Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)

Submission Title: Applications and Requirements for Environmental Remote Sensing
Date Submitted: 9 November, 2011
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Re: Invited on behalf of GRSS Frequency Allocations in Remote Sensing (FARS) Technical Group

Abstract: Several emerging applications of THz frequencies to active and passive remote sensing of the environment are reviewed. The review focuses on he specific frequency bands, technology issues, and potential interference modalities that may be encountered in THz remote sensing., along with a discussion of interference and sharing issues.

Purpose: Briefing to the 802.15 THz IG on THz remote sensing technologies for environmental applications.

Applications and Requirements for THz Environmental Remote Sensing

Prof. Albin J. GASIEWSKI
University of Colorado at Boulder
and
IEEE-GRSS Frequency Allocations in Remote Sensing (FARS) Technical Group
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IEEE 802.15 THz Interest Group
Atlanta, GA, November 9, 2011

- THz absorption and scattering spectrum
- Passive applications
  - Temperature and water vapor profiling
    - Weighting functions
  - Cloud liquid and ice sensing
    - COSSIR, ISSASI, SIRICE, ISS Ice
  - Ground-based T/Q profiling and LWP measurement
  - Geostationary microwave imaging/sounding
  - Interference mitigation
    - Density of Interferers equation

- Active applications
  - Standoff detection
  - All weather landing imager
  - Short range security imaging
  - Double resonance transmission spectroscopy
  - MMW cloud radar (90, 140, 210 GHz)

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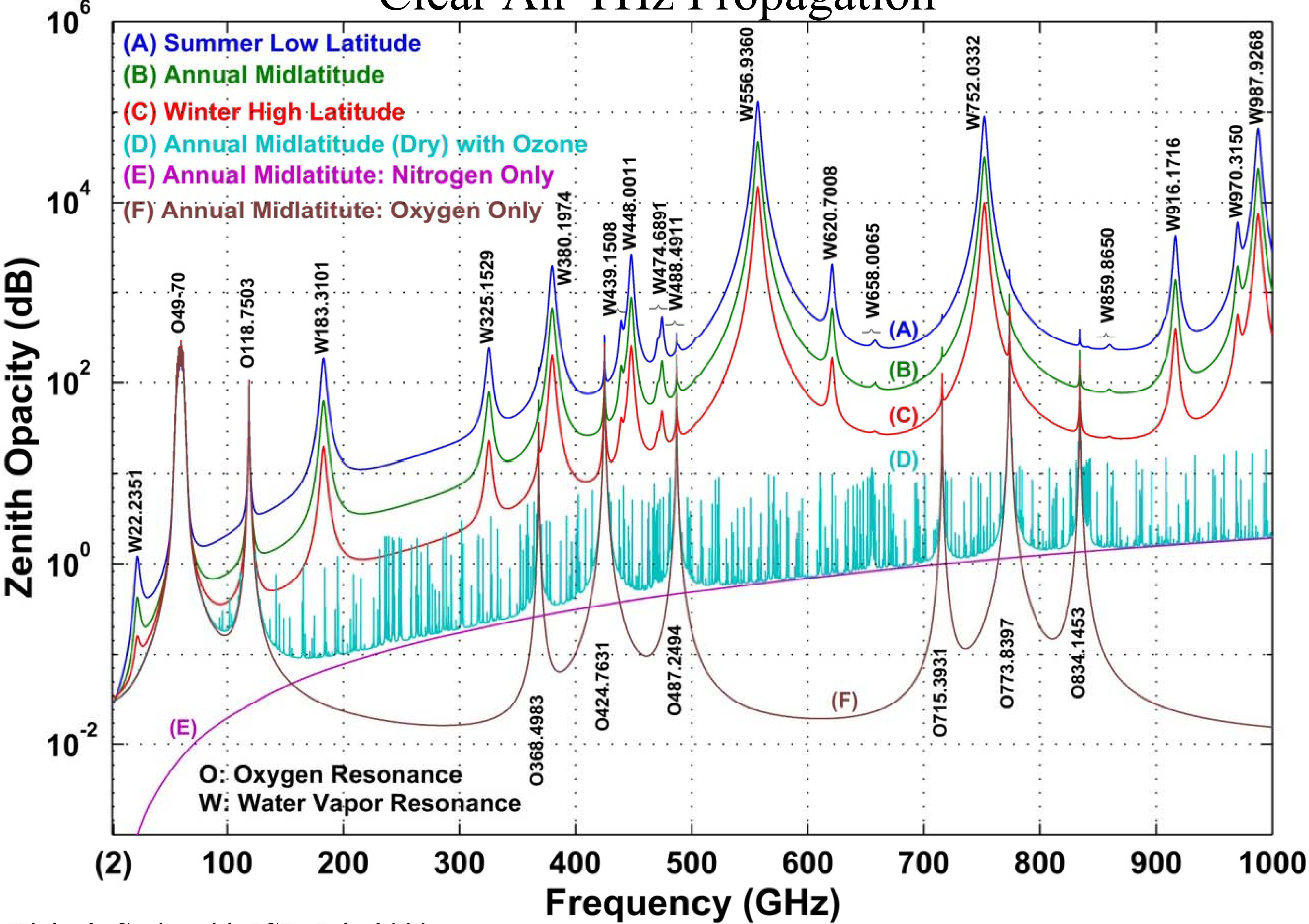
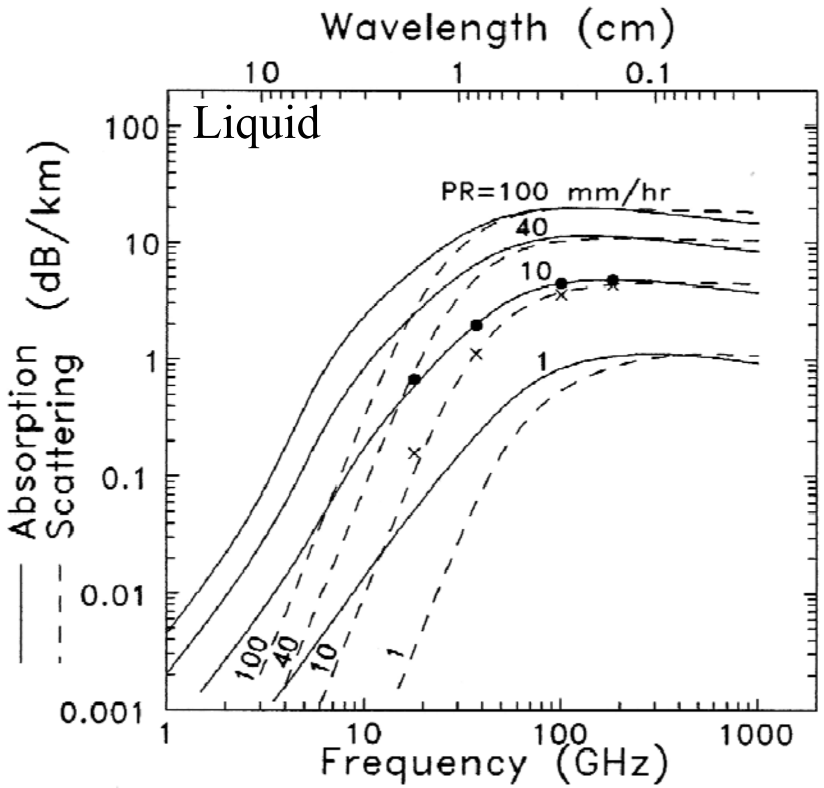
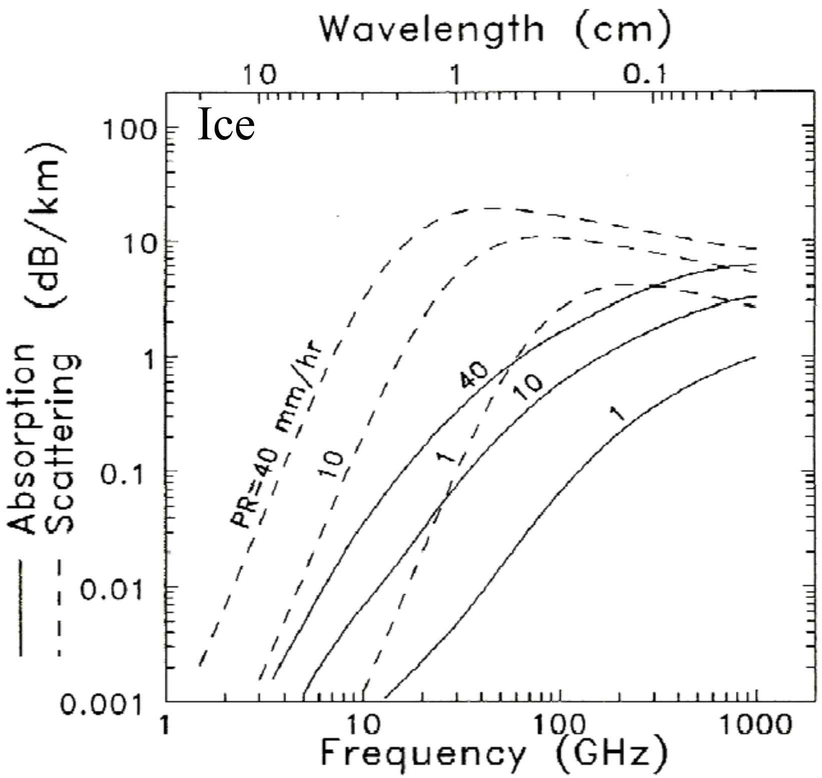
Clear Air THz Propagation



