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A Pilot Program to Examine High-Resolution Modeling of Coastal Land-Air-Sea Interaction in the Monterey Bay

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Award Number: N0001415WX01714

LONG-TERM GOALS

The long term goal of this project is to identify and rectify outstanding obstacles to very high-resolution environmental modeling in the littoral zone. Model enhancements will leverage recent advances in surface representation (ocean modeling, land surface modeling) and data assimilation coupled with technical improvements in high performance computing to expand operational forecasting capability of the coastal environment to spatial scales finer than current mesoscale limits (~ 1 km). Forecasts at these high-resolution spatial scales in the vicinity of the air-sea-land interface serve both mission planning needs and tactical applications. Investigations will utilize METOC data from the pending pilot program observational field campaign in Monterey Bay, CA, USA to construct, test and validate model enhancements.

OBJECTIVE

The objective of this pilot project is to assess the degree to which current state-of-the-science models, such as the Navy's Coupled Ocean-Atmosphere Mesoscale Prediction System (COAMPS), can properly represent the air-land-sea interface and their interactions in the coastal zone when applied at ultra-high resolutions (grid increments of less than 1 km). In this project, we will apply COAMPS at horizontal resolutions not previously considered, such as 100-m to 1 km, and evaluate the performance of the model in the coastal zone utilizing existing datasets (such as surface observations and SAR imagery) and new observations obtain by Prof. Jamie MacMahan of the Naval Postgraduate School. This pilot project will focus on the capability of the modeling system to represent the cross-shore gradients over an approximate 12 km wide zone across the interface in a variety of conditions including during sea breeze events, relaxation periods (with weak winds), storms and frontal passages. Investigators will coordinate closely with Prof. MacMahan and the other collaborators to utilize observations collected during the 2015 pilot program and previous historical cases.

APPROACH

Our approach is to leverage prior investments in a suite of state-of-the-art environmental modeling systems (COAMPS, NAVGEM, NCOM and NAVDAS) to simulate with high resolution the littoral environment of the Monterey Bay. Of primary interest is the assessment of COAMPS forecast performance near the air-sea-land interface of this region when operated with grid increments of less

than 1 km. Land and sea-surface-based observations and remote sensing products will provide a basis for model verification. These resources will also be leveraged to construct a climatology of regional atmospheric and oceanic conditions. This climatology will inform of the local archetypical modes of flow and interaction as well as the range of diurnal and seasonal variability, yielding discrete model simulation scenarios to characterize the region. Through modeling of these scenarios this project will investigate specifically the viability of current mesoscale model parameterizations for sub-grid scale turbulence on a sub-mesoscale grid. Model forecast evaluations will identify and characterize any systematic errors in atmospheric flow structure and test sensitivity of cross-shore gradients to model horizontal resolution. Further investigations will test the integration of high-resolution land-surface and terrain databases.

WORK COMPLETED

Completed work includes: (i) evaluation of the diurnal and seasonal climatology of surface wind and additional fields around Monterey Bay and (ii) preliminary model runs of the study region

i) *Diurnal and Seasonal Climatology*

Near-surface wind, temperature, pressure and humidity composites were created to detect seasonal and diurnal patterns from available stations situated along Monterey Bay. Data was extracted and processed from stations operated by NOAA and the Naval Postgraduate School (NPS) for the period of spring and summer 2015 as well as a 5.5 year dataset at the Del Monte Beach NOAA CO-OP station (DM) ending June 2015. Additional data was collected and processed from the Monterey Bay Aquarium Research Institute (MBARI) M1 buoy near the center of Monterey Bay.

ii) *Preliminary Model Simulations*

Preliminary COAMPS model runs for the atmosphere only (without a coupled ocean model, land surface model or 3D-Var DA system) were configured for a short-forecast lead time simulation of Monterey Bay on 29 May 2015 during a Santa Cruz Eddy (SCE) event (Archer et al. 2005, Archer and Jacobson 2005), a feature common to the region. COAMPS (version 5) runs were integrated to a 24-hour forecast from an analysis at 00Z 29 May 2015 generated from NAVGEM model fields. Five grids were configured through telescopic nesting to achieve an inner-most grid increment size of 333m (27 km: 9 km: 3 km: 1 km: 0.333 km). Figure 1 illustrates the model domain configuration. Two runs of the test case were operated: one with one-way nesting (SCE_290515-b) and the other with two-way nesting (SCE_290515-c). Model performance evaluation concentrated on the near-surface wind field with respect to the observed horizontal circulation consistent with the characteristics of a SCE. Surface station data collected for climatological assessment, as well as data from the NPS 915 MHz wind profiler, served as sources for model forecast verification.

