11D.6 PERFORMANCE OF MOS STATISTICAL WEATHER FORECAST GUIDANCE OVER THE TROPICAL WESTERN PACIFIC WARM POOL

James C. Su *
Meteorological Development Laboratory
Office of Science and Technology
National Weather Service, NOAA
Silver Spring, MD

1. INTRODUCTION

Since the early 1970's, the model output statistics (MOS) weather forecast guidance system has been a popular aid to forecasters. The MOS system was initiated (Glahn and Lowry 1972) and has been improved continuously by the Meteorological Development Laboratory (MDL), of NOAA's National Weather Service. The guidance provides an objective interpretation of the underlying numerical weather prediction (NWP) model. The traditional MOS guidance tunes the forecasts to the observations at specific stations. The MOS system discussed in this paper is called traditional because a new MOS system is being developed within MDL for gridpoints and is called gridded MOS (Glahn et al. 2008), which is not in the scope of this paper.

The MOS system provides estimates for many of the weather elements that the forecasters must include in their products, such as probability of precipitation (PoP), wind speed and direction, temperature and dewpoint, and more. The guidance products have been developed based on NWP models of the National Centers for Environmental Prediction (NCEP) and are provided for the contiguous United States (CONUS), Alaska, Hawaii, and Puerto Rico.

Since 2005, new MOS forecast guidance products for the tropical western Pacific island sites have been added to the existing MOS system. These products are based on the model output of the global forecast system (GFS, Alpert et al. 1991) and are provided for the islands in the area from 15° S to 30° N and from 130° E to 170° W (Su, 2005; 2007). Most of the subject area overlaps with the tropical western Pacific warm pool, which has its sea surface temperature (SST) higher than 28°C (Weier and Simmon 2001; Webster and Lukas 1992). The warm pool has significant impact on the atmosphere above and the climate in the world, through the interaction between the atmosphere and the ocean. In this paper, the performance of the MOS guidance over the warm pool area will be evaluated and possible improvement for the future MOS development will be addressed.

2. METEOROLOGICAL BACKGROUND

The warm pool lies in the tropical area from the eastern Indian Ocean to the western Pacific Ocean, with its core in the latter area. It is also located under the ascending branch of the Walker circulation (Bjerknes 1969). The atmosphere over the tropical western Pacific warm pool area is characterized by many scales and forms of convection, large amount of annual precipitation, and strong atmospheric heating. The warm pool has a high variability over a wide range of timescales: from minutes to years (Johnson et al. 2001). It interacts with the atmosphere above in a complex manner through heating, moistening, precipitation, and evaporation (Lin and Johnson 1992; Johnson and Lin 1997). It is perceived as a "center of action" for the El Nino Southern Oscillation (ENSO) phenomena in the atmosphere and the ocean. Except for typhoons, the short range weather forecast is not a high-impact subject in the area. Instead, numerous studies have been conducted on the warm pool related subjects in the perspective of climate.

Over the warm pool, there is a remarkable feature of the atmospheric circulation called Madden-Julian Oscillation (MJO), which was first documented by Madden and Julian (1971, 1972, 1994). An MJO event features a large scale, eastward moving center of strong deep convection and precipitation (Zhang 2005). On both the east and west sides of the MJO, there are weak regions of deep convection and precipitation. The

* *Corresponding author address:* James C. Su, Meteorological Development Laboratory, National Weather Service, NOAA, 1325 East-West Highway, Silver Spring, MD 20910-3283; e-mail: James.Su@noaa.gov.

MJO is normally confined to the area over the warm pool because the convective instability can be sustained only over the warm sea surface. It has a local period of 30-90 days. The MJO is an isolated or discrete pulse-like event rather than a wave. The MJO signal propagates eastward at an average speed of 5 m/s across the equatorial Indian and western/central Pacific oceans. A distinct feature of the MJO is the episodic strong westerly surface winds lasting up to 30 days. Around the MJO, at the 850-mb level and near the surface, strong westerly winds exist to the west of the center of convection, and easterly winds on the east side. The zonal winds reverse direction in the upper troposphere at the 200-mb level; this is referred to as the coupling of the MJO dynamics. The interval between two consecutive MJO events is irregular and their propagation speeds may vary. The MJO has been one of the main research themes in the study of tropical weather and climate.

3. MODEL OUTPUT STATISTICS SYSTEM

3.1 *General Description of MOS System*

The MOS system consists of regression equations that express the statistical relationships between predictands and predictors. Predictors include the output variables from the underlying NWP model which the regression equations are based upon. The sinusoidal functions of the day of the year are also used to account for the annual and semi-annual variations of predictands. Observed variables are also used as predictors sometimes. In addition, there are computed predictors, such as vorticity and moisture convergence, as well as binary and grid binary predictors (Jensenius 1992) computed from original predictors.

In the station-based MOS system, the predictands are obtained for individual station locations, and the model output predictors are interpolated from the gridpoints to the stations. Predictands are the weather elements to be forecast. They have continuous values of some meteorological variables, such as, temperature and dewpoint, and probabilities of other variables, such as probability of precipitation (PoP). For some predictands, a group of regression equations are used to compute categorical forecasts, such as quantitative precipitation forecast (QPF) which provides probability forecasts of precipitation categories with amounts of greater or equal to 0.01 in., 0.1 in., 0.25 in., 0.5 in., etc.

3.2 *Sample Data for MOS Development*

To develop a MOS system based on an NWP model, output data from a stable model is important. Usually, at least two years of direct model output data are needed. For continuous meteorological variables, such as temperature and dewpoint, regression equations for single stations can be developed for individual seasons. For event variables, such as precipitation, the sample is usually small. For example, the average relative frequency of precipitation in the CONUS is about 20%. In order to increase the event sample size, stations with similar characteristics in a geographical region are combined to form a group, for which one regression equation is developed. In general, the developmental sample data are usually stratified into seasons and geographical regions.

3.3 *Development of MOS Equations*

For the development of MOS equations, potential predictors are provided based on the availability of variables from the underlying NWP model output. Considerations of dynamics and physics in the atmosphere are also taken into account when potential predictors are chosen. The predictors to be included in MOS equations are chosen by a screening method called forward selection procedure in the regression analysis (Glahn et al. 1991).

3.4 *Operational MOS Products*

Before implementation in the operations suite, all the MOS equations developed are evaluated and verified on test data. Skill scores are compared with those of existing forecast guidance products (if any), or the forecasts directly from the underlying NWP model if nothing else is available for comparison. Before the forecast guidance is disseminated, some post-processing procedures are also applied to some elements to ensure the consistency of the forecasts.

The operational MOS products are disseminated in the form of alphanumeric messages, and in the BUFR (World Meteorological Organization 2002) messages. Most of the MOS forecast guidance is available for four cycles (0000, 0600, 1200, and 1800 UTC). The MOS guidance for the island sites in the tropical western Pacific Ocean is currently available for 0000 UTC and 1200 UTC cycles only.

4. ANALYSIS APPROACH

The purpose of this analysis is to study the skill of MOS forecasts at various locations over the tropical western Pacific warm pool (Figure 1), and to explore whether the MOS system could recognize the coupling between the lower and upper troposphere, observed during the episode of deep convection within the MJO over the warm pool.

Locations of the 15 island sites (Figure 2) for which NWS provides MOS forecast guidance, are listed in Table 1, along with their International Civil Aviation Organization (ICAO) Codes and elevations. Referring to the geographic location of the warm pool, five island sites are selected for this study. They are (a) Andersen AFB, Guam (PGUA), (b) Pohnpei WSO, Micronesia (PTTP), (c) Koror WSO, Palau (PTKR), (d) Midway Islands NAS (PMDY), and (e) Pago Pago, American Samoa (NSTU).

The locations of the aforementioned stations relative to the tropical western Pacific warm pool can be seen by comparing Figures 1 and 2. Andersen AFB is located outside but near the border of the warm pool. Pohnpei WSO is located around the border, Koror WSO is outside but close to the border, and Midway Islands NAS is outside and far away from the border of the warm pool. Pago Pago, American Samoa is located in the interior of the warm pool in the Southern Hemisphere.

In order to understand the possibility of coupling between the lower and upper troposphere reflected in the MOS system, the inclusion of predictors at the 200-mb and 850-mb levels in the temperature and dewpoint forecast equations are investigated. As a benchmark, we use the climate data of the subject stations as a basic reference for the discussion of analysis results found in Section 7.

5. CHARACTERISTICS OF MOS FORECAST EQUATIONS

For the western Pacific island sites, MOS forecast equations were developed for two seasons, two cycles (0000 UTC and 1200 UTC), and for projections up to 84 hours. The temperature and dewpoint forecast equations were developed for projections of every 3 hours up to 84 hours. For each projection, the temperature and dewpoint forecast equations could include predictors from three time points: 3 hours before the projection, on the projection, and 3 hours after the projection. Only GFS model output predictors are used in the discussion in this section; no observed predictors are included.

The selection of predictors on the 200-mb and 850-mb levels for each projection are shown in Tables 2 and 3, respectively for two extreme cases, Midway Islands and Pago Pago, American Samoa. The purpose is to examine the contributions of predictors from the upper and lower troposphere, whence to explore the possibility of the coupling between the two parts of the troposphere in the MOS system. In those tables, the cell format shows the selection of predictors at the 3 hours around the projection. For example, at the projection of 36 hours, the symbol "X _ _", "_ X _", and "_ _ X" mean that predictors at 33 hour, 36 hour, and 39 hour, respectively, were selected for the equation. The predictors on those two levels that were selected include: temperature, dewpoint, zonal wind component (u-wind), meridional wind component (v-wind), wind speed, vertical velocity, and grid binary of vertical velocity with a break point of zero.

For Midway Islands NAS, the selections of predictors from the 200-mb and 850-mb levels are shown in Tables 2(a) and 3(a). No predictors are selected from the 200-mb level up to 63 hour projection. From the 850-mb level, the selected predictors are dominated by meridional wind component (v-wind) and temperature. However, no temperature is selected beyond 39 hour projection.

Pago Pago, American Samoa is the only station in the Southern Hemisphere for which the NWS provides MOS forecast guidance. The selection of predictors from the 200-mb and 850-mb levels are shown in Tables 2(b) and 3(b), respectively. The selection of predictors from the 200-mb level at this station is significant. They are dominated by the zonal wind component (u-wind), followed by vertical velocity. This implies the impact of zonal wind and deep convection on the MOS surface temperature and dewpoint forecasts. The selection of 850-mb predictors is dominated by dewpoint, followed by temperature and wind components. The selection of zonal wind component and vertical velocity at the 200-mb level, along with dewpoint and zonal wind component at the 850-mb level, implies that the MOS system is capable of simulating the coupling between the upper and lower troposphere, the deep convection with supply of moisture in the lower troposphere, and their impact on the temperature and dewpoint forecasts near the surface at this station.

Although not shown in this paper, at Andersen AFB, more temperature and dewpoint than other predictors at the 200-mb level are selected. At the 850-mb level, the selection of predictors are scattered among projections and predictors although v-wind and wind speed are selected a little more often but not significantly. This implies that the thermodynamic factors in the upper troposphere play a significant role on the temperature and dewpoint changes near the ground, while both thermodynamic and dynamic factors at the 850-mb level play equally important roles.

Few predictors are selected from the 200-mb level at Pohnpei WSO. From the 850-mb level, predictors selected are mainly wind speed, zonal wind component (u-wind), and grid binary of vertical velocity, especially wind speed. For the MOS temperature and dewpoint forecasts at this station, the 200-mb level has little contribution. The wind speed at the 850-mb level has dominant impact on the temperature and dewpoint forecasts.

At Koror WSO, few predictors are selected from the 200-mb level. From the 850-mb level, the selection is dominated by dewpoint, along with wind speed and grid binary of vertical velocity although the latter is selected for projections beyond 51 hours. Similar to Pohnpei WSO, the 200-mb level has little contribution to the MOS temperature and dewpoint forecasts.

Note that the MOS forecast equations used in this discussion are for the period from November to April, which corresponds to the boreal cool season and austral warm season. The results of Pago Pago show that the MOS system can reflect the coupling between the upper and lower troposphere and deep convection in the warm season.

Based on the discussion above, it is likely that the MOS system is capable of simulating the coupling between the upper and lower troposphere, as well as deep convection over the warm pool. The MOS system is based on the underlying NWP model and the conclusion of this discussion implies that it carries the capability of the GFS model towards its forecast guidance. This capability is valid for the warm season over the warm pool.

For the cool season, the MOS system does not show coupling between the upper and lower troposphere, and deep convection near the warm pool. Far away from the warm pool (Midway Island NAS), especially for the cool season, the upper troposphere does not show impact on the MOS surface temperature and dewpoint forecasts.

6. CHARACTERISTICS OF THE CLIMATE IN THE AREA

In the evaluation of the skill of MOS forecast guidance, the climate is often used as a benchmark for verification, such as, improvement of probability of precipitation (PoP) over climate in terms of Brier score (Brier 1950). The climate data of precipitation amount and temperature for the subject stations are presented as follows.

