The Sensitivity of Air-Sea Gas Transfer to Wind Speed and Stress

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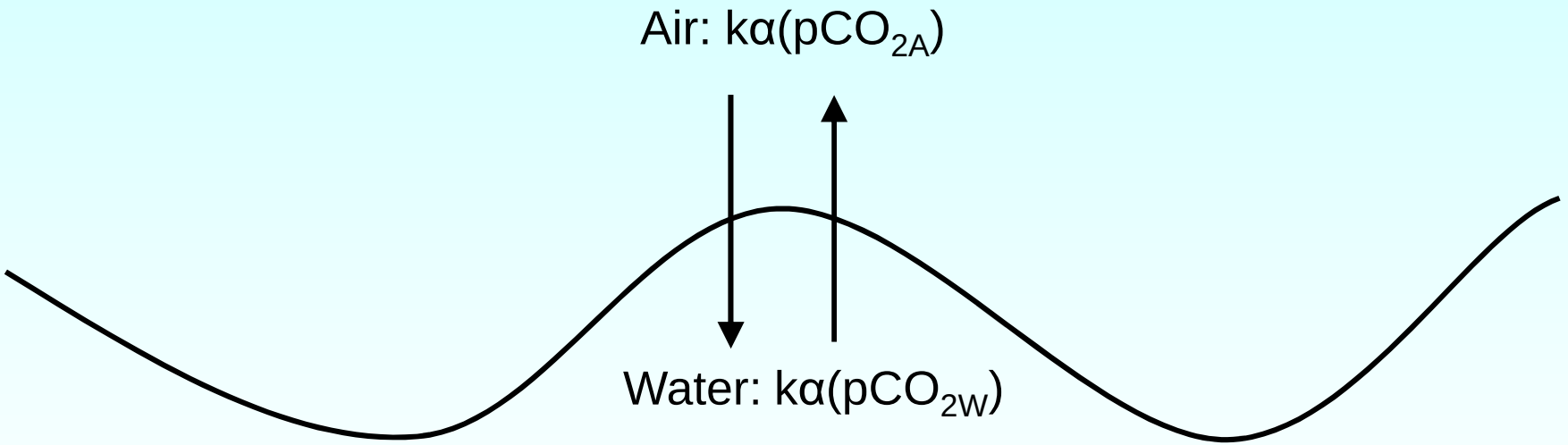
Overview

- Objectives
  - Assess accuracy of gas transfer velocity derived from satellite inputs using physically-based COARE parameterization
  - Construct error budget and derive sensitivity to wind speed and other input parameters
- Outline
  - Background
  - Implementation of COARE model with satellite inputs
  - Estimation of uncertainties and wind sensitivity
  - Assessment of predicted velocities with other satellite approaches and direct observations

Gas Flux Estimation



Net air-sea flux: $F = k\alpha\Delta(pCO_2)$

Transfer velocity: k = F(wind, bubbles, surfactants, wave slope)

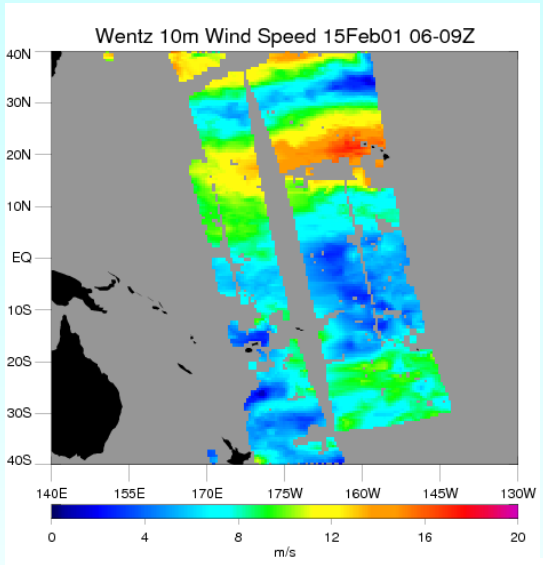
Transfer Velocity Methods

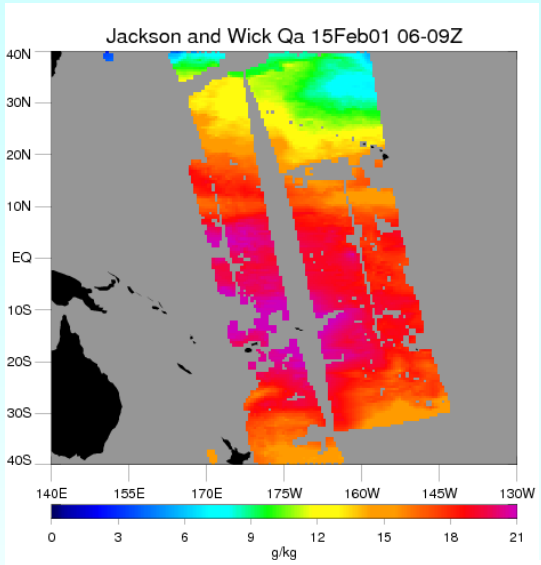
- Simple wind speed parameterization
- Physically-based gas transfer models
- Direct relationship to surface roughness and wind stress

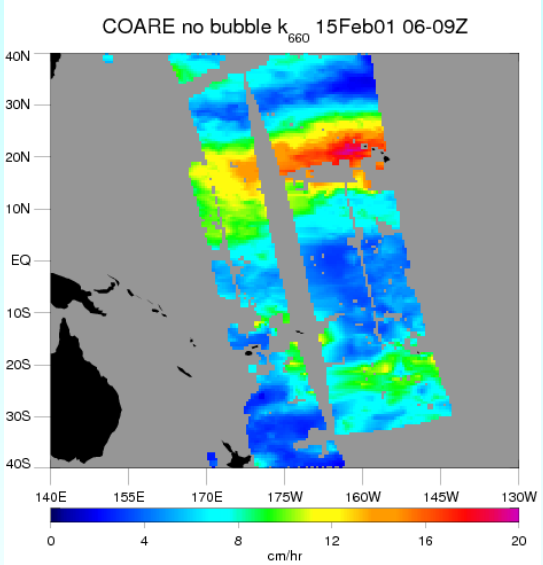
Implementation

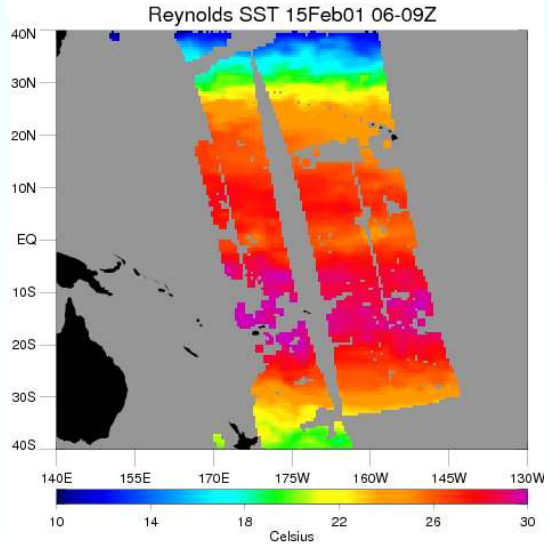
- NOAA COARE air-sea gas transfer parameterization
  - Micrometeorological approach matching the turbulent and molecular processes on both sides of the interface
  - Incorporates surface renewal concepts
  - Utilizes empirical bubble and wave-breaking enhancement model (Woolf 1997)
  - Applies to multiple gases including CO_2, DMS, and ozone
- Satellite-based inputs
  - Wind speed (Wentz)
  - SST (Reynolds)
  - Near-surface air temperature and humidity (Jackson et al.)
  - Downwelling solar and longwave radiation (ISCCP and NCEP)

