Wagging the Tail & Flying with LORAN-C Data Communications

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Background

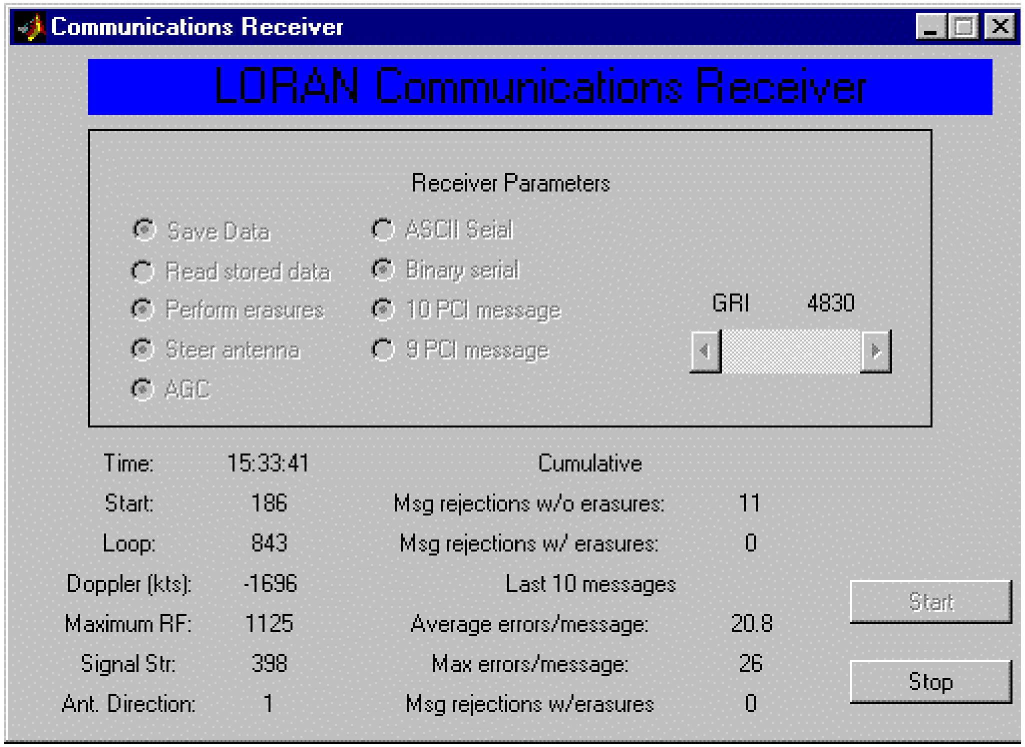
- Full WAAS capability, 250 bit msg every second
  - 16-ary Intrapulse Frequency Modulation (IFM)
  - 60 byte message, 32 bytes for WAAS msg including 24 bits of CRC, 28 bytes for Reed Solomon Forward Error Correction
- Previous papers at Bonn 3/00 & 2/01, ILA 11/00, US ION 6/01 outlined issues, alternatives & architectures of transmitter & receiver.
- Results of May & June 2001 flight tests using LSU transmitter presented @ June US ION
- This presentation is mainly focused on August flight trials in Alaska & is much the same as ION-GPS 9/01

Outline

- Receiver features
- Projected/necessary coverage of Tok transmitter
- Flight test results
  - FAA-TC Convair 580 flight to Prudoe Bay
  - Convair 580 flight to Juneau
  - Ohio U. King Air C-90SE flight to SW Alaska (E field)
- Anecdotal results on loss of GEO signal in turns
- Conclusions & future efforts

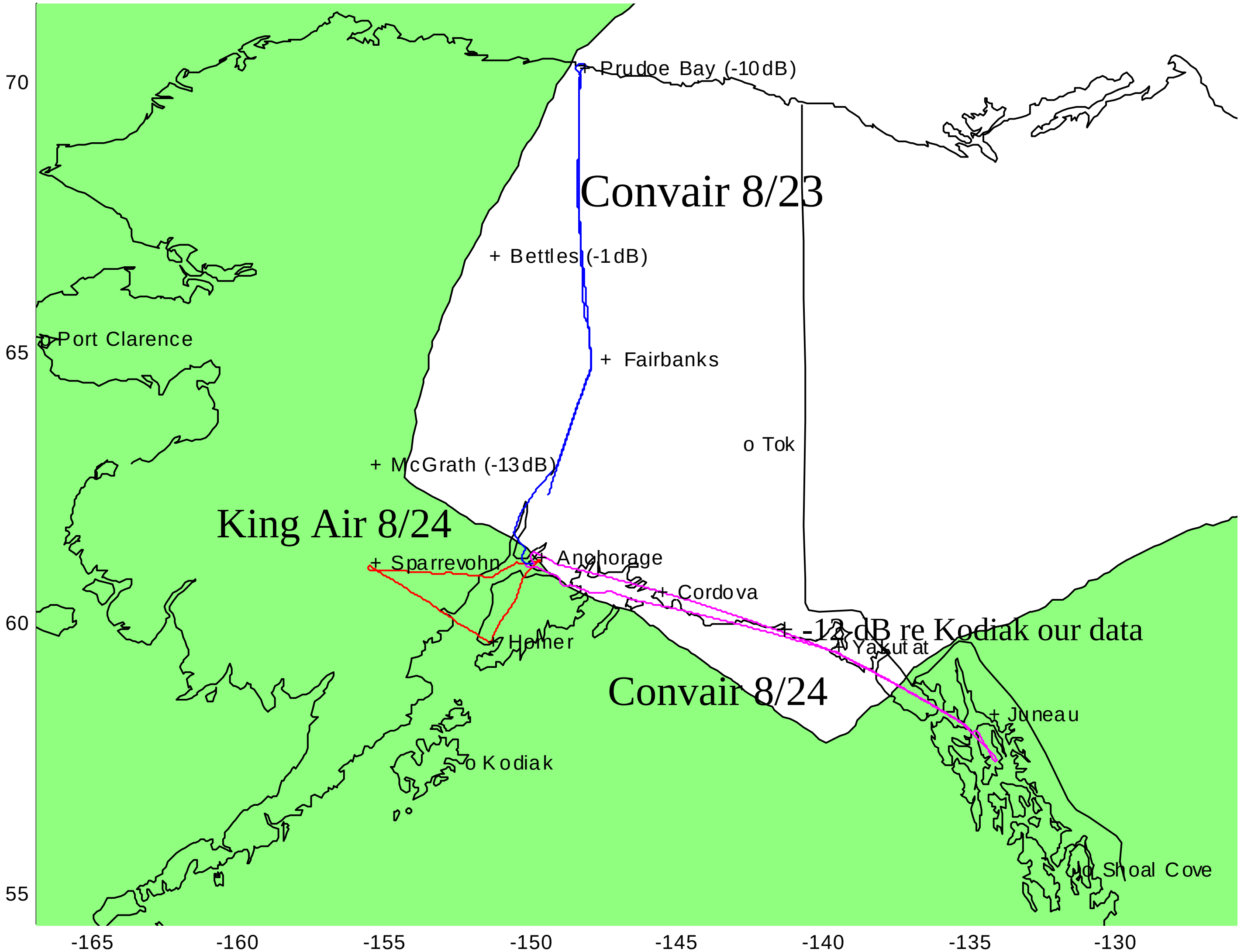
Receiver features

- Dual magnetic loop antenna steered in software to maximize signal/(noise + interference)
- Acquires & tracks in transport aircraft dynamics
- 1e-7 HMI integrity from 24 bit CRC in WAAS msg.
- Except for acquisition phase, receiver pulse templates based on received RF
  - Skywaves are signal, not interference
- If errors only decoding fails, bytes are erased in order of worst fit to templates
- Serial output is identical to Novatel OEM-4 WAAS msg.

