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PPS03-01 会場:202 時間:5 月 20 日 14:15-14:30

LLR simulation study for future observations
LLR simulation study for future observations

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Introduction: Lunar Laser Ranging (LLR) measures the distance between laser link stations on the Earth and retroreflectors on the Moon by detecting the time of flight of photons from a high-powered laser pulse emitted from the ground stations. Since the Earth-Moon distance contains information on lunar orbit, lunar solid-body tides, and lunar orientation and rotation, we can estimate the inner structure of the Moon by constraining relevant physical parameters. Several lunar landing missions which will carry new retroreflectors to the lunar surface are under study in several countries. Furthermore, retroreflectors with a larger single aperture are under development for more precise ranging, apart from the conventional array-type retroreflectors that were realized in the Apollo and Luna mission from 1969-1973. It is not obvious how lunar physical parameters such as Love numbers will be better constrained by using range data with higher accuracy. Therefore we have conducted a simulation study of the LLR observations by using the LLR analysis software of JPL.

Method: Simulated data were created by adding noise to the predicted distances between the Earth surface and retroreflectors on the Moon using the lunar ephemeris and range model. The simulated data were fit using a least-square solution, and then the uncertainties of the fit were evaluated. There are high degrees of freedom for the creation of simulated data in terms of the number and locations of retroreflectors, the amount of data from each retroreflector, etc. In this study we set the condition as follows:

-the number of yearly range data was set to be about 600, monthly about 50
-the numbers of range data toward the new retroreflectors are at the same level as for the Apollo 11 and 14 sites
-range accuracy for new retroreflectors was set one order-of-magnitude higher than that of the existing retroreflectors
-locations of the new retroreflectors are near the north pole, near the south pole, and the mid-latitude.

Results and remarks: After about 35 years of observation, the uncertainty of some parameters is reduced by about 1/2 by adding one high-accuracy retroreflector compared to the case in which only existing retroreflectors are ranged. It is suggested that the uncertainty could be reduced by observing high-accuracy retroreflectors more than existing ones, or changing the weighting of data.

キーワード: LLR, rotation, tide, Moon, retro-reflector, simulation
Keywords: LLR, rotation, tide, Moon, retro-reflector, simulation

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Determination of the normal modes of the Moon's libration
Determination of the normal modes of the Moon's libration

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The Lunar Laser Ranging experiment has been active since 1969 when Apollo astronauts placed the first retroreflector on the Moon. The data accuracy of a few centimeters, over a time-span of several decades, along with the numerically integrated ephemeris, DE421, encourages analysis of the lunar physical librations, and especially the detection of three modes of free physical librations (longitude, latitude, and wobble modes). This analysis was performed by using iteratively a frequency analysis and linear least-squares fit of the wide spectrum of DE421 Moon's physical librations. From this analysis we identified and estimated about 130 terms in the angular series for latitude librations and about 70 terms in the longitude angle and polar coordinates. In this determination, we found the non-negligible amplitude of the three modes of free physical libration. The determined amplitudes become 1.296" in longitude (after correction of two close forcing terms), 0.032" in latitude and 8.196" X 3.312" for the wobble, with the respective periods of 1056.13 days, 8822.88 days (referred to the moving node), and 27257.27 days. The presence of such terms, despite short damping times of 104 to 106 yr, suggests the existence of some source of stimulation acting in geologically recent times.

キーワード: Libration, Moon
Keywords: Libration, Moon

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PPS03-03 会場:202 時間:5 月 20 日 14:45-15:00

THE THEORY OF THE MOON ROTATION AND DETERMINATION OF FOURTH MODE ITS FREE PHYSICAL LIBRATION

THE THEORY OF THE MOON ROTATION AND DETERMINATION OF FOURTH MODE ITS FREE PHYSICAL LIBRATION

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Resume. In result of the comparison of our analytical theory of lunar physical libration, in particular the free librations, and available now, the empirical theory of the Moon's rotation (Rambaux, Williams, 2011), we have identified period, amplitude, and the initial phase of the forth mode of free libration of the Moon, caused by liquid core.

Analytical theory. The main study here is a construction and development of a highly accurate analytical theory of physical libration of the two-layer Moon (with uniform ellipsoidal liquid core and non-spherical elastic mantle). The core of the Moon is modeled by ellipsoid with an ideal homogeneous fluid. The mantle is considered as non-spherical solid body. The theory is developed on the basis of the canonical equations in Andover - Poincare variables and by special methods of the perturbation theory on construction of quasi-periodic solutions and investigation of their vicinity (based on the relevant equations in variations). The tables of values of the amplitudes and periods of forced and free librations for Andoyer ? Poincare variables describing the libration of the Moon and the core, for the variations of the components of the angular velocity of rotation of the Moon and the angular velocity of rotation of the coordinate system of Poincare (with respect to which a simple fluid motion is determined) have been obtained and studied. In first we have studied contributions in librations of the Moon of the second harmonic of selenopotential in accordance with the modern Selena model of gravitational field of the Moon (Matsumoto et al., 2010). The novelty of the theory and its practical significance are determined by the following principal provisions:

1.New forms of equations of physical libration of the two-layer model of the Moon (in particular in Andoyer ? Poincare variables) and new methods for their study; 2.Highly accurate description of the developments of spherical functions of the coordinates of the Moon, in the expression of the force function; 3.The new two-layer Mizusawa model of the Moon and Selena model of the gravitational field of the Moon; 4.Cassini rotation of the Moon, forced and free librations of the Moon in analytical form and their tables; 5.Dynamical effects in forced and in free librations caused by a liquid core; 6.Dynamical effects in forced and free librations of the Moon caused by its elasticity; 7.Determination of the forth mode of free libration caused by the liquid core; 8.Identification of some terms of modern Rambaux-Williams empirical theory.

