

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

David Morabito, Robert Clauss,
and Michael Speranza

Jet Propulsion Laboratory
California Institute of Technology

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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
- The Deep Space Network is supporting work to characterize the Ka-band atmospheric noise contribution at each of its three complexes

Background

- Ka-band provides an advantage of 11.6 dB (14.5 ratio) over X-band (8.4 GHz) in the spacecraft EIRP
- This downlink advantage is reduced to -7 dB due to higher atmospheric noise, decreased ground station antenna efficiency and increased weather susceptibility
- This higher 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

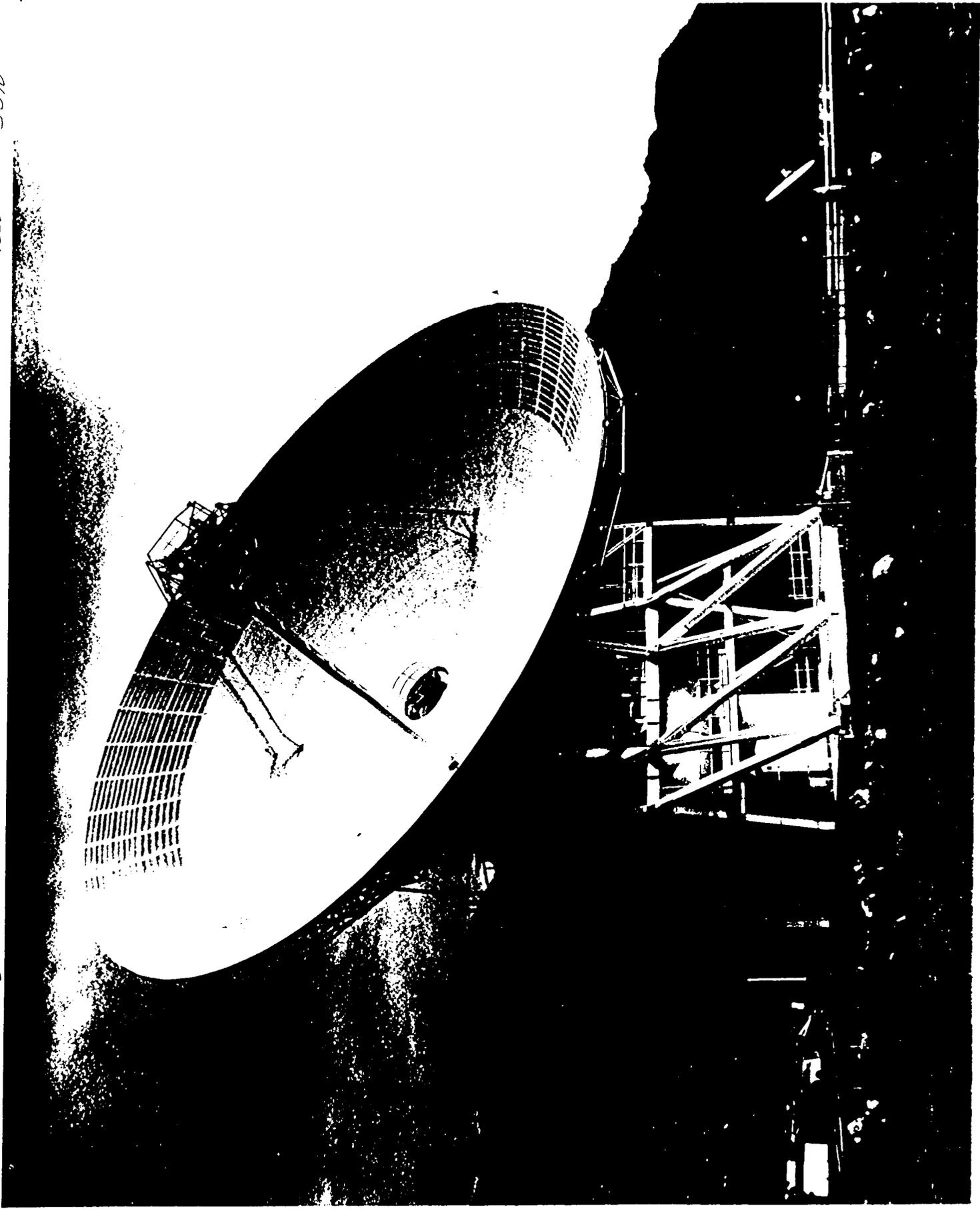
Surfsat-1

- Surfsat- 1 was launched on November 4, 1995 on a Delta-11 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

