BULLETIN OF THE EARTHQUAKE
RESEARCH INSTITUTE
Vol. 39 (1961), pp. 491-521

16. *Observations at Miyagi-Enoshima Tsunami Observatory during the IGY Period.*

By Ryutaro TAKAHASI, Kintaro HIRANO, Isamu AIDA, Tokutaro HATORI and Shizuko SHIMIZU,

Earthquake Research Institute.

(Read January 26, 1960.—Received June 30, 1961.)

1. Miyagi-Enoshima Station-site

Miyagi-Enoshima is a small rocky island only 800 m in diameter, situated about 15 km east of Onagawa harbour, a fishery base for the Sanriku fishing grounds. The island, roughly speaking, is conical in shape, surrounded by cliffs 10–30 m high, but it has two small indentations on its northern coast. The western and larger one furnishes the only landing-place on the island. About 1200 inhabitants, mostly fishermen and their families, live on the steep slope around this landing place. This is the sole inhabited remote island on the north-eastern Pacific coast of Honshu, which is the main island of Japan. It directly faces the Sanriku seismic region frequented with tsunamis.

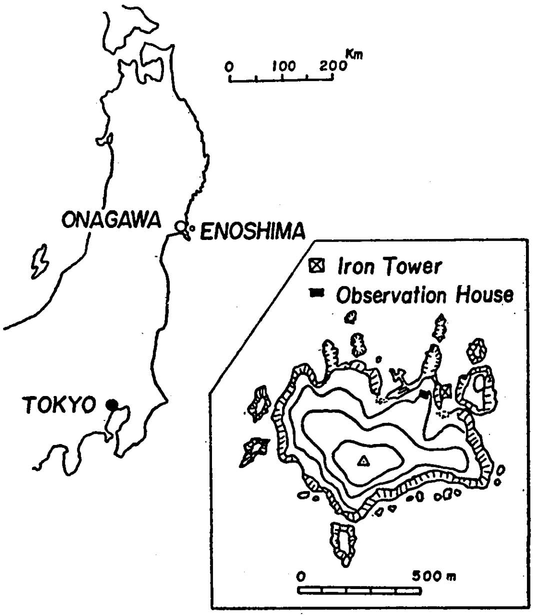

Fig. 1. The map of Enoshima.

The depth of the sea around the island is about 100 m, and the distance to the nearest margin of the island shelf of Honshu from this island is about 25 km.

Miyagi-Enoshima is usually called Enoshima, without using the prefix Miyagi, but since there is another Enoshima in Kanagawa prefecture, we sometimes refer to the island in question by adding the name of the prefecture to which it belongs.

In 1941, the Earthquake Research Institute installed on the island a tide-gauge specially designed for recording tsunami. The tide-gauge was installed in a wooden shelter on the top of a concrete pedestal 2.5×2.5 m wide and 3.5 m high above MSL, erected in water 3 m in depth in the eastern indentation mentioned above. This indentation is incomplete but it has a rock in front of it, to shelter the tide-gauge from rough seas and swells. Numerous sea-gulls gather on this rock.

Unfortunately however this tide-gauge was washed away by an unusually heavy storm in 1942, and was not restored till 1954, when an iron tower was erected on the concrete pedestal that remained, and a pressure-type tide-gauge was installed in a tide-gauge well at the centre of the pedestal. The recording part of the instrument was installed in a small shed on the cliff nearest to the iron-tower, the pressure changes

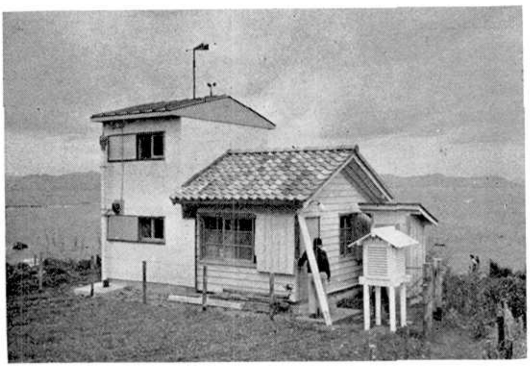

Fig. 2. Observation house.

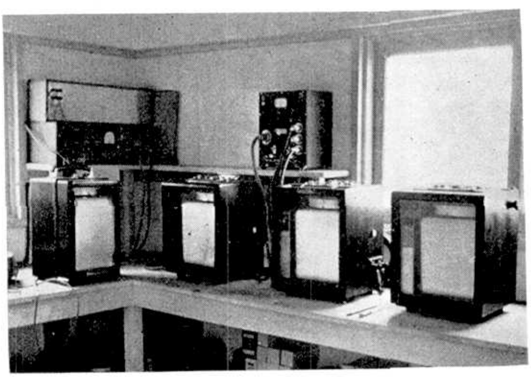

Fig. 3. Interior of observation house.

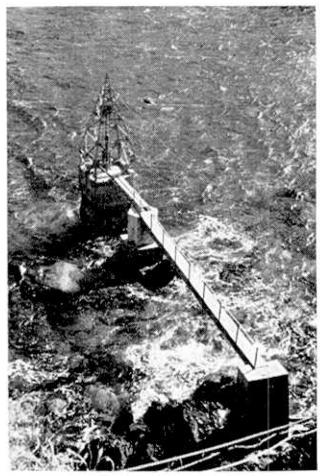

Fig. 4. Iron tower, looking down from the observation house.

produced at the sensing part in the well being led by a thin copper tube, spanned from the iron tower to the shed.

In 1956, an ERI-III tsunami recorder was installed in the well under the iron tower. This is essentially a differential tide-gauge which records tides and long waves separately. The details of this instrument will be given below.

In April, 1957, a long wave recorder of the Van Dorn type was installed in the same well as the ERI-III tsunami recorder. The recording galvanometers for these two gauges were installed in a newly built observation house as shown in Figs. 2∼4. Cables were spanned from the iron tower to a concrete anchor half way down the cliff and then to the station house.

During the IGY period of 1957–58, this station participated in long wave observations. Its CSAGI No. is C-118 and the geographic position 141°36′E, 38°24′N. Observations of sea and swell, microbarometric oscillations and other conventional meteorological elements were also carried out.

In the following we will give some explanations of each instrument which is used at the station and the results of the observations.

2. Instruments

a) *ERI-III tsunami recorder*. Two identical 6″ galvanized iron pipes, C_1 and C_2, each 5.5 m long, are erected in the sea, with a float F in each of them. They differ only in the diameters of the copper capillary tubes R_1 and R_2 at the lower end of each iron pipe, through which the sea water communicates with the interior of the pipes. The water surface in C_1 follows the sea surface variation of periods longer than about 2 min., while the water surface in C_2 follows the sea surface variation of periods longer than 120 min. The rise and fall of each float are transmitted to a pully by means of nylon string. The pulley rotates a low-torque potentiometer (Helicalohm) on its axis. The potentiometers are fed with 6 volts. Thus the motions of the floats are transformed into DC electric signals. The difference of the electric signals from the two potentiometers, which follows thus the long waves of periods from 2 to 120 min., is recorded by two recording galvanometers, connected in parallel. Each recording galvanometer has a transistor amplifier fed with 24 v. The sensitivity of one galvanometer is $0\sim\pm1.5$ volts for full scale, and can record the long waves of heights $0\sim\pm2.5$ m. The other recording galvanometer is of the range $0\sim\pm0.3$ volts full scale which

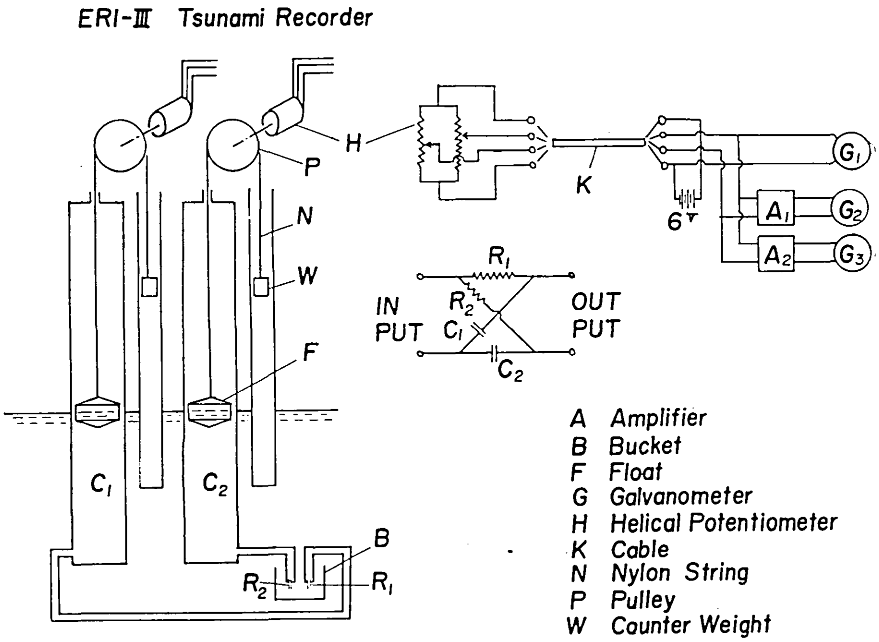

Fig. 5. The ERI-III tsunami recorder and its equivalent circuit.

corresponds to the long waves of the range $0\sim\pm0.5$ m. Beside these two galvanometers there is another one with the range $0\sim6$ volts full scale, and is fed with an electric signal directly from one of the potentiometers for the purpose of recording tide. Recording charts are driven at the speed of 6 cm/hr for long waves and 2 cm/hr for the tide.

The sensitivity of this long wave recorder is adjusted to show the maximum value of 0.53 div. per cm of wave height at the central period of 12 min. and fall at the rate of 6 db/octave on both sides of this central period.

Results obtained by this ERI-III long wave recorder are not given in the present report because they were almost the same as those obtained from the Van Dorn long wave recorder.

b) *The Van Dorn long wave recorder.* This instrument, invented by Dr. W. G. Van Dorn of the Scripps Institution of Oceanography, was provided by him in March, 1957, and was installed in the same well as ERI-III. The observation of long waves with the use of this instrument has been executed since April 1, 1957 without any serious interruption.

No detailed descriptions of this instrument will be given here but only a brief explanation just necessary for the present report, since details would be given elsewhere by the inventor. The present recorder is entirely different from that written by him in 1956.[1]

The recorder is shown schematically in Fig. 6. It consists of a standpipe C_1, a hydraulic filter C_0, and a piece of rubber hose connecting them. The hydraulic filter consists of two capillary tubes of different diameters R_1, and R_2, a U-tube C_2 which contain mercury, and a wire-strain pressure transducer T of high sensitivity. The hydraulic filter is installed just under the L. W. level. A long vinyl hose is connected to the bottom of the filter. Sea water is led into the hydraulic filter through this vinyl hose and a strainer at the other end of the hose. The strainer has been fixed in a bucket placed on the bottom of the well to facilitate the step-function calibration. The hydraulic filter is filled with silicon oil. The hydraulic filter and the stand pipe are fixed to a 3 inch galvanized iron pipe and have been installed in the concrete well mentioned above.

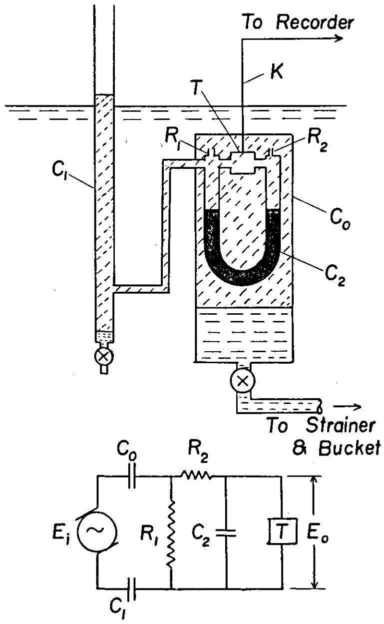

Fig. 6. The Van Dorn L. W. recorder and its equivalent circuit.

The pressure differences produced between two legs of the mercury U-tube are transformed by the pressure transducer into electric signals and are sent to a transistor amplifier and then to the Esterline-Angus recording galvanometer, both installed in the station house on the cliff.

The over-all sensitivity of the Van Dorn L. W. recorder, as calibrated by giving a step-function input, is about 1.35 division on the chart for 1 cm change in the sea level at the central period of 20 min. Since the width of 1 div is 2.4 mm at the centre of the chart, the Van Dorn instrument describes the long waves with the minification of about 1/3 the actual height. The chart speed was kept at 3″/hour.

The sensitivity remained fairly constant during the IGY period, although small fluctuations have been noticed, which seem to have their

1) VAN DORN, W. G. "A portable tsunami recorder," *Trans. Amer. Geophys. Union*, **37** (1956), 27–30.

cause in the change in viscosity of silicon oil, due to the sea water temperature change.

