Analyse de la baisse récente de l'albedo du Groenland

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METEO FRANCE | CNRS | LGGE Laboratoire de Glaciologie et Géophysique de l'Environnement | Université Joseph Fourier Sciences. Technologie. Médecine | OSUG Observatoire des Sciences de l'Univers de Grenoble

Plan

- Quelques faits sur l'évolution récente du Groenland
- Revisite de la baisse récente de l'albedo :
  focalisation sur la zone d'accumulation et le printemps
- Assombrissement systématique au printemps depuis 2009
- Role des impuretés à la surface de la neige

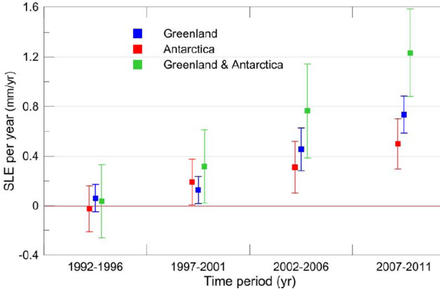
Essentiellement résultats de Dumont et al., 2014

Importance de la calotte du Groenland (GrIS) dans le système climatique

Quelques chiffres

- Surface : 1.7 million km^2
- Epaisseur moyenne de glace $\sim$ 2 km
- Equivalent en niveau des mers : 7.4 m
- Diminution récente de la glace
- Répartie également entre :
  - bilan de masse superficiel (SMB)
  - calving et fonte par l'océan

  ==> env. 0.7 mm/yr de s.l.r entre 2007 et 2011 (IPCC AR5)



Rôle de l’albedo de la neige et de la glace

Importance de l’albedo dans le bilan de masse superficiel

- $\sim$ +0.3 mm/an de hausse du niveau des mers du au GrIS SMB de 2002 à 2011 (IPCC AR5)
- l’albedo de la neige et de la glace est un paramètre clé du bilan de surface et donc de la fonte
- l’albedo a diminué sur la plus grande partie du GrIS de 2000 à 2012 :
  - plus en zone d’ablation qu’en zone d’accumulation
  - de façon plus prononcée en juillet
  (Box et al., 2012 ; Tedesco et al., 2013 ; Stroeve et al., 2013)
- la forte anomalie <0 de 2010 à 2012 a été attribuée à l’anomalie de circulation atmosphé rique (NAO-) et aux rétroactions neige/albedo

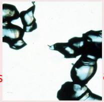
Important snow albedo / climate feedbacks : metamorphism and impurities concentration

Snow metamorphism

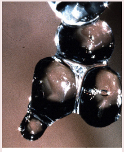
Warmer snow
==> grain growth
==> snow albedo decreases
(near-infrared spectrum)
==> warmer snow

a few days

a few hours if liquid water



a few days if liquid water



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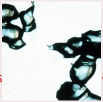

a few days if liquid water

Surface impurities concentration by snow surface melting

Surface melting
==> Impurities are retained at the surface
==> Snow albedo decreases
(visible spectrum)
==> Melt rate increases

+ higher darkening efficiency of impurities for larger snow grains

Processing of MODIS observations

Blue-sky broadband albedo

- daily MOD10A1 data reprojected onto 15-km stereographic polar grid
- filtered as in Box et al.(2012) eval. against AWS albedo

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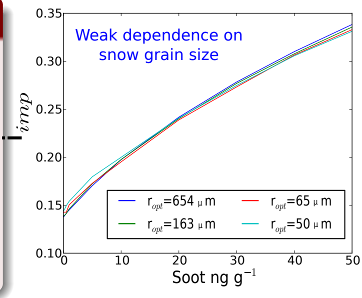
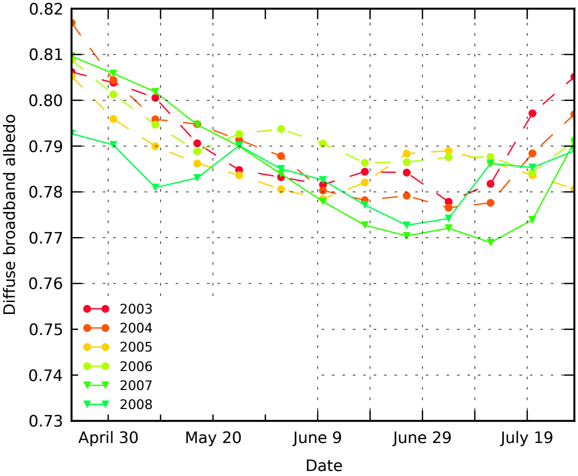
Spectral white-sky albedo

- MCD43A3 + MCD43A2
- 15 km grid reprojected
- filtered for solar zenith angles <65°
- best quality data, 8-day data
- eval. by Stroeve et al. (2013)

$\Rightarrow$ Snow impurity index : $I_{imp} = \frac{\ln \alpha_{550nm}}{\ln \alpha_{850nm}}$



Evidence of GrIS darkening also in Spring and at high elevations (> 2000 m)



