The Assimilation, Analysis and Dissemination of Pacific Rain Gauge Data: PACRAIN

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1. Project Summary

Tropical rainfall data taken over both land and ocean is particularly important to the understanding of our climate system. Not only is it a tracer of latent heat, it is vital to the understanding of ocean properties as well, including latent and sensible heat flux, salinity changes and concomitant local ocean circulation changes. In addition, rain gauge observations from low-lying atolls are required to conduct verification exercises of nearby TAO/TRITON buoy-mounted rain gauges, which are funded by NOAA's Ocean Climate Observing Program (OCO). Tropical island rainfall is also required for verification work by satellite rainfall algorithm programs funded by NASA, NOAA and various international programs.

This project supports the NOAA objective to "build and sustain the global climate observing system that is needed to satisfy the long-term observational requirements of the operational forecast centers, international research programs, and major scientific assessments". Our current and future efforts include expanding our mission to collect, analyze, verify and disseminate global rainfall data sets and products deemed useful for Operational Forecast Centers, International Research Programs and individual researchers in their scientific endeavors. Housed in the School of Meteorology at the University of Oklahoma, the Comprehensive Pacific rainfall Database (PACRAIN) and the Schools of the Pacific Rainfall Climate Experiment (SPaRCE) have built upon work from past NOAA-supported projects to become a unique location for

scientists to obtain scarce rain gauge data and to conduct research into verification activities. These data are continually analyzed to produce error-assessed rainfall products and are easily assessable via our web page (http://pacrain.evac.ou.edu/). We're also actively involved using PACRAIN data in assessing the quality of other NOAA OCO supported projects (e.g. Morrissey et al. 2012, and others).

2. Scientific and Observing System Accomplishments

Due to the importance of tropical Pacific rainfall data to climate research and operational and climate forecasting we work collaboratively with the Pacific Island Global Climate Observing System (PI-GCOS) program to effectively and efficiently match the areas of commonality among both COM's and PI-GCOS's objectives. One of these common areas is the strengthening of the existing Pacific observation climate network for both atmosphere and ocean.

2.1. Summary of Deliverables

Specifically, we seek to support all programs that required rainfall data to assess vulnerability to weather and climates extremes (OCO objective #1). Given the vastness of the Pacific basin it is critical to collect all available rain gauge data 1) in environmentally sensitive areas, 2) where dense rain gauge networks exist but are not assimilated into a single database, and 3) where agreements can be made to help construct and upgrade rain gauge networks in these critical locations. These data are assimilated, homogenized, and error-checked and then made available to the general research community through a single web site. To create the most comprehensive Pacific raingauge database possible it is necessary to continue to work closely with the Pacific Islands meteorological services (PIMS) to help them sustain their quality gauge networks. One of our most successful efforts during the last few years is the implementation of a large network of new manual-read rain gauges and automatic data-logger equipped tipping bucket rain gauges located on various atolls and islands managed by the local PIMS. A total of approximately 60 automatic, high quality tipping bucket gauges are being operated by various Pacific Island meteorological services. We currently are collecting the data in tip format and converting it to one-minute resolution. One of efforts this year has been to conduct research using this new tipping bucket data. The PACRAIN data set has been used by many researchers for a variety of purposes (e.g. Delcroix et. al, 1996, Xie et al., 2007, etc.). The uses include incorporation into climate models, climate studies, and the verification of satellite rainfall algorithms. The data set is also referenced by many programs (e.g., the International Precipitation Working Group, (IPWG), the Global Energy and Water Cycle Experiment (GEWEX), etc.) and is included in NASA's Global Change Master Directory.

It is our belief that by working directly with the PIMS, we bring tangible benefits to the global climate research community through data base development and enhancement. In turn, the local meteorological services also benefit directly through enhanced forecast products developed by the scientific community using these critical data sets.

Our Pacific educational program, the Schools of the Pacific Rainfall Climate Experiment (SPaRCE; http://sparce.evac.ou.edu/) directly enhances the PACRAIN database through the

contribution of Pacific schools taking manual read daily rain gauge measurements while learning about the importance of weather and climate. Underlying these projects is the long-term effort to help build the stakeholder outreach capacity of the all the PIMS. This will ultimately result in the PIMS being able to self-sustain their data networks. We continue to contribute to this effort by providing what we can in terms of needed supplies, education and communication infrastructure (e.g. involvement in the Radio/Internet (RANET) project) until the PIMS become completely self-sustainable.