Determination of the period, amplitude and phase of the fourth mode of the free libration of the Moon caused by the liquid core. We have been compare free libration terms from our analytical theory with some unidentified terms from empirical theory (Rambaux, Williams, 2011). In results 8 unidentified terms for classical variables in empirical theory were explained and amplitude, initial phase of the Moon free libration have been determined. The period of free libration of the pole of the Moon with liquid ellipsoidal core appreciated by us in 205.7 yr. The amplitude and initial phase of Poincare long-periodic argument of the free libration in pole motion due to liquid core have been determined in 0"0395 and -134 degrees (for initial epoch 2000.0 JD). In accordance with developed analytical theory this period corresponds to the sum of dynamic compressions of the core in 7.24x10(-4), that is in agree with seismographic data and data of laser observations (Barkin, Hanada et al., 2012). In assumption about similarity of ellipsoidal core and the entire Moon we have obtained the estimations of oblatenesses of the liquid core: 4.42x10(-4) and 2.83x10(-4).

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キーワード: Moon, rotation, resonance, free librations, LOD
Keywords: Moon, rotation, resonance, free librations, LOD

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PPS03-04 会場:202 時間:5 月 20 日 15:00-15:15

測地および月震データよる月内部構造制約のシミュレーション研究
A simulation study for constraining the lunar internal structure by geodetic and seismic data

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Internal structure and composition of the Moon provide important clue and constraints on theories for how the Moon formed and evolved. The Apollo seismic network has contributed to the internal structure modeling. Efforts have been made to detect the lunar core from the noisy Apollo data (e.g., [1],[2]), but there is scant information about the structure below the deepest moonquakes at about 1000 km depth. On the other hand, there have been geodetic studies to infer the deep structure of the Moon. For example, LLR (Lunar Laser Ranging) data analyses detected a displacement of the lunar pole of rotation, indicating that dissipation is acting on the rotation arising from a fluid core [3]. Bayesian inversion using geodetic data (such as mass, moments of inertia, tidal Love numbers k2 and h2, and quality factor Q) also suggests a fluid core and partial melt in the lower mantle region [4]. Further improvements in determining the second-degree gravity coefficients (which will lead to better estimates of moments of inertia) and the Love number k2 will help us to better constrain the lunar internal structure. Such improvements will be made by future lunar missions including Japanese SELENE-2. A preliminary simulation study shows that the k2 accuracy of better than 1% is anticipated by the SELENE-2 differential VLBI mission for which one of the radio sources is fixed on the moon serving as the reference to determine the orbiter's trajectory.

We carried out a feasibility study using Bayesian inversion on how well we can constrain the lunar internal structure when such improvements are made on the geodetic data. It is difficult to tightly constrain the internal structure from the geodetic data only because there are trade-offs among crust, mantle, and core structures. However, when combined with the existing Apollo seismic data which constrain the structures of crust and mantle, such geodetic data will contribute to narrow the range of the core structure models. We will discuss the impact of the crustal structure uncertainties on the estimation of the core structure, and also the assumption we have to place on the mantle structure in order to recover the core structure.

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キーワード: 月, 重力場, 潮汐ラブ数, 内部構造, VLBI, SELENE-2
Keywords: Moon, gravity field, tidal Love number, internal structure, VLBI, SELENE-2

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PPS03-05 会場:202 時間:5 月 20 日 15:15-15:30

月深部状態から揮発性成分を探る：SELENE-2 VLBI-LLR 計画
Investigation of lunar interior volatile from the state of the core and the lower mantle: SELENE-2 VLBI-LLR proposals

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現在有力な月の起源説では、46 億年前の原始地球に火星サイズの天体が衝突したときに放出された物質から形成されたという、ジャイアントインパクト（巨大衝突）説が有力である。形成時の月は、高温溶融状態で、マグマオーシャンが形成され、その中で金属核が分離した。月内部は揮発性物質に乏しくなるはずである。

ルナプロスペクタ、かぐやの磁気探査により、月表層の磁気異常が確実となり、過去に溶融核でダイナモ作用が起きた可能性が高い。月レーザ測距による自転変動の解析から、誤差が大きいが現在も核が融けていることが示唆されている。月下部マントルでは月震源が無いことから、剛性率が低く、融けているか、柔らかい可能性がある。しかし、アポロ着陸計画で設置された熱流量計のデータの再解析は、従来の見積よりも低い熱流量値を示す。高温月内部モデルは考えにくい。月の核が融けているならば、硫黄が融点を下げている可能性が高い。月の下部マントルは、地球のアセノスフェアの圧力に相当するので、月の深部に水が存在すれば剛性率は低くなる。月内部の揮発性成分の存在は、巨大衝突による月の高温起源説に修正を求めることになる。

月の深部状態を明らかにするため、我々は低次重力場係数と潮汐ポテンシャルラブ数 k_2 の精度改善を目的とした新たな月重力場計測ミッションを SELENE-2 へ提案している。着陸機と周回衛星の両方に VLBI 用電波源を搭載し、同一ビーム VLBI 観測を用いて重力場を計測する。かぐやでは 2 機の小型衛星の軌道を同時に求めたのに対して、SELENE-2 では、電波源の一方が月面に固定されており、これを基準としてもう一方の電波源（周回衛星）の軌道を決定するという手法をとる。また、電波源間の離角が常時同一ビームの条件を満たすように周回衛星の軌道を選定すること、また 2 つの電波源の離角が大きいときに別々の受信機で観測すること（２ビーム）により、高精度で大量の VLBI 観測データを取得し、低次重力場係数と k_2 の精度を効率的に向上させることを目指す。

また、月レーザ測距では、反射板が月面の南半球に無いこと、秤動により反射板アレイの両端の間で時間差が生じるため、月内部のエネルギー消散過程に関係する微小変動を求めるには精度がこれまで不十分であった。SELENE-2 では、既存の反射板から離れた南半球に新たな単一型の反射鏡を設定して、月回転変動を高精度に測定することを提案している。

キーワード: 月の起源・進化, 月下部マントル, 月コア, 潮汐ラブ数, 月回転, 揮発性成分
Keywords: origin and evolution of the moon, lunar lower mantle, lunar core, tidal love number, lunar rotation, lunar volatiles

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PPS03-06 会場:202 時間:5 月 20 日 15:30-15:45

METHOD OF ANALYSIS OF EXISTANCE OF THE ZONES OF LOWER SEISMIC VELOCITIES OF PLANETS AND SATELLITES

METHOD OF ANALYSIS OF EXISTANCE OF THE ZONES OF LOWER SEISMIC VELOCITIES OF PLANETS AND SATELLITES

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In connection with the planned space missions to the Moon and Mars to study the internal structure of these celestial bodies by seismic methods seem to be very relevant theoretical studies of possible features or internal structures of these celestial bodies. The mechanism of forced oscillations of the core and mantle of the celestial bodies and study of their geodynamic and geophysical consequences gives us opportunity to study some inner structures of the Earth, the Moon and Mars and some others celestial bodies (in particular the zones of lower seismic velocity).

