ATMOSPHERIC EFFECTS ON EARTH SATELLITES

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ABSTRACT: Stations all over the world report apparent height variations with a one-year and a four-month periodicity if station coordinates are derived by Doppler tracking of OSCAR type NNSS satellites. It is demonstrated that this effect may be a consequence of mismodeling of atmospheric density variations in the orbit determination procedure of NNSS satellites.

INTRODUCTION

For two decades a group of Hungarian astronomers at the Konkoly Observatory has been analyzing total density variations of the neutral upper atmosphere. Interesting results related to the geomagnetic effect as well as to unmodeled extra heating of the atmosphere have been presented at different COSPAR conferences and have been published (Almar and Illes-Almar, 1971; Almar and Illes-Almar, 1973; Illes-Almar; Illes-Almar et al.1979). We are convinced that current models of total density need further improvement during quiet as well as during disturbed conditions. Important contributions of solar corpuscular heating controlled by the geomagnetic field seem to have been neglected in every atmospheric model used up to now in orbit computations.

ATMOSPHERIC EFFECTS ON GEODYNAMIC RESULTS

There are certain indications in the literature that several geodynamic results derived by the tracking of geodetic satellites may directly or indirectly be influenced by atmospheric variations. There is a direct link between the length of the day and changes in the angular momentum of the atmosphere. Anderle (Anderle and Malyevac, 1982) has suggested an indirect connection between the larger residuals in computed pole positions (derived by Doppler tracking of NNSS satellites) and increased atmospheric drag. Anderle's view is that the periods of increased scatter correspond to periods of high atmospheric drag because of high geomagnetic activity. We compared his drag curves (Fig. 1, lower part) for the year 1981 with similar total density curves derived for 1982 by two NNSS satellites together with their CIRA-72 and DTM model curves (Fig. 1, upper part). The two maxima, one in April and the other in November, belong without doubt to the well-known semiannual effect in the upper atmosphere, which is the dominating effect in these years at 1000 km altitude. Mismodeling of the semiannual effect may be the real cause of the increased scatter in the pole position.

LONG-PERIOD VARIATIONS OF STATION COORDINATES

Spectral analysis of geocentric coordinates derived by long-term Doppler observations at different tracking stations indicates variations of the height coordinate H with periodicities of approximately four months, one year and about 12 years. The phenomenon is almost independent of the latitude of the station. The relative importance of the peaks in the power spectrum is different in every case and probably sows a variation with time as well. There is no station with a long enough record of Doppler observations where the virtual height variation is definitely missing.

Based on the literature, **Table I** summarizes the available data concerning this effect in height variation. In Fig. 2, three power spectra are plotted for comparison. Besides station name and coordinates, Table I gives information on the period, amplitude and averaging interval of the four-month effect, indicates the relation between the amplitudes of the four-month and one-year peaks, and refers to the ephemeris and to the literature. In the last two cases (Calgary and Honolulu) the variation with approximately four-month periodicity can directly be traced in published figures (Jenkins et al., 1979). It is interesting that the period of variation at Calgary is similar not only in length and in amplitude to that at Honolulu, but also in phase (see also upper part of Fig. 3). Height coordinates derived from Doppler data at Ukiah Latitude Observatory are published separately for the same year for each NNSS satellite; there is at last one case when the height variation is again in phase with the Hawaii and Calgary curves (see the second curve in Fig. 3). Height coordinates derived from Doppler data at Ukiah Latitude Observatory are published separately for the same year for each NNSS satellite; there is at least one case when the height variation is again in Phase with the Hawaii and Calgary curves (see the second curve in Fig. 3). The amplitude is smaller at Ukiah. Results from Wettzel indicate that if the precise ephemeris is used the amplitude of the four-month periodicity is smaller by 50%, but even so it still exists.

