Pathfinder Advanced Radar Ice Sounder :PARIS

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Agenda

PARIS: Pathfinder Advanced Radar Ice Sounder

2007 Mission to Greenland

The Way Forward

Objective

Develop techniques to enable and/or to enhance the visibility of internal layering and bottom topography of (*continental*) ice sheets when probed (*sounded*) by a high-altitude radar (*from aircraft or spacecraft*)

Perspective

The Major Challenges: Clutter; Weak Signals

Clutter dimensions: **Along-track suppression**
Across-track suppression

Weak signal mitigation: **Innovative radar design**
large dynamic range, very low side-lobes, extreme linearity, generous power

NASA-IIP-supported proof-of-concept system: PARIS

150 MHz (*vision: Antarctica; planetary prototype*)
High altitude (*first successful demonstration, P-3 aircraft*)

Prototype for PARIS: D2P radar altimeter

(*previous NASA IIP project*)

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- Along-track clutter suppression
- Delay-Doppler processing
- Radar design: key features

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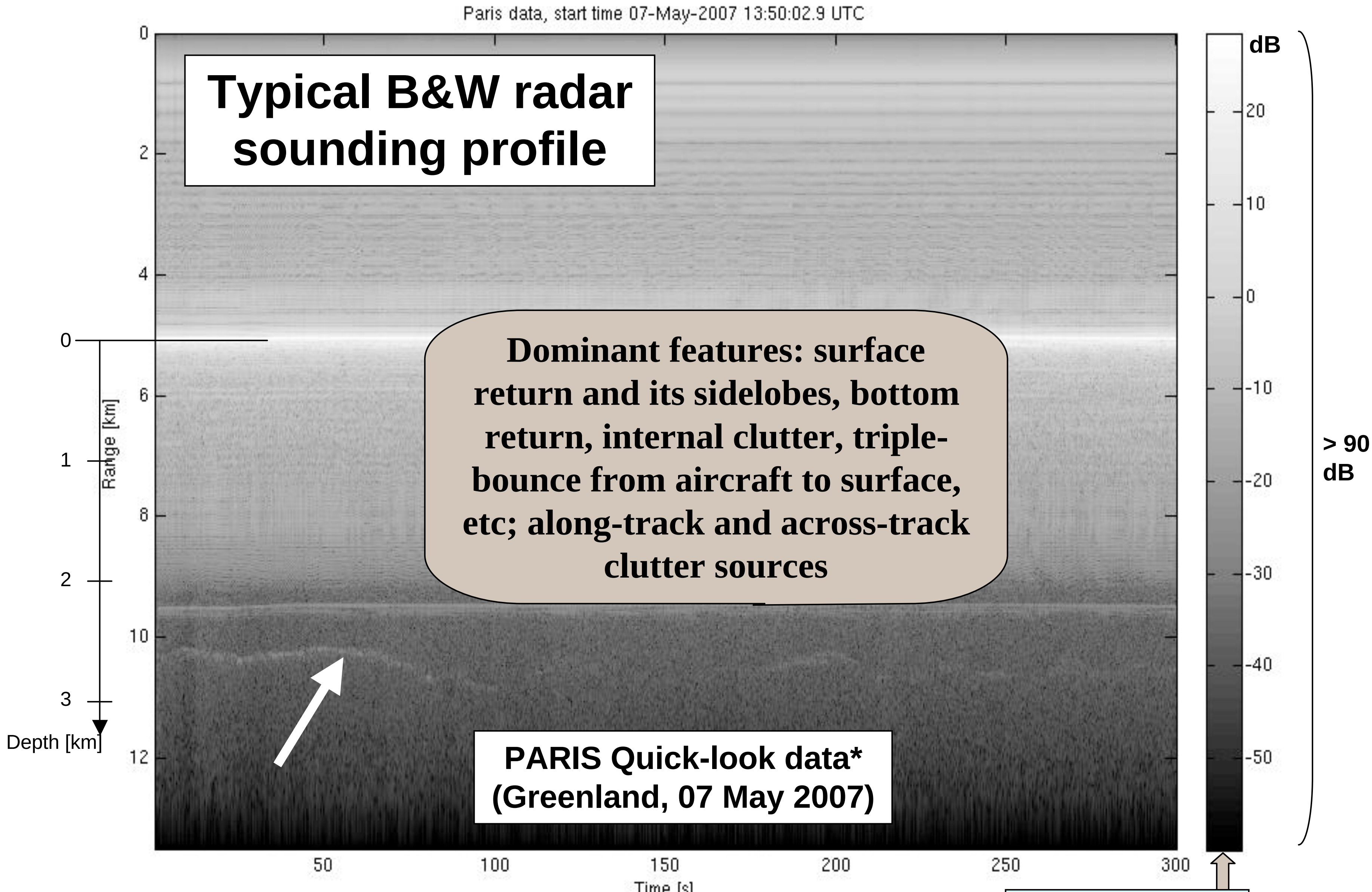
APL

