# Ramp Tool and Metric (RT&M) Readme File

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*Main Reference: L. Bianco, I. V. Djalalova, J. M. Wilczak, J. Cline, S. Calvert, E. Konopleva-Akish, Cathy Finley, Jeff Freedman, 2015:* ***A Wind Energy Ramp Tool and Metric for Measuring the Skill of Numerical Weather Prediction Models****, submitted to Weather and Forecasting.*

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## 1. Introduction

This Ramp Tool and Metric (RT&M) has been developed out of recognition that during relatively rare ramp events (large changes of generated wind or solar power, $\Delta p$, that occur over short periods of time, $\Delta t$) it is more difficult to balance electric load with power production than during the quiescent periods between ramp events. A ramp-specific metric is needed because standard metrics (such as mean absolute error or root mean square error) that do not give special consideration to ramp events may not adequately represent model skill or model skill improvement.

This RT&M has three components:

1) The first is a process to identify ramp events in the time series of power. Three different ramp identification methods can be applied.
2) The second component is a method for matching in time each forecast ramp event with the most appropriate observed ramp event.
3) The third and last component of the RT&M is a process through which a skill score of the forecast model is determined. The skill score is calculated from a utility operator's perspective, incorporates phase and duration errors in time as well as power amplitude errors, and recognizes that up and down ramps can have significantly different impacts on grid operation.

Since no single pair of power and time thresholds defines a ramp, and in fact some utilities may be interested in several different ramp definitions at the same time, the ramp skill metric integrates skill over a range of changes in power over different time windows. To test the RT&M we used the 13 km horizontal resolution NOAA/ESRL Rapid Refresh Numerical Model (RAP), providing forecasts out to 15 hours, and tall tower anemometer observations that were collected during the Wind Forecast Improvement Project (WFIP), and we provide the user with

this same dataset so that he/she can test the RT&M first and then use it with his/her data, appropriately organized.

## 2. Installation

To run the RT&M the user might have or not have Matlab installed on his/her computer.

For Matlab users:
- Create a directory for RT&M functions and subdirectories.
- Copy all RT&M components (from the 'RT&M_ForMatlabUsers' directory) into the new directory.
- This directory will contain two 'Input' directories (already containing testing data sets).
- Make the RT&M directory your working directory in Matlab.
- In the Matlab workspace, type: >> StartRampTool

For users without Matlab:
- Create a directory for RT&M functions and subdirectories.
- Copy all RT&M components (from the 'RT&M_Executable' directory) into the new directory.
- This directory will contain two 'Input' directories (already containing testing data sets).
- Read the readmefile.txt and run the MCRInstaller.exe.
- Run the StartRampTool.exe.

## 3. Input

The first step of the ramp identification process is to generate equal length time-series of model forecast and observational wind speed data. For this we provide two different approaches that we will refer to as the "Stitching Method" and the "Independent Forecast Run Method" (see Main Reference for details).
For the "Stitching Method" the user needs to create a time-series of model forecasts for a particular forecast horizon.
For the "Independent Forecast Runs Method" the RT&M uses sets of individual forecast runs, not concatenated, in our case each with a length of 15 hours.
We include both of these approaches in the RT&M, allowing the user (through the GUI interface, clicking on the "Stitching method" or "Forecast run method") to choose the one that best addresses their analysis needs.
We want to note that for the way the input data files are created, the "Stitching Method" can be used only for models with hourly runs, while the "Independent Forecast Run Method" can be used with models with hourly runs as well as with models with more coarse runs (every three hours, six hours, twelve hours….).

