The University of Reading

NATURAL ENVIRONMENT RESEARCH COUNCIL
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Assimilating Satellite SST Observations into a Diurnal Cycle

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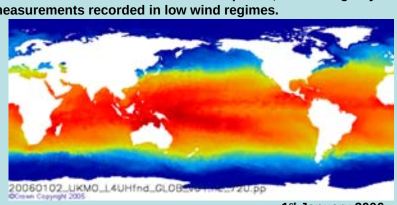
1. Introduction

The Sea Surface Temperature (SST) is one of the most important properties governing the exchange of energy between the atmosphere and ocean and as such it is of paramount importance in air-sea flux calculations. Satellites now provide accurate SST measurements over the global ocean. These can be derived from either microwave or infrared instruments. These observations can be merged together (see below) and assimilated into ocean models. However satellite derived measurements, in-situ observations, and modelled output represent temperatures at different depths in the near surface. Observations also occur at various times throughout the day. The effects of diurnal variability of SST are not usually quantified and can cause biases. In this work we develop an ocean model capable of providing diurnal warming estimates, these estimates are then improved by using a new method to assimilate satellite observations into the diurnal cycle model.

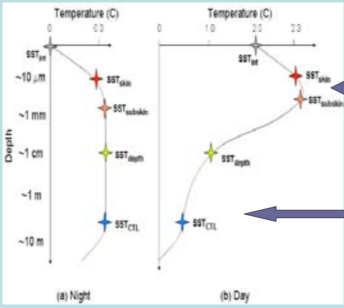
OSTIA, a UK Met. Office 1/20° daily foundation SST observational product produced by merging GHRSST (www.ghrsst-pp.org) satellite observations over a 24 hour period, discarding daytime measurements recorded in low wind regimes.



1st January 2006

2. Diurnal Variability

Intense diurnal warming of the surface of the ocean commonly occurs in low wind and clear sky conditions, when the wind-driven turbulence is insufficient to erode the near-surface stratification caused by absorption of solar radiation during the day. This buoyant highly stratified warm layer leads to an afternoon (local time) diurnal peak, after which the amplitude decays as surface cooling triggers oceanic convection and surface stress causes vertical shear, breaking down the diurnal thermocline (Price, 1986).



Satellites observe these temperatures

Ocean models resolve an SST here

3. Model

A one-dimensional mixed layer ocean model called the General Ocean Turbulence Model (GOTM) is used to estimate diurnal variability of SSTs. GOTM is publicly available at http://www.gotm.org.

Improvements:

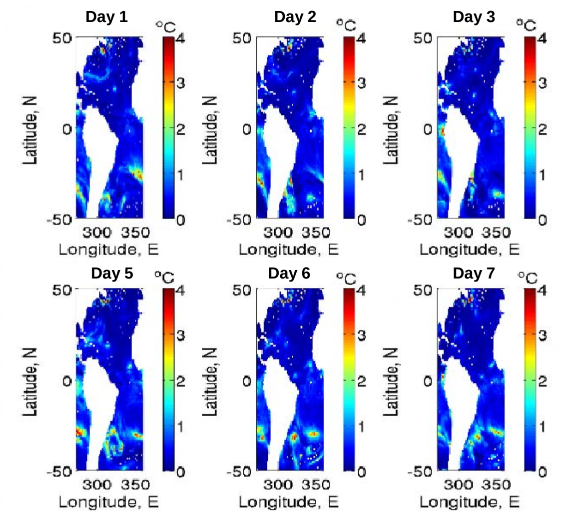
- The model is given a fine near surface vertical grid (of order centimetres) so that near surface diurnal variability can be better resolved.
- The TOGA COARE air-sea flux algorithm of Fairall et al, 2003 is implemented.
- Air-sea fluxes are calculated dynamically using surface meteorological data (ECMWF) together with the modelled SST.
- The important quantification of solar absorption in the upper ocean is improved by implementing the Ohlmann, 2000 ocean radiant heating parameterisation and using remotely sensed chlorophyll data (SeaWiFS).
- The model was tested using observations from the upper ocean mooring data archive at http://kuvasz.whoi.edu/uopdata/uopdata.html.
- 6 hourly SWR is resolved on a finer time scale to improve estimation of diurnal variability.

