P5.12 Development of a Thunderstorm Algorithm from Very High Resolution AFWA MM5 Data

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1. INTRODUCTION

To provide weather support to Department of Defense military personnel, the Air Force Weather Agency's (AFWA) operational mesoscale forecast model (MM5) is run for various worldwide domains at 45km and 15km horizontal resolutions. For output at these resolutions, the Grell convective parameterization scheme (CPS) is used to produce convective precipitation output tailored for displays suitable for use by forecasters. AFWA's precipitation type product subsequently uses this information to differentiate between non-convective precipitation (i.e., rain, freezing rain, sleet, and snow) and convective precipitation (i.e., thunderstorms or severe thunderstorms. Severe thunderstorms are delineated using a regression equation described by Knapp and Brooks (2000).

However, in AFWA's higher horizontal resolution domains (e.g., 5km), convection is explicitly resolved and a CPS is not included as part of the run. Thus, no convective precipitation output is directly calculated for these finer scale runs. DoD users of high-resolution output still require a point-in-time area display of thunderstorm forecast information from this model output.

To address this need, research toward the development of one or more thunderstorm potential algorithms suitable for use in higher resolution MM5 domains is underway. Work accomplished thus far has focused on algorithm development tailored to convective events across Southwest Asia and centered on Iraq and surrounding areas. Three multivariate linear regression equations were derived and verified. This paper summarizes the research accomplished thus far to develop and verify the equations, with the ultimate goal being implementation of one equation that will compensate for the lack of CPS output of convective precipitation forecasts from high resolution MM5 output.

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2. ALGORITHM DEVELOPMENT: DATABASE AND DERIVATION

Data from 5km MM5 output centered over Iraq during Spring 2003 were collected. Stability index values were tabulated from model output for each of the nearly 1500 cases studied across the Iraq region. The cases covered valid forecast times from 6-30 hours past initialization times of 06 UTC and 18 UTC. Values for the following stability indices were recorded for each case: K-Index (K), Lifted Index (LI), Total Totals (TT), Convective Available Potential Energy (CAPE), SWEAT, Energy-Helicity Index (EHI), Lid Strength Index (LSI), and Precipitation Type. These values were correlated with the presence/absence of thunderstorms over six specific topographic regions of this 5km window domain (see Figure 1), as derived from high-resolution satellite imagery.

Four indices were found to be the best correlated and statistically significant for predicting yes/no forecasts of thunderstorms based on the given database across the entire Iraq area. Work has not been completed to determine if specific equations for each of the six Iraq regions would produce different results. Different combinations of these indices (K, SWEAT, LSI, and CAPE) were correlated against the occurrence/non-occurrence of thunderstorms. This led to computing the highest correlation coefficients and significance statistics, which were produced from the following three probability of thunderstorm occurrence (Y, in percent) equations:

$$Y = [.016(K) + .0011(SWEAT) - .0002(CAPE) - .2247] \times 100 \quad (1)$$

$$Y = [.019(K) + .0007(SWEAT) - .0274(LSI) - .2065] \times 100 \quad (2)$$

$$Y = [.0128(K) + .0008(SWEAT) - .1724] \times 100 \quad (3)$$

3. DATA COLLECTION AND VERIFICATION PROCEDURES

From March through June 2004, hourly satellite data and surface observations, and output from the 5km MM5 runs (twice per day) were collected. Hourly surface observations and satellite data were used to determine YES/NO thunderstorm occurrence. Thunderstorms, thunder without rain, and lightning reported at an observing site counted as an observed=YES. The 5km MM5 runs produced several derived parameters that were collected and analyzed including the SWEAT, K, and Lid Strength Indices, CAPE, and Precipitation Type. Observation data from 1100 UTC to 1300 UTC was used to verify forecasts valid at 1200 UTC (1500 local time), and data from 2300 UTC on "day N-1" to 0100 UTC on day N verified forecasts valid at 0000 UTC on day N (0300 L). Since the 5km runs take place at 0600 and 1800 UTC, 6hr and 18hr forecasts were verified from each run.

