

Radiation climate variability in Svalbard: surface and satellite observations

Jon Børre Ørbæk, Vidar Hisdal
& Lars Edin Svaasand



This paper performs a climatological investigation of the surface radiation budget (SRB) in Svalbard, on the basis of the Norwegian Polar Institute's radiation measurements from Ny-Ålesund (1981–1997) and the NASA/Langley Surface Radiation Budget Dataset (1983–1991). The radiation climate is related to meteorological conditions and surface properties, and compared to surface radiation fluxes measured from space. The natural variability of the short-wave and long-wave radiation fluxes in Ny-Ålesund is generally governed by the large annual variation in the incoming light with polar night and polar day conditions, the large changes of surface albedo – especially during spring – and the atmospheric circulation with frequent cyclone passages during winter with alternating periods of warm, humid maritime air from the south and cold, dry Arctic air from the north.

Comparison with the satellite derived surface radiation fluxes shows that Ny-Ålesund is to a large extent influenced by the “ocean” climate to the west of Svalbard during the summer and autumn, but has a more “continental” radiation climate representative of the more central parts of the island during winter and spring. Ny-Ålesund is located in a fiord on the north-west coast of Svalbard, where the ocean cloud cover and the Arctic sea fog play an important role during the summer. During the winter and spring, however, the fiords are frozen and the drift ice covers a large extent of the surrounding ocean.

J. B. Ørbæk, V. Hisdal & L. E. Svaasand, Norwegian Polar Institute, Polar Environmental Centre, N-9296 Tromsø, Norway.

Introduction

The surface radiation budget and feedback mechanisms connected to cloud radiation and surface albedo are of major importance for the Arctic climate and energy balance. As a probable result of increasing concentrations of greenhouse gases in the atmosphere, the global mean surface temperature has slowly risen by 0.6°C since the late 19th century (Nicholls et al. 1996). While the regional effects of this temperature rise on precipitation patterns, winds, cloud cover, etc. are difficult to describe, most global circulation models show a poleward amplification of the climate signals. As a result of the intensified temperature gradients in the atmosphere, a warming climate is therefore expected to give early and large effects in the polar areas, and, with a significant increase in climate variability with more extreme weather situations,

deeper cyclones, stronger seasonal cycles and increased precipitation. No significant trend in surface temperature is found in Svalbard, but the precipitation has increased by as much as 25% since the beginning of this century (Førland et al. 1997). The negative annual radiation budget of the Arctic is balanced by the poleward transport of warm water and humid air from the Atlantic Ocean. According to Orvig (1970), an average of 4–8 cyclones/month are found passing over the Norwegian and Barents seas. The European Arctic is therefore potentially sensitive to climate perturbations.

This study describes some fundamental features of the natural variability of the radiation climate of Svalbard and, particularly, Ny-Ålesund. Because the Arctic is sensitive to climate perturbations, identification of the basic features and natural variability of the radiation climate is therefore

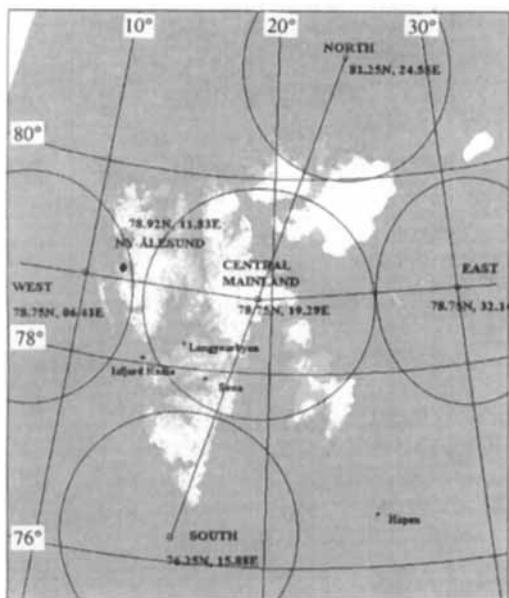


Fig. 1. Map of Svalbard with the location of ISCCP grid points used in the analysis, as well as the location of Ny-Ålesund. Only five grid-points are selected, dividing Svalbard into five different climate zones representing the central glaciated mainland (including the seasonally ice-covered fiords) and the ocean areas to the south, west, east and north of Spitsbergen.

