# ANALYSIS OF REPEATED ICESAT FULL WAVEFORM DATA: METHODOLOGY AND LEAF-ON / LEAF-OFF COMPARISON

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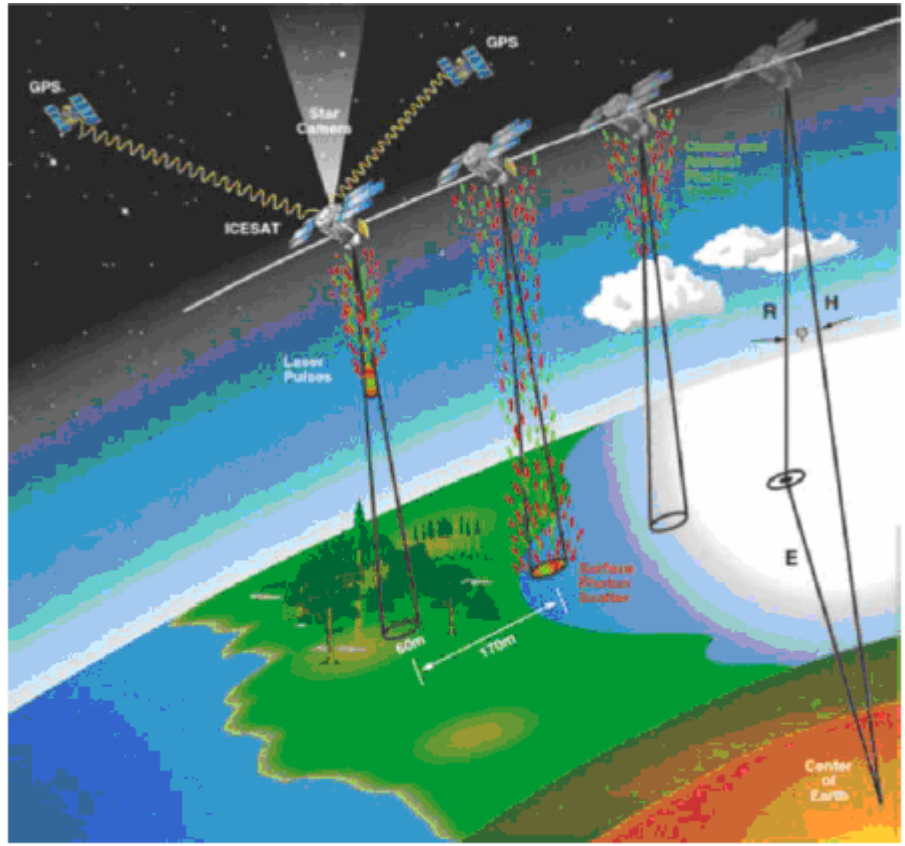
# Outline

- Introduction
  - ICESat/GLAS.
  - Waveform groundtracks in study area
- Waveform processings
- Results and Discussion.
- Conclusion

# ICESat Facts

- Main goals: measuring ice sheet mass balance, cloud and aerosol heights, as well as land topography and vegetation characteristics.

- Altitude: 600km
- NASA mission
- Launched 2003
- Life time 5 years
- Carries GLAS instrument



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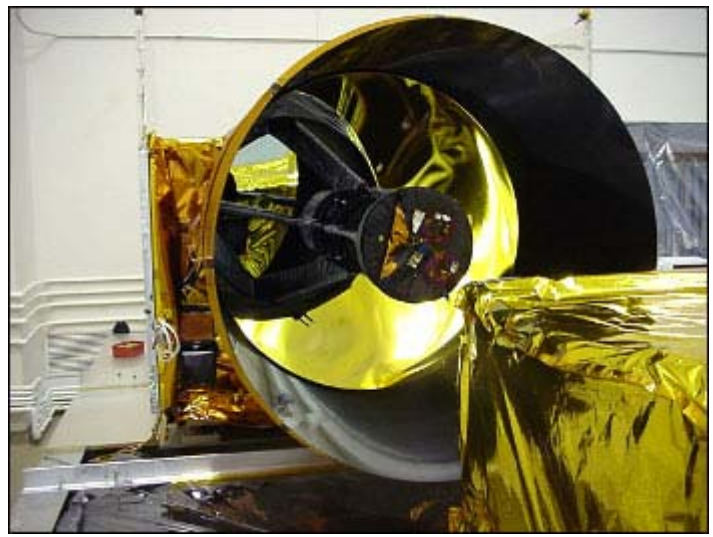
# GLAS instrument

- Footprint: 70m diameter
- Spot space: 175m
- 3 sensors: L1 (failed), L2 and L3
- Geolocation: star tracker and GPS



