Enhancement of SHIPS Using Passive Microwave Imager Data

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1. Summary

All of the Year 1 objectives of this project have been met, with the exception of receiving feedback from the forecasters based on *direct* experiences with the Statistical Hurricane Intensity Prediction Scheme with Microwave Imagery (SHIPS-MI) in 2005. SHIPS-MI forecasts were only generated at UAH and posted to the web during 2005, but not evaluated by forecasters. Feedback was received based on presentations at the end of the season instead. SHIPS-MI forecasts are now being provided to forecasters during 2006.

Documentation and software were initially provided to NHC, while SHIPS-MI was run at UAH and posted to a web page in near real time. The software was tested at NHC in January, and has run there for the first Atlantic and Eastern North Pacific storms of 2006. It continues to run in parallel at UAH. Output from the Western North Pacific version, STIPS-MI, is sent in ATCF format from UAH to Colorado State University. From there, it is relayed to the Joint Typhoon Warning Center. The SHIPS-MI content and output format were both adjusted based on feedback from NHC during the winter, in order to make SHIPS-MI look more similar to the already familiar SHIPS.

The SHIPS-MI training sample was extended back from 1995 to 1988 during the winter and spring. After this and the changes that had been suggested by NHC, SHIPS-MI forecasts were re-run for the 2005 storms. Results were presented at the Interdepartmental Hurricane Conference. After the 2005 best tracks were issued, these were added to the training sample and the SHIPS-MI regression coefficients were re-derived. Small changes that Mark DeMaria implemented in SHIPS for 2006 were also implemented in SHIPS-MI. This newest version of SHIPS-MI is ready for testing at NHC, and STIPS-MI is ready for testing (via the transfer of ATCF files) by JTWC.

More details on these Year 1 activities are presented below. Much of this was summarized in the semi-annual report and/or the renewal proposal.

2. Implementation

Upon initiation of the project in August, documentation was available on the webpage: http://nsstc.uah.edu/~tjones
This included past conference presentations, a manuscript that had been submitted to *Weather and Forecasting*, and descriptions of the SHIPS-MI input and output. Forecasts for active tropical cyclones were also posted to that page. Since then, the *Weather and Forecasting* manuscript has been accepted for publication and the readme documentation on the web page has been streamlined.

Source code (in the IDL language) and shell scripts for generating SHIPS-MI forecasts were sent to NHC in November. There were a few iterations of corrections / simplifications made to the source code, followed by a visit to NHC in early January. During this visit, Alison Krautkramer was able to successfully generate test SHIPS-MI forecasts at NHC. Discussions with Krautkramer, Chris Sisko, and Chris Landsea, in particular, led to a simplified format for additional SHIPS-MI output files. After a few more iterations of fixing problems, the code seems to be working well on an NHC computer. SHIPS-MI forecasts have been generated there in real-time during the 2006 season already. The process begins with the acquisition of satellite data by NHC and ends with text output files going to the printers for consideration by NHC forecasters. Minor corrections to the software are likely to continue. Some recent examples include correcting a bug in which microwave data contaminated by land had been accidentally used in forecasts, and adjusting a read program to account for unannounced changes in the AMSR-E input file format.

SHIPS-MI was also discussed with Stacy Stewart during the NHC visit. Stewart and Landsea both suggested making changes to SHIPS-MI in order to improve the long range forecasts, even though the benefit from adding microwave data is realistically confined to the first ~48 hours of the forecast. In response to this feedback, some of the SHIPS predictors that are useful at 48-120 hours were added to SHIPS-MI. The SHIPS-MI regression coefficients were re-derived including these predictors, and also using an expanded training sample (after adding microwave data for 1988-1994 to the sample that already included 1995-2004). For this new version of SHIPS-MI, errors based on the training sample tend to be ~5% smaller than those from SHIPS for the first 36 hours of the forecast, and roughly comparable to those from SHIPS for the remaining forecast out to 120 hours.

Based on suggestions from Landsea, Sisko, and Stewart, the new version of SHIPS-MI was used to regenerate forecasts for the 2005 cases in which we initially collected forecast information. Some initial results were presented at the 2006 Interdepartmental Hurricane Conference and are repeated below.

