SEISMIC METHODS OF TROPICAL CYCLONE INVESTIGATION

M.I.Yaroshevich, V.N. Yakhryushin
Institute of Experimental Meteorology
82, Lenin Avenue
Obninsk, Kaluga Region
249020, Russia
Tel: (08439) 7-15-44
Fax: (095) 255-22-25
Telex:412633 Institute Meteorology

KEYWORDS

tropical cyclones, hurricanes, typhoons, seismic methods, storm microseismic waves

ABSTRACT

An approach is described and illustrated for the study of tropical cyclones via microseismic processes occurring in the geophysical environment under their impact.

INTRODUCTION

Tropical cyclones (TC, hurricanes, or typhoons) can be related to major disastrous and destructive natural phenomena. A problem facing science is to develop techniques and facilities with the capability to diminish their tragic affect.

Solutions to this problem can be realized in two ways: the development of forecasts of tropical cyclones' movement and evolution; and the development of techniques of impacting cyclones with a view to weakening them.

DESCRIPTION OF THE PROPOSED APPROACH

Studies of TCs were started long ago. A certain ideology of studies has taken shape. But, tropical cyclones are far too complicated, and the processes occurring in them are serious research problems.

It is characteristic of TC studies, particularly, that they always deal directly with the processes occurring in the centre of a TC or in its close periphery, and are based on the results of direct measurements. Measurements of the parameters are made at sites of stationary observations, on board a ship or an aircraft, or via satellite. Stations for making constant meteorological observations are mainly located on the continents and are often far from the active zone of TC development, which cannot but influence information authenticity. Aircraft and ship cruises are rather rare. For effectiveness they must be carried out on a regular and constant basis, but that requires great financial means. There are also problems with satellites' observation facilities. We believe that for studying such a complex subject as TCs, some principally new techniques are needed along with those used previously.

TCs are not isolated phenomena; and, having great energy, they influence the processes occurring in the ocean and the Earth's crust, the relatively remote lower atmospheric periphery, possibly the ionospheric layers, etc. (Khain and Sutyrin 1983, Yeruschenkov *et al.* 1990).

The proposed approach is that TCs should be studied via the processes occurring in the geophysical environment under their impact. In fact, this approach is tackling the inverse task. The usefulness of such an approach is quite reasonable. Reasoning from the reactions occurring in the geophysical environment, it is possible to detect new particulars of TCs. Besides, TC studies involve facilities and techniques applied in allied geophysical branches.

It has long been known that TC movement has an effect on layers of the Earth's crust through the ocean. Under such a process microseismic waves are produced—storm microseismic waves (SMW) (Tabulevich 1986)—which have been studied long ago. Seismologists tackled different problems, related naturally to seismology. Technical means of SMW registration and processing could not at that time lead to essential results of an applied character.

Presently, the situation has substantially changed. Many seismic stations perform registration of data in a digital computerized form on a regular round–the–clock basis. A great number of seismic stations can be counted today and the tropical zones are fairly covered by them. In contrast to meteorological stations, the distance from seismic stations to a tropical cyclone is of no importance under certain adjustments of instruments. It would be rather more important to know the seismic tracks. The real distances of TC tracks to many stations in combination with seismic waves' speed suggest the possibility of SMW registration a on real–time basis. The seismic stations are generally provided with computers and reliable communications facilities, which is of vital importance under simultaneous fast processing of data for a number of stations. Information on the earthquake is valuable for seismologists; the information we need is considered as background for seismologists, hence expenses for its acquisition are relatively small. The above considerations clearly demonstrate the possibilities of seismic stations in studying TCs.

Before going into investigations of SMW we stated a number of problems: to find out what new information on TC structure or developing processes can be obtained via seismic research techniques; how it is possible to produce fast evaluation of major TC parameters based on seismic information; and, what would be a research policy. Thus, our tasks differed from those which had been carried out by seismologists previously: they should principally be of an applied character.

Archived seismograms have been used in the work which had been recorded at a number of seismic stations in the USA, Japan, and China. We needed seismograms for the days when particularly powerful TCs occurred. But the archive has been based on earthquakes. That is why most often we had to choose seismic information which did not correlate with TCs of interest to us, and we had to consider the cyclones for which information was available.

We considered seismogram fragments of one hour with a discrete spacing of one second. Two fragments were analysed daily: at 00.00 and 12.00 GMT. Below the results are briefly given by fragments.

