Development of Elevation Angle PDFs for Non-Geostationary Satellite Constellations

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Topics

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- NGO Constellation Parameters
- Elevation Angle Determination
- PDF Determination
- Future Plans
- Conclusion

Motivation

- Interest in industry to apply propagation models developed for Geostationary Earth Orbit (**GEO**) satellites to Non-Geostatioanry Orbit (**NGO**) satellites
- Most models have elevation angle as one of the input parameters

Motivation

- With NGO constellations, the elevation angles are time-variable
- To make a weighted attenuation model, a set of PDFs of elevation angle for the constellation is needed
- Joint statistics are needed to determine diversity improvement

NGO Constellation Parameters

- To determine the NGO elevation angle PDFs, we need
  - satellite orbital elements
  - minimum elevation angle allowed in constellation operational plan
  - constellation configuration

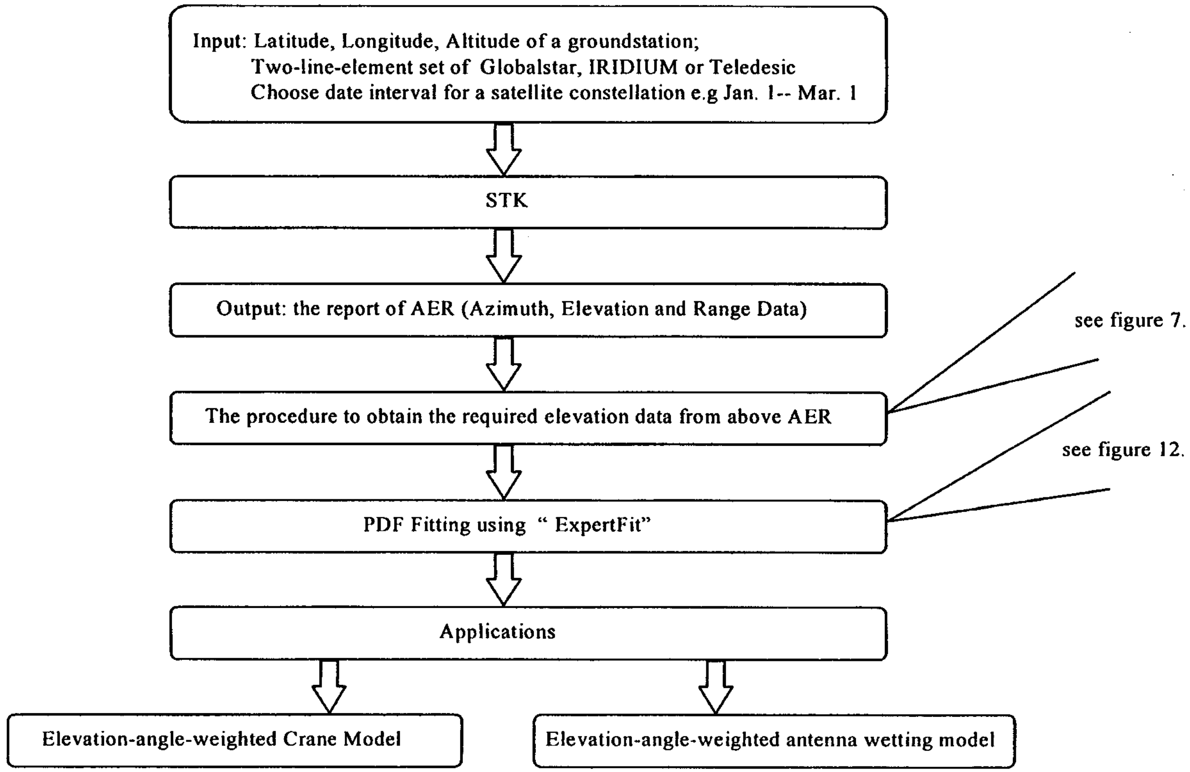
NGO Constellation Parameters

	Globalstar	Iridium	Teledesic
Orbit class	LEO	LEO	LEO
Altitude (km)	1410	780	695-705
Number of satellites	48 active 8 in-orbit spares	66 active 6 in-orbit spares	288
Number of planes	8	6	21
Inclination (°)	52	86.4	98.16
Period (minutes)	114	100.1	98.8
Satellite visibility time (minutes)	16.4	11.1	3.5
Minimum mobile terminal elevation angle (°)	10	8.2	40
Minimum earth station elevation angle (°)	10	--	40
Number of earth stations	100 –210	15 - 20 planned; 11 constructed	--
Coverage	within ±70°	global	nearly global (2° hole at each pole)

