INTERFERENCE MITIGATION IN PASSIVE MICROWAVE RADIOMETRY

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Background

- The radio spectrum is a limited natural resource with multiple applications. It is currently in relentlessly increasing demand.
- Radio regulations established by the International Telecommunications Union (ITU) govern the use of the spectrum for a wide range of passive and active uses:

  Telecommunications (mobile, fixed, satellite, broadcast, point-to-point), passive remote sensing, radioastronomy, radar (weather, tracking), telemetry, research, …

- Both existing applications and new applications often have high economic & social value, but also often overlap bands that are invaluable for passive microwave radiometry. The passive applications include weather & climate monitoring from satellites, aircraft, ships, and ground sites.

Soil Moisture Sensing

- The effective microwave dielectric constant of bare soil is modified by its volumetric moisture content (VSM) within the top ~0.5-3 cm:

  <5% ➔ very dry ~40% ➔ saturated

  A signature of ~140K is available for 5-40% VSM change at L-band (1400-1427 MHz).

- C- or X-band systems (~6-10 GHz) are more practical from an antenna size standpoint, but exhibit greater sensitivity to vegetation cover & surface roughness. Nonetheless, C-band sensitivity to surface soil moisture is ~1/2 that available from L-band, viz:

  5-40% VSM ➔ ~60K change at 6.9 GHz H-pol

- AMSR-E on the EOS Aqua spacecraft (May 2002) has a conically-scanned 6.925 GHz channel (V&H) with 75 x 43 km footprint. NPOESS CMIS will also, but of slightly differing footprint size.

…Background (cont'd)

However:

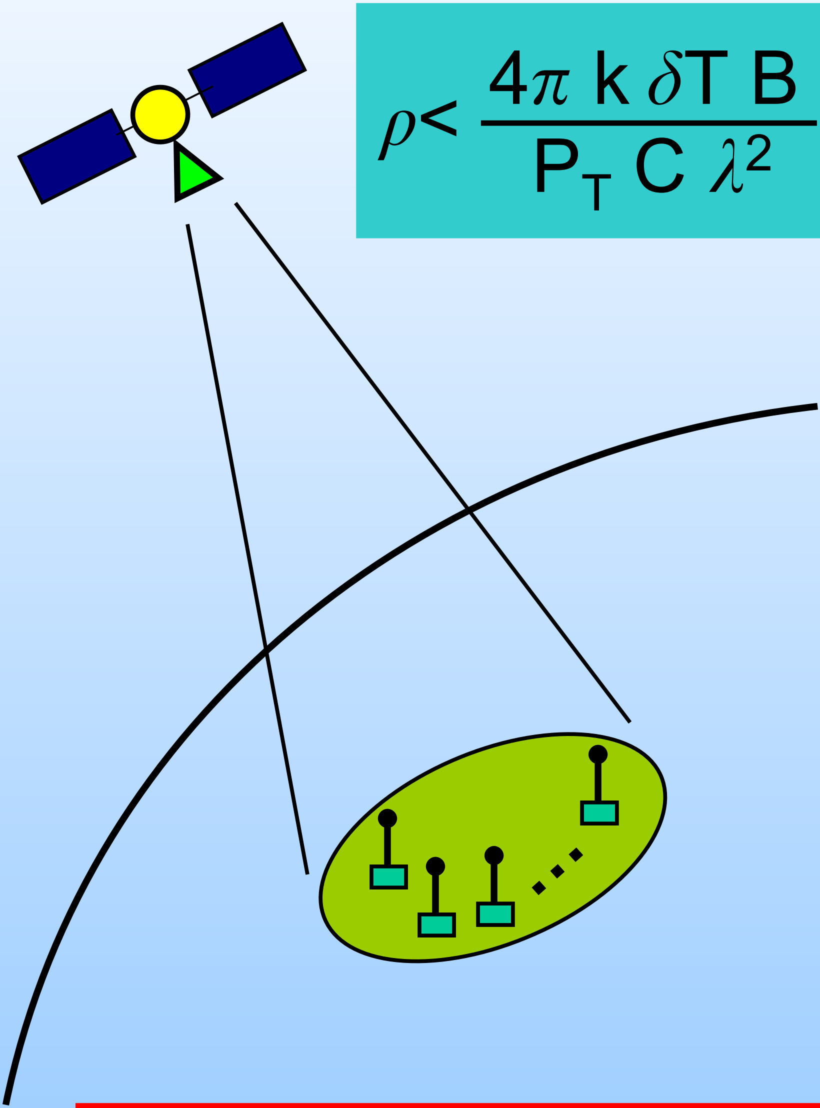
- Anthropogenic emission in key microwave bands (L, C, X, Ku, Ka) increasingly threatens the ability to conduct environmental remote sensing for either research or operations.
- Only small amounts of interfering power are necessary to corrupt environmental data. Worst case is for interference power levels that are indistinguishable from thermal emission, i.e.,

$$\delta P_{INT} \sim k\delta TB \quad \text{with} \quad \sim 0.1 < T < \sim 10\ K$$

- Persistent undetected interference can be expected to have adverse impacts on microwave radiometer-based climate records, weather forecasts, and nowcast products.
- International band allocations are critical, but even primary allocations can't guarantee long-term immunity.

C-Band Interference Example

$$\rho < \frac{4\pi\, k\, \delta T\, B}{P_T\, C\, \lambda^2}$$



ρ = Density of interfering transmitters (m^{-2})
δT = Interference threshold (K)
B = Detection bandwidth (Hz)
λ = Wavelength (m)
P_T = Power transmitted per interferer (W)
k = Boltzmann's constant (1.38E-23 J/K)
C = Antenna coupling factor

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

P_T = 100 mW (20 dBm)
δT = 1 K
B = 200 MHz
λ = 4.3 cm (6.9 GHz)
C = 1 (main-main lobe coupling)

➔ **ρ < 1.9E-4 (km^{-2})**
Or, an average transmitter separation distance of **~73 km** is required for non-interference.

Essential Interference Mitigation Techniques

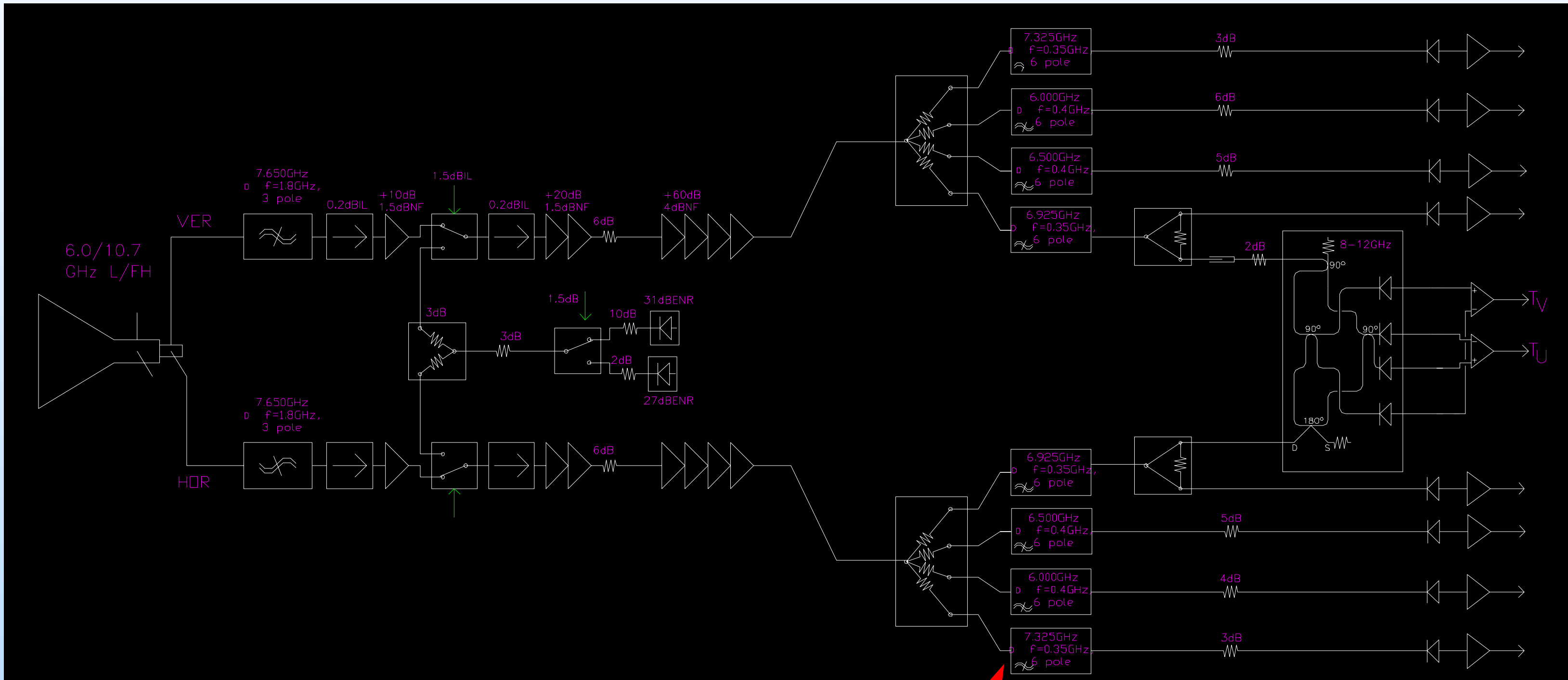
1) **Subband diversity** – Anthropogenic interference often narrowband (~a few to hundreds of MHz) WRT radiometric bands.

