Darkening of the Greenland ice sheet by microbes makes it melt faster

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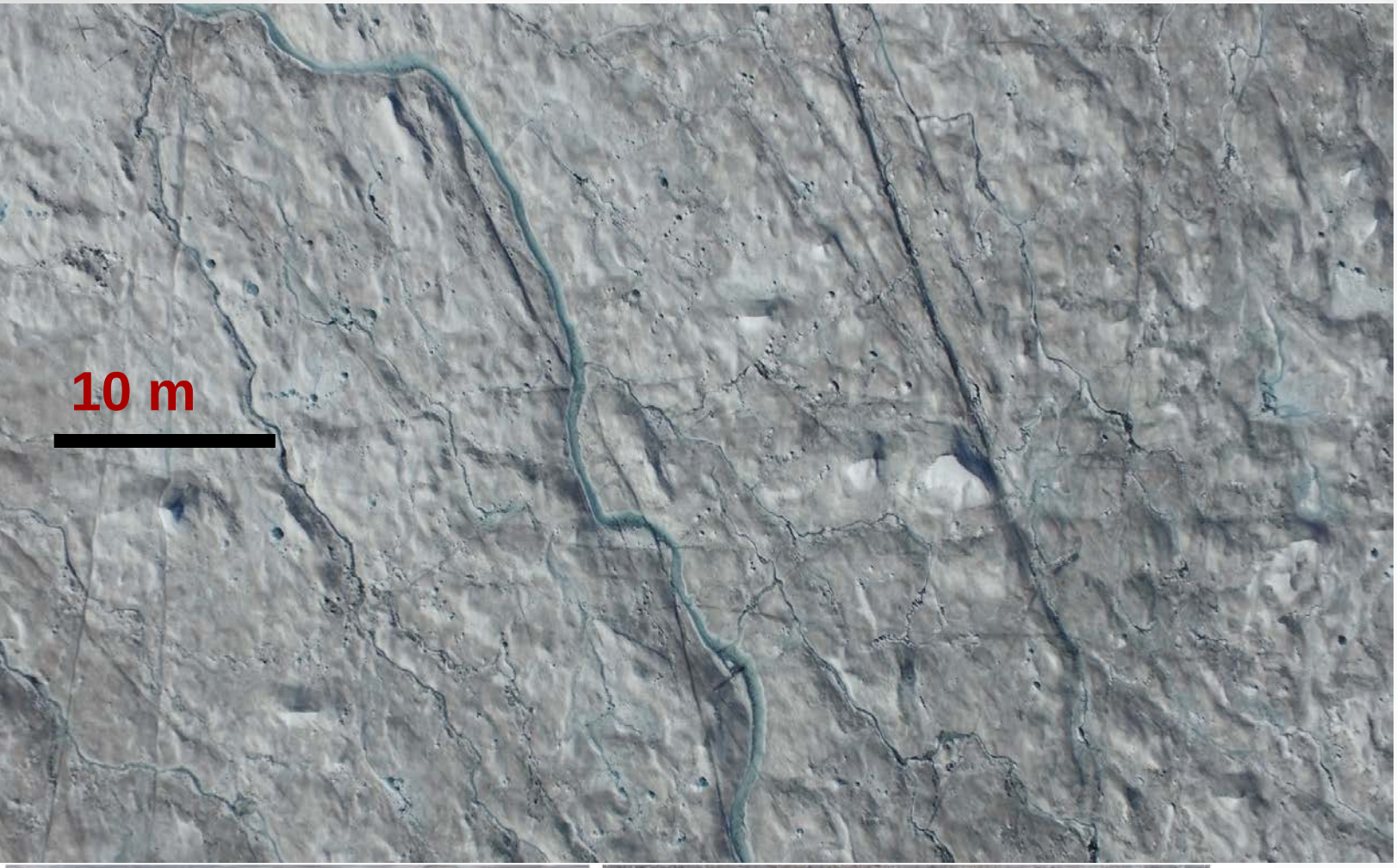
