G31D MC: 121 Wednesday 0830h

Multidisciplinary Studies of Present-Day Sea Level Change *(joint with IP, OS, T, GC, HG)*

Presiding: **R S Nerem,** University of Colorado**; J L Davis,** Harvard-Smithsonian Center for Astrophysics

G31D-01 0830h

The Contribution of Satellite Altimetry to Measuring Long-Term Sea Level Change

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Satellite altimetry measurements from the TOPEX/POSEIDON (T/P) mission now provide a precise record of sea level change covering late 1992 to the present. As the satellite record lengthens, we can begin to use the record to test models of current sea level change. We will review the observations of long-term sea level change made by T/P, including the changes observed during the 1997-98 ENSO event. In addition, we will review the pros/cons of these measurements as compared to tide gauge measurements. Measurements of long-term sea level change using satellite altimetry must also be accompanied by an independent calibration of the instrument performance. We will review the recent results using tide gauges to calibrate the T/P instruments, and discuss the need for monitoring the position of the tide gauges using geodetic techniques and how this relates to sea level change studies using tide gauges exclusively. We will also address the question of when satellite altimetry will be able to make quantitative contributions to climate change science.

G31D-02 0845h INVITED

Variations in Global Mean Sea Level from a Combination of Tide Gauges and Altimetry

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Low frequency variability in global mean sea level (GMSL) is studied for the period 1950 to 2000 by interpolating sparse tide gauge data to a global grid using empirical orthogonal functions (EOFs) of sea level variability determined from TOPEX/Poseidon (T/P) altimeter data. The EOF reconstruction technique is discussed, and the resulting GMSL time series is compared to GMSL time series from Geosat and T/P altimetry, and proxy GMSL time series estimated from global sea surface temperature data. The error assessment suggests the accuracy of the GMSL time series reconstructed from the tide gauge data is 2-4 mm RMS for a 1-year running mean smoothing, and about 1 mm for a 5-year running mean smoothing. Significant correlation between GMSL and El Nino/Southern Oscillation and the Pacific Decadaloscillation is discussed. GMSL appears to have been generally higher than normal in the late 1950s and early 1960s, in the early 1980s, and has been rising throughout the 1990s, when T/P is observing. The implication of the low frequency signals on the determination the secular rate of GMSL from satellite altimetry is discussed.

G31D-03 0900h INVITED

Sea Level Rise during the 1990s from satellite and in situ observations

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For nearly a decade, sea level is monitored worldwide by altimeter satellites, in particular Topex/Poseidon. We compute the global mean sea level change observed by Topex/Poseidon between January 1993 and July 2001. After accounting for instrumental bias and drift, the rate of mean sea level rise amounts to 2.5 +/- 0.2 mm/yr for this 8.5 years time span. Using global data of sea water temperature, we compute the thermosteric sea level change during the 1993-1998 period and show a close correspondence between thermal expansion of the upper 500-m ocean layer and satellite altimetry estimate (3.1 +/- 0.4 mm/yr and 3.2 +/- 0.2 mm/yr respectively). The spatial correlation between Topex/Poseidon-derived and thermosteric sea level trends is impressive, indicating that thermal expansion captures almost all the sea level change in the 1990s. The residual global mean sea level presents a small, non significant, trend of 0.2 +/- 0.2 mm/yr. Using time series of global soil moisture and snow data, we compute the contribution of continental waters to the residual sea level rise during the 1993-1998 time span. An upper bound of the remaining contributions is estimated.

G31D-04 0915h

Sea Level Change During the Past 40 Years From in Situ Observations.