The monthly normals computed from the observed data for the period from 1971 to 2000, for precipitation amount (in inches) and temperature (in degrees F) are shown in Figures 3 and 4, respectively. Among the five stations chosen for study in this paper, those located around or in the interior of the warm pool have more precipitation than Midway Island NAS, which is far away from the warm pool. At Andersen AFB, the range of annual variation is approximately from 4 to 14 inches, with distinctive dry and wet seasons around March and August, respectively. Pohnpei WSO is the wettest among the five stations used. Its annual variation has a range approximately from 10 to 19 inches, with a brief dry season around February. Koror WSO is also a wet station but a little dryer than Pohnpei WSO, with a range of annual variation approximately from 9 to 17 inches, and a distinctive peak around June and July. Midway Islands NAS is the driest among the five stations. It has its precipitation amount normals ranging from 1.5 to 4 inches with the driest month in June. Pago Pago has the range of precipitation amount approximately from 6 to 14 inches, with the driest and wettest months in July and January, respectively.

The temperature normals show little annual variations over the warm pool and nearby area, with the ranges within 3°F. The stations located in this area include Andersen AFB, Pohnpei WSO, Koror WSO, and Pago Pago. At Midway Islands NAS, the temperature normals show a significantly larger annual variation, with a range of more than 14°F. For stations with small ranges, the annual variations are still visible in the graphs. The ranges for the stations closer to the Equator (Pohnpei WSO and Koror WSO) have smaller ranges compared to those located further away from the Equator (Andersen, Pago Pago, and

Midway Islands). Midway Islands NAS is the furthest from the Equator and has the largest range in the annual variation. In particular, Pohnpei has larger temperature difference between minimum and maximum during the "warm" season.

7. EVALUATION OF THE MOS GUIDANCE

The forecasts of PoP, temperature, and dewpoint are tested on independent data, which are not used in the development of the MOS forecast equations. Some test results of 12-hour PoP, temperature, and dewpoint are discussed in the following sub-sections.

7.1 *Probability of Precipitation*

The improvement of 12-hour PoP over climate in terms of Brier score for two seasons: (1) from November to April and (2) from May to October, and for projections from 18 hours to 84 hours is shown in Figure 5 for regions around the five stations chosen for this paper. The positive improvement means that the forecasts have skill. The PoP forecast equations were generally developed for geographical regions rather than single stations. The precipitation data of stations were combined for several geographical regions to increase the number of precipitation events in the sample datasets for MOS PoP forecast equation development. Midway Islands NAS and Pago Pago are far from other stations, and single station equations were developed for them. In general, the improvement shows a downward trend towards longer projections, which means a decrease in forecast skill for longer projections.

The forecast skill is better for season 1 than season 2, for all projections in the Pohnpei and Midway Islands areas. The comparison of skill between two seasons is not straightforward for Andersen, Koror, and Pago Pago areas.

For the Andersen area, the improvement ranges from -2% to 10%, with negative improvement at three projections for season 2. For the Pohnpei area, the range of improvement is between -1% and 16%, with negative improvement only at two long projections. For the Koror area, the improvement ranges from 2.5% to 22%, with positive skill for all projections. For Midway Islands, the improvement ranges between -3% and 22%, with only one negative improvement for season 2 at 60 hour projection. For Pago Pago, the range of improvement is between -6% and 25%, with negative improvement at three longer projections.

In general, the improvement curves are smoother for regional PoP forecasts than for single station PoP forecasts. The differences in skill between two seasons are larger for single station forecasts than regional forecasts. In addition, the skill differences between regions or individual stations are not related to their locations relative to the warm pool.

7.2 *Bias of Temperature and Dewpoint*

The biases of the MOS temperature and dewpoint forecasts are shown in Figure 6. In general, the biases fluctuate randomly. The dewpoint biases are close to the temperature biases for the stations that are closer to the Equator, and are warmer than the temperature biases for the stations further away from the Equator.

At Andersen, both temperature and dewpoint forecasts have warm biases. The temperature bias fluctuates between 0.3 and 0.7°F, and dewpoint bias between 0.6 and 1.6°F. At Pohnpei, the temperature bias fluctuates between -0.6 and 0.2°F while the dewpoint bias fluctuates between -0.4 and 0.2°F. For most projections, both temperature and dewpoint forecasts have cold biases. At Koror, the temperature bias ranges from -0.5 to 0.45°F and dewpoint bias ranges from -0.1 to 0.25°F. For most projections, the temperature forecasts have cold biases and dewpoint forecasts have warm biases. At Midway Islands NAS, the temperature forecasts have biases ranging approximately from -0.75 to -0.1°F, with cold biases for all projections. The dewpoint forecasts have biases ranging approximately from -0.05 to 0.4°F, with warm biases for almost all projections. At Pago Pago, the temperature bias fluctuates about the zero line, with a range from -0.3 to 0.4°F. The dewpoint bias fluctuates between 0.5 and 1.6°F.

Overall, Andersen, Midway Islands, and Pago Pago have dewpoint biases larger than that of temperature forecasts, while Pohnpei and Koror have biases of temperature and dewpoint forecasts close to each other. In particular, Midway Islands NAS has colder temperature bias than all other stations.

7.3 *Mean Absolute Error of Temperature and Dewpoint*

The mean absolute errors (MAE) of temperature and dewpoint forecasts versus projection are shown in Figure 7. The MAE of temperature forecasts for all five stations show prominent peaks with 24 hours between two adjacent ones, while the MAE of dewpoint forecasts do not.

At Andersen, the temperature MAE fluctuates ranging approximately from 0.8 to 1.3°F, without a trend toward longer projections. The dewpoint MAE ranges between 1.2 and 2°F, with an upward trend toward longer projections and dips in the curve at the peaks of temperature MAE. At Pohnpei, the temperature MAE ranges between 1.2 and 2.3°F and the dewpoint MAE ranges between 0.9 and 1.4°F. At Koror, the temperature MAE fluctuates between 1.0 and 2.2°F, while the range of the dewpoint MAE is between 0.9 and 1.4°F. At Midway Islands NAS, the temperature MAE ranges between about 1.0 and 2.2°F and dewpoint MAE ranges approximately between 1.3 and 2.5°F. Both MAE curves have upward trends towards the longer projections. At Pago Pago, the temperature MAE fluctuates between 1.2 and 2.3°F, with a small upward trend towards longer projections. The dewpoint MAE fluctuates between 1.2 to 2°F without a trend.

Overall, the dewpoint MAE is larger than the temperature MAE for Andersen AFB and Midway Islands NAS, while the reverse is true for Pohnpei, Koror, and Pago Pago. There are upward trends towards longer projections for the temperature MAE curves, for Midway Islands NAS and Pago Pago, as well as for the dewpoint MAE curve for Midway Islands NAS.

8. CONCLUDING REMARKS

Five island sites were used for the study of MOS system performance over the tropical western Pacific warm pool. Among the five stations, three are near the boundary of the warm pool in the Northern Hemisphere (Andersen AFB, Pohnpei WSO, and Koror WSO), one is located far from the warm pool in the Northern Hemisphere (Midway Islands NAS), and one is located in the interior of the warm pool in the Southern Hemisphere.

The analysis of MOS temperature and dewpoint forecast equations shows that the MOS system is capable of reflecting the coupling between the upper and lower troposphere, as well as the impact of deep convection over the interior of the warm pool during the austral warm season (Pago Pago, American Samoa). It also shows little or no impact from the upper troposphere on the MOS surface temperature and dewpoint forecasts in the Northern Hemisphere during the boreal cool season. Further studies are needed to determine whether the findings are valid for the other austral and boreal seasons.

Some characteristics of the climate for locations relative to the warm pool are identified in this study. They are used as benchmarks for the evaluation of MOS forecast guidance.

The evaluation of the 12-hour MOS PoP forecasts for the subject stations shows that the skill decreases towards longer projections. However, most of them have positive improvements over climate. The differences in skill for various stations are not related to their locations relative to the warm pool.

For all five stations, the biases of temperature and dewpoint forecasts do not show any trend towards longer projections, which means that the biases generally remain the same for all projections up to 84 hours. The cold bias of temperature forecast seems larger for locations far away than over the warm pool area in the Northern Hemisphere during the boreal cool season. The warm bias of dewpoint forecast seems about 1°F higher than the temperature bias in the interior of the warm pool in the Southern Hemisphere during the austral warm season.

The MAE of temperature forecasts shows prominent peaks with 24-hr intervals at two stations near the boundary of the warm pool, while that of dewpoint forecasts is less pronounced. For a station far away from the warm pool in the Northern Hemisphere, the MAE curves of both temperature and dewpoint have an upward trend towards longer projections during the boreal cool season. The upward trend also appears on the curve of temperature MAE for a station in the interior of the warm pool in the Southern Hemisphere during the austral warm season, but not on the dewpoint MAE curve.

Some findings about the MOS system performance over the tropical western Pacific warm pool have been obtained from the preliminary study in this paper. They can provide useful information for the improvement of MOS guidance development in the areas of input predictors selection and developmental data stratification, i.e., seasons and geographical regions. This may also benefit the future development of gridded MOS for the Guam area.

9. REFERENCES

Alpert, J. C., K. A. Campana, P. M. Caplan, D. G. Deaven, M. Iredell, B. Katz, H.-L. Pan, J. Sela, and G. H. White, 1991: Recent changes implemented into the global forecast system at NMC. *Wea. Forecasting*, **6,** 425-435.

Bjerknes, J., 1969: Atmospheric teleconnections from the equatorial Pacific. *Mon. Wea. Rev*., **97**, 163-172.

Brier, G. W., 1950: Verification of forecasts expressed in terms of probability. *Mon. Wea. Rev.*, **75**, 1-3.

Glahn, H. R., and D. A. Lowry, 1972: The use of model output statistics (MOS) in objective weather forecasting. *J. Appl. Meteor.*, **11**, 1203-1211.

_____, A. H. Murphy, L. J. Wilson, and J. Jensenius, Jr., 1991: Programme on short- and medium-range weather prediction research. PSMP No. 34, WMO/TD No. 421, World Meteorological Organization, Geneva, XX-64 pp.

_____, K. K. Gilbert, R. Cosgrove, D. Ruth, and K. Sheets, 2008: Gridded MOS guidance in the national digital guidance database. *19th Conference on Probability and Statistics,* 11.3, New Orleans, LA, Amer. Meteor. Soc., 13 pp.

Jensenius, J. S., Jr., 1992: The use of grid-binary variables as predictors for statistical weather forecasting. *Preprints Twelfth Conference on Probability and Statistics in the Atmospheric Sciences,* Toronto, Amer. Meteor. Soc., 225-230.

Johnson, R. H., and X. Lin, 1997: Episodic trade wind regimes over the western Pacific warm pool. *J. Atmos. Sci.*, **54**, 2020-2034.

_____, P. E. Ciesielski, and J. A. Cotturone, 2001: Multiscale variability of the atmospheric mixed layer over the western Pacific warm pool. *J. Atmos. Sci.*, **58**, 2729-2750.

Lin, X., and R. H. Johnson, 1996: Heating, moistening, and rainfall over the western Pacific warm pool during TOGA COARE. *J. Atmos. Sci.*, **53**, 3367-3383.

Madden, R. A. and P. R. Julian, 1971: Detection of a 40-50 day oscillation in the zonal wind in the tropical Pacific. *J. Atmos. Sci*., **28**, 702-708.

_____, and _____, 1972: Description of global-scale circulation cells in the tropics with a 40-50 day period. *J. Atmos. Sci.*, **29**, 1109-1123.

_____, and _____, 1994: Observations of the 40-50 day tropical oscillation—a review. *Mon. Wea. Rev.*, **122**, 814-837.

Su, J. C., 2005: GFS-based MOS wind forecast guidance for islands in the tropical western Pacific Ocean. *21st Conference on Weather Analysis and Forecasting/17th Conference on Numerical Weather Prediction*, 13B.4, Washington, DC, Amer. Meteor. Soc., 5 pp.

_____, 2007: GFS-based MOS precipitation forecast guidance for islands in the tropical western Pacific Ocean. *22nd Conference on Weather Analysis and Forecasting/18th Conference on Numerical Weather Prediction,* 6A.6, Park City, UT, Amer. Meteor. Soc., 21 pp.

Webster, P. J. and R. Lukas, 1992: TOGA COARE: the coupled ocean-atmosphere response experiment. *Bull. Amer. Meteor. Soc*., **73**, 1377-1416.

Weier, J. and R. Simmon, 2001: Reverberations of the Pacific warm pool, NASA Earth Observatory, http://earthobservatory.nasa.gov/Study/WarmPool/, 11 pp.

World Meteorological Organization, 2002: Guide to WMO table driven code forms: FM 94 BUFR and FM 95 CREX, Geneva. Layer 1 and layer 2, 57 pp.; layer 3, 137 pp.

Zhang, C., 2005: Madden-Julian oscillation. *Rev. Geophys*., **43**, 36 pp.

Table 1. Island stations in the western Pacific Ocean for which GFS MOS forecast guidance is provided.