RESULTS

i. Diurnal and Seasonal Climatology

Large-scale prevailing winds were found to dominate the wind signal at most stations. A component of diurnal oscillation in the wind speed and direction at several coastal stations suggests impacts from land/sea breeze circulations, whose frequency was found to vary seasonally. The DM station provided the largest quantity of observations available for assessment, spanning over five years. Additional observation data sources are anticipated from collaborating investigators. Of interest to impending

investigations of surface flux, the monthly-average sea-surface temperature (SST) at station DM was found to vary seasonally with considerable inter-month variability in Spring and Fall seasons (Figure 2). The same dataset also indicates a slight diurnal oscillation of SST, generally peaking in the hours after sunset. Wind patterns at station DM, evaluated over three years (2010-2012), reveal predominantly westerly flow (Figure 3). A bimodal character of the wind direction frequency distribution was found (SSW, and NW) which is likely influenced by adjacent topographical features and, to a lesser extent, built-up surface obstacles, though further investigation is needed.

ii. Preliminary Model Simulations

Preliminary COAMPS test runs generally captured the broad horizontal circulation of separate nocturnal ("SCE_1") and diurnal ("SCE_2") SCE events on 29 May 2015. With the exception of southern Monterey Bay stations PG (Pacific Grove) and DM, the highest resolution model grid (grid 5: $\Delta x = 333$m) roughly captures the observed wind direction at the available verification sites during SCE_1. Figure 4 depicts the COAMPS forecast of SCE_1 during its mature phase, coupled with observations spanning the duration of the SCE_1 event (approximately 05 – 09Z 29 May 2015). Further investigation is needed to diagnose the cause of model forecast wind direction error at stations PG and DM. Grid 5 also depicts fine-scale structure in the wind speed gradients over Monterey Bay during the mature phase of SCE_1 (Figure 5c) not found in its parent grid (grid 4: $\Delta x = 1$ km; Figure 5a). Observations are unavailable to confirm the accuracy of these structures. Model forecasts of wind speed match observed values reasonably well, but precise wind observations are unavailable (1 kt increments only). The forecast SCE circulation in SCE_1 was found to extend a limited distance over land along the coastal plain out to approximately 6 km from the coastline in grid 5 (Figure 5c), with slightly stronger wind speed in places versus grid 4 (Figure 5a). Model simulation of the weaker diurnal SCE_2 event (16 - 19Z 29 May 2015) performs variably with respect to wind observations (Figure 6), with non-negligible errors in forecast wind speed and direction at station SC and direction at PG and DM. Shifts in the center of SCE circulation of O (10^0km) found between the one-way and interactive nesting (case SCE_290515_c) forecasts of SCE_2 require further investigation and model verification. As in the model simulation of SCE_1, grid 5 forecasts for SCE_2 reveal detailed structure not present in grid 4 (Figure 5 b, d), particularly in the southern part of Monterey Bay.

Model forecast vertical profiles of wind and boundary layer depth agree well qualitatively with available observations from the NPS 915 MHz Wind Profiler (Figure 7), operated at site of the former Fort Ord National Monument. Vertical cross-sections of the model forecast north-south wind component during the SCE_1 event suggest a vertical extent of roughly 200-300m above the surface (Figure 8), consistent with observed SCE depths (Archer et al. 2005). Model forecasts of SCE_1 also suggest that the maximum tangential wind speed on the eastern flank of the SCE is found over land at the eastern edge of the coastal plain, with a difference of nearly 2 ms^{-1} at 100-150 m above the surface. Comparison of grids 4 and 5 also reveals some impact of horizontal resolution (of the atmosphere and surface topography) on the location and strength of this eastern SCE flank, as well as on the upper structure of the SCE circulation.

REFERENCES

Cristina L. Archer, Mark Z. Jacobson, and Francis L. Ludwig, 2005: The Santa Cruz Eddy. Part I: Observations and Statistics. *Mon. Wea. Rev.*, **133**, 767–782.

Cristina L. Archer, Mark Z. Jacobson. (2005) The Santa Cruz Eddy. Part II: Mechanisms of Formation. *Monthly Weather Review* **133**:8, 2387-2405.

