PARALLAX APPLICATIONS WHEN COMPARING RADAR AND SATELLITE DATA

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Abstract

The paper addresses parallax computation for geostationary satellites with the Earth described by a reference ellipsoid. Application of parallax correction to comparison of radar and satellite data is demonstrated on a cold-ring shaped storm on 21-22 June 2006 above Austria using MSG/SEVIRI observations. Values of parallax, especially for higher cloud tops, are not insignificant. Therefore, parallax correction is essential for correct interpretation of high cloud top features in satellite imagery and may also have a crucial impact on some satellite-derived products.

INTRODUCTION

Parallax is an apparent displacement of cloud location with regard to the Earth's surface in satellite imagery which results from a non-zero viewing angle of the satellite (Fig. 1). Parallax depends on the height of the cloud top, its geographic location as well as the position of the satellite. This study focuses on parallax for geostationary satellites.

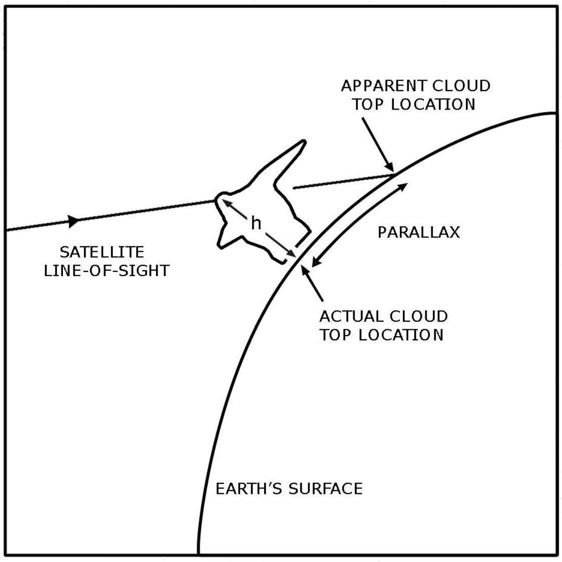

Figure 1: **Schematic illustration of parallax.**

Parallax correction is important when comparing satellite and radar data, especially for high Cumulonimbus clouds. Two ways of correction are possible. In the first case, each cloud pixel in satellite imagery is shifted by a corresponding parallax value. In such a case it is necessary to know accurately the cloud top heights. The second possibility, which is used in this study, is based on a transformation of data that are to be compared with satellite imagery (radar data in our case) into the geostationary projection, i.e. their adjustment at particular height levels by the computed values of parallax shift.

COMPUTATION OF PARALLAX FOR GEOSTATIONARY SATELLITES

The computation is based on geometry with the Earth described by a reference ellipsoid. Two systems of coordinates are used: Cartesian coordinates – $\vec{x}$ = (x, y, z) and geodetic coordinates – *Φ* (geodetic latitude), *θ* (geodetic longitude), *h* (geodetic height). A reference ellipsoid as well as both types of coordinates are illustrated in Fig. 2.

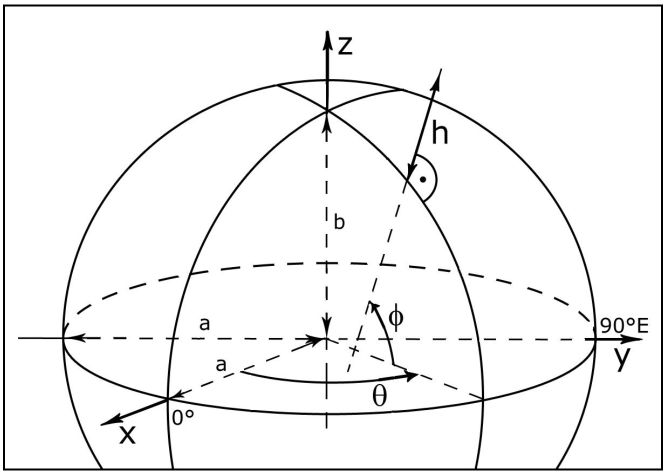

Figure 2: **Reference ellipsoid (semimajor axis: *a* = 6378.137 km, semiminor axis: *b* = 6356.752 km) and two used coordinate systems – Cartesian coordinates: $\vec{x}$ = (*x*, *y*, *z*) and geodetic coordinates: *Φ*, *θ*, *h*.**