STATION	ICAO CODE	LATITUDE	LONGITUDE	ELEVATION (ft)
Northern Hemisphere and Eastern Hemisphere				
Wake Island	PWAK	19.28 °N	166.65 °E	13
Saipan, Guam	PGSN	15.12 °N	145.73 °E	213
West Tinian, Guam	PGWT	14.97 °N	145.60 °E	40
Rota, Guam	PGRO	14.18 °N	145.25 °E	607
Andersen AFB, Guam	PGUA	13.57 °N	144.92 °E	532
Agana, Guam	PGUM	13.48 °N	144.80 °E	269
Yap, Micronesia	PTYA	9.48 °N	138.08 °E	52
Bucholz AFB, Marshall Islands	PKWA	8.73 °N	167.73 °E	26
Truk, Micronesia	PTKK	7.47 °N	151.85 °E	7
Koror WSO, Palau	PTKR	7.33 °N	134.48 °E	94
Majuro Atoll, WSO, Marshall Islands	PKMR	7.08 °N	171.20 °E	13
Pohnpei WSO, Micronesia	PTTP	6.97 °N	158.22 °E	120
Kosrae, Micronesia	PTSA	5.33 °N	163.03 °E	13
Northern Hemisphere and Western Hemisphere				
Midway Islands, NAS	PMDY	28.22 °N	177.37 °W	43
Southern Hemisphere and Western Hemisphere				
Pago Pago, American Samoa	NSTU	14.33 °S	170.72 °W	30

Table 2(a). Predictors at the 200-mb level selected for the temperature and dewpoint forecast equations, season 1 (Nov. – Apr.), 0000 UTC cycle, Midway Islands NAS. Note that the cell format (e.g., x _ _, _ x _, and _ _ x, etc.) shows the selection of individual predictors at 3-hour intervals: 3 hours before, on the projection hour, and 3 hours after the projection hour, respectively.

Projection	002000008	003100008	004010008	004110008	004260008	005000008	005000508
	TEMP	DEWPOINT	U-WIND	V-WIND	WND SPD	VERTICAL Vel	GB VERT VEL
06 hr							
09 hr							
12 hr							
15 hr							
18 hr							
21 hr							
24 hr							
27 hr							
30 hr							
33 hr							
36 hr							
39 hr							
42 hr							
45 hr							
48 hr							
51 hr							
54 hr							
57 hr							
60 hr							
63 hr							
66 hr		_ _ X					
69 hr		_ X _					X _ _
72 hr							
75 hr							
78 hr							
81 hr							
84 hr		X _ _					

Table 2(b). Same as 2(a), except for Pago Pago, American Samoa.

Projection	002000008	003100008	004010008	004110008	004260008	005000008	005000508
	TEMP	DEWPOINT	U-WIND	V-WIND	WND SPD	VERTICAL Vel	GB VERT VEL
06 hr			X _ _		_ X _		
09 hr		_ _ X	_ _ X				
12 hr				X _ _			
15 hr							_ X _
18 hr				_ _ X			
21 hr							
24 hr			_ _ X				
27 hr							
30 hr			X _ _		_ X _		
33 hr			_ _ X	X _ _			
36 hr	_ _ X		_ X _			X _ _	
39 hr							
42 hr							
45 hr			X _ _				
48 hr			_ _ X				
51 hr			_ X _				
54 hr			_ X _			_ _ X	
57 hr			_ _ X			X _ _	
60 hr	_ _ X					_ _ X	
63 hr							
66 hr							
69 hr			X _ _				
72 hr	_ _ X		_ _ X				
75 hr		_ _ X	_ X _				
78 hr			X _ _				
81 hr			_ _ X			X _ _	
84 hr						X _ _	X _ _

Table 3(a). Predictors at the 850-mb level selected for the temperature and dewpoint forecast equations, season 1 (Nov. – Apr.), 0000 UTC cycle, Midway Islands, NAS. Note that the cell format (e.g., x _ _, _ x _, and _ _ x, etc.) shows the selection of individual predictors at 3-hour intervals: 3 hours before, on the projection hour, and 3 hours after the projection hour, respectively.

Projection	002000008	003100008	004010008	004110008	004260008	005000008	005000508
	TEMP	DEWPOINT	U-WIND	V-WIND	WND SPD	VERTICAL Vel	GB VERT VEL
06 hr							
09 hr	_ _ X			_ X _		X _ _	
12 hr				_ X _			
15 hr	_ X _			X _ _			
18 hr	_ _ X			X _ _			
21 hr		X _ _			X _ _		
24 hr	_ X _						
27 hr							
30 hr							
33 hr			_ X _				
36 hr			_ X _		_ X _		
39 hr	_ _ X			_ X _			
42 hr			_ X _				
45 hr							
48 hr							
51 hr				X _ _			
54 hr							
57 hr							
60 hr							
63 hr							
66 hr							
69 hr						_ _ X	
72 hr						_ _ X	
75 hr							
78 hr				X _ _			
81 hr							
84 hr							

Table 3(b). Same as 3(a), except for Pago Pago, American Samoa.

Projection	002000008	003100008	004010008	004110008	004260008	005000008	005000508
	TEMP	DEWPOINT	U-WIND	V-WIND	WND SPD	VERTICAL Vel	GB VERT VEL
06 hr				X _ _			
09 hr		X _ _					
12 hr							
15 hr							
18 hr		_ X _					
21 hr							
24 hr		X _ _					
27 hr	_ X _	X _ _			X _ _		
30 hr			_ _ X				
33 hr				_ X _			
36 hr	X _ _	_ X _					_ X _
39 hr				_ _ X			
42 hr							
45 hr		_ _ X					
48 hr			X _ _				
51 hr	_ _ X						
54 hr							
57 hr			_ X _	_ _ X			
60 hr							
63 hr						X _ X	
66 hr							
69 hr							X _ _
72 hr		_ X _					
75 hr	X _ _	X _ _	X _ _				
78 hr							
81 hr			_ X _				
84 hr		X _ _					

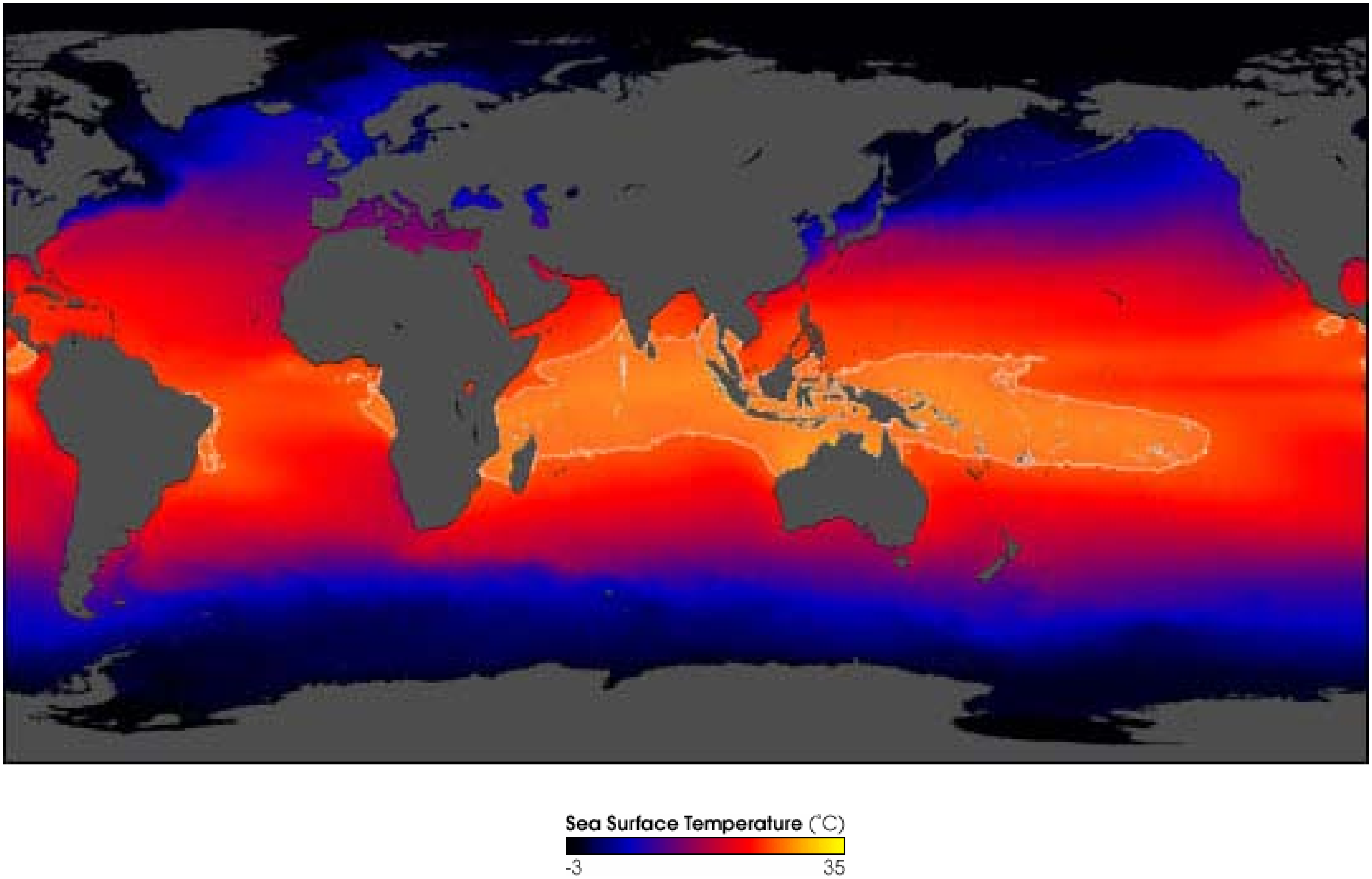

Figure 1. Distribution of sea surface temperature in the world ocean showing the location of the warm pool over Indian Ocean and the western Pacific Ocean (source: Weier and Simmon 2001)

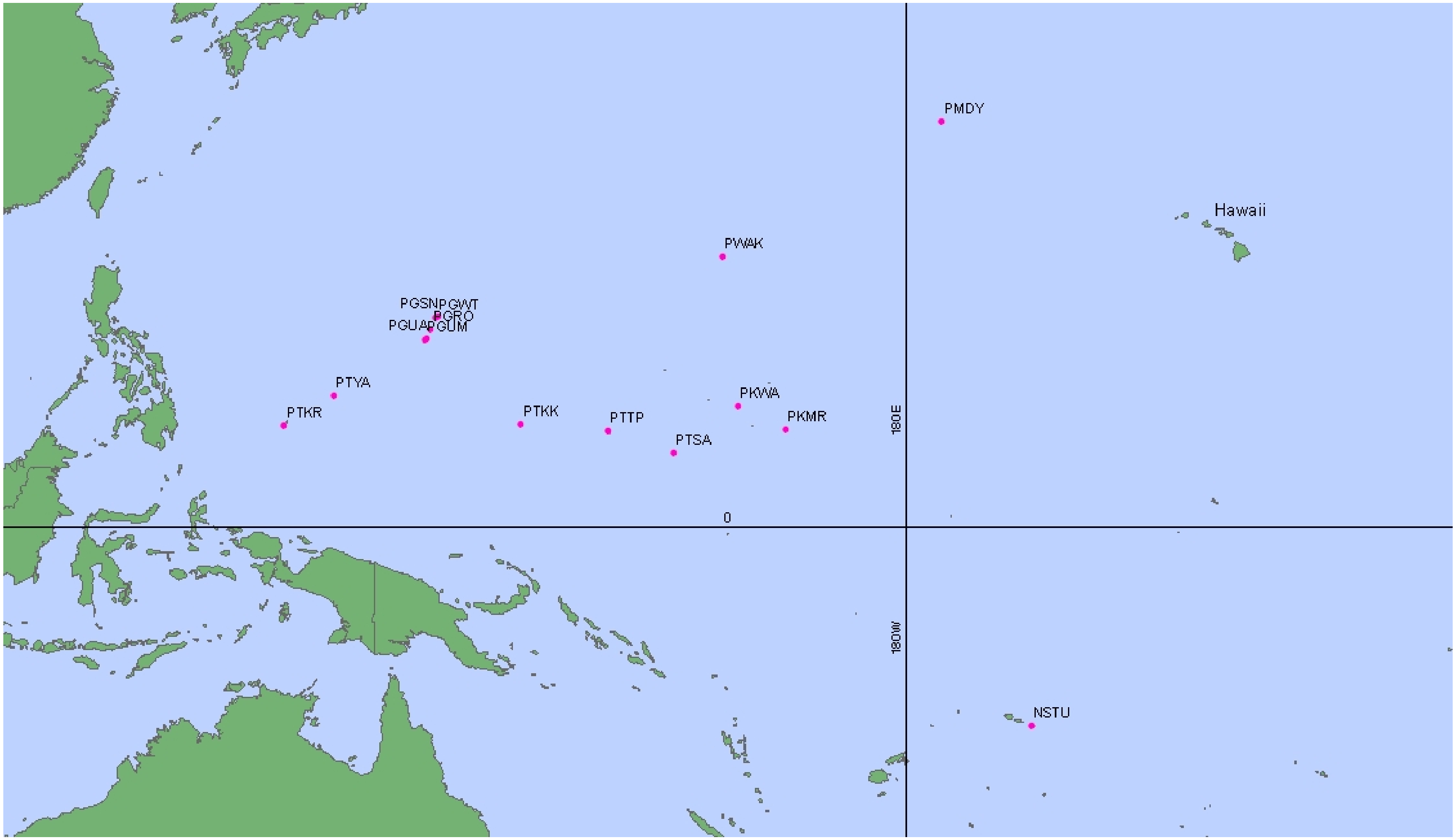

Figure 2. The locations of island stations in the western Pacific Ocean for which GFS MOS forecast guidance is provided.