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During the 20th century, measurement of sea level change has been traditionally based on tide gauge records. These in situ observations indicate an average rate of sea level rise in the range 1-2 mm/yr for the past century. Tide gauges however are located at continents or islands coastlines, hence do not globally sample the spatial variations of the sea level change. A recently released global sea water temperature data allows us to compute a global thermosteric sea level for the period 1955-1996. It appears that the thermosteric sea level trends have significant regional variations. According to the 3rd assessment report of the IPCC, thermal expansion is the largest contribution to the global sea level rise for the past decades, the sum of others climate-related components contributing less. Moreover, it is generally assumed that spatial variation of sea level rise is caused by non uniformity in thermal expansion, other contributions leading rapidly to uniform sea level change. For the period 1955-1996, the sea level rise derived from tide gauge data agrees well with thermal expansion computed at the same locations. However, we find that sub sampling the thermosteric sea level at usual tide gauge location leads to a thermosteric sea level rise twice as large as the 'true' global mean. As a possible consequence, the past few decades estimated sea level rise from tide gauge records may have been overestimated.

G31D-05 0930h

Fifteen Years of Global Sea Level Change from Satellite Altimetry by Linking GEOSAT and TOPEX/Poseidon

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Global and regional sea level rise has been precisely measured by satellite altimetry from the TOPEX-Poseidon spacecraft over the past 8 years. In order to observe global and regional sea level changes before 1993, altimeter data from GEOSAT are linked to TOPEX-Poseidon data via a relative bias calibration using the sea level measurement histories from select island tide gauges. From the combined satellite altimetry, global and regional time series and maps of sea level changes are produced which span the past 15 years. Large (cm per y) regional changes are observed especially around Antarctica and a small global rise (mm per y) is noted. These sea level changes are compared regionally to Sea Surface Temperature(SST) records and to a global tide gauge reconstruction model.

G31D-06 0945h

Formation of Coastal Salt Barren and Its Indication to the Recent Sea Level Change

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Coastal salt barrens are narrow, distinctive, non-vegetative belts found in the midst of, otherwise, lush coastal marshes. The striking feature of a salt barren is almost inescapable by any observer yet the cause of its formation remains unexplained. I investigated the cause of salt barrens formation in the coastal marshes of north Florida, USA. The results indicate that salt barrens were formed by a hypersaline condition developed slightly above the mean high water (MHW) level. The formation of a coastal salt barren is a sequential event that starts with a formation of salinity maximum above the MHW. If the salinity maximum in porewater reaches 40-50 ppt, thinging of vegetation begins. Vegetation thining then increases soil temperature and thus the evaporation and salinity. The increased salinity induces more vegetation thinging and those mutually reenforced factors finally create a hypersaline barren belt slightly above the MHW in which porewater salinity could reach saturation. The location of a salt barren is, therefore, dictated by the mean sea level (MSL). That is, as the MSL rises, falls or stays stationary the location of the salt barren moves landward, seaward or stationary accordingly. The sediment profile property of a salt barren thus registered the recent history of sea level changes. If archived aerial photographs are available, the horizontal movement of salt barrens over time can be translated into the vertical rate of sea-level changes. The coastal salt barren in the North Florida has moved inland 3-8 m horizontally from 1951 to 1997, which translated to a 37 mm increase in MHW, or 0.82 mm/y increase in sea level. Corrected for the post-glacial continental rebound factor, the rate of sea-level rise since 1951 is estimated at 1 mm/y. Since there is no reliable long-term tidal gauge record available around the "zero post-glacial rebound" areas, study of coastal salt barren around those areas may contribute to a better understanding of the recent sea level change.

G31D-07 1020h INVITED

Vertical Reference Frames for Sea Level Monitoring

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In order to measure changes in sea level a reference system is needed relative to which the change is measured. The surface of the earth does not provide directly an ideal system because this surface can be also undergoing changes. To define a reference system for height measurements, the most important quantities are the origin and scale of the system. On an ellipsoidal Earth, orientation also plays a role in that rotating an ellipsoid about an equatorial axis (equivalent of polar motion) will slightly change the spherical radius of a point fixed to the surface. At 45° latitude, the change in radius is approximately 0.2 mm/mas of rotation. With current geodetic systems a larger problem is the definition of origin and scale. For Earth orbiting satellite systems, the natural choice of origin is the center of mass of the Earth although this origin is not perfect in that mass redistribution will change the position of the center of mass relative to the center of figure. In this paper, we concentrate on definition of scale for satellite systems with particular emphasis on the long term stability of the scale for the global positioning system (GPS). Analysis of a long series of global GPS measurements between 1992 and the present suggests that the GPS scale may be changing by as much as 0.5 parts-per-billion/year (ppb/yr) which is equivalent

to 3 mm/yr of changes in height. We discuss the possible origin of this change with emphasis on the effects of the GPS-satellite phase-center models, including the position of the phase-center with respect to the center of mass of the satellite, and that the apparently systematic changes in scale are due to the slow evolution of the GPS constellation from Block I to Block II, IIA and currently block IIR generations of satellites.

