

# **Wagging the Tail & Flying with LORAN-C Data Communications**

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International Loran Association

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# Background

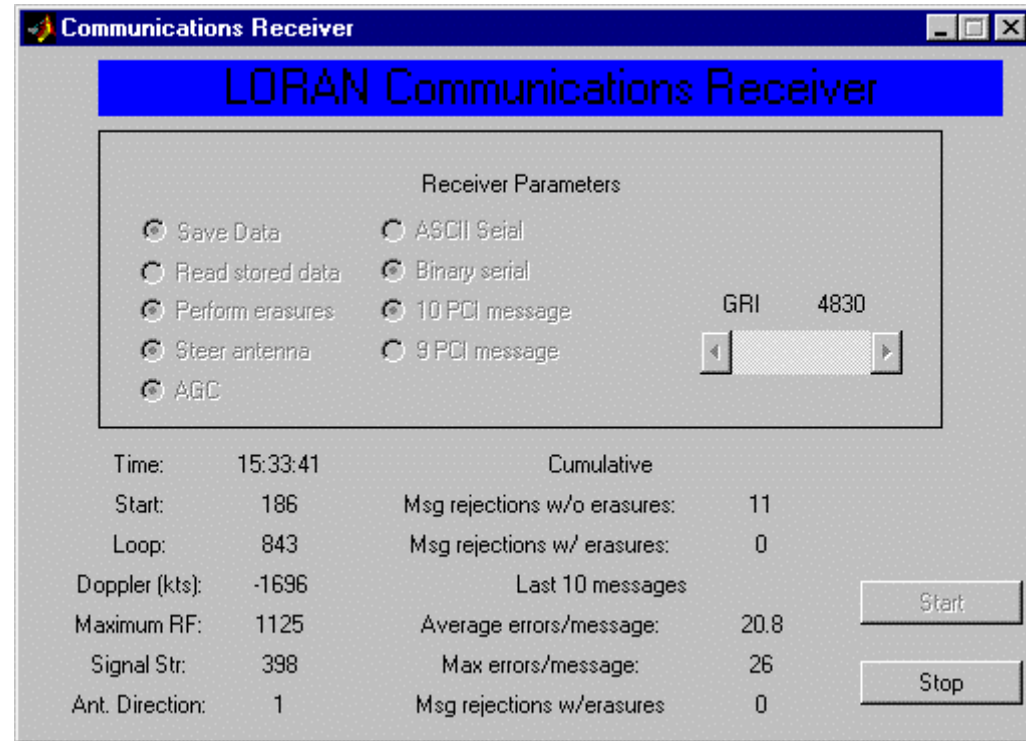
- Full WAAS capability, 250 bit msg every second
  - 16-ary Intrapulse Frequency Modulation (IFM)
  - 60 byte message, 32 bytes for WAAS msg including 24 bits of CRC, 28 bytes for Reed Solomon Forward Error Correction
- Previous papers at Bonn 3/00 & 2/01, ILA 11/00, US ION 6/01 outlined issues, alternatives & 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

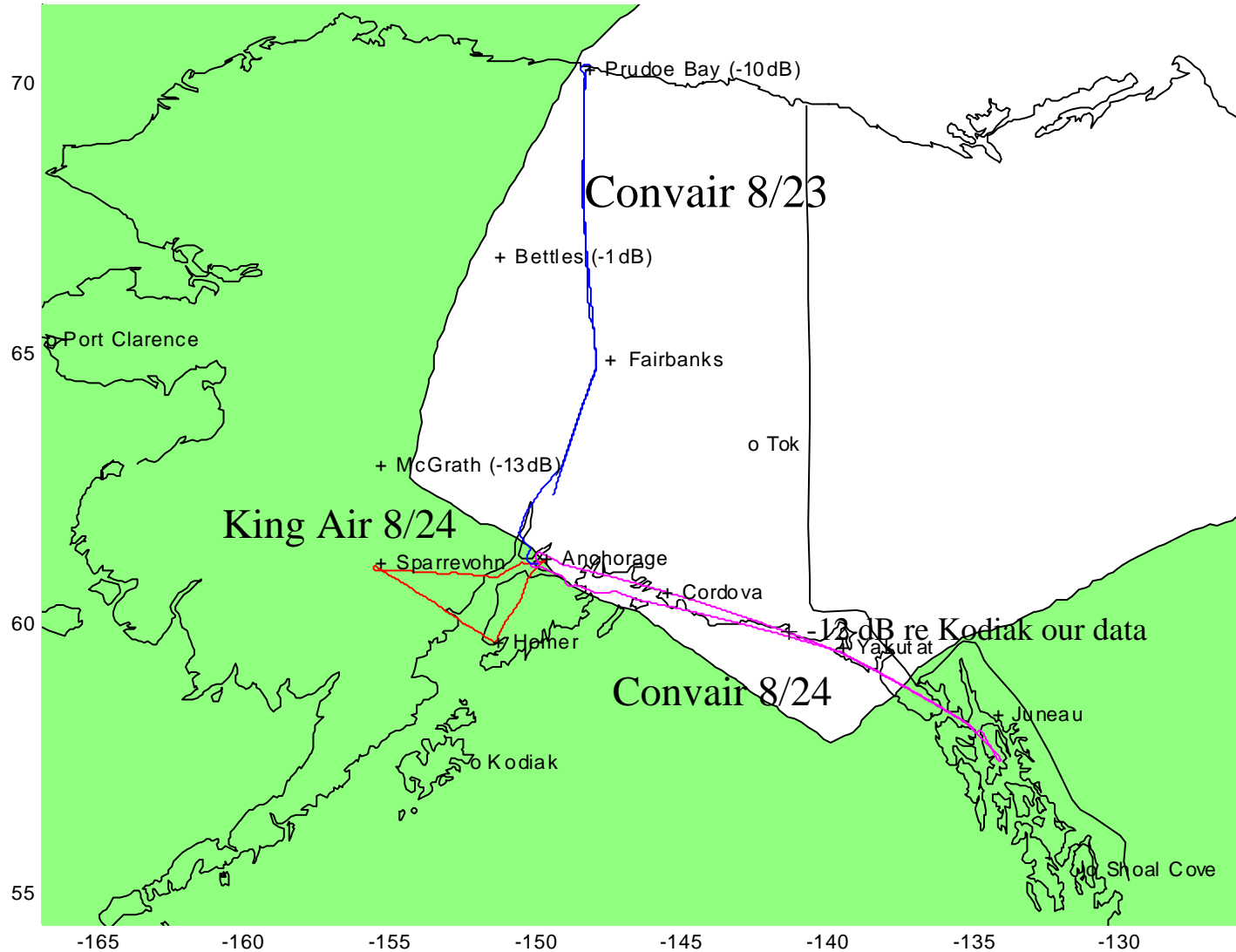
- Receiver features
- Projected/necessary coverage of Tok transmitter
- Flight test results
  - FAA-TC Convair 580 flight to Prudoe Bay
  - Convair 580 flight to Juneau
  - Ohio U. King Air C-90SE flight to SW Alaska (E field)
- Anecdotal results on loss of GEO signal in turns
- Conclusions & future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

