SAR Altimetry Experts Group Meeting

NOC Southampton, UK

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SAR Mode, LRM, and Continuity

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Agenda

- SAR mode
  - ✓ Minimize SSH measurement uncertainty
  - ✓ => Maximize number of (*uncorrelated*) looks
- LRM
  - ✓ Closed burst *vs* open burst
  - ✓ Continuous (*low*) PRF
- Continuity
  - ✓ LRM precedent takes priority
  - ✓ Extend to (*simultaneous*) SAR mode
  - ✓ Benefits and options

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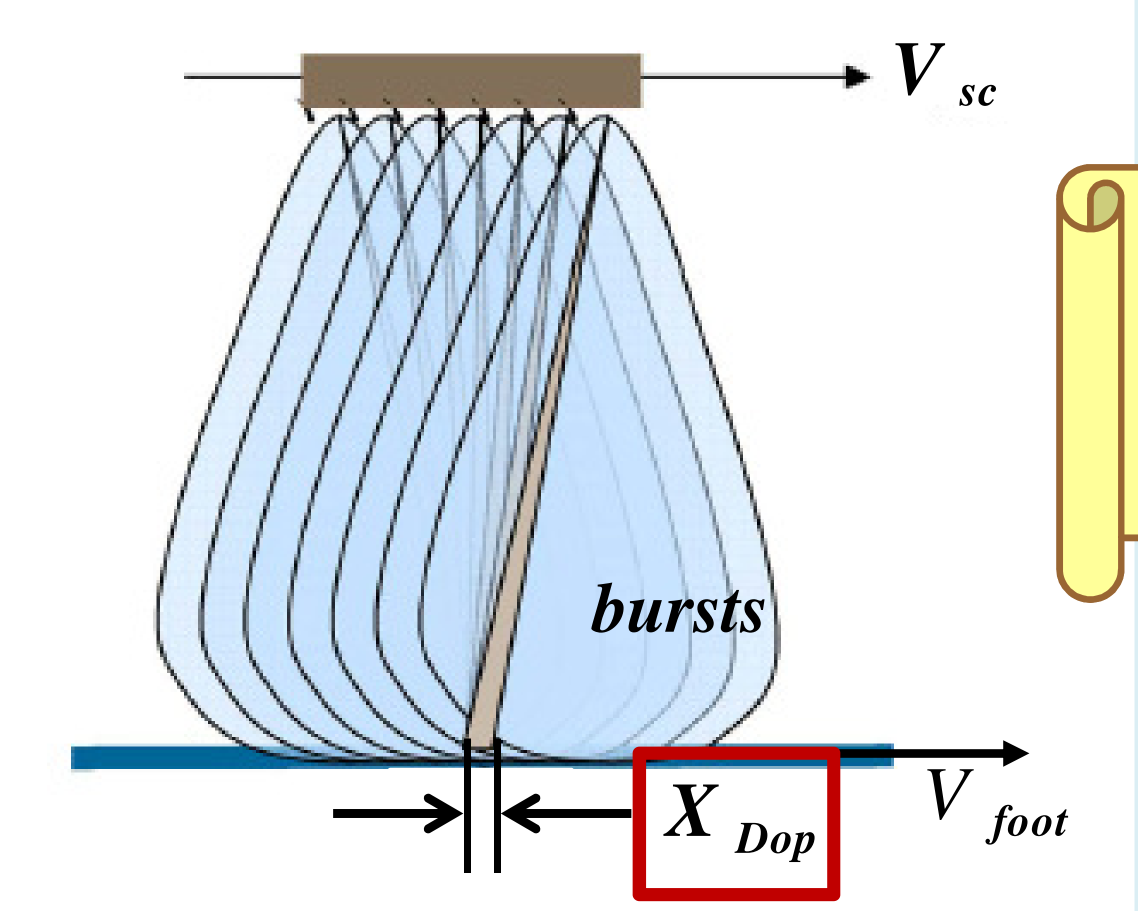
Maximum precision (*minimum SSH std*) => maximum number of uncorrelated looks



Smaller X_{Dop} implies larger number of looks per second N_{sec}

…but of course there are other considerations and trades

Maximum number of uncorrelated looks *(1 of 2)*

Number of looks per second

$$N_{sec} = N_{bin} \, N_{dt} \, N_{useful}$$

Maximum number of statistically independent looks within each Doppler bin

$$N_{bin} = \frac{2\alpha X_{Dop}^{2}}{h\lambda}$$

evaluated for the maximum burst repetition frequency (generalized Walsh bound)

