Long-term trends of pan evaporation and an analysis of its causes in Finland

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Abstract:
Long - term trend of pan evaporation which was a key factor of hydrologic cycle and water resources management was investigated with the long-term variation of meteorological data: precipitation, air temperature, relative humidity, and wind speed. The causes of trends of pan evaporation were revealed from two points of view: complementary relationship and Penman's equation. The variations of pan evaporation showed the decreasing trends at the 5 stations and the increasing ones in the other 2 stations. The mechanistic causes for the decreasing trends were mainly the increases of the precipitation and the aerodynamic term in Penman's equation (1948).

1. Introduction

The recent global warming causes the climate changes such as concentrated rainfall or flood, and affects the evapotranspiration which is an important factor of hydrologic cycle and water resources management. Many of the previous studies have reported the decrease trends of pan evaporation in the area of the continental climate of the middle latitude. However, few studies in the region in a high latitude area such as Finland haven't been carried out so far.

The purpose of this study is to investigate the long term variations of pan evaporation in Finland located in a high latitude using a trend analysis. In addition, the relationship between pan evaporation and meteorological elements is discussed to clarify the causes of the long-term trend of pan evaporation.

2. Study locations and meteorological data

Seven meteorological stations from southern to northern parts in Finland were selected for this study (Fig. 1). Table 1 also shows those details: latitude, longitude, amplitude, and a measurement height of wind speed.

Pan evaporation data were obtained from the Finnish Environment Institute. The meteorological data : precipitation, air temperature, humidity, wind speed, and radiation (or sunshine duration), were provided by the Finnish Meteorological Institute. The pan evaporation data were measured with a Class A evaporation pan which was the most common method of measurement of open water evaporation.

The data except wind speed were the time series of daily records. The wind speed data recorded at 0600, 1200, and 1800 hours were averaged and converted the daily data.

The analysis period was 52 years (1960 - 2011). The data in June to September in each year were analyzed because there were many missing data in October to May mainly due to freezing of water. The integrated values of those 4 months in the pan evaporation and the precipitation data, and the average values of the 4 months in the other meteorological data were used.

A linear regression model which was the most commonly used method was used to detect the trend for all data. The trend slopes for the data except air temperature were showed as the percentage per decade which was normalized by the average value over the period. The trend slopes of the regression model were tested against the hypothesis of null slope by means of a one-tail t-test at a confidence level of 95 % or 99 %.

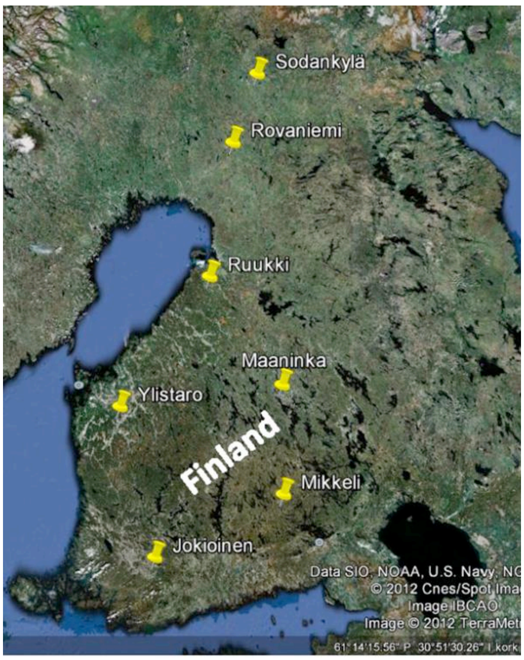


Fig. 1 Location of meteorological stations.

Table 1 Details of selected stations

Station ID	Name of station	Latitude (N)*	Longtitude (E)*	Altitude (m) a.s.l	Height of wind speed (m)
1201	Jokioinen	60°48'	23°30'	104	30
2602	Mikkeli	61°40'	27°13'	101	10
3101	Ylistaro	62°56'	22°11'	26	12
3603	Maaninka	63°08'	27°19'	90	18
5402	Ruukki	64°41'	25°05'	48	12
7502	Rovaniemi	66°34'	26°01'	106	12
7501	Sodankylä	67°22'	26°37'	179	22

*WGS-84

3. Results

3.1 Pan evaporation

Fig. 2 shows the yearly variation of pan evaporation and its regression line. Table 2 presents the average and the trend. The pan evaporation decreased in Jokioinen, Ylistaro, Ruukki, Rovaniemi, and Sodankylä, and increased slightly in Mikkeli and Maaninka. The average decrease percentage and the average value at 7 stations were - 2.82 (%) and 343 (mm), respectively.

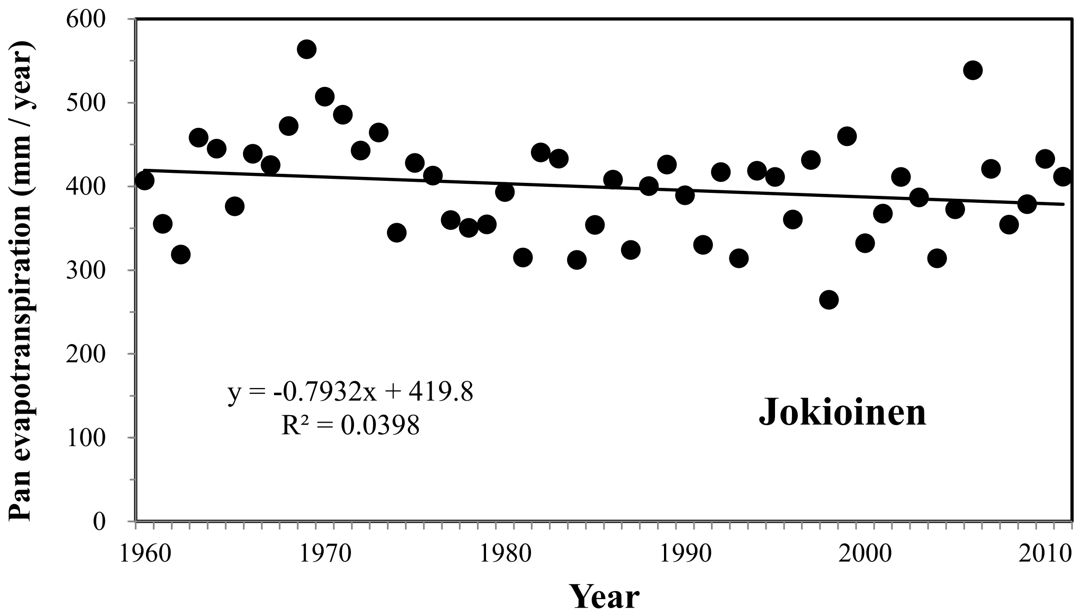
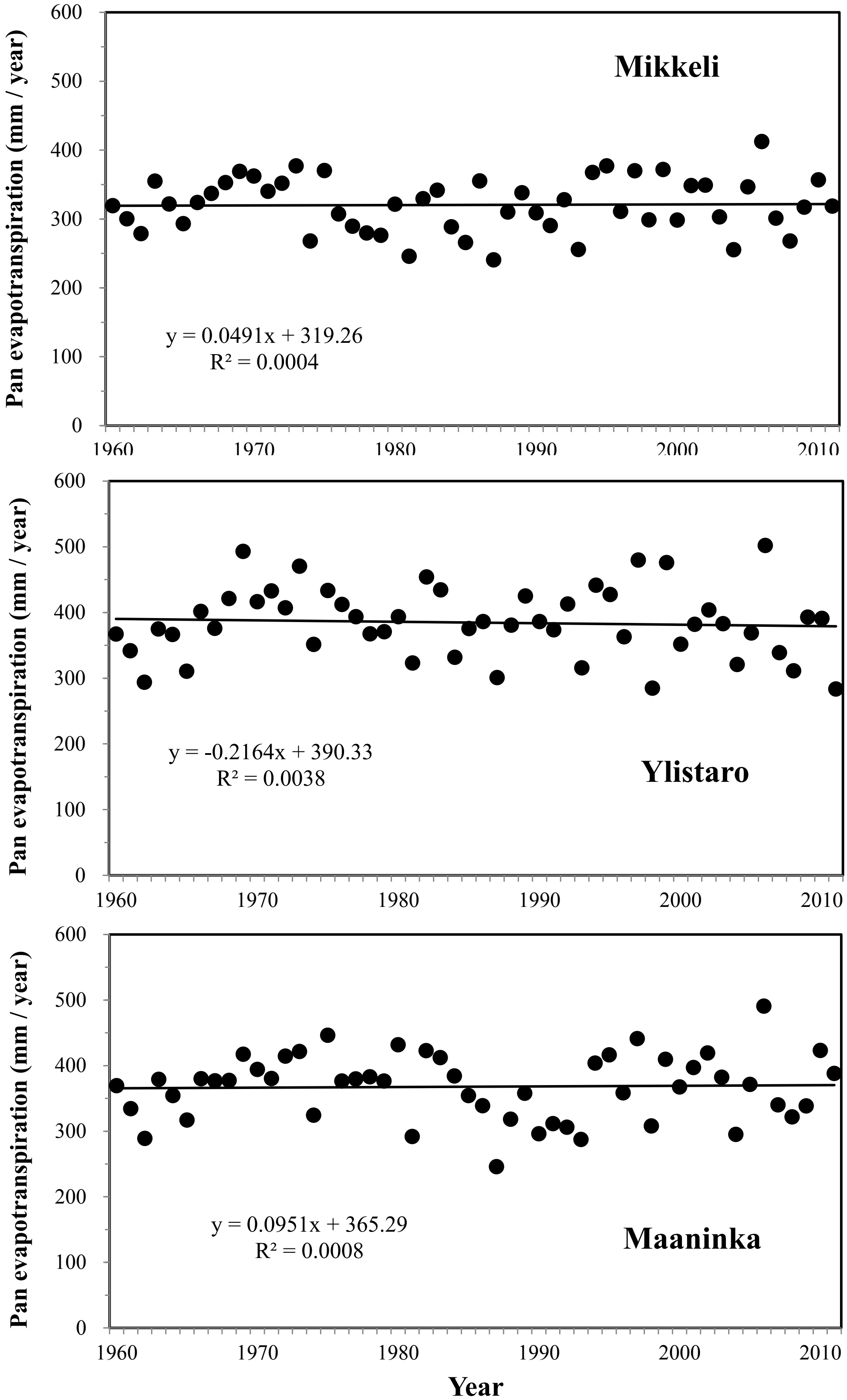


Fig. 2 Temporal variation of pan evaporation from 1960 to 2011. The regression line is showed together.



