Long-term Trends of the Pan Evaporation as an Index of the Global Hydrological Change

Jun Asanuma[1] and Hideyuki Kamimera[2]

[1] Terrestrial Environment Research Center, Tsukuba University, Tsukuba, Ibaraki, 305-8577, Japan

[2] Graduate School, Nagaoka University of Technology, Nagaoka, Niigata, 940-2188, Japan

ABSTRACT: Pan evaporation measured over 30 years at 14 meteorological observatories operated by Japan Meteorological Agency were analyzed in terms of their long term trend over 30 years. It was found that decreasing trends of the pan evaporation are found in most regions of Japan, and that the clearest decreasing are found at the stations on the Pacific coast. Anlaysis of other meteorological variables indicates that this decreasing trends of the pan evaporation are accompanied with the increase of air temperature and vapor pressure deficit.

1 INTRODUCTION

It is a confirmed and well-known fact that the global mean surface temperature has been and is increasing at the rate around 0.015°C/year. Possibility that along with the climate change hydrological cycle, as a important part of the climates system, may vary from its past status is of the greatest interest of the enginieers as well as scientists.

In a simple thought, increased temperature would results in the increased volume of the water vapor in the air, which could cause the increase in rainfall amount in a single storm event. The increased precipitation, and thus the increased soil wetness can be easily connected to the increase of the river water discharge and the evaporation from the landsurface. In this way (as such), global temperature rise is expected to cause acceleration in the global hydrological cycle. On the other hand, activitated cloud-precipitation is associated with the increased amount of the cloud, and thus with the decrease in solar radiation, which is a negative feedback to the evaporation, and thus to the whole hydrological cycle.

Validation of the accelerated hydrological cycle has been done mainly through the analysis of the observed precipitation over the land [e.g. *Houghton et al.*, 2001]. Evaporation, however, has not been investigated much since its long-term records are not widely available due to its difficulty in direct measurements. Recently, pan evaporation, evaporation from a water-filled pan evaporimeter, has come to the light as an index of the "actual" evaporation, and efforts are ongoing to validate or invalidate the accelerating hydrological cycle.

2 EVAPORATION PARADOX AND GLOBAL HYDROLOGY

The first to pay attention to the pan evaporation as an index of the changing hydrological cycle and "fired" the discussion is *Peterson et al.* [1995], who investigated the measurements of pan evaporation over the past half century at 190 stations in United States (US) and at 746 stations in the Former Soviet Union (FSU). Out of these measurements, they found, 4 regions, except the central asia of FSU,

exhibit the decrease in pan evaporation, namely in European FSU, Siberian FSU and eastern and wetern US. They interpreted this widely-found decrease in pan evaporation as an indication of decrease in the terrestrial evaporation, and claimed that this interpretation does not contradict to three observational facts, namely 1) decrease in daily maximum air temperature during the summer, 2) decreased degree day in Siberia and the European FSU and 3) increase in the river discharge observed in the European FSU and northen US. *Peterson et al.* [1995] also reported that the results of the other meteorological vaiables show that the decreased pan evaporation is most correlated with the decreased daily temperature range, and that it is negatively correlated with the increase in the cloud amount.

Following *Peterson et al.* [1995], decreasing trends in past pan evaporation records has been reported from India[*Chattopadhyay and Hulme*, 1997] and Venezuella[*Quintana-Gomez*, 1997]. The interpretation of the decreased pan evaporation by *Peterson et al.* [1995] is based on the notion that the pan evaporation is an indicator of the potential evaporation, that is, maximum possible evaporation from the landsurface. It is, however, a common knowledge among the hydrologists that the pan evaporation is among types of potential evaporation that is negatively correlated with the "actual" land surface [e.g., *Brutsaert and Stricker*, 1979]. When the landsurface evaporate less water, the drier air comes over the pan evaporimeter that stimulate the more evaporation from the pan, and vice versa. This complimentary relationship between pan and "actual" evaporation is easily understood with the fact that evaporation from a pan is at its largest amount when it is placed in a dessert, where the "actual" evaporation is small.

