Center for Earth Observation and Digital Earth
Chinese Academy of Sciences

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Forest structure parameter inversion and global comparative study using remote sensing techniques

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OUTLINE

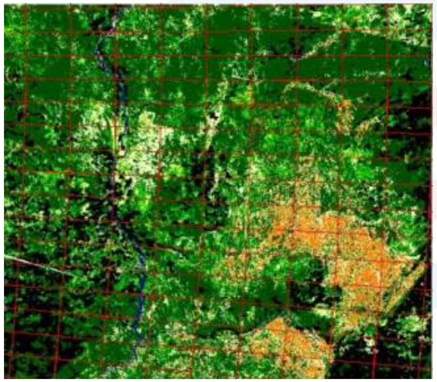
- Background
- Inversion method of forest height using CS-Pol-TomoSAR
- Global forest height mapping using GLAS datasets
- Conclusion and future work

Background

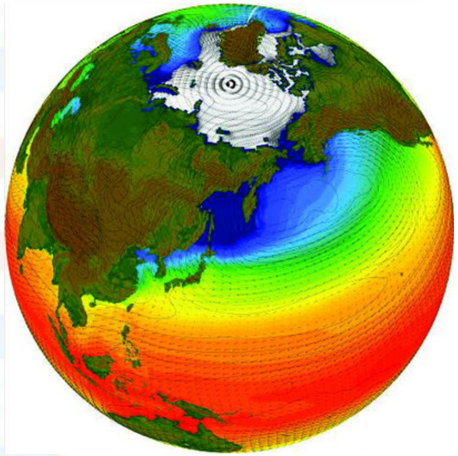
Forest three dimensional structure parameters, especially for forest height, have key significance for biomass estimation and global carbon cycle study.

■The measurement of forest 3-D structure will improve the estimation accuracy of biomass, and then, reduce the uncertainty of global carbon distribution and carbon cycle.

■InSAR, TomoSAR and LIDAR technique are powerful tools to estimate the forest 3-D structure parameters



Forest parameters estimation



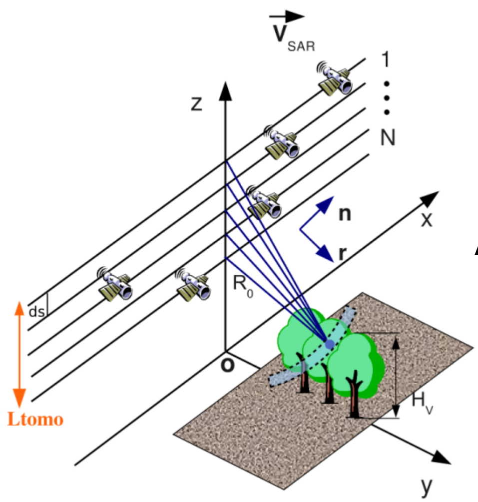
Global carbon cycle model

Inversion method of forest height using CS-Pol-TomoSAR

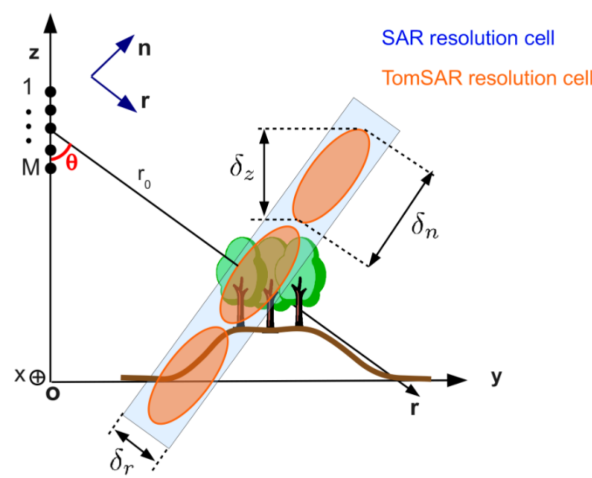
- Introduction
- Methodology
- Experimental analysis
- Summary

Introduction

- **Synthetic aperture radar (SAR) tomography (TomoSAR)** extends the synthetic aperture principle into the elevation direction for 3-D imaging, and the refine structure of targets, scatters distribution and its space position change. It has been successfully used for urban 3-D reconstruction, terrain surface subsidence and forest parameters inversion.



Acquisition geometry



Vertical focusing

- Vertical aperture:L_{tomo}
- Resoluton:$\delta_z = \delta_n \sin\theta$ with $\delta_n = \dfrac{\lambda R_0}{2L_{tomo}}$

Introduction

✓A common 3-D SAR focusing approach is **Fourier-based** SAR tomography, which have some drawbacks:

- ☐ the low number of acquisitions
- ☐ not regular spacing.
- ☐ resolution in elevation is limited by the overall acquisitions baseline extent.

✓ A novel 3-D SAR data imaging based on **Compressive Sensing** (CS) theory is presented to overcome those drawbacks efficiently.

Introduction

- Compressive Sensing is a new signal sampling or reconstruction method proposed by Candes, Romberg, Tao and Donoho(2006).

If signal $X \in R^N$ is sparse in a specific orthogonal base Ψ, its transform coefficient $\Theta = \Psi^T X$ is the equivalent sparse representation, a stationary and incoherent $M \times N$ dimensional observation matrix Φ which is incoherent with transform basis Ψ is used to measure Θ, and, the measurements were $Y = \Phi\Theta = \Phi\Psi^T X$, and if $\Phi\Psi^T$ meet the RIP (Restricted isometry property) requirement, it can be proved that signal X can be unique recovered by L_1 minimization from the Y measurements as follows.

$$min\|X\|_1 \ \ s.t. \ Y = \Phi\Theta = \Phi\Psi^T X$$

Introduction

✓ The CS TomoSAR technique bases on the fact that the image to be focused has usually a **sparse representation** along the elevation direction . It has more advantages:

- ☐ **a small number of measurements.**
- ☐ **irregular spacing.**
- ☐ **super-resolution imaging:** the super-resolution factor is

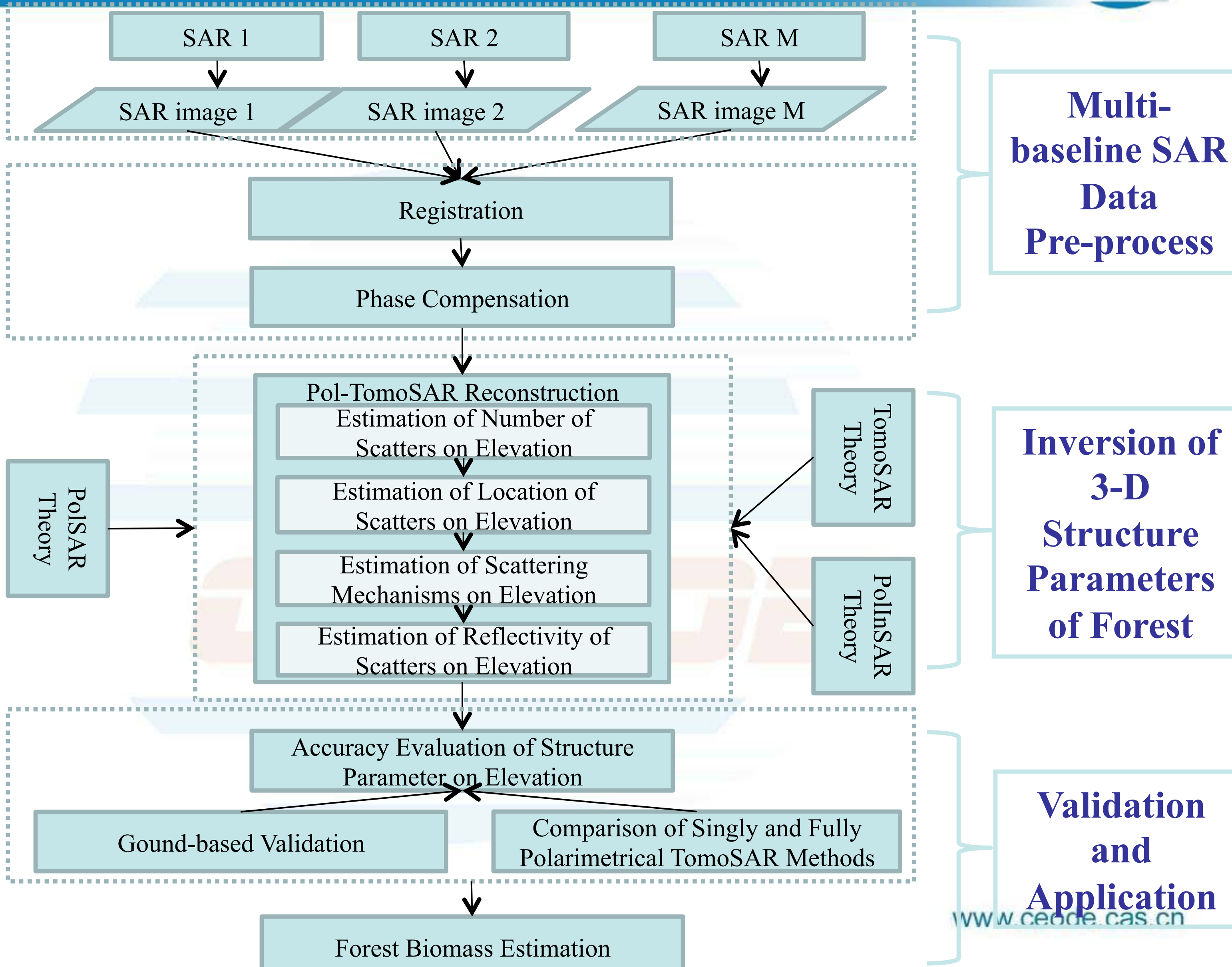
$$\eta_{sup} \leq exp\left[\left(\frac{M}{CK}\right)^{\frac{1}{4}}\right]\frac{\lambda R_0}{2S_1S_T}$$

M: the number of scenes
C: very small constant
K: the number of nonzero coefficients of signal
λ: wavelength
R_0: Range distance
S_1: the illuminated scene extension in the elevation direction (Range of possible elevations)
S_T: the overall baseline span

Based on TomoSAR, Polarimetric SAR and Compressive Sensing theory, a forest height inversion method using CS-Pol-TomoSAR technque was proposed.

Methodology

The flow chart of Inversion method of Forest height Using CS-Pol-TomosSAR



The Sparse Representation of forest scattering signal

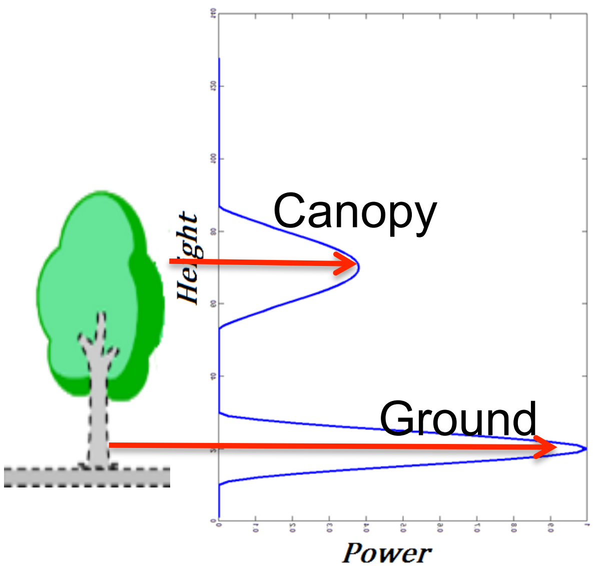
- Base on CS theory, signal must be sparse in the sense that it can be written either exactly or accurately as a superposition of a small number of vectors in some fixed basis.

- The scattering signal of forest might not be sparse in the space domain.

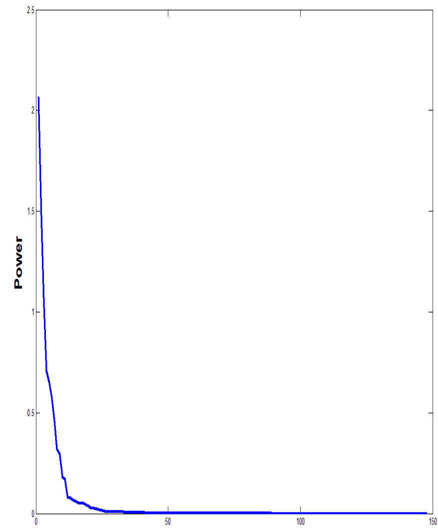
- Finding a sparse basis, which may suitable for analysis of forest scattering signal.

