Radar Altimeter Fundamentals and Near-Shore Measurements

A brief commentary on well-known concepts, presented to help unify terminology and focus discussions in this Workshop

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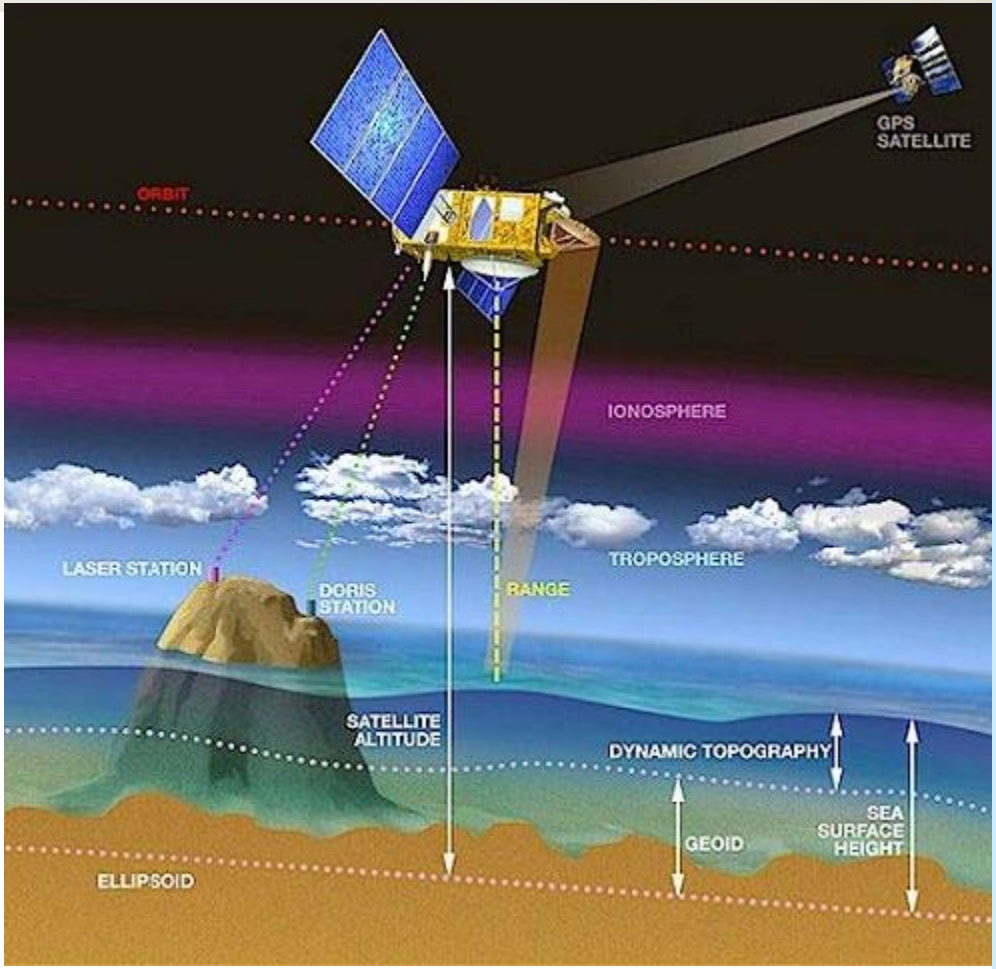
The Playing Field



(Acknowledgement CNES/D. Ducros)

Pertinent parameters:

- SSH, SWH, WS, other*
- Averaging*
- Resolution*

- *Antenna pattern (full)*
- *Pulse-limited footprint*
- *Radiometer pattern(s)*
- *Propagation delays*
- *Waveform integrity*
- *etc*

* *Themes of this brief*

Outline

- Fundamental background concepts
- Replay in the coastal environment
- Summarize main themes

- **Fundamental background concepts**
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The Altimeter as a Radar

- **Fundamental radar parameters***
  - ***Range resolution*** (1/Bandwidth) (single pulse) ~ 50 cm
  - Footprint ***resolution*****:** Pulse-limited (~2 km - ~10 km)
  - Antenna ***Beamwidth*** (-3 dB typically ~ 15 km)

- **Single waveform** *(backscatter from one transmitted pulse)*
  - ***Waveform* ==** |compressed & detected received time series|^2
  - Coherent self-noise **(*speckle*)** => signal/speckle ratio = 1

- **Averaged waveforms (*N* *statistically independent waveforms)***
  - Coherent self-noise (standard deviation) reduced by 1/sqrt(*N*)
  - Presumes that the geophysical signal remains highly correlated among the ensemble of waveforms averaged

"Gotchas" in the near shore

**Altimeter-dependent*

Averaged Waveform PDFs

- Gamma Distribution *(N statistically independent looks)*
  - Normalized to mean = 1
  - Standard deviation = sqrt(1/N)