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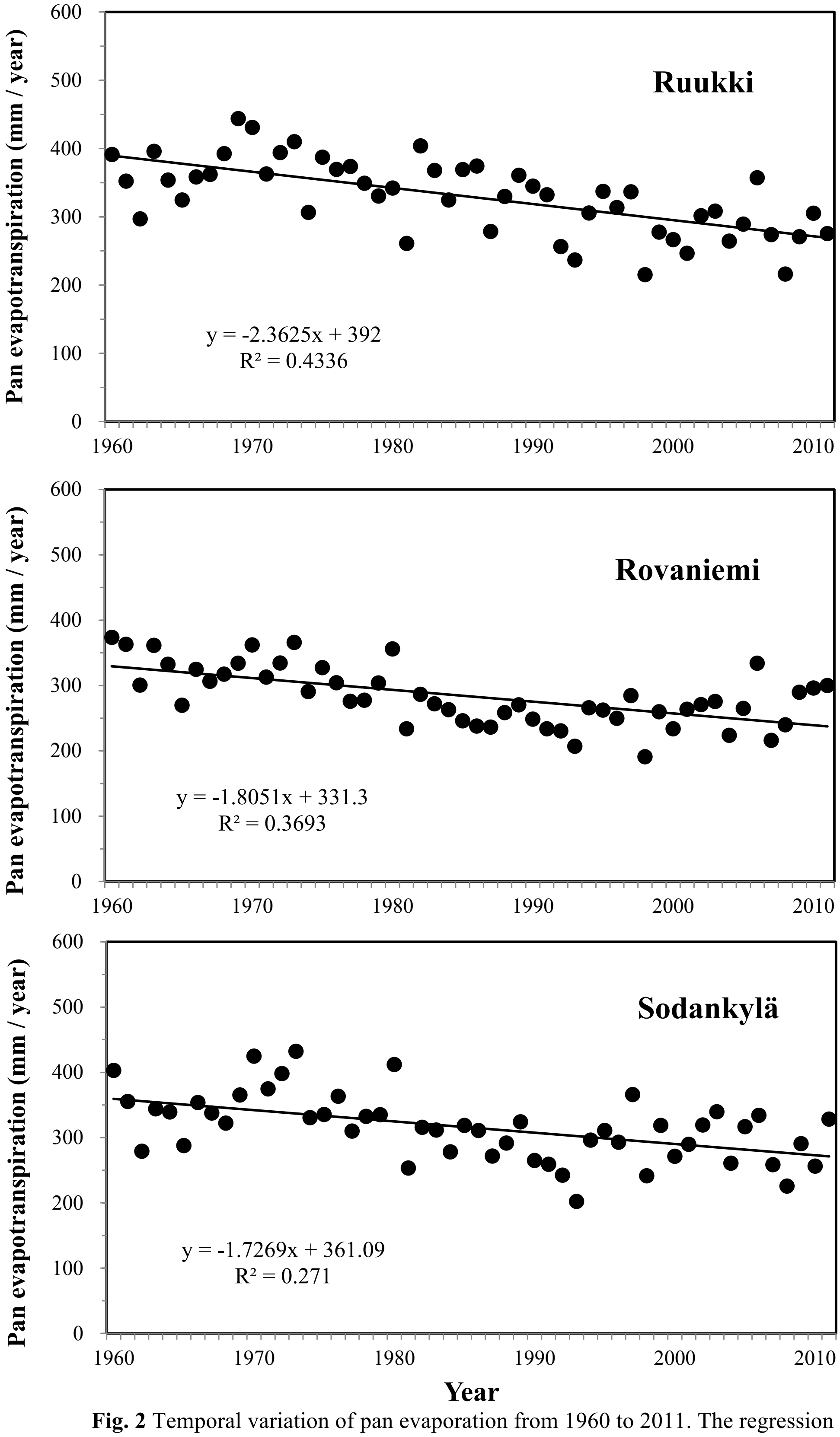


Fig. 2 Temporal variation of pan evaporation from 1960 to 2011. The regression line is showed together.

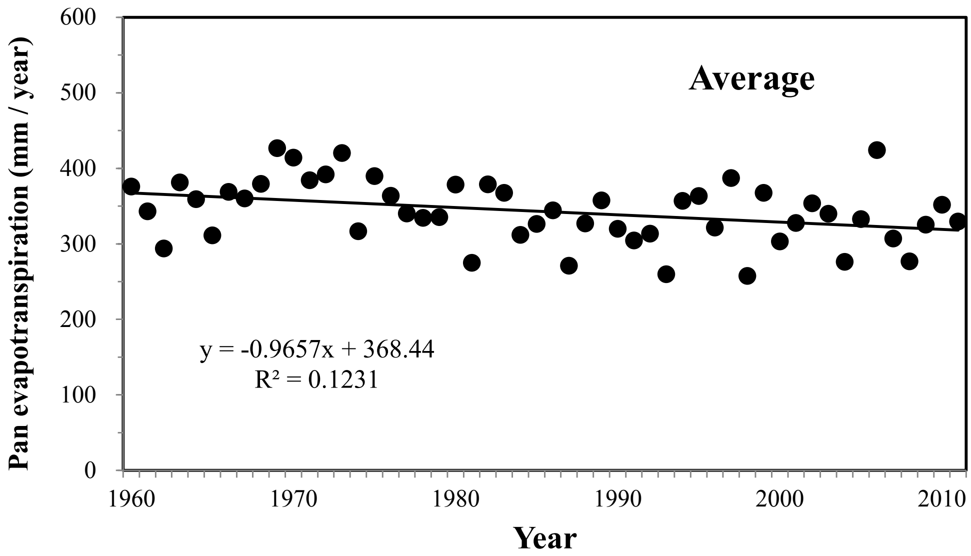


Fig. 2 Temporal variation of pan evaporation from 1960 to 2011. The regression line is showed together.

3.2 Precipitation

Figure 3 shows the yearly variation of precipitation and its regression line. The precipitation increased in all stations. Especially, the trends in Jokioinen, Ylistaro, and Ruukki close to sea were relatively larger than those in the other stations (Table 2). The average decrease percentage and the average value at 7 stations were 0.80 (%) and 255 (mm), respectively.

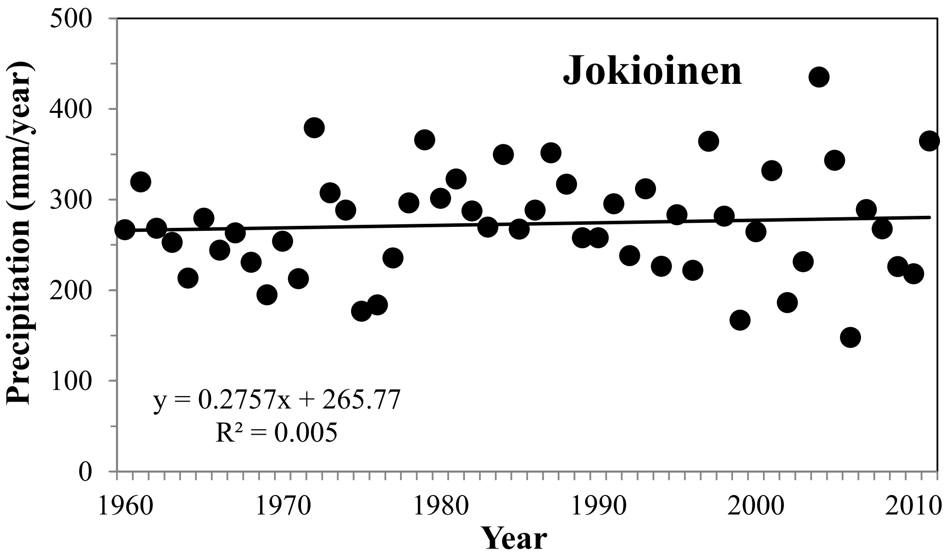


Fig. 3 Temporal variation of precipitation from 1960 to 2011. The regression line is showed together.