Number of Doppler bins (at nadir) traversed per second

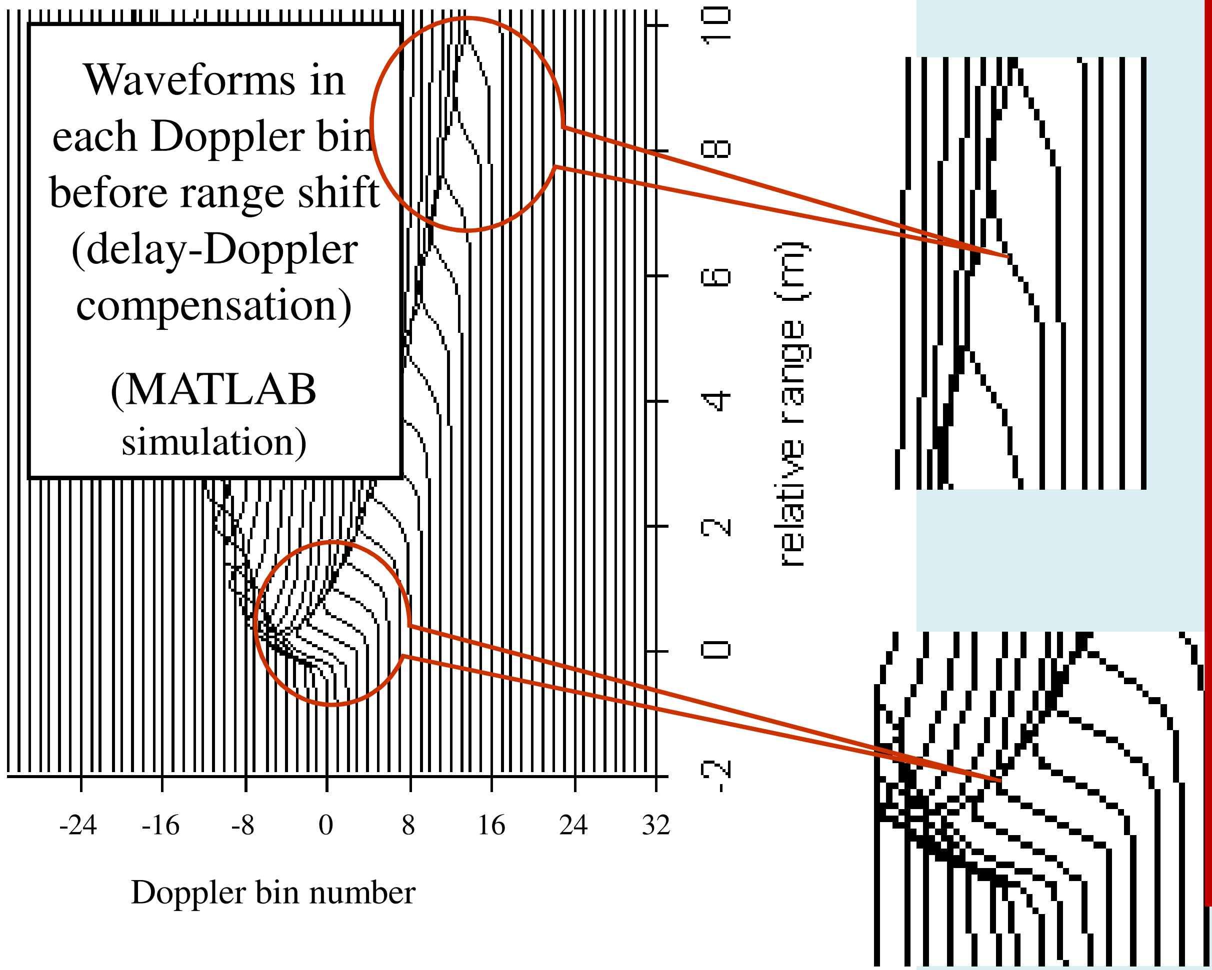
$$N_{dt} = \frac{V_{sc}}{\alpha X_{Dop}}$$

$$\alpha = \frac{V_{SC}}{V_{foot}}$$

Useful Doppler Bins

(diminishing returns)

