The forecast, warning, and response experience of PEAC can help small island countries in the Pacific develop adaptation strategies for longer time-scale climate variability and change.

The U.S.-Affiliated Pacific Islands (USAPI) is composed of the Territory of Guam (Guam), Commonwealth of the Northern Mariana Islands (CNMI; Saipan), Republic of Palau, Marshall Islands (RMI; Majuro, Kwajalein), Federated States of Micronesia (FSM; the States of Chuuk, Kosrae, Pohnpei, and Yap), and American Samoa (Pago Pago; see Fig. 1). The small size of the islands, their remoteness, and their limited financial and natural resources render them, their populations, and their ecosystems highly vulnerable to climate variability and change (Shea et al. 2001). Many of the islands are low-lying atolls (Fig. 2), which are periodically affected by coastal inundation. Even the high islands are not immune, because most of the transportation and commerce are located near the coastline. Most of the USAPI (throughout, USAPI and the USAPI region are synonymously used) are located near the center of activity of the major variations in atmospheric and oceanic circulation associated with El Niño–Southern Oscillation (ENSO; see, e.g., Bjerknes 1966, 1969; Ropelewski and Halpert 1987; Barnston and He 1996; Chu and Chen 2005; McPhaden et al. 2006). These variations, which can greatly impact the USAPI, appear in sea level patterns (Chowdhury et al. 2007a), seasonal rainfall distribution (Yu et al. 1997), and tropical cyclone activity (Lander 1994). For example, the 1997/98 ENSO warm event resulted in water rationing in RMI and the Federated States of Micronesia, crop losses in the Federated States of Micronesia, grass fires in Guam.
and the Federated States of Micronesia, death of livestock on Tinian (CNMI), and increases in unemployment in many locales (Hamnett et al. 1999). Despite these impacts, the people and local governments were able to make early preparations to better endure the event with minimal suffering. This was in part due to the accurate predictions of the Pacific ENSO Applications Center (PEAC) (Hamnett et al. 1999; also see Lynch and Brunner 2010). During the 2007/08 long-lasting La Niña, several episodes of unusually large surf coupled with anomalously high sea levels inundated land and damaged roads and infrastructure on the northern and eastern shores of many islands. The high surf also impacted aquaculture, and altered surface and groundwater quality (Chowdhury et al. 2010). While PEAC scientists flagged the potential for coastal inundation, they did not initially anticipate such a large impact from this event.

In the early 1990s, governments in the USAPI expressed concerns about their vulnerability to climate variability and their need for customized climate services. In response, in 1994 the PEAC was established within the Joint Institute for Marine and Atmospheric Research (JIMAR) at the University of Hawaii at Manoa. The center’s name was changed to Pacific ENSO Applications Climate Center (PEAC) in 2007. Collaborating partners were the National Oceanic and Atmospheric Administration (NOAA)/Office of Global Programs, the National Weather Service (NWS) Pacific Region, the University of Guam (UoG), the Pacific Basin Development Council (a consortium of USAPI governments plus the state of Hawaii), and the East-West Center. In the early 2000s, NOAA’s involvement largely shifted to the Weather Forecast Offices (WFOs) at Honolulu, Hawaii, and Guam. There is now very close coordination and collaboration between those NWS offices and PEAC. The current mission of PEAC is multifaceted and can be summarized as follows: i) to provide tailored, understandable technical information and products for support of planning and management in climate-sensitive sectors, such as water resources, fisheries and aquaculture, agriculture, emergency management, utilities, and coastal zones; ii) to identify impacts from and provide advisories for current and expected 1-yr seasonal changes in rainfall, sea level, and tropical cyclone activity through publication of the quarterly Pacific ENSO Update newsletter (hereafter “newsletter”); and iii) to provide periodic educational and event warning outreach to the USAPI.

By 1994, scientific advances in seasonal-to-interannual climate prediction led to the ability to generate skillful ENSO forecasts with lead times of up to 1 yr (McPhaden et al. 2006). In addition, substantial progress had been made in understanding regional behaviors and impacts of the ENSO cycle, which is the

**Fig. 2. Typical Pacific Island coastal area, Chuuk, FSM, illustrating a coastal inundation event. [Photo courtesy of Joe Konno, Chuuk.]**
dominant source of climate variability for the region (also see McPhaden et al. 2006, and references therein). Because of this, PEAC’s initial focus was to i) improve the historical rainfall datasets for the main islands and develop datasets for the “outer” islands in the tropical Pacific basin; ii) develop the rainfall and tropical cyclone relationships with ENSO; iii) expand access to and interpretation of ENSO forecast products developed by the NWS, the International Research Institute for Climate and Society (IRI), and other forecasting and research institutions in the region; iv) increase public awareness of the ENSO cycle, its societal impacts, and the potential societal benefits of forecasts; and v) identify specific applications needs. The first two objectives led to development of A Precipitation Climatology for Stations in the Tropical Pacific Basin atlas (He et al. 1998), which was important to the development of improved predictions at the PEAC and the Climate Prediction Center (CPC). The latter two focus elements entailed outreach to the USAPI entities. One of the keys to the success of the PEAC was that it met “eyeball to eyeball” with the stakeholders, listened to their needs, attempted to incorporate most of those needs into the products, and provided a sense of partnership. From the beginning, personnel support to the PEAC has also been provided via the NOAA Commissioned-Officer Corps. The NOAA corps officer conducts the monthly conference call, edits and disseminates the quarterly newsletter, and is one of the leaders in the regional climate information system.