Elevation Angle Determination

- Use Satellite Tool Kit to simulate satellite constellation
- Use ground stations placed every 10° to gather elevation angle statistics
- Over one month of simulated time to ensure full coverage

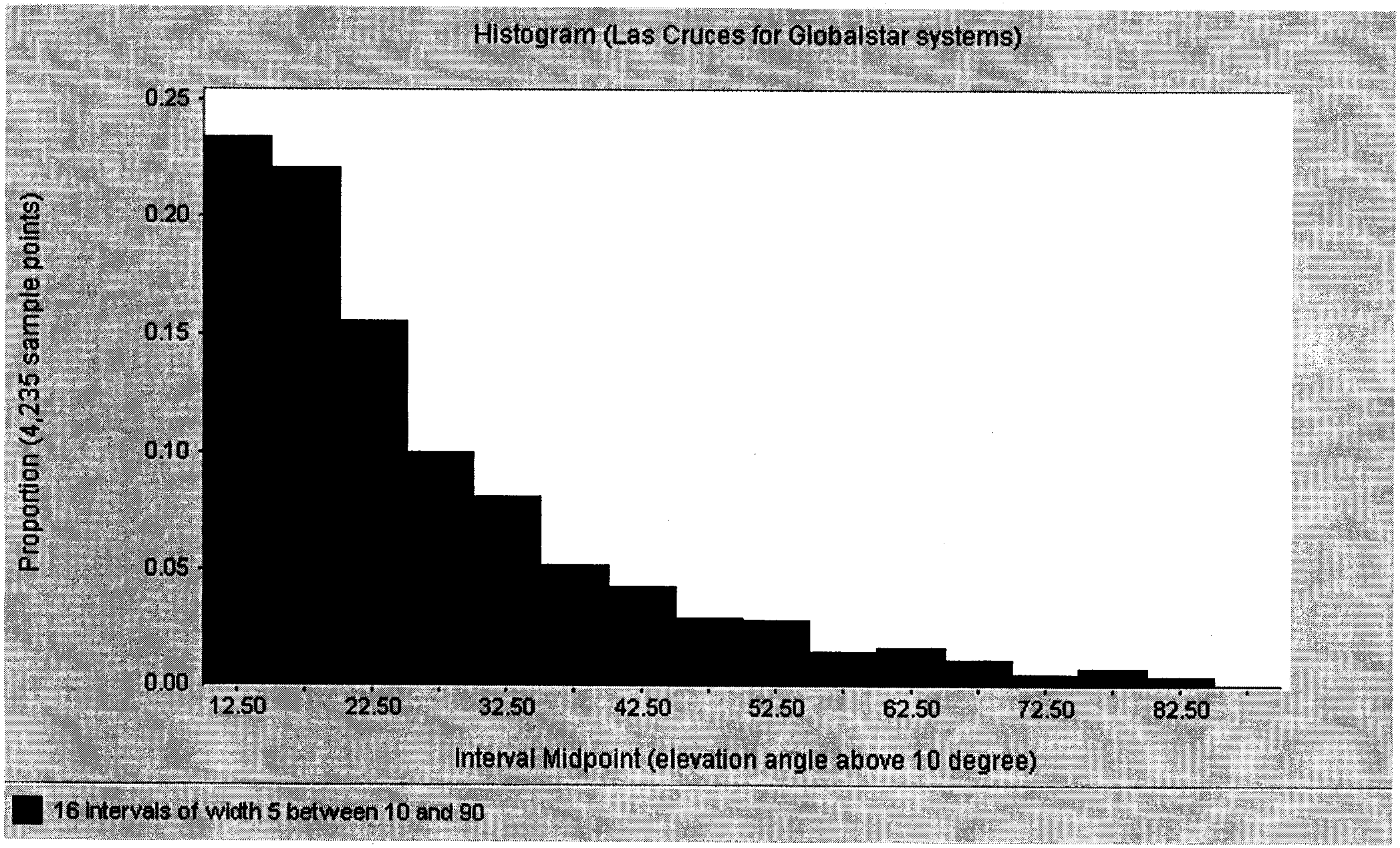
PDF Determination