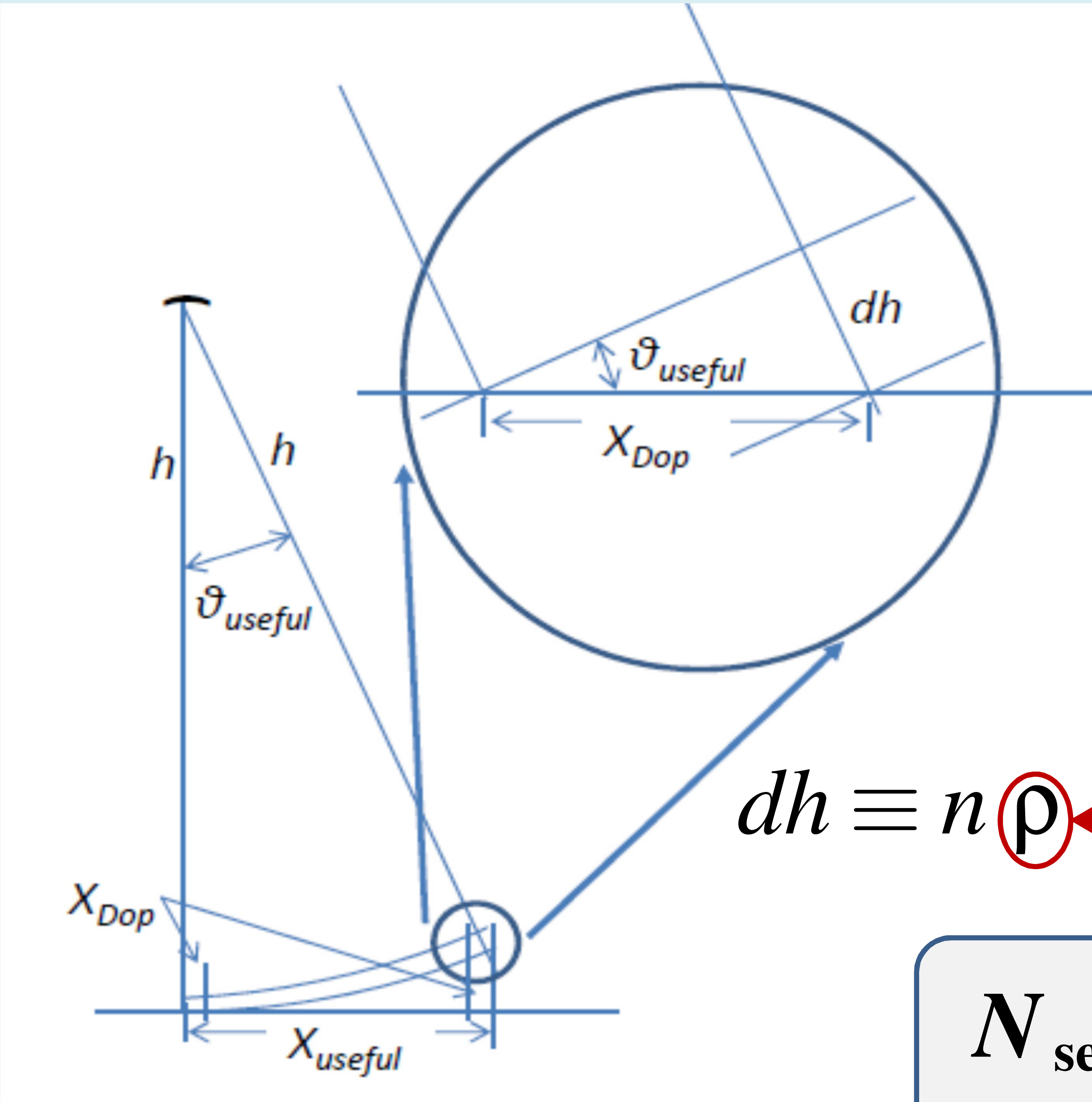
Raney, IGARSS95; Raney, TGARS 1998; Raney patents:
U.S.# 5,736,957; European # EP 0 929 824 B1



Waveform usefulness for determining range delay of the leading edge decreases as the square of the distance from nadir

See also D.J. Wingham, L. Phalippou, C. Mavrocordatos and D. Wallis, IEEE Trans. Geosci. Remote Sensing, 42, no. 10, pp. 2305-2323, 2004.

