Implementation of a skin SST scheme into the MetUM-GC2

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Introduction

Sea surface temperature (SST) is an important aspect of ocean-atmosphere interactions, and its diurnal cycle is an important mode of variability. In the current coupled atmosphere-ocean model, the SST that drives the atmosphere is at 0.5m depth, which sits within the warm layer.

Here, we show results from the implementation of a warm layer and cool skin scheme into the coupled atmosphere-ocean model, which calculates a skin SST that is used by the atmosphere model.

We have tested the scheme in the MetUM-GC2 (Williams et al, 2015) global model in two different configurations:

- Coupled NWP hindcasts at N216-ORCA025 resolution. Here, we present results from 31 5-day hindcasts initialised from operational NWP (atmosphere) and FOAM (ocean) analyses at 0Z on each day of December 2011.
- 10-year coupled climate run at N96-ORCA025 resolution.

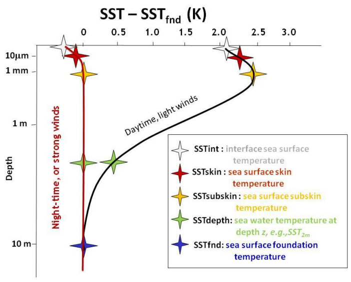


Fig 1: Diagram showing idealised night time and daytime temperature profiles, and definitions of SST at different depths. Taken from *https://www.ghrsst.org/science-and-applications/sst-definitions/*

Warm layer

The warm layer scheme is based on Zeng and Beljaars (2005) and is solved in the NEMO ocean model (Madec, 2008) every timestep to get a sub-skin SST.

$$\frac{\partial \Delta T_{wl}}{\partial t} = \frac{Q(\nu+1)}{d\rho c_p \nu} - \frac{(\nu+1)\kappa u_w^*}{d\Phi(\frac{d}{L})}\Delta T_{wl}$$

$$L = \frac{\rho c_p {u_w^*}^3}{\kappa g \alpha_w Q}$$

$$\Phi(\zeta) = \begin{cases} 1+5\zeta, & \zeta \ge 0 \\ (1-16\zeta)^{-\frac{1}{2}}, & \zeta < 0 \end{cases}$$

ΔT_{wl} = warm layer
Q = surface heat flux
d = warm layer depth
c_p = heat capacity
u_w^* = friction velocity
α_w = thermal expansion coefficient
t = time
ν = structure parameter
ρ = sea water density
κ = von Karman constant
g = gravitational acceleration

Cool skin

The cool skin scheme is based on Artale et al (2002). It is solved along with the non-solar surface heat fluxes in the surface exchange scheme in the JULES surface model (Best et al , 2011).

$$\Delta T_{cs} = \frac{Q_{ns}\lambda\nu}{k_t u_*}$$

$$\lambda = \frac{u_* k_t C}{\rho c_w h \nu \gamma}$$

$$\gamma = \begin{cases} 0.2u+0.5, & u \le 7.5 \\ 1.6u-10, & 7.5 < u < 10 \\ 6, & u \ge 10 \end{cases}$$

ΔT_{cs} = cool skin
Q_{ns} = non-solar heat flux
h = reference depth
C = seconds in a day
k_t = thermal conductivity of sea water
ν = kinematic viscosity of water
u_* = friction velocity
c_w = heat capacity of water
u = wind speed

Diurnal cycle of skin SST

In fig 2, we sort the data from the first 24 hours from each hindcast by local solar time and mean over the region covered by the SEVIRI satellite (70W-70E, 70N-70S, see fig 3) to get the diurnal cycle in this region.

The dashed red line and the solid blue line are the SSTs used as the lower boundary condition for the atmosphere without and with the skin scheme respectively. The new skin SST has a larger diurnal range, due to the action of the cool skin overnight, and a warming during the day due to the action of the warm layer.

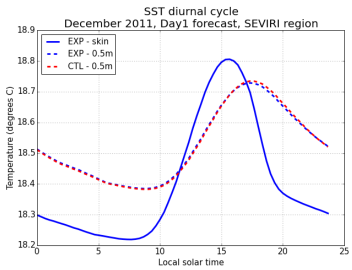


Fig 2: Diurnal cycle of skin SST (solid) and 0.5m SST (dashed) in the control without the scheme (red) and with the scheme (blue) over the SEVIRI region, averaged over day 1 from each coupled NWP hindcast in December 2011.

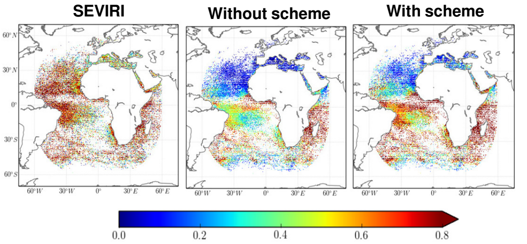


Fig 3: Average SST diurnal cycle range for December 2011 from (left) SEVIRI satellite observations, (middle) 0.5m SST without the scheme and (right) skin SST with the scheme, averaged over day 1 from each coupled NWP hindcast.

This better matches satellite observations over the Atlantic Ocean (fig 3), where the SST without the scheme tends to underestimate the diurnal range.

