Enhancement of SHIPS Using Passive Microwave Imager Data

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1. SHIPS-MI Project Summary

The Statistical Hurricane Intensity Prediction Scheme with Microwave Imagery (SHIPS-MI) was slightly modified to more closely match the way SHIPS is constructed and presented. It was run locally at the National Hurricane Center during 2006 for the Atlantic, East Pacific, and Central Pacific basins (independent of it being run at UAH). Performance was disappointing in the Atlantic and Central Pacific, but the errors were slightly smaller than those from SHIPS (Table 1). In the East Pacific, however, SHIPSMI had smaller mean absolute errors than any of the other guidance, for most forecast durations (Table 2). Afterwards, the 2006 season was added to the developmental sample and regression coefficients re-derived by UAH. This revised 2007 version has been sent to NHC to be run locally there again. The procedures for making this end-of-season update have been simplified and documented, in order that NHC can maintain SHIPS-MI itself for future seasons, if it so desires.

In most cases, the SHIPS-MI forecast is within a few knots of the SHIPS forecast. Occasionally the differences are much greater (10 kt or more). Of course there are some cases where the SHIPS forecast is more accurate, but more often the SHIPS-MI forecast is more accurate. The error statistics are on average smaller for SHIPS-MI (Tables 3 and 4). The major drawback is that SHIPS-MI is not reliably available every six hours; it is only run for those forecast periods where recent SSMI, TMI, or AMSR-E data are available.

A Western Pacific version (STIPS-MI) was run at UAH during 2006. Results were briefly sent to JTWC. However, substantial changes were soon required when JTWC stopped producing the large-scale diagnostic files used as input. Most of the remainder of the 2006 season was spent modifying STIPS-MI for use with the ensemble-STIPS large scale diagnostic files from NRL-Monterey (Buck Sampson). The microwave inputs to the Western Pacific forecasts had not been as useful as for the Atlantic and Eastern Pacific forecasts. This, combined with data latency issues in generating and transmitting Western Pacific forecasts, prevent STIPS-MI from being useful at this time. A 2007 version is not currently running. Some alternative approaches may be tried in the future.

Table 1. Atlantic basin 2006 mean absolute errors (kt) for Decay SHIPS-MI (DSHM); Decay SHIPS (DSHP); NHC official forecast (OFCL); SHIFOR 5-Day (SHF5); Logistic Growth Equation Model (LGEM); GFDL Interpolated (GFDI); and NOGAPS Interpolated (NGPI). Errors are taken from the homogeneous set of forecasts (number listed in bottom row) where guidance is available from all these sources. The lowest mean absolute errors at a given forecast duration are marked in bold italics. Note that inland decay is not routinely accounted for in the SHIPS-MI output, but can be added as the difference of Decay SHIPS minus SHIPS.

Duration	*0*	*12*	*24*	*36*	*48*	*60*	*72*	*84*	*96*	*108*	*120*
DSHM	**2.5**	**6.4**	**9.4**	**13.2**	**16.2**	**20.6**	**23.2**	**25.4**	**23.4**	**21.7**	**21.3**
DSHP	**2.4**	**6.5**	**9.6**	**13.7**	**17.2**	**22.3**	**24.1**	**24.6**	**22.2**	**19.0**	**16.2**
OFCL	***1.8***	6.4	10.4	13.7	15.3		20.7		21.8		17.3
SHF5	2.4	6.4	8.3	***10.2***	***11.2***	***12.8***	***12.9***	***13.7***	***11.3***	***13.0***	***12.4***
LGEM	2.4	***6.4***	***8.1***	11.2	14.2	17.7	19.0	20.1	19.4	17.6	16.4
GFDI	2.8	7.7	9.5	11.4	13.3	16.4	18.3	19.3	20.2	18.5	21.9
NGPI	6.4	11.5	14.5	17.3	18.9	22.4	24.7	27.9	30.1	33.6	34.5
# forecasts	*74*	*70*	*64*	*57*	*54*	*45*	*42*	*36*	*33*	*30*	*26*

Table 2. As in Table 1, but for Eastern North Pacific basin 2006 mean absolute errors (kt).