# Receiver features

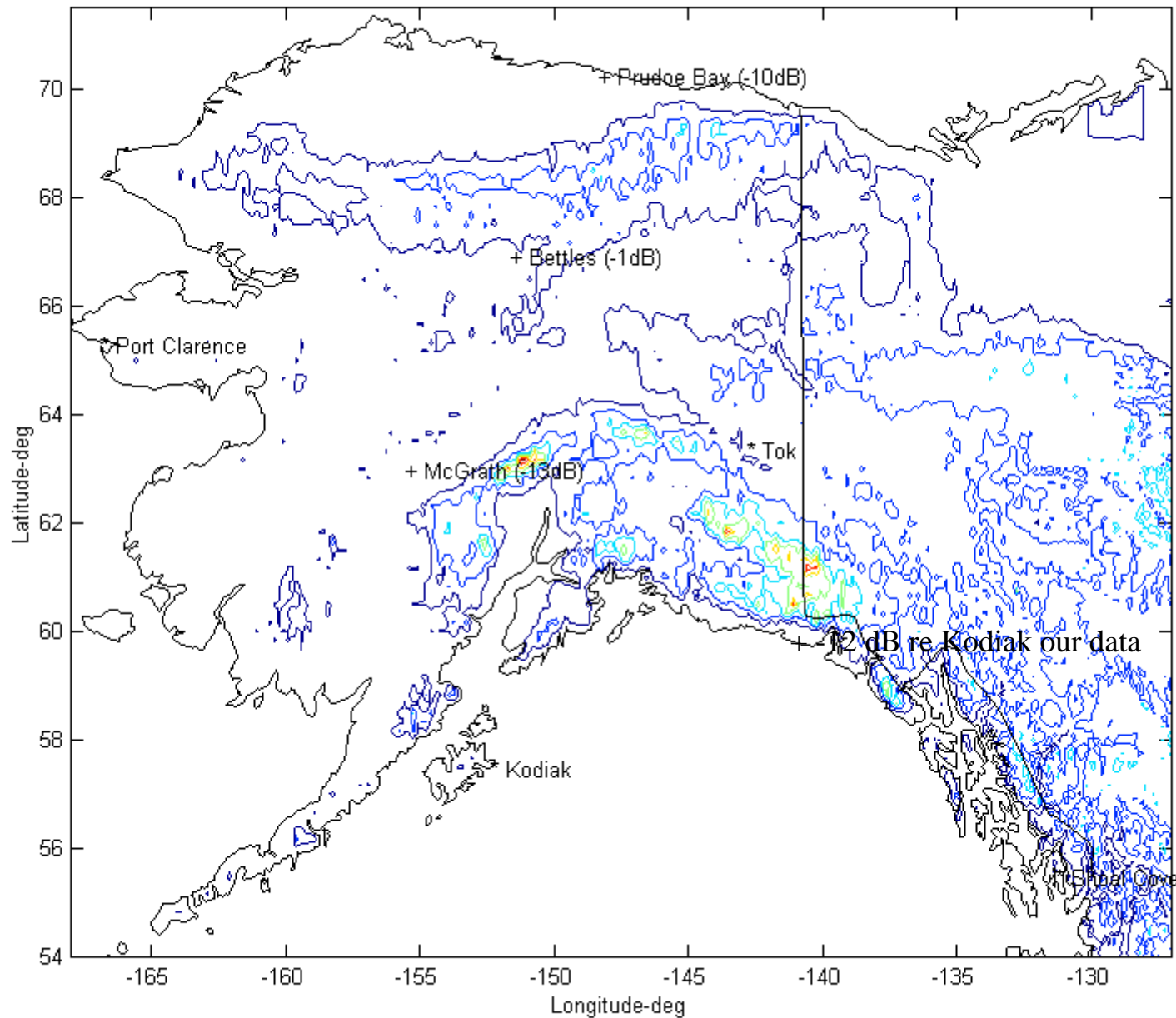
- Dual magnetic loop antenna steered in software to maximize signal/(noise + interference)
- Acquires & tracks in transport aircraft dynamics
- 1e-7 HMI integrity from 24 bit CRC in WAAS msg.
- Except for acquisition phase, receiver pulse templates based on received RF
  - Skywaves are signal, not interference
- 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.



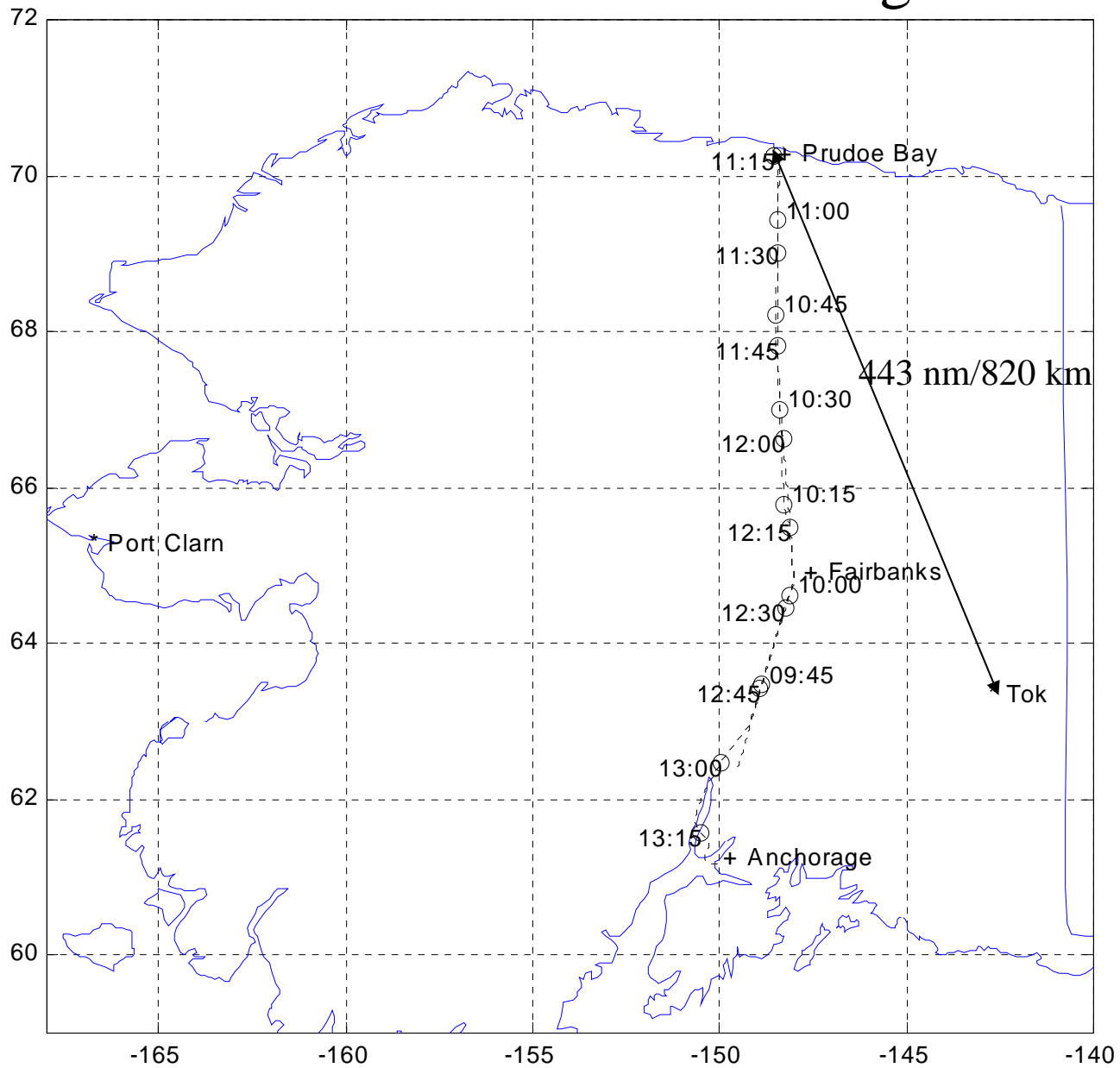
Flight paths and area where Tok would be strongest LORAN signal based on smooth earth (Millington's method) model.  
Data in ( ) from is Tok SS re Port Clarence from 1988 FAA survey.



