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Sea surface temperature: Modeling of the diurnal cycle of the sea surface temperature and air-sea exchange of carbon dioxide in application to remote sensing techniques

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Large diurnal variations of sea surface temperature (SST) develop in the areas of the ocean where intensive insolation coexists with low wind speed zones. Cornillon and Stramma (1985) and Gentemann et al. (2003) found that extended regions of the World Ocean are subject to large diurnal warming events. These events are transient and localized in a relatively thin near-surface layer of the ocean (Soloviev and Lukas, 2006). Under calm weather conditions, the sensitivity of the diurnal warming amplitude to the air-sea temperature difference increases significantly. This results in a rapid increase of the sea surface temperature when the air temperature is higher than the water temperature and calm weather persists. These conditions are often observed in the upwelling areas, which are generally coastal areas of the eastern boundary currents, and in the equatorial cold tongue. Large diurnal warming events reduce the CO2 saturation level, which may result in an increase of the CO2 flux from the ocean to the atmosphere (Schluessel and Soloviev, 2002; Soloviev and Schluessel, 2002). Accounting for the diurnal cycle of SST in application to remote sensing techniques is a complex problem. It poses two major challenges: 1) in order to have wide geographical coverage, the adequate hydrodynamic model should include essential physics (diurnal mixed layer and thermocline, cool skin, surface waves, and surfactants), while still being computationally effective; 2) for modeling the diurnal mixed layer and thermocline, strictly speaking, not only the direct forcing parameters (heat, radiation, and momentum flux, etc.) are desirable but also their daytime history. SST depends on a number of processes in the near-surface layer of the ocean. We consider here the diurnal warming cycle including the thermal diffusion sublayer below the sea surface (often referred to as the cool skin). For the numerical simulation of the near-surface layer of the ocean, we will use a 3D LES model implemented with the computational fluid dynamics (CFD) software Ansys Fluent. The solar radiation is included as a volume source of heat, while the sensible and latent heat and long-wave radiation are included as surface fluxes. In contrast to local (diffusion type) models, the LES model accounts for non-local transport and has a better performance in non-stationary conditions of the deepening diurnal mixed layer (Fujimura et al., 2010). The effect of surfactants on the temperature difference across the cool skin was reproduced by setting an elastic (rheological) boundary condition at the surface (Matt et al., 2011); the results of numerical simulations compare well with the available laboratory data (Soloviev et al., 2011). The 3D CFD model, however, is computationally expensive. For remote sensing applications, we propose a computationally effective 1D model of the diurnal cycle, in which the vertical temperature profile in the diurnal thermocline is approximated: with a piecewise linear profile during noon hours (Kudryavtsev and Soloviev, 1998); with an exponential vertical temperature profile in non-stationary conditions during the evening deepening of the thermocline (Bezverkhny and Soloviev, 1986). The vertical profile of temperature may contain a jump at the bottom of the mixed layer following the Barenblatt (1982) model for unsteady heat- and mass exchange in a fluid with a strong stratification. This 1D model can then be fine tuned using the 3D CFD model results. Finally, we discuss how the available satellite SST products revealing large diurnal warming events can be exploited to improve the estimation of the CO2 exchange rates between the ocean and atmosphere in the coastal and equatorial upwelling zones.