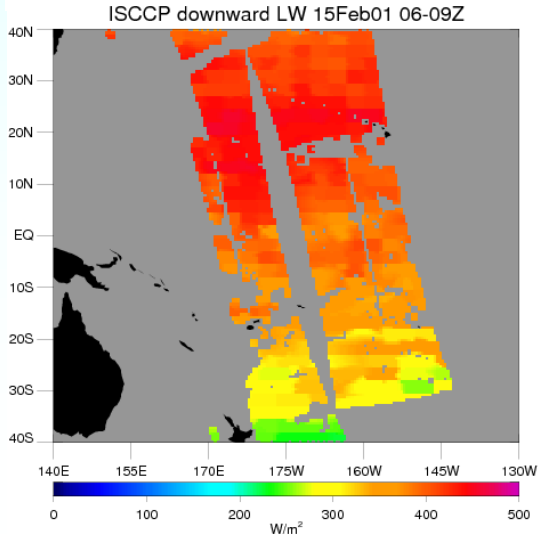
Implementation Example

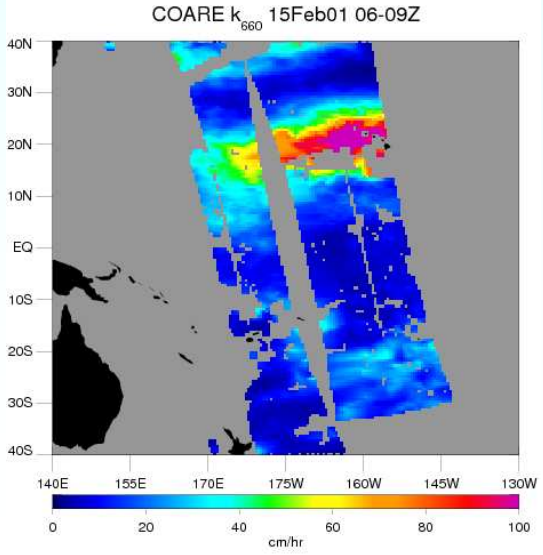






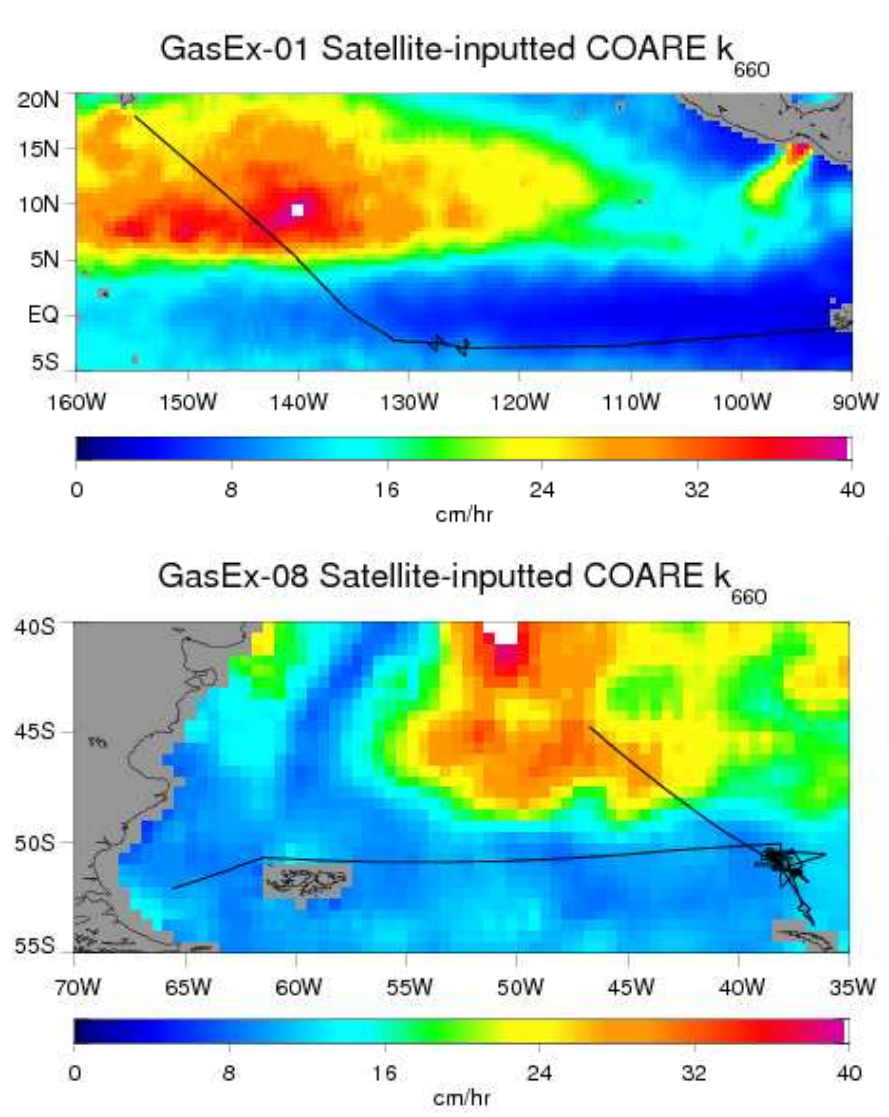




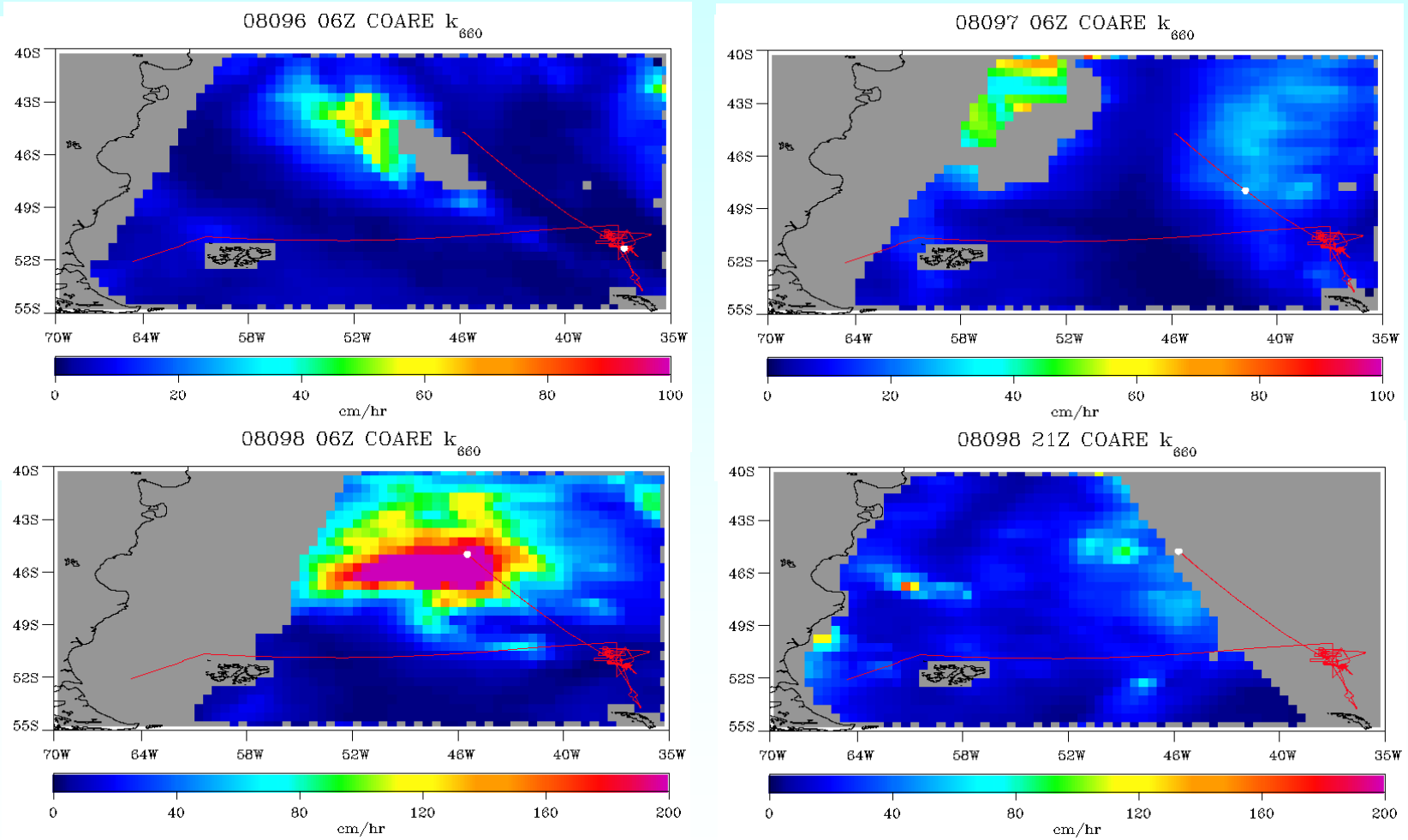


Application of Satellite-Derived Gas Transfer Velocity

- Campaigns
  - GasEx 98
  - GasEx 01
  - SO GasEx
- Transfer velocity computed for region with satellite inputs
  - 3 hr and 0.5°resolution
- Satellite results collocated with surface observations
  - Matching within 50 km, 3 hr

