SURFACE WIND DIVERGENCE, CONVECTIVE TRANSPORT, AND HYDROLOGIC FORCING ON THE OCEAN

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1. Introduction

The tack of measurements over ocean has hampered the understanding of the hydrological balance and its annual and interannual variabilities. Ground-based measurements of precipitation (P) are extremely spotty and quite unreliable due to platform interference and there is practically no direct measurement of evaporation (E). Evaporation estimated from the bulk formula is limited to the distributions of volunteer ships. There is some degree of success in retrieving both P and E from spacebased observations recently, but further improvement and validation arc still needed [Liu, 1993]. In the past, the large scale surface water flux (F=E-P) was derived by using the budget method based on the conservation principal in which F is equated to horizontal divergence of the integrated water vapor transport assuming that the change of storage is negligible. The computation of integrated water vapor transport requires measurements of the vertical profile of wind vector and humidity in the atmosphere which, traditionally, come from serological (rawindsonde) data [Baumgartner and Reichel, 1975; Bryan and Oort, 1984]. Over oecan, even rawindsonde data arc sparse and the uniformly gridded outputs from numerical weather prediction (NWP) model have been used, with insufficient accuracy and resolution. Since most of the water vapor resides near the surface, the accuracy of lower level winds is expected to outweigh upper level winds in importance. Spaceborne scatterometers which provide frequent observations of surface wind vectors at high spatial resolution (25-50 km) may contribute to the estimation of F [Liu et al., 19931. The impact of adding scatterometer winds to NWP data in the estimation of F is studied in this report. First, the impact is examined over the period and the area of the TOGA-COARE (Tropical Ocean and Global Atmosphere-Coupled Ocean Atmosphere Response Experiment) which was conducted in the highly convective area over the warm pool in the western Pacific. hen, the extension of the instantaneous impact to monthly averages over the global ocean is explored.

2. HYDROLOGIC BALANCE

Integration of the equation for conservation of atmospheric water vapor in the vertical gives

$$\frac{\partial W}{\partial t} + \nabla\cdot\Theta = E - P \qquad (1)$$

where,

$$\Theta = \frac{1}{g}\int_0^{p_s} q\, u\, dp \qquad (2)$$

is the integrated water transport and

$$W = \frac{1}{g}\int_0^{p_s} q\, dp \qquad (3)$$

is the precipitable water. In these equations, g is the acceleration due to gravity, p is the pressure, ps is the pressure at the surface, q and u are the specific humidity and horizontal wind vector at a certain level.

The scatterometers are designed to provide superior surface level wind observations over ocean. The influence of surface level winds will be felt throughout the atmospheric column because of mass conservation. Eq. (1) can be expressed as

$$E - P = \frac{1}{g}\int_0^{p_0} Q_2\, dp \qquad (4)$$

Since $\nabla.\mathbf{u}q = u\nabla q + q\nabla.\mathbf{u}$, and $\nabla.\mathbf{u} = \partial\omega/\partial p$, the following approximation on the moisture sink, Q2, has been made by Yanai et al.[1973] and others

$$Q_2 \cong - \left(\frac{\partial q}{\partial t} + \mathbf{u}.\nabla q + \omega \frac{\partial q}{\partial p} \right) \qquad (5)$$

where ω is the vertical velocity in pressure coordinate. The conservation equation in the form of (5) is particularly useful in convective regions where vertical advection (the third term on the right), dominates over the horizontal advection (second term) and the change of storage (first term). The computation of ω at a certain level depends on the horizontal wind velocities at that level and all level below;

$$\omega(p) = - \int_{p_s}^{p} \nabla.\mathbf{u}\, dp$$

T?re errors in the computation of wind divergence accumulate and the accuracy of surface wind divergence influences ω at higher levels. Since the estimations of ω deteriorate with height, the errors are usually reduced with the constraints of mass balance as proposed by O'Brien [1970] and others.

3. DATA

The scatterometer on ERS-1 sends microwave pulses to the ocean surface and measures the, backscatter power. Wind vectors at 10 m were retrieved from the normalized backscatter power with an empirical model function by Freilich and Dunbar [1993]. The wind vectors have 50 km spatial resolution, but arc sampled every 25 km. The data were interpolated onto a twice daily, 1° longitude and 1° latitude grid by Tang and Liu [1995]using a successive correction method. At a particular time, an ECMWF field was used as a initial guess and ERS 1 data within a time of influence (1.5 day) were used to correct for wind vectors at grid points. The contribution of an ERS - 1 observation to the correction was weighted by its distance in space and time from the grid point.

