ANALYSIS OF SIGNAL DETECTABILITY WITH NON-COHERENT AND SPECTRAL-BASED PROCESSING

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Practical cloud radar signal processing options

- Pulse-pair algorithm
  - Reflectivity determined from non-coherent power averages
    - Estimate of signal power at range gate *i*: $\langle S_i + N_i \rangle - \langle N \rangle$
    - Velocity derived from phase of covariance of lag0 and lag1 samples
- Spectral processing
  - Power average of *M* FFTs of length *N*
  - Reflectivity, velocity and spectral width from first three moment of power spectrum

Constraints

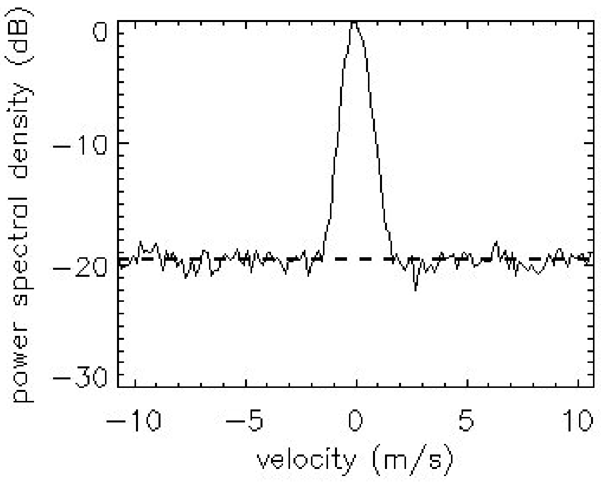
- Total number of samples available=NM:
  - FFT length=N
  - number of spectral averages=M
- Limited number of radar pulses
  - Scanning radar: on the order of NM=100 pulses
  - Fixed pointing: on the order of NM=10,000 pulses

Optimization of spectral processing

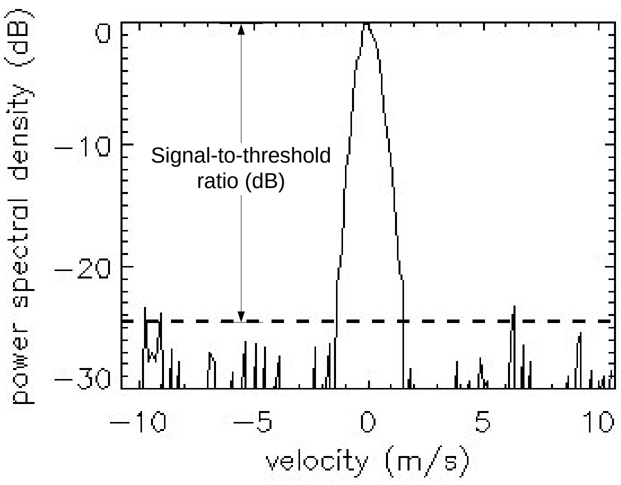
- Find optimal combination of N and M to provided highest probability of detection, P_d, for a given false alarm rate
- Compare to non-coherent P_d to determine which method yields best sensitivity

