Starlab Space

SCOOP: Science Review

WP4000: Echo Modelling and Retracking

Francisco Martín*
Antonio Reppucci,
Research Engineers,
WP4000–27/01/2016

Starlab
Living Science

Outline

- WP Objectives.
- Overview.
- SAMOSA-3 Retracker.
- Scattering amplitude.
- Antenna Gain.
- Power Waveform Analytical Expression.
- Radar System Point Target Response.
- Range Cell Migration Correction.
- Point Target Response as a function of SWH-
- Estimation TN.

WP Objectives

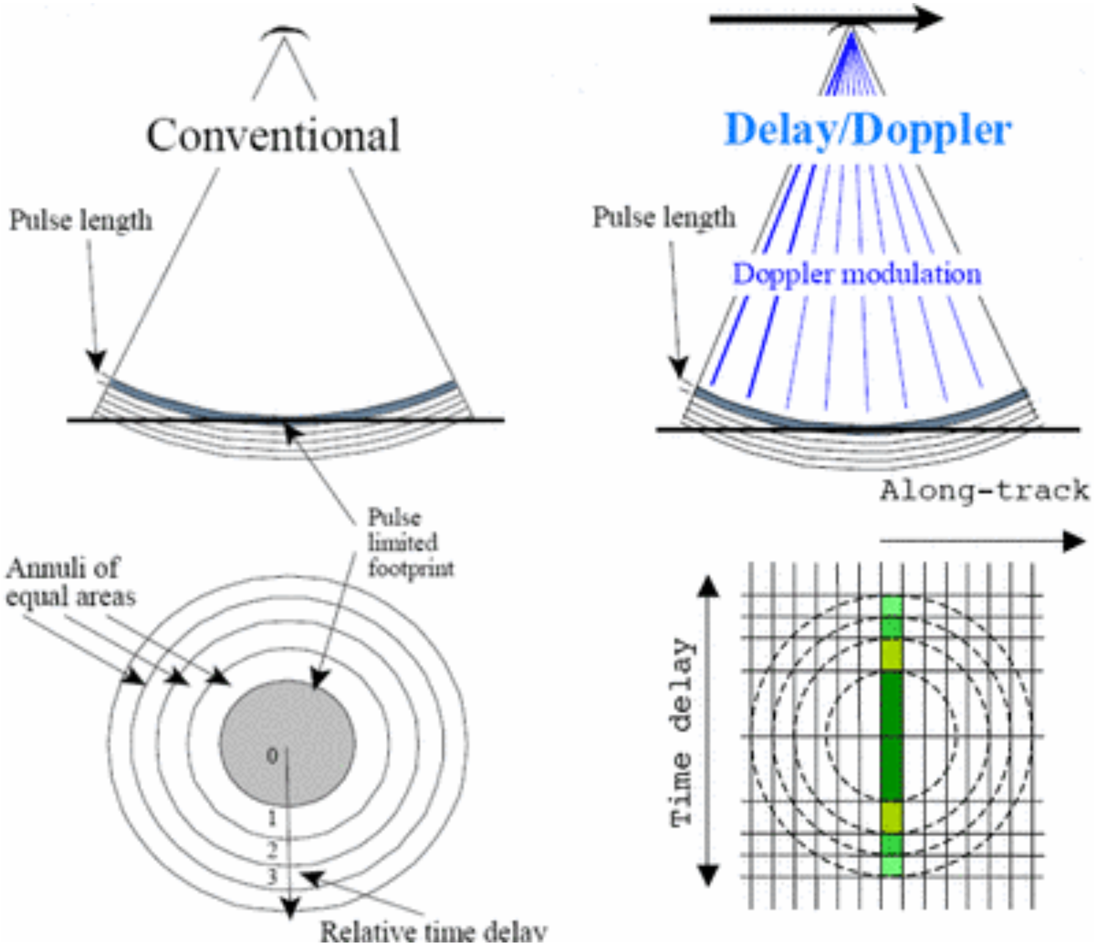
- WP4100: SAMOSA Retracker adaptation for Sentinel-3.:
  - Adapt the SAMOSA analytical modle to Sentinel-3 configuration.
  - Implement it within a full-waveform retracker.
- WP4200: Generate L2 Open Ocean Test Data Set.
- WP4300: SAMOSA Retracker adaptation for Sentinel-3: Implementation for Coastal Zone.
- WP4400: Generate L2 Coastal Zone Test Data Set.