As was previously done during the data collection period for regression equation determination, the 5km MM5 window was split into six geographically or logistically similar regions (Fig. 1). For example region 1 combined the mountainous terrain of NE Iraq and NW through W-Central Iran.

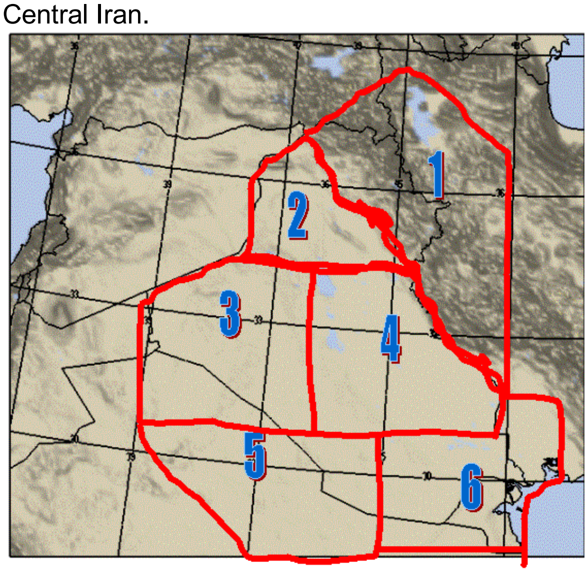

Figure 1. The six regions used in this study.

Station observation trends were closely monitored for scientific and temporal reliability, with two stations from each of the six regions ultimately chosen for verification. Thus for each MM5 forecast hour verified (e.g., 0000 UTC), there were 12 observations and forecast values available for computing values from the three equations. The complete data set had 3636 observation-forecast pairs.

4. RESULTS

Table 1 summarizes initial results compiled during this study for each equation after the data was stratified by (1) all observations, (2) observed=NO only, and (3) observed=YES only.

	Eqn 1	Eqn 2	Eqn 3
N (Y/N obs)	3636	3636	3636
Average value	20.8	20.0	21.0
n > 42	330	339	307
% > 42	9.1	9.3	8.4
N (obs=NO)	3569	3569	3569
Average value	20.3	19.5	20.6
N > 42	288	294	264
% > 42	8.1	8.2	8.4
N (obs=YES)	67	67	67
Average value	47.6	47.5	44.8
N > 42	42	45	43
% > 42	62.7	67.2	64.2

Table 1. Summary of results for the three regression equations (threshold value of 42).

The threshold value of 42 is suggested here based on the analysis of several potential threshold values. The results were similar for the three equations, but there were two concerns regarding the statistically derived choices of variables for the equations that led to a preference for equation 2. First and foremost was the lack of meteorological soundness in penalizing higher CAPE environments as in equation 1. Indeed, careful analysis showed several events where there was observed convection at one of the 12 observing sites and the MM5 CAPE values were relatively high there compared to surrounding areas. But this served to actually lower the values of equation 1 to below the threshold of 42, thus convection would not be indicated were this value used to display thunderstorm areas on the 5km precipitation type products. Second, especially in this domain, a strong cap is a major inhibitor of convection. It was thus believed beneficial to incorporate model information regarding the strength of the cap, and equation 2 is the only one that contains the LSI term.

5. CASE STUDY

This case study visually illustrates the regression equations in action, most specifically, equation 2 (hereafter, 5TP-2 – **5**km MM5 **T**hunderstorm **P**otential Equation-**2**). The figures are placed at the end of this paper for enhanced readability. On April 11, 2004 at 0000 UTC, thunderstorms developed over much of Kuwait (Figure 2). Several images capture the performance of the 5km MM5 at this time. Figures 3, 4, and 5 provided at the end of this paper show the 18-hr forecast K Index, SWEAT Index and Lid Strength Index valid at this time, respectively.

The K Index of 30 near Kuwait International Airport is adequate for convection but not very high. In many instances throughout our data set values greater than 40 were forecast, and the average K Index value for all observed=YES events was 33.

The SWEAT Index is well below 250. This is unusual because in this study there was a strong correlation of higher values of SWEAT to observed convection. In fact, when thunderstorms were observed the average SWEAT value was 246 (250 or greater, 70% of cases). When thunderstorms were not observed, the average was only 122.