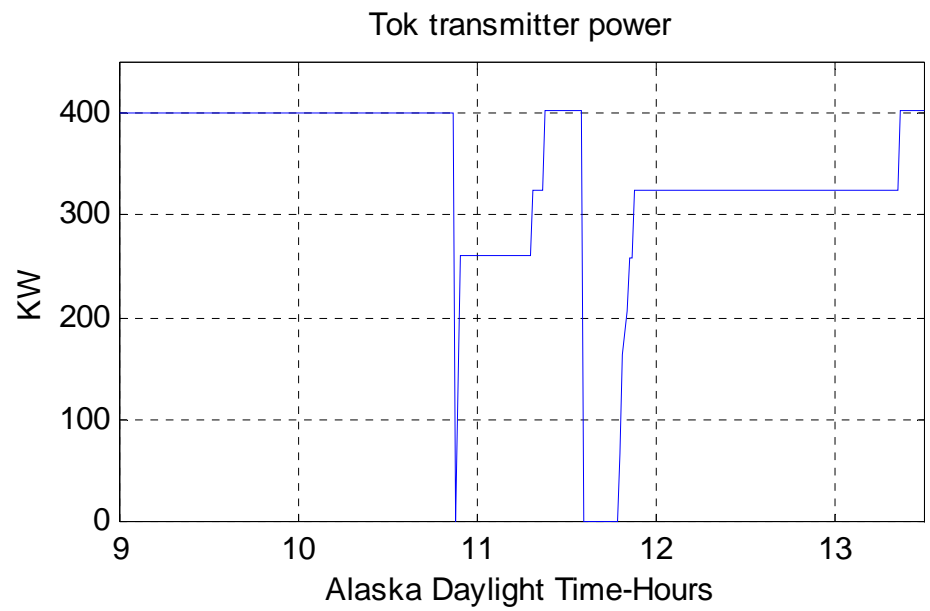
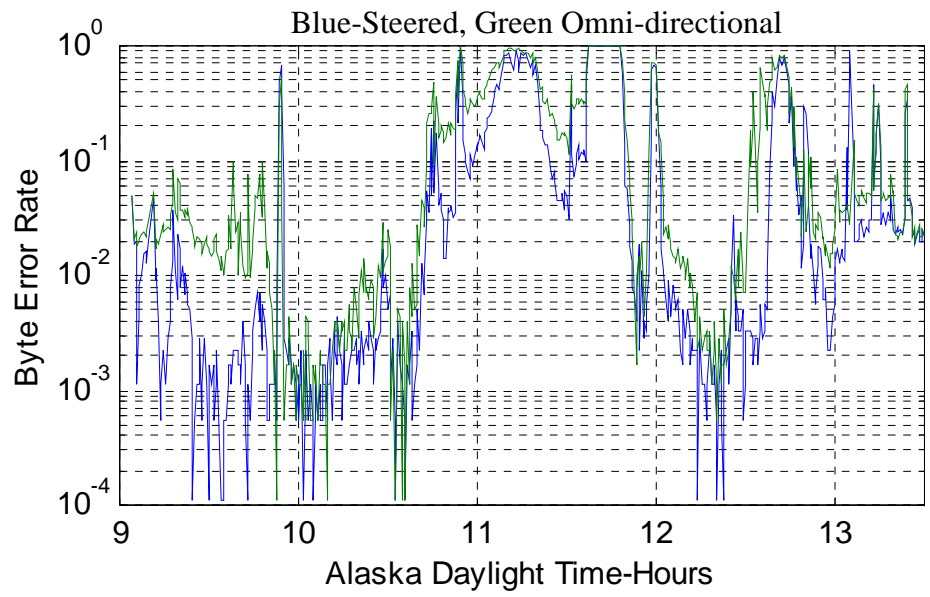
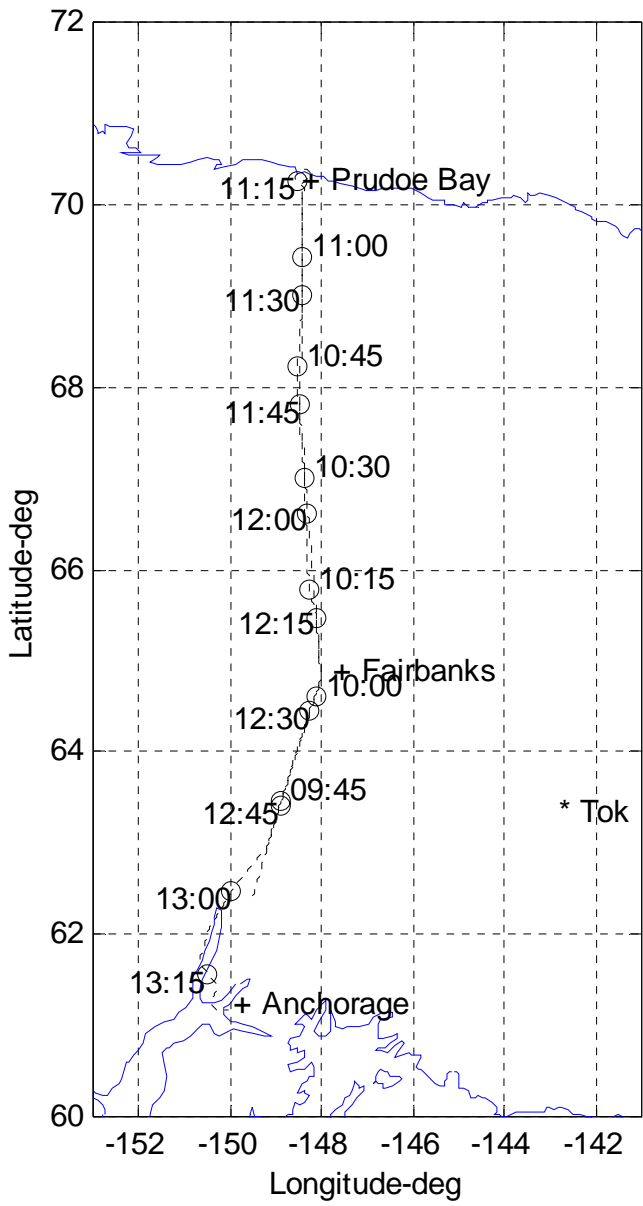
# Elevation contours in increments of 2000 ft



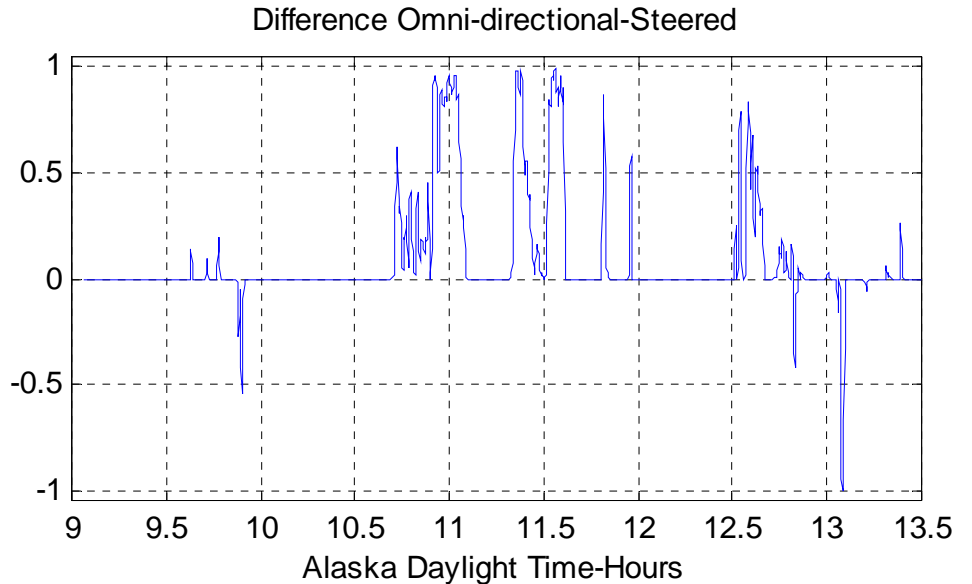
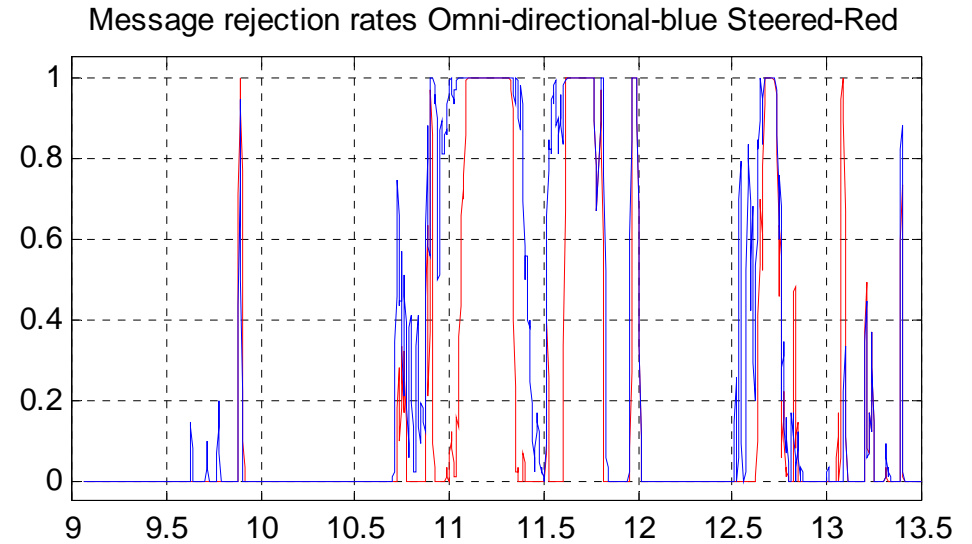
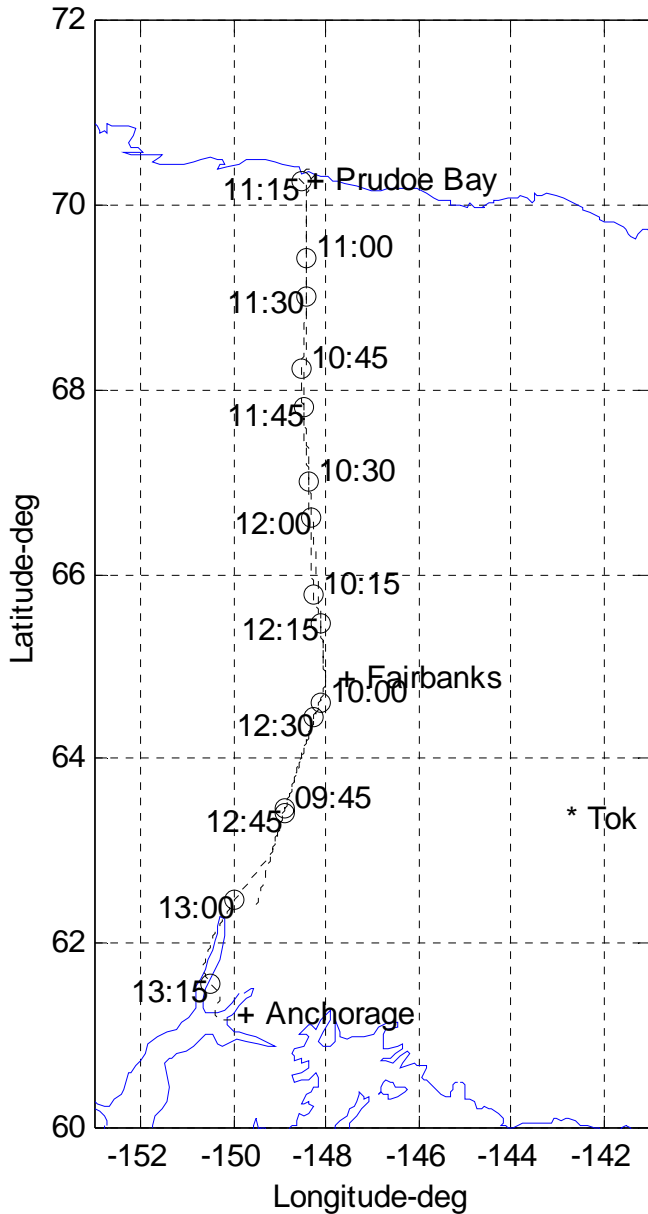
# Path of 23 AUG Convair flight



