

# **Configuring the HYSPLIT Model for National Weather Service Forecast Office and Spaceflight Meteorology Group Applications**

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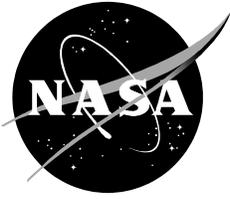
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## Executive Summary

The National Weather Service Forecast Office in Melbourne, FL (NWS MLB) is responsible for providing meteorological support to state and county emergency management agencies across East Central Florida in the event of incidents involving the significant release of harmful chemicals, radiation, and smoke from fires. NWS MLB currently relies on a PC-based version of the National Ocean and Atmospheric Administration Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model to provide such guidance. HYSPLIT provides a complete system for computing atmospheric trajectories, complex dispersion, and concentration simulations using either puff or Lagrangian particles. The NWS Spaceflight Meteorology Group (SMG) is responsible for all weather forecasts for Space Shuttle landings including cumulus cloud development and visibility issues from smoke and high-level trajectory forecasts for thunderstorm anvils. SMG has expressed interest in using HYSPLIT to provide trajectory forecasts in support of Space Shuttle landings.

The PC-based version of HYSPLIT is run through a graphical user interface (GUI) for ease in setting up a trajectory, concentration, or deposition guidance. While the PC-based GUI is convenient for making single-use trajectory and concentration simulations it is difficult for forecasters to run and manage in an operational environment. To alleviate the difficulty in providing scheduled real-time trajectory and concentration guidance, the Applied Meteorology Unit (AMU) was tasked to configure a Linux version of HYSPLIT that ingests input from several National Center for Environmental Prediction (NCEP) model products and the Weather Research and Forecasting (WRF) model. These objectives were met successfully.

The AMU configured HYSPLIT to provide forecasters with automated guidance from a number of source locations using meteorological input from the NCEP North American Mesoscale (NAM) and the Rapid Update Cycle (RUC) models. For the NAM guidance, HYSPLIT was configured to run four times a day, from a variety of user defined source locations and forecast intervals. For shorter-range guidance, the AMU configured HYSPLIT to run eight times per day using the operational RUC products from various source locations and forecast times. The scheduled guidance is controlled through cron jobs that automatically download the NCEP model products, convert the meteorological grids into HYSPLIT binary format, run the model, and post-process the data to create output graphics, including an option to display the output in Google Earth™ or within Geographic Information System (GIS) applications.

NWS MLB and SMG run locally-configured versions of the WRF model within the Environmental Modeling System (EMS). The WRF EMS model configurations are initialized with local observations and are run at finer spatial and vertical resolution than provided by the NCEP model guidance. WRF can provide input into HYSPLIT that may better predict the unique mesoscale environment in Florida and southern California than with the NCEP guidance. Therefore, the AMU was tasked to configure a utility program to convert EMS output into HYSPLIT binary format. Since SMG uses the Advanced Research WRF (ARW) within the EMS package, a converter recently made available in HYSPLIT could be used without modifications. On the other hand, NWS MLB is running the Nonhydrostatic Mesoscale Model (NMM) version of WRF within the EMS and no such conversion program for HYSPLIT exists. The AMU configured a conversion program for the NMM output by modifying existing source code used to convert the NAM model output into HYSPLIT format. The end product allows forecasters to automatically provide trajectory and concentration forecasts on a scheduled basis using either the NCEP products or locally configured versions of WRF and, therefore, provide timely information on hazardous conditions to their customers.

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## 1. Introduction

The National Weather Service Forecast Office in Melbourne, FL (NWS MLB) is responsible for providing meteorological support to state and county emergency management agencies across East-Central Florida in the event of incidents involving the significant release of harmful chemicals, radiation, and smoke from fires and/or toxic plumes into the atmosphere. Accurate and timely guidance is critical for decision makers charged with protecting the health and well-being of populations at risk. Information that can describe the geographic extent of areas possibly affected by a hazardous release, as well as to indicate locations of primary concern, offers better opportunity for prompt and decisive action. NWS MLB uses the National Oceanic and Atmospheric Administration (NOAA) Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model to provide trajectory, concentration, and deposition guidance during such events.

Forecasters at the NWS Spaceflight Meteorology Group (SMG) in Houston, TX have also expressed interest in using HYSPLIT to assist with weather Flight Rules (FR) during Space Shuttle landings at the Kennedy Space Center in Florida and Edwards Air Force Base in California. In particular, SMG would provide low and mid-level HYSPLIT trajectory forecasts for cumulus clouds associated with smoke plumes, and high-level trajectory forecasts for thunderstorm anvils. Another potential benefit for both NWS MLB and SMG is using HYSPLIT concentration and deposition forecasts in dense fog situations related to smoke plumes from fires.

For expedience in delivering dispersion forecasts in the diversity of operational situations, NWS MLB had become increasingly reliant on the PC-based version of HYSPLIT accessed through a graphical user interface (GUI). While the PC-based GUI offers unique advantages when compared to running the model from a command line, it is still difficult for forecasters to run and manage in an operational environment. Therefore, the first goal of this task for the AMU was to obtain and configure a Linux version of HYSPLIT that ingests the National Centers for Environmental Prediction (NCEP) guidance, such as the North American Mesoscale (NAM) and the Rapid Update Cycle (RUC) models. The AMU configured scripts to automatically download the NCEP model products, convert the meteorological grids into HYSPLIT binary format, run the model from several pre-selected latitude/longitude sites, and post-process the data to create output graphics.

NWS MLB and SMG run locally configured versions of the Weather Research and Forecasting (WRF) model contained within the Environmental Modeling System (EMS; Rozumalski 2006). These locally configured versions of WRF are run at finer spatial and vertical resolution than provided by the NCEP model guidance. The WRF configurations are initialized with their own local data assimilation systems and can provide input into HYSPLIT that may better predict the unique mesoscale environment in Florida and southern California than the coarser resolution NCEP guidance. Therefore, the second goal of this task was to develop a utility to convert local WRF output into HYSPLIT binary format. The AMU created a conversion program for the WRF output by modifying existing source code used to convert the NAM products. This allows forecasters to automatically provide trajectory and concentration guidance on a scheduled basis using either NCEP products or a locally configured WRF model and, therefore, provide timely information on hazardous conditions to their customers.

This report is organized as follows. Section 2 provides a brief technical description of the HYSPLIT model. Section 3 gives an overview of the local HYSPLIT model configuration that uses the operational NCEP model guidance for NWS MLB. Section 4 provides a description of the local HYSPLIT configuration using the WRF model contained within the EMS run at both NWS MLB and SMG. A summary of the project is given in Section 5. Finally, a user guide that describes the model structure and description of the various HYSPLIT variables is given in Appendix A.

## 2. HYSPLIT Model Description

The HYSPLIT model has been developed over many years at the NOAA Air Resources Laboratory (ARL). The model is a complete system for computing atmospheric trajectories, complex dispersion and simulations using either puff or Lagrangian particles (Draxler 2007). HYSPLIT applications include tracking and forecasting the release of pollutant material, air-parcel trajectories, volcanic ash, and smoke from wildfires. The model is used operationally by NOAA through various forecasting agencies such as NCEP and local NWS offices. HYSPLIT uses gridded meteorological data to drive the trajectories and concentrations either forwards or backwards in time at regular time intervals. The software is written mainly in Fortran with several modules in C code. A complete description of the model, code, and software structure can be found in Draxler (1997, 2007).

Dispersion of a pollutant is calculated by assuming either puffs or particles are released into the wind field. In the puff model, puffs expand until they exceed the size of a pre-defined meteorological grid cell and then split into several new puffs, each with a share of the pollutant mass. In the particle model, a fixed number of particles are moved by the mean horizontal and vertical wind field including a turbulent component. For default simulations, HYSPLIT assumes a puff distribution in the horizontal and particle dispersion in the vertical direction. This allows for greater accuracy of the vertical dispersion parameterization combined with the advantage of having an ever-expanding number of particles to represent the pollutant distribution. HYSPLIT trajectories are calculated by running the model without dispersion, thus computing the advection of a single pollutant particle within the mean wind. For both trajectory and concentration computations, the model can be run forward or backward in time in order to locate an unidentified pollutant source location.

The gridded meteorological data fields required to run HYSPLIT can be obtained from archived data sources or forecast model output available at NCEP. Fortran preprocessors are required to convert the model output fields, usually in the Gridded Binary (GRIB) format, into HYSPLIT's own binary format, hereafter referred to as ARL format. GRIB is a mathematically concise data format commonly used to store historical and forecast weather data. The ARL data structure is a compressed binary direct-access format where multiple time-periods can be contained in each file for quick read access at model run time. Each time period contains a separate index record that includes grid definition, quality control (QC) flags, variable identification and vertical level information. The model can accept gridded meteorological data from multiple grid configurations including polar, global latitude/longitude such as in the Global Forecast System (GFS) model, and Lambert conformal such as in the NAM model. During conversion of the GRIB data records, the input meteorological fields are interpolated to an internal sub-grid chosen by the user to reduce memory requirements and increase computational speed. In addition, HYSPLIT calculations can be performed on nested multiple grids, usually specified from fine to coarse resolution, which allows users the flexibility of using their own locally configured model.

