Automated Method in Deriving Local Sea Level Height from ATM L1B data

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A method to automatically determine sea level for referencing snow freeboards and computing sea ice thicknesses from NASA IceBridge airborne LIDAR

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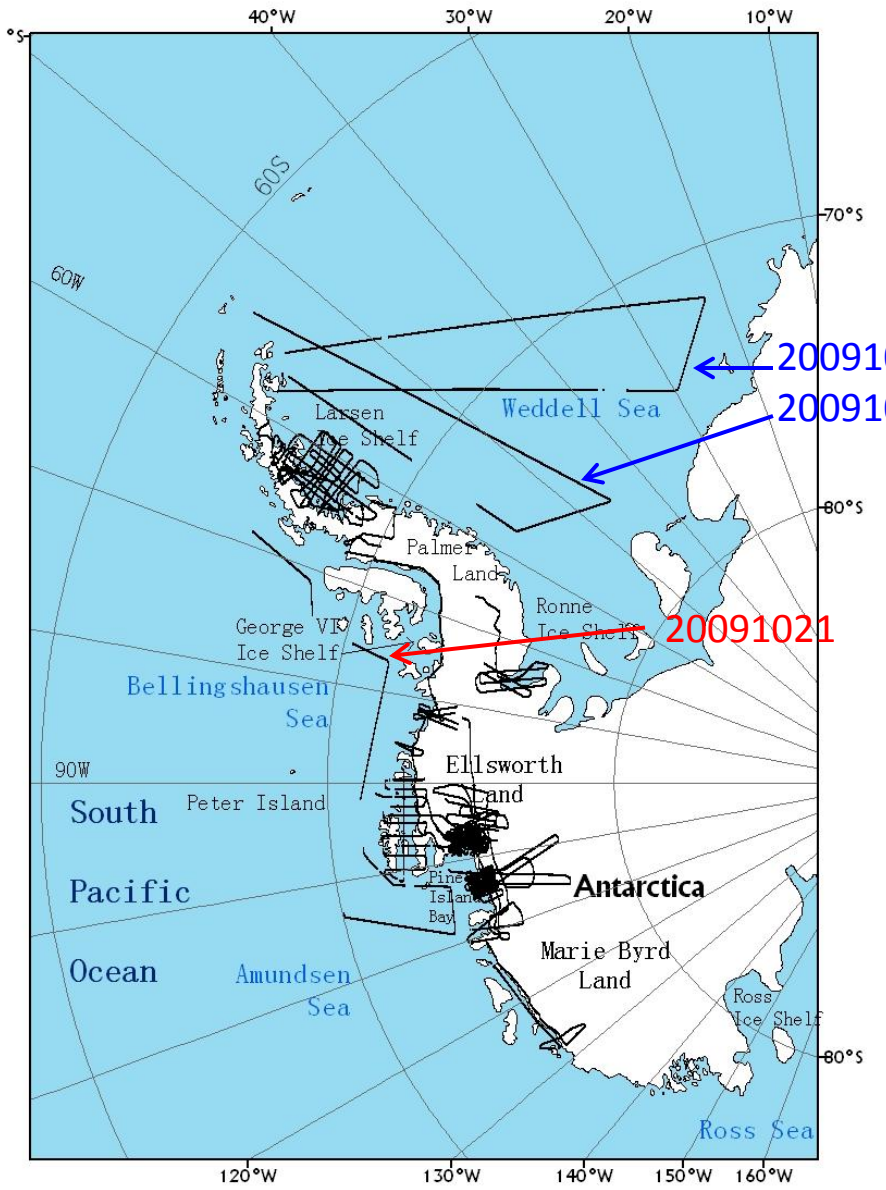
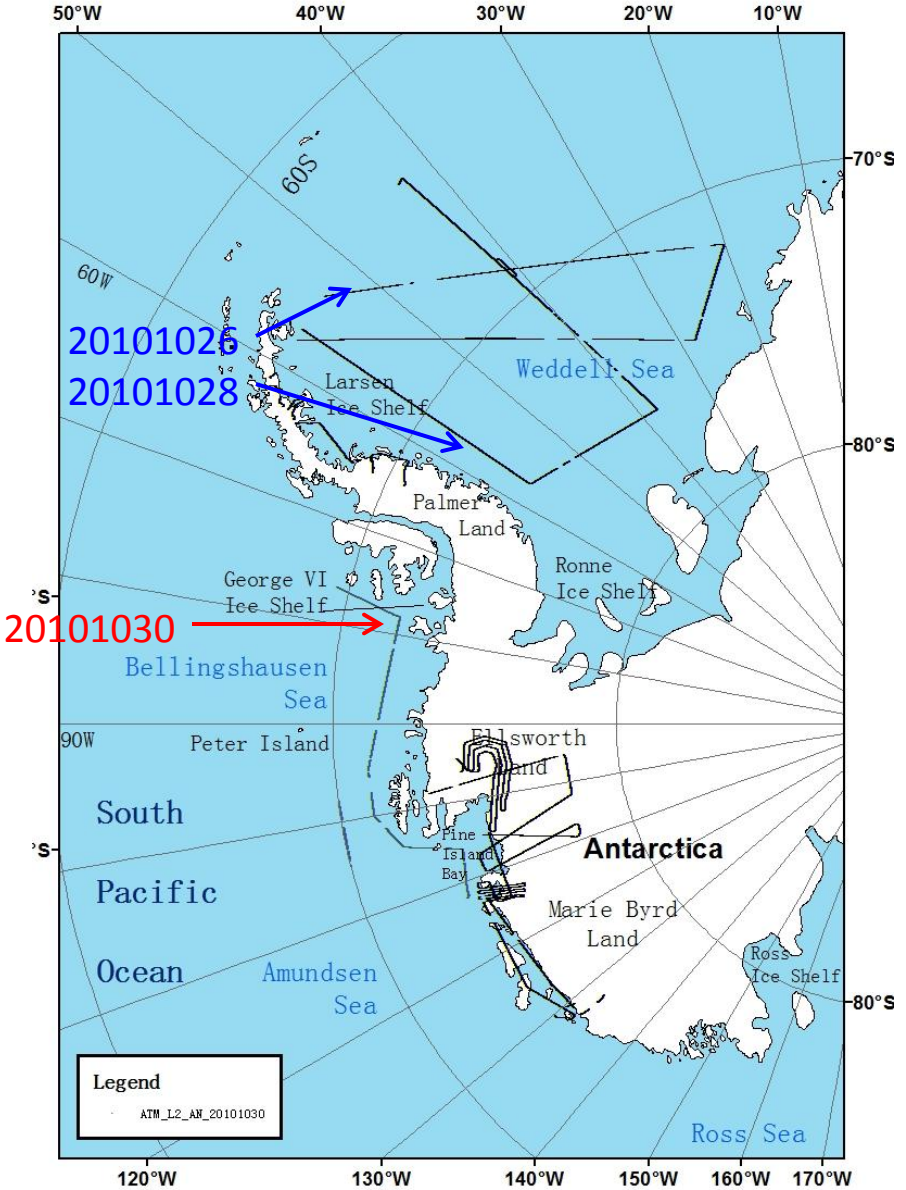


