The Hydrology Bureau of the Global Geophysical Fluids Center

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1 Goals of the Special Bureau for Hydrology (SBH)

The purpose of the SBH is to provide a bridge between the communities of climate sciences and geodesy. Modern space geodetic observations are influenced in a direct way by the variable distribution of water mass. The geodetic community requires a measure of the time variable load of water on the land surface over the entire Earth, as a function of time, in order to estimate both local effects on geodetic site displacements, and global effects on earth rotation, geocenter, and gravity field changes. The hydrologic problem of estimating water redistribution is considered one of the fundamental challenges in climate science. It is pursued aggressively by a community much larger than the geodetic community. Thus, it is sensible to tap the resources of the climate science enterprise, especially employing results from global numerical data-assimilating models.

We intend to use the SBH web page to distribute both water load time series data in gridded form, and commonly used global integrals of it. These global integrals would include time series of excitation functions of earth rotation changes, and variations in the global gravity field Stokes coefficients. The real challenge is to identify data resources, and to collaborate with those developing state-of-the-art land-surface models, and other data sources. There are two promising future resources for estimating water load variations on a global basis. One is the GRACE satellite mission, which will provide variations in Earth's gravity spherical harmonic coefficients on a monthly basis. A second resource would be estimates from Global Land Surface Models (LSM) under development at Goddard Space Flight Center, and perhaps at other centers. There exist other data resources on the web pertaining to global water budgets. For example, there is an interesting site at <[1]> (University of Delaware) holding gridded monthly mean soil moisture and snow load fields, and there may be other resources as well to be added.

2 SBH Website Current Contents

ECMWF and NCEP-NCAR models produce global gridded atmospheric reanalysis of all available weather observations for the past several decades. In a reanalysis, the numerical model is fixed. The surface boundary over land is given a primitive hydrologic cycle with some coupling to the atmospheric model. Generally, hydrologic parameters of the land surface are not connected to a river runoff model. Instead the hydrologic parameters are used to provide proper boundary conditions for the atmospheric calculations, that are of primary importance. Because the land surface model is of secondary importance, it is difficult to understand exactly how soil and snow values are calculated. Documentation tends to be poor because the hydrologic boundary conditions are not of primary interest. For both the NCEP-NCAR and ECMWF results we have drawn conclusions based on an inspection of the time series and global maps of the average seasonal behavior.

[1] http://climate.geog.udel.edu/~climate/

Variability in total water load is the sum of water changes in several soil layers, plus a snow load component. The water load changes are not based on observed precipitation and runoff, and may be considered representative, but not good measures of time variability. There is no obvious way to assess quantitatively the size of the errors in these time series. Qualitatively, we observe that NCEP-NCAR results show little inter-annual variation (they are dominated by near-sinusoidal annual variations). On the other hand, average seasonal ECMWF water loads resemble the global seasonal water balance climatology published in the mid-1980's by Willmott and Rowe. This climatology is not nearly so sinusoidal, and is based on many decades of evaporation, precipitation, and runoff data averaged by month, and gridded for the globe. ECMWF coupling to the atmosphere model seems to provide some interannual variability. Because neither NCEP-NCAR nor ECMWF includes coupling to ground water or continental ice sheets (both long term storage reservoirs), it is likely that no gridded model output now available correctly estimates long-term load variations that may arise in the hydrologic system.

Daily continental water storage, defined as the sum of soil wetness and snow water, is computed from the two reanalysis models. We obtained ECMWF results from a UCAR website (http://dss.ucar.edu/pub/ec-reanalysis.htm) instead of the official website (http://www.ecmwf.int). Refer to the websites for descriptions of the reanalysis models. The table lists information about data sets currently in the SBH website. In addition to gridded values there are also time series of hydrological excitations of polar motion and LOD computed from NCEP reanalysis daily water storage data. We also provide a table to list global major artificial reservoirs with water capacity exceeding 10 km^3 or 10^{13} kg.

	NCEP/NCAR	ECMWF
Time-span	Jan.1979–Dec.2001	Jan.1979–Dec.1993
Resolution (degrees)	2	2.5
soil layers	2	4
layer thickness (cm)	10, 190	7, 21, 72, 189
sampling	daily	6 hours
Monthly Means 1 x 1 degree NCEP Snow and soil	1993–1998	
LOD and PM daily exc.	1948–2001	
Daily grid water load NetCDF format	1948–2001	

3 New Land Surface and Climate Models

Although there is at present no global land surface model operating along the lines of the analysis and forecast atmospheric models (NCEP, ECMWF, with data assimilation) there are developments at a number of laboratories. One global data assimilating model that has been analyzed for its geodetic implications is that of Shmakin, Milly, and Dunne (J. of Hydrometeorology, v. 3, p. 311, 2002). This model has been developed at the Geophysical Fluid Dynamics Laboratory (GFDL) of Princeton University. Water storage variations from an early version were employed by van Dam and others (Crustal Displacements due to continental water loading, Geophysical Research Letters, 2000) to estimate load deformation at GPS sites. With ground water storage, and a river runoff scheme, the GFDL model provides land surface elements suitable for a global coupled model. It has been tested with a standard data

set, the ISLSCP data, for forcing it over calendar years 1987–88. Lack of suitable data for assimilation in a real-time sense (especially precipitation) has been a limitation. Even for historical retrospectives, many data sets are monthly mean samples. Some interpolation to short time intervals is required to force the model at time step sizes suitable of a day or less. Thus, adjustment of monthly precipitation totals to estimate daily or subdaily forcing is required. The GFDL model has the potential to be forced by fields from data assimilating atmospheric models like ECMWF or NCEP. However, the precipitation estimates from these forecast models is widely recognized as being biased. There have been some bias-corrected precipitation data sets from NCEP and ECMWF that are being consider for the Goddard Space Flight Model, as described below.

