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GFS-BASED MOS PRECIPITATION FORECAST GUIDANCE FOR ISLANDS IN THE TROPICAL WESTERN PACIFIC OCEAN

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1. INTRODUCTION

New Model Output Statistics (MOS, Glahn and Lowry 1972) precipitation forecast guidance based on the Global Forecast System (GFS, Alpert, et al. 1991) has been added to the existing GFS MOS wind forecast guidance products for 15 island sites in the tropical western Pacific Ocean (Su 2005). The new guidance was implemented on April 24, 2007, effective 1200 Coordinated Universal Time (UTC) cycle. The elements provided by the new guidance included probabilities of precipitation in 6-hr (PoP6) and 12-hr (PoP12) periods, as well as on the hour (PoPO).

Several MOS precipitation forecast guidance packages for the contiguous United States (CONUS), Alaska, Hawaii, and Puerto Rico have been developed by the staff of the NWS Meteorological Development Laboratory (MDL, see, e.g., Antolik 2004; Cosgrove and Sfanos 2004). The precipitation related elements that were provided by the MDL MOS guidance products include probability of precipitation (PoP), quantitative precipitation forecast (QPF), probability of freezing precipitation occurrence, probability of snow, precipitation type, etc. Among the MOS precipitation forecast elements, only the liquid precipitation is relevant in the tropics. The MOS precipitation forecast guidance presented in this article is the first one that has been developed for the tropical western Pacific Ocean.

The difference in precipitation characteristics between the tropics and the mid-latitude is revealed by satellite pictures, e.g., infrared imagery (Figure 1). Precipitation in the tropics is mainly in the inter-tropical convergence zone (ITCZ). In particular, the cloud mass in the subject area that covers the 15 stations (compare with Figure 2) consists mainly of convective clouds, some of them are almost stationary and others move westward. Those convection plumes grow and dissipate in a period of several hours. In the mid-latitudes of both hemispheres, cloud masses move from one area to another eastward more rapidly than those in the tropics. Thus, the precipitation in the tropics would be of mostly convective type and whose variation of occurrence would have shorter periods than in the mid-latitudes.

Tropical cyclones also form in the subject area; some of them intensify into typhoons, and move westward. However, they are rare events in the developmental sample for the MOS system. Typhoons and tropical cyclones are not included in the scope of this article.

In Section 2, the data and development process for the guidance is described. Post-processing applied on the forecasts computed from MOS equations is described in Section 3. The results of independent tests on the PoP6, PoP12, and PoPO are presented in Section 4. The operational products are listed and briefly explained in Section 5. In Section 6, operational considerations and some precautions on the usage are explained. Some concluding remarks are given in Section 7. Finally, articles referred to in this paper are listed in Section 8.

2. DEVELOPMENT

2.1 *Stations*

The MOS precipitation forecast guidance has been developed for the 15 island sites that currently have an operational wind forecast guidance product (Table 1). Locations of these sites are shown on the map in Figure 2. These islands are located in the area from 15° S to 30° N and from 130° E to 170° W. Thirteen of the 15 stations are

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located in the Eastern Hemisphere and two of them in the Western Hemisphere. One of the latter is located in the Southern Hemisphere. Among these 15 sites, four of them (PGRO, PGWT, PTSA, and PWAK) do not have observed data and no climate data are available either. Climatic precipitation amount normals of 11 stations were used as guidelines for developmental data stratification, and will be discussed in a later section. Eleven stations that have observed data were used in the development of MOS precipitation forecast guidance, and operational guidance is disseminated for all 15 stations. The inclusion of the four stations not used in the development will be explained later.

2.2 *Predictands*

The predictands in this guidance package included probability of precipitation in a 6-hr period (PoP6), probability of precipitation in a 12-hr period (PoP12), and probability of precipitation on the hour (PoPO). All three predictands were binary variables, and each of them had a value of zero (0) for non-occurrence or one (1) for occurrence. For PoP6 and PoP12, the predictand values equaled one when the precipitation amount was at least one hundredth of an inch (≥ 0.01 in.), and zero, otherwise.

For PoPO, the predictand value was one when any type of precipitation (in liquid, freezing, frozen, or mixed form) occurred on the hour regardless of the amount. The precipitation types accounted in PoPO included drizzle, rain, snow, snow grains, snow pellets, ice crystals, ice pellets, hail, as well as mixture of any possible precipitation types (e.g., rain and snow). PoPO also included precipitation of various types (rain, snow, hail, etc.) in showers or thunderstorms. Any unknown precipitation from the ASOS data was also included in PoPO.

Observed data for 0000, 0300, 0600, …, and 2100 UTC were used in the PoPO development for projections at 3-hr increments from 6 to 84 hours after the initial model time. Similarly, observed data for 0000, 0600, 1200, …, and 1800 UTC were used in the PoP6 and PoP12 developments for projections at 6-hr increments from 12 to 84 hours, and from 18 to 84 hours, respectively, after the initial model time. Forecasts of PoP6, PoP12, and PoPO are computed from the MOS equations and have values ranging from zero to one.

2.3 *Predictors*

In the development of MOS forecast equations, potential predictors that could impact the forecast elements were offered to the regression analysis for selection. Potential predictors from the GFS model output included mean relative humidity in an isobaric layer, total precipitation in a time period (3-hr, 6-hr, or 12-hr), total precipitable water, moisture divergence on an isobaric level, wind components and speed, vertical velocity, relative vorticity, and K index. Potential predictors which were not obtained from the model output directly were computed by using MOS software. In addition, sinusoidal functions of the first and second harmonics of the day of the year were offered to accommodate annual and semi-annual variations. Furthermore, the monthly relative frequency of precipitation computed from the MDL archives of observed data was also offered to account for the climatology of the precipitation at the stations.

Many grid binary predictors (Jensenius 1992) were offered. They were derived from mean relative humidity in an isobaric layer, total precipitation amount in a time period, vertical velocity, and K index, although their corresponding continuous predictors (except the total precipitation amount) were also used. No point binary predictor was used in this development. Compared to a point binary predictor, a grid binary predictor would produce a more stable contribution to the forecast rather than an abrupt discrete jump.

The grid binary predictors of total precipitation amount were offered in different arrangements for PoP12, PoP6, and PoPO. For PoP12, the 6-hr and 12-hr grid binary predictors of total precipitation amount were offered. The 6-hr grid binary predictor for 12 hours before and after the forecast projection time was offered while the 12-hr grid binary predictor at the forecast projection time was also offered. For PoP6, the 6-hr grid binary predictor for 6 hours before, at, and 6 hours after the forecast projection time was offered. For PoPO, the 3-hr grid binary predictor at the forecast projection time and 3 hours after was offered.

Monthly mean relative frequency of 12-hr precipitation was offered as a climatic predictor to the regression analysis for the PoP12 equation development, and that of 6-hr precipitation was offered for the PoP6 and PoPO equation development. Other predictors (excluding total precipitation predictors) were offered in the same manner for all seasons, cycles, and projections.

All predictors for stations that were derived from the GFS model output were obtained by using a bilinear interpolation scheme, after a 25-point smoother was applied. They included all continuous and grid binary predictors offered to the regression analysis. Predictors derived from observed data, such as precipitation amounts or corresponding grid binary predictors were not used in this development.

2.4 *Developmental Sample and Climatic Data*

The GFS model output data for this development were obtained from MDL's Pacific GFS archive system (Su 2005). The archive data were available from the model cycle time (zero hour projection) at 3-hr increments out to 180 hours, and then at 12-hr increments out to 384 hours. The data used as predictors in this development were provided with a 3-hr resolution out to 84 hours in advance.

Observed data were obtained from the MDL archives of hourly observed data, which had been processed by using the MDL hourly data quality control procedures. The observed hourly data were available for every hour from 0000 through 2300 UTC daily. The data were used as predictands and matched in time with the GFS model output data. In addition, observed hourly data for the period from December 1997 to November 2005 were used to compute monthly relative frequencies of precipitation for 6-hr and 12-hr periods ending at 0000, 0600, 1200, and 1800 UTC, for 11 stations. The purpose for computing the monthly relative frequencies was twofold. First, the monthly relative frequency was used as a climatic variable predictor. Second, it was also used as a reference in the stratification of sample data into groups associated with seasons and geographical regions. For the four stations that did not have observed data, bogus values were estimated from monthly relative frequencies of neighboring stations. In addition, the climatic data of monthly precipitation amount normals were provided by the NWS Pacific Region Headquarters and used as guidelines for bogus estimates. The monthly precipitation amount normals were computed by using observed data for the period from 1971 to 2000.

