ICESat Between-Period Elevation Biases: Range Biases from Waveform Skew

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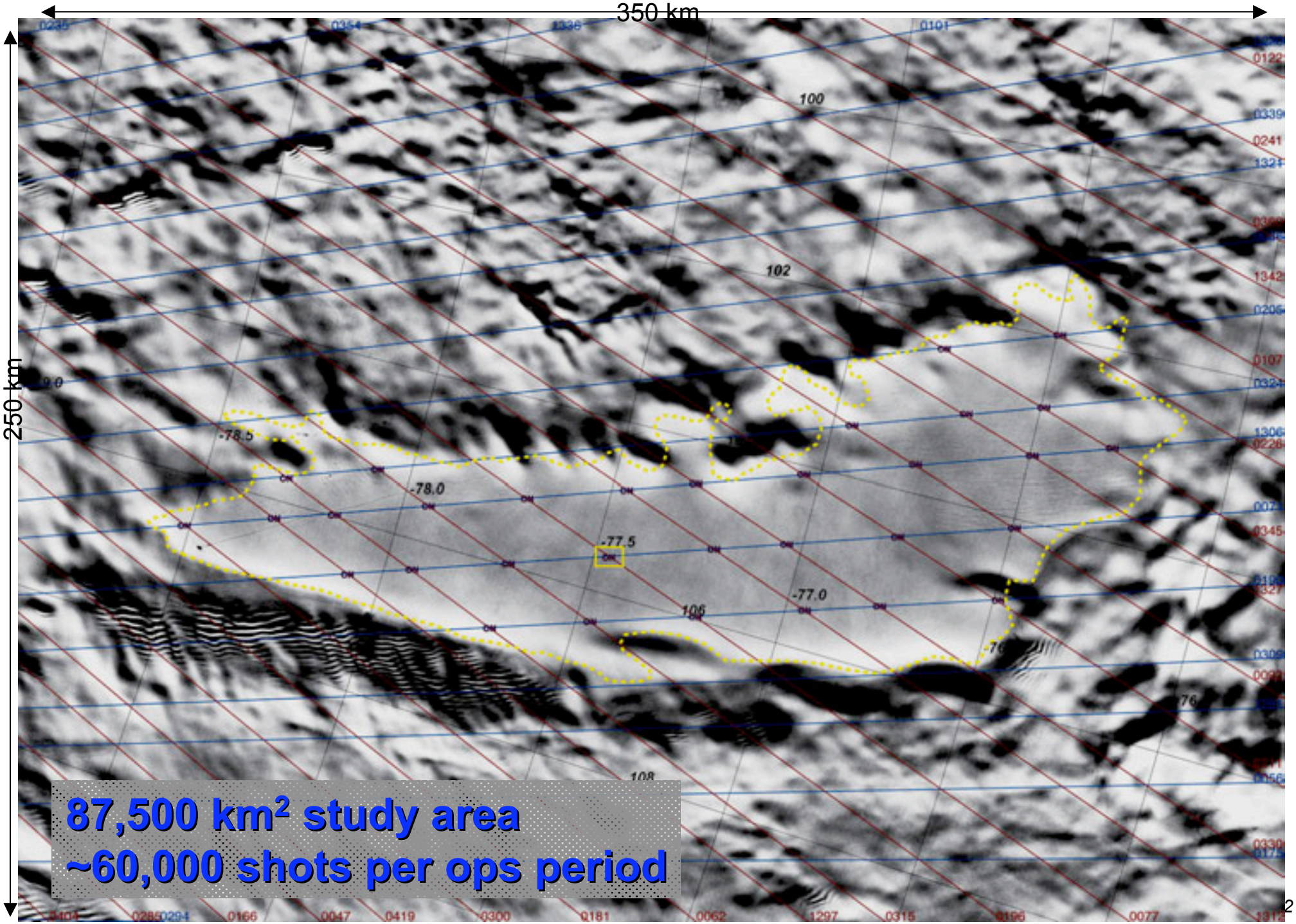
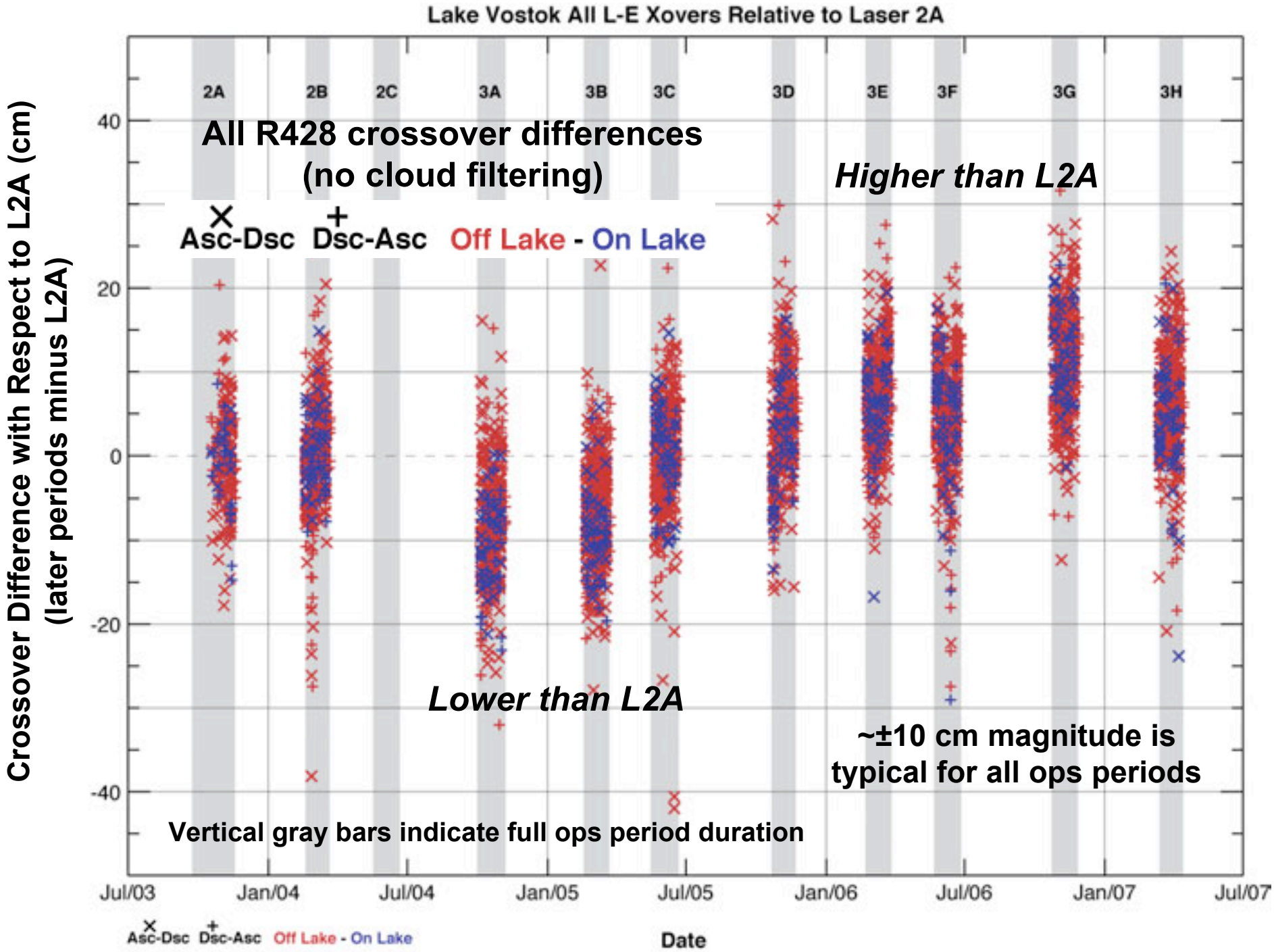
Vijay Suchdeo, Claudia Carabajal, Jack Saba, Steve Palm

ICESat Science Team Meeting
Boulder, CO
March 25, 2008

ICESat Time Series Studies On and Around Lake Vostok



Lake Vostok Area Crossover Time Series



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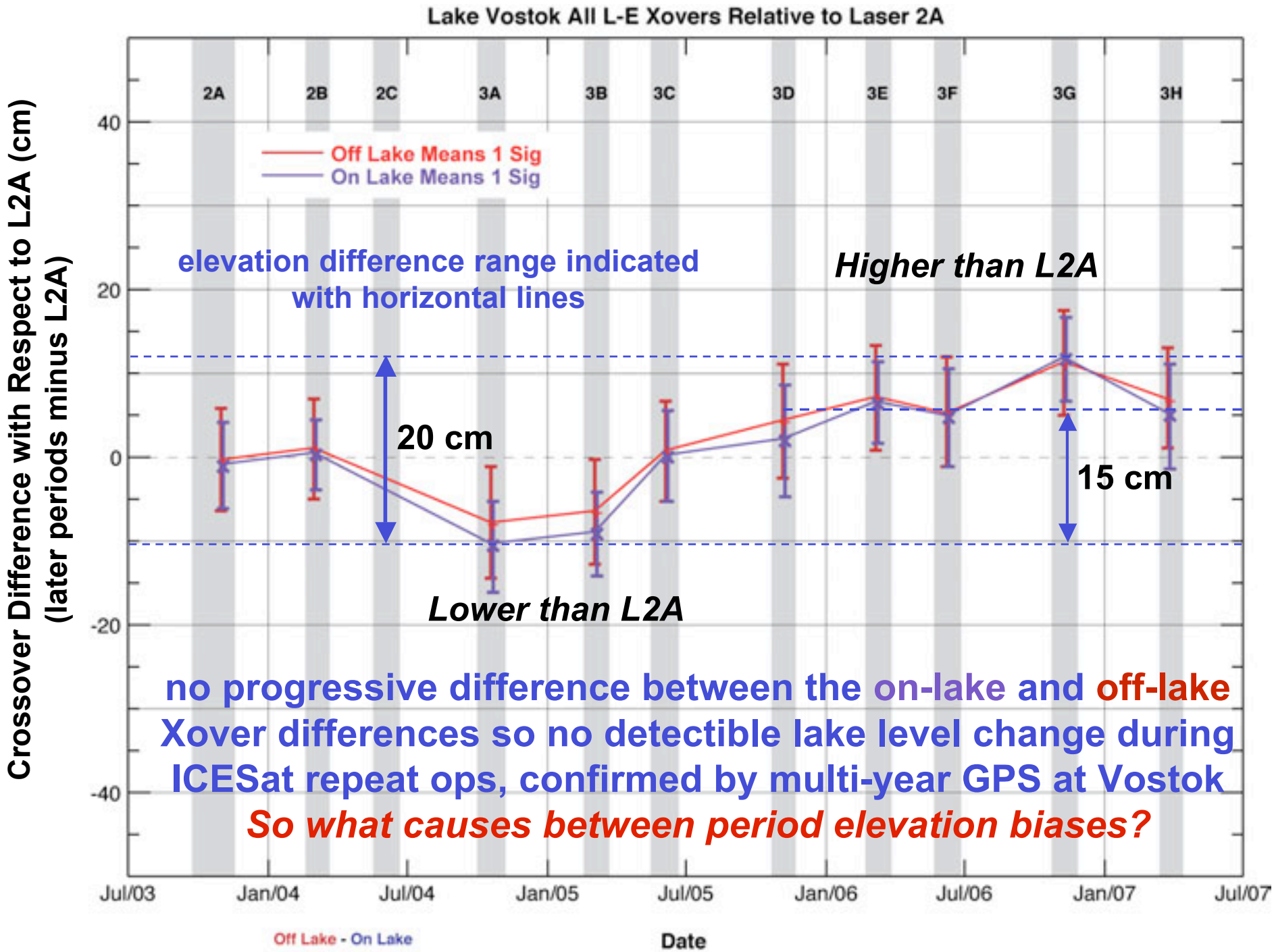
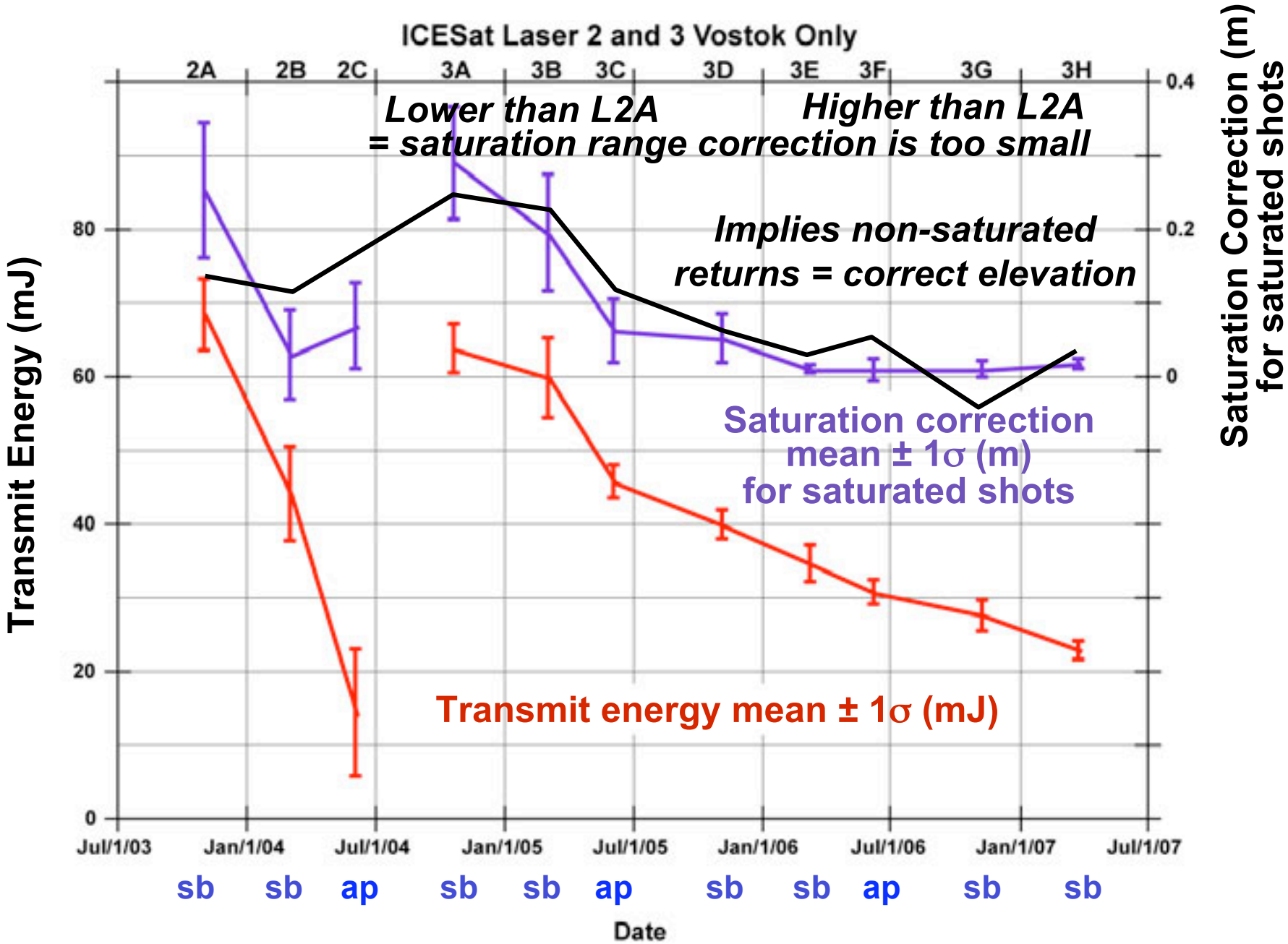


no progressive difference between the on-lake and off-lake Xover differences so no detectible lake level change during ICESat repeat ops, confirmed by multi-year GPS at Vostok

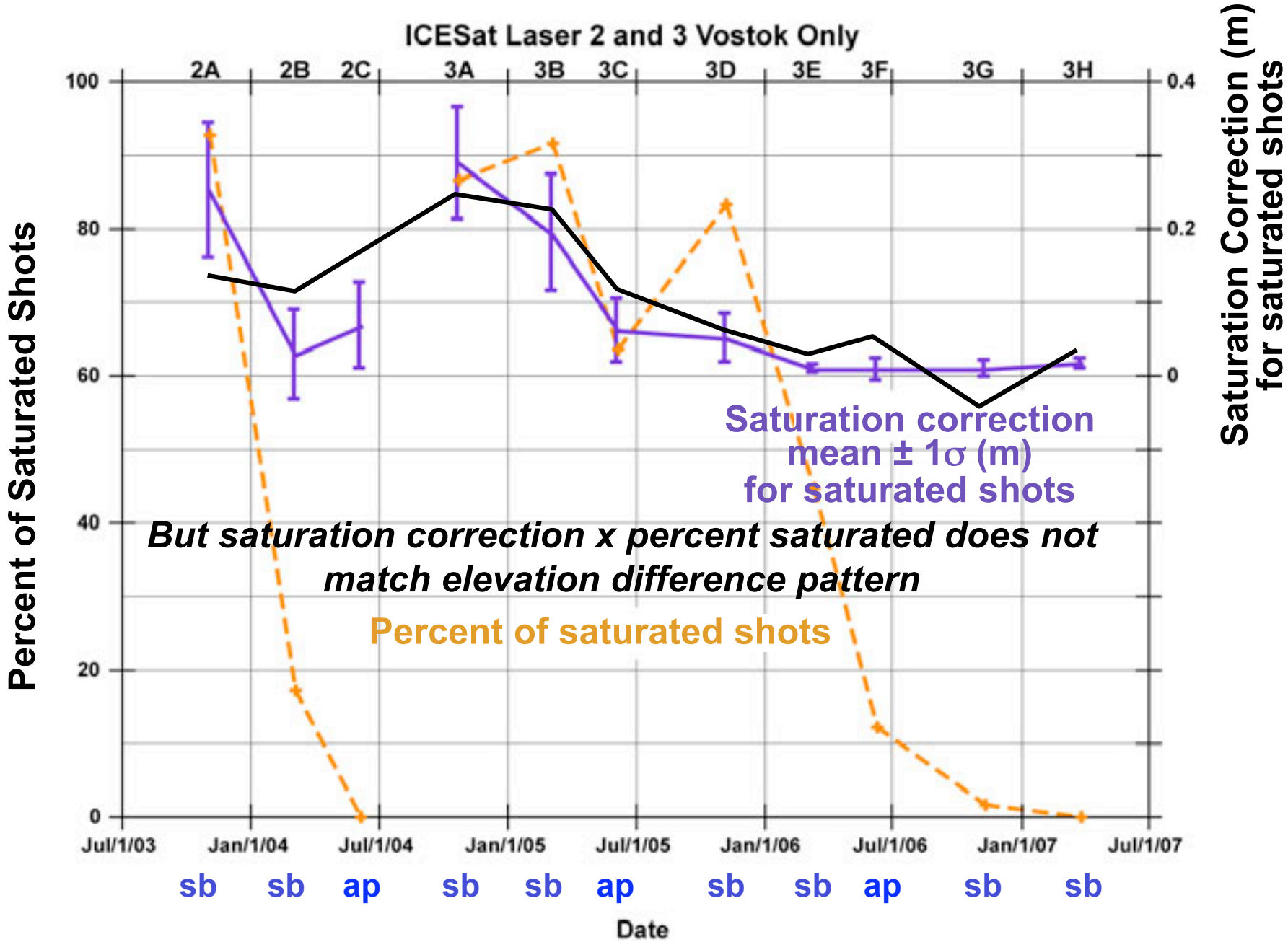
So what causes between period elevation biases?