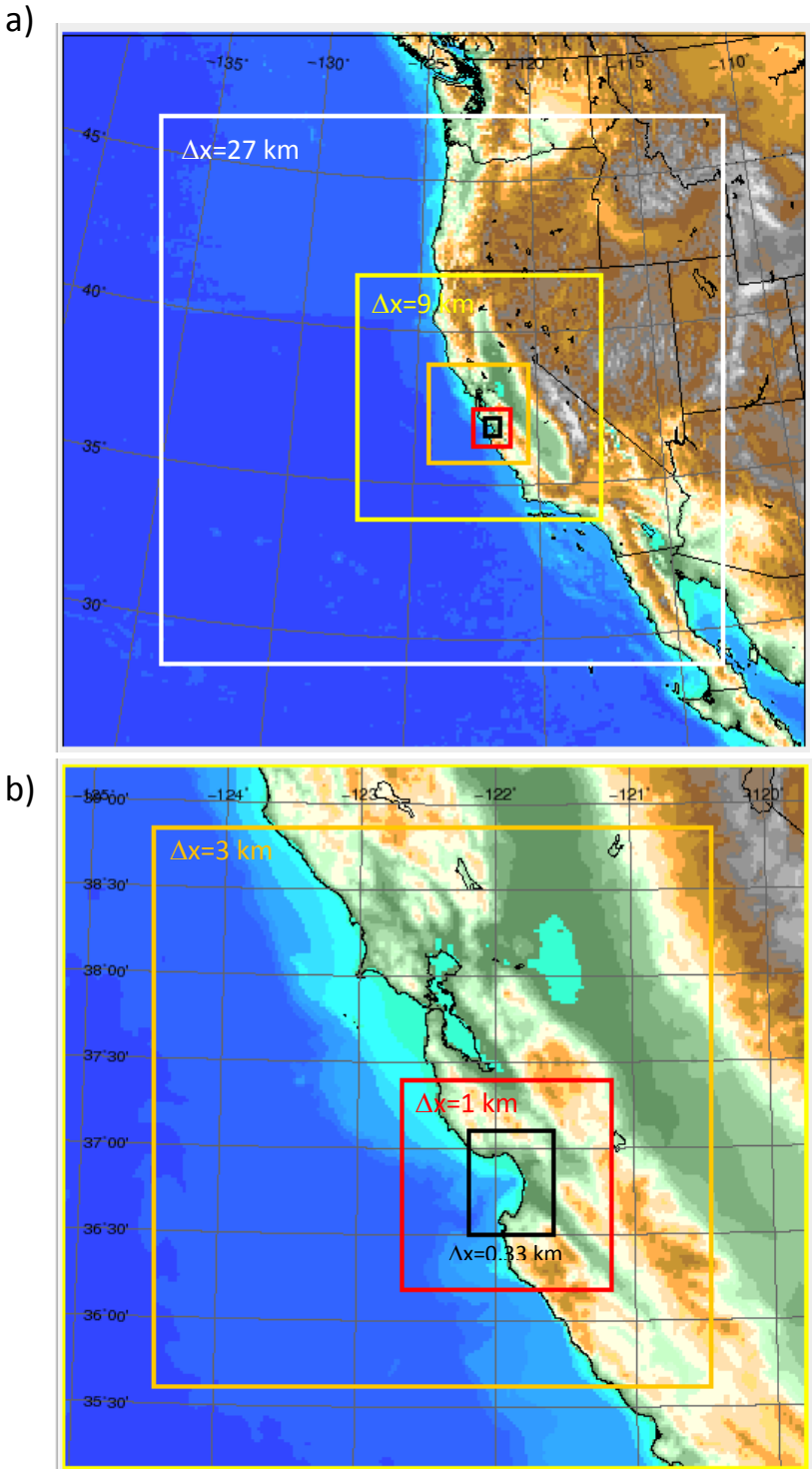

Figure 1. COAMPS model grids configured for simulation of the Santa Cruz Eddy event of 29 May 2015 (a), with a closer perspective of the inner-most grids (b).

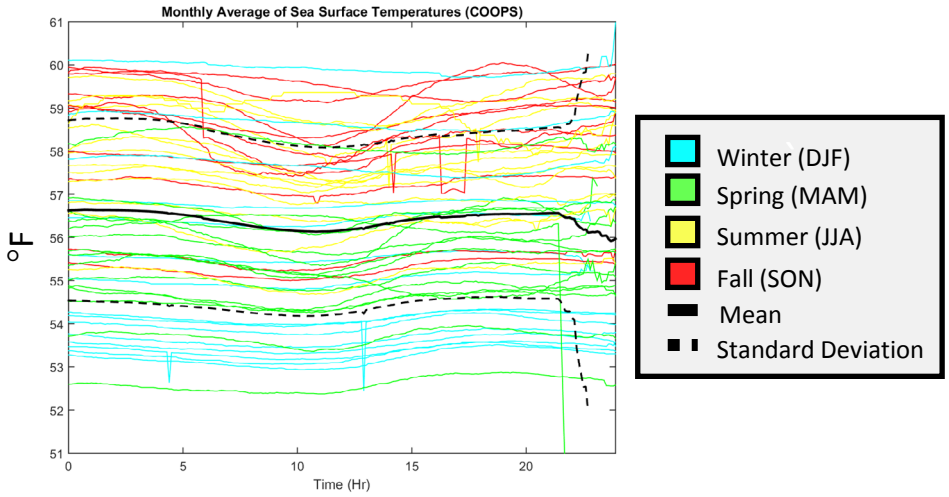

Figure 2. Monthly average sea-surface temperature in degrees Fahrenheit versus local time of day, color-coded by season. Each month available is plotted as a separate graph. Temperatures are shown for the Del Monte Beach NOAA CO-OP station in Monterey, CA, USA from December 2009 through June 2015. The data is not quality controlled.

