# Algorithm improvement of SGLI snow products and their validations (FY2019-2021)

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# Aims of the Project

- <u>Algorithm improvement</u> for snow/ice physical parameters such as snow grain size, snow impurity concentration, snow/ice albedo, bare ice and dark ice extent using GCOM-C and MODIS.
- <u>Cal/Val</u> for snow products in Japanese snow area and polar regions including mainly Greenland Ice Sheet.
- <u>Application Research</u> to improve physical processes of cryosphere using regional climate model (NHM-SMAP) and global climate models (ESM).

| JFY | 2019 | | | | 2020 | | | | 2021 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Month | 4-6 | 7-9 | 10-12 | 1-3 | 4-6 | 7-9 | 10-12 | 1-3 | 4-6 | 7-9 | 10-12 | 1-3 |
| Algorithm improvement | | | Cloud mask validation | | Snow grain size | Bare ice/ Dark ice | | | | Albedo<br>Snow impurity | | Sum-mary |
| Cal/Val | | | | Hokkaido | | ~~Greenland~~<br>→ Past Antarctic data | | Hokkaido<br>GSAF & HISSGraS development | | ~~Greenland~~<br>→ Past Greenland data | | Hokkaido |
| Application Research | | | | | | Process model improvement | | | | | | |

# Result in FY2019

1. Surface melting of the GrIS in the 2019 summer season was the second-largest since 2000. Snow surface temperature ($T_s$) and surface snow grain size ($R_{s1}$) derived from MODIS and SGLI in 2019 were compared with cloud masked temperature and NIR-albedo measured with AWS at SIGMA-A site on the ice sheet.

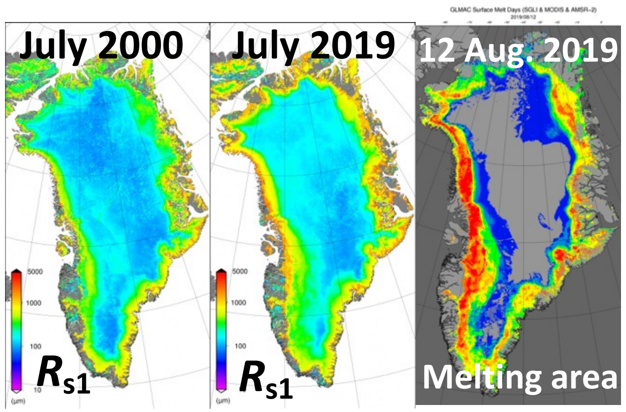



Fig.1

2. MODIS-derived $T_s$ and $R_{s1}$ sometimes contained errors due to the insufficient cloud mask ($C_1$), leading to underestimates of both parameters.

*Possible underestimate of MODIS $R_{s1}$ due to insufficient cloud mask

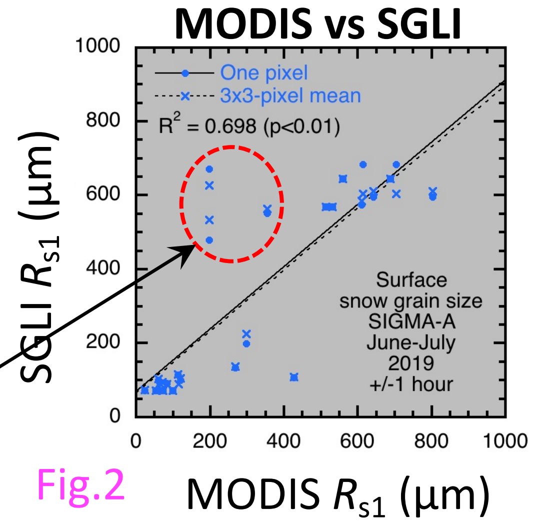
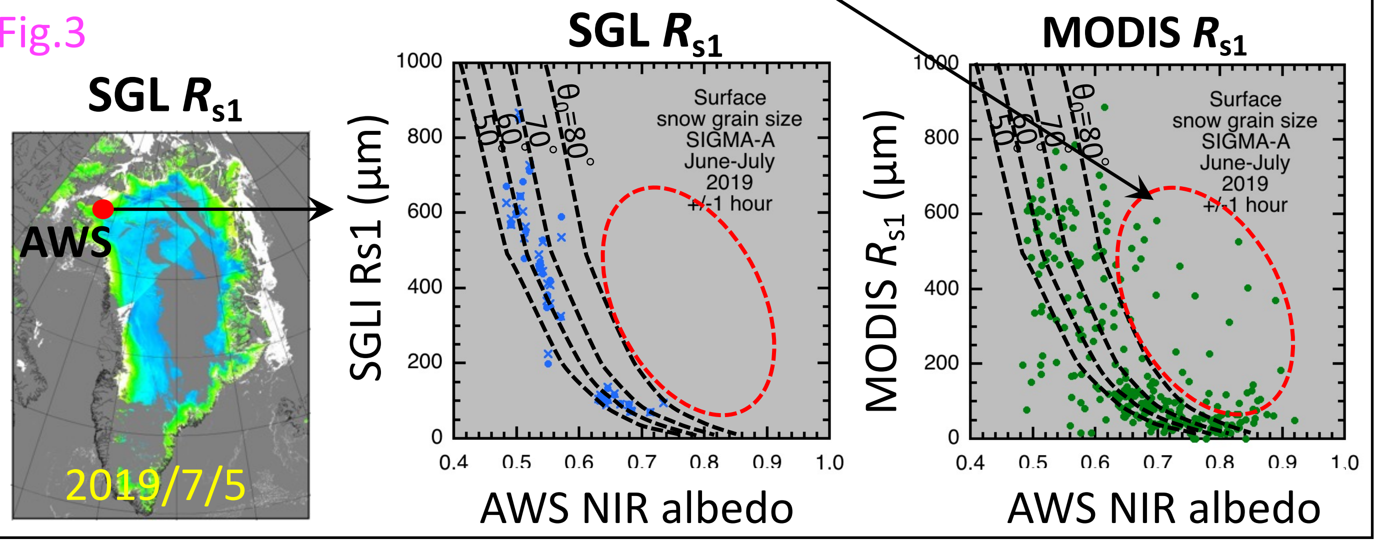



Fig.2

3. SGLI-derived $R_{s1}$ using new cloud mask (SCM) was consistent with AWS-measured NIR albedo and agreed with MODIS-derived $R_{s1}$ except for some MODIS-underestimated outliers.

Fig.3



# Result in FY2020

1. SGLI-derived snow grain size ($R_{SGLI}$) and snow surface temperature ($T_{SGLI}$) were validated with the field data measured at Dome Fuji in 2018-19, Antarctica, and Nakasatsunai, Japan 2020.
   - ✓ $R_{SGLI}$ Ver. 2 at Dome Fuji was underestimated due to possibly the atmospheric diamond dust or some algorithm issues (Fig.1).
   - ✓ Some $R_{SGLI}$ and $T_{SGLI}$ at Nakasatsunai agreed well with the in-situ measurements, whereas some $R_{SGLI}$ were positive-biased under a hazy condition.