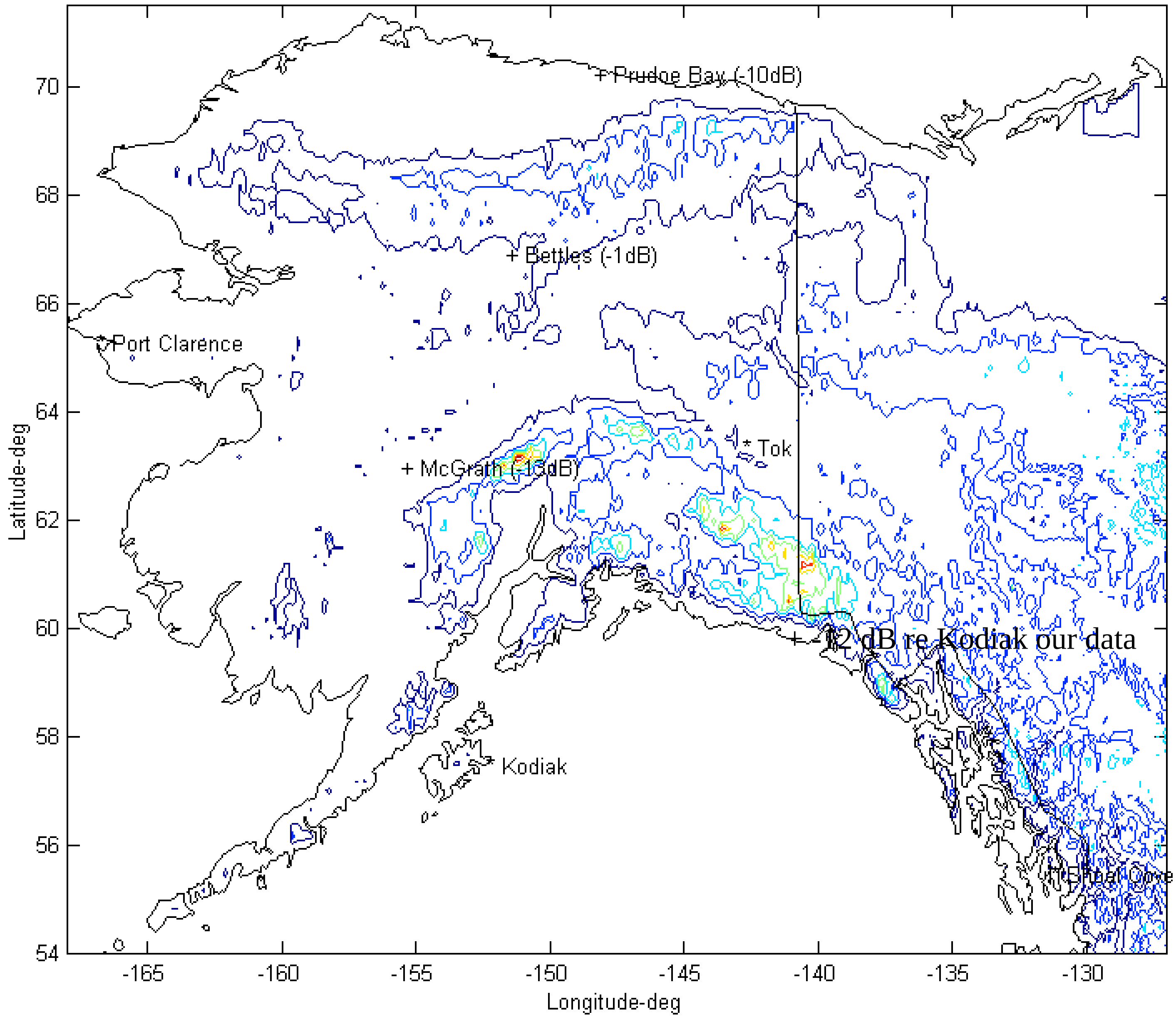


Flight paths and area where Tok would be strongest LORAN signal based on smooth earth (Millington's method) model.

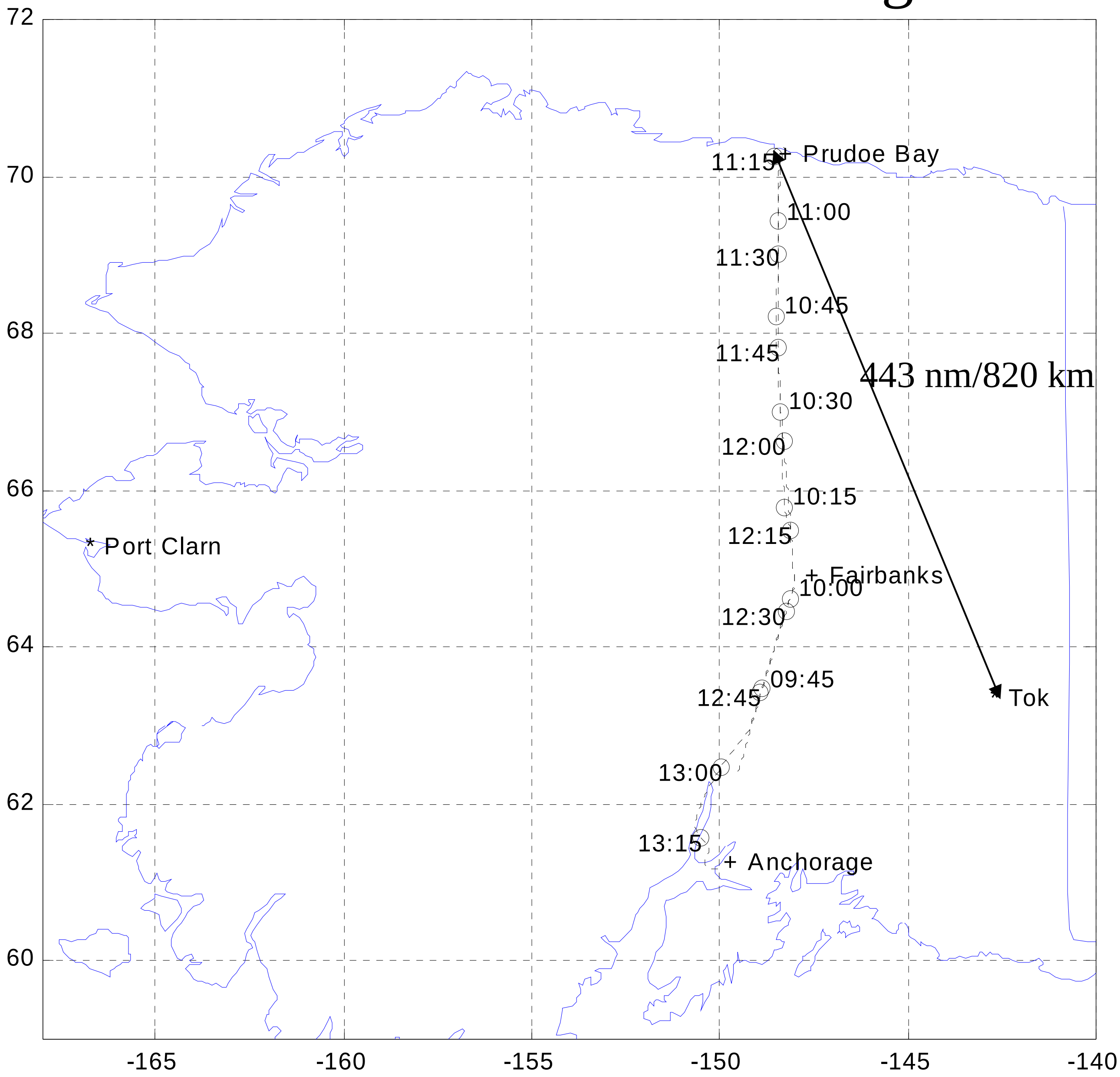
Data in ( ) from is Tok SS re Port Clarence from 1988 FAA survey.



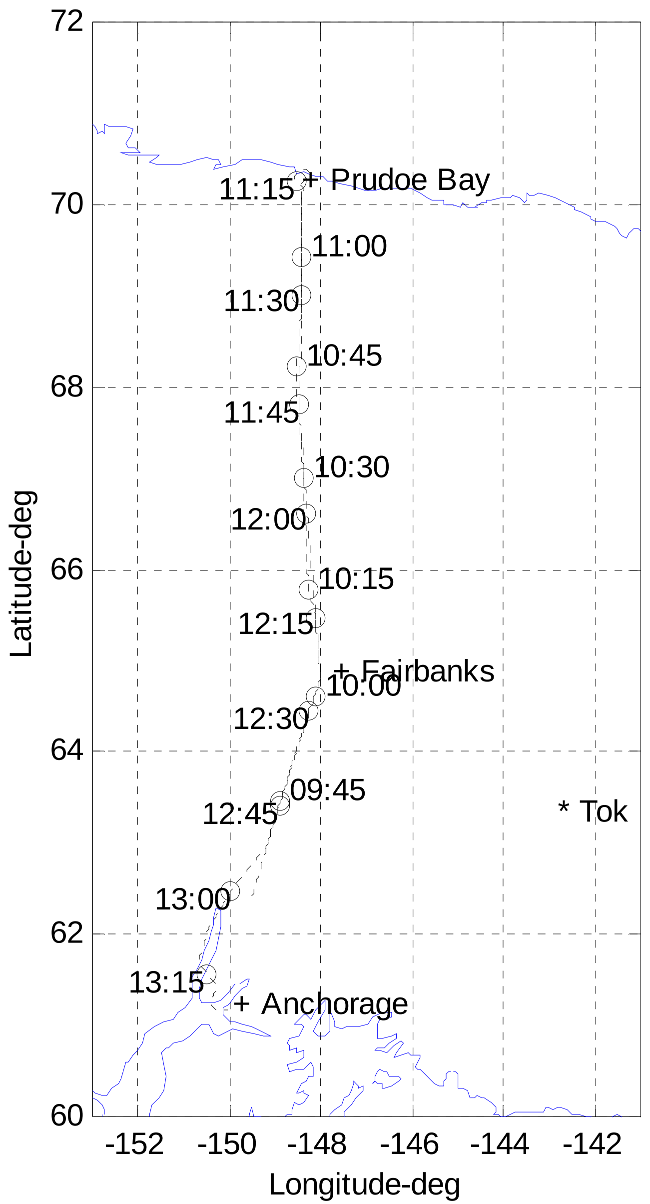
Elevation contours in increments of 2000 ft