Typical power spectrum

prior to noise-subtraction



after noise-subtraction

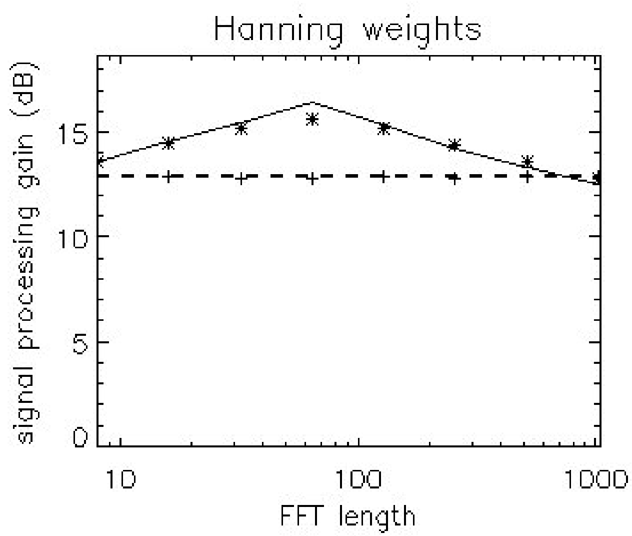


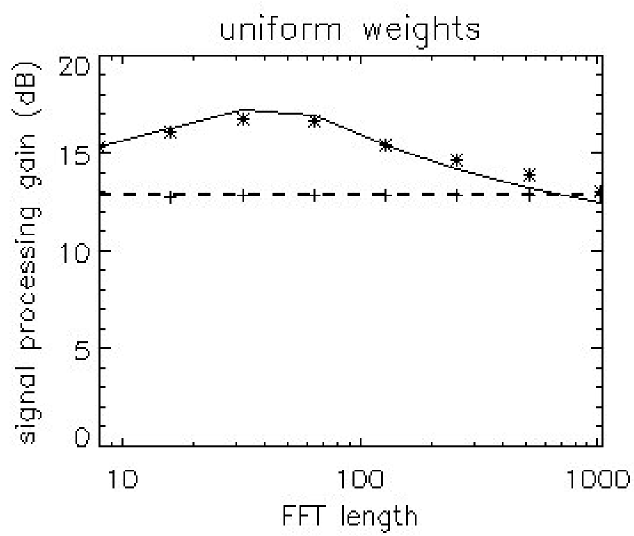
FFT-length for optimal signal-to-threshold ratio

- Function of:
  - Normalized spectral width
  - FFT-weighting function loss factor, L_w
    - ($L_w = \frac{2}{3}$ for Hanning window)

$$N^{opt} = \sqrt{\frac{2ln2}{\pi}} \cdot \frac{1}{L_w \sigma_n} = \sqrt{\frac{ln2}{2\pi}} \cdot \frac{F_p \lambda}{L_w \sigma_v}$$

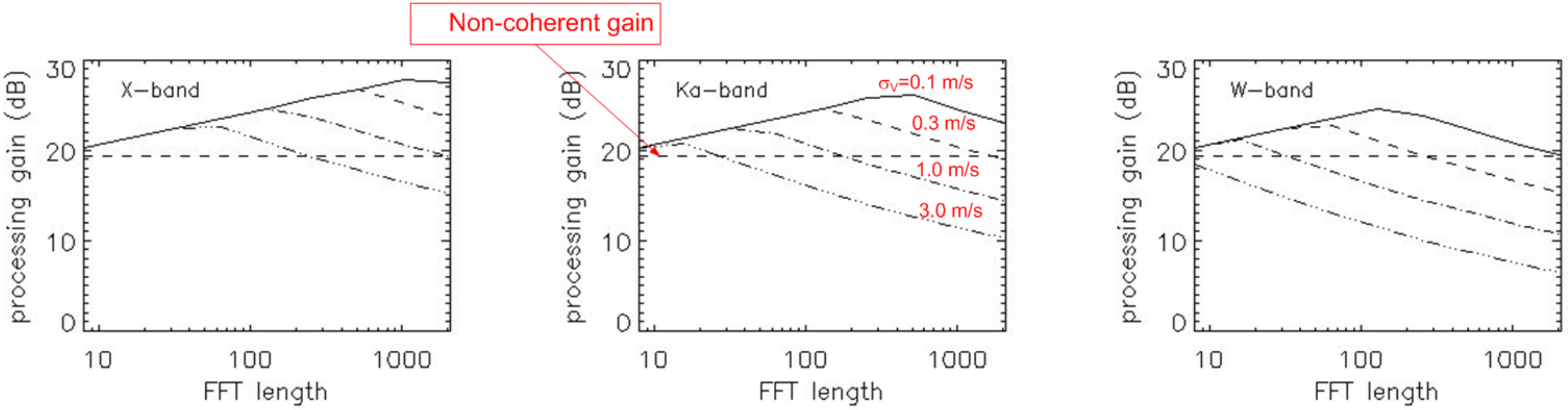
Simulated and theoretical signal processing gain