2. Monthly mean values of MODIS-derived snow grain size $R_{S1}$, bare ice, and dark ice extents for the Greenland Ice Sheet (GrIS) are improved by employing an exclusive surface classification (Fig.2).

3. This improvement revealed that the albedo averaged overall GrIS highly correlates with $R_{S1}$ for the summer season from May to August (Fig.3).

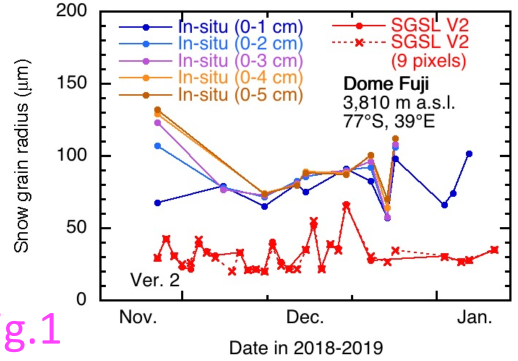



Fig.1

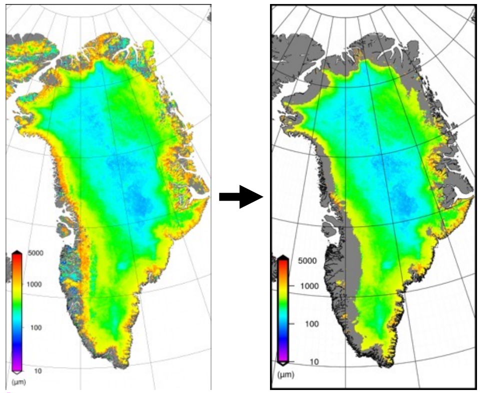


Fig.2

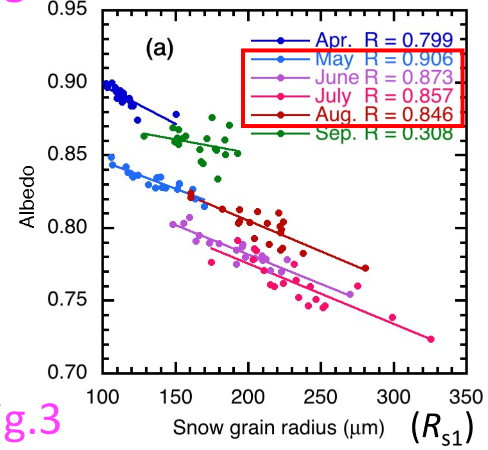
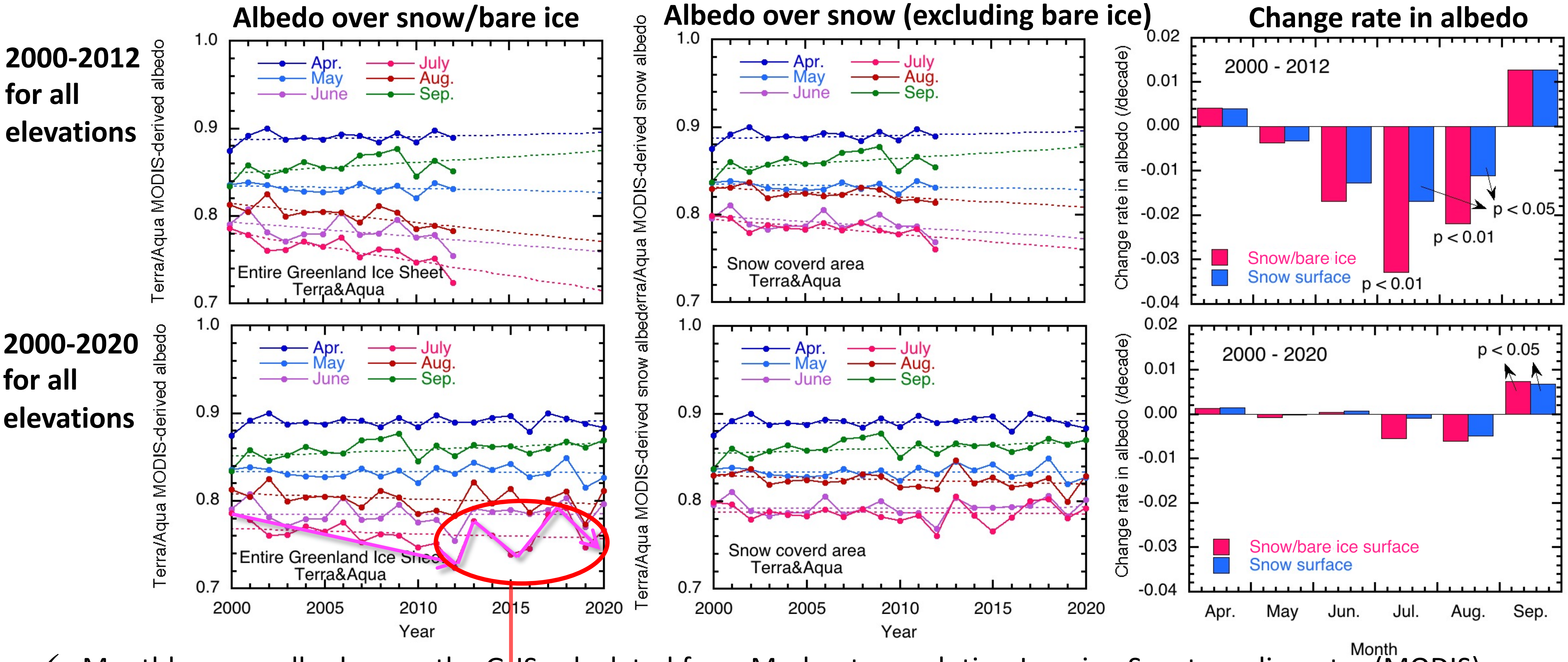



Fig.3

# Result in FY2021

# Surface albedo variation over the GrIS




- ✓ Monthly mean albedo over the GrIS calculated from Moderate resolution Imaging Spectroradiometer (MODIS) snow product[*1] (Hall et al., 1995) decreased with a statistically significant trend ($p$ < 0.01) in linear regression for July (trend: -0.033/decade) and Aug. (trend: -0.022/decade) from 2000 to 2012.
- ✓ However, there are no significant trends for the period from 2000 to 2020 in any month. This is due mainly to the <u>large albedo fluctuations since 2013</u>.

