CANOPUS Quiet Day Curve Generation

Introduction

A riometer works on the premise that high-energy particle precipitation will cause deviations in the amount of cosmic radio noise that passes through the ionosphere at certain frequencies. When these particles enter the upper atmosphere, the fractional ionization significantly increases. The increased number of free electrons at altitudes where electron motion is collision-dominated attenuates the cosmic radio waves. The fractional amount of attenuation depends on the energy flux of particles and the frequency of the radio wave. At frequencies below 20MHz the radio waves are often extinguished before they pass through the ionosphere, leading to a radio blackout. Higher than 50MHz, the attenuation is difficult to distinguish from the signal itself. Using frequencies between the two (20-50MHz) a riometer monitors the "steady" signal of the cosmic background, and detects a reduction in the signal strength during particle precipitation events. Isolating the signature of these particles requires the characterization and removal of the background. Our current method of baselining is built on an understanding of what a riometer sees and involves the creation of a single baseline curve for each riometer. We try to characterize the shape of the cosmic background rather than producing curves specific to any subset of the data. Our baseline curves are specific to each riometer site and each beam pattern. Each baseline curve is representative of the sidereal day field of view for each riometer and is independent of instrument parameters and environmental conditions both of which common vary.

What a Riometer Sees

Each CANOPUS riometer is a 30 MHz zenith oriented 4-element antenna with a single 150 kHz broadband receiver[1]. Essentially a radio receiver, the instruments record the voltage/power of the 30MHz cosmic background noise. This signal has a sidereal day variation induced by the Earth's rotation sweeping the riometer field of view across the sky. The varying fluxes of cosmic radio noise form a periodic curve in riometer data which is the baseline or quiet day curve.

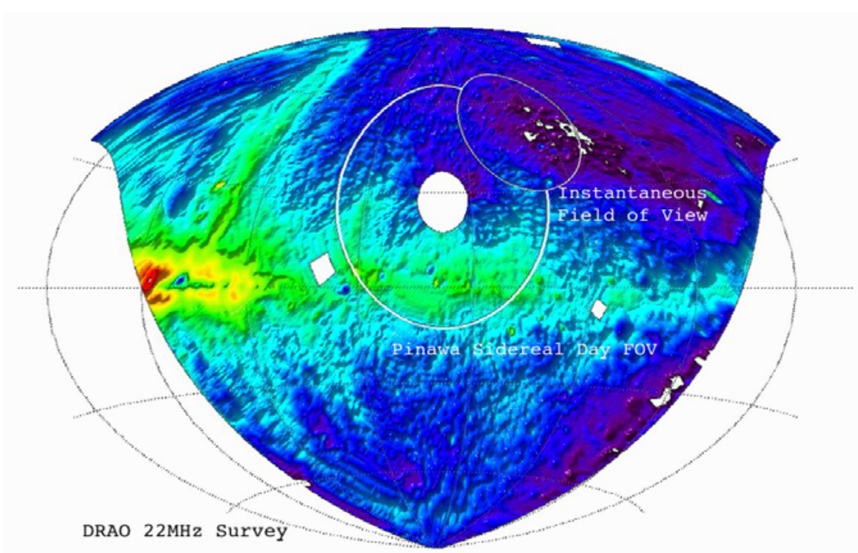

Figure 1: DRAO 22 MHz Galactic Survey (courtesy of Tom Landecker). The sidereal day path of the Pinawa riometer (large circle), along with the instantaneous FOV (small circle).

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[1] Instruments supplied by La Jolla Sciences of Solana Beach, California.

