Global Precipitation Estimation from Satellite Image Using Artificial Neural Networks

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ABSTRACT

Better understanding of the spatial and temporal distribution of precipitation is critical to climatic, hydrologic, and ecological applications. However, in those applications, lack of reliable precipitation observation in remote and developing regions poses a major challenge to the community. Recent development of satellite remote sensing techniques provides a unique opportunity for better observation of precipitation for regions where ground measurement is limited. In this presentation, we introduce a satellite-based precipitation measurement algorithm named PERSIANN (Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks). This algorithm continuously provides near global rainfall estimates at hourly 0.25^o x 0.25^o scale from geostationary satellite longwave infrared imagery. An adaptive training feature enables model parameters to be constantly adjusted whenever independent sources of precipitation observations from low-orbital satellite sensors are available. The current PERSIANN algorithm has been used to generate multiple years of research quality precipitation data. This data has been used to characterize the variations of water and energy cycle at various spatial and temporal scales. PERSIANN data is available through HyDIS (Hydrologic and Data Information System: http://hydis8.eng.uci.edu/persiann/) at CHRS (Center for Hydrometeorology and Remote Sensing), UC Irvine. The system development of PERSIANN algorithm, data service, and applications are discussed.

1 Introduction

Precipitation is the key hydrologic variable linking the atmosphere with land surface processes, and playing a dominant role in both weather and climate. The Global Water and Energy cycle EXperiment (GEWEX), recognizing the strategic role of precipitation data in improving climate research, strongly emphasized the need to achieve global measurement of precipitation with sufficient accuracy to enable the investigation of regional to global water and energy distribution. Additionally, many other international research programs have also placed high priority on the development of reliable global precipitation observation.

During the past few decades, satellite sensor technology has facilitated the development of innovative approaches to global precipitation observations. Clearly, satellite-based technologies have the potential to provide improved precipitation estimates for large portions of the world where gauge observations are limited. Recently many satellite-based precipitation algorithms have been developed (Ba and Gruber, 2001; Huffman et al., 2002; Joyce et al., 2004; Negri et al., 2002; Sorooshian et al., 2000; Tapiador et al., 2002; Turk et al., 2002; Vicente et al., 1998; Weng et al., 2003). These algorithms generate precipitation products consisting of higher spatial and temporal resolution with potential to be used in hydrologic research and water resources applications. Evaluation of recently developed precipitation products over various regions is ongoing (Ebert, 2004; Kidd, 2004; Janowiak, 2004).

In this presentation, we will introduce one near global precipitation product generated from PERSIANN (Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks) algorithm. PERSIANN is an adaptive, multi-platform precipitation estimation system, which uses artificial neural network (ANN) technology to merge high-quality, sparsely sampled data from NASA, NOAA and DMSP low altitude polar-orbital satellites (TRMM, DMSP F-13, F-14, & F-15, NOAA-15, -16, -17) with continuously sampled data from geosynchronous satellites (GOES) (Hsu et al., 1997, 1999; Ferraro et al., 1995; Janowiak et al., 2000; Sorooshian et. al., 2000; Weng et al., 2003). The precipitation product generated from PERSIANN covers 50°S-50°N at 0.25° spatial resolution and hourly temporal resolution.

2 Near Global PERSIANN Precipitation Data for Hydrologic Applications

Figure 1 shows the precipitation generation flow from the PERSIANN algorithm. PERSIANN algorithm provides global precipitation estimation using combined geostationary and low orbital satellite imagery. Two major stages are involved in processing a satellite image into surface rainfall rates. The algorithm first extracts and classifies local texture features from the long-wave infrared image of geostationary satellites to a number of texture patterns, and then it associates those classified cloud texture patterns to the surface rainfall rates. PERSIANN generates rainfall rate at every 30 minutes. To setup PERSIANN for better capturing the high temporal variation of precipitation, the whole globe is separated into a number of organized subdivisions, while each subdivision consists of an area coverage of 15^o x 60^o. PERSIANN model parameters in each subdivision are adjusted from passive microwave rainfall estimates processed from low-orbital satellites from NASA, NOAA and DMSP low altitude polar-orbital satellites (TRMM, DMSP F-13, F-14, & F-15, NOAA-15, -16, -17) (Ferraro et al., 1995; Weng et al., 2003). Although other sources of precipitation observation, such as ground-based radar and gauge observations, are potential sources for the adjustment of model parameters, they are not included in the current PERSIANN product generation. Evaluation of PERSIANN product using gauge and radar measurements is ongoing to ensure the quality of generated rainfall data. PERSIANN generates near-global (50°S-50°N) product at 0.25° spatial resolution and hourly temporal resolution.