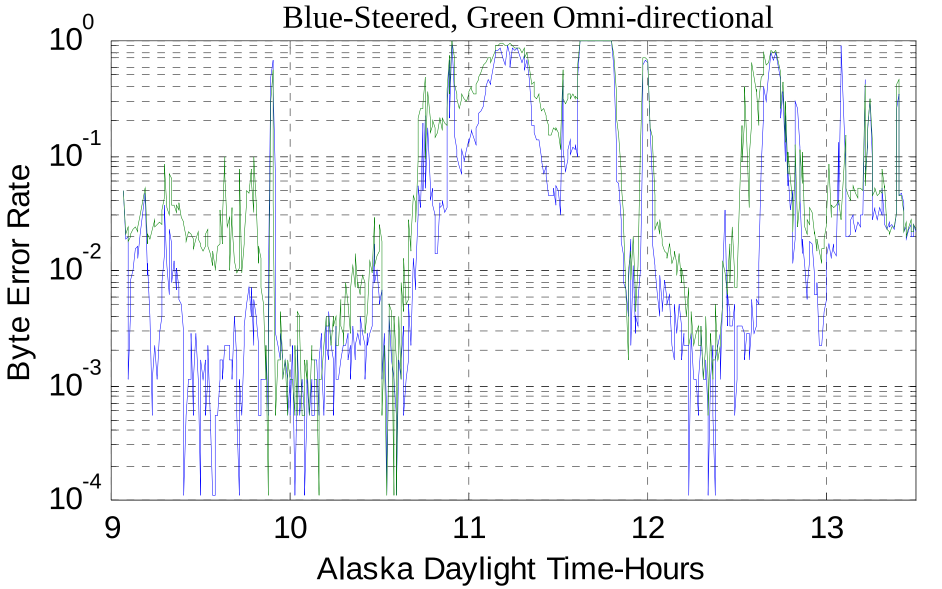


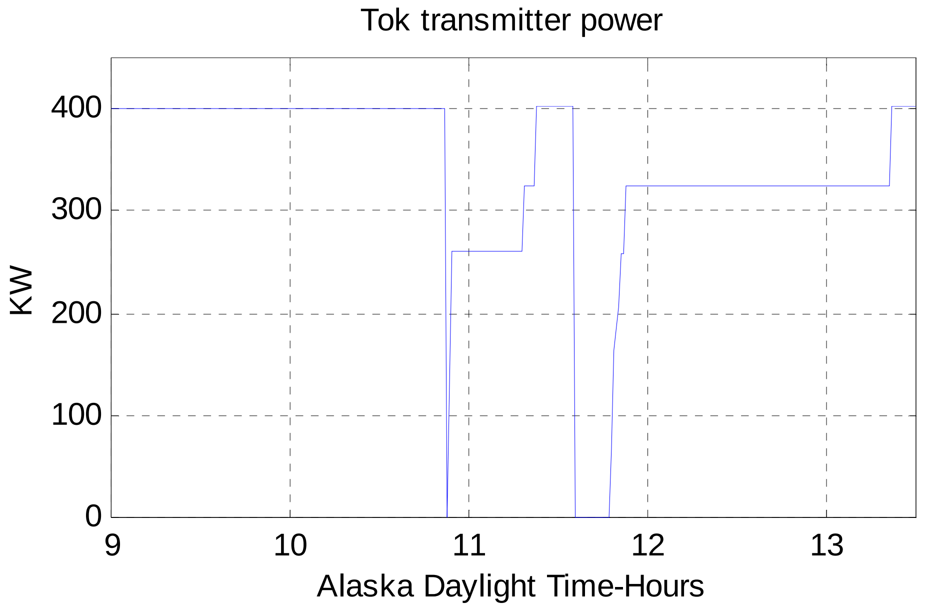
Path of 23 AUG Convair flight



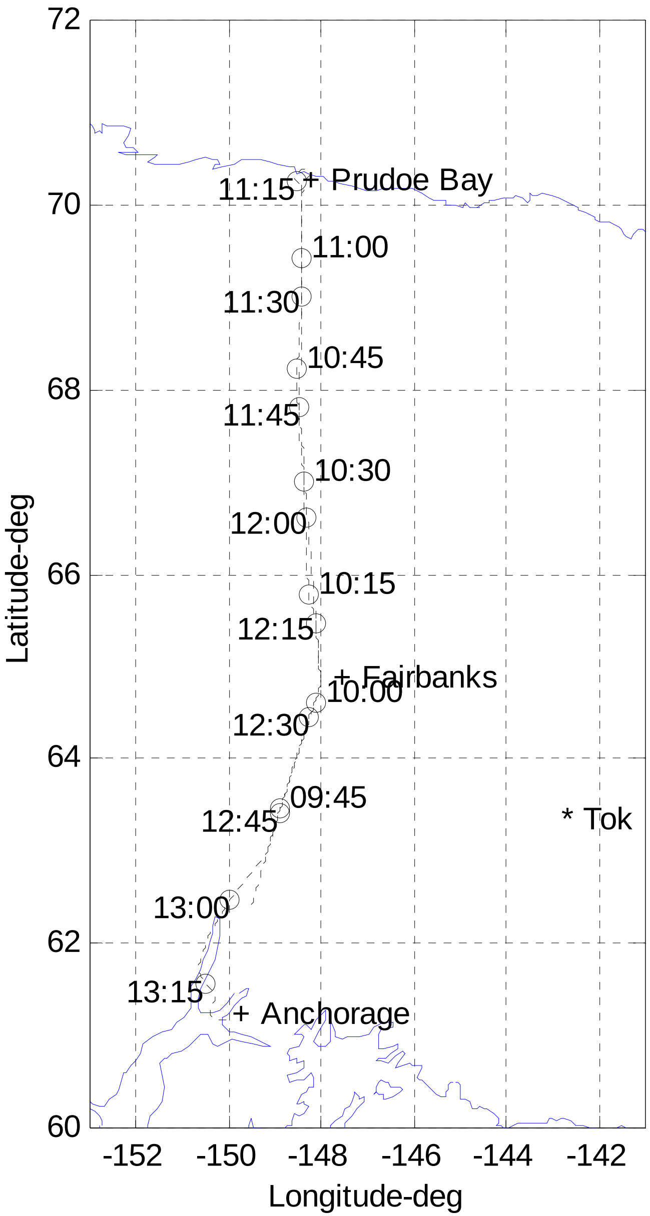
Byte error rates for Convair 23 AUG flight