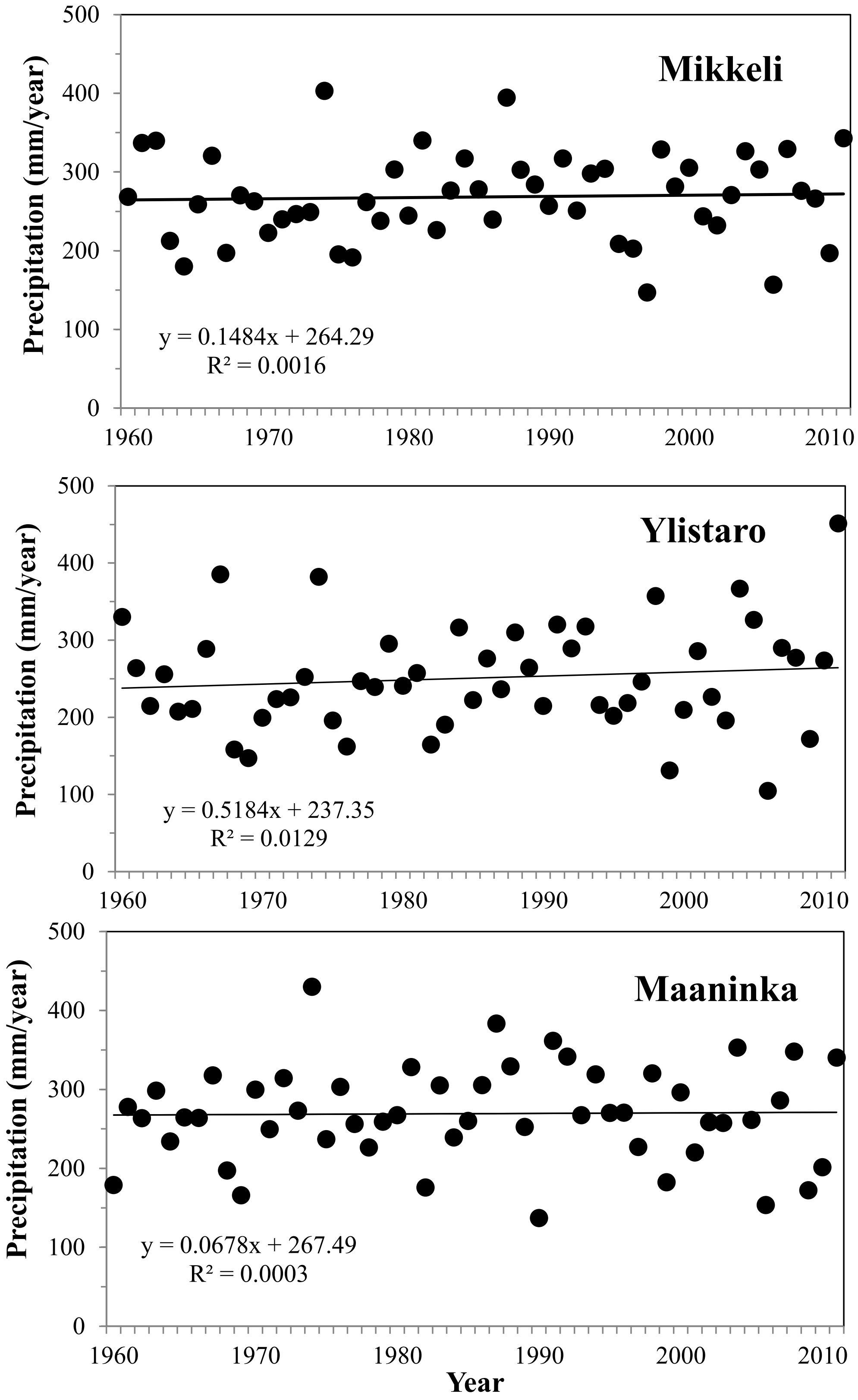


Fig. 3 Temporal variation of precipitation from 1960 to 2011. The regression line is showed together.

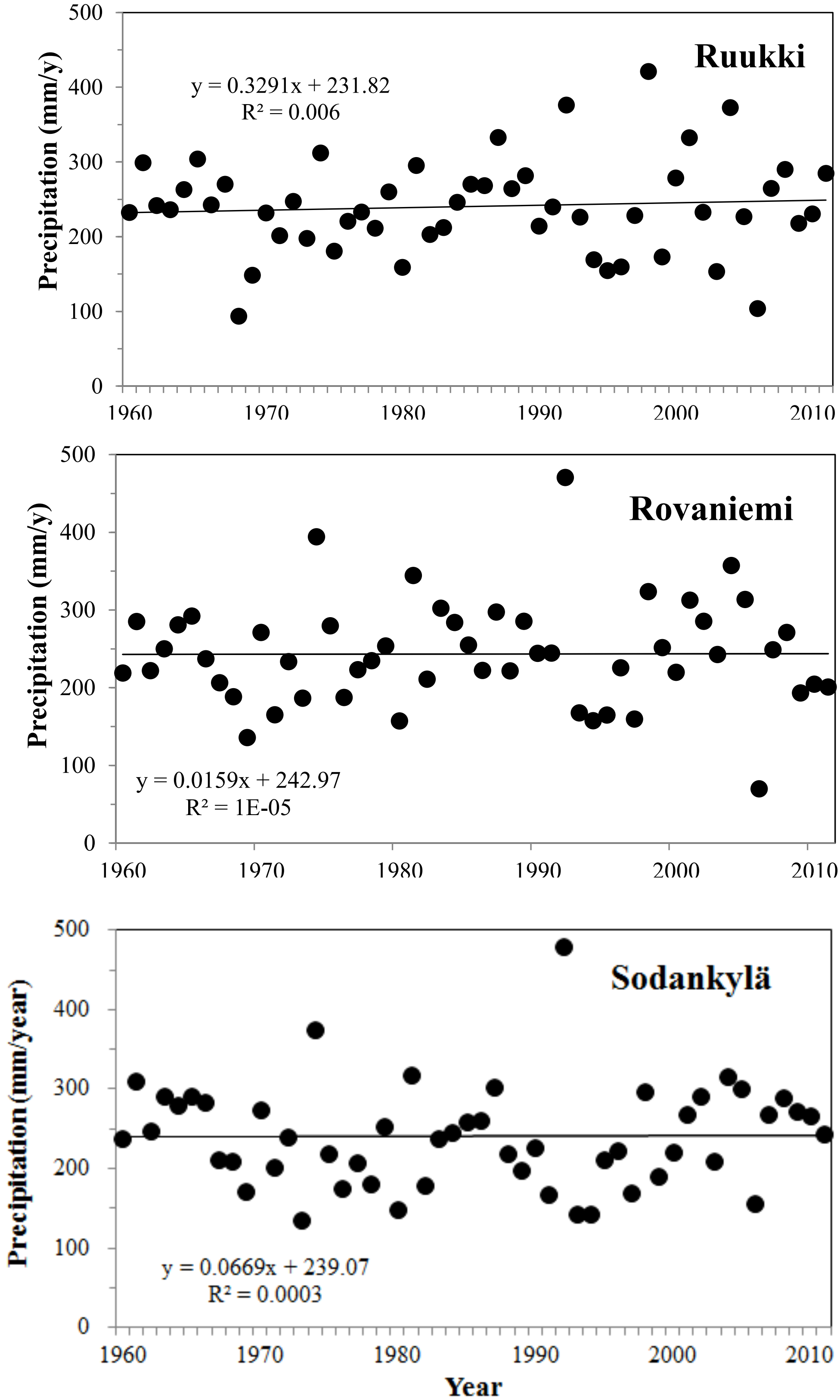


Fig. 3 Temporal variation of precipitation from 1960 to 2011. The regression line is showed together.

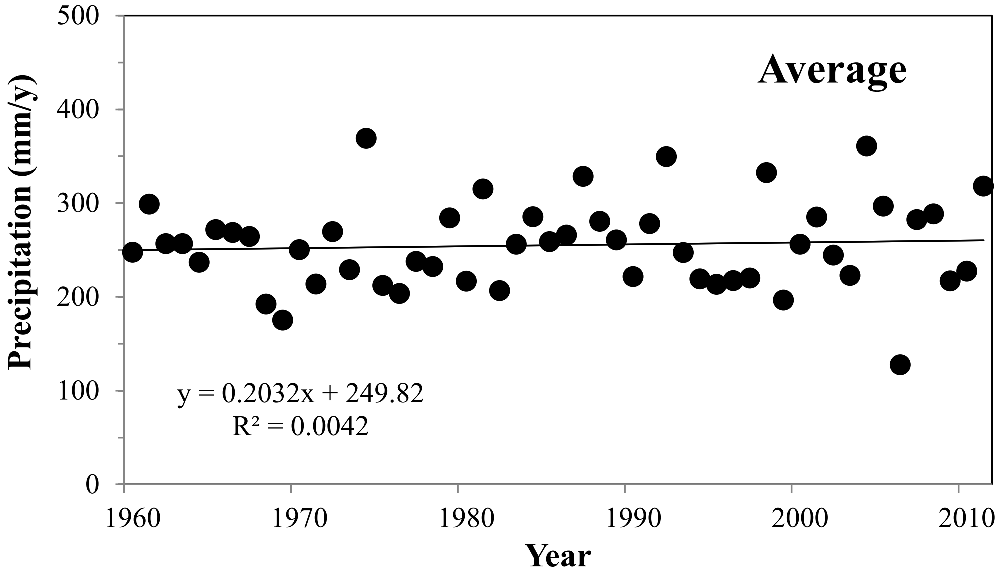


Fig. 3 Temporal variation of precipitation from 1960 to 2011. The regression line is showed together.

3.3 Air temperature

Figure 4 shows the yearly variation of air temperature and its regression line. The air temperature increased in all stations (Table 2). The average decrease percentage and the average value at 7 stations were 1.65 (%) and 12.8 (℃), respectively.

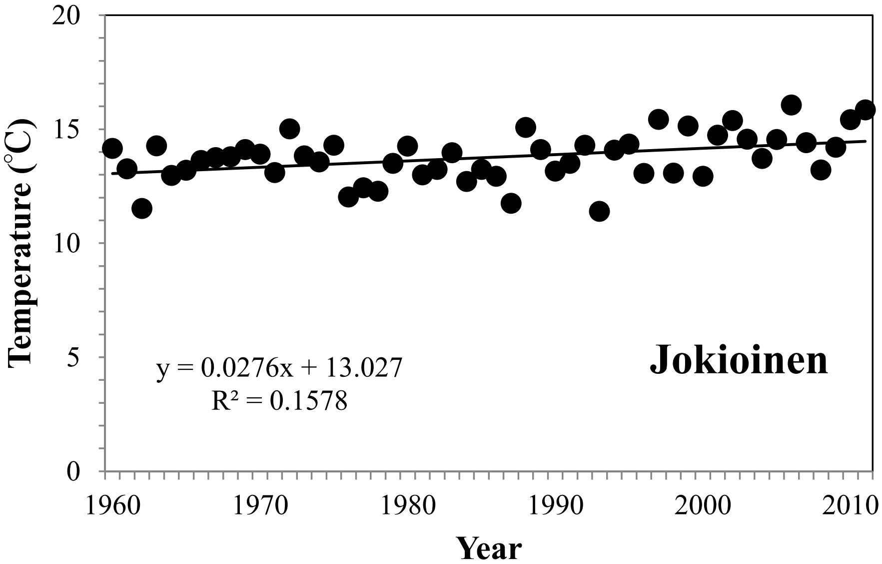


Fig. 4 Temporal variation of air temperature from 1960 to 2011. The regression line is showed together.