WP 4100: SAMOSA Retracker adaptation for Sentinel-3

- Sentinel-3 retracking will be based on the SAMOSA Analytical Model, including the updates done in the framework of CP40,
  - Appropiate handling of energy distribution on stack.
  - Variable width PTR as a function of SWH.
  - SAMOSA full implementation.
  - Thermal noise estimation.
- The retracker will inlcude the estimation of.
  - Sea Surface Height (SSH).
  - Significant Wave Height (SWH).
  - Waveform Power (Pu).

Sigma_o

Overview



*Credits: K. Raney

- Main advantages SAR mode:
  - Greater pulse-to-pulse averaging → better precision.
  - Smaller along-track footprint.
    - Resolve short-scale ocean features.
    - Better performance near to land.
  - Improved along track resolution (no increases with SW).
    - SAR mode, 300m.
    - Conv. Mode,~1.7km, (~3 km for SWH~2m),
  - Better performance (~10 times).

Overview

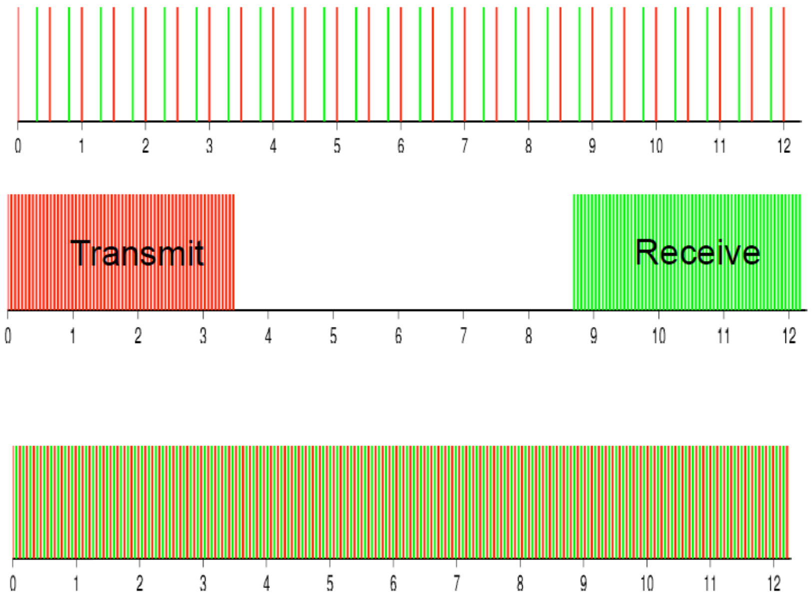
- ❑ Conventional altimetry:
  - ❑ LRM (Low Resolution Mode).
  - ❑ Pulses tansmitted and received using Low PRFs.
    - Pulses are only partially correlated.
    - Noise reduction using → Inc. Averaging.
    - Upper bound PRF → Walsh limit → 1800 waveforms per second.
- ❑ SAR mode
  - ❑ Pulsed transmitted and received in burst 64 pulses.
  - ❑ High PRF → pulses within bursts correlated.
    - E.g. CryoSat-2

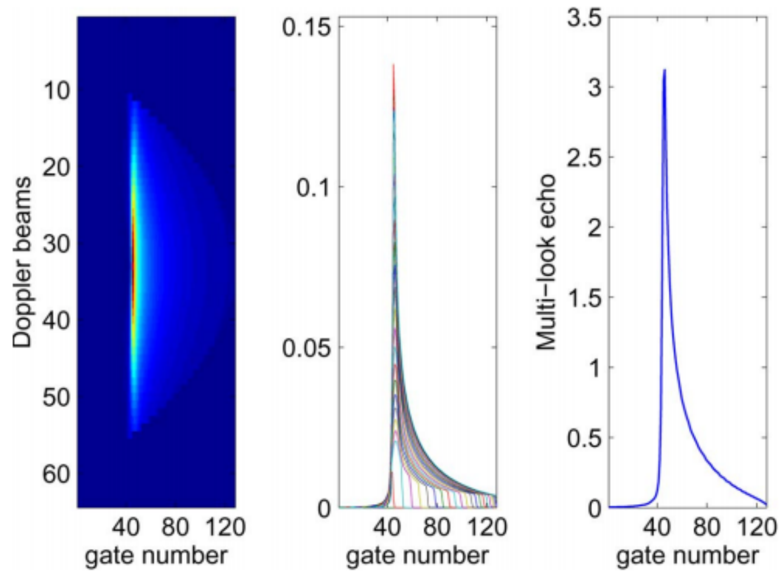
      PRF-18KHz, duration 3.5ms, interval between burst data ~11.8 ms→70% not used.

