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Revisiting the effects of surface fluxes on rapid marine cyclogenesis

Nuss, Wendell A.; Miller, Douglas K.

2.4 REVISITING THE EFFECTS OF SURFACE FLUXES ON RAPID MARINE CYCLOGENESIS

Wendell A. Nuss and Douglas K. Miller
Naval Postgraduate School, Monterey, California

1. INTRODUCTION

The role of surface sensible and latent heat fluxes in rapid oceanic cyclone development was a common topic in the late 1980s and early 1990s. The debate centered on the importance of these fluxes in overall storm development. Upward fluxes of water vapor and heat contribute to decreased low-level static stability (Reed and Albright 1986) and can pre-condition the storm environment for subsequent development (Kuo and Low-Nam 1990, and Kuo, Reed, and Low-Nam 1990). Depending on the phasing of the low-level fluxes relative to the baroclinic zone, the fluxes could either damp or amplify overall cyclogenesis during the period of storm development (Nuss and Anthes 1987, and Kuo, Reed, and Low-Nam 1990). The purpose of this study is to revisit the role of surface sensible and latent heat fluxes for a case of rapid oceanic storm development in order to better quantify and categorize, in both space and time relative to the developing surface cyclone, instances when surface sensible and latent heat fluxes amplify or dampen its development.

In order to accomplish the stated purpose, this study will examine the sensitivity of mesoscale model forecast solutions to varied sea surface temperature (SST) configurations for a case study observed during the PACJET Field Experiment that took place on 13 February 2001 in the vicinity of the California Bight region. In this particular case, Touchton (2002) noted that the air-sea fluxes in the early stages of cyclone development might have helped to [1] enhance its associated low-level baroclinic zone and [2] destabilize the lower atmosphere making the environment potentially unstable. Observations from PACJET, in addition to satellite imagery and standard observations, will be used to confirm structures generated by the mesoscale model. Background will be presented in Section 2, preliminary model results will be given in Section 3, and a summary of the study will be made in Section 4.

Corresponding author address: Wendell A. Nuss, Department of Meteorology, Naval Postgraduate School, Monterey, CA 93943; email: nuss@nps.navy.mil.

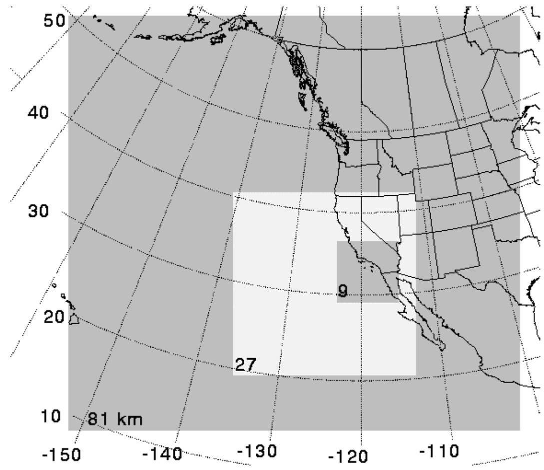

Figure 1: *COAMPS nested grid configuration with grid spacings decreasing from 81 to 9 km in multiples of 3.*

2. BACKGROUND

The numerical simulations have been generated using the U.S. Navy Coupled Ocean Atmosphere Mesoscale Prediction System (COAMPS, version 2.0.15) non-hydrostatic mesoscale model for testing the sensitivity of simulated mid-latitude cyclone development to surface sensible and latent heat fluxes. The mesoscale model domain configuration, whose location is shown in Figure 1, consists of three nested domains ranging from 81 to 9 km grid spacing, with a grid spacing ratio of 3 between consecutive domains.

The model top was prescribed to be at 20 km with 47 vertical levels from the surface to model top. Each mesoscale model forecast consists of a 24-h simulation generated using a “cold-start” approach, wherein the initial conditions have been computed using two-dimensional multiquadric univariate interpolation (2DMQ, Nuss and Titley 1994) blending available National Weather Service observations with the U.S. Navy Operational Global Atmospheric Prediction System (NOGAPS) model forecast fields for creating initial and lateral boundary conditions updated every 12 hours.