NM=1024; F_p=5.12 kHz; λ=.0086; σ_v=.3m/s; P_{fa}=.05

Spectral-based signal processing gain: NM=20000

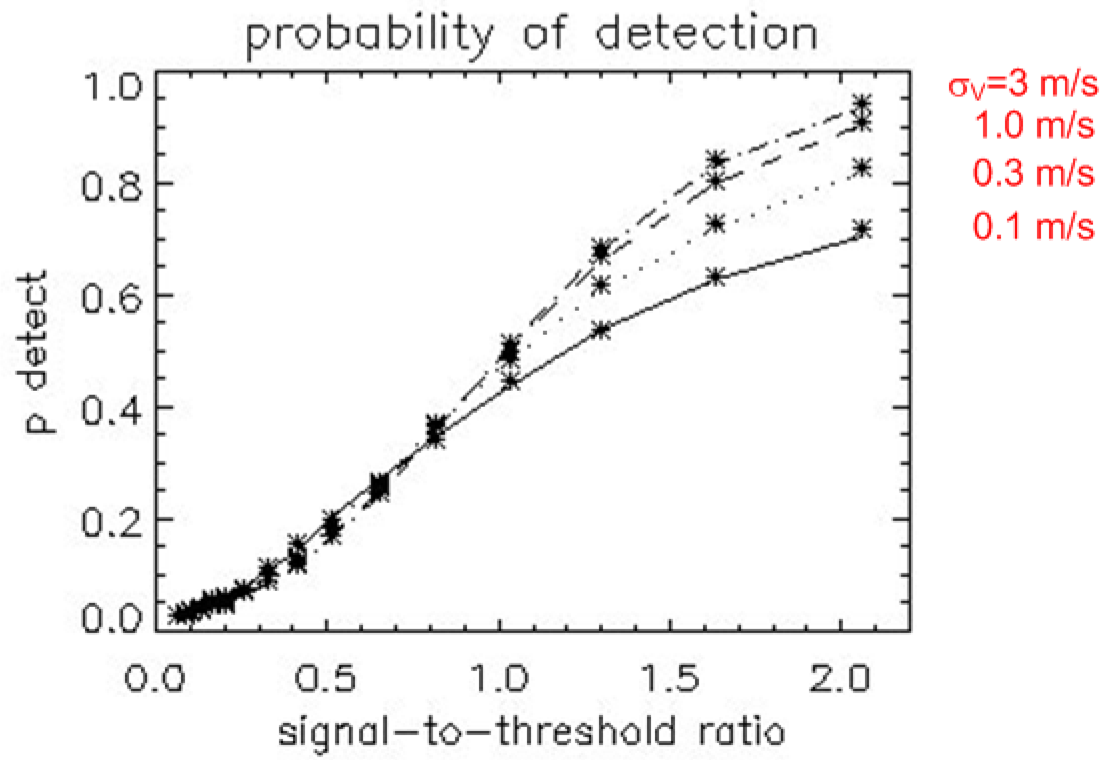


$$G^{opt} = f_{ao}^{-1} F_p \sqrt{\frac{L_w \lambda T_{obs}}{\sigma_v} \sqrt{\frac{ln2}{2\pi}}}$$

Probability of detection

- Probability of detection is a function of the following
  - Number of samples
  - Spectral width
  - PRF
  - Transmit frequency
  - false alarm rate
  - FFT length for spectral processing

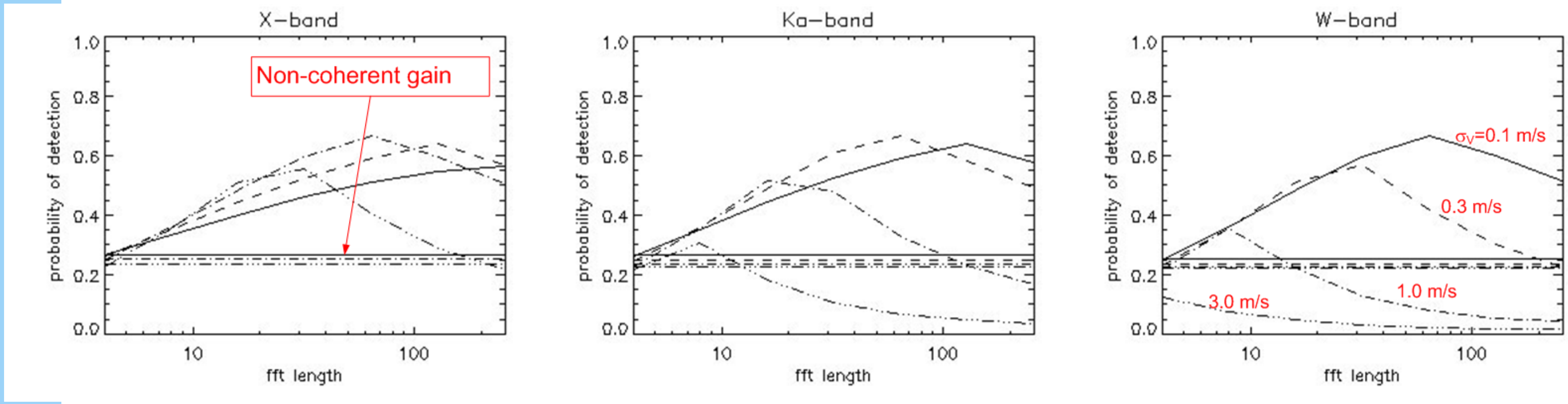
Probability of Detection for Non-coherent processing



