Communications Research Centre Canada
An Agency of Industry Canada

Centre de recherches sur les communications Canada
Un organisme d'Industrie Canada

Observations of Attenuation Due to Liquid-bearing Stratocumulus Clouds Over Ottawa Using a Ground-based Profiling Radiometer

Dr. Pierre Bouchard
Communications Research Centre Canada

MicroRad 2008
Session on the Atmosphere
March 13, 2008

Canada

CRC

Outline

1) Experimental Method;
2) Dataset of Stratocumulus;
3) CRC Extraction Method for Cloud Attenuation
4) Cloud Attenuation Modelling;
5) Results: CDFs of Measured & Modelled Cloud Attenuation;
6) Conclusions & Future Work.

Multifrequency Profiling Radiometer (Radiometrics TP/WVP-3000)

- Retrieves temperature and humidity profiles up to 10 km in clear sky and cloudy conditions.
- 12 Microwave Channels:
  - Five between 22.235 and 30 GHz;
  - Seven between 51.25 and 58.8 GHz;
  - Not sensitive to ice clouds.
- One Infrared Channel (9.6-11.5 μm) :
  - Estimates the cloud base height of the lowest optically thick layer (either liquid, ice or mixed phase).
- Vertical resolution:
  - 100 m between 0 and 1 km;
  - 250 m between 1 km and 10 km.
- High temporal resolution.
- Elevation-angle scanning currently in use (15º, 27.4º, 45º and 90º).

Why Stratocumulus?

- One of the most frequently-occurring liquid-bearing cloud type over the 5°x 5° grid that includes Ottawa, according to the land cloud atlas of Hahn and Warren (1971-1996);
- Comparison with the 6-year Sc cloud climatology of the ARM SGP site in Oklahoma was possible (Dong *et al., J. Climate,* 2005);
- The original idea was to gain confidence in the data retrieved by our profiler;
- A **good agreement** was found between the two locations for yearly averages of *daytime liquid water path, cloud base and cloud top heights* but **differences in seasonal averages** for these parameters likely due to dissimilarities in climate between northern Oklahoma and eastern Ontario.

Dataset of Daytime, Non-precipitating Stratocumulus (Sc) Clouds over Ottawa (April 2005-April 2006)

- Profiles retrieved when daytime non-precipitating overcast or near overcast Stratocumulus (Sc) clouds were present over the profiling radiometer;
- Retrieved L was less than 1 mm. *L > 1mm was observed during either rainy periods or in advance of rain or drizzle episodes when large liquid water drops aloft had not yet reached the ground and wetted the radome;*
- Cloud base height measured by the infrared thermometer < 2 km, consistent with WMO;
- Cloud top height estimated with CRC's cloud detection algorithm < 4 km;
- L was subadiabatic: $|L_{ad} – L_{retr}| / L_{ad} < 10\%$;
- *All 457 profiles selected satisfied all of these criteria (similar to those used by Dong et al.).* **L ranged from 0.05 mm to 0.55 mm**.

Extraction Method for Cloud Attenuation from Time Series of Total Attenuation

- Frequencies of interest: 30 GHz and 51.25 GHz.
- Total attenuation A_{tot} (dB) due to gases & non-precipitating clouds is calculated from brightness temperature T_b using:

$$A_{tot} = 10\log_{10}\left(\frac{T_{mr} - T_c}{T_{mr} - T_b}\right) \quad (dB)$$

where T_{mr} is the effective medium temperature & T_c = 2.73 K.

- T_{mr} is computed using the Rosenkranz 2007 model with composite (retrieved + radiosonde) profiles as input data. Also uses retrieved cloud liquid profiles from the surface up to 4 km.

Extraction Method for Cloud Attenuation from Time Series of Total Attenuation

- Both the MPM '93 and the Rosenkranz 2007 models are used to assess gaseous absorption (A_g). Input data are:
  - Retrieved profiles of T and RH (0-10 km above ground);
  - Reconstructed pressure profiles (0-10 km) obtained by solving the hydrostatic equation for thin layers of moist air;
  - All of these retrieved profiles are "topped-up" with the closest (in time) **radiosonde** profiles from the Maniwaki station from 10 km up to the level of balloon puncture (typically at around 30 km).
- Attenuation due to non-precipitating clouds $A_c(t)$ is given by: $\mathbf{A_c(t) = A_{tot}(t) - A_g(t)}$.
- For **slanted A_c:** natural cubic spline interpolation is used to estimate **L, A_g, and T_{mr}** at times when non-zenithal measurements of T_bs take place.