duration	*0*	*12*	*24*	*36*	*48*	*60*	*72*	*84*	*96*	*108*	*120*
DSHM	**2.5**	**8.5**	***11.6***	***12.3***	***13.1***	***13.6***	***15.1***	***15.5***	**15.2**	**18.0**	**18.8**
DSHP	**2.5**	**8.5**	**12.9**	**14.1**	**15.3**	**16.2**	**17.2**	**17.6**	**18.4**	**20.5**	**20.6**
OFCL	***2.0***	***7.4***	11.8	13.0	14.0		17.3		15.6		17.2
SHF5	2.5	9.4	13.4	14.5	16.6	18.3	19.0	19.2	19.2	18.9	20.8
LGEM	2.5	8.9	12.9	13.2	14.8	15.8	16.6	***15.5***	***14.8***	***16.2***	16.6
GFDI	3.0	9.9	13.5	14.8	16.9	19.4	23.0	20.1	18.7	16.5	***15.8***
NGPI	5.7	13.4	19.0	23.1	26.8	30.8	33.3	30.4	27.3	25.4	26.4
# forecasts	*132*	*119*	*105*	*93*	*83*	*66*	*56*	*50*	*42*	*31*	*25*

Table 3. Error statistics from dependent developmental sample for 2007 Atlantic SHIPSMI, and for SHIPS trained on the same sample.

Time (h)	Sample Size	SHIPS-MI Mean Absolute Error	SHIPS Mean Absolute Error	SHIPSMI RMS Error	SHIPS RMS Error
12	2145	5.32	5.52	7.23	7.51
24	1885	8.27	8.70	10.72	11.27
36	1645	10.38	10.95	13.21	13.85
48	1440	11.88	12.34	15.12	15.68
60	1263	13.38	13.88	17.10	17.68
72	1110	14.48	14.91	18.57	18.97
84	983	15.03	15.33	19.25	19.56
96	858	14.79	15.05	18.78	19.03
108	764	14.53	14.80	18.71	18.88
120	692	14.58	14.78	18.79	18.93

Table 4. Error statistics from dependent developmental sample for 2007 East Pacific SHIPSMI, and for SHIPS trained on the same sample.

Time (h)	Sample Size	SHIPS-MI Mean Absolute Error	SHIPS Mean Absolute Error	SHIPSMI RMS Error	SHIPS RMS Error
12	2164	5.52	5.87	7.55	7.96
24	1931	9.73	10.38	12.89	13.63
36	1704	12.87	13.69	16.56	17.50
48	1504	15.29	16.16	19.54	20.42
60	1303	16.58	17.42	21.21	21.92
72	1125	17.19	17.79	21.94	22.45
84	975	17.46	17.85	22.03	22.40
96	843	17.44	17.73	22.23	22.47
108	718	17.21	17.35	22.13	22.28
120	606	17.53	17.60	22.36	22.63

2. Components of SHIPS-MI

One of the key suggestions from NHC forecasters was to make SHIPS-MI as similar to SHIPS as possible, other than the addition of microwave-based predictors:

- A text output format was created for the forecasts that matches the output format used for SHIPS forecasts. A separate, more detailed output page is also produced, in order to diagnose the details of how predictors contribute to a given individual forecast.
- The SHIPS-MI forecasts were extended from 72 to 120 hours, although ***users are strongly cautioned that the sample size is not robust for producing SHIPS-MI forecasts beyond 72 hours***.
- Other than the two microwave-based predictors, the SHIPS-MI predictors now match those used in SHIPS. The exceptions are that (1) a latitude predictor is still included for the Eastern North Pacific, as it does substantially improve the forecasts; and (2) the SHIPS adjustment terms from infrared and ocean heat content data are still not used in SHIPS-MI. Changes to SHIPS for 2007 (e.g., vertical wind shear calculated relative to the 850 hPa vortex in the GFS model) were duplicated for SHIPS-MI.

The predictors and their 24-h regression coefficient values are listed in Table 5. The full set of regression coefficients out to 120-h are provided separately to NHC in text files with the 2007 SHIPS-MI programming.

Regression coefficients for most predictors have fairly similar values when comparing SHIPS-MI and SHIPS. Those predictors have similar effect on the forecast from both models. The greatest exception in the Atlantic at 24 h (in Table 1) is for the Initial Intensity predictor (MSW0), which is essentially replaced by the 0-100 km Mean 19 GHz predictor (MEANH19) in SHIPS-MI. The mean brightness temperature is highly correlated with initial intensity – an intense hurricane usually has a great deal of inner core precipitation, and subsequently a high mean 19 GHz brightness temperature. This was especially noticeable when Hurricane Dean was ~130 kt over the Western Caribbean. It had a high mean brightness temperature (> 240 K), and the microwave term contributed around 10 kt intensification to the SHIPS-MI forecast. But the SHIPS-MI forecast was quite similar to SHIPS, because SHIPS had a similar contribution from the MSW0 predictor. The lesson is that SHIPS-MI will forecast a stronger storm than SHIPS primarily if the storm's microwave presentation (i.e., its integrated inner core rain rate) is substantially greater than normal for that storm's initial intensity (e.g., if a Category 2 hurricane looks like Dean did). And vice versa, SHIPS-MI will forecast a weaker storm than SHIPS if there is substantially less inner core rain than normal for that storm's initial intensity (e.g., if Dean's rain field had deteriorated before the maximum wind responded). Some of this reasoning does not apply for the longer-range forecasts, as the regression coefficients change. The strength of using microwave inputs to SHIPS-MI is mainly in the first ~48 h.

