On the pathways for air-sea gas transport through sea ice-covered waters

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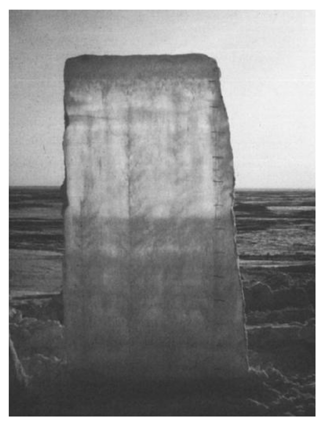
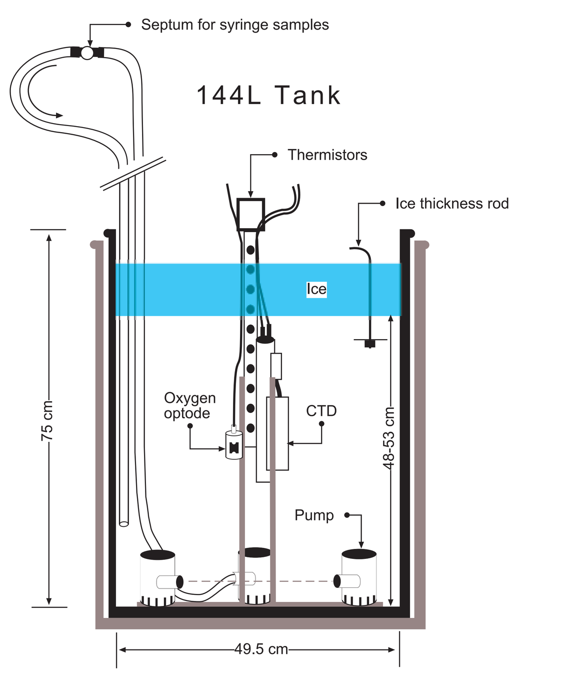
Introduction



SOURCE: Cole and Shapiro, (1998)

- The pathways of gas transport through sea ice have been identified but transport rates are poorly constrained.
- **This study attempts to quantify the rate of bulk diffusive gas transport through the porous microstructure of sea ice in comparison to air-sea exchange through open water in the ice pack.**

I) Laboratory estimate of buk gas diffusion through sea ice



- The time evolution in O_2, SF_6 and ice thickness were used to infer the rate of bulk gas diffusion, D.
- Bulk diffusion rate (L^2t^{-1}):

$$D = \frac{hz_{ice}}{\Delta t} \ln\left(\frac{C_i - C_{eq}}{C_f - C_{eq}}\right)$$

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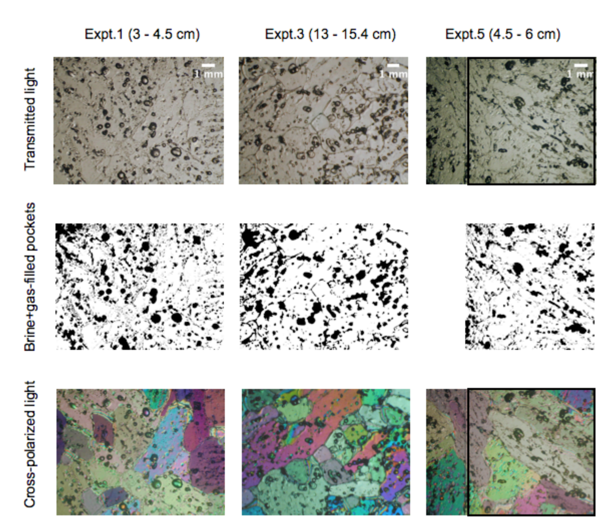
- $h =$ depth of water beneath ice.
- $C_{eq} =$ atmospheric concentration in solubility equilibrium.
- SF_6: initially high in water (evasion).
- O_2: initially high or low (invasion) during successive experiments.

Ia) Porosity (ϕ) in ice cores.

