Cooperative Institute For Climate & Satellites

AMSU navigation and geolocation errors

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Geolocation, mapping satellite data to the earth surface

- Geolocation is a very important part of the postlaunch calibration process.
- We combine different satellite and modeled data to retrieve geophysical variables like temperature, rainfall, water vapor, and etc. So it is critical to know the exact location of each measurement or simulation.

Main sources of geolocation errors

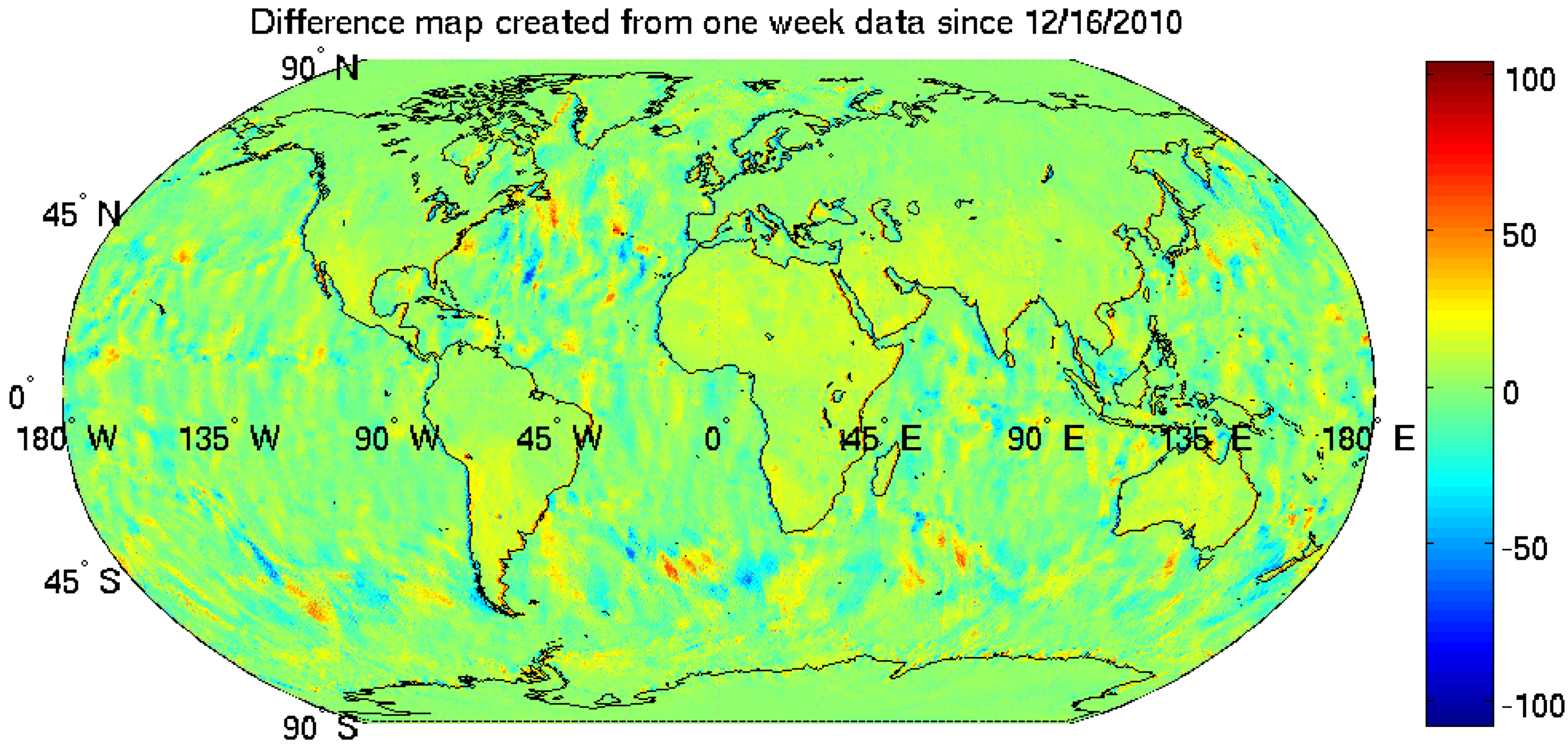
- 1. Poor spacecraft ephemeris data (right ascension, altitude, declination)
- **2. Satellite and sensor pointing / attitude errors**
- 3. Time offset

How to quantify geolocation errors

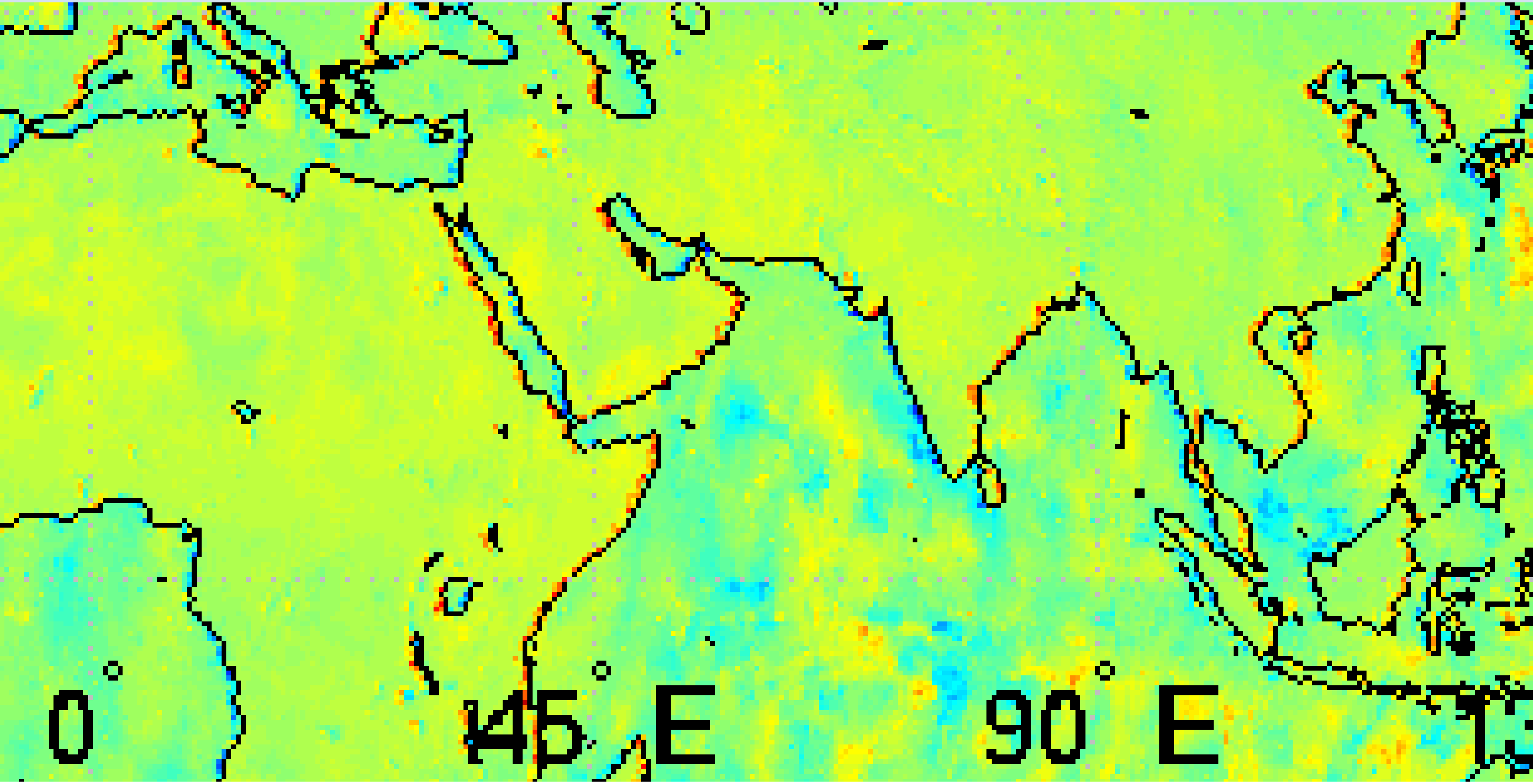
The difference map for ascending/descending nodes

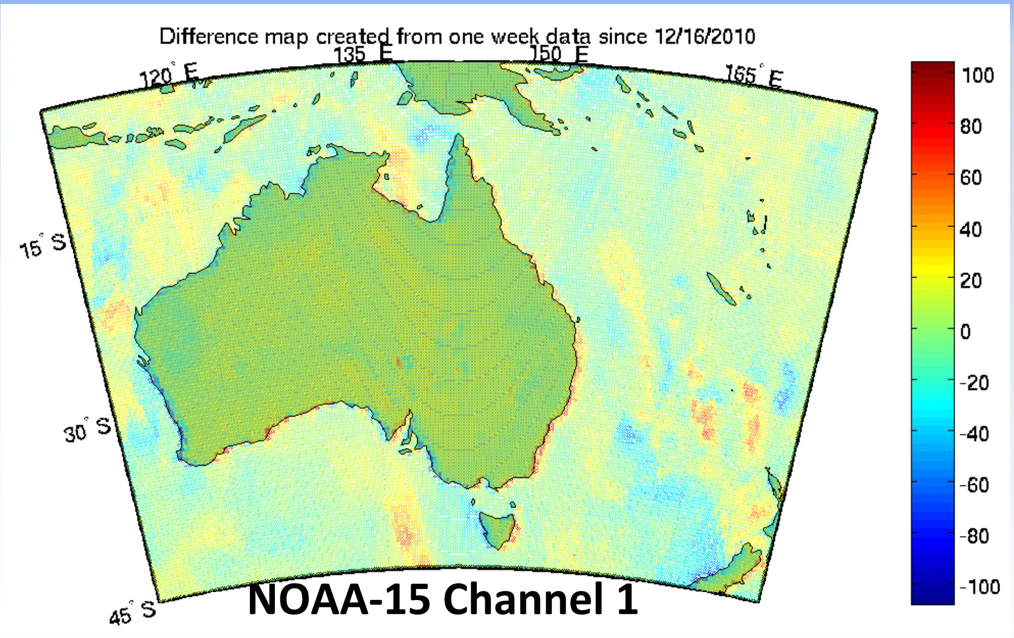
- The time difference between ascending/descending orbits is about 12 hours and normally one of them is daytime and the other one is nighttime.
- During day the surface temperature is hot and it is cold in night but the ocean surface temperature does not change that much.
- The difference map should not distinguish any difference at the coast lines
- ***negative alongtrack* offset => *northern* coastlines will have a *cold* edge, and *southern* coastlines will have a *warm* edge.**
- ***negative crosstrack* offset => *western* coastlines will have a *cold* edge and the *eastern* coastlines will have a *warm* edge**
- ***The reverse is also true***

NOAA15 AMSU-A Channel 1

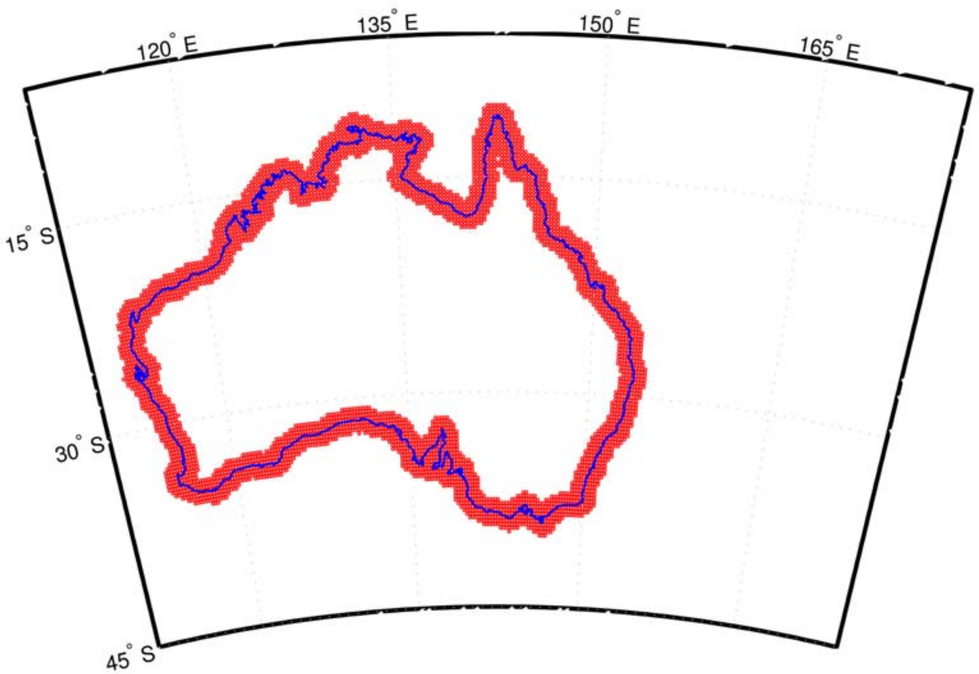


NOAA15 AMSU-A Channel 1





$$RMSE = \sqrt{\frac{\sum_{pixels} \Delta Tb^2}{n}}$$



$$SD = \sqrt{\frac{\sum_{pixels} \left(\Delta Tb - \overline{\Delta Tb}\right)^2}{n}}$$

Previous studies

An algorithm for correction of navigation errors in AMSU-A data
Seiichiro Kigawa and Michael P. Weinreb, 2002, NOAA Technical Report

- used the cross correlation method and AMSU-B Channel 16 data, as the reference, to investigate the geolocation errors in AMSU-A Channels 1 and 2.

- They reported a roll angle of the order of 1 deg exists in the NOAA-15 AMSU-A Channels 1 and 2.

Table 4 shows the shift values calculated with the average of the pattern matching measurements shown in Figure 5.

Since the reference imagery of the pattern matching is AMSU-B channel 16,

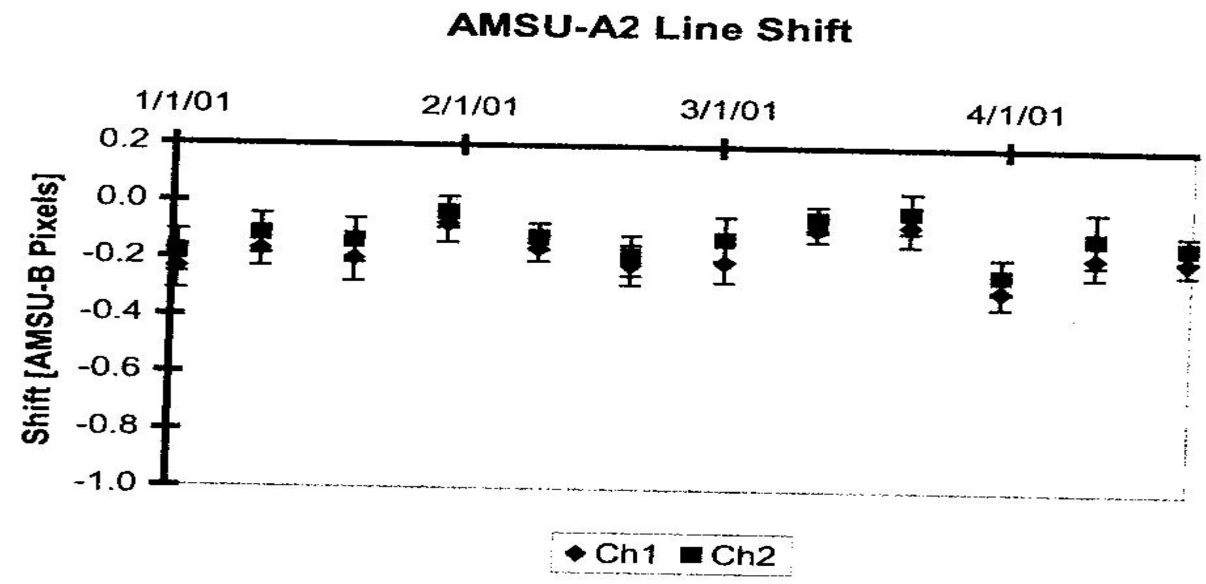
1) if a line shift is positive, AMSU-A imagery has an offset to the direction of orbital velocity compared with AMSU-B.
2) if a pixel shift is positive, AMSU-A imagery has an offset to the scan direction compared with AMSU-B.