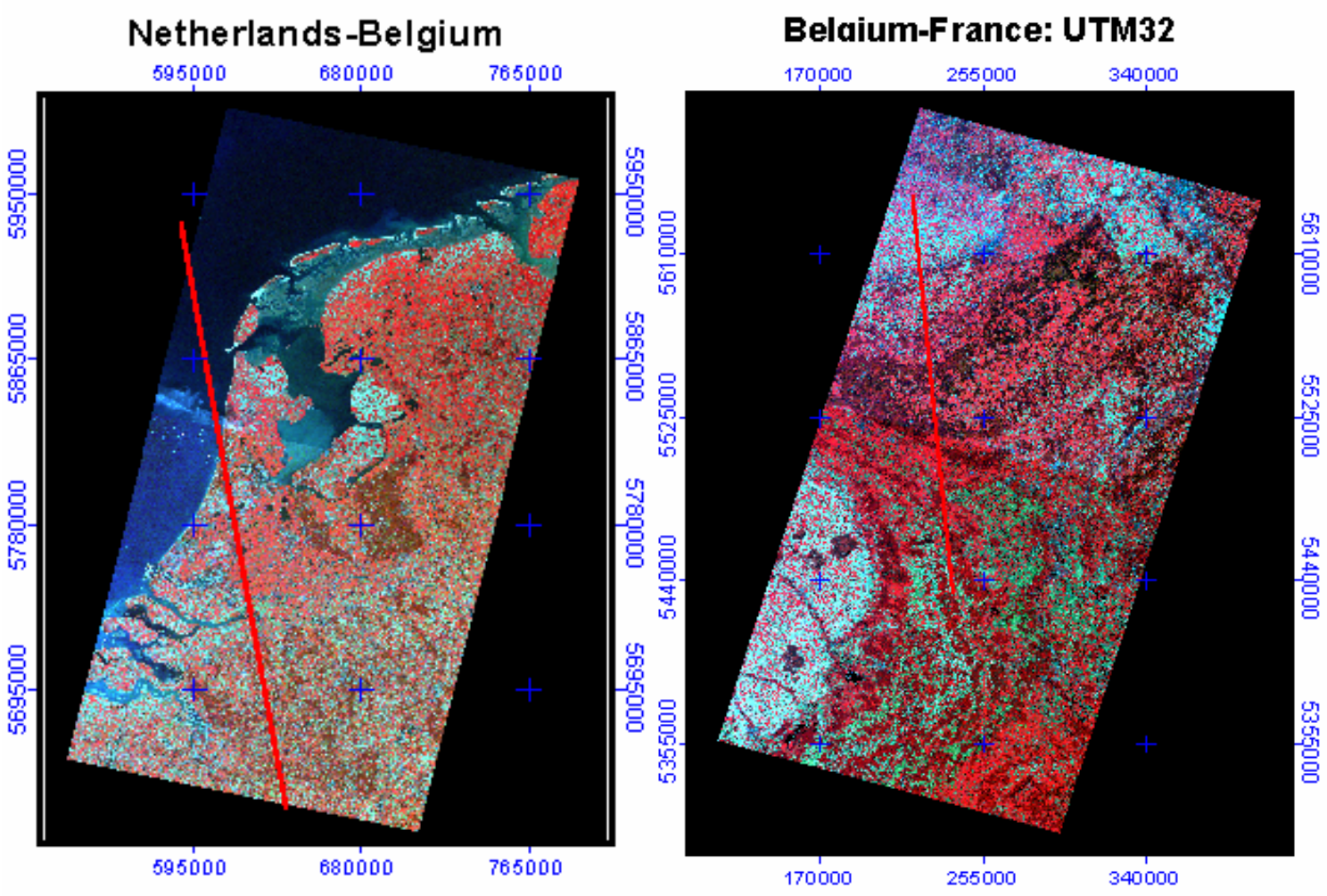
Full waveform laser altimetry!

# ICESat repeated tracks

February:
1840
waveforms

September:
2942
waveforms

Forest pairs:
358



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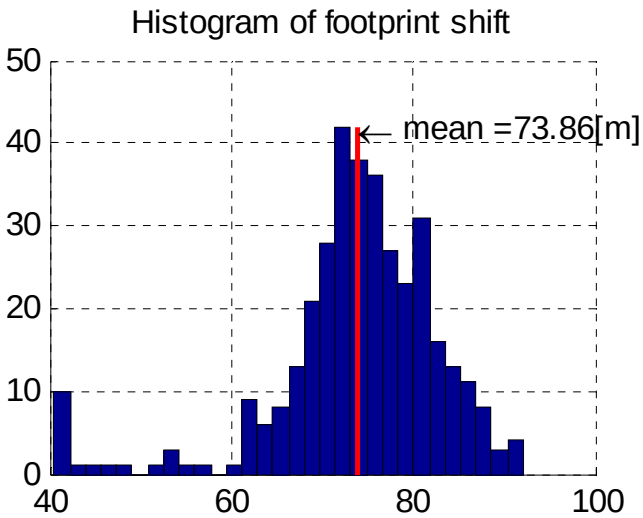
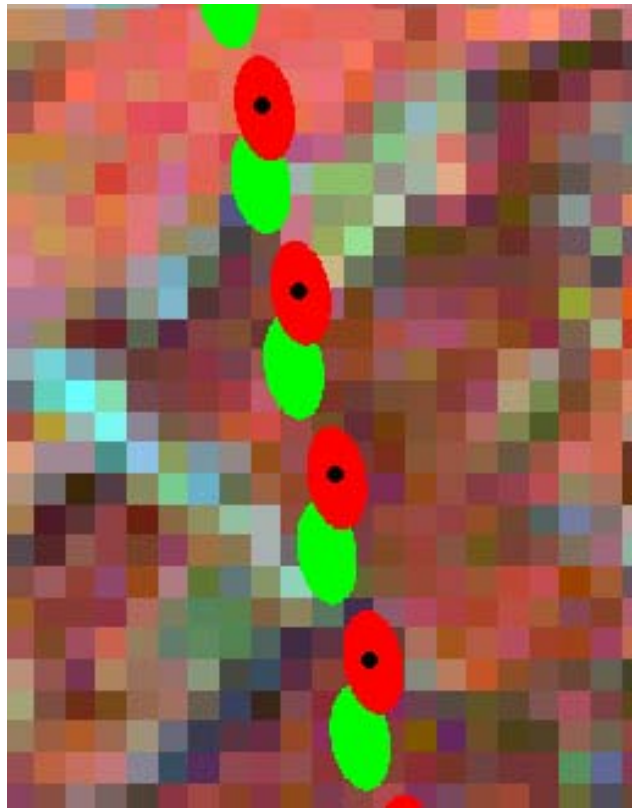
# ICESat repeated tracks

- Green: February 2003
- Red: September 2003



- Select forest footprints manually by comparing to Landsat images.



