Snowdrift and blowing snow in East Antarctica:
a comparison of satellite and ground-based remote sensing observations at Princess Elisabeth Station

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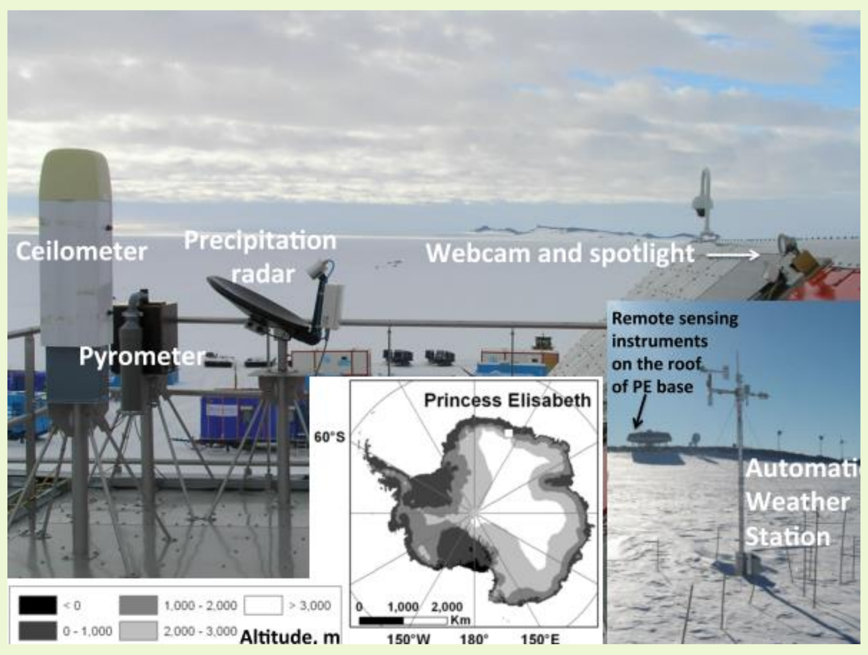
1. Project framework and aim

- Antarctic surface mass balance is not well constrained : scarcity of observations and challenges of regional climate modeling
- There is a large uncertainty on the contribution of drifting/blowing snow events on surface mass balance: relocation of snow (accumulation or erosion) and drifting snow sublimation (Gorodetskaya et al., 2015)
- The representation of blowing/drifting snow is a challenge in climate modeling and of the estimation of their impact on surface mass balance and stability of ice shelves
- The aim here is to provide a "ground truth" for blowing snow, not limited by clouds, sunlight and other limitations applying to satellite data

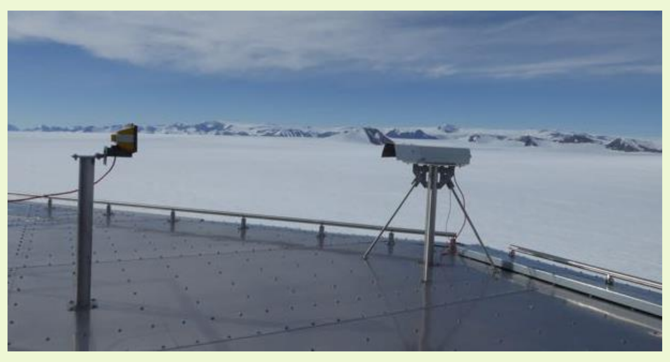
2. Ground-based remote sensing instruments

Cloud- precipitation observatory set up on the roof of the Belgian Princess Elisabeth station, located in East Antarctica (72º South, 23º East, 1380 m asl) : since 2009, the robust set of instruments delivers ground-based remote sensing data :

- ceilometer: backscatter profiles to detect cloud base heights and top of the drifting snow layers at 910 nm
- micro-rain radar: snowfall determination and rates
- pyrometer : cloud base temperature
- automatic weather station: near-surface air temperature, wind speed and direction, relative humidity, atmospheric pressure and broadband radiative fluxes, snow temperatures at various depths and snow height changes
- webcam with spotlight to monitor the instruments and weather
- A snowflake video imager was installed during the 2015-2016 summer campaign and gives information about particles size distribution, fall speed and precipitation rates (Newman et al., 2009)