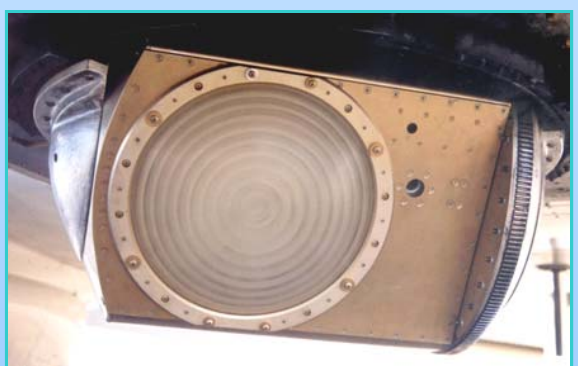
2) **Polarization diversity** – Geophysical v-h difference often predictable to within a few K, while v-h interference deviations are often larger.

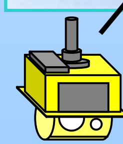
3) **Polarimetric detection** – Anthropogenic interference is often highly polarized in 3rd or 4th Stokes parameter while most natural surfaces are either predictably polarized or mostly unpolarized.

4) **Azimuthal diversity** – Many natural surfaces are predictably isotropic whereas interference is highly isotropic (applicable to conical scanning).

PSR/C 4-Subband Radiometer Hardware for SGP99*







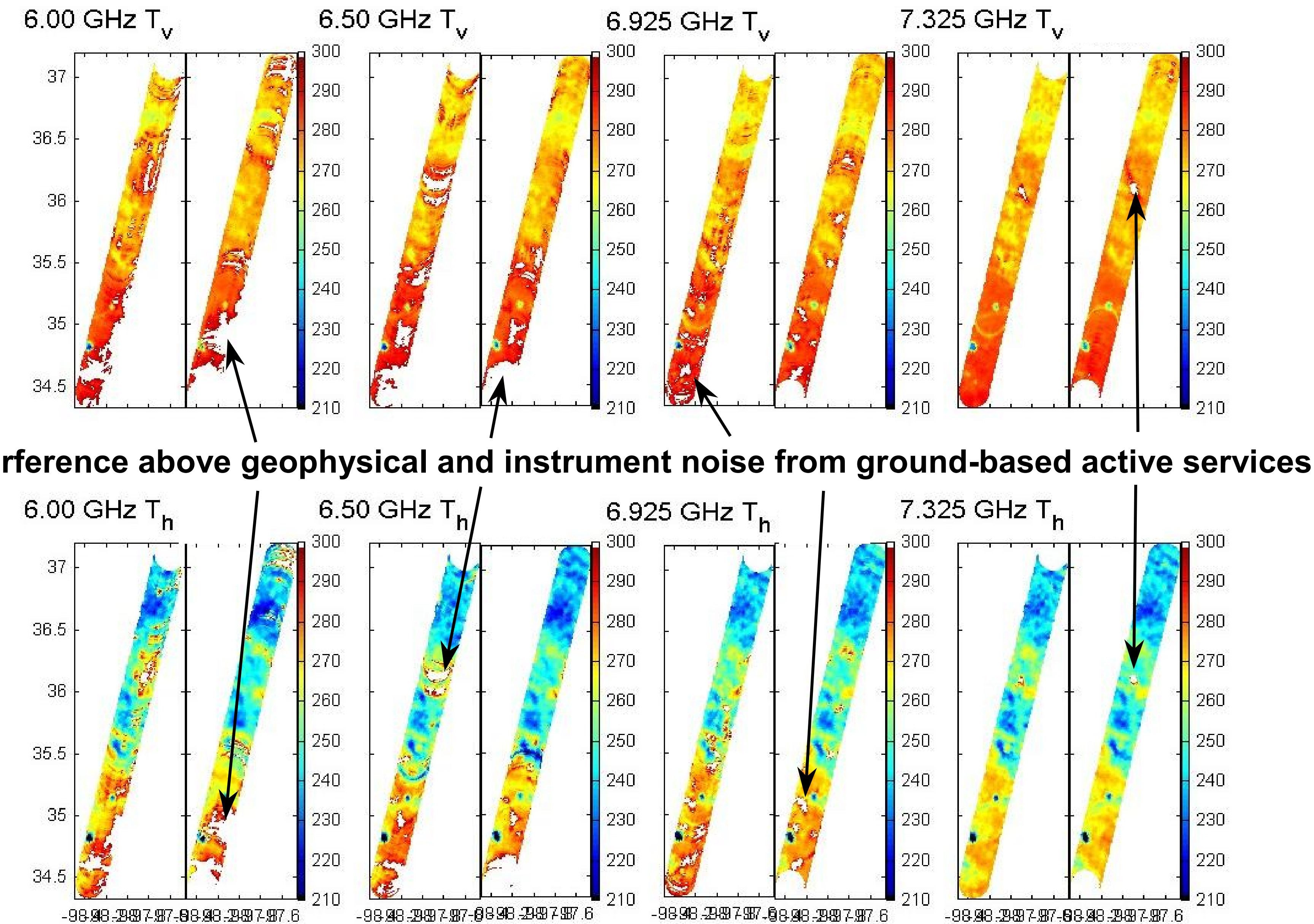
Subbands (GHz):

5.80-6.20 (v,h)
6.30-6.70 (v,h)
6.75-7.10 (v,h,U,V)
7.15-7.50 (v,h)

*** Southern Great Plains Experiment June-July, 1999 over Oklahoma**

Calibrated (uncorrected) Imagery

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



Basic Spectral Algorithm

1) Perform linear spectral fit (M=2 DOF) for N spectral subbands.