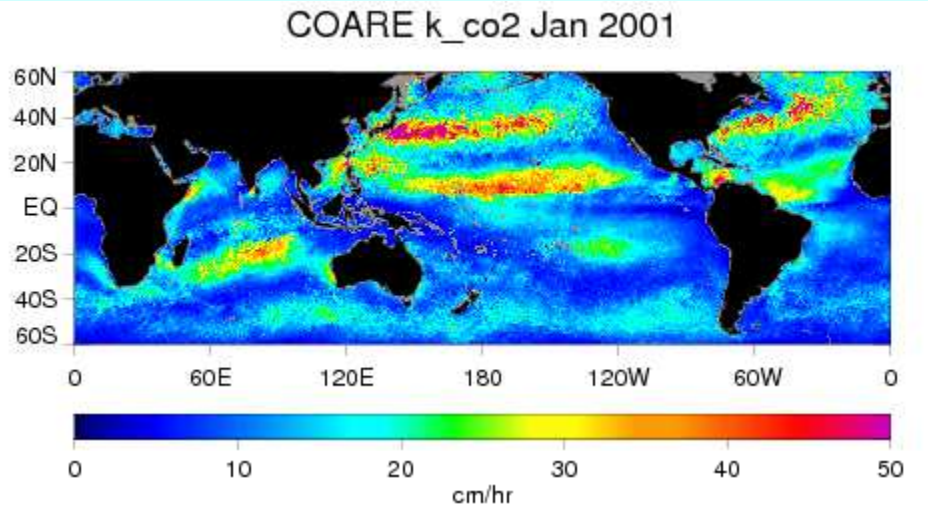


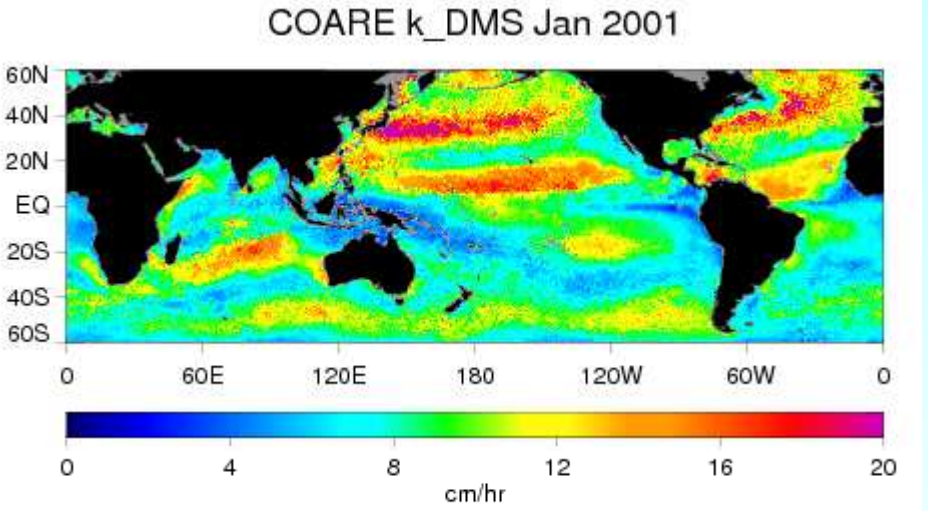
COARE Satellite Product



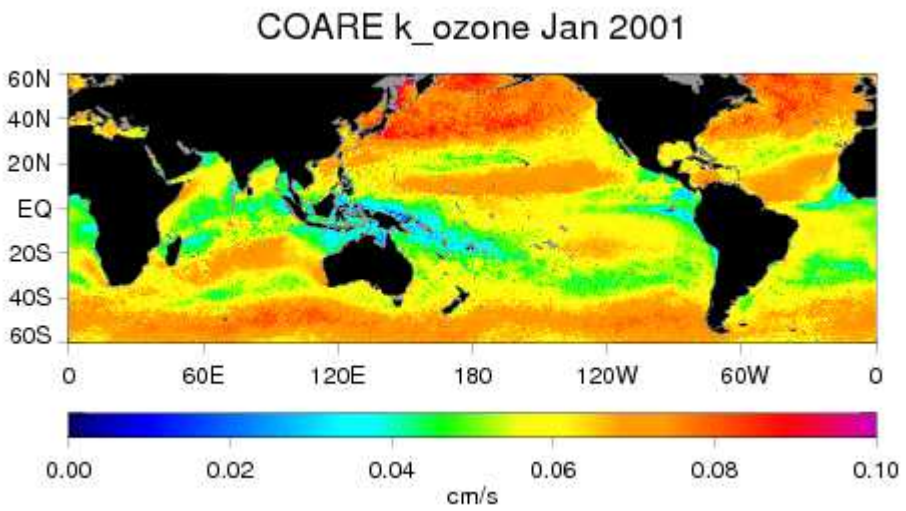
- Example of 3-hourly satellite-derived product from SO-GASEX
- Note strong day-to-day and regional variability
- Regional structure a complement to ship observations

Global Transfer Velocities





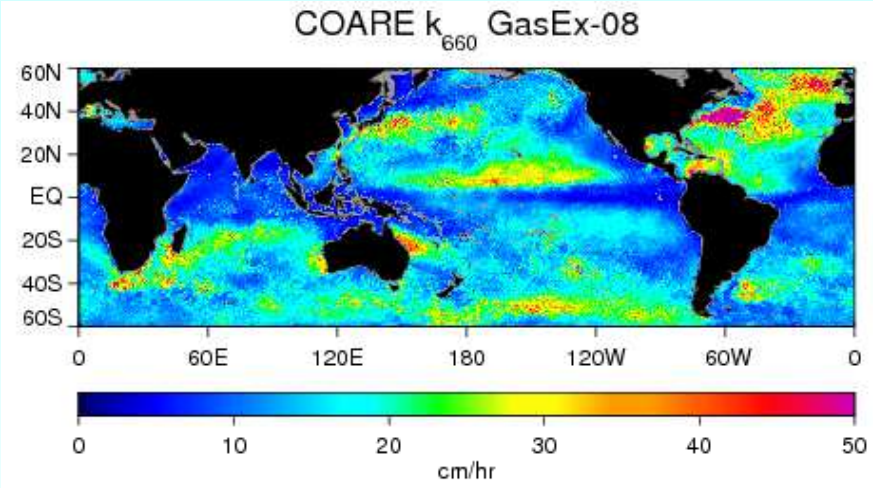
- Product also computed globally to explore seasonal and interannual variability
- Transfer velocities computed for CO_2, DMS, and ozone