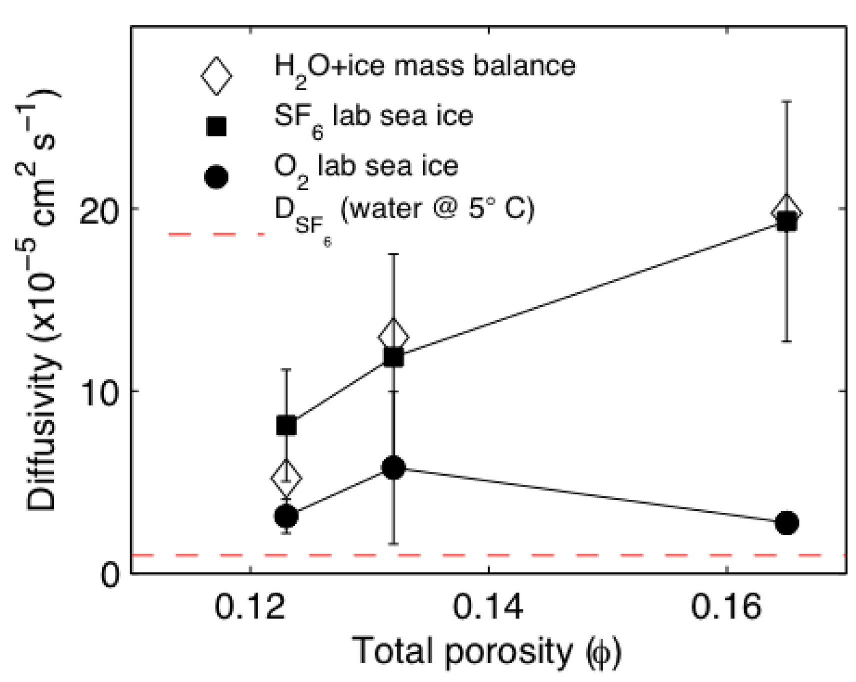
- Estimates of total porosity, ϕ, taken from thin section micrographs.

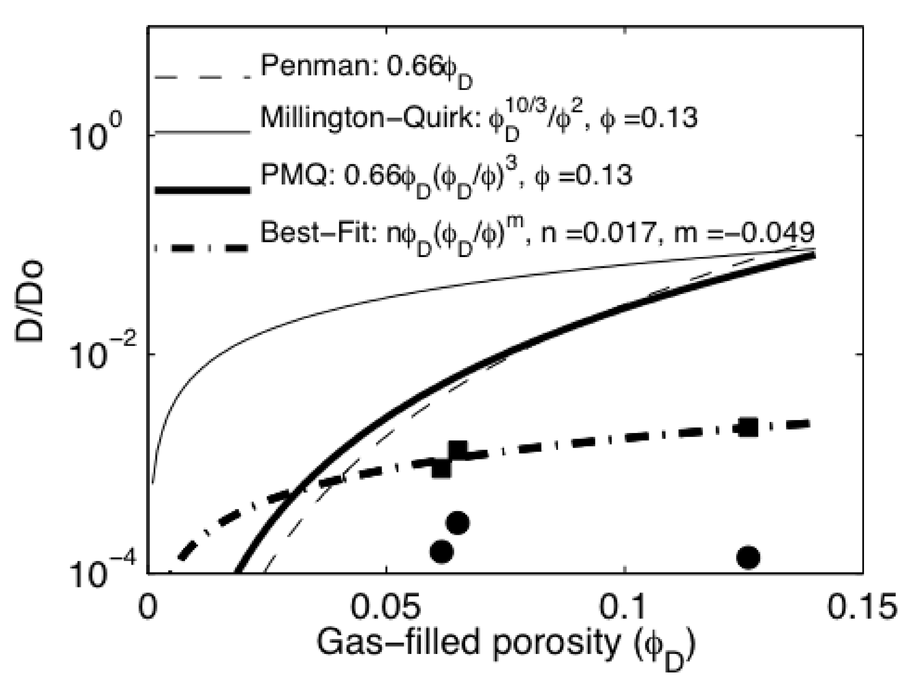
Ex.5 Core depth	ϕ	Ex. 1 Core depth	ϕ	Ex.3 Core depth	ϕ
0-1.5 cm	0.103	0-1.3 cm	0.077	0-2 cm	0.133
3-4.5 cm	0.120	3-4.5 cm	0.156	2-4 cm	0.146
4.5-6 cm	0.148	4.5-6 cm	0.124	7.5-9.6 cm	0.172
		7.5-9 cm	0.171	13-15.4 cm	0.213
St. dev.	0.02	St. dev.	0.04	St. dev.	0.04
Mean	0.12	Mean	0.13	Mean	0.17