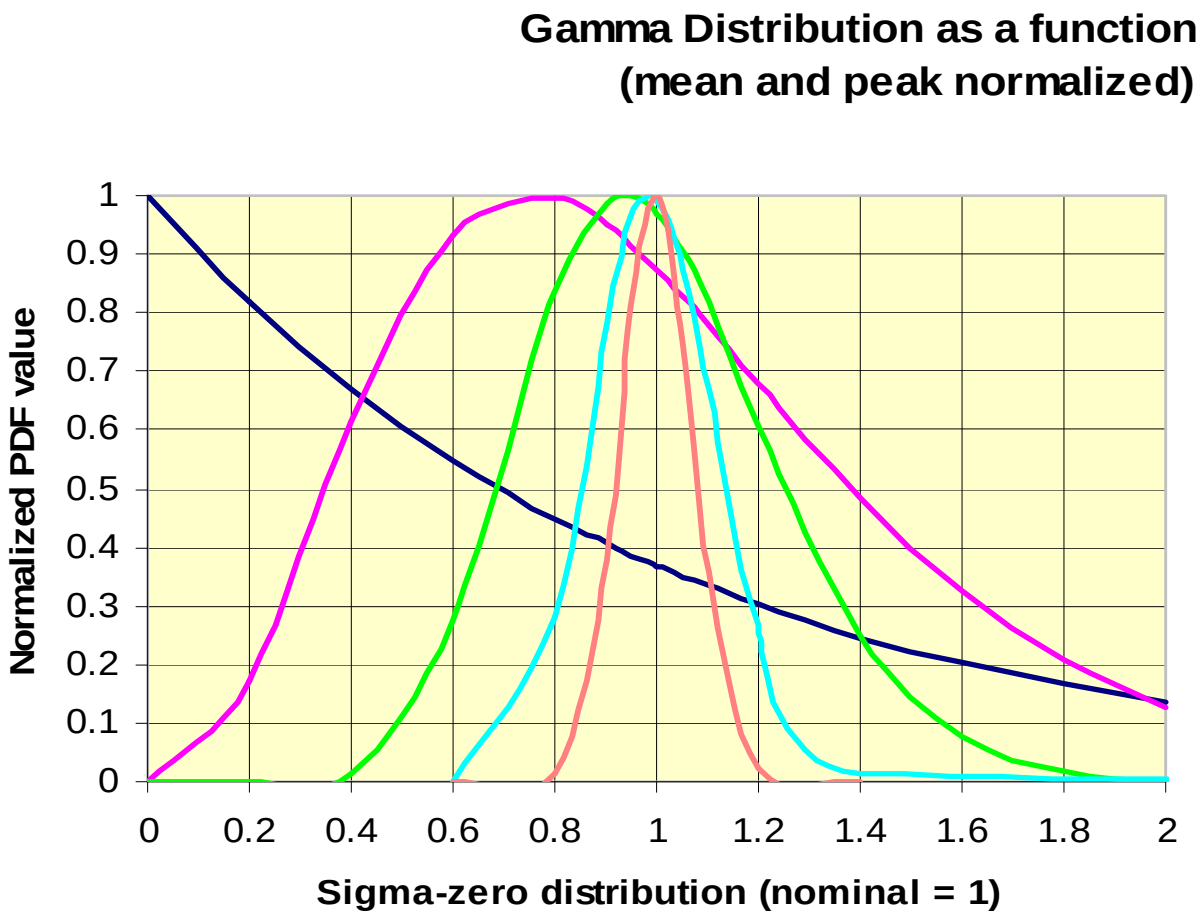
$$f_{\Gamma}(x;N,N) = \frac{x^{(N-1)}N^{N}}{(N-1)!}\exp(-Nx)$$

- Large N Approximation ***(Stirling)***

$$f_{\Gamma_{N>>1,\,\mathrm{mar}=1}}(x;N,N) = x^{(N-1)}\exp[-N(x-1)]$$

APL

Waveform PDFs (Examples)

