Dai 38 Gō.
(Nuki-gaki)

Kaze no Sokudo no hukisokuna Henkwa ni tuite.

*Syoin, Rigakuhakusi, Terada-Torahiko,*
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naraanni

*Gitë (maci), Nisida-Koki.*

(1) Tsuyasa ga Tōsō-ga-Sanhyakunensai-Kinenkai no Kenkō-sokin kara hōyō wo ukete motometa Ziki hōkoku-tei wo Tōkyō Teikoku-Daigaku-Rigakulu no Yane ni toriture, eitaka 6-nen no aidai kwansokusita "Kaze no Iki" no Kiroku ga aru; sore wo tōkeitekini sirabeta Kekkwa no motometa no ga kono Hōkoku-ya de aru.

(2) Kaze no Iki no Teido wo simesu tamenin bennrī hitetüno Ryō, go, wo sadameta. Kere wa mai-15-hun gete ne Heikin-sokudo, 11, de, sone 15-hun no aidani okera Sokudo no Saidai te Saiyō to no Sa no Hanbu, a, wo watara mono de aru.

(3) Kere go te 11 no aidane Kwankei wo ireirene Kaze no Hōkō ni tuite, maiyetu betubetuni sirabeta. Hiruma wo Yoru wo wa betunisite sirabeta (Du 1 wa sone hitetüne Rei).

(4) Kimatta 11 ni taiuru go no Atai ga Toki ni yette ireirenin kawaru Myō wo Hinde-kyekusen (frequency curve) wo tuttte tōkeitekini sirabeta. Tekubetuni, Huya wo Kita-kaze to Natu wo Minami-kaze to wo kurabete mita (Du 3 a, d).

(5) Kono Hinde-kyekusen wo, 11 no taisai Bāai to ōkii Bāai to, huitatune Kuni ni wakete, sone onēnena Kuni ni tuite, g-L' no Kwankei ga Kise to yette dō kawaru ka wo sirabeta (Du 3e). Sone Kwankei no Natu to Huyu to no Tīgai ga Taiyō no Hukusu no Tīgai de daitaini setumeisareru kete wo renzita.

(6) g-L' no Kwankei wo, yattunu Kise to yattunu Hōgaku no lauruisite sirabeta (Du 4). Mata subete Hōgaku wo heikinsita Mon no dasita (Du 5).

(7) Haru Natu to Aki-Huyu te de g-L' no Kwankei ga itiziruku tīgai Ten wo age, mata sene Wake wo renzita. Kere to kwankeisite Hiruma wo Yoru to no Tīgai mo nebute aru.
(8)  $g$ to Kaze no Hōkaku, $\theta$ to Kwankei wo sirabeta (Da 6, 7).

(9)  Dīmen ga sene Tikei ni yotte Kaze-ne-Iki wo esesa, sene Dūai to hakaru Kyō, $K$, we sadame, kore wo Tikei-insi (topographical factor) te naduketa. Inimono Muki to Kaze ni taisuru $K$ ne Atai wo Tīdu kara keisansita (Da 8); sōite, kore wo maeno $g$ to Kwankei to karabeta (Da 9).

(10)  $g(\theta)$ to $K(\theta)$ to no Sa (Da to) wo tette mirute, sere wa Yamanete no Takadai ga Sitanati no hikui Heitī ni tukidete iru sene Kade no Tekore (Tīdu 8 ne A, B, C) no Eikyō de aru Keto ga sōōsareru. Onazi Eikyō ga Hiru te Veru te no $g(\theta)$ ne Kyokusen no Sa kara no mirareru Koto wo simesita (Da 11, 12).

(11)  $g$ to Tuki-Heikin no Atai ga Itiense ne aidani kawaru Meyō wo sirabeta (Da 13). Sene Meyō wo setumisuru tameni Taikī no Ūdu-ne-Tuyesa (vorticity), $S$, ga Takasa to temenī kawaru Meyō wo, yettuno Kiseta ni tuite sirabeta (Da 14). Sono Kekkwa kara, $g$ no Nendyū-henkwa to $S$ no sere to ga tagaini yoku niyotte iru Kete wo simesita (Da 15).

(12)  Ueno (10) de nobeta Tikei no Eikyō ni kwaneisita kantama Zikken no Sīka to sene Kekkwa to wo nobete, zissaino Baai no Arīsama wo sōōsaru Tegakari te sīta.
No. 38.

(Published June 1928.)

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On Gustiness of Winds.

By

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Member of the Institute,

Mituho Tamano, the assistant in the Institute
and
Koki Nisida, formerly the assistant in the Institute.

(With 2 Plates.)

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I. Introduction.

In 1918, an anemograph of Dines's type and a self-recording wind-vane were set up on the roof of the Physical Institute(1) of the Faculty of Science, Tokyo Imperial University. The expense had been granted from the research fund of Tōsyōgū-Sanbyakunensai-Kinenkawai, established in commemoration of the Tercentenary of Tōsyōgū Shrine by Prince Tokugawa, by the kind intervention of the authorities of the Imperial Academy.

The instrumental records of winds were taken during the period from December 1918 to August 1924. Owing to the lack of a regular observer(2) we were occasionally compelled to interrupt the observation so that the record is not quite continuous as in the case of a routine observatory. This will, however, not affect much the general results of the investigation of the kind as is here made.

(1) The building has now been demolished on account of the damage due to the Great Earthquake of 1923.

(2) We must acknowledge our indebtedness to Dr. M. Akiyama who took the trouble of keeping the observation for sometime.
II. Method of Investigation.