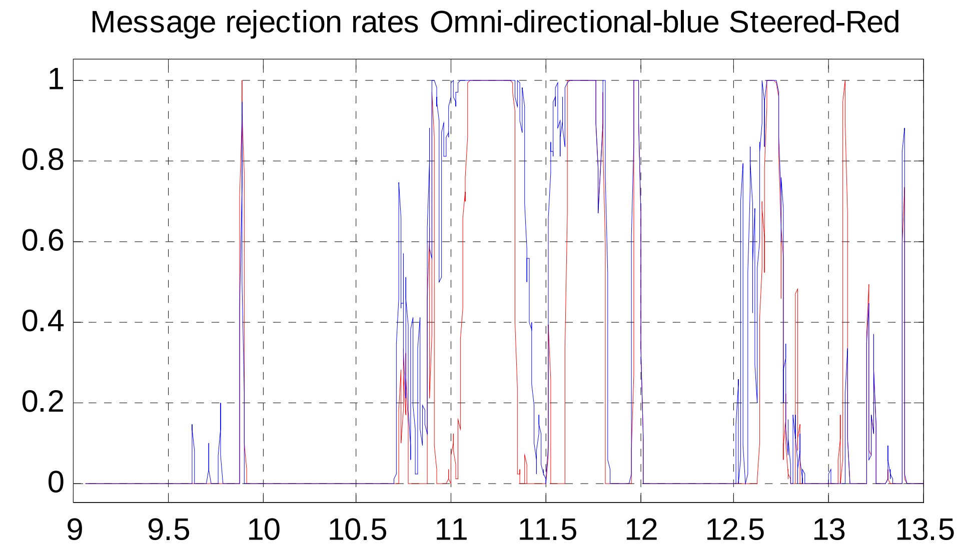


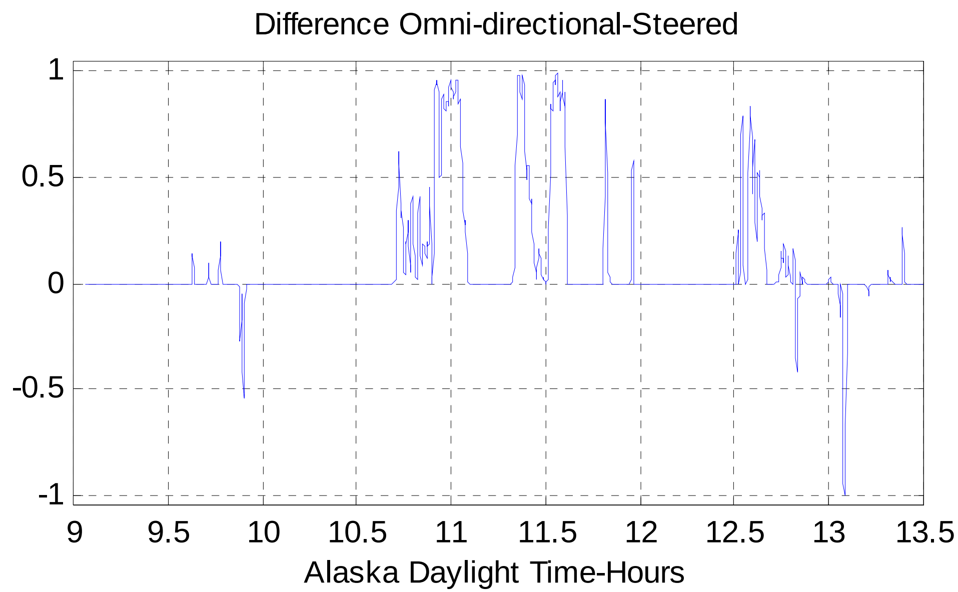




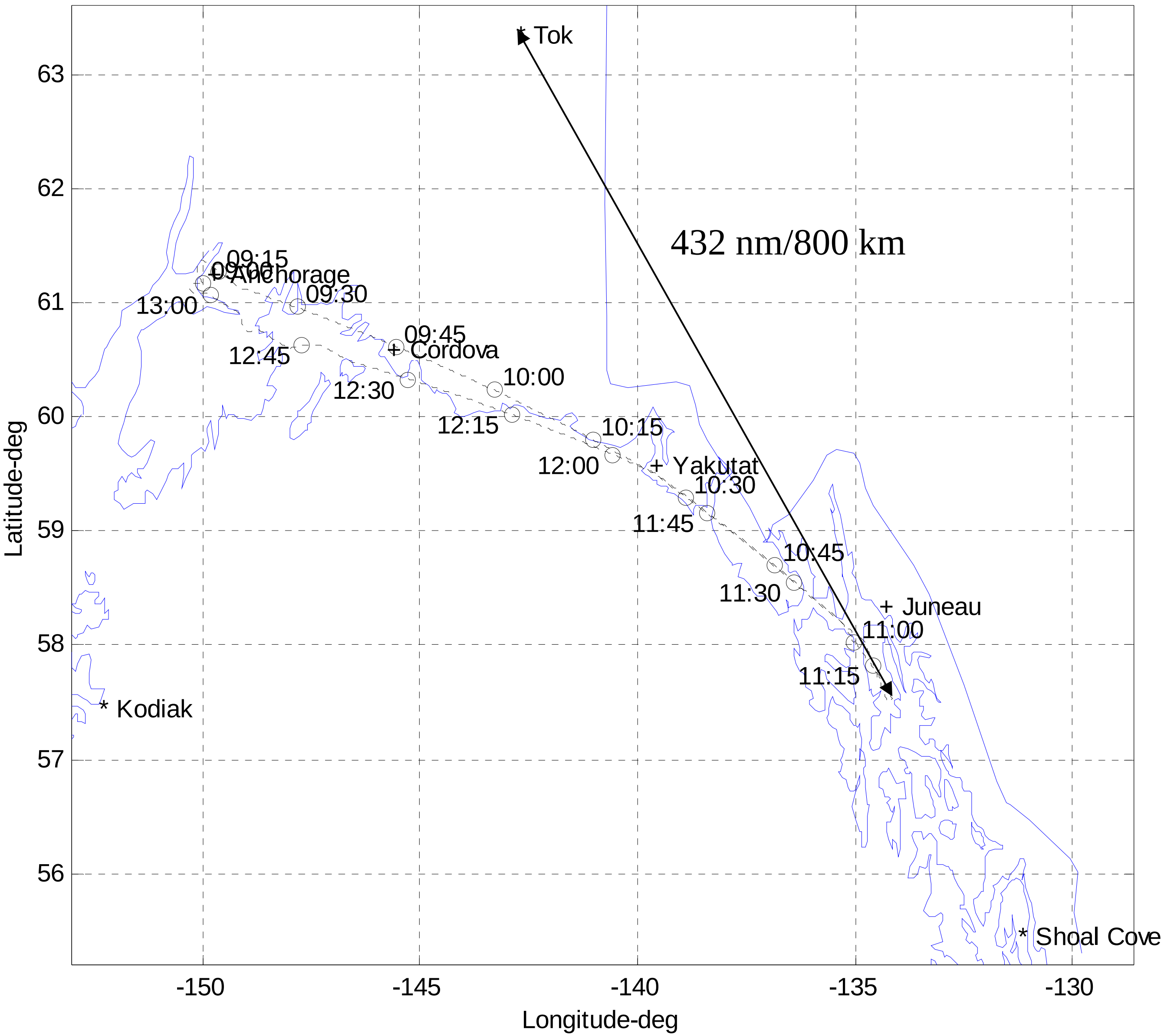
Message Rejections for Convair 580 on August 23rd.



