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Angular and Range Deviations for the Earth Science Afternoon Constellation

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November 2003

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ANGULAR AND RANGE DEVIATIONS FOR THE EARTH SCIENCE AFTERNOON CONSTELLATION

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ABSTRACT

This paper investigates the angular spread between the five satellites that will make up the Earth Science Afternoon Constellation starting in October 2004. Simulations are performed to propagate the satellites for a time period of one year to observe the position for each satellite. Small angular spread between the satellites together with the variability in the angles suggests the use of adaptive array antennas for inter-satellite communication links.

1 INTRODUCTION

The Earth Science Morning (AM) and Afternoon (PM) constellations are being assembled to provide near-contemporaneous observation by multiple sensors, on different spacecraft for the purposes of obtaining 'greater than the sum' science return [1]. However, the short distances between the satellites are suspected of leading to small angular spreads between the elements of the constellation, thereby complicating inter-satellite communications—if the angular spread between two spacecraft transmitting in the same band (e.g. CDMA transmission) is small then receiver capacity is reduced due to in-band interference. This interference can be significantly reduced through the use of advanced antenna designs such as adaptive arrays.

In this memo, the angles between spacecraft in the constellation are estimated over a period of one year. This is accomplished by propagating satellite orbits to obtain the satellite locations. Satellite position vectors are used to calculate the angular spread between satellites in the constellation as well as the range between the satellites. These geometric parameters, when combined with assumptions concerning communications-gear parameters (such as antenna type, transmit power, etc), can be used to estimate link margin. However, the current focus is to interpret the geometric parameters (i.e. separation angles between transmitting spacecraft and their temporal variability) qualitatively to determine if further investigation is warranted.

2 SETUP

There are four satellites that make up the AM Constellation: Landsat-7, EO-1, SAC-C, and Terra. There are five proposed satellites to be part of the PM Constellation: Aqua, Aura, CALIPSO, CloudSat, and PARISOL. All of the satellites in each constellation have their orbit planes offset so that each spacecraft passes over the same point on the ground [1]. Currently, every satellite in the AM Constellation is in orbit, while only the Aqua satellite is in orbit for the PM Constellation. The AM Constellation and Aqua's orbits were propagated in STK using two-line element set data from June 13, 2003 [2]. By knowing their orbital parameters and the ground trace time separations between all of the satellites in each constellation, the orbits for the remaining four satellites are estimated.

The Landsat-7 satellite is the leading satellite for the AM Constellation. All of the satellites have a Low Earth Orbit (LEO). Table 1 below, lists the proposed time separations in the ground trace for the remaining three satellites relative to the leading Landsat-7 satellite [1].

Table 1.—AM Constellation Ground Track Time Separation

SATELLITE	TIME SEPARATION
Landsat-7	Lead Satellite
EO-1	1 Minute
SAC-C	27 Minutes
Terra	28 Minutes

In the PM Constellation, the Aqua satellite will lead, until 2007 in which OCO will lead without line of sight range to Aqua, the remaining satellites in the constellation. All of the satellites will be in LEO. Table 2 below, lists the proposed time separations in the ground trace for remaining four satellites relative to the leading Aqua satellite [1].

Table 2.—PM Constellation Ground Track Time Separation

SATELLITE	TIME SEPARATION
Aqua	Lead Satellite
CloudSat	1 Minute
CALIPSO	1 Minute, 15 Seconds
PARISOL	3 Minutes
Aura	8 Minutes

Satellite Tool Kit (STK) was used to propagate the orbits and to collect position vectors every 10 minutes for one year's time. MATLAB was used to determine the ranges and angles between the satellites. MATLAB was also used to plot the histograms of the ranges and angles for the entire set of data.

Starting with the Keplerian parameters for the Aqua satellite, the Right Ascension of the Ascending Node (RAAN) and Mean Anomaly (MA) were iteratively adjusted until the specified temporal displacements from the Aqua orbit were achieved for each satellite in the constellation. This technique proved to be sufficient for the purposes of the developing the simulation in which geometric constellation was maintained for a year. Figure A.1 in Appendix A shows a side view of the AM Constellation orbits, while Figure A.2 shows the PM Constellation orbits. As seen from figure A.1, there is no line of sight between the EO-1 and SAC-C satellites in the AM Constellation, and therefore the AM Constellation will not be analyzed further as the need is non-existent.

The next step after creating the orbits for the PM Constellation was to propagate the constellation for a one year's worth of time. This was done at the starting date of June 13, 2003 and the end of the propagation was at June 13, 2004. A year's worth of data averages out the effects of the variations in the Earth's orbit and the orbit of the satellites repeat their ground trace several times in one year.

3 CALCULATIONS AND RESULTS

J2000 Position data was collected at a sample period of 10 minutes throughout the propagation. Range vectors between the satellites are used to calculate the angles of the constellation geometry. Histograms of the ranges in the satellite triangles (3 satellites that can form a receiver-source-interference combination) are shown in Appendix B, with the angles in the satellite triangles shown in Appendix C. The minimum and maximum ranges and angles were calculated for satellite pair or triangle, respectively. The spread of these values are shown in table D.1 in Appendix D. It is assumed that the central satellites in the constellation will have two antennas for the purpose of pointing towards the leading and lagging sides of the constellation. Thus, the large angles in the satellite triangles are not of concern.

A central angle calculation was done as the average of the minimum angle and maximum angle for each of the thirty distinct angles in the PM Constellation. The distribution of these angles can be illustrated in figure 3 below.

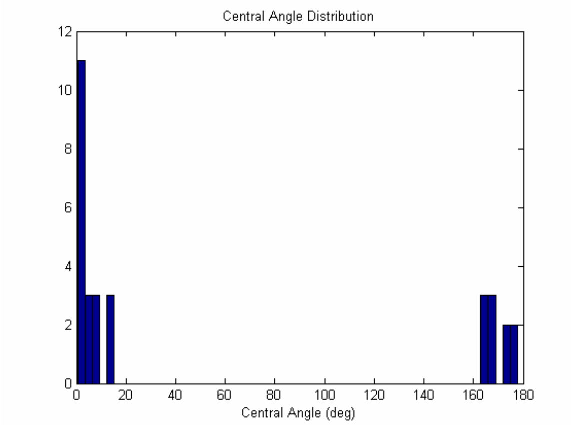

Figure 3.—Central Angle Distribution

As can be seen in Figure 3, the angles are concentrated near zero and 170 degrees. These distributions of the angles are caused from the spatial arrangement of the satellites. The satellites that are in the central portion of the constellation will have large angles around 170 degrees, to the outer satellites, due to the co-linearity of the orbits of the satellites. These angles are not of concern in the inter-satellite communications problem due to the spatial separation of the satellites in the constellation. However, all of the satellites except CALIPSO would have to accommodate the interference of the inter-satellite transmissions due to the small angles between sources and interferers. The next two figures, figures 4 and 5, will illustrate the small and the large angles that occur within the PM Constellation, respectively.

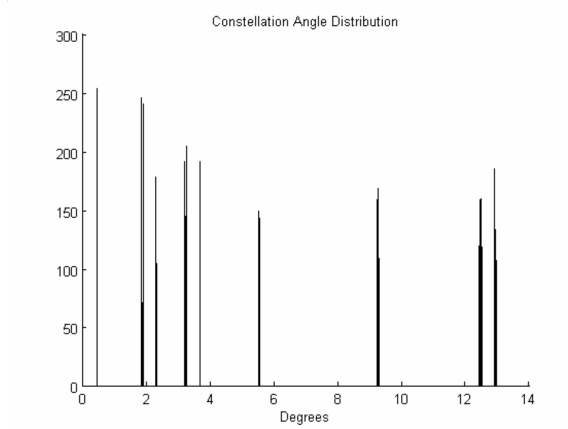

Figure 4.—Constellation Angle Distribution—Small Angles

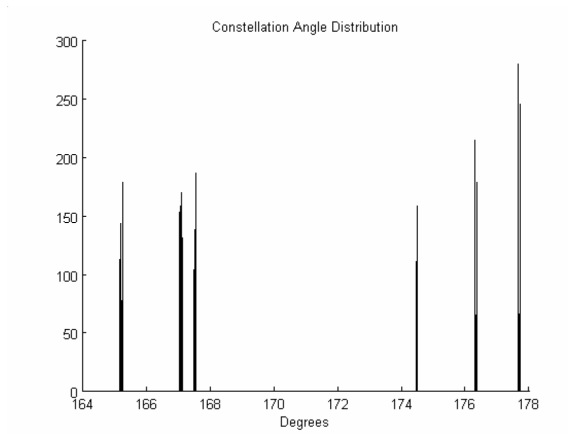

Figure 5.—Constellation Angle Distribution—Large Angles

4 CONCLUSIONS AND FUTURE WORK

Figures 4 and 5 illustrate the small variations of the angles that exist within the movement of the PM Constellation. These small variations in the angles can be hazardous to the communications for a standard phased array antenna in which fixed nulls are directed towards the directions of interferences. This is due to the steep slope that exists at the locations of the nulls along with the narrow width of the null. Therefore, if these issues are not dealt with in the design of the communications system, then the bit error can be high. However, adaptive antenna arrays have the ability to redirect nulls to decrease the signal strength of interference. It is from these small variations of the angles and ranges that were calculated in this analysis, along with the small angles between possible transmitters, which illustrate a need for adaptive antennas to be used for the inter-satellite links in the PM Constellation. In the AM Constellation however, there would be no need for research into the use of adaptive antennas for inter-satellite communication links due to the lack of line of sight between the two central satellites.