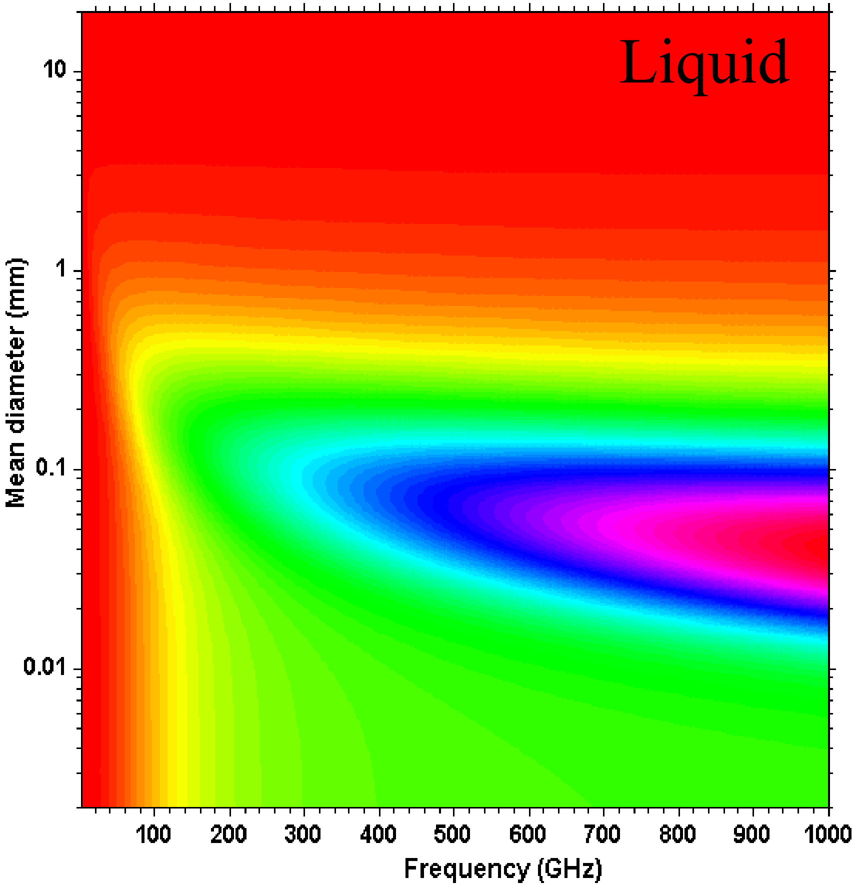
Klein & Gasiewski, JGR, July 2000

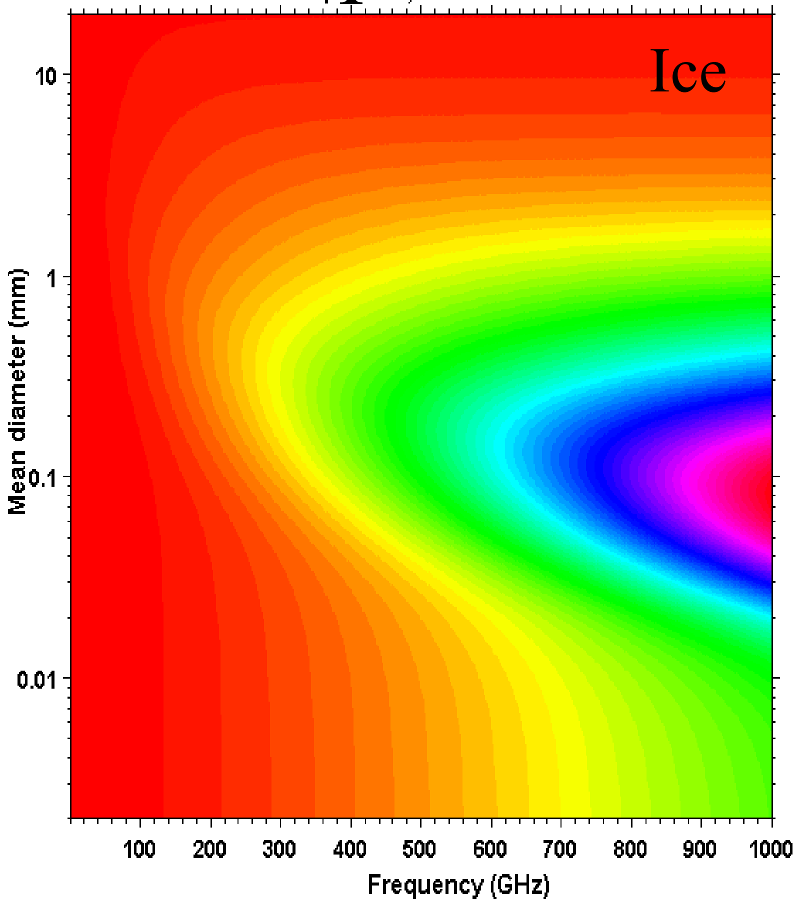
Effects of Hydrometeors on Propagation





Fast B-Spline Mie Absorption

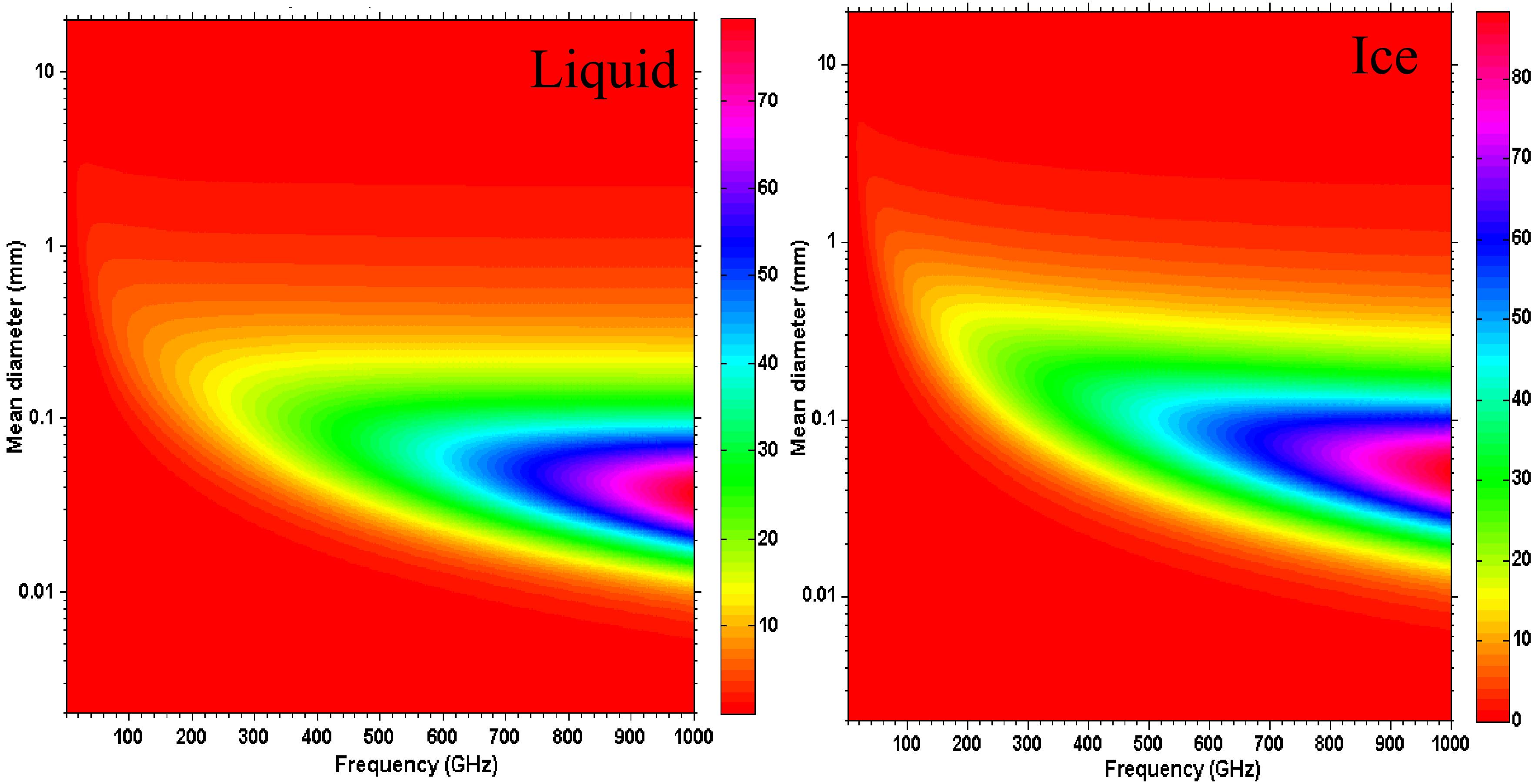




0^oC Exponential Polydispersion

Sandeep and Gasiewski, 2011

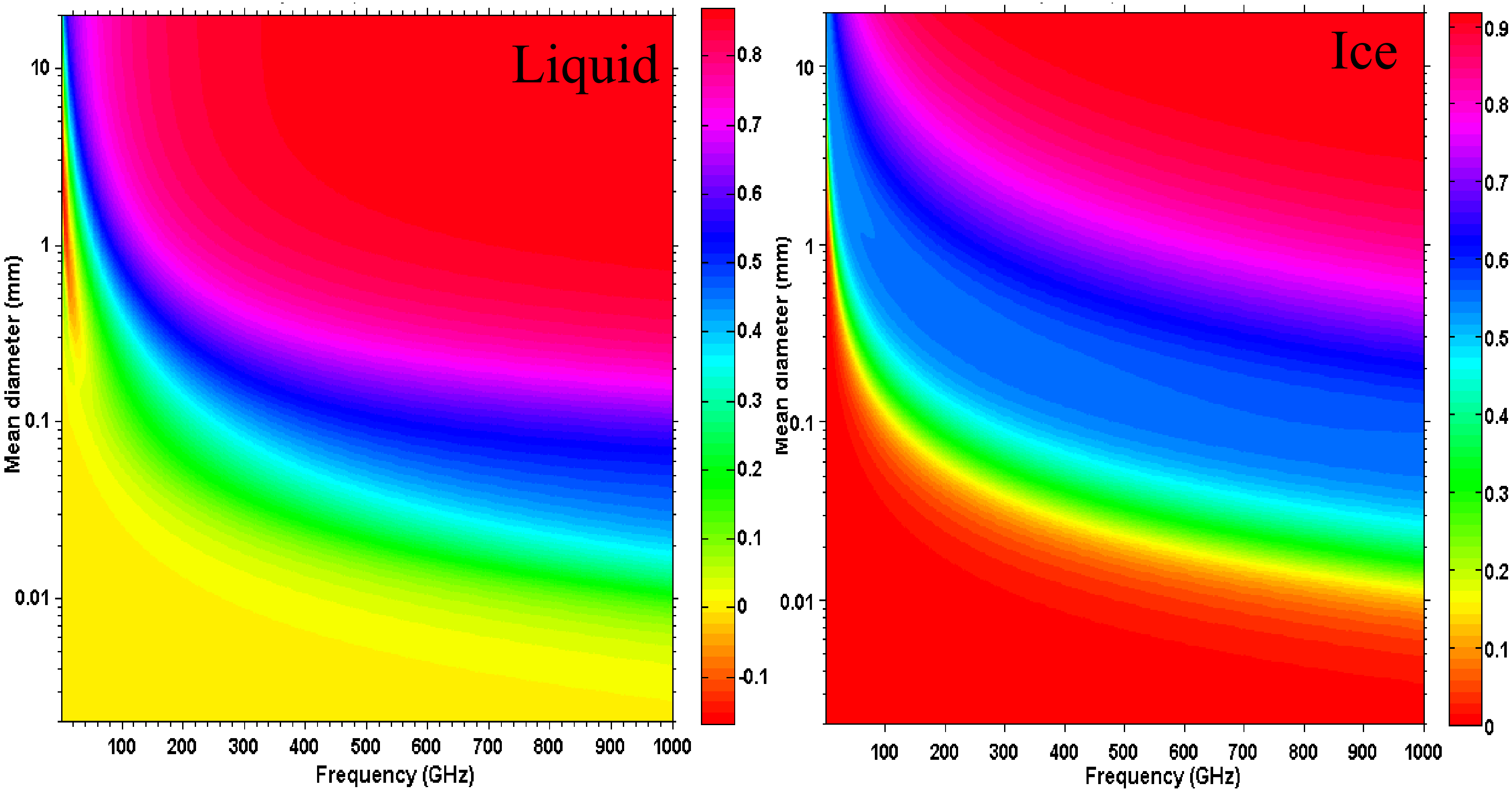
Fast B-Spline Mie Scattering



0°C Exponential Polydispersion

Sandeep and Gasiewski, 2011

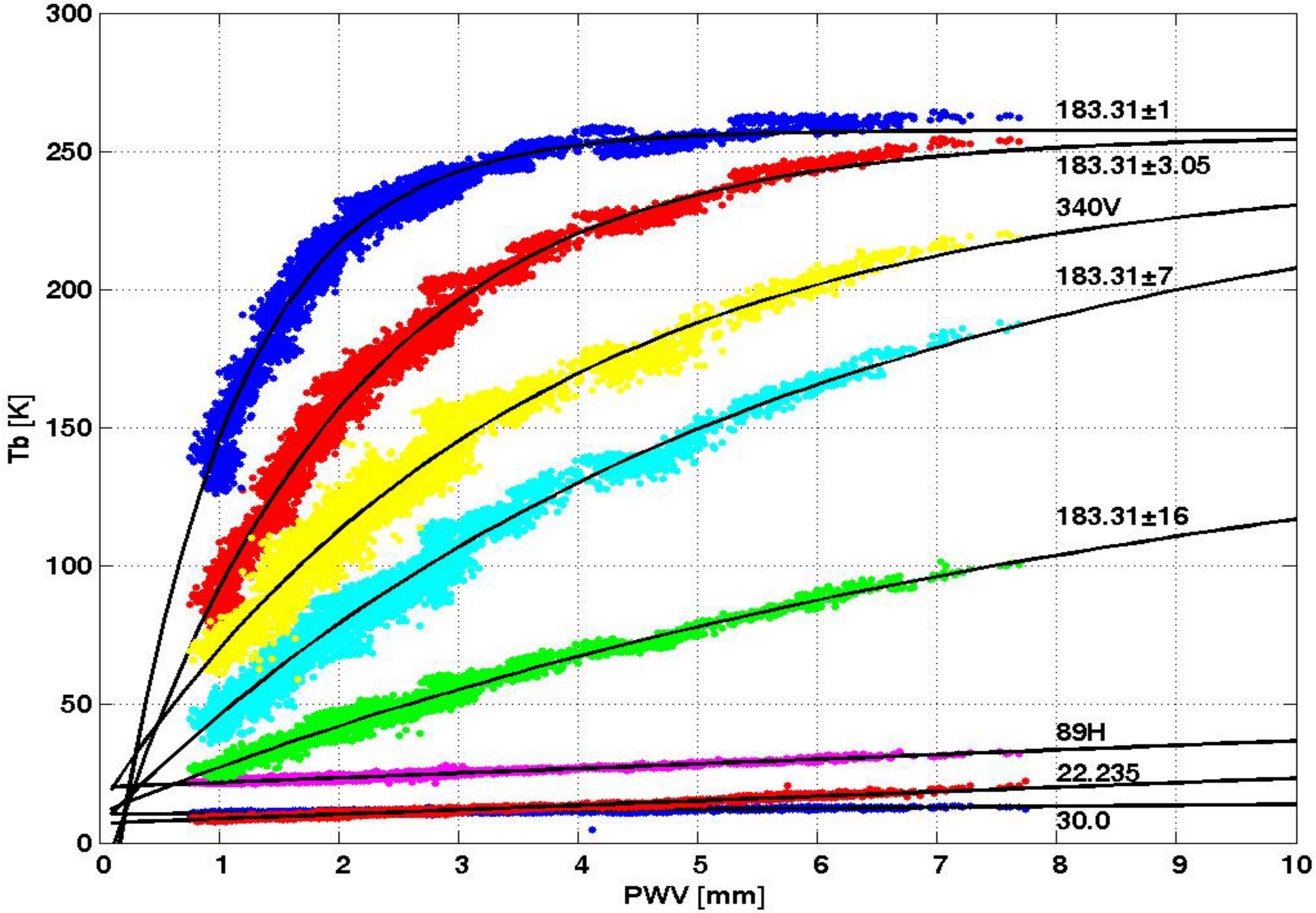
Fast B-Spline Mie Asymmetry



0°C Exponential Polydispersion

Sandeep and Gasiewski, 2011

Sensitivity of Brightness Temperature Model to Water Vapor from 22.235 to 340 GHz



Cimini, D., E. R. Westwater, A. Gasiewski, M. Klein, V. Leuski, J. Liljegren, TGARS, 2007

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Vertical Sounding Capabilities

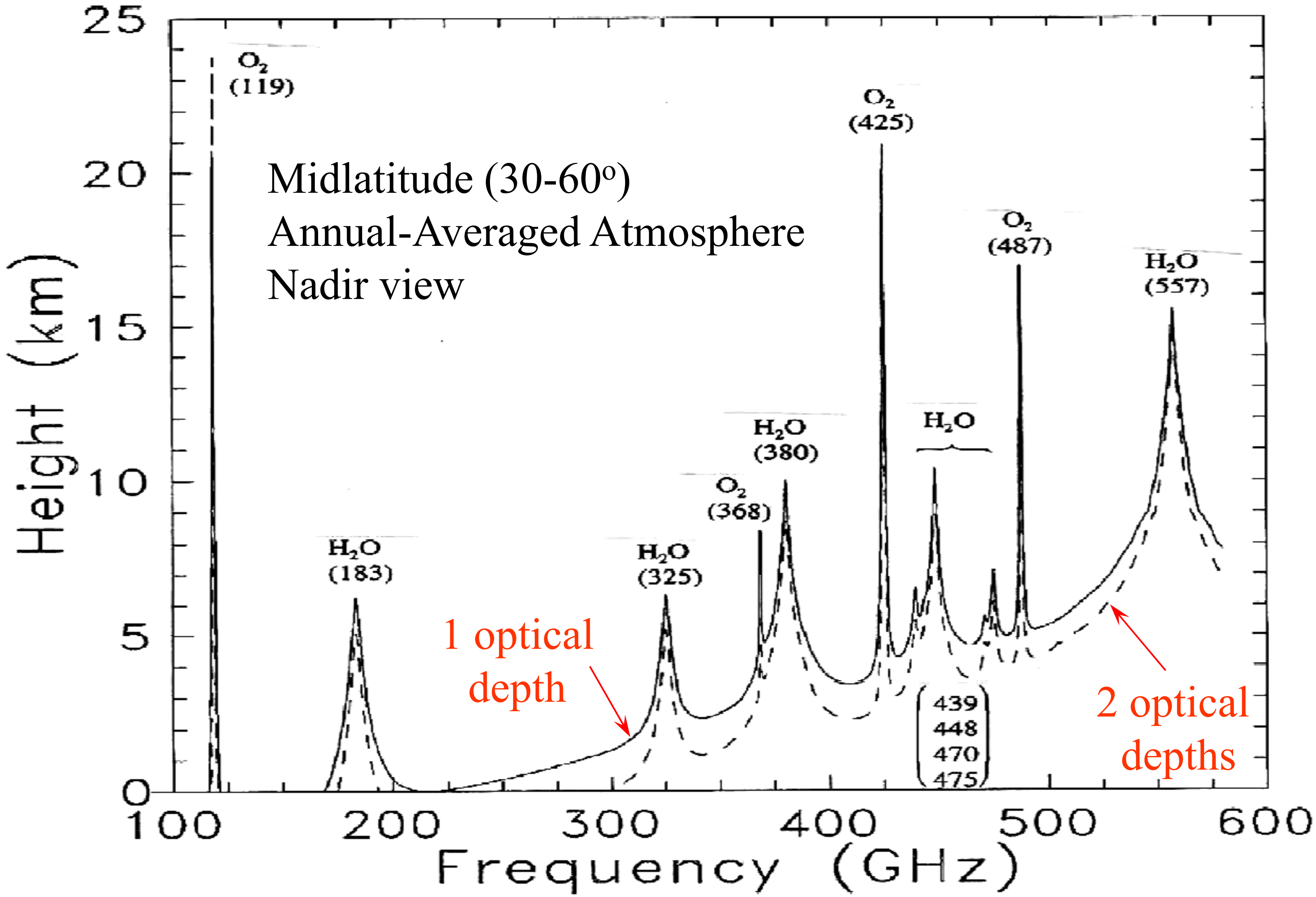
Clear-air incemental weighting functions

