Enhanced Line of Sight Velocity Analysis Using an Aperiodic Pulse Sequence on the Kodiak and King Salmon Radars.

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The Ideal Multi-Pulse Sequence

The goals to be achieved simultaneously include:

- Provide long lags to increase low velocity resolution.
- Provide short lags to increase Nyquist upper bound.
- Maximize number of lags to increase available spectral information.

The constraints are:

- Lags must not be repeated to minimize range aliasing.
- All lags must be a multiple of 10 usec for radar operation.

The resulting optimized multi-pulse sequence is:

- **A 16-pulse aperiodic pulse sequence designed by M. Balaji, and reported on last year.**

Why Use this Aperiodic Multi-Pulse Sequence?

Parameter	SuperDARN 8-pulse Sequence	Extended 16-pulse Sequence
Longest Lag Interval	36 ms	149.5 ms
Shortest Lag Interval	1.5 ms	0.4 ms
Number of Unique Lags	23	121
lags lost due to Tx-ON Rx-OFF conflicts 225 Range Gates, 15 km range resolution	30.4% 7	24% 29
Mean Nyquist Velocity at 12 MHz	3819 m/s	5013 m/s
Ability to resolve multiple components in a range cell	No	Yes

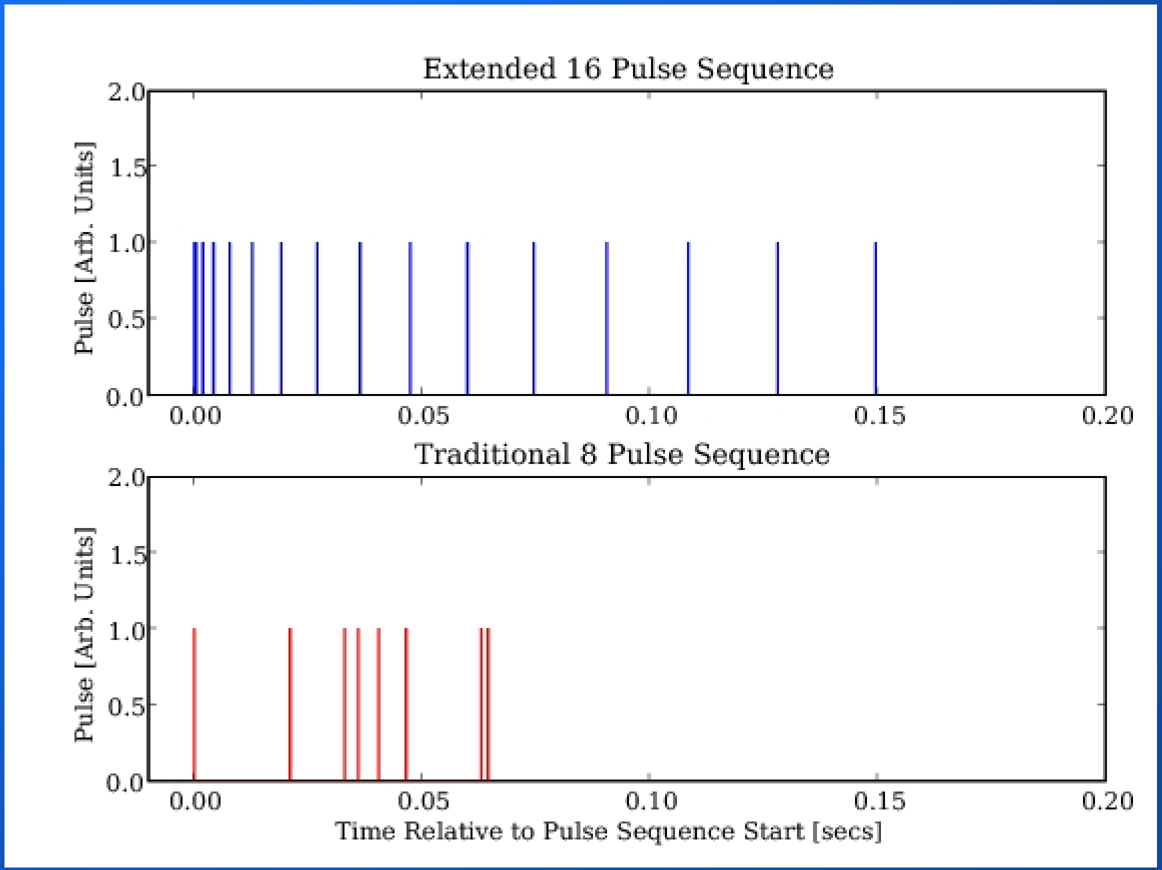
Pulse Sequences Compared

Extended Pulse Sequence:

- 16 pulses
- ~ 150 millisecond span

Traditional Pulse Sequence:

- 8 pulses
- ~ 65 millisecond span

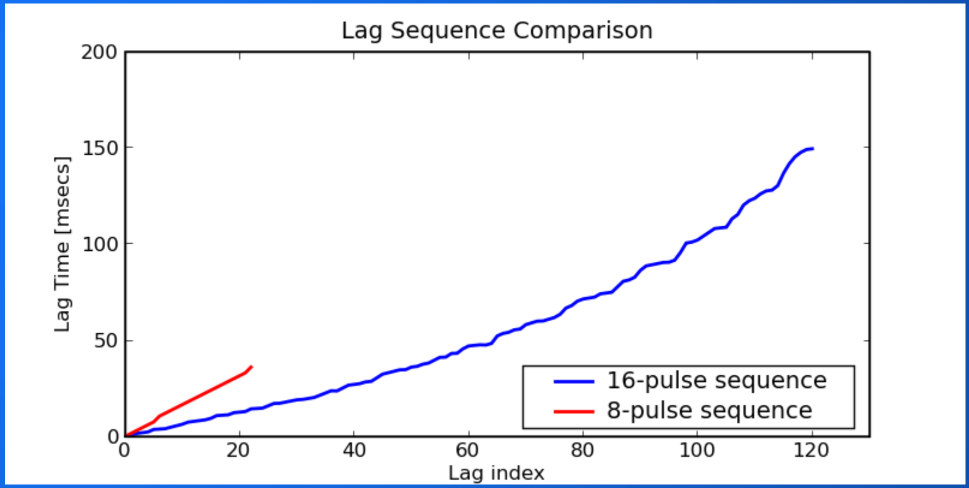


(All pulses 100 microseconds long)