DETECTING AND TRACING TROPICAL CYCLONE MOVEMENT

A variant of the TC detection technique is proposed as well as tracing its movement using SMW parameters.

A region is chosen, characterized by high occurrence of tropical cyclones. It may be, for example, the region confined within a rectangle of 0–50N and 100–180E. A set of seismic stations is then selected, preferably those disposed bilaterally along the chosen region for all stations. The region is divided into squares, e.g. 2x2 degrees. The distance from the station to the center of each square is calculated for all stations. For any fixed point in the region the ratio between SMW amplitudes registered at two stations (for one and the same period, T) is a constant value and does not depend on the source energy. For the center of each of the squares the ratio of amplitudes is calculated in pairs for all stations combined in any way (Yaroshevich *et al.* 1994):

$$\frac{A_{ik}}{A_{jk}} = \frac{R_{jk}^2}{R_{ik}^2} \times \frac{\beta + R_{ik}\sqrt{R_{ik}}}{\beta + R_{jk}\sqrt{R_{jk}}} \exp\left[\alpha(T) \times \frac{\left|R_{jk} - R_{ik}\right|}{2}\right] \quad (1)$$

where A_{ij} is the amplitude of a microseismic wave at the proper station for a specific period T; R is the distance from the source of SMW to the observation point; $\alpha(T)$ is the coefficient of SMW attenuation; β is a coefficient characterizing the relationship among volume and surface waves; i,j is the station's numbering; and, k is the number of the square. A great diversity of values (1), determined by the number of stations, squares, and values T, is entered into a personal computer.

Using values A (for the same values of T) measured at different stations within one and the same GMT period (1-2 hours), the relations $(A_i/A_j)m$ are arranged in pairs for each pair of stations. With the help of a computer the area of possible source position is determined using the following inequality:

$$\left|\frac{A_{ic}}{A_{jc}} - \frac{A_{im}}{A_{jm}}\right| \leq \sigma \quad (2)$$

where (A_{ic}/A_{jc}) and (A_{im}/A_{jm}) are calculated from (1) and the relation of the measured amplitudes, respectively, and σ is a specified range of the values' spread. The overlapping of areas, determined from (2) for all pairs of stations, detects the decreased area of SMW source location. The size of the decreased area is governed by an optimal number of stations, sets of values A and T, and accuracy in their measurement. The first TC position can result in an area of about 10x10 degrees square.

This is an important result which makes possible fast detection of an area of particular interest to the scientists studying TCs, and to meteorological and navigational services. On occasion, specialists studying tsunamis of meteorological origin should be aware of this.

Further tracking of TCs is somewhat easier. The calculations are made within a reasonable vicinity of an area of the initial TC position. This vicinity is determined from the time interval between the earlier and later determination of TC position, possible speed of its movement, and an operator's skill.

At the very start of technique testing we had a rather small amount of information; the number of stations was also insignificant. As a result, the discrepancy between TC coordinates, determined on the basis of meteorological data and SMW, was relatively large and amounted to 3-4. With sufficient amounts of information, an optimal number of stations, and thorough determination of parameter values A and T, the accuracy of calculating TC positions will be improved. Of prime importance in this technique is the possibility of constantly tracking TC movement.

ON THE PERIODS OF STORM MICROSEISMS

It is commonly supposed that the source of SMWs is the TC; SMWs are directly generated by wind oceanic waves produced by cyclones. For the most part, the total energy of wind waves is in the range of periods of about 4-25s, which are probably considered as a range of SMW periods. The best known theories of the mechanism generating SMWs are related to the theory of standing wind waves, emerging mainly in the rear part of TCs, and a "surf" theory. According to the first theory, periods of SMWs are two times less than those of wind waves. By the second "tidal" mechanism, SMWs with periods of approximately 20s are generated at the expense of hurricane waves moving from TCs to the shelf (Tabulevich 1986).

The spectral analysis of SMWs suggested that under great changes of TC intensity the values of SMW amplitudes within 4-6s should change the same way, which is consistent with either of the two theories mentioned above. However, we have detected waves whose period was several tens of seconds. As a TC is strengthened (or depressed) the range of amplitudes is identically changed within great and small periods (Fig. 1). Reasoning from this, we can come to the conclusion that the whole range of SMWs under consideration (4-100s) is of a common origin—tropical cyclones.

The result obtained is an interesting one by itself, but needs further investigations to be made. The result was found useful in solving one applied task given below.

