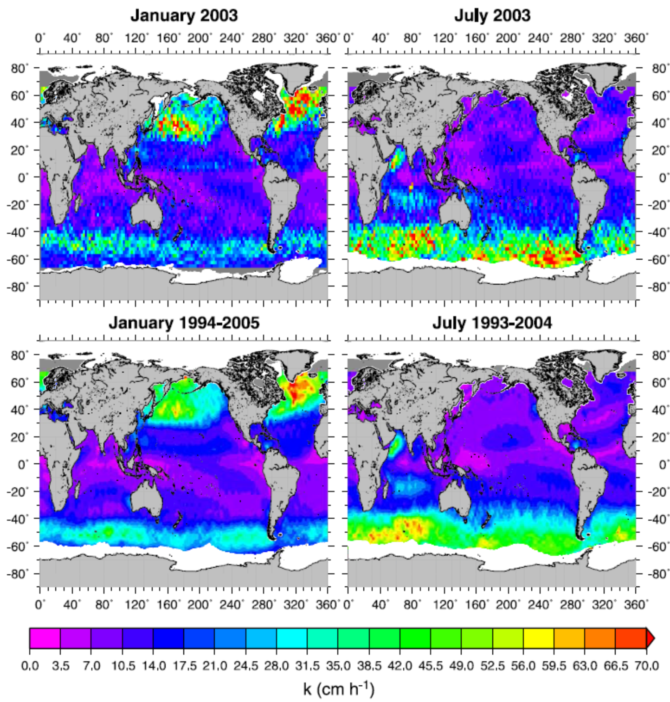
Estimates of Gas Transfer Velocity from Radar Backscatter



Outline

- Introduction
- Mean Square Slope
- Altimetry-based k
- Scatterometry-based k
- Summary

$$F_{CO2} = k_{660}\Delta[C_{CO2}]\left(\frac{Sc(T,S)}{660}\right)^{-\frac{1}{2}}$$

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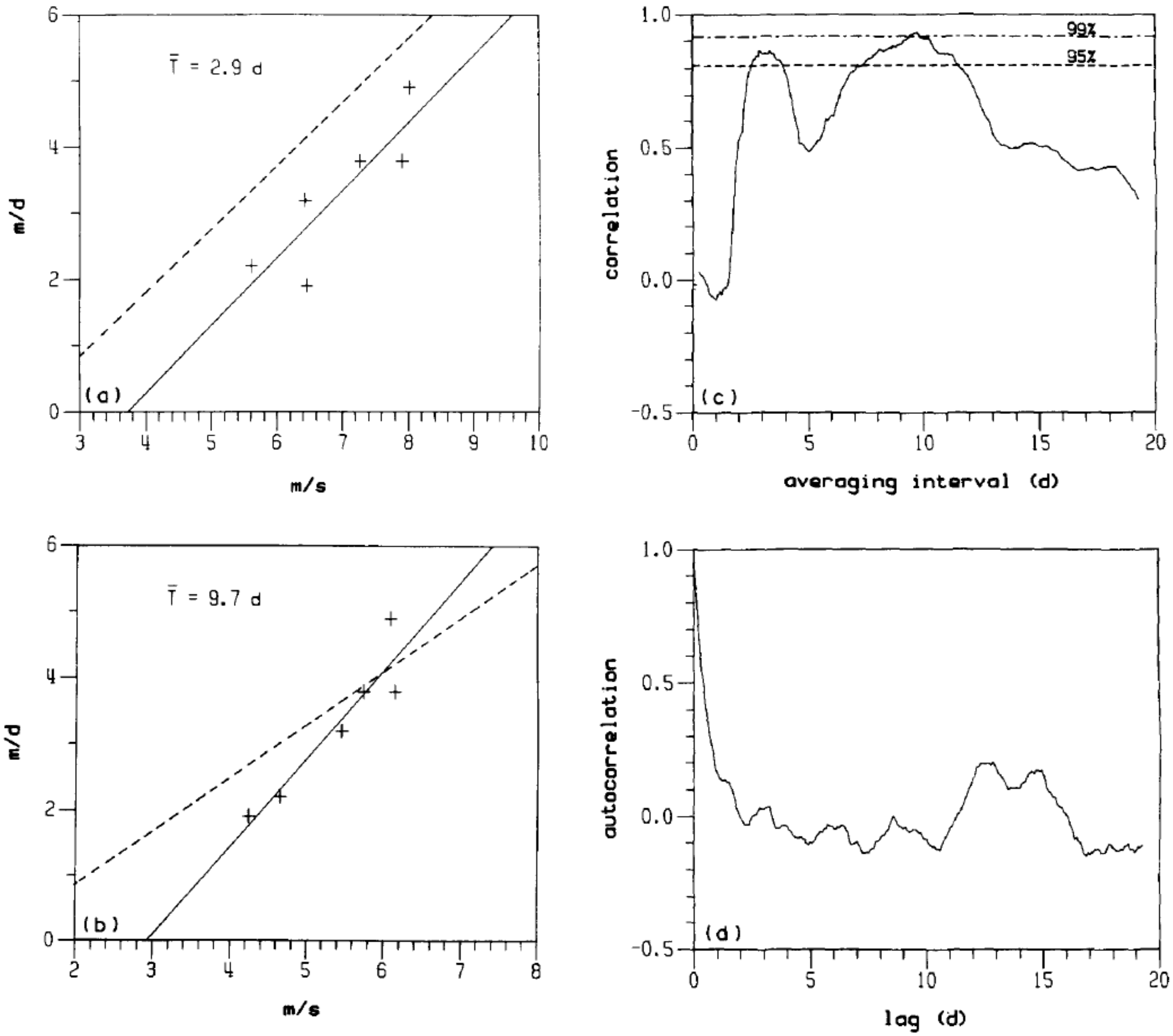
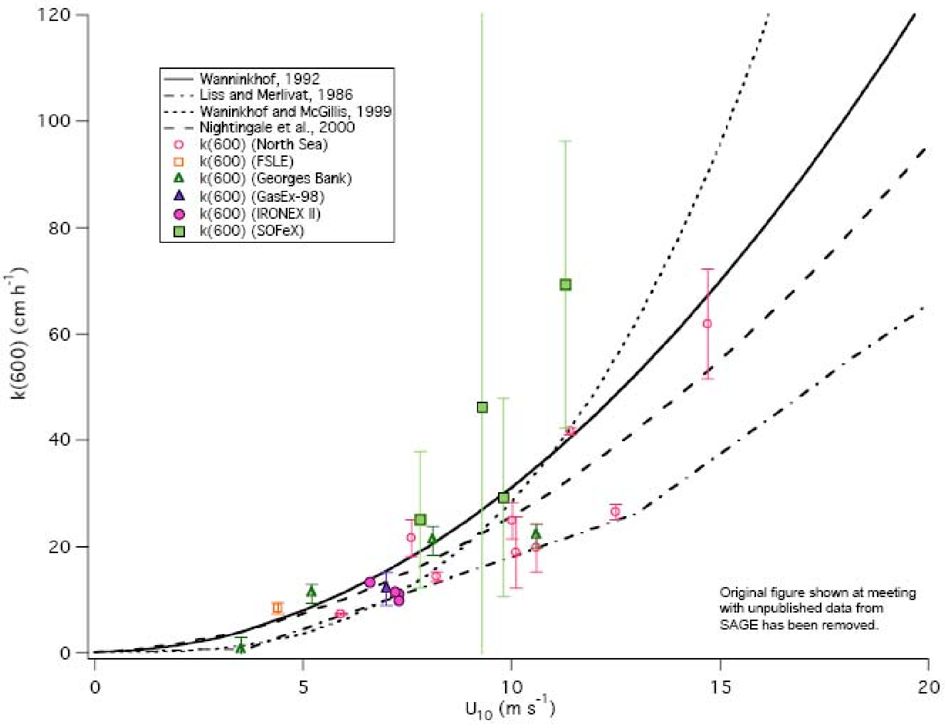
Scatterometry and Climate Workshop