### 3.1. For users using the "Stitching method"

The observational dataset must be saved in a file called 'observations.txt' in the 'Input_Stitching' folder in your RT&M directory (already available for you to test the code).
In this file, observed data (in our case the resolution for this dataset is 10-minutes) are presented in the form:

```
TOWER    LAT        LON        ELV        T_Height
FAH      45.0539    -102.2630    797.0000     80.0000
LVL      43.4331    -101.5545    944.0000     80.0000
LWY      45.2772    -99.9861     663.0000     80.0000
REL      43.9681    -99.5944     628.0000     80.0000

Data is recorded as TOWER WindSpeed

20120070900
FAH      7.4880
LVL      4.1000
LWY      10.4000
REL      9.9800
20120070910
FAH      6.8640
LVL      4.7120
LWY      9.4400
REL      10.1400
20120070920
FAH      6.8970
LVL      4.7450
LWY      9.3800
REL      10.3300
……————————
```

Where in the first lines the positions of the towers (4 in this case) are described in terms of latitude, longitude, elevation, and the height of the measurement. The next 3 lines are reserved for comments. Then, for each time acquisition, one line is reserved for the time stamp in the format:
yyyyJJJhhmm
where yyyy = year; JJJ = Julian day; hh = hour in UTC; mm = minutes.
The next lines (as many as the number of towers) contain the information on the name of the tower and the corresponding wind speed in $ms^{-1}$ (or power normalized between 0 and 1, where 1 is the maximum generated power).
Then this set of (number of towers+1) lines is repeated for the next observational time stamp, until the end of the time series is reached. Bad flag values should be identified by '-999'.

The model input data are also saved in the 'Input_Stitching' folder (already containing a testing data set). Each forecast hour has its own file and the files are called 'model_frct00.txt', 'model_frct01.txt',…
In our case there will be 15 model input data files.

Here, for each forecast horizon there is a file containing the same info as for the observational data, in the format:

```
TOWER    LAT        LON        ELV        T_Height
FAH      45.0539    -102.263   797.000    80.0000
LVL      43.4331    -101.554   944.000    80.0000
LWY      45.2772    -99.9861   663.000    80.0000
REL      43.9681    -99.5944   628.000    80.0000
```

Data is recorded as TOWER WindSpeed

```
20120070900  Forecast00
FAH      8.72869
LVL      7.13753
LWY      6.83793
REL      8.06388
20120070915  Forecast00
FAH      8.27311
LVL      7.03210
LWY      6.57792
REL      7.93740
20120070930  Forecast00
FAH      7.93552
LVL      6.65024
LWY      6.54109
REL      7.94728
……————————
```

Where the only difference with the observed data structure is in the lines containing the information of the time stamp. Here for each time acquisition the time stamp has the format:
yyyyJJJJhhmm ForecastXX

where yyyy = year; JJJ = Julian day; hh = hour in UTC; mm = minutes; and XX = forecast hour.

<u>In the RT&M the model dataset is interpolated to the observational resolution</u>, because the model data are smoother compared to the observations. In our case the observational dataset temporal resolution is higher than the modeled one, but in any case the code will interpolate the model data to the observational times.

## <u>3.2. For users using the "Independent Forecast Runs Method"</u>

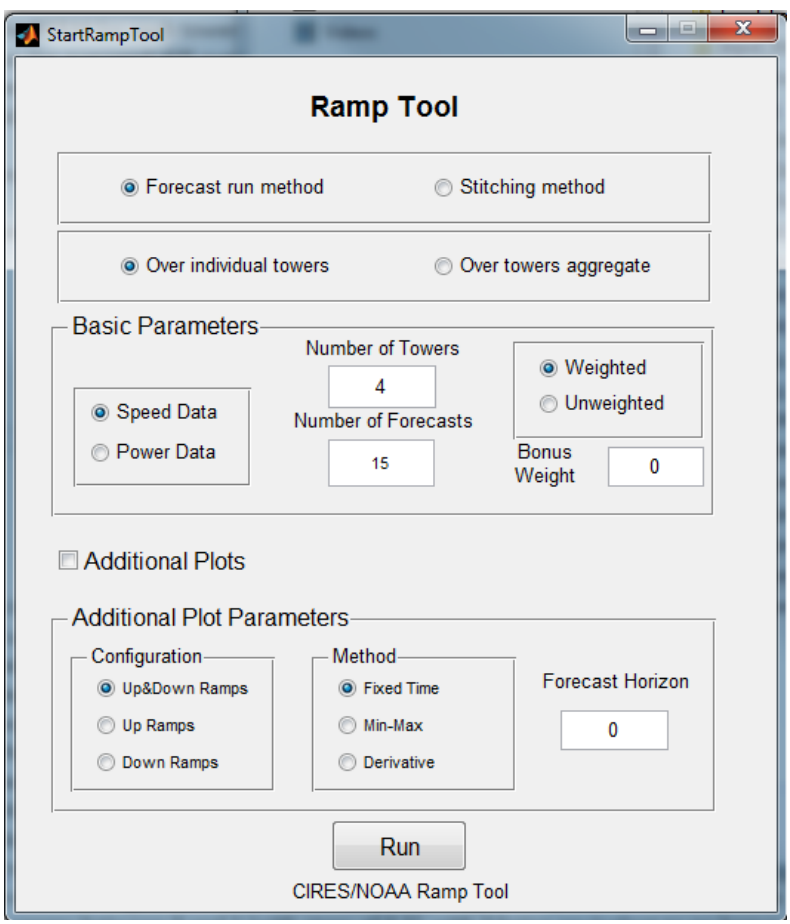
The <u>observational dataset</u> must be saved in a file called 'observations.txt' in the 'Input_Forecast_Run' folder in your RT&M directory (already available for you to test the code).
In this file, the observed data format is exactly the same as the one presented for the "Stitching method".