In the given context two notes should be made. SMWs with periods of tens of seconds can not be accounted for by the above theories, hence it is necessary to specify the mechanism generating storm microseisms. And second, for many years seismic information has been registered via photorecord. The microseisms' parameters have been manually registered and strictly within the ranges where the latter were distinctly viewed. Considering the amplitude and frequency characteristics of the available seismographs, the representative ranges of SMWs could hardly be obtained. Only at present has it become possible, solely on the basis of information from those stations where the data are registered on computer media, and under certain characteristics of the seismographs.

ON THE SIGNS OF IDENTIFYING STORM MICROSEISMS

It is in fact an ordinary matter that a seismogram results from the superposition of a number of seismic signals (earthquakes, their "tails", SMWs, etc.). We had to produce signs for identifying the sources against the background of the seismograms, since an analysis of SMWs is justified only if other signals can be neglected. It is particularly difficult if the values of SMWs and the earthquakes are comparable.

It appeared that spectral analysis would allow us to come close to solving this problem. We succeeded in finding out the fact that in the absence of clear evidence of earthquakes, the amplitude spectrum of SMWs in the range of periods of 4–80s has one pronounced peak within a range of 5–8s. This situation occurred when no severe or close earthquakes took place for approximately 5–10 hours prior to the analyzed fragment of SMWs. In Fig.2 the amplitude spectra (in representative units) of SMW seismograms registered at several seismic stations are given.

Typically, no severe earthquakes had been identified since long before these seismograms were registered according to the "Seismological Bulletin." Thus, it is believed that the prevailing signals on the seismograms are those of SMWs. In Figures 2a, 2b, 2c, and 2d, SMW spectra are given for 00.00 GMT 28.09.1992 (TC "Ward") at the following stations respectively: "MAJO" (36,542N-138,209E), "ANMO" (34,946N-106,456W), "PAS" (34,148N-118,172W), and "KIP" (24,423N-158,015W); in Figure 2e and 2f, for 12.00 GMT 20.11.1992 (TC "Gay") at stations "PAS" and "KIP," respectively. It is seen from these Figures that despite the different geographical locations of the seismic stations, the effect is identical.

If an earthquake occurs, two and more clearly pronounced peaks emerge in SMW spectra. The first one is produced at the same area that would prove a cyclone "presence;" the rest of other peaks are shifted to the area of large periods, 20 and more seconds (Fig.3). Most often this takes place when an earthquake occurs shortly before the SMW fragment is considered, or if a severe earthquake occurs. The height of peaks in a spectrum depends on the source's impact and the form of frequency characteristics of the seismographs.

In Figure 3 the spectra of SMW amplitudes are given for (22.11.92, 12.00 GMT) seismostations "PAS" (1) and "KIP" (2). These seismograms are probably suggestive of certain impacts of the earthquake "tail."

Thus, we have obtained the first possibility of fast–detecting seismograms using the spectrum, where the main signal is that of SMW. Applying such seismograms we improve the accuracy of determination of TC parameters, thereby increasing the efficiency of calculations for TC forecasting. Apart from this, the results obtained may also prove to be interesting for seismology.

ESTIMATION OF VARIATION IN TROPICAL CYCLONE INTENSITY

Along with determining the TC position, a possibility of estimating the relative variation of its intensity has been identified. Considering the typical speed of variation in energetics' parameters of TC intensity, it would be sufficient to make estimation of it every 3–4 hours.

We have shown that with the "classic" periods of SMWs (5–10s) TC intensity variations are not necessarily tracked against the amplitude background. This occurs more often than not within the periods 60–100s, which once again proves their cyclone origin (Yaroshevich and Yakhryushin in publication).

But in some cases, it has been found that with the increase of TC intensity the values of amplitudes have suddenly been decreased for the whole range of periods. This has been noticed on all sides of the cyclone, which relates in our opinion to the mechanism of SMW generation within a wide range of frequencies. We have noticed that more effective in tracking the TC intensity was the parameter characterizing the relationship between the mean amplitude (amplitude square) calculated for the range of large periods (e.g. 60-100s), and the amplitude similarly calculated for the range of small periods (e.g. 10-15s).

The above considerations are demonstrated in Figures 4a and 4b with the cyclone "Omar" (1992) taken as an example. It should be noted here that only those days have been considered, as in other cases, when no extraneous signals were observed in seismogram spectra.