Motivation: Glover and Reeburgh (1987) never found the simple, linear relationship between wind speed and gas transfer velocity.

Based on PROBES 1981 ^{222}Rn Data



Objectives

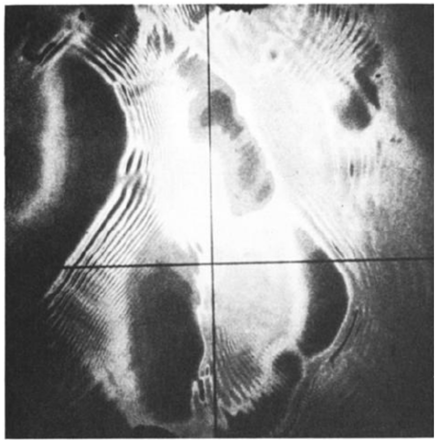


from D. Ho and R. Feely

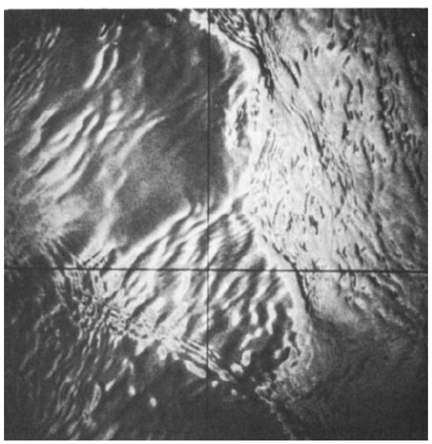
- Make direct measurements of sea surface roughness accounting for:
  - Atmospheric stability
  - Surfactants
  - Wave age, wind fetch, wave-wave and wave-current interactions, *etc*.
- Use this roughness as a proxy to study the near-surface turbulence that drives gas transfer across the air-sea interface.
- Implement an "operational" gas transfer velocity algorithm on global and regional scales using remotely sensed data.

Mean Square Slope

<u>21 m fetch</u>



2.7 m/s



8.1 m/s

Based on data from the large IMST wind/wave facility, Jähne et al. (1987) concluded the following:

• An increase in mass transport starts with the onset of waves.

• In one way or another waves are the active source of near-surface turbulence.

• Waves can not grow indefinitely, the energy must, eventually, be dissipated by near-surface turbulence.

