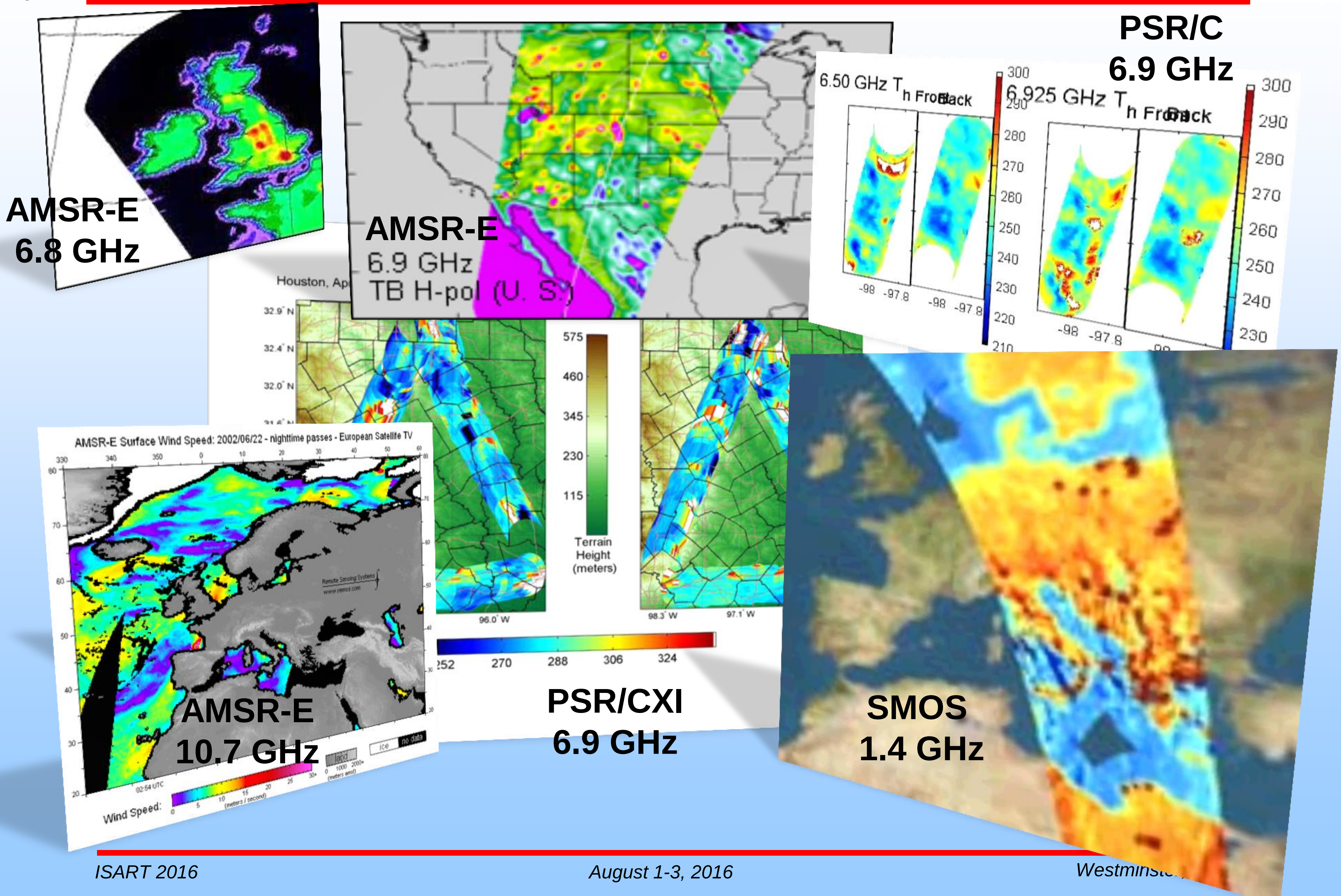
Spectrum Forensics:
New Observations and Analytics

Prof. Albin J. Gasiewski

Center for Environmental Technology
Department of ECEE
University of Colorado
Boulder, CO

al.gasiewski@colorado.edu

Anthropogenic RFI in Passive Microwave Measurements

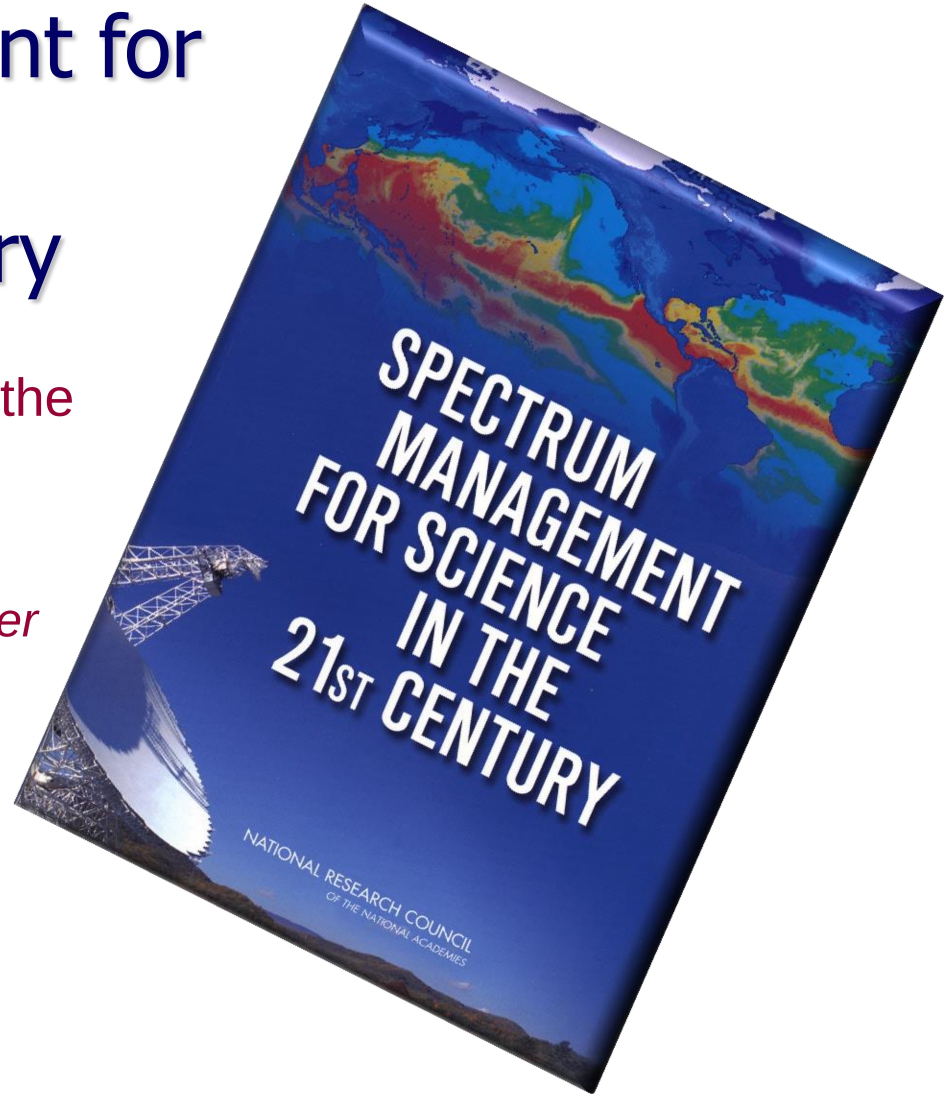


Spectrum Management for Science in the 21st Century

Committee on Scientific Uses of the Radio Spectrum

David B. Lang *NRC Program Officer*
Albin J. Gasiewski, *Co-Chair*
Marshall H. Cohen, *Co-Chair*

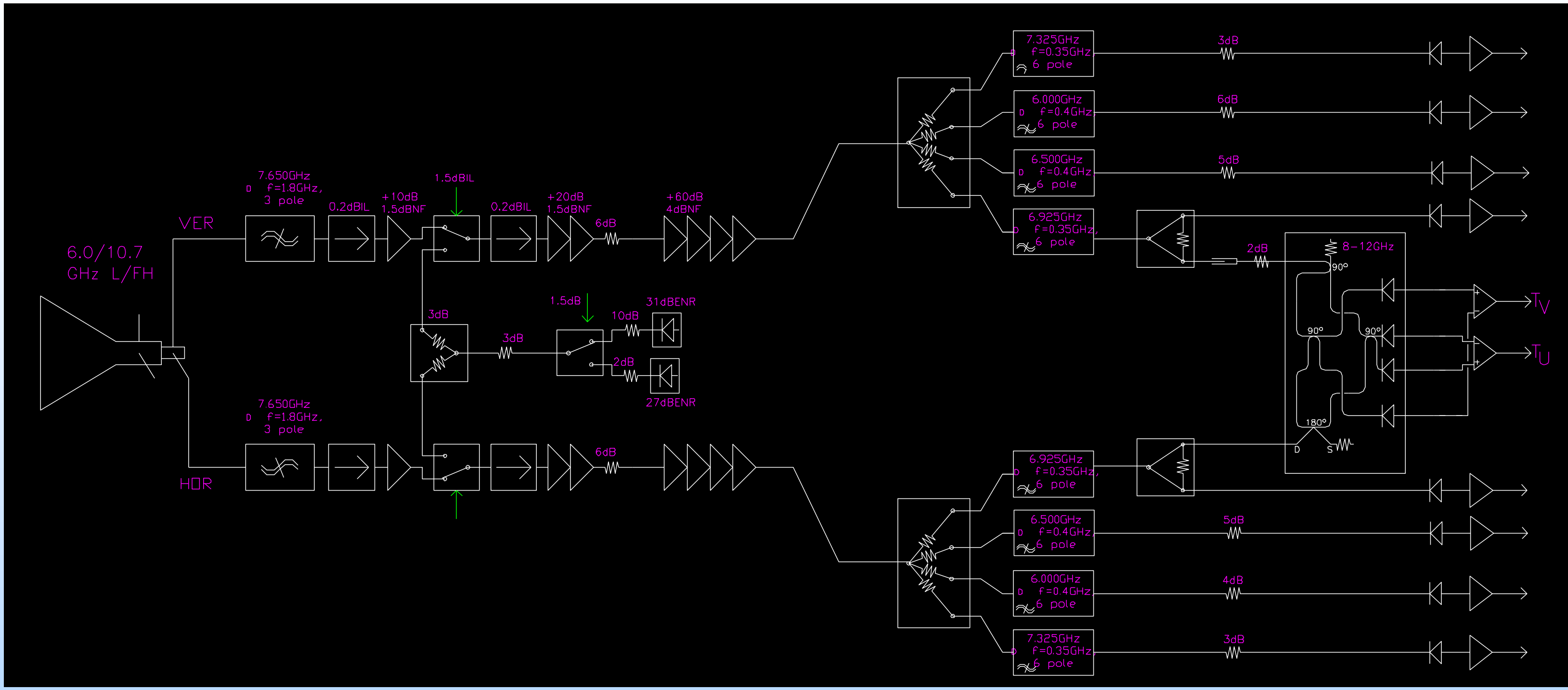
on behalf of the full committee



Passive Interference Mitigation Methods

Technique	Use Case	Limitation
Threshold Blanking	General RFI	No Data Recovery
Multiple Receiver Subband Mitigation (e.g. χ^2, threshold, etc.)	Narrowband RFI	Loss of Bandwidth
FT Subband Threshold Blanking	Narrowband Nyquist Sampled RFI	Loss of Bandwidth
Amplitude Statistic Threshold Methods (e.g. Kurtosis)	General Nyquist-Sampled RFI	No Data Recovery
FT Subband Amplitude Statistic Thresholds	Narrowband Nyquist-Sampled RFI	Loss of Bandwidth
Coherent Demodulation Bayesian Estimation	Nyquist-Sampled Coherent RFI	Requires Coherence and Known Modulation & Digital RFI
N-Dimensional Maximum Likelihood Optimization	≥ Nyquist-Sampled RFI w/ Knowledge	Requires Known Modulation & Digital RFI

PSR/C* 4-Subband RFI Detecting Radiometer Hardware



Subbands & Polarizations:

5.80-6.20 GHz (v,h)

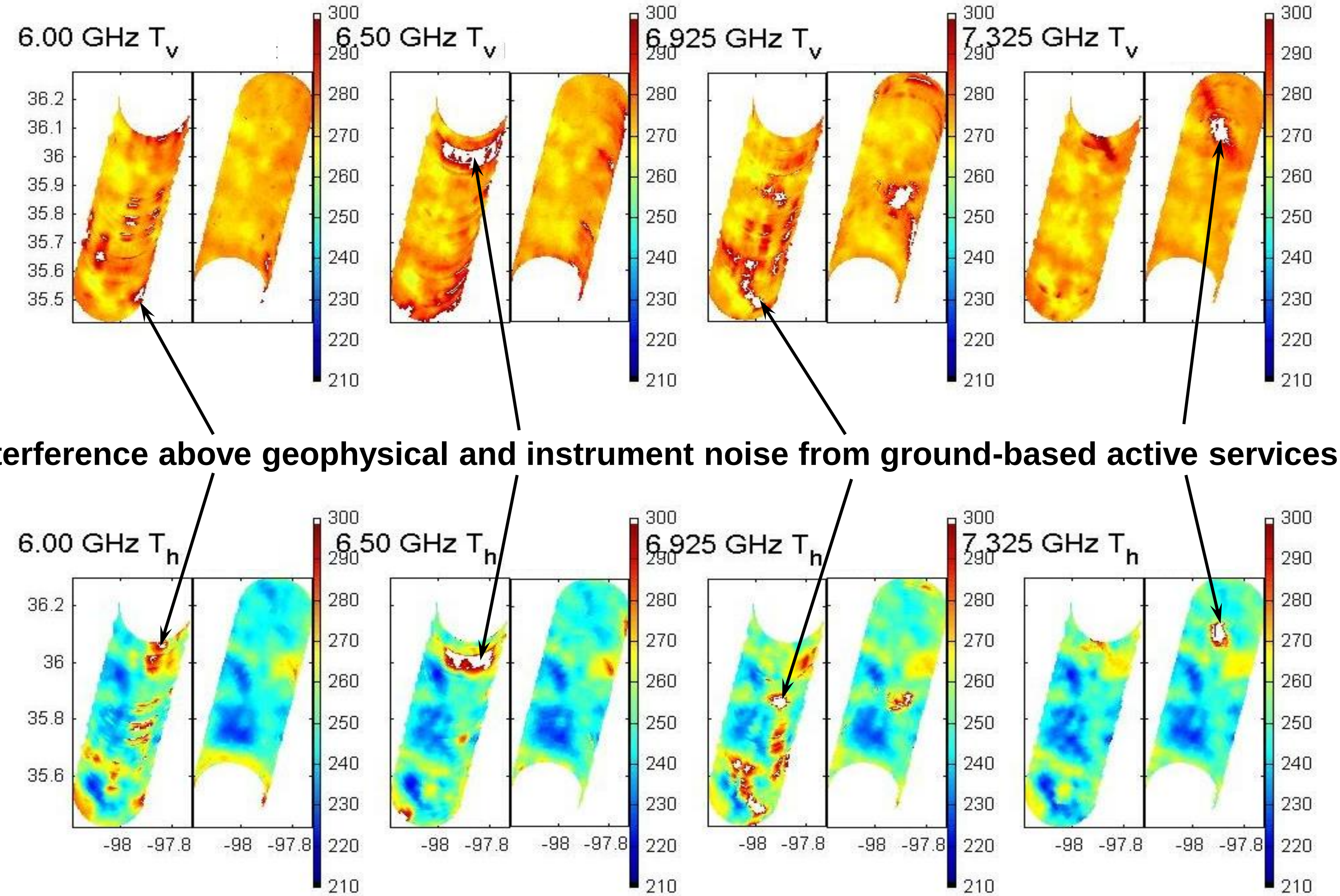
6.30-6.70 GHz (v,h)

6.75-7.10 GHz (v,h,U,V)

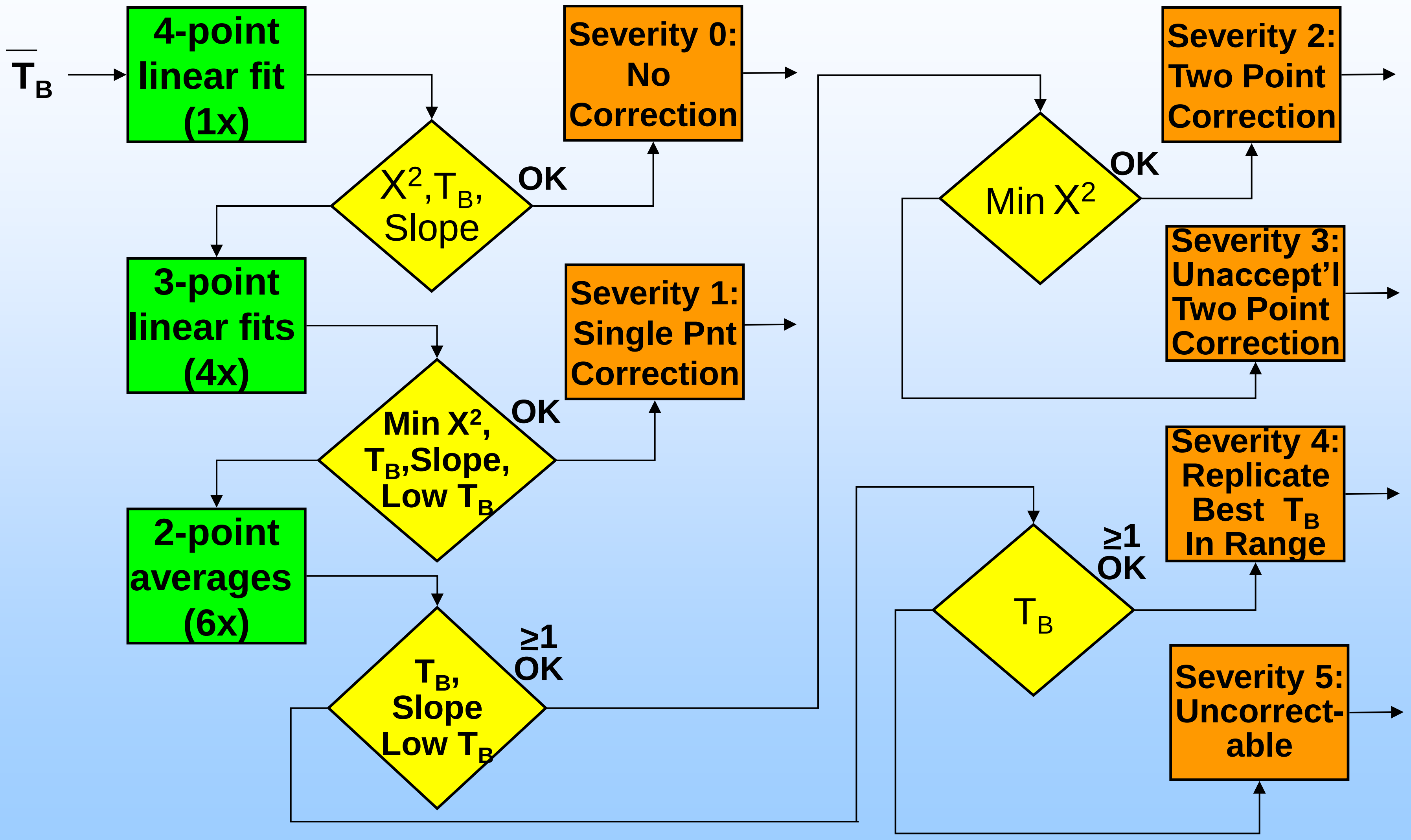
7.15-7.50 GHz (v,h)