important as a basis for further studies and long-term monitoring. It is also important to know to what extent the radiation climate in Ny-Ålesund is representative of other parts of Svalbard. The Norwegian Polar Institute has collected measurements of the surface radiation budget on a permanent basis in Ny-Ålesund since 1974, with the main objective of investigating the long- and short-term variability of the Arctic radiation climate as related to other parameters, such as seasonal snow cover, atmospheric variability and meteorological conditions. The programme includes solar radiation measurements of global, diffuse, direct, reflected, UV and UV-B short-wave (SW) radiation, long-wave (LW) downward and LW upward radiation, as well as derived quantities like SW net, LW net, net radiation and surface albedo (Vinje 1976–1980; Hisdal et al. 1992; Hisdal & Finnekåsa 1996).

The NASA/Langley (LaRC) 8-year Surface Radiation Budget (SRB) data set contains monthly averaged SRB parameters from July 1983 to June 1991. The parameters are SW and LW downward radiation for all sky and clear sky conditions, net SW and LW radiation, SW and LW cloud forcing,

total net radiation and total net cloud forcing, surface albedo and cloud amount. Surface fluxes are derived from the International Satellite Cloud Climatology Project (ISCCP) data, radiation schemes developed at LaRC and top of atmosphere (TOA) clear sky albedos from the Earth Radiation Budget Experiment (ERBE) satellites (Whitlock et al. 1993, 1995).

Figure 1 shows a map of Svalbard and the location of ISCCP 280 × 280 km grid points used in the analysis, as well as the location of Ny-Ålesund. The five selected grid points effectively divide Svalbard into five climate zones comprising the central glaciated mainland (including the seasonally ice-covered fiords) and the ocean areas to the south, west, east and north of the islands. The five different zones with gridpoints are Ocean Area South at 76.25N, 15.86E (South), Ocean Area West at 78.75N, 06.43E (West), Central Mainland at 78.75N, 19.28E (CM), Ocean Area East at 78.75N, 32.14E (East) and Ocean Area North at 81.25N, 24.54E (North), as well as Ny-Ålesund (78.92N, 11.83E).

Surface radiation budget and climate

Meteorological conditions: The main features affecting the climate of Svalbard are the general atmospheric circulation, the annual variation in light conditions and the Arctic sea ice and ocean currents. A general description of the climate of Svalbard has been given by Hanssen-Bauer et al. (1990) and Førland et al. (1997).

The general large-scale circulation is governed by the Iceland Low and the high pressure systems over Greenland and the Arctic Ocean, forcing warm and humid air from the North Atlantic Ocean along the cyclone tracks to the Norwegian and Barents seas. The large difference in air temperature between air masses of Arctic or Atlantic origin cause a large fluctuation in weather conditions, especially during winter.

The northern part of the Norwegian current, the West Spitsbergen Current, causes ice-free condition along the west coast during the whole year, as well as partially ice-free waters north of Svalbard even during winter. According to the frequency distribution of sea ice charts (Vinje 1982), the sea ice is much more dominant on the eastern side, with large annual variation. In winter the sea ice may reach down to Bjørnøya (74.50N, 19.00E)