The methods of estimate for the bogus monthly relative frequencies were as follows: four stations needed bogus values, and they were Rota (PGRO), West Tinian (PGWT), Kosrae (PTSA), and Wake Island (PWAK). The bogus values for PGRO and PGWT were obtained by interpolation from PGSN and PGUA using the distance in the meridional direction since these four stations are located close to one meridian (145° N). For PTSA, the ratio of its monthly precipitation amount normals to that of PTTP was used as a guide to estimate the monthly relative frequencies of PTSA from PTTP. The monthly relative frequencies of PKWA and PKMR were used as references for the estimate. For PWAK, the monthly relative frequencies were estimated subjectively by using those of PGSN and PKWA as references. The monthly precipitation amount normals of PMDY and PWAK were also used as references. Note that monthly relative frequencies were computed, or estimated in this development, whereas the monthly precipitation amount normals were supplied by the NWS Pacific Region Headquarters.

The GFS model output and hourly observed data used in this development were for the period from April 2000 to May 2006. The monthly relative frequencies and monthly precipitation amount normals were used to stratify the developmental data into seasons. Distinguished jumps in these monthly values between adjacent months were identified and used to separate forecast seasons. The determination of seasons was based on those inter-monthly jumps of the majority of stations. Then the monthly distribution patterns of relative frequencies and precipitation amount normals were examined. Stations with similar distribution patterns of wet and dry months were grouped to represent a geographical region. The developmental sample was determined to have two seasons (season 1 and season 2) and five geographical regions (see Table 2). Two geographical regions had single stations. The titles of seasons did not represent wet or dry seasons because dry and wet seasons were opposite across the equator. Note that in this development there is one station (NSTU) in the southern hemisphere.

2.5 *Equation Characteristics*

The GFS MOS forecast equations of PoP6, PoP12, and PoPO were developed for five geographical regions, two seasons, and for 0000 and 1200 UTC cycles. The MOS regression analysis software was set to allow up to 10 terms (predictors) for each forecast equation.

The reduction of variance by predictors in forecast equations can serve as an indication of the robustness of those equations. In this development, the reduction of variance averaged over

5 geographical regions ranged from 0.094 to 0.212 for PoP12 (for projections from 18 to 84 hours), from 0.069 to 0.181 for PoP6 (for projections from 12 to 84 hours), and from 0.046 to 0.150 for PoPO (for projections from 6 to 84 hours). The general trend of reduction of variance was from high values at short projections to low values at long projections. It was also higher for season 1 than season 2.

For the analysis of forecast equation characteristics, the potential predictors were put into six groups: total precipitation predictors, other moisture predictors, dynamic predictors, stability predictors, harmonic predictors, and climatic predictors. Note that the observed data were not used as predictors in the development of precipitation forecast equations.

Details of those six groups are summarized in Table 3. The total precipitation predictors group included those of 3-hr, 6-hr, and 12-hr total precipitation amounts. The breakpoints were 0.01 in., 0.1 in., 0.25 in., and 0.5 in. The other moisture predictors group included mean relative humidity in isobaric layers, precipitable water, and moisture divergence on the isobaric levels. The dynamic predictors group included earth-oriented wind components, wind speed, vertical velocity, and relative vorticity. The instability predictor group was composed of the K-index. The harmonic predictors group included the first and second harmonics of the day of the year. Finally, the climatic predictors group included monthly mean relative frequencies of the 6-hr and 12-hr precipitation.

For the purpose of discussion on the specific forecast equations of PoP12, the grid binary predictors of the 12-hr total precipitation amount were isolated in the total precipitation predictors group, and the grid binary predictors of 6-hr total precipitation amount were put in the other moisture predictors group. For PoP6 and PoPO, the total precipitation predictors group included only the grid binary predictors of 6-hr and 3-hr total precipitation amounts, respectively.

In this development, selection of predictors in the forecast equations was different between seasons and projections. An example is presented in Figures 3(a)-3(d) for seasons 1 and 2, and for 0000 and 1200 UTC cycles. The graphs show the percentage points of predictor groups selected for PoP12 forecast equations, and their variations with respect to projections. The percentage points of six predictor groups add up to 100% for each projection. The magnitudes of percentage cannot be compared between predictor groups because all groups do not have the same number of predictors. The 12-hr total precipitation predictor group had a few percentage points difference between seasons and cycles. The total precipitation predictors group, the other moisture predictors group and the dynamic predictors group had more significant variations with respect to projections than other groups. A prominent feature in the graphs is that the moisture predictors had significantly higher percentage for season 2 than season 1. Another noticeable feature is that K-index was selected more often for season 2 and not selected for many projections for season 1. In summary, season 2 needed more moisture predictors to account for reduction of variance (which was not explained by other predictors) in the MOS regression analysis.

3. POST-PROCESSING

MOS forecast equations provide estimates of the probability of precipitation. By definition, the values of PoP6, PoP12, and PoPO must range from zero to one. The post-processing procedures ensure that the PoP6, PoP12, and PoPO values be non-negative and not exceed one.

Furthermore, a consistency check was performed on PoP6 and PoP12. In every 12-hr period, the PoP6 values of two consecutive 6-hr periods were compared with the PoP12 value. If any of the PoP6 values was greater that the PoP12 value, then the PoP12 value was raised to the larger one of the two PoP6 values. For example, the PoP6 value of the 12 – 18 hour projection period and that of the 18 – 24 hour projection period were compared with the PoP12 value of the 12 – 24 hour projection period. If the PoP6 value of any 6-hour sub-period was greater that the PoP12 value, then the PoP12 value of the 12 – 24 hour projection period was raised to the larger one of the 12 – 18 hour or 18 – 24 hour PoP6 value.

The forecasts of PoP6, PoP12, and PoPO were converted from decimal values to percentage points. So, values ranging from zero percent to 100% are produced and disseminated in the operational precipitation forecast guidance.

4. VERIFICATION

Independent tests on the MOS forecast equations were performed on all the MDL MOS forecast products before they were implemented. In this development, the sample data for 5 periods: October 2000 – May 2001, October 2001 – May 2002, …, and October 2004 – May 2005 were used to develop the test equations for season 1 (November – April). The sample data for October 2005 – May 2006 were used to perform independent tests on the season 1 test equations. Similarly, the sample data for 5 periods: April - November 2000, April - November 2001, …, and April - November 2004 were used to develop the test equations for season 2 (May – October). The sample data for April - November 2005 were used to perform independent tests on the season 2 test equations. The sample data of May and October were used in both seasons to ensure smooth transition and avoid abrupt jumps between seasons.

Before the independent tests were performed, the standards for tests were planned. For PoP12 and PoP6, mean relative frequencies of 12-hr and 6-hr precipitation were used as test standards, respectively. For PoPO, climatic PoPO forecast equations were developed and used to produce "climatic" PoPO forecasts for test standards. For climatic PoPO equations, mean relative frequencies of 6-hr precipitation and harmonic predictors (sine and cosine functions of the day of the year) were offered to the regression analysis. This was a subjective decision due to lacking of better choice.

For verification, PoP12, PoP6, and PoPO were evaluated for their improvement over climate in terms of Brier scores. For PoP12, the improvement averaged over 5 regions for two seasons is shown in Figure 4(a). The scores for season 1 are generally about 3% - 5% better than those of season 2. The MOS forecasts of PoP12 have about 17% and 12% of improvement over climate at the 18-hr projection for seasons 1 and 2, respectively. The percentage points of improvement for both seasons decrease monotonically to the 48-hr projection. Beyond the 48-hr projection, the improvement for season 1 levels off and that for season 2 decreases further. For season 1, the improvement decreases below 5% at the 84-hr projection. For season 2, the improvement falls below 5% beyond the 48-hr projection.

Similarly for PoP6, the improvement over climate averaged over 5 regions for two seasons is shown in Figure 4(b). The improvement for season 1 is generally about 2% - 5% better than that of season 2. The MOS forecasts of PoP6 have about 14% and 12% of improvement at the 12-hr projection. The scores for both seasons decrease toward higher projections. The improvement for season 1 falls below 5% at the 66-hr projection, and that for season 2 falls below 5% at the 42-hr projection.

