Estimation of downward longwave radiation for clear sky conditions during the cold season in eastern Siberia

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Abstract

Downward longwave radiation (DLR) is an important incoming radiation in high latitude area, especially during winter and snowmelt season. In eastern Siberia, DLR during winter (from October to next April) is strongly affected by the surface temperature inversion layer which is developed in conjunction with remarkable air temperature decrease on the inland surface. Few estimation schemes for the DLR at land surface represent the effect of strong surface inversion as appeared in eastern Siberia. In the present study, an estimation of DLR for clear sky conditions during winter based on the relationship between DLR and surface temperature inversion was examined using observed DLR data and upper air data in 2000 (during GAME-Siberia experiments) in Yakutsk. Generally DLR is estimated based on Stefan-Boltzmann radiation law using atmospheric emissivity associated with accumulated water vapor content and air temperature at screen height as effective temperature. In the present study, the effect of surface inversion layer (dT_e) is added to the surface air temperature. A difference between surface air temperature and mean temperature in inversion layer is highly correlated with dT_e. In addition, this inversion temperature difference has liner relationship with surface air temperature below -10˚C. The estimation in the present study shows good agreement with the estimation used in the dataset of the International Satellite Land Surface Climatology Project (ISLSCP) with a RMS difference of 5.1Wm^{-2}.

Keyword: Downward longwave radiation, inversion layer, accumulated water content, cold season, Siberia

1. Introduction

During the cold season in Siberia, air temperature near the surface has severe decrease corresponding with remarkably developed surface inversion layer aloft. Downward longwave radiation (DLR) substantially affected by this characteristic temperature profile is most important component as accounting for the surface energy budget during the cold season in Siberia. In general, DLR at a site without direct observation used to estimate using air temperature and water vapor pressure at screen height. However, as the case during winter in Siberia, conventional estimation of DLR using surface parameters is mostly unsuitable without taking account of the effects of inversion.

In the present study, DLR estimation under clear sky was improved for the cold season in Siberia based on the estimation of Kondo (1994) which is often used in Japan. In addition, the efficiency was compared with other estimation applied in other polar sites for the cold region.

2. Data

Observational meteorological data in Yakutsk of eastern Siberia was used for the present study. Duration of used data was in April and from October to December, 2000. Direct observation of DLR was measured by a ventilated pyrgeometer (MS-202, EKO INSTRUMENTS Ltd.) at the top of a larch forest tower (32m above the surface) near Yakutsk. Observed DLR was corrected using the temperature difference between dome and sensor (Shiobara and Asano 1992). Vertical profiles of air temperature and water vapor content were from upper air data observed at Yakutsk observatory (62.01 °N, 129.43 °E) every 0:00 UTC compiled by ADP (an abbreviation for Automated Data Processing) Global Upper Air Observation Subsets (DS353.4: radio sonde data). Precipitable water in the National Centers for Environmental Prediction /National Center for Atmospheric Research (NCEP/NCAR) Reanalysis set (Kistler et al. 2001) was used for the comparison. In addition, surface meteorological elements at Yakutsk observatory were used from Baseline Meteorological Data in Siberia (BMDS) Version 3.

3. Methods

Reference value of DLR for clear sky conditions was calculated by radiation chart (Yamamoto 1952) using upper air data. An accuracy of DLR from the radiation chart was ±5 Wm^{-2} (Kondo 1994). We confirmed the accuracy compared with multiple model predictions of DLR derived from typical profiles of five climate zones in Intercomparison of Radiation Codes Used in Climate Model (ICRCCM; Ellingson et al. 1991). As a result, Estimated DLR by radiation chart was within a standard deviation of model predictions (±5 Wm^{-2}).

According to Kondo (1994), DLR under clear sky condition (L_{df}) at surface is estimated as follows:

$$L_{df} = \varepsilon' \sigma T_e^4 \tag{1}$$

$$\varepsilon' = 0.59 + 0.038 \ln(\omega *) + 0.011 \left(\ln(\omega *)\right)^2 \tag{2}$$

where T_e is air temperature at the height near the surface (from 0 to 1 km) referred as effective temperature, ε' is emissivity of atmosphere, $\omega*$ (1mm<$\omega*$<80mm) is effective accumulated water vapor content within a column