2009 in Antarctica:
18 days, 18 flights, 85 hours

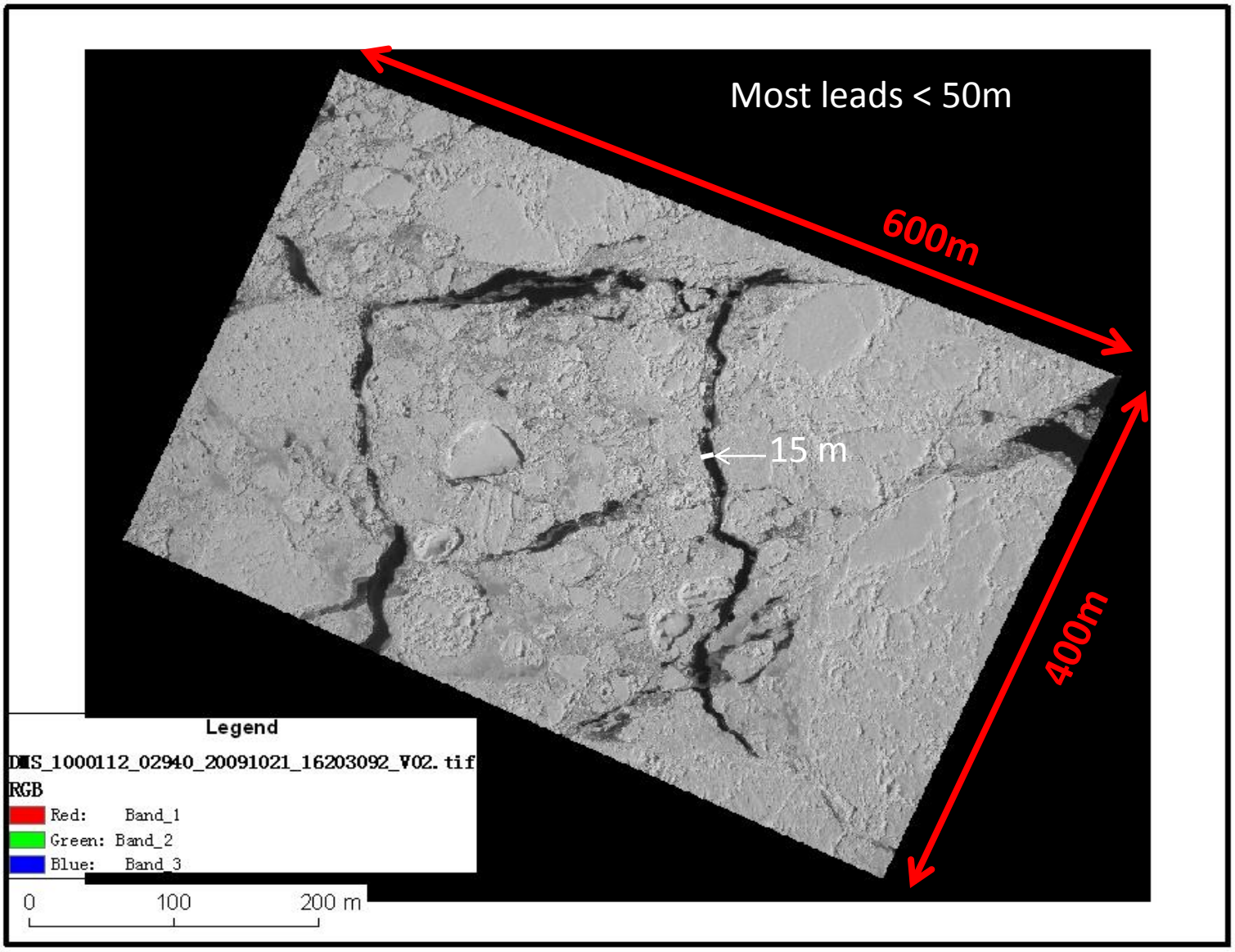


2010 in Antarctica:
8 days, 8 flights, 37 hours

Motivation

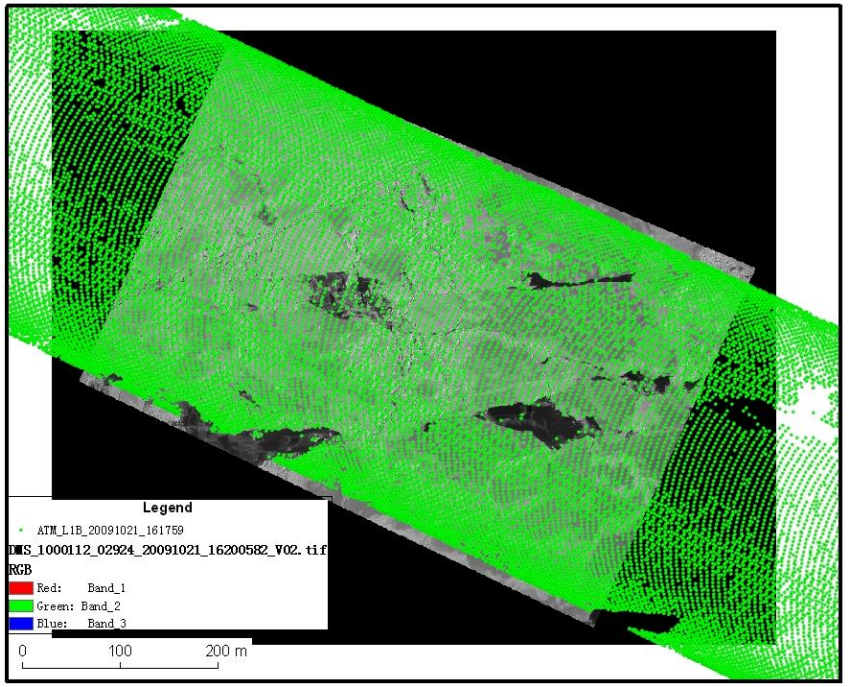
- Current numerical models to model the ocean surface topography (or the gravitational equipotential sea surface, geoid) are not capable to provide the required accuracy and spatio-temporal resolution for Antarctic.
- In order to determine the snow freeboard (the height from air/snow to local sea level) using the ATM elevation, a local sea level reference or sea surface height using the same set of ATM elevation data must be obtained first.
- Zwally et al. (2008) used the lowest 2% in a 50km track to determine local sea level from ICESat
- Can we use the lowest 2% for ATM L1B?