Experiment Set-up:

- The model is initialised with sea temperature and salinity profiles from the 1 degree UK Met. Office operational ocean model (FOAM).
- The OSTIA SST is then assimilated into the model by adjusting mixed layer temperatures.
- GOTM is forced using ECMWF 6 hourly meteorology and SWR.
- A mesh of GOTM models are run on a 1 degree latitude-longitude grid.
- By evaluating the maximum minus the minimum modelled SST at each location for each day, spatial maps of the diurnal signals can be produced (see graphs on the left).

Modelled Diurnal Warming Maps

Atlantic Ocean: 1st to 7th January 2006



A comparison is made to GHRSST L2P satellite derived SST observations from SEVIRI, AMSRE, and TMI. The results presented in the table below compare model output to 77228 observations at the observation times.

°C	BIAS	RMS ERROR
MODEL - OBS	0	0.58

4. Dynamic Observation Operator

Daytime satellite observations of the SST can be susceptible to diurnal warming signals. Current ocean models are not able to adequately represent features of diurnal variability and therefore the assimilation of daytime SST observations presents difficulties.

In the assimilation process the innovation vector *Hx-y* uses an observation operator *H* to transform model variables *x* onto an observed quantity *y*, so that a like-for-like comparison can be made. The sea temperature at the minimum modelled depth, typically 5m or deeper in an ocean model, needs to be transformed in space and time to give a temperature at the near surface, as measured by the satellite. The use of GOTM as outlined in this poster can be viewed as providing a dynamic observation operator *H*. In modelling the diurnal cycle and providing good near surface resolution we are able to quantify the transformation from foundation temperature to skin or sub-skin temperature.

5. Statement of Data Assimilation Problem

To improve the modelled estimates of diurnal variability satellite observations taken over the day can be used. The extent of diurnal variability is predominantly dependent on two key factors: sea surface wind speeds and the strength of the insolation, whose variance at a given location and time is largely determined by cloud cover. Therefore we can view the modelled SST, θ , as a function of fractional cloud cover, *n*, and wind speed forcing,

$$w = \sqrt{u^2 + v^2}$$

Parameters ε_A and ε_B are introduced

$$n = n_{obs} + \varepsilon_A$$

$$w = (1 + \varepsilon_B)\sqrt{u_{obs}^2 + v_{obs}^2}$$

These parameters remain fixed over each 24 hour time window, although the observed forcing data: n_{obs} , u_{obs} , *and* v_{obs} change every 6 hours. The SST can now be viewed as a function of the parameters $\theta = \theta(\varepsilon_A, \varepsilon_B)$

We define a cost function $J = J(\varepsilon_A, \varepsilon_B)$ as $J = \sum_{i=1}^{N} \left(\theta_i - \theta_i^{obs}\right)$

where *N* is the number of observations over the 24 hour window. The data assimilation problem can now be stated as follows.

An 'optimal' parameter pair $(\varepsilon_A^*, \varepsilon_B^*)$ *is sought such that for all feasible* $(\varepsilon_A, \varepsilon_B)$

$$\left|J(\varepsilon_A^*, \varepsilon_B^*)\right| \le \left|J(\varepsilon_A, \varepsilon_B)\right|$$

6. Results

This optimisation problem was solved with a procedure that keeps computational cost low. The assumption used is that the cost function, *J*, varies linearly within the feasible parameter range. GHRSST L2P satellite derived SST observations from SEVIRI, AMSRE, and TMI were used in the assimilation.