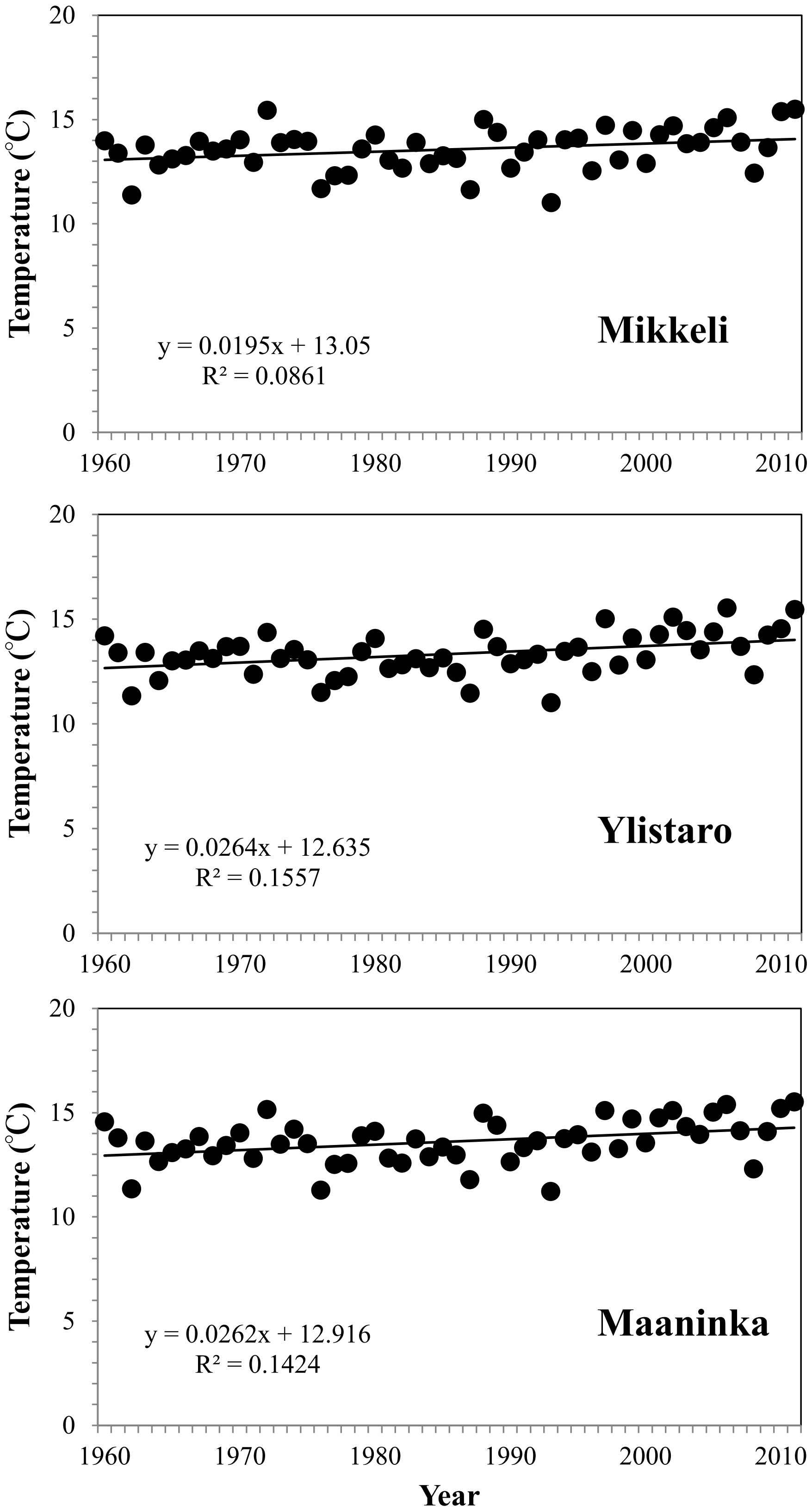


Fig. 4 Temporal variation of air temperature from 1960 to 2011. The regression line is showed together.

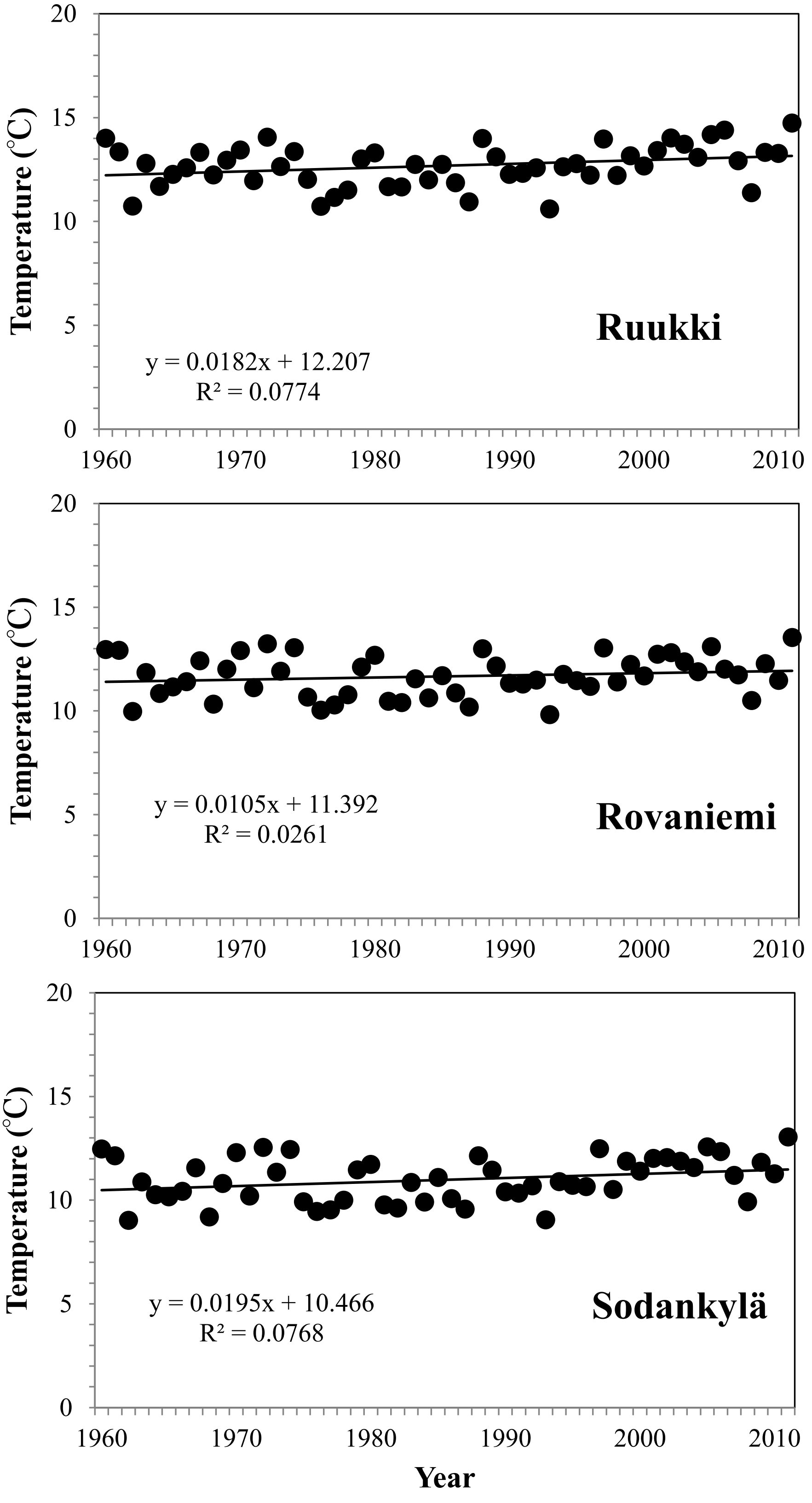


Fig. 4 Temporal variation of air temperature from 1960 to 2011. The regression line is showed together.

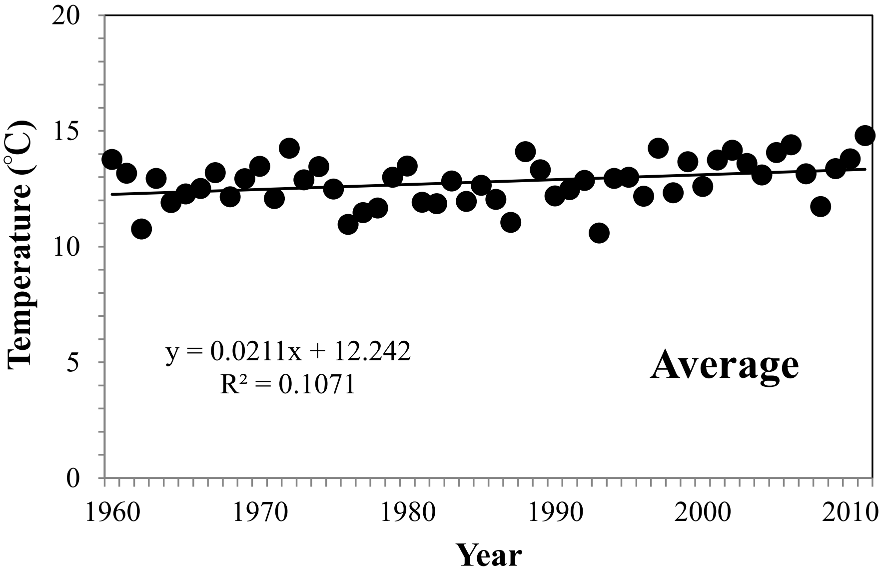


Fig. 4 Temporal variation of air temperature from 1960 to 2011. The regression line is showed together.

3.4 Relative humidity

Figure 5 shows the yearly variation of relative humidity and its regression line. The relative humidity increased in the 5 stations except Mikkeli and Sodankylä (Table 2). The average decrease percentage and the average value at 7 stations were 0.90 (%) and 73.4 (%), respectively.