The method here used for investigating the gustiness of winds from the anemograms is the same as was previously adopted by one of the present authors in conjunction with Messrs. Ōmae and Mituhasi(1) for a kindred study of the gustiness of winds at Sinagawa Observatory near Tōkyō. Thus, the anemographic records were examined day by day. The maximum and minimum wind velocities in each of the successive 1/4-hour-intervals were estimated respectively and, thence, the following quantities were defined and calculated:

\[ M: \text{ Maximum wind velocity within \( \frac{1}{4} \) hour, in m/sec.}, \]

\[ m: \text{ Minimum \( \frac{1}{4} \) hour, in m/sec.} \]

\[ V = \frac{(M+m)}{2} : \text{ Mean velocity in the same interval,} \]

\[ a = \frac{(M-m)}{2} : \text{ Amplitude of variation in wind velocity in the interval.} \]

\[ g = \frac{a}{V} = \frac{M-m}{M+m} : \text{ Gustiness.} \]

The above definition and procedure were adopted for the sake of simplicity and seem to suffice for the purpose as is here concerned.

III. Results of Investigation.

1. \( g-V' \) diagram.

The data for \( g \) in every quarter-hour were at first classified according to 12 months and 16 directions of winds. For each of the 192 combinations of 12 months and 16 directions a diagram was constructed on which the values of \( g \) are plotted as ordinate, taking the corresponding wind velocity, \( V' \), for the abscissa. Fig. 1, Pl. 8, is reproduced for an illustration, showing the \( g-V' \) diagram for January-North wind. Here, the black dots and the red ones stand respectively for the data for the

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day-time and the night-time, the division of the two times being placed at 6 a.m. and p.m. The mean values of $g$ for successive 0.5 m/sec. intervals of $V$ are marked by black and red o respectively.

Referring to this diagram we may remark the following:

(a) Below $V=1.5$, the points are remarkably scattered, viz. $g$ varies widely for the same $V$. For small $V$ the mean value of $g$ approaches unity. These characteristic tendencies are apparent and mainly due to the definition of $g$ as well as the defect of the instrument. Thus, for small $V$, the observed minimum velocity $m$ tends to zero and thence $g$ to 1. Moreover, a small fluctuation of $m$ will result in a large fluctuation of $g$. Hence, in the later discussion, it will be plausible to put the data for $V<1.5$ out of account. For the investigation of these very weak winds a special kind of anemograph must be devised.

(b) For $1.5<V<4.0$ say, the distribution of the points on the diagram is generally dense enough for allowing a statistical treatment.

(c) For $V>5.0$ the number of points is generally scanty for a reasonable statistical treatment, especially for those combinations of the season and direction with small number of cases. As far as may be judged from the data available, however, the general character of the distribution is not much different from that for the range $1.5<V<4.0$.

(d) The mean values in the successive intervals are generally greater for the day-time than for the night-time.

(e) The general characters of the diagram above described are similar for the different combinations of the months and directions. However, the total number of the points is widely different for different combinations, since the frequency of wind varies considerably for different directions for different seasons as is well known.

(2) Frequency diagram.

The $g-V$ diagrams above mentioned seemed to show some tendency to an anomaly in the statistical distribution of points about the respective mean value, at least for a certain velocity. To investigate this point
more closely the following procedure was taken. For each of the successive 0.5 m/sec. intervals of $V$, the frequency curve for different values of $g$ was constructed, as exemplified by Fig. 2, which corresponds to Fig. 1, Pl. 8, above referred to. The full line curve refers to the day-time and the broken curve to the night-time. Though the frequency diagrams thus obtained for different combinations show some respective points of interest, it was considered proper to refrain from discussing these points, since the data here available are still insufficient for allowing us to enter into such details. In order to obtain, therefore, some general character of the frequency distribution, the following method was adopted:

The three neighbouring prevailing directions for each of the warm and cold seasons were taken together and the respective average frequency distributions were calculated. Thus,

for the mean of

Summer (June, July, August): SSE, S, SSW,
Winter (December, January, February): NNE, N, NNW.

The results are shown in Fig. 3. From these diagrams, we may remark:

(a) The maximum of frequency for the day-time lies at a greater value of $g$ than for the night-time, in summer as well as in winter.

(b) The frequency curve for $2.5 < V < 4.5$ in winter and that for $3.0 < V < 4.5$ for summer are similar to the usual error curve.

(c) For small $V$, an apparent maximum appears at $g=1$ which causes an asymmetry of the frequency curve.

(d) For summer, a remarkable tendency of the night-curve maximum to be displaced relative to the day-curve maximum towards the smaller value of $g$ may be discerned. Though the number of data is not sufficiently large, a systematic tendency revealed in the diagram can scarcely be overlooked\(^{(1)}\).

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\(^{(1)}\) This may probably mean that the anticyclonic nightly winds in winter are associated with a remarkably stable stratification of the lower layer of the atmosphere.
On Gustiness of Winds.

Fig. 2 Frequency distribution of $g$ for January N Wind.

Fig. 3 Frequency distribution of $g$ for the prevailing winds in winter and summer.
The frequency diagrams were then classified into two groups, for the smaller and larger values of velocity, i.e. for $V = 1.0 - 3.5$ and $3.5 - 6.0$ respectively. The mean frequency diagrams obtained for these two groups respectively are shown in Fig. 3 c. From this diagram, we may quote the following:

Winter (N, NNE, NNW).
$V = 3.5 - 6.0$ m/s.

Summer (S, SSE, SSW).
$V = 3.5 - 6.0$ m/s.

