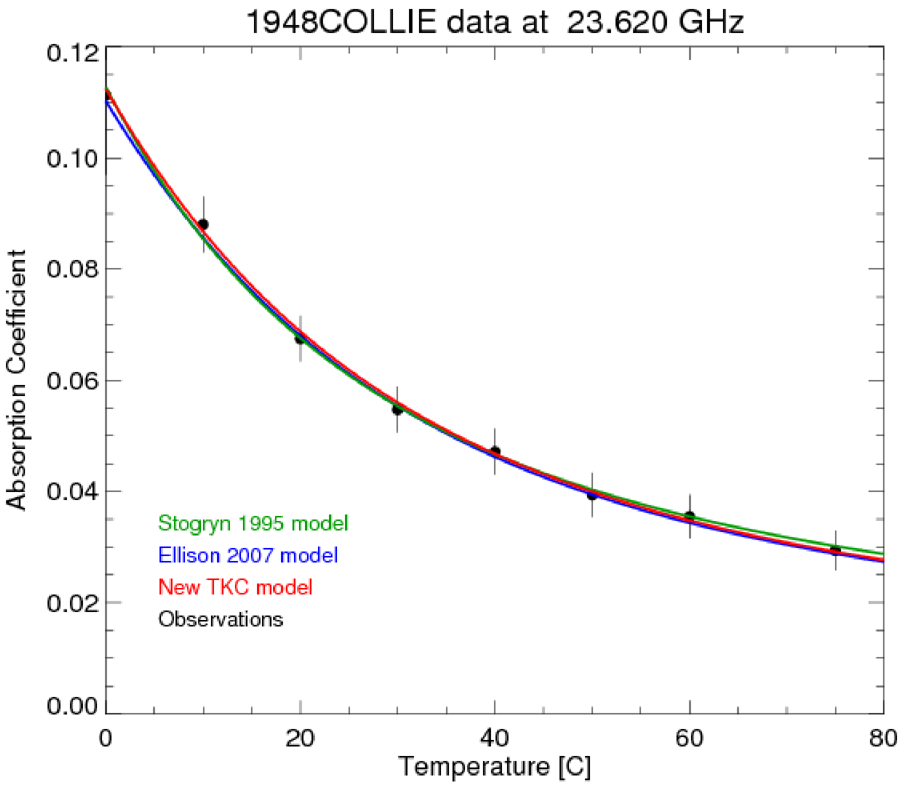
Building a new model

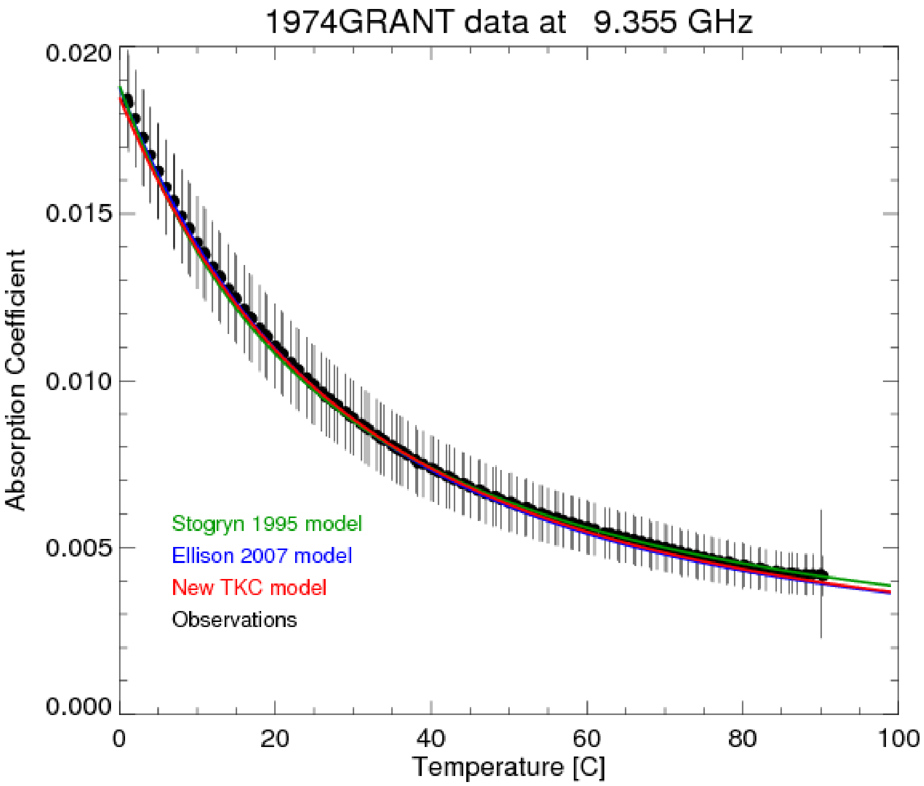
- Previous models built using laboratory measurements to constrain semi-empirical models
  - Lab observations typically at temps between 0 and 100°C
    - 70% of lab measurements between 0 and 30°C
  - Observations span frequencies from 0.5 to 900 GHz
    - 87% of lab measurements are at frequencies below 60 GHz
- Most models assume a “double Debye” form (9 parameters)
- Ellison (2007) packaged the lab data into an easy-to-use format
- Added our opacity ratio obs at supercooled temps to dataset
  - Used absorption by Stogryn model at 90 GHz to translate these opacity ratios into absorption coeffs at 31, 52, 150, and 225 GHz
  - Supported by Cadeddu and Turner (2011), Mätzler et al. 2010
- Used optimal estimation to fit new parameters for a double-Debye model
  - Uncertainty estimates and information content provided as result

