Snow in Antarctica

M. Poizat[1], G. Picard[1], L. Arnaud[1], C. Narteau[2], C. Amory[1] and F. Brun[1]

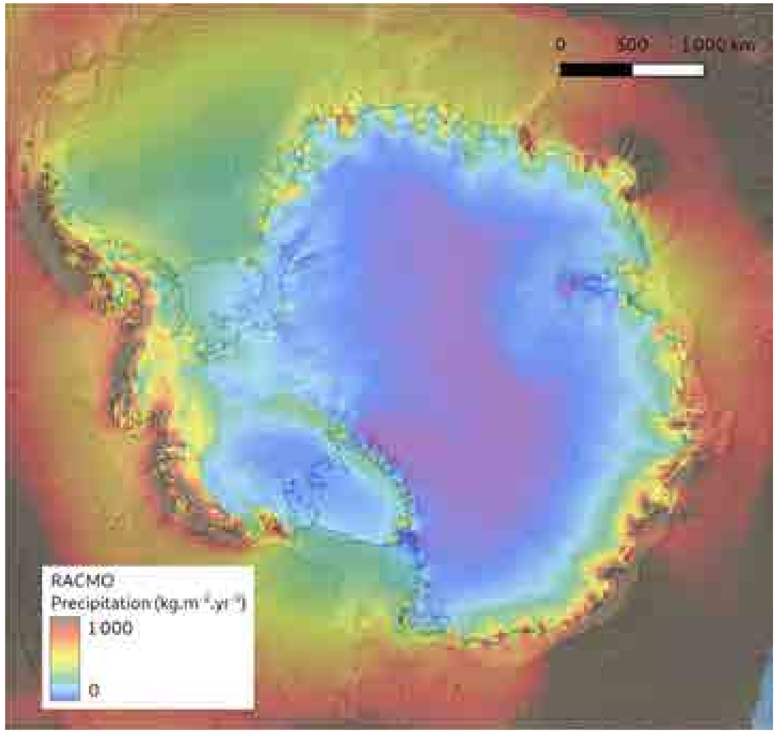
1. Univ. Grenoble Alpes, IRD, CNRS, Grenoble INP, IGE, 38000 Grenoble, France

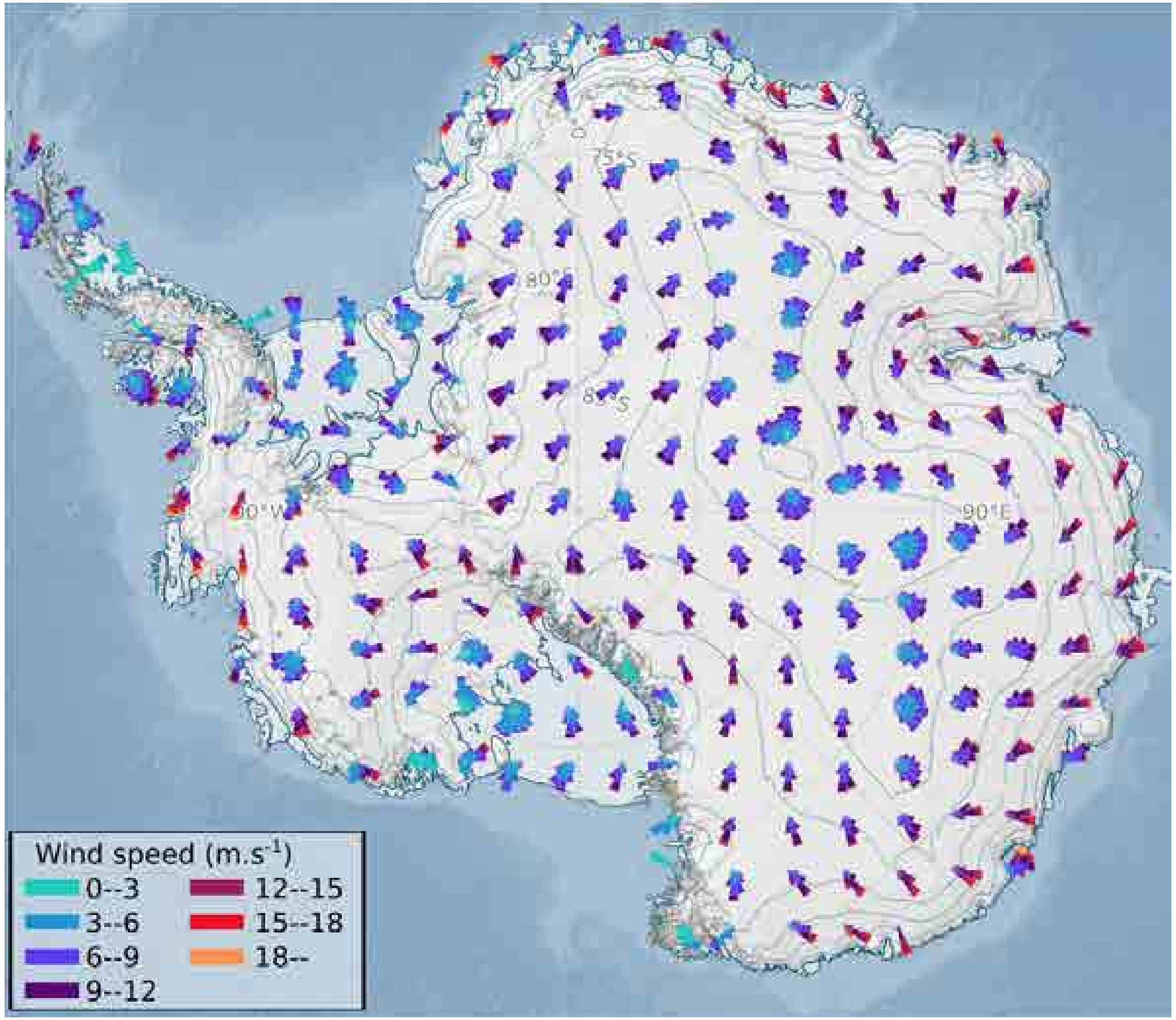
2. Univ. Paris Cité, Institut de physique du globe de Paris, 75005 Paris, France

View of the snow bedforms in Adelie Land, Antarctica

View of the snow bedforms near Concordia station, Antarctica

Antarctica

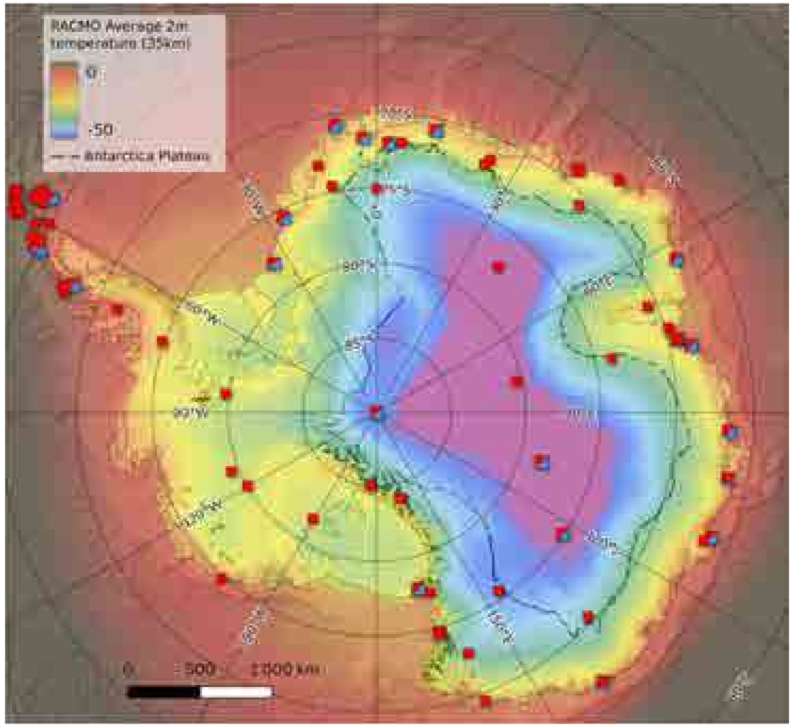


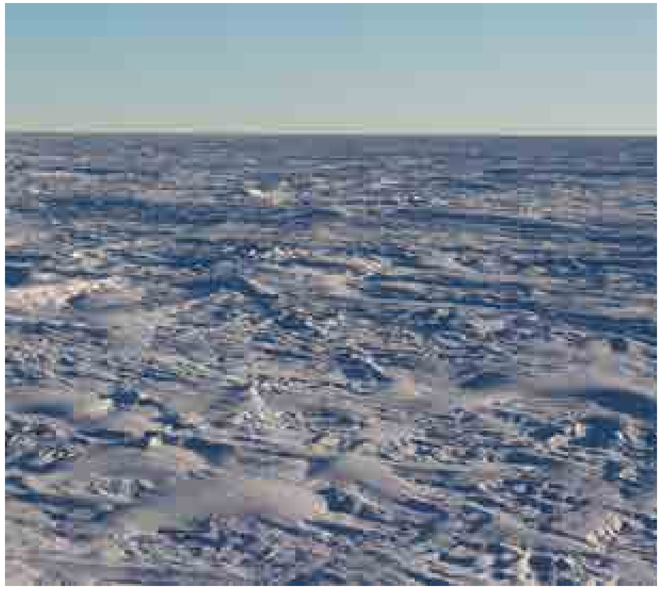


- Variable topography : steep coasts, flat inland
- Wind regimes depend on topography
- Precipitation from 30mm/yr to 1000mm/yr
- Air temperature from -80°C to 0°C

⇨ Highly **variable conditions** depending on the regions

Antarctica Plateau





View of the snow bedforms near Concordia station, Antarctica

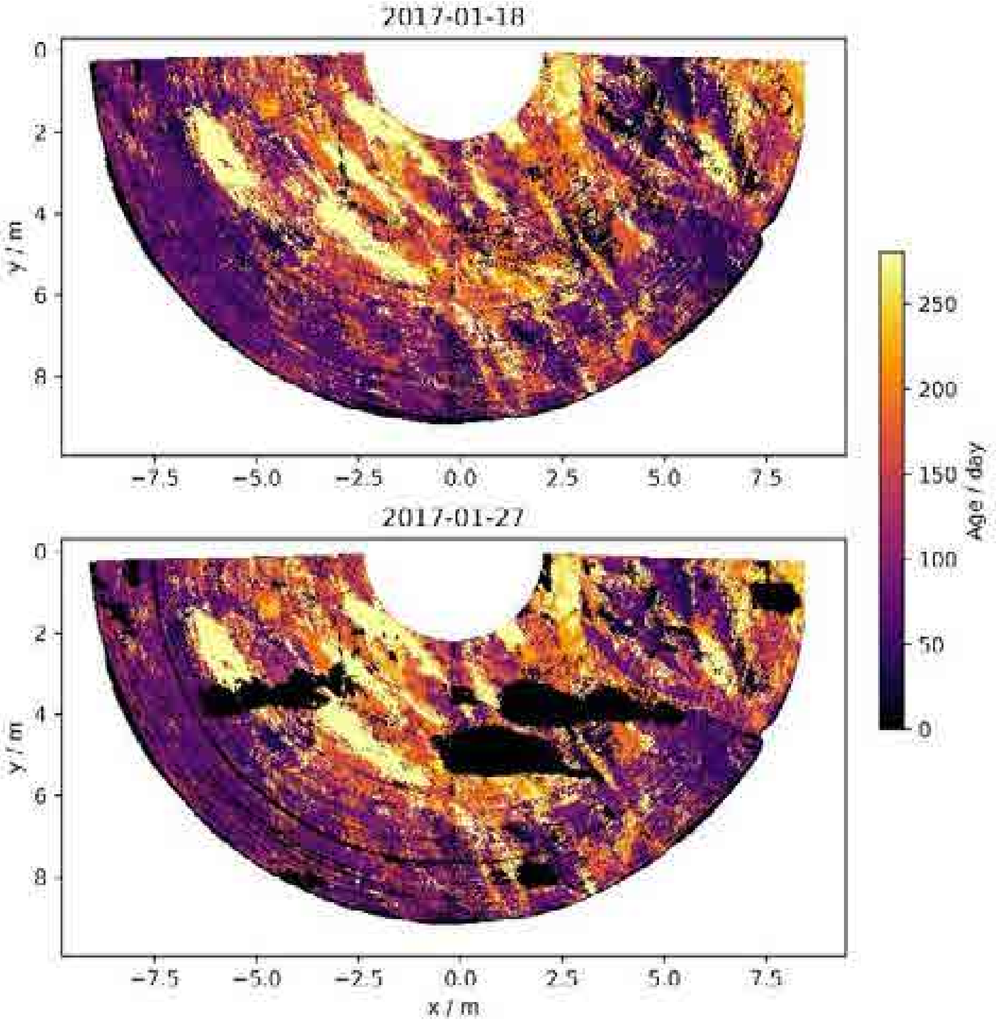


Figure 11. Map of age of the snow on the surface for two dates.