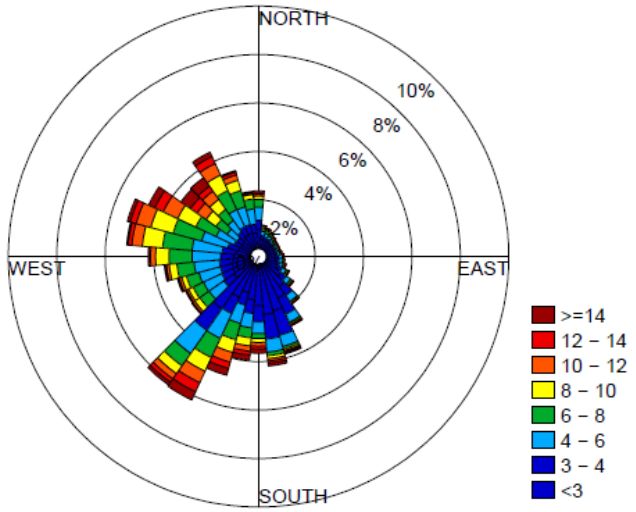

Figure 3. Wind rose of surface wind observations at the Del Monte Beach NOAA CO-OP station in Monterey, CA, USA. Spokes represent bins of 10 degrees with colors corresponding to speed (knots) as shown in the legend. The distance from the spoke edge to the rose origin corresponds to frequency of occurrence. The figure include s observations available from 2010-2012 (inclusive).

