A New Microwave Snow Emissivity Model

Fuzhong Weng[1,2]
1. Joint Center for Satellite Data Assimilation
2. NOAA/NESDIS/Office of Research and Applications

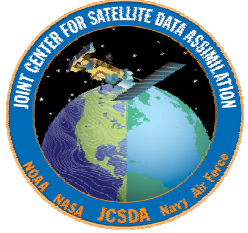
Banghua Yan
DSTI. Inc

The 13th International TOVS Study Conference

October 30, 2003

Sainte Adele, Canada

JCSDA Road Map (2002 - 2010)



Science Advance

By 2010, a numerical weather prediction community will be empowered to effectively assimilate increasing amounts of advanced satellite observations

The radiances can be assimilated under all conditions with the state-of-the science NWP models

Resources:

OK

Deficiency

NPOESS sensors (CMIS, ATMS…)
GOES-R

Advanced JCSDA community-based radiative transfer model, Advanced data thinning techniques

The CRTM includes scattering & polarization from cloud, precip and surface

AIRS, ATMS, CrIS, VIIRS, IASI, SSM/IS, AMSR, more products assimilated

The radiances from advanced sounders will be used. Cloudy radiances will be tested under rain-free atmospheres, and more products (ozone, water vapor winds) are assimilated

Improved JCSDA data assimilation science

A beta version of JCSDA community-based radiative transfer model (CRTM) transfer model will be developed, including non-raining clouds, snow and sea ice surface conditions

AMSU, HIRS, SSM/I, Quikscat, AVHRR, TMI, GOES assimilated

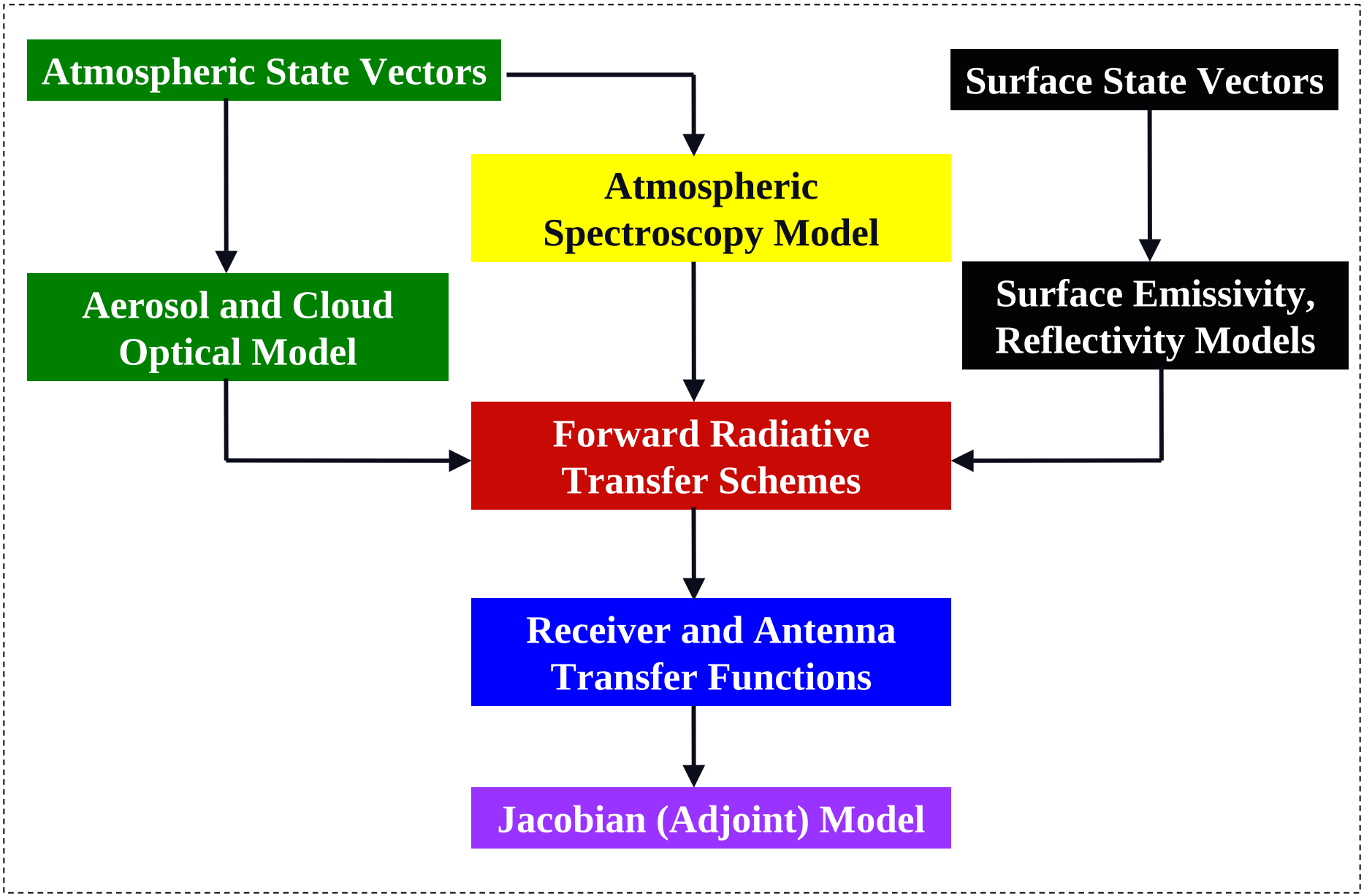
The radiances of satellite sounding channels were assimilated into EMC global model under only clear atmospheric conditions. Some satellite surface products (SST, GVI and snow cover, wind) were used in EMC models

Pre-JCSDA data assimilation science

Radiative transfer model, OPTRAN, ocean microwave emissivity, microwave land emissivity model, and GFS data assimilation system were developed

2002 2003 2004 2005 2007 2008 2009 2010

JCSDA Community-based Radiative Transfer Model



Surface Emissivity Model

Natural Scenes

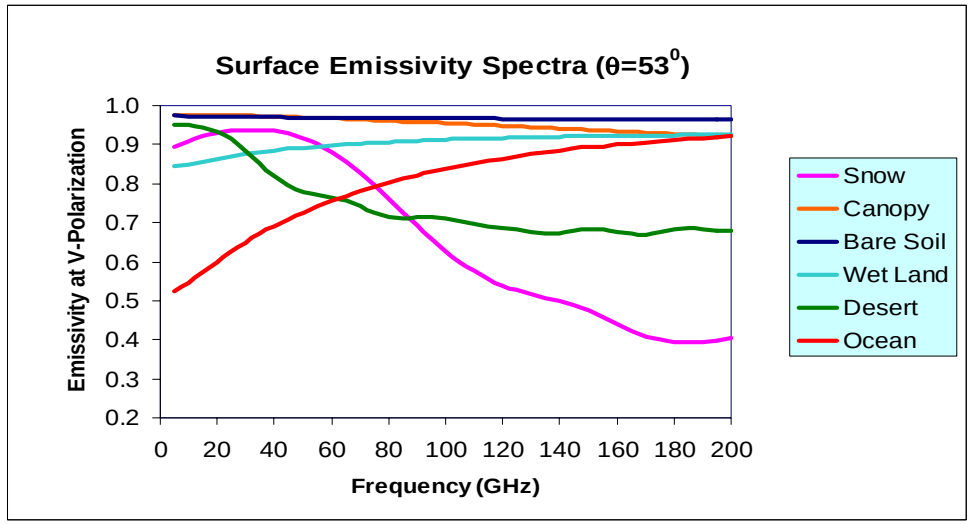
Theory Base

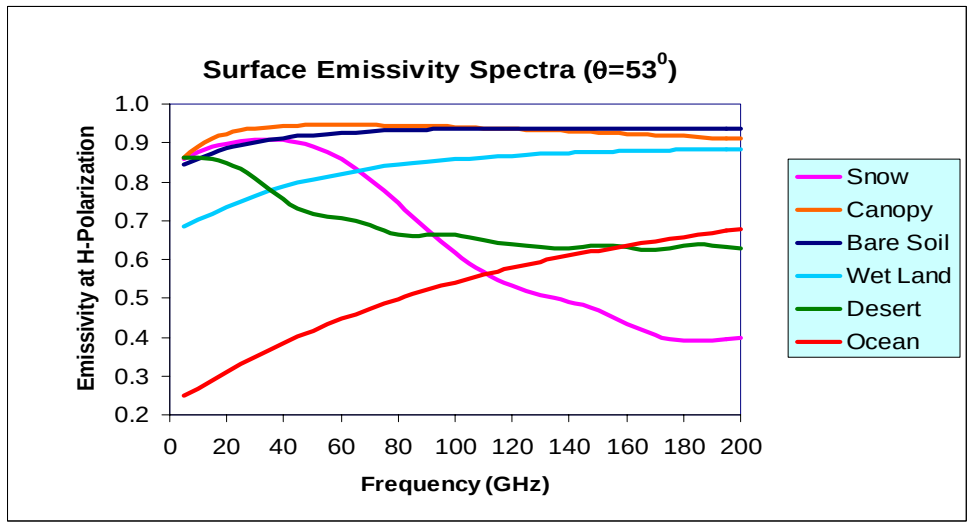
Two-Scale Approx.	Scattering/ observations
Geometric Optics	Scattering/ observations

Surface Emissivity

- **Open water –** two-scale roughness theory
- **Sea ice –** Coherent reflection
- **Canopy –** Four layer clustering scattering
- **Bare soil –** Coherent reflection and surface roughness
- **Snow/desert –** Random media

Weng et al (2001, JGR)





Deficiencies of Snow Modeling

- Not applicable for aged snow
- Limited at frequencies less than 50 GHz
- Not applicable for vertically stratified snow
- Two stream radiative transfer approach

