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Analyzing the Surface Height of Nam Co by using CryoTrack

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Abstract

In recent decades, the global climate change is increasingly accelerating and intensifying. The plateau climate is an important part of the global climate. In this thesis, we will take the plateau lake Nam Co as an object to research and analyze the climatic variation in this area. Since Nam Co is located in Tibet Plateau with a high elevation and it doesn't have too much human disturbance, it is an ideal study object to observe. In this thesis, we will use the data from the satellite CryoSat-2 and the software CryoTrack to obtain the surface height of Nam Co as well as the trend of the water level variation of it. Meanwhile, by using CryoTrack we can also observe the frozen and breakup time of the lake ice.

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3.28 04-22-2014 32
3.29 05-08-2014 32
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Chapter 1

Introduction

1.1 Introduction of Nam Co

Nam Co (30°.42E, 90°.33N) is an endorheic lake located in Qinghai-Tibetan plateau (25°–40°E, 74°–104°N, average elevation 4000–5000 m), southwest China. It is the second largest lake in Tibet as well as the third largest saltwater lake in China. It has a surface area of about 1982 km^2, 78.6 km long along east-west direction, 24.9 km wide along north-south direction. Nam Co is surrounded by mountains and hills, to the south of it there is the Nyenchen Tanglha Mountains (average elevation 6000 m), on its east there is the Gangdise Mountains (elevation 5500–6000 m) and on the north and west is hilly area.[11] The glacial melt water as well as the precipitation are the main water recharge of Nam Co. The Nam Co basin area is cold all year round, there is a long meteorological winter and no meteorological summer. The weather of this area can change abruptly, the sudden snowstorm happens commonly.[14]

1.2 Introduction of CryoSat-2

CryoSat-2 is an environmental research satellite of ESA. Its mission is to measure the thickness of polar sea ice and to monitor the variations in the extent of ice sheet that cover the Greenland and Antarctica. The satellite was launched on 8 April 2010 to replace the satellite CryoSat, which lost due to a launch failure in October 2005.[7] CryoSat-2 satellite has a mass of 720 kg (incl. 37 kg fuel) and a dimension of $4.6 \cdot 2.4 \cdot 2.2\ m^3$, it flies in a low earth orbit at an altitude of 717 km, inclination of 92°, non-sun-synchronous. Its repeat cycles is 369 days with a 30 days sub-cycle.

It is designed to monitor the most dynamic area of earth's cryosphere. It measures the ice sheet altitude and freeboard. Comparing with other earth-observing radar, with the synthetic aperture radar and interferometry techniques, the accuracy of measurement over rugged ice sheet margins and sea ice in polar waters has been increased.[1]

1.2.1 Primary Satellite Payload

The primary payload of CryoSat-2 is the SAR Interferometric Radar Altimeter (SIRAL). It is an altimeter system for the ice sheet interiors, sea ice, ice sheet margins and other topography.

Previous radar altimeters concentrated on measuring over land and ocean, SIRAL is the first altimeter that is designed for ice, besides the ability to detect tiny variations in the height of the ice, it is also able to measure sea level with a high accuracy.[7]

In principle, it measures the time delay in receiving reflected signals from ground facets scanned by the passed over instrument. The Geophysical elevation will be corrected regarding to precise orbit parameter and path delays. The radar pulse length and the amount of averaging determines the height precision. The height is defined as the minimum range between the scatters and the radar which lies along the ground track of the satellite.

SIRAL has three operating modes:

1. Low resolution mode (LRM) for the ice sheet interiors and ocean.
2. Synthetic aperture (SAR) operation for sea ice.
3. Dual-channel synthetic aperture/interferometric (SARIn) operation for ice sheet margins.[8]

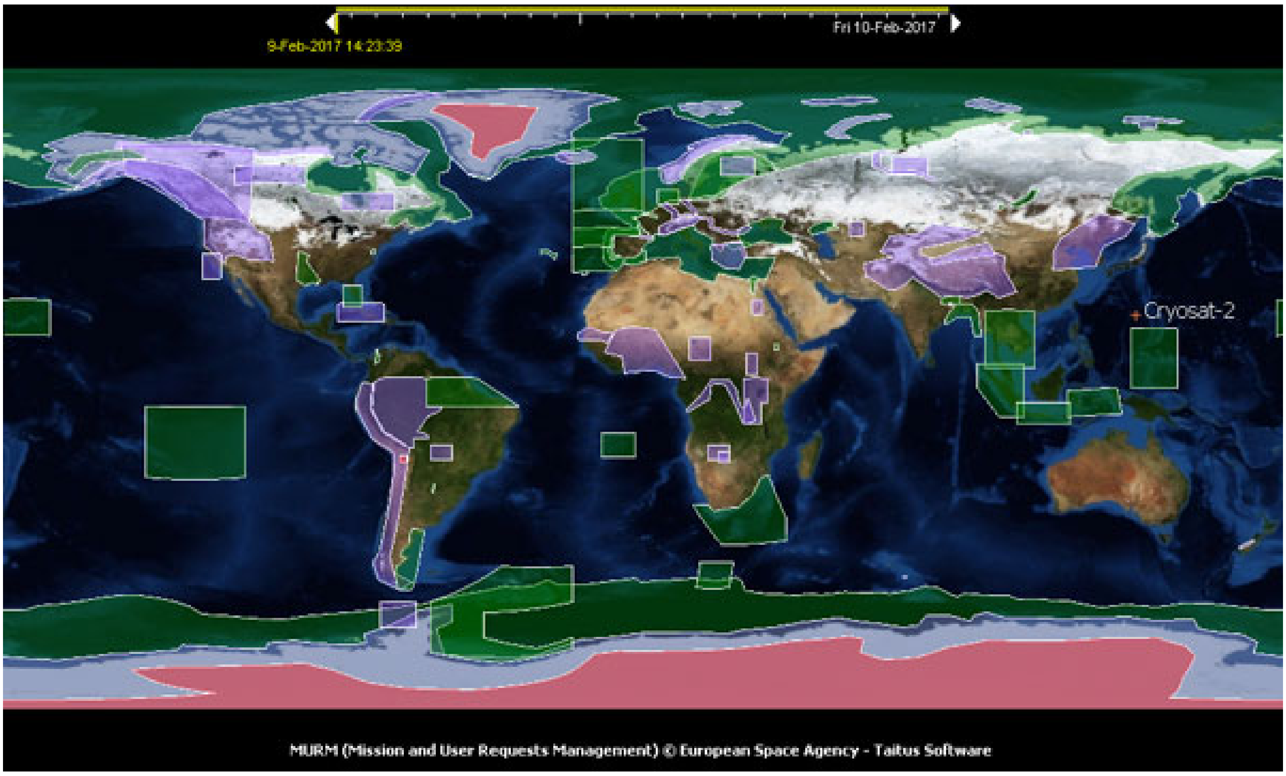

Figure 1.1: *Geographical Mode Mask*

For each measurement of the earth's surface CryoSat-2 will be operating in different mode. The choice is depending on the instrument status and current operational geographical mode mask. As the mode mask above shows, in the area of Nam Co only SARIn mode (or SIN mode, for short) is available. The SIN mode improves the altitude estimates over ice sheets.

During flying, CryoSat-2 will switch three measurement modes automatically according to the geographic mode mask. SAR mode (green zone) will be used over sea-ice areas, some ocean basins and costal zones. SIN mode (purple zone) will be operated over small ice caps and areas of mountain glaciers or precipitously sloping ice-sheet margins as well as some major hydrological river basins. LRM mode will be applied over continental ice sheets (red zone), oceans and land which has no other modes covered yet.

Moreover, CryoSat-2 also carries a radio receiver named Doppler Orbit and Radio Positioning Integration by Satellite (DORIS) and a small laser retroreflector to guarantee that the position of the CryoSat-2 will be precisely tracked. Additionally, three star trackers measure the orientation of the baseline. It also carries a small laser retroreflector.[10]

Chapter 2

Data Processing

2.1 CryoSat-2 Data

2.1.1 L2-Data Record

The CryoSat-2 data products are distributed by FTP. The level-2 GDR (Geophysical Data Record) is the main user product. It satisfies most needs of scientific researches. The time of measurements, the geolocation and the altitude above the reference ellipsoid will be recorded in GDR. The error such as instrument effects, propagation delays, measurement geometry, atmospheric and tidal effects will be totally corrected. GDR includes LRM, SAR and SIN mode. All the measurements of different modes are connected and will be ordered in correct time and presented in the same record format.[2]

The sampling frequency of L2 data is about every second. Each record includes a block of 20 higher rate measurements. Each L2 product is about 4948 seconds long.

2.1.2 File Structure

CryoSat-2's products consists of two files: a XML header file (.HDR) and a product file (.DBL). For most users the DBL files is enough for scientific use without HDR files.

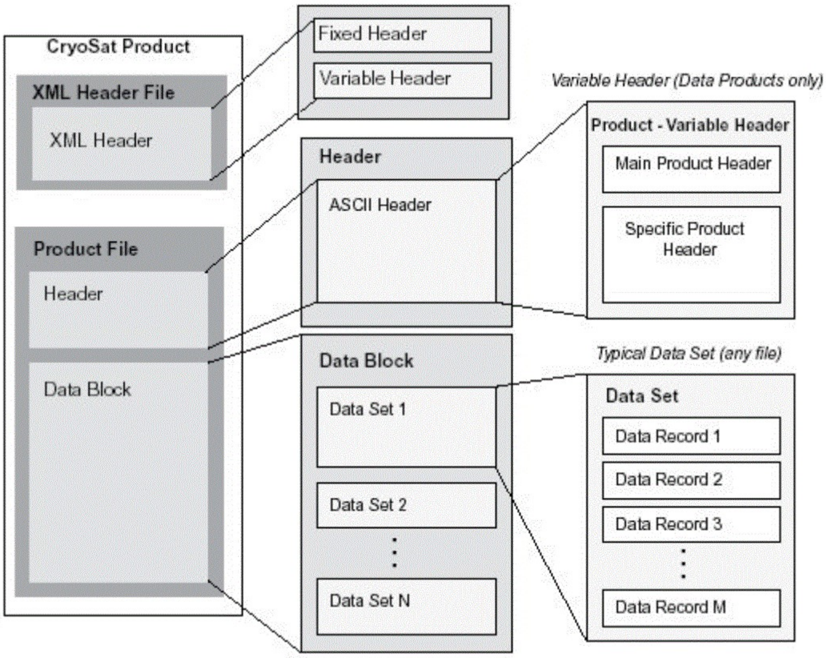

Figure 2.1: *Product File Structure*

2.1.3 File Naming Convention

The construct of the file name is a conventional form based on the standard guidelines for Earth Explorer missions. The format is as follows:

```
MM_CCCC_TTTTTTTTTT_yyyymmddThhmmss_YYYYMMDDTHHMMSS_vvvv.ttt
```

Where:

File type	Description
SIN_LRM_1B	SIRAL LRM level 1b
SIR_FDM_1B	SIRAL FDM level 1b
SIR_SAR_1B	SIRAL SAR mode level 1b
SIR_SIN_1B	SIRAL SIN mode level 1b
SIR_LRM_2_	SIRAL LRM level 2
SIR_FDM_2_	SIRAL FDM level 2
SIR_SAR_2A	SIRAL SAR mode level 2 without ice freeboard measurements
SIR_SAR_2B	SIRAL SAR mode level 2 with ice freeboard measurements
SIR_SIN_2_	SIRAL SIN mode level 2
SIR_SID_2_	SIRAL degraded SIN mode level 2
SIR_GDR_2A	SIRAL geophysical data record without ice freeboard measurements
SIR_GDR_2B	SIRAL geophysical data record with ice freeboard measurements

Table 2.1: *File Type*

Abbreviated letters	Description
MM	the mission identifier, which is CS for CryoSat.
CCCC	file class, for example OFFL (Off-Line Systematic Processing), NRT (Near Real Time), RPRO (ReProcessing), TEST (Testing), LTA (Long Term Archive).
TTTTTTTTTT	file type as listed below.
yyyymmddThhmmss	start time window as extracted from Job Order.
YYYYMMDDTHHMMSS	stop time window as extracted from Job Order.
Avvv or Bvvv	the version number of the file. "A" accords. with IPF1 version J and IPF2 version I or previous versions. "B" accords with IPF1 version K and IPF2 version J.
ttt	the extension: tgz for a gzipped tar file, HDR for an extracted header and DBL for extracted binary data.

Table 2.2: *Description of Abbreviated Letters of File Name*

2.1.4 Other Conventions

1. Latitude and longitude limits. The range of longitude $\lambda \in$ [-180°,180°)

2. Range correction sign convention

Since:
Satellite altitude − range measurement = surface height
Follows:
Satellite altitude − (range measurement + ionospheric correction) = surface height corrected for the ionosphere effect.

2.1.5 Timestamp Format

Each timestamp is expressed as 3 integers:

Time	Format
Day:	signed long integer
Seconds-of-day:	unsigned long integer
Microseconds:	unsigned long integer

Table 2.3: *Timestamp Format*

The time in the main and specific product headers is in UTC not in TAI.

Time corrections between UTC and TAI are provided via the orbit files and account for the correct offsets due to leap seconds. To be specific, 1st Jan 2000 at 00:00 UTC = 1st Jan 2000 at 00:32 TAI.

2.2 Cryoread

ESA provides the Matlab functions to read the L1b, L2 and L2I CryoSat products. The matlab functions will read the DBL data and will output 2 structs with all the CryoSat data and annotations. But with CryoSat the DBL data can only be read one by one. To improve the efficiency of the data read, the Matlab function CryoSeqRefMat has been created.

