Passive Microwave Remote Sensing

Lecture 14

Oct 17, 2005

Reading materials: Three papers

Principals

- While dominate wavelength of Earth is 9.7 um (**thermal**), a continuum of energy is emitted from Earth to the atmosphere. In fact, the Earth passively emits a steady stream of **microwave** energy as well, though it is relatively weak in intensity due to its long wavelength.
- The spatial resolution usually low (kms) since the weak signal.
- A suit of radiometers developed can record it. They measure the **brightness temperature** of the terrain or the atmosphere. This is much like the thermal infrared radiometer for temperature.
- A matrix of brightness temperature values can then be used to construct a passive microwave image.
- To measure soil moisture, precipitation, ice water content, sea-surface temperature, and etc.

Planck equation – frequency form

$$L_\nu = \frac{2h\nu^3}{c^2\left(e^x - 1\right)}, \text{ where } x = \frac{h\nu}{kT}$$

Slide

c	speed of light	3.00×10^8 ms^{-1}
h	Planck's constant	6.63×10^{-34}Js
k	Boltzmann's constant	1.38×10^{-23}JK^{-1}

Rayleigh-Jeans approximation

$$L_\nu = \frac{2h\nu^3}{c^2\left(e^x - 1\right)}, \text{ where } x = \frac{h\nu}{kT}$$

$$\text{Recall } e^x \approx 1 + \frac{x}{1!} + \frac{x^2}{2!} + \ldots \approx 1 + x$$

$$\text{Substitute, and } L_\nu \approx \frac{2\nu^2 kT}{c^2}$$

The really useful simplification involves emissivity and brightness temperature

$$L_\nu \approx \frac{2\nu^2 kT}{c^2}$$

$$\text{so } \frac{2\nu^2 kT_B}{c^2} = \varepsilon_\nu \frac{2\nu^2 kT}{c^2}$$

$$\text{and } T_B = \varepsilon_{\nu,P} T$$

- Emissivity varies with frequency and polarization

Jeff Dozier

Some important passive microwave radiometers

- Special Sensor Mirowave/Imager (SSM/I)
  - It was onboard the Defense Meterorological Satellite Program (DMSP) since 1987
  - It measure the microwave brightness temperatures of atmosphere, ocean, and terrain at 19.35, 22.23, 37, and 85.5 GHz.
- TRMM microwave imager (TMI)
  - It is based on SSM/I, and added one more frequency of 10.7 GHz.

EOS Aqua satellite

- Six instruments, 3 in microwave
- AIRS
- CERES
- AMSR-E, Advanced Microwave Scanning Radiometer for EOS
  - AMSR also flies on ADEOS-II (Japanese)
- AMSU, Advanced Microwave Sounding Unit
- HSB, Humidity Sounder for Brazil
- MODIS

AMSR-E

- Advanced Microwave Scanning Radiometer – EOS
- It observes atmospheric, land, oceanic, and cryospheric parameters, including precipitation, sea surface temperatures, ice concentrations, snow water equivalent, surface wetness, wind speed, atmospheric cloud water, and water vapor.
- At the AMSR-E low-frequency channels, the atmosphere is relatively transparent, and the polarization and spectral characteristics of the received microwave radiation are dominated by emission and scattering at the Earth surface.
- Over land, the emission and scattering depend primarily on the water content of the soil, the surface roughness and topography, the surface temperature, and the vegetation cover.
- The surface brightness T (T_B) tend to increase with frequency due to the absorptive effects of water in soil and vegetation that also increase with frequency. However, as the frequency increase, scattering effects from the surface and vegetation also increase, acting as a factor to reduce the T_B

AMSR-E

AMSR-E Nominal Instrument Characteristics

Center frequency (GHz)	6.925	10.65	18.7	23.8	36.5	89.0
Bandwidth (MHz)	350	100	200	400	1000	3000
Sensitivity (K)	0.3	0.6	0.6	0.6	0.6	1.1
3-dB footprint (km)	75 x 43	51 x 29	27 x 16	32 x 18	14 x 8	6 x 4
Sample spacing (km)	10 x 10	10 x 10	10 x 10	10 x 10	10 x 10	5 x 5
Integration time (ms)	2.5	2.5	2.5	2.5	2.5	1.2
Main-beam efficiency (%)	95.1	94.8	95.8	94.8	93.9	94.0
Beamwidth (deg)	2.2	1.5	0.8	0.92	0.42	0.19
Antenna diameter (m)	1.6					
Scan period (s)	1.5					
Antenna offset angle (deg)	47.5					
Earth-incidence angle (deg)	55					
Orbit altitude (km)	705					
Swath width (km)	1445					
Orbit type	Sun-synchronous, 1:30 pm equator crossing					
Orbit period (min)	98.8					
Sub-spacecraft velocity (km s^{-1})	6.76					