Fitting the new model

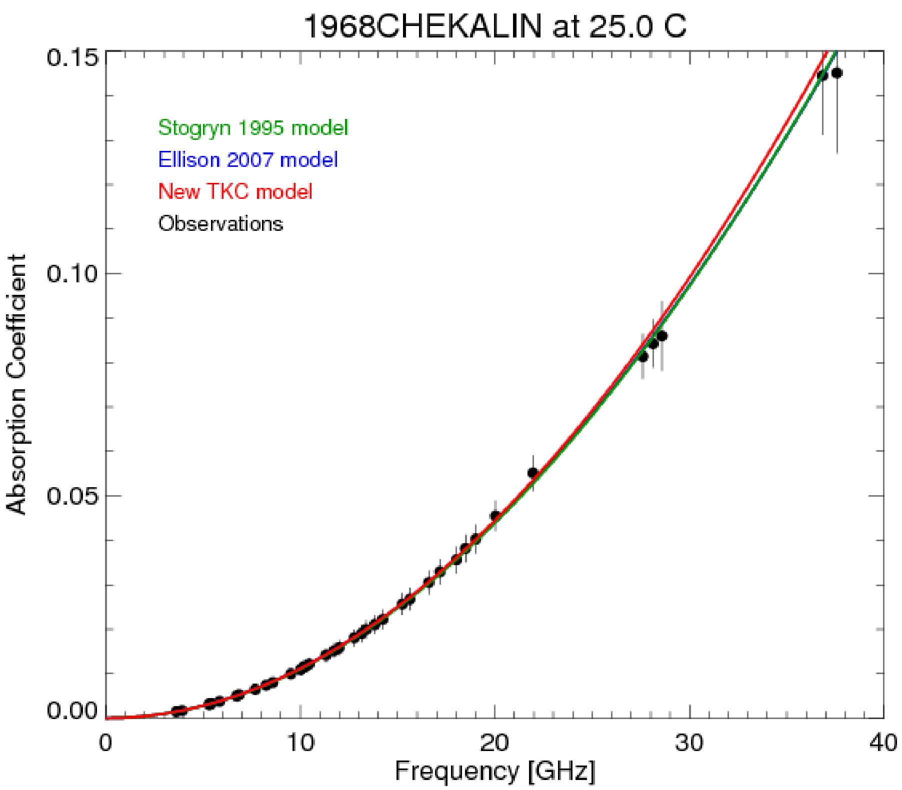


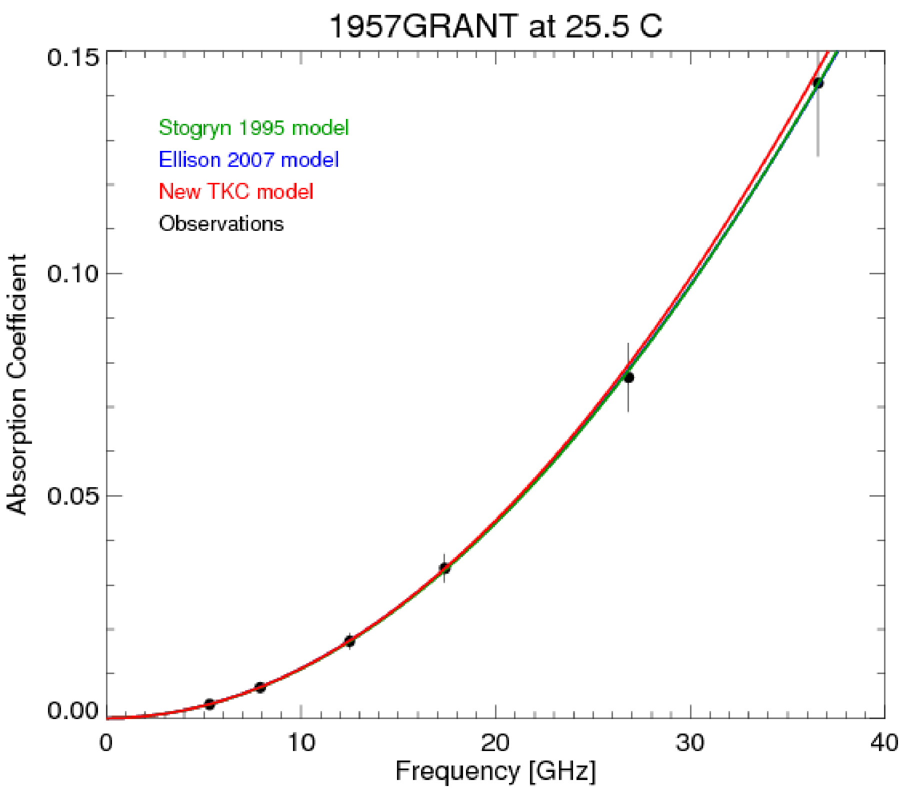
Evaluating the new model: Lab data (1)