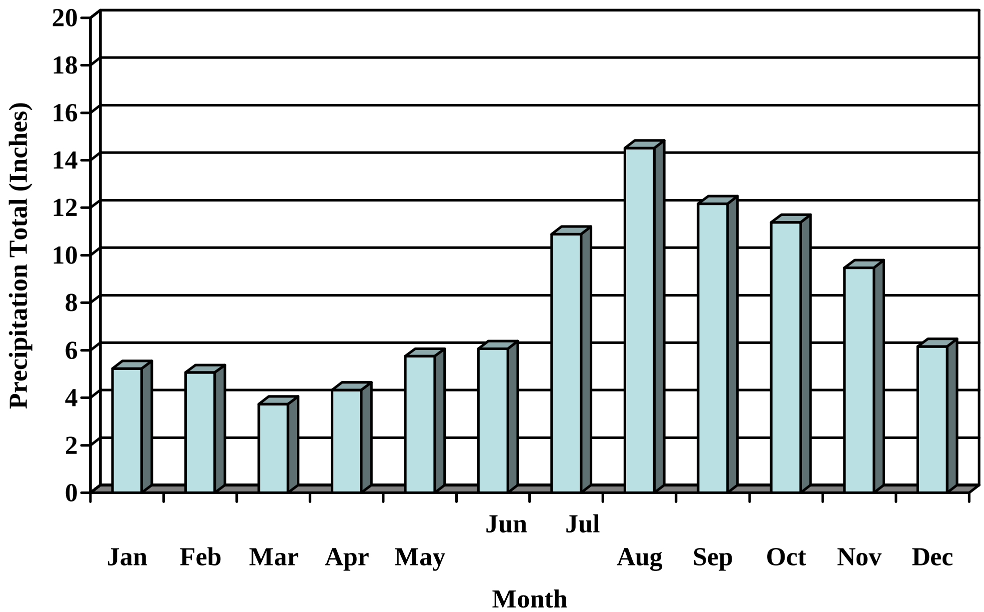

Figure 3(a). Monthly precipitation normals computed from the climate data for the period from 1971 to 2000, for Andersen AFB, Guam.

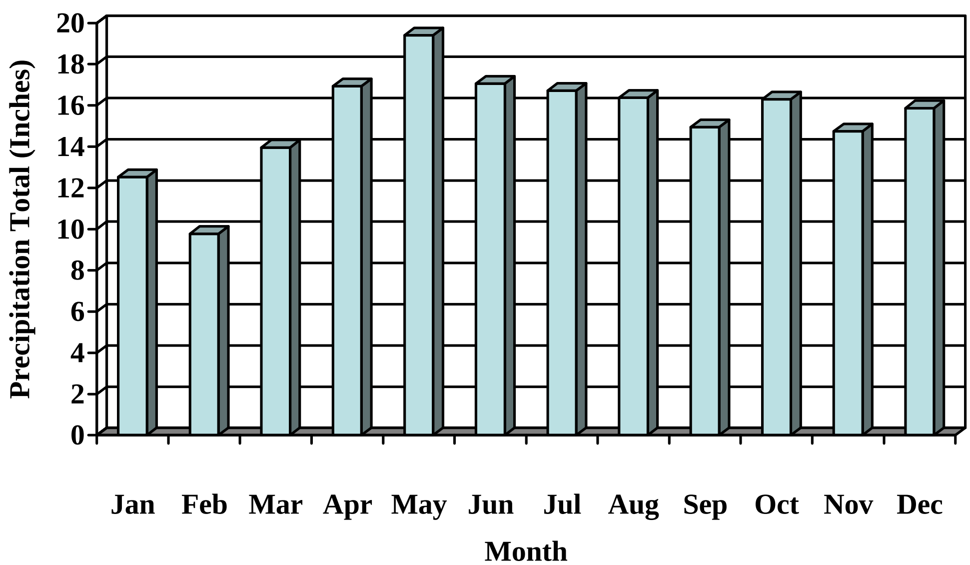

Figure 3(b). Same as Figure 3(a), except for Pohnpei WSO, Micronesia.

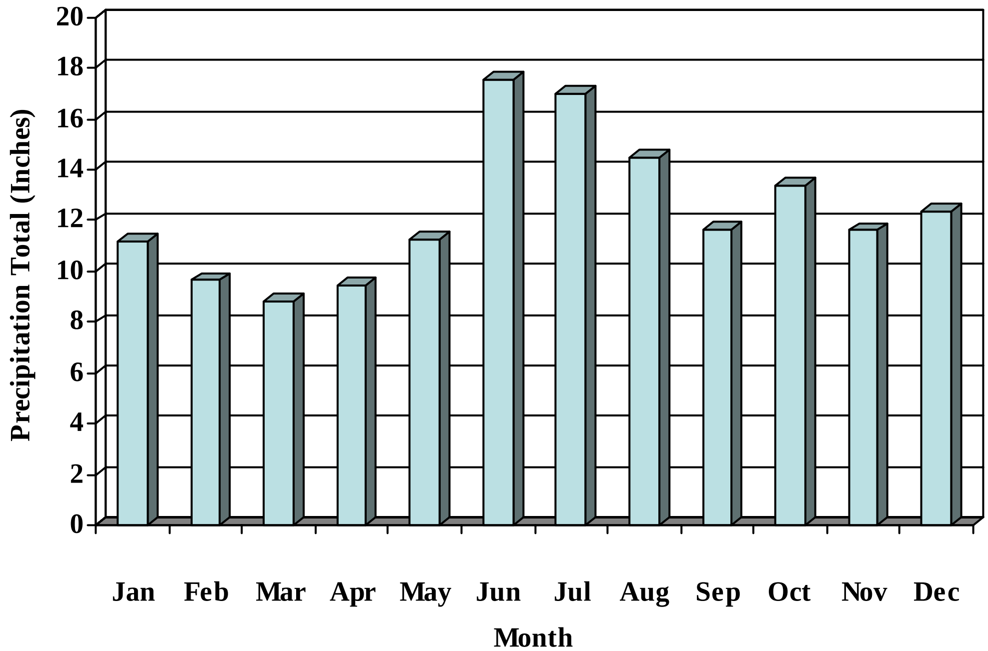

Figure 3(c). Same as Figure 3(a), except for Koror WSO, Palau.

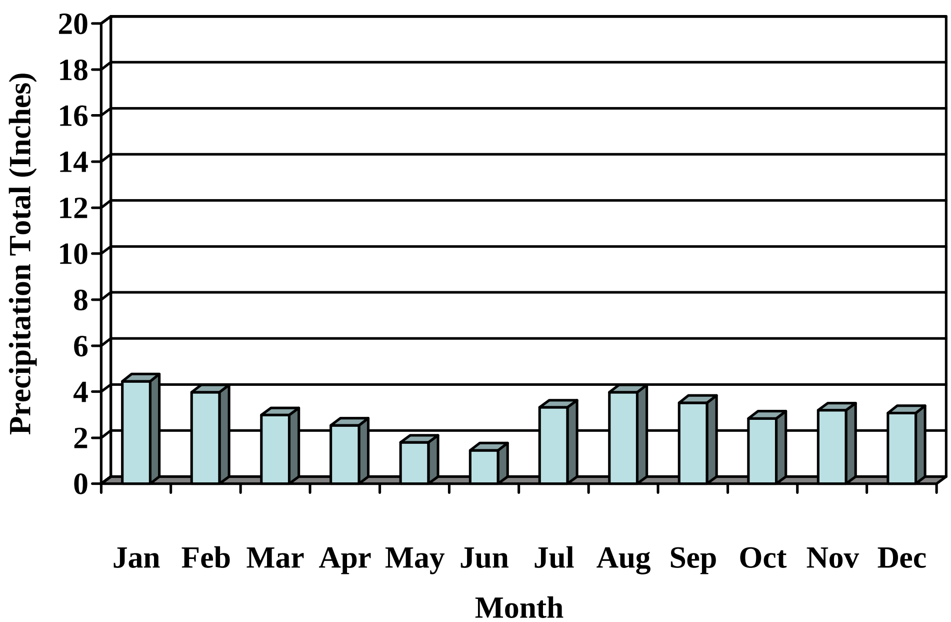

Figure 3(d). Same as Figure 3(a), except for Midway Islands NAS.

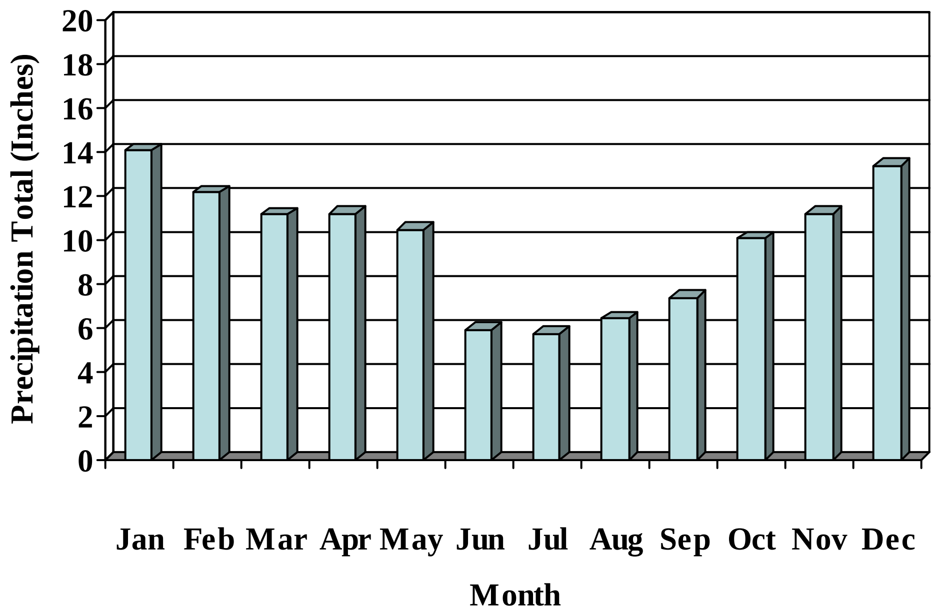

Figure 3(e). Same as Figure 3(a), except for Pago Pago, American Samoa.

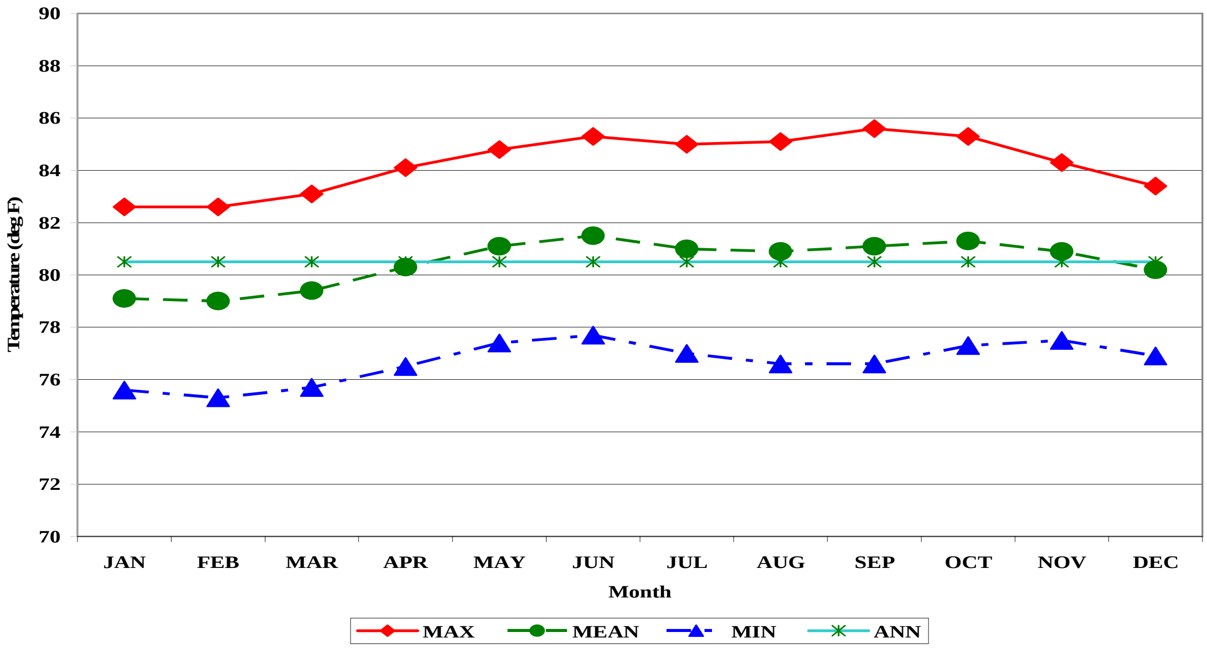

Figure 4(a). Monthly normals of maximum, mean, and minimum temperatures, along with the annual mean temperature, computed from the NCDC climate data for the period from 1971 to 2000, for Andersen AFB, Guam. Data source: NCDC Climatology of the United States No. 81 (1971-2000).

