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STUDY TITLE: Boundary Layer Study in the Western and Central Gulf of Mexico

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BACKGROUND: The vertical and horizontal variability of the atmospheric boundary layer (ABL) in the Gulf of Mexico has been an uncertainty. The depth of the ABL and its vertical stability and wind and turbulence structure can vary greatly in Outer Continental Shelf (OCS) zones due to horizontal variations in water skin temperature and the overlying air mass. The Minerals Management Service (MMS) now has available new observations of vertical profiles in the ABL for the OCS from six meteorological stations in the Gulf of Mexico. Two stations collected ABL observations for three years from May 1998 through October 2001, and four stations collected observations from September 2000 through October 2001. For the first time in the Gulf of Mexico region, the required full vertical profiles of meteorological variables can be input into transport and dispersion models.

OBJECTIVES: To characterize the ABL structure and evaluate how the ABL structure influences the transport and dispersion of pollutants in the western and central Gulf of Mexico to support techniques for evaluating the effects of oil and gas exploration, development, and production activities in the OCS on air quality over coastal areas

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DESCRIPTION: Observations of vertical profiles in the ABL were collected from six meteorological stations in the Gulf of Mexico. These stations were equipped with 915-MHz radar wind profilers (RWP), 2-KHz Radio Acoustic Sounding Systems (RASS), and surface meteorological stations. Two stations collected ABL data for three years from May 1998 through October 2001, and four stations collected data from September 2000 through October 2001. The RWPs and RASS measure winds and virtual temperatures, respectively, from near the surface to heights of a few kilometers, and the surface stations measure skin temperature as well as wind speed, wind direction, air temperature, and water vapor mixing ratio at an elevation of about 25 m on an oil platform. In addition to the new data from the vertical profilers, routine meteorological observations from buoys and from shoreline stations were included in the analysis.

The new and routine data collected were analyzed to investigate the over-water surface energy balance, the climatology of latent heat versus sensible heat fluxes, mixing depths, the frequency of occurrence of very stable conditions, and the horizontal spatial variability of wind speed and direction. Estimates of the scaling velocity and scaling temperature were studied. Three-dimensional prediction fields of surface winds, heat and momentum fluxes, and wind profiles from the National Center for Environmental Protection's Eta model were compared with the observations from the RWPs and buoys. Annual, seasonal, and diurnal variations of the ABL characteristics were determined. Using the new data as inputs, test runs with CALMET and CALPUFF were made for seven case study periods, covering a range of representative synoptic conditions and seasons, such as strong-wind January days and light-wind July days, to determine typical plume trajectories and relative dispersion rates. Arbitrary assumptions were used for hypothetical tracer releases from three oil platforms: Breton Island Platform (BIP), South Marsh Island (SMI), and Shallow Water Platform (SWP). Twenty-four-hour trajectories were calculated for releases at heights of 10 m, 75 m, and 350 m using (1) CALMET wind fields and a trajectory model (TRAJMOD) and (2) Eta Data Assimilation System (EDAS) wind fields and the HYSPLIT trajectory model. The various data sets were collected, and quality assurance/quality control procedures were applied to produce a single, user-friendly database.

SIGNIFICANT CONCLUSIONS: The fluxes and scaling parameters calculated by the COARE algorithm in the Gulf of Mexico are physically consistent with expectations and are similar in magnitude to the observations and COARE calculations for the Tropical Ocean-Global Atmosphere (TOGA) research project, which took place in the warm western Pacific Ocean near the equator. The COARE-calculated monthly average friction velocity using data from the buoys, the C-MAN sites at the shoreline, and the SMI platform near shore shows agreement among these sites well within a factor of two and often within 20%. This agreement is important because the monthly average friction velocity is the key scaling velocity for estimating transport speeds and dispersion rates.

The EDAS-simulated wind fields can be improved if EDAS ingests offshore measurements of aloft wind data; such data can be obtained from offshore RWPs.

The CALMET diagnostic wind fields and EDAS-HYSPLIT trajectories agree within 20° to 30° most of the time, although the speeds of the EDAS trajectories are larger by as much as a factor of two. The CALPUFF-simulated plumes from three oil platforms sometimes impact the shoreline or offshore islands, depending on wind direction. The simulated concentrations are higher during light winds, when dilution is less. It is fortunate that the most persistent winds, associated with onshore impact near the same location for several hours, are nearly always strong; consequently, simulated concentrations are lower. When winds are light and variable, the local centerline concentration may be higher, but the plume does not remain for long over a specific point.

The CALMET-CALPUFF estimates of over-water mixing depth were low, about 100 to 200 m, in contrast to observed mixing depths of about 600 m. This factor of three to six differences causes model overpredictions in concentrations, because the plume is constricted to the mixing layer. The underpredictions of mixing depth appear to be due to the neglect of convective mixing processes offshore, where CALMET currently assumes that the mixing depth is due solely to mechanical mixing and is therefore proportional to wind speed.

STUDY RESULTS: The EDAS-simulated wind fields and the observed RWP winds from six sites were compared. The mean wind speed (WS) bias was near zero close to the shore but increased with offshore distance, so that the EDAS mean WS exceeded the RWP mean WS by 1 to 2 m/s at 50 km offshore and by 2 to 6 m/s at 100 to 200 km offshore. Mean wind direction (WD) bias was small, a difference of about 10° to 20° (e.g., if the RWP WD was 180°, then the EDAS WD would be 160°). Standard deviations of the differences (with mean bias removed) were 1 to 2 m/s for WS and 20° to 40° for WD, in agreement with findings for other domains and models.

