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Effect of surface albedo, water vapour, and atmospheric aerosols on the cloud-free shortwave radiative budget in the Arctic

C. Di Biagio (1,2), A.G. di Sarra (1), P. Eriksen (3), S.E. Ascanius (4), G. Muscari (5), and B. Holben (6)

(1) ENEA, UTMEA-TER, Rome, Italy (claudia.dibiagio@enea.it), (2) University of Siena, Department of Earth Science, Siena, Italy, (3) DMI, Danish Meteorological Institute, Copenhagen, Denmark, (4) DMI, Danish Meteorological Institute, Qaanaaq, Greenland, (5) INGV, Istituto Nazionale di Geofisica e Vulcanologia, Rome, Italy, (6) NASA Goddard Space Flight Center, Greenbelt, Maryland, USA

The Arctic region plays a central role in the global climate system. As a consequence of climate changes and global warming in the Arctic we expect a decrease in the surface albedo, caused by the reduction in both the area covered by snow/ice and the thickness of the ice-pack, as well as an increase in atmospheric water vapour and atmospheric aerosols, due to an increase of both the long-range transport and the local production. The surface energy balance sensitivity to variations in surface albedo (A), water vapour (wv), and aerosol occurrence is one of the main key factors to evaluate when assessing how the Arctic will respond to future climate changes.

The main objective of this study is to derive the individual contributions of wv, A, and atmospheric aerosols in affecting the cloud-free shortwave irradiance (SW) at the surface. Four years of data of SW, aerosol optical properties, and column wv measured at Thule Air Base, TAB, (76.5°N, 68.8°W, Greenland), and co-located satellite observations of A are used in this study. The measurements are combined with radiative transfer model calculations in order to reproduce the observed shortwave surface fluxes and to separate the radiative effect of each parameter.

In the daylight period of the year (March to October at Thule), water vapour varies between 0.1 and 1.6 cm, with maxima in summer. The surface albedo ranges between 0.66 and 0.05; the melting season occurs typically between mid-May and mid-June. The aerosol optical depth at 500 nm (τ) is generally lower than 0.2 and shows an evident seasonal cycle with larger values in spring, during the haze season, and lower values in summer and early autumn.

The results of our study indicate that the shortwave radiation at the surface is mainly affected by water vapour absorption, which produces a reduction of SW as low as -100 Wm^{-2}. The seasonal change of A produces an increase of SW by up to +25 Wm^{-2}. The annual mean radiative effect is estimated to be –(21-22) Wm^{-2} for wv, and +(2-3) Wm^{-2} for A.

Atmospheric aerosols produce a reduction of SW as low as -32 Wm^{-2}. The instantaneous aerosol radiative forcing (RF$_\tau$) reaches values of -28 Wm^{-2} and shows a strong dependency on surface albedo. The derived radiative forcing efficiency (FE$_\tau$) for solar zenith angles between 55° and 70° is estimated to be (-120.6±4.3) Wm^{-2}for $0.1<A<0.2$, and (-41.2±1.6) Wm^{-2} for $0.5<A<0.6$.

Between 2007 and 2010 the annual mean wv shows an increase of +0.065 cm (which produces a decrease of the annual mean SW by -0.93 Wm^{-2}). The annual mean A decreases by -0.027, inducing a change of SW by -0.41 Wm^{-2}. The maximum of the interannual variability in the radiative effects of wv and A is observed in May and in June, thus indicating late spring as the most sensitive period to variations in A and wv for surface shortwave radiation.