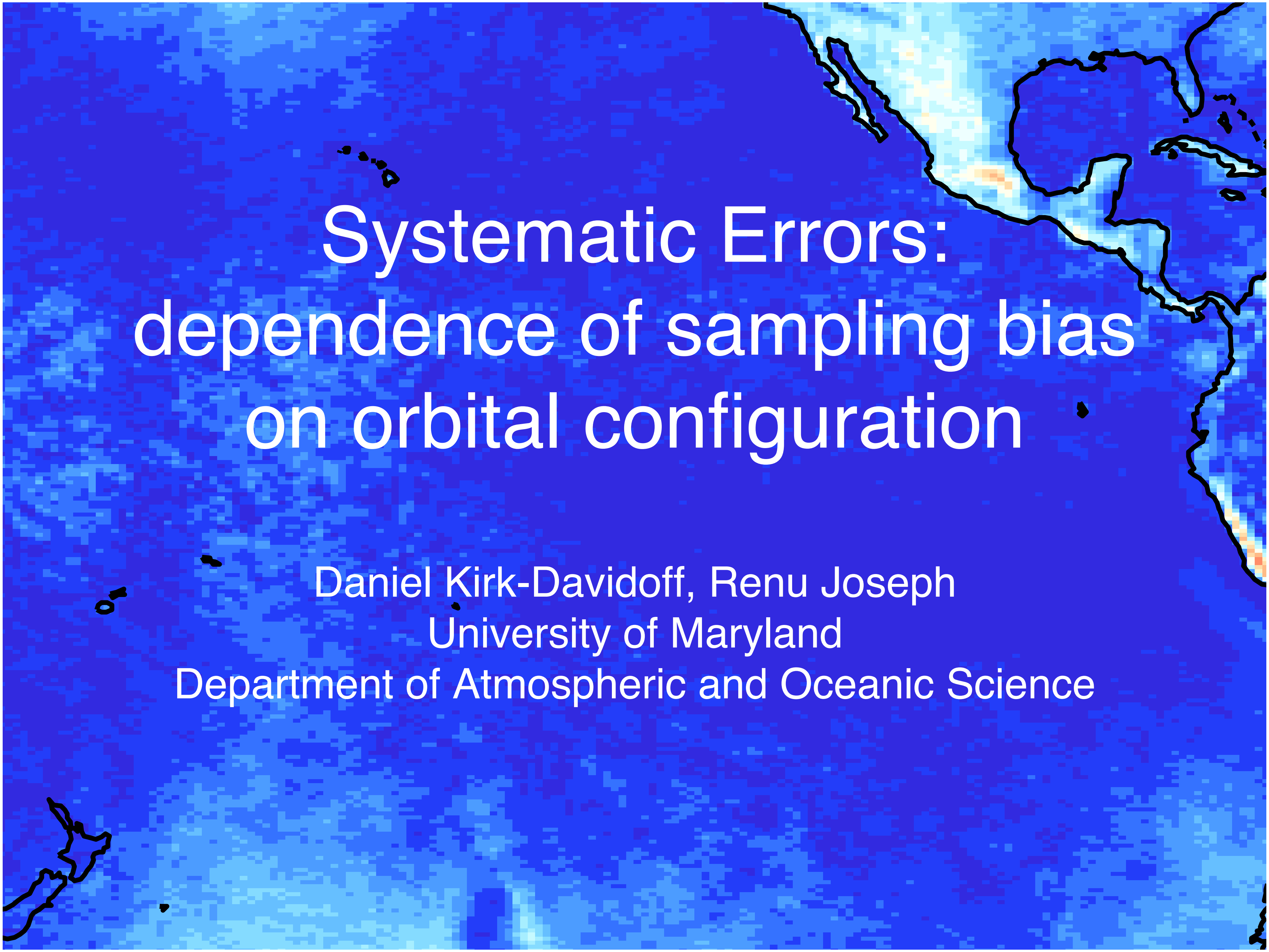

Systematic Errors: dependence of sampling bias on orbital configuration

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University of Maryland
Department of Atmospheric and Oceanic Science

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

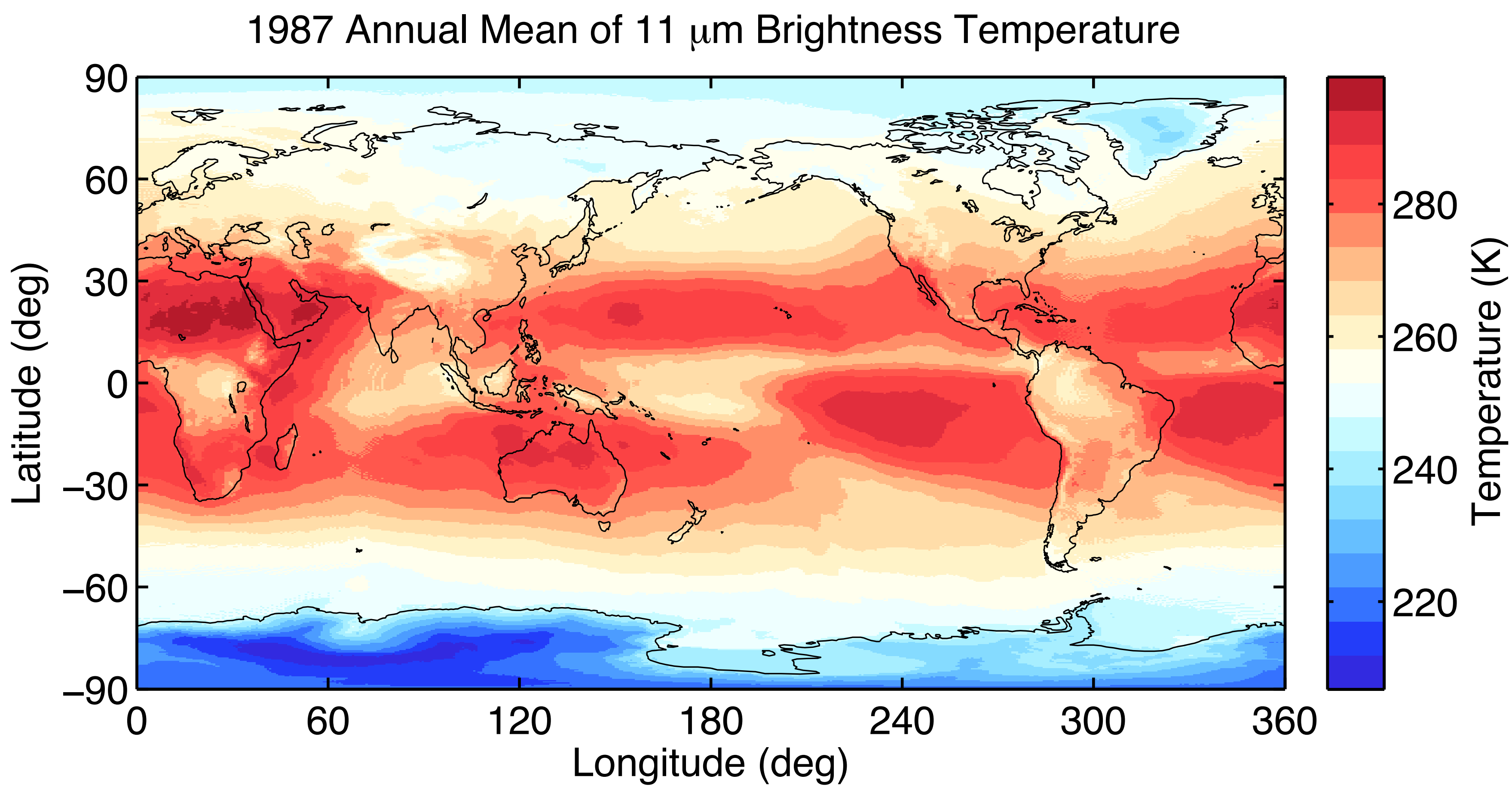
   A. Diurnal sampling bias

   B. Seasonal sampling bias

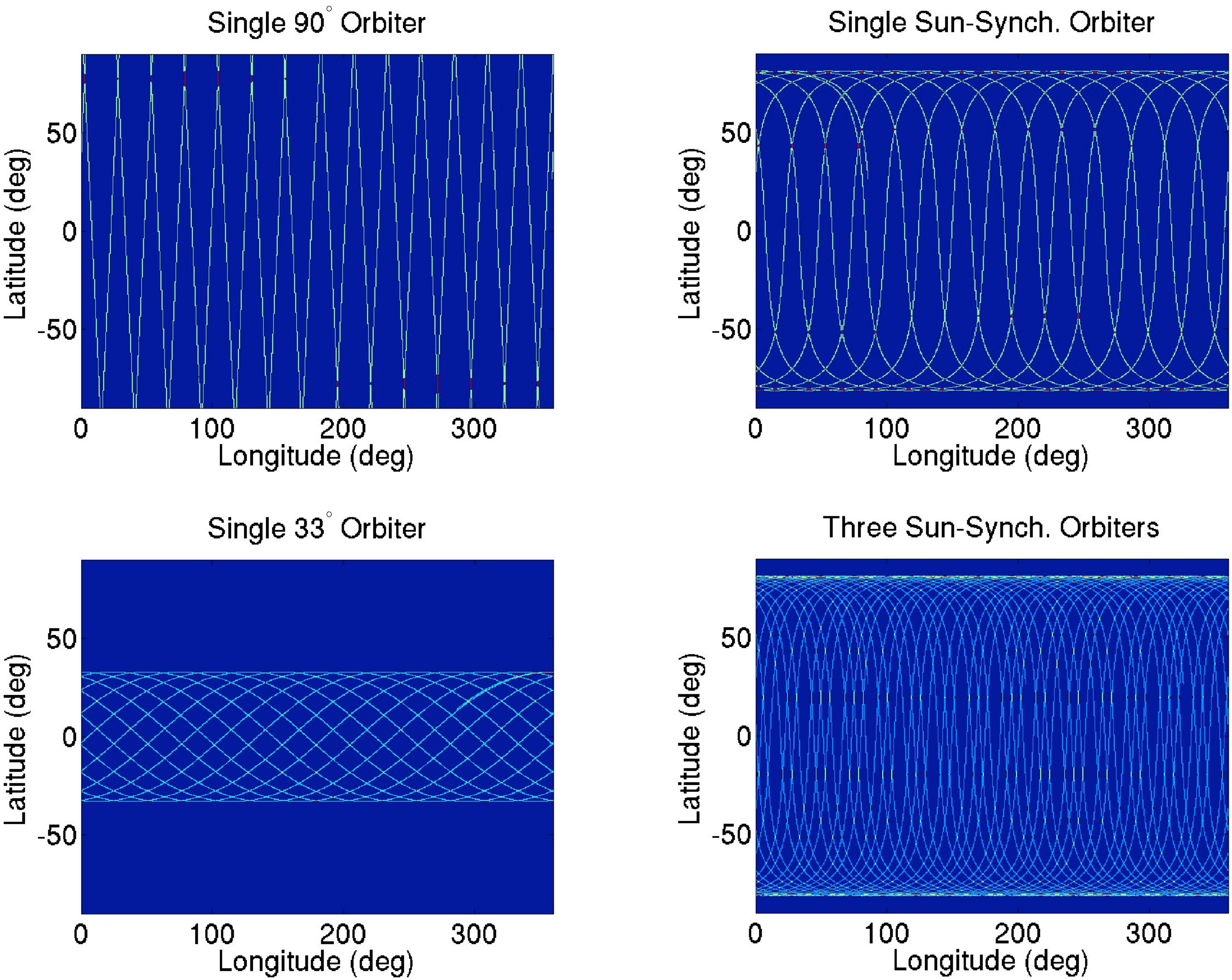
   C. Spatial sampling bias

II. Random weather noise

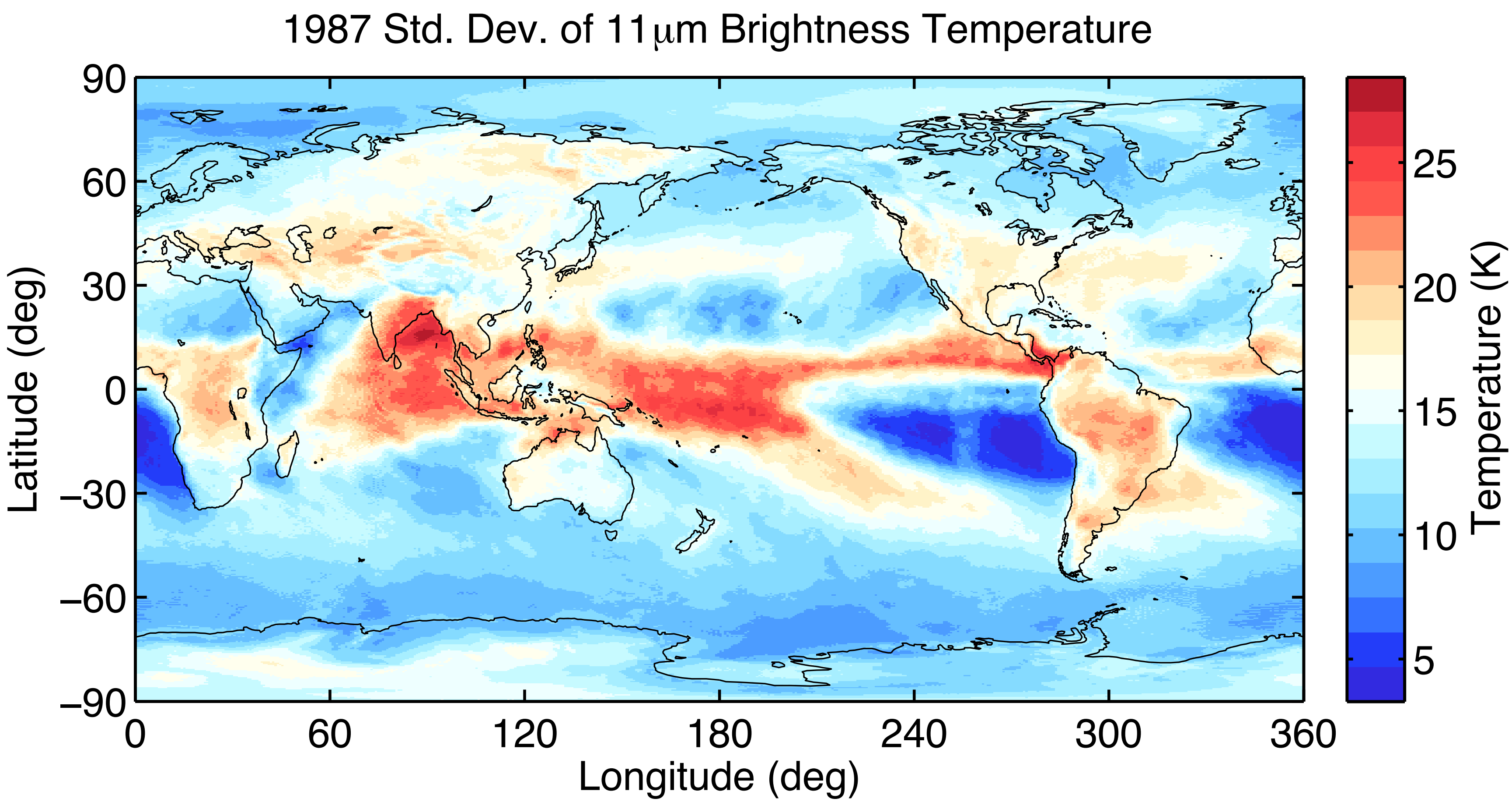
We'll estimate these errors by sampling both real and modeled brightness temperature error using virtual orbiters in a variety of orbits.



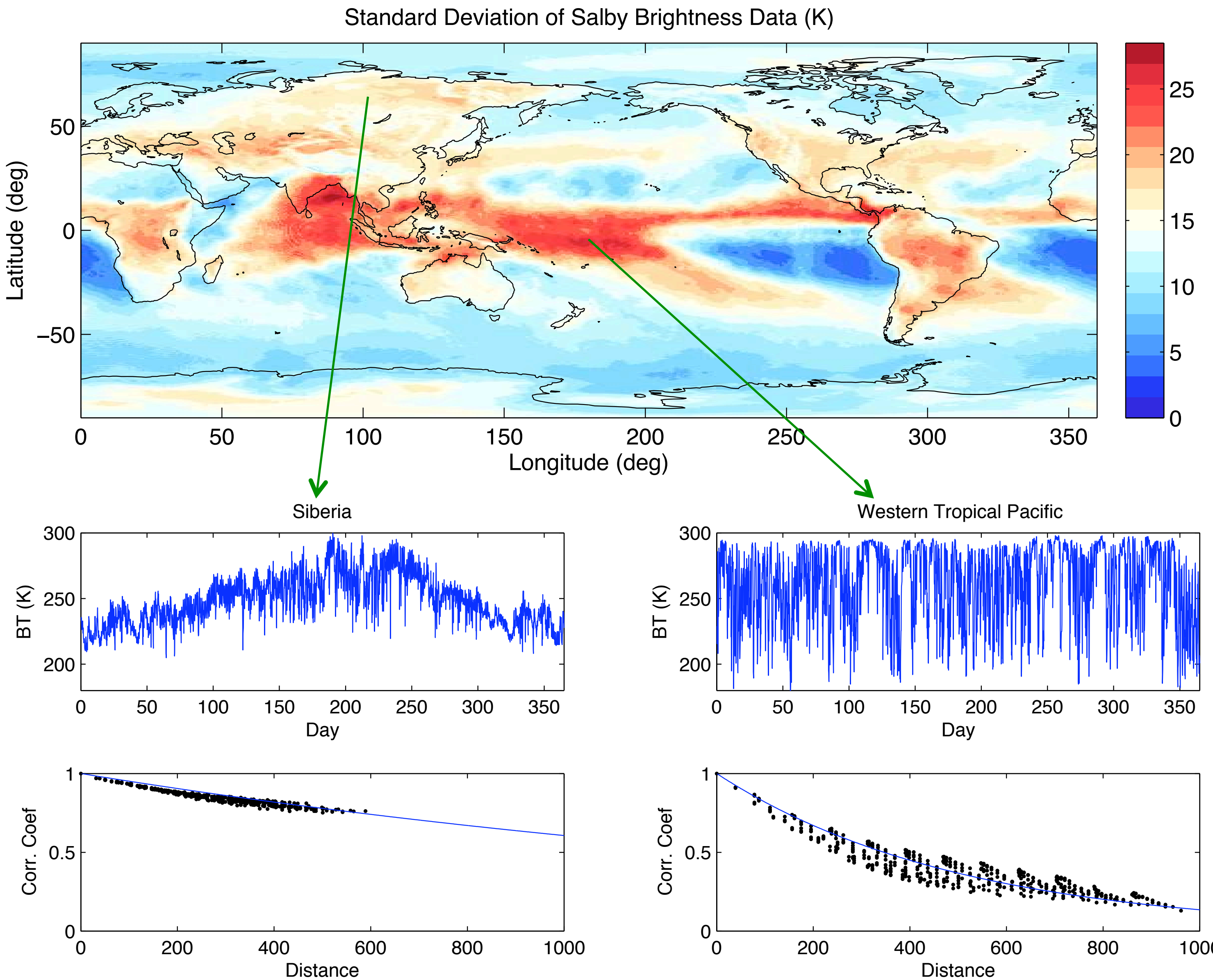
Data courtesy of Murry Salby



Single 90° Orbiter
Single Sun-Synch. Orbiter
Single 33° Orbiter
Three Sun-Synch. Orbiters
Latitude (deg)
Longitude (deg)
50
0
-50
0
100
200
300

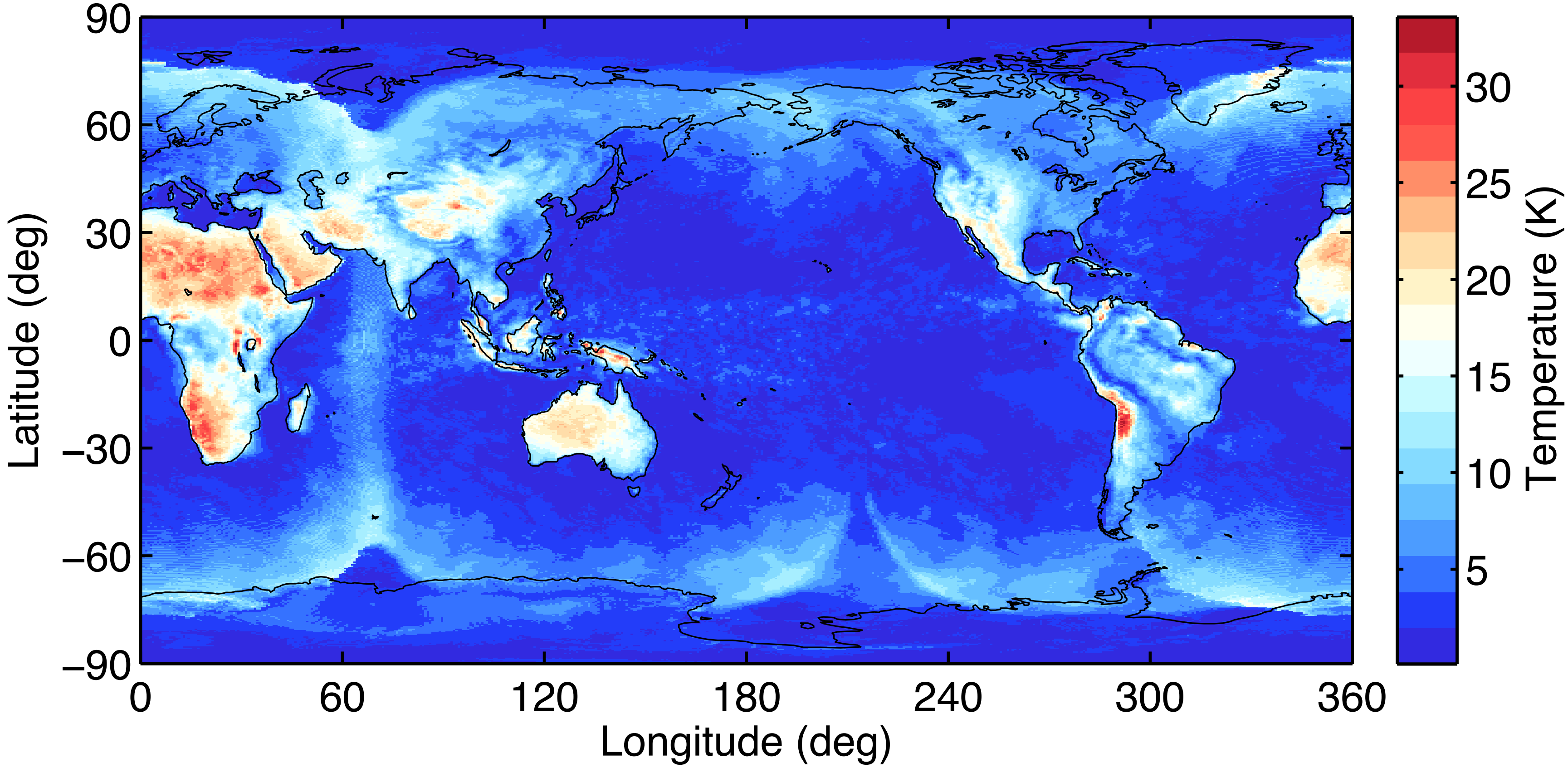


1987 Std. Dev. of 11μm Brightness Temperature
90
60
30
0
−30
−60
−90
Latitude (deg)
0
60
120
180
240
300
360
Longitude (deg)
25
20
15
10
5
Temperature (K)