Typical B&W radar sounding profile

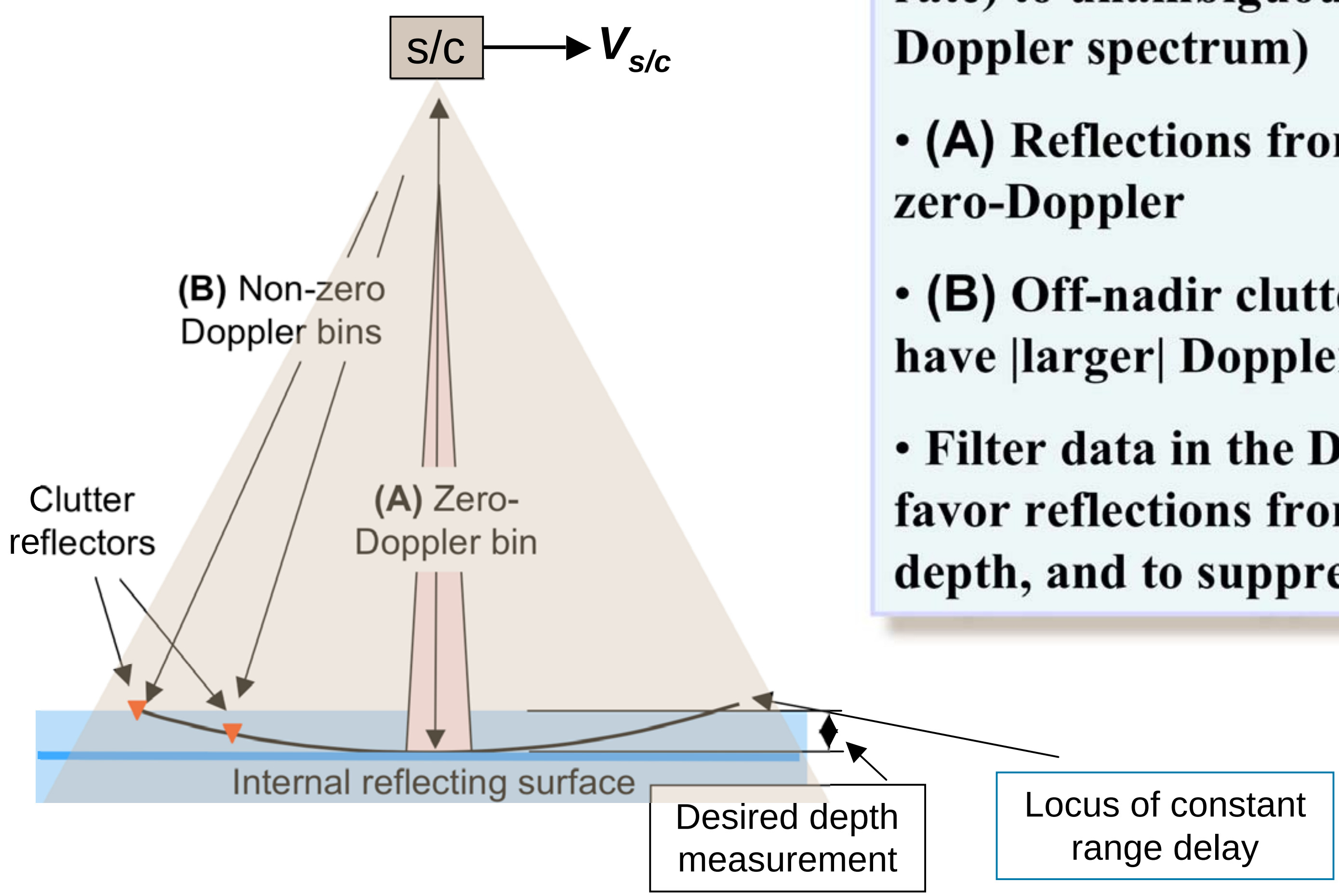


*No Doppler processing, range compression with an approximate matched filter

Excellent radar dynamic range

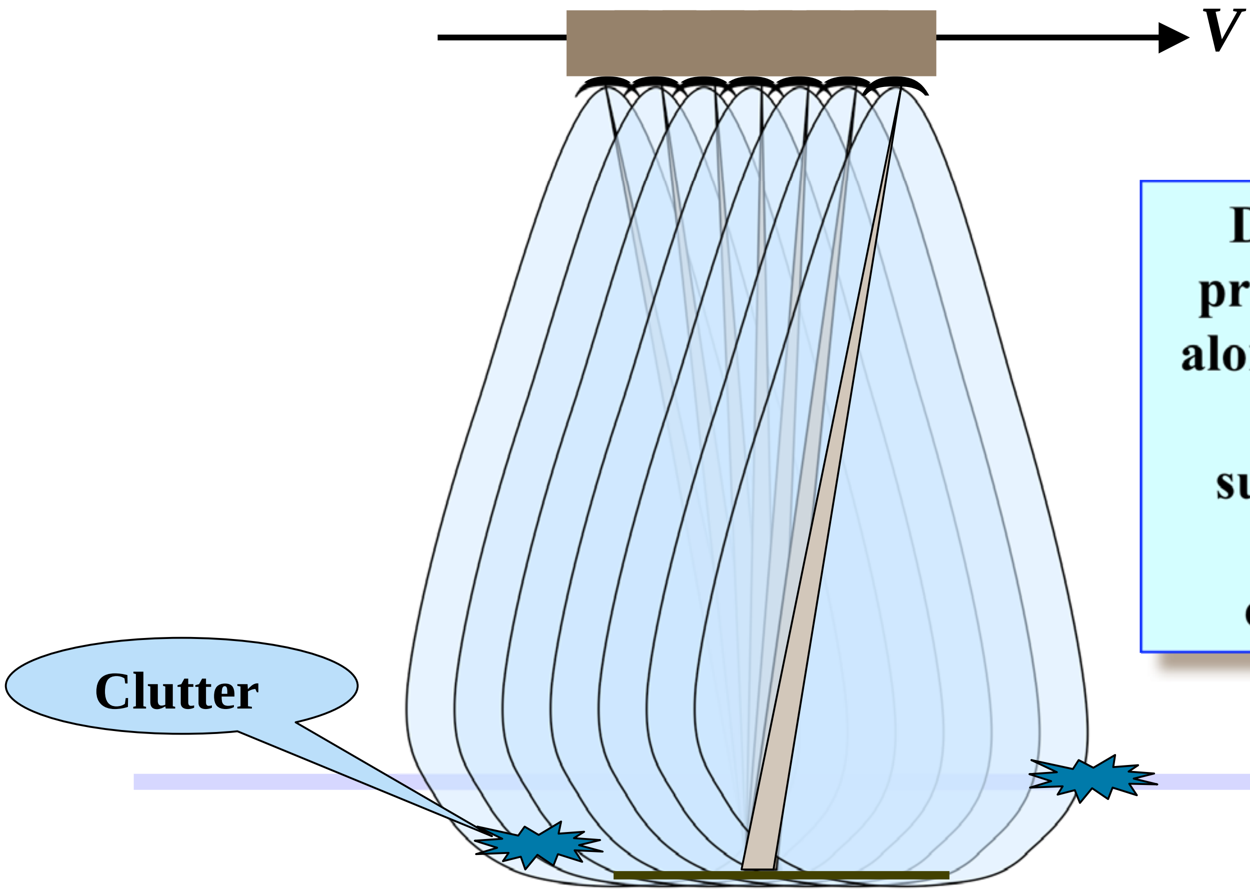
Along-Track Clutter Suppression: Partially-Coherent Doppler

View of along-track plane



- **Transmit "high" PRF (> Nyquist rate) to unambiguously retain Doppler spectrum)**
- **(A) Reflections from nadir will be at zero-Doppler**
- **(B) Off-nadir clutter reflections will have |larger| Doppler frequencies**
- **Filter data in the Doppler domain to favor reflections from layers and depth, and to suppress clutter**

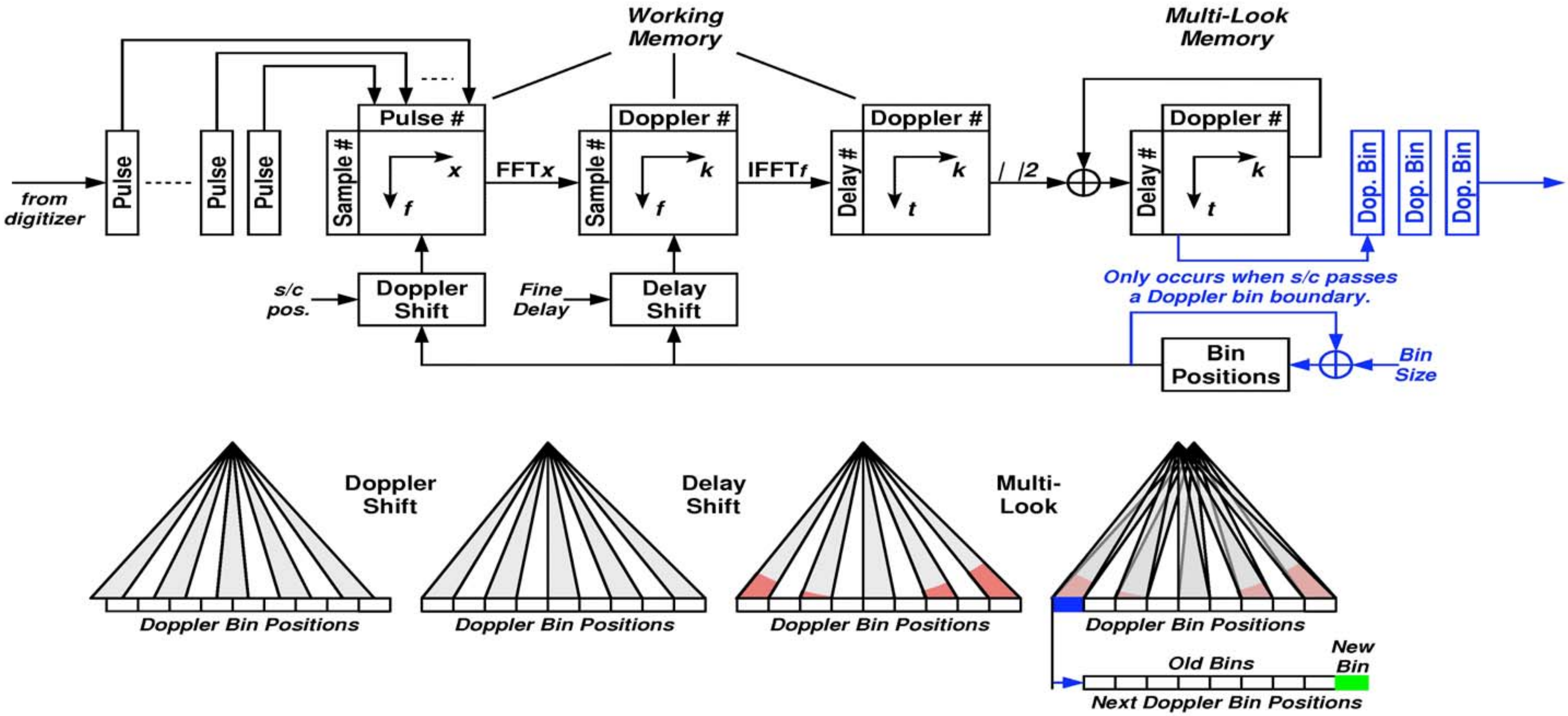
Along-Track Clutter Suppression: Doppler



