3.7 CATALINA EDDY CAPTURED BY NASA QUIKSCAT SATELLITE

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1. INTRODUCTION

In the southern California bight, an area of ocean between Point Conception and the Mexican border, the surface wind pattern is characterized by westly and northwestly flows. Occasionally, this typical pattern is interrupted when upper level large-scale flow off Point Conception interacts with the complex topography of the southern California coast to form a low-level cyclonic wind circulation called Catalina Eddy, with its center near Catalina Island. During a Catalina Eddy event, the northwestly flow within ~100 km from the southern California coast becomes southly, marine layers deepen and spread into Los Angeles basin, low-level cloudness also increases, resulting in cooler temperatures and better air quality inland (Mass and Albright 1989). The duration of Catalina Eddy events varies from a few hours to several days, and such events are most common from late spring through early fall, with a maximum frequency in May and June. This seasonal distribution is mainly due to less frequent broad-scale weather systems which tend to be deleterious to eddy formation or maintenance.

Several mechanisms have been proposed regarding the evolution and dynamics of Catalina Eddy: a wake low produced by the topography east of Point Conception (e.g., Rosenthal 1972; Wakimoto 1987), topographically trapped Kelvin waves (e.g., Dorman 1985; Clark 1994), leeside topographic troughing (e.g., Bosart 1983; Mass and Algright 1989), and others. Numerical simulations (e.g., Ueyoshi and Roads 1993; Ulrickson et al. 1995; Thompson et al. 1997; Davis et al. 2000) have reproduced many observational features of Catalina Eddy. It may appear that the Catalina Eddy is a well-studied phenomenon, but there are still major issues regarding its dynamics and the structure evolution. Forecasting Catalina Eddy events has often been an uncertain exercise, partly due to the lack of a coherent physical model of the origin, structure and evolution of Catalina Eddy event (Mass and Albright 1989). On the other hand, with the small size of the eddy and the sparsity of coastal observations, comparisons between numerical simulations and observations are less comprehensive. Also, how the local ocean upwelling system may response to the Catalina Eddy event has not been studied.

The primary objective of this study is to introduce a new data set which is complementary to other studies mentioned above for understanding the Catalina Eddy event. This new data set is collected from a scatterometer on the NASA QuikSCAT satellite, launched in June 1999. QuikSCAT measures oceanic surface wind speeds and directions, covering 93% of the global ocean in a single day. Although the Catalina Eddy often accompanies with low-level cloudness which are obstacles to spaced based visible-infrared sensors, the scatterometer operated on microwave frequencies can “see through” these clouds and detects surface winds. The standard QuikSCAT wind product has 25-km spatial resolution, but special products with 12.5-km resolution for selected regions have been produced. Recent studies have shown that the high spatial resolution of 12.5-km data provides detailed descriptions of small or intense weather systems (Liu et al. 2000 and 2001).

In this paper, we present case studies using QuikSCAT winds, in conjunction with in-situ measurements and products from numerical weather prediction models. Model forecasts with different spatial resolutions are also discussed.

2. OBSERVATIONAL DATA SETS

The 12.5-km resolution QuikSCAT wind data set was derived using the Direction Interval Retrieval with Thresholded Nudging (DIRTH) method which improves the quality of the less accurate portions of the swath, in particular near the far swath and nadir (Stiles 1999). To avoid land contaminations, observations within 15 km to coastlines were not used in this study.

There are several moored buoy stations operated by National Data Buoy Center (NDBC) in the bight of California, station identifiers are shown in Figure 1. We used 10-minute average values of continuous wind and direction, air temperature, water temperature, and

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Dewpoint temperature. To compare with QuikSCAT winds at 10-m height, NDBC buoy winds at different heights are converted to equivalent neutral winds at 10-m height using a method by Liu and Tang [1996].

Upper air sounding observations from balloons which record temperature, humidity, and winds were used in this study; there are two available sites (shown in Figure 1), Vandenberg Air Force Base (VBG) near Point Conception at (34.65^{o}N, 120.57^{o}W) and Miramar Nas (NKX) near San Diego at (32.85^{o}N, 117.12^{o}W), obtained from Radiosonde Data Archive at the Forecast Systems Laboratory.

Clouds are identified from SeaWiFS true color images provided by Distributed Active Archive Center (DAAC) at NASA Goddard Space Flight Center. We used the SeaWiFS High Resolution Picture Transmission (HRPT) data at 1-km resolution obtained at HUSC station (34.4^{o}N, 119.7^{o}W) at the University of California Santa Barbara.