The improvement of MOS PoPO forecasts over climate does not vary as smoothly as those of PoP12 and PoP6. At the 6-hr projection, the improvements are about 14% and 11% for season 1 and season 2, respectively. The improvements fall below 5% at the 21-hr projection for season 1 and at the 18-hr projection for season 2. Then the improvements for both seasons bounce back at the 27-hr projection for season 1 and at the 24-hr projection for season 2. The improvements fall below 5% again at the 36-hr projection for both seasons. For season 2, the MOS PoPO forecasts are worse than climate at the 69-, 81-, and 84-hr projections.

In summary, the MOS forecasts of PoP12 are better than those of PoP6, and those of PoP6 are better than those of PoPO. The MOS forecasts of PoP12 and PoP6 for season 1 are better than for season 2, which is not true for PoPO. The MOS forecasts for PoP12 have skill (improvement over climate) for the period of 18 to 84 hours. Both of PoP6 and PoPO are skillful for the period from 12 to 84 hours for season 1, and 12 to 66 hours for season 2.

5. OPERATIONAL PRODUCTS

The GFS MOS precipitation forecast guidance for 15 island sites in the tropical western Pacific Ocean became operational on April 24, 2007, beginning with the 1200 UTC cycle. They were added to the existing wind forecast guidance products. As arranged before (Su 2005), the guidance of NSTU and PMDY was added the Hawaiian products, whose WMO headers are FOPA20 KWNO for the text message and JSMT20 KWNO for the Binary Universal Form for the Representation (BUFR) of meteorological data products. The guidance for the other 13 stations was added to the corresponding existing wind forecast guidance products, whose WMO headers are FOPA21 KWNO for the text message and JSML KWNO for the BUFR message. The new precipitation forecast guidance products are available for the 0000 and 1200 UTC cycles.

Four stations that do not have observed precipitation data were not included in the developmental process. They were PGRO, PGWT, PWAK, and PTSA, and were added into the groups of stations in their corresponding geographical regions. The regional forecast equations of their corresponding regions are used to produce the precipitation forecasts for these stations.

A sample of the first operational alphanumeric (text) messages is shown in Figure 5. The text message provides predictions for probability of precipitation in a 6-hr period (P06), starting from 12 hours after the model cycle time, with a 6-hr increment, out to 72 hours. It also provides predictions for probability of precipitation in a 12-hr period (P12), starting from 18 hours after the model cycle time, with a 12-hr increment, out to 66 hours. The predictions of both P06 and P12 are provided in percent (%).

In the BUFR messages, the predictions for probability of precipitation in a 12-hr period are provided starting at 18 hours after the model cycle time, with a 6-hr increment, out to 84 hours. There is a 6-hr overlap between two adjacent 12-hr periods. The predictions for probability of precipitation in a 6-hr period are provided starting at 12 hours after the model cycle time, with a 6-hr increment, out to 84 hours. The predictions for probability of precipitation on the hour are provided starting at 6 hours after the model cycle time, with a 3-hr increment, out to 84 hours.

6. OPERATIONAL CONSIDERATIONS

A few words of caution in using the GFS MOS precipitation forecast guidance in operations are discussed in this section. The basic requirements for developing a set of robust MOS forecast equations include a stable numerical weather prediction (NWP) model to provide statistically sound output data and an archive of consistent historical observed data. The developmental data obtained from the GFS model output for the development of this forecast guidance were reasonably stable. The MDL archives of observed hourly data provided developmental data for 11 stations. Four stations (PGRO, PGWT, PWAK, and PTSA) did not have observed precipitation data for most (or all) of the hours throughout the day. No usable observed data were available for those four stations. The forecast equations implemented were regional equations and did not have contribution in terms of observed data from those four stations. Note that Region 1 has two stations, Regions 2 and 3 have multiple stations, and Regions 4 and 5 have single station each. The specific local characteristics of individual stations in Regions 1 through 3 may have been smoothed out in the regression analysis. Hence, the forecast equations for Regions 1 through 3 may be less sensitive to specific local characteristics than those for Regions 4 and 5.

Independent tests showed that the skill of GFS MOS precipitation forecast guidance had improvement over climate. The largest improvements which were at the first forecast projections of all three elements were around 15%. Further improvement of the operational precipitation forecasts is needed.

In the tropics, most of precipitation is from relatively small scale local convection. The convective plumes are of sub-grid scale relative to the NWP model grid, and cannot be properly resolved by the model. Another source of tropical precipitation is from typhoons and tropical storms (or tropical cyclones). These are vortex-type, relatively fast moving storms, which are rare events in the tropics. Due to the nature of regression analysis procedures used in the MOS equation development, which requires substantial amount of sample data, the MOS system cannot forecast these rare events.

At various island sites, there are locally specific characteristics of terrain and coastal areas that could impact the precipitation patterns. Examples may include, but are not limited to, high mountains on the island, lagoons on the coastline, etc. Prevailing wind direction and speed may also be factors that would impact the precipitation pattern on the island.

Field forecasters are reminded to take into account the locally specific features and adjust the MOS precipitation forecast guidance accordingly. Furthermore, in the event of typhoons or tropical cyclones, forecasters should use their own experience in predicting precipitation when these rare storms are over, or in the vicinity of, the station.

7. CONCLUDING REMARKS

The GFS MOS precipitation forecast guidance developed for the island sites in the tropical western Pacific Ocean has improvement over climate. In the forecast equations that produce the guidance, the average reduction of variance explained by predictors is small compared to that for the precipitation guidance developed for the CONUS, which is mostly in the mid-latitude. The deficiency may be due to the fact that the precipitation mechanism in the tropics is not fully understood.

The potential predictors offered to the regression analysis did not have sufficient correlation with the predictands. Better observed data, both in quantity and quality control are important for the development. Improvement in the forecast skill of the parent NWP model for the tropics will have the most important impact.

8. REFERENCES

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

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

Table 2. Island stations in geographical regions for which GFS MOS precipitation forecast guidance was developed.

Region 1	Region 2	Region 3	Region 4	Region 5
Koror (PTKR) Yap (PTYA)	Rota (PGRO)* Saipan (PGSN) Andersen AFB (PGUA) Agana (PGUM) West Tinian (PGWT)* Wake Island (PWAK)*	Majuro Atoll (PKMR) Bucholz AFB (PKWA) Truk (PTKK) Kosrae (PTSA)* Pohnpei (PTTP)	Pago Pago (NSTU)	Midway Islands (PMDY)

* **Remarks:** The stations marked with asterisks (*) were not included in the actual development process (regression analysis) due to missing observed data. Corresponding regional forecast equations were applied to these stations to provide forecasts in operations. Note that observed data were not used for predictors in the forecast equations.

Table 3. Groups of potential predictors.

GROUP NAME	PREDICTOR NAME	PREDICTOR TYPE	LAYER / LEVEL	BREAK POINTS	PHASE
Total Precipitation Predictors	3-hr total precipitation	Grid binary	N/A	0.01 in., 0.1 in., and 0.25 in.	On the projection hour, and 3 hours after
	6-hr total precipitation	Grid binary	N/A	0.01 in., 0.1 in., and 0.25 in.	On the projection hour, 6 hours before, 6 hours after, 12 hours before, and 12 hours after
	12-hr total precipitation	Grid binary	N/A	0.01 in., 0.1 in., 0.25 in., and 0.5 in.	On the projection hour.
Other Moisture Predictors	Mean relative humidity in an isobaric layer	Grid binary	500 mb – 300 mb	40%, 50%, 60%, 70%, and 80%	On the projection hour.
			850 mb – 500 mb	60%, 70%, and 80%	
			1000 mb – 850 mb	60%, 70%, and 80%	
	Precipitable water	Continuous	N/A	N/A	On the projection hour.
	Moisture divergence	Continuous	500 mb, 850 mb, and 1000 mb	N/A	On the projection hour.