O_2
118.750 GHz
424.763 GHz

H_2O
183.310 GHz
380.197/340

Klein & Gasiewski, *JGR-ATM*, July 2000

Spaceborne Sensing Heights



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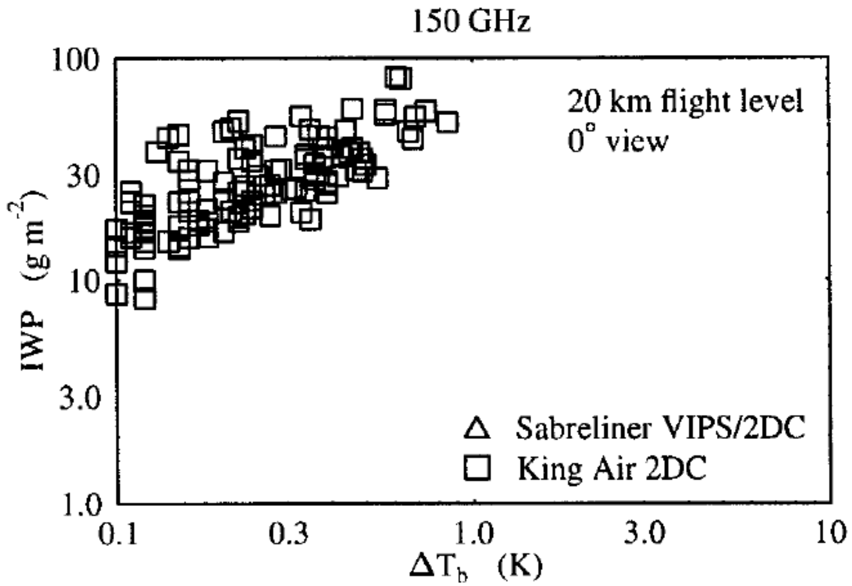
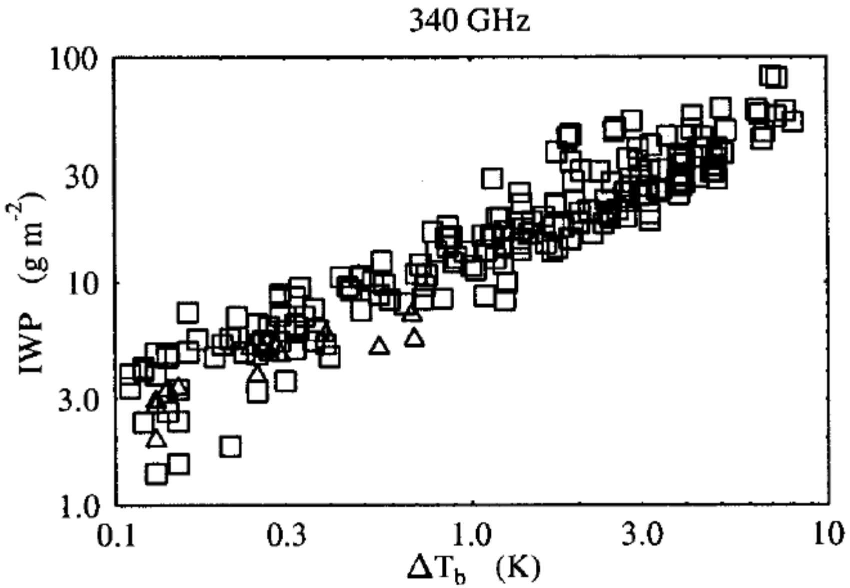
Nadir IWP Brightness Signatures

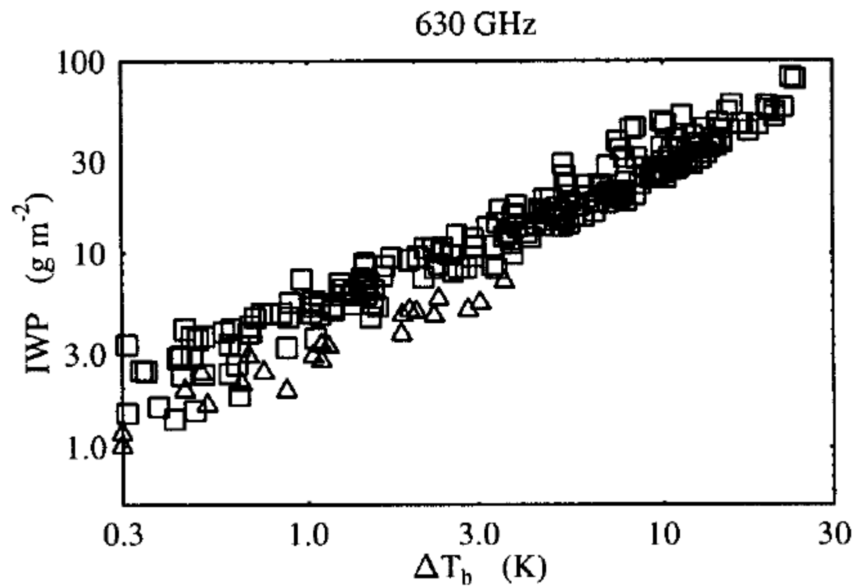




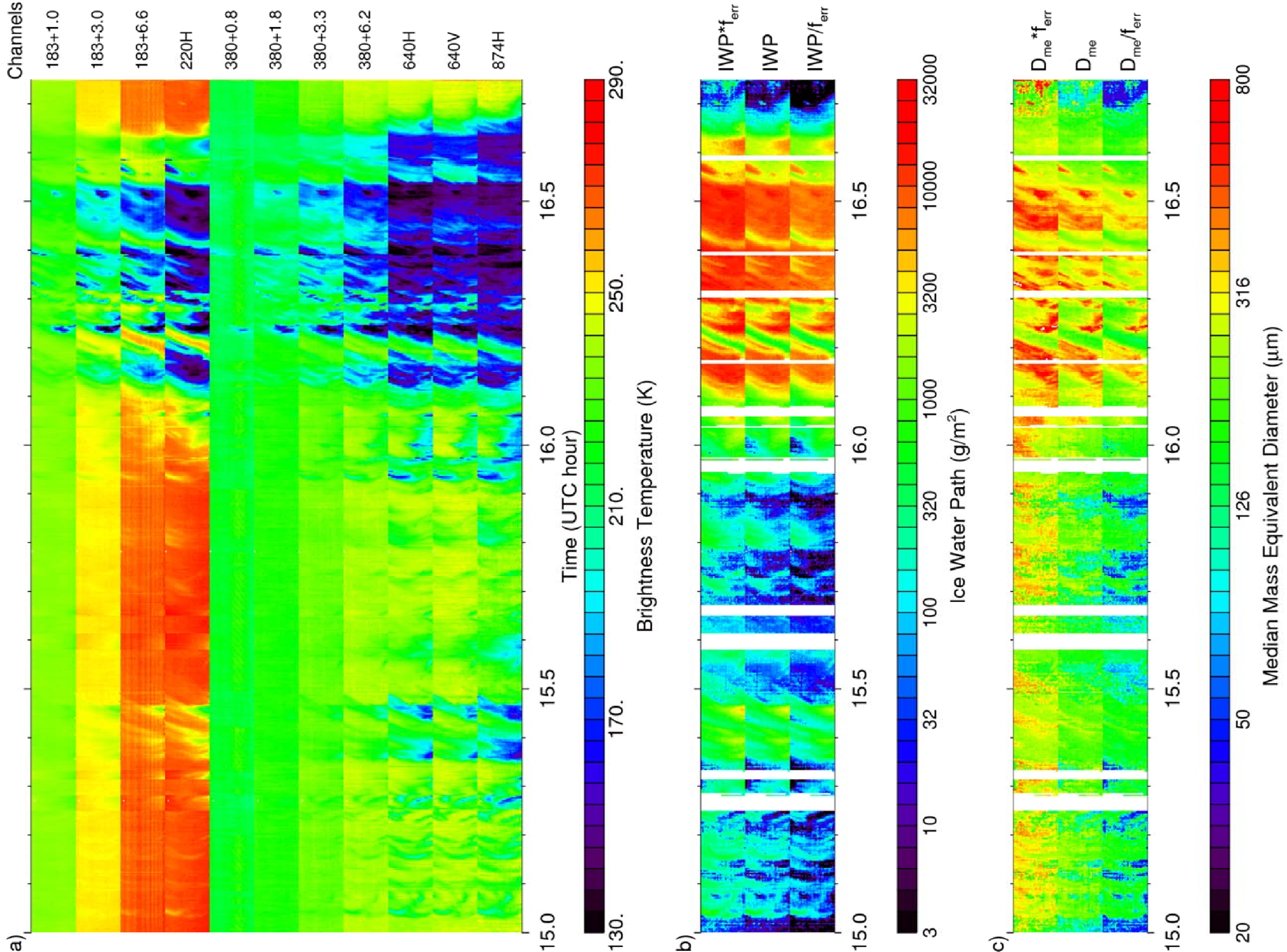
Brightness temperature depressions using discrete dipole approximation for several ice crystal habits.

THz frequencies provide greater sensitivity to IWP and mean ice particle size.