(from MODIS MCD43A3 product)

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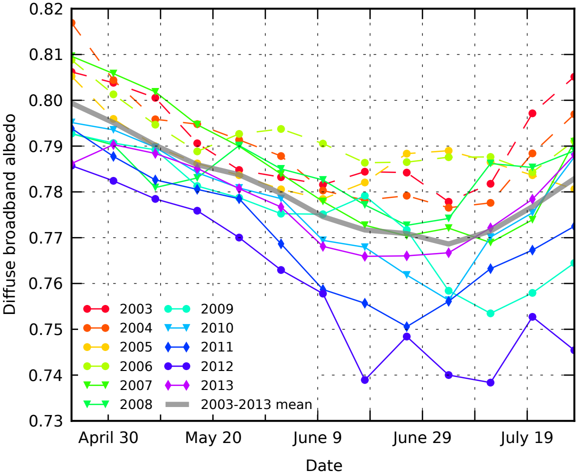

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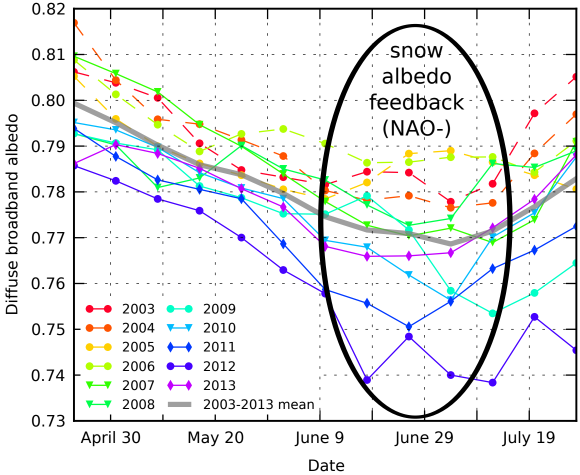

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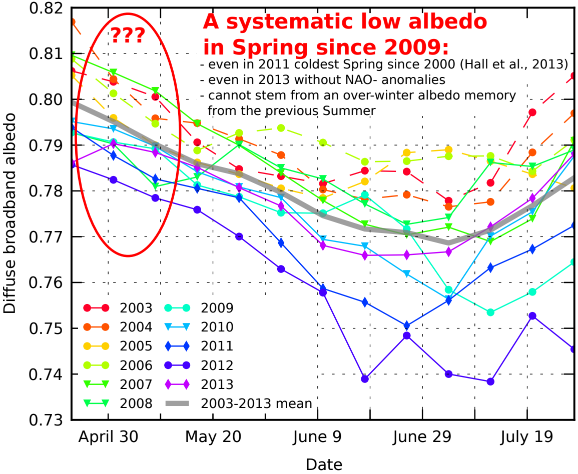

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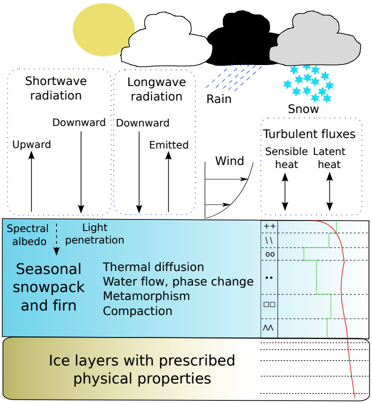
Snow simulations to explain GrIS Spring darkening



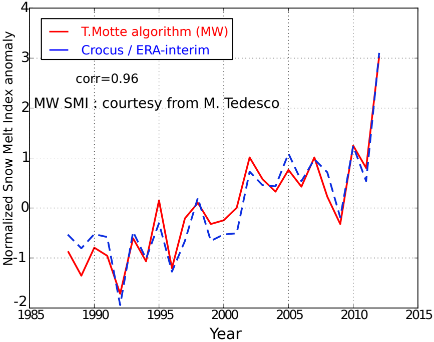
Crocus snow model configuration

- Off-line mode with following forcings :
  - ERA-interim downscaled onto a 15 km GrIS grid
  - vertical corrections from Cosgrove et al. (2003)
  - snow-rain partition from the altitude of iso-T 1˚C.
- snow albedo function of :
  snow grain size and age

Snow albedo feedbacks (metamorphism and impurities) are simulated with a constant impurities deposition rate

⇒ simulated albedo depends on meteorological conditions only

Evaluation of Crocus/ERA-int simulations over GrIS



Interannual variability of snow melt events

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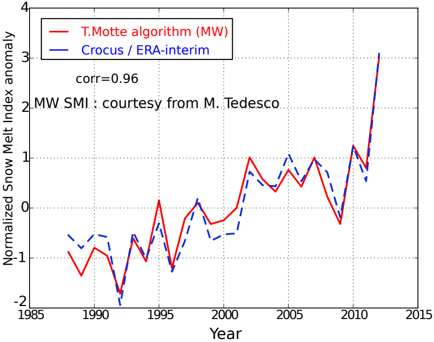