Fig, 1: The cloud–precipitation meteorological observatory. (center and right lower inset: the instruments. Middle inset : location of PE station on the Antarctic ice sheet together with the orography (meters asl). (Gorodetskaya et al., 2015)



Fig, 2: The snowflake video imager: camera pointing towards a halogen lamp

3. Satellite remote sensing blowing snow detection

- Sources (Palm et al., 2011):
  - satellite lidar data : Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) at 532 nm,
  - events in sunlight: Moderate resolution Imaging Spectroradiometer (MODIS)
- Routine to detect the blowing snow events, estimate their spatial and temporal frequency, layer height, optical thickness and mass transport based on :
  - backscatter threshold at the lowest level based on a scaling factor times the magnitude of the 532 nm attenuated molecular scattering
  - wind speed threshold of 4m. s^{-1} at 10 m above ground level
  - decreasing backscatter profile with height

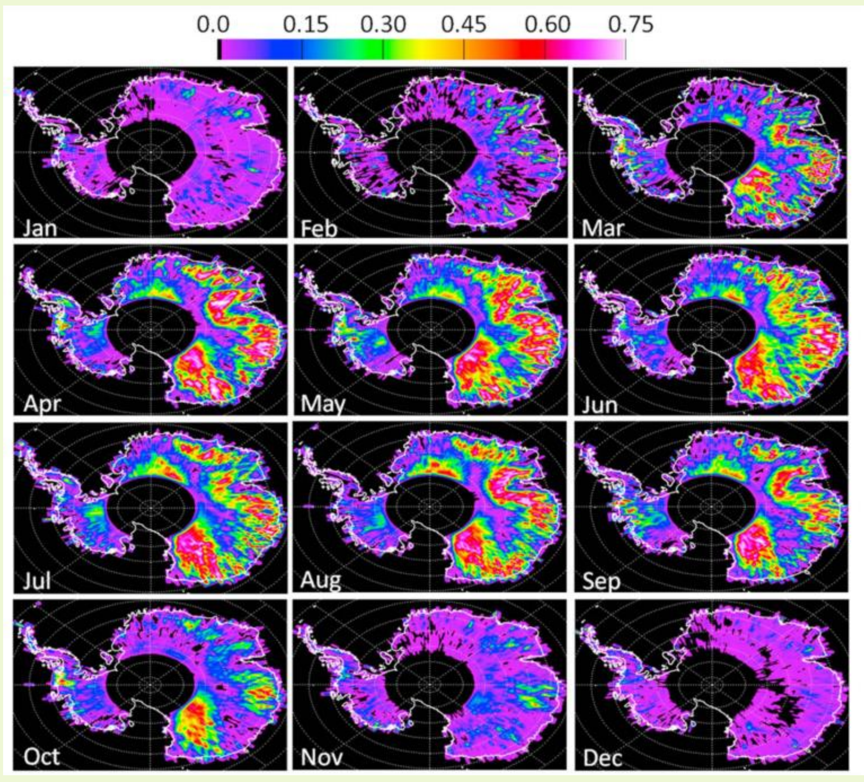


Fig 3: Blowing snow frequency (fraction) and spatial distribution over Antarctica for each month of 2009 as determine from analysis of CALIPSO/CALIOP data (Palm et al., 2011)

- Limitations :
  - minimum layer thickness of 20-30 m for blowing snow events to be detected
  - thick clouds impede blowing snow detection : limitation to cloud-free conditions
  - detection from above : the algorithm has to distinguish snow particles present above the bright surface, which induces a relatively high backscatter threshold

4. Development of an algorithm for blowing snow detection

- Advantages of the ceilometer:
  - closer to the event: detects below 30 m
  - detection during cloudy skies and precipitation events
- Based on the :
  - ceilometer attenuated backscatter
  - ceilometer backscatter profile shape
  - distinction between 3 cases: clear-sky / cloudy / precipitation

4.a. 4.b. 4.c. 4.d.