N_{useful}



$$dh \equiv n\rho$$

Range resolution

Number of useful Doppler bins (*working approximation*)

$$N_{useful} = \frac{2\,h\,n\rho}{X_{Dop}^2}$$

$$N_{sec} = N_{bin}\,N_{dt}\,N_{useful}$$

Maximum number of uncorrelated looks (2 of 2)

Number of uncorrelated looks per second for a SAR-mode radar altimeter, analogous to the Walsh PRF upper bound for a conventional LRM altimeter

$$N_{\sec} = \frac{4V_{sc}}{\lambda} \frac{n\rho}{X_{Dop}}$$

Other than choice of wavelength and the radar's range resolution, the principal determining parameter value is the resolved along-track footprint X_{Dop}

Aside: LRM *vs* SAR-mode N_{sec}

Classic Walsh upper bound

$$N(LRM)_{sec} = \frac{2V_{sc}}{\lambda}\frac{2r_{PL}}{h}$$

$$N(SAR)_{sec} = \frac{2V_{sc}}{\lambda}\frac{2n\rho}{X_{Dop}}$$

Doppler frequency | *Angular sector*

Example: Best available intrinsic (SSH) precision

$$<\Delta r>_{min} = \left(\frac{\lambda\rho X_{Dop}}{4\,n\,V_{sc}}\right)^{1/2}$$

where $$X_{Dop} = \frac{PRF\,\lambda h}{2V_{sc}\,N_P}$$

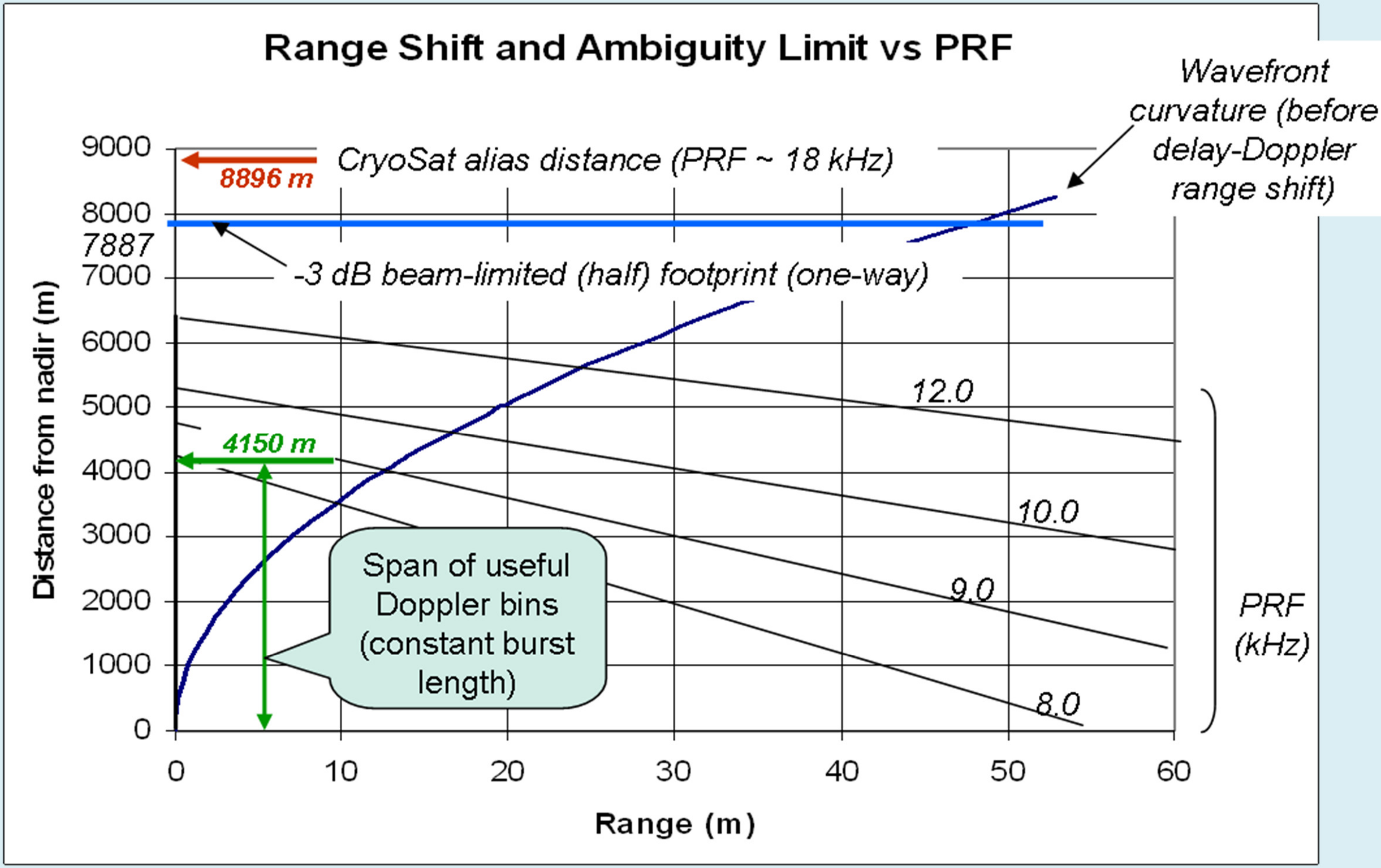
and $$PRF_{max} = \frac{N_P}{\overline{BP}_{\min}}$$