Delay-Doppler processing selects along-track (small) footprints, suppressing off-nadir clutter contributions

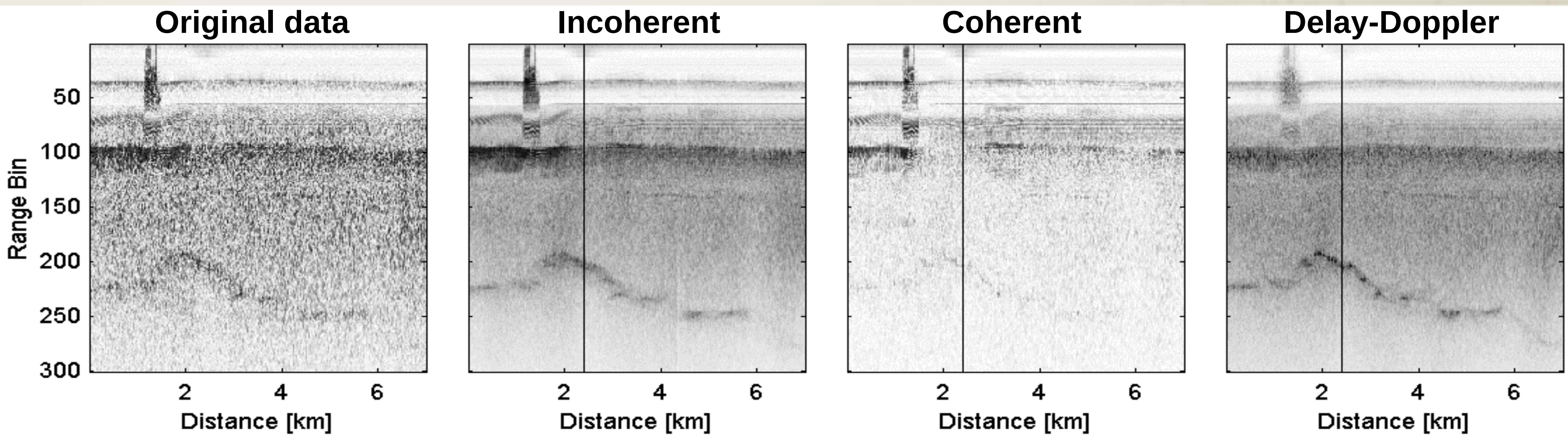
Delay-Doppler Technique

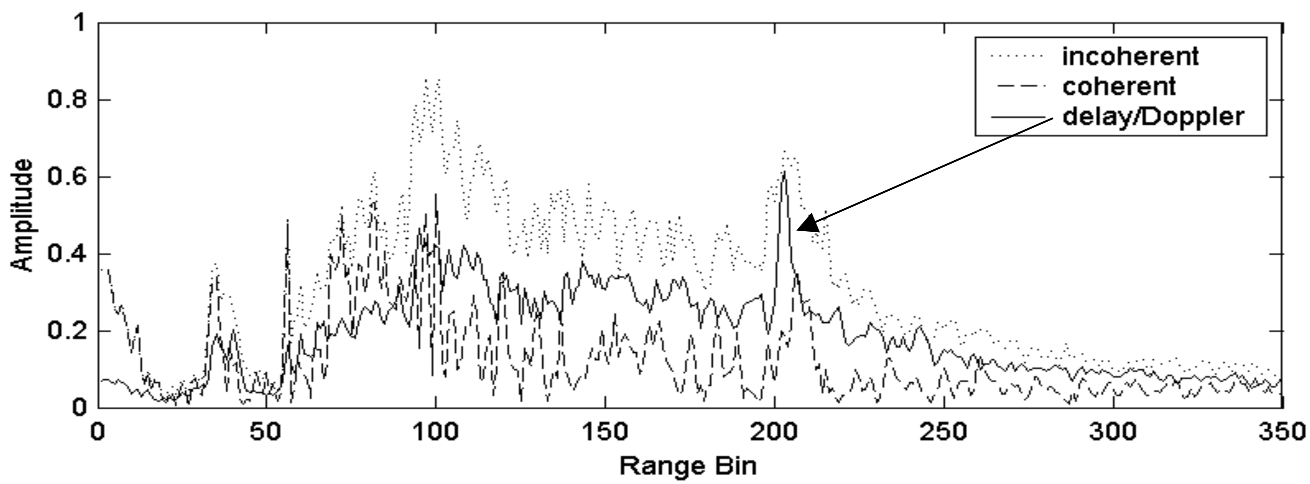
Spacecraft altimeter example



In situ **sounding: dielectrics of ice differ from air => different velocity of propagation and Doppler scaling in ice.**

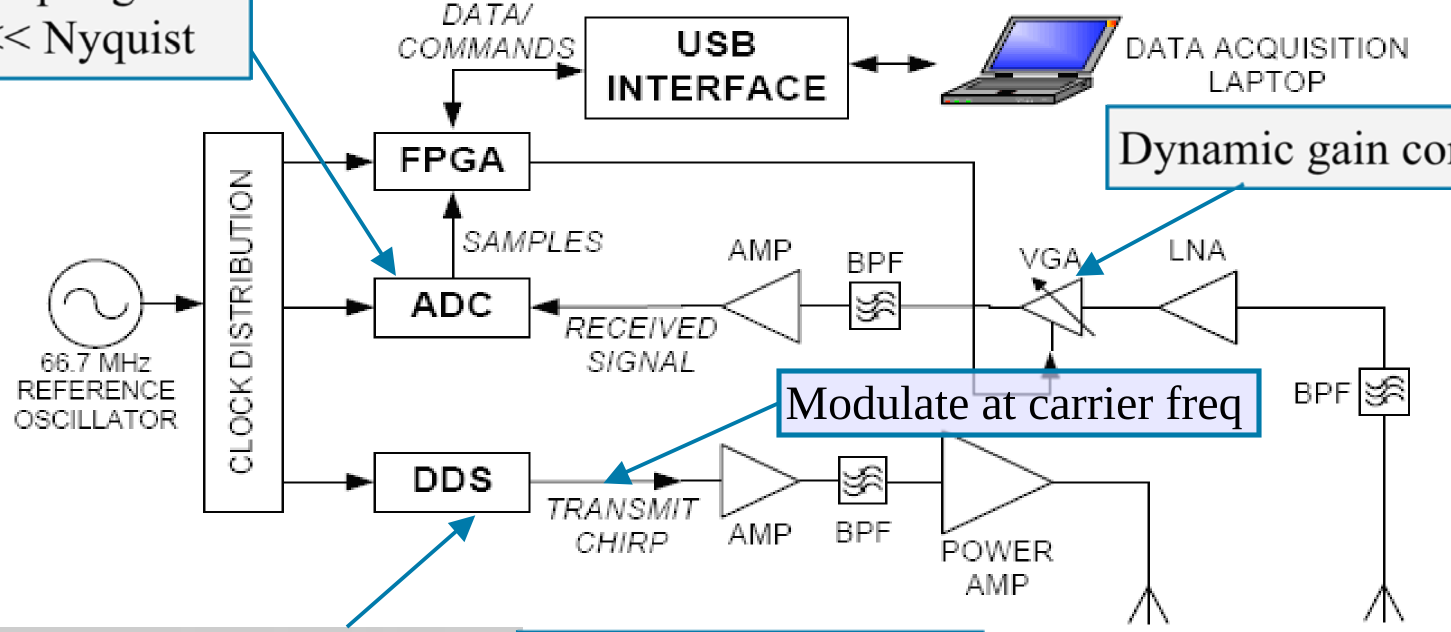
Benefits of partially-coherent Doppler processing