The work of PEAC consists of coordinated research and applications activities. The spatial resolution of climate models is too coarse to render them directly applicable to local island environments (Hamnett et al. 1999). As such, the large-scale models used widely by climate researchers and modelers do not meet the critical needs of the people with whom PEAC works. PEAC scientists directed their research effort to the study of local island climates during each stage of ENSO, and to the development of statistical models to tailor long-range forecasts for specific islands. With a richer knowledge of local environments, the outputs of large-scale models were used to help develop canonical correlation analysis (CCA) statistical models for rainfall and sea level forecasts on seasonal time scales for each of the main islands and a few of the outer islands with unique climate responses. In large part, PEAC plays the role of both provider and user of its own unique products and expertise. These tailored island-specific forecasts have allowed the USAPI governments to respond to seasonal climate variability, either avoiding or minimizing potentially disastrous impacts.

As a facilitator of cooperation among various stakeholders, PEAC has strengthened the ties among the scientists, forecasters, and users in a participatory process of design, delivery, and evaluation. The major objective of this paper is to synthesize the current operational procedures of PEAC and illustrate how these procedures contribute to the development of plans and actions that help mitigate the effects of short-to-medium time-scale climate variability. This paper also suggests that the PEAC experience can positively contribute to the development of capabilities for addressing longer time-scale climate variability and change for the small island countries in the Pacific.

**PEAC’S METHODOLOGY FOR REDUCING VULNERABILITY TO CLIMATE HAZARDS.**

The current operational “Climate forecasting, warning, and response” activities of PEAC are organized broadly into the following five categories: i) forecast preparation, ii) forecast interpretation, iii) forecast dissemination, iv) response and feedback, and v) review and analysis [e.g., Parker (2003, and references therein) for a review of forecasting, warning, and response systems].

*Forecast preparation: On the basis of previous and current meteorological, oceanic, and hydrological conditions, this stage predicts the occurrence and magnitude of hazards.* The value of seasonal forecasts depends on their accuracy and on the taking of appropriate actions by all participants [e.g., Stern and Easterling (1999) for a review of consensus forecasts]. PEAC forecasts (sea level, rainfall, tropical cyclone activity, ENSO status, etc.) are produced with contributions from the regional NWS WFO (e.g., Guam), local Weather Service Offices (WSOs; e.g., Majuro, Pohnpei, Yap, Chuuk, Koror, and Pago Pago), and climate representatives from the main island communities. Proposed PEAC forecasts are presented for prereview via e-mail, and are set up for formal discussion within a PEAC-sponsored monthly teleconference. The WSO representatives are invited to participate in this conference. Representatives from the prediction centers [i.e., the IRI, CPC, WFO Honolulu, WFO Guam, and National Climatic Data Center (NCDC)] are also invited. During this hour-long teleconference, issues related to past, present, and future ENSO conditions are discussed. Within a teleconference format, technical and nontechnical discussions are held on regional and local climate dynamics, forecast methodologies, and numerical model seasonal predictions. Near the end of the
meeting, a final consensus forecast is achieved from a blend of forecast model output (see "rainfall forecasts" section for the list of models) and some fine-tuning from the recommendations of the teleconference participants. For each zone, rainfall forecasts for the upcoming season are expressed as tercile probabilities of occurrence, while the CCA statistical sea level forecasts are expressed in a deterministic format. The other types of forecasts (i.e., the anticipated status and evolution of ENSO) that the PEAC produces are based on interpretation of the existing dynamical/statistical model outputs, and discussion with international climate communities via the teleconference and via e-mail. The following sections discuss the types of forecasts prepared at PEAC and the methodology for producing them.