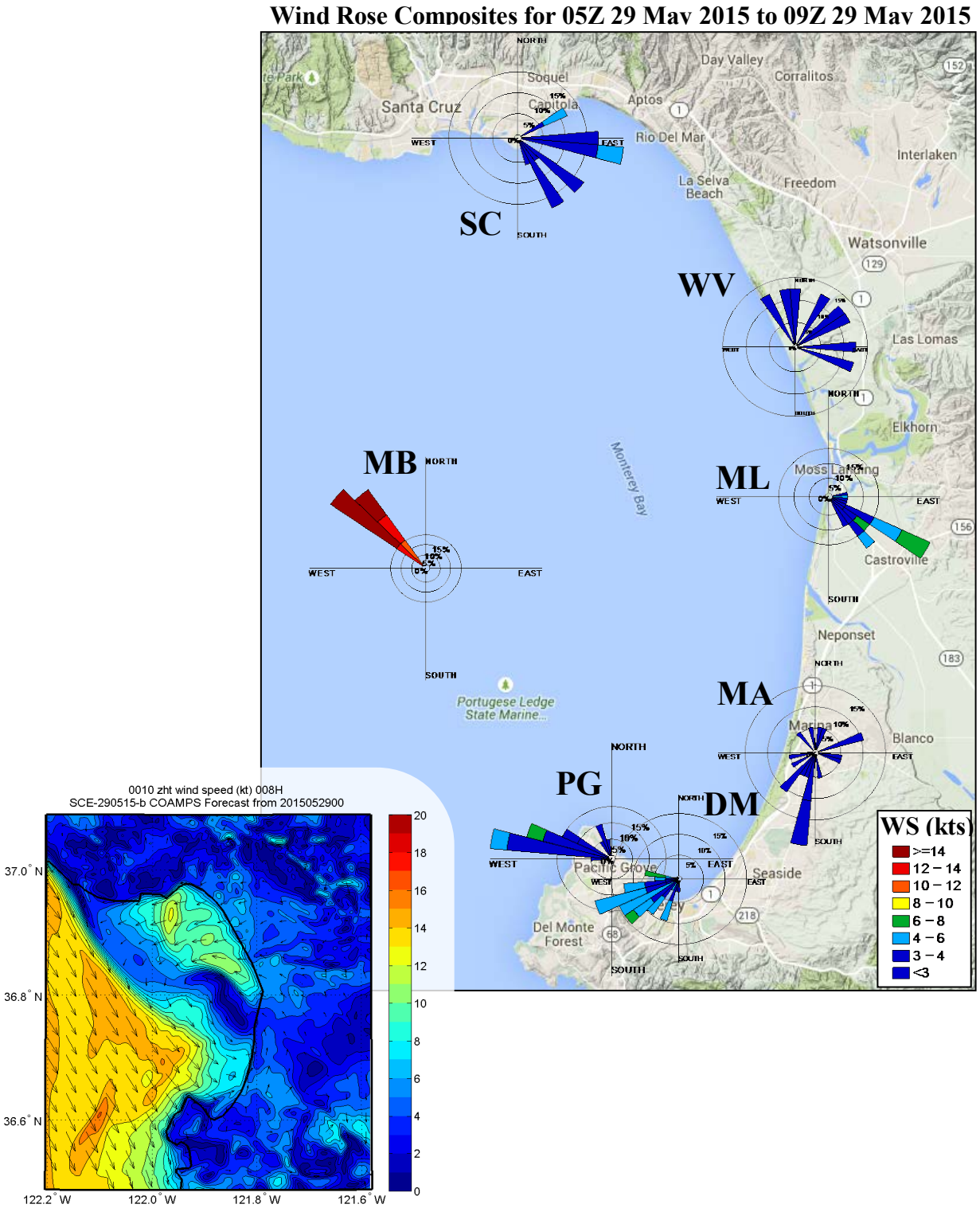

Figure 4. (top) Wind rose composite of surface wind observations from 05Z to 09Z 29 May 2015. Spokes represent bins of 10 degrees with colors corresponding to speed (kts) as shown in the legend. The distance from the spoke edge to the rose origin corresponds to the frequency of occurrence during this period. (bottom) Wind speed in kts (color contours) and direction (wind barbs) from a COAMPS model 8-hour forecast valid at 08Z 29 May 2015 in grid 5 of case SCE_290515_b.