Satellite coordinates are marked with a subscript *S* in the text below. Because we consider only geostationary satellites, latitude Φ_S = 0° and geodetic height $h_S = R - a$, where *R* (= 42168 km) is the distance between the satellite and the center of the Earth, and *a* is the semimajor axis of reference ellipsoid. Parallax is computed for a spot in a cloud top with known coordinates Φ_C, θ_C, h_C. The line connecting this spot and the satellite is given by:

$$\vec{x}(t) = \vec{x}_S + (\vec{x}_C - \vec{x}_S)\cdot t, \qquad (1)$$

where *t* is a parameter determining the location on the line. Since Eq. (1) gives the satellite line-of-sight for a given spot on a cloud top, t_{IM} exists such that $\vec{x}\,(t_{IM})$ is the apparent position of the spot (as seen by the satellite) on the Earth's surface (in geodetic coordinates: Φ_{IM}, θ_{IM}, h_{IM} = 0 km).

Converting Eq. (1) from Cartesian to geodetic coordinates, we get the system of equations:

$$\begin{aligned} &R\cdot\cos\theta_S + (a\cdot\cos\phi'_C\cdot\cos\theta_C + h_C\cdot\cos\theta_C\cdot\cos\phi_C - R\cdot\cos\theta_S)\cdot t_{IM} = a\cdot\cos\phi'_{IM}\cdot\cos\theta_{IM} \\ &R\cdot\sin\theta_S + (a\cdot\cos\phi'_C\cdot\sin\theta_C + h_C\cdot\sin\theta_C\cdot\cos\phi_C - R\cdot\sin\theta_S)\cdot t_{IM} = a\cdot\cos\phi'_{IM}\cdot\sin\theta_{IM} \\ &(b\cdot\sin\phi'_C + h_C\cdot\sin\phi_C)\cdot t_{IM} = b\cdot\sin\phi'_{IM}\,, \end{aligned} \qquad (2)$$

where

$$\begin{aligned} \phi'_C &= \arctan\left(\frac{b}{a}\cdot\tan\phi_C\right) \\ \phi'_{IM} &= \arctan\left(\frac{b}{a}\cdot\tan\phi_{IM}\right). \end{aligned} \qquad (3)$$

By solving Eqs. (2) we obtain coordinates Φ_{IM}, θ_{IM} that are needed for computation of parallax, i.e. the distance between (Φ_C, θ_C, *h* = 0 km) and (Φ_{IM}, θ_{IM}, h_{IM} = 0 km). Geodetic coordinates change linearly on the shortest line between these two points:

$$\begin{aligned} \phi &= \phi_C + (\phi_{IM} - \phi_C)\cdot t \\ \theta &= \theta_C + (\theta_{IM} - \theta_C)\cdot t, \end{aligned} \qquad (4)$$

where $t \in \langle 0,1 \rangle$. By substituting Eqs. (4) into the equations describing the surface of the reference ellipsoid, we get a parametric representation of the curve $\vec{x} = \vec{x}(t)$ along the Earth's surface, whose length is equal to the parallax:

$$P = \int_0^1 \sqrt{\left(\frac{dx}{dt}\right)^2 + \left(\frac{dy}{dt}\right)^2 + \left(\frac{dz}{dt}\right)^2}\, dt. \qquad (5)$$

It is worth noting that EUMETSAT recently published tables for parallax corrections which cover every MSG pixel for all MSG satellite positions – for longitude 0°, 3.4°W and 9.5°E (http://convection.satreponline.org/parallax.php).

