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P770 Use of the NOAA ARL HYSPLIT Trajectory Model For the Short Range Prediction of Coastal Stratus and Fog

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1. Introduction

The prediction of low stratus and fog is a critical forecast problem for aviation, marine 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 sometimes 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 Rolph 2015; Rolph 2015). As of early 2015, only the NCEP Global Forecast System (GFS) is considered to be quasi-Lagrangian.

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. Research has shown that pre-conditioning of the low level air mass by long overwater trajectories in a Lagrangian framework is needed for coastal fog formation (Koracin et al. 2005).

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2. Procedures and Data

More than 60 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. (For local applications, a 1-deg matrix is preferred.) Once the model parameters were selected, HYSPLIT produced 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 60 HYSPLIT analyses were obtained for a variety of coastal California fog and stratus events between 1 May 2013 and 31 Oct 2014. 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) (Johnstone and Dawson 2010). 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. The fog and stratus are driven inland due to the pressure gradient caused by an inland heat low.

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 (such as the Catalina eddy) with relatively weak flow

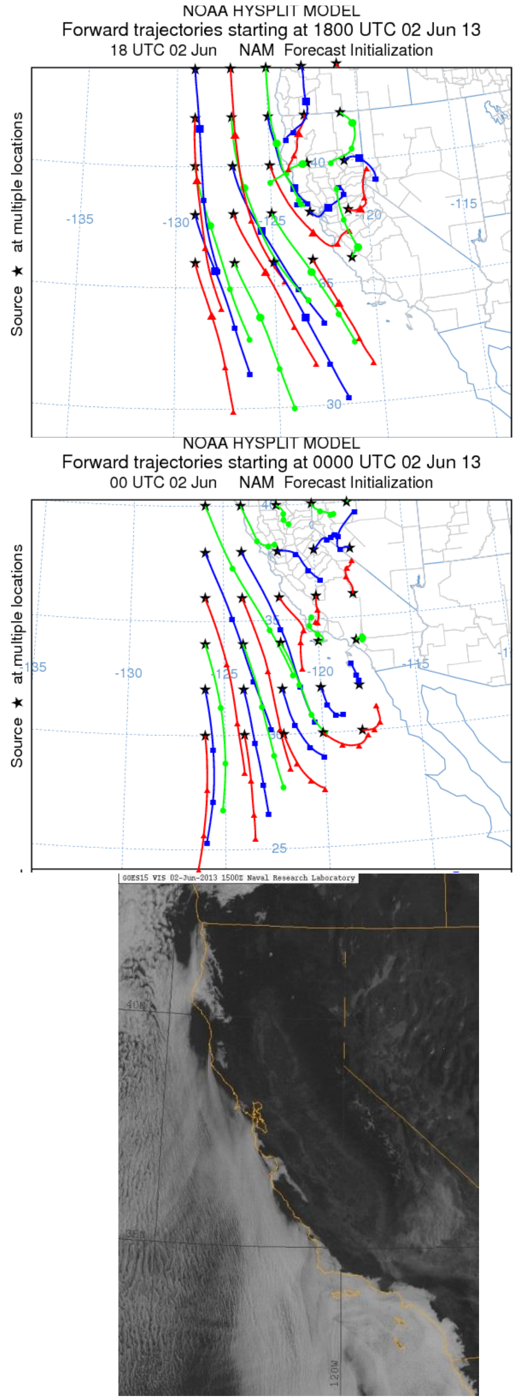

Figure 1. *24-h forecast HYSPLIT matrix trajectories based on NAM data at 0000 UTC, 2 June 2013 for north (top) and central and southern CA coasts (middle). GOES-15 visible image at 1500 UTC, 2 June 2013 (bottom) shows extent of fog.*