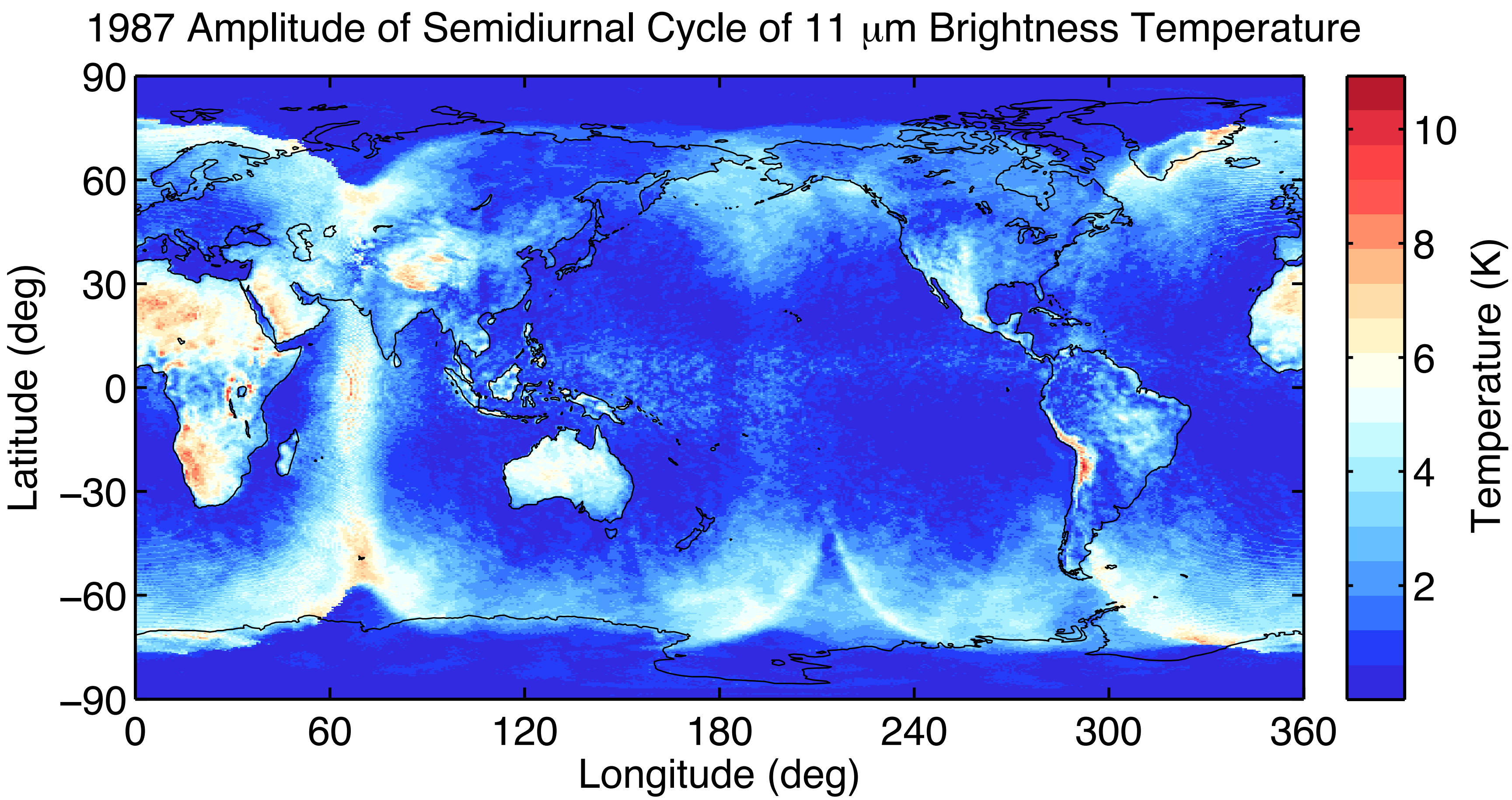


Standard Deviation of Salby Brightness Data (K)
Latitude (deg)
Longitude (deg)
Siberia
Western Tropical Pacific
BT (K)
Day
Corr. Coef
Distance

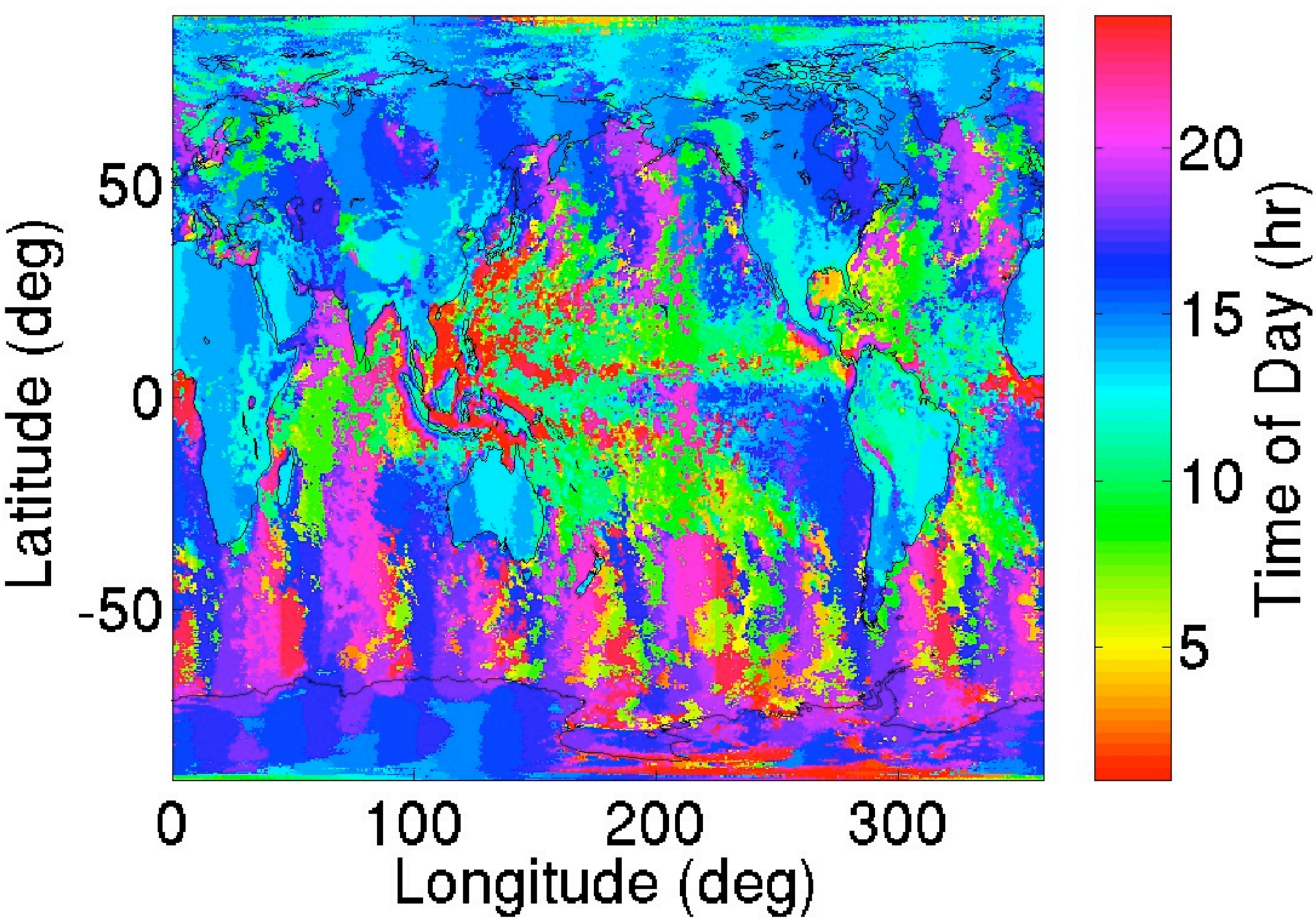
1987 Amplitude of Diurnal Cycle of 11 μm Brightness Temperature

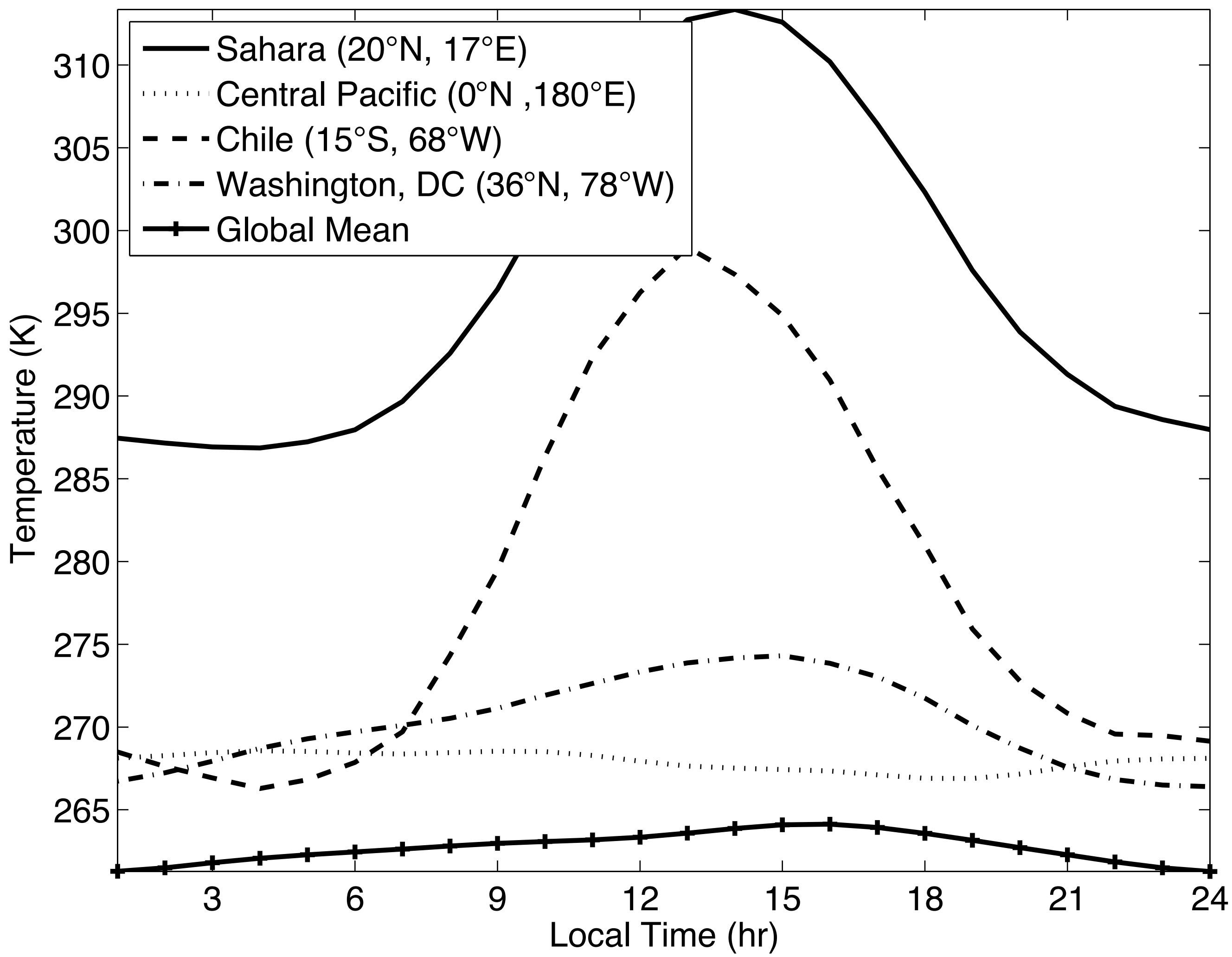


Note the regions of large diurnal cycles where geostationary and polar satellite data are patched together (Over the Indian Ocean, and at high latitudes)


1987 Amplitude of Semidiurnal Cycle of 11 μm Brightness Temperature
90
60
30
0
−30
−60
−90
Latitude (deg)
0
60
120
180
240
300
360
Longitude (deg)
10
8
6
4
2
Temperature (K)

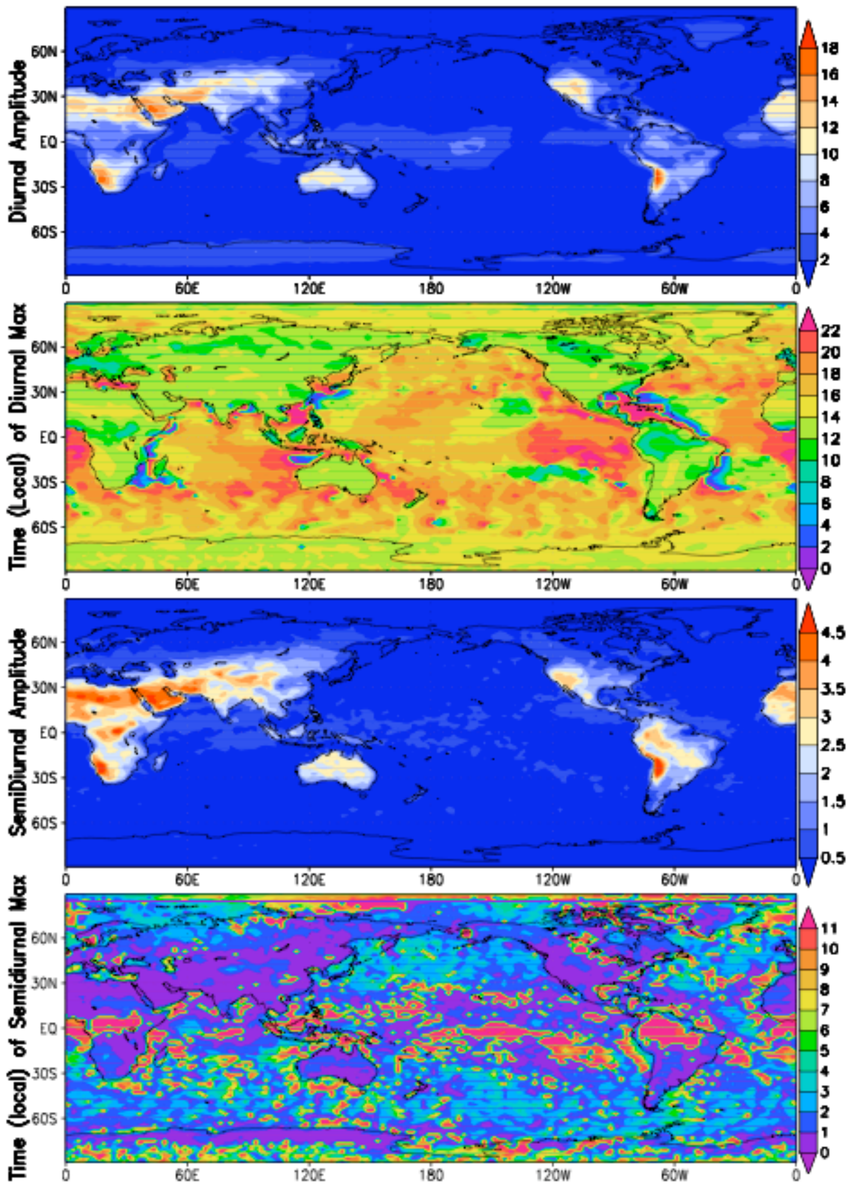
Time of Day of B.T. Max, 1988 Annual Mean



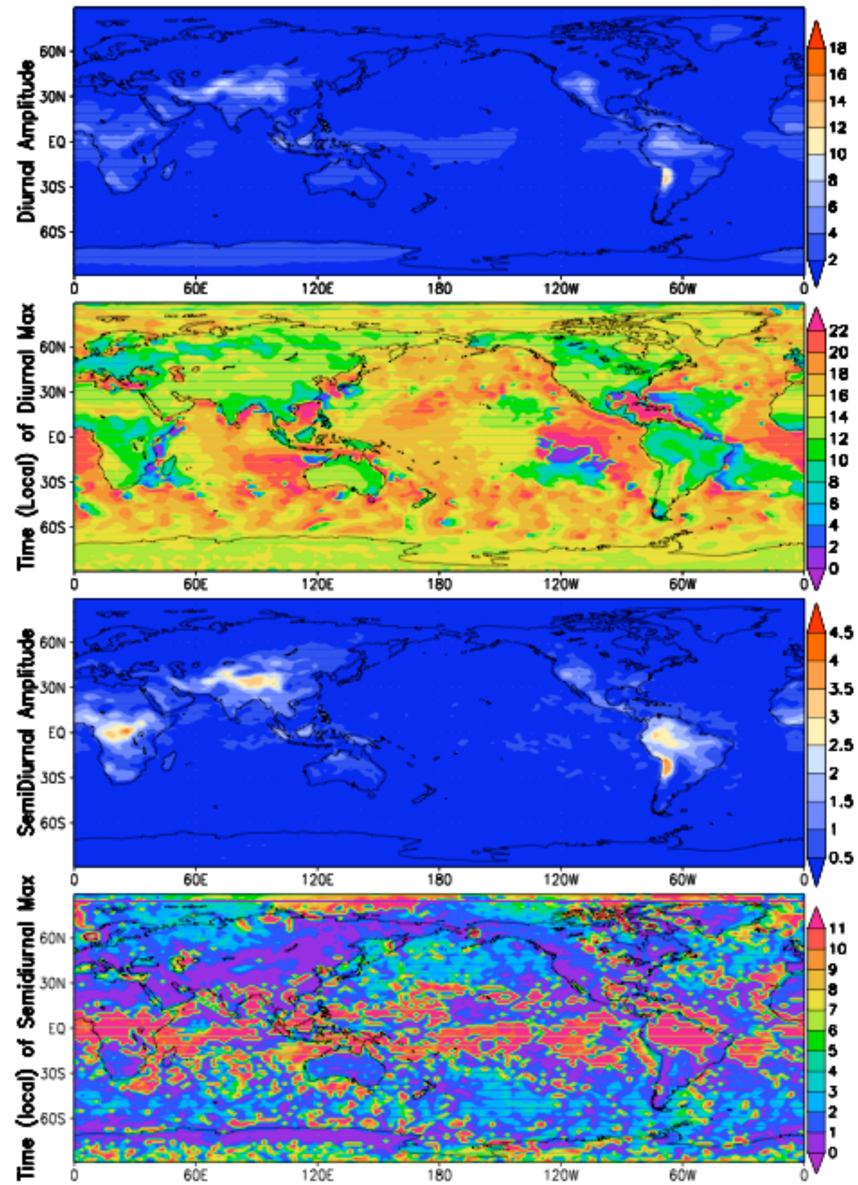


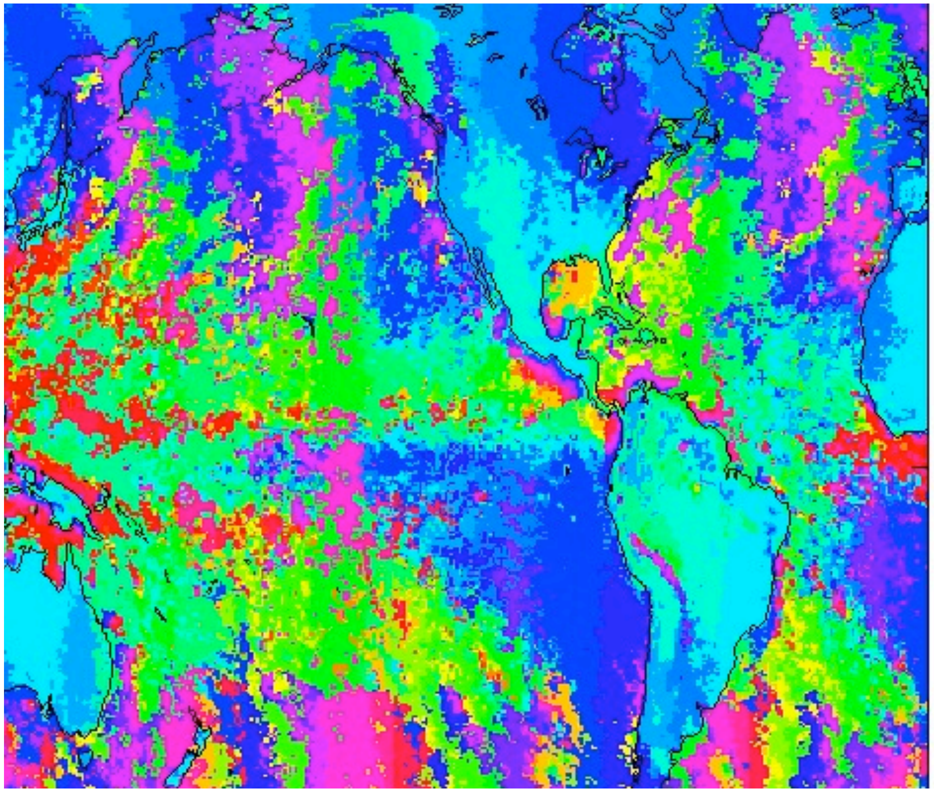
Sahara (20°N, 17°E)
Central Pacific (0°N ,180°E)
Chile (15°S, 68°W)
Washington, DC (36°N, 78°W)
Global Mean
Temperature (K)
310
305
300
295
290
285
280
275
270
265
3
6
9
12
15
18
21
24
Local Time (hr)