AMSU-A2 [Ch1, 2]		AMSU-A1-2 [Ch3]		AMSU-A1-1 [Ch15]		Note
Line [Along-track]	Pixel [Cross-track]	Line [Along-track]	Pixel [Cross-track]	Line [Along-track]	Pixel [Cross-track]	
-0.15	-0.92	-0.26	0.20	-0.29	0.20	04/23/2001

Table 4. AMSU Image Shift Values expressed by AMSU-B Lines and Pixels.

AMSU-A2 [Ch1, 2]		AMSU-A1-2 [Ch3-5,8]		AMSU-A1-1 [Ch6,7,9-15]		Note
Pitch	Roll	Pitch	Roll	Pitch	Roll	
-3.1	18	-5.5	-3.8	-6.1	-3.8	04/23/2001

Table 5. AMSU Correction Angles (milli-radians).



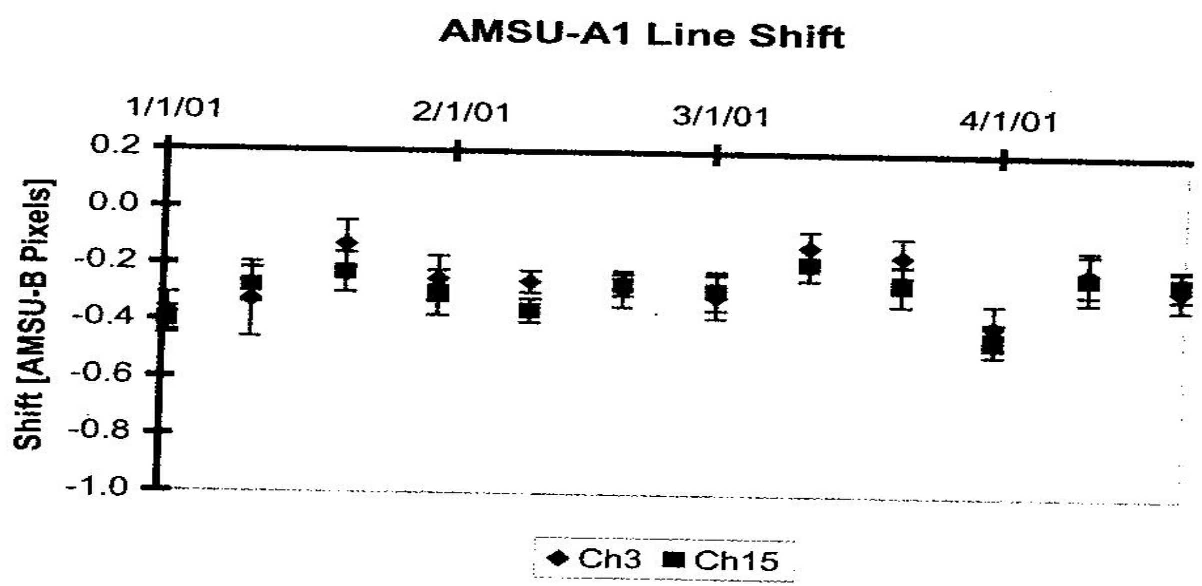


Figure 5a. NOAA-15 AMSU-A Line (along-track) Shift.

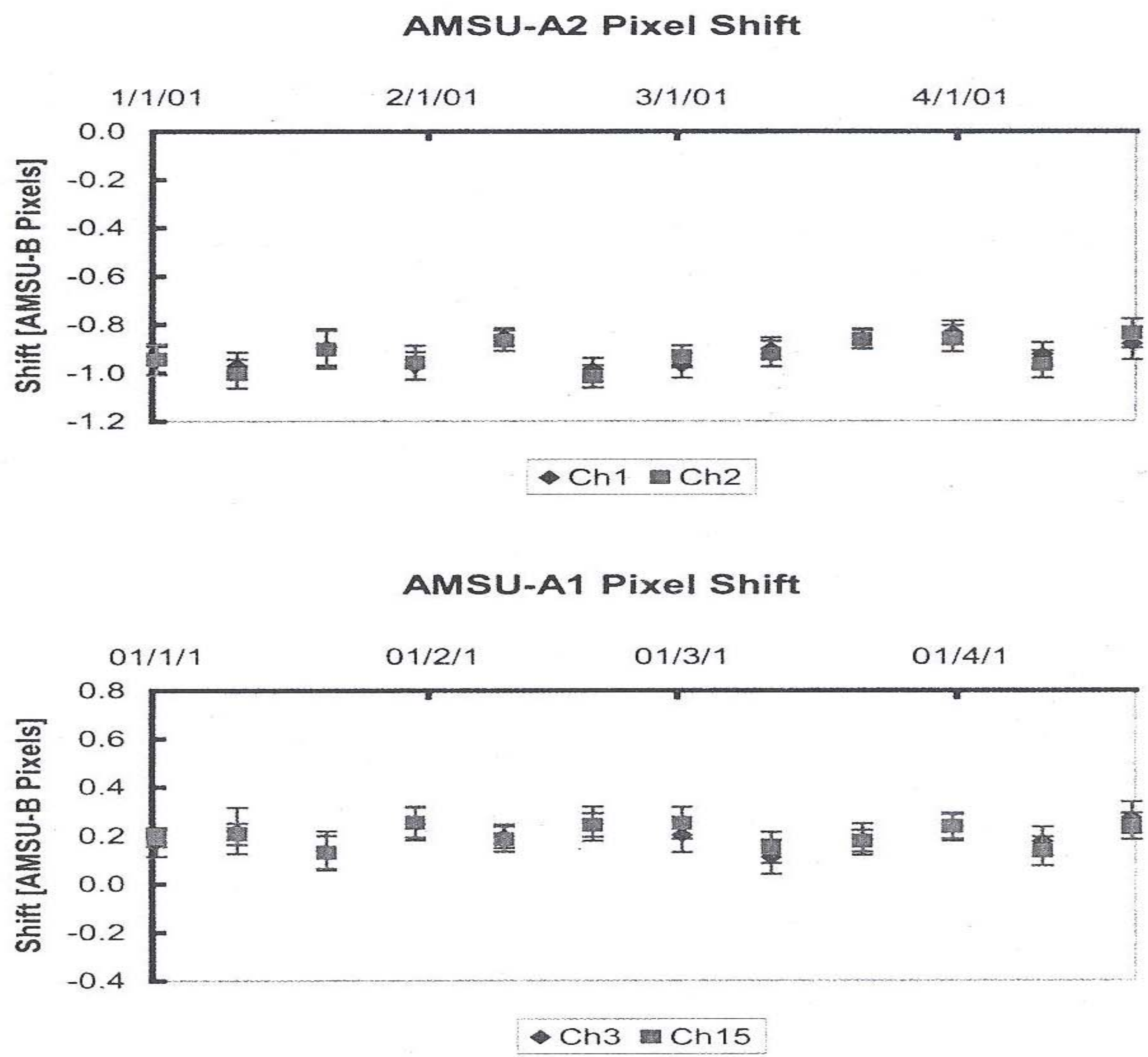
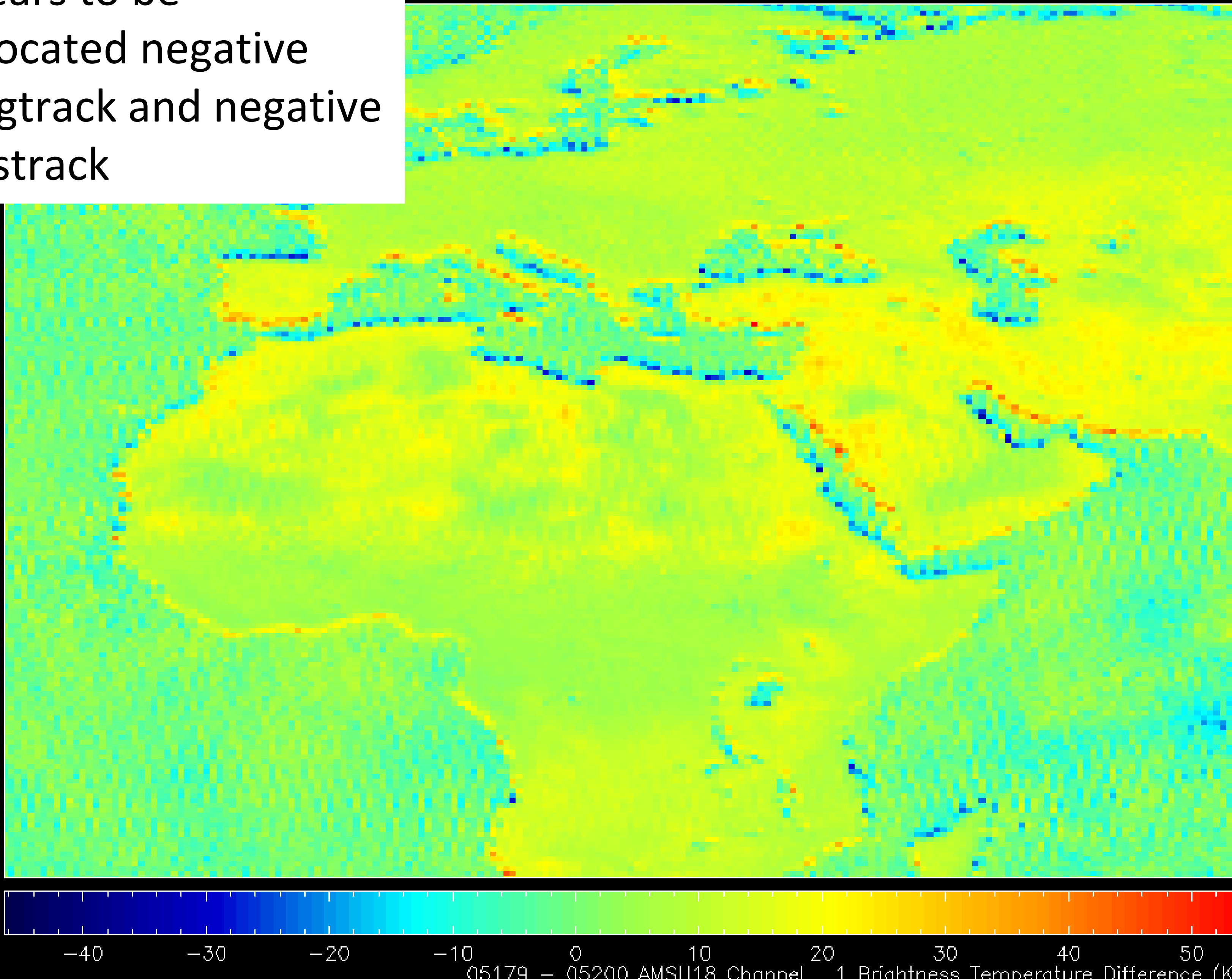


Figure 5b. NOAA-15 AMSU-A Pixel (cross-track) Shift.

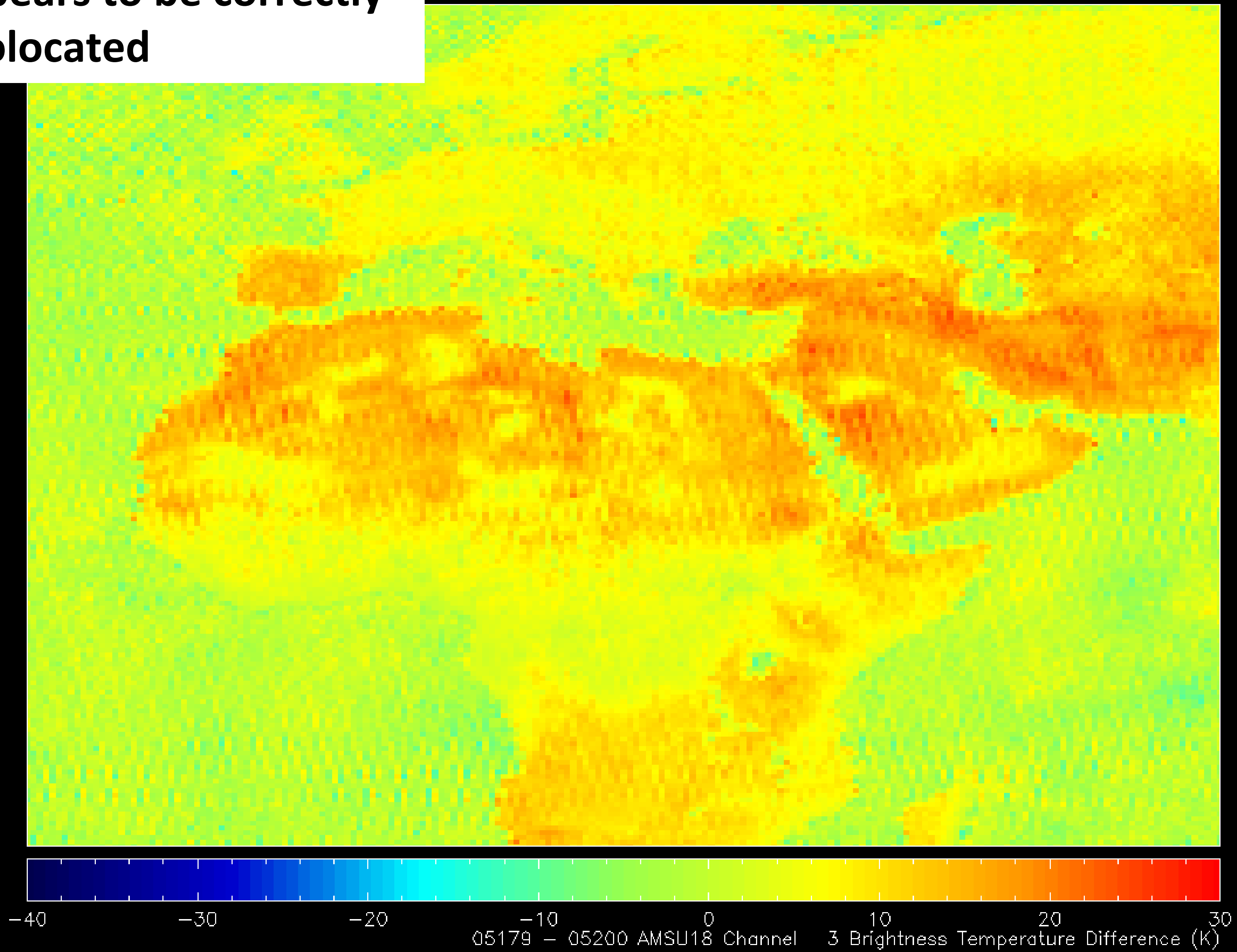
NOAA-18 AMSU-A2 appears to be geolocated negative alongtrack and negative crosstrack