Najoku et al. 2005

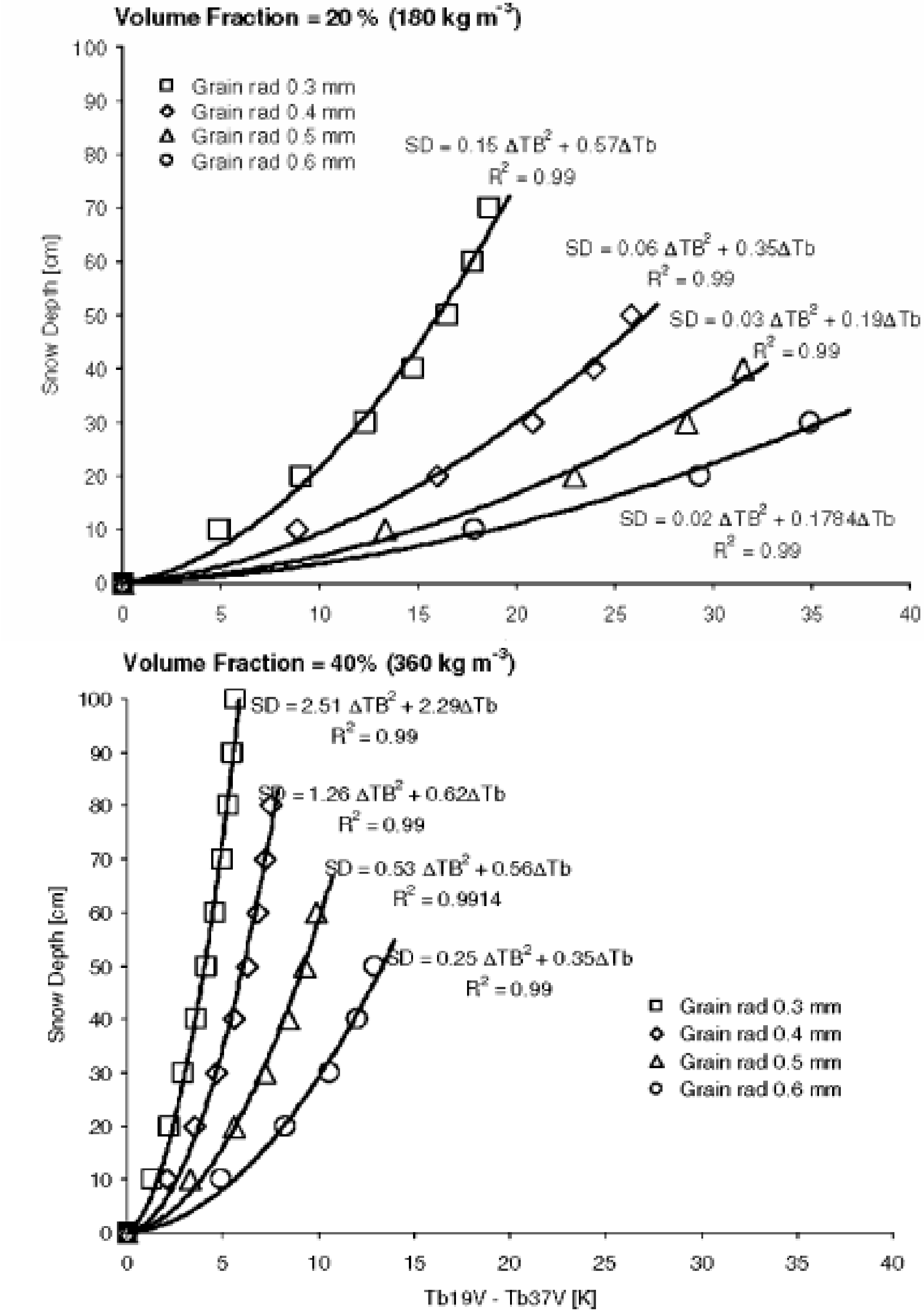
Example1: Snow depth or snow water equivalent (SWE)