APPLICATION OF PARALLAX CORRECTION TO A COMPARISON OF RADAR AND SATELLITE DATA

A cold-ring shaped storm (Setvák et al., 2008) on 21-22 June 2006 over Austria (48.487°N, 15.768°E) was chosen to demonstrate an application of parallax correction to a radar and satellite data comparison. Values of parallax and its eastward and northward components were computed for a spot in the cloud top corresponding to the position of this storm and various geodetic heights for the MSG-1 satellite (till April 2008 at nominal position 3.4°W; see Tab. 1, Fig. 3).

h [km]	P [km]	P_e [km]	P_n [km]
10	16.4	6.9	14.9
11	18.1	7.6	16.4
12	19.7	8.3	17.9
13	21.4	9.0	19.4
14	23.1	9.7	20.9
15	24.7	10.4	22.4
16	26.4	11.2	23.9
17	28.0	11.9	25.4
18	29.7	12.6	26.9
19	31.3	13.3	28.4
20	33.0	14.0	29.9

Table 1: **Parallax (*P*) and its eastward and northward components (P_e and P_n) related to geodetic height (*h*) of the spot in cloud top located at 48.487°N and 15.768°E for the MSG-1 satellite.**

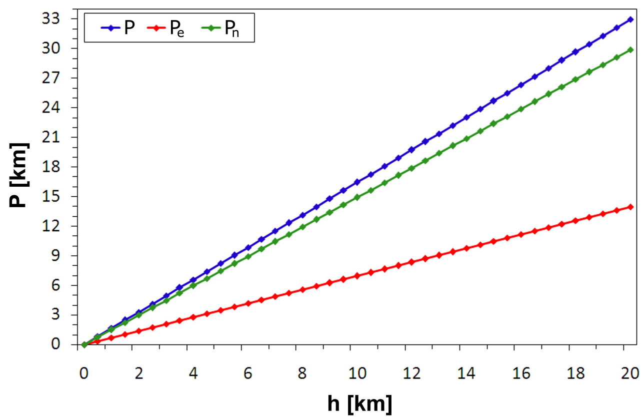

Figure 3: **Parallax (*P*) and its eastward and northward components (P_e and P_n) related to geodetic height (*h*) of the spot in cloud top located at 48.487°N and 15.768°E for the MSG-1 satellite.**

Parallax grows with cloud top height almost linearly and is not insignificant, especially for the higher cloud tops. The influence of the geographic location of the cloud as well as the satellite position on the parallax also grows with cloud top height.

The cold-ring shaped storm on 21-22 June 2006 above Austria had cloud tops reaching above the tropopause, as can be seen in its vertical radar cross-section (Fig. 4). Soundings for this case from Vienna on 21 June 2006 at 12 UTC and 22 June 2006 at 03 UTC are illustrated in Fig. 5. There is a strong inversion perceptible above the tropopause, the presence of which is probably essential for the formation of a warm spot inside the cold ring.

An application of parallax correction is demonstrated in Figs. 6 and 7. These show color enhanced images in the IR10.8 band of the MSG-1 satellite, with radar data (CAPPI 15 km) superimposed – without the parallax correction (Fig. 6) and after the correction (Fig. 7). From these two figures it is obvious that there is a large difference in the relative location of the satellite and radar data with and without the parallax correction.

Parallax correction is important for determining the accurate location of a warm spot with respect to the radar data, which is essential for better understanding the mechanism of formation of warm spots inside cold rings. In Fig. 4, the location and extent of the warm spot with regard to the radar data is marked by a black arrow.

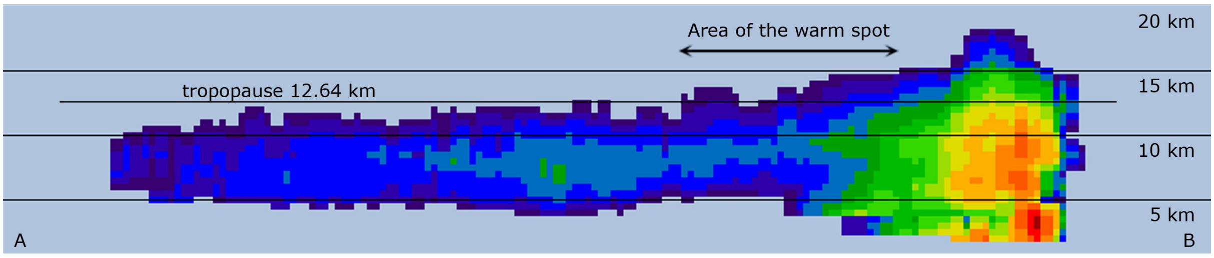

Figure 4: **Radar cross-section of the cold-ring shaped storm above Austria - along the line A-B in Fig. 7. This experimental vertical cross-section, extended up to 20 km, is based on CAPPI products (step 0.5 km) derived from the radar reflectivity volume data on 22 June 2006, 00 UTC.**