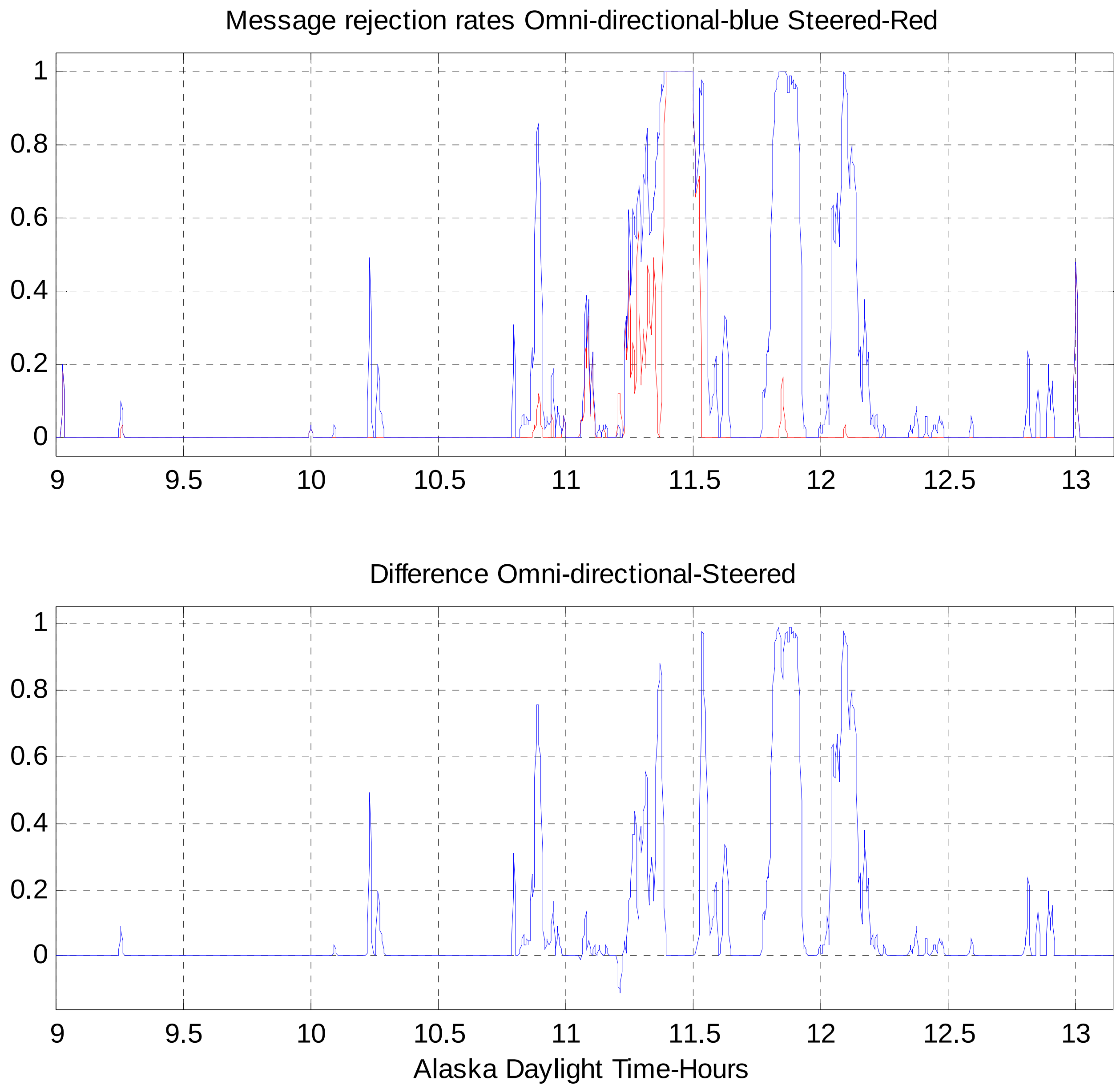




Path of 24 AUG Convair flight

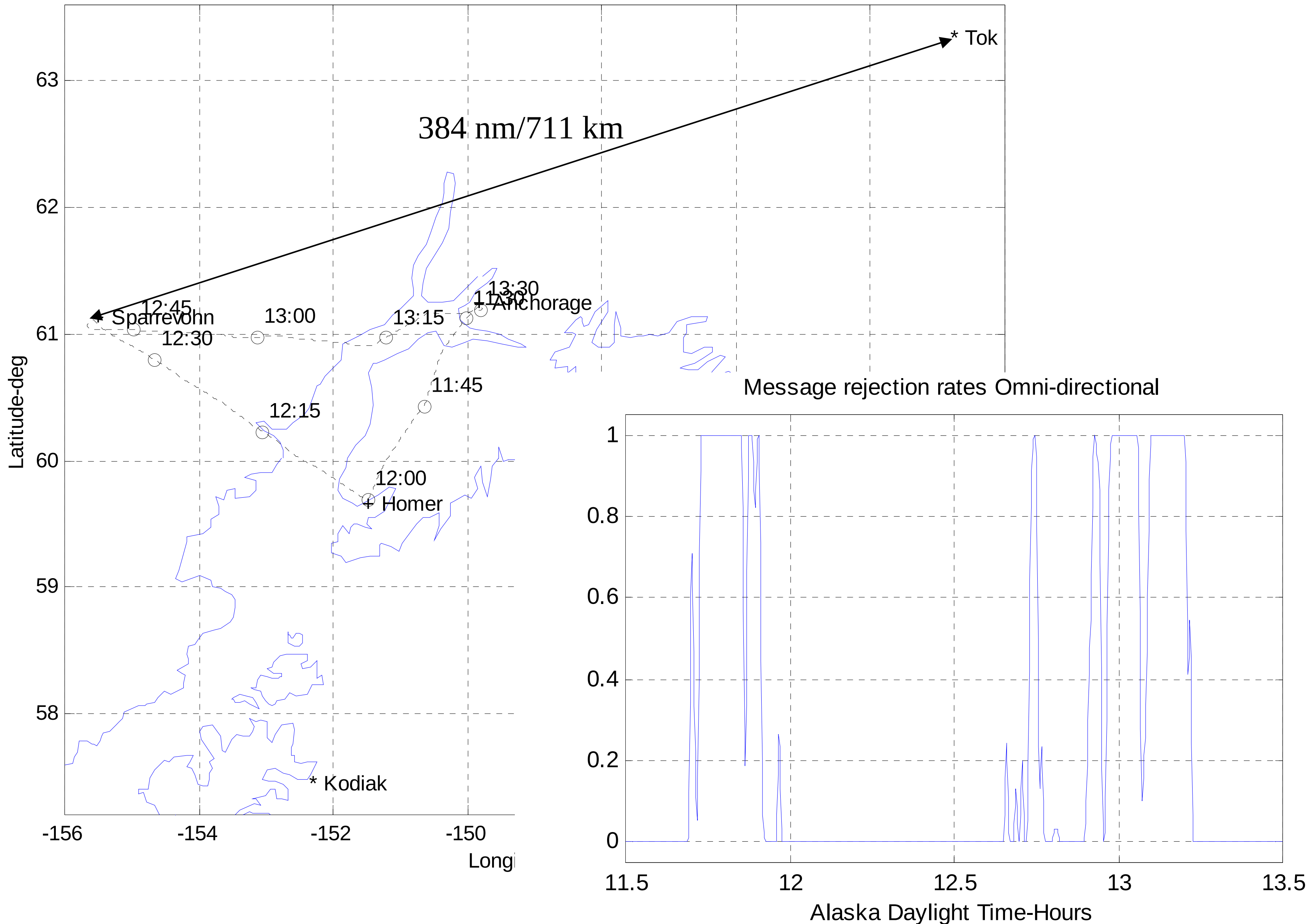


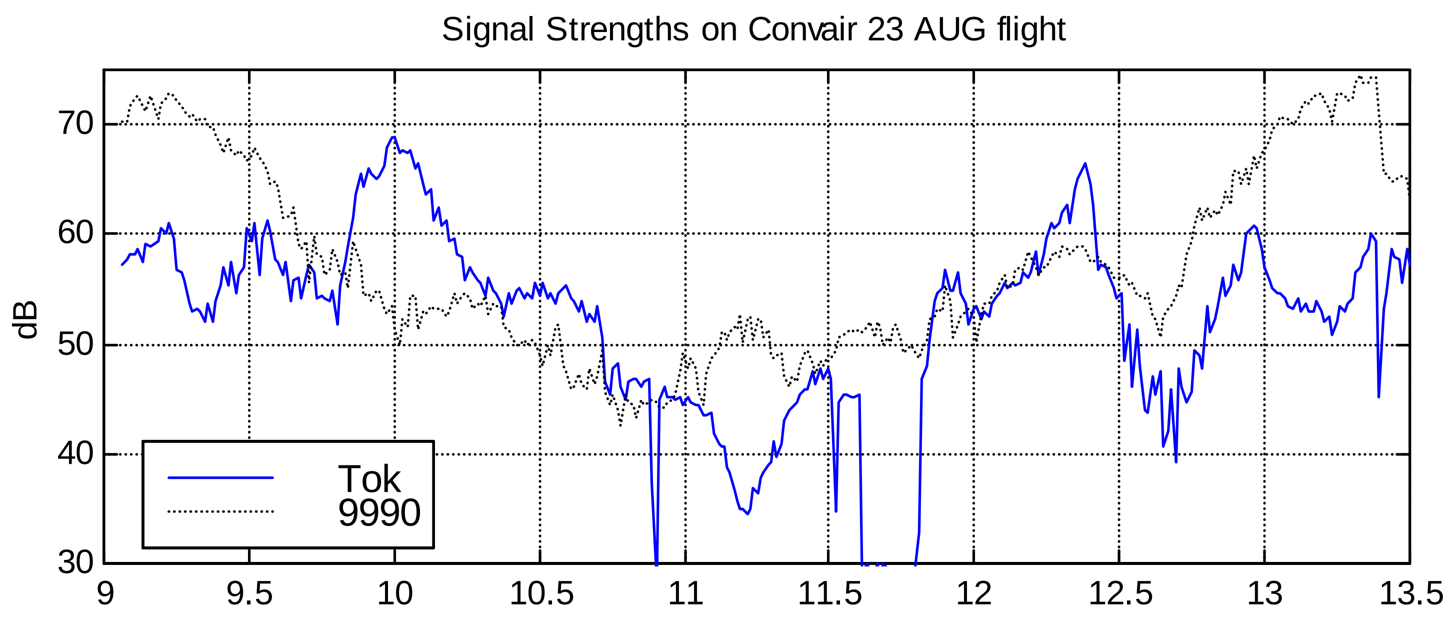
Message rejection rates for Convair – 24 August