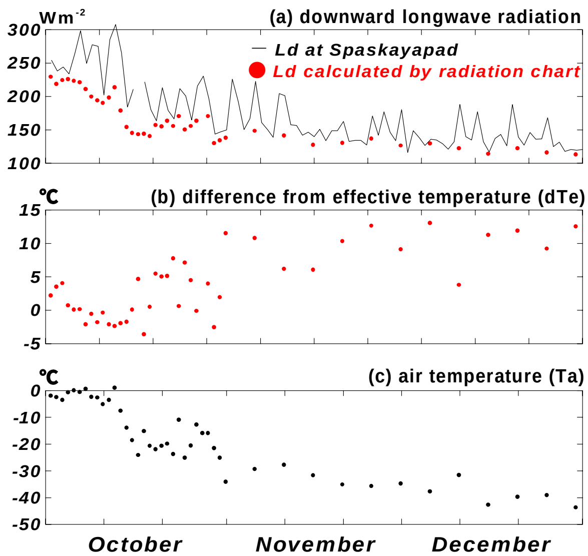

Fig. 1: Time series in meteorological components concerning downward longwave radiation from October to December 2000
a: observed and estimated DLR, b: effective temperature by inversion layer (dT_e), c: screen height air temperature (T_a)

of atmosphere of unit area. Generally, in the case of absence of upper air data, daily averaged air temperature is used as T_e.

However, under conditions of remarkable establishment of inversion layer during the cold season in Siberia, using only air temperature exceedingly underestimates DLR. Thus, T_e with the effect of inversion layer (dT_e) is newly defined as follows:

$$T_e = T_a + dT_e \tag{3}$$

Using upper air data at Yakutsk during April and from October to December, DLR for clear sky was estimated by radiation chart, and dT_e was calculated backward from DLR, ω^* and T_a (Fig. 1).

In order to examine relationship between dT_e and development of inversion layer, inversion layer index (dT_{sum}) was defined; that is, average temperature of upper air with more than T_a (Fig. 2).

As shown in Fig. 3, this index (dT_{sum}) shows high correlation with dT_e. Liner approximation between dT_{sum} and dT_e is as follows:

$$dT_e = 1.16\, dT_{sum} - 0.84 \quad \left(R^2 = 0.944\right) \tag{4}$$

If we have only surface observation data, dT_{sum} can be estimated by those surface data. Surface air temperature with less than -10 °C (263K) has good liner correlation with dT_{sum} (Fig. 4) as follows:

$$dT_{sum} = -0.382\, T_a + 99.3 \quad \left(R^2 = 0.786\right) \tag{5}$$

(but T_a < 263.15 [K] (-10 °C))

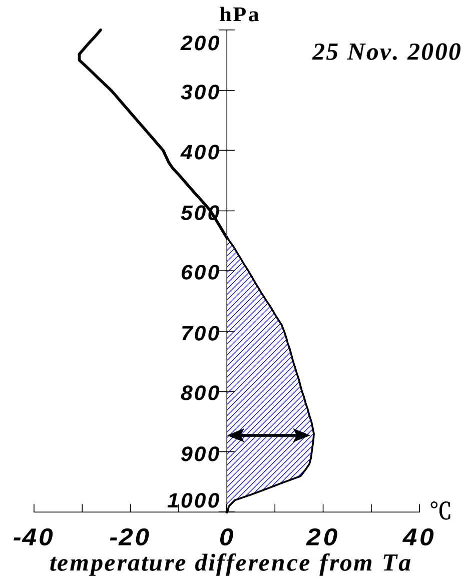

Fig. 2: An example of inversion layer index (dT_{sum}) on 25 November 2000

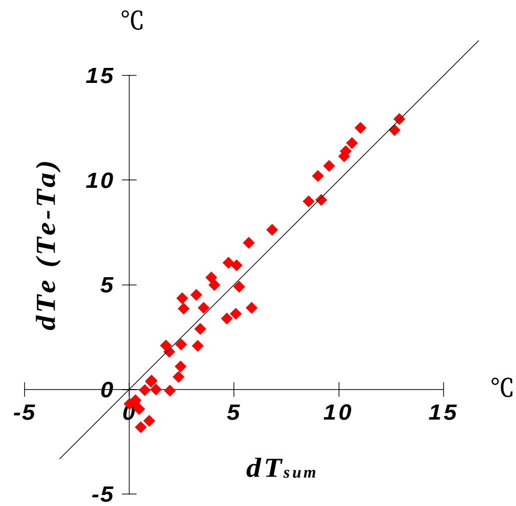

Fig. 3 Relationship between inversion layer index (dT_{sum}) and dT_e
Data were from 1 to 30 April and from 1 October to 31 December, 2000