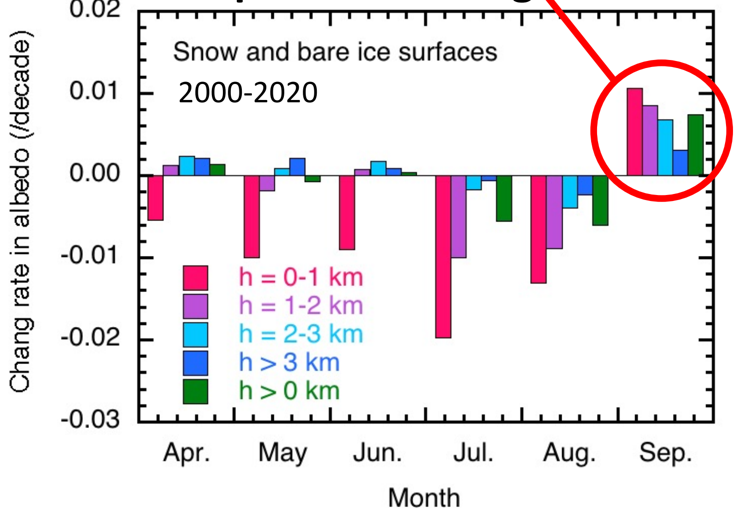
[*1] MODIS albedo product

# Snow and ice albedo variation over the GrIS

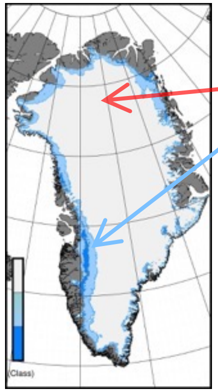
## Snow and ice surface albedo

- ✓ There are no significant interannual albedo trends ($p$ > 0.05) of linear regression from 2000 to 2020 for any elevation zone.
- ✓ The slopes of linear regression in albedo variation are negative over all elevations in July and Aug. and at $h$ = 0-1 km from Apr. to Aug., but positive in Sep., suggesting a possible increase in snowfall in Sep.

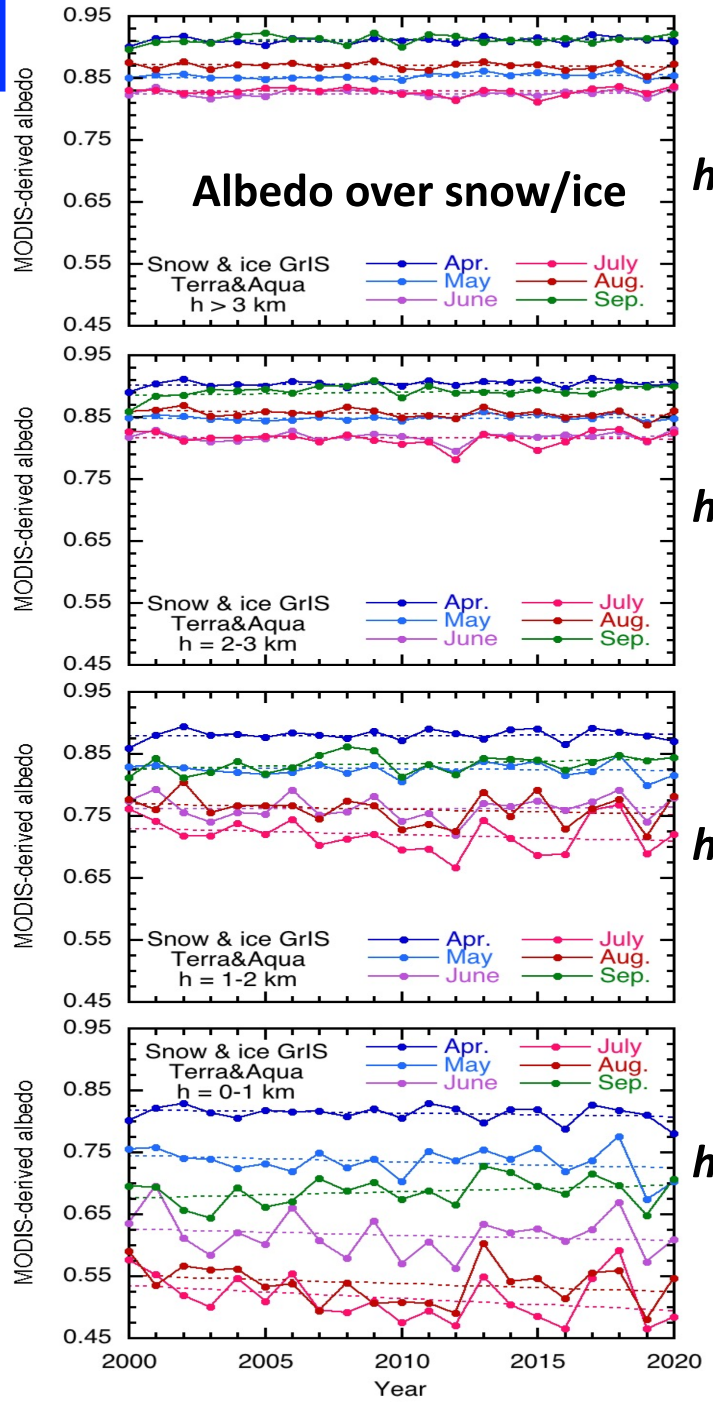
**Slope of linear regression**




July 2012



Albedos over snow /bare ice surfaces at $h$ > 2 km are the same as those in the right figs because there are scarcely bare ice surfaces.




*h* > 3 km

*h* = 2-3 km

*h* = 1-2 km

*h* = 0-1 km

# Snow albedo variation over the GrIS

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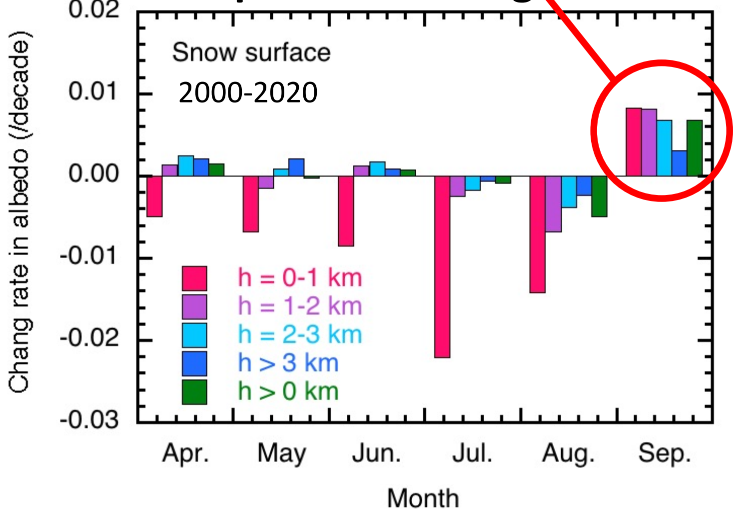
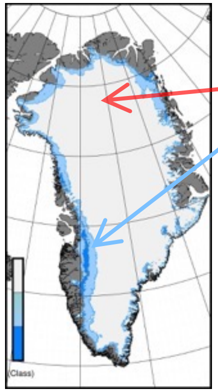



