Ka-Band Atmospheric Noise Temperature Measurements Using a 34-Meter Beam-Waveguide Antenna

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Background

- NASA's Deep space missions have used 960 MHz, 2.3 GHz, and 8.4 GHz for spacecraft communication downlinks
- Ka-band (32 GHz) is being considered as a downlink frequency for future flight projects
  - Ka-band provides an advantage of 11.6dB (14.5 ratio) over X-band (8.4 GHz) in the spacecraft EIRP using the same transmitter output power and same antenna size
  - This downlink advantage is reduced to ~7 dB due to higher atmospheric noise, decreased ground station antenna efficiency and increased weather susceptibility at Ka-band
  - The higher Ka-band versus X-band downlink advantage can reduce cost, power, mass and volume of future space missions
  - In order to quantify this advantage, it is important to carefully characterize atmospheric effects at specific sites
- The Deep Space Network is supporting work to characterize the Ka-band atmospheric noise contribution at each of its three complexes

Surfsat- 1

- Surfsat-1 was launched on November 4, 1995 on a Delta-II Rocket
    - Carries an experiment to evaluate X/Ka link advantage and transponders to test Space VLBI ground stations at X and Ku bands
    - Is in a sun synchronous polar orbit (937 km by 1494 km)
    - Is observable 2-3 times near sunrise and sunset from the DSN R&D 34-m beam waveguide antenna DSS 13 in Goldstone near Barstow, Calif.
- Link experiment work deferred - Signal level data at X-band and Ka-band not yet fully modeled due to unanticipated dynamic motion of spacecraft
- Total Power Radiometer (TPR) data acquired from 192 tracking passes were processed to produce zenith atmospheric noise temperatures at Ka-band

Atmospheric Noise

- At microwave frequencies, atmospheric attenuation is a significant source of external noise in earth-space communication systems
- Opacity (or absorption) in earth's atmosphere at mm and cm wavelengths is primarily due to the combined effects of water (H_2O) and oxygen (0_2)
  - 0_2 is well distributed in the atmosphere and is relatively steady during a pass (8 km scale height)

    ~2K at X-band (8.4 GHz)

    ~4.5K at Ka-band (32.0 GHz)
  - H_2O vapor is concentrated in the lower 2 km near surface and is the principle variable component in atmosphere (2 km scale height)

    > ().2 K at X-band (8.4 GHz)

    >3 K at Ka-band (32.0 GHz)
  - H_2O hydrometeors

    variable on time scales of minutes

Data Acquisition

- Surfsat- 1 tracking data were acquired at DSS- 13 in Goldstone, California
  - Passes occurred within 3 hours of sunrise or sunset
  - Passes were typically 5 to 20 minutes in duration
  - 418 total tracks between launch (November 1995) and December 1996
  - Elevation angles ranged from 7 deg (8.2 air masses) up to 90 deg (one air mass) depending upon particular track across sky
- Total Power Radiometer (TPR) data were acquired for noise floor calibration of received signal strength data
  - 20 MHz filter bandwidth at X-band (8.4 GHz); 30 MHz at Ka-band (32 GHz); 5 sec integration time
  - Spacecraft signal was not in filter bandpass
- WVR and surface meteorological data also acquired
  - WVR 31.4 GHz averaged brightness temperature over BWG tip curve time period was converted to 32 GHz for intercomparison.
  - Surface meteorological data converted to estimates of atmospheric noise temperature using model of Ulaby, Moore and Fung.