2002 Brightness Temperature for 909 cm^{-1}



2002 Brightness Temperature for 465 cm^{-1}

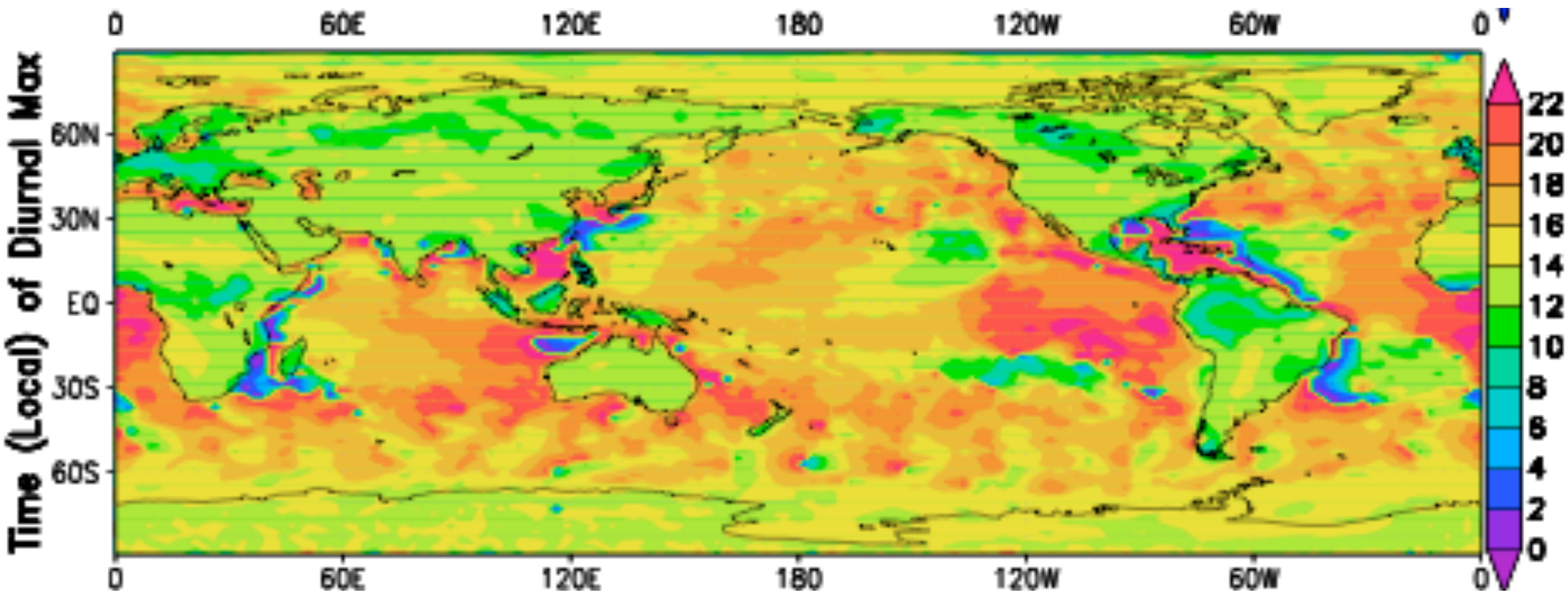


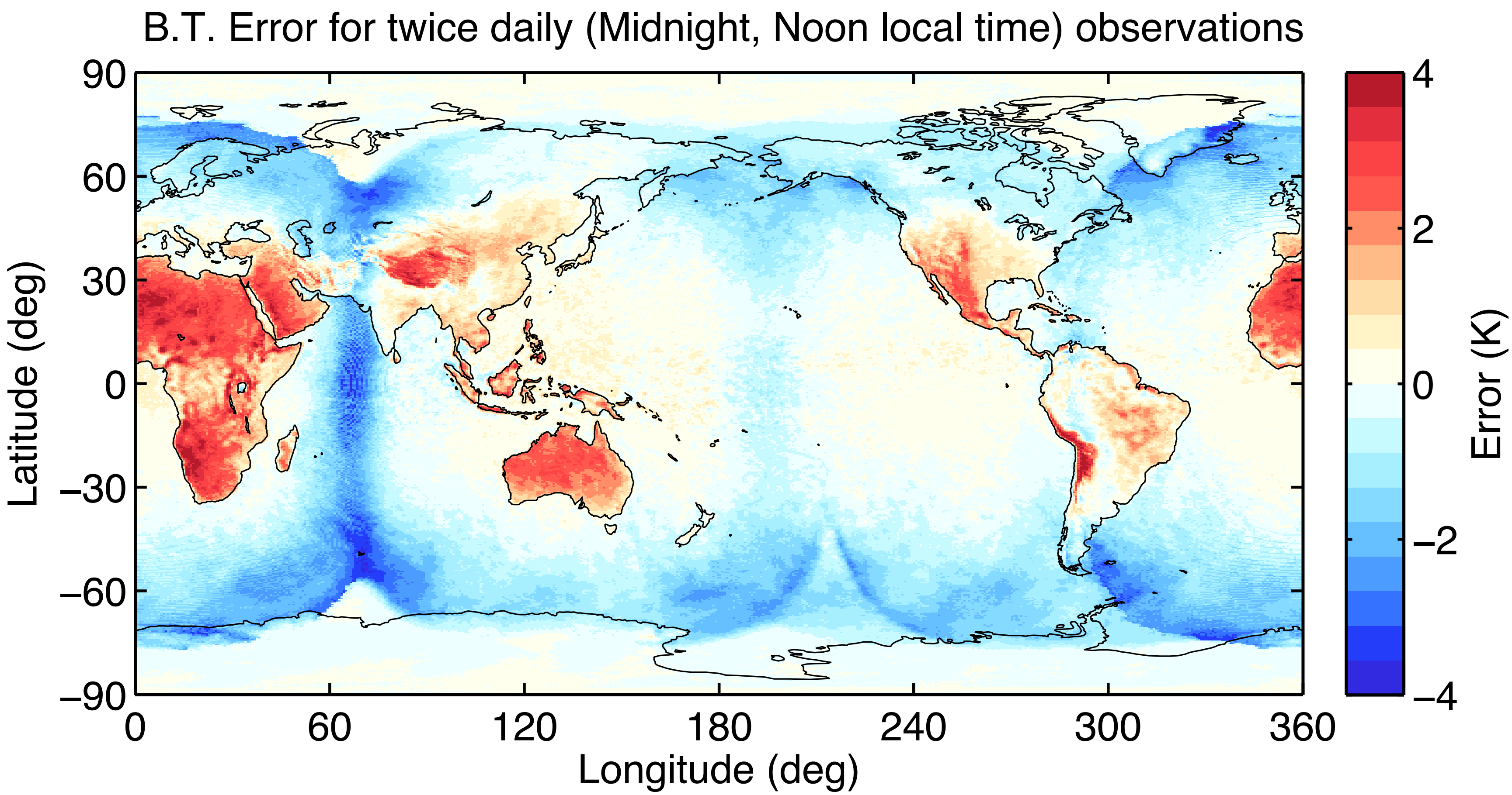


Observed local time of diurnal brightness temperature maximum

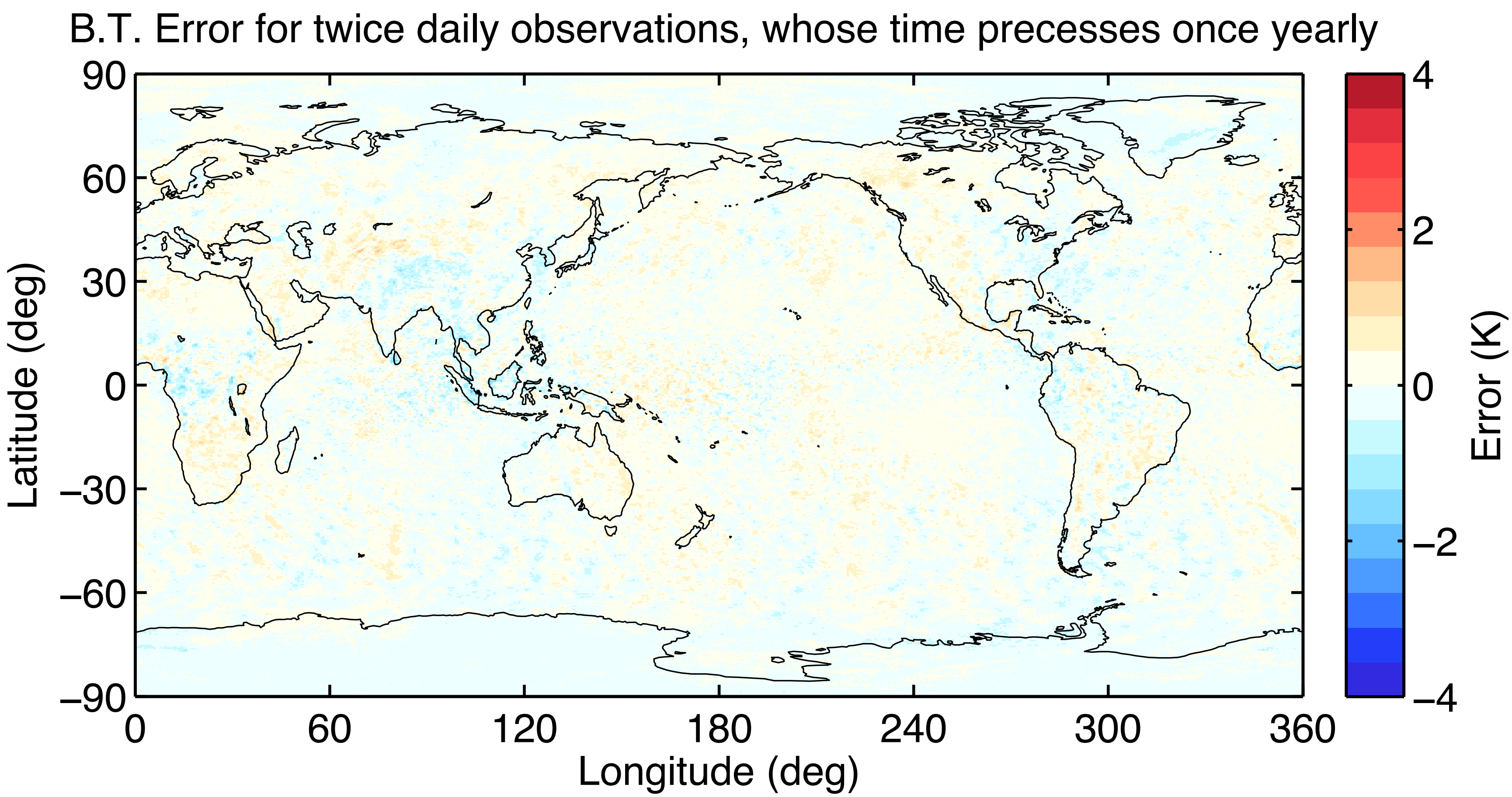
Vs.

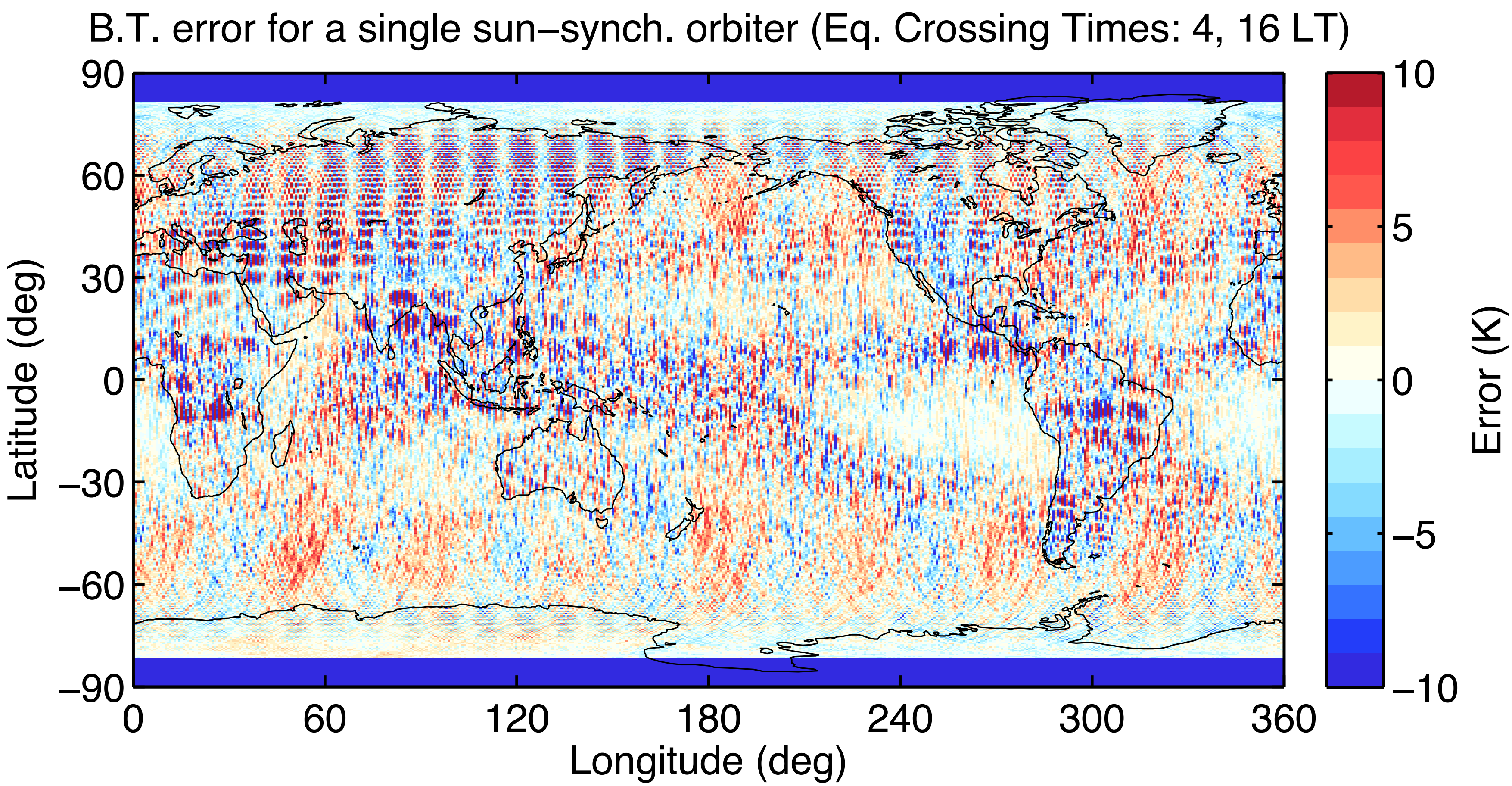
Modeled (below)



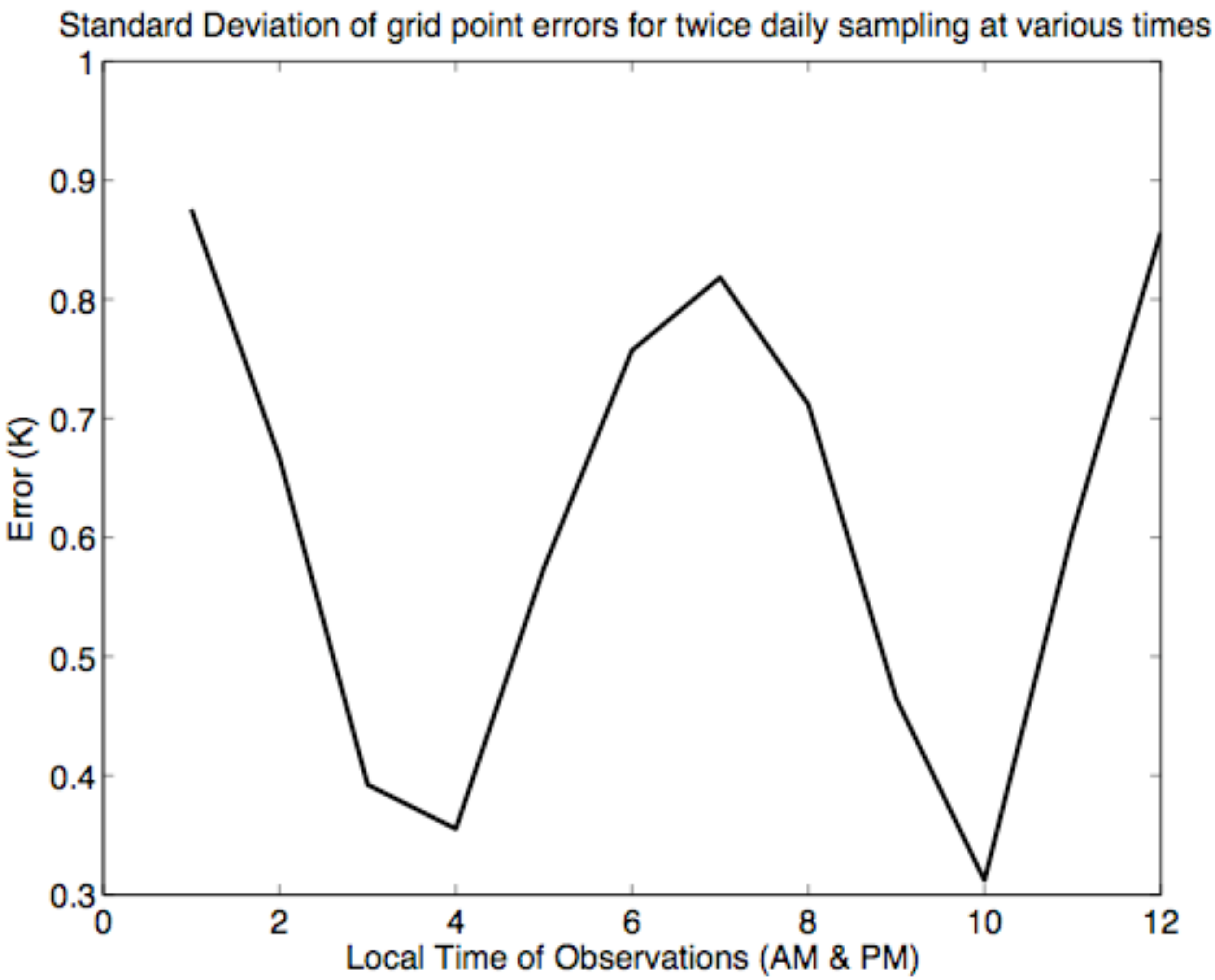


Note that the large negative errors over the Indian Ocean and at high latitudes are spurious results of the process of patching together geostationary and polar satellite data.


B.T. Error for twice daily observations, whose time precesses once yearly
Latitude (deg)
90
60
30
0
−30
−60
−90
Longitude (deg)
0
60
120
180
240
300
360
Error (K)
4
2
0
−2
−4

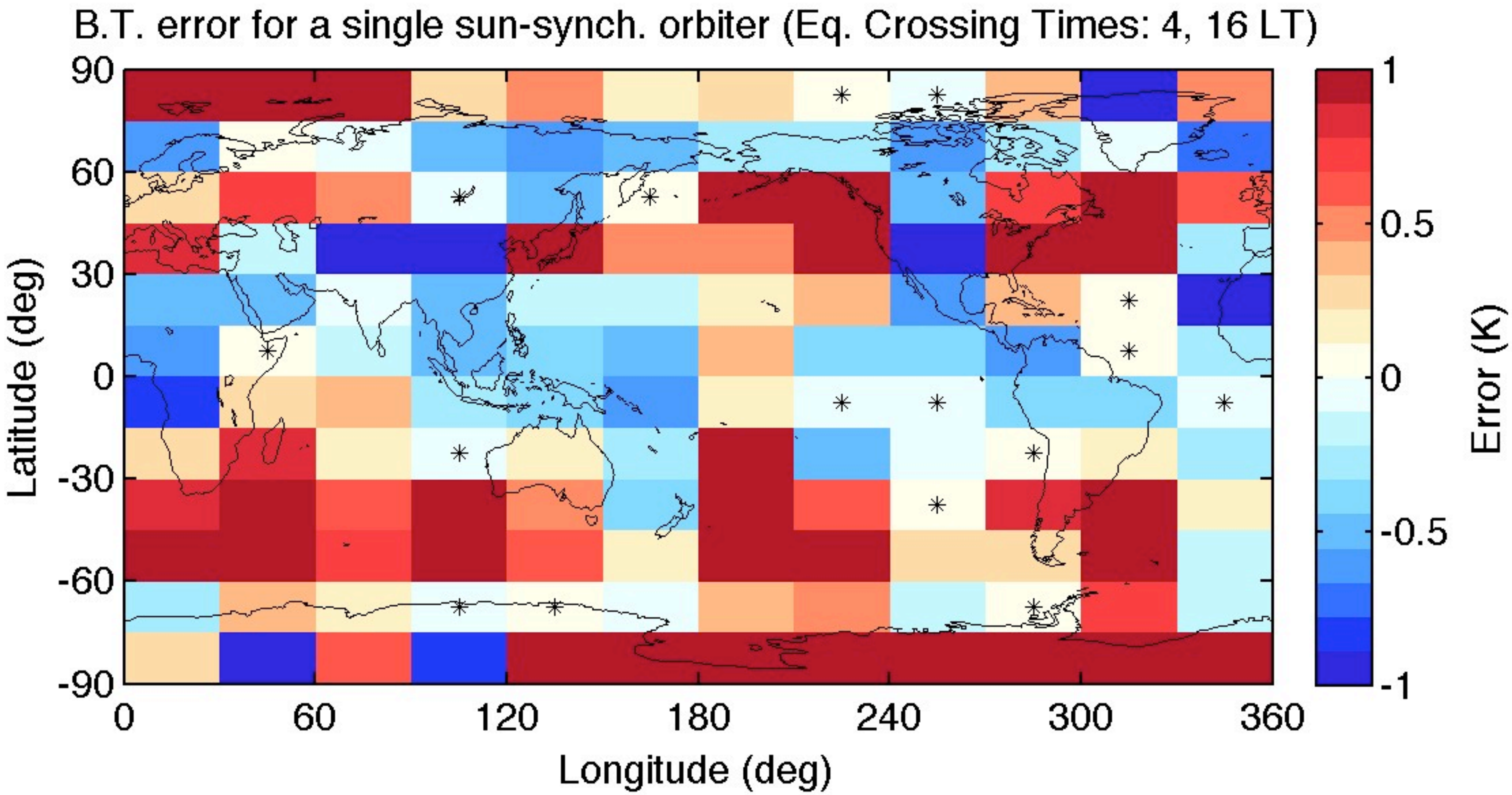


B.T. error for a single sun−synch. orbiter (Eq. Crossing Times: 4, 16 LT)
90
60
30
0
−30
−60
−90
Latitude (deg)
0
60
120
180
240
300
360
Longitude (deg)
10
5
0
−5
−10
Error (K)

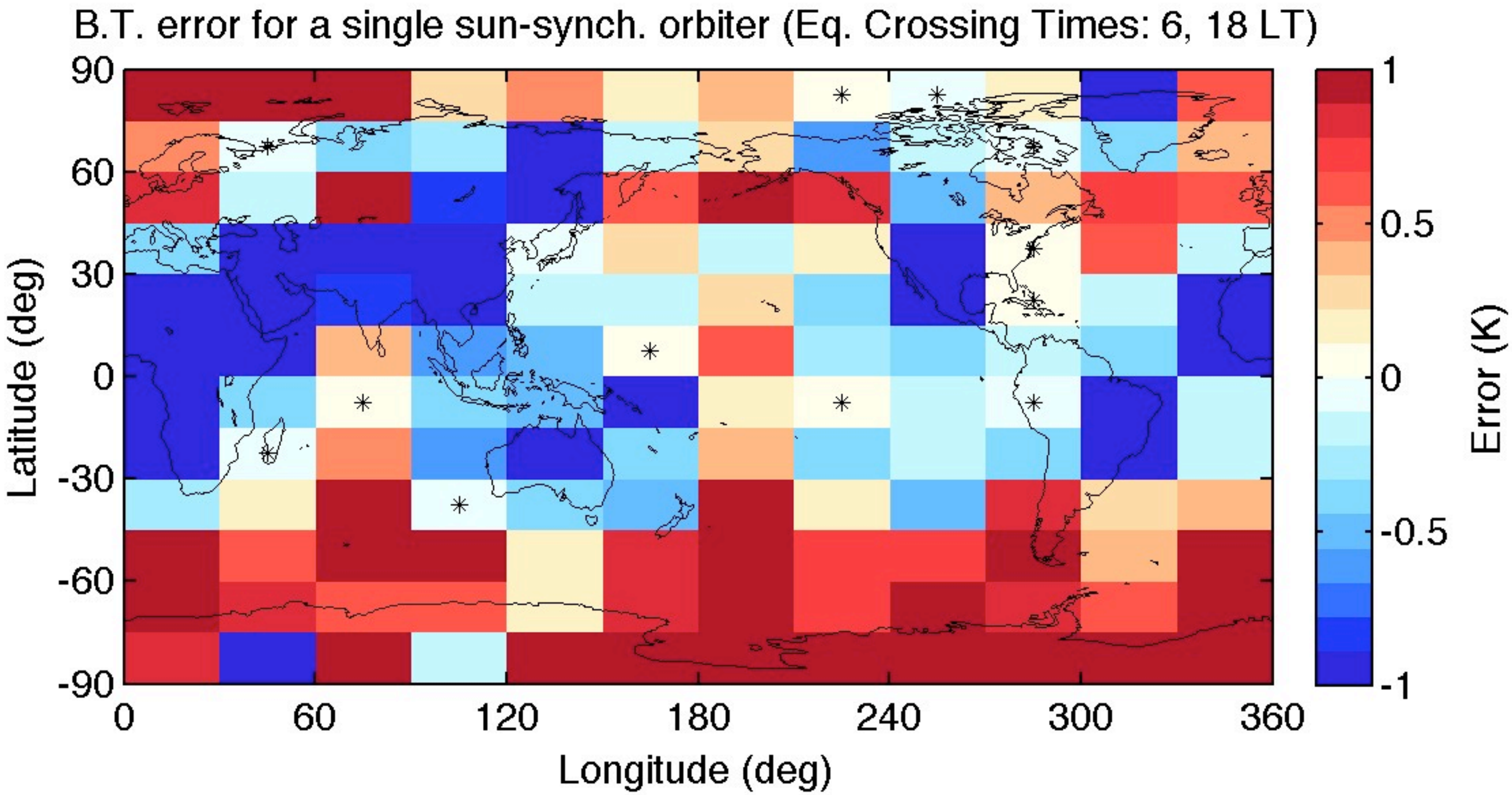

Standard Deviation of grid point errors for twice daily sampling at various times
Error (K)
Local Time of Observations (AM & PM)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0
2
4
6
8
10
12

We now create simulated satellite data records by subsampling the modeled brightness temepratures using a number of orbits and combinations of orbits

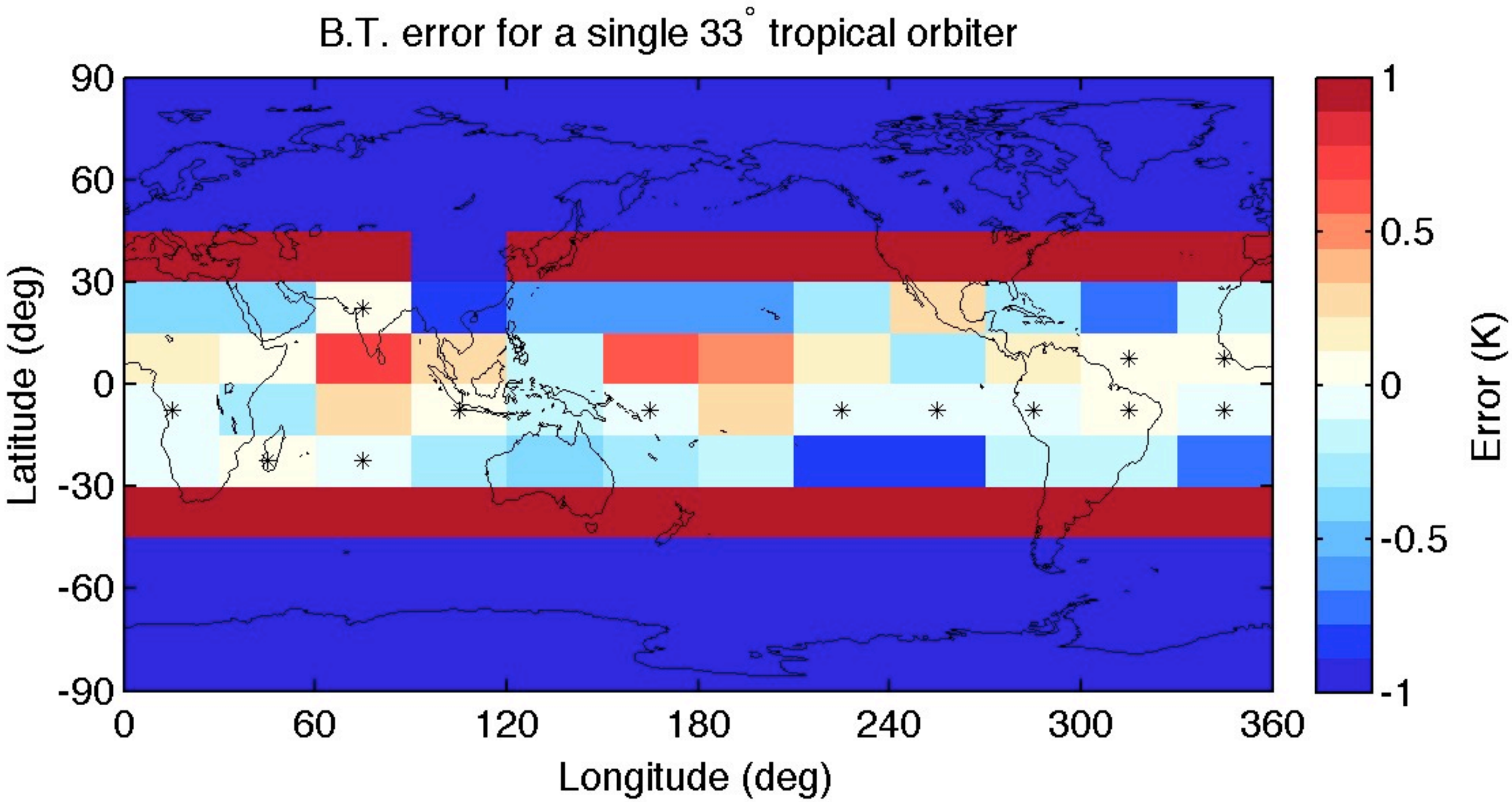
- 90° inclination "true" polar orbits at various initial longitudes- observations rotate through 24 hours of local time twice over the year.
- Sun-synchronous polar orbits at a range of equator crossing times
- 60° inclination orbits with more rapid precession- observations rotate through 24 hours of 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.



