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# P2.9 Use of the NOAA ARL HYSPLIT Trajectory Model For the Short Range Prediction of Stratus and Fog

GARY P. ELLROD
Ellrod Weather Consulting (EWxC, LLC), Granby, CT

## 1. Introduction

The prediction of low stratus and fog is a critical forecast problem for aviation and surface transportation operations. An important element in forecasts of advection fog and stratus is low level flow from sources of moisture into the forecast area. During the transition from offshore to onshore flow, rapid changes in wind direction and speed make it difficult for forecasters to visualize the origin of the air mass over the area after 18-24 hrs.

The National Oceanic and Atmospheric Administration (NOAA) Air Resources Laboratory's (ARL) Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model can provide forecasts of low level trajectories out to 24 hours using data from a variety of numerical prediction models generated by the National Centers for Environmental Prediction (NCEP) (Draxler and Hess, 1998). As of late 2013, none of the NCEP prediction models is Lagrangian, although the Global Forecast System (GFS) may become quasi-Lagrangian in the near future.

The HYSPLIT model was intended for use mostly in Hazardous Materials (HazMat) events such as nuclear accidents, smoke plumes from wildfires, and volcanic eruptions, as well as during air pollution episodes. However, other meteorological applications, such as its use for prediction of coastal advection fog and stratus, are also possible since the model is tunable with respect to the altitude of the trajectory starting points.

*Corresponding author address:* Gary Ellrod, PO Box 240, Granby, CT 06035, Email: gary.ellrod@gmail.com

## 2. Procedures and Data

More than two dozen HYSPLIT cases for the California coast were run and displayed via NOAA-ARL's web site:

**http://ready.arl.noaa.gov/HYSPLIT.php**

California coastal stratus and fog was chosen for the bulk of the model runs as the initial experiments were conducted as part of the Pacific Coast Fog Project (PCFP) (Ellrod et al. 2013). Additionally, some proof-of-concept cases were collected for the Gulf of Mexico, South Atlantic, and New England coasts. The sample cases were obtained by running HYSPLIT using the matrix of trajectories option, based on data from the North American Mesoscale (NAM) or GFS models for 18 to 24-h with an arbitrarily selected starting altitude of 50m. The model grid spacing used was initially 2-degree Lat/Lon as this provided a good regional overview of expected boundary layer flow patterns. Once the model parameters were selected, HYSPLIT outputs the graphics in less than 1 min on a PC. Trajectories were then compared to stratus and fog coverage in GOES visible or IR satellite imagery near the verifying time to see if those originating over water could help determine extent of fog and the locations of fog boundaries.

## 3. Analysis of Results

### *a. California coast*

More than two dozen HYSPLIT analyses were obtained for a variety of coastal California fog and stratus events between 1 May 2013 and 9 Aug 2013. The fog season along the Pacific Coast of the U. S. peaks in mid-summer due to an enhanced maritime inversion, and strong northerly flow associated with the North Pacific Anticyclone which leads to upwelling and cooler sea surface temperatures (SST). Pronounced nighttime radiational cooling near the top of the boundary layer is also present due to the absence of middle and high cloud cover typically found with cold season Pacific frontal systems.

Two cases will be shown as examples: (1) an extensive coastal fog event on 2-3 June 2013 (Fig. 1) and (2) a no-fog case associated with Santa Ana conditions on 2-3 May 2013 (Fig. 2). In coastal stratus events such as on 2-3 June 2013, low-level NAM HYSPLIT trajectories showed strong north to northwest flow, with paths that intersected the coast line, sometimes with pronounced curvature into coastal bays such as San Francisco and Monterey. In Southern California, cyclonic eddies with relatively weak flow were observed in the Los Angeles bight during significant onshore stratus and fog events. In some instances, it was possible to differentiate which sections of coast line would be affected by stratus the following morning versus those which were not affected.

