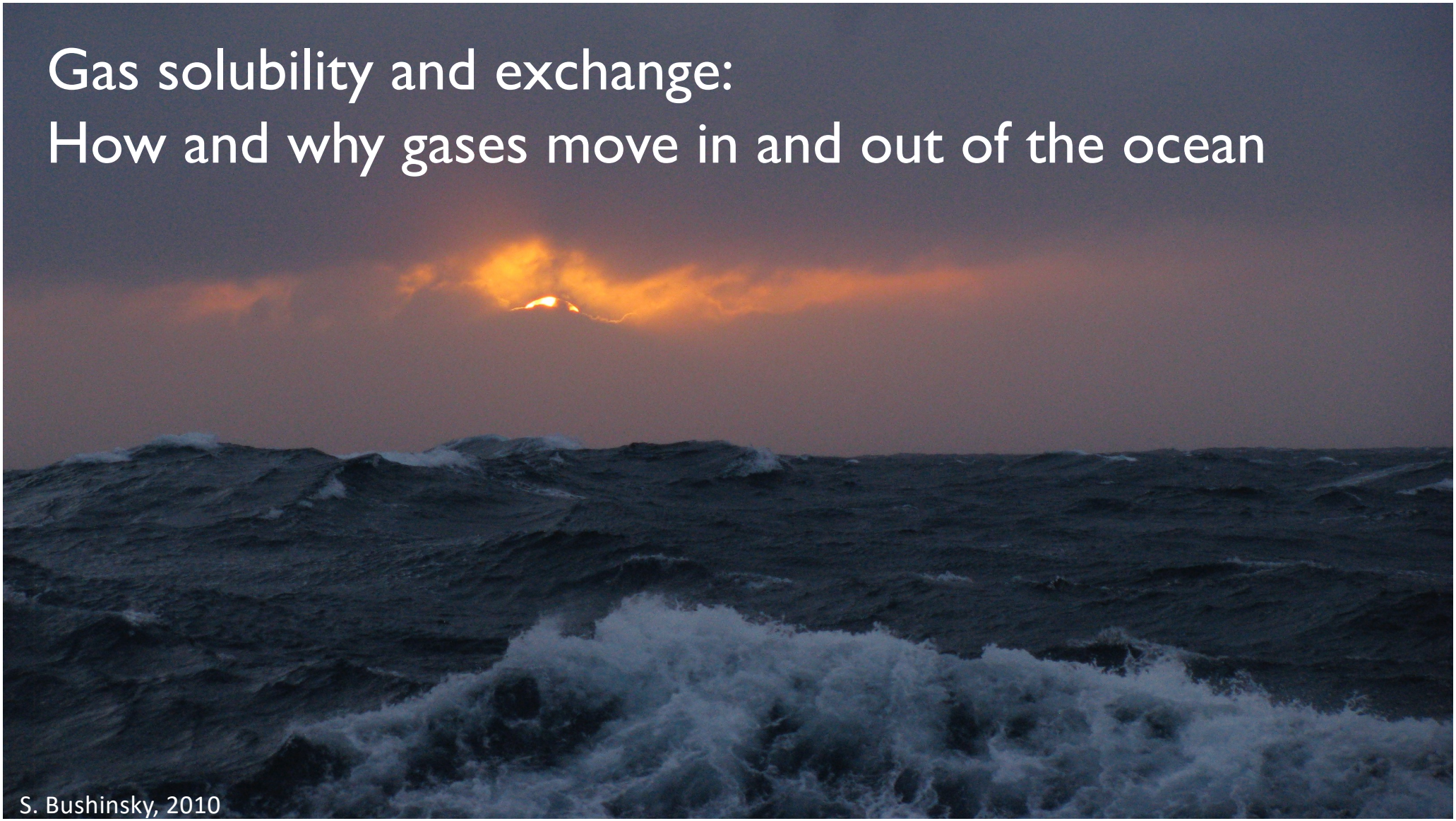
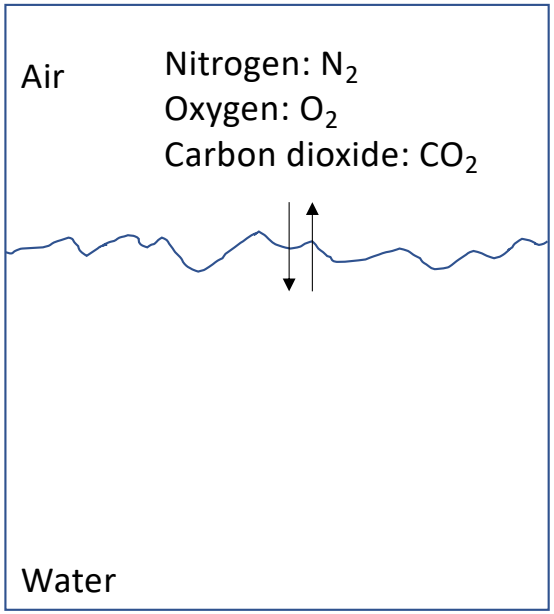
Gas solubility and exchange:
How and why gases move in and out of the ocean



S. Bushinsky, 2010

Why are gases useful?

- Tracers for physical processes:
  - mixing, deep water formation, air-sea exchange, circulation
- Biological processes: biological production, respiration, oxygen deficient zones
- Atmospheric chemistry/global climate change
- Tracers of large-scale ocean changes



What controls gas concentrations?