The mechanism of forced relative oscillations, displacements and rotations of shells of given celestial body under the action of the gravitational attraction of external celestial bodies [1] in the last decade has attracted wide attention of specialists in various geosciences and planetary science. On the base of this geodynamical mechanism and model some fundamental problems of geodynamics and celestial mechanics, geology, geodesy and geophysics have been solved in last 10-15 years. Here we study the possible role of forced relative oscillations of the core and mantle of the Earth and Mars, some satellites of Jupiter and Saturn in the formation of the shell structures (layers) of these celestial bodies. First and foremost, the existence and nature of the zones of low seismic velocities (LVZ), as well as the zones of the extreme radial deformation of the spherical layer of the mantle. For the Earth and Mars the zones of low seismic velocity correspond to the spherical zones of the mantle for which the displacements of the particles due to gravitational action of displaced core are either small or absent and the change in directions of radial displacements is observed.

Our results suggest that for the Earth, the origin of the low-velocity zone and its position (with mean depth about 144 km) is determined by the mechanism of forced displacements of the Earth's core. A similar low-velocity zone at about 300 km depth we have been predicted for Mars. The style of deformations of the mantle layers of the Mars and the Earth (and probably for Venus) have much in common. Therefore the existence of the low-velocity zone of the planet Mars, at a depth of 300 km, seems quite real. Similar studies we fulfill now for some synchronous satellites of Jupiter and Saturn (Io, Ganymede, Europa, Titan, Enceladus, etc.) to identify zones of extreme radial deformations that occur during forced relative radial oscillations of the shells. In the report the preliminary findings on the positions situation of the zones with extreme largest deformation and the zone in which the deformations are small or absent are discussed.

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キーワード: Core, motion, mantle, deformation, existence, LVZ
Keywords: Core, motion, mantle, deformation, existence, LVZ

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PPS03-07 会場:202 時間:5 月 20 日 15:45-16:00

測月学および測地学のための小型望遠鏡の開発におけるいくつかの技術的課題
Some technological problems in development of a small Telescope for selenodesy and geodesy

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Observations of the lunar rotation are one of the essential and basic selenodetic observations for investigation of the interior of the Moon as well as those of gravity fields, and high accuracy of the observations have a potential to detect signals related to the structure of lunar deep interior including the core. Technological development dedicated to highly accurate observations for the Moon, on the other hand, can return to the application to the Earth again. We are developing a small telescope for observations of Lunar rotation with a target accuracy of 1 milli arc second, and it has a potential to observe deflection of the vertical on the ground with high accuracy. This accuracy is epochal also for the observation of the deflection of the vertical even if it may be deteriorated to some extent by atmospheric fluctuations etc.

Major problems in the observations on the Moon are large temperature change and the difficulty of adjustment. We developed an objective using a diffractive lens in order to loosen the condition of the temperature change, and we adopted PZT (Photographic Zenith Tube) having a horizontal reference plane of a mercury surface in order to realize an adjustment-free system. Observations on the ground, on the other hand, are mostly affected by ground vibrations and atmospheric fluctuations. The effect of temperature change is not very large and it is relatively easy to control the temperature around the tube.

As the results of laboratory experiments, it is possible that the vibration of the mercury surface caused by the ground vibrations lead to fluctuations of star positions on CCD as large as 1 second of arc. The amplitude of the fluctuations depend on the amplitude of the ground vibrations and the depth of mercury pool. We can reduce the effect of the vibrations by making the mercury pool shallow down to the minimum depth. In the case of the mercury pool of 64mm diameter, the depth of 0.5mm is the minimum depth judging from our experience. Shallower pool will shorten the life time and will be affected more easily by the tilt.

It is important to keep the proper period of the mercury pool away from the period of ground vibrations in order to avoid the resonance. It is also effective to lengthen the integration time, and it can improve the reliability of the mean value of the center of a star image by statistical procedure. Adaptive optics is widely used for compensating the effects of atmospheric fluctuations and for obtaining sharper images approaching the diffraction limit. The adaptive optics, however, is not always effective for the astrometric telescope like PZT because it is possible to shift the center of star image by deformable and tip-tilt mirrors.

We investigate the cause of fluctuations which can affect the observations on the ground, and we explore the possibility for a new effective observations with the telescope like PZT.

キーワード: 月回転, 鉛直線偏差, 写真天頂筒, 水銀面, 地盤振動, 熱変形
Keywords: lunar rotation, deflection of the vertical, PZT, mercury surface, ground vibration, thermal deformation

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New findings in Earth‘s sciences
New findings in Earth‘s sciences

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An excitation mechanism and forced relative translational oscillations, swing and rotation of the Earth shells (and other planets and moons) under the gravitational action of external celestial bodies is a powerful source of endogenous activity with pronounced cyclical manifestations at different time scales endogenous energy of the planet as an open thermodynamic system (represented by the scheme with threads of different types of energy, the entropy and others) made it through gravitational interaction of external celestial bodies. The energetic of this mechanism allows to specify the energy budget of the Earth in comparison with contributions of another acting mechanisms. The estimates of the power dissipation for a viscous-elastic deformation of the Earth’s mantle caused by the relative displacements of the center of mass of the mantle and core have been obtained. The inversion phenomenon of the Earth’s climate changes with respect to Northern and Southern hemispheres its contemporary manifestations are analyzed and discussed.