Extraction Method for Cloud Attenuation: Gaseous Absorption Models (Rosenkranz 2007 vs. MPM '93)

- As a check for this extraction method we also compared measured A_g with modelled A_g using over 1700 retrievals under **clear sky conditions** during the same period & found that:
  - *At **30 GHz, Rosenkranz '2007** has the lowest bias and RMS error compared to observations* at the four elevation angles (15°-90°);
  - *At **51.25 GHz, MPM '93** provides the closest match to the observations (lowest bias and RMS error);*
- All 1700 retrieved profiles were "topped-up" with the closest in time radiosonde data (10 km up) from Maniwaki station & used as input to the models.

Extraction Method for Cloud Attenuation: Gaseous Absorption Models (Rosenkranz 2007 vs. MPM '93)

- This approach is used to select the best gas model because CRC does not launch radiosondes routinely;
- Moreover the Maniwaki radiosonde station does not issue METARs and is located about 100 km North of Ottawa;
- Maniwaki radiosonde RH profiles are different from those retrieved over Ottawa but V values are usually very close;
- Hewison *et al.* (*Met. Zeit.*, 2006) drew similar conclusions on gaseous absorption models by comparing **modelled** T_bs from radiosondes launched **in clear skies** with **measured** T_bs from the TP/WVP-3000 during the TUC experiment in Payerne (Switzerland).

Cloud Attenuation Modelling

- *Current ITU-R cloud attenuation model (Rec. P. 840-3):* Attenuation due to clouds at a given elevation angle for a given probability value "p" is given by:

$$A_c(p,\theta) = \frac{K_l L(p)}{\sin\theta}$$

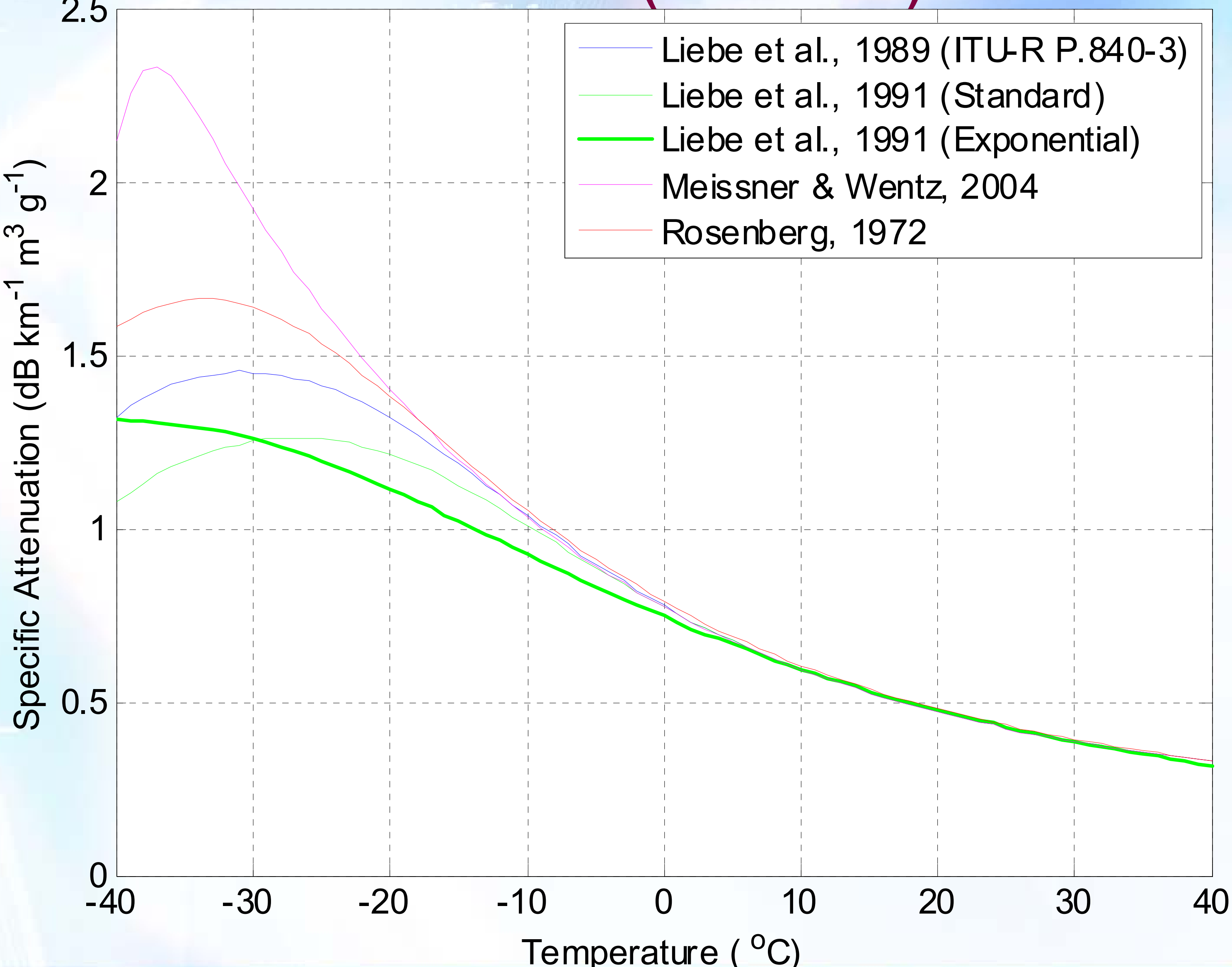
where:

K_l is the specific attenuation coefficient in (dB/km)/(g/m^3);

L is the reduced liquid water path in mm.

- *K_l is based on the MPM '89 cloud module &* assumes cloud liquid is at 0 ºC*.*
- We use this model with contemporaneously retrieved time series of non-reduced L values and temperature at the cloud base (T_{ir}) as input. Comparisons were performed with various dielectric models for liquid water including MPM '89.

Absorption Due to Cloud Liquid for Various Models (30 GHz)

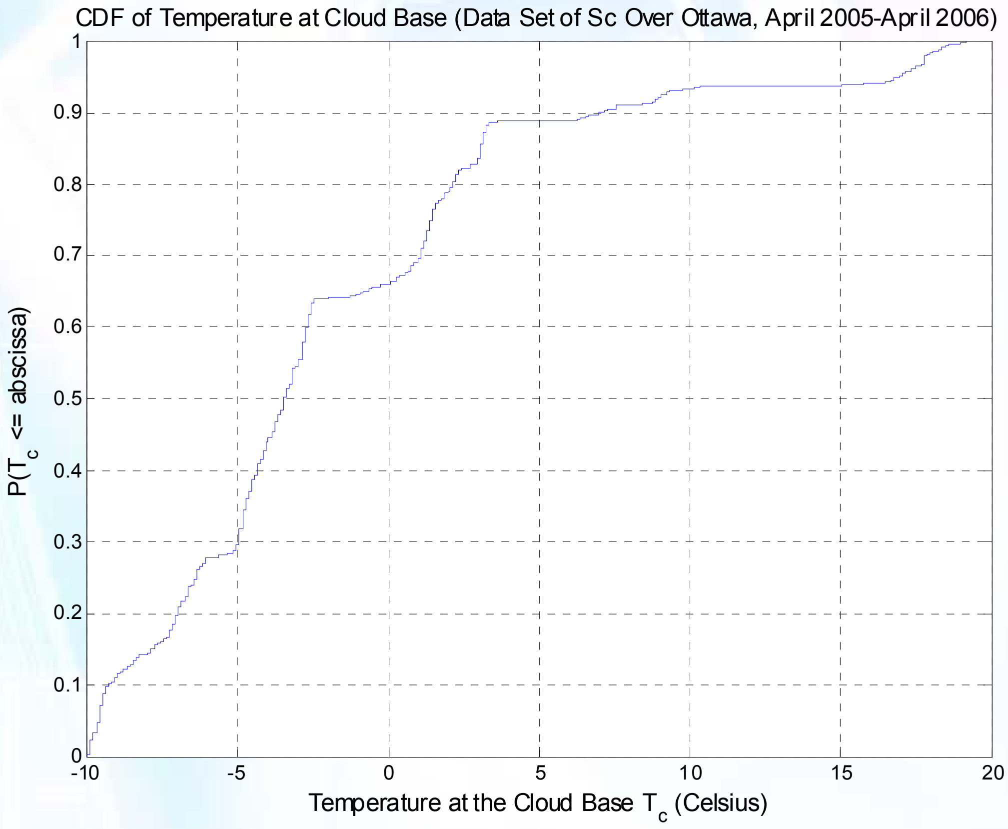


Cloud Attenuation Modelling :
