# The Transit Instrument under Optimum Conditions

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## Summary

On the basis of experience with RA determinations during the polar nights of 1974-1977 on West Spitzbergen and of RA determinations of the Sun, Mercury and Venus at high latitutes one can conclude as follows: At high geographical latitudes the polar night conditions are nearly optimal for absolute determinations of stellar coordinates; high altitude sites near the equator are best for day time observations. It is suggested that observatories be built for absolute position determinations on Spitzbergen, and on McMurdo on the Antarctic Continent. The link between observations in the northern and the southern hemispheres can be established through observations at a high-altitude equatorial observatory, where the Sun and the planets can also be observed.

The problem of improving the accuracy of fundamental catalogues has always been one of the most timely tasks in astrometry. The most important aspects of this problem and, unfortunately, also the most difficult, are

1) the absolute determination of stellar coordinates, and

2) finding the coordinates of the Sun and the planets in the system of an absolute (or of a fundamental) catalogue.

We think that the best way for the determination of absolute star positions is carried out by observations from high-latitude locations on the Earth during the polar nights. The coordinates of the Sun and the planets are best determined by observations made from locations on high mountain plateaus near the terrestrial equator. In extreme geographic latitudes, for example Spitzbergen, or in the American village of McMurdo in the Antarctica, the polar night lasts several months. Consequently, the air temperature is, during a full sidereal day, only weakly correlated with the hour angle of the Sun. Under these almost isothermal conditions, it will be possible to obtain uninterrupted series of observations of the stars lasting all of 24 hours. This will make it possible to determine to the extent of a fundamental azimuth the orientation of the transit instrument during any



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measurement and the right ascensions of the stars without having to use the chain method.

High mountain conditions, in particular the transparency of the atmossphere, are usually better than those at sea level and are considerably better than around polluted cities where most of the big observatories are located. It will therefore be possible to observe in mountain conditions a sufficient number of reference stars even when they are relatively close to the Sun, as well as to obtain very precise coordinates of the Sun, Mercury, Venus and the other planets, and use these for the improvement of the catalogue equinox as well as for an improvement of the planetary orbits themselves.

The astronomical observatory in Nikolayev has gathered the experience of working during polar nights and on high mountain locations. In the following, we shall discuss the main results of this work.

During the three polar nights from 1974 to 1977, right ascensions of stars were fundamentally determined on the West Spilzbergen Island (latitude +78° 06'). The observations were made with a portable transit instrument of the type APM 10 (focal length 1000 mm, objective diameter 100 mm) equipped with photoelectric registration of stellar transits. The instrument was reversed and the level was read during each observation.

During the first polar night (1974-5), the following persons participated in the observations: The late N.S. Kalishevitz, G.M. Petrov, A.P. Chelombitko, during the second, V.I. Kiyayev, and V.N. Pyshnyenko and during the third, A.S. Pavlov, G.I. Pinnigin and V.N. Pyshnyenko. The observers were relieving each other at the instrument, and thus obtained continuous observation series of maximum possible duration, the longest having been 115 hours. The bulk of the observations was obtained during twenty-five series, none lasting less than eighteen hours.

As expected, the ambient air temperature during the observations showed virtually no dependance on the Sun's hour angle, as illustrated by Fig. 1 which shows a plot of the means of the air temperature during the continuous series lasting 24 hours each (eight series during November and December, and twelve in January).

531 FK4 stars were included in the observing program. Once every hour, one of these was observed in each 10° wide declinaton zone, starting from 30° to 80° in both culminations, which means that 12 hours after each observation, the star was also observed in the opposite culmination. We thus obtained during each hour ten absolute determinations of Bessel's n. This overdetermination of the values for n aided in finding the dependence of n on the declination. These values, which were also used for the reduction of the observations, are shown in Table 1. Note that in moderate geographic latitudes it would not have been possible to find the instrument errors in this way, and the accuracy of the measurements would thus unavoidably have suffered.

