CO2 EXCHANGE COEFFICIENT IN THE WORLD OCEAN USING SATELLITE DATA

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ABSTRACT

CO2 transfer velocity is one of the key parameters for CO2 flux estimation at air − sea interface. However, current studies show that significant inconsistency still exists in its estimation when using different models and remotely sensed data sets, which acts as one of the main uncertainties involved in the computation of CO2 exchange coefficient between air − sea interface.

In this study, wind data collected from SSM/I and scatterometer onboard ERS−1, in conjunction with operational NOAA/AVHRR, are applied to different models for calculating CO2 exchange coefficient in the world ocean. Their interrelationship and discrepancies inherent with different models and satellite data are analyzed. Finally, the seasonal and inter−annual variation of CO2 exchanges coefficient for different ocean basins are presented and discussed.

INTRODUCTION

The earth's thermal regime is believed to be largely dependent on concentration of greenhouse gases in the atmosphere, the concentration of which has been steadily increasing for the past one hundred year. The possible climate change caused by this effect is the main research subject for many scientists. The ocean plays an important role in adjusting CO2 concentration .In the atmosphere, not only due to that it contains more than 50 times carbon than the atmosphere, but also its function as a buffer limiting the concentration of CO2 in atmosphere is less than the rate of carbon release, some released carbon dioxide must be absorbed by either the terrestrial biosphere or the ocean absorbed by either the terrestrial biosphere or the ocean (IPCC, 1990). As a result, the exchange of CO2 at air−sea interface is of great concern for human being.

The variation of CO2 concentration in ocean is controlled by three different processes. i.e. physical, biological and chemical processes. All their Processes are not well understood so far. In this research, an effort is made in evaluation of the air–ocean CO2 exchange field, especially in estimating gas exchange coefficient by using satellite data. CO2 exchange coefficient between ocean and atmosphere is primarily under the control of assorted physical processes as well as chemical processes. Physical influences generally include wind stress, waves, bubbles and turbulence.

The results derived from different satellite data sets and calculation approaches, including one proposed by our investigations, are presented.

METHOD

Liss and Merlivart(1986) proposed relationship between gas transfer velocity, K and wind speed based on tracer gas exchange experiment, wind–tank data and field data held on in lake. The transfer velocity has been adjusted to SC=600, corresponding to CO2 gas at 20 degree Celsius. Liss and Merlivart relation consists of three liner segments, related to smooth surface, rough surface and breaking wave regimes.

$K=0.17U_{10}$ for $0\square\ U_{10}\square 3.6$ m/s
$K=2.85U_{10}-9.65$ for$3.6<U_{10}\square 13$m/s
$K=5.9U_{10}-49.3$ for $13<U_{10}$ (1)

With is wind speed at 10ms above sea suface. Gas transfer velocity K is in cm/hr. Generally,

gas exchange coefficient E used in CO2 gas flux estimation, is obtained by E=KL. After considering temperature and salinity influence, we can rewrite the exchange coefficient E as follows.

$$E=0.0876*K*L(T)(SC\ (T)/660)^{-n} \quad (2)$$

When $n=2/3$ for $U_{10}\square 3.6$m/s and $n=1/2$ for $U_{10}>3.6$m/s.E is in mole $m^{-2}year^{-1}$ $uatm^{-1}$

The water temperature T is in degree Celsius. L is CO2 gas solubility with unit of mole/liter, or mole/kilogram per atmosphere. Weiss (1974,1980) proposed an empirical formula to estimate CO2 gas solubility L on the basis of data fitting between the solubility L on the basic of data fitting between the solubility, temperature and salinity,

$$LnL=A1+A2\ (100/Tabs)+A3\ (Tabs/100)+S\ [B1+B2\ (Tabs/100)+B3\ (Tabs/100)^2] \quad (3)$$

Where Tabs is the absolute temperature in K and S is solubility with unit of psu

Tans Model(1990)