Methodology

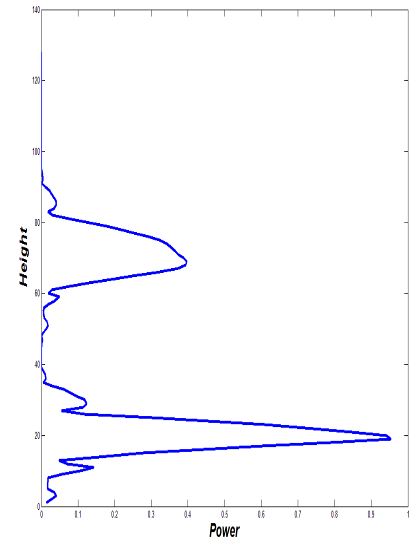
The Sparse Representation of Vertical Power of Tree Base on Wavelet Basis



Expected vertical power distribution of the effective scattering



Sorted magnitudes of the transform coefficients using a Daubechies Symmlet wavelet with 4 vanishing moments



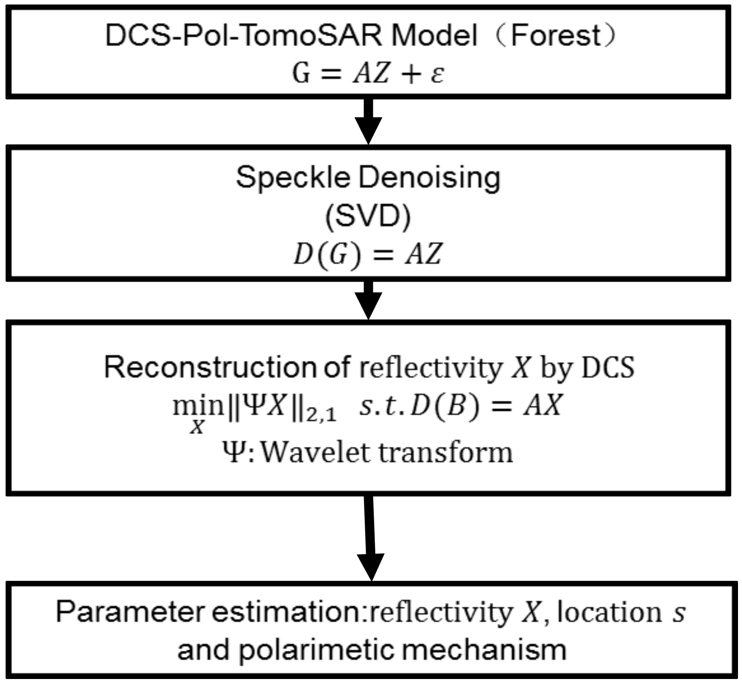
Power of the inverse DWT after zeroing out all but the largest 5 coefficients .

Numerical simulation results:

The rapid decay of the sorted magnitudes of the transform coefficients using a Daubechies wavelet with 4 vanishing moments. It means that, on the wavelet basis, the number of big coefficient of vertical power are little, and the small coefficient are large. As a result, we can attain considerably sparse representations.

Methodology

Multi-signal CS-Pol-TomoSAR algorithm:



(Aguilera 2011)

(Aguilera 2011)

(Aguilera 2012)

Flow chart of Multi-Signal CS-Pol-TomoSAR for Forest height

Experimental analysis

✓ Experimental Data

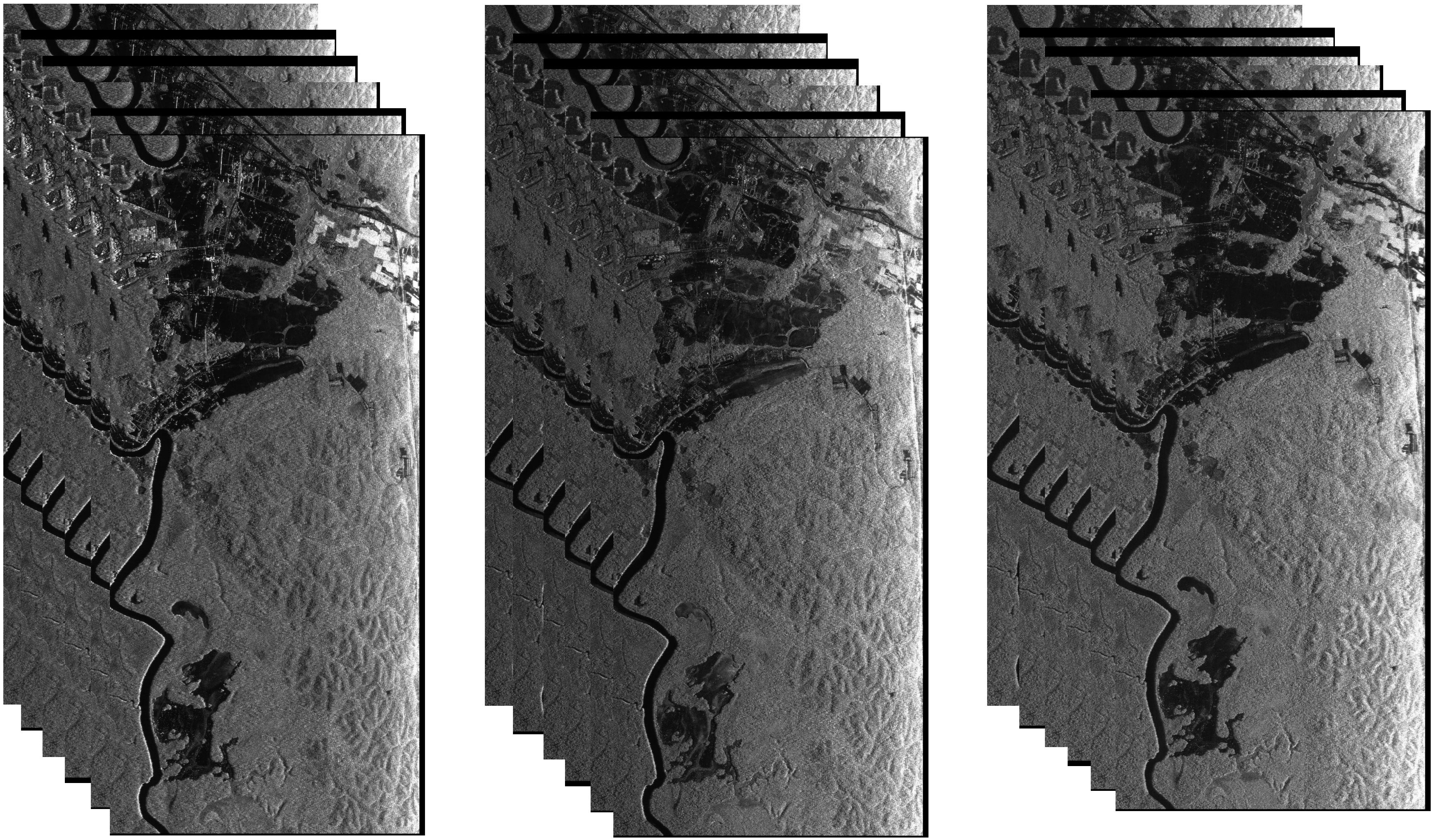
The experiment of this method uses 6 fully polarimetric P-band airborne TropiSAR images acquired by The French Aerospace Lab (ONERA)'s SETHI system over the test site in Paracou, French Guiana. FURTHERMORE, an extensive in-situ databases, acquired over several decades, were made available for verification. 16 forest plots in Paracou were included in the dataset, for which all trees with a diameter larger than 10cm have been tagged, positioned and measured.

SAR data baisic parameters

Number of SAR image	6
Wavelength	0. 7542 m （P-Band）
Range resolution	1.000 m
Azimuth resolution	1.245 m
Polarimetric	HH HV VV

Experimental analysis

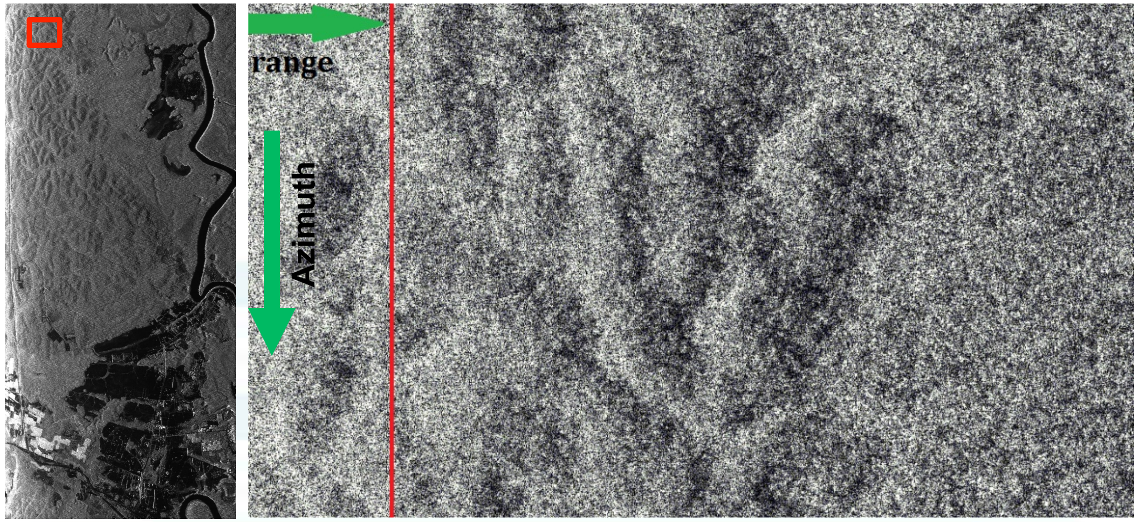
✓ Multi-baseline SAR Data Pre-process



Registered and Compensated SLC Stack in each Polarimetrical Channel

Experimental analysis

✓Experimental Area (Red line profile)

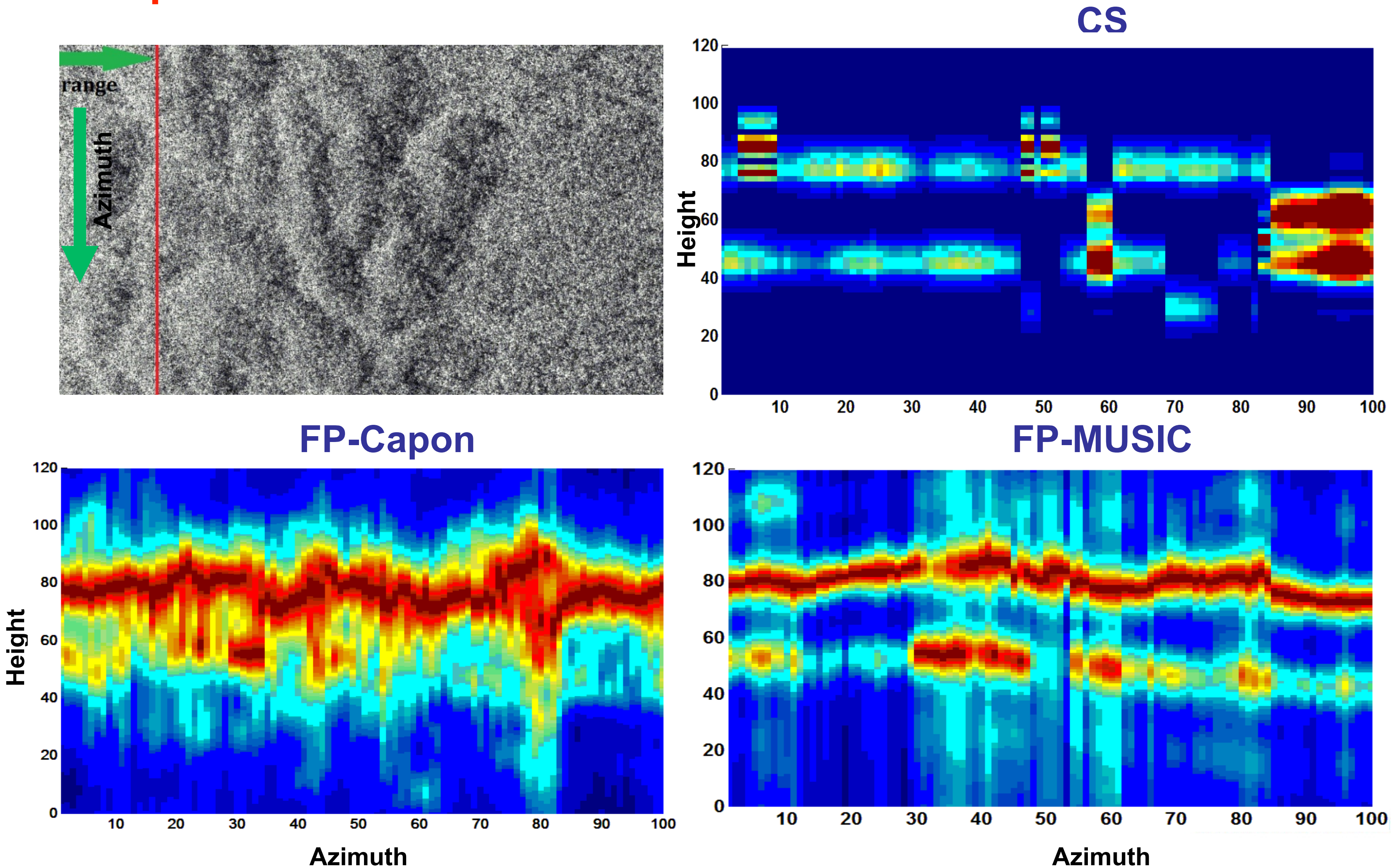


Baseline Parameters

No.	Flight Date	Vertical baseline (m)	Spatial (elevation) frequency
1	24/08/2009	0	0
2		-14.4879	0.004500
3		-30.1163	0.009353
4		-43.8343	0.013613
5		-60.0632	0.018653
6		-74.9683	0.023283
Slant Range		4905 m	
View angle		35.0614°	

