巨大地震による地殻変動から発生した、長周期大気波動の伝播

三 雲　健 (1953 年卒)

2014 年 3 月 15 日に、地球物理同窓会(知球会)において、標記のような題名で講演を行ったので、その概要を以下に記します。

内容は、次の 4 回の巨大地震の際に国内や IMS(International Monitoring System) の観測点で観測された気圧波から、bandpass-filtering によって acoustic mode と gravity mode の波を検出したこと。一方では地震学的、測地学的に推定されるこれらの震源域から発生したと考えられる気圧波の理論波形を計算して、観測波形と比較し、これらの波を発生させた地殻変動の振幅と時間関数（ライズ・タイム）などを推定しようとしたこと。あわせてこれら 4 回の巨大地震のパラメタに特徴的な差や共通性が見られるかを追求しようとしたものである。これらの巨大地震は、

1. 1964 年 03 月 28 日 Alaska 地震 (Mw=9.2)
2. 2004 年 12 月 26 日 Sumatra-Andaman 地震 (Mw=9.2)
3. 2010 年 02 月 12 日 Maule, Chile 地震 (Mw=8.8)
4. 2012 年 03 月 11 日 東北地方太平洋沖地震 (Mw=9.0)

これらの研究の詳細については、原稿登稿中の No.3 の場合を除き、すでに以下の論文に掲載しているので、その Abstract をそのまま載せることとした。

（1）

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Atmospheric Pressure Waves and Tectonic Deformation Associated with the Alaskan Earthquake of March 28, 1964

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Atmospheric pressure disturbances with periods as long as 14 min have been recorded by sensitive microbarographs at five stations along the Pacific coast and at a station in Alaska after the great Alaskan earthquake of March 28, 1964. The phase and group velocities of the disturbances are consistent with those so far observed in atmospheric nuclear explosions and with theoretical dispersion curves for acoustic-gravity waves. These velocities and field

observation of the tectonic deformations in the epicentral region suggest that the pressure disturbances might have been caused by the rapid vertical ground displacement at the source area. Theoretical barograms appropriate to the Berkeley station have been constructed on the basis of reasonable estimates for the source dimension, the amount of uplift and subsidence, and the time rate of the displacement, taking the atmospheric and instrumental responses into account. Agreement between general features of the observed and theoretical barograms appears sufficient to support the above generation hypothesis, suggesting a possible range for the time rate of the surface tectonic deformation.

(2)

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Low-frequency acoustic-gravity waves from coseismic vertical deformation associated with the 2004 Sumatra-Andaman earthquake (M_W = 9.2)

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Atmospheric pressure perturbations from the 2004 Sumatra-Andaman earthquake (Mw = 9.2) were observed by sensitive microbarographs at several global stations. Among these observations, very low-frequency acoustic-gravity waves (1.4–2.8 mHz) with a group velocity around 300–314 m/s and amplitudes ranging between 1 and 12 Pa can be clearly identified through data processing at four stations on the Japanese Islands and also at four International Monitoring System (IMS) stations around the Indian Ocean.
Assuming several seismic source parameters for this great thrust earthquake, we produce synthetic barograms using a realistic thermal structure in the atmosphere up to an altitude of 220 km. For this modeling, we incorporate the source dimensions in different zones, the expanding velocity of the source region, the vertical displacements of uplift and subsidence, and their time constants. Combinations of these source parameters provide synthetic waveforms consistent with the general features of the observed low-frequency records. The results clearly indicate that the recorded waves may have been generated by large-scale coseismic uplift and subsidence of the sea bottom and associated swelling and depression of the sea surface over the source region extending for 1500 km. The uplift in the south-central zone of the Andaman-Nicobar regions may be substantially larger than in the other zones. The time constant of the coseimic vertical deformation is found to be in the range of 1.0–1.5 min, which may correspond to the time elapsed shortly before the generation of tsunami waves.

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Atmospheric Gravity Waves from the 2010 Maule, Chile earthquake (Mw8.8)

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Low-frequency atmospheric pressure waves were recorded after the 2010 Maule, Chile earthquake (Mw=8.8) by microbarographs at seven International Monitoring System (IMS) stations in the distance range up to 7,680 km. By applying bandpass-filtering, we extracted gravity waves, removing atmospheric noise and higher-frequency acoustic modes, and then estimated their phase velocities as around 332-341 m/s. To compare with these observations, we constructed synthetic waveforms, referring to the source dimension and coseismic vertical ground displacements based on geodetic measurements, with incorporating a standard atmospheric sound velocity structure up to a height of 220 km. The comparison between the observed and synthetic waveforms provides generally satisfactory agreement, and suggests the time constant of vertical ground displacements between 3 and 2 min both in the northern and southern segments of the entire source region extending for about 500 km.