At the Goddard Space Flight Center NASA's Global Land Data Assimilation System (GLDAS) is being developed. The goal is to develop a gridded numerical model that can assimilate observations from satellite sensors and other sources with the most promise for globally uniform coverage. The model has quarter-degree resolution, and provides for a complete water balance computation including runoff and ground-water storage. Development plans include simulations for a variety of forcings, including ECMWF and NCEP, and bias-corrected versions of these data sets, as well. Early indications are that the model possesses a realistic variation in water storage, including long-term variability. This contrasts with the NCEP and ECMWF data sets now available on the SBH website, which are dominantly seasonal, with little long-term variability. Members of the GLDAS development team participate in the SBH, and communication is therefore excellent. Some GLDAS results are therefore expected to be available on the SBH website by mid-2003.

4 Assessing the quality of global hydrologic data sets

It is possible on a local or even water-shed scale to compare the predictions of a hydrologic model with observations, but how is this done on a global scale? There are few obvious measures of the hydrologic cycle at the global scale that can be considered 'ground truth'. Currently only geodetic observations might be considered for such a global measure. We consider these possibilities in section 4.2, after a brief review of remote sensing opportunities for the future.

4.1 Remote Sensing of the Hydrologic Cycle

Space-based remote sensing of the hydrologic cycle offers the global perspective needed to assess hydrologic model performance. Some space-based data will be assimilated into models, as the GSFC is being designed to do. Thus, independent data, not planned for assimilation, are appropriate to test model performance. The NASA River & Wetland Processes Working Group headed by Doug Alsdorf of UCLA is studying prospects for monitoring surface water levels from space. There has been some success already in this field, notably from the use of radar altimeters, such as TOPEX, in monitoring levels in lakes and other water bodies, but the analysis is not yet a routine process with available satellites.

The most promising technologies in future satellite missions are active radar and lidar methods that measure inundation area, water heights, and changes. Radar altimetry has an along-track spatial resolution of several km and absolute height accuracy over rivers and wetlands of a few cm. Lidar altimeters, such as the GLAS instrument (Geoscience Laser Altimeter System) onboard the upcoming ICESat mission (Ice, Cloud and land Elevation Satellite), are capable of about 70 m along-track spacing and cm-scale height measure-

ments in clear weather. SAR antennae with wavelengths capable of canopy penetration, e.g., L-band, can image inundation area with decimeter scale spatial resolution whereas passive microwave radars, e.g., SSM/I (Special Sensor Microwave/Imager), utilize differences in polarized brightness temperatures to estimate flooded areas with kilometer scale spatial resolution. Radar altimeters, specifically designed for oceanic applications, may lack the along track resolution necessary to define smaller rivers and wetlands with important discharge. It may be possible to improve spatial resolution of radar altimeters via a SAR-like processing mode, and there are satellite proposals (none yet funded) that show the feasibility of this idea.

4.2 Constraints from geodetic data

Redistribution of mass in the hydrologic cycle will change the gravity field, load the earth, and alter the Earth's rotation. Geodetic observations of these effects are now available with a precision that makes it feasible to monitor the time variable load of water. Generally these geodetic measures are global in scale. The relevant observations for Earth rotation are Polar Motion (PM), influenced by degree2-order 1 changes and Length of Day (LOD), influenced by degree 2 order 0 changes. For the gravity field variations, time series of low degree/order Stokes coefficients are available from satellite laser tracking, up to degree and order (4,4) or more. There should soon be available Stokes coefficient time series from satellite gravity missions such as GRACE and GOCE up to much higher degree and order, perhaps (100,100). GPS observations of station positions have recently been shown to measure degree-1 spherical harmonic loads (Blewitt et al., Science 294, p. 2342, 2001), and the estimation of higher degree loads, and related sea level change from GPS station positions is now a possibility.

It is proposed that these geodetic time series be employed to evaluate water load variations estimated by GLDAS and other models. For the moment, this reverses the traditional role seeking to validate Earth rotation observations. However, consider that many of the geodetic observations, especially of rotation, are now extremely precise, whereas there is virtually no global scale quality control on the hydrologic models. The other main contributors to geodetic variations are the atmosphere and oceans, both of which are modeled in a mature way at a variety of centers, with many resulting time series posted on the websites of the GGFC. Therefore, geodesy now provides, on a global scale, a realistic means of measuring the quality of the global hydrologic models. This evaluation can certainly begin with the seasonal cycle, and proceed to other frequency bands.

5 Conclusions

For the moment, the big challenge is to obtain global gridded data sets and put them on the website archive. In the near future, collaboration with groups constructing global land surface data assimilating models should yield geodetically interesting time series. Geodetic time series of Stokes coefficients, earth rotation, sea level and GPS station displacements now offer a reasonable way to test the predictions of global hydrologic models.