Lag Sequences Compared

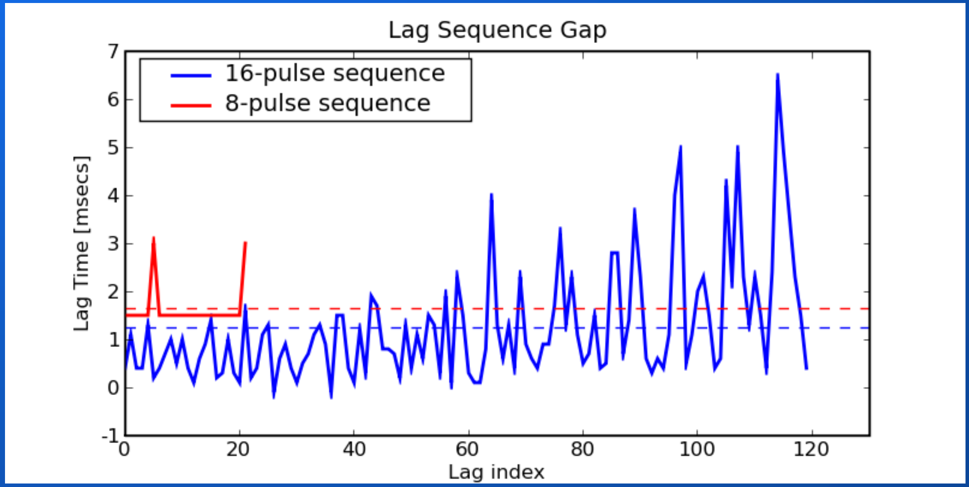
Extended Lag Sequence:

- 121 lags
- ~ 150 millisecond span
- mpinc = 0.1 msec
- Many irregular lag intervals
- Average lag interval ~ 1.24 msec



Traditional Lag Sequence:

- 23 lags
- ~ 36 millisecond span
- mpinc = 1.5 msec
- *Nearly* regular lag intervals
- Average lag interval ~ 1.63 msec