DMS image of Sea ice



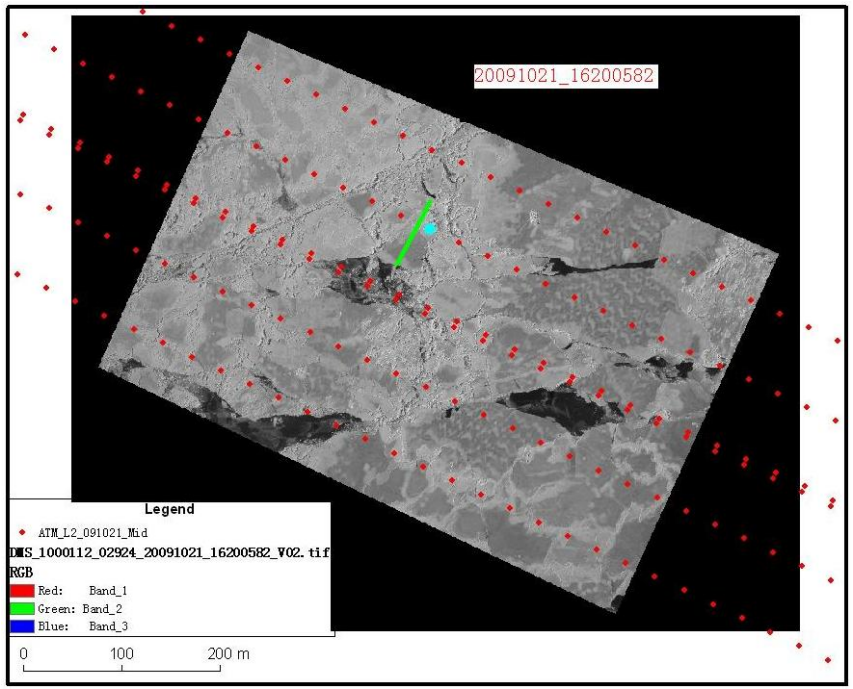
Very High Resolution: 0.1 m at 500m flight height

ATM L1B



Footprint 1-2m
Along track interval 5m

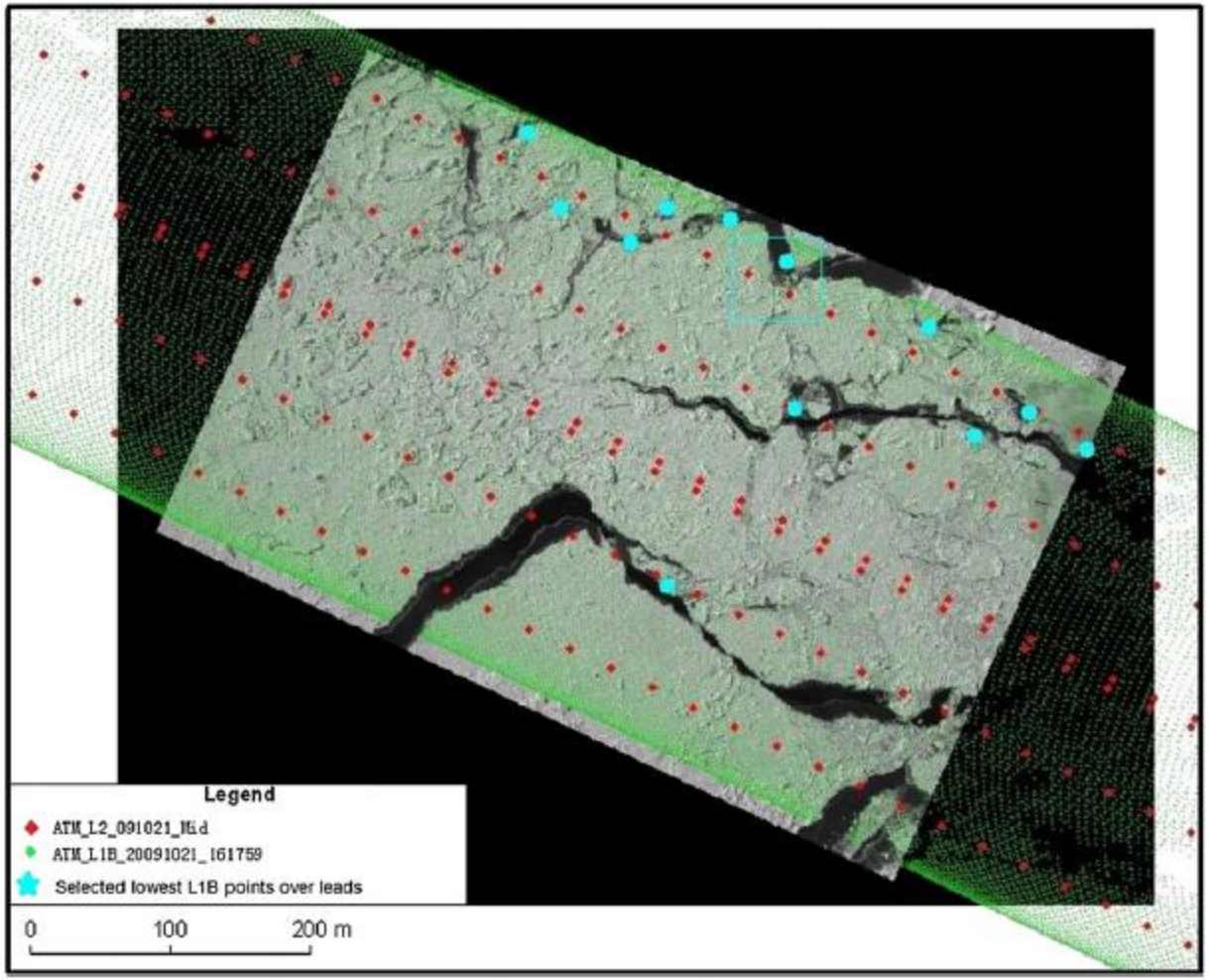
ATM L2



L2 data is formed by fitting a "patch" or "platelet" of individual L1B elevations to a plane, alone track of ~60m