P_D for FFT-based processing
for fixed SNR (256 samples)

SNR=-10 dB

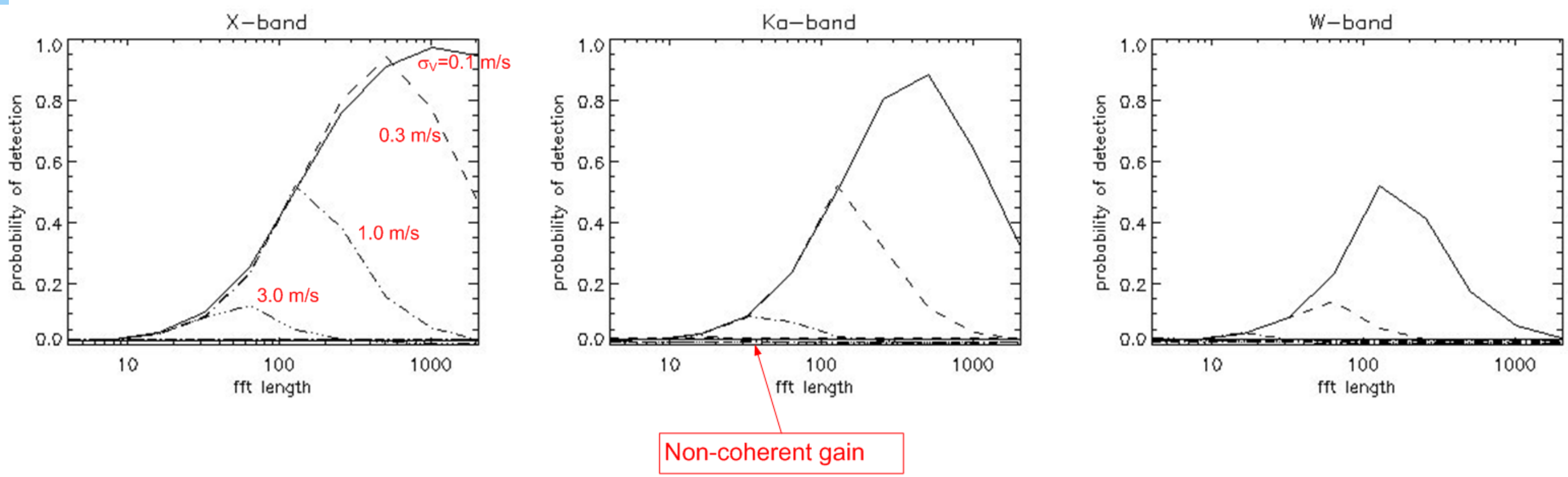
P_{fa}=.01



P_D for FFT-based processing
for fixed SNR (20000 samples)