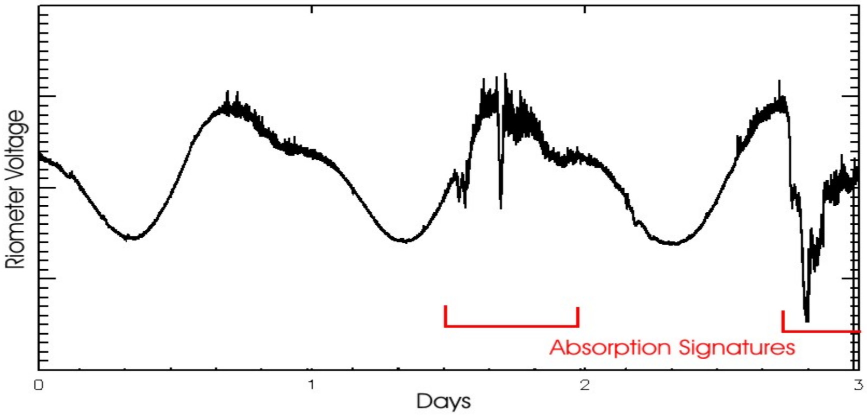
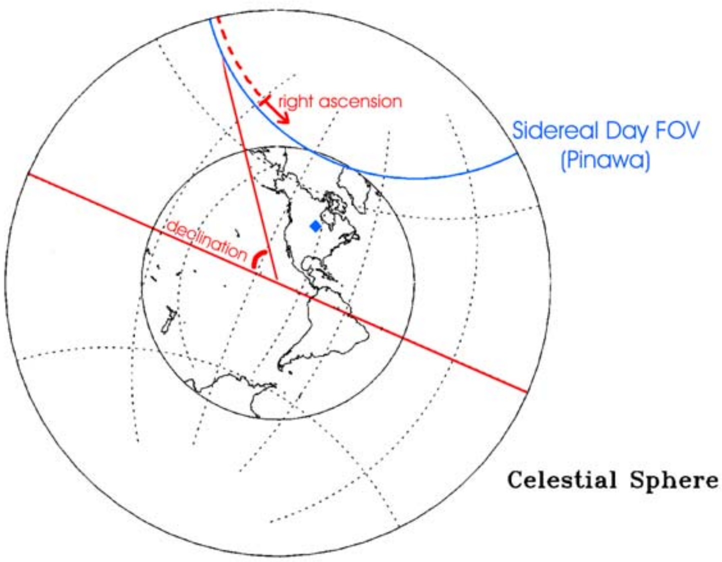


Figure 2: Three days of riometer data.

Superimposed on the quiet day curve are the absorption signatures associated with magnetospheric phenomena. Absorption signatures are typically on a shorter time scale than the quiet day curve and are easily distinguishable by eye. The key to our baselining technique is to separate these two fundamental signatures and sort the "quiet times" in term of where in the sky the riometer is observing. For this reason we introduce celestial coordinates.

Celestial coordinates are a latitude, longitude system (called declination and right ascension respectively) used by astronomers to describe a location on the celestial sphere, a sphere concurrent with the Earth. The Earth rotates within the celestial sphere with a period of a sidereal day (23hr 56min 4s), as opposed to the standard 24hour clock. Since right ascension will repeat every sidereal day it is often referred to as sidereal time, with each hour equivalent to 15.04 degrees.



The zenith orientation of the antennae implies that the declination of the centre view is always constant (and equal to the geographic latitude of the station). The quiet day curve will then be solely a function of right ascension.

Binning riometer data according to sidereal time is the first step towards creating a quiet day curve.

Problems Associated with Using the Raw Data to Determine the Quiet Day Curve

Riometer data is subject to numerous instrumentation problems that arise from environmental conditions. Snow pack around the antenna can reduce the overall power levels recorded, seasonal changes in the amount of photo ionization in the upper atmosphere can change the lensing properties of the ionosphere and thus the beam pattern, changes in permafrost levels, ground temperature / moisture, all of this can change the riometers perception of the "absolute" power level. It is unclear on any given day what power level should be assigned to the cosmic background.