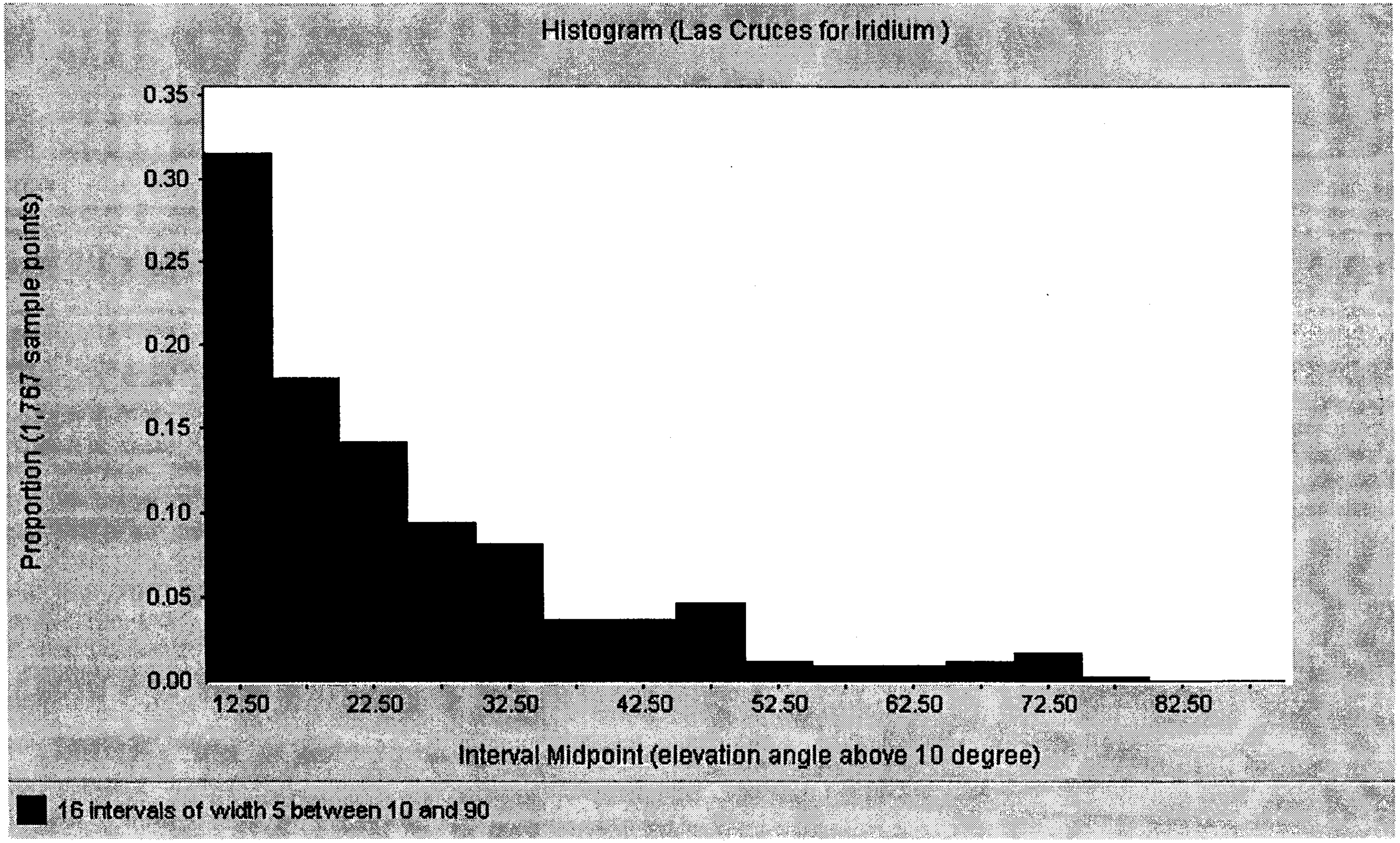
PDF Determination

- Once the elevation data is obtained, use Expert Fit to determine the best statistical description for a PDF
- Expert Fit allows the user to choose from many candidate density functions and ranks them based on confidence of the fit

