Contribution of surface and snowdrift sublimation to the surface mass balance at the Belgian Antarctic station Princess Elisabeth

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Abstract: In the near-coastal regions of Antarctica, a significant fraction of the solid precipitation is removed again through sublimation, either directly from the surface or from drifting snow particles. Meteorological observations from an Automatic Weather Station (AWS 16) near the Belgian research station Princess Elisabeth in Dronning Maud Land, East-Antarctica, are used to study surface and snowdrift sublimation and to assess their impacts on both the surface mass balance and the surface energy balance. From February 2009 to September 2010, surface sublimation was found to remove 3% of the annual solid precipitation. Vertically-integrated snowdrift sublimation was estimated using three different 'state-of-the-art' parameterisations: on average, this process was responsible for ablating 4% of all solid precipitation at AWS 16. Application of SNOWSTORM, an atmospheric surface layer/snowdrift model, confirms that the three snowdrift sublimation parameterisations succeed in predicting snowdrift sublimation amounts. A detailed process study and investigation of the near-surface meteorological conditions are conducted to explain these anomalously low sublimation values at AWS 16.

Surface & snowdrift sublimation at Princess Elisabeth

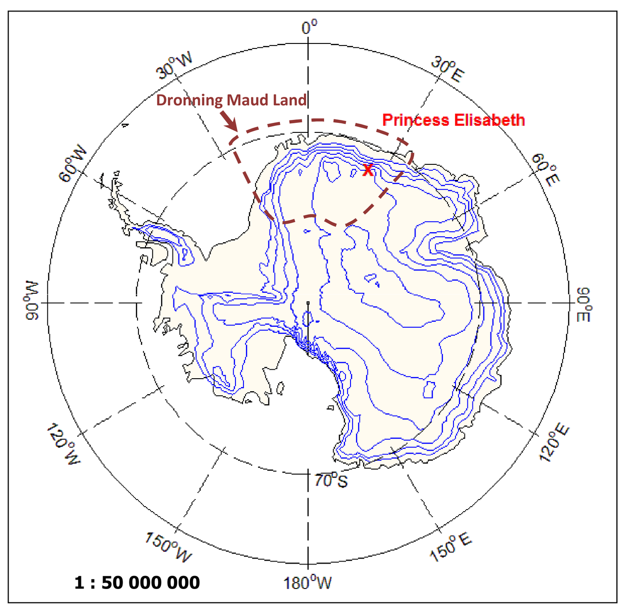

Figure 1: Location of Princess Elisabeth station in Dronning Maud Land, East-Antarctica.

Location and Methods

- An estimation of the individual SMB components at the Belgian Antarctic station Princess Elisabeth (fig.1, 3) was done using meteorological observations gathered there since February 2009 (fig.2) and following the method developed by Van Den Broeke and colleagues (2004). The core of this SMB model builds on the findings from Monin-Obukhov similarity theory, and contains three different parameterisations for snowdrift sublimation: B98 (Bintanja, 1998), BR01 (Bintanja and Reijmer, 2001), DY01 (Déry and yau, 2001).
- The SEB components were investigated using a SEB model (Van Den Broeke et al., 2005).
- Comparison is made to three other stations in Dronning Maud Land, namely AWS 5 (Wasa/Aboa), 6 (Svea Cross) and 9 (Kohnen).
- The numerical snowdrift model SNOWSTORM (Bintanja, 2000a) is applied as a benchmark for testing the three snowdrift sublimation parameterisations and for process study.

Results

- From February 2009 till September 2010, surface and snowdrift sublimation removed a mass equivalent to 5 mm w.e. yr^{-1}, respectively 8 mm w.e. yr^{-1} at Princess Elisabeth (fig.5a,c).
- The three parameterisations withstand testing by SNOWSTORM (fig.5c).
- Considered together, surface and snowdrift sublimation have a significant impact on the SMB at Princess Elisabeth (fig.5d): sublimation removed nearly half of the total accumulation during the first 8 months of 2010, compared to only 3% in 2009. Note that accumulation was very limited in 2010 (fig.5d).
- Snowdrift sublimation is not marked by a seasonality (fig.5c-d), whereas surface sublimation clearly is a summer phenomenon, with even deposition occurring during winter (fig.4; fig.5a).
- **Compared to two other katabatic stations in Dronning Maud Land, AWS 5 and 6, both surface and snowdrift sublimation are anomalously low (fig.5b,d). Factor 3-4! Why?**