The 9 km COAMPS domain terrain elevation field generated for the simulations (Figure 2) shows the

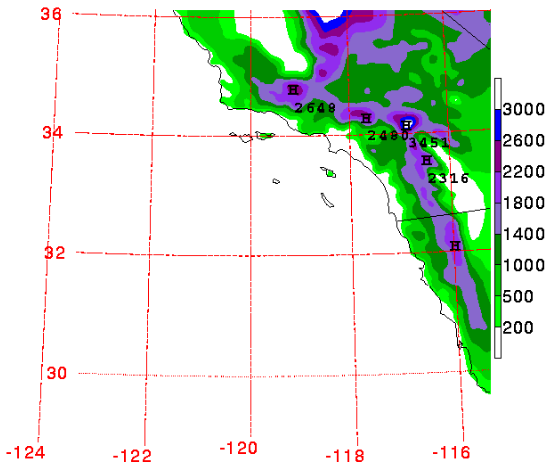

Figure 2: *COAMPS 9 km domain terrain elevation (m).*

coastal mountains that form a wall along the California Bight southward into Mexico and whose peaks reach to nearly 3500 m above sea level.

The preliminary COAMPS simulations are initialized with relatively coarse surface temperatures (Figure 3) at 0000 UTC 13 Feb 2001 created by blending a NOGAPS 1^{o} SST analysis with available ship and buoy observations. SSTs range from 8 ^{o}C to the north of the 9 km domain to greater than 16 ^{o}C along the coastline of Mexico. Future simulations will investigate initializing COAMPS from higher resolution SST fields.

The synoptic pattern as derived from the U.S. Navy NOGAPS model analyses blended with available surface and upper-air observations valid at 0000 UTC 13 February 2001 (Figures 4 – 6) shows a positively tilted trough at the 250 hPa level (Fig. 4) which indicates a jet streak directed toward the Baja Peninsula having a maximum wind speed just above 70 m s^{-1}. North of the jet streak is a warm pool at 250 hPa (not shown) centered in the trough indicative of warm thermal advection in the upper troposphere downstream of the trough. The 500 hPa level pattern (Fig. 5) indicates positive vorticity advection occurring downstream of the trough, corresponding to the position of the developing surface cyclone (Fig. 6) located at 31^{o}N, 122^{o}W. The incipient surface cyclone is collocated with a lower-tropospheric baroclinic zone associated with the trough evident at the 250 and 500 hPa levels.

Touchton (2002) analyzed the 13 Feb 2001 case and determined that it had deepened 14 hPa from 0000 to 1200 UTC, exceeding most thresholds for

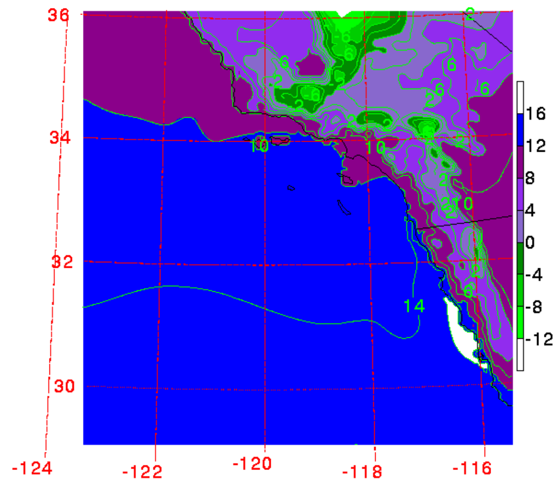

Figure 3: *Sea surface and ground temperature (^{o}C) analysis valid at the model initial time of 0000 UTC 13 FEB 2001.*

categorizing this cyclone as having undergone rapid cyclogenesis. Most operational numerical weather prediction guidance from the National Center for Environmental Prediction and U.S. Navy global and mesoscale simulations under-predicted both the cyclone intensity and its intensification rate. The surface and upper-air analyses used to initialize the operational global and mesoscale models were consistent in depicting a surface cyclone with favorable synoptic scale upper-tropospheric/ lower-stratospheric dry dynamic and thermodynamic support for development.

Satellite imagery along with observations taken during a PACJET intensive observation period indicate a complicated synoptic and mesoscale circulation with its associated complex cloud structure (Touchton 2002). Based on the supplementary PACJET data, Touchton (2002) analyzed the surface cyclone at 0000 UTC 13 Feb southwest of the California coast with a central pressure of 1005 hPa. By 1200 UTC 13 Feb, the primary cyclone had deepened to 991 hPa and moved to just offshore of Los Angeles.

