Recent evolution of the snow surface in East Antarctica

Teaching Unit (UE) SCI 121

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Presentation outline

General context & Introduction

I. Surface quick changes

II. Surface slow evolution

III. Surface spatial variations

Conclusion & Opening
General context & Introduction

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Conclusion & Opening
Global warming since 1900...

Fast, significant & global

+ 0.8°C since 1900 on average at the earth surface

IPCC, 2013

The most faster and significant since 1000 years

MetOffice, 2013
Mainly due to the increase of greenhouse gases concentration in the atmosphere ($\text{CO}_2$, $\text{CH}_4$, $\text{O}_3$, …)

- $\text{CO}_2$: + 35 % between 1850 and 2010
- $\text{CH}_4$: + 150 % between 1850 and 2010

*IPCC, 2013*
Consequences?

- Mean and global sea level rise: +0.2 m between 1900 and 2010
- Winter snow cover decrease in the northern hemisphere
- Summer sea ice extent decrease in the Arctic: -40% between 1900 and 2010
- Increase in global average upper ocean heat content

IPCC, 2013
**Mean sea level**

- mean and global sea level rise: + 0.2 m between 1900 and 2010
- winter snow cover decrease in north hemisphere
- summer sea ice extent decrease in Arctic: - 40% between 1900 and 2010
- Increase in global average upper ocean heat content

**Bangladesh**: 10% of the land below 1 m high = 10% of the population

=> 15 million people ...

=> estimation of sea level rise: + 0.4 to 0.8 m for 2100

=> consequences for Bangladesh ???
Antarctica: 14,000,000 km²

France: 550,000 km²

Antarctica: 14,000,000 km²
Antarctica: a huge continent ...

If we put France at the right scale ...
... cover by 3 km of ice, very flat and desert!
Antarctica: a huge quantity of ice

Jean Louis Etienne

VOLUMES COMPARÉS DES GLACES D’EAU DOUCE DE LA PLANÈTE

INLANDSIS ANTARCTIQUE
30 millions de Km3

INLANDSIS ARCTIQUE
3 millions de Km3

AUTRES GLACIERS
0,1 millions de Km3

NEIGE
0,001 millions de Km3

Jean Louis Etienne
Pourquoi étudier l'Antarctique ?

- gain de masse entre 5 et 7 mm de « niveau des mers » par an
- perte de masse entre 6 et 7 mm de « niveau des mers » par an

Pourquoi étudier la surface ?

- échanges d'énergie et de matière
Pourquoi étudier l'Antarctique ?

- gain de masse entre 5 et 7 mm de « niveau des mers » par an
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Pourquoi étudier la surface ?

- échanges d'énergie et de matière

Actuellement, sous l'effet du réchauffement climatique, le niveau moyen des mers s'élève d'environ 3 mm par an
- average temperature: – 54.5 °C
- mean windspeed : 10.5 km h⁻¹
- mean accumulation: 10 cm of snow per year

French - Italian Concordia base (Dome C)
- high: 3233 m
- latitude : 75°06' S
- longitude : 123°21' E
Why following the snow surface evolution?
General context & Introduction

What are the processes responsible of surface changes?

⇒ in 10 days, the surface aspect changed
Surface processes:
- precipitation
How do the snow precipitation occur?
General context & Introduction

Surface processes:
- precipitation
- wind (erosion, deposition, sublimation, compaction)
How wind model the snow surface?

Windspeed is never more than 50 km h$^{-1}$
Mean windspeed is around 10 km h$^{-1}$
Surface processes:
- precipitation
- wind (erosion, deposition, sublimation, compaction)
- hoar formation
General context & Introduction

How form and evolve hoar crystals on the surface?

Porte pass, France, L. Arnaud

Dome C, Antarctica

Nicolas Champollion - UE SCI 121
Surface processes:
- precipitation
- wind (erosion, deposition, sublimation, compaction)
- hoar formation
- grain growth / flat surface formation
- melt
- ...
Surface Mass Balance (SMB)

\[
\text{SMB} = \text{precipitation} + \text{snow deposition by the wind} + \text{condensation} - \text{sublimation} - \text{runoff} - \text{snow erosion by the wind}
\]

At Dome C, SMB ≈ + 0.1 m of snow per year

Near the coast, SMB ≈ + 0.5 to 3 m of snow per year

At Dôme du Goûter (France), SMB > 3 m of snow per year

Arthern, et al., 2006
Energy exchanges at the surface:

- reflection / absorption of the incident radiance
- condensation / sublimation (state changes)
- long wavelength emission
- turbulence exchange / airing
- conduction
- ...
Surface Energy Budget (SEB)
What is characterizing the snow surface?

- kind of crystals present on the surface (form, size, ...)
- rugosity at different scales
- density
- ...

1 m
1 m
Only one automatic weather station (temperature, humidity, wind, pressure) for 500 000 km²

No snowfall measurement

Only few located measurements

Snow surface is not well known and few observed on the Antarctica Plateau
Studying the snow surface and its evolution depending on the atmospheric conditions

- kind of crystals present on the surface (form, size, ...)
- rugosity at different scales
- density
- ...

1 m
General context & Introduction

Thesis =>

Studying the snow surface and its evolution depending on the atmospheric conditions

- kind of crystals present on the surface (form, size, ...)
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1 m
General context & Introduction

Studying the snow surface and its evolution depending on the atmospheric conditions

- kind of crystals present on the surface (form, size, ...)
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- density
- ...