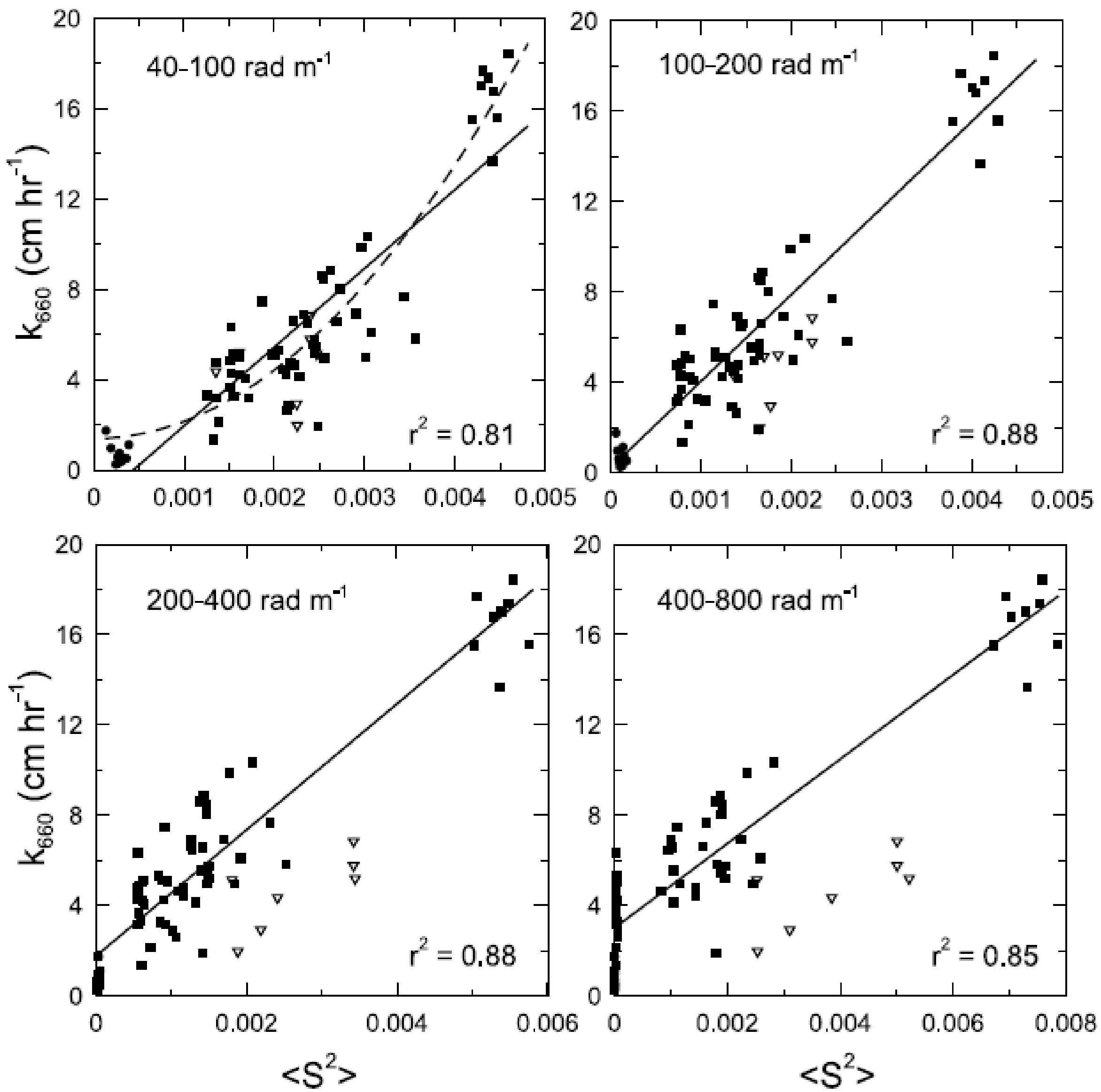
• Since the energy cascade moves from the large waves to smaller, "*It is clear no other parameter of the wave field than the slope can be used. The slope characterizes the stability of the waves.*"

Transfer Velocity Function

$$k_{660} = f\left(\left\langle s^2 \right\rangle\right)$$

- Laboratory (Jähne et al., 1987; Bock et al., 1999) and field work have revealed that the mean square slope $\langle s^2 \rangle$ is a robust predictor
  - Better accounts for the hydrodynamic boundary condition
  - Energy gain by the waves from the action of the wind is transferred to the near-surface turbulence

CoOP-1997



Frew et al. (2004) examined the mean square slope of small capillary/gravity-capillary waves from 40-800 rad/m and found:

- A linear relationship between ‹s²› and k_{660} except in low wavenumber ranges such as 40-100 rad/m where a quadratic fit better.
- Surfactants significantly reduced k_{660}, yet ‹s2› was a more robust predictor than either U_{10} or u^*_w.
- All that was needed was a way to measure ‹s2› efficiently.

Altimeter Estimation of Mean Square Slope

Jackson et al. (1992) presented a Geometric Optics (GO) model for quasi-specular scattering of microwave radiation:

$$\sigma_o^{GO} = (\rho_g \sec^4\theta / \langle s_g^2 \rangle) \exp(-\tan^2\theta / \langle s_g^2 \rangle) \qquad (1)$$

For a nadir-looking altimeter ($\theta = 0$):