July 2012



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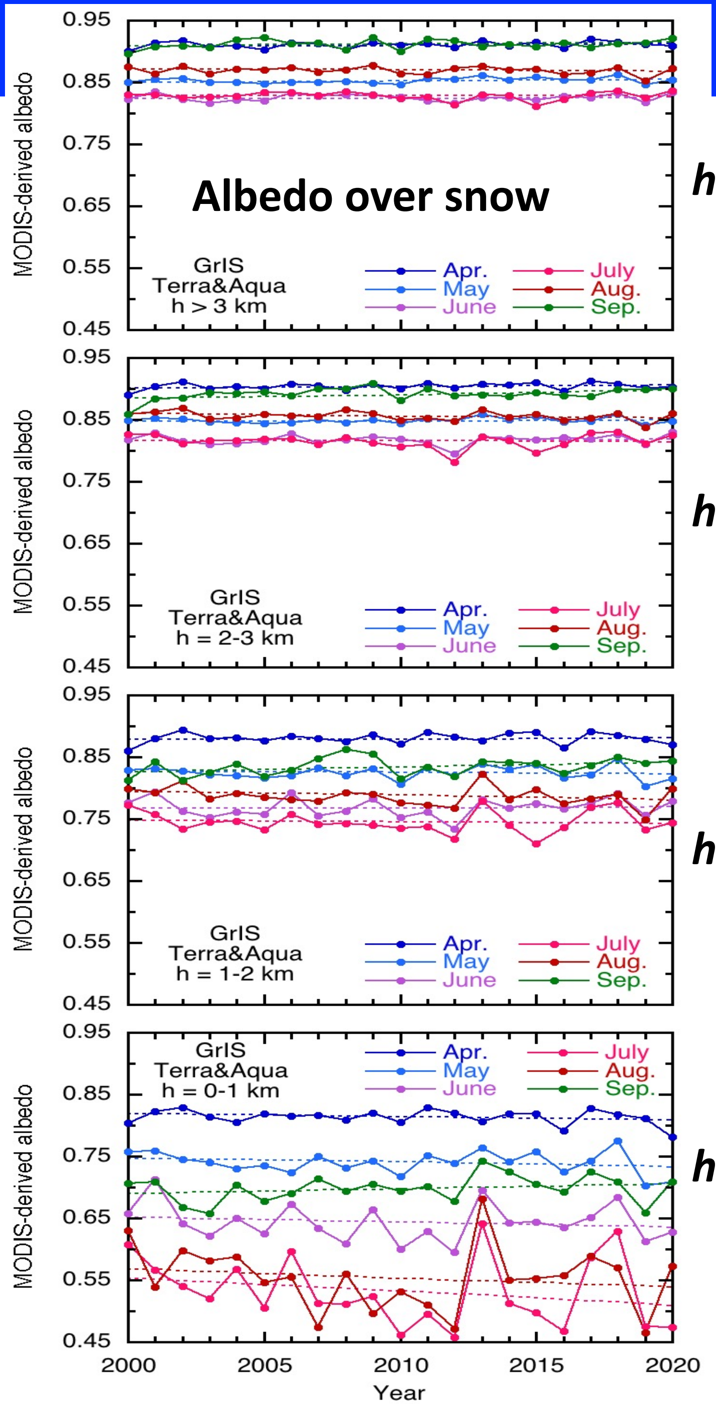


