Comparison of clear sky models for estimating downward longwave radiation in Thailand

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Abstract:
In this study, downward longwave radiation data collected on clear sky days at three different sites in Thailand were compared with the values estimated from 12 clear sky longwave radiation models. The downward longwave radiation data used in the comparisons were collected using pyrgeometers installed at three solar monitoring stations located in Nakhon Pathom, Chiang Mai and Ubon Ratchathani. The comparisons showed that model of Prata (1996) gave the best agreement with the values collected at Nakhon Pathom station with mean bias difference (MBD) and root mean square difference (RMSD) of -0.14% and 2.74%, respectively. For Chiang Mai station, the best fit was obtained from model of Brusaert (1982) with MBD and RMSD of -0.43% and 3.94%, respectively. On the other hand, the values obtained from model of Sutterlund (1979) showed the best agreement with the data collected at Ubon Ratchathani station with MBD and RMSD of 0.36% and 3.80%, respectively. Comparison of hourly average longwave radiation derived from all stations showed that the best model for estimating longwave radiation in Thailand is model of Brusaert (1982).

Keywords: *downward longwave radiation; clear sky models*

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1. Introduction

Atmospheric downwelling longwave radiation (LW_c) is very useful for many studies such as earth's radiation balance, greenhouse effect, and climate change. The variation of downward longwave radiation flux mainly depends on the amounts of atmospheric water vapor and surface temperature. The general form of the LW_c equation is

$$LW_c = \varepsilon(e_a,T_a)\sigma T_a^4 \tag{1}$$

where ε is atmospheric emissivity, and σ is is the Stefan-Boltzman constant (5.67×10^{-8} $Wm^{-2}K^{-4}$).

Many researchers estimated the LW_c from the relationship between clear sky longwave radiation and vapor pressure such as Ångström (1918), Brunt (1932), Swinbank (1963), Idso and Jackson (1969), Brutsaert (1975), Sattterlund (1979), Prata (1996), Crawford and Duchon (1999), Iziomon (2003) and Kjaersgaard (2006).

This study aims to compare downward longwave radiation in Thailand with the calculated values derived from 12 clear sky longwave radiation models.

2. Material and methods

2.1 Measurement data

Ground-based measurements of downward longwave radiation were conducted using pyrgeometers (Kipp & Zonen, model CGR4) installed at three solar monitoring stations located in Nakhon Pathom (13.82°N, 100.01°E), Chiang Mai (18.78°N, 98.98°E) and Ubon Ratchathani (15.25°N, 104.87°E). Voltage signals from the pyrgeometers were collected and stored into data logger (Kipp & Zonen, model Logbox SD) every 1 minute from 2011 to 2013. The voltage signals obtained from the pyrgeometers were converted into the values of downward longwave radiation using calibration factors and temperature of the sensors. The longwave radiation data obtained from these measurements were further used in the model comparisons.

2.2 Model comparisons

In this work, 12 clear sky longwave radiation models (Table 1) were selected and used to estimate hourly average of downward longwave radiation at the locations of solar monitoring stations. To determine clear sky days, images of sky over the sites taken from sky camera (prede, model PSV100) were used to identify the sky condition for this work. At each station, ambient air temperature and humidity data were also collected using humidity-temperature transmitters.

Saturation vapor pressure (e_s in hPa) can be determined as a function of temperature (T in C°) by using the equation of Bolton (1980) as follows:

$$e_s = 6.112 \exp\left(\frac{17.67T}{T+243.5}\right) \quad (2)$$

Actual vapor pressure of the air (e_a) is the product of the e_s and relative humidity (RH):