Ib) Relationship between porosity and bulk diffusion

- Diffusion in the soil vadose zone provides a physical analog to sea ice. In soils, diffusion is related empirically to porosity.
- Empirical models for gas diffusion in soils show a steeper trend with porosity, indicating that tortuosity is greater in sea ice.

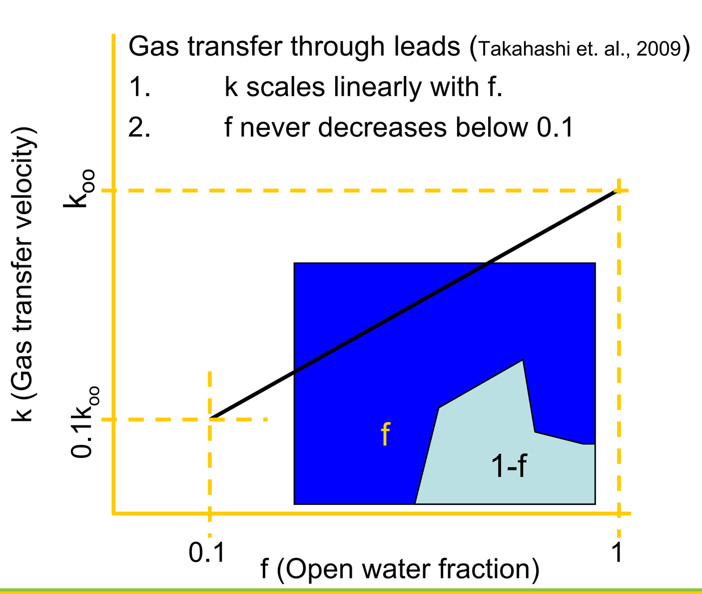




- **Bulk gas diffusion (D) was within the range of 3 - 20 x 10^{-5} cm^2s^{-1}. For comparison, molecular gas diffusion in water is $O(10^{-5})$ cm^2s^{-1}.**

Ic) Diffusive flux (F_d) of CO_2 compared with air-sea CO_2 flux (F_{Gex}) through leads.

Using the maximum of D ($D_{CO_2} = 2.5\text{x}10^{-4}cm^2s^{-1}$) and ice thickness of 50 cm, we compare the diffusive flux to gas exchange through leads from Takahashi et al., (2009).



- Takahashi et. al., (2009):

$$F_G = k_{oo}\Delta C$$
$$= 1.7\Delta C \text{ (at } f = 0.1)$$

- This study:

$$F_G = k_{oo}\Delta C$$
$$F_D = 0.014\Delta C \text{ (through 50 cm of ice)}$$

- F_{Gex} is 100 times greater than F_d, when the fraction of open water area, f is 10%.

II) What is the gas transfer velocity (k) in the seasonal ice zone?

- Fanning and Torres, (1991) used ^{222}Rn:^{226}Ra activity to estimate k in the Barents Sea:
  Late winter, $f \sim 0.1^*$, $k = 1.4$ m d^{-1}
  Late summer, $f > 0.3^*$, $k = 2.2$ m d^{-1}