In conjunction with the various phases of PERSIANN development, we have also developed the Hydrologic Data and Information System (HyDIS), which has been providing various means to share research quality PERSIANN data with researchers and the general public world wide. HyDIS is a river basin and country-based web GIS system that includes a global precipitation-mapping server, which provides direct access to near real-time global 6 hourly PERSIANN precipitation estimates (http://hydis8.eng.uci.edu/hydis-unesco/). Currently, multiple years of PERSIANN data since year 2000 are generated. The data are distributed through the HyDIS system to our partners worldwide to conduct model evaluation and data assimilation studies at climate-, meso-, and hydrologic-scales. PERSIANN data visualization and service through HyDIS demonstration page is listed in Figure 2. The friendly interface of HyDIS enables users to view and collect data in a selected region and required accumulated interval period. For those users who would like to receive multiple years of global data, six-hour global PERSIANN data is added together at the end of month. The data is also available through HyDIS at: hydis8.eng.uci.edu/persiann.

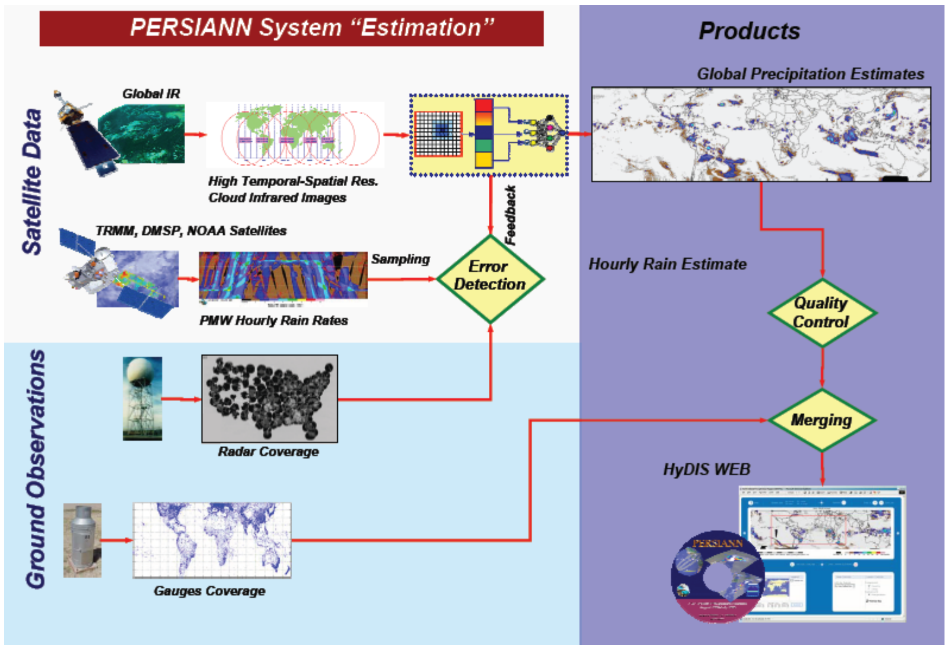

Figure 1. Current operational implementation of the PERSIANN system produces and distributes near-real-time global precipitation products at 0.25° 6 hourly resolution.