Scientists need only to access the PACRAIN web site to obtain the most comprehensive Pacific rainfall data set anywhere in the world. Many of these regional data sets are impossible or impractical to obtain elsewhere. The PACRAIN project serves the research community by actively working with individual countries in environmentally important locations to help provide them with infrastructure, education and other short and long-term support. One example is our collaboration with the International Precipitation Working Group (IPWG) in conducting satellite rainfall algorithm verification studies. The return on this investment by NOAA has been significant in terms of enabling PACRAIN to provide the scientific community with critical, one-of-a-kind rain gauge data sets and to have established ongoing mutually beneficial relationships that should lead to future collaborations. Past successes with this strategy have proven very worthwhile on a cost-benefit basis.

2.2. Primary Institutional Data Users of PACRAIN

- **NCDC National Historical Climate Network (NHCN)**: Data are merged with the NHCN. Individual ocean/Atmosphere researchers investigating both climate- and shorter-term physical relationships at the ocean-atmosphere interface.
- **Pacific Island GCOS Program**: Data are integrated into this database for climate research.
- **Global Precipitation Climatology Project**: Data are used in satellite rainfall algorithm verification exercises.
- **NASA Tropical Rainfall Measuring Mission and Global Precipitation Measuring Mission**: Data are used by NASA primarily for satellite rainfall verification research.

2.3. Specific Deliverables in 2013

2.3.1. Pacific Rainfall Climate Network Development in Vanuatu

During FY2013, PACRAIN, in collaboration with the Oklahoma Mesonet, provided rain gauges, solar panels and other equipment to the Vanuatu Meteorological Service to enhance their real time rainfall climate observation network. We have been able to leverage funds through our collaboration with the Oklahoma Mesonet, and this continued collaboration will greatly enhance the spatial density of rainfall observation in the western Pacific.

2.3.2. PI-GCOS Tipping Bucket Raingauge Project

Rain rate measurements over open ocean regions are very important in the assessment of satellite rain algorithms and climate change and modeling of physical processes. Until recently, no Pacific island rainfall measurements have been available at resolutions less than one hour. In another example of our ability to leverage additional resources from the University of Oklahoma toward this project, the we have collected a series MetONE rain gauges tipping bucket gauges that equipped with data loggers. These have been given to the PI-GCOS Coordinator, headquartered at SPREP, for distribution to the various PIMS. We have deployed over 60 of these gauges throughout the Pacific region since 2008. We are currently receiving rainfall tip data back from many PIMS and these data are inserted into the PACRAIN database. These data are particularly important in the understanding of basic tropical rain systems and consequently, more accurate global climate models. These data are all included in the PACRAIN database.

The achievement of this objective could not be accomplished without the close collaboration of the PI-GCOS Steering Group and the current PI-GCOS Coordinator. Other important collaborative groups are the Global Ocean Observing System (GOOS), the New Zealand Meteorological Service, and the New Zealand Institute for Research in Water and Atmosphere, the Australian Bureau of Meteorology, Meteo-France and the US National Weather Service.

The PI-GCOS Tipping Bucket Project web sites is at http://www.pi-gcos.org/. (the P.I. initiated the PI-GCOS web site in collaboration with the GOSIC project at the University of Delaware. It now under the auspices of the NOAA National Climatic Data Center.)

2.3.3. Other Network-Building Activities

Rain gauges were sent to the NWS Weather Service Offices on Majuro and Chuuk. These gauges will be distributed to community observers to enhance the local climate observation networks.

2.3.4. Provided high spatial density world regional rain gauge datasets for use in satellite rainfall algorithm verification (ongoing)

PACRAIN maintains a database of selected high density raingauge network data for use in satellite rainfall algorithm assessment. Parts of our responsibilities include provide surface validation rainfall data to researchers associated with the Global Precipitation Climatology Project (GPCP) and the IPWG. Our tasks in this capacity include identifying and collecting these data sets and making them available to researchers for this purpose. We also conduct studies on the errors involved when comparing satellite and rain gauge data. During 2008 we began research on the rain rate characteristics of tropical rainfall by developing a tropical point process model. The fit of the model at various temporal scales was tested using the data from the tipping bucket gauges.