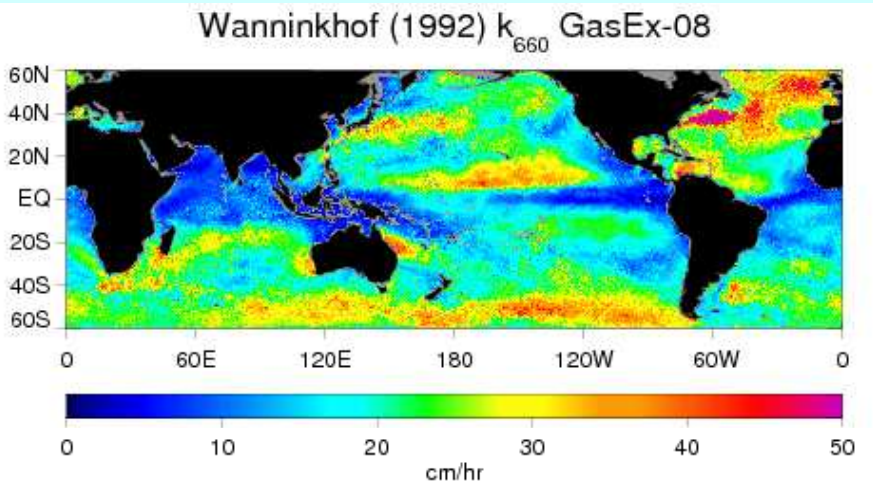


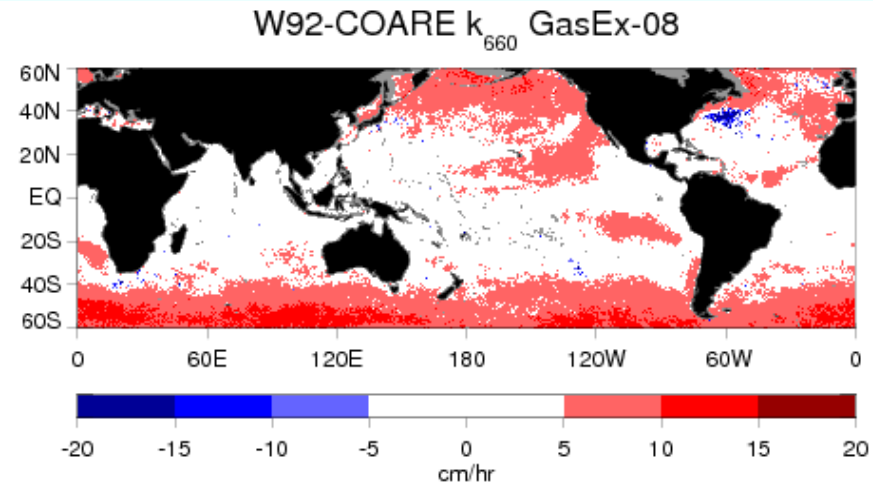
Uncertainties

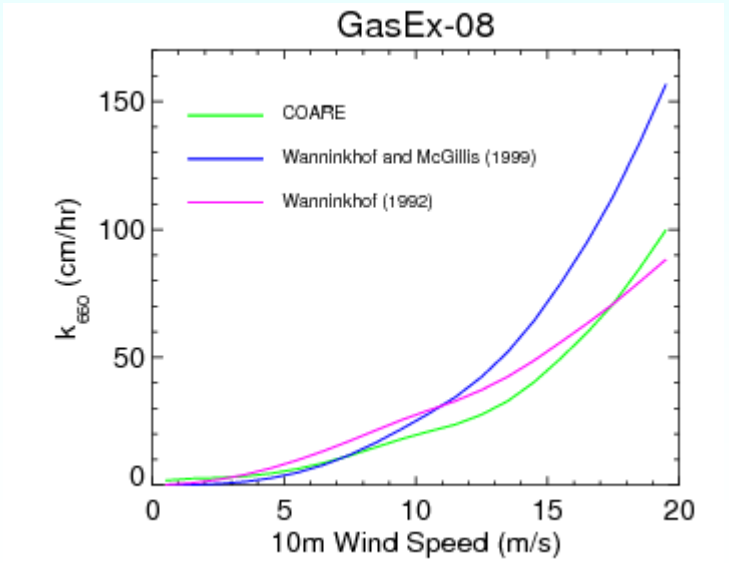
- Satellite representation of the input parameters
- Uncertainty in the physical formulation of the parameterization

Comparison of Satellite-Derived Products

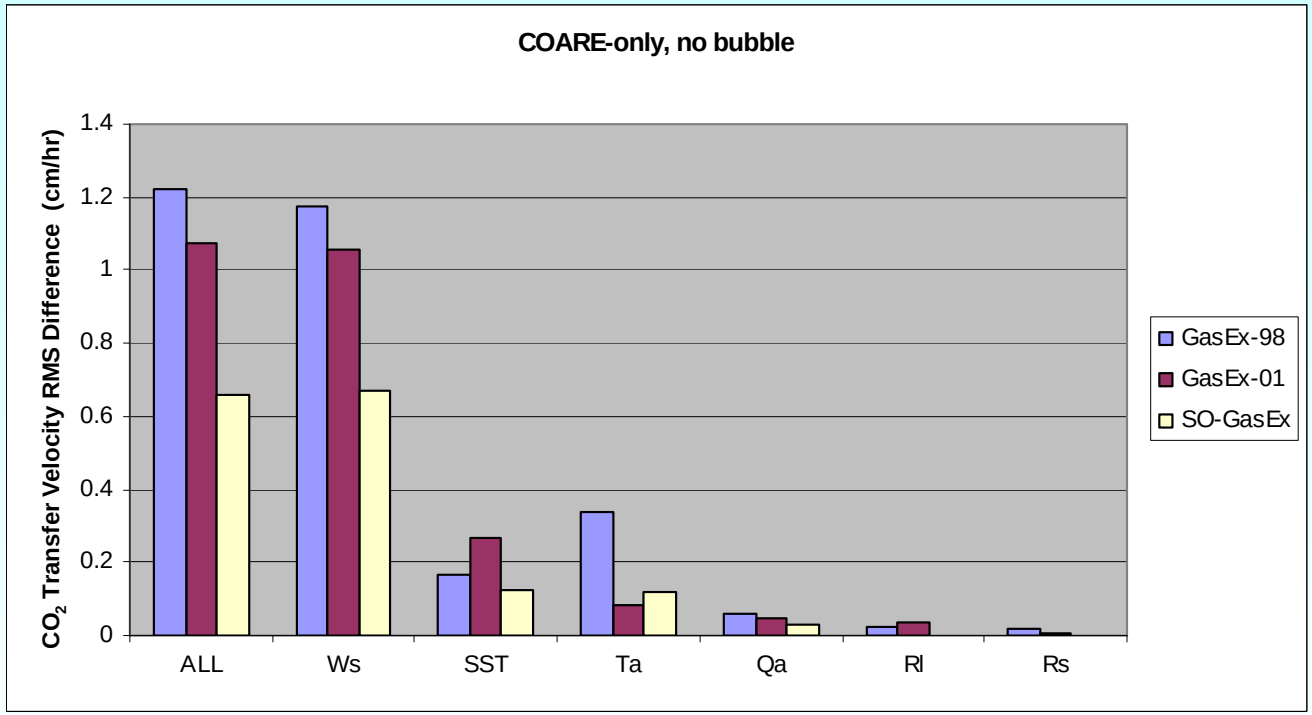








Sensitivity to Input Parameters

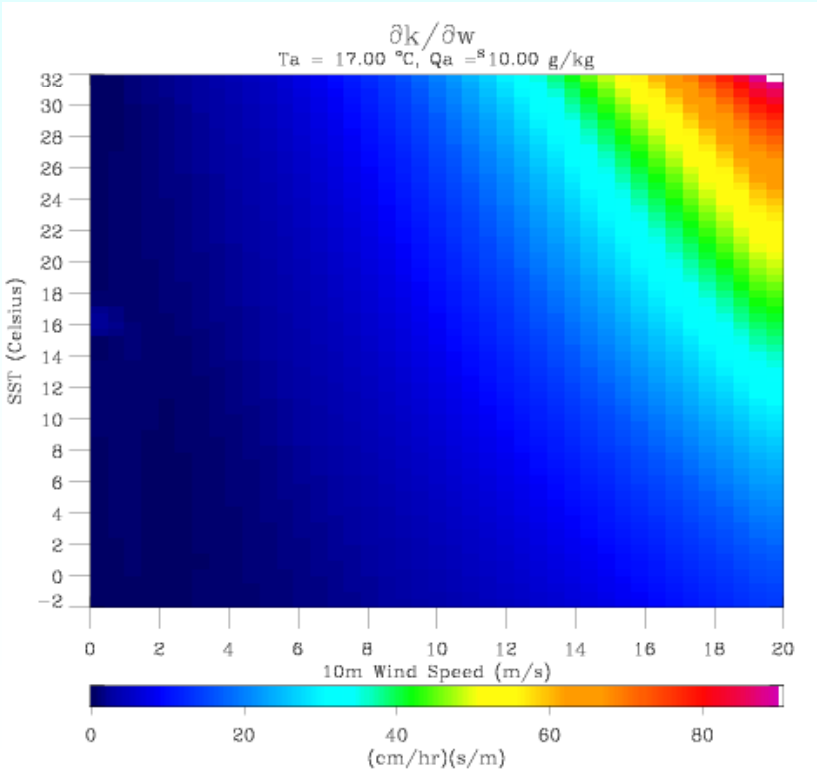


- Examined difference between satellite- and ship-computed transfer velocities replacing only individual parameters with satellite observations
- RMS differences reflect both errors in the parameters and their sensitivity
- Largest sensitivity arises from wind speed differences