The HYSPLIT model can be run interactively on the internet through the NOAA website at <http://www.arl.noaa.gov/HYSPLIT.php> with appropriate permissions, or the source code can be downloaded and built on a Linux system. The website version has been configured with some limitations to avoid computational saturation of the NOAA server, but the PC or Linux version of the code has no such restrictions. The model includes a Tool Command Language (Tcl/Tk) GUI for ease in setting up a trajectory, concentration, or deposition simulation. The main GUI includes capabilities to download model input data from a defined File Transfer Protocol (FTP) server, convert the data to ARL format, run the trajectory or concentration model, and post-process the output graphically.

The HYSPLIT post-processing programs include several graphical packages used to generate multiple color or black and white postscript images. Recent additions to the software have allowed users to output graphics directly to Google Earth™ format. This option creates a compressed Google Earth .kml file that allows for animated four-dimensional images. HYSPLIT includes the capability of displaying concentration or trajectory guidance on detailed map backgrounds by changing the background file name. The file format is an American Standard Code for Information Interchange (ASCII) latitude/longitude file each user can edit. The model also has the capability to generate output for Geographic Information System (GIS) applications.

### 3. Automated HYSPLIT Configuration

The Tcl/Tk GUI available in the HYSPLIT source code is convenient for managing and configuring single use simulations. However, NWS MLB and SMG forecasters require automated trajectory and/or concentration guidance to be made on a regularly scheduled basis, so they requested a Linux version of the software that can be automated for real-time applications. A Linux version of HYSPLIT would also allow NWS MLB and SMG to make use of meteorological data already located on their local servers. The AMU contacted and obtained HYSPLIT version 4.8 from the model developer, Dr. Roland Draxler of NOAA. This version is flexible enough to be run on a PC or compiled on a Linux system.

The AMU compiled the source code using both the GNU Fortran compiler and Portland Group Fortran (PGF) compiler at the request of NWS MLB and SMG. This allows the forecasters the flexibility of using the code on several different Linux platforms and, more importantly, allows compatibility with other software programs built with each compiler. The NWS MLB version of HYSPLIT and several preprocessors were built using the GNU Fortran compiler; while the SMG version of the code was compiled with PGF compiler due to their local configuration of WRF to ARL converter as described in Section 4.1. The AMU tested and configured the newly compiled versions of HYSPLIT on the local AMU Linux cluster before building all model executables at NWS MLB and SMG.

Once the HYSPLIT source code was configured the resulting executables were tested with the Tcl/Tk GUI to ensure the model would run successfully on Linux. At the request of NWS MLB, the AMU configured several scripts to automatically download several NCEP model products, convert the meteorological grids into ARL format, run the model from multiple latitudes, longitudes, and elevations, and post-process the data to create output graphics. The scripts were configured to run on a scheduled basis using cron jobs, which enable users to execute commands or scripts automatically. The scripts control the automatic downloads of both the NCEP RUC and NAM model data. HYSPLIT was also configured to run using the GFS guidance, but due to its coarse horizontal resolution, the forecasters requested the NAM and RUC to be their preferred input data. The cron jobs reference central parameter files for each NCEP product that contain many of the necessary trajectory and concentration HYSPLIT model runtime variables. This allows forecasters to quickly make changes to the model configuration without having to edit the automated scripts.

The cron jobs configured for NWS MLB launch three different automated processes on a scheduled basis. The scheduled times are a compromise between when the NAM and RUC model guidance becomes available on the NCEP FTP server and computational limitations on the NWS MLB Linux machine. Mr. Peter Blottman, of NWS MLB, developed a master script for the NAM and RUC guidance to oversee each step in the automated HYSPLIT system. The master script checks for successful completion of each step contained in the cron jobs before the next. This ensures the next step will not run if there are significant delays in download times or missing data at any step during the process. The master script also ensures that two or more implementations of HYSPLIT do not interfere with each other by creating a temporary lock file at the start of the script. The lock file is deleted at the end of the master script after all the steps in the cron are completed successfully. The details of each step run via the cron jobs are described below.

#### 3.1 Gribmaster Program

The first step in the automated HYSPLIT system is to obtain the necessary NCEP forecast products. These files are downloaded from the NCEP FTP server using the gribmaster utility program written by Dr. Robert Rozumalski at the NOAA NWS Science and Training Research Center (STRC). The gribmaster program is a Perl utility that allows users to automatically download multiple forecast times of operational model data including the GFS, NAM and RUC GRIB files from the NCEP FTP server. In addition, the gribmaster program has an option to convert the newer NCEP GRIB version 2 files into the older GRIB version 1 files. This option was activated since the HYSPLIT GRIB to ARL conversion utilities only accept GRIB version 1 files.

The AMU configured the gribmaster utility scripts to automatically download the operational NAM 12-km and RUC 13-km forecast products. For shorter-range (< 12-hour) HYSPLIT simulations, NWS MLB prefers to use the RUC to drive HYSPLIT since it is updated hourly and assimilates many types of observations, including surface and aircraft data, at a higher temporal resolution than either the NAM or GFS. The RUC is used by the NWS, aviation, and severe weather community for short-range forecasts. The RUC was designed to provide numerical forecast guidance for a 12-hour period (Benjamin et al. 1998). It assimilates observations every hour at the surface and aloft and is run every hour, which is the highest frequency of all forecast models at NCEP. The AMU configured the

RUC gribmaster script to obtain products every 3 hours, with guidance every 3 hours out to 12 hours. After the GRIB version 2 files are downloaded from the NCEP FTP server the gribmaster utility converts them into GRIB version1 format.

For medium range, (< 48-hour) HYSPLIT simulations, NWS MLB prefers the NAM 12-km model over the operational GFS products due to the better spatial resolution. The NAM model produces an 84-hour forecast every 6 hours, or four times per day. The AMU configured the NAM gribmaster utility program to download the NAM 12-km model guidance four times per day, each at 3-hour forecast intervals out to 48 hours. The NAM gribmaster utility also converts GRIB version 2 files into the older version 1 format.

NCEP has the NAM model output available in smaller subsets, called tiles, instead of the entire Continental United States (CONUS) domain (Figure 1). For the NWS MLB configuration, the AMU modified the original NAM gribmaster program to download NAM tile 16, which is centered over much of Florida (Figure 1). This option saves NWS MLB computational download time along with significant hard drive space on their Linux system. There are no such tiles available for the operational RUC guidance, so the entire CONUS domain is used.

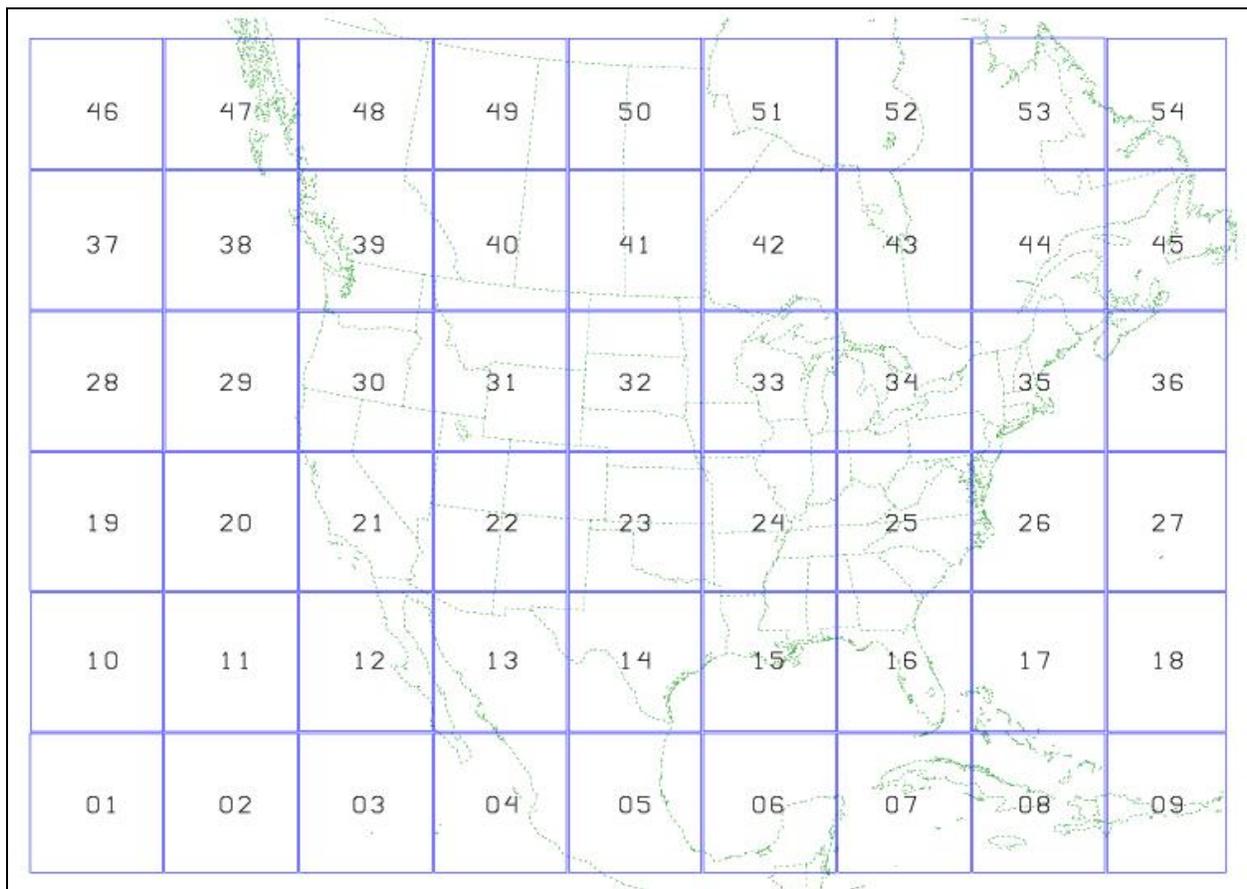


Figure 1. The NCEP operational NAM 12-km model domain. The output is available in the smaller tiles numbered from 1 to 54.