This year featured the publication of two major articles, one comparing NASA Tropical Rainfall Measuring Mission (TRMM) tropical cyclone rainfall estimate to PACRAIN data (Chen, Y., E. E. Ebert, K. J. E. Walsh, and N. E. Davidson, 2013) and the other using PACRAIN to analysis satellite and reanalysis estimates in the Pacific (Pfeifroth, U., R. Mueller, B. Ahrens, 2013)

2.3.5. Assessing the Consistency of the TAO/TRITON Buoy Capacitance Raingauges through a Comparison with PACRAIN Island Tipping Bucket Gauges

Collaboration with oceanographers is one of our top priorities. The common use of remotely-located, buoy-mounted capacitance rain gauges in the tropical oceans for satellite rainfall verification studies provides motivation for an *in-situ* gauge bias assessment. A comparison of the biases in rainfall catchment between Pacific island tipping bucket rain gauges and capacitance rain gauges mounted on TAO/TRITON moored buoys in the tropical Pacific was conducted using the relationship between the fractional-time-in-rain and monthly rainfall initially investigated by Morrissey et al. (1994). This study utilized the widespread spatial homogeneity of this relationship in the tropics to assess the rain catchment of both types of gauges at given values for the fraction-time-in-rain. The results indicate that the capacitance gauges are not statistically significantly biased relative to the island-based tipping bucket gauges. In addition, given the relatively small error bounds about the bias estimates any real bias differences among all the tested gauges are likely to be quite small compared to monthly rainfall totals. The paper is published in the Journal of Atmospheric and Oceanic Technology (Morrissey et al., 2012). Work proposed next year will include investigating wind biases in the TAO/TRITON gauges.

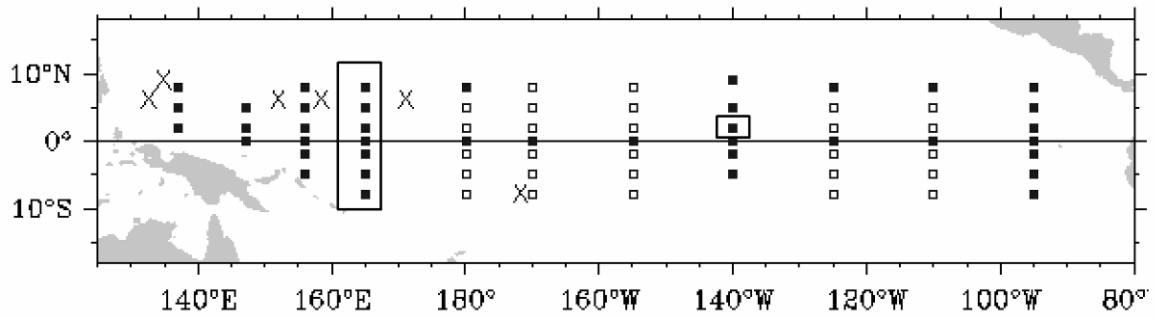

Figure 1 Solid squares indicate TAO/TRITON buoy locations mounted with capacitance gauges. Solid squares surrounded by a rectangle are the 8 Pacific buoys with capacitance gauges used in this study. Island TB gauges used in this study are located by an 'x'. . Note buoys located at 8N^o,125^o W, 8N^o , 110^o W and 8N^o 180^o W were only equipped with gauges for a few years and, thus, have limited records.

2.3.6. Rainfall Trends in the Pacific

It is known that global warming has an effect on the prevalence of precipitation extremes, with both high-precipitation events and droughts becoming more common, as shown, for example in some of our previous research related to this project (Greene, et al., 2007). These changes in rainfall distribution can have significant hydrologic consequences even if the average precipitation in an area does not change. Areas with limited groundwater and surface water capacity will face the greatest consequences, which describes most of the islands in the central Pacific Ocean.