Picard et al., 2019

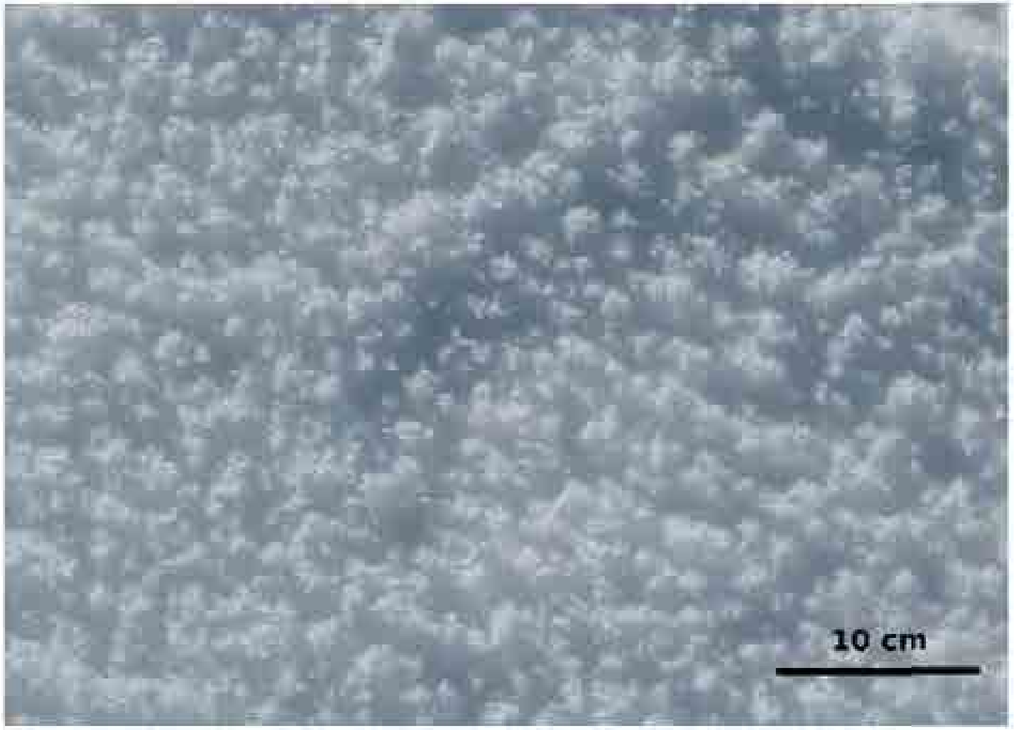
Antarctica Plateau (altitude >2500m) characterized by

- **Low temperature** (mean of -46°C)
- **Low accumulation** (mean of 50 kg/m²/yr)
- **Low wind speed** (mean of 6.2 m/s)

=> Snow can be exposed at the surface during **several months** and undergoes **metamorphism**

Surface crystals

Champollion et al., 2013



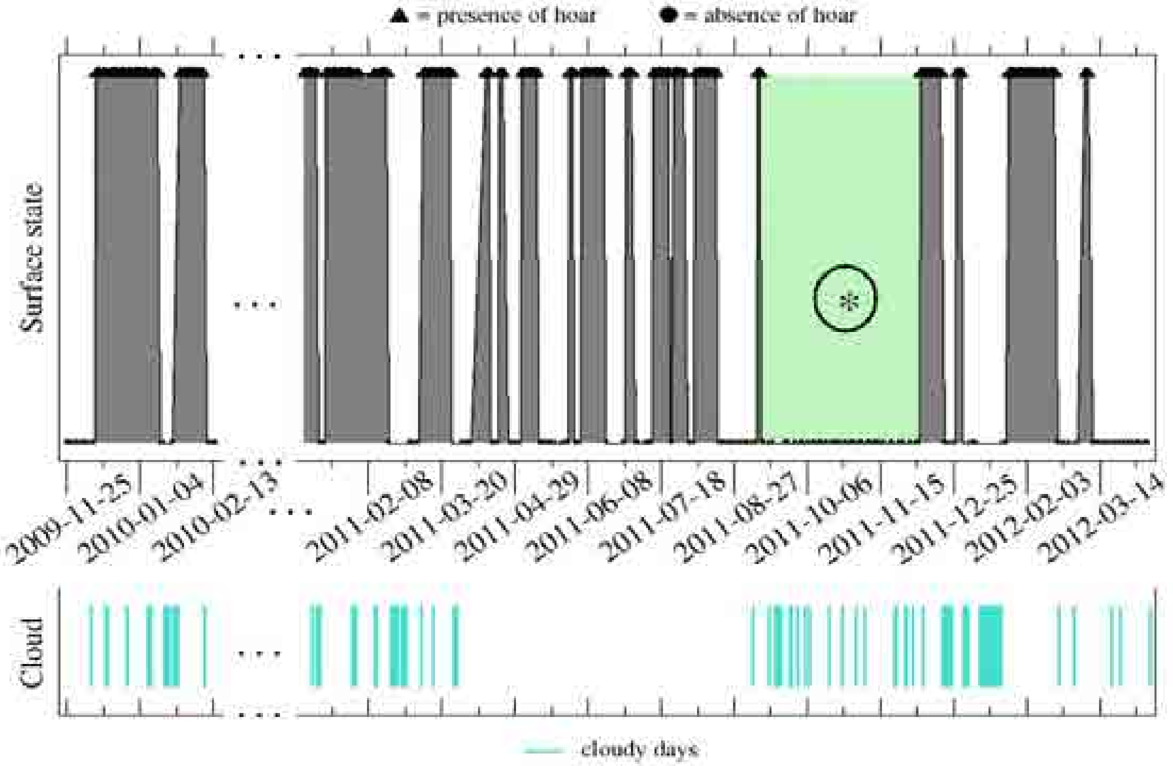
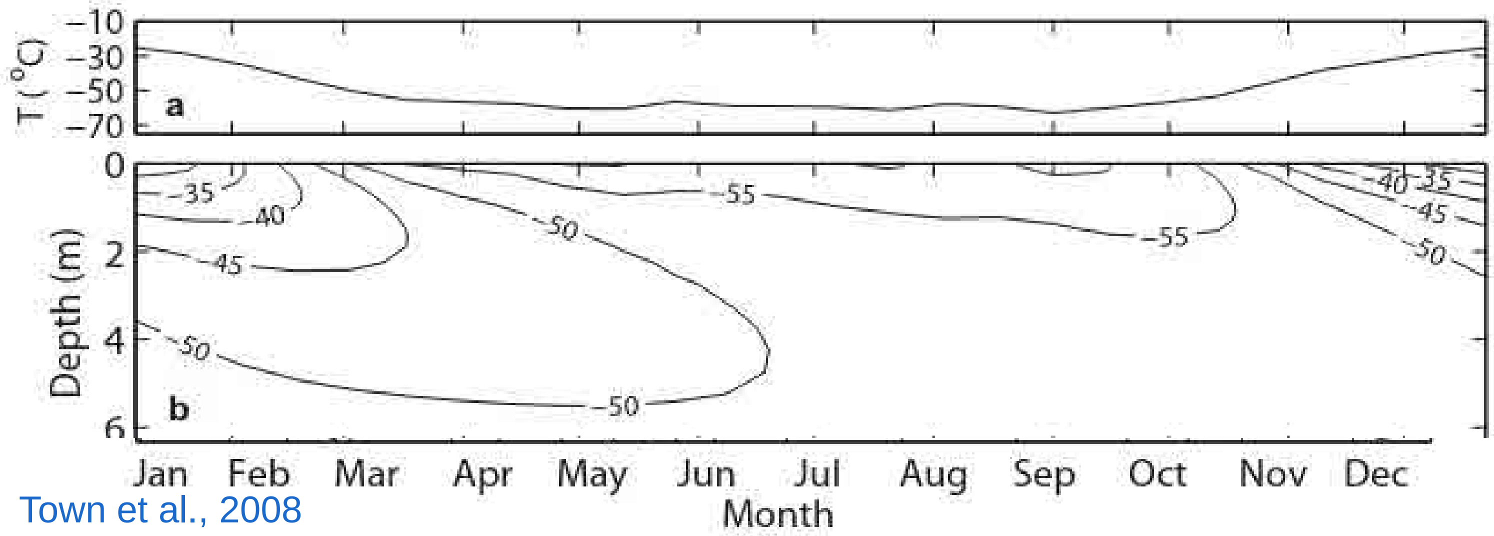


Fig. 6. Evolution of the surface state at Dome C (dark and dotted areas show periods with presence of hoar), from 23 November 2009 to 16 February 2010, and from 3 January 2011 to 11 April 2012. Green and dotted area (*) is a remarkably long period without hoar crystals and cyan lines show cloudy days.

