JP2.6 SATELLITE OBSERVATIONS OF AIR-SEA INTERACTION DURING A SANTA ANA EVENT

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1. INTRODUCTION

Santa Ana is a local weather condition that occurs in southern California and is characterized by strong offshore surface winds, low relative humidities, and clearing of clouds (Lynn and Svejkovsky, 1984). Forecasting the Santa Ana event is important because a Santa Ana sometimes can be of a potential threat to public safety, such as spreading destructive fires, windstorm damage to property, and low-level wind shear for aircraft. Santa Anas occur mainly in the fall and winter, and may last one to several days. The formation of Santa Ana wind is associated with an intense high pressure system in the Great Basin (referred to Nevada and Utah regions) and a weak low pressure system off the southern California coast (Sommers 1978; Small, 1993). The strong pressure gradients produce offshore mountain downslope winds. When downslope winds are channeled by mountain gaps such as canyons and passes, their speeds are increased and sometimes distinguished wind jets are formed. The name of Santa Ana was given by early settlers at Santa Ana, California.

In this paper, we will present a case study of Santa Ana event occurred during the February of 2002. High-resolution satellite observations are used to study air-sea interaction activities enhanced by strong Santa Ana winds. Satellites observed that Santa Ana wind jets picked up land surface dust and spread them over the coastal waters. Along the wind jets, cold-water plumes with high color chlorophyll concentration are created by intense vertical mixing of the surface water.

2. SATELLITE OBSERVATIONS

In this study, ocean color chlorophyll data are from Sea-viewing Wide Field-of-view Sensor (SeaWiFS) provided by Distributed Active Archive Center (DAAC) at NASA Goddard Space Flight Center. Santa Ana dust plumes are identified from SeaWiFS High Resolution Picture Transmission (HRPT) true color images at 1-km resolution, obtained at HUSC station (34.4^{o}N, 119.7^{o}W) at the University of California Santa Barbara. Ocean surface winds at 12.5-km resolution measured by NASA QuikSCAT scatterometer were derived using the Direction Interval Retrieval with Thresholded Nudging (DIRTH) method with improvements on 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 of coastlines were not used in this study. Sea surface temperature (SST) measurements are from the Moderate Resolution Imaging Spectroradiometer (MODIS) aboard the NASA EOS-Terra satellite at thermal IR bands (daily level 3 product at 4-km resolution) obtained from Physical Oceanography DAAC at NASA Jet Propulsion Laboratory.

3. RESULTS

Dusty skies over southern California can be detected by satellite optical sensors. During a Santa Ana event on 10 February of 2002 (Fig. 1), the true color images from SeaWiFS revealed dust plumes with a length of several hundred kilometers spreading toward the Southern California Bight. The marine clouds usually occupying in this region were cleared by the strong off-shore Santa Ana winds. This dusty event was also evident in aerosol measurements made by the Multi-angle Imaging SpectroRadiometer (MISR) aboard on EOS-Terra satellite.

Strong surface winds during this Santa Ana event were clearly identified in the QuikSCAT measurements (Fig. 2). Mountain jets extended several hundred kilometers into the coastal waters with velocities above 10 m/s. Those jets were so strong that they picked up surface dusts and carried dust clouds over the coastal ocean, as shown in Fig. 1. Besides wind jets, off-shore winds blew over all of the Southern California Bight during strong Santa Ana episodes. According to QuikSCAT wind observations, these persistent off-shore surface winds lasted less than three days.

Our study was motivated by the question: Is there any responses, either physical or biological, from the ocean to the wind forcing during a Santa Ana event? Fig. 3 is the sea surface temperature measurement from

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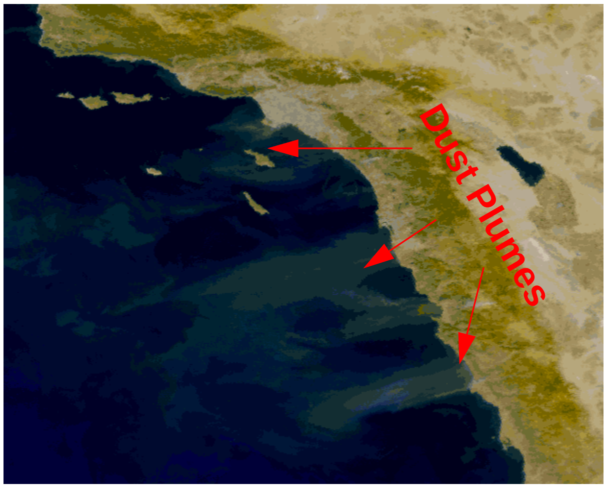