Tans et al (1990) provided a relation related to gas exchange coefficient and wind speed, assuming that gas exchange takes place only with wind speed greater than 3m/s,

$E\ (\text{mole m}^{-2}\text{year}^{-1}\ \text{uatm}^{-1}) = 0.016(U_{10} - 3.0)$
When $U_{10} > 3.0\text{m/s}$
$E\ (\text{mole m}^{-2}\text{year}^{-1}\ \text{uatm}^{-1}) = 0.0$
When $U_{10} < 3.0\text{m/s}$
(4)

Where U_{10} is the monthly climatological wind speed of long term wind speed at 10 meters height over the ocean surface. Temperature effect has not been taken into consideration based on that CO2 gas solubility and Schmidt number have inversely temperature effect.

Whitecap Model

The whitecap model, proposed firstly by Monahan and spillane(1984), is applied as below,

$$KL = Km(1 - W) + KeW \tag{5}$$

Where km is the transfer velocity referring to no whitecap area and Ke is the transfer velocity referring to the sea surface of turbulent whitecap. W is the fraction of sea surface covered by whitecaps due to wave breaking. Km and Ke are estimated from the radon data taken during GEOSEC and TTO cruises as the value of 9.85 cm/hr and 475.07 cm/hr, respectively. W can be calculated according to sugimori & Zhao(1995),

$W = 0.066U^{*3}$
With $U^{*3} = 0.0010U10^2 + 0.0454\ U_{10}^2 - 0.013$ (6)

Carbon dioxide gas transfer velocity can estimated from the dependence of gas transfer velocity on Schmidt number is defined as,

$$Sc = \nu / D \tag{7}$$

Where ν is kinematics viscosity of fluid and D is the coefficient of molecular diffusivity of the gas of interest. Based on the analogy between momentum and mass transfer, it has been shown that the gas transfer is related to friction velocity (U^*) and similarly is also proportional to the ratio of the transfer coefficient for momentum (kinematics viscosity, ν) and the mass (molecular diffusivity, D). Wind tunnel experiment shows K is proportional to $Sc^{-3/2}$ at low wind speed, and to $Sc^{-1/2}$ at higher wind speed (Jahne et al ,1987).This relationship provides an approach to reduce the gas transfer velocities from one gas to another. As a result, CO2 gas transfer is

$$Kco2=Kradon(Scco2/Scradon)^{-n} \quad (8)$$

Where n=2/3 for U <3.6 m/s and n= 1/2 for U >3.6 m/s. Schmidt number for CO2 and radon gas in seawater under the condition of S =35 psu can be estimated from temperature (Wanninkhof,1992) as below,

$$Scradon =3412.8-224.30*T+67954*T^{2}-8.3*T^{3} \quad (9)$$

$$Scco2 =2073.1-125.62*T+3.6276*T^{2}+4.3219*10^{-2}*T^{3} \quad (10)$$

Finally,CO2 gas exchange coefficient K can calculated using transfer velocity Kco2 multiplied by CO2 gas solubility, which can be estimated from equation(3).

DATA

The Advanced very high resolution radiometer(AVHRR),boarded on NOAA series operation satellite, provides the global sea surface temperature. Although AVHRR SST will have bias ,the Multi-channel Sea surface temperature (MCSST) or Cross-Products SST(CPSST) can give an accuracy of 0.5C (McClain et al 1985). On the other hand, two sets of the space-based global wind fields are available for this investigation The first are available for this investigation. The first is obtained from Special Sensor Microwave Image (SSM/I) board operational satellites of the Defense Meteorological Space Program(DMSP) since 1987.

SSM/I sensor is a microwave radiometer and can measure the ocean surface parameters

such as wind speed water vapor, rain data and possible wind direction due to the variation of microwave emission based on the surface roughness (Wentz,1992).The wind speed derived by Wentz algorithm (Wentz 1992) or the environmental Research Technology Inc(ERT) algorithm has attained an accuracy of less than 2 m/s (Goodberlet and Awift 1992).The other one is available from the Active Microwave Instrument (AMI) board on the European Remote Sensing Satellite (ERS-1),lanced in 1992.AMI sensor by scatterometer mode, measures wind vector by Brag scattering between the microwave and the sea surface wave.