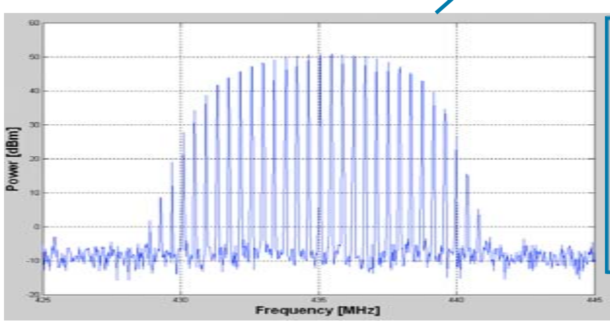
Radar sounder architecture (*minimize RF operations*)

Sampling rate << Nyquist



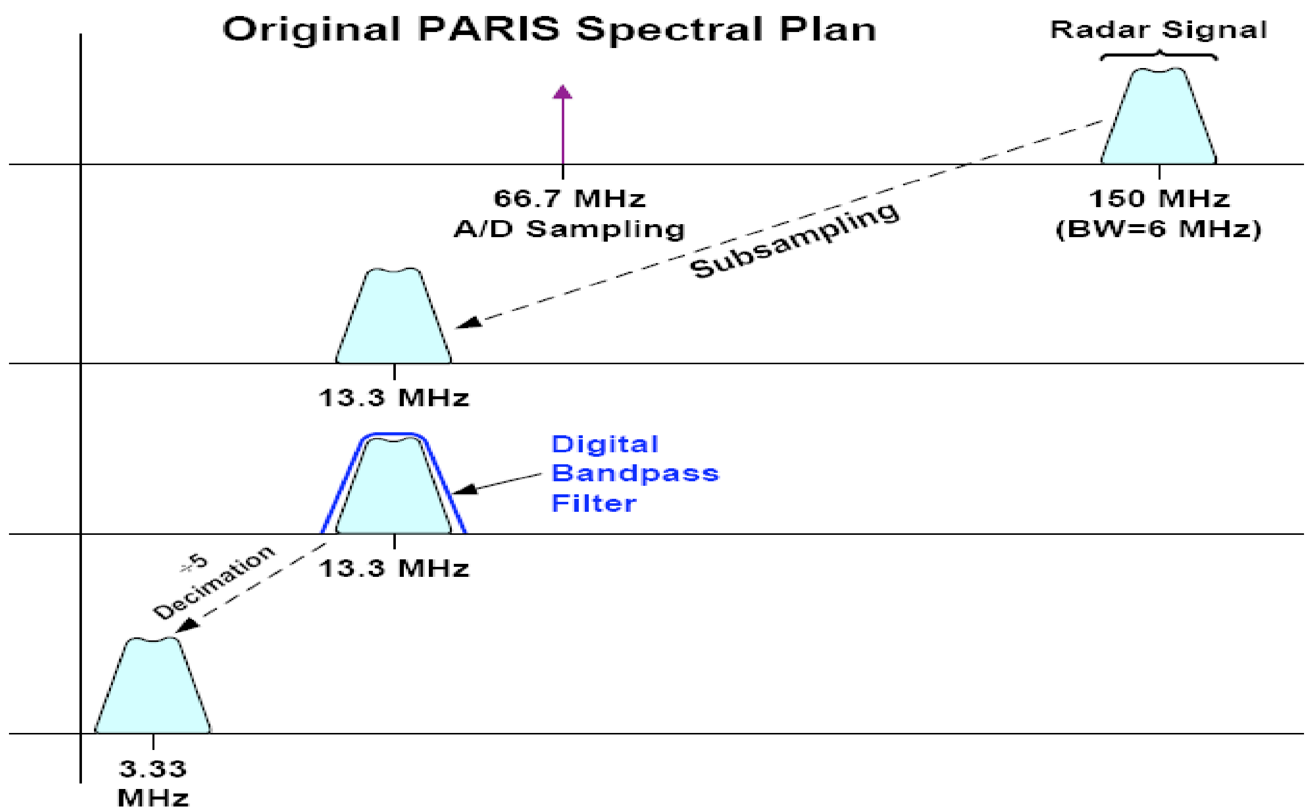
Dynamic gain control (STC)

Modulate at carrier freq



Heavily weighted waveform is essential to suppress remote sidelobes

Design: isolate aliased (under-sampled) signals



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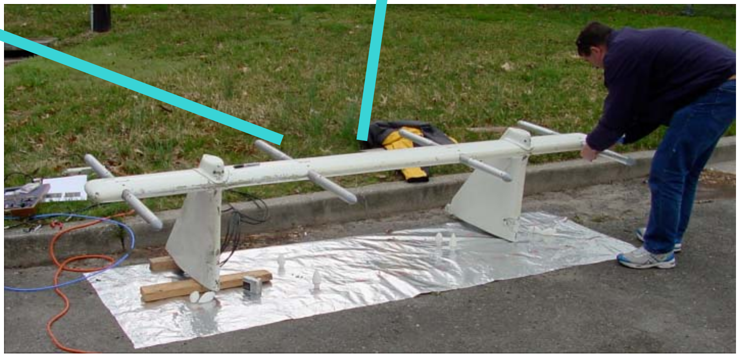
- **Quick-time and initial results**

