

Parallax - Polar winds Dave Santek University of Wisconsin-Madison

An issue usually ignored when tracking features in geostationary images is parallax: the apparent displacement of a feature above ground that results from non-nadir viewing angles. Parallax is not as important in geostationary data because the change in parallax between images is usually insignificant as the features move very little with respect to the scanning geometry of the sensor. This is unlike images from polar orbiting satellites where the view may change substantially, orbit-to-orbit.

A cloud that is viewed off-nadir will appear to be further from the nadir position than it actually is (Figure 5).

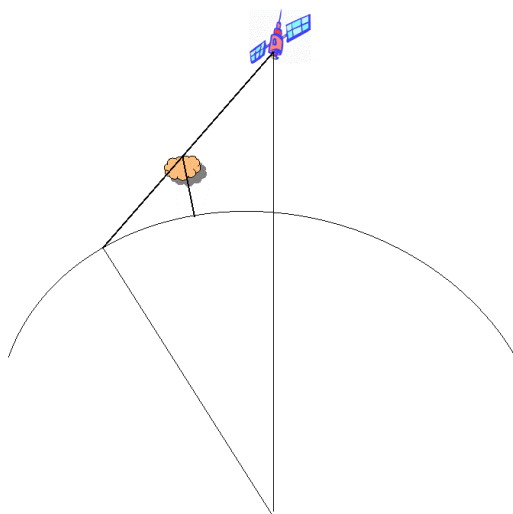


Figure 5: Off-nadir viewing of a cloud from a satellite.

The greater the viewing angle, the greater the displacement. For example, at 700 km from nadir the apparent location of a cloud with a height of 5 km will be approximately 5 km further from nadir than its actual position (Figure 6). At a 1000 km from nadir the displacement is 7 km. The displacement is not the same for a feature from one orbit to the next, as the viewing

geometry and the actual cloud position change. Figure 7 illustrates that in this idealized overlap region, the speed error due to parallax for a 5 km cloud is generally less than 1.5 m s^{-1} . This theoretical error is confirmed in statistics from a three-week period that resulted in a mean speed error of less than 1 m s^{-1} . Also, it's important to note that the MODIS geolocation values have been adjusted for terrain elevation, which means the error due to parallax is inherently less over high terrain. See *Appendix A: Parallax Correction* for details on how the parallax is determined and applied to the wind vectors.