Future work on this project could include the formulation of a link budget to compare the SNIR ratios between various types of antennas (aperture, non-adaptive, adaptive) to determine the benefit in link margin for adaptive antennas.

REFERENCES

[1] Kelly, Angelita C., “Earth Science Morning and Afternoon Constellations,” International EESS Wideband Workshop, Orlando, Florida, March 24–-27, 2003, <spectrum.nasa.gov/eessworkshop/day2/02-03-kelly.pdf>.

[2] Kelso, T.S., <celestrak.com/NORAD>, June 13, 2003.

APPENDIX A
3D Side Views

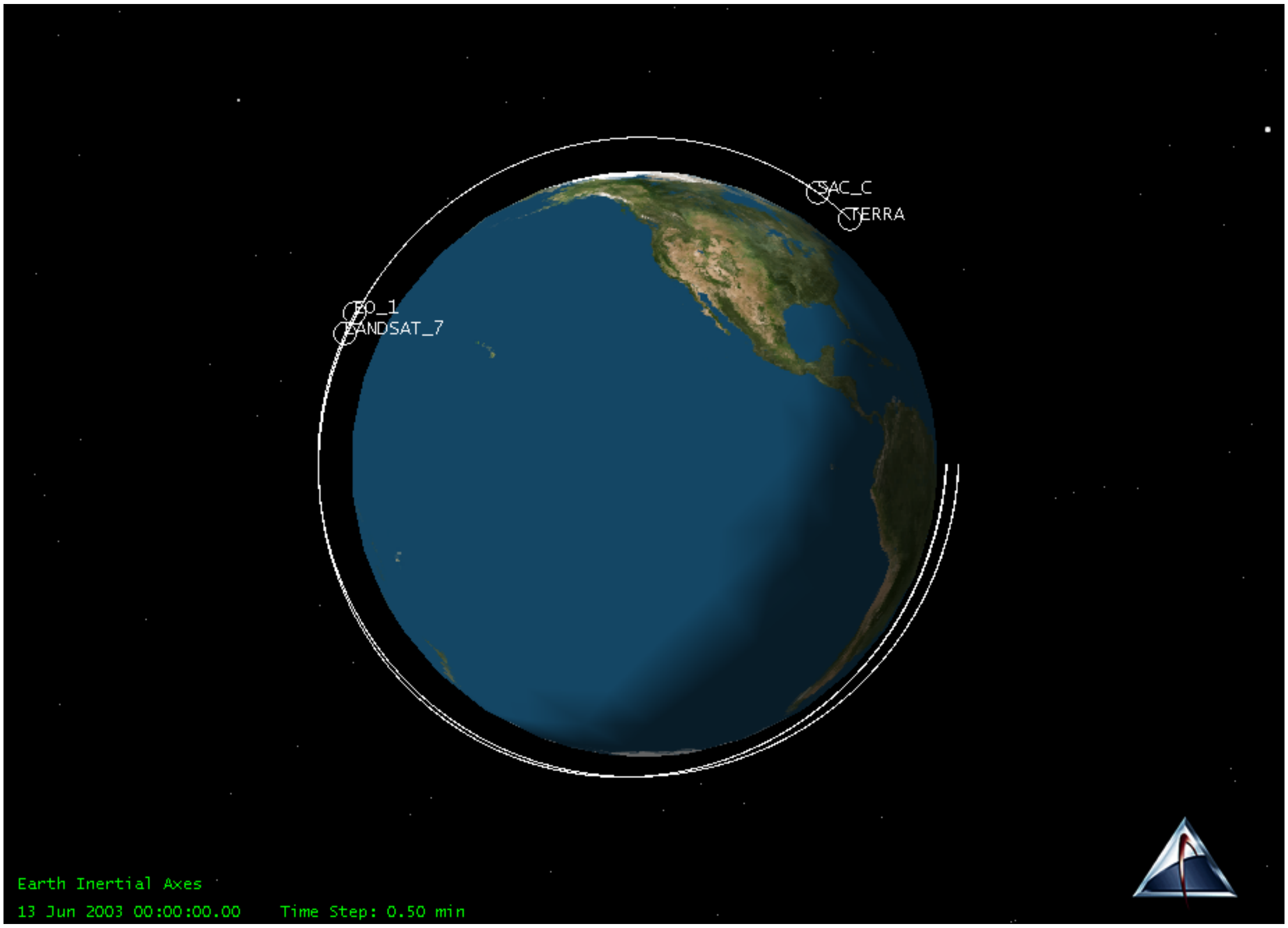

Figure A.1.—3-D Orbit Side View of AM Constellation.

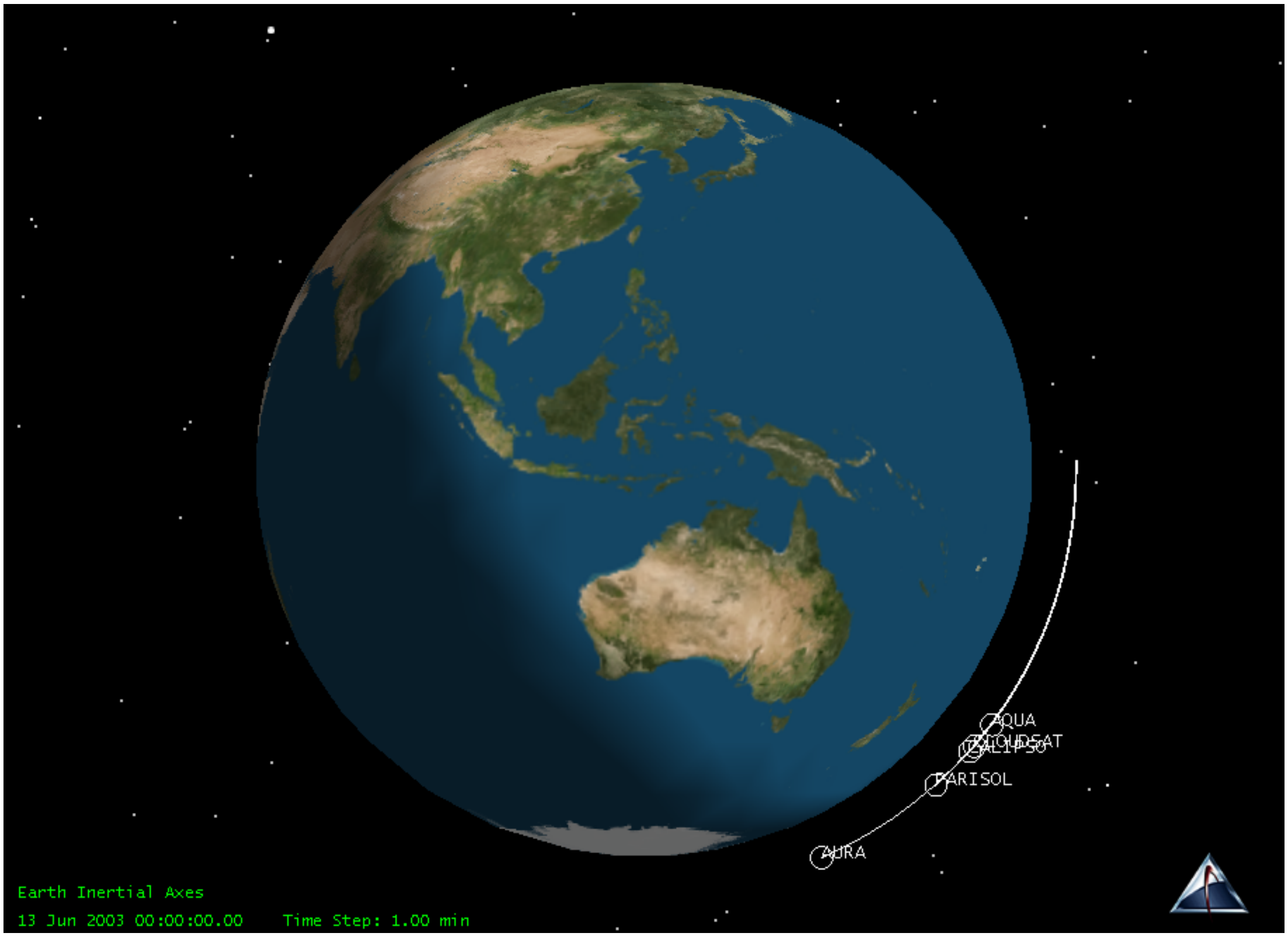

Figure A.2.—3-D Orbit Side View of PM Constellation.