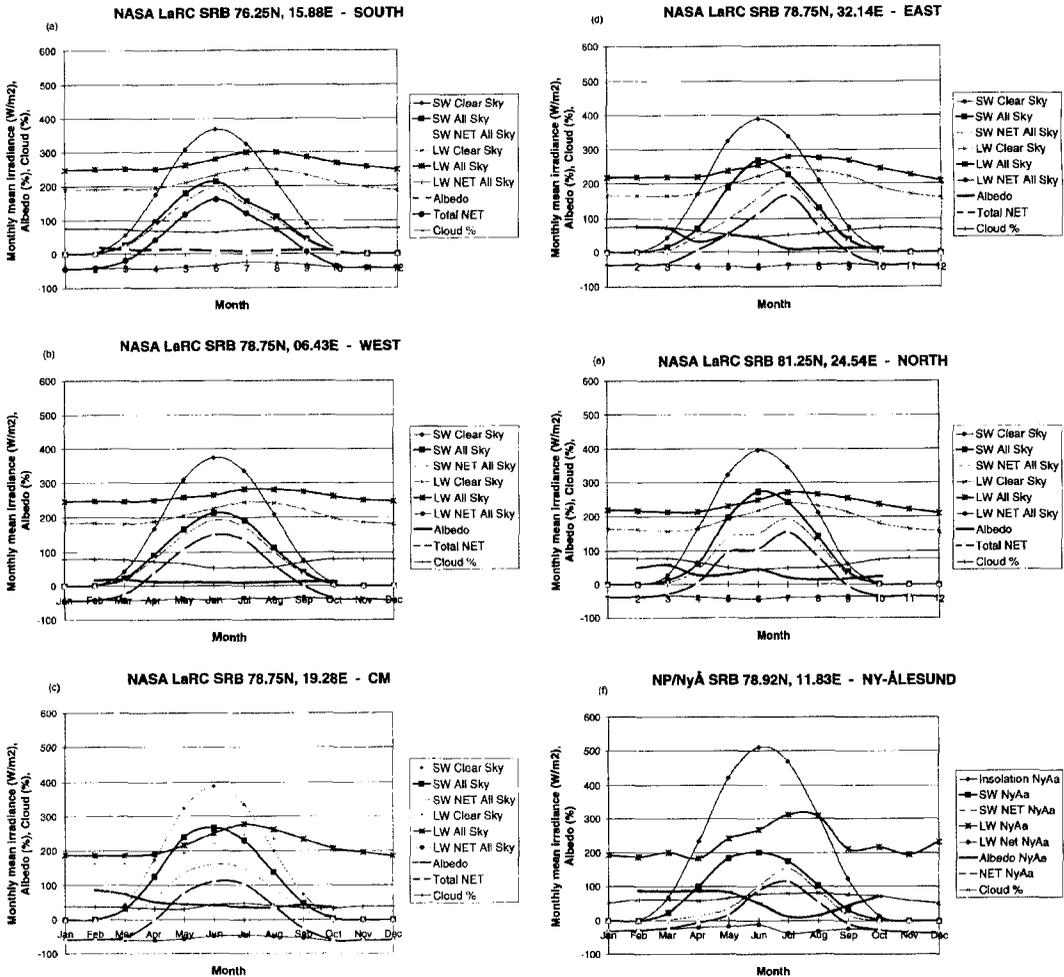


Fig. 2. Mean surface radiation budget fluxes at Svalbard 1983–1991: NASA Langley SRB data set for five different zones: (a) South; (b) West; (c) Central Mainland; (d) East; and (e) North; as well as (f) the Norwegian Polar Institute Ny-Ålesund SRB data set of mean radiation quantities. The plots include the following parameters: short-wave (SW) clear sky, all sky and Net all sky radiation, long-wave (LW) clear sky, all sky and Net all sky radiation, Albedo, Total Net radiation and cloud cover. For Ny-Ålesund the SW top of the atmosphere radiation replaces the clear sky values, and the cloud cover data are based on manual observations.

along the cold southward ocean current in that area, whereas it retreats almost completely during summer.

Førland et al. (1997) include four stations on the Svalbard mainland (Longyearbyen Lufthavn, Isfjord Radio, Sveagruba and Ny-Ålesund) and three ocean/island stations (Hopen, Bjørnøya and Jan Mayen) in their analysis. The results show that the number of days with overcast sky as well as the frequency of Arctic sea fog is highest during summer at all stations, and highest at the ocean/island stations. The number of clear days in Ny-Ålesund is 5–8 days/month during the winter

months and only 1 day/month during the summer months June to September, with a sharp transition occurring from May to June.

Førland et al. (1997) also showed that the characteristic winter air temperatures at Svalbard are relatively high with large fluctuations. The fluctuations are lowest for the ocean/island stations like Hopen and Bjørnøya and largest for the stations on the mainland. Longyearbyen and Svea have the most continental climate with winter temperatures 2–5°C lower and summer temperatures 1–2°C higher than the coastal station at Isfjord Radio. For Ny-Ålesund, the winter tem-

peratures are similar to Longyearbyen, whereas the summer temperatures are more like Isfjord Radio. This situation, with a more continental climate for Ny-Ålesund during winter and a coastal climate during summer is explained by its location in a fiord on the north-west coast of Svalbard, which is frozen during winter but open and strongly influenced by the ocean during summer (Førland et al. 1997).