The CryoSeqRefMat function will read all DBL files of a folder i.e. all DBL files of a month. The matlab function is as follows:

```
CryoSeqRefMat(mode,year,month,L2path)
```

To run this matlab function, the mode, year, month and the folder address of data should be given.

For example:

```
CryoSeqRefMat('SIN',2010,07,'C:\Users\Documents\CryoSat\Data\')
```

After running the CryoSeqRefMat function, a reference matrix will be created, it contains the longitude and latitude data of every track of a month. The longitude and latitude are compressed to 0.2 Hz. Therefore, the CryoTrack can use it to plot the tracks quickly. The reference matrix will be saved as a MAT-file, named as followed convention:

Ref02Hz_⟨*mode*⟩_⟨*year*⟩_⟨*month*⟩.mat

The running of CryoSeqRefMat lasts a few minutes for each month of files.

2.3 CryoTrack

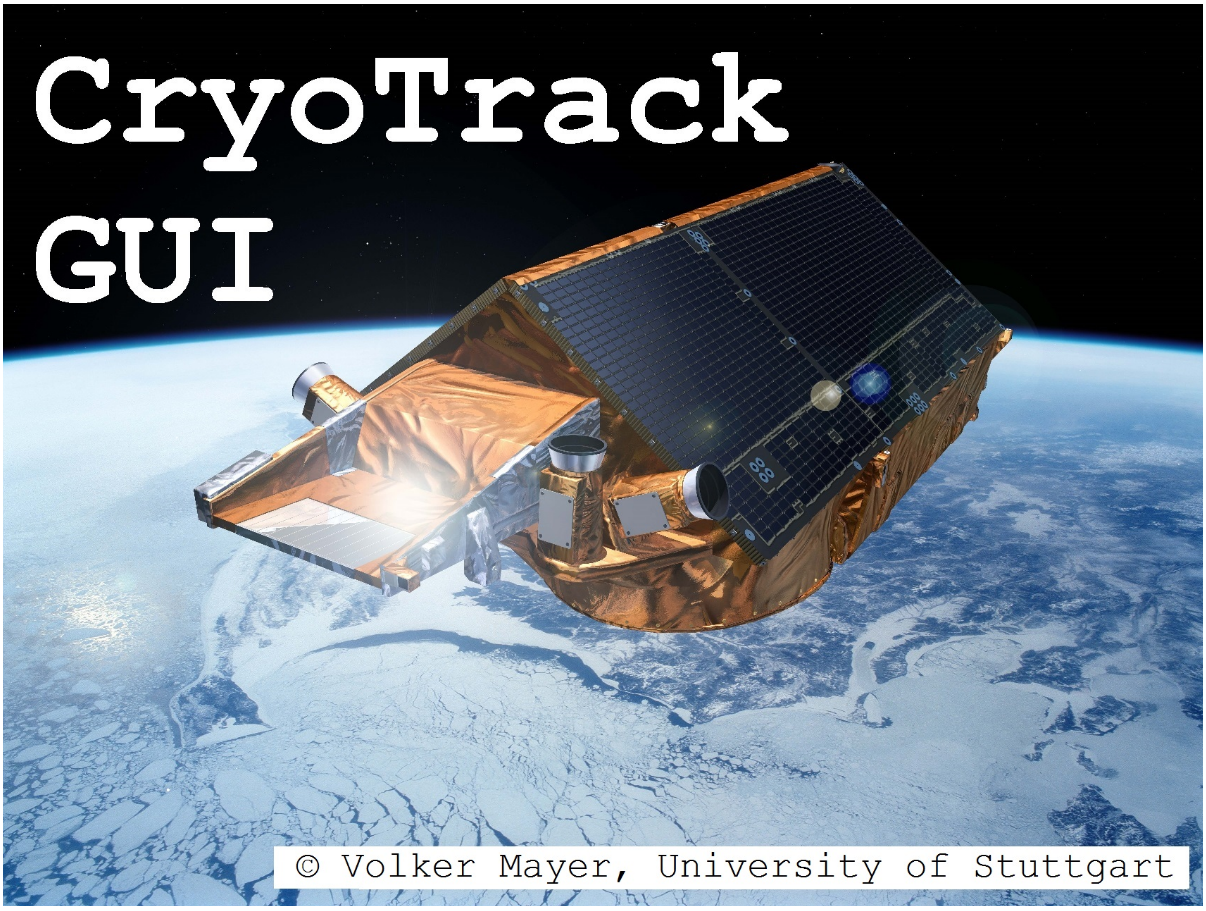

Figure 2.2: Cover of CryoTrack

The program CryoTrack is developed to simplify the use of CryoSat-data for hydrological purposes.[15] It is a GUI program base on MATLAB. It provides all three SIRAL modes for users. By inputting the L1b or L2 data of CryoSat-2 and selecting the location of the water area as well as the month and year, with the pre-existing reference matrix the GUI program will show the surface height, peakiness and backscatter of the selected track of CryoSat-2 in this area. In this thesis the mode SIN and the Shapefiles "Lakes" will be selected.

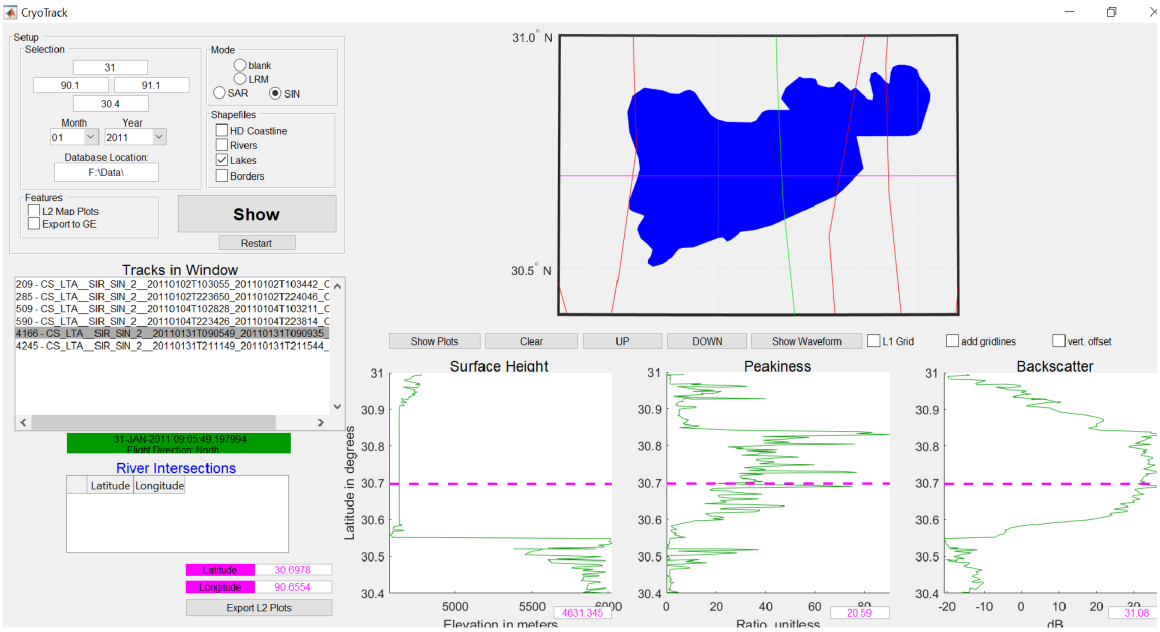

Figure 2.3: *GUI Panel of CryoTrack*

As we can see in the figure 2.3 above, the blue area represents the lake Nam Co. As an example, in January 2011, there are 4 tracks that flew over Nam Co. As we select a track in left panel "Tracks in Window", the selected track will turn green, by clicking the button "Show Plots" the three graphs will be plotted. By pressing the button "up" and "down", the pink dotted line will thereupon move up and down and the current surface height, peakiness and backscatter values as well as the latitude and longitude will be shown.

The data from January 2011 to December 2015 will be processed with CryoTrack. Every month we can find 0–4 tracks. Because of the sparsity of the tracks, the surface height that we received from CryoTrack is sparse too. There could be measurement errors to effect the result of the measurement.

Chapter 3

Data Analysis

3.1 Example of CryoTrack

For example, the figure 3.1 is plotted direct by CryoTrack. It shows the result from track No. 4166 from January 2011. We can see that there is a smooth straight line between latitude 30.6° to 30.9°, this section is supposed to be the section within the lake area. With the help of the pink dotted line in the shapefile panel we can determine the latitude range of the track to pick up the measured surface height of the lake Nam Co manually.

To visualize the surface height variation over time, a time-varying surface height diagram is provided.

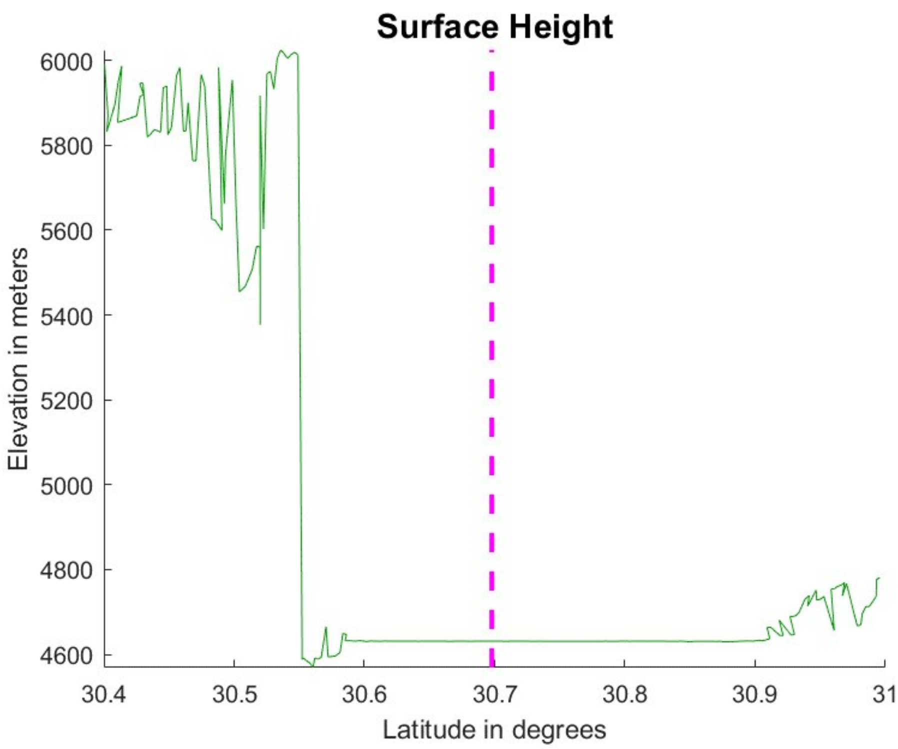

Figure 3.1: *Example Figure of CryoTrack*

3.2 Median and arithmetic Mean

3.2.1 Median

The median is the middle value which separates the higher half of data from the lower half of data. The advantage of using the median as the typical value of a data is that it is not affected by extreme values. From January 2011 to December 2015 we can find 98 tracks that flew over Nam Co, on average there are 1–2 tracks per month. In every track there are dozens to hundreds of measurements of surface height. To build a time-varying surface height diagram, the median of those measurements from each track is picked out. Using the CryoRead function we can find out the exact timing of the surface height.

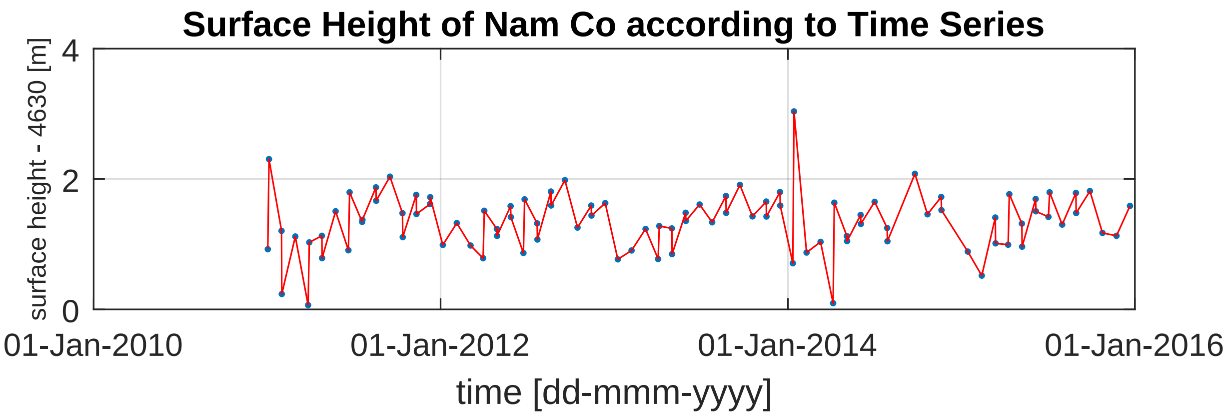

Figure 3.2: *Surface Height according to Time Series*

From the result we can see that most of data are in the range between 4630.5 m to 4632.5 m. The diagram shows a periodic undulation. According to that, we can suppose that the water level of Nam Co presents seasonal and even regular fluctuation.

There could be many sources of errors in the result and it could be caused by plenty of reasons. For example, the error might be caused by wind waves over the lake surface or by ice over the lake during winter. Also, the snow that covers the lake surface will influence the surface height of Nam Co.