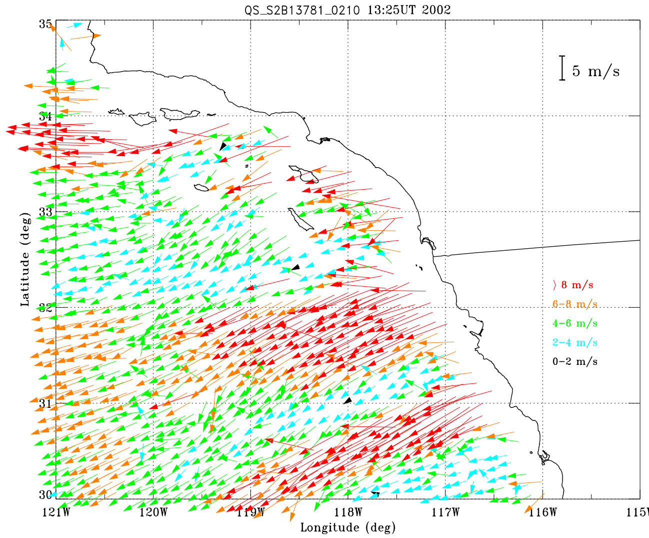

Figure 1. On February 10, 2002, strong Santa Ana winds blew through canyons and mountain passes in southern California, picked up surface dust and spread them into coastal ocean. These dust plumes are identified from SeaWIFS high resolution (1-km) true color image collected from HRTP HCAN station at

Figure 2. QuikSCAT observed the Santa Ana event reported in Fig. 1. Strong offshore surface wind jets overlap with dust plumes in Fig 1. These 12.5-km wind data are taken on February 10, 2002 at 13:25UT.

MODIS thermal infrared sensor on February 10, 2002. Black areas over the ocean represent missing data due to clouds. Shown in Fig. 3, there are plumes of cold water in response to Santa Ana wind jets. These cold-water plumes were created by intense vertical mixing of the ocean due to the strong surface winds. The vertical mixing brought cold water and nutrients from the deep water into the surface layer, and hence decreasing the sea surface temperature and increasing biological activities. Cold-water plumes associated with Santa Ana wind jets were also observed by the Advanced Very High-Resolution Radiometer (AVHRR) on the NOAA series polar orbing weather satellites. The high-resolution (1.1 km) AVHRR SST data were obtained from NOAA CoastWatch Program. Cold-water plumes generated by mountain jets are also found off the Pacific coast of Central America (Chelton et al., 2000)

The ocean's biological response to the Santa Ana event is shown in the ocean color chlorophyll data from SeaWiFS (Fig. 4). Increased chlorophyll concentration was observed along the Santa Ana wind jets. The data are on February 12, 2002, a dust-clear day and two days following the dust event. The black areas in the ocean are lack of chlorophyll measurements due to cloud coverage. Mouliin et al. (2001) showed that Saharan dust has strong absorption to the blue, and hence affects ocean color chlorophyll retrievals. Although the Santa Ana dust concentration is much lower than that of Sahara dust event, in this study we only use chlorophyll data that are clearly post-dust event.

During the normal condition, the coastal biological activity in the Southern California Bight is enriched by the strong upwelling due to the along-shore equatorward surface winds. During the Santa Ana event, the surface winds change to off-shore directions, thus resulting in downwelling processes. Fig. 5 is the upwelling indices obtained from the NOAA Pacific Fisheries Environmental Laboratory. The indices are calculated using forecast products from the U.S. Navy Fleet Numerical Meteorological and Oceanographic Center (FNMOC). The magnitude of upwelling index is based on the offshore component of Ekman transports, representing the amount of water upwelled from the base of the Ekman layer, with positive values implying upwelling and negative ones for downwelling. The indices shown in Fig. 5 are for a location at ($119^oW, 33^oN$) in the Southern California Bight. During the Santa Ana event, the upwelling due to Ekman transport was suppressed, however, entrainment of deep water into the surface layer due to vertical mixing of the ocean was increased. The interplay of these two processes results in the net changes of the ocean's physical and biological responses to a Santa Ana. By Comparing SST and chlorophyll data made during the Santa Ana event and during a clear-sky normal condition (5 February 2002, figure not shown here), it is found that over the strong Santa Ana wind jet areas, the vertical mixing process dominates thus the SST decreases and chlorophyll increases; elsewhere near coastal waters, the downwelling process dominates thus SST increases and