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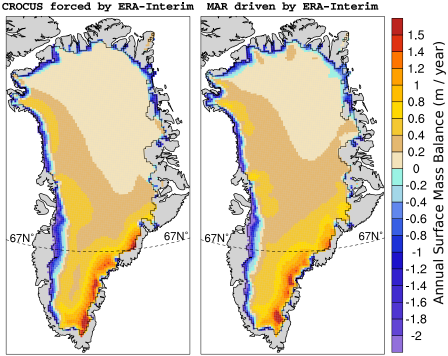
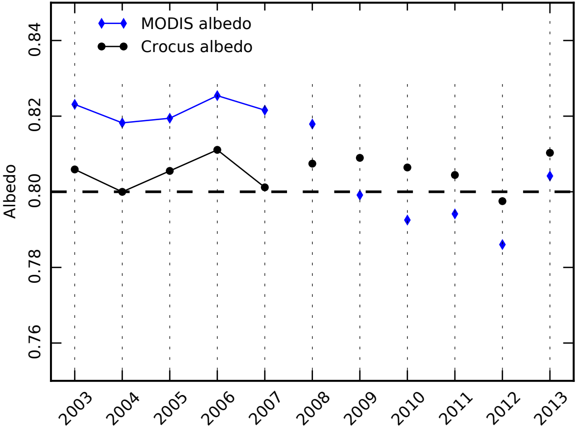


1989-2008 Annual Surface Mass Balance

Observed / simulated albedo May-June above 2000 m



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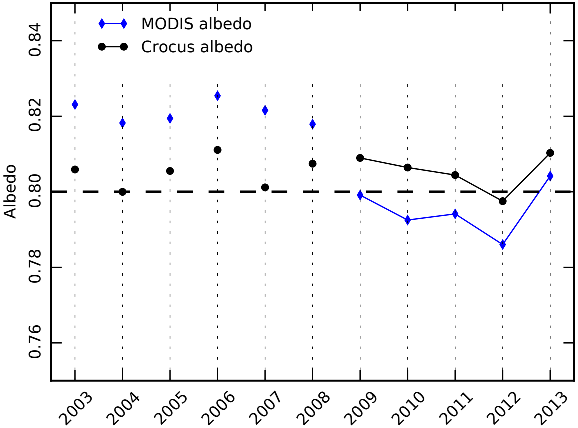

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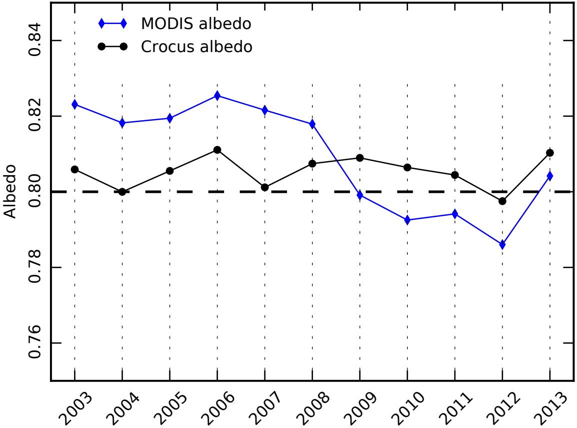

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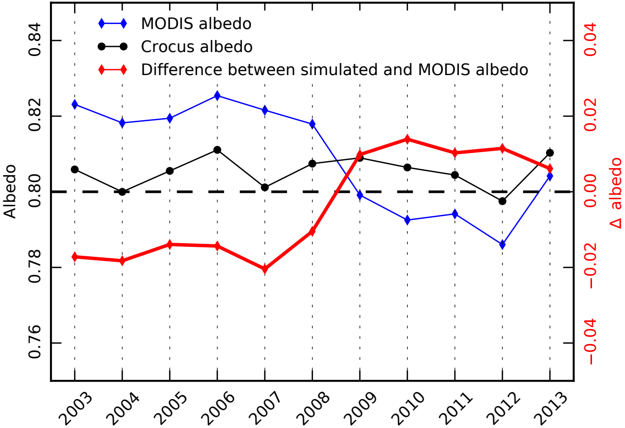
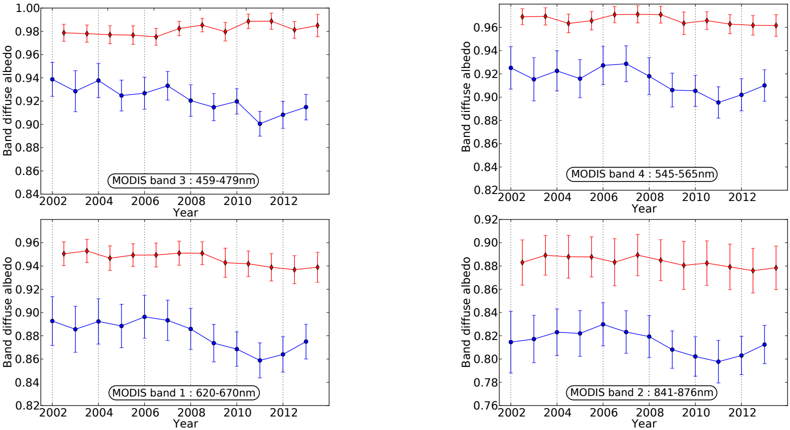