INTERPRETATIONS OF THE VIRTUAL HEIGHT VARIATIONS

It has recently been suggested (Jenkins et al., 1979; Dehant and Paquet, 1983) that virtual height variations are induced by unmodeled perturbations acting on the propagation of radio signals and originating mainly from ionospheric refraction. According to Clynch and Renfro (1982) : "the variations can be significantly reduced if third order ionospheric effects are considered." The frequency shift due to the propagation through the ionosphere is usually determined with two simplifications: the truncation at the second order of the refractive index expanded in powers 1/f, and the neglect of the ray curvature in the estimation of the wave path length. The total electron content, N, is derived using local $(f_oF2)^2$ measurements; $\vec{N}$, however, is not a smooth function of time as it depends on solar activity (Souriau et al., 1984). Djurovic (1983) states that a four-month cycle can be detected by Fourier analysis in UT2 and in A_p variations - which, on the other hand, may also be influenced by solar activity.

Studies of differences between the heights of mean sea level computed gravimetrically and heights computed geometrically from Doppler observations show that the consistency can significantly be improved for selected sites in North America by calculating a regression coefficient between the height-difference and the sunspot number ((Tscherning and Goad, in print, quoted by (Anderle and Colquitt, 1984)). "Studies have shown systematic variations in the computed heights of stations with the variations correlating with near-annual and long-period variations of sunspot activity." (Anderle and Colquitt, 1984).

Even though it is obvious that neglected ionospheric effects must also be taken into account, it is difficult to accept that the phenomenon is only a consequence of ionospheric mismodeling. Namely there are several problems connected with this ionospheric explanation:

- In the power spectra of height variations there are only two very conspicuous peaks, viz. one year and 124 days. In the power spectra of solar and geophysical data, on the other hand, the later peak is not remarkable at all, being less significant than peaks at 27 days or 3 months. It is difficult to understand why even a barely visible four-month periodicity of solar activity should affect- through the total electron content of the ionosphere - one of the station coordinates.
- In stations located far from the magnetic equator and far from polar regions (i.e. in Europe and US) the ionospheric effect should be of low amplitude (Souriau et al., 1984). There is, however, no apparent dependence on magnetic latitude in the amplitude of height variations (see Table I).
- If the ionospheric explanation is correct, the amplitude of the height variations ought not to depend on orbital information or ephemeris (PE or BE).

We are of the view that the virtual variation in station coordinates may well be connected with mismodeling of drag forces acting on the motion of the

"OSCAR-type" NNSS satellites. According to Black (Black, 1977) the effect of incorrectly modeled surface forces (air-drag) in satellite position is 10-25 m, though uncorrected ionospheric propagation effects contribute only 1-5 m to the single pass error budget. Current models of the neutral upper atmosphere must be used with caution at around 1000 km altitude, particularly during high solar activity periods. There is some controversy concerning atmospheric models with regard to the phase and amplitude of the diurnal effect. Just this kind of uncertainty may be the cause of an error which has a period of four months and one year. Namely, these periods may easily be found in the relative motion of the perigee of a Transit satellite with respect to the center of the diurnal bulge. The period of the argument of perigee for NNSS satellites Nos. 13, 14, 19, 20 and 48 - used in Doppler positioning - is between 124.16 and 125.42 days; the mean period is 124.42 days which lies astonishingly near to the mean value of the four-month peak (Table I): 124.47 days.

The polar orbit of NNSS satellites, on the other hand, sifts slowly in longitude with time, taking approximately **one year** for a complete revolution. The superposition of the motion of the perigee and that of the orbital plane is the origin of the variation of the angular distance of the perigee from the center of the diurnal bulge with a beat period of oscillations similar to the two most important peaks in the power spectrum of the height variations (4 months, 1 year). This striking coincidence suggests that mismodeling of the atmospheric diurnal effect may at last be partly responsible for the phenomenon. The satellite used dominantly in station positioning may influence by its along-track error the value of the Z and H coordinates of the tracking station in particular.