Thomas J. Kleespies, NOAA/NESDIS/ORA, 9 August 2005



NOAA-18 AMSU-A1-2 appears to be correctly geolocated

Thomas J. Kleespies, NOAA/NESDIS/ORA,
9 August 2005



Correction necessary to match coastlines

			Cross-Track		Along-Track	
Instrument	**Orbit**	**Des/Asc**	[MHS FOVS]		[MHS Scan lines]	
AMSU-A1 89 GHz			-0.60 **(=-10.2 km @ nadir)**		-0.40 **(=-6.8 km @ nadir)**	
AMSU-A2 23 GHz	D05172 S0244	D	+0.30	+0.50	+0.50	+0.70
	D05172 S0952	A	-0.10	-0.10	+0.70	+0.80
	D05172 S0434	A	+0.50	+0.30	+0.80	+0.80
	D05172 S1747	D	+0.40	+0.30	+0.60	+0.70
A2-Average			**+0.26** **(=+4.7 km@nadir)**		**+0.70** **(=+12.5 km@nadir)**	
AMSU-A1 50 GHz	D05172 S0244	D	+0.20	+0.20	-0.30	-0.35
	D05172 S0952	A	-0.20	-0.10	+0.00	+0.00
	D05172 S0434	A	+0.20	+0.30	0.00	0.00
	D05172 S1747	D	+0.20	+0.20	+0.20	+0.00
A1-Average			**+0.13** **(=+2.2 km@nadir)**		**+0.06** **(=+1.0 km@nadir)**	
MHS 89 GHz	D05172 S0244	D	+0.35	+0.35	-1.00	-1.00
	D05172 S0952	A	+0.10	+0.00	-0.90	-0.90
	D05172 S0434	A	+0.10	+0.10	-0.70	-0.80
	D05172 S1747	D	+0.20	-0.20	-0.80	-1.20
MHS-Average			**+0.18** **(=+3.2 km@nadir)**		**-0.92** **(=-16.4 km@nadir)**	

AMSU-A2 offset

~3-4 km uptrack, xtrack OK

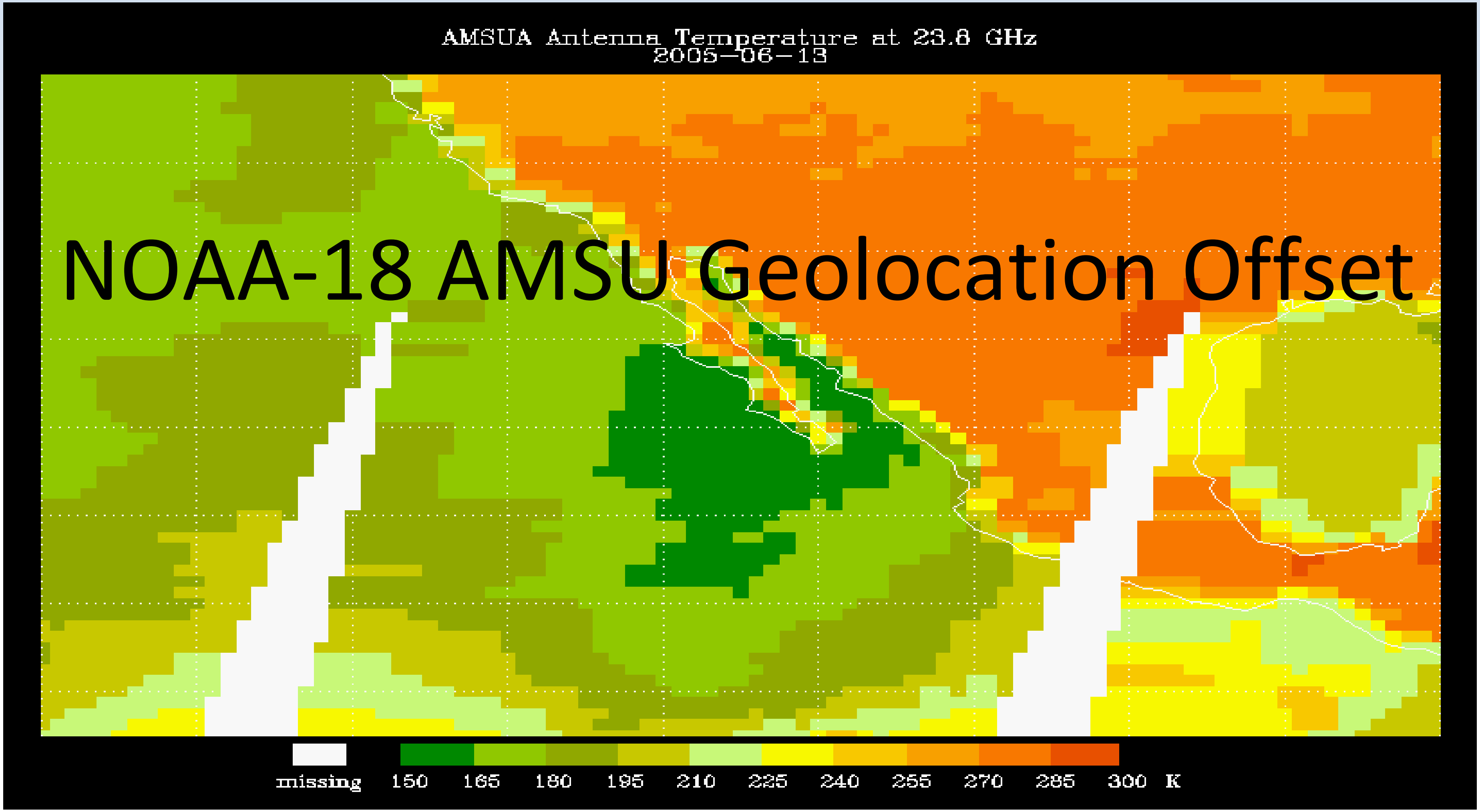
AMSU-A1-2 offset

~8-9 km uptrack xtrack OK

AMSU-A1-1 offset

~ 4-5 km uptrack xtrack probably OK

NOAA/NESDIS/Office of Research and Applications
Weekly report of June 13-17, 2005

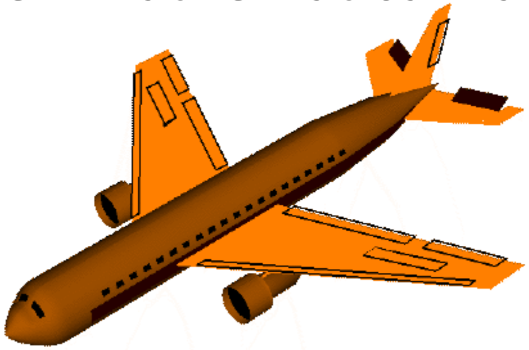


AMSU-A channel 1 image over the west coast of California. The striking contrast between land and ocean from microwave window channel is normally used for a sanity check for geolocation. It appears that there is one pixel offset in AMSU earth location in both E-S and N-S directions. This offset is being under investigation

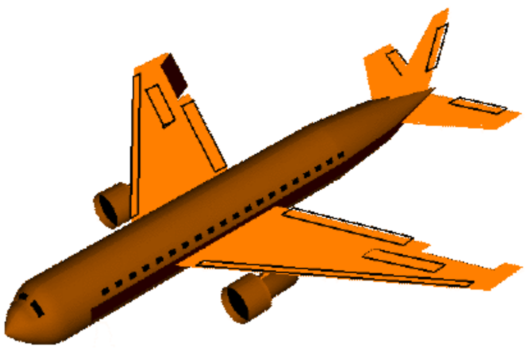
AMSU Pointing/Attitude Errors

Flight dynamics parameters in 3D Euclidian space are known as Pitch, Roll and Yaw but in mathematics they are often known by their mathematical name, Euler angles

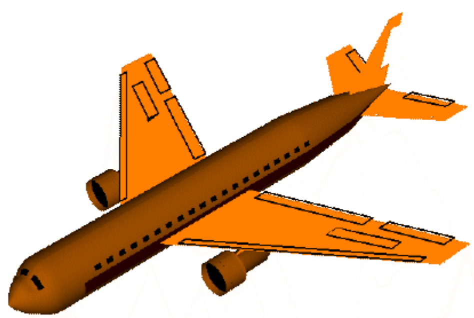
Pitch



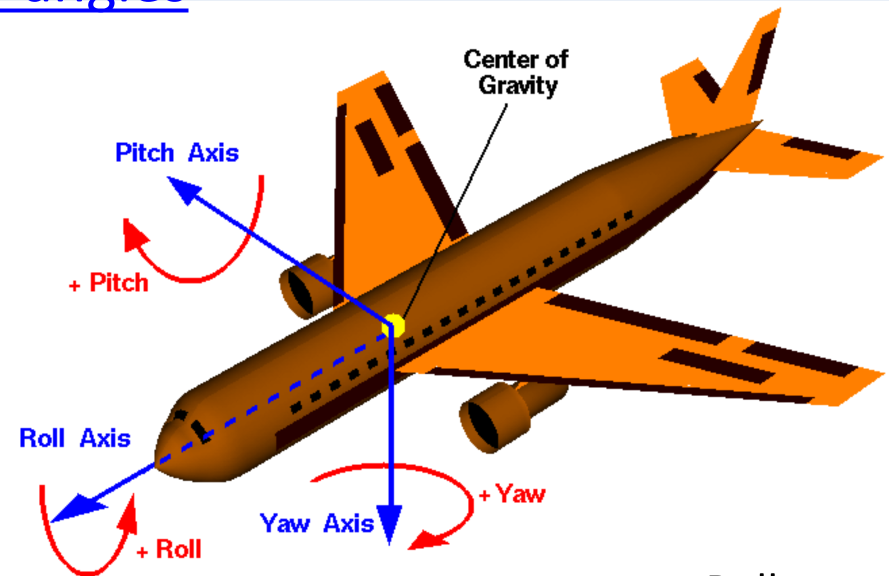
Roll

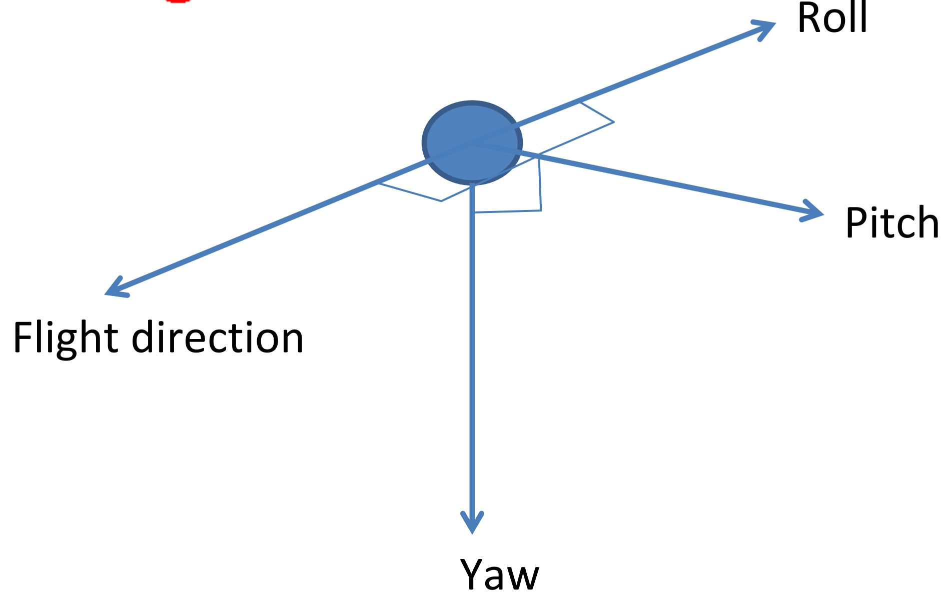


Yaw

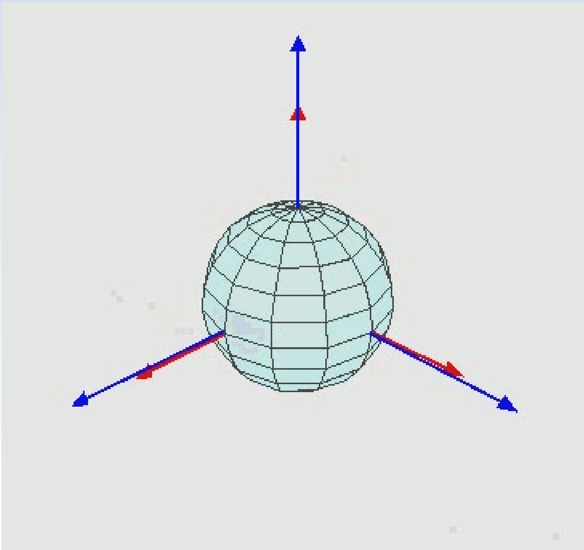


Pictures from wikipedia

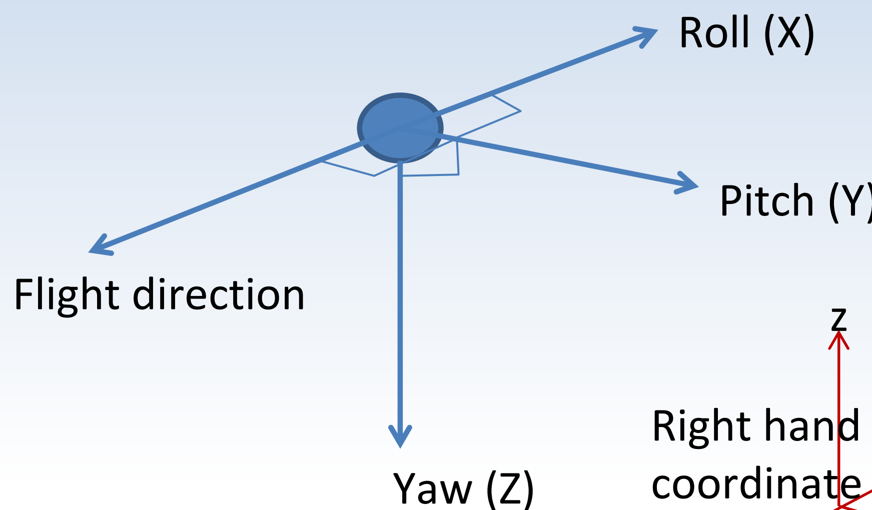


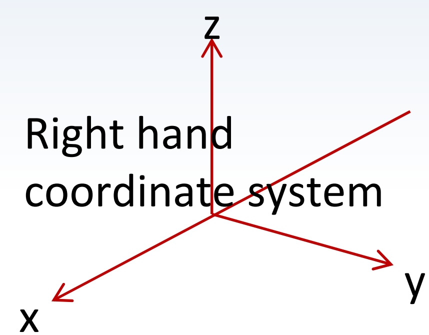


Methodology



Rotating the coordinate system (Wikipedia)





$$L = \begin{bmatrix} \cos\theta_1 & 0 & \sin\theta_1 \\ 0 & 1 & 0 \\ -\sin\theta_1 & 0 & \cos\theta_1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_2 & -\sin\theta_2 \\ 0 & \sin\theta_2 & \cos\theta_2 \end{bmatrix} \begin{bmatrix} \cos\theta_3 & -\sin\theta_3 & 0 \\ \sin\theta_3 & \cos\theta_3 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$\theta_1 = \Delta R$

$\theta_2 = \Delta Y$

$\theta_3 = \Delta P$

Rotation matrix (Kigawa and Weinreb, 2002)

Corrected pointing vector in the platform coordinates is given by

$$\begin{pmatrix} x_{cpp} \\ y_{cpp} \\ z_{cpp} \end{pmatrix} = L \begin{pmatrix} \cos\theta \\ 0 \\ \sin\theta \end{pmatrix}$$