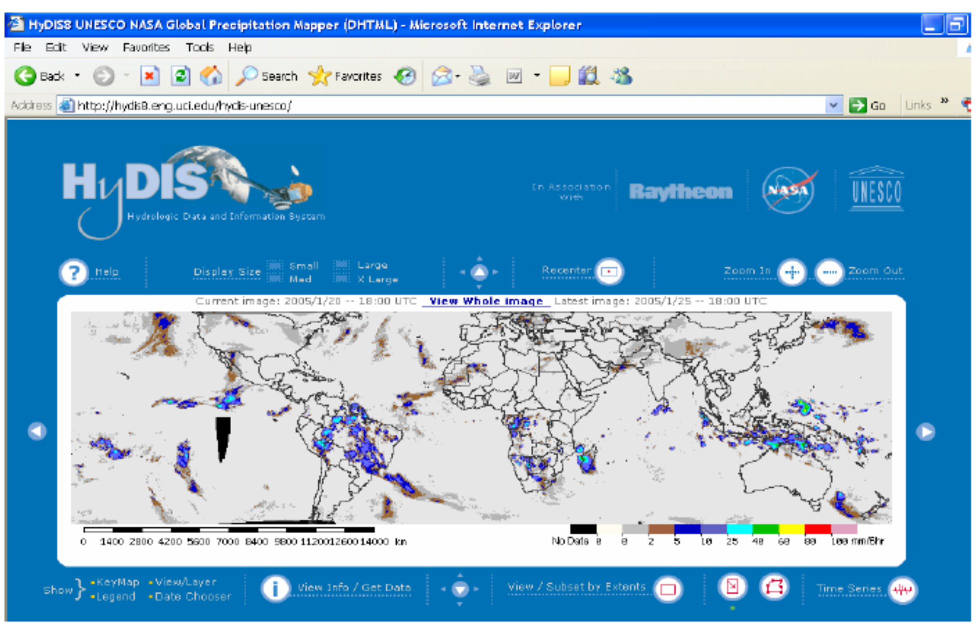

Figure 2. PERSIANN Data visualization and service through the HyDIS system

In addition to the interactive map server, which provides the flexibility of regional selection, zooming, and data subsetting, HyDIS tools were expanded to accommodate UNESCO's Global Water and Development Information (G-WADI: http://www.sahra.arizona.edu/unesco/about.html) project. The expanded tools include automated generation of country-based aridity mapping and multiple access points to PERSIANN Data: (a) original HyDIS Mapserver interface, (b) pull-down menus, which allow the user to select continental region and country, and (c) text listing of countries within each continent, and Water resources relevant information were provided through the ability to select from several precipitation accumulation intervals (6hrs, 1, 3, 5, 15, and 30 days). Pull-down menu access-point widget was designed to permit mirror sites to provide HyDIS data access. Access to the text tabulation is provided through a simple image page that allows the user to click on a continental region to access its relevant table. Future updates will include histograms of aridity as well as land cover classes within political divisions of each country.

3 Evaluation and Applications

Several regional evaluation studies of current satellite high-resolution precipitation products including PERSIANN and several others are ongoing. These regions include: Australia (BMRC precipitation validation page: http://www.bom.gov.au/bmrc/SatRainVal/dailyval.html) and the United States (CPC precipitation page: http://www.cpc.ncep.noaa.gov/products/janowiak/us_web.shtml). Ground gauge and radar data are used in the evaluation to provide an overview of daily as well as seasonal statistics of satellite and ground-based precipitation observations. Figure 3, which shows a sample BMRC evaluation over Australia, also demonstrates PERSIANN's ability to capture the distribution of daily precipitation in a manner consistent with daily gauge analysis for January 22, 2005. Other validation sites cover part of Western Europe (University of Birmingham precipitation validation page: http://kermit.bham.ac.uk/%7Ekidd/ipwg_eu/ipwg_eu.html) and PERSIANN GEWEX Coordinated Enhanced Observation Period (CEOP) sites (http://www.ceop.net/) are under preparation (http://hydis0.eng.uci.edu/CEOP/).