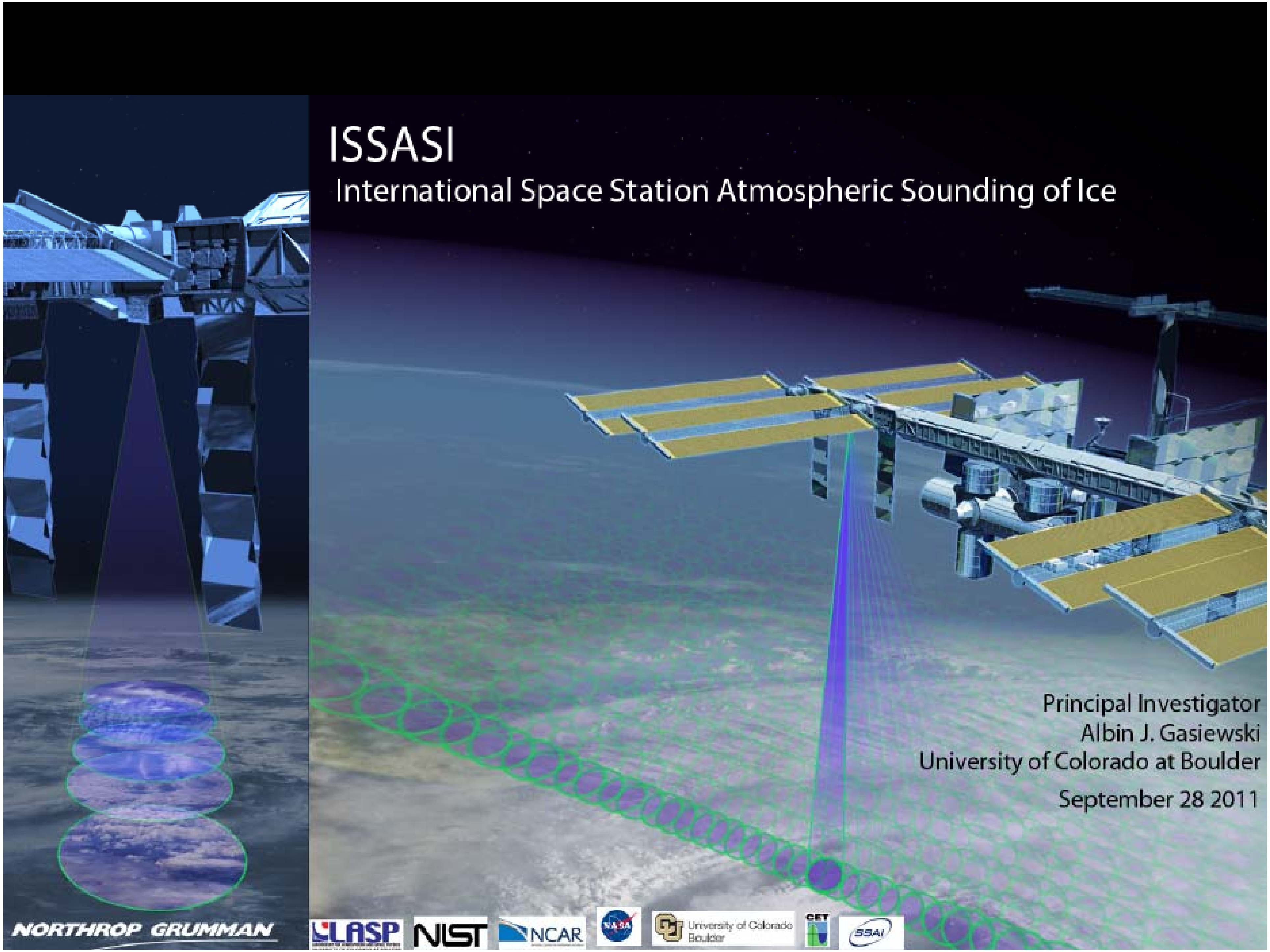
Evans et al., JAM, 1998



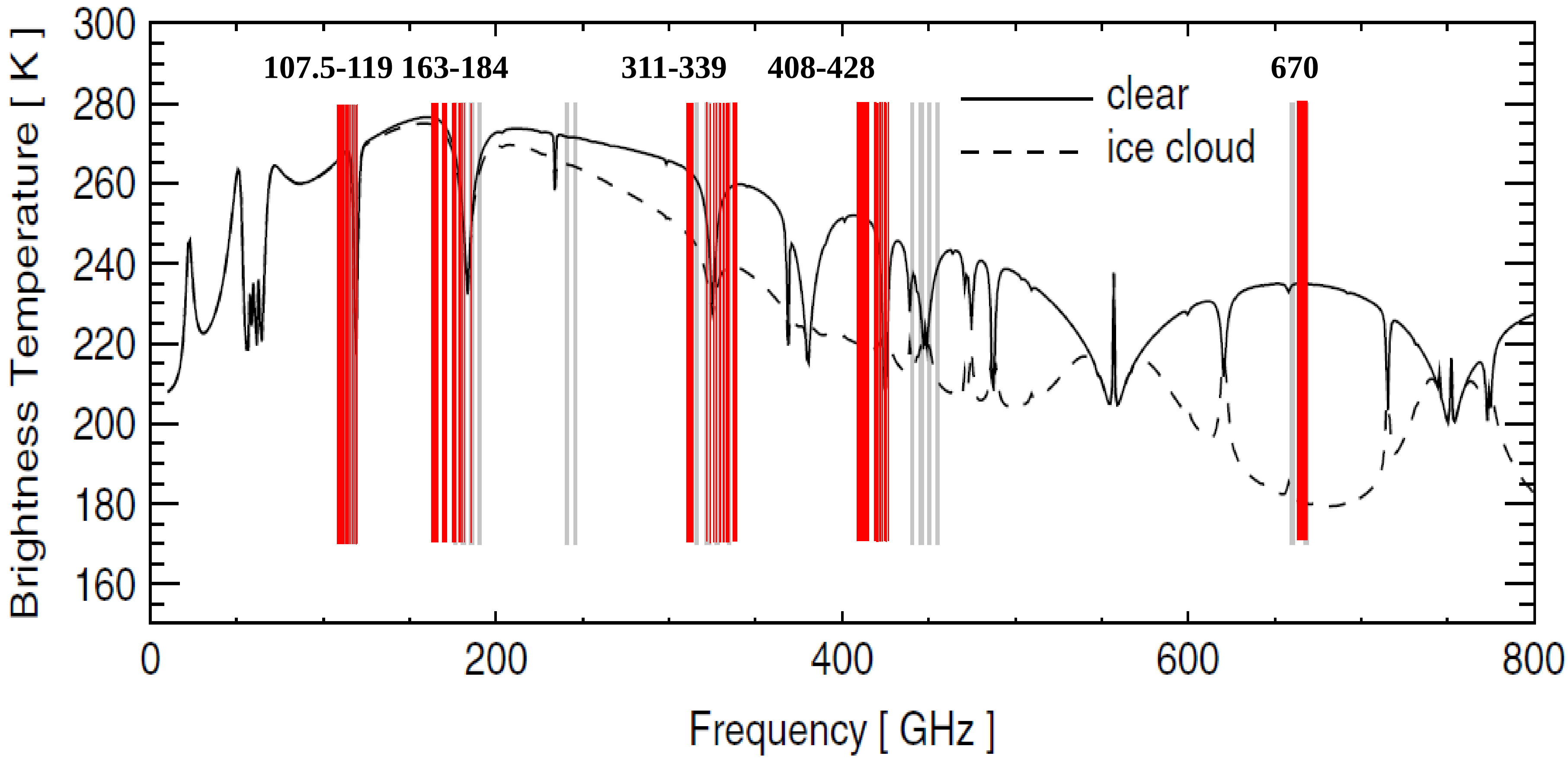
Cloud Ice Sensing using MMW/SMMW Bands



F. Evans, et al., 1998


ISSASI
International Space Station Atmospheric Sounding of Ice
Principal Investigator
Albin J. Gasiewski
University of Colorado at Boulder
September 28 2011
NORTHROP GRUMMAN
LASP
NIST
NCAR
NASA
University of Colorado Boulder
CET
SSAI

ISSASI and CIWSIR THz Passive Bands



ISSASI = International Space Station Atmospheric Sounding of Ice (red)
CIWSIR = Cloud Ice Water Submillimeter Imaging Radiometer (gray)

Calculations for clear air and 8-10 km ice cloud with 80 g/m^2 IWP, D_{me}=100 μm

Buehler et al., QJRMS, 2007

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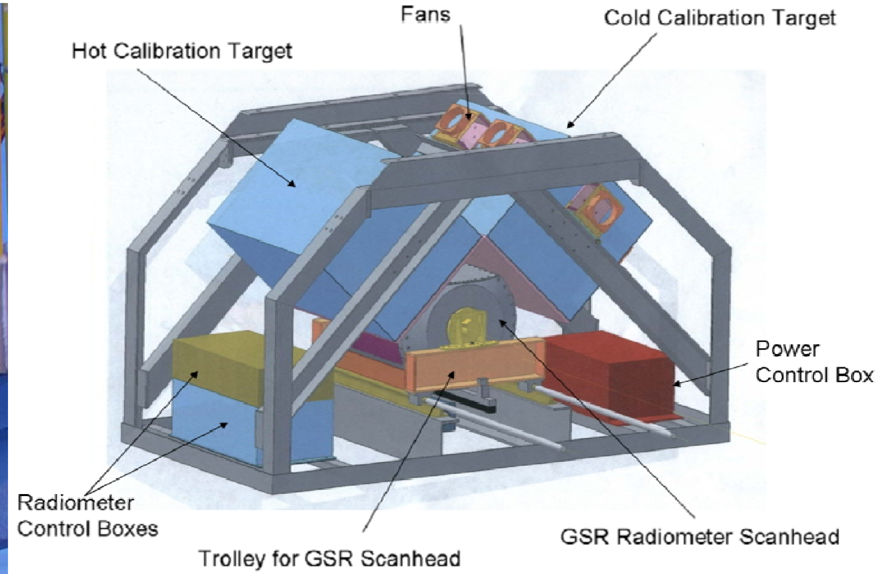
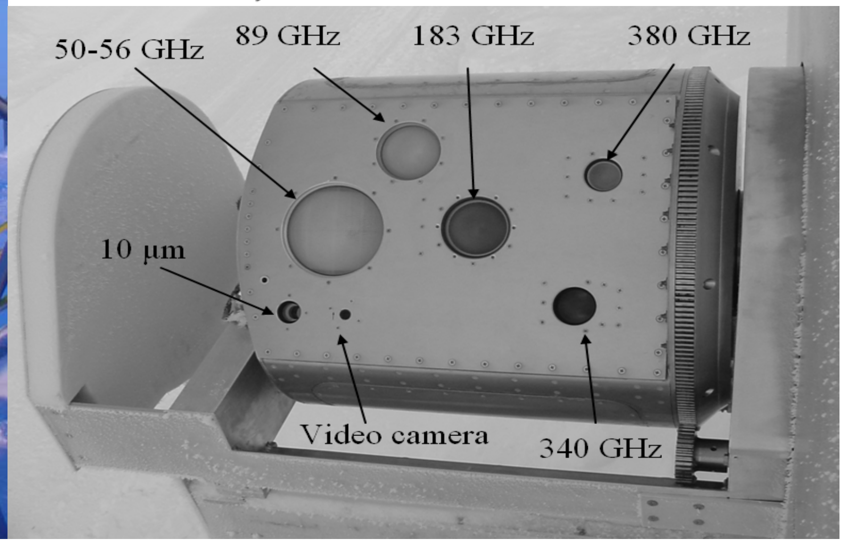
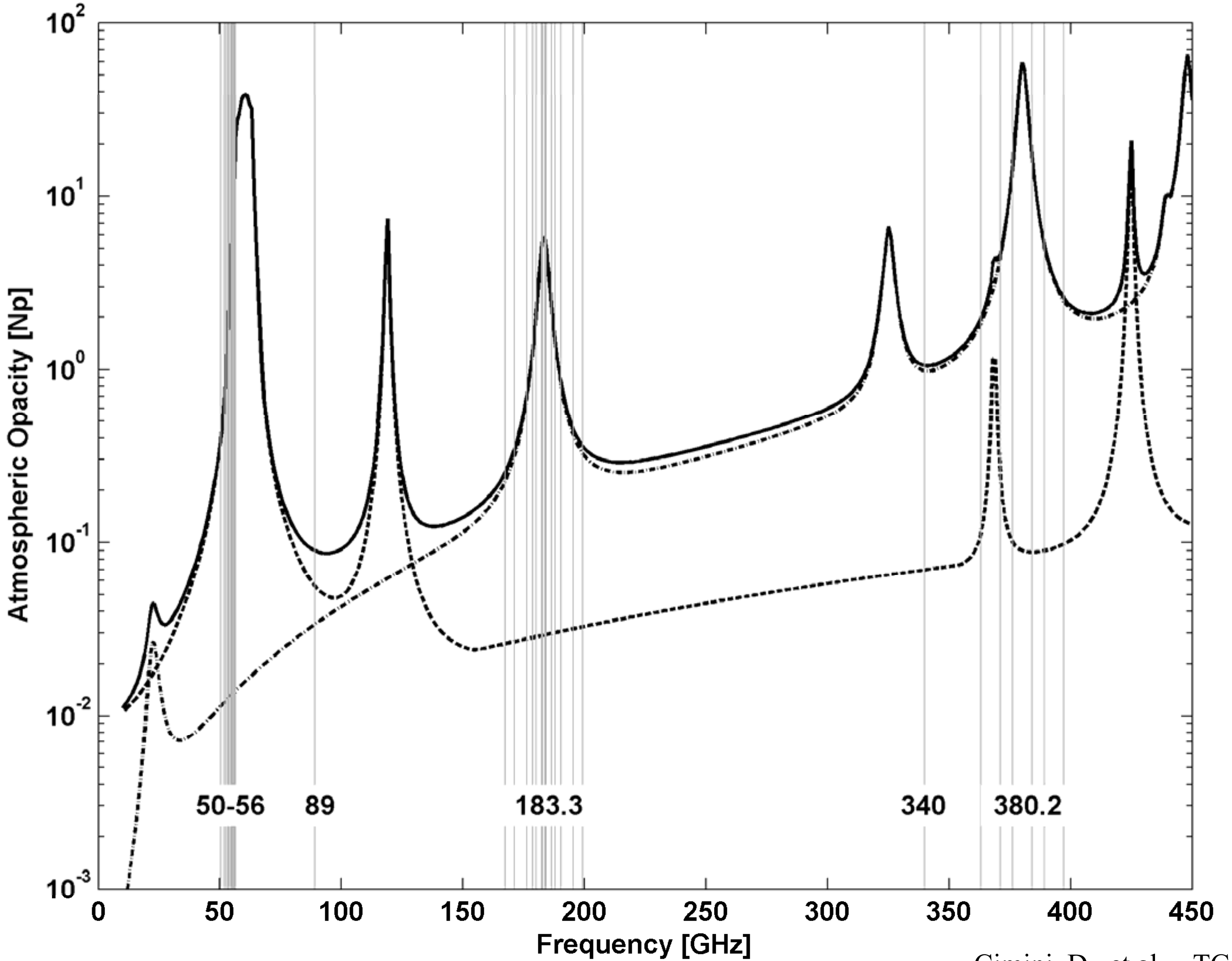
Ground-based Scanning Radiometer (GSR)



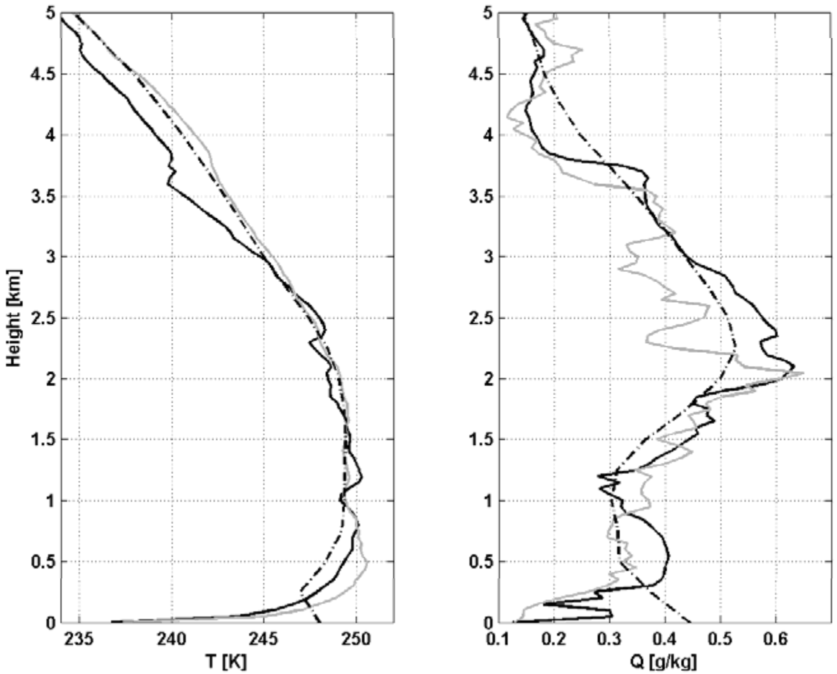


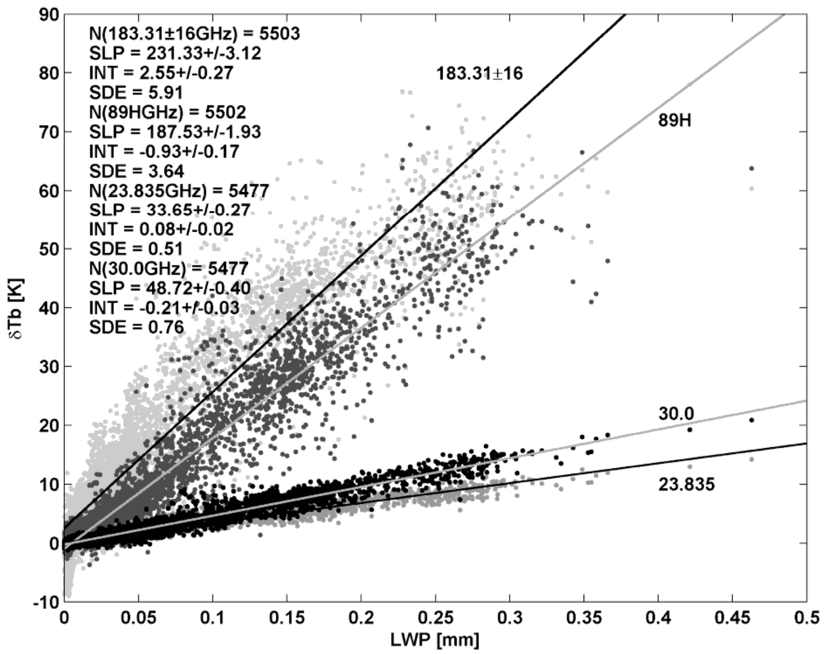
Ground Based Scanning Radiometer Channels