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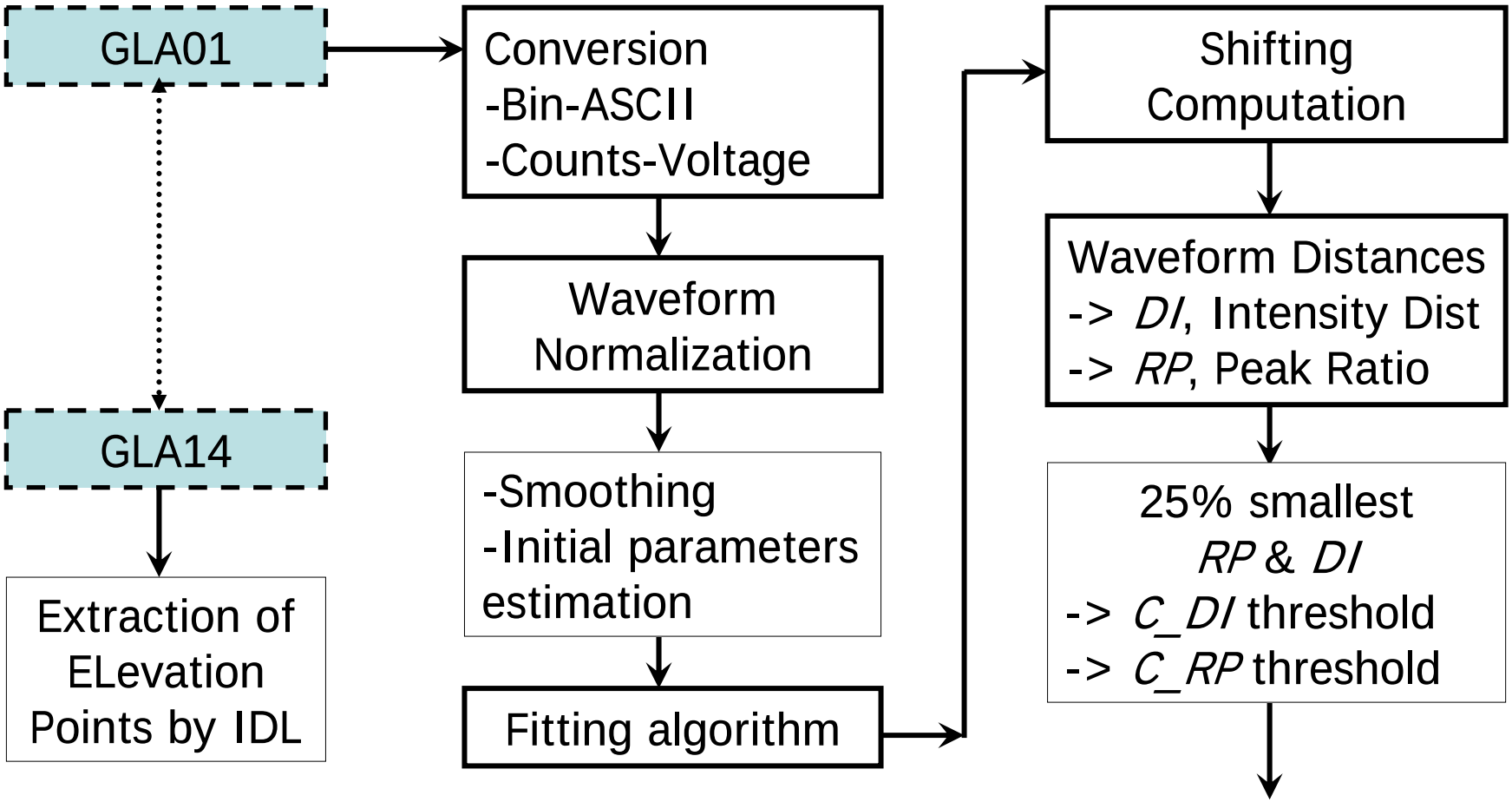
# Target: detect waveform changes