The model input data are also saved in the 'Input_Forecast_Run' folder (already containing a testing data set), but now, each forecast run has its own file and the files are called 'model_yyyyJJJhh.txt',…
where yyyy = year; JJJ = Julian day; hh = hour in UTC when the forecast run was generated. In our case, since the RAP output is hourly, there will be as many files as many hours for which a forecast run was generated.
If the user decides to use the "Independent Forecast Runs Method" to compare the model output with the observations, he/she has to make sure that the last model output does not go beyond the last observational time, to avoid creating unrealistic unmatched events.

Again, in the RT&M the model dataset is interpolated to the observational resolution, because the model data are smoother compared to the observations. In our case the observational dataset temporal resolution is higher than the modeled one, but in any case the code will interpolate the model data to the observational times.

## 4. GUI Overview

Once the RT&M is started, it will automatically open a GUI window that looks like:



First the user has to select if to use the “Forecast run method” or the “Stitching method” to compare model output versus observations.

Afterward, a user can:

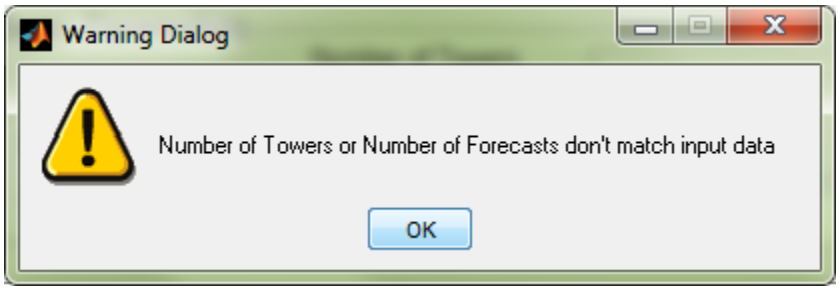
1) run the RT&M for each tower’s time series input (whether it is wind speed or power) and look at the averaged skill over the towers (clicking on ’Over individual towers’),
2) or average the towers’ time series input (whether it is wind speed or power) and look at the skill of the Model over this aggregate (clicking on ’Over towers aggregate’).

Other options that the user can choose from are in the area called ’Basic Parameters’.

Here the user can select:

1) if the input dataset is in wind speed (which will be converted into power by the RT&M itself using a standard IEC class 2 wind power curve), or if the input is already in normalized power (ranging between 0 and 1).
2) number of towers and number of forecast hours in the user’s input data (4 towers and 15 forecast hours in our case)
3) whether to apply a weighting function before averaging the score matrix that accounts for the fact that the skill scores for the more extreme events will have a greater impact on grid operations than the weaker ramps (find more info about how the weighting function works in the Main Reference);
4) what value to assign to the bonus weight (a bonus that can be applied to the model skill when excess energy production can be reduced through wind plant curtailment). This value ranges between 0 and 1 (with steps of 0.1), with 0 being equivalent to no bonus and 1 being the maximum (find more info about how the bonus weight works in the Main Reference);