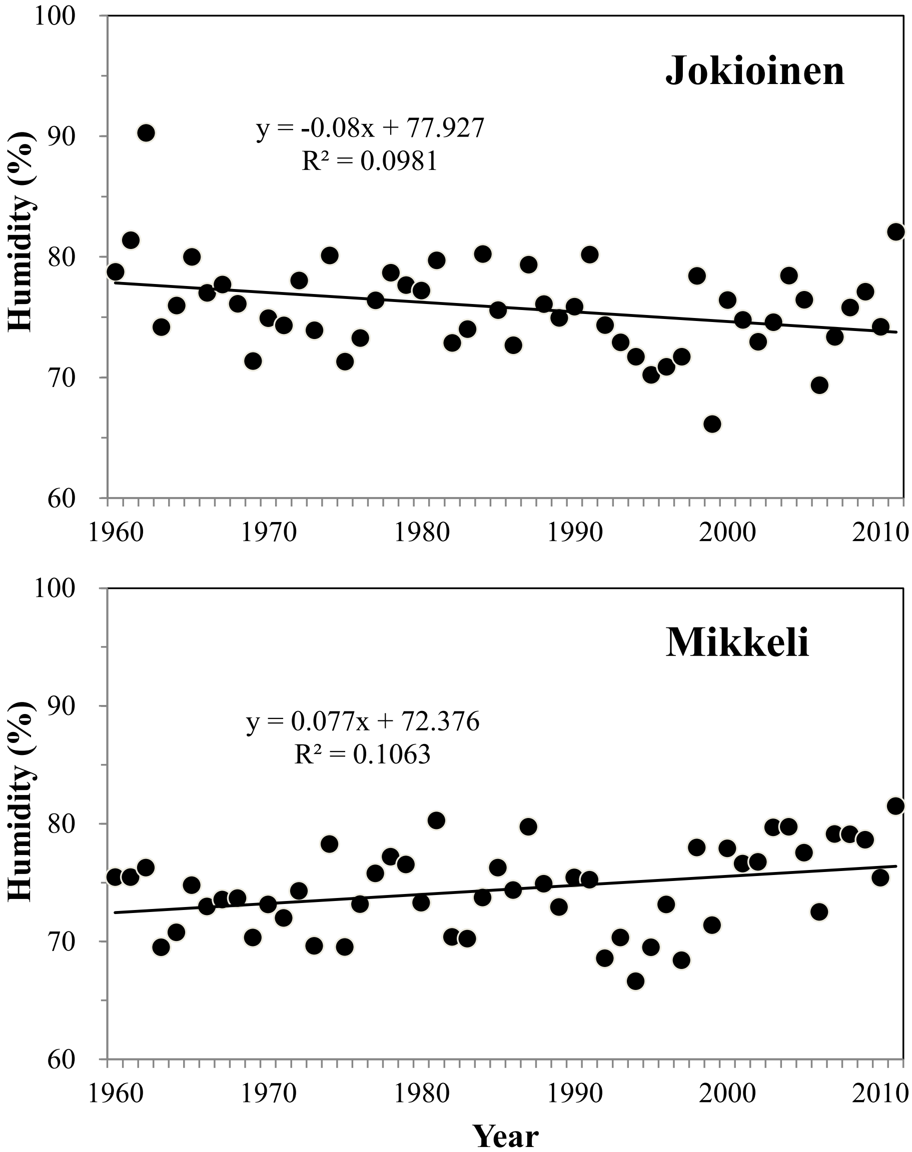


Fig. 5 Temporal variation of relative humidity from 1960 to 2011. The regression line is showed together.

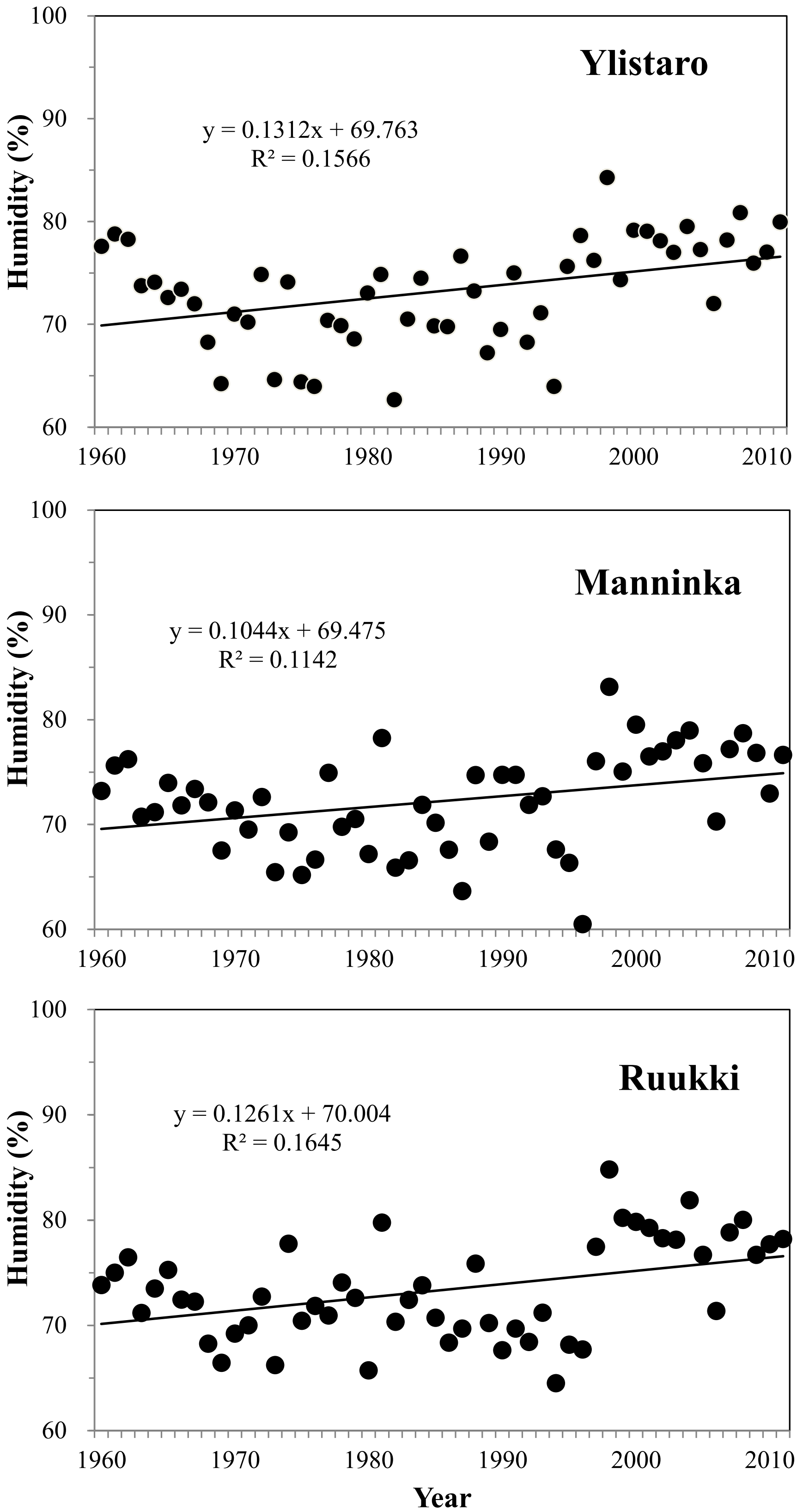


Fig. 5 Temporal variation of relative humidity from 1960 to 2011. The regression line is showed together.

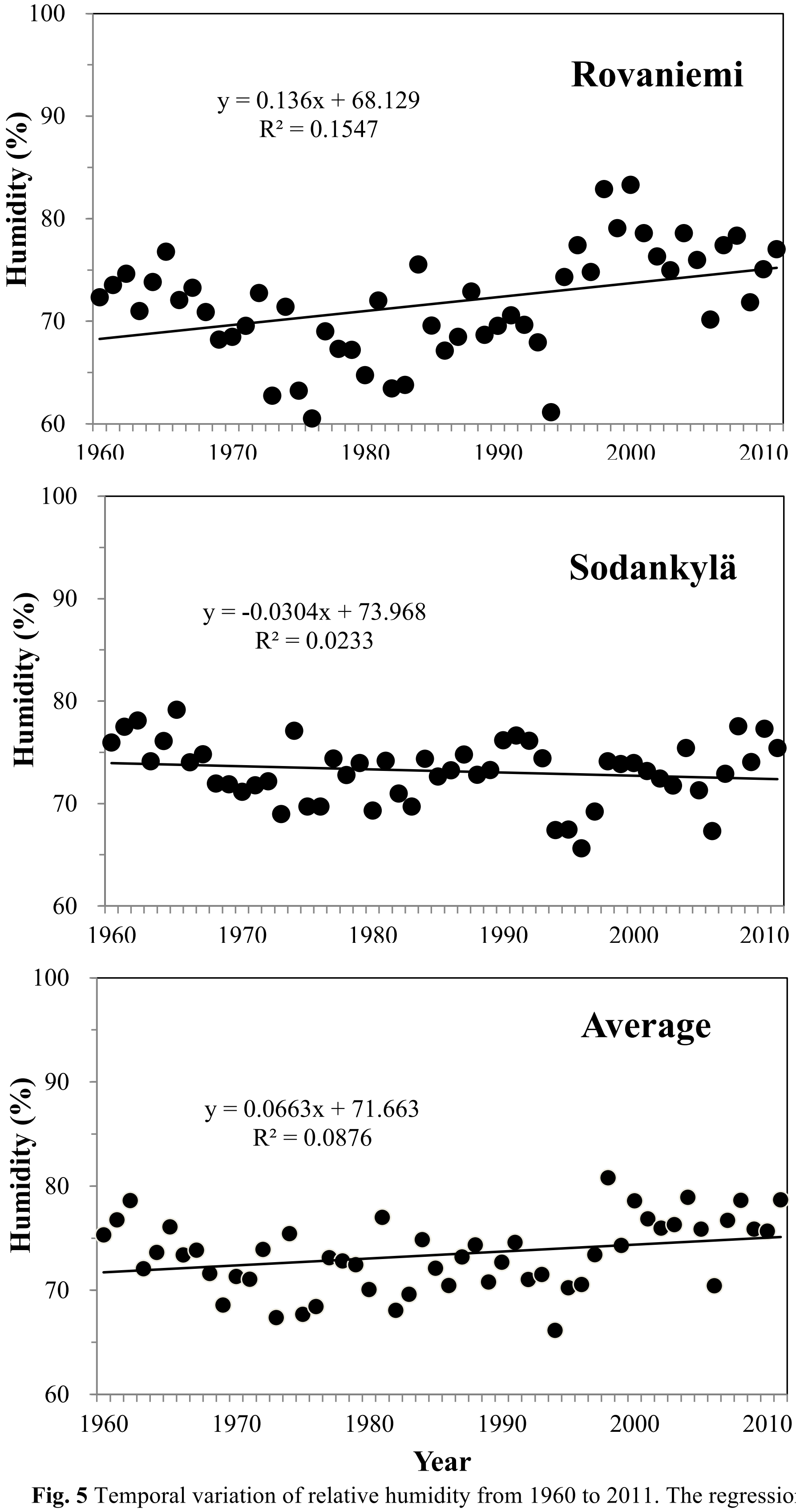


Fig. 5 Temporal variation of relative humidity from 1960 to 2011. The regression line is showed together.