Saturation Correction Magnitude & Transmit Energy



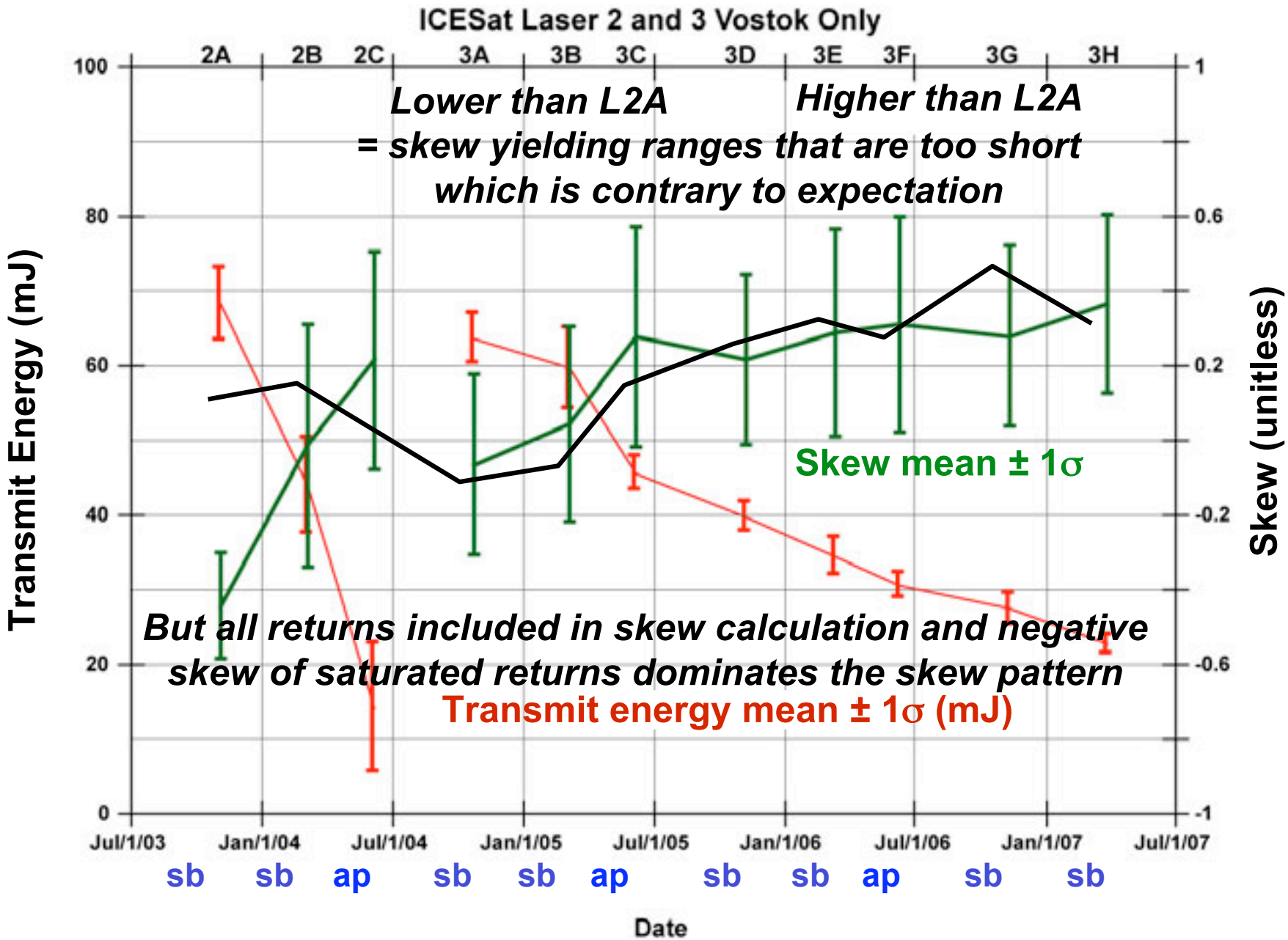
Decline in saturation correction magnitude with decline in transmit energy

Saturation Correction Magnitude & Percent Saturated



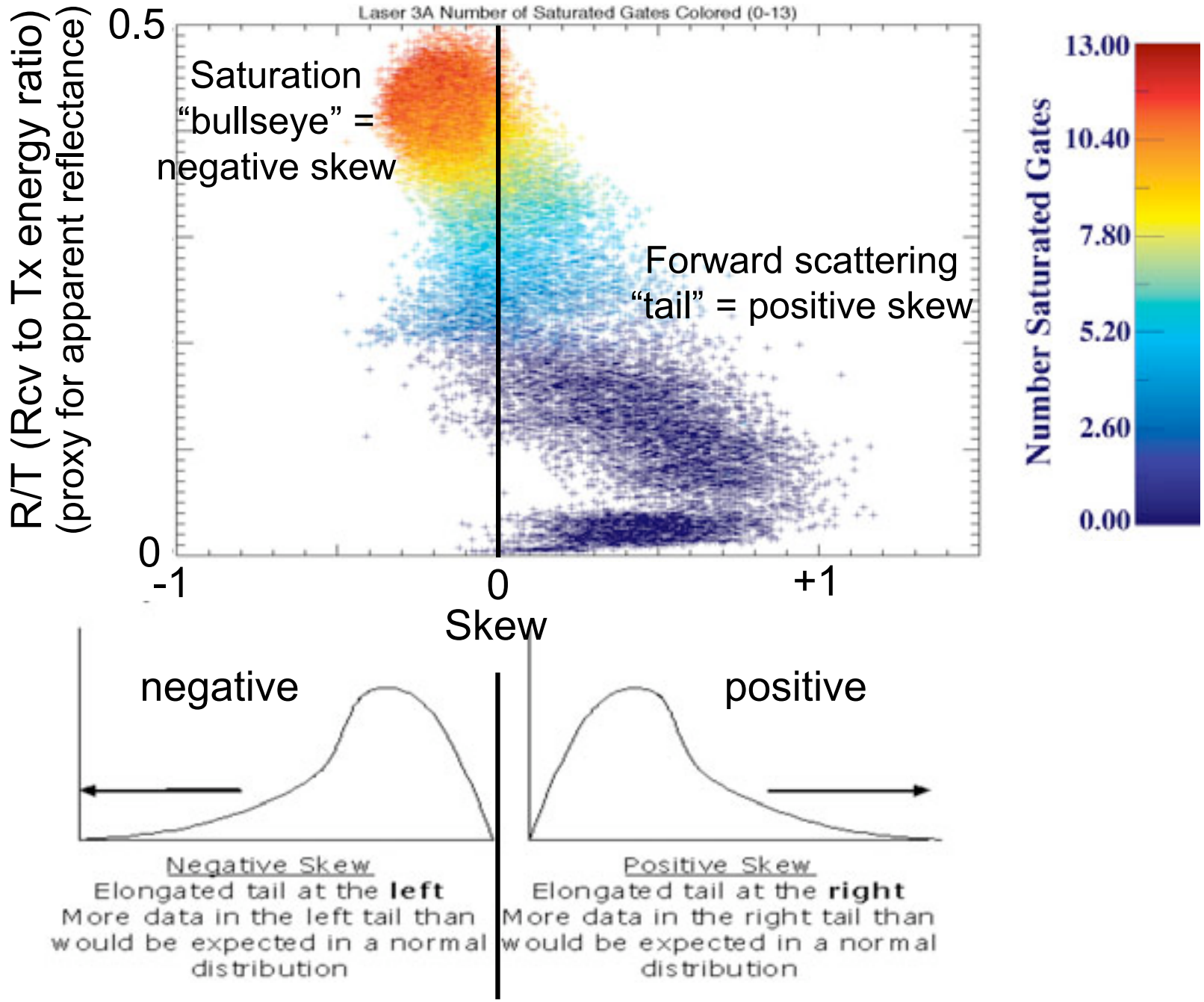
Few saturated shots for 2B, 2C, 3F, 3G, 3H

Waveform Skew & Transmit Energy

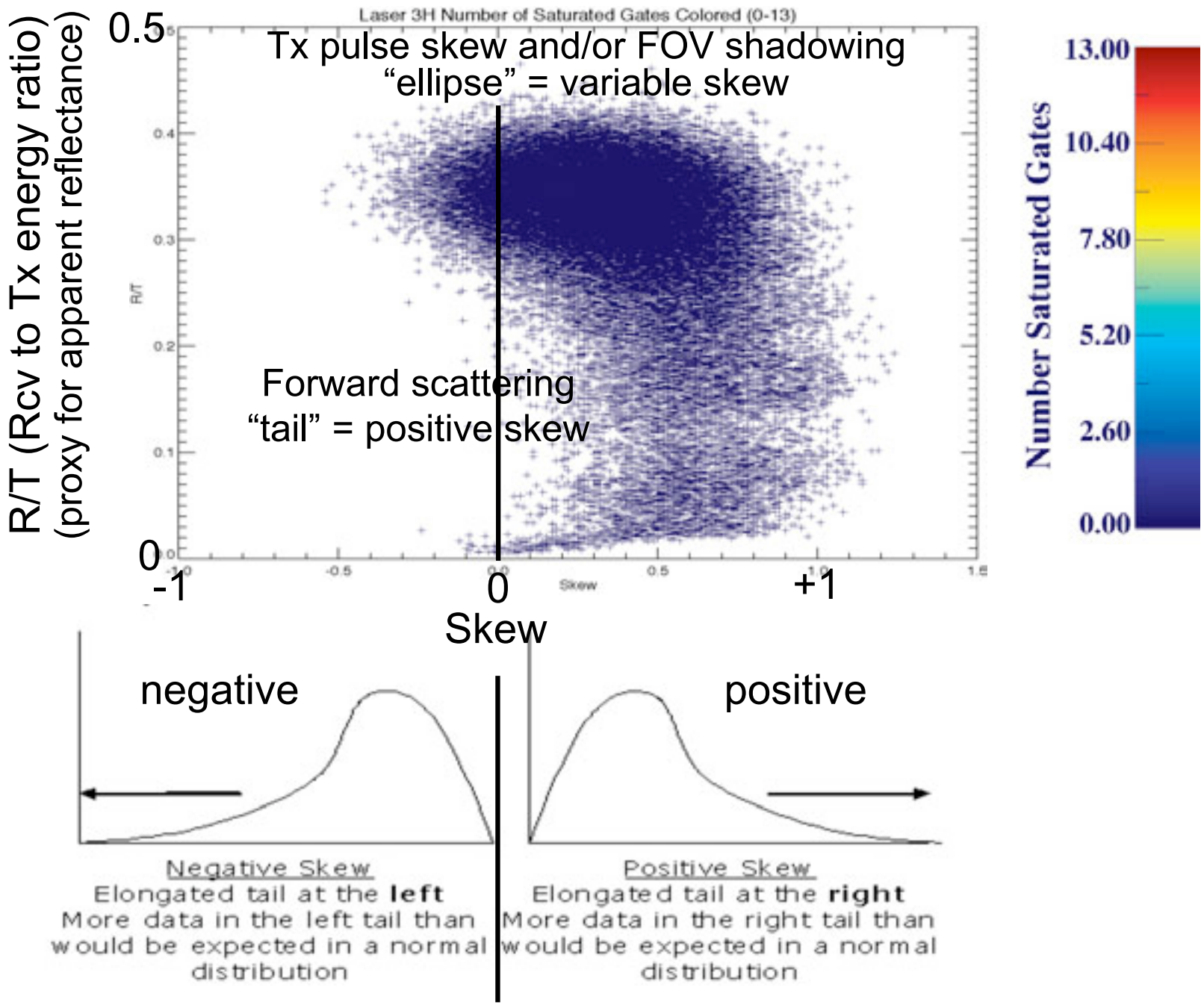


Increase in positive skew with decline in transmit energy

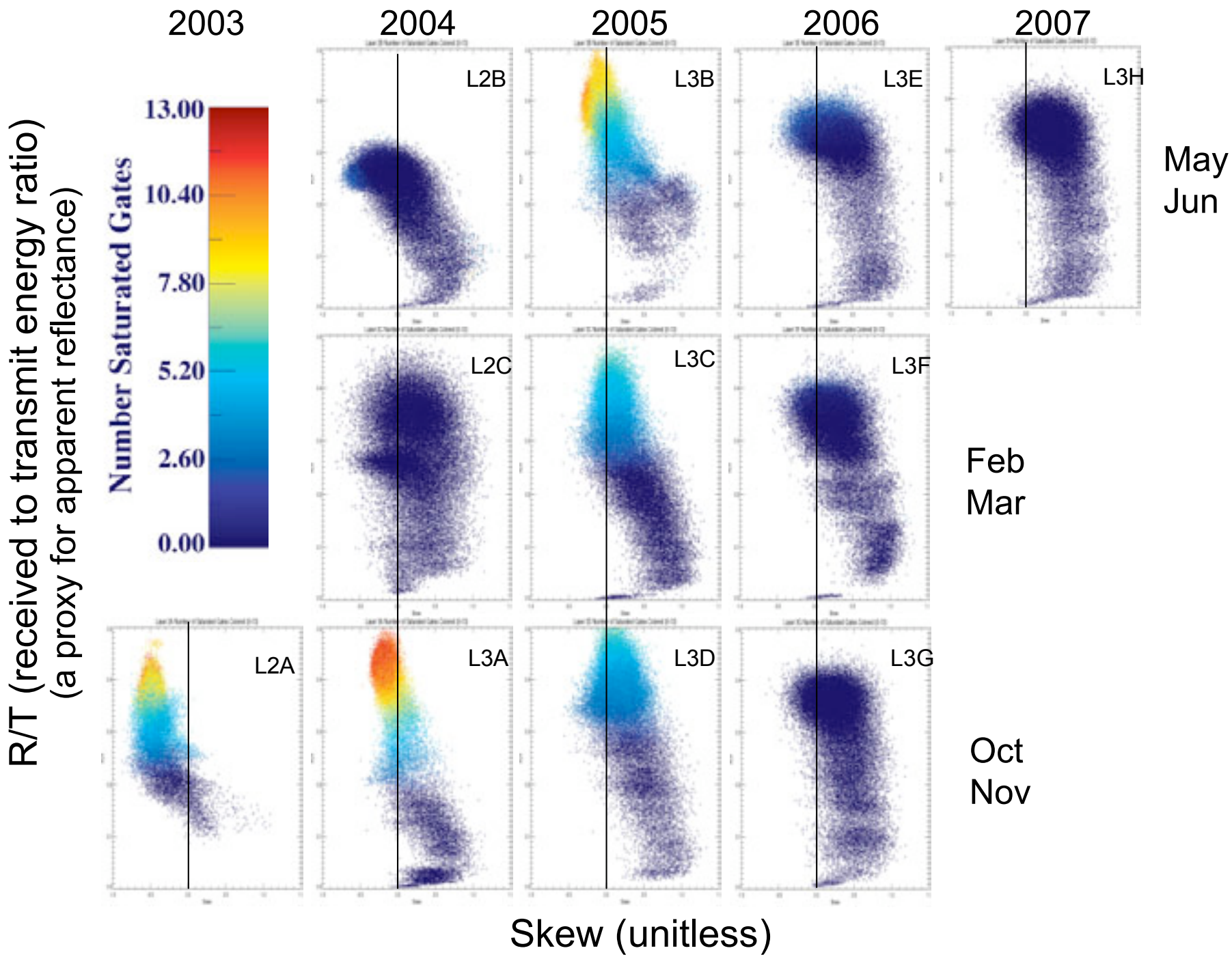
Waveform Skew vs. R/T Color-coded by Number of Saturated Bins