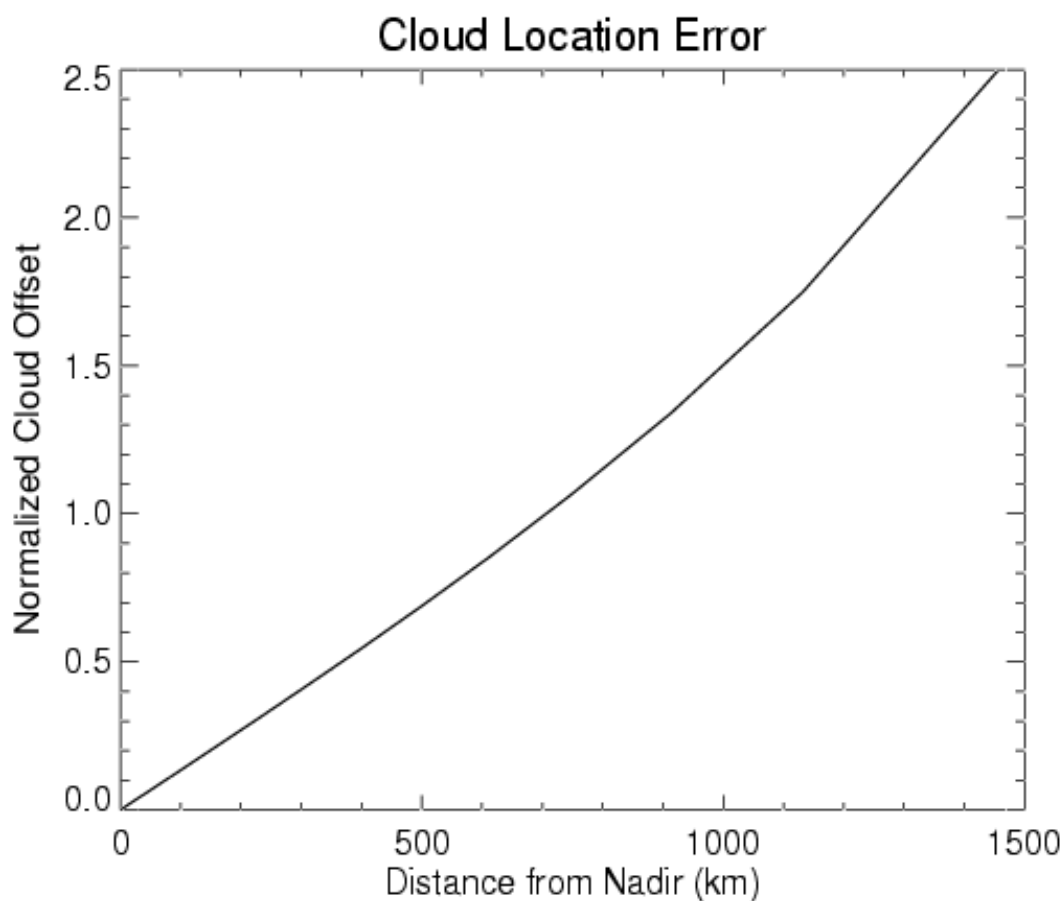


Figure 6: Error in cloud position due to parallax, relative to the cloud height.

5 km Cloud Maximum Speed Error (m/s)

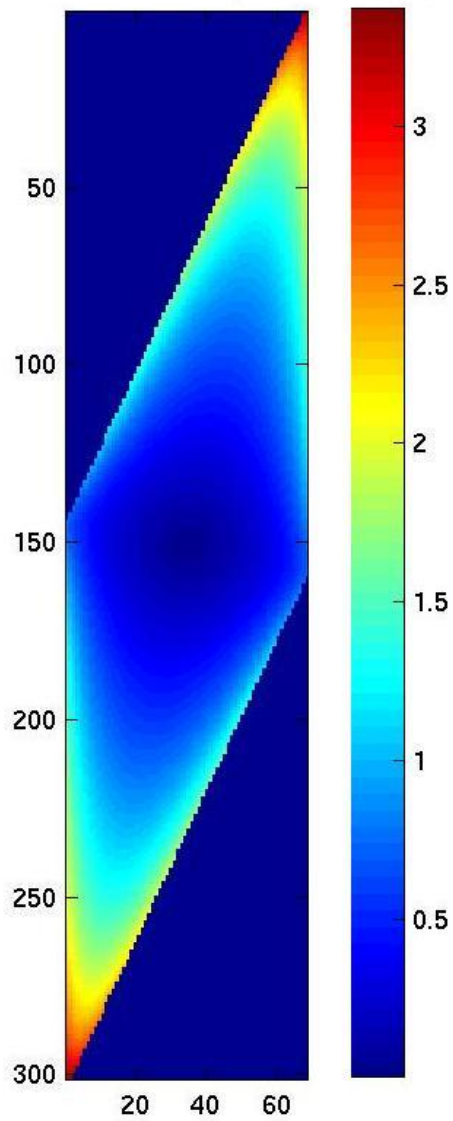


Figure 7: Error in wind speed (m s^{-1}) due to parallax shift. The parallelogram approximates the overlap region in three orbits as seen in Figure 3.

Appendix A: Parallax Correction

The following equations are used to compute the arc distance along the earth from the point directly below the cloud to the apparent position as viewed from the satellite. The known quantities are: the height of the satellite, height of the cloud, radius of the earth, and the scan angle from the satellite to the cloud. The quantity *dist* is the error in kilometers due to parallax, and is measured from the apparent position as seen from the satellite to the point beneath the cloud at the earth's surface (arc distance a_2) (Figure 48).