Finally, one of the suggestions from Stewart was to refine the vertical wind shear predictor that is used in the forecasts. For many cases, particularly late last season, the shear averaged over a large radius around the tropical cyclone does not accurately represent the shear that is being experienced by the tropical cyclone. Toward this end, a SHIPS-MI web page is under development that allows users to adjust the input value for vertical wind shear or any other predictor. This functionality can be used to fine tune a particular forecast, or simply to explore the behavior of the statistical model in response to varying input conditions. Currently this web page is offline and still under development using archived forecasts, not current forecasts. It is expected to go online at some point during the 2006 season.

Implementation of STIPS-MI *at* JTWC is more problematic and is not anticipated during 2006. Running STIPS-MI requires inputs from STIPS diagnostic files and microwave brightness temperature files. The STIPS files are sent from the Naval Research Laboratory (NRL) in Monterey to JTWC, and retrieved from JTWC by UAH. The microwave data is downloaded at UAH and STIPS-MI is run here. Output files in the ATCF format are ftp'd to Colorado State University, and retrieved from there by JTWC. This process prevents timely forecasts from being available during the operational forecast cycle. Instead, forecasts are provided with a six-hour lag. For example, the *x*-hour STIPS-MI guidance sent to JTWC for consideration in its 12 UTC forecast is actually an *(x+6)*-hour forecast based on inputs that were valid at 06 UTC. This process is based on discussions during the 2006 Interdepartmental Hurricane Conference. Due to

mis-communication concerning the file naming convention, and the slow start to the Western North Pacific season, STIPS-MI forecasts were not successfully sent until July (tropical cyclone 04W). Based on analysis from the developmental sample, STIPS-MI forecasts (relative to STIPS) appear less promising than SHIPS-MI forecasts (relative to SHIPS). This, together with the time lag, lowers our expectations for STIPS-MI to be useful to JTWC. We are nonetheless anxious to see how it performs during 2006.

3. Results for the 2005 Atlantic Season

Forecasts for the 2005 season were re-created after the developmental sample had been extended to include 1988-2004 and the forecast scheme extended to 120 hours. This was done before 2005 was added to the developmental sample, and before other final changes were made for 2006. The results below are based on verification using NHC's operational intensity estimates, since the 2005 best tracks were not yet complete at the time these tables were generated.

SHIPS-MI forecasts are only generated when the satellite data is available during an appropriate time window. The forecasts here use only satellite data that was collected between T-4 and T-1 hours (e.g., 0200 – 0500 UTC for a 0600 UTC forecast). Using this criterion, we were able to generate SHIPS-MI forecasts for about 25% of all synoptic times. This fraction should have been higher (30-40%), but some forecasts were missing due to network, power, or scripting issues at UAH. In operations, some forecasts may be available slightly later than T-1 hours, but the analysis here assumes a worst-case-scenario.

For the homogeneous sample of forecasts where SHIPS-MI can be compared against SHIPS, SHIFOR, and OFCL, we get the RMS errors in Table 1 and bias in Table 2. These exclude any forecasts in which landfall occurred before the forecast verified.

Table 1. RMS Errors for 2005 forecasts, excluding landfalls.

	12-h	**24-h**	**36-h**	**48-h**	**72-h**	**96-h**	**120-h**
# fcsts	*115*	*103*	*94*	*85*	*71*	*58*	*45*
SHIPS-MI	8.5	12.4	16.0	19.3	21.9	22.5	27.7
SHIPS	8.7	12.6	16.4	18.7	21.3	21.7	26.3
OFCL	7.4	11.1	14.6	17.7	20.9	22.9	28.4
SHIFOR	9.2	14.0	18.8	21.0	24.8	25.4	25.5

Table 2. Bias for 2005 forecasts, excluding landfalls.