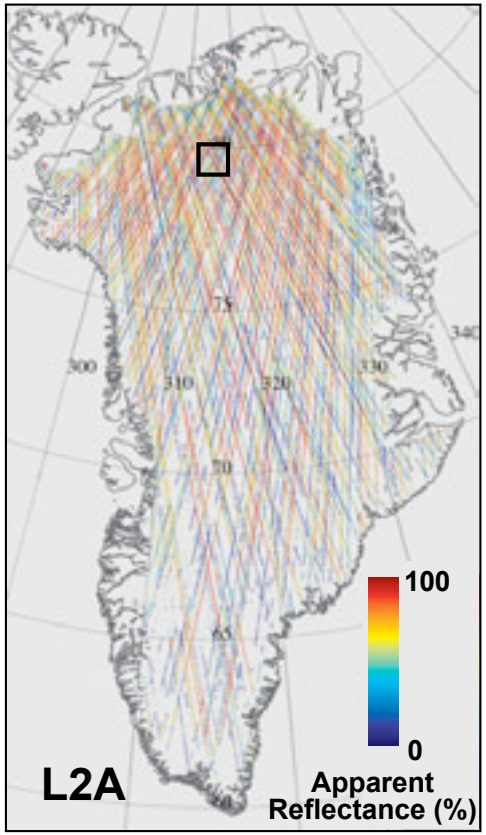
Waveform Skew vs. R/T Color-coded by Number of Saturated Bins

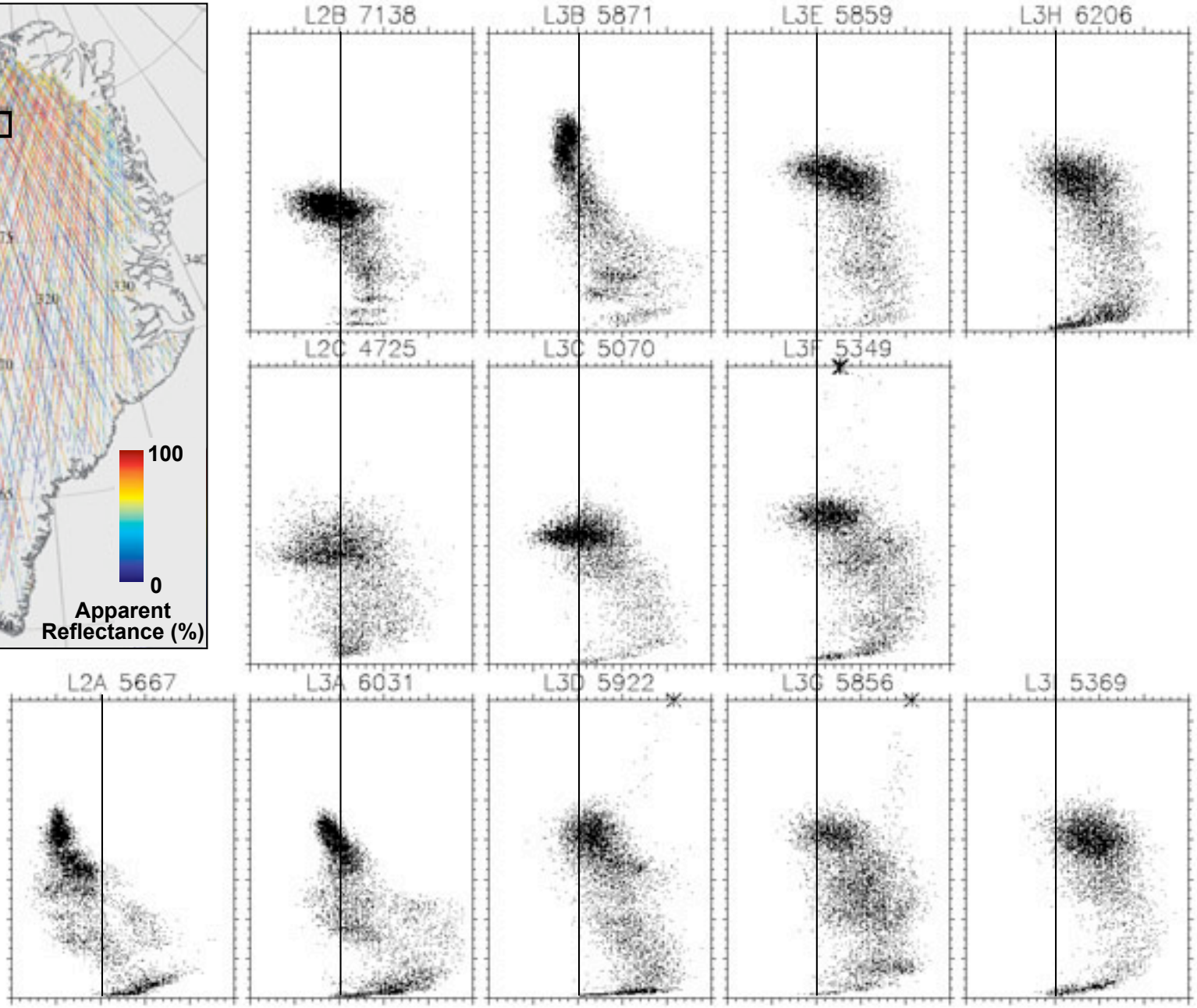


Waveform Skew vs. R/T Color-coded by Number of Saturated Bins



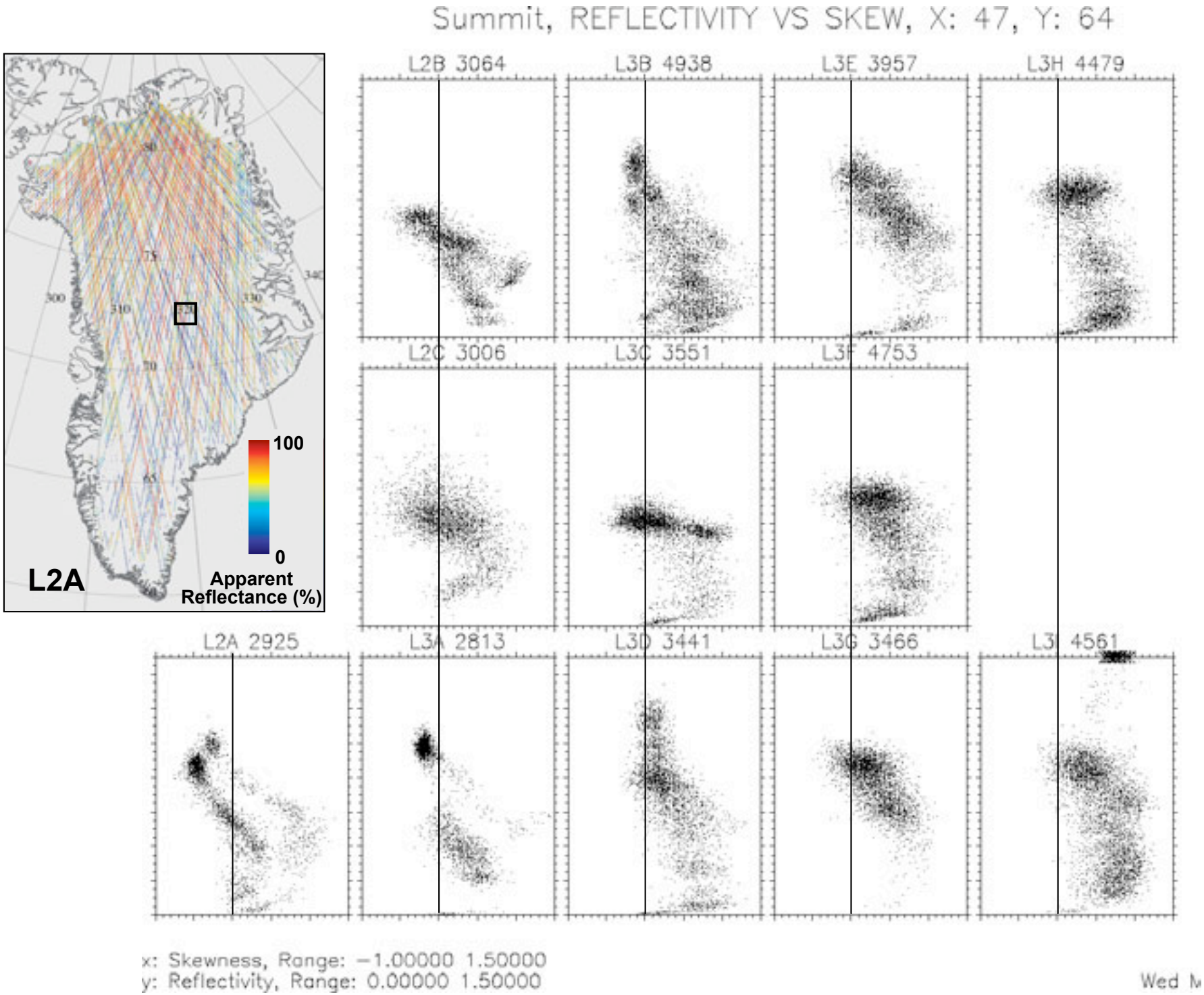
cell (x,y) = (45,56), Center lat,lon = (79.870985,315.0), REFLECTIVITY VS



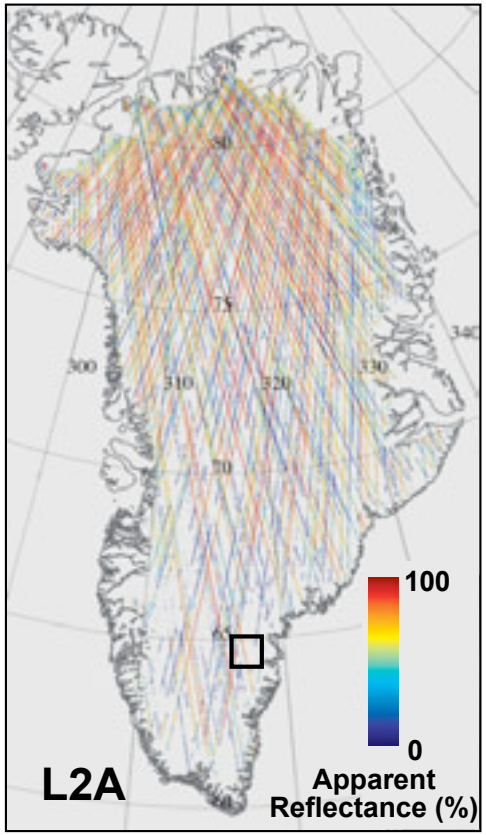


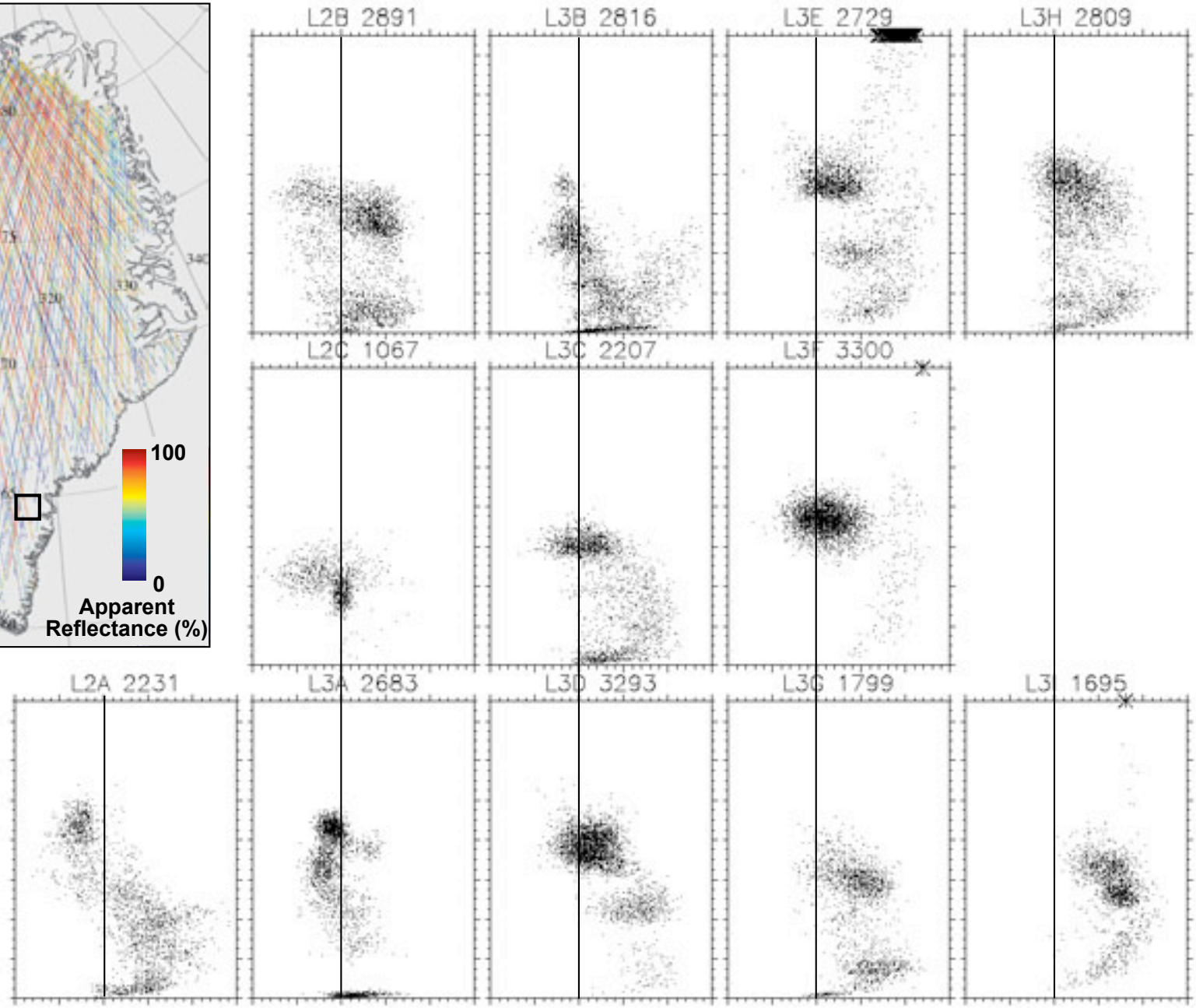
x: Skewness, Range: −1.00000 1.50000
y: Reflectivity, Range: 0.00000 1.50000

Wed Mar 19


Summit, REFLECTIVITY VS SKEW, X: 47, Y: 64
L2B 3064
L3B 4938
L3E 3957
L3H 4479
L2C 3006
L3C 3551
L3F 4753
L2A 2925
L3A 2813
L3D 3441
L3G 3466
L3I 4561
100
0
L2A
Apparent
Reflectance (%)
x: Skewness, Range: −1.00000 1.50000
y: Reflectivity, Range: 0.00000 1.50000
Wed M

cell (x,y) = (46,73), Center lat,lon = (64.546082,317.045408), REFLECTIVIT





x: Skewness, Range: −1.00000 1.50000
y: Reflectivity, Range: 0.00000 1.50000

Wed Mar 19

Origins of ICESat Waveform Skew

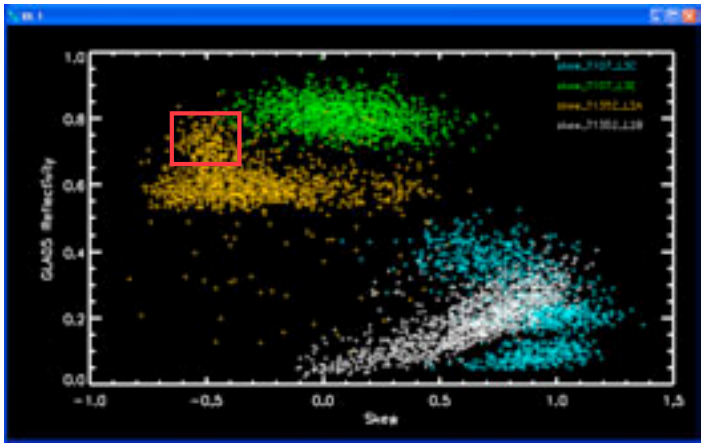
(1)<u>Waveform saturation = Negative Skew</u>