REDUCE TO 53%

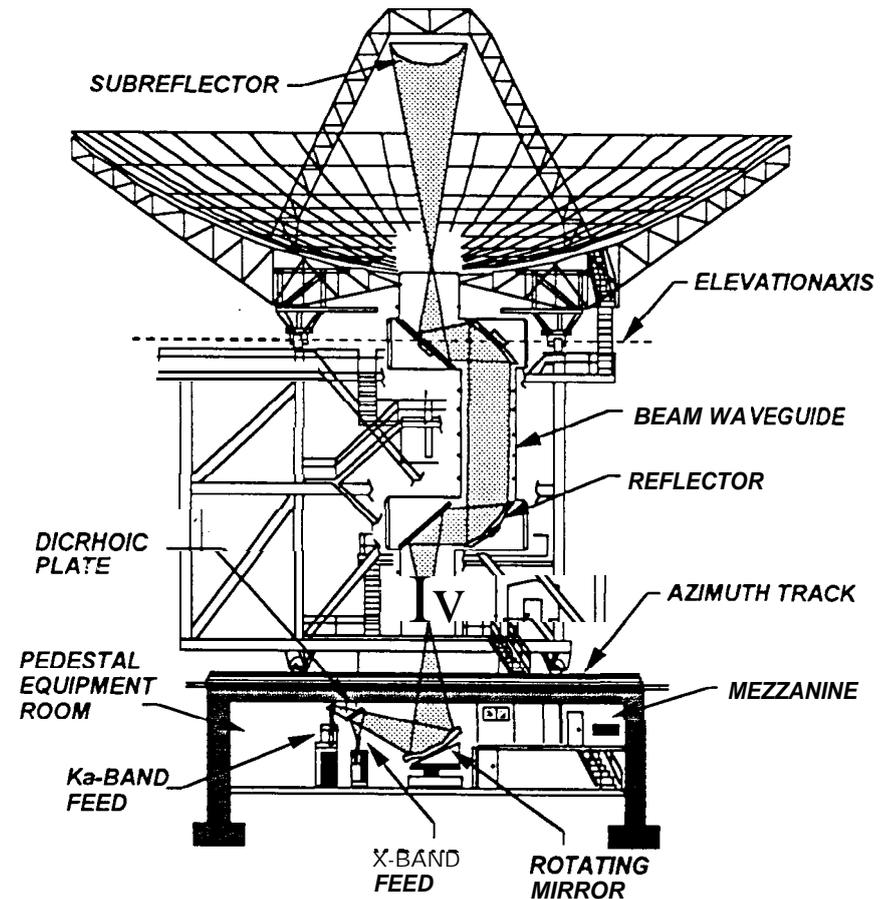
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FIG. 1 PAGE 153



DSS 13 R&D Beam Waveguide (BWG) Antenna

- R&D 34-m BWG antenna constructed as a prototype for the evolving DSN BWG subnet
- Provide stable environment for feed, receiver and electronics development
- Provide easy access to multiple development stations at feed ring located in the pedestal room
- Lower maintenance costs compared to non-BWG antennas
- Less susceptible to weather, for example, lower attenuation during rain
- Unique radio science and radio astronomy facility



Atmospheric Noise

- At microwave frequencies, atmospheric attenuation is a significant source of external noise in earth-space communication systems
- Absorption in earth's atmosphere at these frequencies is primarily due to the combined effects of H_2O and O_2
 - O_2 is well distributed in the atmosphere and is relatively steady during a pass (8 km scale height)
 - H_2O vapor is concentrated in the lower 2 km near surface and is the principle variable component in atmosphere (2 km scale height)
 - H_2O droplets
 - variable on time scales of minutes