APPENDIX B
Range Histograms

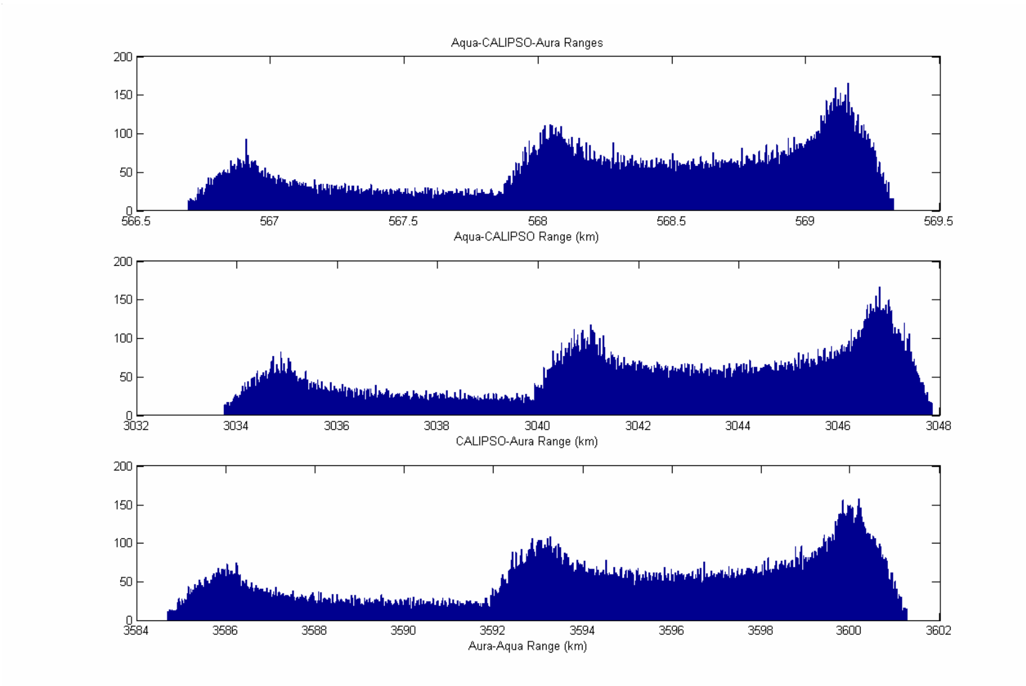

Figure B.1.—Aqua-CALIPSO-Aura Ranges.

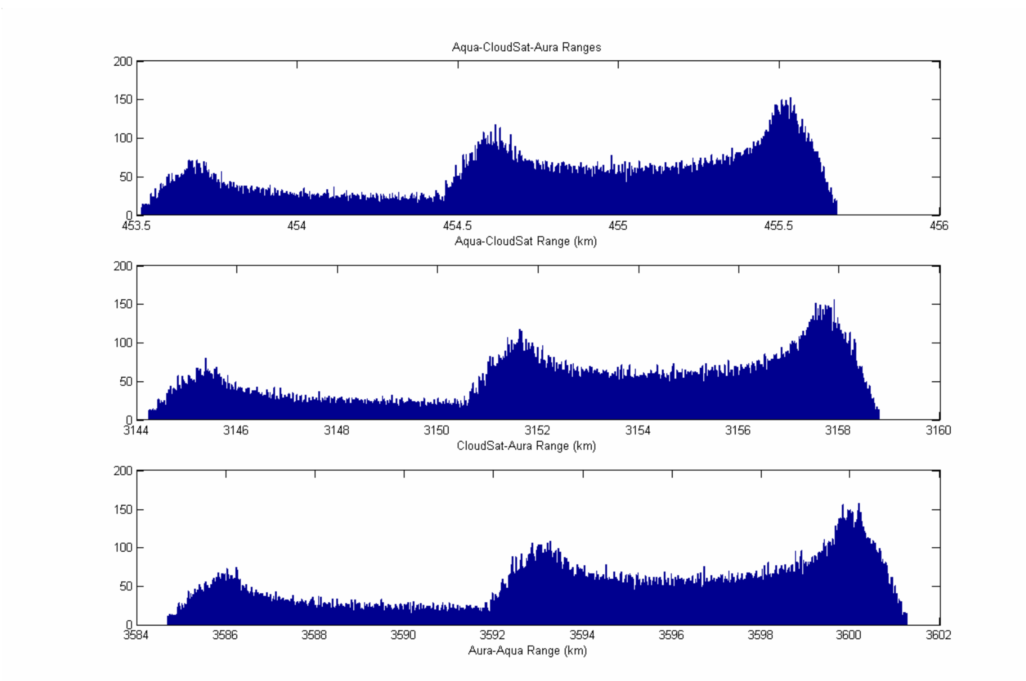

Figure B.2.—Aqua-CloudSat-Aura Ranges.

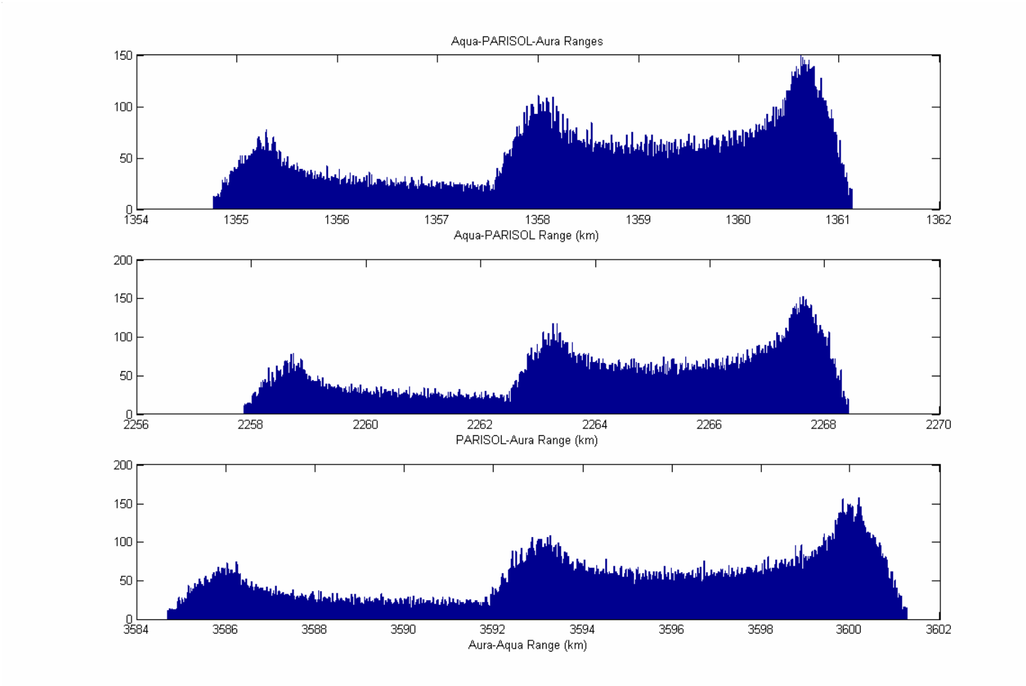

Figure B.3.—Aqua-PARISOL-Aura Ranges.