Fig 2 also shows the diurnal range in the 0.5m SST (dotted blue line) is slightly reduced with the scheme.

The timings of the diurnal cycle minimum and maximum have been brought forward by a couple of hours. This improves the bias on the timing of the diurnal cycle minimum, but makes the diurnal cycle maximum too early.

t_{min}

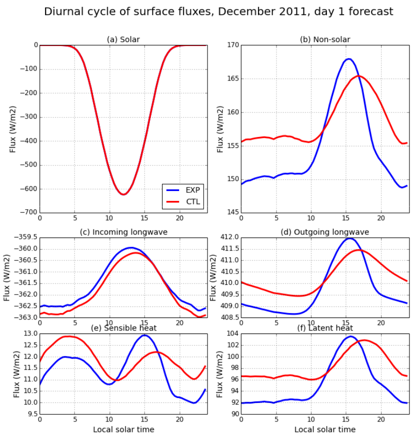
	BIAS	RMS
Without scheme	2.23	4.70
With scheme	0.69	4.23

t_{max}

	BIAS	RMS
Without scheme	0.49	3.51
With scheme	-0.76	3.49

Table 1: Bias and RMS from timing of diurnal cycle minimum (left) and maximum (right) for 0.5m SST (CTL) and skin SST (EXP) against SEVIRI satellite observations.

Diurnal cycle of surface heat fluxes



The scheme mainly affects the turbulent surface fluxes (fig 4). The sensible heat flux is reduced overnight, when the SST has cooled with the skin scheme, and increased during the day when the skin SST is warmer. The same is true for the latent heat flux.

The net effect on the non-solar fluxes (which are coupled to the ocean) is in fig 6b – a reduction of ~5W/m2 overnight and a slight increase during the day.

Fig 4: Diurnal cycle of surface heat fluxes without the scheme (red) and with the scheme (blue) over the SEVIRI region, averaged over day 1 from each coupled NWP hindcast in December 2011. In (b), non-solar surface heat flux is the sum of net longwave, sensible and latent heat fluxes.

Climate – annual mean SST

Across most of the globe, the daily mean skin SST is cooler than the 0.5m SST (mean over 10 annual means). The 0.5m SST changes slightly with the scheme (see fig 5c), with some areas showing a warming with the scheme (eg. North and equatorial Atlantic), and cooling in other regions.

Generally, the skin SST with the scheme is cooler than the 0.5m SST without the scheme run (see fig 5b) - this shows the difference in temperatures that are being used to drive processes in the atmosphere.

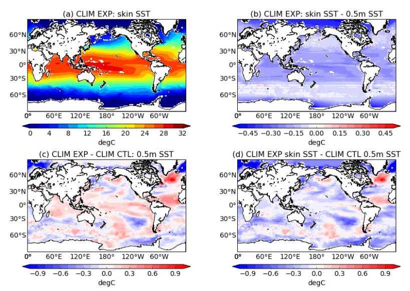


Fig 5: Annual mean SSTs (10 years): (a) skin SST with scheme, (b) difference between skin SST and 0.5m SST with the scheme, (c) difference between 0.5m SST with and without the scheme, (d) difference between the skin SST with the scheme and the 0.5m SST without the scheme.

Conclusion

- Inclusion of the scheme in coupled NWP hindcasts shows improvement in the representation of the diurnal cycle of the SST that is used by the atmosphere model when compared with SEVIRI satellite observations, with an increased diurnal cycle range. The timing of the diurnal cycle minimum and maximum are both brought forward, which improves the bias on the timing of the minimum.
- This change to the SST impacts the diurnal cycle of the surface fluxes, though we haven't managed to find sub-daily observations of sensible and latent heat fluxes to use to validate the modelled diurnal cycle of surface fluxes.
- In the model climate, the cooling of the daily minimum SST leads to a cooler daily mean skin SST compared to the daily mean 0.5m SST used by the atmosphere without the scheme.

References

- Artale, V., Iudicone, D., Santoleri, R., Rupolo, V., Marullo, S., and D'Ortenzio, F. (2002). Role of surface fluxes in ocean general circulation models using satellite sea surface temperature: Validation of and sensitivity to the forcing frequency of the Mediterranean thermohaline circulation. Journal of Geophysical Research: Oceans (1978–2012), 107(C8):29–1.
- Best, M., Pryor, M., Clark, D., Rooney, G., Essery, R., Menard, C., Edwards, J., Hendry, M., Porson, A., Gedney, N., et al. (2011). The Joint UK Land Environment Simulator (JULES), model description – part 1: energy and water fluxes. Geoscientific Model Development, 4(3):677–699.
- Madec, G. (2008). NEMO ocean engine. France, Institut Pierre-Simon Laplace (IPSL), 300pp. (Notedu Pole de Modlisation 27)
- Williams, K., Harris, C., Bodas-Salcedo, A., Camp, J., Comer, R., Copsey, D., Fereday, D., Graham,T., Hill, R., Hinton, T., et al. (2015). The met office global coupled model 2.0 (GC2) configuration. Geoscientific Model Development Discussions, 8(1):521–565.
- Zeng, X. and Beljaars, A. (2005). A prognostic scheme of sea surface skin temperature for modelling and data assimilation. Geophysical Research Letters, 32(14).

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