Brightness Temperature Sensitivity to Surface Emissivity

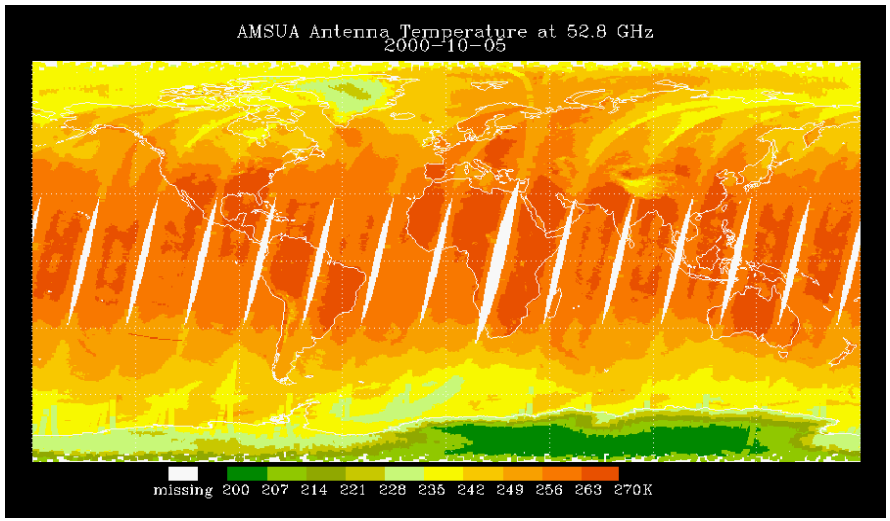
Freq (GHz)	Ts = 230 K and TPW = 0.5 mm					
	Ps = 600 (mb)			Ps = 1000 (mb)		
	T_d(K)	τ	ΔT_B(K)	T_d(K)	τ	ΔT_B(K)
50.3	49.30	0.774	5.593	112.5	0.487	2.289
52.8	111.2	0.492	2.337	188.6	0.153	0.253
150	4.4	0.980	8.844	12.5	0.944	8.209
183.3±7	16.6	0.925	7.893	43.5	0.807	6.018
183.3±3	55.3	0.750	5.242	104.1	0.538	2.709
183.3±1	134.6	0.392	1.496	160.1	0.288	0.806

$$\Delta T_B = \tau (T_s - T_d) \Delta \varepsilon \qquad \Delta\varepsilon = 0.04$$

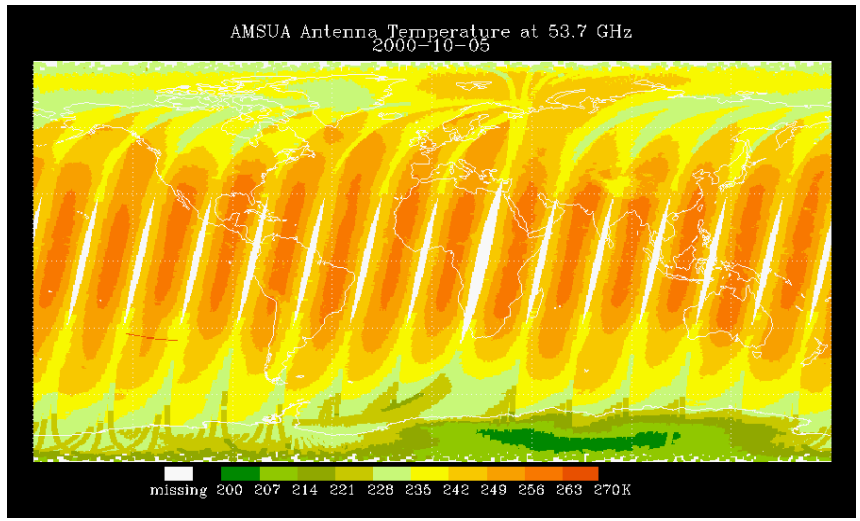
Advanced Microwave Sounding Unit

Sounding Channels

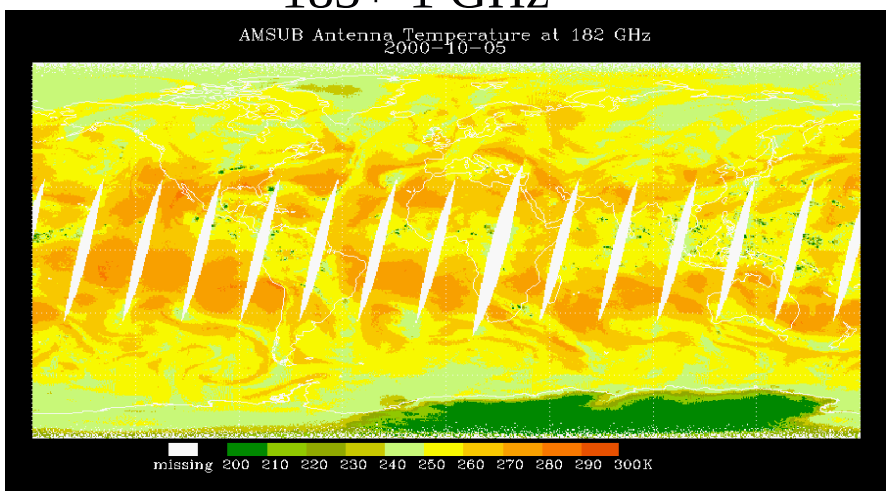
52.8 GHz



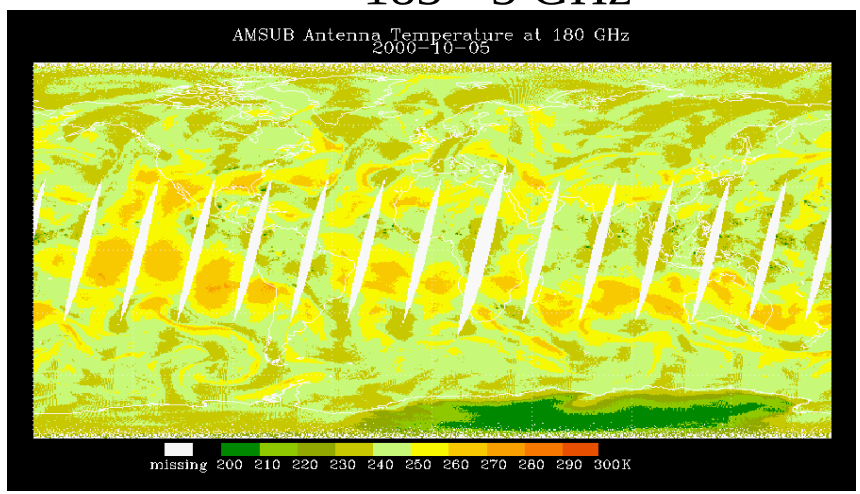
53.7 GHz



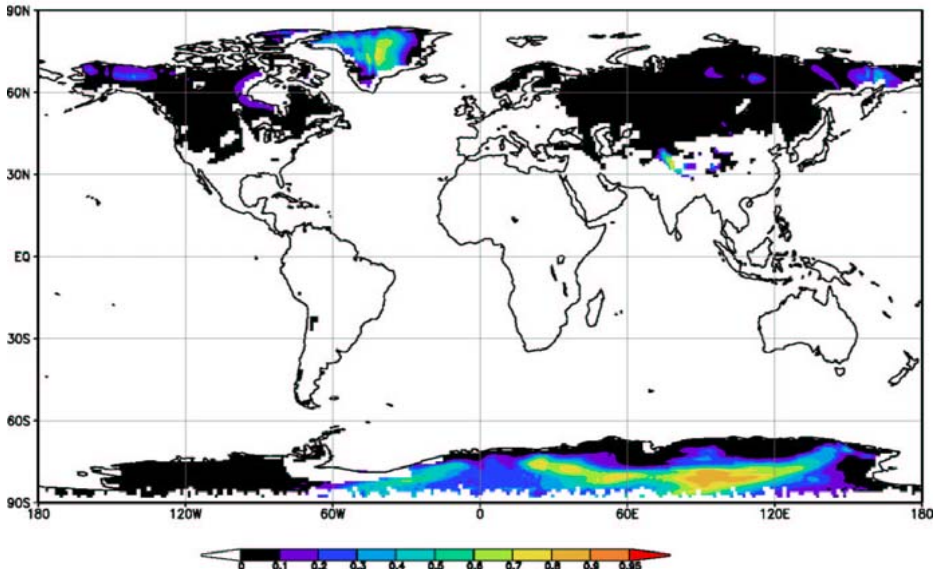
183+-1 GHz



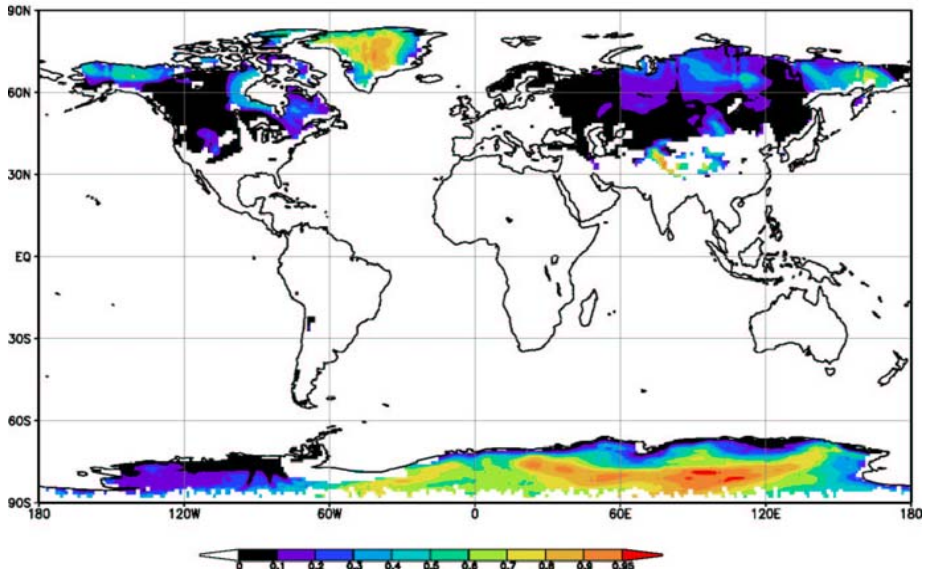
183+-3 GHz



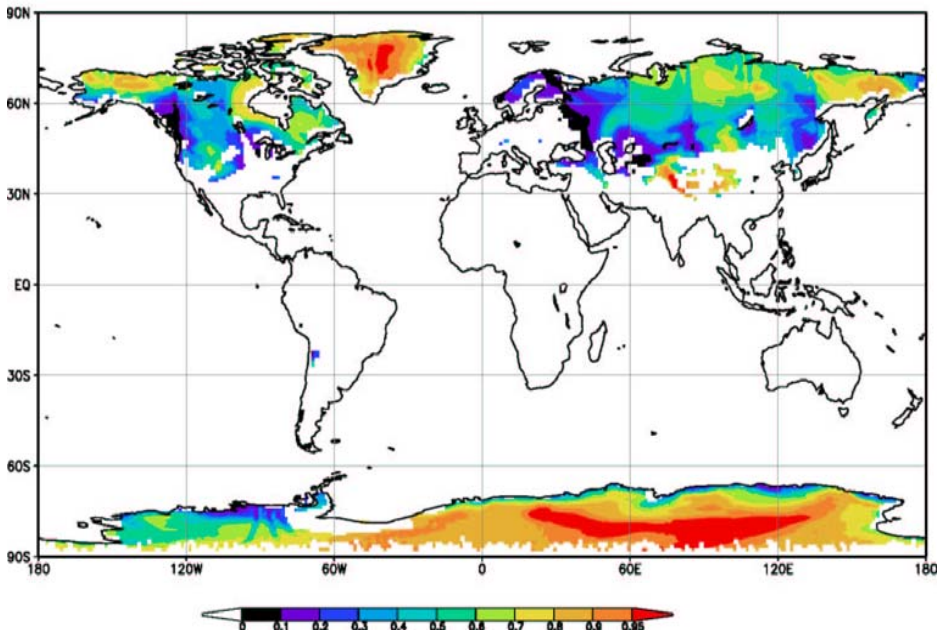
Atmospheric Transmittance at 183.3 ± 1 GHz