3. CATALINA EDDY CAPTURED BY SATELLITES, BUOYS, AND SOUNDING BALLOONS

Figures 2 (a) and (b) are two examples of Catalina Eddy events observed by QuikSCAT. Figure 2 (a) shows observations at 13:11 UT on 13 March 2000, and Figure 2 (b) at 13:33 UT on 1 April 2001. The heavy arrows are equivalent neutral winds at 10-m calculated from continuous 10-minute averages of wind and direction on each NDBC station. It is obvious that QuikSCAT provides a much more complete coverage of the eddy circulation than these sparse stations. As a complement to space-based cloud images, QuikSCAT has obtained the first complete visualization of observed low-level eddy wind circulation. Although the station winds are selected within 10 minutes to the QuikSCAT overpassing time, some discrepancies between buoy and QuikSCAT observations still exist. Since each QuikSCAT observation represents a spatial average of 12.5 km in an instant while each buoy measurement is a 10-min average on a single point, it may not be surprise to see these discrepancies as local winds are highly variable. The average eddy winds observed by QuikSCAT are around 3-5 m/s, with a spatial range of southly winds about 100 km from the coastline, consistent with a comprehensive study using NDBC buoys by Mass and Albright (1989).

One of the important feature of Catalina eddy is to deepen the marine layer and cool the temperature in the

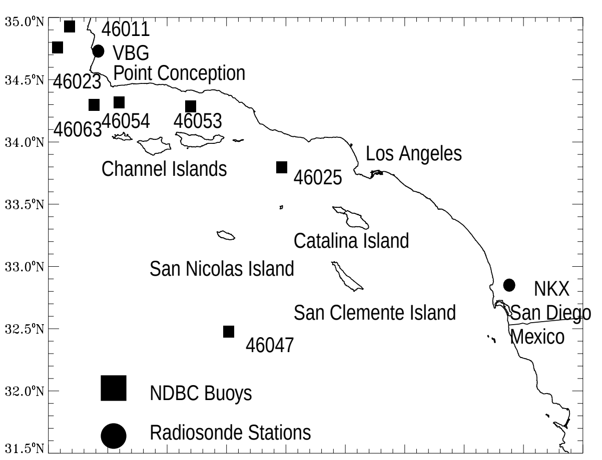

Figure 1. A map which shows the bight of southern California, seven locations of NDBC buoys, and two Radiosonde stations.

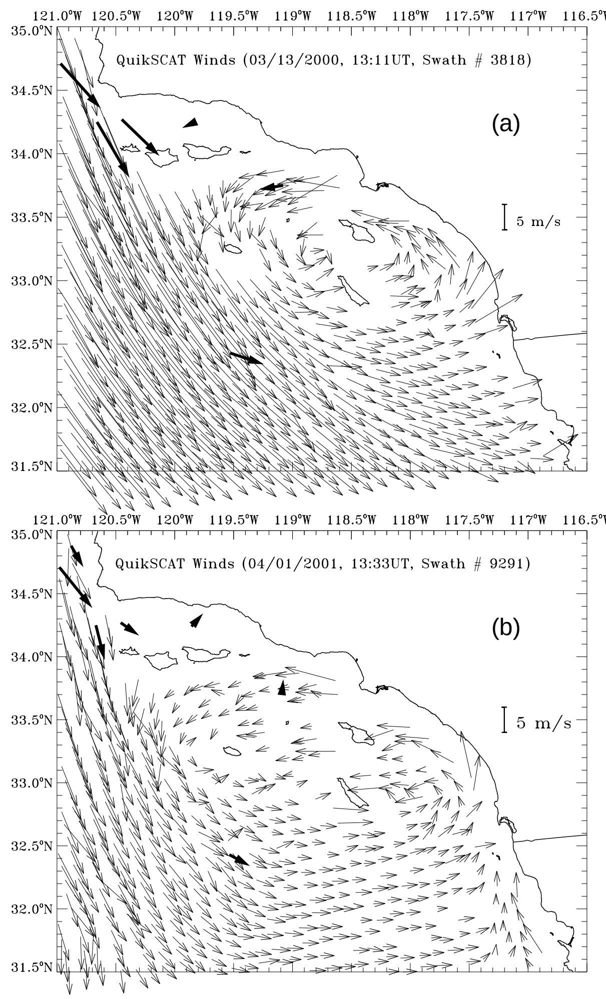

Figure 2. A complete Catalina Eddy circulation captured by QuikSCAT surface wind observations, (a) on 13 March 2000, and (b) on 1 April 2001.

southern California (e.g., Mass and Albright 1989). Figure 3 shows the upper air sounding of relative humidity (in black color) and air temperature (in grey color) from Miramar Nas (NKX) near San Diego on a non-eddy day at 12:00UT 31 March 2001 (dashed lines) and during an eddy event at 12:00UT on 1 April 2001 (solid lines). The marine layer showed a depth of 800 meters during the eddy event on April 1, and deepened to over 1000 meters on April 2 (no shown). The air temperatures also dropped 2-4^{o}C degrees while eddy was present. Sometimes, the air temperature can drop over 20^{o}C degrees.