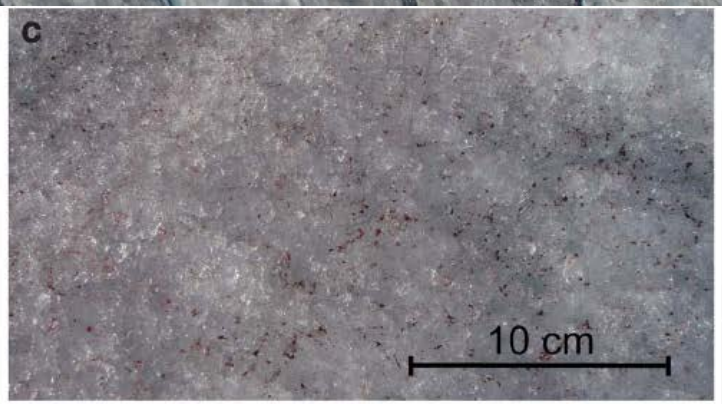
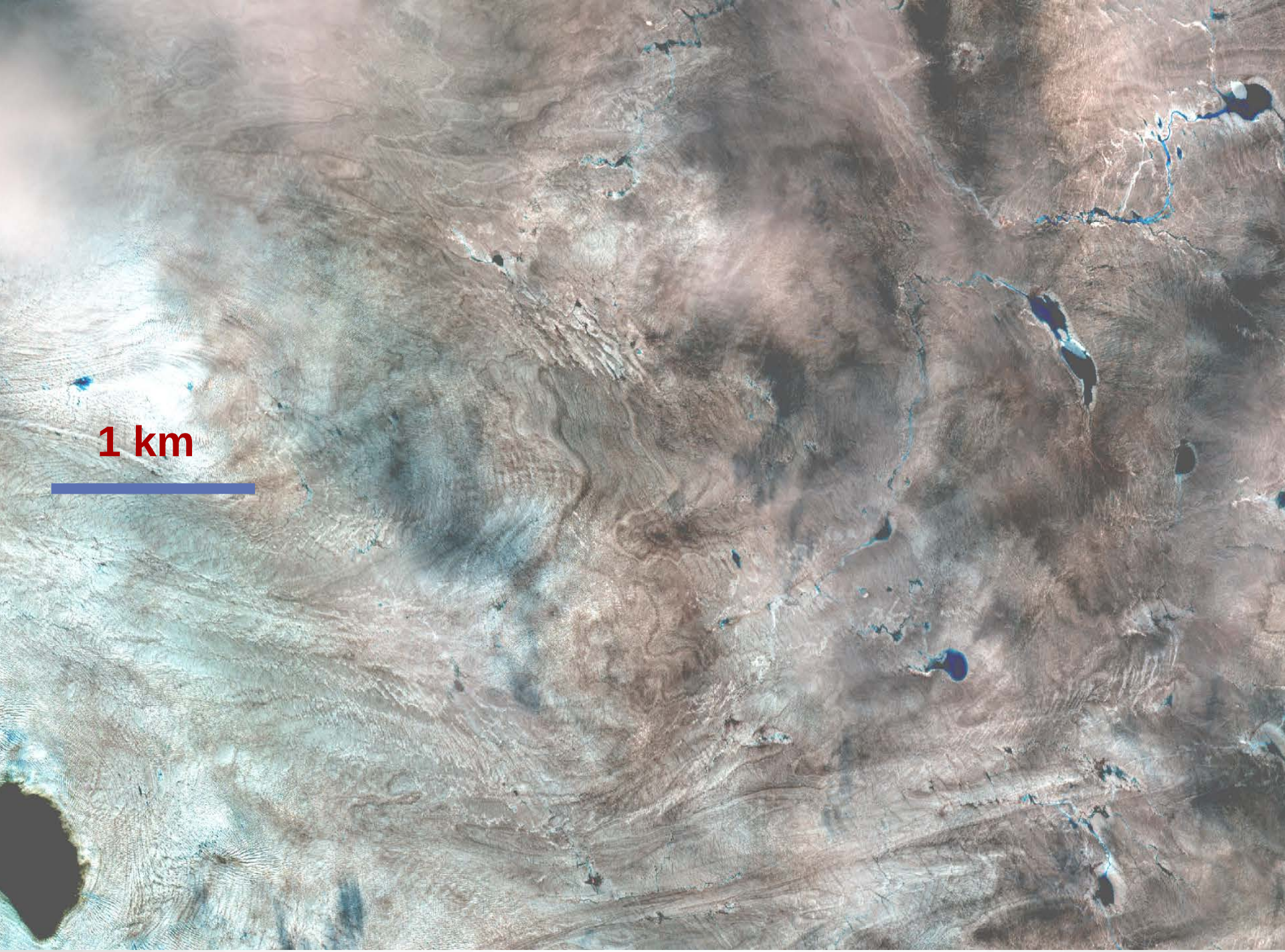
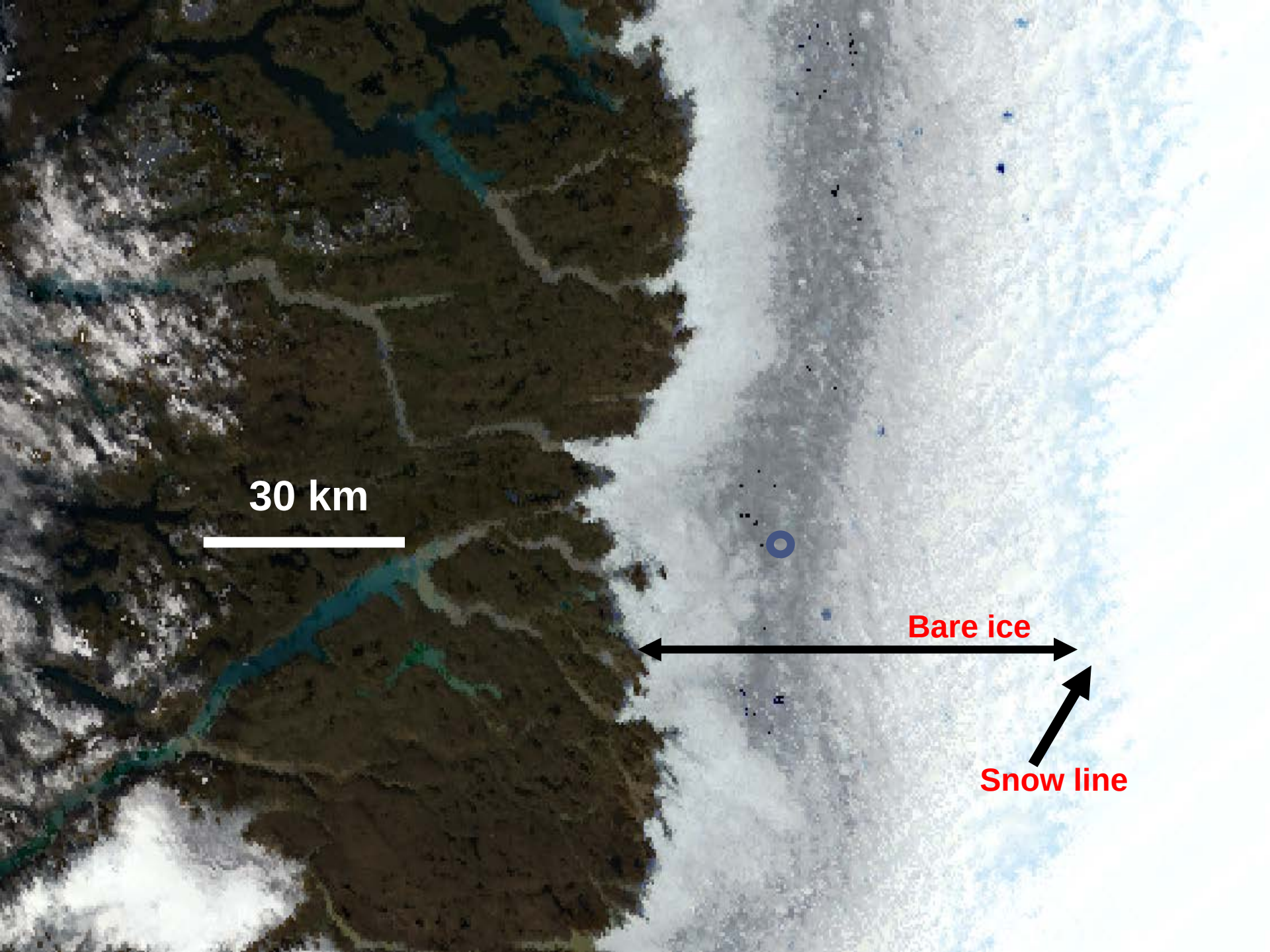
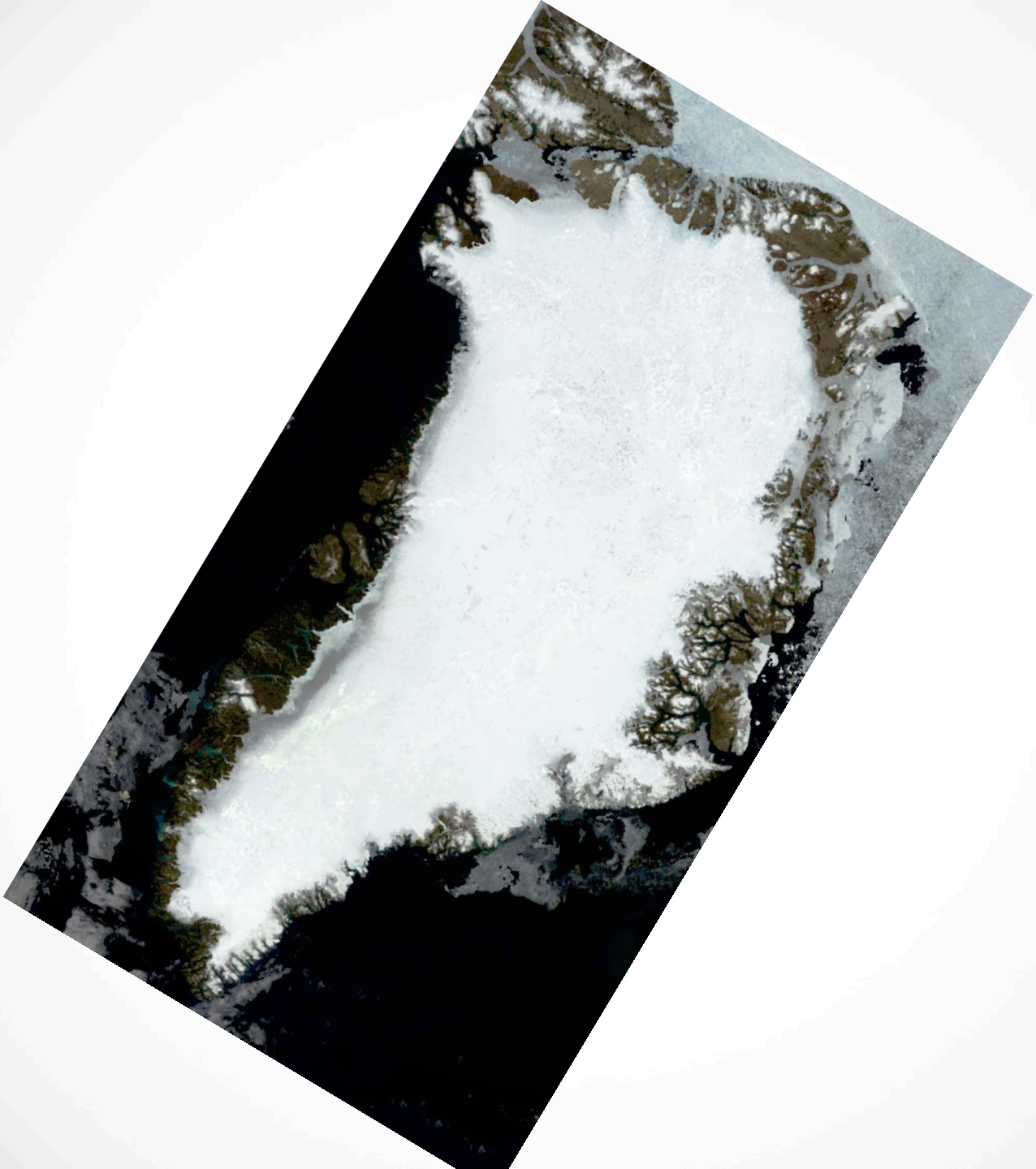