3.5 Wind speed

Figure 6 shows the yearly variation of wind speed and its regression line. The wind speed decreased in the 6 stations except Rovaniemi (Table 2). The average decrease percentage and the average value at 7 stations were -4.07 (%) and 2.78 (m/s), respectively.

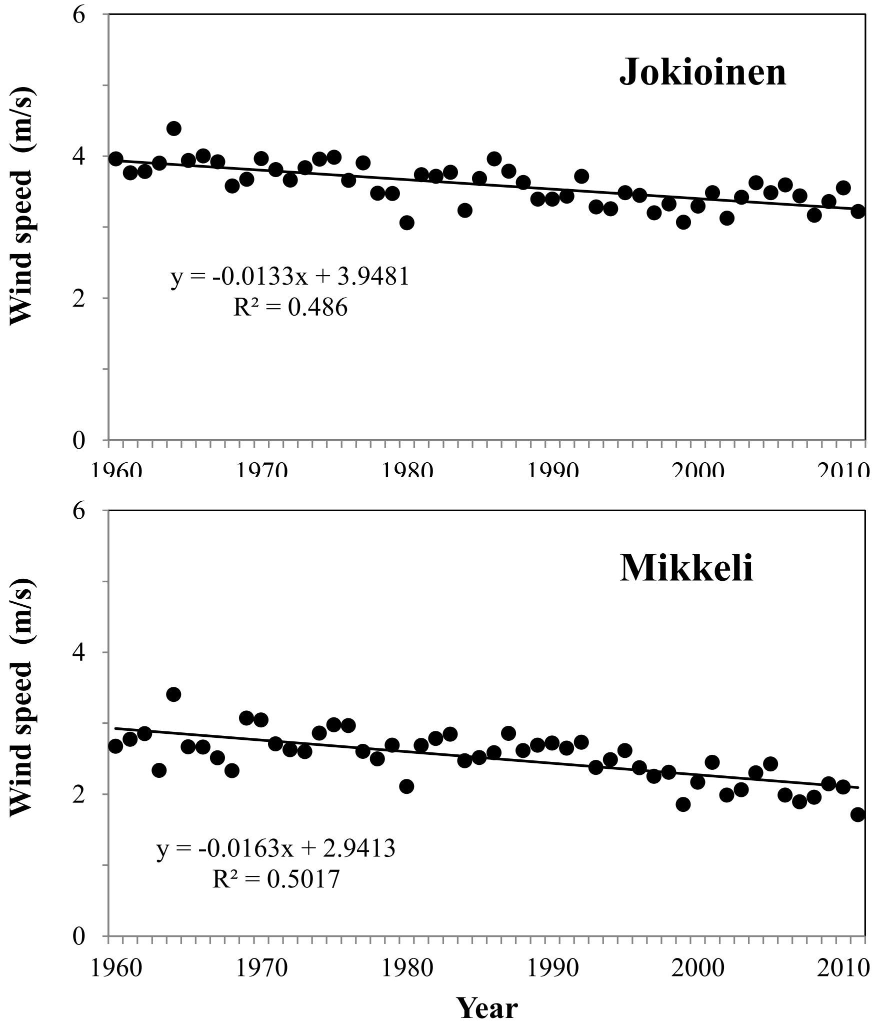


Fig. 6 Temporal variation of wind speed from 1960 to 2011. The regression line is showed together.

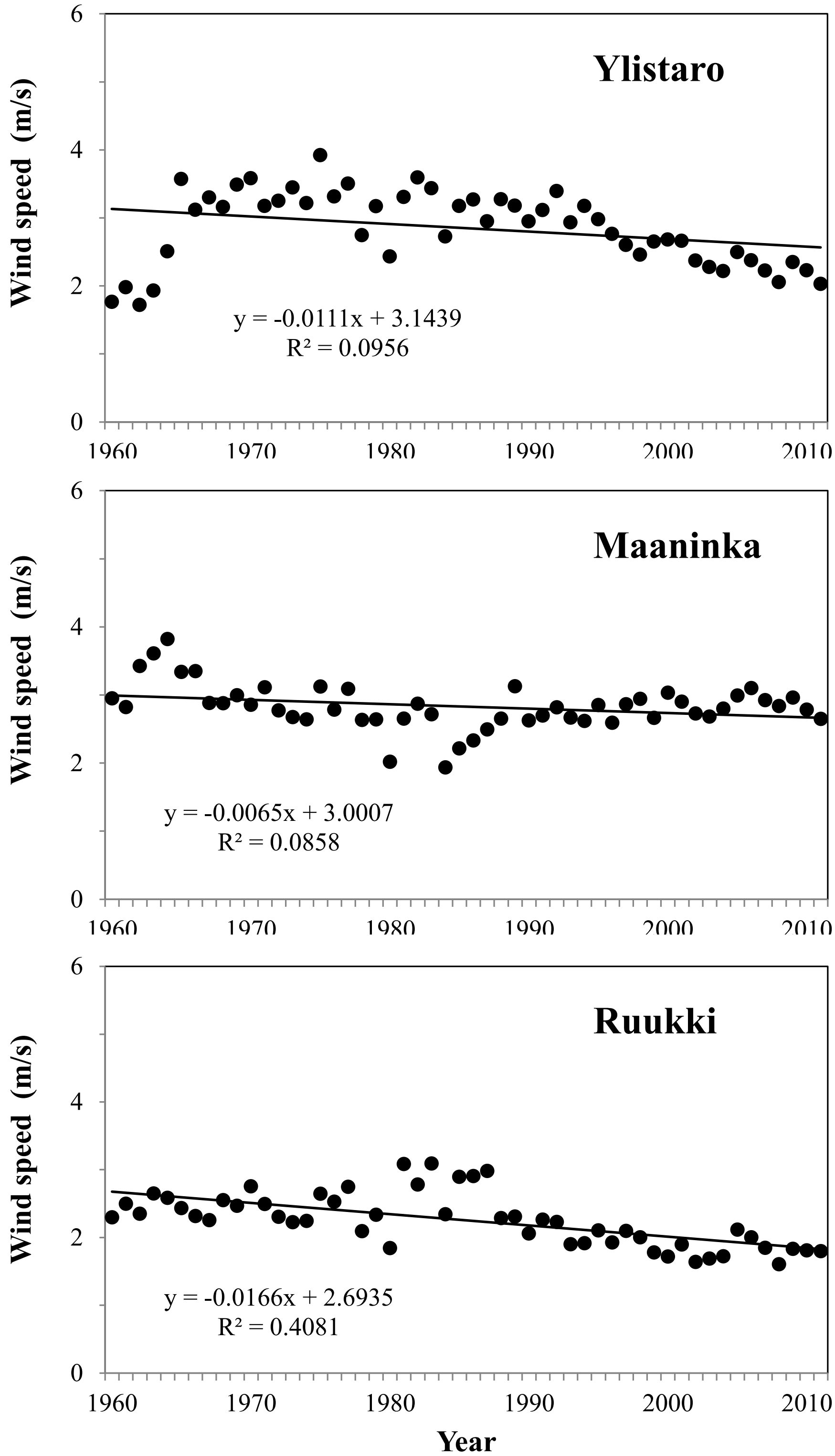


Fig. 6 Temporal variation of wind speed from 1960 to 2011. The regression line is showed together.