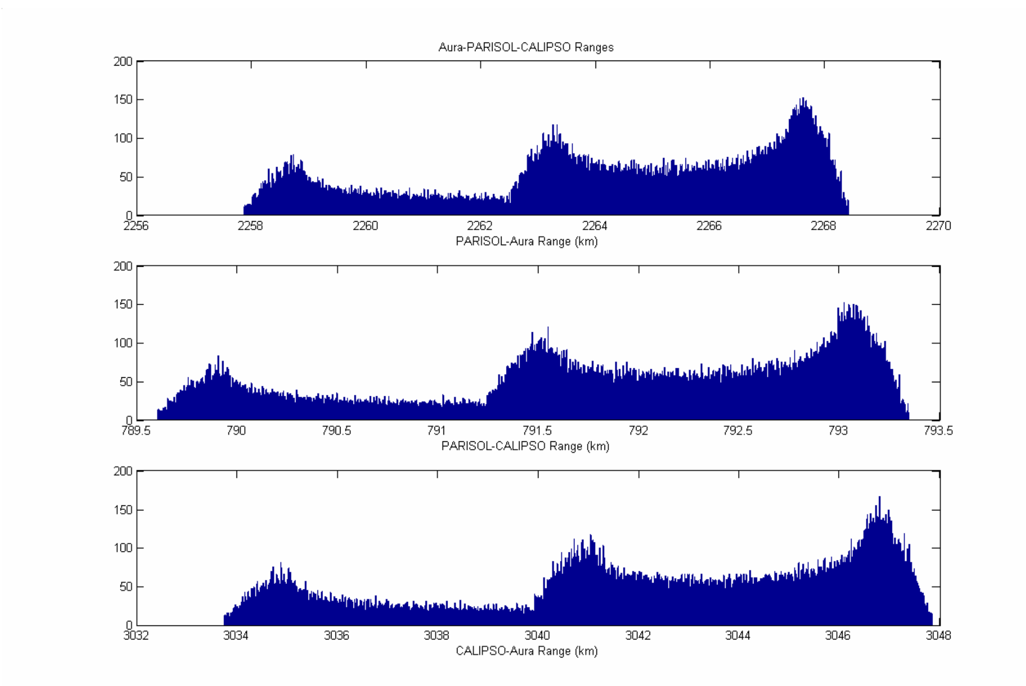

Figure B.4.—Aura-PARISOL-CALIPSO Ranges.

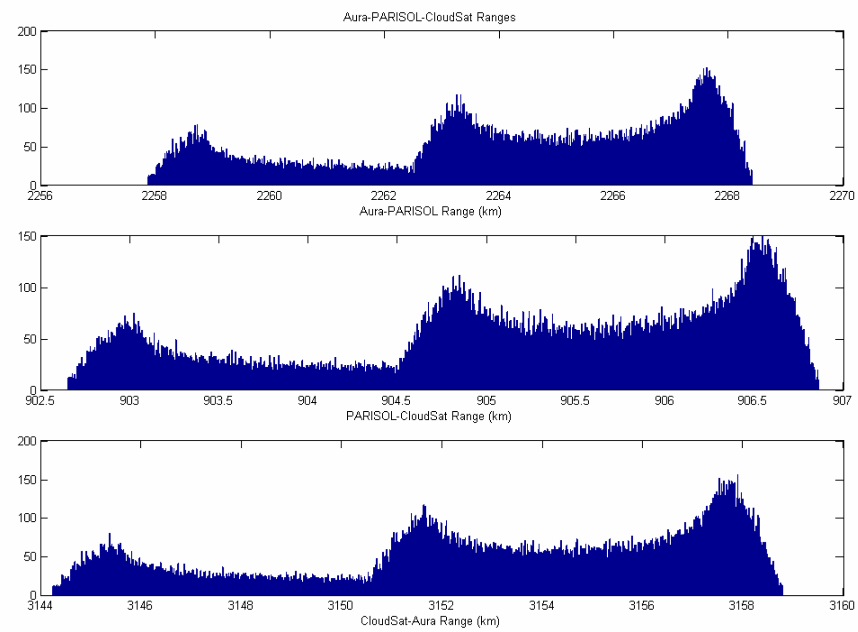

Figure B.5.—Aura-PARISOL-CloudSat Ranges.

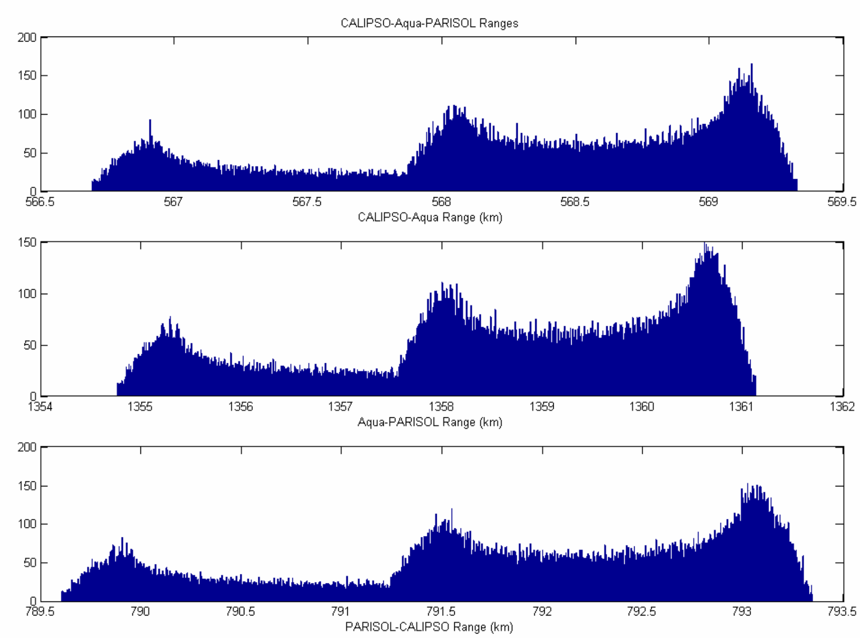

Figure B.6.—CALIPSO-Aqua-PARISOL Ranges.

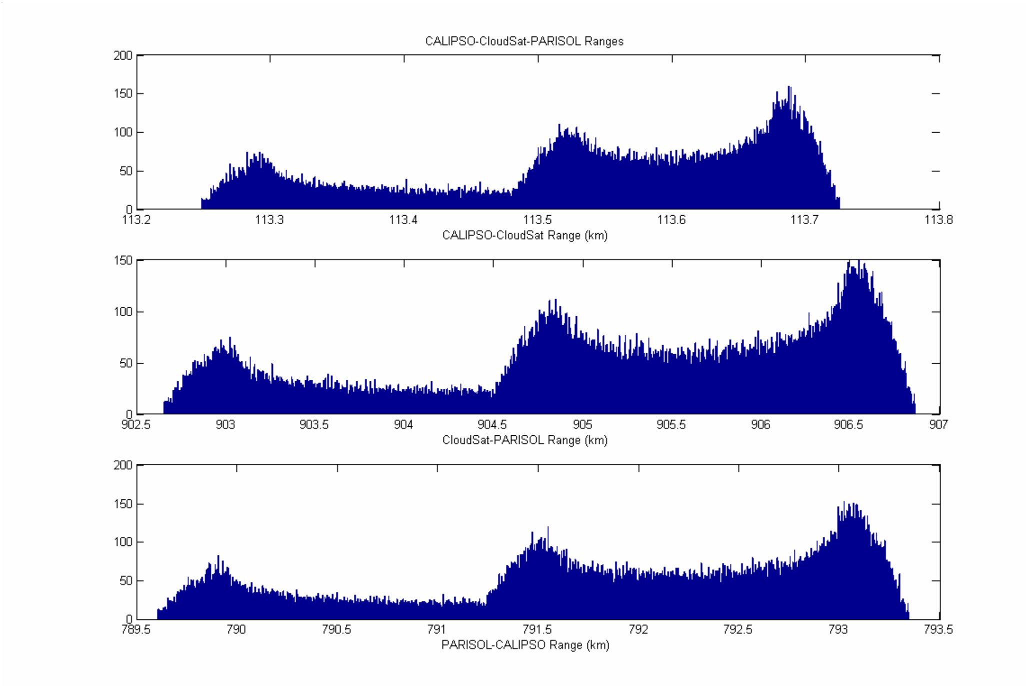

Figure B.7.—CALIPSO-CloudSat-PARISOL Ranges.