(c) If we denote the gustiness at the maximum frequency for the smaller velocity by $S$ and that for the larger velocity by $L$, we have the relations as shown by the annexed schema.
This result may be explained as follows. In winter, the less windy days may be characteristic of those weather type in which the lapse rate of temperature is small and the atmosphere is therefore stable. In summer, the calm days are associated with the comparatively warm lower layer and thence with large values of \( g \).

(f) For smaller velocities, especially for daytime in summer, the frequency curve is remarkably unsymmetrical. The unsymmetry is too remarkable to be explained by an apparent cause such as mentioned above. It may probably be due to a particular class of convection current of some local character.

Referring to Fig. 3, we may roughly estimate the difference, or ratio of the amounts of gustiness between the daytime and night:

<table>
<thead>
<tr>
<th>Velocity</th>
<th>Winter (N-wind)</th>
<th>Summer (N-wind)</th>
<th>Ratio: Summer:Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>( U=3.5-6.0 )</td>
<td>Day 5.3</td>
<td>Night 4.9</td>
<td>( \frac{5.2}{4.4} = 1.2 )</td>
</tr>
<tr>
<td></td>
<td>Dif. 0.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( U=1.0-3.5 )</td>
<td>Day 4.5</td>
<td>Night 4.3</td>
<td>4.4</td>
</tr>
<tr>
<td></td>
<td>Dif. 0.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( U=1.0-6.0 )</td>
<td>Mean Dif. 0.30</td>
<td>1.05</td>
<td></td>
</tr>
</tbody>
</table>

(In this table the values of \( g \times 10 \) are given.)

For a given mean velocity \( V \), the gustiness depends on the convectional component of velocity. The latter component may be considered to be composed of the two terms, i.e.

\( v \): the component independent of the solar radiation and equal for day and night,

\( v' \): the component depending on the solar radiation and vanishing with it,
The gustiness is then

\[ g_d = \frac{\tau + \tau'}{V} \quad \text{for daytime}, \]

\[ g_n = \frac{\tau'}{V} \quad \text{for night}. \]

The difference is \( g_d - g_n = \frac{\tau'}{V} \).

Thence, the ratio

\[ \frac{g_d - g_n \text{ for Summer}}{g_d - g_n \text{ for Winter}} = \frac{\tau'}{\tau'} \text{ for Summer}. \]

On the other hand, the ratio of the amounts of the solar radiation at 40° of latitude, for the two epochs June 21 and Dec. 21, may be estimated at 3.14, according to the data commonly given in text-books of meteorology.

If the solar heat be totally converted into the kinetic energy of convection and the mass involved in convection is independent of the season, we may expect

The ratio: \((\tau' \text{ for Summer}) / (\tau' \text{ for Winter}) = \sqrt{3.14} = 1.77\). However, the observed ratio is 3.5 for the whole range of \(V = 1.0 - 6.0\). Taking the stronger winds only, i.e. \(V = 3.5 - 6.0\), the ratio is 2.0 which is much nearer the above radiation ratio.

Such a discrepancy must have been expected from the highly crude nature of the assumption made. The above calculation will, however, be of some significance in illustrating the possible order of magnitude of the influence of solar radiation in causing the gustiness of winds, without assuming any mechanism of convection.

(3) Relation between the mean gustiness and the wind velocity.

For each of the \(g-V\) diagrams mentioned, the mean value of \(g\) was calculated for each of the successive 0.5 m/sec. intervals of velocity.
Thus, the averaged relation of the mean gustiness as a function of the wind velocity was obtained for each direction of each month. The results were then grouped into four seasons and eight directions as follows:

<table>
<thead>
<tr>
<th>For the Seasons</th>
<th>The mean taken of</th>
<th>For the Directions</th>
<th>The mean taken of</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring</td>
<td>March, April, May</td>
<td>N</td>
<td>NNE, N, NNW</td>
</tr>
<tr>
<td>Summer</td>
<td>June, July, August</td>
<td>NE</td>
<td>NNE, NE, ENE</td>
</tr>
<tr>
<td>Autumn</td>
<td>September, October, November</td>
<td>etc.</td>
<td>etc.</td>
</tr>
<tr>
<td>Winter</td>
<td>December, January, February</td>
<td>etc.</td>
<td>etc.</td>
</tr>
</tbody>
</table>

The mean $g_1$ relations thus obtained for these seasons and directions are shown in Fig. 4. As the number of data contributing to the mean value is widely different for different ranges of the velocity, along a given curve, the weights of the mean values are distinguished by the following marks in plotting the points:

<table>
<thead>
<tr>
<th>Mark</th>
<th>Number of cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>○</td>
<td>9 − 7</td>
</tr>
<tr>
<td>△</td>
<td>6 − 4</td>
</tr>
<tr>
<td>●</td>
<td>3 − 1</td>
</tr>
</tbody>
</table>

In the subsequent discussions, therefore, the points marked by ● may better be put out of account.

From these figures, we may remark the following facts, or tendencies:

(a) Spring and summer on one hand, and autumn and winter on the other hand form two distinct groups for themselves, as regards the type of curve and its variation with direction.

(b) Night curves show generally a less dependency on the velocity than day curves, except in winter, especially for NW, W, SW, and SW.

(1) The fact that in winter night the stability of the lower layer of the atmosphere increases with the decrease of $V$, due to the nightly cooling, especially in an anticyclonic area, may partly explain the small values of $g$ for the smaller $V$. 

(2) The occurrence of the wind gusts, especially in the wind ranges of NE and NNE, is very pronounced in all seasons. 

(3) The results of the presented investigations are valuable for the meteorological practice of small vessels, particularly in the tropical regions. 