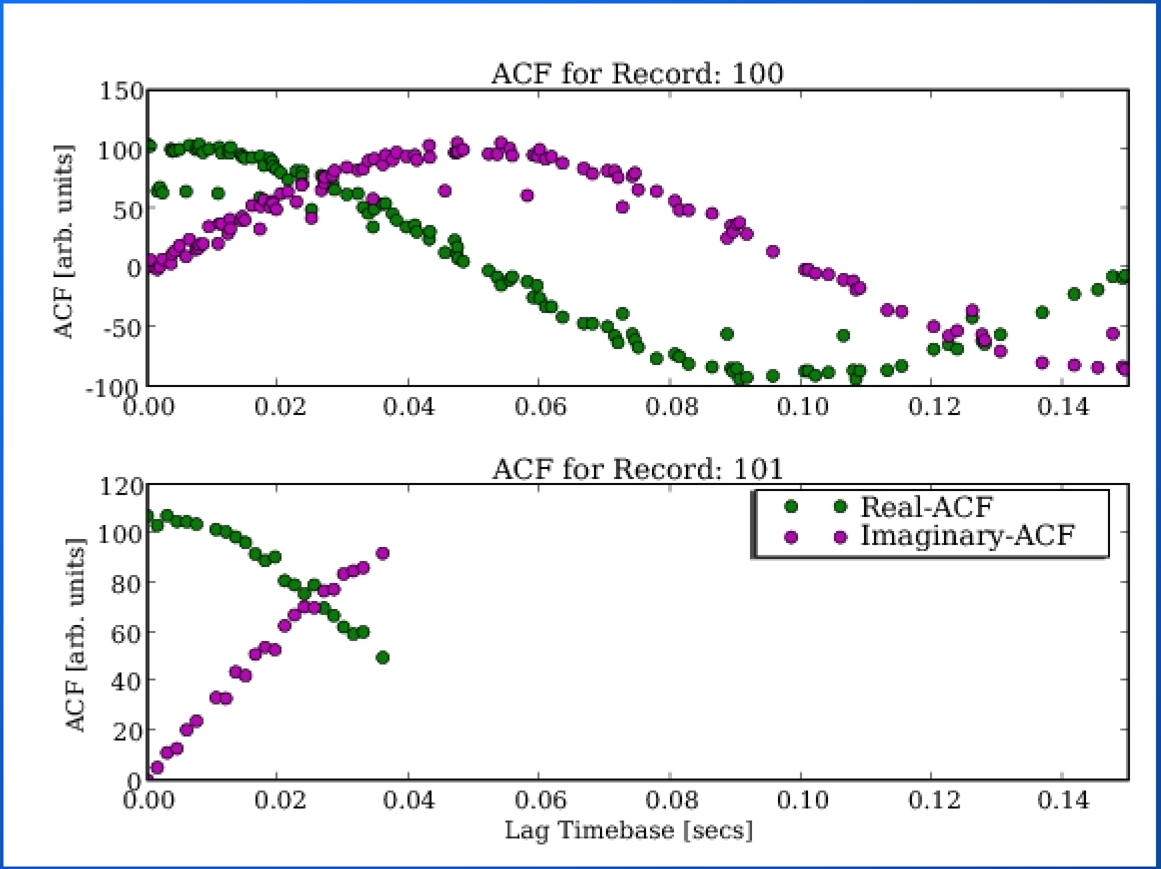


ACF Comparison

Extended Pulse Sequence:
6 second integration

Range: ~375 km

Traditional Lag Sequence:
6 second integration



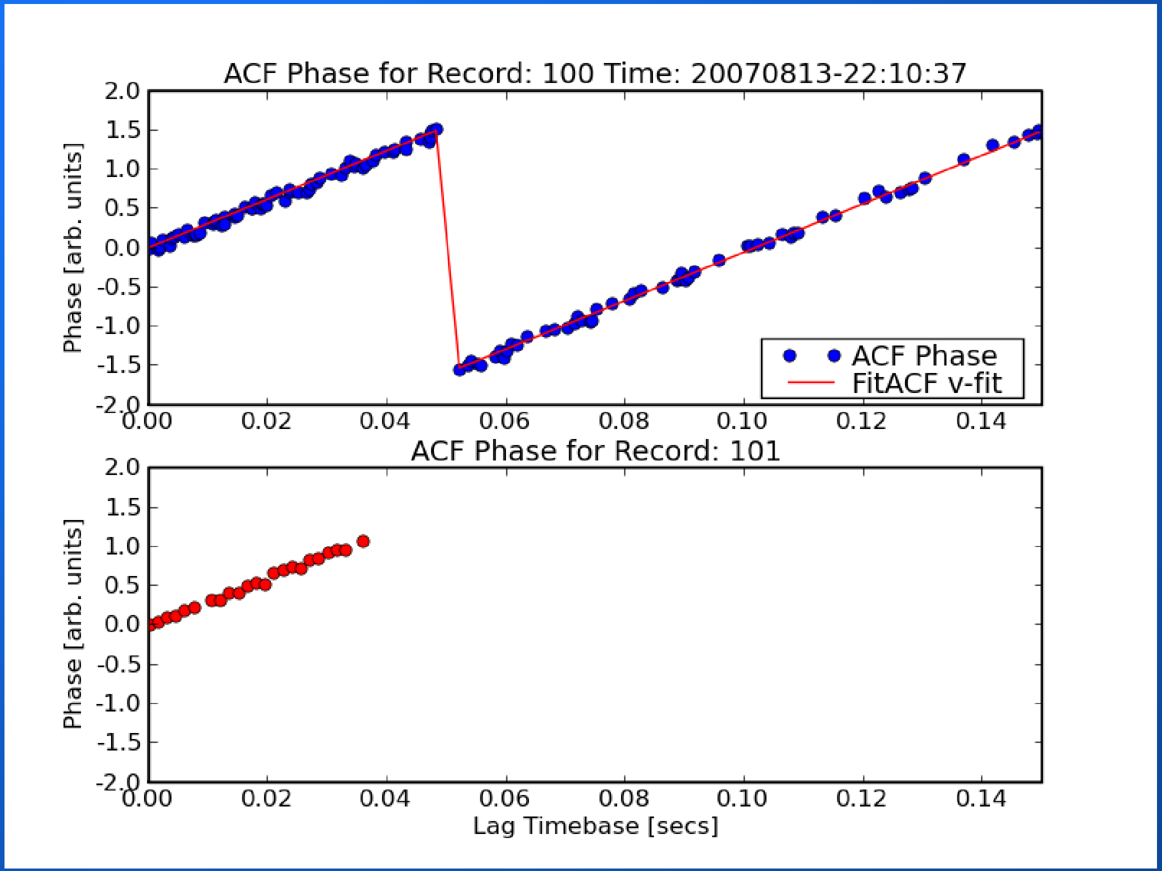
Experimental data from 2007-08-13 ~ 22:10 UTC

Phase Comparison

Extended Lag Sequence:

Example of a target with
FITACF v ~ 50 m/s

Traditional Lag Sequence:



Experimental data from 2007-08-13 ~ 22:10 UTC

Need to Enhance Velocity Fitting to Recover Spectral Information

- ACFFIT Doppler frequency fitting uses a least squares fit of ACF phase: $\Phi=\omega t$
  giving line of sight velocity as: $v=c * (\omega)/(4*\pi*f)$

- Assumes a single velocity target.

- Candidate techniques for estimating Doppler frequency spectrum include:
  - **Lomb Periodogram**
  - Maximum Entropy Spectral Estimation
  - SparSpec Algorithm

An Introduction to the Lomb Periodogram

The Lomb periodogram uses sinusoidal model functions to for the data of the form:

$$d(t_i) = A\cos(2\pi\omega t_i - \theta) - B\sin(2\pi\omega t_i - \theta) + n_i$$

The probability that the data is fitted by a model function for a given frequency is:

$$P_{LS}(\omega) = \frac{R_{LS}(\omega)^2}{C} + \frac{I_{LS}(\omega)^2}{S}$$

and using least squares constraints.