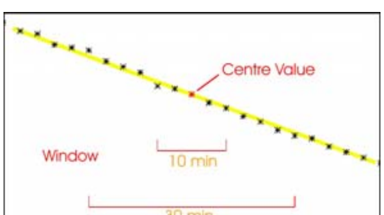
One constancy during these effects is the fractional change in observed flux as the riometer field of view sweeps across the sky. That is, if the riometer were to record a certain value, say 100dB while looking toward the centre of the galaxy then we can say that 2hr prior to that (assuming instrument parameters are constant) the riometer should have received on the order of 80dB. This is actually the derivative of the signal with respect to sidereal time/ right ascension. By identifying the derivative we no longer have to worry about the "absolute" power level. We can generate a curve that is independent of instrument conditions and purely a function of the riometer's orientation.

Generating the Quiet Day Curve

1) The Quiet Day Database: The first step in the process of creating a quiet day curve is to identify the subset of data that can be called "quiet". A "quiet time" was identified as an interval exceeding two hours in which no visible absorption or instrument effects were present. By searching through a minimum of three years of data from each station, we identified approx. 2000 hours of quiet time readings from each riometer. This comprises the database from which the rest of the calculations took place. This database can be compiled in either the raw data units, in our case volts, or dB (preferred). The conversion to dB was unavailable at the time we generated the quiet day curves so all calculations were done in volts. Since the dB conversions are stable over a period of three years the errors introduces by using voltage should be negligible.

2) Derivative with Respect to Sidereal Time: Each quiet interval is put through the same process. It is binned according to sidereal time[2], which is the longitude of the zenith in celestial coordinates. Then median filtered into a standardized sidereal time array (576 points, corresponding to one point every 2.5 minutes). The first derivative was approximated for each sidereal time using an expanding window around each point.

This is done using pairs of points centred about the initial value and calculating the value of,



$$\frac{df}{dx} \approx \frac{f(x+h) - f(x-h)}{2h}$$

for pairs spanning up to 55 minutes. The median value of these 11 values was assigned as the derivative of the centre point. Completing this procedure for **all** values of **all** quiet intervals compiles a derivative database for the quiet day curve.

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[2] Conversion from local time to sidereal time is done with ZENPOS,CT2LST,JDCNV. IDL code obtained from the NASA's IDL Astronomy User's Library (http://idlastro.gsfc.nasa.gov/contents.html).

The derivative database contains more than 60 derivatives for each sidereal time. The systematic variation of # of values with sidereal time can be attributed to selection criteria for quiet intervals. There is a tendency not to select quiet times when the noise level is high, however some noise is directly related to cosmic radio sources. When those sources enter the riometer field of view there will naturally not be as many selected quiet intervals. The use of 2000 hours of quiet time allows us to compile enough quiet intervals over those periods which are typically noisier.

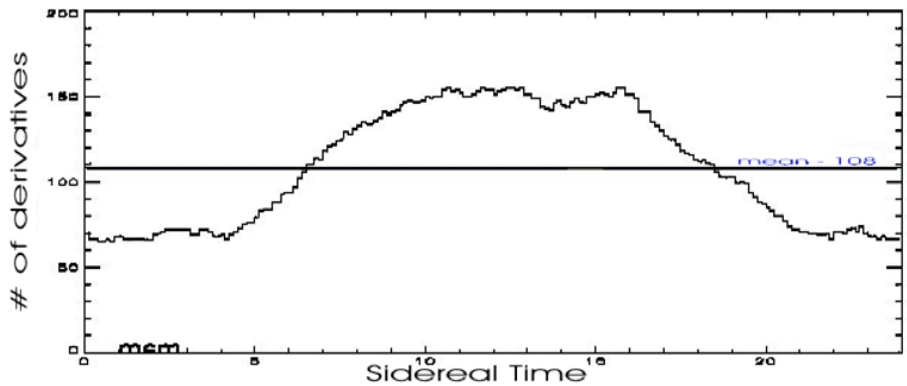

Figure 3: The number of points in the derivative database as a function of sidereal time for mcm.

3) Re-Generating the Curve: Using the derivative database and taking the median value of the derivative for each standard sidereal time, a single derivative curve is constructed. On average we are taking the median value of 108 derivatives to construct the quiet day curve. Numerical integration generates the quiet day curve in either dB or volts.