Experimental analysis

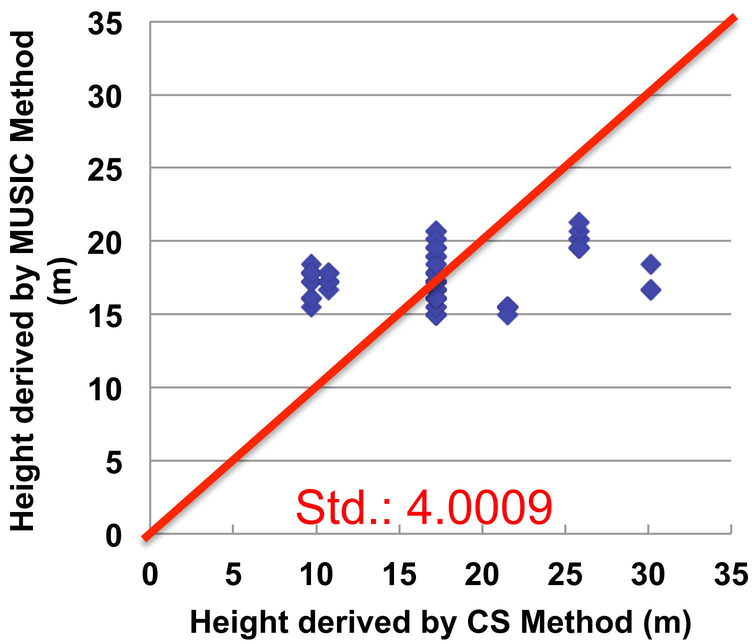
✓Experimental Results: Profile results



Summary

✓Results validation： cross validation

Method	Range of possible elevations	Height sampling	Mean of Distance between ground and canopy
CS	120 m	1.875 m	17.2453 m
FP-MUSIC	120 m	1 m	17.4755 m



Remark：

➢The result from CS method are consist with Music method's results, the mean distance between ground and canopy are **17.2453** m and **17.4755** m respectively.

Future work:

➢Future work will focus on evaluating the estimation accuracy of CS method using in situ data.

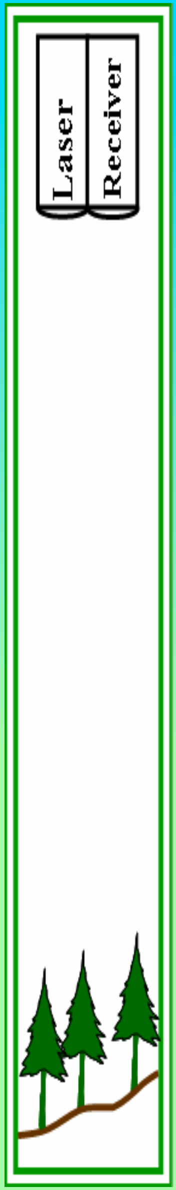
➢ More optimized sparse basis need to be created;

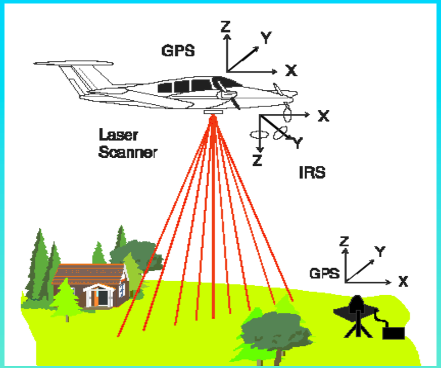
➢ To extend proposed method from the multi-polarization to polarimetric case.

Global forest height mapping using GLAS datasets

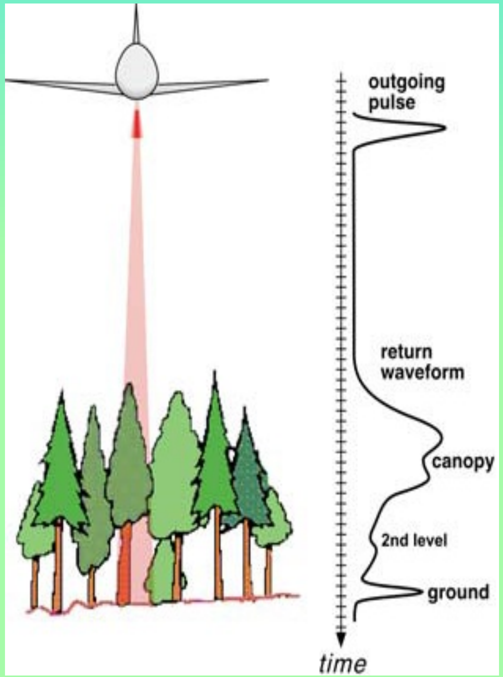
- LiDAR Introduction
- Waveform LiDAR Data Processing
- Global Forest Height Mapping

LiDAR Introduction





$$R = (c \cdot t)/2$$



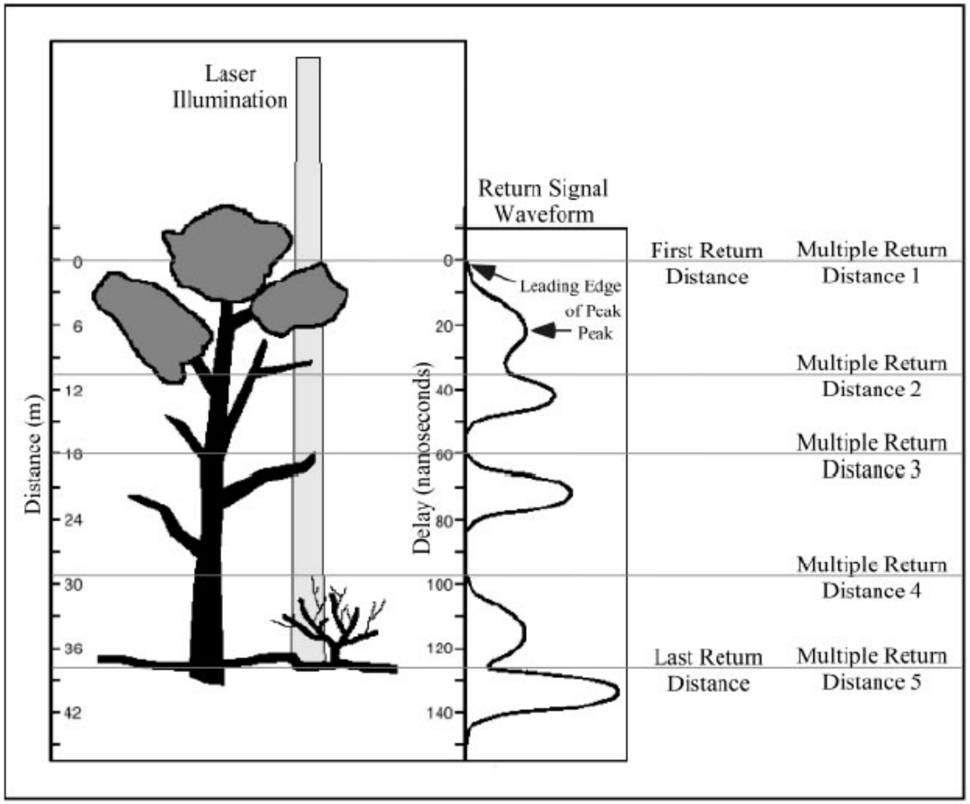
<u>What is LIDAR</u>?

LIDAR stand for **Light Detection and Ranging**. This is a term used for a method of distance measurement using laser light. The journey time of the laser beam, from leaving the instrument to it's return after reflection, is measured and knowing the speed of light, a distance can be computed.

LiDAR Introduction

Waveform Recording vs. Discrete-return LIDAR

Conceptual differences between waveform canopy LIDAR and discrete-return LIDAR devices.



Waveform LiDAR:

LIDAR waveform would be collected by a waveform-recording sensor over the same area.

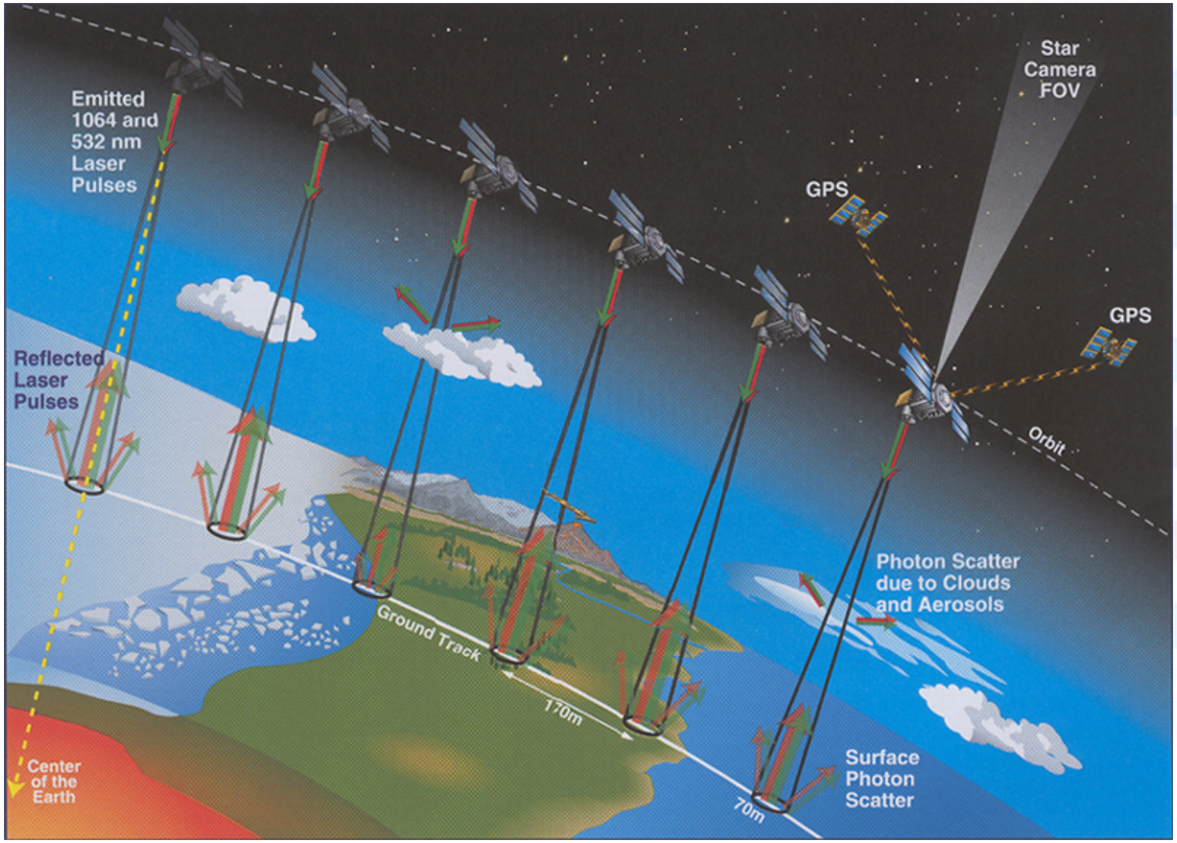
Discrete-return LIDAR:

- **First-return** LIDAR devices record only the position of the first object, whereas
- **Last-return** LIDAR devices record the height of the last object in the path.
- **Multiple-return** LIDAR, a recent advance, records the height of a small number (generally five or fewer) of objects in the path of illumination.

LiDAR Introduction

GLAS (Geoscience Laser Altimeter System)

GLAS provided continuous global measurements of the Earth's land surface topography.