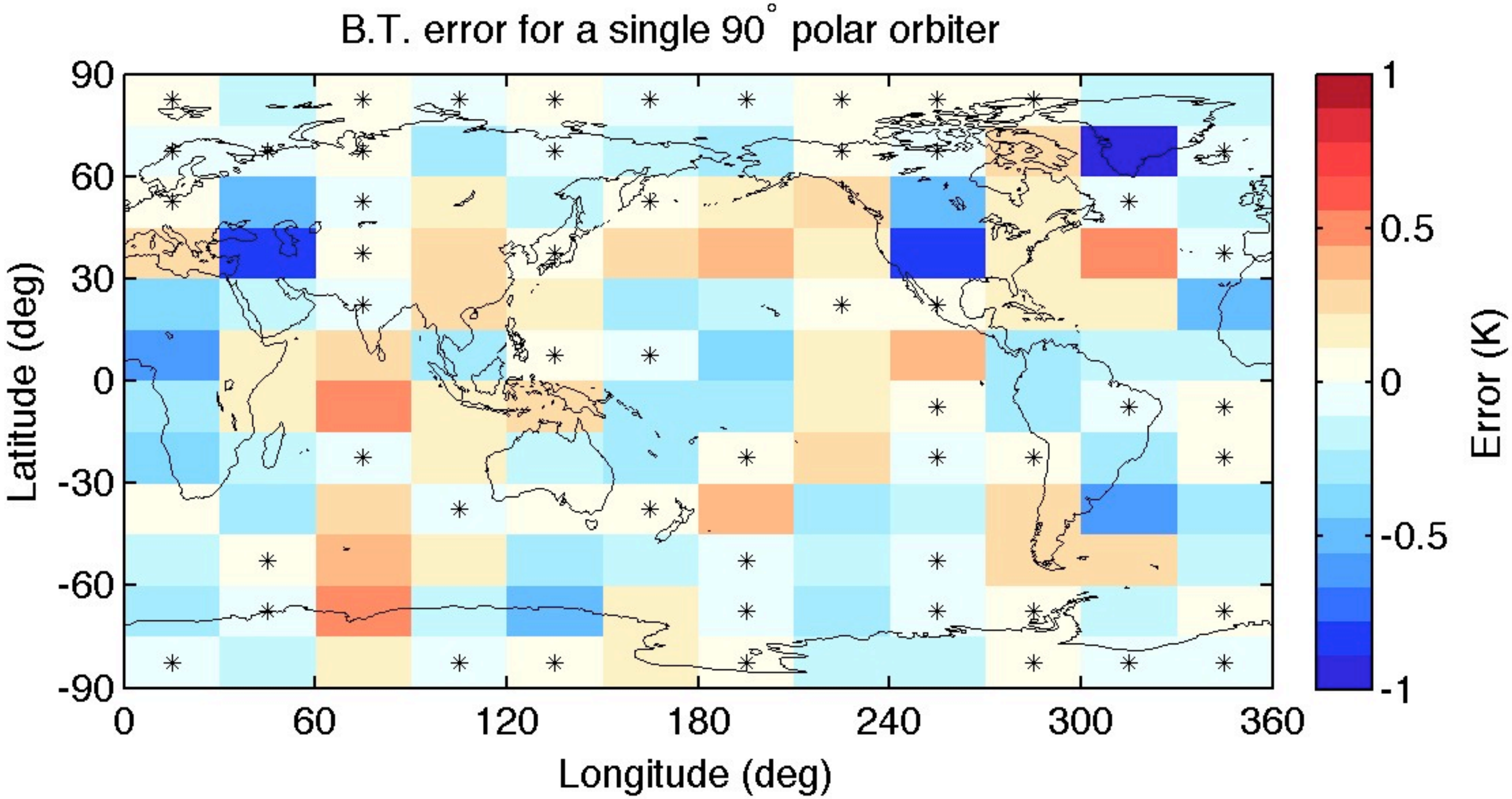
B.T. error for a single sun-synch. orbiter (Eq. Crossing Times: 4, 16 LT)
Latitude (deg)
Longitude (deg)
Error (K)
90
60
30
0
-30
-60
-90
0
60
120
180
240
300
360
1
0.5
0
-0.5
-1



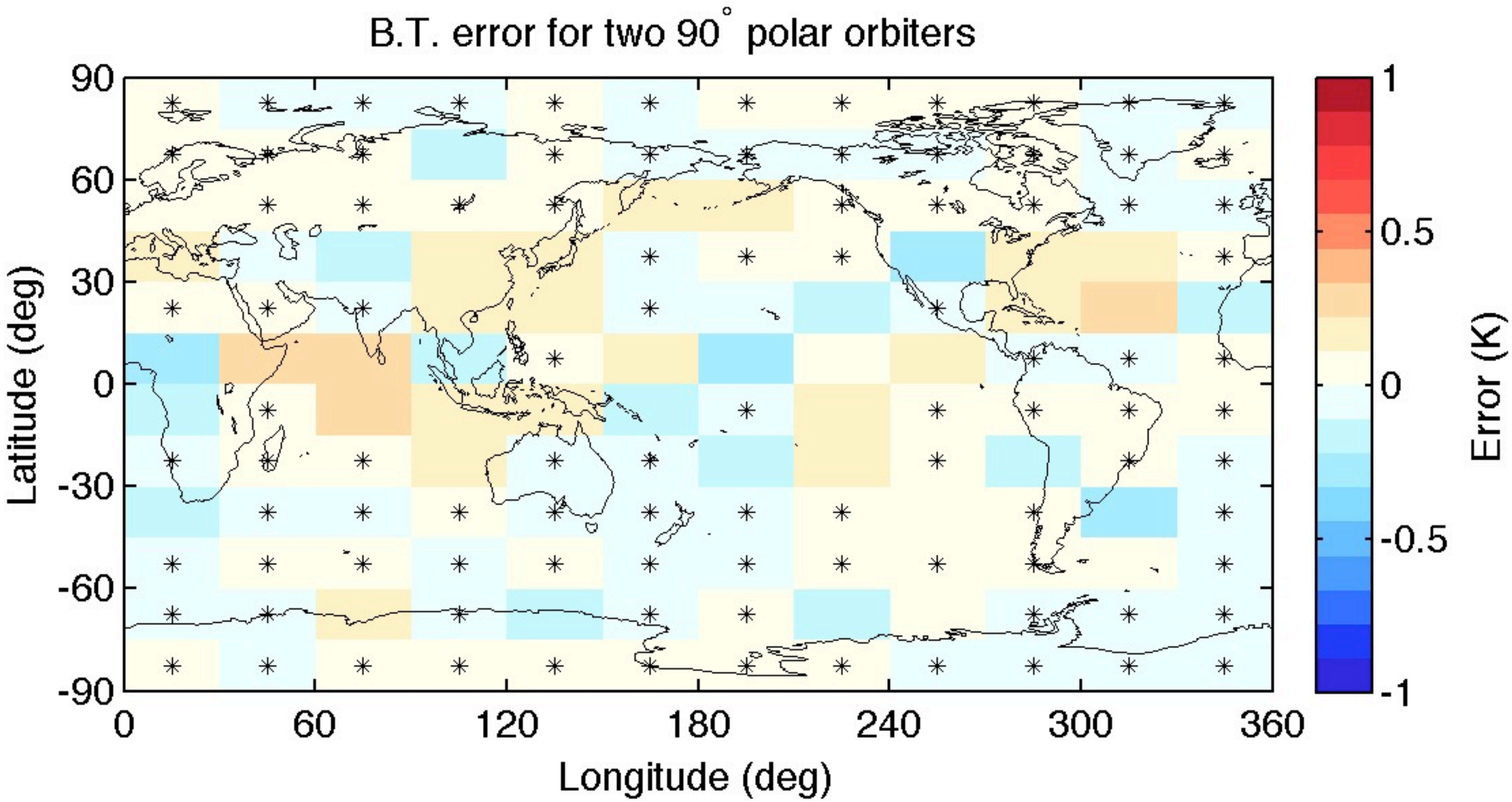
B.T. error for a single sun-synch. orbiter (Eq. Crossing Times: 6, 18 LT)
Latitude (deg)
Longitude (deg)
Error (K)
90
60
30
0
-30
-60
-90
0
60
120
180
240
300
360
1
0.5
0
-0.5
-1

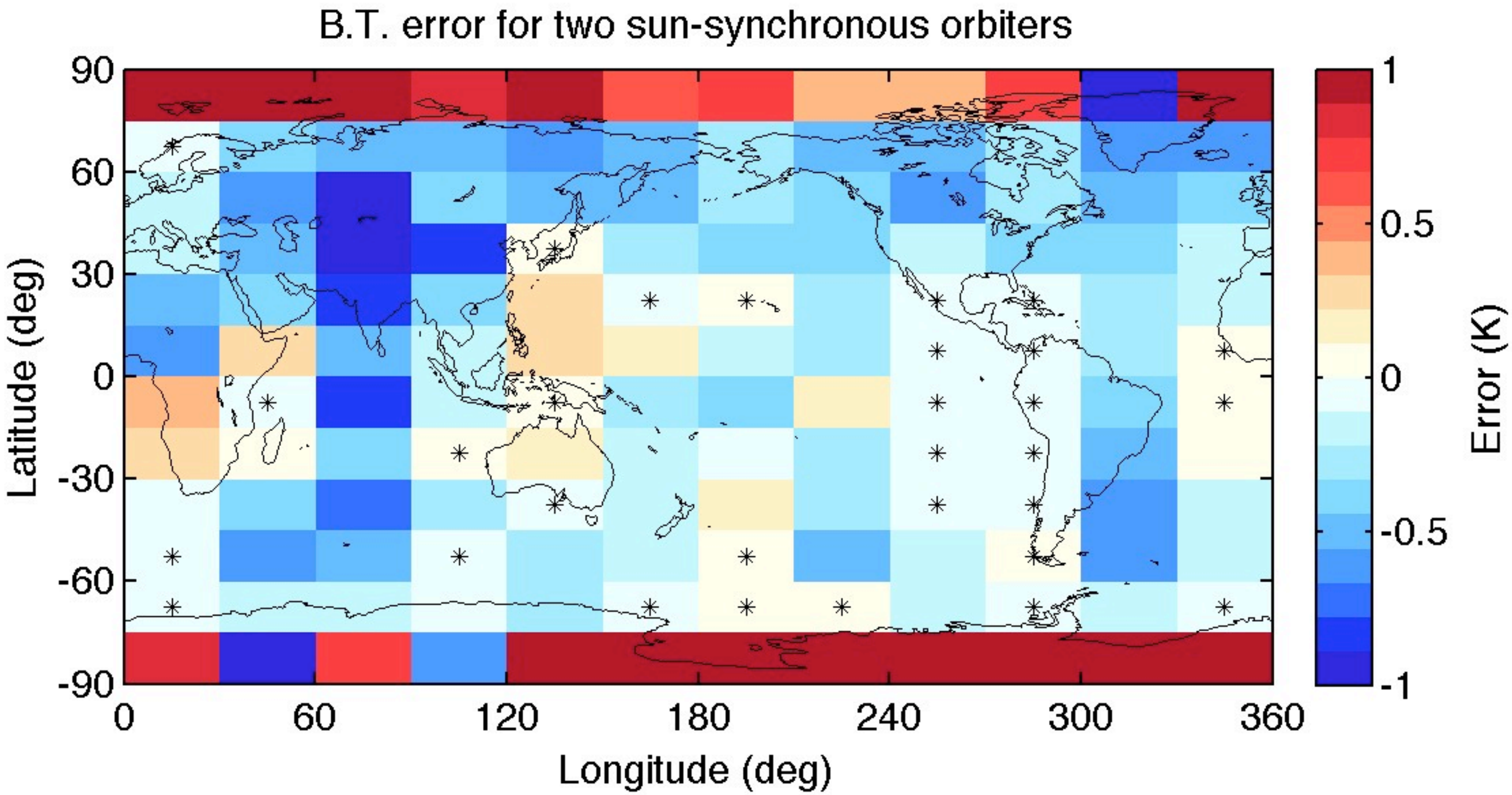


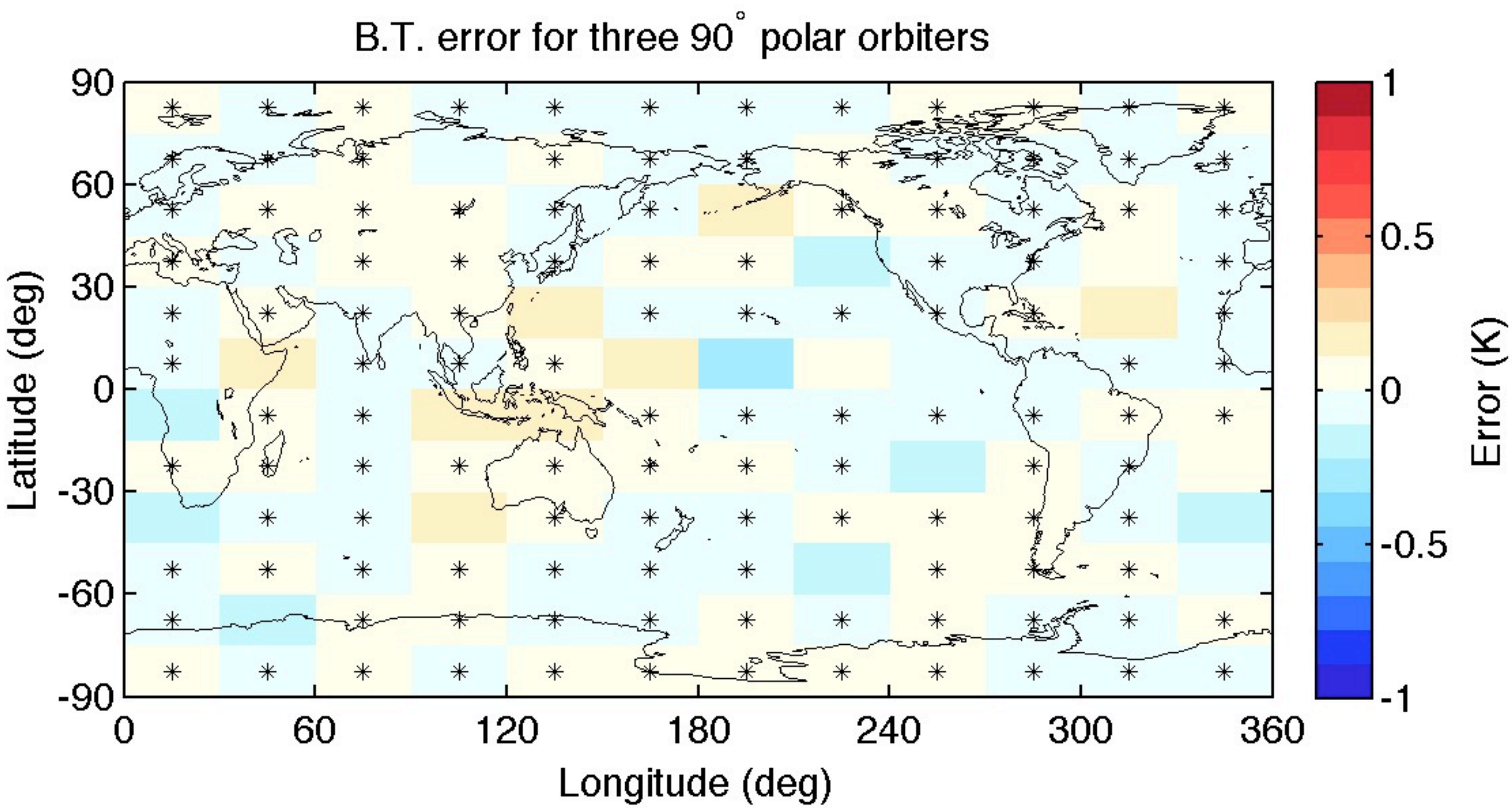
B.T. error for a single 33° tropical orbiter
Latitude (deg)
90
60
30
0
-30
-60
-90
0
60
120
180
240
300
360
Longitude (deg)
Error (K)
1
0.5
0
-0.5
-1



B.T. error for a single 90° polar orbiter
Latitude (deg)
Longitude (deg)
Error (K)
90
60
30
0
-30
-60
-90
0
60
120
180
240
300
360
1
0.5
0
-0.5
-1

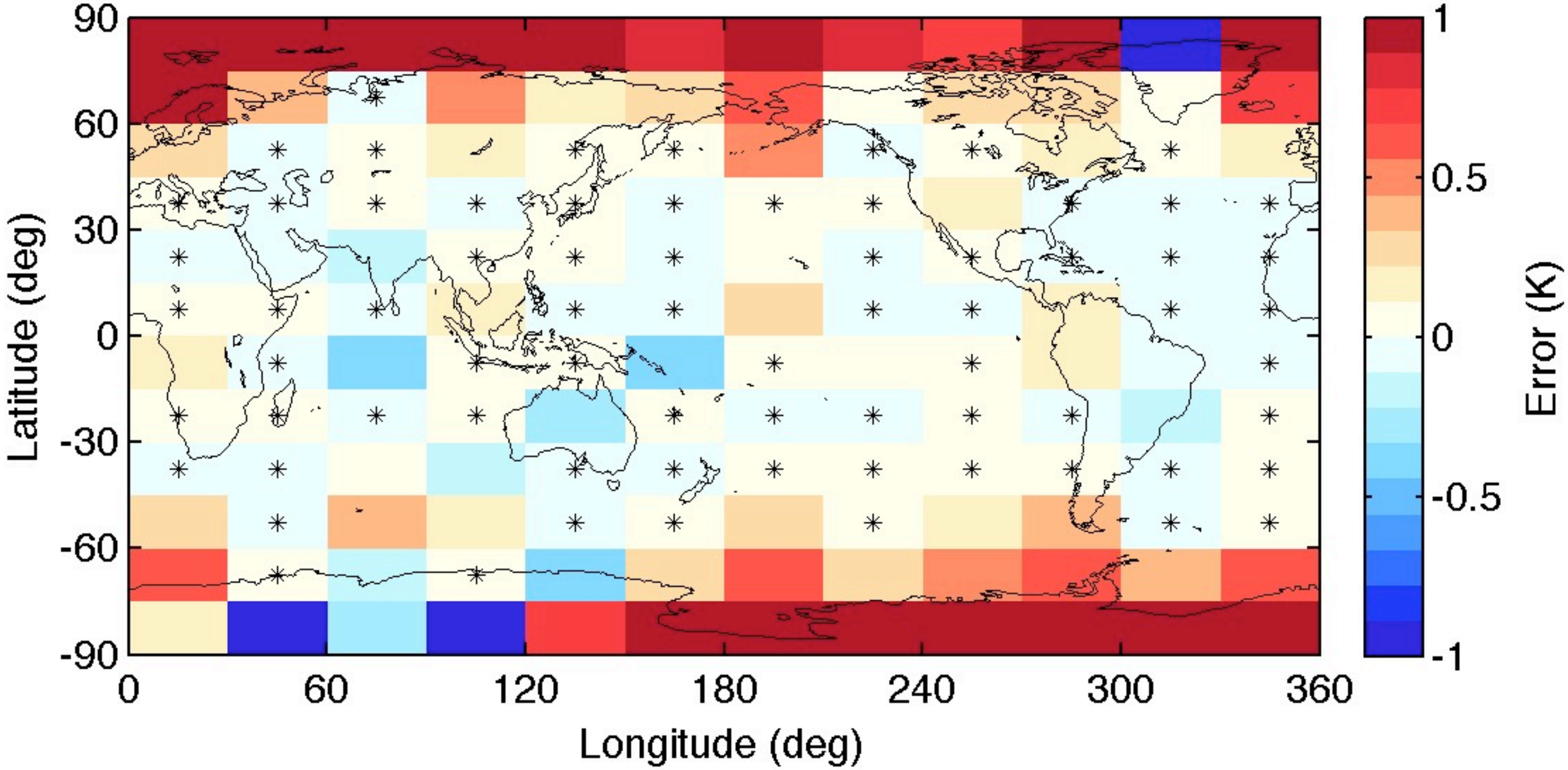

B.T. error for two 90° polar orbiters
Latitude (deg)
Longitude (deg)
Error (K)
90
60
30
0
-30
-60
-90
0
60
120
180
240
300
360
1
0.5
0
-0.5
-1

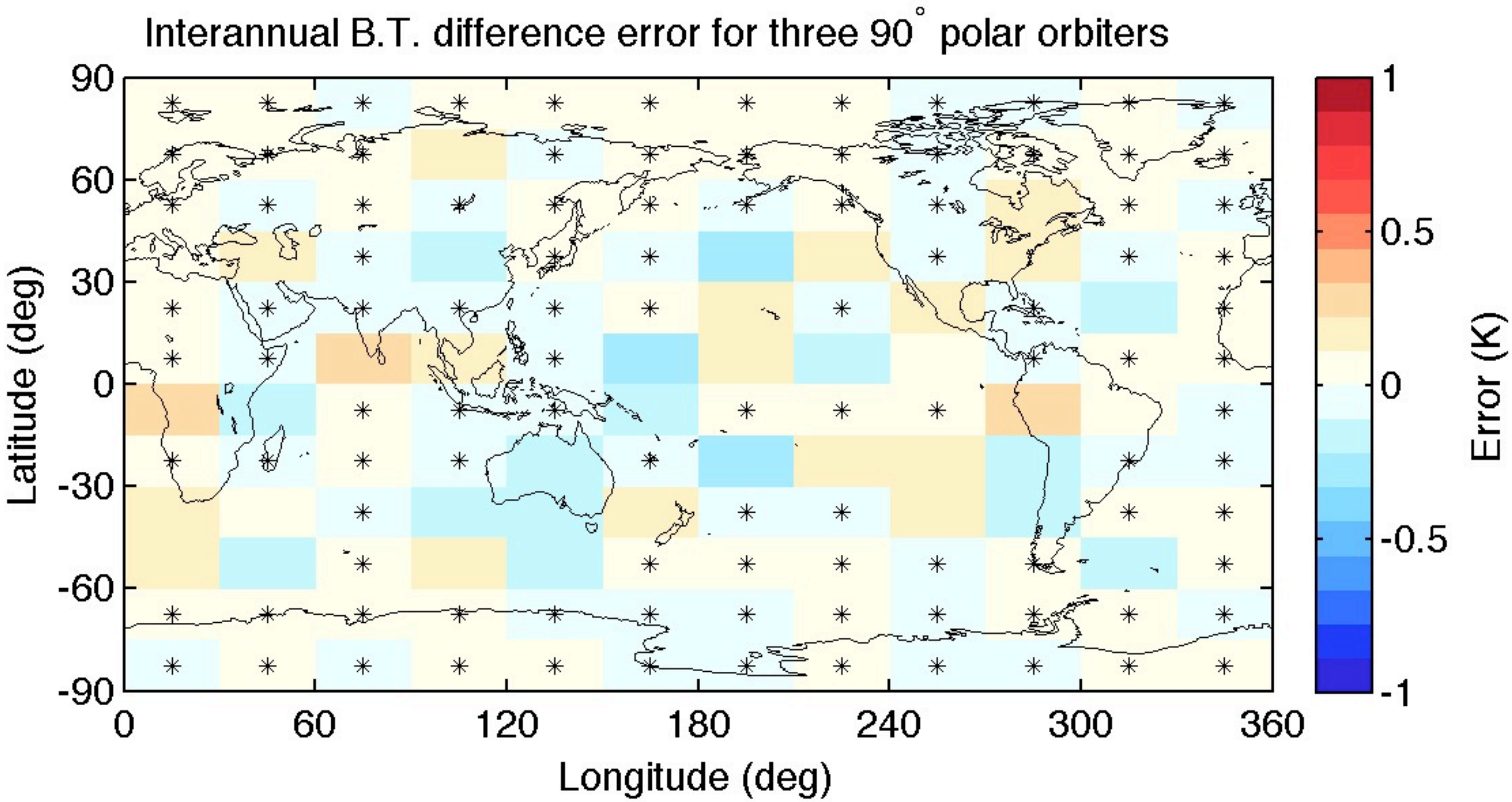

B.T. error for two sun-synchronous orbiters
90
60
30
0
-30
-60
-90
0
60
120
180
240
300
360
Latitude (deg)
Longitude (deg)
1
0.5
0
-0.5
-1
Error (K)

