Clear-Air Forward Microwave and Millimeterwave Radiative Transfer Models for Arctic Conditions

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1) Arctic moisture and clouds play a key role in our climate, but are difficult to measure because of small concentrations.

2) Conventional instruments (MWR, GPS, radiosondes) show small sensitivity to low Precipitable Water Vapor (PWV) and Liquid Water Path (LWP). Therefore, scaling of radiosondes by PWV (done by ARM) is questionable.

3) Radiometers operating at mm- and submm-wavelengths offer greatly-enhanced sensitivity to PWV and LWP.

4) To utilize enhance sensitivity to small amounts of vapor and clouds, accurate forward models are imperative.
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Co-PIs: A.J. Gasiewski, M. Klein, V. Leuski
ARM: J. C. Liljegren, B. M. Lesht
Period: March-April 2004
Location: ARM NSA, Barrow, Alaska

**Instruments:**

1) Dual channel Microwave Radiometer (MWR):
   23.8; 31.4 GHz

2) 12-channel Microwave Radiometer Profiler (MWRP):
   22.235; 23.035; 23.835; 26.235; 30.0 GHz
   51.25; 52.28; 53.85; 54.94; 56.66; 57.29; 58.8 GHz

3) 25-channel Ground-based Scanning Radiometer (GSR)
   50.2; 50.3; 51.76; 52.625; 53.29; 53.845; 54.4; 54.95; 56.215; 56.325 GHz
   89 V; 89 H GHz
   183.31±0.55; ±1; ±3.05; ±4.7; ±7; ±12; ±16 GHz
   340 V; 340 H GHz 380.197±4; ±9; ±17 GHz
Atmospheric Opacity for Arctic Conditions

NSA WP02004 GWT 2004/03/15 23:00 (Ps=1012mb, Ts=248K, RHs=78%, PWV=3mm) Rosenkranz 1998

Atmospheric Opacity [Np]

Frequency [GHz]

- H$_2$O
- O$_2$
- TOT
- GSR
WVIOP2004 Time series of meteorological variables

- T_s [°C]
- PWV [mm]
- T_r [K]
- LWP [mm]
- IWP [kg/m²]

Julian day 2004
VAISALA RS90-A

4 times per day at the ARM Duplex (00, 06, 12, 18 UTC)
1 time per day at the ARM “Great White” (00 UTC)

Temperature sensor: F-Thermocap (capacitive wire)
Humidity sensor: Heated twin-sensor H-Humicap

GPS Mark II & Meteolabor “SNOW WHITE” (NASA)

5 at night, 3 during the day

Temperature sensor: VIZ short rod thermistor;
Humidity sensors: VIZ carbon hygristor;
Meteolabor chilled mirror

Dual-radiosonde launches: Vaisala RS90 and Sippican Mark II & Meteolabor Snow White

VIZ-B2
(National Weather Service)

2 times per day in Barrow (00, 12 UTC)

Temperature sensor: VIZ long rod thermistor; Humidity sensor: VIZ carbon hygristor
INPUT TO MODELS = T, RH, AND P FROM RADIOSONDES
CLEAR SKIES DETERMINED FROM MWRP IR

<table>
<thead>
<tr>
<th>Models</th>
<th>Radiosondes</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Liebe 1987</td>
<td>• Vaisala RS90 (Dplx)</td>
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<tr>
<td>• Liebe 1993</td>
<td>• Chilled mirror</td>
</tr>
<tr>
<td>• Rosenkranz (1998)</td>
<td>• VIZ (NASA)</td>
</tr>
<tr>
<td>• Rosenkranz (2003)</td>
<td>• Vaisala RS90 (GW)</td>
</tr>
<tr>
<td>• Liljegren (2005)</td>
<td>• VIZ(NWS)</td>
</tr>
</tbody>
</table>
Some Details of Forward Model Comparisons

Radiometer Calibration
Internal Loads (10 ms)
External Blackbody Targets (2 min)
Tip Calibration (Window Channels)

Calculations from Radiosondes

Compute band-averaged Tb
Corrections to Monochromatic up to 2.5 K!