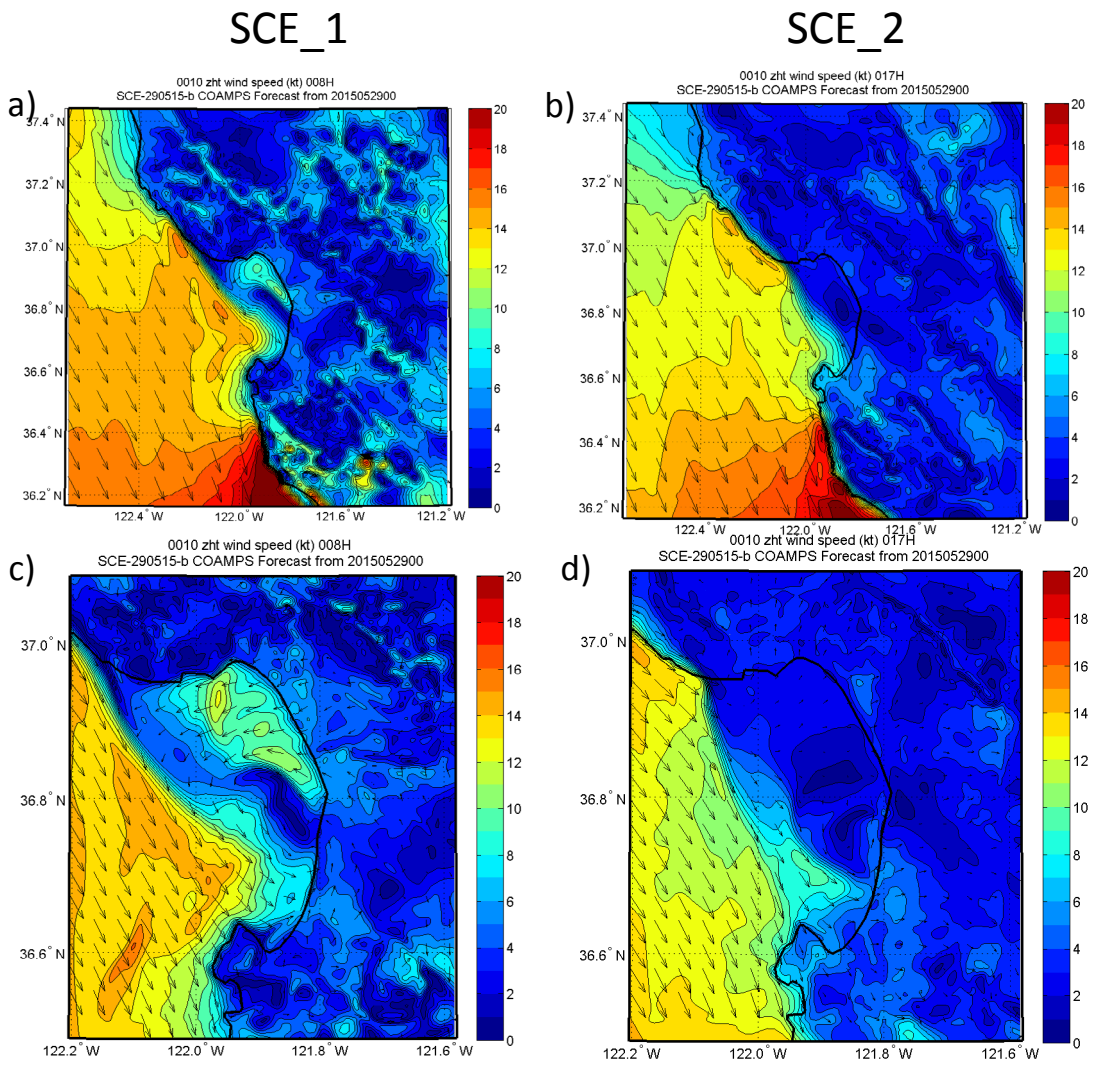

Figure 5. COAMPS forecast (case SCE_290515_b) of wind speed in kts (color contours) and direction (barbs) for two Santa Cruz Eddy events (SCE_1, SCE_2). Model forecasts are shown from grid 4 (a,b) and grid 5 (c,d) with an 8-hour lead time valid at 08Z 29 May 2015 (a,c) and with a 17-hour lead time valid at 17Z 29 May 2015 (b,d).