In the actual observation, an additional low pass filter, consisting of a 40000μF shunt condenser, was inserted in front of the amplifier for the purpose of cutting off the 2.5 min. oscillations inherent to the station site.

c) *The wave recorder.* This is essentially a stand-pipe type wind wave recorder. A 3″ iron pipe is fixed to the outer surface of the concrete pedestal mentioned above. The sea water flows in and out the iron pipe through its lower end and compresses and rarefies the air in the pipe. The air pressure variation is fed to a metalic bellows through copper tubing. The bellows has a slow leak capillary to eliminate slow changes in the sea level. The motion of the bellows turns a low torque potentiometer. The electric signal thus produced is sent to the moving coil type recorder in the station house. The record is made on smoked paper wound on a rotating drum run by a spring motor. Recording speed is 0.5 mm/sec. The sensitivity characteristic is shown in Fig. 7.

The recording range is 0~1.2 m. In case of heavy seas the sensitivity can be reduced to 1/5 of the usual value, the recording range

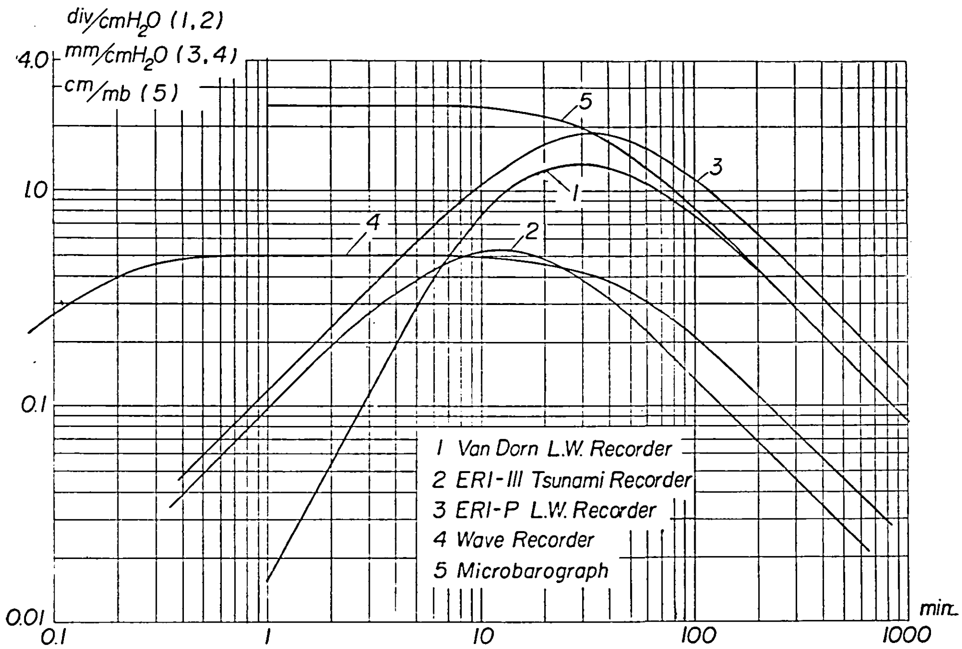

Fig. 7. The sensitivity characteristics of various instruments at Enoshima.

being accordingly increased to 0∼6 m.

d) *Microbarograph.* This is a one-cup microbarograph to record the oscillation of the atmospheric pressure of periods shorter than 100 min. An 18-litre glass bottle provided with a slow leak is connected with the interior of the microbarograph cup. The glass bottle is buried in the ground to avoid the effect of air temperature changes. The sensitivity of the microbarograph has been calibrated by giving a step-wise pressure change to the glass bottle. The sensitivity has been 2.42 cm for a change of one millibar.

e) *Other instruments.* Various other meteorological instruments are installed at the station. They are listed as follows:

1 barograph; 1 thermograph; 1 recording wind vane and 1 wind speed recorder; 1 hygrograph; 1 maximum and minimum mercury thermometer; 1 dry and wet bulb hygrometer.

3. Calibration of long wave recorders

The Van Dorn instrument is equivalent in principle to the electric band-pass filter shown in Fig. 6. Electric parts are denoted by the same letters as the corresponding mechanical parts in the hydraulic filter.

Since the filter is heavily tapered, its frequency characteristics can be shown as

$$E_0/E_i = j\frac{\omega}{\omega_1} \Big/ \left(1+j\frac{\omega}{\omega_1}\right)\left(1+j\frac{\omega}{\omega_2}\right),$$

where ω is the angular frequency of the pressure variation E_i, and $\omega_1=1/CR_1$, $1/C=1/C_0+1/C_1$, $\omega_2=1/C_2R_2$.

The sensistivity of the filter takes the maximum value of $\omega_2/(\omega_1+\omega_2)$ at the central frequency $\omega_0=\sqrt{\omega_1\omega_2}$. For small values of ω, $E_0/E_i \fallingdotseq j\omega/\omega_1$, and for large values of ω, $E_0/E_i \fallingdotseq \omega_2/j\omega$.

The calibration of the Van Dorn long-wave recorder has been made at intervals of 3∼6 months during the IGY period. The calibration was made by lifting the bucket B, Fig. 6, above the sea level to make an artificial sea surface in the bucket. The height of the bucket was then suddenly changed (lifted and/or lowered) by about 10 cm. Corresponding to this step-function imput, the recorder will describe on the chart a response

$$R(t)=D\cdot H\frac{\omega_2}{\omega_2-\omega_1}\left(e^{-\omega_1 t}-e^{-\omega_2 t}\right),$$

where H is the height of the imput step function, D the deflection which would be produced on the chart when a pressure equivalent to 1 cm of water column was applied across the pressure transducer T. D, ω_1 and ω_2 are three quantities to be determined by the calibration. The quickest and easiest way of getting their values is to plot $R(t)$ on a sheet of logarithmic section paper. Since $R(t)/H$ can be approximated by $D\frac{\omega_2}{\omega_2-\omega_1}e^{-\omega_1 t}$ for large values of t, we can easily read off the values $\omega_2 D/(\omega_2-\omega_1)$ and ω_1 from the logarithmic section paper. Then the values of $D\frac{\omega_2}{\omega_2-\omega_1}e^{-\omega_1 t}$ for small values of t are read on the section paper by producing the tail of the response curve. The differences of these values from $R(t)$ represent $D\frac{\omega_2}{\omega_2-\omega_1}e^{-\omega_2 t}$. Plotting these values again on the same logarithmic section paper, we can obtained ω_2. From $\omega_2 D/(\omega_2-\omega_1)$, ω_1 and ω_2 thus obtained, we calculated D, ω_1, ω_2 and $\omega_0=\sqrt{\omega_1\omega_2}$.

The results of calibration have been reported to the IGY World Data Centers in the form of spectral sensitivity curves attached to the monthly report. We will here briefly summarize the results of calibration carried out during the IGY period.

Table 1.

Date	(div/cmH_2O) D	(rad/min) ω_1	(rad/min) ω_2	(min) $T_1=2\pi/\omega_1$	(min) $T_2=2\pi/\omega_2$
1957 III 31	1.55	0.0886	0.627	71.0	10.0
VI 29	1.60	0.121	0.744	52.0	8.45
XII 11	1.60	0.105	0.530	60.0	11.9
1958 III 26	1.59	0.109	0.609	57.7	10.3
X 12	1.75	0.129	0.649	48.8	9.7
1959 IV 28	1.58	0.0948	0.635	66.4	9.9

The calibrations have been done with and without the additional electric low-pass filter of which the cut-off frequency ω_3 is almost the same as ω_2. In the actual observation, the spectral sensitivity of the recorder showed therefore the decrease of 12 db per octave for frequencies larger than ω_2, and the decrease of 6 db per octave for frequencies smaller than ω_1.

The ERI-III tsunami recorder is equivalent in function to the electric circuit shown in Fig. 5. The spectral response is therefore

$$E_0/E_i = \frac{\omega_2 - \omega_1}{\omega_2} \cdot \frac{j\omega/\omega_1}{(1+j\omega/\omega_1)(1+j\omega/\omega_2)},$$

which has the maximum value of $(\omega_2-\omega_1)/(\omega_2+\omega_1)$ at $\omega_0=\sqrt{\omega_1\omega_2}$, and decreases at the rate of 6 db/octave on both side of ω_0. Calibration for the ERI-III recorder has been made separately for the recording galvanometer and for two capillary tubes R_1, R_2. Effective values for R_1 or R_2 have been obtained in the laboratory by the discharge test of water through the capillary tube under consideration.

Fig. 7 shows the average sensitivity curves for various long wave recorders, the wave-meter and the microbarograph which are being used at Enoshima.

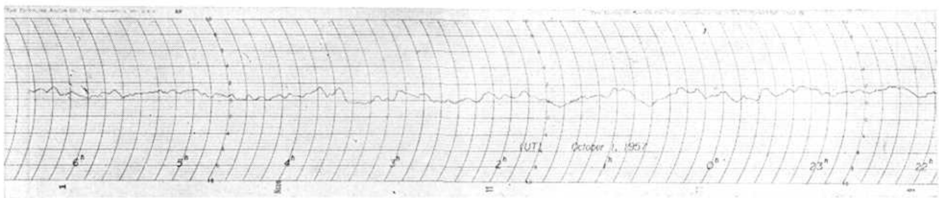

Fig. 8. Feature of long wave record obtained at Enoshima on an ordinary day.

4. Results of Observations

Fig. 8 shows the typical feature of the record obtained by the Van Dorn long wave recorder at Miyagi-Enoshima on an ordinary day. The incessant fluctuations of the sea level of periods ranging from 10 to 70 min. have been observed. The ranges of these fluctuations, measured from a trough to the following crest, were mostly less than 4 divisions on the chart, or about 3 cm in actual scale. In the IGY monthly report sent to the World Data Centres, all remarkable fluctuations which surpassed 4 divisions in height have been given, together with the time of starting and the termination, the mean period, the maximum amplitude and its time of occurrence, etc.

Some of these remarkable disturbances resulted from obvious causes such as a tsunami, a nuclear explosion or typhoons: on Sept. 27, 1958 the typhoon "Kanogawa" passed 15 km east of Enoshima, the atmospheric pressure at the centre having been 980 mb. approximately. On this occasion, the long wave attained as much as 26 divisions in height, the highest value observed during the IGY period. The long waves developed to 4 divisions in height as early as 0517, 26th UT and lasted for about 32 hours. The maximum wind speed during these hours was

17.0 m/s blowing from ESE.

A similar remarkable disturbance was experienced on 26th December, 1958, which had been due to a heavy cyclone. The Van Dorn recorder was out of order for forty hours on account of this storm (From 0650, Dec. 27 to 2300 Dec. 28, 1958, UT). According to the ERI-recorder, the maximum height of the long wave during this storm was 21.5 cm.

On November 6th, 1958, a tsunami caused by an earthquake near Iturup Is. was observed. This was the only seismic tsunami observed in Japan during the IGY period. The origin time of the earthquake was 2258 Nov. 6, 1958 UT, the epicentre being at 44°3N, 148°5E. At Enoshima, the tsunami started at 0005 Nov. 7, UT, the maximum amplitude of 14.5 divisions having been observed at 0129 of the same day. The record is reproduced in Fig. 9.

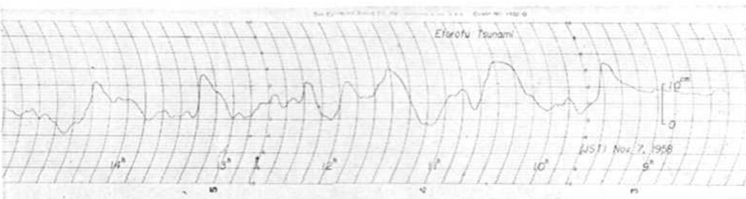

Fig. 9. Record of Iturup Tsunami on Nov. 7, 1958.

A minute disturbance, about 4 divisions in amplitude, was observed on June 29, 1958. This was probably the tsunami caused by the nuclear explosion near Eniwetok atoll on June 28, 1958, UT. The waves started at 0024 UT and lasted for about 9 hours.

The incessant disturbances, of lengthy periods but of small height, which form the back-ground noise to the remarkable long waves, seem to have a close relation with the fact that Enoshima lies on the continental shelf along Honshu. We seldom observed such back-ground noise at Hachijo Island, which stands on a deep ocean floor. These disturbances might be shelf seiches or edge waves generated by meteorological disturbances which are progressing on or outside the coastal waters.