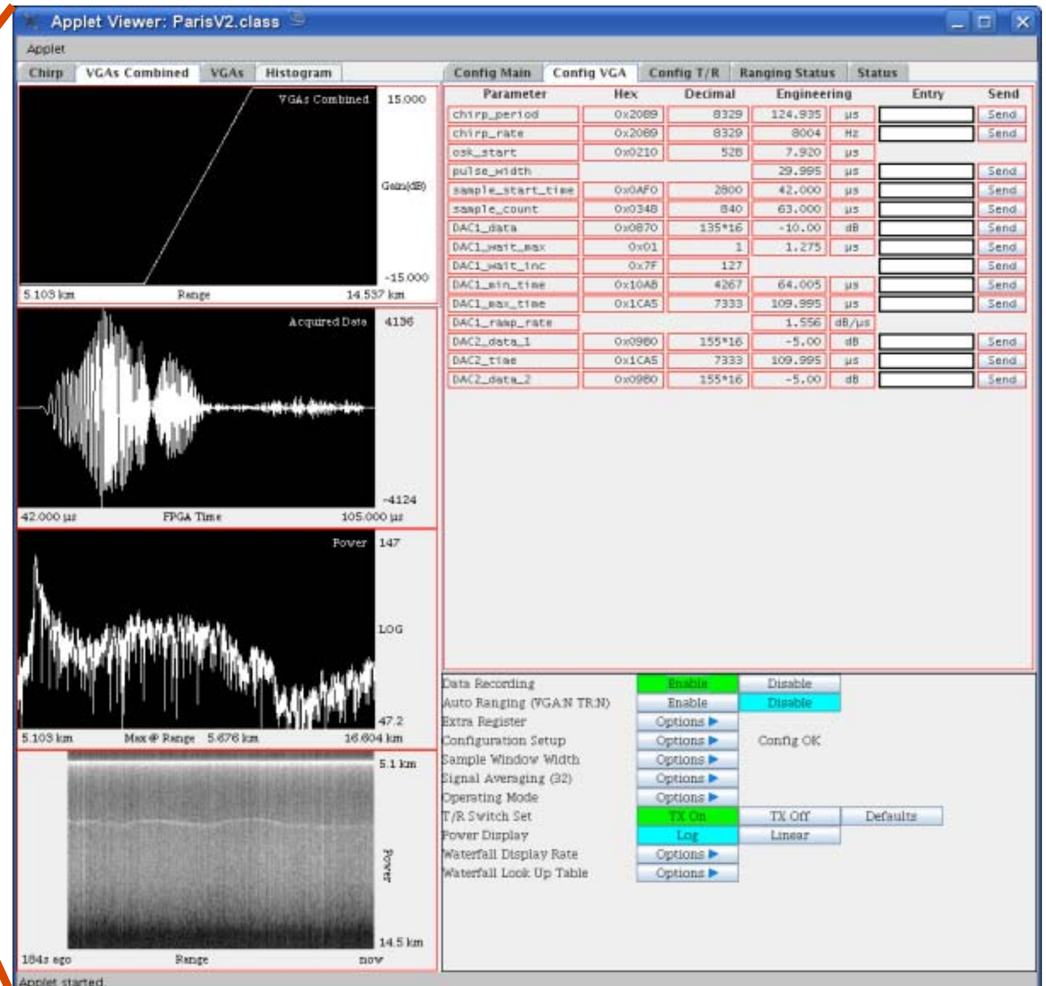
The Way Forward

PARIS on the NASA P-3



- **Univ. of Kansas' CRESIS antennas (shared with PARIS)**

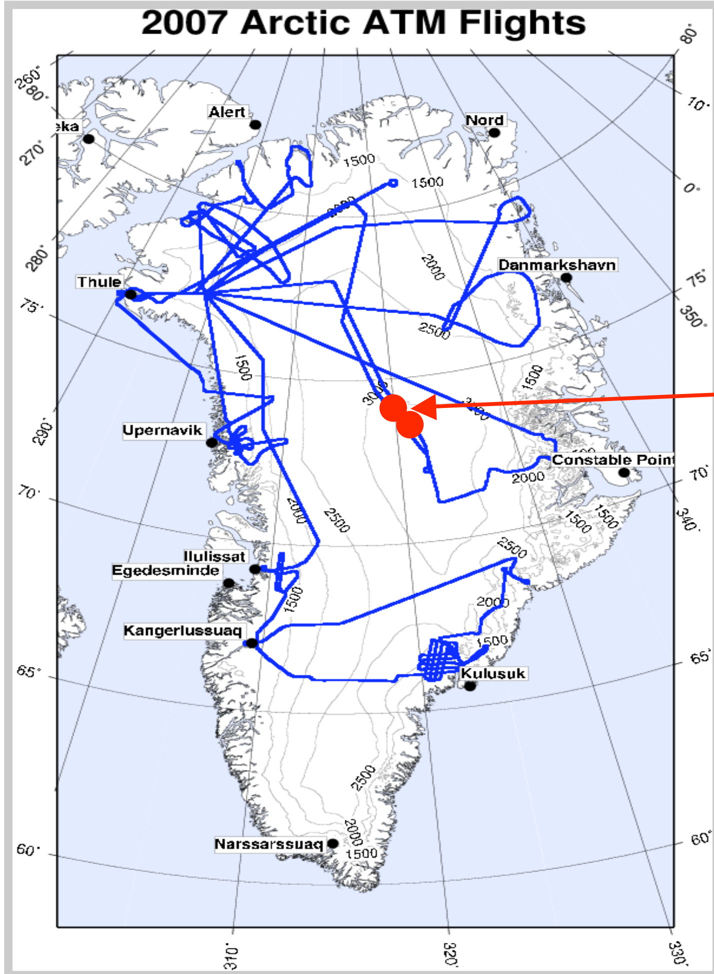
PARIS: Inside the P-3



PARIS-I Radar in Operation

Arctic '07 Mission Tracks

- **PARIS shared the NASA P-3 w/ Airborne Topographic Mapper (ATM)**
- **PARIS operated during ATM (low-altitude) flights**
- **925 GB of PARIS data collected over 10 days**
- **High altitude data acquired 04 and 07 May**