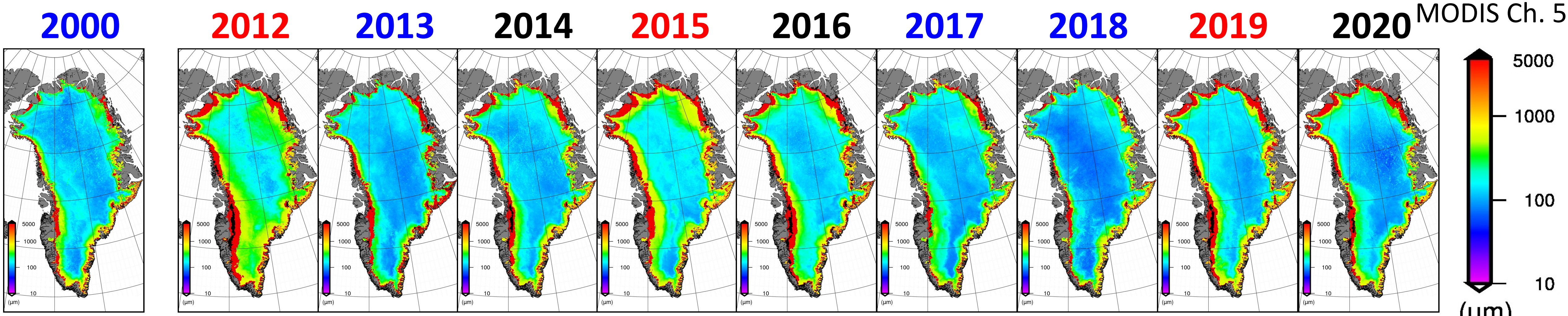

***h* > 3 km**

***h* = 2-3 km**

***h* = 1-2 km**

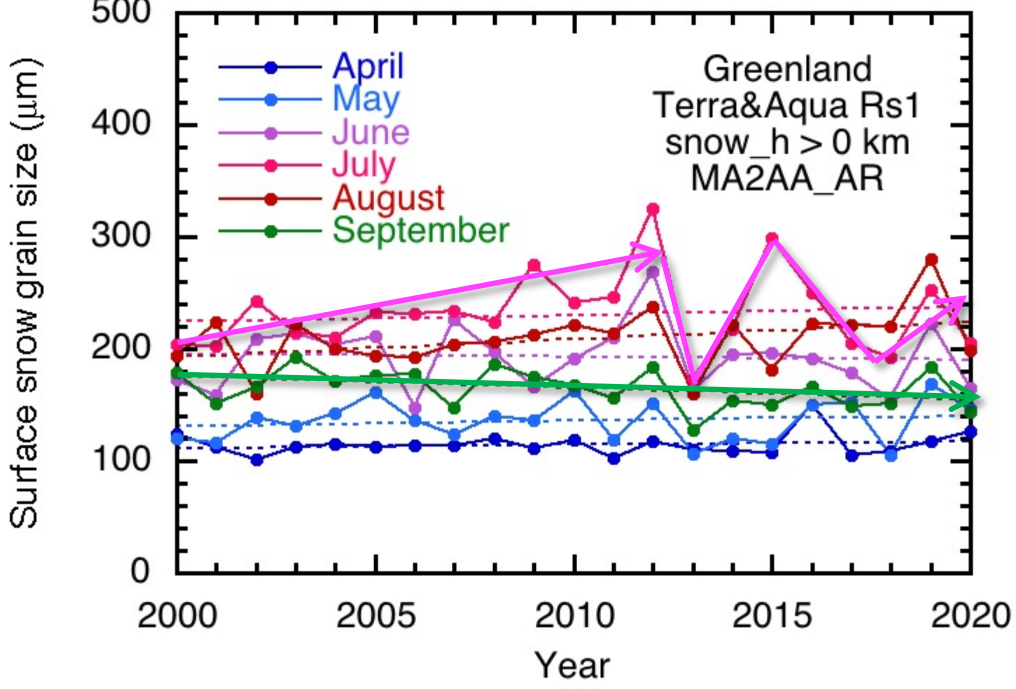
***h* = 0-1 km**

# MODIS-derived snow grain radius (SGR = $R_{s1}$) over snow-covered area



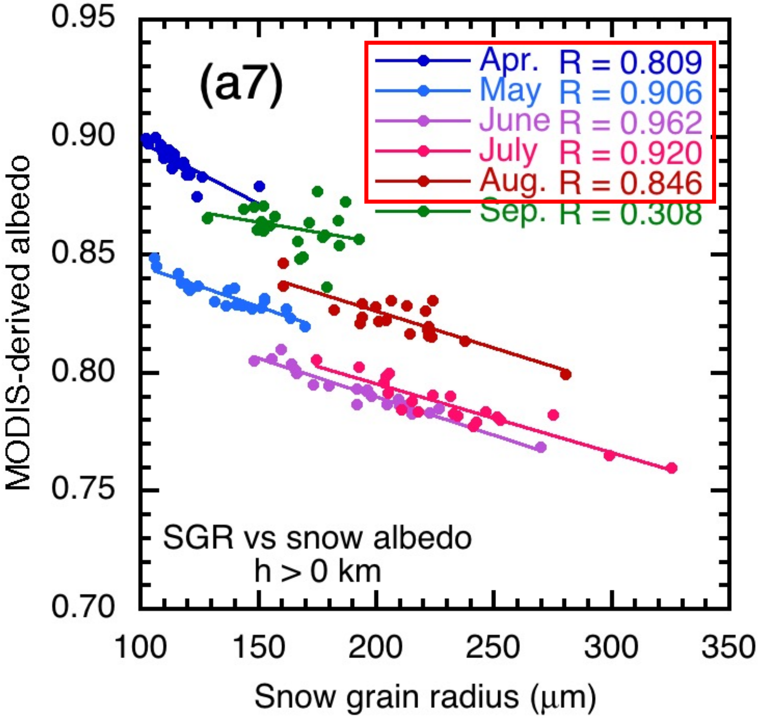

↑ July-mean SGR

SGR averaged over snow-covered area

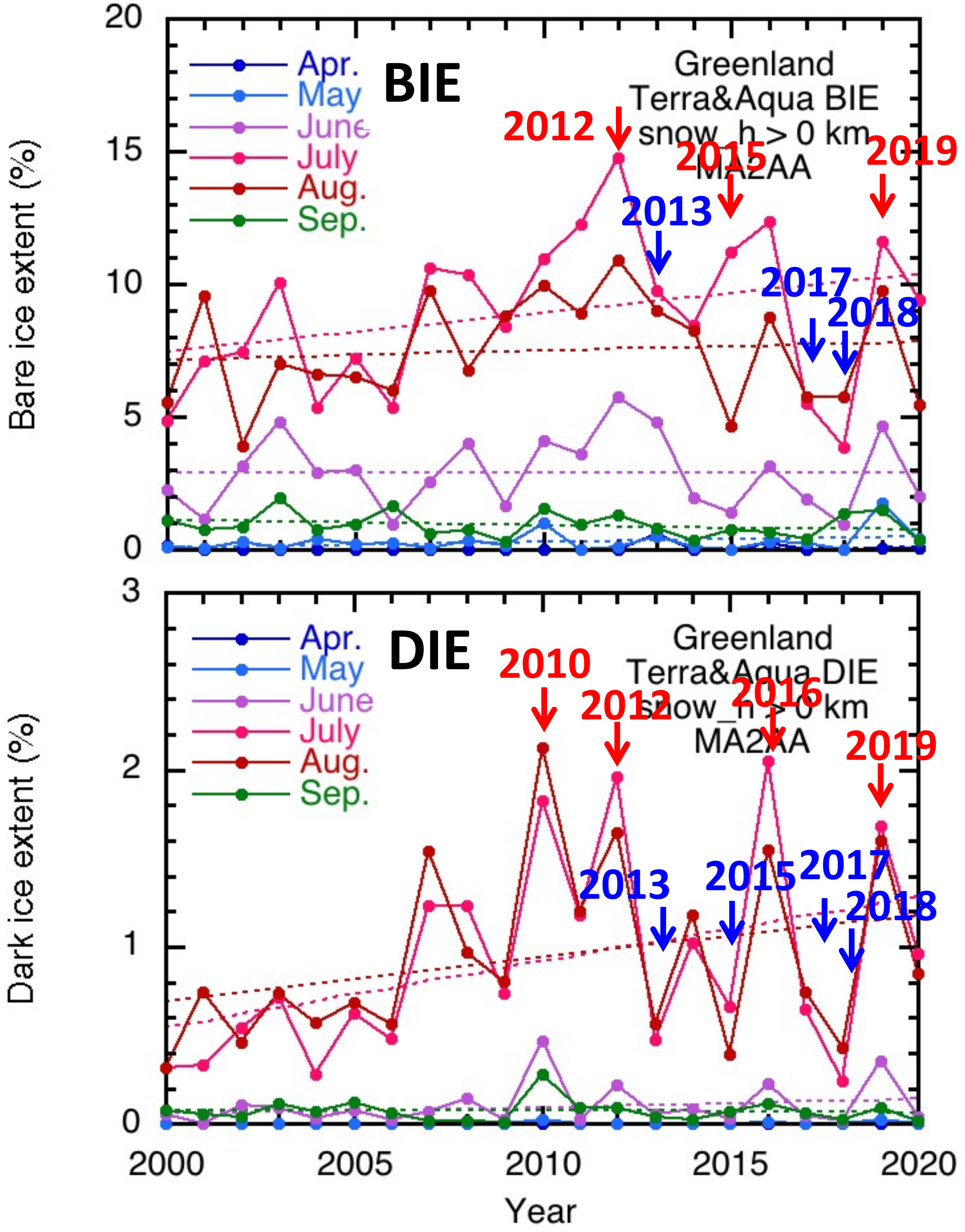



- ✓ Increasing trend in summer season until 2012, but large interannual variation after 2013.
- ✓ Decreasing trend in September
- ✓ Highly correlation with albedo over snow surface.

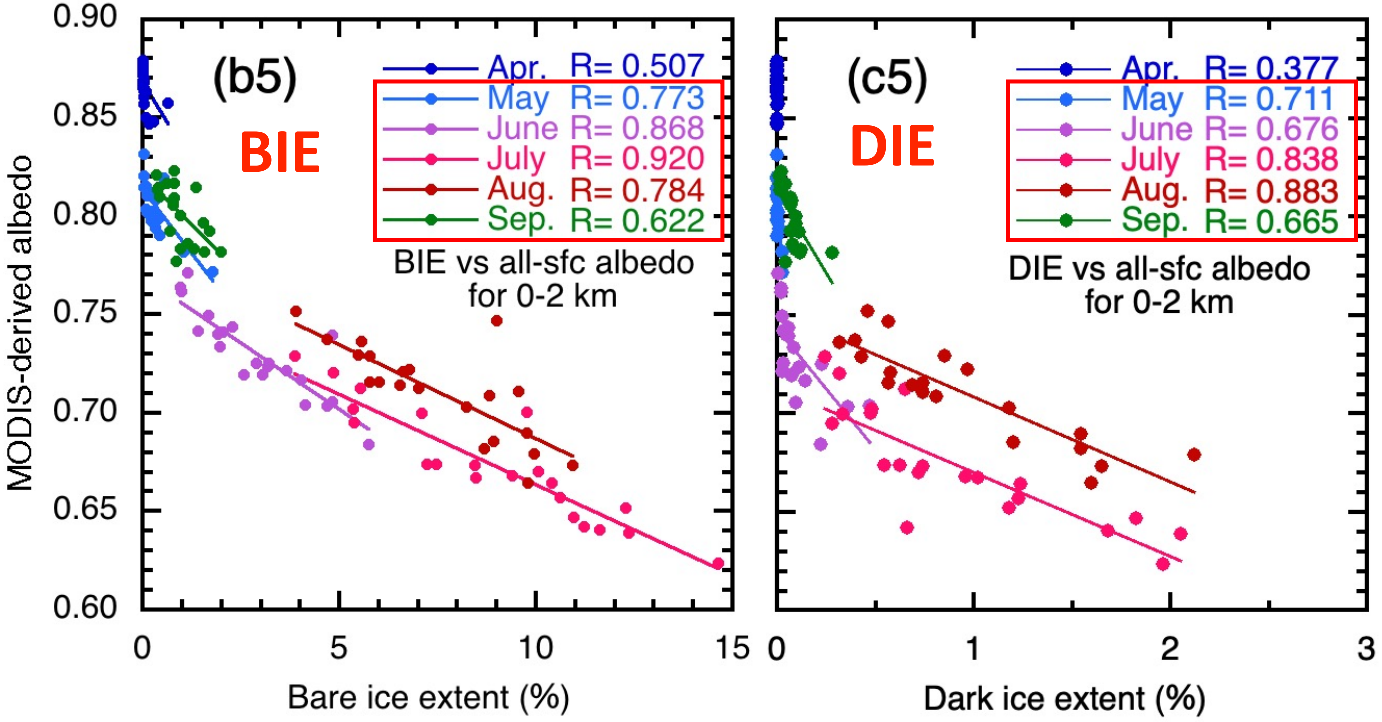
| Statistic significance to albedo | |
|---|---|
| SGR | $p < 0.01$ (Apr. - Aug.) |