Liebe (1991) Permittivity Model for Liquid Water

Two formulations for the first relaxation frequency in Liebe (1991) (Lipton *et al*., *IEEE TGRS* (1999)):

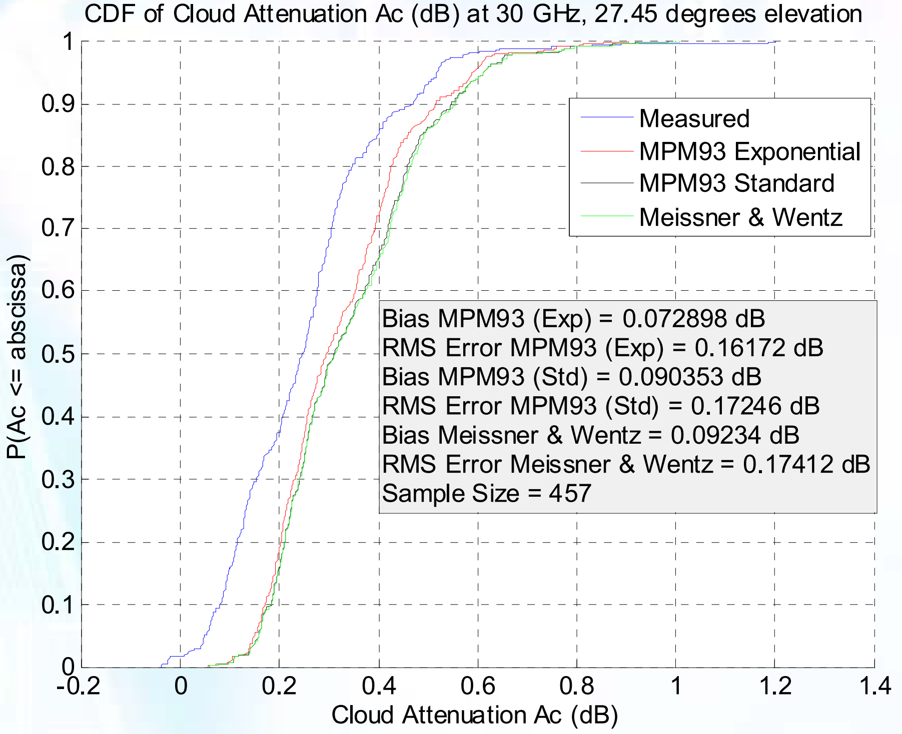
- Quadratic form (standard) *best fit to the data:*
$$\gamma_1 = 20.20 - 146(\vartheta - 1) + 316(\vartheta - 1)^2 \quad (GHz).$$
- Exponential form *(more consistent with theory) :*
$$\gamma_1 = 20.1\exp(7.88(1 - \vartheta)) \quad (GHz)\, with\ \vartheta = 300 / T.$$
- This exponential form is used in the cloud module of the Rosenkranz model.