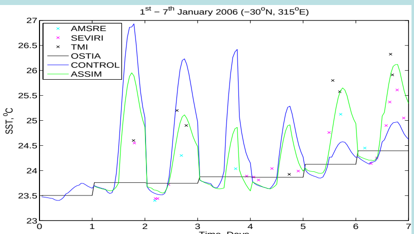
The model was run from the 1st to 7th January 2006 in an area of the South Atlantic off the coast of Brazil. This particular area experiences strong diurnal warming during this week, as can be seen in the maps above.

An example at one particular location, is shown in the graph below. Here the assimilation is seen to bring the modelled SST warming estimates closer to the observations.

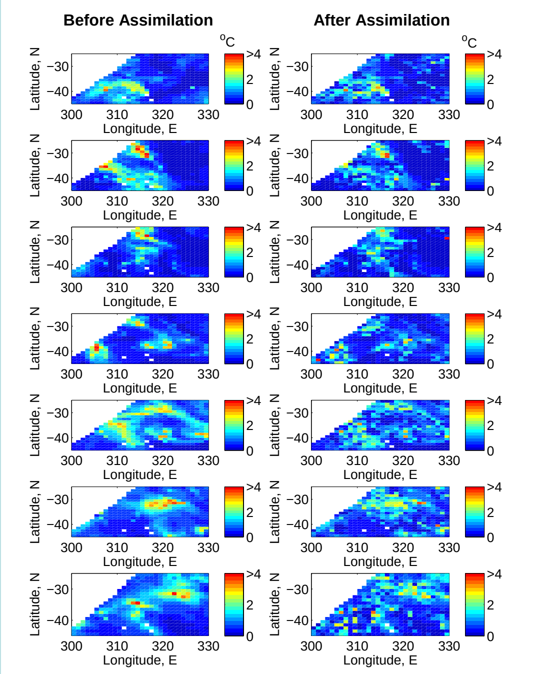
The maps to the right reveal how the assimilation has reduced some of the larger warming signals seen in the control. Areas where the assimilation has increased warming can also be seen, particularly in days 6 and 7.

The results in the table below show that the assimilation run interpolates and smoothes the observations in time to provide a better fit to the data. Improvements are made on the control run estimates and the daily mean foundation SSTs of OSTIA.

°C	BIAS	RMS ERROR
CONTROL-OBS	0.25	0.77
OSTIA-OBS	-0.17	0.69
ASSIMILATION - OBS	0.07	0.49



Modelled Diurnal Warming Maps



Spatial maps of modelled diurnal warming estimates before and after the assimilation. The graphs down the column represent successive days from the 1st to the 7th January 2006.

7. Conclusions

- Daytime satellite derived SST measurements often have a diurnal signal. This can lead to problems when producing foundation SST products and when assimilating observations into ocean models.
- A mixed layer ocean model is developed for the purposes of accurately modelling diurnal variability. The modelled output is compared to SEVIRI, AMSRE, and TMI observations and shown to have good accuracy. This model could be used as a dynamic observation operator to remove diurnal signals in observations.
- To improve modelled SST estimates over the diurnal cycle, wind speed and cloud cover values are adjusted to induce diurnal warming estimates commensurate with SST observations. This method assimilates observations into the diurnal cycle. In correcting wind speed and cloud cover values, within uncertainty bounds, it also attempts to give a better balance between thermal and dynamical fields. This assimilation scheme was successfully demonstrated by using a combination of infrared and microwave satellite SST observations in an area of the Atlantic Ocean.

8. Future Work

- Implement a more advanced data assimilation algorithm, utilizing statistical information and minimizing variance.
- Use the method to build a climatology of diurnal warming estimates in different seasons and different parts of the oceans. This will improve our understanding of the extent of diurnal variability in SSTs and the conditions under which it occurs.
- Implement the method developed in a coupled climate model used in the tropics so that the diurnal warming can be incorporated into the model and its effects analysed.

References

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