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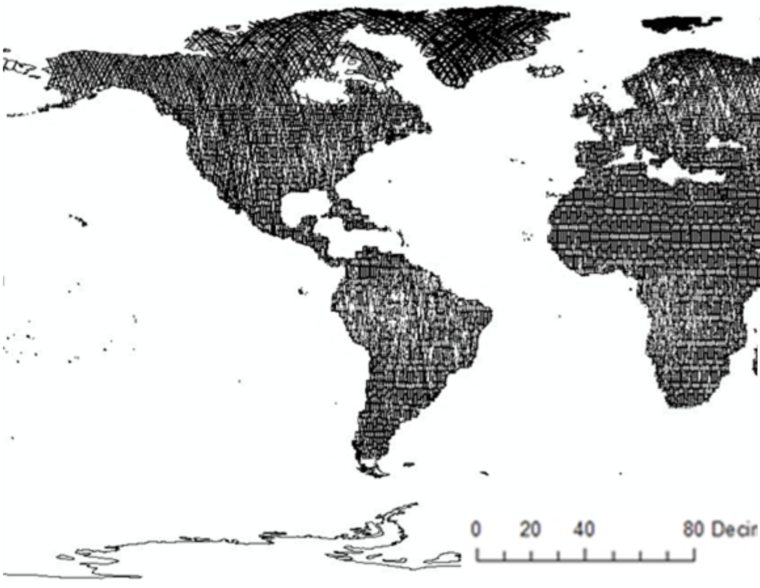
http://icesat.gsfc.nasa.gov

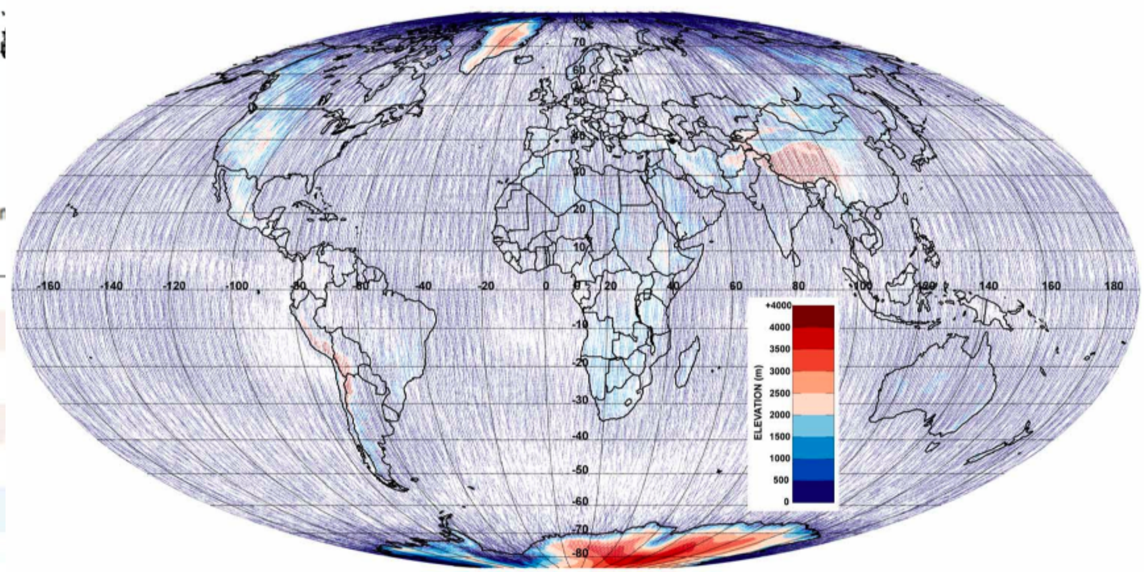
Technical characteristics

Status	launched Jan. 2003
Platform	space-borne
Wavelength 1064 nm	(vegetation)
Pulse frequency	40 Hz
Pulse width 5 ns	
Pulse form Gaussian	
Footprint diameter	**60-70 m**
Transmit energy	5 mJ
Along-track separation 170 m	
Cross-track max	**15 km**
Cross-track min	**2.5 km**
Repeat cycle	183 days
Life-time	3 years