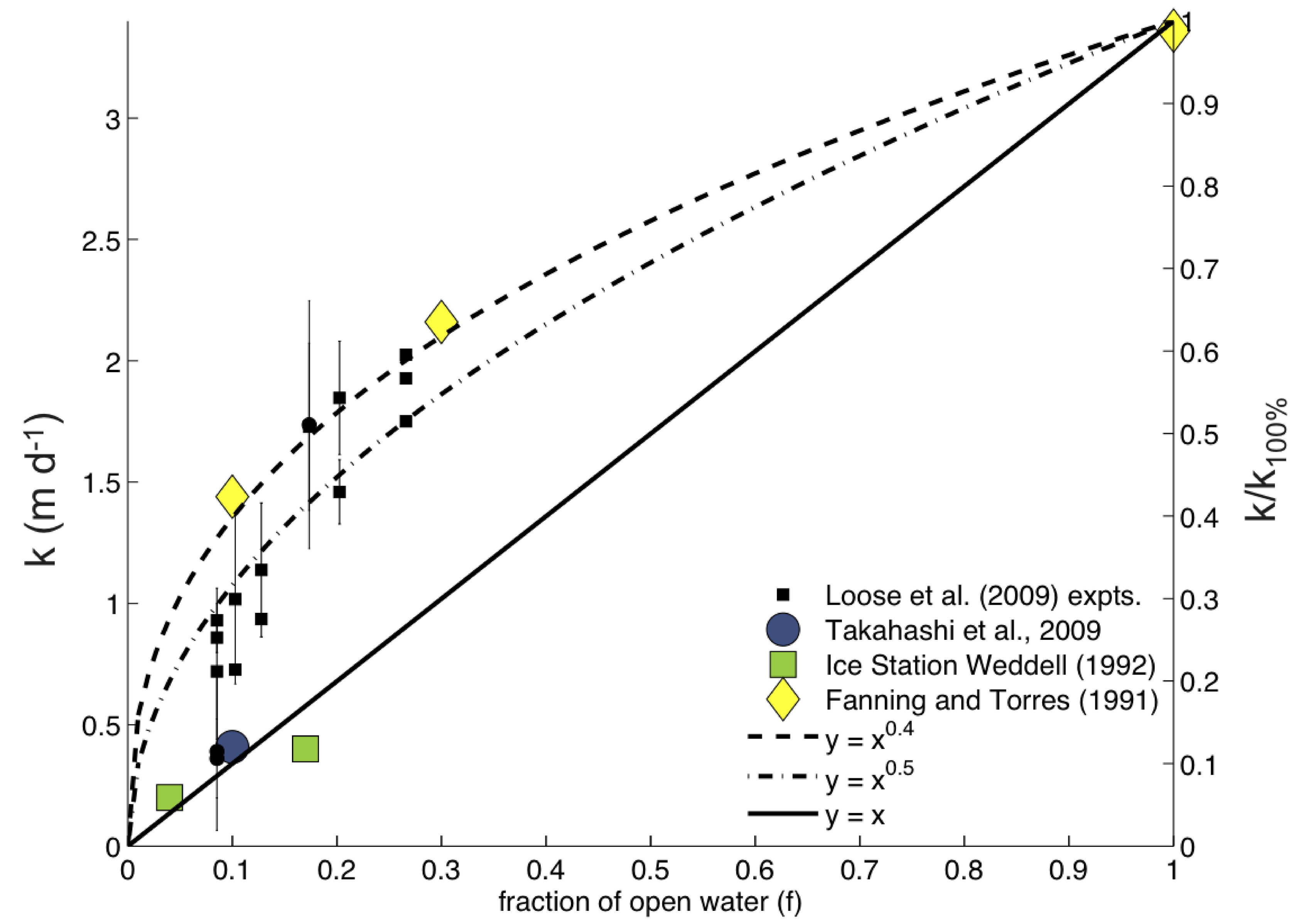
IIa) How does k scale with sea ice cover?