The complexity of the storm is also evident in several PACJET dropsonde soundings showing low-level potential instability in the cyclone warm sector. This led Touchton (2002) to hypothesize that surface fluxes were important in contributing to the 13 Feb storm development. Two preliminary model experiments are presented to examine this hypothesis; the control (CON) allows full COAMPS-depicted physics and the no-surface-flux (NSF) simulation does not allow the exchange of

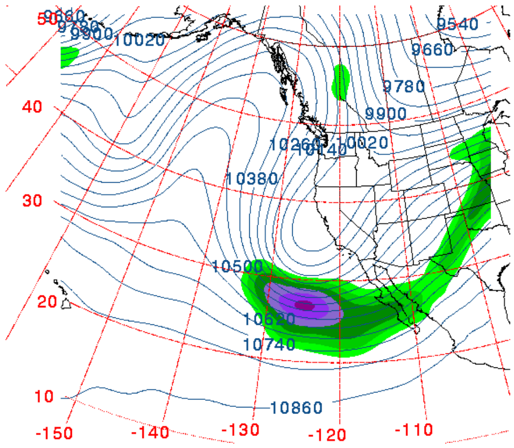

Figure 4: *Geopotential height (m, contours) and isotachs (m s^{-1}, shading) at the 250 hPa level valid at 0000 UTC 13 FEB 2001.*

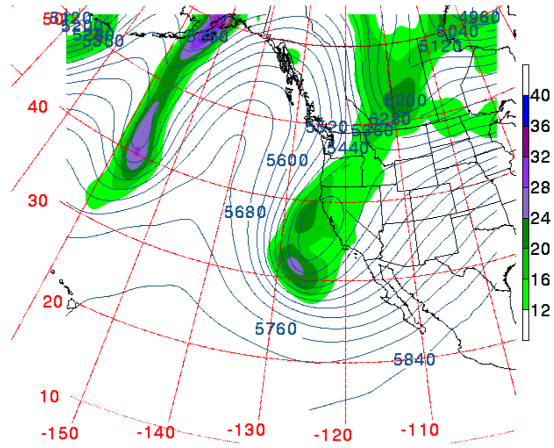

Figure 5: *As in Figure 4, except absolute vorticity (x 10^{-5} s^{-1}, shading) at the 500 hPa level.*

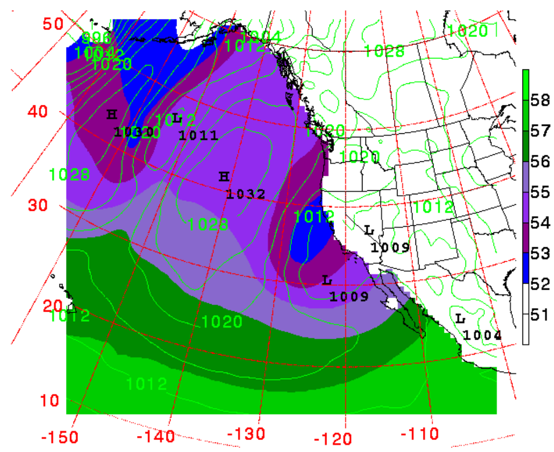

Figure 6: *Mean sea level pressure (hPa, contours) and 1000-500 hPa thickness (hm, shading) valid at 0000 UTC 13 FEB 2001.*

sensible heat or moisture at the model surface. The latter experiment provides a baseline test of a simulated atmosphere lacking direct and indirect surface flux effects on overall cyclone development.

3. PRELIMINARY NUMERICAL RESULTS

Although the initial 0000 UTC 13 Feb 2001 sea level pressure analysis indicates a less intense cyclone than suggested by Touchton (2002), the intensification rates of the two experiments are explosive as evident in Figures 7 and 8. The NSF development rate exactly matches Touchton's analysis (14 hPa in twelve hours) with the surface central pressure decreasing from 1009 to 995 hPa.

The CON storm shows almost 1.4 in of rain falling in three hours on the windward side of the coastal mountains just north of Los Angeles (Fig. 7) by 1200 UTC 13 Feb. An offshore precipitation maximum at 31^{o}N 120^{o}W is associated with an upper-level shortwave vorticity feature (not shown), while precipitation bands southeast of the primary cyclone suggests the release of some hydrodynamic instability.

The NSF storm replicates the orographic rainfall of the CON storm north of Los Angeles (Fig. 8) by 1200 UTC 14 Feb. In contrast, the simulated offshore NSF precipitation is generally smaller, and is associated with the shortwave, or is non-existent as seen by the absence of banded features southeast of the primary cyclone. A significant amount of the available atmospheric moisture to the south rains out over the coastal ranges of the Baja Peninsula, giving a second accumulated precipitation maximum of almost 1.0 in.

The differences in structure between the CON and NSF simulations is rather remarkable given that only twelve hours have elapsed from the time of initialization to the period depicted in Figures 7 and 8. A comparison of low-level temperature differences (temperature at the surface minus temperature at 10m above ground level, T_{sfc}-T_{10m}) can be made by comparing the CON result (Figure 9) to the NSF result (Figure 10) valid at 0600 UTC 13 Feb 2001. The temperature difference (dT) is an indicator of the direction of the surface sensible heat flux, when permitted.