Overview

- ❑ Raney proposed:
  - ❑ PRF of 9 KHz.
    - High enough, to ensure pulse-to-pulse coherency.
    - Low.enough, to allow space between transmitted pulses.

      Interveleaded mode → Jason – CS.

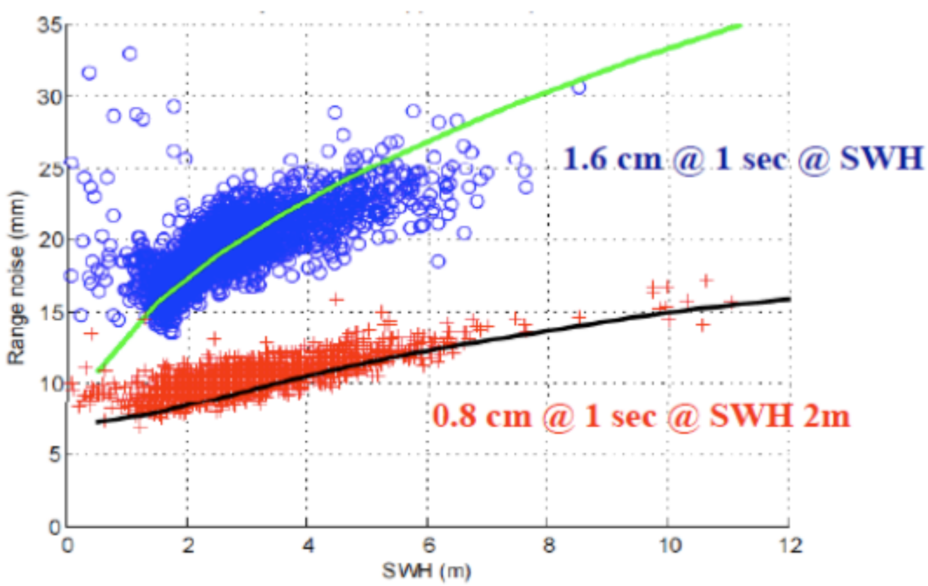




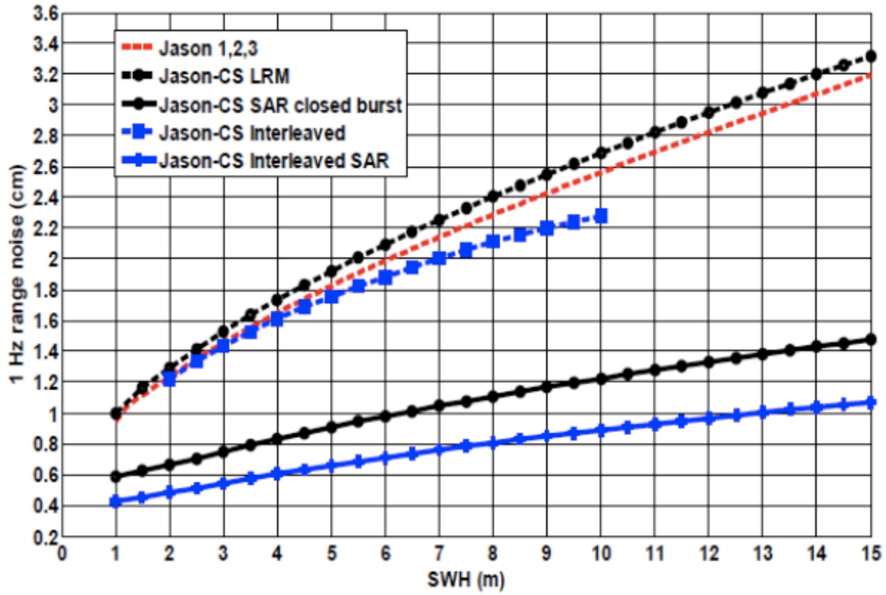
*Credits: A. Halimi

Overview

- ❑ Noise reduction on range and SWH, using Cryosat



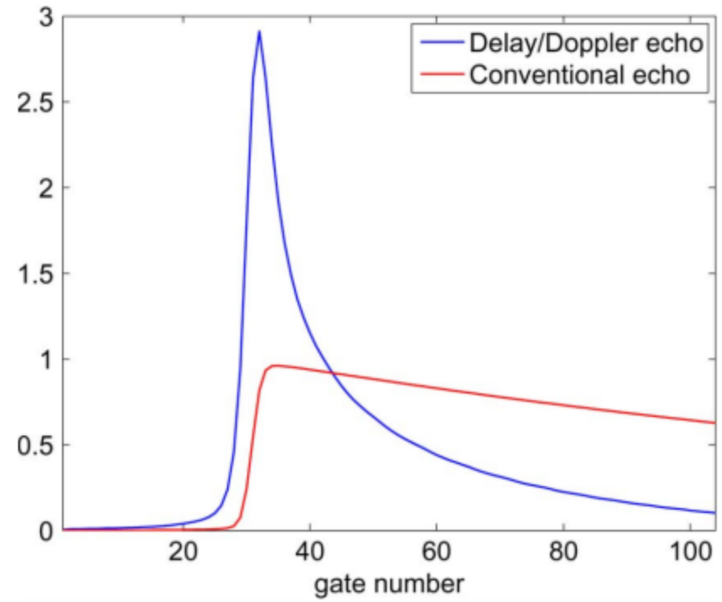
- ❑ Range Noise with SAR interleaved mode



*Credits: Phalippou and Demeestre

Overview

- ❑ Conventional Pulse-Limited Alt→ Brown model.
  - Flat Sea Surface Response (FSSR).
  - Radar Point Target (PTR).
  - Probability Density function (PDF) of surface elevation.



*Credits: A. Halimi

- ❑ SAR Altimeter:
  - Surface Impulse Response (Psurf).
  - System Point Target Response (PTR).
  - Sea Surface Height Probability Density function (PDFsea).

SAMOSA-3 Retracker

- Equation can be solved:

$$P(f,t) \propto \sigma^0 G^2(f,t) P_{surf}(f,t) * PTR(f,t) * PDF_{sea}$$

- Numerical
  - Offers an exact solution.
  - Computationally expensive → Look Up Table for a wide range of geophysical, geometrical, and orbital parameters.