Satellite radiation fluxes: The SRB parameters of the NASA/LaRC data set are given on the (ISCCP) 280×280 km grid, using only five grid points to be analysed for the Svalbard region. The satellite SRB fluxes from the five different zones – South, West, CM, East and North – are plotted in Fig. 2a–e. In addition the mean radiation quantities from Ny-Ålesund are plotted in Fig. 2f for the same period of time (1983–1991).

The short-wave (SW) downward radiation fluxes range up to a summer maximum of approximately 200 W/m^2 for the ocean areas South and West of Svalbard as well as Ny-Ålesund, whereas the ocean areas East and North and the central mainland have SW maxima of about 280 W/m^2 . The surface albedo is always low for the ocean areas South and West and show intermediate averaged albedo values for the East and North. This is reflected by the frequency distribution of sea-ice concentration in the areas (Vinje 1982). The ocean areas South and West are almost always ice-free, whereas the East and North are partially ice-covered throughout the seasons, with ice-free conditions during summer and autumn. However, whereas the polynya north of Svalbard is partially ice-covered throughout the winter, the ocean to the East is totally ice-covered. The gridded albedo of the central mainland is representative of the spatial averaged high albedo glacier surfaces and the seasonally ice-covered fiords, giving intermediate and less variable satellite albedo values.

The asymmetry of the SW fluxes with respect to the top of atmosphere (TOA) insolation, and the net SW fluxes with respect to the SW fluxes, are induced by the seasonal variation in surface albedo. Multiple reflection and scattering of the SW radiation between the surface and the atmosphere enhance the SW fluxes over high albedo surfaces. This is pronounced in Ny-Ålesund as the snow melts during May/June as well as in the ocean areas North and East when the ice cover withdraws northwards in late spring.

The satellite derived LW downward radiation fluxes of Fig. 2a–f show less variation over the year with similar summer values of about 300 W/m^2 for all zones. However, the winter fluxes are larger (about 250 W/m^2) over the two open ocean areas (South and West) as compared to the ice- and snow-covered areas (Ny-Ålesund, CM, North and East), which show winter LW downward fluxes on the order of 200 W/m^2 . This means that variation in LW downward radiation from winter to summer conditions is larger over the ice/snow-covered areas than over the two open ocean areas. This is consistent with the warmer and more humid atmosphere above the relatively warm ocean. The cloud amount is large throughout the year for the open water areas, less for the partially ice-covered areas to the North and West, and lowest for the central mainland areas. The annual variation in cloud amount is larger for the central mainland and seasonally ice-covered areas than the open ocean areas (Førland et al. 1997). Ny-Ålesund has an ocean-like cloud climate during summer and a more “continental” climate (central mainland) during winter.

Surface radiation budget from Ny-Ålesund: The polar night in Ny-Ålesund lasts from 25 October to 17 February. Figure 3a–f shows the annual variation of the SW and LW downward radiation, SW and LW net radiation, the mean SRB and the albedo, for the period 1981–1997, on the basis of total daily radiation values. The daily total mean, maximum and minimum radiation values for the 17 years series are included in the figures. Most interesting to note is the asymmetry on Fig. 3a of the SW radiation with respect to the extra-terrestrial global radiation. The maximum surface SW radiation is shifted towards early June with increased mean radiation in spring as compared to the autumn values, due to the higher frequency of clear days in spring (April, May) than in the summer months. Because of the high albedo of the snow-covered ground in winter and spring, the successive reflections and multiple scattering of the SW radiation between the ground and the atmosphere and clouds will enhance the SW radiation at the surface, hence apparently increasing the atmospheric transmittance. This effect also reduces the difference between clear and cloudy conditions. In contrast, from late June until the end of August multiple reflection is not possible over the low albedo bare ground, causing a larger variation in SW