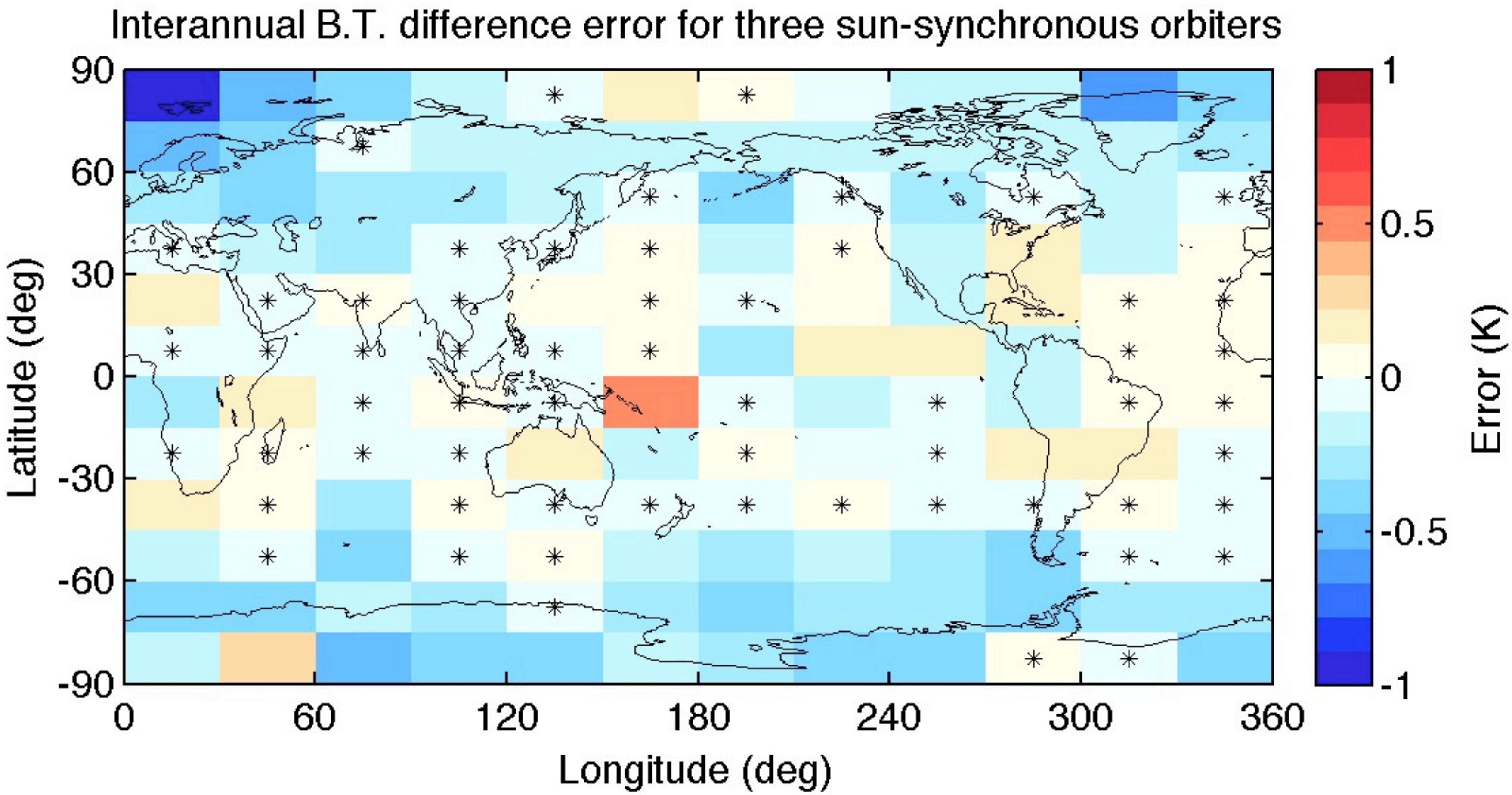


B.T. error for three 90° polar orbiters
Latitude (deg)
90
60
30
0
-30
-60
-90
0
60
120
180
240
300
360
Longitude (deg)
Error (K)
1
0.5
0
-0.5
-1

B.T. error for three sun-synchronous orbiters



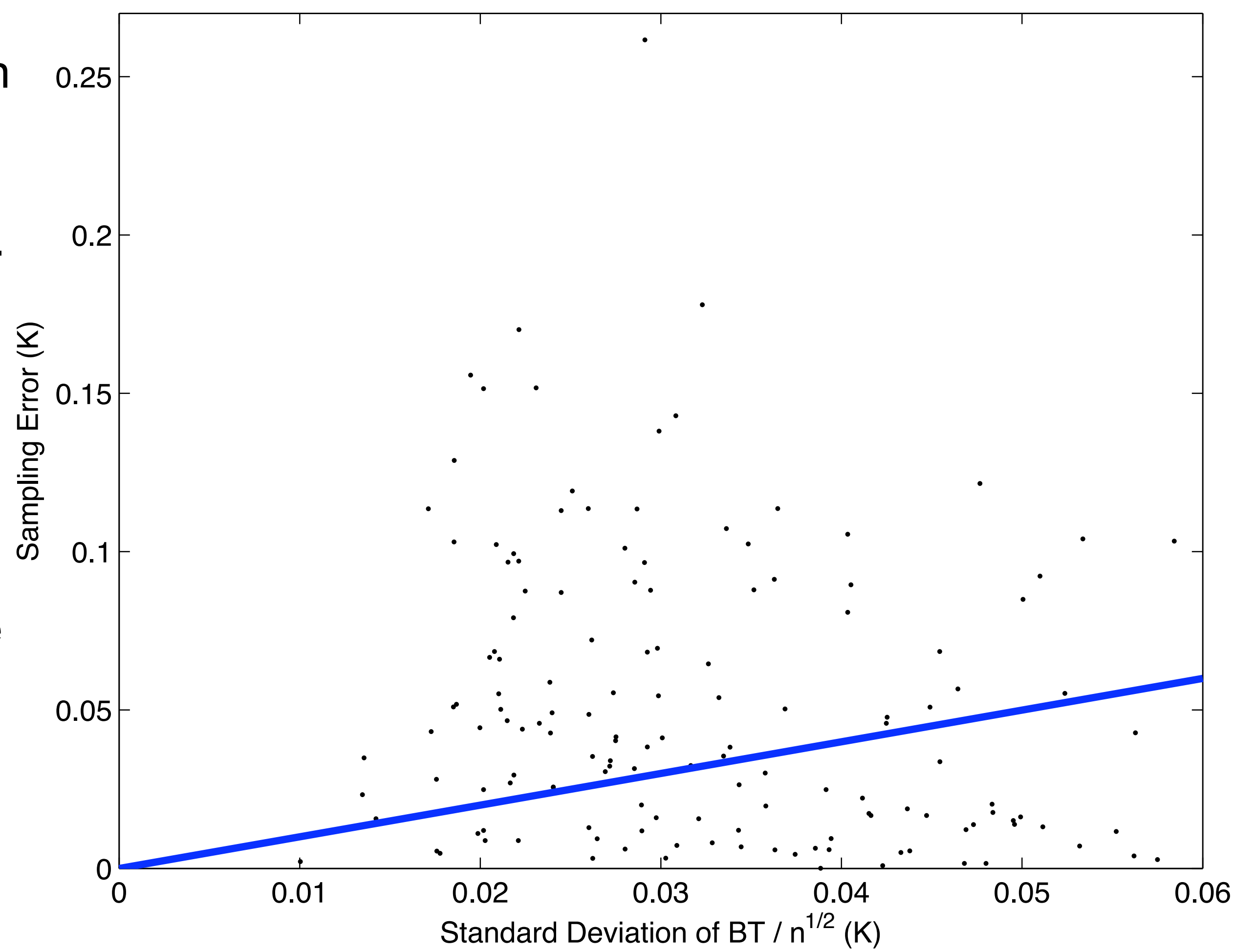

Interannual B.T. difference error for three 90° polar orbiters
Latitude (deg)
90
60
30
0
-30
-60
-90
Longitude (deg)
0
60
120
180
240
300
360
Error (K)
1
0.5
0
-0.5
-1



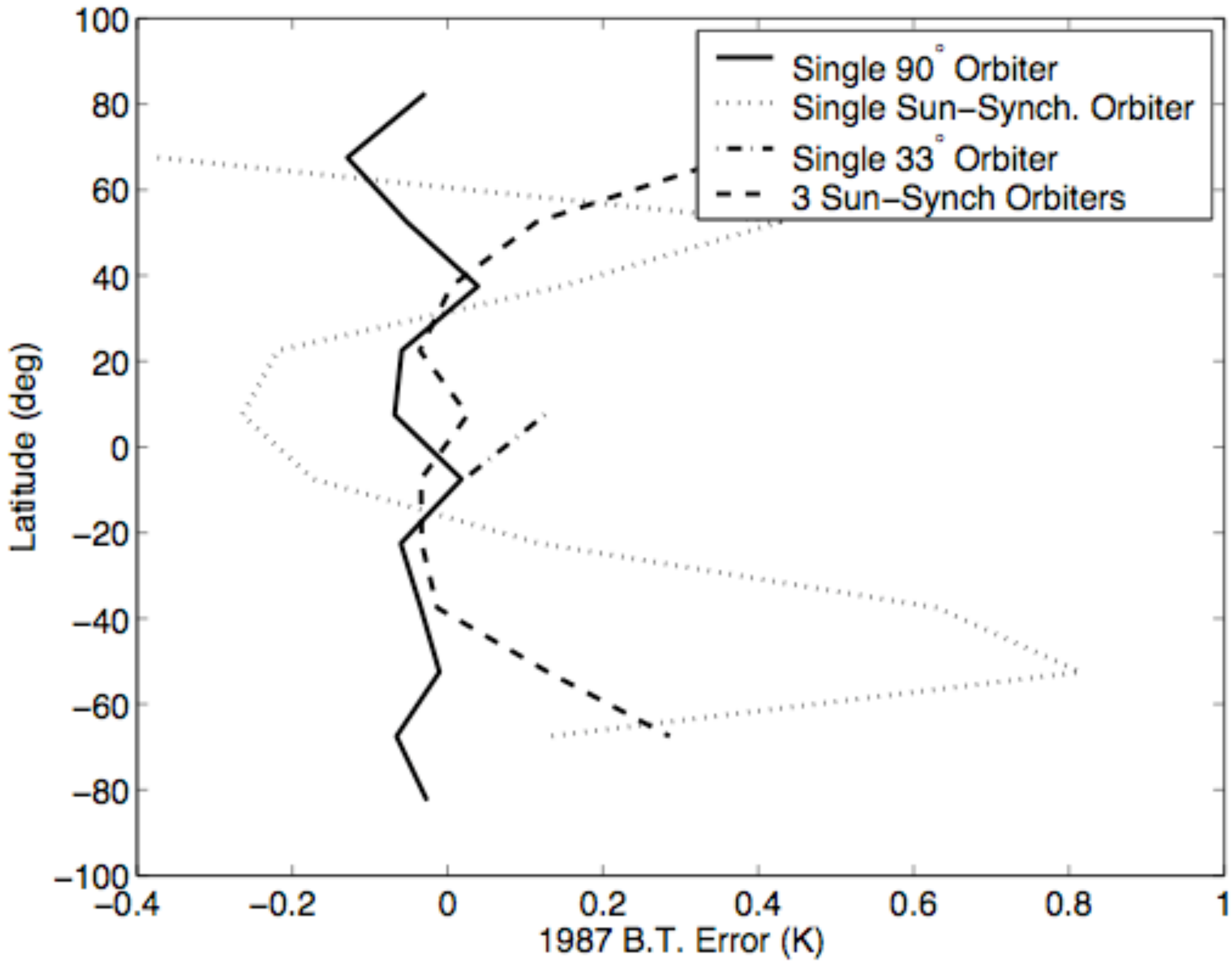
Interannual B.T. difference error for three sun-synchronous orbiters
90
60
30
0
-30
-60
-90
Latitude (deg)
0
60
120
180
240
300
360
Longitude (deg)
1
0.5
0
-0.5
-1
Error (K)

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.



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**.

HASKINS ET AL.: A STATISTICAL METHOD FOR TESTING A GCM

We choose a frequencies that sample a wide range of regions in the atmosphere.

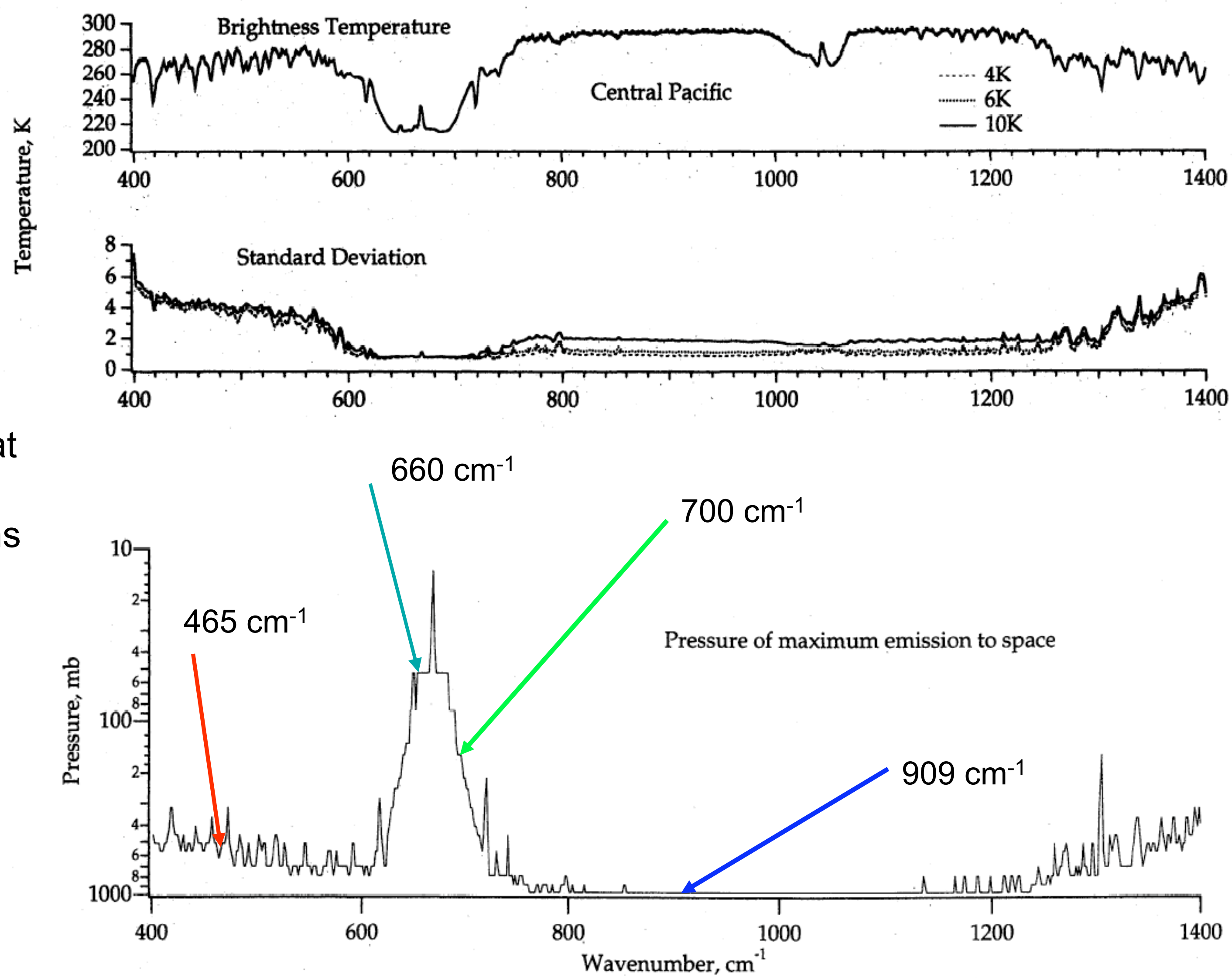
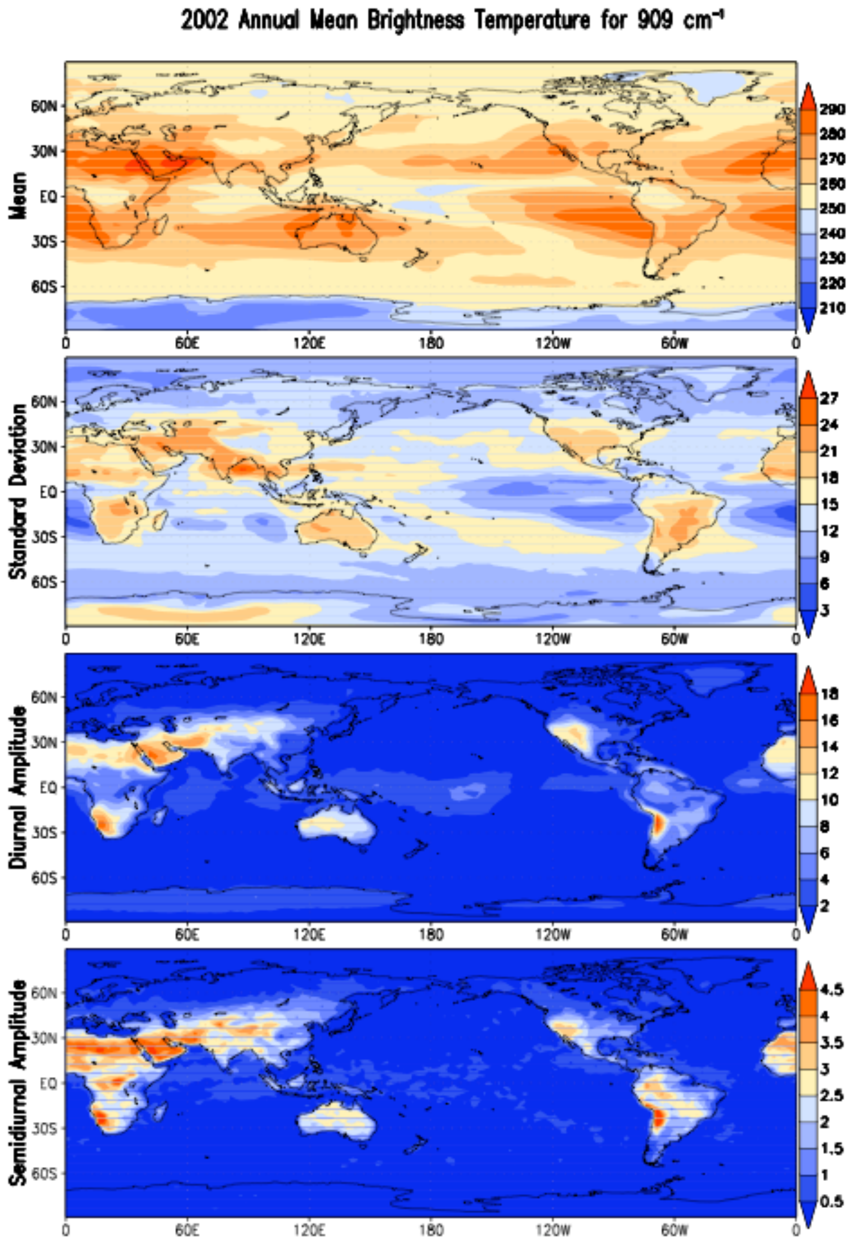
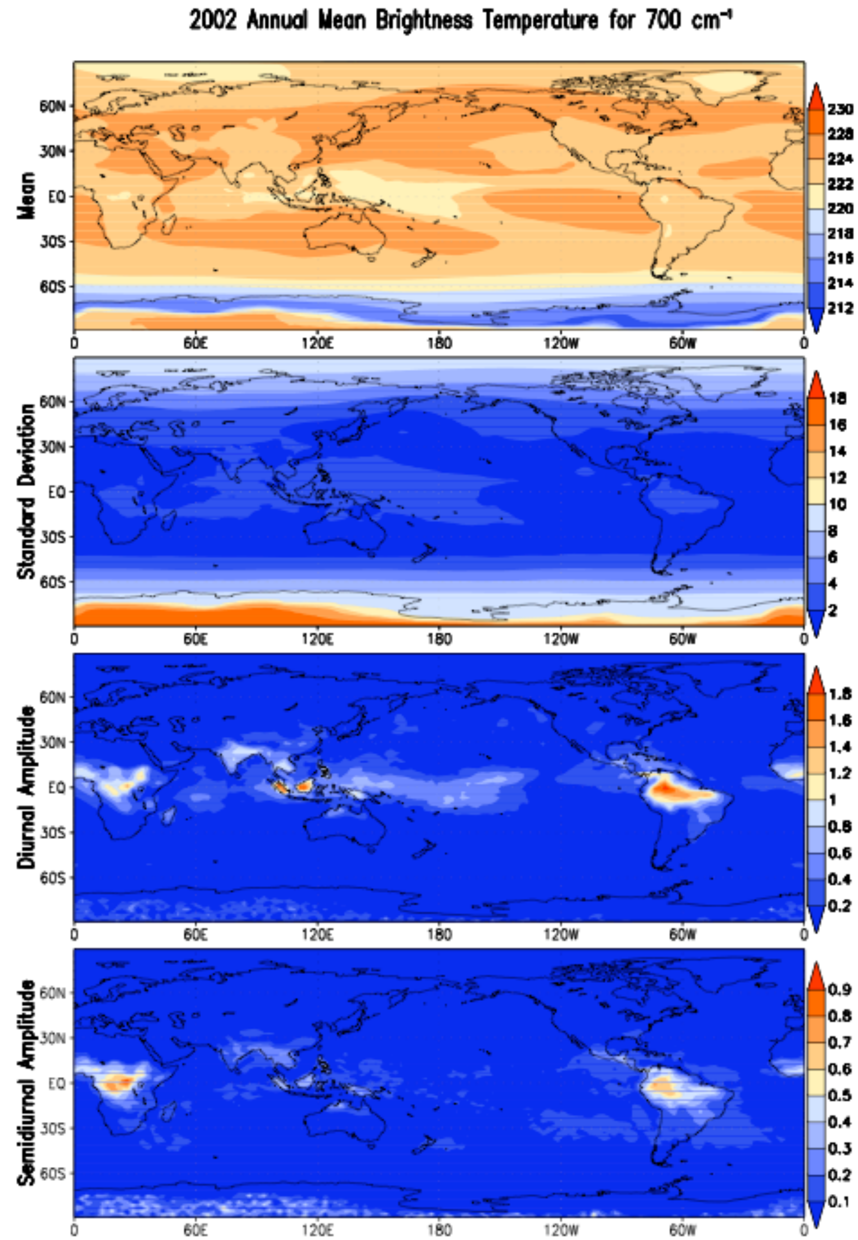


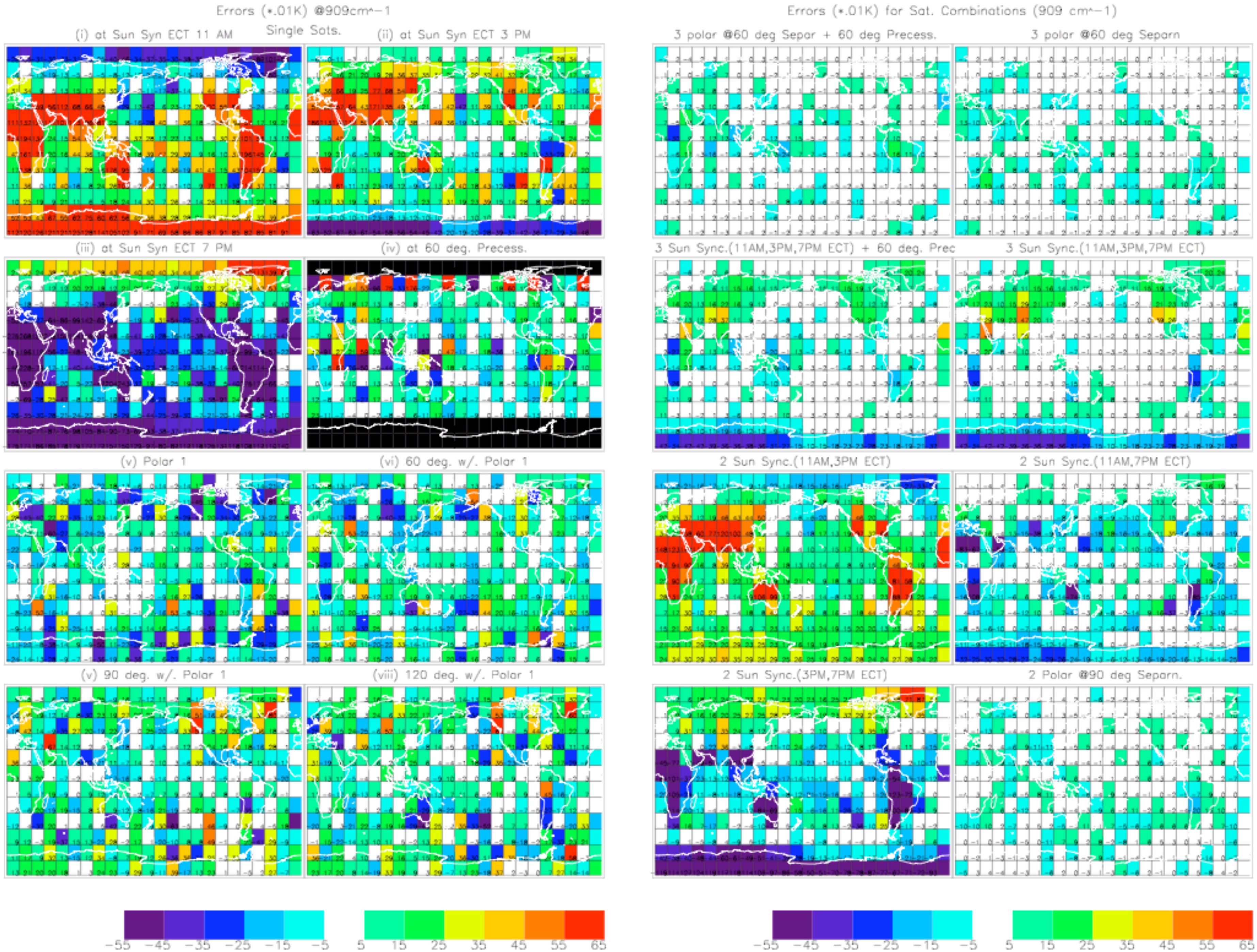
Figure 2. (top) Brightness temperatures measured from the IRIS data and calculated from the GCM data. The spectra are averaged over all 10 months of observations and over three tropical regions. (bottom) The pressure level of the maximum emission to space for each wavenumber calculated using MODTRAN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