- Semi-analytical → SAMOSA 2.
- Fully-analytial:
  - SAMOSA-1
    - Gaussian ocean surface statistics.
    - No curvature effect cross-talk.
    - No misspointing acrros-track.
    - Circular antenna.
  - SAMOSA-3
    - Simplification of SAMOSA-2 for Gaussian ocean surface statistics.

Scattering amplitude

- EM Scattering model is assumed isotropic rough surface of Gaussian statistics.

$$\sigma(\theta) \approx \sigma_0(0)\exp\left(-\frac{\tan^2\theta}{\sigma^2{}_{\text{slopes}}}\right)$$

Inc. angle

Variance of the total sea surface (MSS)

$$\sigma_{\text{slopes}} = \frac{\sqrt{2}\sigma_s}{L_c}$$

RMS height of the specular point.
Ocean correlation length.

Antenna Gain

- Assumed elliptical antenna pattern.

$$G(x,y) = G_0 \exp\left(-4\ln(2)\frac{x^2}{h^2\theta_x^2} - 4\ln(2)\frac{y^2}{h^2\theta_y^2}\right)$$

$$\boxed{\alpha_x = \frac{8\ \ln(2)}{h^2\theta_x^2} \qquad \alpha_y = \frac{8\ \ln(2)}{h^2\theta_y^2}}$$

$$G(x,y) = G_0 \exp\left(-\alpha_x\frac{x^2}{2} - \alpha_y\frac{y^2}{2}\right)$$

- In presence of misspointing.