Construction of Error Budget

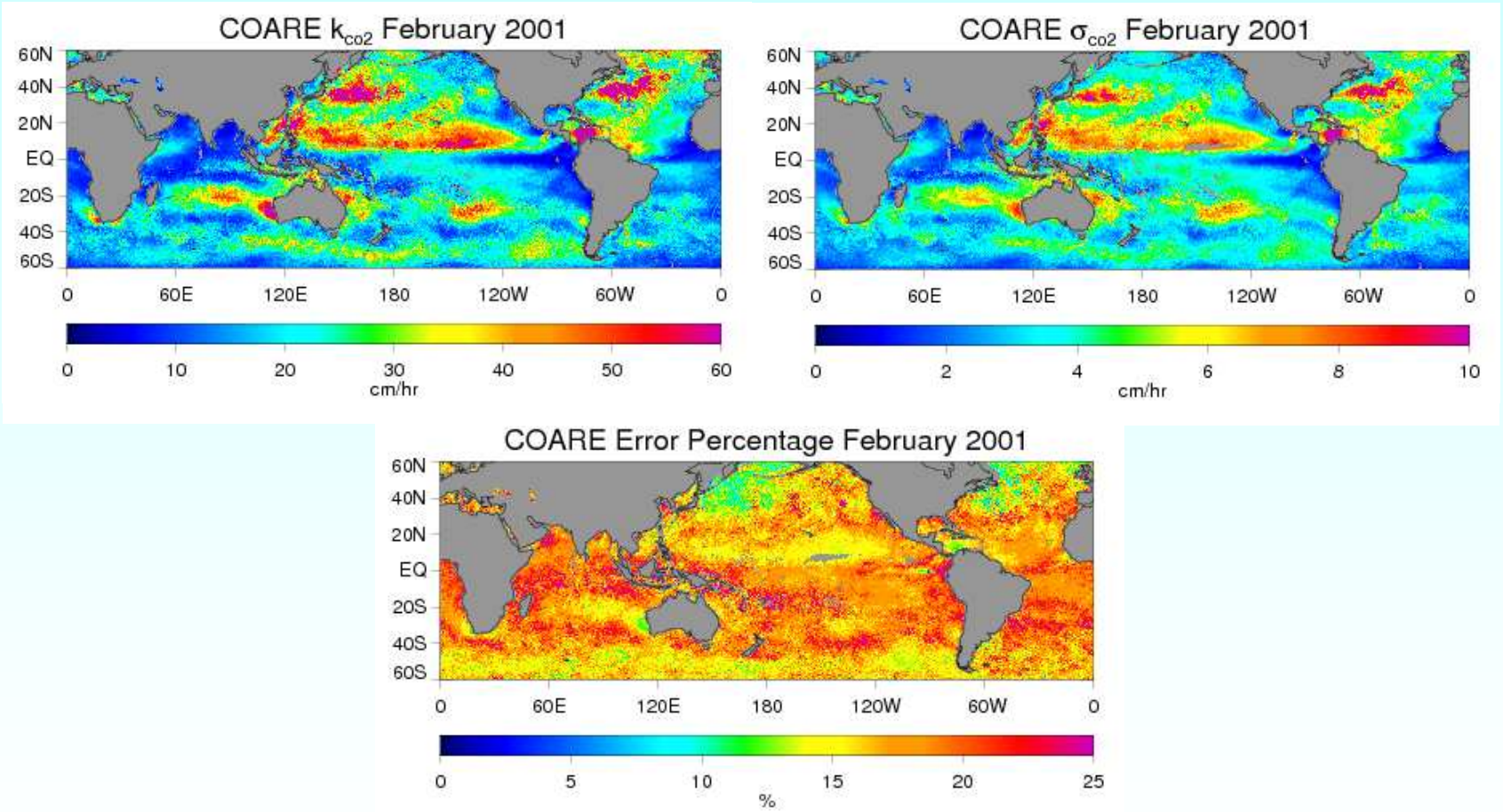
$$\sigma_k^2 = \left(\frac{\partial k}{\partial Ws}\right)^2 \sigma_{Ws}^2 + \left(\frac{\partial k}{\partial SST}\right)^2 \sigma_{SST}^2 + \left(\frac{\partial k}{\partial Ta}\right)^2 \sigma_{Ta}^2 + \left(\frac{\partial k}{\partial Qa}\right)^2 \sigma_{Qa}^2 + 2\frac{\partial k}{\partial SST}\frac{\partial k}{\partial Ta} COV_{SST,Ta} + 2\frac{\partial k}{\partial Ws}\frac{\partial k}{\partial Qa} COV_{Ws,Qa} + 2\frac{\partial k}{\partial Ta}\frac{\partial k}{\partial Qa} COV_{Ta,Qa}$$

- Derived and evaluated error propagation model
- Partial derivatives computed numerically from COARE
- Covariance terms calculated on grid with 1-year time series



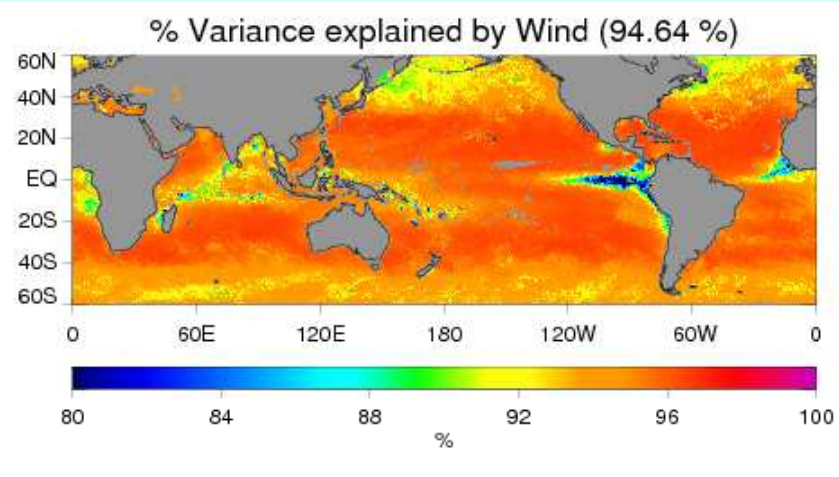
Sensitivity greatest at high winds and SST