The decrease in Spring albedo above 2000 m cannot be explained by local meteorological conditions only

Confidence in MODIS albedo observations :

- comparison Greenland / Antarctica at the same observing zenithal angles

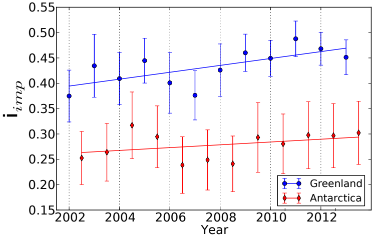
Greenland : May-June 75-80˚N ; 30-50 ˚W ; above 2000 m
Antarctica : Nov-Dec 75-80˚S ; 110-150 ˚E



- the MODIS albedo decrease over GrIs is not due to sensor degradation
- The albedo decreases more in the visible than in the NIR spectrum

Confidence in the increase in surface snow impurities over the GrIS :

- comparison Greenland / Antarctica and MODIS / MERIS



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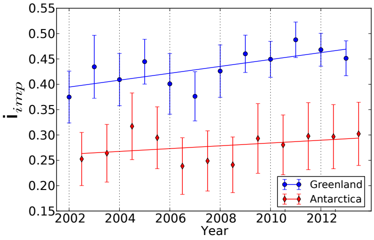

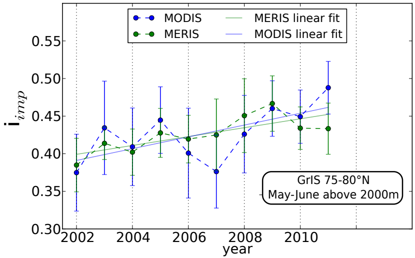

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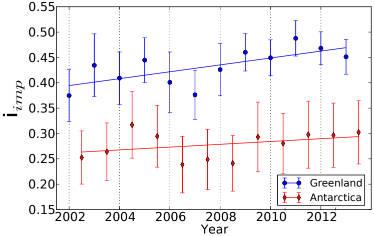
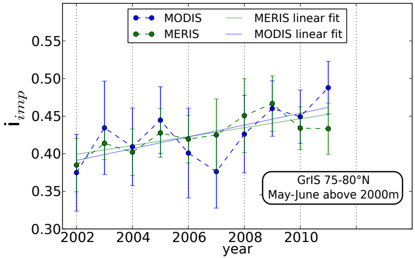
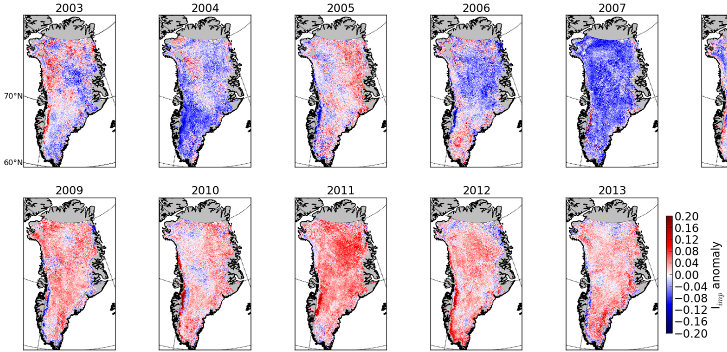




- the impurity index i_{imp} increases much more over Greenland
- MERIS and MODIS detect a similar increase over Greenland
- only 1/3 of the albedo decrease could stem from an artefact in MODIS retrieval algorithm due to the increase in the Atmospheric Optical Depth

$\Rightarrow$ Evidence for an actual increase in light absorbing impurities in snow

Evolution of Impurity Index (May-June)

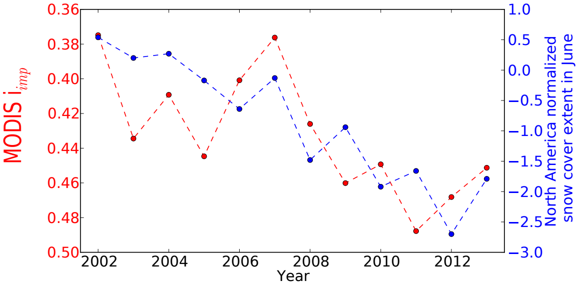


Possible origins of the increase in surface snow impurities (1/2)

No substantial in-situ evidence of the impurity sources but :

- Reddish colour of the impurities
- Similar trend with the extension of the Arctic snow extent in Spring

⇒ likely due to an increase in deposition of dust exported from extending snow-free areas and associated increase in biomass fires



Snow Cover Extent data updated from Derksen and Brown (2012)