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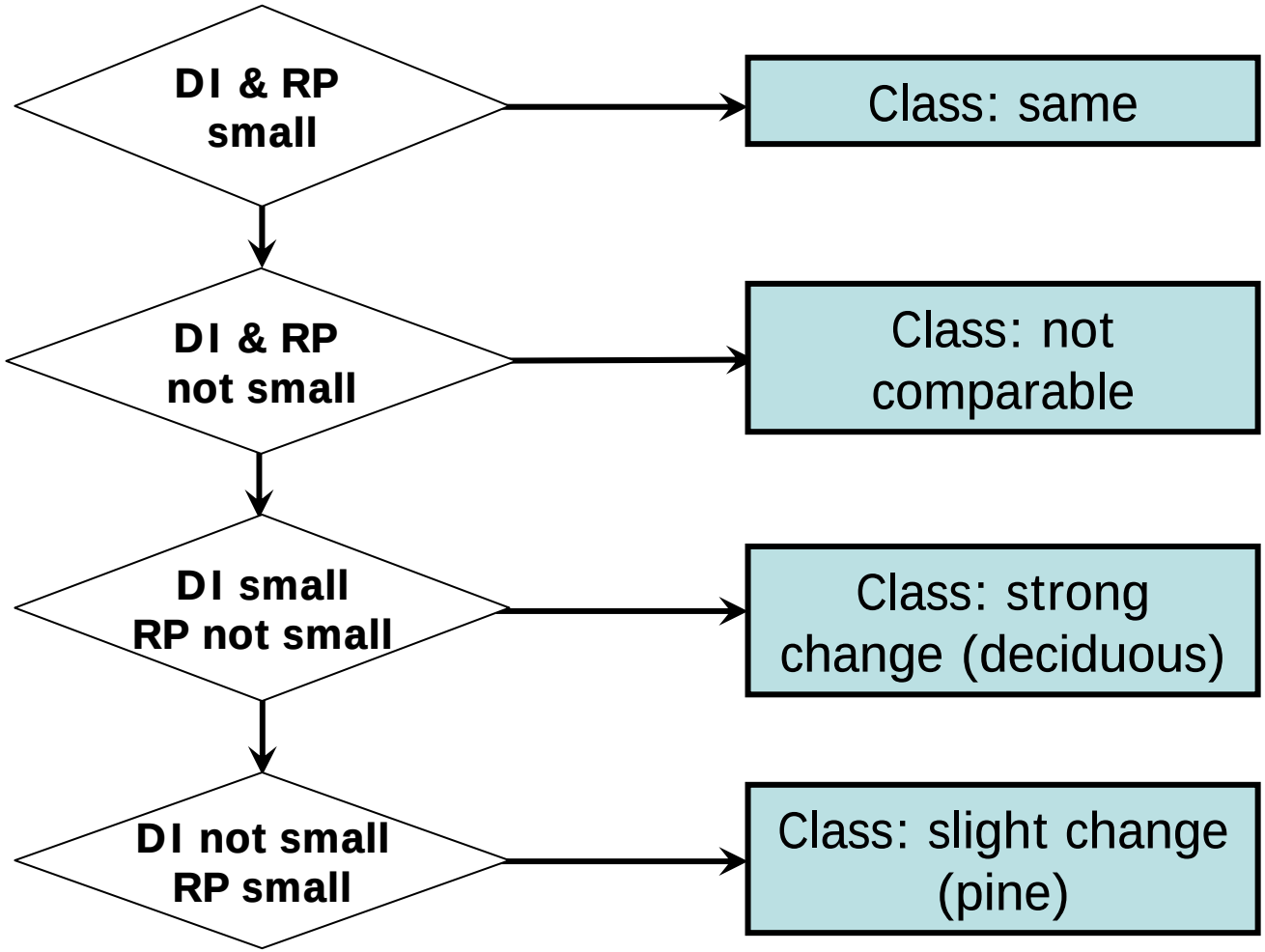
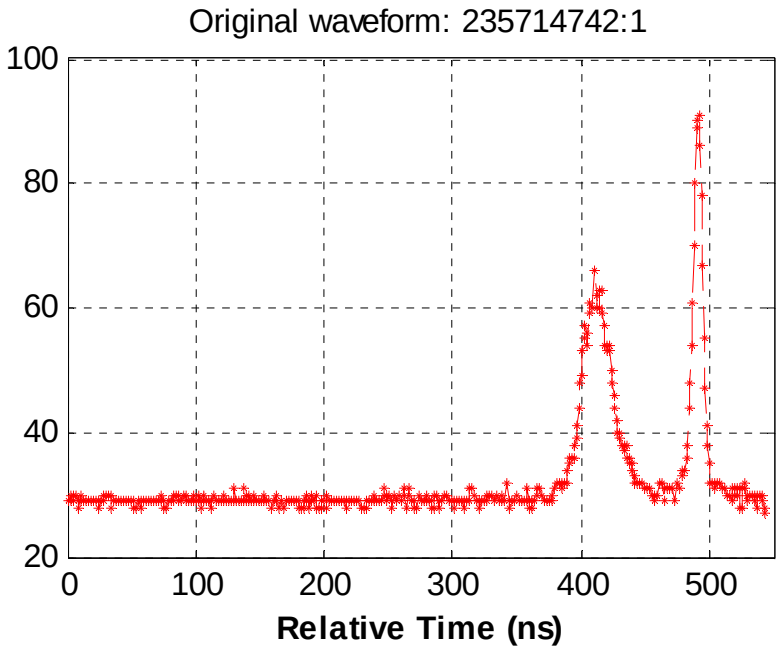
# Target: detect waveform changes