### 3.2 GRIB to HYSPLIT ARL

After downloading the NAM and RUC guidance from the NCEP FTP server, the cron jobs convert the GRIB files into ARL format. The NAM 12-km tiles are converted into the ARL format using the *eta12arl* Fortran program available in the HYSPLIT source code. The *eta12arl* program does not allow users to convert multiple NAM-12km tiles into a single ARL file. If users want to use multiple NAM-12km tiles to drive HYSPLIT the scripts would have to be configured to create an ARL file for each NAM tile. The *eta12arl* program converts the GRIB files on pressure levels to the ARL format. Only a single model time can be converted at once, so the AMU configured a script called *nam12arl.scr* to run the *eta12arl* program to convert each downloaded GRIB file into ARL format. Currently, the

script is configured to convert NAM tile 16 so the other tiles would need to be downloaded from the NCEP FTP server via the *gribmaster* program. The *etal2arl* program converts the GRIB files on pressure levels to the ARL format. The *nam12arl.scr* then combines the various ARL files into a single larger file to cover the desired forecast period. A single 12-km ARL file containing all desired forecast times is then used to drive both the NAM HYSPLIT trajectory and concentration products. It is important to note the NAM analyses fields do not contain diagnostic surface fields such as pressure, temperature, and 10-m winds, therefore no HYSPLIT guidance is started at those times. However, a forecast field from the previous 6-hour NAM cycle is used to fill in the gap.

The RUC 13-km GRIB files are converted using the *ruc2arl* Fortran conversion program. This code was not available in the default HYSPLIT source code, so the AMU obtained and modified existing code from Mr. Glenn Rolph at NOAA. The *ruc2arl* program was originally written to convert the older RUC 20-km grids into ARL format, so the source code array dimensions were enlarged to support the higher resolution grid configuration. It is important to note there is an error output message displayed routinely upon running the *ruc2arl* program due to missing mean sea level pressure in the analysis hour of the RUC GRIB files. Even though this variable is missing in the model output, HYSPLIT does not use mean sea level pressure in any trajectory or concentration calculations, rather it uses surface pressure or terrain height from the meteorological input file so the message can be ignored. This issue was confirmed and discussed with Dr. Draxler and is a result of a QC routine within the *ruc2arl* code that analyzes the meteorological variables in the input file. Similar to the NAM 12-km HYSPLIT guidance, the RUC 13-km GRIB to ARL conversion is controlled by a script, called *ruc2arl.scr* that combines multiple times into a single larger file and is used to drive the requested RUC HYSPLIT simulations.

### 3.3 HYSPLIT Runtime Scripts

The final step in the Linux cron jobs is to produce automated trajectory and/or concentration guidance using the ARL formatted files created in the previous step. The scripts are configured for guidance from a pre-determined number of source locations throughout the NWS MLB County Warning Area and can be easily tuned for any location. The scripts read in central parameter files that allow the user to configure all the critical HYSPLIT variables for the automated runs. More importantly, the parameter files allow forecasters to tune the model without having to edit the automated scripts in real-time. A complete description of the variables contained in each parameter file can be found in Appendix A. Even though there are separate parameter files for each NCEP model product, the options in each parameter file are identical. This allows forecasters to configure HYSPLIT differently for each NCEP model product.

The runtime scripts are configured to automatically provide trajectory and concentration guidance using the variables defined in the parameter files. For each NCEP product, the cron jobs run the trajectory model first and then the concentration model afterwards. Output graphics are created for each source location and are date-stamped according to the NCEP model cycle. After the concentration model is run for each desired source location the ARL files are deleted. This ensures the directory structure is clean and ready for the next HYSPLIT scheduled runtime.

The NCEP trajectory runtime scripts are called *run\_nam12\_traj.scr* and *run\_ruc13\_traj.scr*. Each script does the following:

1. Reads in the NAM or RUC parameter file.
2. References latest ARL file created by earlier cron steps.
3. Creates the baseline *CONTROL* file for the trajectory model. The *CONTROL* file contains the number of source locations, latitude, longitude and elevation of each source location, trajectory lengths, data directories, and output file names. There is no need to edit the script since it passes these variables in automatically from the central parameter file for each NCEP model type. A complete description of the variables contained in each parameter file can be found in Appendix A.
4. Creates an advanced configuration file for trajectory and dispersion guidance. For default simulations the advanced file is not required; however it contains variables such as model time step, number of vertical levels, and trajectory end point intervals. The script passes the variables in automatically from the central parameter file.
5. Runs the HYSPLIT trajectory executable (*hymodelt*) for each requested forecast time.
6. Creates postscript graphics file, converts it to Graphics Interchange Format (GIF), and creates Google Earth output files using the HYSPLIT *trajplot* program. The postscript file is deleted after the conversion to GIF

format. The graphics are then named by NCEP model type, model cycle time, and forecast hour. A single graphics file is created no matter how many source locations are requested. This enables forecasters to view multiple trajectories on a single image. Figure 2 shows an example of three 12-hour forecast trajectories initialized in real-time by the RUC 13-km guidance on a Google Earth map.

- Creates GIS shapefiles if the *traj\_shpfile* option is activated in each parameter file. This is done by re-running the *traplot* program and requesting an Earth Resource Surveys Incorporated (ESRI) formatted text file. The text file is then converted to shapefile format using the *ascii2shp* conversion utility available within HYSPLIT. Each parameter file contains options to create trajectory shapefiles consisting of points or lines. The shapefiles are then named by NCEP model type, model cycle time, and forecast hour and written to the requested output directory.

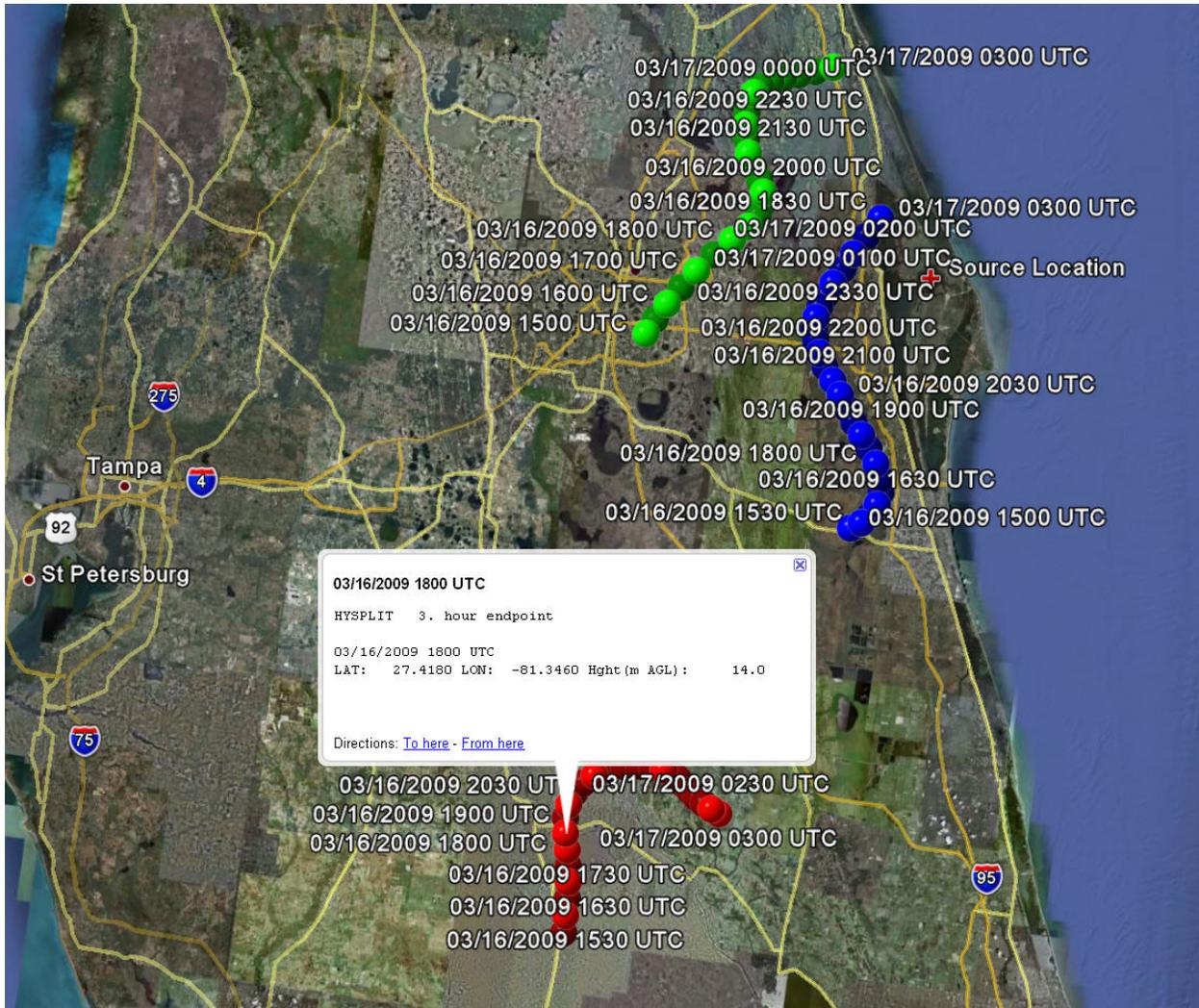


Figure 2. Example HYSPLIT trajectories showing 12-hour forecasts from three source locations within the NWS MLB forecast area. The HYSPLIT trajectories begin at 1500 UTC 16 March 2009 and are initialized using RUC 13-km forecast data. Users can click on each trajectory end-point to get the time, latitude, longitude, and elevation along each trajectory.