Typical results of Forward Model Analysis
Near 183.31 GHz
Forward model comparisons near 183.31 GHz

LBE93

LIL05
Forward model comparisons near 50-60 GHz
For MWRP and GSR

LBE93

LIL05
Forward model comparisons from 22.235 to 30.0 GHz for MWRP

**LBE93**

**LIL05**

Graphs showing calculations versus measurements for MWRP Tb for LBE93 and LIL05 frequencies.
Forward model comparisons at 89 GHz for the GSR: A Puzzle

89V:LIL05

Dplx + GW + SW 89V LIL05

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>$\text{Dplx}$</td>
<td>$-2.15 \pm 0.14$</td>
</tr>
<tr>
<td>$\text{std}$</td>
<td>$0.65 (0.57, 0.77)$</td>
</tr>
<tr>
<td>$\text{int}$</td>
<td>$-5.01 \pm 0.76$</td>
</tr>
<tr>
<td>$\text{slp}$</td>
<td>$1.11 \pm 0.03$</td>
</tr>
<tr>
<td>$\text{sde}$</td>
<td>$0.50 (0.44, 0.59)$</td>
</tr>
<tr>
<td>$\text{Dplx: n} = 85$</td>
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GW: $n = 20$

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>$\text{ovg}$</td>
<td>$-2.54 \pm 0.34$</td>
</tr>
<tr>
<td>$\text{std}$</td>
<td>$0.26 (0.25, 0.50)$</td>
</tr>
<tr>
<td>$\text{int}$</td>
<td>$-3.07 \pm 1.23$</td>
</tr>
<tr>
<td>$\text{slp}$</td>
<td>$1.02 \pm 0.05$</td>
</tr>
<tr>
<td>$\text{sde}$</td>
<td>$0.34 (0.26, 0.51)$</td>
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</tbody>
</table>

89H:LIL05

Dplx + GW + SW 89H LIL05

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<tr>
<td>$\text{Dplx}$</td>
<td>$-2.27 \pm 0.15$</td>
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<tr>
<td>$\text{std}$</td>
<td>$0.68 (0.59, 0.80)$</td>
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<tr>
<td>$\text{int}$</td>
<td>$-5.10 \pm 0.82$</td>
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<td>$\text{slp}$</td>
<td>$1.11 \pm 0.03$</td>
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<tr>
<td>$\text{sde}$</td>
<td>$0.54 (0.47, 0.64)$</td>
</tr>
<tr>
<td>$\text{Dplx: n} = 85$</td>
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GW: $n = 20$

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<tbody>
<tr>
<td>$\text{ovg}$</td>
<td>$-2.65 \pm 0.36$</td>
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<tr>
<td>$\text{std}$</td>
<td>$0.27 (0.27, 0.52)$</td>
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<tr>
<td>$\text{int}$</td>
<td>$-3.34 \pm 1.28$</td>
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<tr>
<td>$\text{slp}$</td>
<td>$1.03 \pm 0.05$</td>
</tr>
<tr>
<td>$\text{sde}$</td>
<td>$0.35 (0.27, 0.52)$</td>
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</table>

15 20 25 30 35 40

Tb_GSR

15 20 25 30 35 40

Tb_GSR

ITSC-15

Oct. 4-10 2006

Maratea, Italy
REFERENCES


Conclusions

- OVER A WIDE RANGE OF FREQUENCIES, THE LILJEGREN MODEL WORKS AS WELL OR BETTER THAN THE OTHER FIVE MODELS SHOWN

- MWRP AND GSR MEASUREMENTS AT TWO NEARLY COINCIDENT FREQUENCIES AGREE WITH EACH OTHER BUT NOT WITH ANY OF THE MODELS: TEMPERATURE DEPENDENCE OF O2 MODELS?

- UPWARD-LOOKING, MULTI-FREQUENCY RADIOMETERS ARE AN EXCELLENT TOOL FOR CLEAR-AIR FORWARD MODEL STUDIES

Work in Progress

- RETRIEVALS FROM BOTH MWRP AND GSR USING OPTIMAL ESTIMATION
- ANOTHER WINTER EXPERIMENT WILL BE CONDUCTED IN FEB.-MAR 2007

Thank you very much for your attention