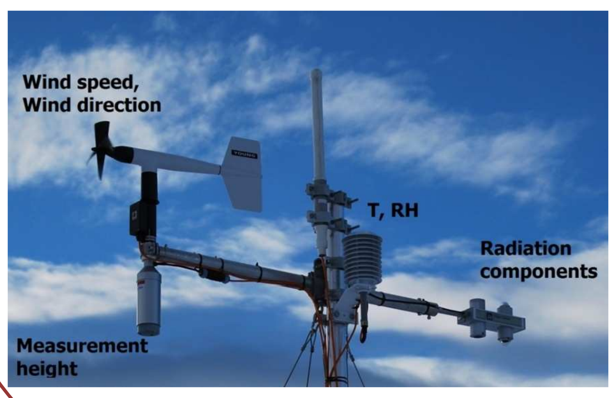

Figure 2: AWS 16 sensors.

Figure 3: 'Mini' snowdrift event at Princess Elisabeth.

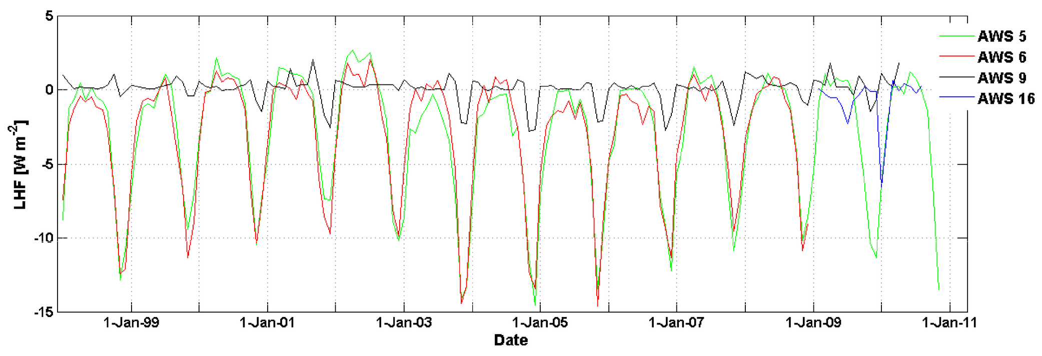

Figure 4: Monthly mean latent heat flux at AWS 5, 6, 9 and 16. from simulations with a SEB model.