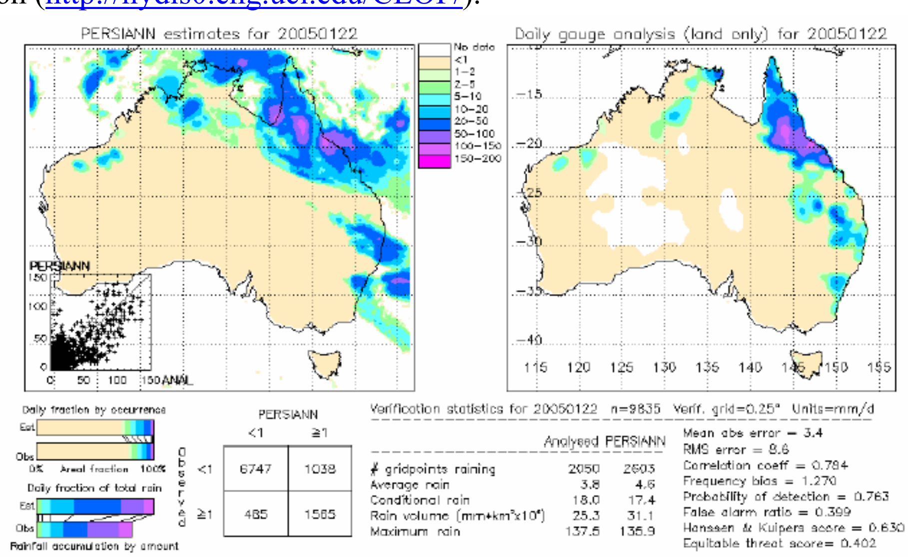

Figure 3. Evaluation of PERSIANN daily precipitation data over Australia region (this figure adopted from: http: http://www.bom.gov.au/bmrc/SatRainVal/dailyval.html)

Precipitation is a key forcing variable of the global/regional/and local water and energy cycle. Providing reliable precipitation observation will contribute to improving our understanding of the evolution of convective precipitation during the Monsoon season and the diurnal evolution of the precipitation cycle. Similarly, the product will provide modelers with a unique data set that could be utilized to improve numerical weather predictability as it provides a critical element for data assimilation and ensemble forecasts. For years PERSIANN precipitation products have been used in a number of hydrologic research and application studies. These studies have included: (1) validation of daily rainfall and diurnal rainfall patterns against observations provided by the TRMM field campaign, (2) evaluation of MM5 numerical weather forecast model estimates over the Southwest U.S., Mexico, and adjacent oceanic regions, (3) assimilation of PERSIANN data into a Regional Atmospheric Modeling System (RAMS) model to investigate the land-surface hydrologic process, (4) mergence of gauge and PERSIANN system over Mexico Region, (5) the use of satellite-based precipitation estimates for runoff prediction in un-gauged basins, (6) investigation of the impacts of assimilating satellite rainfall estimates on rainstorm forecast over southwest United States, and (7) analysis of multiple precipitation products and preliminary assessment of their impact on the Global Land Data Assimilation System (GLDAS) land surface states (Gochis et al., 2002; Guevara, 2002; Gottschalck et al., 2004; Hong et al. 2005; Li et al., 2003; Xu et al., 2004; Sorooshian et al., 2002; Yi, 2002; Yucel et al., 2002).

Figure 4 shows the diurnal precipitation patterns retrieved from PERSIANN data and NCEP WSR-88 radar data during summer season (JJA) 2002 around central and northern American. Note that both sources of data show consistent diurnal precipitation pattern over the land and ocean; the amplitude of the data is similar to one another; in the phase, however, there is approximate a one-hour lag in between PERSIANN and WSR-88 radar estimates. A more detailed discussion of using PERSIANN data in documenting the diurnal precipitation pattern is described in Sorooshian et al. (2002).