$$e_a = (e_s RH)/100 \quad (3)$$

Table 1 Model for estimating clear sky downwelling longwave radiation

Author	Model	Coefficients
1. Ångström (1918)	$LW_c = [A-(B\times 10^{-Ce_a})]\sigma T_a^4$	A= 0.82, B=0.25, C=0.168
2. Brunt (1932)	$LW_c = [A+B\sqrt{e_a})]\sigma T_a^4$	A= 0.52, B=0.0065
3. Swinbank (1963)	$LW_c = [AT_a^2)]\sigma T_a^4$	$A=9.2\times 10^{-6}$
4. Idso and Jackson (1969)	$LW_c = [1-A\exp(B(273-T_a^2))]\sigma T_a^4$	A= 0.261, B= -0.000777
5. Brutsaert (1975)	$LW_c = [A\left(\frac{e_a}{T_a}\right)^{1/7})]\sigma T_a^4$	A=1.24
6. Satterlund (1979)	$LW_c = A[1-\exp(-ea^{T_a/B})]\sigma T_a^4$	A= 1.08, B=2016
7. Prata (1996)	$LW_c = [1-(1+w)\exp(-(A+Bw)^{1/2})]\sigma T_a^4$	A= 1.2, B=3.0, $w=46.5\left(\frac{e_a}{T_a}\right)$
8. Crawford and Duchon (1999)	$LW_c = [A+B(\sin(m+2)(\frac{\pi}{6})(\frac{e_a}{T_a})^{1/7}]\sigma T_a^4$	A= 1.22, B=0.06, m=month in year
9. Swinbank (1999)	$LW_c = A\sigma T_a^4 - B$	A=1.195, B=171 W/m^2
10. Idso and Jackson (1981)	$LW_c = [1-A\exp(-B(T_c-T_a)^2)]\sigma T_a^4$	A= 0.261, B= -0.000777, T_c= 273 K
11. Brutsaert (1982)	$LW_c = [Ae_a^{1/7}]\sigma T_a^4$	A= 0.552
12. Iziomon (2003)	$LW_c = [1-A\exp(-\frac{Be_a}{T_a})]\sigma T_a^4$	A= 0.35, B=10.0

For each station, the values of e_a, e_s and T_a were used as the main inputs of the models and the values of hourly average downward longwave radiation were estimated. The comparisons between clear sky downward longwave radiation derived from the measurements and models were examined for the period between 2011 and 2013.

Performance of the models were evaluated using mean bias difference (MBD) and root mean square difference (RMSD), which are respectively written as

$$MBD = \frac{\frac{\sum_{i=1}^{n}(LW_c - LW_m)}{N}}{\frac{\sum_{i=1}^{n} LW_m}{N}} \times 100\ \% \quad (4)$$

$$RMSD = \frac{\sqrt{\frac{\sum_{i=1}^{n}(LW_c - LW_m)^2}{N}}}{\frac{\sum_{i=1}^{n} LW_m}{N}} \times 100\ \%, \quad (5)$$

where LW_c is longwave radiation from model, LW_m is longwave radiation from measurements and N = the total number of data used in the comparisons.

3. Results and discussion

The results from the measurements showed that hourly averages of downward longwave radiation at Nakhon Pathom, Chiang Mai and Ubon Ratchathani varied within the ranges of 354.9-392.4 Wm^{-2}, 334.4-374.8 Wm^{-2} and 346.1-390.5 Wm^{-2}, respectively. The highest values of hourly average downward longwave radiation at Nakhon Pathom, Ubon Ratchathani and Chiang Mai stations were 372.8 Wm^{-2}, 367.5 Wm^{-2} and 354.0 Wm^{-2}, respectively.