**Rainfall Forecasts.** At present, a probabilistic outlook on seasonal rainfall is prepared subjectively by PEAC forecasters on the basis of experience, visual interpretation of current and forecast conditions, and knowledge of the area. Every month, the PEAC produces a 3-month outlook on a monthly basis for 14 stations within the USAPI and Hawaii. Outputs from six dynamical and one statistical model are consulted for these interpretations. The dynamical models are the Met Office (UKMO) seasonal forecasts, National Aeronautics and Space Administration’s (NASA’s) Seasonal-to-Interannual Prediction Project (NSIPP), the European Centre for Medium-Range Weather Forecasts (ECMWF), IRI Climate Prediction (IRICP), National Centers for Environmental Prediction (NCEP) coupled, and the Pacific Region Integrated Data Enterprise (PRIDE). The lone statistical model is NCEP constructed analog (CA). While it can be difficult to quantify and determine the exact seasonal changes in rainfall accurately with these subjective assessments, these 3-month rainfall forecasts have proven to be very useful in identifying expected trends in seasonal rainfall for the USAPI region. Since 2006, these forecasts have been evaluated monthly using the Heidke skill score (Barnston 1992), which has shown a continued increase in forecast skill (Fig. 3, positive numbers show skillful forecasts). Finally, a composite of subjective and objective assessments is assembled to present the seasonal rainfall outlook in tercile format, expressing probabilities of below-normal, near-normal, and above-normal rainfall occurrence with respect to the long-term mean.

The local variability summaries found in PEAC’s quarterly newsletter contain long lead-time forecasts for rainfall, an outlook for tropical cyclone activity, and, when significant, an outlook for sea level out to 1 yr. The forecasts for the first 3-month block of the year-long outlooks found in the newsletter mirror the 3-month forecasts determined for each locality in the most recent PEAC teleconference. Routine model guidance is usually not available for lead times of 1 yr for most climate variables, so the forecast status of ENSO for the upcoming year plays a dominant role in developing the specific 1-yr lead-time subjective forecasts for rainfall distribution. These 1-yr lead-time forecasts are based on the anticipated status and evolution of ENSO. In order for the PEAC forecasts to be useful for planning in the USAPI, it is necessary that the forecast distributions go beyond 3 months. The performance of the PEAC during 1997 is one of the reasons that it became (and remains) a trusted source of climate information in the USAPI region. The forecasts are based on well-known relationships between the state of ENSO and climate variables in the USAPI; when one is confident of the status of ENSO (e.g., it is the fall of a strong El Niño year), it is then possible to skillfully outline the evolution of climate variables for up to 1 yr.

The Pacific rainfall atlas is particularly helpful in assessing rainfall trends given the status of ENSO and the time of the year. It is worth noting that a statistical approach known as the CA (van den Dool and Barnston 1995) is one of the most skillful aids for the 3-month local island rainfall forecasts.

**Tropical Cyclone Forecasts.** The relationships between tropical cyclone (TC) activity in the USAPI and ENSO are strong in the western North Pacific (Lander 1994). The largest effects are a) a shift to the west in TC activity during La Niña years and in the year following an El Niño event (regardless of whether or not the follow-on year evolves to be ENSO neutral or La Niña), and b) a shift to the east in TC activity during an El Niño year. The TC forecasts for the Pacific are based on forecasts made from four independent groups—i) the Laboratory for Atmospheric Research (LAR) at City University of Hong Kong (western North Pacific activity; see http://weather.cityu.edu.hk/tc_forecast/2011_forecast_APR.htm), ii) CPC (central and eastern North Pacific activity; see www.cpc.ncep.noaa.gov/products/Epac_hurr/Epac_hurricane.html), iii) the Benfield Hazard Research Centre, University College London (Atlantic, Australian region, and western North Pacific activity; see http://weather.cityu.edu.hk/tc_forecast/2011_forecast_APR.htm), and iv) and an evolving experimental statistical forecast of western North Pacific activity produced at the Guam WFO. On the basis of these four TC activity outlooks,
PEAC scientists at the University of Guam and the WFO Guam make their own interpretations of yearly typhoon behavior in the western Pacific (www.prh.noaa.gov/peac/peu/2011_4th/tc_summary.php), while PEAC scientists in Hawaii generate hurricane outlooks for their region. PEAC TC activity forecasts are primarily based on the status and forecast evolution of ENSO, and the available guidance from the aforementioned sources, which generate TC activity forecasts at least 6 months in advance of the time period of interest and provide updates at selected times in the progress of the year.

**ENSO FORECASTS.** PEAC scientists study most available dynamic and statistical ENSO forecast models and develop probable impact scenarios for the USAPI region. While most of the major climate models are consulted, the ENSO diagnostic discussions provided by CPC and IRI largely shape the contents of the ENSO outlook for the quarterly newsletter and the 1-page monthly “Pacific ENSO discussion” produced by the WFO Guam. PEAC makes every effort to have ENSO forecasts and outreach material that is consistent with CPC and IRI guidance. This is partly guaranteed by coordination made during the monthly conference calls, and by continual behind-the-scenes discussion. To avoid confusion, PEAC is extremely careful to synchronize its discussion of the status of ENSO and the forecast evolution of ENSO with the latest thinking of the CPC and the IRI. In this respect, the actual determination of the status of ENSO and the forecast evolution of ENSO is one of the least time-consuming activities of the PEAC (although there is always ongoing background discussion and feedback among PEAC scientists and the major ENSO players).