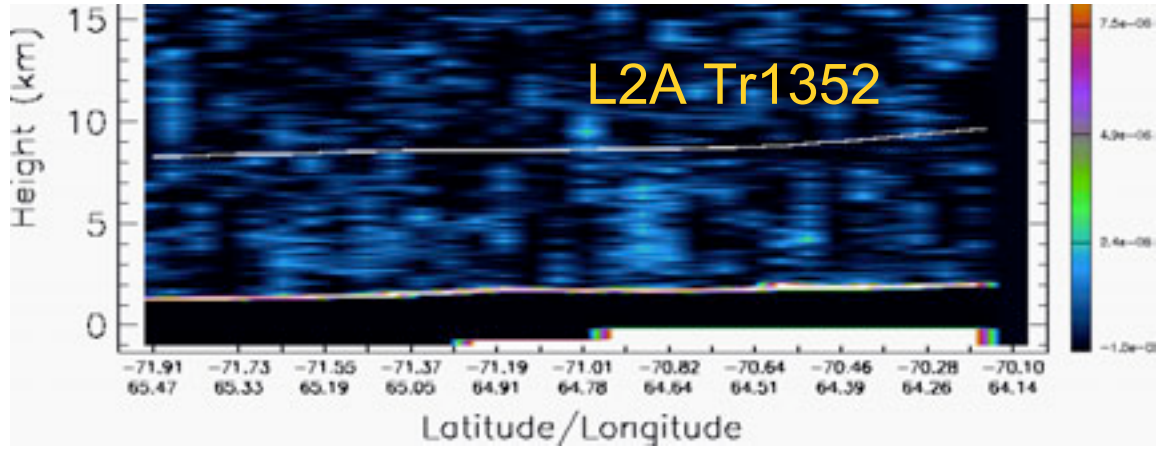
(2) Transmit pulse " back porch" = Positive Skew

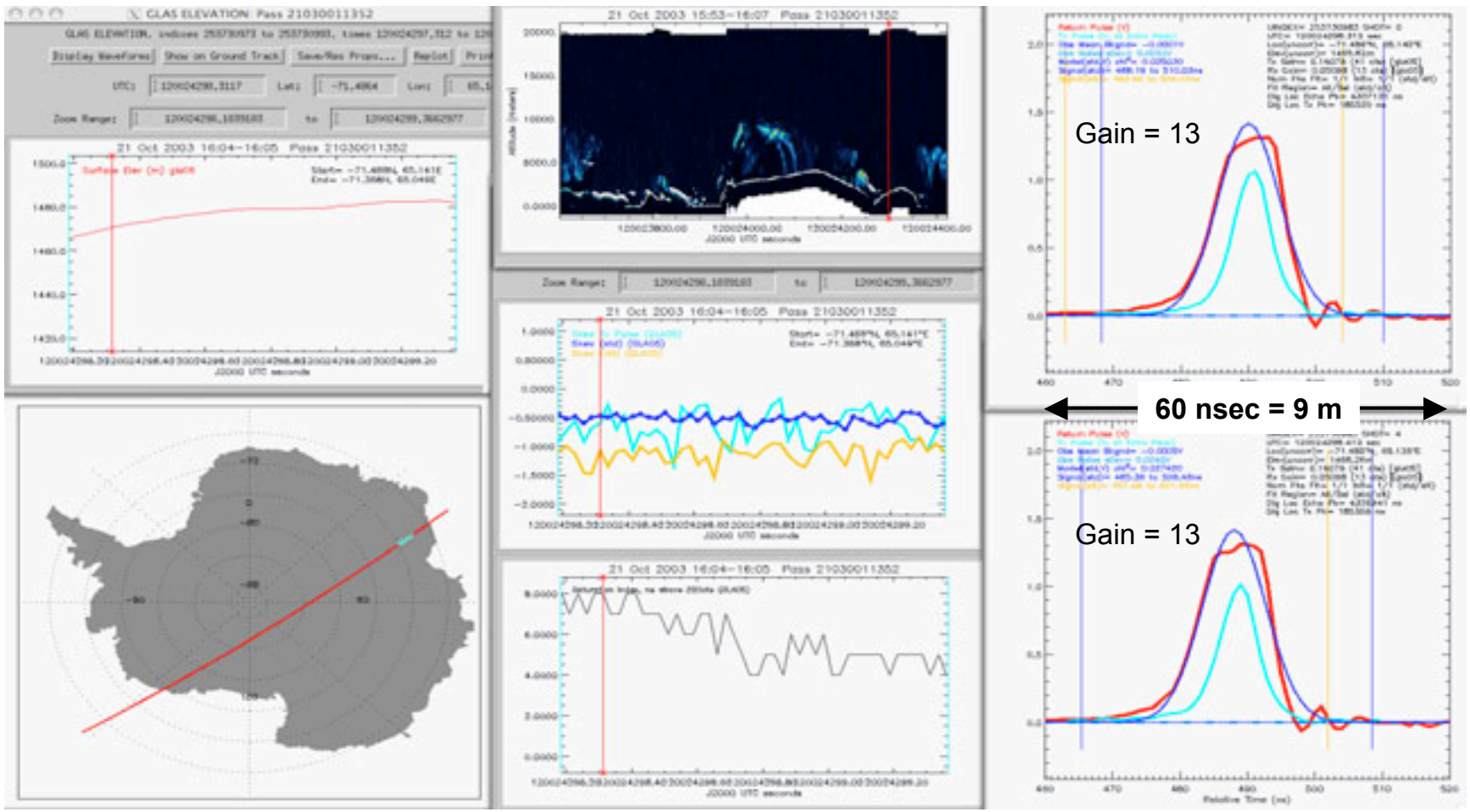
(3) FOV shadowing due to boresight misalignment = Variable Negative and Positive Skews

(4) Atmospheric forward scattering by clouds and/or blowing snow = Positive Skew

Saturated Returns from Surface through Clear Atmosphere: Negative Skew



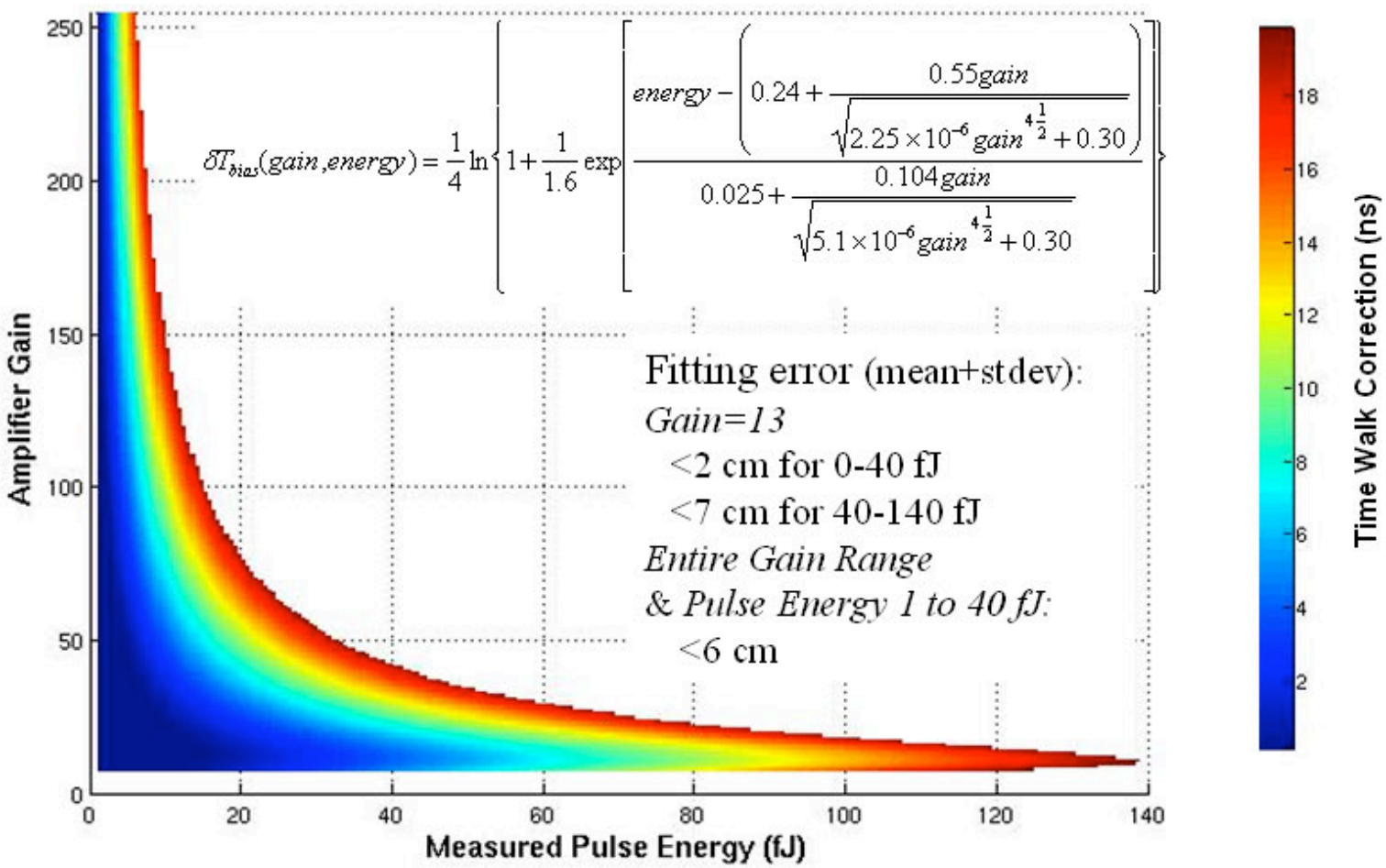




Saturation pulse shape broadening and skewing distortion is accounted for by X. Sun Saturation Range Correction

Modeling of the Range Bias Using the Laboratory Test Data

- A least square fit to the lab measurement data to use as a look-up table for range bias correction (subtract from the raw measurement) for <0.5° sloped surface



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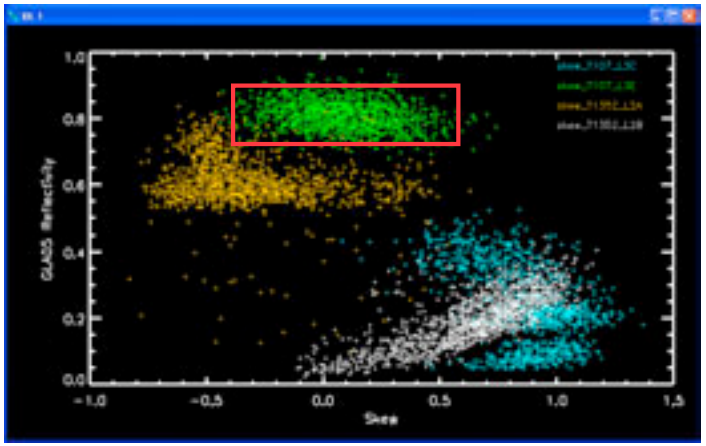
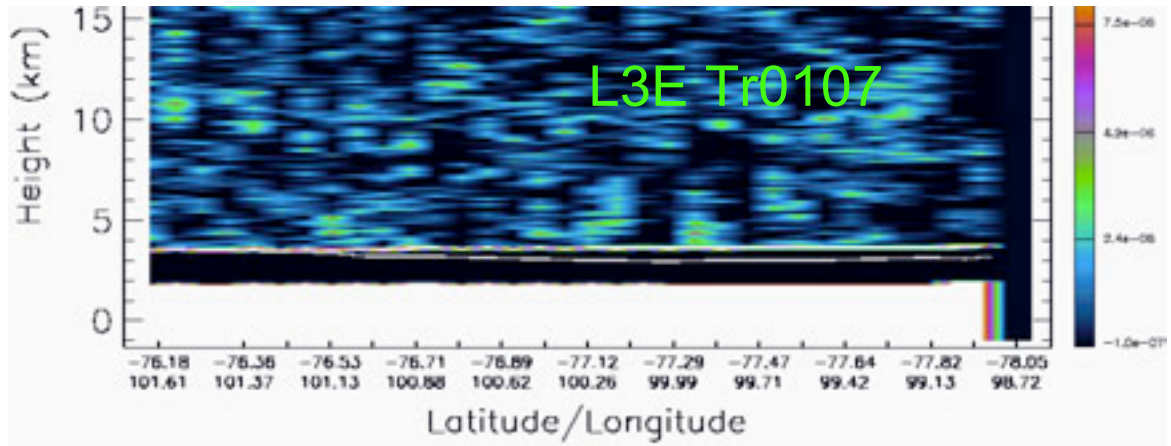
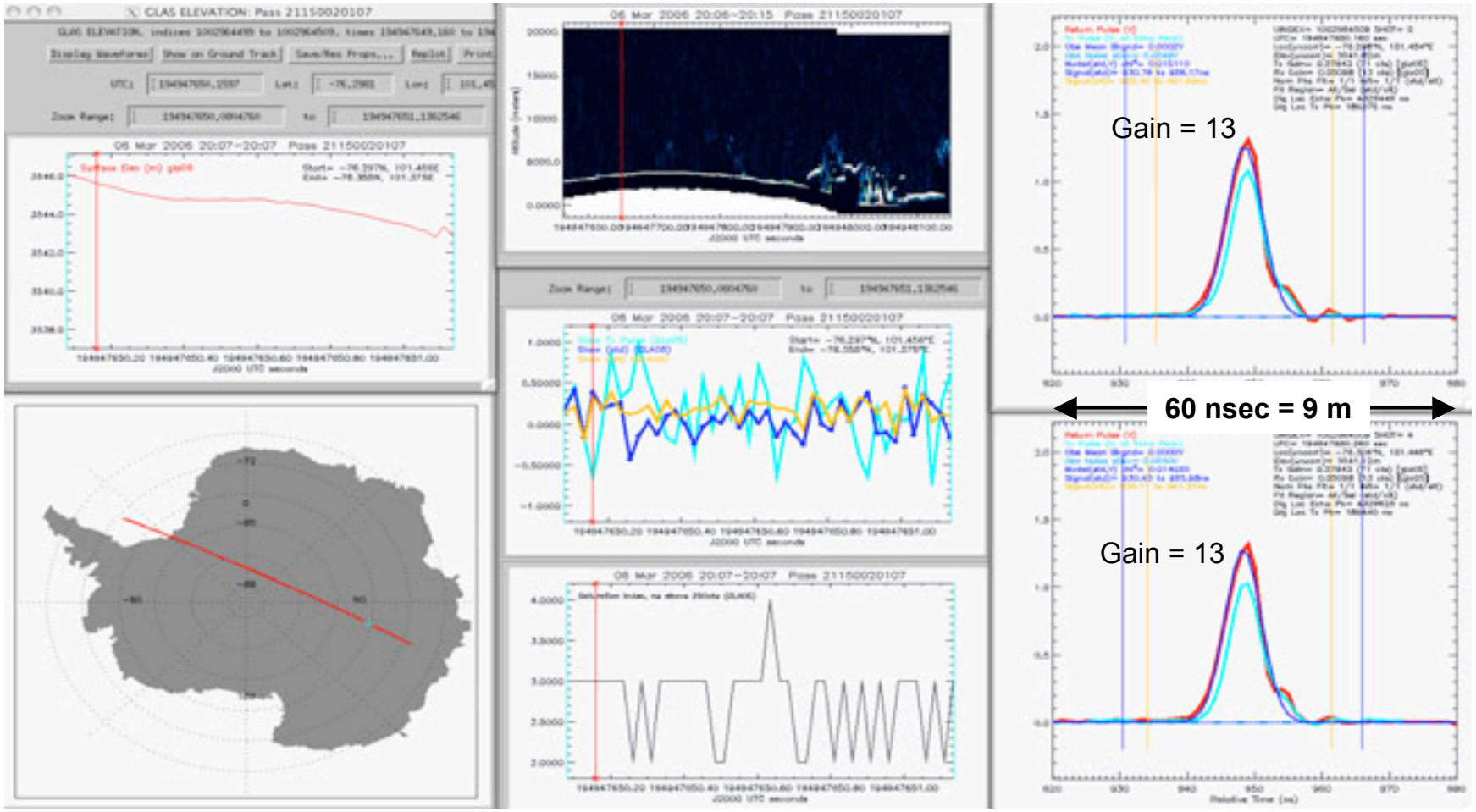
(4) Atmospheric forward scattering by clouds and/or blowing snow = Positive Skew

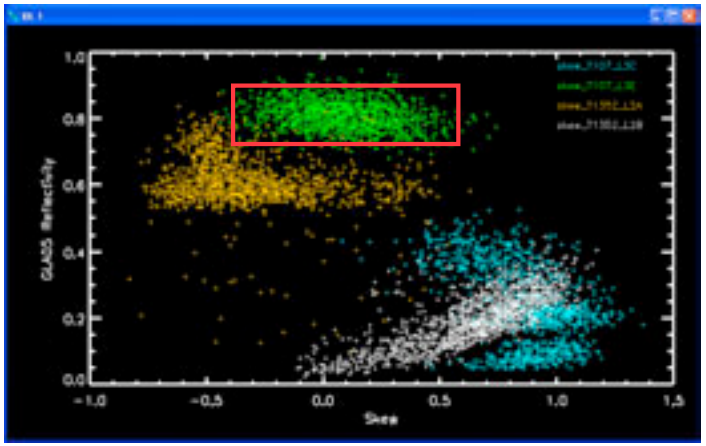
“Back Porch” Returns from Surface through Clear Atmosphere: Positive Skew

