HIGH RESOLUTION ACCURATE WRF FORECASTS FOR THE MIDDLE EAST

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1. Introduction: My company, Weather-It-Is, LTD (www.weather-it-is.com), provides forecasts for the Israeli public/tourists, and specialized information to clients, e.g., the Israel Electric Company. Forecasts are also provided through the Internet for the public and neighboring Lebanon, Jordan, and Egypt. Forecasts are also distributed over the cell-phone through an intermediary company.

The climatology of Israel is unique in that there are deserts, shrub lands, mountain pine forests, and Mediterranean environments within very close proximity to each other. There is also intensive farming within less and more arid environments. It rains predominately in the winter, and even snows in the higher elevations. The sharp variation in topography (including sharp changes in ground elevation) provides quite a challenge to forecasters, and requires a forecast model with high numerical accuracy and a terrain following coordinate system that does not produce spurious results in such an environment.

Weather forecasting and weather related hazards are technically the responsibility of the Israel Meteorological Service (IMS). However, a number of considerations preclude the IMS from properly fulfilling their responsibility. i) Their offices are undergoing an extended reorganization. Hence, no new research scientists have been hired in the recent past. ii) The government requires that the IMS charge businesses and research institutions for their services. No "start-up" can afford their services, and because the IMS sells very little data it is unable to justify further investments in producing higher quality data. iii) A lack of appreciation for the types of information the public requires. Their Internet page lists relatively few cities, and the information is too general, and even not useful for those living outside the main cities. In comparison, we list over 100 cities on our forecast pages.

It is this "forecast vacuum" that my company is seeking to fill. Three developments have made this possible. i) The increasingly high reliability of the Global Forecast Systems (GFS) forecast data (from day 1 to day 10). This forecast data can be used for downscaling with a forecast model, and provides a reasonably good set of time varying boundary conditions during the forecast period. ii) The continuing development of and improvements in the Weather Research and Forecasting Model (WRF; Skamarock et al, 2005), which is a more accurate forecast tool than the MM5 (Dudhia et al., 1993). This is actually an integrated system that includes preprocessing and post processing programs, and includes the support personnel to address user related issues. iii) A greater awareness of industry and the public in Israel on

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the possible utility of accurate weather forecast information.

2. Approach: The weather forecast data for Israel and surrounding countries is produced using the Weather Research Forecast Model (WRF). The WRF was developed by the National Center for Environmental Prediction (NCEP) and the National Center for Atmospheric Research. Weather It Is uses the "ARW" version of the WRF model. The GFS data to run WRF is produced every six hours, and comes from NCEP's Global Forecast Model (GFS). The data from the GFS is available for the WRF about 5 hours after the GFS model forecast begins. The forecast data from the GFS can be downloaded at 100 X 100 km^2 and 50 X 50 km^2 resolution. The latter is about twice the resolution of the outer grid used to produce the Weather It Is forecasts.

Three types of forecasts are produced for this page. The WRF forecasts are produced on a 30 km, 10 km, and now even 5 km grid. The short-range (two-day) forecasts are produced using a 30 km and 10 km grid (these use the 100 km grid resolution GFS data). The 5km grid resolution forecasts extend out to twelve hours (they use the 50 km grid resolution GFS data). A long range forecast (for days three to seven) uses the 30 km grid. The goal is that the twelve hourly and short-range forecasts will be produced every six hours, while the long-range forecasts are done twice a day for the morning and evening. (Occasionally, as reported here, simulations were produced using a 3.3 (or 3) km grid within a 10 (or 9) km grid.) By comparison, the IMS and Tel Aviv University forecasts are updated twice a day (at least for the public) and they use a 20 X 20 km^2 resolution grid.

Comparisons of WRF forecast data and observations were made for selected cities. Various investigations were conducted to determine the optimum model physics configuration. Because this information is proprietary, it cannot be repeated here in great detail (although more information will be given at the American Meteorological Society meeting in Park City, Utah this June).