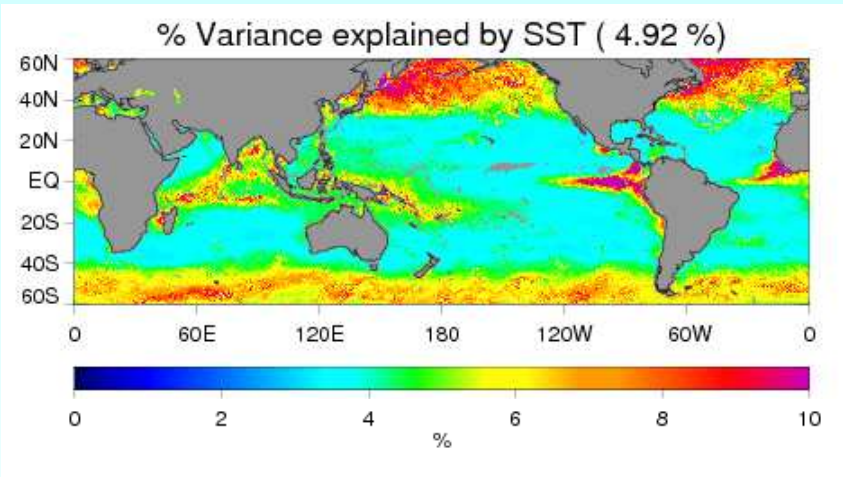
Estimated Uncertainty from Inputs

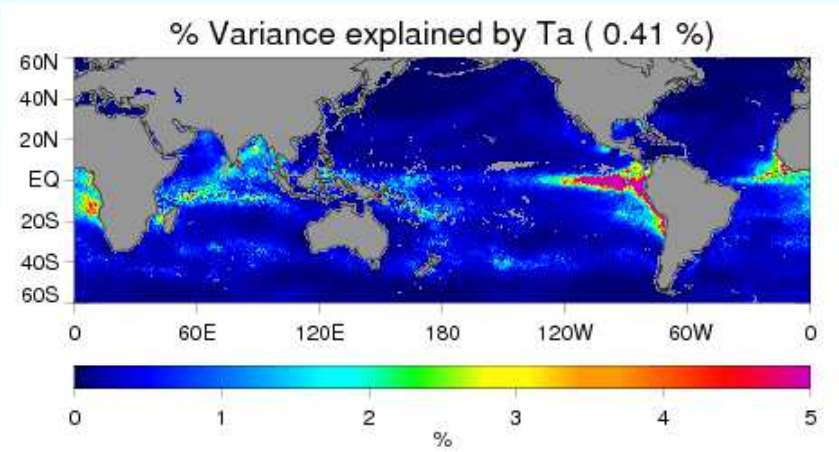


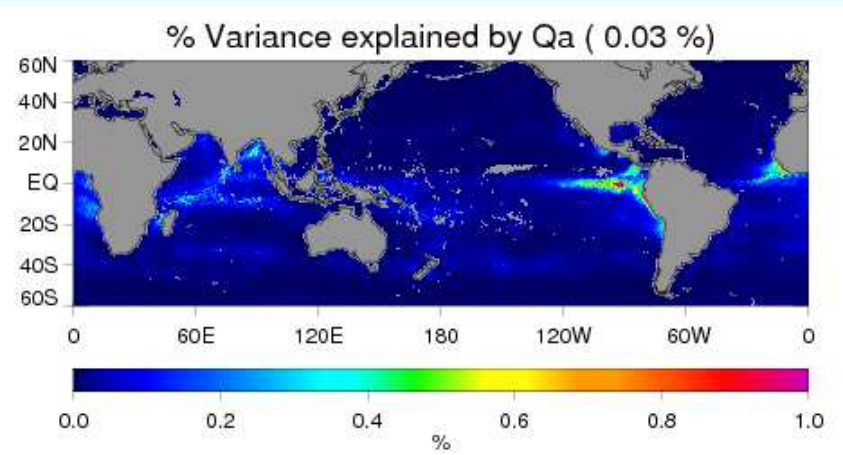
- Assumed uncertainties of 1 m/s in wind, 0.5 K in SST, 1 K in T_a, and 1 g/kg in q_a
- Percentage errors relatively uniform between 15-20%

Relative Contribution to Errors





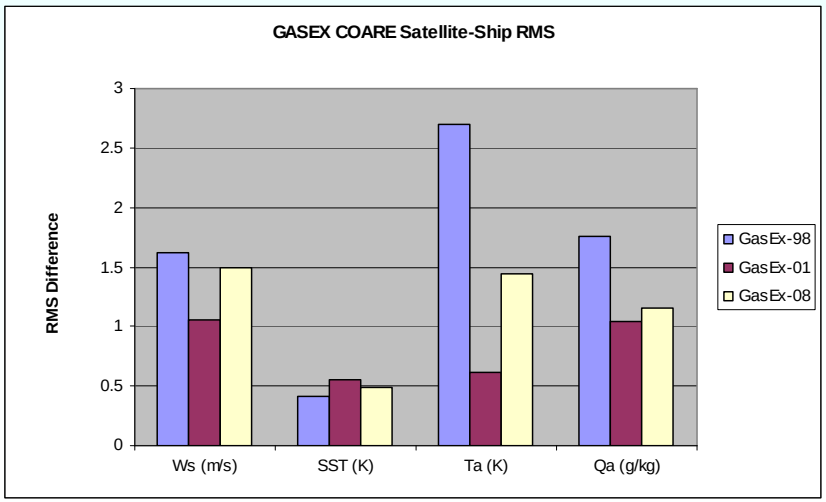


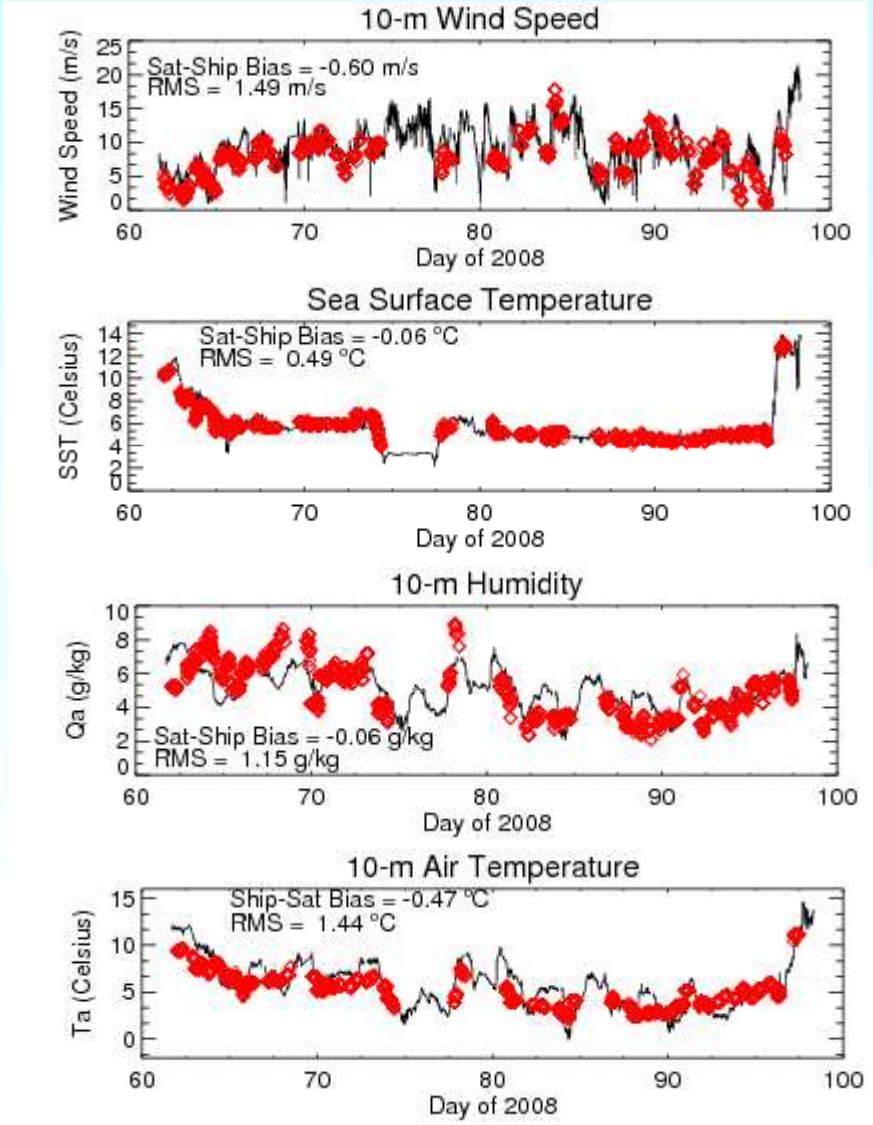


Nearly 95% of the variance related to the wind speed

Evaluation of Satellite-Derived Inputs

- Satellite inputs to the COARE model compared against direct observations during SO-GASEX
- Agreement generally favorable for a region with limited previous validation
- Satellite-derived transfer velocities, therefore, similar to computations from ship inputs