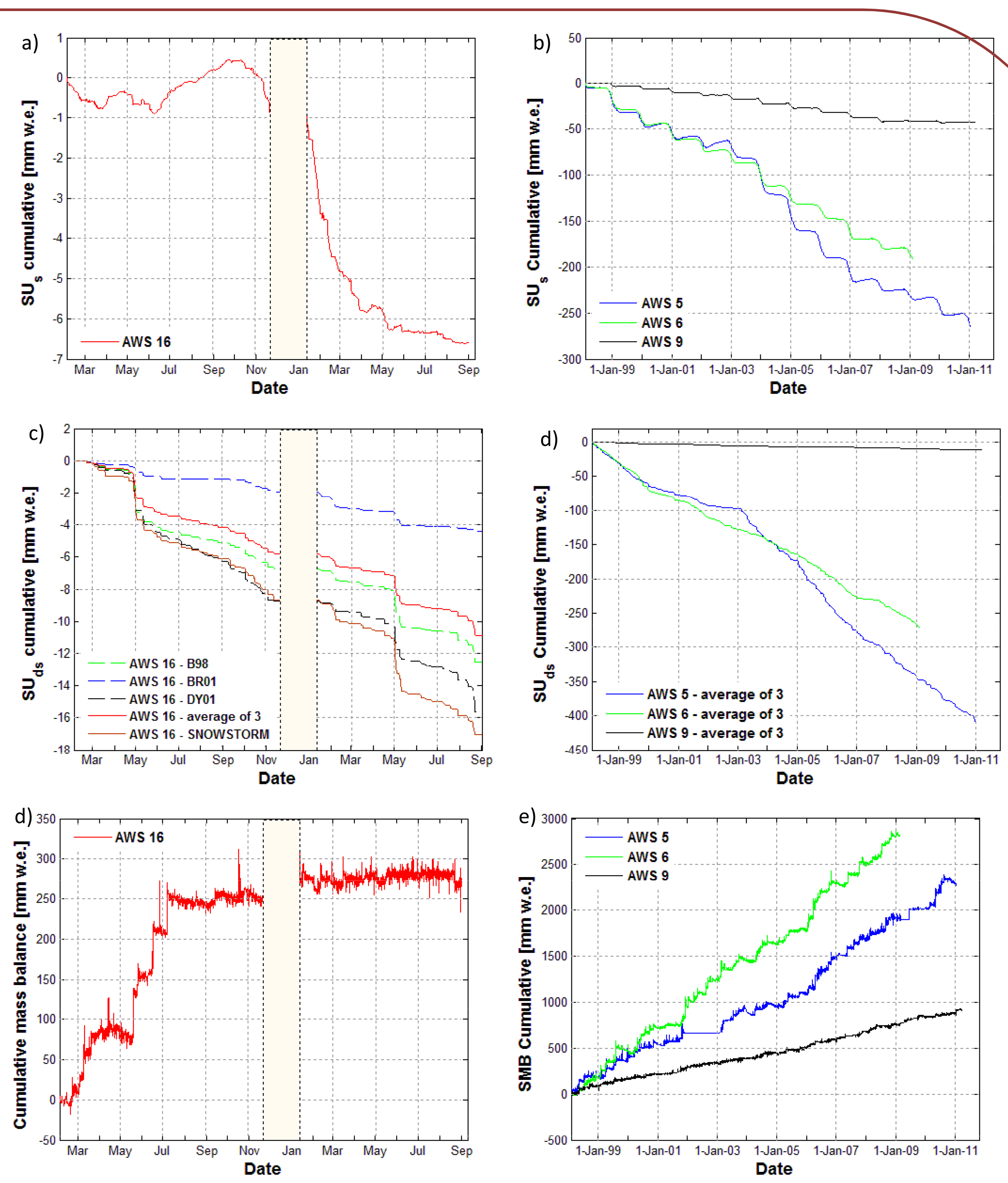

Figure 5: cumulative mass fluxes at AWS 16 (left column) compared to AWS 5, 6 and 9 (right column). Top to bottom: cumulative surface sublimation SU_s, cumulative snowdrift sublimation SU_{ds} and cumulative mass balance SMB.

Explaining low surface sublimation: sensitivity analysis

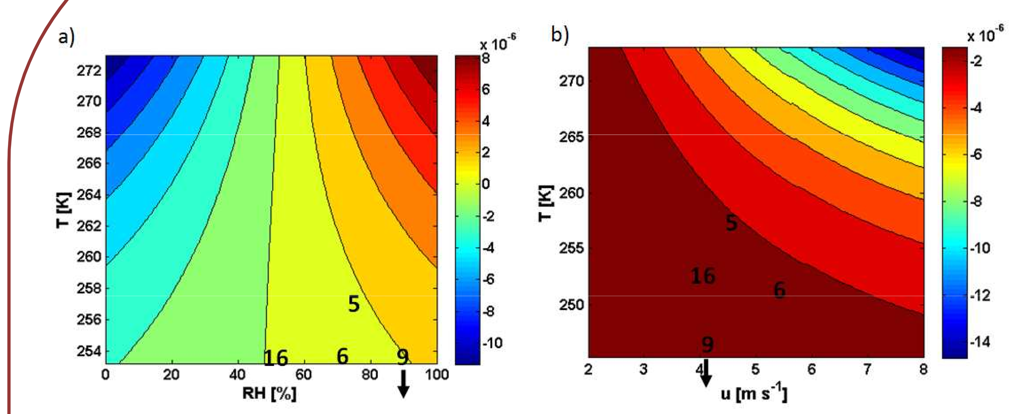

Figure 6: Surface sublimation theoretical sensitivity experiment with situation of each station: (a) u = 5 m s^{-1}; (b) RH = 20%.