(4)

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Acoustic-gravity waves from the source region of the 2011 Great Tohoku earthquake (Mw=9.0)

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Atmospheric pressure waves were recorded within 5 h after the 2011 great Tohoku earthquake (Mw=9.0) by sensitive microbarographs at four regional stations and eight International Monitoring System stations at distances up to 6700 km. While its apparent phase velocity between the regional stations is 341 m/s, the global stations include weak dispersive wave trains with low frequencies between 1.6 and 4.8 mHz, propagating with an average phase velocity around 364 m/s. The low-frequency waves may be interpreted as acoustic-gravity waves excited by upheaval and depression of the sea surface in the source region due to coseismic uplift and subsidence of the sea bottom during this great thrust earthquake. Assuming the source dimension and the average coseismic vertical displacements of the sea surface, with reference to tsunami observations, we calculate

synthetic waveforms for some of the far-field stations by incorporating a standard sound velocity structure in the atmosphere up to an altitude of 220 km. The synthetics provide reasonable explanations for the general features of the observed waveforms, suggesting possible ranges for the source parameters generating these acoustic-gravity waves. Our analysis suggests that the average initial upheaval of the sea surface in the central zones of the source region may exceed 4-6 m and that the risetime of the coseismic deformation may be in the range between 3 and 4 min. In the eastern zone adjacent to the Japan Trench, the deformation has significantly higher initial amplitude and shorter risetimes.

上記の 4 回の巨大地震は、何れも海洋プレートが大陸プレート下に沈み込む際に 2 つのプレート間の広大な領域に発生した逆断層運動によるもので、megathrust earthquake とも呼ばれるものである。これらの逆断層の傾斜角は地震波の解析から 15º-40º 、傾斜する断層面の面積は地震毎に異なる。これに伴って発生する海底の隆起と沈降を生ずる領域すなわち震源域の広がりは(200-500) km x (100-200) km を占めることが多く、ここでの隆起量は 3-8 m, 沈降は 1-3 m 程度と推定されている。この海底と海面の隆起と沈降によって、これに接する大気の擾乱が気圧波を発生させると考えられるが、この大きさを直接支配するのがこの平均変動量と時間関数(ライズ・タイム)であり、さらに気圧波を有効に発生する領域の面積と震源域の面積の割合がこれらを支配する。これらの巨大地震の場合の震源域の大きさと変動量は上に述べたように、地震毎にかなり異なるが、ライズ・タイムは何れも 1.5 –3.5 min（＜最大 4 min）程度の範囲内にある。2010 年 Chile 地震の場合は、断層面の傾斜角が比較的浅く、したがってこの規模の大地震としては海底の隆起量があまり大きくなかったために、気圧変動もあまり大きくなく、acoustic mode が十分には検出されず、重力波のみを取り上げた。

なおこれらの論文の和文による概要(添付図なし)は、2013 年 12 月に全国日本学士会から刊行された ACADEMIA No,143 のpp.17-27 に「グローバル地球観測から見た、大地震と気圧波の発生」と題する筆者のレビューにも述べられているので、関心を持たれた方はそちらも参照して頂ければ幸いです。このレビューの内容は

1. グローバル観測網
   1.1.グローバル地震観測網、1.2 グローバル地球測位システム、
   1.2.グローバル気圧波観測網
2. 大地震と気圧波の発生
   2.2 プレートテクトニクスと大地震
   2.2 巨大地震による長周期気圧波の発生
   この中に上記の 4 回の巨大地震の場合を含む

3. 初期の気圧波観測と波動伝播理論
   3.1 初期の気圧波観測
   3.2 気圧波伝播理論
   3.3 短周期気圧波、および地震レイリー波のよって
        励起された気圧波
   3.4 大地震のよって発生した音波・重力波の電離層への伝播
4. まとめと今後の課題
   参考文献

なおこれらのうちの一部は、別にすでに「京大地球物理学研究の百年(II)］(竹本修三、広田　勇、荒木徹編) pp.45－54、およびさらに詳しくは日本地震学会会誌「地震」第2輯第64巻、pp.47-62にも「大地震、津波、火山大爆発などから発生した気圧波」として掲載されているので付記しておきたい。

(以上)