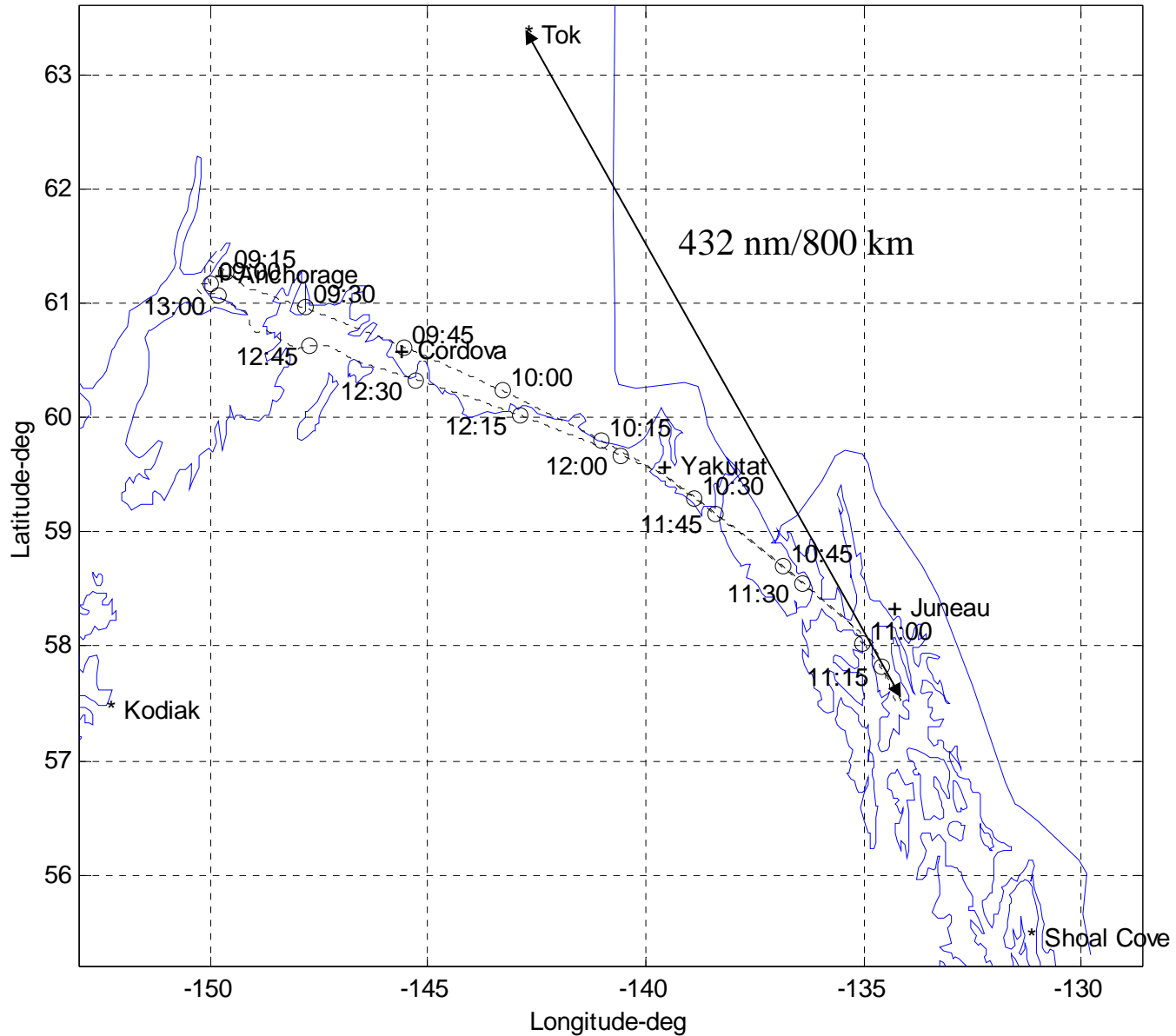
# Byte error rates for Convair 23 AUG flight