Originally AMI sensor has other two modes, one is wave mode that can measure the ocean wave spectra in spatial scale of 5km*5km globally, and the other is working as Synthetic Aperture Radar(SAR),which can be used to obtain ocean surface feature such as wind waves.

The atlas of monthly mean distributions of SSM/I surface wind speed, ARGOS buoy drift,AVHRR/2 sea surface temperature, AMI surface wind components and ECMWF surface wind components (Halpen 1994) show the potential of satellite sensors in providing surface wind and SST data. Therefore, it is reasonable to estimate carbon dioxide gas exchange in global scale combining use of their satellite data. Satellite data used in this study are DMSP/SSMI and ERS/SCAT wind speed data and AVHRR/2 SST data, which are provide by JPL PODAAC. Wind speed is derived by Wentz algorithm and change to 10m height above ocean surface by multiplying a scale 0.943.

RESULTS

Figure 1 shows the variation of computed CO2 exchange coefficient versus wind speed by Liss Model, Tans Model,and our whitecap method, respectively. All result is normalized at 20 degree Celsius. It is clear that the three algorithms agree with each other quite well when wind speed is smaller that 5 m/s. For the range of 5−10m/s, results of Liss Model and our whitecap method are in good agreement while both are almost half that derived from Tans Model. For high wind speed region, the difference between Liss and Tans Models remains almost constant. However, the whitecap results demonstrate a much higher gradient of increase. Figure 2 (a)~(d) show the distribution of CO2 exchange coefficient in global ocean in summer and winter of 1992, derived by ERS−1/scatterometer measurement from Liss and Tan Model, respectively. The dominant features of CO2 exchange coefficient corresponds well with that of wind distributions in both hemispheres. And it is apparent that Tans results are larger than Liss, implying that inconsistency exists among results produced by different models. Figure 3 shows the CO2 exchange coefficient in the winter of 1991 derived from SSM/I data and by Liss, Tans and whitecap model, respectively.

It seems that the CO2 exchange coefficient is higher for SSM/I data than ERS−1/SCAT data even when using the same method, especially at high wind regions. Figure 4 exhibits the monthly variations of CO2 exchange coefficient obtained through the three ocean basins, i.et., Indian Ocean ,Pacific Ocean and Atlantic Ocean. Generally speaking an annual cycle is dominant in its variation.

CONCLUSION

This work summarized several approaches currently used for the computation of CO2 exchange coefficient at air − sea interface. However, significant inconsistencies are found when different methods are applied and different satellites are used. To overcome this, more field works are required in order to get better understanding of all circumstances under which CO2 gas transfer are affected. However, this work is believed to improve our knowledge of the spatial distribution of CO2 exchange coefficient over the world ocean as well as its temporal variations.