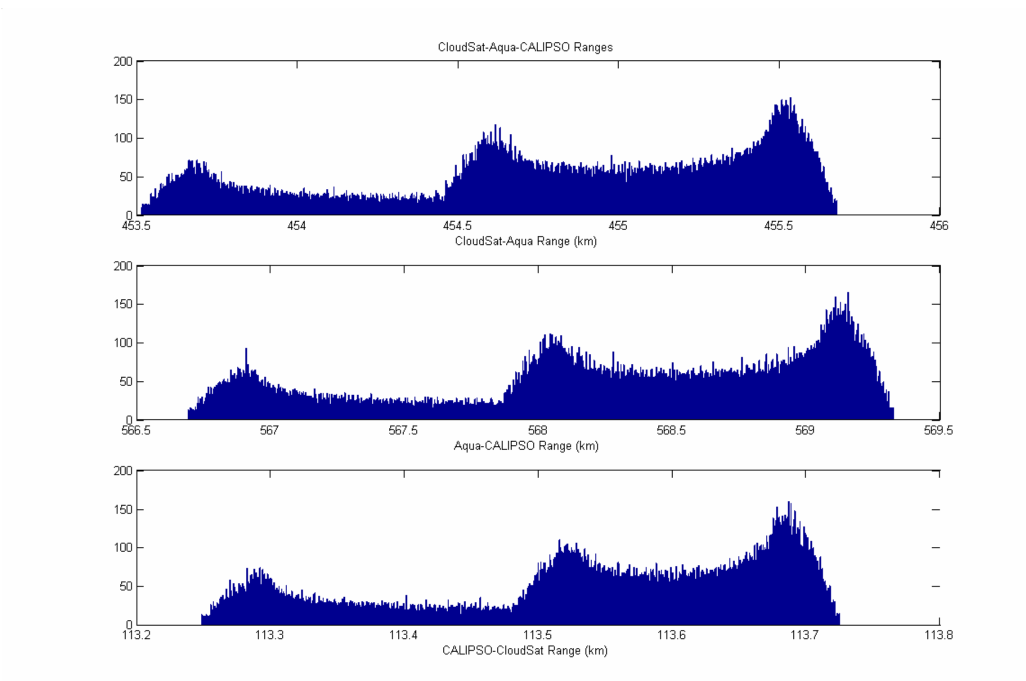

Figure B.8.—CloudSat-Aqua-CALIPSO Ranges.

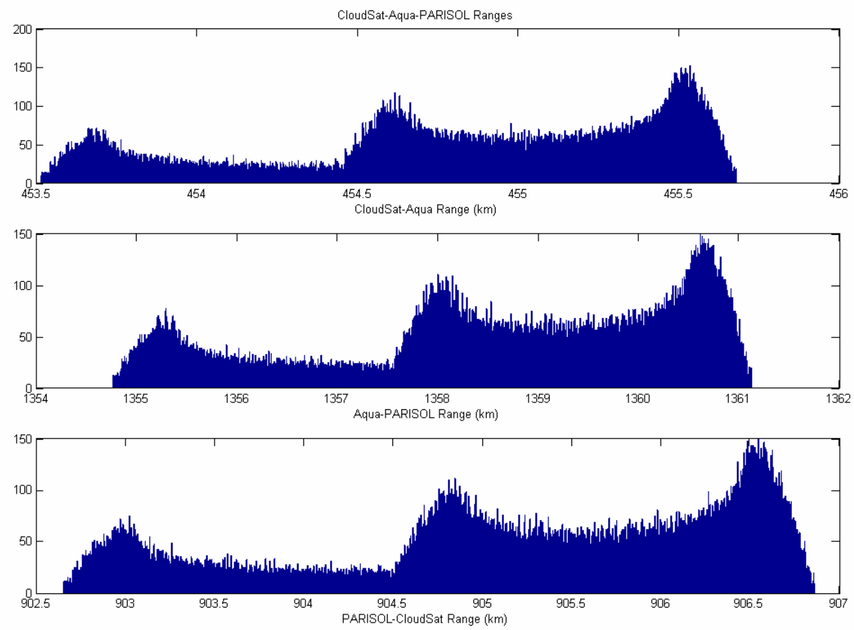

Figure B.9.—CloudSat-Aqua-PARISOL Ranges.

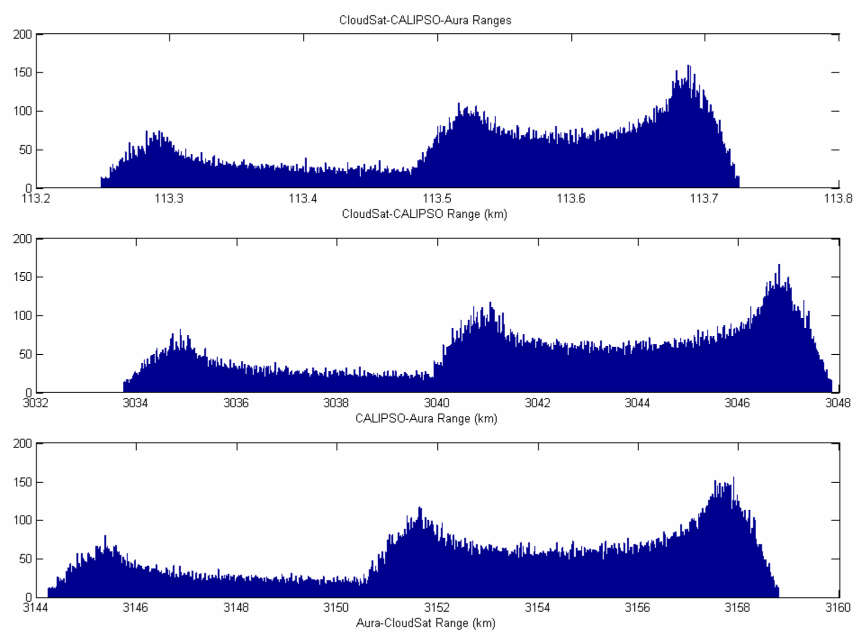

Figure B.10.—CloudSat-CALIPSO-Aura Ranges.

APPENDIX C
Angle Histograms

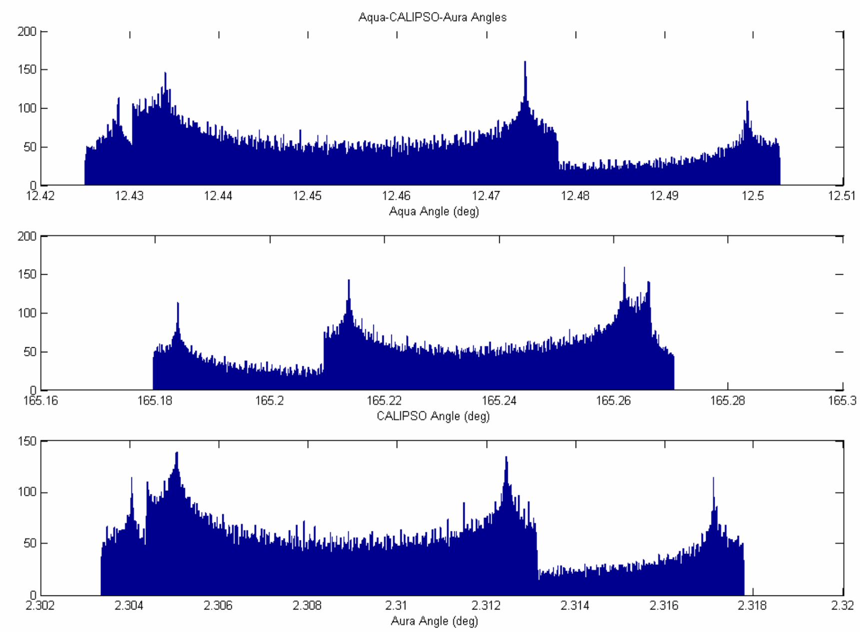

Figure C.1.—Aqua-CALIPSO-Aura Angles.

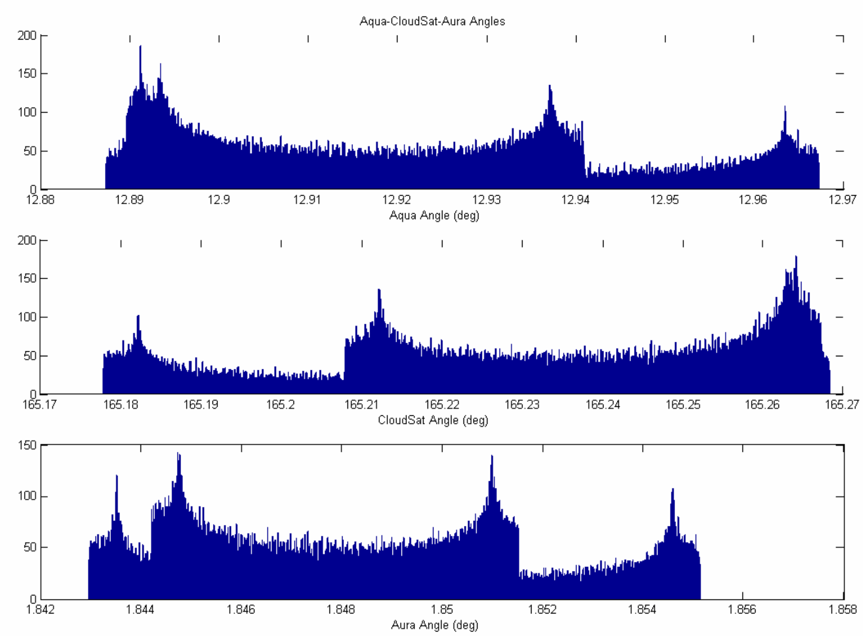

Figure C.2.—Aqua-CloudSat-Aura Angles.