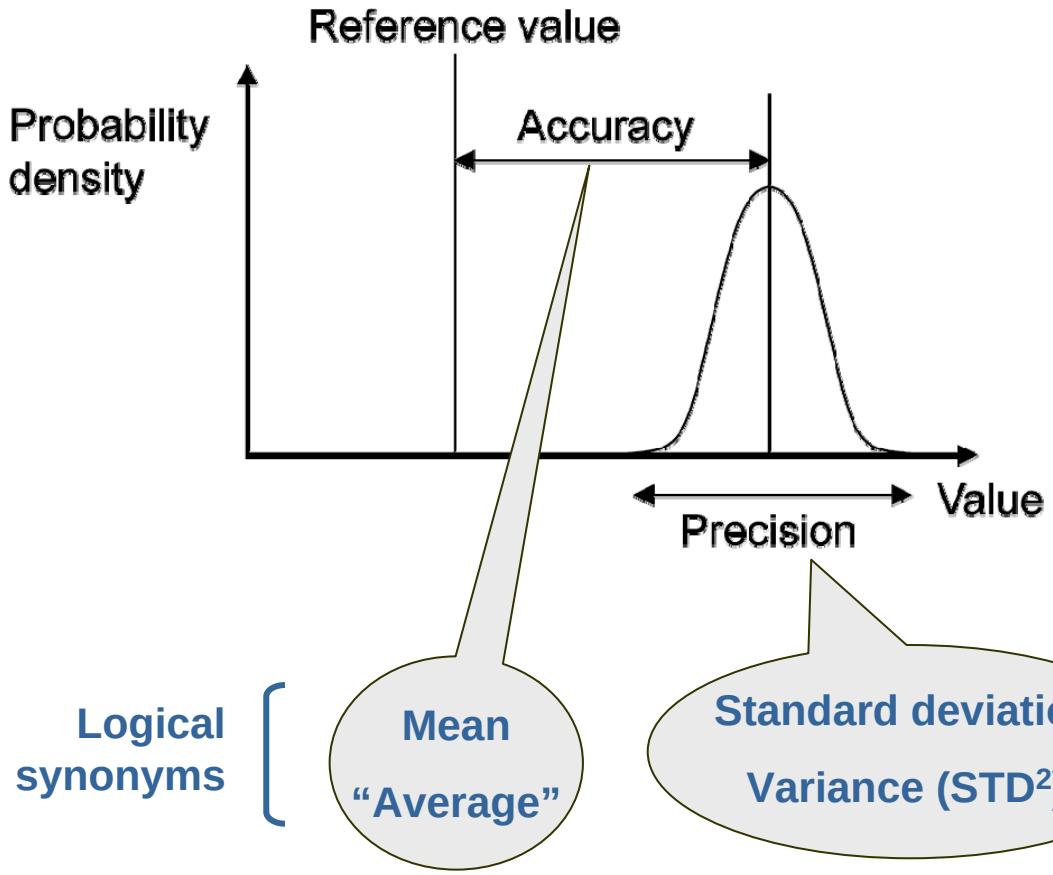


All radars are "precision-challenged"

- N = 1 (Single-look SAR)
- N = 4 (Typical SAR image)
- N = 16 (Mini-RF Lunar SAR)
- N = 64 (WS scatterometer)
- N = 200 (Radar ALT @ 10 Hz)

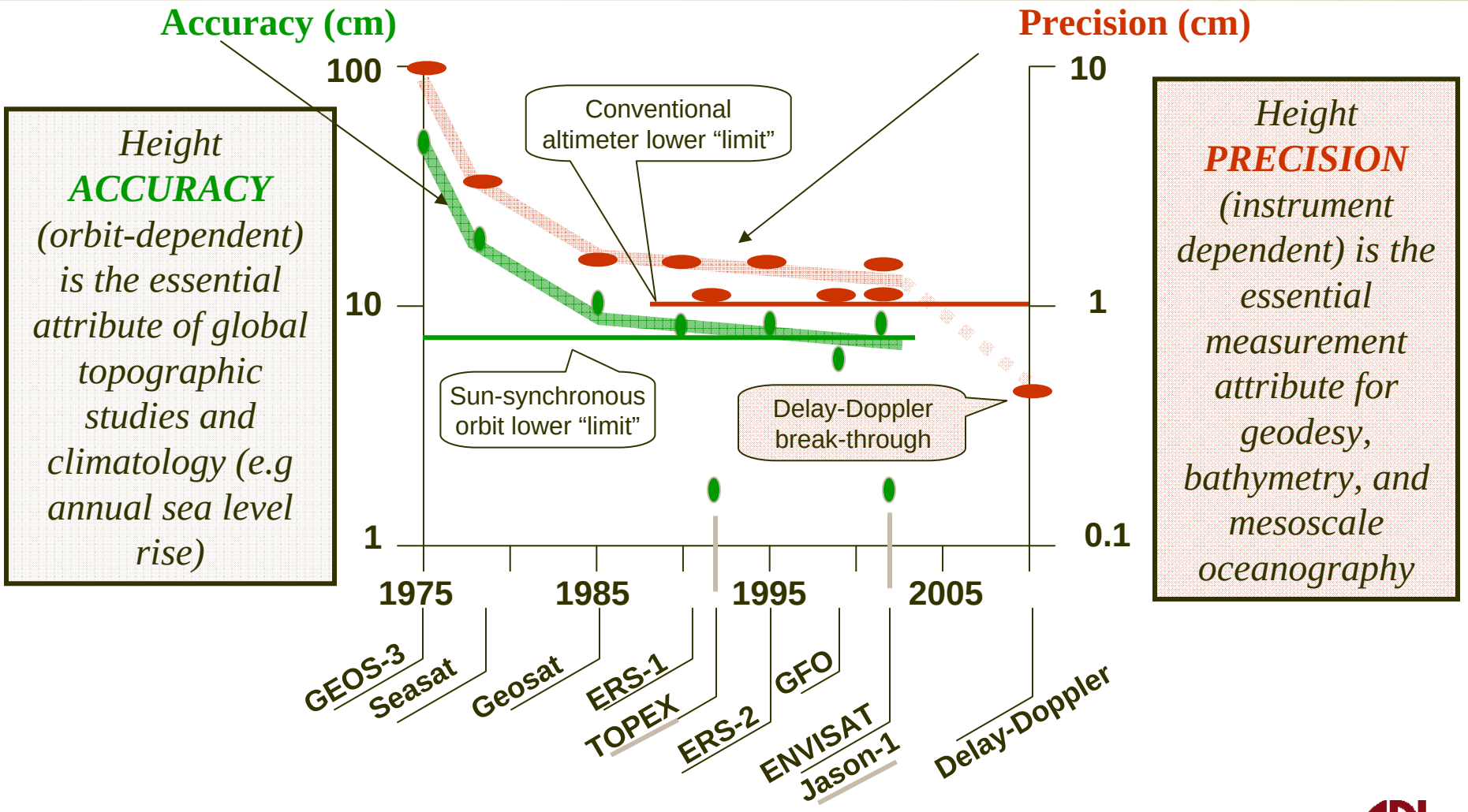
N is the number of statistically-independent samples averaged for a given measurement

Accuracy *vs* Precision



ACCURACY
and
PRECISION
two terms in common use (*and mis-use*) in radar altimetry; fundamental concepts that apply especially to near-shore measurements

