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On the prevailing wind in early summer judged by bending shapes of top-twigs of persimmon trees at the Akaho Fan, Nagano Pref., Japan

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Abstract

The author and his collaborators measured the bending directions of top-twigs of persimmon trees at about 230 points in the region of Akaho Fan, Nagano Prefecture, Japan, which covers an area of about 25 square kilometers.

They found that the bending of tree-tops was a very good indicator of the local prevailing wind. The direction which they bend shows, with the interval of confidence of about $\pm 15^\circ$ the direction of the wind that prevails during the growing season of persimmon trees which is roughly from April to June.

Using the observed results, the author investigated the effects of the local topographical features and surface covers upon the prevailing wind of the locality.

Moreover, we made several actual and simultaneous wind observations at various places for some days when the southerly wind prevails at the surface of the fan. The precise local characteristics of the wind obtained through these observations agree surprisingly well with those estimated from the bending of the tree-tops.

1. Introduction

This previous papers, the author stated that as a method to estimate local climates at an unknown region, there is a way which observes various natural and cultural landscapes reflecting sensitively the climatic conditions of the locality. As an example of this method of estimation, the author wishes to report the result of research of local wind conditions. Observations were made at the Akaho Fan, Nagano Prefecture, the same place as stated in the previous papers. The wind conditions can be estimated by measurements or the bending directions of top-twigs of a tree. This is because that young top-twigs of a tree has a tendency of bending toward the blowing direction of the prevailing wind, when they are exposed to it for fairly a long duration. The bending takes a more distinct form when the prevailing wind is more frequent and stronger.

As an index of observation, the author chose persimmon trees, because they are found at most every place in this region. Moreover the bending shape of top-twigs is most attractive. The measurements were carried out as minutely as possible, and especially at places where surface conditions are intricate, the measurements were made on all persimmon trees that could be found. Observations were done in November, 1945 and May, 1946, and the number of the points of observation was about 230. The area of this research field is about 5 km square. Therefore, the points of observation are located at approximately 100 m apart.

Moreover, several actual observations were made on the prevailing southerly wind of early summer in May, 1946. Observations were made at several places which show some typical differences on their surface conditions, and the observed results were compared with the bending directions of persimmon twigs which were measured near the respective wind observation points.

2. The bending shapes of top-twigs of persimmon trees and the prevailing wind

In this country, it is not seldom that top-twigs of persimmon trees show conspicuous bendings toward certain directions. This phenomenon suggests us that the bending is affected by the prevailing wind of that place. At the Akaho area, the southerly wind generally prevails almost throughout the year. But its precise direction, both frequencies and strengths are not always the same by seasons. Fortunately, we were able to obtain the wind observation records for about 10 years at the Akaho Elementary School which is located at almost in the centre of this region. The observed results are tabulated by the author as shown in Tab.1.

Tab. 1. Annual wind conditions at Akaho. (1936-1945)

Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Total south component	181.5	50.5	42.5	222.5	244.0	244.0	211.0	145.0	90.0	-9.5	30.0	151.0	—
Resultant* direction	N2°E	26°E	46°E	7°W	4°W	6°E	1°E	7°E	4°W	78°W	52°E	8°E	N7°E

Average distinction of bendings of 6 tree-tops near the observation point

$$N11^{\circ}W \pm 12^{\circ}$$

* These directions show the directions to which the winds blow, in order to compare with the bending directions of tree-tops. Therefore usual direction will be given by adding 180°.

The southerly winds mostly dominate in early summer, but become fairly obscure in the months of September to November, February and March. When the wind is strong and frequent, it tends to blow from due south and when the wind is not so strong, its direction is apt to deviate to the east or to the west.

The bending directions of top-twigs of some persimmon trees near the School were observed repeatedly with great care. The average value of observed bending direction points to N14°W. This direction agrees mostly well with the blowing direction of the prevailing wind during the period of April to May. This period is the growing season of young leaves and twigs of persimmon trees, and, moreover,

Fig. 1 Wind Rose of May at Akaho. (1936-1944)

Tab. 2. Frequencies of stronger wind (more than 3rd class of wind force) observed at Akaho 1935-45 in percentage

	March	April	May	June	Ann.
N	8	3	5	1	4
NE	0	2	1	0	1
E	—	—	—	—	0
SE	4	10	10	3	4
S	10	15	18	11	12
SW	3	0	—	3	1
W	—	1	—	0	0
NW	9	2	2	1	2
Total frequency(%)	37	32	37	19	24

it is the most windy season of the region (see Tab. 2).