	12-h	**24-h**	**36-h**	**48-h**	**72-h**	**96-h**	**120-h**
SHIPS-MI	-0.1	0.1	1.0	0.2	-0.2	0.8	3.5
SHIPS	-0.9	-1.1	-0.6	-2.1	-3.7	-3.2	-3.4
OFCL	0.2	-0.5	0.0	-2.7	-4.9	-5.1	-4.9
SHIFOR	-0.8	-1.6	-2.1	-5.0	-6.6	-6.3	-6.7

Generally, SHIPS-MI forecasts are within a few knots of the SHIPS forecasts. For short range forecasts (< 48 h), SHIPS-MI is usually nudging the SHIPS forecast in the correct direction, although the opposite is sometimes the case. For the 24 h forecasts, SHIPS-MI is more accurate than SHIPS 60% of the time. These differences for 2005 are smaller than expected; errors in the training sample are generally around 5% smaller for SHIPS-MI than for SHIPS.

Individual 2005 Storms

For most storms, only a few forecasts are available for analysis and it is difficult to make meaningful statements about forecast quality in those storms. Those with at least ten 36-hour forecasts are listed in Table 3. In some cases, the scripts at UAH did not keep up with the record-setting pace of storm development in 2005 (i.e., a storm name was not added to the script until after forecasts had been missed; the scripts have been corrected to prevent this from happening in the future). In other cases, the sun-synchronous DMSP satellites visit parts of the Western Caribbean and Gulf of Mexico at a bad time of day (near 00 and 12 UTC) for the data to be included in the normal forecast cycle. Dealing with this latter issue will be a point to address with NHC – for example, can a SHIPS-MI forecast be at all useful if it arrives late? Is it preferable to have a forecast that uses data several (>4) hours old? For 2006, UAH makes extra runs at 2 and 3 hours after the synoptic time. In some cases this will post an extra SHIPS-MI forecast to the web that had not been available during the operational forecast issuance.

Table 3. 36-h RMS errors for those storms that had at least ten SHIPS-MI forecasts.

Storm	# fcsts	SHIPS-MI	SHIPS	OFCL	SHIFOR
Emily	13	24.9	27.3	18.5	33.5
Irene	15	12.3	8.6	8.8	8.2
Maria	12	8.7	9.9	12.3	10.5
Epsilon	13	15.2	17.6	17.1	15.1

Results From the Training Sample

Beginning with 1995, infrared (IR) and oceanic heat content (OHC) data is available for use in SHIPS. That data is *not* used in SHIPS-MI, because an insufficient number of forecasts have the full combination of microwave, infrared, and oceanic heat content data. SHIPS is developed from a 1982-2005 training sample, with the IR and OHC correction in the 1995-2005 sample. SHIPS-MI is now developed from a 1988-2005 training sample. A homogeneous sample of 1995-2005 forecasts is used to compare SHIPS-MI and SHIPS forecast errors. Note that this is a dependent subset of the training samples for both SHIPS and SHIPS-MI. This is a slight update to the figures shown in the semi-annual progress report, which showed results for the 2005 model developed from a 1988-2004 training sample.