A cloud image (Figure 4) from the SeaWiFS satellite shows low clouds spreading into inland from the coastal ocean, another evident that Catalina eddy circulation spells cool and overcast weather over southern California.

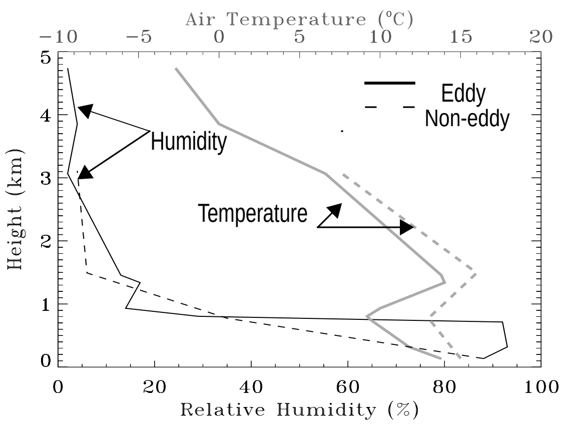

Figure 3. Radiosonde measurements from NKX station near San Diego. The gray lines are air temperatures, and black lines are relative humidity. The solid lines are for a eddy event at 1200UT on April 1, 2001, and the dashed lines represent a non-eddy day on 1200UT on March 31, 2001.

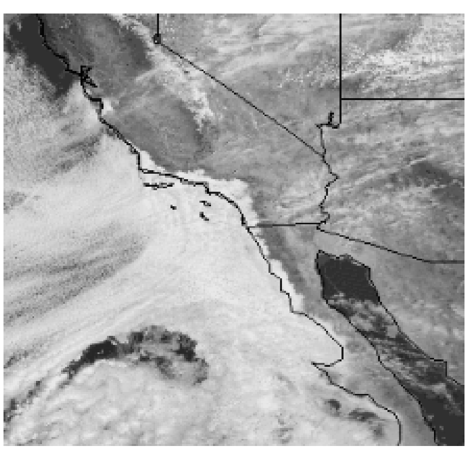

Figure 4. A SeaWiFS cloud image illustrates low-level stratus spreading into Las Angeles basin during a Catalina Eddy event on April 1, 2001.

4. LOW-LEVEL AND UPPER-AIR ANALYSIS

The analysis fields presented here are products of National Centers of Environment Prediction (NCEP)'s mesoscale numerical weather prediction (NWP) model, known as the Early Eta Model and its associated 4-D data assimilation system. The name "Eta" derives from the model's vertical coordinate known as the "eta" or "step-mountain" coordinate (Rogers et al. 1996). The Eta model used in this analysis is called Eta-32 with a 32-km horizontal resolution and 45 vertical layers, and with output horizontal grids on 40-km. It covers most of North America and the nearby oceans. The data set is archived at National Center for Atmospheric Research (NCAR).

During a Catalina Eddy event on 13 March 2000, as shown in Figures 5 (a), the 850-mb geopotential height

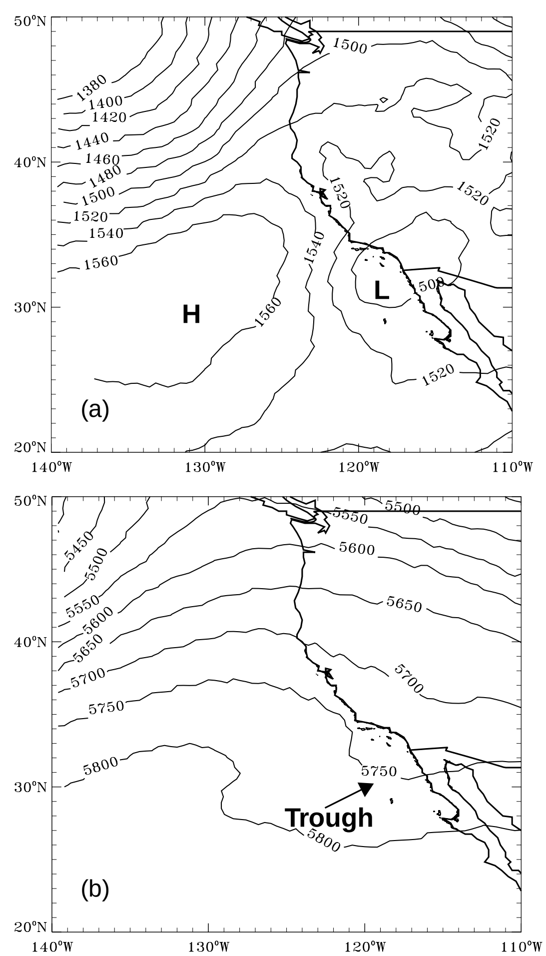

Figure 5. NCEP Eta Geopotential heights for the Catalina Eddy event at 1200UT on 13 March 2000, (a) at 850 mb and (b) at 500 mb.

indicates a closed high over the eastern subtropical Pacific, and a closed low with enhanced gradients accompanying the eddy event in the bight of southern California. The 500-mb Geopotential height, shown in Figure 5 (b), has a trough developed in the bight of southern California to help speeding up the eddy circulation. In response to this trough, a low is building up there as shown in Figure 5 (a).