Research presented at the AMS 93rd Annual Meeting focused on the geographic distribution of trends in extreme rainfall associated with three of the models used in the Coupled Model Intercomparison Project. Some of the key results, in this case focused on the Australian CSIRO Mk 3.5 model:

- Trends are consistent with an increase in total rainfall and extreme rainfall events across the northwest tropical Pacific (i.e. Micronesia) during the Northern Hemisphere (NH) cool season; no large-scale spatial trends were evident outside of this region.
- At the individual analysis sites across the Tropical Pacific, wet trends outnumbered dry trends by 7:1 during the NH cool season and 2:1 during the NH warm season.
- Most of the statistically significant trends were observed during the NH cool season.

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2.3.7. Investigation into differences observed between the PACRAIN data and the Global Historical Climate Network

The Global Historical Climate Network (GHCN) dataset is maintained by the National Climatic Data Center as a compilation of climate data from around the world. It has been recently observed that are significant differences in the data records between corresponding sites in the GHCN and the PACRAIN data set. We are presently involved in an investigation into the nature of these differences and how they came about. Our preliminary results comparing the TD3200 data set to GHCN and PACRAIN are summarized below.

The GHCN-Daily dataset is NCDC's data set of record for global daily climate observations. GHCN replaces a number of NCDC data sets, including the TD3200 Cooperative Summary of the Day data set. While both of these data sets use the same source data, they have different quality assurance schemes that lead to differences between the two data sets in some cases. Also, TD3200 was limited to the US first-order and cooperative observation networks so the geographic scope of GHCN is much greater. The TD3200 data set was discontinued in 2011.

The PACRAIN database includes a mix of GHCN and TD3200 data depending on when the data were ingested. Starting with the 2011 data year, all values for NCDC data are from GHCN; prior to then most values are from TD3200 except for cases where a correction to an existing observation was issued in the GHCN data feed. While GHCN data are available for the South Pacific—primarily for ICAO aviation observation sites—PACRAIN exclusively

uses NIWA data for this region. The existence of redundant data provides an opportunity to compare GHCN to the PACRAIN database with the goal of identifying discrepancies between the two data sets. Thus, research has begun and results will be available shortly.

2.3.8. Data Status

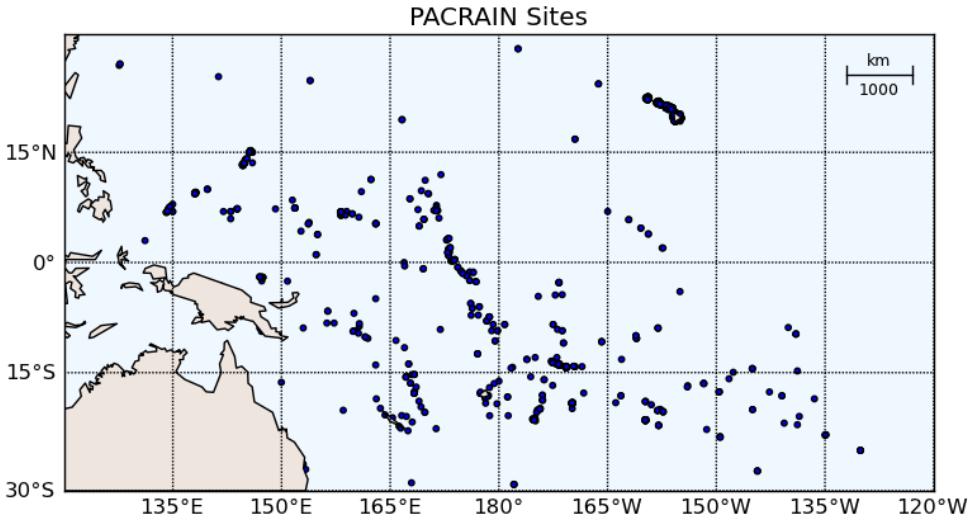


Figure 2 Current and past PACRAIN sites.

- The database currently contains 2.67 million observations from 990 sites. Records begin in January 1874.

- All data are available at http://pacrain.evac.ou.edu. The database was last updated on October 1 with data through August 2013. Data availability varies by site.

- Data are not available in real time and thus are not distributed via GTS. Data are collected for climate research and frequently arrive from very remote locales after several months.