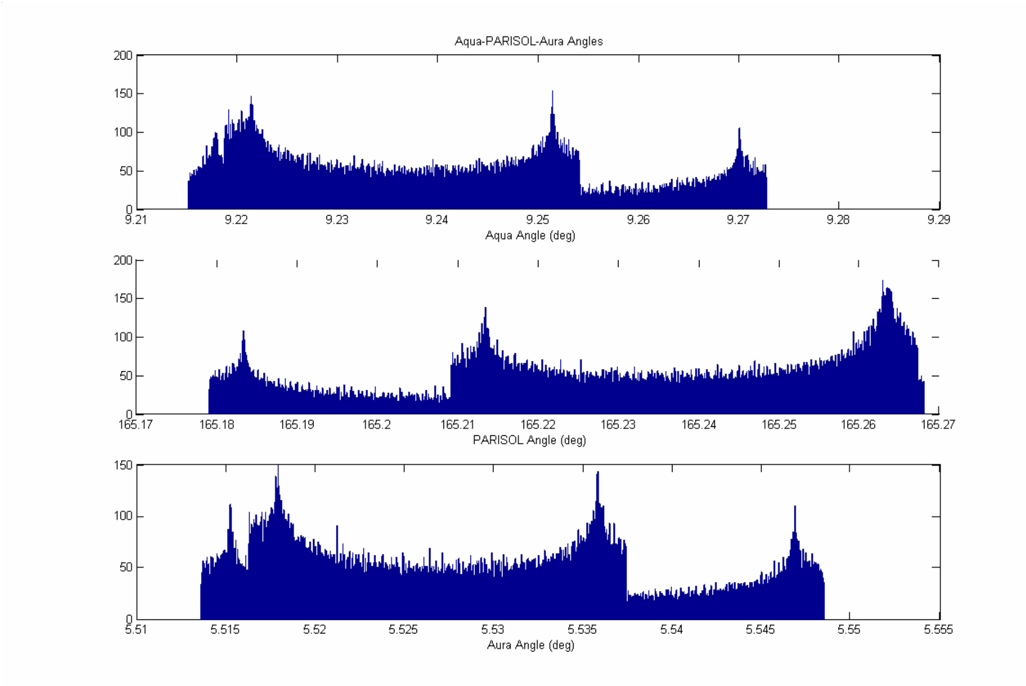

Figure C.3.—Aqua-PARISOL-Aura Angles.

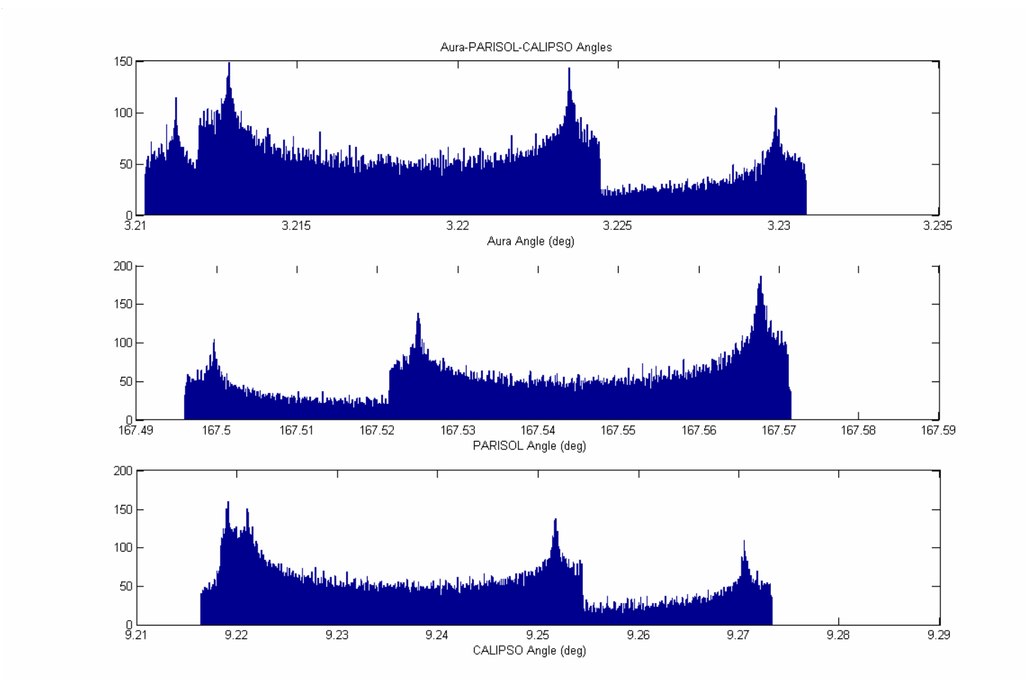

Figure C.4.—Aura-PARISOL-CALIPSO Angles.

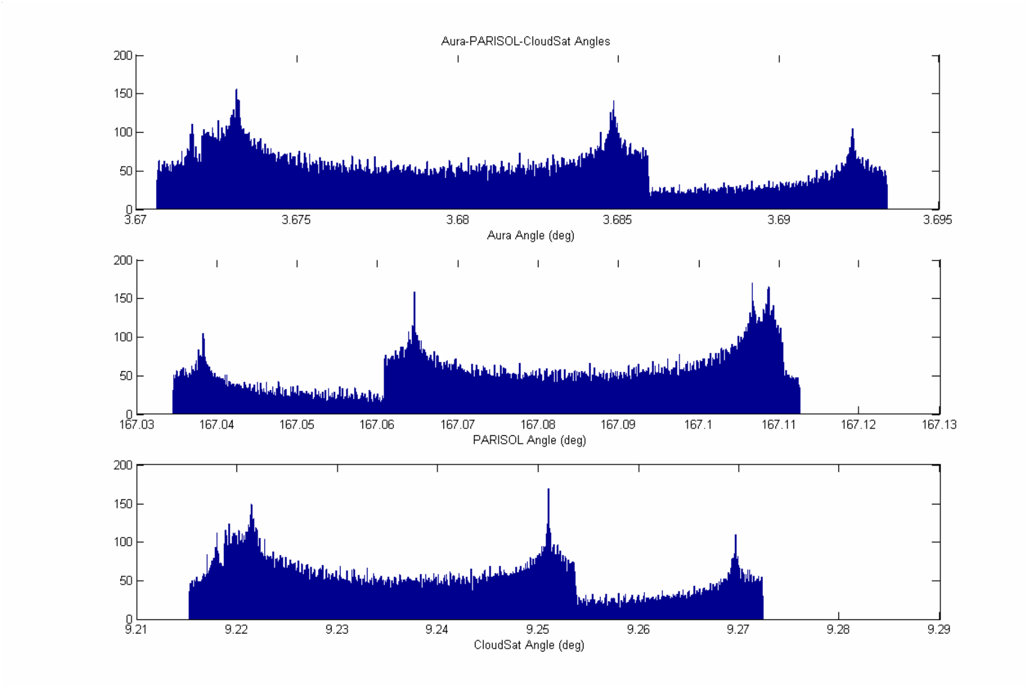

Figure C.5.—Aura-PARISOL-CloudSat Angles.

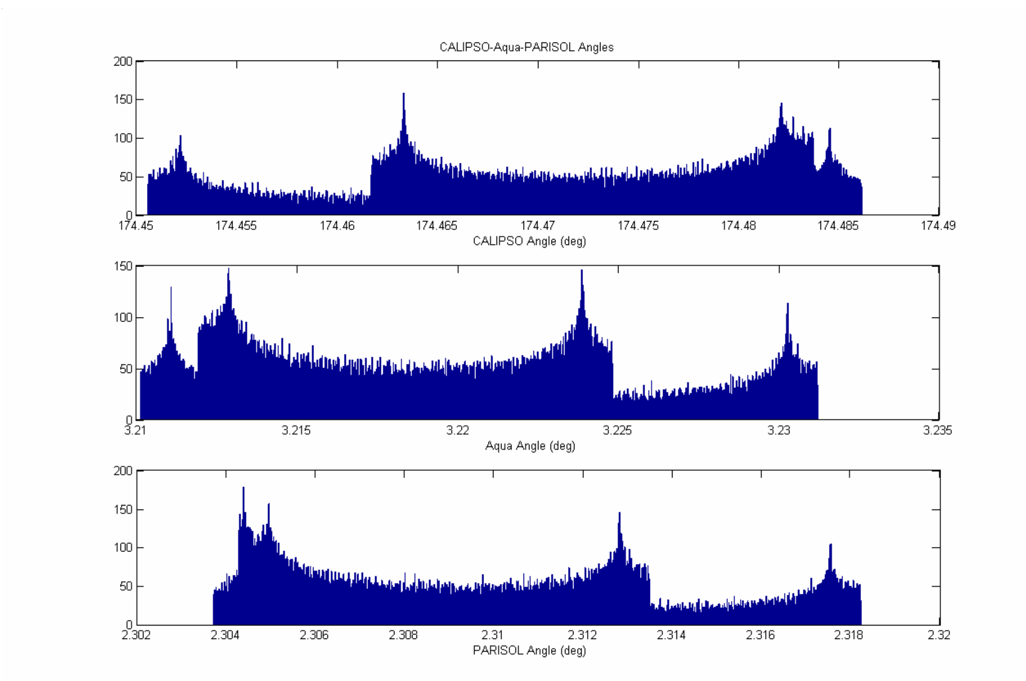

Figure C.6.—CALIPSO-Aqua-PARISOL Angles.