Using equation 3 to 5, effective temperature T_e during the cold season with less than -10 °C of surface air temperature can be estimated as follows:

$$T_e = 0.557\, T_a + 114.35 \tag{6}$$

It should be noted, however, that temperature profiles during April and early October when surface air temperature ranges from -10 to 0 °C demonstrate un-developed and developed inversion layer, respectively. Thus, further evaluation is needed for the estimation of DLR during the turn of the seasons.

In order to estimate accumulated water content (ω^*), comparison was made among precipitable water by upper air observation, by NCEP/NCAR Reanalysis data, and by estimation using surface dew temperature (Kondo 1994). As shown in Fig. 5, precipitable water of upper air and the Reanalysis data has high correlation, especially during cold season with less than 10mm of precipitable water with a root-mean square (RMS) difference of ±0.53mm. Although relationship with estimated precipitable water by surface dew temperature largely scattered during warm season, high correlation appeared during cold season with a RMS difference of ±1.13mm. The season with less than 10mm of precipitable water is from October to next April, namely the accumulated water content during cold season, can be estimated adequately even if only surface observation.

4. Comparison with other estimations

DLR for clear sky computed with the modified estimation in the present study was compared with other two estimation models. A set of 122 days sampled from upper air and surface data at Yakutsk observatory for April and from October to December, 2000, was used for this comparison.

König-Langlo and Augstein (1994) represented the simplest estimation of DLR for clear sky: that is, emissivity of atmosphere (ε') is fixed as 0.765. They made this estimation using dataset at coastal sites in polar region. As shown in Fig. 6, however, DLR estimation using their estimation shows larger radiation with a RMS difference of 22.1 Wm^{-2}. This deviation is likely due to not only difference in temperature and water vapor profiles, but also in aerosols, haze, ice crystals even in a cloudless atmosphere between coastal and inland sites.

Another estimation takes account of temperature profile. Gupta et al. (1992) made the estimation model using data from the International Satellite Cloud Climatology Project (ISCCP). This estimation is used for the DLR dataset in the International Satellite Land Surface Climatology Project (ISLSCP). The parameterized equation was expressed as:

$$L_{df} = \left(A_0 + A_1 V + A_2 V^2 + A_3 V^3\right) T_e^{3.7} \qquad (7)$$

where $V = \ln PW$, PW is the precipitable water (mm), T_e is the effective temperature, A_0 (=1.791×10^{-7}), A_1 (=2.093×10^{-8}), A_2 (=-2.748×10^{-9}), and A_3 (=1.184×10^{-9}) are regression coefficients. T_e was represented as a weighted sum of upper air temperatures:

$$T_e = k_s T_s + k_1 T_1 + k_2 T_2 \qquad (8)$$

where T_s is the surface temperature, T_1 and T_2 are the temperatures of the first (surface to 800hPa) and second (800 to 680hPa) atmospheric layers. The values of coefficients are k_s=0.60, k_1=0.35, and k_2=0.05.

Comparing with the estimation of König-Langlo and Augstein (1994), the result shows much better relationship with our estimation (Fig. 6) with a RMS difference of 5.1Wm^{-2}. Gupta et al. (1992) examined careful comparison between the estimation and the detailed radiation models using 330 soundings covered global meteorological conditions from pole to pole; surface temperature ranged from 239 to 317K and confirmed precision for their