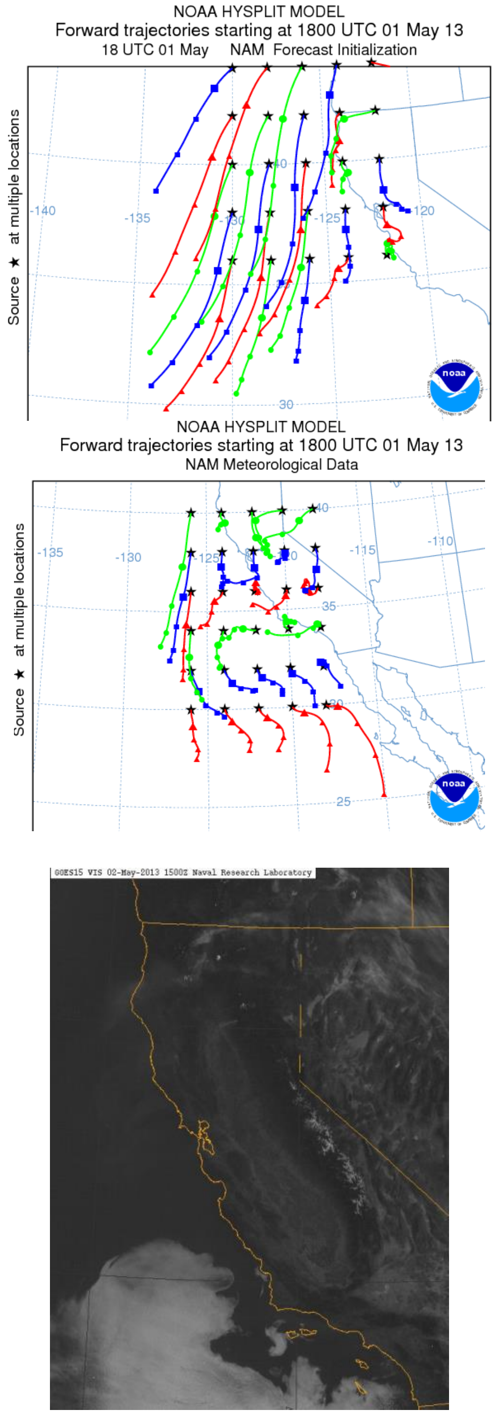

Figure 2. *18-h forecast HYSPLIT matrix trajectories based on NAM data at 1800 UTC, 1 May 2013 for north (top) and central and southern CA coasts (middle). GOES-15 visible image at 1500 UTC, 2 May 2013 (bottom) shows that fog is well offshore.*

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.

Days with no fog such as on 1-2 May 2013 (Fig. 2) 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.

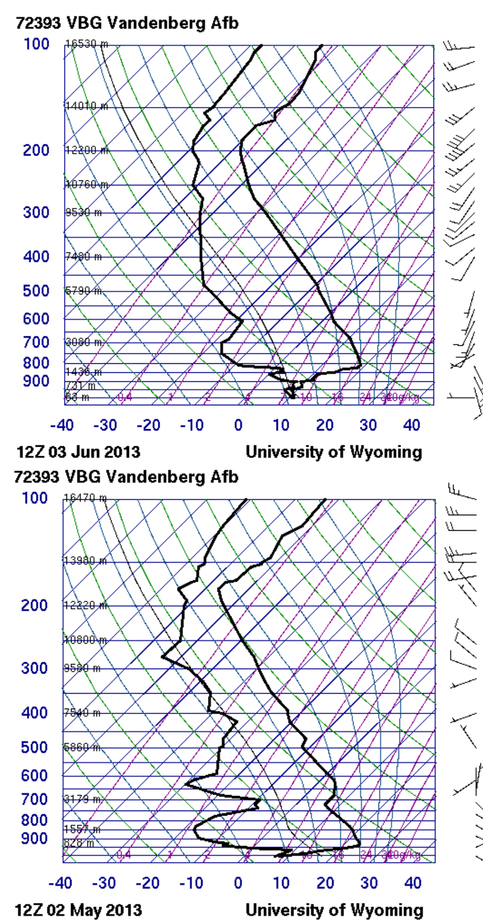

Figure 3. *Vandenberg AFB radiosonde plot at 1200 UTC, 3 June 2013 (top) and 1200 UTC, 2 May 2013 (bottom). (Source: U. of Wyoming web site)*

b. Mesoscale Application: San Francisco Bay

San Francisco International Airport (SFO) is among those with the highest average flight delays in the U. S., due to frequent summer stratus and closely spaced, parallel runways (Reynolds et al., 2012). 18-h HYSPLIT forecasts using GFS model data were run for 30 cases of both stratus and no-stratus valid at 1200 UTC in May-Sep of 2013-14, starting from a point west of SFO (37.5N - 123w). Mean trajectories (Fig. 4) show onshore flow for days of stratus, and stronger along-shore flow on cloud-free days. The standard deviations for each sample (not shown) overlap south of San Jose, indicating that a probabilistic scheme may help with afternoon forecasts of stratus at SFO/OAK for the following morning.