IF ρ*=0.5 m, h=800 km,* λ*=0.022 m,* N_P*=64, n=2 (choices)*
and X_{Dop}*=188 m (unfocused limit),* **THEN**

BP_{min}*=6.3 ms* N_{sec}*= 7202*

$$< \Delta r >_{min} = 5.9\ mm$$

PRF=10.182 kHz $N_{sec}/N_{Walsh} = 5.1$


Range Shift and Ambiguity Limit vs PRF
Wavefront curvature (before delay-Doppler range shift)
CryoSat alias distance (PRF ~ 18 kHz)
8896 m
7887
-3 dB beam-limited (half) footprint (one-way)
4150 m
12.0
10.0
9.0
8.0
PRF (kHz)
Span of useful Doppler bins (constant burst length)
Distance from nadir (m)
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
10
20
30
40
50
60
Range (m)

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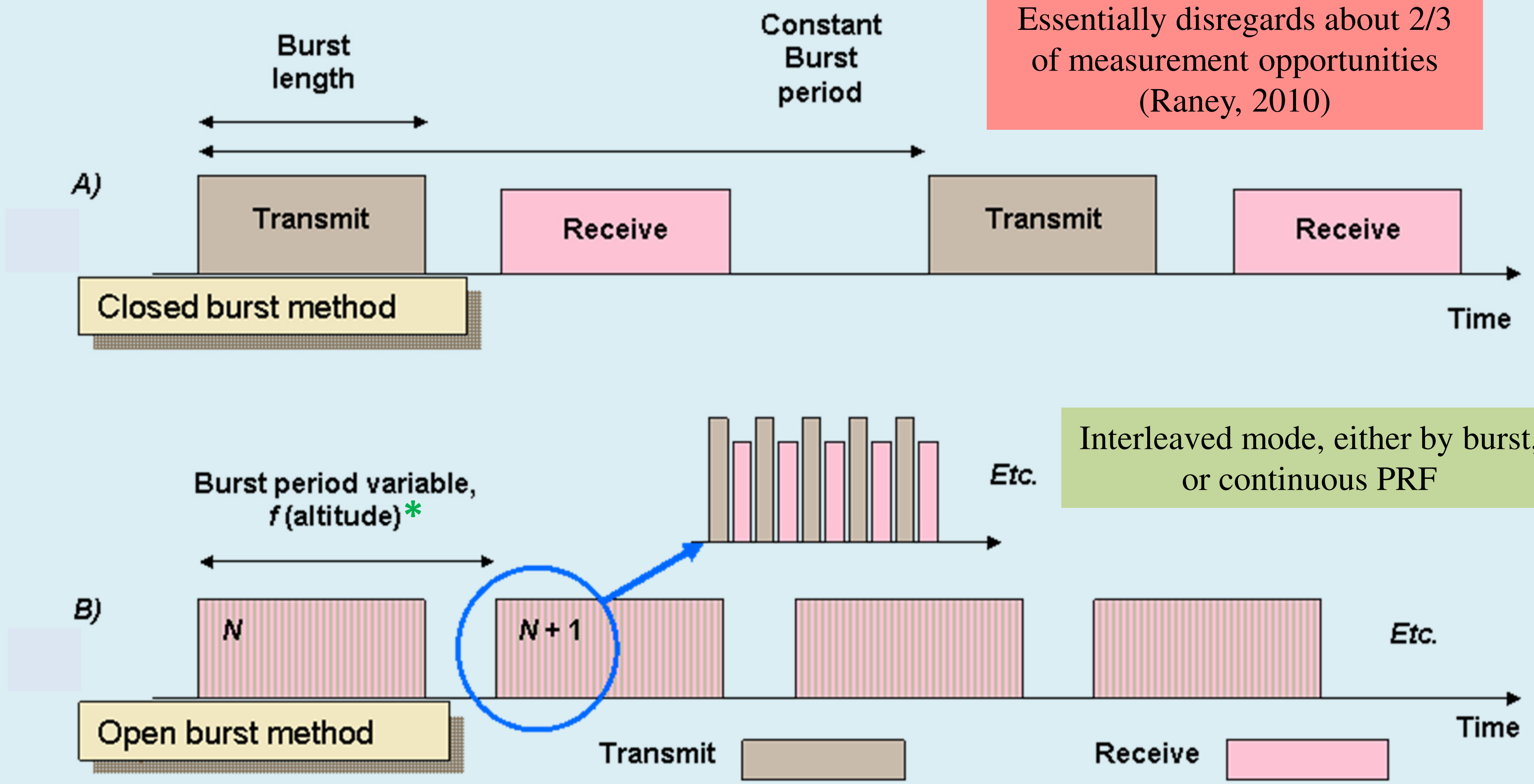
Closed Burst *vs* Open Burst