There is one interesting case in 1978 when changes in the height values of at least 3 tracking stations - distant in latitude - are almost simultaneous (see upper part of Fig. 3).

The first maximum in the last days of 1977 is followed about four months later in May in 1978 by the second maximum of the year. We found a figure in Black (1977) demonstrating the variation of the rate of change of the along-track error (i.e. satellite position error) for NNSS satellite No. 14 as a function of time in 1977 (see lower part of Fig. 3). According to a formula of Eisner and Yianoulis this parameter, A_1, is proportional to the error in the modeled mean air density δ_ρ:

$$\delta_\rho = -\frac{2}{C_D}\left(\frac{mn}{3AV}\right)\frac{A_1}{V\Delta t},$$

where C_D is the drag coefficient, m is the satellite mass, n is the mean motion, A is the frontal area of the satellite, V is the speed of the satellite, Δt is the time interval and A_1 is the slope of the along-track error growth in meters per unit change in the mean anomaly. The lower left part of Fig. 3 demonstrates that the error in the modeled mean air density changed with a four-month periodicity in 1977 and it indicates a similar maximum in the last days of 1977. Clearly, this kind of coincidence between the lower and upper part of Fig. 3 suggests that the mismodeling of the drag component affects really the variation of station coordinates.

Another argument in favor of the above explanation has been found in the variation of height determined by means of different satellites at the Ukiah tracking station (Strange et al., 1982), Fig. 4. The time resolution is generally not fine enough to show the superposed four-month variation (except perhaps in 1980-82) but the one-year periodicity is clearly visible. There is, however, a definite time shift between curves determined by means of different satellites. Such differences are difficult to explain by the ionospheric propagation effect. Lower horizontal scales indicate times of maxima belonging to different satellites; the phase shifts correspond - at least qualitatively - to the relative position of the respective orbital planes as shown in Fig. 5 based on Hoskins.

There are also certain problems with the air-drag interpretation. If 3 or 4 satellites are used simultaneously to determine station coordinates, phase differences should significantly diminish virtual height variations. In an ideal case the use of PE instead of BE should make the effect disappear.

It should be mentioned that Borza and Varga claim that the four-month fluctuation is a virtual effect due to a non-adequate use of long period harmonics of the geopotential in the orbital model.

CONCLUSION

The apparent inconsistencies in both assumptions lead us to suggest that uncorrected ionospheric propagation effects plus incorrectly modeled air density (diurnal effect) combine to produce the apparent variations in station coordinates. There are certain possible means of controlling and separating the two effects; one such way is to determine station coordinates based solely on drag-free NOVA satellites. Without solving this problem there is no hope of increasing to any great extent the accuracy of geocentric station coordinates and determining crustal motion directly by means of Doppler techniques (Anderle and Malyevac, 1983).

ACKNOWLEDGEMENT

The author thanks Dr. J. Adám and Dr. T. Borza of the Satellite Geodetic Observatory, Hungary, for valuable discussions and technical help.

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TABLE I: "FOUR-MONTH EFFECT" IN HEIGHT VARIATIONS

Station	Country	ϕ	λ	Period (days)	Ampl. (m)	Relation to one yr. peak	Time	Averaging (days)	Ephemeris	Ref.
Penc	Hungary	+48	19E	125	0.8	smaller	1978-83	5-7	BE	19
Graz	Austria	+47	15E	125.8		larger	1978-81	5	PE	20
Wettzell	FRG	+49	18E	122.5	0.6	smaller	1978-81	5	BE	21
Wettzell	FRG				0.3				PE	
Uccle	Belgium	+50	4E	122-127	0.14		1972-80	10	PE	22
Ukiah	USA			125		smaller				15
Calgary	Canada	+50	245E	(120)	0.4	(larger)	1977-78		PE	6
Honolulu	Hawaii	+21	202E	(14)	0.8	(larger)	1977-78		PE	6

