4.6 SIMULATIONS OF MARINE FOG AND STRATUS USING COASTAL-ARPS

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1. INTRODUCTION

Marine fog and low ceiling stratus are among the most dominant weather events affecting aviation and navigation along the west coastal area of California during much of the warm season. From late spring through summer, the dominant synoptic system in the northeastern Pacific Ocean is the Pacific High, typically centered several hundred kilometers to the west and south of California and creating a northerly flow of air along the west coast of central North America. This persistent flow, along with a large scale subsidence of air along the coastal region, causes upwelling in the eastern Pacific and a strong inversion above a well-mixed marine boundary layer. The marine fog and stratus system is prevailing within the marine boundary layer below the inversion (Pilie et al. 1979; Clark and Wilson 1997). Figure 1 shows a satellite image of the typical wedge-like fog-stratus system off the California coast.

Since marine fog is a kind of *threshold phenomenon*, numerical simulation and forecasting of it is a challenging topic in that the accurate prediction of marine boundary layer temperature and humidity structure and evolution, correct representations of turbulent mixing, radiation transfer, and microphysics process are required in the numerical models with great precision. During the past three decades many numerical studies have been devoted to these problems though the ability to forecast the formation and dissipation of fogs has improved very limitedly. Among them, however, the majority of the numerical investigations are using 1D models and for radiation fog over land (Zdunkowski and Nielsen 1969; Brown and Roach 1976; Turton and Brown 1987; Duynkerke 1991; Bergot and Guedalia 1994; and Guedalia and Bergot 1994). Ballard et al. (1991) might be the first attempt to use the UKMO (UK Meteorological Office) 3D mesoscale model in the sea fog evolution over northeast Scotland. Their study concluded that correct initialization was crucial to predict the diurnal evolution of this marine fog.

In this study, an enhanced version of the ARPS (Advanced Regional Prediction System), dubbed as Coastal-ARPS or CARPS, emphasizing in better simulation and prediction of the coastal marine boundary layer and weather phenomena in the coastal environment, has been tested in an attempt to simulate the marine fog and stratus system along the California coast. The ARPS model, developed by CAPS (Center for Analysis and Prediction of Storms) at the University of Oklahoma, was designed primarily for forecasting severe local thunderstorms (Xue et al. 1995). The major enhancements of CARPS over ARPS include improved cloud microphysics and radiation parameterizations, better treatment of MBL with real SST input, and positive definite advection of scalars. A new vertical grid adaptation scheme is ongoing to put in CARPS.

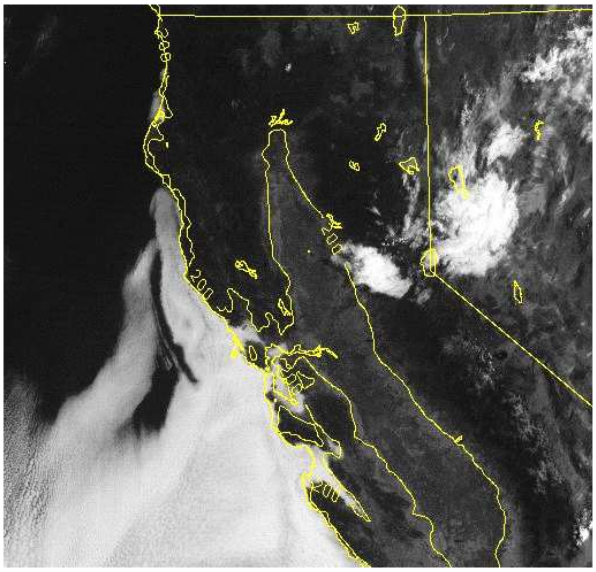

Figure 1: GOES-9 visible image at 1600 UTC on 25 July 1997. (Source: NRL-Monterey)

2. SPECIFICATION

ARPS is a three-dimensional limitted-area, nonhydrostatic and fully compressible mesoscale model with generalized terrain-following coordinate plus a wide