3. Results: WRF model results were validated against observations for the late summer (2006) and winter (2006/2007). Validations of heat index, temperature, dew point, and wind were conducted at two locations, Ben Gurion Airport and the city of Jerusalem. Figure 1 shows the diurnal Heat Index forecast from the WRF

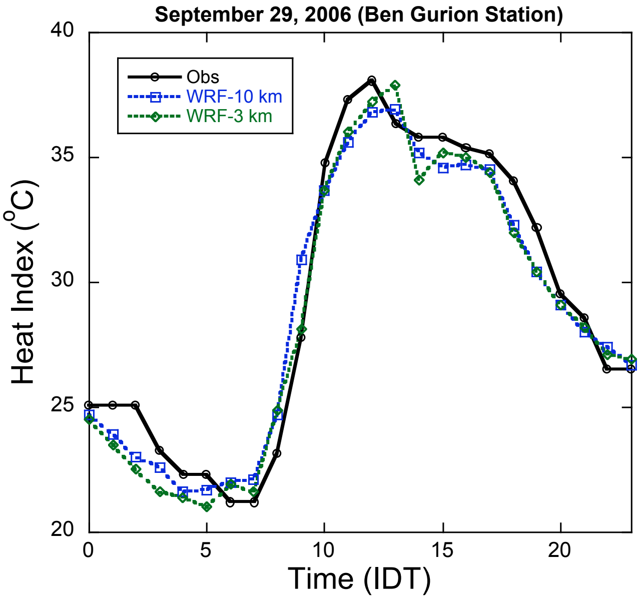

Figure 1: Diurnal variation of the heat index for Observation and the WRF model using either 10 km or 3 km grid resolution.

with 10 km and 3.3 km grid resolution for 29 September 2006. This was the hottest day of the year at Ben-Gurion, Israel airport. Both model configurations did exceptionally well, but the 3 km simulation appears to even better "catch" the diurnal variation in the Heat Index than the Heat Index calculated from the 10 km simulation data.

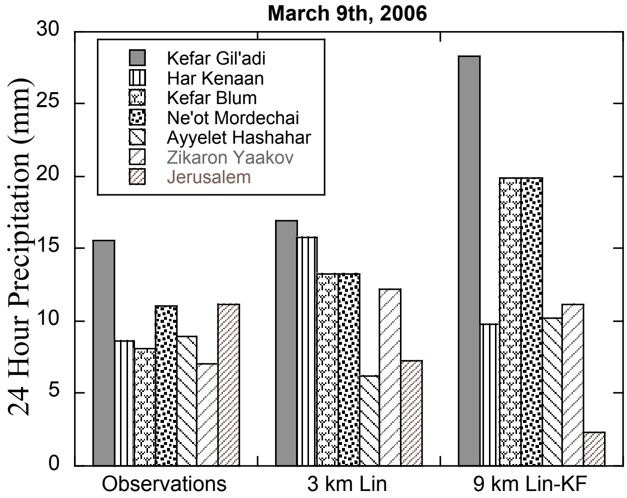

Figure 2: Simulated versus observed precipitation from 6z March 9th, 2006 until 6z Marth 10th, 2006. The simulation with the 3 km grid resolution used only the "Lin" microphysical parameterization. The simulation with 9 km grid resolution also used the "Kain-Fritsch" cumulus parameterization.

Figure 2 shows twenty-four hour rainfall amounts simulated with the WRF model using the 9 km and 3 km grid resolution simulation domains. The interesting result is how the 3 km simulation improved on the simulated precipitation amounts by generally simulating less precipitation at stations that were over predicted in the 10 km simulation (e.g., Kefar Giladi), and more precipitation at the stations that were under predicted (e.g., Jerusalem). The results from the 3km simulation suggest that the 5 km grid resolution simulations may provide more accurate precipitation amounts than the 10 km grid simulations during the upcoming winter season (2007/2008). The ability of the model to simulate precipitation amounts was also quite impacted by the choice of boundary layer scheme and convective parameterization (here not shown).