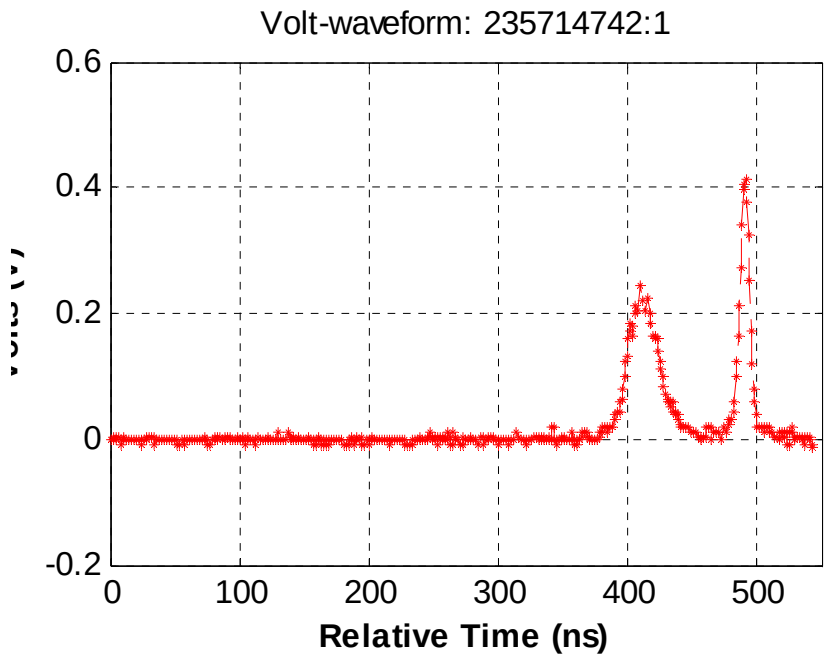


# Waveform units

Y axis: Original waveform in counts (0-255) is converted to voltage units

X axis: 1ns ~ 15cm



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# Normalization

Total intensity: $\sum_{i=1}^{544} V_i$

Mean total intensity

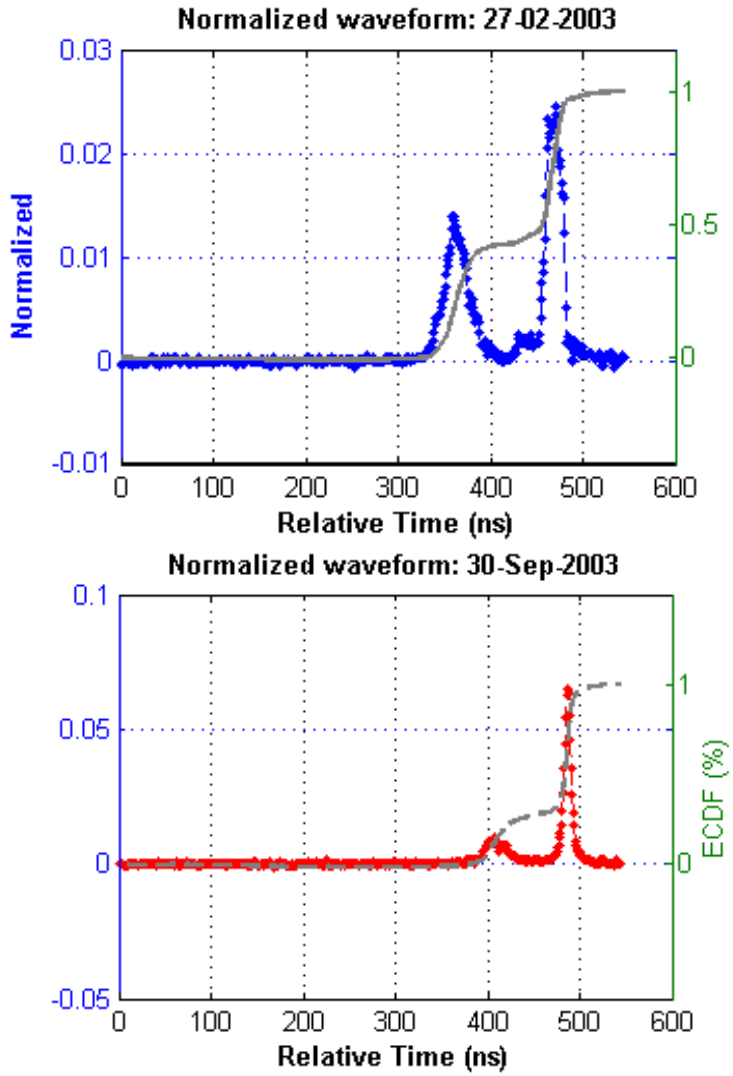
February: 116.48

September: 39.90

=> Normalization step: $V_{nori} = \frac{V_i}{\sum_{i=1}^{544} V_i}$

Area under waveform equals to 1.

After that we smooth the waveform.



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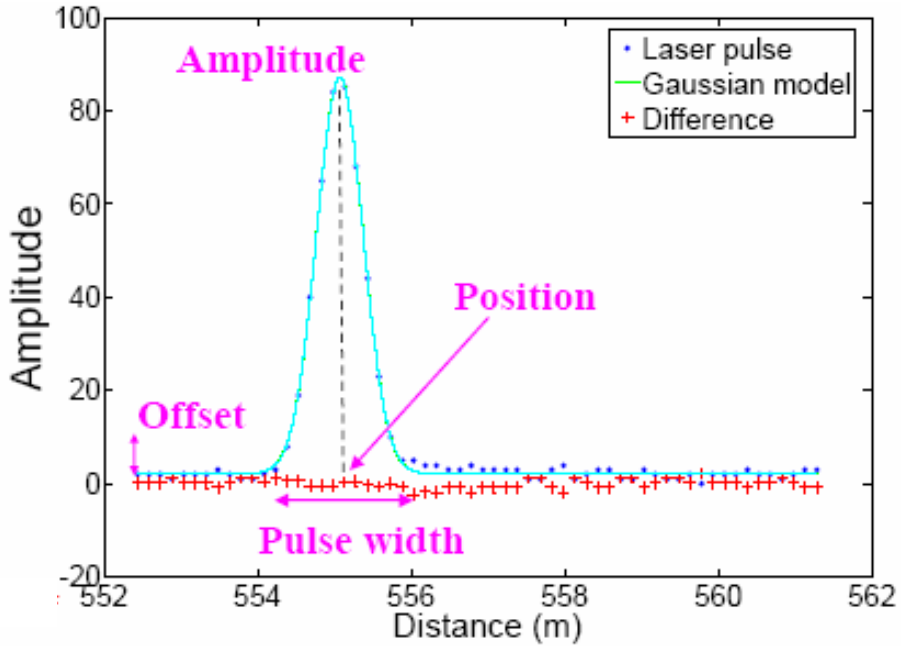
# Fitting: Gaussian decomposition

- Transmitted pulse is in Gaussian model
- Return waveform is a sum of Gaussian components
- Fitting algorithm: least square estimation