Also unusual is the fact that the atmosphere was not capped over Kuwait during this event. This area (and most of the domain) was frequently strongly capped during the study. Figure 5 shows the LSI is near 0 and the atmosphere uncapped in that area. Combining these factors (the CAPE was also low, about 200 J/kg) yielded values of 33.1, 45.3, and 30.4 for equations 1, 2 (5TP-2), and 3, respectively. Given the threshold value of 42, only the 5TP-2 exceeded the threshold. Since there was preexisting rain in the 5km precipitation type product near Kuwait (Figure 6), 5TP-2 would be the only equation to indicate the higher potential for thunderstorms (or *convective* precipitation) as opposed to simply displaying rain in this case.

6. SUMMARY AND OPERATIONAL APPLICATIONS

At the heart of this study is the question, how many times would the 5km MM5 forecast precipitation type be switched from an existing type (rain, freezing rain, sleet, or snow) to "thunderstorms" as shown in the case study presented? During the study period, there were 24 occasions of an observation site reporting thunderstorms and the 5km MM5 forecasting precipitation *exactly* at that site. Of these pairings, 5TP-2 had an average value of 54.2 and was greater than 42 for 19 of these occurrences. Thus, the precipitation type would have been changed to "thunderstorms" about 80% of the time.

Results indicated that each of the three equations performed well during the large majority of the cases when thunderstorms or lightning were reported. For the reasons previously discussed, and based on initial verification results tabulated thus far, the 5TP-2 may provide a scientifically sound choice for differentiating convective from non-convective precipitation types for the AFWA high-resolution precipitation type products.

Based upon the satisfactory completion of final verification analysis work, and assuming the results continue to prove the accuracy of the 5TP-2 equation, AFWA plans to prototype the use of 5TP-2 in conjunction with the existing 5km precipitation type information (rain, snow, sleet, and freezing rain). This would occur for this 5km window first, as further testing will be required before applying 5TP-2 to other 5km theaters. Incorporating the 5TP-2 allows thunderstorm potential to be shown for the first time on high-resolution products available at the Joint Air Force & Army Weather Information Network (JAAWIN) web page. Additionally, the new precipitation type information will be made available to JAAWIN users via the Interactive Grid Analysis and Display System (IGrADS), as well as on our extremely popular meteograms for Southwest Asia locations.

In addition to the potential implementation of the 5TP-2 equation on JAAWIN, it may also be considered for future application on Army weather support systems which will rely on mesogamma and microscale modeling forecasts for accurate mission execution nowcasts.

7. BIBLIOGRAPHY

Knapp, D. I., and G. R. Brooks, 2000: Use of a new thunderstorm potential index for 12-hour forecasts using mesoscale model data. Preprint, 9th Conf. on Aviation, Range, and Aerospace Meteorology. J54-58.