While the general rule is that the weaker the event, the weaker the impacts, there are exceptions to that rule. For example, moderate El Niño events are worse than strong events for TC threats to American Samoa. The PEAC is constantly assessing the uncertainty of the predictions and conveys that uncertainty to the customers. By keeping close contact with the WFO Guam and with the customers that may be impacted by an event, PEAC can make timely recommendations as to when the customer needs to respond. This way, unnecessary funds are rarely expended. For strong events, the impacts are more certain. Threats associated with La Niña events are generally not as severe as those associated with El Niño events. Because the PEAC newsletter is published every quarter, forecasts that begin to degrade are improved during the next set of predictions. Occasionally, conditions can change rapidly, and an amended ENSO update is published. However, the monthly ENSO conference call and the WFO Guam Drought Information Statements allow the PEAC to flag trends and deviations rather early, making customers aware of potential changes and impacts.

**SEA LEVEL FORECAST.** PEAC, at present, develops a prediction of seasonal mean sea level in the USAPI using the teleconnections with tropical SSTs. Based on an operational CCA statistical model, this scheme can predict sea level in real time, quantifying the skill at lead times of several months or longer (Chowdhury et al. 2007b). The ENSO climate cycle and the sea surface temperatures (SSTs) in the tropical Pacific Ocean are taken as the primary factors in modulating sea level variability on seasonal time scales or longer. The CCA model provides useful skill (Fig. 4) in predicting sea level in the Pacific Islands. Based on this operational forecasting technique by the CCA model, PEAC has been publishing the real-time forecast of sea level deviations for nine USAPI stations at its official website (available at www.prh.noaa.gov/peac/sea-level.php). This information has also been distributed through the printed version of the newsletter.

Based on the generalized extreme value (GEV) model, PEAC provides information on the extremes of sea level on seasonal and annual time scales (Chowdhury et al. 2009). The demand for this product is increasing due to the occurrence of dangerously
high (low) water levels and the associated erosion and inundation (coral exposure and bleaching) problems in the USAPI region. Therefore, information related to various temporal fluctuations in water level is necessary to plan and implement strategies to protect coastal infrastructure, aquifers, and agriculture (e.g., taro patches) on short-to-longer-term time scales. These seasonal extremes are also distributed through the web and hardcopy newsletter. Added to this, NOAA’s website for tides and currents (available at http://tidesandcurrents.noaa.gov/station_retrieve.shtml?type=Tide+Predictions) are used to generate high and low water-level plots for 3-month periods. Based on the availability of data, currently predicted water-level plots are prepared for three to five USAPI stations. This information is distributed through the web version of the newsletter.

Finally, based on information from CCA forecasts, GEV results, and predicted tides, a scenario on seasonal sea level outlook is generated. This outlook has significantly enhanced the capabilities of the USAPI governments to make preparation for the impacts of sea level fluctuations on short-to-medium time scales. Then, the WFO of Guam combines this information with astronomical new and full moon phase predictions, satellite data, and WAVEWATCH III (Tolman 2009) ocean swell predictions to issue high-surf advisories and coastal inundation “warnings” for the USAPI.

When all the forecasts are done, the PEAC always tries to identify if there is any gap between what the users want (i.e., more accurate, more downscaled information) and what science can provide (i.e., often neither accurate nor finescaled enough information) and attempts to bridge this gap. For example, it can be stated here that initially the PEAC newsletter provided only qualitative sea level forecasts. The U.S. Navy indicated that it needed quantitative predictions to support its water management models for the reservoir on Guam. Thus, PEAC began providing quantitative forecasts for Guam. As PEAC began to look at the developing 1997 El Niño in 1996, it became apparent that all locations would need quantitative predictions. Rainfall climatology, especially in relation to ENSO, was not available. This shortfall was identified, and the NOAA/CPC partnered with PEAC to develop the NCEP/CPC rainfall climatology. That atlas provided statistical relationships of rainfall at selected Pacific Islands under El Niño, La Niña, and average conditions. This enabled PEAC to predict the timing and duration of the events. PEAC selected the 1982/83 El Niño event as a likely analog to the 1997/98 event. PEAC then used an outstanding unpublished study of Micronesian rainfall characteristics based on provisional U.S. Geological Survey (USGS) data acquired during the 1982/83 El Niño drought to estimate the amplitude and the likely associated impacts. Afterward, PEAC scientists derived rainfall climatologies for the outer islands that only had short rainfall records. PEAC scientists used tropical cyclone information from the Joint Typhoon Warning Center (JTWC) to assess the relationships between tropical cyclones and the ENSO state. Predictions were refined with the development of formalized Pacific tropical cyclone prediction programs based largely on the state of ENSO.