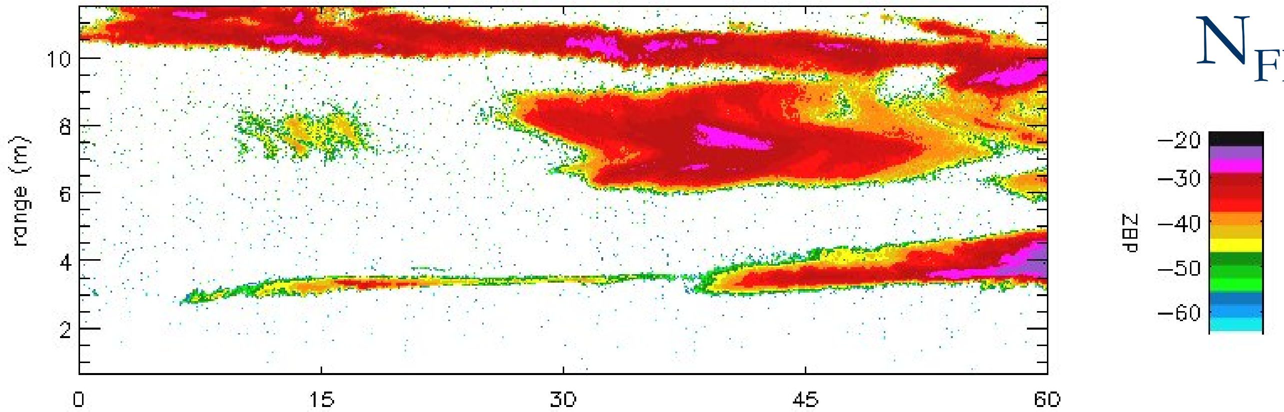
SNR=-24 dB

P_{fa}=.01

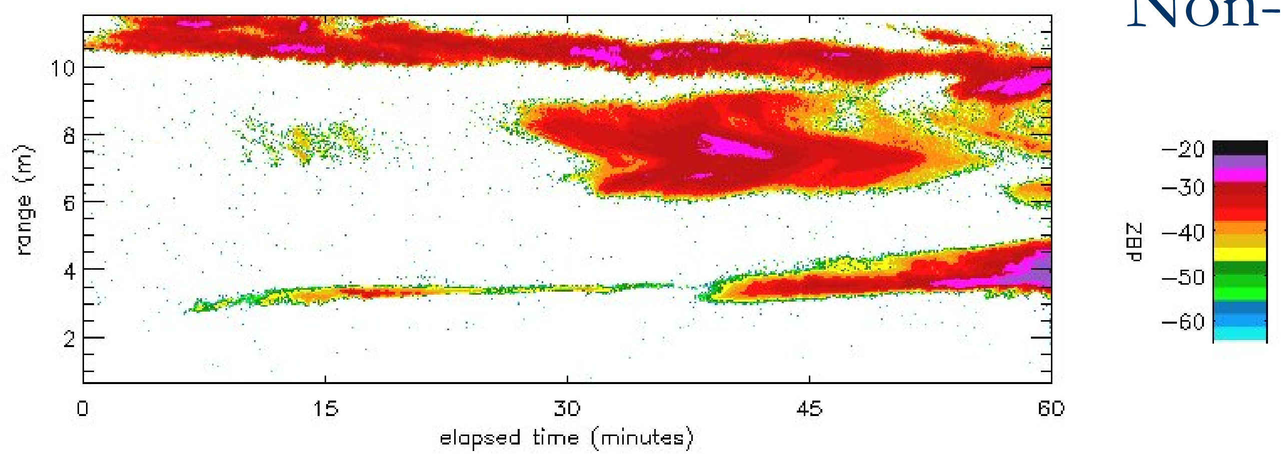


Bottom line: *Benefit of FFT increases with increased dwell time*

W-band Reflectivity P_{FA}=.01 *NM*=10240

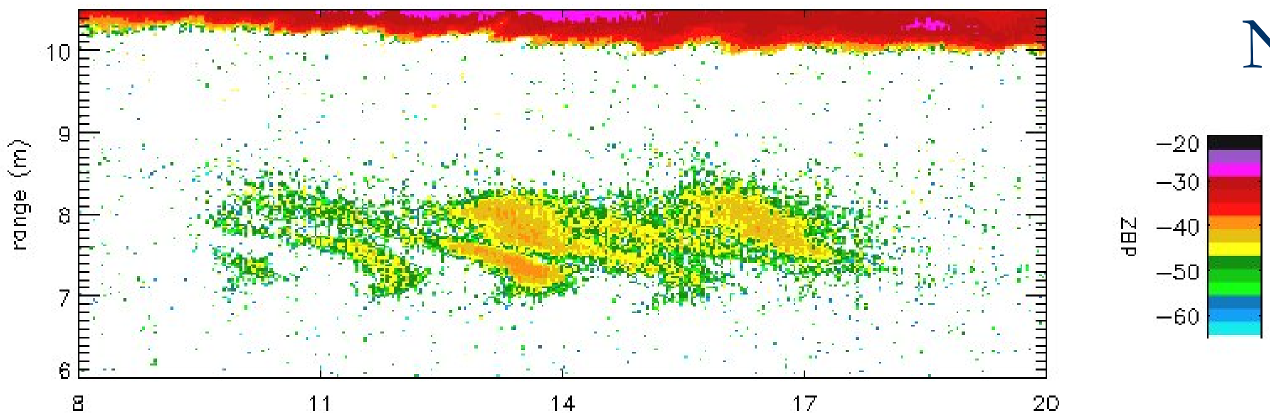


N_{FFT}=128

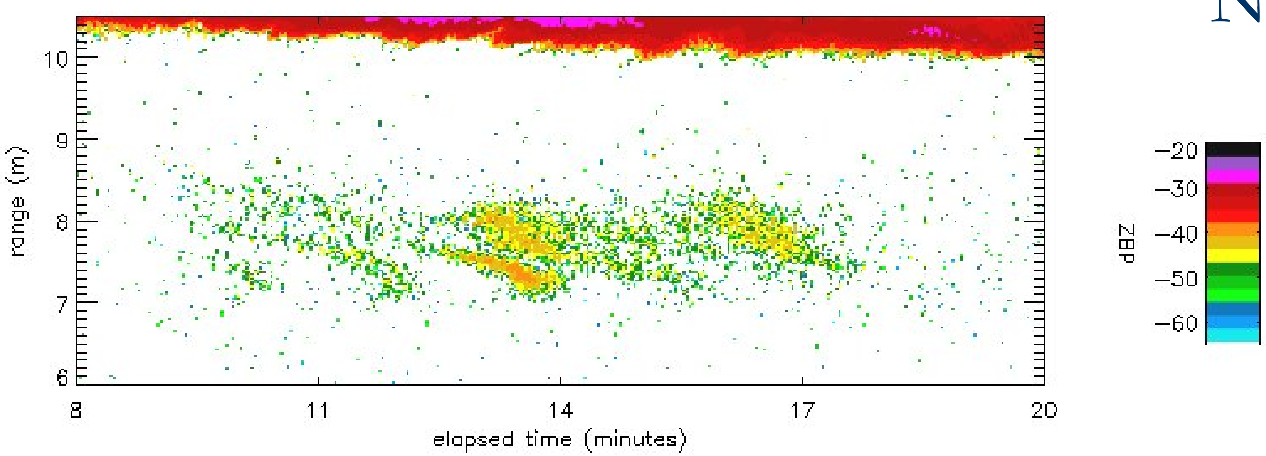