# Message Rejections for Convair 580 on August 23<sup>rd</sup>.

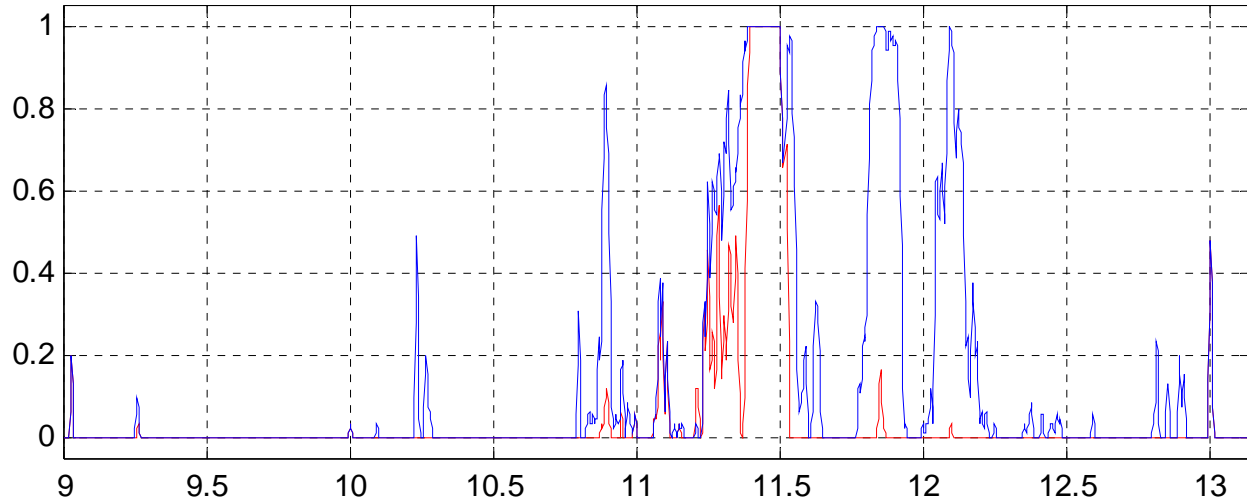


# Path of 24 AUG Convair flight

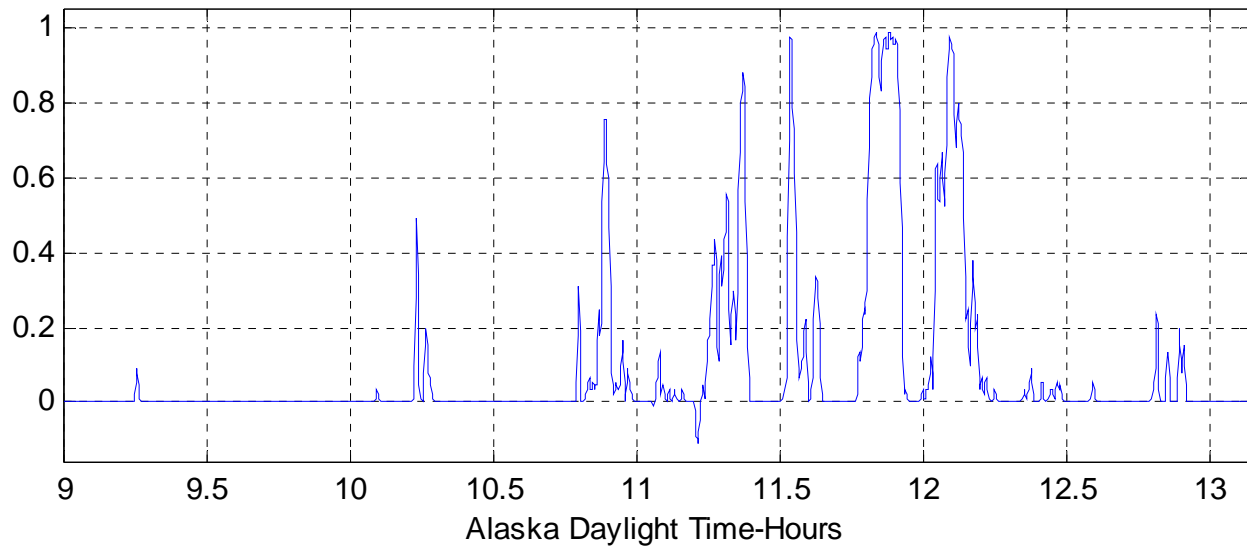


# Message rejection rates for Convair – 24 August

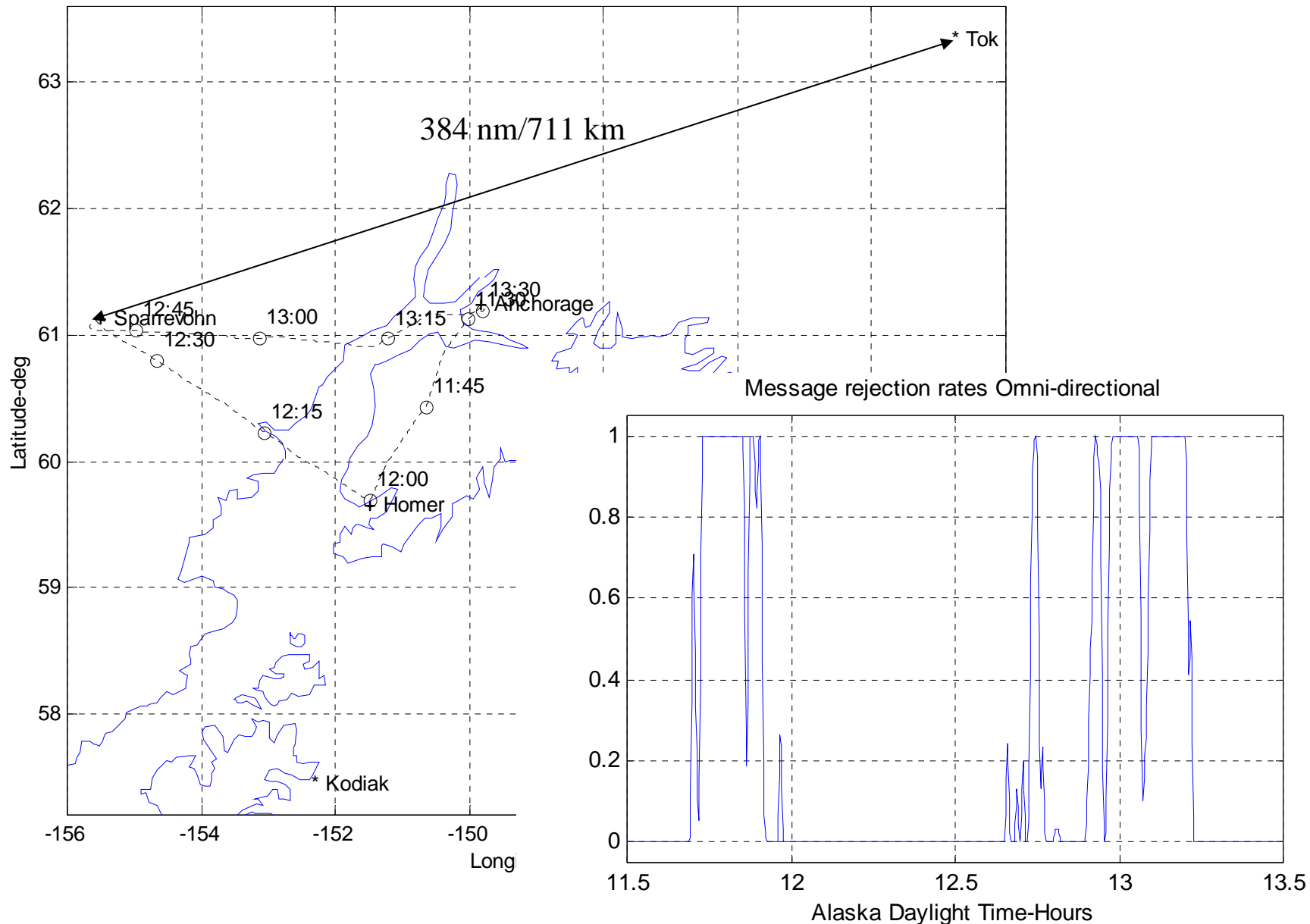
Message rejection rates Omni-directional-blue Steered-Red



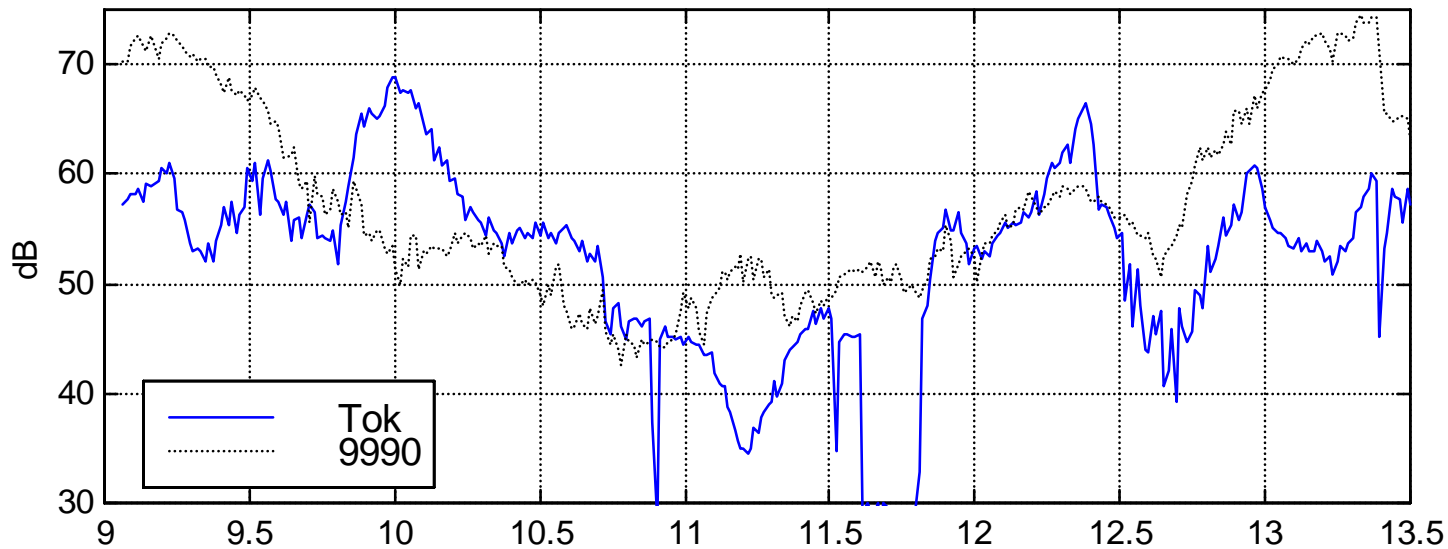
Difference Omni-directional-Steered



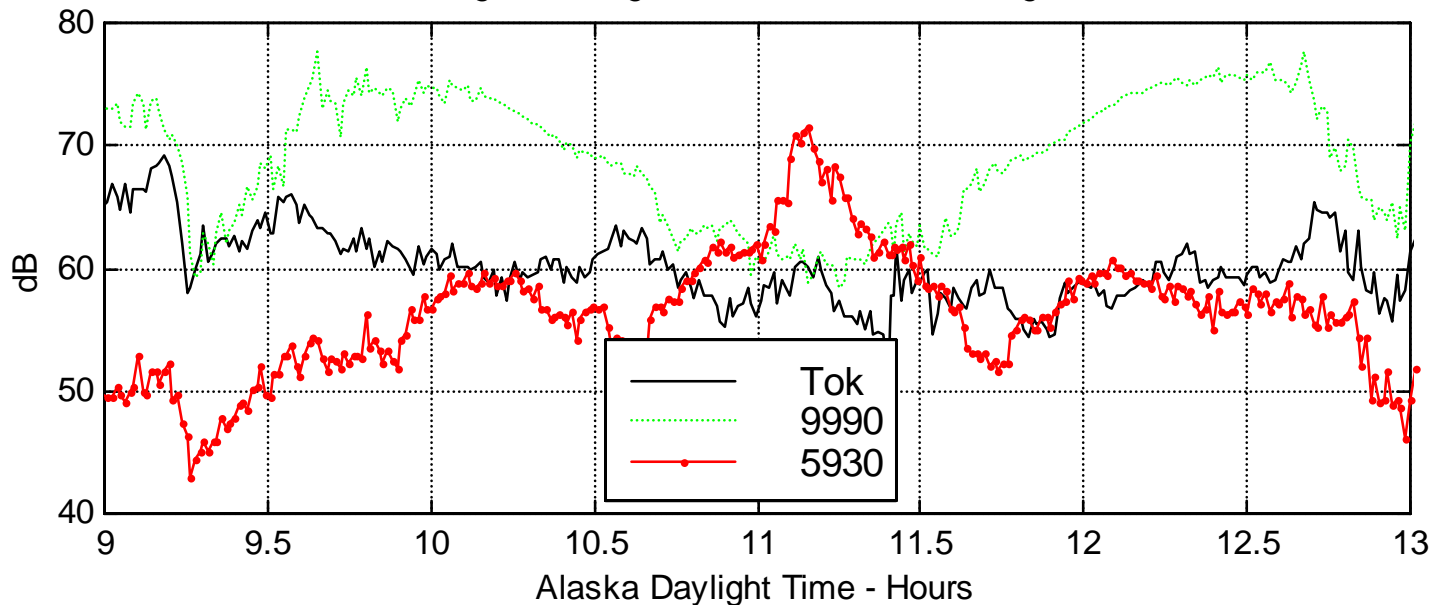
# Path of 24 AUG Ohio U. King Air flight E field whip antenna