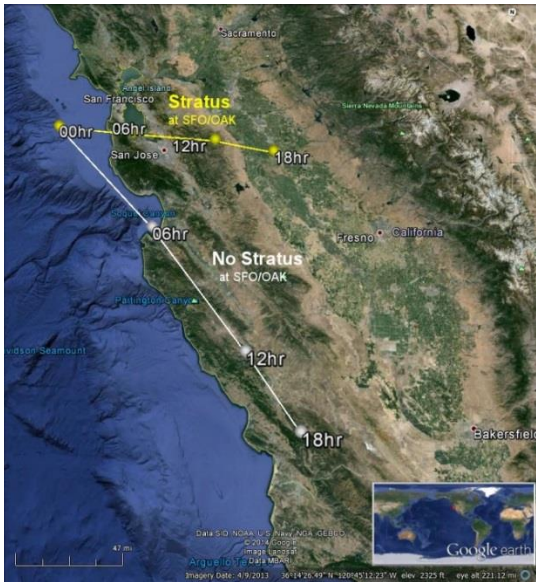

Figure 4. *Mean 18h GFS HYSPLIT trajectories for 30 days of stratus (yellow) vs no stratus (white).*

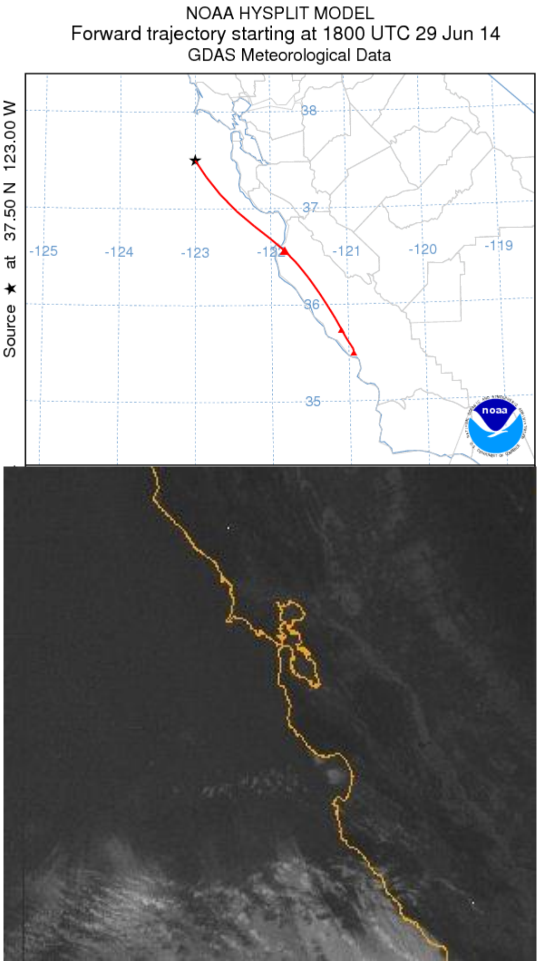

Figure 5. *18-h GFS HYSPLIT from 1800 UTC, 29 Jun '14 (top) and GOES-15 visible image at 1400 UTC, 30 Jun '14 (bottom)*

Two sample cases are shown in Figures 5 and 6. In Figure 5, the along-shore 18-h trajectory is nearly the same as the mean for non-stratus days in Fig. 4 and stratus is absent. In Figure 6, the flow on 8-9 July was essentially straight inland, crossing the coastal foothills into the interior valleys. As a result, GOES visible imagery shows thick stratus and fog were extensive in the interior valleys, including SFO Bay. At SFO, stratus formed around Midnight 9 Jul '14 and persisted until 8AM PST. The stratus persisted for about 12 hours at OAK.

