

SHALLOW WATER ANALYSIS AND PREDICTION SYSTEM FOR THE SOUTH CHINA SEA

Peter C. Chu

Naval Postgraduate School

Department of Oceanography

408-656-3688 (o), 408-656-3686 (f), chu@nps.navy.mil

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LONG-TERM GOALS

The main goal is to establish a nowcast system for regional seas, including the South China Sea. This system will have the capability of diagnosing three dimensional velocity, temperature, and salinity fields from satellite and sparse in-situ observations. This system will be easily embedded into the prediction system (e.g., Princeton Ocean Model). The combined nowcast/forecast system will greatly enhance existing operational capability.

OBJECTIVES

The major objectives of this project are (1) to establish an open boundary diagnosis module for the improvement of the South China Sea modeling; (2) to develop high-order difference schemes for coastal modeling; (3) to develop a data analysis and assimilation system for processing Navy's MOODS data for the coastal regions; (4) to investigate the physical causes of the recently detected South China Sea warm-core and cold-core eddies, their transient features and effects on the monsoon onset; and (5) to develop a coastal environmental assessment system including feature detection and variability detection.

APPROACH

With the ONR support, I invited several professors and scientists from external institutions to the Naval Ocean Analysis and Prediction (NOAP) Laboratory at NPS for collaborative research.

(1) We used an optimization method to establish an open boundary diagnosis module for determining open boundary conditions from interior observations. The module was tested by the Princeton Ocean Model (POM).

(2) We used the GFDL Modular Ocean Model (MOM) to study the ocean surface flux correction and ocean climate drift.

(3) We proposed ordinary and compact sixth-order difference schemes for coastal ocean models, and used the Semi-spectral Primitive Equation Model (SPEM) with a steep sea mount to test the advantage of using the sixth order schemes.

(4) We used composite analysis scheme to obtain the seasonal signals and the Empirical Orthogonal Function (EOF) analysis scheme to obtain the non-seasonal signals from the Navy's MOODS data.

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(5) We used the Princeton Ocean Model (POM) to investigate the physical causes of the recently detected South China Sea warm-core and cold-core eddies, their transient feature, and used the Community Climate Model Version 3 (CCM3) from the National Center for Atmospheric Research (NCAR) to study the effects of the South China Sea on monsoon onset.

(6) We used covariance model and parametric model to detect the Yellow Sea thermohaline feature and variability. Through this work, we establish a coastal environmental assessment system.

(7) We participated several workshop to initiate the oceanographic component of international South China Sea monsoon Experiment (SCSMEX).

WORK COMPLETED

(1) We developed a coastal environmental assessment to detect features and variabilities from the observational data; (2) We identified South China Sea warm-core and cool-core eddies, and the thermohaline variability of the South China Sea, Yellow Sea, and Sea of Japan. (3) We have developed and verified high-order difference schemes for coastal modeling. (4) We developed and tested a parametric model has been developed for obtaining physical characteristics (SST, mixed layer depth, thermocline depth, thermocline strength, ...) from vertical profiles. (5) We developed and tested an optimization method has been developed for determining the open boundary conditions of coastal models. (6) We validated the P-vector inverse method using MOM model. (7) We found incompatibility between ocean dynamics and surface forcing. (8) We validated the South China prediction system by AXBT measurements. (8) We developed and tested several high-order difference schemes. (9) We initiated the oceanographic component of the U.S. participation in the international SCSMEX.

RESULTS

(1) Temporal and spatial decorrelation scales were identified for the Yellow Sea shelf (Chu et al., 1997a). The temporal and spatial signals fluctuate according to the Asian monsoon. Variation of surface forcing from winter to summer monsoon season causes the change of the thermal structure, including the decorrelation scales. The surface horizontal decorrelation scale is around 90 km from 158 km in winter to 251 km in summer, and the seasonal variation of the surface temporal decorrelation scale is around 2.4 days from 14.7 days in winter to 12.3 days in summer. The temporal decorrelation scale increases with depth in both summer (evident) and winter (slight). The near-bottom water has the longest temporal scale in summer, which could be directly related to the existence of the Yellow Sea Cold Water (YSCW) throughout the summer in the middle of the Yellow Sea. The temporal and spatial decorrelation scales obtained in this study are useful for running optimum interpolation models and for designing an optimum observational network. The minimum sampling density required to detect thermal variability in the Yellow Sea shelf would be a 50-80 km and 4-6 day intervals per temperature measurement with the knowledge that the subsurface features will also be adequately sampled.

