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学 位 論 文 題 目	Result of the Antarctic VLBI experiments during JARE39 and their geodetic interpretations
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論文内容の要旨

Antarctica, most of which is covered with thick ice sheet, is a geologically distinct continent from the others and its characteristics have not been well revealed yet. In order to uncover interesting Antarctic tectonics, which are motion of the Antarctic plate, intra-plate deformation and uplifting by the Post Glacial Rebound, space geodetic methods play more important role than those for the other continents.

The Antarctic plate is unique because it surrounded by the expansion area. There have been established several GPS and DORIS points in Antarctica. It has been reported that the crustal velocities in Antarctica acquired by these space geodetic points does not show the systematic residuals after subtracting fitted rigid plate motion. Also, shortness of the observation period prevents interpretations of more complicated movements.

Current uplifting velocity of the Ongul Islands periphery was not clarified. Tide gauge's data that is recorded at Syowa Station shows subsiding of the sea level at a speed of 9.5mm/y. However, the observation period is not long enough to obtain a quantitative estimate. This result is larger than the averaged uplifting speed of 4mm/y, which is estimated as the Postglacial Rebound by geological survey in the Ongul Islands periphery.

Syowa Station is built on a continental shield formed by old rocks. Generally, such a place is geologically very stable. Four space-geodetic techniques, which are GPS, DORIS, PRARE and VLBI, establish the observation points on the base-rock in Syowa Station. Accordingly, this Antarctic station is one of the largest space-geodetic observatories in Antarctica and plays the central role to the clarification of the Antarctic tectonics.

Among the space geodetic techniques, VLBI occupies a distinct position that it can directly determine positions on the Earth's surface with respect to a quasi-inertial reference frame realized by positions of extra-galactic radio sources. Then VLBI is free from the influence by the fluctuation of the Earth's gravity center. This is the important characteristic that differs largely from other space geodetic techniques that the satellite's orbits used as the reference of measurement method. Accordingly, it is expected that the VLBI's results become a reference to the other space geodetic techniques' in Syowa Station.

Also, because there are only a few VLBI stations in the southern hemisphere, the accuracy of the radio reference frame is worse compared with that in the northern hemisphere. As the south extremity of VLBI stations, Syowa Station is expected to play very important role in the construction of an accurate reference frame in the southern hemisphere.

The multipurpose 11m parabolic antenna at Syowa Station is one of the most important geodetic instruments in Antarctica since it is the only antenna for VLBI in East Antarctica..The first experimental VLBI observation was carried out in January, 1990 by JARE30 and the position of the VLBI reference point was estimated. However, after this experimental observation, logistic difficulties and severe observational environment made subsequent VLBI observations abandoned until 1998. The regular VLBI observation project using this antenna started by JARE39, as a core of the research project for monitoring motion of the Antarctic plate and crustal movement around Lützow-Holm BayThis project is called the Syowa experiment. During the summer operation, the VLBI observation system including hydrogen maser frequency standards was built up and its performance was checked. JARE39 brought two hydrogen maser frequency standards to Syowa Station and installed them in the seismograph room. Other equipments such as the front-end, the back-end and antenna control system were also installed in the 11m antenna and the satellites data reception room. It is the first case that a complete system for geodetic VLBI observation including two hydrogen maser frequency standards was installed at Syowa Station.

An important characteristic of the Antarctic VLBI network is that two different types of data recording system, namely, K4 at Syowa and S2 at Hobart and HartRAO are used. It is the first case in the world to carry out geodetic VLBI experiment in the network that S2 and K4 are simultaneously used. The Mitaka FX correlator correlated the VLBI raw data obtained with this network because it is the only facility that can process both the types of recorders. This correlator has been primarily used for processing astrophysical data and no geodetic data have been processed with this. So, this is the first occasion to process the geodetic VLBI observation data with the Mitaka FX correlator.

The VLBI experiments were carried out (February, May, August, and November) 4 times in 1998. Participating stations were Syowa, HartRAO, Hobart, and other temporal stations. Two problems specific to Syowa Station arose during the wintering.. They were decline of sensitivity in the X band and sudden increase of recording error rate. Due to these problems we could not detect fringes in the X band in the February observation and quality of the data of the May and August experiments was not enough to perform subsequent analyses. The increase of the error rate was considered to be due to insufficient control of humidity in the observing room. In the November experiment the recording head of the recorder was cleaned carefully and this kind of trouble did not occur during the observation. Good correlation results were obtained for all the baselines in the November experiment.

The Mitaka FX correlatior provides the correlated data in the form of FITS. However, the structure of FITS is not suited to geodetic analysis. So, the various steps are necessary before starting geodetic analyses. The new geodetic analysis software was developed. The bandwidth synthesis and time system transformation are mainly developed in this software.

A standard algorithm is used in the bandwidth synthesis except for input and output interfaces. However, the observed delay that the software outputs is expressed in a time system that differs from the one used in the standard geodetic analysis. In processing of the Mitaka FX correlator, a delay is defined as a difference of epochs when the same wave-front from a celestial body passes the geocenter and a ground station, respectively, while observed delay is the difference in the time when this wave front passes two ground stations. The geometrical delay between two ground stations is computed as a difference of the delays between the geocenter and individual ground stations. On the other hand the reference time of a priori delay used in geodetic analyses is the time when the wave-front from a celestial body reaches a reference station on the ground. Therefore, time system transformation is necessary to compensate the influence of the difference of time systems between the observed and a priori delays. The magnitude of the delay due to the difference of the time systems is 1～10 nanoseconds.