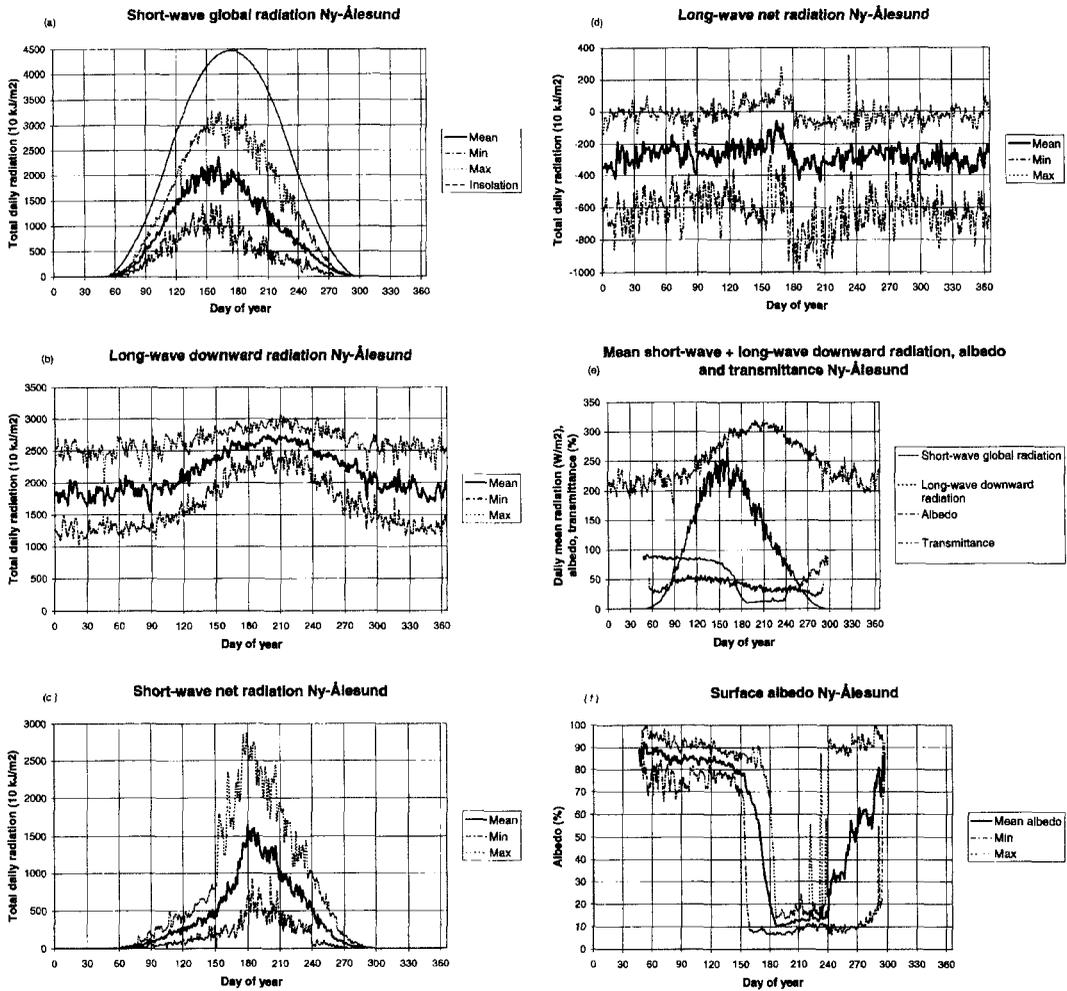


Fig. 3. Mean surface radiation budget fluxes from Ny-Ålesund 1981–1997; Norwegian Polar Institute Ny-Ålesund data set with mean, maximum and minimum daily total radiation values of the 17 years series, showing the annual variation of the (a) short-wave (SW) global radiation, (b) long-wave (LW) downward radiation, (c) SW Net radiation, (d) LW Net radiation, (e) the mean SW/LW radiation and (f) the surface albedo.

radiation due to changing clear and cloudy weather conditions.

The LW downward radiation also shows an asymmetry with peak radiation conditions occurring during the warm summer months of July and August. The variability of the downward LW radiation is highest during the winter months and much lower in the summer. The large variability during winter reflects the variable weather conditions with fluctuating clear and cloudy days between periods of stable, cold Arctic air and warmer, humid air transported to the Arctic by low pressures from the south. During summer condi-

tions, the warmer and more humid atmosphere increases the downward LW radiation compared to the low winter values. The variance induced by clear and cloudy days is reduced in the summer due to the stable high atmospheric temperature and humidity during clear summer days.