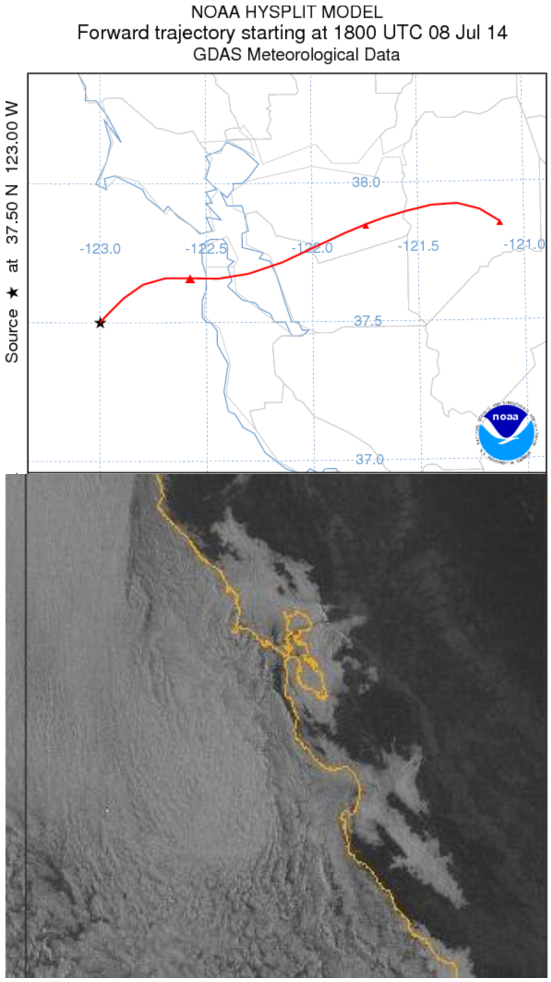

Figure 6. *18h HYSPLIT forecast from 18Z, 8 Jul 14 (top), and GOES-15 visible image at 14Z, 9 Jul 14 (bottom)*

c. South Atlantic coast

In both 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.

On the morning of 3 Dec 2012, the Southeastern U. S. experienced fog and stratus as the center of a cold high pressure system moved eastward, resulting in return flow off the Atlantic Ocean. The 24-h GFS 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 dashed line indicates the approximate boundary between onshore and offshore (or inland) trajectories. The GOES visible image at 1300 UTC (8AM EST), 3 Dec 2012 (Fig. 8) and the NWS weather depiction chart at 1320 UTC (Fig. 9) showed the extent of the low cloud cover and low visibilities over eastern portions of GA, SC, NC, and even the FL panhandle.

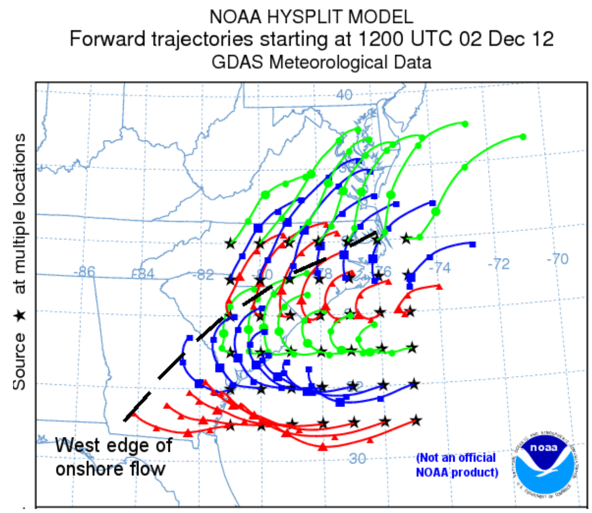

Figure 7. *24-h HYSPLIT model trajectories starting at 1200 UTC, 2 Dec 2012 based on GFS forecast data.*

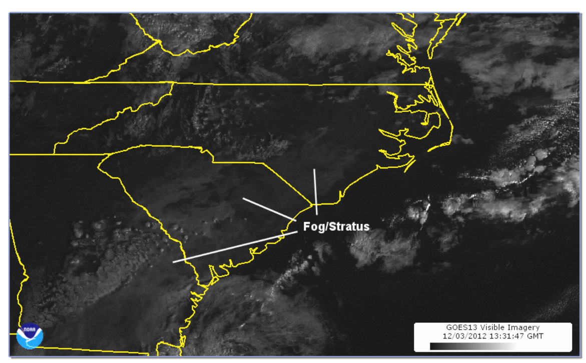

Figure 8. *GOES-13 visible image at 1330 UTC, 3 Dec 2012.*

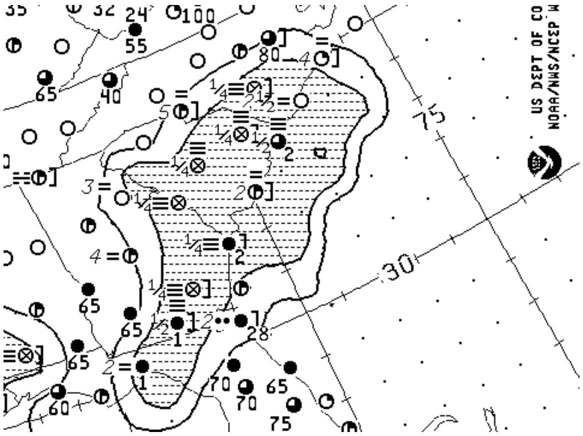

Figure 9. Weather depiction chart at 1320 UTC, 3 Dec 2012.

d. 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.