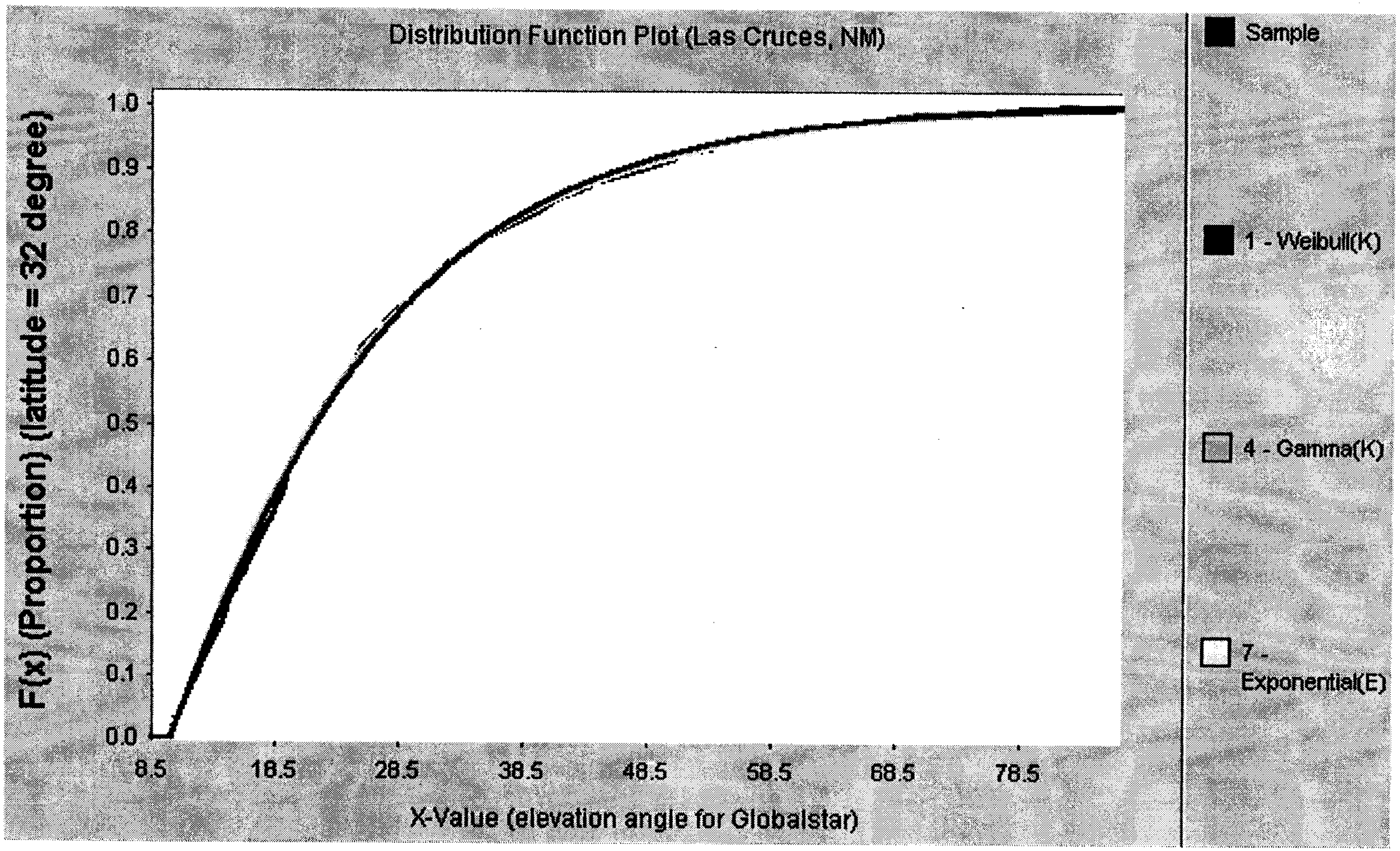
PDF Determination



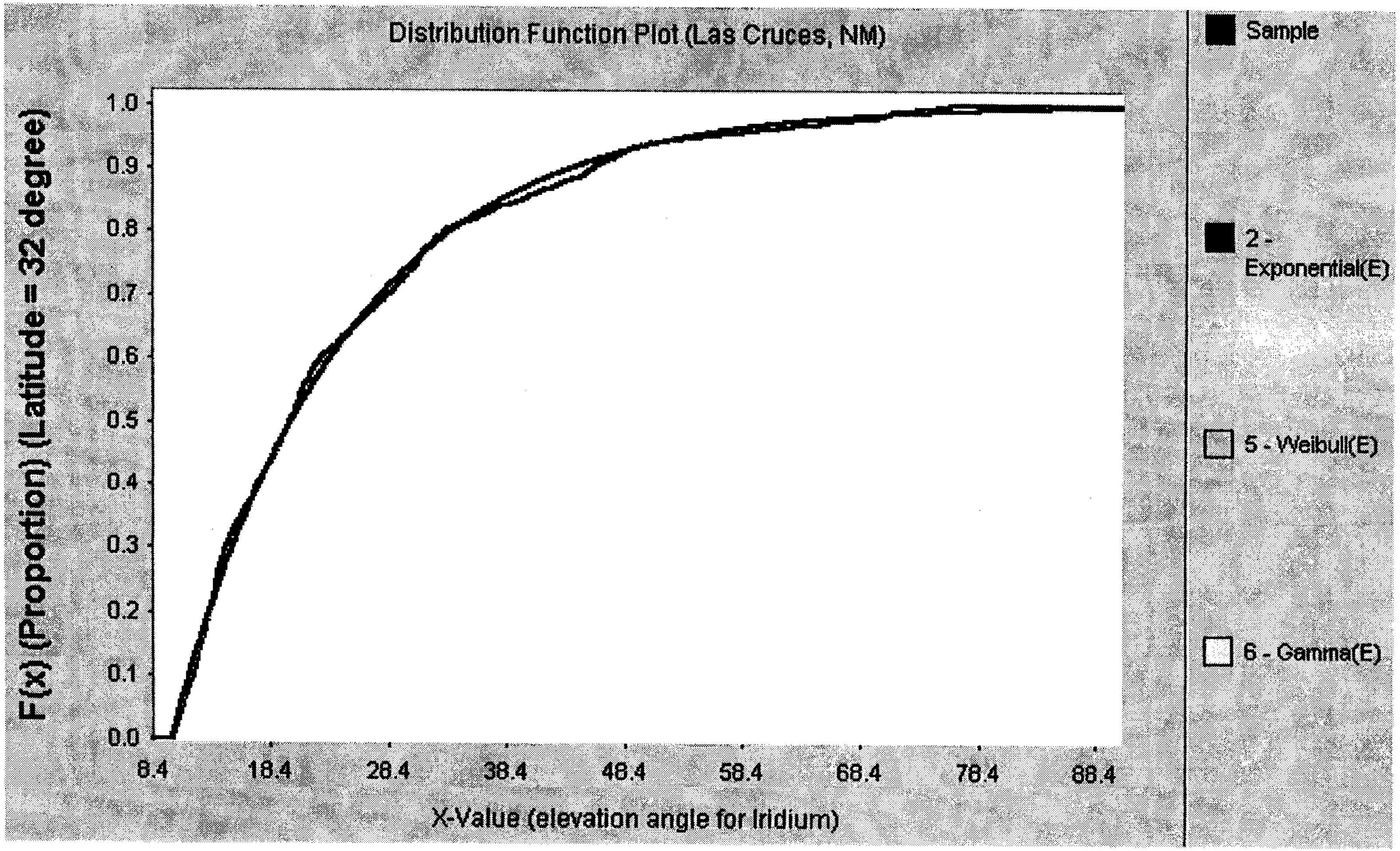
PDF Determination



PDF Determination



PDF Determination



PDF Determination

- Problem Areas
  - Not every latitude has the same PDF for a given constellation
  - Some latitudes cannot be fit at a 99% or 95% confidence level with any density function