If the input data provided by the user can’t be read or if the number of towers or forecasts input to the GUI doesn’t agree with the provided input data the GUI will show this alert box:



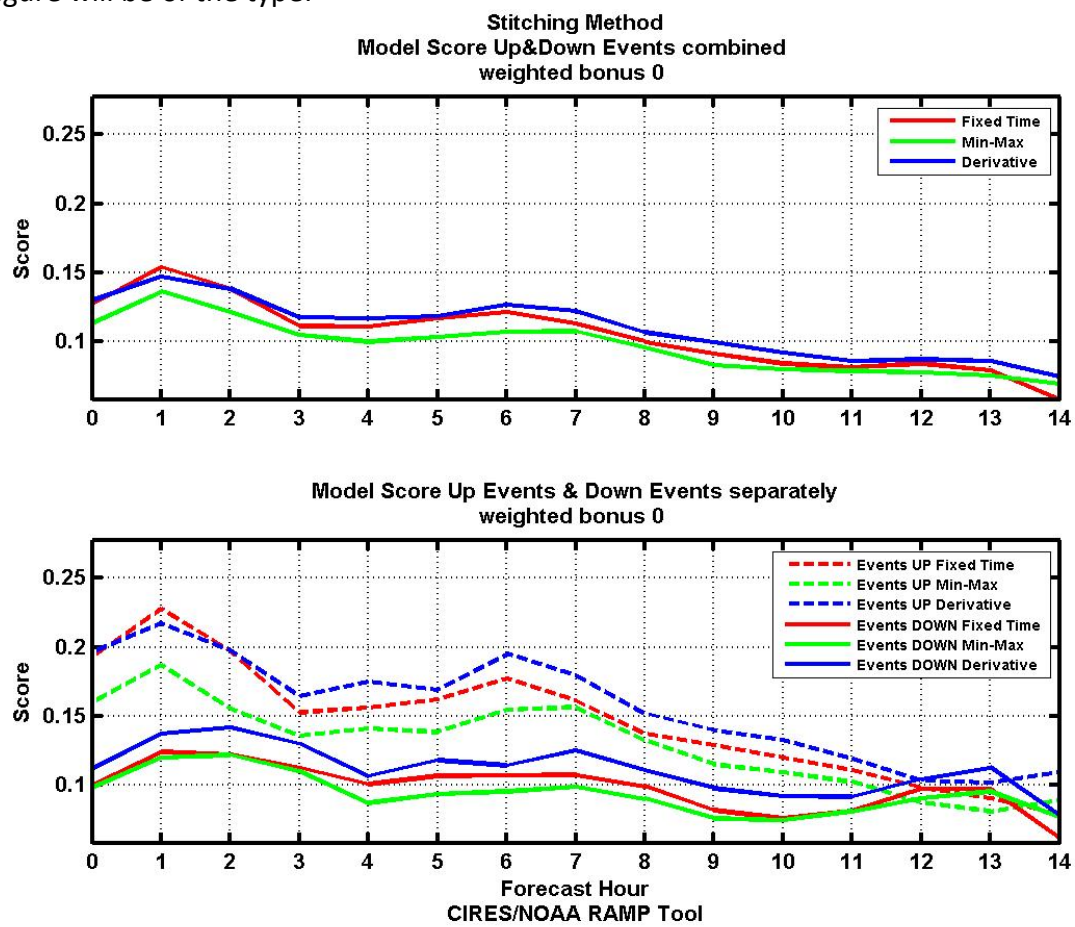

The user can also select to get the additional plots (checking the box ’Additional plots‘) and, if this is the case, he/she can select whether to look at up and down ramps combined, only up-ramps or only down-ramps; which ramp identification method; and which forecast horizon to look at.

The input files will be read once the user hits the ‘Run’ button for the first time. While the GUI stays open, the program will store the input data in the workspace and will not read it again but

will allow the user to reprocess it with different parameters and settings. If the user needs to read new input files he/she has to close the GUI and restart the program.
Finally we want to remark that a user could change other parameters or settings (for example he/she could be interested at measuring the skill of the model on other time windows and power thresholds than those selected by the authors of this RT&M), but in this case he/she has to have Matlab installed on his/her computer and be enough experienced to amend the Matlab code.