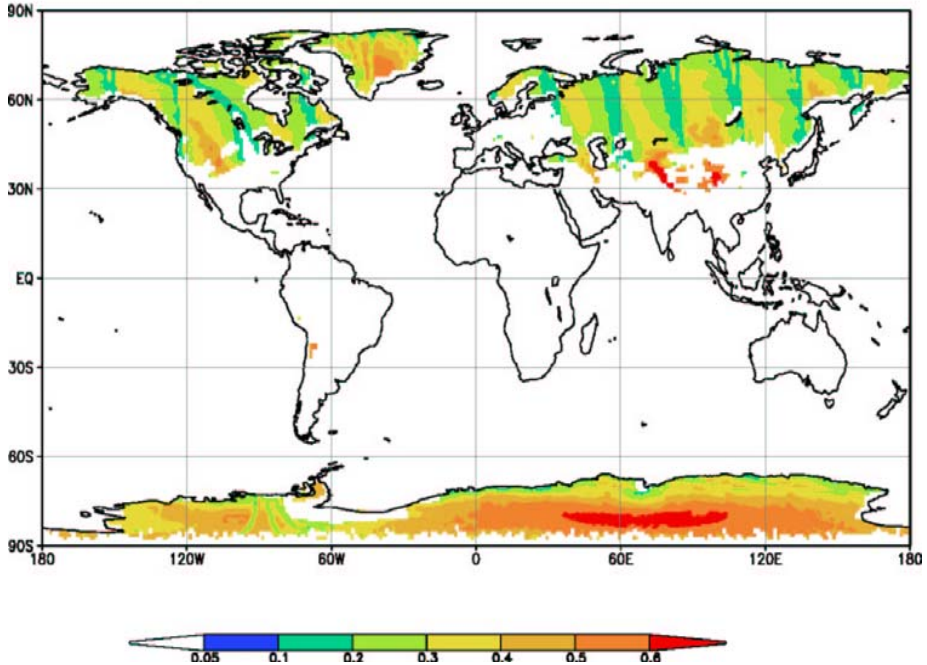
Atmospheric Transmittance at 183.3 ± 3 GHz



Atmospheric Transmittance at 183.3 ± 7 GHz



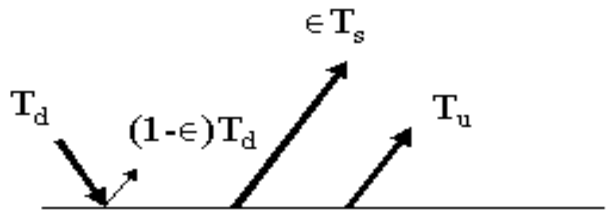
Atmospheric Transmittance at 52.8 GHz



Snow Emissivity Data Base

Emissivity Retrieval:

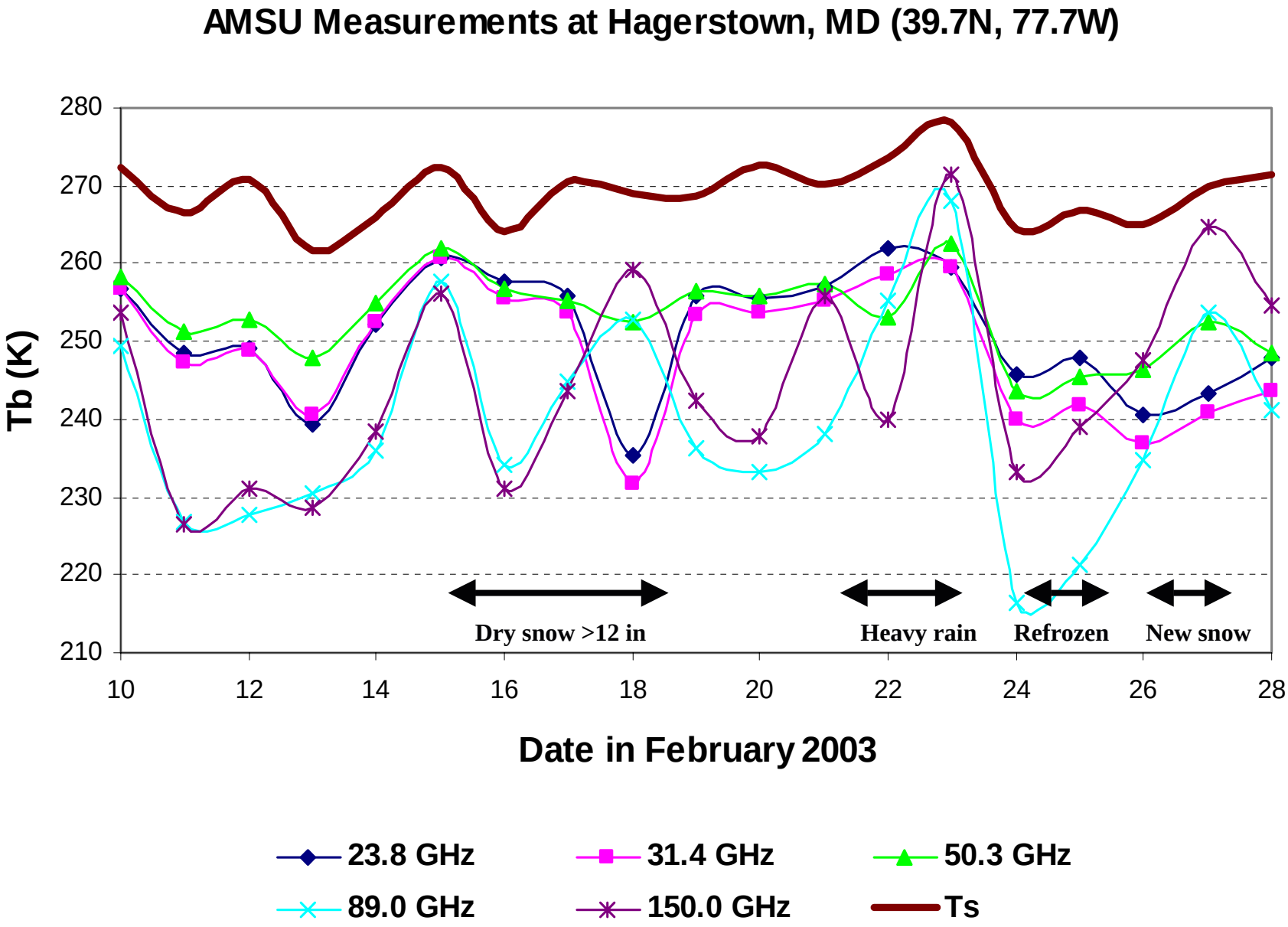
$$\varepsilon = \frac{T_b - T_u - T_d\,\tau}{\tau\ (T_s - T_d)}$$



AMSU-A: 23.8, 31.4, 50.3, 89 GHz
AMSU-B: 89, 150 GHz
AVHRR: Ts
RAOBS temperature/q profiles

Winter season of 2003: Eastern part of US: persistent snow cover during February

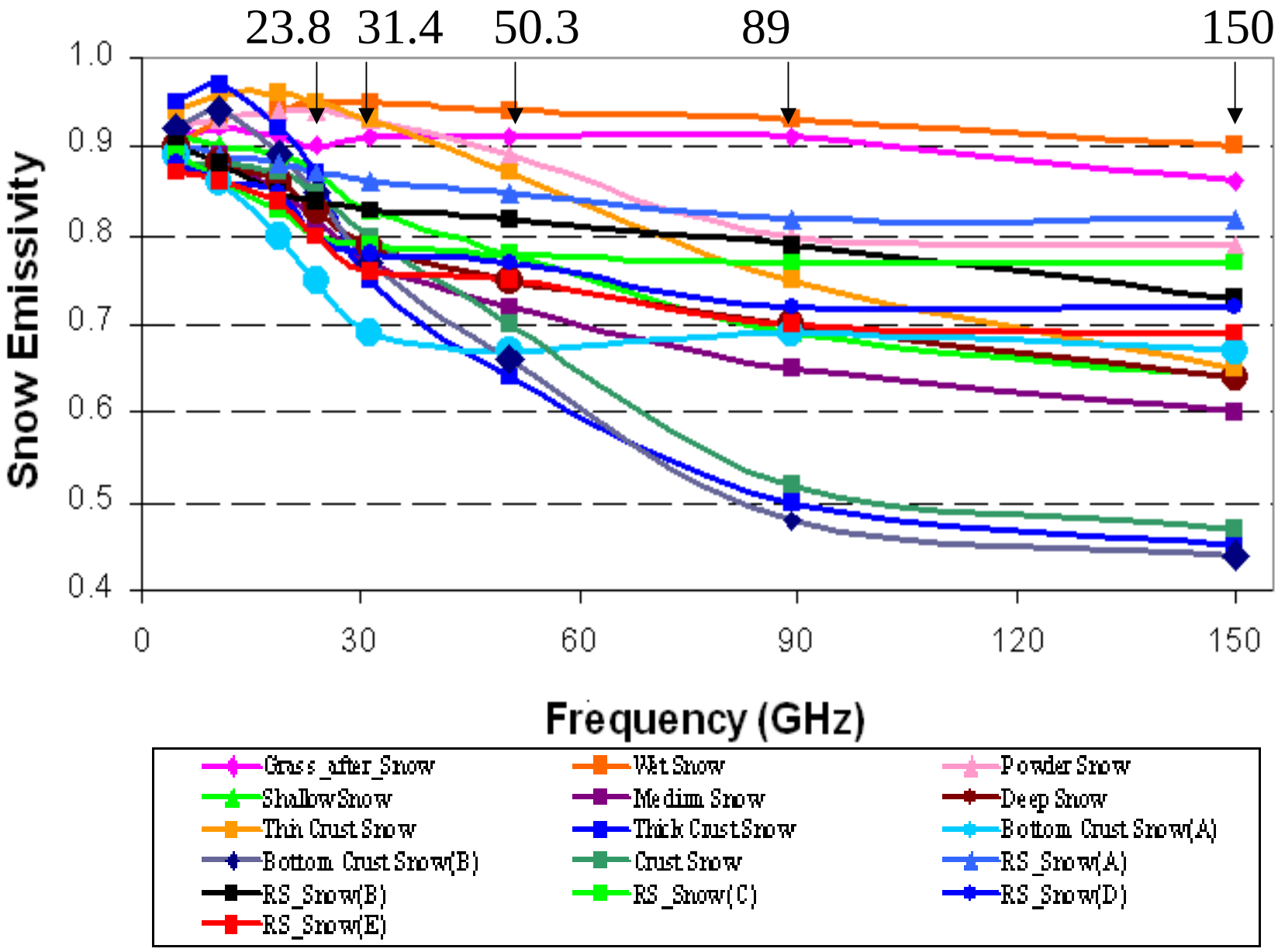
Snow Storms (February 2003)