Cimini, D., et al., , TGARS, 2007

Retrieved Water Vapor Profiles and Liquid Water Path Sensitivity





Cimini, D., et al., , TGARS, 2007, 2010

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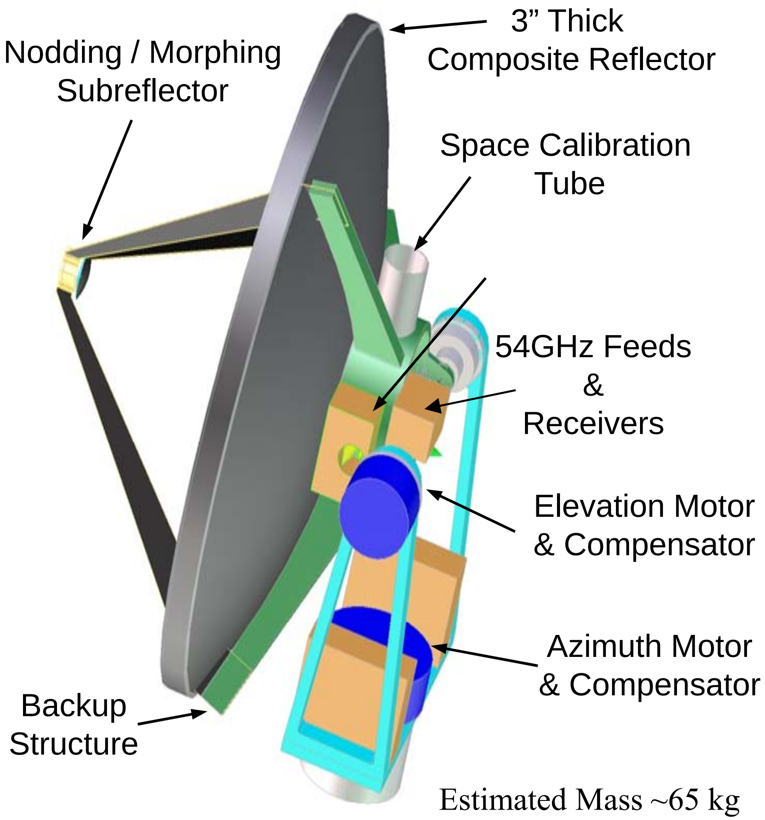
Filled Aperture Geostationary Spatial Resolution

Frequency (GHz)		Aperture size (m) 0.1	0.25	0.5	1	1.5	2	4.4	8	15	30	Tolerance (mm)
6.8	W	19611.0	7844.4	3922.2	1961.1	1307.4	980.5	445.7	245.1	130.7	65.4	1.764
10.7	W	12463.1	4985.2	2492.6	1246.3	830.9	623.2	283.3	155.8	83.1	41.5	1.121
18.7	W	7131.3	2852.5	1426.3	713.1	475.4	356.6	162.1	89.1	47.5	23.8	0.641
37.0	W	3604.2	1441.7	720.8	360.4	240.3	180.2	81.9	45.1	24.0	12.0	0.324
56.0	O2	2381.3	952.5	476.3	238.1	158.8	119.1	54.1	29.8	15.9	7.9	0.214
89.0	W	1498.4	599.3	299.7	149.8	99.9	74.9	34.1	18.7	10.0	5.0	0.135
118.8	O2	1123.0	449.2	224.6	112.3	74.9	56.1	25.5	14.0	7.5	3.7	0.101
166.0	W	803.3	321.3	160.7	80.3	53.6	40.2	18.3	10.0	5.4	2.7	0.072
183.3	H2O	727.5	291.0	145.5	72.8	48.5	36.4	16.5	9.1	4.9	2.4	0.065
220.0	W	606.2	242.5	121.2	60.6	40.4	30.3	13.8	7.6	4.0	2.0	0.055
325.1	H2O	410.2	164.1	82.0	41.0	27.3	20.5	9.3	5.1	2.7	1.4	0.037
340.0	W	392.2	156.9	78.4	39.2	26.1	19.6	8.9	4.9	2.6	1.3	0.035
380.2	H2O	350.7	140.3	70.1	35.1	23.4	17.5	8.0	4.4	2.3	1.2	0.032
424.8	O2	313.9	125.6	62.8	31.4	20.9	15.7	7.1	3.9	2.1	1.0	0.028
448.0	H2O	297.7	119.1	59.5	29.8	19.8	14.9	6.8	3.7	2.0	1.0	0.027
556.9	H2O	239.5	95.8	47.9	23.9	16.0	12.0	5.4	3.0	1.6	0.8	0.022
620.0	H2O	215.1	86.0	43.0	21.5	14.3	10.8	4.9	2.7	1.4	0.7	0.019
752.0	H2O	177.3	70.9	35.5	17.7	11.8	8.9	4.0	2.2	1.2	0.6	0.016
916.2	H2O	145.6	58.2	29.1	14.6	9.7	7.3	3.3	1.8	1.0	0.5	0.013
987.9	H2O	135.0	54.0	27.0	13.5	9.0	6.7	3.1	1.7	0.9	0.4	0.012

GEosynchronous Microwave (GEM) Sensor

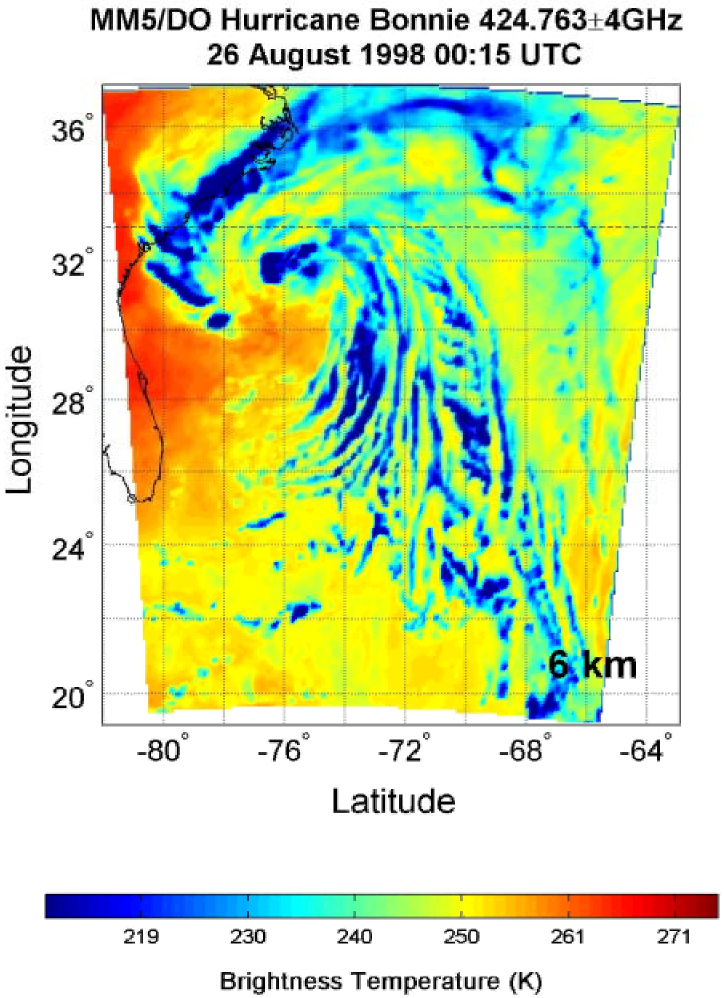
- Baseline system using 54, 118, 183, 380, and 424 GHz with ~2 m diameter Cassegrain antenna.
- ~16 km subsatellite resolution (~12 km using oversampling) above 2-5 km altitude at highest frequency channels.
- The 380 and 424 GHz channels selected to map precipitation through most optically opaque clouds at sub-hourly intervals. (Gasiewski, *TGARS*, 1992)
- Temperature and humidity sounding channels penetrate clouds sufficiently to drive NWP models with ~hourly data.

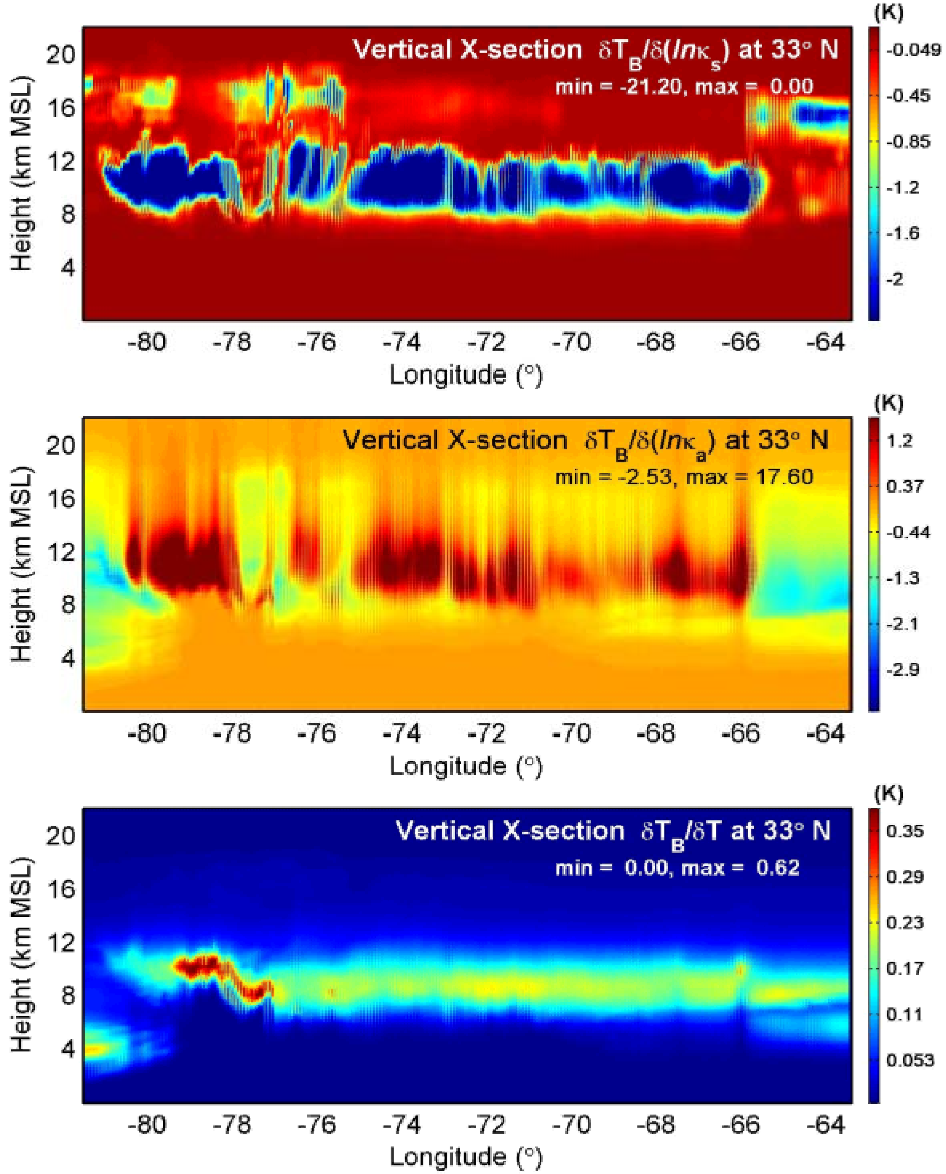


Estimated Mass ~65 kg

Geosynchronous Microwave Sounder Working Group (GMSWG): Chair: D.H. Staelin (MIT)

