Evapotranspiration of West Japan by Means of Water Vapor Budget Analysis (II)

—Computation of Evapotranspiration in Kyūshu during 1964—1967

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Abstract

Seasonal march of evapotranspiration in Kyūshu Island during 1964—1967 is calculated by means of atmospheric water vapor budget. The details of calculation scheme and the discussion on error in its numerical analysis are described in the 1 st report of this study. Results reveal that the availability of this method is approved by comparing with the other conventional methods to estimate amount of evaporation.

1. Introduction

There have been established various methods to measure the evaporation (Thornthwaite[1], Veihmeyer[2], Yamamoto and Kondo[3], but especially when we try to determine the evaporation from somewhat larger areas, each of them is not usually satisfactory because of requirement of precise estimation of meteorological conditions near the ground. Recently, A. Nyberg[4] computed the amount of monthly evaporation in Southern Sweden of which scale is about 300Km×200Km during 1957 by means of studies of precipitation and the net flux of water vapor into the area, and he found that the method seemed useful even over the rather small area studied. In this paper the authors describe the results that this method has been modified and applied to determine the evapotranspiration in Kyūshu Island which has about same area as South Sweden during 1964—1967.

2. Methods of Computation

Calculation scheme of the evapotranspiration by the water vapor flux method is presented as follows. Generally the water budget of the air column is given by the following equation.

$$\int_P^{P_0} \frac{dq}{dt}\frac{dP}{g} = \int_P^{P_0} \frac{\partial q}{\partial t}\frac{dP}{g} + \int_P^{P_0} \nabla q \mathbb{V} \frac{dP}{g} + (\rho \bar{q} \omega)_P = E - R \qquad (1)$$

Where P_0, P is the air pressure at the earth's surface and the top of the air column, respectively, and q the specific humidity, g the acceleration of gravity, $\mathbb{V}$ the horizontal wind vector, ρ the air density, ω the upward velocity of the air at the level P. E, R is the evaporation and precipitation in the area studied. The vertical velocity ω is evaluated by integrating the horizontal divergence,

$$\omega = \int_P^{P_0} \nabla \mathbb{V}\, dP + \omega_0 \qquad (2)$$

ω_0 is the vertical velocity on the earth's surface and is assumed to be zero. The flux divergence and divergence of water vapor flux in eqs. (1), (2) are computed by the following equations,

$$\nabla \mathbb{V} = \frac{1}{S}\oint v_n\, ds \qquad (3)$$

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$$\nabla q\mathbb{V}=\frac{1}{S}\oint q\ u_n\ ds \qquad (4)$$

where S is the area enclosed by the circuit and u_n is the wind velocity component normal to the line element ds of the circuit. The circuit around the area studied, Kyūshu Island, is shown in Fig. 1, where also is shown the upper air sounding stations and surface stations.

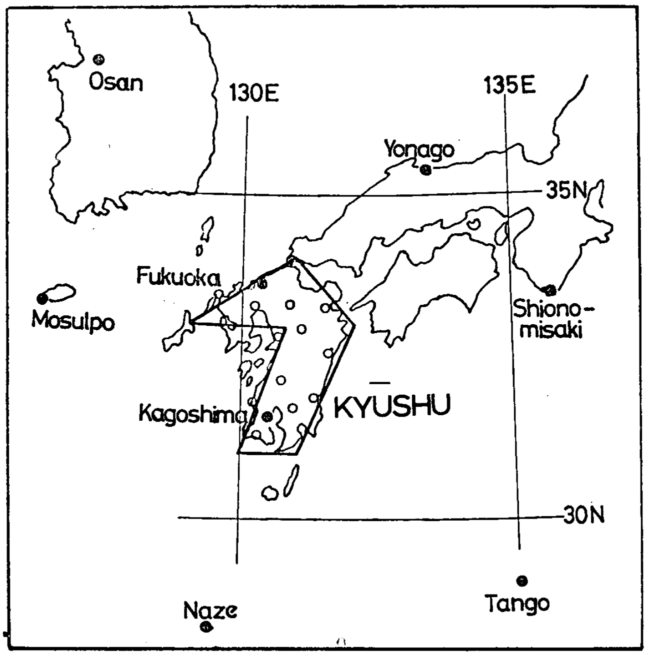

Fig.1 Map of Kyūshu Island and the area studied.