The surface temperature and humidity were verified against observations for one to six days using data from the 10 km resolution simulations. Table 1 summarizes some of these results: for instance, for Jerusalem during the late "Summer" (September/October 2006) and Winter (January 2007). The table shows the linear correlation coefficient, the mean, and the bias for a comparison of 30 days of forecasted variables versus observations. The data comparison is observations versus the same day forecast. The analysis suggests that the forecasted maximum is exceptional, while the forecast of minimum temperature and humidity was quite good. The model was also able to simulate the day-to-day variation in daily maximum wind speeds in January, although the forecast of minimum daily wind speed was not as good (we were not able to retroactively examine model versus observed wind speeds in July). We also compared same day forecasted maximum wind speeds at Ben Gurion to observed daily maximum wind speeds. The bias was smaller than in Jerusalem, 4.6 m s^{-1}. The differences in the wind biases at the Jerusalem station and Ben Gurion airport may reflect the model's suitability to simulate momentum transfer in an urban versus non-urban environment.

We also verified that the model can simulated maximum temperatures in the summer out to at least five days (with a linear correlation coefficient of 0.82). In Jerusalem, we verified that the model was able to simulate surface temperatures at 6, 12, 18, and 0z out to six days, although the model forecasted temperature explained less than half the variance in surface temperature by the end of the forecast period.

The model validation of simulated rainfall was applicable only in the winter (rainy-season) months. The data was initially validated against observations from sixteen stations distributed fairly evenly over the state of Israel. The observations are from 6z on any particular day to 6z on the next day, which corresponds to using forecast data from 12 to 36 hours of the forecast period. There were 32 days with precipitation during the winter of 2006/2007. The accumulated rain amounts from each of the 16 stations on each day were averaged to obtain a mean amount for each day. The maximum amount of precipitation from any of the stations was also tabulated. Finally, the root mean square of the station data on each day was recorded. The root mean square measures the variability in precipitation between the different stations. We found that the model produced very high correlation coefficients for the 16 station mean accumulated twenty-four hour rainfall amounts, as well as station maximum and root mean square. The high correlation coefficient suggests that the WRF downscaling of the GFS forecast to the local topography is in an important outcome of the WRF simulation forecasts.

Otherwise, there is an apparent dry bias in the simulated rainfall amounts (not shown). The dry bias was largest among stations located in the central mountains (e.g, Jerusalem, Rosh Tzurim). We hypothesize that the proximity of these locations to the Jordan Valley reduces the utility of the WRF downscaling of the GFS data, where the relatively coarse resolution of the GFS grid does not adequately distinguish between the relatively wet Jerusalem locale and the desert to the east. The result is that the atmosphere

Table 1: Results of statistical analysis for Jerusalem 2006/2007 during the months below. Temperatures in degrees Celcius, winds in m s^{-1}.

11 September to 11 October 2006			
Variable	Linear-Coefficient	Bias	RMS
Max Temperature	0.95	0.03	1.03
Min Temperature	0.83	-1.26	1.48
Max Dew Point Temperature	0.91	-0.75	1.32
Min Temperature	0.70	2.74	3.11
January 2007			
Max Temperature	0.93	0.77	1.16
Min Temperature	0.84	-1.40	1.42
Max Dew Point Temperature	0.86	-0.39	1.10
Min Dew Point Temperature	0.66	0.34	2.02
Max Winds	0.87	6.24	8.32
Min Winds	0.50	3.68	4.59

Table 2: Statistical comparison of observed versus modeled precipitation. The rainfall observations are from 32 days when it rained between December 2006 and March 2007. The rain is accumulated from 6z to 6z on the next day. The model forecast started at 18z of the previous day.