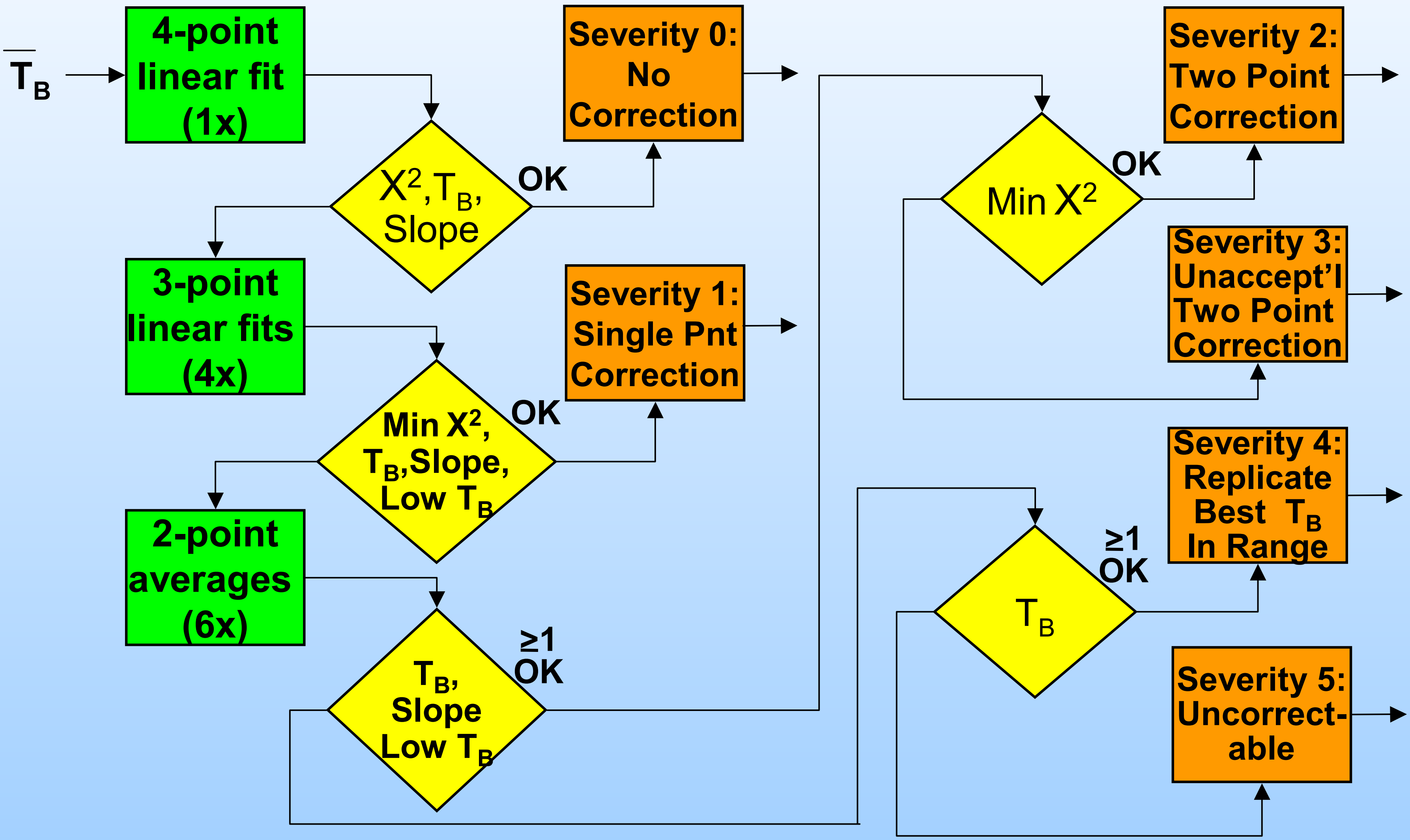
2) Check for $\chi^2 < N-M$, M=2 (“good” fit).

3) If not “good”, perform linear fits using all permutations of N-1 subbands, then check all χ^2 values. Select N-1 subbands with smallest χ^2. Replace missing subband with fit.

4) Repeat above until either “good” fit obtained or N=2. If N=2 use average across two remaining spectral subbands.

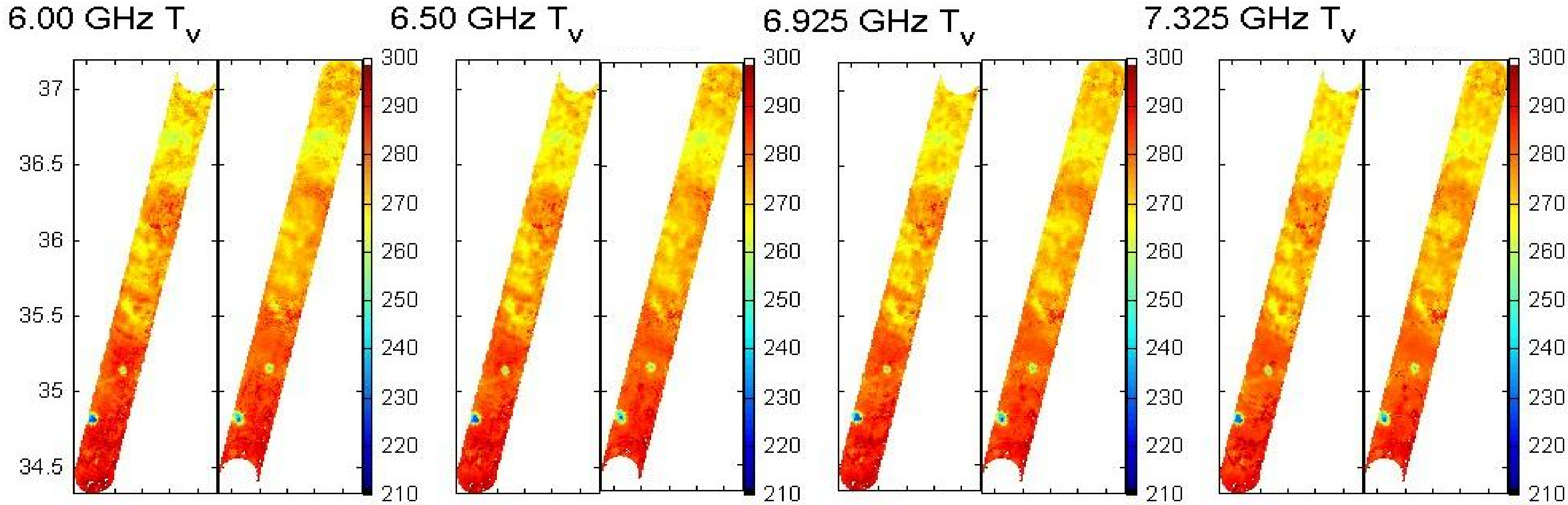
5) Also incorporate spectral slope and subband brightness thresholding.