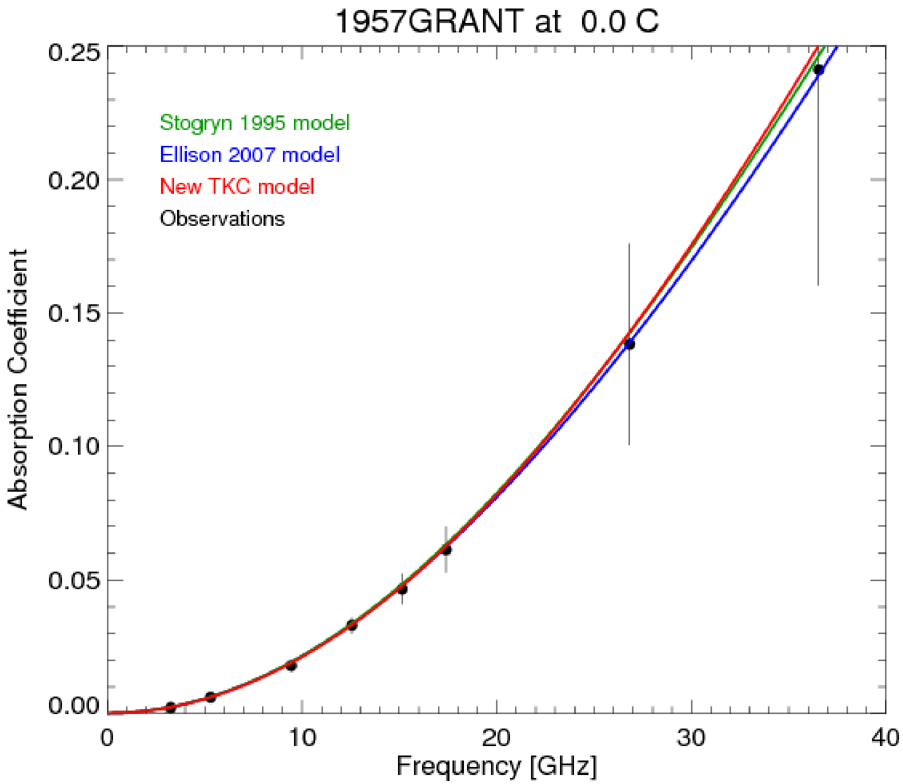


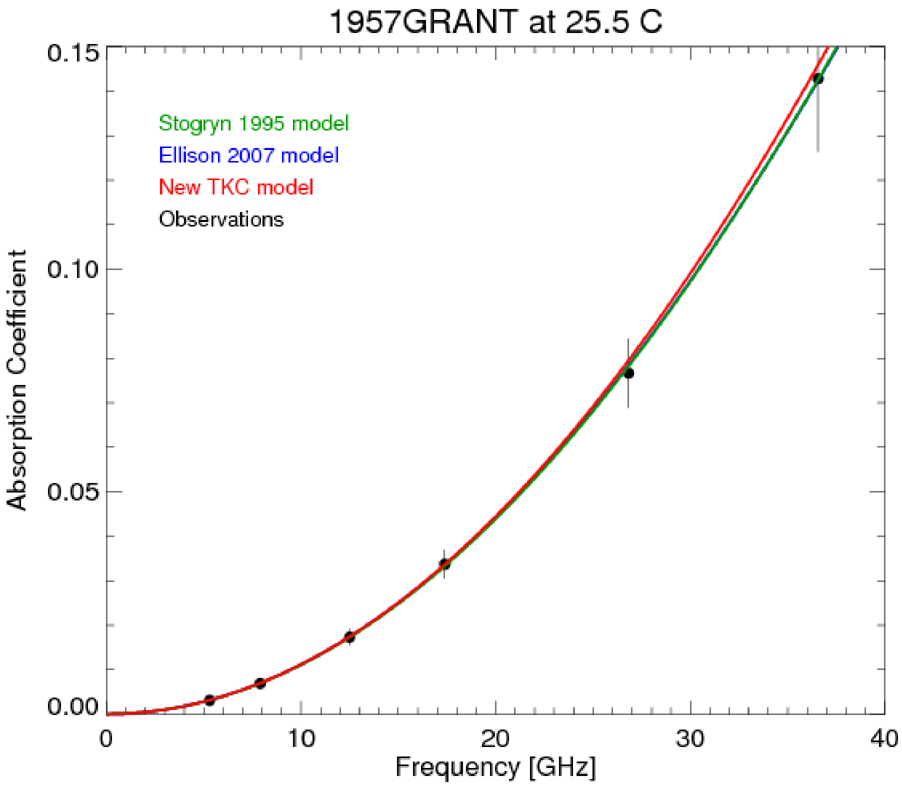
Evaluating the new model: Lab data (2)