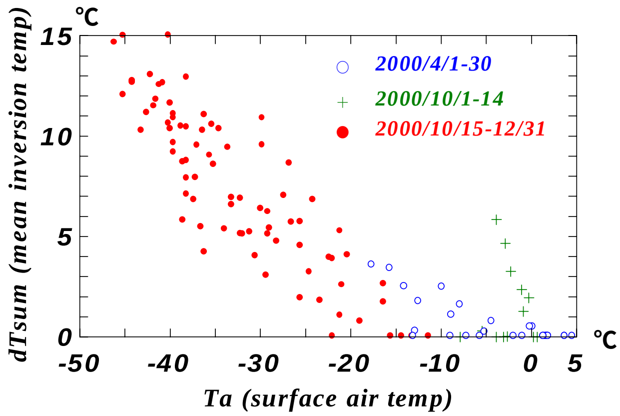

Fig. 4: Relationship between T_a and dT_{sum}

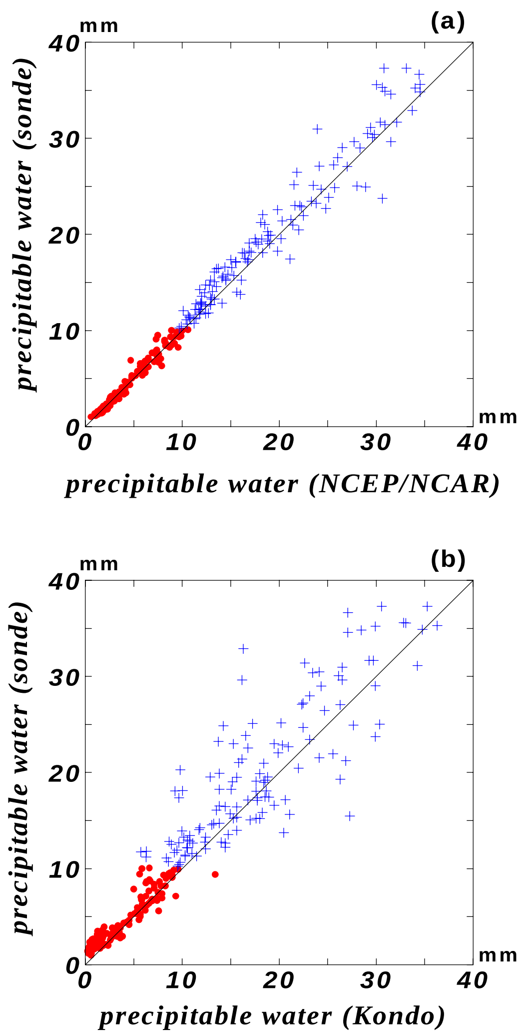

Fig. 5: Comparison of precipitable water at Yakutsk
a: nearest grid data of NCEP/NCAR Reanalysis data and upper air data, b: estimation by surface dew temperature data and upper air data
Dots and crosses denote less or more than 10mm of precipitable water calculated using upper air observation at Yakutsk, respectively.

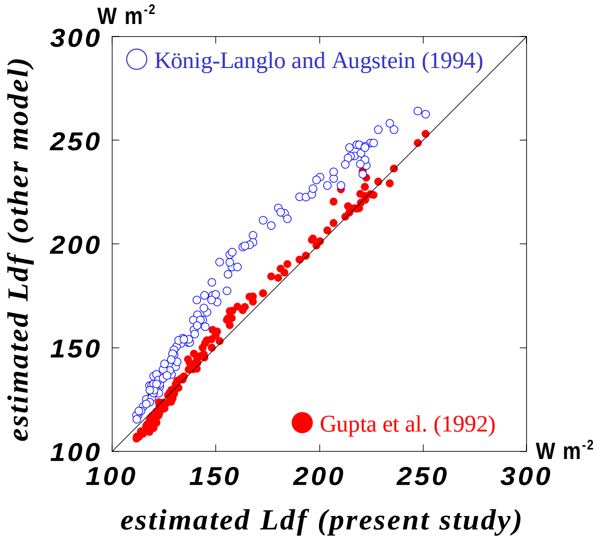

Fig. 6: Comparison of downward longwave radiation for clear sky conditions between estimations of the present study and others.

estimation. Therefore, the good agreement with their estimation can be concluded that modified estimation in the present study can be used as a concise estimation for DLR for clear sky conditions during the cold season.

5. Conclusions

In the present study, we conducted an estimation of DLR under clear sky during winter in eastern Siberia based on the relationship between DLR and surface temperature inversion and intercomparison with different estimation models. Conclusions are summarized that:

(1) A difference between surface air temperature and mean temperature in inversion layer is adequate measure for the effect of surface inversion layer on an estimation of DLR for clear sky based on the estimation of Kondo (1994).

(2) This inversion temperature difference has liner relationship with surface air temperature below -10˚C at Yakutsk observatory.

(3) The accumulated water content during cold season can be estimated by using only surface water vapor pressure on daily basis.

(4) Estimation in the present study shows good agreement with the estimation used in the dataset of the International Satellite Land Surface Climatology Project (ISLSCP) with a RMS difference of 5.1Wm^{-2}.

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