At Dome C, hoar layer thickness can be more than 2cm and **hoar detected all year** long despite very different meteorological conditions between winter and summer

Different crystals observed : surface hoar and sublimation crystals

Surface hoar formation

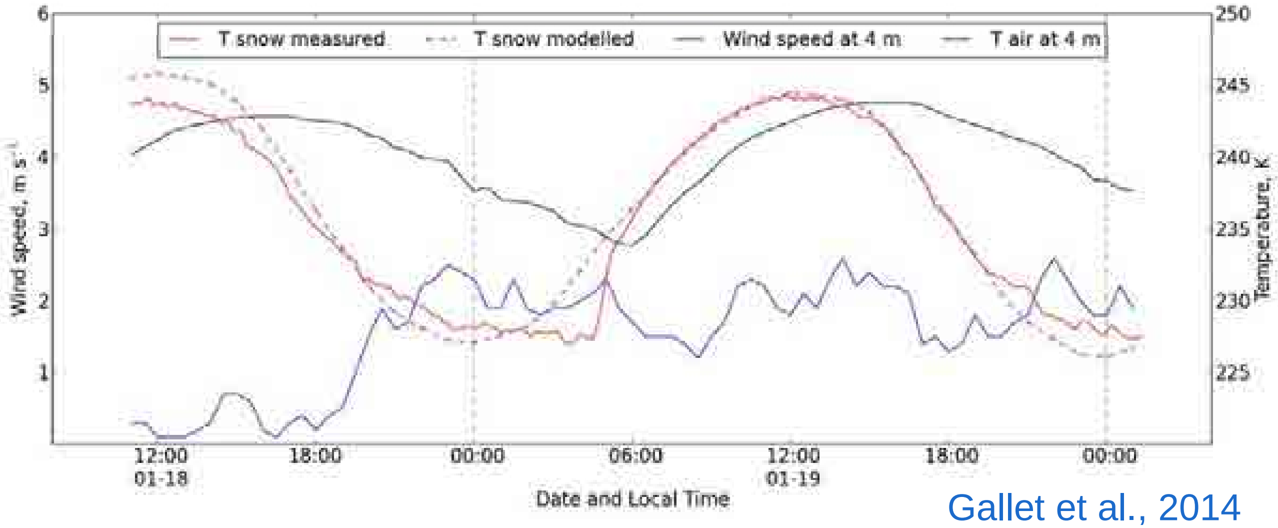


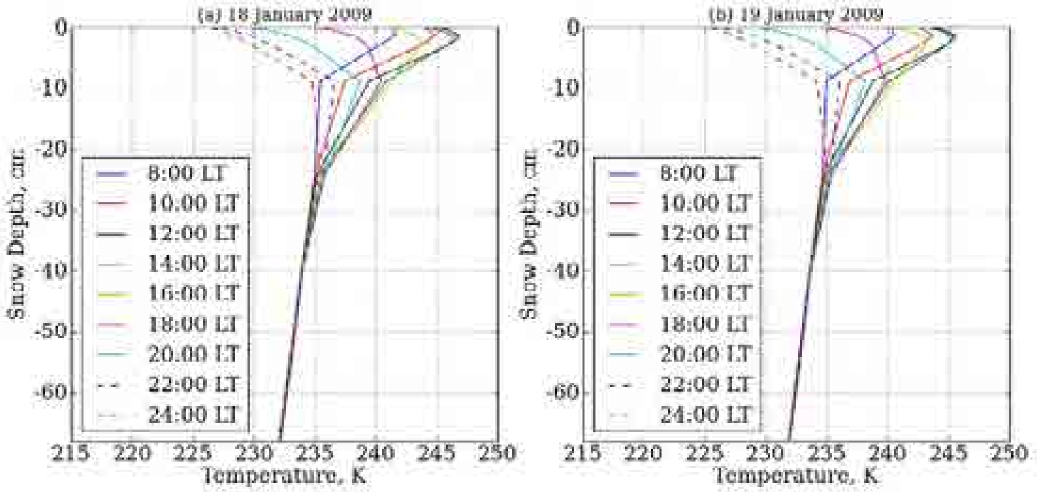
Town et al., 2008

Hoar formation depends on temperature difference between air and snow, relative humidity, and wind conditions

Characteristics of the snowpack at Dome C

- **Diurnal and annual cycles of air and snow temperature** show variations for snow of 10K daily to 25K yearly and 40K yearly for air temperature
- The **high gradient temperature** into the snowpack generates water vapor fluxes => **Vertical water vapor fluxes** both coming from atmosphere and the underlying snowpack





Gallet et al., 2014

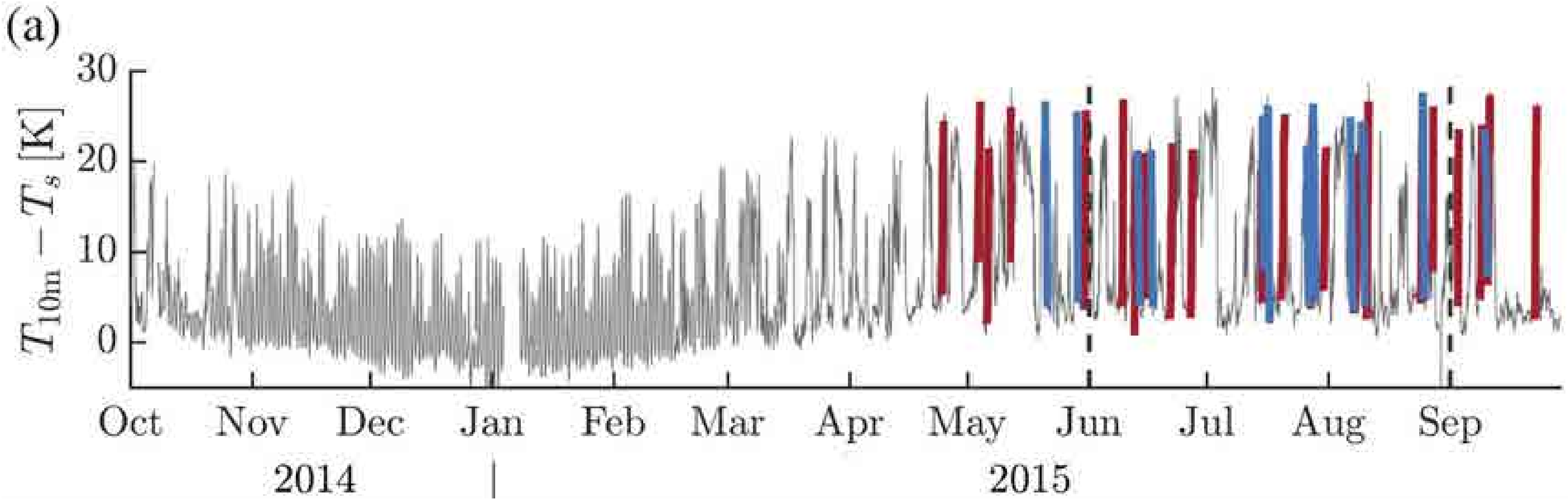
Surface hoar formation

Different processes

Sublimation crystals = the condensation of an upward flux of water vapor coming from the underlying snow layers

Surface hoar = condensation of the atmospheric humidity on the surface, surface colder than air

Mostly **during night** and **winter** thanks to the absence of solar energy and the intense radiative cooling



Baas et al., 2018

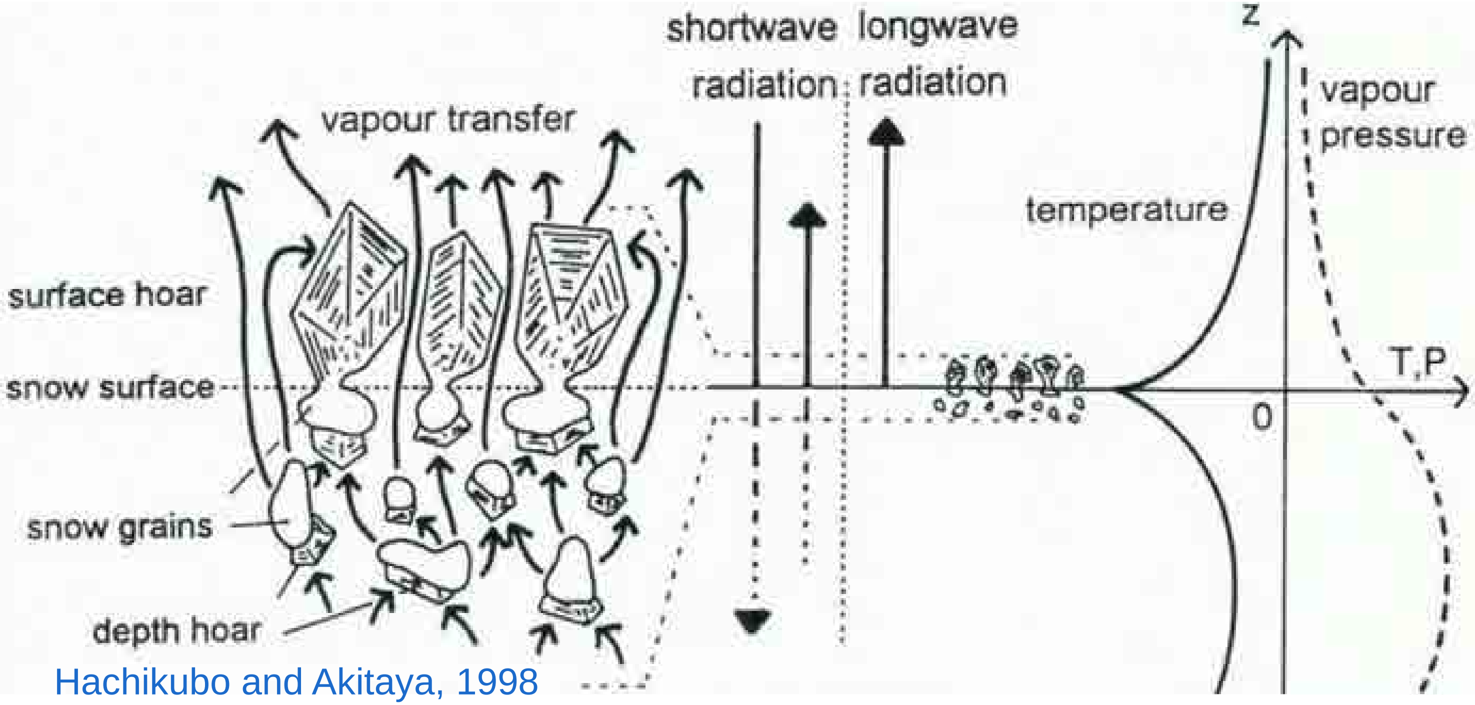
Sublimation crystal formation

Different processes

Sublimation crystals = the condensation of an upward flux of water vapor coming from the underlying snow layers

Surface hoar = condensation of the atmospheric humidity on the surface, surface colder than air

Mostly **during day** as air and snow surface temperature increase, relative humidity decreases