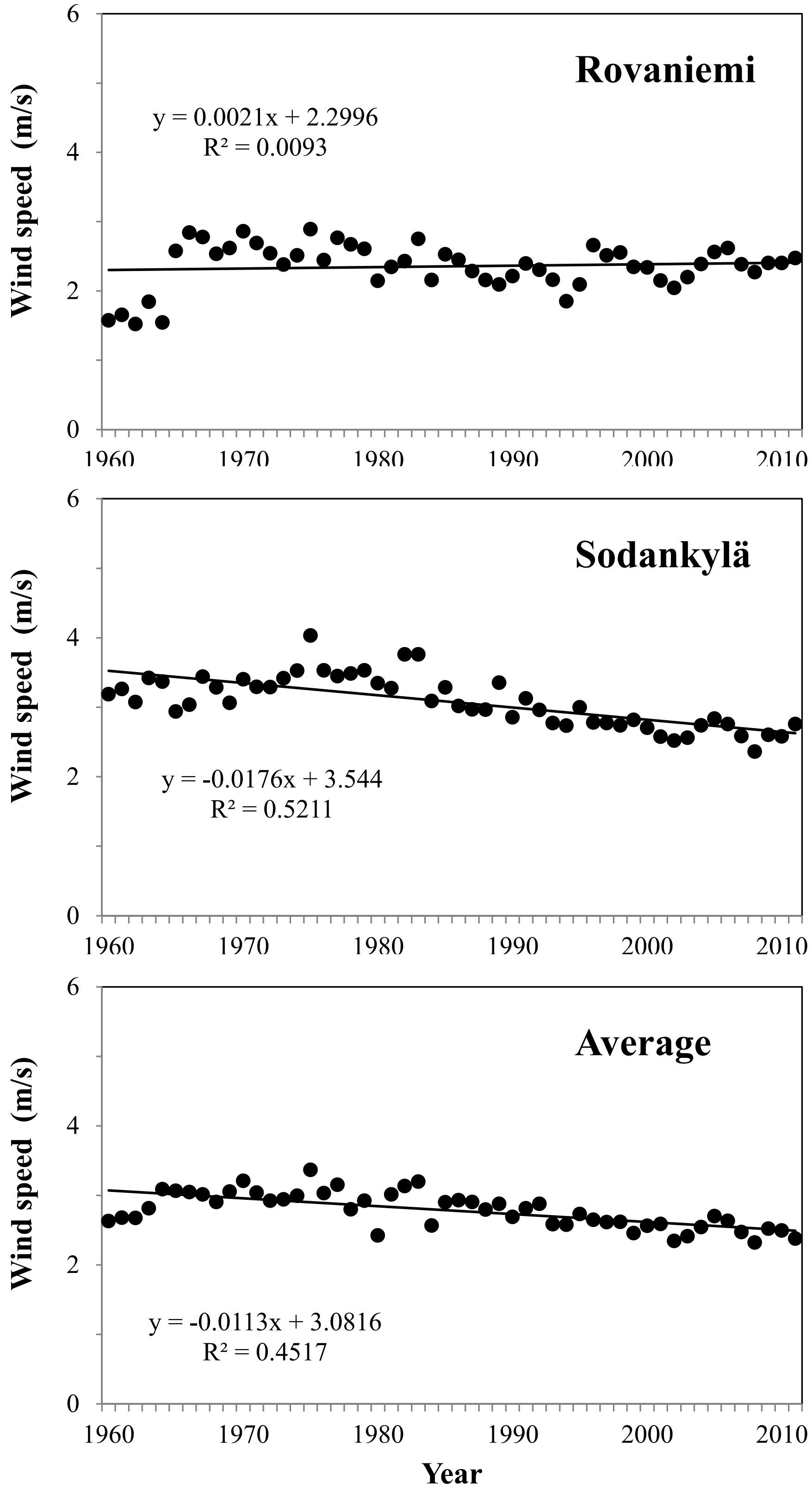


Fig. 6 Temporal variation of wind speed from 1960 to 2011. The regression line is showed together.

Table 2 Mean and normalized trends of pan evaporation, precipitation, air temperature, humidity, wind speed and the second term of Penman's equation. The bold and underline values show the 99% significant level, and the bold ones the 95%.

Station	Pan evaporation		Precipitation		Temperature		Humidity		Wind		2nd term of penman	
	Mean ($mm\,y^{-1}$)	Trend (%/decade)	Mean ($mm\,y^{-1}$)	Trend (%/decade)	Mean (℃)	Trend (℃/decade)	Mean (%)	Trend (%/decade)	Mean (%)	Trend (%/decade)	Mean (mm/d)	Trend (%/decade)
Jokioinen	399	-1.99	273	1.01	13.8	**2.01**	75.8	**-1.06**	3.60	**-3.70**	1.28	1.53
Mikkeli	321	0.15	268	0.55	13.6	**1.44**	74.4	**1.03**	2.51	**-6.48**	1.18	**-6.45**
Ylistaro	385	-0.56	251	2.06	13.3	**1.98**	73.2	**1.79**	2.85	**-3.88**	1.32	**-6.79**
Maaninka	368	0.26	269	0.25	13.6	**1.93**	72.2	**1.45**	2.83	**-2.29**	1.30	**-4.52**
Ruukki	329	**-7.17**	241	1.37	12.7	**1.44**	73.3	**1.72**	2.25	**-7.36**	1.10	**-8.35**
Rovaniemi	283	**-6.37**	243	0.07	11.7	0.90	71.7	**1.90**	2.36	0.89	1.15	**-4.17**
Sodankylä	315	**-5.48**	241	0.28	11.0	**1.77**	73.2	-0.42	3.08	**-5.73**	1.20	-2.07
Mean	343	**-2.82**	255	0.80	12.8	**1.65**	73.2	**0.90**	2.78	**-4.07**	1.22	**-4.33**

4. Discussion

4.1 Relationship between pan evaporation and precipitation

Brutsaert and Parlange (1998) discussed the cause of the decrease trend of pan evaporation using the complementary relationship (CR) of which the concept had been suggested by Bouchet (1963). The schematic diagram of the CR is shown in Figure 7. According to the CR, the pan evaporation which is a kind of potential evaporation decrease if the actual evaporation increases, vice versa. In this section, we discuss the results of this study using the CR.

The variation of precipitation showed the increase trend at all stations (Table 2). The increase of precipitation induce the increase of actual evaporation due to the increase of land moisture. Therefore, according to the CR, the increase trend of precipitation is at least one of the causes for decrease trend in the 5 stations except Mikkeli and Maaninka . Figure 8 shows the relationship between pan evaporation and precipitation. The pan evaporation decreased when the precipitation increase. However, the CR was not applicable for the results in Mikkei and Maaninka.

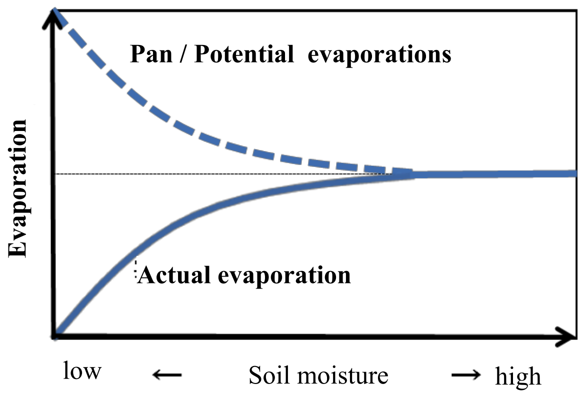


Fig. 7 Schematic diagram of complementary relationship

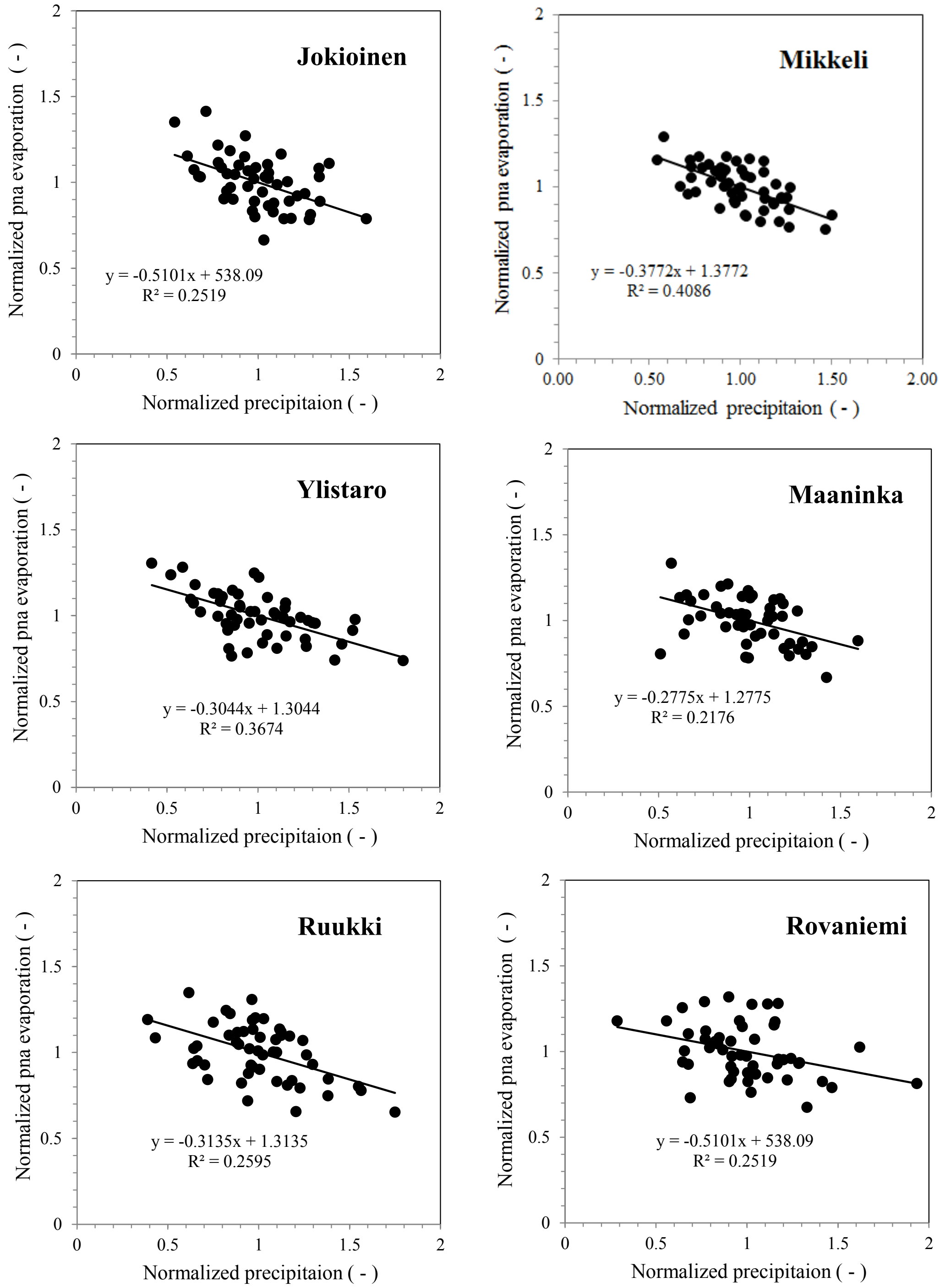
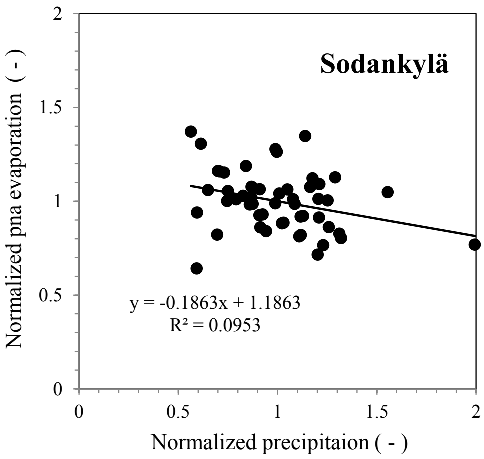


Fig.8 Relationship between normalized precipitation and pan evaporation.



