

Performance of Four Sea Surface Temperature Assimilation Schemes in the South China Sea

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Abstract

Four existing sea surface temperature (SST) assimilation schemes are evaluated in terms of their performances in assimilating the Advanced Very High Resolution Radiometer Pathfinder Best SST data in the South China Sea using the Princeton Ocean Model. Schemes 1 and 2 project SST directly to subsurface temperature according to model-based correlations between SST and subsurface temperature. The difference between these two schemes is related to the order of vertical projection and horizontal optimal interpolation (OI). In Scheme 1, the spatially non-uniform SST observations are first projected to subsurface levels, followed by horizontal OI at each level. While in Scheme 2, the remotely sensed SSTs are first optimally interpolated to all grid points at the surface, followed by projecting gridded SSTs to subsurface levels. Scheme 3 assumes that the mixed layer is well mixed and has a uniform temperature vertically. In Scheme 4, the SST is propagated to subsurface levels using a linear relationship of temperature between any two neighboring depths, which is derived by Empirical Orthogonal Function technique. Since baroclinic modes always exist in a real ocean, we allow projections of out-of-phase relationship in Scheme 4. To verify the results of the four schemes, the authors use the Conductivity-Temperature-Depth data from two cruises during the South China Sea Monsoon Experiment in April and July 1998. It was shown that all four schemes could improve the SST field by reducing about 50% of the Root Mean Square Errors (RMSEs). All but Scheme 3 can improve model thermocline structure that is too diffused otherwise, though the RMSEs increase in the thermocline, especially for Scheme 2. Scheme 3 fails in the subsurface by increasing the thermocline depth, especially when there is a cold model bias. Scheme 4 performs well in the mixed layer by correcting the bias to near zero. Due to better correlation of principal components between neighboring levels, the depth to which SST can be successfully projected downward is deeper in Scheme 4 than in the others. Moreover, with mode decomposition in Scheme 4, projecting temperature with an out-of-phase relationship becomes possible; as a result the results can more correctly reflect the baroclinic modes in the ocean.

Methodology

Ocean model: Princeton Ocean Model (POM); Average spatial resolution is about 13 km; The vertical sigma coordinate has 23 levels.

Observation data: AVHRR best SST is assimilated. To assess the results, the CTD data from two cruises during the South China Sea Monsoon Experiments in April and July of 1998 are used.

For scheme 1-2, Projecting SST is as followed:

$$C_{TT} = \frac{(\delta T \delta T^{surf})}{[(\delta T)^2 (\delta T^{surf})^2]^{1/2}}; F_{TT} = \frac{(\delta T \delta T^{surf})}{(\delta T^{surf})^2}$$

$$T_{TT}^{obs} = T + F_{TT} \delta T^{surf}$$

For scheme 4, EOF decomposition is as below:

$$T(x, z, t) = \sum_{i=1}^M \psi_i(x, z) \times \phi_i(z, t)$$

Assimilation method:OI

$$T_a = T_b + BH^T (R + HBH^T)^{-1} (T_o - T_b)$$

$$B = a \cdot e^{-\alpha_j^2 / \delta^2}; i=1, 2, \dots, N; j=1, 2, \dots, N$$

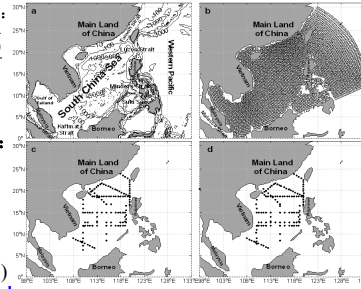


Figure 1: (a) South China Sea and its surroundings; (b) model grid; (c) cruise track in the South China Sea Monsoon Experiments in April 1998; (d) cruise track during the South China Sea Monsoon Experiments in July 1998.

Table 1. Summary of the four schemes:

Scheme	Description
Scheme 1	Horizontal OI at the surface, followed by projecting SST to subsurface levels based on correlation coefficients, and horizontal OI at the subsurface.
Scheme 2	Projecting SST subsurface levels based on correlation coefficients, and horizontal projecting SST to subsurface levels based on correlation coefficients, and horizontal OI at all levels including surface.
Scheme 3	Projecting SST to subsurface levels based on the assumption that the mixed layer has a vertically uniform temperature, and horizontal horizontal OI at all levels including surface.
Scheme 4	Horizontal OI at the surface, followed by projecting PCs to subsurface layers based on correlation coefficients, and horizontal OI in subsurface.

Result

The results all represent the large-scale SST features reasonably well, which include the bifrontal temperature structure and the SST distribution associated with currents. In the control run, the position of the front represented by the 26.5 °C contour is located too south in comparison with assimilation results and observation.

the control run has a cold bias over a large area of the model domain. By assimilating SST data using the four schemes, this bias can be effectively corrected.