The European Center for Medium Range Weather Forecasts (ECMWF), has created and maintains an archive of Level III atmospheric data computed within their data assimilation scheme, to support projects of the World Climate Research Program. The ECMWF/TOGA Basic Level 111 data of this archive were used in this study. They were uninitialized analysis values interpolated to a 2.5" latitude by 2.5° longitude grid, twice daily at O and 12 UTC. Geopotential height, horizonal wind components, temperature, and relati ve humidity at 10 levels were used in this study. Their values were interpolated bilinearly onto a 10 grid to match the wind field.

Maps of rain rate during TOGA COARE were estimated from cloud-top temperatures, using an algorithm by Janowiak and Arkin [1991). The cloud top temperatures are derived from the composite infrared images of the Japanese Geostationary Meterological Satellite., calibrated and regridded by Flament and Bernstein [1993].

4. RESULTS

On January 17 and 23, the scatterometer ground tracks passed through the TOGA COARE area near 12 UTC. The distribution of surface wind divergence in the vicinity of TOGA COARE area computed from scatterometers winds differs significantly from those derived from ECMWF and from the COARE sounding arrays. The scatterometer winds also have strong impact on the ω profile computed from ECMWF data. As examples, the hydrologic forcing was computed by various approximations and compared with the. rain maps at 12 UTC in Figs. 1 and 2. On January 17, the rain map shows maxima lying in a northwest to southeast axis (Fig. Id), but the hydrologic forcing computed using ECMWF data alone (Fig. 1a) shows only a single maximum lying on the equator with no northwest to southeast trend. With the addition of scatterometer winds, the pattern of the computed hydrologic forcing (Fig. lb) becomes much closer to the rain maps; maxima appear along the northwest to southeast axis with a slight northeastward extension at 154°E. The ω profile adjustment does not significantly change the pattern but increases the magnitude of the hydrologic forcing (Fig. 1c). On January 23, the GMS rain map shows rainfall decreases from north to south and rainfall over 1 mm /hr appears largely north of the equator with a maximum at 155°E and 4"N (Fig. 2d). The hydrologic forcing, computed from ECMWF data alone. shows rainfall decreases from west to east and over 1 mm/ hr rainfall appears only near 150°E north of the equator. The addition of scatterometer winds again beings the patterns of hydrologic forcing closer to the rain map. The addition of the ω profile adjustment (Fig. 2c) again increases the intensity with only a slight change in pattern. Since we arc not confident in the magnitude of rain rates computed from GMS data and we do not have accurate evaporation measurement at such time scales, wc cannot draw any conclusion on the magnitude of the hydrologic forcing wc computed.

The monthly-mean distributions of hydrologic forcing over global tropical oceans for January 1993 are shown in Fig. 3 as an example. Adding the scatterometer winds does not change the general pattern very much. The largest differences lie afong the equator and over the warm pool.

6. CONCLUSION

The lack of in situ data coincident with scatterometer measurements and with sufficient resolution, even during an intensive experiment such as TOGA COARE, has frustrated our validation effort. During TOGA COARE, the addition of scatterometer winds changes significantly the surface divergence field and the vertical velocity profiles, and brings the pattern of hydrologic forcing estimated from ECMWF data closer to the rain map derived from geostationary satellite observations. The impact on global monthly-mean hydrologic forcing is less obvious, probably because of the poor coverage of the ERS- 1 scatterometer. Scatterometer winds have better spatial resolution and they will resolve small and mesoscale features within the ground swath better than ECMWF data. *However, the* scatterometer on ERS-1, whose data arc used in this study, scans only on one side of the spacecraft; it has narrow swaths with large gaps between them. The NASA scatterometer (NSCAT) which is to be launched in August 1996 will scan on both sides of the spacecraft and will have twice the coverage of the HIM-1 scatterometer; it has the potential of providing more significant improvement in the estimates of hydrologic balance over ocean