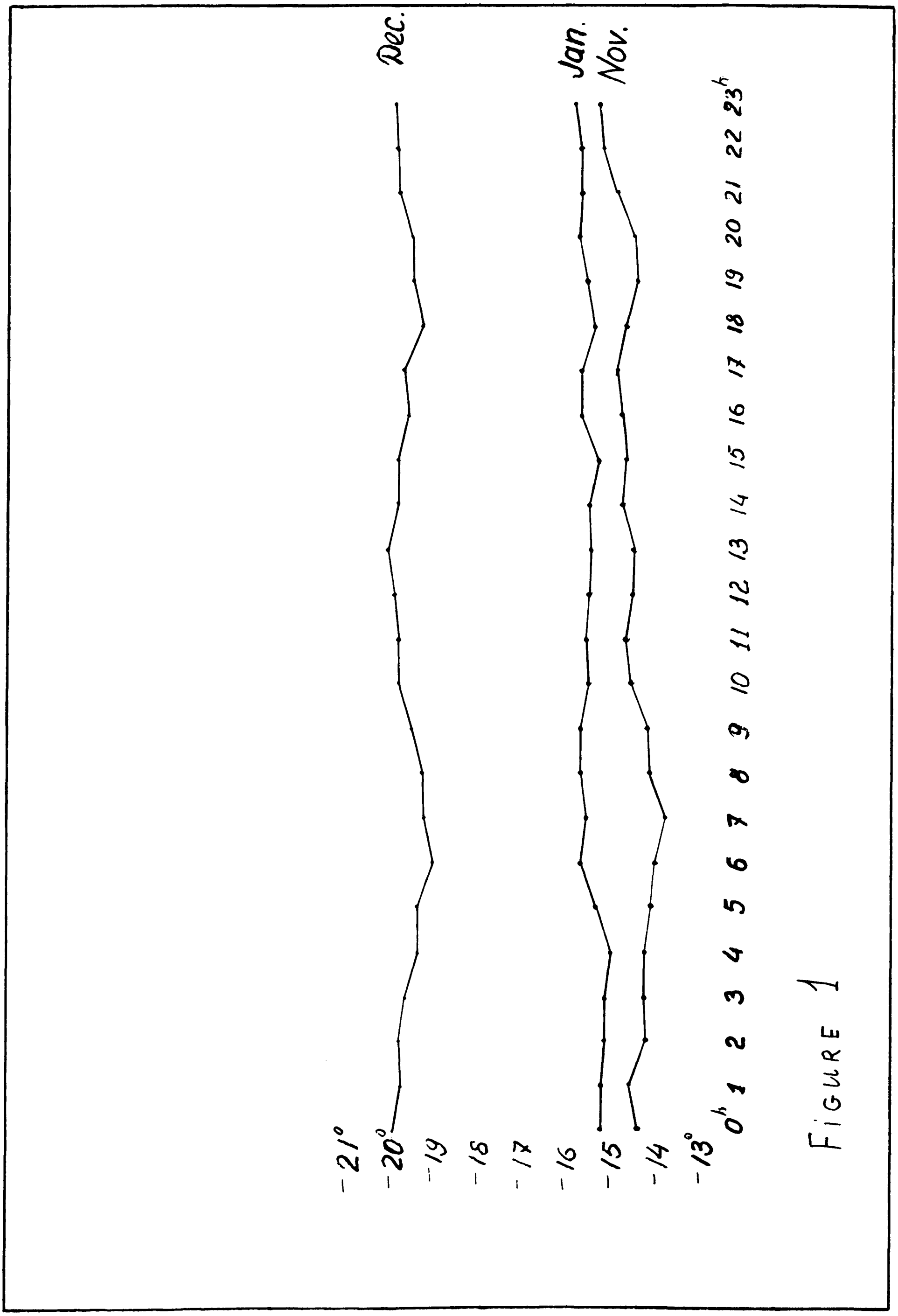


FIGURE 1

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Table 1
The dependence of n on declination (unit: $0\overset{s}{.}001$)
(zero point normed to the zone +40° to +80:)

| | 30°-40° | 40°-50° | 50°-60° | 60°-70° | 70°-80° |
|---|---|---|---|---|---|
| first night | +12 | + 6 | - 3 | - 2 | - 3 |
| second night | +10 | + 1 | 0 | - 1 | 0 |
| third night | + 3 | + 2 | 0 | + 1 | - 2 |

For the determination of the parameter u + m (in the observing program) we observed groups of clock stars with average declinations of +30°, on the average three stars per hour. These stars were observed in a certain sequence, and during the three polar nights, we succeeded in observing each group no less than thirty clocks. These observations were used for adjusting the right ascensions of the time stars after that we had calculated absolute values of u + m for every series of observations.

The quasi-absolute right ascensions obtained for the 531 stars were reduced to the epoch and coordinate system 1975.0. These positions created an observed catalogue of absolute right ascensions of 531 stars between +10° and 80°, which was named NIK (Sp)75(Nikolayev-Spitzbergen).

In order to find possible sytematic errors, NIK(Sp)75 was compared with the FK4. Tables 2, 3 and 4 show the results of these comparisons in $\Delta\alpha_\delta \cos\delta$, $\Delta\alpha_\alpha \cos\delta$ and $\Delta\alpha_m \cos\delta$. These tables also show analogous differences between the compilation catalogue of the time service of the USSR (Pavlov et al. 1971) and the FK4, as well as the Pulkovo catalogue Pu58 (Nemiro et al. 1977) and the FK4. N is the number of stars which contribute date to the tabulated mean.