Basic Spectral Algorithm

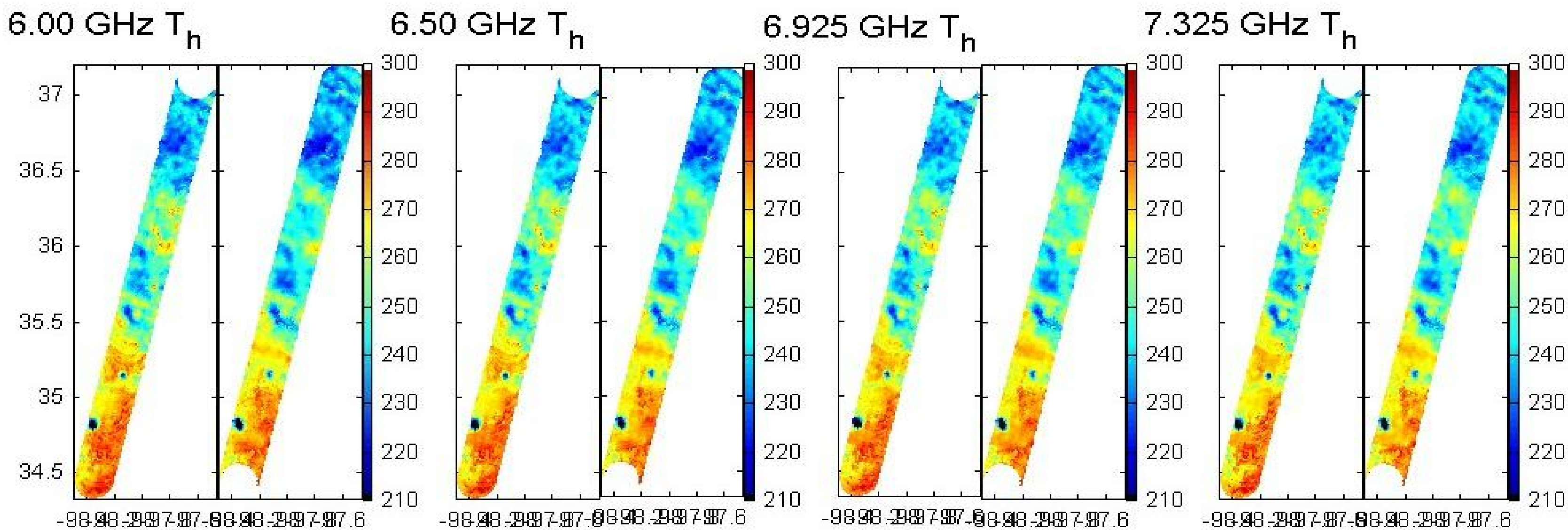


Interference-Corrected Imagery

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

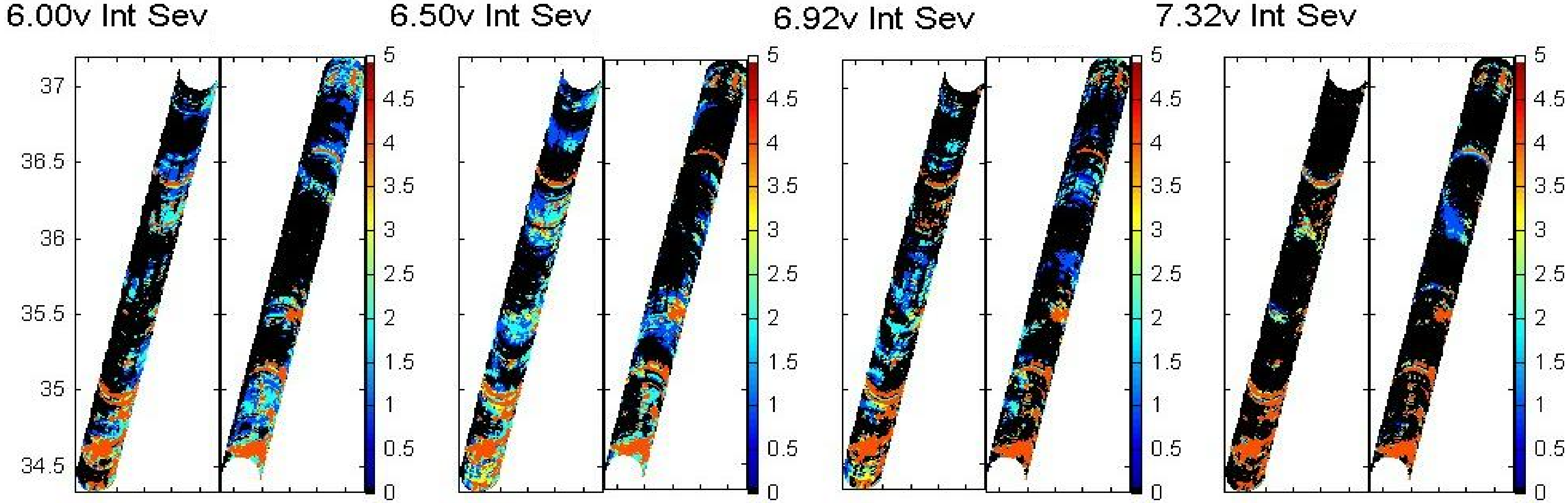


Interference mostly removed for purposes of soil moisture measurement

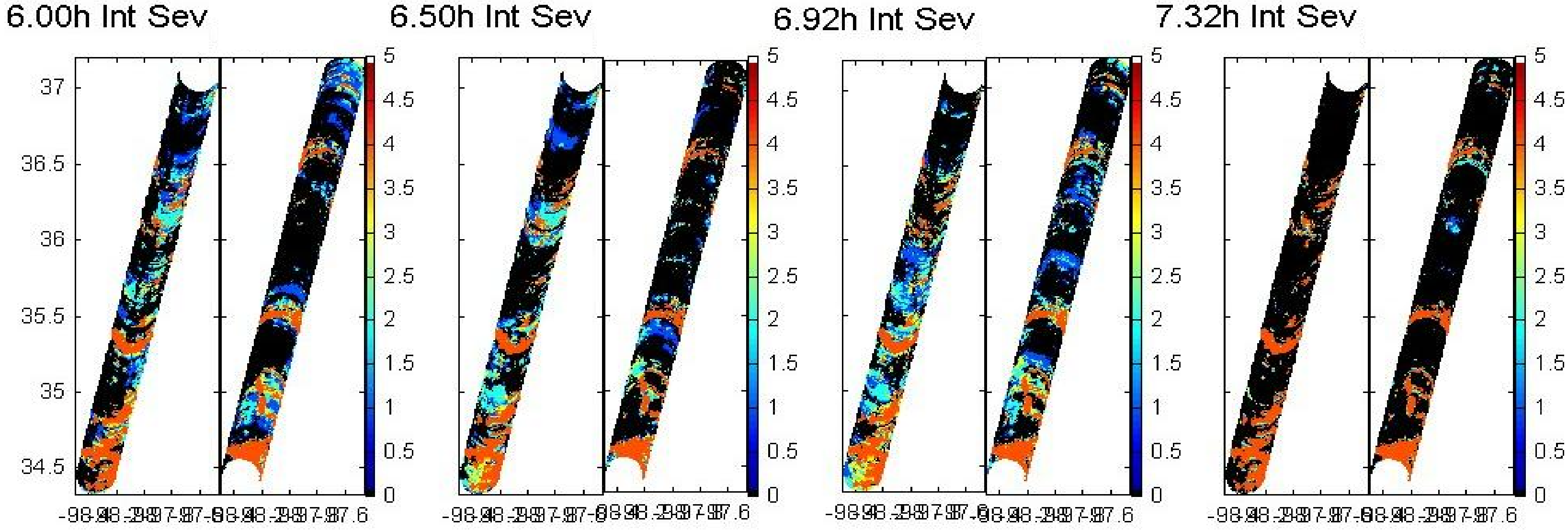