5. MODEL FORECAST

Figure 6 (a) is the 12-hour forecast of Eta-32 winds valid at 1200 UTC 13 March 2000, about 71 minutes earlier than the QuikSCAT overpass shown on Figure 2 (a). The forecast predicts the eddy circulation, but the eddy's wind speeds are about ~ 1m/s, much lower than the QuikSCAT winds which are about 3-5 m/s.

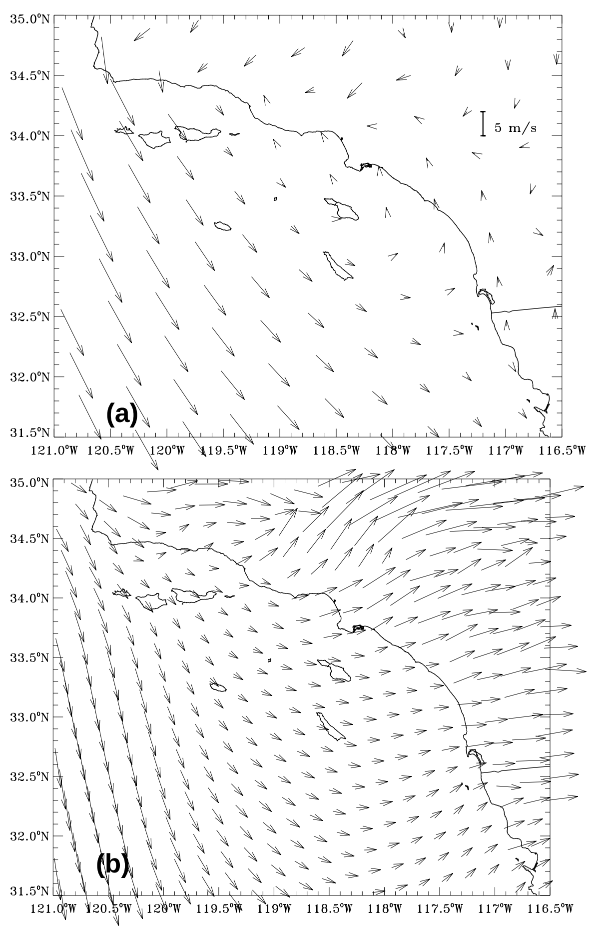

Figure 6. The 12-h forecast 10-m winds, (a) valid at 1200UT 13 March 2000 from NCEP Eta-32 model, and (b) valid at 1200UT 1 April 2001 from NCEP Eta-22 model. Wind scales for (b) are the same as (a).

Previous studies (e.g., Mass and Albright 1989) have pointed out that forecasting the Catalina Eddy is a very challenging task, and one of the causes is that the operational forecast models do not have enough horizontal resolutions to accurately simulate eddy circulations. To address this issue, we have investigated some Catalina Eddy events using other recently available Eta models with higher spatial resolutions. One is the operational Eta-22 model at 22-km resolutions (outputs at grids on 20-km) and another one is an experimental Eta-10 model at 10-km western U.S. Figure 6 (b) shows the 12-hour forecast of Eta-22 winds valid at 1200 UTC 1 April 2001, about 93 minutes earlier than the QuikSCAT overpass shown on Figure 2 (b). It was surprise that the 12-hour forecast did not show any eddy circulations. We also have looked at Eta-10 and Eta-32 model forecast for this event, and neither of them shows any eddy circulation.

A recent investigation of the Eta-10 model has discovered some problems especially in boundary layer processes and many of these problems are likely occurring in the other courser resolutions of the Eta models (Staudenmaier and Mittelstadt 1997). The QuikSCAT observations provide a unique opportunity for verifying numerical simulations. Furthermore, although current operational models still can not accurate forecast the Catalina Eddy, they often provide valuable information on the larger scale flow responsible for eddy formation.

6. CONCLUSION

The scatterometer on the NASA QuikSCAT satellite has obtained the first complete visualization of observed low-level eddy wind circulation. Case studies presented in this paper using QuikSCAT winds, buoy winds, air temperature and relative humidity from radiosonde sounding, and NWP products illustrated many typical Catalina Eddy features. Our investigations on the forecast models with different spatial resolutions indicate that forecasting Catalina Eddy events is still a uncertain task even with sufficient horizontal resolutions. Another important utilization of the QuikSCAT winds is to incorporate them into numerical ocean models to study the ocean response to the Catalina Eddy.

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