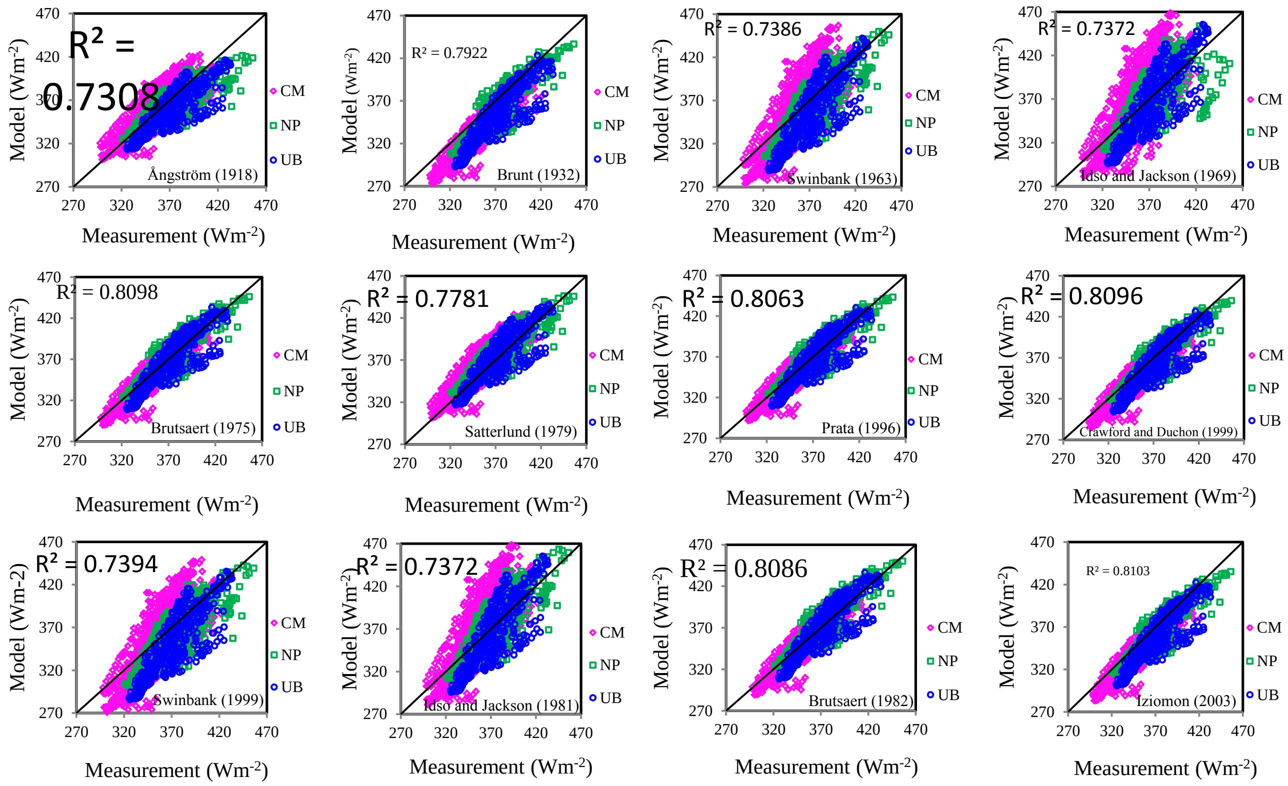

Fig. 1 Comparisons of hourly longwave radiation estimated from 12 models versus the measurements at three solar monitoring stations in Thailand (2011-2013).

Table 2 Comparison statistics of hourly average longwave radiation between the measurements and the 12 models

Model	Nakhon Pathom		Chiang Mai		Ubon Ratchathani	
	MBD(%)	RMSD(%)	MBD(%)	RMSD(%)	MBD(%)	RMSD(%)
1. Ångström (1918)	-2.59	4.37	0.26	4.55	-3.65	5.13
2. Brunt (1932)	-3.17	4.39	-5.75	6.49	-5.73	6.87
3. Swinbank (1963)	-3.37	5.55	-1.16	7.56	-5.43	7.71
4. Idso and Jackson (1969)	-1.20	5.52	1.27	8.14	-2.95	6.59
5. Brutsaert (1975)	0.49	2.83	-1.18	3.25	-1.72	4.04
6. Satterlund (1979)	1.34	3.29	2.22	4.61	**0.36**	**3.80**
7. Prata (1996)	**0.14**	**2.74**	-0.92	3.26	-1.95	4.09
8. Crawford and Duchon (1999)	-0.98	2.92	-2.65	3.99	-3.17	4.79
9. Swinbank (1999)	-3.97	5.85	-1.84	7.52	-6.06	8.10
10. Idso and Jackson (1981)	-0.77	4.76	1.44	8.09	-2.95	6.59
11. Brutsaert (1982)	0.92	3.03	**-0.83**	**3.28**	-1.38	4.07
12. Iziomon (2003)	-2.05	3.42	-3.56	4.65	-4.26	5.53