3.2.2 Arithmetic Mean

The arithmetic mean is the most common and understandable method to report central tendencies. Assuming a dataset x with n values $x_1, x_2, x_3, ..., x_n$. The arithmetic mean $\overline{x}$ is defined by the formula below:

$$\overline{x} = \frac{1}{n} \sum_{i=1}^{n} x_i \tag{3.1}$$

$$x_i = \frac{x_1 + x_2 + x_3 + ... + x_n}{n} \tag{3.2}$$

Figure 3.3 shows the mean value of surface height.

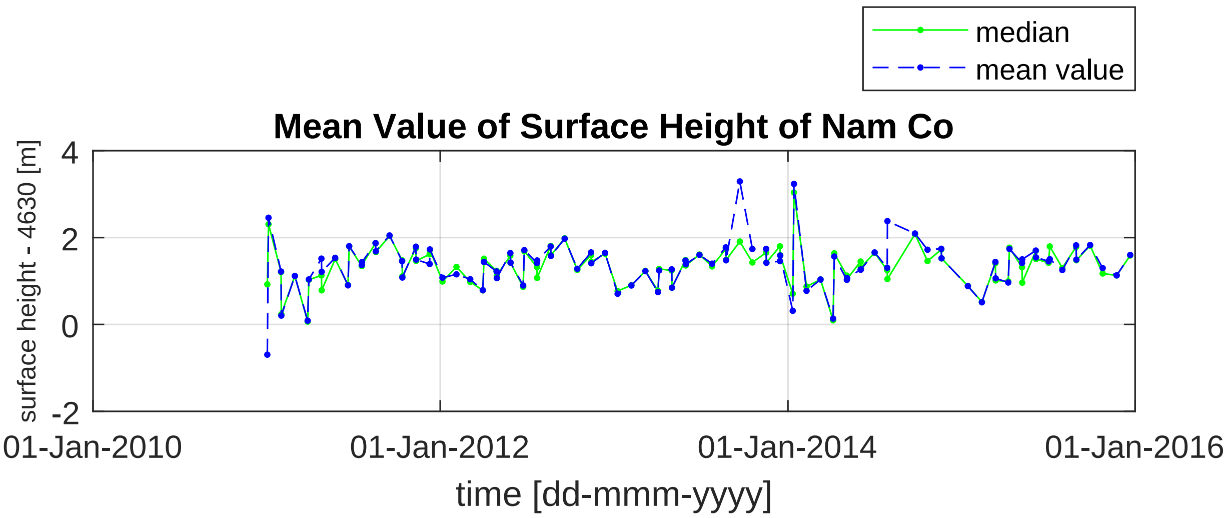

Figure 3.3: *Mean Value of Surface Height of Nam Co*

Comparing the mean with the median we can see that the mean of surface height seems to have more extreme values.

3.3 Standard Deviation

Standard deviation is a widely used robust measure that represents the degree of dispersion of a data, namely the variation of the data around the mean value. It is the square root of the variance of a data. For a data $x = \{x_1, x_2, ..., x_n\}$, the formula to calculate the standard deviation is defined as:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \overline{x})^2}{n-1}} \tag{3.3}$$

Where:

n : Amount of the data.
$\overline{x}$: Mean value of the data.

A low standard deviation means that the data are close to the mean value. On the contrary, a high standard deviation shows that the data are distributed in a wide range.

In this thesis, the standard deviation of every track of data has been calculated and plotted.

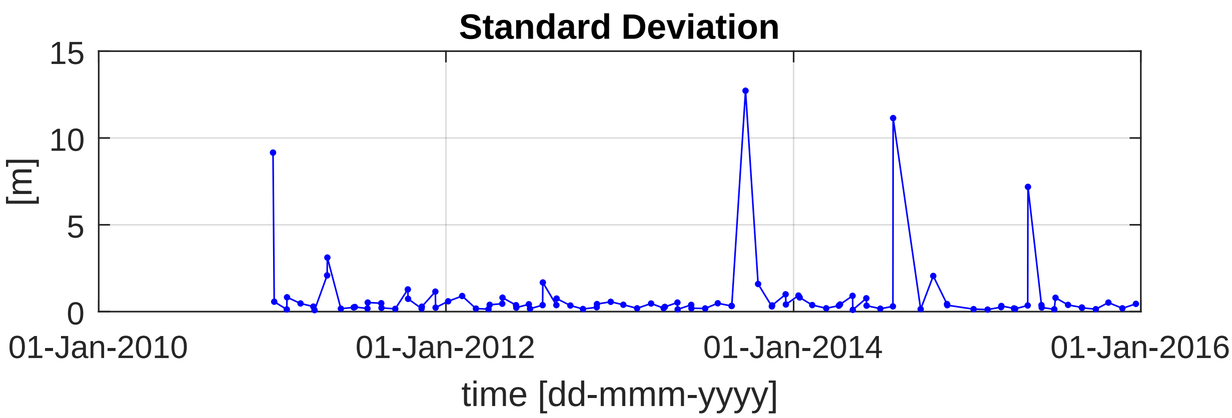

Figure 3.4: *Standard Deviation of Raw Data*

3.4 Outlier Rejection

As we can see from the figure 3.4, most of the standard deviations are in the range [0,1], which means that the measurement of those data are good. But several standard deviation are quite big. There are many methods to reject the outliers, in this thesis we will use Grubbs's test to reject the outliers.

3.4.1 Grubbs's Test

Grubbs's test named after Frank E.Grubbs, who published the test in 1950, also known as the maximum normalized residual test or extreme studentized deviate test, is a statistical test used to detect outliers in a univariate data set assumed to come from a normally distributed population.[5] It is defined for the hypothesis:

$$\begin{aligned} \mathrm{H_0}: &\quad \text{There are no outliers detected in the data set.} \\ \mathrm{H_a}: &\quad \text{There is exactly one outlier in the data set.} \end{aligned}$$

The Grubbs's test statistic is defined as:

$$x_i - \overline{x} = s \cdot G_i \tag{3.4}$$

Find the right critical value $G_p(i)$, the critical value can be calculated through the formula[4]:

$$G_{\text{crit}} = \frac{i-1}{\sqrt{i}} \sqrt{\frac{t^2_{\frac{\alpha}{2i}, i-2}}{N - 2 + (t_{\frac{\alpha}{2i}}, i-2)^2}} \tag{3.5}$$

Where:

Abbreviations	Description
$\overline{x}$	mean value of the sample.
s	standard deviation of sample.
i	amount of the sample.
α	the significance level, in this thesis we will take the value 0.05a
$\mathrm{t}_{\frac{\alpha}{i-2}}$	the upper critical value of a t-distribution with $i-2$ degrees of freedom.

Table 3.1: *Abbreviations of Grubbs's Test*

To determine whether the outlier should be rejected or not, we must compare the G test statistic to the G critical value:

Hypothesis	Description
$\mathrm{G_{test}} < G_{\text{crit}}$	The data is not an outlier
$\mathrm{G_{test}} > G_{\text{crit}}$	The data is an outlier and should be rejected

Table 3.2: *Hypothesis of Grubbs's Test*

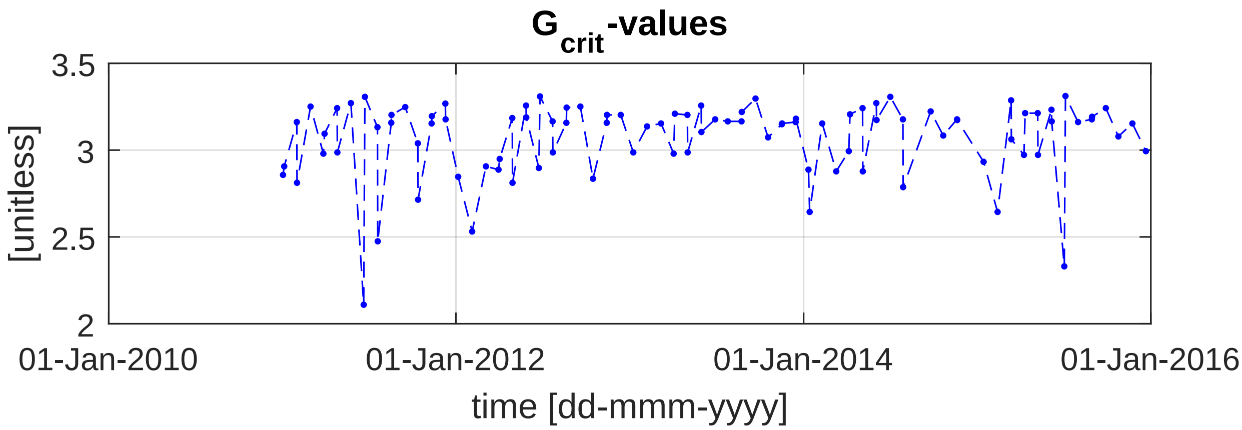

Figure 3.5: *G_{crit} Values*

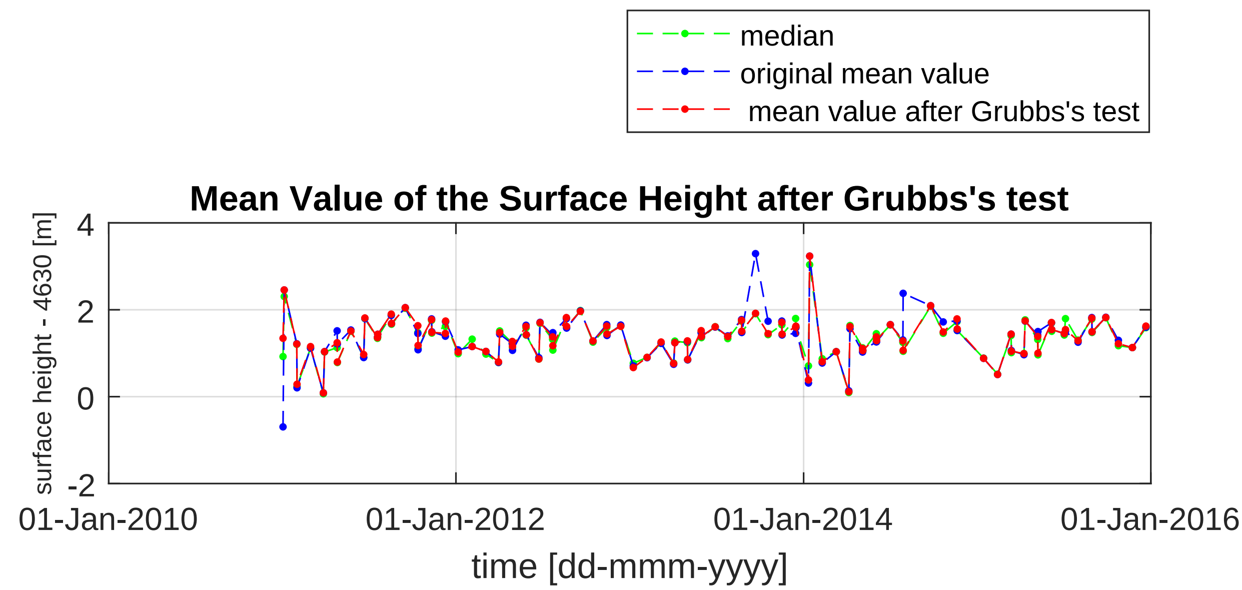

Figure 3.6: *Mean Value of Nam Co after doing outlier rejection*

From figure 3.6 we can see that several mean values have been corrected by outlier rejection.

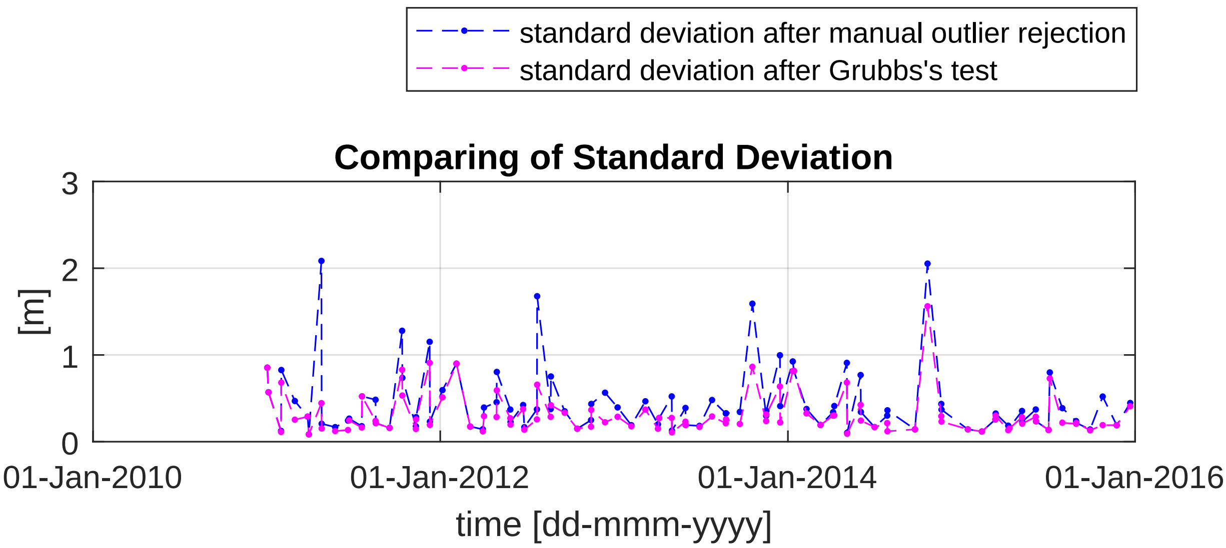

Figure 3.7: Comparing of Standard Deviation

We can see after Grubbs's test the standard deviation has been apparently decreased.