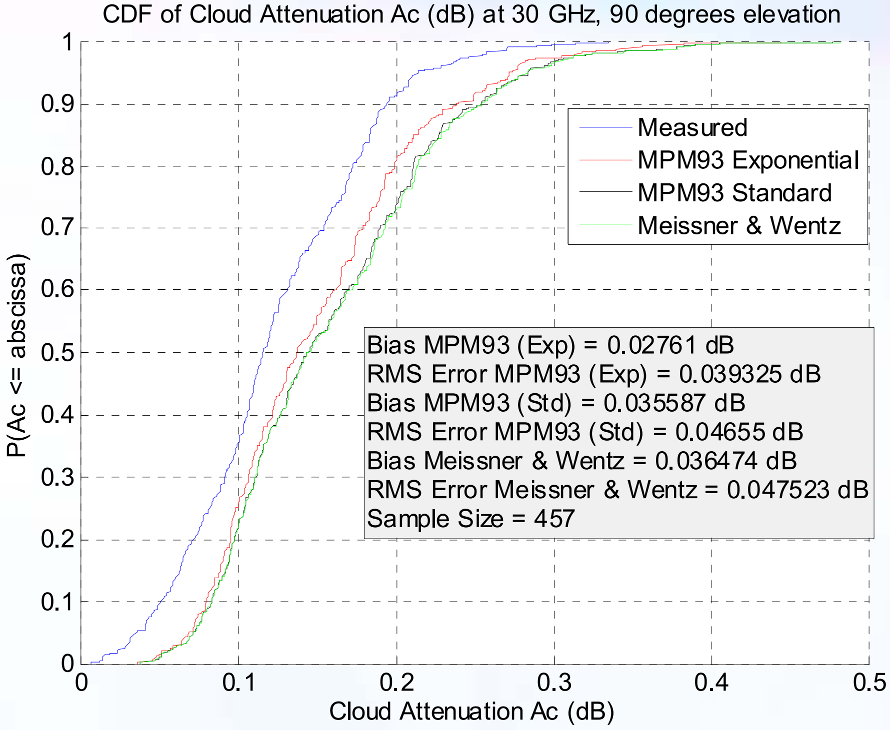
Temperature of Cloud Liquid for Daytime Sc over Ottawa



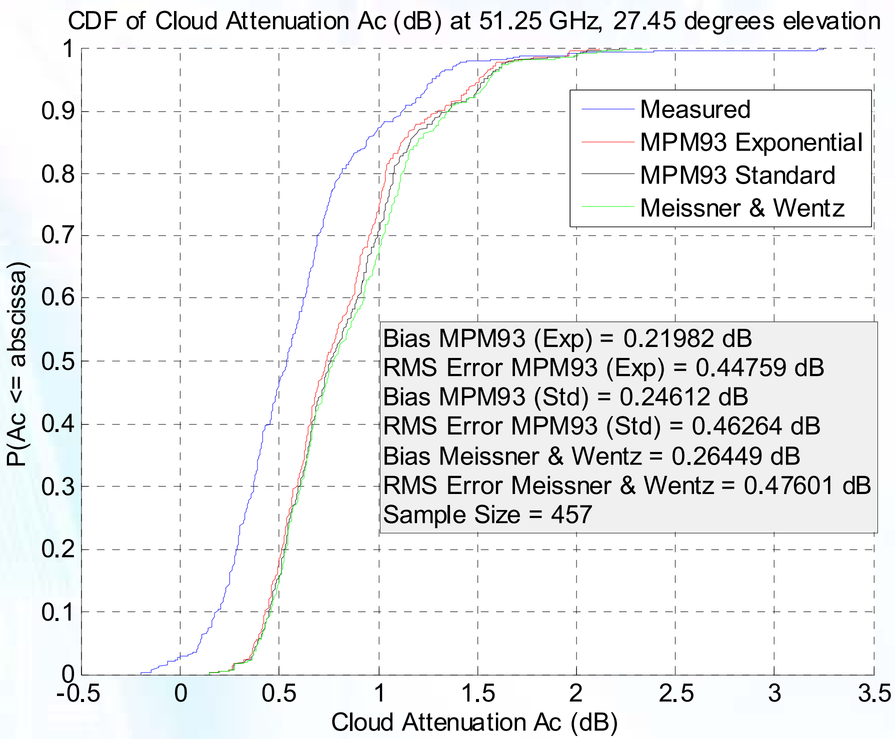
- Mean T_c = -1.7°C;
- Median T_c = -3.5°C;
- Std of T_c = 6.7°C;
- Differences between dielectric models for T_c > -10 °C are not too large;
- *Only 11% of the Sc clouds sampled had* ***all*** *of their liquid above 0°C.*