- Data access is verified at least monthly with each regular update. Users are encouraged to report access problems so that they can be corrected as soon as possible. Database availability for the past year has been over 99%.

- For the 12 month period of June 2012 through May 2013, PACRAIN users retrieved nearly 34.6 million records. Approximately 25% of users made more than one query.

- A new PACRAIN data server has been acquired that will greatly increase database performance.

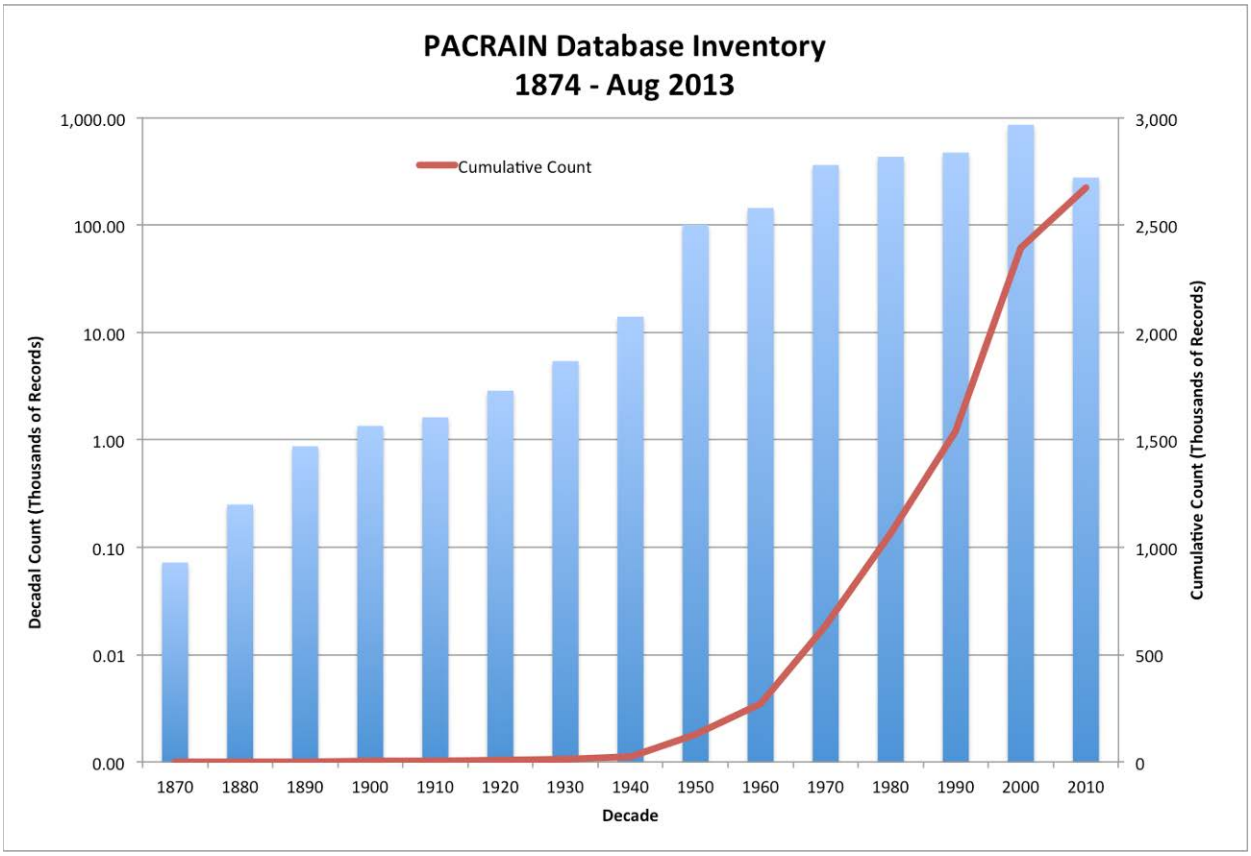


Figure 3 Availability of records by decade.

3. Outreach and Education

For the past 25 years the Schools of the Pacific Rainfall Climate Experiment (SPaRCE) project at the University of Oklahoma has been working directly with elementary and high school teachers around the Pacific. During this time, we have also worked informally with the Pacific island meteorological services to aid them with their own local educational outreach projects. However, given the age of the SPaRCE materials there is a need to upgrade them to include more relevant information, e.g. the PI-GCOS program, Global Warming, cyclones, cyclone preparation brochure, etc.