*(Vienna Univ. of Tech.)*



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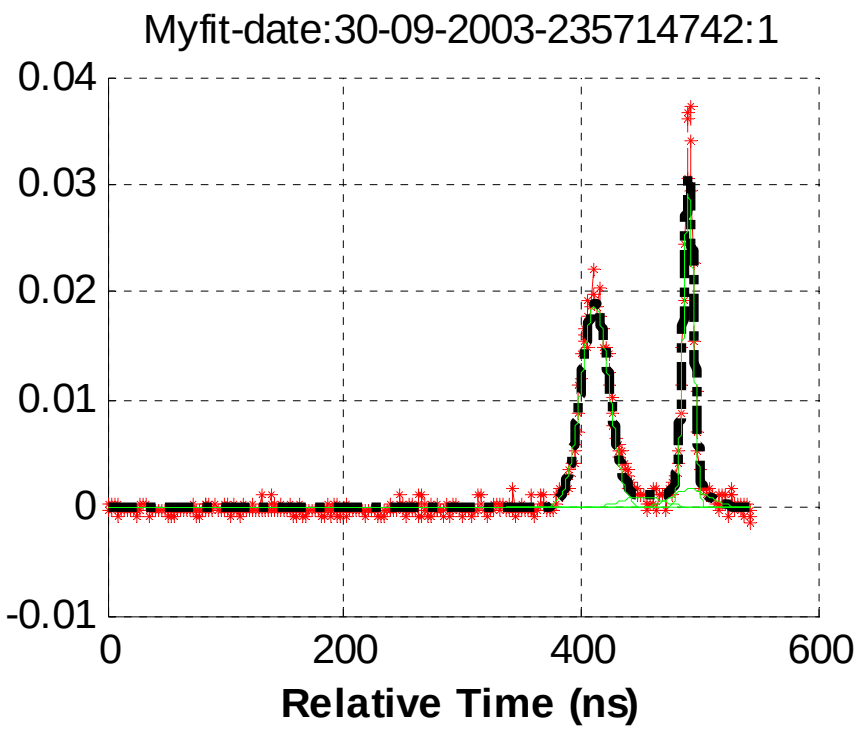
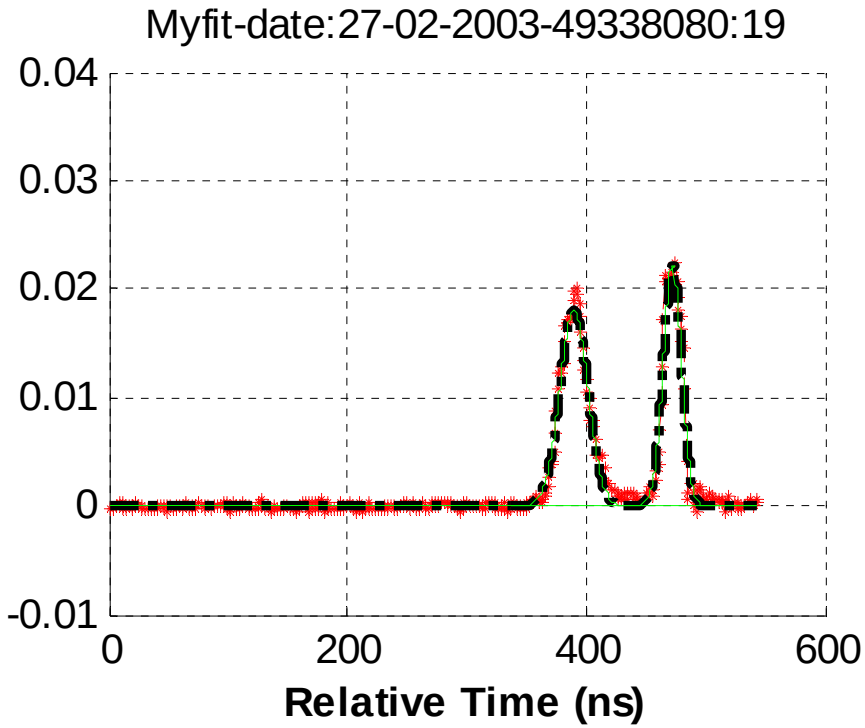
# Results of Gaussian decomposition

