SST Assimilation Experiments in a 1-D Ocean Model

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Introduction

Sea surface temperature (SST) is the most important property governing the exchange of energy between atmosphere and ocean. It can be seen being determined by a balance of many processes, including air-sea exchange, ocean transport and vertical mixing. An understanding of these processes and their interactions is vital for the beneficial inclusion of global high resolution SST observations into ocean models.

Model

A one-dimensional water column model called GOMM (General Ocean Turbulence Model) was chosen for this research. This model solves one dimensional versions of the heat and momentum equations and is supplied with a suite of turbulent closure schemes. The one dimensional heat equation with its initial and flux boundary conditions is given by

\[ \frac{\partial T}{\partial t} + \nabla \cdot (c_p \nabla T) = \frac{1}{\rho_s} \frac{\partial}{\partial z} \left( \rho_w \frac{Q}{L} \right) + \frac{1}{\rho_s} \frac{\partial}{\partial z} \left( \rho_w \frac{\nu}{L} \right) \]

where \( T \) is the sea temperature, \( c_p \) the specific heat capacity, \( \rho_s \) the seawater density and \( \rho_w \) the density of water.

Data

Meteorological and sea temperature observations are obtained from the ocean surface at selected points. Work presented here is from three of these deployments. Details of locations and duration of each time series is given in the table below. The model is initialised with temperatures down the column and then forced through the surface boundary conditions by the meteorological observations. The meteorological observations are used in a state-of-the-art air-sea flux algorithm \( [1] \) to parameterise the air-sea exchange. The rest of the temperature observations are used for comparison with a small number of SST observations being used for assimilation into the model.

The daily cloud values are not known; nevertheless, they have the potential to produce large modifications to the SWR and therefore the upper ocean heat budget.

We have developed a scheme that estimates these cloud values from the SST assimilation. When the SST observations are assimilated, as described earlier, heat is supplied or extracted from the system. We determine whether these errors in the heat budget accumulated over the day could have been rectified at an improved heat flux into the ocean for that day. The associated cloud value change needed to provide this change is then calculated. This estimated cloud value becomes our best estimate for the next day.

Results

The ST assimilation is very successful at reducing the model drift. Figure 2 shows how the model drift has been eliminated because of the assimilation. The mean error (SST observed - SST modelled) has been reduced by 0.6°C, 0.8°C and 0.6°C for the three sites COARE, ARABIAN and SUBDUCTION respectively.

The feedback between the atmosphere and ocean is represented by using the modelled interfacial (skin) temperature to calculate the air sea fluxes. The improvements in the mean SST due to assimilation are, therefore, expected to improve the air-sea fluxes. This improvement is seen in Figure 3 and is particularly strong after day 260. A comparison with Figure 1b at this time shows the SST of the control to be significantly warmer than the observations. This warming bias causes the SST of the model to rise above atmospheric temperatures (not shown), thus changing the magnitude and direction of the sensible heat flux. This process diverges at day 260 in Figure 3.

Cloud Adjustment

In GOMM the SWR parameterisation is given by the Reed formula \( [2] \)

\[ I_{SWR} = 0.035 \times (1 - 3.5 \times 10^{-3} T - 0.0019 T^2) \]

where \( T \) is the clear sky SWR, \( \phi \) the daily fractional cloud cover, \( \alpha \) the noon solar elevation angle and \( \beta \) the albedo.

Figure 4 gives an indication as to how well we are able to estimate cloud cover values from the SST observations. The graph reveals day to day variations in the SWR obtained using the assimilation, whereas in the control there is none. These variations due to changing cloud amounts show some degree of correlation with those of the observed values. The assimilation however is limited by the constraints of the SWR parameterisation. The correction of SST error by adjusting the cloud value is not necessarily always physically realistic; the cloud amount is also compensating for other causes of error present in the model.

A major cause of error in the model is that created by advection. A comparison of a one dimensional heat budget modelled heat content changes, as given in Figures 5 and 6, is a good way of assessing this influence. For the Arabian Sea (Figure 5) there are occasions (e.g. days 10-15, 25-40, 40-80 and 270-280) when the 1-D budget does not have an error correction present, which isn’t true however at the subduction site (Figure 6) where the SST assimilation in the mixed layer is able to constrain accurately all temperatures in the water column.

Conclusions

The assimilation of daily SST data into the mixed layer improves both the SST and the air-sea flux estimates. Improvements to the radiative fluxes through a cloud parameter determined from SST observations have been achieved but have been hampered by other errors in the model such as those caused by advection.

References


Footnotes

* Adapted from the original text. ** Available at http://www.ponta.rs/edukacija/Aplikacije/3. The mixed layer depth is taken to be the grid depth at which the sea temperatures is 0°C below the maximum temperature. **

Typical time and depth resolution

7.5 minutes for the meteorological observations

15 minutes for the temperature observations

between 13 and 35 temperature observations in top 150 metres

Future Plans

In future experiments two SST observations, a noon and night time value each day, will be used to improve the diurnal warming of modelled SSTs. This may be achievable by adjustments to the wind fields or the SWR. It is hoped that errors associated with the observational data can be de-ducted through this process after the sensitivities of the system to the data are understood.

Figure 1. Time series comparisons of modelled and observed SST (a) a 120 day simulation in the Western Pacific at depth 0.45m (b) a 365 day simulation in the Arabian Sea at depth 0.17m and (c) a 720 day simulation in the Atlantic Ocean at a depth of 1m. The control runs have parameterised fluxes with a fixed cloud value of 0.5 and do not use SST observations.

Figure 2. Time series comparisons of the control run, the SST assimilation (without cloud adjustment) and observations at the COARE site.

Figure 3. Temperature profile at the ARABIAN site of the sum of the LWR, latent and sensible heat fluxes calculated from the control run, the assimilation (without cloud adjustment) and observations (using the air-sea flux algorithm with all observed temperatures and observed observed LWR).