Sample Data 07 May

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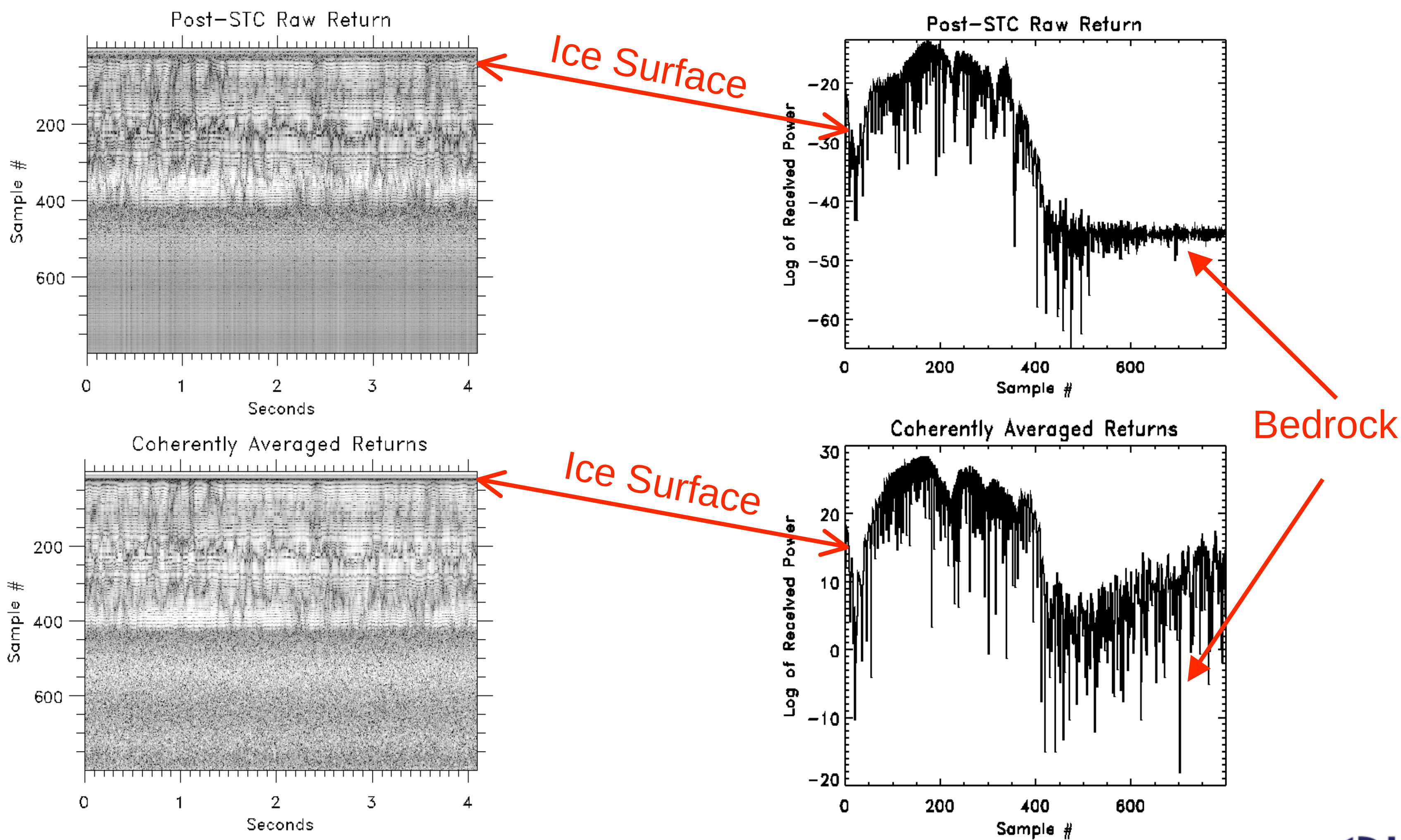
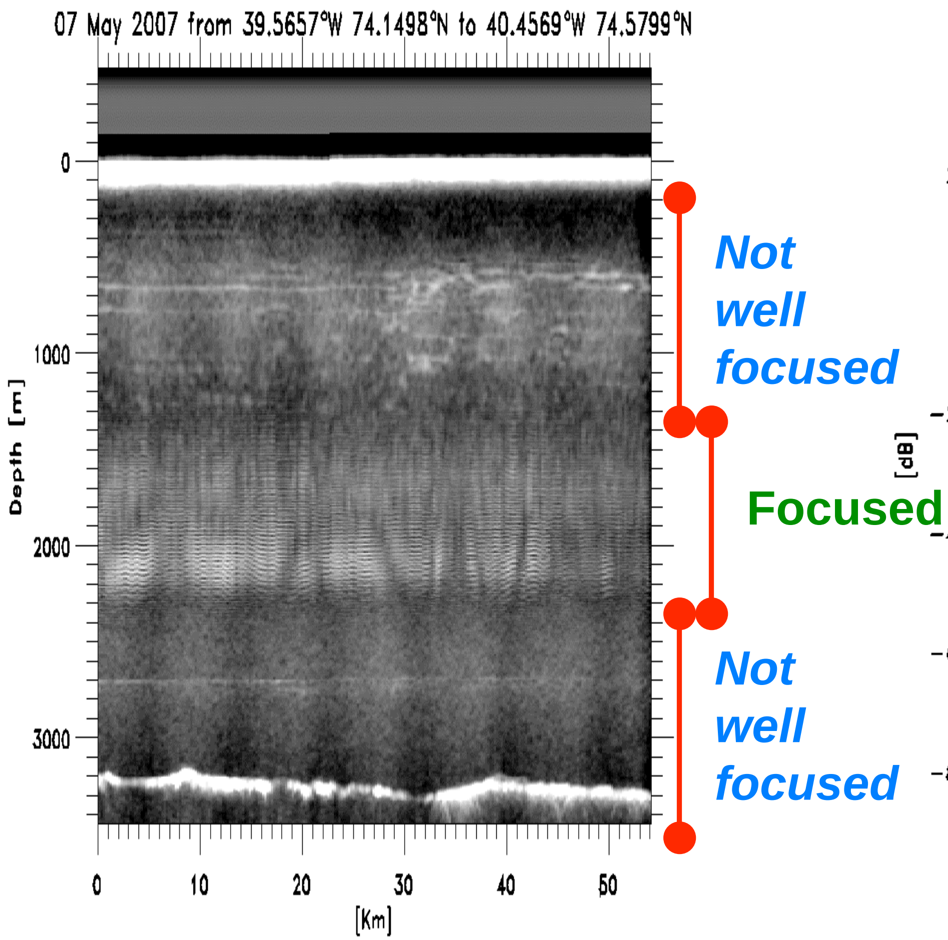
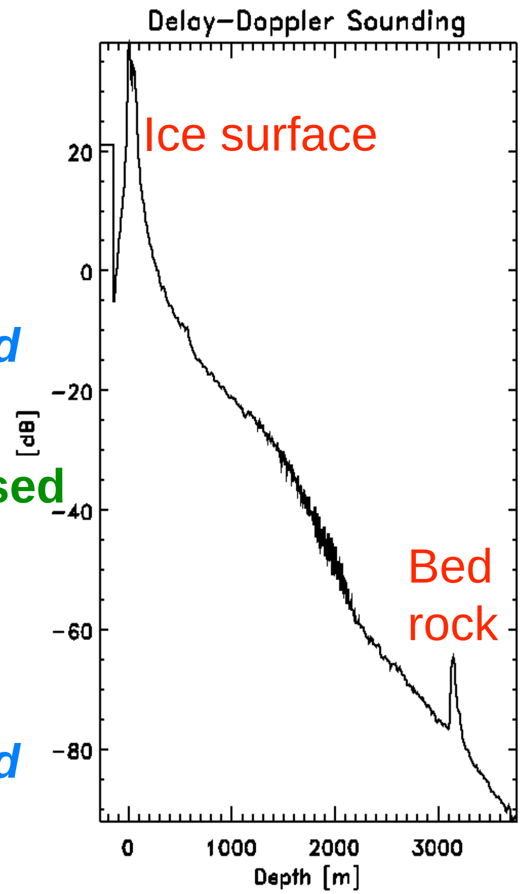
Raw Data 07 May 2007 14:10:45-14:16:00

(sub-sample – first four seconds)



Delay-Doppler (*partially-coherent*) Sounding





Processing continues to progress.

> Range focus of top and bottom third of ice

> Along-track "scalloping"

> Extend to more difficult clutter-limited cases

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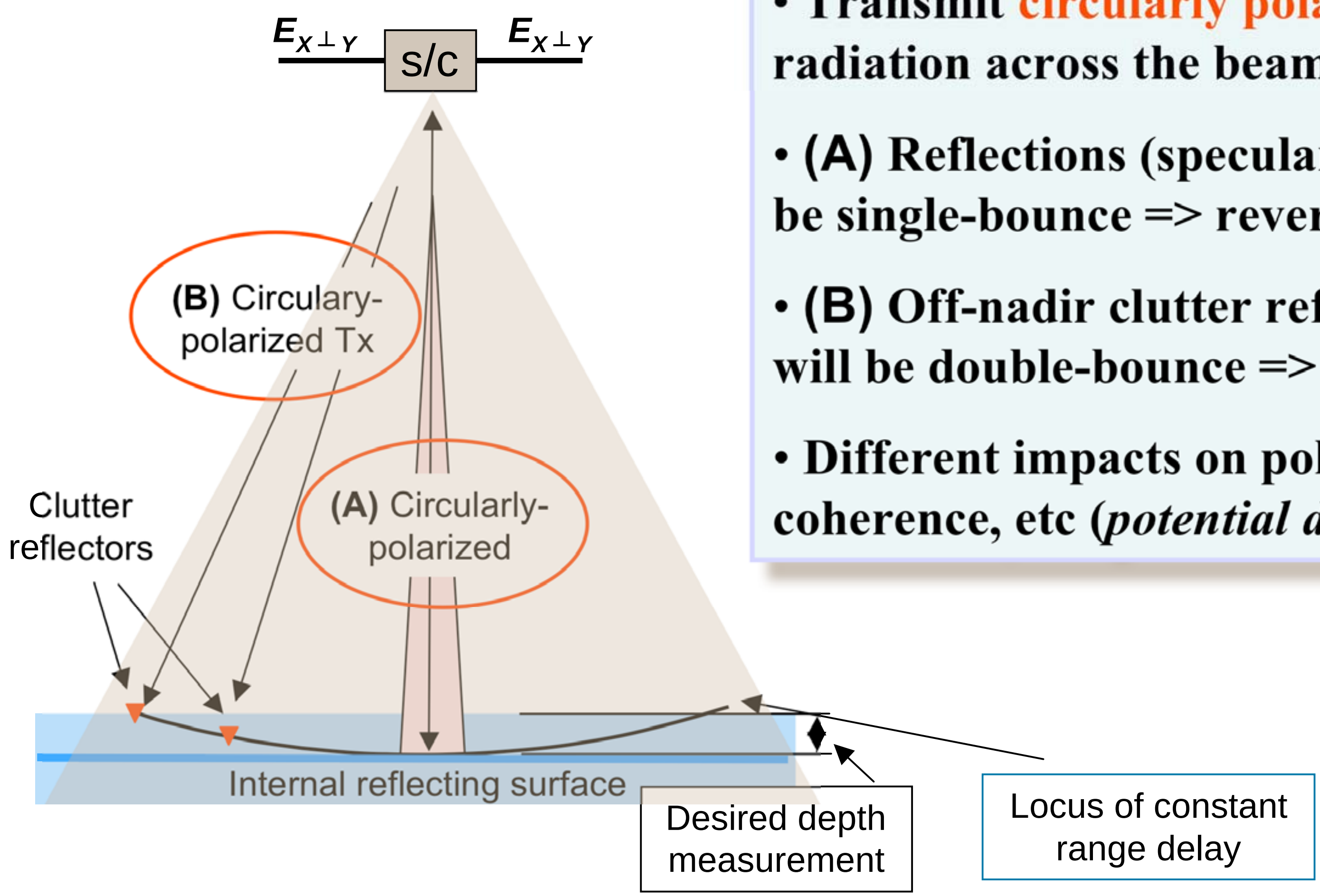
The Way Forward

- Refine along-track processing algorithm
- Cross-track clutter suppression
- Conclusions

Cross-Track Clutter Suppression: Polarization (*new concept*)

View of cross-track plane



- **Transmit circularly polarized (CP) radiation across the beam**
- **(A) Reflections (specular) from nadir will be single-bounce => reversed sense CP**
- **(B) Off-nadir clutter reflections usually will be double-bounce => same sense CP**
- **Different impacts on polarization, coherence, etc (*potential discriminants*)**

Why Transmit Circular Polarization?