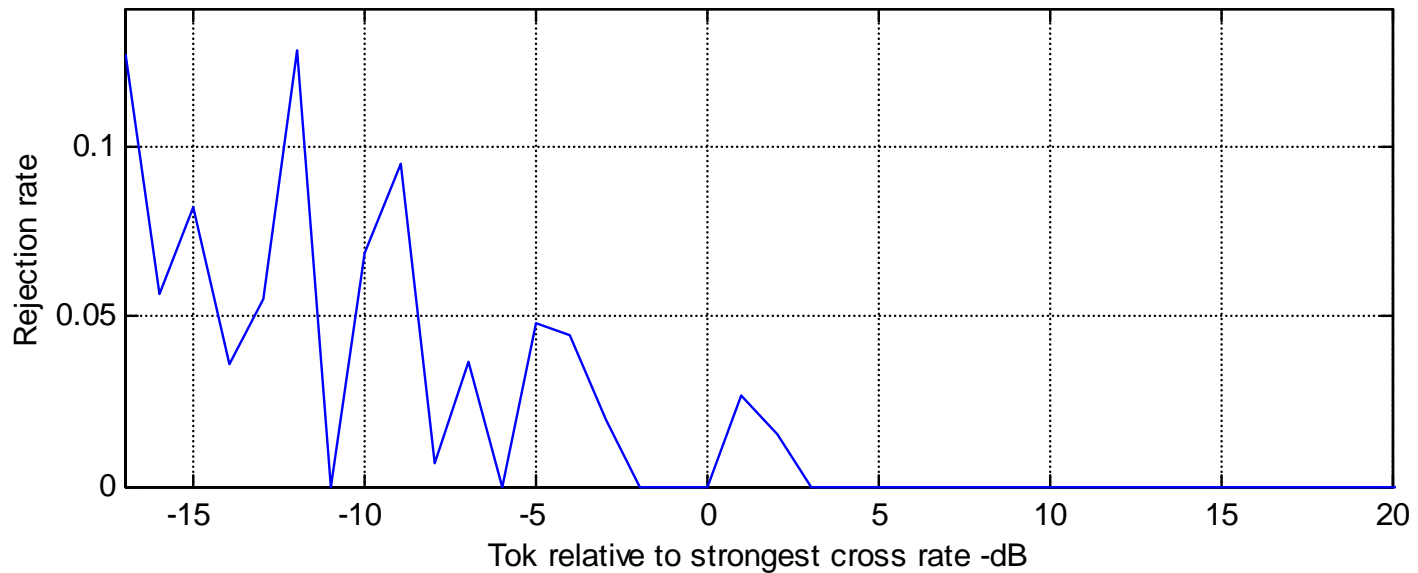
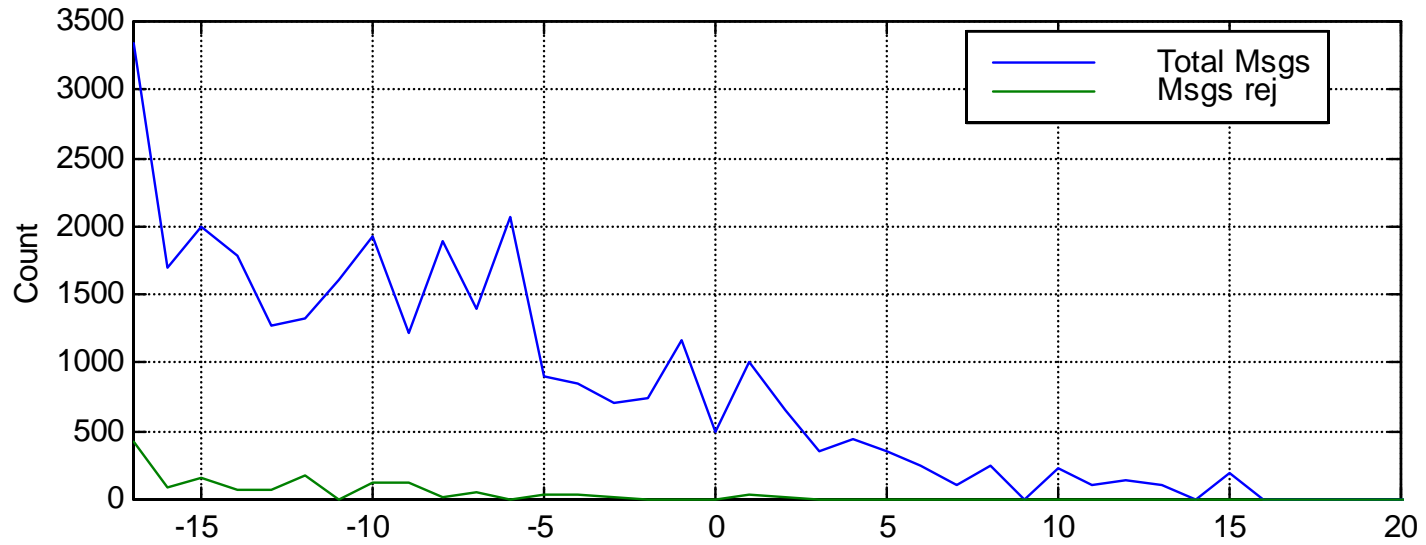
Signal Strengths on Convair 23 AUG flight



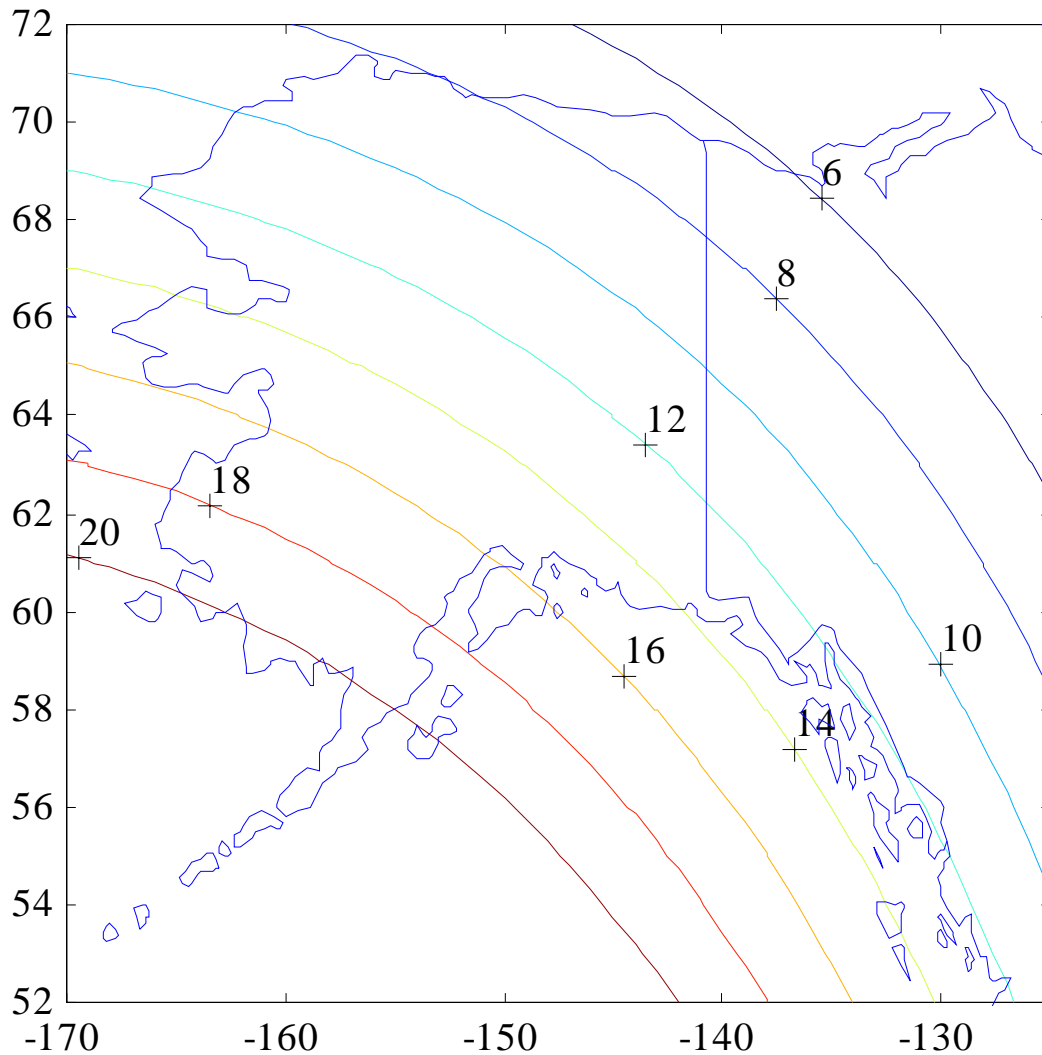
Signal Strengths on Convair 24 AUG flight