To see the relation between the growth and decay of long waves and various meteorological elements, we have made summary diagrams of various observed quantities at Enoshima for each month during the IGY. They are shown in Figs 10～27, and contain : daily weather, wind wave height, long wave period, long wave height, atmospheric pressure, microbarometric oscillations of long and short periods, wind velocity and direction.

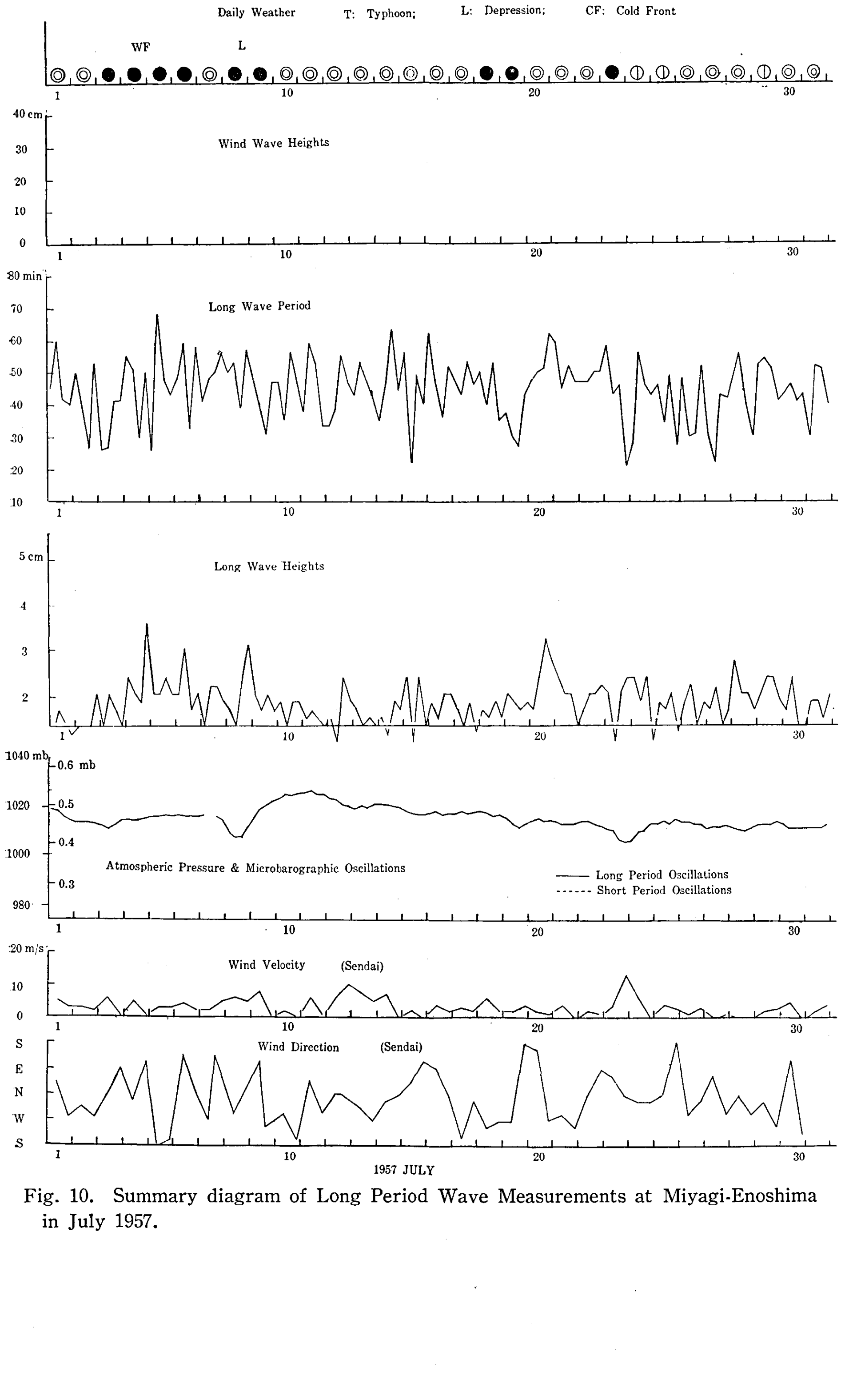

Fig. 10. Summary diagram of Long Period Wave Measurements at Miyagi-Enoshima in July 1957.

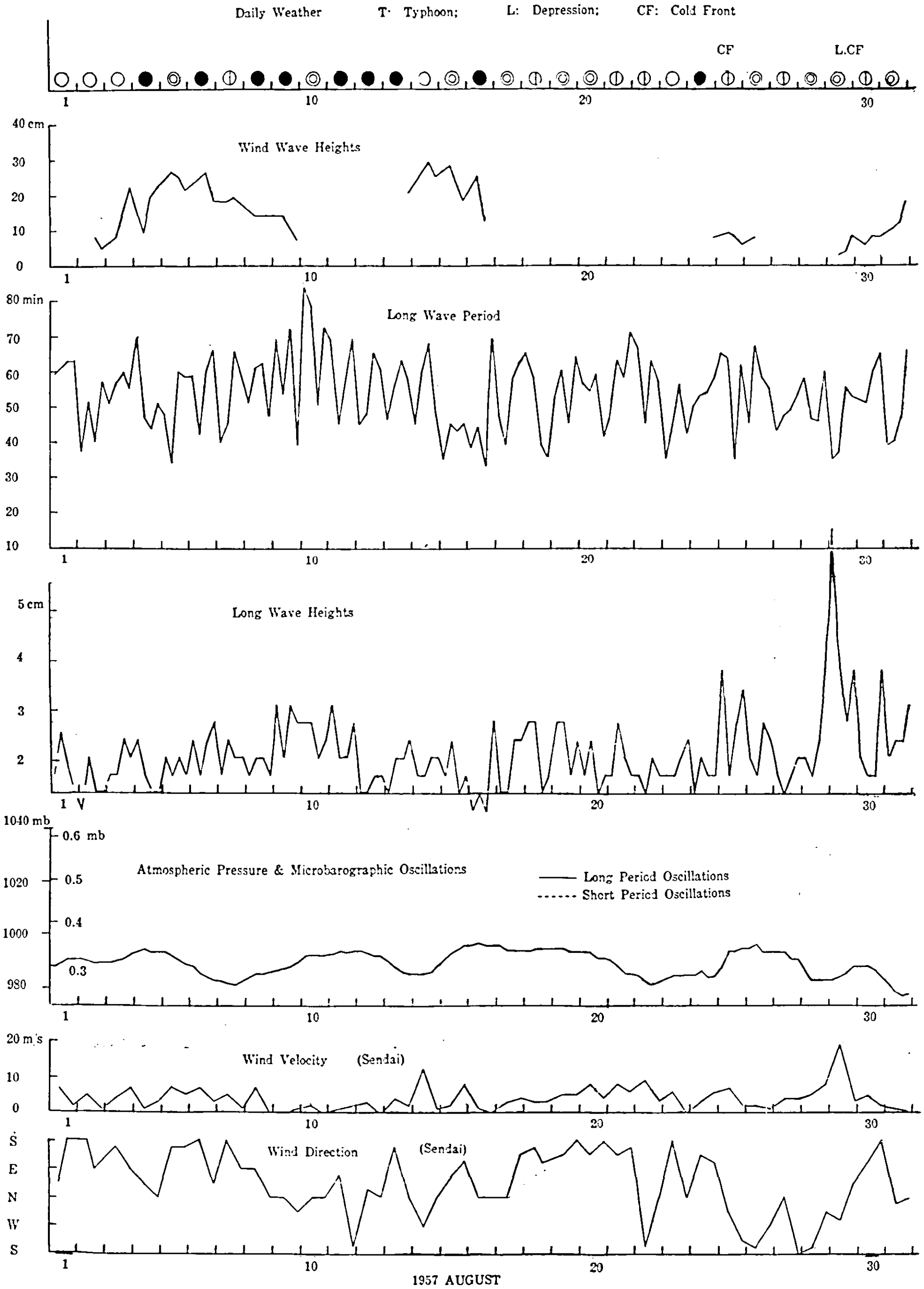

Fig. 11. Summary diagram of Long Period Wave Measurements at Miyagi-Enoshima in August 1957.

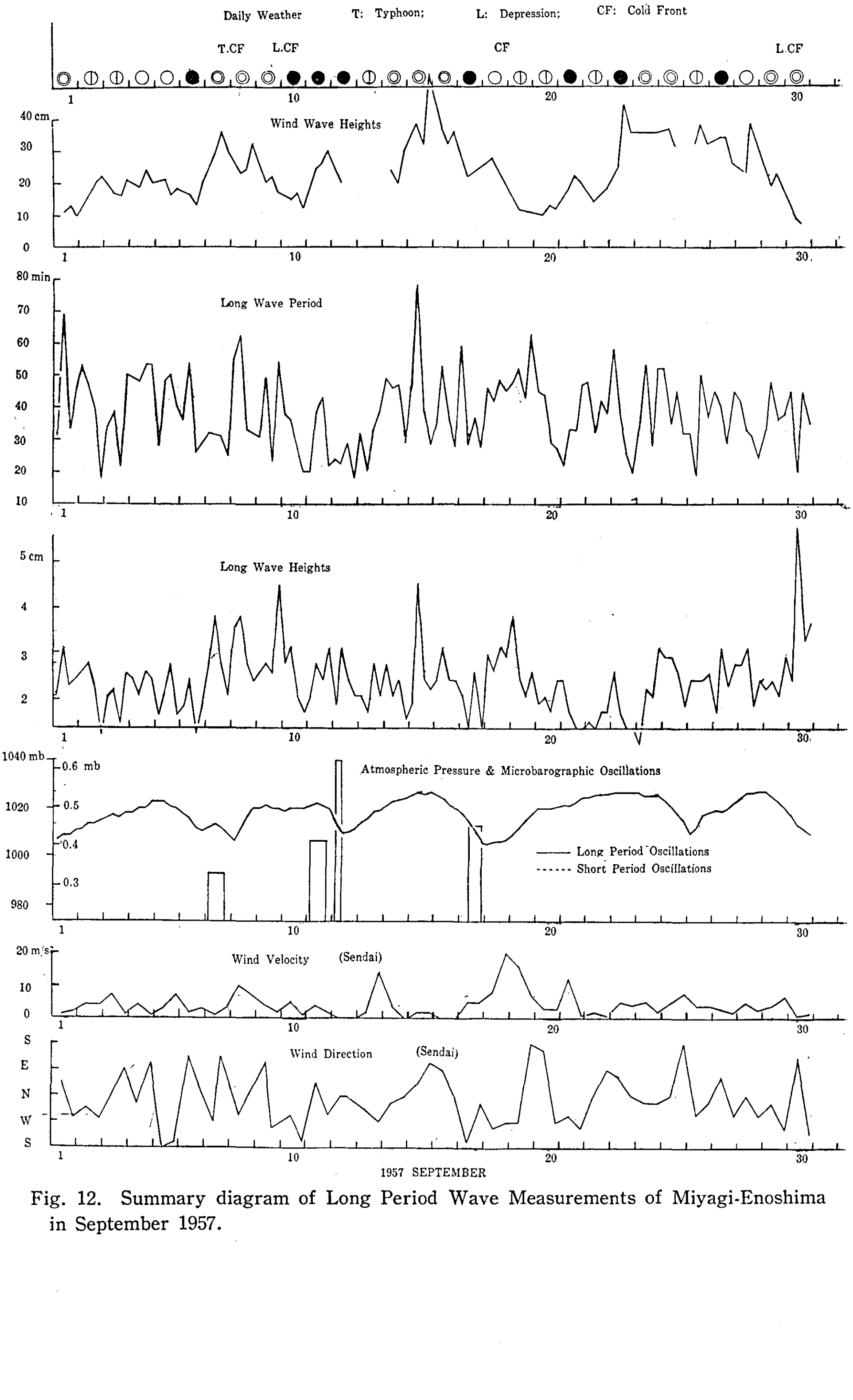

Fig. 12. Summary diagram of Long Period Wave Measurements of Miyagi-Enoshima in September 1957.