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scope of options in turbulence treatment, surface layer and radiation parameterizations, cloud microphysics, and data analysis and assimilation techniques. Its enhanced version, CARPS, is used in the fog-stratus simulation. NWC ETA output ($48km$, grid #212) on the days with marine fog-stratus system off California coast are used to generate initial and boundary conditions. In this preprint, the simulations are initialized at 0000 UTC on 25 July 1997 with a domain of $1440 \times 1440 km^2$, roughly centered at the San Francisco Bay and with horizontal resolution of $18km$ (Figure 2). Figure 1 shows the fog-stratus system at later time (1600 UTC) on the same day. The vertical grid is highly stretched so that the lowest level has a depth as thin as $5m$ in order to provide enough resolution at the lowest several hundred meters. Higher resolution simulations ($6km$) are carried out through one-way nesting from the coarse runs. The coarse and fine resolution simulations have 85×85 and 101×101 grids, respectively, in horizontal and 45 levels in vertical.

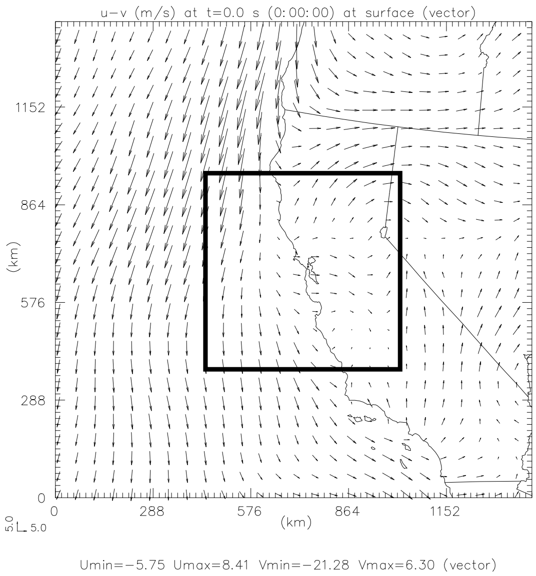

Figure 2: Model coverage region with surface wind taken from NWC ETA analysis at 0000 UTC on 25 July 1997, the heavy box is the $6km$-resolution nesting domain.

The original version of ARPS model does not read and interpolate surface quantities when using external data to initialize simulations. Since surface fluxes and marine boundary processes are extremely crucial to the formation and migration of marine fogs, the enhanced ARPS model, or CARPS, is able to allow the sea surface temperature along with other necessary surface quantities to be read from external data set and interpolated into the model domain. Figure 3 shows the initial surface temperature obtained from NWC ETA data.

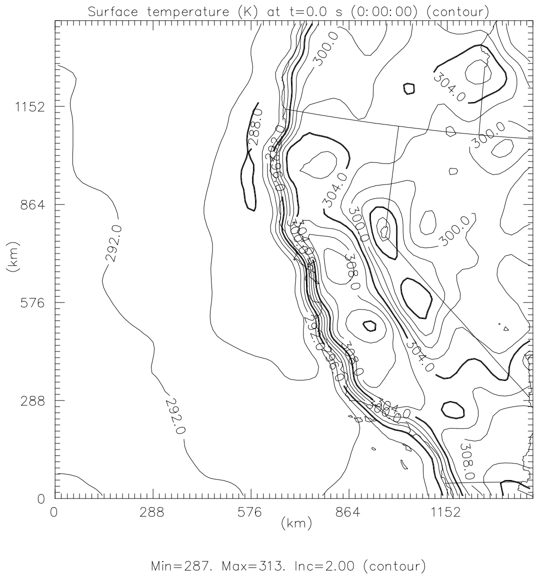

Figure 3: Initial surface temperature from NWC ETA analysis at 0000 UTC on 25 July 1997.

An array of NRL-Monterey GOES-9 products, including high resolution visible images, daytime and nighttime fog/stratus products based on the near-infrared ($3.9\mu m$) reflectance and the difference of $3.9\mu m$ channel and $10.7\mu m$ channel temperatures, and surface weather maps are also used to help selecting actual simulation days, and to verify model results. The special observational data from MIT/Lincoln Laboratory through its San Francisco Marine Stratus Initiative (Clark and Wilson, 1997) are also served as verification data set for the simulations. As an ongoing work in this study, all the available data are considered to be used in the ARPS Data Analysis System (ADAS) to provide more accurate initial condition, especially the wind, temperature and humidity structure in the lower marine boundary layer for the fog prediction and simulation.