Variable	Station Max/Min	Linear Coefficient	Mean	Bias
Daily Accumulated	42.02/0.03	0.88	-3.52	3.87
Station Max Accumulated	88.00/0.05	0.87	-11.23	12.42
Root Mean Square	27.47/0.12	0.83	-3.12	3. 52

and land surface in the WRF most likely initializes with a dry bias in the Jerusalem locale. Another contributing factor may be the use of the 10 km grid in the operational forecasts, rather than the 3km grid, which relatively reduces the upslope forcing of the mountains on precipitating systems.

The model predicted rainfall amounts out to seven days were also verified against observations. We linearly regressed simulated rain amounts for each forecast day between one and seven versus observed amounts, using the data from each of the 32 rainy days. Figure 3 shows the number of stations whose correlation coefficient is highly significant over six days (day seven is not shown). The model data was from the 30 km grid resolution simulations. The data shows that up to four days, at least 14 of the 16 stations exhibit predictability in rainfall amounts. On the fifth day, half of the stations exhibit predictability, while no stations exhibit predictability (at the P < 0.01) on the sixth day.

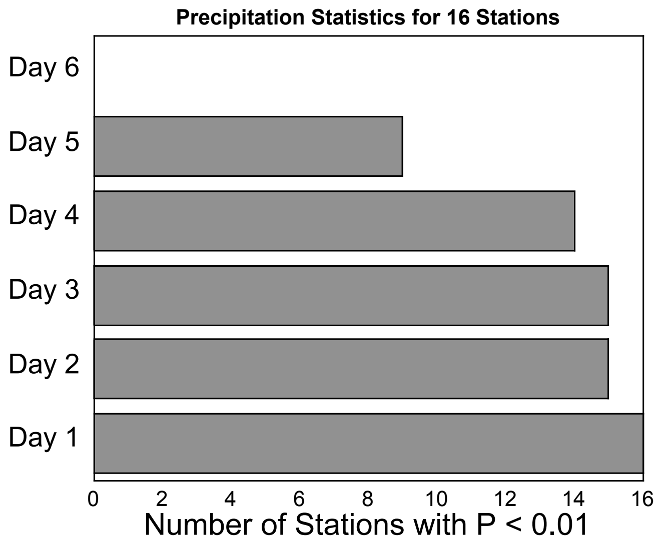

Figure 3: The number of stations (out of 16) that had a highly significant correlation between predicted rainfall and observed rainfall after one ("Day 1") to six forecast ("Day 6") days .

4. Conclusion: WRF model two-meter temperatures and humidity, and ten-meter wind speeds were verified against observations for late summer and winter (the dry and rainy season). Precipitation at a number of stations was verified in the rainy season. The model produced exceptional correlations and very small biases for surface temperature and good correlations for humidity and wind. The correlation between observed and simulated: mean sixteen station daily precipitation amounts, the daily maximum station precipitation (from the sixteen stations), and daily root mean square of the sixteen station precipitation amounts were also well forecasted – although the model forecasted rain amounts exhibited a dry bias, especially in the Jerusalem locale. The importance of using the WRF to downscale the GFS forecast data is demonstrated by the high correlation between observed root mean square and the forecasted root mean square. The model forecasted precipitation exhibited predictability out to five days.

The "correct" choice of boundary layer, microphysical scheme, and cumulus parameterization was essential for obtaining the "best" forecast results. Other studies have indicated a lack of predictability of rainfall for Israel using other models, e.g., the MM5. Hence, the results shown here are comparatively an important improvement over the previous situation.

6. References:

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Validation tests and simulation of an Atlantic cyclone and cold front. Mon. Wea. Rev 121: 1493-15.

Skamarock, W. C., J. B. Klemp, J. Dudhia, D. O. Gill, D. M. Barker, W. Wang, and J. G. Powers, 2005: A description of the Advanced Research WRF Version 2. NCAR Tech Notes-468+STR.