LiDAR Introduction

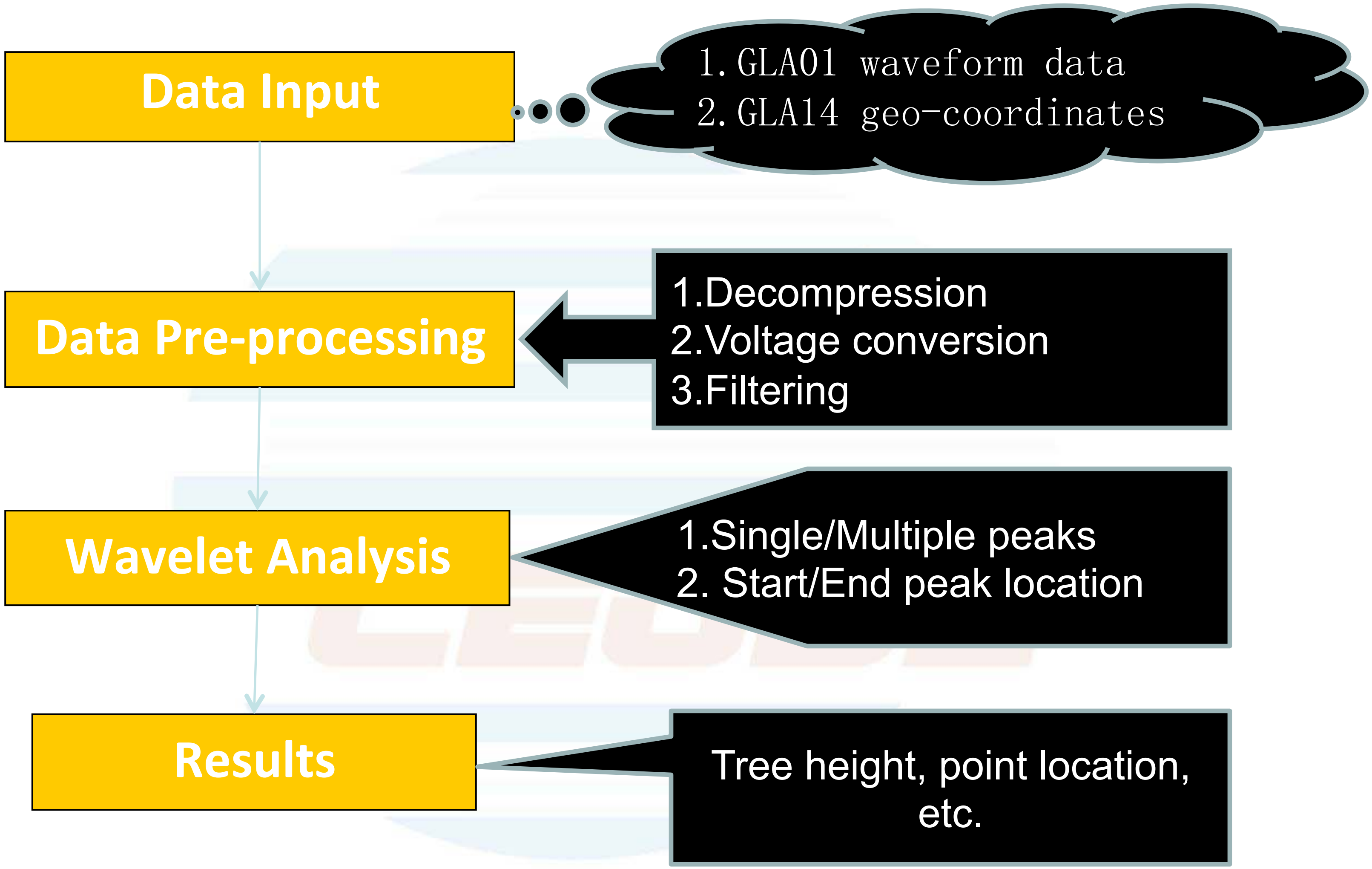


GLAS point distribution in Feb. 2004



Global DSM

Waveform Data Processing



Waveform Data Processing

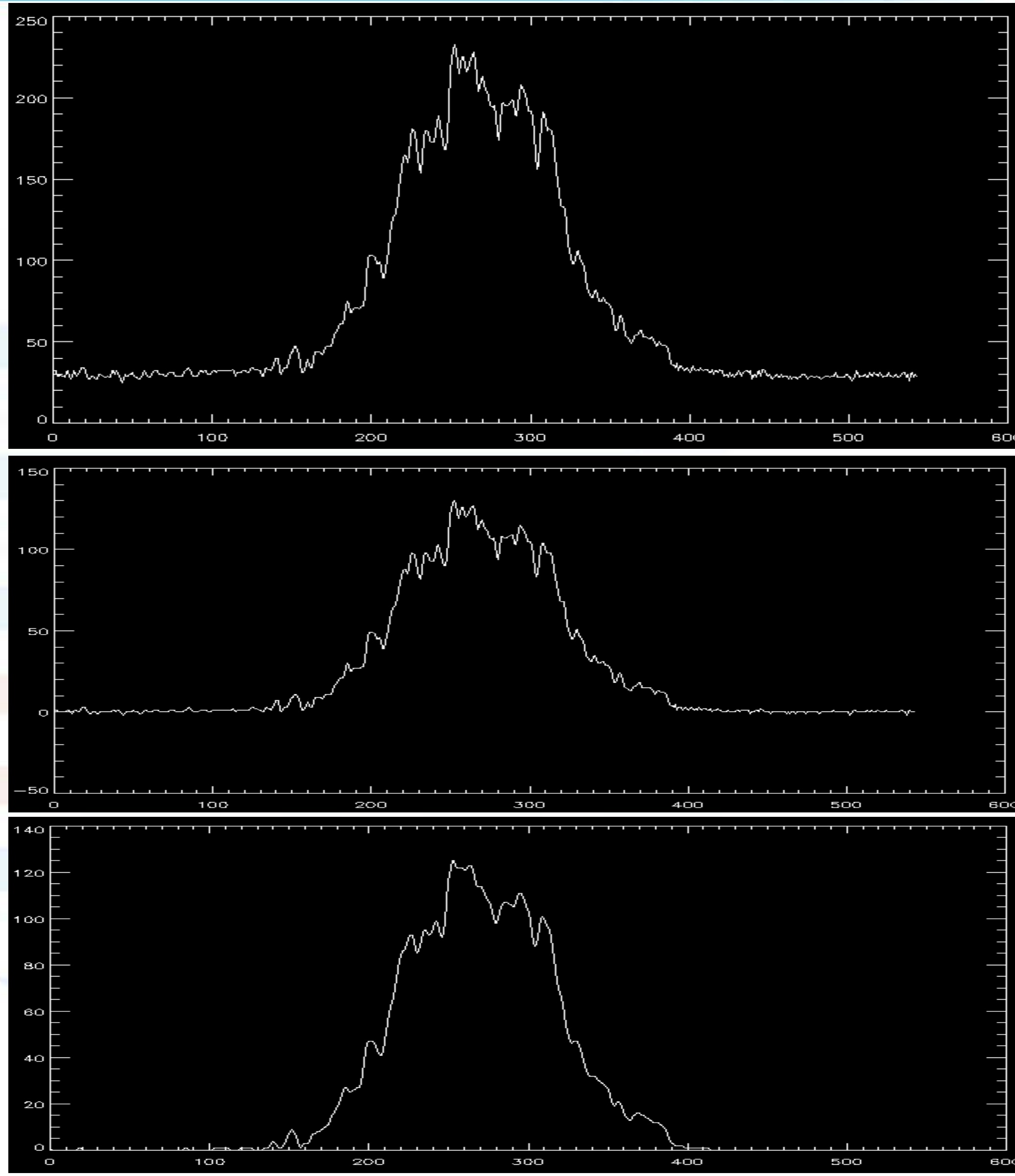
GLAS waveform

↓

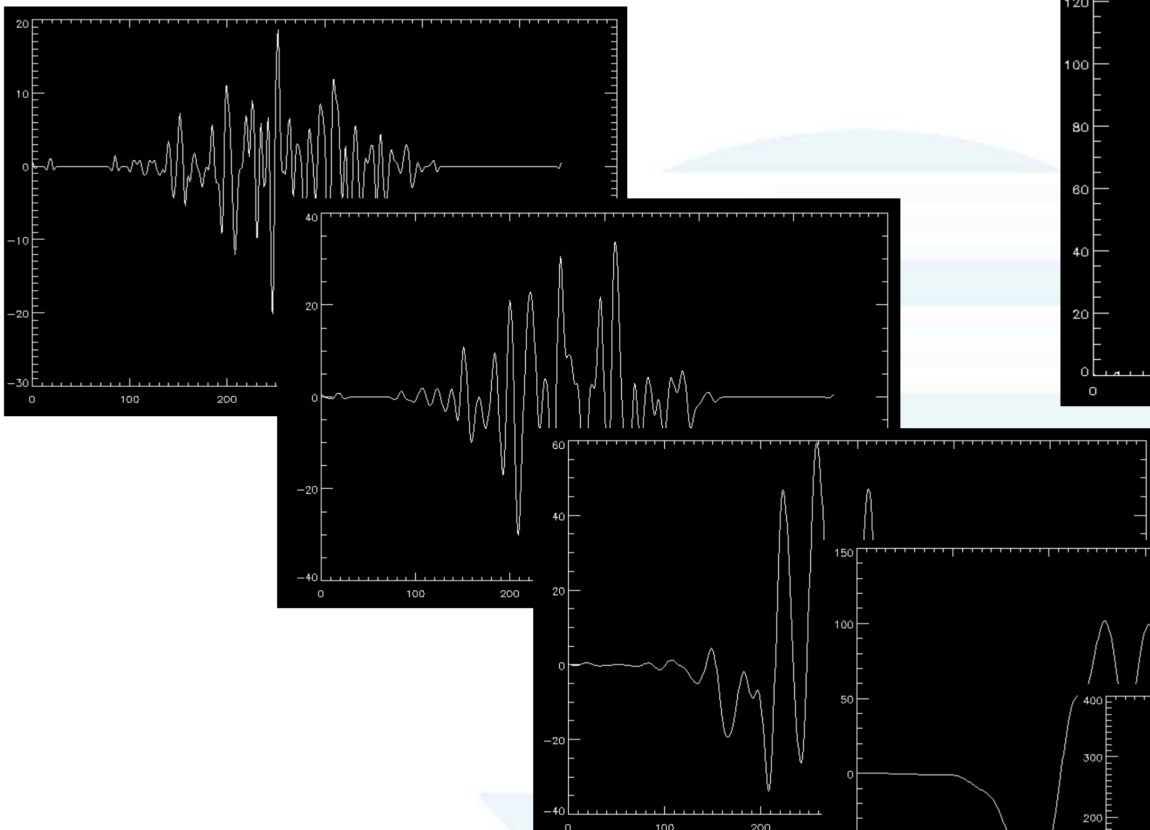
Transfer to volt waveform

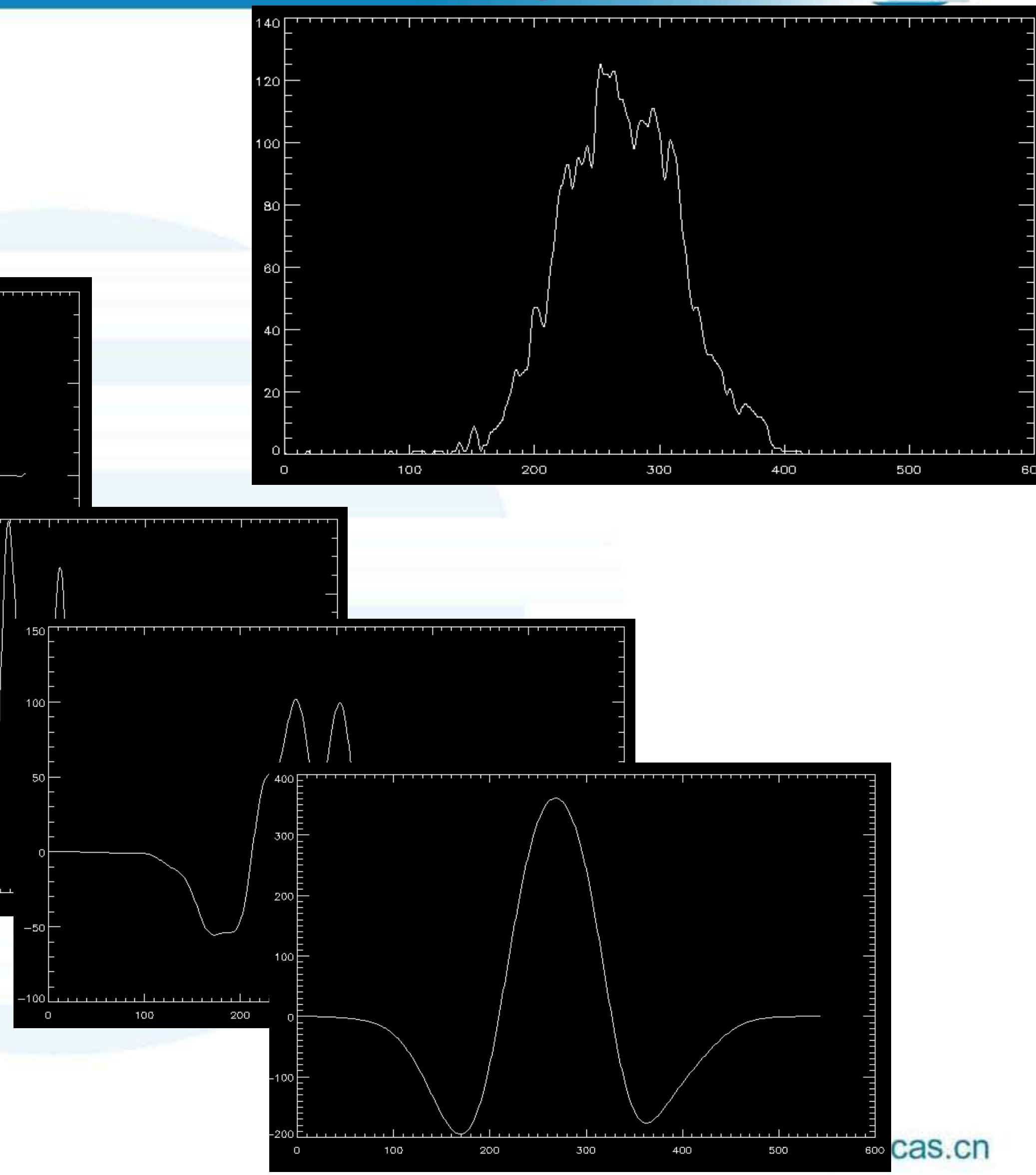
↓

Filtered waveform



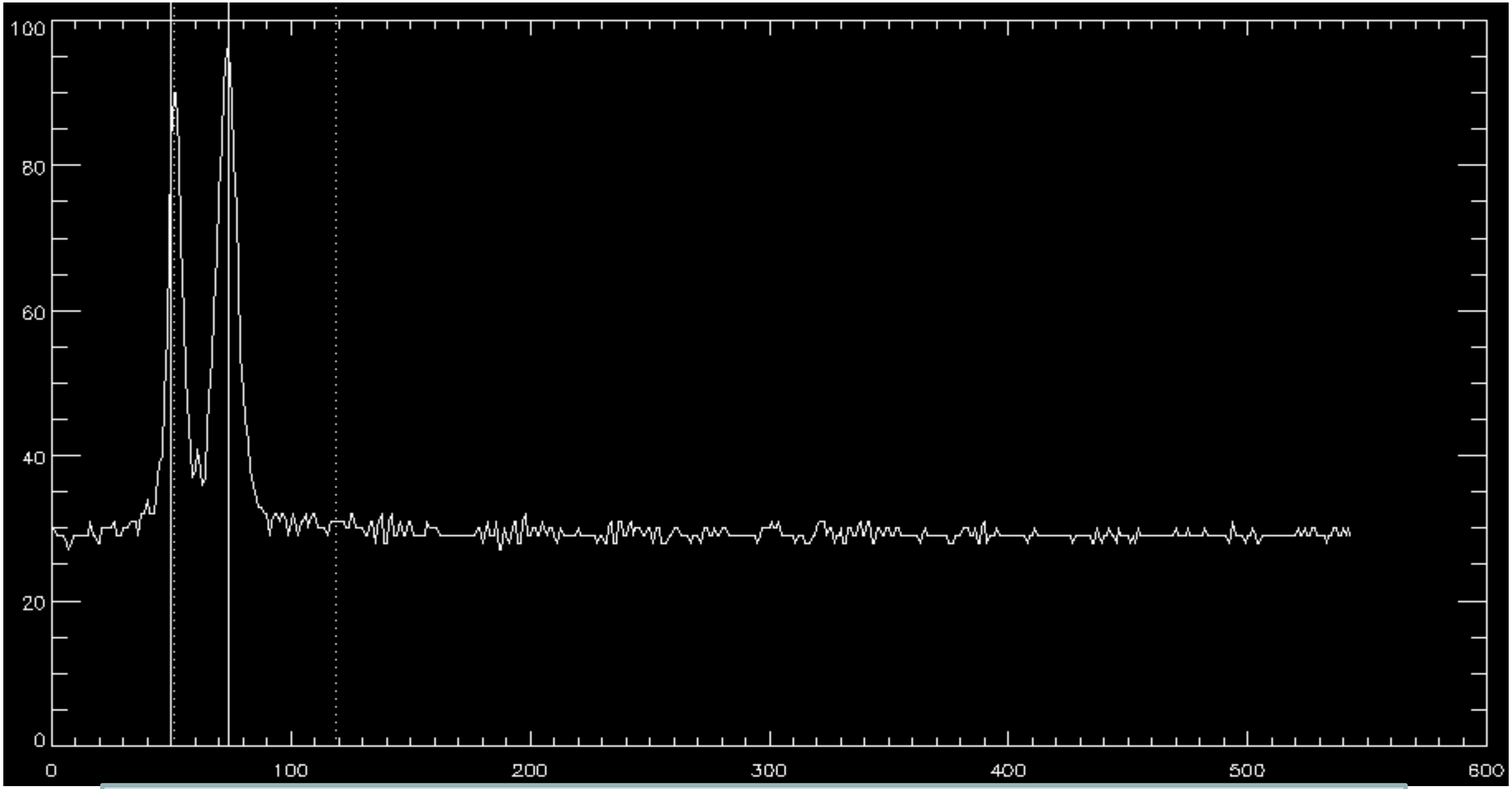
Waveform Data Processing





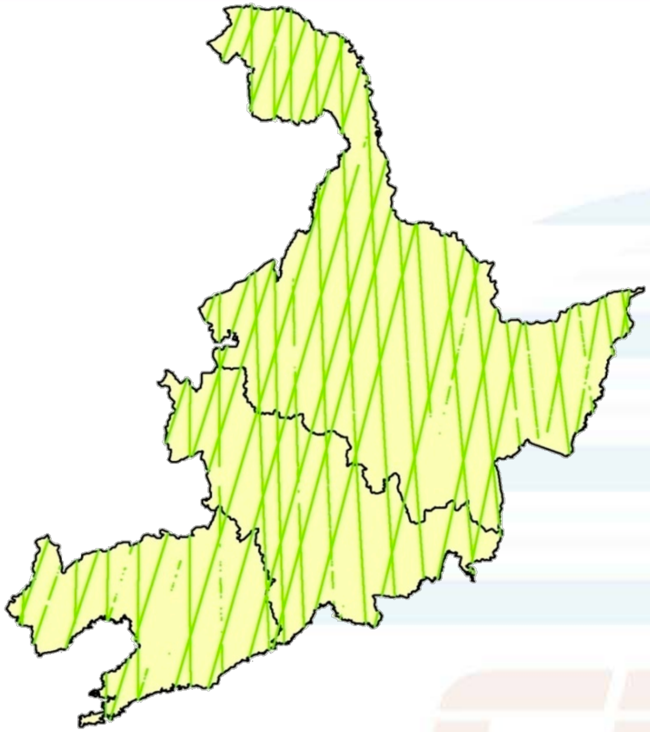
Wavelet Analysis：Using a group of wavelet functions to simulate a signal (or function). The wavelet functions are the transformation and shift of a basic wavelet function.