$$G(x,y,x_p,y_p) = G_0 \exp\left(-\alpha_x\frac{(x-x_p)^2}{2} - \alpha_y\frac{(y-y_p)^2}{2}\right)$$

$$G(x,y,x_p,y_p)^2 = {G_0}^2 \exp\left(-\alpha_x(x-x_p)^2 - \alpha_y(y-y_p)^2\right)$$

Antenna Gain

- However, Sentinel-3 circular antenna, and not elliptical.
- Assuming,

$$\theta_x = \theta_y = \theta_c \qquad \alpha_x = \alpha_y$$

- It can be expressed as,

$$G(\theta) \approx G_0 \exp\left(-\frac{4\ln(2)}{\theta_c}\sin^2(\theta)\right)$$

Power Waveform Analytical Expression

- Power Waveform expression

$$\bar{P}_{k,l} = P_u \sqrt{g_l}\, \Gamma_{k,l}(0)\{\left[1 - \frac{< z_0 > - z_{\mathrm{EM}}}{L_\Gamma} T_k(y_p)\right] f_0\left(g_l\left(k + \frac{\langle z_0\rangle - z_{\mathrm{EM}}}{L_z}\right)\right) +$$
$$\frac{\sigma_z}{L_\Gamma}\, T_k(y_p)\, g_l\, \sigma_s\, f_1\left(g_l\left(k + \frac{\langle z_0\rangle - z_{\mathrm{EM}}}{L_z}\right)\right)\}$$

- where,
  - Pu is a variable that includes all the multiplicative factors.
  - zo is the mean sea height.
  - k is a variable with 128 samples.
    - 64 samples considered for CryoSat-2 in the SAR mode.

$$g_l = \sqrt{\frac{2\alpha_g}{1 + 4\left(\frac{L_x}{L_y}\right)^4 (l - l_s)^2 + 2\alpha_g\left(\frac{\sigma_z}{L_z}\right)^2}}$$

- σz, std of the sea height.
- Lx along track inde that contains the SP

$$L_x = \frac{ch}{2V_s f_c T} \approx 293\mathrm{m}$$

$$L_y = \sqrt{\frac{ch}{\alpha B_r}} \approx 777\mathrm{m}$$

$$L_z = \frac{c}{2B_r} = 0.4683\mathrm{m}$$

$$x_l = L_x l$$

$$y_k = \begin{cases} L_y\sqrt{k} & \text{if } k > 0 \\ 0 & \text{otherwise} \end{cases}$$

$$\alpha_g = 1.6813$$

Power Waveform Analytical Expression

$$\Gamma_{k,l}(0) = \exp\left[-\alpha_y y_p^2 - \alpha_x (x_l - x_p)^2 - \alpha_\sigma x_l^2 - (\alpha_y + \alpha_\sigma) y_k^2\right] \cosh(2\alpha_y y_p y_k)$$

- Xp, yp, location of the center of the beam on the sea surface.

$$\alpha_x = \frac{8\ln(2)}{h^2\theta_x^2} \qquad \alpha_y = \frac{8\ln(2)}{h^2\theta_y^2} \qquad \alpha_\sigma = \frac{L_c^2}{2\sigma_z^2 h^2}$$

- ❑ Lc sea surface correlation lenght.
- ❑ Θ, full along track and accross track width of the beam.

$$T_k(y_p) = \begin{cases} (1+\frac{\alpha_\sigma}{\alpha_y}) - \frac{y_p}{L_y\sqrt{k}} \tanh(2\alpha_y y_p L_y \sqrt{k}) & \text{for } k > 0 \\ (1+\frac{\alpha_\sigma}{\alpha_y}) - 2\alpha_y y_p^2 & \text{for } k \leq 0 \end{cases}$$

- ❑ Omitiing the slope dependence,

$$g_l = \sqrt{\frac{2\alpha_g}{1 + 4\left(\frac{L_x}{L_y}\right)^4 l^2 + 2\alpha_g\left(\frac{\sigma_z}{L_z}\right)^2}}$$

Power Waveform Analytical Expression

- Omitting zo and the elctromagnetic bias,

$$\bar{P}_{k,l} = P_u \sqrt{g_l}\, \Gamma_{k,l}(0) \left\{ f_0\,(g_l k) + \frac{\sigma_z}{L_\Gamma}\, T_k(y_p)\, g_l\, \sigma_s\, f_1\,(g_l k) \right\}$$