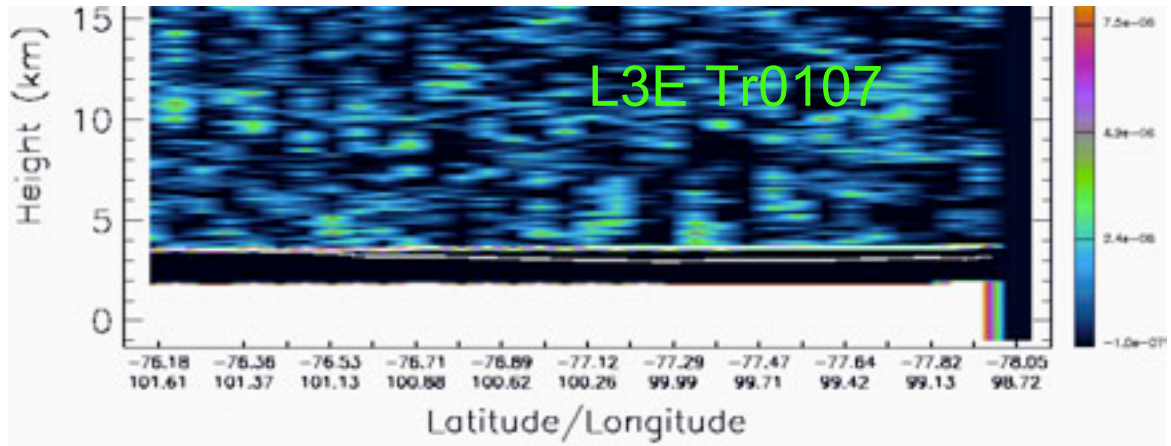


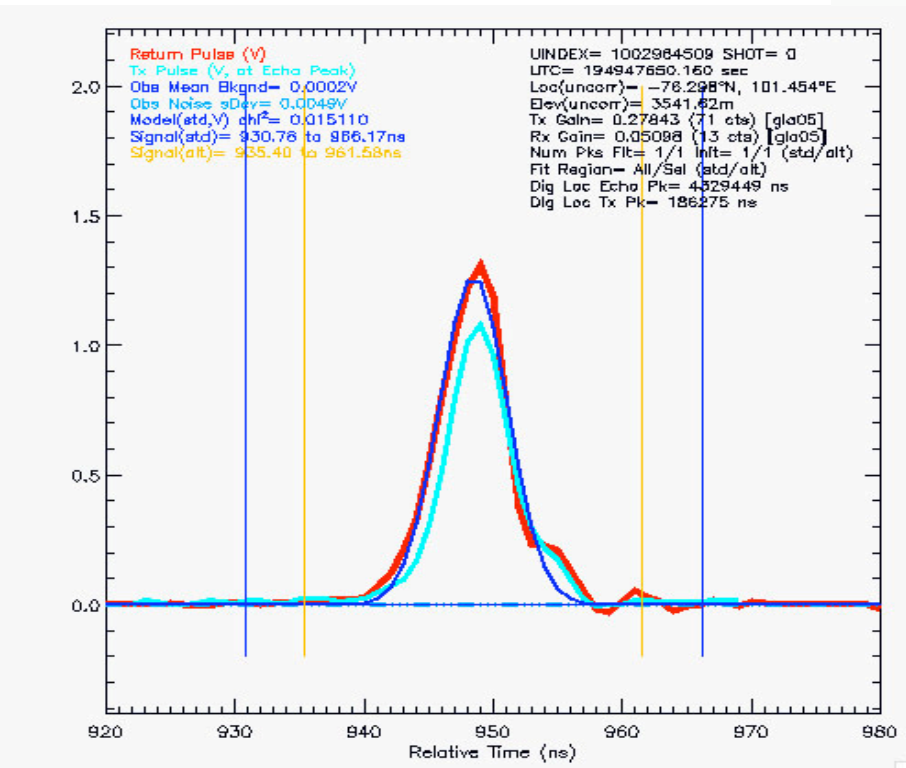


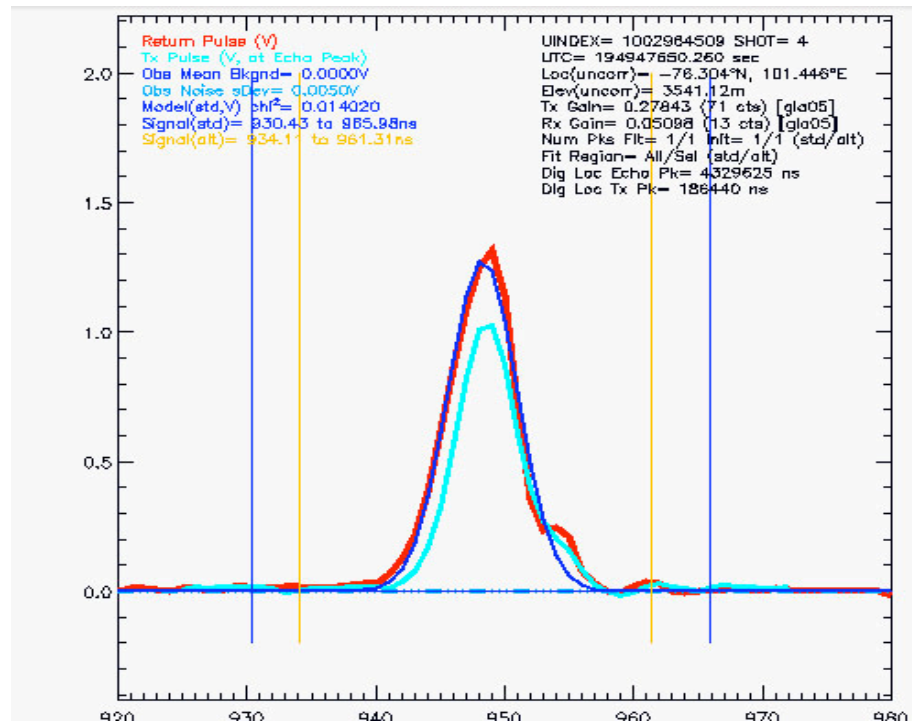


“Back Porch” Returns from Surface through Clear Atmosphere: Positive Skew









Gaussian fits to Tx and Rcv waveforms with equivalent “back porches” should yield and unbiased range

Origins of ICESat Waveform Skew

(1) Waveform saturation = Negative Skew

(2) Transmit pulse " back porch" = Positive Skew

(3) <u>FOV shadowing due to boresight misalignment = Variable Negative and Positive Skews</u>

(4) Atmospheric forward scattering by clouds and/or blowing snow = Positive Skew

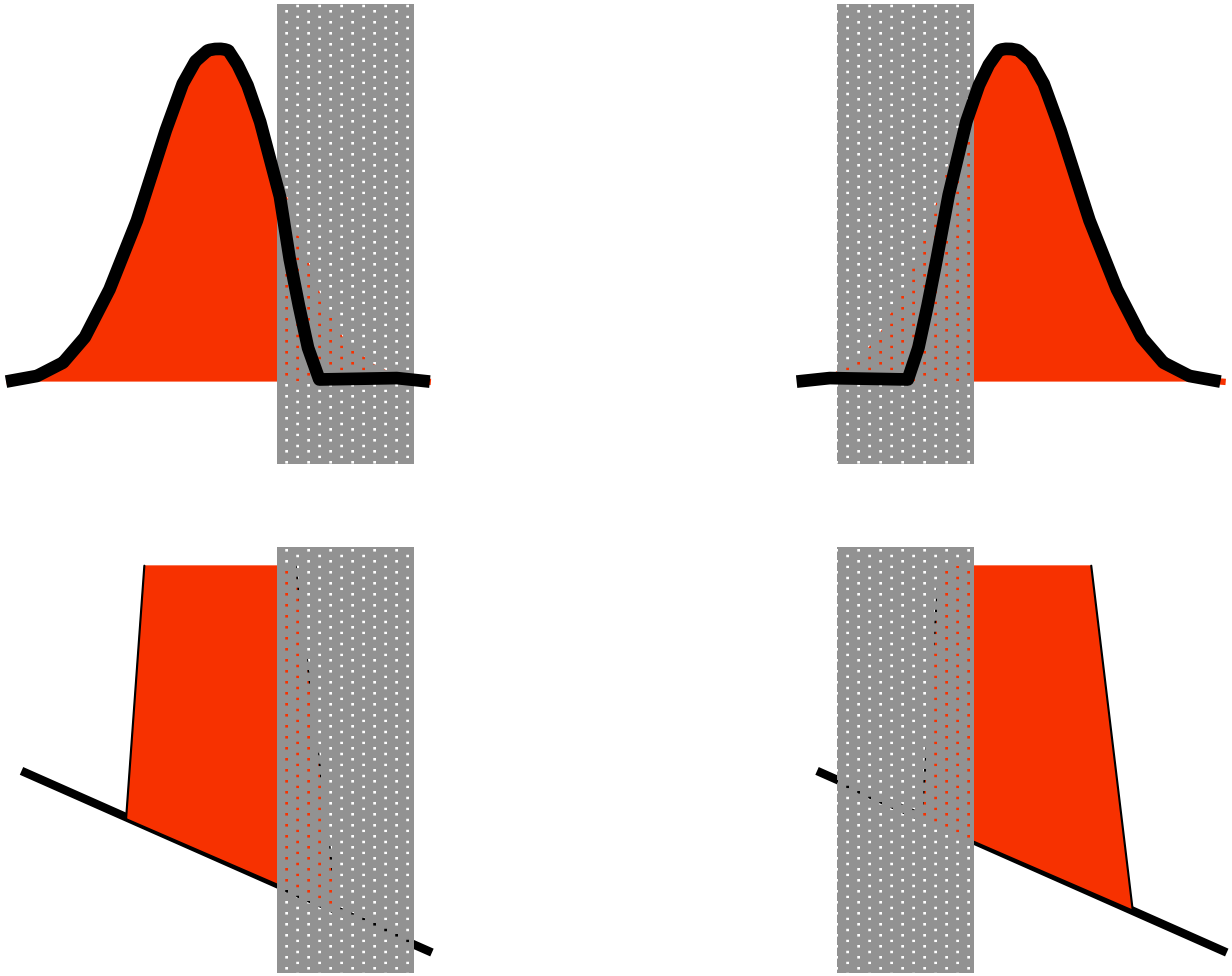
FOV shadowing due to boresight misalignment:

Negative Skew

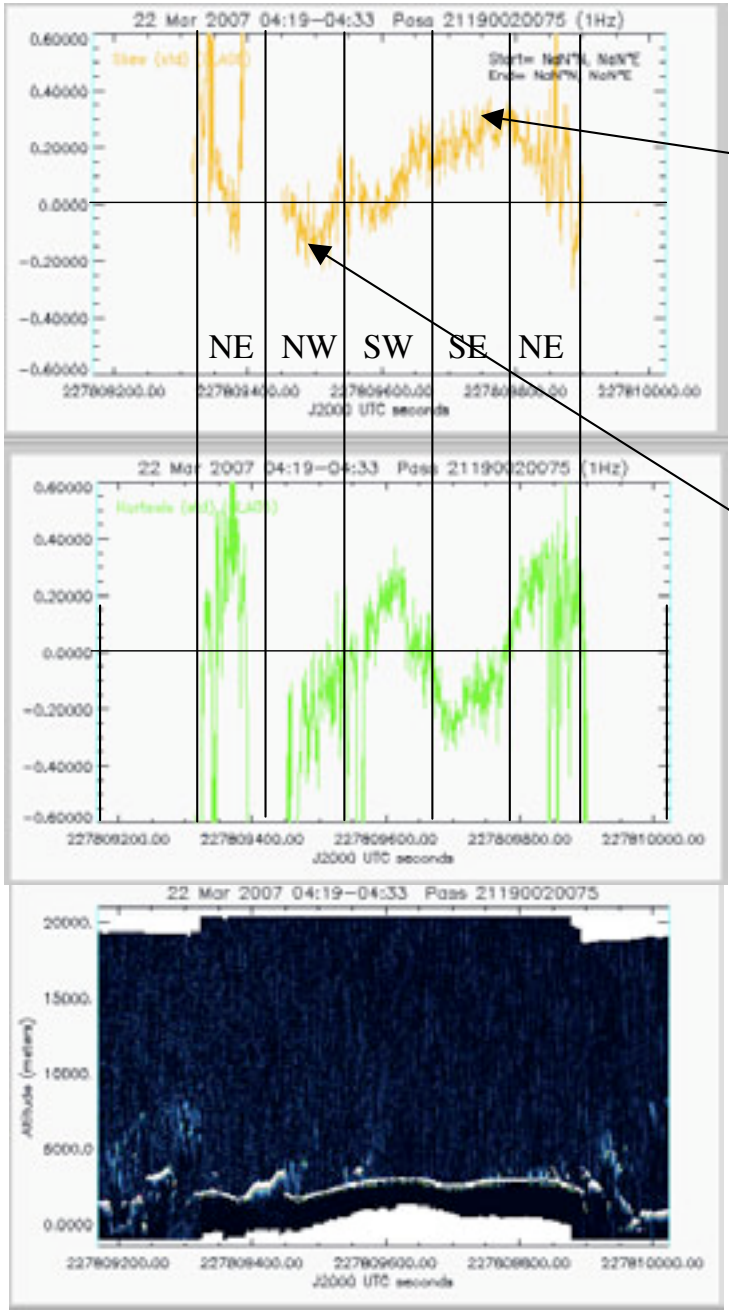
longer ranges are shadowed (trailing edge)

Positive Skew

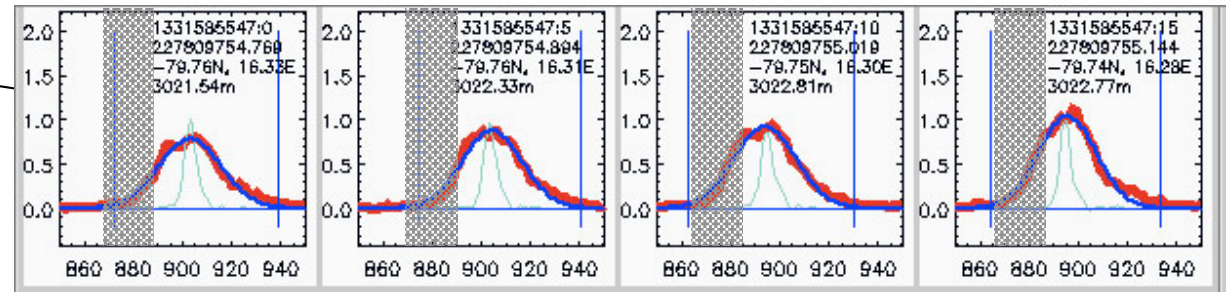
nearer ranges are shadowed (leading edge)



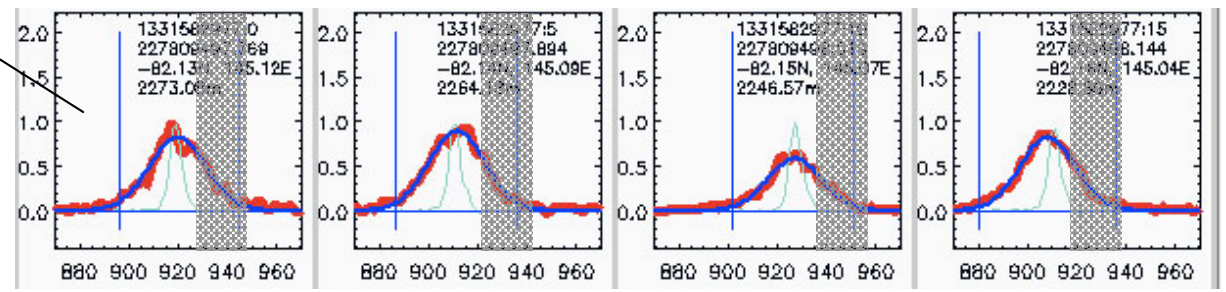
FOV Shadowing: Variable Negative and Positive Skews Round the World Scan at ~ 5° Off-nadir



Shorter ranges shadowed when pointing to SE



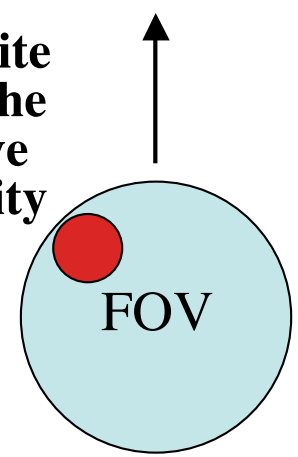
Longer ranges shadowed when pointing to NW

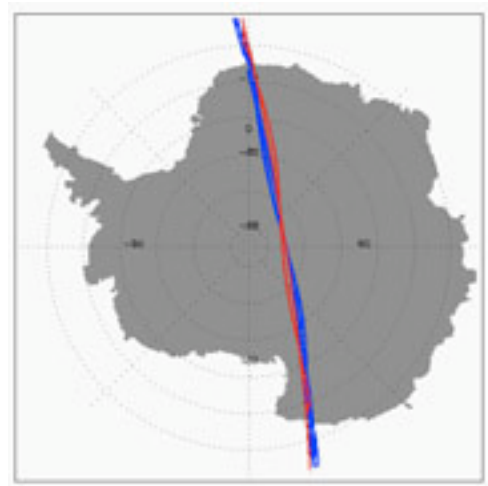


100 nsec = 15 m

velocity vector = -Y GLAS axis

Laser boresite is offset to the NW relative to the velocity vector





Range Implications of FOV Shadowing:

Skew varies from positive to negative depending on direction of boresight offset relative to plane of the incident angle defined by laser vector and surface normal

Skew magnitude depends on the magnitude of the boresight offset and the incident angle

Low slope ice sheet surfaces and small off-nadir angle (~ 0.3°) = small incident angles = small skew values

Random sampling of slope magnitude and azimuth = increased ranging noise but no regional range bias

If it is a bias source (i.e., from constant pitch forward) it would be accounted for by PAD pointing bias calibration (Luthcke, pers. comm.)