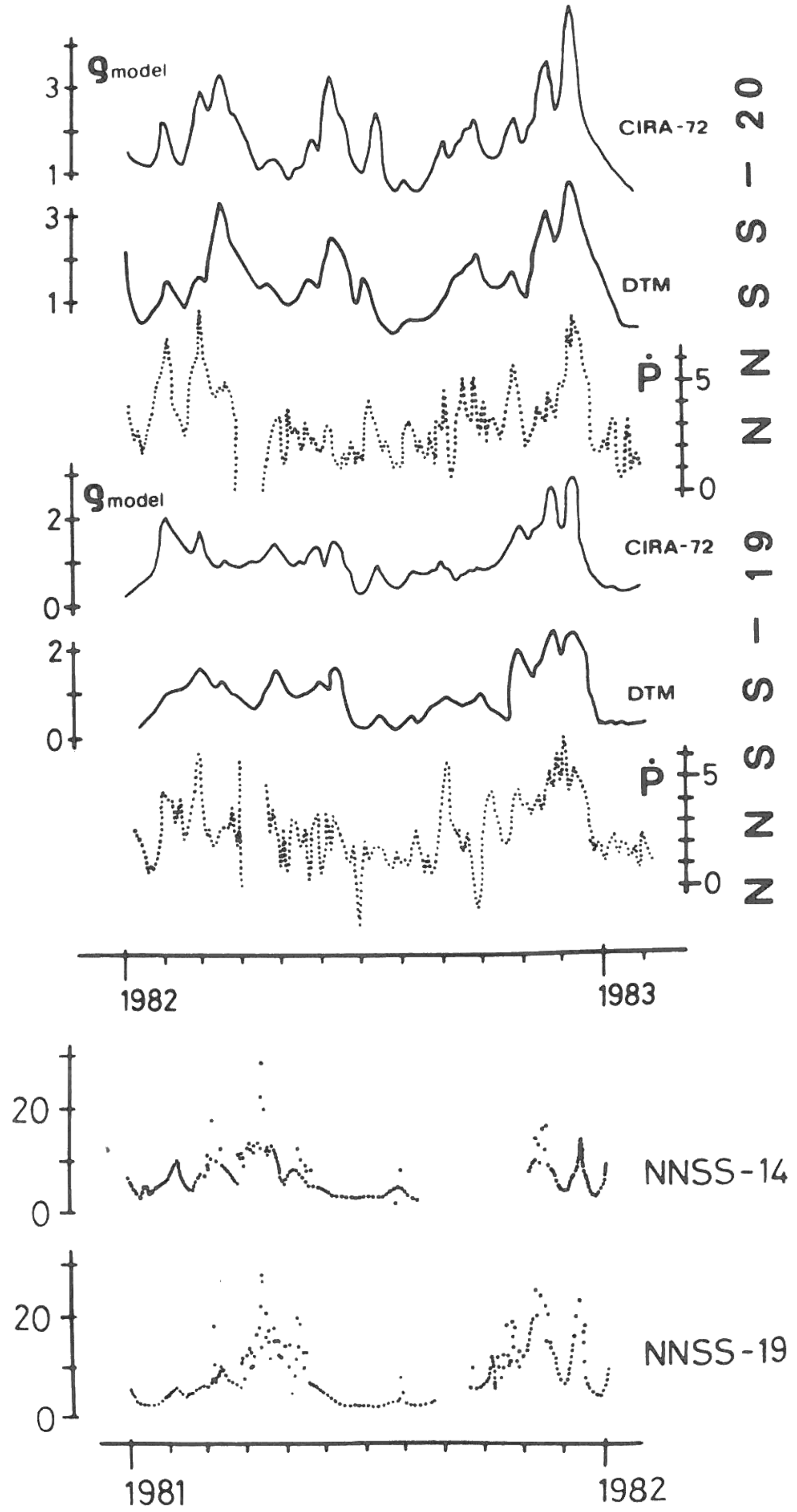

FIGURE 1
Total atmospheric density versus time derived by OSCAR type NNSS satellites. The lower curves are from Anderle [5]; the upper curves, $\dot{P}$, were calculated using BE of Doppler satellites recorded in Hungary. Corresponding model density curves (CIRA-72 and DTM) are given for comparison.