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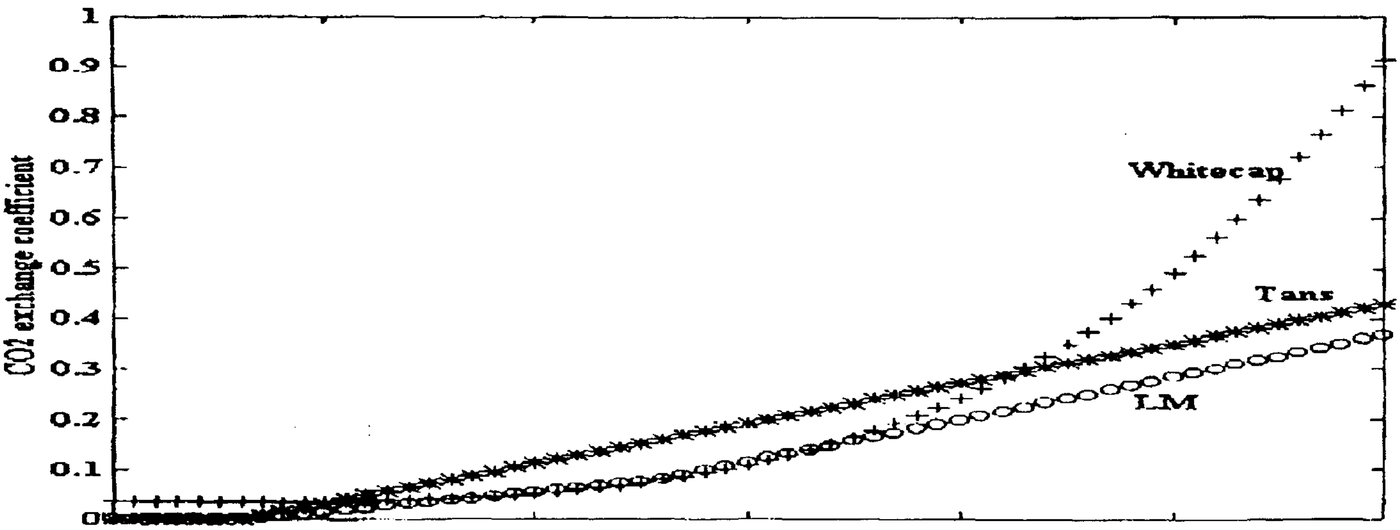
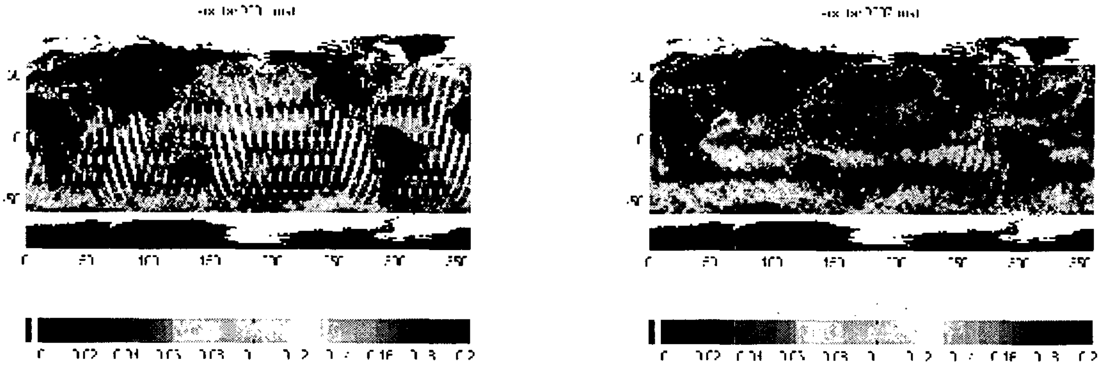


Fig.1 Relation of CO2 exchange and wind.

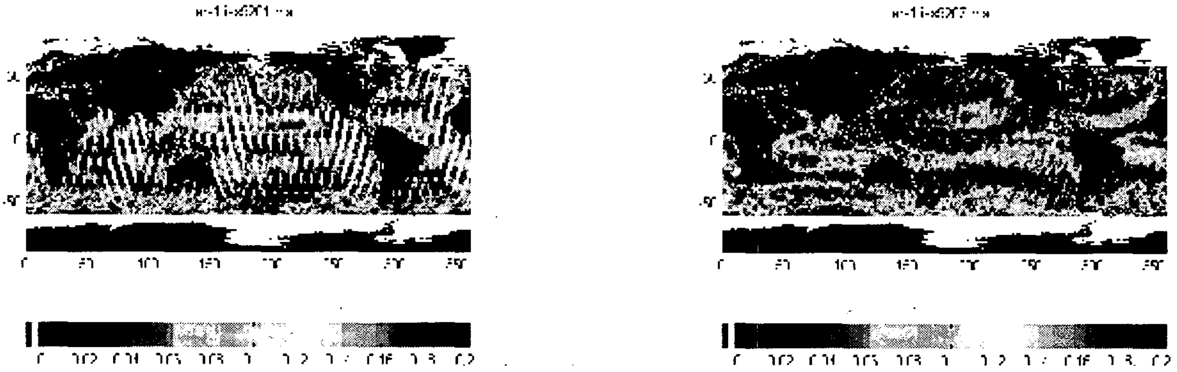
The CO2 exchange coefficient are nomalized at 20 degree Celsius