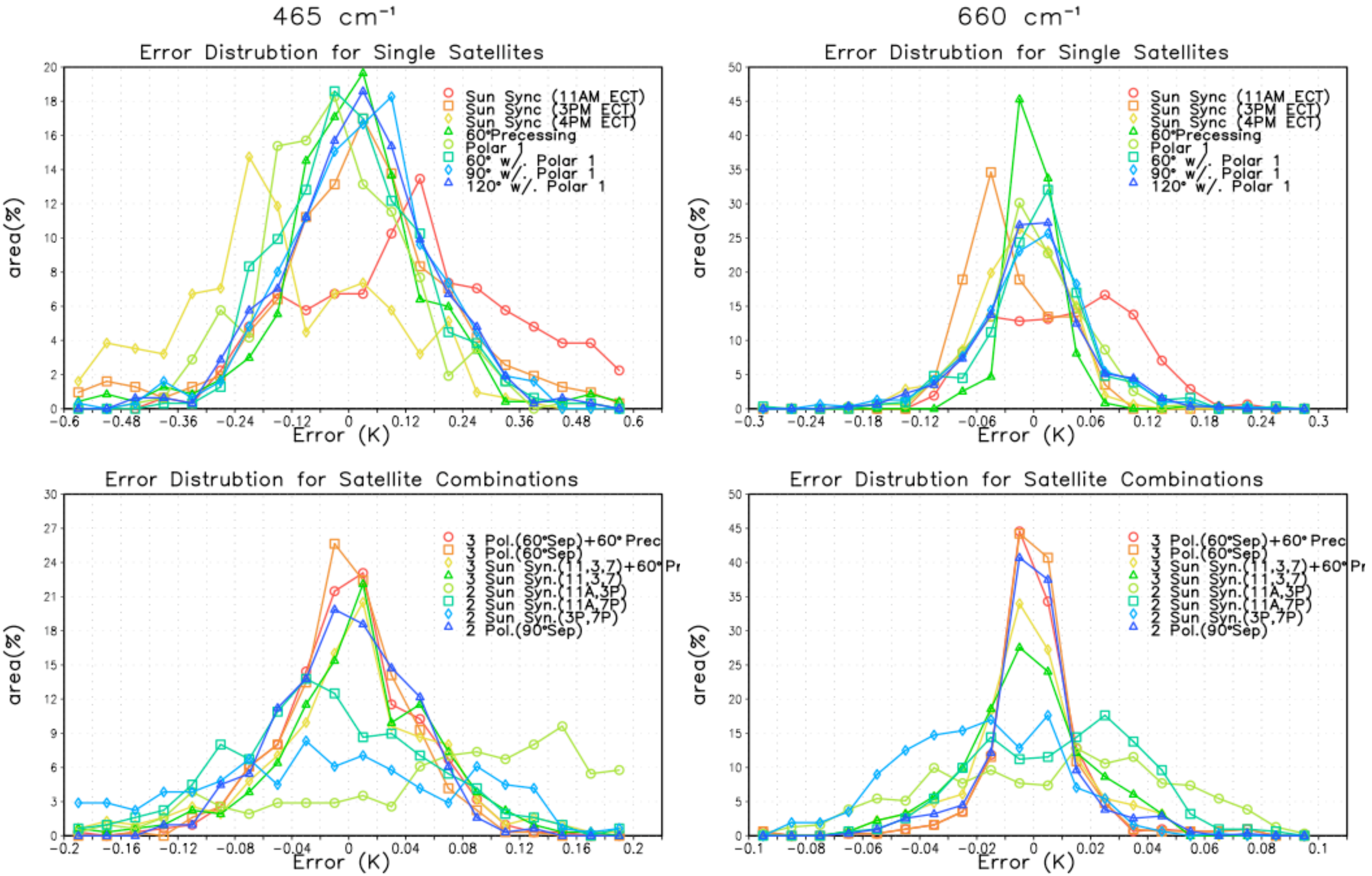


Window channel

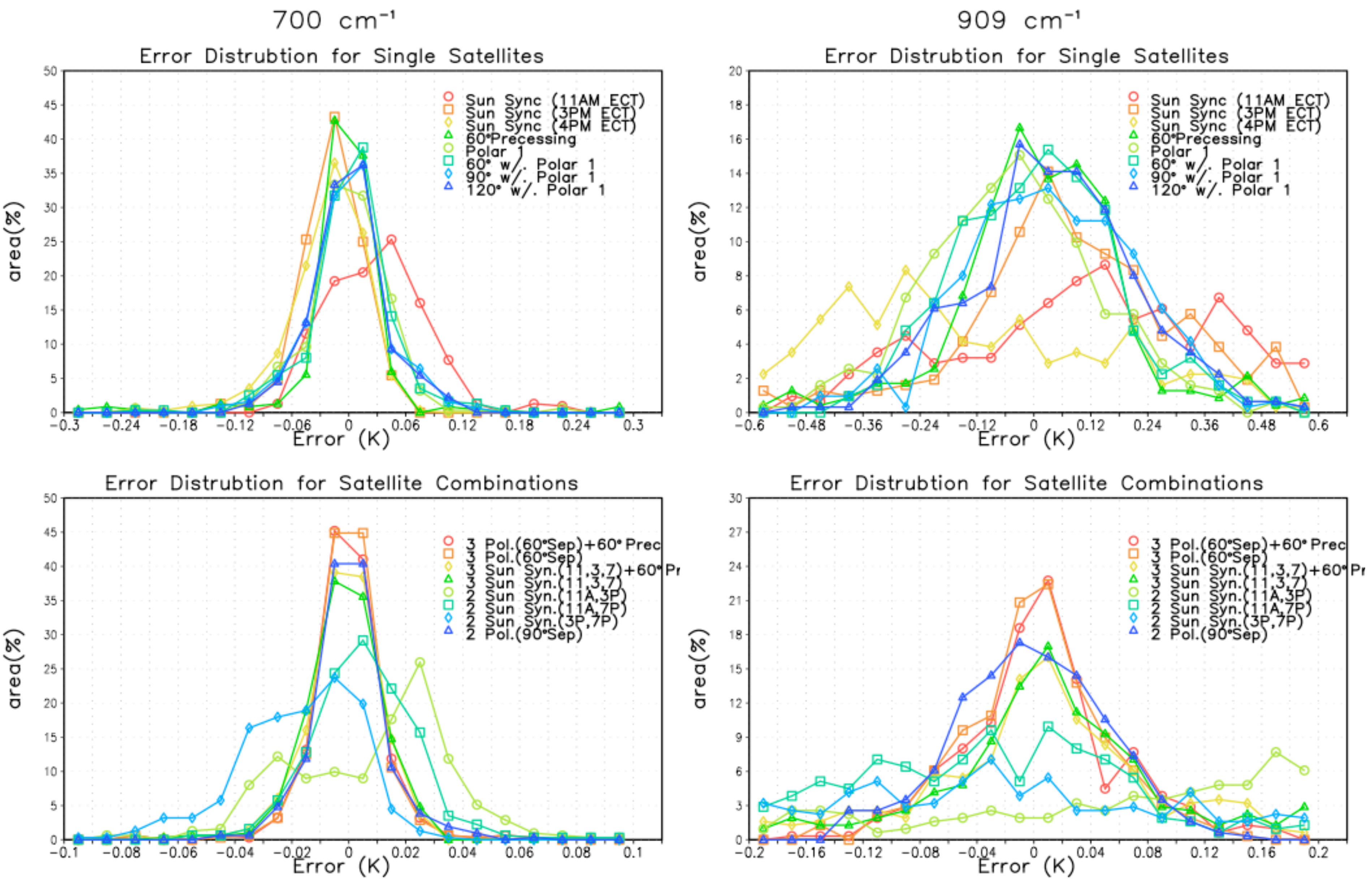


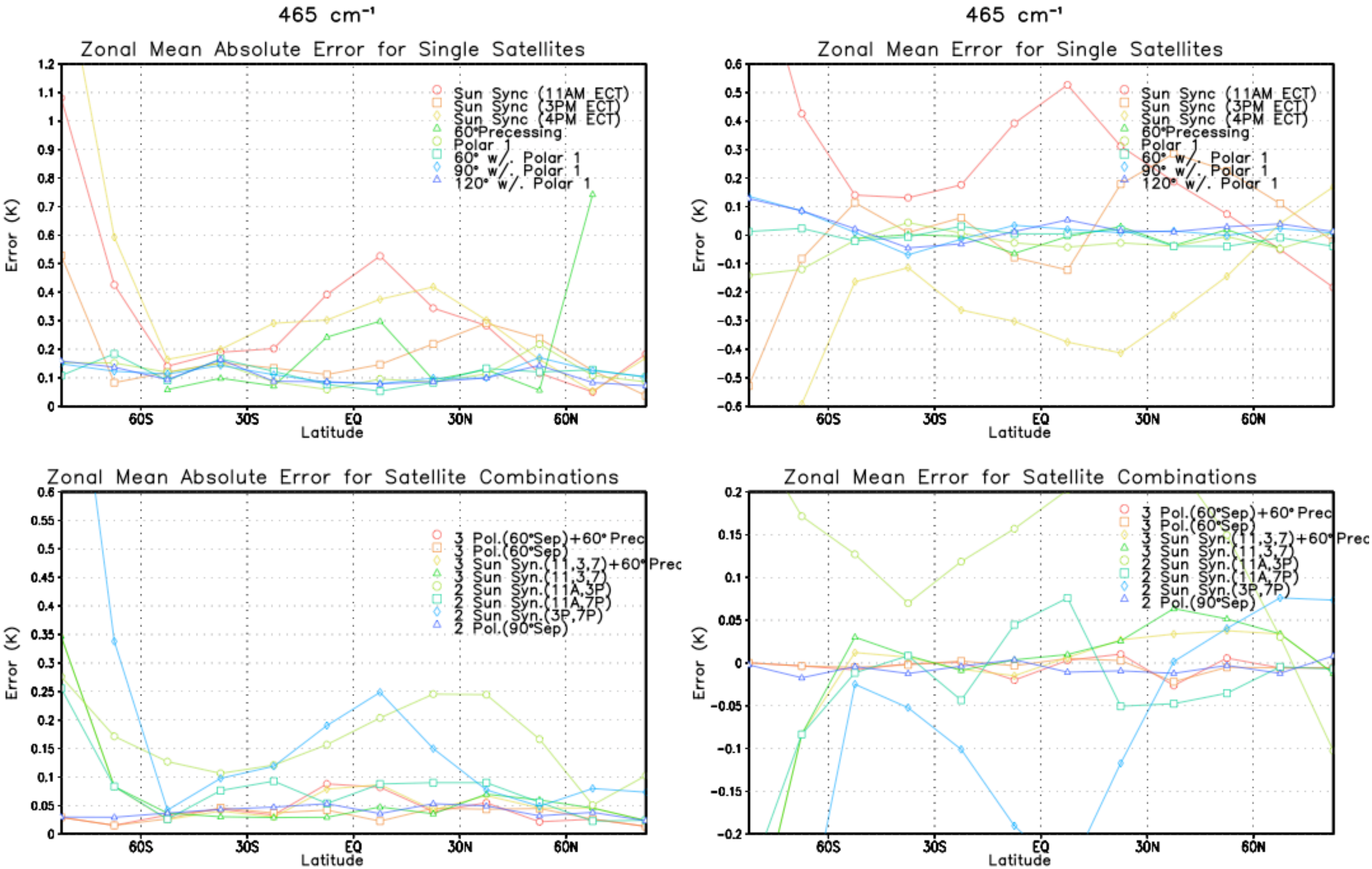
~250 hPa

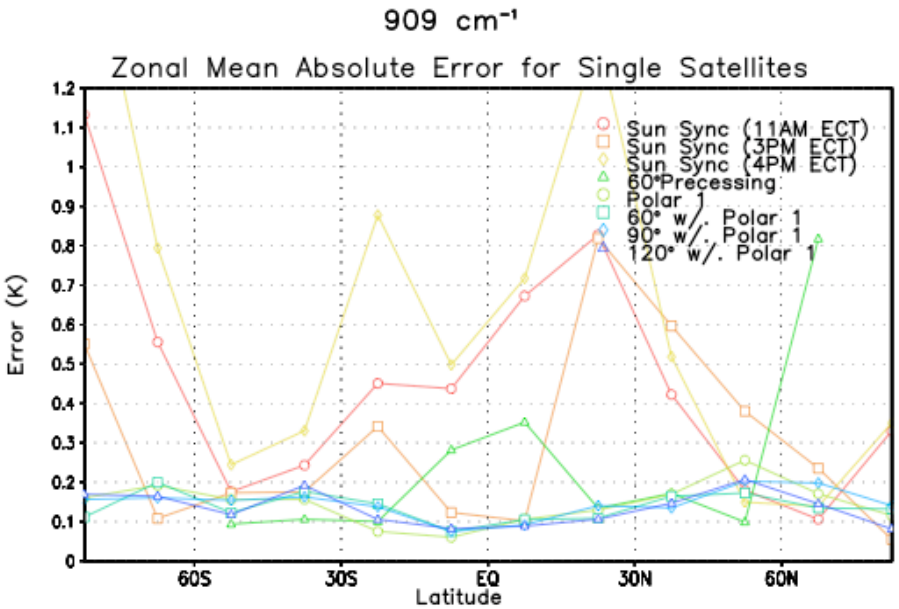

Errors (*.01K) @909cm^-1
Single Sats.
(i) at Sun Syn ECT 11 AM
(ii) at Sun Syn ECT 3 PM
(iii) at Sun Syn ECT 7 PM
(iv) at 60 deg. Precess.
(v) Polar 1
(vi) 60 deg. w/. Polar 1
(v) 90 deg. w/. Polar 1
(viii) 120 deg. w/. Polar 1
-55 -45 -35 -25 -15 -5
5 15 25 35 45 55 65
Errors (*.01K) for Sat. Combinations (909 cm^-1)
3 polar @60 deg Separ + 60 deg Precess.
3 polar @60 deg Separn
3 Sun Sync.(11AM,3PM,7PM ECT) + 60 deg. Prec
3 Sun Sync.(11AM,3PM,7PM ECT)
2 Sun Sync.(11AM,3PM ECT)
2 Sun Sync.(11AM,7PM ECT)
2 Sun Sync.(3PM,7PM ECT)
2 Polar @90 deg Separn.
-55 -45 -35 -25 -15 -5
5 15 25 35 45 55 65

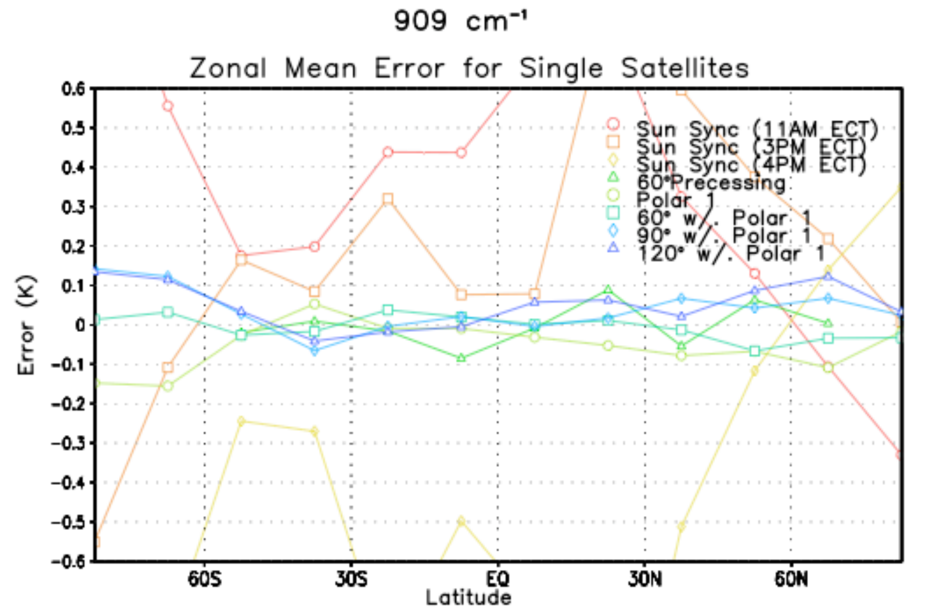


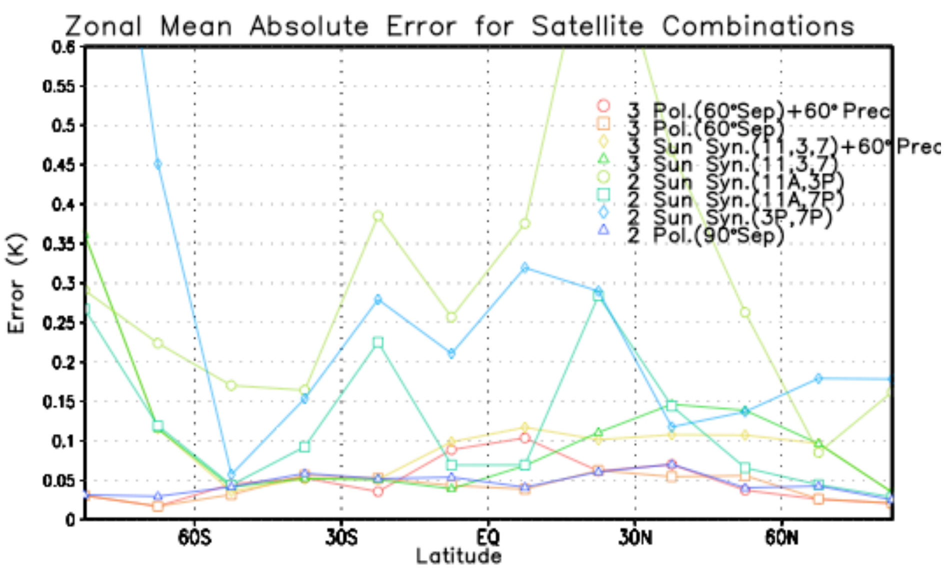
465 cm⁻¹
660 cm⁻¹
Error Distrubtion for Single Satellites
Sun Sync (11AM ECT)
Sun Sync (3PM ECT)
Sun Sync (4PM ECT)
60°Precessing
Polar 1
60° w/. Polar 1
90° w/. Polar 1
120° w/. Polar 1
Error Distrubtion for Satellite Combinations
3 Pol.(60°Sep)+60° Prec
3 Pol.(60°Sep)
3 Sun Syn.(11,3,7)+60° Pr
3 Sun Syn.(11,3,7)
2 Sun Syn.(11A,3P)
2 Sun Syn.(11A,7P)
2 Sun Syn.(3P,7P)
2 Pol.(90°Sep)
area(%)
Error (K)

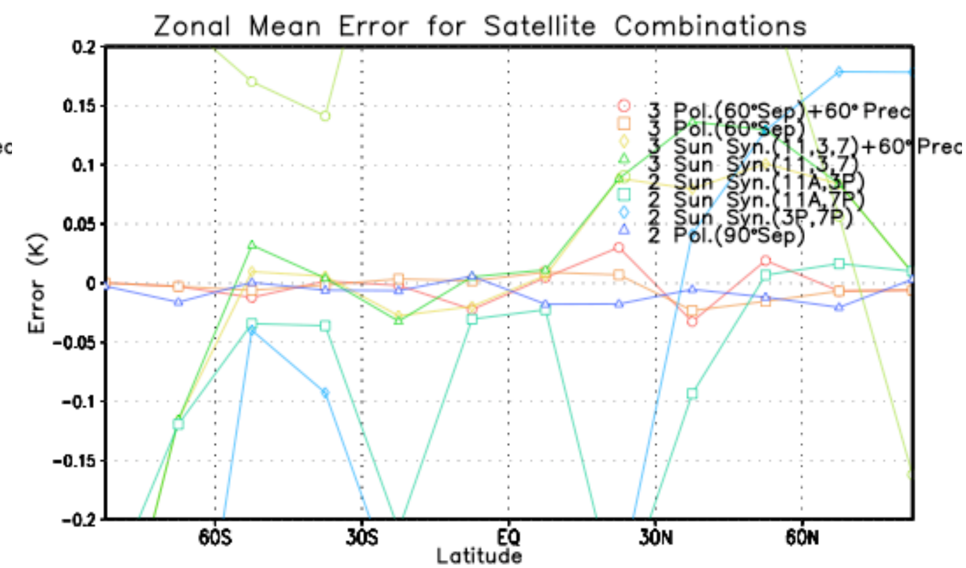

700 cm⁻¹
909 cm⁻¹
Error Distrubtion for Single Satellites
Sun Sync (11AM ECT)
Sun Sync (3PM ECT)
Sun Sync (4PM ECT)
60°Precessing
Polar 1
60° w/. Polar 1
90° w/. Polar 1
120° w/. Polar 1
area(%)
Error (K)
Error Distrubtion for Satellite Combinations
3 Pol.(60°Sep)+60° Prec
3 Pol.(60°Sep)
3 Sun Syn.(11,3,7)+60° Pr
3 Sun Syn.(11,3,7)
2 Sun Syn.(11A,3P)
2 Sun Syn.(11A,7P)
2 Sun Syn.(3P,7P)
2 Pol.(90°Sep)

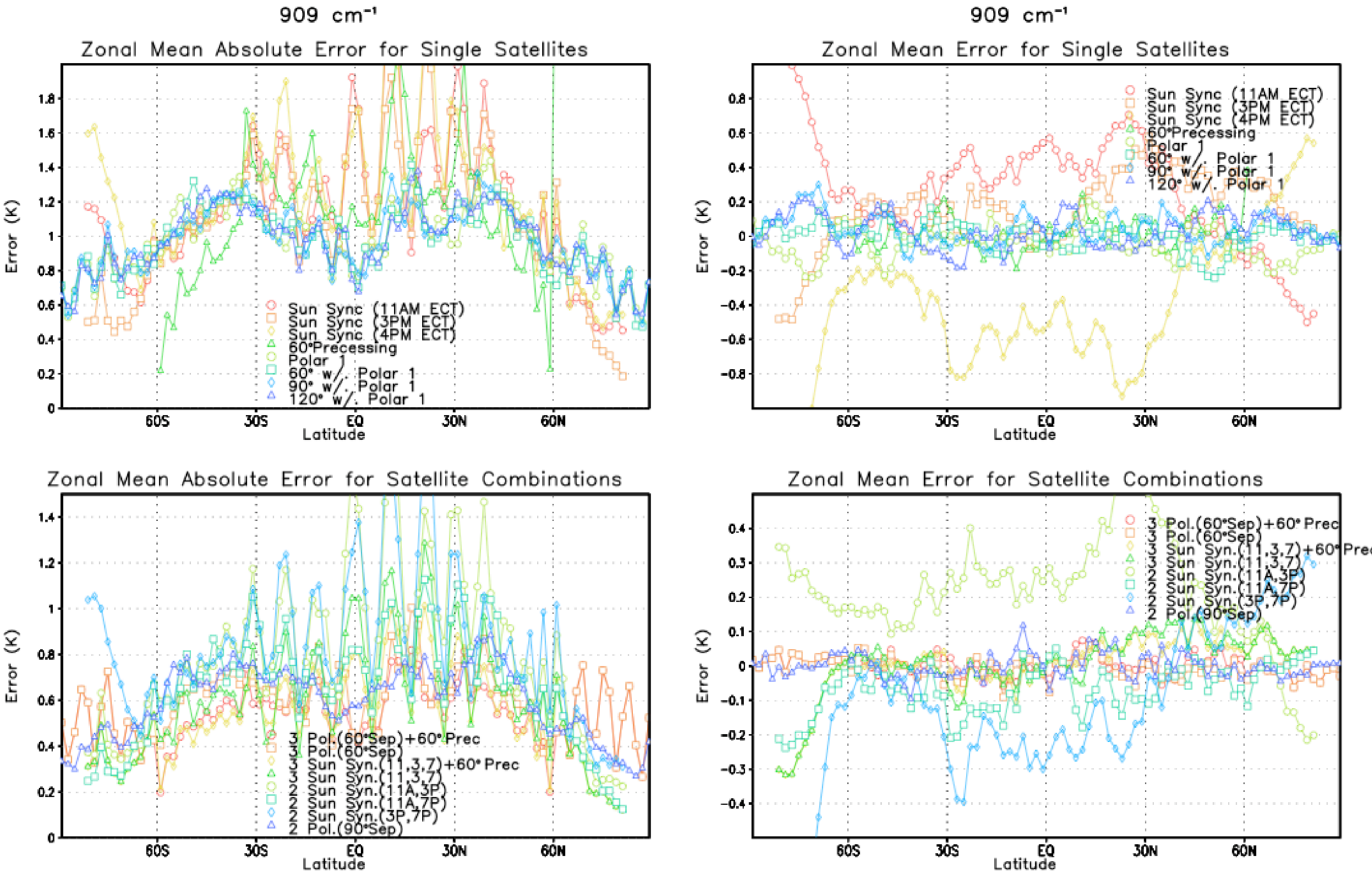

465 cm⁻¹
Zonal Mean Absolute Error for Single Satellites
Sun Sync (11AM ECT)
Sun Sync (3PM ECT)
Sun Sync (4PM ECT)
60°Precessing
Polar 1
60° w/. Polar 1
90° w/. Polar 1
120° w/. Polar 1
Error (K)
Latitude
60S 30S EQ 30N 60N
465 cm⁻¹
Zonal Mean Error for Single Satellites
Zonal Mean Absolute Error for Satellite Combinations
3 Pol.(60°Sep)+60° Prec
3 Pol.(60°Sep)
3 Sun Syn.(11,3,7)+60° Prec
3 Sun Syn.(11,3,7)
2 Sun Syn.(11A,3P)
2 Sun Syn.(11A,7P)
2 Sun Syn.(3P,7P)
2 Pol.(90°Sep)
Zonal Mean Error for Satellite Combinations