(4) The present investigation is based on a limited amount of data, and further studies are necessary to extend and refine the conclusions.
Fig. 4. Relation between gustiness and wind velocity.
(c) In day curves for spring and summer, \( g \) is large for small \( V \) and decreases with the increasing \( V \), tending to a normal value near at 0.5. This tendency will be evident for SW, S, SE in summer and SE, E, NE in spring.

(d) In winter, a tendency is observed such that at first \( g \) decreases a little with increasing \( V \) and shows a minimum at a certain value of \( V' \). This is most apparent for the southerly winds in night time, which must evidently be associated with a particular weather condition, as the normal wind in this season is northwesterly.

(e) In spring and summer, the difference between day and night is most conspicuous for the low values of \( V \).

In Fig. 5 are shown the average \( g-V' \) relations for the four seasons respectively, taking the means of all directions. The contrast between spring-summer and autumn-winter will be seen most evidently from these curves.

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Fig. 5. Relation between \( g \) and \( V' \) for the four seasons; --- day; -- night.
For the explanation of some characteristic features of $g-V'$ curves above obtained, we may be allowed to attempt some theoretical discussions.

Suppose there exists a normal value of gustiness depending upon the purely mechanical turbulence corresponding to the normal distribution of the lapse rate of temperature. This normal value will be assumed to be independent of $V'$ as is usually made. The deviation of the lapse rate due to the daytime warming or the nightly cooling of the lowermost layer of the atmosphere will affect the stability of the lower strata and contribute a positive or negative additional term of the turbulent component of the velocity. Put

$$g = \frac{\tau_n + \tau_r}{V'} = g_n + g_r,$$

where $\tau_n$ denotes the normal amplitude of fluctuation corresponding to the normal lapse rate and $\tau_r$ the component due to the abnormal deviation caused by the radiation.

The value of $\tau_r$ depending on the stability of the lower stratum may plausibly be assumed to be determined by the excess of the temperature, $\theta$, on the ground above that corresponding to the normal state. We will thus assume roughly

$$\tau_r \propto \theta.$$

The temperature on the ground will be given by an equation of the form

$$K^2 \frac{d\theta}{dt} = P - (QV + R)\theta,$$

where $P$ depends on the radiation, being positive for the insolation and negative for the nightly cooling. $Q$ and $R$ are positive constants. For the stationary state, we have

$$\theta = \frac{P}{QV + R}.$$
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As \( \tau_n \) is nearly proportional to \( V \), we may also assume \( \tau_r \) to be approximately so. Thus, we put

\[
\tau_r = AV' \theta = \frac{APV}{QV + R}.
\]

Thence

\[
g_r = \frac{AP}{QV + R}.
\]

In general, we may assume also

\[
\frac{\tau_n}{V} = f(V)
\]

and the difference of \( g \) for day and night will be given by an amplitude

\[
\frac{AIP}{QV + R},
\]

where \( \Delta P \) is the algebraic difference of \( P \)'s for day and night.

The above, though based upon somewhat arbitrary assumptions, will serve for a qualitative explanation of the general tendency of the difference in gustiness between the daytime and night. The characteristics of the different seasons are due to the combinations of various causes. The difference between winter and summer may partly be due to the following fact. In winter, a fine weather in Tokyo is apt to be associated with a windy day and the following calm night, while a cloudy day is generally characterized by weak winds. In summer, however, a low wind velocity is rather frequent in sunny daytime. Moreover, the nightly cooling in a calm summer night seems to be relatively small on account of the excessive humidity of the lower layer. Though we have no statistical data at hand to demonstrate the above tendency, every inhabitant in Tokyo may be well aware of this tendency. The above \( g - V \) relation may therefore be taken at least as an indirect demonstration of the above fact.
IV. The Relation of Gustiness with Topography.

It is well known that the gustiness of winds depends much on the topographical conditions of land, especially on the wind side of the station of observation. In order to study this effect in the present case, a procedure was taken which is similar to that employed in the previous investigation of winds at Sinagawa Observatory, by one of the present authors, in conjunction with Messrs. Ōmae and Mituhasi.\(^{(1)}\)

![Graphs showing variation of gustiness with direction and wind speed](image)

Fig. 6 (a).
Variation of \(g\) with direction: —— day; —— night.

\(^{(1)}\) *Loc. cit.*
For every direction of wind in every month, the mean gustiness was calculated (1) for the winds with $V = 1.5 - 3.5 \text{ m/sec.}$ and (2) for the winds with $V \geq 4.0$. The mean gustiness thus obtained for each month was plotted against the direction angle as abscissa. Again, from
these results, the relation between \( g \) and the directions, for each of the four seasons and finally for the entire year were obtained which are shown in the diagrams given in Fig. 6 and 7. In these figures, the different marks \( \bigcirc, \Box, \bigtriangleup, \times \) and \( \bullet \) show the degrees of reliability in the decreasing order of the values of the points, as estimated by the numbers of data used for obtaining the values represented by these points.

Here, also, the difference between day and night appears conspicuously.

\[ I' = 1.5 - 3.5 \text{ m/s}^2 \]

\[ I' \geq 4.0 \text{ m/s}^2 \]

Fig. 7.

Variation of \( g \) with direction: --- day; -- night.
The fact that the day curve and the night curve show generally a similar mode of dependence upon the direction and also that these curves exhibit some common character in different seasons, will show that the main fluctuation of the curves is not merely due to the errors attributable to the scantiness of material, but due to some real effect of topography.