Waveform Data Processing

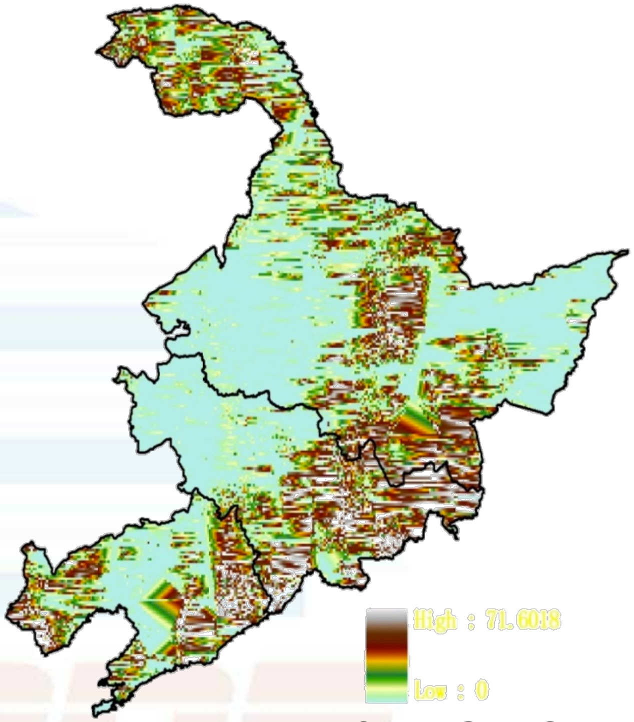


White solid line : start and end positions determined by wavelet analysis;
White dash line: start and end positions offered by NASA GLAS team

Global Forest Height Mapping



GLAS points of the northeastern China

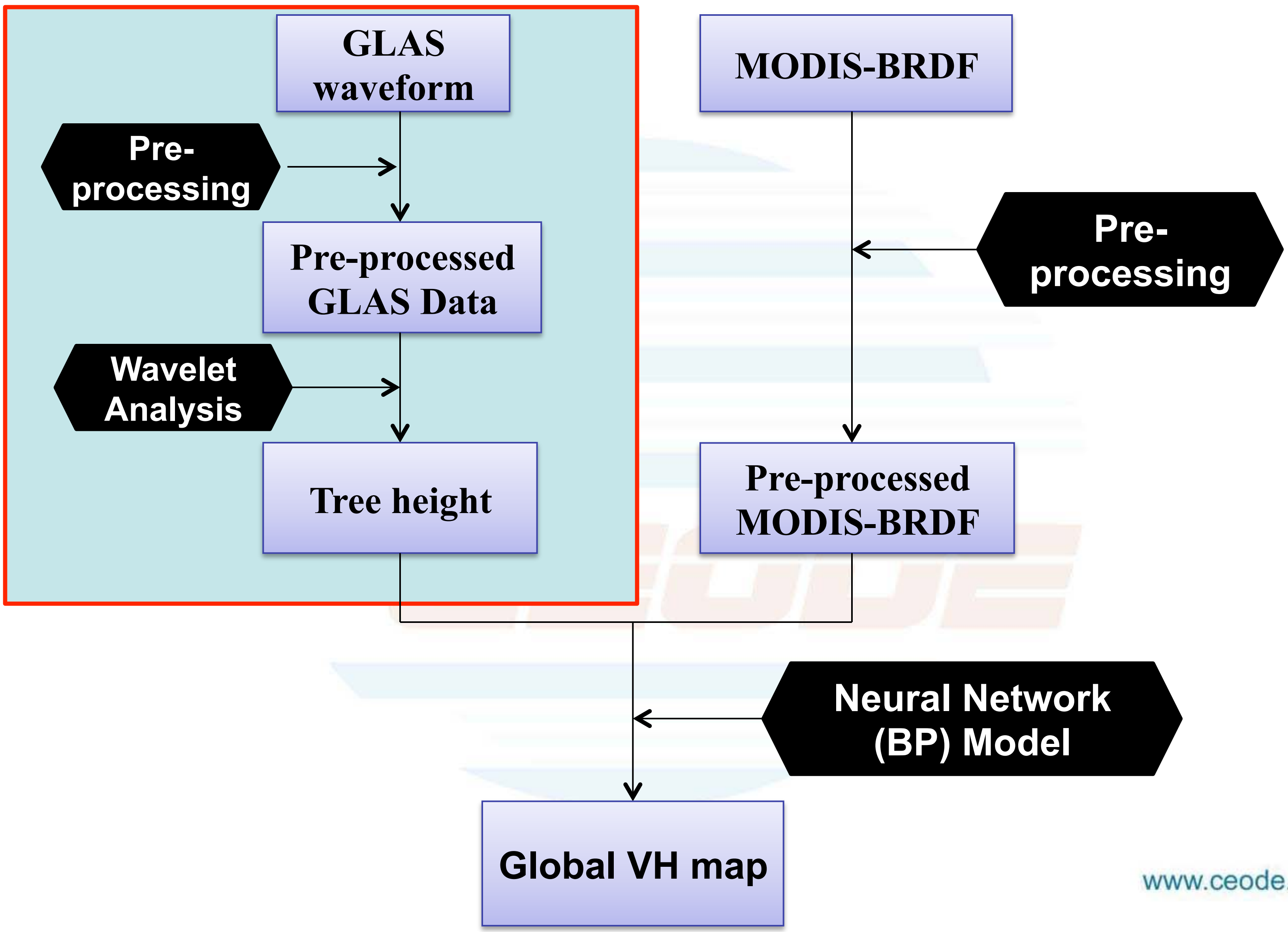


Interpolated FH map from GLAS points

- **Low resolution of GLAS data led to low accuracy of the interpolated FH map**
- **MODIS-BRDF can offer vegetation structural infromation (LAI, vegetation height, etc.)**

Integrate GLAS to MODIS-BRDF data for global forest height mapping

Global Forest Height Mapping



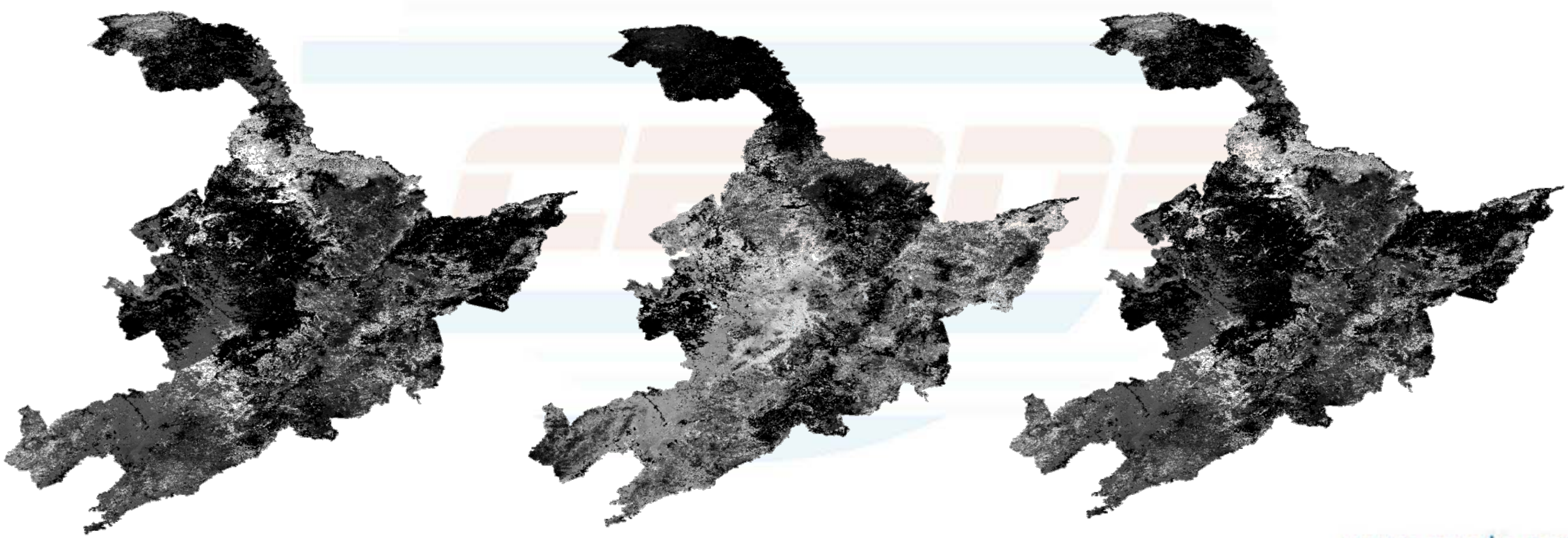
Global Forest Height Mapping

MODIS: 36 spectral bands、middle resolution（0.25Km～1Km）

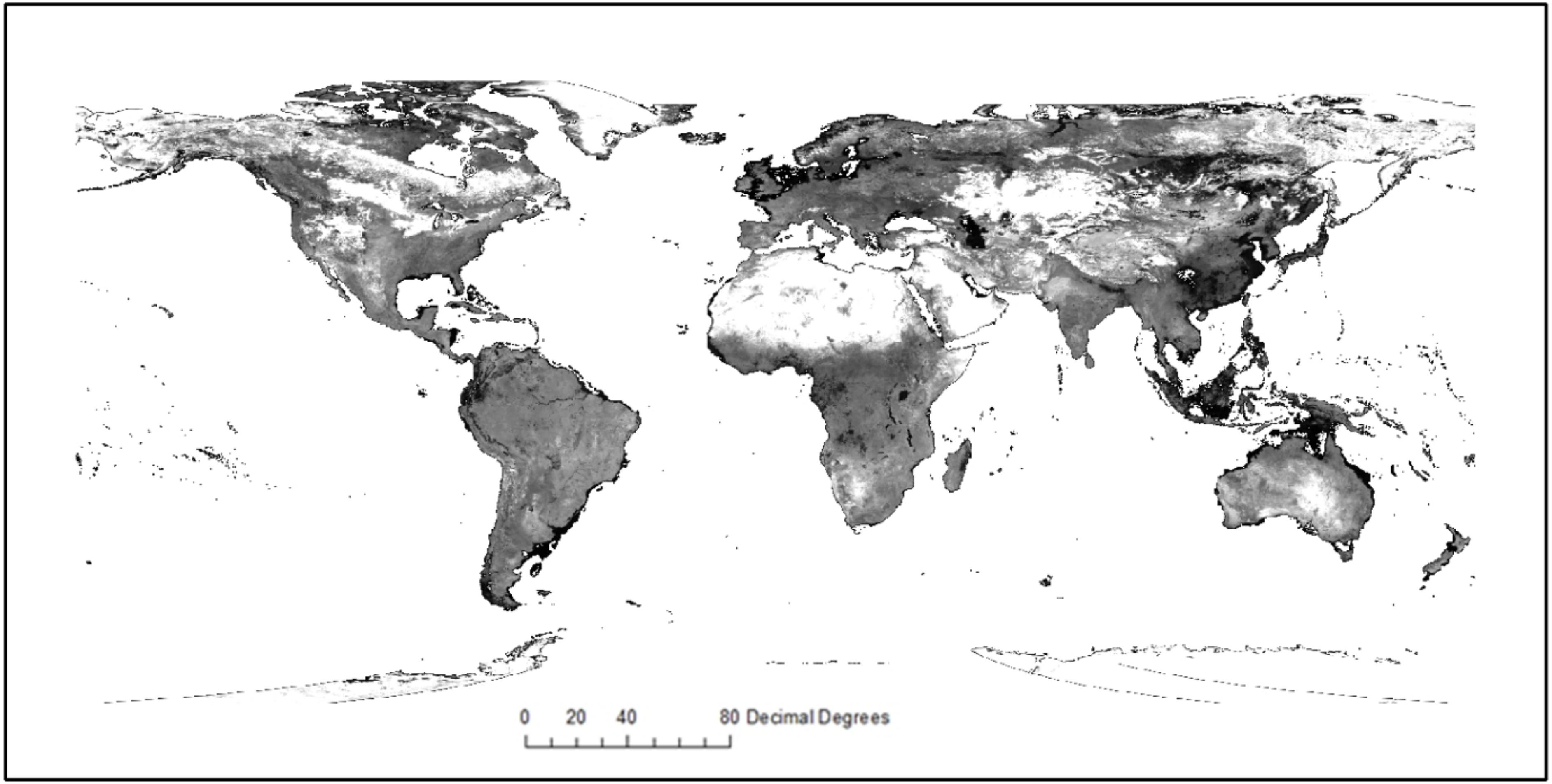
MODIS-BRDF

$$R(\theta,\vartheta,\phi,\wedge) \equiv f_{iso}(\wedge) + f_{vol}(\wedge)K_{vol}(\theta,\vartheta,\phi) + f_{geo}(\wedge)K_{geo}(\theta,\vartheta,\phi)$$