3.5 Root Mean Square

The root mean square (abbreviated RMS) is defined as the square root of mean square. For a data set of n values $[x_1, x_2, , x_n]$, the formula of calculating RMS is defined as:

$$RMS(x) = \sqrt{\frac{1}{n}(x_1^2 + x_2^2 + ... + x_n^2)} = \sqrt{\frac{29}{30}}\sigma \quad (\text{if } \overline{x} = 0) \tag{3.6}$$

It is also a way to show the typical value of a dataset with many values. Same as above, the RMS of all datasets has also been calculated.

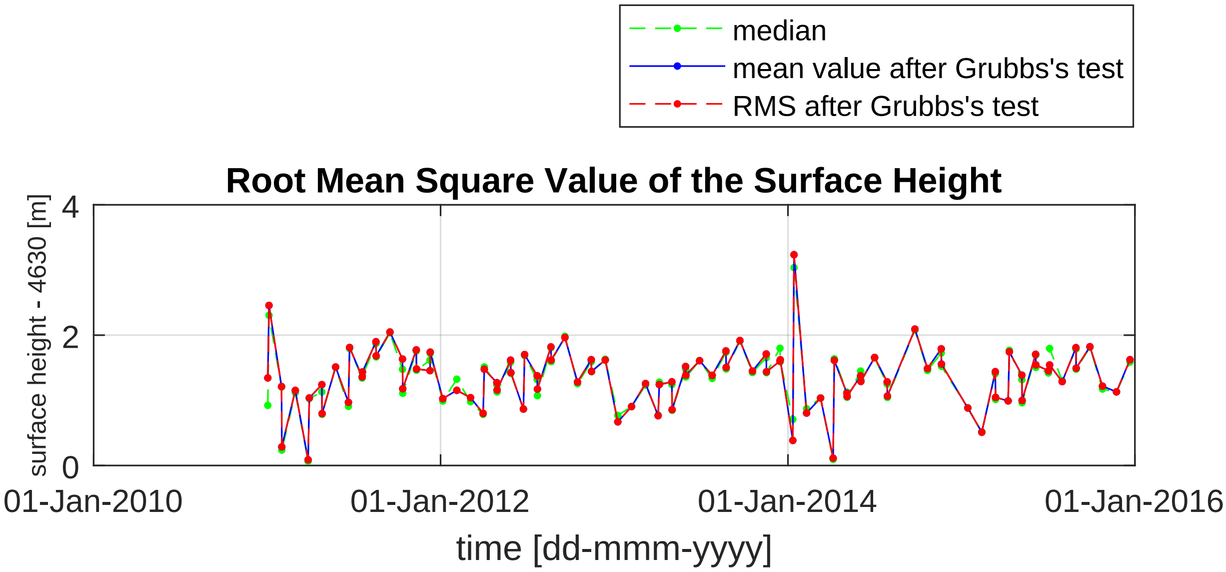

Figure 3.8: *Root Mean Square of Surface Height of Nam Co*

It can be seen that the values of the corrected root mean square and the corrected mean are very close. That means the result of the Grubbs's test is good. There is no more extreme values in the time-varying surface height.

3.6 Fitting

Since the surface height of Nam Co is measured during 5 years, it is possible to analyze the trend of the water level variation of the lake by fitting.

3.6.1 Least Squares Method

Least squares method is a common way to help people finding the best approximation of discrete data. It provides a good linear fitting for the time-varying surface height. The principle is to minimize the sum of the squares of the offsets. Supposing the time coordinate is the independent variable and the surface height is the dependent variable, the formula of least square method can be defined as:

$$h = a + b \cdot t \tag{3.7}$$

$$\begin{bmatrix} h_1 \\ h_2 \\ \vdots \\ h_n \end{bmatrix} = \begin{bmatrix} 1 & t_1 \\ 1 & t_2 \\ \vdots & \vdots \\ 1 & t_n \end{bmatrix} \begin{bmatrix} a \\ b \end{bmatrix} \tag{3.8}$$

The calculation process is defined as: [12]

$$y = Ax + e \tag{3.9}$$

For the unknown e we have the equation:

$$y = \hat{y} + \hat{e} = A\hat{x} + \hat{e} \tag{3.10}$$

Left multiply matrix A′ by both sides of the equation follows:

$$A'y = A'A\hat{x} + A'\hat{e} = A'A\hat{x} \tag{3.11}$$

Because A is orthogonal to the product, therefore:

$$A'\hat{e} = 0 \tag{3.12}$$

The least square estimate of x turns out to be:

$$\hat{x} = (A'A)^{-1}(A'y) \tag{3.13}$$

The least square estimate of y is:

$$\hat{y} = A\hat{x} \tag{3.14}$$

The figure 3.9 below shows the result of linear fitting.

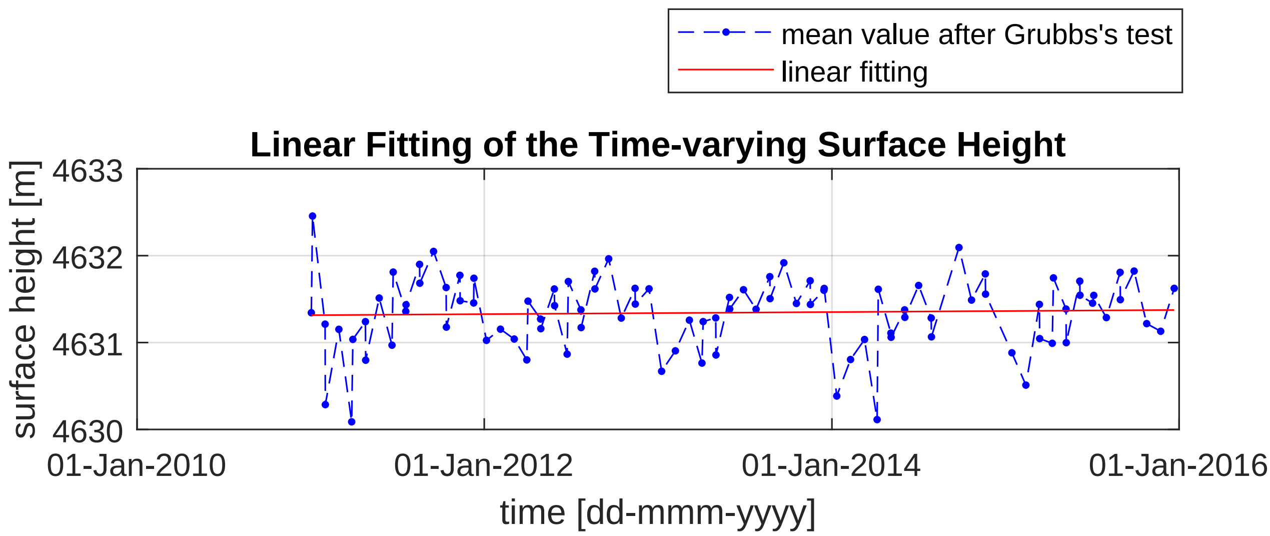

Figure 3.9: Linear Fitting of Mean

By observing the slope from figure 3.9 the water level of Nam Co has slightly raised during 2011-2015. The result of the linear fitting is:

$$h = 0.00004791 \cdot t + 4596.1281 \tag{3.15}$$

Base on the linear fitting result the Surface of Nam Co has raised for about 9 cm during 5 years.

According to the previous research and monitoring about Nam Co, in the past decade the area of Nam Co has increased 79.4 km^2.[16] The glacial melt-water from Nyenchen Tanglha Mountains and the increased precipitation might be the main reasons.

The least square method can also be used to do the seasonal fitting. It is defined as follows:

$$h = a + b \cdot t + c \cdot \cos \omega t + d \cdot \sin \omega t \tag{3.16}$$

$$\begin{bmatrix} h_1 \\ h_2 \\ \vdots \\ h_n \end{bmatrix} = \begin{bmatrix} 1 & t_1 & \cos \omega t_1 & \sin \omega t_2 \\ 1 & t_2 & \cos \omega t_2 & \sin \omega t_2 \\ \vdots & \vdots & \vdots & \vdots \\ 1 & t_n & \cos \omega t_n & \sin \omega t_n \end{bmatrix} \begin{bmatrix} a \\ b \\ c \\ d \end{bmatrix} \tag{3.17}$$

Where: $\omega = \frac{2\pi}{1year}$

The result of the seasonal fitting is as follows:

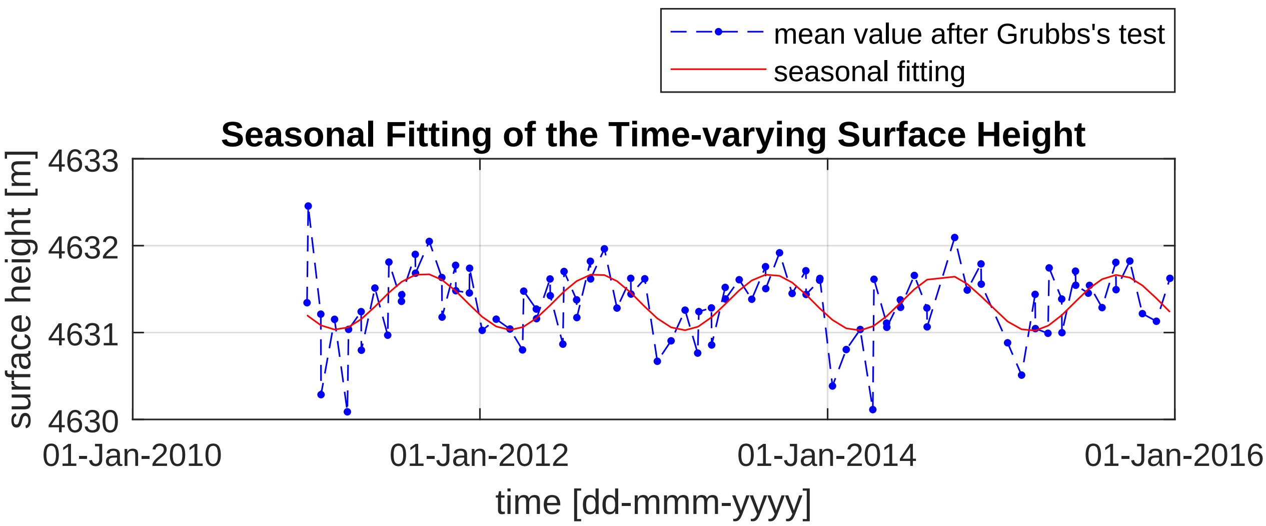

Figure 3.10: Seasonal Fitting of Mean

From figure 3.10 we can see that the surface height of Nam Co has a regularly periodic fluctuation. The period of the fluctuation is about a year. Usually, the surface height of Nam Co peaks in September and October and hits the bottom between March and April.

The result of the seasonal fitting is:

$$h = 4620.825 + 0.0000143 \cdot t + 0.299 \cdot cos\omega t + 0.11 \cdot sint \tag{3.18}$$

3.6.2 Residual

The residual of an observed value is the difference between the observed value and the estimated value. The residual namely estimate of e is:

$$\hat{e} = y - \hat{y} \tag{3.19}$$

A standardized residual is the residual divided by its standard deviation. Because the standard deviation for residuals in a fitting model can vary to a great extent from point to point, we choose to use the standard residual instead of residual to make the analysis more meaningful. The standard residual of the linear and seasonal fitting are shown as follows:

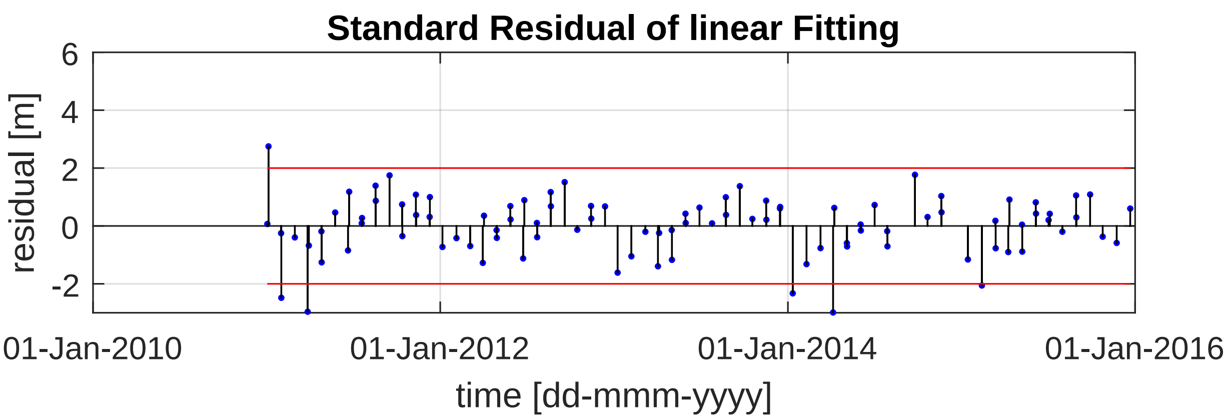

Figure 3.11: *Standard Residual of linear Fitting*

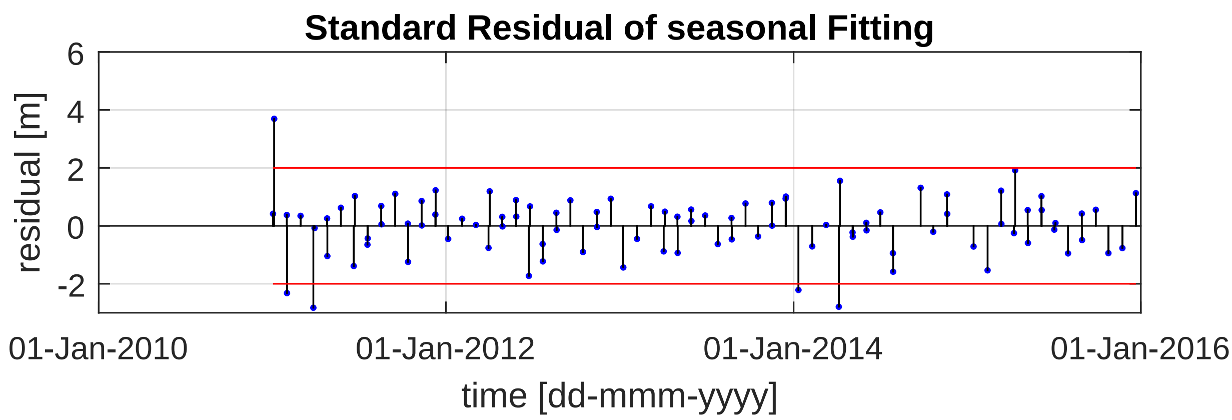

Figure 3.12: *Standard Residual of seasonal Fitting*

As can be seen from figures 3.11 and 3.12, it turns out that more than 95% of the standard residuals are between [-2,2], which means that both linear and seasonal fitting can well and truly represent the trend of the surface height variation.