Table 3. Groups of potential predictors. (Continued)

GROUP NAME	PREDICTOR NAME	PREDICTOR TYPE	LAYER / LEVEL	BREAK POINTS	PHASE
Dynamic Predictors	Earth oriented wind u-component	Continuous	300 mb, 500 mb, and 850 mb	N/A	On the projection hour.
	Earth oriented wind v-component	Continuous	300 mb, 500 mb, and 850 mb	N/A	On the projection hour.
	Wind speed	Continuous	300 mb, 500 mb, and 850 mb	N/A	On the projection hour.
	Vertical velocity	Continuous, and grid binary	300 mb and 850 mb	0, 12 pa/sec, 14 pa/sec, and 16 pa/sec	On the projection hour.
	Relative vorticity	Continuous	300 mb, 500 mb, and 850 mb	N/A	On the projection hour.
Instability Predictors	K-index	Continuous, and grid binary	N/A	30	On the projection hour.
Harmonic predictors	Sin(day of year)	Continuous	N/A	N/A	N/A
	Cos(day of year)	Continuous	N/A	N/A	N/A
	Sin(2*day of year)	Continuous	N/A	N/A	N/A
	Cos(2*day of year)	Continuous	N/A	N/A	N/A
Climatic predictors	Mean relative frequency of 6-hr precipitation	Continuous	N/A	N/A	N/A
	Mean relative frequency of 12-hr precipitation	Continuous	N/A	N/A	N/A

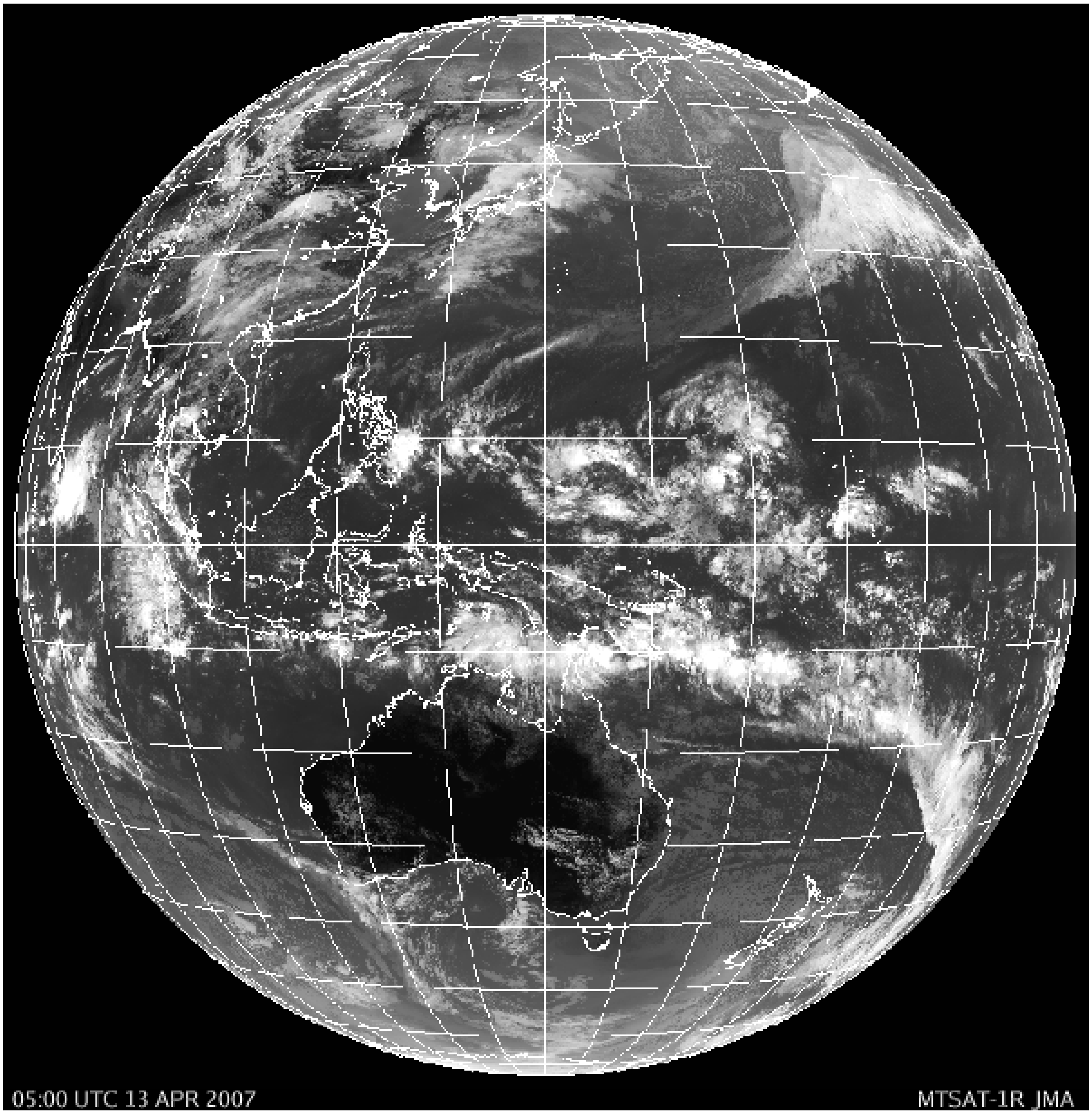

Figure 1. Example of satellite infrared imagery that shows convective clouds in the tropical western Pacific Ocean. (The imagery was downloaded from the web site of the Japanese Meteorological Agency's MTSAT series through the NOAA home page.)

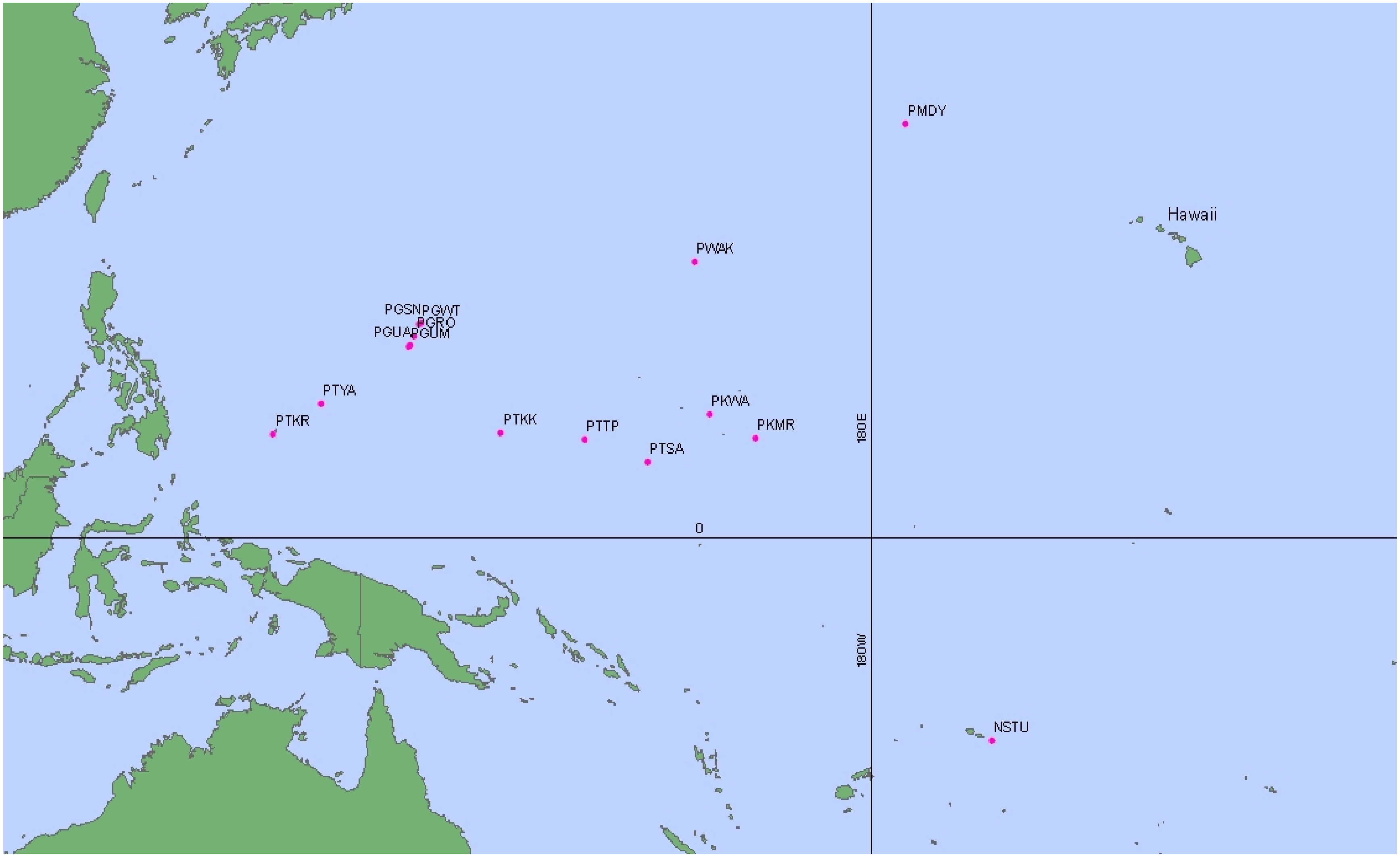

Figure 2. Locations of Island stations in the tropical western Pacific Ocean for which GFS MOS precipitation forecast guidance is provided.