AMSU Measurements at Hagerstown, MD (39.7N, 77.7W)
Tb (K)
280
270
260
250
240
230
220
210
10
12
14
16
18
20
22
24
26
28
Dry snow >12 in
Heavy rain
Refrozen
New snow
Date in February 2003
23.8 GHz
31.4 GHz
50.3 GHz
89.0 GHz
150.0 GHz
Ts

Brightness Temperatures in Relation to Snow Properties

- For newly formed and deep snow, brightness temperature decrease as frequency increases (2/15-2/16)
- While snow experiences metamorphosing, brightness temperature at lower frequencies can be strongly depressed due to an increasing scattering of large particles (2/18)
- After snow refrozen, brightness temperature decreases with frequency and then increases (2/24-2/25)
- For new snow falling on the top of a layer of crust ice, brightness temperatures increases with frequency (2/27)

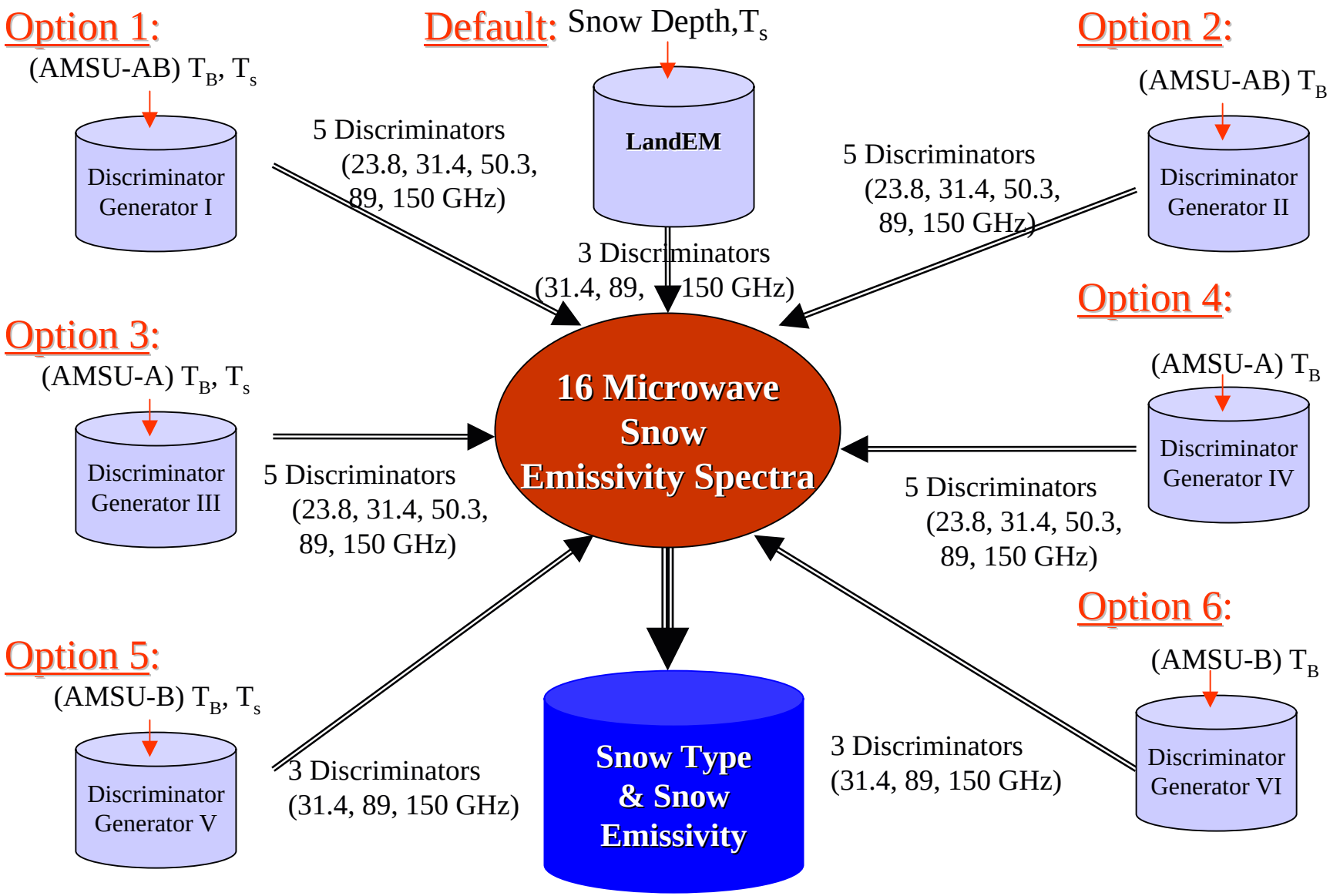
Snow Emissivity Spectra



Detection of Snow Types

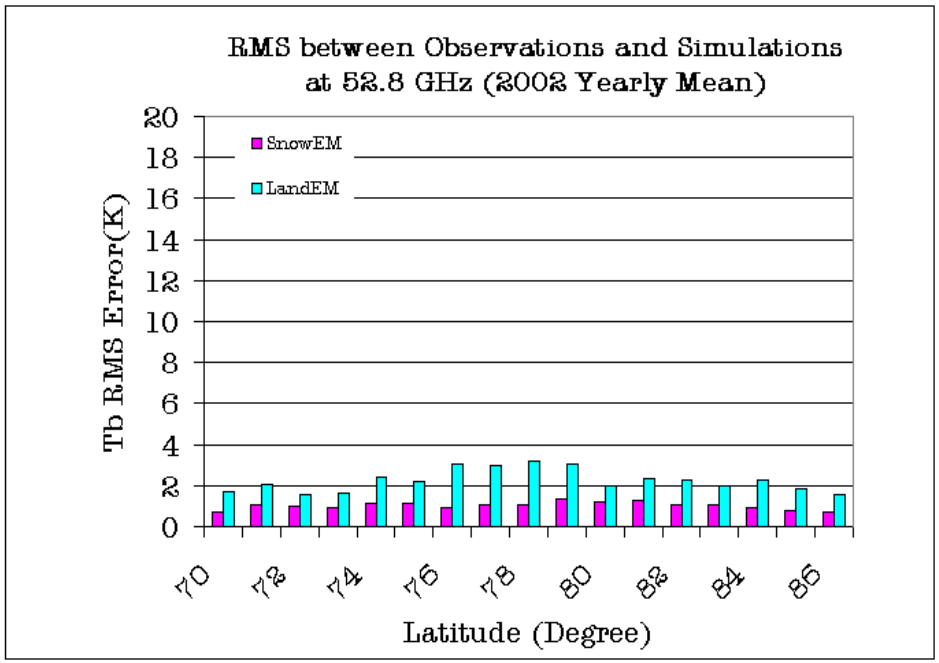
- A set of discriminators was developed using AMSU window channels and other auxiliary data
- A neural network approach was used to define the coefficients in discriminators

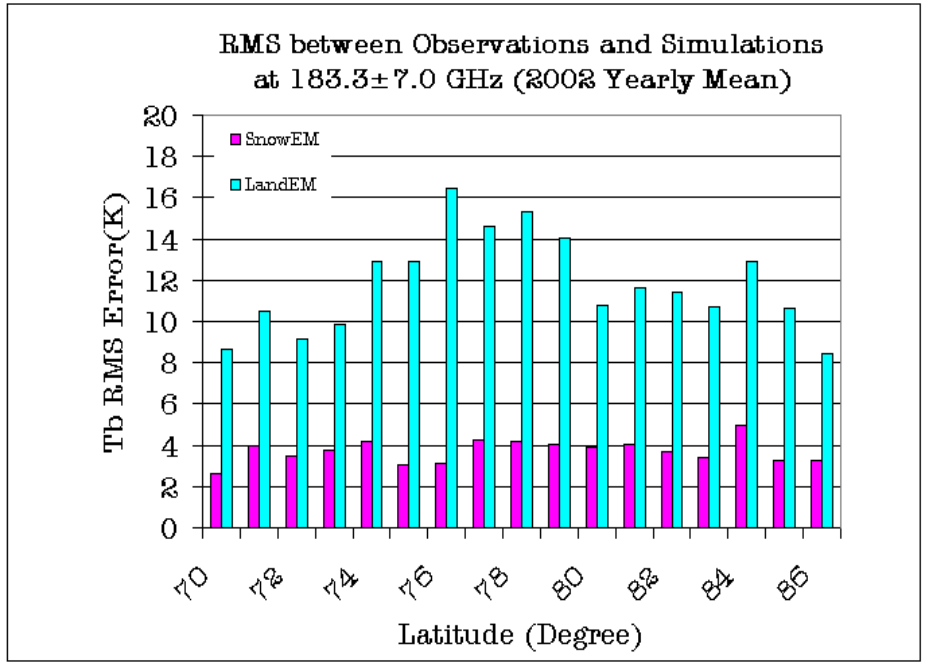
Microwave Snow Emissivity Model (SnowEM)