Simulated GEM 424+/-4 GHz Imagery - 15 min time steps





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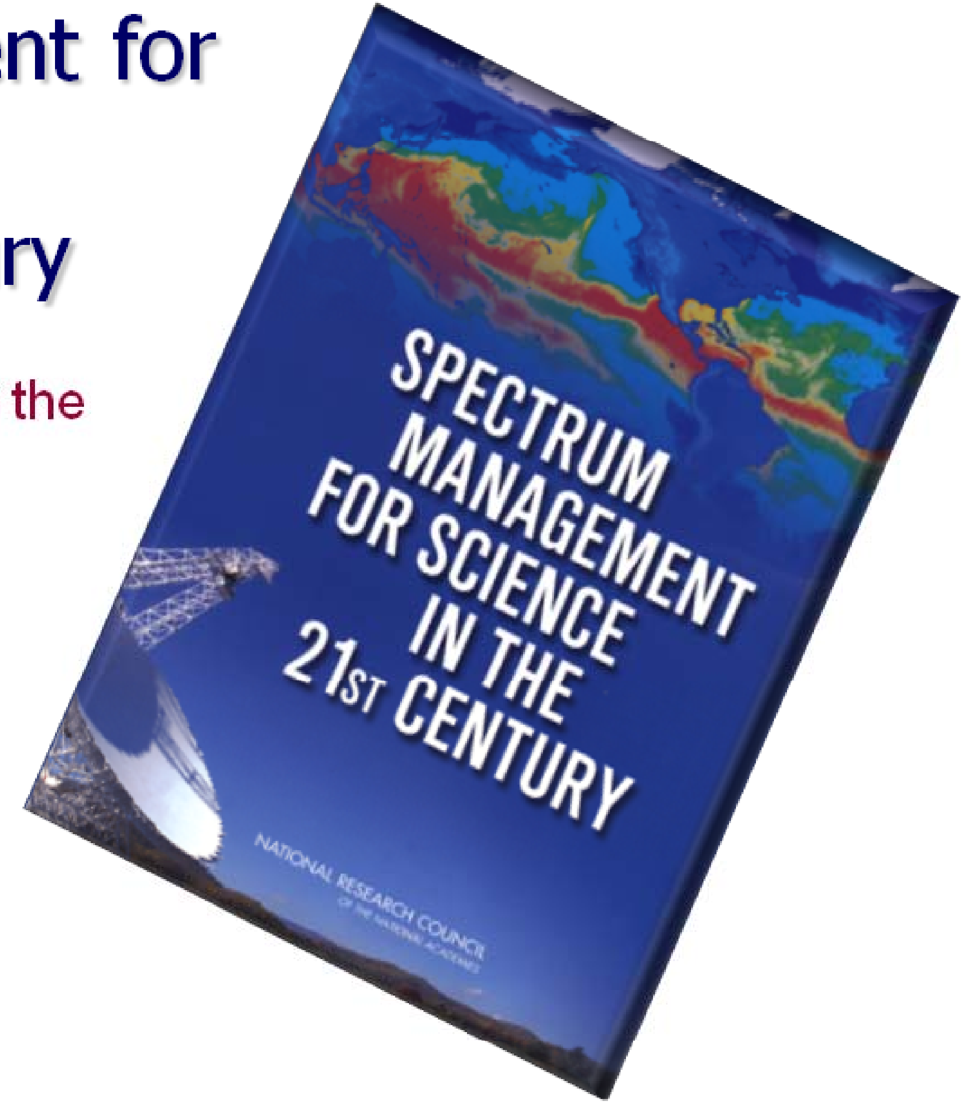
Spectrum Management for Science in the 21st Century



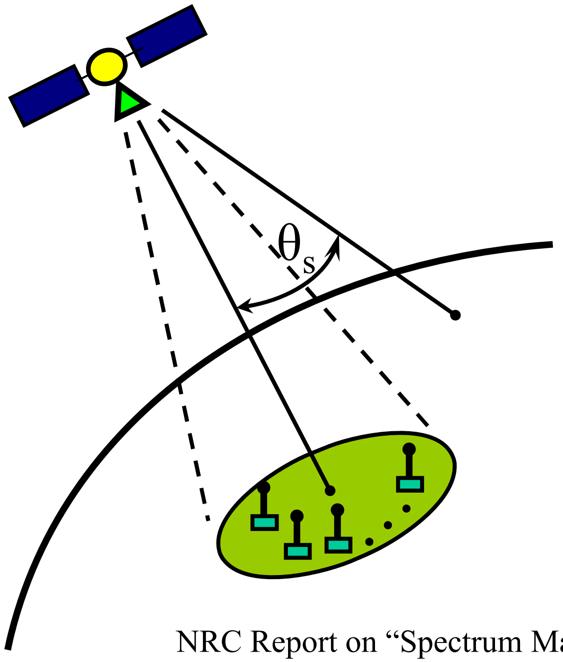
Committee on Scientific Uses of the Radio Spectrum

Marshall H. Cohen, *Co-Chair*
Albin J. Gasiewski, *Co-Chair*
on behalf of the full committee

Density of Interferers

From Friis formula and *kTB* thermal noise:

$$\frac{P_T G_T}{A} < \delta T \frac{kBe^{\tau}}{\lambda^2}\left(\frac{64}{\pi}\right)$$



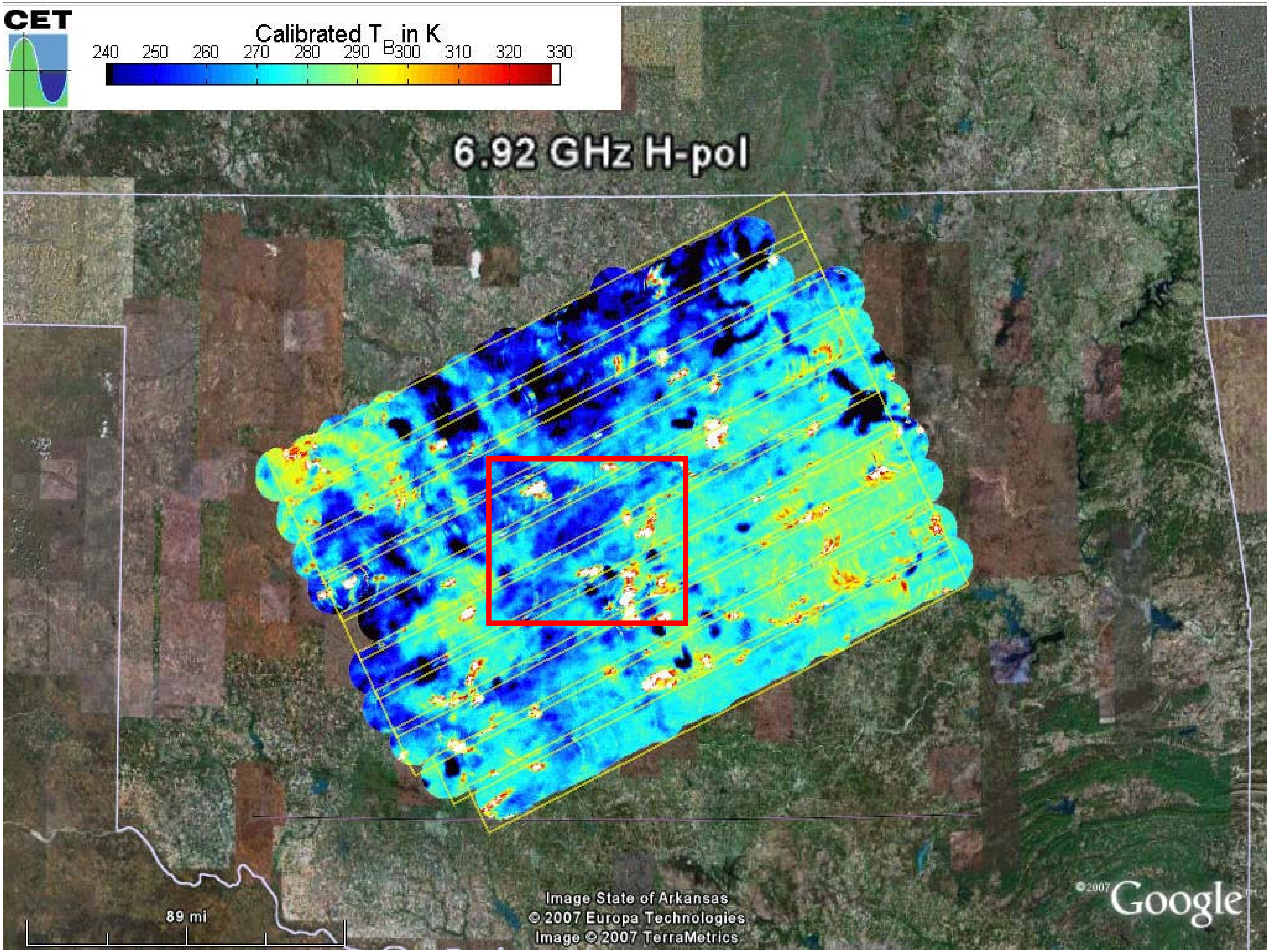
<u>AMSR-E C-band Example:</u>

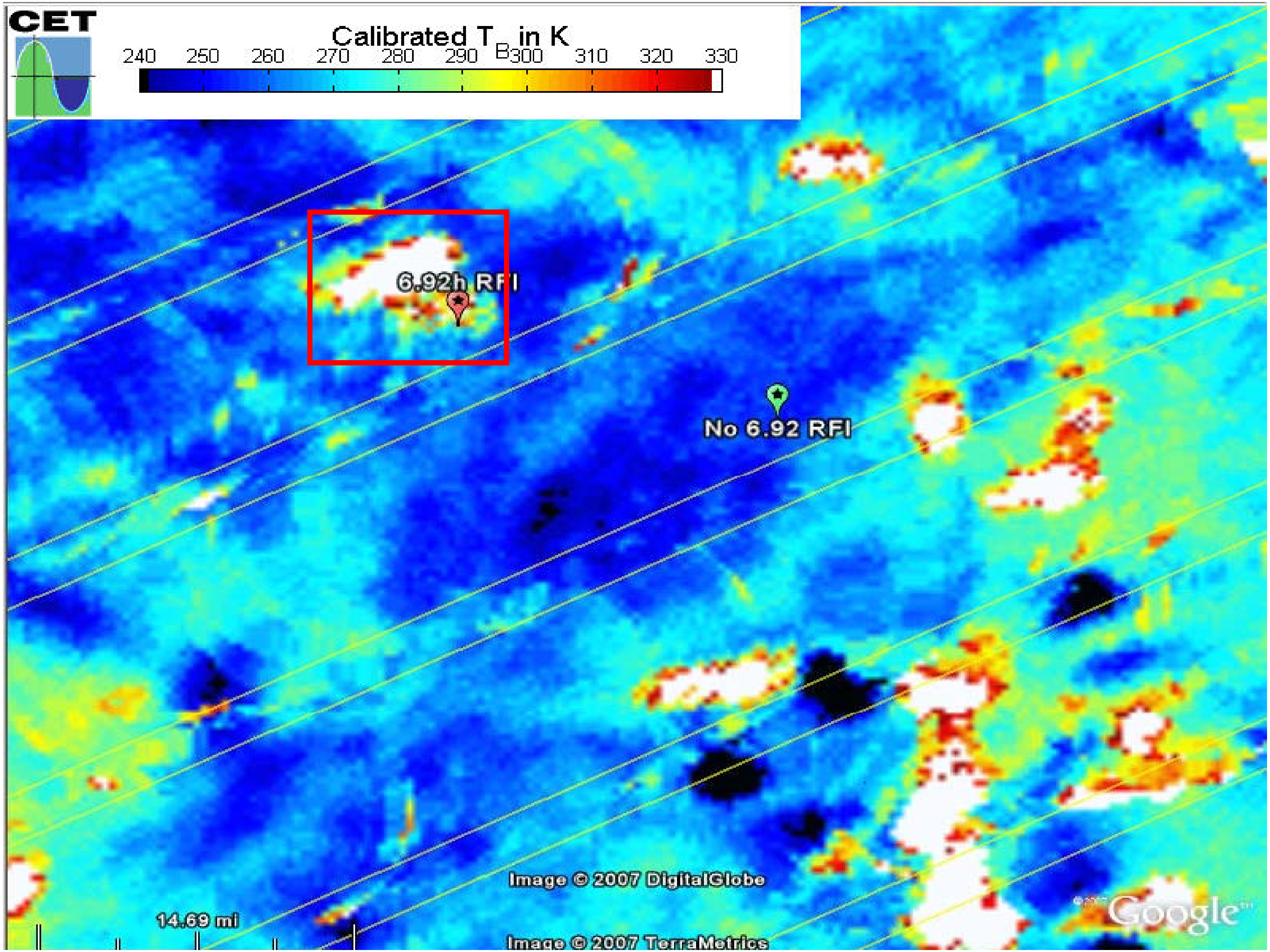
P_T = 1 mW (0 dBm)
δT = 0.3 K (SA.1029-2 recommendation)
B = 350 MHz
λ = 4.3 cm (6.9 GHz)
C = 1 (direct isotropic radiation)
τ = 0.02 (<0.1 dB atmospheric loss)
θ_s = 55° incidence WRT nadir