Brutsaert and Parlange [1998] pointed out that if the widely-observed decrease in the pan evaporation indicates an decrease in the terrestrial evaporation, it is inconsistent with the observed increase in the terrestrial precipitation. They called this as "Evaporation paradox". Using the complimentary relationship mentioned above, they explained that the decrease pan evaporation can be interpreted as an increase in the terrestrial evaporation, which does not contradict with increasing precipitation. Following this hypothesis, *Lawrimore and Peterson* [2000] investigated the precipitation and the pan evaporation during the warm season over continental US, and found a negative correlation between them. If a positive correlation between the precipitation and the terrestrial evaporation during the warm season is assumed, their finding validates the negative correlation, i.e. complimentary relationship, between the pan evaporation and the terrestrial evaporation over a long term. *Golubev et al.* [2001], in a similar vine, confirmed the complimentary relationship between the pan evaporation and the evaporation measured with a lysimeter at 7 stations in FSU and the 1 station in US, spread over different latitudes. Using this relationship, they calculated a trend in the terrestrial evaporation forming a increasing trend over southern FSU and over continental US.

Findings by *Lawrimore and Peterson* [2000] and *Golubev et al.* [2001] confirmed that the complimentary relationship between the pan and the terrestrial evaporation hold even on the long term basis. This complimentary relationship, however, is mainly associated with drying and wetting of the landsuface, and the wetness of the landsurface does not solely control the evaporation. *Roderick and Farquhar* [2002] recently argued that the decreasing solar radiation associated with the increased clound amount and aerosols may have caused the decrease in pan evaporation, and the discussion regarding the pan evaporation trend and the global hydrological change has been set back to the begining. *Ohmura and Wild* [2002] summarized the problems and its solution on this issue.

Contribution to this "Pan evaporation" issue from the eastern Eurasia continent are limited so far. One of the few is by *Xu* [2001] who analyzed the data measured at 7 stations in China and 1 station in Japan for about 20 years and reported that the past pan evaporation records showed an increasing trend in the arid region in China while decreasing trends are found in the humid region. She commented that

Figure 1: Meteological stations subject to the analysis

this decreasing trend in humid of China and Japan together with the similar trend India [*Chattopadhyay and Hulme*, 1997] may be common to the monsoon climate system.

This paper, aiming to be another contribution from the easterbn Eurasia, investigates the pan evaporation records observed at 14 stations in Japan, and discusses the implication of the result of its trend analysis.

3 DATA

Data subject to the analysis in this paper is daily pan evaporation and other meteorological variables measured at 14 meteorological stations operated by Japan Meteorological Agency (JMA), and are distributed in CD-ROMs published by Japan Meteorological Business Support Center. Most of the JMA stations ceased pan evaporation measurements around mid-1960's when JMA started to use WMO class-A pan, and the 14 stations had continued the measurements upto March, 2002. Figure 1 shows their location.

Period of the analysis is from 1967 to 1996. Daily measurements (accumulated value or daily mean value) are averaged over the four seasons (DJF, MAM, JJF and SON), the warm season (May to October) and the whole year period, and they are analyzed in terms of its interannual variability. The warm season is particularly intended as the longest season for the analysis available at all the stations, since the pan evaporation measurement are recessed during most of the colder season in the northen stations. Besides the pan evaporation, air temperature, wind speed, vapor pressure, vapor pressure deficit, daily temperature range, precipitation and solar radiation are analyzed in order to investigate the controling factors to the pan evaporation.