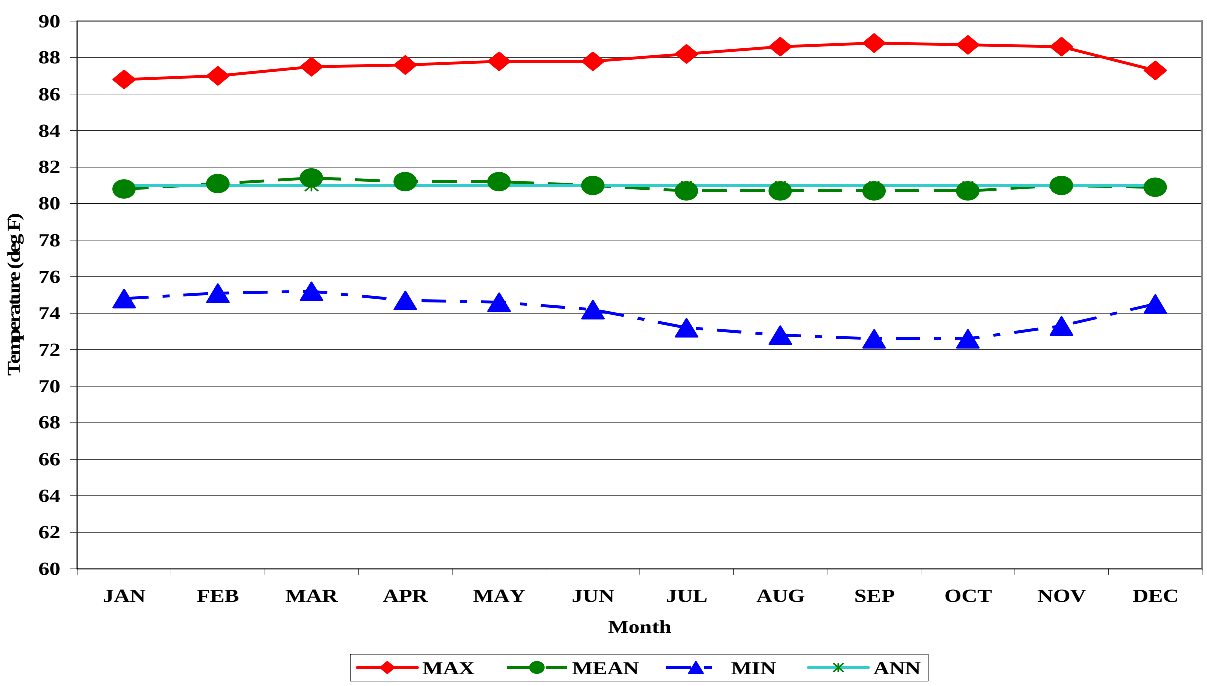

Figure 4(b). Same as Figure 4(a) except for Pohnpei WSO, Micronesia.

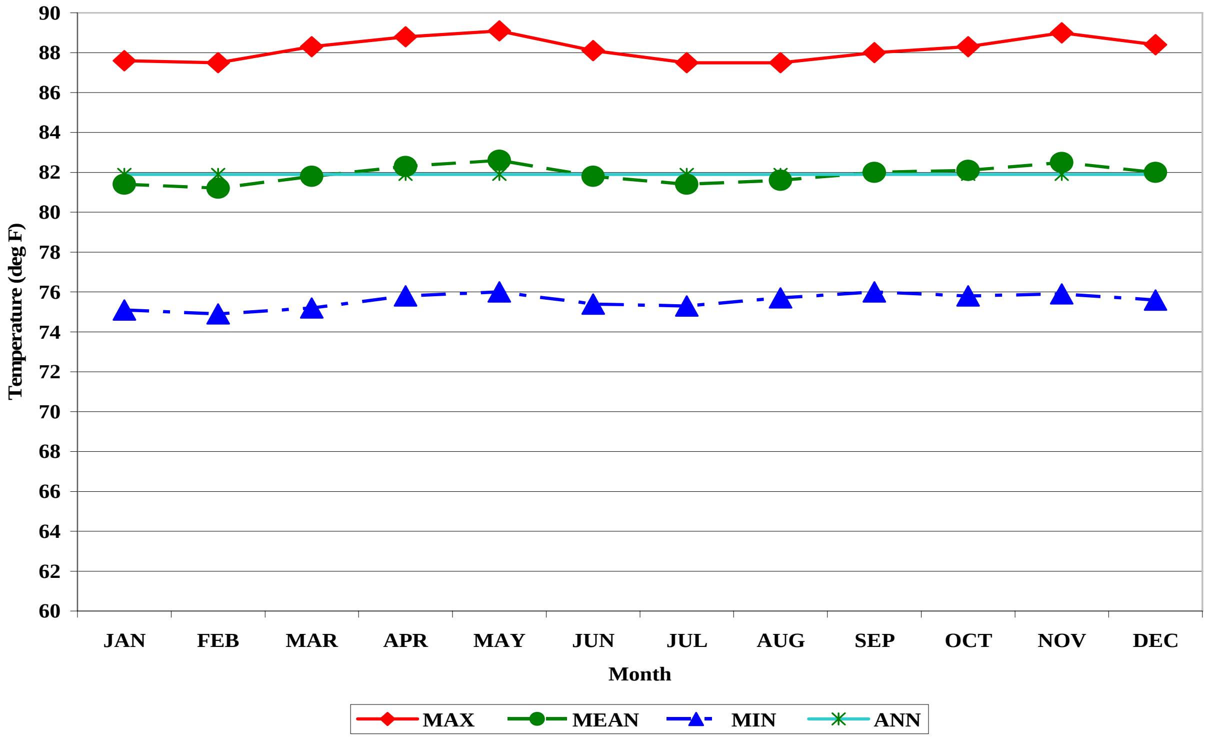

Figure 4(c). Same as Figure 4(a) except for Koror WSO, Palau.

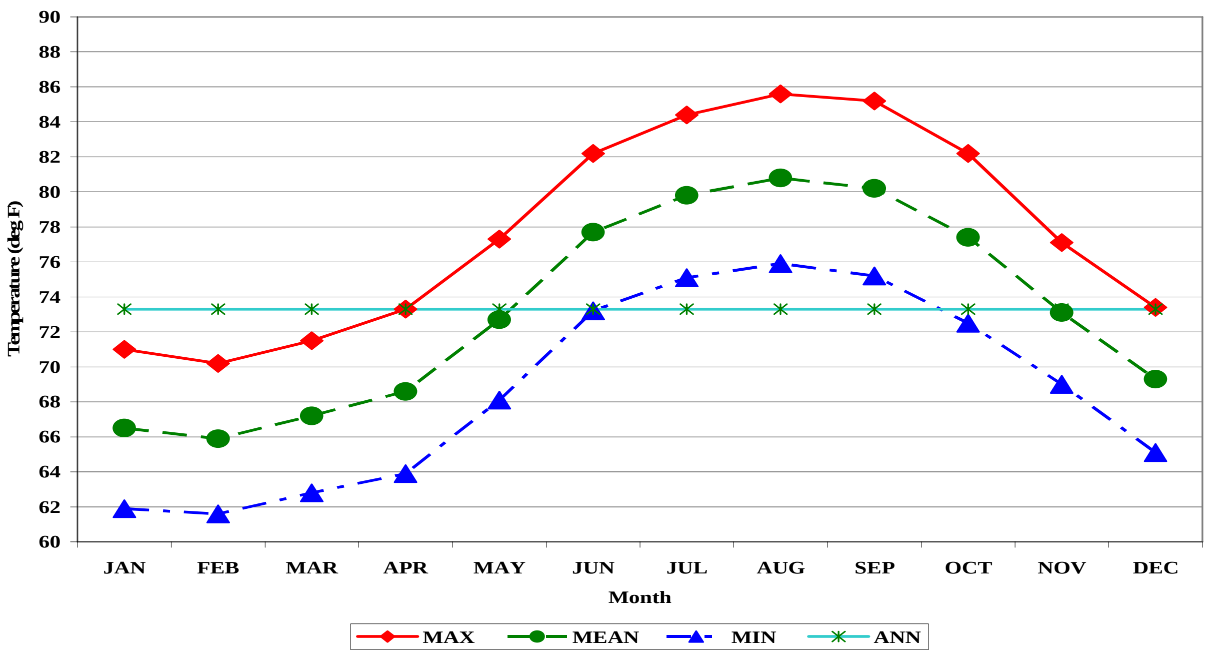

Figure 4(d). Same as Figure 4(a) except for Midway Islands NAS.

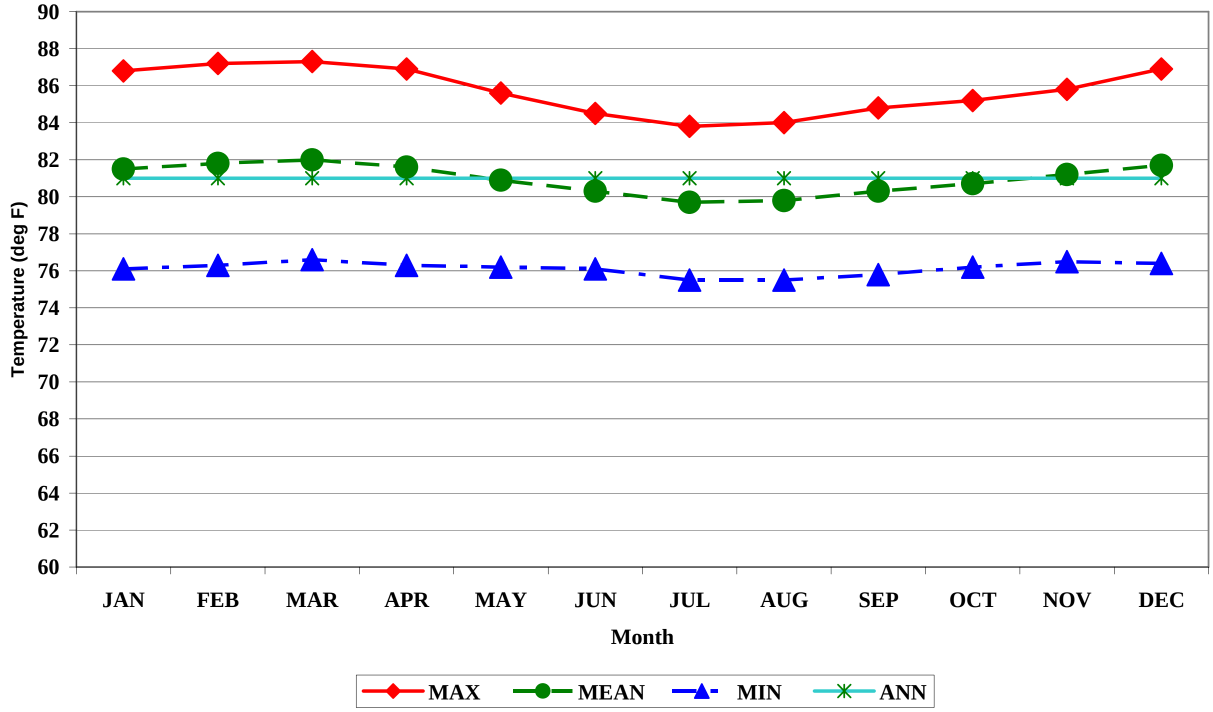

Figure 4(e). Same as Figure 4(a) except for Pago Pago, American Samoa.