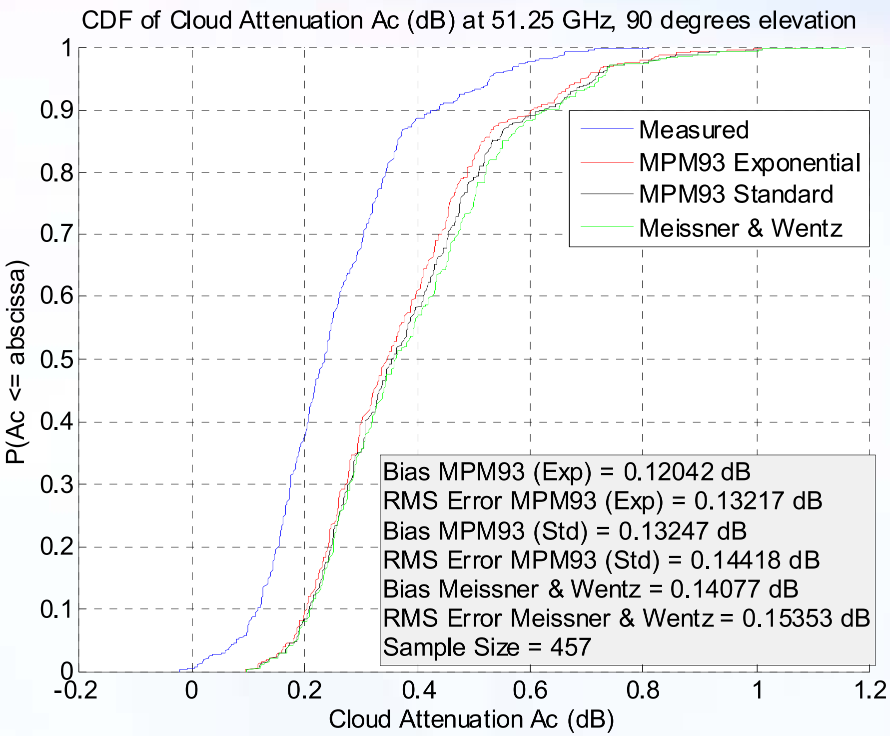
CDF of Cloud Attenuation 30 GHz (27.4° and 90°) Rosenkranz 2007 (Gases & T_{mr}) 457 Profiles





CDF of Cloud Attenuation
51.25 GHz (27.4° and 90°)
MPM '93 (Gases) & Rosenkranz 2007 (T_{mr})
457 Profiles





Conclusions

- An extraction method of cloud attenuation was developed & applied to a data set of T_bs and zenith profiles retrieved for non-precipitating, overcast, liquid-bearing Stratocumulus over Ottawa during the daytime;
- Frequencies of interest were 30 GHz and 51.25 GHz;
- Four elevation angles between 15º and 90º;
- Biases and RMS errors between measured and modelled A_c were larger at 51.25 GHz than at 30 GHz;
- At 30 GHz, **Rosenkranz '2007** model was found to be the most suitable for gaseous absorption;
- At 51.25 GHz, **MPM '93** model was the best for gases.

Conclusions & Future Work

- MPM '89 cloud module used in the ITU-R model was found to overestimate A_c compared to measurements;
- Liebe (1991) model with exponential form for the first relaxation frequency yielded the lowest bias & RMS error compared to measured A_c;
- Standard formulation of the MPM '93 cloud module and Meissner & Wentz model were **very close**;
- The cosecant elevation angle dependence of the ITU-R model performed fairly well, but with increasing error as the angle decreased. A reduction factor is needed at low angles;
- Our extraction method will soon be tested with a data set of overcast, **non-precipitating**, liquid-bearing **Altocumulus** over Ottawa (**SLW is dominant**).

Thank you !

For more information:

Pierre.Bouchard@crc.ca

Tel.: 613-998-2441