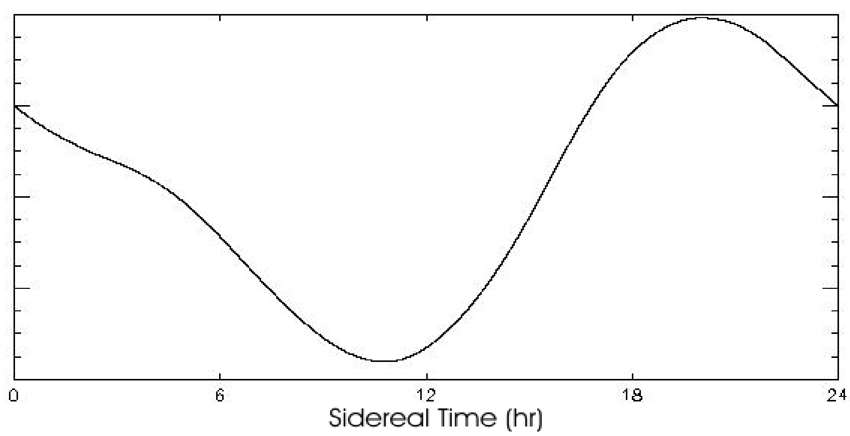

Figure 4: Quiet day curve for mcm.

This produces a curve that is unique to the instrument and the beam pattern. Only one curve is generated for each CANOPUS riometer.

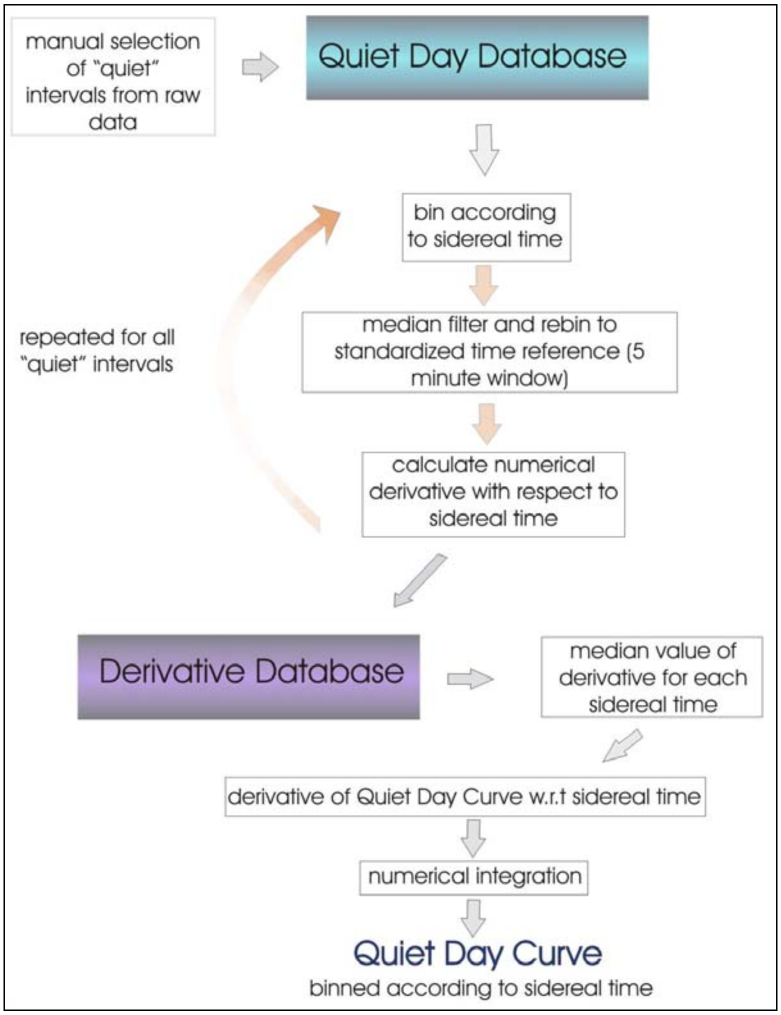

Figure 5: CANOPUS quiet day curve generation

The major draw back of this technique is that these parameters, representative of the instrumental conditions, must be added. The DC offset and amplitude, both of which seem to change with the gain and environmental conditions, are added to subsets of the raw data using our fitting procedure.