Data Acquisition

- Surfsat- 1 tracking data were acquired at DSS-13
 - 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
- Water Vapor Radiometer (WVR) and surface meteorological data were 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)
- Pre-fit Top’s are estimated from raw TOP measurements by removing non-atmospheric dependent effects ;

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

- The remaining signature in ATOP is atmosphere dependent;

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

where

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

$T_{atm}(\theta) = T_{O_2} [1 - \exp -\tau_{O_2} A(\theta)] \exp -\tau_{H_2O} A(\theta) + T_{H_2O} [1 - \exp -\tau_{H_2O} A(\theta)]$

$L_{atm}(\theta) = \exp [(T_{O_2} + \tau_{H_2O}) A(\theta)]$, $A(\theta)$ is airmass number ($\sim 1/\sin(\theta)$)

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

Model and Fit Strategy

- 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 $\tau_{\text{H}_2\text{O}}$ are solve-for parameters from least-squares fit. (τ_{O_2} 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 $\pm 0.5\text{K}$ in elevation dependent signature of non-atmospheric antenna model (tripod scatter and backlobe pickup)
- Selection effect - near-dawn or near-dusk observations only

Results

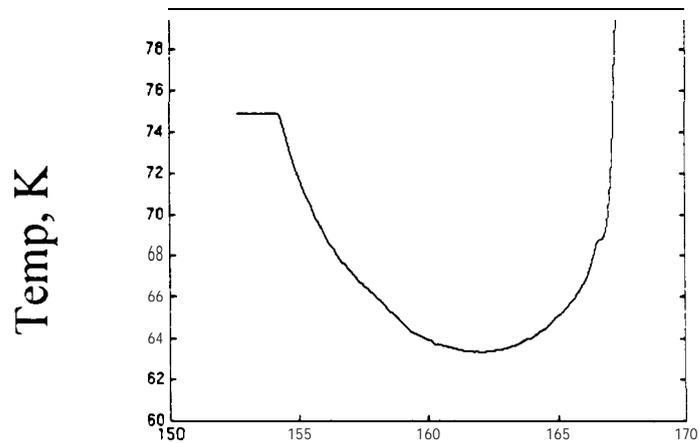
- For each pass, an Atmospheric Noise Temperature at zenith, $T_{\text{atm}}(90)$ was estimated from available BWG Tip Curve, WVR, and surface model meteorological data
- Statistics on these estimates over all available passes are presented below

	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	1.8 K	6.1 K	16.2 K	173

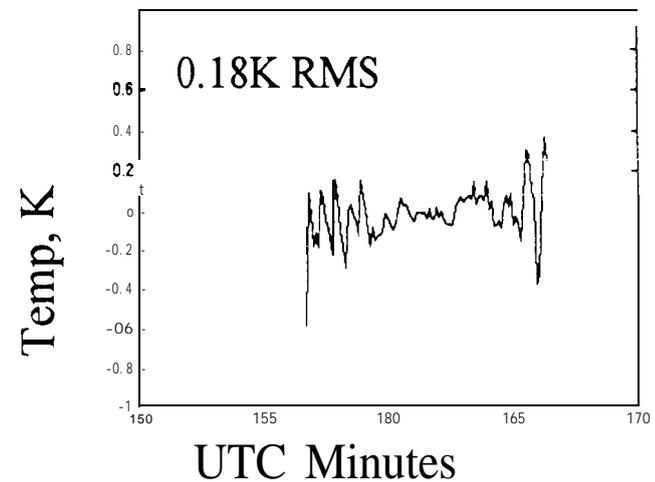
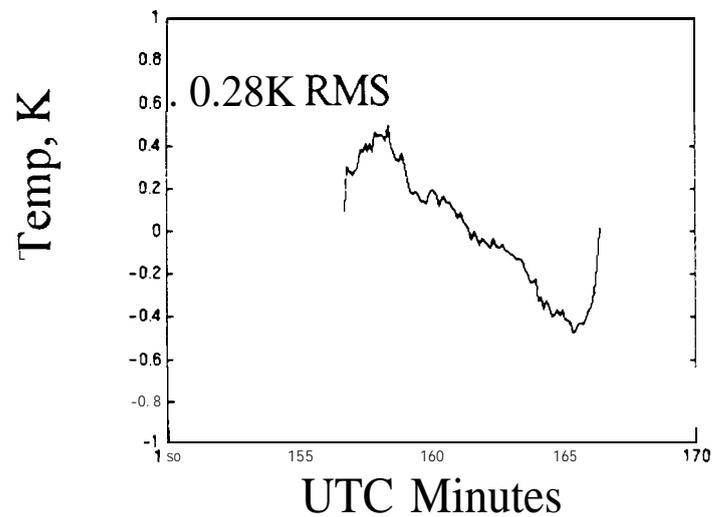
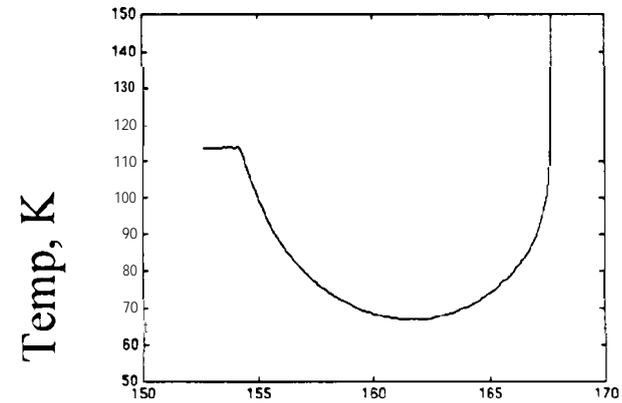
Example of 'Clear' Weather Data