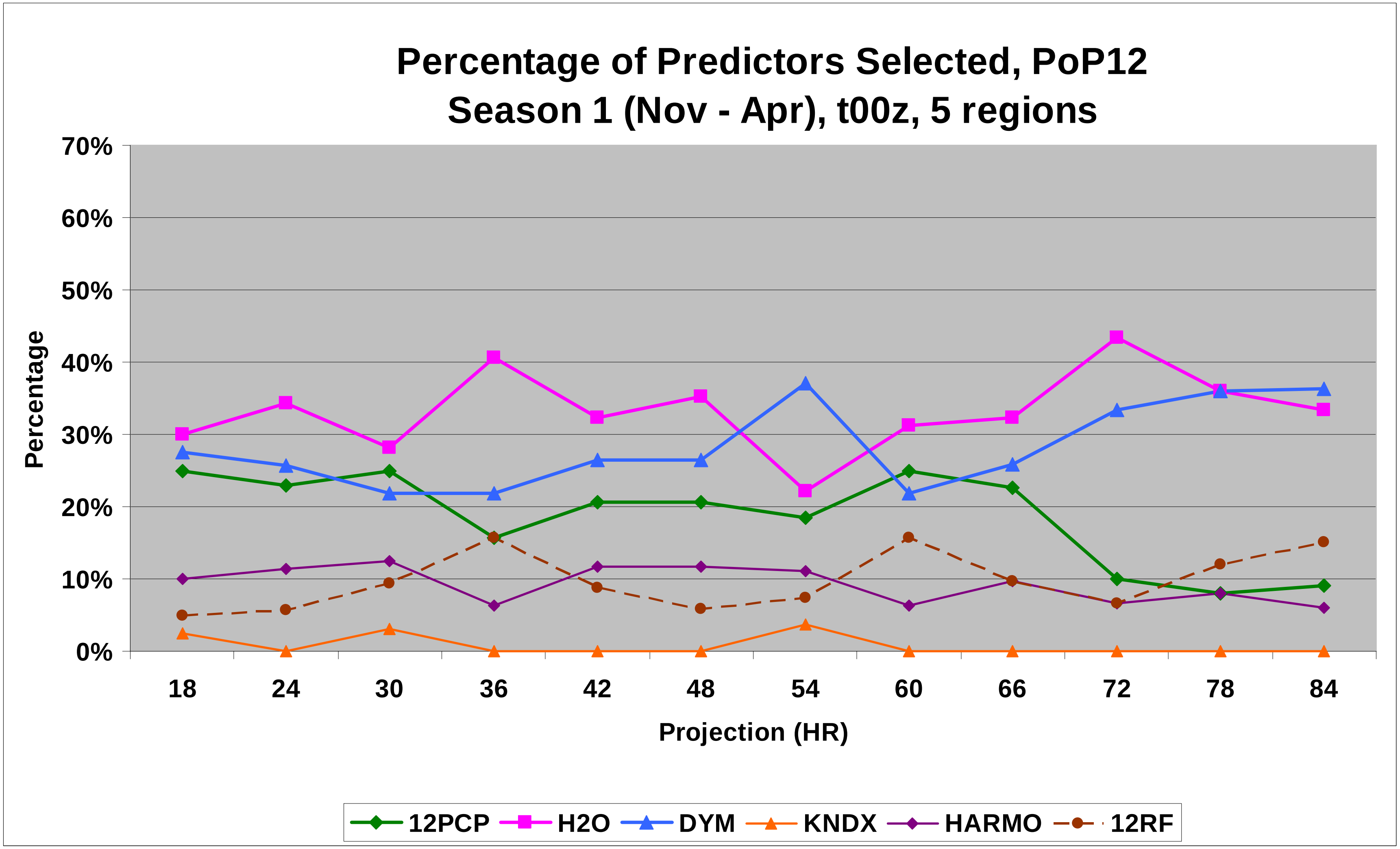

Figure 3(a). Selection of predictor groups for the 12-hr probability of precipitation forecast equations, season 1, 0000 UTC cycle, where 12PCP means the total precipitation predictors group, H2O means the other moisture predictors group, DYM means the dynamic predictors group, KNDX means the instability predictor group, HARMO means the harmonic predictors group, and 12RF means the climatic predictors group.

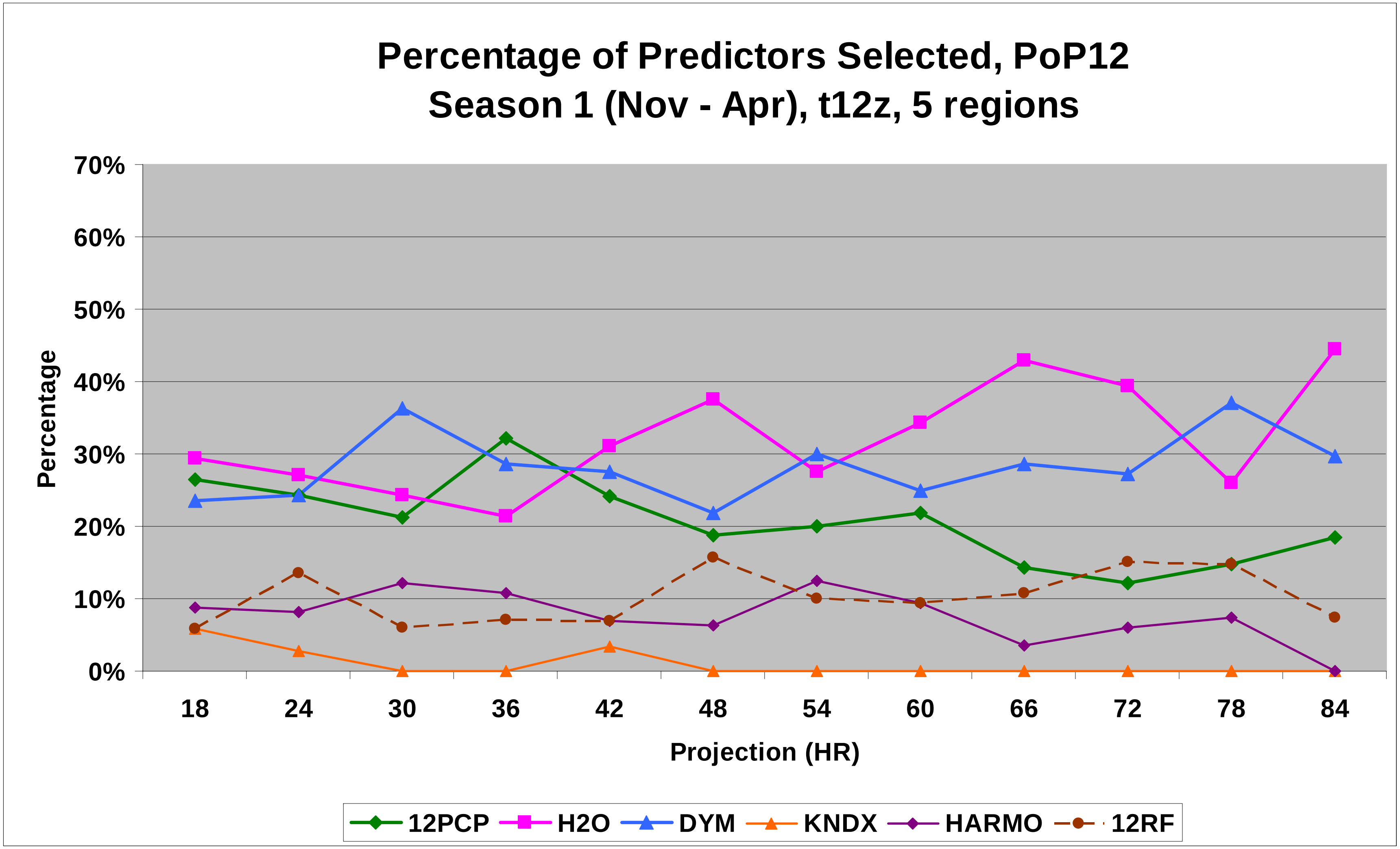

Figure 3(b). Same as Figure 3(a) except for season 1, 1200 UTC cycle.