Interference Severity Maps

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

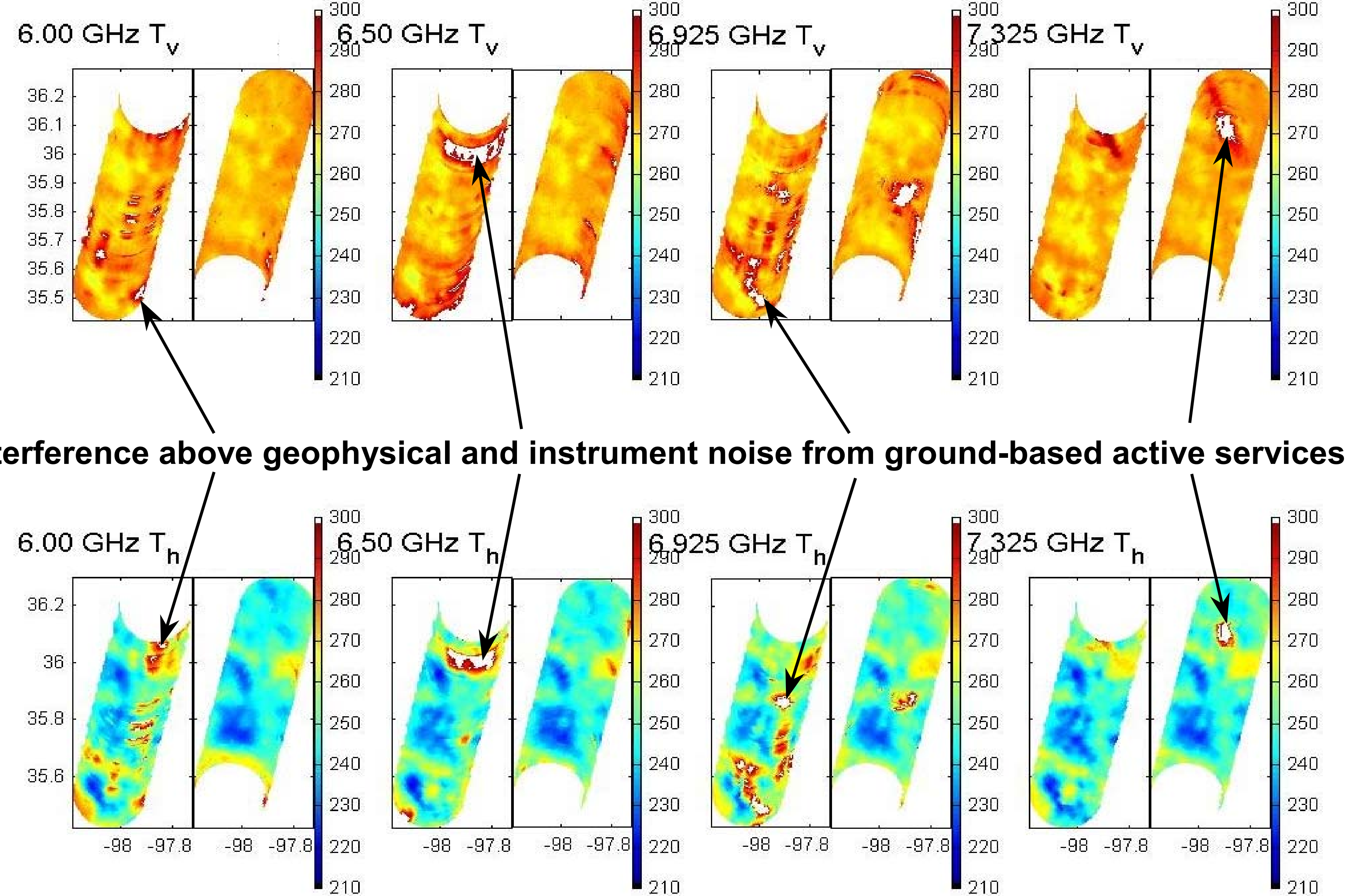


Interference severity varies according to subband, look direction, and location



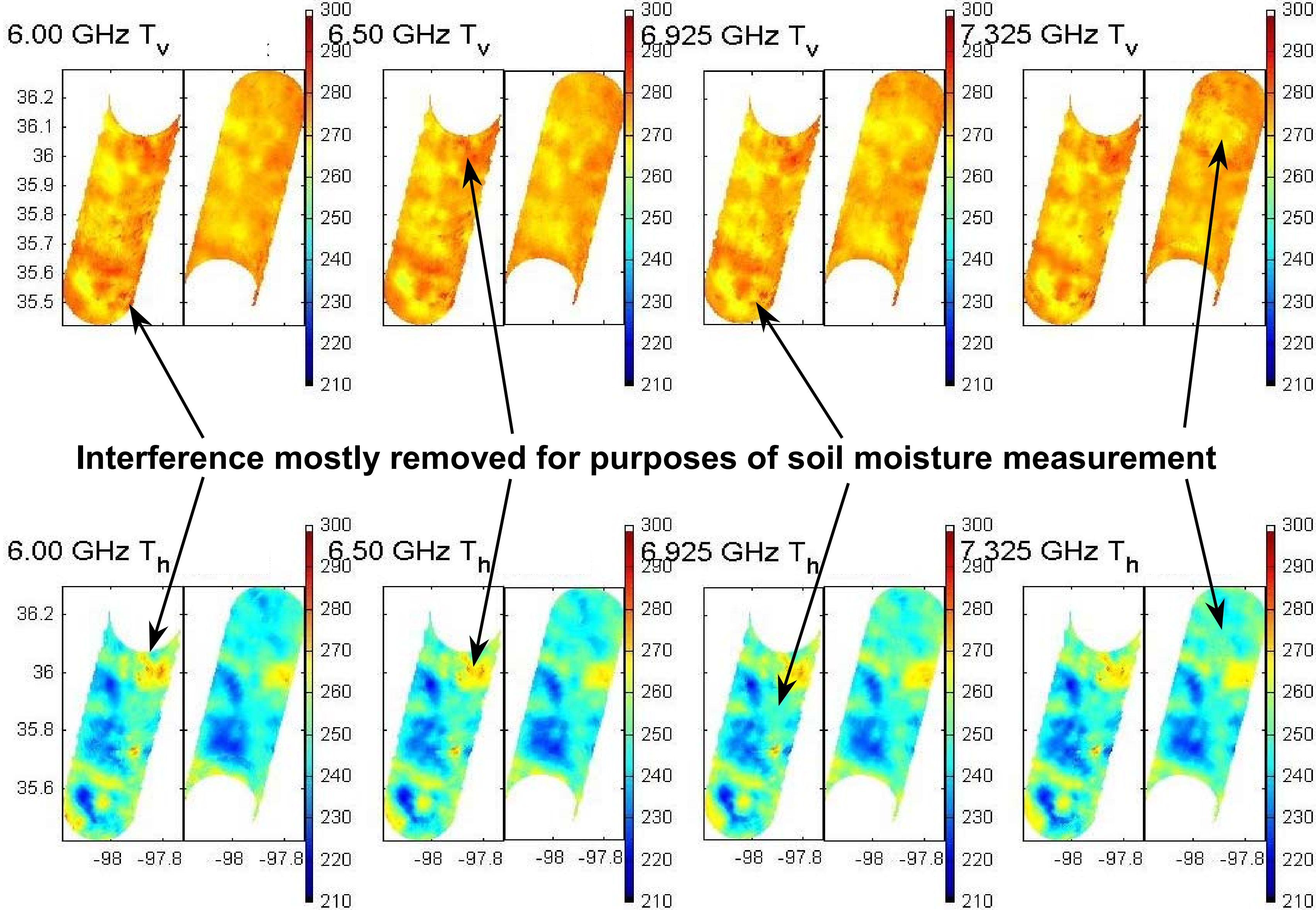
Calibrated (uncorrected) Imagery

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