In this period, windy days (i.e., the strength is equal to or over the third class of the wind force which corresponds to 6-10 m/sec), occupy about one third of the total days. And they blow chiefly from due south or from the SSE. So, as it seems, it is natural that top-twigs of a tree would be apt to bend toward due north or NNW. In fact, we could know that almost every tree in this region points their tops

toward the north or NNW at almost every place. From these facts, the effects of the prevailing wind of this season upon persimmon tree-tops are undeniable.

3. Measurement of bending directions of top-twigs and limits of confidence of the observed values

To measure the bending directions, we used clinometers or portable compasses. Measurements were conducted as follows; at first, we stand at any point located at about 40-50 steps apart from the root of the persimmon tree which we intend to measure. Looking first over the general shape of the tree, we judge the main direction of the bending as we walk around the tree. Then we stop at a point to whose direction the bended tree-top points. From there, we observe the main trunk of the tree carefully, and measure the direction of the tree-tops.

It might be expected that fairly large observation error would occur in judgement and measurement of the main direction of bendings. Also it is difficult to avoid personnel errors in observations. Therefore it is most necessary to know the magnitudes of the possible errors before we start the measurement. Then the

author measured the bending directions of four persimmon trees as samples with 22 collaborators, each independently in November, 1945. The results are shown in Tab. 3. The author calculated the mean directions of each tree and estimated the limits of confidence of mean directions under the probability of 90% using Fisher's t-table. The maximum difference reached more than 90° but the intervals of confidence of mean direction were about $20-25^\circ$. Therefore, it is enough for us to estimate the maximum personnel and observation errors at $\pm 15^\circ$. Considering these situations and in order to make the errors of observation as small as possible,

Tab. 3. Variance of the observed values of bending directions of tree-tops by many observers.

No. of tree observer	No. 1	No. 2	No. 3	No. 4	No. of correct observation
N	N36°E	N32°W	N30°W	N18°E	1
KA	8 E	16 E	24 E	54 E	1
M	70 E	20 E	30 E	15 W	1
KO	10 E	40 W	5 W	20 E	3
KM	40 E	20 E	N	10 W	1
H	20 E	24 W	10 W	N	4
MA	10 W	20 W	40 W	20 E	2
Y	45 E	30 W	5 E	55 E	1
S	20 E	60 W	N	N	3
YN	N	20 W	20 W	N	4
KR	30 E	30 W	35 W	15 E	3
KW	35 W	45 W	40 W	20 W	0
NS	10 E	20 W	15 W	20 W	3
T	40 E	34 E	8 W	2 E	2
KU	8 E	14 W	16 W	14 E	4
YS	10 E	20 W	20 W	40 E	3
KK	N	20 W	N	5 W	3
KN	10 W	25 W	10 W	20 E	3
KT	20 W	20 W	30 W	50 E	1
SA	5 E	50 W	20 W	25 E	3
TK	20 E	40 W	N	E	2
I	14 E	26 W	9 W	20 E	4
O	10 E	55 W	15 W	70 E	2
mean direction	N17°E	N17°W	N11.5°W	N14.5°E	
unbiased estimate of population variance	470.4	768	316.4	665.0	
confidence interval	(27-7°) ±20°	(31-4°) ±26°	(19.5-3.5°) ±16°	(27.5-2.5°) ±25°	
max. deviation	90°	110°	70°	80°	

we made some trios of observers and measured the direction with each observer independently on each tree. And we calculated an average value of observed directions.

4. Geographical effects on the distribution of the directions of estimated prevailing winds

Measurements were done twice at different dates: in Nov., 1945 and May, 1946. In the former, 22 collaborators joined the observation and measurements were done at about 200 points, about three fourths of all points. Then we could know the general tendency of the prevailing wind at the fan surface. However, there remained some questionable areas and some regions where the measurements lacked accuracy. Then we made the second phase of observation with several collaborators.