# Bare ice extent (BIE) and dark ice extent (DIE) over GrIS




← BIE variation is almost the same as that of SGR, while DIE variation differs from that of BIE in some years, suggesting DIE could be affected by other factors such as nutrient.

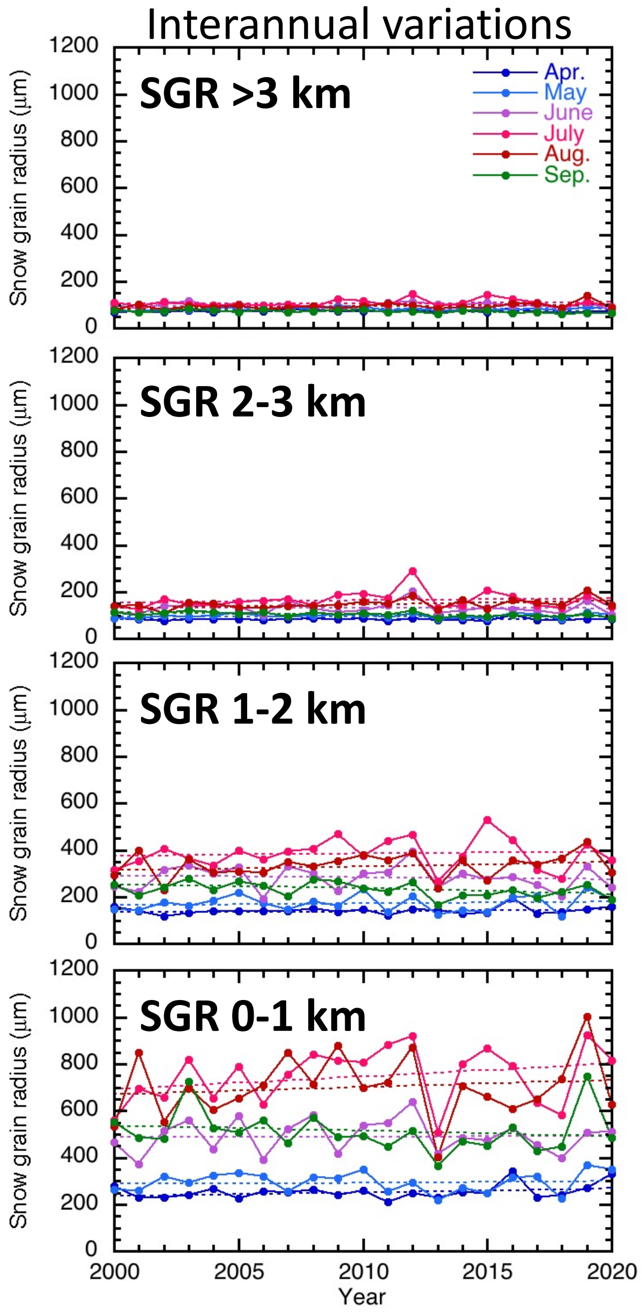


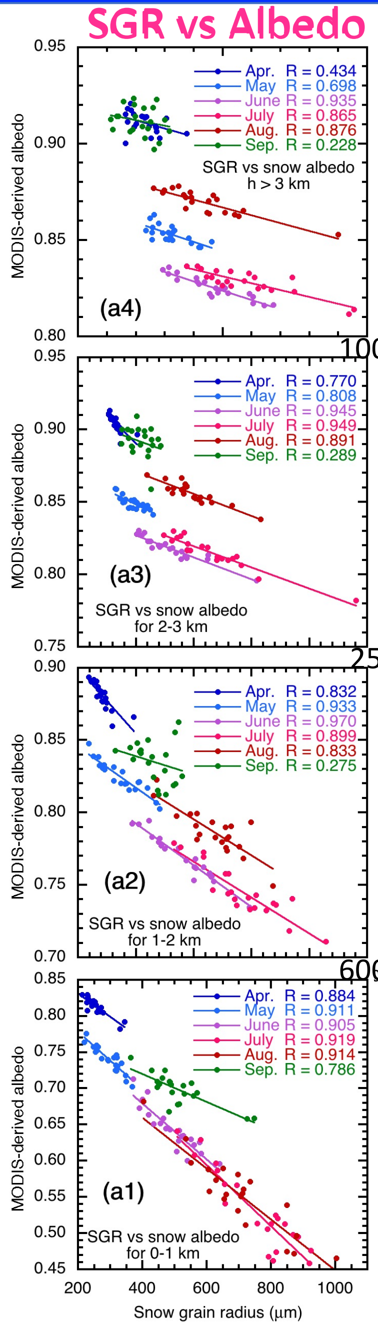

✓ BIE correlates with $\alpha$ ($p<0.01$) for $h<2$ km, in summer season (May – Aug.), and DIE correlates with $\alpha$ ($p<0.01$) in July and Aug.

*No BIE & DIE for $h$ > 2km.

| Statistic significance to albedo | |
|---|---|
| BIE | p < 0.01 (May – Aug.) |
| DIE | p < 0.01 (May – Sep.) |

# SGR, BIE and DIE and their relations with albedo at different elevation zones




## SGR:

- ✓ Larger absolute values and variations at lower *h*
- ✓ High correlation with May - Aug. albedos at any *h*.

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## BIE:

- ✓ Larger variations at *h* = 1-2 km than 0-1 km
- ✓ High correlation with May - Aug. albedos.