Wind Rose Composites for 16Z 29 May 2015 to 19Z 29 May 2015

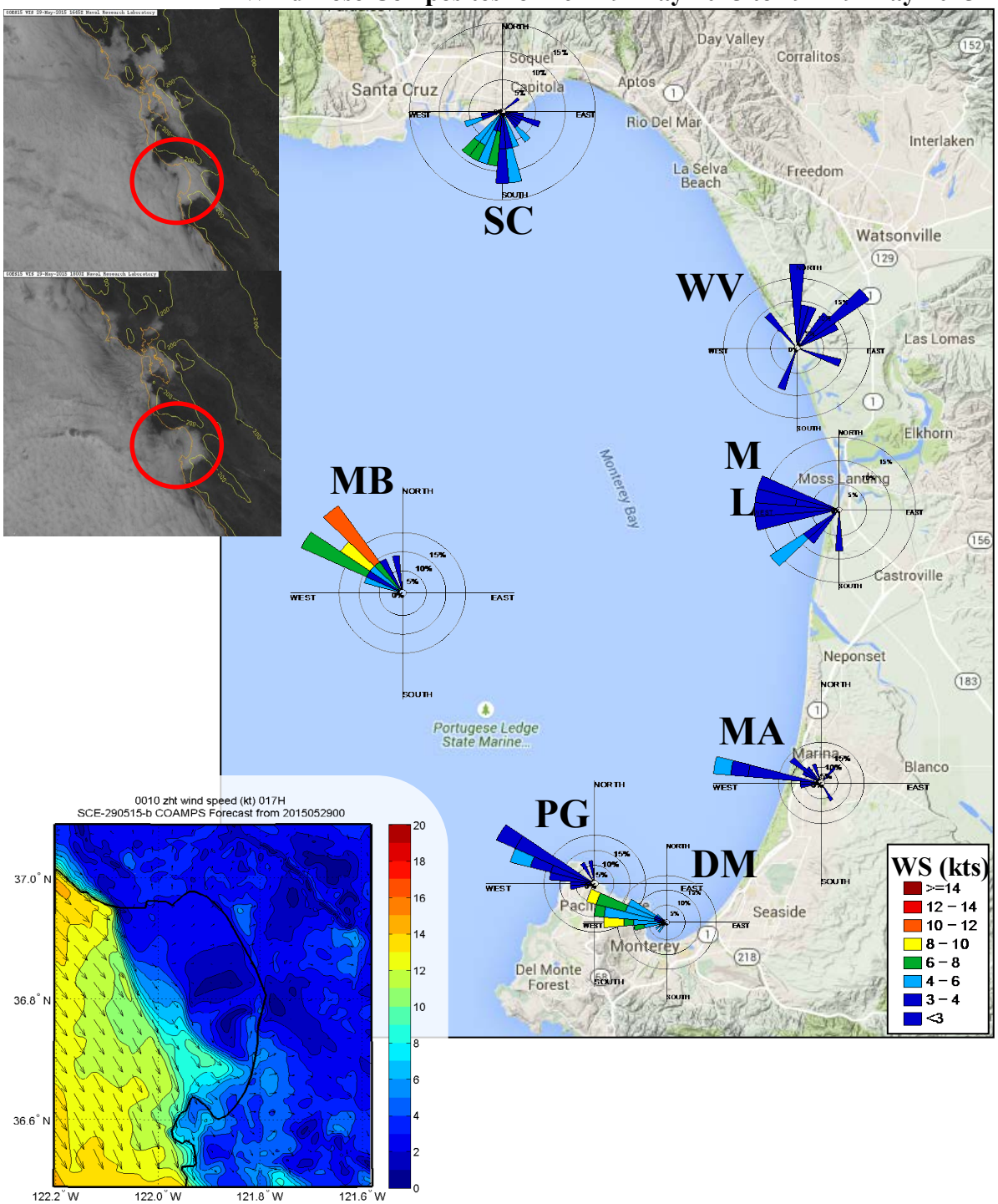

Figure 6. (top right) Wind rose composite of surface wind observations from 16Z to 19Z 29 May 2015. Spokes represent bins of 10 degrees with colors corresponding to speed (kts) as shown in the legend. The distance from the spoke edge to the rose origin corresponds to the frequency of occurrence during this period. (bottom left) Wind speed in kts (color contours) and direction (wind barbs) from a COAMPS model 8-hour forecast valid at 17Z 29 May 2015 in grid 5 of case SCE_290515_b. (upper left) GOES15 visible satellite imagery of Monterey Bay(highlighted in red) at 1645Z (top) and 1800Z (bottom) 29 May 2015.

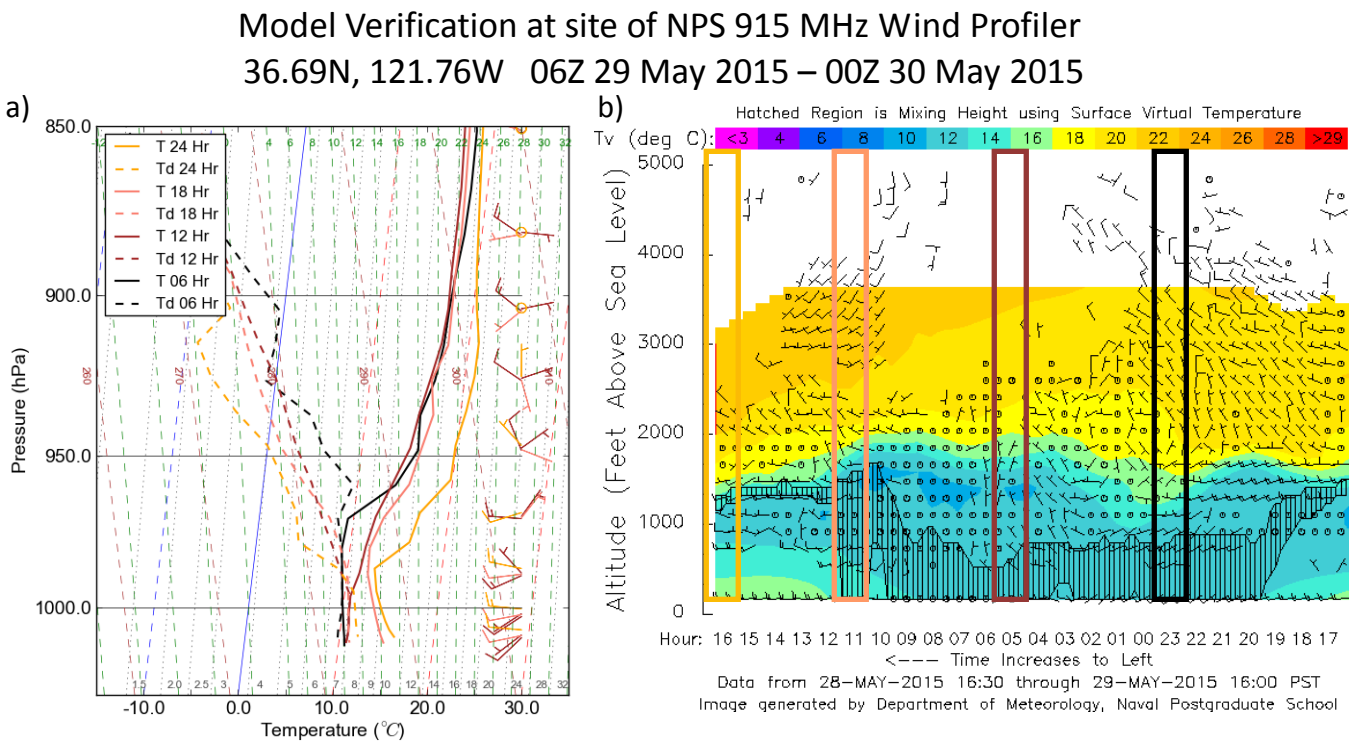

Figure 7. (a) Skew-T ln(p) diagram of profiles from COAMPS run SCE_290515_b showing forecasts of 6, 12, 18 and 24 hours from the 00Z 29 May 2015 analysis interpolated to the site of the Naval Postgraduate School 915 MHz Wind Profiler. (b) Time-height cross-section of virtual temperature (filled contours) and wind (barbs) from the Naval Postgraduate School 915 MHz Wind Profiler. Shaded rectangles highlight measurements at the validation time of the color-corresponding model forecast profiles in (a). Pacific Standard Time (PST) = UTC (Z) – 8 hours.