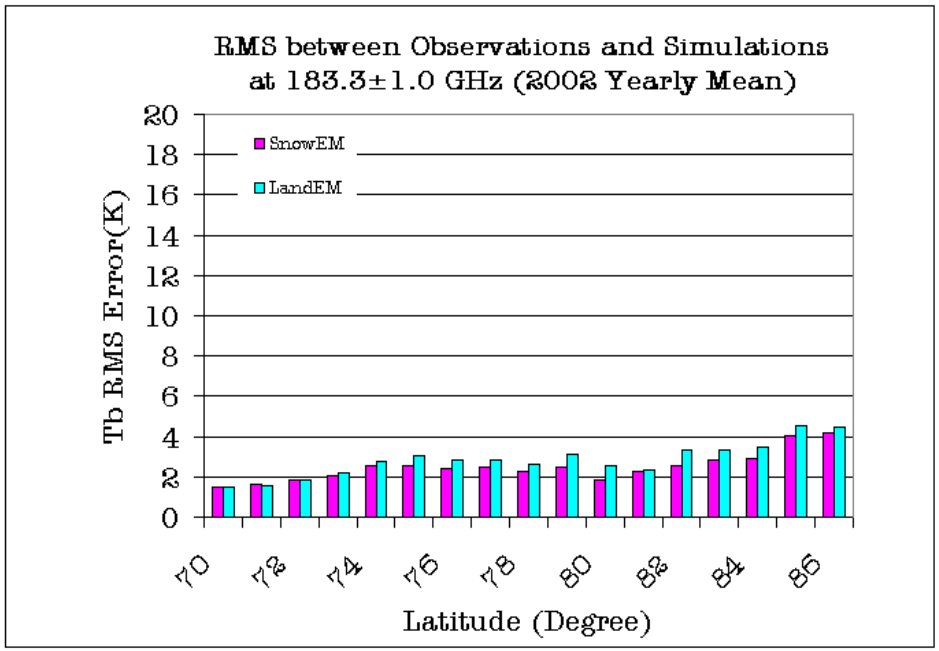


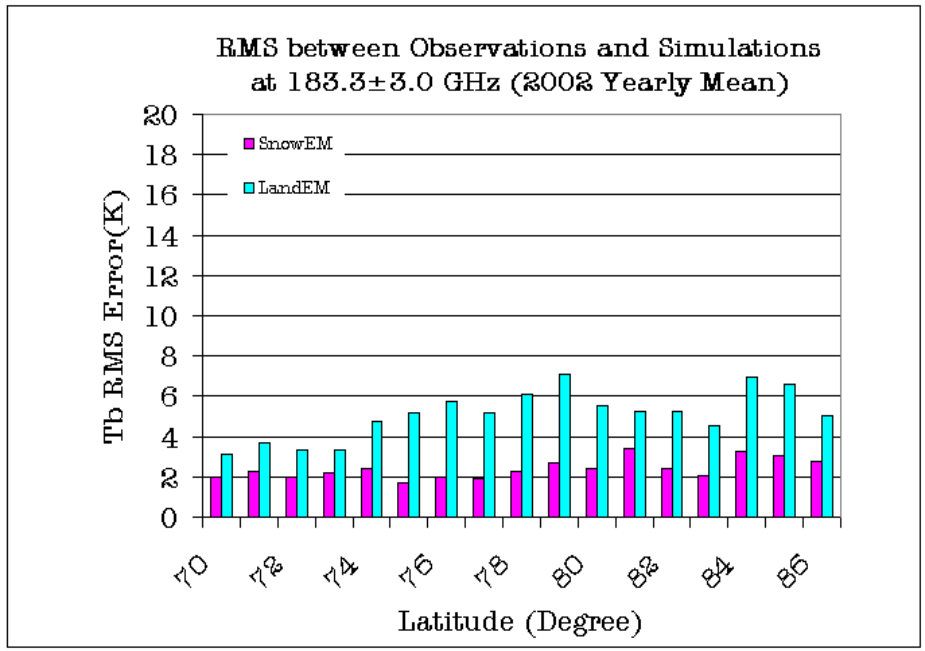
Performance of SnowEM

Option	Mean RMS Error				
	23. 8 (GHz)	31.4 (GHz)	50.3 (GHz)	89 (GHz)	150 (GHz)
AMSU-AB & Ts	0.02	0.01	0.02	0.01	0.01
AMSU-AB	0.03	0.02	0.03	0.02	0.03
AMSU-A& Ts	0.02	0.01	0.03	0.02	0.02
AMSU-A	0.03	0.02	0.03	0.02	0.03
AMSU-B & Ts	0.05	0.04	0.04	0.01	0.01
AMSU-B	0.05	0.04	0.04	0.03	0.04
LandEM	0.06	0.06	0.06	0.05	0.05


RMS between Observations and Simulations
at 52.8 GHz (2002 Yearly Mean)
SnowEM
LandEM
Tb RMS Error(K)
0
2
4
6
8
10
12
14
16
18
20
70
72
74
76
78
80
82
84
86
Latitude (Degree)


RMS between Observations and Simulations
at 183.3±7.0 GHz (2002 Yearly Mean)
SnowEM
LandEM
Tb RMS Error(K)
0
2
4
6
8
10
12
14
16
18
20
70
72
74
76
78
80
82
84
86
Latitude (Degree)


RMS between Observations and Simulations
at 183.3±1.0 GHz (2002 Yearly Mean)
SnowEM
LandEM
Tb RMS Error(K)
0
2
4
6
8
10
12
14
16
18
20
70
72
74
76
78
80
82
84
86
Latitude (Degree)

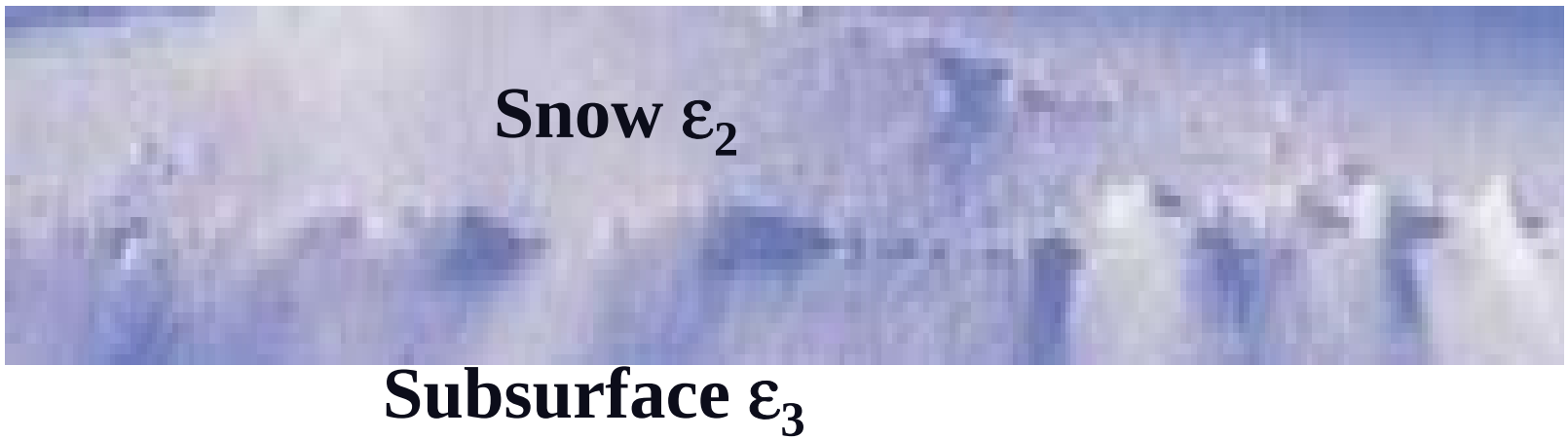

RMS between Observations and Simulations
at 183.3±3.0 GHz (2002 Yearly Mean)
SnowEM
LandEM
Tb RMS Error(K)
0
2
4
6
8
10
12
14
16
18
20
70
72
74
76
78
80
82
84
86
Latitude (Degree)

Next Step

- Extensive tests are needed in GDAS (EMC operational implementation) to understand the impacts
- Extend the current approach to polarization sounding measurements (e.g. SSMI/S, CMIS)
- Apply the current approach to derive sea ice emissivity at AMSU-A/B, ATMS, SSMIS

Backup Slides

Random Media Scattering Model



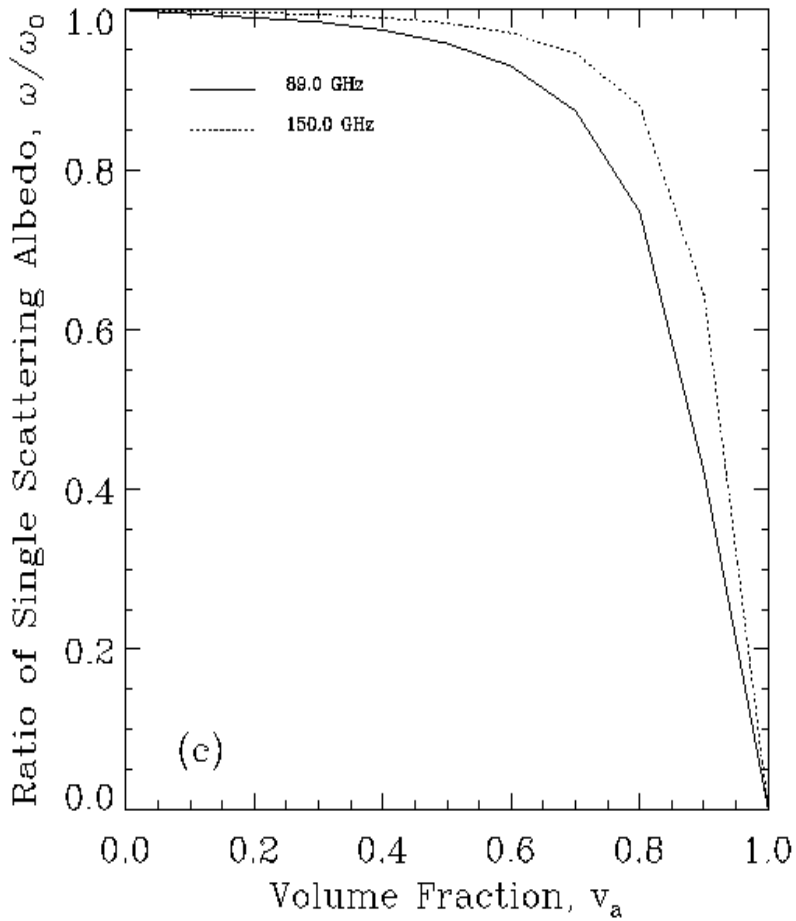
- It is a dense media with a high volume fraction of scatters
- Its permittivity varies during snow metamorphosing
- Reflection occurs at interfaces as snow melt and refrozen