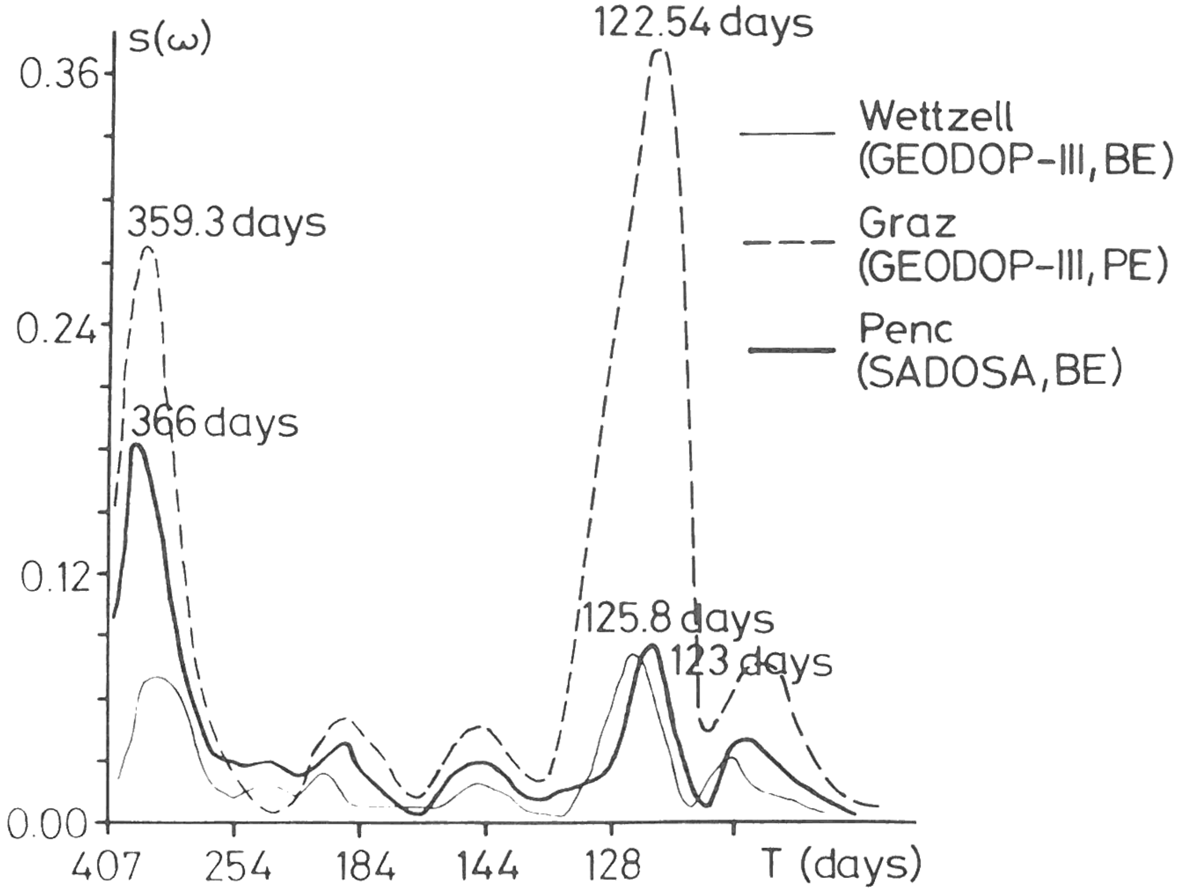

FIGURE 2
Power spectra of height variations recorded at Penc, Hungary, Wettzel, FRG, and Graz, Austria. The geocentric coordinates were determined from BE or from PE. Standard GEODOP and Hungarian SADOSA programs were used.