Curve 1 in Figure 4a is the lapse of pressure (DeltaP = 1020 mb – Pmin); where, 1020 mb = pressure outside the cyclone; and, Pmin = pressure in the center of the cyclone (one of the characteristics of TC intensity). The curves of squares ratio for mean amplitudes (A1*A1/A2*A2): are also given here; curve 2—station "KIP," where A1 is calculated for the range of periods 50–120s, and A2 for the range 10–12s; and, curve 3—station "ANMO," where A1 is calculated for the range 50–120s, and A2, 12–15s.

In Figure 4b the dynamics of mean amplitude A (representative units) are shown for the station "ANMO" for the same days: 1,2,3 correspondingly for the ranges 5–6s, 50–120s, 12–16s. It is seen from the Figure that for the given case, mean amplitudes for both small and large periods are not characteristic of the development of cyclone intensity. The marked trend of cyclone activity would rather be tracked via the ratio of amplitudes. In many papers published long ago, it was noticed that with cyclone escalation, a rise of amplitudes within "classic" periods of SMWs was also observed. Altogether, we do not deny this fact. But one point should be noted: in those papers the comparison was generally given of the days for which the difference in values of Pmin was maximal. As to us, we were striving to find out characteristics of minor variations in the development of cyclone activity.

It is necessary to emphasize that every station is characterized by its individual particulars. That is why the range of periods as well as types of seismic channels should be thoroughly selected for each of the stations.

CONCLUSIONS

If we consider the results given in the context of their applied usage we may speak of the beginning of TC investigations via seismic techniques. Active studies in this field would tangibly promote not only TC investigations, but undoubltly enrich the knowledge of the processes occurring in the allied geophysical environment. Deepening of those studies may be of interest to the USA, Japan, China, and other countries, particularly to their meteorological and seismic services.

REFERENCES

Khain, A.P. and G.G. Sutyrin. 1983. "The Tropical Cyclones; Their Interaction with the Ocean." *L. Gidrometeoizdat,* 271.

Tabulevich, V.N. 1986. "Complex Studies of Microseismic Oscillations." *Nauka,* Novosibirsk, 151.

Yaroshevich,M.I., V.D. Feofilaktov, and V.N. Yakhryushin. 1994. "On Seismic Estimation of Certain Features of the Tropical Cyclones." *Vulcanologia and Seismologia,* no. 3: 90–97.

Yaroshevich,M.I. and V.N. Yakhryushin. (In publication)."On Expanded Range of Storm Microseisms." *Izvestia of the Russian Acad. of Sci., ser. Earth Phys.*

Yeruschenkov, A.I., M.I.Yaroshevich *et. al.* 1990. "Infra–Sound and Storm Microseismic Oscillations Emerging Under the Cyclone (Typhoon) Movement Over the Oceans." *Physics of the Atmosphere and the Ocean 26,* no. 6: 644–651.

FIGURES

Fig. 1. Amplitude spectra of SMW registered at the "ANMO" station:
1 - September 28, 1992, 00 GMT, Pmin = 990 mb;
2 - October 3, 1992, 00 GMT, Pmin = 945 mb.

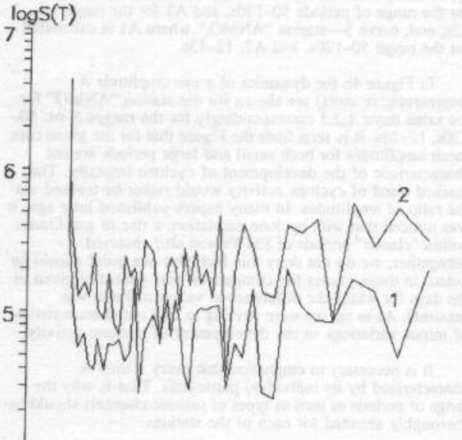

Fig. 2. Amplitude spectra of "pure" SMW from different seismic stations.

