Systematic Errors: dependence of sampling bias on orbital configuration

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Goals

We are aiming to set up a observing system that can produce accurate climate statistics of IR brightness temperatures at a wide range of frequencies.

For the purposes of this talk we assume:

1. A satellite design capable of
   a) making 6 observations per minute, with a circular footprint of radius 30 km
   b) with a precision of < 1.0 K
   c) with an accuracy of < 0.1 K

2. A range of 1 to 3 satellites.

Then we ask: what accuracy can be achieved in spectrally resolved brightness temperature at a given spatial and temporal resolution.
Sources of sampling error

I. Systematic
   A. Diurnal sampling bias
   B. Seasonal sampling bias
   C. Spatial sampling bias

II. Random weather noise

We’ll estimate these errors by sampling both real and modeled brightness temperature error using virtual orbiters in a variety of orbits.
1987 Std. Dev. of 11 μm Brightness Temperature
Note the regions of large diurnal cycles where geostationary and polar satellite data are patched together (Over the Indian Ocean, and at high latitudes)
1987 Amplitude of Semidiurnal Cycle of 11 μm Brightness Temperature
Time of Day of B.T. Max, 1988 Annual Mean
Local Time (hr)

Temperature (K)

- Sahara (20°N, 17°E)
- Central Pacific (0°N, 180°E)
- Chile (15°S, 68°W)
- Washington, DC (36°N, 78°W)
- Global Mean
Observed local time of diurnal brightness temperature maximum

Vs.

Modeled (below)
Note that the large negative errors over the Indian Ocean and at high latitudes are spurious results of the process of patching together geostationary and polar satellite data.
B.T. Error for twice daily observations, whose time precesses once yearly
B.T. error for a single sun-synch. orbiter (Eq. Crossing Times: 4, 16 LT)

The diagram represents a heat map showing the distribution of error (in Kelvin) across various latitudes and longitudes. The error values range from -10 to 10 Kelvin, with color coding to visually indicate the magnitude and direction of the error. The map covers the entire globe, with latitude and longitude scales providing context for the data representation.
Standard Deviation of grid point errors for twice daily sampling at various times.

Error (K)

Local Time of Observations (AM & PM)
We now create simulated satellite data records by subsampling the modeled brightness temperatures using a number of orbits and combinations of orbits:

- **90° inclination “true” polar orbits at various initial longitudes** - observations rotate through 24 hours of local time twice over the year.

- **Sun-synchronous polar orbits at a range of equator crossing times**

- **60° inclination orbits with more rapid precession** - observations rotate through 24 hours of local time up to six times per year.

- **Note that random errors from weather noise are essentially defeated for yearly means at 15x15 resolution, since we have ~9000 observations (for a 90 degree orbiter) per grid square.** Diurnal sampling bias is the much more important error source.
B.T. error for a single sun-synch. orbiter (Eq. Crossing Times: 4, 16 LT)
Interannual B.T. difference error for three 90° polar orbiters
Interannual B.T. difference error for three sun-synchronous orbiters
How do the statistical properties of the data influence the grid-box errors?

There is no strong relationship between the standard deviation of the Brightness Temperature and the error in each grid box. This implies that 10 second samples are not statistically independent, and so that additional observations near the nadir track will reduce errors by less than a factor of the square root of $n$. 

![Graph showing relationship between Standard Deviation of BT / $n^{1/2}$ (K) and Sampling Error (K)]
Errors in zonal mean annual mean brightness temperatures
Spectral dependence of sampling errors: Calculations using model derived brightness temperature.

We now consider sampling errors of brightness temperature at several frequencies, calculated by applying Modtran to archived results of a one year run of the GFDL coupled climate model. We then sub-sample this data using a range of possible orbits and combinations of orbits to estimate the annual mean sampling error for a range of orbits.
We choose frequencies that sample a wide range of regions in the atmosphere.

**Figure 2.** (top) Brightness temperatures measured from the IRIS data and calculated from the GCM data. The spectra are averaged over all 10 months of observations and over three tropical regions. (bottom) The pressure level of the maximum emission to space for each wavenumber calculated using MODTRAN with a standard tropical atmosphere.
Window channel

~250 hPa
To understand the errors for high inclination orbits better we look at sampling error at $2^\circ\times2.5^\circ$ resolution, for a range of orbit altitudes, holding inclination constant.
Number of observations.
Sampling error in retrieving the local time.
Sampling error in retrieving the day of the year.
Errors for 2.5° model grid resolution
Prediction of errors for 15° grid boxes

- Actual Error (909 cm\(^{-1}\))
- Time of Day Error
- Time of Year Error
- Time of Half Year Error
A check on random errors

Do our proxy data accurately reflect the real variability that a CLARREO orbiter would see?

We select six representative 15° x 15° regions within which to test the sensitivity of CLARREO sampling errors to the frequency and footprint of observations.
Conclusions

• A single nadir-viewing satellite in a precessing orbit can achieve 1-σ sampling errors in 25 degree grid boxes less than 0.1 K for brightness temperatures in the spectral regions that mostly sample the upper troposphere and lower stratosphere.

• In the mid-troposphere channels and in the window channel, a single precessing orbiter requires zonal averaging to reliably attain errors of less than 0.1 K.

• For multiple orbiters, precession has large advantages in establishing accurate mean radiances, because a configuration of several sun-synchronous orbiters must sample the diurnal cycle evenly. For instance, if there are initially three orbiters separated by 8 hours in equator crossing time, the loss of a single orbiter will greatly reduce the accuracy of the remaining two orbiters, assuming they maintain their station.

• If only a single satellite is to be launched, the preferred orbit for climate monitoring is a true polar (precessing) orbit, as this substantially reduces errors in mean brightness temperatures, and creates a climate record that is independent of orbital parameters (e.g. equator-crossing time).

• For a climate record with high accuracy and high spatial resolution, and particularly to resolve the diurnal cycle, three cross-track scanning radiometers would be ideal. Can such instruments be made as accurate as a nadir-pointing instrument?