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Anomalous Refraction and its Influence on Digital Zenith Camera Measurements

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Atmospheric refraction is a phenomenon that occurs when light travels through the Earth's atmosphere. It is causing the apparent position of objects in the sky to appear slightly different from their true position, especially when they are near the horizon. Under normal conditions, atmospheric refraction should follow the laws of geometric optics and, knowing parameters of Earth's atmosphere, could be predicted using standard atmospheric refraction models.
However, anomalous refraction can occur under certain conditions, leading to deviations from the predicted refraction. Anomalous refraction in the atmosphere is caused by variations in the temperature and pressure of the air, which can lead to changes in the refractive index of the atmosphere.
Anomalous refraction is the main limiting factor of ground-based astrometric observation's precision, causing low-frequency irregular angular displacements of observed stars.
One of such observation types where anomalous refraction interferes with observation results are deflection of vertical measurements by digital zenith cameras (DZC). Deflection of vertical (DoV) is the angle between the direction of the gravity vector (plumbline) at a point on the Earth's surface and the ellipsoid's normal through the same point. Therefore, DoVs characterise the direction of Earth's gravity field and can be used for, e.g., geoid determination. DZCs use image coordinates of observed stars at the zenith direction and star catalogue data as high accuracy reference for DoV determination.
According to standard atmospheric refraction models, there should be no refraction effect at the zenith direction. However, anomalous refraction still exists at the zenith direction and affects also observations of DZCs. Comprehensive study of Taylor et al. [1] on anomalous refraction impact on astrometric observations has approved that it ubiquitous and it is not directly dependent on ground weather conditions (temperature, wind speed, pressure). No correlation was found between simultaneous observations with two or even three closely located telescopes in TDI mode (Time-Delay and Integrate CCD readout or drift-scan mode). Taylor et al. concludes that source of anomalous refraction is at low heights (~10–100 m) and physical scale of involved turbulence cells is small (~2 m), and proposes a hypothesis that anomalous refraction might be caused by an atmospheric disturbance created by the dome or telescope itself or it is a result of the integration of quasi-stochastic atmospheric dynamics over the entire air column, with the greatest contributions originating in the surface layer.
Anomalous refraction has also been observed as an error source in several studies employing DZCs [2, 3, 4, 5]. Hirt [2] has used observations collected in the single site for 6 nights which is the only study of anomalous refraction using DZC. This study concludes that the anomalous refraction effect at the zenith reaches from 0.05 arcseconds up to about 0.2 arcseconds.
Attempt to understand anomalous refraction by using DZC VESTA (VErtical by STArs) of University of Latvia has been done by performing DZC VESTA observations at test site with four points during two-year time. Overnight (5–10 h long) observations were done during all seasons over various weather conditions. Initially one meteo-sensor measuring temperature, atmospheric pressure and relative humidity was installed on DZC VESTA.
The amplitudes of the observed zenith coordinate fluctuations reach several arcseconds, and the amplitudes of the final DoV values are within ~0.2-0.5 arcseconds during overnight session. Warm weather front passing observation site caused high DoV amplitudes of ~0.5 arcseconds. For comparison, accuracy of DZC VESTA DoV values is 0.1 arcsecond for typical session of 45-60 minutes. DoV observations performed during warmer weather of summer months tend to have higher residuals. Apart from that, no correlation was found between result DoV residuals and atmospheric pressure.

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