The corrected pointing vector in the earth fixed coordinates is expressed as

$$\begin{pmatrix} x_{cp} \\ y_{cp} \\ z_{cp} \end{pmatrix} = \begin{pmatrix} x_{yaw} \\ y_{yaw} \\ z_{yaw} \end{pmatrix} x_{cpp} + \begin{pmatrix} x_{roll} \\ y_{roll} \\ z_{roll} \end{pmatrix} y_{cpp} + \begin{pmatrix} x_{pitch} \\ y_{pitch} \\ z_{pitch} \end{pmatrix} z_{cpp}$$

The corrected view vector (X'_p, Y'_p, Z'_p) directed from the platform to the point of interest is given by:

$$a = (1-f)^2(x_{cp}^{\ 2} + y_{cp}^{\ 2}) + z_{cp}^{\ 2}$$

$$b = (1-f)^2(Xo \cdot x_{cp} + Yo \cdot y_{cp}) + Zo \cdot z_{cp}$$

$$c = (1-f)^2(Xo^2 + Yo^2 - \mathrm{Re}^2) + Zo^2$$

$$k = \frac{-b \pm \sqrt{b^2 - ac}}{a}$$

(smaller absolute value should be employed)

Xo, Yo, and Zo indicate the satellite position

$$\begin{pmatrix} X_p' \\ Y_p' \\ Z_p' \end{pmatrix} = \begin{pmatrix} Xo \\ Yo \\ Zo \end{pmatrix} + k \begin{pmatrix} x_{cp} \\ y_{cp} \\ z_{cp} \end{pmatrix} \quad (44)$$

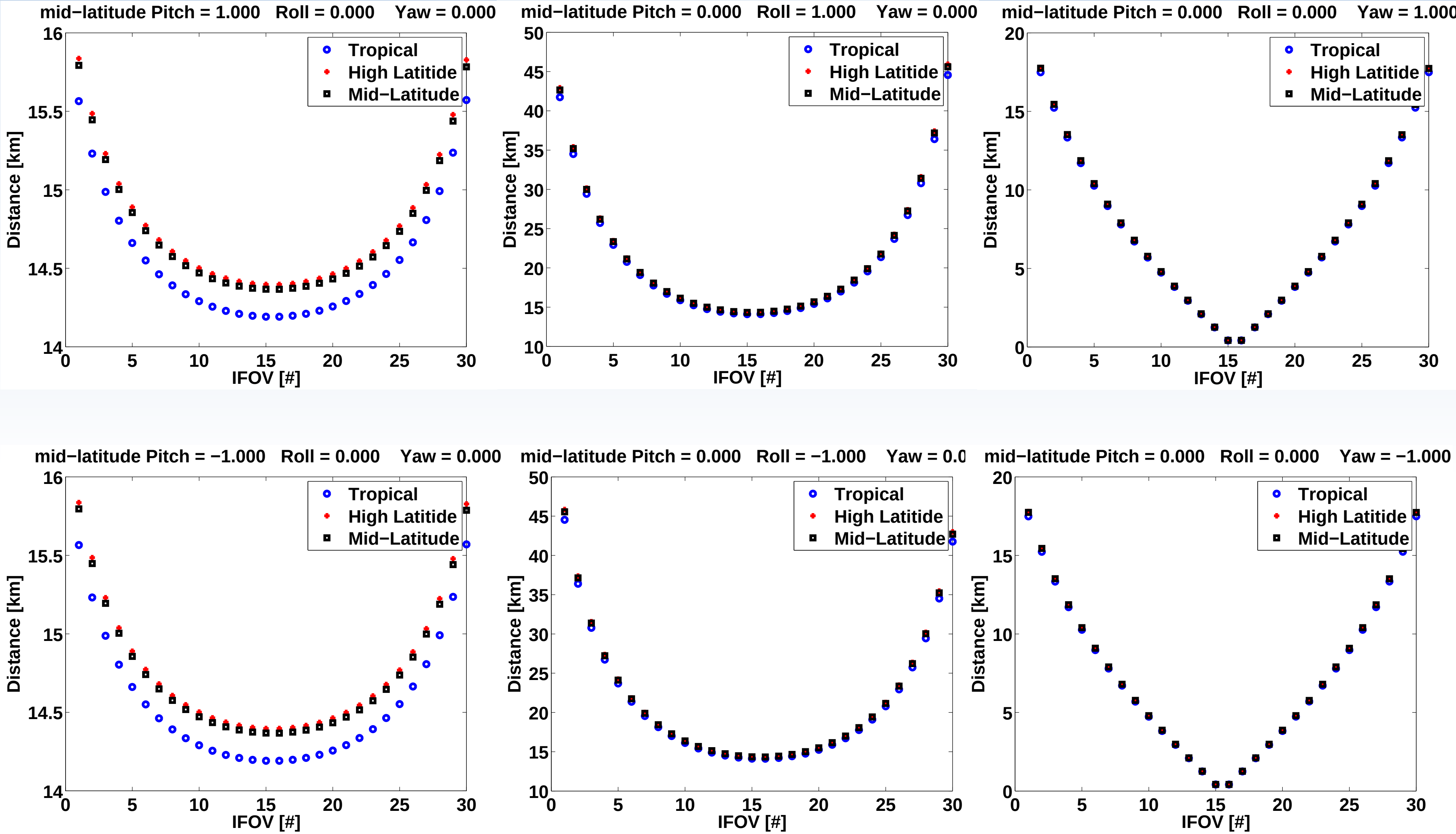
2.12 Corrected latitude and longitude

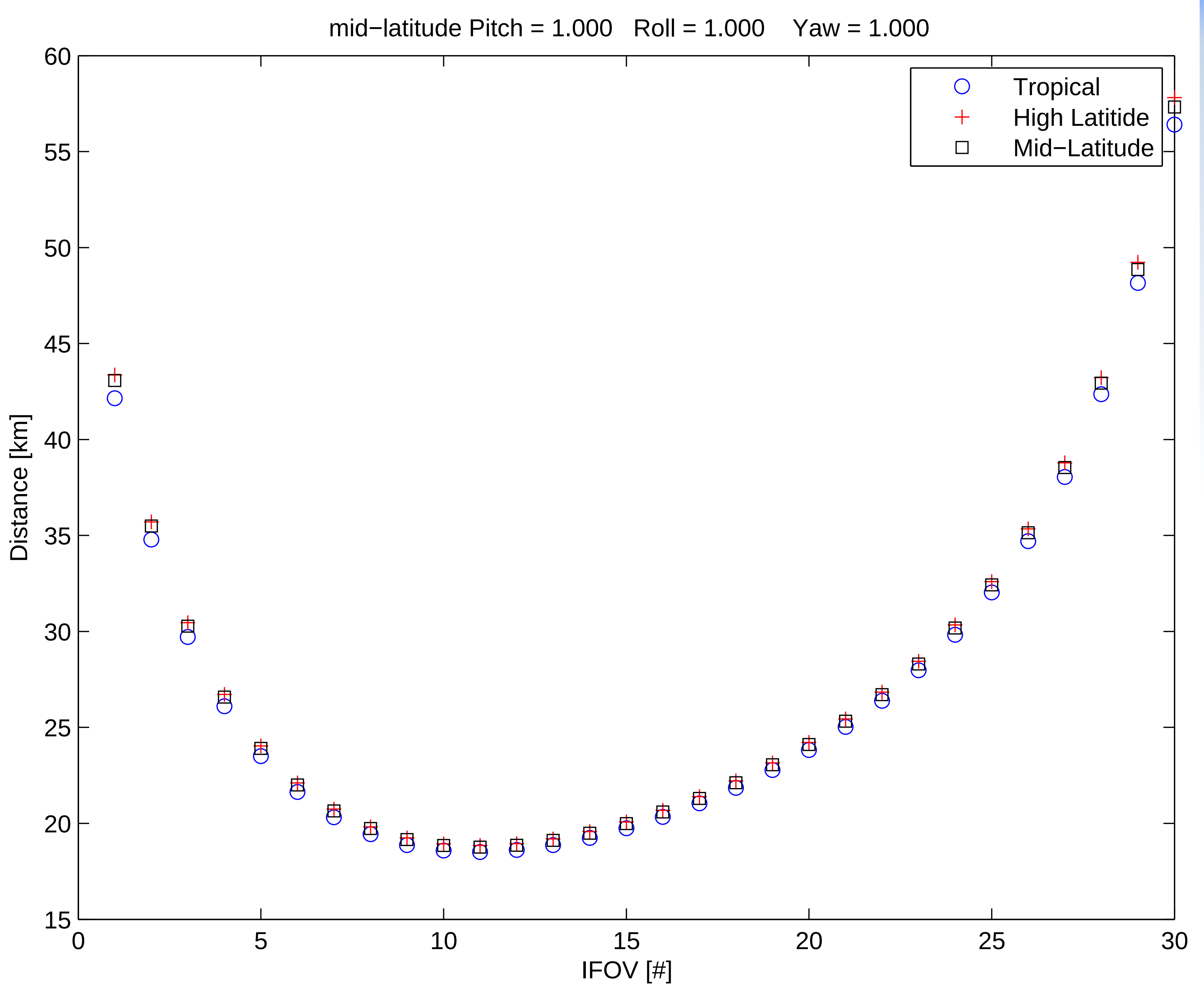
The corrected latitude and longitude of the point of interest are given by

$$\varphi' = \tan^{-1}\left(\frac{Z_p'}{(1-f)^2\sqrt{(X_p')^2 + (Y_p')^2}} \right) \quad (45)$$

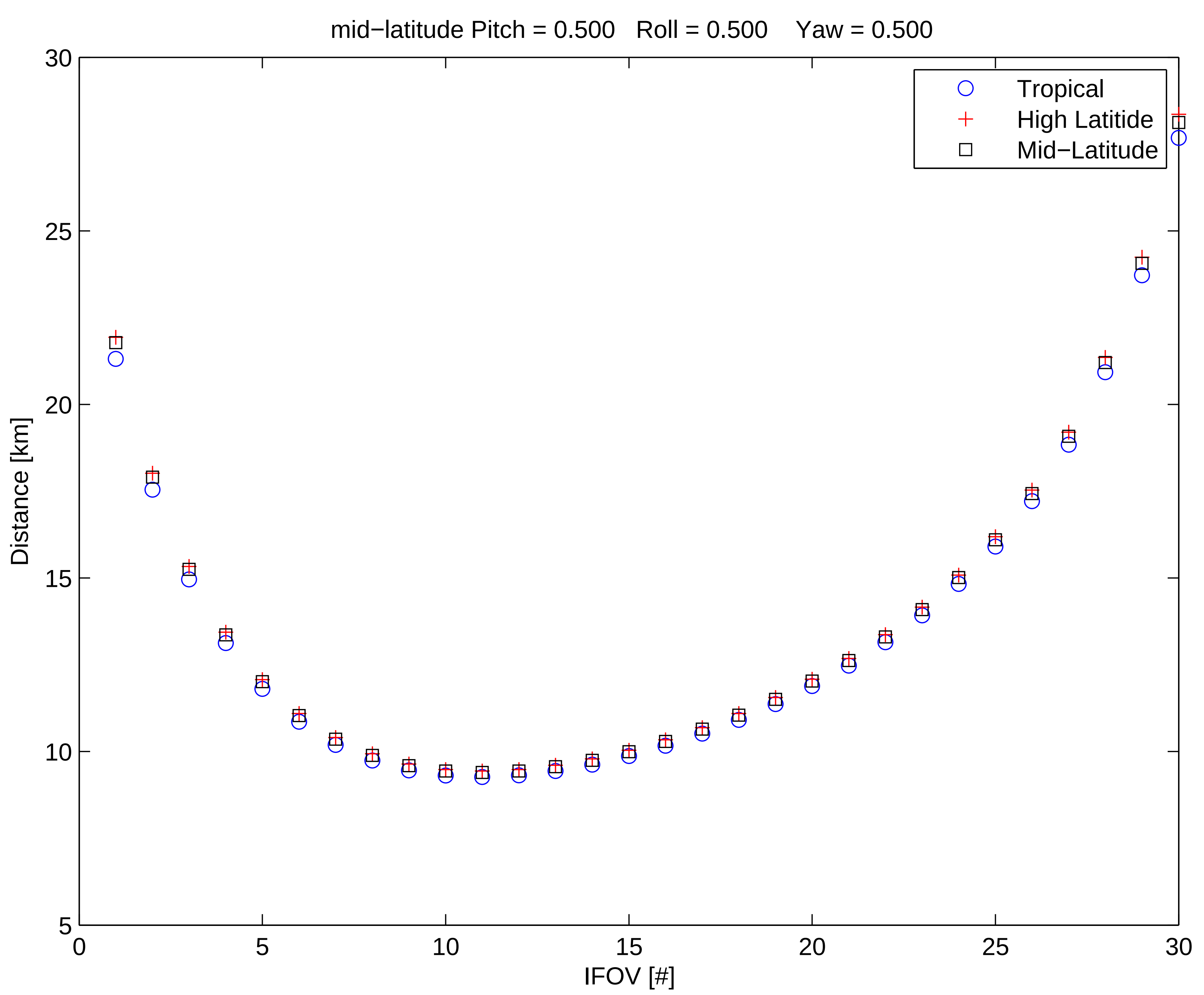
$$\lambda' = \tan^{-1}\left(\frac{Y_p'}{X_p'} \right) \quad (46)$$

Results

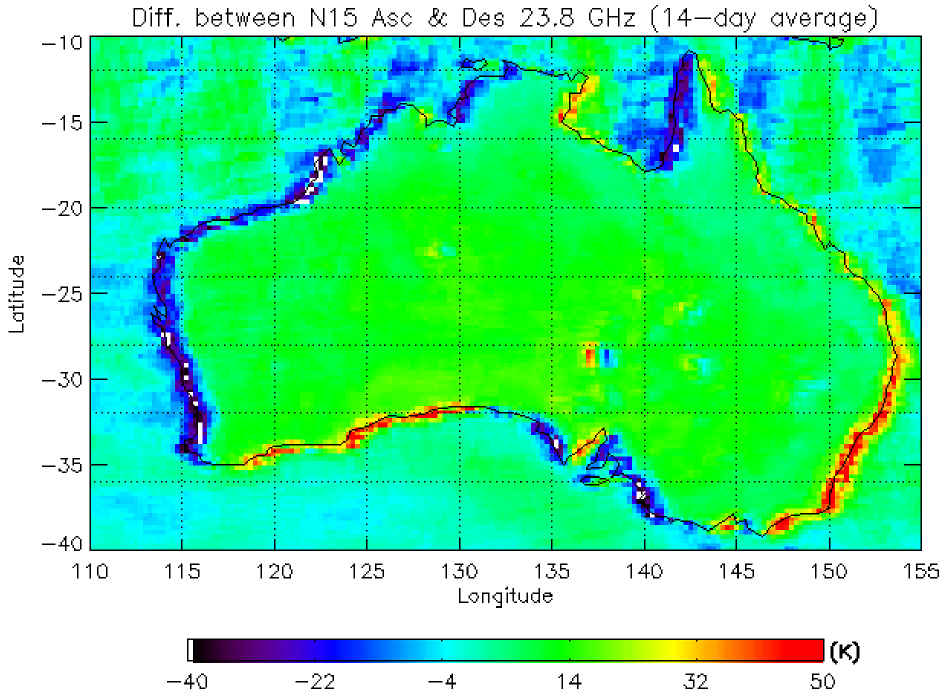

mid−latitude Pitch = 1.000 Roll = 0.000 Yaw = 0.000
mid−latitude Pitch = 0.000 Roll = 1.000 Yaw = 0.000
mid−latitude Pitch = 0.000 Roll = 0.000 Yaw = 1.000
mid−latitude Pitch = −1.000 Roll = 0.000 Yaw = 0.000
mid−latitude Pitch = 0.000 Roll = −1.000 Yaw = 0.0
mid−latitude Pitch = 0.000 Roll = 0.000 Yaw = −1.000
Tropical
High Latitide
Mid−Latitude
Distance [km]
IFOV [#]