Red: raw waveform

Green: Gaussian components




First mode: left most Gaussian component

Last mode: right most



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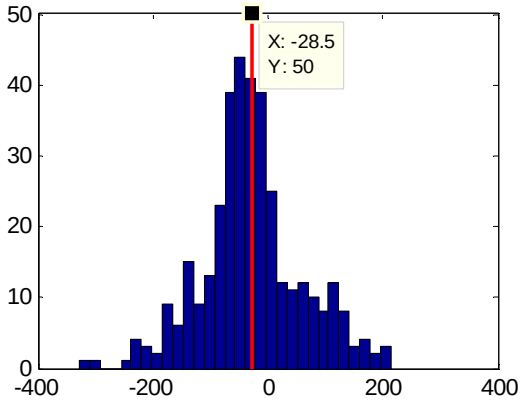
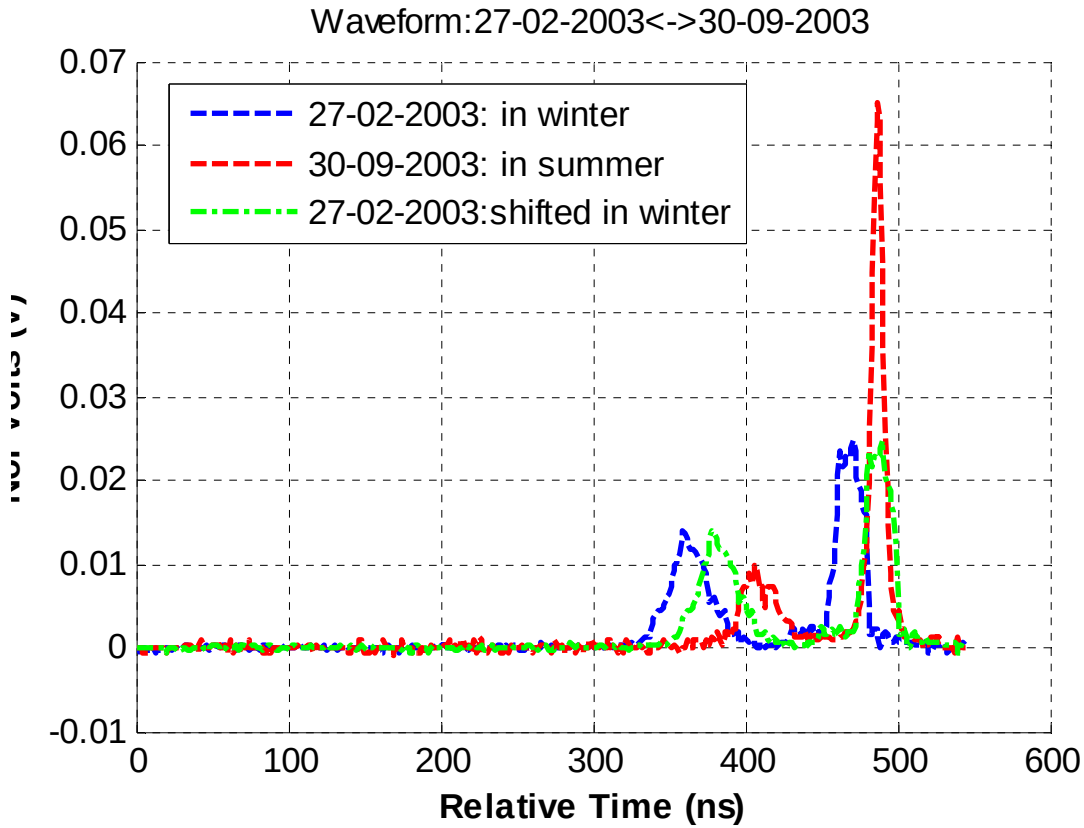
# Shift

Blue: winter waveform
Red: summer waveform
Green: shifted winter waveform




The average shift of 4.26[m] maybe caused by changes in the GLAS configuration



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# Waveform distances

Along vertical axis

Intensity distance:

$$DI(W_F, W_S) = \sum_{i=1}^{544} \frac{(V_F(i) - V_S(i))^2}{544}$$

Along horizontal axis

Peak ratio:

$$RP(W_F, W_S) = \begin{cases} \dfrac{LM_F - FM_F}{LM_S - FM_S} - 1, & LM_F - FM_F > LM_S - FM_S \\ \dfrac{LM_S - FM_S}{LM_F - FM_F} - 1, & LM_F - FM_F \le LM_S - FM_S \end{cases}$$