- The microwave brightness temperature emitted from a snow cover is related to the snow mass which can be represented by the combined snow density and depth, or the SWE (a hydrological quantity that is obtained from the product of snow depth and density).

$$\mathrm{SD} = b(\Delta \mathrm{Tb})^2 + c(\Delta \mathrm{Tb}) \ [\mathrm{cm}] \qquad (6)$$

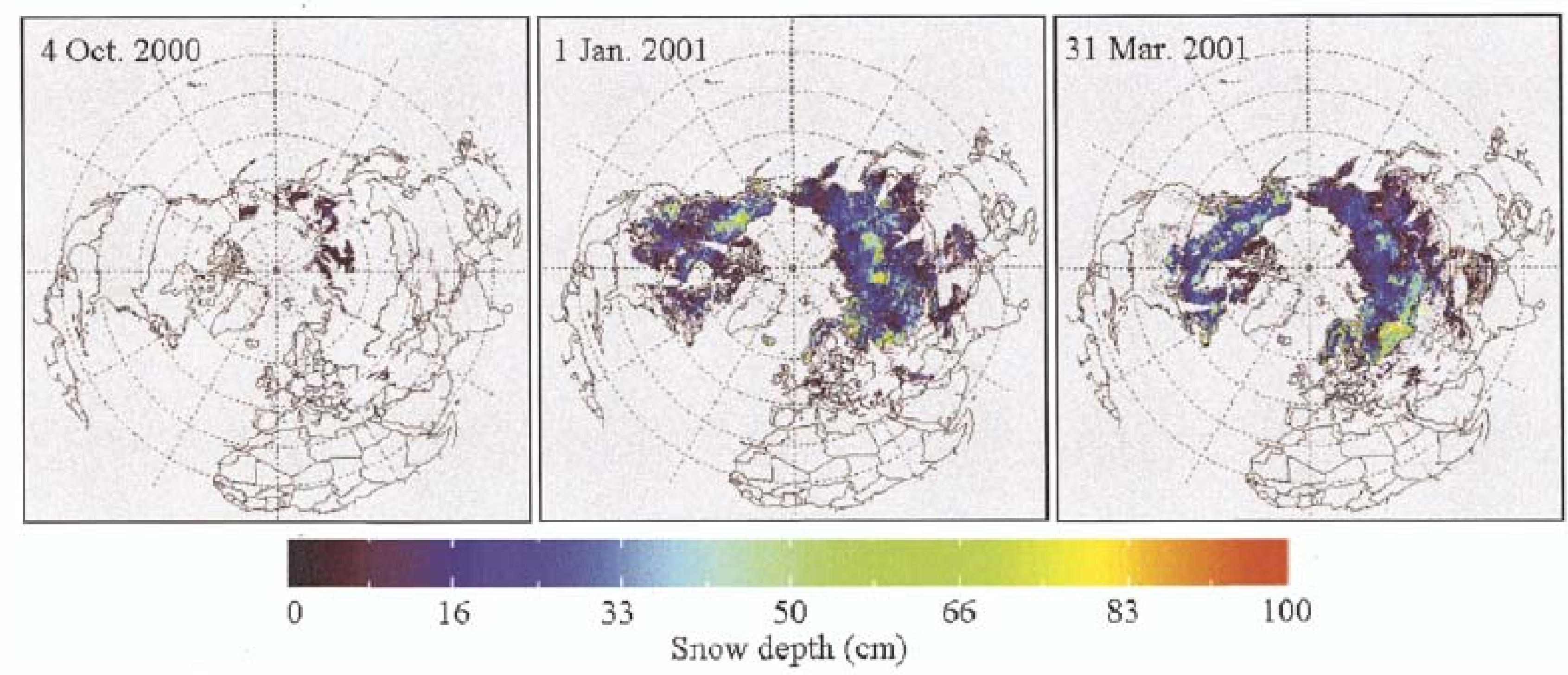
where b and c are coefficients empirically related to the grain size and the volume fraction thus