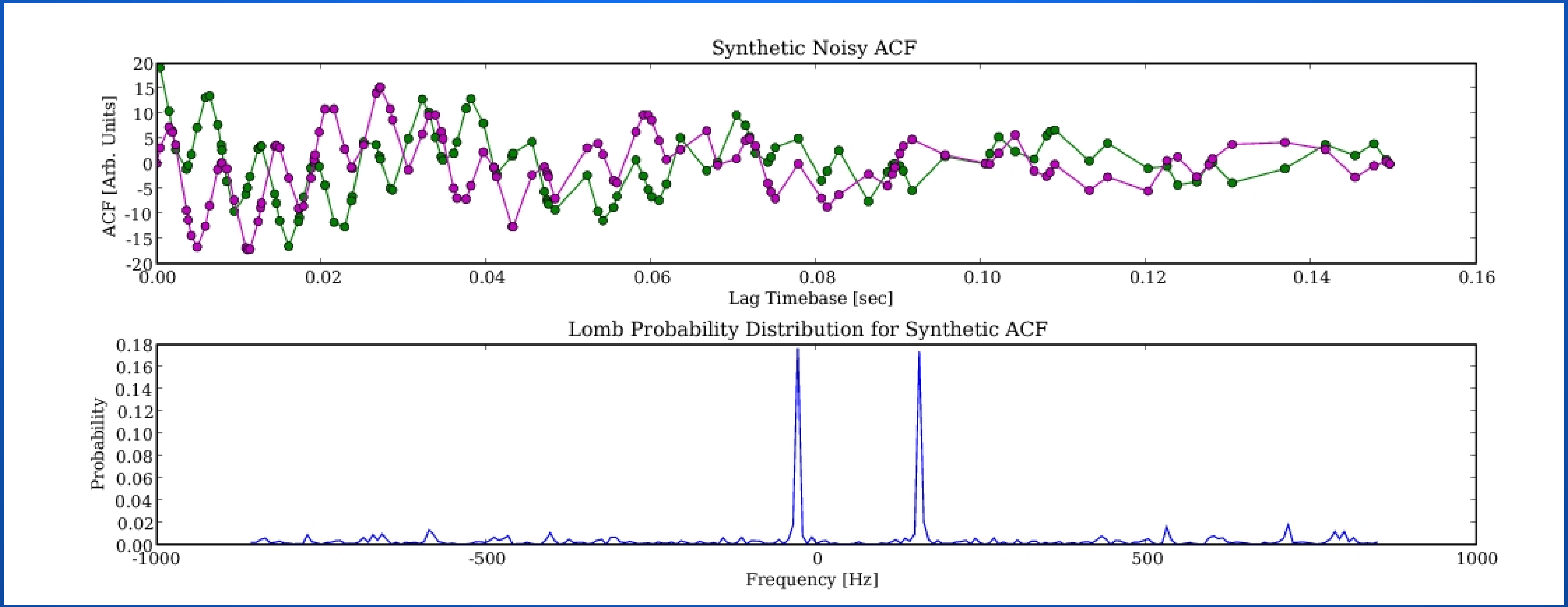
$$R_{LS} \equiv \sum d(t_i)\cos(2\pi\omega t_i - \theta) \qquad I_{LS} \equiv \sum d(t_i)\sin(2\pi\omega t_i - \theta)$$

$$C \equiv \sum \cos^2(2\pi\omega t_i - \theta) \qquad S \equiv \sum \sin^2(2\pi\omega t_i - \theta)$$

θ is chosen so that the sine and cosine model functions are orthogonal on the aperiodic dataset d(t).

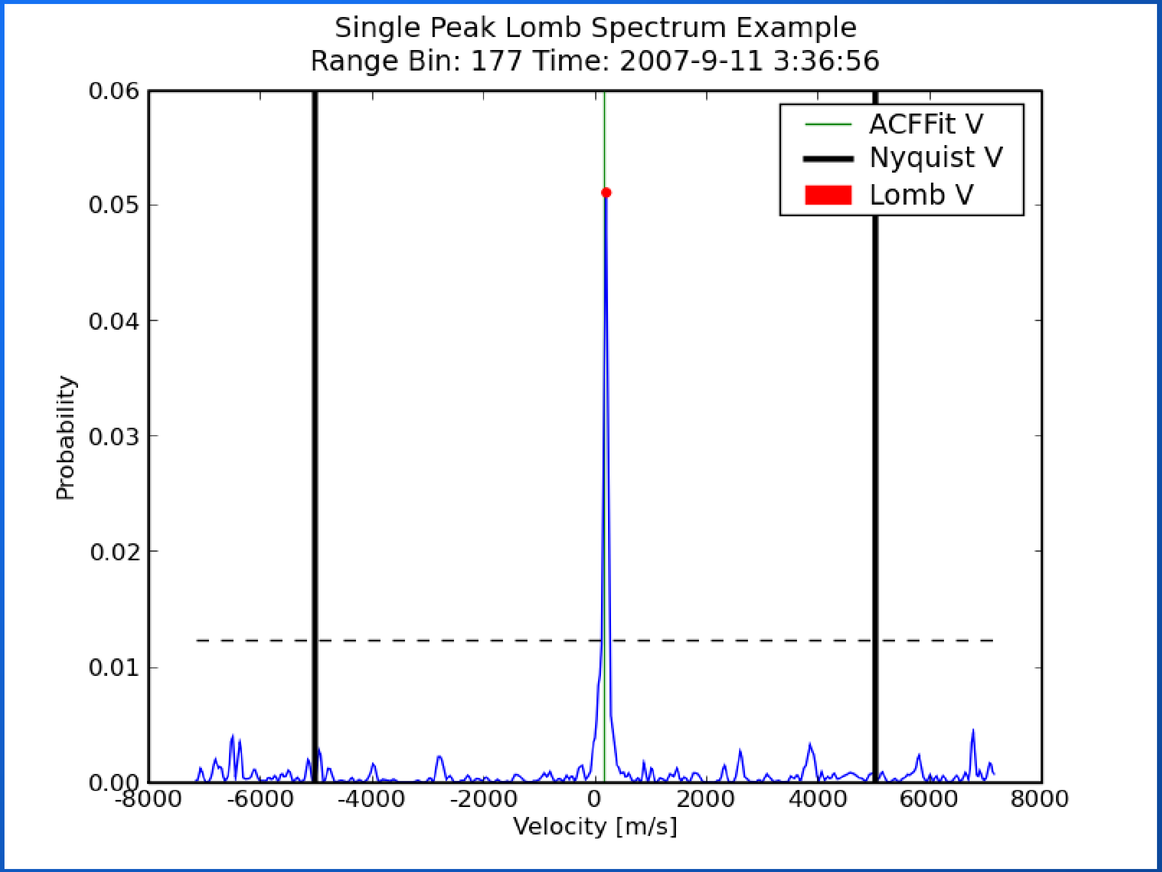
Synthetic Example of Lomb Periodogram

- Synthetic noisy ACF constructed using -28 Hz and +156 Hz components.
- ACF sampled using the extended pulse sequence (16 pulses, 121 lags).