Table 5. 24-h regression coefficients for SHIPS-MI, as compared to SHIPS.

Predictor	SHIPS-MI Atl.	SHIPS Atl.	SHIPS-MI E. Pac.	SHIPS E. Pac.
MSW0 Initial Intensity	-0.01	0.33	-0.21	0.20
WCG12 Persistence	0.44	0.50	0.25	0.40
EDAY Day of year, relative to season's peak	-0.02	0.03	0.07	0.01
USPD Zonal motion	-0.03	-0.05	-0.04	-0.08
PSLV Pressure at steering level	-0.04	-0.04	0.01	-0.02
VPER (MSW0*WCG12)	-0.28	-0.32	-0.00	-0.10
POTC (MPI – MSW0)	0.92	1.05	0.75	1.05
SHDC 200-850 hPa Wind Shear	-0.12	-0.23	-0.39	-0.13
T200 200 hPa Temperature	-0.12	-0.09	0.11	0.06
T250N 250 hPa Temperature	-0.11	-0.09	-0.18	-0.10
EPOS Theta-E Excess for parcel	0.17	0.08	0.09	0.10
RHMD 700-500 hPa Rel. Humidity	0.02	-0.00	0.05	0.06
TWAT Tendency of 850 hPa Vort.	0.05	0.09	0.11	0.08
Z850 850 hPa Vorticity	0.11	0.10	0.02	0.02
D200 200 hPa Divergence	0.10	0.09	0.08	0.08
SHDCLAT (SHDC * sin(Latitude))	0.46	0.46	0.44	0.06
MSWSHDC (MSW0 * SHDC)	-0.61	-0.50	-0.16	-0.25
POTC2 POTC Squared	-0.56	-0.60	-0.46	-0.59
LAT Latitude (E. Pac. Only)	0	0	-0.22	0
MEANH19 Mean 19 GHz TB	0.42	0	0.37	0
MAXH19 Maximum 19 GHz TB	0.02	0	-0.05	0

Notes on the predictors: T250N is computed differently in the Atlantic compared to the East Pacific. In the Atlantic, it is computed as the deviation below a threshold value.

This deviation is set to zero if the temperature is above that threshold. No such threshold is used for the East Pacific. This matches the T250N implementation in SHIPS. MEANH19 is computed *after* removing pixels that are located inside the eye, if an automated algorithm identifies an eye in the 85 GHz data.

The regression coefficients for the East Pacific are less straightforward. Initial Intensity contributes to several predictors, not just MSW0. Some of these, especially the Potential for Intensification (POTC = Maximum Potential Intensity minus Initial Intensity), do have substantial changes when comparing SHIPS-MI and SHIPS. The inclusion of the Latitude term in SHIPS-MI also complicates things, as it affects some of the non-linear terms. Latitude is also included in the SHDCLAT (vertical wind shear times sine of latitude) predictor, so its weighting changes. This carries over into changes for other predictors that include vertical wind shear. As a result, it is more complicated to analyze the cause of differences between particular SHIPS-MI and SHIPS forecasts in the East Pacific. But in general, the SHIPS-MI forecasts do tend to be more accurate.

3. Real-time Forecast Generation

The source code required for running SHIPS-MI has been provided to NHC, with some of the scripting written or revised there by Alison Krautkramer. The basic process of generating the forecasts is summarized below. Some additional documentation and "housekeeping" (removing old, obsolete portions of code) in the source code will be provided to NHC separately.

The required inputs for SHIPS-MI are the SHIPS large scale diagnostic file (listing values for fields such as sea surface temperature, vertical wind shear, etc.) from ftp://ftp.tpc.ncep.noaa.gov/atcf/lsdiag/ and passive microwave brightness temperature data. The microwave data is acquired from the NASA Global Hydrology Resource Center by anonymous ftp to 198.122.199.239, directory /pub/data/ssmi-f1*/current-tb/hdf-swath/ for SSMI data (contact: Matt Smith msmith@itsc.uah.edu); NASA TRMM Science Data Information System by ftp to 198.118.235.45 for TMI data (contact: Tony.Stocker@gsfc.nasa.gov); NASA EOSDIS by ftp to nanuk.eosdis.nasa.gov for AMSR-E data (contact: Paul.Haggerty@noaa.gov). It was expected that SSMIS data could also be used, but apparently its brightness temperature calibration is not suitable for direct incorporation into SHIPS-MI. I do want to explore empirical adjustments that would make it consistent with the other microwave data sources in the future.