ΔTb = Tb19V-Tb37V



Kelly et al. 2003

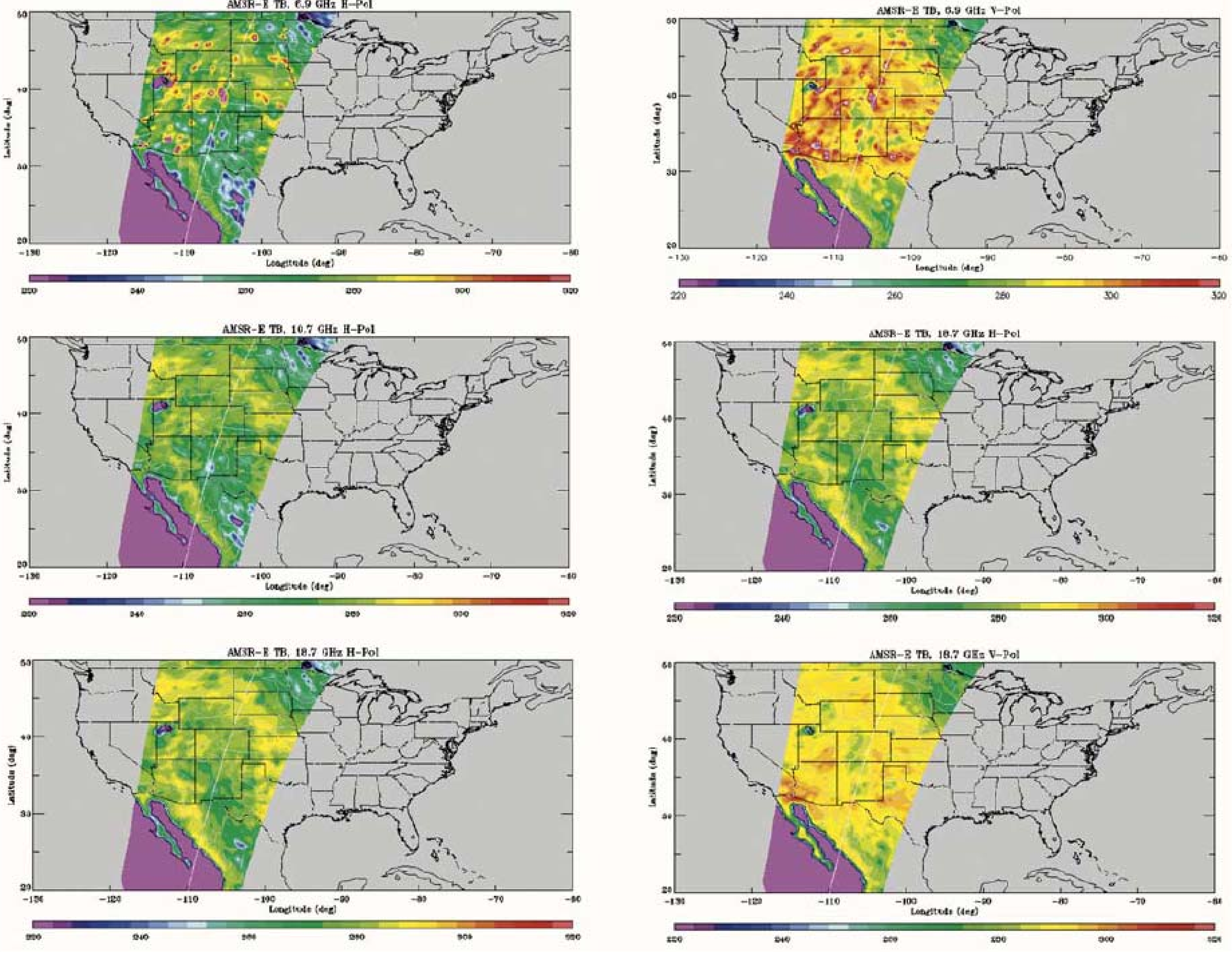
Arctic Snow Depth Change



Kelly et al. 2003

Example2: Radio-frequency interference contaminate the 6.9 and 10.7 GHz channels

- Radio-frequency interference (RFI): the cable television relay, auxiliary broadcasting, mobile. RFI is several orders of magnitude higher than natural thermal emissions and is often directional and can be either continuous or intermittent.
- Radio-frequency interference (RFI) is an increasingly serious problem for passive and active microwave sensing of the Earth.
- The 6.9 GHz contamination is mostly in USA, Japan, and the Middle East.
- The 10.7 GHz contamination is mostly in England, Italy, and Japan
- RFI contamination compromise the science objectives of sensors that use 6.9 and 10.7 GHz (corresponding to the C-band and X-band in active microwave sensing) over land.