Precision and Accuracy Trends



Height ***ACCURACY*** *(orbit-dependent) is the essential attribute of global topographic studies and climatology (e.g annual sea level rise)*

Height ***PRECISION*** *(instrument dependent) is the essential measurement attribute for geodesy, bathymetry, and mesoscale oceanography*

Precision *vs* Resolution

Variance x Resolution > Constant

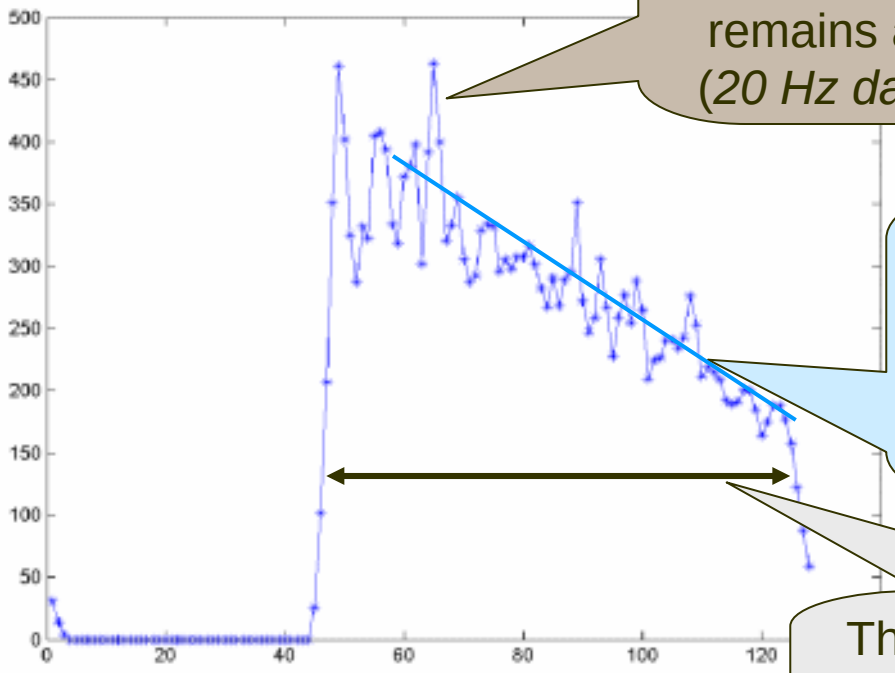
PRECISION and (Spatial) RESOLUTION
Fundamental trade-off, a measurement Uncertainty Principle

It follows from information theory that resolution and precision each require bandwidth (channel capacity). Hence, any system imposes an upper bound on their product

Consequence 1: Application requirements need to specify BOTH measurement resolution and precision requirements

Consequence 2: Radar altimeters need to specify achievable resolution and precision that can be realized simultaneously with a given measurement

Typical RA-2 (Envisat) Waveform



This "hash" is dominated by speckle noise that remains after averaging (*20 Hz data ~ 100 looks*)

Slope of the waveform tail is due to antenna pattern weighting, to mis-pointing of the antenna, and/or to sea surface specularity

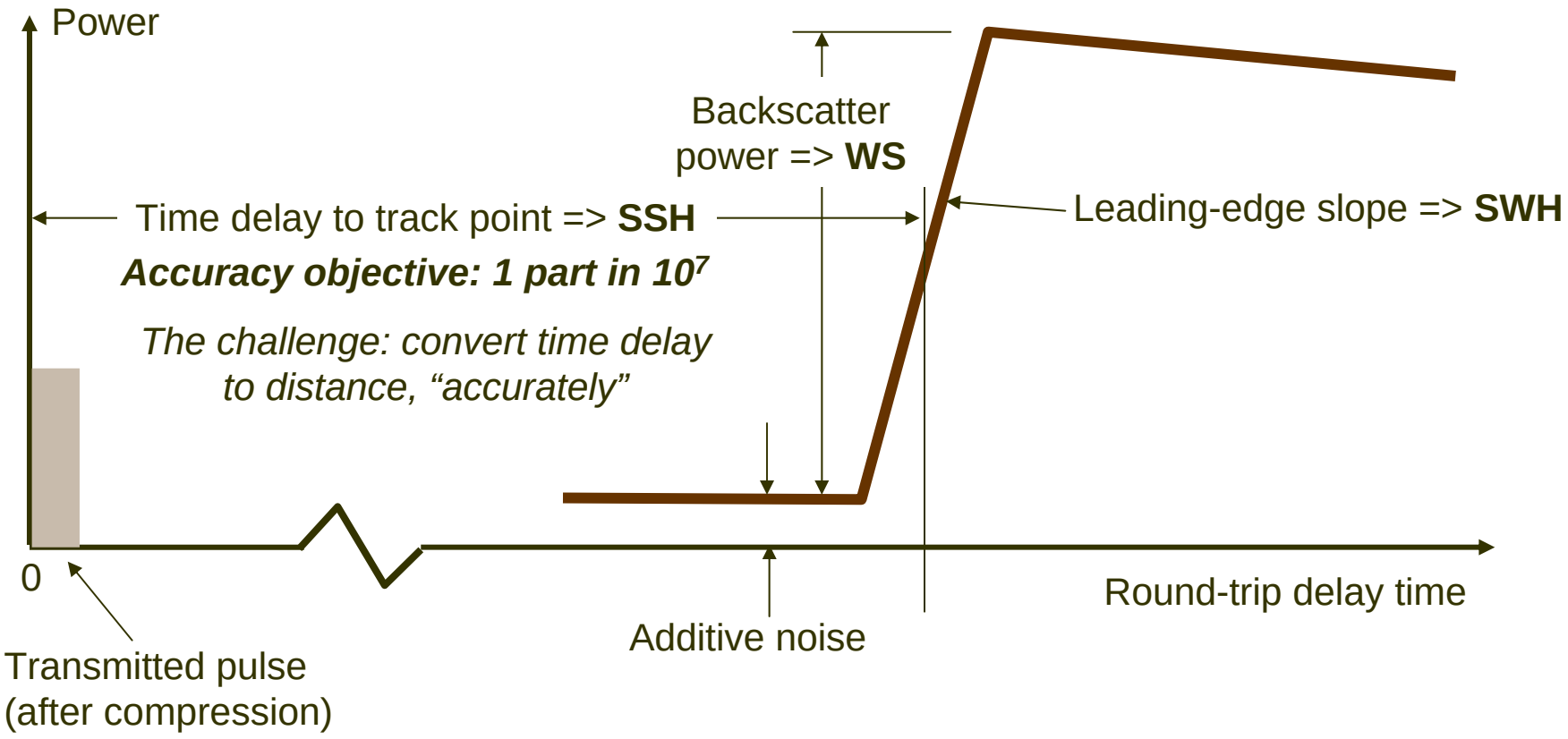
The tail of the waveform comes from sea surface backscatter up to 8 km - 10 km from nadir*