Interference-Corrected Imagery

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



Interference Severity Maps

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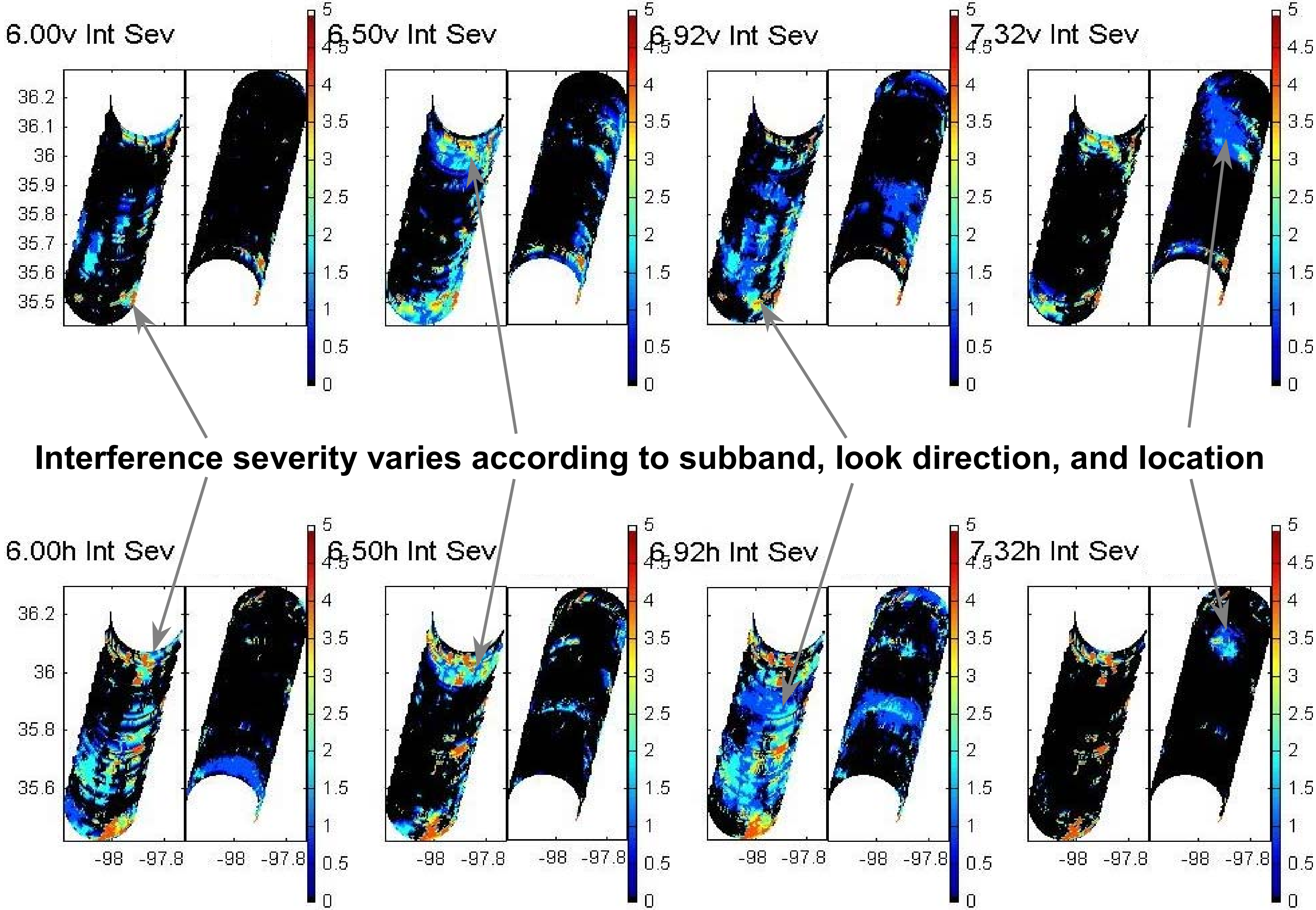
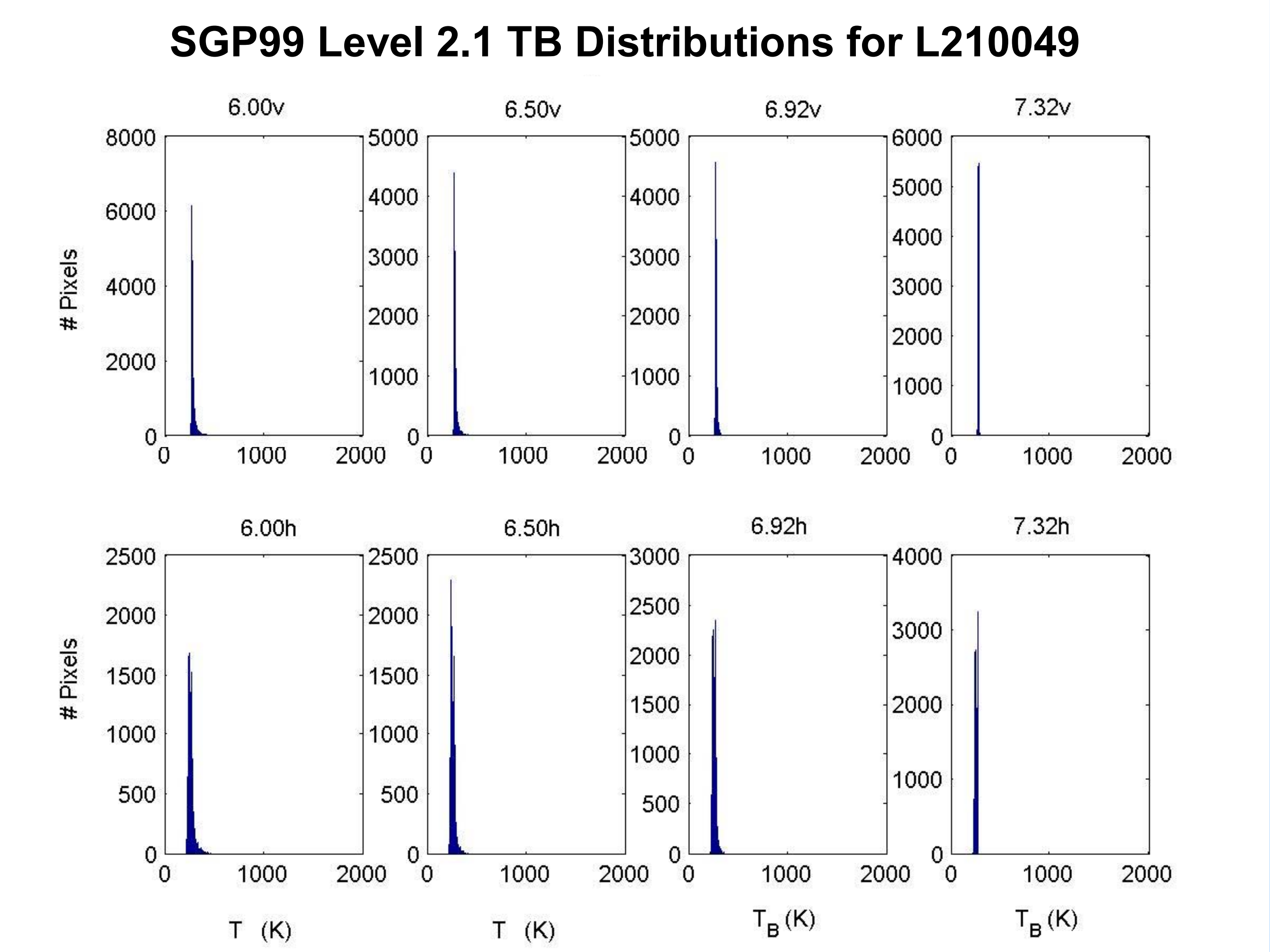
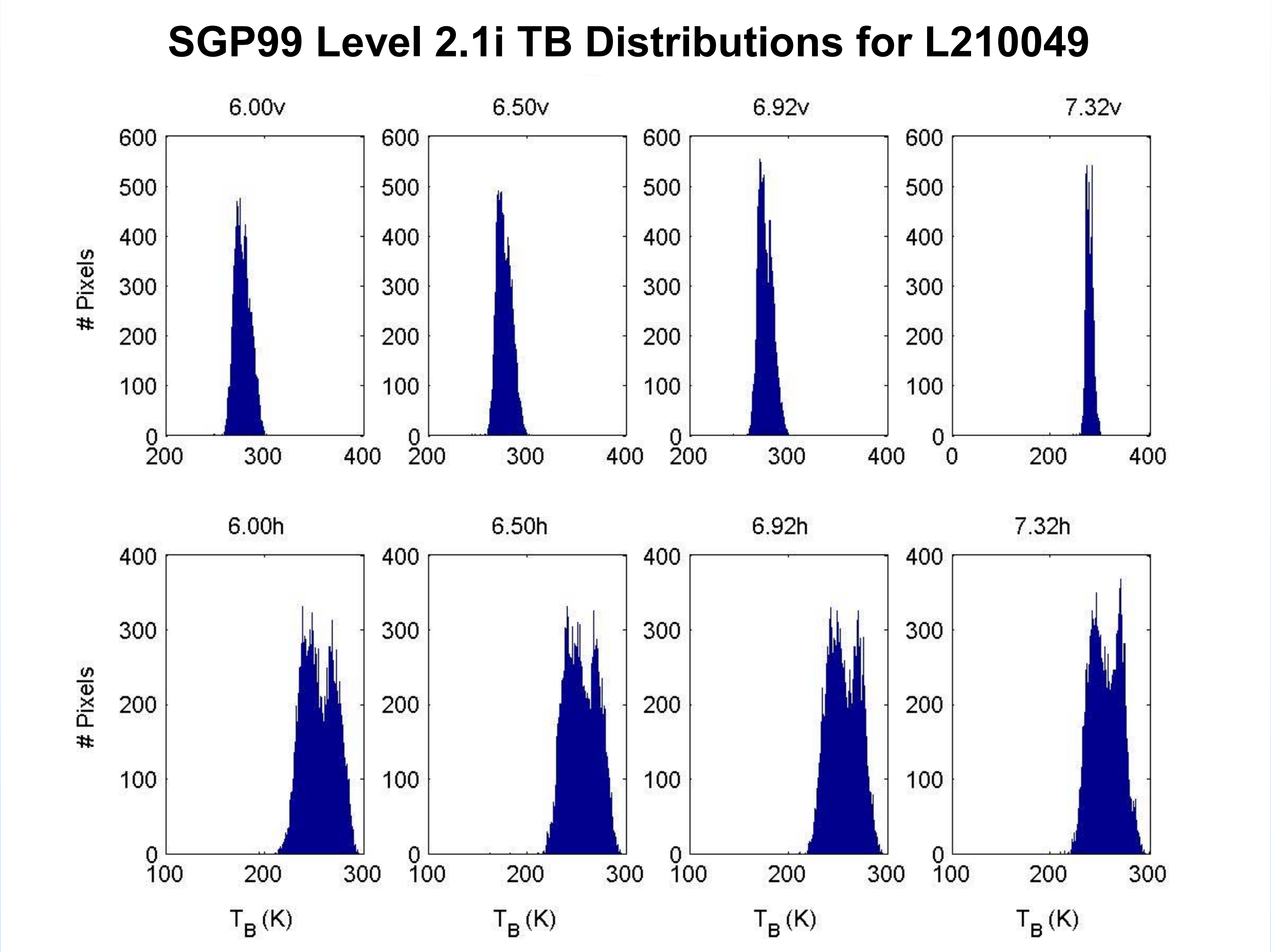