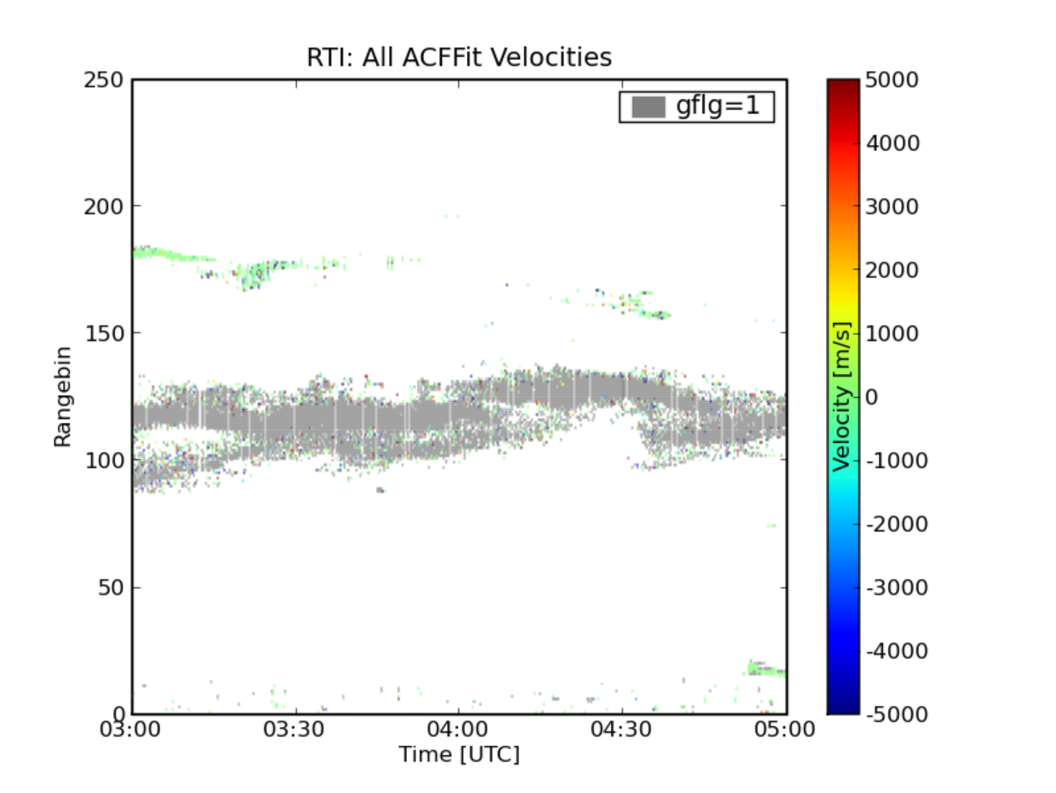


Lomb Periodogram Example Using Kodiak Radar Data

- Peak Lomb velocity: ~ 200 m/s
- Good agreement with ACFFIT Velocity ~ 160 m/s
- Nyquist velocity: ~5000 m/s



Pulse Sequence Operational Comparison Along Beam 5

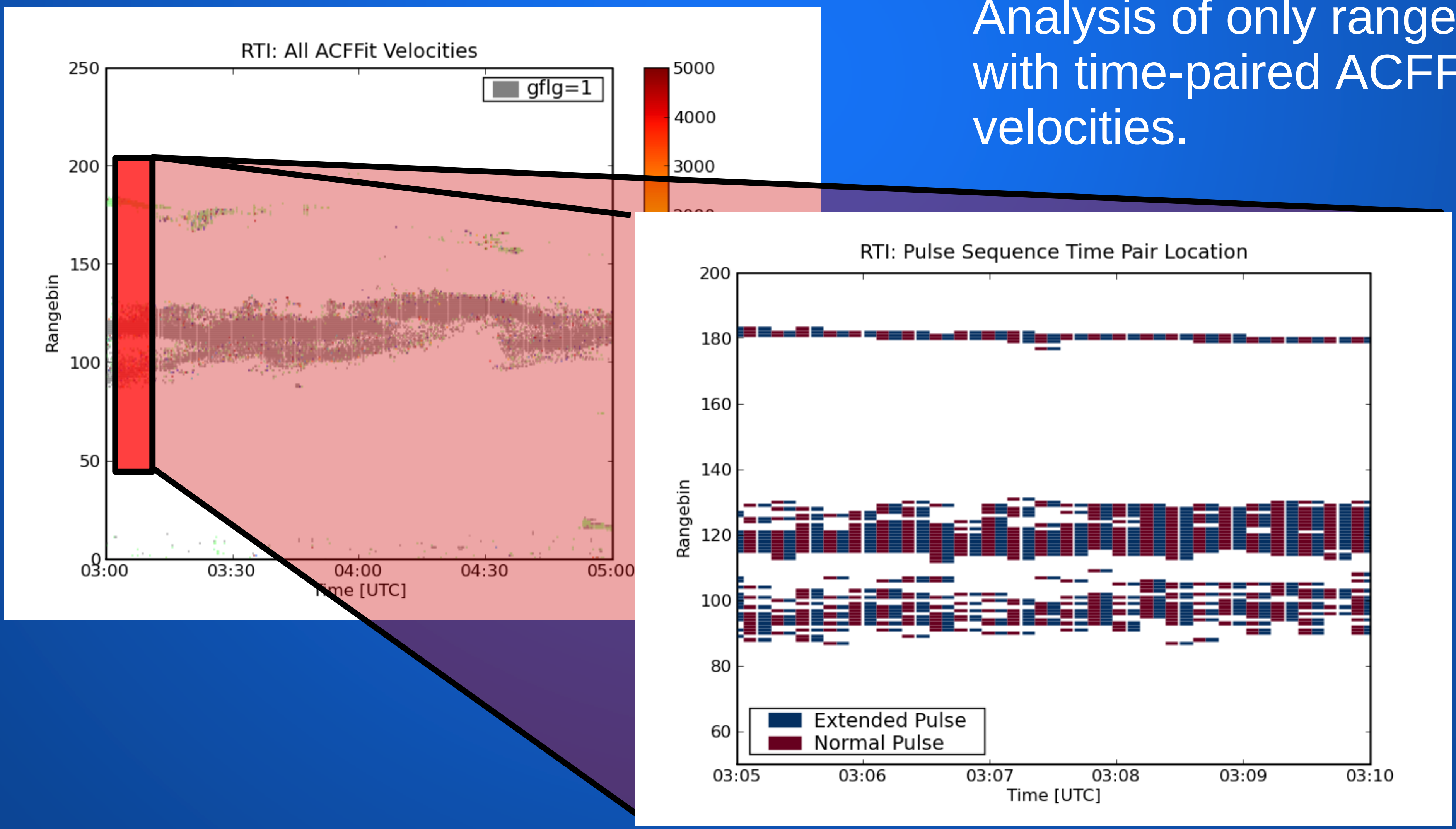


- Extended 16-pulse sequences interlaced with normal 8-pulse sequences
- ACF integration time : 6 seconds
- Beam Direction: 5

Radar ACF data from Kodiak radar on 2007-09-11.

