A Summary of Geodetic Satellite Measurements at the South Pole and Relationship to the Annual Pole Marker Location

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Beginning in 1975 and continuing through 1991, the U.S. Geological Survey (USGS) deployed and operated a continuous Doppler satellite measurement and positioning system in the vicinity of the South Pole, at the U.S. research base Amundsen-Scott Station, Antarctica. In December 1991, the Doppler satellite observations were terminated, and more accurate measurements were begun with observations on satellite signals of the Global Positioning System (GPS).

The estimated accuracy for the positions previously determined with the Doppler satellite positioning technology is about a meter, whereas, GPS determined positions are accurate to a few centimeters. The ongoing collection of GPS data at the South Pole provides an accurate reference for geopositioning activities in the region and contributes to a variety of glaciological and geophysical investigations.

The geographic location of the South Pole GPS continuous operating reference station (named AMUN) and all other facilities at South pole changes about 10 meters a year due to the flow of the polar ice cap. The Antarctic ice sheet is about 2820 meters (9250 feet) thick in this region and flows as an immense glacier in the direction of the Weddell Sea. Thus, when we refer to determining the position of the GPS reference station AMUN, we mean its trajectory or time-dependent position. The current estimates for the movement of the Antarctic ice sheet over the South Pole are in very good agreement with the historical Doppler positioning records.

The GPS data through 1999 indicates movement of the ice sheet with a velocity of 9.98 ∀ 0.01 meters per year (2.7 centimeters per day), north along about 40E46’56” west longitude meridian. This includes an estimate for downward motion of the ice sheet of about 0.19 ∀

0.02 meter per year. Scientists of the Geosciences Research Division (GRD), National Geodetic Survey (NGS), National Oceanic and Atmospheric Administration (NOAA) determined these estimates for position and velocity relative to other permanent stations of the global network for continuous tracking stations of the International GPS Service (IGS).

In the most recent solution by the GRD scientists, the centimeter-level accuracy positions for station AMUN were determined referenced to permanent stations located in Antarctica: IGS station MCM4 at McMurdo Base (about 1100 km from the South Pole), IGS station OHIG at O'Higgins (Antarctic Peninsula), IGS station CAS1 at Casey ((South of Indian Ocean), IGS station DAV1 at Davis (South of Indian Ocean), IGS station HARK at Hartebeesthoek, South Africa, and, IGS station SANT, Santiago, Chile (6078 km from the South Pole).

Go to website: http://www.scar-ggi.org.au/geodesy/perm_ob/gps/gps.htm for information on Permanent GPS Observatory Sites in Antarctica and to: http://igscb.jpl.nasa.gov/network/netindex.html for information on the IGS Tracking Network.

The present estimates for the ice motion at South Pole based on GPS observations is limited to the period of December 1991 to December 1999. GPS observations have been continuous at station AMUN except for a break between January 1994 and November 1994, when the GPS receiver was returned to the U.S. for an upgrade.

Annually, around the end of December or early January, members of the USGS geodetic team, in –25 to –35° F temperatures, perform high-accuracy geodetic surveys with portable GPS positioning systems to place a new marker in the ice surface at where the Pole is located January 1 at 0 hours Coordinated Universal Time (formerly Greenwich Mean Time). Over the following 12 months, the marker moves away from the "mean" Pole location due to the ice flow. This has resulted in a line of markers trailing away from the current location of the "mean" Pole in the direction of the flow.

There is no particular scientific significance to the annual survey to establish the position for a new marker. On the other hand, placement of the annual marker allows visitors and people working at the Pole the opportunity to stand next to where the Pole was located on January 1 of each year and to walk around the Earth's mean axis of rotation. However, because of the ice motion the marker set on January 1, begins its slow journey away from the "mean" Pole, heading for the Weddell Sea, about 1,400 km away, at the rate of about 2.7 cm per day. At this rate the current South Pole marker will drop into the sea in about 140,000 years.

Although we know from results of our satellite observations that the ice flow has been quite consistent over the years, the line of annual pole markers is not perfectly linear, as one might expect from the historical measurements of the ice movement. There have been a variety of methods employed to establish the location of each marker, accompanied by varying accuracies, resulting in minor offsets along the theoretical linear motion of the ice. This level of accuracy was acceptable for the new annual Pole markers set for ceremonial purposes.