Calculated monthly average sensible heat fluxes in the Gulf of Mexico ranged from 5 to 30 W/m^2, typical of other over-water areas. Similarly, calculated monthly average latent heat fluxes ranged from 50 to 150 W/m^2, also typical of other over-water areas. Both the latent and sensible heat fluxes were highest in the late fall and early winter and lowest in the late spring and summer. Sensible heat flux is maximized for post-trough synoptic conditions, which are likely to be marked by above average wind speeds and by low air temperature. The latent heat flux is consistently large during the post-trough synoptic condition, due to higher wind speeds and low dew points that follow a cold front. The calculated fluxes are generally in good agreement with the monthly average Eta model latent and sensible heat fluxes.

COARE-calculated monthly average friction velocities using data from the platform sites further from shore are 30% to 40% less than at the other sites. These platforms (Vermillion offshore oil platform [VRM], BIP, Deep Water Platform [DWP], Mid-Buoy Platform [MBP], SWP, and West Delta Platform [WDP]) are typically in deeper water. A possible explanation is that the wave height and frequency are estimated from empirical relations given observations of wind speed at the platforms, whereas they are directly measured at the buoys. The monthly average Eta model friction velocity was usually within about 10% to 20% of the COARE-calculated friction velocity.

The differences between the observed water skin and air temperatures were, on average, +1 to +3°C at most sites all year. The differences were lower in late spring and greater in late fall and early winter. This persistent positive temperature difference suggests that the ABL is usually well-mixed and unstable.

STUDY PRODUCTS: MacDonald C.P., P.T. Roberts, M.R. Lilly, C.A. Knoderer, D.S. Miller, and S.R. Hanna. 2003. Boundary Layer Study in the Western and Central Gulf of Mexico: A final report by Sonoma Technology, Inc. for the U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2004-060. MMS Contract Number 1435-01-99-CT-30919. 588 pp.

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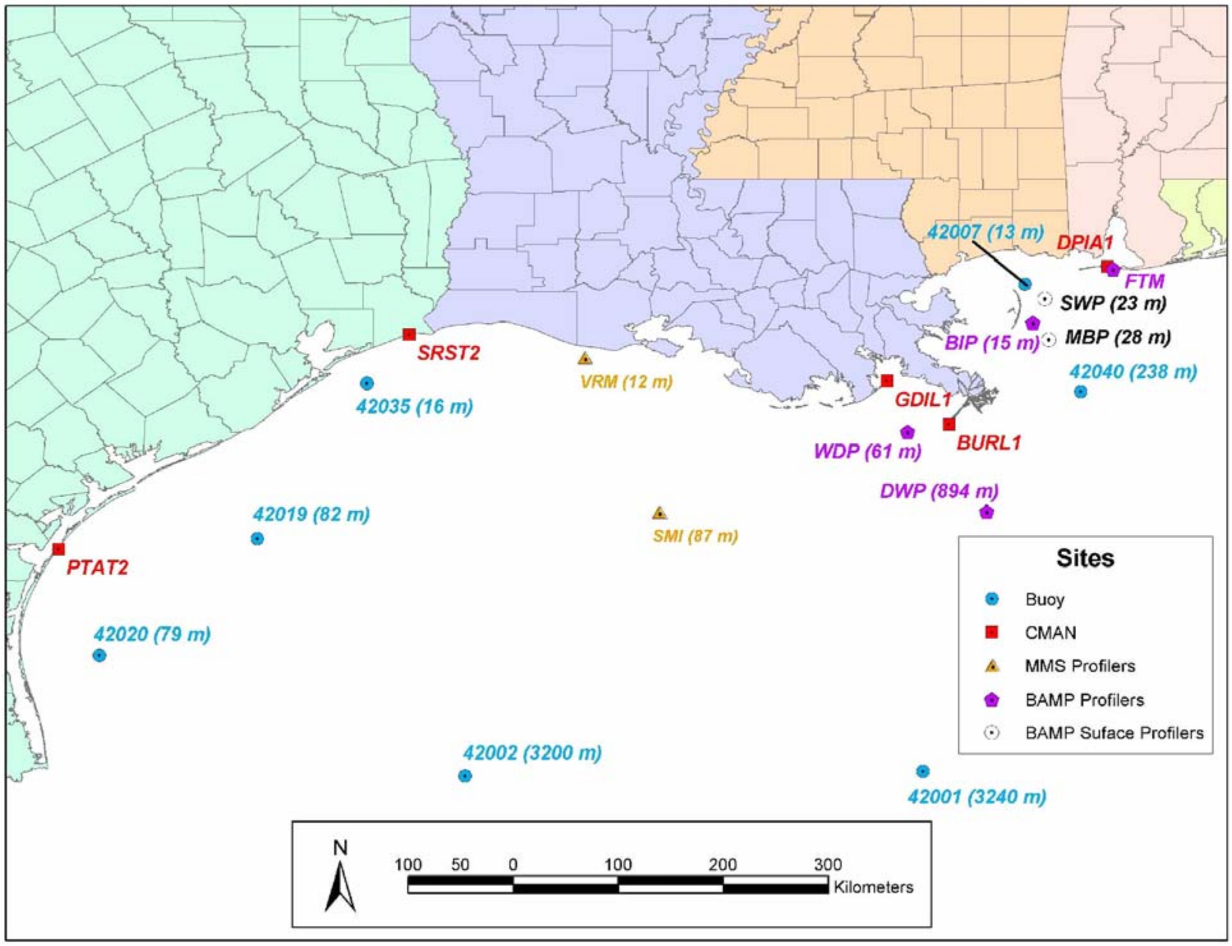

Map of the MMS study region depicting locations of C-MAN, buoy, and RWP platform monitors.