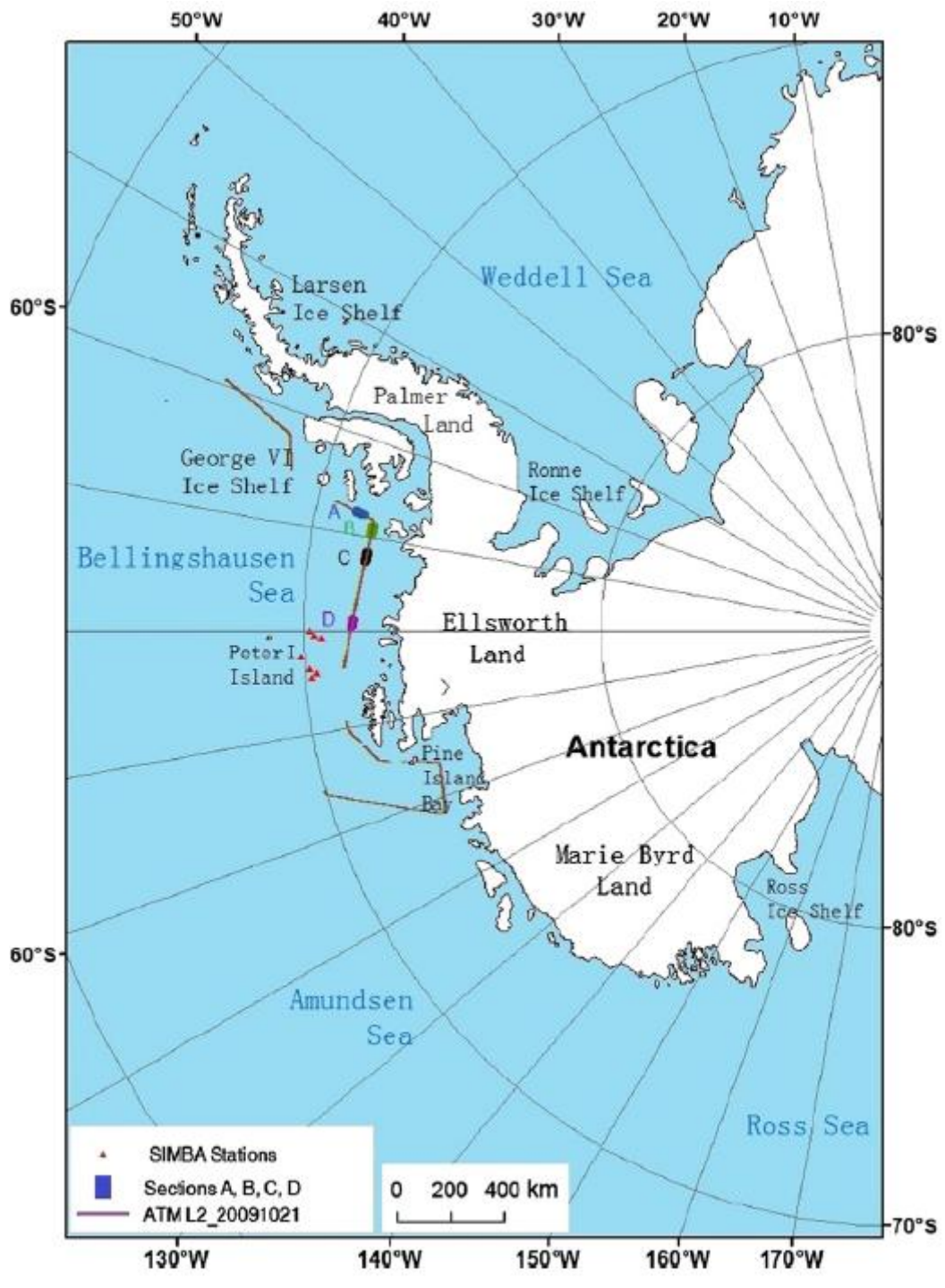
Footprint 60m,
mean of ~50 L1B Data

Manually select the lowest L1B or L2 spots over leads/thin ices



Mean height of those lowest spots is taken as the local sea level of the DMS image area

Lowest 2%, 1%. 0.5%. 0.2%, and 0.1% L1B data



Method

- Select A,B,C,D sections of 30km each, a total about 500km from A to D
- Manually get sea level for each DMS image, treated as ground truth
- Automatically use the Lowest 2%, 1%. 0.5%. 0.2%, and 0.1% L1B data
- Compare them with the ground truth

Table 1
Selected four sections of ATM L1B files and the DMS images in the mid flight on October 21, 2009 in the Bellingshausen Sea, Antarctica.

Sections	L1B files	Length (km)[a]	L1B shots	Selected DMS images	DMS images with leads
A	20091021_161759	30.3	994001	29	28
B	20091021_162951	33.2	851435	30	18
C	20091021_164142	30.8	1048575	29	21
D	20091021_171316	28.9	1048575	28	20

[a] Length is the distance between the first and the last laser shot of the ATM L1B file on each section.

Results

Table 2
Mean Difference (MD) of sea level heights between auto-calculations using certain percentage of the lowest ATM L1B data and thos
tified by DMS images, e.g., (L1B_2%_Auto–L1B_Manual), and between manual selection from ATM L2 and L1B data over DMS ima

Sections	DMS images with Leads	Mean Difference (L1B_Auto–L1B_Manual)[a] (m)					Mean Difference (manual)
		2.0%	1.0%	0.5%	0.2%	0.1%	L2–L1B
A	28	0.07	0.04	0.01	−0.04	−0.07	0.32
B	18	0.14	0.11	0.07	0.02	−0.01	0.42
C	21	0.08	0.05	0.02	−0.02	−0.05	0.23
D	20	0.15	0.10	0.06	0.01	−0.03	0.49
Mean of Mean Difference		0.11	0.07	0.04	−0.01	−0.04	0.36
Mean L1B data points		435	217	109	43	22	n/a

[a] Sea level range in the parenthesis is the difference between the highest and the lowest sea level heights within a L1B file section
computed as the ratio of the sea level range along one L1B section to the length of that L1B section.