MODIS-BRDF has three parameters（ISO,VOL,GEO）

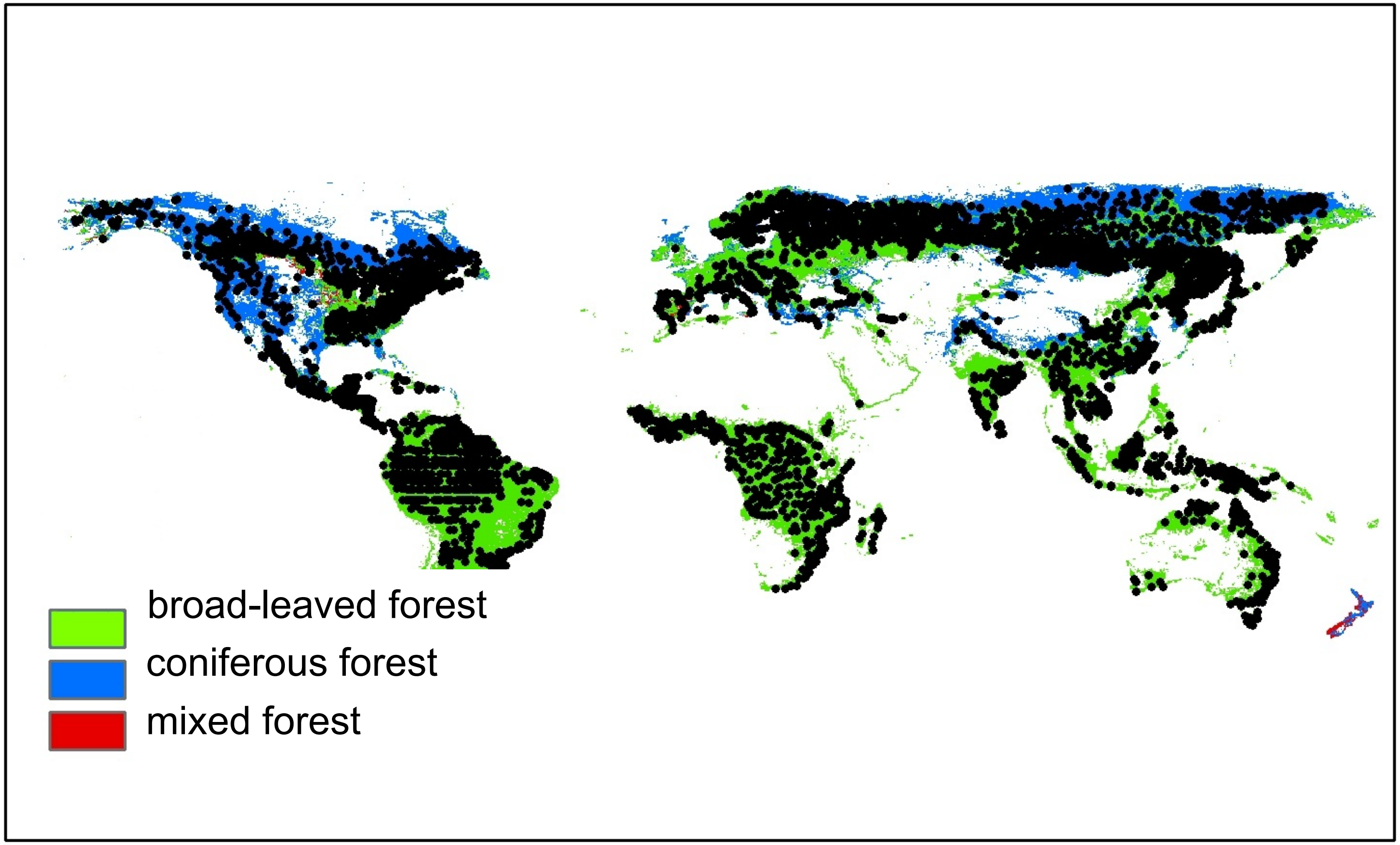


Global Forest Height Mapping



Composited MODIS image (near infrared band)