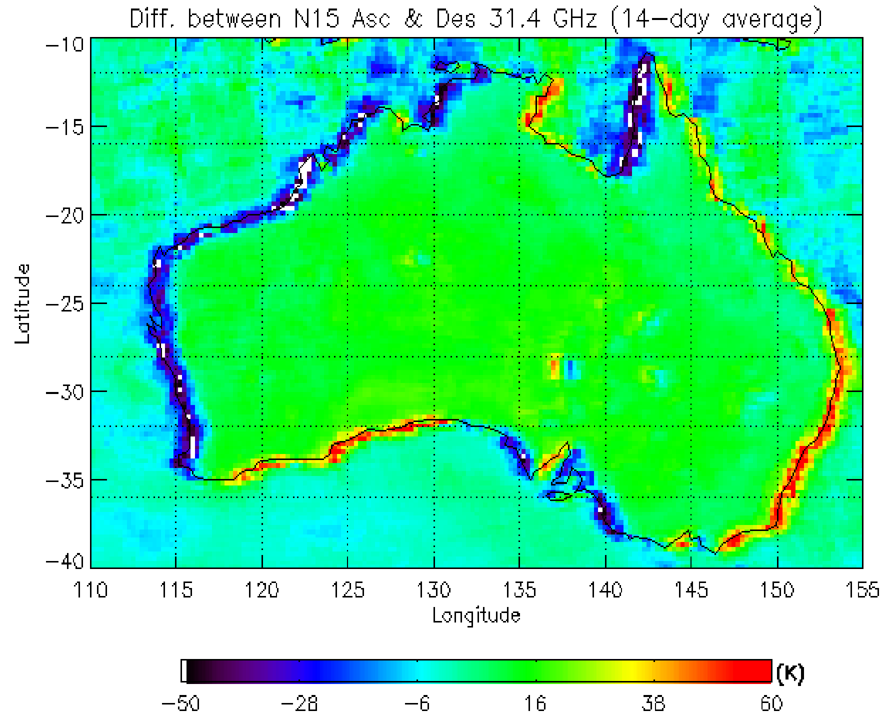


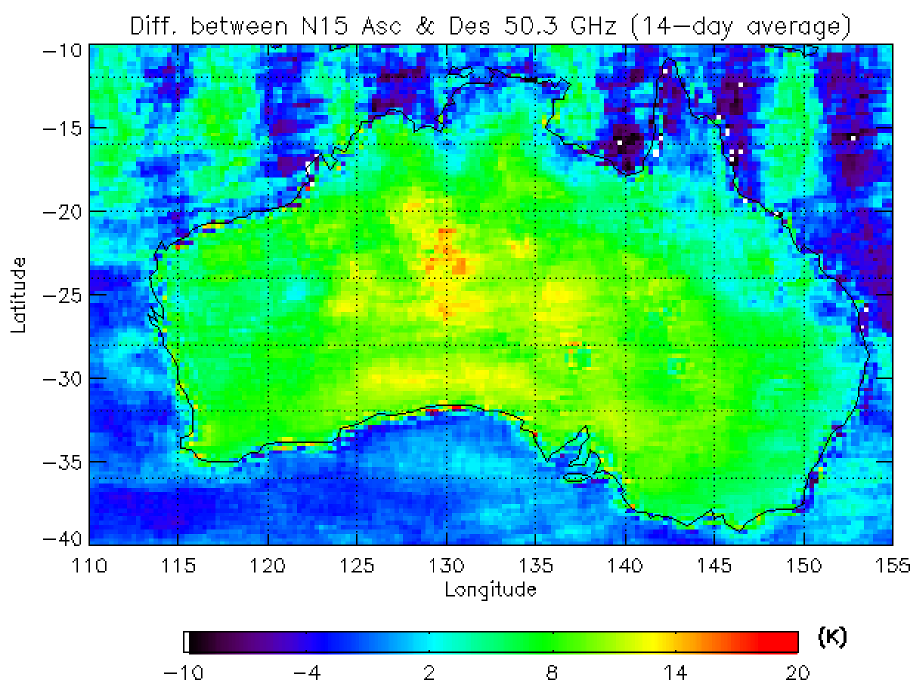
mid−latitude Pitch = 1.000 Roll = 1.000 Yaw = 1.000
Tropical
High Latitide
Mid−Latitude
Distance [km]
60
55
50
45
40
35
30
25
20
15
0
5
10
15
20
25
30
IFOV [#]

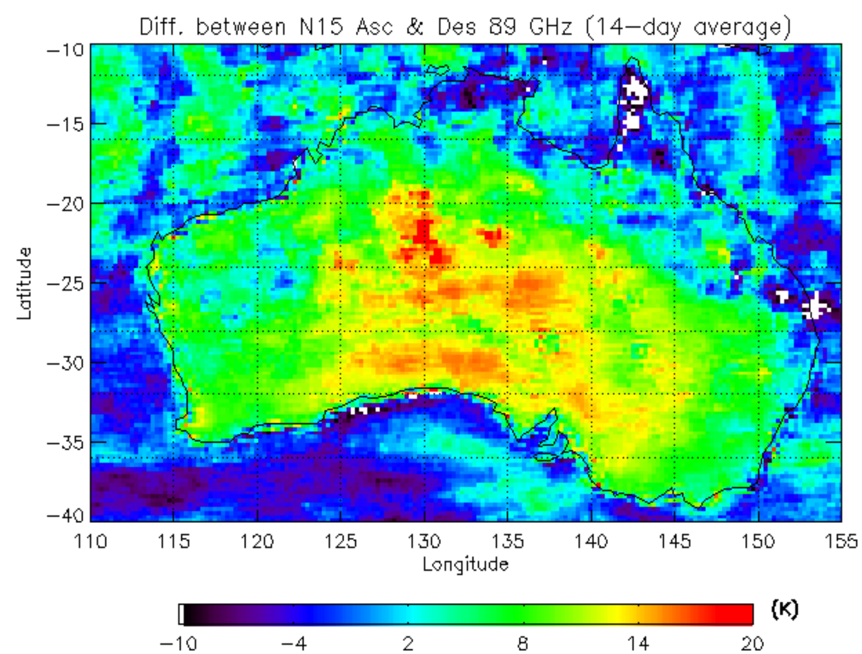


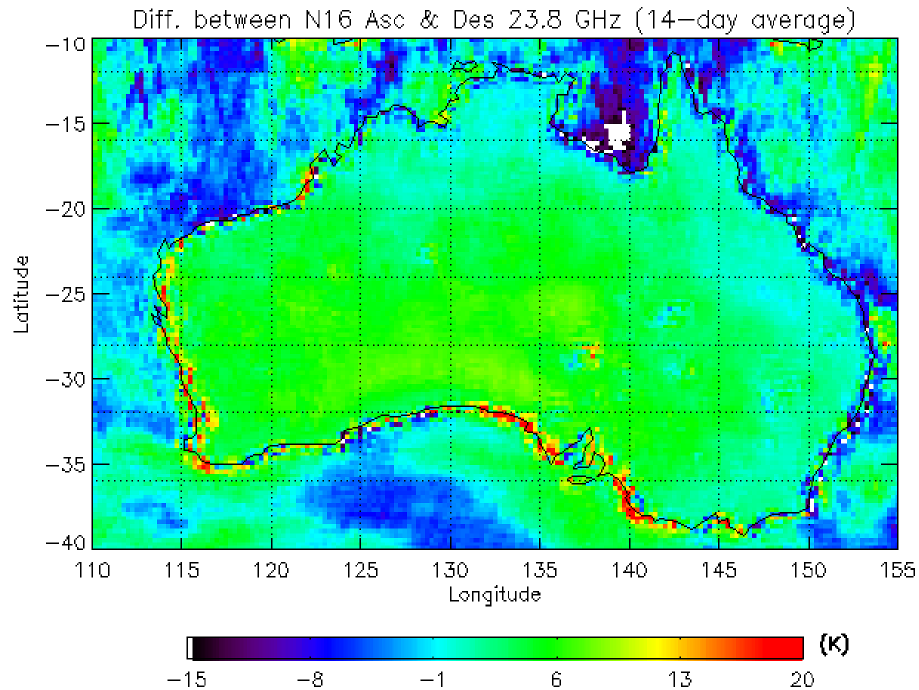
mid−latitude Pitch = 0.500 Roll = 0.500 Yaw = 0.500
Tropical
High Latitide
Mid−Latitude
Distance [km]
IFOV [#]
30
25
20
15
10
5
0
5
10
15
20
25
30


Diff. between N15 Asc & Des 23.8 GHz (14-day average)
Latitude
−10
−15
−20
−25
−30
−35
−40
110 115 120 125 130 135 140 145 150 155
Longitude
(K)
−40 −22 −4 14 32 50

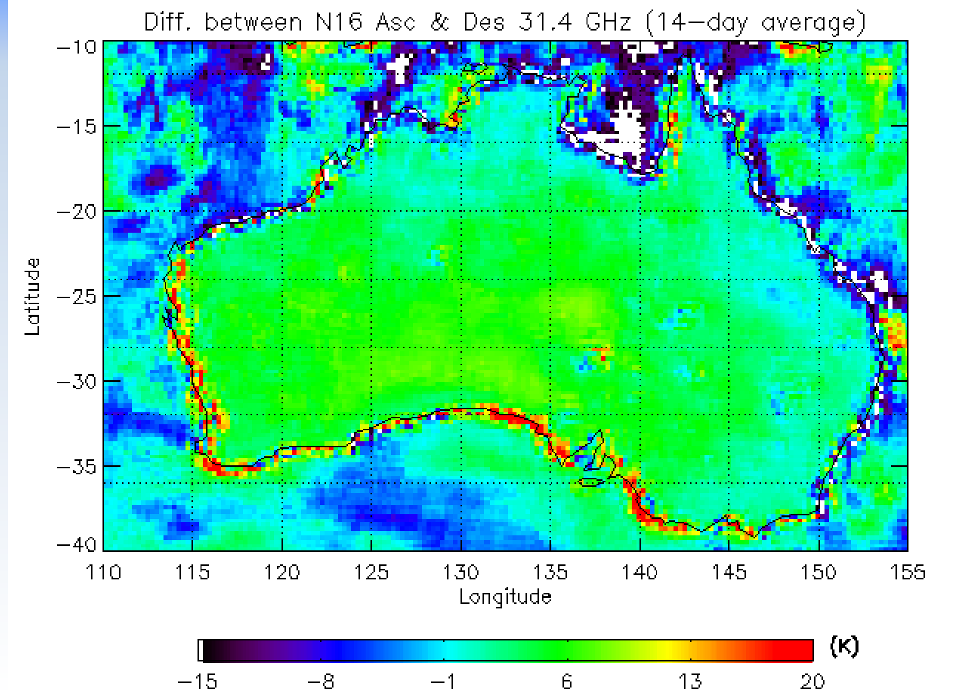

Diff. between N15 Asc & Des 31.4 GHz (14-day average)
Latitude
−10
−15
−20
−25
−30
−35
−40
110 115 120 125 130 135 140 145 150 155
Longitude
(K)
−50 −28 −6 16 38 60


Diff. between N15 Asc & Des 50.3 GHz (14-day average)
Latitude
−10
−15
−20
−25
−30
−35
−40
110 115 120 125 130 135 140 145 150 155
Longitude
(K)
−10 −4 2 8 14 20

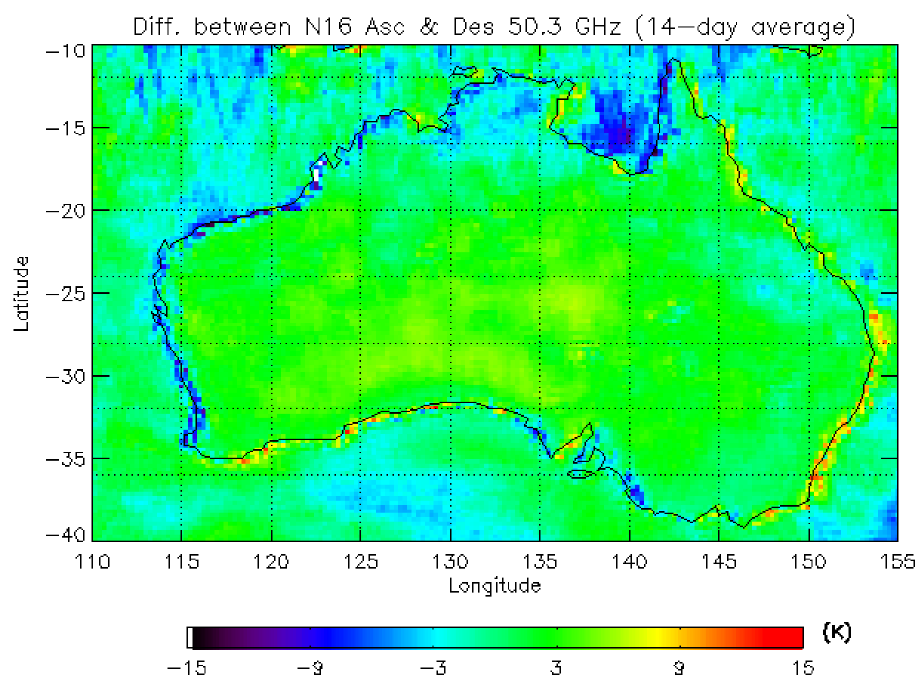

Diff. between N15 Asc & Des 89 GHz (14-day average)
Latitude
−10
−15
−20
−25
−30
−35
−40
110 115 120 125 130 135 140 145 150 155
Longitude
(K)
−10 −4 2 8 14 20



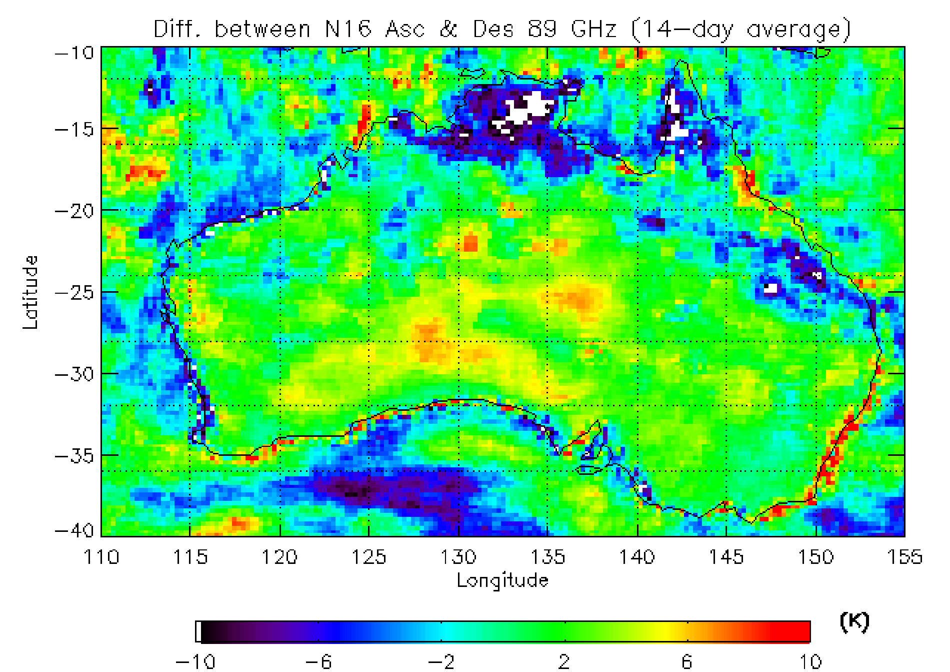
Diff. between N16 Asc & Des 23.8 GHz (14–day average)
Latitude
−10
−15
−20
−25
−30
−35
−40
110
115
120
125
130
135
140
145
150
155
Longitude
−15
−8
−1
6
13
20
(K)