After this data is acquired and uncompressed, a script called shipsmi_run.pl controls the remaining programs. It runs the IDL program shipsmi_run_rt.pro for each tropical cyclone or invest with a current large scale diagnostic file. This IDL program calls other IDL programs to:

- read the large scale diagnostic file
- compute predictors (performing the necessary time-averaging, computing maximum potential intensity from the sea surface temperature and storm translational speed, and similar calculations)
- read the microwave data and write smaller, subsetted files containing only data near the tropical cyclone

- read the subsetted microwave files and determine which one has the most timely data covering the innermost 100 km from the tropical cyclone center
- compute predictors from the microwave data if it is timely enough; if no data are available from within 6 hours before the forecast time, then exit without generating a SHIPS-MI forecast
- read the file containing regression coefficients, sample means, and standard deviations for each predictor and each timestep
- check for any unacceptable predictor values; compute SHIPS-MI forecast and alternate SHIPS-85 forecast using 85 GHz data instead of 19 GHz (for use when land contaminates the background microwave signal)
- write basic text output file (similar to SHIPS output format), detailed text output file, and ATCF text output file. Use SHIPS-85 in the basic text output if land contaminates the background microwave signal.

Examples of the output from the UAH runs of SHIPS-MI in 2007 are at:
http://nsstc.uah.edu/shipsmi/Output/Atlantic/
http://nsstc.uah.edu/shipsmi/Output/Pacific/
http://nsstc.uah.edu/shipsmi/Output/detail/

4. End of Season Updates

Just as new predictors are tested and regression coefficients re-derived for SHIPS each year after adding the previous hurricane season to the developmental sample, the intention is to have SHIPS-MI add these same new predictors and have the previous season's microwave statistics also added to the sample. The basic steps for doing this are described below. The source code has been provided to NHC. As with the programs used for real-time forecasts in Section 3, the source code will be cleaned up a bit more and provided to NHC. More complete documentation, and the microwave predictor values in the 1988-2006 training sample, will be provided to NHC by the end of the 2007 season.

The microwave data used in real-time comes with the disclaimer that post-processed data should be used when it becomes available later. So this post-processed data is acquired for the developmental sample after each season. The first step is to identify the dates and times when a microwave imager passes over a tropical cyclone. The satellite tracks are obtained from the NASA Global Hydrology Resource Center Coincidence Search Engine at:

http://ghrc.nsstc.nasa.gov/orbit-cgi-bin/execute?orbit+concur

These satellite tracks are compared to the tropical cyclone best tracks, identifying the times that the satellites saw the tropical cyclone. For each of these times, the satellite data is spatially subsetted around the tropical cyclone location.

The brightness temperature data files can be downloaded from http://datapool.msfc.nasa.gov or by anonymous ftp from moby.itsc.uah.edu/data/ssmi/ for DMSP SSMI data. Both "Tb" (brightness temperature) and "hn" (high-resolution geolocation) files are needed. TRMM TMI data (product 1B11) are available from http://disc.sci.gsfc.nasa.gov/data/datapool/TRMM/index.html. AMSR-E data are not used in the developmental sample, because its frequencies are too dissimilar from those on TMI and SSMI. For real-time forecasts, this is accounted for using an empirical adjustment.

From these subsetted microwave files, predictors are computed. Predictor values from the most timely satellite overpass are appended to the SHIPS training file (acquired from Mark DeMaria). For previous years, the microwave predictors are read from the previous year's SHIPS-MI training file.

Any changes to the format of the SHIPS training file (i.e., addition of new variables; re-arranging the order in which variables are listed; changing the way a predictor is computed from the variables in the training file) need to be accounted for in the read-programs used for that file. The read-program returns several variables that can be used as predictors. The regression program lists the desired predictors to be used for each basin. The line listing these will need to be modified for any addition or removal of predictors. This regression program writes a text file with the regression coefficients, sample means, and standard deviations, for use by the real-time forecast code.

Similarly, any changes to the format of the real-time SHIPS large scale diagnostic files will need to be accounted for in its read-program. This should be similar to changes in the read-program for the training file. In both cases, whoever updates the programs can search for occurrences of a similar variable in the read-program, and duplicate those lines while using the new variable.

I do expect to perform this end-of-season update myself in 2008, in order to continue running SHIPS-MI at UAH. However, the programming and documentation should be suitable for NHC to perform the update itself, if it so desires.