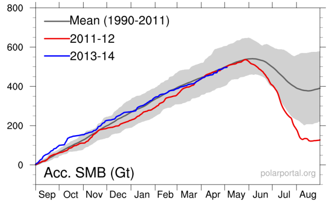
Possible origins of the increase in surface snow impurities (2/2)

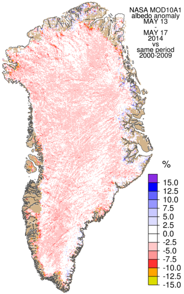
Other possible sources

- Extension of the development of cyanobacteria /algae to the accumulation area due to warming and melt events $\Rightarrow$ additional unexpected climate feedback
- Increase of dust emissions from industry
- General increase in dust load of the Arctic atmosphere
- Volcanic eruptions (Eyjafjallajökull April 2010 ; Grimsvötn May 2011)

Field investigation required to identify the impurity source(s)

Situation en mai et juin 2014





(polarportal.org - DMI GEUS DTU)

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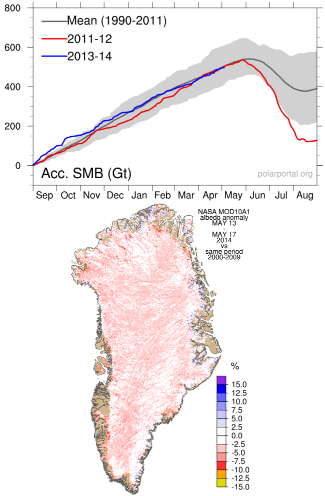

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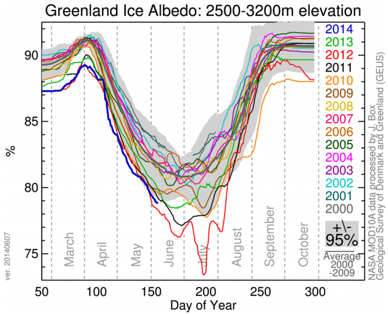
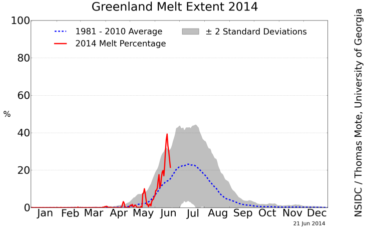
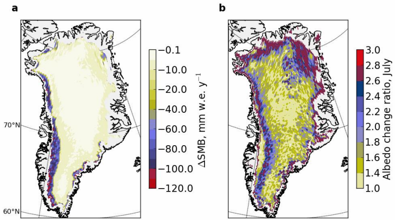
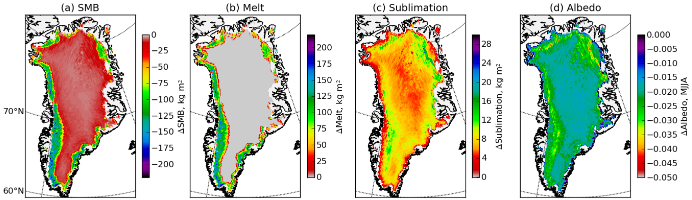




Amplification of a 0.01 decrease in fresh-snow albedo by the snow albedo feedbacks (Crocus simulation)





⇒ GrIS SMB difference = -27 GT/yr (2009-2012 mean)

Conclusion

Principal results

- A detailed analysis of MODIS albedo observations
  + Numerical simulation of the GrIS snowpack
  $\Longrightarrow$ Evidence of a recent Spring darkening of the GrIS accumulation area due to an increase in light-absorbing impurities
  $\Longrightarrow$ Likely linked with the earlier melting of the Arctic snowpack (climate feedback)
- Strong impact of increasing snow impurity on the GrIS SMB :
  -0.01 in Crocus new/fresh snow albedo $\Rightarrow$ -27GT/yr
- Open issues :
  - No substantial in-situ evidence of the impurity sources
  $\Longrightarrow$ requires field investigations
  - Are other components of the Arctic Cryosphere concerned ?
- Several feedbacks since the publication likely to initiate cooperative studies

Remerciements

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- CNES TOSCA program : projects CONCORDIASI and Ts-Antar
- COMBINE EU-FP7
- French ANR MONISNOW programme ANR-11-JS56-005-01
- French ANR programme NEEM (ANR-07-VULN-09-001)

Current state of snow albedo modelling over GrIS

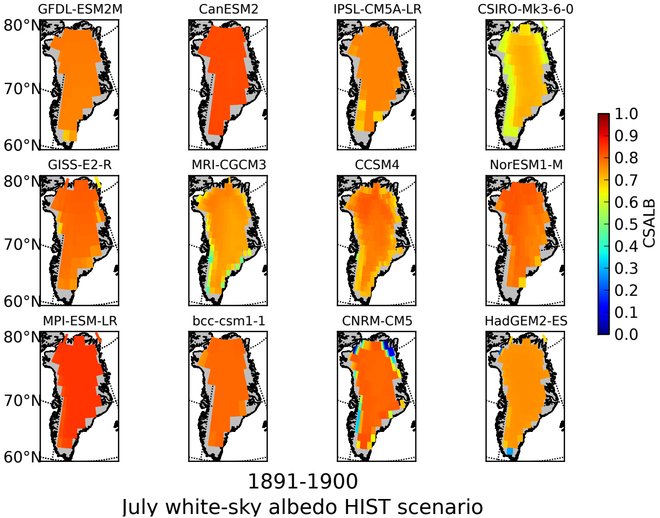
The higher resolution of CMIP5 vs CMIP3 induces a better representation of physical processes over the GrIS but :