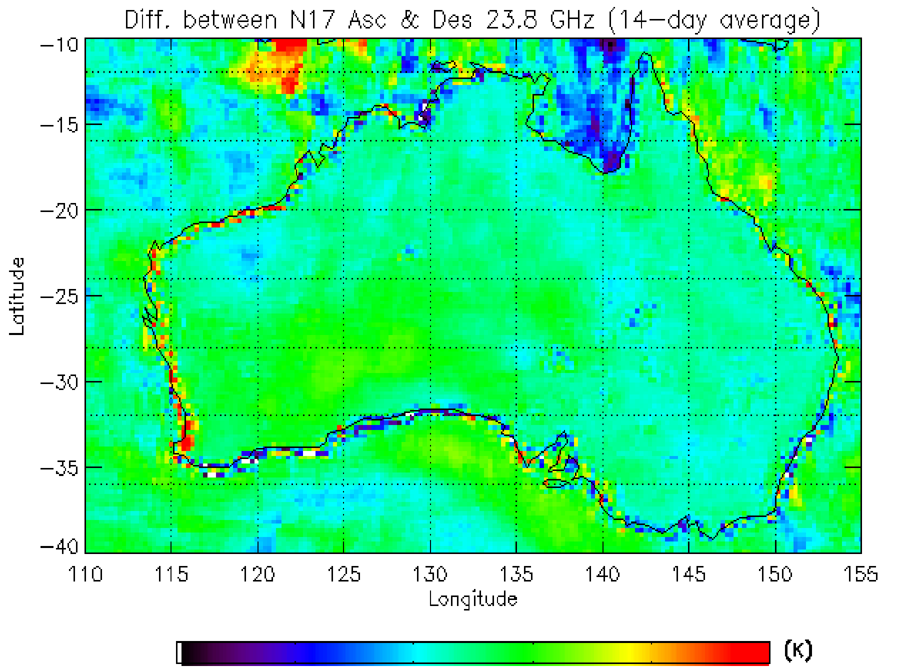
Diff. between N16 Asc & Des 31.4 GHz (14–day average)
Latitude
−10
−15
−20
−25
−30
−35
−40
110
115
120
125
130
135
140
145
150
155
Longitude
−15
−8
−1
6
13
20
(K)

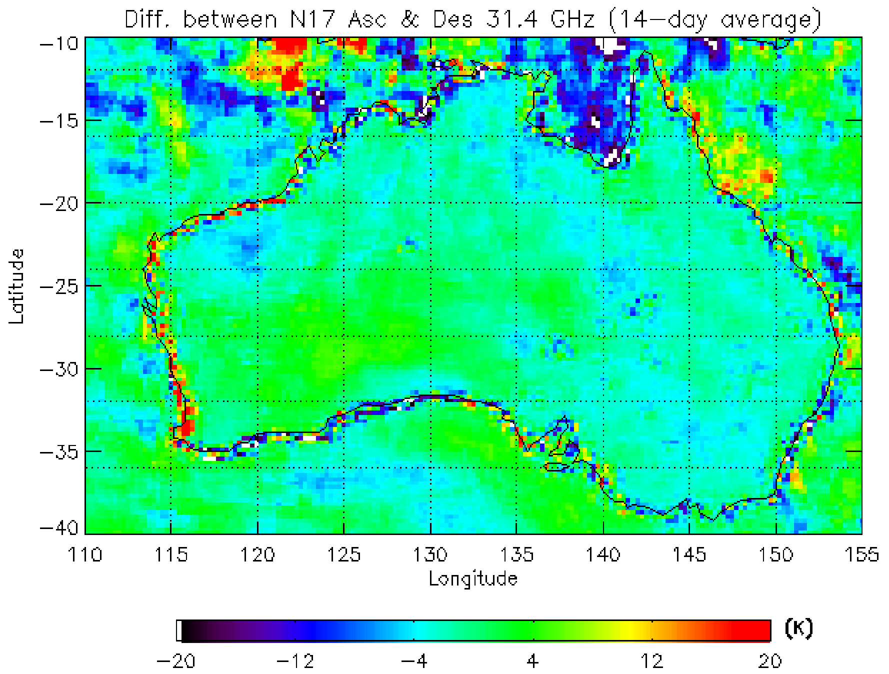


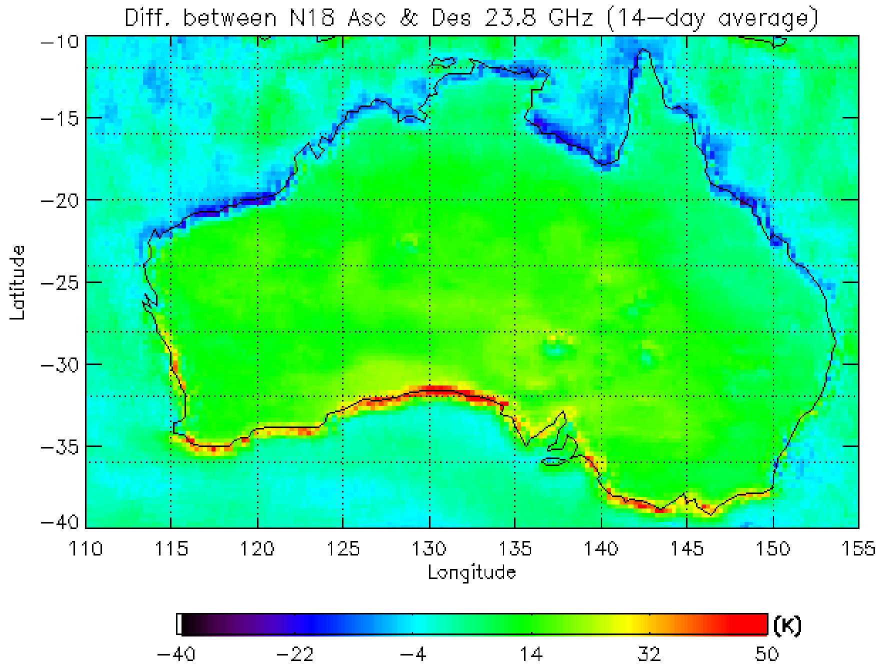
Diff. between N16 Asc & Des 50.3 GHz (14–day average)
Latitude
−10
−15
−20
−25
−30
−35
−40
110
115
120
125
130
135
140
145
150
155
Longitude
−15
−9
−3
3
9
15
(K)

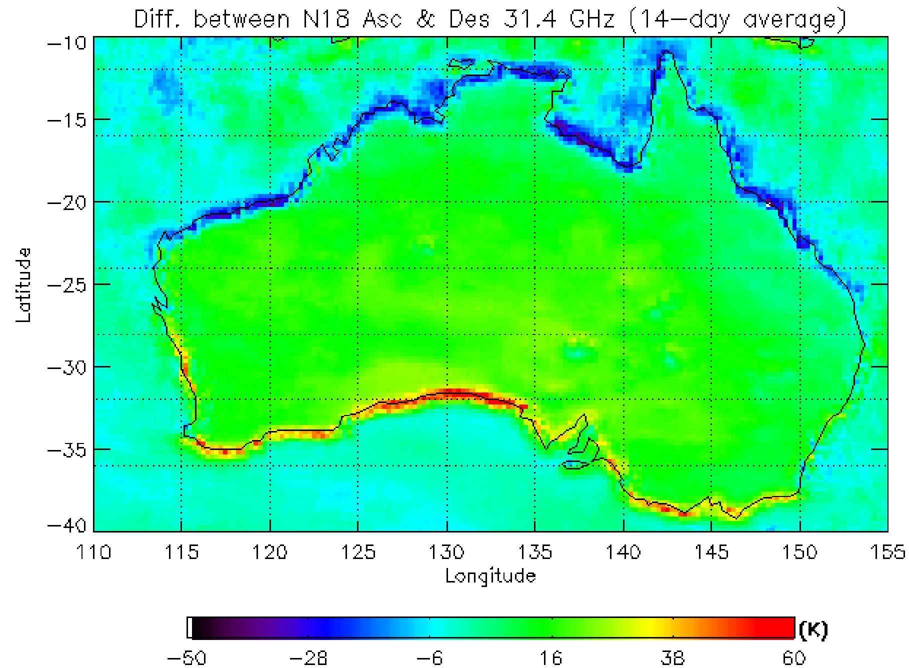


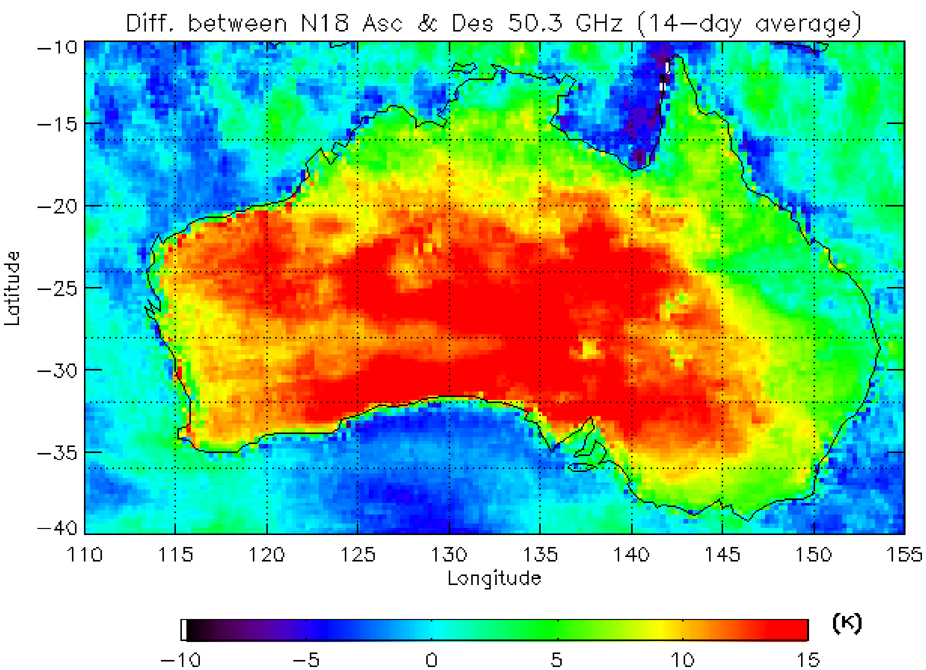
Diff. between N16 Asc & Des 89 GHz (14–day average)
Latitude
−10
−15
−20
−25
−30
−35
−40
110
115
120
125
130
135
140
145
150
155
Longitude
−10
−6
−2
2
6
10
(K)


Diff. between N17 Asc & Des 23.8 GHz (14–day average)
Latitude
−10
−15
−20
−25
−30
−35
−40
110
115
120
125
130
135
140
145
150
155
Longitude
(K)


Diff. between N17 Asc & Des 31.4 GHz (14–day average)
Latitude
−10
−15
−20
−25
−30
−35
−40
110
115
120
125
130
135
140
145
150
155
Longitude
(K)
−20
−12
−4
4
12
20


Diff. between N18 Asc & Des 23.8 GHz (14–day average)
Latitude
Longitude
−10
−15
−20
−25
−30
−35
−40
110 115 120 125 130 135 140 145 150 155
(K)
−40 −22 −4 14 32 50


Diff. between N18 Asc & Des 31.4 GHz (14–day average)
Latitude
Longitude
−10
−15
−20
−25
−30
−35
−40
110 115 120 125 130 135 140 145 150 155
(K)
−50 −28 −6 16 38 60