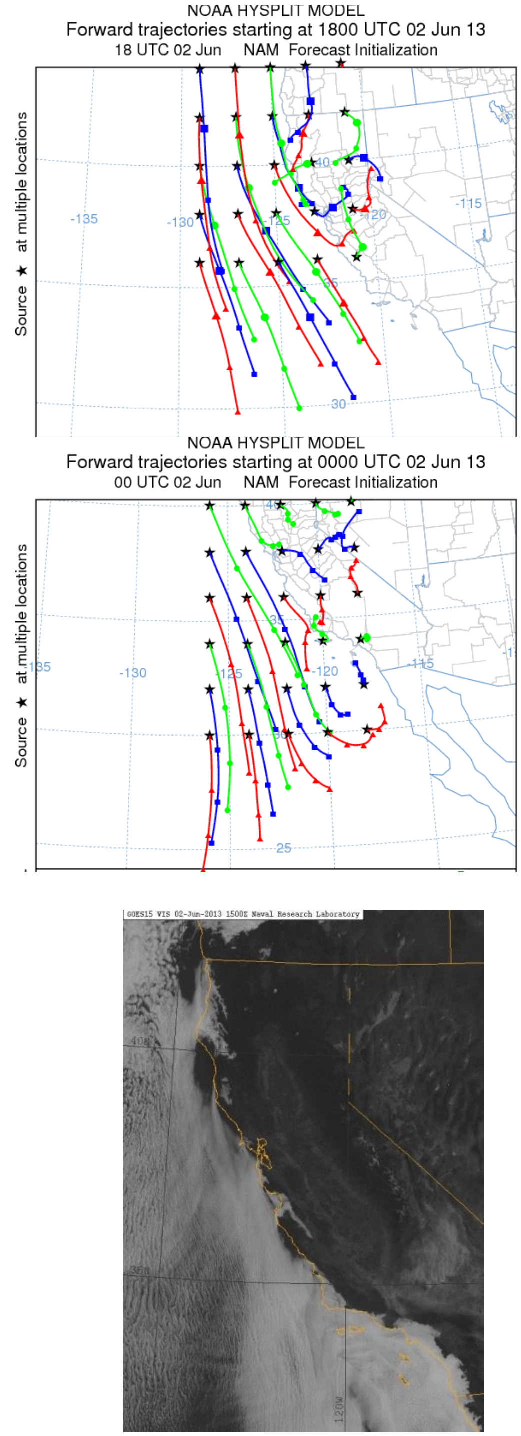


**Figure 1.** 24-h forecast HYSPLIT matrix trajectories based on NAM data at 0000 UTC, 2 June 2013 for north (top) and central and southern CA coasts (middle). GOES-15 visible image at 1500 UTC, 2 June 2013 (bottom) shows extent of fog.