- **Single-bounce (specular) reflection always reverses the sense of the illuminating (circular) polarity**

- **(*Linear polarization sense-reversal is not observable*)**

- **Most reflections from nadir (and from depth) will be specular => opposite sense circularly polarized**

- **Specular reflections => high coherence (~ degree of polarization)**

- **Reflections from clutter almost always will have different polarization properties**

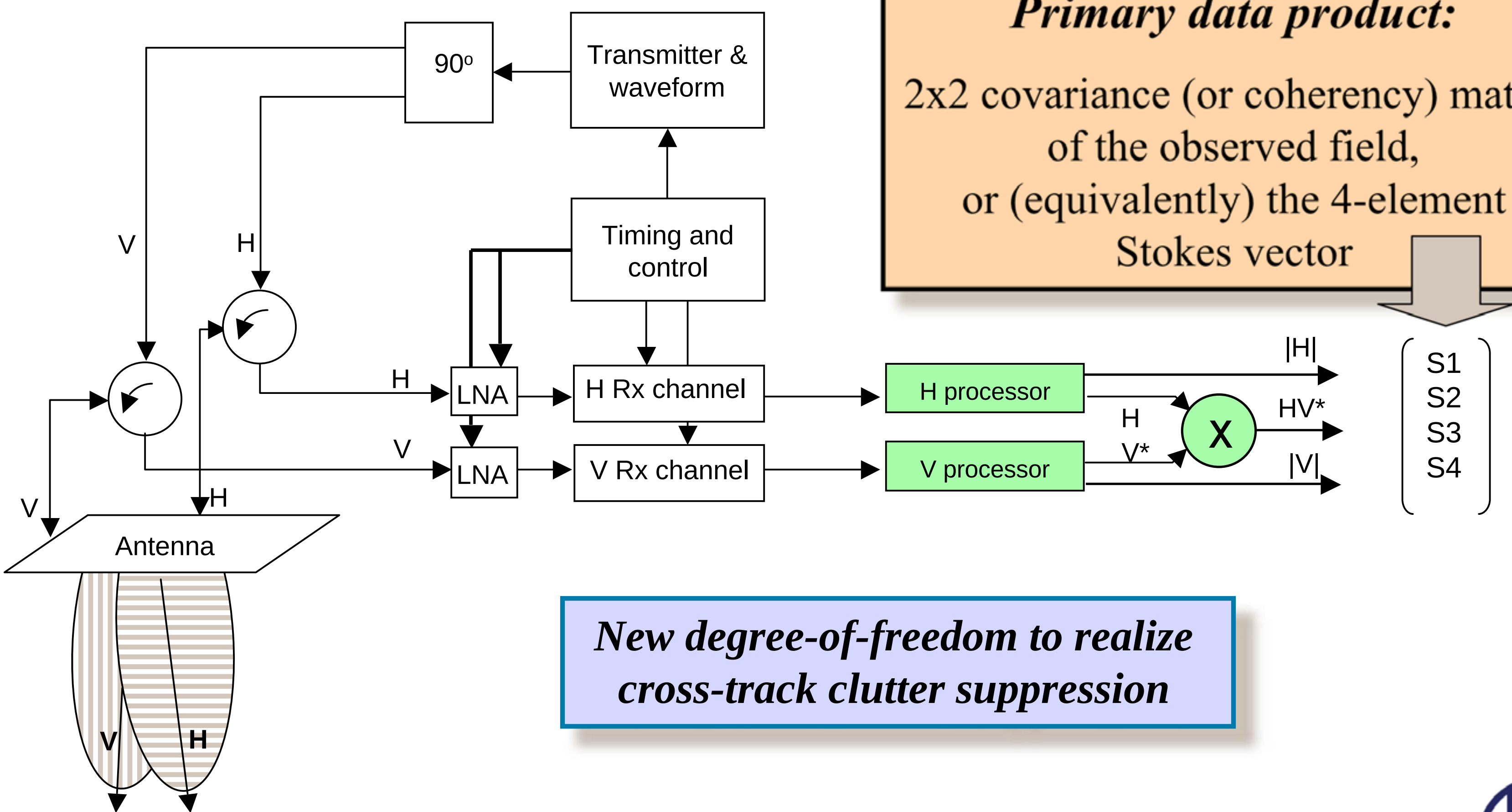
Dual Hybrid-Polarity Radar Sounder

Transmit Circular Polarization

Receive (*coherently*) linear (H & V)

Primary data product:

2x2 covariance (or coherency) matrix of the observed field, or (equivalently) the 4-element Stokes vector



New degree-of-freedom to realize cross-track clutter suppression

On Polarimetric Parameters

- **Stokes parameters fully characterize the received EM field => *innovation for radar sounder data***
- **Stokes parameters support parametric discrimination**