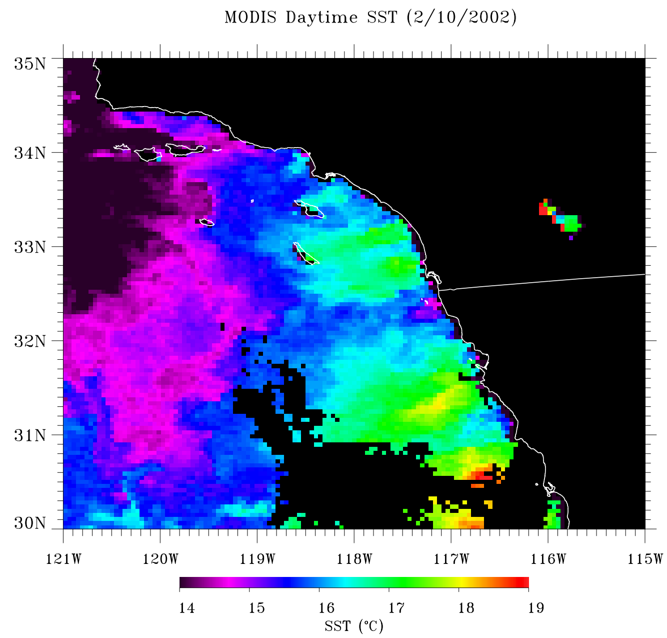

Figure 3. Sea surface temperature measurements from MODIS indicated that there are plumes of cold water in response to Santa Ana wind jets. Data are MODIS level-3 product with 4-km resolutions on February 10, 2002. The black areas in the ocean are lack of SST measurements due to cloud coverage.

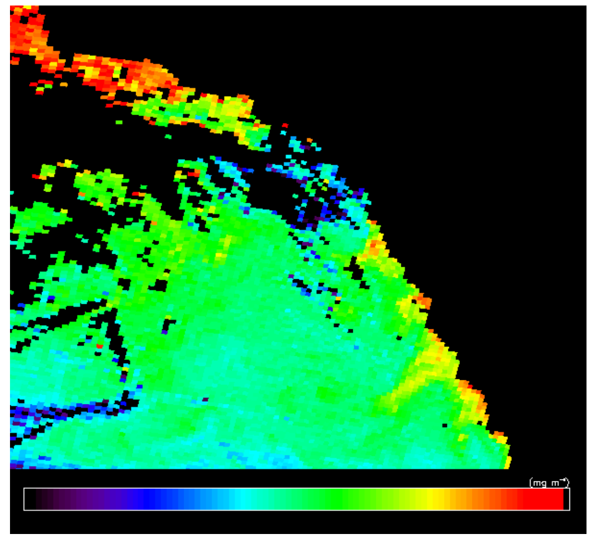

Figure 4. The ocean's biological response to the Santa Ana event is shown in the chlorophyll data from SeaWiFS. Increased chlorophyll concentration is observed along the Santa Ana wind jets. The data are on February 12, 2002, a dust-clear day and two days following the dust event. The black areas in the ocean are lack of chlorophyll measurements due to cloud coverage.