Finally, background historical information has a considerable role to play in forecast preparation and applied research at PEAC, and the historical information databases are continuously being updated. Statistical studies on regional climatology and the ENSO cycle are conducted at the University of Hawaii, the Water and Environmental Research Institute (WERI) at the UoG, and at the WFOs at Honolulu and Guam. These background information sources identify ENSO-related impact criteria for the
islands, through examination of historical floods and droughts, their causes, and their impacts on agriculture, water resources, and other sectors in each regional area. Therefore, information related to the patterns of severe weather phenomena, such as hurricane and typhoon frequency in each regional area, is generated here. Also, based on the ENSO climate cycle, diagnostic discussions on the characteristics of sea level variability, both from the current situation and from a historical perspective, are regularly prepared.

**Interpretation and stakeholders.** This stage identifies the onset, duration, and probable impacts of hazards on vulnerable communities. A broad-based development approach that incorporates input from the users, a clear understanding of the needs and abilities of the targeted at-risk audience, and, as observed in a PEAC review survey, a respect for the local culture and indigenous practices, has led to a high level of credibility and high confidence in the system. The stakeholders of PEAC products include local WSO officials, local administrative offices (e.g., agricultural, fisheries, emergency management, utilities, etc.), nongovernment organizations (NGOs; e.g., Red Cross), and international organizations [the Secretariat of the Pacific Environmental Program (SPREP), International Organization for Migration (IOM), etc.]. They require information on sea level (height, time, and duration of anticipated extremes), rainfall (specific locations/areas, onset times, magnitude, and duration of drought conditions or potential for flash floods and mudslides), and TC activity (seasonal anomalies, track distribution, and risk). The PEAC prepares impact scenarios about the probable effects of anticipated hazards. Experience from similar past events helps guide the development of the contents of these impact scenarios. For example, it can be restated here that during the El Niño of 1997/98, which resulted in severe water rationing in Majuro (Fig. 5), in Yap State, Chuuk State, and Pohnpei State in the Federated States of Micronesia; in Palau; in CNMI; and eventually in American Samoa, PEAC proactively worked to help people by providing preemptive information about the impact of El Niño. In the USAPI, drought can be a life or death event. Therefore, as early as April 1997, the PEAC had predicted very dry conditions in Micronesia for early 1998. As early as July 1997, the PEAC predicted that a near-record drought comparable to the 1982/83 El Niño–associated drought would affect Micronesia. The information was reflected in the respective quarterly newsletters. In August, it became evident that the islands were not responding to the predictions, so the PEAC scheduled outreach visits to each of the main Micronesian islands. A UoG hydrologist and/or meteorologist visited Palau, Yap, Chuuk, Pohnpei, Kosrae, and Majuro to make presentations about the upcoming drought and its likely impacts. Before the scientists left each major island, the respective president or governor formed a drought-response committee and allocated funds to combat the drought. The PEAC scientist(s) helped the committees formulate a drought-response plan. The need to actually visit the islands and converse with the island leadership in order to elicit a desired response was coined eyeball-to-eyeball interaction. The islands were given 6–8 months of lead time concerning the severe drought, but only responded after the eyeball-to-eyeball outreach resulted in a clear understanding of the potential consequences of not responding. This occurred 2–4 months before the onset of the severe drought conditions, depending on the location. PEAC outreach trips were delayed a few weeks because the timing coincided with the new fiscal year budgetary process. Because of the large magnitude of the drought, the Federated States of Micronesia and

**Fig. 5.** People line up for water in the Marshall Islands in early 1998 to receive a ration once every 14 days. [Photo courtesy of Federal Emergency Management Agency.]
RMI rapidly exhausted their internally allocated funds and had to depend on outside assistance. The eyeball-to-eyeball outreach process allowed the island leadership to measure PEAC’s credibility, determine its intentions, and ascertain its sincerity.

The PEAC was convinced that the evolving drought would result in death and suffering unless fresh water could be delivered before April. The PEAC contacted the Federal Emergency Management Agency (FEMA), which was able to assist the Federated States of Micronesia and the Marshall Islands in developing and submitting presidential declaration requests. They were elevated to U.S. President Clinton, who rapidly approved them. Thus, FEMA addressed a new hazard, drought, and introduced a new paradigm of response in acting to avert a disaster instead of responding to one after it had already occurred. Similarly in 2007/08, when high sea levels inundated land and damaged roads and infrastructure throughout the atolls of Chuuk State (Fig. 6), PEAC provided early warnings to people on the probable impact of La Niña and its accompanying elevated sea level. In addition to 1997/98 and 2007/08, there were many other ENSO-related extreme events for which PEAC advised people well ahead of time (e.g., 3–8 months) about the potential impacts of those extreme ENSO events. Such advance information helped people develop a real-time response plan. For example, restricting water distribution in Majuro to 7 h every 15 days was an effective response to address the ENSO-related water crisis in 1997/98 until desalination units could be provided several months into the record drought. Similarly, the use of boulders and sandbags to protect the land from saltwater intrusion and massive erosion in 2010/11 was an effective mitigation plan for many of the small atolls and islands of the Federated States of Micronesia (Fig. 7) and atolls of the RMI.