3.7 Monitoring the Freeze and Breakup Time of the Lake Ice of Nam Co

3.7.1 Backscatter and Peakiness

Backscatter is the portion of the emitted radar signal that is reflected back towards the radar antenna from the target. The normalized measure of the returned radar signal is the backscatter coefficient σ_0. It is defined as the radar cross section per unit area on the ground. It is a function of the radar frequency, polarization and incidence angle and the target surface roughness, geometric shape and dielectric properties. [2] The formula to calculate the backscatter coefficient σ_0 is defined as:[6]

$$\sigma_0 = 10\log(\frac{P_u}{T_{xp}wr}) + 10\log(K) + \text{bias\_}\sigma_0 \tag{3.20}$$

Where:

$$K = \frac{(4\pi)^3 R^4 L_{\text{atm}} L_{\text{RX}}}{\lambda_0^2 G_0^2 A_{\text{SAR}}} \tag{3.21}$$

Where A_{SAR} is the resolution ground-cell in SAR-mode

$$A_{\text{SAR}} = (2 \cdot L_y) \cdot (wf \cdot L_x) \tag{3.22}$$

$$L_y = \sqrt{\frac{c_0 \cdot R \cdot PTR_{\text{width}}}{\alpha_{\text{earth}}}} \tag{3.23}$$

$$L_x = \frac{\lambda_0 \cdot R}{2 \cdot V_s \cdot \tau_B} \tag{3.24}$$

$$\alpha_{\text{earth}} = 1 + \frac{R}{R_{\oplus}} \tag{3.25}$$

$$\alpha_{\text{earth}} = 1 + \frac{R}{R_{\oplus}} \tag{3.26}$$

ITEM	DESCRIPTION	SOURCE/VALUE
R	Range from Satellite CoM to surface reflection point	output of the re-tracker scheme and expressed in meter
Tx_Pwr	Transmitted Peak Power[4]	Field 24 in SAR FBR format structure (and expressed in watts)
L_{atm}	Two Ways Atmosphere Losses	to be modelled and expressed dimensionless in linear scale
L_{RX}	Receiving Chain (RX) Waveguide Losses	to be characterized and expressed dimensionless in linear scale
λ_0	Radar Wavelength	to be extracted from IPF database, and expressed in meter, default value 0.022084 m
c_0	Speed light in vacuum	299792458 m/sec
wf	footprint widening factor[5]	1 in case of no weighting window application and $1.486 \cdot rv$ in case of Hamming window application on burst data[6]
$R_{\oplus}$	Mean Earth Radius	6371000 m
G_0	Antenna Gain at Boresight	10^(4.28): from [RD10] and expressed in linear scale.
PTR_width	3dB Range Point Target Response Temporal Width	to be extracted from IPF database, and expressed in sec, default value 2.819e-09 sec
V_s	Satellite Along Track Velocity	From Field 11 in SAR FBR format structure and expressed in m/sec
τ_B	Burst Length	to be extracted from IPF database, and expressed in sec, default value 0.00352 sec
bias_sigma_0	CryoSat-2 System Bias for sigma nought (dB)	to be defined

Figure 3.13: *Description of Abbreviations*

Peakiness is a measure that shows the sharpness of the peak of an echo. It is defined as the ratio of the highest bin value to the mean value of all bins above the retracking point. A high peakiness indicates a very specular reflection, for example sea ice.

By using CryoTrack we can also plot the backscatter coefficient and the peakiness of every track directly. The value of the backscatter depends on many factors, it is hard to determine the lake ice by only using the backscatter values. On this occasion we will compare the peakiness values with the backscatter values in the analysis.

The backscatter and peakiness are plotted month by month as follows:

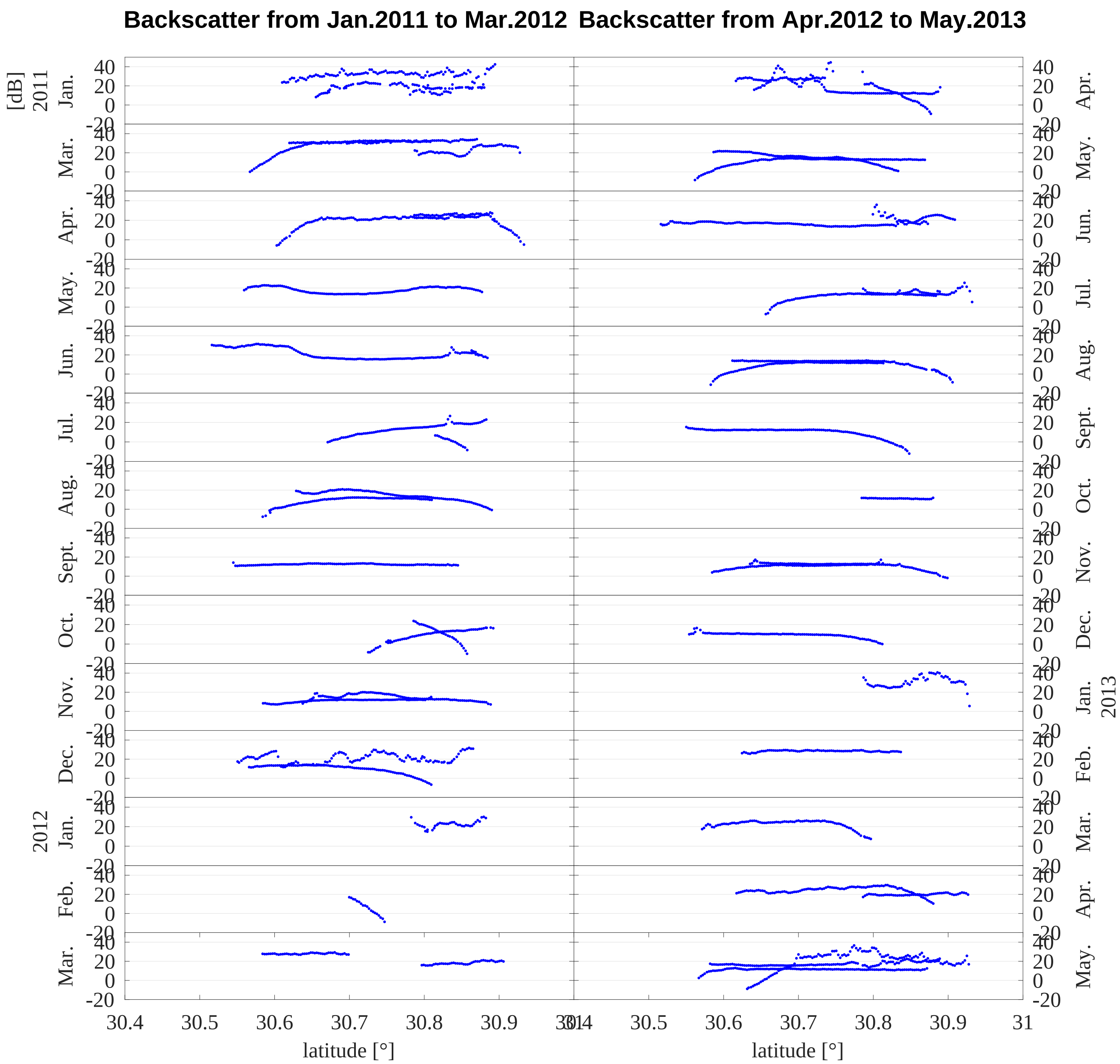

Figure 3.14: *Backscatter Values from Jan. 2011 to May. 2013*

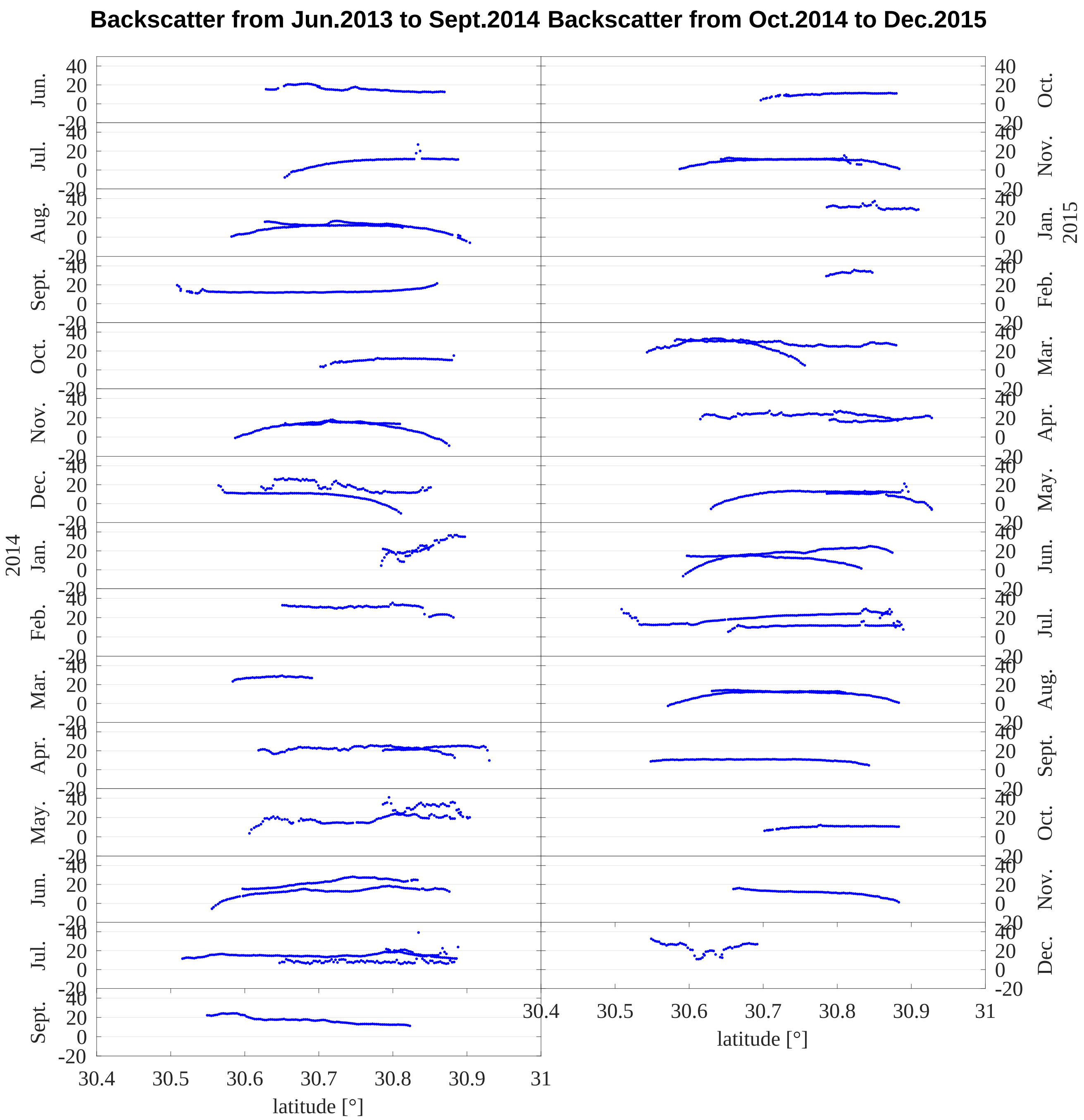

Figure 3.15: Backscatter Values from Jan. 2013 to Dec. 2015

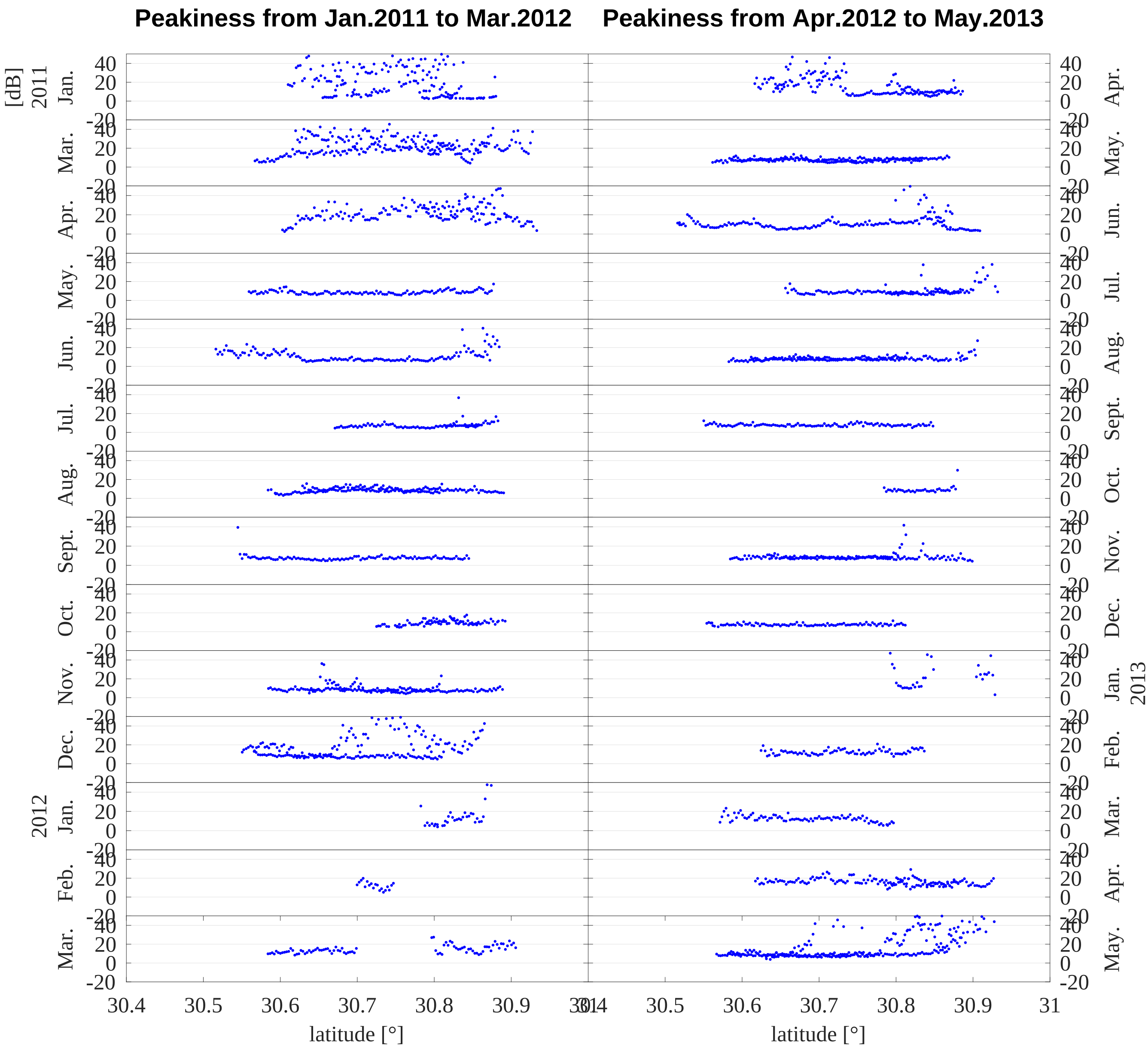

Figure 3.16: *Peakiness Values from Jan. 2011 to May. 2013*

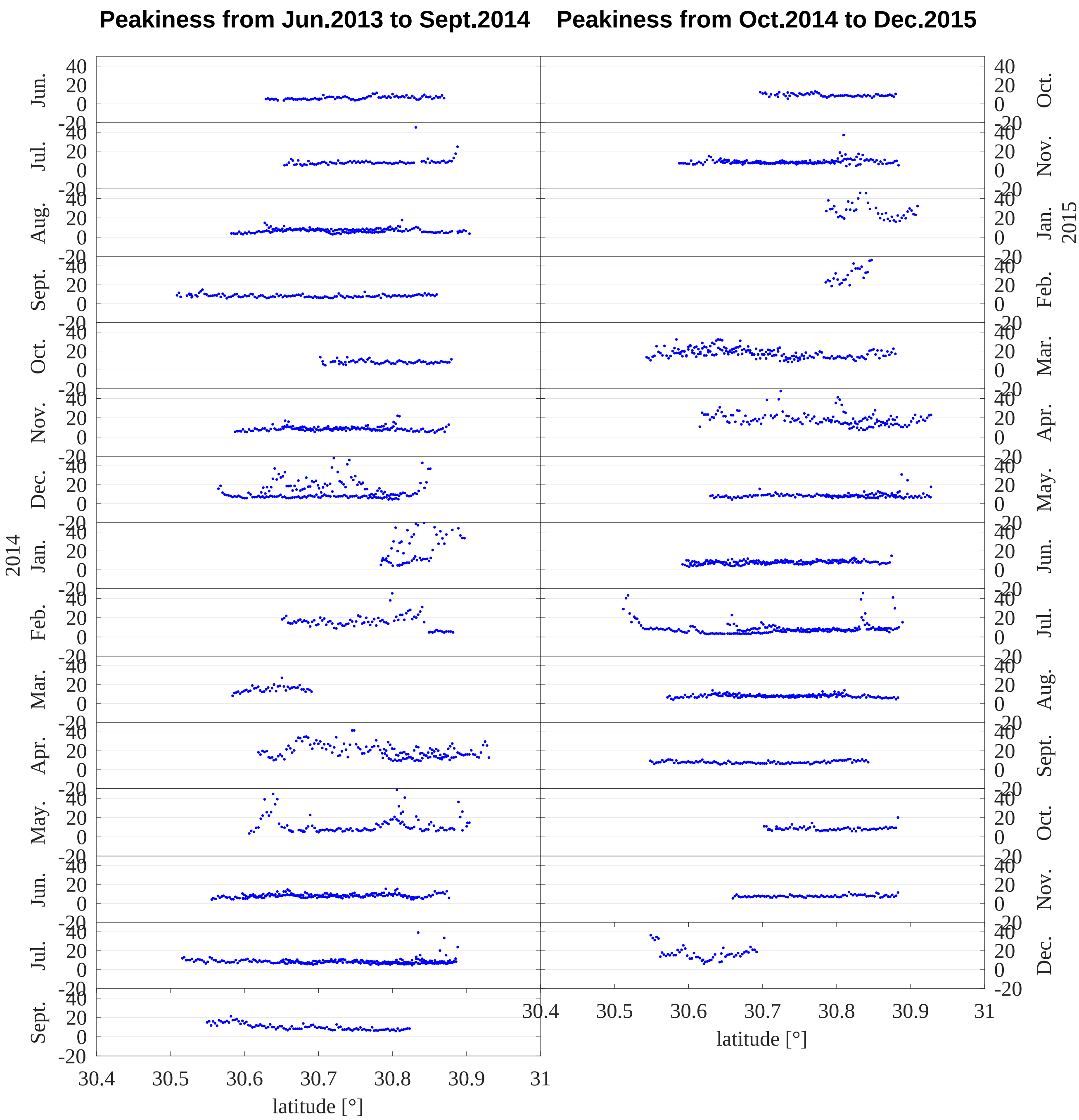

__Figure 3.17:__ Peakiness Values from Jan. 2013 to Dec. 2015

3.8 Analyzing the freeze and breakup time of Nam Co

The radar cross section σ_0 of lake water and lake ice is different, which can be used to distinguish lake water and lake ice. Water has only surface scattering but inside the lake ice there are scatterers such as small salt particles, they have both surface and volume scattering. Moreover, the roughness of lake ice surface and lake water surface are also different. Basically, the backscatter coefficient of lake ice should be higher than lake water. The value of backscatter can be affected by many reasons. For example, it depends on the incident angle, the roughness and the brightness temperature of the target surface, the concentration of atmospheric fine particles, etc.[13] Also, the brightness temperature of water can change dramatically because of the wind, but the brightness temperature of ice is stable. Because there is no constant backscatter coefficient of ice and water. We must compare the backscatter value with the peakiness value to distinguish water and lake ice.

According to previous research, usually, Nam Co starts to freeze in October and it could be completely frozen in February. The lake ice would start to breakup in May.[16] The backscatter and the peakiness are plotted track by track to see their characteristic.

3.8.1 Histogram

The diagrams 3.18 and 3.19 are the histogram of backscatter and peakiness. From the figure 3.18 we can see that the amount of data has been divided into 20 bins. The histogram of backscatter presents approximately normal distribution. From figure 3.18 we can see that most data fall in the 9th, 10th and 11th bin which have the average values of 12 dB, 15 dB and 18 dB.

The histogramm of peakiness shows that most values are in the 1st and 2nd bins which have the values of 5.4 and 11.3. This histogramm represents a exponential distribution.