Calibrated (RFI uncorrected) Imagery

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

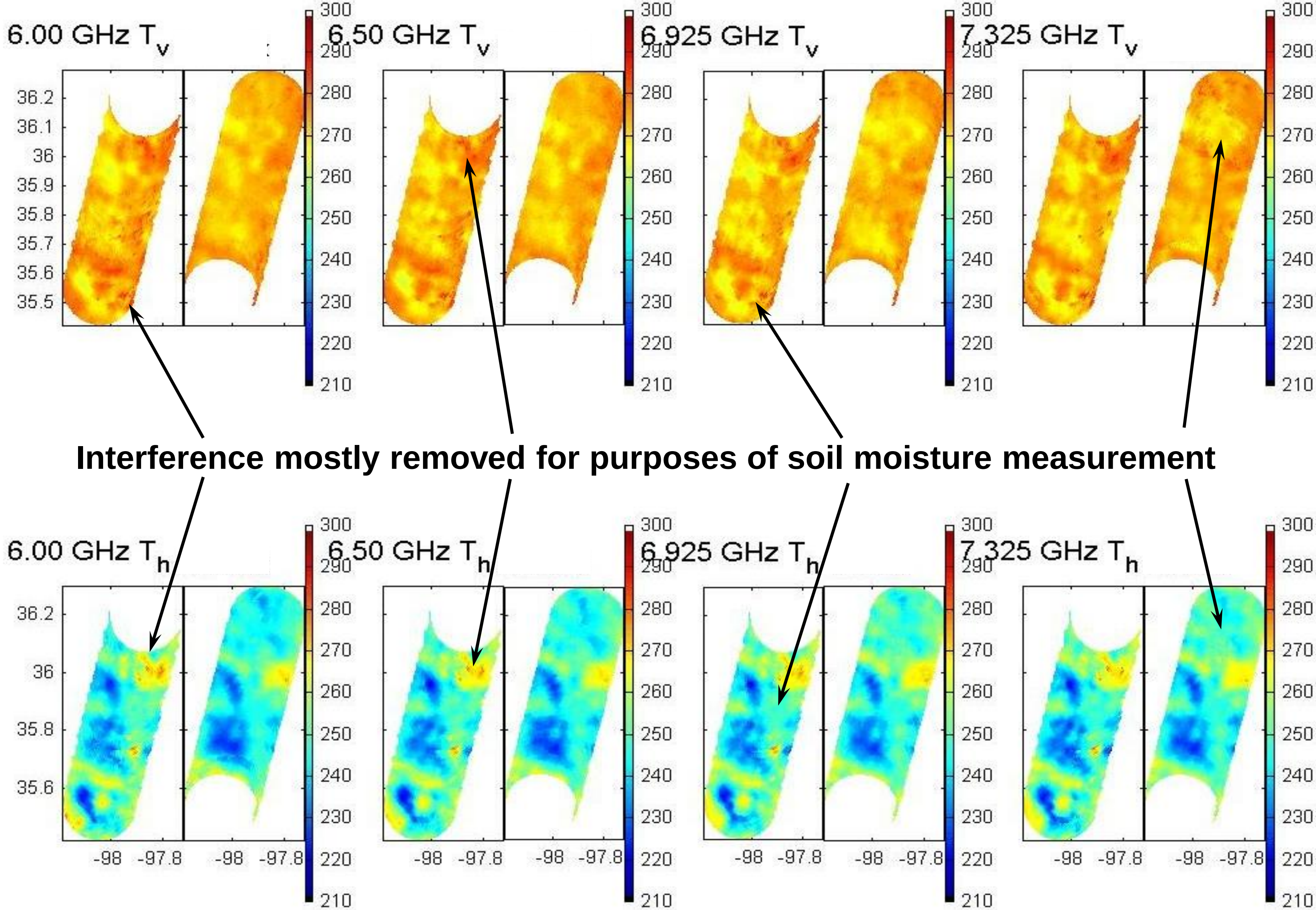


Basic Spectral Consistency Algorithm



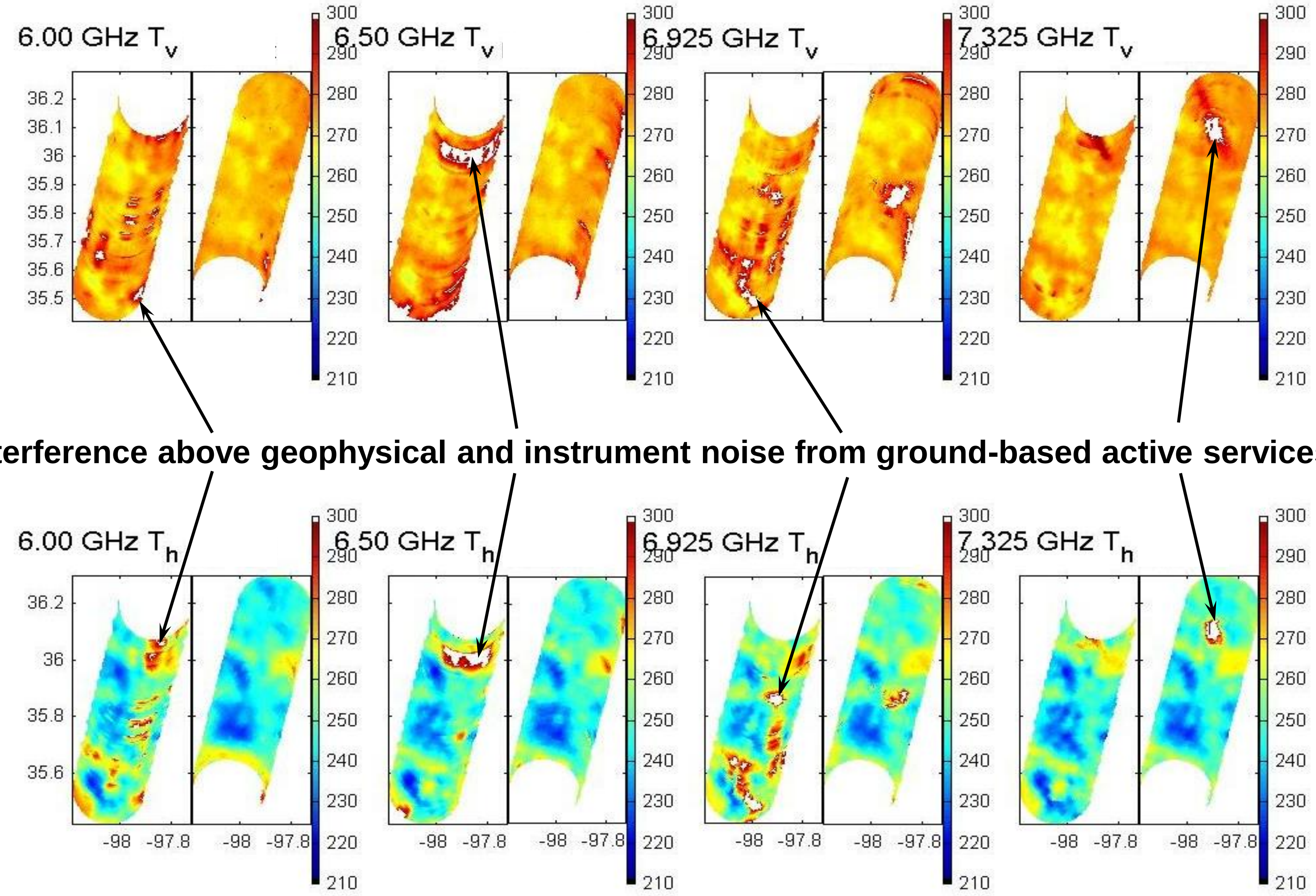
Interference-Corrected Imagery

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



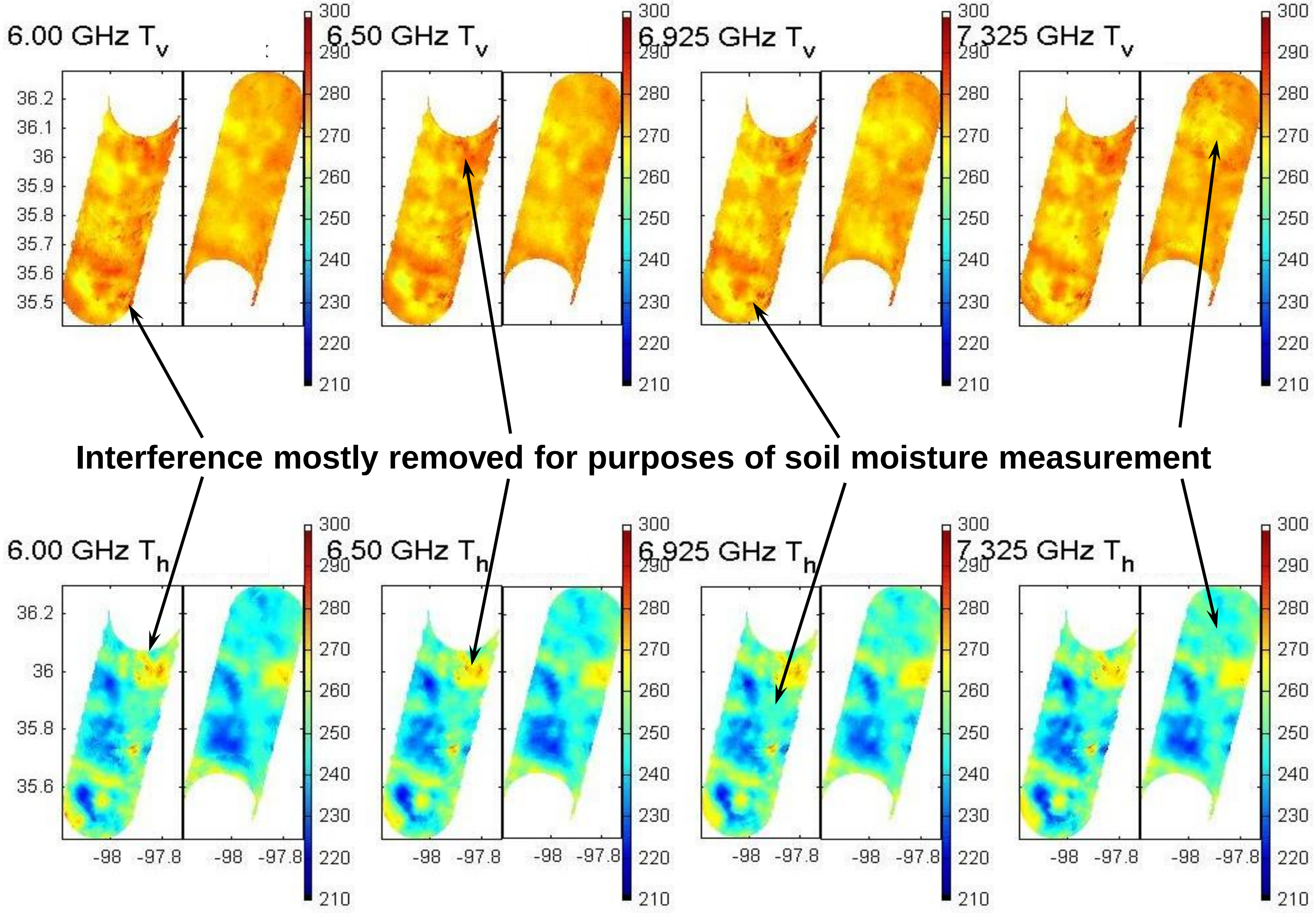