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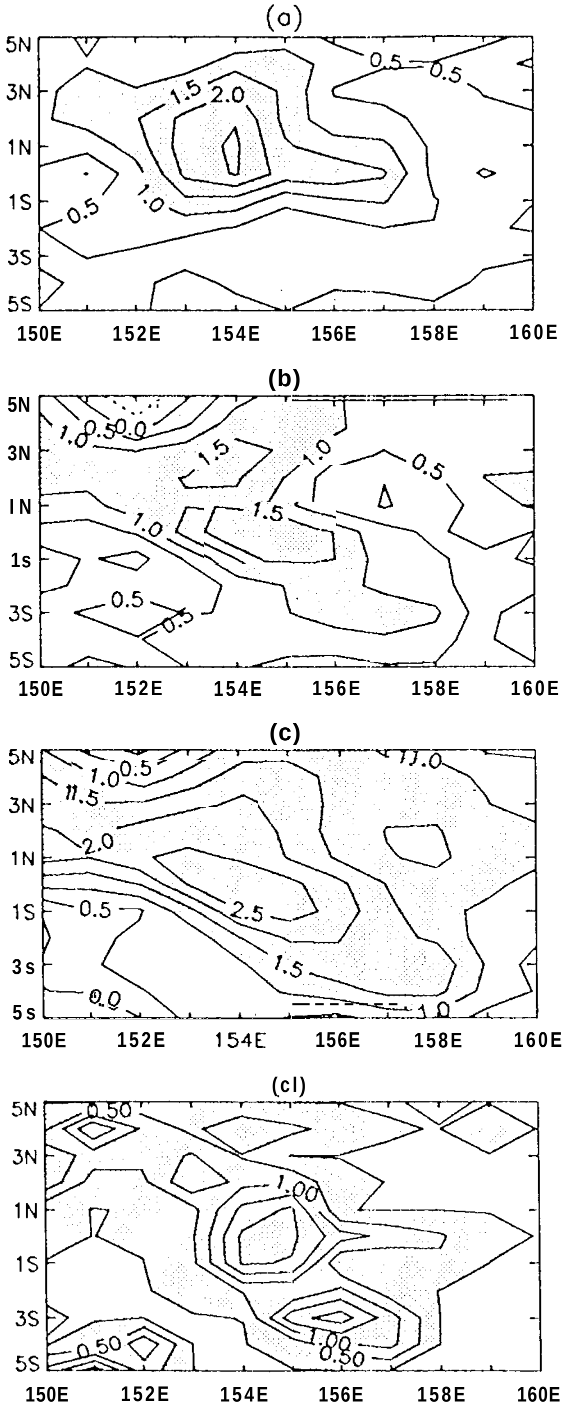

Fig.1 (a) hydrologic forcing computed from ECMWF data (Eq. 4); (b) same os (o) but with the surface level winds replaced by ERS-1 scatterometer winds; (c) some as (b) but with the adjustment of w profile; (d) rein rote derived from GMS image, for 17 January 1993. The unit is mm/hr ond the contour interval is in 0.5 mm/hr.