As the meteorological services in the Pacific islands continue to expand and enhance their technological capabilities, there is an increased awareness and appreciation by meteorological service personnel for the need of an educated public. For example, more cooperative climate observer networks are being proposed and implemented in these countries, modeled after the U.S. Cooperative Observers Network (e.g. in Vanuatu, Samoa, and Tonga). There are many challenges in implementing a sustainable cooperative observer program in the developing tropical Pacific island nations, one of which is the availability of easily understood educational materials that can be used by meteorological service personnel in recruiting and training potential observers. In addition, disasters such as the December 2004 and 2011 Japan tsunamis have emphasized the need for a basic understanding of any potentially dangerous phenomenon, such as hurricanes, by the general public. The SPaRCE program is uniquely situated to be able

to both continue collaborating directly with schools, and to aid the meteorological personnel in the islands to develop easily understood educational materials that can be used in a variety of circumstances. Additional funding for the SPaRCE program will be used to provide Pacific island meteorological services with low-cost rain gauges for their cooperative observer networks, and to hire a student to work with meteorological service personnel to develop and deliver educational materials aimed at both potential cooperative observers as well as the general public.

3.1. 2013 Progress Related to the SPARCE Program

- Met 2012 objectives. Presenting 25 schools actively participating. SPaRCE data are available via a dedicated online interface at <http://sparce.evac.ou.edu/>
- Participants can enter data online at the SPaRCE website, although no participants are currently using this feature.
- A quarterly SPaRCE newsletter is published and distributed to participants and other interested parties.
- Twelve new or reinstated sites in past 12 months.
- Updated application and supporting documents
- Mailed out recruitment packets to over 200 schools.
- Contacted each PIMS to enroll more schools.
- Created 2013 SPaRCE calendar for participants.
- Created SPaRCE Facebook group to encourage participant networking.
- Updated the SPaRCE brochure.
- Working on sending out a large mailing to schools we have had in the past and new schools (about 150 total + addresses from meteorological services), to join SPaRCE.
- Workbook updates.

4. Publications and Reports

4.1. Recent Publications by Principal Investigators

Morrissey, M. L., H. Diamond, M. J. McPhaden, H. P. Frietag and J. S. Greene, 2012: *An Investigation of the Consistency of TAO Buoy-mounted Capacitance Rain Gauges along the Equatorial Tropical Pacific*, J. Atm. Ocean. Tech., 29, 834-845.

Klatt, M. D., M. L. Morrissey. J. S. Greene, 2012: *Trends in Tropical Pacific Rainfall Extremes.* Presented at the 28th Conference on Interactive Information Processing Systems, New Orleans, January 23-26, 2012.

Klatt, M. D., M. L. Morrissey. J. S. Greene, 2014: *Comparison of the PACRAIN Database to the Global Historical Climatology Network Data Set,* submitted for presentation at the 94th AMS Annual Meeting, Atlanta, 2–6 February 2014.

Klatt, M. D., M. L. Morrissey. J. S. Greene, 2013: *Future Trends in Tropical Pacific Rainfall Extremes,* Presented at the 25th Conference on Climate Variability and Change, Austin, 6-10 January 2013.

4.2. Past Relevant Publications (Sample)

Morrissey M.L., 2009: Superposition of the Neyman-Scott Rectangular Pulses Model and the Poisson White Noise Model for the Representation of Tropical Rain Rates. *Journal of Hydrometeorology*, 10, 395-412.

Morrissey, M. L. and J. S. Greene 2007: "Ground Validation for the Global Precipitation Climatology Project" in "*Measuring Precipitation from Space - EURAINSAT and the future*" Levizzani, Vincenzo; Bauer, Peter; Turk, F. Joseph (editors), 2007, Approx. 745 p., Hardcover ISBN: 978-1-4020-5834-9.. p. 381-392.

Greene, JS, M Klatt M Morrissey, and S Postawko, 2008: "The Comprehensive Pacific Rainfall Database: An enhanced tool for research and education. *Journal of Atmospheric and Oceanic Technology*, **75,** 71-81.