Courtesy, CLS
Ramonville Saint-Agne
France

***Altimeter/altitude-dependent**

ALT Measurements

The familiar idealized model (Brown function)



Open Ocean Measurements

Measurement	**Precision?**	**Accuracy?** (*t* => distance)	**Comments**
WS	Yes	_	*Large area averages*
SWH	Yes	_	*Large area averages*
Surface slope (*Mesoscale*)	Yes	_	*Premium on simultaneous precision and resolution*
SSH	Yes	Yes	*Requires 2 frequencies & WVR; precision orbit determination*

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Issues: ALT Near Shore

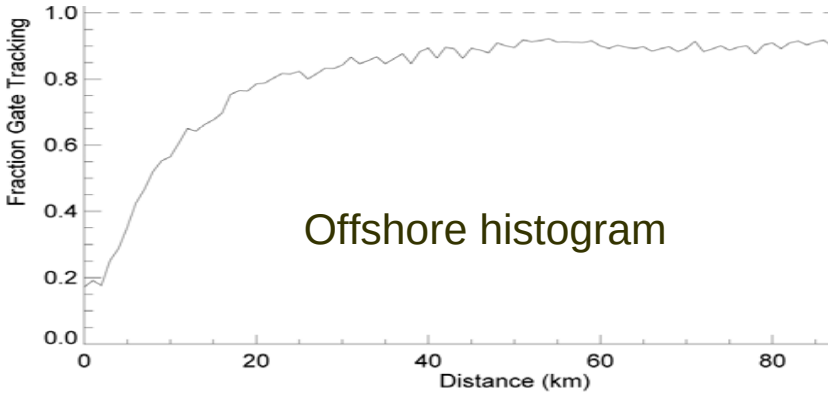
Selected examples

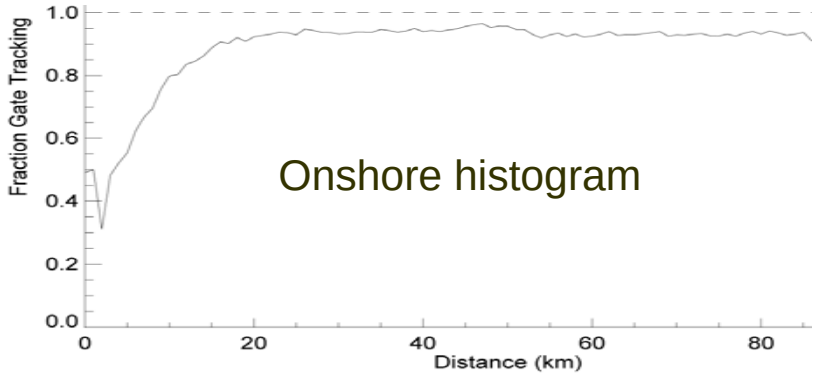
Facts	Consequences
Near-shore waveform corruption	Need adaptive or special tracker treatment, and/or re-tracking
Large radiometer footprint may spoil WVR estimates	SSH accuracy compromised
Antenna beamwidth* ~ 18 km	WS, SWH measurement reliability may suffer for near-shore observations
Sample posting rate @ n Hz => along-track footprint length (D_{SWH} + 6.7/n) km	Along-track spatial resolution* can never be better than the pulse-limited footprint diameter D_{SWH} (> 2 km)
Shorter correlation lengths of temporal/spatial features	Compromised measurement precision

Altimeter/altitude-dependent

Probability(fine-gate tracking)