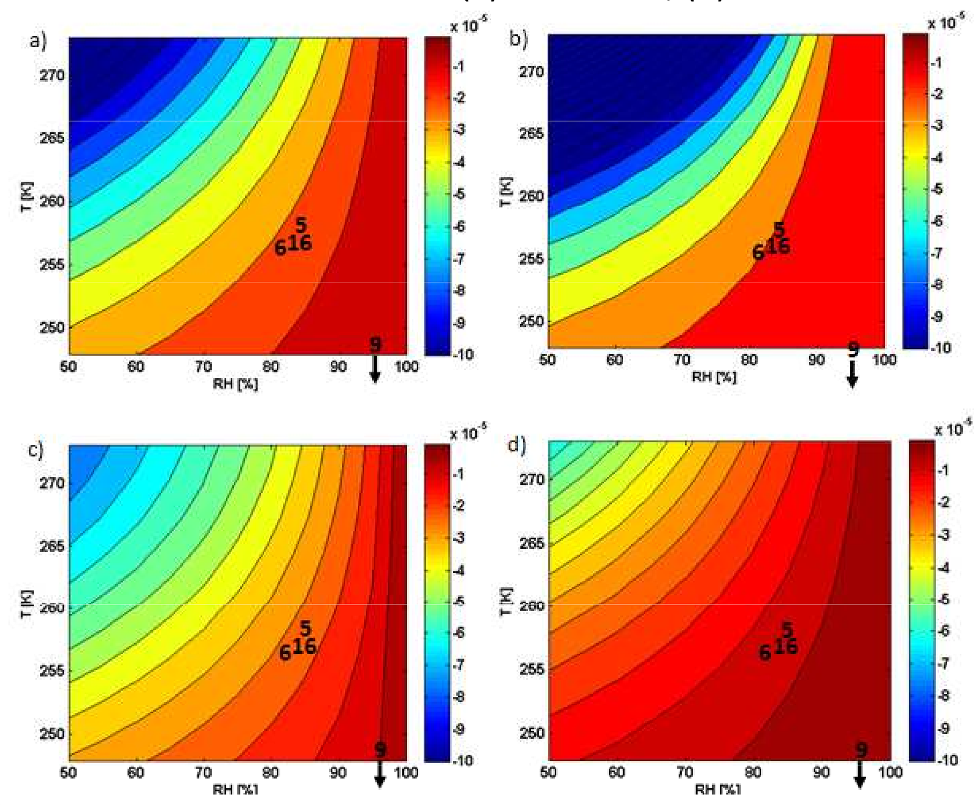

Figure 7: Snowdrift sublimation theoretical sensitivity experiment with situation of each station: (a) B98; (b) BR01; (c) DY01; (d) SNOWSTORM. Assumed: u=20 m s^{-1}.

- Surface sublimation predominantly depends upon RH (fig.6a): for a RH below ~50%, sublimation takes place, while it is replaced by deposition for larger humidity values. Also the magnitude of the temperature inversion is a main determinant: a strong inversion dampens turbulence and therewith surface sublimation. Temperature and wind speeds are equally important, but only represent second order effects (fig.6b)
- The sensitivity analysis can explain anomalously low surface sublimation at AWS 16: compared to AWS 5 (6), reduced surface sublimation can be attributed to lower T (u) (fig.6b), but most of all to local topography, which protects the station from strong katabatic winds and consequently allows for a strong surface inversion to persist throughout most of the year.
- As for snowdrift sublimation, RH is the main controlling variable in situations with an ambient RH close to saturation level; However, at RH levels below ~70-80%, the influence of ambient T clearly becomes dominant over RH (fig.7). Similar reasoning holds for the RH versus u.
- Although differences exist, in general all 4 methods consistently show consistent dependencies. (fig.7a-d).
- However, the sensitivity analysis cannot explain anomalously low snowdrift sublimation at AWS 16.

Explaining low snow drift sublimation: near-surface meteorology

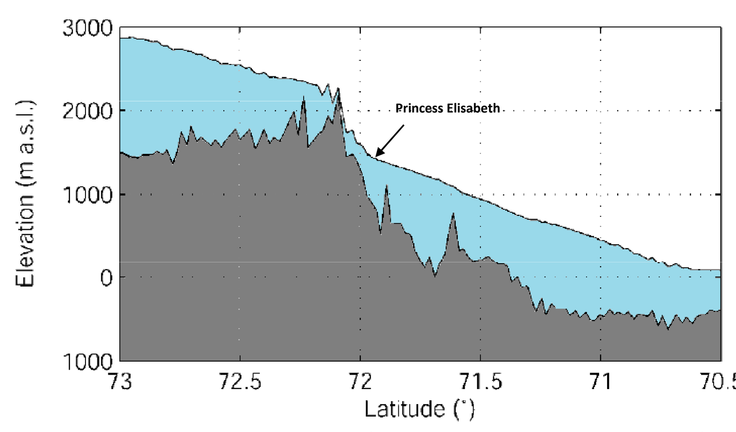

Figure 8: : Surface (Bamber et al., 2009) and bedrock (Lythe and Vaughan, 2001) topographic transect along the 23°E meridian (adapted from Pattyn et al., 2009).