Calibrated (RFI uncorrected) Imagery

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



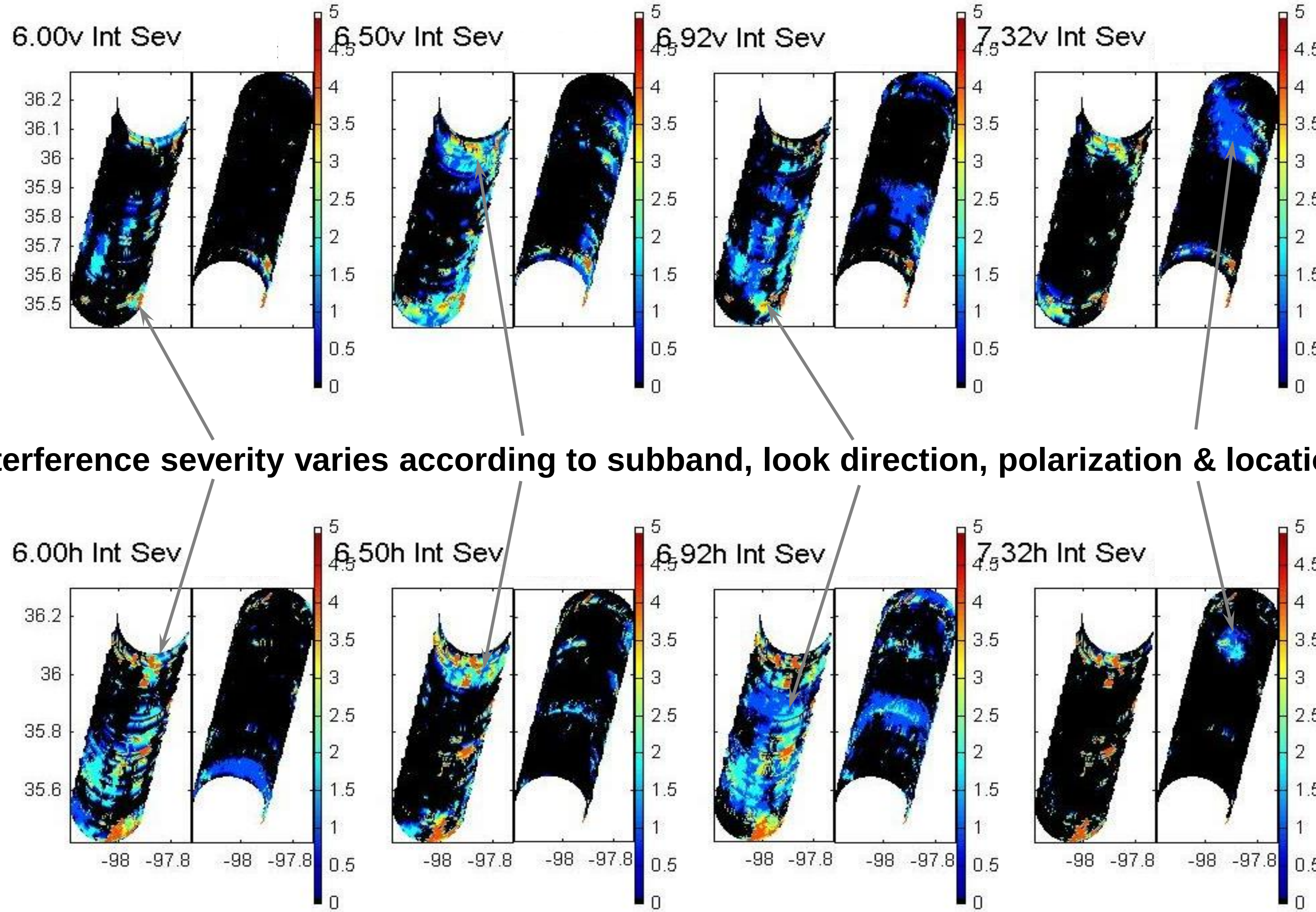
Interference-Corrected Imagery

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

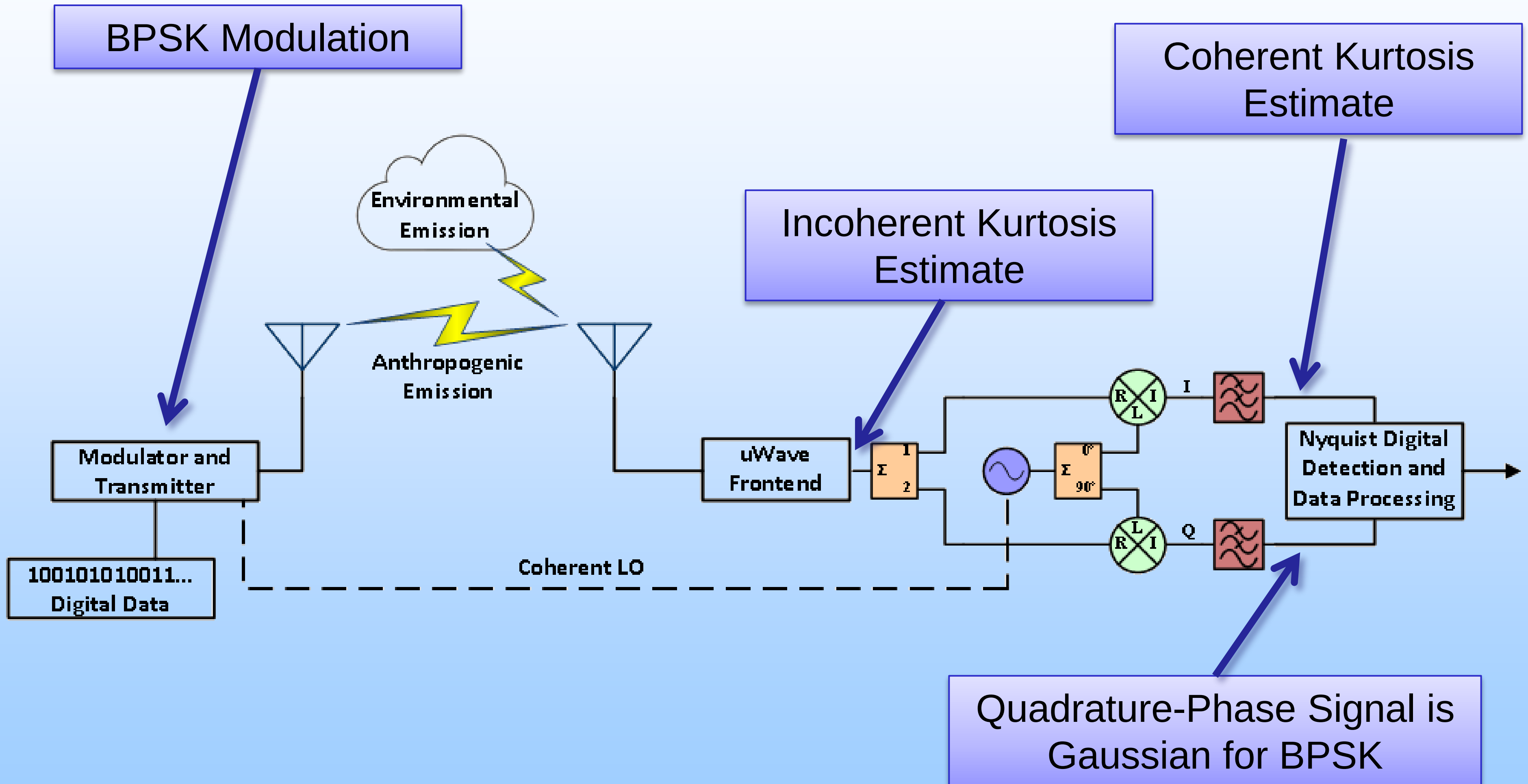


Interference Severity Maps

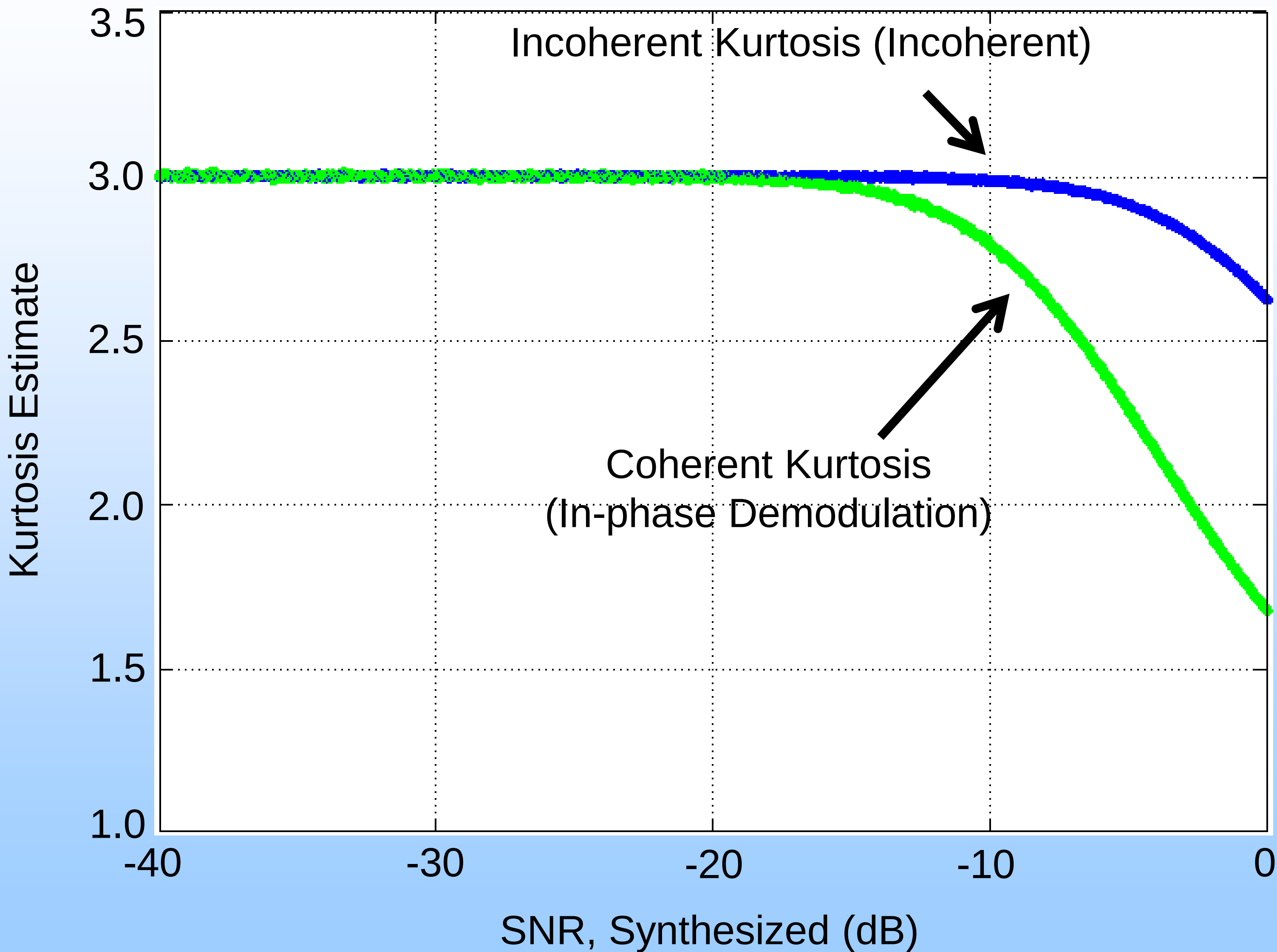
PSR/C SGP99 7/14/99 – Oklahoma – SN 0049