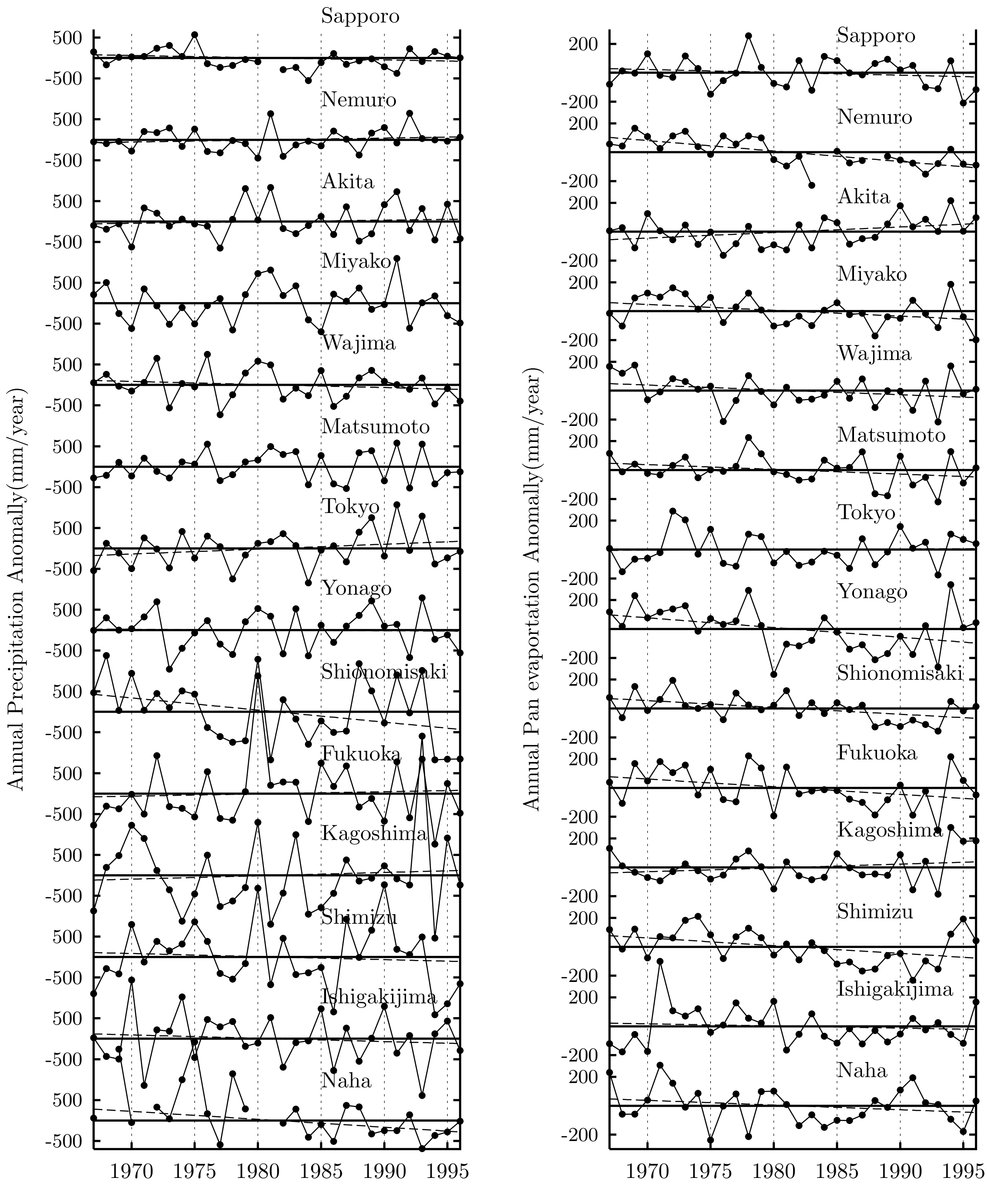

Figure 2: Anomally (deviatin from the mean) of the precipitations (left panel) and the pan evaporation (right panel)at each site. The broken lines indicate the linear regression line.

4 ANALYSIS

Figure 2 shows the anomally of the warm season average of the precipitation and the pan evaporation, together with the linear trend described below. One astonishing feature here is that pan evaporations

Table 1: Trend a (mm/year) of the precipitation calculated through the linear regression analysis. The values in **<u>underlined bold face</u>** and those in **bold face**, respectively, are increasing/decreasing trends with the significance level of 97.5%, and 95% detemined by t-test.

Station	Whole year	Warm season	MAM	JJA	SON	DJF
Sapporo	-0.7	-5.4	-0.6	-12.0	0.2	8.8
Nemuro	0.9	4.8	-1.2	8.3	2.7	**-10.4**
Akita	0.2	3.9	-2.5	6.6	4.3	-10.5
Miyako	-0.7	0.2	0.9	5.3	-3.0	-7.9
Wajima	**-10.1**	-7.6	-6.9	-3.2	-17.8	-11.9
Matsumoto	-0.4	0.7	3.2	-9.2	7.0	-2.6
Tokyo	6.9	12.0	8.3	13.4	12.1	-7.8
Yonago	-2.5	-1.7	3.2	-10.5	-0.8	2.6
Shionomisaki	**-22.2**	**-29.6**	-15.0	**<u>-52.4</u>**	-8.8	-16.6
Fukuoka	1.7	5.4	9.8	4.4	0.1	-8.1
Kagoshima	6.9	8.2	8.7	21.5	-2.1	-3.0
Shimizu	0.8	-7.5	6.9	-17.9	19.5	-8.8
Ishigakijima	0.2	-8.1	28.2	-11.3	-23.9	6.1
Naha	-11.0	-19.3	9.0	**-40.9**	0.0	-14.1

Table 2: Same as Table 1, but for the pan evaporation.