The CON dT field (Fig. 9) shows sea surface temperatures almost uniformly warmer than the temperatures at 10m AGL over the ocean. The exception is for two areas (shaded green) at 118^{o}W. The maximum dT is in the southwest corner of the COAMPS 9 km domain. Examination of the corresponding surface sensible heat flux field (not

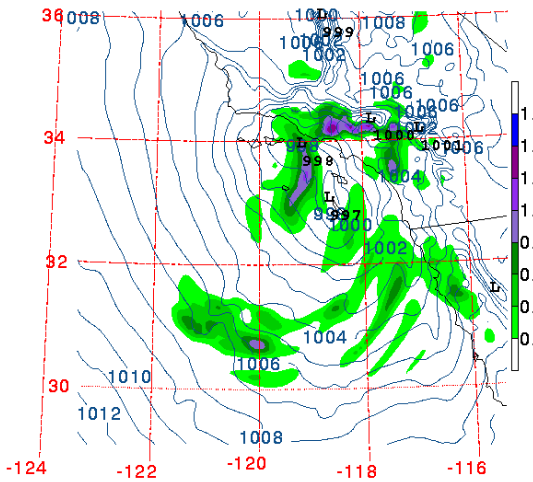

Figure 7: *Simulated CON mean sea level pressure (hPa, contours) and 3-h accumulated precipitation (in., shading) valid at 1200 UTC 13 FEB 2001.*

shown) indicates fluxes for this region in the 80 – 100 W m^{-2} range. Surface sensible heat flux CON values over most of the ocean rarely exceeded 60 W m^{-2} at 0600 UTC 13 Feb.

The NSF dT field (Fig. 10) shows sea surface temperatures uniformly warmer than the temperatures at 10m AGL over the entire ocean, the sole exception being the coastal region immediately south of Los Angeles. The oceanic NSF dT amounts exceed the CON dT, indicative of the lack of heating in the lower NSF atmosphere resulting from the surface fluxes being shut off. This effectively stablizes the lower NSF atmosphere compared to the full physics CON atmosphere.

A comparison of low-level moisture (temperature at the surface minus dewpoint temperature at 10m above ground level, T_{sfc}-Td_{10m}) can be made, assuming saturated conditions at the surface over the ocean, by comparing the CON result (Figure 11) to the NSF result (Figure 12) valid at 0600 UTC 13 Feb 2001. The dewpoint temperature difference (dTd) is an indicator of the direction of the surface latent heat flux, when permitted.

The CON dTd field (Fig. 11) indicates greater vapor at the ocean surface than at 10m AGL. Examination of the corresponding COAMPS surface latent heat flux values over the ocean (not shown) indicates magnitudes in the 60 - 300 W m^{-2} range. The NSF dTd field (Fig. 12) shows significantly greater amounts over the ocean indicating a drier lower atmosphere, effectively

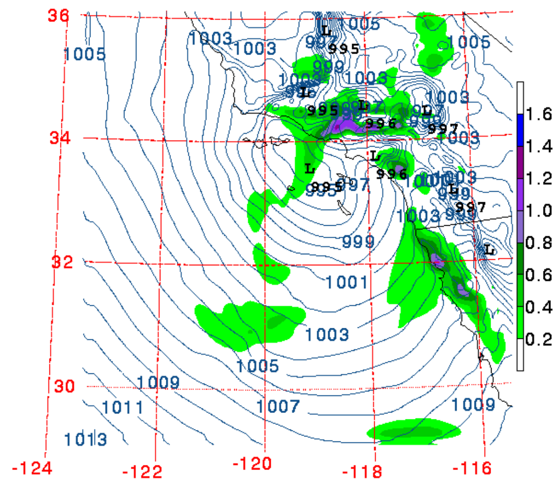

Figure 8: *As in Figure 7, except for NSF simulation.*

stabilizing it compared to the full physics CON atmosphere.

4. SUMMARY

Preliminary results indicate that surface fluxes may have played a significant role in the development of a case of rapid marine cyclogenesis that took place over the California Bight on 13 February 2001. Based on the results, a cursory examination would lead one to conclude that surface fluxes damped development by reducing the low-level barclinic zone. However, these simulations were produced using a coarse resolution SST analysis that may have oversmoothed the warm water features leading to an overdone reduction in the low-level baroclinic zone.

The no-surface-flux (NSF) simulation showed a more rapid intensification rate that may have been the result of an effective decoupling of the free atmosphere from the surface thereby reducing the frictionally induced spin-down. Greater analysis and further experiments will identify the causes for the increased intensification and will be given at the oral presentation.