The concentration runtime scripts are called *run\_nam12\_conc.scr* and *run\_ruc13\_conc.scr*. Each script does the following:

1. Reads in NAM or RUC parameter file.
2. References latest ARL file created in earlier cron step.
3. Configures the model to release pollutants at user-defined source locations over a defined number of forecast hours. The concentration model is run separately for each source and start-time; however the number of iterations is controlled in the parameter file. A complete description of the variables contained in each parameter file can be found in Appendix A.
4. Creates the baseline *CONTROL* file for the concentration model. This file contains the source location information, emission rate and duration, sampling grid information, number of pollutants, and deposition information. These variables are configured in central parameter files.
5. Creates an advanced configuration file for the concentration guidance. The file controls model variables including time step, model type such as particle, puff or Gaussian, number of particles or puffs released, time splitting information, and a chemistry model option. All variables are set in the parameter file and are passed into the script at runtime.
6. Runs the HYSPLIT concentration executable (*hymodelc*) for each source location and forecast hour.
7. Creates postscript graphics files, converts it to GIF format, and creates Google Earth output files using the HYSPLIT *concpplot* program. The postscript file is deleted after the conversion to GIF format. The graphical output files are named by the NCEP model type, source identification, model cycle time, and forecast hour. At the request of NWS MLB, separate graphics files are created for each source location because multiple plumes could overlap and cause confusion to the forecaster. The Google Earth files allow for animated guidance products depending on the output interval defined in the parameter file. Figure 3 shows output from the HYSPLIT concentration model for a single source release west of Melbourne, FL of a pollutant initialized in real-time by the RUC 13-km guidance on a Google Earth map.
8. Creates GIS shapefiles if the *conc\_shpfile* option is activated in each parameter file. This is done by running the *concpplot* program and requesting an ESRI-formatted text file. The text file is then converted to shapefile format using the *ascii2shp* conversion software available within HYSPLIT. The parameter file contains options to create concentration shapefiles consisting of polygons or lines. The shapefiles are then named by NCEP model type, source identification, model cycle time, and forecast hour. It is important to note that activating the concentration shapefile option can take a long time to process depending on the resolution and number of sampling times requested in the parameter files.
9. Removes the HYSPLIT ARL file for each NCEP model type. Note this step is not done in the trajectory runtime scripts as a new ARL file will be created at the next download time, which is controlled by the automated cron jobs.

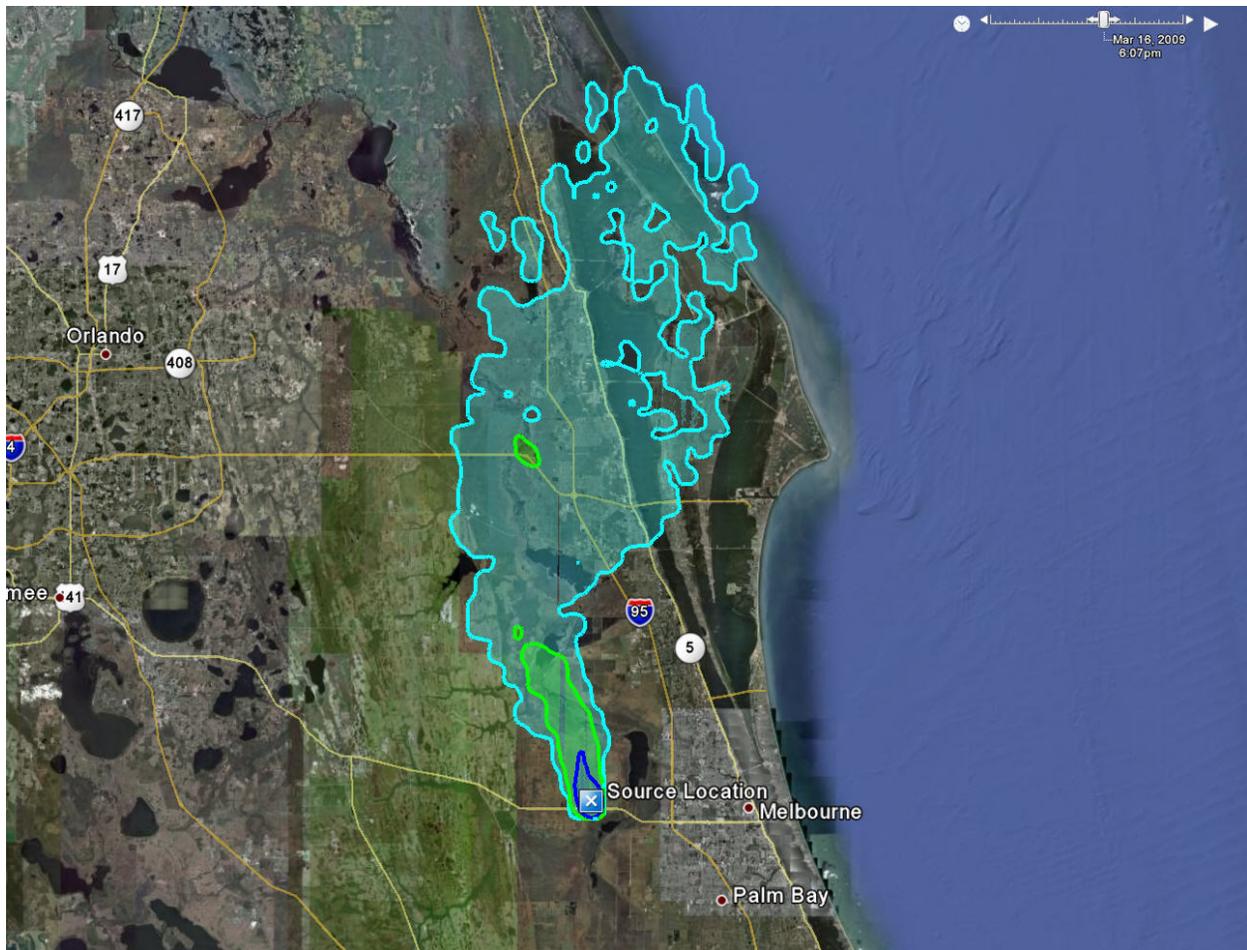


Figure 3. Example HYSPLIT concentration output showing a potential pollutant release of time-integrated air concentrations averaged between 2000 and 2100 UTC March 2009. The concentrations are shown in the 0 to 50-m layer above ground as defined in the parameter files. HYSPLIT was initialized using real-time RUC 13-km forecast data at 1500 UTC 16 March 2009. The contour levels plotted in this example are  $10^{-10}$ ,  $10^{-11}$ , and  $10^{-12}$  mass units and are available in the Google Earth legend. Even though this image represents a static concentration plot during a 12 hour forecast, animated concentration output is available by using the animation toolbar in Google Earth.

#### 4. HYSPLIT WRF EMS Configuration

NWS MLB and SMG run locally-configured versions of the WRF model. The model consists of two dynamical cores, the Advanced Research WRF (ARW) and Nonhydrostatic Mesoscale Model (NMM). The ARW core was developed primarily at the National Center for Atmospheric Research, while the NMM was developed at NCEP. The NWS MLB and SMG forecasters run the WRF model using the EMS system (Rozumalski 2006). The EMS is a complete, full-physics, and numerical weather prediction package that incorporates dynamical cores from both the WRF ARW and NMM models into a single end-to-end forecasting system. The EMS includes all the pre-compiled binaries necessary to run all pre- and post-processing programs so no source code compilation is required on each user's platform. More details on the WRF EMS can be found at <http://strc.comet.ucar.edu/wrf/index.htm>.

The local versions of the WRF EMS are run at finer spatial and vertical resolution than either the RUC or NAM model guidance. Additionally, the NWS MLB version of WRF is initialized with the Local Analysis and Prediction System (LAPS; McGinley 1995). LAPS is a 3D weather analysis program that integrates data from meteorological observations into a gridded meteorological background field such as the RUC model. These locally tuned WRF models can provide input into HYSPLIT that may be a better depiction of the mesoscale environments than the coarser resolution NCEP guidance.

Older versions of HYSPLIT relied on output from operational synoptic and mesoscale models provided by NCEP; however, recent modifications have allowed users the flexibility of using guidance from WRF simulations. Recent source code was made available to convert ARW model output in Network Common Data Form (NetCDF) format to ARL format; however no such code exists to use NMM output.

