Monitoring Precipitation over the Arctic Terrestrial Drainage System: Data Requirements, Shortcomings and Applications of Atmospheric Reanalysis

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ABSTRACT

The hydro-climatology of the Arctic terrestrial drainage plays an important role in the climate system. The primary freshwater source to the Arctic Ocean is river discharge. River discharge influences ocean salinity and sea ice conditions which can impact on freshwater fluxes through the Fram Strait and Greenland Sea into the North Atlantic. The degree of surface freshening in the North Atlantic is thought to influence the global thermohaline circulation. Changes in the terrestrial hydrologic cycle may alter soil moisture, impacting on plant communities and their grazers. Arctic soils serve as potentially significant sources of carbon dioxide and methane. Fluxes appear to respond sensitively to altered soil moisture and temperature. There is hence a clear need to monitor the Arctic system and better understand interactions between system components. The terrestrial hydrologic budget is a high priority.

A project known as Arctic-RIMS (Rapid Integrated Monitoring System) is bringing data sets and techniques together to provide readily accessible hydrologic products. Arctic-RIMS is a collaborative effort between University of Colorado, University of New Hampshire, the Ohio State University and the Jet Propulsion Laboratory. The project uses satellite data, the NCEP reanalysis, in-situ records and a permafrost/water balance model to compile fields of precipitation (P), precipitation less evapotranspiration (P-ET), ET, temperature, soil moisture, soil freeze/thaw state, active layer thickness, snow extent and its water equivalent, soil water storage and other variables. Historical time series are provided along with updates at a 1-2 month time lag. Gridded products are assembled over the complete Arctic terrestrial drainage, defined as areas emptying into the Arctic Ocean as well as into Hudson Bay, James Bay, Hudson Strait, the Bering Strait and northern Bering Sea. Here we describe a core element of Arctic-RIMS - the provision of historic time series and updates of gridded precipitation. Details are provided in the upcoming paper of Serreze et al. [2003].

Provision of gridded historic time series has in itself proven to be a daunting and at times frustrating task. The required station density to assemble quality gridded time series at a spatial scale useful for input to hydrologic models exceeds what is available over most of the Arctic drainage. The problem is compounded by large errors in the measurement of solid precipitation

and degradation of the station network since about 1990, the latter due to budget cuts in both the Former Soviet Union (FSU) and Canada. For example, the station coverage for the FSU in 1996 is about half of that available in the mid 1980s. Canada is also seeing a trend toward the replacement of manual observations by automated systems, providing data of suspect quality.

To assess the impacts of station density for generating historical time series, Monte-Carlo experiments were performed for the few well-instrumented areas of the Arctic drainage in Canada. Briefly, monthly grid box time series were compiled using all the stations in 175 km grid boxes. These were taken to be the "true" time series. Time series were then compiled by randomly removing stations from the boxes, and were compared to the true time series. It is concluded that for 175 km grid cells, the Arctic station network over the period 1960-1989 is generally sufficient to estimate the mean and standard deviation of precipitation at this scale (hence the statistical distributions). However, as for most regions of the Arctic, one must obtain grid box values by interpolating from stations well outside of the grid box bounds, the true grid box time series are often poorly represented. The Monte Carlo experiments indicate that to accurately capture the true monthly time series (e.g., to get a squared correlation exceeding 0.70), one must have at least four stations per 175 km cell and more in topographically complex regions. However, only 38% of cells across the Arctic terrestrial drainage contain even a single station.

We next consider four options for monitoring precipitation: (1) make do with gridding available updates of station data; (2) make direct use of gridded precipitation forecasts from the NCEP reanalysis; (3) use the gridded observed precipitation time series and NCEP output for 1960-1989 (forecasted precipitation and other variables such as vertical motion) to develop linear regression models which can be applied to NCEP updates (a form of statistical downscaling); 4) use non-parametric methods to constrain NCEP output by the statistical distributions of the gridded observations over the 1960-1989 period. A common thread between options 2-4 is that output could be subsequently adjusted via assimilation of any available station data updates.

The problem with Option 1 is that station coverage since 1990 is much more sparse than for earlier decades and is insufficient by itself. Regarding Option 2, NCEP forecasts of precipitation in the Arctic contain large biases (especially in summer) and cannot be used "as is" [Serreze and Hurst 2000]. Option 3 (e.g., multiple linear regression) is clearly problematic in that it requires faith in the observed gridded precipitation time series. As concluded from the Monte-Carlo simulations, the grid box time series are often of poor quality, meaning that one will be regressing against noise. The time series of individual stations represent truth (with due consideration of gauge undercatch and other biases). However, regression against station time series runs into problems of scale (relating point observations to relatively coarse scale NCEP output). Gridding the resulting station reconstructions also runs into the same problems of station density that were just discussed.