The most important process in the conversion is addition of twice the atmosphere propagation delay

The geodetic estimation was performed for the data in November, 1998, by using a program called MSLV3. The position of the Syowa VLBI point is estimated to be 1766194.143m, 1460410.932m and -5932273.353m with standard deviations of 2.9cm, 2.5cm and 6.2cm in the x-, y- and z-components in the geocentric Cartesian system. These errors are larger than typical values of recent inter-continental VLBI experiments. Nevertheless, the movement of Syowa VLBI reference point is shown clearly, when this estimated position is combined with other experiments in January, 1990, and November, 1999. The velocity vector of Syowa Station in the local topocentric frame is 0.53cm/y, 0.01cm/y and 1.17cm/y in the north, east- and upward components and their errors are 0.22cm/y, 0.17cm/y and 1.00cm/y, respectively.

This movement of VLBI reference point is compared with velocities observed with GPS and DORIS, predicted by NNR-NUVEL1A plate motion model, and taken from ITRF2000.The horizontal movements of Syowa Station can evidently be classified into two groups. One is the northward motion composed of VLBI and NUVEL1A. The other is the north-east motion composed of DORIS, IGS and ITRF2000. Close agreement of the horizontal movements between the VLBI observations and the NNR-NUVEL1A prediction may support the rigid plate motion model. The vertical motion obtained from VLBI shows that Syowa Station is uplifting. Its speed is close to that of the sea level change estimated from Syowa tide gauge data. Movements determined from GPS, Doris and the geological survey support this direction. In summary, the result of the present thesis is in good accordance with the global plate motion model and the Post Glacial Rebound.

Standard deviation of the post-fit residual is about 300 pico seconds, which is fairly larger than typical values. The causes of the large standard deviation must be clarified to confirm the reliability of the newly developed analysis system and the analysis result. However, the reason of this large standard deviation is not yet revealed and left to the future investigation. In order to distinguish possible error sources, namely, those specific to this experiment and those of the analysis system, a comparison is necessary between the Syowa experiment and referential geodetic VLBI experiments by using baselines and radio sources with well determined positions, and a correlator and a analysis system with established performance.

The Syowa experiment is continuing after JARE39 and improvement of reliability is expected to the position and velocity of Syowa VLBI reference point. The main part of the geodetic analysis system for the Mitaka FX correlator is considered to be usable as one of the core parts of a VERA analysis system and a large contribution is expected in the VERA project.

論文の審査結果の要旨

申請者は1998－99年の第39次南極観測隊に越冬隊員として参加し、以下のようにVLBI定常観測システムの構築、オーストラリア、南アフリカ及び日本（鹿島）との間での観測の実施、帰国後の三鷹FX相関器を用いた測地解析システムの構築、取得したデータの解析から昭和基地VLBI観測点の位置決定を行い、その測地学的意味について検討した。

1）昭和基地アンテナの天体観測用制御システム、VLBIバックエンド、周波数標準の設置及び調整を行い、標準レベルの観測システムを構築した。これにより定常観測が可能となった。

2）1990年の試験観測以来中断していた観測を再開し、国際観測を行った。国内では未経験な昭和基地の環境条件、観測の成功・失敗が翌年観測テープを日本に持ち帰った後にしかわからず、対策を立てにくいという状況で、成功したのは４回のうち1988年11月の１回のみであったが、40次隊以降は39次隊で確立されたシステムにより順調に観測が行われている。

3）三鷹FX相関器による測地データ処理のために、時刻系変換及びそれに伴う補正を行うソフトウェアを開発し、三鷹FX相関器を用いた測地データ解析を可能とした。これにより、オーストラリア及び南アフリカで使用されたS2システムを用いた測地観測も可能となった。

4）以上の観測及び解析システムを用いて観測したデータを解析し、昭和基地の位置を$x=1766194.143\pm0.029$m、$y=1460410.932\pm0.025$m、$z=5932273.353\pm0.062$mと決定した。誤差は東西、南北、鉛直成分では0.018m、0.021m、0.067mである。この誤差はVLBIの典型的な値より大きいが、申請者は原因について考察を行い、熱雑音、地球物理学的モデルの不確かさ、時系変換誤差、観測局及び電波源位置誤差では説明できないことを示した。昭和のシステムないし相関処理に起因する可能性については、それを切り分け特定する観測及び試験を提案している。

5）本論文の結果と1990年の試験観測及び1999年のCORE-O’Higgins観測による結果を用いて、昭和基地の運動の東西、南北、鉛直成分を-0.97 ± 0.28cm/y、0.65 ± 0.28cm/y、0.98 ± 1.00cm/yと求めた。水平成分は人工衛星を用いたGPS及びDORISによる観測結果よりもプレート運動モデルからの予測値に近い。また、鉛直成分については後氷期地殻上昇を反映している可能性がある。

以上のように申請者が昭和基地という困難な環境にも拘わらずほぼ独力でVLBI観測システムを立ち上げ、定常観測への道筋をつけたことは評価に値する。また、三鷹FX相関器を測地観測処理可能としたことも、南極VLBIのみならず、VERA等の今後の日本のVLBIの発展にとって重要なことである。南極大陸は、大陸氷床の存在と露岩領域が極めて小さいこと、大陸内部の地震活動が極めて低調であることなどからそのテクトニクスの解明にはVLBIを始めとする宇宙測地観測の重要性が他の大陸よりも高い。昭和基地は南極大陸では数少ない露岩の上に建設されており、南極テクトニクスの解明において極めて重要な地位を占めている。成功した観測が少なかったこともあり、観測結果は地球物理学的に確定的な結論を導くには十分とはいえないが、長期間観測の蓄積を必要とする測地データの基礎となるものであり、評価できる。今後のデータの蓄積を待って南極のテクトニクスの解明に貢献する貴重なデータである。