L1B_0.2% method the best

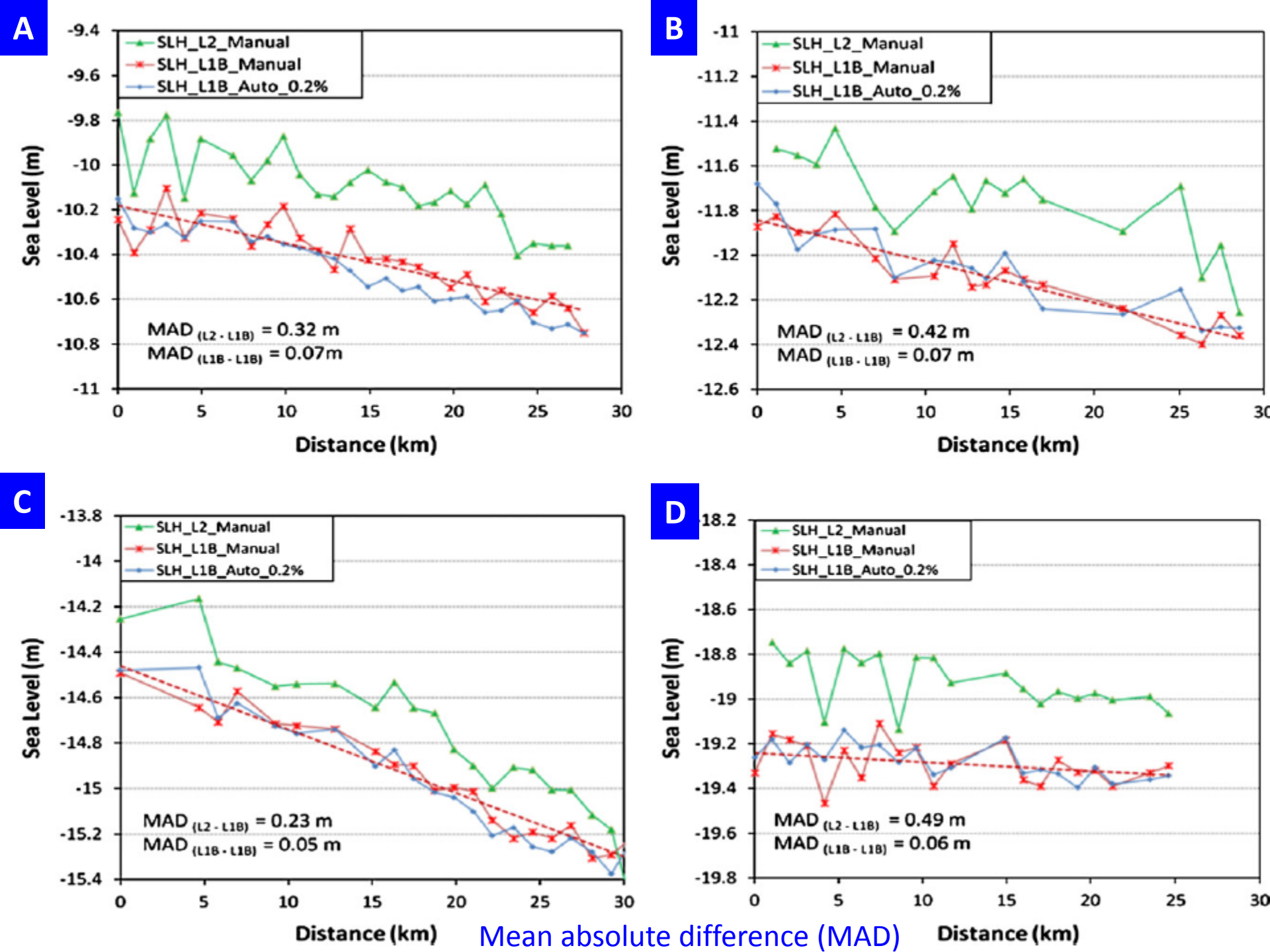
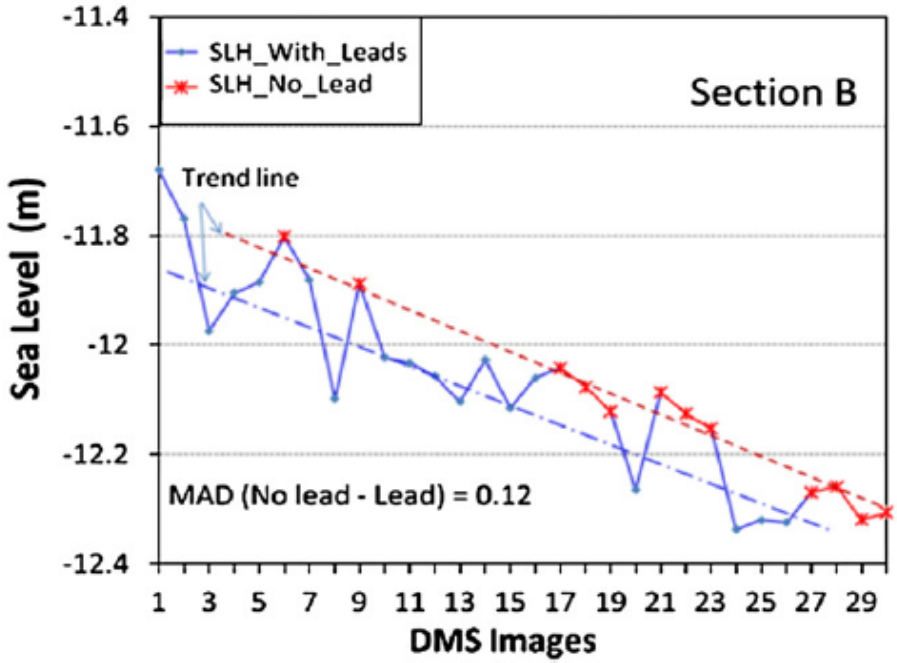

A
SLH_L2_Manual
SLH_L1B_Manual
SLH_L1B_Auto_0.2%
Sea Level (m)
Distance (km)
MAD (L2 - L1B) = 0.32 m
MAD (L1B - L1B) = 0.07m
B
SLH_L2_Manual
SLH_L1B_Manual
SLH_L1B_Auto_0.2%
Sea Level (m)
Distance (km)
MAD (L2 - L1B) = 0.42 m
MAD (L1B - L1B) = 0.07 m
C
SLH_L2_Manual
SLH_L1B_Manual
SLH_L1B_Auto_0.2%
Sea Level (m)
Distance (km)
MAD (L2 - L1B) = 0.23 m
MAD (L1B - L1B) = 0.05 m
D
SLH_L2_Manual
SLH_L1B_Manual
SLH_L1B_Auto_0.2%
Sea Level (m)
Distance (km)
MAD (L2 - L1B) = 0.49 m
MAD (L1B - L1B) = 0.06 m
Mean absolute difference (MAD)

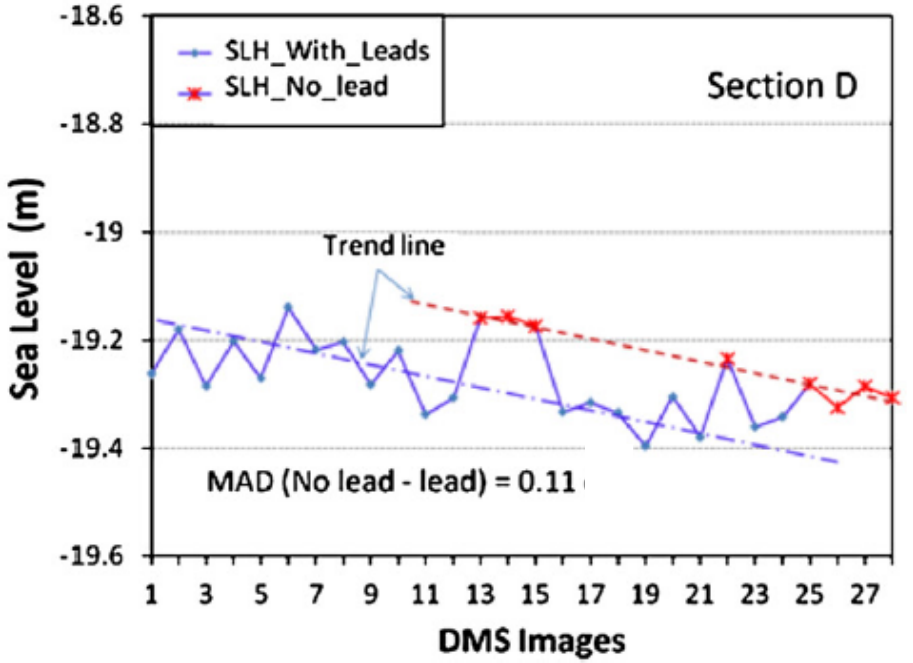
Table 1
Selected four sections of ATM L1B files and the DMS images in the mid flight on October 21, 2009 in the Bellingshausen Sea, Antarctica.