3. RESULTS

Only the results from the high resolution ($6km$) run are presented in this section. The simulation started at the same time as the $18km$ (0000 UTC) run and ended at 1800 UTC, with the boundary condition provided from the hourly output of the coarse run. Initial fog-stratus formed over the East Pacific Ocean about $100km$ southwest off San Francisco at 0500 UTC (2200 LCT). The system then expanded northeastward. After arriving the coast 2 hours later (0000 LCT) and covering southern San Francisco Bay area, the marine fog-stratus turned to propagate southward along the coastal zone. The simulated cloud water mixing ratioes at $90m$ high for 8, 10, and 12 h of simulation (corresponding to 0100, 0300, and 0500 LCT, respectively) are presented

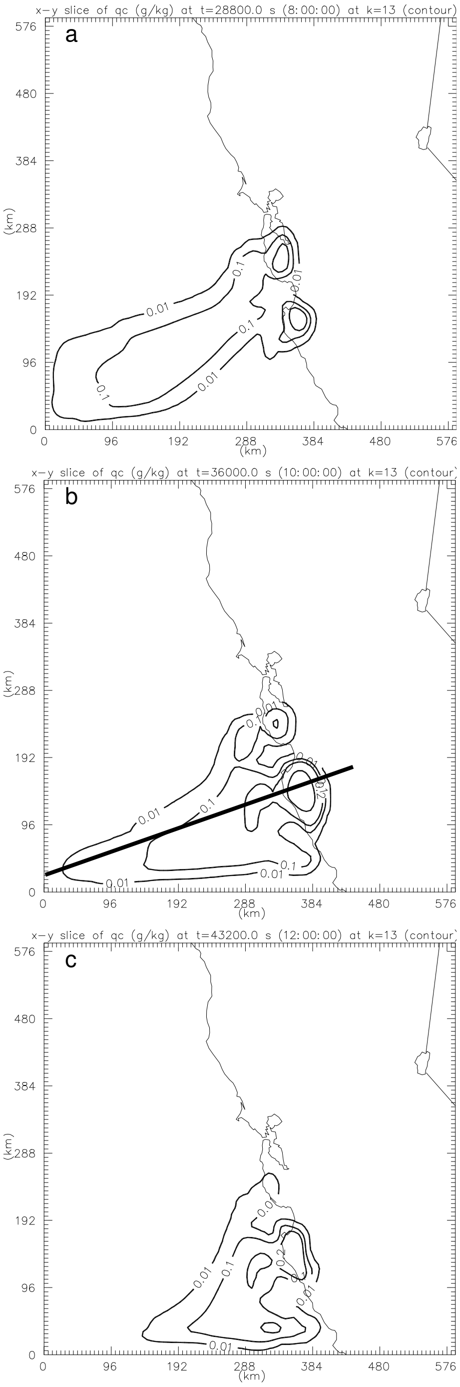

Figure 4: Cloud water distributions from the high resolution simulation at the height of $90m$ at 0800 UTC (a), 1000 UTC (b), and 1200 UTC (c), respectively. The straight line in (b) marks the cross sections in Figure 6.

in Figure 4. It can be seen that the northern edge of the fog-stratus layer has good agreement to the satellite

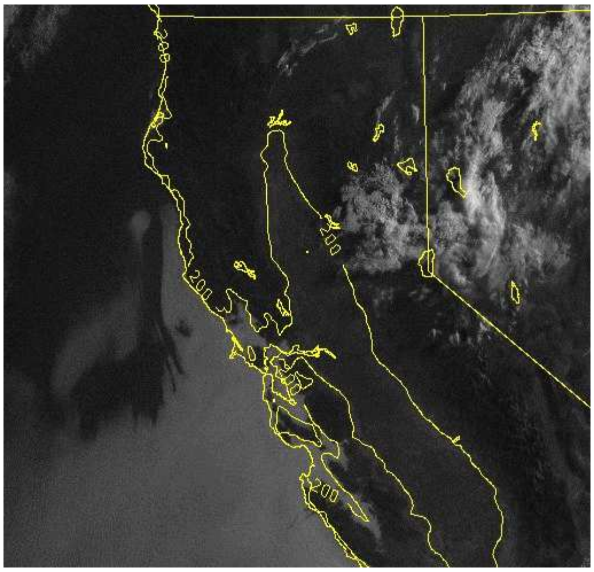

Figure 5: GOES-9 visible image at 1400 UTC on 25 July 1997. (Source: NRL-Monterey)