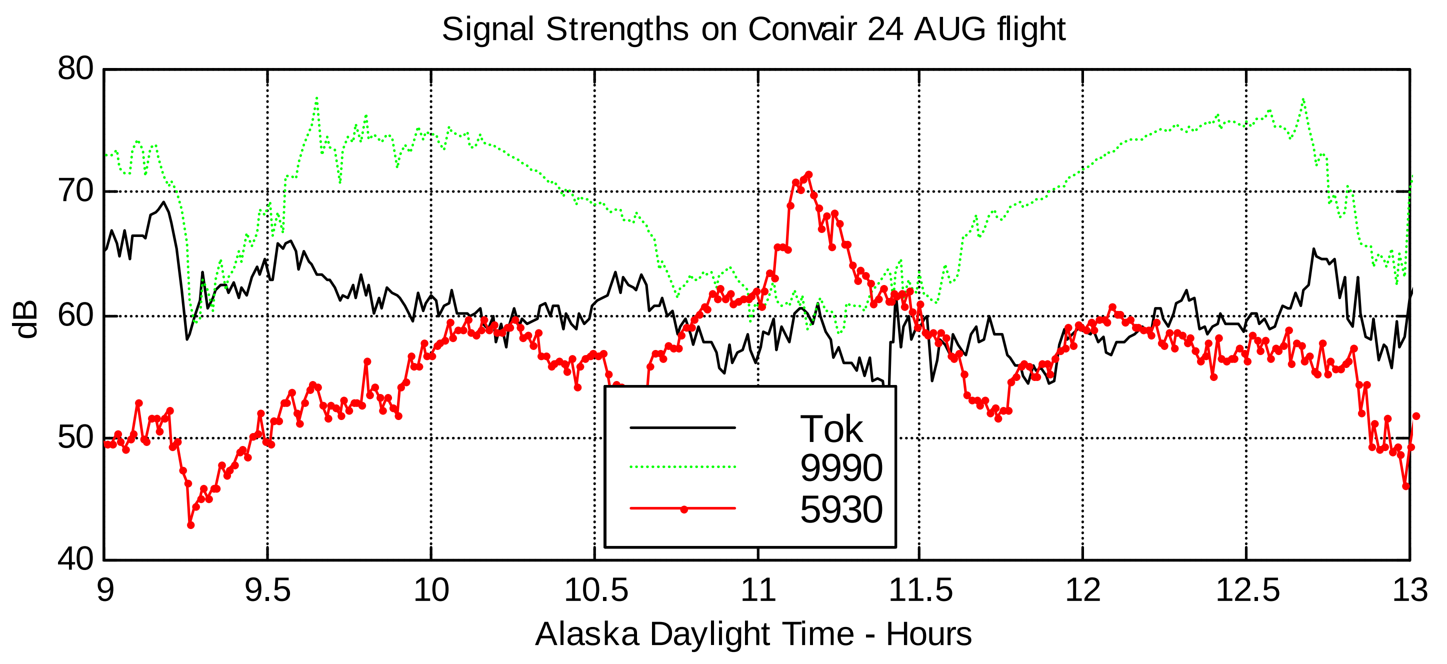
Path of 24 AUG Ohio U. King Air flight

E field whip antenna



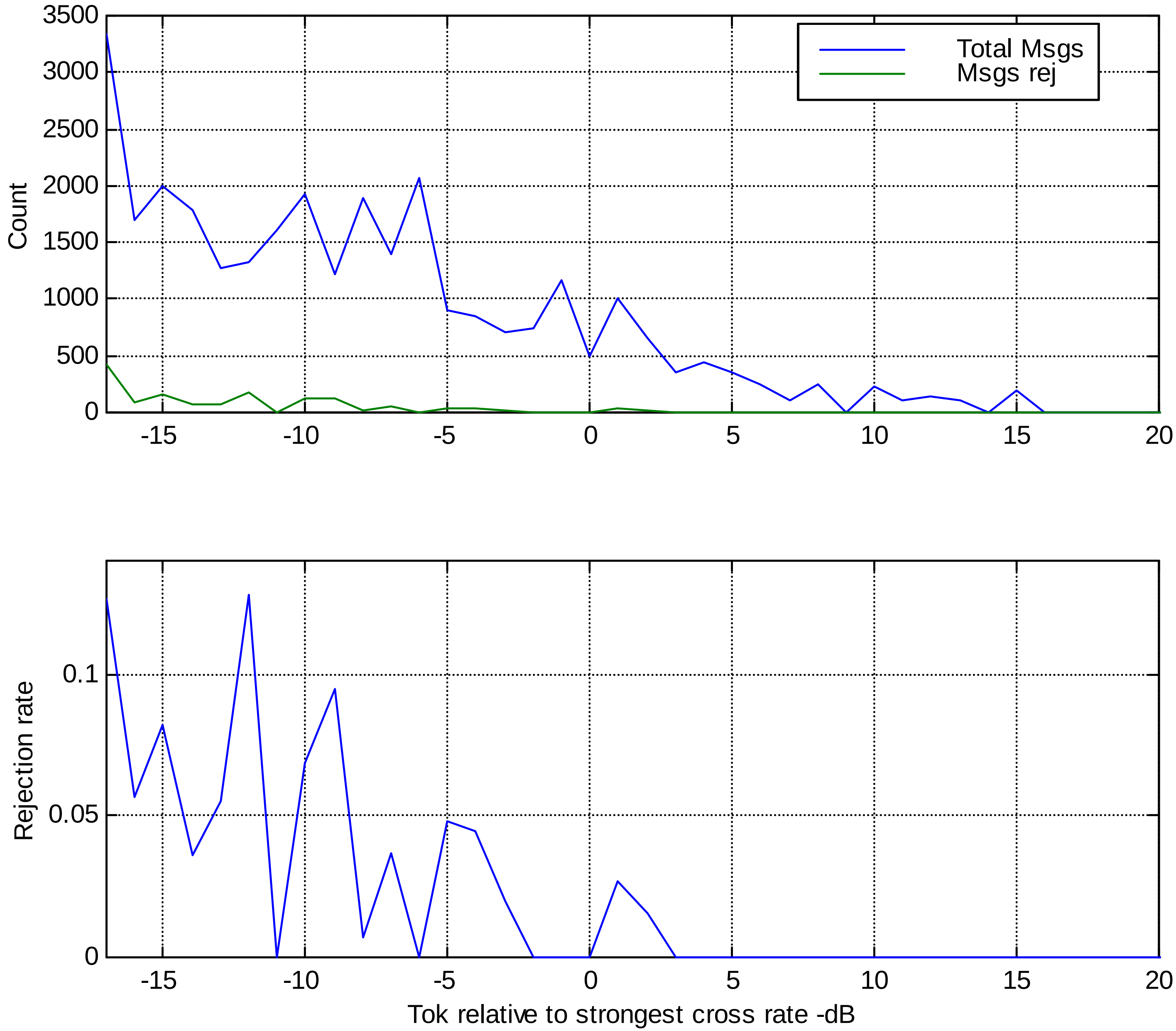


Signal Strengths on Convair 23 AUG flight
dB
70
60
50
40
30
9
9.5
10
10.5
11
11.5
12
12.5
13
13.5
Tok
9990