Option 4 emerges as the most viable. It recognizes that: 1) biases in NCEP precipitation forecasts are at least in part systematic; 2) systematic biases can be accounted for through re-scaling procedures (a non-parametric probability transform, see Panofsky and Brier [1963]) that require only the statistical distributions of observed precipitation rather than accurate representation of the gridded time series themselves; 3) re-scaling procedures can be applied to reconstruct precipitation from other variables, such as aerological estimates of P-ET (from the vapor flux convergence and the tendency in precipitable water), which can replace the re-scaled NCEP precipitation forecasts if they are shown to provide better skill. The utility of these P-ET fields for assessing the Arctic moisture budget has been demonstrated in several recent studies [e.g., Rogers et al., 2001].

Cross-validated correlation analyses indicate that re-scaled monthly NCEP forecasts (re-projected to a 175 km grid) have considerable skill in some parts of the Arctic drainage (squared correlations exceeding 0.50), but perform poorly over large regions. A fundamental problem, however, is that in data sparse regions, the observed gridded time series are themselves of poor quality. Hence, the term "validation" is perhaps inappropriate. In data-sparse areas, it may well be that the NCEP forecasts are performing better than is indicated from the correlations.

Treating climatology as a first guess with replacement by re-scaled NCEP values in areas where skill can be demonstrated yields a marginally useful monitoring product on the scale of large watersheds such as the Ob, Yenisey and Lena. Further improvements are realized by assimilating data from a limited array of station updates (taken as representative of the network which will be available in the next decade) via a simple replacement strategy. In turn, the product can be further improved by including aerological estimates of P-ET within the initial re-scaling procedure. In some areas, such at the Lena basin in summer, the re-scaling technique (even without data assimilation) works extremely well.

We also examined the alternative approach of reconstructing precipitation via multiple linear regression (Option 3), using as predictors the NCEP precipitation forecasts along with other reanalysis variables such as P-ET computed from wind and humidity profiles, monthly sums of upward vertical velocity (omega) at 500 hPa, zonal and meridional moisture fluxes, sea level pressure and a measure of lower-tropospheric stability. The apparent skill is comparable to that based on the re-scaling approach using NCEP precipitation and P-ET. There are issues of co-linearity between predictors. There are methods to resolve these issues, but as just discussed, the re-scaling approach is on a better statistical footing in that unlike regression, it does not assume that the observed time series are themselves accurate. Only the statistical distributions need be known. We have also used the re-scaling approaches to reconstruct precipitation at the station locations, with subsequent interpolation of the reconstructed station values to the 175 km grid cell array. In general, the results are worse than those based on first interpolating the station data to the grid cell array.

An obvious need for doing a better job is to have better observations. However, the station data base in the Arctic has always been sparse, and as mentioned, has seriously degraded over the past decade. We need to look into satellite-based precipitation retrievals. The brightest avenue, however, is having access to output from an improved atmospheric model. We have had the opportunity to examine several years of precipitation forecasts from ERA-40. While ERA-40 appears to perform little better than ERA-15, performance is much better relative to NCEP. The monitoring approach will hence transition to the use of ERA-40 as soon as significant portions of the data stream become available to us. Note that precipitation output from the NCEP-DOE AMIP-2 reanalysis is no better than that from the primary NCEP data stream. A dedicated Arctic System Reanalysis (ASR) has been proposed under the National

Science Foundation (NSF) Study for Environmental Arctic Change program [SEARCH SSC, 2001]. The proposed ASR will draw on lessons learned from ERA-40 and the NCEP North American Regional Reanalysis (NARR).

References

Panofsky, H.A. and G.W. Brier, 1963: *Some Applications of Statistics to Meteorology*. Mineral Industries Continuing Education, College of Mineral Industries, the Pennsylvania State University, University Park, Pennsylvania, 224 pp.

Rogers, A.N., D.H. Bromwich, E.N. Sinclair, and R.I. Cullather, 2001: The atmospheric hydrologic cycle over the Arctic Basin from reanalyses Part 2. Interannual variability. *J. Climate*, 14, 2414-2429.

SEARCH SSC, 2001: *Study of Environmental Arctic Change, Science Plan*, Polar Science Center, Applied Physics Laboratory, University of Washington, Seattle, 91 pp.

Serreze, M.C., M.P. Clark and D.H. Bromwich, 2003: Monitoring precipitation over the Arctic terrestrial drainage system: Data requirements, shortcomings and applications of atmospheric reanalysis. *J. Hydrometeorology* (in press).

Serreze, M.C. and C.M. Hurst, 2000: Representation of mean Arctic precipitation from NCEP-NCAR and ERA reanalyses. *J. Climate*, 13, 182-201.