# 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.

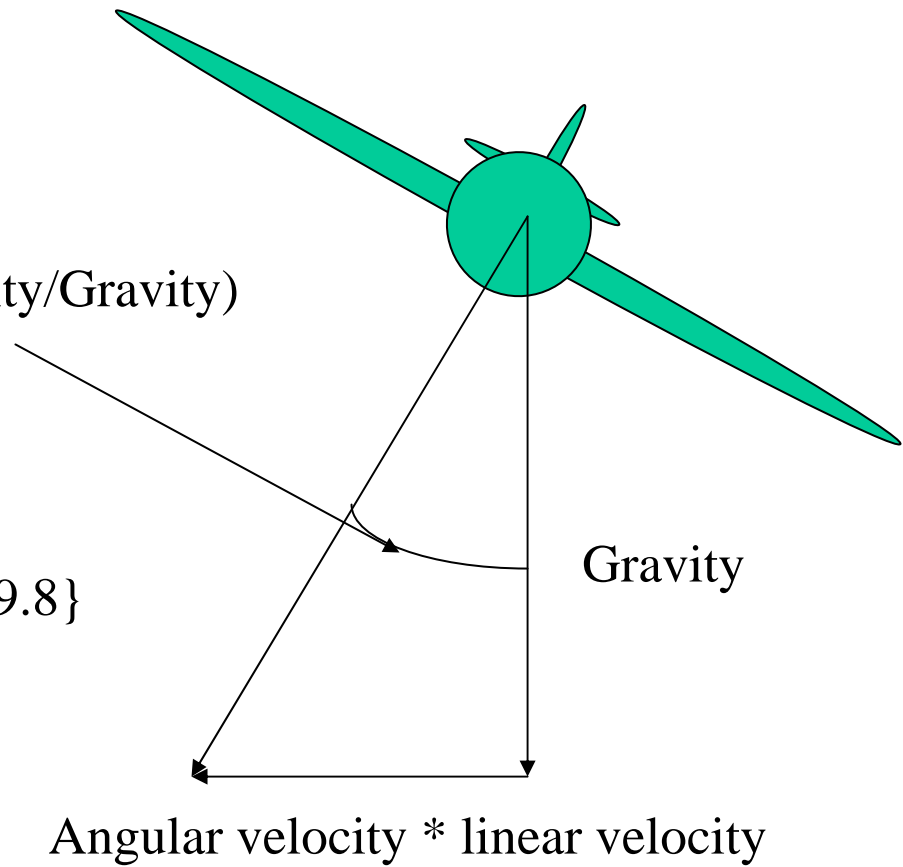
# Estimation of roll angle from lat/lon data

$$\text{atan}(\text{Angular velocity} * \text{linear velocity} / \text{Gravity})$$

Example: 2 min. turn at 250 knots

$$\text{Roll angle} = \text{atan}\{(2\pi/120) * 129/9.8\}$$

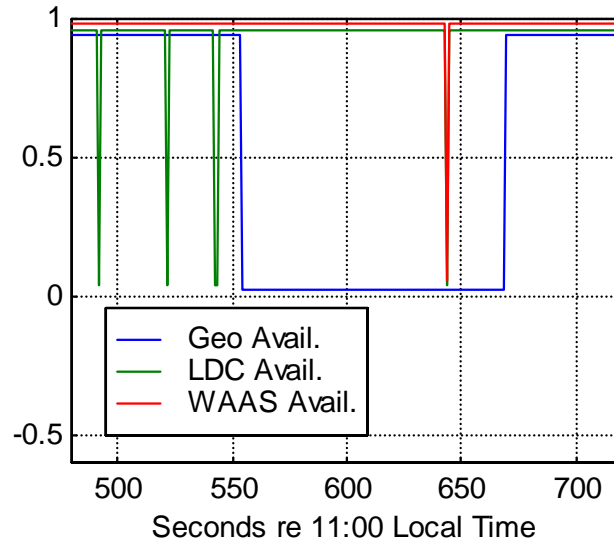
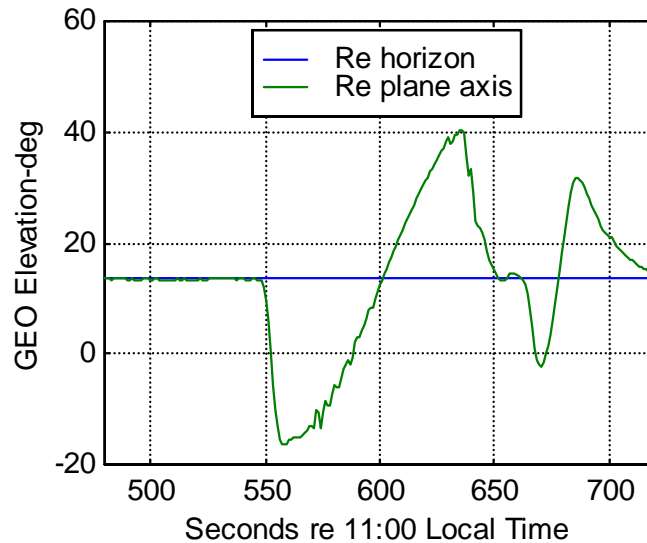
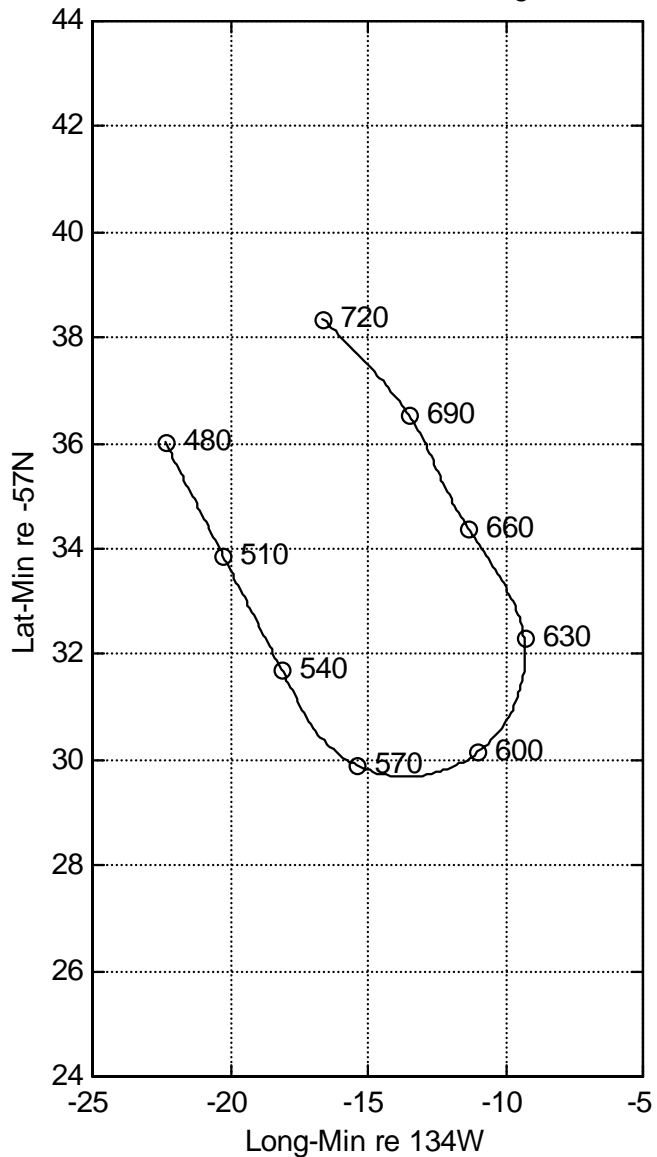
$$= 34.6 \text{ degrees}$$