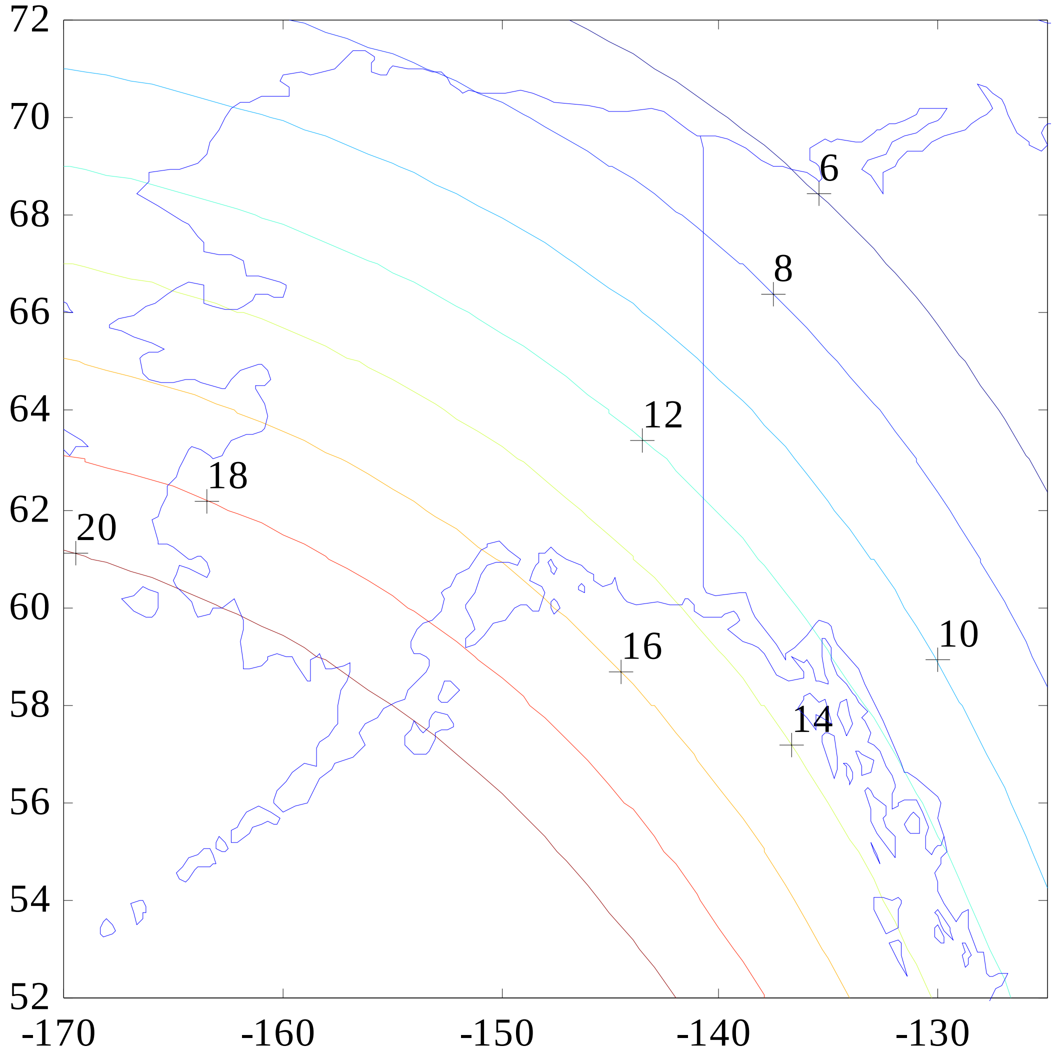


Signal Strengths on Convair 24 AUG flight
dB
80
70
60
50
40
9
9.5
10
10.5
11
11.5
12
12.5
13
Alaska Daylight Time - Hours
Tok
9990
5930

Convair 8/23 & 24, messages lost vs Tok re other LORAN



Elevation of POR in Alaska



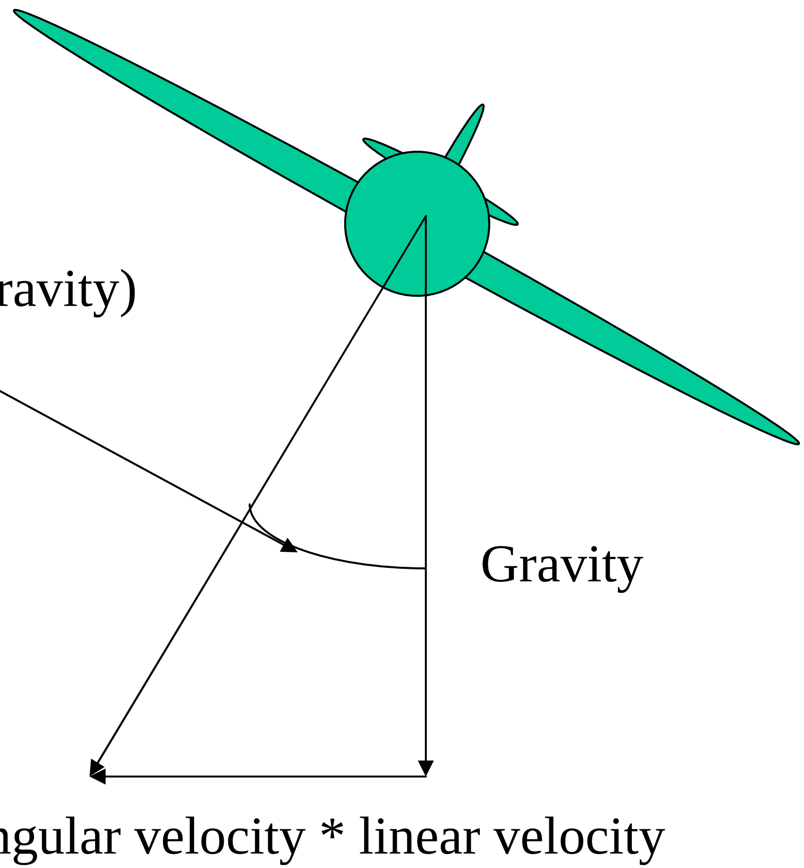
Two mechanisms for loss of geo signal at high latitude

1. Terrain in the propagation path (to be studied by UAA).

2. Aircraft rolls in a turn & geo signal drops below the response of the antenna.

Estimation of roll angle from lat/lon data

atan(Angular velocity * linear velocity/Gravity)