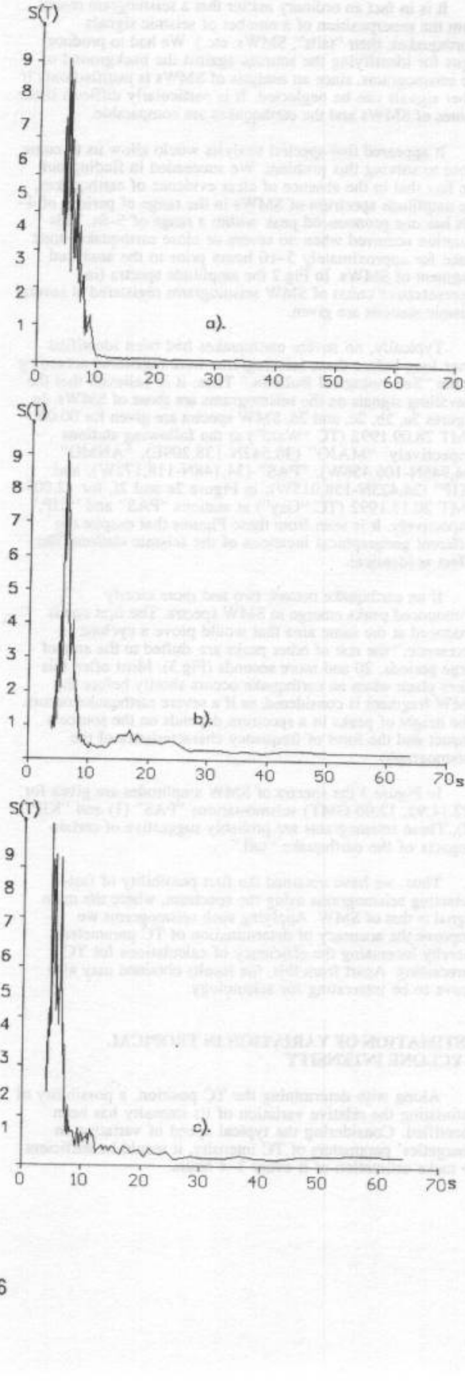

Fig. 2 (continued).

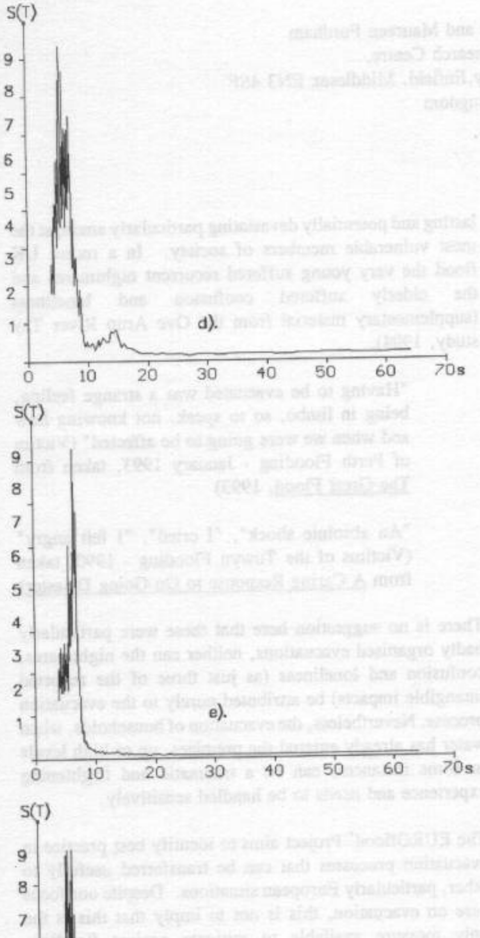

Fig. 3. Amplitude spectra of SMW in the case of superposition of signals.

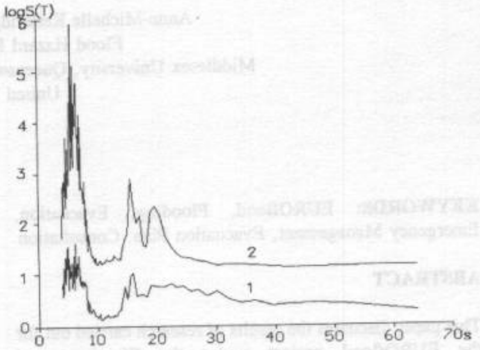

Fig. 4a. Pressure drop (DeltaP) in cyclone (1); ratio of squared average amplitudes of SMW from the "KIP" station (2), and from the "ANMO" station (3).

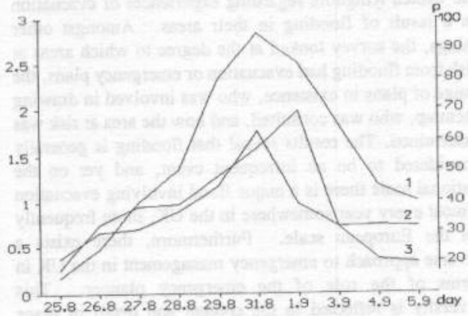

Fig. 4b. The change in the average amplitudes of SMW over the ranges:
1: (5–6)s; 2: (50–120)s; 3: (12–15)s.