And computed by Liss Model, Tans Model and our whitecap method, respectively.



(a)winter ,Tan Model

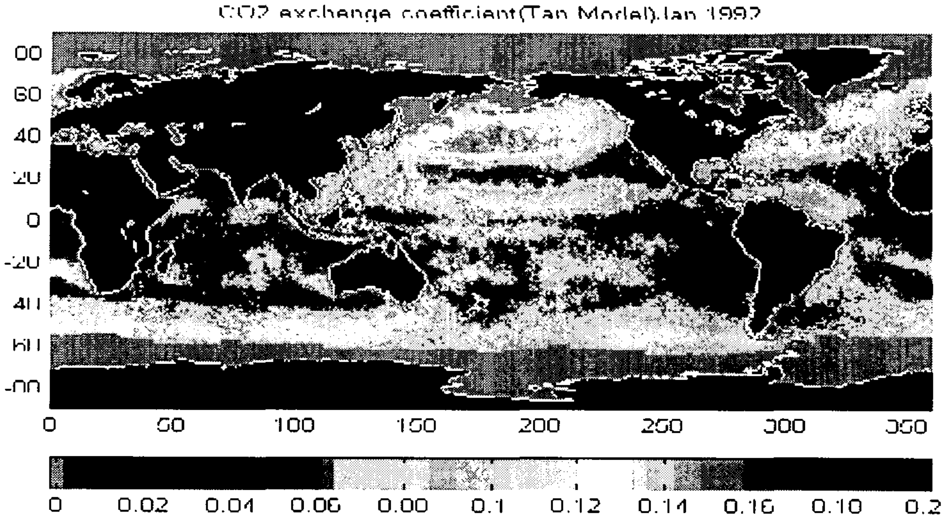
(b)summer, Tans Model



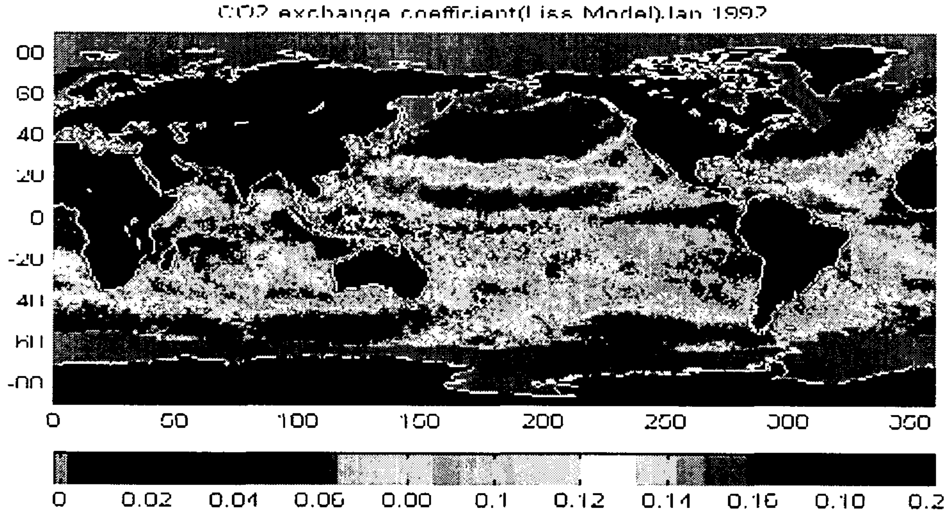
(c)winter, Liss Model

(d) summer Liss model

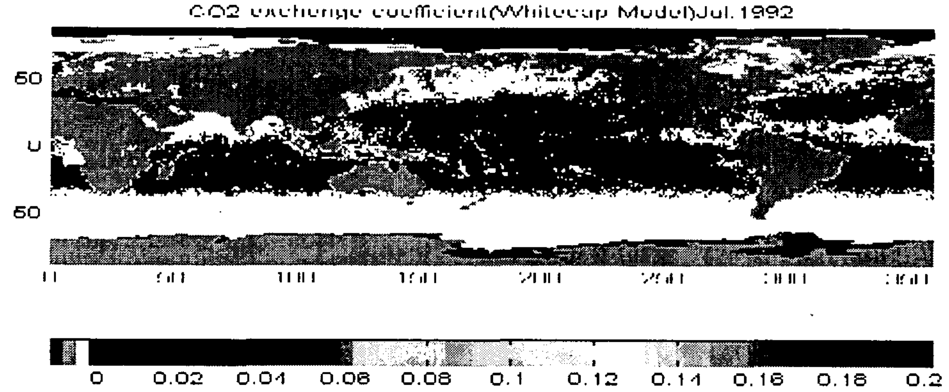
Fig.2 CO2 exchange coefficient in boreal winter and summer of 1992 from ERS-1/SCAT