Non-coherent

W-BAND REFLECTIVITY
ZOOMED IN ON WEAK CLOUD LAYER

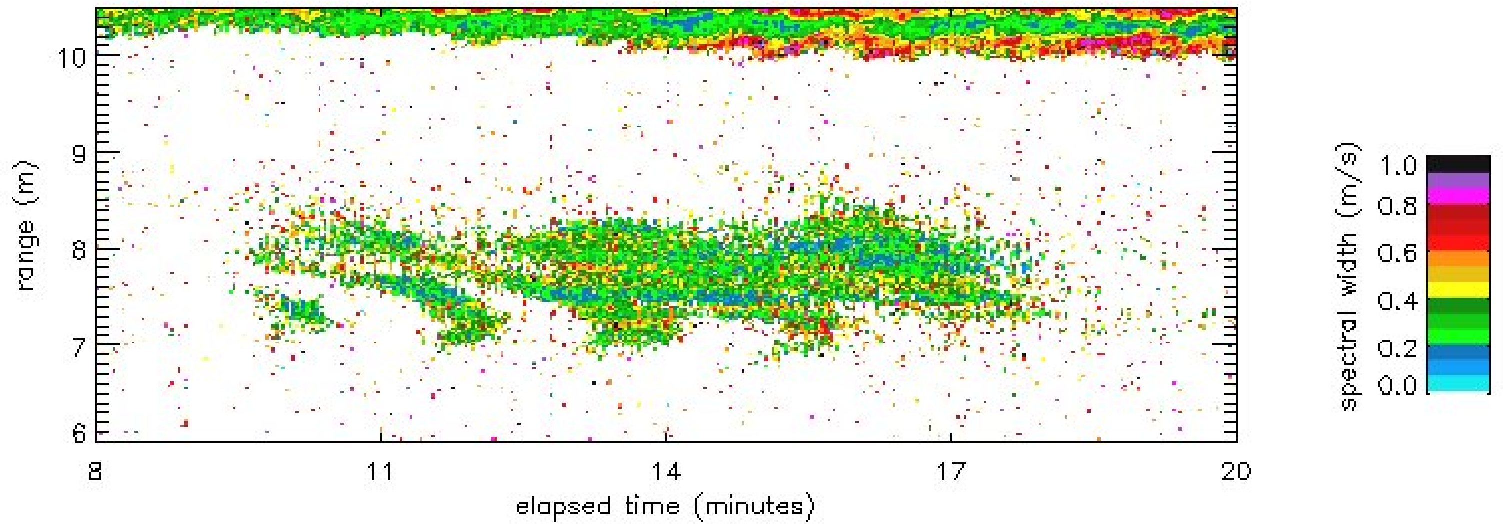


$N_{FFT}=128$

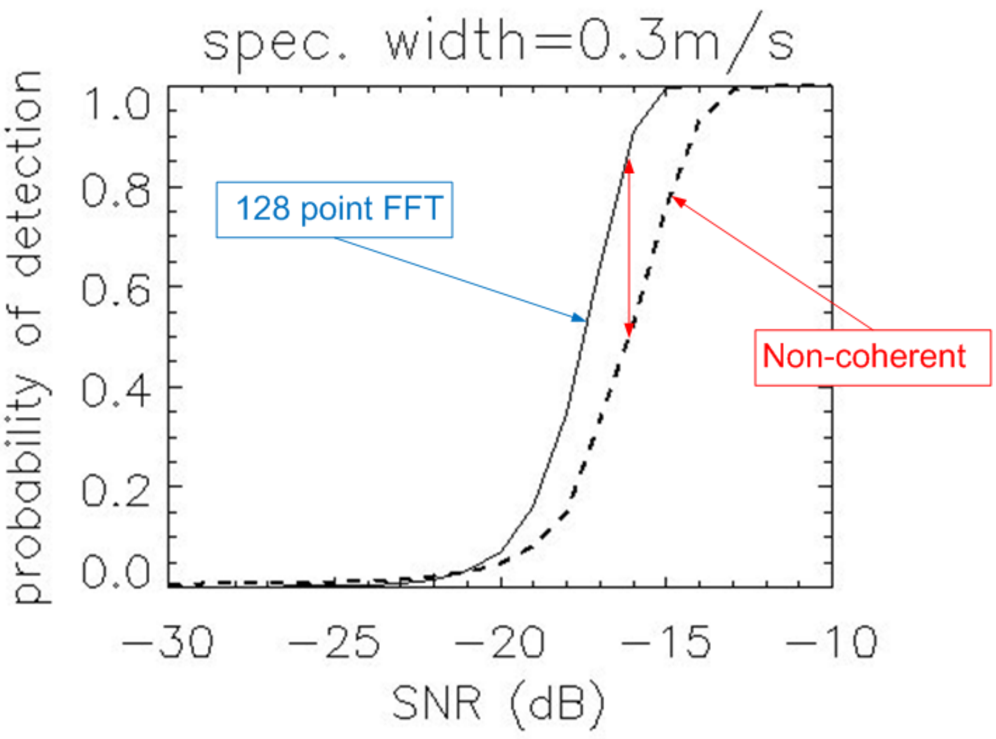


Non-coherent

Spectral width



P_D for W-band
0.3 m/s spectral width; 10240 samples



P_{fa}=.01

What next?

- Next software release computes FFT moments and raw pulse-pair products simultaneously
  - Stores separate files for FFT and PP (doubles data volume)
- Recommendation for near-term
  - Gather X-band, Ka-band and W-band data at select times with both FFT and PP modes
  - Analysis data to confirm theoretical P_d model