e.g.: **> Measurement of relative (E_X :: E_Y) phase δ**

> Degree of polarization *m*

Hybrid Polarity

$$S_1 = < |E_X|^2 + |E_Y|^2 > + 2N_o$$

$$S_2 = < |E_X|^2 - |E_Y|^2 >$$

$$S_3 = 2\,\mathrm{Re} < E_X E_Y^* >$$

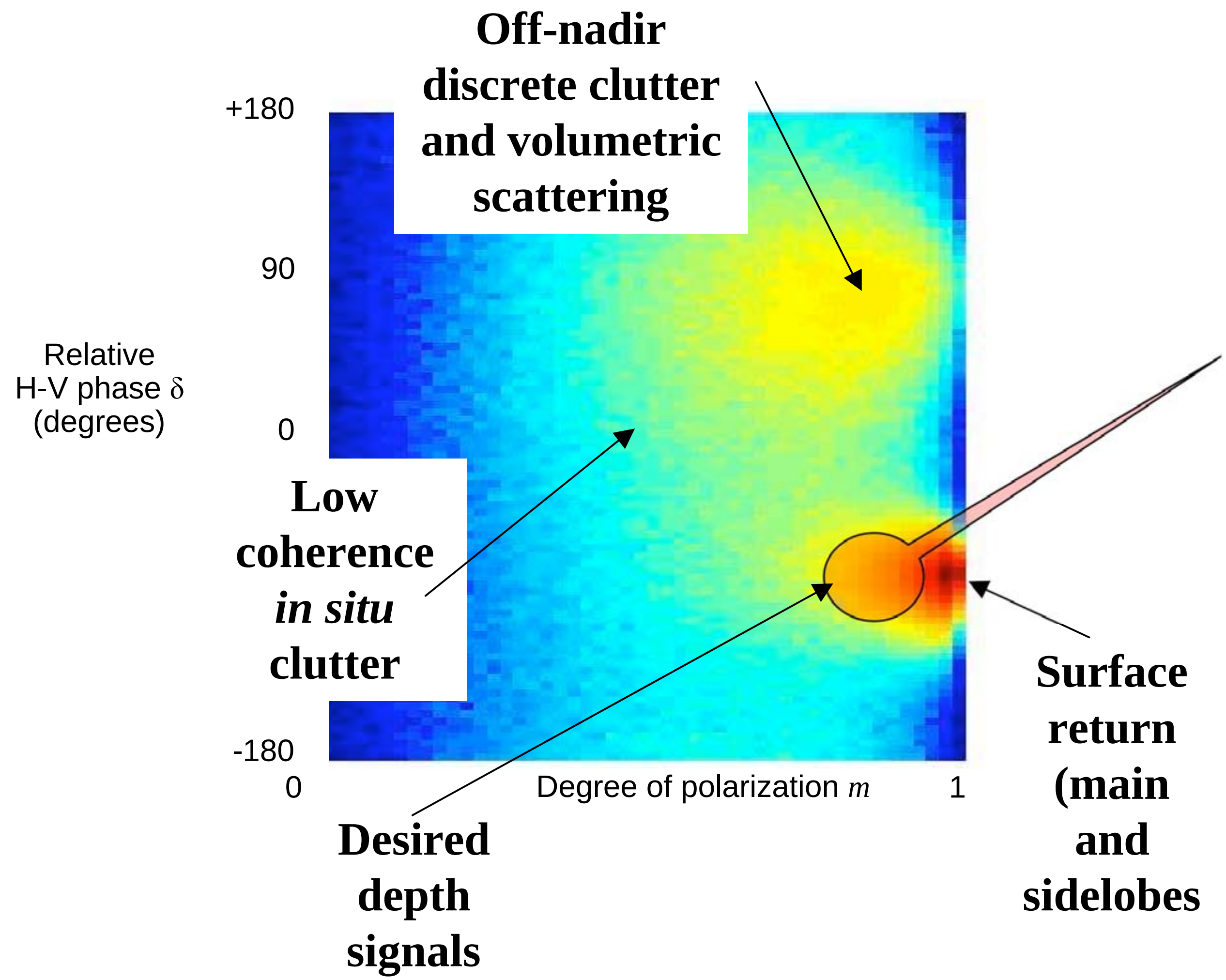
$$S_4 = -2\,\mathrm{Im} < E_X E_Y^* >$$

$$m = (S_2^2 + S_3^2 + S_4^2)^{1/2} / S_1$$

$$\delta = \arctan (S_4 / S_3)$$

Clutter *vs* Signal in *m-delta* Feature Space

Transmit left-circular polarization (Example: Real non-ice data)



Hypothesis: Desired depth signals will differ from clutter in a decomposition feature space.

Selective filtering in a polarimetric feature space can enhance depth returns, and suppress clutter

Clutter Suppression Issues (Recap)

A good sounder => a "clean" radar: dynamic range, linearity, extreme side-lobe control, etc

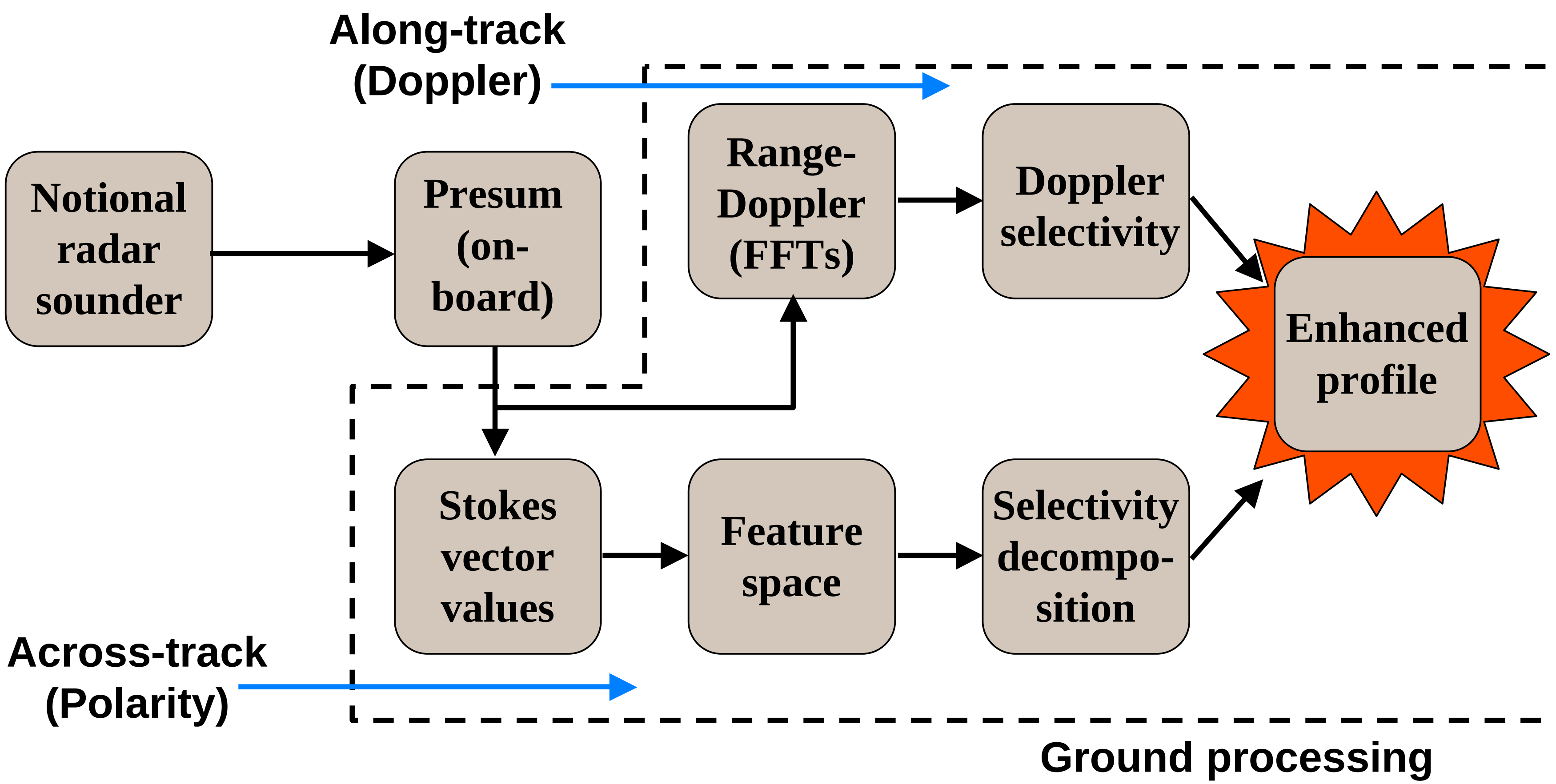
Doppler (along-track): ***Well established***

- **Proven technique (PARIS, Marsis, etc.)**
- **Ground processing**
- **Optimal performance => must match ice index of refraction**

Polarization (across-track): ***New strategy***

- **Developmental technique: requires proof-of-concept**
- **Ground processing**
- **Optimal performance may imply adaptive selectivity in response to clutter and depth polarization signatures**

Conceptual Flow of Clutter Suppression



Comments on hybrid-polarity

- **Hybrid-polarity is a proven methodology for (*compact*) polarimetric SAR (*classification by matrix decomposition*)**

- **The cross-track polarimetric method is fully compatible with along-track enhancement techniques (*Doppler and/or polarimetric*) for a radar sounder**

- **Sidelobes from the surface return can be suppressed if their polarimetric signature differs from depth signals**

- **The same technique could help to suppress the triple-bounce reflection of the aircraft (*ideal for a UAV or airborne radar sounder application*)**

Conclusions

- **Delay-Doppler is successful for suppressing along-track clutter, enhancing radar sounding signals**
- **High-altitude radar sounding proven to be feasible**
- **PARIS design successfully demonstrates robust (*and generalizable*) radar sounder principles**
- **Cross-track clutter suppression by polarimetric selectivity is a promising (*but as yet untested*) technique**
- **In practical situations for which clutter *vs* signal polarimetric phase distributions are significantly different, then large SCR gain is likely**
- **Recommend continued development of these themes**