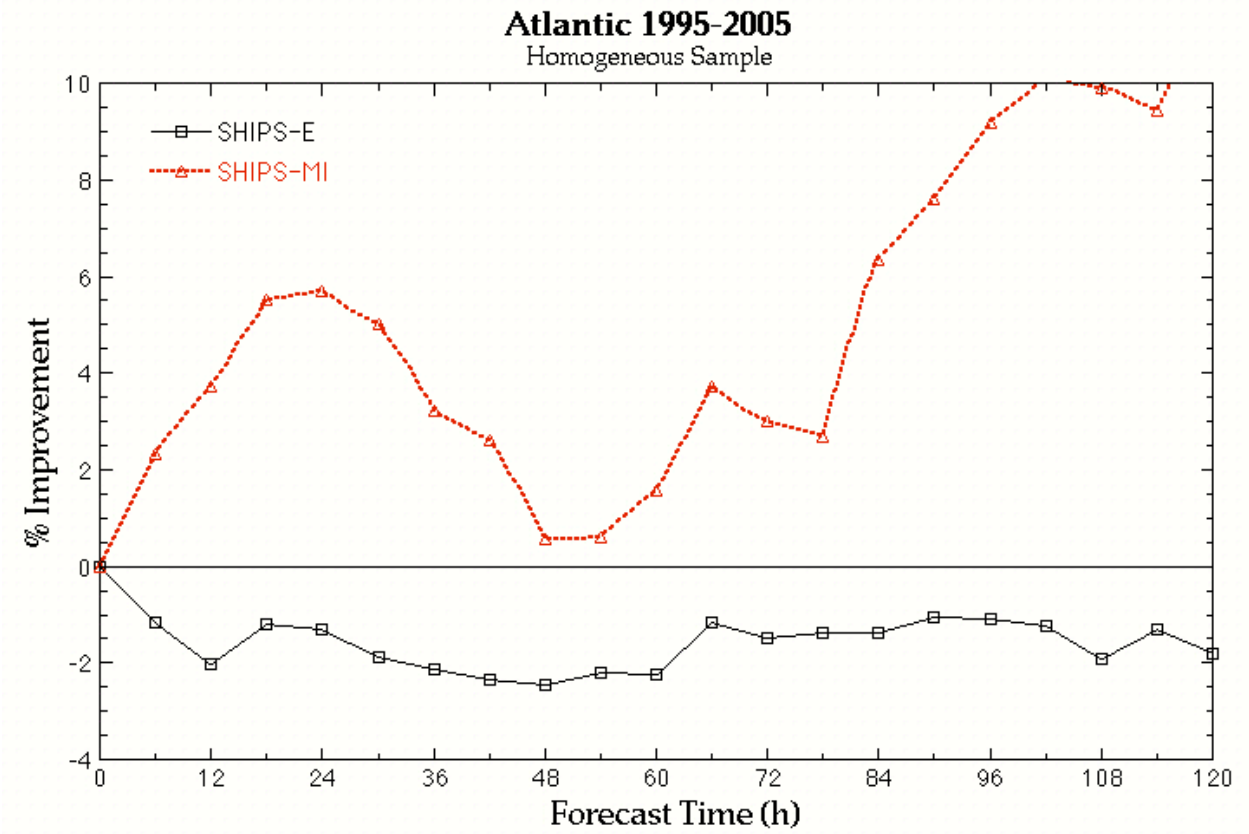

Figure 1. Percentage improvement of Atlantic SHIPS-MI mean absolute errors, compared to SHIPS using the 2006 version of the model. A homogeneous 1995-2005 sample is used for verification, allowing inclusion of the IR and OHC corrections in SHIPS. This is a subset of the dependent training sample for both SHIPS-MI and SHIPS. "SHIPS-E" is SHIPS without the IR and OHC corrections.

Mean absolute errors are normalized against those from SHIPS in Fig. 1 for the Atlantic and Fig. 2 for the Eastern North Pacific. That is, the zero line represents forecasts generated using the 2006 operational coefficients for the SHIPS model. Atlantic SHIPS-MI mean absolute errors are up to 6% smaller than those from SHIPS at 18-30 hours (Fig. 1). The apparent improvements beyond 60 hours should be disregarded, as the small sample size for long-term forecasts makes these insignificant. The black line in Fig. 1 shows the detrimental effect of removing IR and OHC inputs from SHIPS ("SHIPS-E"). The forecasts are up to about 2% worse than SHIPS if no satellite data is included. That is, the IR and OHC inputs reduce the errors by 2% and the microwave inputs further reduce the errors by up to 6%. For the Eastern North Pacific (Fig. 2), SHIPS-MI mean absolute errors are also 6% smaller than SHIPS at 24 hours.