24-h GFS HYSPLIT model trajectories beginning 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. The dashed line denotes the onshore/offshore boundary. 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-13 visible image at 1245 UTC, 28 Aug 2013 (Fig. 12) reveals sea fog over southeast MA, RI, and adjacent coastal waters, close to the dashed line in Fig. 10. The fog in interior New York and New England is radiation fog in the Connecticut, Hudson, and other river valleys. The weather depiction chart (Fig. 13) showed very low visibility (0.5 mi) over Cape Cod.

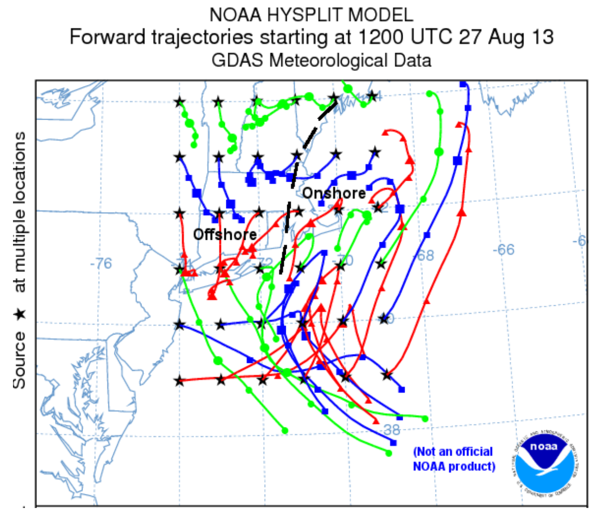

***Figure 10.** 24-h, 1-deg HYSPLIT trajectories starting at 1200 UTC, 27 Aug 2013 based on GFS forecast data.*

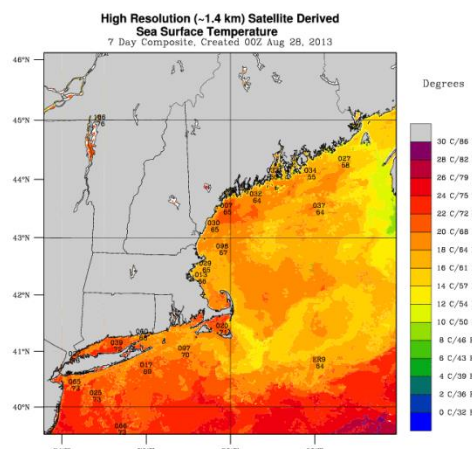

***Figure 11.** NOAA AVHRR 7-day SST composite valid 28 Aug 2013.*

4. Conclusions

Based on analysis of numerous cases in coastal California, and a limited number in the eastern U. S., 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

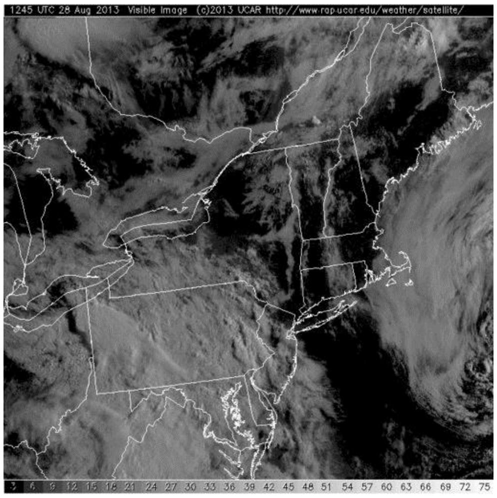

Figure 12. *GOES-13 visible image at 1245 UTC, 28 Aug 2013.*

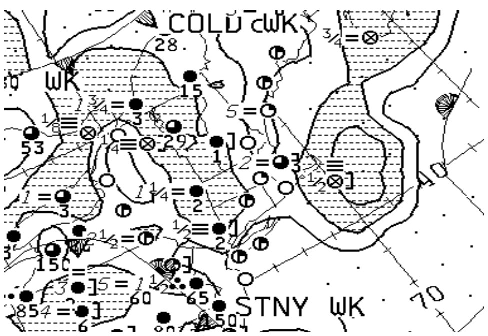

Figure 13. *Weather depiction chart at 1320 UTC, 28 Aug 2013.*

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, based on analysis of the inland extent of onshore flow. In the San Francisco Bay area, mean 18-h trajectories showed a distinct difference between stratus and no stratus days. 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.

ACKNOWLEDGMENTS

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