##### 4.1 SMG

SMG uses the ARW within the EMS package so the converter recently made available in HYSPLIT could be used without modifications. However, the ARW to ARL source code required NetCDF libraries to be built on Linux. During the installation on the local AMU Linux cluster, the AMU noted that NetCDF could only be compiled using the PGF compiler so the ARW to ARL converter was also built using the PGF compiler. However, during the HYSPLIT installation at SMG, it was discovered that the NetCDF libraries could be built on their Linux system with the GNU Fortran compiler while the HYSPLIT source code could be built with the PGF compiler. At the request of SMG, the PGF compiler was used to compile their version of HYSPLIT. Therefore, it is important to note the SMG version of HYSPLIT differs from the NWS MLB version of the model due to the Fortran compilers used in each case. If NWS MLB decides to use the ARW to ARL converter in the future it may require NetCDF and the converter to be built with the PGF compiler as was found on the AMU Linux cluster.

The ARW to ARL source code directly converts model native output files in NetCDF format to ARL format. The code was made flexible enough to allow any horizontal and vertical grid configuration. The only limitation is users can only convert one ARW grid configuration and model output time upon execution. To alleviate this restraint the ARW ARL files can be combined together to link multiple model output times. The AMU developed a script, called *arw2arl.scr*, to convert ARW output into ARL format and to combine multiple times into one file. The AMU also tested the newly compiled source code to ensure the HYSPLIT model would run correctly off example ARW model output. HYSPLIT and the ARW converter were recently installed and configured on the SMG Linux system and were tested successfully.

##### 4.2 NWS MLB

NWS MLB is running the NMM version of WRF within the EMS. The HYSPLIT conversion program already developed for the ARW could not be used to convert NWS MLB WRF output due to the different horizontal and vertical coordinate systems between the ARW and NMM. The AMU investigated whether existing source code could be modified or if a new program needed to be developed to ingest the locally configured NMM output. After investigation, the AMU decided to modify the existing Fortran code for converting the NAM operational output (*nams2arl*) into ARL format. The modifications included changing the horizontal and vertical grid arrays within the code to match the operational grid configuration used at NWS MLB. It is important to note the new *nams2arl* program converts NMM GRIB output as opposed to the native model NetCDF output. This requires the users to run the WRF post processing program (WRFPOST), the last step within the EMS, in order to convert the model output files from NetCDF into GRIB format. This is an important difference between the NWS MLB and SMG WRF to HYSPLIT conversion programs.

The NMM to ARL conversion program allows for any desired WRF horizontal grid configuration; however, the model sigma levels are currently hardwired to the current operational NWS MLB vertical grid structure. It would be beneficial to have the program read in the vertical grid configuration at runtime since it would allow forecasters to use different NMM vertical grid configurations without having to recompile the HYSPLIT source code. However, this was not done in the current task because it would require the WRFPOST program contained within the EMS to write out the individual sigma levels within the output GRIB files. Since the EMS contains pre-compiled binaries, changes to the WRF NMM output structure were not possible without going through the EMS developer. The AMU contacted Dr. Rozumalski about making this change in future versions of the EMS; however this was not addressed before the task ended.

For compatibility with the EMS, the new *nams2arl* routine required several changes to the EMS Perl scripts and configuration files. The changes included:

1. Activating the WRF native level model output in the *wrf\_cntrl.parm* file. This file controls what variables are written to the GRIB files within the EMS. The *nams2arl* code needs model variables directly on the native vertical grid coordinate system. By default, the EMS version of WRFPOST outputs variables on pressure levels, so it was critical that native model levels be output as well. The *nams2arl* program required the following variables on model levels: pressure, height, temperature, turbulent kinetic energy, specific or relative humidity, u and v wind components, and a vertical wind component.
2. Keeping the de-staggered Awakara E-grid WRF GRIB, or referred to as native model output files in the EMS scripts. By default, the *wrfpost.pl* EMS script deletes these files after interpolation to a normal latitude/longitude grid for ingestion into other meteorological software programs. This required deactivating the line in the *wrfpost.pl* script within the EMS system that deletes the de-staggered GRIB files.

Once the above changes were made to the EMS, the AMU wrote a script to convert NMM model output into ARL format similar to one developed for SMG. The AMU also configured a HYSPLIT runtime script and parameter file similar to those developed to handle the operational NCEP guidance.

Even though an NMM to HYSPLIT utility program was developed in this task, the operational implementation has not yet been employed due to an issue within the EMS. During initial testing of the new conversion program, the AMU discovered a bug with the treatment of NMM vertical levels within the EMS. The model output vertical levels were written in a top-down approach instead of the normal ground-up configuration contained in the operational version of WRFPOST run at NCEP. The files created by the WRF EMS postprocessor caused a runtime error when ingested into HYSPLIT. The AMU debugged this issue with Dr. Rozumalski and it has since been corrected in the latest version of the EMS, which was released in February 2009. The new EMS was tested and configured on the AMU Linux cluster; but due to other customer priorities it has not yet been installed at NWS MLB. It is important to note the newly created NMM to HYSPLIT conversion program developed in this task only works with the newest version of the WRF EMS. Based on discussions with NWS MLB, it was deemed beyond the scope of this task to modify the older version of the EMS to be compatible with HYSPLIT. However, NWS MLB is expected to upgrade their EMS version in the near future. Once the upgrade is complete it will be important that the changes outlined above are made.

## 5. Summary

The first goal of this task was to obtain and install the latest version of HYSPLIT on a Linux system that ingests routine NCEP model products. The second goal of this task was to configure a utility program to convert WRF EMS output into HYSPLIT binary format. Both of these objectives were met successfully. NWS MLB uses HYSPLIT to provide trajectory and concentration guidance during the significant release of harmful chemicals, radiation, and smoke from fires and/or toxic plumes into the atmosphere. SMG forecasters have also expressed interest in using HYSPLIT to assist with Shuttle FR, in the event of low-level smoke plumes, cumulus clouds associated with smoke plumes, and high-level trajectory forecasts for thunderstorms. NWS MLB and SMG rely on the PC-based version of HYSPLIT through the use of a GUI; however it is difficult for forecasters to run and manage in an operational environment. To alleviate this difficulty the AMU configured the latest version of HYSPLIT on Linux that ingests several gridded meteorological forecast products.

The AMU wrote several scripts that are scheduled to run through Linux cron capability to produce automated HYSPLIT trajectory and concentration guidance from the RUC and NAM models. The scripts are configured to automatically download the NAM and RUC guidance, convert the meteorological grids into ARL format, run the model from several latitude/longitude sites, and post-process the data to create output graphics. The scripts reference parameter files for each NCEP product that contain many of the necessary trajectory and concentration HYSPLIT runtime variables. This allows forecasters to make changes to the model configuration without having to edit the automated scripts.

NWS MLB and SMG run local versions of the WRF model within the EMS that are run at finer spatial and vertical resolution than provided by the NCEP model guidance. This can provide input into HYSPLIT that may better predict the unique mesoscale environment in Florida and southern California to support Space Shuttle landings. SMG uses the ARW within the EMS package so a converter recently made available in HYSPLIT could be used without modifications. On the other hand, NWS MLB is running the WRF NMM within the EMS. No similar conversion program for HYSPLIT existed for this dynamic core. Therefore, the AMU created a conversion program for NMM output by modifying existing source code used to convert the NAM products. Even though this program was developed and tested as outlined in the task directive, the operational implementation was not employed at NWS MLB. This was due to an error in the way the WRF model vertical levels were written to the GRIB files in the EMS. The bug has since been corrected in the latest version of the EMS, which will be employed soon at NWS MLB. This will allow forecasters to automatically provide trajectory and concentration guidance on a scheduled basis using either the NCEP products or high-resolution local WRF output and, therefore, provide timely information on hazardous conditions to their customers.

Forecasters at NWS MLB and SMG have expressed interest in a follow on task to develop a new GUI that would allow users to more easily make any needed adjustments to the central parameter files developed in this task through an intuitive interface. The GUI would support adjustments to the automated scheduled guidance from the NAM, RUC, and/or WRF products through changes to the parameter files that were developed in this task.

## Appendix A

### Local HYSPLIT Directory Structure and Parameter Files

This appendix provides a brief description of the local HYSPLIT directory structure and parameter files. The installation on Linux includes various sub-directories and files needed for model execution. It is important to note the directory structure as outlined below is similar to the default HYSPLIT configuration, but has additional directories due to the automated scripts. There are several differences between the directories and files at NWS MLB and SMG due to the local configuration of WRF at each location. For a more complete description of the directory structure and code, refer to Draxler 2007. Many of the directories also contain Readme files that provide a description of the contents beyond what is outlined here:

**ARW** – contains the processed ARW ARL files for each scheduled HYSPLIT run. This directory also contains the *arw2arl.scr* conversion scripts.

**bdyfiles** – files for controlling gridded land use, roughness length, and terrain data. The horizontal resolution of each product is currently one degree; however the source code is flexible enough to allow users to input their own data. The files are read in at model execution so there is no need to recompile the source code.

**browser** - contains Tcl/Tk GUI interface code for the HyperText Markup Language (HTML) browser and is used to display help files. Note these files are referenced by the main HYSPLIT GUI used to make single use simulations.

**cluster**- includes several sub-directories for configuring HYSPLIT on a computing cluster.

**cmag**- source code to convert HYSPLIT concentration output into the Community Modeling and Analysis System (CMAQ) model format.

**csource** –source code used by the default HYSPLIT GUI in the *guidcode* directory. Several archived satellite databases are also included in the directory.