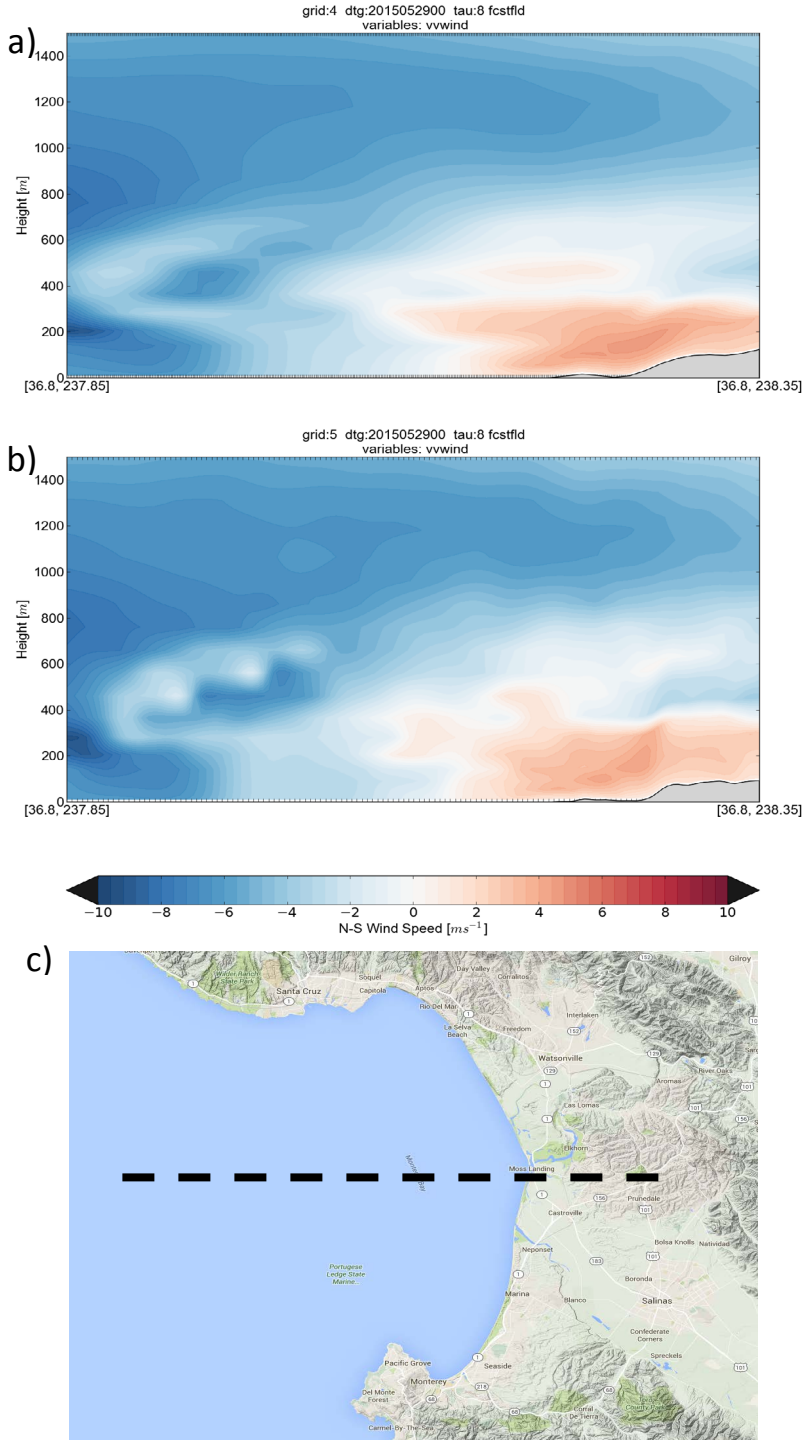

Figure 8. (a, b) COAMPS 8-hour forecast of north-south grid model wind speed (vvwind) valid at 08Z 29 May 2015 illustrated as a vertical cross-section extending west-to-east at 36.8°N latitude from 122.15(237.85°E) to 121.65°W (238.35°E) and extending vertically from the local surface to 1500 m MSL. Model forecasts from grid 4 for case SCE_290515_b (dx = 1000m) are shown in (a) and grid 5 (dx=333m) in (b).Topography is shaded in gray. A relief map illustrating the approximate horizontal extent of the cross-section with respect to Monterey Bay is shown in (c).