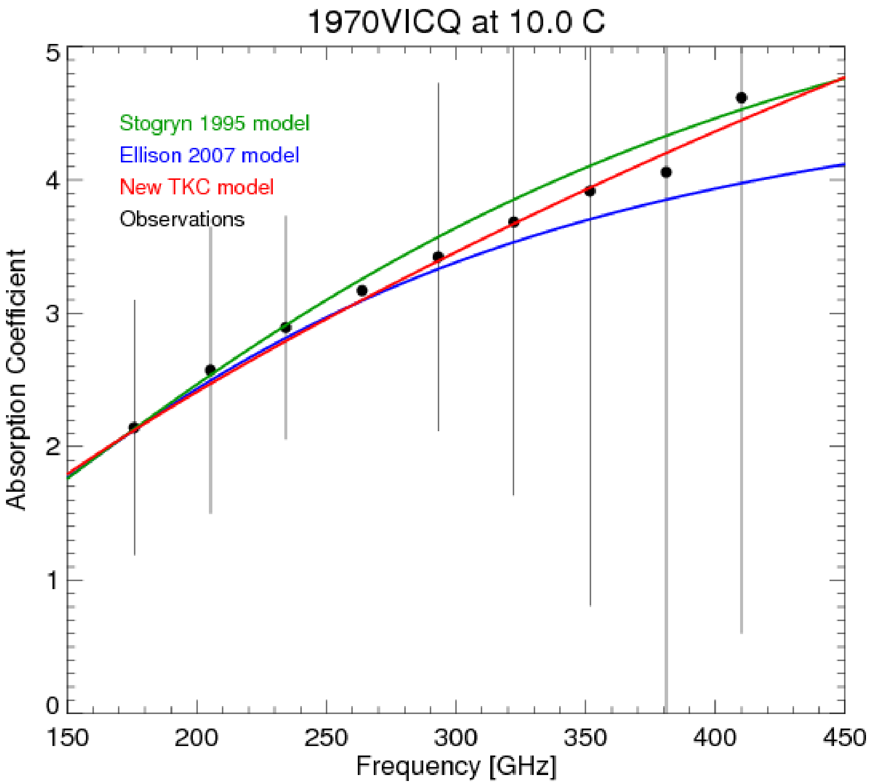


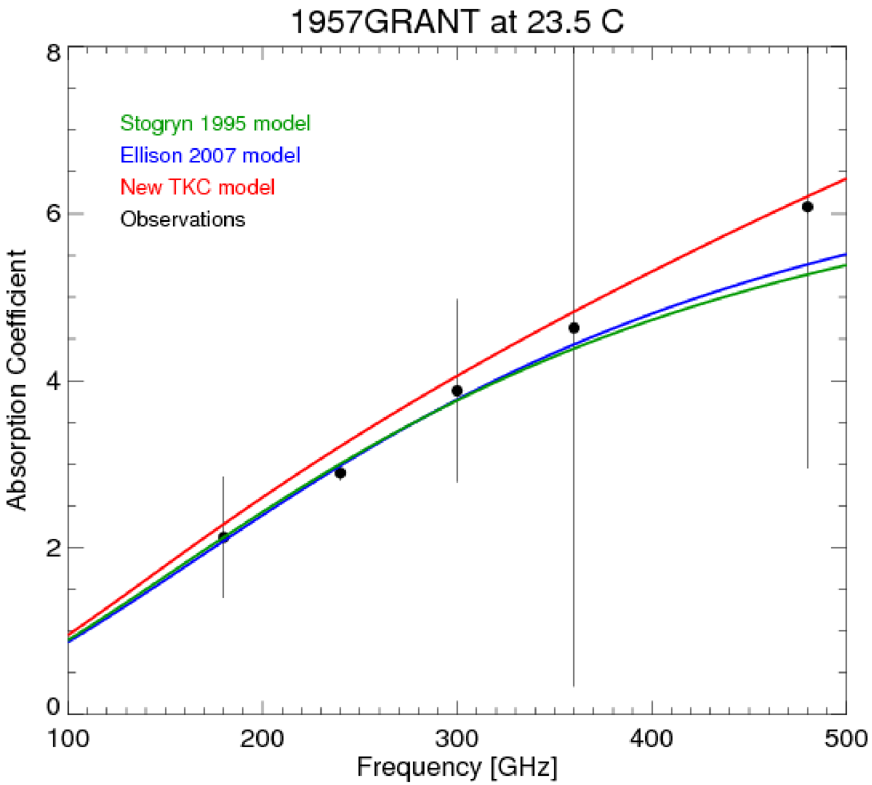
Evaluating the new model: Lab data (3)