Schemes 2 and 3 yield better results than Schemes 1 and 4 in terms of correcting the cold bias. Scheme 4 has the largest cold bias among the four schemes.

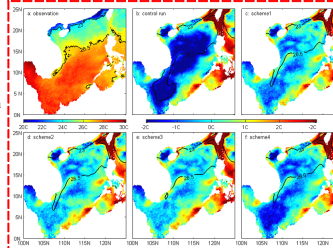


Figure 2: (a) Monthly AVHRR SST in Jan. 1998; (b-f) Surface temperature deviation between assimilation and observation in Jan. 1998 for the control run and those using the four schemes. The solid curves are the isotherms of 23°C and 26.5°C.

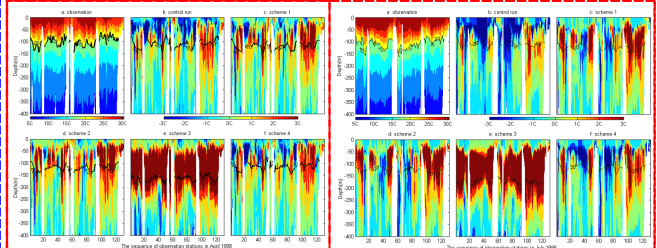


Figure 3: Vertical sections of (a) observation and (b-f) temperature bias between assimilation and observation of the control run and the four schemes in April 1998. The solid contour is the isothermal of 20°C.

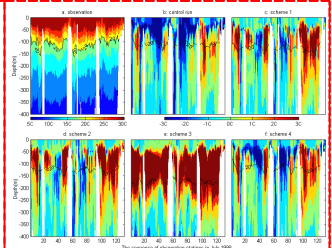


Figure 4: Same as Figure 3 except for July 1998.

- All four schemes can correct model temperature fields above 50m depth. Beneath the thermocline, however, the improvement is insignificant.
- Scheme 3 deepens the mixed layer and changes the position of the thermocline too much. As a result of this scheme, the errors increase sharply in thermocline.
- At surface, the RMSEs can be reduced by about 50% for all schemes but scheme 3, especially for Scheme 2. Below the 50-m depth, there are bigger RMSEs in Schemes 1 and 2 than in the control run till 300 m and the maximum RMSEs appear between 50 and 100 m.
- In Scheme 3, with a severely destroyed thermocline, the construction of stratification is broken down, which results in a faulty distribution. The other three schemes exhibit their ability in enhancing the stratification and improving model's thermocline.

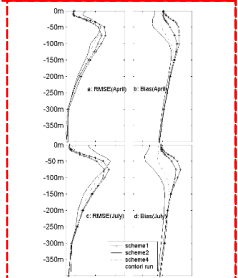


Figure 5: Vertical distributions of horizontally averaged (a) RMSEs in April 1998, (b) bias in April 1998, (c) RMSEs in July 1998, and (d) bias in July 1998.

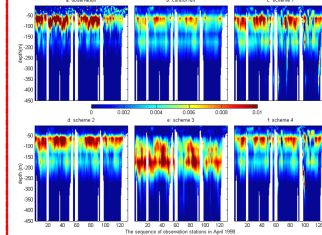


Figure 6: Brunt-Vasala (B-V) frequency along the cruise track in April 1998 from (a) observation, and from (b) the control run and (c-f) the assimilations.

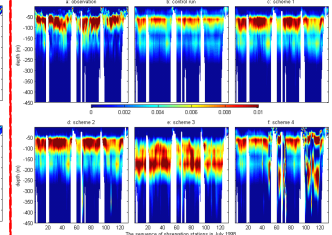


Figure 7: Same as Figure 6 except for July 1998.

Conclusion and discussion

- At surface level level, all four schemes can improve the distribution of SST by correcting the cold bias in the control run and reducing the RMSEs by about 50%. Schemes 2 and 3 are better at achieving this than the other two schemes because more innovation is obtained in the mixed layer, which makes the surface increment decay more slowly in time.
- All four schemes can correct temperature in the mixed layer to some extent. However, Scheme 3 is not recommended due to the distorted vertical distribution of temperature and stratification after the assimilation.
- All but Scheme 3 can provide a better stratification of the thermocline that is rather diffused in the control run. At the same time, however, errors increase in the thermocline, especially in Scheme 2.
- In Scheme 4, projecting SST downward between two neighboring levels by EOF technique can deepen the depth of assimilation to 100 m, so the gradients of temperature do not change sharply over 100 m relative to the control run. Scheme 4 can correct cold bias in the mixed layer more effectively than Schemes 1 and 2. Projecting out-of-phase relationship can also reduce errors and increase the vertical temperature gradient in the thermocline.

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