**data2arl** – includes example programs to convert gridded meteorological data, including the ARW, in various formats to the ARL format.

**document**– includes various readme and help files for configuring HYSPLIT, including a copy of Draxler 2007.

**examples**– contains several example scripts and batch files that can be used to create automated simulations.

**exec** - contains all the HYSPLIT executable programs, including the trajectory and concentration models, and graphical plotting programs. This directory also includes several programs for debugging and viewing the meteorological variables contained in each ARL file. Several of these programs were used extensively by the AMU in the testing phase of this task. They include:

**chk\_times** –examine the model times that are each ARL files.

**chk\_data** –read and unpack the ARL formatted meteorological data.

**chk\_file** –examine the header and data records of an ARL file.

**chk\_rec** –dumps the first 50 bytes of each meteorological data record.

**contour** –creates a postscript file for a specified variable in the ARL file with contours and colors for a specified variable and time.

**cdit\_miss** – interpolates missing times within the ARL formatted meteorological file.

**graphics** –source code and libraries for the trajectory and concentration postscript programs. This directory contains the map background files for all postscript plots, which is defined in the parameter files. A description of how to configure a customized background map can be found in the readme file contained in this directory.

**guidcode** – contains a Tcl/Tk GUI interface for configuring and running HYSPLIT. The *hysplit.tcl* is the top-level script that will run all other program scripts.

**html** –directory for main HYSPLIT GUI run from the *guidcode* directory.

**IMAGES** – contains the graphical output images from each automated HYSPLIT simulation. This directory includes sub-directories to store the ARW, RUC, NAM, NMM guidance and is defined in the model parameter files.

**library** – includes various code libraries used to compile the model.

**NCEP** – contains the NAM and RUC GRIB and ARL files for each scheduled HYSPLIT run. This directory also contains the *nam12arl.scr* and *ruc2arl.scr* conversion scripts.

**NMM** – contains the processed WRF NMM files for each scheduled HYSPLIT run. This directory also contains the *nmm2arl.scr* conversion scripts.

**paramfile** – contains the HYSPLIT parameter files used to edit and configure the automated HYSPLIT simulations. There is a separate parameter file for the RUC, NAM, and WRF guidance. The configuration of each file is exactly the same, but is used by each automated script to run the various model products.

**qwikcode** – source code used to compile a version of HYSPLIT to make quick trajectory and concentration guidance using default model options.

**source** – includes all the Fortran HYSPLIT source code. This directory includes the new *ruc2arl.f* and *nams2arl.f* conversion programs, which are used to convert the GRIB files into ARL format for the RUC and WRF NMM models, respectively.

**utility** – contains the HYSPLIT build and configuration files, which are referenced upon compilation.

In addition to the sub-directories outlined above, the main HYSPLIT directory is configured as the working directory for the trajectory and concentration runtime scripts and is controlled by the cron jobs. The directory is the default location for all written temporary files such as the *CONTROL* and advanced configuration files. The configuration files are created based upon the variables defined in the parameter files and are stored in the *paramfiles* directory. Each parameter file includes variables to define the trajectory, concentration, and graphical output options. A description of the trajectory and concentration variables contained within each parameter file is outlined in Table 1 and Table 2. The variable names were chosen to be similar to those outlined Draxler 2007.

In most scenarios users should only have to edit the parameter files without having to make changes to the runtime scripts. However, in some contingency situations users may have to refer back to the process outlined in Sections 3 and 4 and make sure the needed meteorological input data is available to drive whatever type of simulation is needed. This is because the cron jobs and various scripts were designed to make automated HYSPLIT simulations at scheduled times.

Table 1. A description of the HYSPLIT trajectory model variables contained in the RUC, NAM, and WRF parameter files. The parameter files are used by the automated scripts to write out the *CONTROL* and advanced configuration files needed to run the trajectory model.

<i>Variable Name</i>	<i>Example Value</i>	<i>Description</i>
<i>&amp; General Parameters</i>		Necessary working directories
working_dir	/data/hysplit4	Directory where HYSPLIT temporary files will be written
grib_dir or netcdf_dir	/data/hysplit4/NCEP/NAM	Directory where GRIB formatted 1 files for the RUC, NAM, and WRF NMM reside. For the ARW HYSPLIT simulations this variable contains the path to the model NetCDF files.
data_dir	/data/hysplit4/NCEP/NAM/	Directory where processed RUC, NAM, and WRF ARL files reside. These files contain the meteorological grids used to drive the HSYPLIT simulation. It is important to keep the syntax of the default filename the same, including the last forward slash, as shown in the example as the HYSPLIT <i>CONTROL</i> file expects this syntax. The directory also contains the GRIB to ARL conversion scripts referenced by the cron jobs.
image_dir	/data/hysplit4/NCEP/IMAGES	Directory where final output graphics are written, including Google Earth and any other requested graphics after successful HYSPLIT completion.
shp_dir	/data/hysplit4/NCEP/SHPFILES	Directory where output GIS shapefiles, if requested, are written.
map_file	/data/hysplit4/graphics/floridamap	ASCII text map background file for postscript graphics. This file can be edited or changed if the user desires.
<i>&amp; Basic Trajectory Parameters</i>		Basic trajectory parameters. These variables are needed for each simulation and used to create the <i>CONTROL</i> file.
traj_year	00	Two-digit start year of trajectory simulation. Only change this variable for contingency runs as when set to zero HYSPLIT defaults to the start of the meteorological guidance. The scripts will automatically process through the chosen times based upon the current meteorological input type and the variable <i>num traj fhour</i> .
traj_month	00	Start month of trajectory simulation. When this parameter is set to zero it defaults to the start month of the meteorological guidance.

Table 1. A description of the HYSPLIT trajectory model variables contained in the RUC, NAM, and WRF parameter files. The parameter files are used by the automated scripts to write out the *CONTROL* and advanced configuration files needed to run the trajectory model.

<i>Variable Name</i>	<i>Example Value</i>	<i>Description</i>
traj_day	00	Start day of trajectory simulation. When set to zero the model defaults to the start day of the meteorological guidance.
traj_hour	00	Start hour of trajectory simulation. When this parameter is set to zero the model uses the start hour of the meteorological guidance
num_traj_fhour	4	Number of start times for trajectory simulations. The automated runtime scripts will use this parameter to determine the number of trajectory iterations.
fhour_traj	03	Start-times (hours) of trajectory simulation in relation to meteorological data files. The number of start-times is based upon the <i>num_traj_fhour</i> parameter.
traj_source_number	10	Number of source locations.
traj_lat	28.02	Latitude (degrees) of each source location.
traj_lon	-80.10	Longitude (degrees) of each source location.
traj_elev	10	Altitude (meters) of each source location.
traj_length	12	Length of trajectory simulation (hours). Backward calculations are configured by setting the time to a negative value.
traj_vert_motion	0	Vertical motion option for trajectory model, 0 – use vertical motion directly from meteorological input data, 1 – derive from isobaric data, 2 – derive from isentropic data, 3 – constant density , 4 – constant internal sigma coordinate, 5 – compute from velocity divergence , 6 – correct the vertical velocity when mapped from quasi-horizontal ETA surfaces.
traj_model_top	10000	Sets the vertical limit (meters) of HYSPLIT model calculations.
traj_num_grids	1	Number of simultaneous input meteorological grids. For automated runs this option will not change.
traj_out	mlb.traj	Output trajectory file. The filename is used internally within the scripts, but is not used to name output graphics.

Table 1. A description of the HYSPLIT trajectory model variables contained in the RUC, NAM, and WRF parameter files. The parameter files are used by the automated scripts to write out the *CONTROL* and advanced configuration files needed to run the trajectory model.

<i>Variable Name</i>	<i>Example Value</i>	<i>Description</i>
<i>&amp; Advanced Trajectory Parameters</i>		Advanced trajectory parameters. These are not necessary for each simulation; however the variables are used to create the advanced <i>TRAJ.CFG</i> file.
traj_ratio	0.75	Defines fraction of grid cell a trajectory is allowed to transit in one advection time step. Reducing this value will reduce the time step and increase computation time.
traj_delt	1.0	Sets the model time step to a fixed value between 1 and 60. By setting the value to zero it allows the model to automatically calculate the time step according to the maximum wind speed, meteorological grid spacing and the <i>traj_ratio</i> . This value must be evenly divisible into 60.
traj_mgmin	10	Minimum size in grid units of the meteorological sub-grid.
traj_khmax	9999	Maximum duration (hours) of any trajectory in the HYSPLIT simulation.
traj_kmsl	0	Flag for input heights to be relative to the terrain height, 0 – Above Ground Level (AGL), or 1 – Mean Sea Level (MSL), 2- treats input height as a fraction of the boundary layer depth.
traj_nstr	0	Model restart interval (hours). A value of zero turns off the restart option.
traj_mhrs	9999	Maximum temporal (hours) trajectory restart period.
traj_nver	0	Number of vertical levels the trajectories are restarted for multiple-trajectory-in-time and space simulations.
traj_tout	60	Write interval (minutes) for trajectory endpoints in output file.
tm_tpot	0	Flag to write out potential temperature (K) along trajectory, 0 – no, 1 – yes.
tm_tamb	0	Flag to write out ambient temperature (K) along trajectory, 0 – no, 1 – yes.
tm_rain	0	Flag to write out precipitation (mm/hour) along trajectory, 0 – no, 1 – yes.
tm_mixd	0	Flag to write out mixing depth (meters) along trajectory, 0 – no, 1 – yes.
tm_relh	0	Flag to write out ambient relative humidity along trajectory, 0 – no, 1 – yes.