## 5. Output

The standard output of the RT&M will be saved in the automatically created 'Output_Stitching' or 'Output_Forecast_Run' directories according to the user decision to use the "Stitching Method" or the "Independent Forecast Run Method" to compare model output versus observations.
The standard output of the RT&M will be a jpg figure and a text file.
The figure will be of the type:

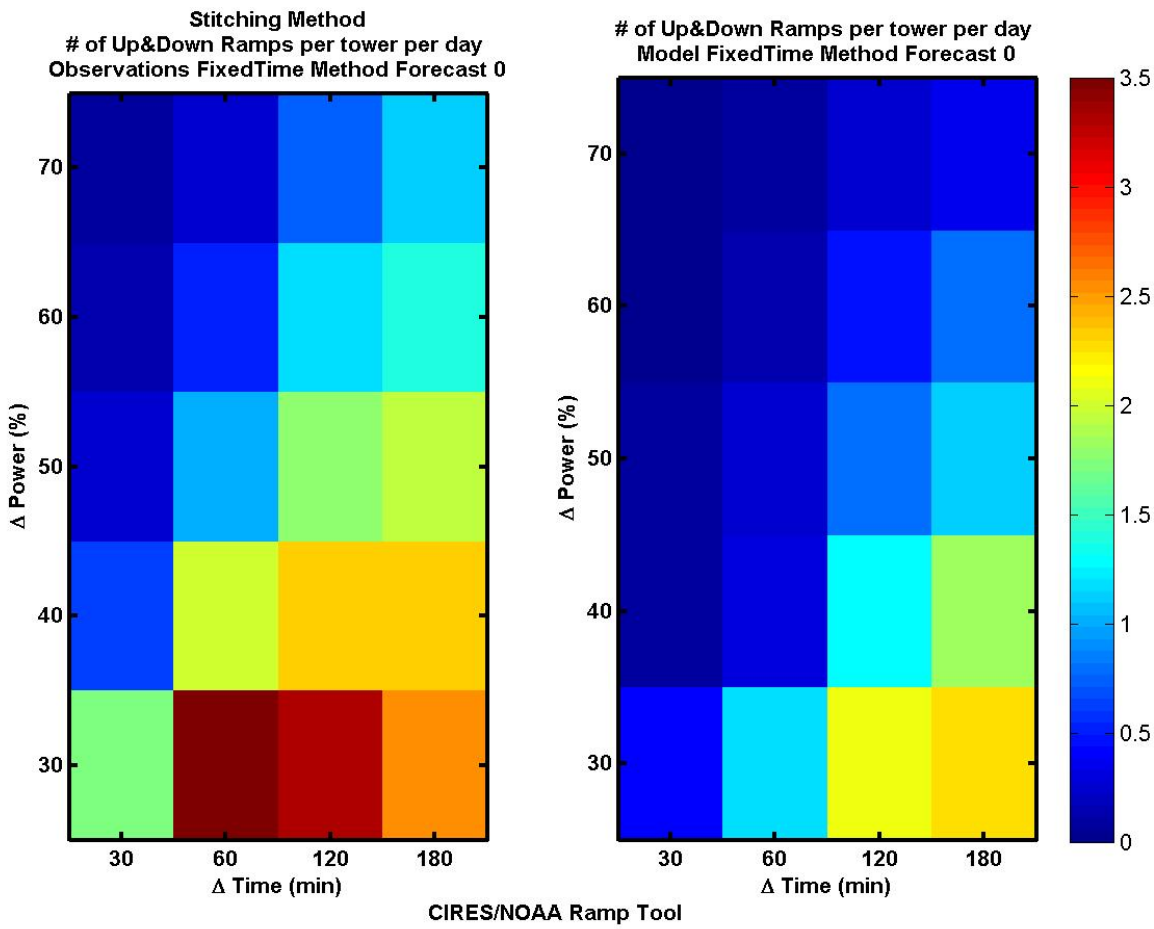


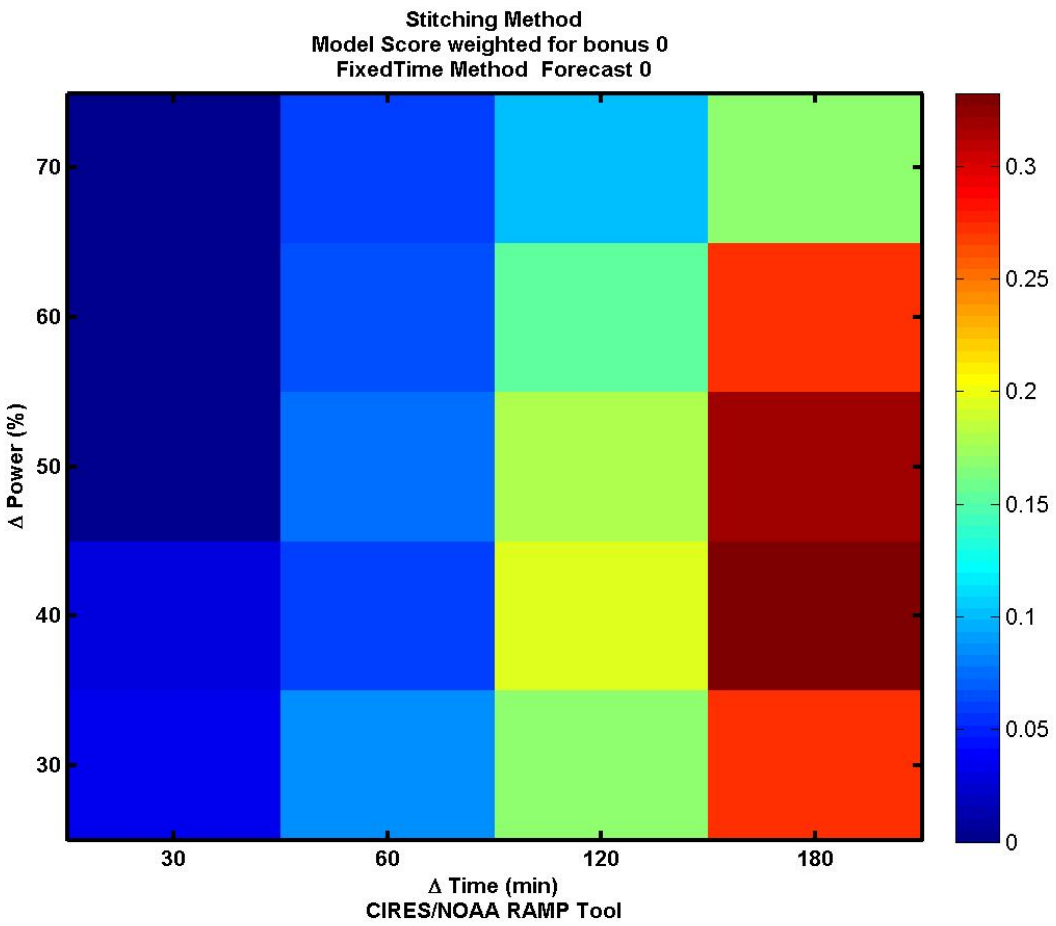

(find more info about this figure in the Main Reference).