- And if the first order term is omitted,

$$\bar{P}_{k,l} = P_u \sqrt{g_l}\, \Gamma_{k,l}(0)\, f_0\,(g_l k)$$

  - where fo can be expressed as a function of Bessel functions.

$$\bar{P}_{k,l} = P_u \sqrt{g_l}\, \Gamma_{k,l}(0)\, e^{-\frac{1}{4}(g_l k)^2} \begin{cases} (-g_l k)^{\frac{1}{2}}\, K_{\frac{1}{4}}\left(\frac{1}{4}(g_l k)^2\right) & \text{for } g_l k < 0 \\ \frac{\pi}{\sqrt{2}}\,(g_l k)^{\frac{1}{2}} \left(I_{\frac{-1}{4}}\left(\frac{1}{4}(g_l k)^2\right) + I_{\frac{1}{4}}\left(\frac{1}{4}(g_l k)^2\right)\right) & \text{for } g_l k > 0 \end{cases}$$

$$I_{-p}(k) = I_p(k)$$

$$I_p(k) = \frac{\exp(k)}{\sqrt{2\pi k}}$$

Radar System Point Target Response

- ❑ SAMOSA-3 omits the following effects,
  - Sea Surface skewness effect.
  - Earth Surface Slope effect.
  - 1st order function term (f1).
  - Mean surface and electromagnetical Bias height.
- ❑ The analytical expression of the Single-Look Model, is derived accounting the system point target response of the DDA.

$$SPTR_{range}(\tau) = \mathrm{sinc}^2(\tau_u \beta \tau) \approx \exp\left(\frac{-\tau^2}{2\sigma_p^2}\right)$$

$$\boxed{\sigma_p = \alpha_p r_B} \qquad \boxed{r_B = {}^{1}/_{B_r}}$$

Radar System Point Target Response

- And for SAMOSA-3, it can be expressed in terms of

$$\alpha_g = \frac{1}{2\alpha_p^2}$$

- Thus,

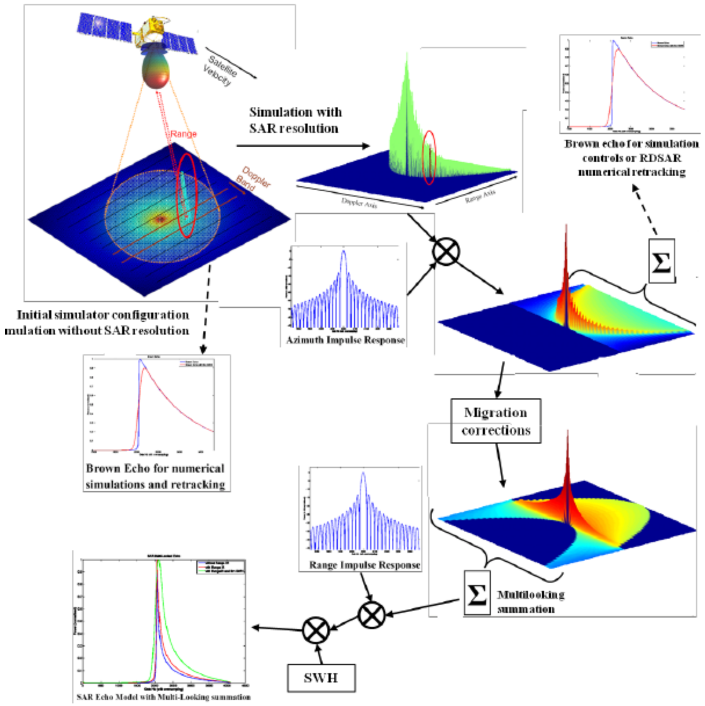
$$SPTR_{range}(\tau) = \mathrm{sinc}^2(\tau_u \beta \tau) \approx \exp\left(-\alpha_g u^2\right)$$

- with,

$$u = \tau B_r$$

Range Cell Migration Correction

- Appropiated handing of the energy distribution over the different echoes of the delay-Doppler stack,
    - To avoid missmodelling with CPP data.
- CPP applies the so-called Range Cell Migration Correction (RCMC).
    - Correct relative range displacement with respect zero Doppler beam.