Typical results from a traditional on-board tracker



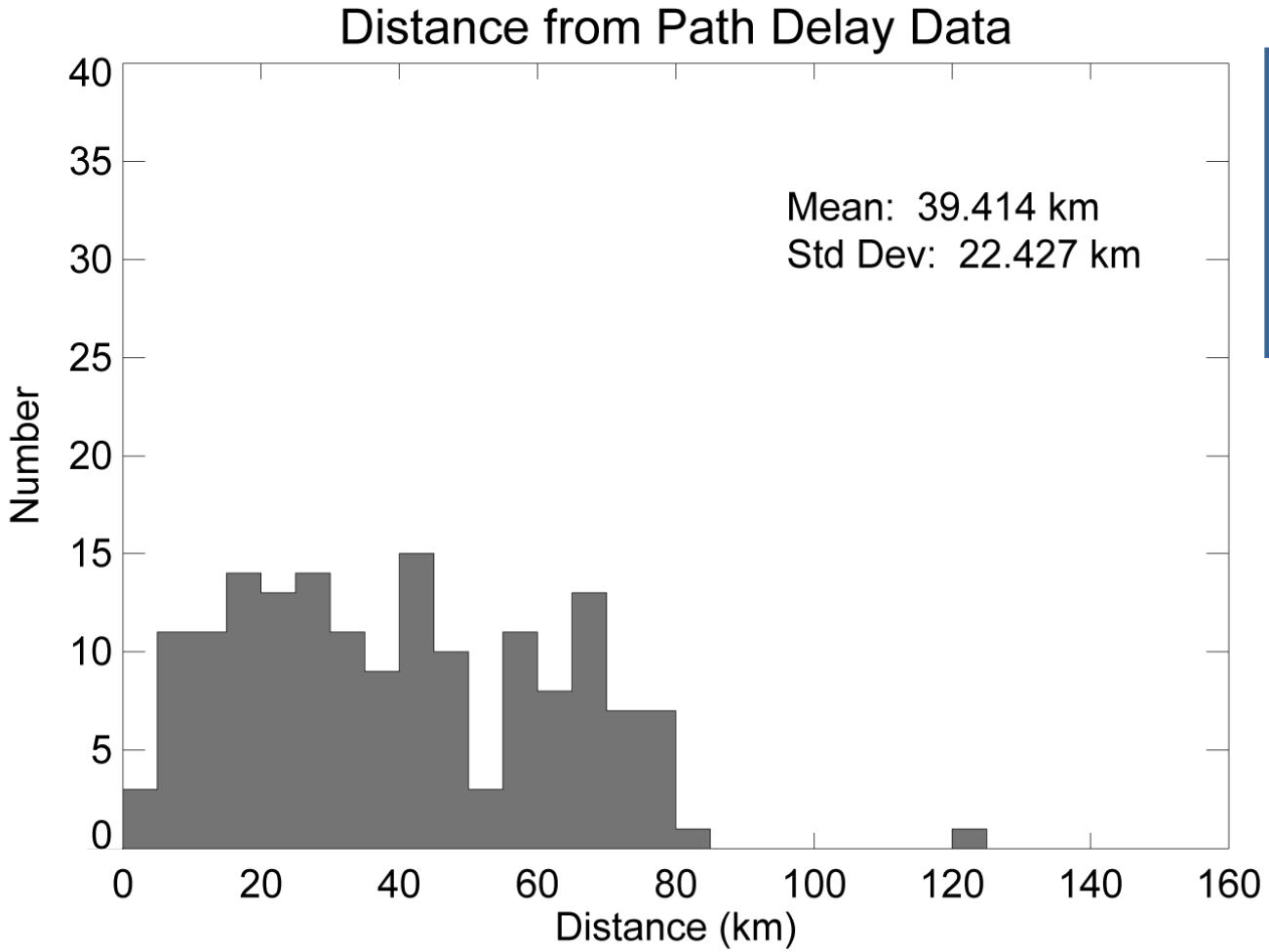


Fine-gate tracking:
Rule based on a set of gate values that fit expected waveform shapes; precision ~2 cm (low SWH).

Alternative: threshold tracking; precision ~50 cm (one gate width)

Based on a JHU/APL analysis of TOPEX performance approaching and leaving shorelines (F. Monaldo, SRO–96M–15 August 30, 1996)