Station	Whole year	Warm season	MAM	JJA	SON	DJF
Sapporo	-	-1.97	-	-0.74	-	-
Nemuro	-	**<u>-7.25</u>**	-	**<u>-8.50</u>**	-	-
Akita	-	**3.84**	-	4.02	-	-
Miyako	-	**-4.05**	-	-4.21	-	-
Wajima	-	-3.34	-	-3.39	-1.79	-
Matsumoto	-	-3.27	-	-2.72	-1.98	-
Tokyo	1.33	0.38	1.31	-1.14	**5.38**	-
Yonago	**-4.28**	**-6.73**	**<u>-5.20</u>**	-7.71	**-3.07**	-
Shionomisaki	**<u>-3.75</u>**	**<u>-4.73</u>**	**-4.52**	**<u>-5.69</u>**	-1.98	**-3.23**
Fukuoka	**<u>-5.98</u>**	**-5.33**	**-4.70**	-6.11	**<u>-5.57</u>**	-
Kagoshima	1.54	2.60	1.20	0.35	**4.69**	-
Shimizu	**-4.09**	**-5.35**	**-4.13**	**<u>-7.00</u>**	**-3.23**	**<u>-4.27</u>**
Ishigakijima	-2.67	-1.50	**<u>-8.08</u>**	0.54	-2.08	-1.56
Naha	**-3.56**	-3.25	**<u>-6.61</u>**	-3.65	-2.06	0.10

records at all of the stations capture the contry-wide climatic events. For example, a cold summer on 1993 and a hot summer on 1994, which is said be triggered by Pinatubo eruption on 1991, were clearly captured in the measurements at the stations except Ishigakijima and Naha. Some of the stations, for example, Tokyo has been largely urbanized during this period, and the measurements are naturally considerted to be under the influence of local urbanization. The fact that the measurements at stations under urbanization could capture a global climatic signal indicates that the past pan evaporation records can also have a signal, or information, regarding the global hydrologic cycle.

Long term trends of each meteological variables at each station are detemined for each season using the linear regression analysis, where the linear trend, $y(t)$, is expressed as,

$$y(t) = at + b \tag{1}$$

where t denotes the time and a and b are constants determined through the analysis. The trend detemined, a, are tested in terms of its statistical significance using the single-sided t-test, where $t = a/\sigma_a$ with σ_a the expected standard deviation of a. Detemined trend value are given in Tables 1 and 2 together with the t-test results with the significance level of 97.5% and 95%.

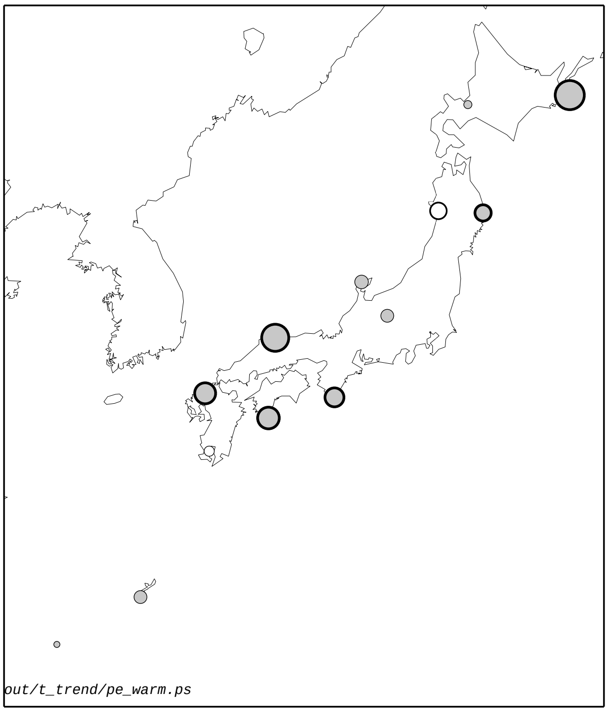

Figure 3: Trend of the pan evaporation for the warm season. White circles and gray circles indicate increasing and decreasing trend, respectively. The size of the circles at each stations indicates the magnitude of the trend while the thick edge of the circles indicates the increasing/decreasing trend with the 95% significance level.

It is shown in Table 1 that statistically significant increasing/decreasing trend cannot be found in the precipitation records at most of the stations. This is partly attributable to large interannual variebilities in precipitation (see Figure 2). Some reports [e.g., *Houghton et al.*, 2001] have shown that while increasing trends in precipitation are clear most of the globe, those in north-eastern pacific region is obscure.