Process of dissemination. This stage communicates and distributes the climate information and warning messages to disaster management agencies and vulnerable communities. In this stage, two different lines of dissemination take place. The first is communication from the PEAC to the local authorities and WSO officials via the same monthly PEAC teleconference and printed newsletter. Subsequently, the WSOs disseminate climate information to their respective vulnerable communities. The information is translated into the local language and disseminated by e-mail and Federated States of Micronesia radio on the main islands and by AM and HF radio to the remote outer islands.

Since January 2005, PEAC has been conducting the monthly teleconference with representatives from WERI, CPC, IRI, WFO Honolulu, WFO Guam, WSO Pago Pago, WSO Yap, WSO Koror, WSO Chuuk, WSO Pohnpei, and WSO Majuro. This hour-long teleconference begins with a recap of the previous month’s climate (rainfall, sea level, etc.). The current ENSO situation is also evaluated here, and a 3-month sea level outlook for selected Pacific islands is given. Finally, a 3-month rainfall outlook for each island group is derived using several rainfall forecast model predictions in combination with the participant’s knowledge of the local climate. The monthly PEAC teleconference has improved the understanding and awareness of seasonal climate variability in the USAPI, and has empowered the regional WSOs to become knowledgeable climate information providers within their respective jurisdictions.

The decisions reached during the PEAC teleconferences form the starting point for the information presented in the quarterly newsletter, which is intended to supply information for the benefit of
those involved in climate-sensitive sectors in the USAPI. The newsletter summarizes current climate conditions (e.g., the status of ENSO, the observed patterns of SST, recent TC activity, observed sea level change, and the adequacy of recent rainfall). There are sections in the newsletter for each major island jurisdiction wherein the current climate situation is discussed and tailored regional and individual island forecasts are presented. Pertinent official advisory or warning messages (e.g., the CPC’s El Niño Alert or WFO Guam Drought Information Statement) are also referenced in the bulletin. The number of subscribers for this hardcopy newsletter now stands at about 500. Depending on the severity of a forecast hazard and the accuracy of the current newsletter, a special issue of the newsletter is occasionally issued, as was done for the strong El Niño event of 1997/98. During 2004/05, the number of e-mail subscribers increased considerably and now number over 200. In response to this increasing demand and customer feedback, a new online newsletter was created for low-bandwidth customers. A web version of the newsletter is now available (www.prh.noaa.gov/peac/update.php).

The second stage of dissemination is from the local authorities and WSO officials to the vulnerable communities. The local authority disseminates area-specific warnings and important climate information to the villagers via radio, posters, handouts, training sessions, and individual contacts. Also, in the case of events where serious impacts are expected, personnel from the PEAC and WFO Guam conduct site visits and organize agency meetings throughout the region. These site visits provide the opportunity to educate users on the ENSO cycle, on the expected hazards and impacts, and on application of the climate forecasts. During the 1997/98 El Niño event, it was that eyeball-to-eyeball outreach that provided the impetus for the jurisdictions to mobilize. After the tailored PEAC presentations, legislature ap

The PEAC website (www.prh.noaa.gov/peac) is an important part of the information dissemination process. Rainfall and sea level outlooks are updated monthly and are presented in a clear and concise format. Stakeholders and users are kept up to date in a “what’s new?” section, and links to relevant articles pertaining to the ENSO cycle and the various USAPI are updated frequently. Additionally, PEAC has integrated Google Maps GIS technology to provide users with a dynamic geographic view of local island information and outlooks. Other PEAC projects or case studies not directly related to seasonal forecast products are also documented on the site.

Response and feedback. This stage addresses concerns aired by agencies and threatened communities for information about the hazards and response to warnings. Once warning messages and other important climate information are disseminated to the people, feedback from them is essential to evaluate the accuracy and usefulness of the forecasts, and to confirm that the warnings were received, understood, and disseminated to local users. Such information is essential to improve the quality of forecasts and to confirm the acceptability and utility of the warning messages. A feedback system is well established in PEAC. At first, the accuracy and promptness of forecasts are evaluated at the local level by the respective WSOs. The local office in collaboration with other agencies also examines the public awareness and response to warning messages. The local office communicates its findings on weakness of forecasts, warning, and response opportunities to the PEAC for improvement. The PEAC teleconference now serves as the primary venue for receiving user feedback through the participating WSO representatives. Shorter-term inquiries or requests are usually satisfied by the responsible NWS WFO. Also, the site visits and agency meetings throughout the region enrich the feedback programs. For example, PEAC, in collaboration with WFO Guam and WERI, conducts workshops, focus group meetings, and local briefings about ENSO in all of the client jurisdictions. This has proved to be an effective way to provide end-to-end climate education and forecasts. At these on-site