96-150b Raw Top Data and Post-Fit Residuals

X-BAND

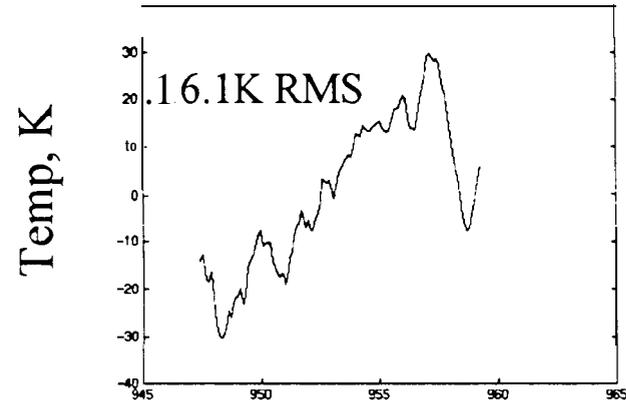
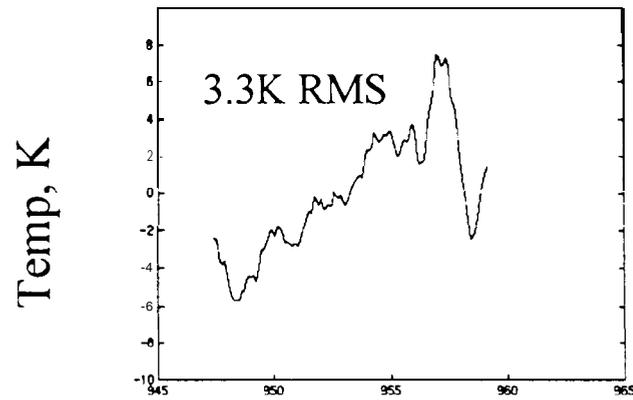
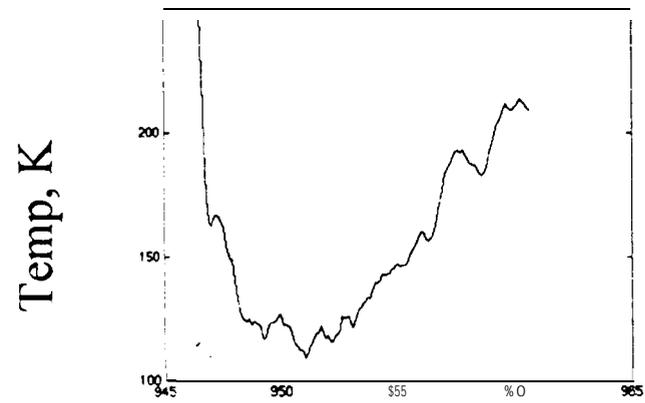
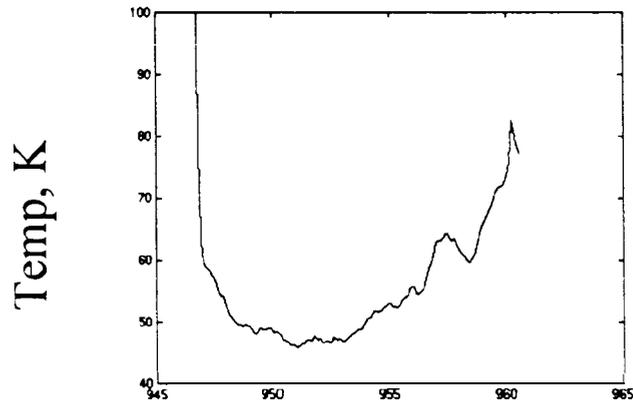