- Whenever snowdrift occurs at AWS 16, it will be associated with warm and moist synoptic conditions: while the Spearman rank correlation ρ between both quantities is 0.19 at AWS 5 ($p < 0.001$) and $\rho = 0.21$ at AWS 6 ($p < 0.001$), the correlation mounts up to a value of 0.38 at AWS 16 ($p < 0.001$).
- Thus, snowdrift sublimation is lower at AWS 16 because average wind velocity is relatively low, but even more because the high wind speed events at Princess Elisabeth coincide with high saturation levels associated with the synoptic wind regime.

- Princess Elisabeth is situated at an altitude of 1420 m a.s.l., at the foot of the steep transition towards the Antarctic Plateau – the so-called escarpment zone (fig.8).
- Due to the specific geographic location of the station, wind fields observed at AWS 16 show a marked behaviour. Predominantly two wind speed regimes reign at AWS 16 (fig.9). Most often, a S-SSE, katabatic wind is blowing at low speed (0-10 m s^{-1}). Strong katabatics are blocked by the surrounding Sør Rondane mountains (fig.8). On the other hand, during approximately 10-20% of the observation period, a strong E, synoptic wind prevails at AWS 16. The highest wind speeds (20-30 m s^{-1}) are all situated within this wind regime.

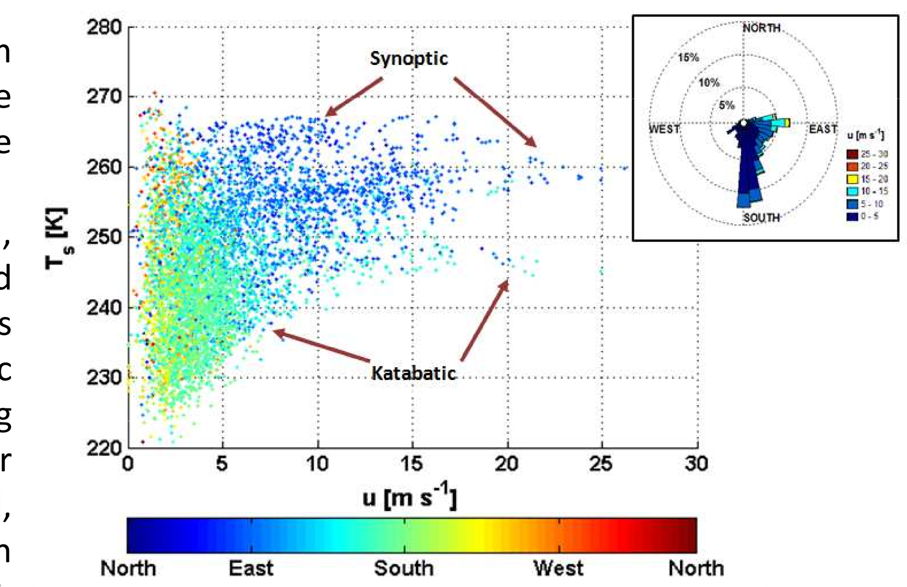

Figure 9: surface temperature versus wind speed, with colours representing wind direction. Inset: dominant wind directions with the contribution of each wind speed class to a given direction.

Conclusion: Orographic shielding from strong, dry katabatics is responsible for both the anomalously low surface and snowdrift sublimation at Princess Elisabeth:

1) A strong temperature inversion persists throughout most of the year, reducing surface sublimation.
2) Whenever strong winds occur, they are associated with high RH values (synoptic regime), therefore not allowing for significant snowdrift sublimation.

References: ***(1)*** Bintanja, R., 1998. The contribution of snowdrift sublimation to the surface mass balance of Antarctica. Annals of Glaciology 27, 251-259. ***(2)*** Bintanja, R., 2000. Snowdrift suspension and atmospheric turbulence. Part I: Theoretical background and model description. Boundary Layer Meteorology 95, 343–368. ***(3)*** Bintanja, R., Reijmer, C.H., 2001. A simple parameterization for snowdrift sublimation over Antarctic snow surfaces. Journal of Geophysical Research 106(D23/31), 739–748. ***(4)*** Déry, S.J., Yau, M.K., 2001, Simulation of blowing snow in the Canadian Arctic using a double-moment model. Boundary-Layer Meteorology 99, 297–316. ***(5)*** Van Den Broeke, M.R., Reijmer, C.H., Van De Wal, R.S.W., 2004a. A study of the surface mass balance in Dronning Maud Land, Antarctica, using automatic weather stations, journal of Glaciology 50(171), 565-582.