- Gas exchange estimated over 12-24 hour period at each open water fraction (f).

f = 0.10

f = 0.13

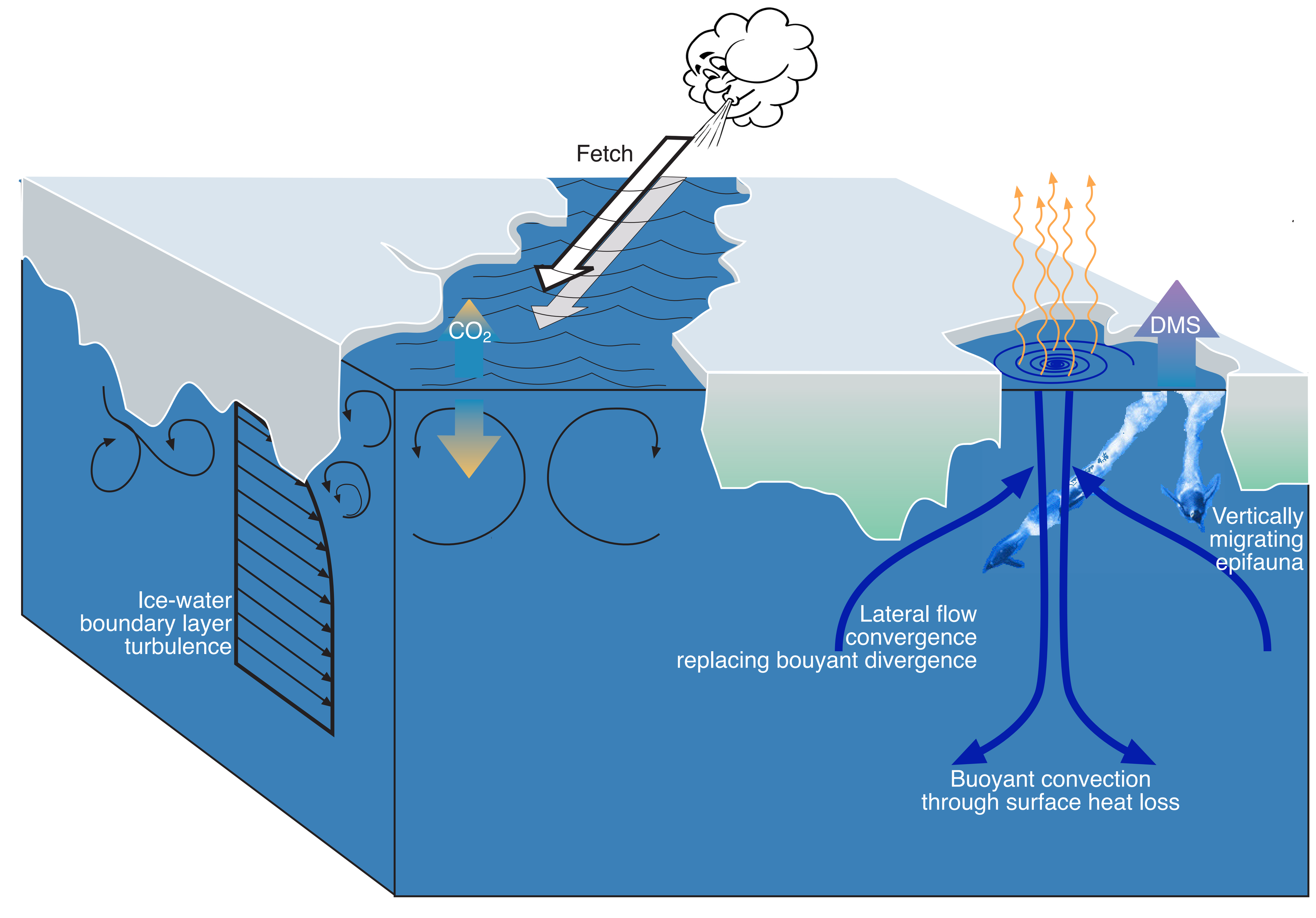
f = 0.26



- Fanning and Torres give very different values from those of the Ice Station Weddell data and the hypothesis of Takahashi, et al. (2009), for similar range of f.
- These results demonstrates that knowledge of f alone is not sufficient to constrain k. Turbulence production is not uniquely controlled by fetch.

Summary

- Diffusion through sea ice microstructure appears to be a small flux pathway for gas transport to the atmosphere during consolidated ice cover.
- The rate of gas transfer in the presence of sea ice remains an open question.
- We require an empirical model that relates the mechanisms of turbulence production to the gas transfer velocity.



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