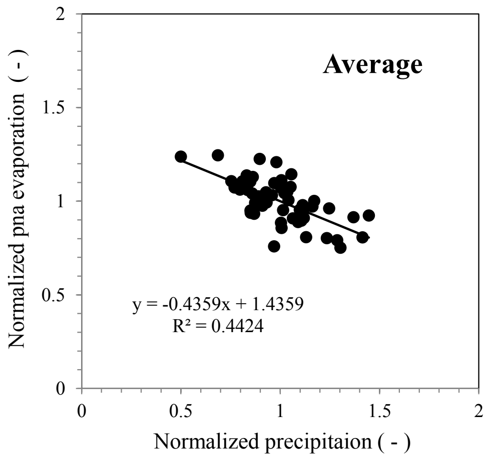


Fig.8 Relationship between normalized precipitation and pan evaporation.

4.2 Analysis by Penman equation

The pan evaporation has the same qualified variation as the potential evaporation, though pan evaporation tends to be larger than the potential evaporation (Brutsaert, 1982). In this section, the mechanistic cause of the trend in the pan evaporation was investigated using the potential evaporation estimated by Penman's equation (1948) which is as follows:

$$E_p = \frac{\Delta}{\Delta+\gamma}\frac{R_n}{l} + \frac{\gamma}{\Delta+\gamma} f(u_2)(e_{sa} - e_a) \qquad (1)$$

where E_P: potential evaporation (mm・d^{-1}), R_n: net radiation (MJ・m^{-2}・d^{-1}), u_2: wind speed at 2m height, $f(u_2)$: wind function (m・d^{-1}・hPa^{-1}) [=0.26×(1+0.54u_2)], e_{sa} : saturated water vapor pressure (hPa), e_a: water vapor pressure (hPa). The first and the second terms on right hand in equation (1) are called a radiative and aerodynamic terms, respectively.

The normalized trends are shown in Table 2. Figure 9 shows the relationship between the normalized trends in pan evaporation and in the normalized 2nd term of equation (1). The normalized trends were decreasing at all stations, which, therefore, caused the decrease trends of pan evaporation at the 5 stations except Mikkeli and Maaninka.

To investigate the mechanistic cause of the trend of the pan evaporation in more detail, we also need to analysis the right hand 1st term of Penman's equation which is related to a radiation.

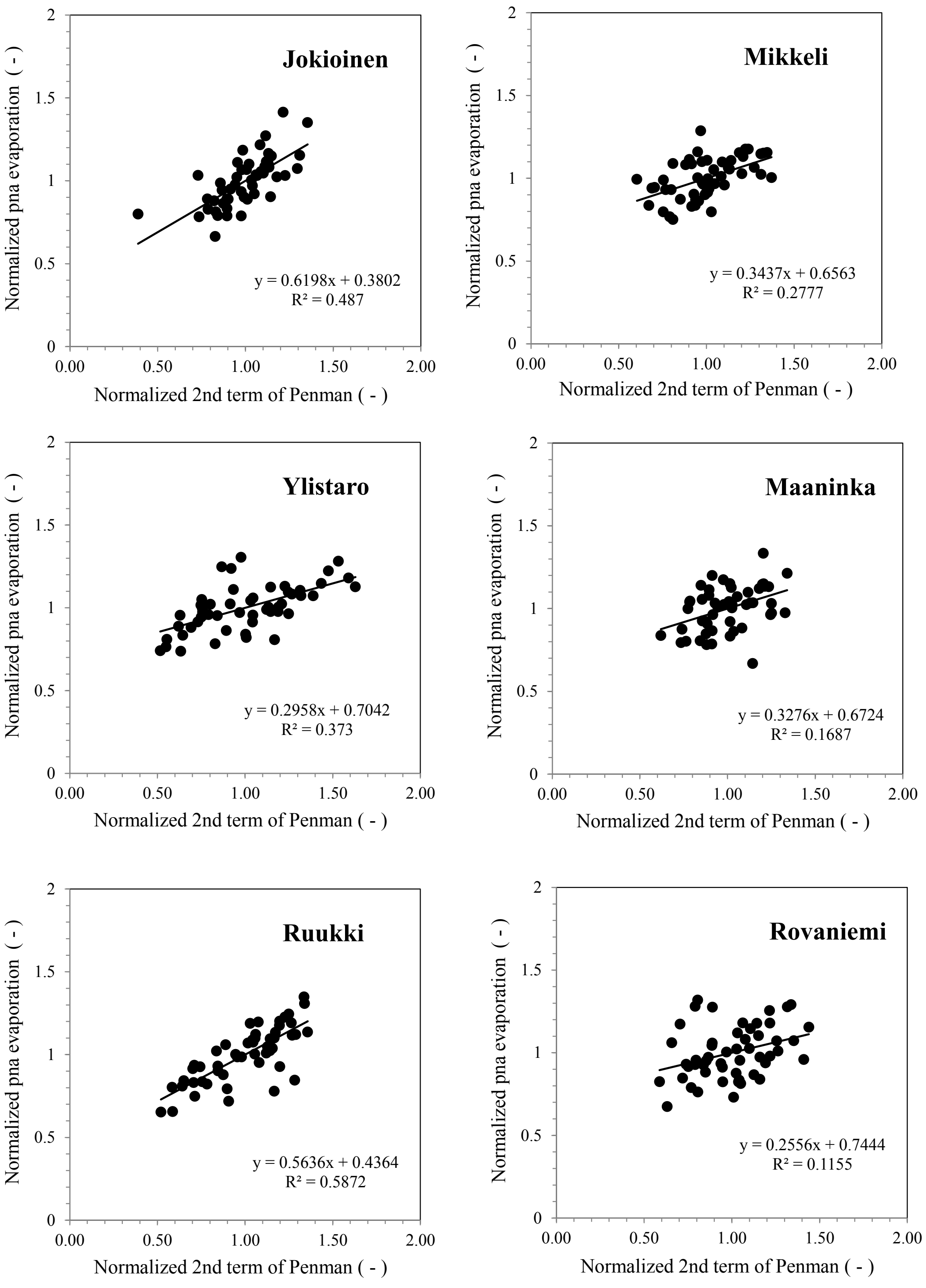


Fig. 9 Relationship between normalized 2nd term in Penman's equation and pan evaporation.

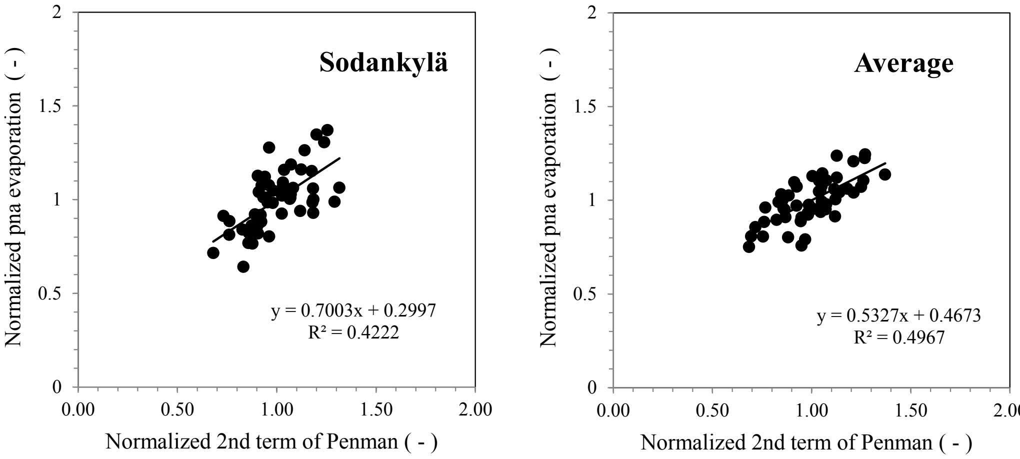


Fig. 9 Relationship between normalized 2nd term in Penman's equation and pan evaporation.

5. Conclusion

The trend analyses of pan evaporation were carried out for 7 stations in Finland located in a high latitude. The causes of the trends of pan evaporation were revealed from two points of view: a complementary relationship and Penman's equation. The results were follows:

(1) The variations of pan evaporation showed the decreasing trends at the 5 stations and the increasing ones in the 2 stations.

(2) The mechanistic causes for the decreasing trends in the 5 stations were mainly the increases of the precipitation and the aerodynamic term in Penman's equation.

(3) The mechanistic causes for the increasing trends in the 2 stations couldn't be revealed .

The following future works are needed:

(1) Radiation or sunshine duration is needed for estimating the right hand 1st term of Penman' s equation.

(2) The Mann-Kendall test is generally better than the T-test to asses the statistical significance of trends, though the t-test was carried out in the present study because a few studies used it.

References

[1] W. Brutsaert and M. B. Parlange, "Hydrologic cycle explains the evaporation paradox", Nature, 396: 30, DOI: 10.1038/23845, 1998.

[2] R. J. Bouchet, "Evapotranspiration reelle, evapotranspiration potentielle, et production agricole", Annales Agronomiques, 14, 743-824, 1963.

[3] W. Brutsaert, “Evaporation into the atmosphere: theory, history, and application", Kluwer Academic Publishers, p.299, 1982.

[4] H. L. Penman, "Natural evaporation from open water, bare soil and grass", Proceedings of the Royal Society of London Series A, Mathematical and Physical Science, 193, 1032, 129-145, 1948.