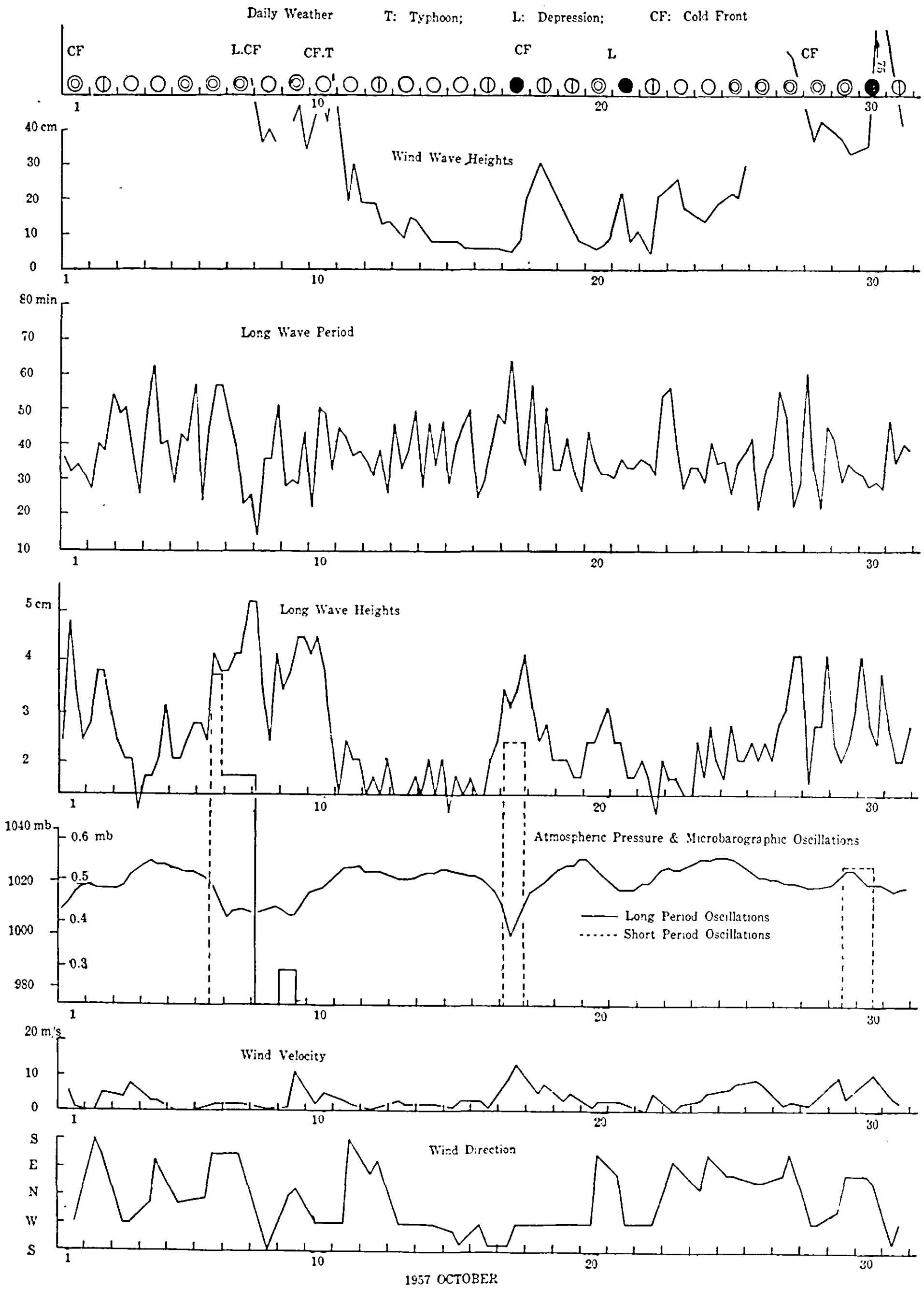

Fig. 13. Summary diagram of Long Period Wave Measurements at Miyagi-Enoshima in October 1957.

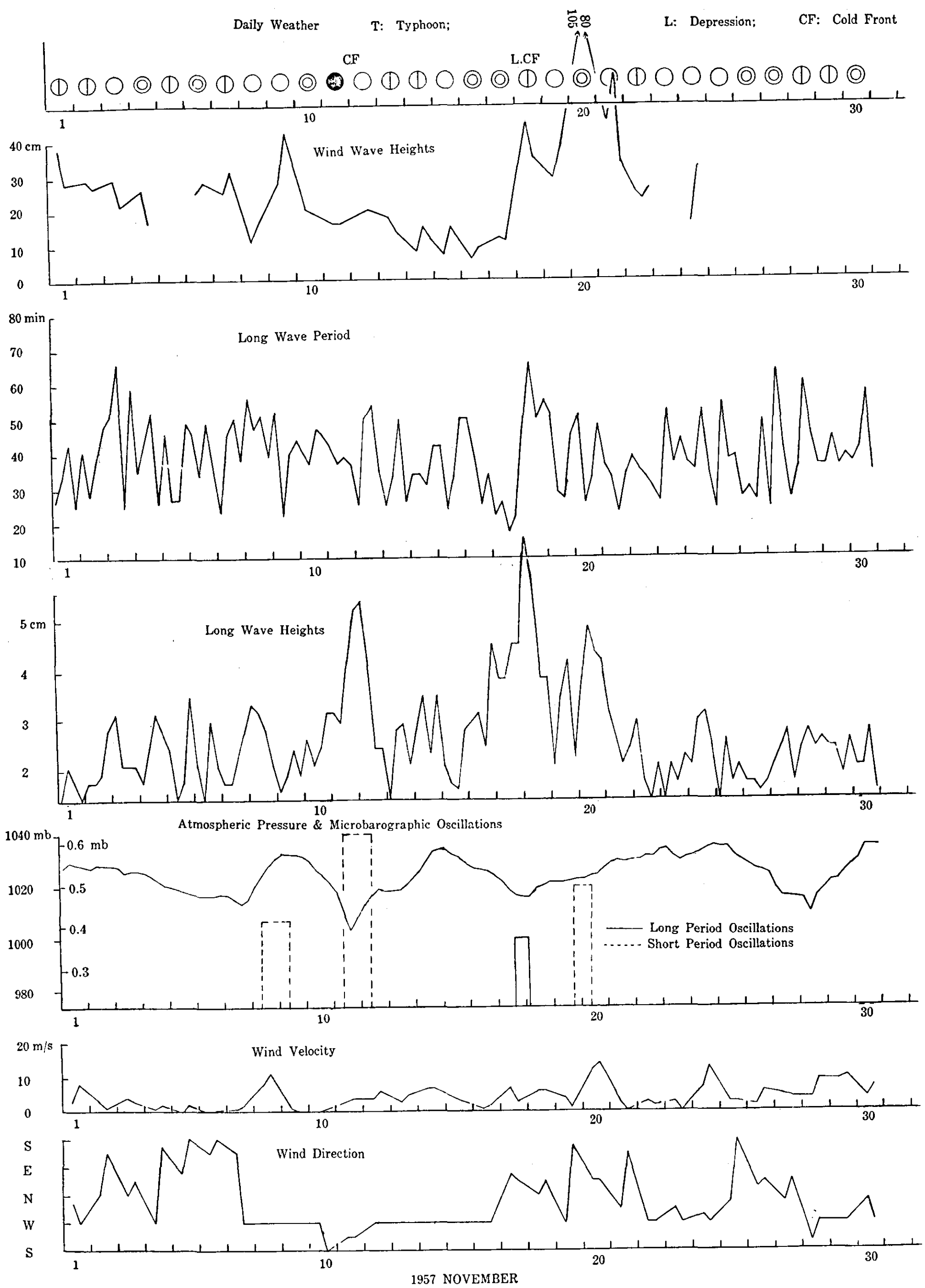

Fig. 14. Summary diagram of Long Period Wave Measurements at Miyagi-Enoshima in November 1957.

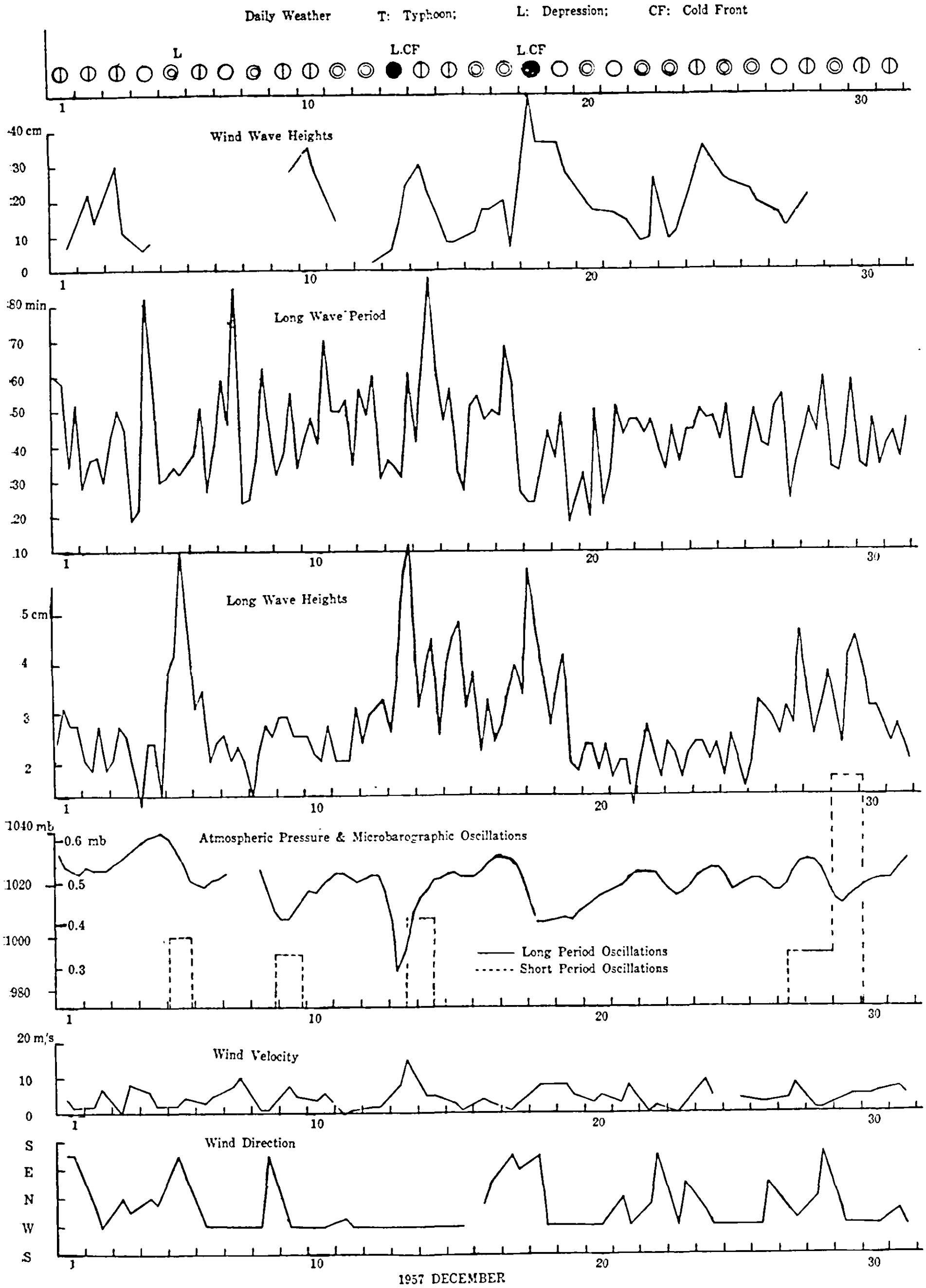

Fig. 15. Summary diagram of Long Period Wave Measurements at Miyagi-Enoshima in December 1957.