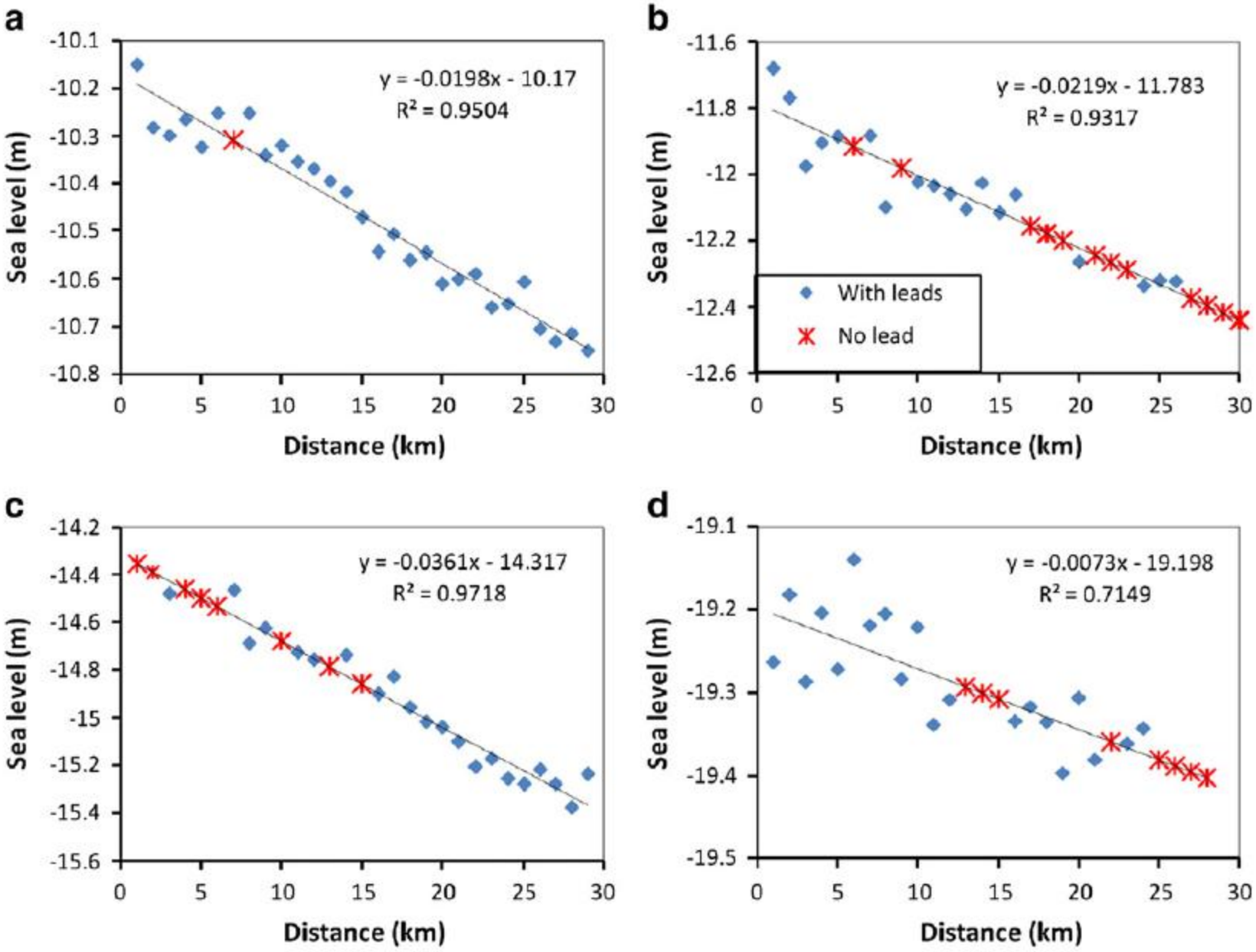
Sections	L1B files	Length (km)[a]	L1B shots	Selected DMS images	DMS images with leads	No leads
A	20091021_161759	30.3	994001	29	28	1
B	20091021_162951	33.2	851435	30	18	12
C	20091021_164142	30.8	1048575	29	21	8
D	20091021_171316	28.9	1048575	28	20	8

[a] Length is the distance between the first and the last laser shot of the ATM L1B file on each section.

Therefore, for the area without leads, the Auto_0.2% overestimate sea level height 0.11-0.12m.

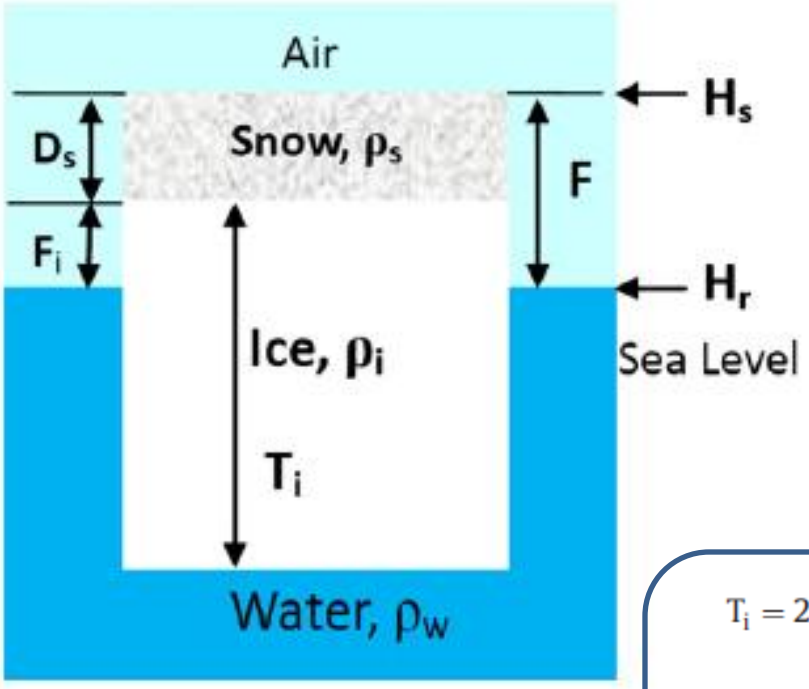






Blue dots are those with leads to derive the linear relation for each section, while red dots are the interpolated sea level for those DMS images with no leads

Derive Snow Freeboard (F) and Ice thickness (T_i)



$$F = H_s - H_r \quad (1)$$

H_s: ATM L1B or L2 reading

$$T_i = 2.8808 \times F + 0.2201 \quad (2)$$

$$T_i = 2.9843 \times F + 0.2064 \quad (3)$$

$$T_i = 2.7527 \times F + 0.2448 \quad (4)$$

$$T_i = \frac{\rho_w F_i + \rho_s D_s}{\rho_w - \rho_i} = 3.16F \quad (5)$$

Xie et al., 2011
Weissling et al., 2011

where F_i is close to zero for Antarctic sea ice, and $D_s \approx F$; ρ_s, ρ_i, and ρ_w are the bulk densities of snow (360 kg/m^3), ice (915 kg/m^3) and sea water (1029 kg/m^3).