Using the Law of Sines, the zenith angle of the satellite from the cloud is:

$$\phi_s = \sin^{-1}\left(\frac{rhs * \sin \theta_s}{rhc}\right)$$

The angle opposite this zenith angle is the angle from cloud nadir to the satellite viewing ground position:

$$\theta_c = \phi_s$$

The Law of Sines is then used to compute the zenith angle of the cloud from the ground position:

$$\phi_c = \sin^{-1}\left(\frac{rhc * \sin \theta_c}{R}\right)$$

It follows that the remaining angles are:

$$a_1 = \pi - \phi_c$$

$$a_2 = \pi - (\theta_c + a_1)$$

And the resulting parallax shift is:

$$dist = a_2 * R$$

where

r_h : satellite distance from earth's center

r_c : cloud distance from earth's center

R : earth's radius

θ_s : sensor viewing angle from satellite nadir

θ_c : ground position viewing angle from cloud nadir

φ_s : satellite zenith angle from cloud

φ_c : cloud zenith angle from ground

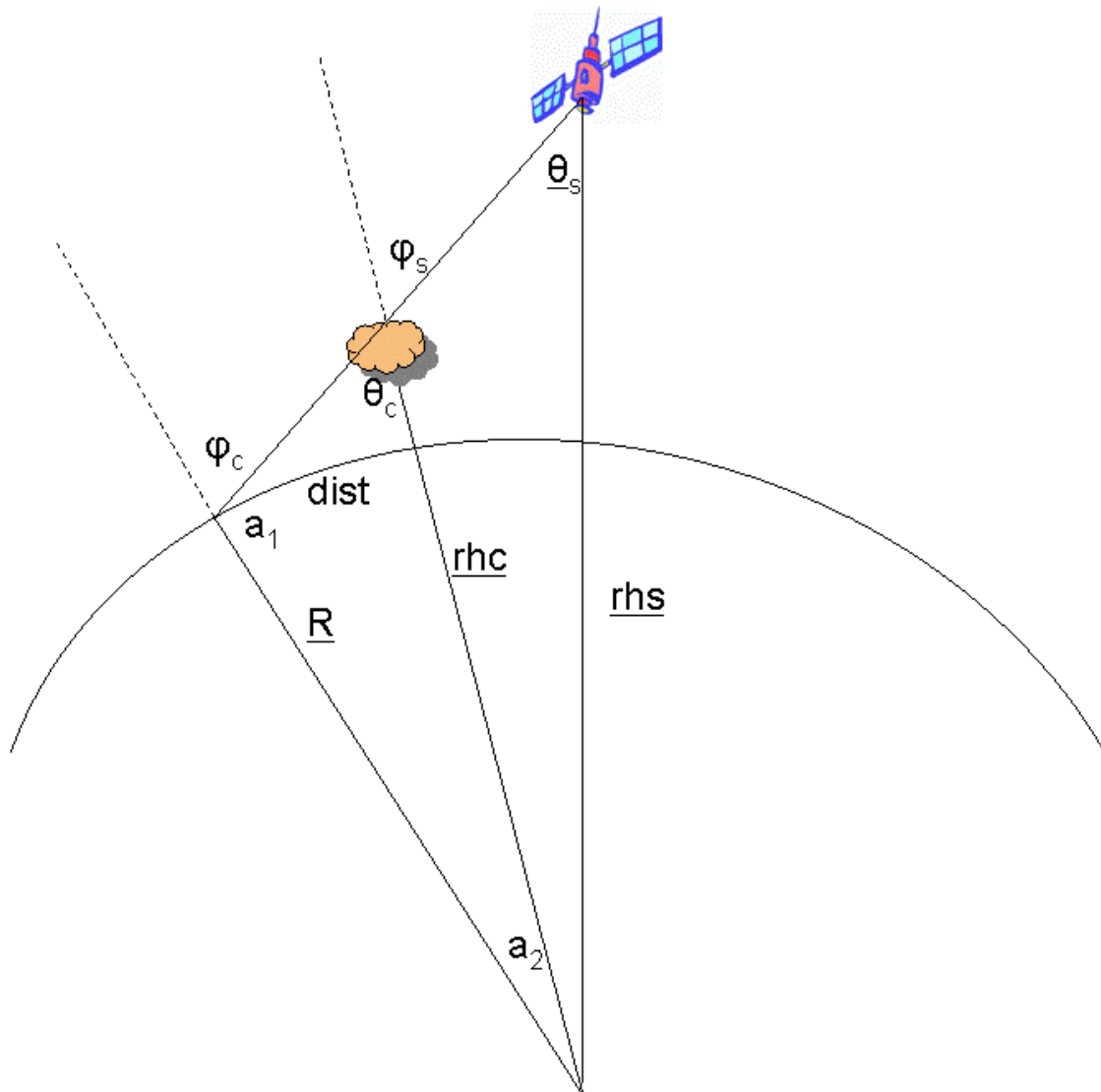
a_1 : supplementary angle of φ_c

a_2 : arc length of parallax distance

dist: error (km) of cloud ground position

The current implementation of the parallax correction algorithm assumes a spherical earth, constant altitude satellite, and a linear variation of the parallax shift with altitude for three reasons: computational efficiency for real-time processing, the inaccuracy of the target height, and the use of an Arctic standard atmosphere to convert the target height in pressure coordinates to altitude in kilometers. The standard atmosphere is used because the winds algorithm does not have the height fields on pressure surfaces as input. This may be modified in the future.

The final output of the algorithm is a parallax shift in terms of a distance and meteorological compass direction for each pixel in the original swath data for a cloud 10 km in altitude. Only one altitude is needed since the parallax shift varies near-linearly with altitude (Figure 6). These files are remapped and composited along with the swath data (see section 2.2.4 *Processing the MODIS passes*), so they can be efficiently accessed during the winds generation.



rhs : satellite distance from earth's center
 rhc : cloud distance from earth's center
 R : earth's radius
 θ_s : sensor viewing angle from satellite nadir