Model and Fit Strategy

- TOP measurements are "raw data" (192 data sets used in study)
- Pre-fit Top's are estimated from raw TOP measurements by removing non-atmospheric dependent effects ;

  $$\text{ATOP}(\theta) = T_{op}(\theta) - T_{ant}(\theta) - T_{equipment}$$

- The remaining signature in ATOP is atmosphere dependent;

  $$\text{ATOP}(\theta) = \text{Bias} + [T_{cb}/L_{atm}(\theta) + T_{atm}(\theta)]/L_{ant}$$

  T_{cb} is effective cosmic background (2.5K at X-band; 2.0K at Ka-band)

  $T_{atm}(\theta) = T_{O2}\,[1 - \exp -\tau_{O2} A(\theta)]\,\exp -\tau_{H2O} A(\theta) + T_{H2O}[1 - \exp -\tau_{H2O} A(\theta)]$

  $L_{atm}(\theta) = \exp\,[(\tau_{O2} + \tau_{H2O}) A(\theta)]$, $A(\theta)$ is airmass number (~$1/\sin(\theta)$)

  Reference: Kutner, M. L., Astrophysical Letters, 1978 Vol. 19, pp. 81-87.

- Ka-band data from 1 airmass (90 deg elev) to 5.5 airmasses (10.5 deg elev) are fit. X-band model derived from Ka-band fit for this study.
- Bias and τ_{H2O} are solve-for parameters from least-squares fit. (τ_{O2} calculated from surface model)
- Post-fit residuals are computed by removing the fitted model from pre-fit residuals. Scatter of these residuals is a measure of goodness of fit and/or "bumpiness" of atmospheric variations over pass.

Error Sources

- BWG Top measurement error sources
  - gain instability (-0.1K)
  - thermal noise (0.005K)
  - atmospheric fluctuations (variable; dependent upon weather conditions)
- Model uncertainty believed to be below ±0.5K in elevation dependent signature of non-atmospheric antenna model (tripod scatter and backlobe pickup)
- Selection effect - near-dawn or near-dusk observations only
- WVR and BWG intercomparisons
  - ±0.5K absolute calibration error of each system
  - BWG and WVR spatially sampling different atmosphere
  - 31.4 GHz to 32 GHz correction accounts for water vapor and oxygen but not for water droplets

Results

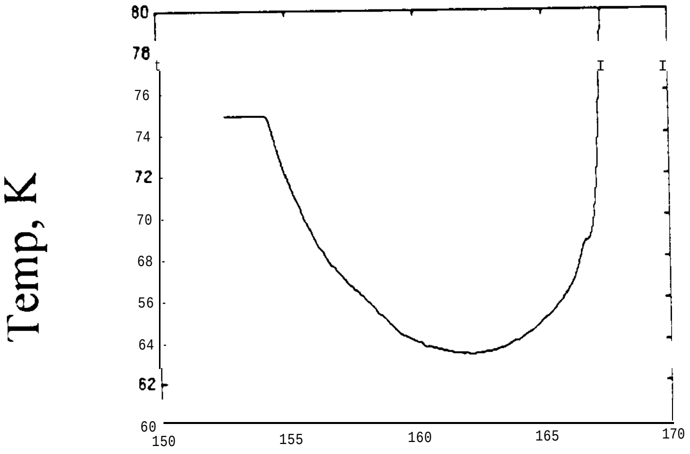
- For each pass, an Atmospheric Noise Temperature at zenith, $T_{atm}(90)$ was estimated from available BWG Tip Curve, WVR, and surface model meteorological data

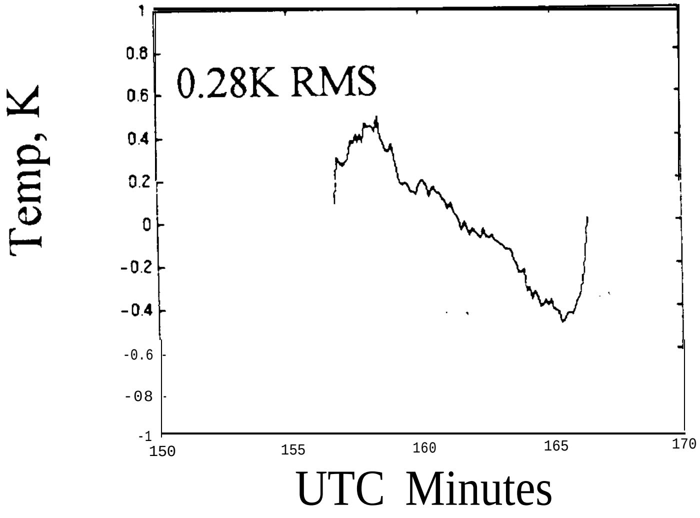
- Statistics on these estimates over all available passes are presented below