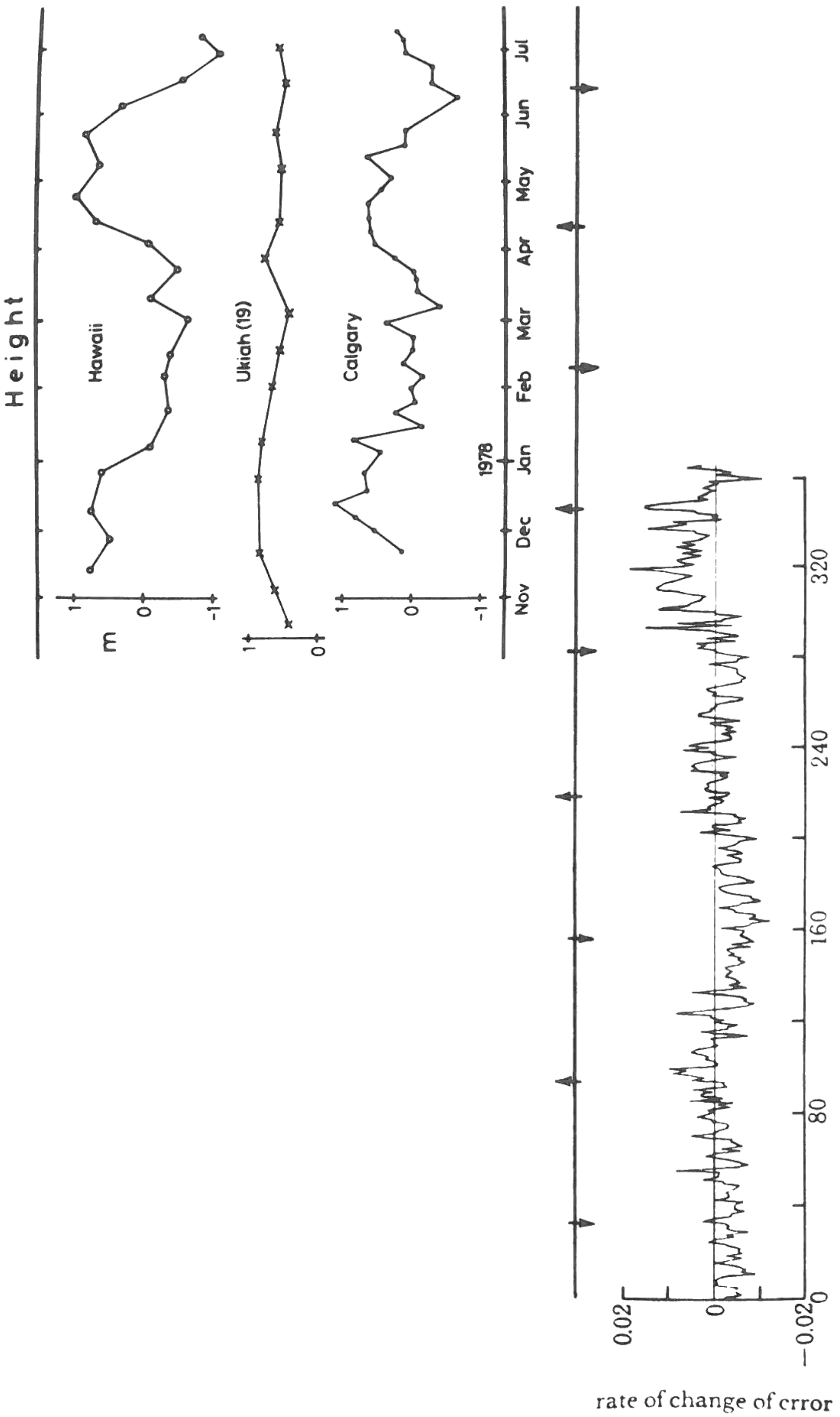

FIGURE 3
Upper: simultaneous variations of the height coordinate recorded at 3 different stations in 1978. Lower: the variation of the rate of change of along-track error, A_1, for an NNSS satellite versus time in 1977 [13]. The scale indicates approximate times of maxima of the four-month variation.