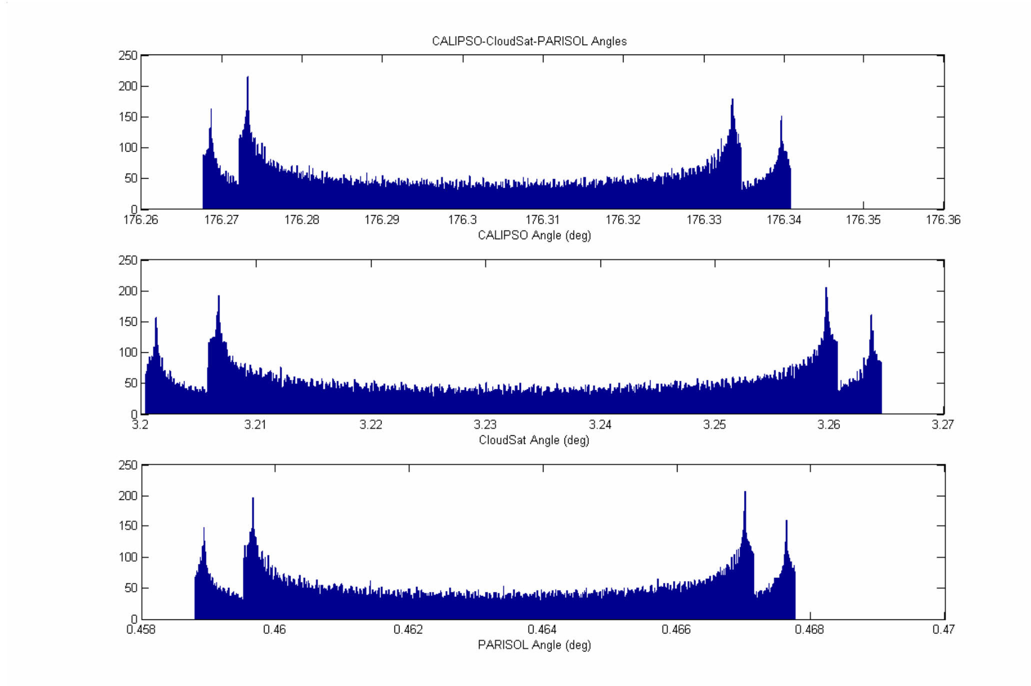

Figure C.7.—CALIPSO-CloudSat-PARISOL Angles.

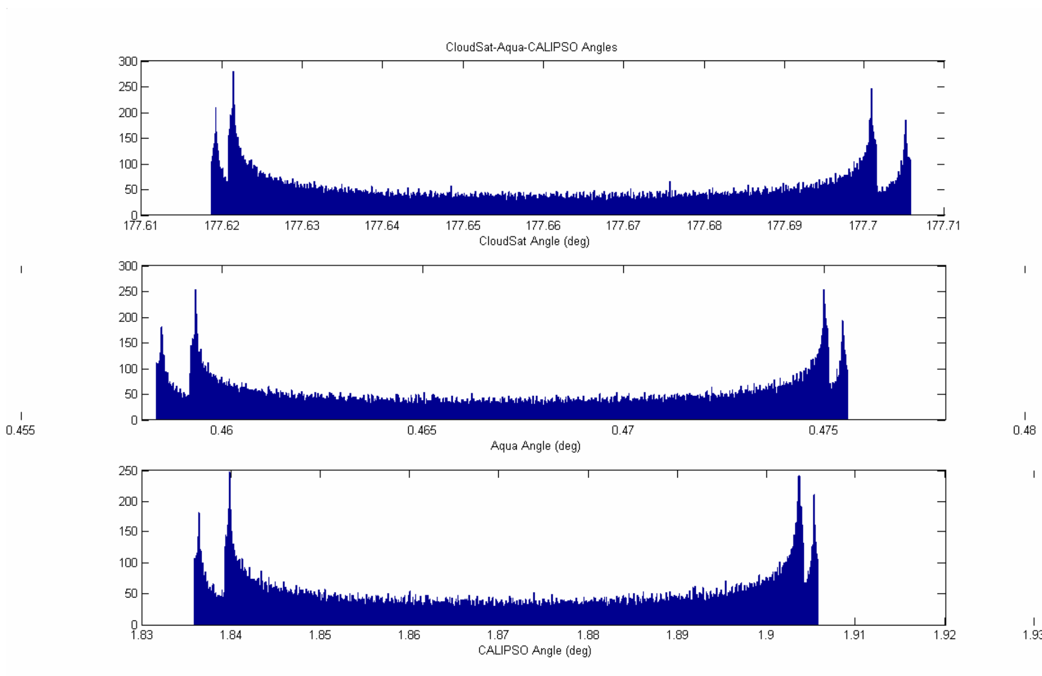

Figure C.8.—CloudSat-Aqua-CALIPSO Angles.

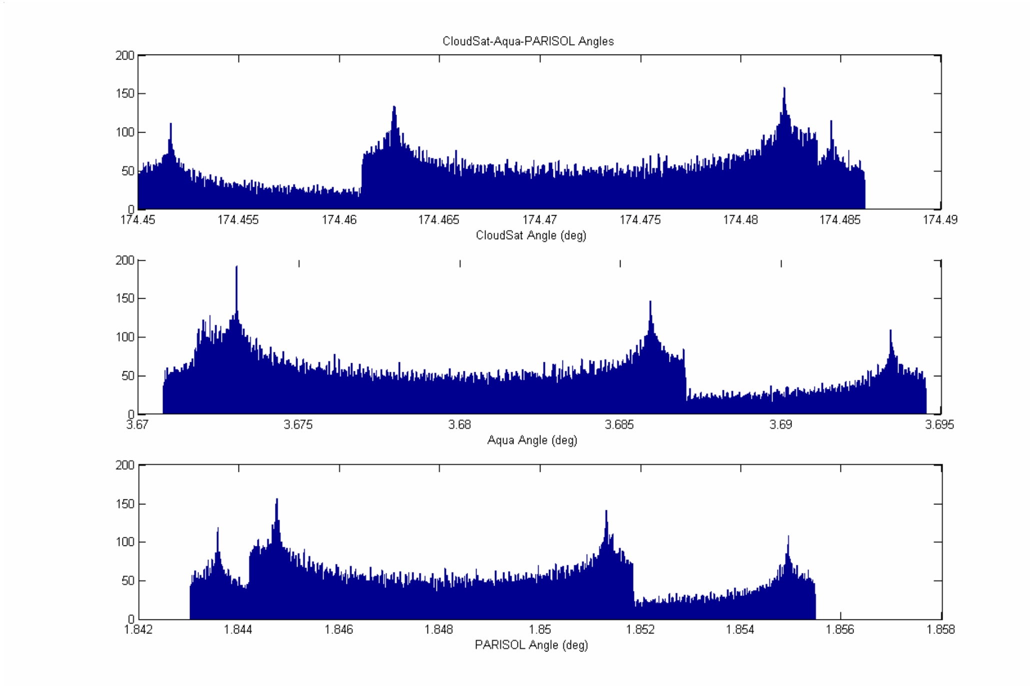

Figure C.9.—CloudSat-Aqua-PARISOL Angles.