Essentially disregards about 2/3 of measurement opportunities (Raney, 2010)

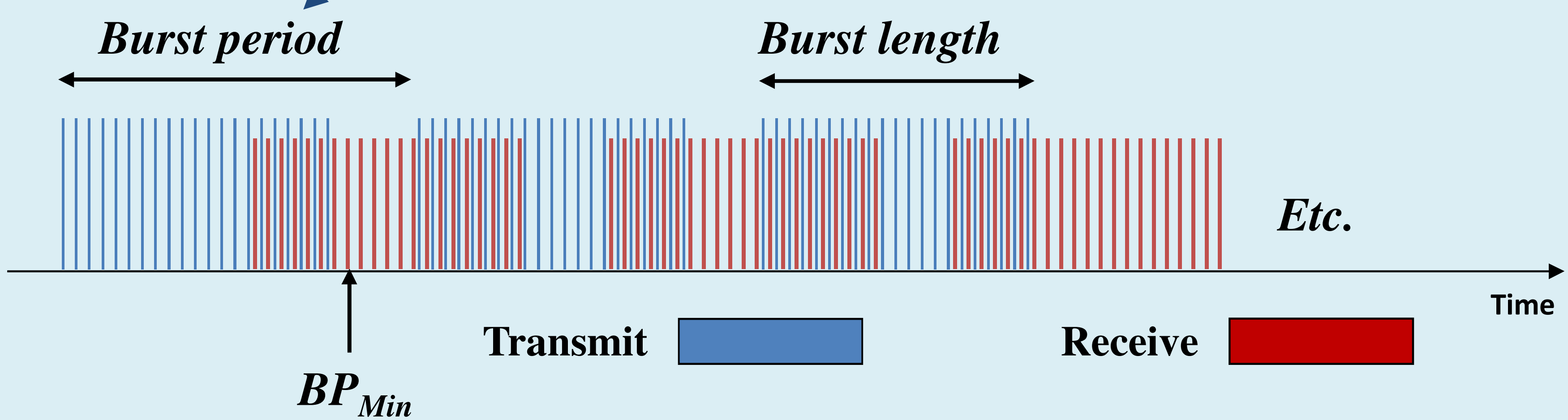


Interleaved mode, either by burst, or continuous PRF

*Precedent: TOPEX (Zieger et al, 1991)

Open Bursts (interleaved) are required to maximize looks/second (N_{Sec})

Burst period *BP* should be reduced to the generalized Walsh lower bound BP_{Min}, thus maximizing the number of statistically-independent looks