	Mean	RMs	Minimum	Maximum	Number of Passes
BWG	10.6 K	4.0 K	7.3 K	56.2 K	192
WVR	11.0 K	2.0 K	8.1 K	16.5 K	115
MODEL	9.4 K	1.8K	6.1 K	16.2 K	173

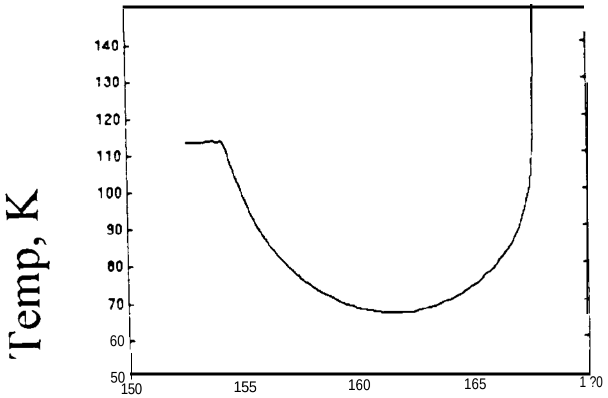
Example of ‘Clear’ Weather Data
96-150b Raw Top Data and Post-Fit Residuals

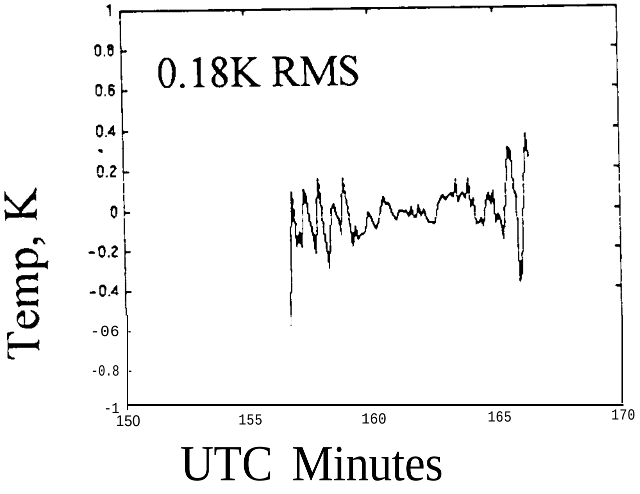
X-BAND



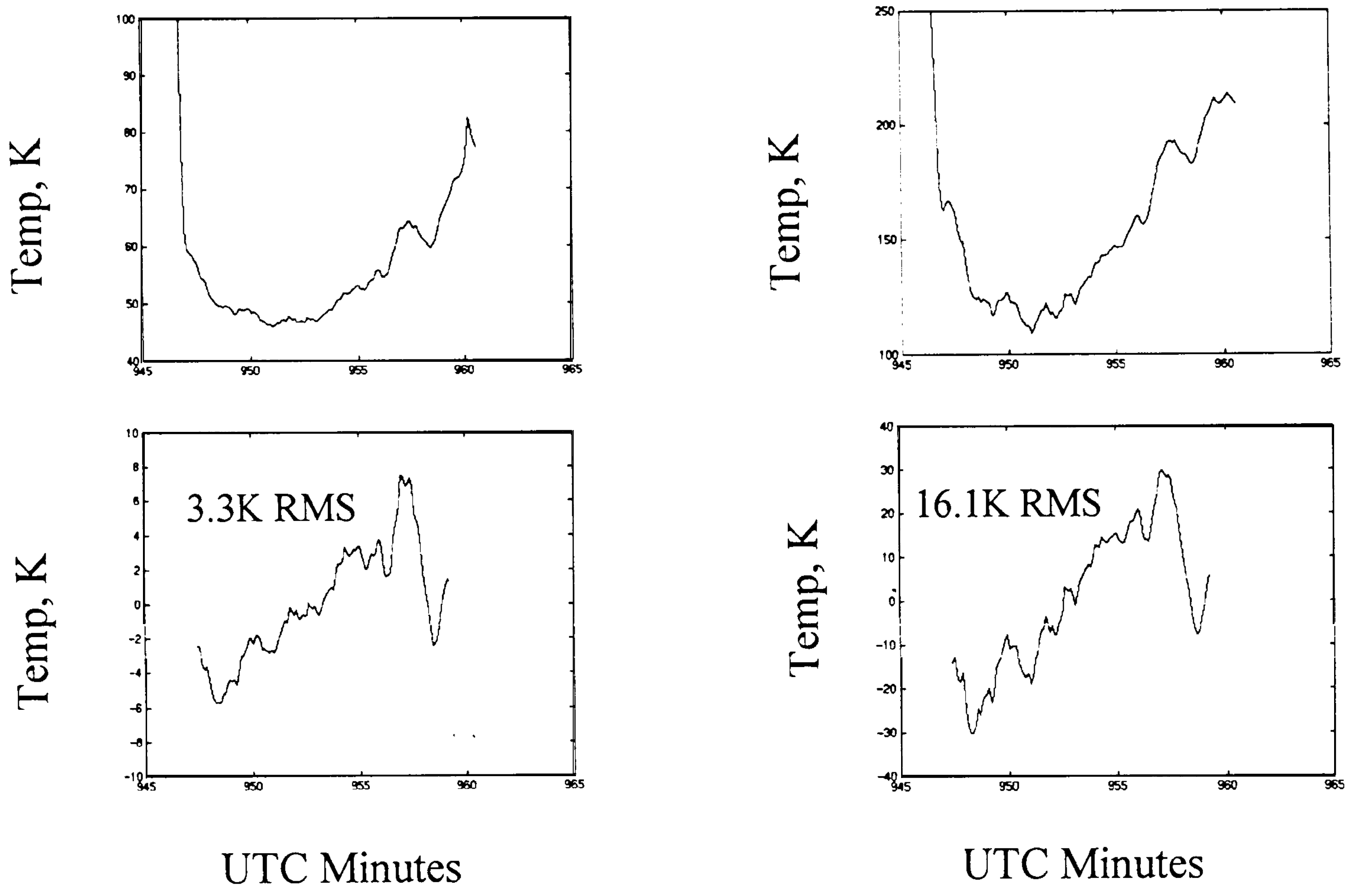


Ka-BAND





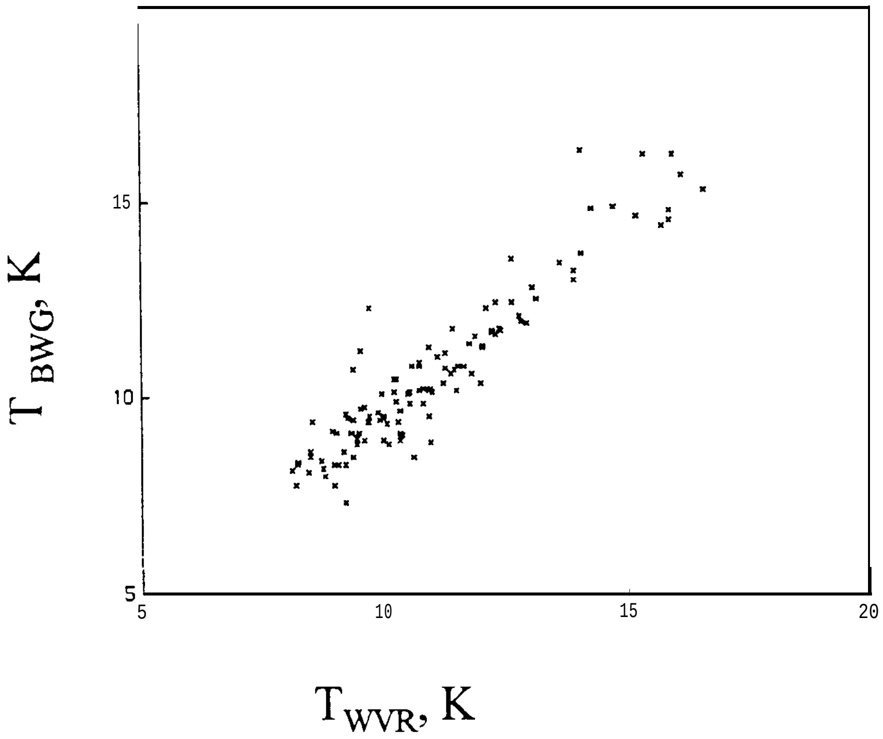
Example of Cloudy Weather Data
96-073d Raw Top Data and Post-Fit Residuals