Spectral Distribution - Uncorrected



Spectral Distribution - Corrected



Spectral Algorithm Statistics

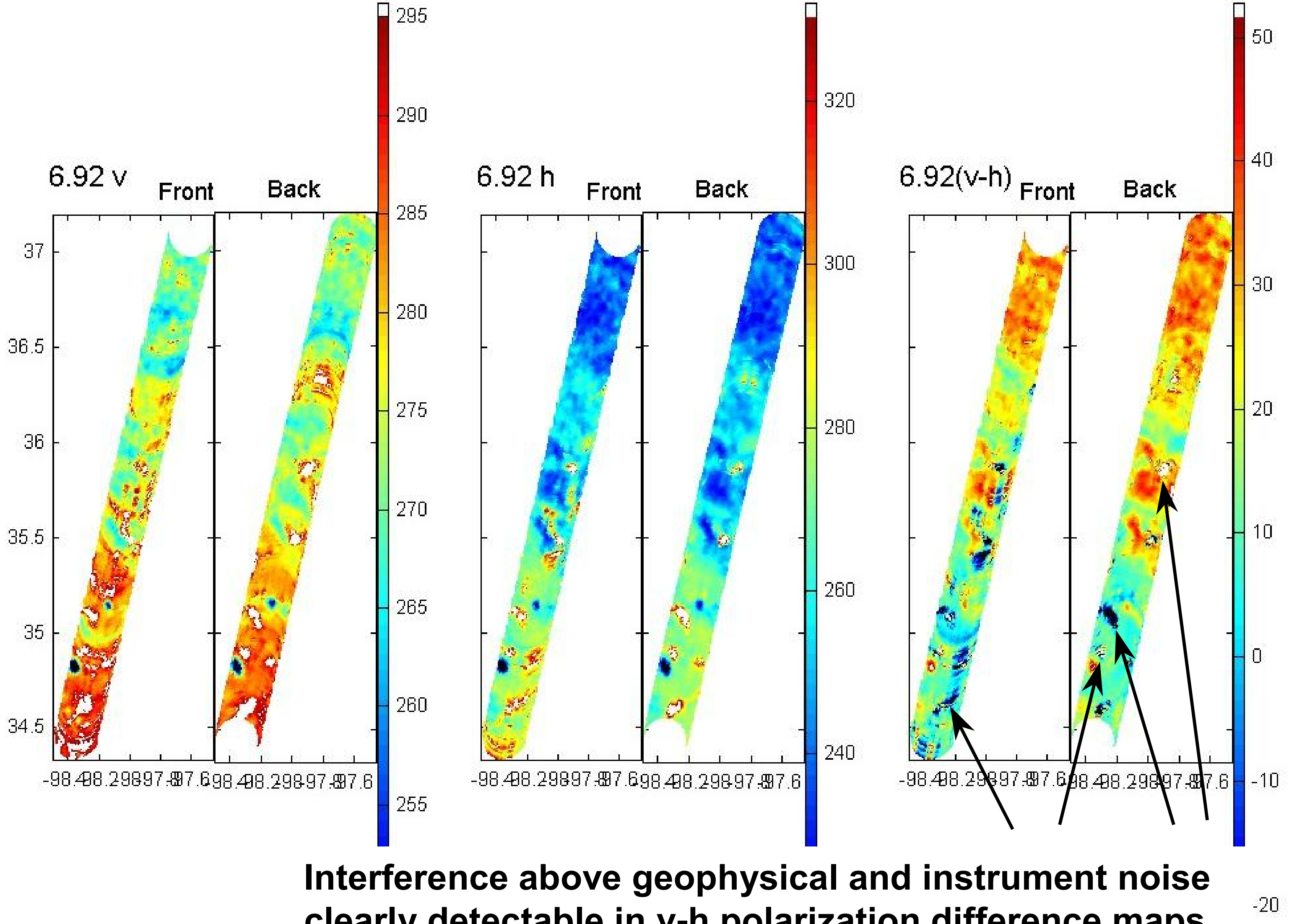
- PSR/C SGP99 data on 7/14/02 over Oklahoma, 76608 pixels
- Tb acceptance range: (v) 190-310 K (h) 130-310 K
- Maximum spectral slope: 7 K/GHz
- Combined geophysical + instrument noise: 2.5K RSS

RF Channel/ Severity	6.00v	6.00h	6.50v	6.50h	6.92v	6.92h	7.32v	7.32h
Level 0	62.1	58.9	58.7	62.0	68.7	54.5	81.8	80.4
Level 1	11.4	10.9	11.6	7.6	6.8	9.9	2.2	0.3
Level 2	12.7	9.8	13.6	9.3	8.6	11.8	1.8	1.4
Level 3	0.6	2.7	2.8	3.5	2.5	6.0	0.9	0.2
Level 4	13.3	17.8	13.3	17.8	13.3	17.7	13.3	17.7
Level 5	0	0	0	0	0	0	0	0

- No correction needed (severity 0): ~27%
- Detected/corrected cases (severity 1-2): ~52%
- "Failure" rate (severity 3-5): ~20%