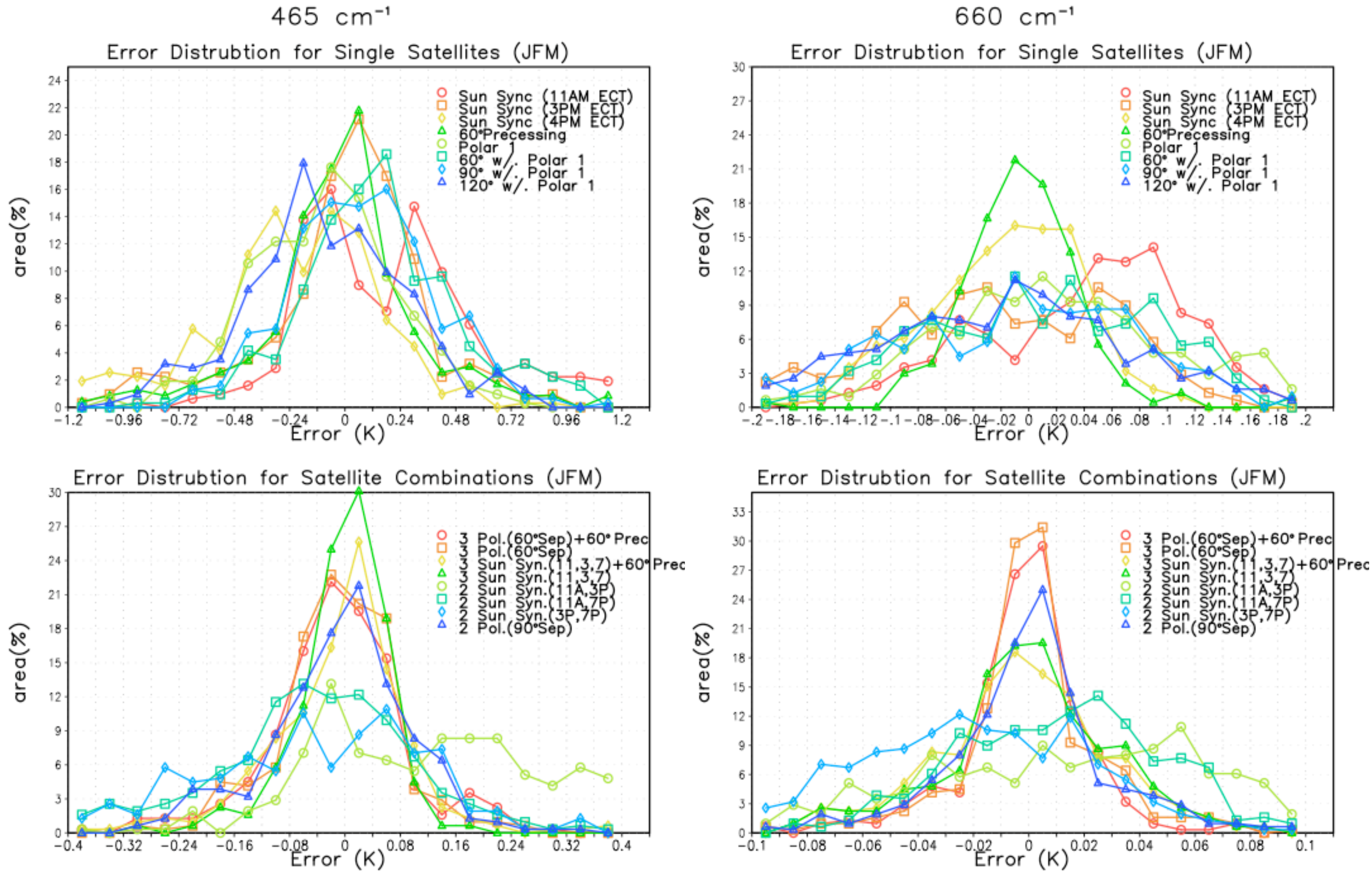

909 cm⁻¹
Zonal Mean Absolute Error for Single Satellites
Sun Sync (11AM ECT)
Sun Sync (3PM ECT)
Sun Sync (4PM ECT)
60°Precessing
Polar 1
60° w/. Polar 1
90° w/. Polar 1
120° w/. Polar 1
Error (K)
Latitude
60S 30S EQ 30N 60N

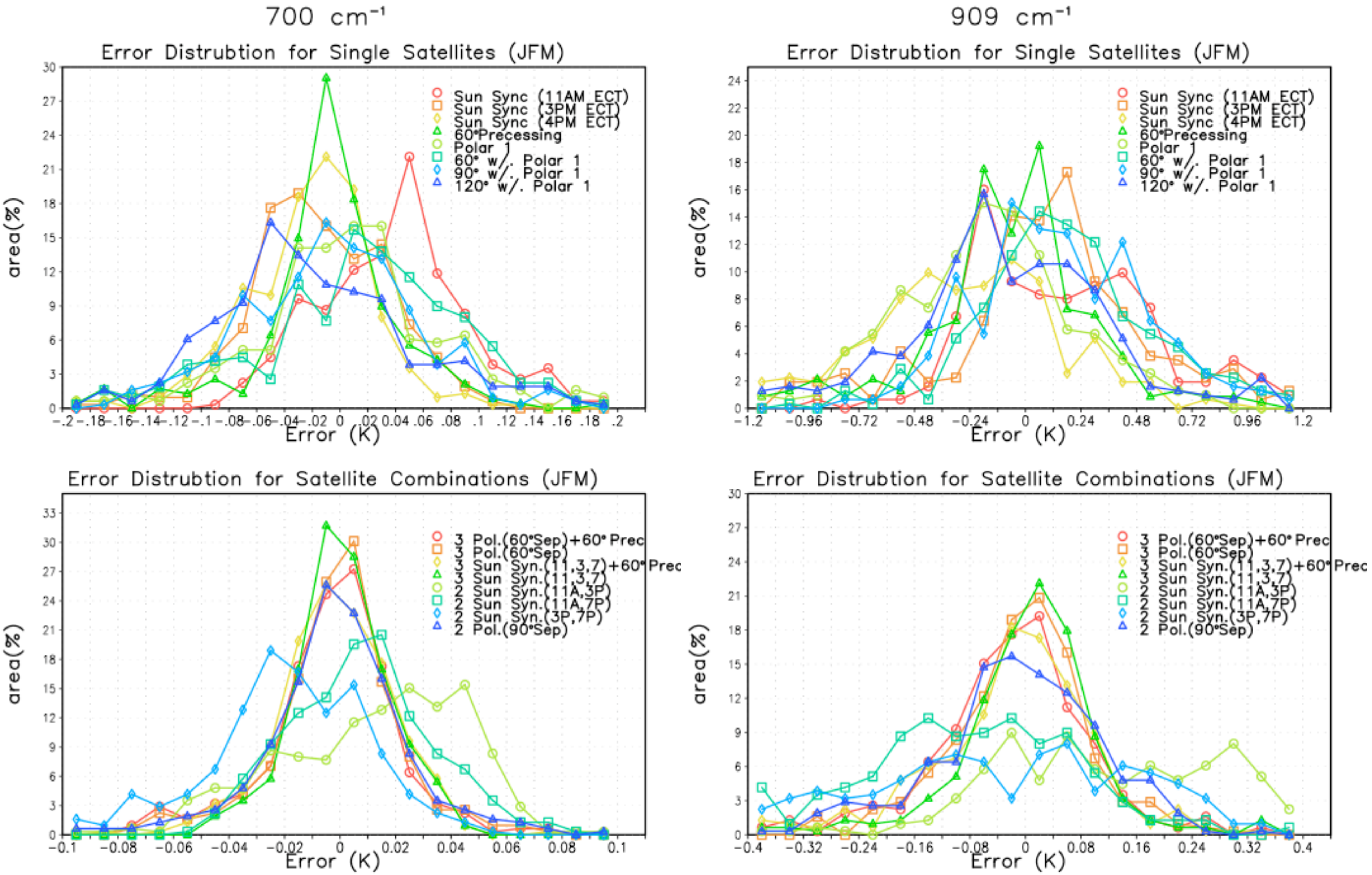

909 cm⁻¹
Zonal Mean Error for Single Satellites
Sun Sync (11AM ECT)
Sun Sync (3PM ECT)
Sun Sync (4PM ECT)
60°Precessing
Polar 1
60° w/. Polar 1
90° w/. Polar 1
120° w/. Polar 1
Error (K)
Latitude
60S 30S EQ 30N 60N


Zonal Mean Absolute Error for Satellite Combinations
3 Pol.(60°Sep)+60° Prec
3 Pol.(60°Sep)
3 Sun Syn.(11,3,7)+60°Prec
3 Sun Syn.(11,3,7)
2 Sun Syn.(11A,3P)
2 Sun Syn.(11A,7P)
2 Sun Syn.(3P,7P)
2 Pol.(90°Sep)
Error (K)
Latitude
60S 30S EQ 30N 60N

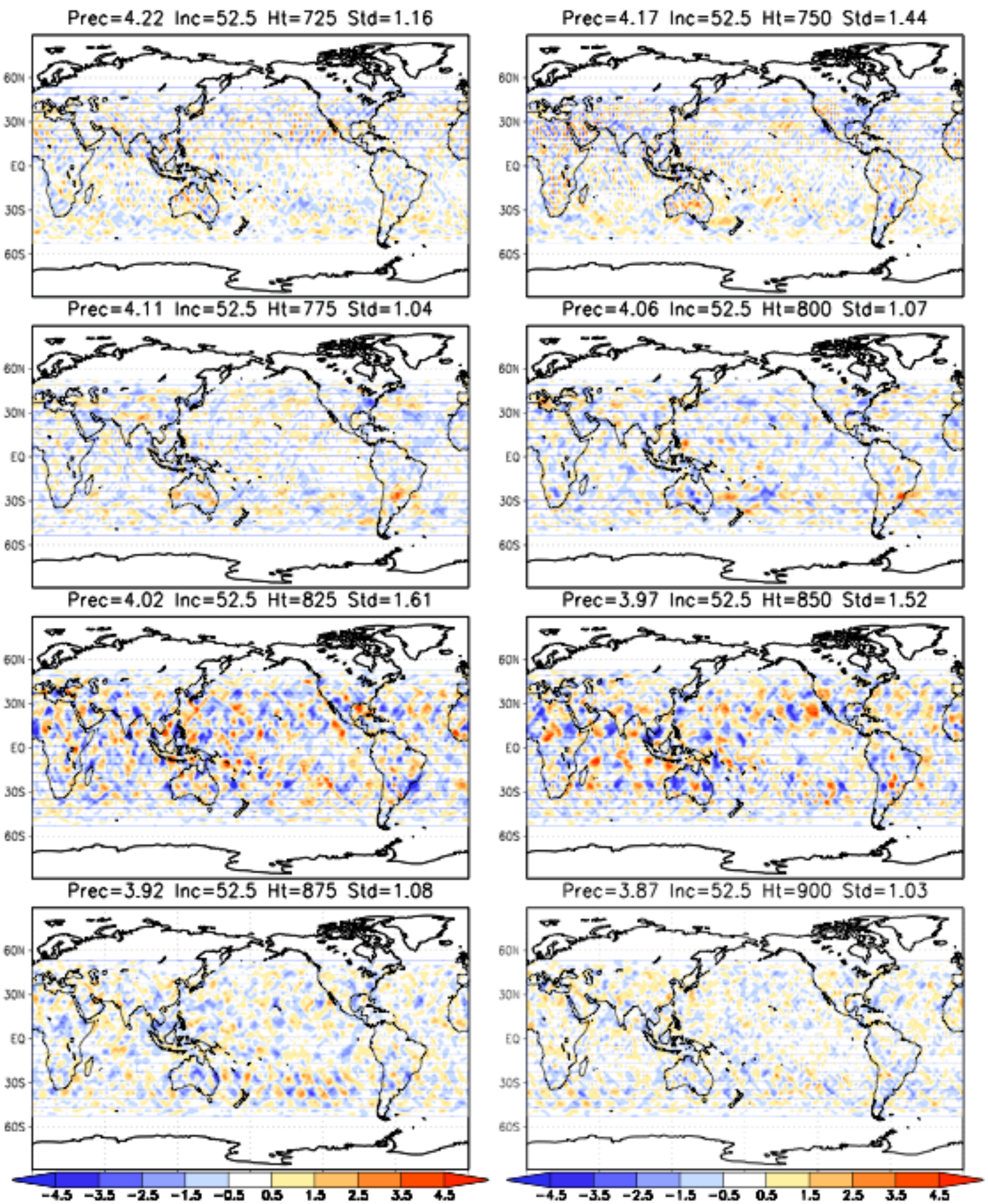

Zonal Mean Error for Satellite Combinations
3 Pol.(60°Sep)+60° Prec
3 Pol.(60°Sep)
3 Sun Syn.(11,3,7)+60°Prec
3 Sun Syn.(11,3,7)
2 Sun Syn.(11A,3P)
2 Sun Syn.(11A,7P)
2 Sun Syn.(3P,7P)
2 Pol.(90°Sep)
Error (K)
Latitude
60S 30S EQ 30N 60N


909 cm⁻¹
Zonal Mean Absolute Error for Single Satellites
909 cm⁻¹
Zonal Mean Error for Single Satellites
Zonal Mean Absolute Error for Satellite Combinations
Zonal Mean Error for Satellite Combinations
Error (K)
Latitude
60S
30S
EQ
30N
60N
Sun Sync (11AM ECT)
Sun Sync (3PM ECT)
Sun Sync (4PM ECT)
60°Precessing
Polar 1
60° w/. Polar 1
90° w/. Polar 1
120° w/. Polar 1
3 Pol.(60°Sep)+60° Prec
3 Pol.(60°Sep)
3 Sun Syn.(11,3,7)+60° Prec
3 Sun Syn.(11,3,7)
2 Sun Syn.(11A,3P)
2 Sun Syn.(11A,7P)
2 Sun Syn.(3P,7P)
2 Pol.(90°Sep)

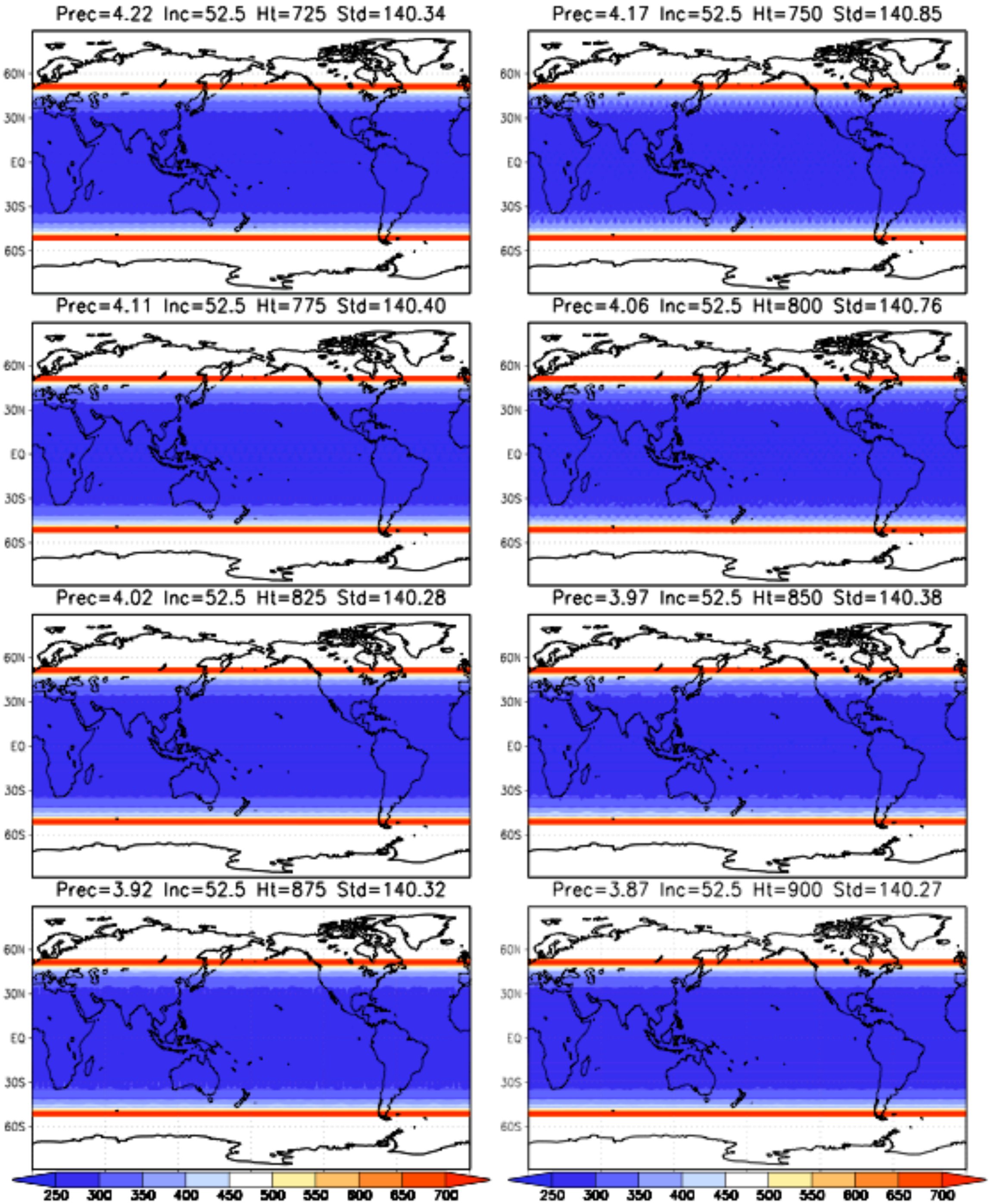

465 cm⁻¹
660 cm⁻¹
Error Distrubtion for Single Satellites (JFM)
Sun Sync (11AM ECT)
Sun Sync (3PM ECT)
Sun Sync (4PM ECT)
60°Precessing
Polar 1
60° w/. Polar 1
90° w/. Polar 1
120° w/. Polar 1
Error Distrubtion for Satellite Combinations (JFM)
3 Pol.(60°Sep)+60° Prec
3 Pol.(60°Sep)
3 Sun Syn.(11,3,7)+60° Prec
3 Sun Syn.(11,3,7)
2 Sun Syn.(11A,3P)
2 Sun Syn.(11A,7P)
2 Sun Syn.(3P,7P)
2 Pol.(90°Sep)
area(%)
Error (K)


700 cm⁻¹
909 cm⁻¹
Error Distrubtion for Single Satellites (JFM)
Sun Sync (11AM ECT)
Sun Sync (3PM ECT)
Sun Sync (4PM ECT)
60°Precessing
Polar 1
60° w/. Polar 1
90° w/. Polar 1
120° w/. Polar 1
Error Distrubtion for Satellite Combinations (JFM)
3 Pol.(60°Sep)+60° Prec
3 Pol.(60°Sep)
3 Sun Syn.(11,3,7)+60° Prec
3 Sun Syn.(11,3,7)
2 Sun Syn.(11A,3P)
2 Sun Syn.(11A,7P)
2 Sun Syn.(3P,7P)
2 Pol.(90°Sep)
area(%)
Error (K)

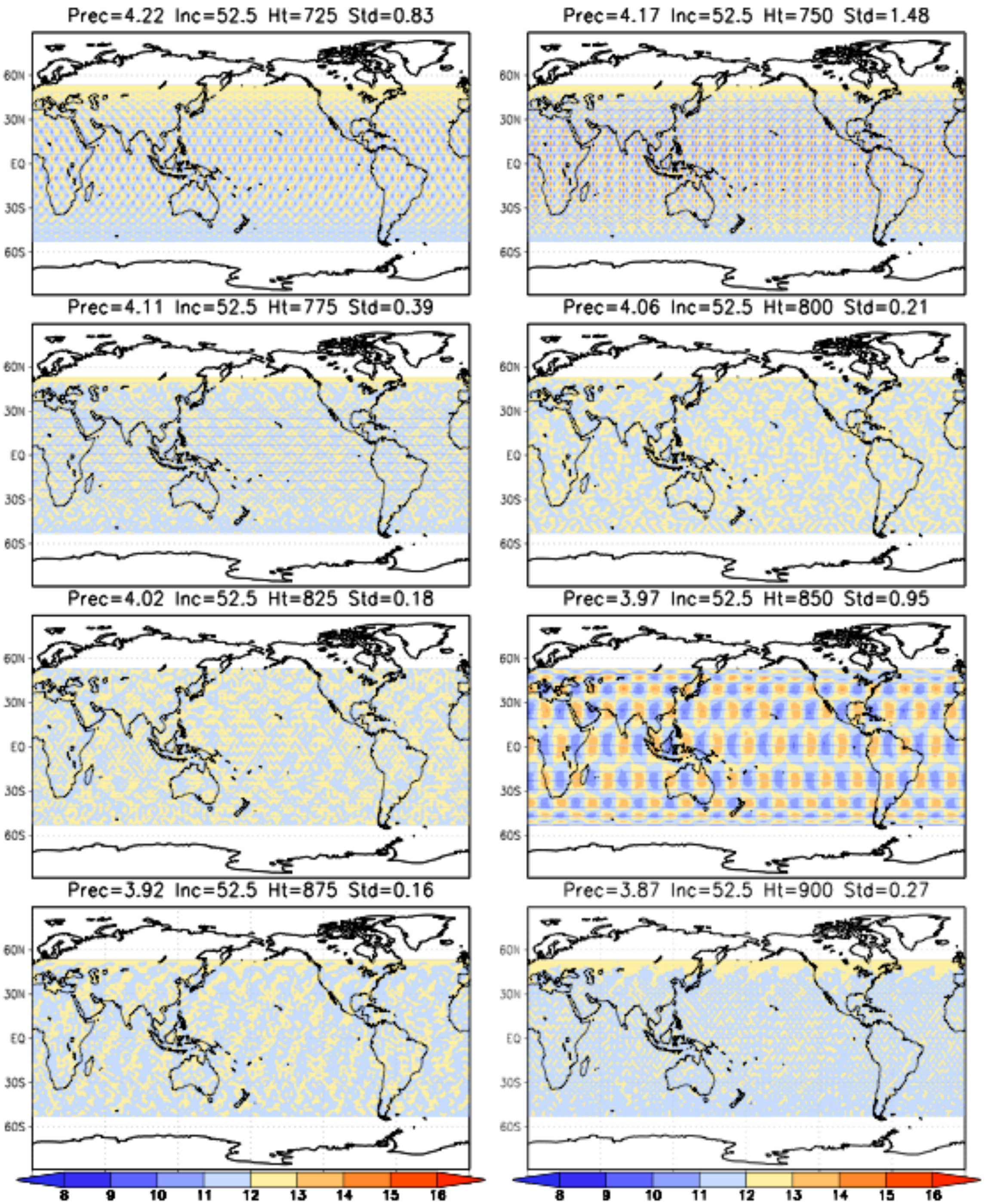
To understand the errors for high inclination orbits better we look at sampling error at 2°x2.5° resolution, for a range of orbit altitudes, holding inclination constant.



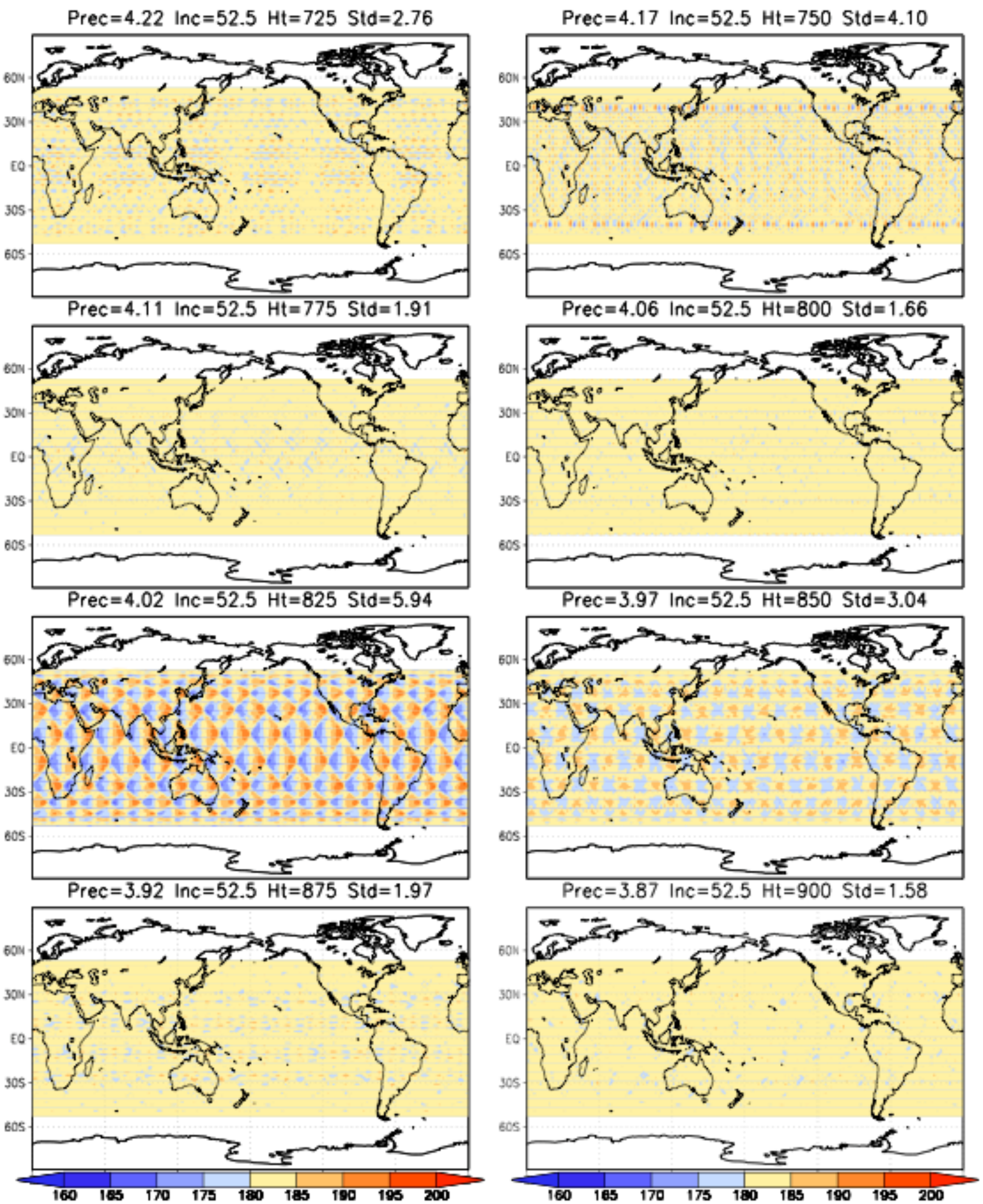
Number of observations.