$$\langle s_n^2 \rangle = \rho_n' / \sigma_o \qquad (2)$$

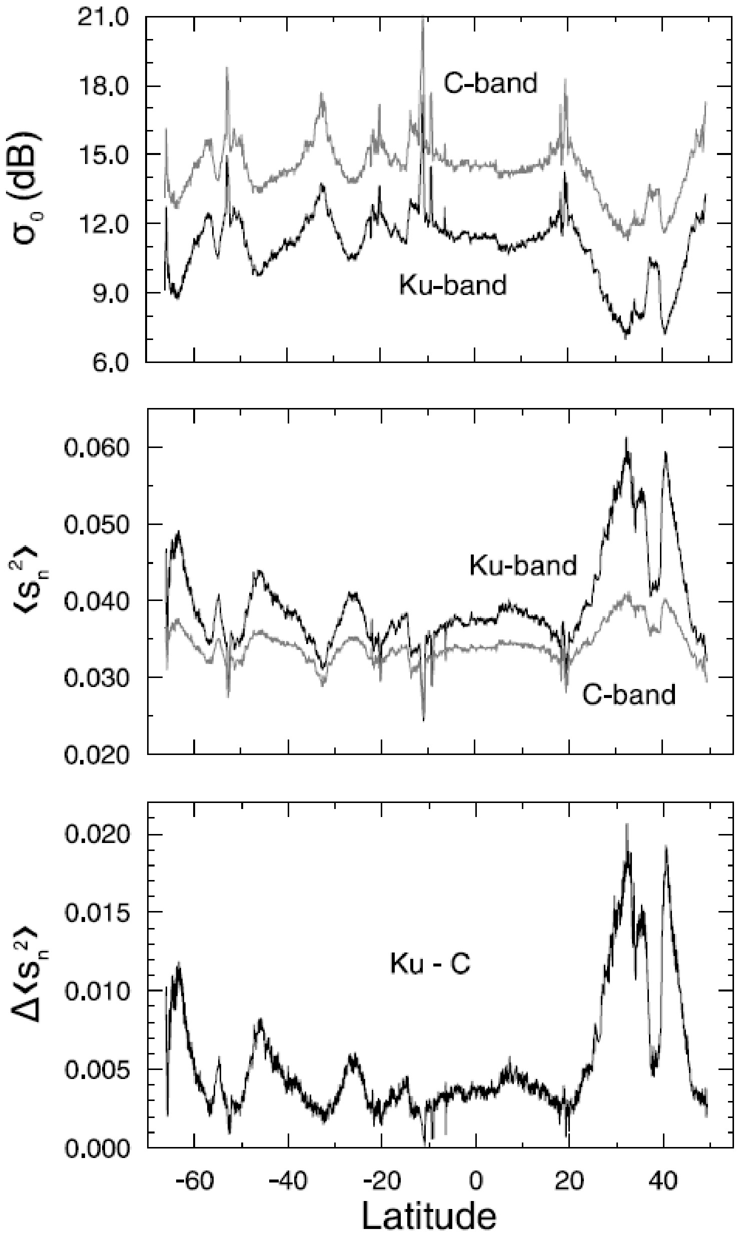
Difference of TOPEX/Jason-1 dual-frequency (Ku- (13.6 GHz) and C-band (5.3 GHz)) slope estimates brackets wavenumbers 40-100 rad/m:

$$\Delta \langle s_n^2 \rangle = \rho_n'^{Ku} / \sigma_o^{Ku} - \rho_n'^{C} / (\sigma_o{}^{C} + \alpha) \qquad (3)$$

Transfer velocity is derived from altimeter differenced mean square slope estimates using a quadratic dependence of ***k*** on mean square slope for this wavenumber range [***Frew et al.***, JGR, 2004]:

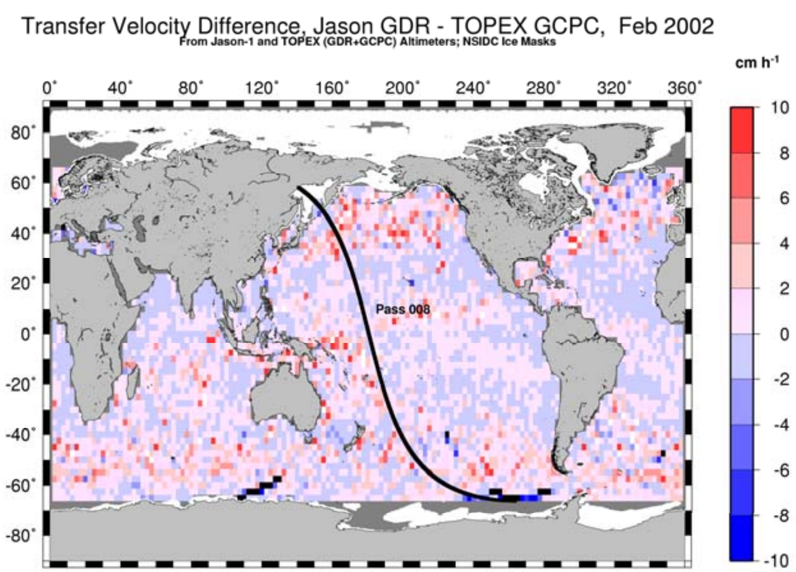
$$k_{Sc(T)} = \left(\frac{Sc(T)}{660} \right)^{-0.5} \cdot (c_0 + c_1 (\Delta \langle s_n^2 \rangle)^2) \qquad (4)$$