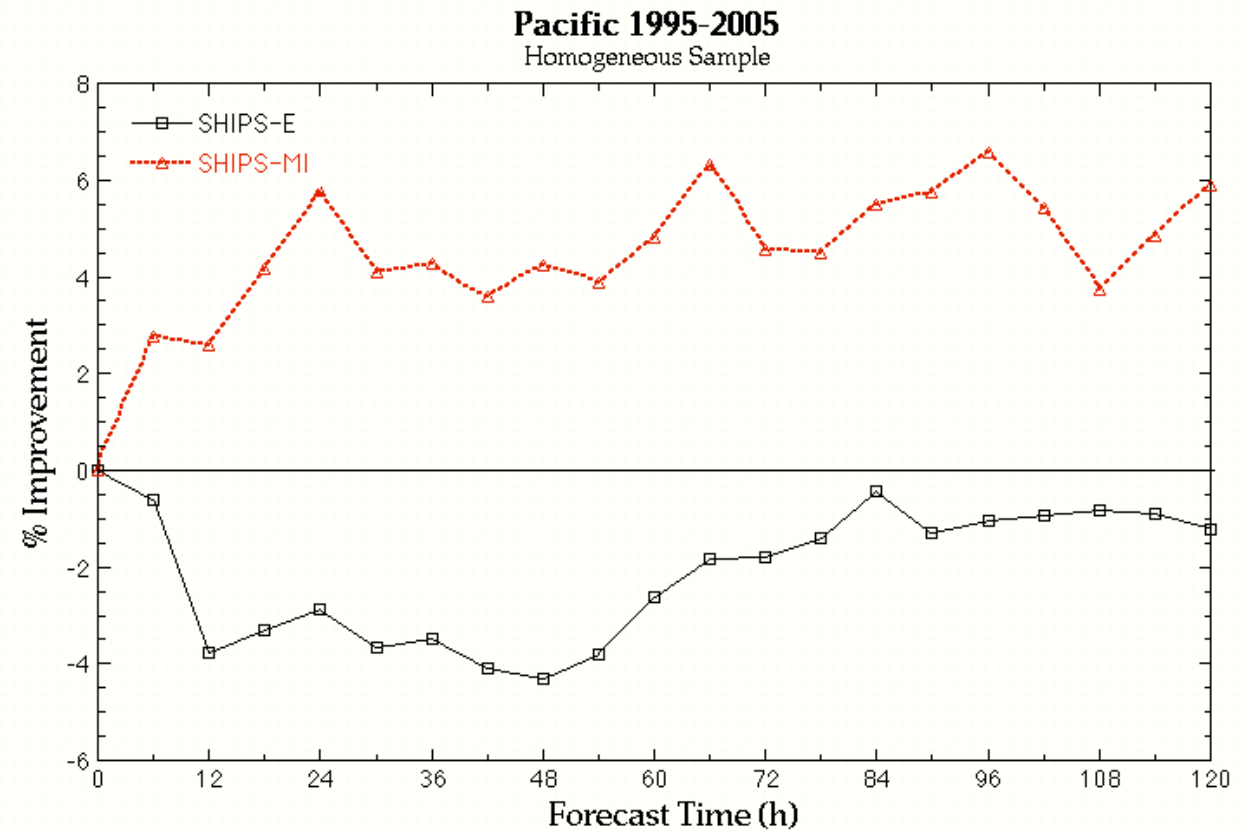

Figure 2. As in Figure 1, but for the Eastern North Pacific.