images at the nearest time (Figure 5) except that the patch northwest of the main system in the satellite image has not been resolved by the simulation and that the simulated northern edge of the fog-stratus does not stretch as far north as in the satellite image. After the marine system fully developed in south and formed a typical wedge-like shape coverage by 1000 UTC (Figure 4b), the northern edge retreated southward under the influence of the northerly air flow over the East Pacific Ocean (Figure not shown). The fog free strip along the south boundary is due to the unrealistic treatment of the nesting boundaries, which deserves further improvement.

Figure 6 shows the cross sections of the lowest $4km$ along the heavy line marked in Figure 4b. Both the cloud water content and the relative humidity are presented. As shown in the figure, the fog-stratus layer has a top height ranging from 200-400m, which is well in agreement with the observed inversion base height of $300m$ ($1000ft$) at the time taken from an acoustic sodar at Half Moon Bay (about $100km$ away from the cross sections) by MIT/Lincoln Laboratory (Figure not shown). The predicted cloud water mixing ratio ranges from 0.01 to 0.5 g/kg (Figure 4 and Figure 6). This magnitude range is consistent with the observation of California coastal marine fog by Pilie et al. (1979). Figure 6a also shows that the maximum liquid content occurs over the elevated coastal terrain and the adjacent sea surface. Within the entire fog-stratus layer, the relative humidity is above 90% (Figure 6b). The increased surface heating due to incoming shortwave radiation after sunrise resulted in the retreat of the fog from the coastal land after 0700 LCT and the fully burnoff

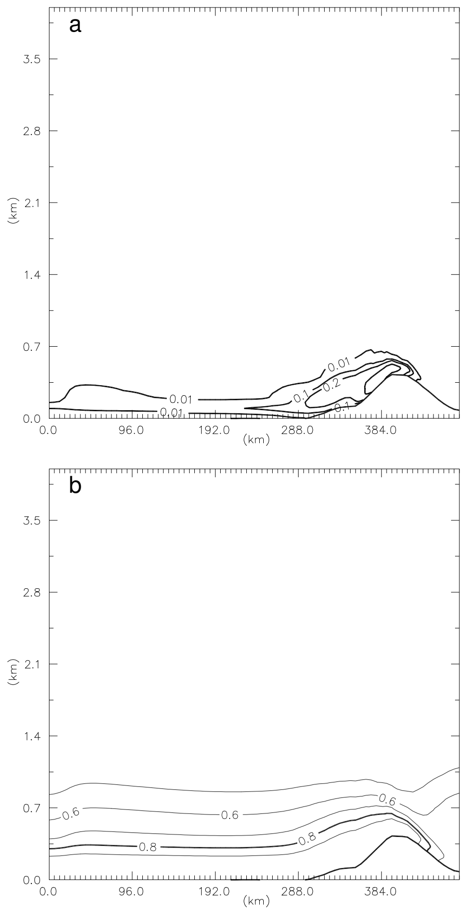

Figure 6: Cross sections along the line in Figure 4b. (a) Cloud water mixing ratio (g/kg), (b) Relative humidity.

around 1000 LCT. The wedge shape fog-stratus system over the ocean is still maintained (Figures not shown). The model seems to retreat too fast southward from the northern region off San Francisco Bay compared to the satellite image in Figure 1.

4. DISCUSSION AND ONGOING WORK

In this preprint the Coastal-ARPS model is tested in an attempt to simulate the prevailing marine fog-stratus system off California coast during warm season. As shown in the above section, the mesoscale model is able to simulate the general formation and burnoff process of the marine fog-stratus system under favourite large scale circulation and sea surface thermal pattern. The initialization without correct analysis of lower level liquid water, thermal and humidity data, low land-sea mask resolution, and insufficient treatment of the surface layer process and radiation might all be to blame for the discrepancies. The ongoing work includes the further improvement of the treatment of various physics processes, and most importantly, the development of the marine fog-stratus data analysis system using all available observation data including fog/stratus satellite product and special surface observations, based on the existing ADAS ARPS Data Analysis System).

5. ACKNOWLEDGEMENTS

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