For analysis the general global astrogeophysical factor - Earth’s rotation rate (ERR) was used. The important role of the lunar-solar gravitational tides for weather, climate and geophysical processes in the atmosphere, oceans, and other geospheres and in the biosphere has been shown. The role of tides by using the ERR has been demonstrated on the base of observational data on precipitation in the Indian monsoon period, in the formation of tropical depressions and typhoons, in the perturbations of Earth’s magnetosphere and during strong earthquakes, as well as in medical terms cardiovascular system patients and other diseases. Earth’s rotation rate is so high compared to the speed of the proper motion of the tidal waves in the solar system of reference, we are dealing only with quasi-diurnal waves and their sub-harmonics. At spectral or harmonic analysis measuring low frequency waves of gravitational tides also merge with the harmonics of daily or annual thermal tides and become virtually invisible to learn. To low-frequency tidal waves are not lost in the spectral analysis, it is necessary to exclude the effects of rotation and revolution of the Earth, that is demodulated time series measurements. It is enough to fix the period of measurement (one measurement: for a day, to prevent rotation of the Earth, or the year to avoid the annual revolution of the Earth). Even before it was established that the weather changes during the lunar month is synchronized to within 0-2 days from the extremes of the EER, describing the motion of the Moon and the Earth around the barycenter. We have detected and studied a week and semi-month lunar tidal waves in the spectrum of the angular momentum of the atmosphere. Estimates have shown that classical gravitational tidal forces can not explain the tremendous energy associated with variations of the angular momentum of the atmosphere. We discuss possible role of the resonance effects in origin observed cyclicities in natural processes. Big prospects here open in dynamical and empirical studies of new tides the nature of which is connected with action of mechanism of forced oscillations of the Earth shells in gravitational field of the Moon, the Sun and all another bodies of solar system. In particular it was shown that mechanism of new tides for discussed in report frequencies and periods of oscillations generates phenomenal power of dissipations (and variations of planetary heat flow) of the order 10 (15) Wt. This energetic is sufficient for explanation of observed activity and cyclisities of all planetary processes.

キーワード: angular momentum, atmosphere, magnetosphere, tidal waves, climate changes
Keywords: angular momentum, atmosphere, magnetosphere, tidal waves, climate changes

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PPS03-09 会場:202 時間:5 月 20 日 16:30-16:45

Geodetic consequences of the northern drift of the Earth's core and their confirmations in the space geodesy data

Geodetic consequences of the northern drift of the Earth's core and their confirmations in the space geodesy data

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In the last 10 - 15 years the Russian and Chinese scientists have been fulfilled geodetic studies of contrast changes in the shape of the Earth, in the northern and southern hemispheres. In the works of Chinese scientists were executed empirical studies of secular variations of volumes of the northern and southern hemispheres, secular changes in the lengths of the circles of latitude in the southern and the northern hemispheres, the secular changes in the mean radius of the northern and southern hemispheres on the basis of current data space geodesy and VLBI data. For what was made a careful selection of monitoring stations and analyzed long series of high-precision measurements of the radii of stations and their displacements in the basically Earth's reference frames. In the works of Prof. Y. Barkin and colleagues (starting from 1995 -1996) the modern geodynamics of the forced librations of the core and mantle of the Earth by the gravitational attraction of external celestial bodies has been developed and has been given wide applications in geosciences, in particular in geodesy.

The most important result is the prediction and justification of the existence of the secular trend of the center of mass of the Earth as a consequence of the secular northern drift of the core of the Earth relative to the mantle. The wide geodynamic, geophysical, geodetic studies and their role in climatic change, seismic and volcanic activity, and in many other natural processes have been fulfilled in the last 15 years. Modern DORIS satellite observations (in space geodesy) indicate the existence of the secular polar drift of the center of mass of the Earth (to the North) at 5.29 mm / year. This drift reflects the Earth's core drift (drift of the center of mass of the core relatively to the center of mass of the mantle) at a rate of 27.4 + / -0.8 mm / year (Barkin, 2005). Gravitational effect of the shifting core causes deformations of all layers of the mantle and various offsets of its points (both on the surface and inside the Earth). As a result of these deformations the mean radius of the northern hemisphere increases with secular velocity about 0.17 mm / year, and the mean radius of the southern hemisphere on the contrary, decreases with the same magnitude of velocity - 0.17 mm / year (Barkin, 2005, 2011). As a result of careful processing of satellite data and VLBI observations at 845 stations in a recent paper (Wenbin Shen et al., 2012, private communication) were obtained related values of 0.46 + / -0.01 mm / year and -0.19 + / -0.01 mm / year, respectively. The theoretical value of the greatest secular velocity of lengthening of latitudinal circles in the southern hemisphere at latitude 45 S is 4.17 + / -0.12 mm / year, and in the northern hemisphere the secular velocity of shortening of latitudinal circle (for latitude 45 N) is - 4.17 + / -0.12 mm / year. According to the processing data of GPS observations Jin Shuanggen in 2005 has obtained related values of secular velocity in 4.2 + / -0.5 mm / year and 10.0 + / -1.0 mm / year for the corresponding hemispheres (Jin, 2005; Barkin, Jin, 2006 , 2007). Thus the main trends of geodetic changes of the northern and southern hemispheres has obtained a nice explanation. Revealed an asymmetry in the shape of the Earth changes are apparently related to the formation of zones of rifting and subduction zones in their asymmetrical arrangement in the northern and southern hemispheres. Also in our joint work we have fulfilled studies of the dependence of the mean radius of the Earth and the mean velocity of secular change in the length of the latitudinal belts from the latitude (Barkin, Jin, 2007; Wenbin Shen, 2012). Theoretical results and data of satellite observations are in good agreement. The report also discusses the expected related phenomena on the Moon and Mars and the possibility of theoretical prediction and detection by high-precision observations in the planned space missions.