Table 2
Values of $\Delta\alpha\delta \cos\delta$ (unit: $0\overset{s}{.}001$)

| declination zone | Nik(sp)+5-FK4 | | KCB-FK4 | | Pu5δ -FK4 | |
|---|---|---|---|---|---|---|
| | Δαδ cosδ | N | Δαδ cosδ | N | Δαδ cosδ | N |
| 10°-20° | - 5 | 92 | - 5 | 58 | - 2 | 52 |
| 20 -30 | - 5 | 103 | - 4 | 55 | - 4 | 55 |
| 30 -40 | + 4 | 87 | 0 | 57 | 0 | 49 |
| 40 -50 | + 3 | 88 | + 1 | 86 | - 3 | 57 |
| 50 -60 | + 5 | 57 | + 2 | 93 | - 1 | 44 |
| 60 -70 | + 6 | 56 | + 5 | 77 | + 4 | 41 |
| 70 -80 | + 5 | 48 | + 5 | 19 | + 5 | 39 |

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In Table 2, note the good agreement of our catalogue with the **KSS** and PU58, which points out conspicuous systematic errors in the FK4. Table 3 shows that the differences $\Delta\alpha_\alpha \cos\delta$ are not too large. This is especially true in the zone from +30° to +50°. As for the $\Delta\alpha_m \cos\delta$, one may say that the FK4 right ascensions are obviously not free from magnitude equation.

The results of our comparisons demonstrates the high accuracy (concerning systematic errors) of our Spitzbergen catalogue.

Table 3
Values of $\Delta = \Delta\delta_\alpha \cos\delta$ (units $0\overset{s}{.}001$)

| α \ δ | 10°-30° | | 30°-50° | | 50°-80° | | α \ δ | 10°-30° | | 30°-50° | | 50°-80° | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Δ | N | Δ | N | Δ | N | | Δ | N | Δ | N | Δ | N |
| $0^h-1^h$ | +3 | 17 | +1 | 13 | 0 | 16 | 12-13 | +3 | 12 | -2 | 13 | -1 | 13 |
| 2 - 3 | -2 | 21 | 0 | 14 | -4 | 15 | 14-15 | +2 | 20 | +4 | 28 | +5 | 16 |
| 4 - 5 | -1 | 19 | -2 | 17 | -4 | 10 | 16-17 | -4 | 15 | -1 | 15 | +5 | 16 |
| 6 - 7 | +2 | 20 | +1 | 13 | +4 | 9 | 18-19 | -4 | 16 | -1 | 9 | +5 | 12 |
| 8 - 9 | 0 | 16 | -1 | 15 | +1 | 14 | 20-21 | -3 | 15 | 0 | 17 | -6 | 12 |
| 10-11 | +7 | 11 | +1 | 16 | -6 | 13 | 22-23 | 0 | 13 | 0 | 16 | 0 | 15 |

Table 4
Values of $\Delta_1 = \Delta\delta_m \cos\delta$ (units of $0\overset{s}{.}001$)

| M | NiK(sp)75-FK4 | | KCB - FK4 | | Pu 58 - FK4 | |
|---|---|---|---|---|---|---|
| | $\Delta_1$ | N | $\Delta_1$ | N | $\Delta_1$ | N |
| 0 - 2 | -3 | 10 | -5 | 14 | -6 | 21 |
| 2 - 3 | -1 | 32 | -3 | 33 | -3 | 43 |
| 3 - 4 | -3 | 91 | -1 | 88 | -1 | 145 |
| 4 - 5 | -1 | 152 | 0 | 132 | +2 | 135 |
| 5 - 6 | +1 | 206 | +2 | 104 | +3 | 118 |
| 6 - 7 | +3 | 42 | +3 | 11 | +3 | 37 |

The evaluation of the precision of the observations (referring the accidental errors) was found from the dispersion of the observed values for the same star against their mean. Averaged over the observers, the average (for all observers) mean square error of a single determination was $\pm 0\overset{s}{.}0151 \sec\delta \sec z$ with an root

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mean square error of $0^s.0004$. Since each star was, on the average, observed 25 times, the mean square error of a catalogue position equals $0^s.003 \sec\delta \sec z$. Note that this error might depend less on z if our transit instrument APM 10 did not have a defect in design, the neutralization of which requires close attention to the rule for observing the star in the photoelectric reticule (Petrov 1957). Unfortunately, the limitations of time sometimes prohibit this.