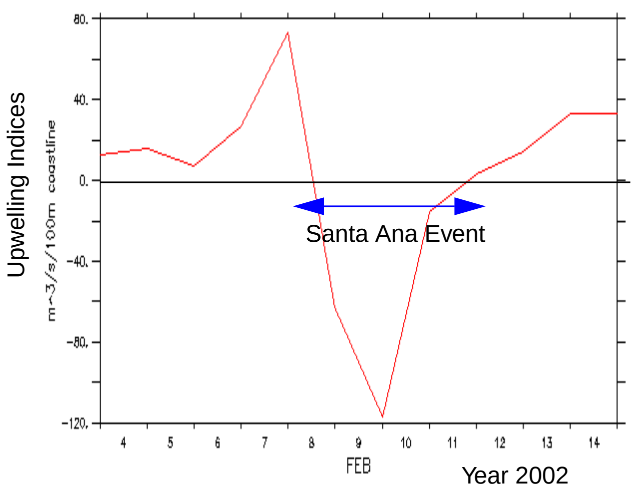

Figure 5. Upwelling indices from the NOAA Pacific Fisheries Environmental Laboratory showed that upwelling due to Ekman's transport is suppressed during the Santa Ana event.

chlorophyll has little changes. Quantitative estimation of the two processes using QuikSCAT winds will be examined in our further study.

As we mentioned earlier that the Santa Ana event is caused by the intense downslope winds. The synoptic patterns associated with Santa Ana flow can be seen in Fig. 6 using the reanalysis product from National Center of Environmental Prediction (NCEP). On 10 February 2002, a strong surface high (surface pressure over 1040 mb) existed over the Great Basin, creating a high surface pressure gradient across the San Gabriel mountains. Santa Ana winds were produced over the west side of the mountain, as shown in Fig. 7. The magnitudes of NCEP surface winds seem to be lower than those of QuikSCAT wind measurements. In sum, this study demonstrates the capability of NASA Earth Observing Satellites to detect the airs-sea interaction activity associated with a small synoptic weather event, such as the Santa Ana event.

Acknowledgments. This study was performed at the Jet Propulsion Laboratory, California Institute of

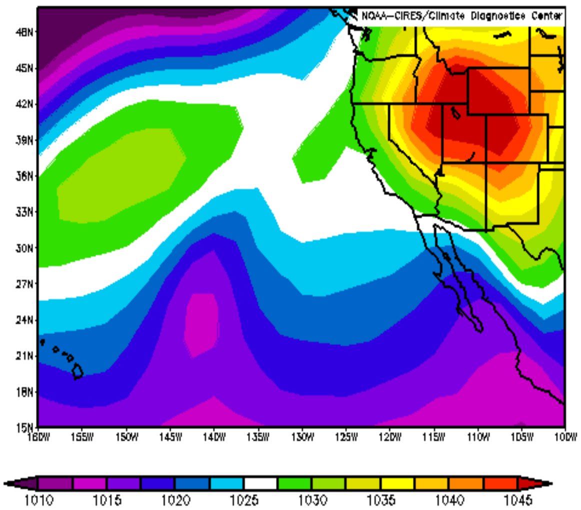

Figure 6. Surface pressure from NCEP reanalysis shows a high pressure in the Great Basin on February 10, 2002.

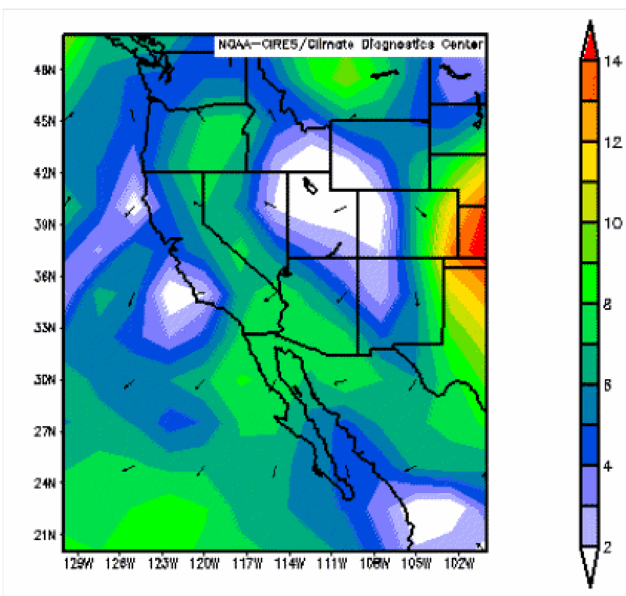

Figure 7. Surface winds from NCEP reanalysis shows strong offshore winds in the southern California on February 10, 2002.

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