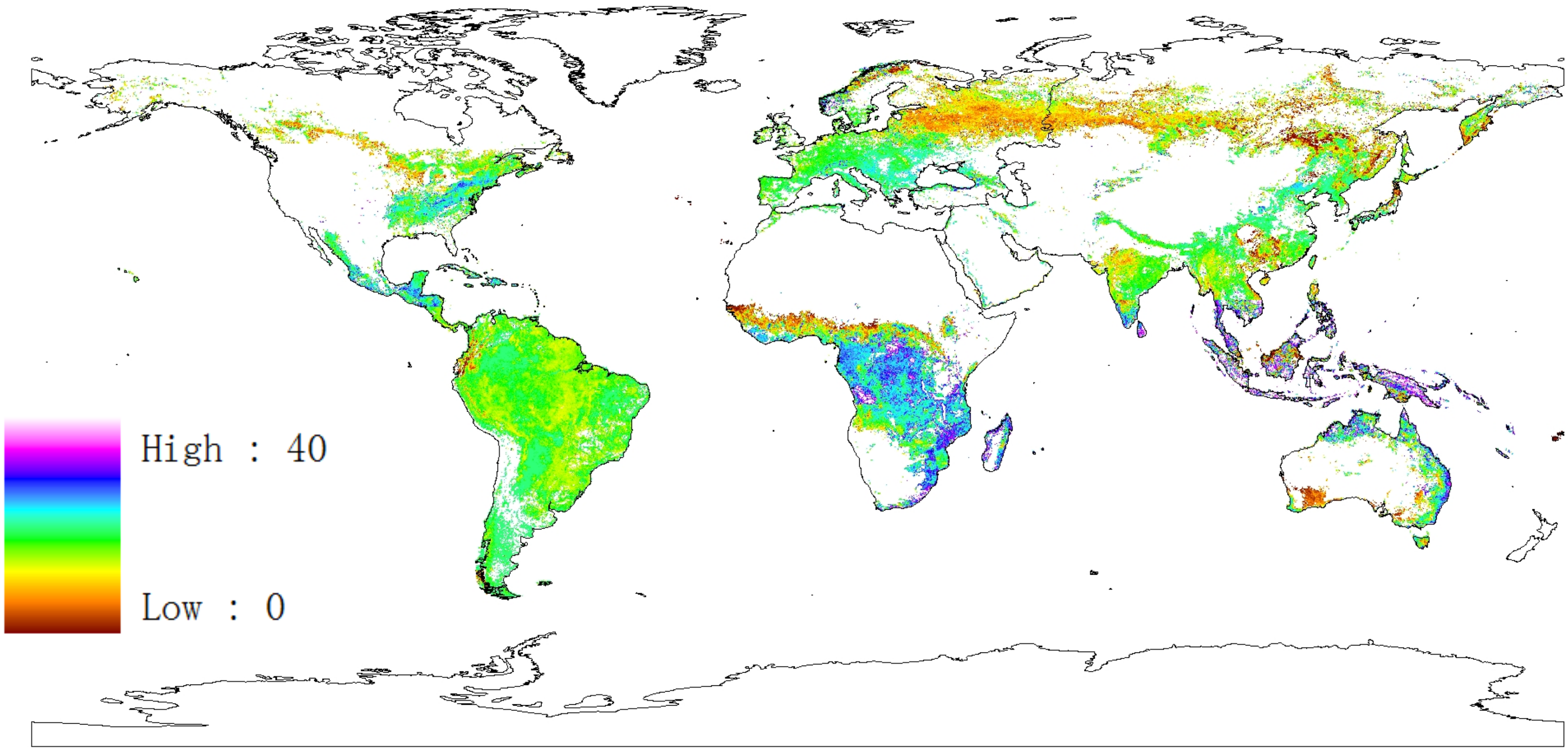
Global Forest Height Mapping



Black points -- GLAS points

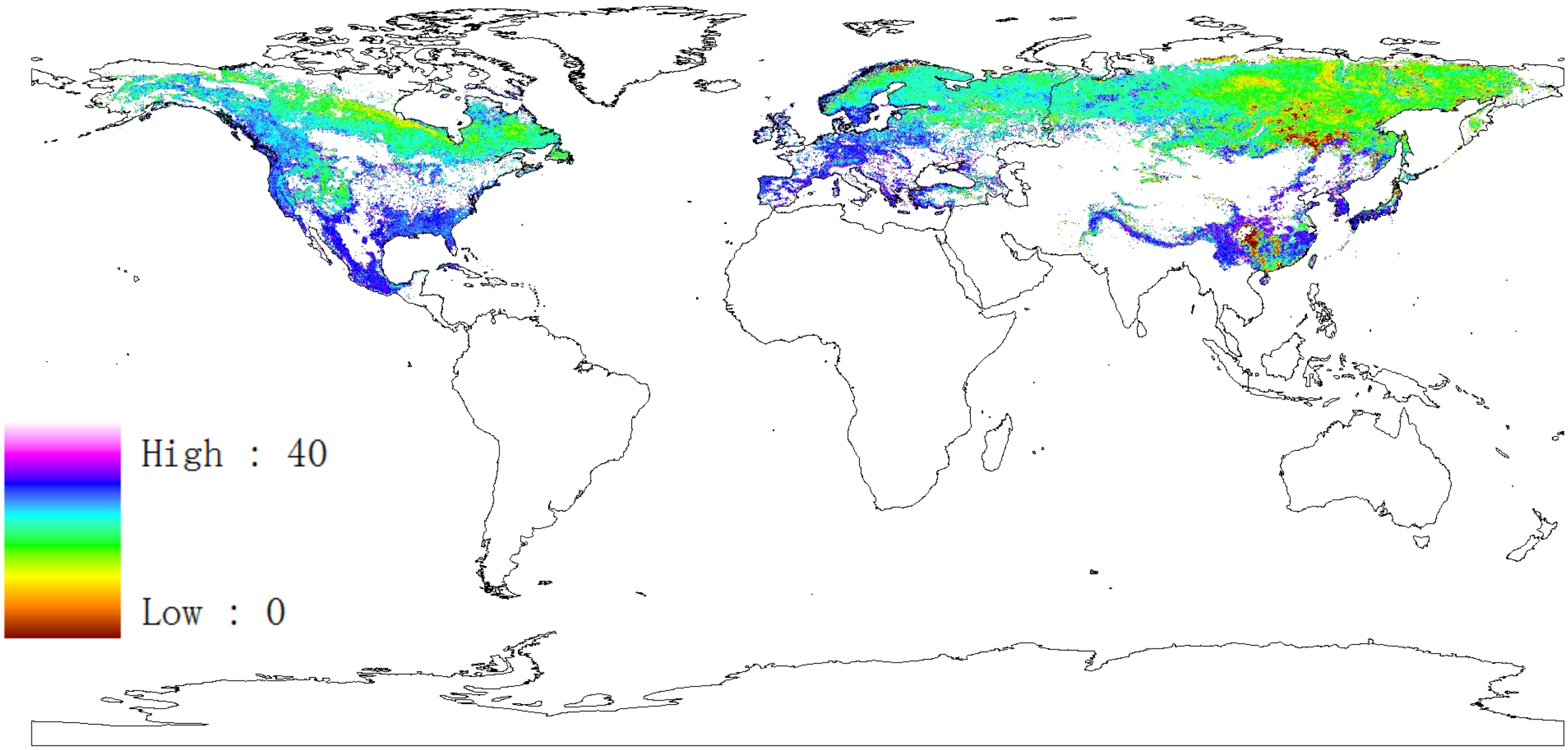
Global Forest Height Mapping

broad-leaved forest



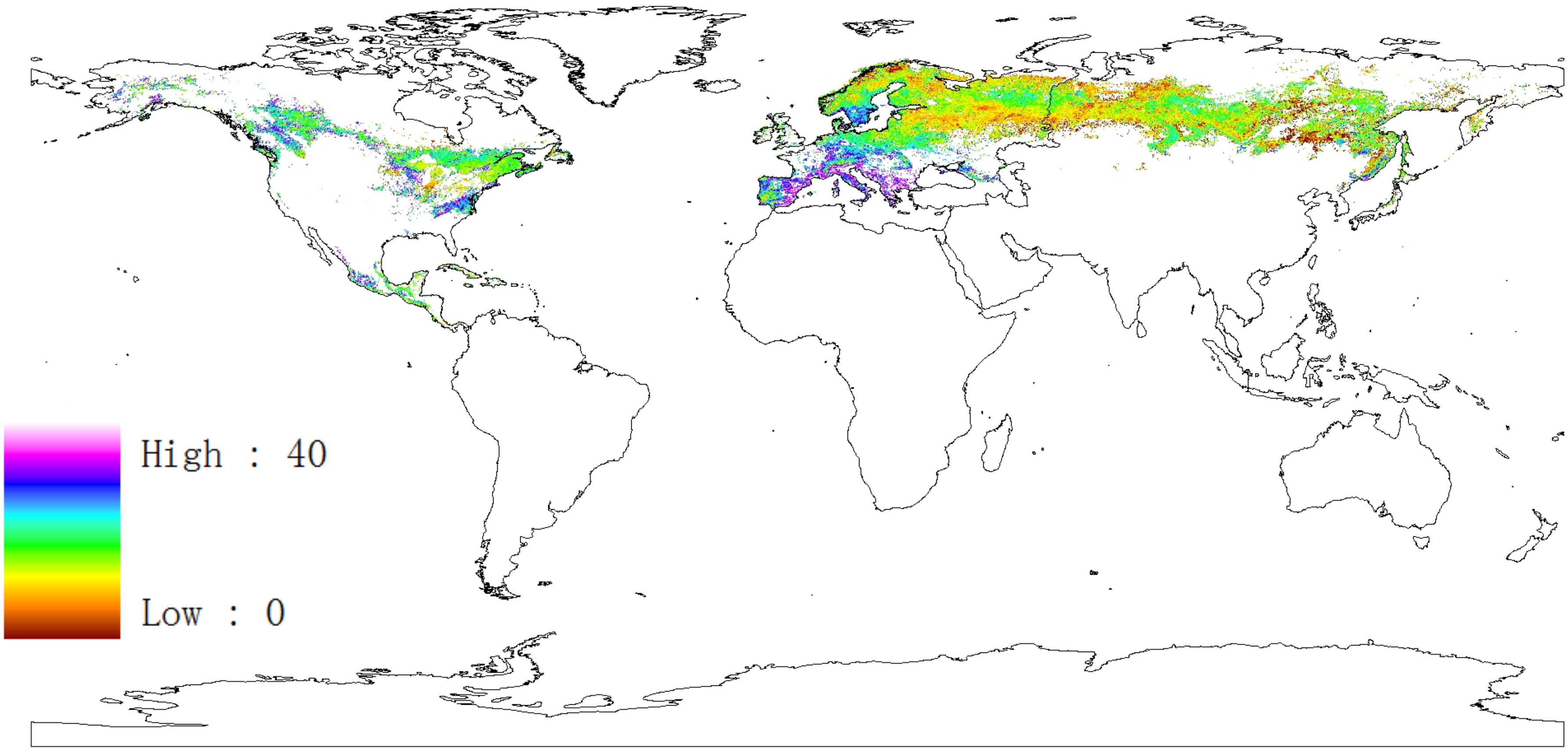
Global Forest Height Mapping

coniferous forest



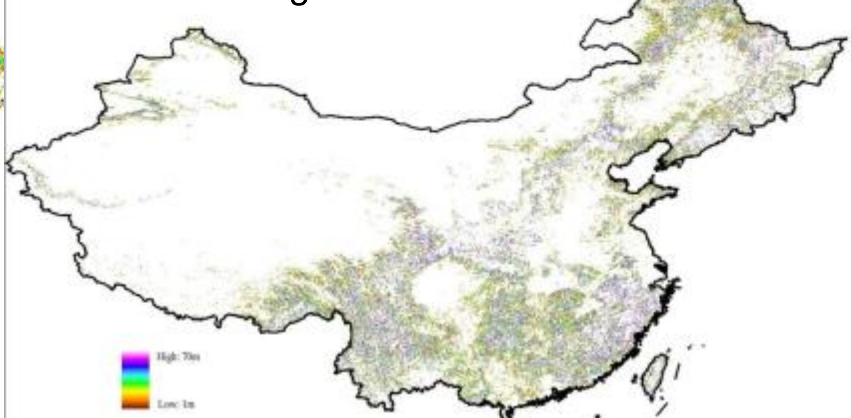
Global Forest Height Mapping

mixed forest

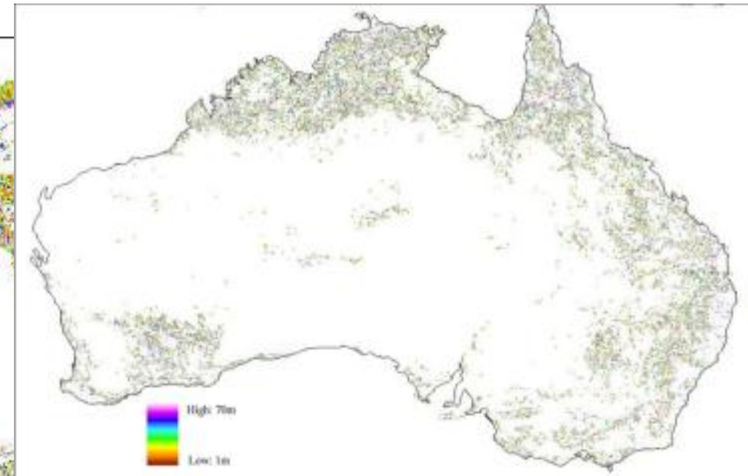


Global Forest Height Mapping

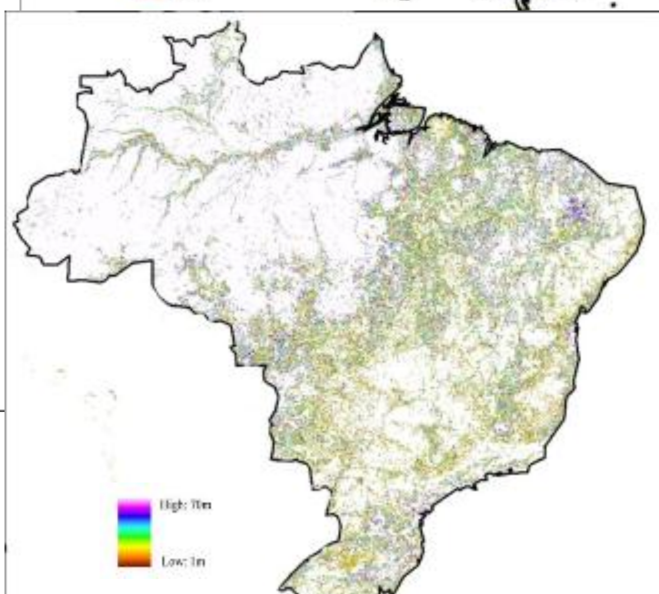
Composited FH map



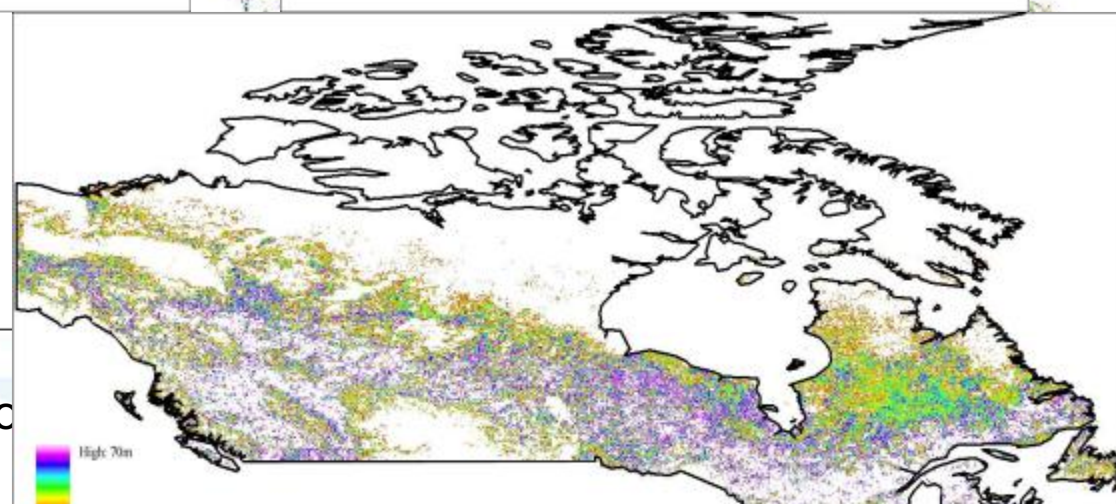
Mean Plant Height of China（2008/02）



Mean Plant Height of Australia（2008/02）



Mean Plant Height of Brazil（2008/02）



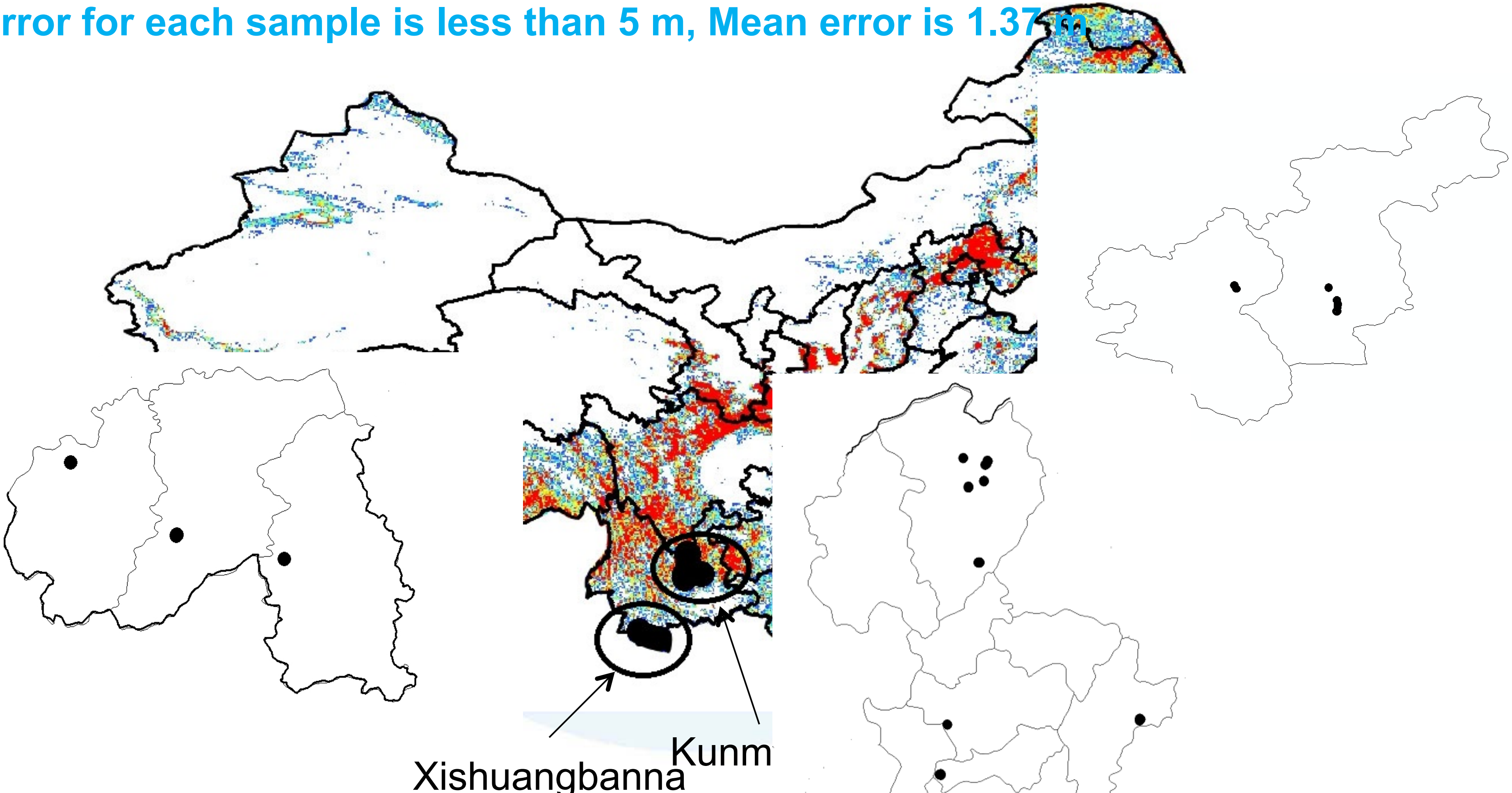
Mean Plant Height of Canada（2008/02）

Summary

Validation:

Number of samples: 36 (Xishuangbanna: 8; Jilin: 8; Kunming: 20)

Error for each sample is less than 5 m, Mean error is 1.37 m.



The good result has been obtained in China test sites, but, more validation are needed on global scale.

Conclusion and future work

Conclusion:

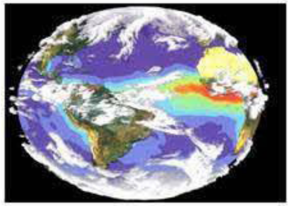
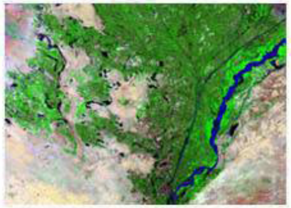
1.All proposed methods show very promising result, but, more validation are needed.

Future work:

1. More optimized sparse basis and the extension of CS-POL-TOMOSAR algorithm from multi-polarization case to polarimetric case are will be proposed, and more validation are needed to conduct,
2. The GLAS forest height mapping result expected to be validated out of China test site, and then global biomass estimation will be conducted in the next steps.
3. The biomass estimation method integrated LIDAR and SAR datasets will be conducted in the future.

Thanks !



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