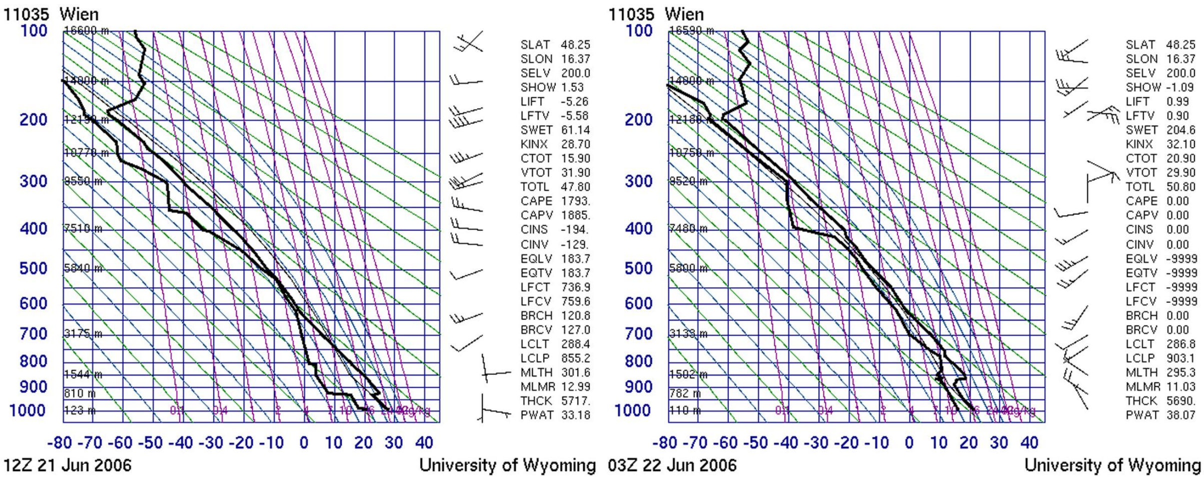

Figure 5: **Soundings - Vienna, 21 June 2006, 12 UTC and 22 June 2006, 03 UTC.**

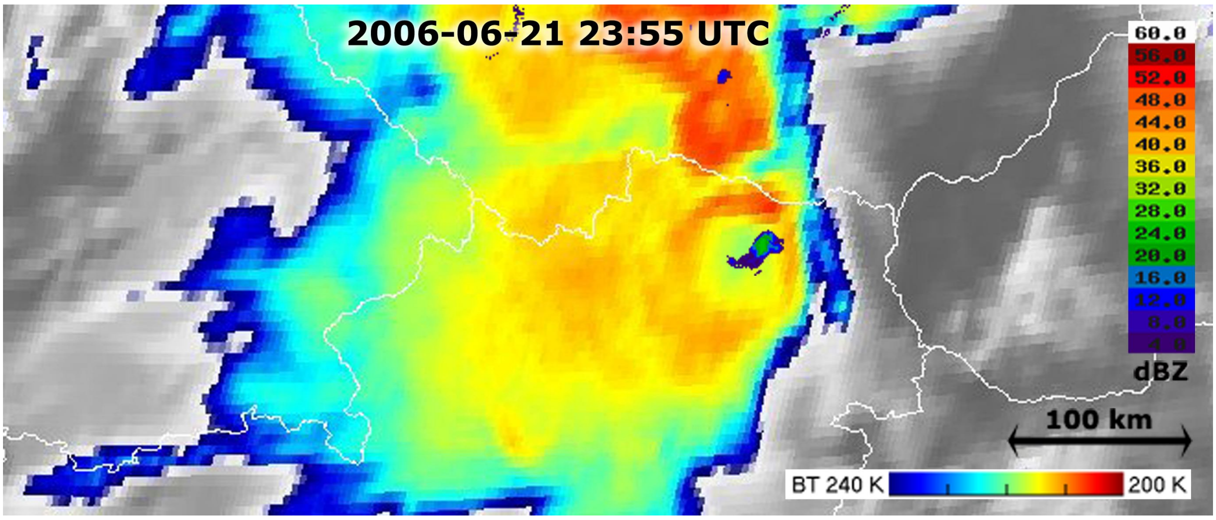

Figure 6: **Cold-ring shaped storm above Austria (21 June 2006, 23:55 UTC) in color enhanced image in the IR10.8 band of the MSG-1 satellite, with radar data (CAPPI 15 km; 22 June 2006, 00:00 UTC) superimposed without the parallax correction.**

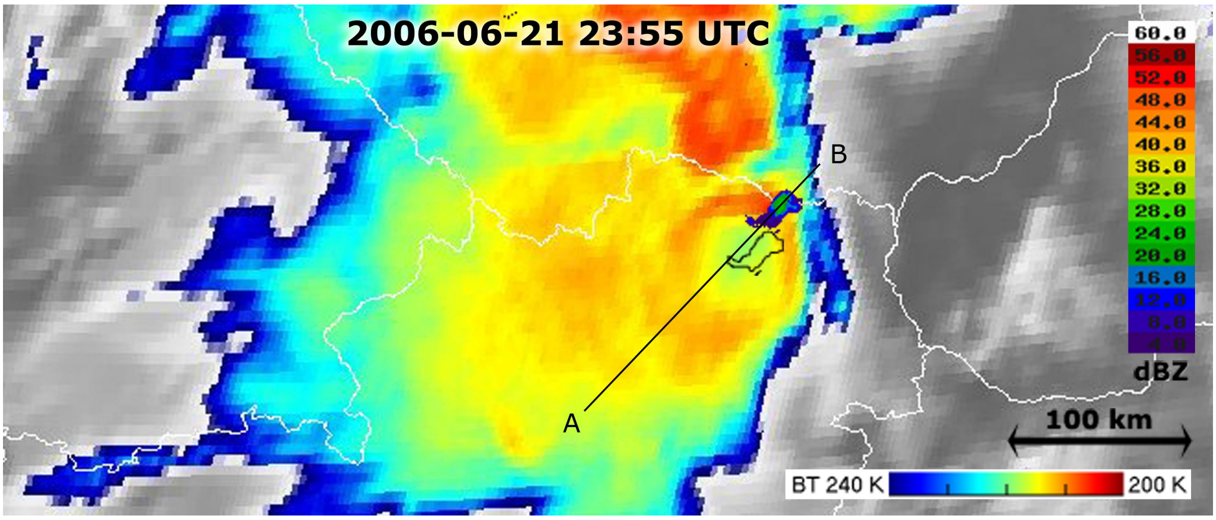

Figure 7: **Same as in the Fig. 6, but with radar data superimposed after the parallax correction. The location of the storm's overshooting top without the parallax correction is marked by the black curve. The line A-B marks the position of the cross-section which is shown in Fig. 4.**

CONCLUSIONS

Parallax correction is essential for proper interpretation of features occurring in satellite imagery depicting high cloud tops, particularly when comparing radar and satellite data. Parallax correction may also have a crucial impact on some derived satellite products, such as convective rain estimates (http://nwcsaf.inm.es/MeteorolProducts.html), CTTH (Šťástka et al., 2008), or storm tracking (e.g. the RDT product, http://www.meteorologie.eu.org/RDT/). Results for the storm on 21-22 June 2006 agree with findings documented for the 25 June 2006 case (Setvák et al., 2008), namely with regard to the spatial arrangement of the highest overshooting tops and the warm spot.

ACKNOWLEDGEMENTS

The work was supported by project *GA CR 205/07/0905* (*Exploitation of remote sensing means for modelling and monitoring of convective storms).* The authors would like to thank Petr Novák and Hana Kyznarová, Czech Hydrometeorological Institute, Prague, for providing and processing the radar data; Martin Setvák, Czech Hydrometeorological Institute, Prague, for his advice during the preparation of this paper; and Daniel T. Lindsey, NOAA/CIRA, Ft. Collins, CO, U.S.A., for English style corrections.

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