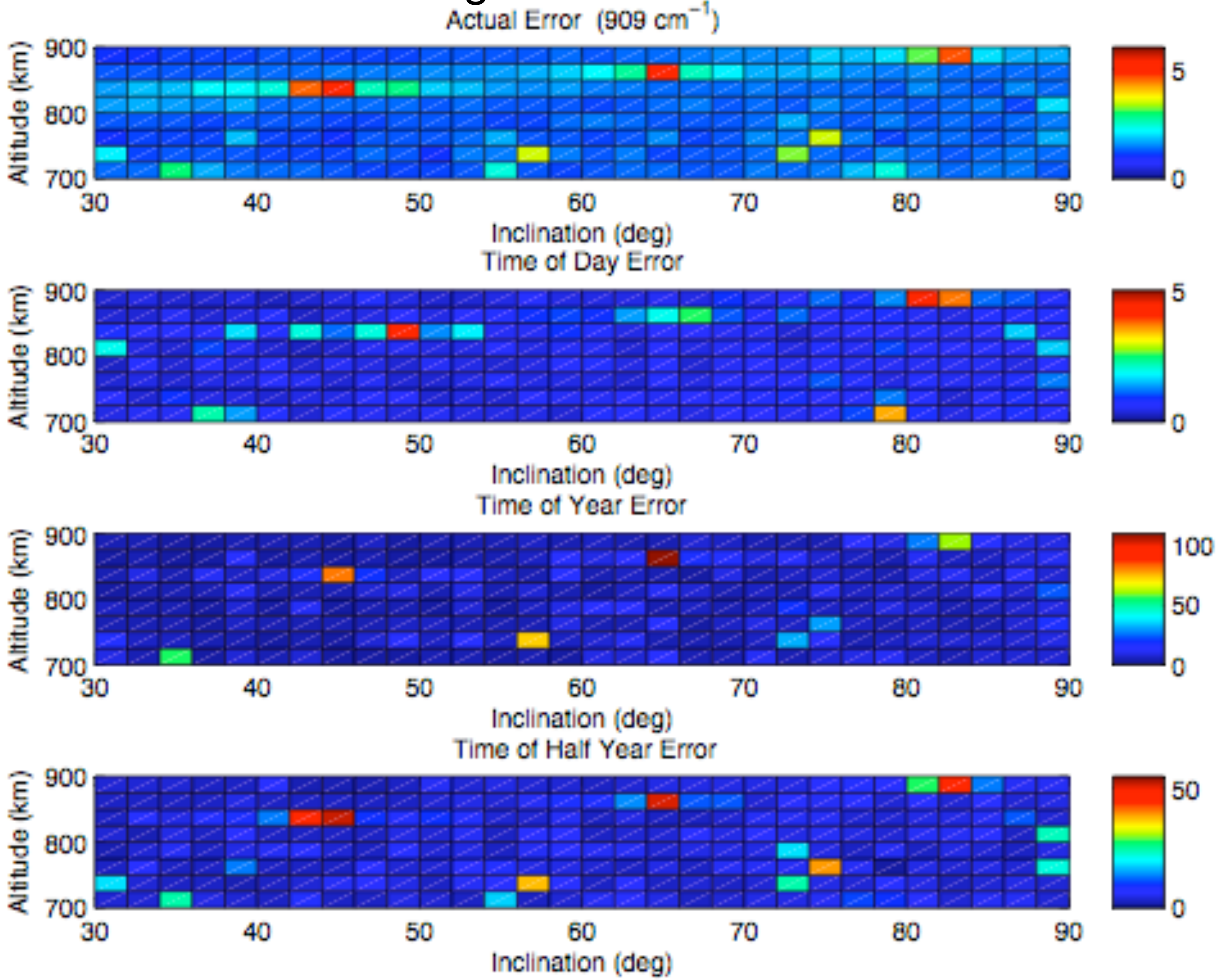
Sampling error in retrieving the local time.

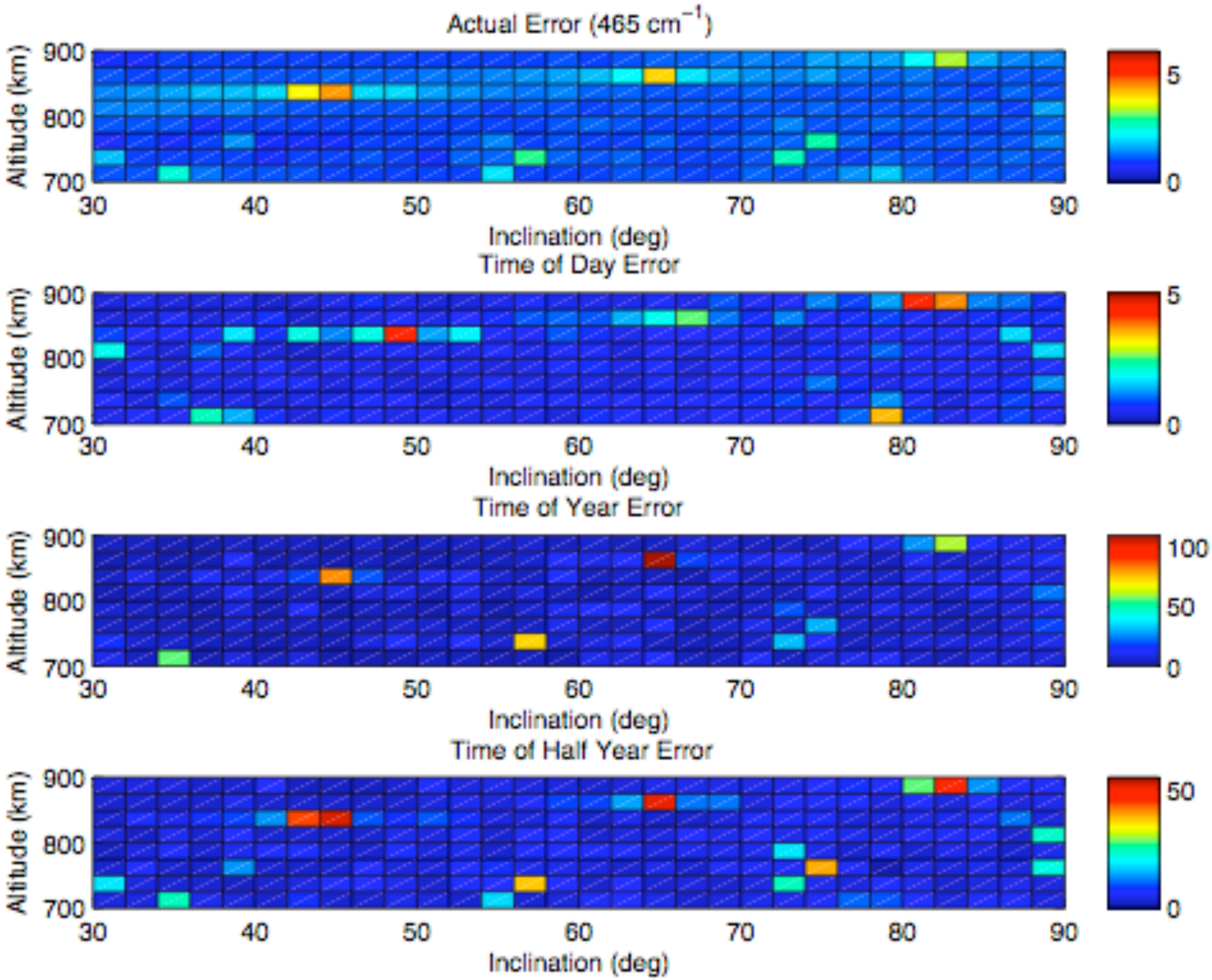


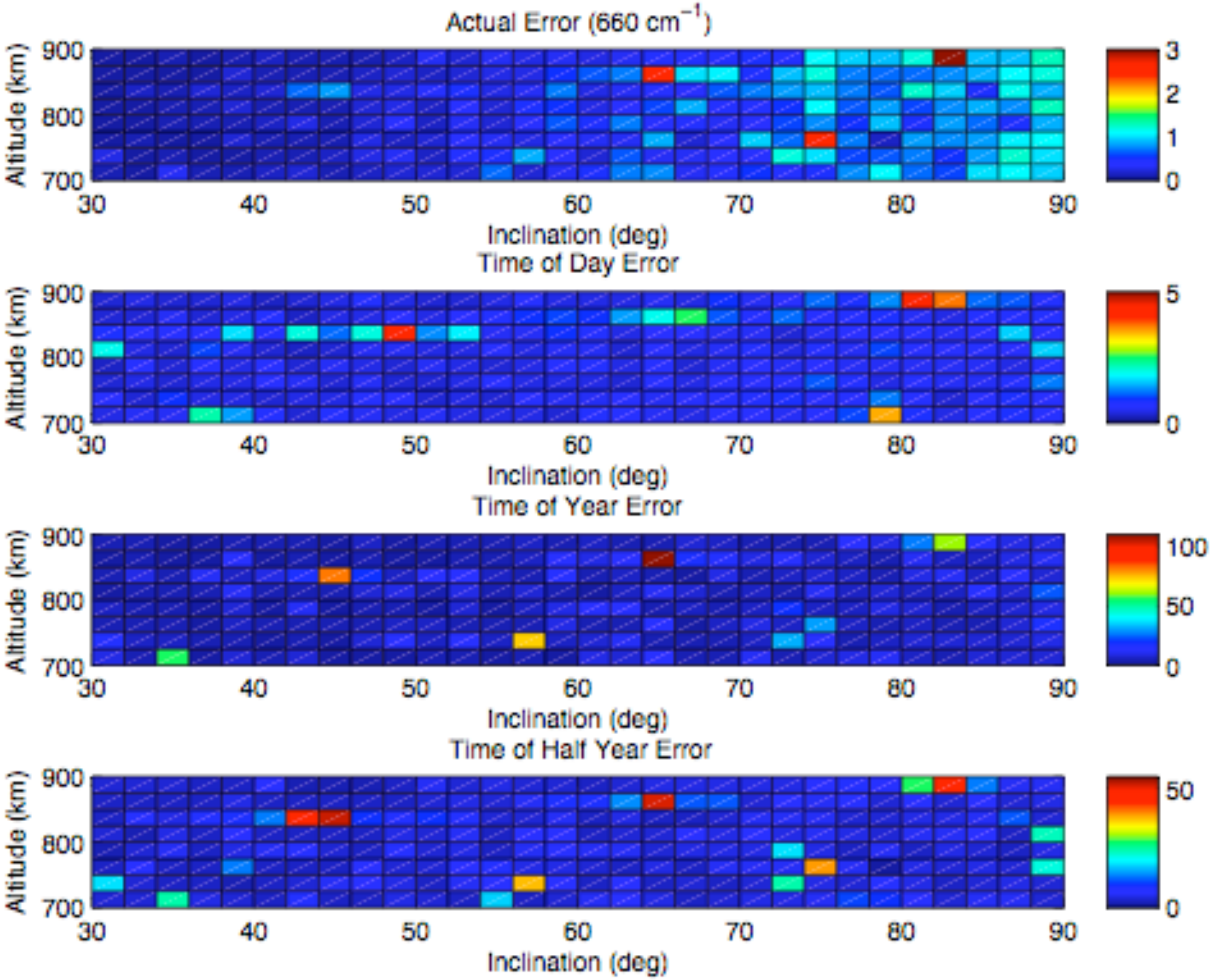
Sampling error in retrieving the day of the year.



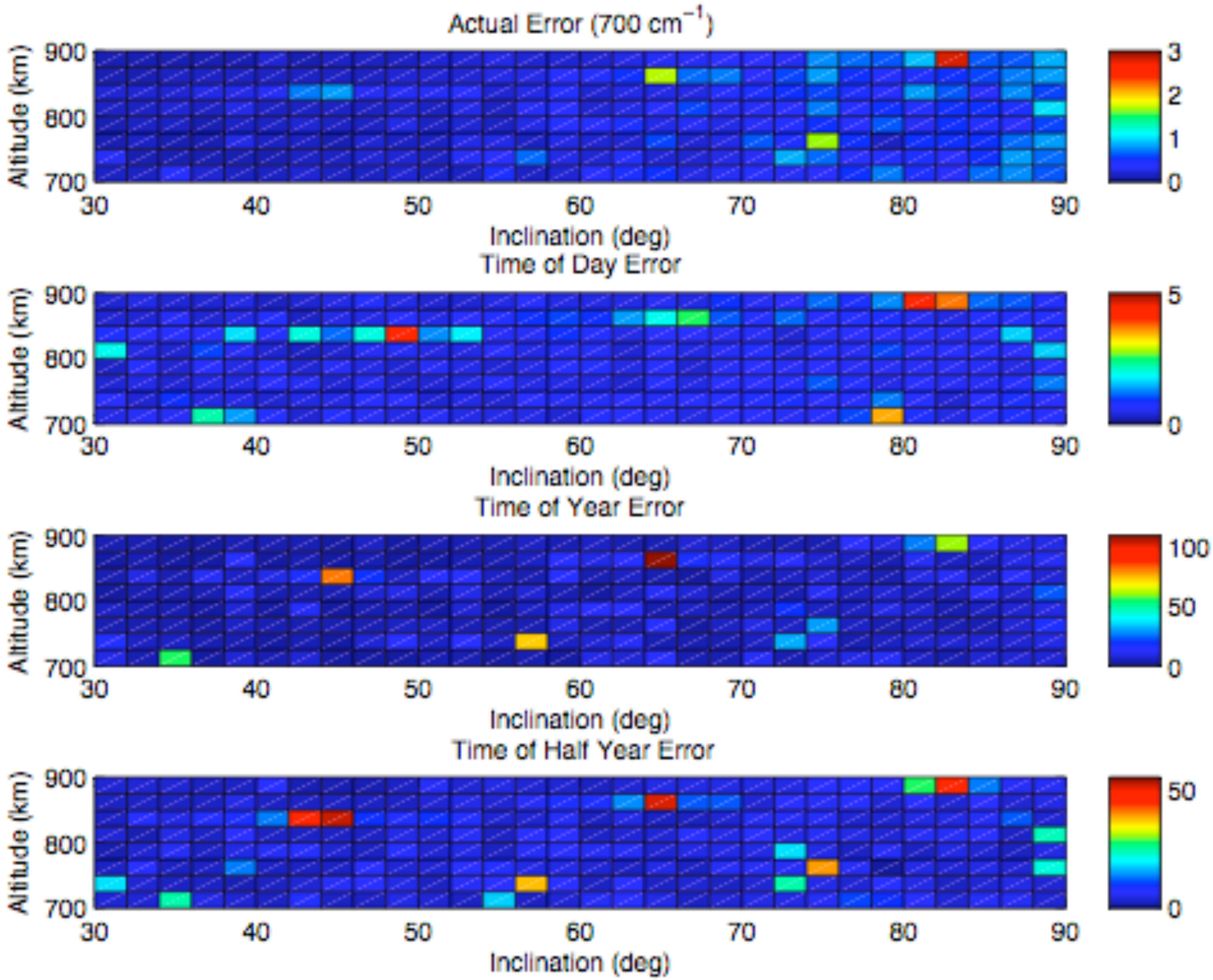
Errors for 2.5° model grid resolution




Actual Error (465 cm^{-1})
Time of Day Error
Time of Year Error
Time of Half Year Error
Altitude (km)
Inclination (deg)
900
800
700
30
40
50
60
70
80
90
0
5
50
100

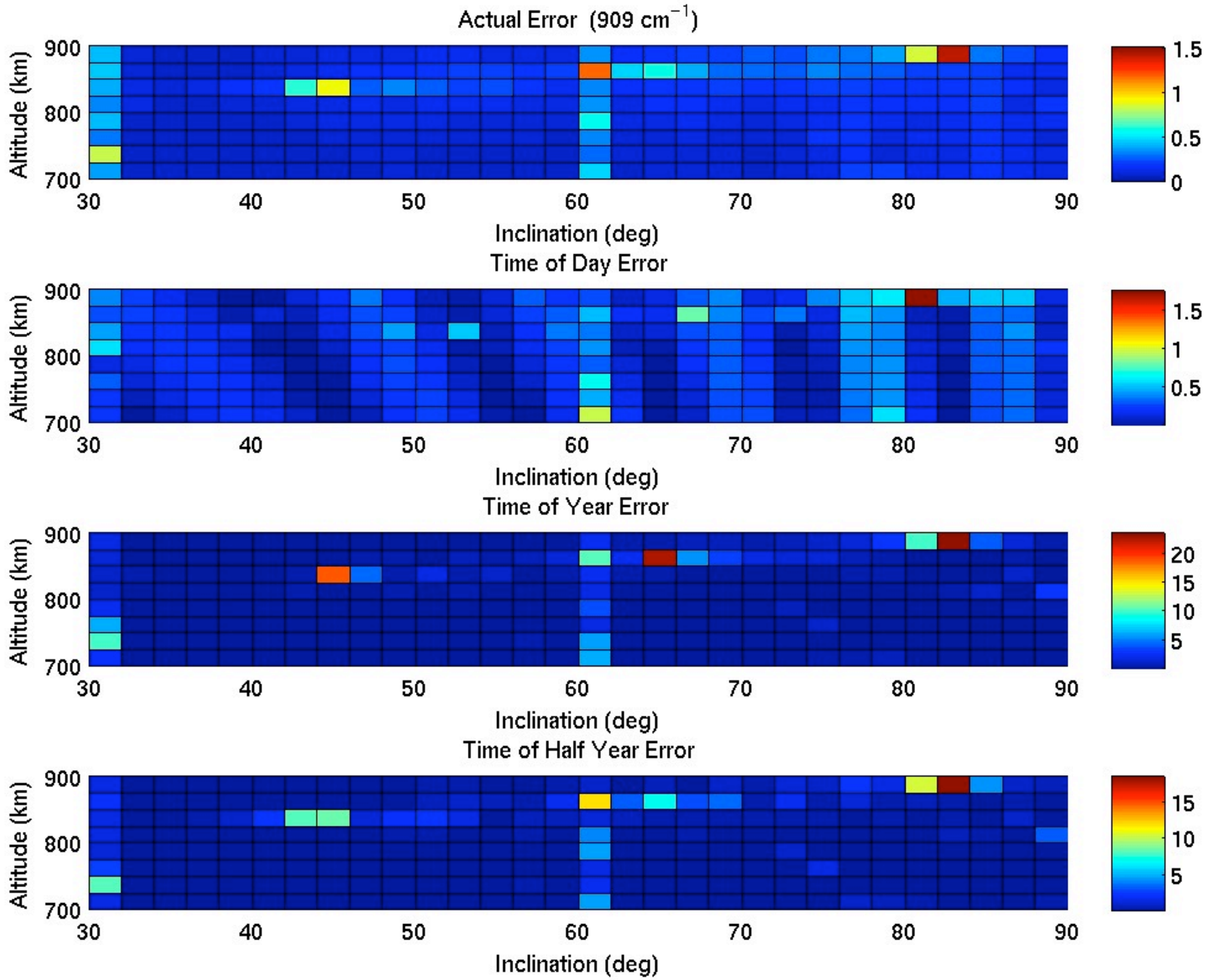


Actual Error (660 cm^{-1})
Altitude (km)
900
800
700
30
40
50
60
70
80
90
Inclination (deg)
3
2
1
0
Time of Day Error
Altitude (km)
Inclination (deg)
5
0
Time of Year Error
Altitude (km)
Inclination (deg)
100
50
0
Time of Half Year Error
Altitude (km)
Inclination (deg)
50
0



Actual Error (700 cm^{-1})
Altitude (km)
900
800
700
30
40
50
60
70
80
90
Inclination (deg)
3
2
1
0
Time of Day Error
Altitude (km)
Inclination (deg)
5
0
Time of Year Error
Altitude (km)
Inclination (deg)
100
50
0
Time of Half Year Error
Altitude (km)
Inclination (deg)
50
0

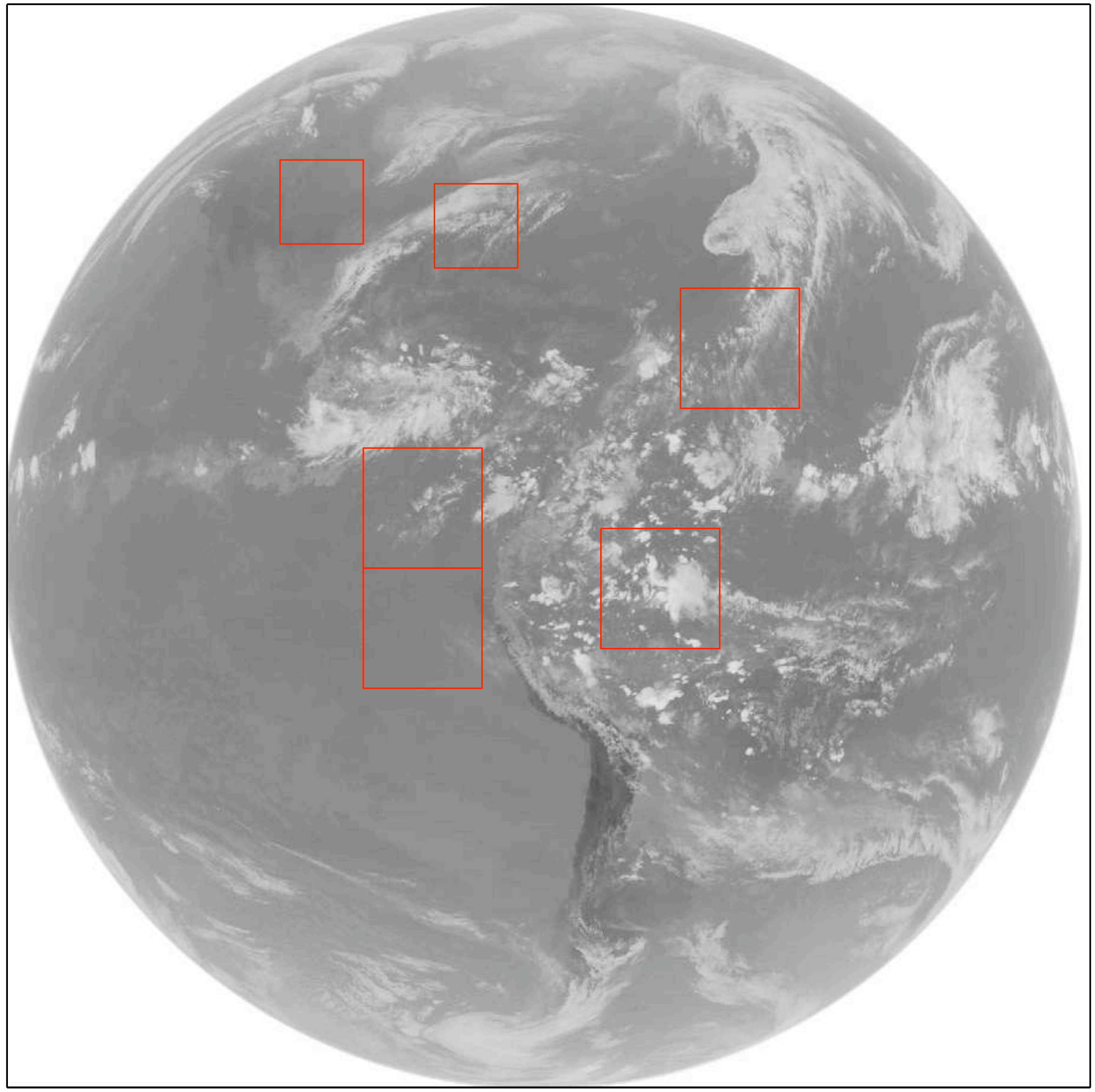
Prediction of errors for 15° grid boxes



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?