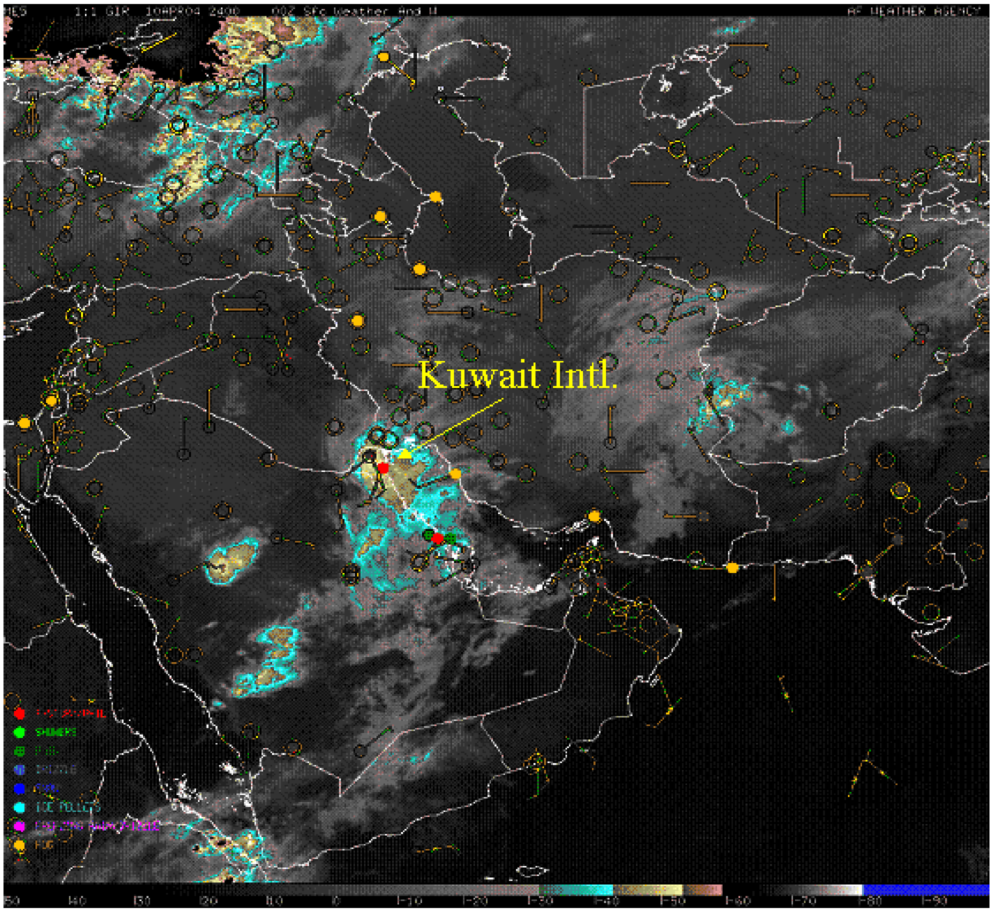

Figure 2. Enhanced IR satellite image from Meteosat 5, 11 April 2004, 0010 UTC. RED circles indicate thunderstorms reported at observation sites.

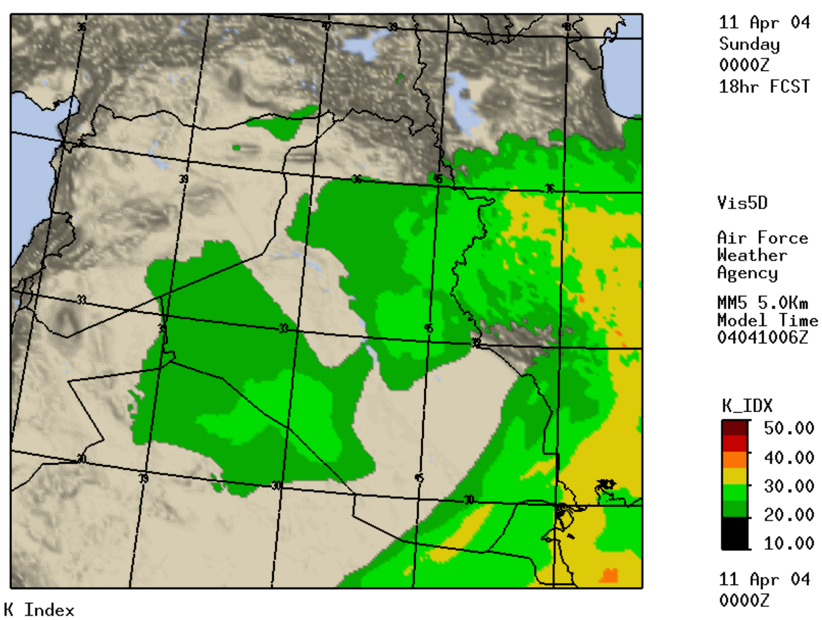

Figure 3. 5km MM5 18hr forecast of the K Index valid 11 April 2004, 0000 UTC. Yellow indicates K Index values from 30 to 35.