10 m


b
1m


c
10 cm


1 km

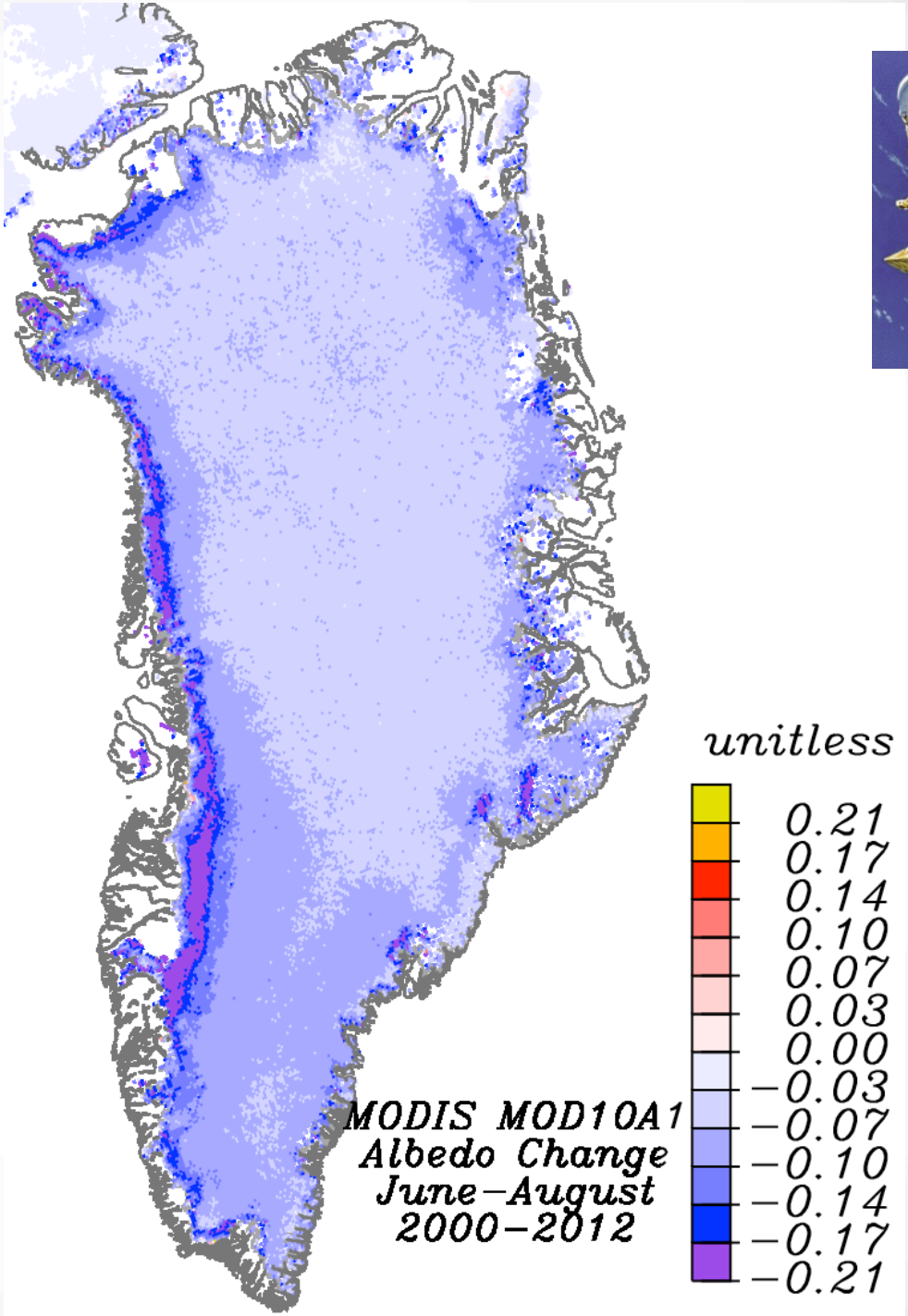

30 km
Bare ice
Snow line



Albedo has changed a lot over last 15 years.

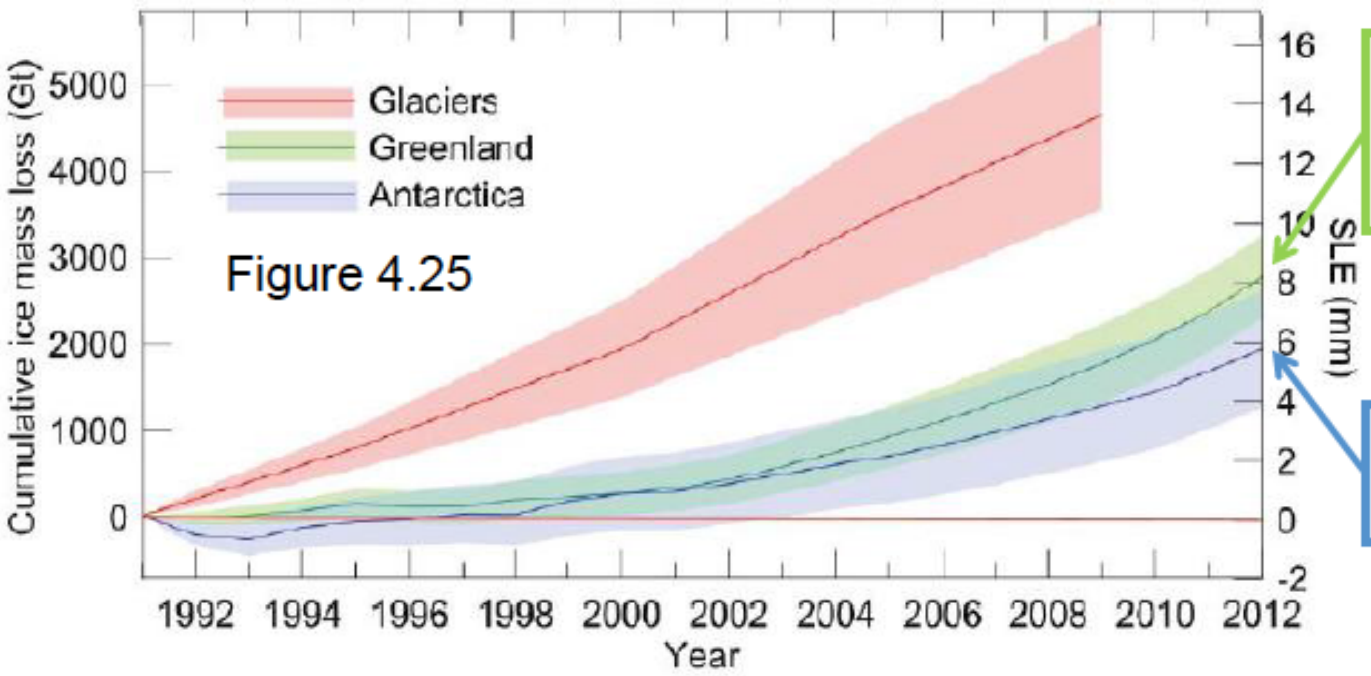
The SW is called the dark zone, and a range of reasons have been put forward to explain its origin.