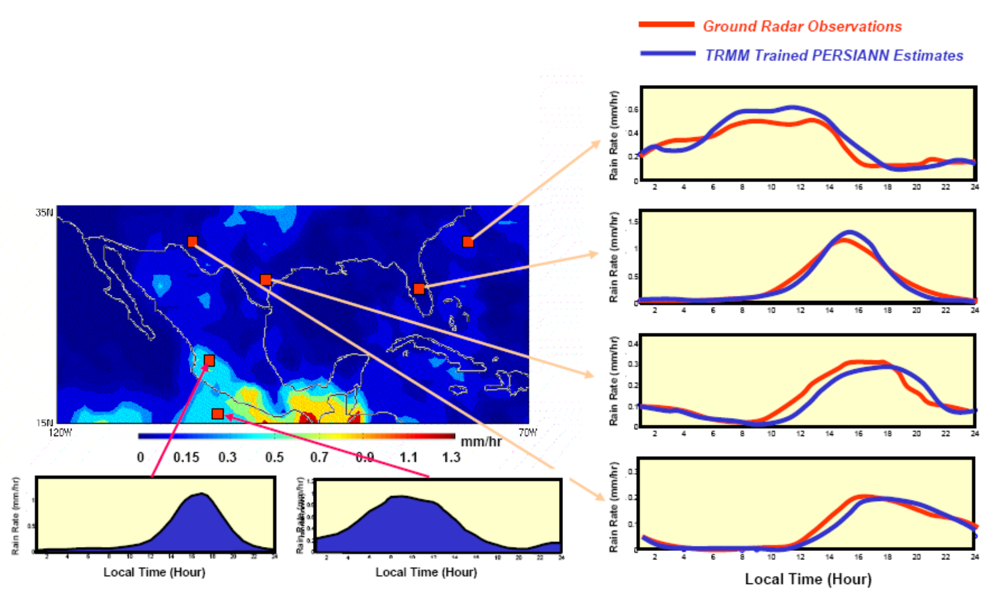

Figure 4. Evaluation of diurnal rainfall pattern of PERSIANN estimates in the summer season (JJA) 2002 using NCEP WSR-88 radar data.

Figure 5 shows PERSIANN rainfall applied in the streamflow simulation of the Leaf River Basin (1949 km^2) near Collins, Mississippi. In this experiment, more than three years of PERSIANN precipitation, as well as gauge and radar merged rainfall data, were collected and applied to generate daily streamflow using an operational conceptual hydrologic model (the Sacramental Soil Moisture Accounting Model of National Weather Service). Compared to basin daily observation, the daily streamflow generated from PERSIANN rainfall are not significantly different from that generated from gauge and radar merged data. This demonstrates that the satellite-based rainfall measurement is reaching a level potentially suitable as a precipitation data source for basin scale hydrologic applications, in particular for regions where ground-based observations are lacking.

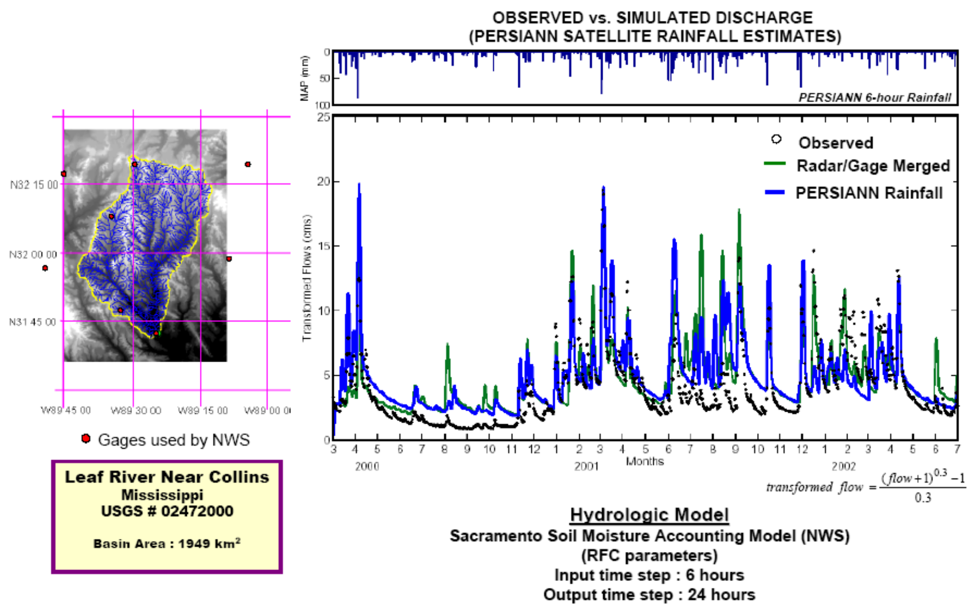

Figure 5. Simulation of daily streamflow using 6-hourly accumulated rainfall from (1) satellite-based PERSIANN data and (2) radar and gauge merged data