At each station, the comparisons of hourly average downward longwave radiation were investigated separately for a number of clear sky days. For Nakhon Pathom station, the best agreement between the calculated values from model of Prata (1996) and the measurements was observed with MBD and RMSD of -0.14% and 2.74%, respectively. For Chiang Mai station, the best agreement was obtained from model of Brusaert (1982) (MBD = -0.83% and RMSD = 3.28%). For Ubon Ratchathani station, model of Satterlund (1979) gave the best agreement with the measured data (MBD = 0.36% and RMSD = 3.80%). The results of the comparisons are summarized in Table 2. Considering all of the stations, the best model for estimating downward longwave radiation was model of Brusaert (1982) with MBD of -0.49% and RMSD of 3.39%.

4. Conclusion

In this study, downward longwave radiation data were collected using pyrgeometers and compared with the values calculated from 12 clear sky downward longwave radiation models. The best models for estimating downward longwave radiation in Nakhon Pathom, Chiang Mai and Ubon Ratchathani stations were Prata (1996), Brusaert (1982) and Satterlund (1979) models, respectively. Overall, model of Brusaert (1982) performed best for the combined data from the three stations.

5. Acknowledgement

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6. References

Ångström, A. 1918. A study of the radiation of the atmosphere. Smith. Inst. Misc. Collect. 65:159–161.

Brunt, D. 1932. Notes on radiation in the atmosphere. Quarterly Journal of the Royal Meteorological Society. 58: 389–418.

Brutsaert, W. 1975. On a derivable formula for long-wave radiationfrom clear skies. Water Resour. Res. 11: 742–744.

Brutsaert, W. 1982. Evaporation into the Atmosphere. D. Reidel Publishing Company, Dordrecht.

Crawford, T.M., Duchon, C.E. 1999. An improved parameterization for estimating effective atmospheric emissivity for use in calculating daytime downwelling long-wave radiation. Journal of Applied Meteorology 38: 474–480.

Idso, S.B. 1981. A set of equations for full spectrum and 8–14 mmand 10.5–12. 5 mm thermal radiation from cloudless skies. Water Resour. Res. 17: 295–304.

Idso, S.B., Jackson, R.D. 1969. Thermal radiation from the atmosphere. J. Geophys. Res. 74: 5397–5403

Iziomon, M.G., Mayer, H., and Matzarakis, A. 2003. Downward atmospheric irradiance under clear and cloudy skies: measurement and parameterization. J. Atm. Solar-Terr. Phys. 65: 1107–1116.

Kjaersgaard, J.H., Plauborg, F.L., and Hansen, S., 2006. Comparison of models for calculating daytime long-wave irradiance using long term data set. Agricultural and Forest Meteorology 143:49–63.

Prata, A.P. 1996. A new long-wave formula for estimating downward clear-sky radiation at the surface. Quarterly Journal of the Royal Meteorological Society 122: 1127–1151.

Rogers, R.R. and Yau, M.K. 1996. A Short Course in Cloud Physics. United States of America: Butterworth-Heinemann.

Satterlund, D.R. 1979. An improved equation for estimating longwave radiation from the atmosphere.Water Resour. Res. 15: 1649–1650.

Swinbank, W.C. 1963. Long-wave radiation from clear skies. Quarterly Journal of the Royal Meteorological Society 89: 339−348.