As a measure of the "roughness" of the ground on the windward region up to a certain assigned distance we took the ratio of the length of that portion of the radius vector drawn toward that direction, corresponding to the portion of land higher than a certain height above the sea level, to the total length of the radius, i.e. the distance considered, in an analogy with the case of the previous work cited, in which the ratio of the land area to the total area including the sea was taken.

On a suitable topographical map of Tokyo\(^0\), a circle with 3 km. radius was drawn with the station of observation as the centre (Fig. 8). Radial lines were then drawn from the centre towards the sixteen directions. For each of these directions, two radii were also drawn making each an angle of 4° on each side of this direction. Then, the mean of the lengths of the parts of these three radii intercepted by the area of land above a certain height was considered to be responsible for for an additional gustiness of the wind from this direction on account of its "roughness" as defined above. For the actual calculation, the ratio of the mean length of the radii lying on the area with the height above the sea level greater than 15 m., to the total length of the radius, 3 km., was estimated, for each of 16 directions.

Instead of taking 15 m. contour lines, we tried also the cases of 5 m. and 20 m. contours respectively. The results were, however, not essentially different from that obtained with the above height. Also, the use of 15 m. contour with 1 km. circle gave the result not much different at least qualitatively.

\(1\) A map with contour lines, issued by the Restoration Bureau of the City of Tokyo was found convenient for the present purpose.
The "roughness" obtained in the above manner may be assumed as an arbitrary measure of the component of gustiness due to the topographical effect, and for convenience's sake may be referred later as the "topographical factor" and denoted by $R$. Fig. 9 gives the result of comparison of the observed gustiness, $g$, with the topographical factor, $R$, above defined. It will be seen that the two curves compared show some points of similarity in their general trends.

As, however, there exists some conspicuous discrepancy between these two curves, we constructed the difference curve, viz., $g - R$, as
shown in Fig. 10(1). The ratio \( g/K \) was also plotted which shows a quite similar form. The difference curve show three marked maxima at NNW, ESE and SW respectively. On consulting the map we find that these three directions nearly correspond to those of the three conspicuous promontories (A, B, C in the map, Fig. 8) of the tableland, consisting the upper quarter of the City called "Yamanote," the Hilly Quarter. This led us to the conjecture that such a promontory of the tableland protruding on the low flat land may be favourable for affecting the gustiness of winds on its leeside, either by the formation of a trail of eddies or by some other causes. To test this idea an experiment was carried out, which will be described in a later section. Though the result of the experiment was not quite conclusive, it will

(1) More properly \( g - kK \), where \( k \) is a constant \((-0.15)\); in Fig. \( g - 0.15K - 0.42 \) is given.
be seen that the general trend of the actual $g$-curve may be explained qualitative by assuming such a specific effect of the promontories together with the topographical factor above considered. Thus, we may assume the difference $g - R$ to be mainly due to the promontory effect.

\[ g - kR - 0.42 \]

\[ \frac{g}{kR} \]

(B A C)

![Graph](image)

($k=0.15$)

Fig. 10. Effect of promontories.

The difference in the efficacy of the land areas with different heights in producing gustiness may in any case be connected with the difference in the effect of the thermal convection in the lower atmospheric layer. This is supported in some measure by the fact that in Fig. 7 a, ($V=1.5-3.5$) the night curve is of a similar form as the curve $g - kR$ (Fig. 10), i.e. the promontory-effect curve. To study this point a little further, we plotted, in Fig. 11, the difference of the respective values of the annual mean gustiness for day and night, which may be expected to show some parallelism with the topographical factor $R$ (Fig. 9, full line), if the above conjecture be correct. The coincidence is not very good, but the difference between $g$'s for day and night for $V \geq 4.0$ (Fig. 11 b) shows some similarity with $R$-curve in general form, as long as we keep our attention on the general difference.
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(a) Weaker winds.

\( V = 1.5 - 3.5 \, \text{m/s} \)

(b) Stronger winds.

\( V \geq 4.0 \, \text{m/s} \)

Fig. 11. Day-value minus night-value of \( g \).

Fig. 12.
between the northerly wind and the southerly one. Fig. 12 gives the comparison of the "relative difference" of the day and night values of $g$ and the topographical factor.


The monthly means of the gustiness were calculated, taking all directions together, the different directions being weighted according to the numbers of the data respectively. The annual course of the monthly means thus obtained is shown in Fig. 13 $a$, $b$ and $c$, for the three ranges of the wind velocity respectively. The day and night curves and also the mean and difference curves of the day and night are respectively shown.

The maximum gustiness falls generally at April-May and August-September, i.e. in the equinoctial seasons, while the minima occur in the solstitial times. This might well have been expected, as the stability of the atmospheric condition is known to be generally large in the latter season compared with the former.

In order to get a clearer insight into this respect, the results of the observations at the Tateno Aerological Observatory were consulted. The observatory is within about 50 km. from Tokyo and the general topographical conditions are not much different for these two places. Utilizing the data published in No. 1 of the Report of the Observatory, the seasonal variation in the resultant vorticity in different layers was calculated.(2)

In Table I, given as the Appendix at the end of the paper, the vertical distribution of the mean velocity and direction of wind is given. The angle of direction is counted from N in the clockwise sense. From

---

(1) The difference of $g$'s for day and night, divided by their mean value.
(2) This part of calculation was entirely carried out by Tamano.
On Gustiness of Winds.

Fig. 13. Monthly variation of $g$.