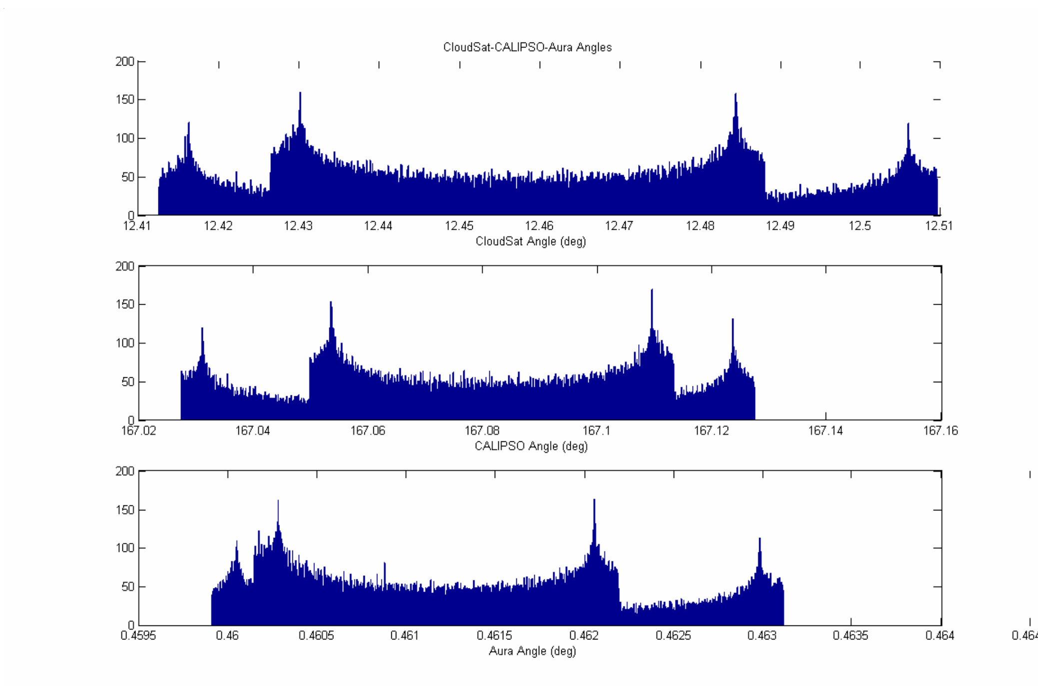

Figure C.10.—CloudSat-CALIPSO-Aura Angles.

APPENDIX D
Minimum and Maximum Angles and Ranges with Deviations

Table D.1.—Minimum and Maximum Ranges and Angles with Deviations

Receiver	Source	Source Distance (km)			Interference	Interference Angle (deg)			Interference Distance (km)		
Satellite	Satellite	Minimum	Maximum	Deviation	Satellite	Minimum	Maximum	Deviation	Minimum	Maximum	Deviation
Aura	PARISOL	2257.90	2268.40	10.50	CALIPSO	3.2103	3.2308	0.0205	3033.70	3047.80	14.10
Aura	PARISOL	2257.90	2268.40	10.50	CloudSat	3.6707	3.6934	0.0227	3144.20	3158.80	14.60
Aura	PARISOL	2257.90	2268.40	10.50	Aqua	5.5136	5.5485	0.0349	3587.40	3601.20	13.80
Aura	CALIPSO	3033.70	3047.80	14.10	PARISOL	3.2103	3.2308	0.0205	2257.90	2268.40	10.50
Aura	CALIPSO	3033.70	3047.80	14.10	CloudSat	0.4599	0.4631	0.0032	3144.20	3158.80	14.60
Aura	CALIPSO	3033.70	3047.80	14.10	Aqua	2.3034	2.3178	0.0144	3587.40	3601.20	13.80
Aura	CloudSat	3144.20	3158.80	14.60	PARISOL	3.6707	3.6934	0.0227	2257.90	2268.40	10.50
Aura	CloudSat	3144.20	3158.80	14.60	CALIPSO	0.4599	0.4631	0.0032	3033.70	3047.80	14.10
Aura	CloudSat	3144.20	3158.80	14.60	Aqua	1.8430	1.8551	0.0121	3587.40	3601.20	13.80
Aura	Aqua	3587.40	3601.20	13.80	PARISOL	5.5136	5.5485	0.0349	2257.90	2268.40	10.50
Aura	Aqua	3587.40	3601.20	13.80	CALIPSO	2.3034	2.3178	0.0144	3033.70	3047.80	14.10
Aura	Aqua	3587.40	3601.20	13.80	CloudSat	1.8430	1.8551	0.0121	3144.20	3158.80	14.60
PARISOL	CALIPSO	789.61	793.34	3.73	CloudSat	0.4588	0.4678	0.0090	902.65	906.86	4.21
PARISOL	CALIPSO	789.61	793.34	3.73	Aqua	2.3037	2.3182	0.0145	1354.80	1361.10	6.30
PARISOL	CloudSat	902.65	906.86	4.21	CALIPSO	0.4588	0.4678	0.0090	789.61	793.34	3.73
PARISOL	CloudSat	902.65	906.86	4.21	Aqua	1.8430	1.8555	0.0125	1354.80	1361.10	6.30
PARISOL	Aqua	1354.80	1361.10	6.30	CALIPSO	2.3037	2.3182	0.0145	789.61	793.34	3.73
PARISOL	Aqua	1354.80	1361.10	6.30	CloudSat	1.8430	1.8555	0.0125	902.65	906.86	4.21
CALIPSO	Aura	3033.70	3047.80	14.10	PARISOL	9.2164	9.2732	0.0568	789.61	793.34	3.73
CALIPSO	PARISOL	789.61	793.34	3.73	Aura	9.2164	9.2732	0.0568	3033.70	3047.80	14.10
CALIPSO	CloudSat	113.25	113.73	0.48	Aqua	1.8359	1.9057	0.0698	566.69	569.33	2.64
CALIPSO	Aqua	566.69	569.33	2.64	CloudSat	1.8359	1.9057	0.0698	113.25	113.73	0.48
CloudSat	CALIPSO	113.25	113.73	0.48	PARISOL	3.2004	3.2645	0.0641	902.65	906.86	4.21
CloudSat	CALIPSO	113.25	113.73	0.48	Aura	12.4127	12.5095	0.0968	3144.20	3158.80	14.60
CloudSat	PARISOL	902.65	906.86	4.21	CALIPSO	3.2004	3.2645	0.0641	113.25	113.73	0.48
CloudSat	PARISOL	902.65	906.86	4.21	Aura	9.2152	9.2723	0.0571	3144.20	3158.80	14.60
CloudSat	Aura	3144.20	3158.80	14.60	CALIPSO	12.4127	12.5095	0.0968	113.25	113.73	0.48
CloudSat	Aura	3144.20	3158.80	14.60	PARISOL	9.2152	9.2723	0.0571	902.65	906.86	4.21
Aqua	CloudSat	453.52	455.68	2.16	CALIPSO	0.4584	0.4755	0.0171	566.69	569.33	2.64
Aqua	CloudSat	453.52	455.68	2.16	PARISOL	3.6708	3.6945	0.0237	1354.80	1361.10	6.30
Aqua	CloudSat	453.52	455.68	2.16	Aura	12.8873	12.9671	0.0798	3587.40	3601.20	13.80
Aqua	CALIPSO	566.69	569.33	2.64	CloudSat	0.4584	0.4755	0.0171	453.52	455.68	2.16
Aqua	CALIPSO	566.69	569.33	2.64	PARISOL	3.2101	3.2312	0.0211	1354.80	1361.10	6.30
Aqua	CALIPSO	566.69	569.33	2.64	Aura	12.4250	12.5028	0.0778	3587.40	3601.20	13.80
Aqua	PARISOL	1354.80	1361.10	6.30	CloudSat	3.6708	3.6945	0.0237	453.52	455.68	2.16
Aqua	PARISOL	1354.80	1361.10	6.30	CALIPSO	3.2101	3.2312	0.0211	566.69	569.33	2.64
Aqua	PARISOL	1354.80	1361.10	6.30	Aura	9.2152	9.2727	0.0575	3587.40	3601.20	13.80
Aqua	Aura	3587.40	3601.20	13.80	CloudSat	12.8873	12.9671	0.0798	453.52	455.68	2.16
Aqua	Aura	3587.40	3601.20	13.80	CALIPSO	12.4250	12.5028	0.0778	566.69	569.33	2.64
Aqua	Aura	3587.40	3601.20	13.80	PARISOL	9.2152	9.2727	0.0575	1354.80	1361.10	6.30

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This paper investigates the angular spread between the five satellites that will make up the Earth Science Afternoon Constellation starting in October 2004. Simulations are performed to propagate the satellites for a time period of one year to observe the position for each satellite. Small angular spread between the satellites together with the variability in the angles suggests the use of adaptive array antennas for inter-satellite communication links.

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