One noticeable jog in the line of markers of about a half meter occurred in 1994. It had been reported in the press this was a correction to previous "errors" and/or a change in the actual position for the "mean" polar axis. These reports are in error or are misleading, especially since it is easy to confuse "moving" the marker relative to the ice surface, with "moving" the known location of the Pole (axis of the Earth's rotation or the geographic position of the polar axis). Many who participate in a new marker placement ceremony popularly call it "moving the Pole," despite the fact that we do not "move" the Pole, nor do we "move" the previous annual marker. Instead, a "new" marker is set each year on January 1.

The half-meter jog in the line of markers occurred at the advent of using for the first time GPS geopositioning methods for placement of a new marker on January 1, 1994. This was the first use of the GPS continuous operating reference station AMUN as the primary geodetic reference for the "most accurate" estimate for the location of the "mean" polar axis and in positioning of a new pole marker on January 1. The adjustment in the line of markers does not indicate that the previous Doppler geopositioning surveys were in error, rather it confirms their accuracy within the expected level of error for Doppler determined positions of ∀1 meter.

In addition to improving the accuracy for the annual survey for the position of the new Pole marker, in 1994 there was also an adjustment to the geodetic datum (reference system) used in referencing the position for the Pole marker. The new datum is the International Terrestrial Reference Frame (ITRF) [http://lareg.ensg.ign.fr/ITRF/].

A geodetic datum is the mathematical system that defines the origin of latitude, longitude, height, and the shape of the Earth. The orbital coordinates for the GPS satellites and the positions for the global network of continuous operating reference stations of the International GPS Service (IGS) [http://igscb.jpl.nasa.gov/] are determined referenced to the ITRF, including the position for the South Pole continuous operating reference station AMUN.

The location of "true" 90E South, relative to the Earth's surface, depends on how accurately the datum defines that surface. Today the accuracy for determining the location of the "mean" Pole is within a few centimeters. Fortunately, because the more accurate positioning of the Pole markers is within the accuracy of the previous Doppler positioning methods, the datum "correction" was less than a meter, thus keeping the exposed pole markers set in the past 12-15 years to be more or less "in line."

ADDENDUM

Location of the Geographic South Pole in 1911-12

The method used by Roald Amundsen's expedition for locating the South Pole on December 14, 1911, and by Robert F, Scott's expedition to confirm the location of the marker for the South Pole on January 18, 1912, was an astronomic method that involved observations of the sun. When at the geographic location for the South Pole, the sun is above the horizon six months of the year. Through a 24-hour period, the sun moves parallel to the horizon a complete rotation around the Geographic Pole. It gradually rises to its' highest angle above the horizon on December 21. Observations to measure the angle of the top edge of the sun above the horizon were made with a sextant or similar instrument. When the angle or altitude above the horizon is equal, the observer is standing at the geographic location for the South Pole. The accuracy for this method is estimated to be about ±300 meters (about 1000 feet).

Relative to January 1, 2000, 88 years have past since Amundsen and Scott's expeditions arrived at the South Pole. Since 1911-12, the tent that was erected by Amundsen's expedition and other artifacts left behind by either Amundsen's or Scott's expedition would be approximately 880 meters (2890 feet) from where the pole marker was placed on January 1, 2000. Due to accumulation of snow over the 88 years, the location of any artifacts is estimated to be 15 to 25 meters below the ice surface.

Mean rotation axis and instantaneous rotation axis

Using high accuracy methods involving observations on distant stars that transmit very stable radio signals and on observations of Earth orbiting satellites, the internationally determined "Mean" location of the polar axis is known to about a centimeter. This mean axis is fixed in solutions for the orbital coordinates of satellites and for defining the International Terrestrial Reference System (ITRF). Thus, the axis of symmetry of the Earth essentially stays fixed in relation to the surface of the Earth. The rotation axis of the Earth relative to the crust, however, does not.

The rotational axis actually wobbles in a roughly 12 meter diameter circle about the South Pole over a period of 435 days. This is called the Chandler wobble and is an example of what physicists call free-space precession. This precession is a result of the fact that the Earth is not a perfect sphere. Additionally, there is a smaller annual oscillation forced by seasonal displacement of air and water masses that characterizes the total motion as a pulsating shape.

By use of appropriate formulas and tables, it is possible to perform a "back" calculation to determine the estimated location of the "instantaneous" axis of rotation relative to the "mean" Pole or mean rotation axis in the IERS Terrestrial Reference Frame (obtained by filtering the Chandler and seasonal terms). For example, on January 1, 2000, the "instantaneous" axis of rotation, was about 10 meters from the "mean" Pole in a direction of about 90° East longitude meridian.

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