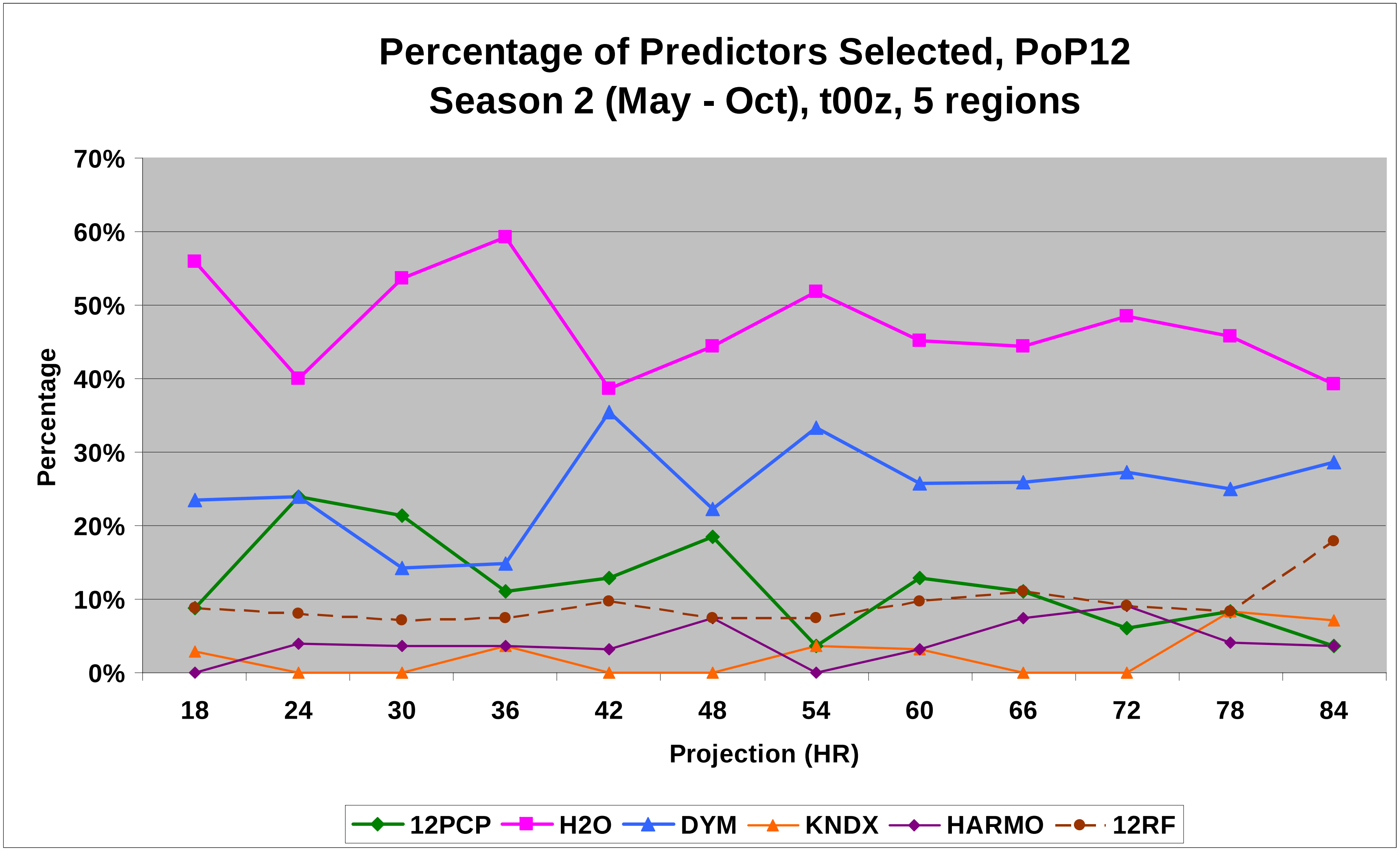

Figure 3(c). Same as Figure 3(a) except for season 2, 0000 UTC cycle.

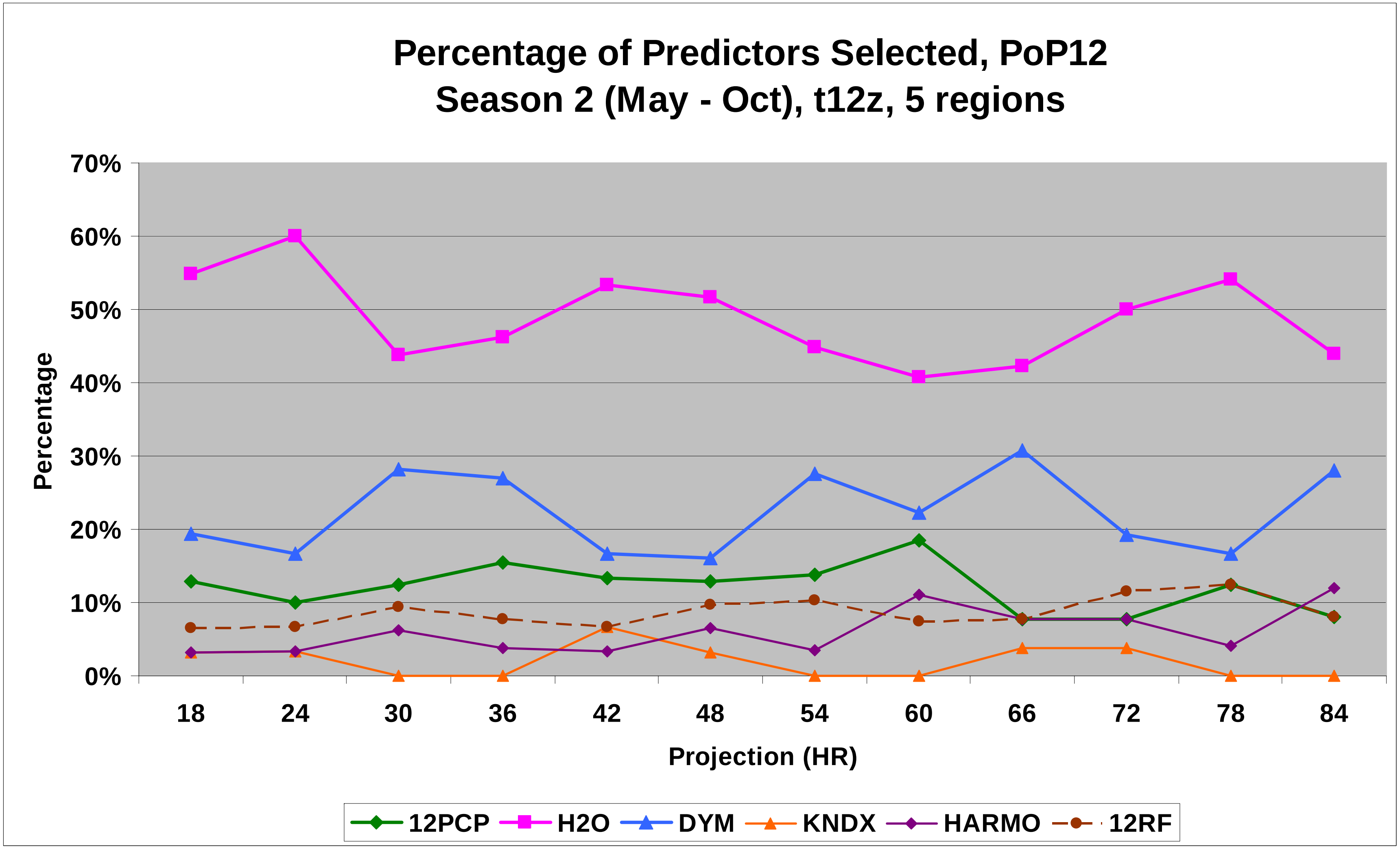

Figure 3(d). Same as Figure 3(a) except for season 2, 1200 UTC cycle.