- Most CMIP5 models implement rather simple snow models :
  - 1 to 5 snow layers only
  - snow albedo mainly depending on ageing and snowfall
  - no explicit representation of the perennial ice beneath seasonal snow

  $\Rightarrow$ internal snow albedo feedbacks are poorly represented
- Atmospheric load of aerosols generally prescribed or poorly represented

Use of HIST (1891-1890) and RCP8.5 (2091-2100) scenarios to illustrate current limitations

Greenland albedo in HIST and RCP8.5 scenarios



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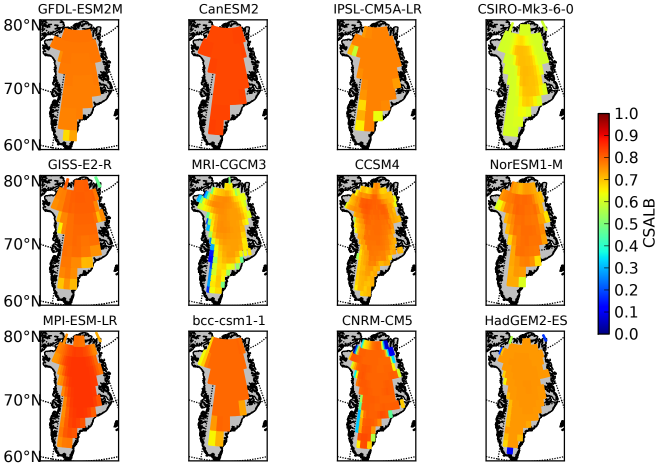
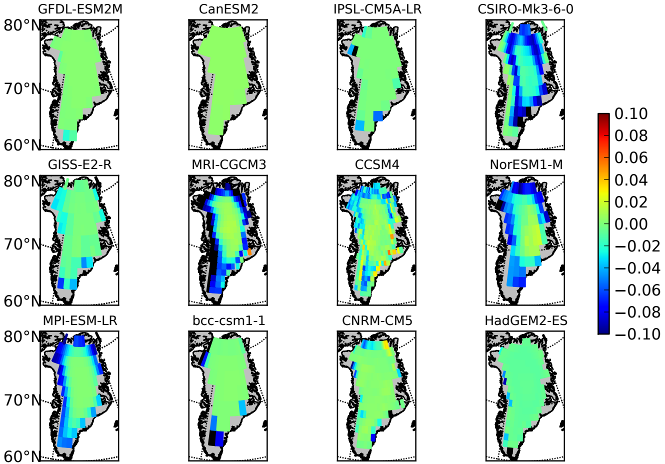


2091-2100

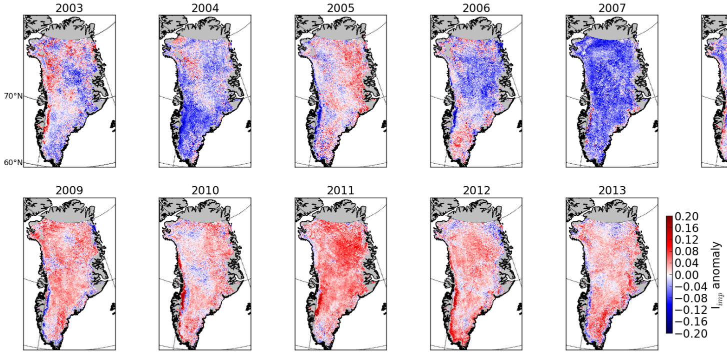
July white-sky albedo RCP8.5 scenario

Greenland albedo in HIST and RCP8.5 scenarios

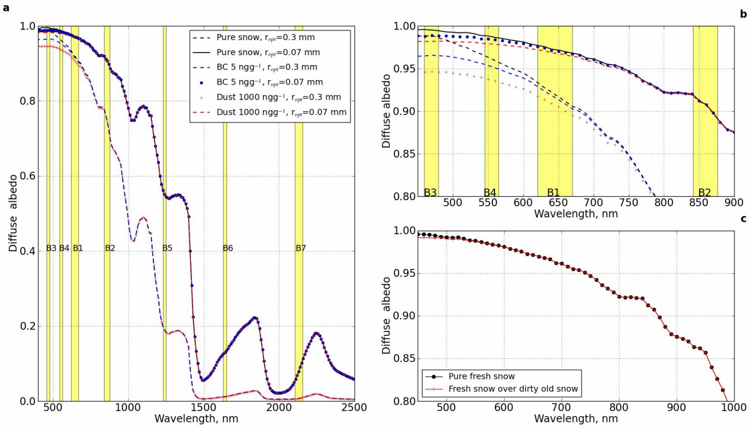


July albedo difference 2091-2100 RCP8.5 - 1891-1900 HIST

Evolution of Impurity Index (May-June)