キーワード: drift of center of mass, secular geodesy variations, mean radiuses of hemispheres, the Earth, Mars
Keywords: drift of center of mass, secular geodesy variations, mean radiuses of hemispheres, the Earth, Mars

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Manifestations of tides in geospheres and in the biosphere

Manifestations of tides in geospheres and in the biosphere

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The gravitational tides in the atmosphere are recorded as the waves with the periods close to one day and its sub harmonics. Some of them are usually interpreted as the proper atmospheric modes. They commonly have either the amplitude or the frequency modulations. A new explanation of the quasi-diurnal and quasi-semidiurnal tides lines in the spectrum of the atmospheric angular momentum and other atmospheric characteristics is proposed. The role of gravity tides in the dynamics of the atmosphere and the ocean is underestimated. The reasons of a wrong estimation of a role of the tidal phenomena in geophysics are explained.

It‘s shown here that zonal tidal forcings with periods of ˜3.5 and ˜7 days determine processes in the atmosphere (weather change, formation of tropical depressions, cyclones (including typhoons), monsoon precipitation periodicity, in the magnetosphere (increasing geomagnetic activity), in the lithosphere (seismic-disturbances, including earthquakes) and increase the medical statistics in cardio-vascular illnesses and in other ones as well (see below). Luni-solar gravitational tides correlates absolutely with Earth rotation rate (ERR) and can be calculated for any time in advance. The correlation of 3,5 and 7 days periods of weather change with the same periods of human health parameters has been established. That has been demonstrated during International Conference ”Space Weather Effects on Humans: in Space and on Earth” (Moscow, from 4-8 June 2012) and II Russian Conference on chronobiology and chronomedcine (in the frames of XIV World congress ¥¥¥”Health & Education millennium¥¥¥” (14-17 November 2012, Moscow, Russia).

We discuss some new physical processes which are very important for Earth‘s climate. An example of our analysis of a number of annual rings of Japanese cypress, 800 years (data for 1100-1920 taken from the book Selected papers on Climatic Change written by well known Japanese climatologist H.Arakava) is given. This analysis shows a clear link of QBO periods with periods of El Nino - Southern Oscillation and the Chandler period (CP) first mentioned by Sidorenkov. Major and decisive role for the Earth as an open system, are external to it gravitationally interacting system of ”oscillators” (Moon, Earth, Sun and planets) and gravity (as well as for the thermal atmosphere of the Earth) tidal forces. The interaction of the tides of all types and multiple binding modes with phase transitions of water vapor forms quasi-three-dimensional structures. Such structures have been discovered on space-time sections, constructed from orbital observations from satellites. We suggest new concept of tidal phenomena in the atmosphere, which is in conflict with the existing classical theory of Chapmen and Lindzen

After conducting field experiments in southern India, and at the equator in the Indian Ocean in March and June 1990 within the framework of the international program DYANA, observing a wide range of fluctuations of the ozone layer and the middle atmosphere of the author formulated a working hypothesis - the atmosphere is a system of oscillators interacting with each other and with oscillators in other geospheres and in space.

A new approach to the problem of long- and short-term prediction of atmospheric phenomena should be done, taking into account all types of tides and their multiple modes. Results of successful experiments on modification of meteorological processes are given.

So, the 1st main conclusion must be done that atmosphere/ocean phenomena are deterministic processes rather than stochastic ones. That leads inevitably to the 2nd important inference: so called the time limit of forecasting (f.e. for weather change) is not exist! 3d one is: we deal with open physical system that is resonant one. Mentions above will open a way to high technology of weather and climate modification.

キーワード: Luni-solar gravitational, Manifestations of tides, Earth‘s climate., weather modification
Keywords: Luni-solar gravitational, Manifestations of tides, Earth‘s climate., weather modification

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PPS03-11 会場:202 時間:5 月 20 日 17:00-17:15

宇宙測地学的手法による火星回転変動計測
Measurements of Martian rotational variations by space geodetic techniques

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一般に固体天体の表層環境の変化や内部構造は，その天体の回転（自転）変動に影響を及ぼし，その変動の振幅や位相は電波航法や VLBI などの宇宙測地学的手法により観測可能である．特に火星は，地球と類似の構成要素を有しながらも，過去から現在に至る進化やダイナミクスの様相は大いに異なっており，その相違を表層環境・内部構造から解き明かすことは比較惑星学的に重要である．

火星の回転変動は，従来は着陸機（ランダー）の追跡データ（2 ウェイ測距・距離変化率計測：RARR など）を利用して計測されており，例えば Viking 1 および 2，Mars Pathfinder によって，歳差や自転速度変動が得られてきた．これらの計測手法には，地球・火星間の経路上および地上局の位相安定度等に起因すると考えられる測定精度の限界がある．そこで欧州の研究グループは，周回探査機（オービター）とランダー間の RARR を利用した電波航法による精度向上を提案している．

一方我が国では，オービターとランダー等の複数探査機を用いた火星複合探査（MELOS: Mars Exploration with Lander-Orbiter Synergy）の検討が開始された．そこで我々は，4 ウェイドプラ計測（FWD），逆 VLBI（iVLBI）等の新たな測地学的手法による，火星回転変動の高精度計測を提案する．4 ウェイドプラ計測（FWD）は，宇宙機の位置・軌道を中継機を経由した 4 経路から決定する測地手法であり，我々は月周回衛星「かぐや」での月裏側の重力場観測という実績を有している．MELOS 計画では，宇宙機の構成は未定であるが，オービターとランダーという構成が一案である．この時，追跡局→オービター→ランダー→オービター→追跡局の経路でドプラ計測（距離変化率計測）を実施する．同時に，オービターとランダーの 2 ウェイ RARR を実施する．本方式で期待される測定精度は従来の電波航法より向上し，オービター・ランダー間 RARR を利用した場合の精度に相当すると推定される．逆 VLBI（iVLBI）は，複数の宇宙機からの同期した信号の位相比較を行って，各々の相対位置を測定する手法であり，測定精度は周波数の逆数に比例し，地上と対象宇宙機の距離に依存しないで高精度で決定できるという特徴を持つ (Kawano et al., 1999)．MELOS 計画では，ランダーから地上への直接送信波と，オービターでコヒーレントに中継された信号を，追跡局で同時またはスイッチングにより計測する．ランダーの位置変化に対する原理的な感度は，想定される最も低い周波数である X 帯を用いた場合でも 0.3mm であり，FWD や RARR 等の従来手法と比べて著しく高精度である．一方，通信機経路内の高精度の位相補償を要することが，現状では技術課題である．