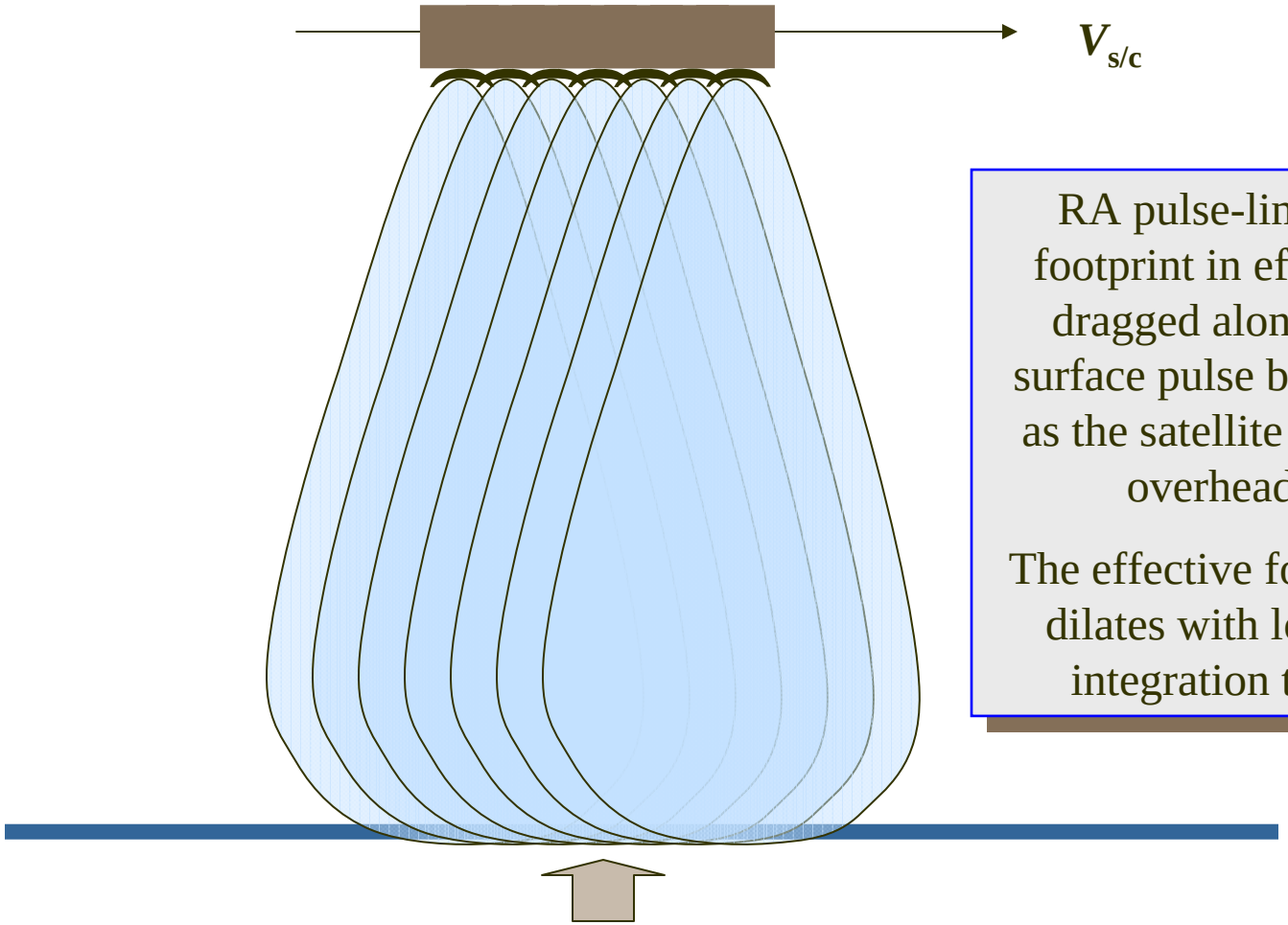
Histogram of WVR Corruption



Method:
Onset of departure from trended WVR data along a 350-km segment of track

Based on an analysis of 162 TOPEX passes over instrumented off-shore buoys (F. Monaldo, JHU/APL, SRO–97M–05, Jan 31, 1997)

