

MIXED LAYER HEAT BUDGET OF KUROSHIO-TANGO TRIANGLE

USING SATELLITE AND SHIP OBSERVATIONS

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ABSTRACT

Using a three dimensional heat flux model, variation of heat storage in the mixed layer of a triangular oceanic area, embedded in the Kuroshio has been studied for a period of a few days in the month of November, 1983. For the estimation of vertical heat flux across the air-sea boundary both satellite (NIMBUS-7 SMMR) and ship observations are used. The advective fluxes across the lateral boundaries of the system are derived from sequential images of AVHRR. The net heat divergence of the triangular system is obtained as the residual of these computed estimates of vertical and advective fluxes. The net heat loss of the system from heterogeneous data set (ship and satellite) is found to be 4.8×10^{13} watt. Whereas using only ship observations the net heat loss is found to be 2.3×10^{13} watt. It is presumed that this observed difference in the two separate budgets is imparted through the better spatial resolution of SMMR derived wind speed and precipitable water.

1. Introduction

Upper ocean heat storage is an important parameter in controlling the climatic processes through air-sea interaction. Knowledge of its

variation in time is a prerequisite for climate studies and its prediction. The heat content variation in the upper layer of the ocean play a key role in understanding the dynamics of such processes of global interests as tropical cyclones, El-Nino southern oscillation (ENSO) and Indian ocean monsoon. The major factors affecting the heat storage of the upper ocean are the heat and momentum flux across the atmosphere-ocean boundary layer and the horizontal advection within the ocean, mainly due to the differential solar heating in low and high latitudes.

The objectives of this study are: 1). To estimate the heat budget in the Tango triangle, incorporating a number of satellite derived input variables in conjunction with classical ship observations. 2). To compare these estimate from heterogeneous data set (ship & satellite) with the estimates from ship observations alone and thereby evaluate the capability of satellite data in the upper ocean heat flux computation. The hydrographic and meteorological data from the preOMLET observations, onboard Bosei Maru II (details are given in section 2) contribute to the ship observations. Nimbus-7 SMMR derived wind speed and precipitable water and NOAA AVHRR derived Sea Surface Temperature (SST) are the satellite observations. In the later sections the net vertical heat

flux across the air-sea boundary(Q) and the net horizontal heat advection across the lateral boundary(F) obtained from ship observation alone are referred to as Q_{sp} and F_{sp} ; whereas the results combining ship and satellite observations are referred to as Q_{st} and F_{st} . The lower case 'sp' and 'st' stand for ship and satellite respectively.

2. Material and Methods:

Estimate of heat content variation in the study area is derived by formulating a closed three dimensional system, enclosing the Tango-Triangle area. The lateral boundaries of the area are defined by the two sections of the Bosei-Maruru observation program during 7 to 18 th November 1983, known as Pre-OMLET(Figure-1). Since the sea surface temperature derived from satellite data can be defined as the mixed layer of the ocean, the depth limit of any system, incorporating satellite data has to be in agreement with the mixed layer depth (MLD). The vertical extend of the system is designed from the mean MLD(90 m) computed for the study area from the temperature profiles of the Bosei Maru observation(Figure2)

Discounting the role of vertical entrainment, the local time change of heat content of this system can be given primitively as

$$\Delta H = Q + F$$

where 'Q' is the net vertical heat flux across the air-sea boundary and 'F' is the net horizontal heat advection into/out of the system due to horizontal advection within the mixed layer. The net vertical flux 'Q' is given by

$$Q = Q_I + Q_B + Q_L + Q_s \quad (2)$$

where Q_I - is net incoming radiation, Q_B the net back radiation, Q_L the latent heat flux, and Q_s is the sensible heat flux.

Heat content variation for the system (ΔH) is estimated as the residual of both vertical and horizontal fluxes Q and F. The following two sections 2.1 and 2.2 describes the methodology, adopted in computing these terms (Q and F) using both the ship and satellite observations and section 2.3 outlines the method, using only ship observations.

2.1 Net Vertical flux (Q_{st}):

As it is mentioned in the introduction, for computing Q both ship and satellite observations are used. Time series observations of meteorological parameters onboard Bosei-Maruru-II during the Pre-OMLET expedition for about 12 days, from 7 th to 18 th November, 1983, contributes to data of the ship observations and monthly mean (November, 1983) wind speed and precipitable water, derived from PARMAP tapes of NIMBUS-7 SMMR contributes to the satellite observations. The PARMAP tapes are received from National Aeronautics and Space Administration(NASA). Values of Q_I and Q_B are estimated using time series observations of meteorological data collected onboard Bosei Maru. For estimating Q_I and Q_B the formulae proposed by Kondo, 1967³ are used.

