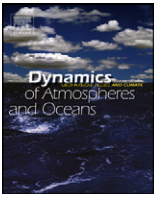
Dynamics of Atmospheres and Oceans 60 (2013) 28–45

Contents lists available at SciVerse ScienceDirect

Dynamics of Atmospheres and Oceans

journal homepage: www.elsevier.com/locate/dynatmoce



Impact of the ocean diurnal cycle on the North Atlantic mean sea surface temperatures in a regionally coupled model

Virginie Guemas[a,b,c,*], David Salas-Mélia[b], Masa Kageyama[c], Hervé Giordani[b], Aurore Voldoire[b]

[a] *Institut Català de Cienciès del Clima, Barcelona, Spain*
[b] *Centre National de Recherches Météorologiques/Groupe d'Etude de l'Atmosphère Météorologique, Météo-France, CNRS, UMR 3589, Toulouse, France*
[c] *Laboratoire des Sciences du Climat et de l'Environnement, UMR 1572, CEA-CNRS-UVSQ, Gif-sur-Yvette, France*

ARTICLE INFO

Article history:
Received 28 November 2011
Received in revised form 16 January 2013
Accepted 17 January 2013
Available online 30 January 2013

Keywords:
Mean climate
Ocean diurnal cycle
Heat entrainment
Vertical resolution
Coupling frequency

ABSTRACT

This study investigates the mechanisms by which the ocean diurnal cycle can affect the ocean mean state in the North Atlantic region. We perform two ocean-atmosphere regionally coupled simulations (20°N–80°N, 80°W–40°E) using the CNRMOM1D ocean model coupled to the ARPEGE4 atmospheric model: one with a 1 h coupling frequency (C1h) and another with a 24 h coupling frequency (C24h). The comparison between both experiments shows that accounting for the ocean diurnal cycle tends to warm up the surface ocean at high latitudes and cool it down in the subtropics during the boreal summer season (June–August). In the subtropics, the leading cause for the formation of the negative surface temperature anomalies is the fact that the nocturnal entrainment heat flux overcompensates the diurnal absorption of solar heat flux. Both in the subtropics and in the high latitudes, the surface temperature anomalies are involved in a positive feedback loop: the cold (warm) surface anomalies favour a decrease (increase) in evaporation, a decrease (increase) in tropospheric humidity, a decrease (increase) in downwelling longwave radiative flux which in turn favours the surface cooling (warming). Furthermore, the decrease in meridional sea surface temperature gradient affects the large-scale atmospheric circulation by a decrease in the zonal mean flow.

* Corresponding author at: Institut Català de Cienciès del Clima, Carrer del Doctor Trueta, 203, 08005 Barcelona, Spain.
E-mail addresses: vguemas@ic3.cat, virginie.guemas@ic3.cat (V. Guemas).

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http://dx.doi.org/10.1016/j.dynatmoce.2013.01.001

1. Introduction

1.1. The diurnal cycle in the current generation of climate models

Reducing climate projection uncertainties is of primary concern for the climatologist community. One way to reach this objective is to improve global CGCMs (Coupled General Circulation Model) by correcting their biases. To do so, research efforts can target either the improvement of existing parameterizations for subgrid scale processes or the inclusion of previously non-resolved processes. This latter option comes with the burden of an increase in CGCM computational cost. Due to the limitations in available computational resources, a crucial question is raised: which missing processes do we really have to include? The answer requires an extensive understanding of their climate impacts.

Up to now, most CGCMs have not resolved the ocean diurnal cycle since, for years, it has been considered to be negligible. However, recent satellite observations show that the ocean diurnal warming can reach 6–8 °C in the Atlantic Ocean during some days in summer (Merchant et al., 2008; Gentemann et al., 2008). Large ocean diurnal warmings can cover regions extending up to 1000 km (Gentemann et al., 2008). Could the representation of the ocean diurnal cycle significantly affect the simulated climate in CGCMs? Before describing our experimental design to address this question, we give a short introduction on the dynamics of the ocean mixed layer and on previous studies tackling this problem.

1.2. The diurnal cycle of the ocean mixed layer (inspired by Bernie et al., 2007)

The diurnal variations in mixed layer depth result from the competition between stabilizing processes such as the absorption of solar heat flux and destabilizing processes such as convective and shear driven turbulent mixing. During the night, as no solar heat flux reaches the surface, the density profile is mixed over depth and the mixed layer reaches its greatest depth just before sunrise. The sunrise causes a rapid shoaling of the mixed layer which accelerates the warming of the surface as the absorbed heat is mixed on a shallower and shallower layer. The minimum in mixed layer depth occurs at about midday and the maximum in sea surface temperature at around 3 pm. During the day, the penetration of solar heat flux also contributes to build a stable stratification below the mixed layer. As the Sun goes down, the stabilizing effect of the solar heat flux decreases and the stratification below the mixed layer is slowly eroded. As the mixed layer deepens, its heat content is mixed downward and the sea surface temperature decreases. The turbulent mixing intensifies during the night and the stratification built up during the day is more or less eroded depending on the intensity of the non solar heat flux and the wind stress.

According to Gentemann et al. (2008), most of the large diurnal warming events which peak around 5 °C and 7 °C and which are spatially coherent over large areas, occur in the extra-tropics. Using satellite data, Kawai and Wada (2007) show that the seasonally averaged ocean diurnal warming amplitude, computed from skin temperature, is about 0.75 °C year round in the Tropics and can also exceed 0.75 °C in most of the mid-latitudes in summer (see their Fig. 5). The ocean diurnal warming can induce an increase in the net surface heat flux towards the atmosphere of more than 50 W m^{-2} during the day, under clear sky and calm conditions (Fairall et al., 1996; Ward, 2006). Hence, the ocean diurnal cycle can impact the atmosphere and take part in atmosphere-ocean coupling mechanisms. For instance, the SST (sea surface temperature) diurnal variations can affect the life cycle of tropical convective clouds (Chen and Houze, 1997; Woolnough et al., 2000; Dai and Trenberth, 2004) and the atmospheric profiles of heat, moisture and cloud properties (Clayson and Chen, 2002).

1.3. Impact of the ocean diurnal cycle on the mean climate

Recent studies show that resolving the SST variability on diurnal timescales can significantly modulate the amplitude of SST variability on intraseasonal timescales (Shinoda and Hendon, 1998; Bernie et al., 2005, 2007; Shinoda, 2005; Bellanger, 2007; Guemas et al., 2011) and even on longer timescales (Bernie et al., 2008; Danabasoglu et al., 2006). It can improve the representation of ocean-atmosphere coupled modes of variability, such as the Madden–Julian Oscillation, by modifying its