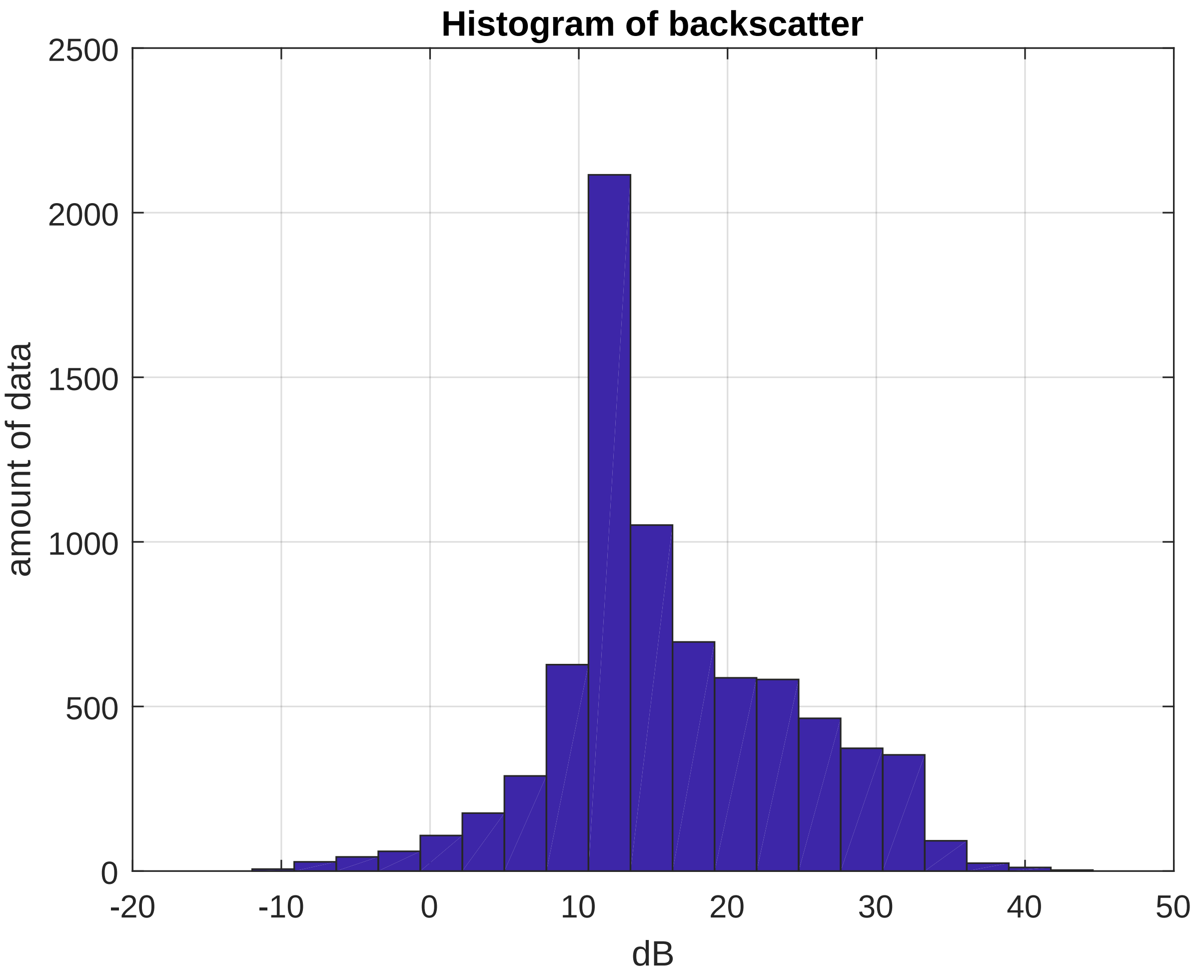

Figure 3.18: *Histogram of Backscatter*

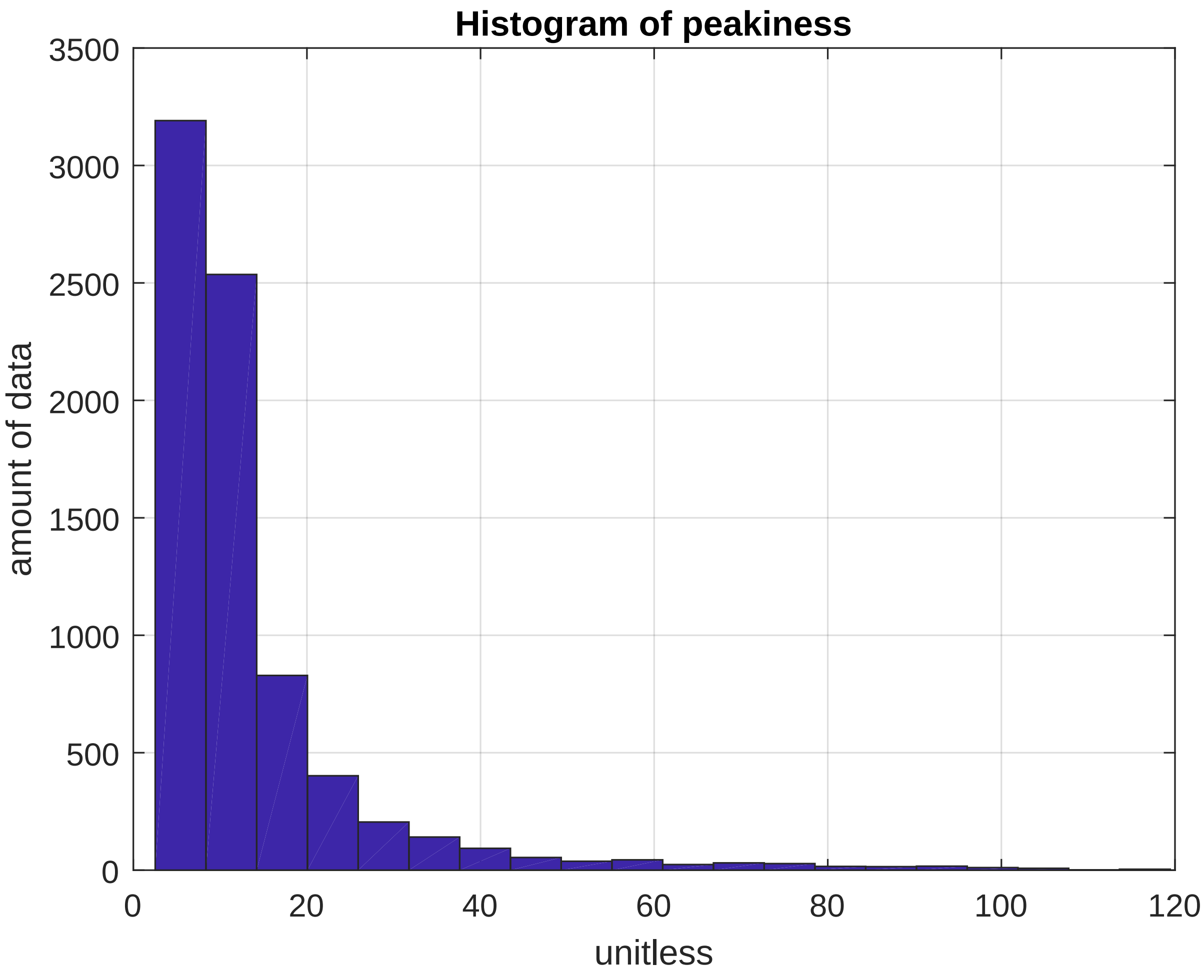

Figure 3.19: Histogram of Peakiness

3.8.2 Threshold Method

To distinguish lake water and lake ice, a direct way is to set a threshold.

3.8.2.1 Real Satellite Imagery

Before doing the threshold method we can use the real satellite imagery to see the real situation about the frozen and break up time of Nam Co.

The satellite imageries of Nam Co are provided by a online application called EO-Browser.[3] By using this application we can acquire the satellite images of the chosen area and chosen time from different satellites. In this thesis all the satellite images of Nam Co are from the satellite Landsat-8.

Unfortunately, there is no satellite image found in 2011 and 2012 on EO-Browser. We can only find the images from 2013 to 2015. Usually there are 1 or 2 images which can be found per month. We can only observe the images which show the variation of the lake ice. As can be seen in the images below, in the year 2013 Nam Co remained frozen until 5th May. In 21th May 2013 the lake ice had almost completely melted. Therefore we can estimate that in 2013 the breakup time of Nam Co should be in the middle of May. From the image of 31th December 2013 we can observe ice in the northeast corner of Nam Co. That means Nam Co had started to freeze again. In 16th January 2014 the lake was still fluid. Nam Co had in 1st Feb 2014 totally frozen. We can suggest that the freeze time in the winter of 2013-2014 is in the late January 2014. Similarly, comparing figure from 22th April and 8th May 2014 the break up time in the summer of 2014 is between late April to early May. In the winter of 2014-2015 Nam Co had frozen in late January 2015. Nam Co had started to melt before 25th April in 2015 and had totally melted between late April and early May. In winter of 2015-2016 the lake would had frozen up later than late January.

In conclusion, we can roughly say that the freezing season of Nam Co of every year is from February to May.

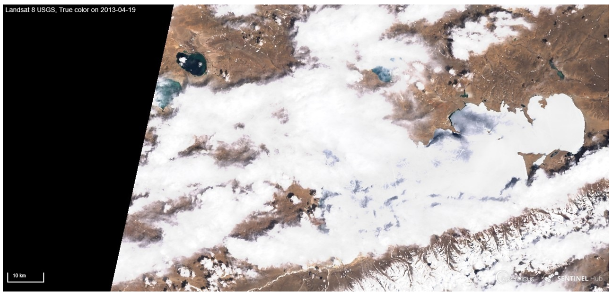

Figure 3.20: *04-19-2013*

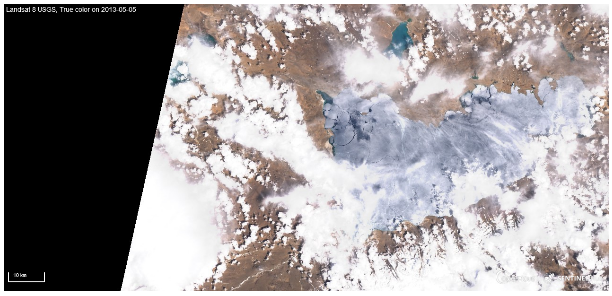

Figure 3.21: *05-05-2013*

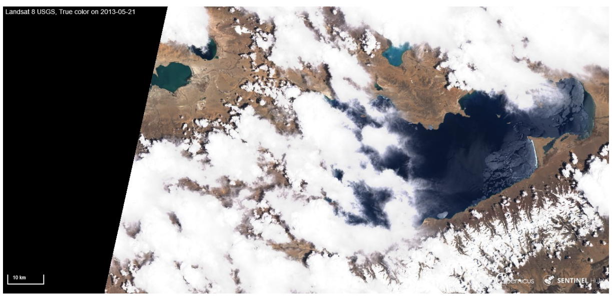

Figure 3.22: *05-21-2013*

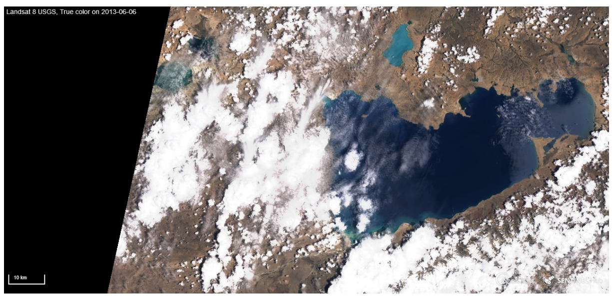

Figure 3.23: *06-06-2013*

Figure 3.24: *12-31-2013*

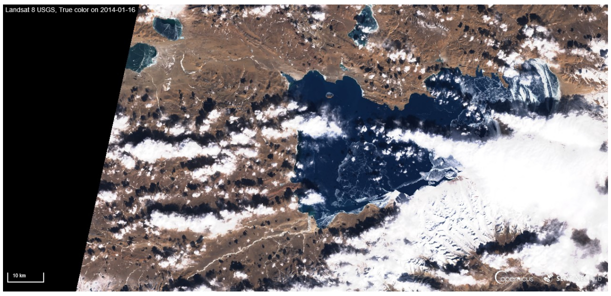

Figure 3.25: *01-16-2014*

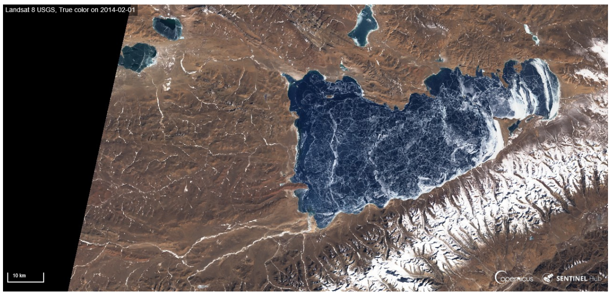

Figure 3.26: *02-01-2014*

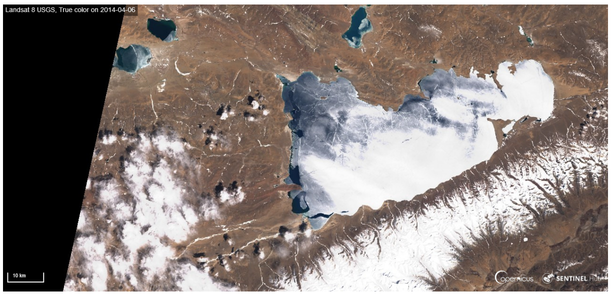

Figure 3.27: *04-06-2014*

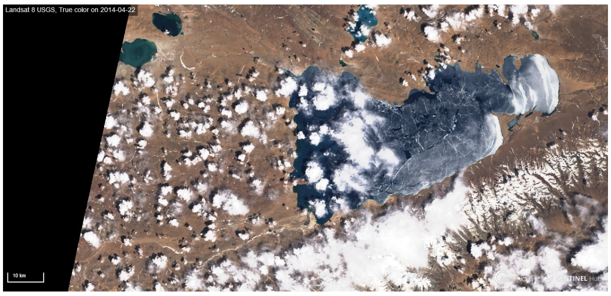

Figure 3.28: *04-22-2014*

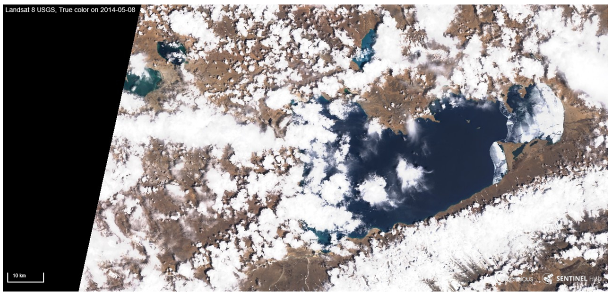

Figure 3.29: *05-08-2014*

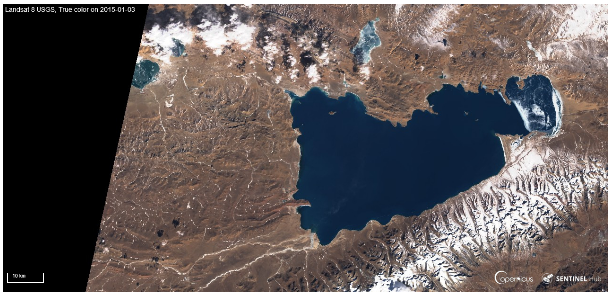

Figure 3.30: *01-03-2014*

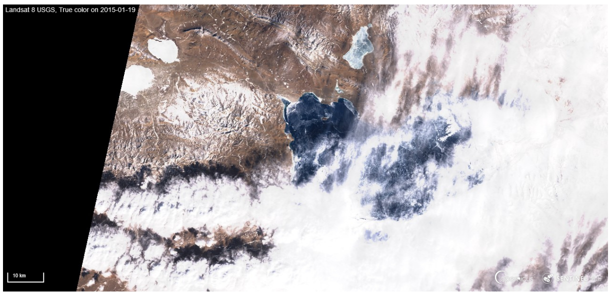

Figure 3.31: *01-19-2015*

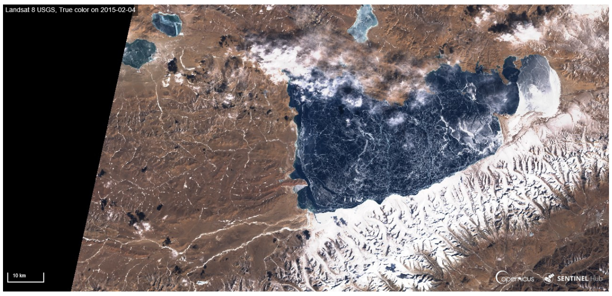

Figure 3.32: *02-04-2015*

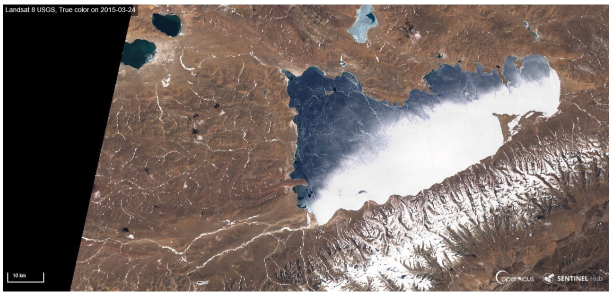

Figure 3.33: *03-24-2015*

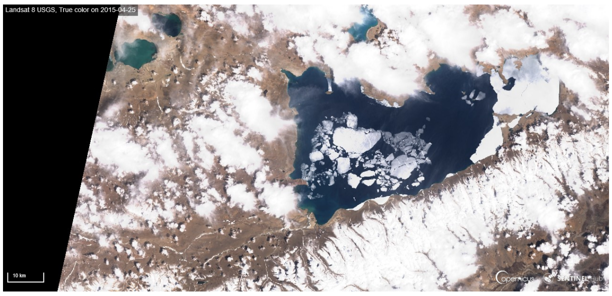

Figure 3.34: *04-25-2015*

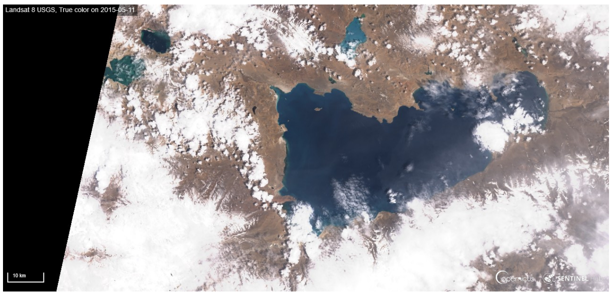

Figure 3.35: *05-11-2015*

Figure 3.36: *12-21-2015*

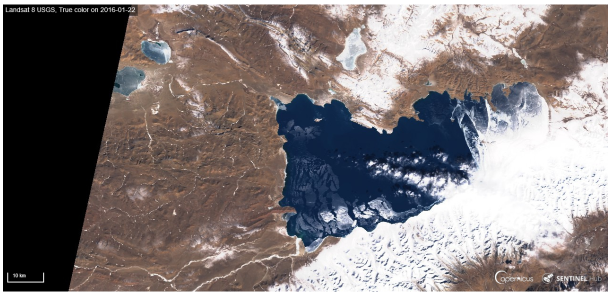

Figure 3.37: *01-22-2016*

3.8.2.2 Backscatter

A threshold for backscatter values will be set. A value that under the threshold will be regarded as lake water, otherwise the value will be regarded as lake ice. From the paragraph above we've already known that Nam Co has 8 months's thawing season and 4 months's freezing season. Hence that the amount of backscatter values of water must be much more than the amount of backscatter values of ice. The backscatter values of a rough water surface may be increased due to wind and current effects.[9] Therefore the threshold should be set relatively higher so that the ice and water can be good distinguished. According to the histogram above, the threshold value of backscatter would be set as 18 dB.