(2) A thermal parametric model has been developed for analyzing observed regional sea

temperature profiles based on a layered structure of temperature fields (mixed-layer, thermocline, and deep layers). It contains three major components: (a) a first-guess parametric model, (b) high-resolution profiles interpolated from observed profiles, and (c) fitting of high-resolution profiles to the parametric model (Chu et al., 1997b). The output of this parametric model is a set of major characteristics of each profile: sea surface temperature, mixed-layer depth, thermocline depth, thermocline temperature gradient, and deep layer stratification. Analyzing nearly 15,000 Yellow Sea historical (1950-1988) temperature profiles (CTD: 4,825; XBT: 3,213; bathythermograph: 6,965) from the Naval Oceanographic Office (NAVOCEANO)'s Master Oceanographic Observation Data Set by this parametric model, the Yellow Sea thermal field reveals dual structure: one layer (vertically uniform) during winter, and multi layer (mixed-layer, thermocline, sublayer) during summer. Strong seasonal variations were also found in mixed-layer depth, thermocline depth, and thermocline strength.

(3) The proposed optimization method provides a useful scheme to obtain unknown open boundary values from known interior values (Chu et al., 1997c). Different from the adjoint method, this scheme can be easily incorporated into any ocean models. Extremely small computational errors are found in applying this method to the Csanady shelf model, which proves the feasibility of using this optimization method for linear models. For time-dependent dynamical models, when the temporally varying values are given at interior observation points, the optimization method can be used for each time step to obtain the unknown open boundary values for that time step. This optimization method performs well even when random noises are added to the 'observational' points. This indicates that we can use real-time data to invert for the unknown open boundary values.

(4) The South China Sea warm-core/cool-core eddies were identified (Chu et al., 1997d,e,f) using the Navy's MOODS data as well as the National Meteorological Center (NCEP) sea surface temperature (SST) fields (1982-94). Four patterns with two out-of phase structure, monsoon and transition patterns, were found. The monsoon pattern features northeast-to-southwest oriented isotherms in the northern SCS and a dipole structure in the southern SCS. This thermal dipole is out-of-phase from winter to summer: The dipole with the Western Borneo- Palawan (WBP) warm anomaly/ Southern Vietnam coast (SVC) cool anomaly is found in winter and with the WBP cool anomaly/SVC warm anomaly in summer. The transition pattern is characterized by the westward expansion of the WBP warm (cool) anomaly and the formation of the SCS warm (cool) anomaly in the spring-to-summer (fall-to-winter) transition. During the spring-to-summer transition (March to May), the warm anomaly is formed in the northern SCS. Four patterns with two out-of-phase structures, monsoon and transition, were found in the surface wind stress curl. The monsoon features a northwest anticyclonic (cyclonic) pattern and a southeast cyclonic (anticyclonic) pattern in winter (summer). The transition pattern features a southern SCS cyclonic/anticyclonic dipole. We found associations between the cyclonic (anticyclonic) wind stress curl and the warm (cool) anomaly with a seasonal phase shift. EOF analysis was applied to the residual SST data to investigate the transient and interannual SST variabilities. EOF1 accounts for 47% of the variance and shows the northern SCS warm/cool anomaly pattern. The strongest northern SCS cool anomaly appears in November 1992 with mean monthly SST anomaly -1.2°C , and the strongest northern SCS warm anomaly shows up with mean monthly SST anomaly 1.3°C in November 1987 and February 1988. We also found two strong warm

anomaly ($\Delta T > 1\text{C}$) periods (October-November 1987 and January-February 1988), and two strong cool anomaly ($\Delta T < -1\text{C}$) periods (March 1986 and November 1992).

(5) The σ -coordinate, pressure gradient error depends on the choice of difference schemes. By choosing an optimal scheme, we may reduce the error in a great deal without increasing the horizontal resolution. Analytical analysis shows that the truncation error ratio between the fourth-order scheme and the second-order scheme is proportional to Δ^2 , and the truncation error ratio between the sixth-order scheme and the second-order scheme is proportional to Δ^4 . Here Δ is the grid spacing. We used the Semi-Spectral Primitive Equation Model (SPEM) to demonstrate the benefit of using the sixth-order scheme (Chu and Fan, 1997). A series of calculations of unforced flow in the vicinity of an isolated sea mount are performed. The results show that the sixth-order scheme has error reductions by factors of 5 comparing to the fourth-order difference scheme, and by factors of 50 comparing to the second-order difference scheme over a wide range of parameter space as well as a great parametric domain of numerical stability. Using the sixth-order scheme does not require much more CPU time. Taking SPEM3.9 as an example, the CPU time for the sixth-order scheme is almost the same as for the fourth-order scheme, and 10\% more than for the second-order scheme.