LRM PRF

- Usually PRF comparable to Walsh limit
  - ✓ Example: Jason-2 (Poseidon-3) – 2060 Hz
- Continuous PRF is limiting condition for open burst mode
  - ✓ Burst period = burst length + δt(altitude)
- Pseudo-continuous PRF
  - ✓ Groups (contiguous bursts) are slightly time-adjusted to adapt to variations in s/c altitude (*e.g.*, TOPEX)

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LRM Precedent: *Continuity* is the Driver

- To assure continuity, use the same (or very similar) parameter values, including PRF
  - Example: TOPEX– 4200 Hz
- Then choose SAR-mode PRF = N x 4200 where N is an integer
  - Example: N = 2 => SAR-mode PRF = 8200 Hz
  - Then calculate remaining SAR-mode parameters
- Result? Simultaneous SAR-mode and LRM
  - Run continuously in SAR-mode
  - LRM is an embedded sub-set (decimation)

Options

- Drive range gate tracking for both modes from the LRM data stream
- Compile the LRM profiles from all N LRM decimated sequences
  - ✓ Why? To maintain good SNR in spite of shorter available transmitted signal duration
- Choose PRF and on-board processing parameters (e.g. X_{Dop}) adaptively
  - ✓ To enhance measurements during coastal encounters
  - ✓ To respond to extreme SWH conditions

Advantages

- Simultaneity (LRM and SAR-Mode data sequences) assures cross-calibration under all conditions
- Continuity with the chosen precedent (LRM) system is assured
- SAR-Mode data and/or LRM data can be selected for any given application without loss or compromise to the alternative mode
- Opportunity to avoid changing trackers for coastal encounter/departure

Conclusions

- SAR-Mode and LRM may be operated simultaneously and continuously
- Requires PRF_{LRM} be chosen to match LRM precedent, then SAR-Mode PRF is N x PRF_{LRM}
- Advantages of both modes are enjoyed, without compromising either mode
- Design may be optimized for measurement precision without compromising continuity
- Suggest simultaneity AND measurement precision be recommended themes for forthcoming missions

References (1 of 2)

A. R. Zieger, D. W. Hancock, G. S. Hayne, and C. L. Purdy, "NASA radar altimeter for the TOPEX/-Poseidon project," Proceedings of the IEEE, vol. 79, pp. 810-826, 1991.

Open burst pseudo-constant PRF design

R. K. Raney, "The delay Doppler radar altimeter," IEEE Transactions on Geoscience and Remote Sensing, vol. 36, pp. 1578-1588, 1998.

Original paper, including modeled time delay/Doppler SAR-mode 3-D waveform. Predicted improved measurement precision, smaller footprint, and its associated advantage of coastal measurement proximity.

J. R. Jensen and R. K. Raney, "Delay Doppler radar altimeter: Better measurement precision," in Proceedings IEEE Geoscience and Remote Sensing Symposium IGARSS'98. Seattle, WA: IEEE, 1998, pp. 2011-2013.

Measurement precision predictions verified by simulations

R. K. Raney, "CryoSat SAR-Mode Looks Revisited," Proceedings, ESA Living Planet Symposium, Bergen, Norway, 2010.

First observation that closed burst limits the available measurements to only about 1/3 of those possible through continuous along-track data collection

References (2 of 2)

R. K. Raney, "CryoSat SAR-Mode Looks Revisited," IEEE Geoscience and Remote Sensing Letters, vol. 9, pp. 393-397, 2012.

Open publication of the central points in the Bergan paper, including estimates of measurement precision of CryoSAT-2 SSH measurements, and the necessity (indeed, desirability) of PRFs much lower than Nyquist, yet much higher than Walsh.

R. K. Raney, "Maximizing the intrinsic precision of radar altimetric measurements," Presentation (and open plenary discussion), 20 Years of Progress in Radar Altimetry, ESA/CNES, Venice, Italy, September 2012.

Closed form estimation of the best attainable SSH measurement precision available from a "signal processing" partially-coherent radar altimeter.

R. K. Raney, "Maximizing the intrinsic precision of radar altimetric measurements," IEEE Geoscience and Remote Sensing Letters, vol. 10, pp. 1171-1174, 2013.

On-line publication February 2013. Complete version of the 2012 Venice paper, including the "Vision" section arguing for simultaneity which was verbally presented during plenary discussion at Venice.