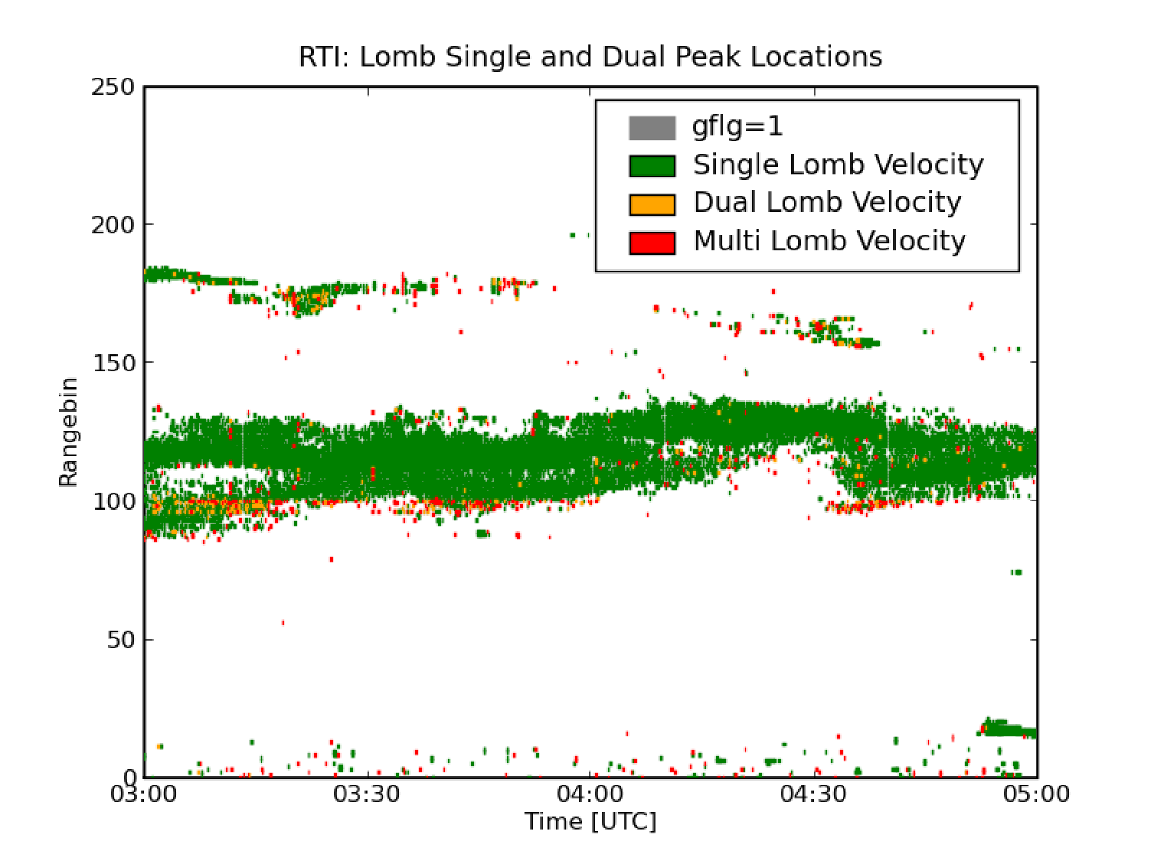
Interlaced 16 and 8 Pulse Sequences for Time Paired Comparison

Analysis of only ranges with time-paired ACFFIT velocities.