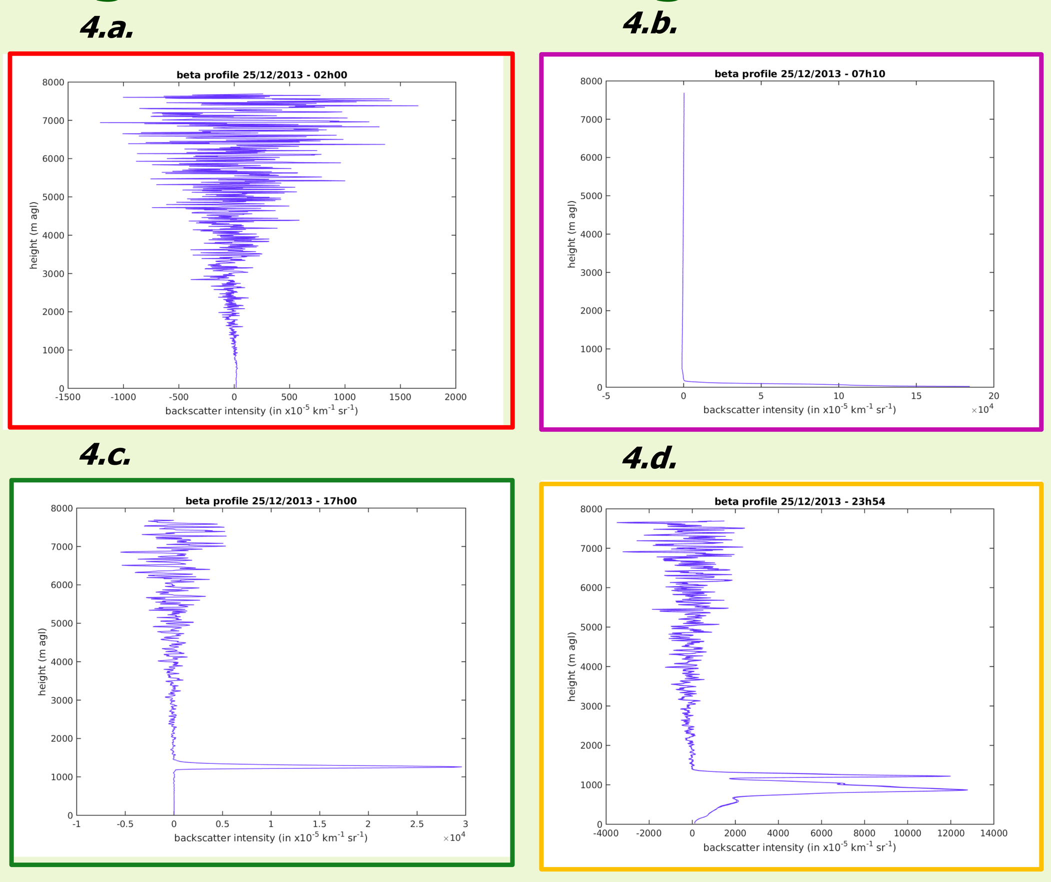


Fig. 4: the ceilometer attenuated backscatter profiles for the 25/12/2013 events marked by colored bar on figure 5.
4.a) clear-sky at 2h00 (red)
4.b) blowing snow at 07h10 (purple)
4.c) cloudy at 17h00 (green)
4.d) precipitation at 23h54 (orange)