 θ_c : ground position viewing angle from cloud nadir
 ϕ_s : satellite zenith angle from cloud
 ϕ_c : cloud zenith angle from ground
 $dist$: error (km) of cloud ground position

Figure 48: Geometry used in parallax correction. The underlined variables are known quantities. The error due to parallax is $dist$, the arc length of angle a_2 .

The target locations that are stored in the output file are not parallax adjusted so that comparisons with uncorrected vectors can be easily performed. This uncorrected location is in error by no more than 20 km, and is usually much less than this, which is below the resolution of the global models (55 km for the GFS). The parallax correction is applied to both the location for the search boxes (which are positioned based on the forecast wind field) and the computation of the vector displacement for the image pairs.

A comparison between parallax corrected and uncorrected winds was conducted over a period of twenty-one days beginning on 23 July 2004 using data from Terra over the Arctic. Co-location was determined by matching vector distances within 10 km and heights within ± 25 hPa.

Table 18: Comparison between parallax corrected and uncorrected co-located vectors for a three-week period beginning on 23 July 2004. These are Terra-only over the Arctic.

	Number	Speed bias	Speed RMS	Vector RMS
IR Winds	200,000	-0.10	0.69	0.97
WV Winds	470,000	-0.15	0.97	1.36

Table 18 summarizes this comparison and as expected, the vector RMS for the WV winds is larger since the features are generally in the middle- and upper-troposphere, where the IR features can also be found in lower levels. An impact study has not been done on how this slight adjustment of about 1 m s^{-1} may impact model forecasts. Note that a 1 m s^{-1} difference in the wind speed corresponds to a 3 pixel difference in the images (2 km pixels with a 100-minute time step).

The speed bias is very close to zero over the 21 days, although it is slightly negative indicating that the parallax corrected speeds are slightly slower. This is reasonable because,

in many cases, correcting for parallax brings the location of the feature closer to nadir in the 2 images at an acute angle, thereby shortening the distance (and reducing the speed).