The surface albedo shows large annual and inter-annual variations. The maximum and minimum values are marked with separate curves. From the time the sun turns above the horizon in late February until the middle of May, the albedo remains high – above ca. 80%. The small reduction of the albedo in the period is due to the slow

metamorphosis of the snow crystals as the snow cover ages. This change of reflecting properties of the snow speeds up during the melting season, starting in beginning of June. During this period, the albedo drops down to summer values below 20% within a very short time period – maximally 15–20 days. Then from the end of August the snow returns, though the snow cover may not be permanent until the end of October. As can be seen from Fig. 3, the spring melt period occurs within a very narrow time frame with little variation from year to year, whereas the broader autumn transition period with the first snowfall shows a larger inter-annual variability.

The period of intense snow melt produce special features in the SW downward radiation (seen in the mean and maximum radiation of Fig. 3a), and the LW net radiation (Fig. 3d). The data show that the melting period and the onset of melt occurs within a very short time frame each year. During a period of 15–20 days, the albedo drops from above 70% to below 20%, the LW net radiation decreases as a result of the heated snow cover and gradually snow-free ground, and the SW radiation is reduced to values representative of snow-free ground with no enhancement caused by the high albedo. The increased atmospheric humidity caused by the increased flux of latent heat from the melting surface will also reduce the SW radiation during a short period. However, the radiative effect of the slow increase in the atmospheric humidity and temperature during the period is less than the effect of the heated surface, reducing the LW net radiation.

The 17 year averaged mean daily values of SW and LW radiation, surface albedo and atmospheric transmittance are plotted in Fig. 4. The plot more easily identifies the asymmetries with respect to midsummer (day 173), as well as the interdependence between the global radiation, the albedo and the short-wave transmittance as discussed above.

Discussion

The satellite radiation fluxes are compared along two different transects in Fig. 4a, b: one longitudinal (West–CM–East) and one latitudinal (South–CM–North). The Ny-Ålesund radiation fluxes are plotted in both graphs.

The mean LW downward radiation plotted on the latitudinal transect shows clearly that the LW

radiation regime of Ny-Ålesund is similar to the continental type of the CM during winter and more like the open ocean area south of Svalbard during summer. The LW radiation on the northern side of Spitsbergen has intermediate values between the CM and the open ocean. This means that the coldest atmosphere is found over the CM during winter, and that the open polynya to the north causes a warmer and more humid atmosphere there. The difference is largest during winter. This is consistent with the albedo variation showing a persistent low albedo on the southern side and intermediate albedos on the partly ice-covered sea on the northern side during winter, with low albedo also for this area during summer. The radiation regime in Ny-Ålesund changes with the albedo during spring and autumn. Fluctuations are caused by the local ice conditions in Kongsfjorden varying markedly from year to year, especially during spring.