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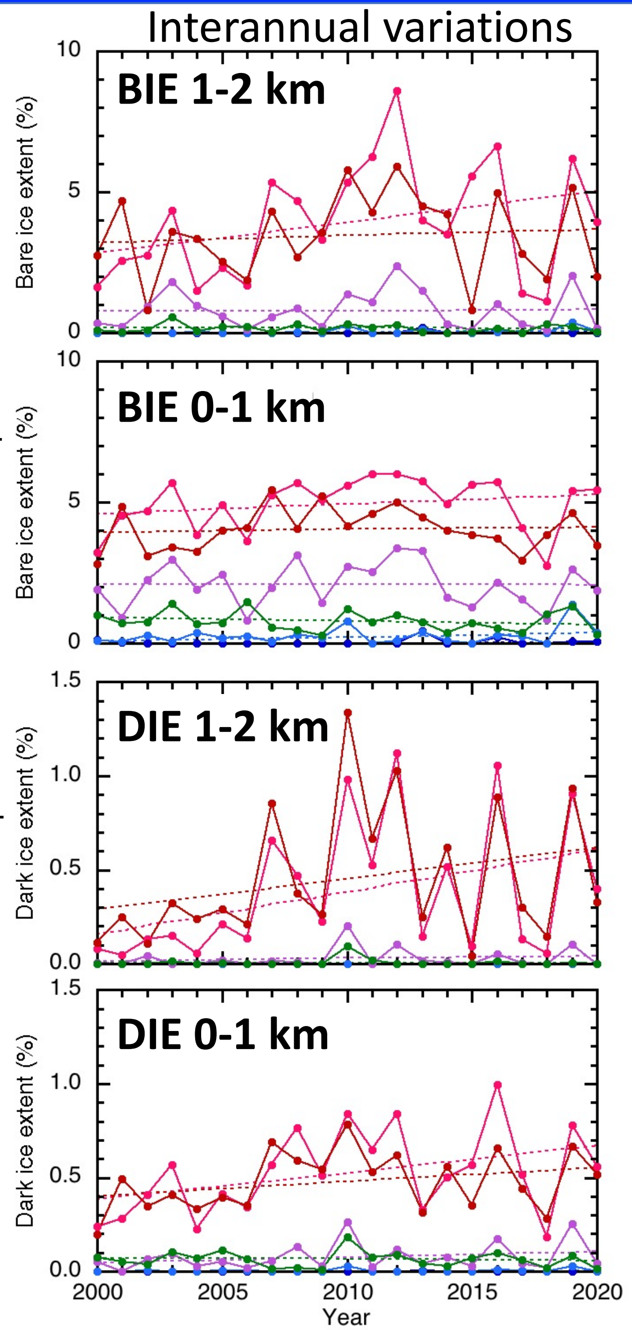
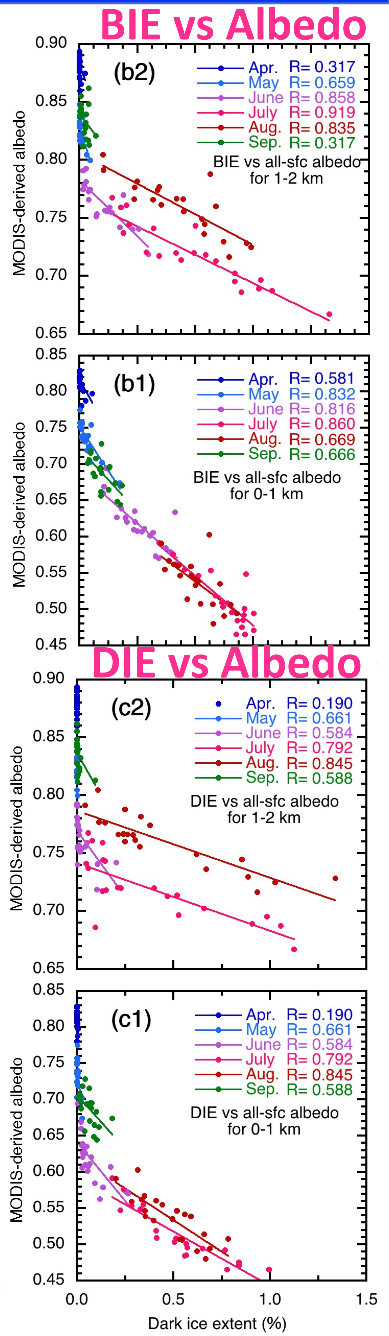
## DIE :

- ✓ Larger variation and increasing rate at *h* = 1-2 km than 0-1 km
- ✓ High correlation with July - Aug. albedos.



# Summary in FY2021

1. nterannual and seasonal variations of snow grain radius (SGR), bare ice extent (BIE) and dark ice extent (DIE) (called “surface physical parameters”) at different elevation zones over the Greenland Ice Sheet since 2000 from MODIS data and their correlations to the surface albedo were analyzed.

2. A statistically significant decrease of surface albedo and an increase of those surface physical parameters were observed from 2000 to 2012, whereas their variations have fluctuated interannually since 2013.

3. Analyses of correlations of surface physical parameters to albedo revealed that:

- ✓ Albedo over the snow-covered region at any elevation is controlled by the SGR and that at an elevation lower than 2 km by the BIE and DIE,
- ✓ Absolute values of SGR and their interannual variations are larger at lower elevations,
- ✓ Interannual variations of BIE and DIE at h = 1-2 km are larger than 0-1 km and increased recently, suggesting a shift of influence of warming climate to the higher elevations.

4. The positive slope of linear regression of interannual variations in albedo and the negative slopes for SGR and BIE are found in only September, suggesting a possible increase in snowfall amount or frequency.

# Publications in FY2019-2021 (1)


**2019**

Uetake, J., N. Nagatsuka, Y. Onuma, N. Takeuchi, H. Motoyama, and T. Aoki, (2019): Bacterial community changes with granule size in cryoconite and their susceptibility to exogenous nutrients on NW Greenland glaciers. *FEMS Microbiology Ecology*, **95**, fiz075, doi: 10.1093/femsec/fiz075.

Niwano, M., A. Hashimoto and T. Aoki, (2019): Cloud-driven modulations of Greenland ice sheet surface melt. *Scientific Reports*, **9**:10380, doi: 10.1038/s41598-019-46152-5.

Kokhanovsky, A. A., M. Lamare, O. Danne, M. Dumont, C. Brockmann, G. Picard, L. Arnaud, V. Favier, B. Jourdain, E. Lemeur, B. Di Mauro, T. Aoki, M. Niwano, V. Rozanov, S. Korkin, S. Kipfstuhl, J. Freitag, M. Hoerhold, A. Zuh, D. Vladimirova, A.-K. Faber, H.-C. Larsen, S. Wahl, J. Andresen, B. Vandecrux, D. van As, K. Mankoff, M. Kern, E. Zege, and J. Box, (2019): Retrieval of snow properties from the Sentinel-3 Ocean and Land Colour Instrument. *Remote Sensing*, **11**, 2280; doi:10.3390/rs11192280.

Yamaguchi, S., Ishizaka, M., Motoyoshi, H., Nakai, S., Vionnet, V., Aoki, T., Yamashita, K., Hashimoto, A., and Hachikubo, A.: Measurement of specific surface area of fresh solid precipitation particles in heavy snowfall regions of Japan. *The Cryosphere*, **13**, 2713–2732, doi: 10.5194/tc-13-2713-2019.