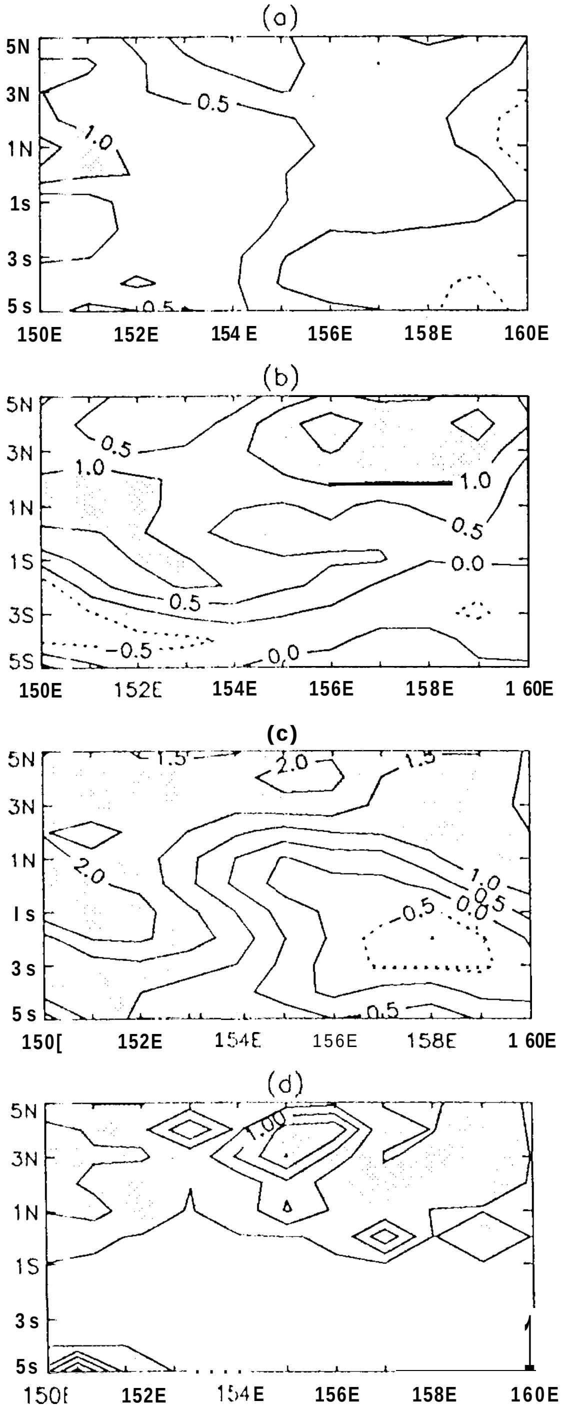

Fig.2 Same os Fig. 1 except for 23 January 1993

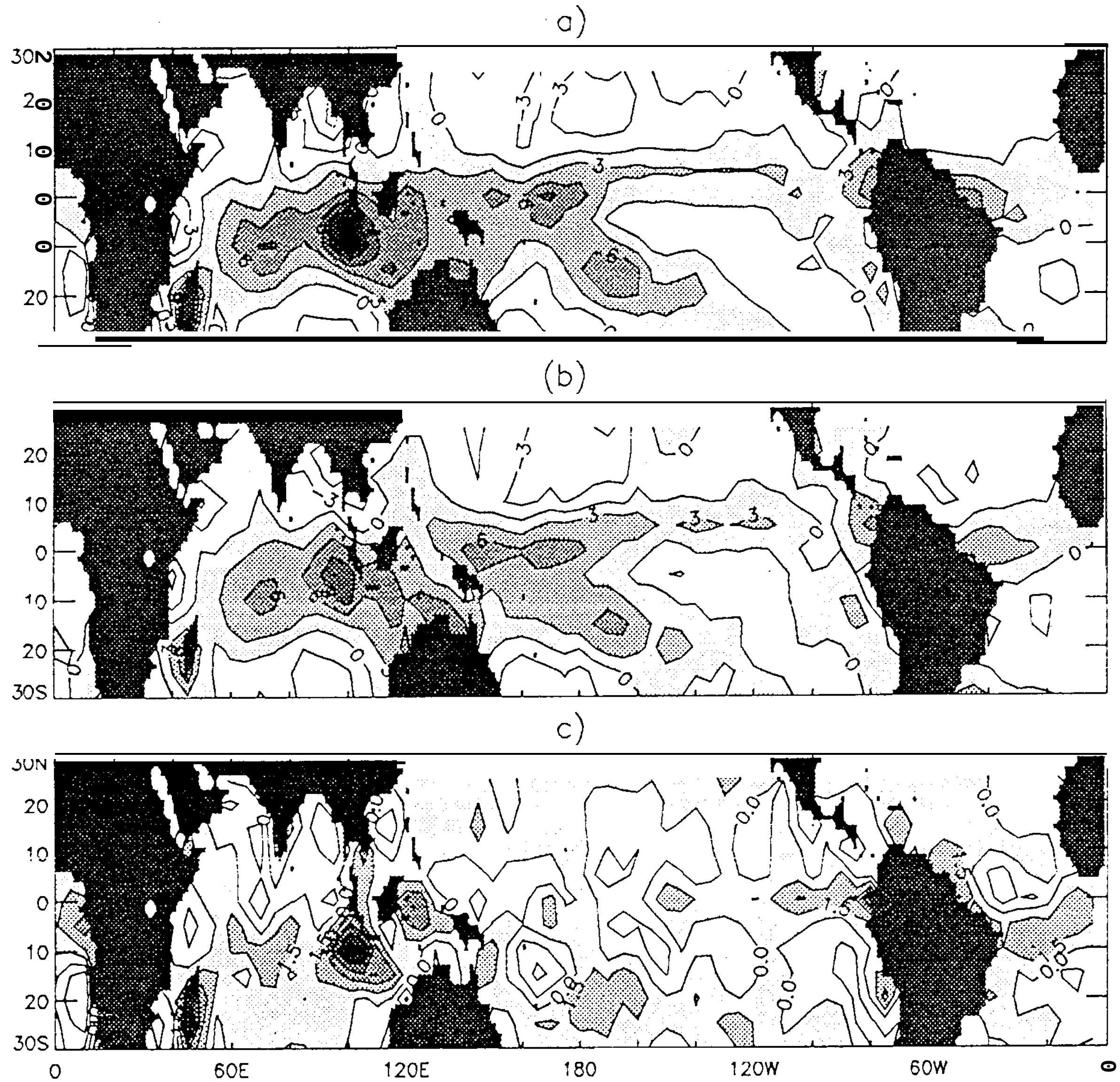

Fig. 3 (a) January 1993 mean hydrologic forcing computed from ECMWF data; (b) same as (a) but with surface level winds replaced by ERS−1 scatterometer winds, and (c) the difference between (a) and (b). The unit is mm/day. The contour interval is 3 mm/day in (a) and (b), and 1.5 mm/day in (c).