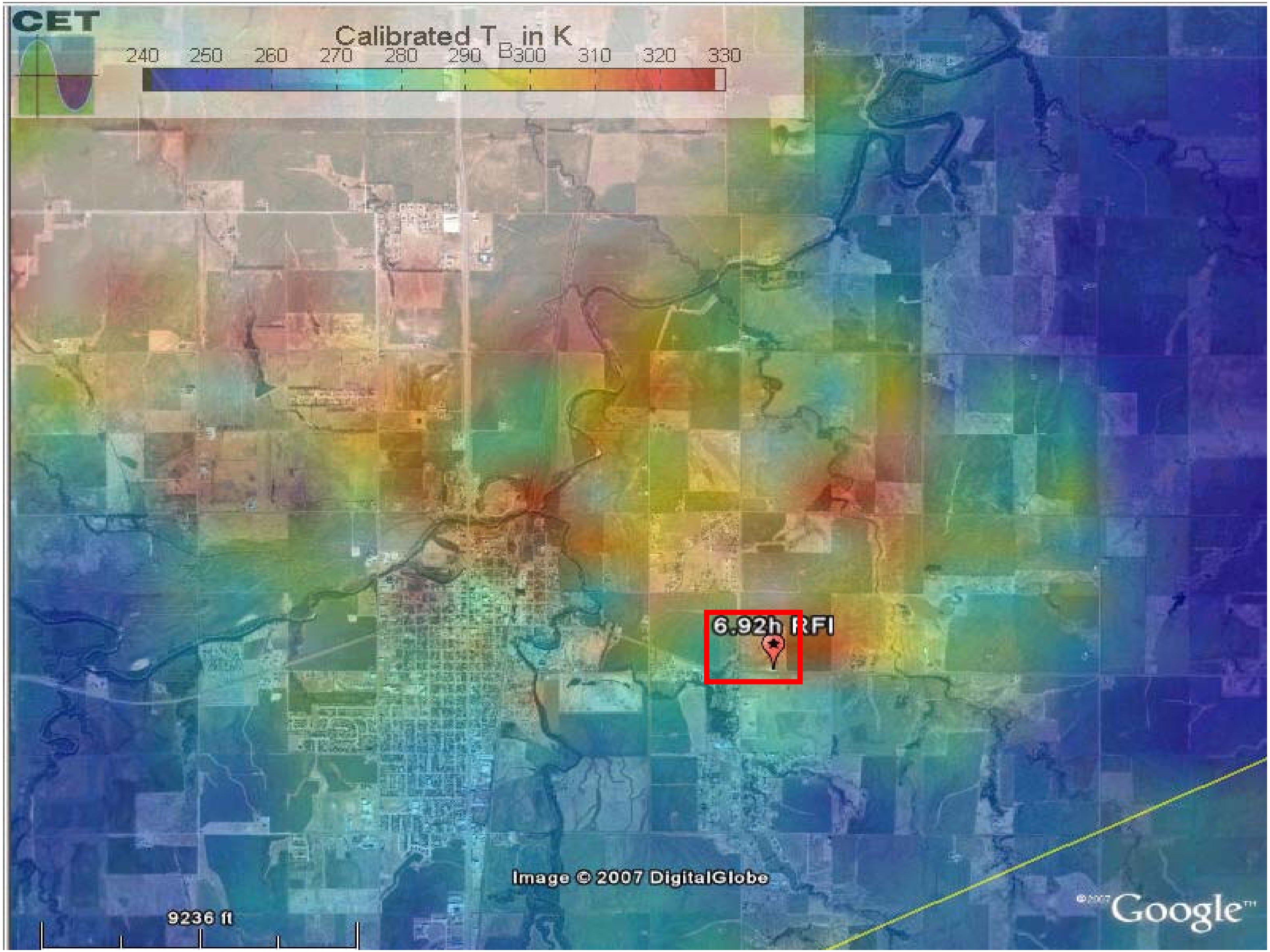
➔ $\rho < 2.3\text{E-}3\ (\text{km}^{-2})$
Or, an average transmitter separation distance of more than ~21 km is required for non-interference (using the ITU 20% criteria).

6.9 GHz was orignally intended as the primary AMSR-E channel for soil moisture measurement

NRC Report on "Spectrum Management for Science in the 21st Century" http://www.nap.edu/catalog/12800.html


CET
Calibrated T_B in K
240 250 260 270 280 290 300 310 320 330
6.92 GHz H-pol
89 mi
Image State of Arkansas
© 2007 Europa Technologies
Image © 2007 TerraMetrics
©2007 Google

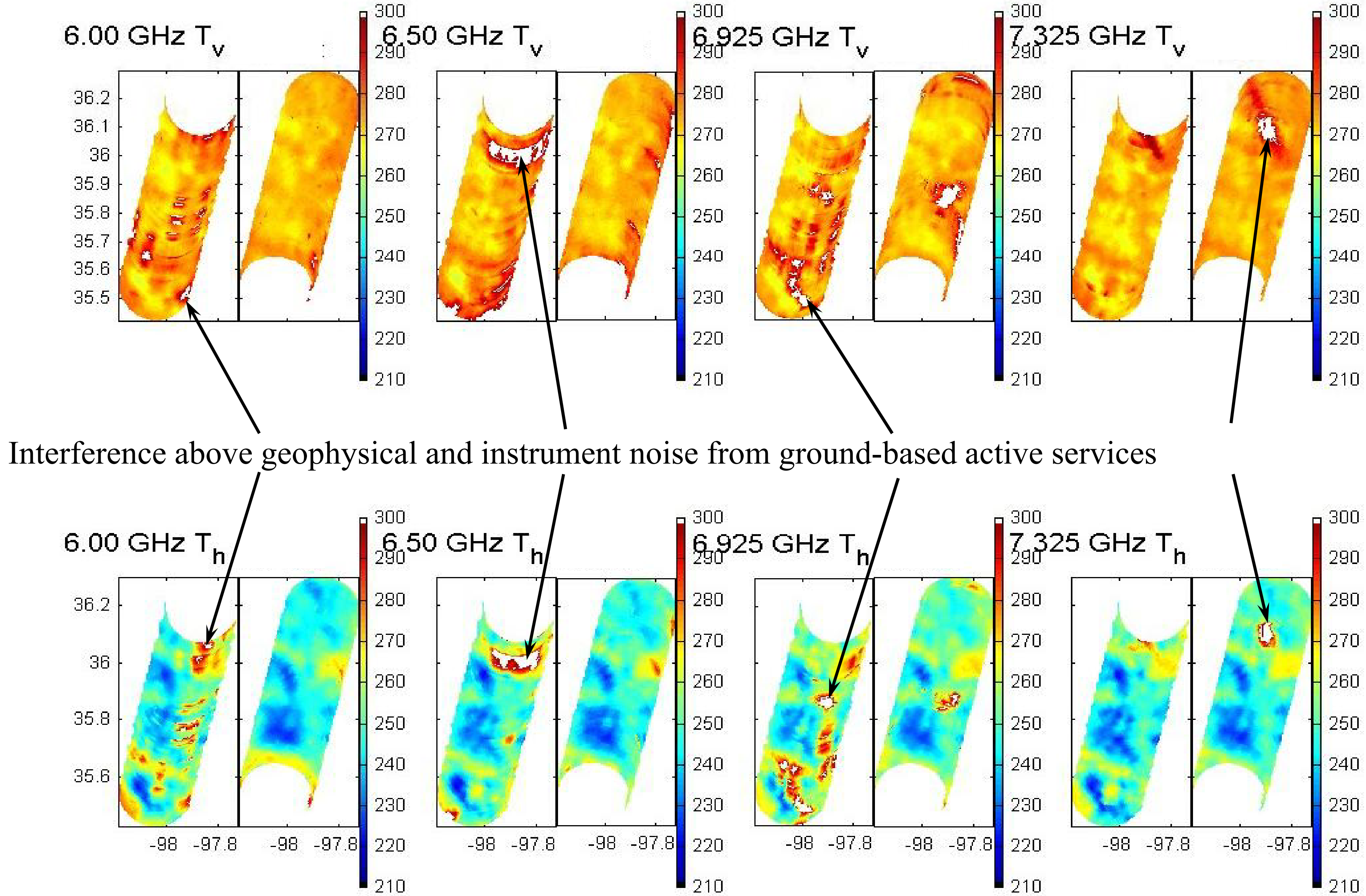

CET
Calibrated T_B in K
240 250 260 270 280 290 300 310 320 330
6.92h RFI
No 6.92 RFI
Image © 2007 DigitalGlobe
14.69 mi
Image © 2007 TerraMetrics
Google


CET
Calibrated T_B in K
240 250 260 270 280 290 300 310 320 330
6.92h RFI
Image © 2007 DigitalGlobe
9236 ft
©2007 Google™

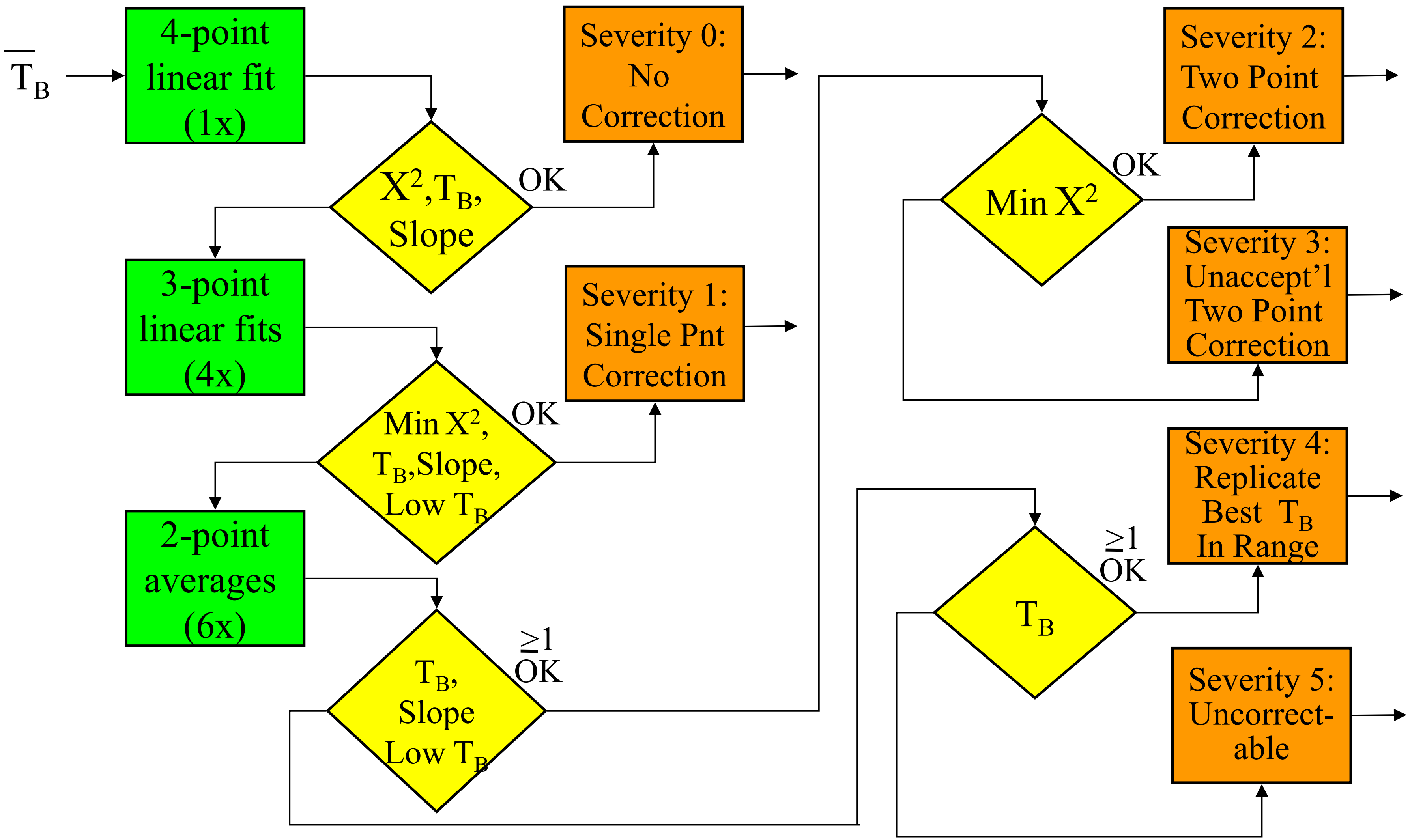

CET
Calibrated T_B in K
240 250 260 270 280 290 300 310 320 330
6.92h RFI
Image © 2007 DigitalGlobe
375 ft
©2007 Google

Calibrated (uncorrected) Imagery

PSR/C SGP99 7/14/99 – Oklahoma – SN 0049

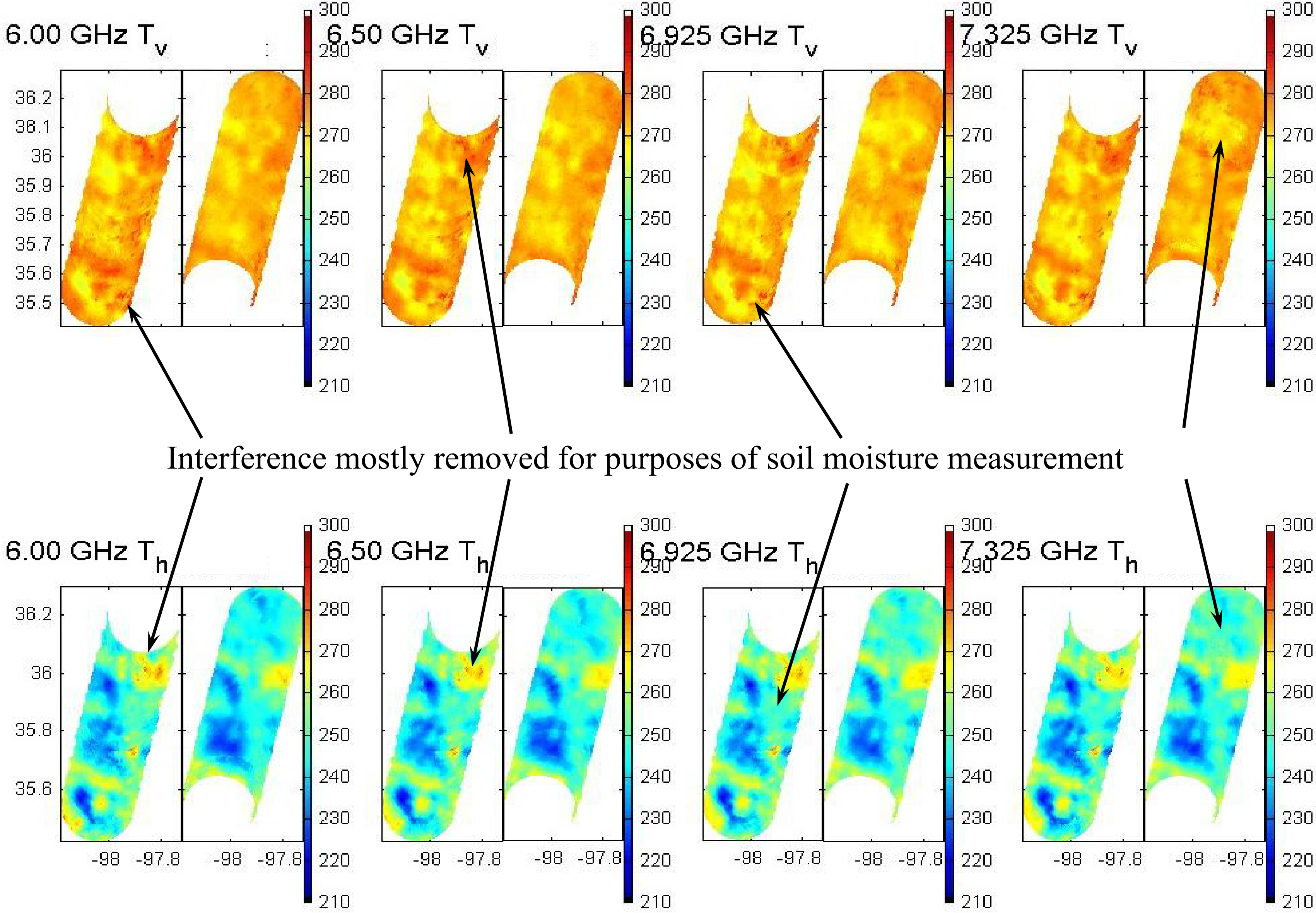


Basic Spectral RFI Mitigation Algorithm



Interference-Corrected Imagery

PSR/C SGP99 7/14/99 – Oklahoma – SN 0049



RFI to Passive Systems at THz Bands

- There is little concern about RFI above 275 GHz at present since all activity is nascent
- As sources become cheaper and receivers are able to be integrated both passive and active applications will expand
  - RFI mitigation efforts and actions at lower frequency bands will be representative
- Water vapor screening (producing exponential decay) can be likely be used to facilitate band sharing:
  - Requires knowledge of humidity fields
  - May require on-board ROM radiative transfer calculations (WRF+MPM on a PDA)