PDF Determination

	Ele.θ ≥ 10°	Exponential				Weibull				Gamma			
Lat.	points	RS	AE	DFDP	pama β	RS	AE	DFDP	pama β	RS	AE	DFDP	pama β
32°	1767	91.7	∨	∠	14.76	91.7	×	∠	14.81 α=1.007	85.3	×	∠	14.52 α=1.016
0°	1499	92.9	∨	∨	14.65	87.5	∨	∨	14.69 α=1.007	83.9	∨	∨	14.43 α=1.015
10°	1518	88.6	∨	∨	14.67	88.6	∨	∨	14.72 α=1.009	81.8	∨	∨	14.41 α=1.017
20°	1595	84.2	∨	∠	14.75	97.3	∨	∠	14.73 α=0.998	92.1	∨	∠	14.78 α=0.998
30°	1753	91.7	∨	∨	14.81	87.5	∨	∨	14.86 α=1.009	84.7	∨	∨	14.56 α=1.017
40°	1978	91.1	∨	∠	14.69	87.5	∨	∠	14.71 α=1.003	84.7	∨	∠	14.57 α=1.008
50°	2374	92.1	∨	∠	14.60	86.8	∨	∠	14.66 α=1.010	84.2	∨	∠	14.26 α=1.024
60°	3171	84.2	∨	∠	14.33	97.4	∨	∠	14.29 α=0.993	92.1	∨	∠	14.46 α=0.992
70°	4216	76.4	×	×	13.16	93.1	×	×	13.07 α=0.983	84.7	×	×	13.18 α=0.994
80°	6018	75.0	×	×	17.31	95.8	×	×	18.02 α=1.120	93.1	×	×	14.85 α=1.116
90°													