Origins of ICESat Waveform Skew

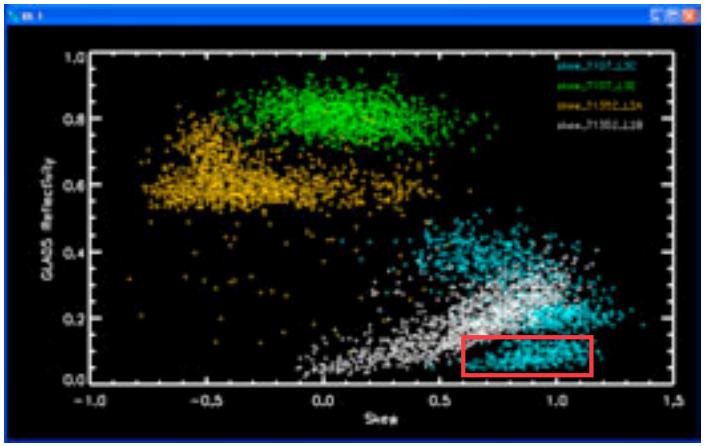
(1) Waveform saturation = Negative Skew

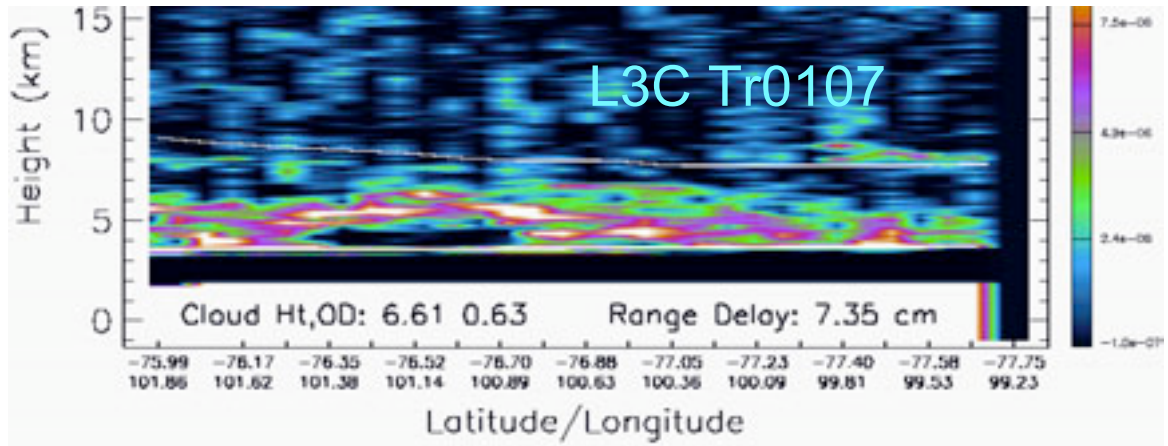
(2) Transmit pulse " back porch" = Positive Skew

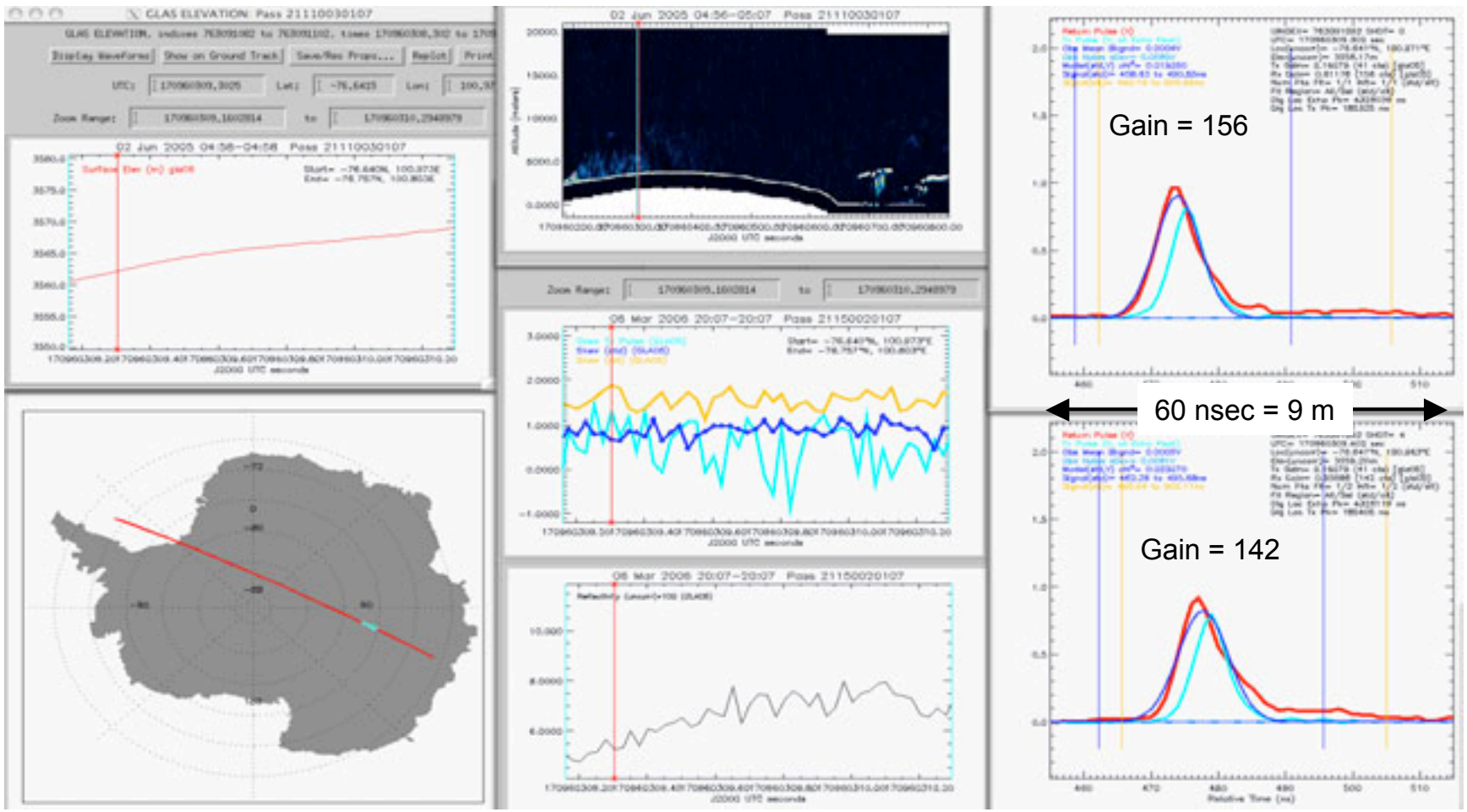
(3) FOV shadowing due to boresight misalignment = Variable Negative and Positive Skews

(4) *Atmospheric forward scattering by clouds and/or blowing snow = Positive Skew*

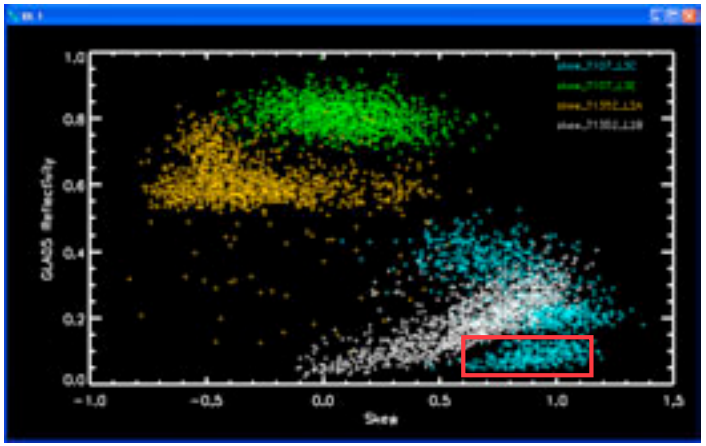
Forward Scattered Returns from Surface through Near Surface Clouds: Positive Skew

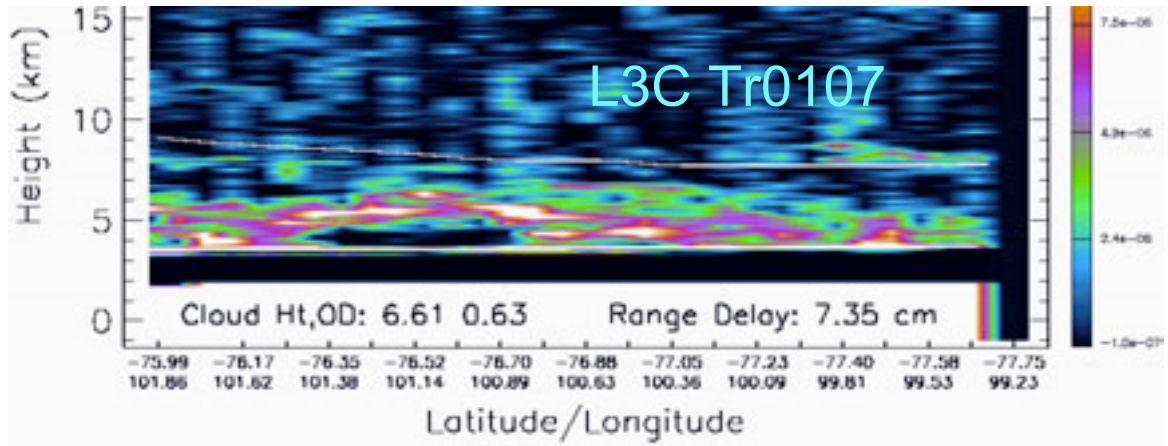


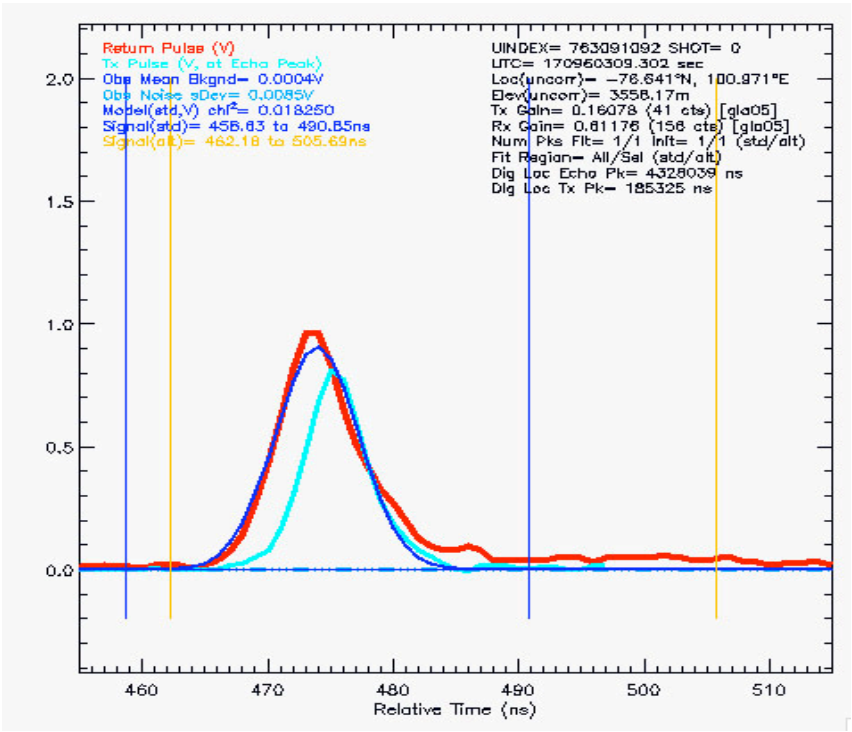


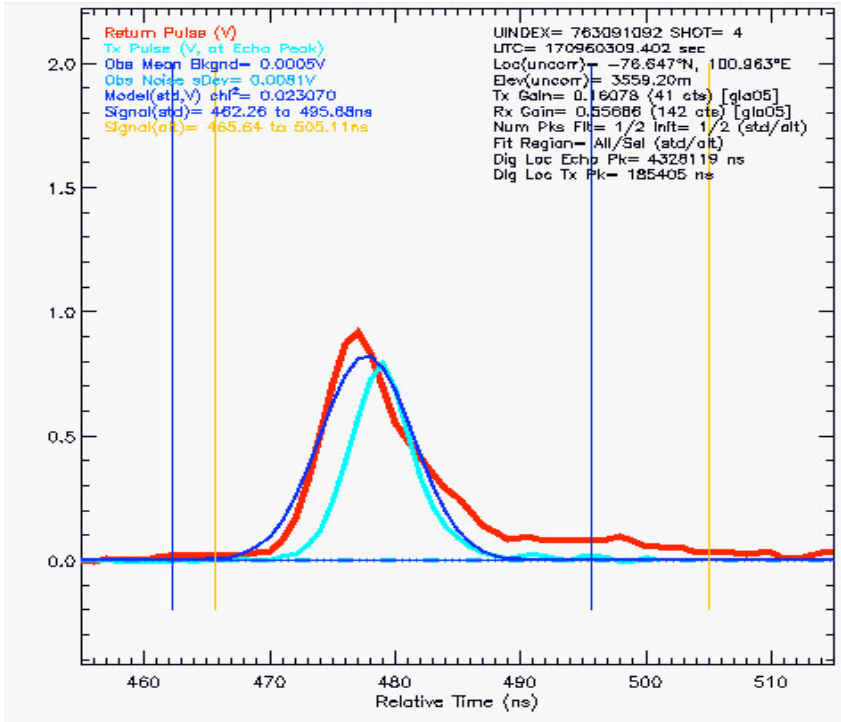


Forward Scattered Returns from Surface through Near Surface Clouds: Positive Skew



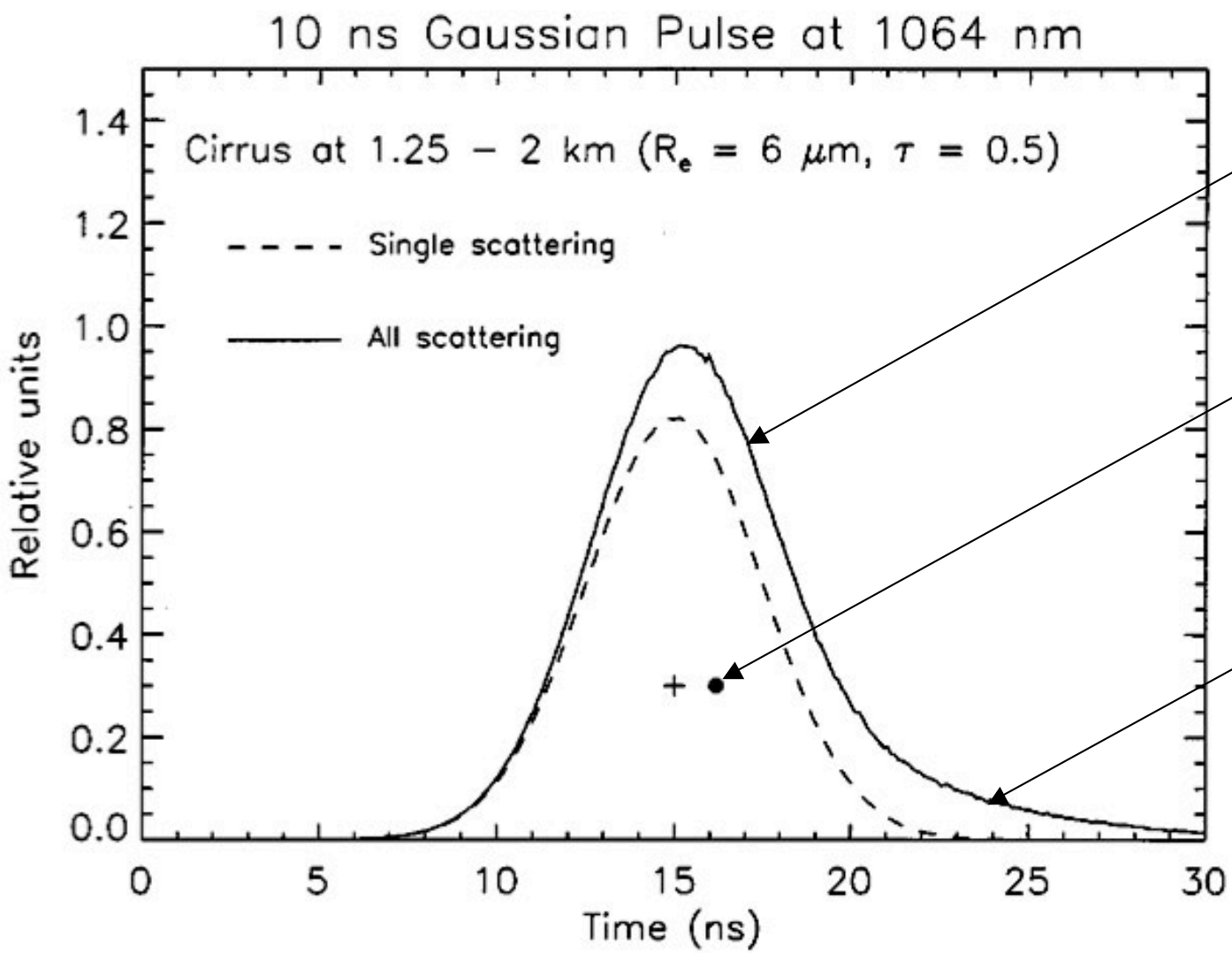






Gaussian fit to forward scattered waveform yields biased range that is too long because return is broadened