DISORT simulations of the effect of impurities on snow albedo



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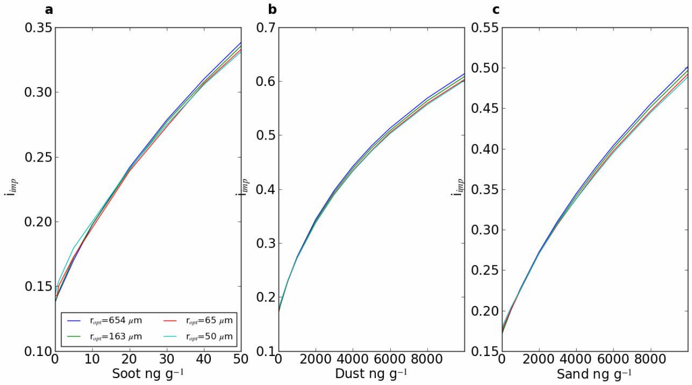
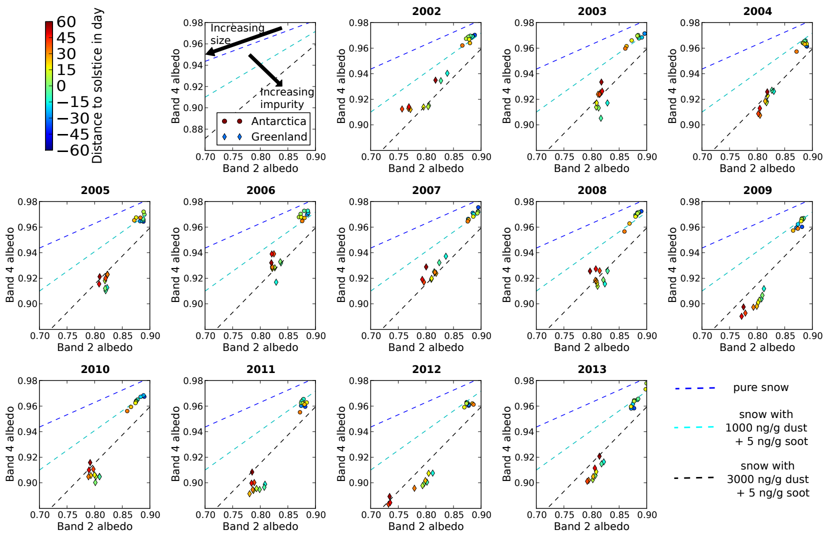
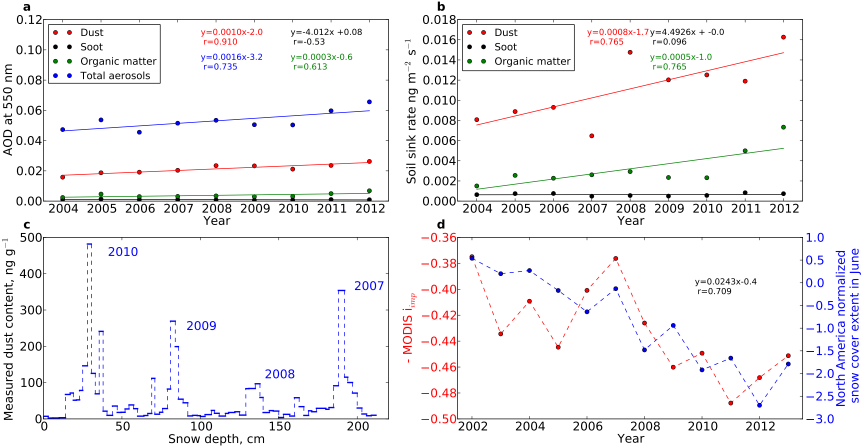


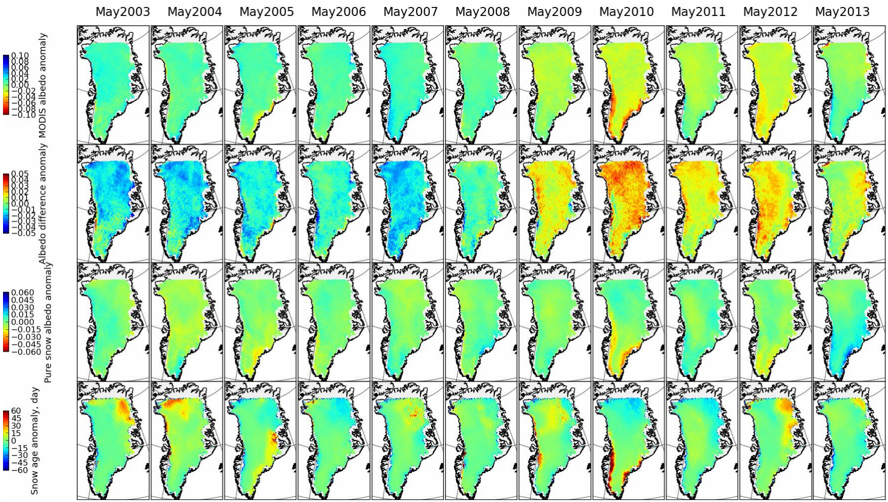
Evolution of band diffuse albedo in Greenland and Antarctica