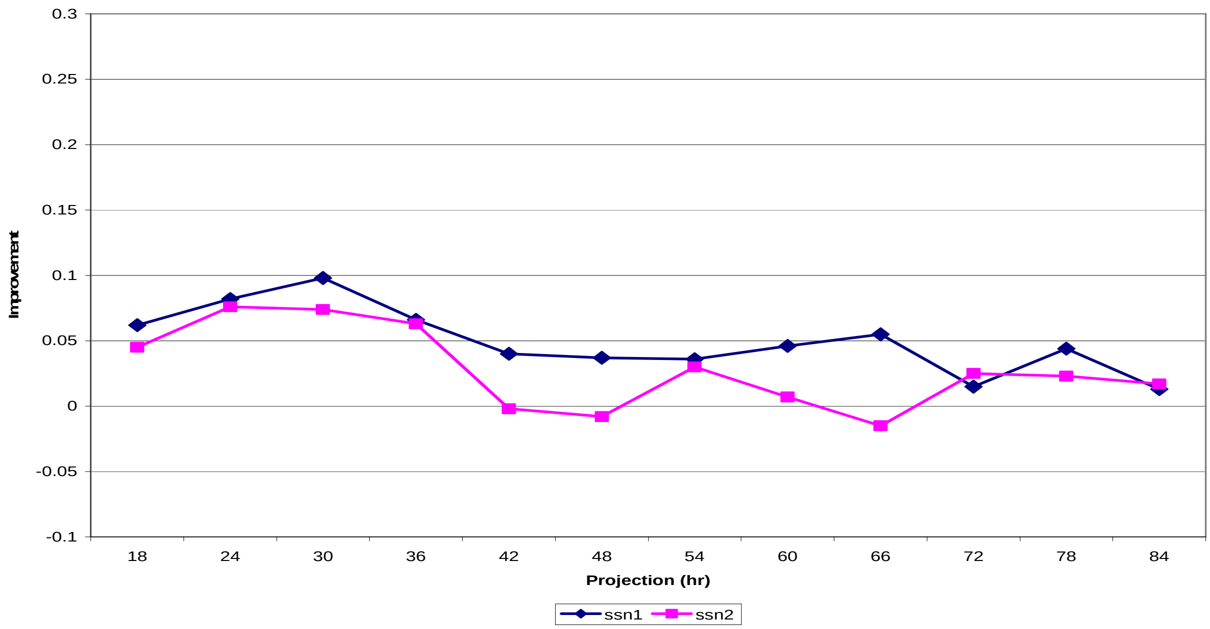

Figure 5(a). Improvement of 12-hour probability of precipitation (PoP) over climate in terms of Brier score, for season 1 (ssn1: Nov. – Apr.) and season 2 (ssn2: May – Oct.), the area of Andersen AFB, Guam.

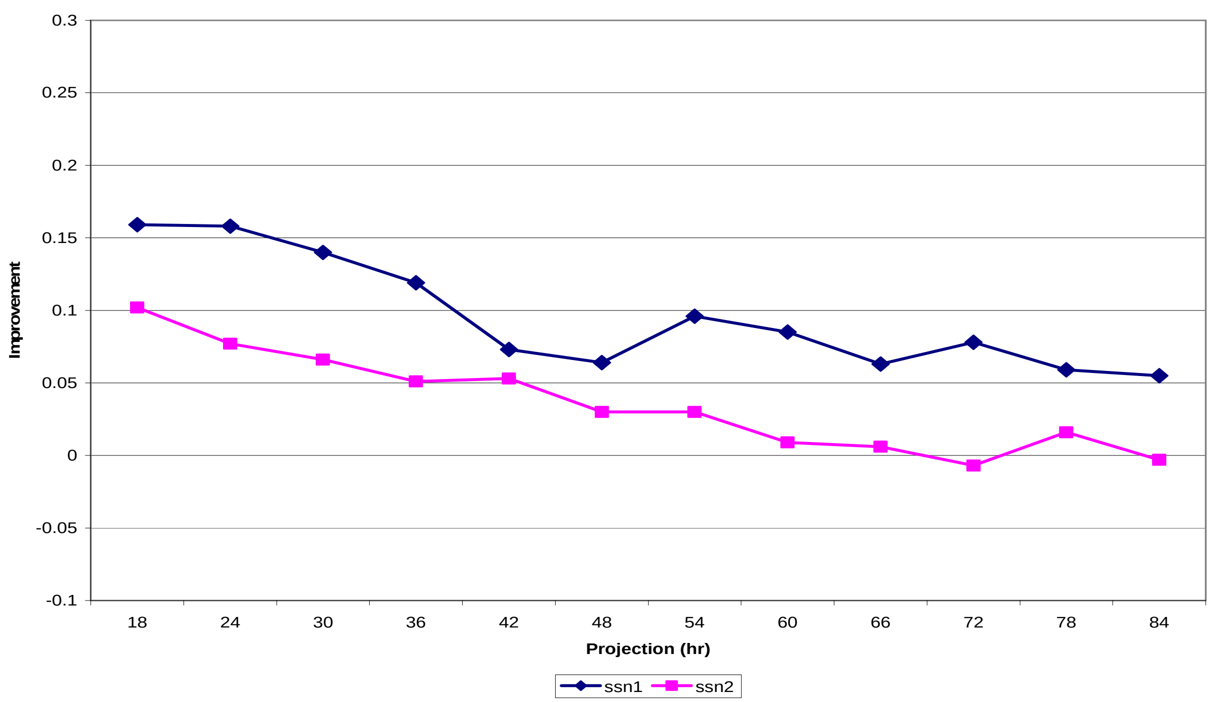

Figure 5(b). Same as Figure 5(a) except for the area of Phonpei WSO, Micronesia.

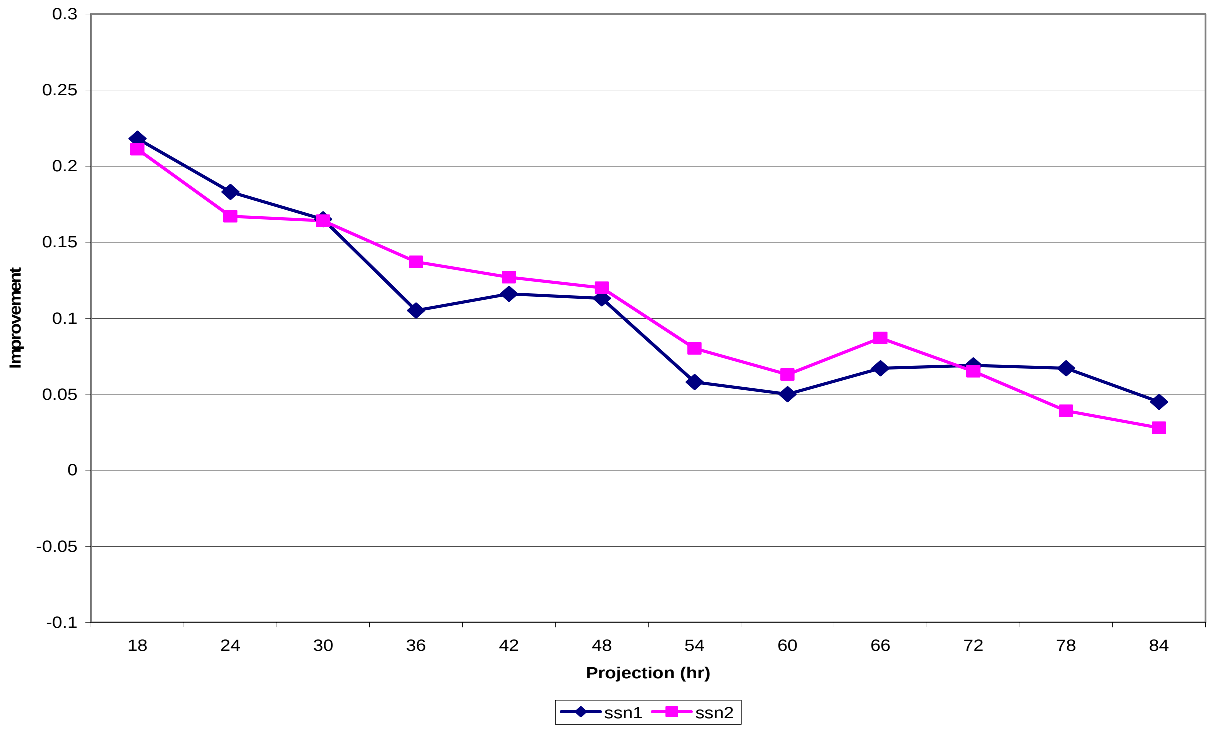

Figure 5(c). Same as Figure 5(a) except for the area of Koror WSO, Palau.

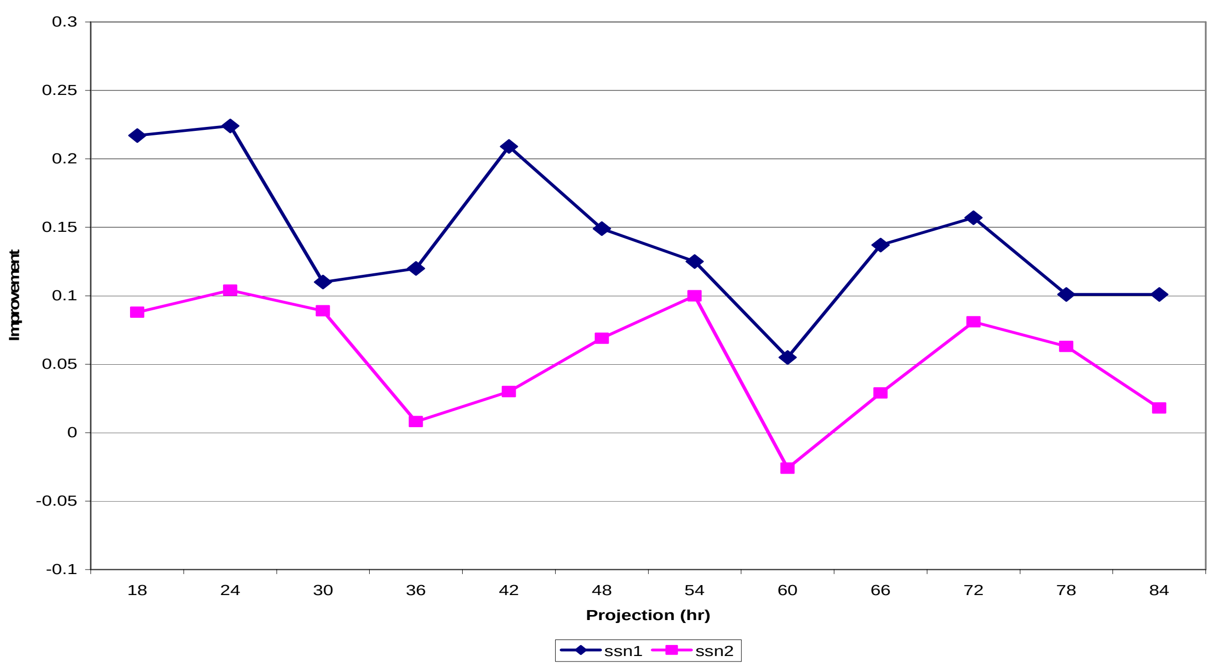

Figure 5(d). Same as Figure 5(a) except for Midway Islands NAS.

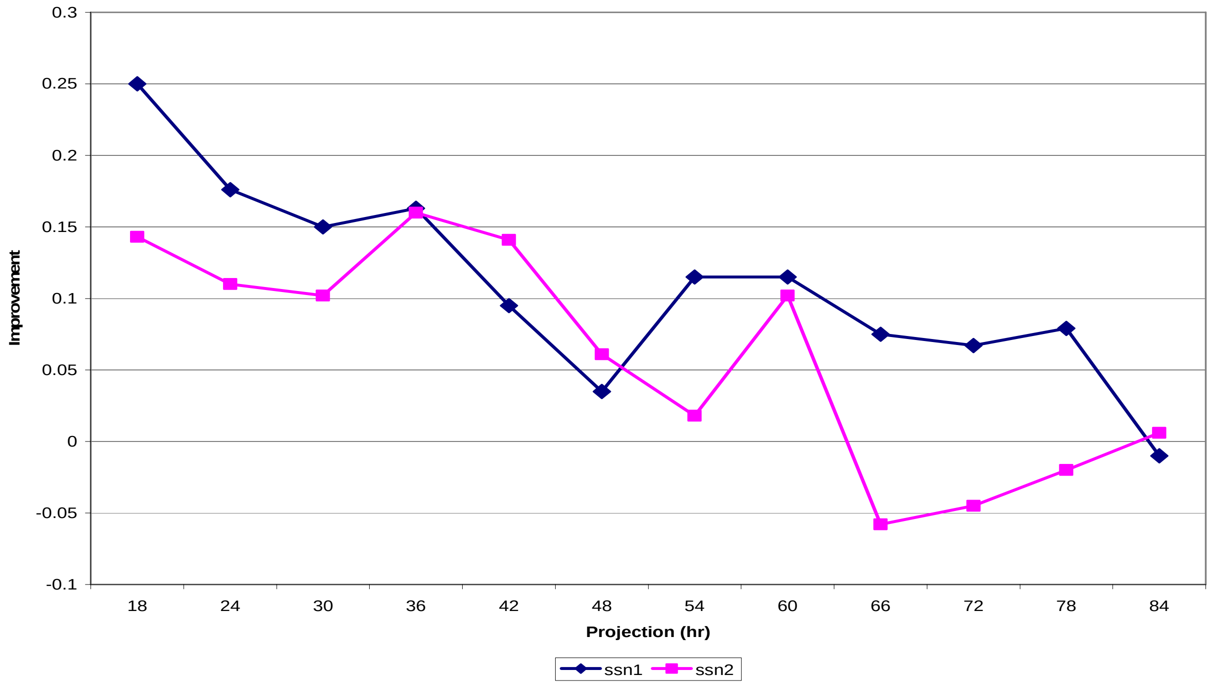

Figure 5(e). Same as Figure 5(a) except for Pago Pago, American Samoa.