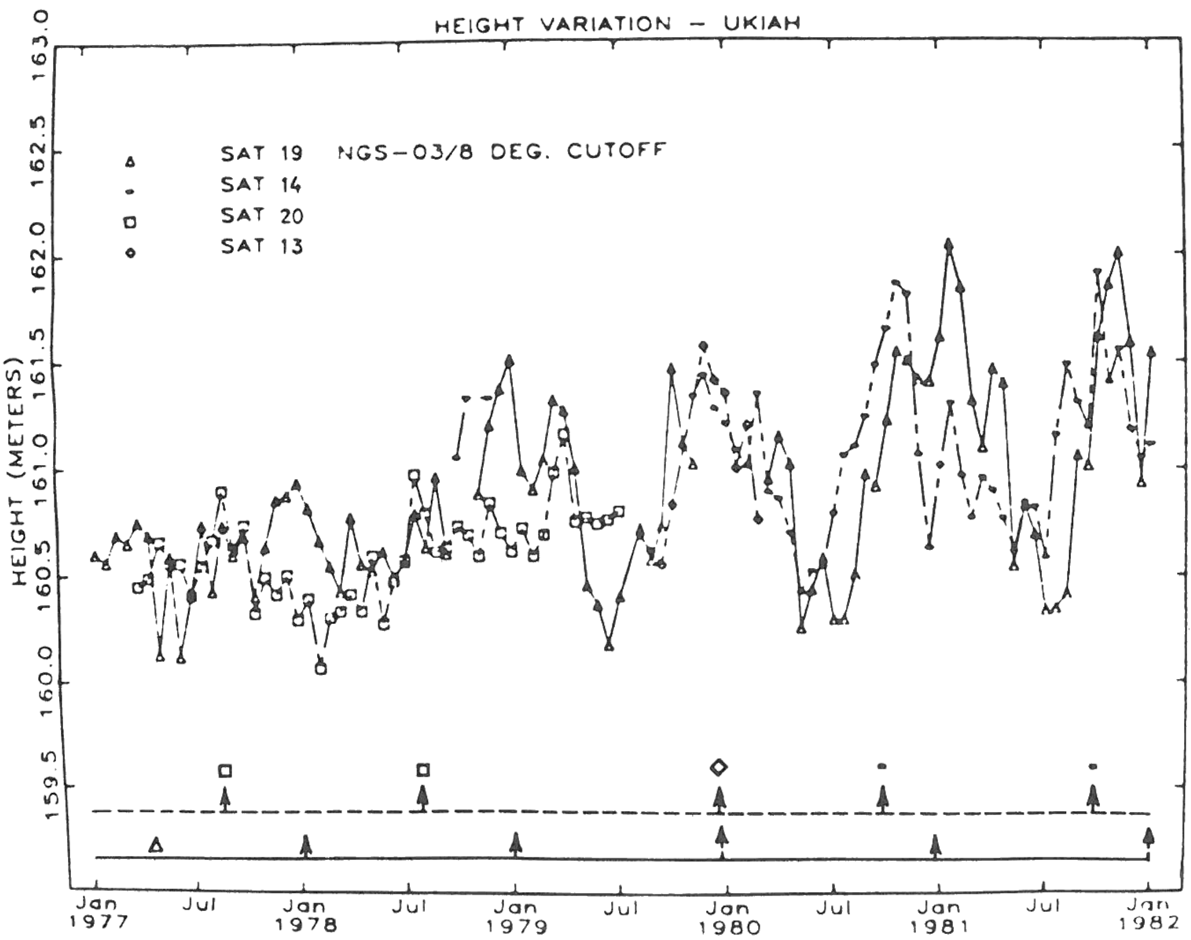

FIGURE 4
Height variation at the Ukiah station from 1977 to 1982 as determined by means of different NNSS satellites [15]. Lower scales indicate times of maxima belonging to the curves of corresponding satellites.