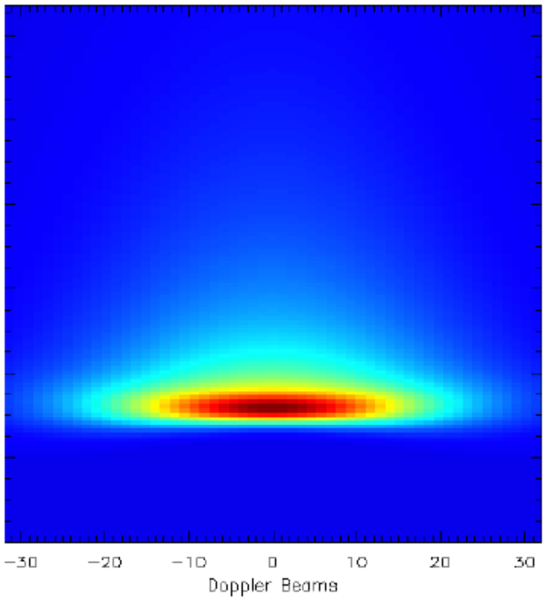
*Credits: Boy, and Moreau

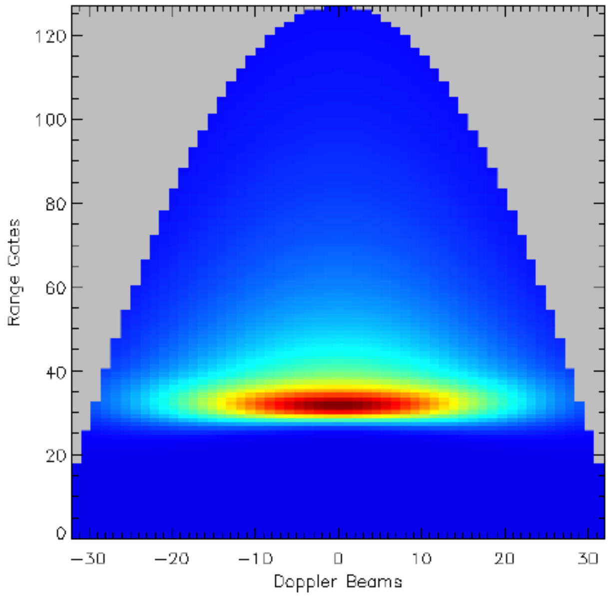
Range Cell Migration Correction

- The SAMOSA stack model needs to be trimmed according to the range cell migration of each Doppler beam.
- Range gates with are Range Migrated are set to zero,

$$e^{i2\pi\beta(\frac{\alpha x_l^2}{ch}-\frac{2sx_l}{c})\tau_n}$$

- Thus, range gates beyond lag 128 should be set zero in the final DDM.
- Final 2D-DDM, parabolic shape.



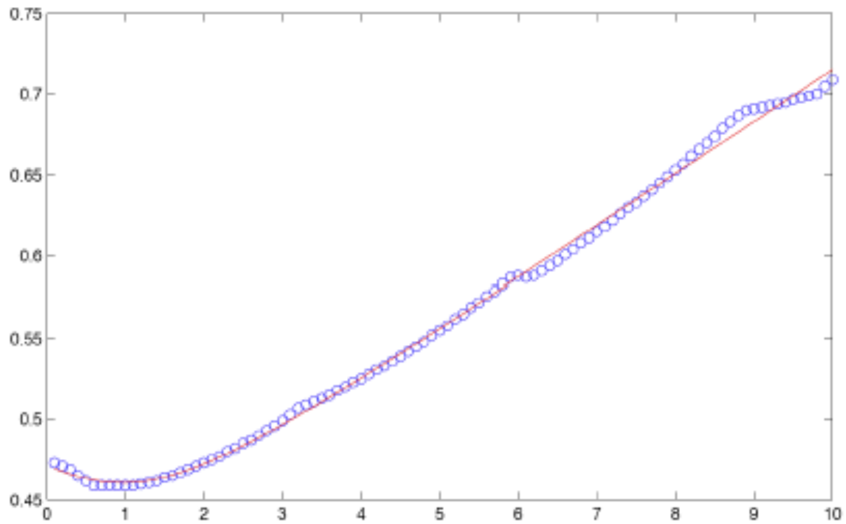


Point Target Response as a function of SWH

- Salvatore Dinardo proposed a solution for the error on the SWH estimation, based on a variable width of the PTR.
  - Alpha-p mapped as a function of SWH.
  - Implemented using a LUT.
- An analytical formula was derived,