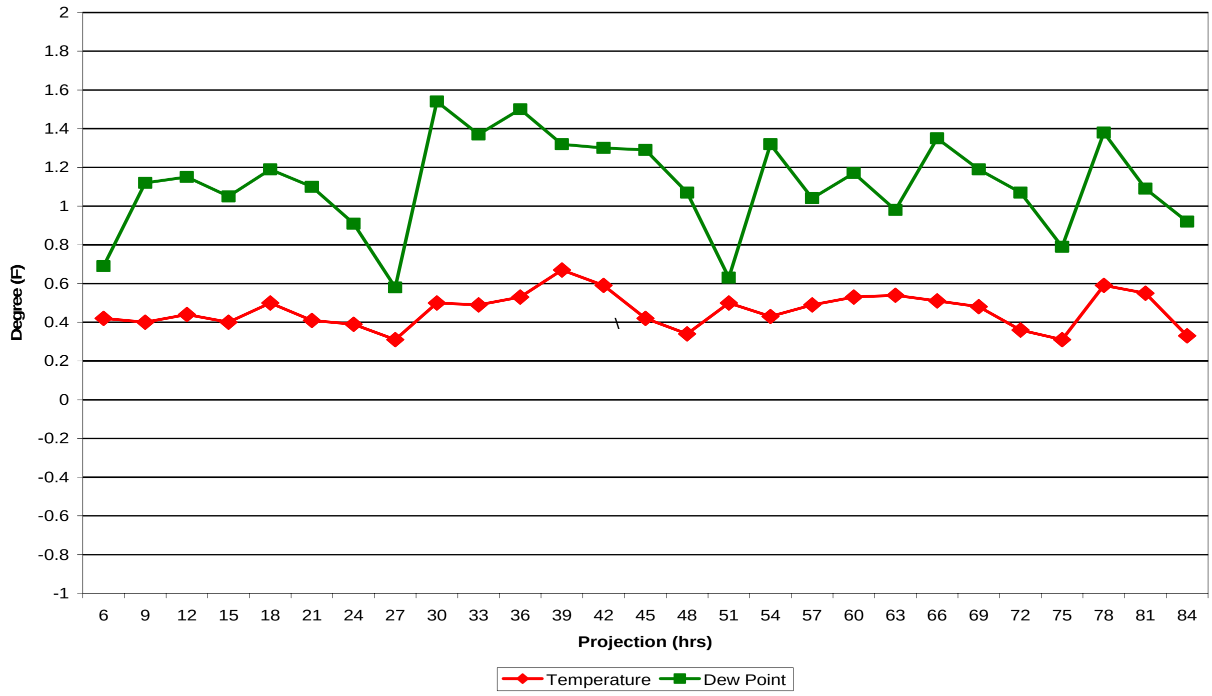

Figure 6(a). Bias of temperature and dewpoint forecasts, for season 1 (Nov. – Apr.), 0000 UTC cycle, Andersen AFB, Guam.

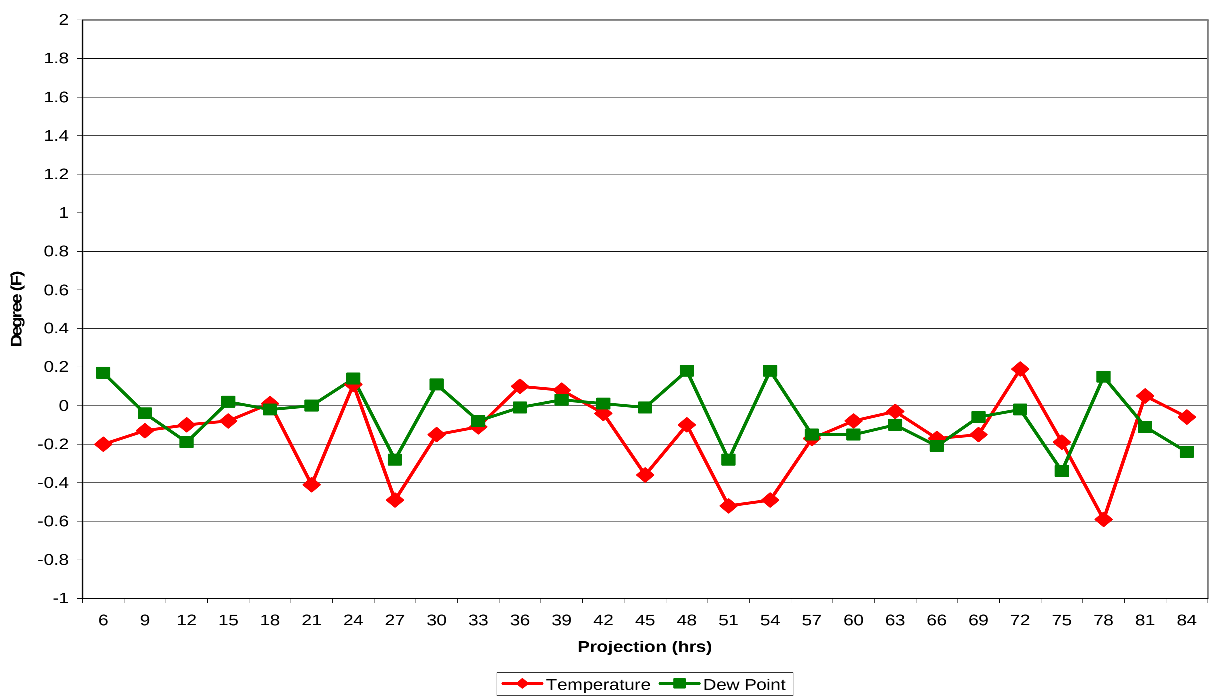

Figure 6(b). Same as Figure 6(a) except for Pohnpei WSO, Micronesia.

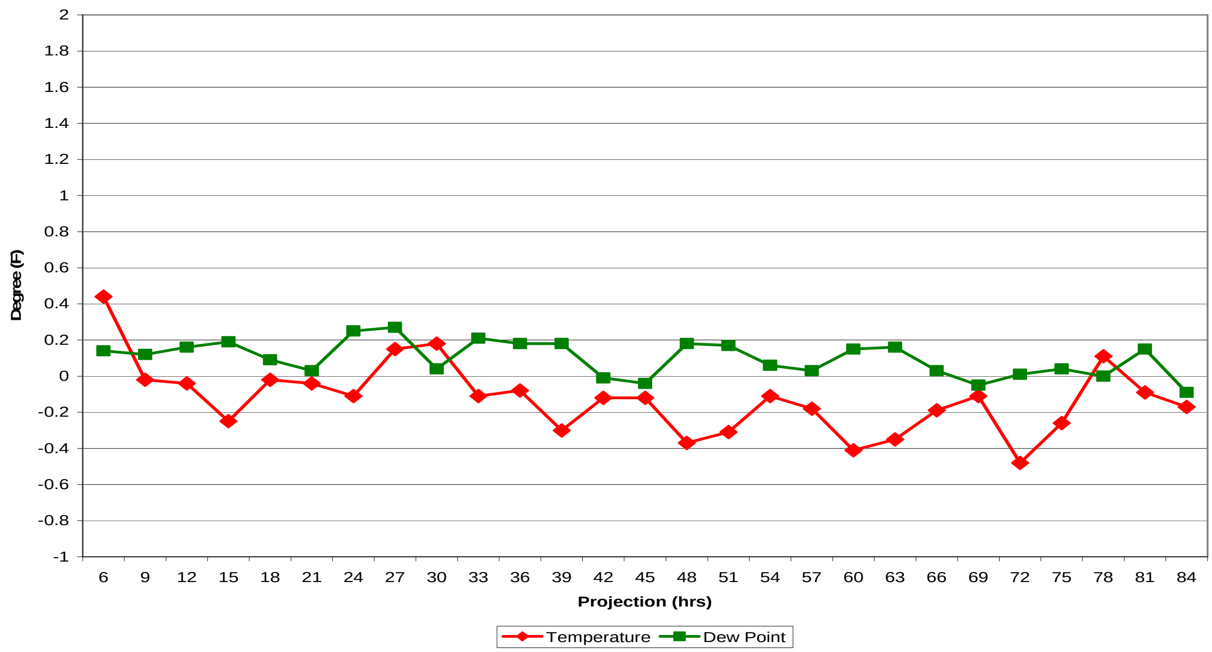

Figure 6(c). Same as Figure 6(a) except for Koror WSO, Paulau.

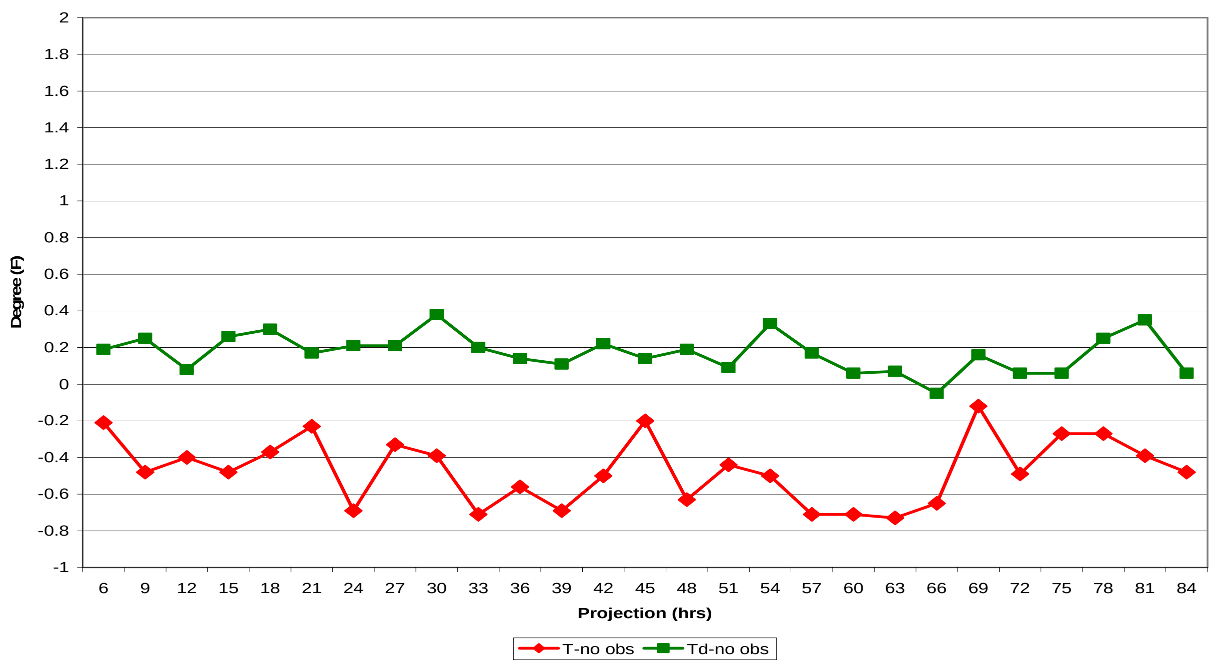

Figure 6(d). Same as Figure 6(a) except for Midway Islands NAS.

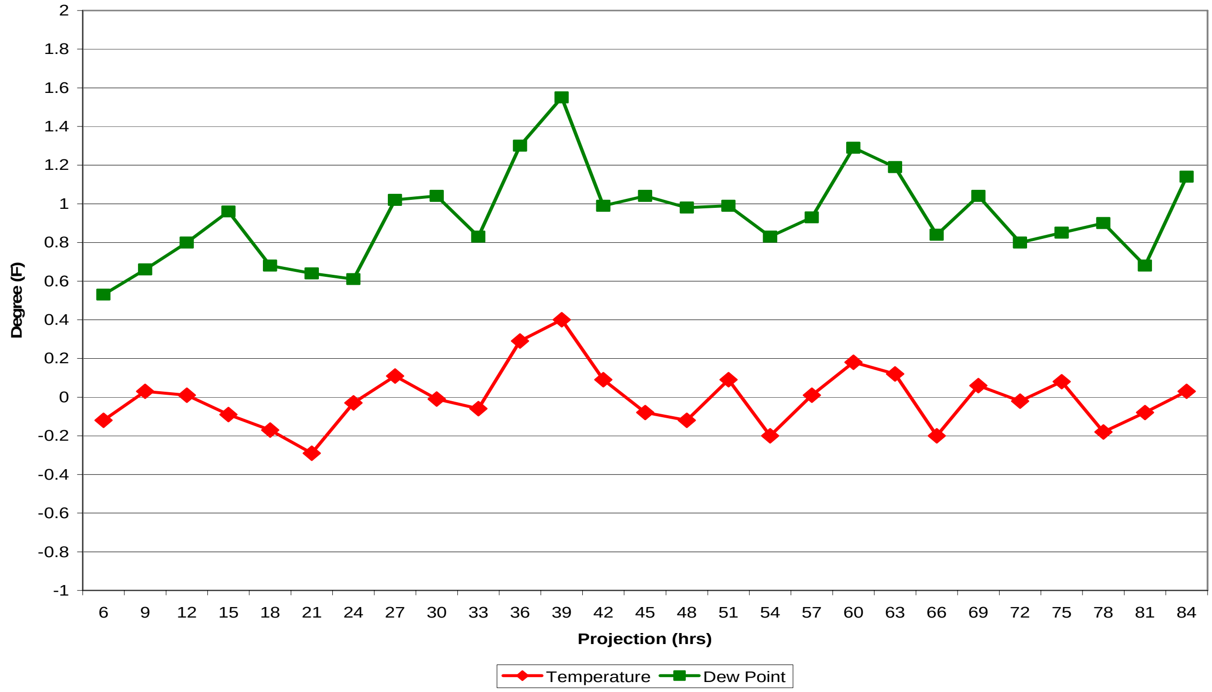

Figure 6(e). Same as Figure 6(a) except for Pago Pago, American Samoa.