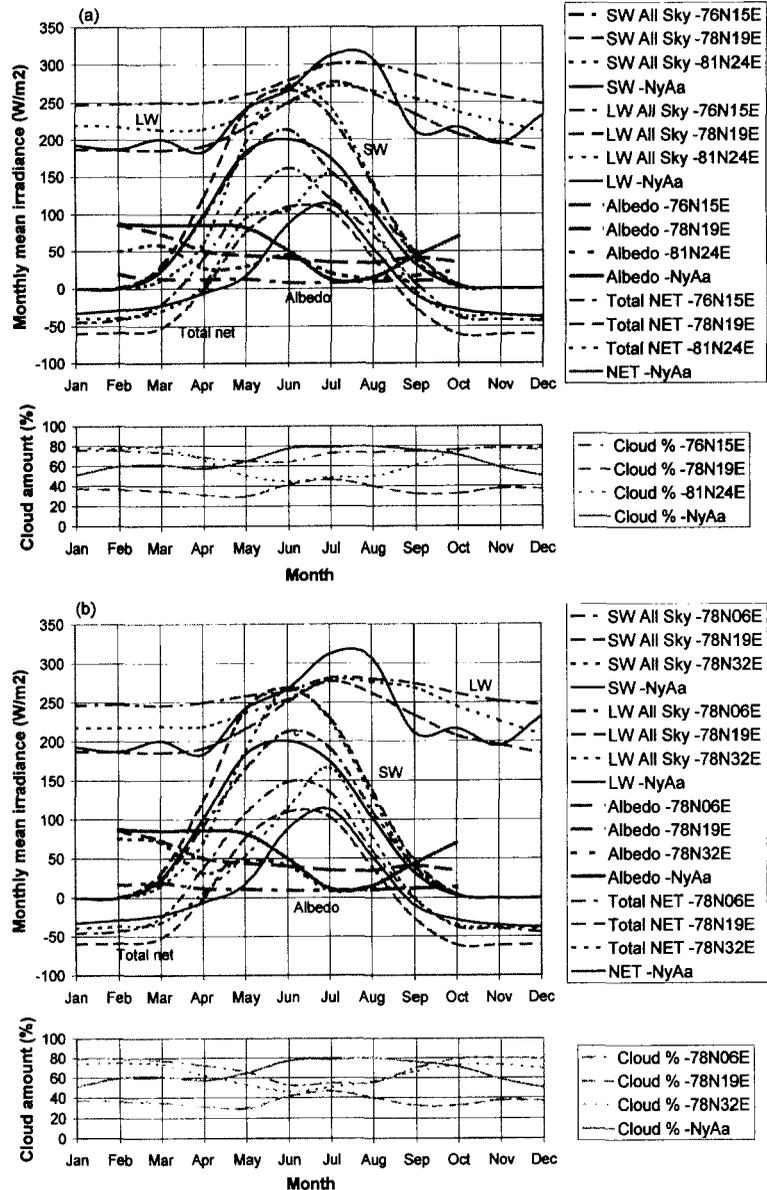
The high surface albedo in Ny-Ålesund and the CM during spring enhance the SW radiation through successive reflections and multiple scattering of the radiation between the surface and the atmosphere. This is not the case for the open ocean to the south and the polynya in the north. The cloud amount at Ny-Ålesund is highest during the summer and similar to the ocean areas, while it is lower during the winter. The cloud amount over the central areas is low throughout the year.

The longitudinal transect shows similar features. The LW downward radiation in Ny-Ålesund is similar to the radiation regime of the central part of Spitsbergen during winter. The variation from West to East is similar to the variation from South to North. The SW incoming radiation is similar to the conditions on the western side, with the spring values enhanced by the high surface albedo. The SW radiation is higher over the central island and on the eastern side during the summer, because of the lower cloud amount, higher albedo and more sea ice there. The net radiation in Ny-Ålesund evolves, on the other hand, similar to the ocean area east during spring because the retreating high albedo ice cover has similar radiative effect as the melting snow cover in Ny-Ålesund.

Conclusions

As shown here, the radiation regime in Ny-Ålesund is influenced by the open ocean climate

Fig. 4. Satellite radiation fluxes along two different transects: (a) NASA Langley SRB latitudinal transect 76–81°N, 15–24°E (South–CM–North); and (b) NASA Langley SRB longitudinal transect 78°N, 06–32°E (West–CM–East). The NP Ny-Ålesund SRB fluxes are plotted in both graphs. The lower part of each figure shows cloud cover changes along the same transects. The cloud cover data from Ny-Ålesund are based on manual observations.



to the west (and south) of Svalbard during summer and autumn, with the Arctic sea fog and the low albedo playing a key role. During winter and spring, the radiation regime is of a more continental type, similar to that in the central part of Spitsbergen, due to the frozen fiords, drifting sea ice and seasonal snow cover. The heterogeneous surfaces found in the Ny-Ålesund area (partly ice-covered fiord, vegetated tundra and glaciers) induce local variations in the radiation

regime at the station, especially during the melting season in spring.

The Arctic radiation climate is a combination of open ocean and continental types. There are significant differences between these two radiation regimes induced by the large annual variation of surface albedo and sea ice cover, as well as the ocean-related Arctic fog conditions during summer. The Ny-Ålesund radiation climate does not represent one typical radiation regime in the

Arctic, but rather a combination of different regimes: ocean-like radiation climate during summer and autumn, continental during the winter and spring. This effect must be taken into account when interpreting the long-term variations of the surface radiation fluxes at the station and the atmospheric conditions and circulation patterns.

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