Diff. between N18 Asc & Des 50.3 GHz (14–day average)
Latitude
Longitude
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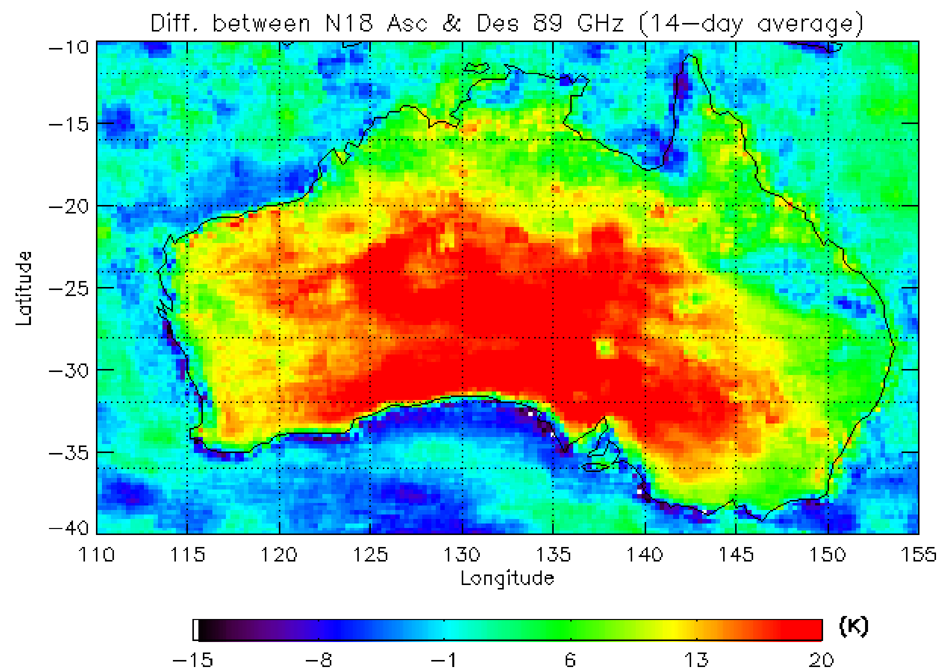
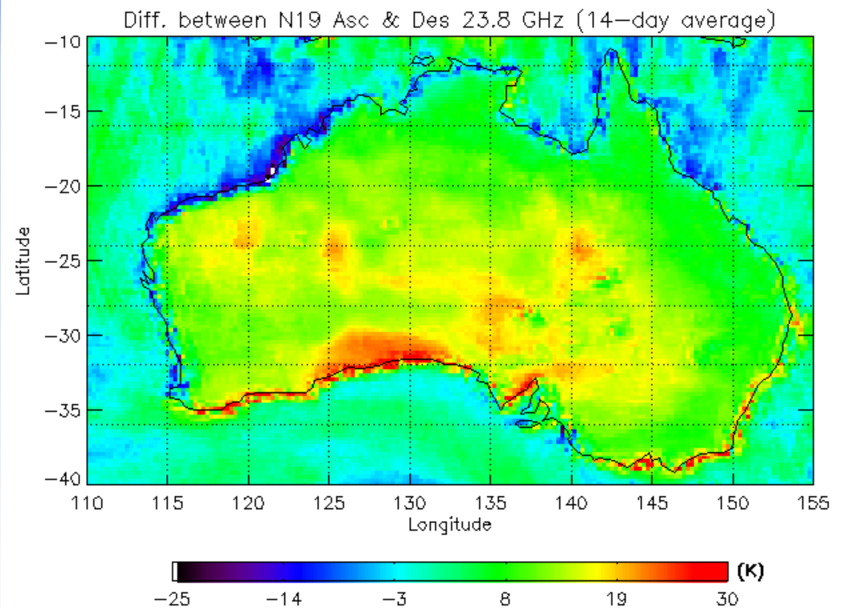
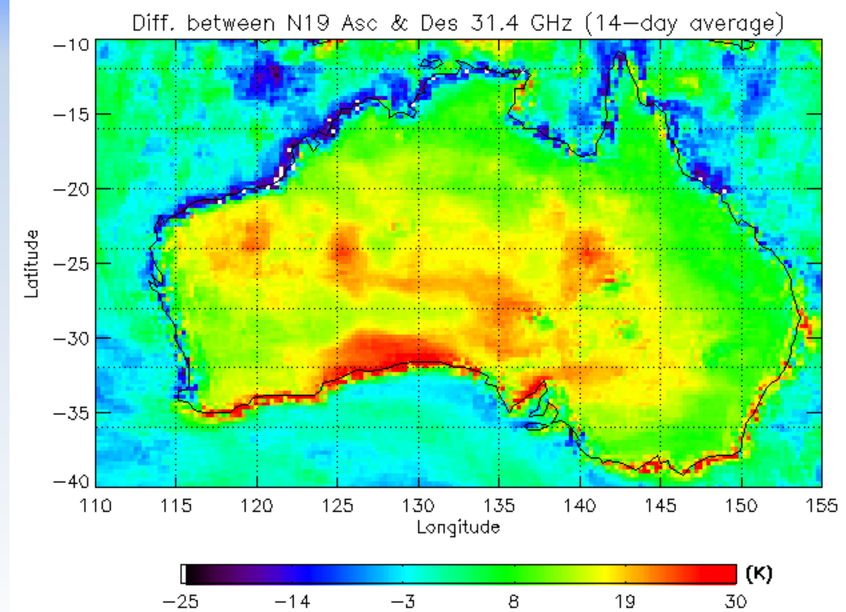
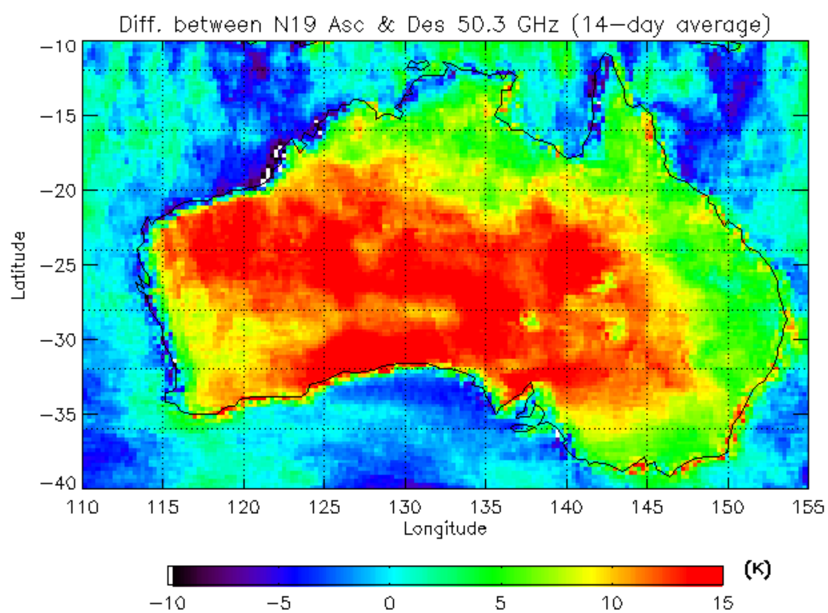
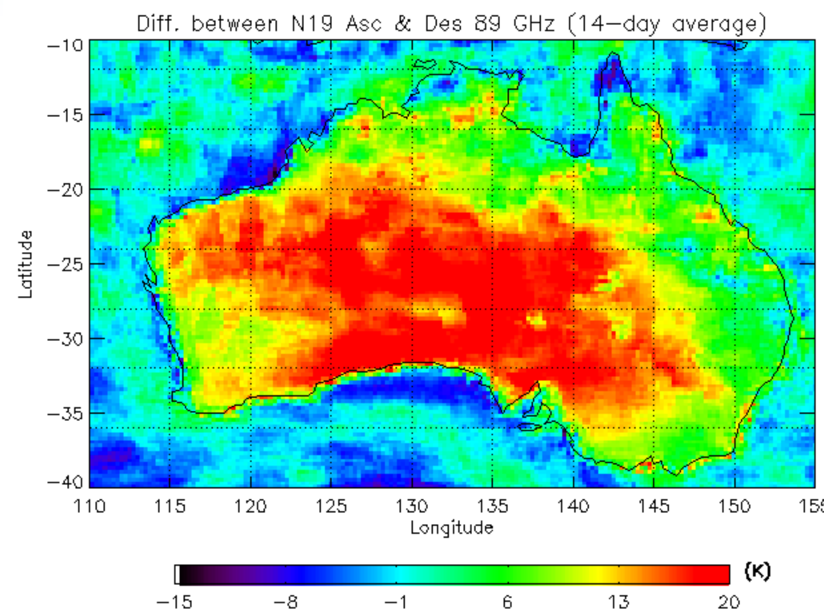
−15
−20
−25
−30
−35
−40
110 115 120 125 130 135 140 145 150 155
(K)
−10 −5 0 5 10 15

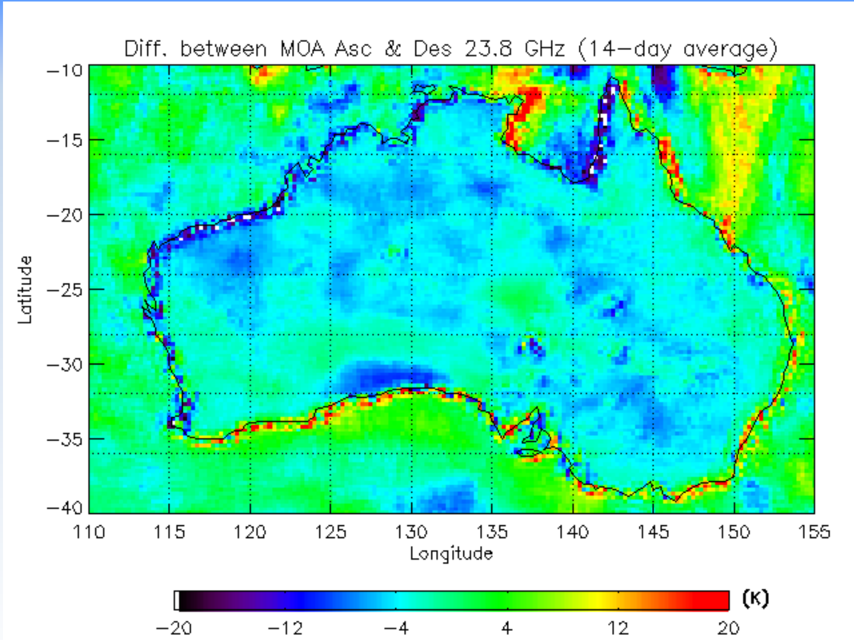

Diff. between N18 Asc & Des 89 GHz (14–day average)
Latitude
Longitude
−10
−15
−20
−25
−30
−35
−40
110 115 120 125 130 135 140 145 150 155
(K)
−15 −8 −1 6 13 20

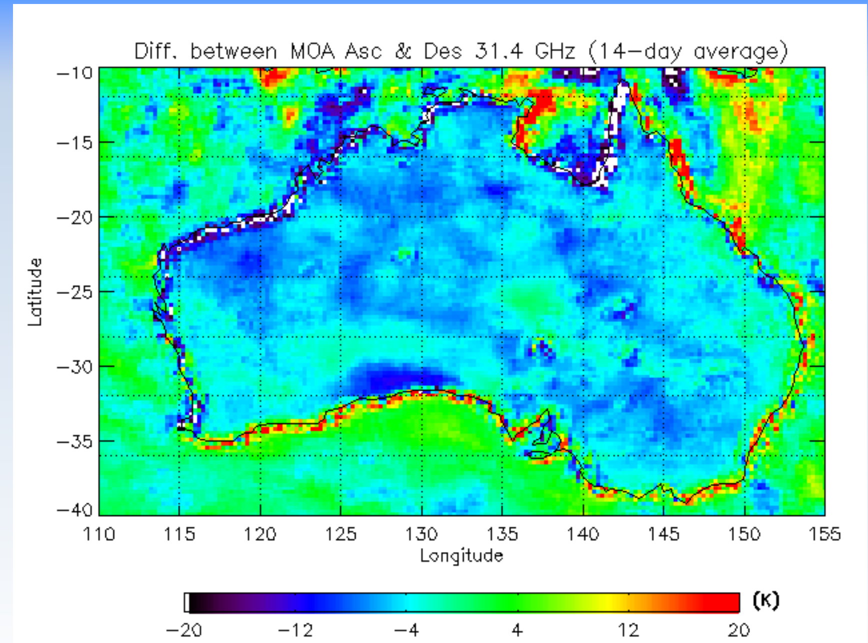

Diff. between N19 Asc & Des 23.8 GHz (14–day average)
Latitude
−10
−15
−20
−25
−30
−35
−40
110 115 120 125 130 135 140 145 150 155
Longitude
(K)
−25 −14 −3 8 19 30

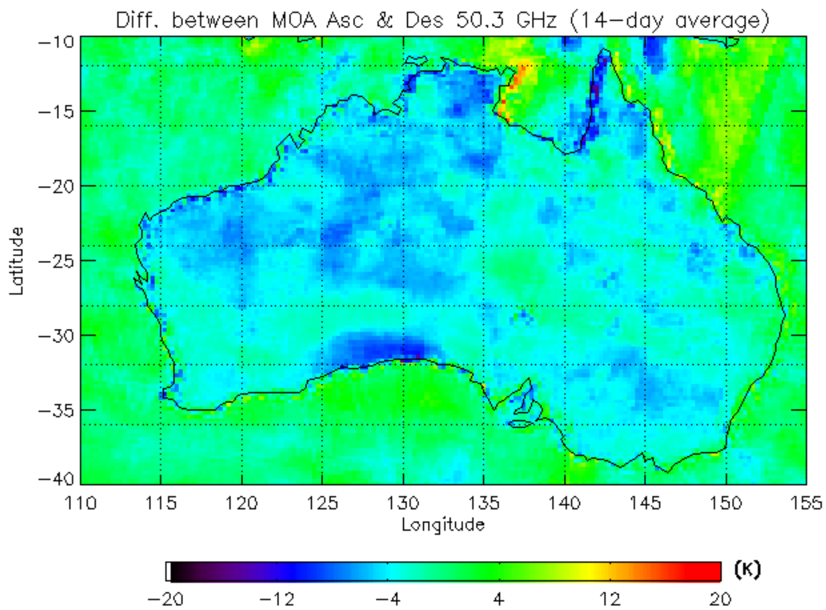

Diff. between N19 Asc & Des 31.4 GHz (14–day average)
Latitude
−10
−15
−20
−25
−30
−35
−40
110 115 120 125 130 135 140 145 150 155
Longitude
(K)
−25 −14 −3 8 19 30

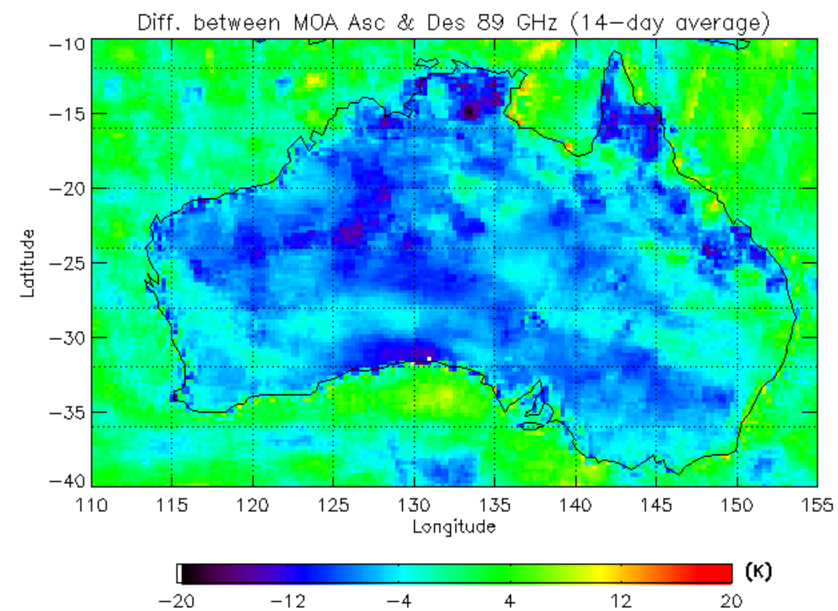

Diff. between N19 Asc & Des 50.3 GHz (14–day average)
Latitude
−10
−15
−20
−25
−30
−35
−40
110 115 120 125 130 135 140 145 150 155
Longitude
(K)
−10 −5 0 5 10 15


Diff. between N19 Asc & Des 89 GHz (14–day average)
Latitude
−10
−15
−20
−25
−30
−35
−40
110 115 120 125 130 135 140 145 150 155
Longitude
(K)
−15 −8 −1 6 13 20

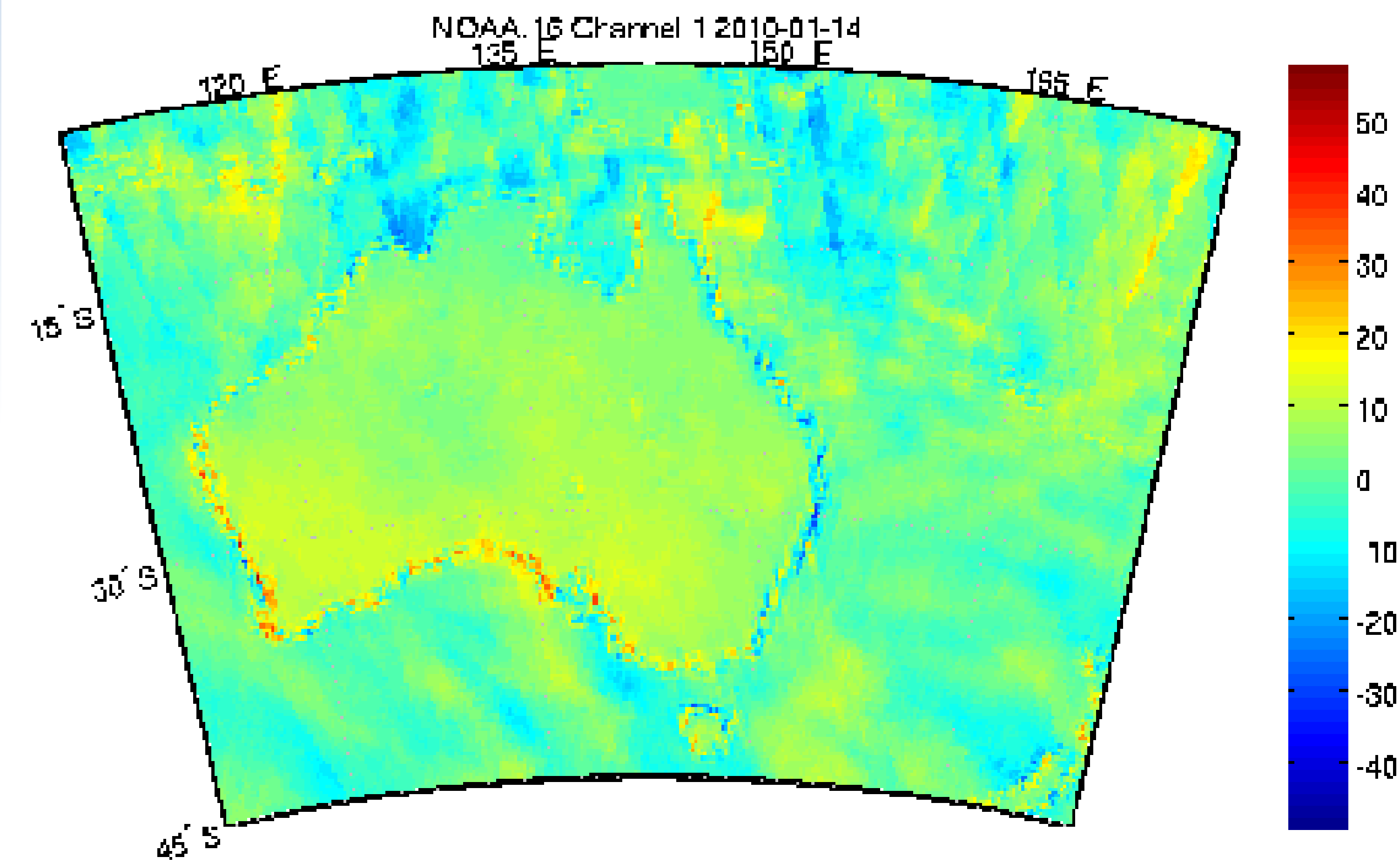

Diff. between MOA Asc & Des 23.8 GHz (14–day average)
Latitude
Longitude
−10
−15
−20
−25
−30
−35
−40
110 115 120 125 130 135 140 145 150 155
(K)
−20 −12 −4 4 12 20


