Physik, M. Sc.

Astronomische Beobachtungsmethoden

First lab - Determination of the Geographical Latitude

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Gruppe 02

Informationen

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1 Introduction

The aim of this laboratory session is to determine the geographical latitude of the experimenter by simply measuring the zenith angle of the sun. This is done using a device called a theodolite. The theoretical background and the setup are explained below.

2 Theoretical description

A theodolite is used to measure the angles of the horizontal coordinate system: the zenith angle z_b (90° - altitude) and the azimuth ϕ. In this lab only the zenith angle is of interest and via its measurement the geographical latitude can be derived. The theoretical background for this is given in the following. First, the relation between the horizontal coordinate system and the τ -δ coordinate system is of interest. The hour angle τ can be determined as follows:

$$\tau(t,l,\alpha) = \Theta(t,l) - \alpha = \Theta_\mathrm{G}(t) - l - \alpha = \Theta_\mathrm{G}(0) + t\left(\frac{366.24}{365.24}\right) - l - \alpha, \qquad (2.1)$$

where $\Theta_\mathrm{G}(t)$ describes the Greenwhich sidereal time, α and δ describe right ascention and declination respectively, t is the observation time in UT, and l and b are the coordinates of observation site. This equation has three solutions for b:

$$b = \begin{cases} \pi - arcsin(cosz/X) - Y, & (b+Y) > \pi/2 \\ arcsin(cosz/X) - Y, & -\pi/2 \geq (b+Y) \leq \pi/2 \\ -arcsin(cosz/X) - \pi - Y, & (b+Y) < -\pi/2 \end{cases}$$

where $X = \sin\delta\sqrt{1+(\cos\tau/\tan\delta)^2}$ and $Y = \arctan(\cos\tau/\tan\delta)$. Which of these three solutions will be used is determined by calculating Y with our measured data and looking up b according to GPS.

As right ascention and declination are only given for the 5th of May 0 UT and the 6th of May 0 UT (according to the Astronomical Almanac), a linear Interpolation for UT = t - Δt and Δt=2h for CEST is needed:

$$\alpha^{sun}(t) = \alpha_1^{sun}(0UT) + \frac{UT}{24\mathrm{h}}(\alpha_2^{sun}(0UT) - \alpha_1^{sun}(0UT)) \qquad (2.2)$$

$$\delta^{sun}(t) = \delta_1^{sun}(0UT) + \frac{UT}{24\mathrm{h}}(\delta_2^{sun}(0UT) - \delta_1^{sun}(0UT)) \qquad (2.3)$$

Additionally, there are several correction factors which have to be taken into account. As the observed light has to pass through the Earth's atmosphere, a change in the direction of the light beam occurs. Therefore, the measured zenith angle is smaller than the real zenith angle. The average refraction for T = 10degC and pressure of 101kPa is given by:

$$\bar{R}(z_\mathrm{b}) = 1/\tan\left((90\,\mathrm{deg} - z_\mathrm{b} + \frac{7.31\,\mathrm{deg}^2}{90\,\mathrm{deg} - z_\mathrm{b} + 4.4\,\mathrm{deg}})\right) \qquad (2.4)$$

leading to the Refraction correction:

$$R(z_\mathrm{b}, T, p) = \bar{R}(z_\mathrm{b}) \left(\frac{p\,[\mathrm{kPa}]}{101} \cdot \frac{283}{273 + T\,[^\circ\mathrm{C}]} \right) \tag{2.5}$$

Next, the index error i has to be taken into account. The latter is defined as follows:

$$i = \frac{360\,\mathrm{deg} - z_0 - z_{180}}{2} \tag{2.6}$$

The index error is the consequence of the displacement of the vertical circle towards the zenith which is defined by the alignment of the tubular spirit level. Additionally the correction for the horizontal parallay φ_2 and the transformation to the centre of the sun (φ_1) has to be taken into account. Combining all, the real value for the zenith angle is obtained as follows:

$$\boxed{z = z_\mathrm{b} + i + R(z_\mathrm{b}, T, p) \pm \varphi_1 - \varphi_2}. \tag{2.7}$$

3 Protocol

3.1 Measuring procedure

The theodolite is set up on a tripod and leveled. It is of great importance to use a solar filter before directing the theodolite at the sun.

The main observation begins by measuring the zenith angle at both the lower and upper edges of the solar disk. Each edge is measured at least ten times, and the exact time of each individual measurement is recorded, resulting in a total of twenty precise observations.

After the solar measurements, the horizontal alignment is checked again to identify any changes or drifts during the procedure. The index error of the theodolite is then determined by measuring the zenith angle of a fixed terrestrial object, such as an antenna. This measurement is performed twice—once with the theodolite in its original position, and again after rotating it by 180° (z_0 and z_{180}).

To account for atmospheric effects, current weather conditions are noted, including temperature and air pressure. These values are recorded both before and after the observations.

Finally, the geographical latitude of the observation site is calculated using data from the Astronomical Almanac, incorporating individual refraction corrections for each data point. The height, latitude, and longitude of the site are also determined using a GPS device, with all relevant details documented for later analysis.

1. Greenwich Mean Sidereal Time at 0UT on the 5th of May 2025
2. Right ascention α_1 and declination δ_1 at 0UT on the 5th of May 2025
3. Right ascention α_2 and declination δ_2 at 0UT on the 6th of May 2025
4. Horizontal parallax ϕ_2 and solar diameter ϕ_1 on the 5th of May

3.2 Raw data

In the table 3.1 the measured values for the time and the zenith angle z_b are including (including the measurements of the other group).

The data of the Astronomical Almanac is:

1. $\Theta_G(0UT) = 14\,\mathrm{h}\,52\,\mathrm{m}\,28.7584\,\mathrm{s}$
2. $\alpha_1 = 2.8197997\,\mathrm{h}$ and $\delta_1 = 16.262748\,°$
3. $\alpha_2 = 2.8841898\,\mathrm{h}$ and $\delta_2 = 16.545533\,°$
4. $\phi_2 = 8.72\,°$ and $\phi_1 = 15' + 51.58''$

Tabelle 3.1: Time and zenith angle z_b measurements for top and bottom edges of the solar disk.

Top/Bottom	**Time**	**Zenith Angle**
Top	11:42:47	39° 09’ 32”
Top	11:44:08	39° 03’ 16”
Top	11:56:50	38° 06’ 06”
Top	11:57:37	38° 03’ 07”
Top	12:04:53	37° 35’ 57”
Top	12:06:03	37° 32’ 02”
Top	11:43:31	38° 49’ 19”
Top	11:45:05	38° 56’ 10”
Top	11:46:20	38° 36’ 37”
Top	11:47:22	38° 48’ 14”
Top	11:51:27	38° 30’ 23”
Bottom	11:49:08	39° 12’ 26”
Bottom	11:51:03	39° 04’ 52”
Bottom	11:59:29	38° 29’ 01”
Bottom	12:01:11	38° 21’ 33”
Bottom	11:23:16	41° 23’ 11”
Bottom	11:24:05	41° 18’ 13”
Bottom	11:31:13	40° 39’ 18”
Bottom	11:32:56	40° 46’ 52”
Bottom	11:36:24	40° 12’ 43”
Bottom	11:38:09	39° 46’ 56”
Bottom	11:42:17	39° 41’ 56”

4 Interpretation

4.1 Calculation of geographical latitude

4.2 Questions

5 Results and Discussion

A Append A

A.1 Teilanhang X

Literaturverzeichnis