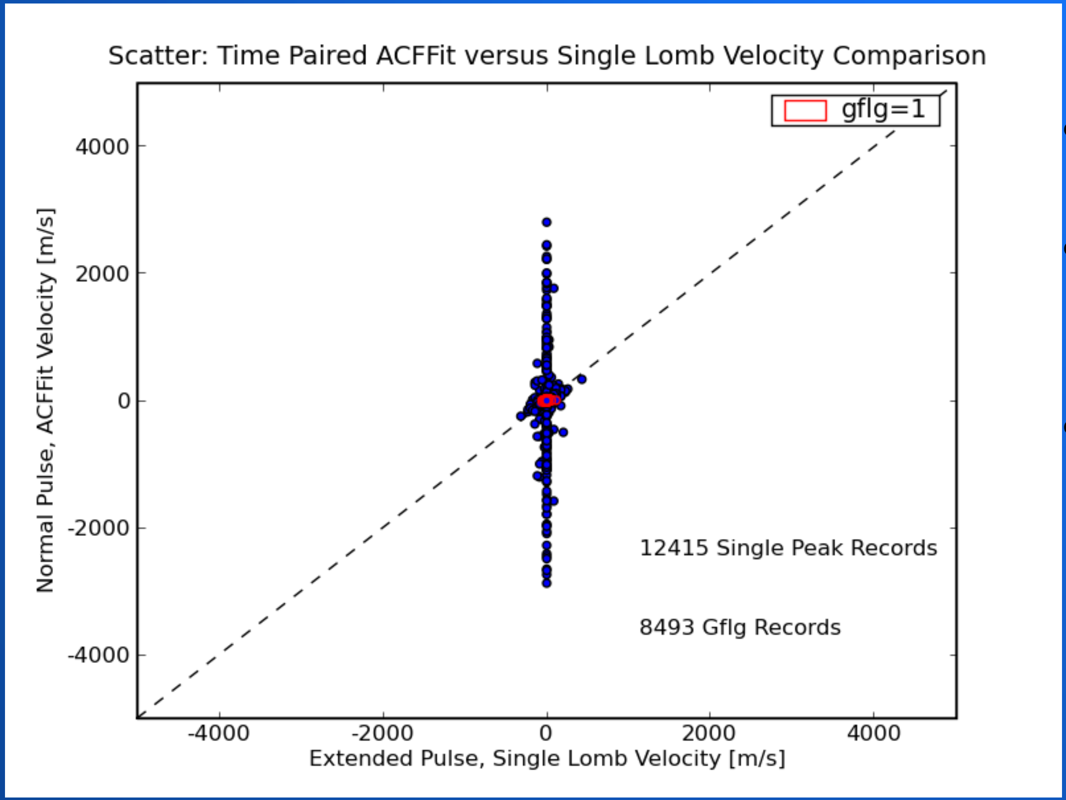


Single Peak Lomb Velocity Analysis Dominates

- Single Lomb Records:
  12415
- Dual Lomb Records:
  329

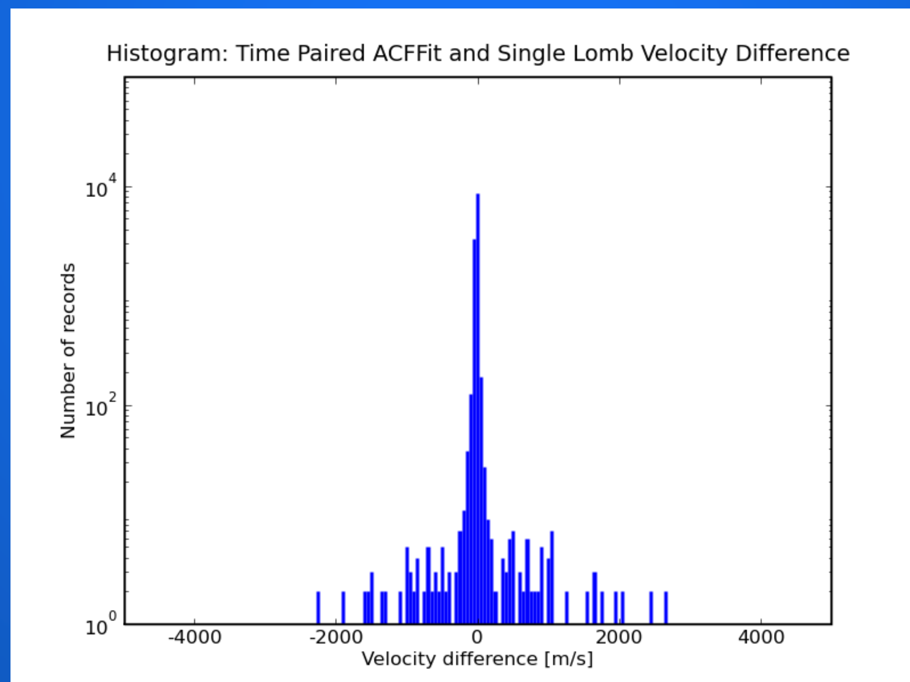


Records with a Single Lomb Velocity Peak

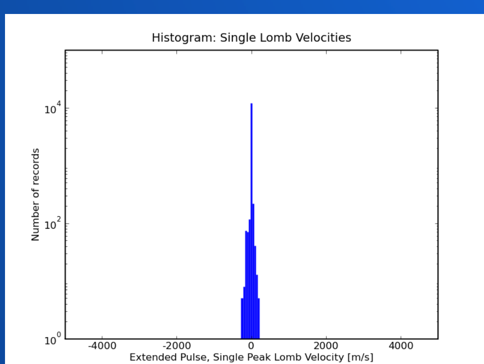


- 12415 time-paired records
- 8493 identified as groundscatter by ACFFit
- All Lomb velocities < 1000 m/s

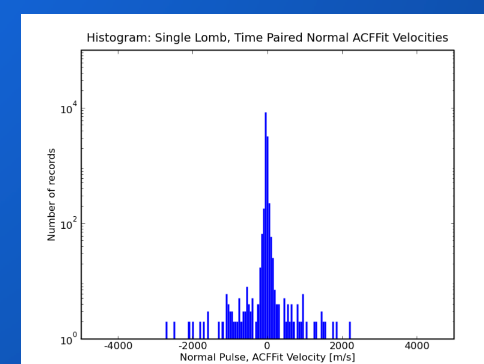
Lomb Velocity Peak is Highly Correlated with ACFFIT Velocity