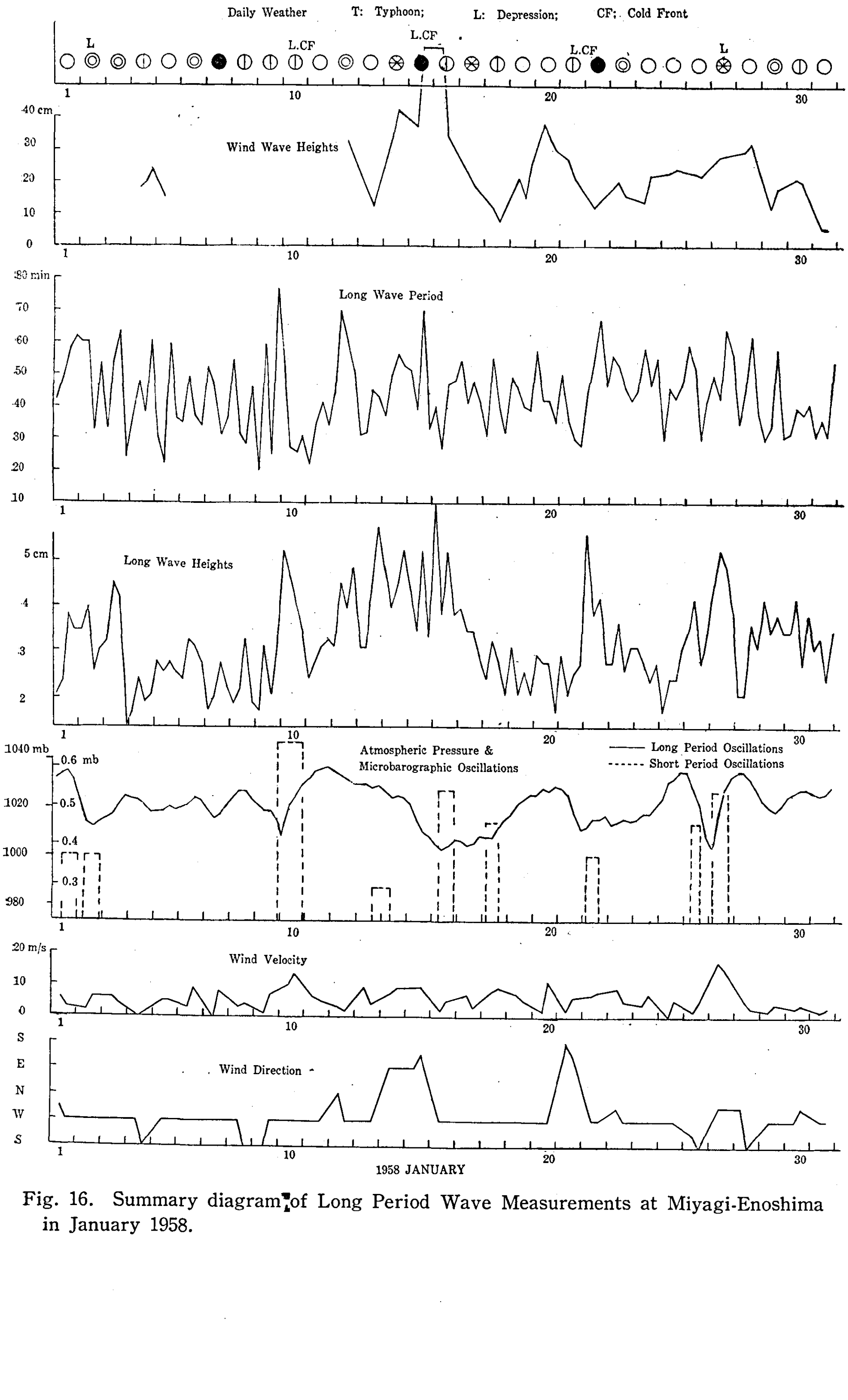

Fig. 16. Summary diagram of Long Period Wave Measurements at Miyagi-Enoshima in January 1958.

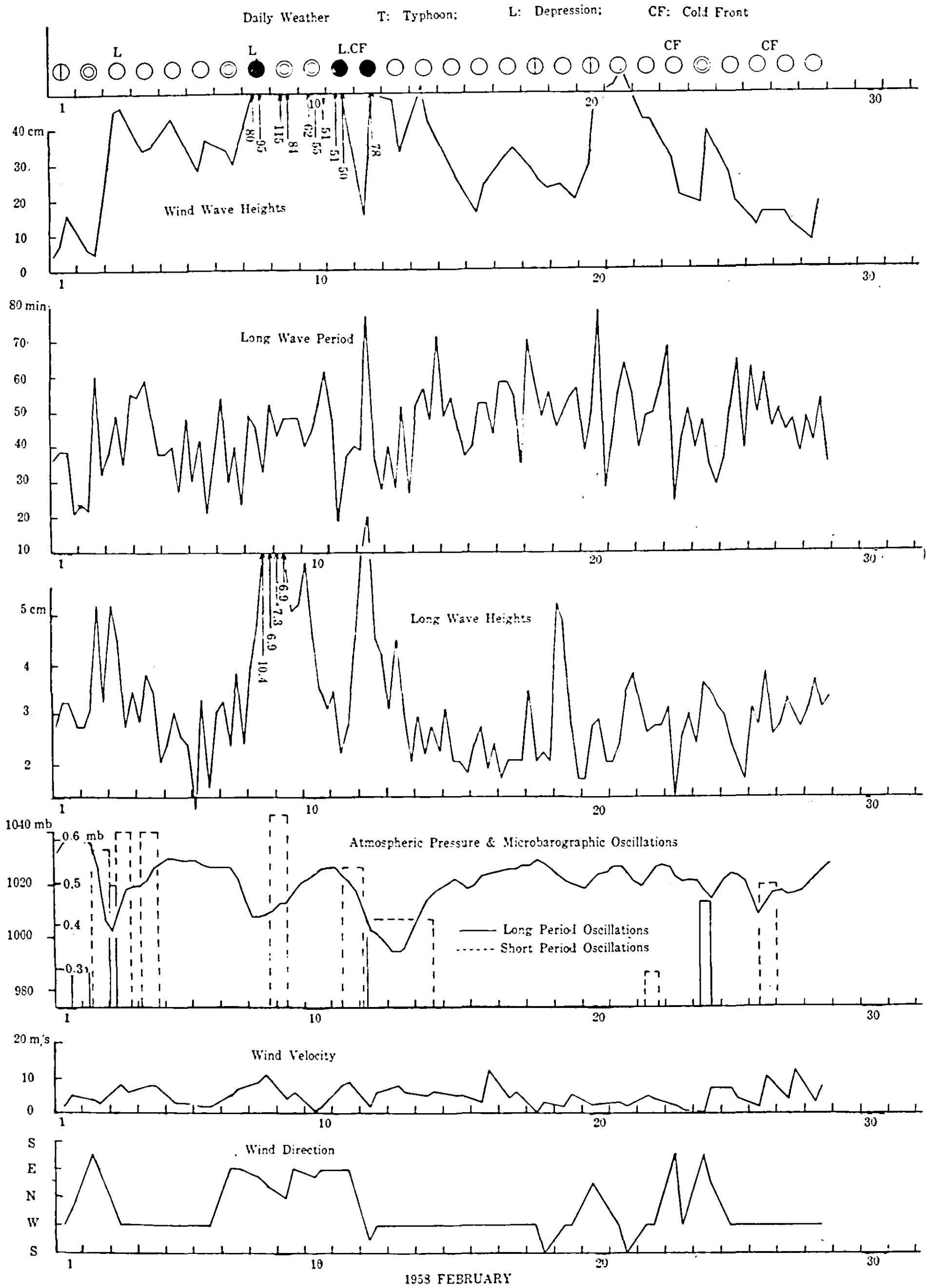

Fig. 17. Summary diagram of Long Period Wave Measurements at Miyagi-Enoshima in February 1958.

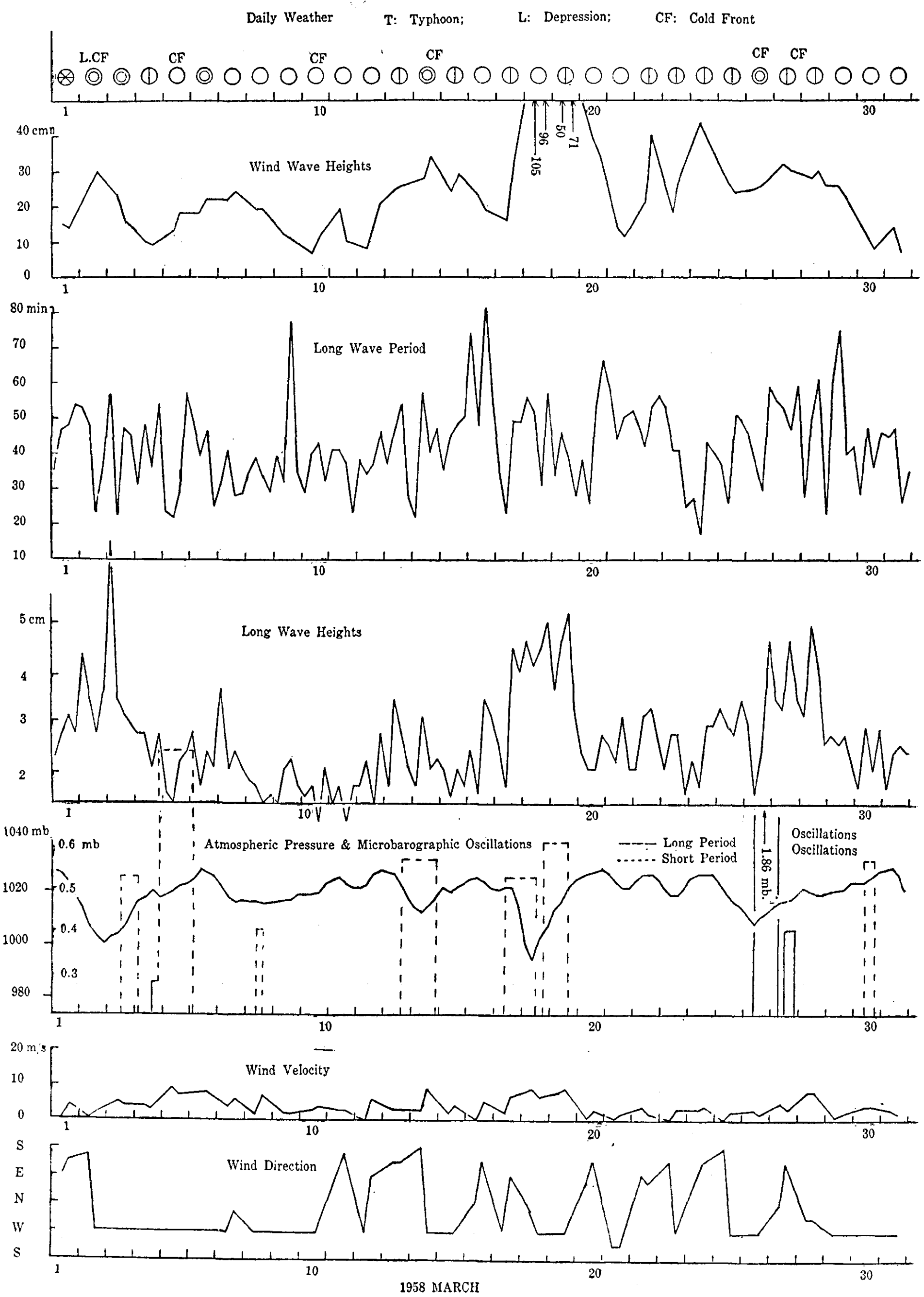

Fig. 18. Summary diagram of Long Period Wave Measurements at Miyagi-Enoshima in March 1958.

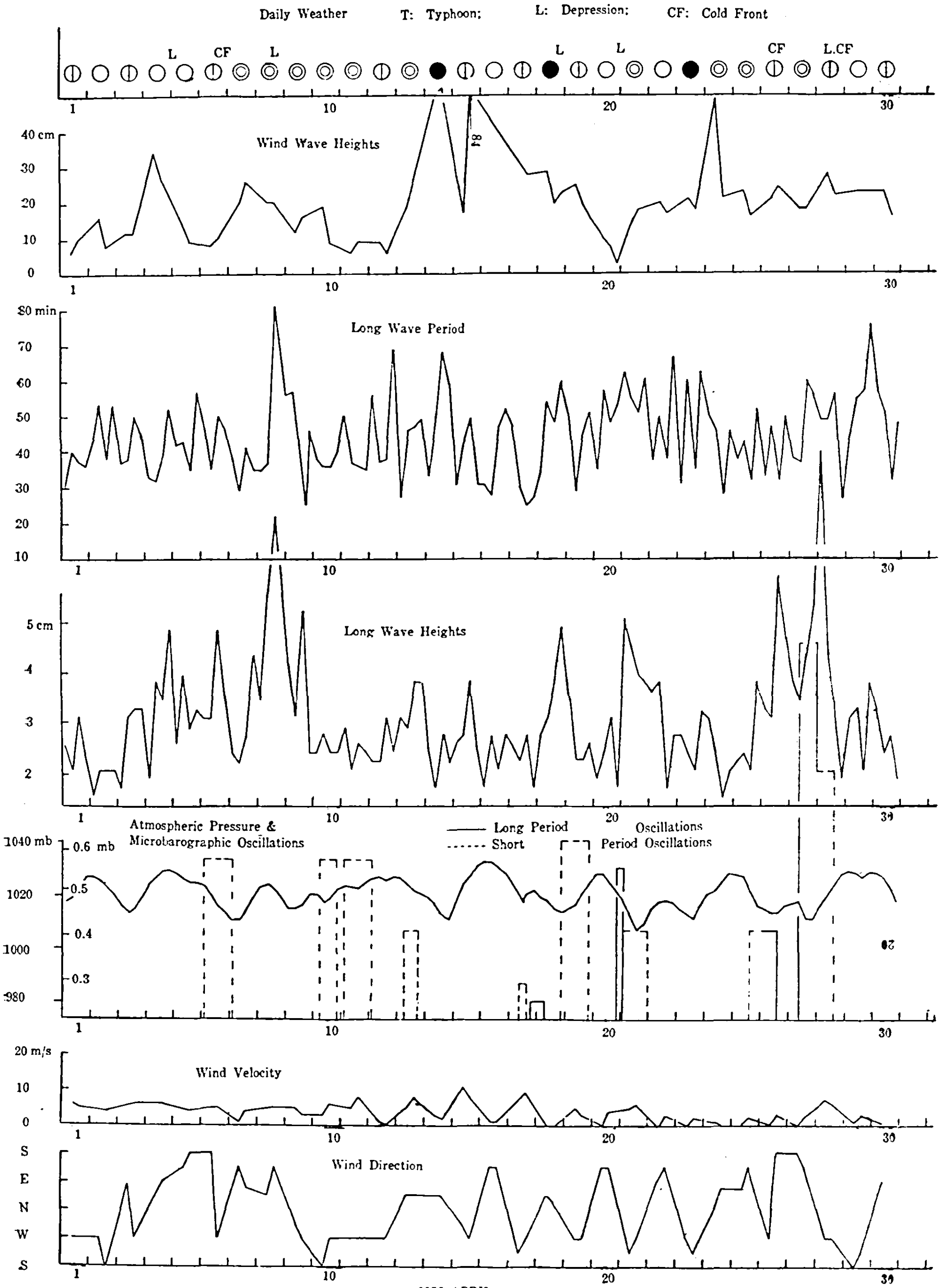

Fig. 19. Summary diagram of Long Period Wave Measurements at Miyagi-Enoshima in April 1958.