キーワード: 火星, 自転, 宇宙測地, 衛星間測距, VLBI
Keywords: Mars, rotation, space geodesy, satellite-to-satellite tracking, VLBI

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PPS03-12 会場:202 時間:5 月 20 日 17:15-17:30

A preliminary observation of 531-day period in wobble of the polar motion
A preliminary observation of 531-day period in wobble of the polar motion

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Previous studies show that the polar motion contains two dominant components, namely the annual wobble (AW) with a 12-month period and the Chandler wobble (CW) with a 14-month period. Some scholars consider that the frequency of the CW varies with its amplitude; some scholars consider that CW has double or multiple frequencies; some scholars consider that the frequency of CW is invariant. In 180s, a 530-day-period wobble in polar motion was marginally detected. Since then, we did not find literatures addressing this wobble period from any kind of observations. In this preliminary study, we apply the ensemble empirical mode decomposition (EEMD) method to analyses of two kinds of observations. First, applying EEMD to two polar motion time series, the EOP C04-05 series with one-day sampling interval spanning 1962 to 2012 and the POLE2010 series with one-month sampling interval spanning 1900 to 2011, we observed a 531-day-period (about 0.68683 cpy) wobble and a 530-day-period (0.68913) wobble, respectively. Noting that the estimated amplitudes and frequencies of this wobble from the two series are different from each other, we consider that the difference is caused by the relative poor quality of the POLE2010 series during 1900-1961. Deleting the poor quality data sets, we obtain the 531-day-period wobble from both time series. Our results show that the frequency modulation of the CW may greatly suppress the 531-day-period wobble so that it cannot be observed in conventional direct power spectra of the polar motion series. Second, applying EEMD to two superconducting gravimeter records with a length of about 15 years and one-day sampling interval, we also observed the 531-day-period wobble. If the 531-day-period wobble really exists, it might be caused by the fluctuations of global atmospheric and oceanic angular momentums. Further investigations are still in progress. This study is supported by NSFC (grant No. 41174011), National 973 Project China (grant No. 2013CB733305) and NSFC (grant No. 41210006, 41128003, 41021061, 40974015).

キーワード: 531-day-period, wobble, polar motion, ensemble empirical mode decomposition, EOP and POLE series, superconducting gravimeter records
Keywords: 531-day-period, wobble, polar motion, ensemble empirical mode decomposition, EOP and POLE series, superconducting gravimeter records

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PPS03-P01 会場:コンベンションホール 時間:5 月 20 日 18:15-19:30

月面コーナーキューブの光学応答解析
Optical Response Simulation of Corner Cube Reflectors for SELENE2 Mission

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The object of these simulations is clearing up the criterion for the Corner Cube Prism (CCP) and the Corner Cube Mirror (CCM) in order to measuring the distance from the Earth to the Moon in cm order. In case of the CCP, the refractive index inhomogeneity restricts its size to small (~10cm), so we did not calculate the effect of any deformation. In case of the CCM, we calculated both effects of the Moon gravity deformation and the thermal deformation.

The Optical responses were calculated with CodeV (Synopsis, Inc.), and we did not consider DAO (Dihedral Angle Offset), because the common optical simulation software cannot calculate its effect.

The Optical response criterion is that the encircled energy within 3.5mrad (half angle) > 50%, where 3.5mrad is equal to the minimum deflection by the velocity aberration without DAO. The velocity aberration deflect 3.5-7mrad from the Laser emitted direction according to the relative speed between the Earth and the Moon.

キーワード: コーナーキューブ, レーザ測距, 点像強度分布
Keywords: corner cube reflector, laser ranging, PSF

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PPS03-P02 会場:コンベンションホール 時間:5 月 20 日 18:15-19:30

DOE を用いた月面天測望遠鏡 (ILOM) の開発
Developement of the telescope for ILOM (In-site Lunar Orientation Measurement) using the DOE (Diffractive Optical Elemen

鹿島 伸悟 [1*], 花田 英夫 [1], 荒木 博志 [1], 鶴田 誠逸 [1]
Shingo Kashima[1*], Hideo Hanada[1], Hiroshi Araki[1], Seiitsu Tsuruta[1]

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ILOM demands the very high performance to the optical system in order to realize the determination of star positions with 1 milli arc second accuracy on the Moon whose environmental condition is very fierce. There are several causes that degrade the optical performance and the most effective cause is the change of the environmental temperature. The temperature change causes the change of lens shape and the change of the refractive index of each lens material and the later is much dominant. The optical system of ILOM is the refractive system so we have to reduce the chromatic aberration using so-called the low dispersion glass, but this type glass has a much bigger dn/dt (the index change for the temperature change) than the normal glasses. In result of this, the optical system using the low dispersion glass lens becomes very sensitive to the change of the environmental temperature.

So we developed the optical system (objective lens) using the DOE (Diffractive Optical Element). Using the DOE, we can reduce the chromatic aberration without the low dispersion glass lens. So we can develop the objective lens that is very tolerant to the environmental temperature change because we can design the objective lens using small dn/dt glass lens only.

キーワード: 月面天測望遠鏡, 回折光学素子
Keywords: ILOM, DOE

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PPS03-P03 会場:コンベンションホール 時間:5 月 20 日 18:15-19:30

Planetary Tectonic System (#2): Classification for the Search of Life Beyond Earth
Planetary Tectonic System (#2): Classification for the Search of Life Beyond Earth

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For life to initiate, diversify, and flourish, it requires a continuous nutrient supply, metabolism with continuous reactions to gain energy, and self-duplication [1; also see Shigenori Maruyama, this conference]. Based on our understanding of the evolution of Earth, which includes the Cambrian explosion [1; also see Shigenori Maruyama, this conference], these conditions can be optimally met through a planetary tectonic system (PTS) that is composed of a nutrient-enriched continental landmass, an ocean, tectonic structures such as rift systems that act as conduits for the migration of volatiles and heat energy, as well as the delivery of toxic elements (e.g., radiogenic nuclides) for the diversification of life (evolution requires perturbations from normal conditions), and a sunlit planetary surface [1].

