Atmospheric effect in the three-space scenario for the Stokes-Helmert method of geoid determination

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Introduction

For the transformation of the gravity anomalies from the real space into the No Topography (NT-) space the effect of atmospheric masses on the gravitational attraction must be evaluated. This effect consists of the direct atmospheric effect and the secondary indirect atmospheric effect. (NT-space is the space obtained after disregarding the external masses , both topographical and atmospheric, above the geoid, i.e. No Topography space, which is also called Bouguer space),

After obtaining the NT-anomalies at the geoid surface, they are further transformed from the NT-space into the Helmert (H-)space. The effect of condensed atmospheric masses on the gravitational attraction must be then evaluated. By analogy with the effect of atmospheric masses, the effect of condensed atmospheric masses consists of the direct condensed atmospheric effect and the secondary indirect atmospheric effect.

The programs used for the evaluation shown here are part of the UNB package for precise geoid determination.

Numerical realization of each of these four effects

For the numerical integration pertaining to the computation of each one of these effects the following DTM spacing was used to model the topography: 30 × 30 minutes for the inner-zone integration; 5 × 5 minutes for the middle zone; and, 1 × 1 degree for the far-zone.

Transformation from real space into NT-space

As mentioned in the Introduction, the direct atmospheric effect and the secondary indirect atmospheric effect on the gravitational attraction are computed to obtain the NT-anomalies from the actual gravity anomalies. Both effects are referred to the earth surface.

Direct atmospheric effect

The direct atmospheric effect is defined as the gravitational attraction of atmospheric masses evaluated at the earth surface. It is described by Newton's volume integral, where the integration is employed over the entire earth's atmosphere. We choose the upper limit of the atmosphere to be 50 km above the sea surface and split the atmosphere into the atmospheric spherical shell from the height 9 km up to 50 km, and the atmospheric spherical roughness term between the topography and the bottom limit of atmospheric shell, i.e., the mean sea level. Since the gravitational attraction of the spherical atmospheric shell at the interior is equal to zero (Mac Millan, 1930), during the process of computation of the direct atmospheric effect only over the (spherical) roughness the numerical integration is employed. The result of the numerical integration is shown in Figure 1. As follows from the result, the gravitational attraction of atmospheric masses is small. Over Canada it varies from approximately 0 mGal (ocean) to -0.18 mGal (mountains), with a mean value of -0.02mGal. Hence, this effect would be systematically negative and since it reaches more than 0.01 mGal (in absolute value), it must be taken into account if the 1cm accuracy geoid is procured (Vanicek and Martinec, 1994).

Secondary indirect atmospheric effect

The secondary indirect atmospheric effect is defined as the atmospheric potential multiplied by 2/r, where r is the geocentric radius of the earth surface at the computation point. This effect is shown in Figure 2. Over Canada this effect varies between 1.68 mGal and 180 mGal with a mean value of 1.77mGal.

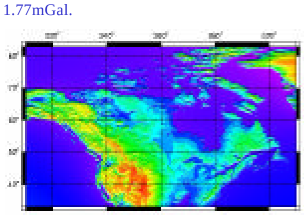

Figure 1. Direct atmospheric effect.

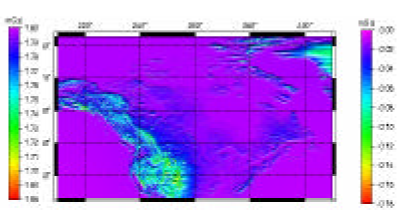

Figure 2. Secondary indirect atmospheric effect.

Transformation from the NT-space into H-space

In this part of the geoid computation, the direct condensed atmospheric effect and the secondary indirect condensed atmospheric effect on the gravitational attraction are computed to obtain the H-anomalies from the NT-anomalies. The computation is realized directly at the geoid surface, because the vertical displacement between the Helmert co-geoid and the geoid is negligible in this context.

Direct condensed atmospheric effect

The direct condensed atmospheric effect is defined as the gravitational attraction generated by the condensed atmospheric masses. As follows from the result shown in Figure 3, the direct condensed atmospheric effect ranges from -0.84 mGal over the ocean to -0.64 mGal at the area of the Canadian Rocky Mountains, with a mean value of -0.82mGal.

The difference between the direct and the condensed atmospheric effects can be seen. For the computation of the direct condensed atmospheric effect the contribution due to the atmospheric spherical shell must be considered. The density of the condensed atmospheric spherical shell is a constant value

Secondary indirect condensed atmospheric effect

The secondary indirect effect of the condensed atmospheric masses on the gravitational attraction is defined as the gravitational potential of condensed atmospheric masses multiplied by the 2/R, where R is the mean radius of the earth which approximates the geocentric radius of the geoid. As follows from the result of our computation over Canada (Figure 4), this effect ranges between 0.71 mGal and 1.39 mGal, with a mean value of 0.81mGal.

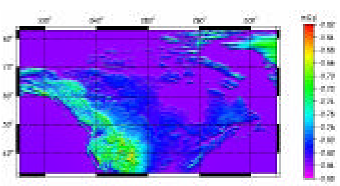

Figure 3. Direct condensed atmospheric effect.

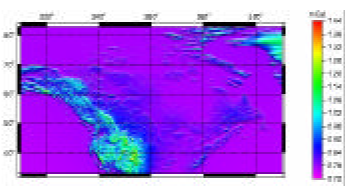

Figure 4. Secondary indirect condensed atmospheric effect.

Conclusions

Summarizing the result of our numerical investigation over Canada, it follows that the direct atmospheric effect is much smaller than the direct condensed atmospheric effect. Moreover, the secondary indirect effect of atmospheric masses and the secondary indirect effect of condensed atmospheric masses are similar but the differences (a few milliGals) are not negligible.

The secondary indirect (atmospheric and condensed atmospheric) effects have a low-frequency character while the direct effects contain also the high-frequency part. Specially the direct atmospheric effect is strongly related to the topography, where over the ocean it is almost negligible while at the Canadian Rocky mountains it reaches up to 180 µGal.

Based on our numerical investigation of all the effects caused by atmospheric and condensed atmospheric masses, the 30 × 30 seconds DTM data are sufficient for the near-zone numerical integration up to 5 minutes of the spherical distance around the computation point, 5 × 5 minutes DTM for the middle-zone up to 3 degree of the spherical distance, and 1 × 1 degree mean heights for the far-zone integration sub-domain.

Acknowledgements

This research was conducted under auspices of the "GEOIDE Network of Centres of Excellence".