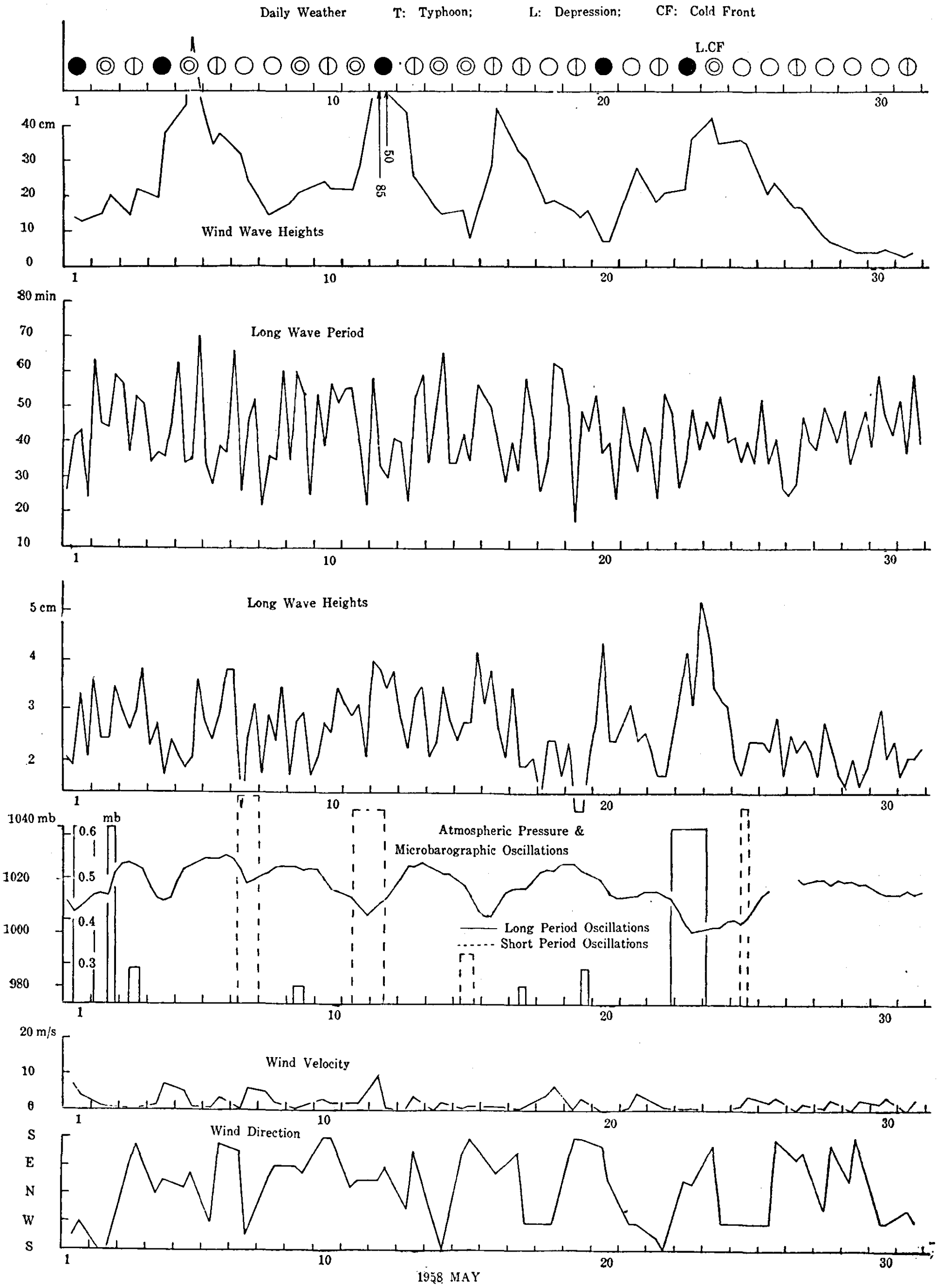

Fig. 20. Summary diagram of Long Period Wave Measurements at Miyagi-Enoshima in May 1958.

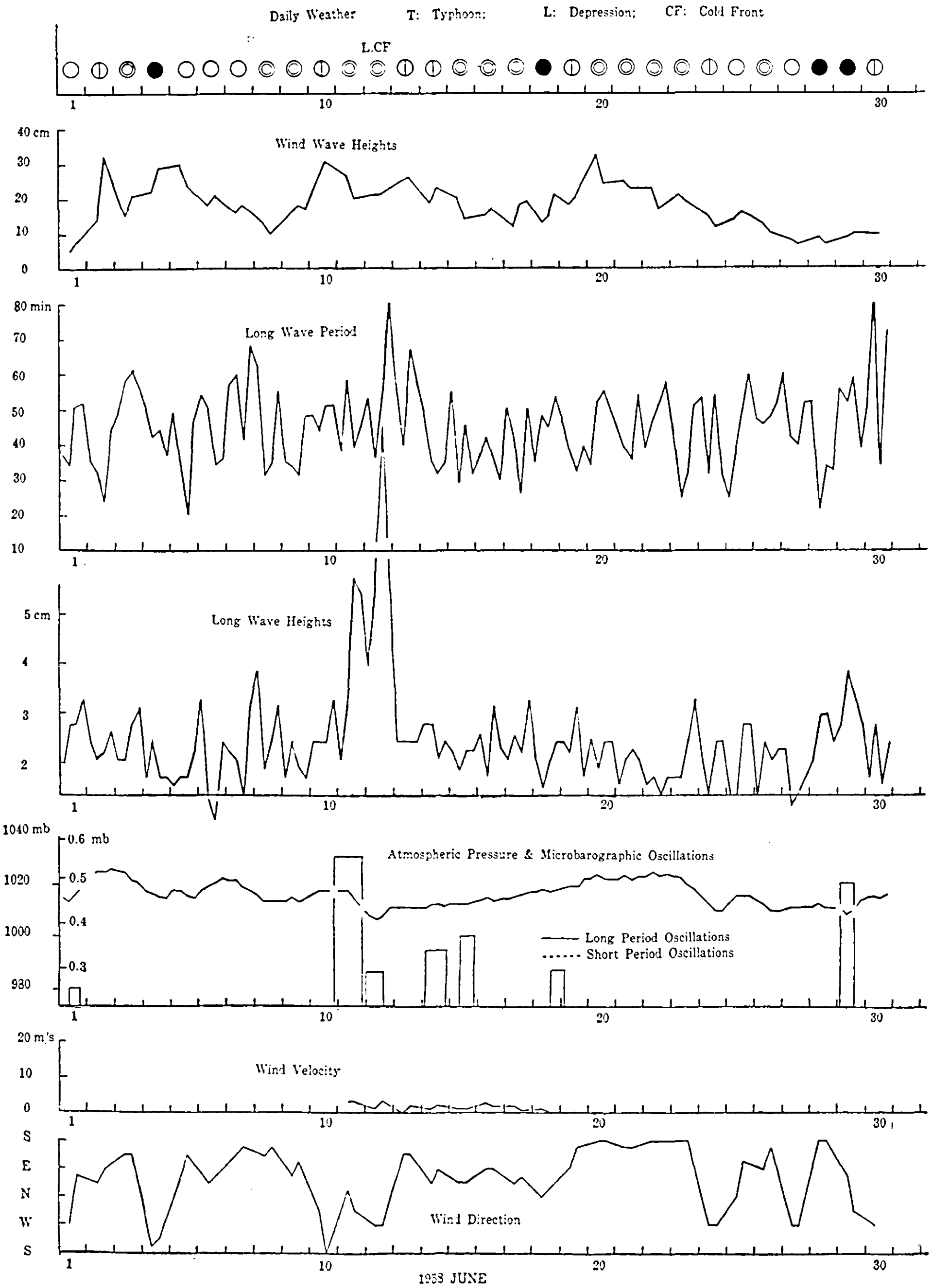

Fig. 21. Summary diagram of Long Period Wave Measurements at Miyagi-Enoshima in June 1958.

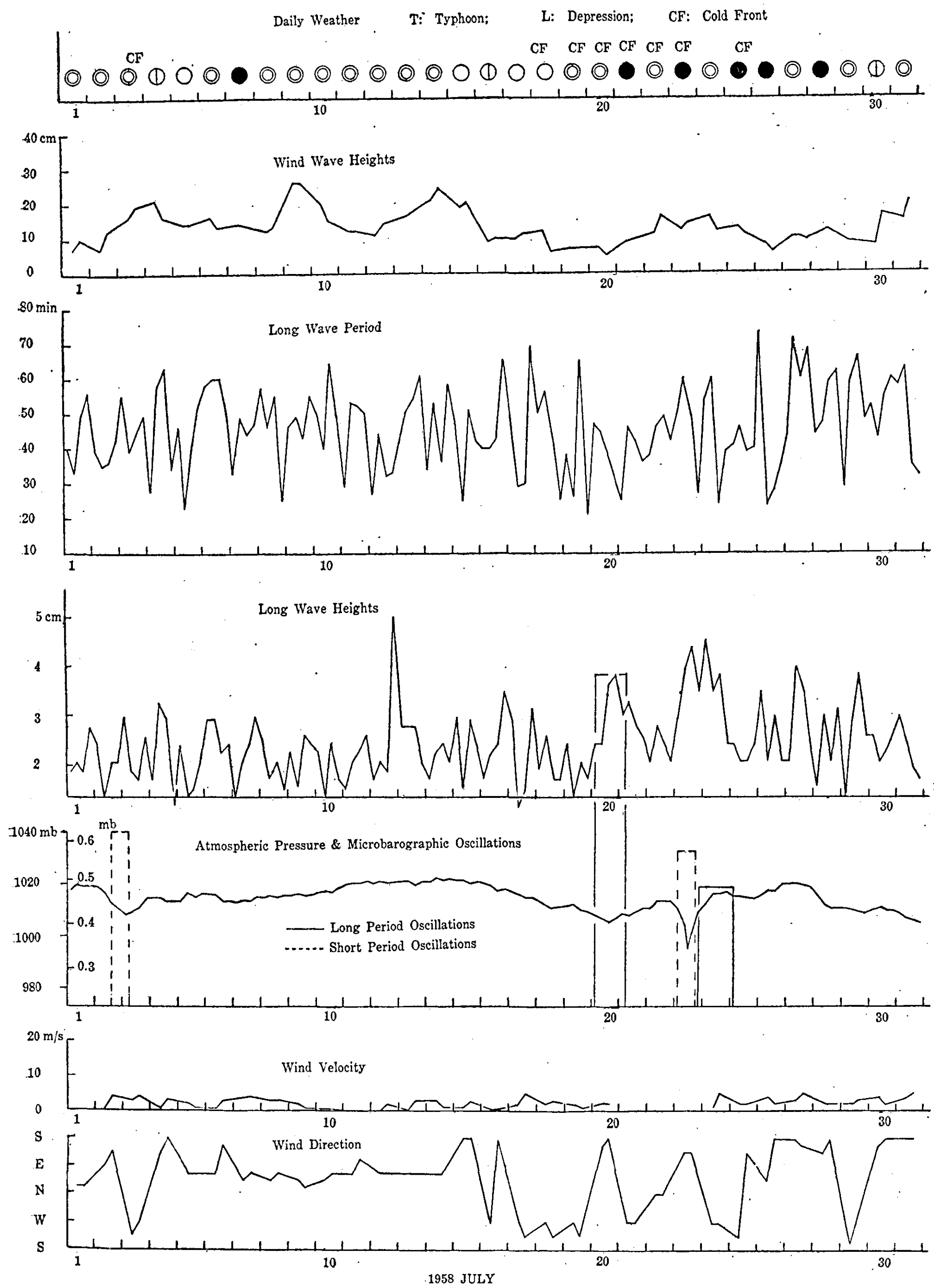

Fig. 22. Summary diagram of Long Period Wave Measurements at Miyagi-Enoshima in July 1958.