G31D-08 1035h

Bringing Tide Gauges Into the Terrestrial Reference Frame: GPS Results to Support Calibration of the Emerging Altimetric Sea-level Record.

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The Topex/Poseidon (T/P) era of altimetry (1992–present) has fortuitously coincided with the emergence of GPS as an invaluable scientific tool in both the geodetic and atmospheric sciences. Many of the observations from terrestrial GPS stations (e.g., vertical land motion, water vapor abundance, total electron content) bear directly on the interpretation of the emerging record of global mean sea level from altimetry. Combined with the rapid growth of the numbers of permanent GPS stations–most notably at coastal and island locations–this has significantly enhanced the potential for exploiting terrestrial GPS as a multi-faceted altimeter calibration tool.

In this paper, we present new determinations of the vertical positions and velocities of tide gauge sites in the International Terrestrial Reference Frame (ITRF2000). We first review the latest results from the Harvest platform experiment off the coast of Central California. In its capacity as a dedicated T/P calibration site, Harvest has hosted a GPS receiver and tide gauges since 1992. We present estimates of the platform vertical motion and local sea level from nearly a decade of continuous monitoring, and discuss implications on the altimeter calibration estimates. In addition, we present results from selected other GPS/tide gauge collocations that support the determination of the stability of the T/P measurement system. The time series of GPS vertical position estimates generally show evidence of annual and longer-term systematic variations. We will discuss potential sources of these signals, including various loading and thermal effects as well as manifestations of GPS measurement errors. Included in our characterization of the latter will be the effects of water vapor delays, and the impact of equipment swaps (e.g., receiver and radome changes).

G31D-09 1050h INVITED

BIFROST project: 3-D site motion inferred from 2500 days of continuous GPS in Fennoscandia and implications for regional changes of sea level

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Beginning in 1993 the BIFROST project has been compiling a large data base of geodetic positions using permanent networks of GPS receivers in Sweden and Finland, SWEPOS and FinnRef, respectively. The continuous GPS observation has provided a total of about 2500 daily solutions.

From this data rates of change of, for instance, vertical position or intraplate deformation can be inferred. Removing, from the data, crustal deformation predictions determined from a glacial isostatic adjustment (GIA) model gives normalised χ^2 values of order 10, showing that GIA dominates the observed deformation field.

Another wealth of data can be found in relative sea level observations obtained from a dense network of tide gauges that has been in operation since typically 50 and, in the case of Stockholm, 220 years. The uncertainties for the relative sea level rates and for the GPS-based land-surface rates have become comparable, 0.2 and 0.4 mm/yr, respectively. Thus, we explore the two data sets in order to infer regional changes of sea level. The tide gauges are approximately colocated with the GPS array and the majority are sampling the Baltic Sea and its sub-basins; hence a regionally constant sea level term is expected to correlate primarily with a change of the North Atlantic level at the North Sea-Skagerak-Kattegat. We are currently exploring deviations from a constant term, which might be indicative of long-wavelength or far-field perturbations of the geopotential. In this regard, we are considering the regional Fennoscandian signal that would arise from a suite of ongoing mass loading/unloading scenarios.