Black carbon is one of them.



MODIS on Terra

Recent and projected mass loss from the ice sheets



About half due to increased surface melting

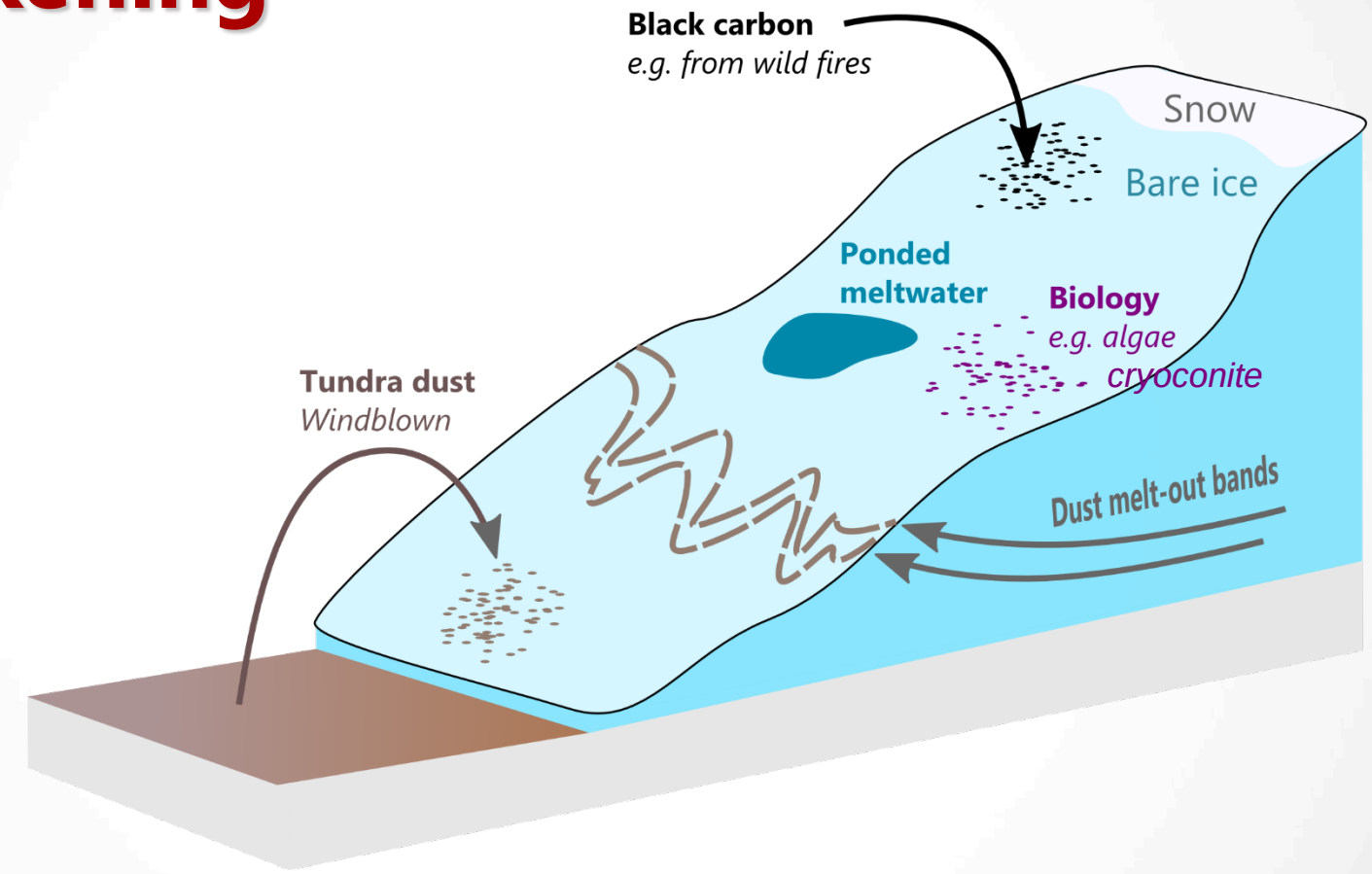
Due to increased ice outflow

High confidence in projections of increasing Greenland surface mass loss.

Medium confidence in projections of increasing Antarctic snow accumulation.

Likely range (*medium confidence*) for the projected contributions from ice-sheet rapid dynamical change, estimated from a combination of process-based modelling, statistical extrapolation of recent trends, and informed judgement.

Sources of darkening



Dillingham, Alaska

http://www.alaskapublic.org/2012/11/08/freezing-rain-snow-quells-dillingham-area-blaze/

LETTERS
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nature geoscience

Anthropogenic aerosols as a source of ancient dissolved organic matter in glaciers

Aron Stubbins[1]*, Eran Hood[2], Peter A. Raymond[3], George R. Aiken[4], Rachel L. Sleighter[5], Peter J. Hernes[6], David Butman[3], Patrick G. Hatcher[5], Robert G. Striegl[4], Paul Schuster[4], Hussain A. N. Abdulla[5], Andrew W. Vermilyea[2], Durelle T. Scott[7] and Robert G. M. Spencer[8]