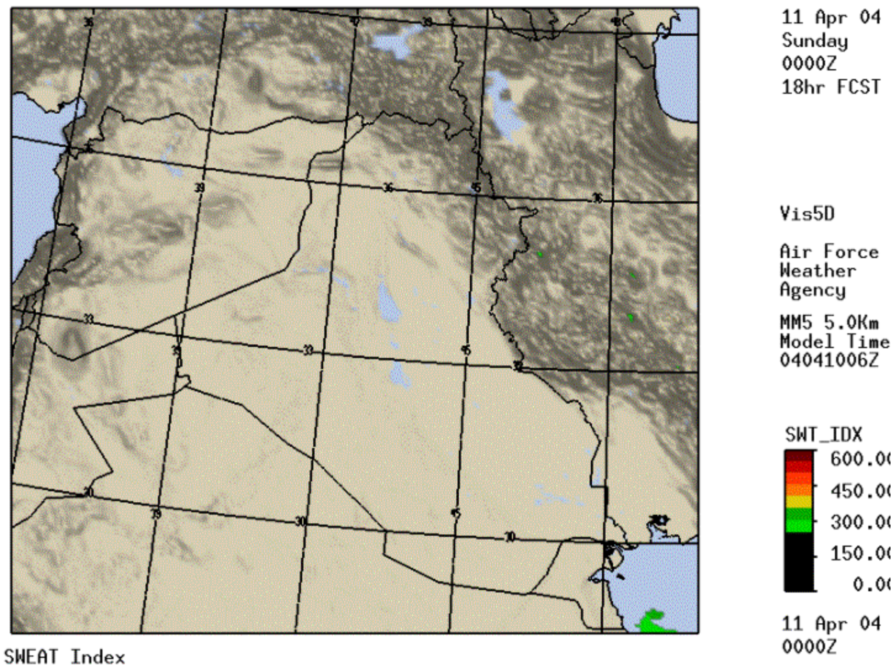

Figure 4. 5km MM5 18hr forecast of the SWEAT Index valid 11 April 2004, 0000 UTC. SWEAT values are below 250 over virtually the entire theater.

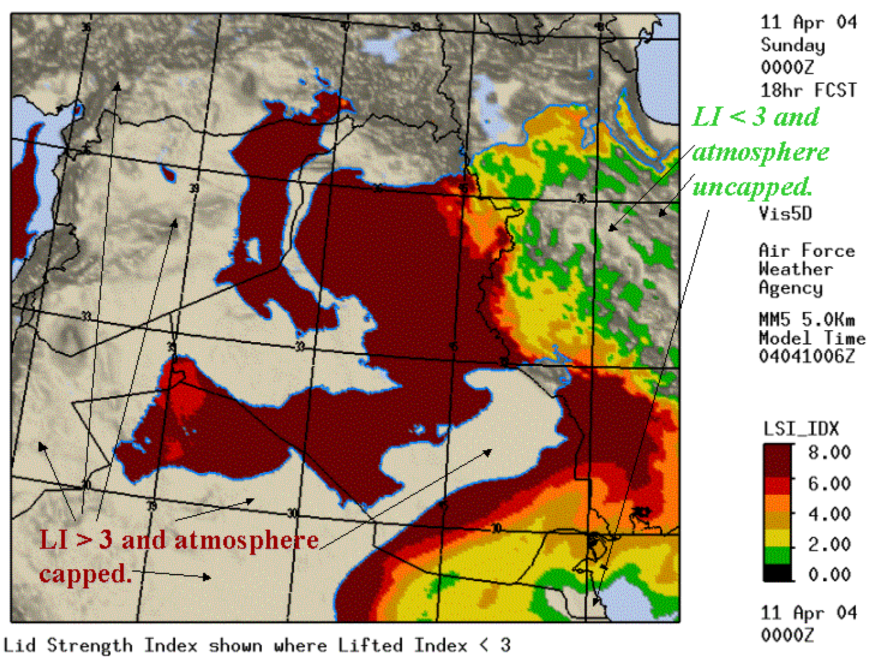

Figure 5. 5km MM5 18hr forecast of the Lid Strength Index valid 11 April 2004, 0000 UTC. To enhance the usefulness of this product for our customers, we only display LSI values where the Lifted Index is less than 3 (i.e., atmosphere unstable or conditionally unstable). Examples of the areas where the atmosphere is capped and LI is greater than 3 are shown with arrows in the left-2/3rds of the image. These are next to the dark red (LSI > 6) and the blue LI=3 contour. Examples of where LI < 3 and there is *no cap* (LSI < 1) show up as just tan land or light blue water are shown also shown on the right side of the image. These areas are adjacent to the lowest colorized LSI areas (green, for LSI =1 - 2) in the extreme right of the image.