- - - - : Day.
- - - - : Night.
- - - - : Day minus night.
- - - - : Mean of day and night.
these data, the component velocities, \( u \) and \( v \) for N and E respectively were calculated. Thence, the component vorticities

\[
\xi = -\frac{\partial v}{\partial h}, \quad \eta = \frac{\partial u}{\partial h} \quad (h=\text{height}),
\]

and the resultant horizontal vorticity

\[
\mathcal{G} = \sqrt{\xi^2 + \eta^2}
\]

were obtained. The results of calculation are given in the Table. The vertical distribution of the resultant horizontal vorticity thus obtained is graphically shown in Fig. 14 for the four seasons respectively.

Winter.

Summer.

Spring.

Autumn.

Fig. 14. Vertical distribution of resultant horizontal vorticity.
As may be seen from the Table and Figures, the large values of the resultant vorticity are mostly confined to the lowest layer, below 1.5 km. say. The increase of $\zeta$ from $h=0.2$ km. downwards is evidently due to the braking effect of the ground surface. A conspicuous maximum of $\zeta$ at somewhere about 0.5$\sim$0.8 km. corresponds to the layer of transition from the upper layer, say above 1 km., with the everlasting westerly wind, to the lower layer with the seasonal variable winds. This will be most clearly seen by plotting the vertical distribution of the wind direction, i.e. $\theta$, from the Table. The maximum of $d\theta/dh$ will be seen to lie in the region near and above 0.5 km., at which height the maximum of $\zeta$ is also situated. Besides, from Fig. 14, the remarkable difference in the magnitudes of $\zeta$ for spring and autumn compared with winter and summer will be noted. In the former seasons, the upper westerly wind is underrun by the lower easterly winds (see Table) and thus a condition is present which is favourable for the downward invasion of the vortices formed at this layer of transition, since the stability of these layers will be lessened on account of the temperature relation which will then prevail.

Referring to Fig. 13 $c$, the difference between day and night appears nearly independent of seasons. This fact seems apparently to stand in contradiction with what we have stated above in connection with the frequency curve (Fig. 3 $c$ and Table in p. 241). What was remarked before, however, refers to the contrast between the N-wind of winter and the S-wind of summer, i.e. the winds for fine weather in the respective seasons. Indeed, by separating the data here in question for the smaller and the larger wind velocities, as in Fig. 13 $a$, $b$, the difference between day and night comes to an evident appearance. For the larger velocities (Fig. 13 $b$), the difference is larger in winter than in summer. This latter fact corresponds to the fact that the fine weather in winter is generally associated with a strong wind brought
VI. Some Experiments on Turbulence Formed on the Leeside of a Ridge.

In a preceding section (p. 253), we have observed that the edge of a terrace protruding upon the lower plain seems to influence the
gustiness of winds in the region situated towards the leeside of it. In order to get some idea of the mechanism of the effect of such an obstacle upon the wind, we devised a simple model experiment, to be carried out with a wind channel in which a suitable miniature terrace or ridge is placed.

Fig. 16. W: wooden model of ridge; AB and AB': two rows of pendulums.

For this purpose, a small wind channel constructed for another kind of experiment was utilized. The breadth of the transverse section of the channel is 25 cm., while the height, which could be varied within a range 0 - 5 cm., was adjusted to 3.1 cm. A piece of wood (Fig. 16, W) 11 cm. × 1.2 cm. × 1.3 cm. which is to represent a protruding ridge of terrace, such as that at the corner of Ueno Park (Fig. 8, A), was stuck to the upper horizontal glass cover of the channel as shown in Fig. 16. On the leeside of the ridge, two rows A B, A'B' of miniature pendulums, each consisting of a small light ball hanging on a fine silken fibre, were suspended from the upper glass cover. The rows were respectively arranged nearly parallel to the ridge, i.e. perpendicular to the general wind direction, at about 7 and 14 cm. from the ridge.

(1) The channel was originally constructed for the experiments of the columnar vertices caused by convection and its dimensions are not suitably large for the present purpose. As the present experiment is merely intended for a very rough qualitative demonstration, we were content with this apparatus at hand.

(2) Thus, the topography is represented upside down.

(3) For the pendulum balls, the pills "Kaol" (3 mm. diam.), or some balls made of paraffin (5 mm. diam.) were used.
respectively. The channel was illuminated from the side wall and photographed from the upper side, first without wind and then with the wind of a definite velocity. Pl. 9, Fig. 17 shows an example of the photogram(1). By measuring the diameters, transverse and longitudinal, of each ball in the photograms obtained with and without wind, with a microscopic micrometer and comparing the measured dimensions for the two cases, we could obtain a rough measure of the wind gust.

A pendulum suspended in a steady wind may also be excited into a vibration on account of the periodic formation of vortices on its leeside, as is well known in the case of the eolian tone for example. The amplitude of vibration due to this cause may probably be assumed to be small in our experiment in which the wind velocity is generally small. On the other hand, the fluctuation of wind especially of the lateral component, may affect the transverse vibration most effectively.

![Diagram](image)

Fig. 18 shows an example of the results obtained; the abscissa stands for the current number of the bob, or its distance from one of

---

(1) In this photogram, streaks of smoke are shown which was sent with the air current to show the general trend of stream lines.
the side walls, and the ordinate for the amplitude, \( a \), of vibration of the
ball, for which the mean value of the two components parallel and
perpendicular to the wind was taken. The position of the obstructing
edge is indicated by the black strip AB. It will be seen that the
amplitude \( a \) is generally large on the leeside of the ridge, and that it
shows a minimum at a little distance off the edge of the ridge and a
maximum at another distance further off. The minimum corresponds
to the region where the stream lines are converged on account of those
lines coming along the edge of the ridge. It is on both sides of this
region where the fluctuation of velocity is the greatest.\(^9\)

The actual case in greater scale will differ of course very much in
its essential hydrodynamical conditions from the case of the present
experiment, especially on account of the constraint imposed by the
upper wall of the wind channel, to say nothing of the absence of
the dynamical similitude, so that we are to be warned against
making any immediate application of the above results of experi-
ment to the actual problem. Still, the above results of the "toy
experiment" seem to give at least some hint on the actual relations
regarding the influence on the gustiness of wind of an edge of a
terrace protruding on a flat land. In any case, the ridge on one hand,
will increase the turbulence on its leeside and the edge of the ridge
on the other hand will produce a zone on its leeway in which the
irregularity of flow will be enhanced by the formation of a train of
vortices, provided the general wind velocity is sufficient for it.