Equivalent to the volumetric mass: mass of snow per volume unit, kg m$^{-3}$
How is measured the snow density?

By weighed a known snow volume.

**Difficulties:**

- snow weight => OK
- snow volume => OK
- do not compact the snow
- completely fill the volume that we would like to measure
- measurement representativity (spatial & temporal)
- snow melt
- field measurements: cold, wind, access difficulties, ...
- and more difficulties for the surface (no flat, without coherence, ...)
- ...

=> Measurement uncertainty between 10 and 15 %
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I. Surface quick changes

Quick temporal evolutions are much greater than spatial variations
I. Surface quick changes

Quick temporal evolutions are much greater than spatial variations

What is responsible of these quick evolutions?

hoar crystals formation
precipitation
wind
I. Surface quick changes

Pictures of the snow surface (4 m²):

- hourly frequency
- vertical observation
- domain of near-infrared
- spotlights during the winter

2 years of data available
I. Surface quick changes
I. Surface quick changes

Why are the pictures red?
Why are the pictures red?
I. Surface quick changes

Why are the pictures red?

Visible (eyes)

Sensibility zone of the camera
I. Surface quick changes

自动算法基于表面雪图的纹理分析，以检测霜晶，无霜晶和阴天（Champollion et al., 2013）
I. Surface quick changes

Temporal evolution of presence / absence of hoar

Hoar crystals cover the snow surface 45% of time
I. Surface quick changes

Hoar formation takes few days

No specific conditions in air temperature and humidity are observed during the formation of hoar
I. Surface quick changes

Hoar disappearance is fast

Hoar disappearance is due to the wind
I. Surface quick changes

**Hoar disappearance**

![Windrose diagram showing wind direction and speed](image1.png)

**All the days**

![Windrose diagram showing wind direction and speed](image2.png)

**All days with hoar disappearance**

- **Windspeed increase** (2.9 to 4.7 m s\(^{-1}\))
- **or wind origin change** (southwest to southeast)
I. Surface quick changes

Other surface changes

Relief evolution on the surface depending on the wind (8 hours in June 2012)
I. Surface quick changes

**Summary**

- **Hoar formation**: 45% of time
- **Hoar disappearance**: high wind (5 m s\(^{-1}\)) or change in the direction of the wind origin (perpendicular)
- Fresh snow deposition on hoar crystals: snow accumulation
- Relief formation on the surface (20 cm in 2 hours)
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II. Surface slow evolution

How can we study the slow evolution of the surface?

=> in situ measurement impossible because of not enough samples and too small observation period

=> automatic measurement (picture) impossible because of again too small period now and instrument broken due to hard field conditions (weather, panne, …)
Solution, la télédétection par satellite !

**Télédétection** : observation à distance

**Thèse** => télédétection micro-onde passive

Mesure de l'énergie micro-onde émise par le manteau neigeux puis transmise à travers l'atmosphère jusqu'au satellite
II. Surface slow evolution

Solution: satellite remote sensing!

Remote sensing: distant observation

Problem?

Satellite measurement is an energy. However, we are interested by the snow density!
II. Surface slow evolution

**Solution: modeling the satellite observations**

**DMRT-ML**: Dense Media Radiative Transfer Multi-Layer (Picard et al., 2013)

**Electromagnetic theory**: emission, absorption and scattering for each layers

**Interface reflections**
II. Surface slow evolution
same order of magnitude for both observations (satellite estimation and in situ measurements)
same quick variations & similar pluri-annual trend
Important trend: density decrease at Dome C of about 10 kg m$^{-3}$ y$^{-1}$
II. Surface slow evolution

Summary

Satellite observation modeling => estimation of the snow density near the surface

Important decrease of the snow density (10 kg m\(^{-3}\) a\(^{-1}\))

Possible physical explanations
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• Between Dome C and Vostok, snow density decrease

• East of Dome C, snow density increase
III. Surface spatial variations

F. Rémy, LEGOS

Passif

Actif

Bascatter trend (dB/yr)
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Conclusion & Opening
Introduction problematic:

How evolves the snow surface on the East Antarctica Plateau (hoar crystals, wind, precipitation...)?

- **Snow surface is dynamic at Dome C:**
  - hoar presence during almost half percent of the time
  - hoar disappearance due to the wind (windspeed > 3 m s\(^{-1}\) and wind direction at 75 - 90° from southwest that is the prevailing direction)
  - relief formation on the surface (20 cm in 2 hours)
  - fresh snow captured by hoar crystals

⇒ All these processes could have a huge impact on the amount of snow that accumulates per year on the surface (BMS) and on air temperature (BES)
• **Slow density evolution at Dome C:**
  - Important and regular seasonal cycle
  - Important snow density decrease of about 10 kg m\(^{-3}\) a\(^{-1}\) for 10 years

• **Spatial variations of the snow density on the Antarctica Plateau:**
  - Snow density decrease between Dome C and Vostok, increase at the East of Dome C
  - Spatial variations also observed with another satellite

⇒ **requirement to understand what is responsible of these temporal and spatial variations of snow density near the surface**
Antarctica snow surface evolves … and it is necessary to understand why!