Diff. between MOA Asc & Des 31.4 GHz (14–day average)
Latitude
Longitude
−10
−15
−20
−25
−30
−35
−40
110 115 120 125 130 135 140 145 150 155
(K)
−20 −12 −4 4 12 20

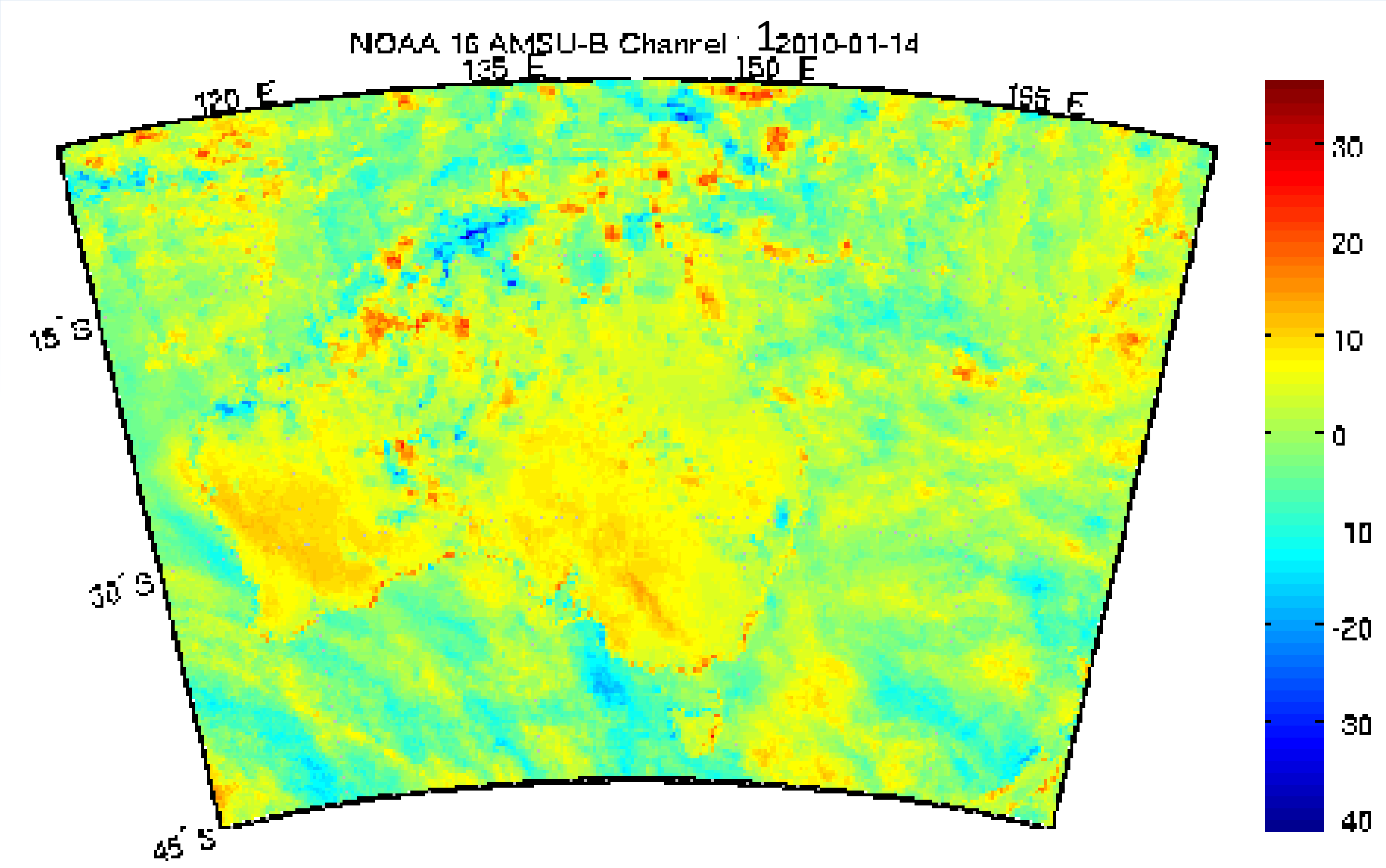

Diff. between MOA Asc & Des 50.3 GHz (14–day average)
Latitude
Longitude
−10
−15
−20
−25
−30
−35
−40
110 115 120 125 130 135 140 145 150 155
(K)
−20 −12 −4 4 12 20


Diff. between MOA Asc & Des 89 GHz (14–day average)
Latitude
Longitude
−10
−15
−20
−25
−30
−35
−40
110 115 120 125 130 135 140 145 150 155
(K)
−20 −12 −4 4 12 20

NOAA 16 – AMSU-A2 Channel 1



The pixel and line shifts for AMSU-B seem to be less variable than AMSU-A2



What’s next

- Calculating roll, pitch and yaw errors for each week and then correcting the current values of latitude and longitude.
- Correcting LZA and LSA using new pitch, roll and yaw
- Including time offset corrections
- Quantifying the uncertainty from satellite ephemeris data.

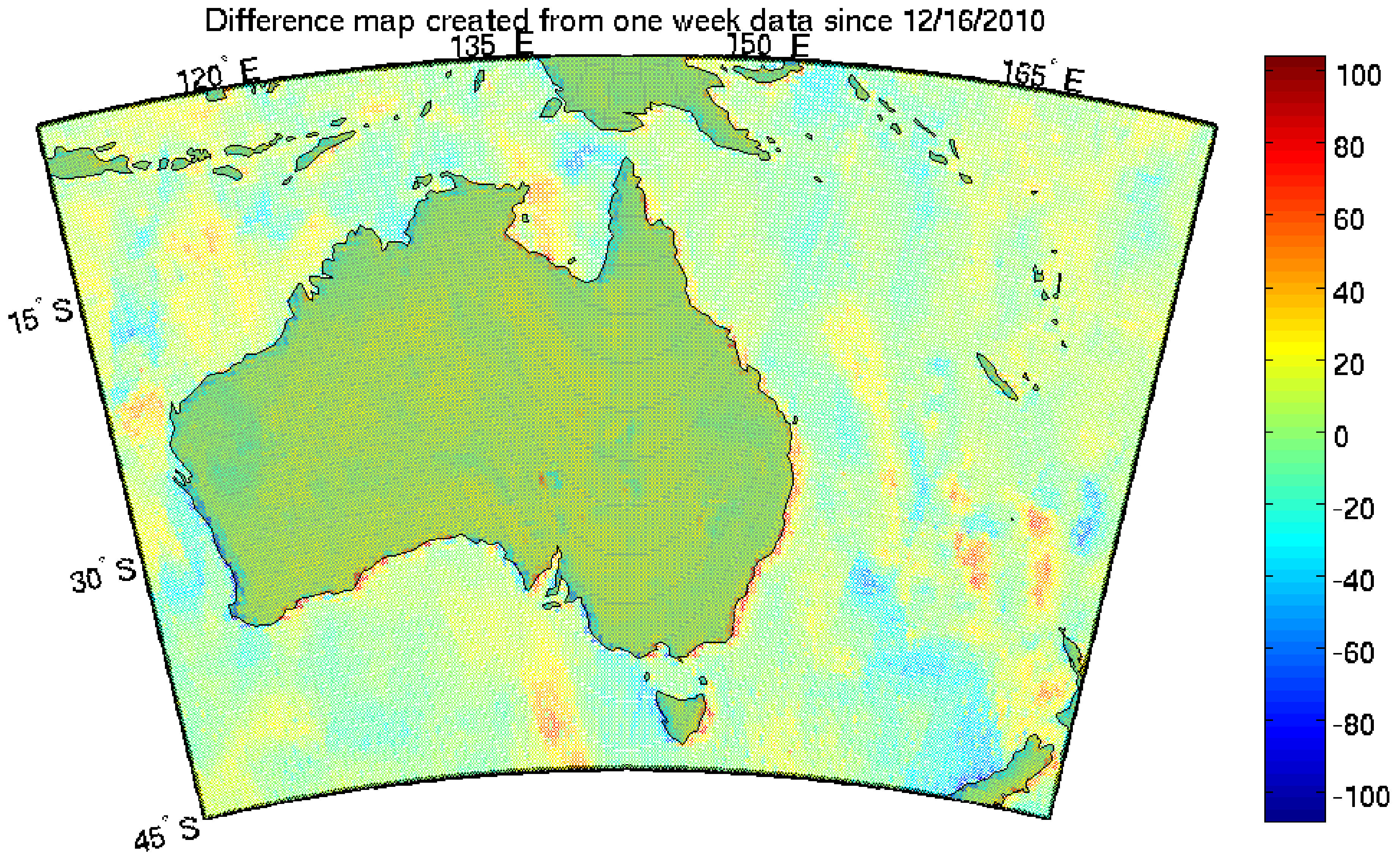
End

AMSU-A Characteristics

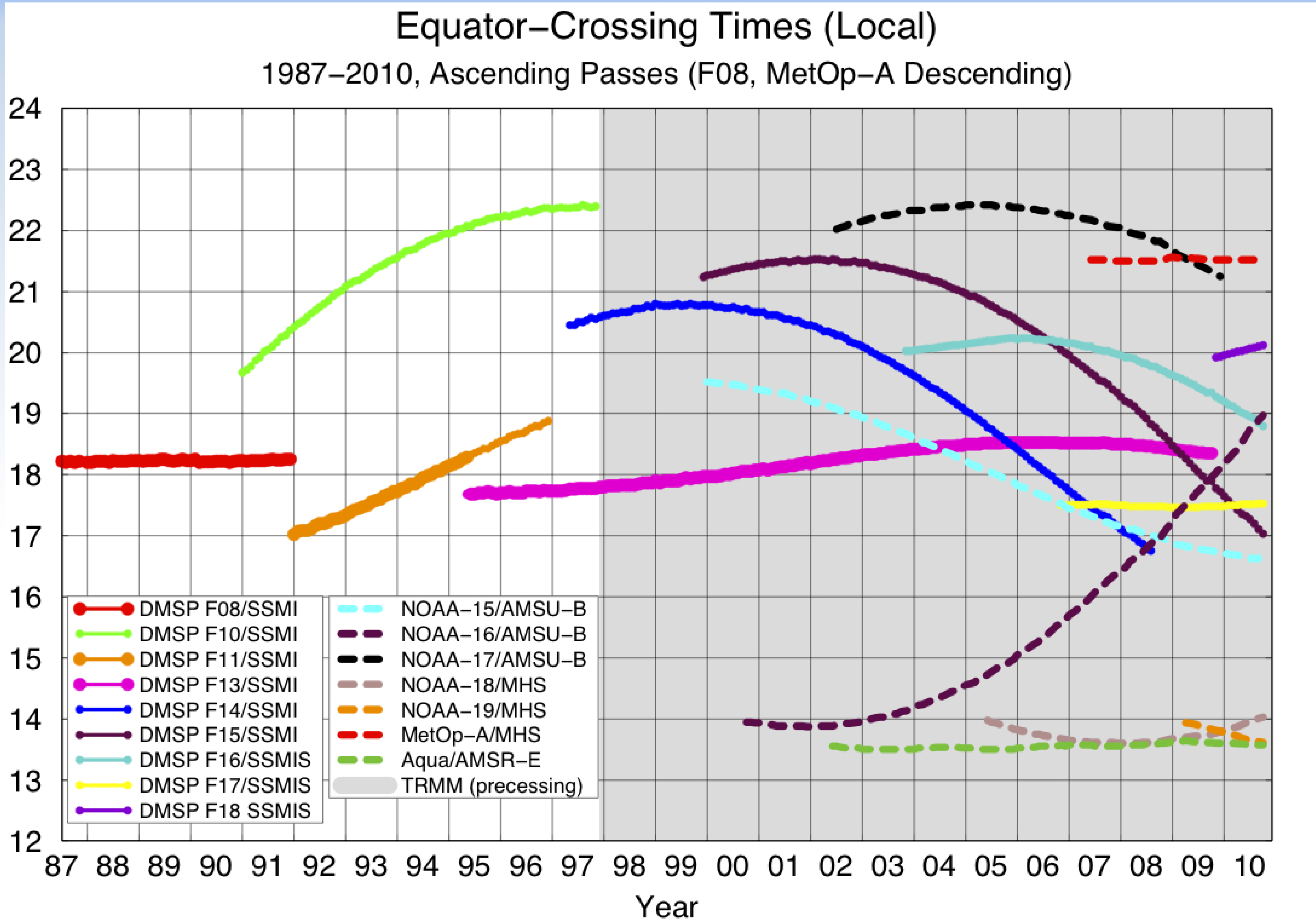
http://www2.ncdc.noaa.gov/docs/klm/html/c3/sec3-3.htm

Channel No.	Frequency (GHz)	Polarization at nadir	Atmospheric transmission (tropical)	(winter subarctic)
1	23.8	V	0.78	0.99
2	31.4	V	0.89	0.96
3	50.3	V	0.63	0.68
4	52.8	V	0.29	0.32
5	53.596 ± 0.115	H	0.11	0.13
6	54.40	H	0.02	0.02
7	54.94	V	0.00	0.00
8	55.50	H	0.00	0.00
9	57.290 = ν	H	0.00	0.00
10	ν ± 0.217	H	0.00	0.00
11	ν ± 0.322 ± 0.048	H	0.00	0.00
12	ν ± 0.322 ± 0.022	H	0.00	0.00
13	ν ± 0.322 ± 0.010	H	0.00	0.00
14	ν ± 0.322 ± 0.0045	H	0.00	0.00
15	89.0	V	0.61	0.91

Prigent, Catherine et al., 2005, *J. Appl. Meteor.*, **44**, 416–426



Difference map created from one week data since 12/16/2010
120° E
135° E
150° E
165° E
15° S
30° S
45° S
100
80
60
40
20
0
-20
-40
-60
-80
-100



Thickest lines denote GPCP calibrator.

Image by Eric Nelkin (SSAI), 20 October 2010, NASA/Goddard Space Flight Center, Greenbelt, MD.