Our best thanks are due to Prince Tokugawa and the Staffs of
Tōsyōgū-Sanbyakunensai-Kinenkwai and also to the Authorities of the
Imperial Academy for the fund granted for the purchase of the in-
struments.

\(^{(1)}\) For a control, similar experiment was made in absence of the model ridge.
Though some irregularities were also obtained in this case, the qualitative aspect of
the above curve (Fig. 18) is not altered, even if we take the difference of it and the
control curve for the case of no ridge.
Summary.

(1) The records of a self-recording anemograph of Dines's type, kept for a period of about 6 years are examined with respect to the gustiness of winds.

(2) The gustiness, \( g \), is defined, which is given as the ratio of the amplitude, \( a \), of the wind velocity to the mean velocity, \( V \), in each of the successive quarters of an hour.

(3) The statistical relations between \( g \) and the corresponding \( V \) are examined for every direction and every month, respectively for day and night (an example in Fig. 1, Pl. 8).

(4) The frequency distribution of the different values of \( g \) is examined for each of the different values of \( V \) (Fig. 2 for N-wind in Jan.). Especially, the distribution is studied for the prevailing winds in the two seasons, winter and summer (Fig. 3 a, b).

(5) The frequency distribution is again grouped according to the magnitude of \( V \) (Fig. 3 c) into two groups, i.e. for the small and large velocities. The difference in \( g-V \) relation according to season is discussed and explained by the difference in the solar radiation.

(6) \( g-V \) relation is classified into the four seasons and eight directions (Fig. 4), and then averaged for all directions (Fig. 5).

(7) The characteristic difference between \( g-V \) relations for spring-summer and autumn-winter, and also the difference between day and night are pointed out and discussed.

(8) The relation between \( g \) and the direction angle, \( \theta \), of wind is examined (Fig. 6 and 7).

(9) A measure of the efficacy in producing gustiness of the "roughness" of the land, named the "topographical factor," \( R \), is introduced. The values of \( R \) are calculated from a topographical map for respective wind directions (Fig. 8) and compared with \( g-\theta \) relation (Fig. 9).

(10) The difference \( g-kR \) as \( f(\theta) \) is taken (Fig. 10) which is ex-
plained as due to the effects of some promontories of terrace protruding on the low flat land. In this connection, the difference of $g$'s for day and night as $f(\theta)$ is compared with $R'\theta$ curve (Fig. 11 and 12).

(11) Annual variation of $g$ is investigated (Fig. 13). For the explanation of the results, the vertical distribution of the resultant horizontal vorticity of the atmosphere, $\xi$, for different seasons, is studied (Fig. 14). The seasonal variation of $\xi$ shows a parallelism with that of $g$ (Fig. 15).

(12) An experiment is described which was made for demonstrating the possible effect of a ridge protruding on a plane upon the gustiness of wind (Fig. 17 and 18).

(13) From the results of the present investigations, it seems plausible to analyse the cause of the gustiness of winds into the following factors:

(A) Mechanical

(a) Vorticity due to the stratified structure of wind layers in the lower atmosphere.

(b) Vorticity due to the local topography.

(B) Thermal

(c) Convection due to the solar radiation.

(d) Influence of the variation in the stability of the lower atmosphere due to the solar radiation and the nightly cooling upon the mechanical effects enumerated in (A).
Appendix.

Table I.

\( h \): Height above the ground.

\( \theta \): Angle of direction counted clockwise from N, in degree.

\( V \): Resultant velocity.

\( u, v \): Component velocities.

\( \Delta u, \Delta v \): Differences of \( u, v \) between the layer denoted by \( h \), and the next upper layer.

\( \Delta h \): Difference of height corresponding to the above.

\( \xi, \eta \): Components of horizontal vorticity, in arbitrary unit.

\[
\xi_n = \frac{1}{2} \left\{ \left( \frac{\Delta v}{\Delta h} \right)_n + \left( \frac{\Delta v}{\Delta h} \right)_{n-1} \right\},
\]

\[
\eta_n = -\frac{1}{2} \left\{ \left( \frac{\Delta u}{\Delta h} \right)_n + \left( \frac{\Delta u}{\Delta h} \right)_{n-1} \right\},
\]

where the suffix gives the number of the layer.

\( \Psi \): Resultant horizontal vorticity.
### Table I.

**Spring.**

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<tr>
<th>$h$ (km)</th>
<th>0.04</th>
<th>0.1</th>
<th>0.2</th>
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<th>0.4</th>
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<td>197</td>
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<td>5.3</td>
<td>5.6</td>
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<tr>
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<tr>
<td>$v$ (m/sec.)</td>
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<td>-5.4</td>
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<td>-0.7</td>
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<td>262</td>
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### Table I (continued).

**Summer.**

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<td>258</td>
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<td>5.0</td>
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<td>-0.9</td>
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<td>-0.5</td>
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<td>0.2</td>
<td>0.5</td>
<td>0.9</td>
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<td>1.1</td>
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Table I (continued).
Autumn.