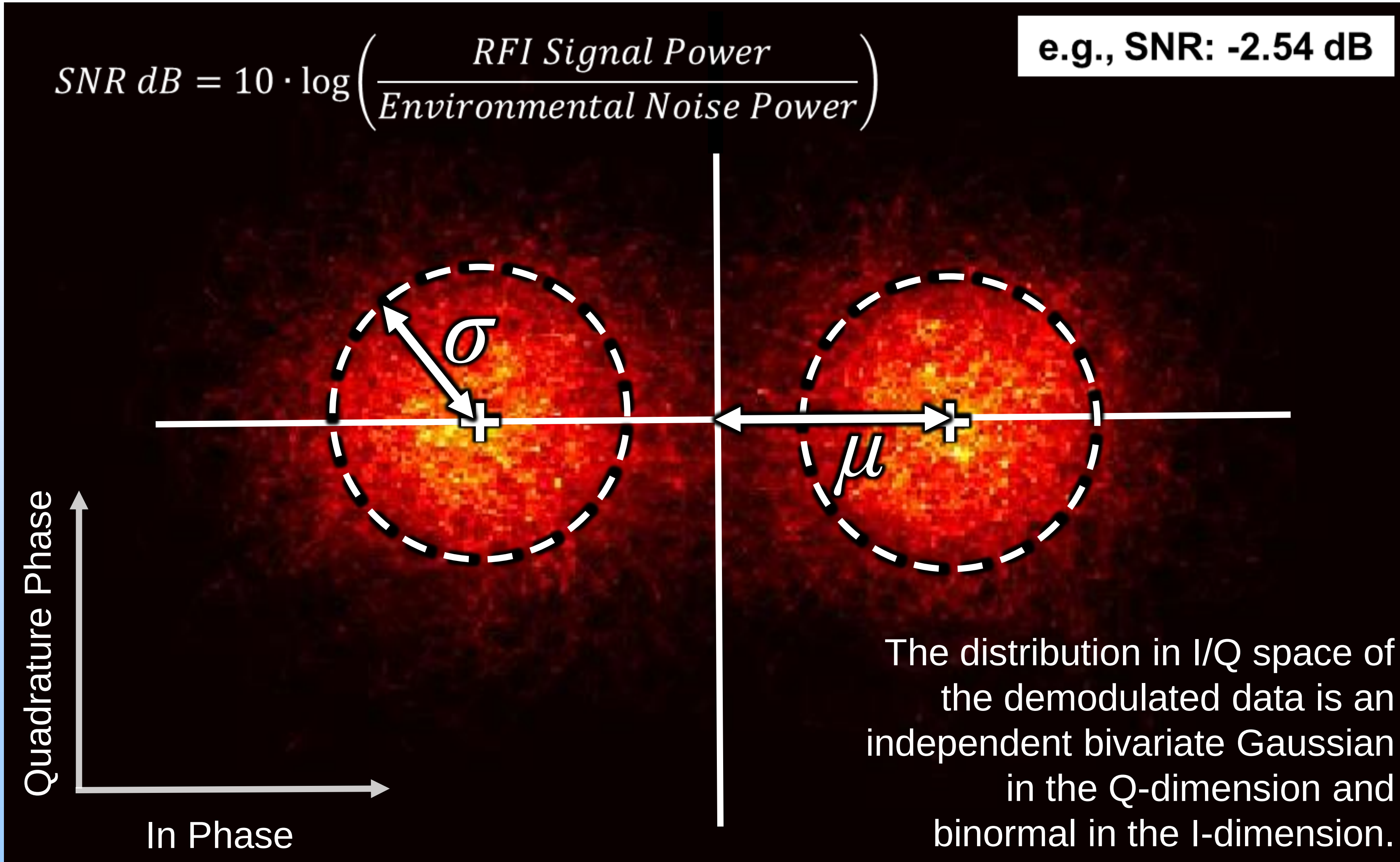
BPSK + Thermal Noise Simulation



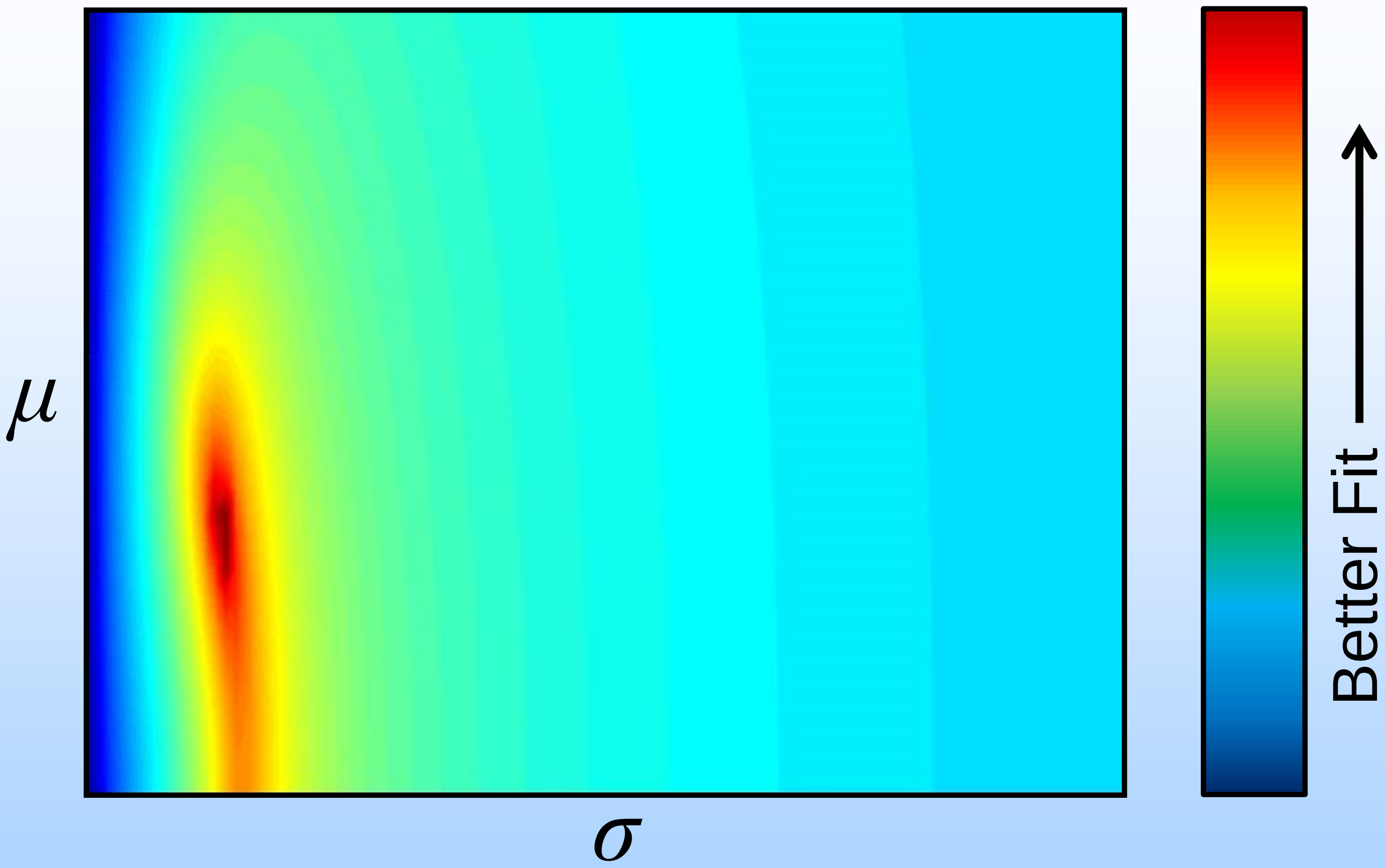
Kurtosis RFI Mitigation



I/Q PDF of Radiometric Noise with BPSK RFI

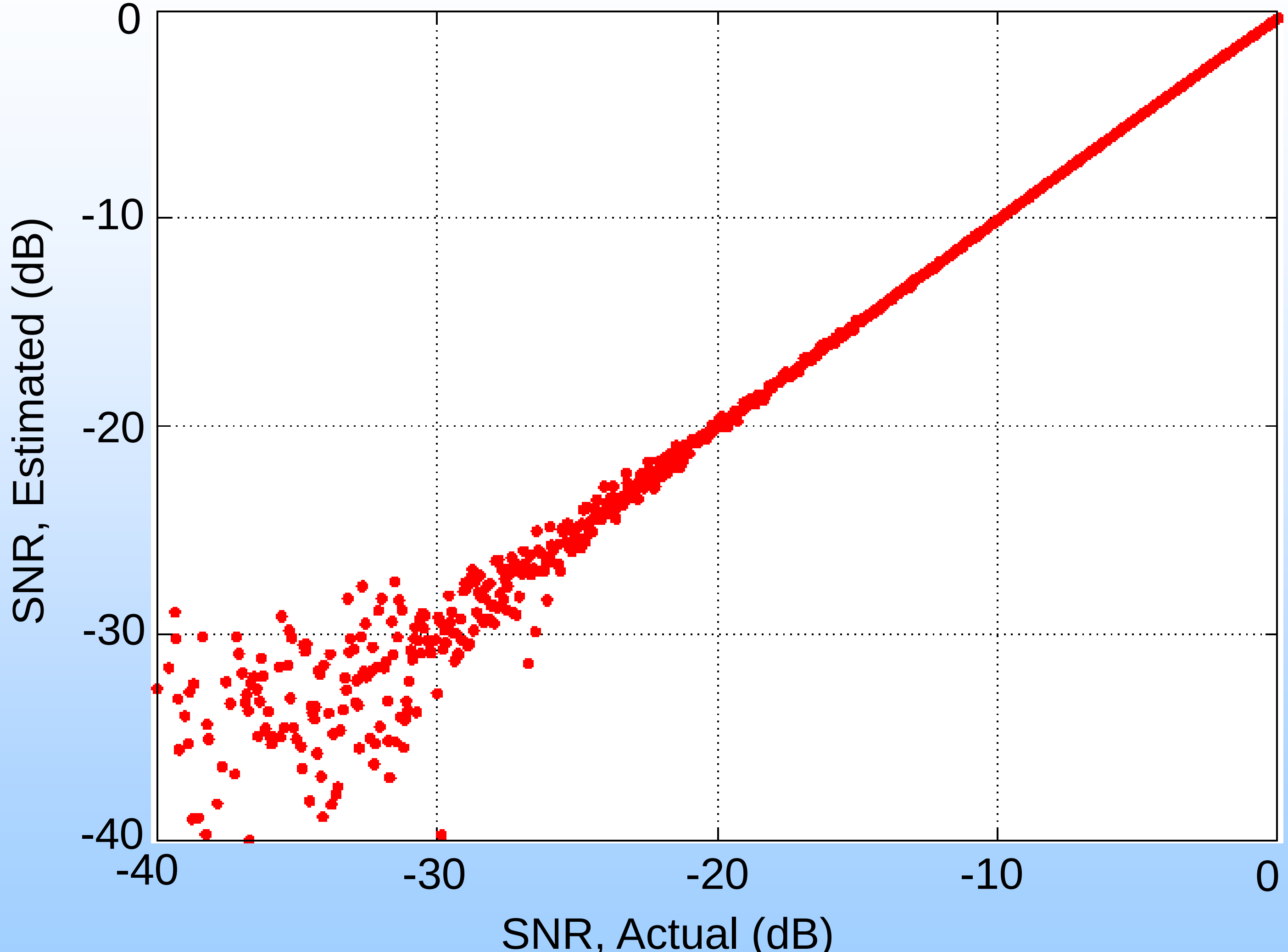


Maximum Likelihood PDF Parameter Estimation



Likelihood function based on Nyquist sampled data is well behaved with a single unambiguous maximum. Requires I/Q sampled vector or additional LO phase estimation.

ML SNR Estimation

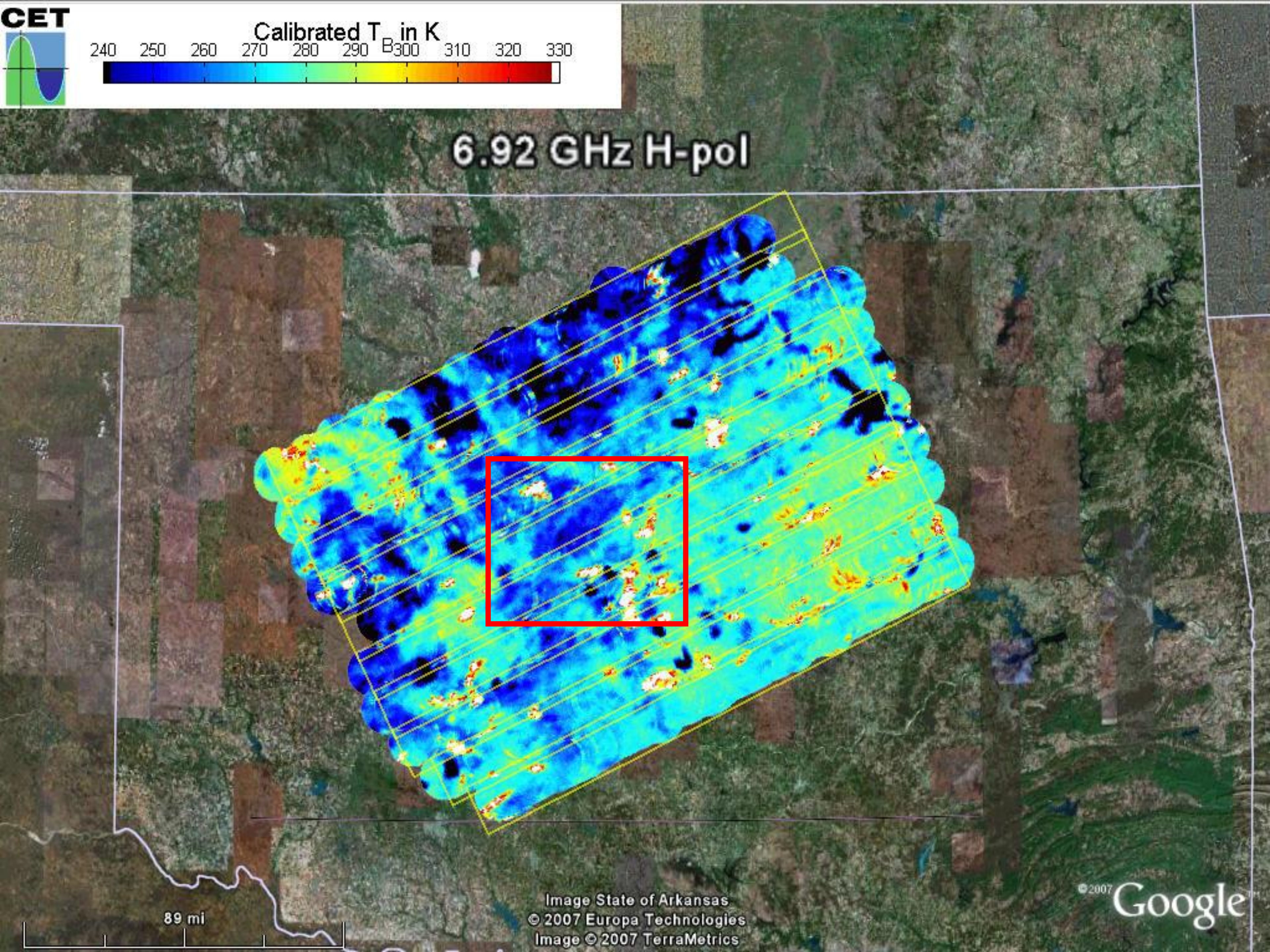


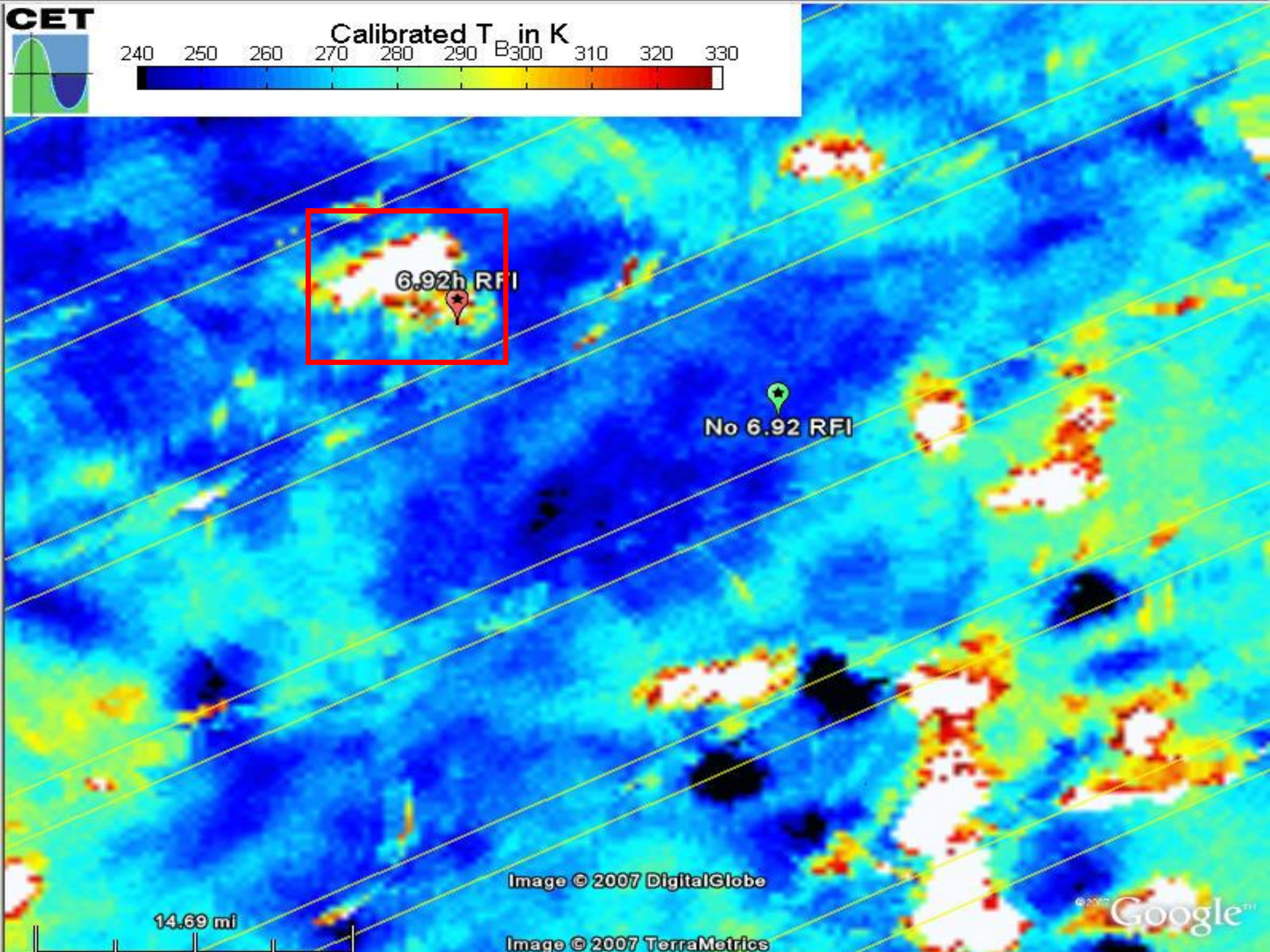
1000 model runs between -40 and 0 dB SNR