Table 1. A description of the HYSPLIT trajectory model variables contained in the RUC, NAM, and WRF parameter files. The parameter files are used by the automated scripts to write out the *CONTROL* and advanced configuration files needed to run the trajectory model.

<i>Variable Name</i>	<i>Example Value</i>	<i>Description</i>
tm_dwsf	0	Flag to write out potential temperature (K) along trajectory, 0 – no, 1 – yes.
tm_terr	0	Flag to show terrain (meters) along trajectory, 0 – no, 1 – yes.
traj_dxf	1.00	West-east grid factor for offsetting meteorological grid in ensemble simulation.
traj_dyf	1.00	North-south grid factor for offsetting meteorological grid in ensemble simulation
traj_dzf	0.01	Vertical grid factor for offsetting meteorological grid in ensemble simulation.
<i>&amp; Trajectory Graphic Options</i>		Graphics options for trajectory plots.
traj_zoom	100	Zoom level (%) for postscript graphics.
traj_arcview	3	Arcview output options, 0 – none, 1 – GIS text file, 3 – Google Earth.
trap_map_proj	1	Map projection for graphics file, 0- Auto, 1 – Polar, 2 – Lambert Conformal, 3 – Mercator.
traj_circle	0	Number of 80 km rings to draw around each source location for postscript graphics. This option is not used for Google Earth plots.
vertical	1	Vertical coordinate system for postscript graphics, 0 – pressure, 1 – AGL (meters), 2 – isentropic (K), 3 – meteorological input model type, 4 – none.
symbol	0	Place a symbol at the source location, 0 – no, 1 – yes.
traj_shp_shpfile	0	Option to create GIS shapefile format, 0 – no, 1 – yes.
traj_shp_type	points	Type of GIS shapefile plot to create, points or lines.

Table 2. A description of the HYSPLIT concentration model variables contained in the RUC, NAM, and WRF parameter files. The parameter files are used by the automated scripts to write out the *CONTROL* and advanced configuration files needed to run the concentration model.

<i>Variable Name</i>	<i>Example Value</i>	<i>Description</i>
<i>&amp; General Parameters</i>		Necessary working directories
working_dir	/data/hysplit4	Directory where all temporary files will be written.
grib_dir or netcdf_dir	/data/hysplit4/NCEP/NAM	Directory where GRIB formatted 1 files for the RUC, NAM, and WRF NMM reside. For the ARW HYSPLIT simulations this variable contains the path to the model NetCDF files.
data_dir	/data/hysplit4/NCEP/NAM/	Directory where processed RUC, NAM, and WRF ARL files reside. These files contain the meteorological grids used to drive the HSYPLIT simulation. It is important to keep the syntax of the default filename the same, including the last forward slash, as shown in the example as the HYSPLIT <i>CONTROL</i> file expects this syntax. The directory also contains the GRIB to ARL conversion scripts referenced by the cron jobs.
image_dir	/data/hysplit4/NCEP/IMAGES	Directory where final output graphics are written. These include the Google Earth and any other requested graphics after successful HYSPLIT completion.
shp_dir	/data/hysplit4/NCEP/SHPFILES	Directory where, output GIS shapefiles, if requested, are written.
map_file	/data/hysplit4/graphics/floridamap	ASCII text map background file for postscript graphics. This file can be edited or changed.
<i>&amp; Basic Concentration Parameters</i>		Basic trajectory parameters. These variables are needed for each simulation and used to create the model <i>CONTROL</i> file.
conc_year	00	Two-digit start year of concentration simulation. When this parameter is set to zero HYSPLIT defaults to the start year of the meteorological guidance. The scripts will automatically process through the chosen times based upon the current meteorological guidance and the variable <i>num conc fhour</i> .
conc_month	00	Start day of concentration simulation. When this parameter is set to zero the model defaults to the start month of the meteorological guidance.

Table 2. A description of the HYSPLIT concentration model variables contained in the RUC, NAM, and WRF parameter files. The parameter files are used by the automated scripts to write out the *CONTROL* and advanced configuration files needed to run the concentration model.

<i>Variable Name</i>	<i>Example Value</i>	<i>Description</i>
conc_day	00	Start day of concentration simulation. When this parameter is set to zero the model defaults to the start day of the meteorological guidance.
conc_hour	00	Start hour of concentration simulation. When this parameter is set to zero the model defaults to the start hour of the meteorological guidance.
num_conc_fhour	1	Number of start times for concentration simulations. The automated runtime scripts will use this parameter to determine the number of concentration iterations.
fhour_conc	00	Start-times (hours) of concentration simulation in relation to meteorological data files. The number of start-times is based upon <i>num_conc_fhour</i> .
conc_source_number	5	Number of source locations. This value controls how many output images are created per time, since the source locations are plotted independently.
conc_lat	28.02	Latitude of each source location
conc_lon	-80.10	Longitude of each source location.
conc_elev	10	Altitude (meters) of each source location.
conc_id	MLB	Source name used to identify output graphics.
conc_length	12	Length of concentration (hours). Backward calculations are configured by setting the time to a negative value.
conc_vert_motion	0	Vertical motion option for concentration model, 0 – use vertical motion from meteorological input data, 1 – derive from isobaric data, 2 – derive from isentropic data, 3 – constant density, 4 – constant internal sigma coordinate, 5 – compute from velocity divergence, 6 – correct the vertical velocity when mapped from quasi-horizontal ETA surfaces.
conc_model_top	10000	Sets the vertical limit (meters) of HYSPLIT model calculations.
conc_num_grids	1	Number of simultaneous input meteorological grids. For automated runs this option will not change.
conc_out	cdump	Output concentration file. The filename is used internally within the scripts, but is not used to name output graphics.

Table 2. A description of the HYSPLIT concentration model variables contained in the RUC, NAM, and WRF parameter files. The parameter files are used by the automated scripts to write out the *CONTROL* and advanced configuration files needed to run the concentration model.

<i>Variable Name</i>	<i>Example Value</i>	<i>Description</i>
num_pollutants	1	Number of different pollutants to track during concentration simulations.
pollutant_name	TEST	Pollutant character name. This must be at maximum a 4-character string.
emission_rate	1.0	Mass units of pollutant released each hour.
emission_duration	12.0	Duration (hours) of pollutant release. Make sure duration is less than or equal to length of available meteorological data.
release_year	00	Two-digit start year of pollutant release for any contingency run. Set this parameter to zero for release to begin at start year of HYSPLIT run.
release_month	00	Start month of pollutant release for contingency run. Set this parameter to zero for release to begin at start month of model run.
release_day	00	Start day of pollutant release for contingency run. Set this parameter to zero for release to begin at start day of model run.
release_hour	00	Start hour of pollutant release for contingency run. Set this parameter to zero for release to begin at start hour of model run.
release_min	00	Start minute of pollutant release for contingency run. Set this parameter to zero for release to begin at start minute of model run.
num_conc_grids	1	Defines the number of concentration grids for sampling calculations.
center_lat	0.0	Latitude of the center of sampling grid. Set this parameter to zero for automatic calculation based upon emission source location.
center_lon	0.0	Longitude of the center of sampling grid. Set this parameter to zero for automatic calculation based upon emission source location.
dx	0.01	Resolution (degrees) of sampling grid in east-west direction.
dy	0.01	Resolution (degrees) of sampling grid in north-south direction
gridx	10.0	Sampling grid span (degrees) in the east-west direction.
gridy	10.0	Sampling grid span (degrees) in the north-south direction.

Table 2. A description of the HYSPLIT concentration model variables contained in the RUC, NAM, and WRF parameter files. The parameter files are used by the automated scripts to write out the *CONTROL* and advanced configuration files needed to run the concentration model.

<i>Variable Name</i>	<i>Example Value</i>	<i>Description</i>
num_vert_lev	1	The number of vertical levels in concentration sampling grid including the surface.
vert_lev_height	50	Height of each level (meters) AGL for concentration output. It is important to keep the number of levels equal to <i>num_vert_lev</i> . Multiple values can be input here.
samp_start_year	00	Two-digit sampling start year. Each grid may have a different start-time. Only use this setting for contingency runs.
samp_start_month	00	Sampling start month. Each grid may have a different start-time. Only use this setting for contingency runs.
samp_start_day	00	Sampling start day. Each grid may have a different start-time. Only use this setting for contingency runs.
samp_start_hour	00	Sampling start hour. Each grid may have a different start-time. Only use this setting for contingency runs.
samp_start_min	00	Sampling start minute. Each grid may have a different start-time. Only use this setting for contingency runs.
samp_end_year	00	Two-digit sampling end year. Each grid may have a different start-time. Set to zero to default to total run length.
samp_end_month	00	Sampling end month. Each grid may have a different start-time. Set to zero to default to total run length.
samp_end_day	00	Sampling end day. Each grid may have a different start-time. Set to zero to default to total run length.
samp_end_hour	00	Sampling end hour. Each grid may have a different start-time. Set to zero to default to total run length.
samp_end_min	00	Sampling end minute. Each grid may have a different start-time. Set to zero to default to total run length.
sampling_type	00	Type of concentration sampling used in calculations, 0 – averaging, 1 – snapshot or instantaneous value at each interval, 2 – maximum concentration observed during <i>sampling_hour</i> and/or <i>sampling_min</i> .
sampling_hour	1	Sampling hour interval.
sampling_min	0	Sampling minute interval.
<i>&amp; Deposition Parameters</i>		Deposition parameters for all emitted pollutants.