Most ACFFit and Lomb velocities agree within 50 m/s



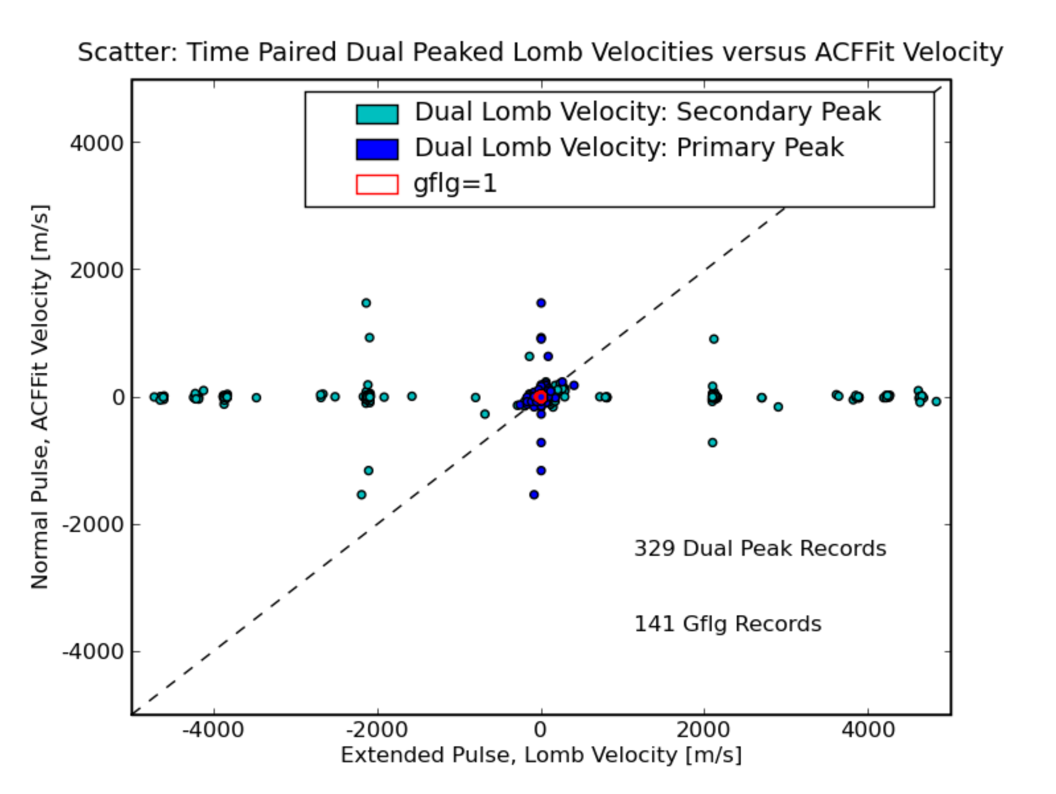
Extended pulse
Lomb peak velocity



Normal pulse
ACFFit velocity

Records with Dual Lomb Velocity Peaks

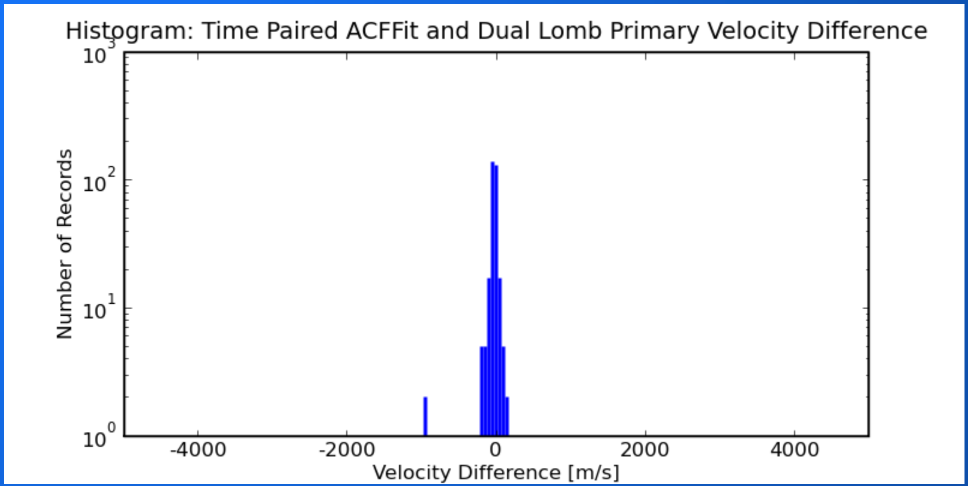
- 329 dual peak records
- 141 identified as groundscatter
- Most probable velocity is typically < 1000 m/s
- Secondary Lomb velocity peaks cluster at velocities > 1000 m/s



Primary Velocity in Dual Peak Lomb Matches ACFFIT Velocity

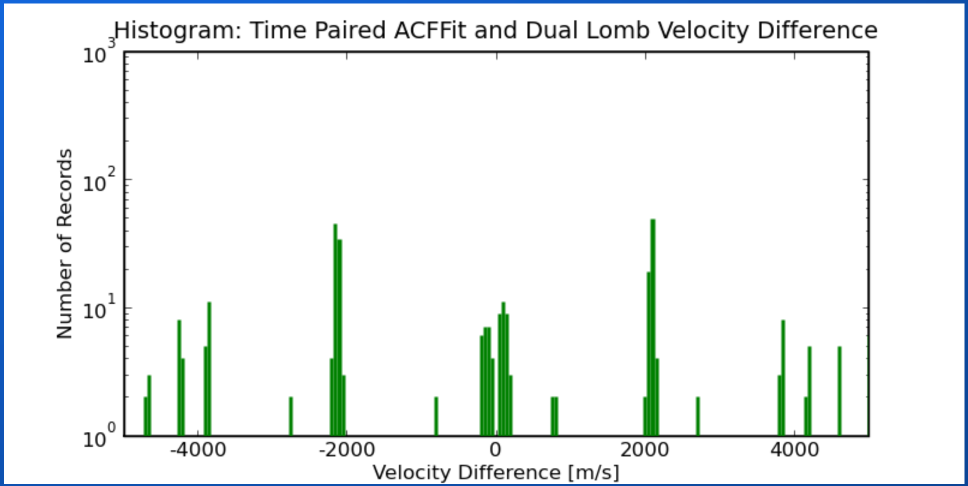
Primary Lomb Velocity:

- Represents most probable velocity in Lomb analysis.
- Velocities are centered near 0 m/s and correlate well with ACFFit velocities.



Secondary Lomb Velocity:

- Highly symmetric clustering of velocities away from 0 m/s.
- Clusters at 2000 m/s associated with records marked as groundscatter by ACFFit.



Summary of Analysis

- Analysis was conducted for a relatively quiet ionosphere, with radar data dominated by groundscatter returns.

- Time-paired extended pulse Lomb and normal ACFFit analysis agree as to the single component nature of the majority of the available line of sight velocity data.

- ~ 3% of the observed pulse ranges have dual Lomb velocity peaks. Multiple peaked ranges have yet to be taken into account.

- Of the dual peak records, the secondary peak velocity distribution also showed an unexplained symmetric behavior not accounted for by sample aliasing.

Future Work

- Implement new peak detection algorithm for use with Lomb analysis.
- Finish implementing complex valued SparSpec algorithm and compare with Lomb velocity analysis results for existing data set.
- Acquire extended pulse data during active ionospheric backscatter activity.