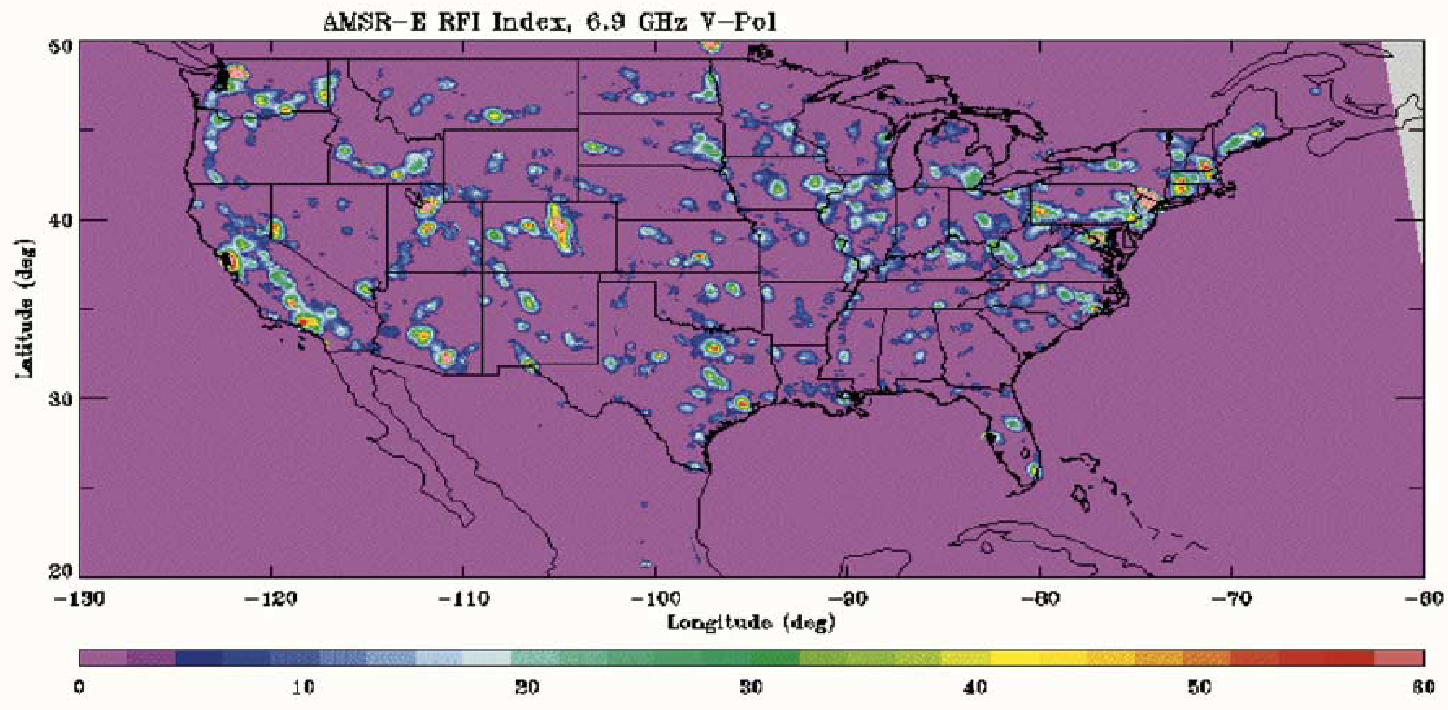


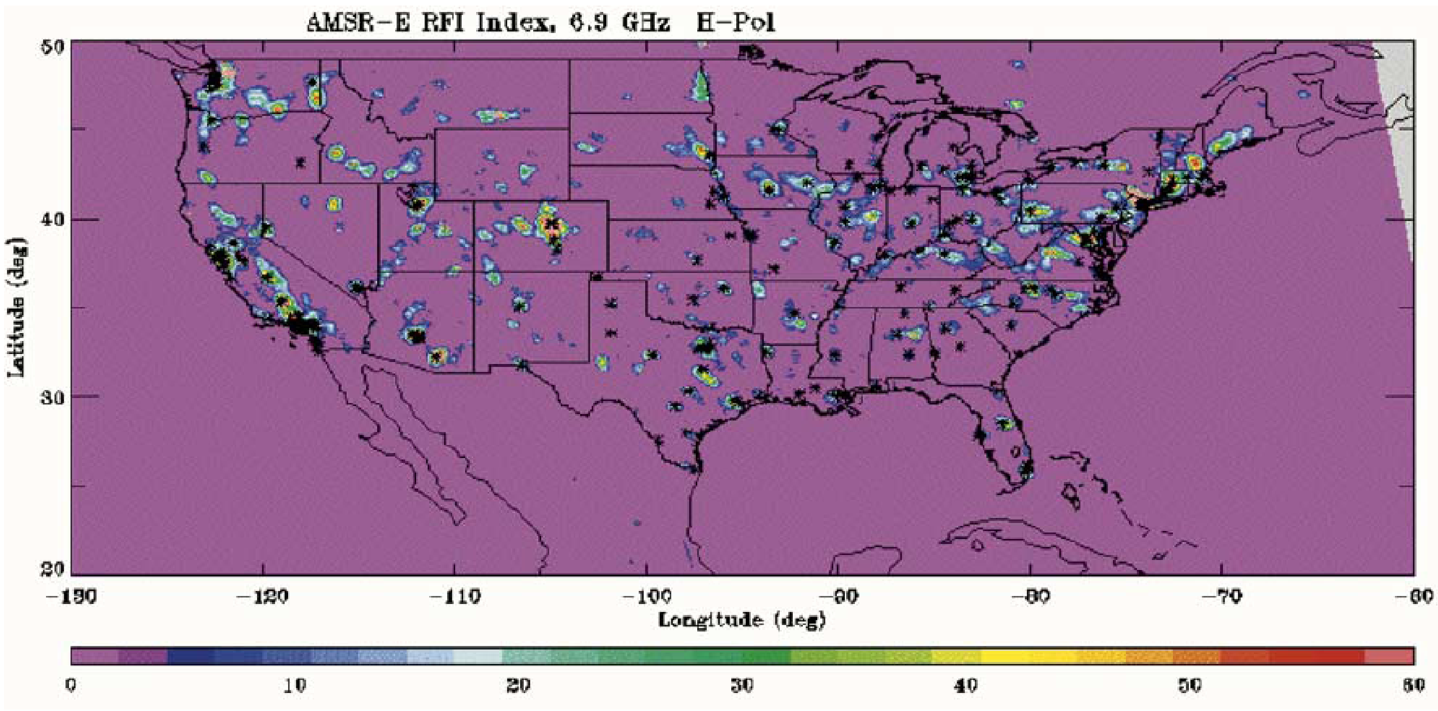
AMSR-E TB, 6.9 GHz H-Pol
AMSR-E TB, 6.9 GHz V-Pol
AMSR-E TB, 10.7 GHz H-Pol
AMSR-E TB, 10.7 GHz H-Pol
AMSR-E TB, 18.7 GHz H-Pol
AMSR-E TB, 18.7 GHz V-Pol
Latitude (deg)
Longitude (deg)
220
240
260
280
300
320

radio-frequency interference (RFI) index (RI)