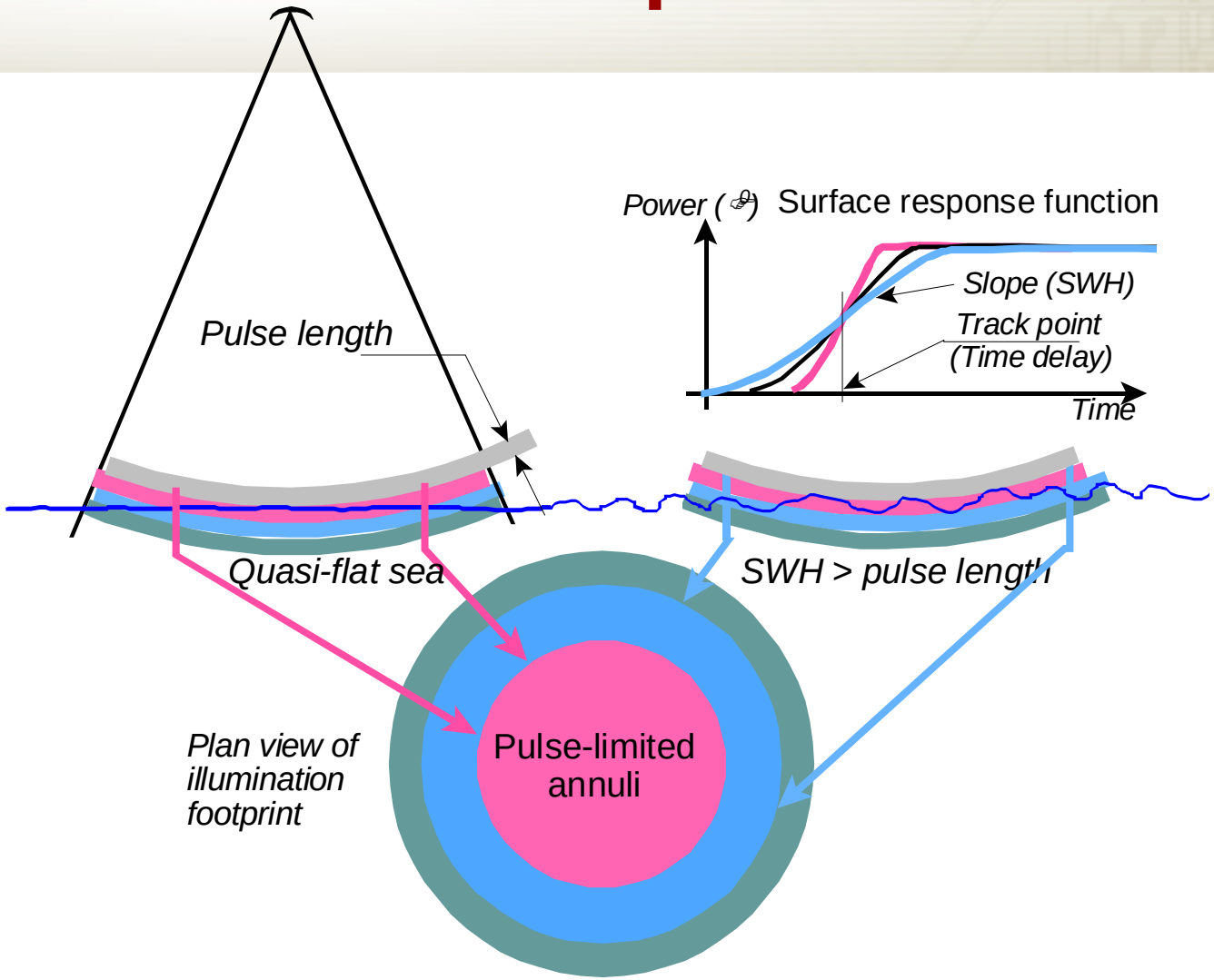
Conventional ALT footprint scan



RA pulse-limited footprint in effect is dragged along the surface pulse by pulse as the satellite passes overhead.

The effective footprint dilates with longer integration time

Pulse-Limited Footprint ~ SWH

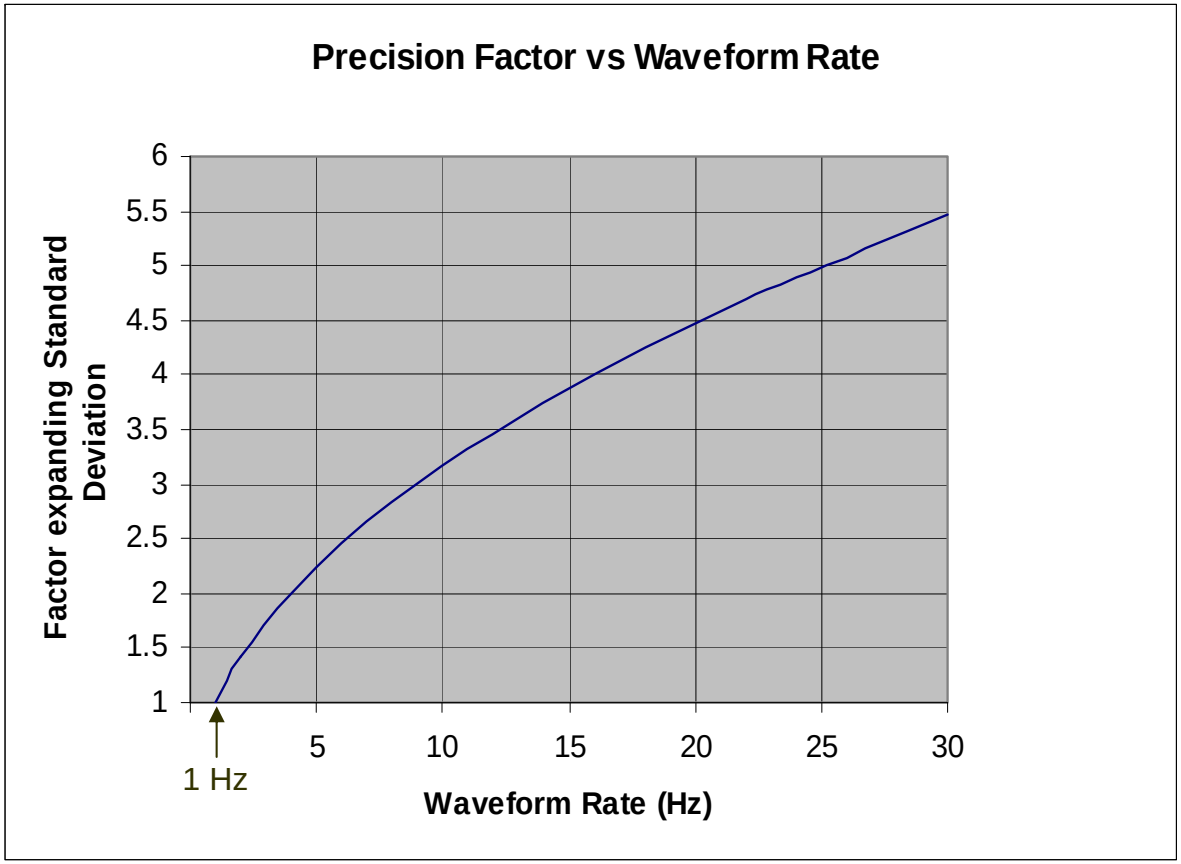


Less Averaging = Worse Precision

Increased waveform rate implies larger measurement standard deviation

Example: SWH precision of 4 cm at 1 Hz, grows to 18 cm at 20 Hz

Comment: *This is the lower bound. Wave profile and other factors may induce further degradation.*



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Principal Themes

Radar altimetry in the near-shore

- **Averaging**
  - Shorter correlation length and time of oceanic features
  - Loss of temporal and spatial degrees of freedom means less averaging; the inherent radar self-noise grows larger
- **Precision**
  - Less averaging => poorer precision
  - Simultaneous fine precision and fine resolution may be challenging
- **Accuracy**
  - Weakening/failure of path length correction methodologies
- **AND Waveform Corruption**
  - Influence from land backscatter (main lobe or side-lobes)
  - Oceanic surface may have anomalous profiles