Future experiments will involve initializing COAMPS with more accurate high resolution SST analyses to examine their impact on storm evolution. A word of caution regarding using mesoscale models to reach conclusions about reality – the virtual oceans act as infinite heat sources or sinks since SSTs are NOT allowed to vary over the course of a model simulation.

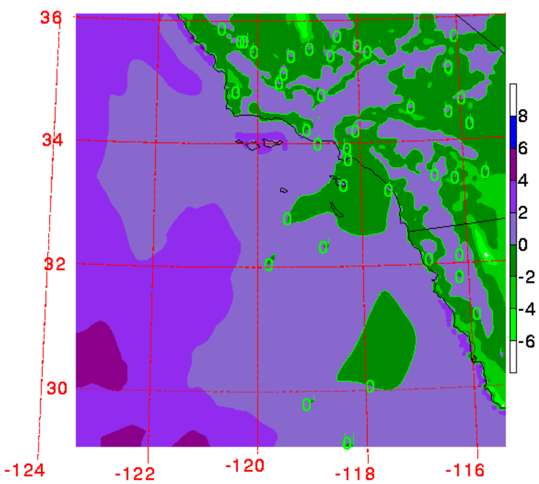

Figure 9: *Six hour CON T_{sfc}-T_{10m} (^{o}C) forecast valid at 0600 UTC 13 FEB 2001.*

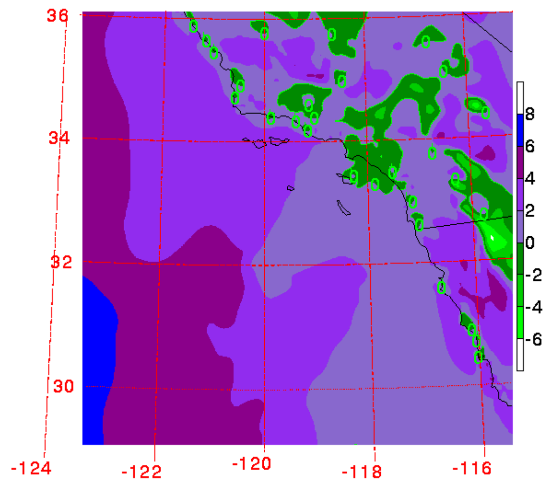

Figure 10: *As in Figure 9 except for six hour NSF T_{sfc}-T_{10m} (^{o}C) forecast.*

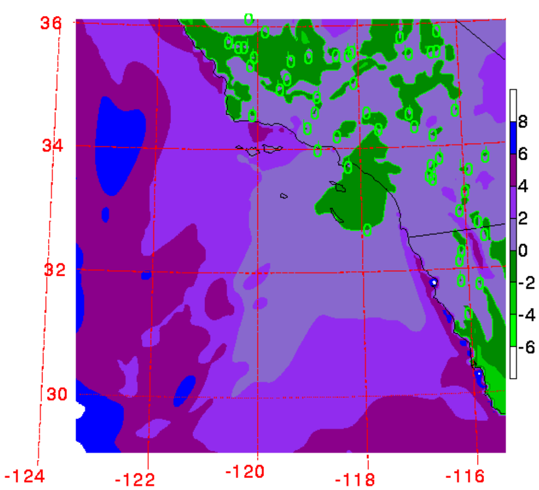

Figure 11: *Six hour CON T_{sfc}-Td_{10m} (^{o}C) forecast valid at 0600 UTC 13 FEB 2001.*

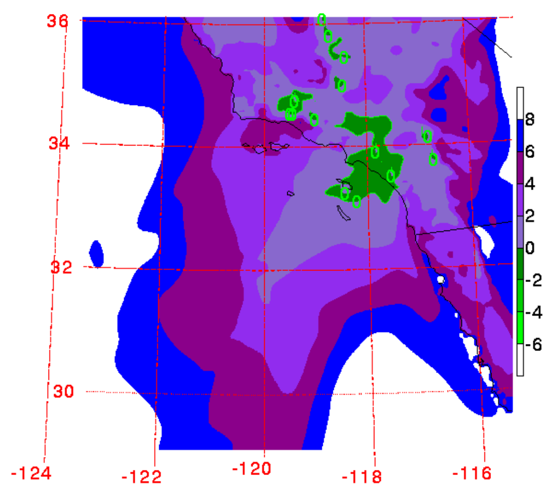

Figure 12: *As in Figure 11 except for six hour NSF T_{sfc}-Td_{10m} (^{o}C) forecast.*

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