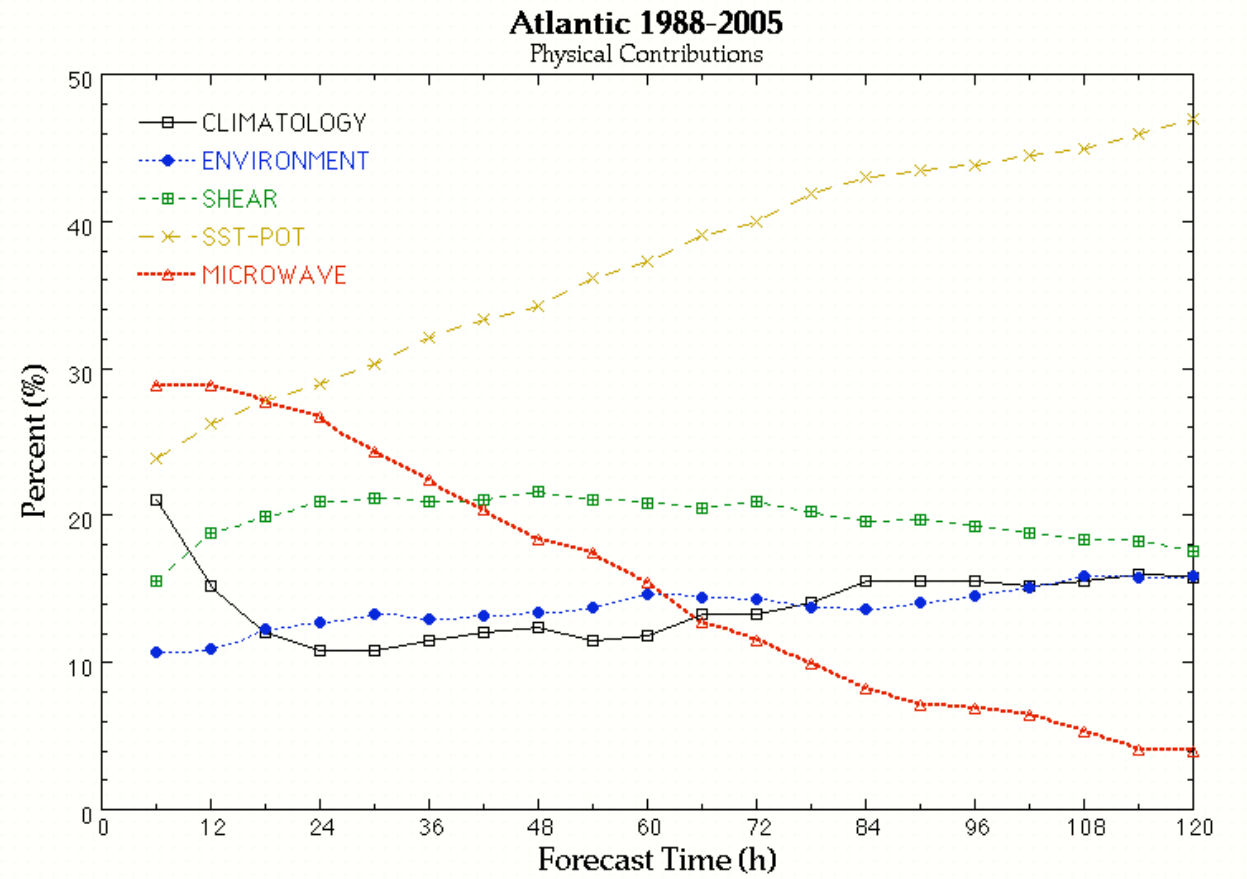

Figure 3. Mean relative contribution to Atlantic SHIPS-MI forecasts from predictors grouped together as microwave; potential for intensification based on sea surface temperature (SST); vertical wind shear; other environmental variables; and climatology and persistence. This accounts for related predictors that sometimes have offsetting effects. At any given forecast period, the lines sum together to 100%.

Fig. 3 shows the relative contribution to the Atlantic SHIPS-MI forecasts from predictors grouped together as microwave; potential for intensification based on sea surface temperature (SST); vertical wind shear; other environmental variables; and climatology and persistence. Since SHIPS-MI is a linear regression model, the forecast intensity change is the sum of individual contributions from each predictor. The contributions from related terms are added together, using the groupings listed above. The relative contributions in Fig. 3 are based on the absolute values of the total contributions from each grouping. For example, if the two SST-related terms yield a net +10 kt to a particular forecast, the two microwave-based terms yield a net –10 kt to the forecast, and all others add 0 kt, then the SST and microwave groupings each have a 50% contribution to the total forecast. While SST is generally the most important type of input in Fig. 3, the microwave predictors are more important than vertical wind shear in the first 36 hours. There is very little contribution from the microwave predictors at 72 hours and beyond – it would be alarming if this were not the case.