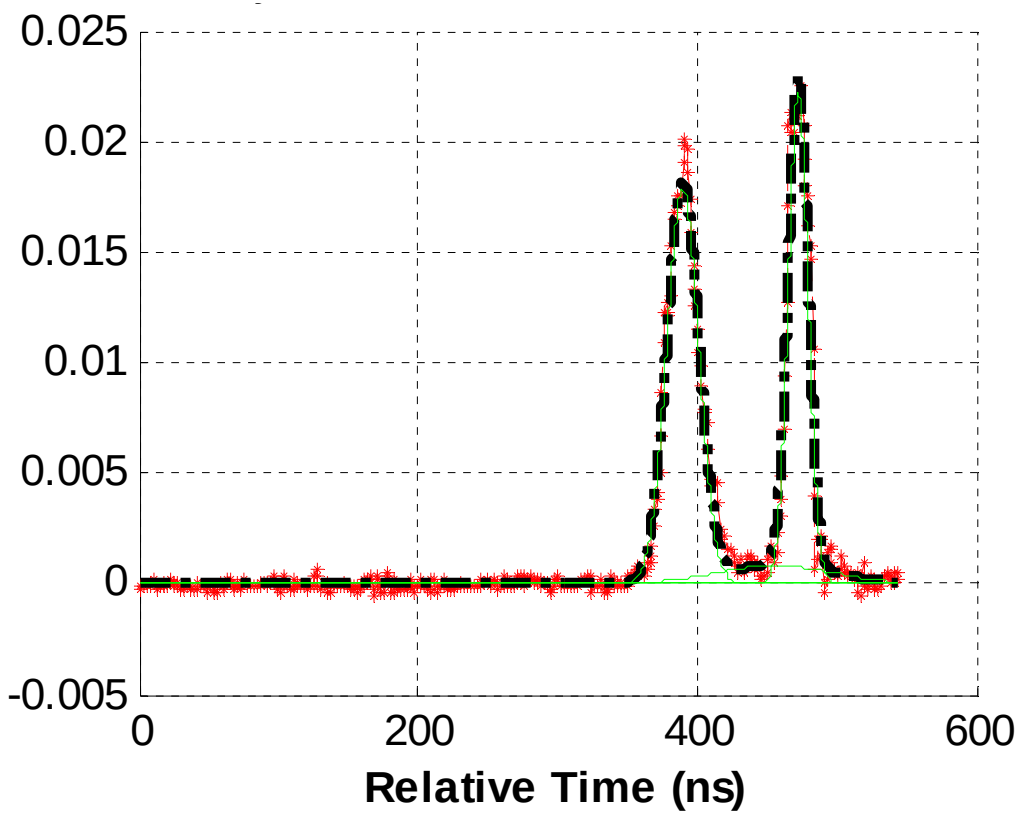
# Waveform parameters

Peak locations
- last mode ~ ground surface
- first mode ~ canopy top

Widths of modes:
~ feature roughness or slope surface, or both, canopy thickness

Amplitudes of modes
- first mode ~ canopy density

Distance first-last mode
~ tree height



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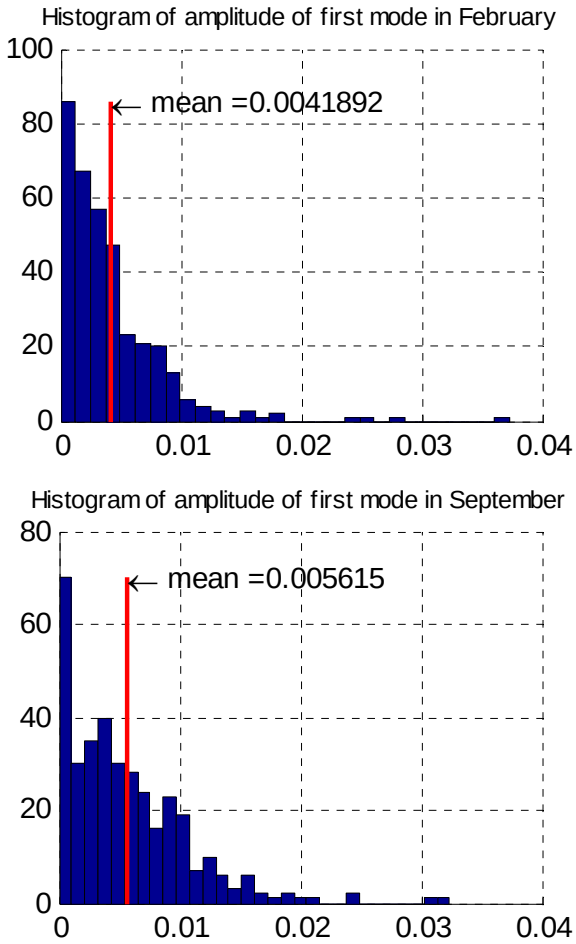
# Mean parameter values

First mode width
- February: 4.28m
- September: 3.74m

First mode amplitude
- February: 0.00418
- September: 0.0056

Last mode amplitude
- February: 0.0083
- September: 0.0088

First-Last peak distance
- February: 20.41m
- September: 19.18m



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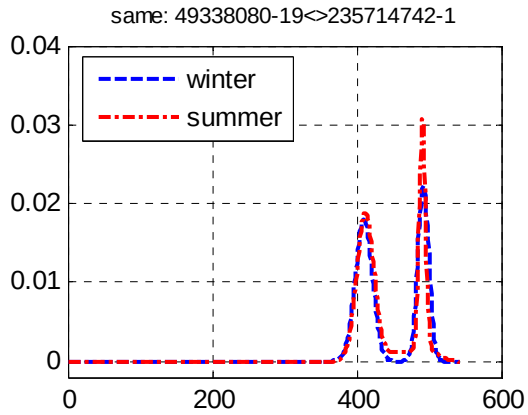
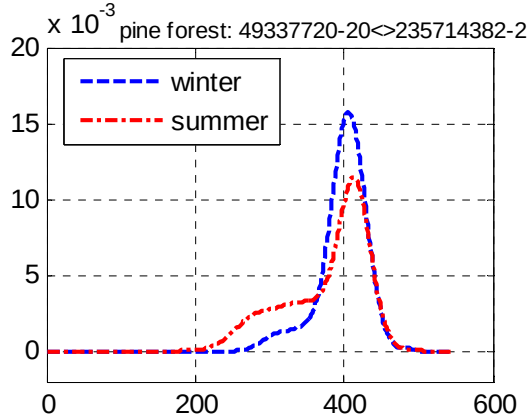
# Results: Waveform classes



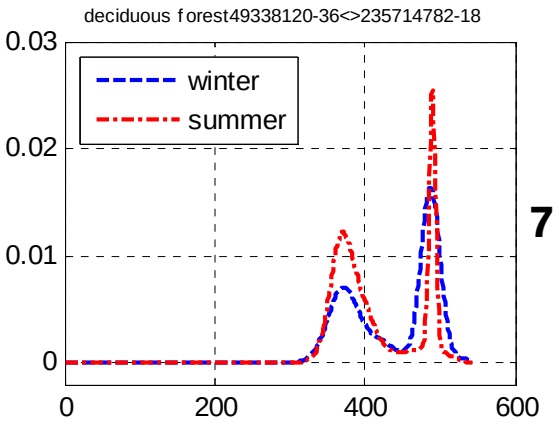

**20 pairs**

small-small



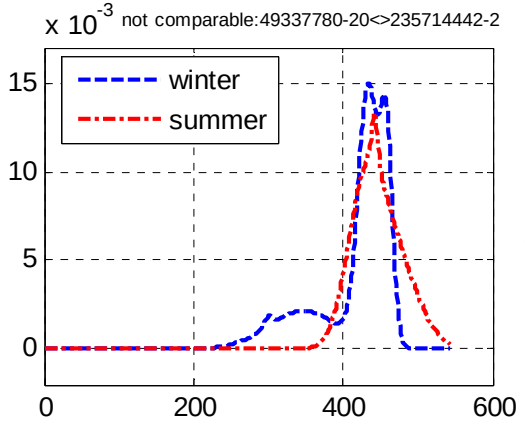

**69 pairs**

not small-small




**70 pairs**

small-not small: deciduous?




**199 pairs**

not small-not small



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# Conclusion

- Possible to compare repeated track ICESat waveform data, but, standardization steps are needed.
- Standardization steps, waveform parametrizations and waveform distances can be applied to non-ICESat waveform data as well.
- Waveform processing procedure should be extended, and tested more extensively on a more controlled data set.

# Upcoming

- Article on land cover classification via analyzing ICESat's full waveform data

(ISPRS Symposium, Enschede, May 2006)