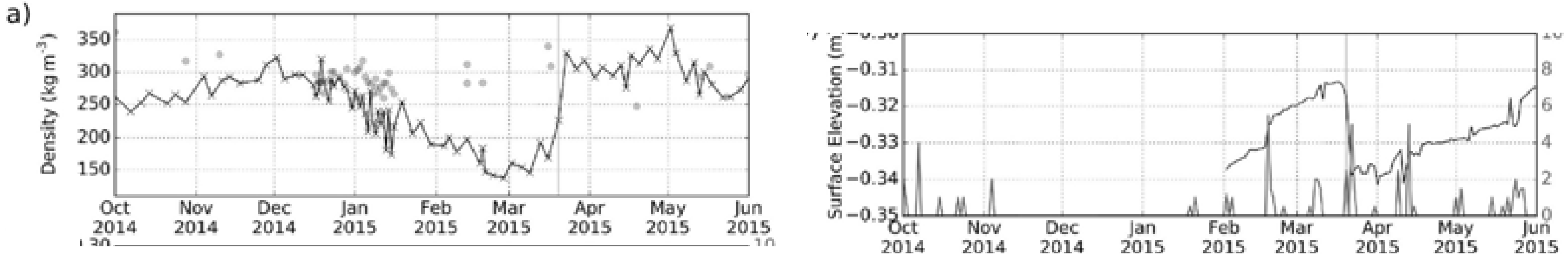


Hachikubo and Akitaya, 1998

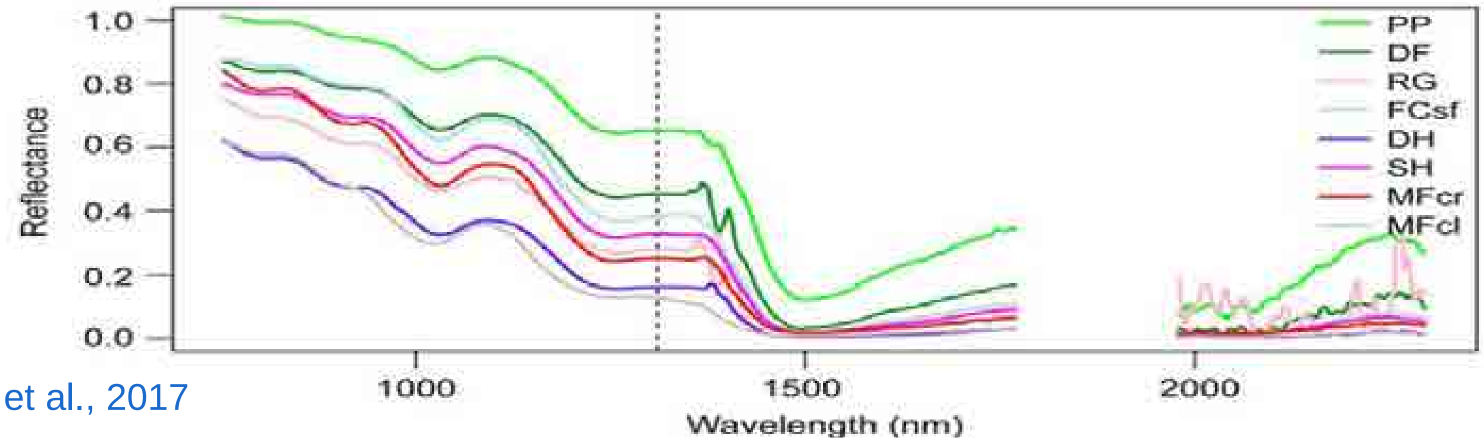
Characteristics of the surface hoar

Characterized by **low density** (~<200kg/m³), **high SSA** (~40 m²/kg)

Surface hoar modifies the **surface roughness, albedo, surface temperature** and therefore **remote sensing measurements** (passive microwave…) but also the **isotopic composition** which depends on the type of hoar



Leduc-Leballeur et al., 2017



Horton et al., 2017

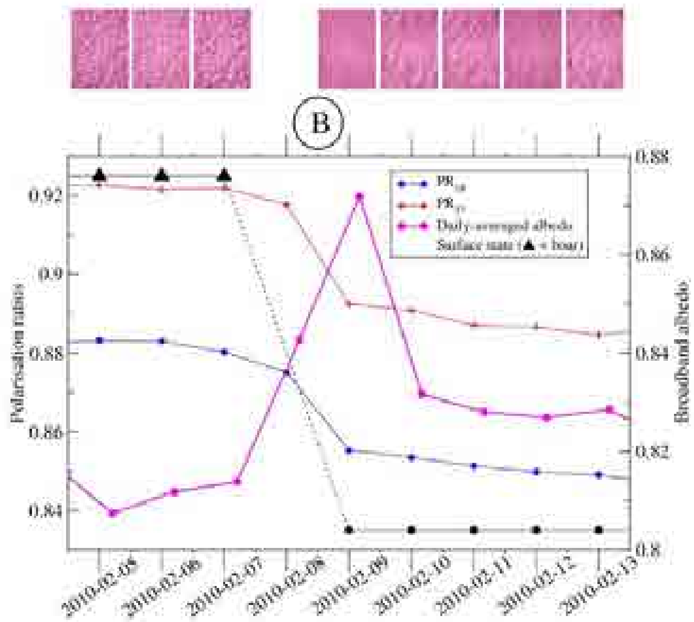


Fig. 14. Observed albedo on 8 and 9 February 2010 at Dome C, during the disappearance of hoar crystals (unscaled black symbols and small pictures above the graph) present on the snow surface (event B in Fig. 7). Between the 8 and 9, a decrease of polarisation ratios at 19 and 37 GHz is also observed.

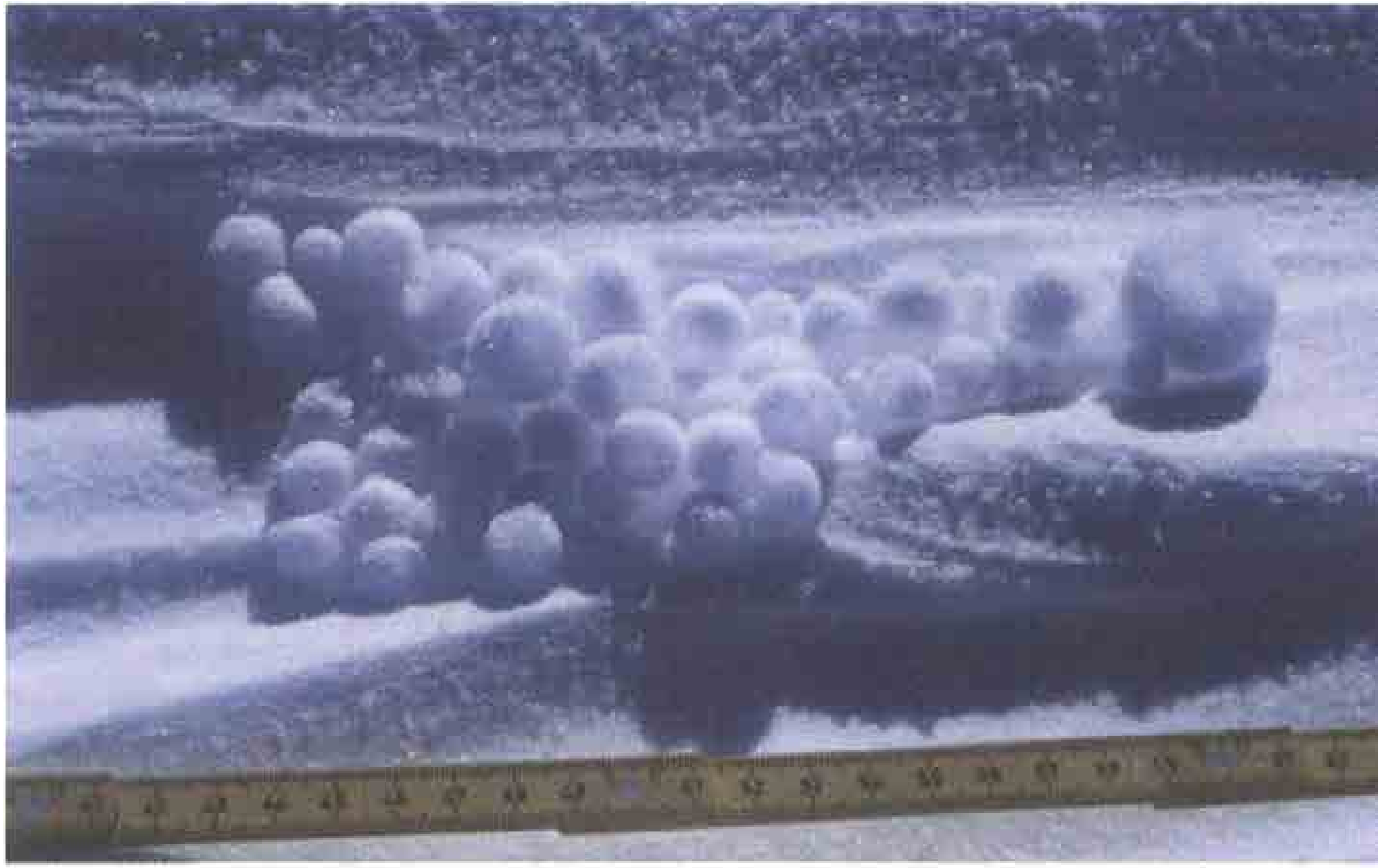
Champollion et al., 2013

Yukimarimo

Formed by the wind

- Composed of solid needle surface hoar crystals
- Favorable conditions for the formation of yukimarimo :
  air temperature between –70 -- –60 °C
  wind speed from 2 to 4 m/s

What are the impact on wind on the snowpack?

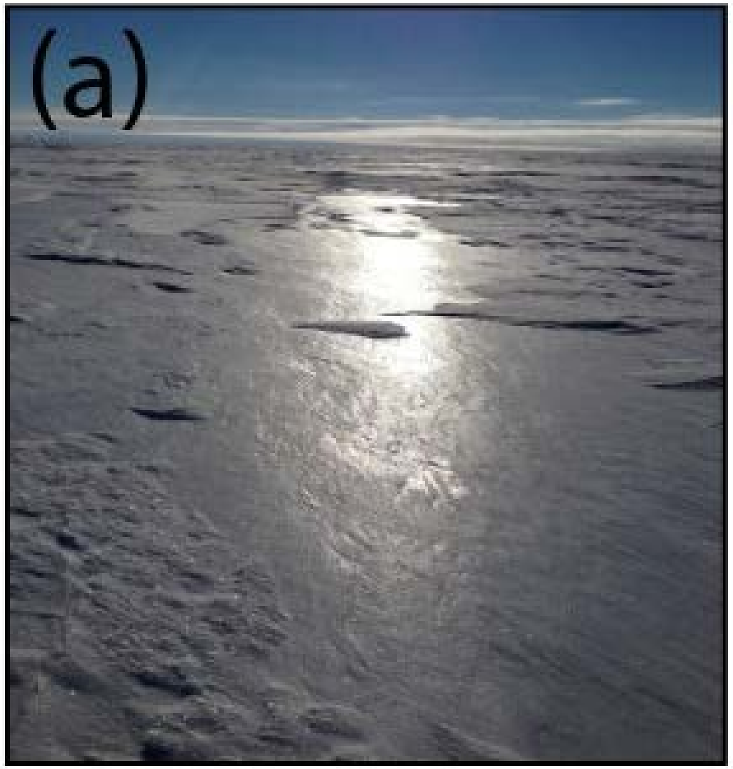


10 cm

Kameda et al., 1999

Impact of wind on snow

Wind impacts all of the Antarctic surface, even low wind areas. It **redistributes the snow** and can create
→ snow bedforms
→ wind crusts
→ wind scour and wind glaze areas



Fegyveresi et al., 2018 (WAIS divide)

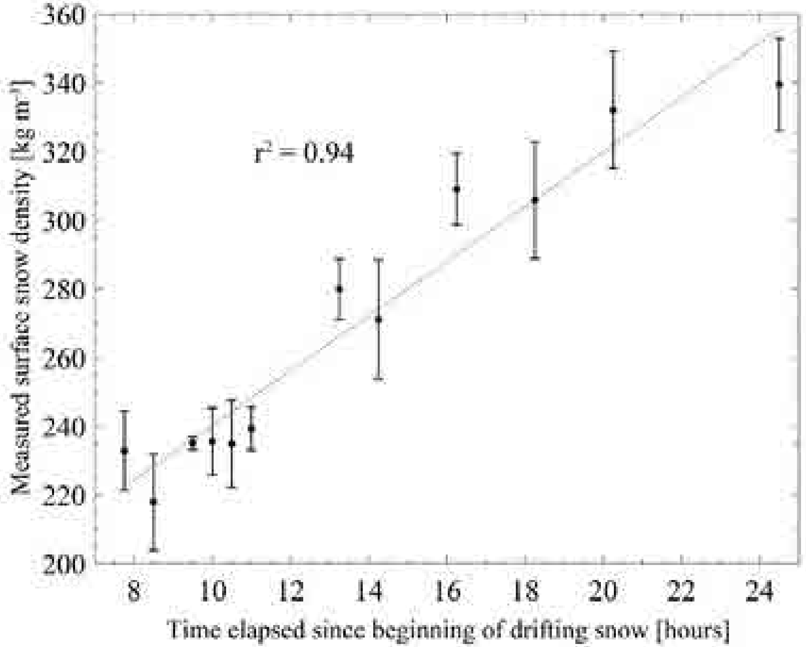
View of the snow bedforms near Concordia station, Antarctica