Greene, J.S., B. Paris, and M. Morrissey, 2007: Analysis of Historical Changes in Extreme Precipitation Events in the Tropical Pacific. *Climate Research*, **34,** 1-14.

Morrissey, M.L., W.F. Krajewski and M.J. McPhaden, 1994: Estimating rainfall in the tropics using the fractional time raining, *Journal of Applied Meteorology*, 33, No. 3, 387-393.

Morrissey, M. L. and N. E. Graham, 1996: Recent trends in rain gauge precipitation measurements from the tropical Pacific: Evidence for an enhanced hydrologic cycle. *Bull. Amer. Meteor. Soc.*, **77**, 1207-1219.

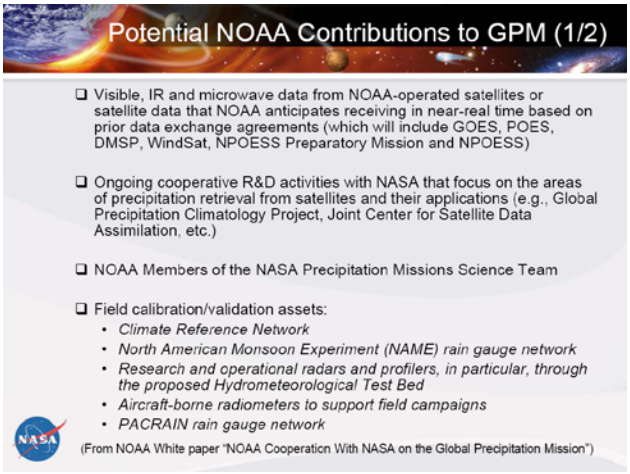
Morrissey, M. L. and J. E. Janowiak, 1996: Sampling-induced conditional biases in satellite climate-scale rainfall estimates. *J. Appl. Meteor.*, **35**, 541-548

4.3. Other Relevant Publications

4.3.1. Institutional Usage and Citations

The PACRAIN database is hosted on NASA Goddard's Global Change Master Directory (http://gcmd.nasa.gov/records/GCMD_ATOLL_RAIN_PACIFIC.html) and linked from a number of project web sites such as PI-GCOS: http://www.pi-gcos.org/data_access.htm, UCAR's CISL Research Data Archive (http://rda.ucar.edu/datasets/ds484.0/), the U.S. Global Change Research Information Office (http://www.gcrio.org/datainfo/index.html). The PACRAIN dataset also makes up part (303 stations) of the Global Historical Climate Network (GHCN) (http://www.ncdc.noaa.gov/oa/climate/ghcn-monthly/index.php) developed and maintained by NOAA's National Climatic Data Center (NCDC). The dataset forms an integral part of many international project such as the Global Precipitation Climatology Project (GPCP). There are also many international organizations which link to our server (SOPAC, http://www.pacificwaterefficiency.com/links.html,.

The PACRAIN dataset will also form a critical component of NASA Global Precipitation Measurement Program (GPM) (see below). One of the most important operational use of the PACRAIN dataset is its inclusion in the CMAP satellite/raingauge merged global precipitation estimates, managed by Pingping Xie from NOAA's Climate Prediction Center (see below).



The CPC Merged Analysis of Precipitation ("CMAP") is a technique which produces pentad and monthly analyses of global precipitation in which observations from raingauges are merged with precipitation estimates from several satellite-based algorithms (infrared and microwave). The analyses are on a 2.5 x 2.5 degree latitude/longitude grid and extend back to 1979. These data are comparable (but should not be confused with) similarly combined analyses by the Global Precipitation Climatology Project which are described in Huffman et al (1997).

It is important to note that the input data sources to make these analyses are not constant throughout the period of record. For example, SSM/I (passive microwave - scattering and

emission) data became available in July of 1987; prior to that the only microwave-derived estimates available are from the MSU algorithm (Spencer 1993) which is emission-based; thus, precipitation estimates are available only over oceanic areas. Furthermore, high temporal resolution IR data from geostationary satellites (every three hours) became available during 1986; prior to that, estimates from the OPI technique (Xie and Arkin 1997) are used based on OLR from polar orbiting satellites.