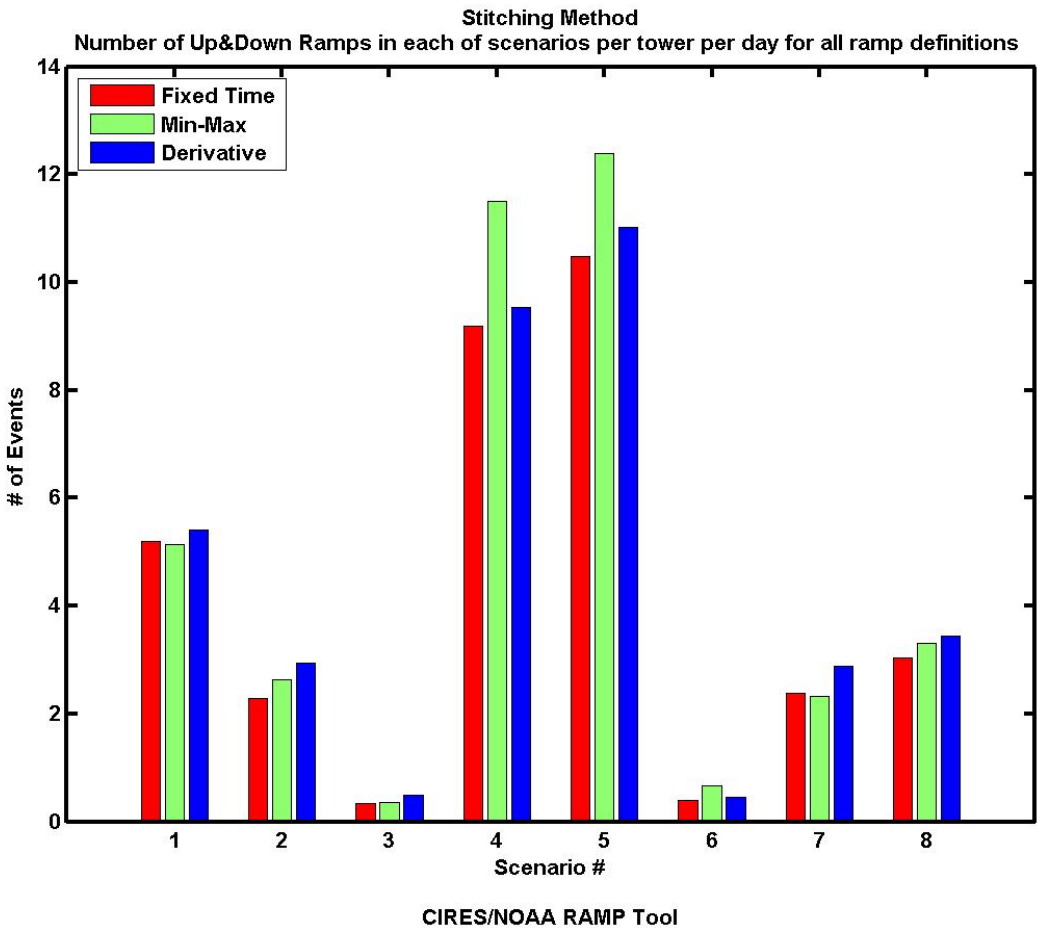
The text file (Total_Score_xxxxxx_bonusX.txt, where xxxxxx is 'weighted' or 'unweighted', and X is the value assigned to the Bonus Weight, according to the setting parameters) will contain the numerical values relative to the above figure. In particular, it will be a matrix of values with 9 rows, with the number of columns equal to the forecast hours (in our case 15).

- Lines 1-3 will be the values of the skill scores relative to the upper panel (ordered by method: first Fixed Time method, second Min-Max method and third Derivative method).
- Lines 4-6 will be the values of the skill scores relative to the up-ramp events (dashed lines of the lower panel, again ordered by method).
- Lines 7-9 will be the values of the skill scores relative to the down-ramp events (solid lines of the lower panel, again ordered by method).

If the 'Additional Plots' option was chosen on the GUI following plots will be created:



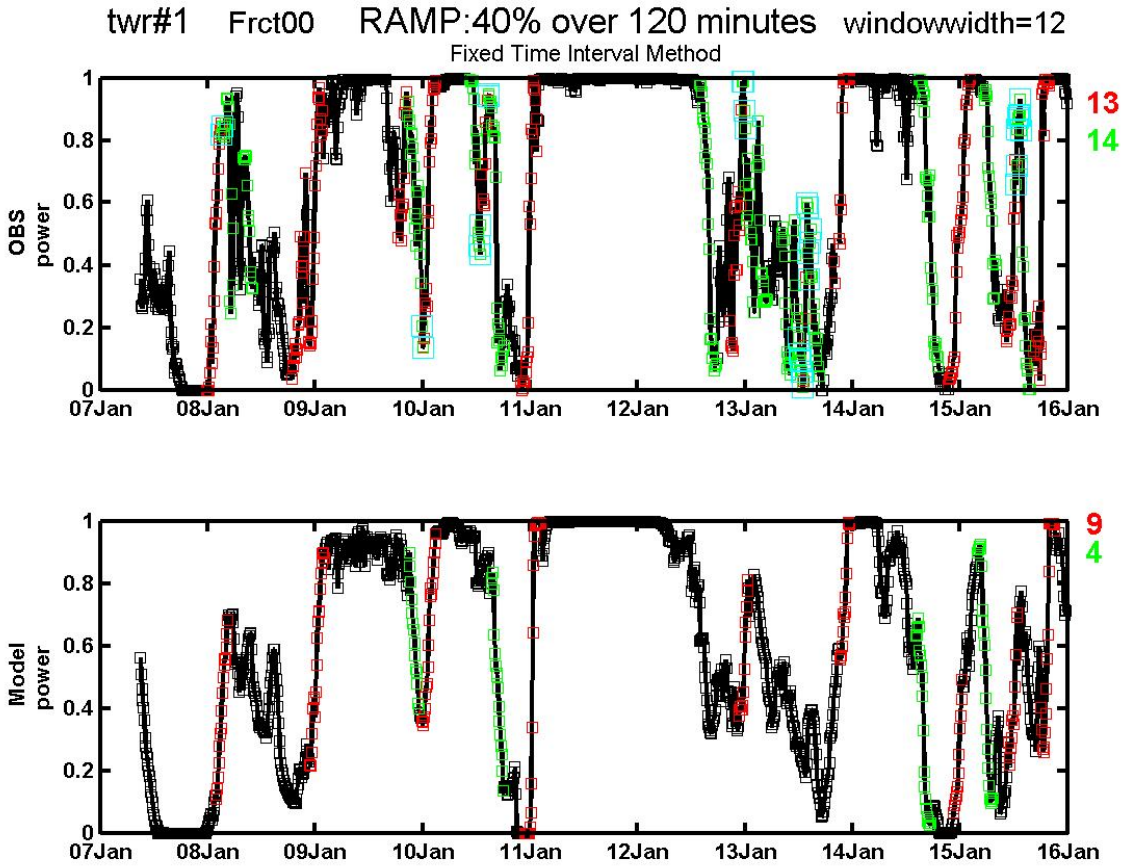

Stitching Method
Model Score weighted for bonus 0
FixedTime Method Forecast 0
Δ Power (%)
70
60
50
40
30
30
60
120
180
Δ Time (min)
CIRES/NOAA RAMP Tool
0.3
0.25
0.2
0.15
0.1
0.05
0




These additional plots will be displayed for the user to view (and eventually change fonts, colors…) and they will also be saved in the 'Output_Stitching' or 'Output_Forecast_Run' directory (according to the user decision to use the "Stitching Method" or the "Independent Forecast Run Method" to compare model output versus observation) in jpeg format (find more info on the content of these figures in the Main Reference).

Finally, for the user's benefit an example of ramps identified in the time series of observations and model output will be displayed for the first tower only (in our case FAH). For this example only the ramps identified with a time window equal to 120 minutes and a delta power equal to 40% are displayed. An example of such a figure is shown below.

Here in the top panel is the time series of 10 min normalized power values estimated from anemometer measurements on the first of the 4 towers used in our study and ramp events identified using the Fixed Time Interval method (using a 40% power change threshold over 2 hours). Similar figures for the other ramp identification methods will be output as well. The lower panel is the same as the top panel but for the model time series of power (at forecast hour 00). In both panels up-ramps are in red and down-ramps are in green, and blue squares denote overlapping ramps of opposite directions. The numbers of ramps found in each time series are shown on the right.


twr#1 Frct00 RAMP:40% over 120 minutes windowwidth=12
Fixed Time Interval Method
OBS power
13
14
Model power
9
4
07Jan
08Jan
09Jan
10Jan
11Jan
12Jan
13Jan
14Jan
15Jan
16Jan