IGE Institut des géosciences de l'environnement

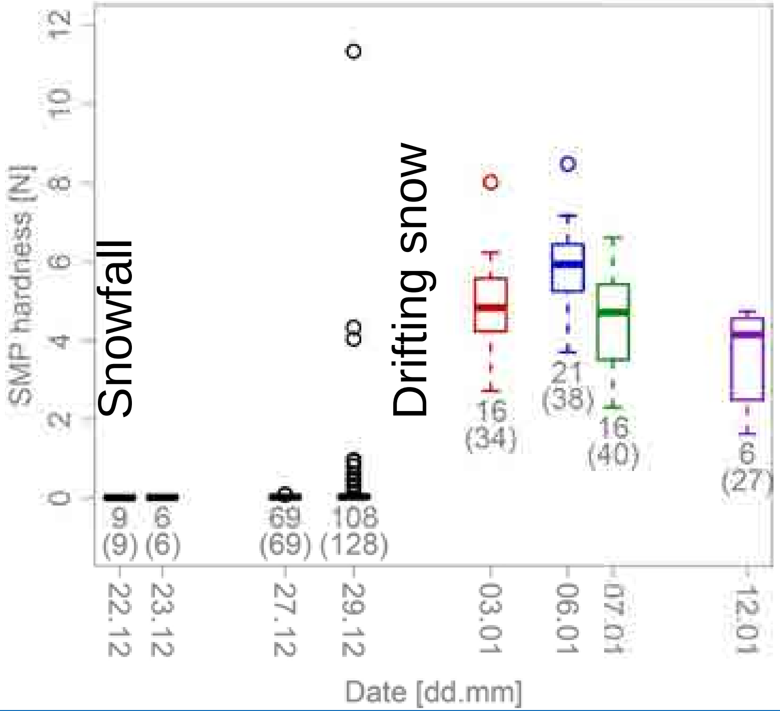
Wind compaction

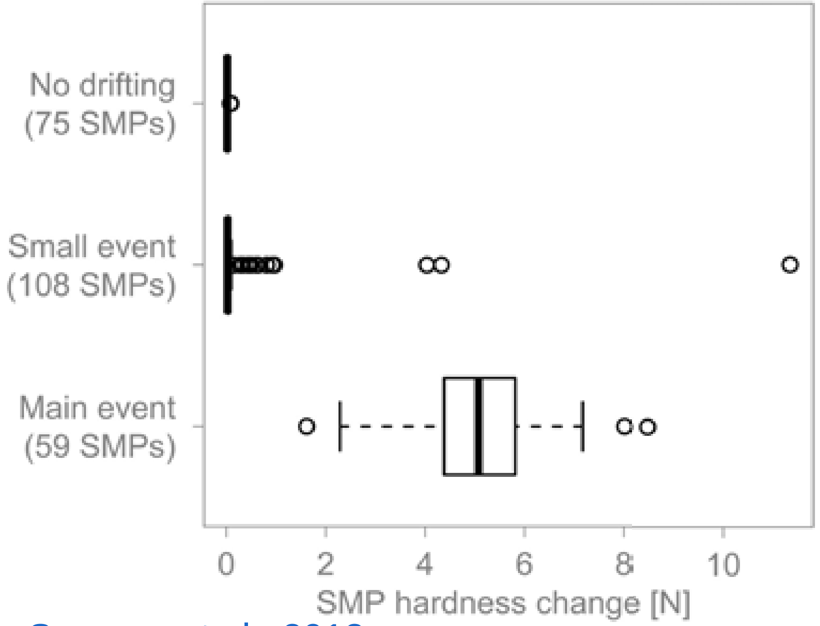
Wind packing = **snow hardening** under the influence of wind but compaction of wind on the snowpack not fully understood.
Wind transport induce snow **particles fragmentation** which can pack into denser layer but drifting snow does not necessarily induce an increase in the hardness

Observation of wind compaction suggests linear relationship between the density of the snowpack and the duration of the drifting snow event



Amory et al., 2021

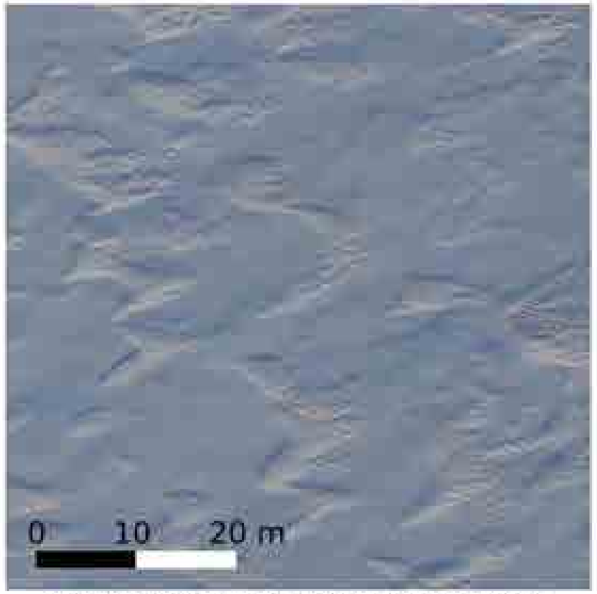




Sommer et al., 2018

Snow bedforms

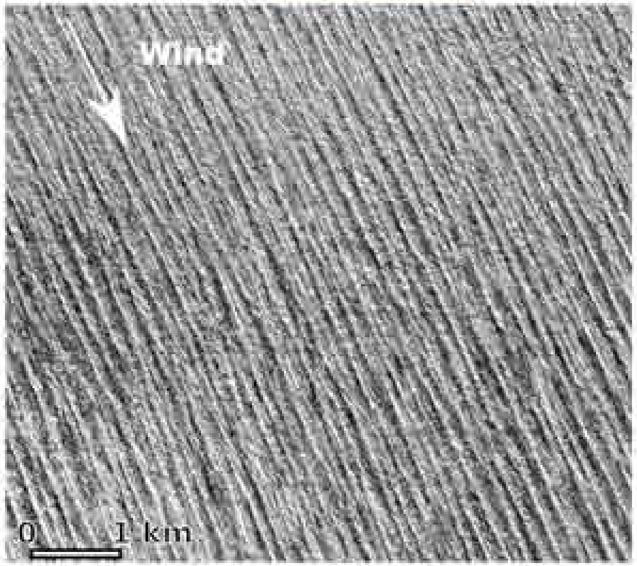
Barchans 10 m



Aerial photograph of barchans during ASUMA, 2017

Linear 100 m

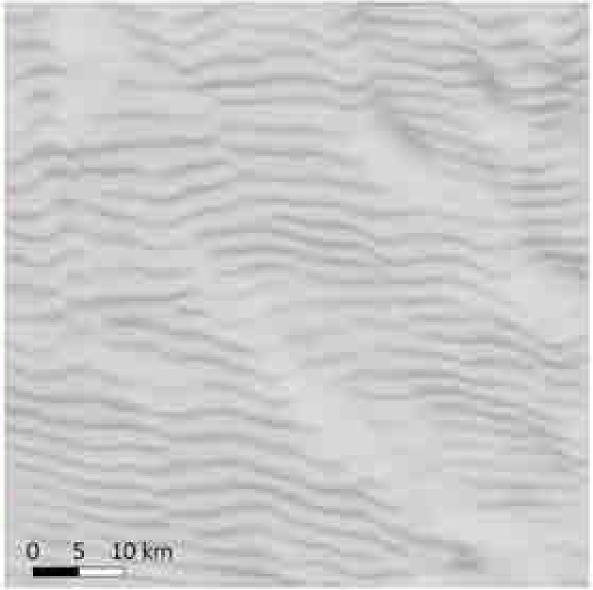
Longitudinal



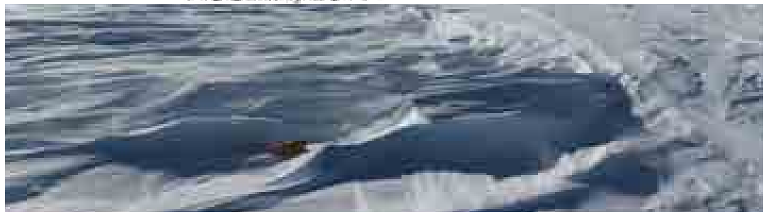
Sentinel-2 image 11/2021

Transverse

Megadunes 4 km



RAMP Radarsat mosaic



Sastrugi

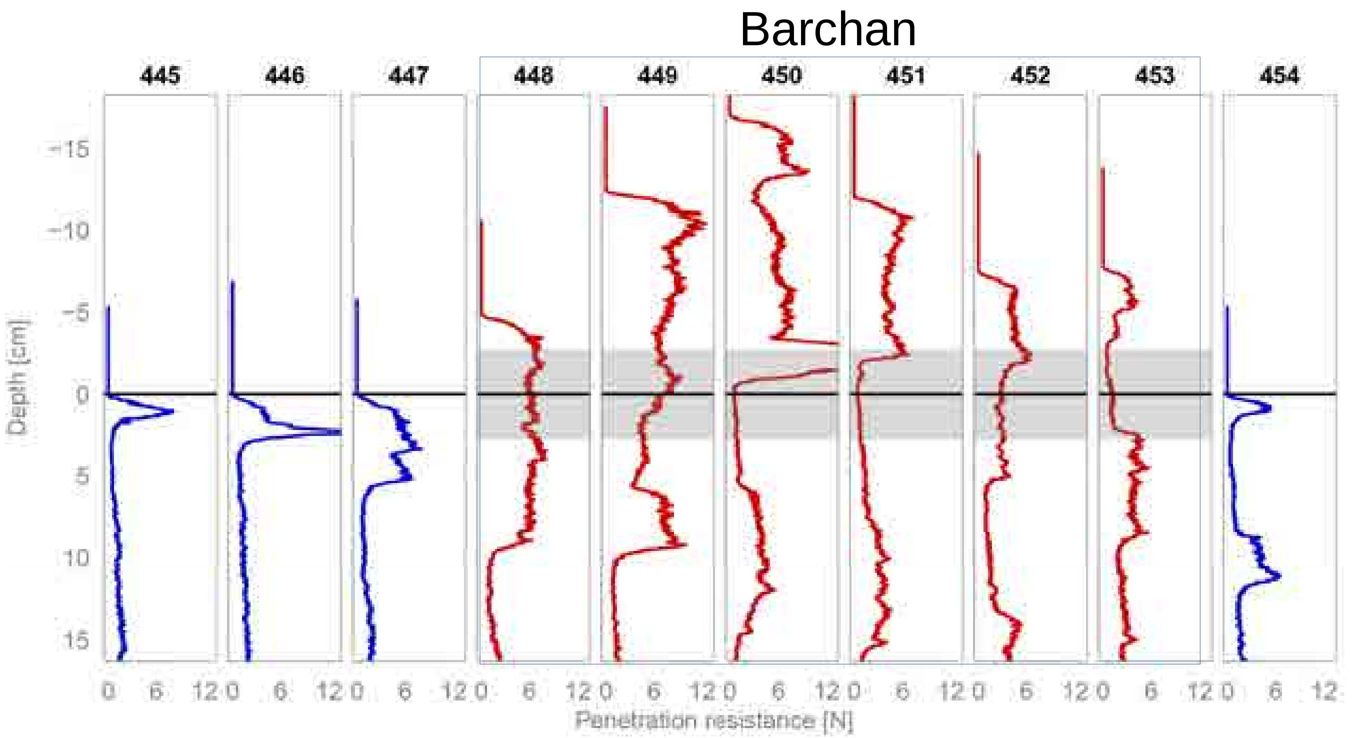
Large variety of snow dunes observable in Antarctica at different temporal and spatial scales