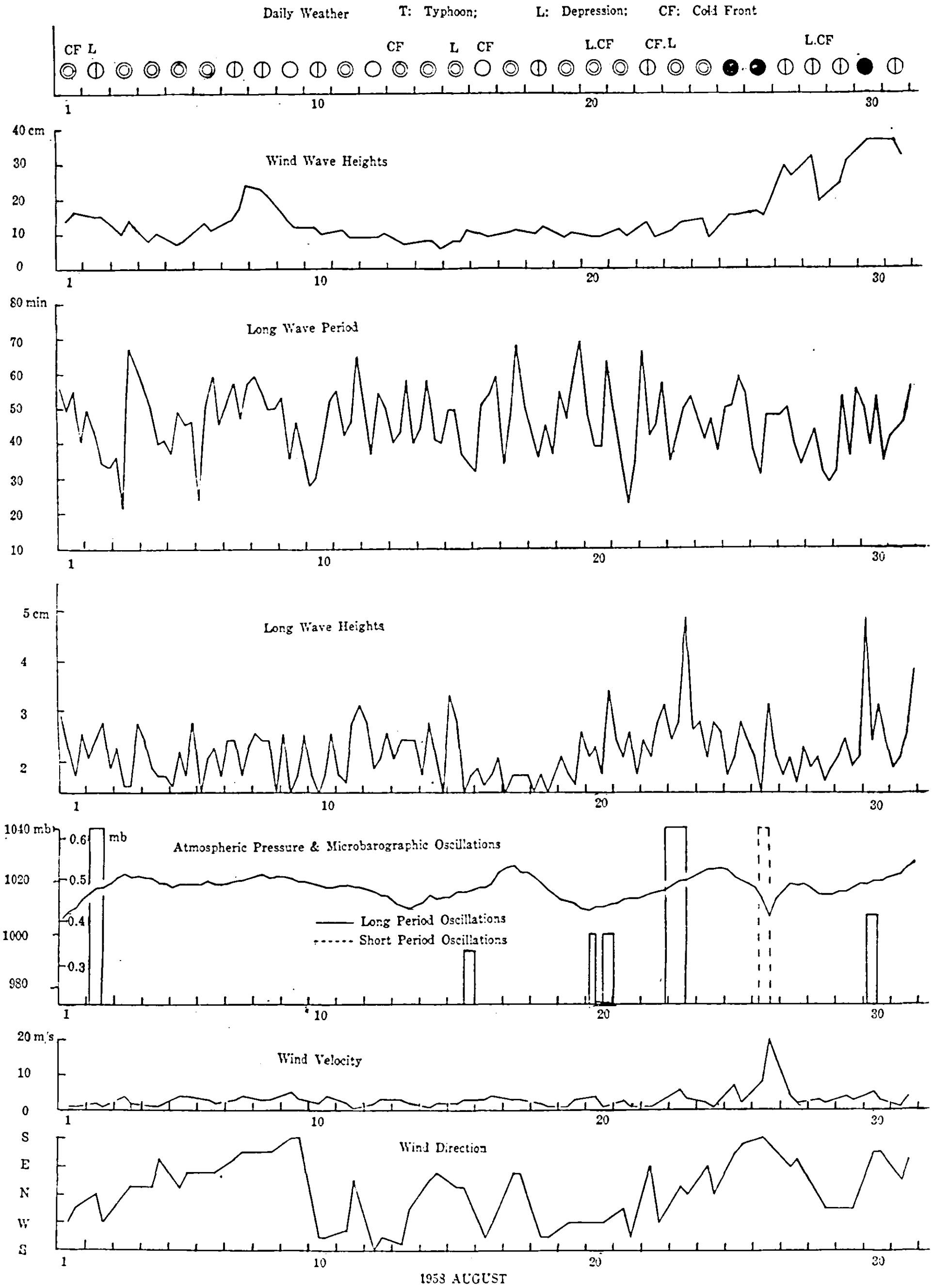

Fig. 23. Summary diagram of Long Period Wave Measurements at Miyagi-Enoshima in August 1958.

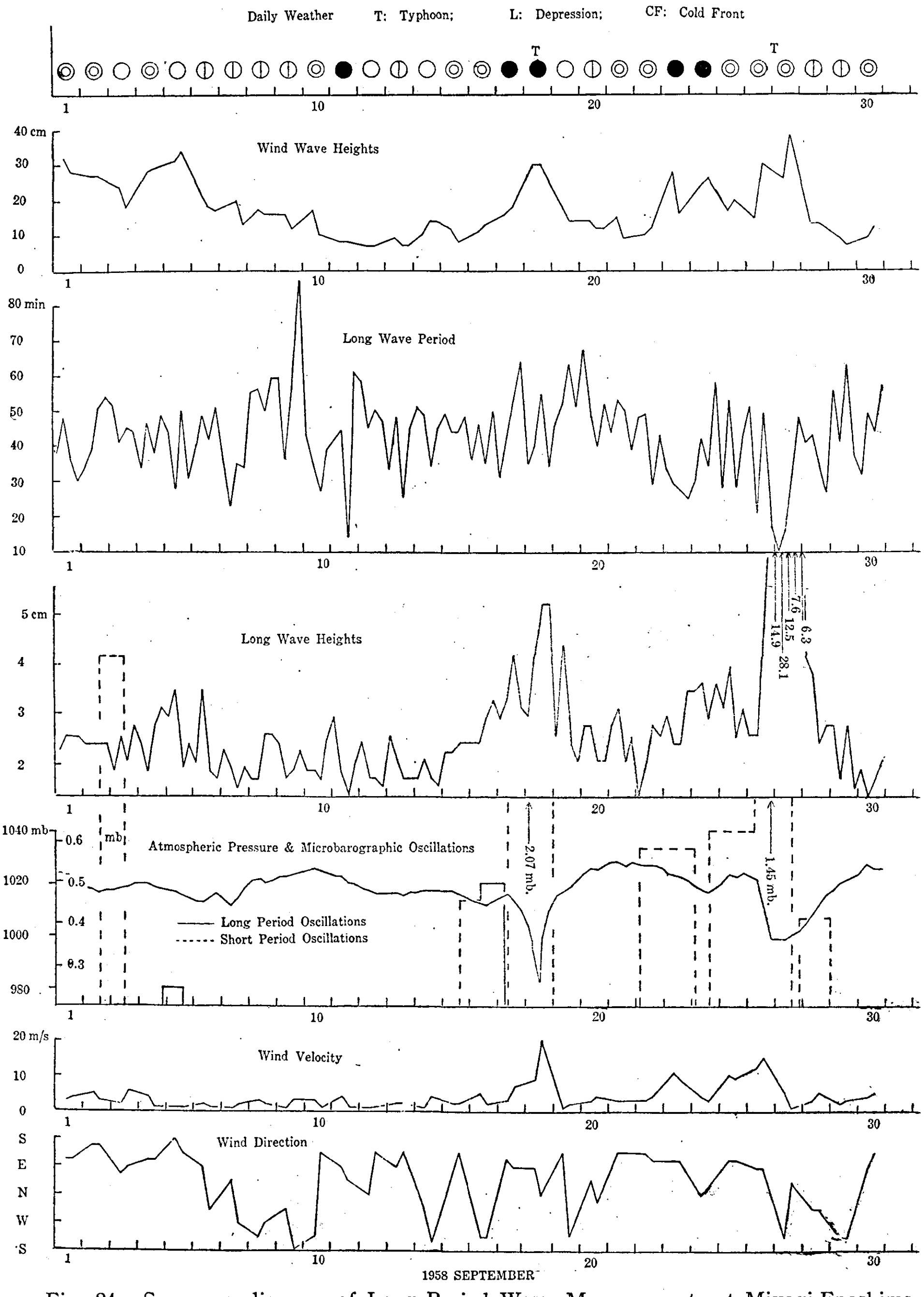

Fig. 24. Summary diagram of Long Period Wave Measurements at Miyagi-Enoshima in September 1958.

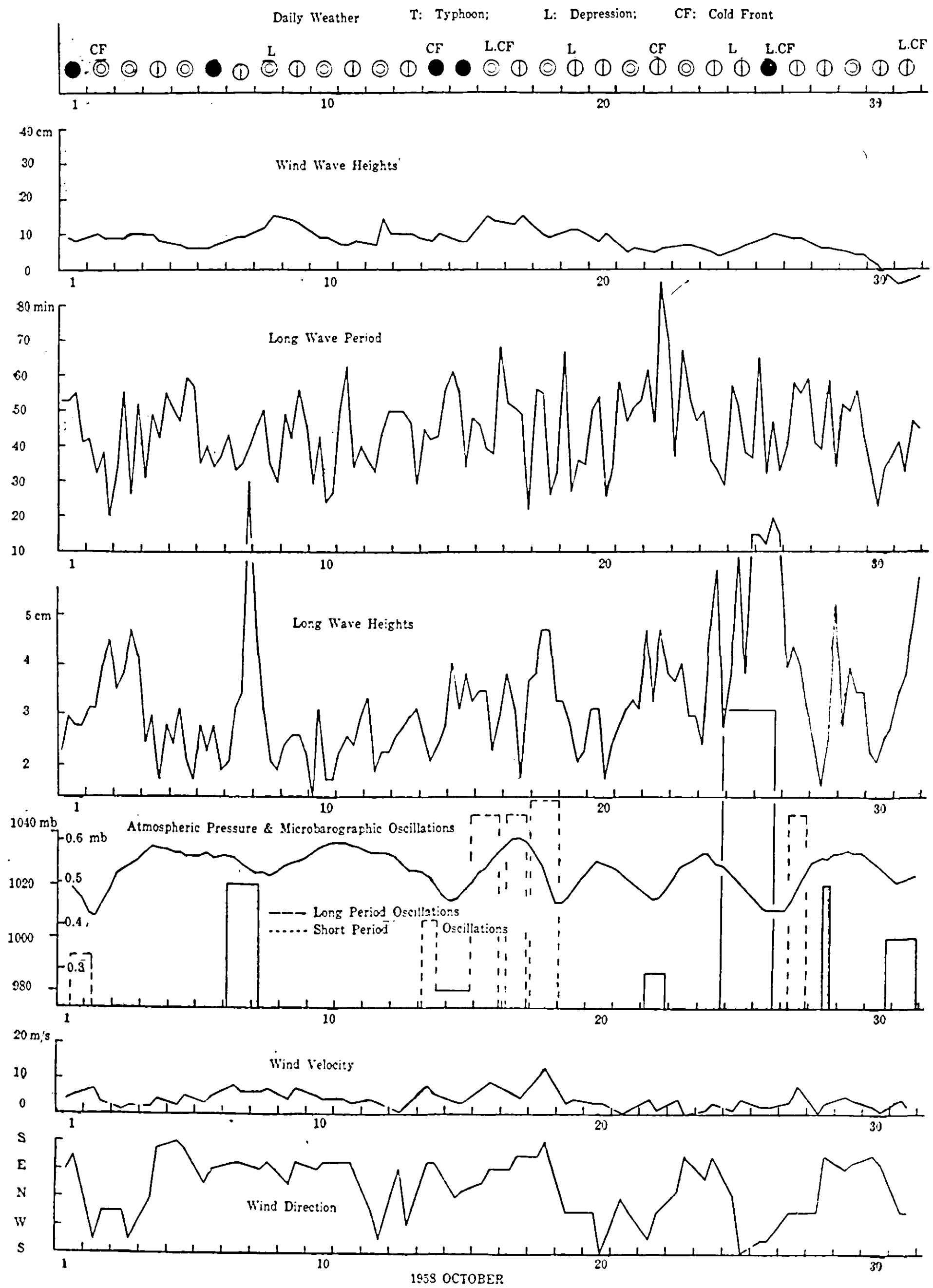

Fig. 25. Summary diagram of Long Period Wave Measurements at Miyagi-Enoshima in October 1958.