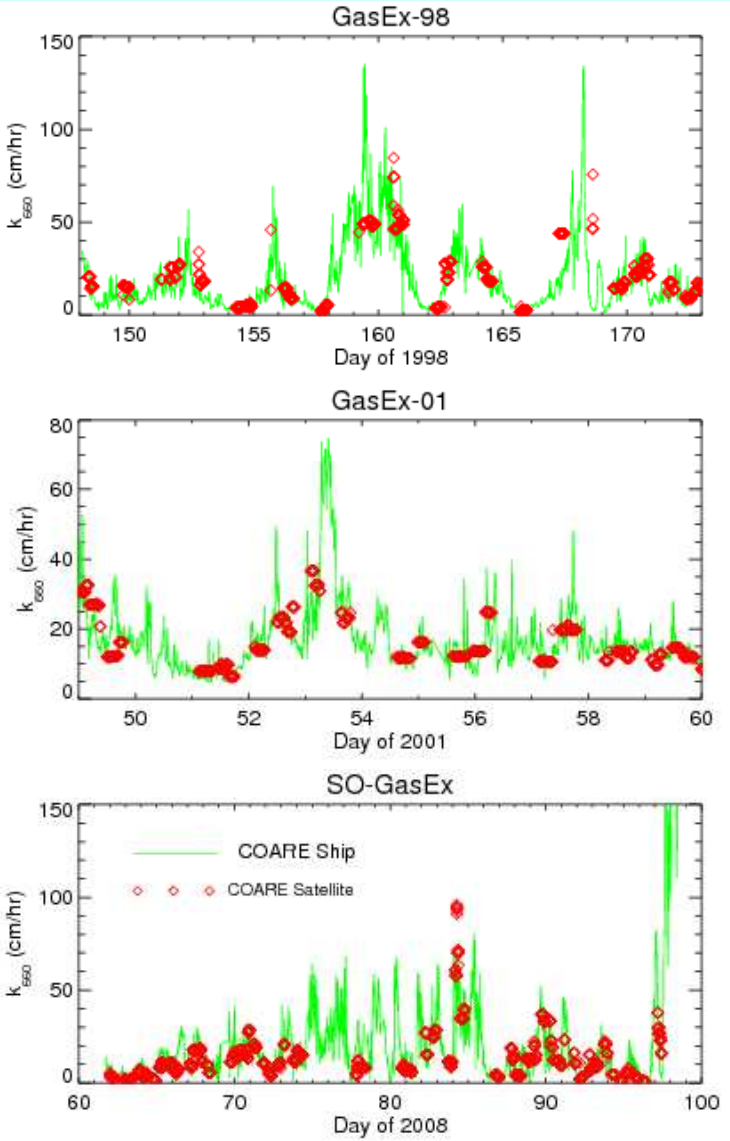


Comparison Between Ship and Satellite Transfer Velocities

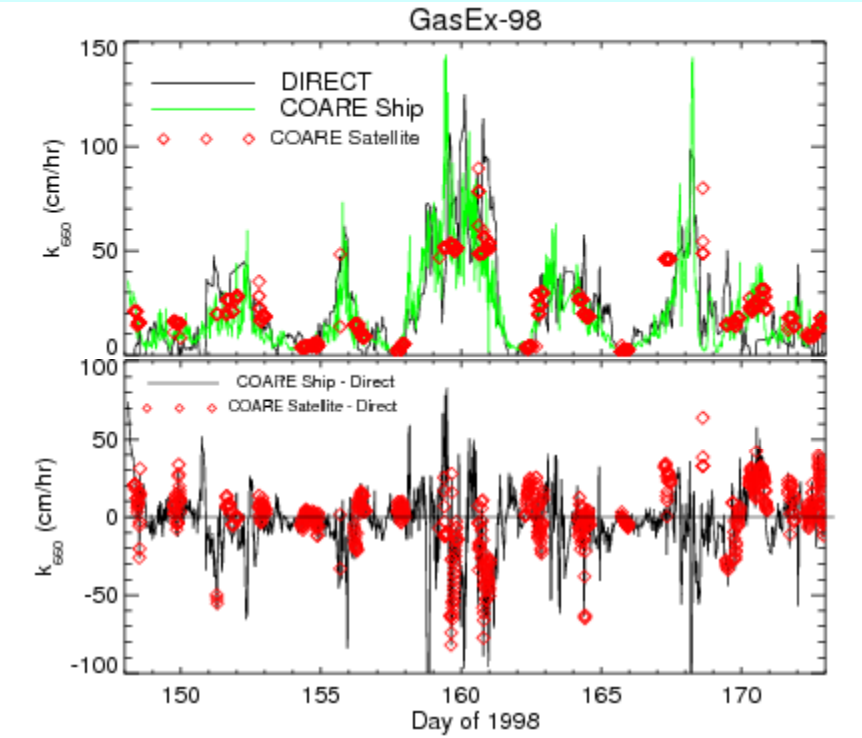
- 10 min ship observations matched to 3 hour/0.5^{o} satellite data
- Satellite-derived COARE transfer velocity agrees well with ship-derived observations
- High transfer velocities from ship data are occasionally missed by satellite due to sampling

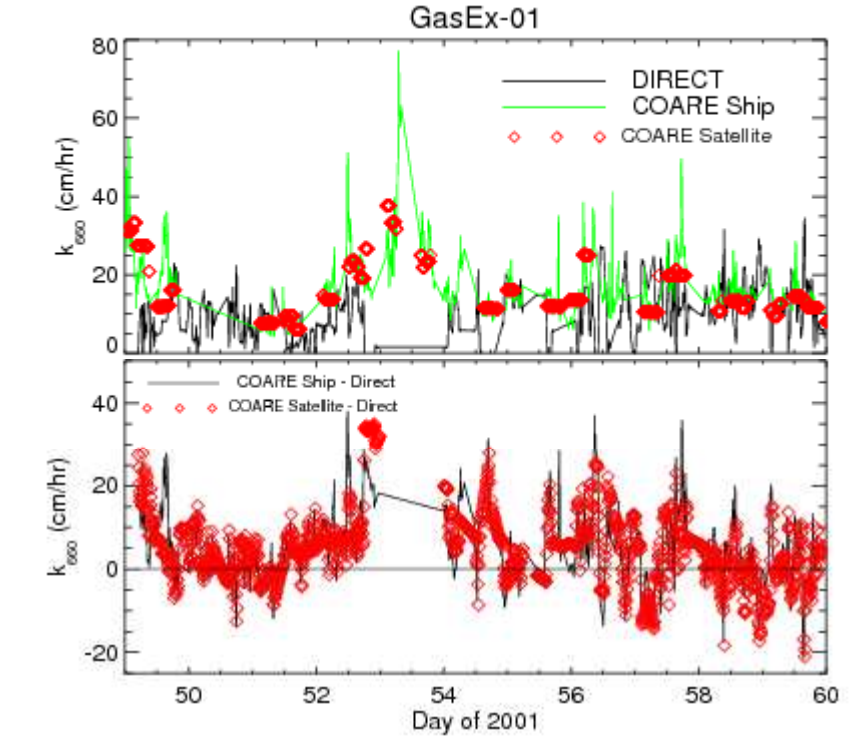
	BIAS	RMS
GasEx-98	2.75 cm/hr	11.22 cm/hr
GasEx-01	-1.85 cm/hr	6.93 cm/hr
SO-GasEx	-1.83 cm/hr	7.19 cm/hr

Bias = Satellite - Ship



Comparison with Direct Observations





- Satellite transfer velocities next compared with available direct covariance measurements
- Statistics very similar for satellite and ship-based estimates

		Bias	RMS
1998	Satellite	0.0 cm/hr	20.5 cm/hr
	Ship	-3.8 cm/hr	21.1 cm/hr
2001	Satellite	5.1 cm/hr	9.9 cm/hr
	Ship	5.4 cm/hr	10.0 cm/hr