In contrast, decreasing trends in the pan evaporation is clearly stated at the most of the stations analyzed during the most of the seasons. Closer investigation reveals that steady decreasing trends are found at Nemuro, Yonago, Shionomisaki, Fukuoka and Shimizu. Miyako, as well, shows a decreasing trend comparable in amount with these 5 stations, but the trend, especially in JJA, is not determined as statistically significant. This is probably due to the large variabliity of the summer climate in Miyako caused by a cold wind blow from the northeast called"Yamase". Thus, Miyako is also considered among stations that give stronger decreasing trend.

5 DISCUSSION

A week increasing trend of the pan evaporation is found at Akita, Tokyo and Kagoshima, all of which are located in an urbanized area that have been urbanized during the last half century. In general, urbanization involves construction of buildings and paving of roads, and as both of them interferes evaporation from the landsurface, terrestrial evaporation tends to decreaseas. Therefore, on the basis of the complimentary relationship described in this text, it is expected that, with the decreasing evaporation from the landsurface, pan evaporation itself increases as a result of the urbanization of the surrounding

areas. With this expectation, increasing trend of the past pan evaporation records at these 3 stations can be attributable to the local urbanization.

If each measurement record is a superimposition of the two signals, a local signal influenced by the urbanization and a large-scale or global signal that reflects the large-scale climate/hydrological system, one can deduct the global signal by removing the local one. It is considerted that other urbanized ares such as Sapporo, Matsumoto, and Naha that show weak decreasing trend, have been affeted by the local urbanization, and, therefore, with the above notion, these three stations are also in support of the decreasing trend of pan evaporation over Japan.

Linear trend of the pan evaporation determined above are plotted on the map in Figure 3. One prominent feature is that 4 stations on the Pacific coast, namely Nemuro, Miyako, Shionomisaki and Shimizu, show a clear decreasing trend. Since these 4 stations are located in or near the rural town on the sea coast, they are relatively free from the effect of the urbanization. Moreover, the observatory at Miyako, Shionomisaki and Shimizu are located on the hill slope open to the sea, and they are under direct influence of the ocean.

6 CONCLUSION

Pan evaporation measured at 14 stations in Japan over 30 years are investigated in conjunction with the long term trend of the global climate/hydrological system. It was found that the decreasing trend of the pan evaporation prevails over Japan, and the stations on the Pacific sea coast show the clearest downward trend. This decreasing trend may be associated with the increasing trend of the ocean evaporation. Trend analysis of the other meteorological variable shows that the decreasing trends of the pan evaporation are accompanied, in most of the cases, with the increasing trend of the air temperature, and the vapor pressure deficit.

References

Brutsaert, W., and M. B. Parlange, Hydrologic cycle explains the evaporation paradox, *Nature*, *396*, 30, 1998.

Brutsaert, W., and H. Stricker, An advection-aridity approach to estimate actual regional evapotranspiration, *Water Resour. Res.*, *15*, 443–450, 1979.

Chattopadhyay, N., and M. Hulme, Evaporation and potential evapotranspiration in India under conditions of recent and future climate change, *Agri. and Forest Meteor.*, *87*, 55–73, 1997.

Golubev, V., J. Lawrimore, P. Groisman, N. Speranskaya, S. Zhuravin, M. Menne, T. Peterson, and R. Malone, Evaporation changes over the contiguous United States and the former USSR: A reassessment, *Geophys. Res. Lett.*, *28*, 2665–2668, 2001.

Houghton, J., Y. Ding, D. Griggs, M. Noguer, P. van der Linden, X. Dat, K. Maskell, and C. Johnson (Eds.), *Climate Change 2001 — The Scientific Basis —, Contribution of Working Group I to the Third Assessment Report of the International Panel on Climate Change*, Cambridge Univ. Press, Cambridge U.K., 2001.

Lawrimore, J., and T. Peterson, Pan evaporation trends in dry and humid regions of the United States, *J. Hydrometeo.*, *1*, 2000.

Ohmura, A., and M. Wild, Is the hydrological cycle accelerating?, *Science*, *298*, 1345–1346, 2002.

Peterson, T., V. Golubev, and P. Groisman, Evaporation losing its strength, *Nature*, *377*, 687–688, 1995.

Quintana-Gomez, R., Changes in evaporation patterns detected in northernmost south America. homogeneity testing, in *Proc. 7th International Meeting on Statistical Climatology*, Whister, BC, Canada, 1997.

Roderick, M., and G. Farquhar, The cause of decreased pan evaporation over the past 50 years, *Science*, *298*, 1410–1411, 2002.

Xu, J., An analysis of the climatic changes in eastern Asia using the potential evaporation, *J. Soc. Hydro. Water Resour.*, *14*, 151–170, 2001, (in Japanese with English abstract).