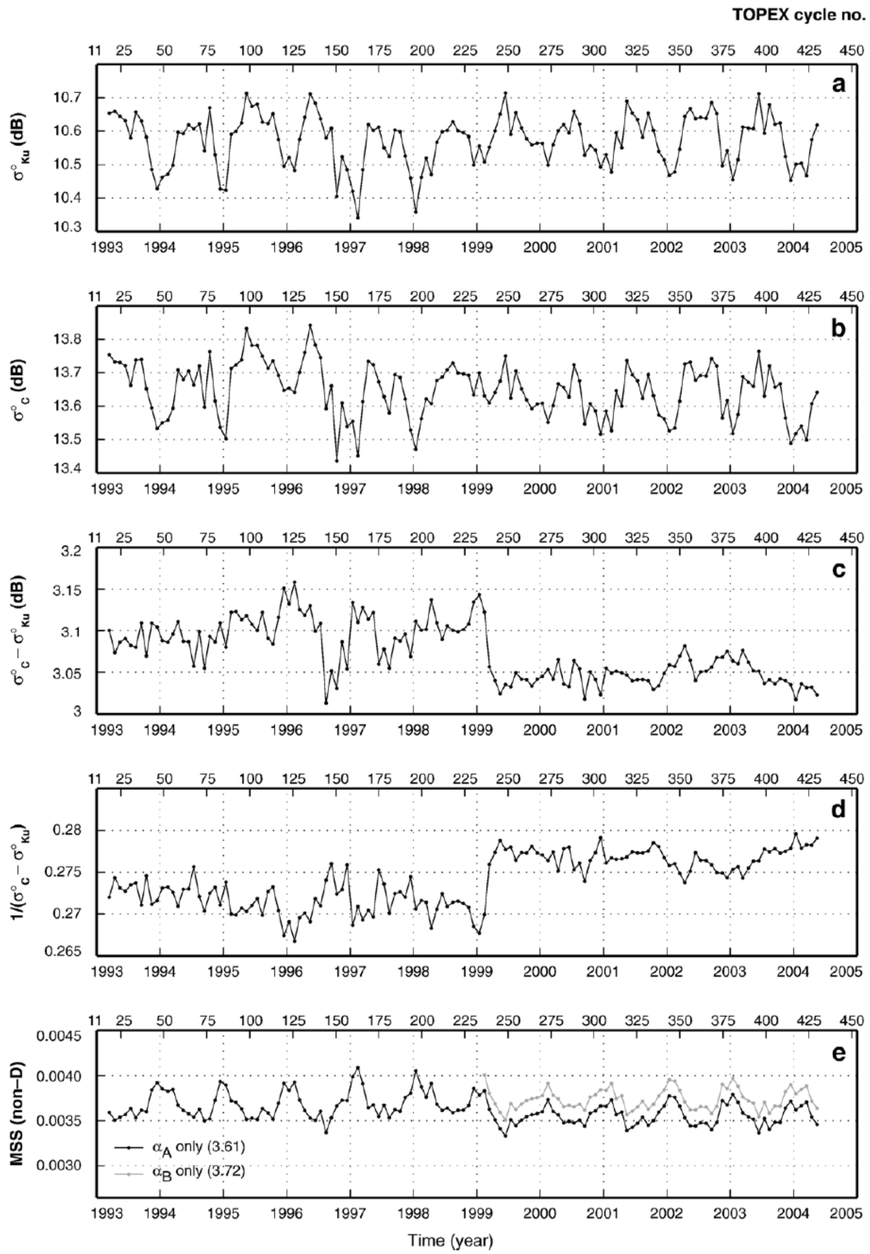
TOPEX pass 008, cycle 313



Frew et al. (2007) found:

- When one considers the Ku-band or C-band σ° from an individual pass one finds about the same dynamic range.
- However ‹s^2› estimated by just one frequency band yielded low dynamic range.
- Differencing the two bands increased the dynamic range and isolated a short wavelength portion of the capillary wave field.