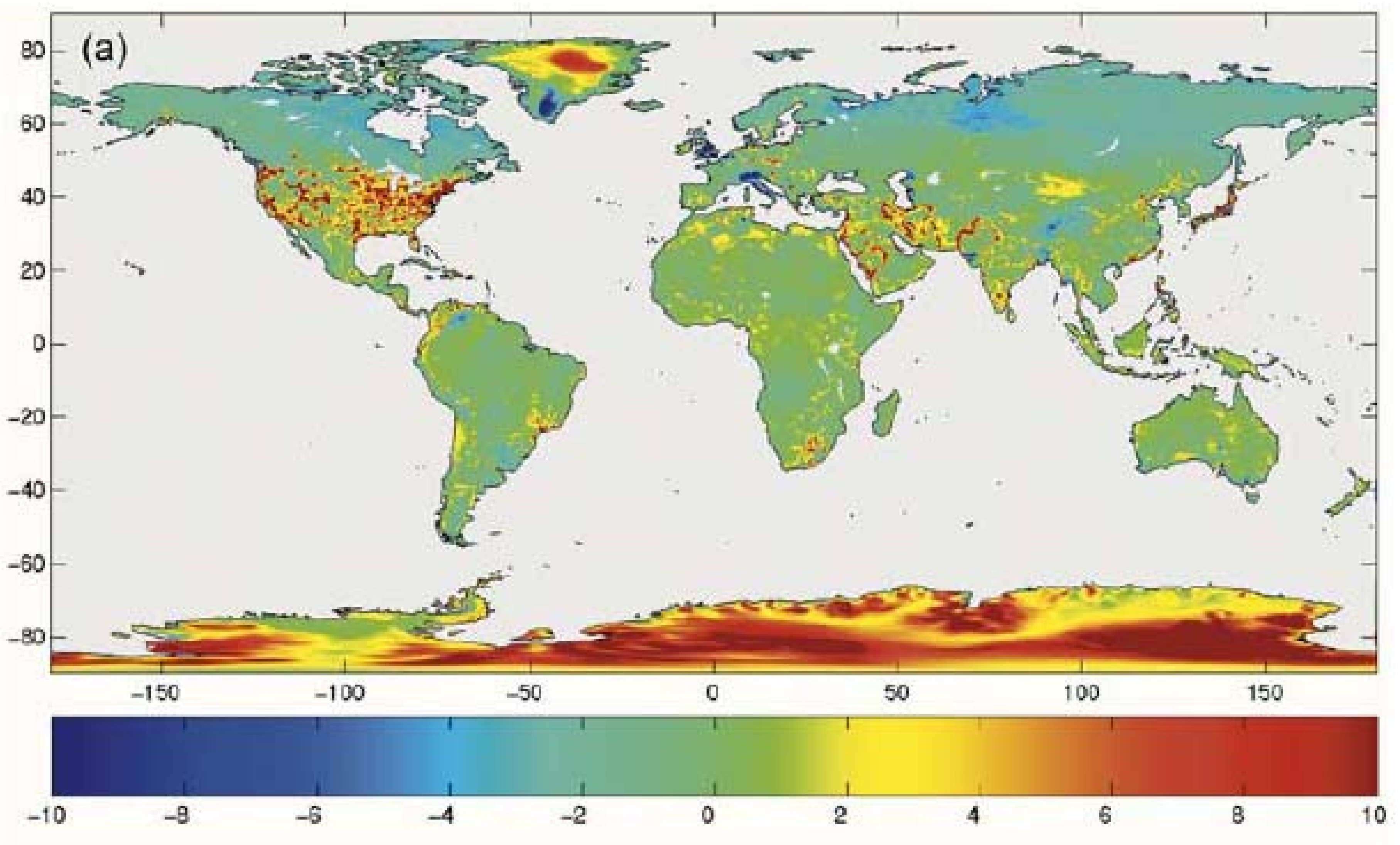
$$\mathrm{RI7p} = \mathrm{TB7p} - \mathrm{TB10p}. \tag{1}$$

This RI can be used not only to identify the location of RFI but also to quantify its intensity. The larger the RI, the stronger the RFI. Note that a slightly negative RI does not necessarily suggest that the region is RFI-free, since the RFI-free TB10p is often intrinsically higher than the RFI-free TB7p (i.e., negative gradient). Weak RFI could thus increase RI slightly, but not enough to make it positive.


AMSR-E RFI Index, 6.9 GHz V-Pol
Latitude (deg)
Longitude (deg)
50
40
30
20
-130
-120
-110
-100
-90
-80
-70
-60
0
10
20
30
40
50
60


AMSR-E RFI Index, 6.9 GHz H-Pol
Latitude (deg)
Longitude (deg)
50
40
30
20
-130
-120
-110
-100
-90
-80
-70
-60
0
10
20
30
40
50
60

Li et al. 2004



6.9 GHz contamination

$$RI_{6V} = TB_{6V} - TB_{10V}$$

Najoku et al. 2005

Advantages of passive microwave remote sensing

- Sees through clouds at lower frequencies
- Emissivity sensitive to state of surface, particularly moisture
  - Soil moisture
  - Snow-water equivalence
- But, because of small amount of energy emitted, pixel size must be large