● : *the upper air sounding stations used for a computation of the evapotranspiration by the water vapor budget method.*

○ : *the surface stations used for calculating the evaporation by other methods*

At first the authors used the exactly same procedures as A. Nyberg, that is, the atmospheric column was taken from the earth's surface to 400 mb level, and the upper wind was approximated by the geostrophic wind. Analyses are made for two months of June and September in 1967 by analyzing the daily five level synoptic charts (1000, 850, 700, 500, 400mb). The results obtained were unsatisfactory for neglecting the divergence of liquid or solid water flux, using the geostrophic wind in a lower layer, and the inaccuracy of estimation of precipitation[5]. And then, in order to eliminate those factors, the air column is taken from the earth's surface to 850mb, because climatologically the cloud base is higher than 850mb level and if it is assumed that the precipitation particles develop or evaporate, neither, the precipitation observed at the surface and 850mb are equall. And the actual wind is used instead of the geostrophic wind.

Fig. 2 shows an example of 900mb level chart for analyzing the water vapor transport according to the modified methods above, where u, v is the eastward and northward wind component, respectively, and q is the specific humidity. On this chart, by knowing the values of u, v, q at the middle point of each perimeter of the circuit, and transforming u, v to v_n, we are able to compute $\nabla\mathbb{V}$ and $\nabla q\mathbb{V}$. By such a analyzing method, nevertheless, it is obliged to take long time to compute a daily evaporation, so that the computing program is designed, assuming that the scalar quantities, u, v, q vary linearly between adjacent stations around the perimeter.

In Fig. 3 the correlation of horizontal water vapor divergence $\rho\nabla q\mathbb{V}$ and vertical water vapor

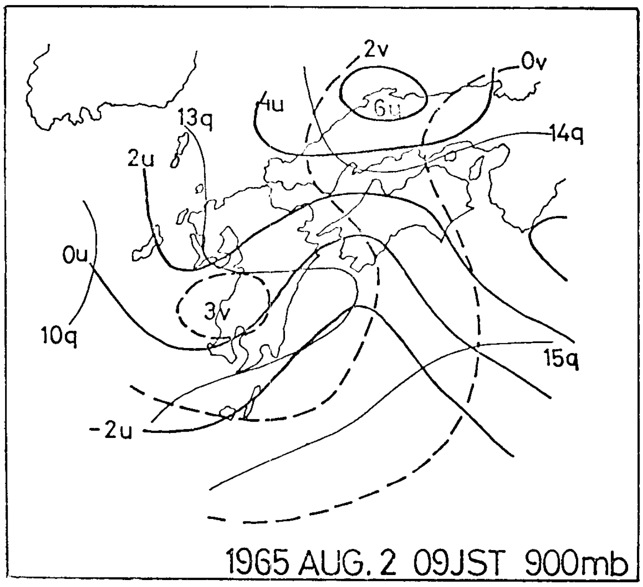

Fig.2 900mb *level chart for analyzing the water vapor transport according to the actual wind.* u : *zonal wind component* (+ : *eastward*), *and* v : *meridional wind component* (+ : *northward*) *in* m/sec. q : *specific humidity in* g/kg

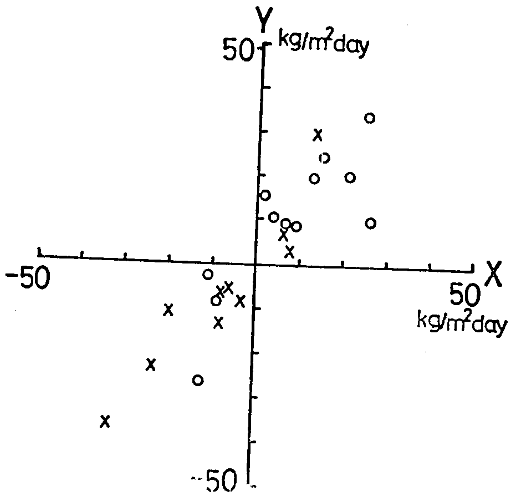

Fig.3 Correlation between the chart method (Y) *and the linear programming method* (X) *plotting the values of horizontal water vapor divergence* (○ : $\rho\nabla p V$) *and vertical water vapor transport* (× : $\rho\bar{q}\omega$)

transport $\rho\ \bar{q}\ \omega$ between chart method and the linear programming method during the first week of August in 1965. It is found to be possible to use the computing procedure with the linear assumption. In this procedure ∇V and $\nabla q V$ are calculated on the 900mb level, and in computing $\rho\ q\ \omega$, q is given by 900mb's $\bar{q}$ when ω is positive or has upward direction and by 850mb's $\bar{q}$ when ω is negative[5]

3. Seasonal March of Evapotanspiration in Kyūshu Island during 1964−1967

Monthly evapotranspiration in Kyūshu Island during 1964−1967 has been computed by the method described above using the aerological data of twice daily soundings at 09 and 21 JST at each station.