From L1B

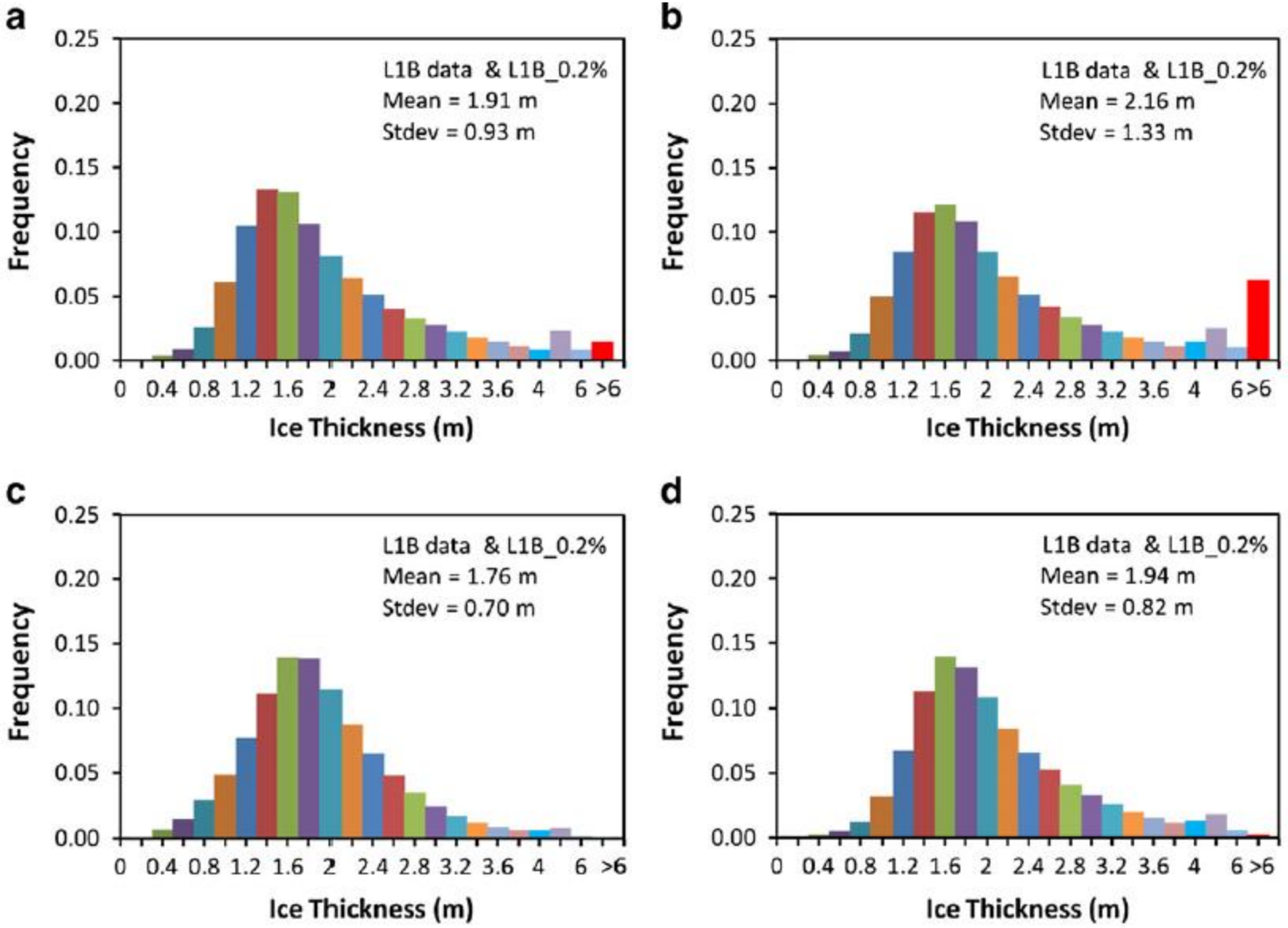
Table 3
Statistics of snow freeboard and ice thickness from ATM L1B data according to the sea level reference calculated by the L1B_0.2% method in the Bellingshausen Sea on October 21, 2009. The sea ice thickness is derived using Eq. (2) for all ice freeboard (positive and negative).