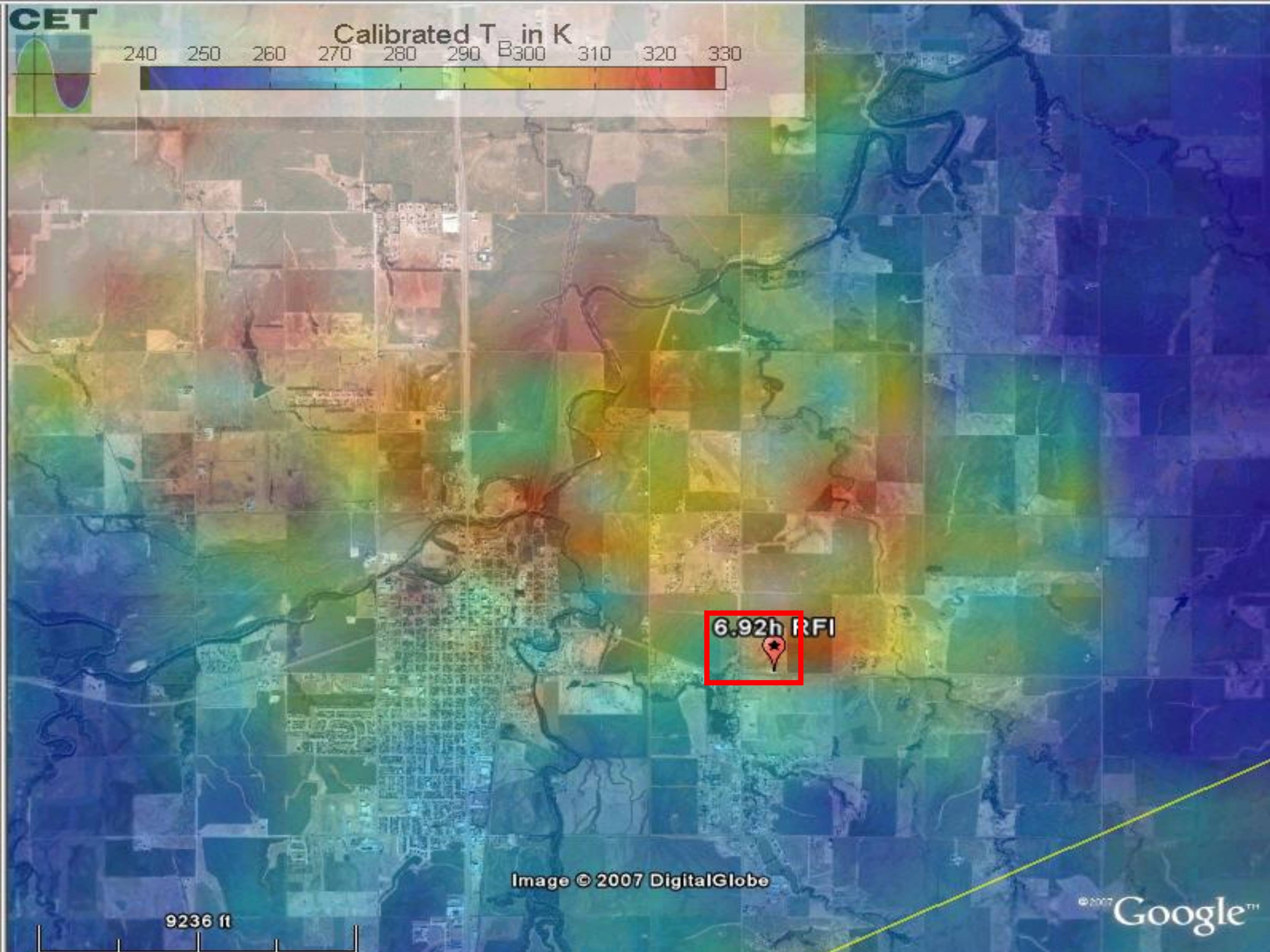
Time-Space Efficient Observations

Airborne imaging systems with ***efficient* (*η_t* ~1)**, ***sensitive*** **(ΔT_{RMS}~0.5-1K ↔ $k(\delta T)B$~-128 dBm in 10 MHz)*, and calibrated*** **(ΔT_{BIAS}~0.5-1K)*,*** radiometers are an effective ($ cost, time, area coverage) means of locating interference.

- Proposed to OSTP as a recommendation from the NRC spectrum study in 2012 (~$10M)
- Demonstrated by CET instruments during over 1200 flight hours since 1996 on manned aircraft (but at high $ cost)
- Now being implemented on small UAS (at low $cost) for commercially-driven applications (e.g., precision agriculture)


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
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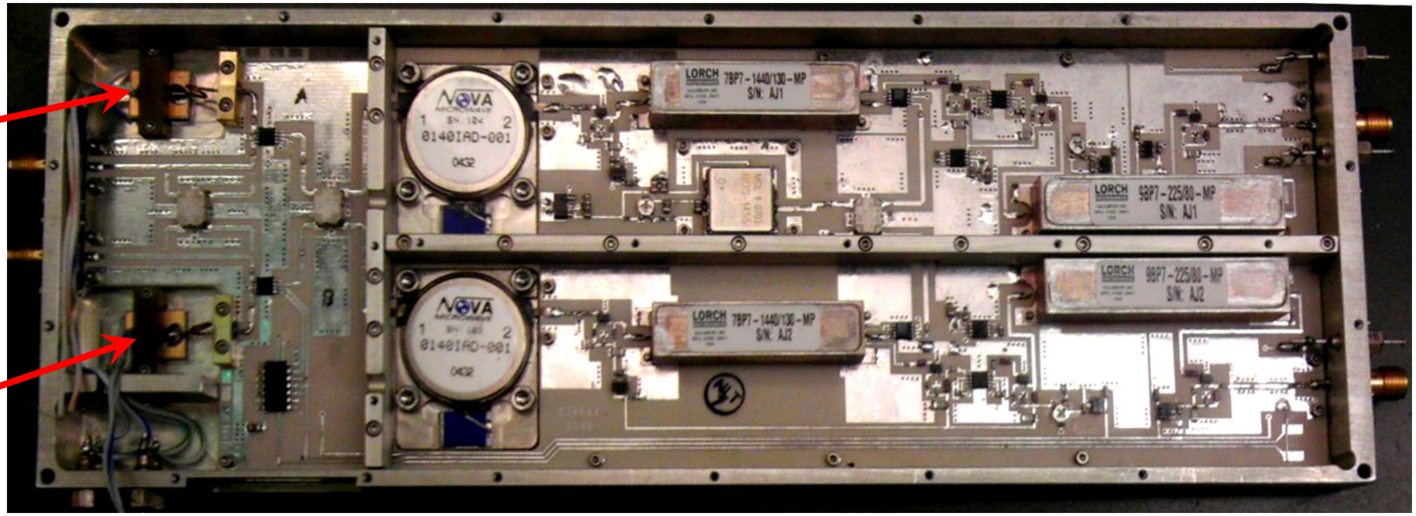
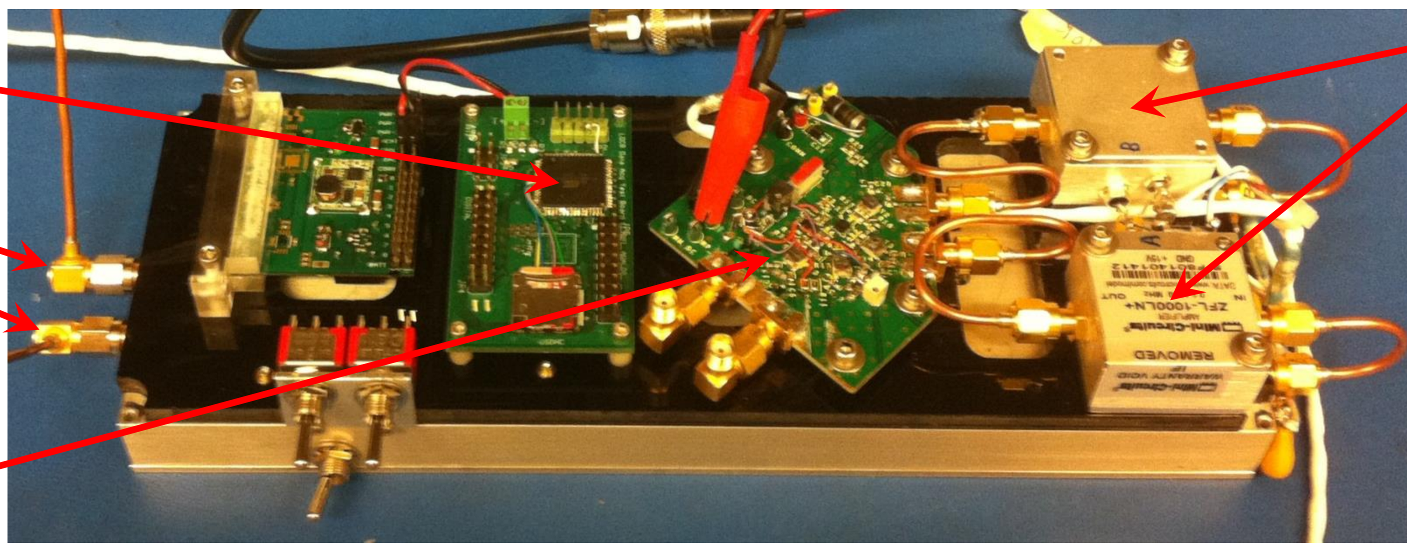
LDCR Receiver (2015 Build)