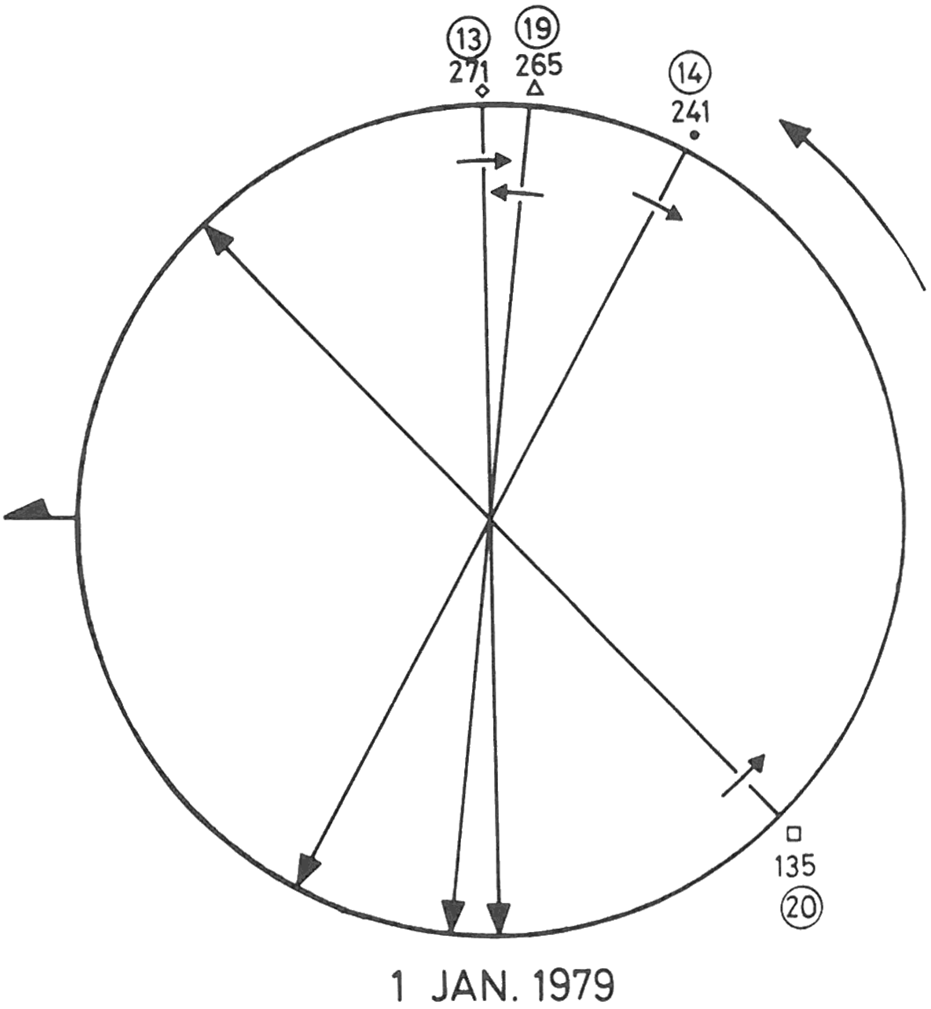

FIGURE 5
Relative position of the orbital planes of the OSCAR type NNSS satellites at 01.01.1979 [16]. Arrows indicate the direction of motion of the orbital planes. For symbols see Fig. 4.