Table 2. A description of the HYSPLIT concentration model variables contained in the RUC, NAM, and WRF parameter files. The parameter files are used by the automated scripts to write out the *CONTROL* and advanced configuration files needed to run the concentration model.

<i>Variable Name</i>	<i>Example Value</i>	<i>Description</i>
num_pollutants_dep	0	Number of pollutants depositing. The number of depositing pollutants must be equal to the number of pollutants released in the simulation.
part_diameter	0.0	Particle diameter ( $\mu\text{m}$ ). A value of zero will treat the pollutant as a gas.
part_density	0.0	Particle density (g/cc). A value of zero will treat the pollutant as a gas.
part_shape	0.0	Particle shape. A value of zero will treat the pollutant as a gas.
dep_velocity	0.0	Dry deposition velocity (m/s). The velocity can also be calculated by the model using the resistance method which requires setting the next four variables. Refer to Draxler 2007 for more details.
pol_mol_weight	0.0	Pollutant molecular weight (Gram/Mole).
sfc_reac	0.0	Surface reactivity ratio.
diff_ratio	0.0	Diffusivity ratio.
eff_henry_con	0.0	Effective Henry's Constant.
act_henry_con	0.0	Actual Henry's constant for wet removal.
in_cloud_rem	0.0	In-cloud removal (L/L). This parameter is defined as a ratio of the pollutant in air to rain measured at the ground.
bel_cloud_rem	0.0	Below-cloud removal coefficient (1/s). This parameter is defined through a removal time constant.
rad_decay	0.0	Radioactive decay half-life (days). A non-zero value initiates decay process of both airborne and deposited pollutants.
poll_resp	0.0	Pollutant re-suspension factor (1/m). A non-zero value causes deposited pollutants to be re-emitted based upon soil conditions, wind, and particle type.
<i>&amp; Advanced Concentration Parameters</i>		Advanced concentration parameters. These variables are not necessary for each simulation; since default options will be used. These variables are used to create the <i>CONC.CFG</i> advanced file at runtime.
conc_tratio	0.75	Defines fraction of grid cell that puff or particles are allowed to transit in one advection time step. Reducing this value will reduce the time step and increase computation time.

Table 2. A description of the HYSPLIT concentration model variables contained in the RUC, NAM, and WRF parameter files. The parameter files are used by the automated scripts to write out the *CONTROL* and advanced configuration files needed to run the concentration model.

<i>Variable Name</i>	<i>Example Value</i>	<i>Description</i>
conc_delt	0.0	Time integration time step (minutes). Set this parameter to a fixed value from 1 to 60, but it must be divisible by 60. A value of zero allows the model to automatically calculate the time step according to the maximum wind speed, meteorological grid spacing and the <i>conc tratio</i> .
conc_initd	0	Concentration model type, 0 – 3D particle and vertical, 1 – Gaussian horizontal puff and top-hat vertical puff, 2 – top-hat horizontal and vertical particle, 3 – Gaussian horizontal puff and vertical particle, 4 – top-hat horizontal puff and vertical particle.
kpuff	0	Option to use, 0 - linear with time puff growth or, 1 – square root with time puff growth in concentration puff model.
conc_khmax	9999	Hours after release for particles or puffs to be eliminated from HYSPLIT simulation.
numpar	10000	Maximum number of particles or puffs to be released over duration of simulation.
maxpar	100000	Maximum number of particles permitted to be carried at any time during simulation.
qcycle	0.0	Number of hours between emission start cycles. A value of zero turns this option off.
efile	‘ ’	Filename for source temporal emission factors if emission file is to be used, but it is not required. Note it is important to keep the single quotes around selected filename.
isot	0	Isentropic turbulence flag, 0 – off, 1 – on.
tkerd	0.18	Daytime ratio of vertical to horizontal turbulence.
tkern	0.18	Nighttime ratio of vertical to horizontal turbulence.
ninit	1	Initialization type for particle model, 0 – no particle initialization, 1 – uses <i>pinpf</i> file to initialize particle model.

Table 2. A description of the HYSPLIT concentration model variables contained in the RUC, NAM, and WRF parameter files. The parameter files are used by the automated scripts to write out the *CONTROL* and advanced configuration files needed to run the concentration model.

<i>Variable Name</i>	<i>Example Value</i>	<i>Description</i>
ndump	0	Interval (hours) to write out particle/puff points at selected time intervals. A value of zero turns this option off.
neycl	0	Interval at which the <i>pouf</i> file is written.
pinpf	PARINIT	Initialization file for particle model in contingency simulations. The model will look for this file in <i>working_dir</i> .
pouf	PARDUMP	Particle dump file name.
mgmin	10	Minimum size in horizontal grid units of meteorological sub-grid for concentration calculations.
conc_kmsl	0	Option for all input heights to be relative to be either, 0 – AGL, or 1-MSL.
ichem	0	In-line HYSPLIT chemistry model option, 0 – none, 1 –restructure concentration grid to a source-receptor format, 2 – convert species at 10% per hour, 3 – enable the PM10 dust storm option, 4 – force concentration grid to be identical to meteorological input grid, 5 – deposit particles rather than reducing mass, 7 – re-transport deposited particles on the ocean surface.
cpack	1	Flag to turn off concentration output packing routine, 0 – off, 1 – on. Turning this flag off will result in larger <i>conc_out</i> file.
cmass	0	Mass output flag, 0 – mass/volume, 1- mass only
kspl	1	Interval (hours) for puff splitting routines to be called.
krnd	6	Interval (hours) for enhanced puff merging.
frhmax	3.00	Maximum puff splitting interval (hours).
splitf	1.00	Puff split size in grid units.
frhs	1.00	Horizontal distance in grid units puff scan merge.
frvs	0.01	Vertical distance in sigma units puffs can merge.
firts	0.10	Fractional difference in the age of puffs for a merger to take place.
p2pcf	1.00	Particle to puff or puff to particle conversion factor.

Table 2. A description of the HYSPLIT concentration model variables contained in the RUC, NAM, and WRF parameter files. The parameter files are used by the automated scripts to write out the *CONTROL* and advanced configuration files needed to run the concentration model.

<i>Variable Name</i>	<i>Example Value</i>	<i>Description</i>
conc_dxf	1.00	West-east grid factor for offsetting meteorological grid in ensemble simulation.
conc_dyf	1.00	North-south grid factor for offsetting meteorological grid in ensemble simulation.
conc_dzf	0.01	Vertical grid factor for offsetting meteorological grid in ensemble simulation.
<i>&amp; Concentration Graphic Options</i>		Graphics options for output concentration plots.
conc_zoom	100	Zoom level (%) for postscript graphics.
conc_arcview	3	Arcview output, 0 – none, 1 – log10, 2 – use explicit values, 3 – Google Earth.
bottom	0	Bottom view layer (meters) of each plot.
disp_top	99999	Top view layer (meters) of plot.
contours	0	Contour type of plot, 0 – dynamic/exponential, 1 – fixed/exponential, 2 – dynamic/linear, 3 – fixed/linear, 4 – fixed <i>values</i> set by user.
values	4+3+2+1	Values for <i>contour</i> option. The example here shows 4 contour values.
display	1	Option to display concentrations by, 1- individual vertical levels, or 2 – average levels together.
conc_map_proj	0	Map projection for graphics file, 0- Auto, 1 – Polar, 2 – Lambert Conformal, 3 – Mercator.
conc_mult	1.0	Concentration multiplier.
conc_circle	0	Number of 80 km rings to draw around each source location. This option is not used for Google Earth output.
conc_shp_shpfile	0	Option to create GIS shapefile format, 0 – no, 1 – yes.
conc_shp_type	polygons	Type of GIS shapefile plot to create, polygons or lines.

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### List of Acronyms

3D	Three-Dimensional	MSL	Mean Sea Level
AGL	Above Ground Level	NAM	North American Mesoscale
AMU	Applied Meteorology Unit	NCEP	National Centers for Environmental
ARL	Advanced Research Laboratory	Prediction	
ASCII	American Standard Code for	NetCDF	Network Common Data Form
Information Interchange		NOAA	National Oceanic and Atmospheric
CMAQ	Community Modeling and Analysis	Administration	
System		NWS	National Weather Service
EMS	Environmental Modeling System	QC	Quality Control
ERSI	Earth Resource Surveys Incorporated	PC	Personal Computer
FR	Flight Rules	PGF	Portland Group Fortran
FTP	File Transfer Protocol	POR	Period of Record
GFS	Global Forecast System	RUC	Rapid Update Cycle
GIS	Geographic Information System	SMG	Spaceflight Meteorology Group
GRIB	Gridded Binary	STRC	Science Training and Research Center
GUI	Graphical User Interface	TCL	Tool Command Language
HTML	HyperText Markup Language	UTC	Universal Coordinated Time
HYSPLIT	Hybrid Single-Particle Lagrangian	WRF	Weather Research and Forecasting
Integrated Trajectory		WRFPOST	WRF Post-processing
LAPS	Local Analysis and Prediction System		
MLB	Melbourne, FL		

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