(6) Haney-type surface thermal boundary conditions connect net downward surface heat flux to air/sea temperature difference (gradient-type condition) or to climate/synoptic sea temperature difference (restoring-type condition). On the basis of cross-correlation and variance analyses on the NCEP net downward surface heat flux and air/sea temperature data during 1 October 1994 - 31 December 1995, we obtain the following results (Chu et al., 1997g): (i) The restoring-type conditions do not represent the surface thermal forcing anywhere in the world oceans. (ii) For the equatorial and subtropical oceans, the gradient-type conditions are not good approximations for the surface thermal forcing. (iii) For the middle and high latitudes away from coasts, the gradient-type conditions are good approximation for the surface thermal forcing. This is based on the high correlation between net downward heat flux and air/sea temperature difference and associating quasi-steadiness of the coupling coefficient. Furthermore, there is a better correlation when the solar short wave component is treated separately. (iv) A value of $70 \text{ Wm}^{-2}\text{K}^{-1}$ for the coupling coefficient is suggested for northern (southern) middle and high latitude zones, no matter whether the data is smoothed or un-smoothed. The suggested values are about twice as it was generally used ($10\text{-}50 \text{ Wm}^{-2}\text{K}^{-1}$). This might increase the net air-sea heat flux and shorten the relaxation time.

(7) We found an interdecadal oscillation in a wind and thermally driven OGCM (Cai and Chu, 1997a). The oscillation is tantalizing in that it occurs under a thermal damping ($26.3 \text{ Wm}^{-2}\text{K}^{-1}$). Detailed examinations involving a two-dimensional OGCM, a simple thermal “flip-Flop” model, and a three-dimensional OGCM with and without the nonlinear effect of temperature in the state equation demonstrate that the oscillation is not driven by mechanisms that exhibit in the so-called convective oscillator, or the advective overshooting oscillator. Instead, the oscillation is associated with the propagation of modeled viscous boundary waves along the weakly or non stratified boundaries. It was found that a long north-south basin extent is conducive to the generation of meridional flows normal to the weakly or non stratified boundary. These flows are crucial for the generation of persistent oscillations.

(8) We demonstrated that an incompatibility between a surface temperature climatology and a given ocean model, into which the climatology is assimilated via Haney restoration, can cause model ocean climate drift and interdecadal oscillations when the ocean is switched to a weaker restoration (Cai and Chu, 1997b). This is done in an idealized Atlantic Ocean model driven by thermal and wind forcing. Initially, the temperature climatology is forcefully assimilated into the model, and an implied heat flux is diagnosed. During this stage any compatibility is suppressed. The restoring boundary condition is then switched to a new forcing consisting of a part of the diagnosed flux and a part of the restoring forcing in such a way that at the moment of the switching the heat flux is identified to that prior to the switching. Under this new forcing condition, the incompatibility becomes manifest, causing changes in convection pattern, and producing drift and interdecadal oscillations. Under this new forcing condition, the incompatibility becomes manifest, causing changes in convection patterns, and producing drift and interdecadal oscillations.

IMPACT/APPLICATIONS

The current work leads to accurate coastal modeling.

TRANSITIONS

(1) The parametric and statistical models has been transferred to the Naval Oceanographic Office for MOODS data processing. (2) The South China Sea model results were utilized in designing the oceanographic component of the international SCSMEX. (3) The high-order difference schemes were distributed to the ocean modeling community. (4) The open boundary module was used by Dr. Oey at the Princeton University.

RELATED PROJECTS

(1) International South China Sea Monsoon Experiment (SCSMEX). The current project is the U.S. oceanographic component of SCSMEX.

(2) Ocean modeling project (Australian Department of Environment, Sport, and Territories) sponsored my collaborator, Dr. Wenju Cai.

(3) Monsoon disturbances over southeast and east Asia and adjacent seas (PI, Dr. C.-P. Chang) sponsored by the ONR Marine Meteorology Program.

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