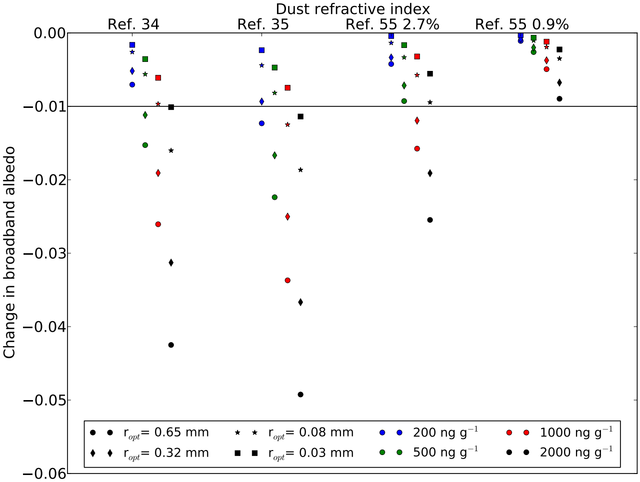
Atmospheric and surface dust content



Observed and simulated albedo in May



Change in diffuse broadband albedo induced by dust



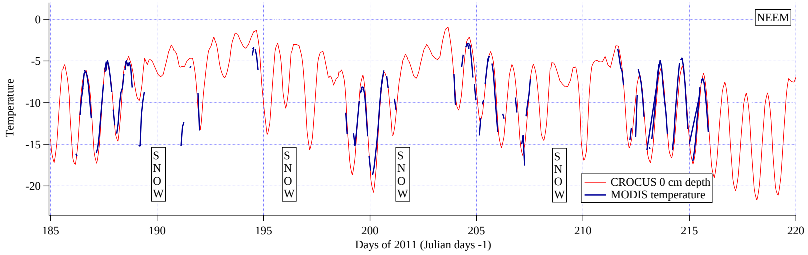
May-June-July mean and standard deviation of measured aerosol optical depth (AOD) at 550 nm (AERONET data)

Stations/Year	Kangerlussuaq	Thule
2007		0.055 (0.021)
2008	0.065 (0.031)	0.081 (0.044)
2009	0.084 (0.030)	0.085 (0.025)
2010	0.048 (0.015)	0.061 (0.024)
2011	0.060 (0.017)	0.061 (0.020)
2012	0.070 (0.034)	0.101 (0.034)

Recent measurements of snow impurities in the dry and percolation zones of Greenland

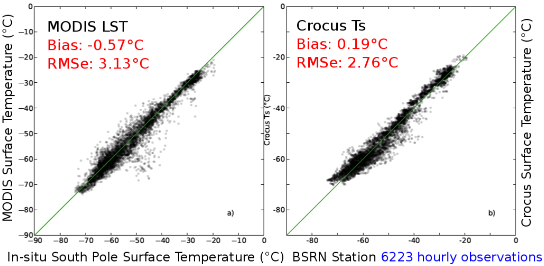
Source	Date	BC (ng g-1)	Dust (ng g-1)	Location and comments
Ref. 31	May and June 2011	0.3±0.3	128±69	Summit
Ref. 15	Spring 2007,2008	4±2	51±6 % absorption from non BC particles	Several locations in Greenland
Ref. 25	2007 to 2010	5 to 100 BC equivalent		Dye-2 (percolation zone)
Ref. 53	June and July 2012	0.9 to 4.9	102 to 1329	Sigma-A (1490 m a.s.l)
Ref. 54	June and July 2006	0.6±0.4	Not measured	Summit

Evaluation of Crocus/ERA-int versus satellite : NEEM hourly surface temperature (see Steen- Larsen et al., 2014)



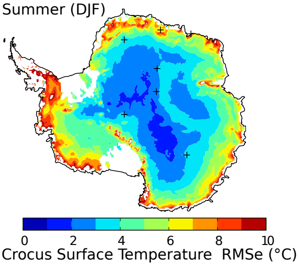
Similar results in Antarctica : extensive evaluation in Freville et al. (TCD)

Evaluation of Crocus/ERA-interim versus satellite : Antarctica hourly surface temperature (Freville et al., TCD)



Evaluation against in-situ observations hourly surface temperature of MODIS (left) and Crocus/ERA Interim (left) South Pole 2009

Evaluation of Crocus hourly surface temperature
against MODIS LST (Summer 2000-2011)



Evaluation of Crocus/ERA-int versus MAR : interannual SMB variability