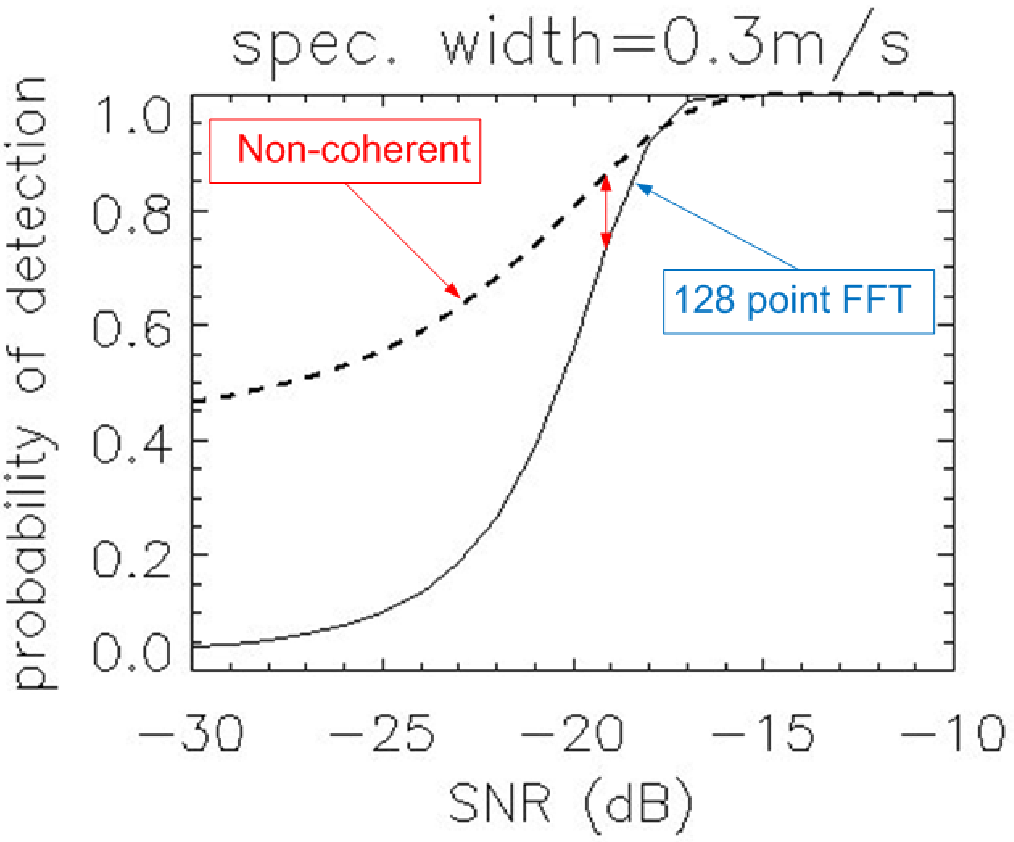
Processing option 1: Select best algorithm given scan type

- Run pulse-pair algorithm when scanning
  - Benefit: frequency hopping to eliminate second trip echo
- Run FFT algorithm when fixed-pointing

Option 2: Merged data product with optimal sensitivity, minimum variance

- Run simultaneous FFT and pulse pair algorithms
- Near-real time program running on separate computer to merge FFT and pulse-pair data
- Use Kalman-filter concepts to optimally combine data
  - Requires additional theoretical study formulating biases and variances for spectral-based moments

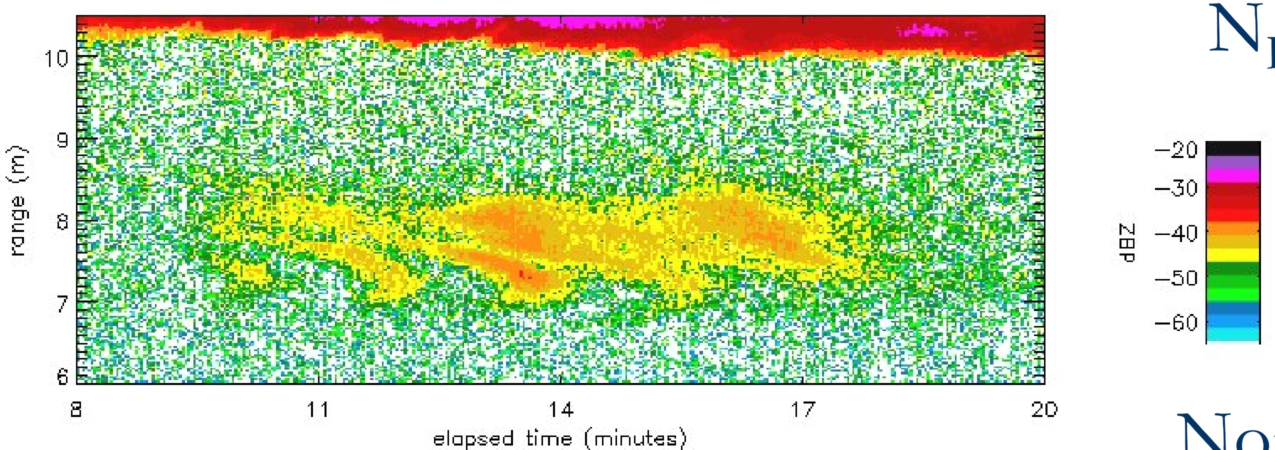
P_D for W-band
0.3 m/s spectral width; 10240 samples



$P_{fa}=.5$

W-band reflectivity P_{FA}=.5 zoomed in on weak cloud layer

N_{FFT}=128



Non-coherent