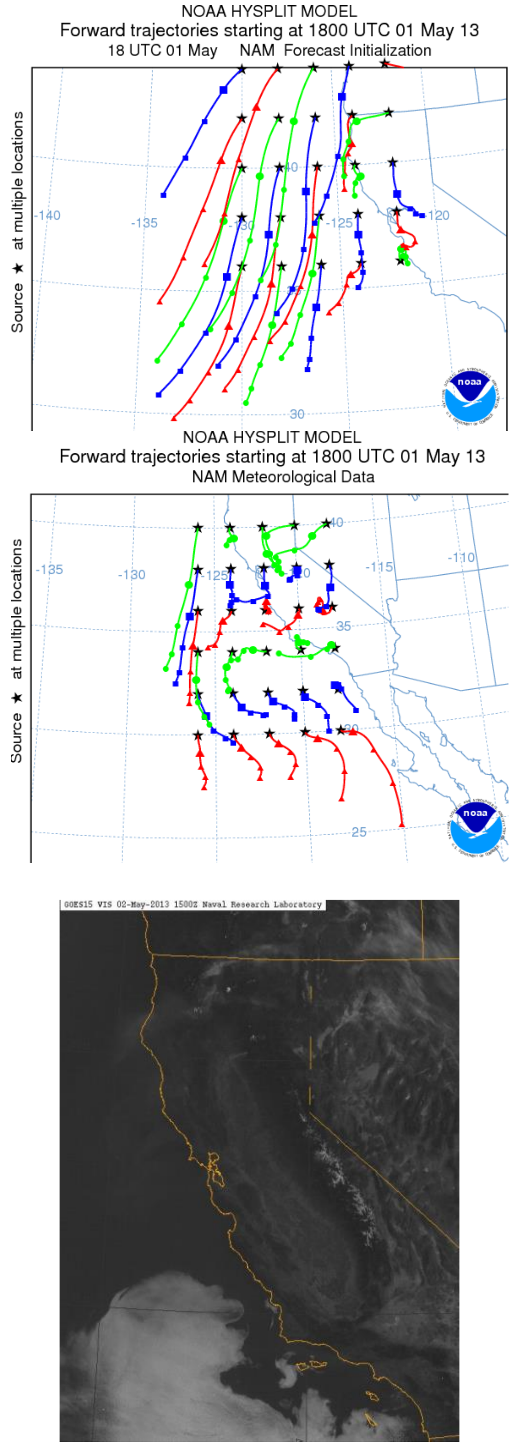


**Figure 2.** 18-h forecast HYSPLIT matrix trajectories based on NAM data at 1800 UTC, 1 May 2013 for north (top) and central and southern CA coasts (middle). GOES-15 visible image at 1500 UTC, 2 May 2013 (bottom) shows that fog is well offshore.

Days with no fog such as on 2-3 May showed predominately offshore trajectories associated with Santa Ana winds. Comparison of the Vandenberg Air Force Base, CA (VBG) radiosonde data for both days (Fig. 3) showed that the marine inversion was much deeper on the day with coastal fog and stratus than for the no fog case, an indication of the varying degree of subsidence associated with the North Pacific Anticyclone. According to Leipper (1994), the compressed marine layer represents the beginning of the next fog/stratus cycle, as fog then reforms due to radiational cooling.

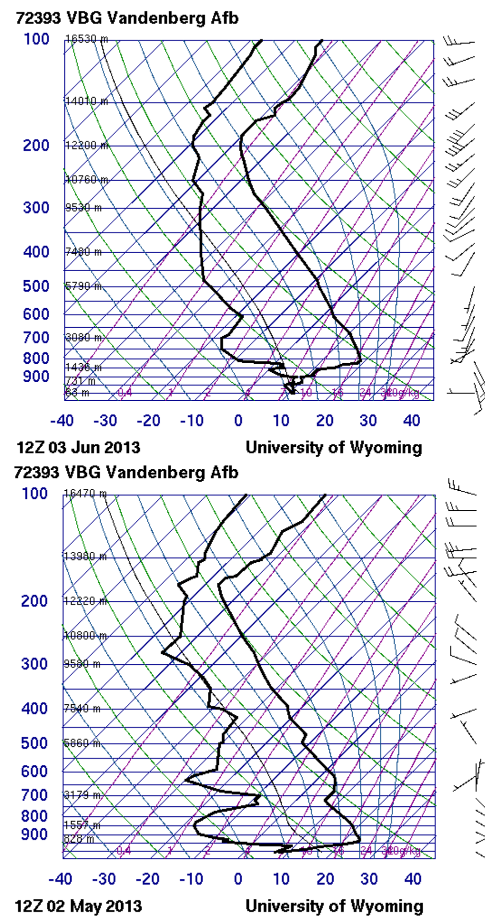


**Figure 3.** Vandenberg AFB radiosonde plot at 1200 UTC, 3 June 2013 (top) and 1200 UTC, 2 May 2013 (bottom). (Source: U. of Wyoming web site)

## *b. Gulf of Mexico/ South Atlantic coasts*

In the Gulf of Mexico and South Atlantic coastal areas, fog and stratus peak during the cooler months, as relatively warm, moist air advects onshore, then cools due to radiation and contact with the cold land beneath.