G31D-10 1105h INVITED

Tide Gauge Data and the Geometry of Present-Day Sea-Level Rise

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It has long been recognized that ongoing mass flux of ice sheets and glaciers will cause a geographically non-uniform sea-level rise. Indeed, in the vicinity of a melting ice complex sea level will fall, while in the far-field of this ice sheet sea level will rise at a rate which exceeds the so-called eustatic value (i.e., the value expected under the assumption of a globally uniform sea-level change). The departure from eustasy arises primarily from the effects of self-gravitation, but loading and rotational signals also contribute. Thus, mass flux associated with any ice center (including major polar ice complexes or mountain glaciers and ice sheets) will be characterized by a unique pattern, or 'fingerprint', of sea-level change.

Tide gauge records of sea-level rates exhibit significant geographic variations, even after correction for the ongoing signal due to glacial isostatic adjustment. However, the potential for rather extreme non-uniformity in sea-level change associated with present-day changes in the global ice budget has not, until recently, been embraced in analyses of these tide gauge data. Indeed, previous analyses have generally ignored the geographic variation by taking a simple average of the tide gauge rates to obtain a global value for sea-level rise. We recently reported on an attempt to separate the unique patterns of sea-level change using an independently published subset of tide gauge rates [Mitrovica et al., *Nature*, 2001; see also Plag and Jüttner, 2001], and demonstrated that several previously identified anomalies in the global tide gauge record could be reconciled using an appropriate weighting of sea-level patterns. In this talk we extend this work to incorporate global patterns of sea-level change due to the steric effect of ocean thermal expansion. These patterns are derived, in part, from the output of coupled atmosphere-ocean general circulation models, and they are characterized by a broad suite of geometries. Accordingly, we focus on the sensitivity of our inferences of ice sheet mass balances to the variation reflected in these geometries.

G31D-11 1120h

Inverting Relative Sea Level Trends for Contributions From Different Climate-Related Processes

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Present-day changes in ice sheets and glaciers, post-glacial rebound and thermal expansion of the ocean are among the processes contributing significantly to local relative sea level trends at many tide gauges. Local relative sea level trends determined from carefully processed tide gauge records can be used to invert for the different processes, if models are available to describe these contributions. The contribution from ice sheets can be parametrised on the basis of the so-called sea level equation. Geophysical models can be used to account for postglacial rebound. Climate models provide information on the pattern of steric expansion. An analysis of the contribution of these three processes to trends observed at globally distributed tide gauges will be presented and the significance of model parameters determined in an inversion of local relative sea level trends will be discussed.

G31D-12 1135h

A Comparison of two methods of gravity inversion and their impact on predictions of Ice Mass Balance

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One of the challenges of using a budgetary approach to measuring sea level rise and ice mass balance are the large uncertainties inherent in measuring the Earth's gravity field and calculating the components of the geopotential. For example, the non-steric portion of sea surface height may make a contribution to the low degree zonal coefficients as large as that as polar ice. We will present two methods of gravity inversion, one that uses a template that fixes the shape of the regions in the ice sheets that are used to find ice thicness, and one that uses an iterative procedure that makes no assumptions about the shape of the thickness profile over polar ice. This analysis gives an estimate of the uncertainties in ice thickness that result from the non-uniqueness of any mass balance inversion from the geopotential. We expect to show that these uncertainties are generally smaller than either the measurement uncertainties of those associated with components of the global gravity budget.

G32A MC: 121 Wednesday 1330h

The Terrestrial Reference Frame: Definition, Long-Term Stability, and Limitations I *(joint with H, OS, S, T, DI)*

Presiding: **K Larson,** University of Colorado at Boulder**; Z Altamimi,** ENSG/LAREG

G32A-01 1330h

The International Terrestrial Reference System. An overview of its background and its future.

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The International Earth Rotation Service (IERS) is in charge of the realization of the International Terrestrial Reference System (ITRS) since its establishment in 1988. An overview of its developments is presented both on technical and organizational aspects, focusing on the quality issues in the broad sense (accuracy, availability...). After the presently available realization (ITRF2000), new challenges are on the spot. A review of some of them is threfore given, investigating how IERS can face them: densification, improvement of site consistency, improved model for ITRS and possible refinement of its definition...

G32A-02 1345h

Review and Progress of the ITRF Datum Definition: New Results From ITRF2000

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