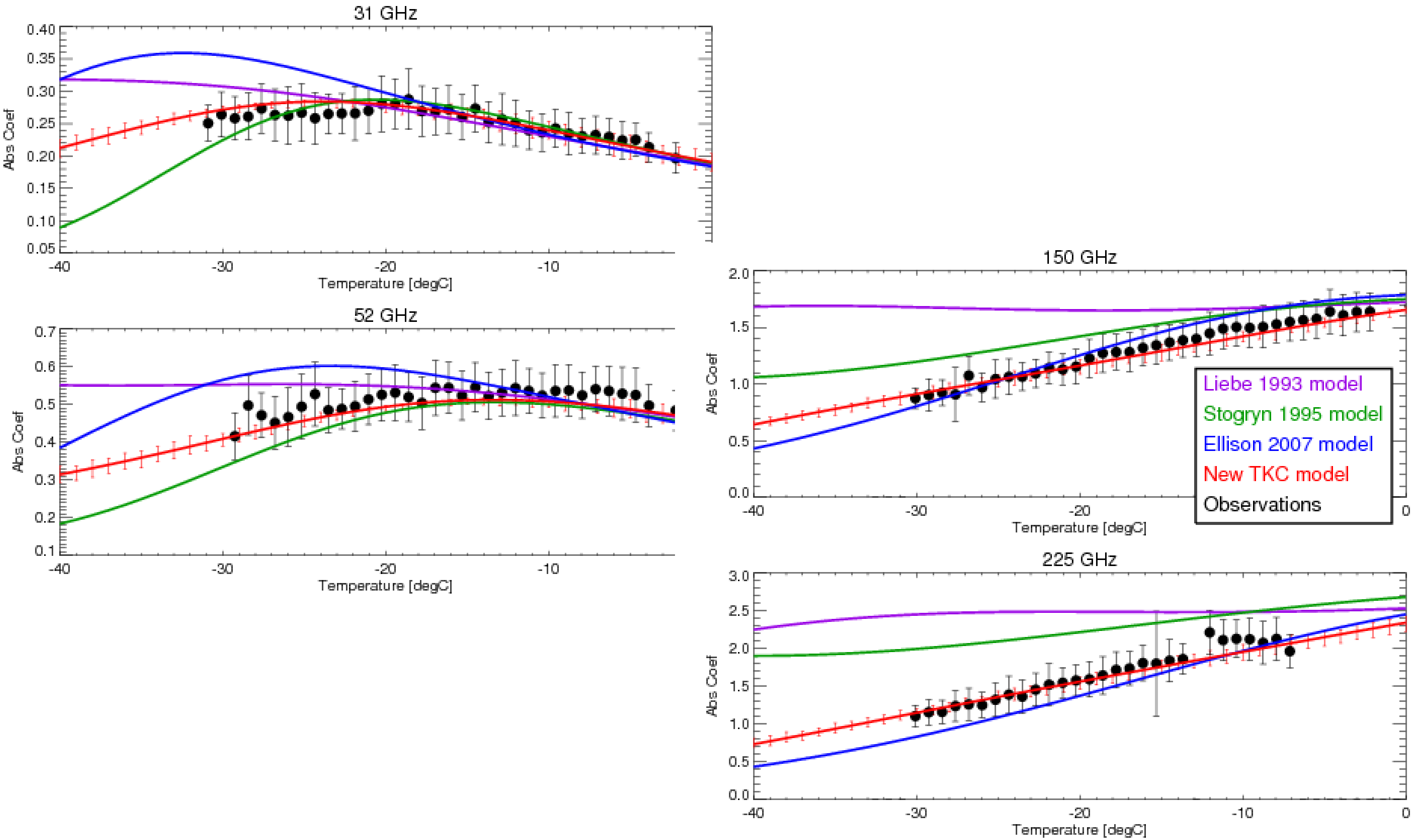


Evaluating the new model: Lab data (4)





Evaluating the new model: Field data



Conclusions

- Multi-freq MWR obs at 3 diff locations demonstrate that:
  - Current liquid water model used by ARM (Liebe) isn't very accurate, especially for higher frequencies
  - Stogryn model seems the best for freqs < 100 GHz
  - Ellison 2007 model seems the best for freqs > 100 GHz
  - No current model properly captures the temp and freq dependence

- A new absorption model was created using lab and field data
  - Used optimal estimation framework; thus have uncertainties and DFS
  - Had to assume Stogryn model at 90 GHz was accurate to convert the opacity ratios from field data into absorption coefficients
  - New model fits both lab and field data well over from $-32 < T_{cloud} < 100$ °C and $0.5 < freq < 500$ GHz

- Kneifel et al., JAMC 2014, in press
  - Discusses opacity ratio technique and evaluation of current models
- Turner et al., in preparation
  - Describes the new LW microwave absorption model