At 1200 UTC, 1 December 2012, HYSPLIT trajectories (Fig. 4) showed a transition to onshore flow along the Gulf Coast during the subsequent 24-h period.  A GOES fog product image at 1015 UTC the following morning (Fig. 5) indicated extensive fog and stratus west of the AL-MS border (yellow shaded region). An absence of high clouds over the region was also critical as it permitted radiational cooling. East of this line, the HYSPLIT trajectories originated over land areas, whereas west of that line, flow clearly originated over the Gulf of Mexico or somewhat cooler shelf waters. Fig. 6 shows the ceilings and visibilities at 1320 UTC on 2 Dec 2013. Extensive Instrument Flight Rule (IFR) conditions existed in the onshore flow areas.

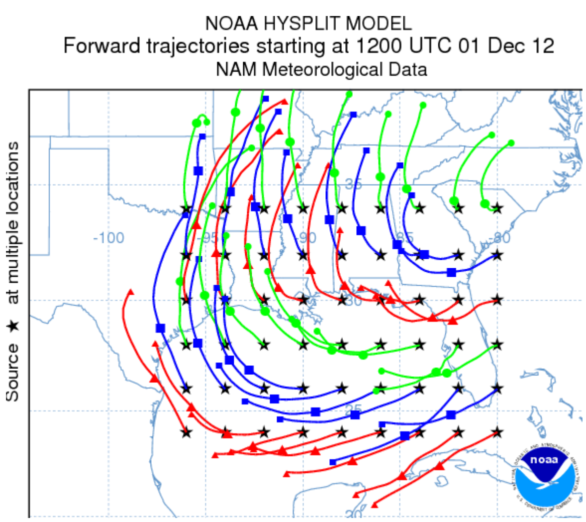


**Figure 4.**  24-h HYSPLIT model trajectories starting at 1200 UTC, 1 Dec 2012 based on NAM forecast data.

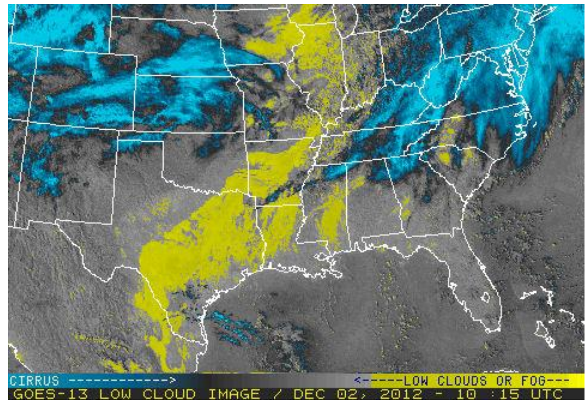


**Figure 5.** GOES fog product image at 1015 UTC, 2 Dec 2012.  Yellow areas show low level stratus clouds or fog. Gray areas are mostly cloud-free.

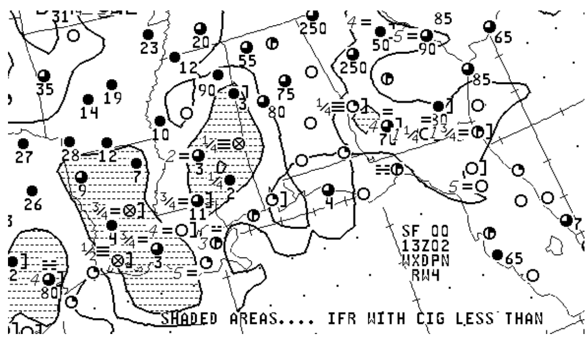


**Figure 6.** Weather depiction chart at 1320 UTC, 2 Dec 2012.

The following morning (3 Dec 2012), the Southeastern U. S. also experienced fog and stratus as a cold high pressure center moved eastward. The HYSPLIT trajectories starting at 1200 UTC, 2 Dec 2012 (Fig. 7) showed onshore advection of warm, moist air from the Gulf Stream, indicating a good situation for fog and stratus. The GOES fog product at 1015 UTC, 3 Dec 2012 (Fig. 8) showed the extent of the low cloud cover over eastern portions of GA, SC, NC, and even the FL panhandle.