Results is shown in Fig. 4, where the evapotranspiration for 09 and 21 JST is computed on the assumption that an instantaneous flux value is representative for the day. In addition to the seasonal march of both computed evapotranspiration and mean value of them, the calculated evapotranspiration by the other methods are also shown and are made comparisons with the ones according to the water vapor flux method. The other methods are (1) the climatological technique by Thornthwaite, (2) the heat flux budget method (S/L) that is calculated here simply by dividing that net radiative energy flux at the ground surface (S) by latent heat of evaporation (L), and (3) the measured evaporation with a pan.

The net radiative energy is obtained by the climatological technique[6] knowing the mean cloud amount and the representative value of Albedo ($\simeq 15$) on the ground surface of considered area. These other three methods have been calculated at the 14 surface stations shown in Fig. 1 to obtain the mean value of evapotranspiration roughly corresponds to the variation of the one obtained with the aid of the heat flux determination (S/L) and from measurements with the evaporation

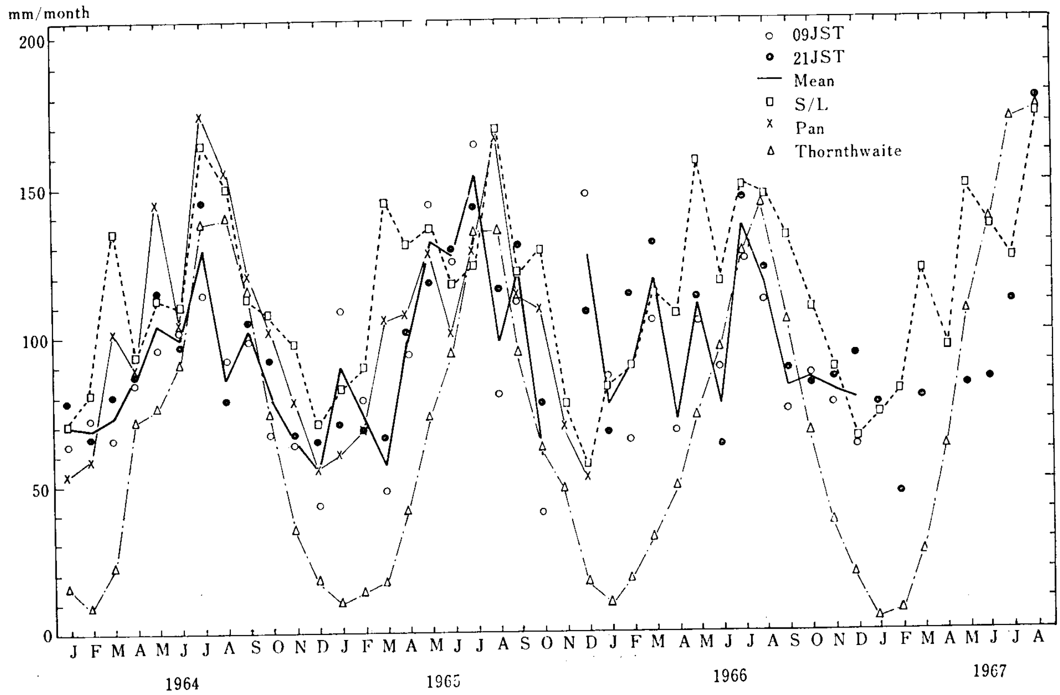

Fig.4 Seasonal march of the monthly evapotranspiration (mm/month) *in Kyūshu Island from Jan.* 1964 *to Aug.* 1967 *obtained by each method*

○ *and* ● *show the values obtained by the water vapor budget method for* 09 *JST and* 21 *JST, respectively, and* — *shows the variation of mean value of them.* □, × *and* △ *show the values obtained by other methods, the heat flux method* (S/L), *the measurement with pan, and Thornthwaite's method, respectively*

pan. This correspondence appears evidently in the series in 1964 and 1966, but not so much in 1965 and 1967, and remarkably on each month of May, August, October, December in 1965 there is even inverse correspondence between them. On the other hand, comparing with these methods the variation of the values by the Thornthwaite's method independently shows the smooth change in each year. Generally in these series the computed evapotranspiration values are obtained higher than the Thornthwaite's and lower than the *S/L* 's and the pan's. This seems to suggest that the present water vapor flux method is probably available to compute the evapotranspiration in the Kyūshu Island. The yearly values with the aid of each method are shown in Table 1.