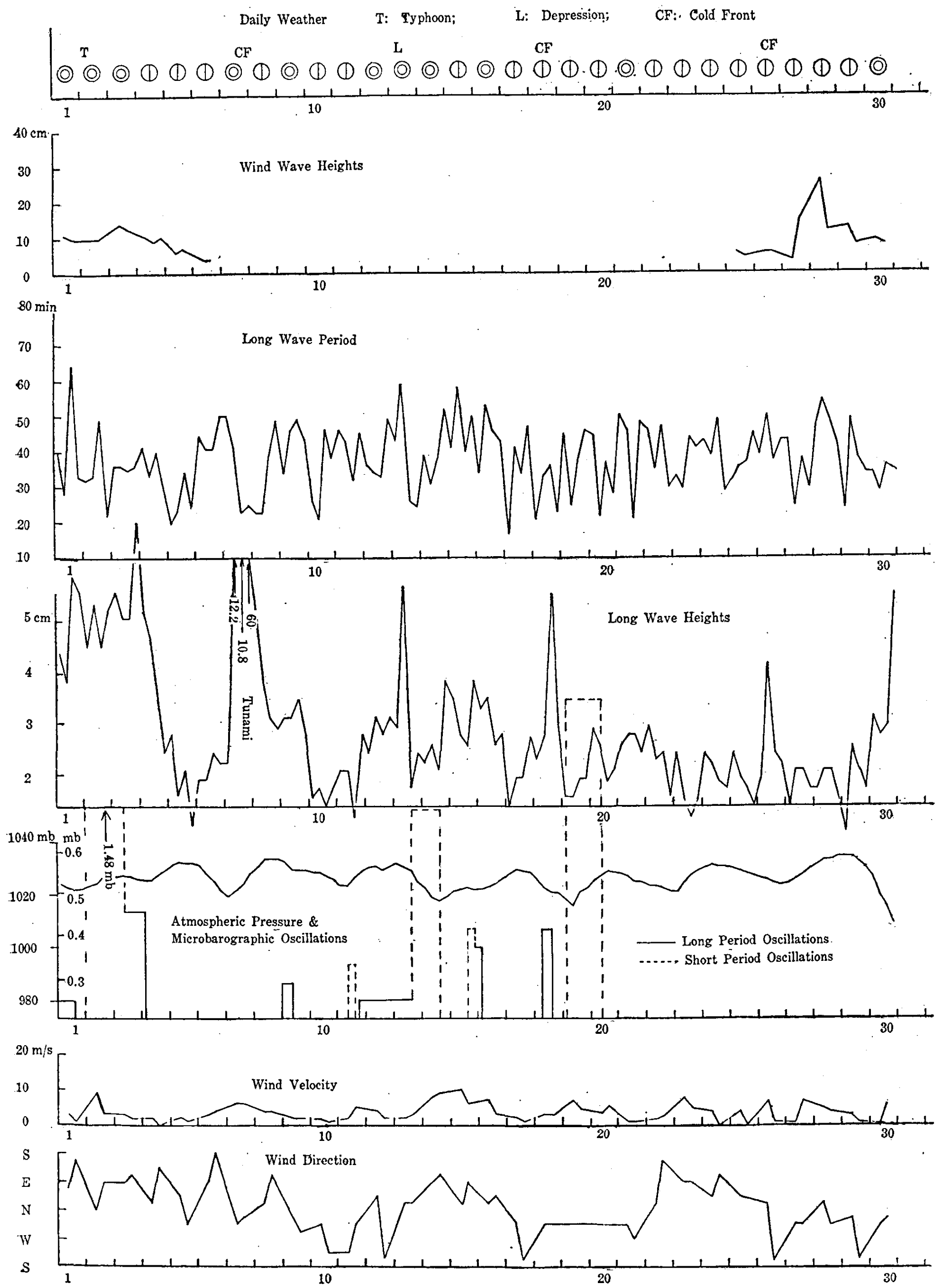

Fig. 26. Summary diagram of Long Period Wave Measurements at Miyagi.Enoshima in November 1958.

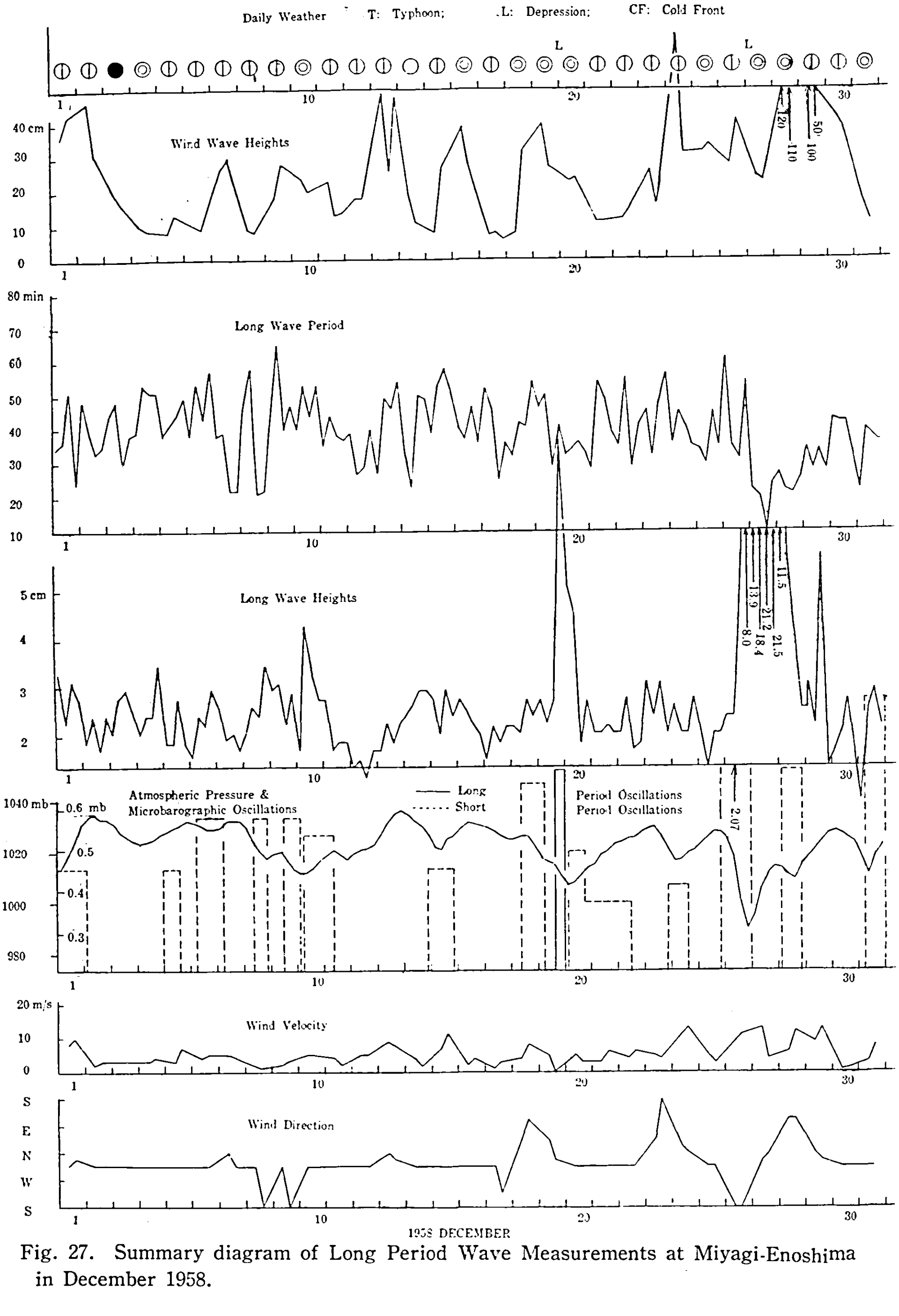

Fig. 27. Summary diagram of Long Period Wave Measurements at Miyagi-Enoshima in December 1958.

The daily weather at 0900 JST has been indicated by signs: ○ fine, ⦶ fair, ◎ cloudy, ● rainy and ⊛ snow fall. The abbreviations Cf. T and L noted in some places show respectively the passage of a cold front, a typhoon and a depression.

Wind wave observation was commenced in Aug. 1957. Waves have been measured at 0900 and 1500 on ordinary days, but on the world days after Feb. 1, 1958, observations at 2100 were added. Recordings were made for 20 min. centred at these time instants and the maximum heights during those 20 min. intervals have been plotted in graphs.

Records of the Van Dorn instrument were divided into intervals of 6 hours, divisions being made at 0^h, 6^h, 12^h and 18^h each day. Then the maximum wave height in each interval and the period of this maximum wave were plotted in the graph.

As to the atmospheric pressure, values at 0^h, 6^h, 12^h, and 18^h were read off on the daily records of the barograph and were plotted to show the atmospheric changes. Superposed on this atmospheric pressure curve, microbarometric oscillations are indicated by columns standing on the time axis. The height of each column shows the maximum double amplitude of the microbarograph oscillation while the width shows the duration of the oscillation. The full line column indicates the microbarographic oscillation of long period while the dotted line column indicates the short period oscillation due to the gustiness of wind. The microbarograph was installed in Sept. 1957, so in the first two months of the IGY, there is no observation of barometric oscillation.

Wind observations at Enoshima were commenced from October, 1957. For the first three months of the IGY period, therefore, wind data observed at Sendai, some 60 km distant from Enoshima, were used. For this period wind velocity and directions at 9^h and 21^h were plotted each day. After October 1957, values at 9^h and 15^h were read off and plotted on the diagram.

It can be seen from these summary diagrams that large long waves are mostly accompanied either by a low depression passing near Enoshima or by the passage of a cold front. In these cases atmospheric pressure usually falls and sometimes microbarometric oscillations are observable. We can see these features most clearly in the diagram of October 1957.

The passage of a typhoon in the near sea always causes remarkable long waves, which seem to occur from 1/2 to 1 day earlier than the full development of ordinary wind waves. Roughly speaking, there is a general tendency that the development and decay of sea and swell go parallel with long waves, but with a time lag of from 1/2 to 2 days.

There is also a tendency for the period of long waves to decrease with the increase in height. This is probably because meteorological disturbances tend more toward exciting the swell and the short period end of the long wave spectrum than the long period end of the long wave spectrum. The time lag seems merely to be due to the difference in propagation velocity of various waves.

Efforts have been made to identify the nature of these long waves, by installing portable long wave recorders at places 10～20 km. distant from Enoshima, but no decisive result has been obtained. They will probably be either edge waves or seiches inherent to the continental shelf along the Pacific side of Honshu, because we could seldom observe long waves of periods greater than 10 min. at Hachijo Island which stands on a deep ocean floor.

In ending this chapter, the writers wish to express their hearty thanks to Yoji Takahasi, for his devotion to the IGY long wave observations. The writers are also grateful to Dr. W. G. Van Dorn through the courtesy of whom we were able to use the long wave recorders during the IGY period.

---

16. 江の島津波観測所における IGY 期間中の観測

地震研究所 高橋龍太郎
平能金太郎
相田　勇
羽鳥徳太郎
清水静子

宮城県女川町の沖合 15 km にある離れ島，江の島で津波の観測を始めたのは，1941 年のことであつた．しかし不幸にして台風の際の激浪のため施設を破壊され，観測は翌 42 年に中止されてしまつた．しかし 1954 年に小規模の観測を復活した．その後 1957 年地球観測年にあたり，わが国における長波観測点に選ばれ，観測計器も充実された．IGY 期間中より現在まで同所で観測を行つている計器は， a) 震研Ⅲ型津波計 b) Van Dorn 型長波計，c) 波浪計，d) 微気圧計，e) その他気象観測計器類である．これらの計器の特性曲線は第 7 図に示してある．

江の島における長波の記録は，平常でも 10～70 分の周期にわたる， 海面の実振巾 3 cm 以下程度の波動が見られる．しかし 1958 年 9 月 27 日の狩野川台風，その他の強い低気圧が附近を通過した際は顕著な長波の発達が見られた．又 1958 年 11 月 7 日には，エトロフ島附近の地震による津波を観測した．その記録は第 9 図に示してある．

江の島において，種々な周期の長波が，常に現われるということは，江の島が本州東岸に沿つた陸棚の上に位置していることによると思われる．今この長波の消長と種々な気象的要素との関係を

見るため，江の島で観測した結果を， IGY 期間中の各月毎にまとめて図示したものが第 10～27 図である．これによつて次のようなことがわかつた．長波の振巾は低気圧或いは前線が江の島附近を通過すると大きくなる，殊に台風の通過の際は顕著であり，長波の発達は風浪の発達より1/2～1日早い．又長波の振巾が増大すると周期が短くなる傾向がある．

なお現地の観測は，高橋湯治氏が種々な困難な事情を克服して，熱心に遂行され，この期間中欠測無しという好成績を挙げられた．ここに特記して謝意を表する次第である．