Figure 3.38 below shows the backscatter of every track according to time series. To intuitively represent the ice and water, the backscatter will be plotted in different colors instead of specific values. The color red represents lake water and blue represents lake ice. Because the tracks of CryoTrack are quite sparse, it is only possible to give a general estimation of the freeze and breakup time of Nam Co.

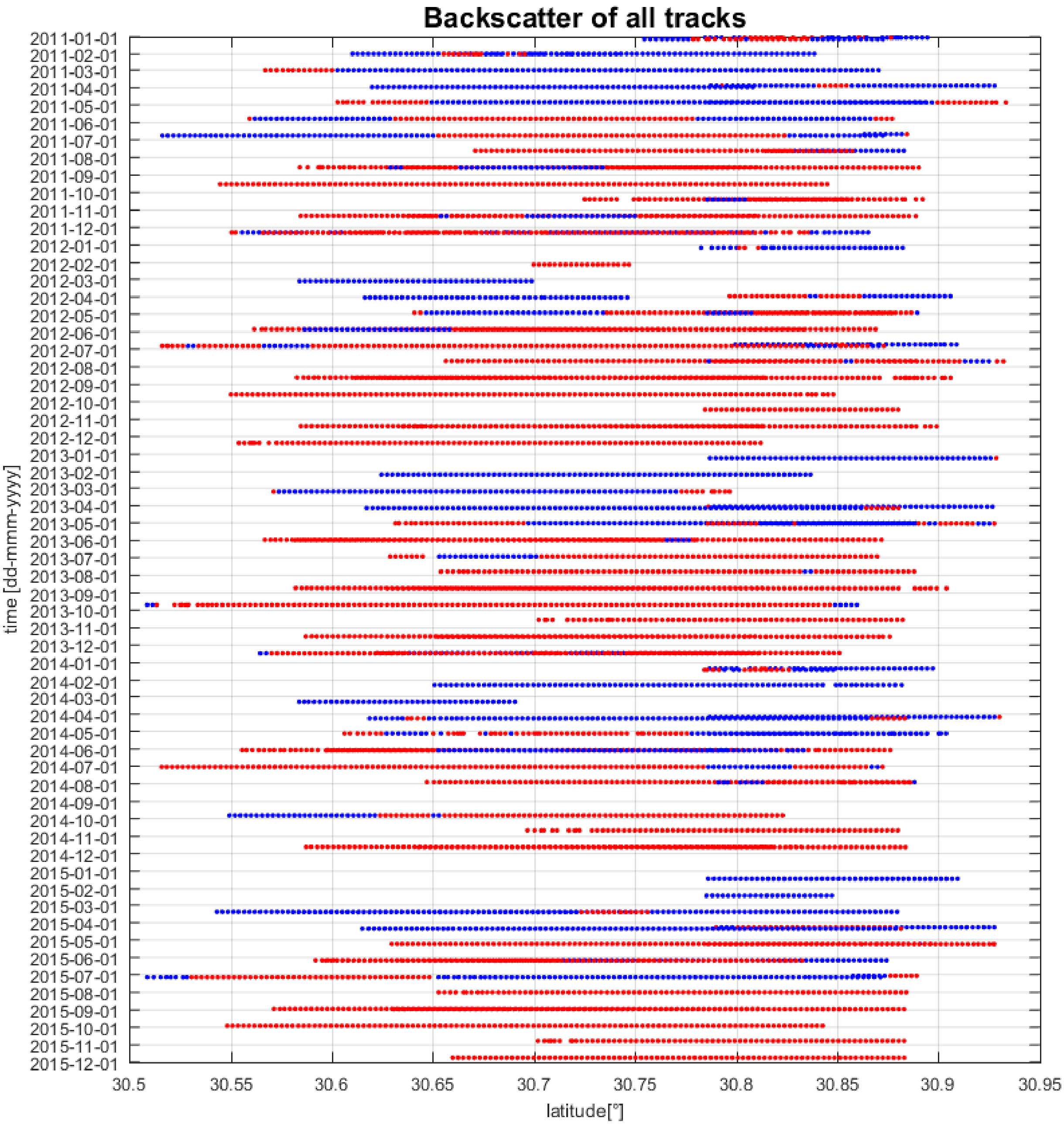

Figure 3.38: Backscatter Values of all Tracks according to Time Series

By observing figure 3.38 above we can give a generally suggestion year by year. From early January 2011 to late April 2011 it was the freezing season of Nam Co. Most of the backscatter values are blue in those tracks. From late May to middle December 2011 Nam Co remained fluid. We can see that during this time most of the backscatter values are red.

In the winter time of 2011–2012 the backscatter values are a little bit confusing. From January to March 2012 there are only a few backsctter values shown in the figure. It is quite hard to determine the exact freeze and break up time of Nam Co. In February there is only a very short track and all backscatter values are red. But comparing the previous and after Months, Nam Co should had frozen in February 2012. Base on that we can regard the time interval from January to April 2012 as the frozen season of Nam Co and the time interval from May to December 2012 as the thawing season of Nam Co. From early January to early May 2013 the backscatter values clearly represent the freezing season of Nam Co. From begin June to middle December Nam Co was in its thawing season. From January to April 2014 Nam Co had frozen again. From the beginning of May the lake would had started to melt. In early June there are two tracks in one day. One is totally red and another is totally blue. The reason of this situation could be complicated. Interference factors such as incidence angle, polarization etc. could all affect the backscatter values. In December 2014 there is no tracks available. Therefore we can't determine weather the lake had started to freeze in this month or not. From January to April 2015 there was the Nam Co's freezing season again . From early May to the end of December 2015 Nam Co had remained melted. Besides, we can see in the beginning of July the backscatter value had presented in blue which may caused by many disturbance factors.

3.8.2.3 Peakiness

The peakiness values can also distinguish lake ice and lake water. Because most of the peakiness values fall into the 1st and 2st bins of the histogram of peakiness which has a value between 0 to 11, the threshold would be set as 11 and the result is as below.

In general, we could say that from 2011–2015 Nam Co had covered by ice from January to May. The result of peakiness is almost as same as the result of backscatter. Different from backscatter, the peakiness value is more unstable. There are always a few red dots in the tracks of frozen season and always a few blue dots in the tracks of melt season.

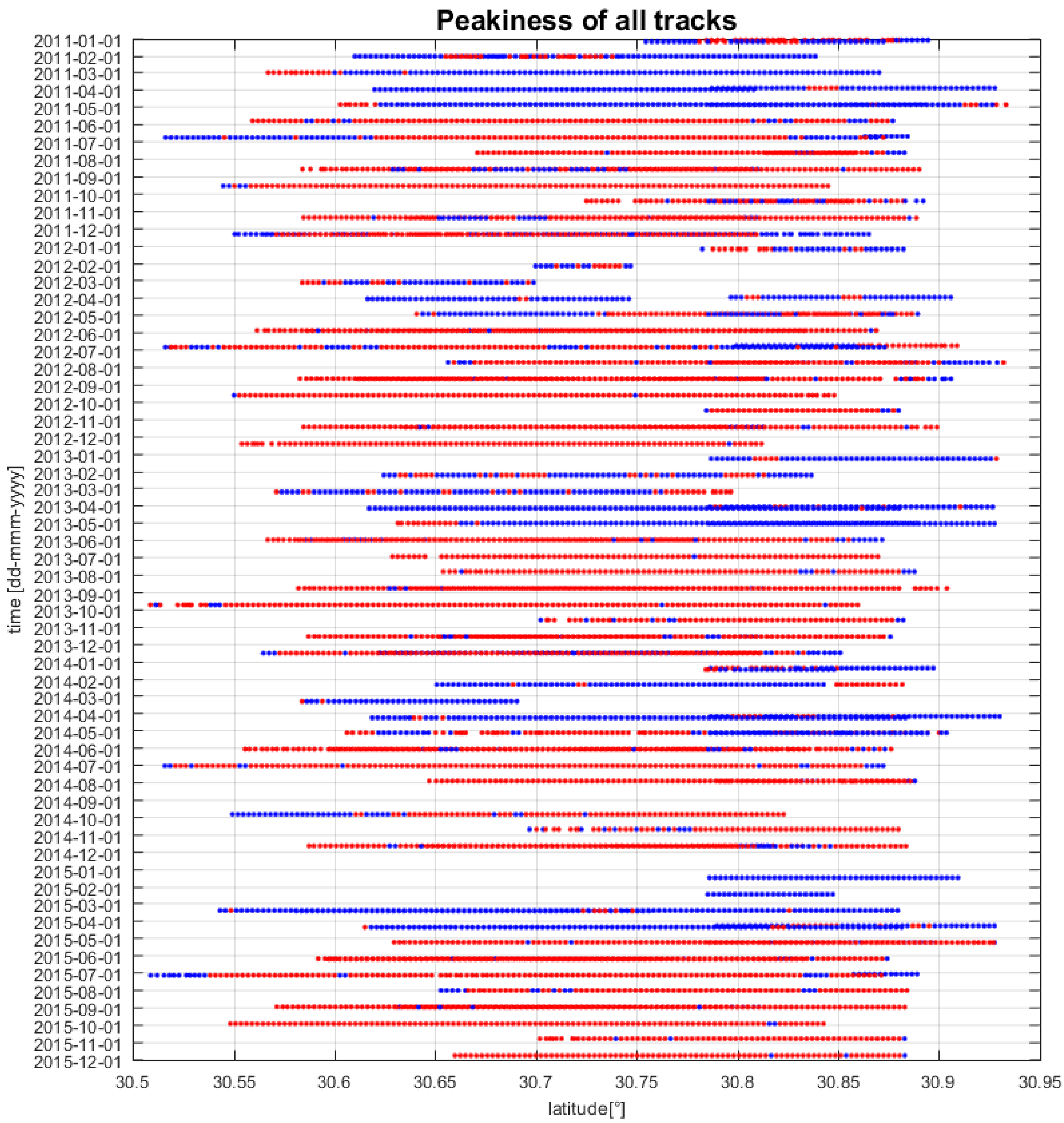

Figure 3.39: *Peakiness Values of all Tracks according to Time Series*

3.9 Comparing the Threshold Method with Satellite Images

Comparing the two threshold methods with the real satellite images we can generally say that both threshold methods can roughly represents the real situation of the seasonal variation of the lake ice of Nam Co. The backscatter and peakiness value can be affected by many interference factors such as wind, illumination, humidity of ice, etc. The threshold method may not provide a precise estimation but it does provide a general trend of the lake ice variation.

Chapter 4

Conclusion

The program CryoTrack provides us a efficiently and intuitively way to process the CryoSat-2 data. The standard deviation of the surface height has been calculated to improve the final result. The synthetic aperture interferometric radar altimeter (SIRAL) that is carried on CryoSat-2 provides a high accurate measurement and the satellite has relatively dense tracks. These guarantee a preciser and more reliable measurement than previous satellite altimetry.

The backscatter and peakiness value of Nam Co has been using for estimating the variation of the lake ice. There must be other good or even better methods to improve the precision of the result such as by observing the freeborad value of each track, but it could be very time-consuming and we can't use CryoTrack to simplify the data processing procedure. Therefore the threshold method is still a quick and easy way to distinguish the ice and water. Since we have both threshold from backscatter and peakiness values, we could compare them so that the errors and biases can be reduced and the final result can be more authentic. To some degree, the selection of threshold is difficult because the backscatter value can always change due to too many factors. We need a lot of reference information such as the previous and usual climate of the Nam Co area to determine a appropriate threshold value.

In this thesis the main goal is to simplify the procedure of the data processing and enhance the efficiency so that people are able to monitor Nam Co in quasi-real time. For further research for example we could detect the ice thickness of Nam Co by using the CryoSat-2 data or maybe other satellite data. By then we will need definitely other programs for the data processing.

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