Högström[7] found in his studies of natural evaporation in Southern Sweden that the ratio of natural evaporation to pan's or Penman's was about 70%—80%. Also in Kyūshu Island as shown in Table 1 the values of this ratio are seen about from 70% to 95% which are almost near to the value in Southern Sweden. Furthermore, as the ratio of the yearly evaporation from the clay soil surface or the free water surface to the yearly precipitation has, so far, been given 50%[8], and in Kyūshu about the same value is calculated. Interestedly there are obtained considerable differences between the values at 09 and 21 JST, similarly as Nyberg's analysis in Southern Sweden. Nyberg explained that this was caused most likely by the random errors. The authors are now engaged in investigating this difference in detail to pay attention to meso-scale high caused by the radiative cooling effect at night because generally the values for at 21 JST are larger than 09 JST.

Table 1 Values of total evapotranspiration by each method, total precipitation, and ratio of the total evapotranspiration by each method to the total value obtained with pan method or by the heat flux method and to total precipitation during 1964−1967

		water vapor flux method		heat flux method	Thornthwaite's method	pan measurement	precipitation
		09 JST	21 JST				
Total evaporation by each method & total precipition (mm)	1964 JAN-DEC	954	1059	1295	804	1223	1893
	1965 JAN-DEC*	1086	1073	1287	696	1136	1873
	1966 JAN-DEC	1054	1173	1357	775	—	2260
	1967 JAN-AUG**	—***	653***	858	607	—	994
Value of ratio of total evaporation by other methods to total evaporation with pan (%)	1964 JAN-DEC	78	87	106	66	*, **, ***; A part of data is lacked for computation during *; Apr., **; Nov., ***; 09 JST, from Jan. to Dec. and 21 JST from Sep. to Dec. (** **); Data of evaporation with pan has been lacked since 1966.	
	1965 JAN-DEC*	96	95	113	61		
	1966 JAN-DEC	—(** **)	—	—	—		
	1967 JAN-AUG**	—	—	—	—		
Value of ratio of total evaporation by other methods to total evaporation by heat flux method (%)	1964 JAN-DEC	74	82	—	62		
	1965 JAN-DEC*	84	83	—	54		
	1966 JAN-DEC	78	86	—	57		
	1967 JAN-AUG**	—	76	—	71		
Value of ratio of total evaporation by each method to total precipitation (%)	1964 JAN-DEC	50	56	68	43		
	1965 JAN-DEC*	58	57	69	37		
	1966 JAN-DEC	47	52	60	34		
	1967 JAN-AUG**	—	66	86	61		

4. Conclusion

As described above, it is found that the water vapor flux method for evaluating the evapotranspiration, the water vapor budget method using the air column from the earth's surface to 850mb level, is available in the meso-scale area such as Kyūshu Island. Although there still remain some problems to make clear, that is, the question that the values in winter, particularly on January and December in 1965, are too high comparing with the values with the aid of conventional other methods, and the considerable differences of the values for 09 and 21 JST and so on, the availability of this method is understood by the correspondence between the water vapor method and the conventional methods, the heat flux method and measurement with a pan, in the seasonal march during 1964—1967, and also understood by that computed yearly evapotranspiration is about 50% of the yearly precipitation and about 70%—90% of the measured yearly evaporation with a pan. And those values agree much well with the hitherto results.

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References

1) C. W. Thornthwaite : Meteorological Monograph, 6, 163—179 (1965)
2) F. J. Veihmeyer : "Handbook of Applied Hydrology" McGraw Hill Book Co., N. Y. (1964) 11, p.33
3) G. Yamamoto and J. Kondo : J. Met. Soc. Japan, Ser. II, 46, 166—177 (1968)
4) A. Nyberg : Tellus, 17, 473—483 (1965)
5) Y. Shiotsuki : J. Agr.Met., 26, 25—33 (1970)
6) A. I. Budagovsky : "Isparenie Pochvennoi Vlagy" Izv. Nauk. Moskva (1964)
7) U. Högström : Tellus, 20, 65—75 (1968)
8) K. Aki, et al : "Handbook of Water Resources" Asakura Shoten, Tokyo (1966) p.659

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