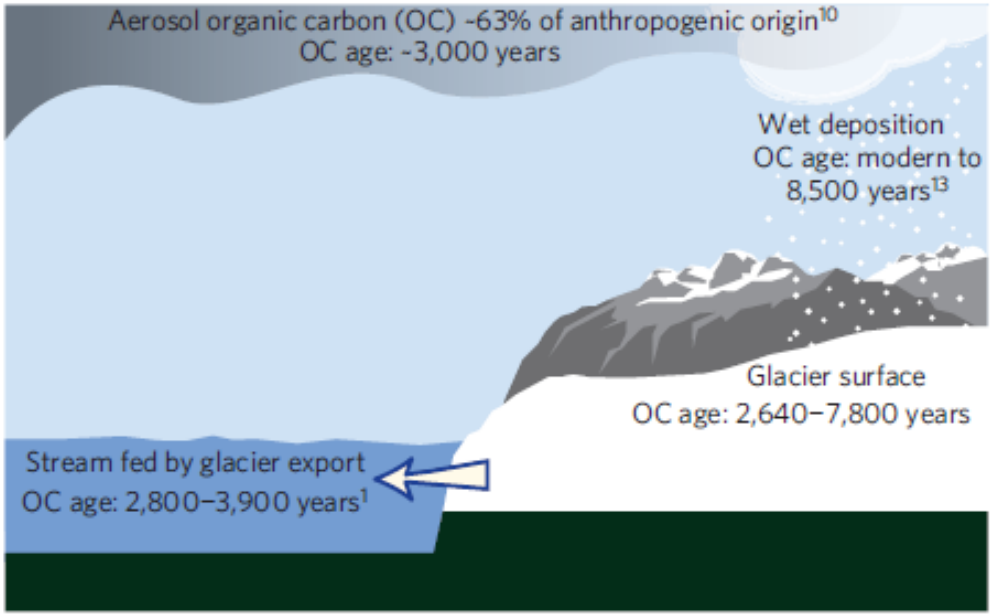
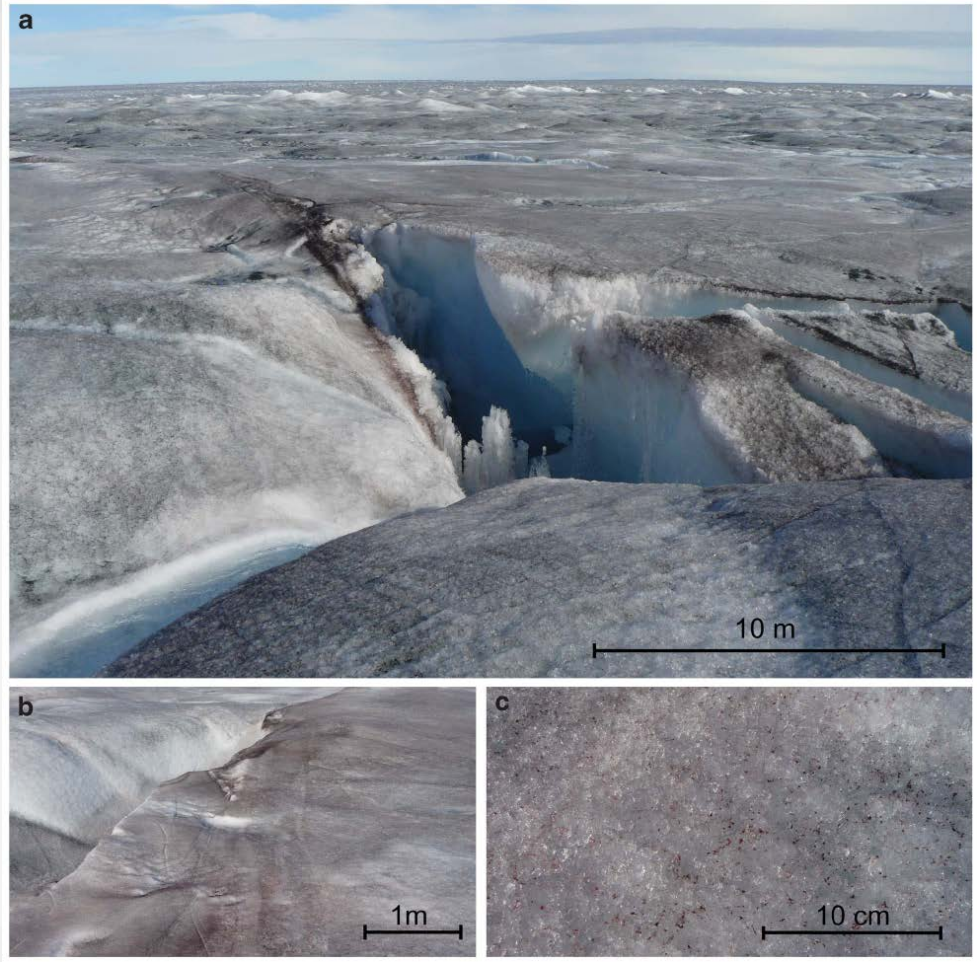
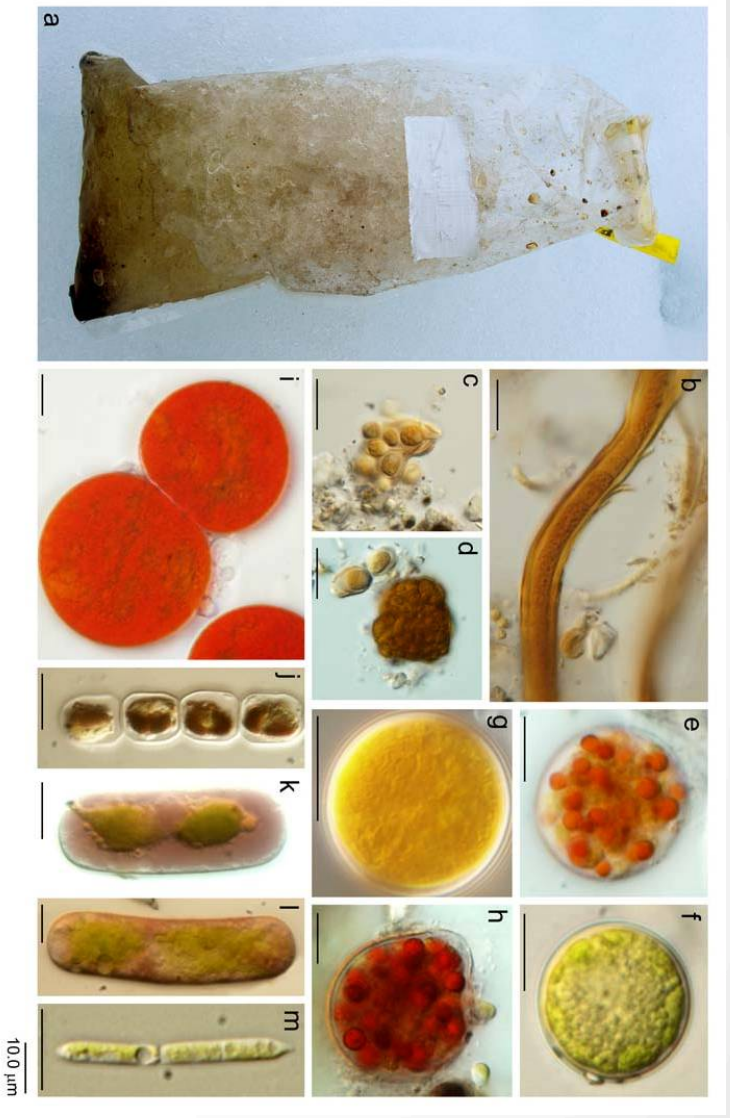


Figure 1 | The glacier organic carbon cycle, including apparent radiocarbon ages associated with the organic carbon fluxes.





Yallop, Anesio et al. 2012. *ISME Journal*

University of BRISTOL

Darkening of GrIS driven by photo-inhibition of ice algal communities

What regulates ice algal biomass and pigment content on the GrIS??

- The magnitude of bio-albedo reduction is dependent on **algal biomass** and **pigment content**

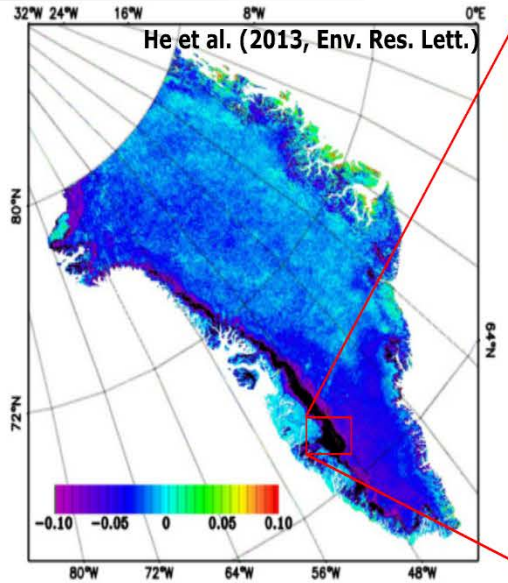


Fig. 1: Decadal rate of change in July albedo of GrIS from 2000 - 2012 shows obvious darkening along the west

Fig. 2: Western GrIS surface habitats show highly-visible loadings of albedo-reducing impurities

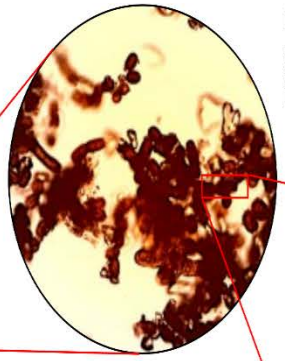


Fig. 3: Impurities include inorganic particles and heavily pigmented ice algal communities