For the estimation of Q_s and Q_L , the Sea Surface Temperature (SST), Water vapor (W) and wind

velocity derived from NIMBUS - 7 SMMR data has been used in conjunction with time series meteorological data, collected onboard Bosei Maru expedition. Figure 3 and 4 represent the SMMR derived water vapor and wind speed respectively. The bulk transfer coefficients under near neutral conditions are selected as a function of wind velocity as proposed by Kondo, 1975⁴. The specific humidity of air required for the estimation of latent heat flux (Q_E) has been derived from SMMR water vapor data using the global 'water vapor-mixing ratio' model, proposed by Liu, 1986⁶.

2.2 Horizontal heat advection (F_{st})

Horizontal heat advection into/out of the system is obtained from the advective surface velocity and temperature structure across the boundaries, using the formula,

$$F = \rho C_p \int_{MLD}^{\circ} V T dz$$

where ρ is the density, C_p is the specific heat at constant pressure, V is the advective velocity across the boundary and T is water temperature. Near-surface velocities in the study area are derived from a set of AVHRR images in November 1983 and is discussed in the following section.

2.2.1) Near Surface Velocity from AVHRR Images:

The details of the AVHRR images are given in Table 1. For deriving near surface velocity field from the AVHRR images we have used two methods, one is the objective feature tracking method,

widely known as the Method of Cross Correlation (MCC) the other is by approximating the geostrophic equation for the near surface layer. Both the methods are described in sections A and B.

A) Method of Cross Correlation:

This method is fully described by Emery et al., 1986²). The method is essentially of identifying the maximum correlation between two subareas of a pair of sequential images. The first image in the sequential pair is divided into contiguous subareas called template windows. For each template, a larger search area is defined in the second image, having the template at its centre. Now, moving the template window the maximum correlation position is located. This position defines the end point of the velocity vector, which has its origin at the centre of the search window. The size of the template and search windows can be varied. In our case we have used a template size of 21x21 pixels and search window size of 41x41 pixels.

B) Geostrophic Approximation:

If variation of surface layer density depends more on variation of surface layer temperature than that of salinity, the geopotential gradient can be approximated as a function of temperature gradient. ie.

$$\frac{\Delta \phi_A - \Delta \phi_B}{L} = F \frac{(T_A - T_B)}{L}$$

where, $\Delta \phi_A$ and $\Delta \phi_B$ are the geopotential at points A and B, L is the distance between the points, and is the horizontal temperature gradient. For deriving the relation between

geopotential and surface temperature we have used the hydrographic data of Bosei Maru observation cruise. The geopotential is estimated relative to 1000 decibar.

2.3) Estimation of Q_{sp} and F_{sp} from Ship Observations Only:

Q_{sp} is computed from meteorological data along the two sections (Figure-1) using the same formulae and bulk transfer coefficients as mentioned in section-2.2. The horizontal heat advection F_{sp} is estimated by deriving the geostrophic current using inverse method by assuming temperature conservation for the layer from surface to 17°C isotherm. The geostrophic velocities across the boundaries were used to compute the heat advection in the mixed layer. The estimates of both Q_{sp} and F_{sp} are given in Figure 5.

3. Results and Discussion:

The derived estimates of both net vertical flux (Q_{st}) and net horizontal heat flux (F_{st}) fluxes for the Triangle area are given in Figure-6. From figure-6, Q_{st} for the triangle area is -7.1×10^{13} watt, showing a net heat loss from the triangle area. This value of Q_{st} is in nearly good agreement with Q_{sp} (-5.4×10^{13} watt). Kurasawa et al., 1983⁵ studied the temporal variation of vertical advective fluxes for the ocean weather station T (falling well within the study area) and obtained the mean flux for November as -184 watt/m². The mean vertical flux for the triangle area (-323 watt/m²) in the present study is comparable with this spot value derived from three hourly time series meteorolog

ical data from moored buoy at Ocean weather station T.

With the present day understanding of the physics of the boundary layer within the ocean-atmospheric interface, the estimates of vertical heat flux by bulk aerodynamic method should be bracketed for its accuracy. Since the bulk formulae are based on some parameterisation of the processes at air-sea interface, the discrepancies arising from using various transfer coefficients is a major problem, yet to be resolved. Blanc, 1985¹ used all the existing standard transfer coefficients to study the variation of bulk derived surface flux, stability, and roughness results due to the use of different transfer coefficients schemes and found that the scheme-to-scheme variation is much larger than the discrepancies arising from sparse sampling.