The influence of spatial-temporal precipitation errors on hydrologic response is further examined using the stochastic simulation of precipitation error. Figure 6 shows the impact of the PERSIANN estimation error to the generation of streamflow over the Leaf River Basin. In our case, the uncertainty of PERSIANN estimates is evaluated based on radar rainfall measurement. The 95% confidence interval of simulated streamflow is plotted. It shows that the reliability of estimated streamflow is highly relevant to the quality of precipitation forcing data. The uncertainty bound is significantly higher during high flow period and is lower in low flow points. The error property of PERSIANN data is under evaluation.

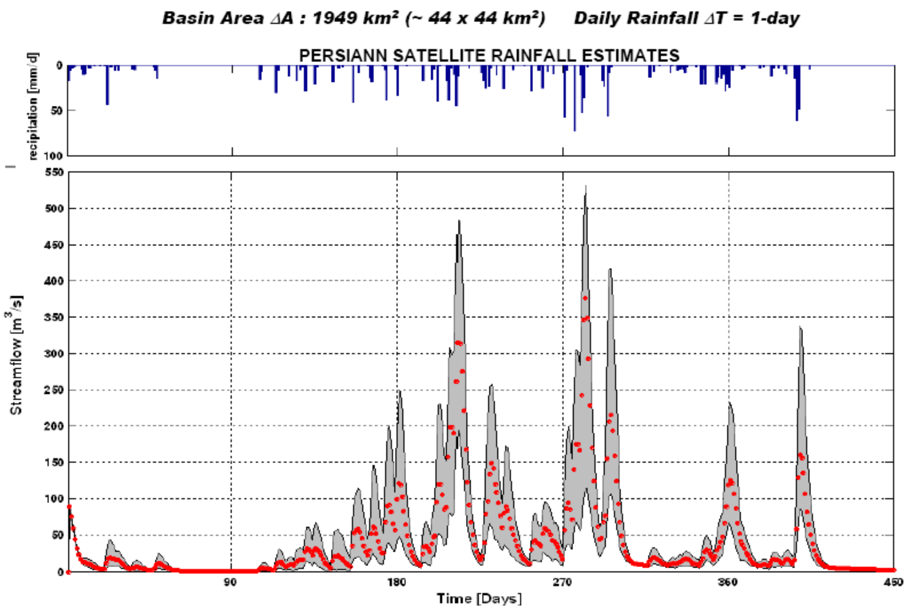

Figure 6. Conference interval (95%) of daily streamflow is generated based on the uncertainty of PERSIANN precipitation estimates,

4 Summary

In summary, we introduced the operation of the PERSIANN satellite-based algorithm to generate a near global coverage of precipitation data. Currently, multiple years of PERSIANN data is generated and available for public access through the HyDIS data visualization and handling system. With our objective of providing reliable precipitation data for basin scale hydrologic studies in mind, we have been continuing operation of the PERSIANN algorithm to generate long-term near global coverage precipitation data, and to improve the quality of data through the development of satellite-based rain retrieval algorithms. In the algorithm development, our recently developed PERSIANN-Cloud Classification System (CCS) uses computer image processing and pattern recognition techniques to process cloud image into rainfall rate (Hong et al. 2004). Preliminary study over Northern America shows promise, with the potential improvement of current PERSIANN estimates. Real-time operation of CCS to produce 4km hourly precipitation over the North America is under development (see: http://hydis8.eng.uci.edu/CCS). Our evaluation of PERSIANN and CCS is ongoing and will be discussed in a separated report.

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