At an area where we could not find a suitable persimmon tree, we directed attention to other kinds of trees, such as mulberry tree, ginkgo tree, etc.

The results were arranged on a map, as are shown in Fig. 2. Analysing these data we found the following characteristics on the prevailing winds of this region.

- 1) The southerly wind prevails remarkably all over the region

This fact is observed especially clearly on the fan surface where there are only few obstacles to winds. At some places, the direction of prevailing wind, more or less, has the easterly or westerly components. But generally speaking, the southerly winds mostly predominate, as are shown in Tab. 4. Almost all values which were measured are distributed within the limits of W 20° to E 30°.

On this table, we investigated more precisely the characteristics of the wind

Tab. 4. Observed frequencies of directions of the estimated prevailing wind on the fan surface.

Direction from the north	Southern part			Central part			Northern part		
	Eastern half	Western half	Total	Eastern half	Western half	Total	Eastern half	Western half	Total
50° E					1	1	1		1
40	1		1	7	2	9	2		2
30	8		8	7		7	3	7	10
20	25	3	28	18	6	24	11	9	19
10	34	10	44	16	18	34	13	7	20
0	11	9	20	7	25	32	18	4	22
10° W	1		9	7	31	38	22	9	31
20		8	11	11	26	37	17	27	44
30		11	4	3	8	11	3	3	6
40		4	2	4	4	8			
50		2			1	1			
60									
70					1	1			

distribution at various places. And we found the following facts on the local wind distribution.

2) There is a general tendency that in the southern area the southerly wind prevails with small easterly component. In the central parts of this region, due south wind blows and in the northern area it has some westerly component.

It may be considered that this characteristic is conditioned by the general situation in the Tenryu valley.

3) Moreover, it was observed that the varying forms of the river valley give very distinct effects upon the prevailing wind.

In this region, the valley is fairly narrow in the southern parts (near Iizima), reaching a minimum of about 4 km. Going further north, its breadth becomes broader. In the central part of the region, near Akaho Town, it becomes the broadest and it extends beyond 10 km, which is 2 times broader than the southern parts. And then it becomes narrower again. In the northern area (near Akagi), the breadth is about 4 km.

If we divide this region into two parts, the eastern and the western halves, and compare the directions and speeds of the prevailing winds of the two, fairly remarkable differences can be found between them. Generally speaking, in the southern and the northern parts, the differences in wind directions are fairly small, but in the central part the deviation is very great; that is, in the southern part it reaches 70° , in the northern part 80° , and in the central part 120° . Moreover, in the southern and northern parts, the differences between the two halves are also fairly small, but in the central part, the difference becomes rather large. Naturally in the eastern half, it can be recognized that the wind is apt to have an eastward tendency, and at the western mountain sides, the reverse is the case. But such a characteristic is most remarkable in the central parts. And in the northern and the southern parts, it is not so much distinct.

These facts mean that in the southern and the northern parts, the stream line of the wind has a tendency to converge and in the central part to diverge. In general, in the area of convergence, the wind speed becomes stronger, and in the area of divergence, the reverse condition occurs. This is also reflected in the bending situations of the tree-tops, i.e., in the southern and the northern parts, the bending shapes are remarkable, but in the central part, they are not so distinct,

4) There is a tendency that wind turns to the right when it blows against an obstruction

At the southeastern corner of this region, there is a small hill about 25 m in relative height and 400 m in length which stretches from NW to SE. The Maruyama is the name of this hill. The results of observation of the prevailing directions of wind around the hill are as follows: At the southern side, the wind blows from due south, and at the eastern side it changes a little westward by about $15-30^\circ$. At the northern side, on the contrary it seems that it blows toward $N 5-20^\circ E$. But at this place, we could not find so much distinct bendings in tree-tops. The author

thinks that this means the wind direction is not so steady and its speed not so strong at this side. At the western side we cannot find any remarkable deflection of wind. It is also the due south wind that prevails.

Similar wind situations were observed actually on May 24, 1947 by the author and his collaborators. At this time, the wind observations were done at the points located at the southern, eastern and northern sides and also the top of the hill with portable wind-vanes and anemometers. The wind directions and their speeds were observed every 10 minutes from 10 o'clock to 18. The results are shown in Fig. 3.