Since a PTS provides the road map for the search for life beyond Earth [also see, Maruyama and Dohm, this conference], we propose a classification of planetary bodies with certain PTSs unfolded through geological investigation using existing planetary data sets.

Such a classification is not only based on the distance of the planetary body from the Sun and its composition, but also by its characteristic PTS. This is important, because the birth place of life and evolution is controlled by an optimal PTS as exemplified during the Cambrian explosion [1; also see Maruyama and Dohm this conference]. Without understanding PTS, it is impossible to target possible candidates of life-sustaining habitable environments both in and outside our solar system.

The types of PTS are: (1) Earth-Cambrian-explosion [1; also see Maruyama, this conference], (2) Ice-house Mars [2,3], (3) Hot-house Venus [3,4], (4) Rigid Mercury, (5) Gaseous-giants, and (6) Frigid, dynamic, and/or hydrologically exotic satellites. Others types (e.g., Kuiper belt planets and dwarf-planets) could be added in the future.

Detailed characteristics of the various PTSs will be detailed at the conference.

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PPS03-P04 会場:コンベンションホール 時間:5 月 20 日 18:15-19:30

Luni-Solar Tides in the Earth Atmosphere
Luni-Solar Tides in the Earth Atmosphere

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The gravitational tides in the atmosphere are recorded as the waves with the periods close to one day and its subharmonics. Some of them are usually interpreted as the proper atmospheric modes. They commonly have either the amplitude or the frequency modulations. A new explanation of the quasy-diurnal and quasy-semidiurnal tides lines in the spectrum of the atmospheric angular momentum (AAM) and other atmospheric characteristics is proposed. The role of gravity tides in the dynamics of the atmosphere and the ocean is underestimated. The reasons of a wrong estimation of a role of the tidal phenomena in geophysics are explained.

We have calculated the power spectrum of the complex series h1+ih2. The resulting spectrum has been analysed. . The most striking detail of the spectrum of h1 + ih2 is a blurred maximum of the spectral density at ?0.85 cpd. Its height is indicative of a high power of h1 and h2, and the width shows considerable ?uctuations of the period. What lies behind this phenomenon and why does the atmospheric circulation produce strong noise in this frequency range? Due to our discovery, it becomes clear why the role of gravity tides in the dynamics of the atmosphere and the ocean is underestimated. The fact is that all hydrometeorological and hydrophysical characteristics are measured at moments of mean solar time, which is the hour angle of the Sun determined by the Earth diurnal rotation and annual revolution. That is, by default, a frame of reference tied to the Sun (referred to hereafter as the solar frame) is used in this case. In this frame, the apparent velocity of a tidal wave is the sum of its proper velocity and the translational velocity. The latter arises due to the Earth diurnal rotation and the Earth annual revolution around the Sun. Its magnitude is very high compared with the proper velocities of tidal waves Therefore, in the solar frame we deal only with quasi-diurnal tidal waves and their subharmonics. In the spectral (or Fourier) analysis of observations, the low-frequency waves of gravity tides are di?cult to distinguish from the harmonics of diurnal or annual thermal tides and are nearly imperceptible for study. Hydrometeorologists construct synoptic maps or time-coordinate sections with a ?xed geographical grid of parallels and meridians. That is, by default they use a frame of reference tied not to the Sun, but rather to the stationary Earth surface. In this frame, the Earth diurnal rotation and orbital revolution are eliminated, while the proper motion of tidal waves is only present. Hydrometeorologists give attention only to fast quasi-diurnal tidal waves predicted by the theory. The proper motion of tidal waves remains unnoticed. All slow waves moving over the Earth surface, including tidal waves, are interpreted as usual atmospheric or oceanic waves. To detect low-frequency tidal waves in spectral analysis, we have to eliminate the e?ects of the Earth rotation and revolution demodulate measured time series. For this purpose, it is su?cient to ?x the time of measurements (one measurementa day to eliminate the Earth diurnal rotation or one measurement a year to eliminate the Earth annual revolution). As a result, weekly and semimonthly lunar tidal waves were detected in the spectrum of the atmospheric angular momentum. This method opens up new opportunities for studying the e?ects of lunisolar tides and functions of the Sun barycentric motion.

キーワード: Luni-solar gravitational, The gravitational tides
Keywords: Luni-solar gravitational, The gravitational tides

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月惑星の重力場におけるカウラ則とカウラ定数のスケーリング則
Kaula's rule and the scaling law of the Kaula constant in the lunar-planetary gravity fields

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月惑星の重力場は重力ポテンシャルを球関数展開した際の係数（ストークス係数）でモデル化される。月惑星の全球的な重力場は、地球は GRACE、月は SELENE や GRAIL といった重力探査衛星で観測される。現在では地球や月では球関数の次数にして数百次までの係数が推定されており、高解像度の重力異常図を描くことが可能になった。高次の係数は細かい重力異常の特徴を、低次の係数は大局的な構造を反映しており、研究の用途に応じて様々な解像度の重力異常が用いられる。

カウラの法則とは、こういった重力場の係数の大きさが次数 n の 2 乗に反比例するというおおざっぱな目安 (rule-of-thumb) である。本研究では、この法則が月・火星・地球・金星で良く成り立っていることを明らかにした。球関数の次数が高いほど重力異常の波長が小さく、低次のものほど大きい。つまりこの法則は重力異常の振幅が波長の二乗に比例して大きくなることに対応している。

本研究では、カウラの法則の比例定数のことをカウラ定数と呼ぶ。一般にカウラ定数は小さい天体ほど大きな値をとるが、ここでいうスケーリング則はその値が表層重力の 2 乗に反比例して小さくなるという法則である（本来の文献 [Kaula,1963] では半径の 4 条に比例、質量の 2 乗に反比例すると書かれている）。月・火星・地球・金星のカウラ定数を比較してみた結果、これら 4 天体に関してはスケーリング則がほぼ成り立つことがわかった。ある天体がこの法則から外れている場合は、その天体の内部を構成する物質の温度や粘性等が他の地球型天体と違っていることが示唆される。最近の Messenger の探査によると、水星の重力場はこのスケーリング則から下にずれるらしい。その原因として、水星は金属でできた中心核の半径が相対的に大きいため、岩石に比べて小さい金属の粘性が低次の重力異常を小さく抑えている可能性が考えられる。