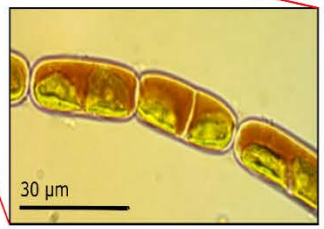
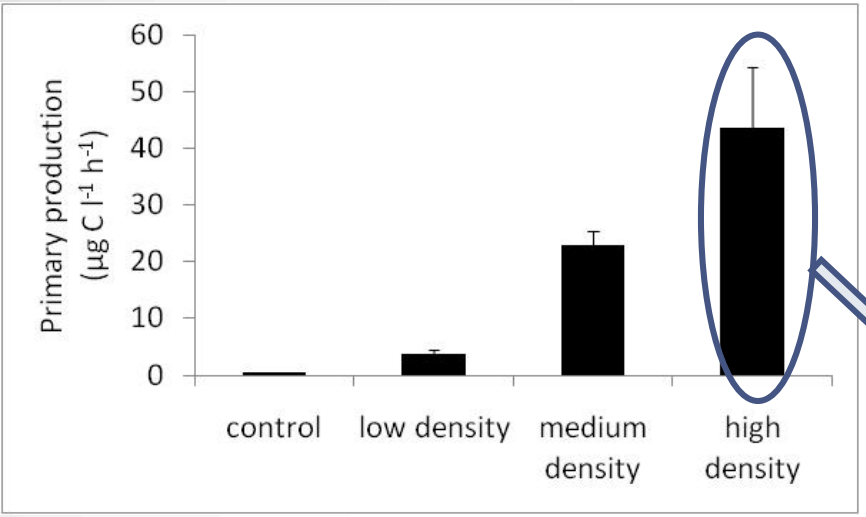
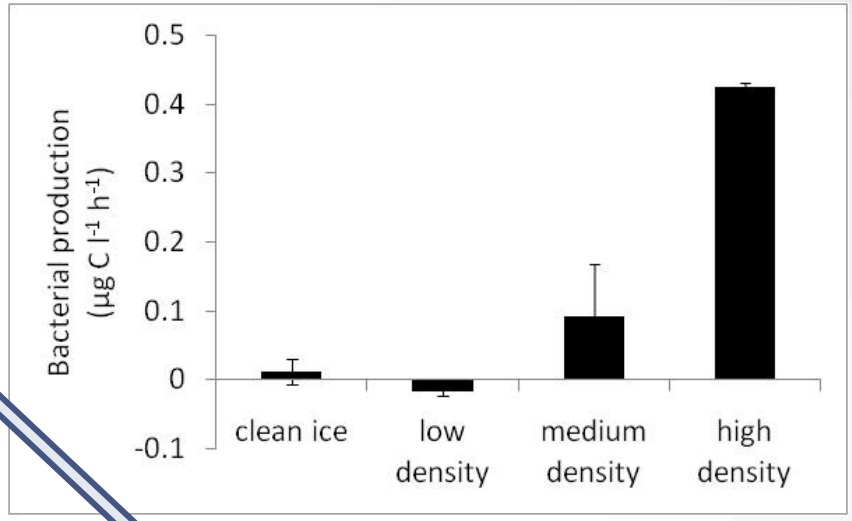


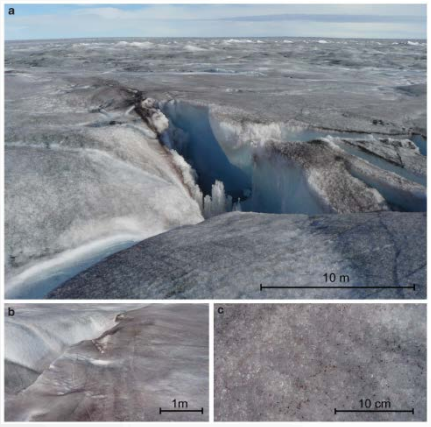
Fig. 4. Ice algae produce a suite of albedo-reducing carotenoid and purpurogalin pigments to protect chloroplasts from excessive irradiance

Primary production



Bacterial production





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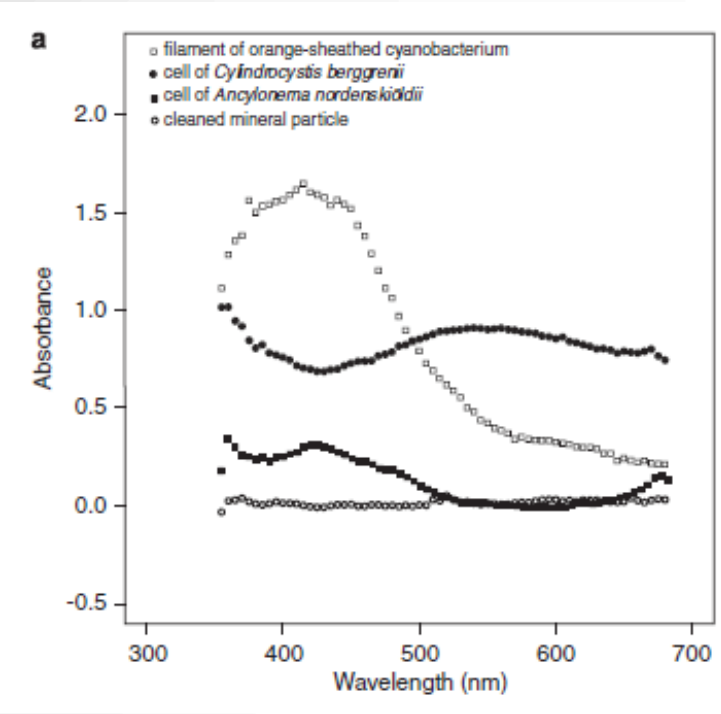
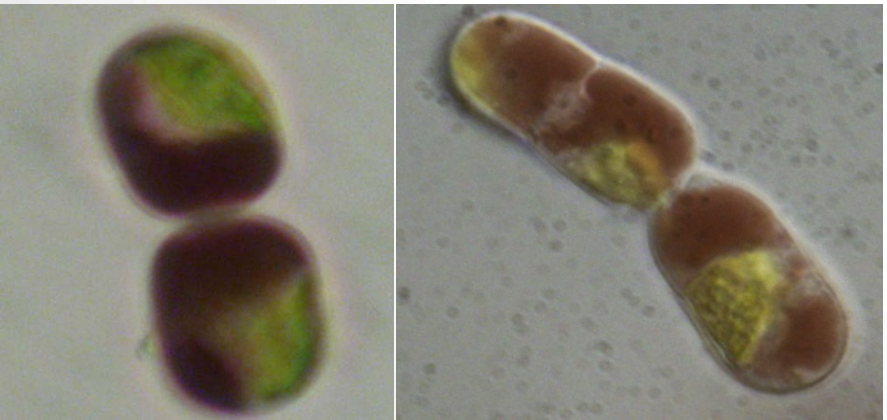
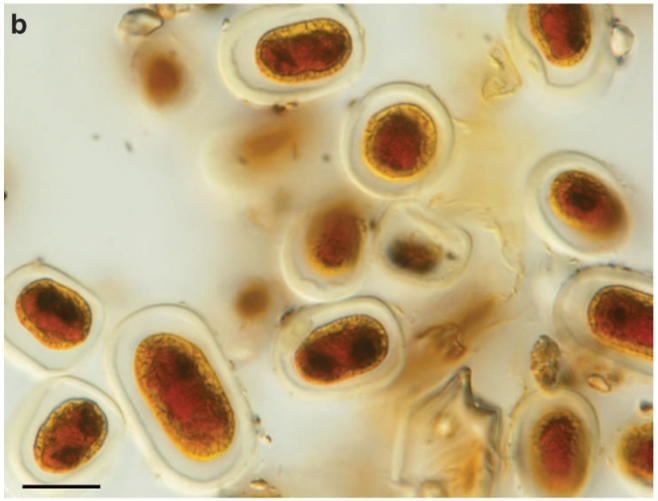
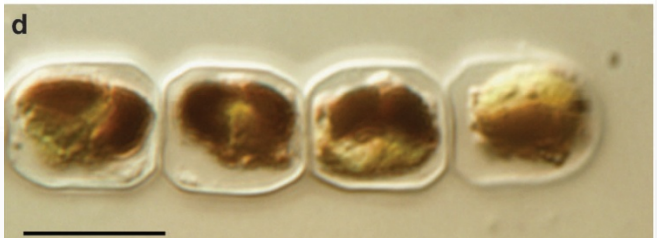
Yallop, Anesio et al. 2012. *ISME Journal*