$$\sigma_g = A + \sqrt{B + \left(\frac{H_s - C}{D}\right)^2}$$

A = 0.4178
B = 0.0019
C = 0.9689
D = 30.6673

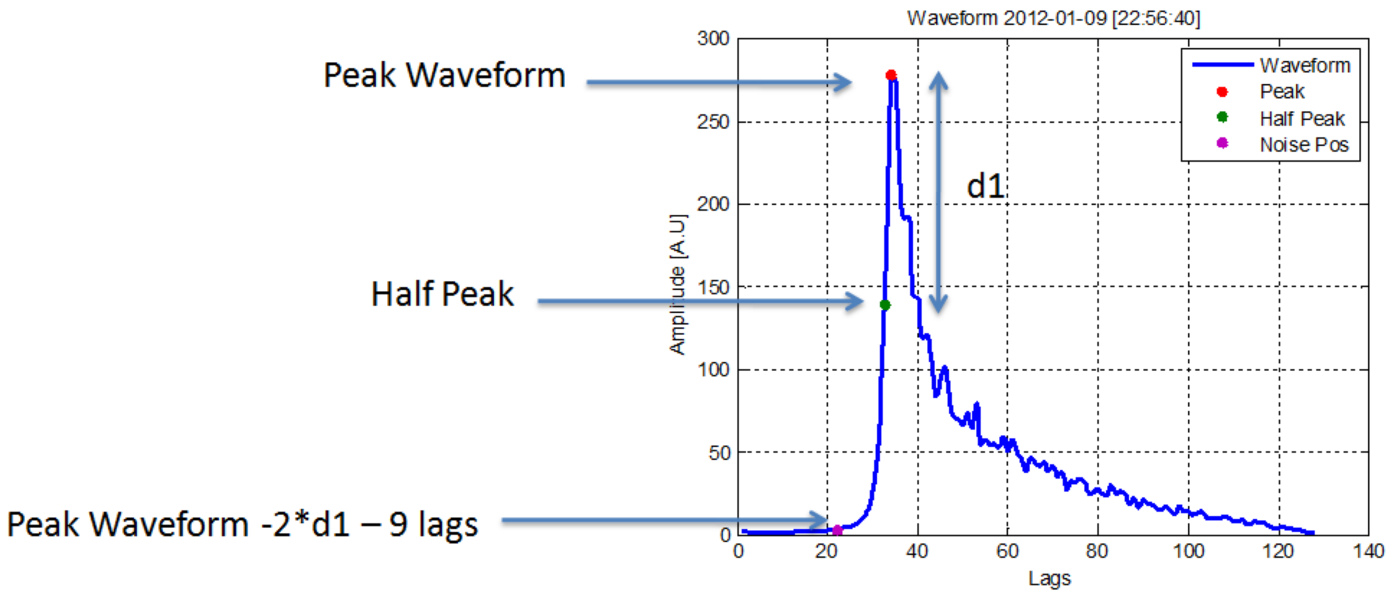


*Credits: S. Dinardo

Thermal Noise Estimation

- Estimation thermal noise is a key parameter in the retracking of the SAR waveforms.
    - Directly related with the estimation of the SWH
- Originally approach was obtained as the average value of the first SAR waveforms lags,
    - Typically lags 11-21.
- However, this approach does not consider the impact that the SWH can have on
    - The leading edge.
    - The amplitude of the averaged SAR waveform.

Thermal Noise Estimation



leading_edge_span = 2*(waveform_peak_pos – half_power_pos),

leading_edge_starting_pos=waveform_peak_pos-leading _edge_span,

noise_calculation_position=leading_edge_starting_pos-(16),

noise_floor = mean(Waveform[noise_calculation_position– 1: noise_calculation_position –+1]),