Yogo, Y., Y. Ioka, T. Tanikawa, M. Hosaka, H. Ishida, and T. Aoki, (2019): Algorithm Theoretical Basis for the Himawari-8, -9/AHI Cryosphere Product, Part 1: Snow Cover. *Meteorological Satellite Center Technical Note,* **64**, 1-12.

Ioka, Y., Y. Yogo, T. Tanikawa, M. Hosaka, H. Ishida, and T. Aoki, (2019): Algorithm Theoretical Basis for the Himawari-8, -9/AHI Cryosphere Product, Part 2: Sea Ice Distribution. *Meteorological Satellite Center Technical Note,* **64**, 13-21.

Mori, T., Goto-Azuma, K., Kondo, Y., Ogawa-Tsukagawa, Y., Miura, K., Hirabayashi, M., Oshima, N., Koike, M., Kupiainen, K., Moteki, N., Ohata, S., Sinha, P. R., Sugiura, K., Aoki, T., Schneebeli, M., Steffen, K., Sato, A., Tsushima, A., Makarov, V., Omiya, S., Sugimoto, A., Takano, S. and Nagatsuka, N, 2019: Black Carbon and Inorganic Aerosols in Arctic Snowpack, *J. Geophys. Res. Atmos.,* **124**., 13325-13356, 10.1029/2019JD030623.

**2020**

Toyoda, T., T. Aoki, M. Niwano, T. Tanikawa, S. Urakawa, H. Tsujino, H. Nakano, K. Sakamoto, N. Hirose, G. Yamanaka, 2020: Impact of observation-based snow albedo parameterization on global ocean simulation results. *Polar Science*, **23**, doi:10.1016/j.polar.2020.100521.

Onuma, O., N. Takeuchi, S. Tanaka, N. Nagatsuka, M. Niwano, and T. Aoki, 2020: Temporal changes in snow albedo, including the possible effects of red algal growth, in northwest Greenland, simulated with a physically based snow albedo model. *The Cryosphere,* **14**, 2087–2101, doi:10.5194/tc-14-2087-2020.

Tanikawa, T., K. Kuchiki, T. Aoki, H. Ishimoto, M. Niwano, M. Hosaka, S. Matoba, Y. Kodama, Y. Iwata, and K. Stamnes, 2020: Effects of snow grain shape and mixing state of snow impurity on retrieval of snow physical parameters from ground-based optical instrument. *J. Geophys. Res. Atmos.,* **125**., e2019JD031858, doi:10.1029/2019JD031858.

Kurosaki, Y., S. Matoba, Y. Iizuka, M. Niwano, T. Tanikawa, T. Ando, A. Hori, and T. Aoki, 2020: Reconstruction of sea ice concentration in northern Baffin Bay using deuterium excess in coastal ice core from Greenland. *J. Geophys. Res. Atmos.,* **125**, e2019JD031668, doi:10.1029/2019JD031668.

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Goto-Azuma, K., T. Homma, T. Saruya, F. Nakazawa, Y. Komuro, N. Nagatsukaa, M. Hirabayashi, Y. Kondo, M. Koike, T. Aoki, R. Grevee, and J. Okuno, 2020: Studies on the variability of the Greenland Ice Sheet and climate. *Polar Science*, **27**, 100557, doi:10.1016/j.polar.2020.100557.

Amino, T., Y. Iizuka, S. Matoba, R. Shimada, N. Oshima, T. Suzuki, T. Ando, T. Aoki, K. Fujita, 2020: Increasing dust emission from ice free terrain in southeastern Greenland since 2000. *Polar Science*, **27**, 100599, doi.org:10.1016/j.polar.2020.100599. .

Sugiyama, S., N. Kanna, D. Sakakibara, T. Ando, I. Asaji, K. Kondo, Y. Wang, Y. Fujishi, S. Fukumoto, E. Podolskiy, Y. Fukamachi, M. Takahashi, S. Matoba, Y. Iizuka, R. Greve, M. Furuya, K. Tateyama, T. Watanabe, S. Yamasaki, A. Yamaguchi, B. Nishizawa, K. Matsuno, D. Nomura, Y. Sakuragi, Y. Matsumura, Y. Ohashi, T. Aoki, M. Niwano, N. Hayashi, M. Minowa, G. Jouvet, E. van Dongen, A. Bauder, M. Funk, A. Anker Bjørk, T. Oshima: Rapidly changing glaciers, ocean and coastal environments, and their impact on human society in the Qaanaaq region, northwestern Greenland, *Polar Science*, **27**, 100632, doi:10.1016/j.polar.2020.100632.

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青木輝夫, 的場澄人, 庭野匡思, 朽木勝幸, 谷川朋範, 竹内望, 山口悟, 本山秀明, 藤田耕史, 山崎哲秀, 飯塚芳徳, 堀雅裕, 島田利元, 植竹淳, 永塚尚子, 大沼友貴彦, 橋本明弘, 石元裕史, 田中泰宙, 大島長, 梶野瑞王, 足立光司, 保坂征宏, 黒﨑豊, 杉山慎, 津滝俊, 東久美子, 八久保晶弘, 川上薫, 木名瀬健, 2021: SIGMA及び関連プロジェクトによるグリーンランド氷床上の大気・雪氷・雪氷微生物研究–ArCS IIプロジェクトへのつながり–. *雪氷*, **83**(2), 169-191.

廣瀬聡, 青木輝夫, 庭野匡思, 的場澄人, 谷川朋範, 山口悟, 山崎哲秀, 北西グリーンランド氷床上SIGMA-Aサイトで観測された雪面熱収支の特徴. *雪氷*, **83**(2), 143 - 154.

庭野匡思, 青木輝夫: 気象研究所における積雪モデリング研究, *大気化学研究*, **44**, 044A03.

# Publications in FY2019-2021 (3)


**<u>2021</u>**

Nagatsuka, N., K. Goto-Azuma, A. Tsushima, K. Fujita, S. Matoba, Y. Onuma, M. Kadota, M. Minowa, Y. Komuro, H. Motoyama, and T. Aoki, 2021: Variations in mineralogy of dust in an ice core obtained from northwestern Greenland over the past 100 years, https://doi.org/10.5194/cp-17-1341-2021, *Clim. Past*, **17**, 1341–1362.

Fujita, K., S. Matoba, Y. Iizuka, N. Takeuchi, A. Tsushima, Y. Kurosaki, and T. Aoki: 2021: Physically based summer temperature reconstruction from melt layers in ice cores. *Earth Space Sci.*, **8**, e2020EA001590, doi:10.1029/2020EA001590.

Tanikawa, T., K. Masuda, H. Ishimoto, T. Aoki, M. Hori, M. Niwano, A. Hachikubo, S. Matoba, K. Sugiura, T. Toyota, N. Ohkawara, and K. Stamnes, 2021: Spectral degree of linear polarization and neutral points of polarization in snow and ice surface. *J. Quant. Spectrosc. Radiat. Transf.*, **273**, 107845, doi:10.1016/j.jqsrt.2021.107845.

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