Liu, 1988⁷ compared the monthly means of latent heat flux derived from SMMR and ship observed sea surface temperature, wind speed and precipitable water for a period of 1980 - 1983 for each 2° lat and 2° long grid in the tropical Pacific (30° N and 30° S). He found that the SMMR latent heat flux have systematic low value. Since in the present study, we have not worked out to find such bias of ship and satellite observation (due to lack of data) from the above comparison Q_{st} is expected to have lower value than Q_{sp} . But, Q_{st} is found to be higher than Q_{sp} . At a first look this leads to conclude that there is an error term in Q_{st} . However, such a conclusion is premature and tenuous as

there are differences in study area and method used in deriving the latent heat flux. For instance, Liu found such SMMR-SHIP systematic bias for tropical area, considering the effects of humidity fluctuations on buoyancy. Where as the flux derived in our study is in the mid latitude on the assumption of near neutral stability.

Horizontal heat transport to the system is obtained from the near surface velocities across the boundaries, derived from AVHRR sequential images using equation 2. The near surface geostrophic currents across the boundaries, estimated by inverse method and the satellite derived surface velocities are found to be comparable.

Figure 6 gives the net horizontal heat advected across the lateral boundaries estimated from AVHRR derived flow field. The flux in to the system across the western section is 36.0×10^{13} watt and flux out of the system across the eastern section is 33.7×10^{13} watt. These are comparable with the corresponding fluxes obtained from hydrographic observations using inverse method (Figure 5). Pullen, 1977⁸ computed the Kuroshio heat transport south of Japan for the period from 1956 to 1964 and found that the net heat flux varies between 6×10^{14} watts and 15×10^{14} watts. Our estimates of net heat flux across the two sections don't include the entire Kuroshio transport and it appears that the Pullens value is comparable only in the order of magnitude.

The net heat loss to

the system is estimated as the residual of both Q and F. Table 2 shows the estimated values of Q_{st} , F_{st} , Q_{sp} and F_{sp} . When we consider the net heat content variation of the system both the estimates of H_{st} and H_{sp} show a net heat loss. Tally, 1983⁹ gives the annual mean net surface heating for the Pacific ocean. The region in the Kuroshio gyre is having a loss term with the order of 30 Wm^{-2} . This climatological annual mean is much less than our mean estimate (-384 Wm^{-2}) for the Triangle area. This difference is due to the smoothing effect of seasonal biases in the annual mean. Both the estimates of F_{sp} and F_{st} from Table-2 illustrate that Kuroshio carry heat from the lower latitudes and dump in the system in the course of its flow through this region and thus compensate for much of the surface layer heat loss during this period.

However this heat gain from horizontal heat transport is not sufficient to compensate for the vertical heat loss in the system. Both the estimates of H_{st} and H_{sp} support this fact. This large amount of heat loss, occurring at the cost of heat content in the surface layer, eventually cause for a drop in sea surface temperature during this period. To support this possibility we don't have any time series observation of SST in this region. However the consistency of these two separate estimates of H_{st} and H_{sp} stress this possibility of drop in SST, within the range of accuracy expecting from bulk method and satellite derived near surface flow field.

5. Summary and conclusions:

Mixed layer heat content variation in the Tango triangle system for a period of a few days in the month of November, 1983 has been studied using a combination of satellite and ship observations. Considering the significance of Kuroshio heat transport a three dimensional system is designed to study the heat budget. Two separate estimates of heat budget are obtained. One is using only ship observation and the other is combining ship and satellite observations. For computing vertical heat flux in both the estimates, we have used bulk method. The net horizontal heat advection (F_{st}) is obtained from the near surface velocity field derived from AVHRR SST using the method MCC and geostrophic approximation. Where as F_{sp} is obtained from geostrophic current across the two hydrographic sections derived by inverse method. Both the estimates show that the system is having loss of heat during the period of observation.

Net vertical heat flux (Q_{sp}) using ship observation alone is found to be underestimated compared to Q_{st} , the corresponding estimate using heterogeneous data set from ship and satellite. It is presumed that the observed difference in Q_{sp} and Q_{st} is imparted through the better spatial resolution of SMMR derived wind speed and water vapor. To compensate for much of the observed vertical heat loss (both of the estimates) the horizontal heat transport from lower latitudes is found to be significant. However the net heat content variation of the system is a loss of heat from system to atmosphere.

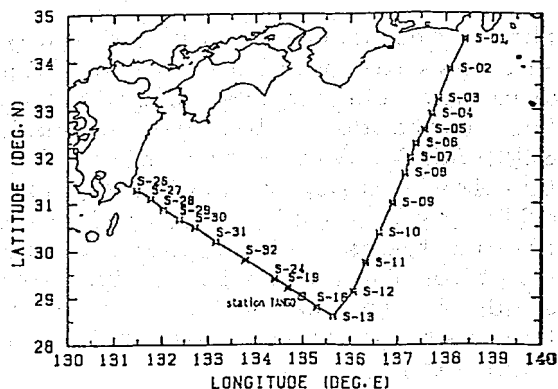


Fig-1. Tango Triangle System.