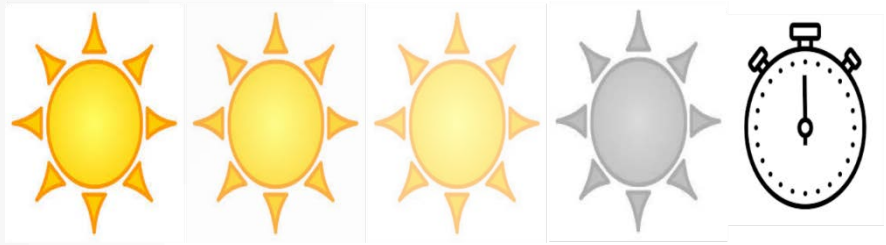
Yallop, et al. 2012. *ISME Journal*







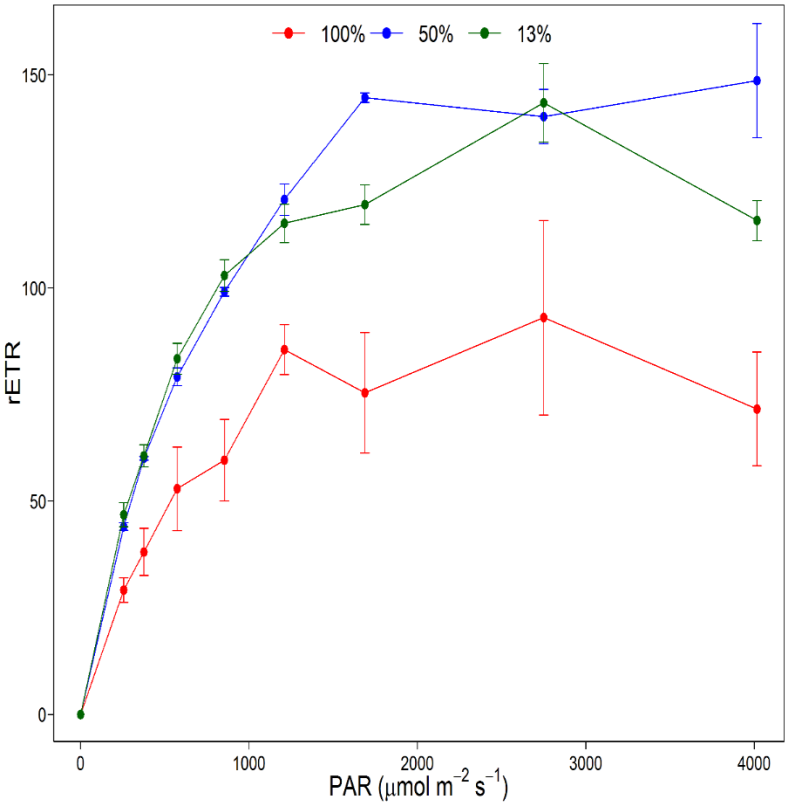
- ***In-situ* manipulative incubations 2: Ambient Nutrients - Irradiance**



100% 50% 13% 0% 24 hr

- Incubated *in-situ* using neutral density filters

Rapid light response curves @ 24 hr



Treatment	Fv/Fm	rETRmax	α	Ek
13 %	0.49 ± 0.02	131 ± 5.6	0.21 ± 0.02	608 ± 62
50 %	0.49 ± 0.08	165 ± 16.5	0.22 ± 0.03	748 ± 104
100 %	0.35 ± 0.03	100 ± 10.7	0.10 ± 0.01	938 ± 86