Atmospheric Forward Scattering: Positive Skew



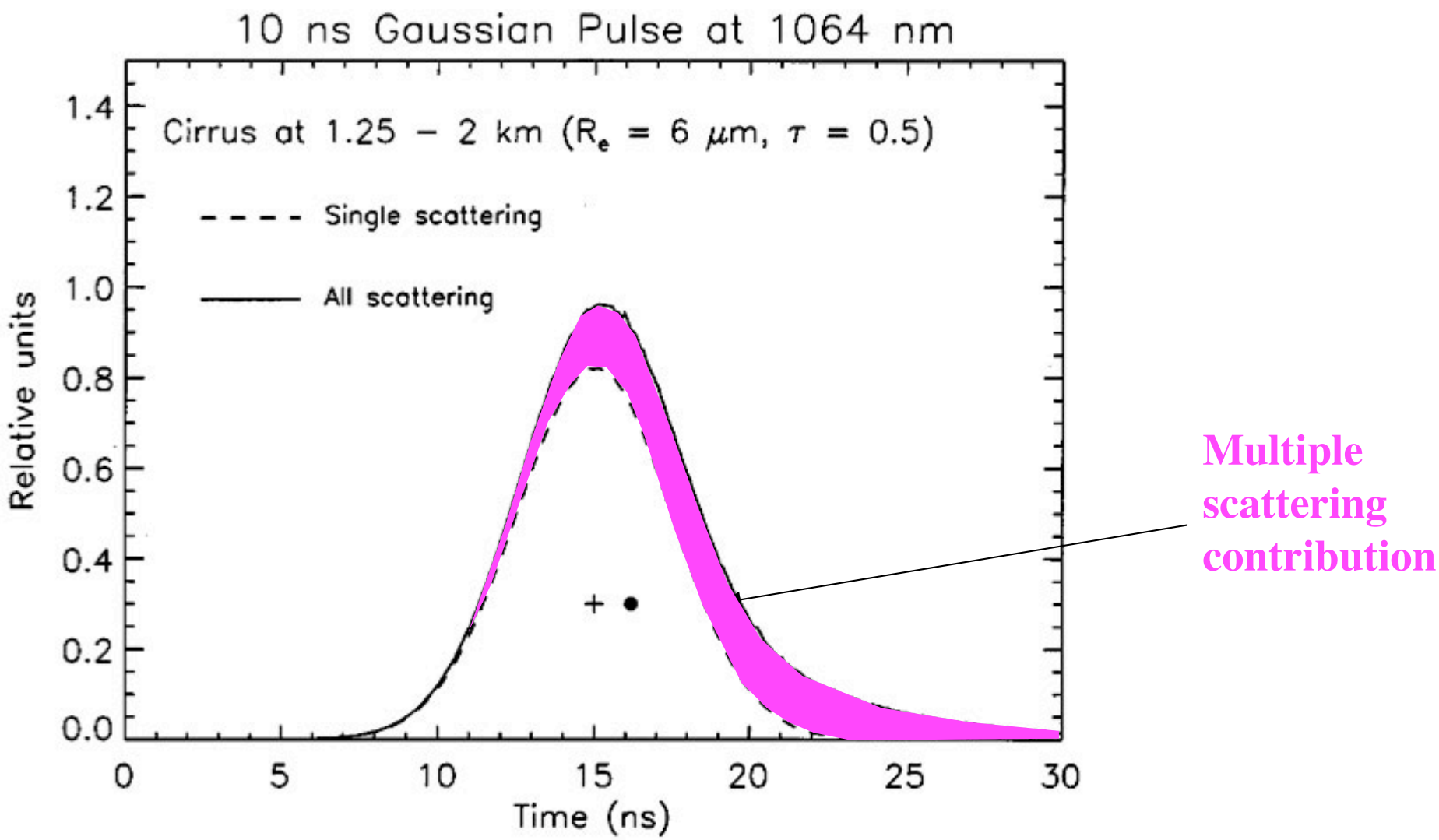
Main peak: broadened by ~1 nsec and amplitude increased

Centroid: shifted late, in this case by 1.2 nsec = 18 cm

Tail formed

D.P. Duda, J.D. Spinhirne and E.W. Eloranta, 2001, IEEE TGRS

Atmospheric Forward Scattering: Positive Skew



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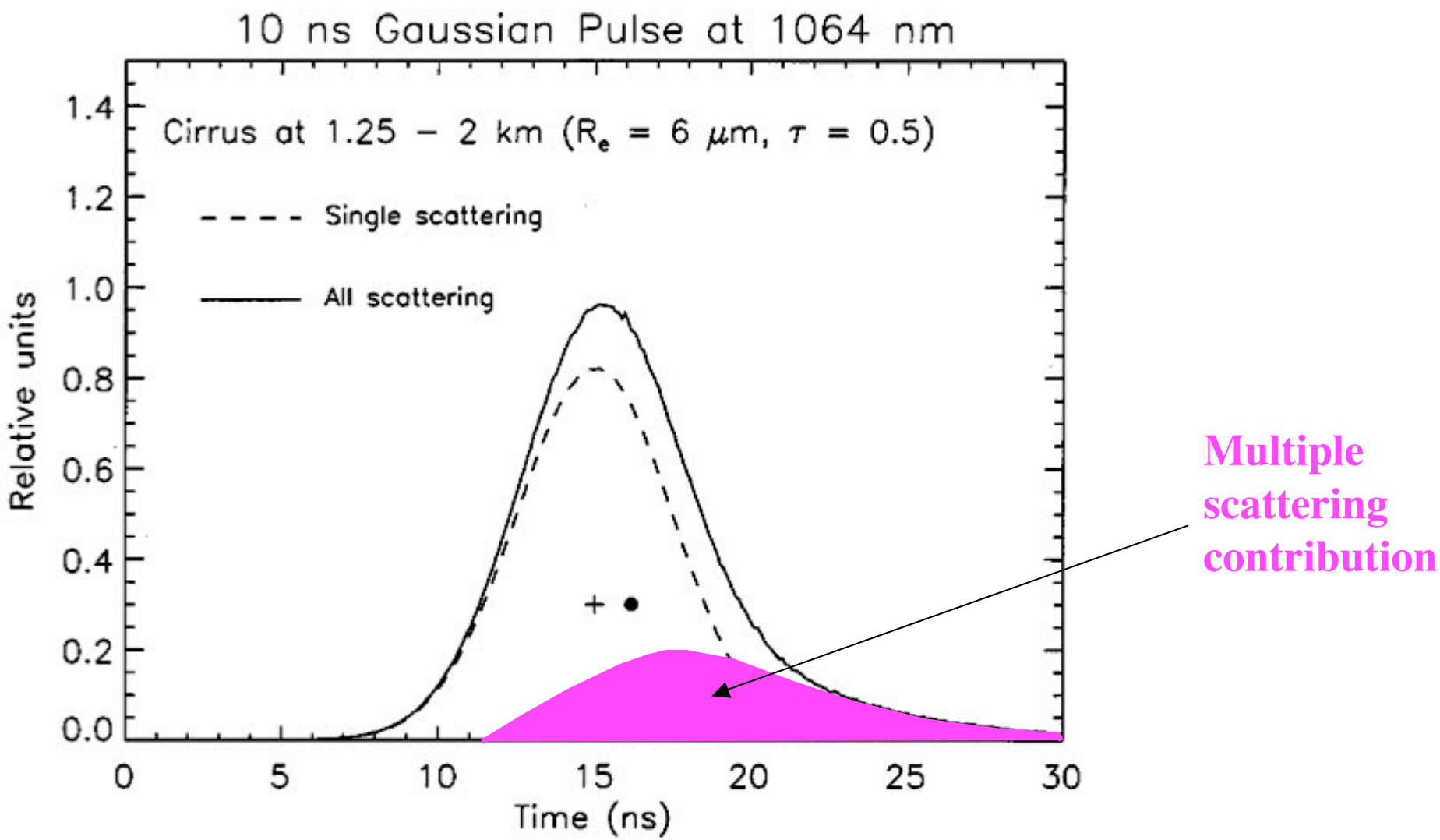

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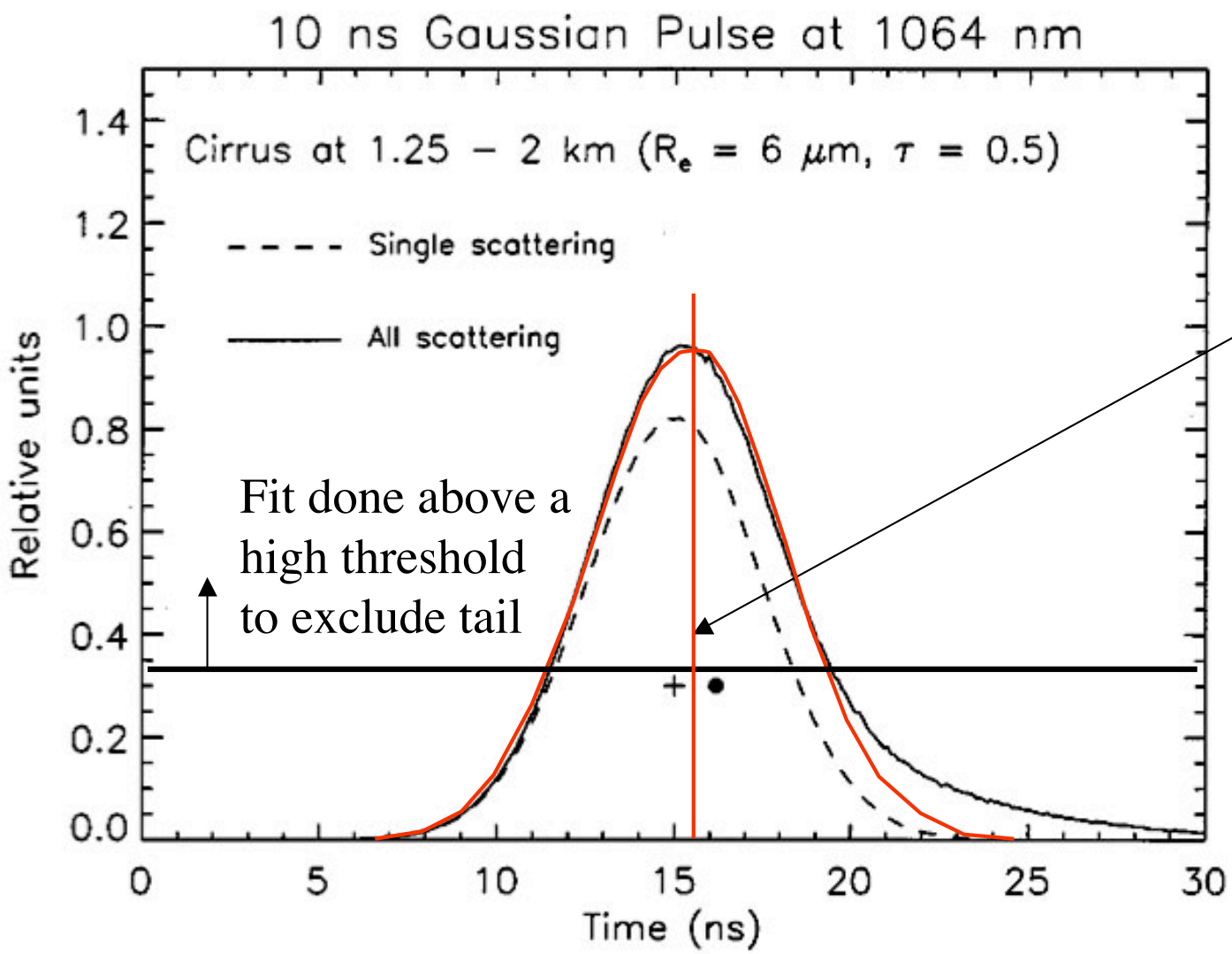
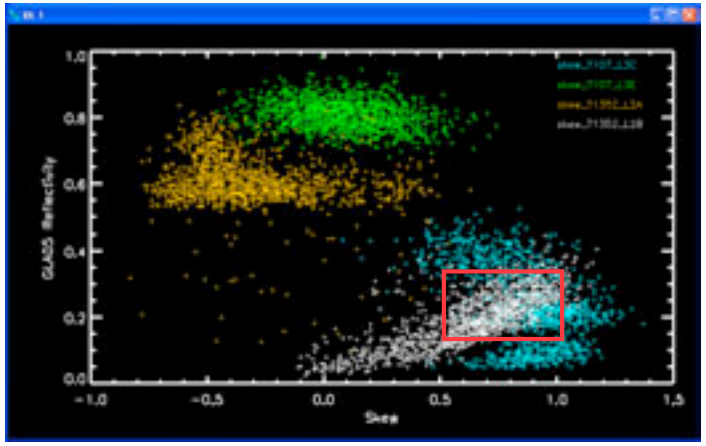
Atmospheric Forward Scattering: Positive Skew

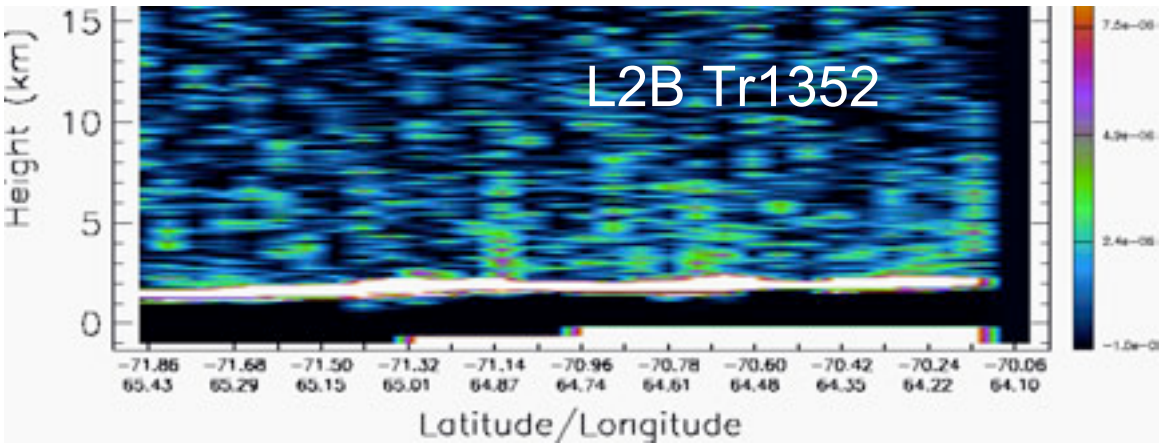


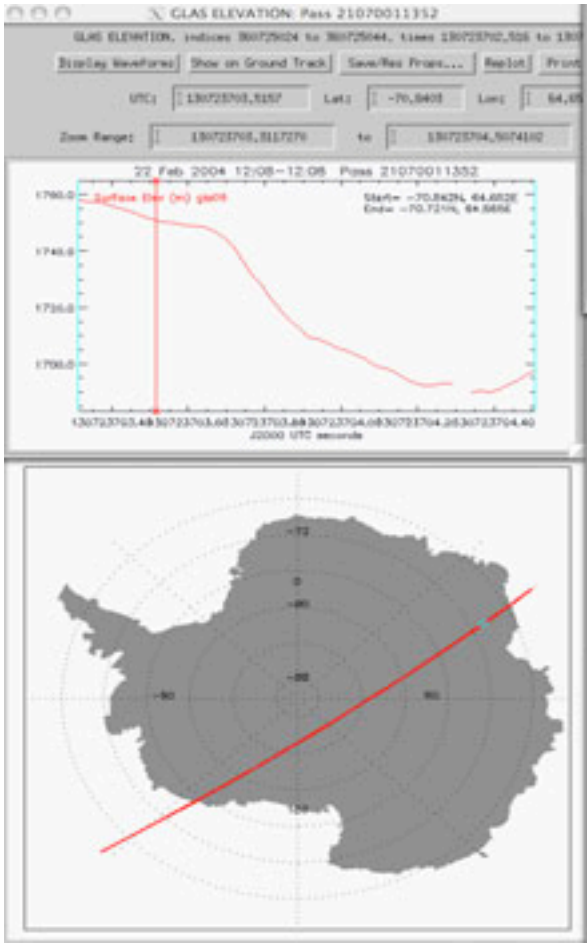
Because return is broadened the Gaussian fit position is shifted late by an amount less than centroid but still significant, in this case by 0.6 nsec = 9 cm

