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**Homework 3**

**Lectures 6-8**

**Problem 1:** Describe the main characteristics of point-geodetic observations versus imaging techniques in terms of spatial and temporal resolution and coverage.

Point-geodetic observations using space-geodetic tracking methods measure the motion of a point over time. These measurements provide high temporal resolution and accuracy, however the spatial resolution is limited by the distribution of measurement sites within a network. As tracking stations are typically placed on land surfaces, measurements are limited to the continents and islands within oceans.

Imaging or remote sensing techniques have a much lower temporal resolution than point-geodetic observations, but have much better spatial coverage. The resolution of the data is limited by the pixel size for the sampling technique, although newer techniques have the potential for high spatial resolution (small pixel size). Measurements are not limited to land surfaces, so remote sensing techniques allow for measurements of the surface of oceans, lakes, and ice sheets.

**Problem 2:** What is the "station motion model" and how does it enter into the analysis of point-geodetic techniques?

The station motion model is a model of geophysical phenomena that interact to change the position of a point-geodetic observation site. The model accounts for short-period fluctuations in the pole tide, solid earth tides, ocean tidal loading, and atmospheric loading. This model is important in analysis of point-geodetic techniques as they measure deformation of the Earth’s surface as a function of distance from a distant objecct and the periodic signals accounted for in the station motion model would otherwise influence the secular velocity of the observation site.

**Problem 3:** Which space-geodetic techniques provide the origin of the reference frame with respect to the center of mass and which provide the scale? Why?

SLR provides the origin of the reference with respect to the center of mass. SLR measures the time a pulse of light takes to travel from the Earth’s surface to a retroreflector on a satellite and back to Earth. The distance between the satellite and the observing station is directly related to the location of the Earth’s center of mass and the Earth’s gravity field, which allows SLR measurements to determine the location of the center of mass of the earth and the origin of the reference frame

VLBI and SLR provide the scale for the reference frame. These two techniques are used to define the scale of the reference from because they measure distances from the Earth’s surface to distant quasars (VLBI) and to geodetic satellites (SLR). GPS, DORIS, and SLR are used to position geodetic satellites in the ITRF, and GPS is used to position instruments on the Earth’s land and sea surfaces.

**Problem 4:** Explain the principle of GNSS reflectometry.

In GNSS reflectometry, direct and ocean-reflected GNSS signals are detected by spaceborne receivers. Altimetric height information is extracted from the delay in arrival times of the reflected signals in relation to the direct signals. Reflectometry can be used to determine ocean and ice altimetry.

**Problem 5:** Why are laser retroreflectors on satellites like Global Navigation Satellites, altimeter satellites, and other satellites that use geometrical principles important?

Laser retroreflectors on satellites allow for Satellite Laser Ranging (SLR) measurements of satellite altitude to be made. SLR measurements determine the scale for terrestrial reference frames and define the Earth’s center of mass, allowing for terrestrial reference frame that connected to the center of mass and therefore have no net rotation. SLR measurements are sensitive to geophysical processes that change the distance between the satellite and observing station, and the measurements are used to create models to fit satellite orbits. Precise knowledge of satellite orbits is essential for GNSS calibration and for the gravity satellites (GRACE, CHAMP, GOCE).

**Problem 6:** Explain briefly the principle of InSAR and identify the major limitations for accuracy and applicability. How could these challenges be addressed?

InSAR is a technique for processing synthetic aperature radar (SAR) images. In the InSAR processing technique, radar scenes from different satellite passes are overlaid on top of each other to measure the differences between the phase of the two scenes, creating interferograms. Once the signals from the satellites, ground, and topography are removed, the interferogram shows the deformation signal. InSAR has been used to measure ice velocities, SRTM topographic data, actively inflating volcanoes, interseismic, coseismic, and postseismic deformation related to earthquakes, deformation due to incipient landslides, and ground subsidence due to water and oil withdrawal.

Data availability is a major limitation in the applicability of the InSAR technique. Because acquisition satellites do not operate continuously, archived data is not available for many places of the world. In order to process images and remove the effects of topography, accurate DEM data must be available, making high latitude images difficult to process. Another source of error in InSAR data is the effect of atmospheric delays as the SAR signal travels through the atmosphere. The delays depend on the air temperature, pressure, and the partial pressure of water vapor in different layers of the atmosphere. These limitations could be addresses by archiving SAR scenes for the entire earth to serve as a initial baseline from which to measure deformation and by developing better models of atmospheric conditions and delay to remove the atmospheric artifacts from the interferograms.

**Problem 7:** What are the main characteristics of in situ, airborne and spaceborne gravity measurements in terms of temporal and spatial resolution, as well as accuracy as function of spatial and temporal scale?

Gravity measurements can be made by in situ, airborne and spaceborne instruments. Instruments measure either absolute or relative gravity. Field-based relative gravimetry surveys are used mainly to improve models of the geoid locally and for exploration purposes. Point measurements are taken over a region, giving spatial coverage through interpolation, but low temporal resolution. Relative gravimeters need to be calibrated before and after measurement campaigns. Shipborne and airborne relative gravimeters measure gravity profiles along a track, resulting in continues spatial coverage along the track, but again have low temporal resolution. These measurements have high spatial resolution over short wave lengths, but have large long wavelength errors due to leveling. Global coverage is difficult as point measurements and topographic height are difficult to determine for the entire Earth surface. Spaceborne gravimeters allow for measurements of the gravity field for the entire Earth by integrating satellite orbit perturbations. These instruments allow for determination of the static or time variable gravity field with low spatial and temporal resolution in comparison to in situ techniques. These instruments measure the long wavelength structure of the gravity field and can be tailored to improve the accuracy of the broad mesoscale features of the gravity field (CHAMP), changes in the gravity field over time (GRACE), and determine gravity anomalies with an accuracy of 1 mGal at a spatial resolution better than 100 km (GOCE). Newer techniques for in situ measurements include highly accurate absolute and relative gravimeters. Absolute gravimeters are generally all free fall models. Measurements of FG% can take a few days. Episodic observations of absolute gravity are used to determine low-frequency variations in gravity at a specific site. Absolute gravimeters for field use require less time to acquire data, but there is a trade off in the precision of the measurements. Highly accurate in situ relative gravimeters (Superconducting (cryogenic) gravimeters and Lacoste-Romberg Earth Tide (LCR-ET) ) are used to measure the changes in gravity over time at a specific point location.

**Problem 8:** Explain the principle of GRACE and its main limitations in terms of accuracy.

The GRACE mission uses twin satellites flying 220 km apart connected by a two-way microwave-ranging link and GPS positioning to map the Earth’s gravity field by comparing frequency shifts in the microwave link to measure small changes in the distance between the two satellites. When the first satellite passes over a high gravity anomaly, it speeds up, increasing the distance between the two satellites. The satellite slows down as it passes the anomaly, while the second satellite speeds up and slows down as it flies over the same anomaly. When this data is combined with precise satellite locations from GPS, scientists are able to construct detailed maps of the Earth’s gravity field. Scientists are able to compare changes in the Earth’s gravity field to understand time-variable processes in oceanography, hydrology, glaciology.

The accuracy of GRACE measurements is limited by sensor accuracy in determining the location and altitude of the satellites, disturbances due to non-gravitational acceleration, the tradeoff between high temporal resolution and spatial resolution, and unmodeled phenomena with sub-monthly periods that alias into GRACE solutions.