Fig. 3 Frequencies of Wind Directions and Speeds around Maruyama Hill.
(1946, 5, 24. 10-18^h at every 10 minutes)

At the southern side the wind blows from due south speed being about 1-6 m/sec with some fluctuations, and at the hill-top the wind from S30°W blows violently, sometimes with a speed of over 10 m/sec. At the eastern side, the direction of wind is similar to that at the southern side, but its fluctuations are more steady. And it blows most frequently with speeds of 3-5 m/sec. At the northern part, the wind is weakest. Observed speed is about 0.5-2.0 m/sec. The wind direction is very changable. But among them, it seems that the wind deflected to somewhat east is rather frequent. These conditions are clearly reflected on the bending shape of trees as described above.

5) The upward current of air along the valley can be found.

Nine small valleys which run from the western mountains down to the present eastern flood plain of the Tenryu River cutting into the fan surface can be found in this region. Along these valleys, we found the occurrence of upward current of air opposite to the southerly prevailing winds on the fan surface.

Tree-tops in the valleys show bendings toward the west against the situation

of the fan surface with deviation of about a rectangular angle, as are shown in Tab. 5. Especially remarkable is that such a condition is observed at the southern two valleys. Similar situations are also found in many shallow valleys frequently, as are shown on the southern side of the Omiike Shrine, upper parts of Kokaji-zawa, etc.

Tab. 5. Observed frequencies of directions of the estimated prevailing wind in the valley area.

Direction from the north	Fan surface	Akasu		Miya- zawa	Tazawa	Furuta- giri	Mago- sawa	Tsuji- sawa	Others
		Upper valley	Lower valley						
90° E									
80						1			1
70									1
60									
50	2								
40	15	5	1		(1)				
30	31	4	1						
20	90	12	2						1
10	106	19	1					1	
0	75	18		2	(1)			1	1
10° W	72			1				1	
20	97			2				3	
30	28		(1)	1				1	
40	18						1		
50	2		(2)					1	
60			1(1)						
70	1		(1)						
80			1(1)				2		
90									

* Values which are given in parantheses shows the deflection from the south

6) In the deep valleys, large eddy turbulences of air are observed. Therefore winds of opposite direction to the fan surface blow at the bottom of valleys, but they are not so strong.

In some deep valleys, as the Miyazawa and the Akasu valleys, it was observed that tree-tops were bending to the south which is opposite to the northward bendings on the fan surface. For instance, in the Miyazawa valley, bending directions are about S20°E contrary to the N or N20°E on the fan surface. At the mouth of the valley where both currents counteract, we could not find any marked bendings. Similar conditions were actually observed on May 20, 1946. Wind observations were made every 10 minutes from 9^h30 to 18^h00 at four points. On the fan surface,

Fig. 4 Frequencies of Wind Directions and Speeds observed at Miyazawa Valley. (1946, 5, 10 9³⁰-10³⁰ at every 10 minutes)

Tab. 6. Wind conditions on the present flood plain. (Shimodaira)

Direction from the north	Shimodaira			Fan surface
	Below the cliff	Present flood plain	Total	
50° E				2
40		3	3	15
30	1	5	6	31
20	4	15	19	90
10	3	15	18	106
0	6	3	9	75
10° W	1	1	2	72
20	5		5	97
30	7		7	28
40	8		8	18
50				2
60				
70				1

strong southwesterly wind blows at a rate of 3-5 m/sec, but at the bottom of the valley a weak northeasterly wind with 1.0-2.5 m/sec prevails. At the northern slope of the valley fairly calm conditions were observed. Moreover, at the present flood plain below the cliff, wind directions turns to the east and the southeasterly wind blows with a speed of 3-4 m/sec.

On the next day, at the inner part of the valley about 200 m from the mouth,

similar conditions were also observed.

And the Akasu valley which is the largest in this region with an average breadth of 500-600 m, we can find two steps of river terraces at the lower parts. Therefore it is formed into a typical landscape of valley in the valley. The upper terrace is the broadest. It has 200-300 m in breadth, found only at the northern side of the valley. The lower terrace is only found at the lower parts where the width is 100-150 m and it lies also on the northern side of the river. It is lower than the upper one by about 2-3 m. Below these two terraces is constructed a narrow bottom lowland with 150-200 m in breadth. Its southern side is bordered by a steep cliff of 30-50 m, and at the northern side, there is also a cliff of 10-15 m amidst the lower terrace.