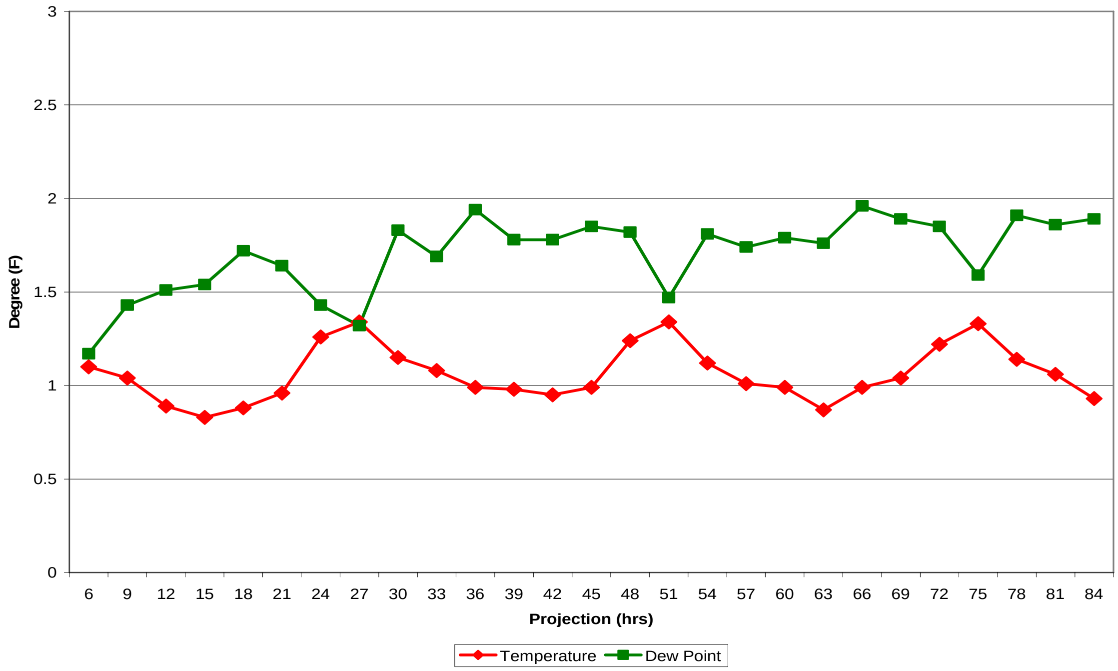

Figure 7(a). Mean absolute errors of temperature and dew point forecasts, for season 1 (Nov. – Apr.), 0000 UTC cycle, Andersen AFB, Guam.

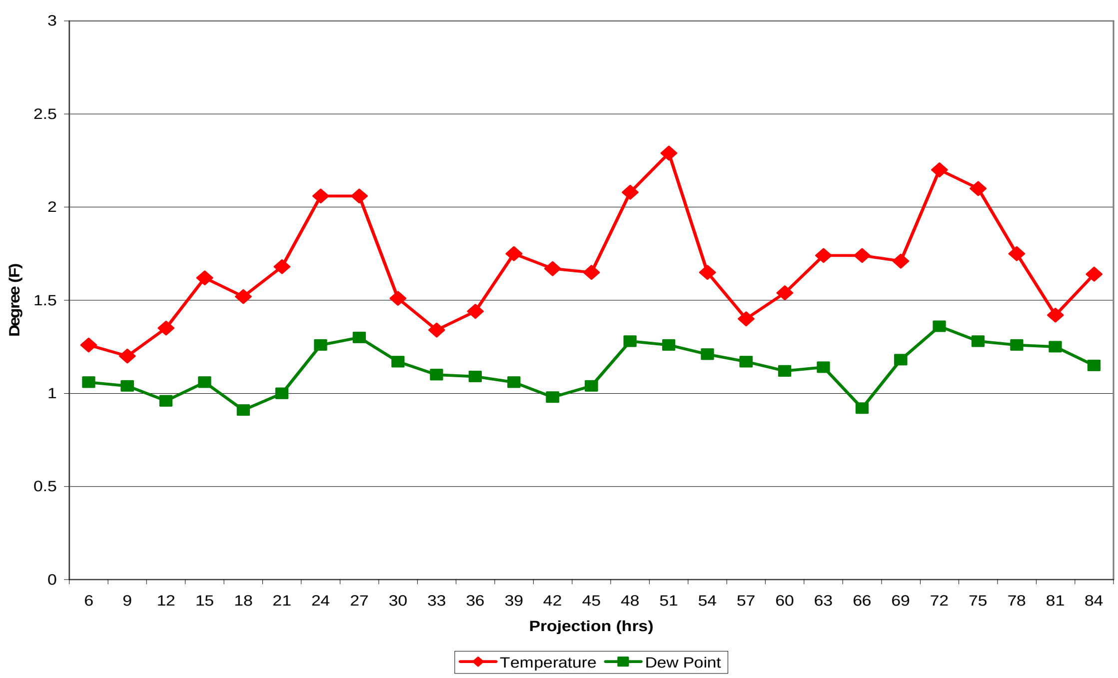

Figure 7(b). Same as Figure 7(a) except for Pohnpei WSO, Micronesia.

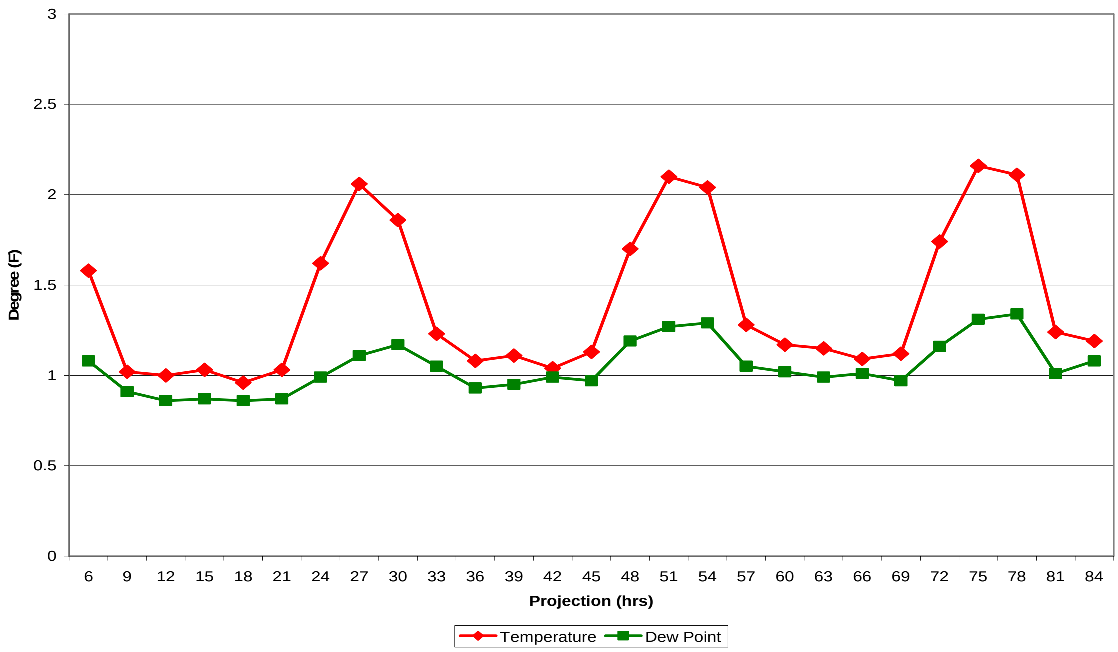

Figure 7(c). Same as Figure 7(a) except for Koror WSO, Paulau.

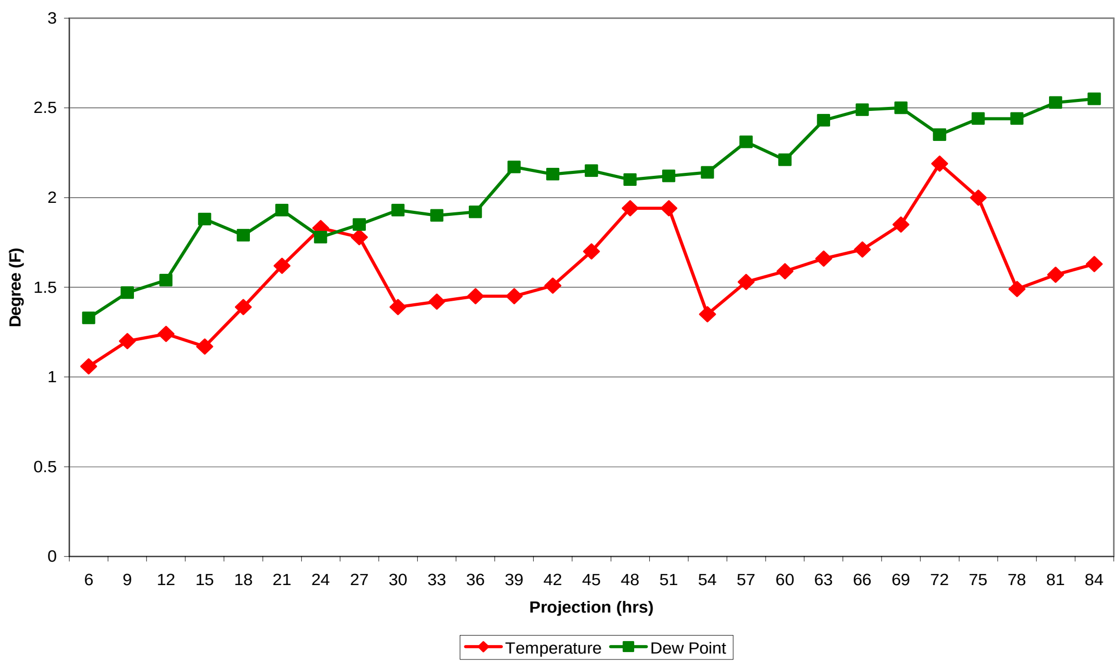

Figure 7(d). Same as Figure 7(a) except for Midway Islands NAS.

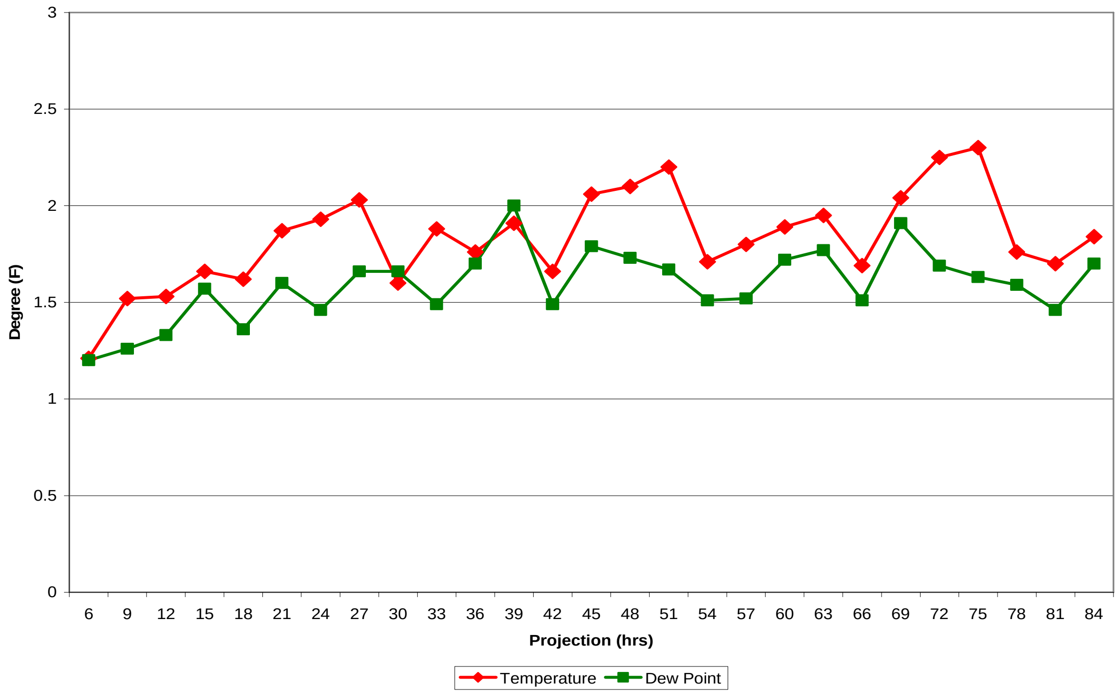

Figure 7(e). Same as Figure 7(a) except for Pago Pago, American Samoa.