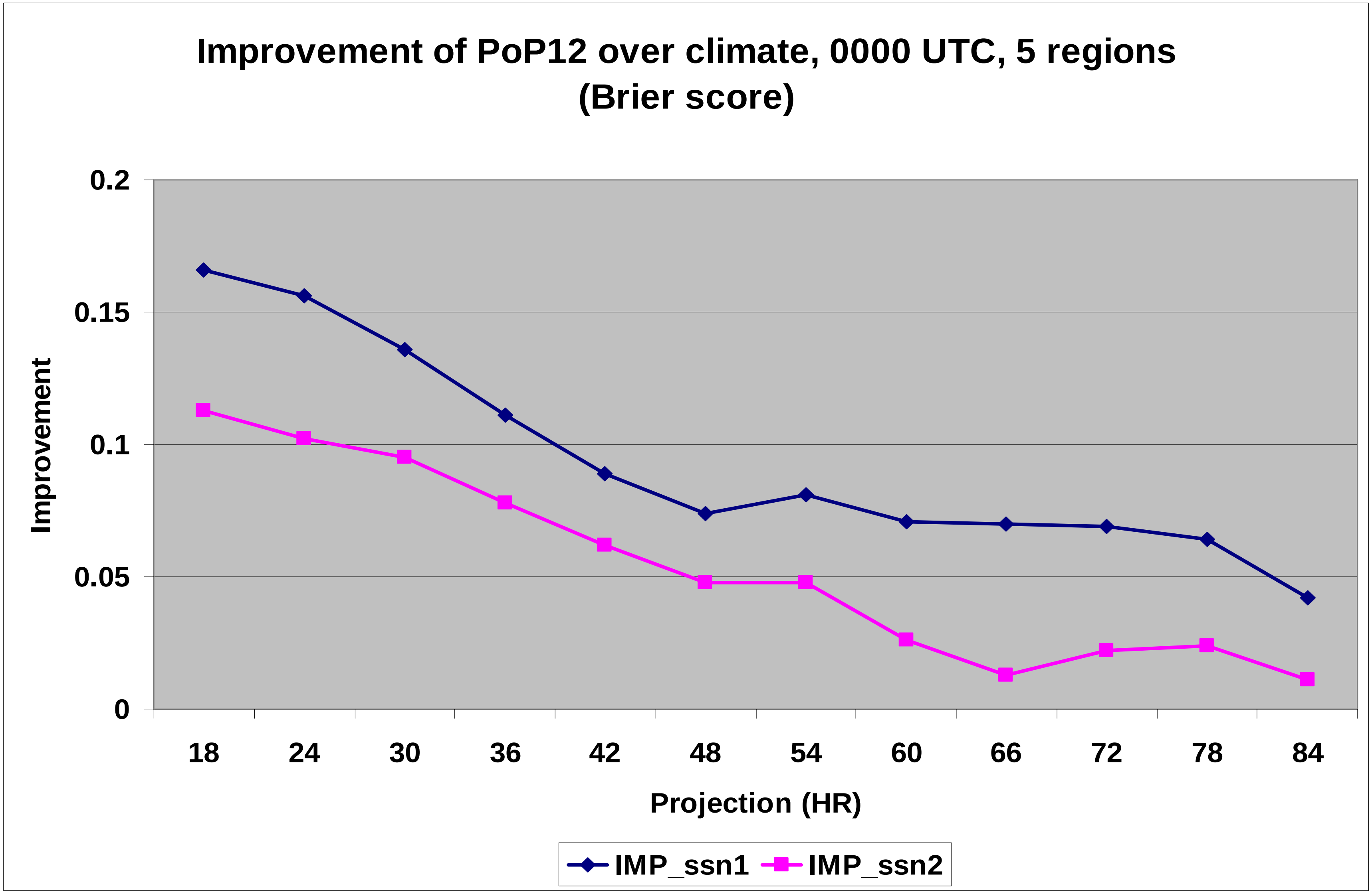

Figure 4(a). Improvement of PoP12 over climate averaged over 5 geographical regions, seasons 1 (ssn1) and season 2 (ssn2), 0000 UTC cycle.

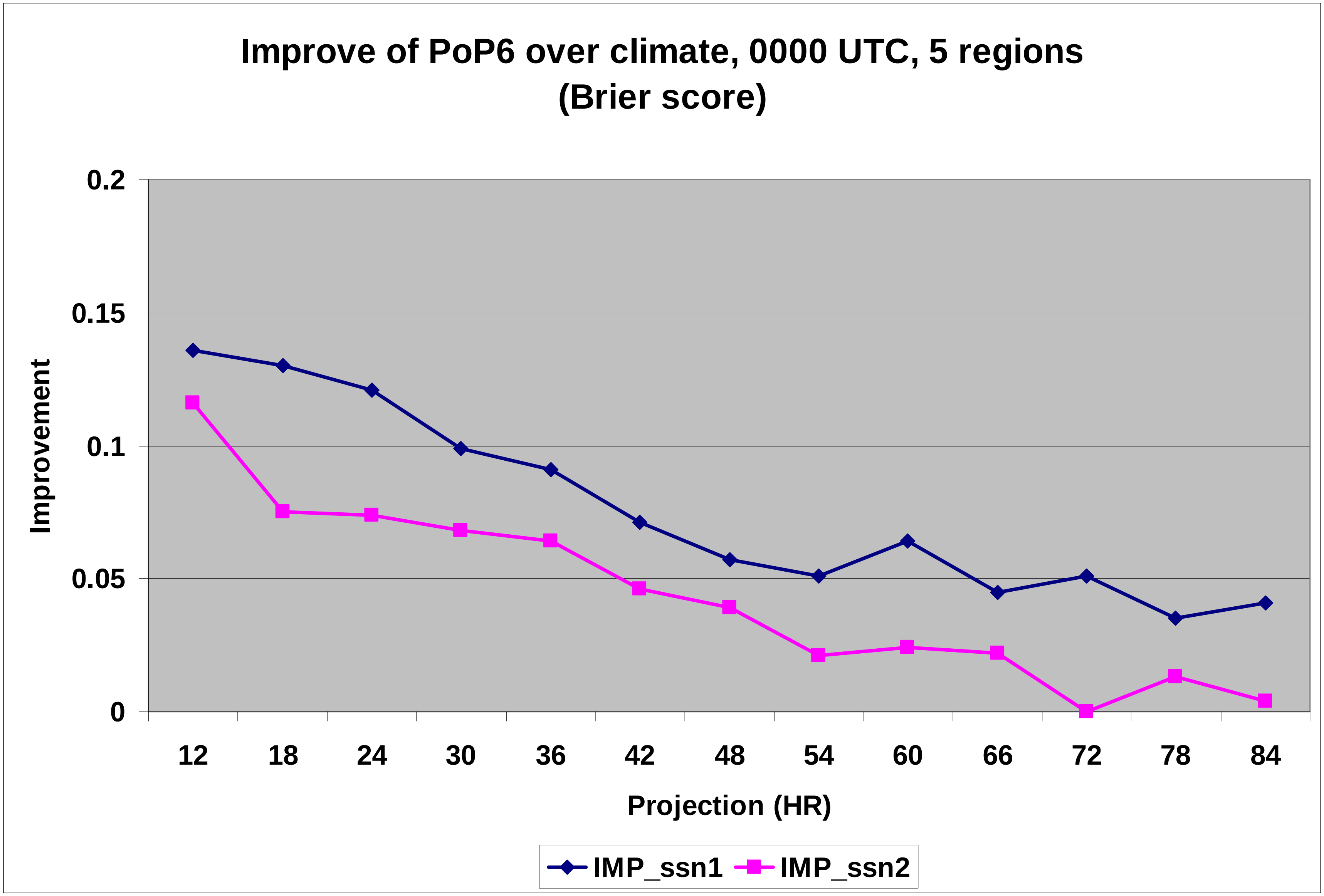

Figure 4(b). Same as Figure 4(a) except for PoP6.