Calibration terminations w/ TE cooler/ heaters

uWave receiver+ carrier mass: 550 g



Micro-controller w/ ADC

Up/down RF inputs

Analog correlator/ video amp

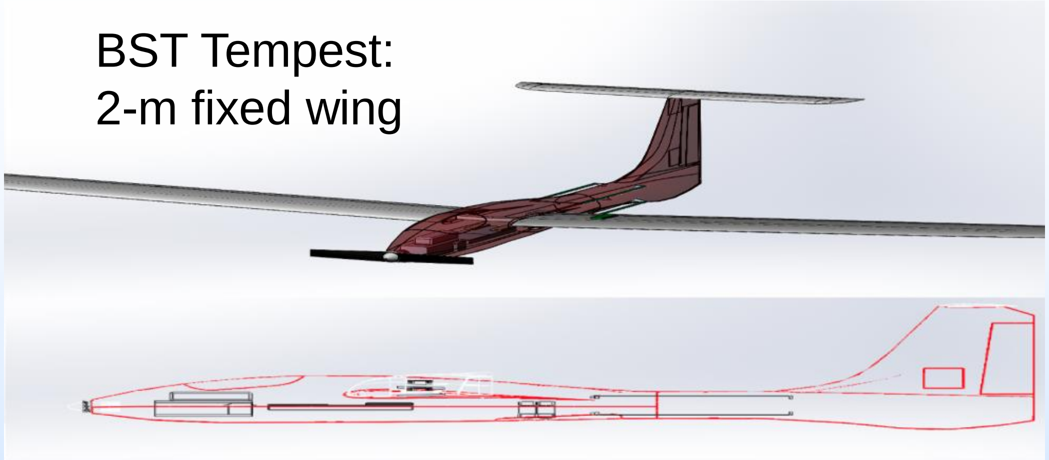
IF gain

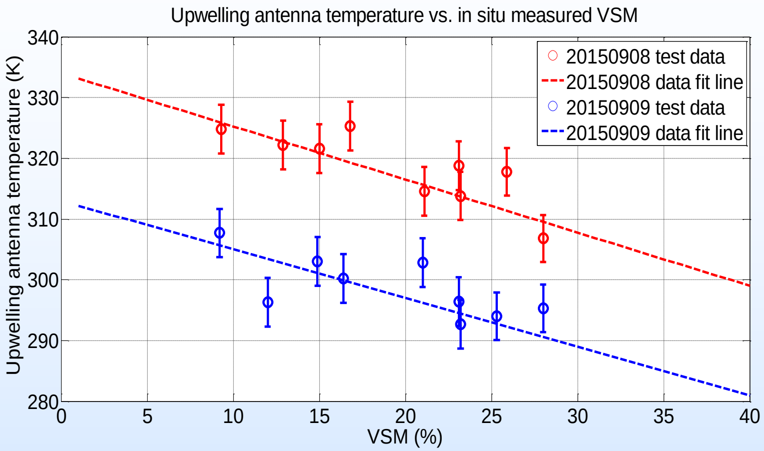
Total mass: 881 g

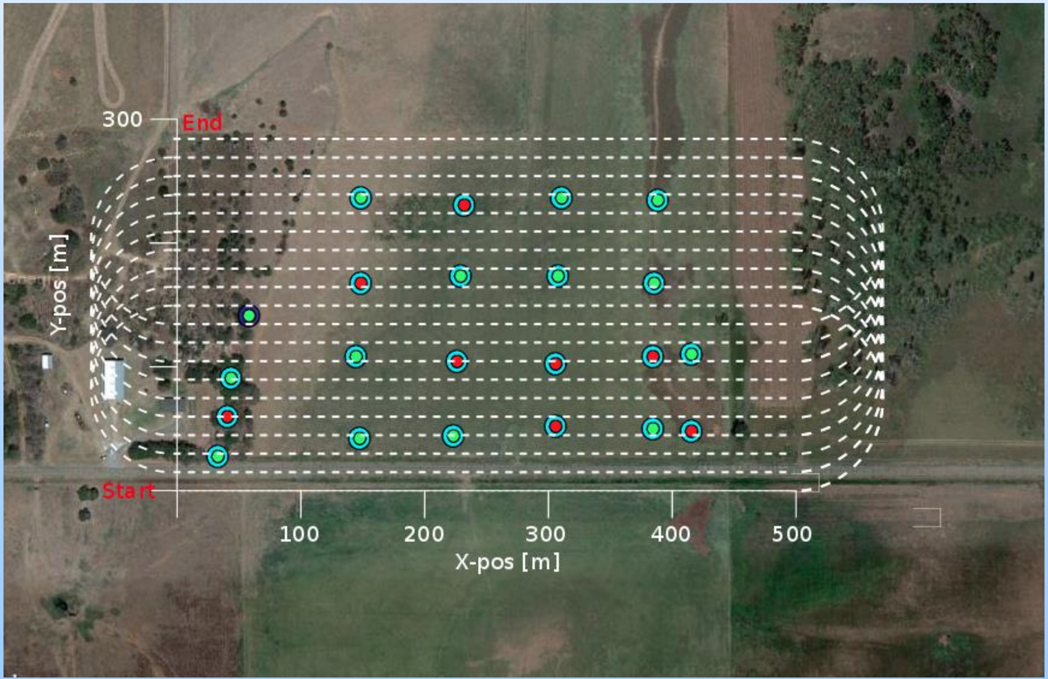
(batttery add'l 364 g)

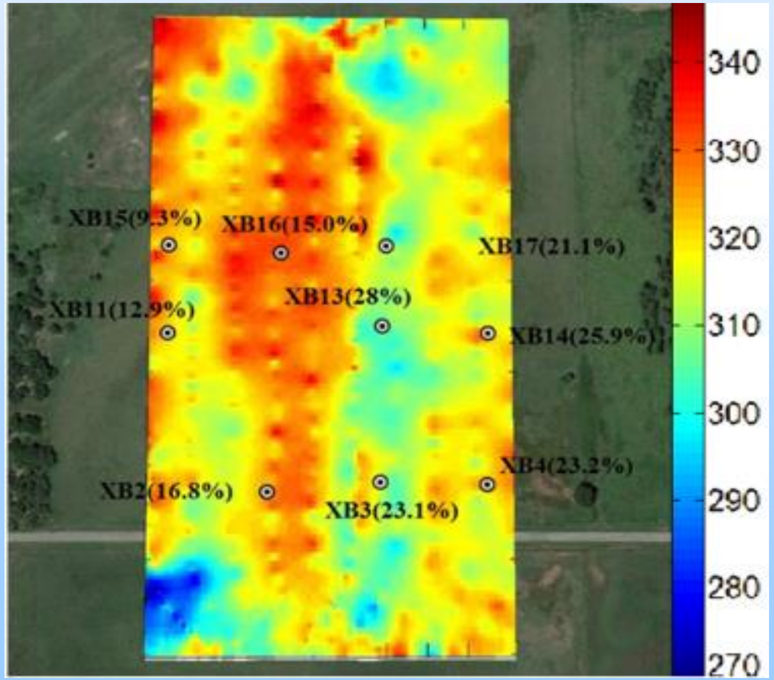
LDCR prototype receiver (23x8x4 cm) with analog correlator, A/D, and microcontroller.

L-Band Soil Moisture Mapping using Small UAS

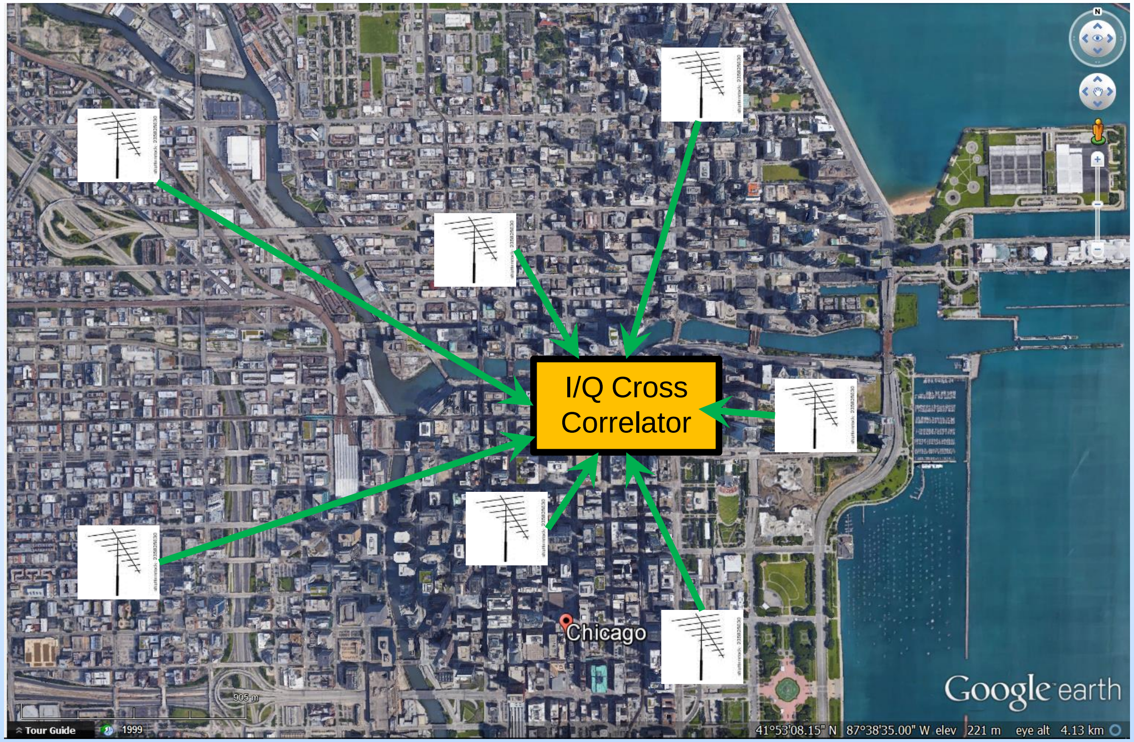








Coherent Spectrum Monitoring
Persistent "Inverse GPS"



$\Delta r \sim c/\Delta f$

$T_s \sim 2/\Delta f$

$N_s \sim R_{max}/(cT_s)$

Example:

$\Delta f = 100$ MHz

$\Delta r \sim 3$ m

$T_s \sim 200$ MSps

$R_{max} = 45$ km

$N_s \sim 2^{15}$

- Nyquist-sampled data from several widely spaced receivers can be time-correlated to geolocate sources (uses phase/time delay and amplitude)
- Transient and multiple sources near noise floor can potentially be accurately geolocated and time-tagged. Use a-priori knowledge to narrow search/track.
- Requires central (not distributed) wideband FPGA-based cross-correlation processor and wideband (e.g., fiber optic or optical free space) data pipes (~10 Gbps).

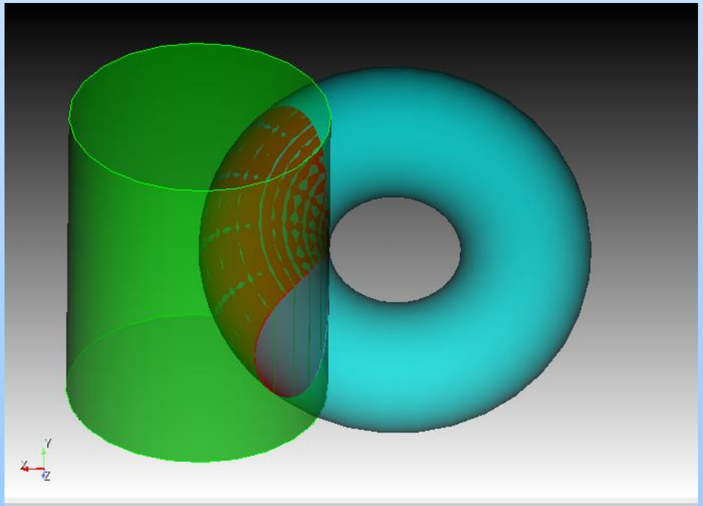
Manifold-Based System for Passive-Active Spectrum Sharing

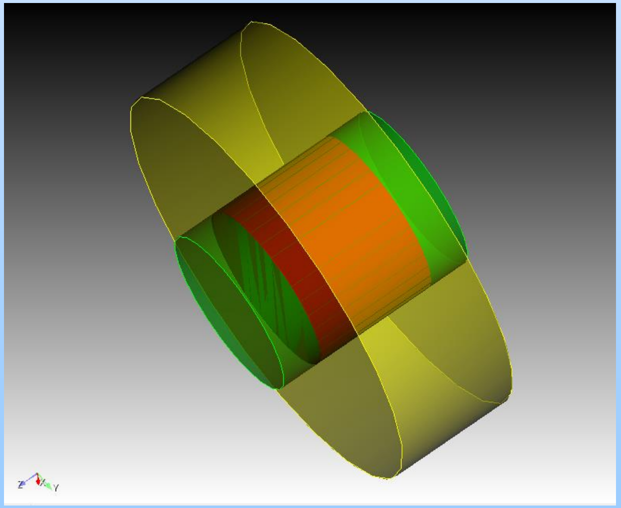
Objective: To develop an automated scalable technique for identifying interference in 7-dimensional "electrospace" ($f, x, y, z, \theta, \phi, t$).