Snow Scattering Properties

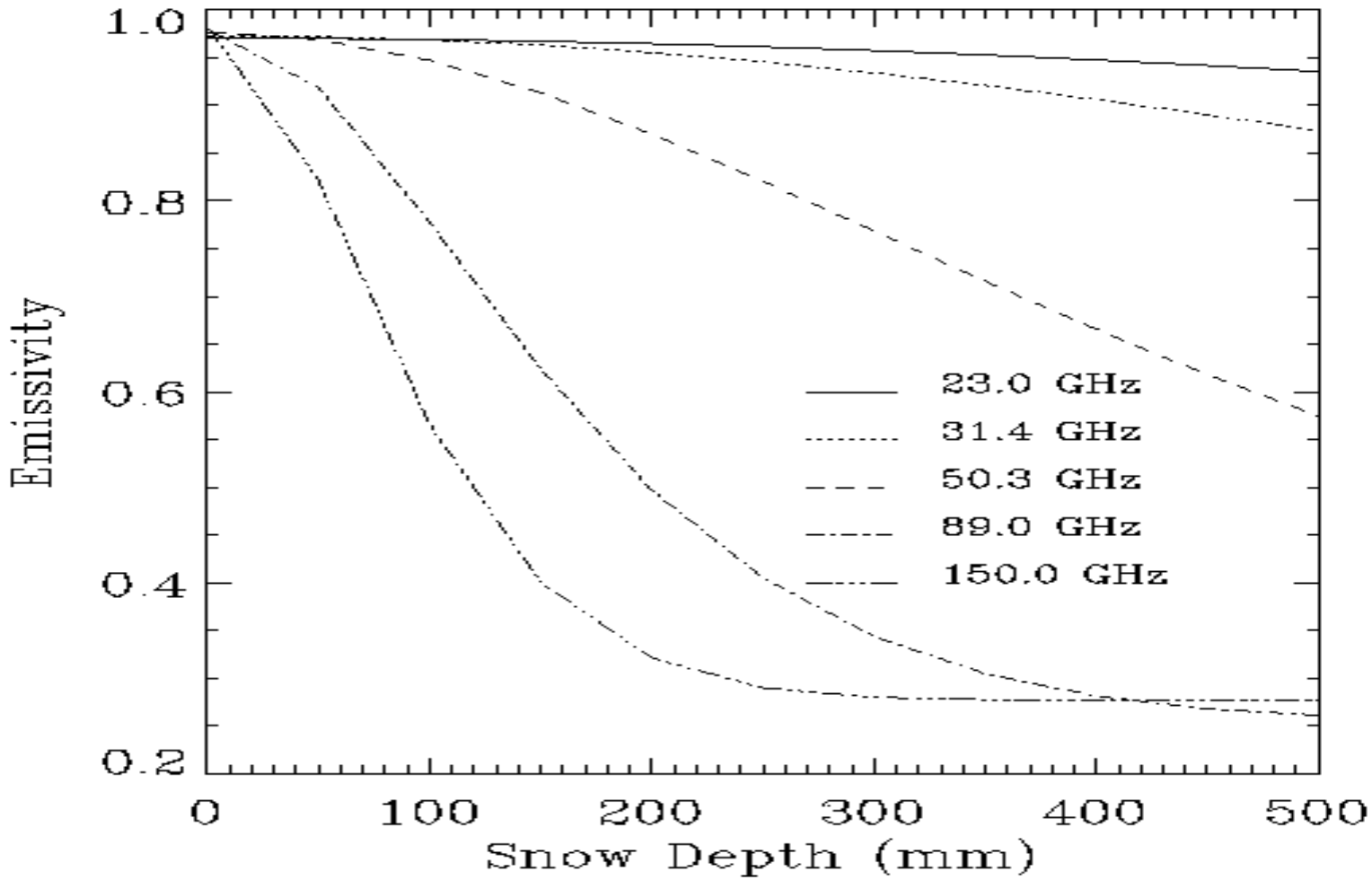
Parameters

- Snow depth
- Volume fraction
- Grain size/bulk density
- Vertical stratification

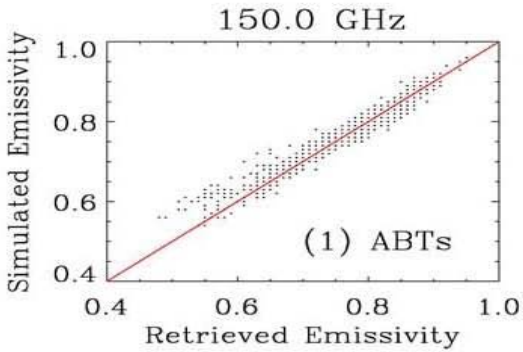
Methodology: Mie theory using an effective permittivity derived from strong fluctuation theory