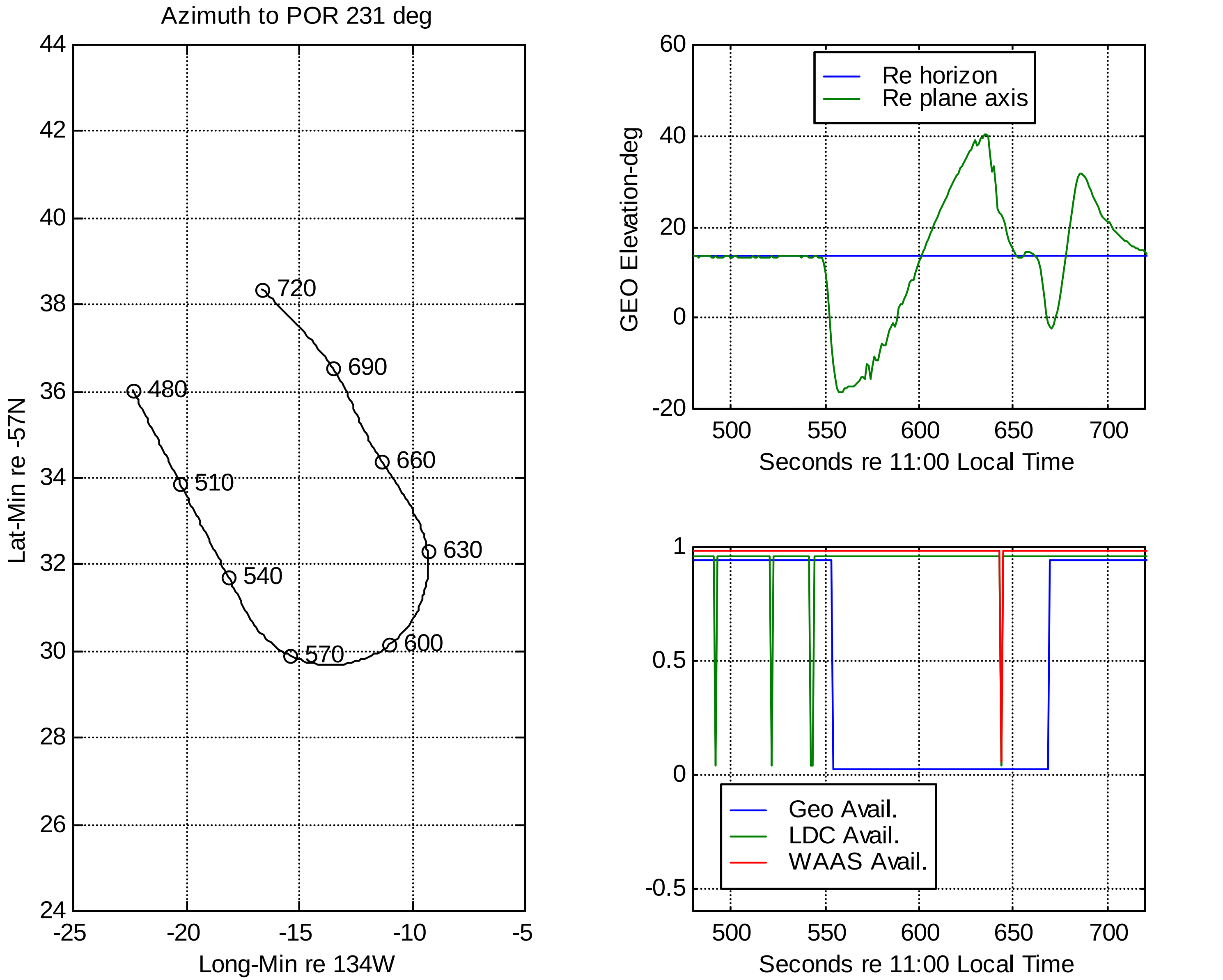
Example: 2 min. turn at 250 knots

Roll angle = atan{(2π/120) * 129/9.8}

= 34.6 degrees

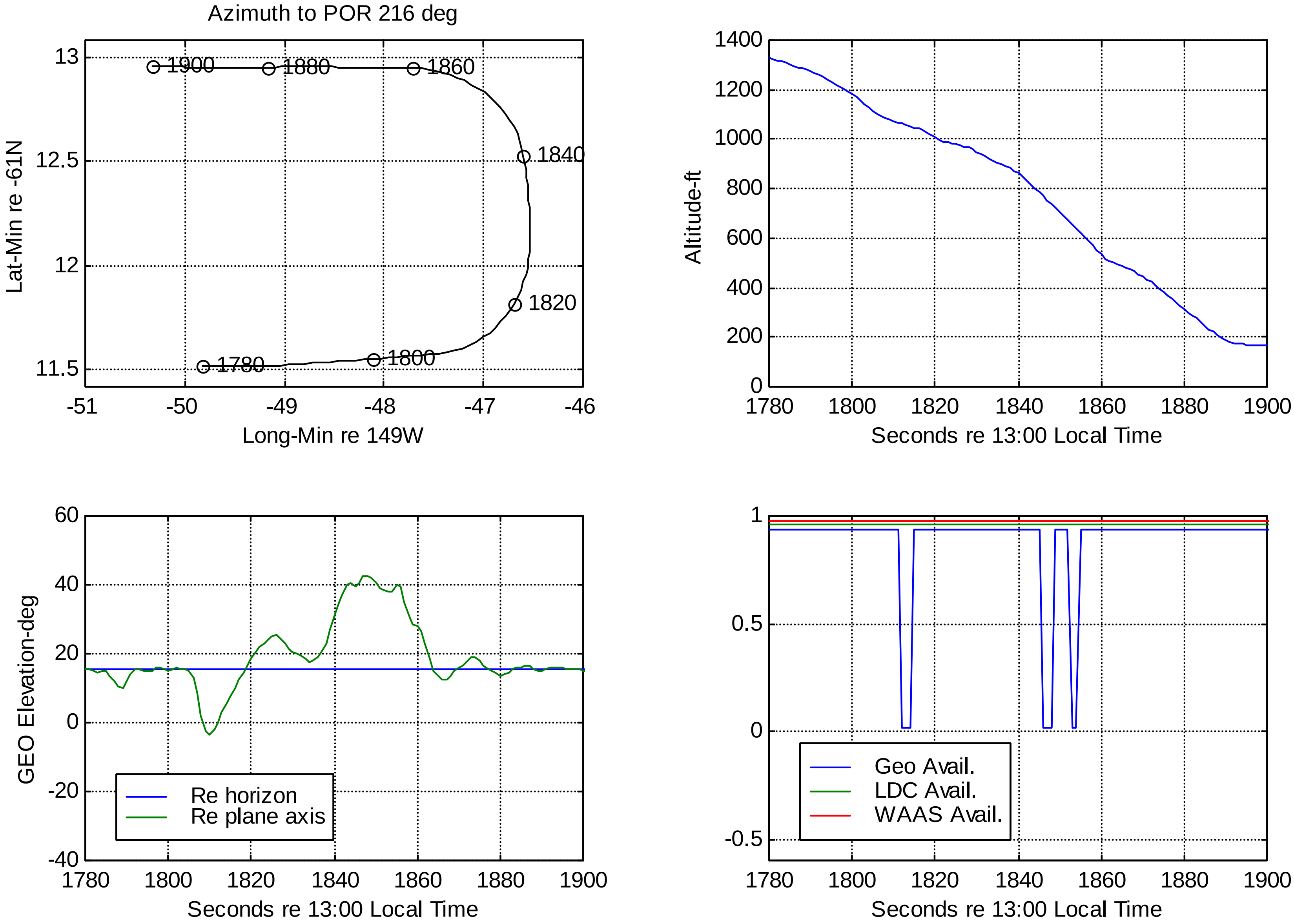
WAAS Availability during turn south of Juneau

Convair 580 on August 23rd SOG 300kts, Tok 423 nm



WAAS Availability during landing at Merrill Field

Ohio U. King Air on Aug.24th.



LOCUS Monitor Data during Tok Tests

	Dist	Sig Str	SNR
	NM	dB 1uv/m	dB
Cold Bay	776	44	-5
Fairbanks	160	83	33
Galena	380	62	18
Juneau	388	53	10
Spruce Cape	433	56	15
St. Paul	888	35	-6
Attu (sky wave)	1494	36	-4

Black: Table 1 from van Willigen, et. al., "Eurofix: Status, Performance and Possible Interoperability with GNSS, WAAS & EGNOS," ION-GPS 2001 Red: Added

	FAA/USCG	Eurofix
Data Rate per station	>250 bps for DualR US stations	>57 bps for NELS stations
Range	Under Investigation	~1000km
Distance between adjacent symbols re ideal LORAN pulse of same amp.	1.02	0.62
Data wipeoff, cross rate canceling, & full pulse tracking, w/o demodulation of weak signals	Yes	No
Loss in Navigation signal power with leading edge pulse tracking	≥ 1.0dB, 0 dB w/ more bw or w/ data wipeoff, 1s msg	0.8dB, 0 dB with data wipeoff, 2-2.7 s msg
Loss in Navigation signal power with full pulse tracking	≥ 6.2dB 0 dB with data wipeoff, 1s msg	0.8dB, 0 dB with data wipeoff, 2-2.7 s msg
Possible range bias	Depending on randomness of data None	None
Multistation reception	?? Yes, but not needed as all stations transmit same data	Yes
Degradation of DGPS/WAAS accuracy with range from station	No	Yes, unless demodulating multiple signals,
Certification of data for aviation	Yes (w/WAAS certification)	No
SBAS Backup	Geo-stationary broadcast only?	SBAS functionality
Influence on legacy users	Under Investigation	Negligible

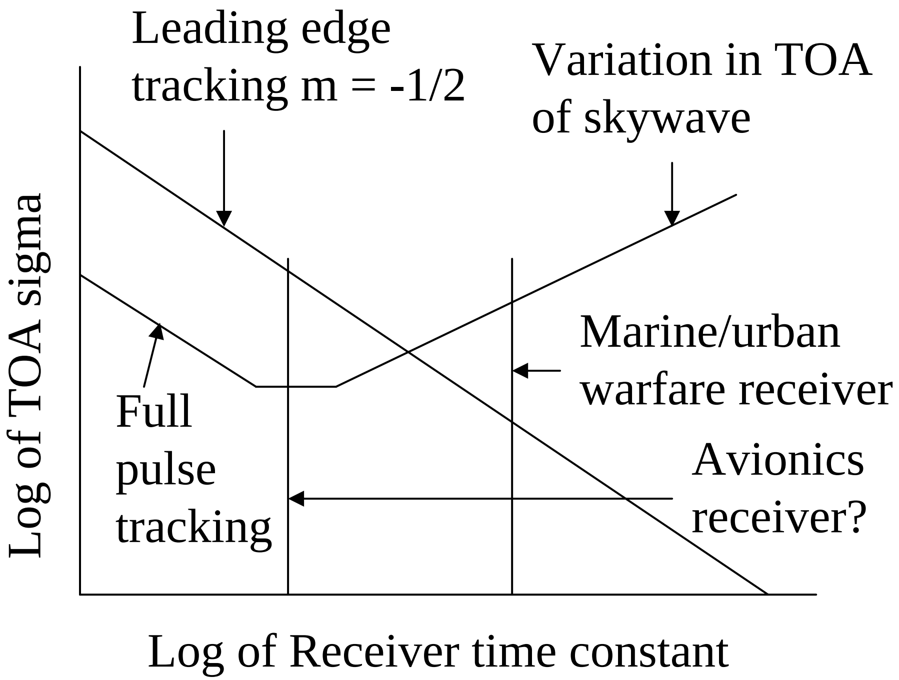
Full pulse tracking

Use phase of full pulse to measure Doppler/change in TOA & enable longer time constant leading edge tracking.

Very similar to carrier aided code smoothing in GPS.

Implemented, evaluated, & rejected in DARPA PC-104 receiver.

Used in LDC receiver, both for Doppler & for averaging templates.



Where do we go from here?

- Signal simulator for testing navigation receivers
- Transmitter & receiver for modulation of both rates on dual rated transmitters
- Signal specification
- Synchronization to LORAN Timing & Control
- Modulation of solid state transmitters

Acknowledgements

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