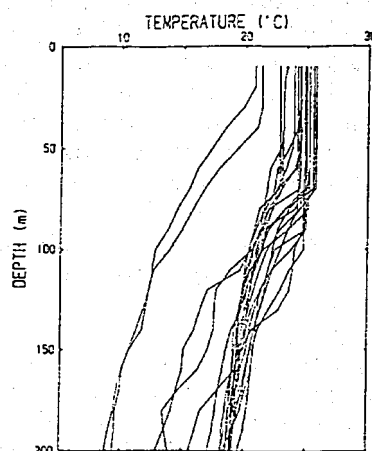


Fig-2. Composite plot of temperature profiles

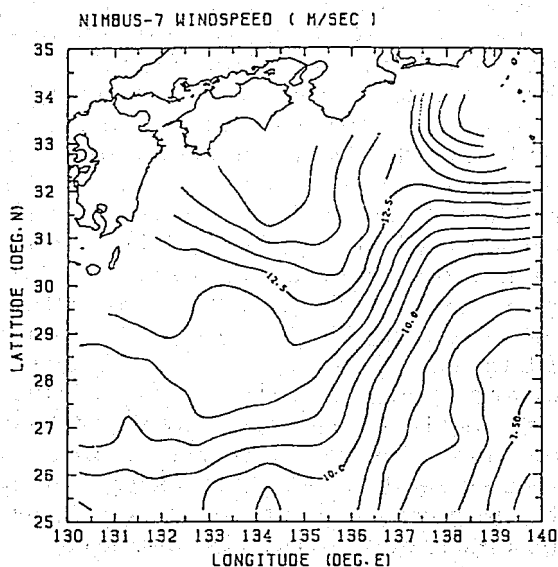


Fig-3. Horizontal distribution of SMMR wind speed.

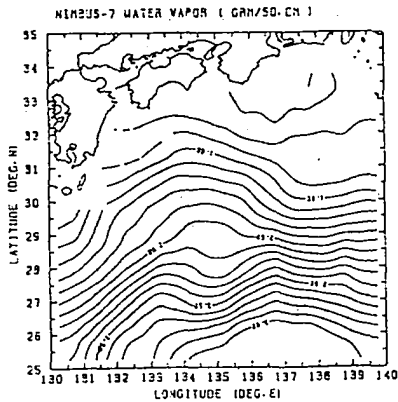


Fig-4. Horizontal distribution of SMMR water vapor.

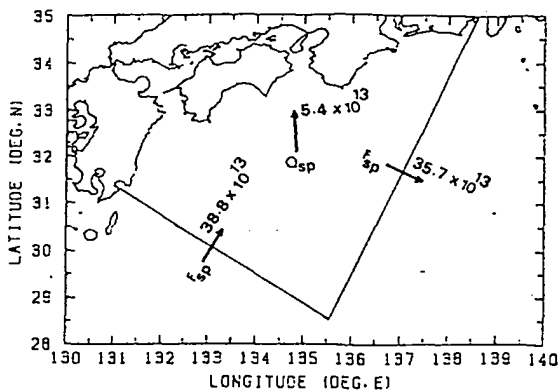


Fig-5. Estimates of heat budget from ship observations alone.

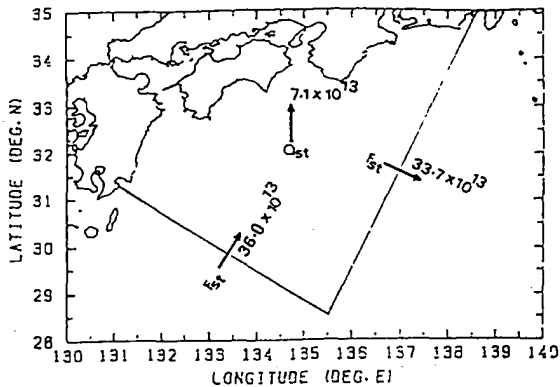


Fig-6. Estimates of heat budget from ship and satellite observations.

E_{sp}	Q_{sp}	ΔH_{sp}	F_{st}	Q_{st}	ΔH_{st}
3.1×10^{13} watt	-5.4×10^{13} watt	-2.3×10^{13} watt	2.3×10^{13} watt	-7.1×10^{13} watt	-4.8×10^{13} watt

Table - 2

Acknowledgment

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