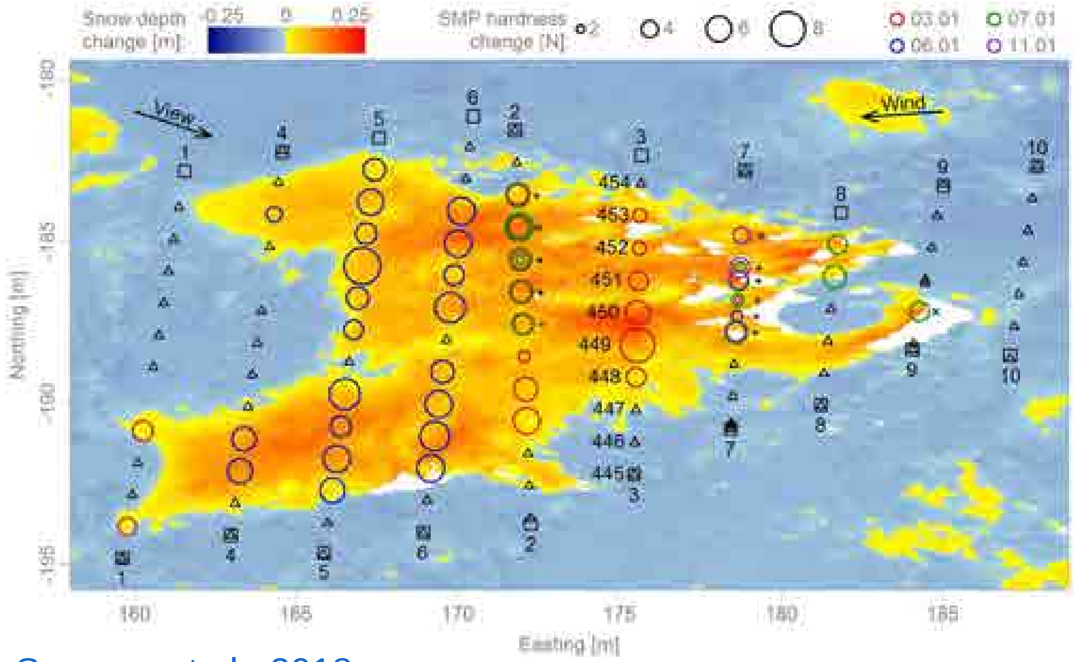
Aeolian processes shape the landscape in Antarctica and impact the snow properties

Barchans properties

Barchan = snow dune which form with low winds (~<10m/s) in low sediment availability conditions

Barchans **density higher** than the surrounding snow (380–500 kg/m³ vs 330 kg/m³ at Kohnen Station)
Snow Micro-Pen measurements showed **higher penetration** resistance than the surrounding snow
→ create layers





Sommer et al., 2018

Barchans properties

Snow grains involved in the formation of dunes are old redistributed snow grains not newly fallen snow grains which can explain the difference in density observed

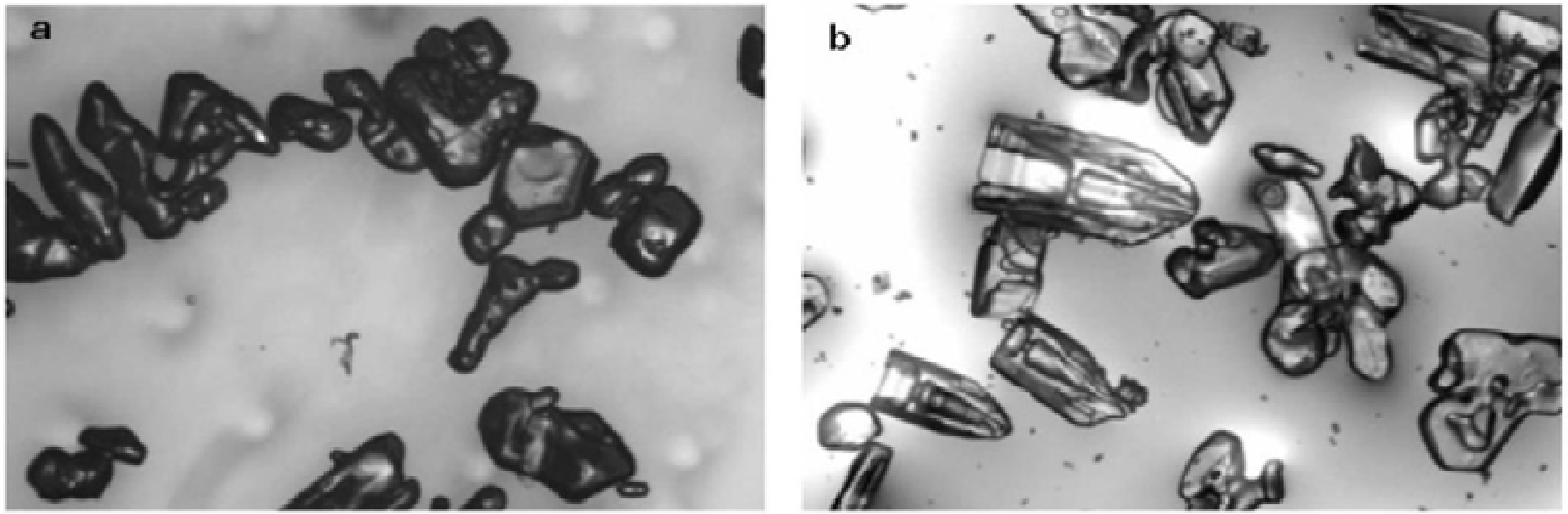


Fig. 3. Snow particles from drifting snow. (a) Particles on 9 December 2005, a day with formation of snow dunes. The width of the picture corresponds to 2.50 mm. (b) Particles on 3 December 2005, a day without formation of snow dunes. The width of the picture corresponds to 1.25 mm. In normal drift snow as shown in (b), the fraction of newly formed crystals (columns, bullet-type crystals or hexagonal plates) is high and appears even to be predominant. Dune snow particles as shown in (a) appear much smoother (weathered) and hardly contain newly formed crystals. Most of the dune snow particles are aged, already ejected snow grains from the former surface.

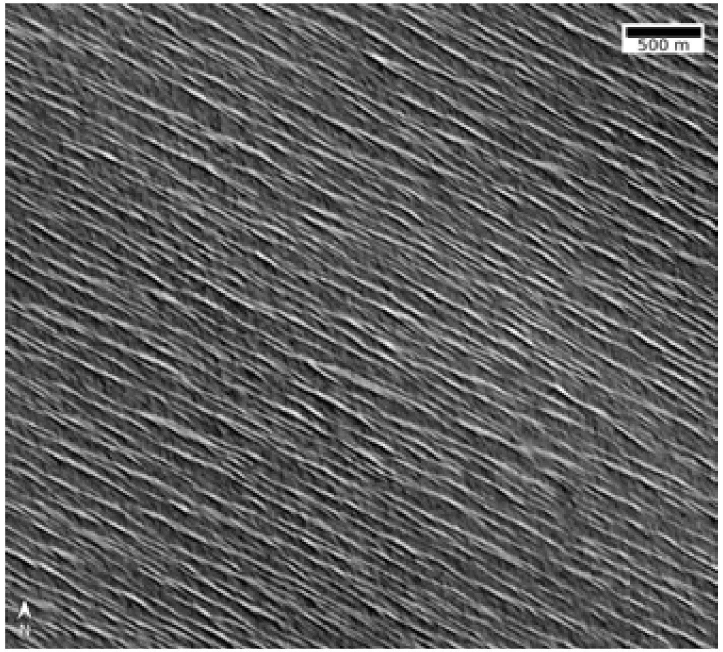
Birnbaum et al., 2010

Large scale structures

Different type of dunes at large scale, from hectometer linear dunes to kilometer megadunes