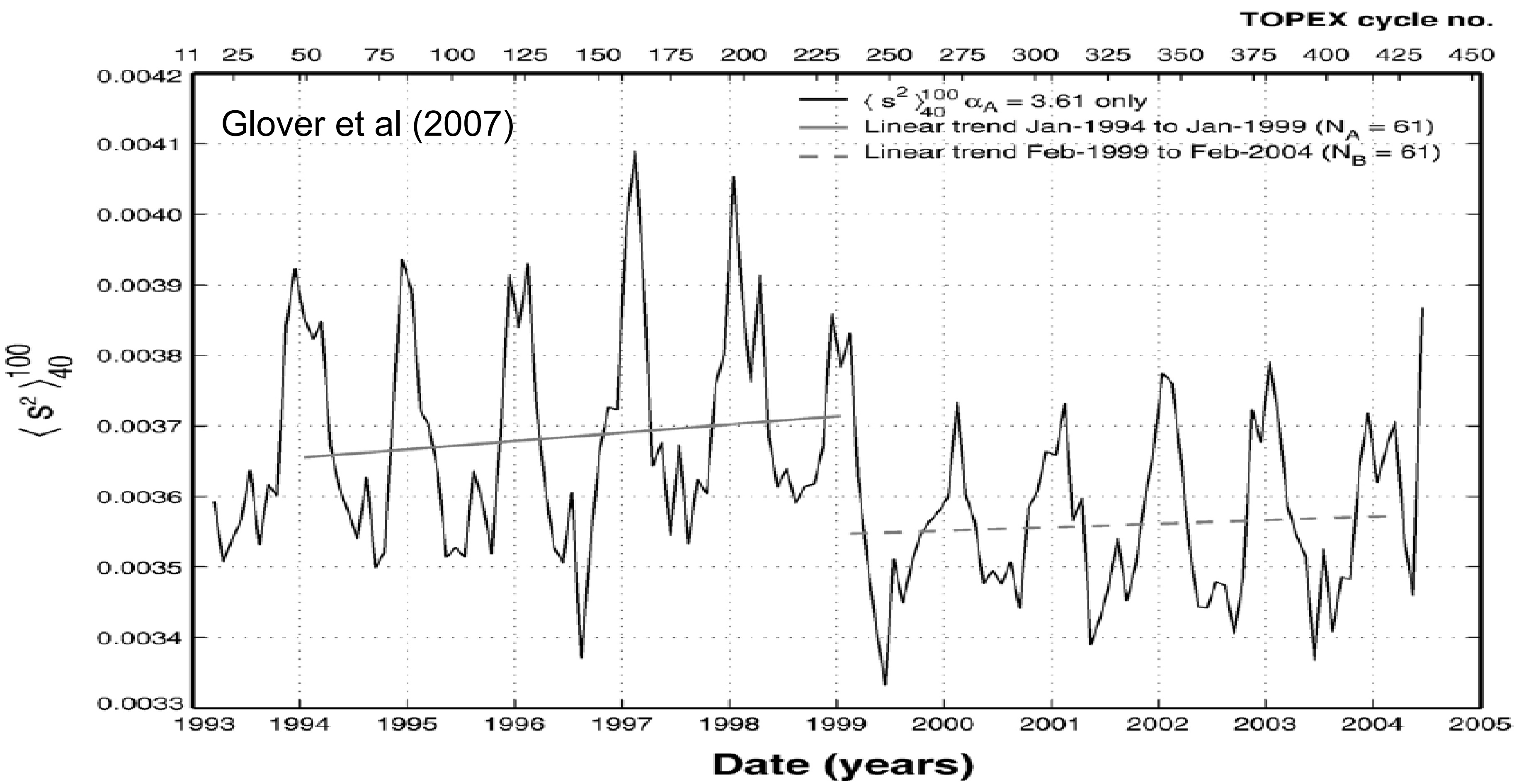




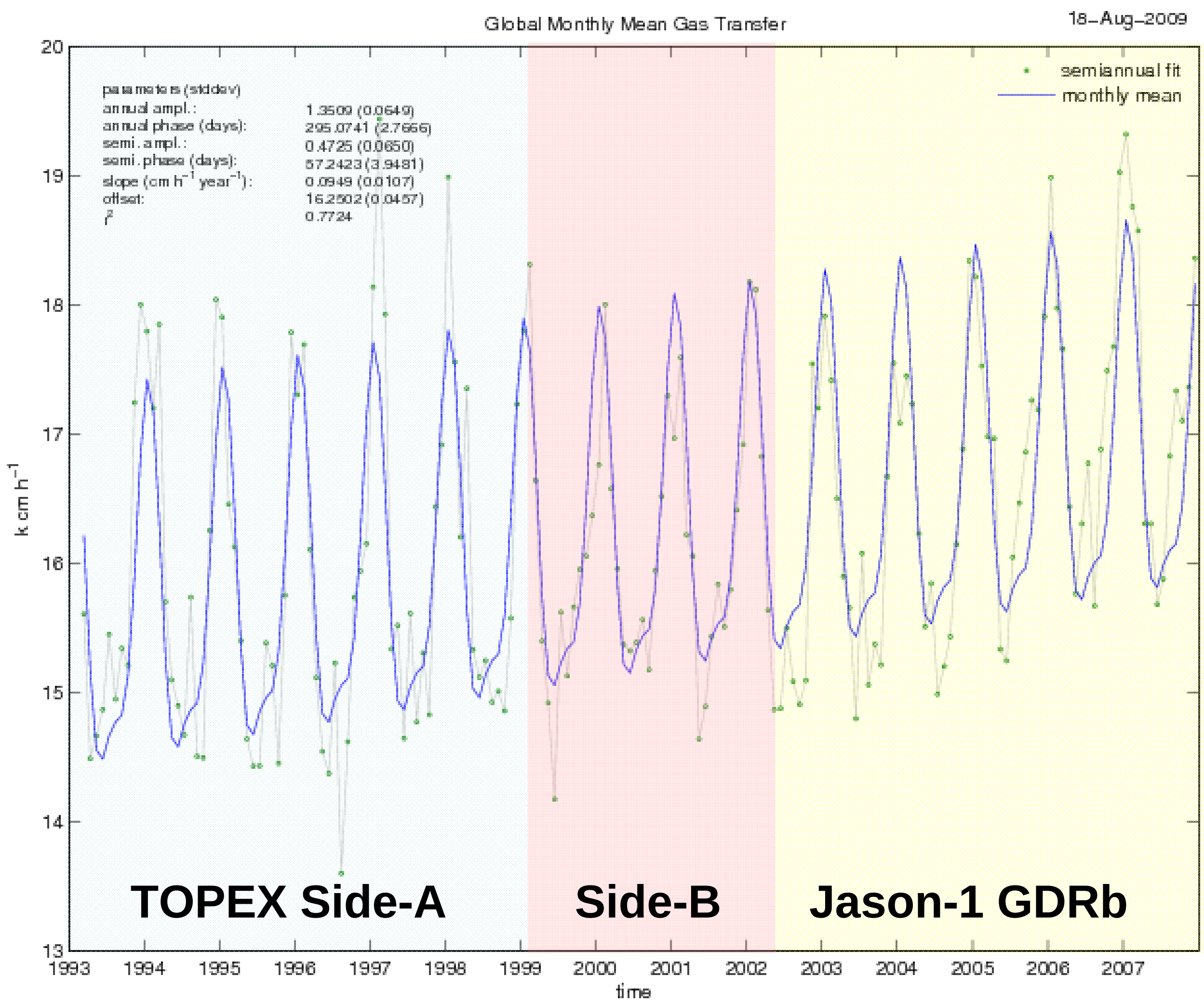
Not all radars created equal

TOPEX had identical redundant radars (Side-A and –B).

- End of Jan 1999 it was concluded Side-A was no longer functioning to specifications and Side-B was activated.
- No obvious difference in σ° was observed ($\Delta\sigma^\circ_{Ku}$(A–B)=−0.02 dB, $\Delta\sigma^\circ_C$ (A–B) = 0.03 dB).
- However the covariance between σ°_{Ku} and σ°_C changed and a step was introduced into the global, area weighted mean derivative products, including k.



$$k_{\mathrm{A}} = C_0 + C_1 \left[\frac{\rho'_{Ku}}{\sigma^{\circ}_{Ku}} - \frac{\rho'_{C}}{\left(\sigma^{\circ}_{C} + \alpha_{\mathrm{A}}\right)} \right]^2 \qquad k_{\mathrm{B}} = C_0 + C_1 \left[\frac{\rho'_{Ku}}{\sigma^{\circ}_{Ku}} - \frac{\rho'_{C}}{\left(\sigma^{\circ}_{C} + \alpha_{\mathrm{B}}\right)} \right]^2$$