(a) winter　Tans model

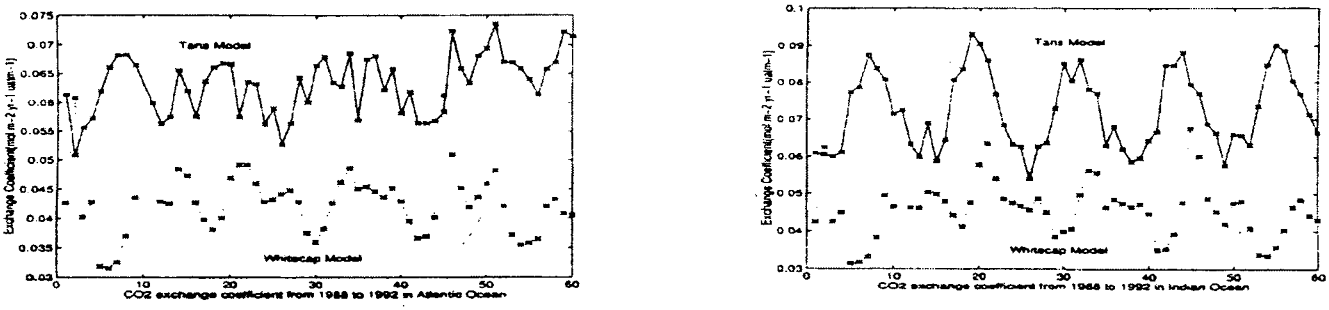


(b) winter　Liss Model



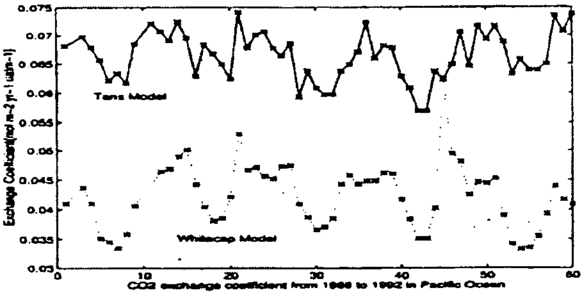
(c)　winter, whitecap Model

Fig3 CO2 exchange coefficient in boreal winter 1991 from SSM/I



(a) Atlantic Ocean

(b) India Ocean



(c) Pacific Ocean

Fig. 4 Monthly distribution of CO2 excha
coefficient in three ocean basins for the pe
of 1988-1992