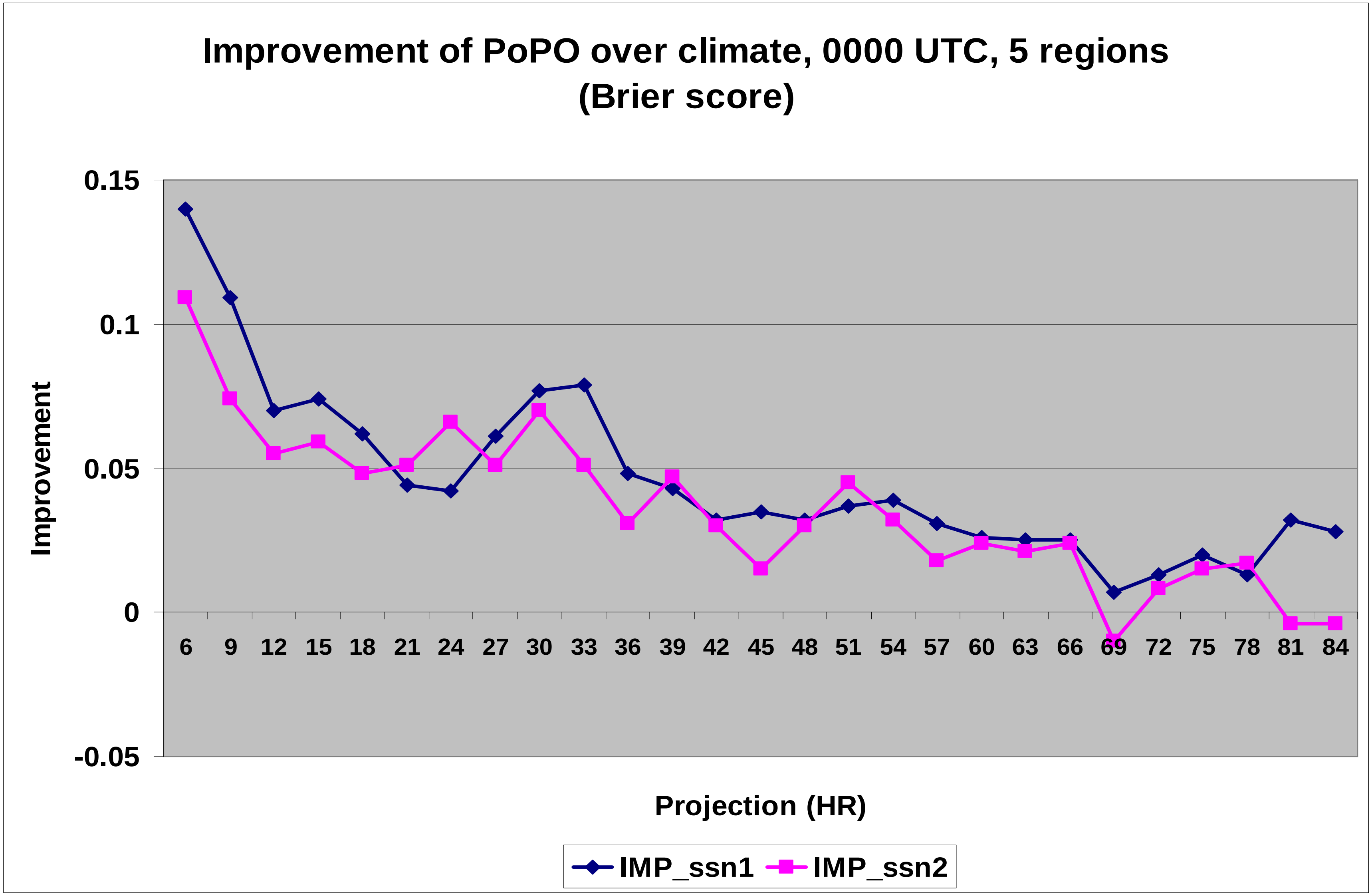

Figure 4(c). Same as Figure 4(a) except for PoPO.

```
PTKR   GFS MOS GUIDANCE    4/24/2007  1200 UTC
DT /APR  24/APR  25                /APR  26                /APR  27
HR   18 21 00 03 06 09 12 15 18 21 00 03 06 09 12 15 18 21 00 06 12
WDR  09 09 10 11 10 08 08 08 07 09 09 09 09 08 07 08 07 07 08 08 06
WSP  05 04 07 08 07 07 05 06 04 04 08 08 08 08 06 07 05 03 08 08 04
P06        46    60    60    49    50    50    42    53    43 37 35
P12              65          73          71          70       60

PGRO   GFS MOS GUIDANCE    4/24/2007  1200 UTC
DT /APR  24/APR  25                /APR  26                /APR  27
HR   18 21 00 03 06 09 12 15 18 21 00 03 06 09 12 15 18 21 00 06 12
WDR  99 09 08 08 08 08 99 99 99 08 08 08 07 07 99 99 99 08 08 07 99
WSP  99 12 15 16 14 12 99 99 99 13 16 16 15 13 99 99 99 13 17 14 99
P06         5     5     8    19    21     9    15    14    14 10 14
P12               5          21          24          26       19

PGSN   GFS MOS GUIDANCE    4/24/2007  1200 UTC
DT /APR  24/APR  25                /APR  26                /APR  27
HR   18 21 00 03 06 09 12 15 18 21 00 03 06 09 12 15 18 21 00 06 12
WDR  08 08 08 08 08 09 09 09 08 08 08 08 07 07 07 08 08 09 08 08 08
WSP  15 15 17 16 14 13 13 11 12 13 16 16 14 13 14 15 15 15 16 14 13
P06         0     1     5     9    15     5    11     7    12  7 12
P12               1           9          15          18       15

PKMR   GFS MOS GUIDANCE    4/24/2007  1200 UTC
DT /APR  24/APR  25                /APR  26                /APR  27
HR   18 21 00 03 06 09 12 15 18 21 00 03 06 09 12 15 18 21 00 06 12
WDR  06 07 07 08 08 08 08 08 08 08 07 08 08 08 08 08 09 08 07 08 08
WSP  11 11 12 09 09 09 08 08 08 11 12 11 13 11 10 10 10 10 11 09 09
P06        64    56    58    65    64    56    55    57    51 51 52
P12              84          80          84          72       74

PTSA   GFS MOS GUIDANCE    4/24/2007  1200 UTC
DT /APR  24/APR  25                /APR  26                /APR  27
HR   18 21 00 03 06 09 12 15 18 21 00 03 06 09 12 15 18 21 00 06 12
WDR  99 07 06 05 99 99 99 99 99 06 05 03 99 99 99 99 99 07 06 99 99
WSP  99 07 09 11 99 99 99 99 99 08 09 09 99 99 99 99 99 07 09 99 99
P06        81    67    66    70    53    59    65    62    64 60 61
P12              96          87          84          83       81

NSTU   GFS MOS GUIDANCE    4/24/2007  1200 UTC
DT /APR  24/APR  25                /APR  26                /APR  27
HR   18 21 00 03 06 09 12 15 18 21 00 03 06 09 12 15 18 21 00 06 12
WDR  10 09 09 08 09 10 10 10 10 10 10 10 09 10 10 09 09 09 09 10 10
WSP  09 10 09 08 07 06 06 06 08 09 10 09 09 09 08 08 10 11 10 09 09
P06        34    36    39    43    42    37    41    41    41 37 41
P12              66          60          52          63       58

PMDY   GFS MOS GUIDANCE    4/24/2007  1200 UTC
DT /APR  24/APR  25                /APR  26                /APR  27
HR   18 21 00 03 06 09 12 15 18 21 00 03 06 09 12 15 18 21 00 06 12
WDR  16 16 17 17 16 14 16 16 14 15 15 16 10 10 13 16 17 19 20 30 34
WSP  07 07 08 07 05 03 03 03 04 05 07 05 04 04 03 04 04 05 06 04 02
P06         0     1     0     0     0     0     0     1     0  3  0
P12               4           0           3           1        3
```

Figure 5. Sample of the first operational alphanumeric messages after the implementation at 1200 UTC cycle, April 24, 2007.