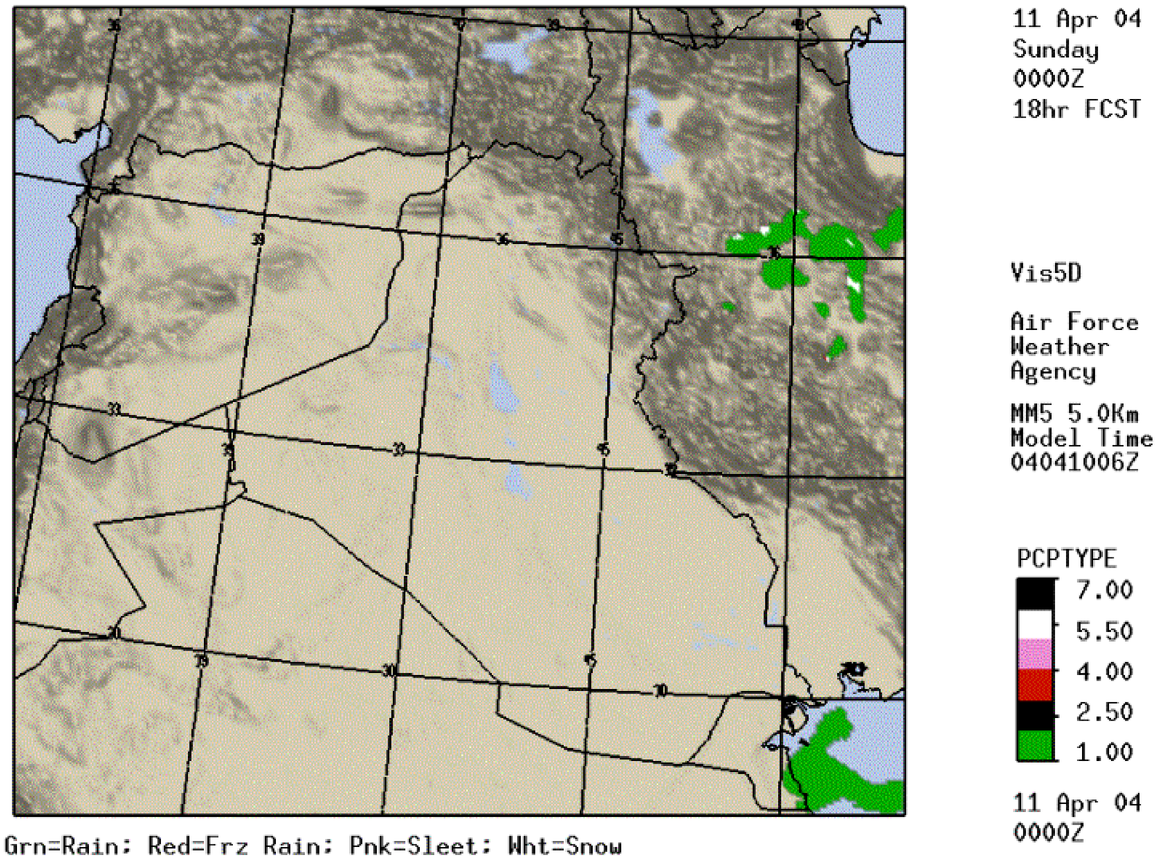

Figure 6. 5km MM5 18hr forecast of the Surface Precipitation Type valid 11 April 2004, 0000 UTC. If the 5TP-2 threshold of 42 was applied to all existing precipitation areas, the green rain area near Kuwait would have become orange to indicate convective precipitation (i.e., thunderstorms). For lower resolution theaters, orange (thunderstorms) is displayed between the green (rain) and red (freezing rain), and blue (severe thunderstorms) appears above the white (snow). Vis5D uses the values 1-7 internally to display the derived precipitation types appropriately.