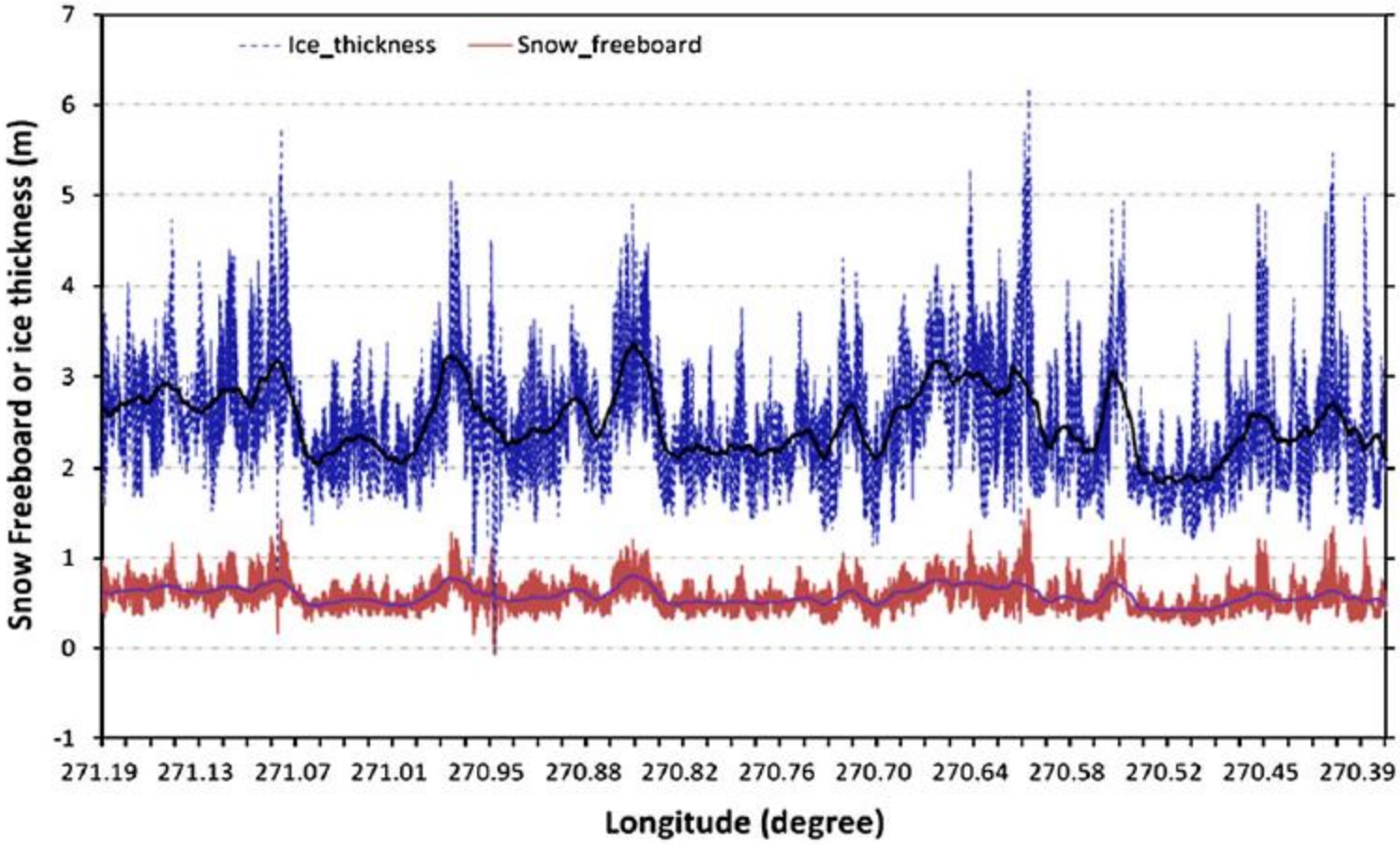
Unit (m)	Section A		Section B		Section C		Section D	
	Snow freeboard	Ice thickness	Snow freeboard	Ice thickness	Snow freeboard	Ice thickness	Snow freeboard	Ice thickness
Mean	0.59	1.91	0.67	2.16	0.53	1.76	0.60	1.94
Mode	0.40	1.40	0.50	1.60	0.50	1.60	0.50	1.60
Median	0.50	1.65	0.53	1.73	0.50	1.66	0.53	1.75
Standard deviation	0.34	0.93	0.46	1.33	0.24	0.70	0.28	0.82

From L2

Table 4
Statistics of snow freeboard and ice thickness from ATM L2 data according to the sea level reference calculated by the L1B_0.2% method in the Bellingshausen Sea on October 21, 2009. The sea ice thickness is derived using Eq. (2) for all ice freeboard (positive and negative).

Unit (m)	Section A		Section B		Section C		Section D	
	Snow freeboard	Ice thickness	Snow freeboard	Ice thickness	Snow freeboard	Ice thickness	Snow freeboard	Ice thickness
Mean	0.54	1.78	0.66	2.14	0.49	1.63	0.59	1.91
Mode	0.50	1.60	0.60	1.60	0.50	1.60	0.60	1.80
Median	0.49	1.63	0.55	1.81	0.49	1.63	0.56	1.84
Standard deviation	0.22	0.64	0.36	1.16	0.14	0.39	0.17	0.49


a
L1B data & L1B_0.2%
Mean = 1.91 m
Stdev = 0.93 m
Frequency
Ice Thickness (m)
b
L1B data & L1B_0.2%
Mean = 2.16 m
Stdev = 1.33 m
Frequency
Ice Thickness (m)
c
L1B data & L1B_0.2%
Mean = 1.76 m
Stdev = 0.70 m
Frequency
Ice Thickness (m)
d
L1B data & L1B_0.2%
Mean = 1.94 m
Stdev = 0.82 m
Frequency
Ice Thickness (m)
0.25
0.20
0.15
0.10
0.05
0.00
0 0.4 0.8 1.2 1.6 2 2.4 2.8 3.2 3.6 4 6 >6



Section D, ATM L2, but using sea level from L1B_0.2%

Ice Thickness from Different Eqs

Table 6
Comparison of ice thickness (m) from ATM L2 data according to the sea level reference calculated by the L1B_0.2% method in the Bellingshausen Sea on October 21, 2009. The sea ice thickness is derived using Eq. (3) for positive ice freeboards and Eq. (4) for negative ice freeboards, and using the buoyancy Eq. (5) with zero ice freeboard assumption.

Ice thickness	Section A			Section B			Section C			Section D		
	Eqn3	Eqn4	Eqn5	Eqn3	Eqn4	Eqn5	Eqn3	Eqn4	Eqn5	Eqn3	Eqn4	Eqn5
Mean	1.82	1.74	1.71	2.19	2.10	2.09	1.67	1.60	1.55	1.96	1.87	1.86
Median	1.67	1.60	1.55	1.85	1.77	1.74	1.67	1.60	1.55	1.88	1.79	1.77
Standard deviation	0.66	0.62	0.70	1.16	1.15	1.20	0.40	0.37	0.43	0.51	0.47	0.54
MAD[a]	0.04	0.04	0.09	0.04	0.04	0.07	0.04	0.03	0.08	0.05	0.04	0.07

[a] MAD is Mean Absolute Difference of ice thickness derived from Eq. (2) in Table 4 and Eqs. (3), (4) and (5).

- **Difference less than 10cm**
- **Both empirical equations and zero-ice freeboard assumption for the buoyancy equation give reasonable estimation of ice thickness**

Summary

- Compared 5 threshold values (2%, 1%, 0.5%, 0.2%, and 0.1%) of the lowest L1B with manually selected local sea level with the assist of the DMS images;
- The L1B_0.2% gives similar sea level as the L1B manual selection, by Mean Difference -0.01m and MAD 0.06m;
- Without leads in a DMS image, the L1B_0.2% method may overestimate local sea level by 11-12cm. Linear interpretation can give good local sea level for those without leads;

- All four equations give similar estimation of ice thickness (MAD less than 10cm). This means zero-freeboard assumption for BA is a reasonable assumption for the spring season;
- ATM L2 data can not accurately resolve sea level but using the L1B_0.2% sea level, L2 can give reasonable snow freeboard and ice thickness estimation (MAD less than 10cm).
- This study then imply: ICESat data (70 m) might not resolve accurate local sea level but with overestimation, then the underestimation of snow freeboard and ice thickness (using any of the four Eqs)

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