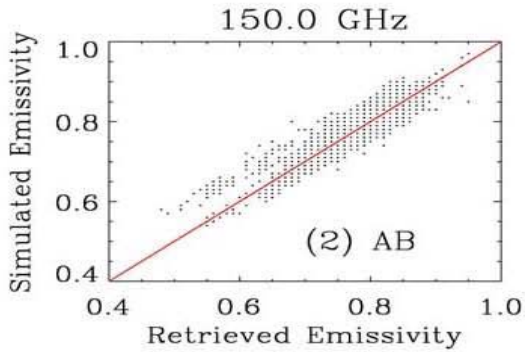


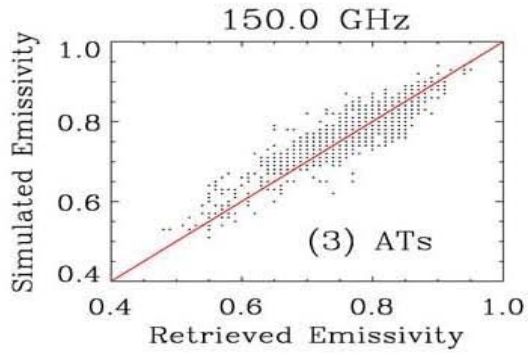
Emissivity vs. Snow Depth

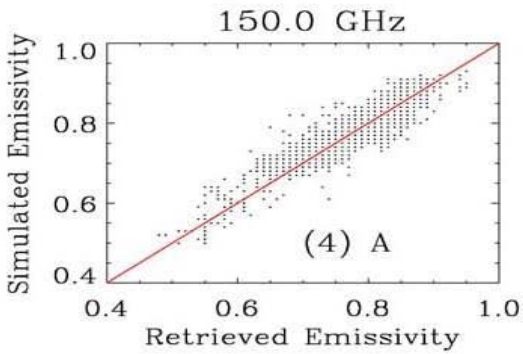


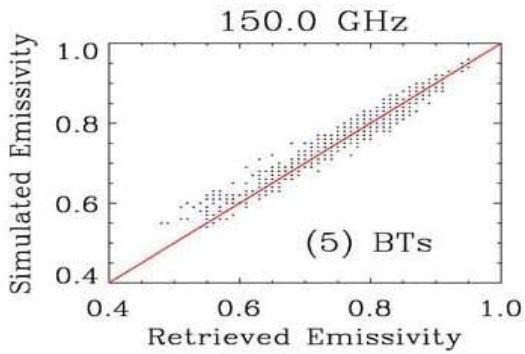
Independent Tests

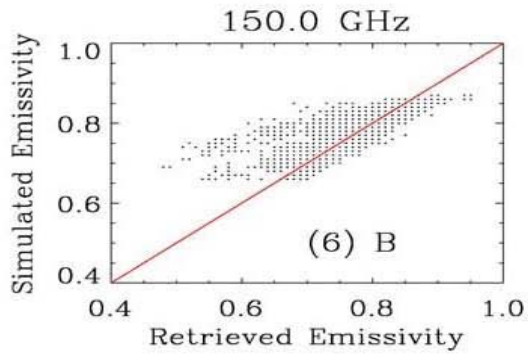


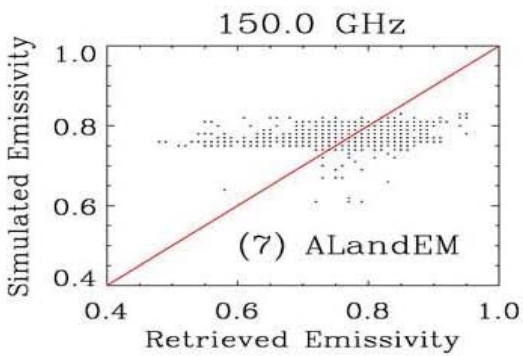




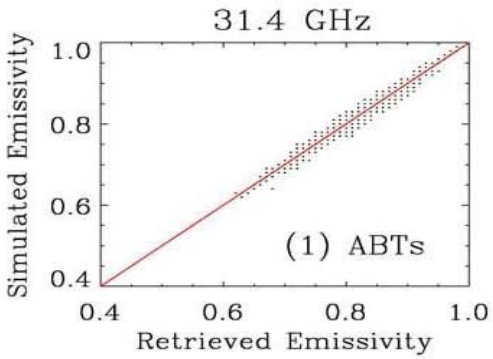


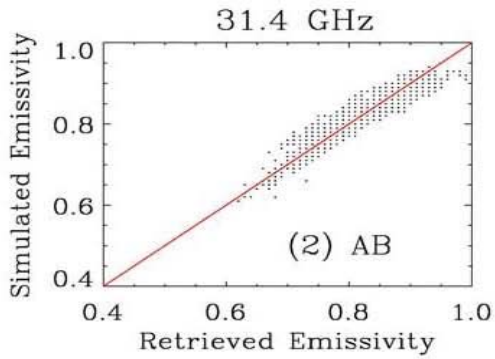


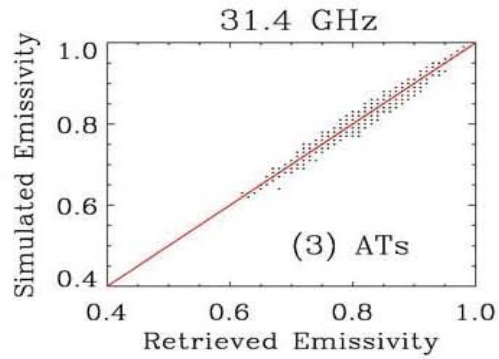


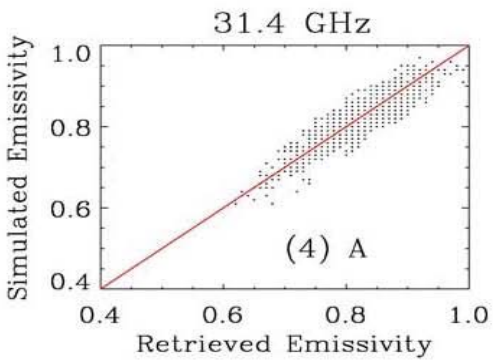


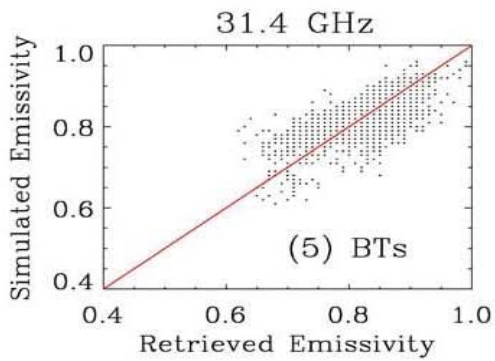
Independent Tests

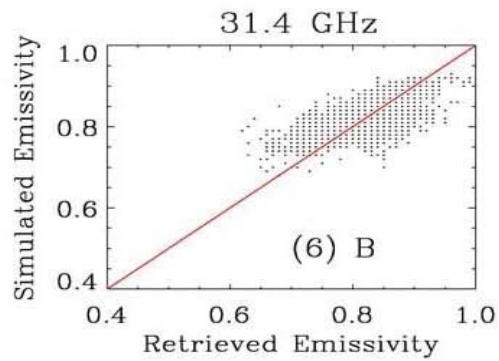


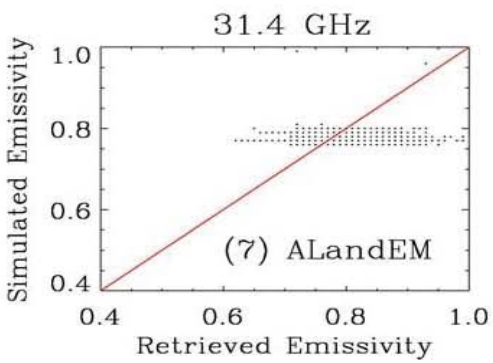




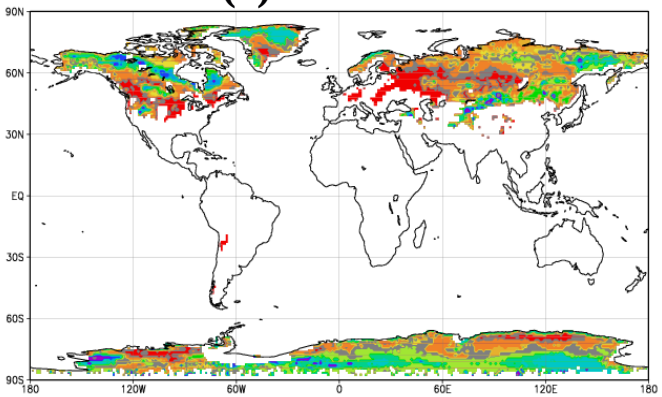




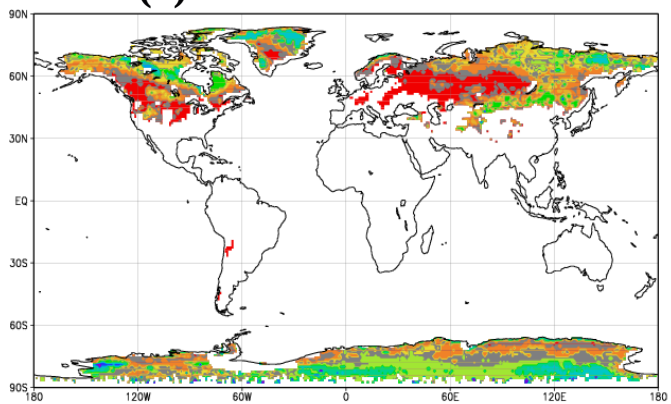




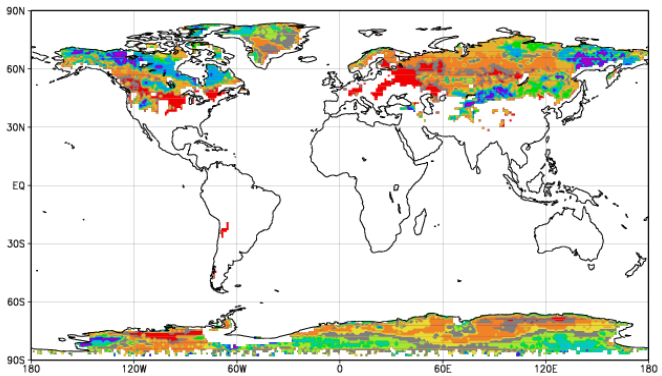
(1) AMSU-AB & Ts



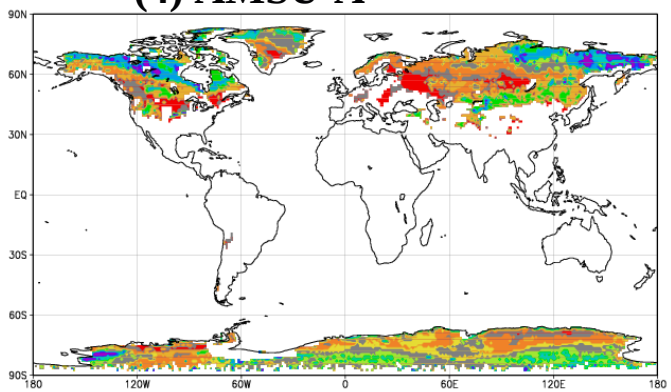
(2) AMSU-AB



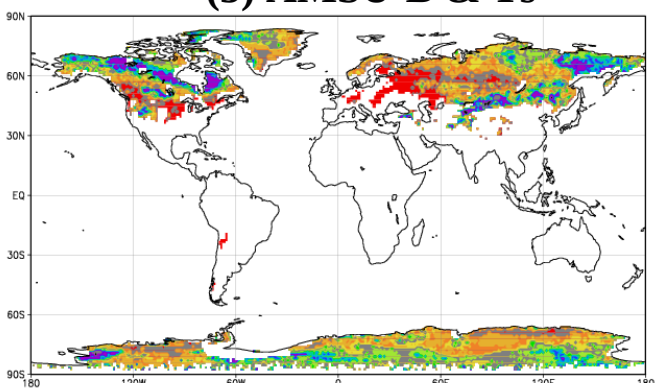
(3) AMSU-A & Ts



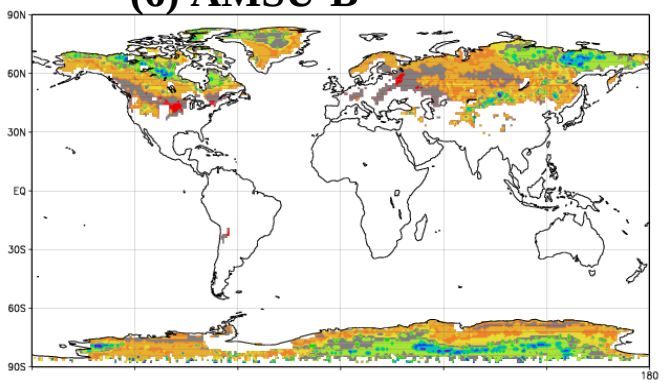
(4) AMSU-A



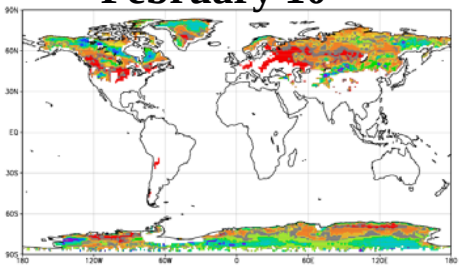
(5) AMSU-B & Ts



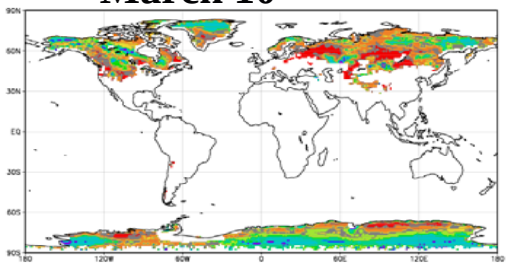
(6) AMSU-B



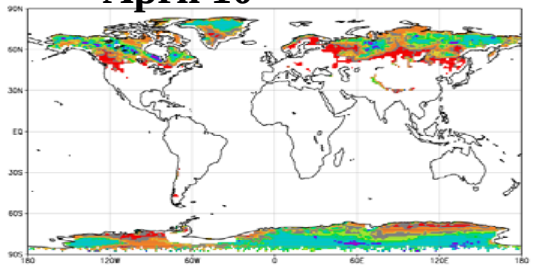
February 10



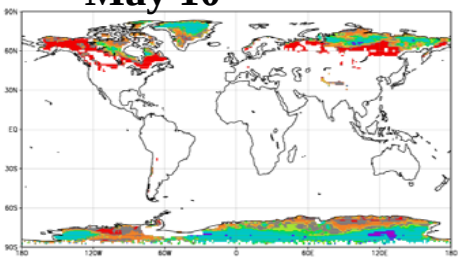
March 10



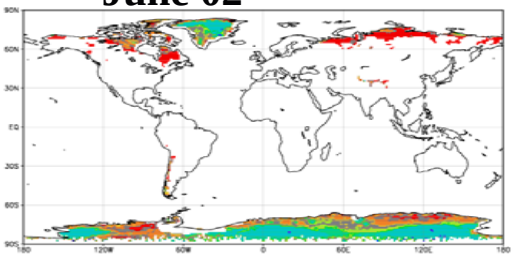
April 10



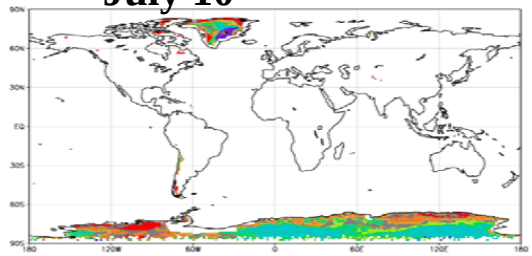