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL ENVIRONMENTAL SATELLITE DATA
AND INFORMATION SERVICE
NATIONAL CLIMATIC DATA CENTER
151 PATTON AVE ROOM 120
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February 4, 2008

Prof. Mark Morrissey
Department of Meteorology
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Norman, OK 73019

Dear Prof. Morrissey,

As you know, we were delighted to be able to incorporate your Pacific Island rainfall data set, PACRAIN, into the Global Historical Climatology Network (GHCN) version 2 precipitation data set. Scientists all over the world have been downloading GHCN precipitation data free of charge from http://www.ncdc.noaa.gov/oa/climate/ghcn-monthly/ and using the data for a wide variety of analyses.

I just discussed the plans for GHCN version 3 precipitation data set and confirmed that PACRAIN is an integral part of global precipitation data as it provides important observations across a wide expanse of the globe where other sources of in situ precipitation measurements are sparse. In addition to being used in the monthly version of GHCN, PACRAIN has been incorporated into GHCN daily which has been used to provide valuable information on changes in extremes. Both GHCN data sets, which means both daily and monthly versions of your PACRAIN data, were used in analyses presented in the Nobel Prize winning Intergovernmental Panel on Climate Change's Fourth Assessment Report.

Thank you for your valuable contribution to these endeavors.

Regards,

Thomas C. Peterson

4.3.2. Research Usage

The following list is an abbreviated list of sampled refereed journal articles citing use of the PACRAIN database:

Chen, Yingjun; Ebert, Elizabeth E.; Walsh, Kevin J. E.; et al , 2013; Evaluation of TRMM 3B42 precipitation estimates of tropical cyclone rainfall using PACRAIN data,*: J. Geophys. Res.-Atm*, Vol. 118, 2184-2196 DOI: 10.1002/jgrd.

Pfeifroth, Uwe; Mueller, Richard; Ahrens, Bodo , 2013; Evaluation of Satellite-Based and Reanalysis Precipitation Data in the Tropical Pacific, *J. Appl. Meteor. and Climatology*, Vol. 52, 634-644, DOI: 10.1175/JAMC-D-12-049.1

Diamond, H. J., Lorrey, A. M., Knapp, K. R. and Levinson, D. H. 2011: Development of an enhanced tropical cyclone tracks database for the southwest Pacific from 1840 to 2010. *Inter. J. Climat*., DOI: 10.1002/joc.2412

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Xie, P. P., A. Yatagi, M. Y. Chen, et al., 2007: A gauge-based analysis of daily precipitation over East Asia. *J. Hydromet*., 8, 607-626.

Huffman, G.J., R.F. Adler, D.T. Bolvin, G. Gu, E.J. Nelkin, K.P. Bowman, Y. Hong, E.F. Stocker, D.B. Wolff, 2007: The TRMM Multi-satellite Precipitation Analysis: Quasi-Global, Multi-Year, Combined-Sensor Precipitation Estimates at Fine Scale. *J. Hydrometeor*., 8(1), 38-55.

Islam, M. N. and H. Uyeda, 2007: Use of TRMM in determining the climatic characteristics of rainfall over Bangladesh. *Remote Sens. Environ*., 108, 264-276.

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Xie, P. P., J. E. Janowiak, P. A. Arkin, et al., 2003: GPCP Pentad precipitation analyses: An experimental dataset based on gauge observations and satellite estimates. *J. Climate*, 16, 2197-2214.

Kummerow, C., Y. Hong, W. S. Olson, et al., 2001: The evolution of the Goddard profiling algorithm (GPROF) for rainfall estimation from passive microwave sensors. *J. Appl. Meteor*., 40, 1801-1820.

Adler, R. F., C. Kidd, G. Petty, et al., 2001: Intercomparison of global precipitation products: The third Precipitation Intercomparison Project (PIP-3). *Bull. Am. Meteor. Soc*., 82, 1377-1396.

Kummerow, C., J. Simpson, O. Thiele, et al., 2000: The status of the Tropical Rainfall Measuring Mission (TRMM) after two years in orbit. *J. Appl. Meteor*., 39, 1965-1982.

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