Jason-2

→

Jason-3

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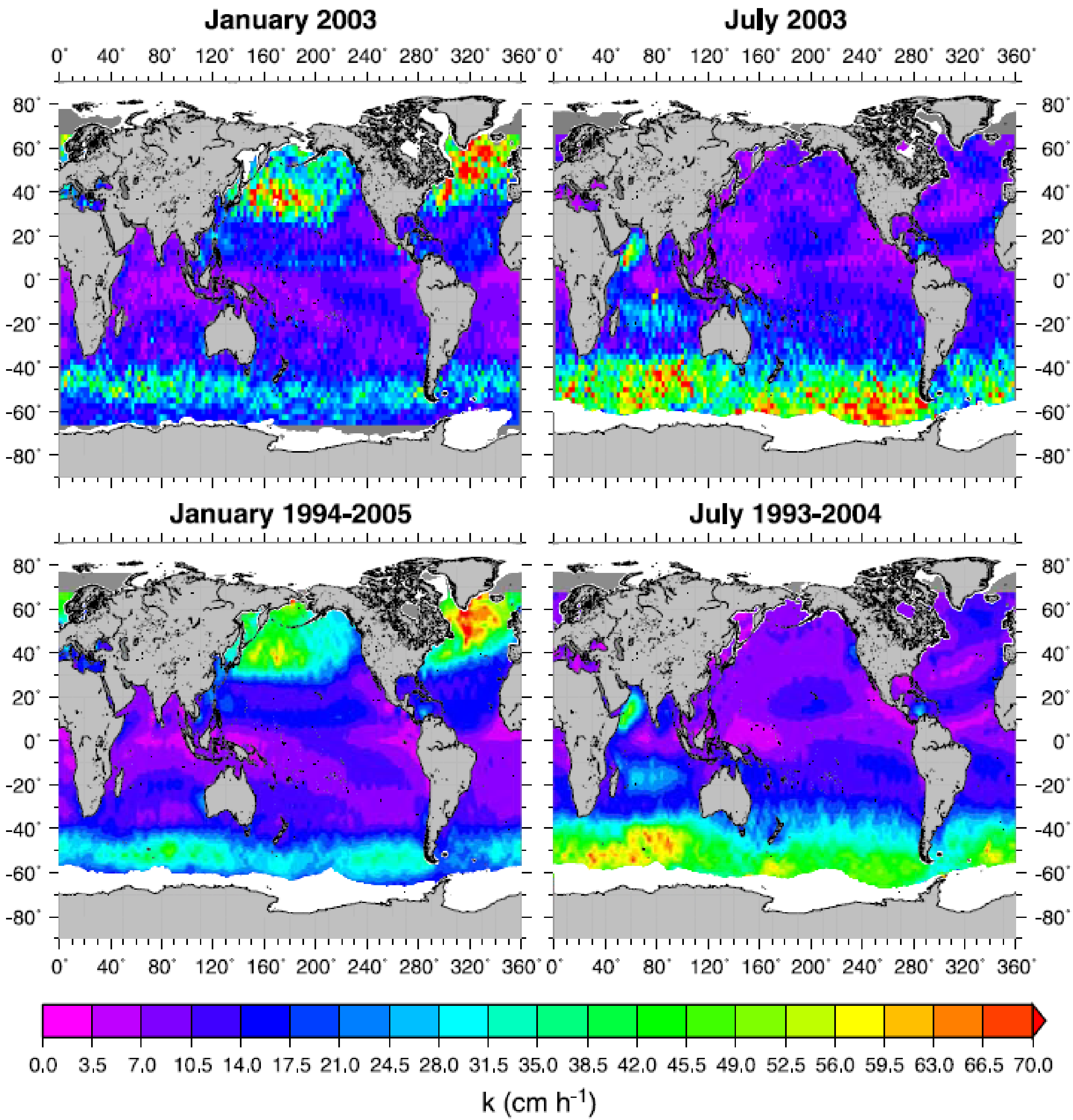
Other challenges with altimetry

- Mean square slope algorithms tend to be very sensitive to ice reflections, consequently very conservative interpretations of SSM/I ice masks (NSIDC) were necessary.
- Rain contamination continues to be a cutting edge problem in the data exclusionary stage of data processing.



Altimetry-based k are:

- Monthly
- 2.5x2.5 degree
- 16 years and continuing
- But what about higher resolution or higher frequency sampling?
- Can this approach be extended to scatterometry?

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Altimeter/Scatterometer Matchups

- Exploit the higher spatial resolution and better coverage of a scatterometer.
- Evaluate product (k_{QS}) properties.
- Primary assumption is that we can calibrate a QuikSCAT algorithm with co-located altimeter data.
  - Can't be done with scatterometry alone
- On any given day find all TOPEX or Jason-1 σ^o that
  - Lie within a QuikSCAT WVC and
  - Were so co-located within $\pm$1 hr of QuikSCAT's overpass.
- These σ^o (altimeter and scatterometer) can be related to each other through the $\Delta\langle s^2\rangle$.