Fig. 7. Mitigation-adaptation at the Blue Lagoon Resort, Weno, FSM, Chuuk prior to the La Niña of 2010/11. [Photo courtesy of C. Guard, WFO, Guam.]
Review and analysis. This stage is where PEAC scientists monitor the performance of the various components of its activities and evaluate them for possible improvement. Extensive validation of PEAC products and activities needs to be conducted periodically and the process also needs to be debated within the context of user feedback. A 10-yr review workshop convened in Honolulu on 1–3 June 2004. Detailed results of the workshop are available online (www.pacificrisa.org/pubs/PEACReviewFinal.pdf; see also Shea 2005, 2006). Workshop participants included scientists from the East-West Center, the University of Hawaii, the University of Guam, the University of Colorado, Harvard University, the New Zealand National Institute of Water and Atmospheric Research (NIWA), and the IRI. Representatives of the U.S. NWS, the Australia Bureau of Meteorology, and a number of Pacific Island national meteorological services, emergency management offices, and utility agencies, fisheries, coastal resource offices, and other climate-sensitive sectors were also present at the workshop.

As part of the review process, individuals and representatives of institutions currently receiving PEAC forecast products and users of the PEAC website were formally requested to complete surveys either in writing or online. In addition, interviews were conducted to provide an overall evaluation of PEAC performance from the current partners at the University of Hawaii, the University of Guam, the Pacific Basin Development Council, and NOAA, including the National Weather Service Pacific Region, NCEP/CPC, and the NOAA’s Office of Global Programs. In addition to their perspectives on current and future applications, these individuals were asked to evaluate PEAC’s performance in terms of products, programs, plans, and documentation.

Although the number of completed surveys was not sufficient to be statistically significant, the results of surveys and interviews with the users of PEAC services were analyzed and summarized during a presentation at the Honolulu workshop. Of the total number of users, 31% were representatives of a government agency, 26% were from the private sector, 16% were from NGOs, 11% were from universities, 11% were from Pacific regional organizations, and 5% identified themselves as being an employee of a national weather service in the region (Shea 2006). The survey questionnaire was designed to elicit input on both PEAC products and the process PEAC used to engage users and identify and respond to their information needs. Using a scale of 1–5 where 5 represented the highest score, PEAC products received high marks for clarity/readability (4.3), relevance (4.2), scientific and technical credibility (4.1), content (3.8), and accessibility (3.8). With an average score of 3.4, survey respondents indicated that the timing of PEAC products and services could be improved. In terms of the process that PEAC used to develop and provide its services, the survey respondents gave high marks to PEAC in terms of responsiveness to questions and queries (3.8), engaging participation of users (3.7), providing opportunities for evaluation of products (3.6), and providing opportunities to identify additional needs (3.6). With scores of 3.5 and 3.3, survey respondents suggested that there was room for improvement in terms of understanding and responding to local concerns and developing new products, respectively.

When asked to identify additional climate products that would be useful, survey respondents identified the following: sea level forecasts (now a part of PEAC forecasts), hydrological forecast and information (which were provided, but perhaps not recognized), wind predictions (general predictions are given), winter swell predictions (general predictions are given), an update to the Pacific rainfall atlas (currently in progress), longer lead forecasts (currently in progress), information on long-term climate variability (currently in progress), information on the skill of current seasonal forecasts (i.e., validation, which is regularly done now), summary articles describing the current models used to produce seasonal forecasts (regularly added to the PEAC newsletter), and information on innovative ways in which other people are applying seasonal-to-interannual forecasts (currently in progress).

As a follow-up to the PEAC review workshop, a PEAC scientist and the PEAC outreach officer traveled to several locations in the USAPI region during 7–18 August 2007 to meet with personnel at the local WSOs, local participants of the earlier Honolulu PEAC review workshop, and other officials involved in climate-sensitive sectors. The primary objective of this visit was to discuss with the user community on how to best enhance the collective efforts of scientific and outreach activities in PEAC at each of these locations. A similar field visit was also conducted in 2011.
SUMMARY AND DISCUSSIONS. The overall activities of PEAC and specific avenues for improvements are as follows.

- **Hydrological background information:** The statistical studies on regional climatology and the ENSO cycle are important components for forecast preparation, especially for the main islands. More comprehensive databases and more reliable statistical information are needed for the outer islands. It would be very helpful if more historical background information, such as historical floods and droughts, their impacts, and other information concerning water resources in each regional area, were added to the PEAC database. This would help to better address ENSO-related impacts on the individual islands.

- **Rainfall forecast:** At present, a probabilistic outlook on seasonal rainfall is prepared subjectively by PEAC forecasters on the basis of visual interpretation and experience and knowledge of the area. PEAC is working with other agencies to create a consolidated ensemble forecast.

- **TC forecast:** The forecasts of TC activity in the western North Pacific from any source have yet to stray more than one standard deviation from normal (i.e., approximately plus/minus four named storms). PEAC therefore only ventures to make a prediction of more than four named TC’s fewer than normal for a year that follows a strong El Niño. For the foreseeable future, PEAC will continue to monitor the progress of seasonal tropical cyclone forecasting within its area of responsibility, and make bolder predictions of enhanced TC activity (or inactivity) commensurate with validated skill of the aids. A forecaster at WFO Guam is currently working on a technique that will provide predictions specifically for regions of Micronesia.