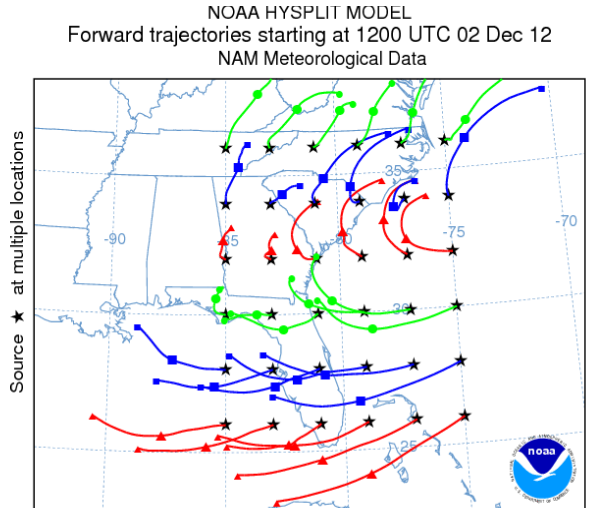


**Figure 7.** 24-h HYSPLIT model trajectories starting at 1200 UTC, 2 Dec 2012 based on NAM forecast data.

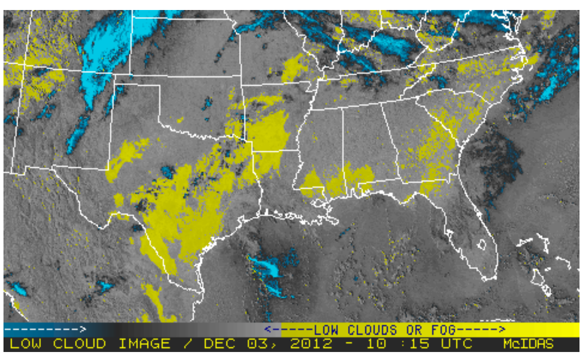


**Figure 8.** GOES fog product image at 1015 UTC, 3 Dec 2012.

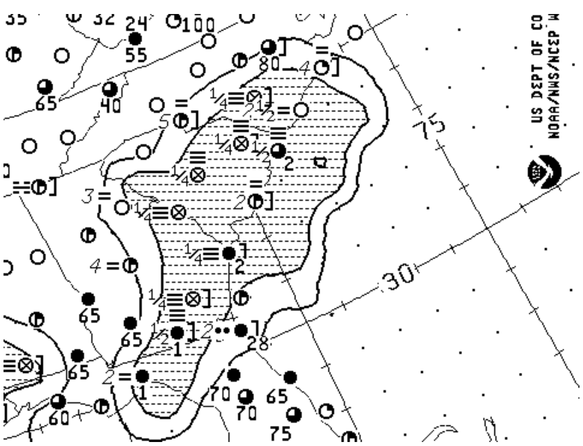

**Figure 9.** Weather depiction chart at 1320 UTC, 3 Dec 2012.

*c. Southern New England*

Along the southern New England coast, sea fog is common during the summer months as warm humid air flowing north around the Bermuda High crosses cool shelf waters associated with the Labrador Current.

HYSPLIT model trajectories at 1200 UTC, 27 Aug 2013 (Fig. 10) showed that low level flow would curve cyclonically around a weak surface low moving northward along the coast. These trajectories would advect moist air from the Gulf Stream across cool shelf waters (as shown by NOAA Advanced Very High Resolution Radiometer (AVHRR) SST in Fig. 11). A GOES visible image at 1245 UTC, 28 Aug 2013 (Fig. 12) reveals sea fog over southeast MA, RI, and adjacent coastal waters. The fog in interior New York and New England is radiation fog in the Connecticut, Hudson, and other valleys. The weather depiction chart (Fig. 13) showed very low visibility (0.5 mi) over Cape Cod.