BWG versus WVR

Concurrent Data Acquired During Tip Curve Periods

Zenith Atmospheric Noise Temperature



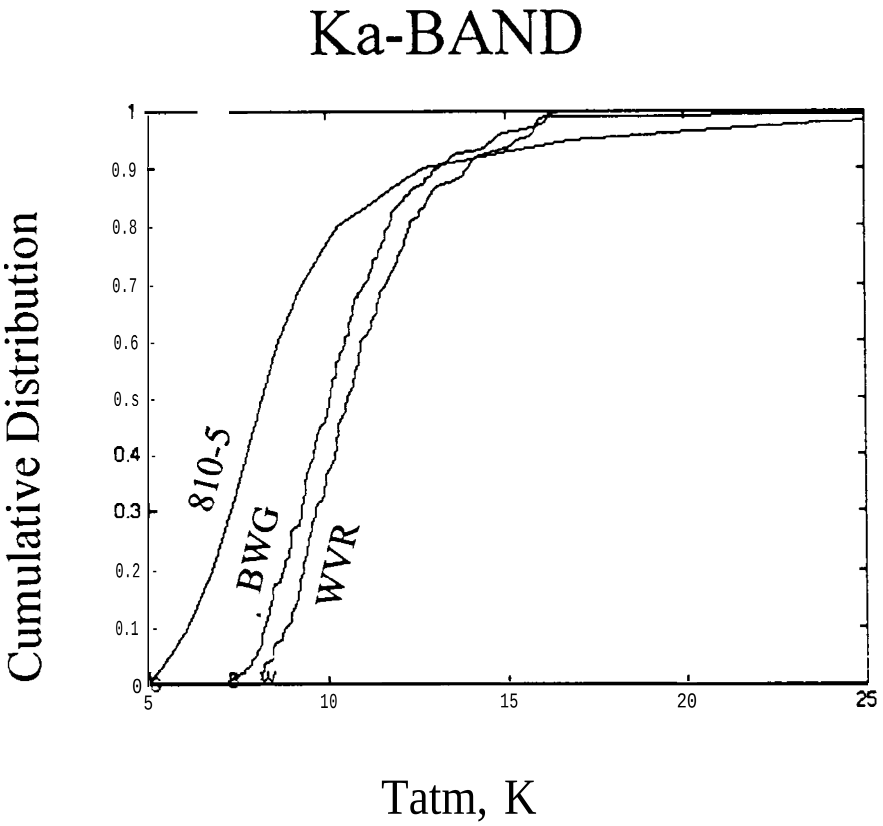
- BWG and WVR $T_{atm}(90°)$ are in general agreement
  - typically within ±0.5K absolute uncertainties of each system
  - larger differences could be explained by both systems sampling different spatial areas of sky
- A linear fit of the 115 common data points yields

$$T_{BWG} = \underset{\pm 0.04}{0.96}\, T_{WVR} - \underset{\pm 0.40K}{0.12K}$$

0.76K rms scatter about fitted line

Cumulative Distribution

810-5 is internal JPL
DSN document used
by flight projects



CONCLUSIONS

- BWG Ka-band TPR Data Acquired During Surfsat-1 Provides Valid Estimates of Atmospheric Noise Temperatures
- BWG and WVR Estimates are in Agreement within Uncertainties of Both Systems