Fitting Procedure

The curve must be re-binned according to universal time and must also be fit with a DC offset and amplitude factor. The DC offset accounts for the gain of the instrument while the amplitude factor accounts for the gain and seasonal variation in ionospheric properties which tend to change the amplitude of the curve, but not the overall shape.

For manual fitting of the quiet day curve we typically use three days of data (longer intervals are used for more active periods). This procedure uses a least square fitting routine that fits the quiet day curve to only those portions of the data deemed to be "quiet".

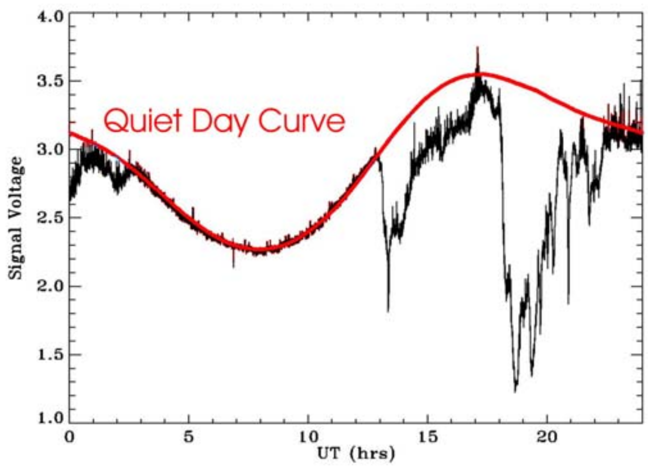

Figure 6: Example fit to one day of raw data.

Quiet intervals are first "selected" by the computer with the ability to manually add and remove data that is used for fitting. A 2D least square fit is used, with the DC offset and amplitude varying between predetermined limits. The DC offset is only allowed to vary between 1 and 4 volts, and the amplitude between 60 – 140% of the original quiet day curve. This ensures that we are fitting to data in which the decibel conversion will not introduce large uncertainties in absorption. Since we are fitting the curve in volts, and the decibel conversion is a logarithmic, the uncertainty in absorption is not constant for the entire day. It will be increase for lower DC and amplitude values. For this reason we do not fit to data with those instrument conditions.

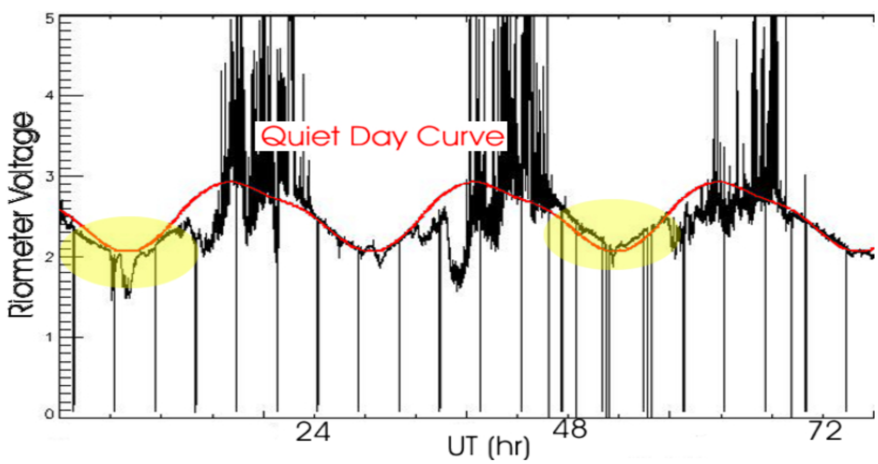

Figure 7: Example of data that cannot be fit using our technique. Yellow circles indicate poor fit due to instrument fluctuations on a day-to-day basis.