May 10



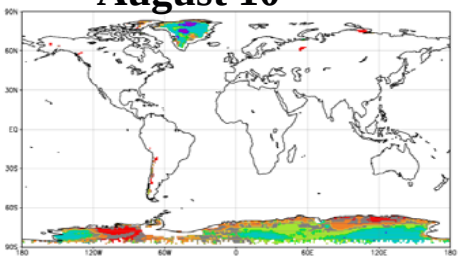
June 02



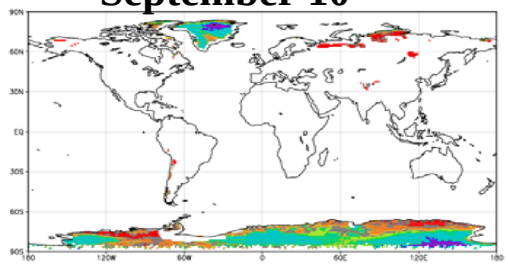
July 10



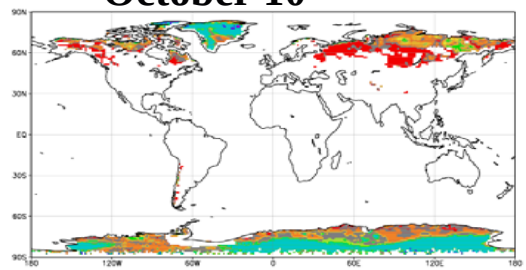
August 10



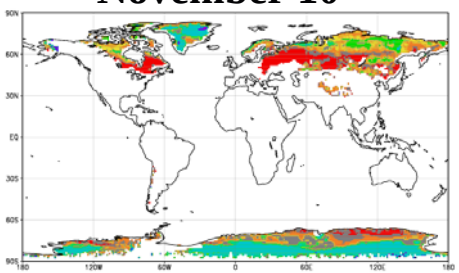
September 10



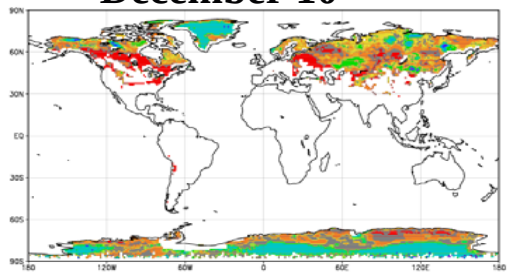
October 10



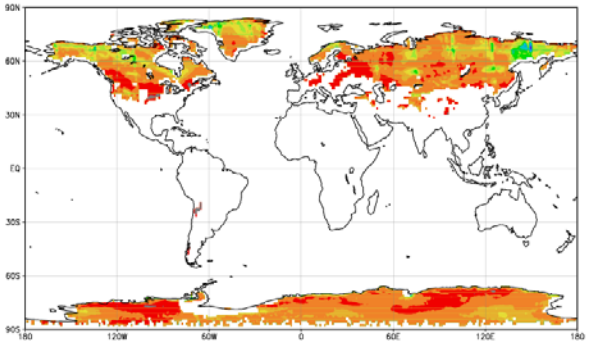
November 10



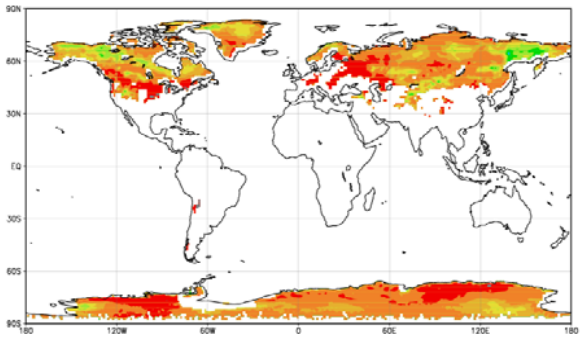
December 10



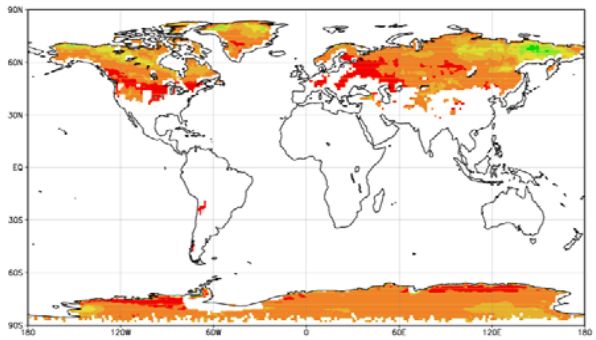
(1) Retrieved



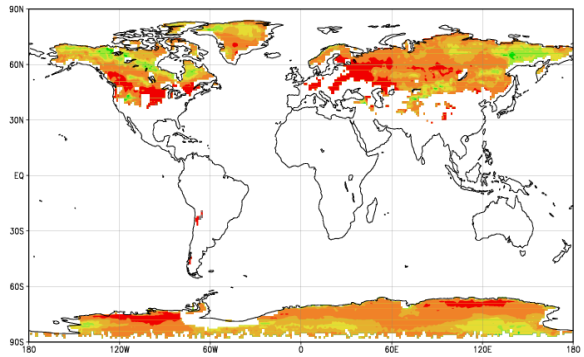
(2) AMSU-AB & Ts



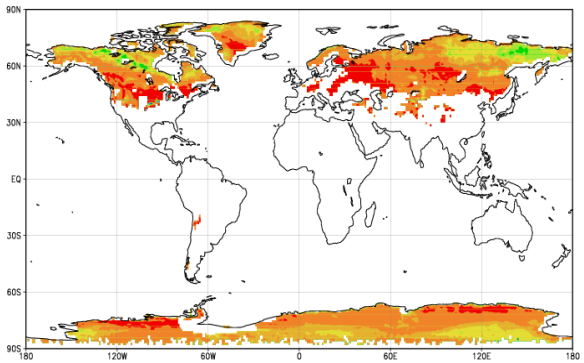
(3) AMSU-AB



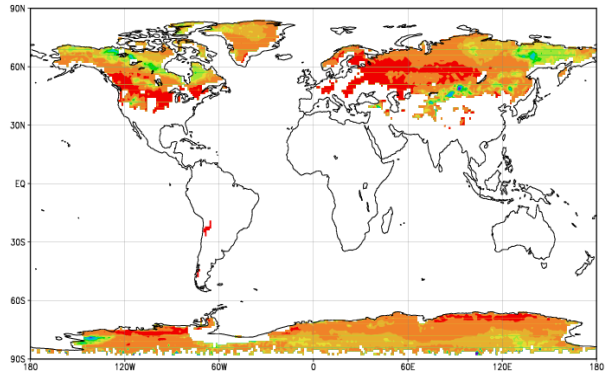
(4) AMSU-A & Ts



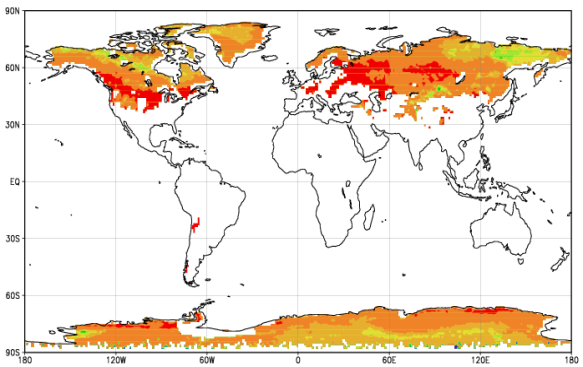
(5) AMSU-A



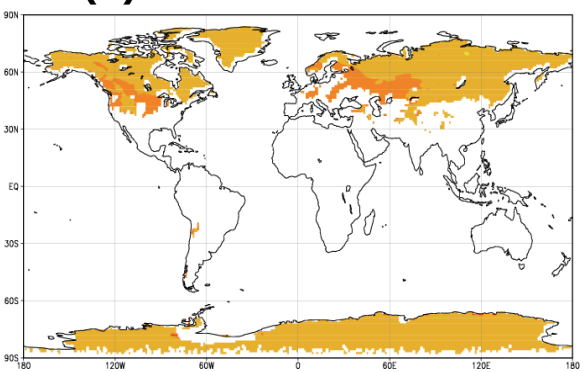
(6) AMSU-B & Ts



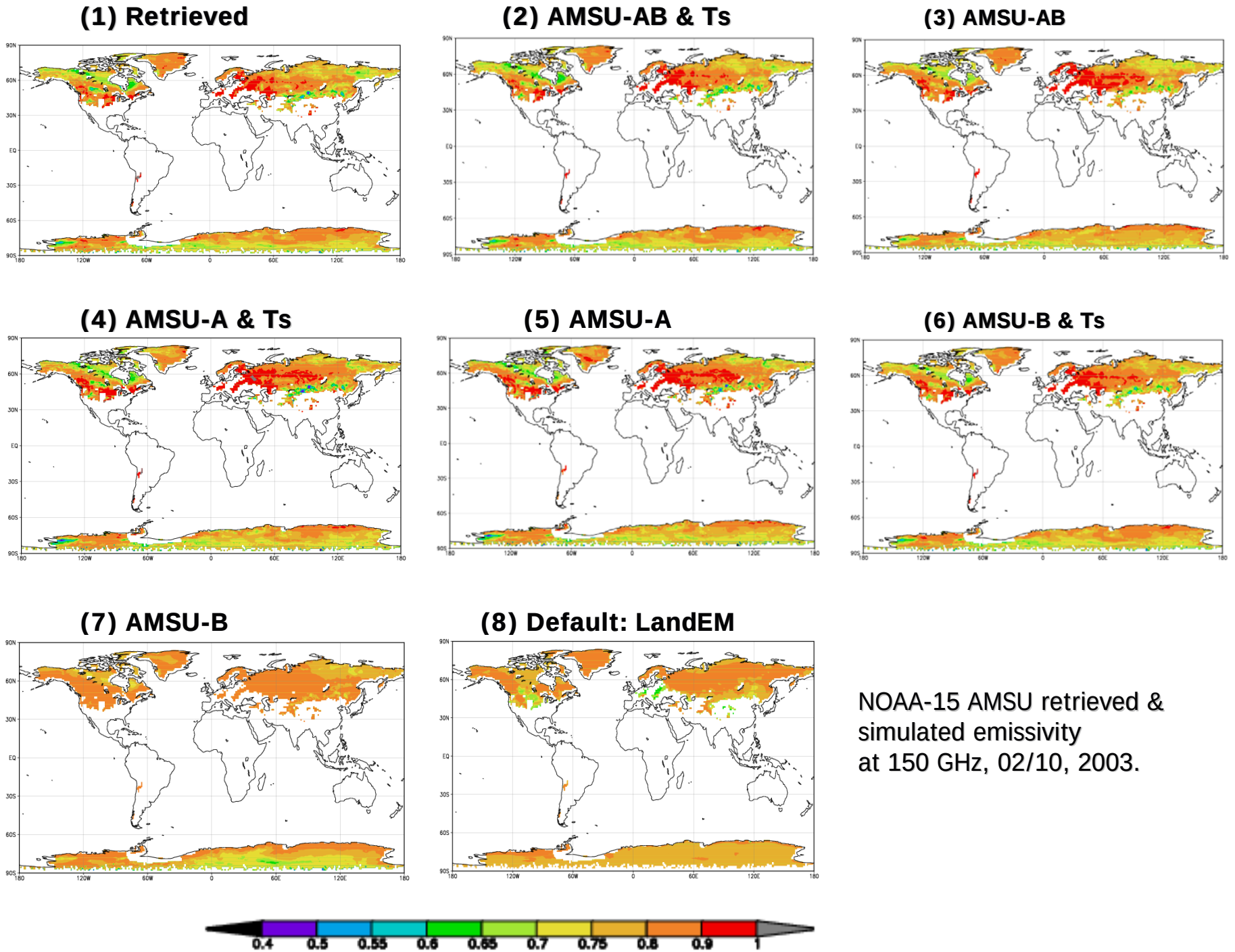
(7) AMSU-B



(8) Default: LandEM



NOAA-15 AMSU retrieved & simulated emissivity at 50.3 GHz, 02/10, 2003.



NOAA-15 AMSU retrieved & simulated emissivity at 150 GHz, 02/10, 2003.

International TOVS Study Conference, 13th, TOVS-13, Sainte Adele, Quebec, Canada, 29 October-4 November 2003. Madison, WI, University of Wisconsin-Madison, Space Science and Engineering Center, Cooperative Institute for Meteorological Satellite Studies, 2003.