月には表側と裏側の二分性があることが良く知られている。表側は地殻が薄く地形が平坦であるが、裏側は地殻が厚く凸凹が多い。二分性の原因については諸説あるが、表裏の熱史の違いを反映している可能性が高い。月の成り立ちや熱史は重力異常図からもある程度推測できる。本研究でこれまで天体間で比較していたカウラ定数を、同一天体の半球間で比較することで、地下構造や熱史の違いを考察した。その結果、裏側でより大きなカウラ定数が得られ、表側よりも裏側の重力異常が相対的に大きいことをカウラ定数の値の形で比較することができた。

キーワード: カウラ定数のスケーリング則
Keywords: scaling law of the kaula constant

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準流体惑星の真の極移動の時間スケール：マントル内部の低粘性層の効果
A time scale of true polar wander on a quasi-fluid planet: Effect of a low-viscosity layer inside a mantle

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固体天体における大規模な真の極移動に関する理論的研究や数値的研究は，それ程には多くないが既に幾つか行なわれている．その一方，地球や火星のような実際の惑星に関しては，主に古地磁気を初めとする地質学的状況証拠から真の極移動が推定されており，こうしたシナリオは上記のようなモデル計算に基づいて力学的に解釈され得る．

しかしながら従来のモデル計算では，マントルの粘性構造の不均一性，取り分け低粘性層の潜在的影響は考慮されていない．現実的には例えば地球のマントルの内部，特にマントルの最上部や最下部において極端に粘性の低い層が存在する，という可能性が地球物理学的観測に基づいて指摘されている．そして火星においても，位置天文学的に見積もられた潮汐散逸や，水の混入の効果を含むマントル対流の数値実験の観点から，類似の顕著な粘性構造不均質が示唆されている．それに対して従来の研究では，大幅に平均化された内部構造を取り扱っており，上述のような物理的に特殊な層の可能性は考えられていない．

もし低粘性層がマントルに存在するならば，それは真の極移動の時間発展に大きな影響を与えると考えられる．何故なら，このような柔らかい層は，長期的観点においては遠心力ポテンシャルに対して事実上液体と同じように振る舞うと予想されるからである．それによって粘弾性変形の緩和モードの強度や特徴的時間スケールが変化する．それは粘性緩和による天体の静水圧形状の再調整の時間スケールが変わる事も意味している．従って低粘性層の有無，そして仮に存在するならその深さに応じて，極位置が定常状態へ至るまでに要する時間も異なる筈である．こうした効果は過去のモデル計算において考察されていない．

この影響を検討する事は，観測量から導かれた真の極移動のシナリオ，特にその時間変化の理論的妥当性を定量的に検討する上で重要である．更に言えば，そのような変遷が起こり得る力学的条件を考察する事によって，当時の粘性構造を制約する上で有益な情報を得る事が出来るかもしれない．

そこで本研究では，固体天体のマントル内部における低粘性層の存在が真の極移動の時間スケールに及ぼす効果について調べる為，粘弾性変形と長期極運動のモデル計算を実施した．ここでは天体として地球と火星を想定したが，これに低粘性領域も組み込んだ．特に重要な点は，この低粘性層に対する粘弾性的応答の依存性である．尚，粘弾性ラブ数の緩和モードの算出に際して変形は非圧縮と見做した事を付記する．この前提に基づく計算の都合上，低粘性領域の存在以外に関しては依然として内部構造を或る程度簡略化した．但しこの簡略化は本研究の議論の妥当性を損なわない．

本計算においては，極運動方程式を非線形のままで積分可能とする準流体近似を適用した．その根拠は，ここで取り扱うような数十度程度の大規模な極運動の場合では線形近似を使えないからである．この準流体近似の適用範囲に従い，ここでは粘弾性変形の特徴的時間スケールよりも遅い荷重の進化を仮定した．この近似的手法自体に関しては，著者自身の研究も含む複数の先行研究によって既に確立されている．ここで扱う積分においても同様の手法を用いた．

上述の計算の結果，低粘性層を有する場合は有しない場合に比べて極位置の時間変化が速い，という事が分かった．その上，低粘性領域が浅い程，極の移動が速くなるという事も明らかとなった．低粘性層を有する天体において極の移動が速い原因は，低粘性層は比較的短期間の外力の変化に対しても流体的挙動を示すからである．これは遠心力ポテンシャルの擾乱に対する静水圧形状の再調整が速くなる事を意味するから，自転軸の変化に追随する慣性能率テンソルの変化の時間スケールも短くなる．そしてこの低粘性層の緩和に伴なう扁平形状の変化の大きさは，低粘性層の流体的変形を弾性的に抑制する上側の層の厚さに対して負の依存性を有する．従って上部の層が薄い，つまり低粘性層が浅い程，極の移動に対する低粘性層の影響が大きくなる．

以上の計算結果から得られる結論は，天体内部に低粘性層が存在する限り，たとえその層が薄くても真の極移動に対して大きな効果を及ぼす，という事である．以前の研究ではマントルの粘性構造が単純化され，その中では低粘性層が無視されていた．それらと比べて今回の研究では，低粘性層の影響を明示的に含む真の極移動の時間発展を計算した．地球の潮汐変形や荷重変形に関する粘弾性的応答においては，このような変形し易い領域が重要な役割を占めている事が過去に指摘されていたが，この傾向は一般に永年的な回転運動でも同様であると言えよう．

但し今回のモデル計算でも他の例と同様に非圧縮性の仮定を含んでいるので，注意が必要である．今後，より現実的なモデル計算を行なう際には，圧縮性の影響も吟味する必要があるだろう．

キーワード: 真の極移動, 準流体近似, 低粘性層, マントル
Keywords: true polar wander, quasi-fluid approximation, low-viscosity layer, mantle