Empirical model function

- Similar to Wentz and Smith (1999) and others

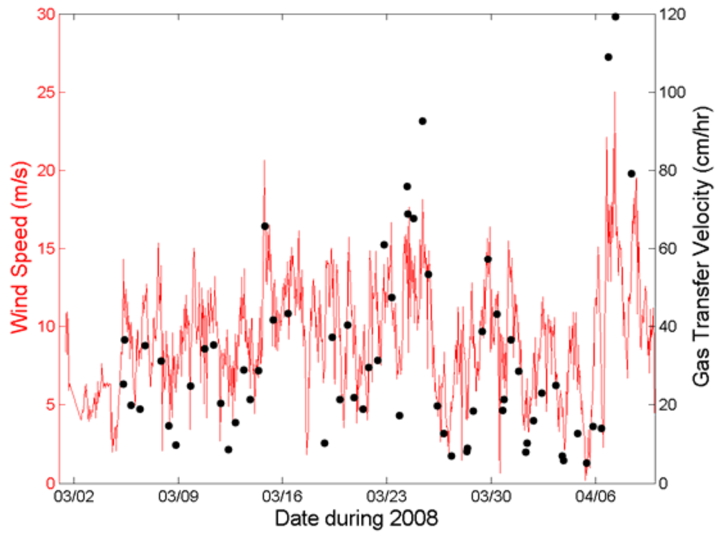
$$\Delta\langle s^2\rangle = p_1(\hat{\sigma}_\circ^{QS})^{p_2}(1 + p_3\cos\phi + p_4\cos 2\phi) + p_5$$

Table 1: Summary of parameter values QSv1.4.1

	p_1	p_2	p_3	p_4	p_5	n^a	m^b
$\theta = 46°$							
2000	0.11	0.69	0.16	-0.26	1.8e-3	166,763	255
2001	0.11	0.69	0.16	-0.26	1.8e-3	179,167	279
2002	0.10	0.68	0.17	-0.26	1.8e-3	145,214	253
2003	0.10	0.68	0.17	-0.26	1.8e-3	155,735	284
mean[c]/total	0.10	0.68	0.17	-0.26	1.8e-3	646,879	1071
std dev[d]	0.04	0.10	0.05	0.05	4e-4		
$\theta = 54°$							
2000	0.22	0.93	0.10	-0.40	2.3e-3	155,354	249
2001	0.20	0.91	0.09	-0.40	2.2e-3	172,902	269
2002	0.20	0.90	0.10	-0.40	2.3e-3	147,045	267
2003	0.20	0.90	0.10	-0.39	2.2e-3	145,923	271
mean/total	0.20	0.91	0.10	-0.40	2.2e-3	621,224	1056
std dev	0.13	0.18	0.06	0.07	4e-4		

[a] Number of matched pairs
[b] Number of days
[c] There may be some round off in the least significant digit
[d] Means and standard deviations are based on the entire 4 yr daily time series

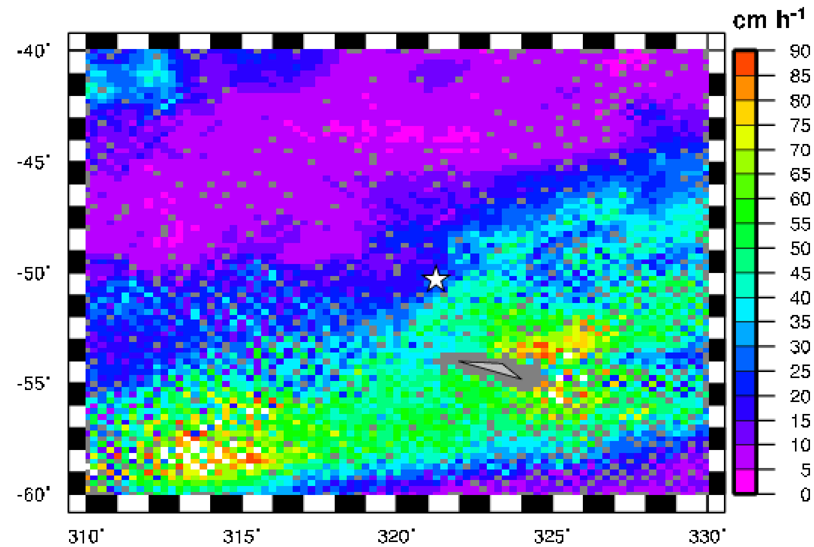
Wind from Jim Edson

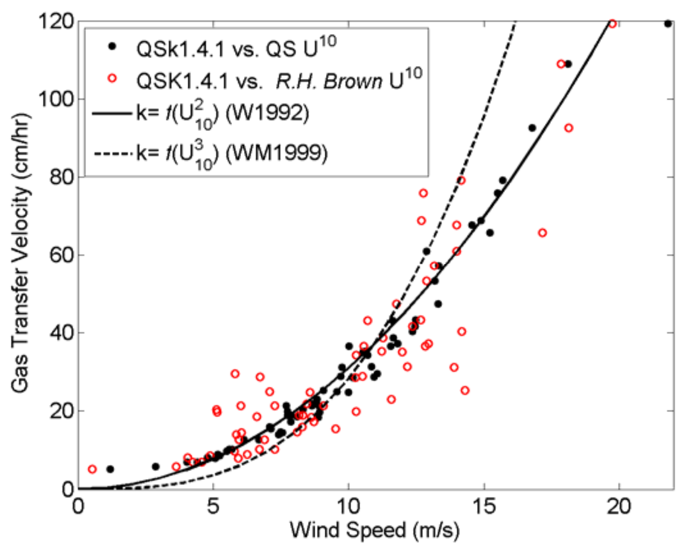


Gas Transfer Velocity, March 07, 2008

From SeaWinds on QuikSCAT Scatterometer Backscatter (norm Sc=660)

☆RV Brown at 321.25 -50.32 at 2008-03-07 15:09





Work is currently under way to compare scatterometry-based transfer velocities with field measurements made as part of the Southern Ocean GasEx experiment.

Observations germane to this meeting

- Dual frequency altimeter data greatly enhances the signal, it's an unsubstantiated assumption it can do the same for scatterometry.
- Even identical radars return subtly different signals and cross-calibration between successive instruments is an absolute must.
- Rain and ice present ongoing challenges to the remote sensing community and the addition of AMSR-E to the data stream would be a great improvement over current passive microwave frequency mixes and spatial resolutions.

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