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<th>0.7</th>
<th>0.8</th>
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<td>353</td>
<td>19</td>
<td>47</td>
<td>62</td>
<td>98</td>
<td>104</td>
<td>113</td>
<td>198</td>
<td>221</td>
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<td>5.6</td>
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<tr>
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<td>+1.1</td>
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<td>-4.2</td>
<td>-2.1</td>
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<td>+2.2</td>
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<td>+2.2</td>
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<td>2.2</td>
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<td>2.2</td>
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<th>1.1</th>
<th>1.2</th>
<th>1.3</th>
<th>1.4</th>
<th>1.5</th>
<th>1.6</th>
<th>1.7</th>
<th>1.8</th>
<th>1.9</th>
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<tr>
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<td>240</td>
<td>256</td>
<td>252</td>
<td>260</td>
<td>260</td>
<td>262</td>
<td>259</td>
<td>263</td>
<td>258</td>
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<td>( V'(\text{m/sec}) )</td>
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<td>6.1</td>
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<tr>
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<td>+0.8</td>
<td>0.5</td>
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<td>-0.6</td>
<td>-0.8</td>
<td>+0.7</td>
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<tr>
<td>( \frac{\Delta z}{\Delta h} )</td>
<td>+1.6</td>
<td>+1.7</td>
<td>-0.2</td>
<td>+0.9</td>
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<tr>
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<td>-0.6</td>
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<td>-0.4</td>
<td>+0.1</td>
<td>+0.2</td>
<td>-0.1</td>
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<td>+0.1</td>
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<tr>
<td>( \Theta )</td>
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</table>
\text{Table I (continued).}

\textbf{Winter.}

\begin{tabular}{l|cccccccccc}
\hline
\textit{h} (km.) & 0.04 & 0.1 & 0.2 & 0.3 & 0.4 & 0.5 & 0.6 & 0.7 & 0.8 & 0.9 \\
\hline
\theta (°)      & 297 & 310 & 330 & 327 & 336 & 320 & 308 & 305 & 289 & 287 \\
\Gamma (m/sec.) & 2.9 & 4.4 & 5.0 & 5.7 & 5.9 & 6.6 & 6.5 & 6.6 & 6.7 & 7.0 \\
\nu (m/sec.)   & +1.3 & +2.8 & +4.4 & +4.8 & +5.4 & +5.1 & +4.0 & +3.8 & +2.2 & +2.0 \\
c (m/sec.)     & −2.6 & −3.4 & −2.5 & −3.1 & −2.4 & −4.2 & −5.1 & −5.4 & −6.4 & −6.7 \\
\frac{\Delta u}{\Delta h} & +2.5 & +1.6 & +0.4 & +0.6 & −0.3 & −1.1 & −0.2 & −1.6 & −0.2 & −1.0 \\
\frac{\Delta c}{\Delta h} & −1.3 & +0.9 & −0.6 & +0.7 & −1.8 & −0.9 & −0.3 & −1.0 & −0.3 & −0.5 \\
\ell          & −1.3 & −0.2 & +0.2 & +0.1 & −0.6 & −1.4 & −0.6 & −0.7 & −0.7 & −0.4 \\
r & −2.5 & −2.1 & −1.0 & −0.5 & −0.2 & +0.7 & +0.7 & +0.9 & +0.9 & −0.6 \\
g & 2.8 & 2.1 & 1.0 & 0.5 & 0.6 & 1.6 & 0.8 & 1.1 & 1.1 & 0.7 \\
\hline
\end{tabular}

\begin{tabular}{l|cccccccccc}
\hline
\textit{h} (km.) & 1.0 & 1.1 & 1.2 & 1.3 & 1.4 & 1.5 & 1.6 & 1.7 & 1.8 & 1.9 \\
\hline
\theta (°)      & 278 & 279 & 277 & 279 & 278 & 277 & 274 & 275 & 274 & 277 \\
\Gamma (m/sec.) & 7.3 & 7.7 & 8.4 & 8.7 & 9.1 & 9.1 & 9.6 & 9.7 & 9.9 & 10.3 \\
\nu (m/sec.)   & +1.0 & +1.3 & +1.0 & +1.4 & +1.3 & +1.1 & +0.7 & +0.9 & +0.7 & +1.2 \\
c (m/sec.)     & −7.2 & −7.6 & −8.3 & −8.6 & −9.0 & −9.0 & −9.6 & −9.7 & −9.9 & −10.2 \\
\frac{\Delta u}{\Delta h} & +0.3 & −0.3 & 0.4 & −0.1 & −0.2 & −0.4 & +0.2 & +0.5 & +0.5 & −0.1 \\
\frac{\Delta c}{\Delta h} & −0.4 & −0.7 & −0.3 & −0.4 & 0 & −0.6 & −0.1 & −0.2 & −0.3 & −0.8 \\
\ell          & −0.5 & −0.6 & −0.5 & −0.4 & −0.2 & −0.3 & −0.4 & −0.2 & −0.3 & −0.6 \\
r & +4.0 & 0 & −0.1 & −0.2 & +0.2 & +0.3 & +0.1 & 0 & −0.2 & −0.2 \\
g & 0.6 & 0.6 & 0.5 & 0.4 & 0.3 & 0.4 & 0.4 & 0.2 & 0.4 & 0.6 \\
\hline
\end{tabular}
Fig. 1. p-W relation for X-Wind in January.

[Black: day, Red: night, ○: mean value for 0.5 internal of P]
Report No. 38.  

(Vol. III.) Pl. 9.

Wind.

Model ridge
Two rows of pendulums.

Fig. 17.