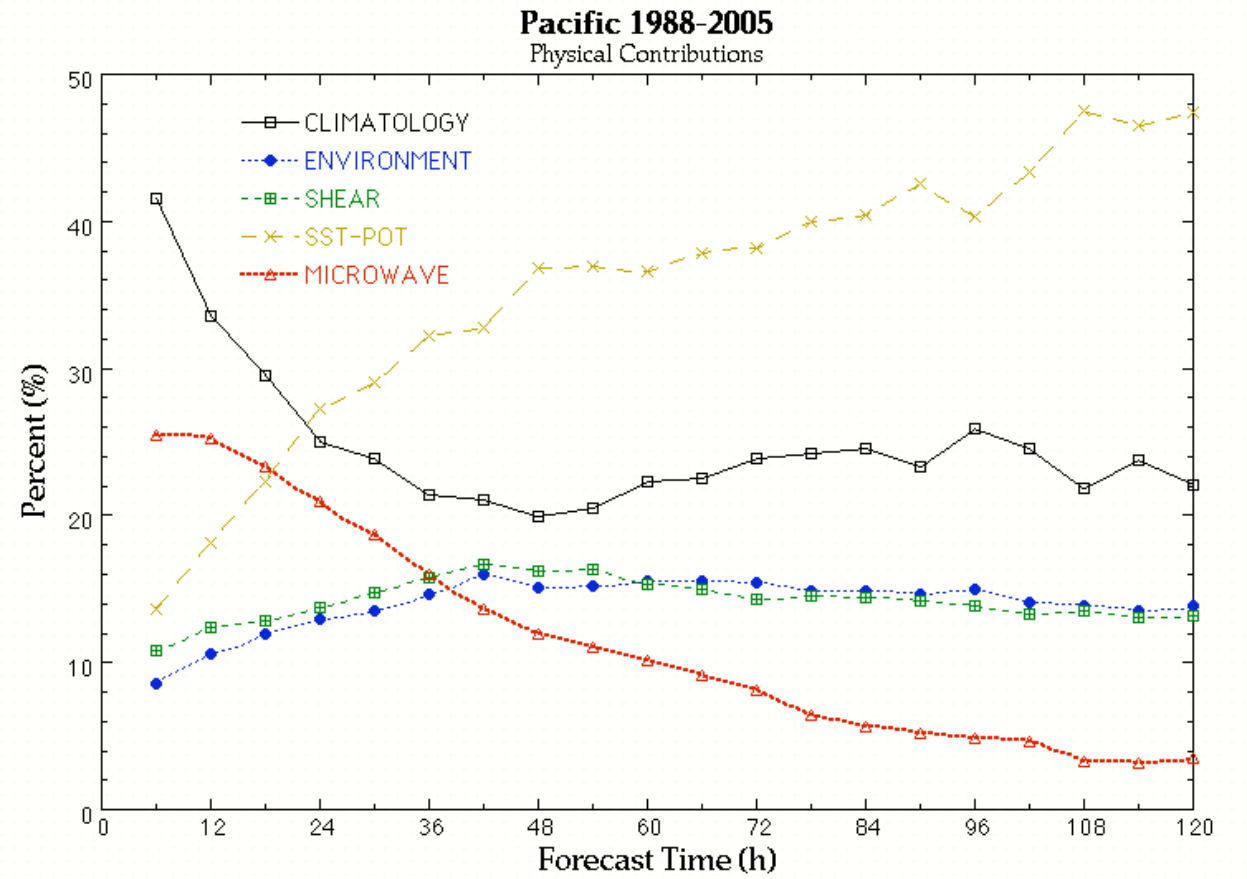

Figure 4. As in Figure 3, but for the Eastern North Pacific.

Similarly, Fig. 4 shows the contributions to the Eastern North Pacific SHIPS-MI. Climatology and persistence has the greatest impact in the first 18 hours, followed by the microwave predictors. SST-based predictors dominate after 24 hours. The microwave predictors provide even less contribution to the long range forecasts for the Eastern North Pacific than for the Atlantic.

Plans for 2006 Hurricane Season

SHIPS-MI has been updated to include 2005 in the training sample. New coefficients for the predictors have been provided to NHC. As noted before, the source code for generating SHIPS-MI forecasts has already been tested at NHC, and some corrections have been made based on these tests. TMI, SSM/I, and AMSR-E satellite data have all been acquired by NHC for real-time use with SHIPS-MI.

SHIPS-MI forecasts are being generated at both NHC and UAH in real time during 2006. UAH will monitor the forecasts, looking for either deficiencies or for instances where consideration of SHIPS-MI could substantially alter an operational forecast. STIPS-MI forecasts are generated at UAH and transferred in ATCF format to JTWC (via ftp through Colorado State University).

Contingencies will hopefully be developed (coordinating with the NHC forecasters for an acceptable solution) to make use of satellite data that arrives at inopportune times, particularly in

the Western Caribbean and Gulf of Mexico where landmasses are threatened and SSM/I data is often late. One such contingency at UAH involves running SHIPS-MI at additional times that are not tied to the operational forecast cycle.