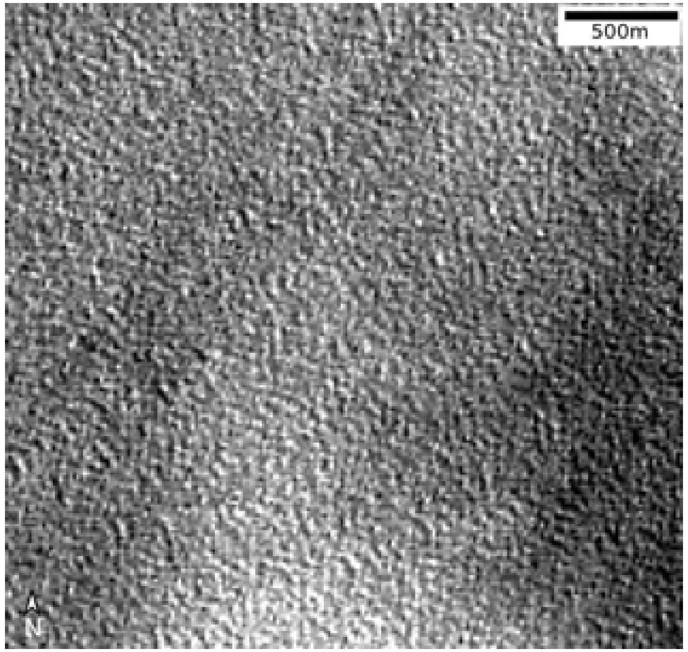
Linear dunes

Longitudinal

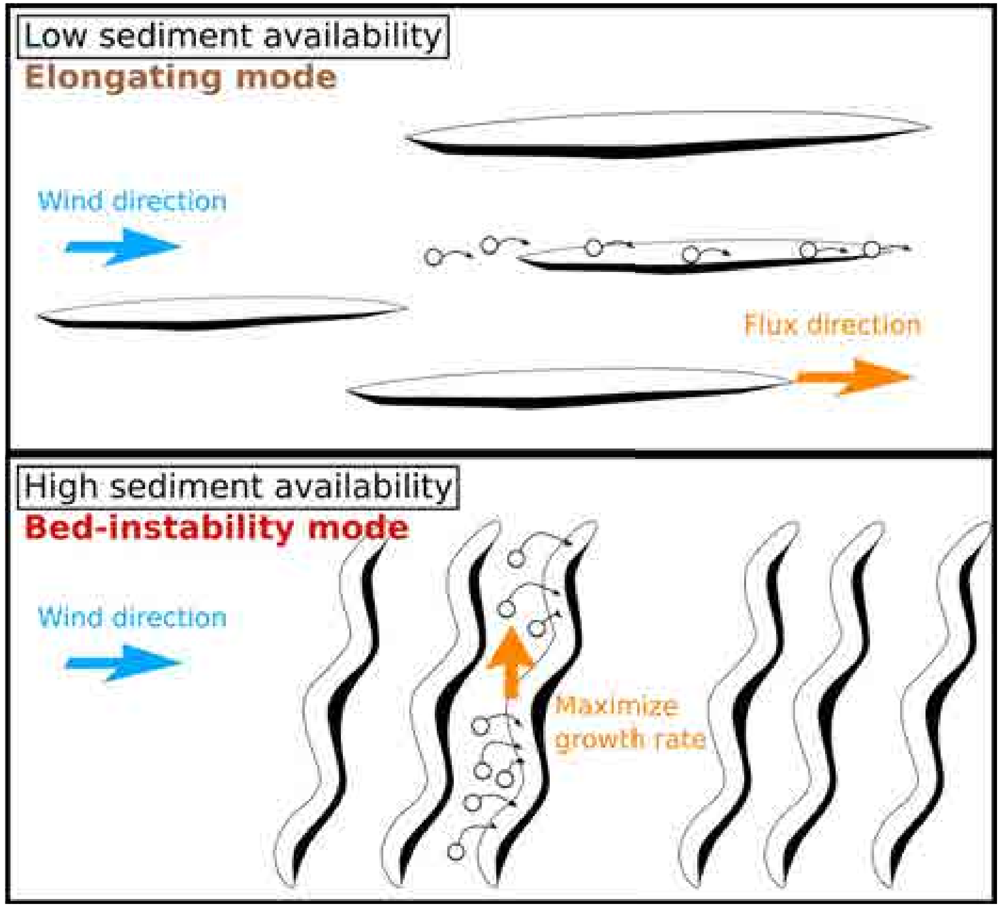


Sentinel-2

Transverse

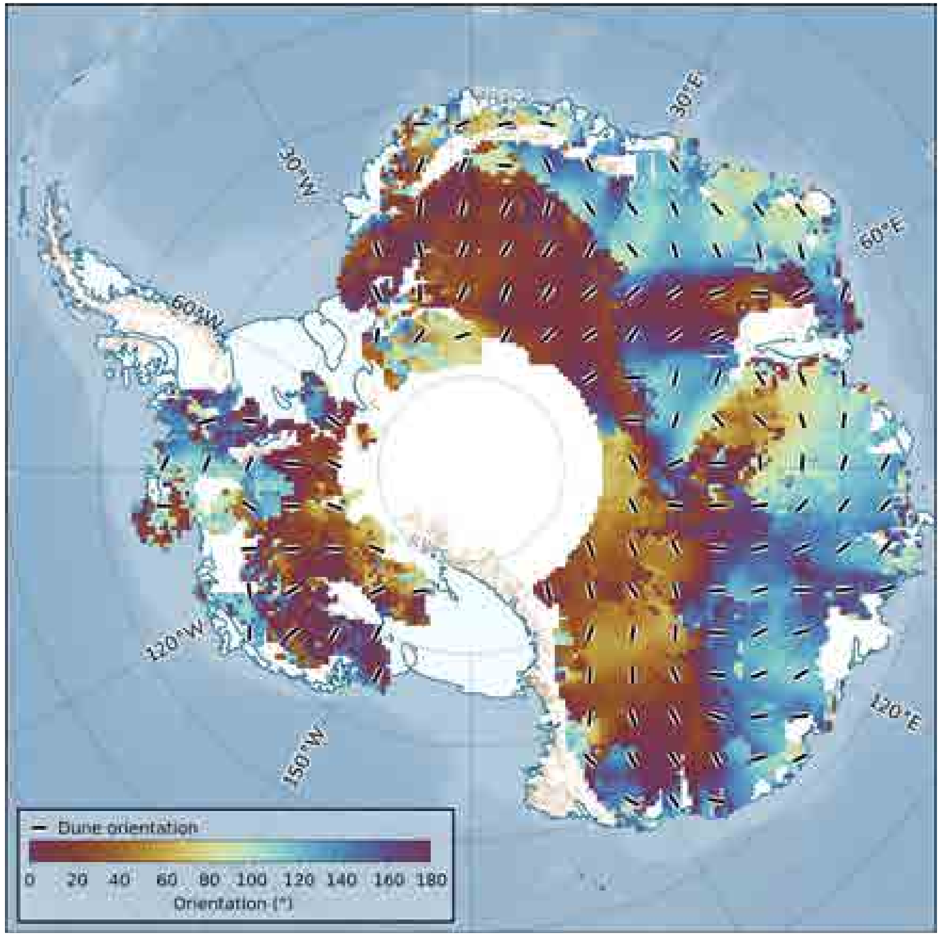


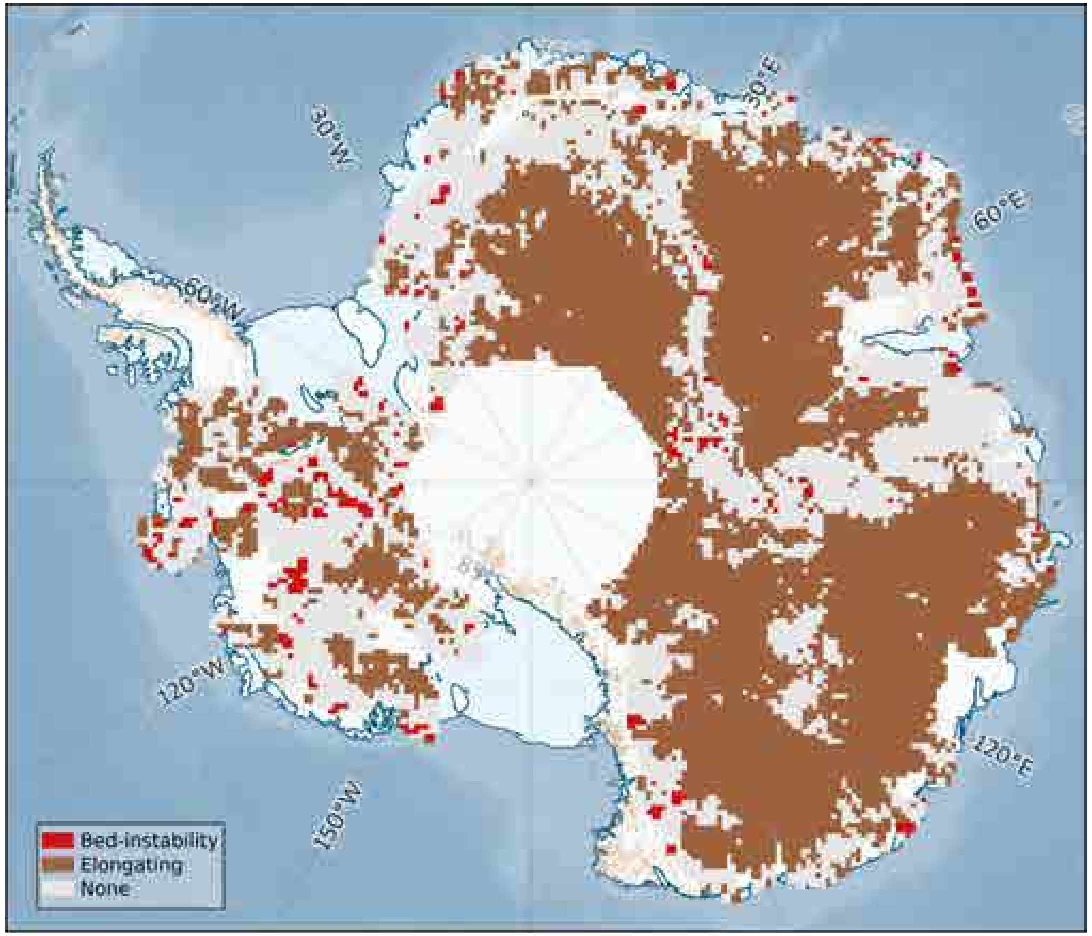
Landsat-8



Large scale structures

Snow dunes omnipresent with heights larger than the annual accumulation
Elongating mode dominant indicative of **low snow available for transport**





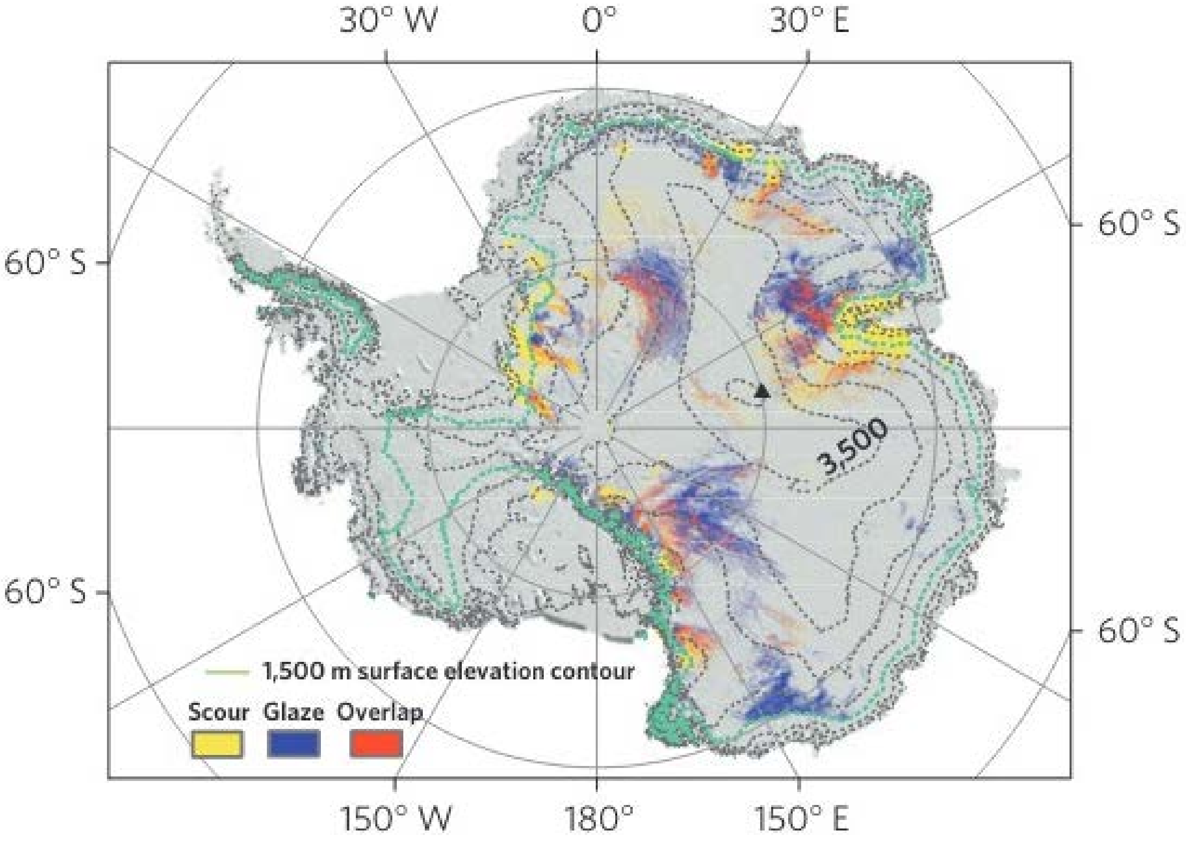
Poizat et al., 2024, in review

Wind glaze

Wind glaze = wind and sublimation remove the annual solid precipitation (SMB ~ 0 kg/m²/yr)
Wind scour = SMB <= 0kg/m²/yr

Polishing surface transmit more solar energy into the firn generating important vertical transport of water vapor
Creation of depth-hoar
Creation of surface cracks