- **ENSO forecasts:** Based on globally available ENSO forecast models, PEAC prepares an impact scenario for the USAPI region. While studies of ENSO-related impacts, such as historical flooding and drought, are numerous, studies concerned with ENSO-related sectorwise socioeconomic impacts are not regularly conducted in PEAC. There is a need for examination of the way in which people occupying areas exposed to hazards perceive and respond to each hazard, and the manner in which they deal with losses caused by hazards. This societal concern can be a taken as a new and essential research component in the future.

- **Sea level forecast:** PEAC currently publishes the CCA and GEV model results for nine tide gauge stations. Work is ongoing to generate these results for additional tide stations. It is also necessary to expand the use of probabilistic forecasts for sea level variability in the region, but with considerable training on its interpretation and application. While the CCA and GEV model results are useful in their current form, attention should be given to linkages to area-specific impacts, such as patterns of historical coastal flooding. As mentioned, the large-scale climate models and modelers most often do not provide more accurate and downscaled information. This creates a gap between “what the users of PEAC’s products want” and “what science can provide for them.” In order to bridge this gap, PEAC scientists directed their research effort to development of statistical models (e.g., CCA) for seasonal forecasts by utilizing the outputs of large-scale models and local tide gauge data.

- **Dissemination:** The strength of ENSO events may vary from strong to weak and the impacts may vary from sector to sector. For example, an early onset of El Niño may severely affect the agriculture sector but may not affect tourism. Therefore, sector-specific warning messages and tailored climate information are needed. An historical analysis of sector-specific impacts from various manifestations of ENSO is needed to develop useful impact scenarios for them.

- **Review:** The last PEAC review workshop was a good opportunity for providers and users of the climate forecasting products of PEAC to explore how effectively these products served the information needs of intended user communities. It also revealed how effectively PEAC’s structure and activities contribute to a comprehensive information delivery system for the region and what could be done to strengthen that system. The workshop was very helpful in identifying information gaps between PEAC products and user needs. One of the major recommendations of the review workshop was to improve the timing of PEAC products and services. Over the years, PEAC has successfully maintained a relatively consistent schedule of dissemination of these products and has considerably improved the quality of forecasts for rainfall and tropical cyclone activity, and the interpretation of ENSO and its impacts. There was a need for sea level forecasts on month-to-seasonal time scales. That product has been provided in the form of mean sea levels, extreme sea levels, and tidal fluctuations for the various locations. There
were also requests for longer lead forecasts on climate variability and change, which are currently under consideration at PEAC. The general wind outlooks (easterly with La Niña and westerly with El Niño) and 1-yr hydrological forecasts are also provided.

During the last decade, enhanced trade winds and high sea levels were dominant throughout much of the USAPI region. Extended drought conditions were particularly noticeable in the Republic of the Marshall Islands. Because of this peculiar decadal shift of climate, the demand for more accurate and area-specific information has increased. Similarly, the demand for PEAC products has considerably increased. Therefore, another review workshop is suggested to revisit the user demands and to improve the products and services of PEAC.

CONCLUSIONS. As PEAC evolved through the 1990s and 2000s, increasing levels of concern developed over matters associated with observed and projected global warming and its implications for local climates. PEAC received a growing number of inquiries about the impacts of global warming, especially as a cause of sea level rise. Currently, we are continually approached with requests to expand our efforts to predict climate variability on longer time scales as well as to ascertain the local climate changes anticipated in a warmer world. We therefore have gradually added climate change to our suite of services. We are now working on this broad issue by using global climate models (GCMs). As a first step, we have made progress to statistically downscale the results of the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4)-coupled GCMs to project the sea level rise in the USAPI region. However, we will continue to provide seasonal forecasts and maintain our practice of applied research and outreach, which has served our clients well.

Despite the limited resources of PEAC, this organization has been identified as a model of success for reducing the vulnerability to climate hazards for small island countries (e.g., Hamnett et al. 1999; Lynch and Brunner 2010). This U.S.-based PEAC program is also an example of increasing diversity and empowering underrepresented groups in atmospheric sciences. Over the last two decades this model has considerably increased human, technical, and physical capacity through the knowledge base developed by PEAC’s research, information dissemination, outreach activities, and hands-on experiences. While the PEAC experience and model is limited to the USAPI region now, it can easily be applied to other regions vulnerable to climate hazards.

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REFERENCES


This volume is a collection of 13 review papers by a distinguished group of scientists, providing a summary of the current scientific understanding of convective storms and the weather they produce, as well as showing how that understanding works in forecasting practice. The volume is loaded with outstanding illustrations, and is destined to become one of the most widely referred-to books on convection and convective processes.