Our three years of expedition work at Spitzbergen showed, that

1) There, it is indeed possible to get uninterrupted series of observations lasting longer than 12 hours which is especially important.

2) The ambient air temperature during the observations changes only little, two degrees to three degrees during 24 hours and is not correlated with the Sun's hour angle. This, too, is quite important.

3) A high accuracy independent catalogue was observed, in spite of a large number of observers and an instrument of not very high quality.

4) The FK4 has conspicuous systematic errors in the declination zone +10° to +80°.

5) We found no difficulties which would affect in principle, observations during a polar night. The quality of seeing was usually satisfactory. The average ambient air temperature during the observations was -15.7C during the first, $-21^\circ.2$ during the second and $-13^\circ.9$ during the third polar night.

All this justifies the statement that the work of the expedition to Sptizbergen proved the advisability of determining absolute right ascensions from stations at extreme geographic latitudes during the polar night. We therefore suggest the establishment of permanent observing stations at such sites, equipped with first quality instruments. During the next years, such stations could relieve the chronic lack of high-quality observations needed for the compilation of fundamental star catalogues. An important argument for conducting observations at high geographic latitudes is also the efficiency of the observing process. During three months, one can obtain as many observations from there as are collected at observatories in conventional geographical latitudes in one year.

The precision of the right ascension determinations of the Sun, Mercury and Venus was evaluated on the basis of observations with a portable transit instrument (Askania-Werke, objective diameter 90 mm, focal length 900 mm) in July 1970 in the Zakavkaz at Agdara ($\phi$=39°) at Nakhichevanska ASSR at an altitude of 2100 m above sea level, and during 1981-1982 with a transit instrument of the type APM 10 (d = 100 mm, F.1. 1000 m) in the north Caucasus at Kislovodsk ($\phi$ = +44°) at an altitude of 2100 m.

In both cases, the instruments were housed in temporary huts, made of corrugated steel, covered with fiberglass cloth painted white. These huts had meridian slits .6 m wide, which could be closed with movable sun screen with three movable shutters for the observation of the sky back ground celestial bodies and the mires.

At Agdara, as a mires we used steel pipe driven into the ground at the top of the neighboring mountain at a distance of 1200 m from the hut. The top part of this pipe was set against the blue sky background and was easily seen in the field of view of the instrument. In the region of Koslovodsk the mire was at a distance of 3 km.

At Agdara the observations were made during only a fortnight and for 9 days the sky was clear. During this time 163 daytime observations of stars up to the 4th magnitude in the zenith were obtained. One could manage to observe the stars of $2^m$ at an angle distance less than 15° from the Sun and it was about $1.5^m$ - $2.0^m$ better than at Nikolaev. This conclusion was confirmed also by observations of faint stars at night time. At Agdara, in spite of the small size instrument, stars of 9th magnitude were reliably visible in the zenith, and stars of $8.6^m$ at a zenith distance of 50°. At Nikolayev, stars of $7.3^m$ can be seen at the same zenith distance and with the same instrument only with great difficulties.

In the region of Kislovodsk, we managed to observe even fainter stars during the daytime close to the Sun than at Agdara. Especially remarkable is the fact that in winter at Kislovodsk one could observe reference stars not only above, but also below the Sun (at Nikolayev, this is impossible) and this helps to use in practice an almost purely differential observing method.

The quality of the solar images was unsatisfatory, but this can be explained by the poor quality of the plane-paralled filters which we had always inserted in front of the instrument with the purpose of reducing the brightness of the solar image. The images of Venus and Mercury were almost always good. Here, I saw for the first time clear phases of Mercury, starting from a narrow circle.

The average quadratic error of our determination of $(d_o - d_c)$, calculated from individiual residual O-C, and the deviation from the monthly means were equal to

$$\sigma \quad = 0\overset{s}{.}038, \ \sigma \quad = 0\overset{s}{.}033, \ \sigma \quad = 0\overset{s}{.}035,$$

which is on the average half of what one gets at Nikolayev.

This precision would evidently have been even better had we had better filters for weakening the brightness of the solar image, reference clocks and good mires. We assume that under conditions at a permanent mountain observatory, large modern instruments, equipped with good accessories, will be able to reach a precision for obserations of the Sun, Mercury and Venus between $0\overset{s}{.}020$ and $0\overset{s}{.}025$.

Such observatories should be located as close to the Earth's equator as possible. In this case, observations of the Sun and the planets could be made close to the zenith where, as is well known, the precision of observations is higher than at large zenith distances. Altogether, except for that, such observatories could also establish a reliable link between the absolute observations of stars at Spitzbergen and McMurdo.

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