=> **no remaining layering or depositional density variations in these areas**



Das et al., 2013

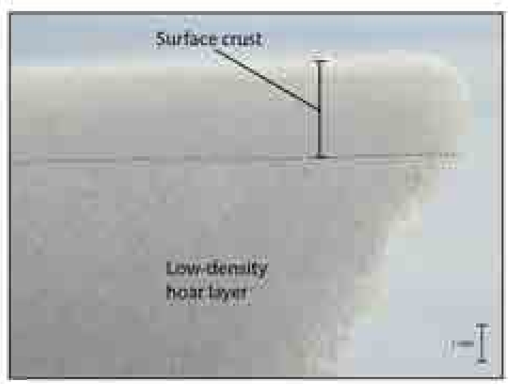
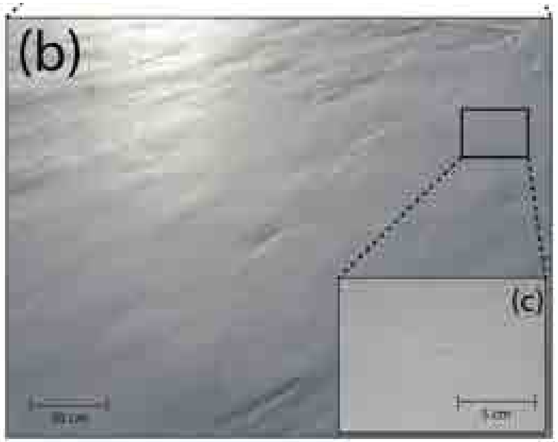
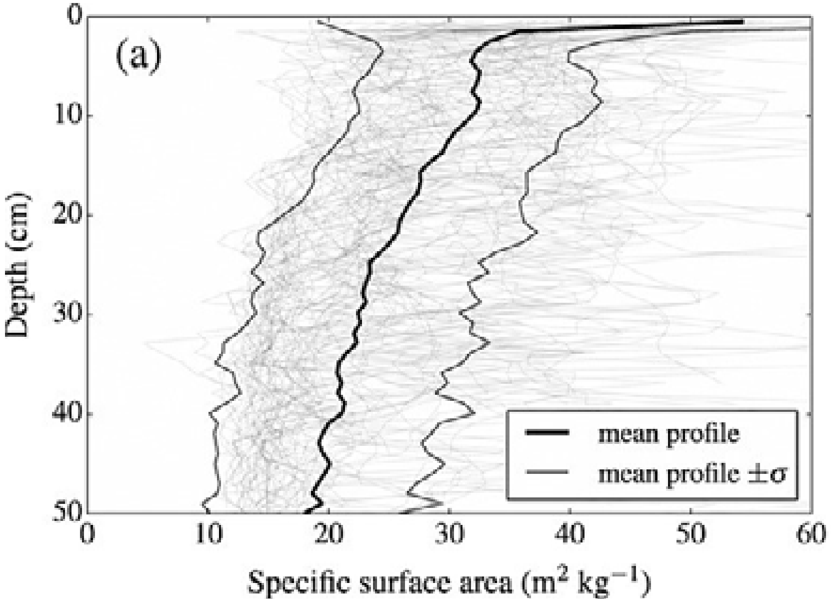


Figure 9. A surface snow sample excavated from a glazed area at WAIS Divide before the onset of polygonal cracking, showing a couplet of an evolved ~ 3 mm high-density (> 400 kg m^{-3}), multi-grain surface crust containing single-grain crusts and overlying a lower-density (< 300 kg m^{-3}) hoar layer.



Fegyveresi et al., 2018 (WAIS divide)

Snow profiles of the Antarctica Plateau



Libois et al., 2014

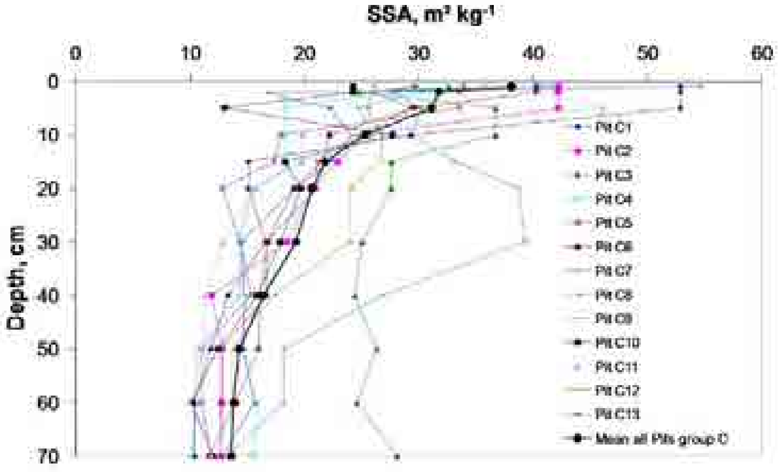
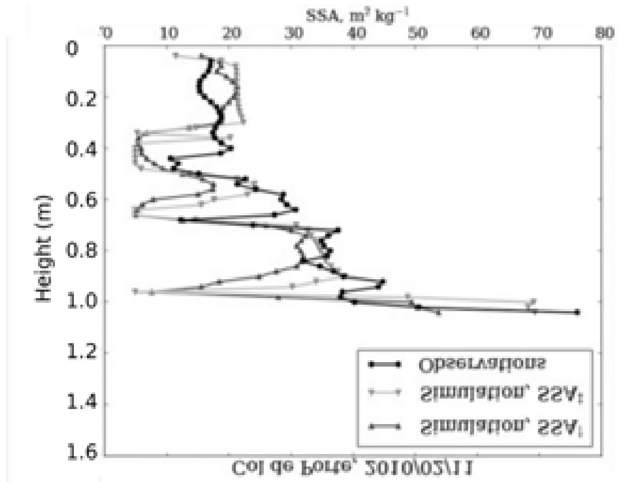


Fig. 4. SSA profiles of group C pits at Dome C.



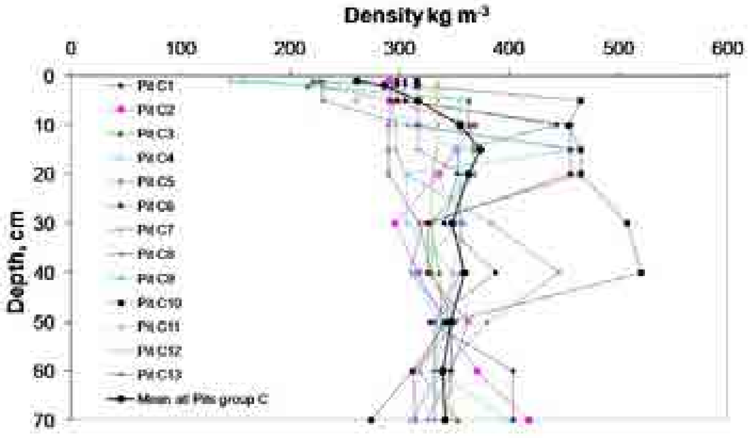
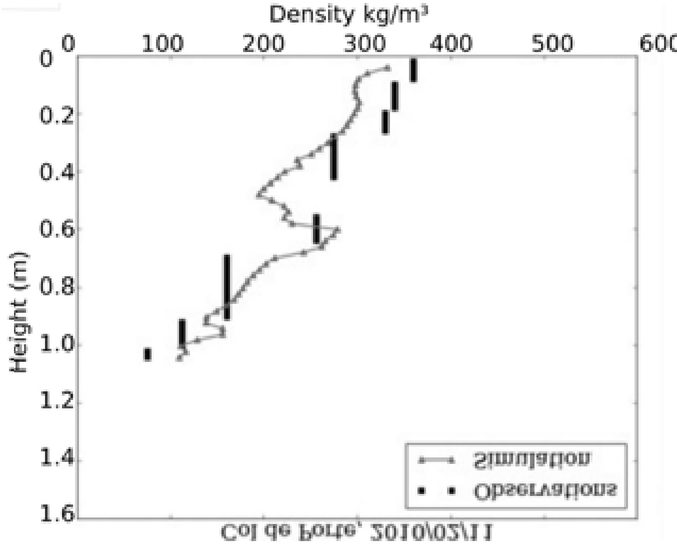


Fig. 5. Density profiles of group C pits at Dome C.

Gallet et al., 2011



Morin et al., 2013

High SSA and **low density** of Antarctica snow compared to Alpine snow

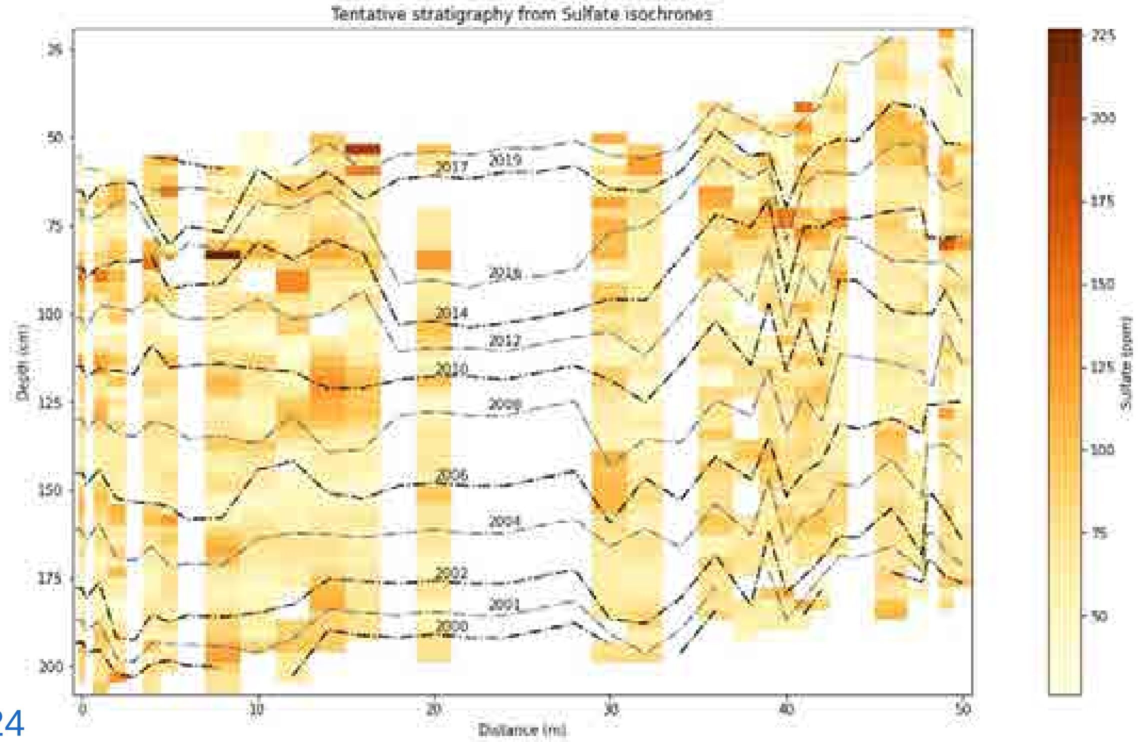
Snow profiles of the Antarctic Plateau

Reconstruction of profiles particularly difficult due to
- low accumulation
- wind distribution which induces mixing and missing snow layers

=> **High spatial variability** of the first meter of SSA and density profiles in Antarctica due to

=> **post-depositional processes**

=> **wind redistribution**



Ooms et al., 2024

Conclusion

- Post-depositional and wind redistribution impact the snow properties
- High spatial variability of the snow properties
- No layering and depositional density variations left