RS: Relative Score in Relative Evaluation of candidate Models %

AE: Absolute evaluation: ∨ => recommed being cautious using this model

× => do not recommed using this model

DFDP: Distribution Function Differences Plot: ∨ => inside blue dashed rectangle

× => cross blue dashed rectangle

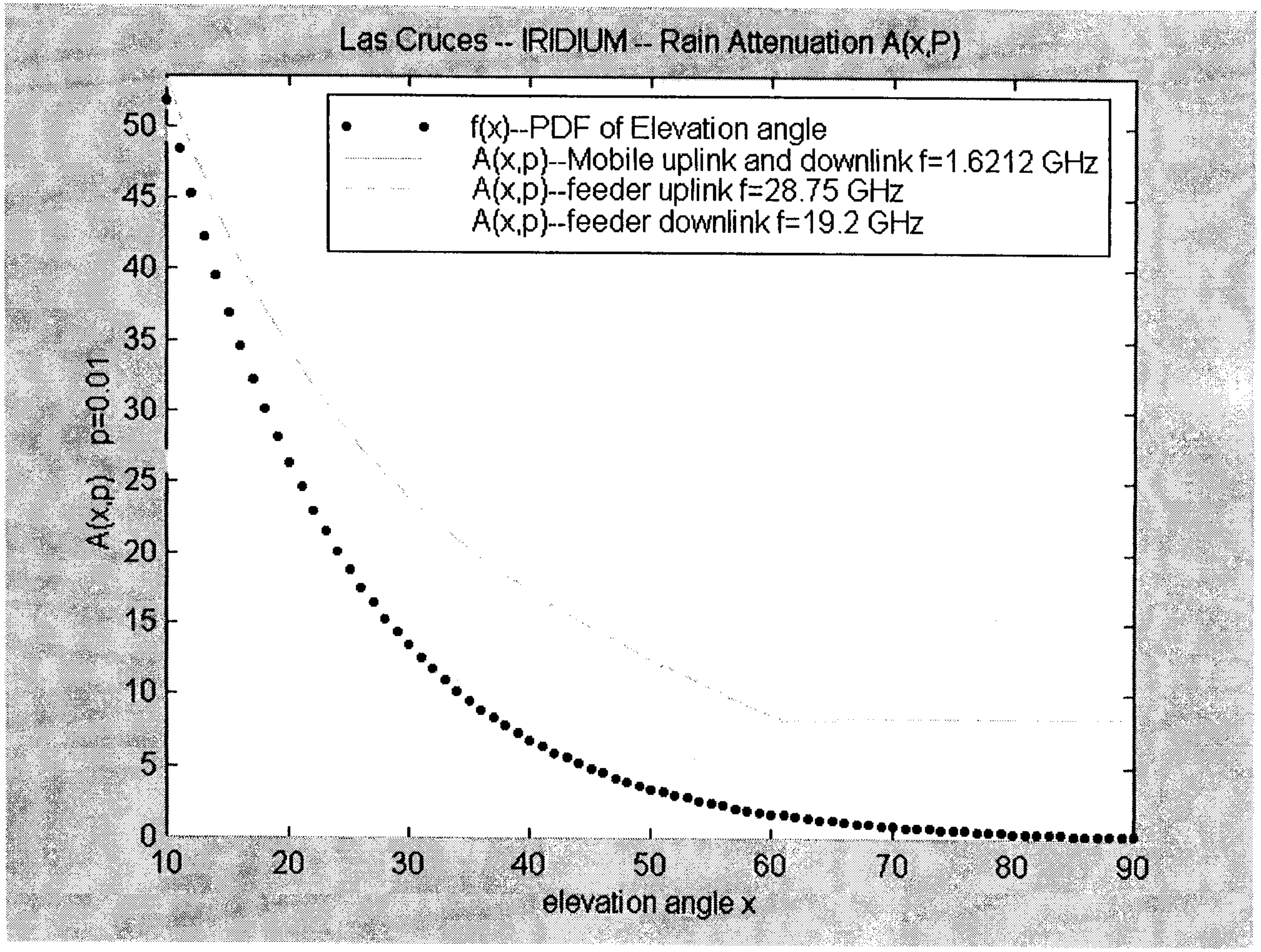
∠=> cross a little

Ele.θ≥ 10° : the elevation angle of sample points is greater than or equal to 10°.

Future Plans

- Use the PDF to estimate elevation-weighted rain attenuation on various links
  - for each satellite system, will need to consider several links depending upon data traffic type and direction
  - will need involve joint statistics for estimating system degradation and diversity

Future Plans



Future Plans

A(p) in dB p = 0.01	Globalstar					Iridium				Teledesic		
Frequency GHz	β	MU 1.618	MD 2.490	FU 5.170	FD 6.965	β	MU &MD 1.6212	FU 28.75	FD 19.2	β	Uplink 28.85	Downlink 19.05
Las Cruces, NM	16.12	.0151	0.0474	0.4302	1.4002	14.77	0.0161	33.916	17.466	12.99	35.511	17.920
Fairbanks, AK	14.74	.0072	0.0205	0.1974	0.6333	14.33	0.0073	15.687	7.9988	12.81	16.372	8.1821
Vancouver, BC	21.73	.0149	0.0434	0.4592	1.5350	14.61	0.0171	38.106	19.999	12.76	39.974	20.570
Greeley, CO	19.54	.0129	0.0373	0.3871	1.2829	14.69	0.0141	31.095	16.232	12.55	32.907	16.842
Tampa, FL	15.60	.0470	0.1397	1.7894	6.4696	14.81	0.0469	113.34	63.036	13.41	114.16	63.652
Norman, OK	15.54	.0272	0.0805	0.9024	3.0099	14.69	0.0278	63.287	33.910	12.55	66.421	34.902
Reston, VA	15.54	.0276	0.0809	0.9136	3.1398	14.69	0.0280	64.020	34.312	12.55	66.800	35.308

β: scale parameter of Exponential PDF of elevaltion angle in equation (1) and (2)

MU: Mobile Uplink MD: mobile Downlink FU: Feeder Uplink FD: Feeder Downlink

Future Plans

- We would also like to weight the results with the customer population density to obtain an estimate for what the most critical link attenuation values will be

Conclusion

- Determination of the PDF for the elevation angles can be done using current simulation (STK) and analysis (Expert Fit) tools
- Results are dependent upon the details of the constellation and the ground network

Conclusion

- Not all locations can always be fit with high confidence
  - we will need to develop ways to estimate "good enough"