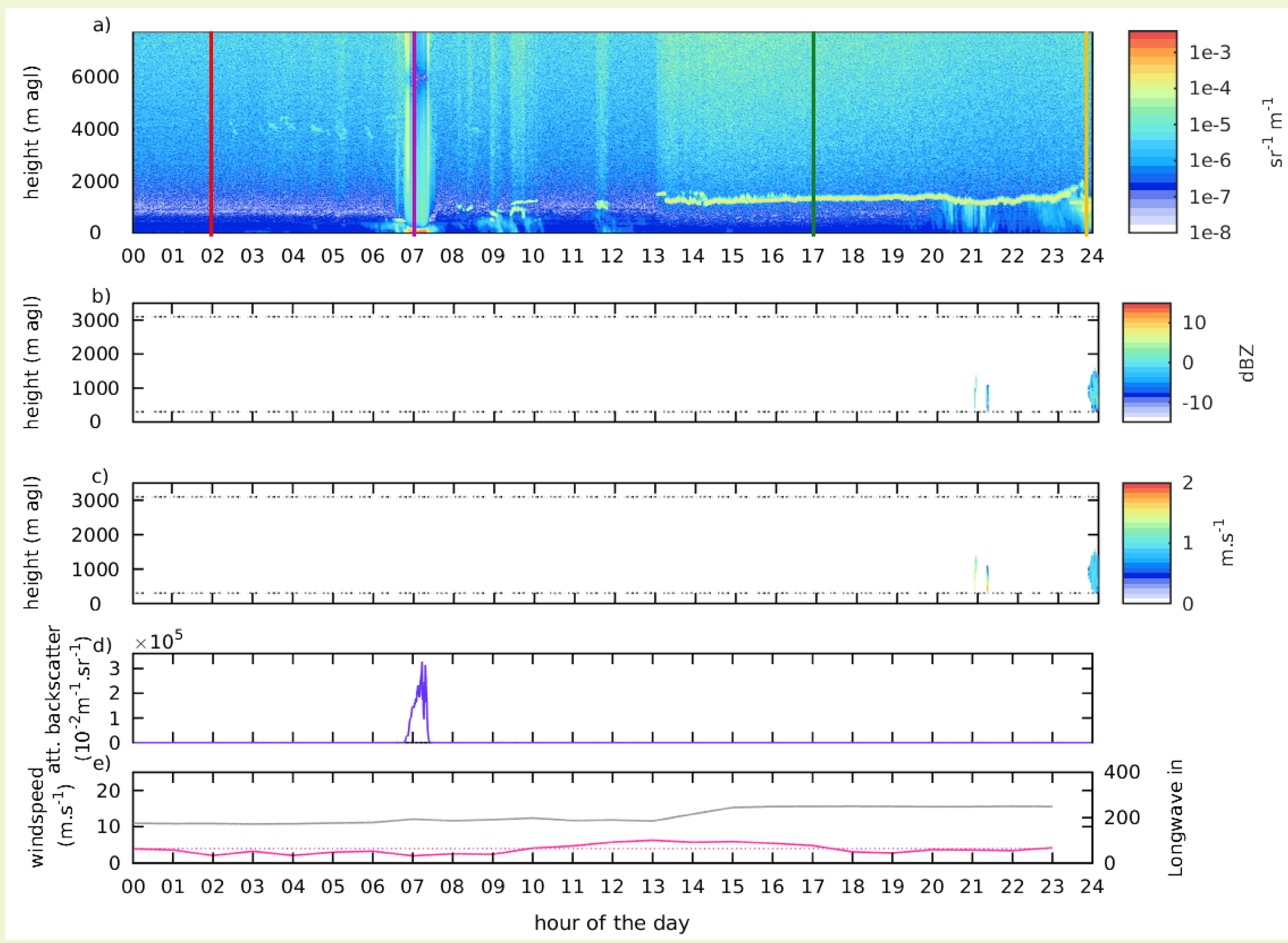


Fig. 5: blowing snow event of the 25/12/2013, a) ceilometer attenuated backscatter b) micro-rain radar effective reflectivity (in dBZ) c) Micro-rain radar Doppler velocity (in m s^{-1}) d) ceilometer attenuated backscatter intensity at the ground level (in 10^{-5} km^{-1} sr^{-1}) d) wind speed (pink, in m s^{-1}) and incoming longwave radiation (grey, in W m^{-2}) from the automatic weather station,

5. Challenges and next steps

- adequate ceilometer backscatter threshold based on the 910nm molecular backscatter empirically determined
- overlap problem for the first two to three bins
- sensitivity of the instrument
- profile characterization : attenuation of the backscatter signal with height and calculation of the total optical depth
- mixed events: identification of the profile of blowing snow occurring together with precipitation events

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