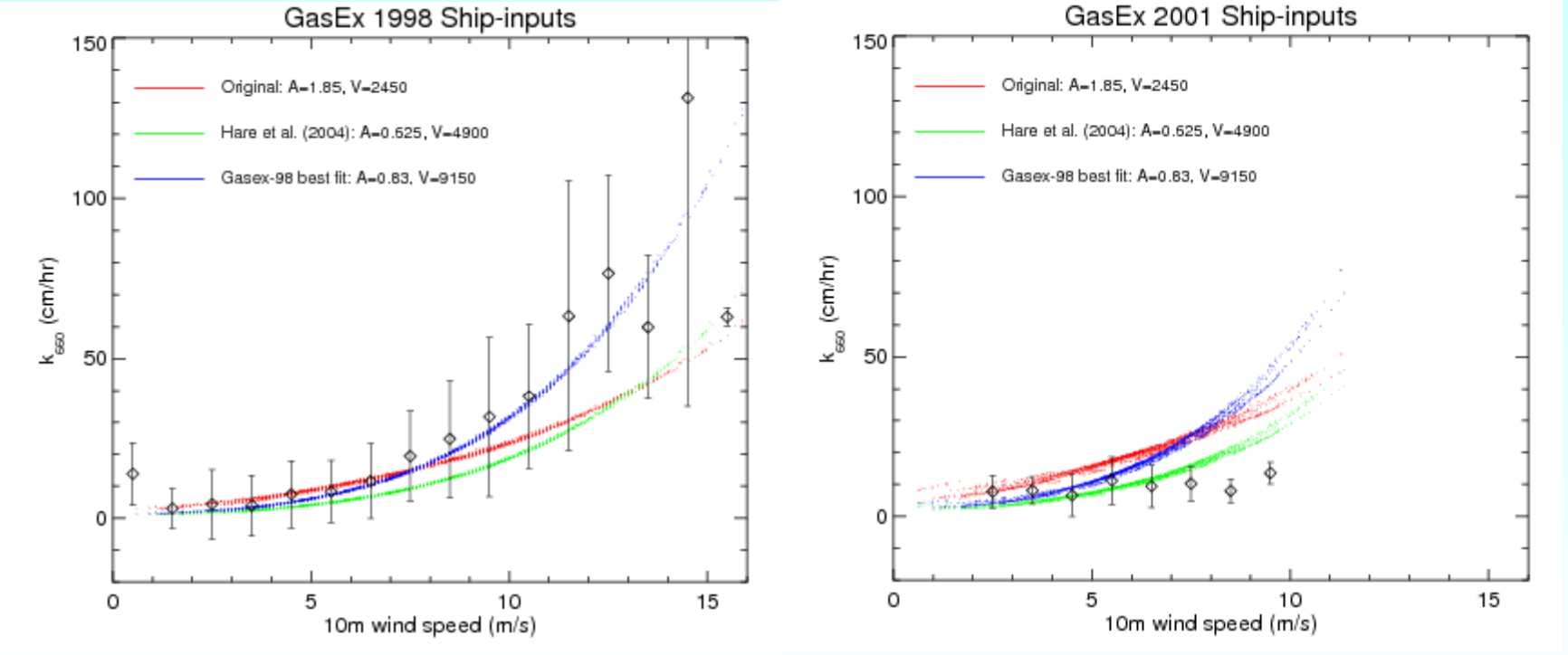
Conclusions

- NOAA COARE model has been successfully implemented for use with satellite-derived inputs
- Analyses show CO_2 transfer velocity variability largely governed by wind speed
- Satellite observations used as inputs to COARE gas model agree well with the ship observations during the GasEx campaigns
- Comparison with available direct observations favorable; accuracy of satellite-derived velocities comparable to computations with ship inputs

Motivation

- Need accurate global measure of air-sea CO_2 flux to quantify net uptake by the oceans and identify sources and sinks
- Remote sensing required to achieve necessary temporal and spatial sampling
- Must first derive estimates of the gas transfer velocity with known error characteristics

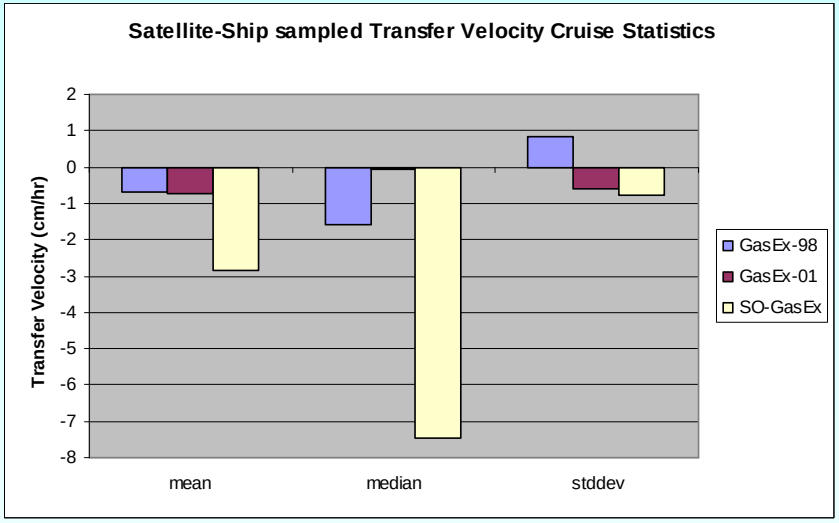
Sensitivity to Model Parameters

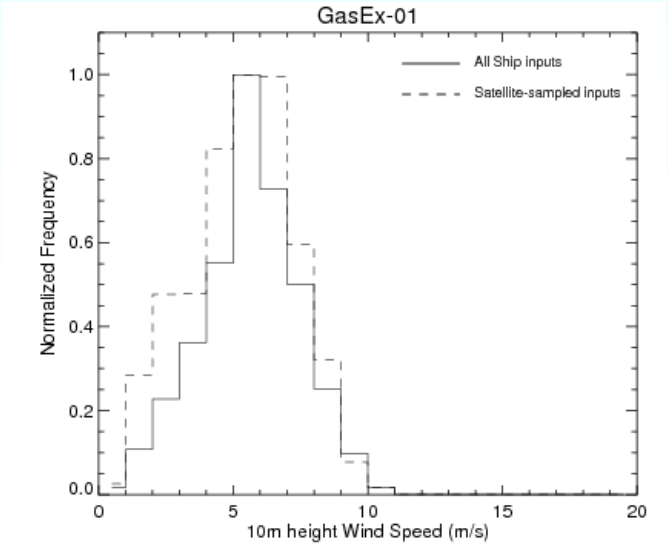


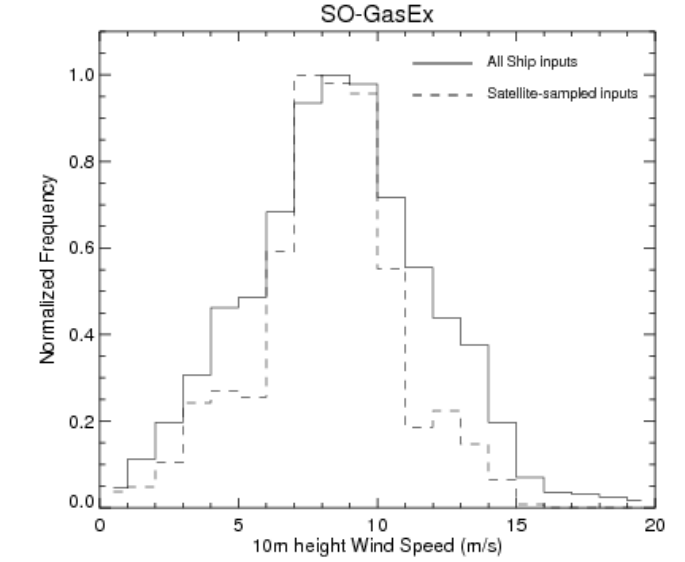
- Two primary empirical parameters in the current COARE implementation
- Graphics show range of behavior in response to changes in these parameters compared with direct observations
- Significant potential variability in behavior

Satellite Sampling Uncertainty

- Satellite sampling during GasEx cruises result in lower mean and median transfer velocity
- Differences largest for SO-GasEx due to greater frequency of high wind events missed by satellite observations.







Bubble Enhancement Sensitivity

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