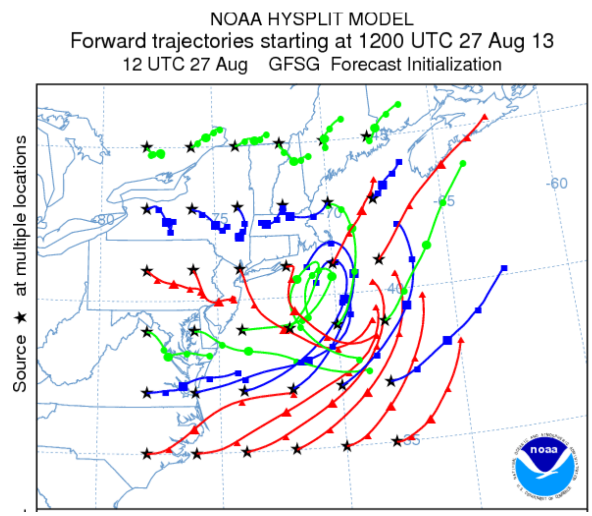


**Figure 10.** 24-h HYSPLIT model trajectories starting at 1200 UTC, 27 Aug 2013 based on GFS forecast data.

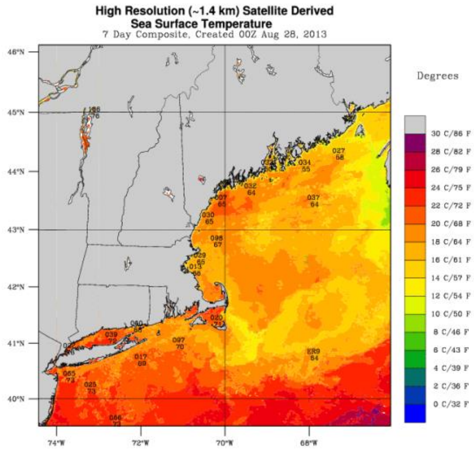


**Figure 11.** NOAA AVHRR 7-day SST composite valid 28 Aug 2013.

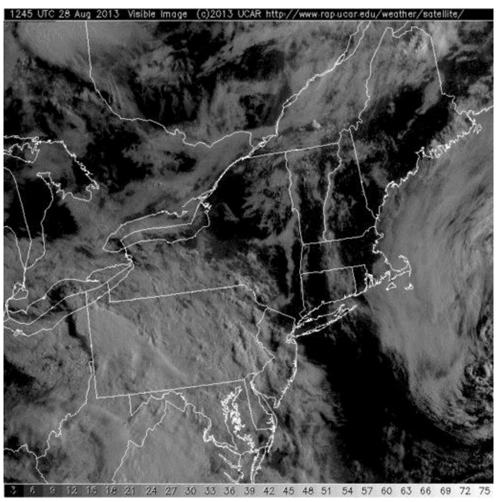


**Figure 12.** GOES visible image at 1245 UTC, 28 Aug 2013.

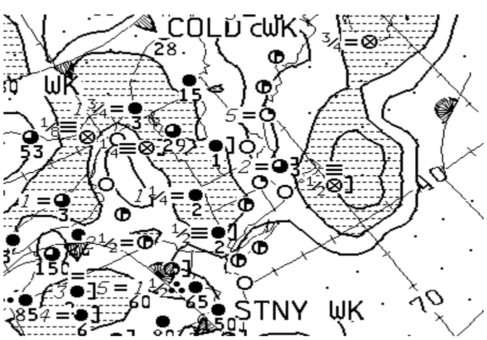


**Figure 13.** Weather depiction chart at 1320 UTC, 28 Aug 2013.

## 4. Conclusions

Based on analysis of more than two dozen cases, it can be concluded that HYSPLIT forecast trajectories can help the forecaster to visualize the flow of boundary layer air parcels up to 24-h in advance of possible coastal advection stratus and fog episodes. In some cases, analysis of HYSPLIT trajectories can shed light on approximately where the boundaries between low ceilings/visibilities and cloud free areas will be located. Further research is needed to better define situations in which the HYSPLIT model is especially useful, and to show how the data improve upon existing model guidance available to forecasters.

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