# WAAS Availability during turn south of Juneau

## Convair 580 on August 23<sup>rd</sup> SOG 300kts, Tok 423 nm

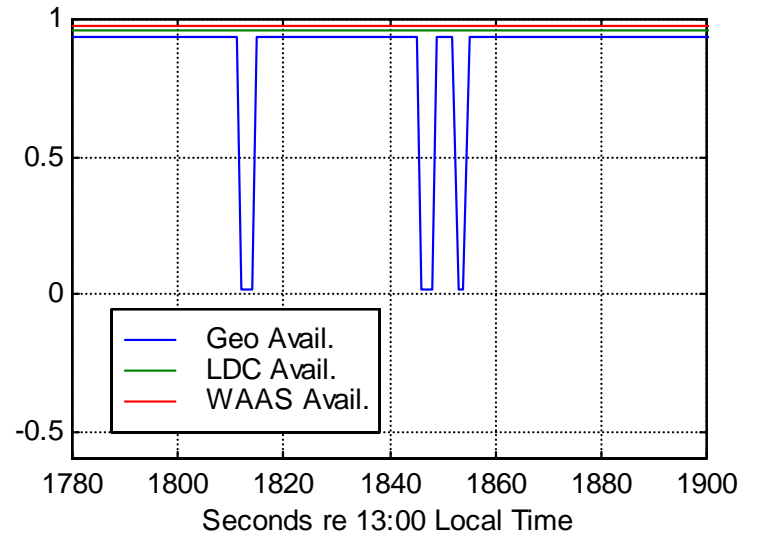
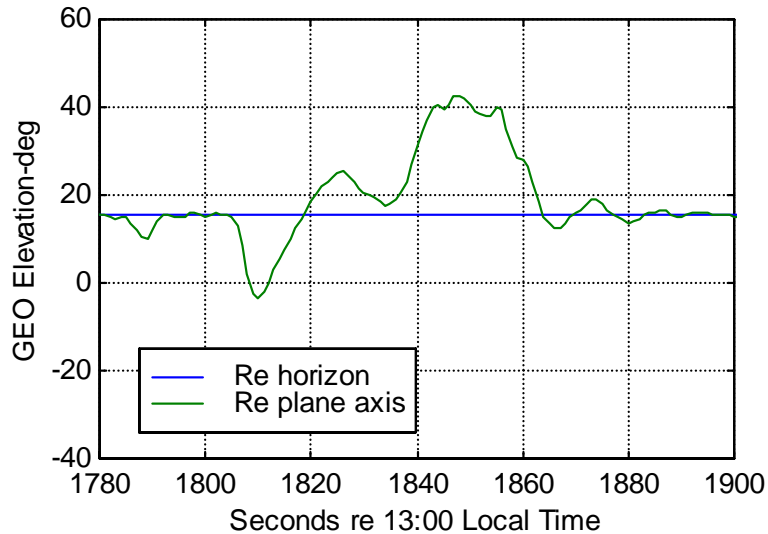
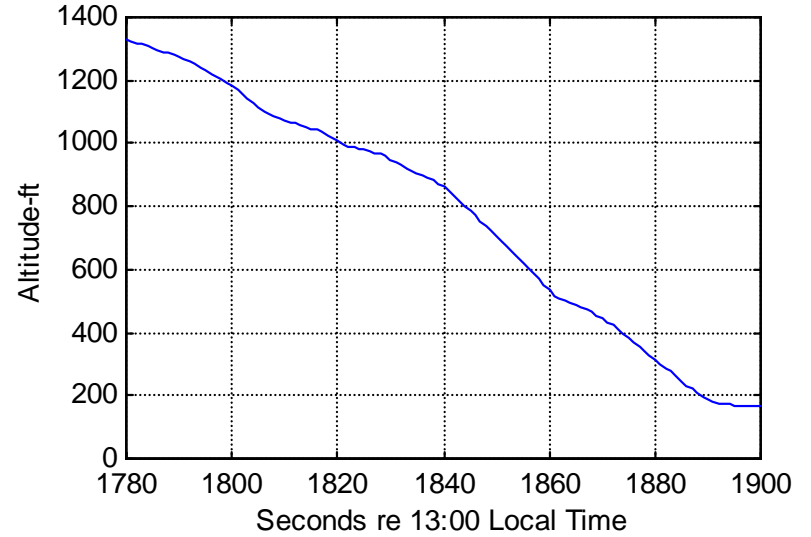
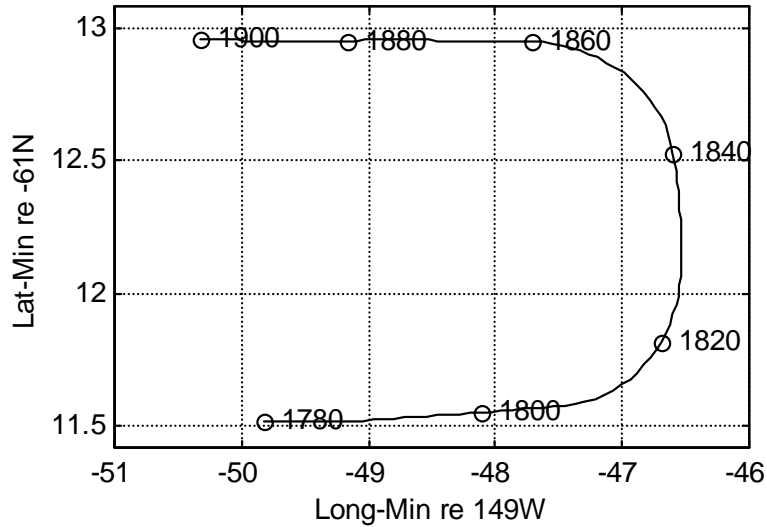
Azimuth to POR 231 deg



# WAAS Availability during landing at Merrill Field

## Ohio U. King Air on Aug.24<sup>th</sup>.

Azimuth to POR 216 deg



# 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	$\geq 1.0\text{dB}$ , 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	$\geq 6.2\text{dB}$ 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 <b>None</b>	None
Multistation reception	?? <b>Yes, but not needed as all stations transmit same data</b>	Yes
Degradation of DGPS/WAAS accuracy with range from station	<b>No</b>	<b>Yes, unless demodulating multiple signals,</b>
Certification of data for aviation	<b>Yes ( w/WAAS certification)</b>	<b>No</b>
SBAS Backup	Geo-stationary broadcast only?	SBAS functionality
Influence on legacy users	Under Investigation	Negligible

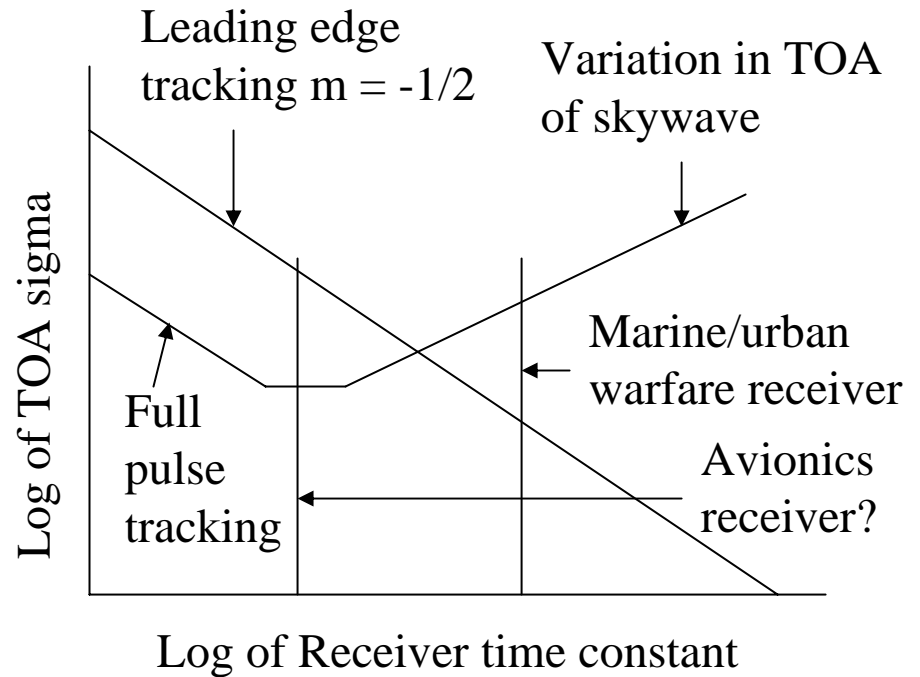
# Full pulse tracking

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

- Funded by Federal Aviation Administration
- FAA Tech Center – Bob Erikson & Scott Shollenberger
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- LORAN Station Tok - ETC Daniel Heineck & crew
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