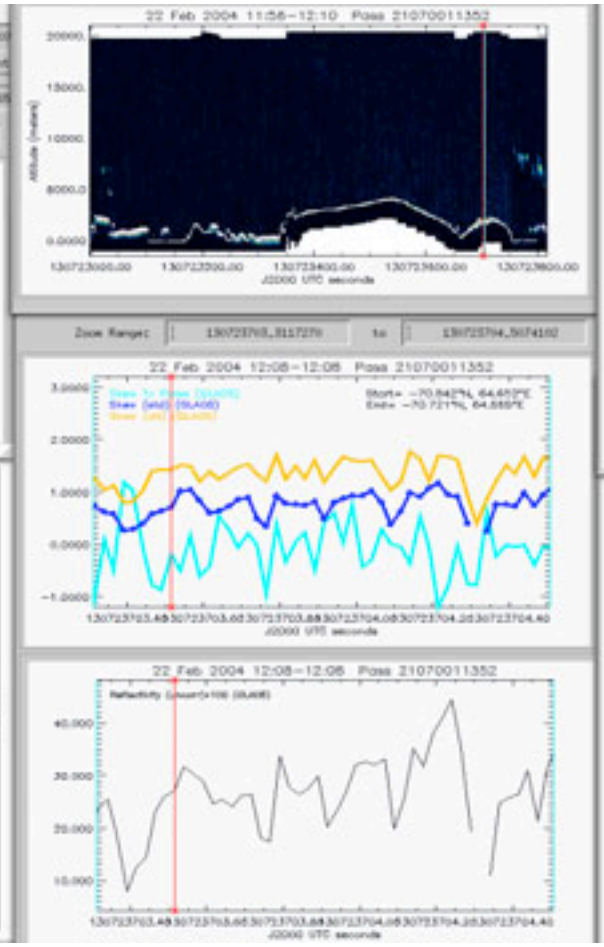
D.P. Duda, J.D. Spinhirne and E.W. Eloranta, 2001, IEEE TGRS

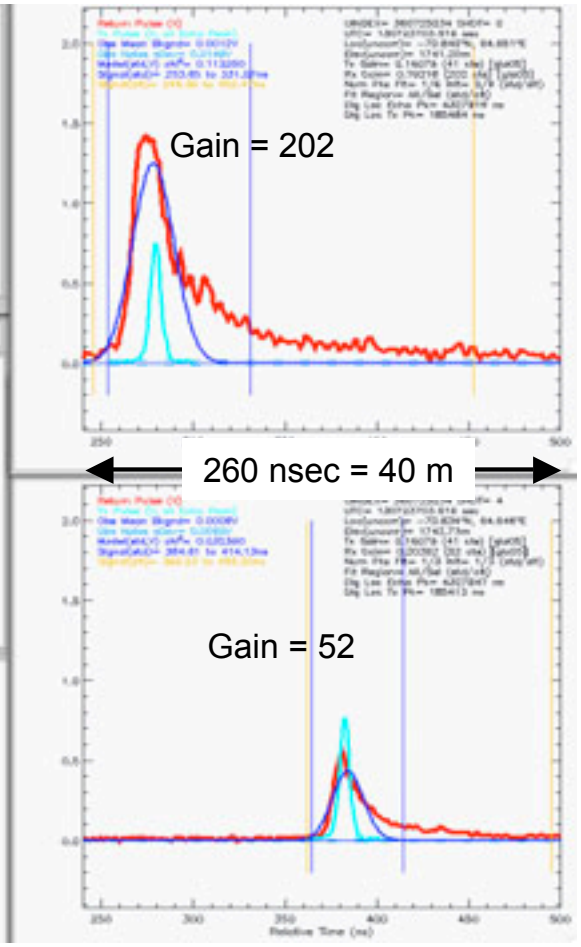
Returns from Blowing Snow Layer ("white out") or Surface through Blowing Snow?











Note that the Rcv wave-forms are very broad

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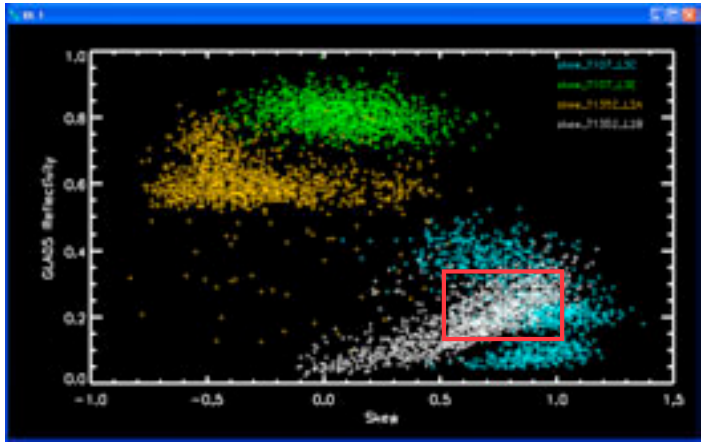
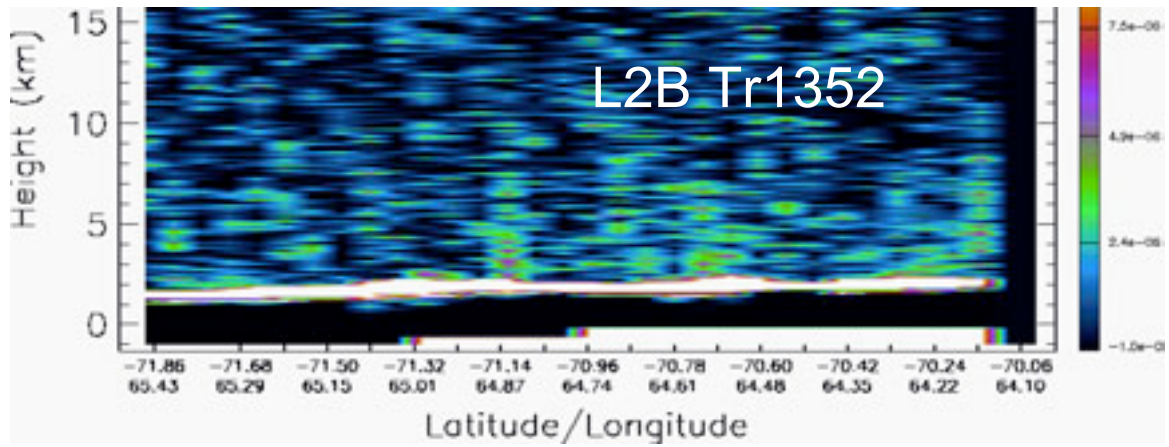
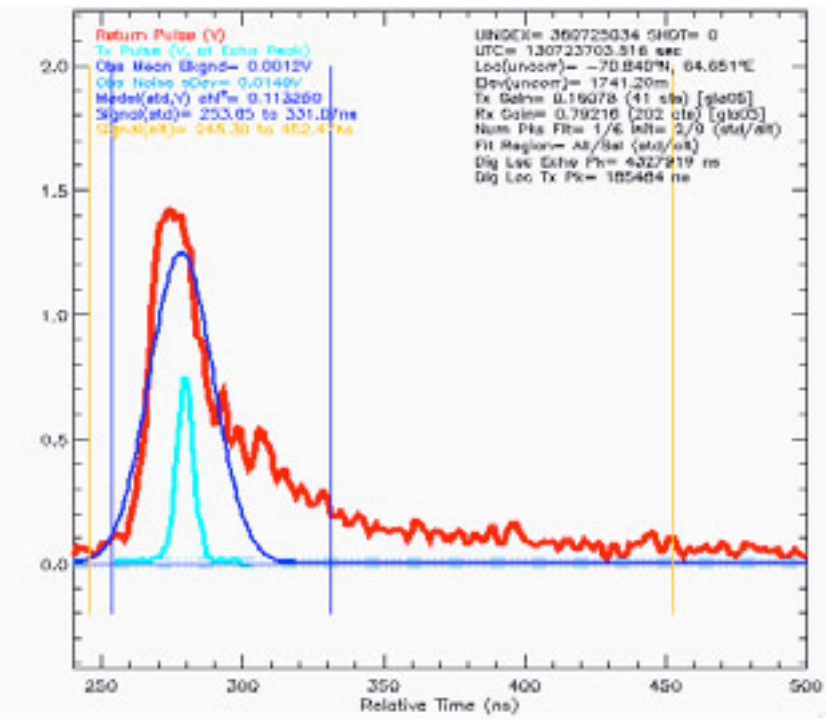
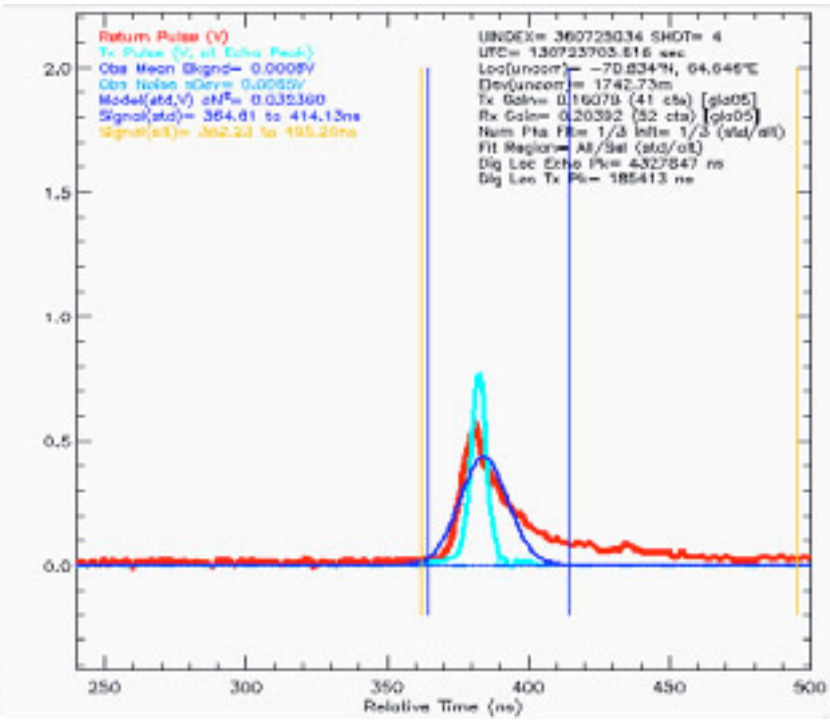








Are these very broad waveforms extinction profiles of the blowing snow layer rather than forward scattered surface returns?

Extinction profiles = too high elevation or Forward scattered returns = too low elevation

Waveform Classes to Flag in Release 429

Skew vs Apparent Reflectance Class	Operation Periods	Percent Saturated	Mean Saturation Correction	Circumstances
Negatively skewed bullseye at high reflectance	L2a L3a L3b	Large	Large	Significant saturation due to high effective pulse energy* and clear atmosphere
Slightly positively skewed bullseye at high reflectance	L3c L3d	Moderate	Small	Minor saturation due to moderate effective pulse energy* and clear atmosphere
Skew ellipse at nearly constant reflectance	L2b *(L2c)* L3e L3f L3g L3h	Small	Small	Not saturated due to low effective pulse energy* and clear atmosphere with variable skew due to skewed Tx pulse and/or FOV shadowing
Tail trending to positive skew as reflectance decreases	All	Minimal ("high gain saturation" at cloud gaps)	Variable	Forward scattering thru clouds and/or blowing snow
Linear trend to zero skew as reflectance decreases	All ops except L2a & L3d	None	None	Very small peaks due to low atmospheric transmission, or extinction profile of blowing snow

*** Effective pulse energy is the result of the combined effects of transmit energy and boresight misalignment causing FOV shadowing**

Waveform Classes to Flag in Release 429

Skew vs Apparent Reflectance Class	Operation Periods	Percent Saturated	Mean Saturation Correction	Range Bias Correction
Negatively skewed bullseye at high reflectance	L2a L3a L3b	Large	Large	X. Sun saturation range correction, calibrated by on-orbit results
Slightly positively skewed bullseye at high reflectance	L3c L3d	Moderate	Small	X. Sun saturation range correction, calibrated by on-orbit results
Skew ellipse at nearly constant reflectance	L2b *(L2c)* L3e L3f L3g L3h	Small	Small	Not a range bias source so no correction needed
Tail trending to positive skew as reflectance decreases	All	Minimal (“high gain saturation” at cloud gaps)	Variable	See options on next chart
Linear trend to zero skew as reflectance decreases	All ops except L2a & L3d	None	None	See options on next chart, or exclude since these are wave-forms with very low amplitude

*** Effective pulse energy is the result of the combined effects of transmit energy and boresight misalignment causing FOV shadowing**

Options for Correcting Forward Scattering Range Bias

1) Model-based Correction (cloud optical depth, height, thickness and particle size)

Use model estimate for range delay using 532 for L2A&B, and 1064 for other periods

- optical depth estimate is at 1 Hz, but a per shot correction is needed
- dependent on unknown particle size
- 1064 is not sufficiently sensitive, especially when transmit energy is low and/or daytime

2) Combined Gaussian and Exponential Waveform Fitting

Fit the skewed tails with an exponential which predicts the complete range distribution of multiple-scattered photons, subtract the resulting distribution from the waveform, and fit the remaining single-scattered population with a Gaussian distribution

- tail is probably insufficiently unique to predict complete multiple-scattered distribution

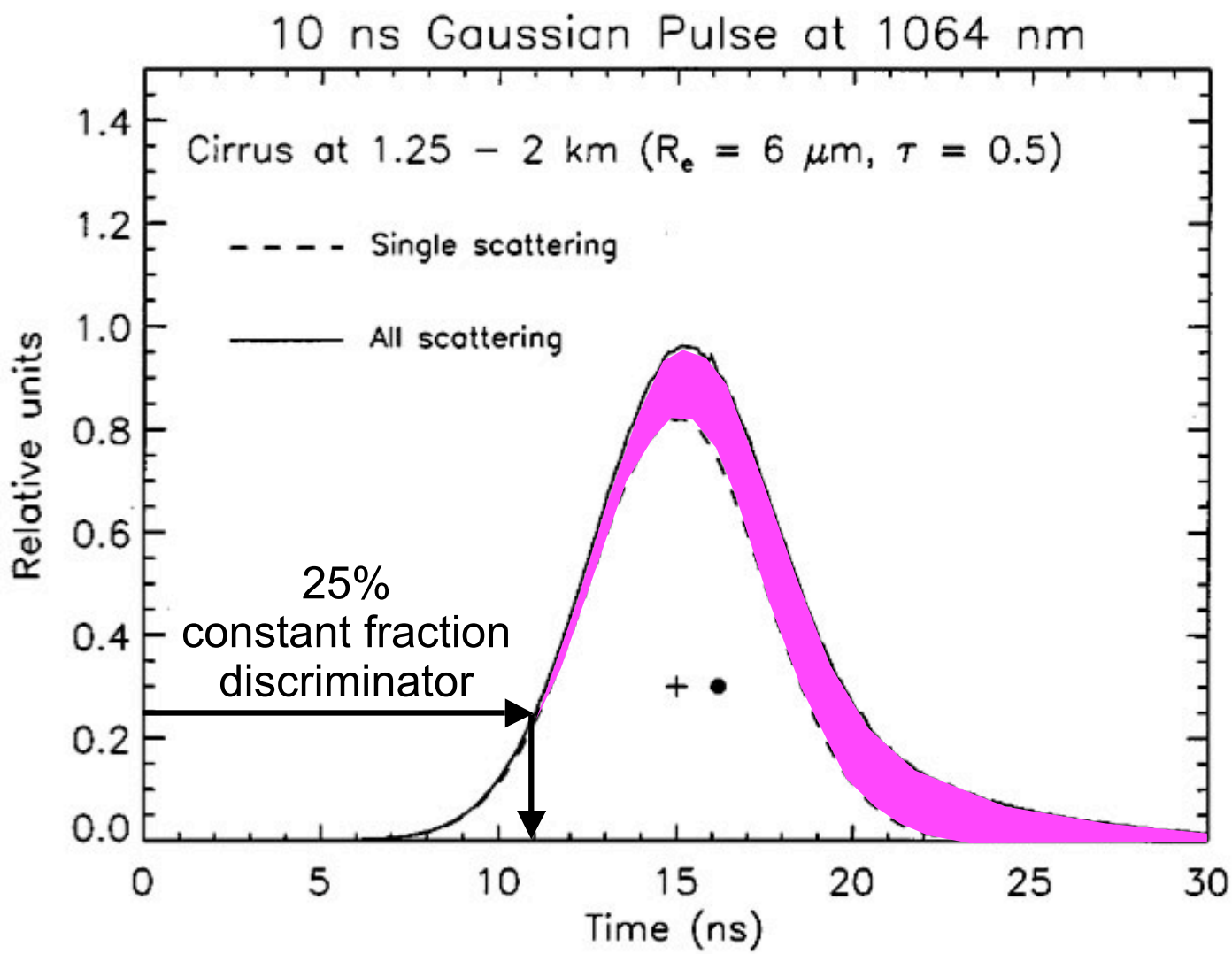
3) Leading-edge Ranging

Use leading-edge ranging, with equivalent timing points on the transmit and received pulses such as a constant fraction discriminator (e.g., at 25% of the peak amplitude)

- only works well for smooth surfaces (but that includes most ice sheet surfaces)
- can't be done for saturated waveforms since peak amplitude is not known (but saturated returns handled by X. Sun range correction)

#3 is only practical solution and should be tested to assess accuracy

Leading Edge Ranging Applied to Transmit & Receive Pulses



D.P. Duda, J.D. Spinhirne and E.W. Eloranta, 2001, IEEE TGRS

Recommendations for ICESat-2

1) Do not saturate
   = lower transmit energy and larger receiver dynamic range

2) Do not have boresight misalignment
   = incorporate boresight misalignment mechanism (BAM)

3a) Make FOV small enough to minimize forward scattering range bias
   = assess using forward scattering model tuned by ICESat-1 on-orbit results, and
   if a FOV of a few tens of meters is indicated therefore requiring a small laser footprint, conduct trade-study of footprint size elevation aliasing vs FOV size forward scattering elevation bias

OR

3b) Use leading edge ranging on forward scattered waveforms to negate range bias
   = important to fully assess and validate using ICESat-1 data