On the upper two terraces, the direction of wind is similar to that on the fan surface and effects of the valley on the wind cannot be clearly found. The valley wind system develops only at the bottom area. The eddy current also prevails similarly as in the Miyazawa valley, but at the upper parts of this valley with shallower depth, an upward wind along the stream can be clearly noticed. These phenomena were also found by the wind observations and by the measurements of the bending direction of tree-tops, as are shown in Figs. 5 and 6.

Fig. 5 Frequencies of Wind Directions and Speeds at the Middle Part of Akasu Valley (1946, 5, 23. 10^h30-14^h00) observed at every 10 minutes

Fig. 6 Frequencies of Wind Directions and Speeds at the Lower Part of Akasu Valley (1946, 5, 22. 10-17^h) at every 10 minutes

ments of the bending direction of tree-tops, as are shown in Figs. 5 and 6.

It was very interesting to find at the middle parts of this valley that some persimmon trees show curious and complicated bending forms. They were planted on the lower bottom of this valley. We noticed that their lower twigs bend all together toward the south but their top-twigs show an inclination to bend toward the west. Obviously these phenomena must be caused by the fact that on the narrower, deeper and lower terrace, eddy turbulences of air develop. However, on the upper

terrace, an upward current along the valley system prevails.

7) Below the cliff that borders the fan surface and the present flood plain of the Tenryu River, the wind strength is weak and we cannot determine the bending directions of tree-tops well.

A high and steep cliff about 50 m in relative height runs from NNW to SSE and the present flood plain of the Tenryu River. And a stretch of wind shadow area is formed below the cliff. In this area, bending forms of tree-tops were indistinct and we could scarcely find any facilities for wind protection and wind breaks around rural houses. It seems that these facts mean that wind strength is fairly weak just below the cliff. Moreover, in this narrow zone just below the cliff we noticed a weak air current blowing along the cliff through careful observations of the bending directions of younger top-twigs. The width of the area where such a phenomenon is observable reaches to about 250 m in width, that is about five times the height of the cliff.

At the other region on the lower flood plain, similar winds as are observed on the fan surface blow dominantly.

8) The effects of settlements and other surface covers are not so distinct.

We could not carry on this kind of measurements, because sufficient persimmon trees could not be found in urban districts and we also could not find big forests in this region. Moreover, we observed the prevailing wind by tree-tops of about 3-5 m in height. This is almost as high as the roof tops of rural houses and top lines of forests. Therefore, it seems that we are unable to observe clearly the effects of the surface covers, of villages, cottages, forests, etc.

5. Summary

The author precisely measured the bending directions of top-twigs of persimmon trees at the Akaho Area, Ina Valley, Nagano Prefecture, and the following facts became known.

1) The bending direction of tree-tops indicates the prevailing wind direction of the locality during the period of about April to June, which is the growing season of persimmon trees in this region.

2) The interval of confidence of these measurements is approximately $\pm 15^\circ$.

The author and his collaborators made such measurements at 230 places, and were able to obtain the following results.

1). In early summer, the southerly wind prevails predominantly all over the area of the broad fan surface.

2) Precisely speaking, however, its direction is affected by the features of the Tenryu Valley in this region. Its direction diverges where the width of valley is broad, and it converges where the valley is narrow.

3) When it encounters some obstructions, the wind generally changes its direction toward the right.

4) In the valleys which cut into the fan surface, the direction of the prevailing wind is different from that of the fan surface above.

- a) In shallow and small valleys, wind blows up along the stream.
- b) In deep and large valleys, the prevailing wind entirely changes its course. The wind blows opposite to that of the fan surface, as a result of eddy turbulences.
- 5) We can find a wind shadow area, about 250 m in width, below the steep escarpment bordering the fan surface and the present flood plain. Here a weak wind blows toward the north.
- 6) These local wind directions calculated by the bending direction of persimmon top-twigs agree well with the results of actual observation of wind directions on some days when the southerly wind prevails on the fan surface.
- 7) The effects of surface covers, villages, cottages, forests, etc. are not recognised so clearly in these observations.

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