Ka-BAND



Example of Cloudy Weather Data

96-073d Raw Top Data and Post-Fit Residuals

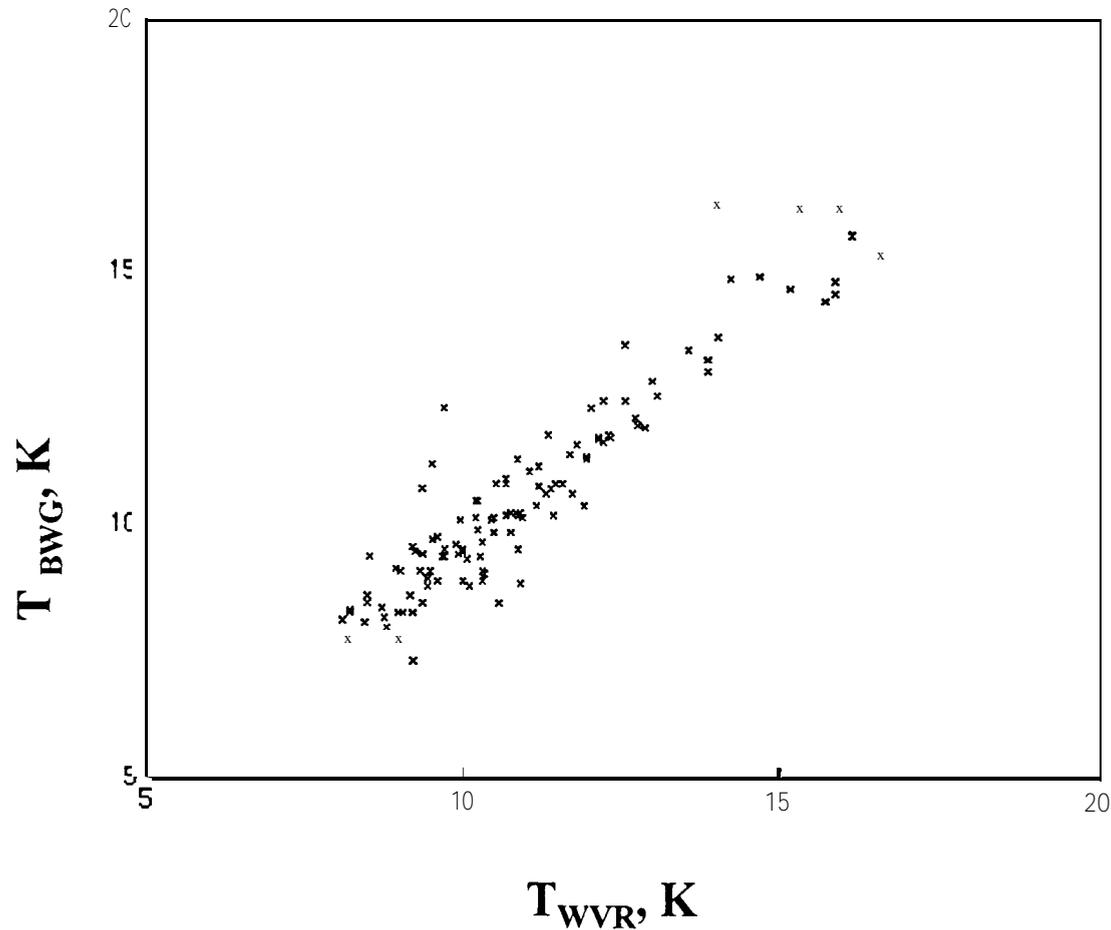


UTC Minutes

UTC Minutes

BWG versus WVR

One Airmass Atmospheric Noise Temperature Concurrently Acquired During Tip Curve Periods