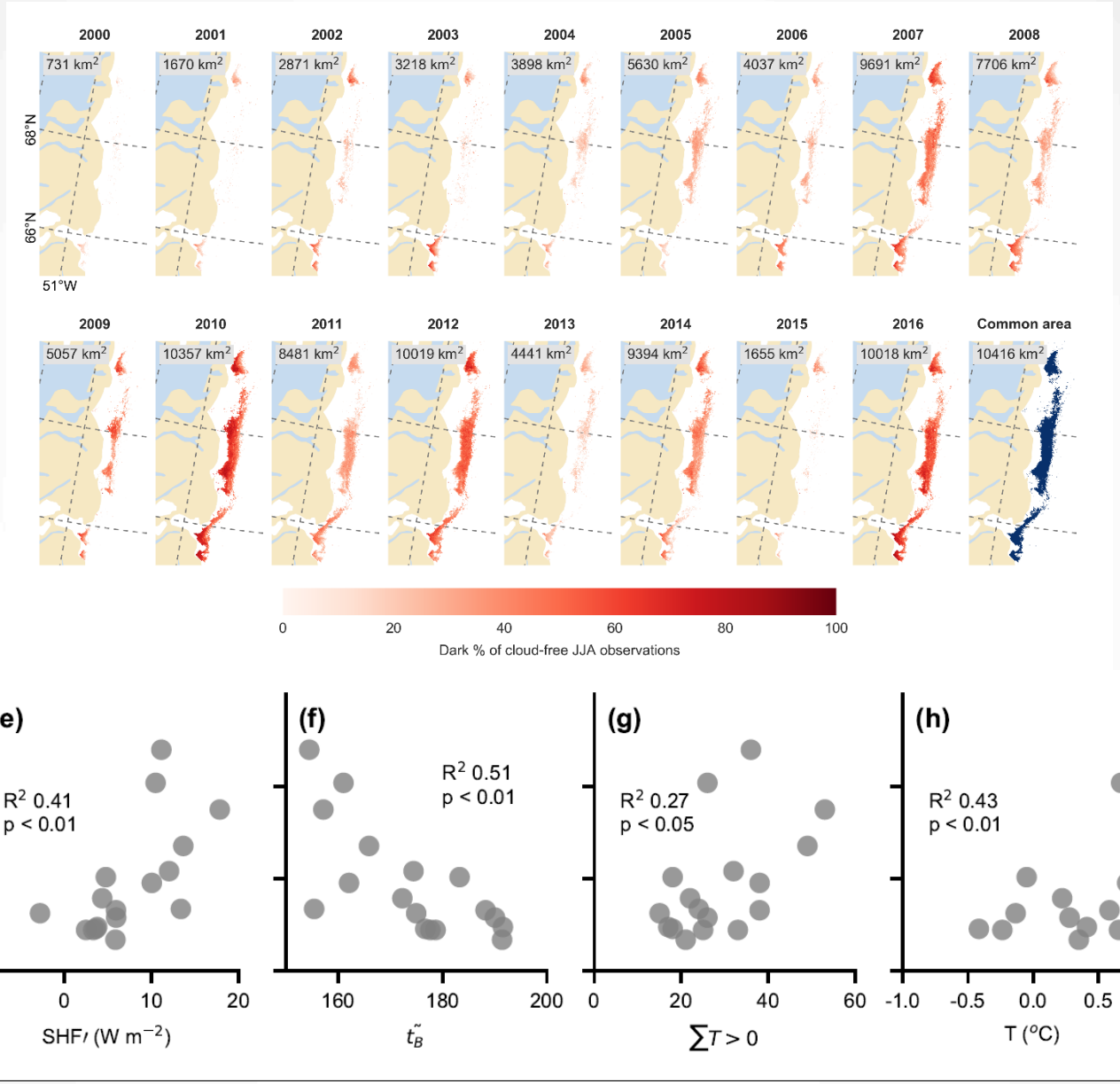
Increased stress

Reduced electron transport

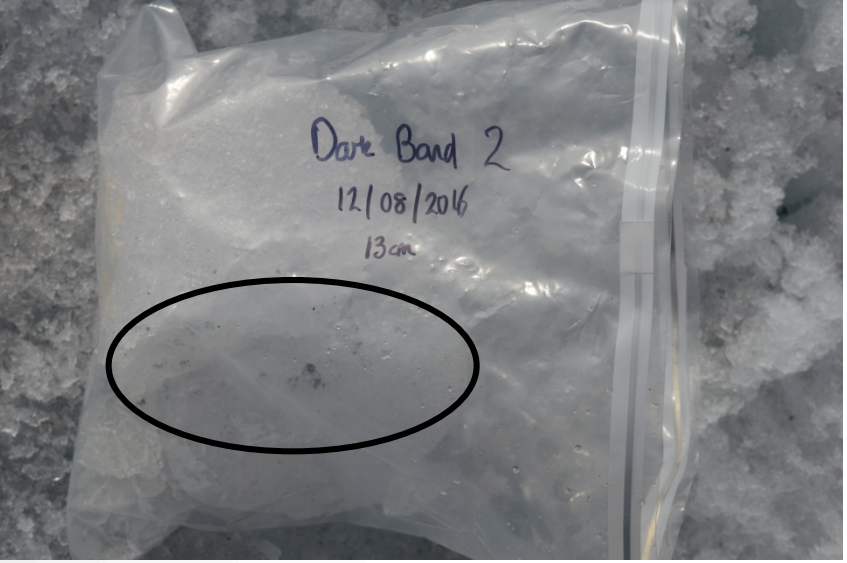
Alteration in pigment content

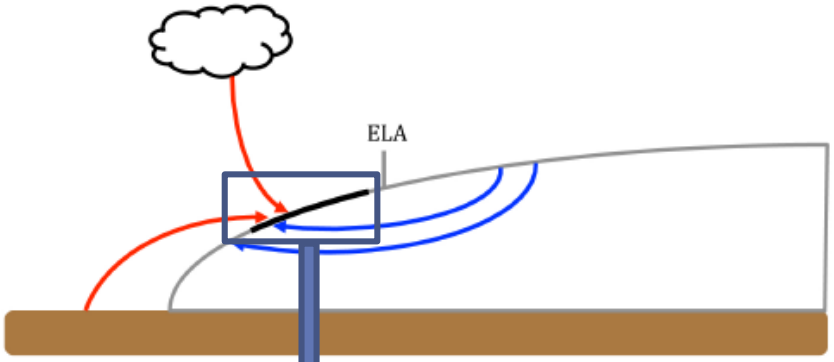
High-light acclimation

Significant limitation of electron transport and down-regulation of photochemistry under ambient irradiance conditions

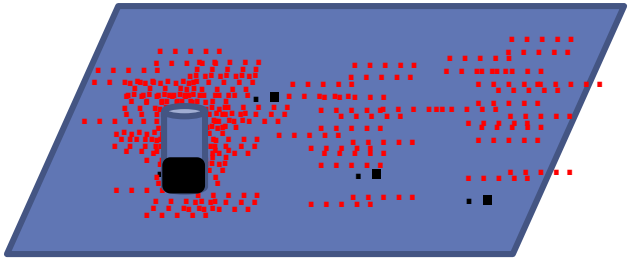

2000
731 km²
2001
1670 km²
2002
2871 km²
2003
3218 km²
2004
3898 km²
2005
5630 km²
2006
4037 km²
2007
9691 km²
2008
7706 km²
68°N
66°N
51°W
2009
5057 km²
2010
10357 km²
2011
8481 km²
2012
10019 km²
2013
4441 km²
2014
9394 km²
2015
1655 km²
2016
10018 km²
Common area
10416 km²
0
20
40
60
80
100
Dark % of cloud-free JJA observations
(e)
R² 0.41
p < 0.01
D_N
SHF′ (W m⁻²)
(f)
R² 0.51
p < 0.01
$\tilde{t_B}$
(g)
R² 0.27
p < 0.05
$\sum T > 0$
(h)
R² 0.43
p < 0.01
T (°C)

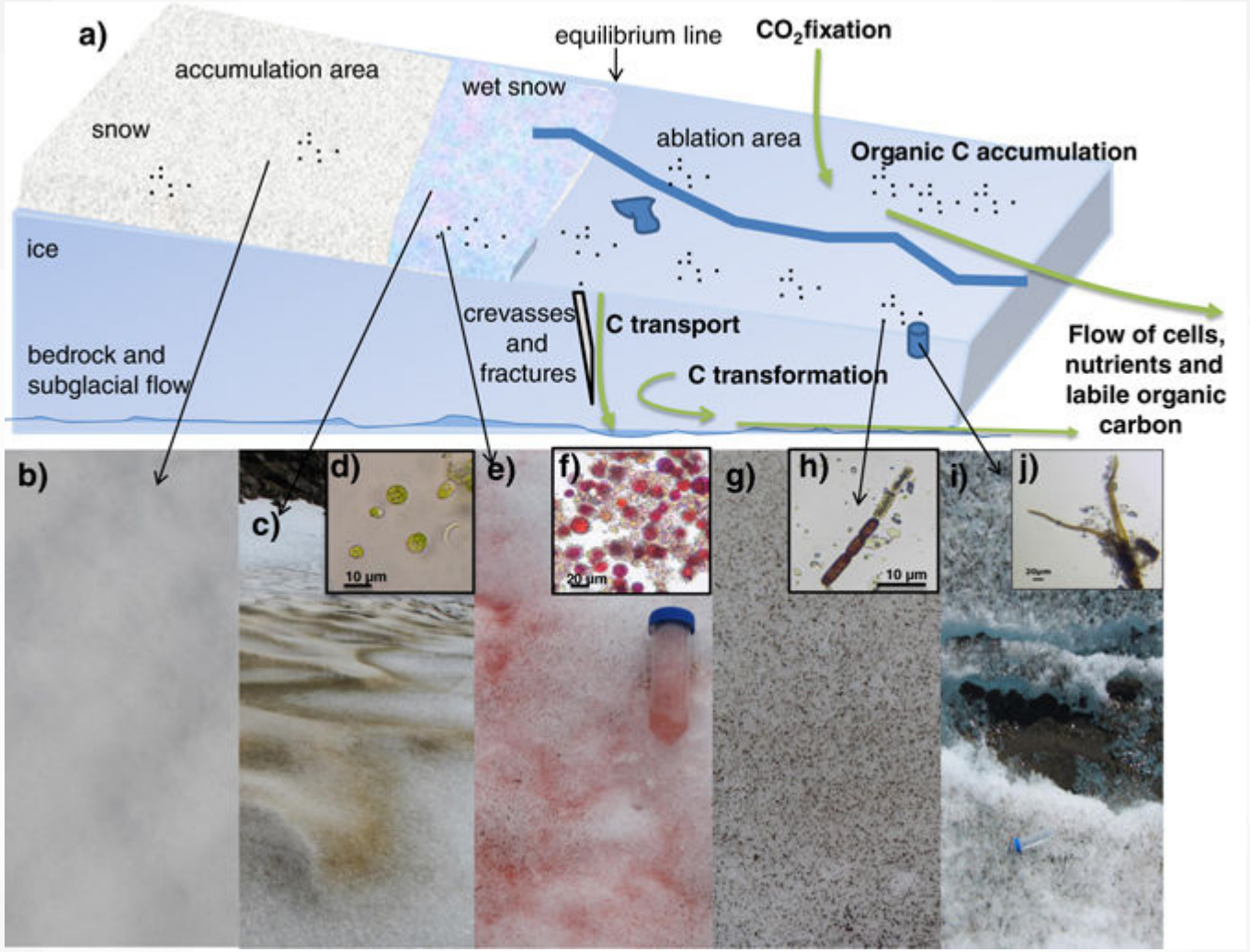
Bio-albedo is a combination of
inorganic impurities
(nutrients)
and **biological growth**
in response to weather and climate





Wientjes et al. 2011. *The Cryosphere*





Anesio et al. 2017. *npj Biofilms and Microbiomes*

Opportunities

- Links with ocean productivity

Thank you

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SCIENCE OF THE ENVIRONMENT

Marie Curie Actions
Human resources and mobility

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THE ROYAL SOCIETY

The Leverhulme Trust