- Active applications
  - Standoff detection
  - All weather landing imager
  - Short range security imaging
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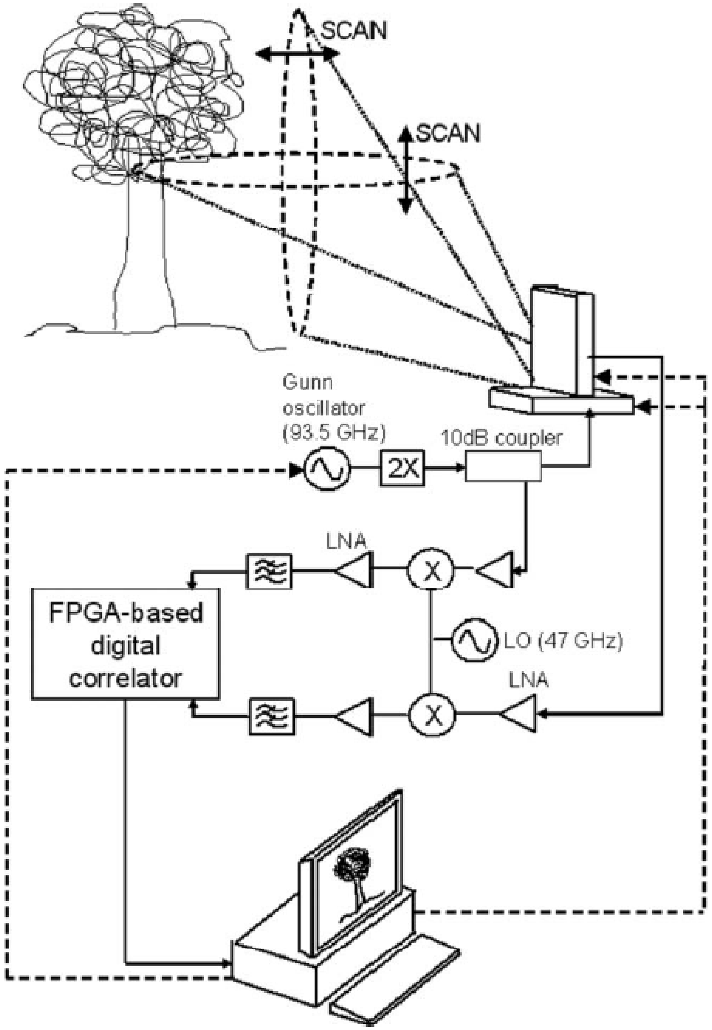
187 GHz Radar Imaging for Security Imaging



"Design and testing of an active 190-GHz millimeter-wave imager"

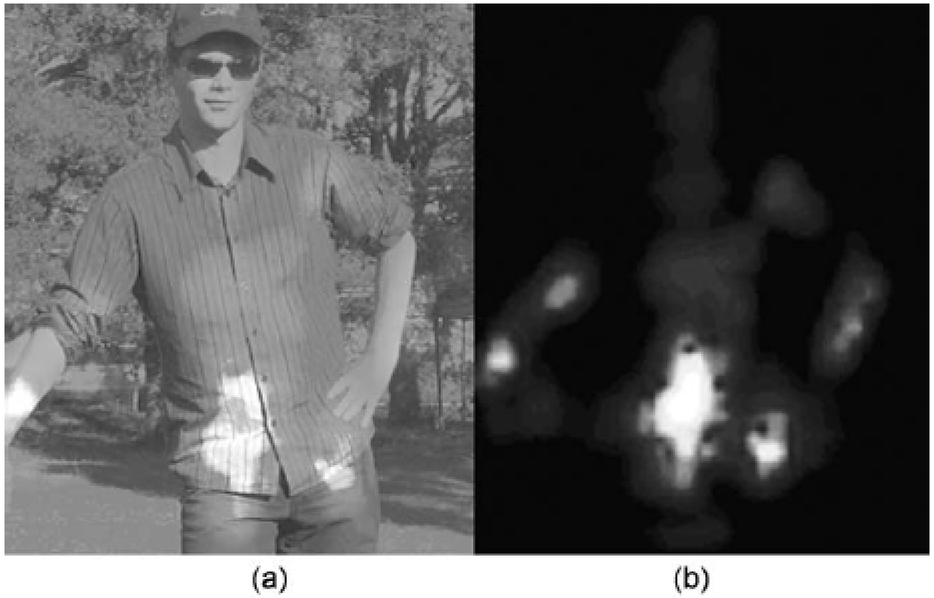
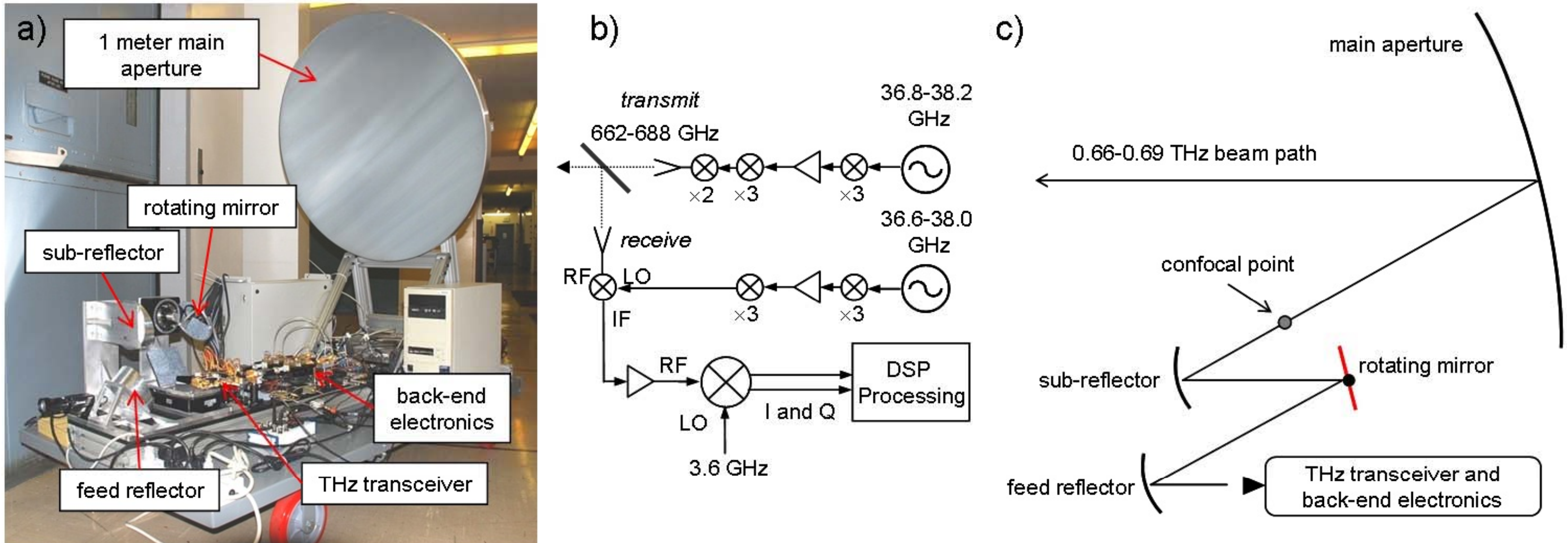
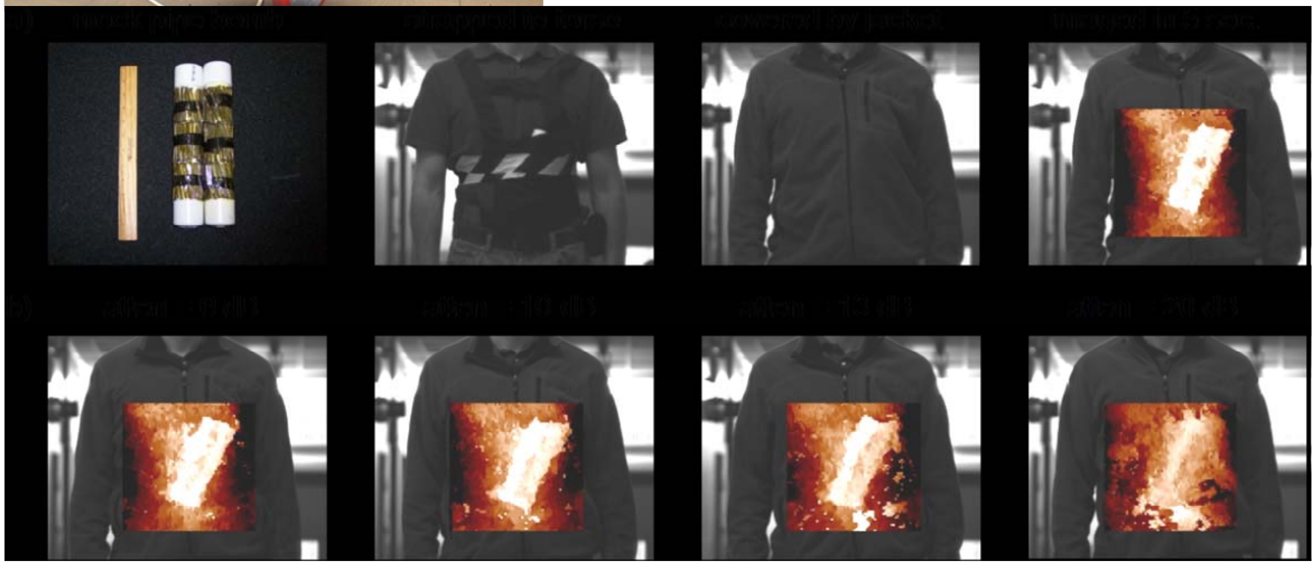


Fig. 6 (a) Composite photograph with superimposed 187-GHz image and (b) active 187-GHz image of a subject with a concealed metallic knife.

Timms et al., J. Electronic Imaging, 2010

675 GHz Radar Imaging for Standoff Detection





Siegel group/JPL:
Cooper et al.,
Trans. MTT, 2008

Airborne Imaging Applications

- Passive MMW Imaging for landing during fog
  - Technology for MMIC receiver arrays demonstrated in late 1990's at 94 GHz
  - MMIC LNA receiver chips being developed up to ~700 GHz
- Radar for landing during brownout being demonstrated at frequencies up to 340 GHz

Double Resonance Spectroscopy

- Proposed active IR/THz technique for remote detection of trace species.

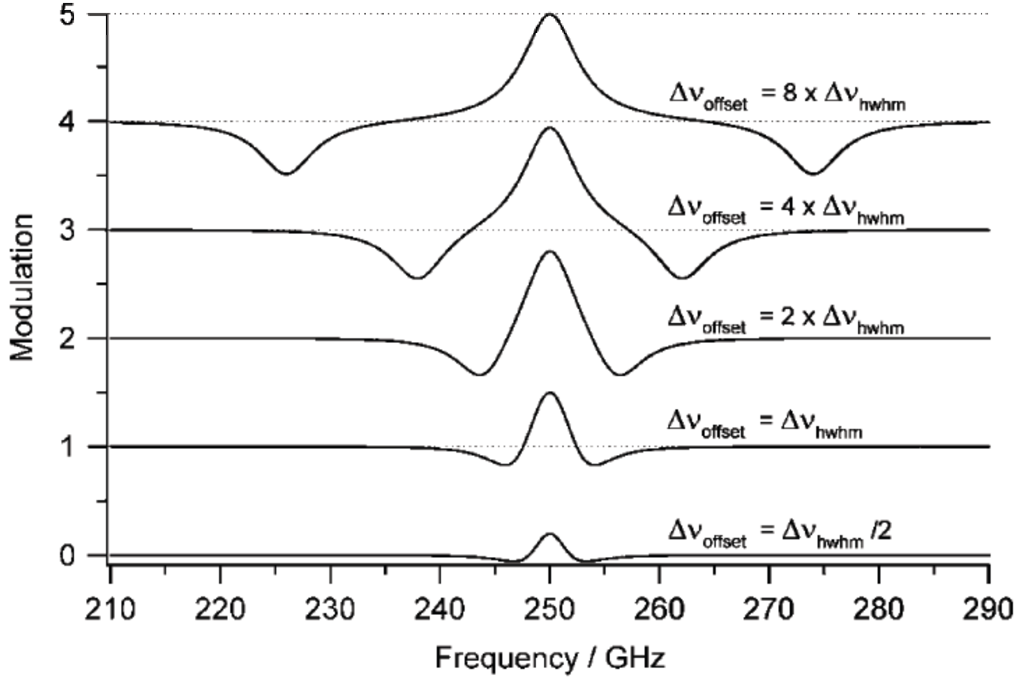


Fig. 2. SMM/THz signature as a function of separation of the pump induced absorption and pump induced emission in units of pressure broadened line width.

DeLucia at al., IEEE J. Quantum Electronics, 2009

Summary

- There is a rapidly growing number of applications of THz technology for environmental (and related) applications
  - Both passive and active
  - Highly dependent on power/cost and propagation requirements
- Current spectral needs are modest, but could be expected to become significant
  - Water vapor screening could potentially be standardized and used to facilitate sharing