BWG versus WVR

One Airmass Atmospheric Noise Temperature

- BWG and WVR $T_{\text{atm}}(90^\circ)$ are in general agreement
 - typically within $\pm 0.5\text{K}$ absolute uncertainties of each system
 - larger differences could be explained by both systems sampling different spatial areas of sky
 - **31.4 GHz to 32 GHz** correction of WVR accounts for water vapor and oxygen but not for water droplets
- A linear fit of the 115 common data points yields

$$T_{\text{BWG}} = \mathbf{0.96} T_{\text{WVR}} - 0.12\text{K}$$
$$\pm 0.04 \qquad \pm 0.40\text{K}$$

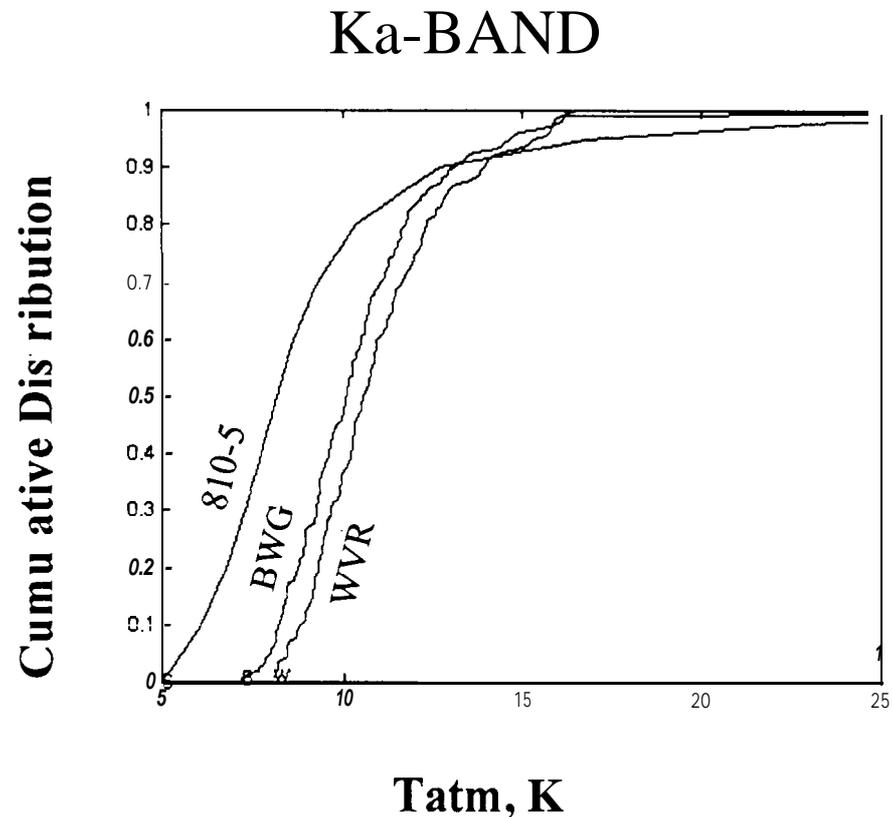
0.76K rms scatter about fitted line

Cumulative Distribution

Cumulative distributions at specific tracking sites are used by planners of future flight projects to assess 900/0 or 95°/0 weather effects for spacecraft-to-ground link budgets

BWG, WVR and 810-5 cumulative distribution curves are plotted here for the common BWG tip curve periods of the studied data sets

810-5 is internal JPL DSN document currently 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
 - The WVR is used to calibrate atmospheric effects for geodetic systems
 - This work verifies the 0.5K accuracy of the atmospheric noise temperatures measured by the BWG