The spectral, spatial, angular, and temporal needs of each eligible service within a band can be defined by a **manifold** (i.e., hypervolume) in 7-D electrospace (Joshua Chong, MS Thesis, 2014).

Intersections of manifolds identify **competitive hypervolumes** for which priority-based arbitration or interference flagging can be used.

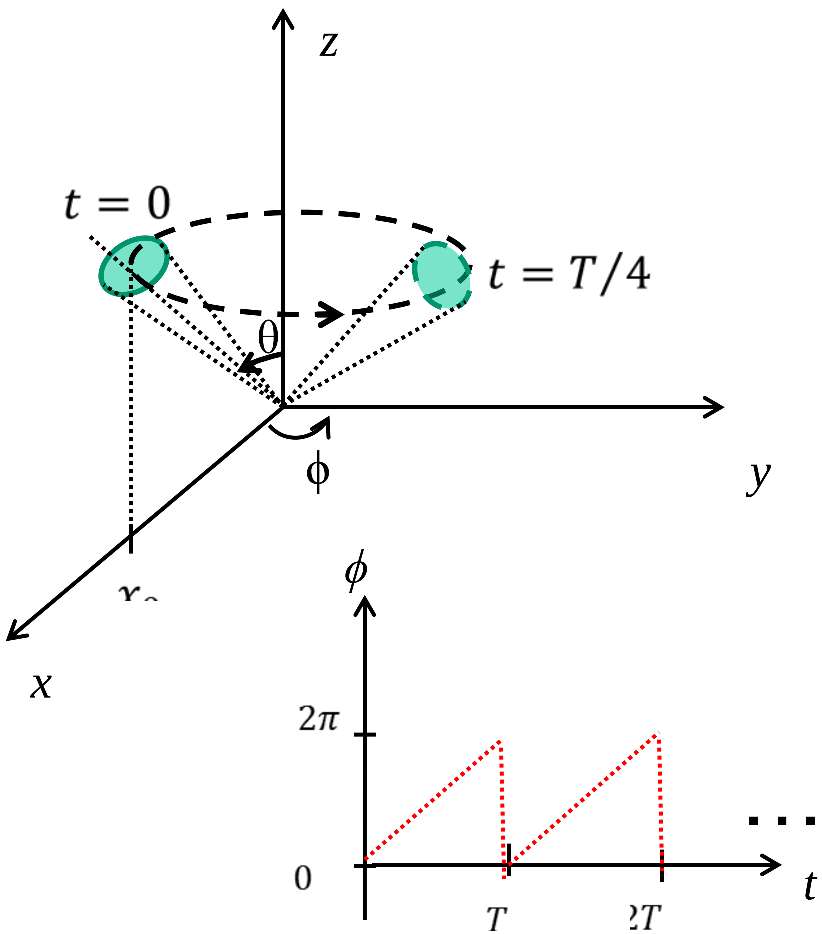
Competitive volumes in 3-D space illustrated by the intersection of one or more 2-D manifolds (i.e., differentiable surfaces)

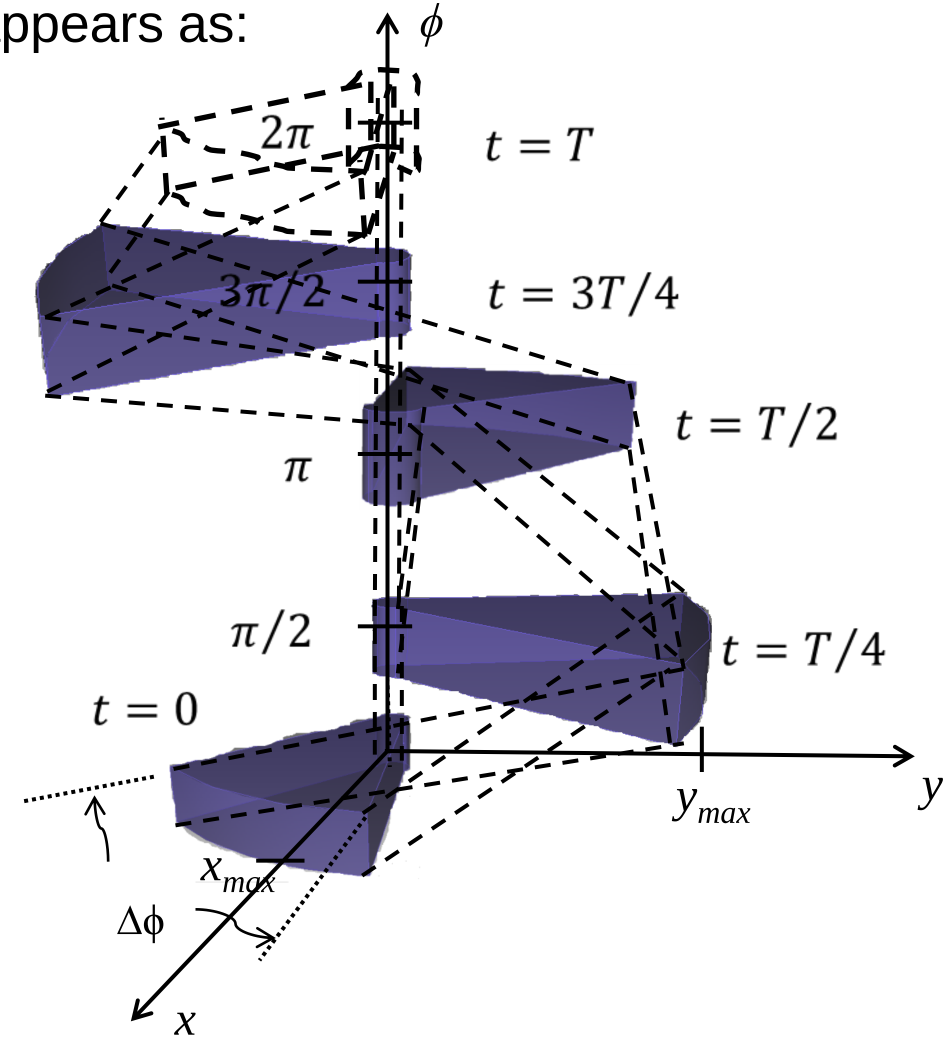




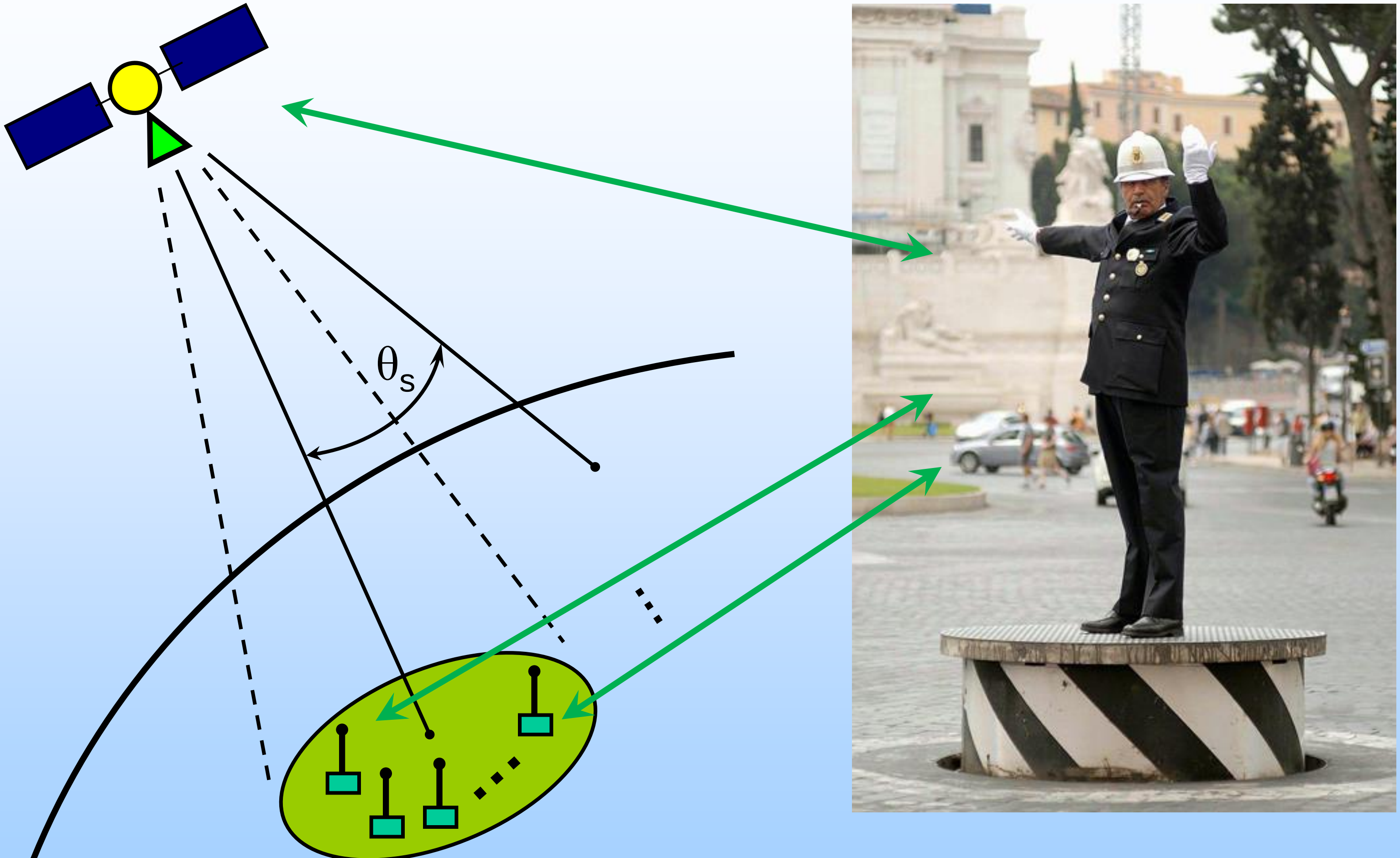
Visualization of Manifolds
Ground-Based Terminal Area Radar

Manifolds can be depicted as **time-dependent hypervolumes** sliced in 3-D space. A **conically-scanned terminal area radar** uses a transmit manifold that when sliced in (x, y, ϕ) appears as:





Manifold Based RFI Mitigation



- Users signal their intention to use electrospace on ~1-10 msec intervals
- Spectrum “broker” provides a real-time non-compulsory assessment of RFI
- Users are free to act on RFI data as they see fit

Enabling Research (at Universities)

- Provide 3-5 year graduate fellowships. *This is an investment opportunity!*
- Provide year-round opportunities for small and regular hardware grant proposals
- Support regular forums for research dissemination (URSI NRSM Commission E sessions)
- Good example: NSF EARS (but opportunities are not often enough, too much “winner-take-all”)

AUGUST 3rd

2:45 Panel **Data Analytics**

Moderator: Tim Hall, NIST/CTL

This panel will focus on the mathematical techniques for analyzing captured signal data, with an emphasis on machine learning, data mining and artificial intelligence techniques. Classical pattern recognition and other statistically-based methods may also be included. The limitations and potential pitfalls of each technique will be considered along with the advantages and capabilities. Related to this topic is the question of what type and quantity of data need to be captured and retained in order to use each technique. Time and frequency resolution and appropriate quantization are examples of this. The panel will not only discuss current research results but will help identify specific topics and techniques where future research is still needed.

Panelists:

- **Tim O'Shea – Virginia Tech**
- **Tom Rondeau – DARPA**
- **Al Gasiewski – Science Band, University of Colorado**
- **Mitch Kokar – Northeastern University**
- **Dirk Grunwald – University of Colorado**

4:45 Closing Remarks **Keith Gremban, NTIA/ITS.D**