Polarization Signature (V-H)
- Sensitivity to Interference -

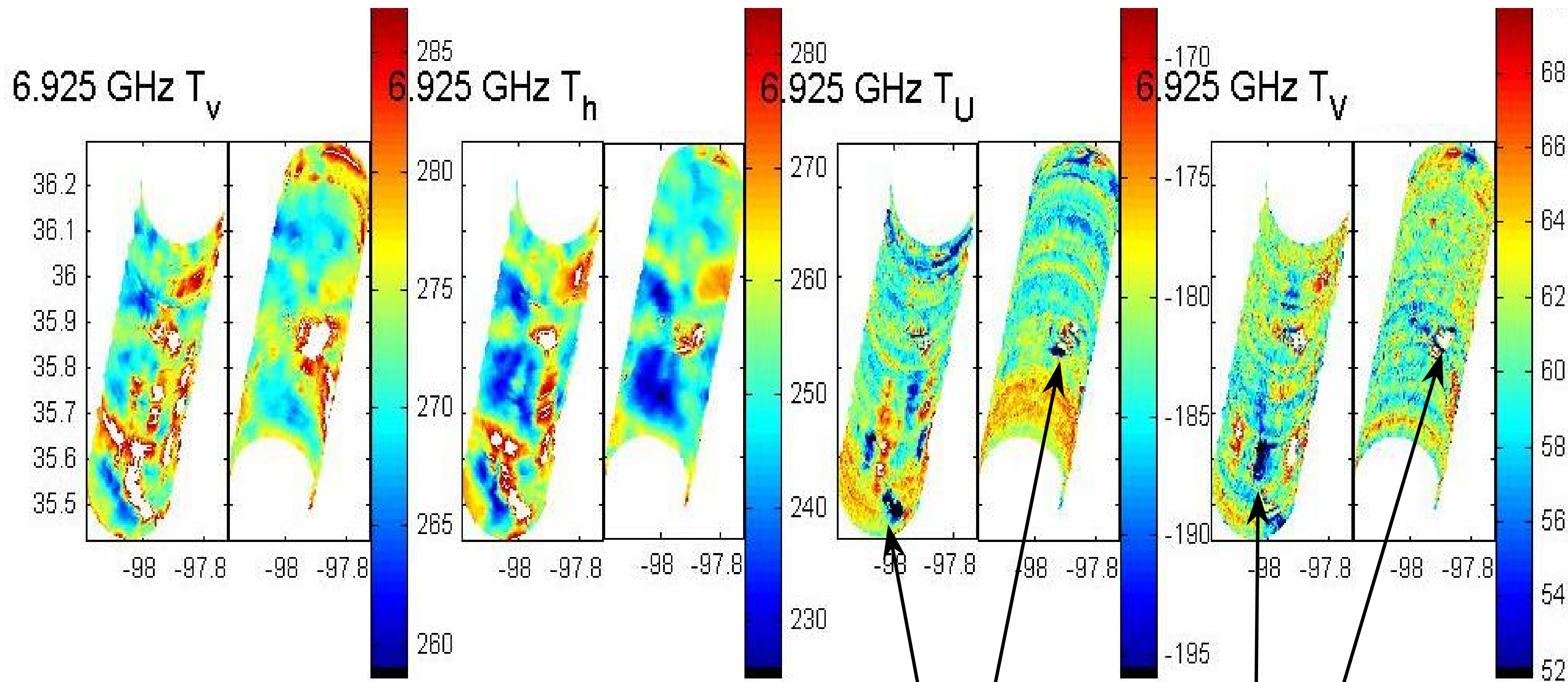
PSR/C SGP99 7/14/99 - Oklahoma – SN 0049



Interference above geophysical and instrument noise clearly detectable in v-h polarization difference maps.

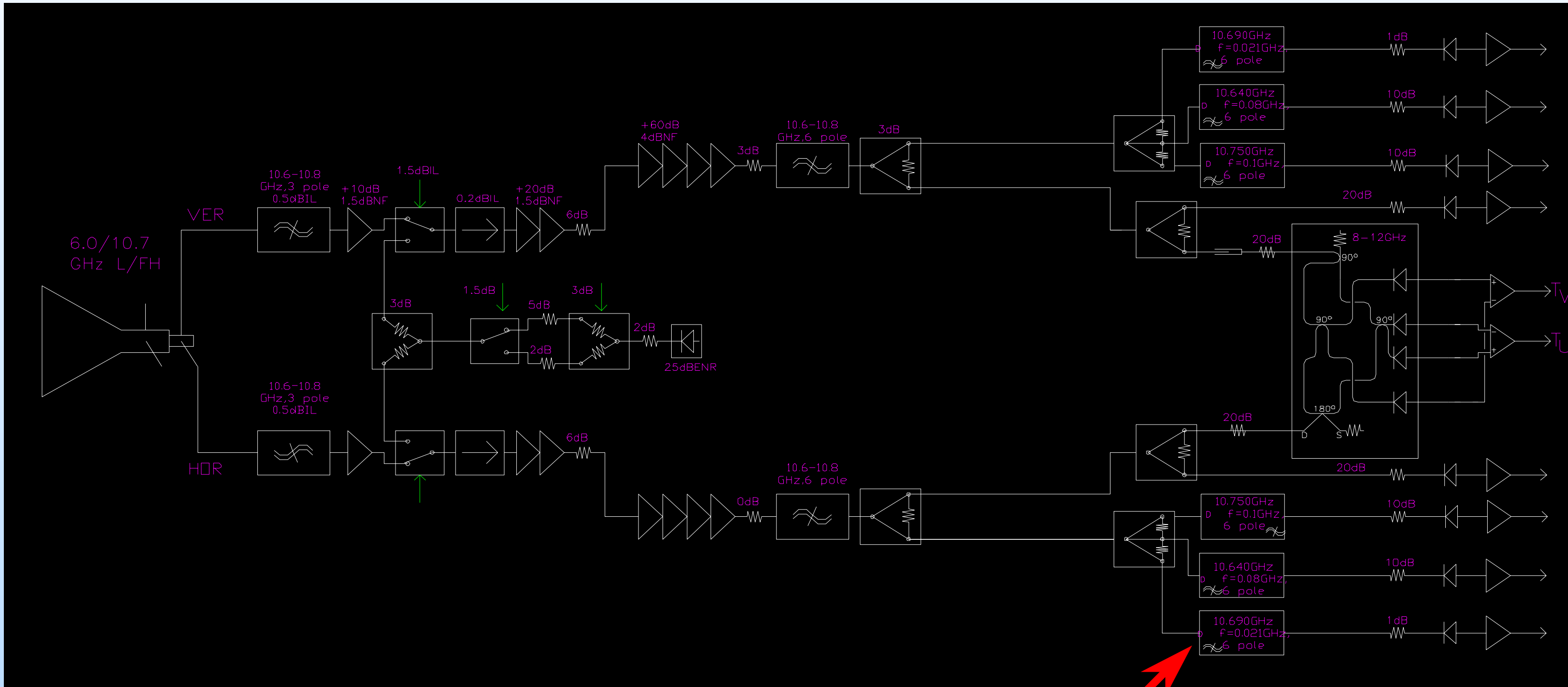
3^{rd} & 4^{th} Stokes Parameter
- Sensitivity to Interference -

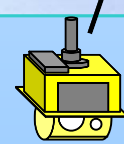
PSR/C SGP99 7/14/99 - Oklahoma – SN 0049



Interference above geophysical and instrument noise clearly detectable in 3^{rd} & 4^{th} Stokes (uncalibrated) channels.

PSR/CX 4-Subband X-Band Hardware for SMEX02





Subbands (GHz):

10.60-10.68 (v,h)
10.68-10.70 (v,h)
10.70-10.80 (v,h)
10.60-10.80 (v,h,U,V)

*** Soil Moisture Experiment June 24 – July 12, 2002 over Iowa**

Summary

- Anthropogenic interference in passive microwave imaging is a growing problem especially at L, C, X, and Ku bands.
- Effective and relatively inexpensive spectral interference mitigation techniques are possible - but certainly not as desirable as clean protected spectrum.
- Effective spectral interference mitigation has been demonstrated using airborne C-band imagery with 4 subbands. Demonstration at X-band ongoing during SMEX02.
- Spatial and polarization-based detection techniques are plausible, and algorithms are being studied.