- Air-sea gas exchange + solubility
- Production and removal within the ocean
- Mixing in the ocean

Composition of the atmosphere

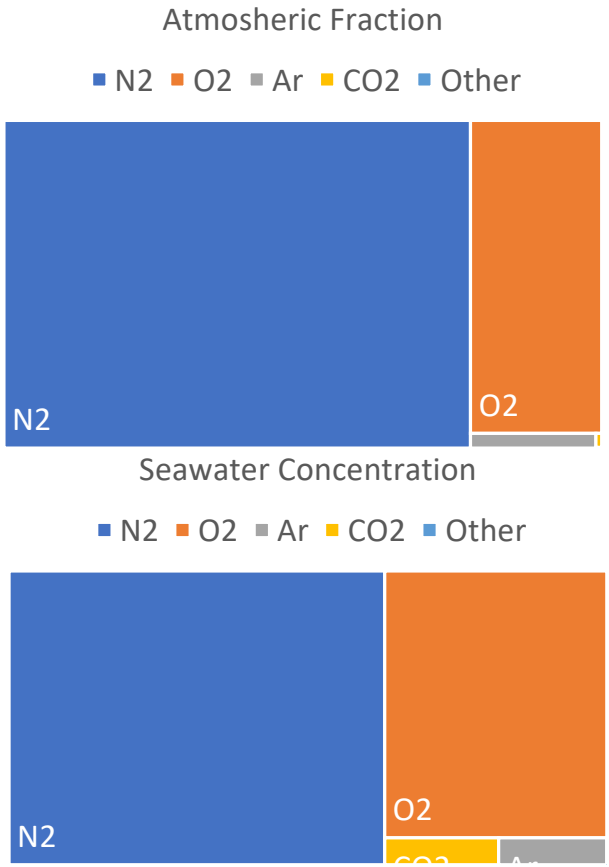
Table 1.5. *The major gases of the atmosphere excluding water vapor, which has a concentration of a few percent at saturation in the atmosphere*

Seawater equilibrium concentrations were calculated from the Henry's Law coefficients at 20 °C and $S = 35$.

Gas	Atmospheric mole fraction (atm)	Seawater equilibrium concentration (μmol kg^{-1})
N_2	7.808×10^{-1}	4.18×10^{2}
O_2	2.095×10^{-1}	2.25×10^{2}
Ar	9.34×10^{-3}	1.10×10^{1}
CO_2	3.65×10^{-4}	1.16×10^{1}
Ne	18.2×10^{-6}	7.0×10^{-3}
He	5.24×10^{-6}	2.0×10^{-3}
Kr	1.14×10^{-6}	2.0×10^{-3}
Xe	0.87×10^{-7}	3.0×10^{-4}

~ 99%

Mole fraction is the amount (atm or moles) of a gas relative to atmosphere as a whole



Emerson and Hedges, 2007

Dalton's law of partial pressures

- Partial pressure (p_i) is the pressure of an individual gas:
  - So if oxygen is ~20% of atmospheric pressure, and atmospheric pressure is 1atm, the partial pressure of oxygen is 0.2 atm
- Total pressure in a fixed volume is equal to the sum of the partial pressures of the components of the mixture

$$P_T = \sum p_G = p_{N_2} + pO_2 + pAr + pH_2O + \cdots$$

- Dalton's Law implies ideal behavior, i.e. all gases behave independently of one another.

Gas solubility

- The solubility of a gas determines its partitioning between the atmosphere and water
  - The amount of a gas that will be present in water at a given T and P_T (total atmospheric/headspace pressure)
- Solubility coefficients are a type of chemical equilibrium constant that defines the solubility of a gas in water

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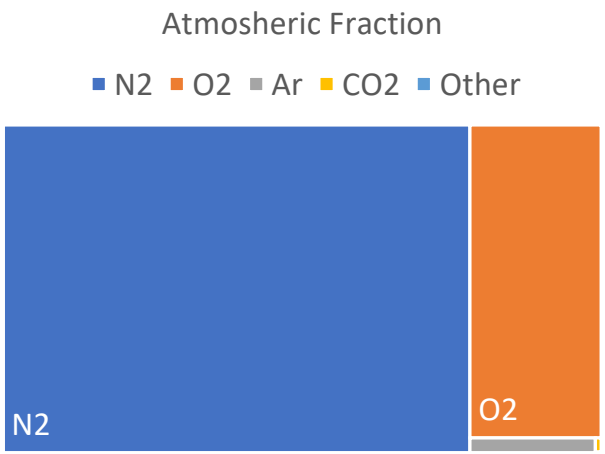
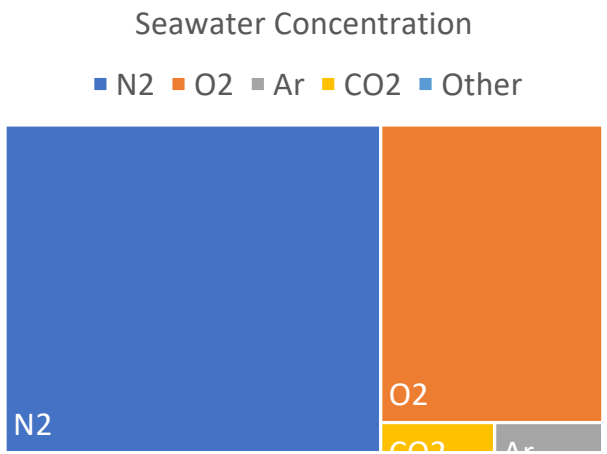
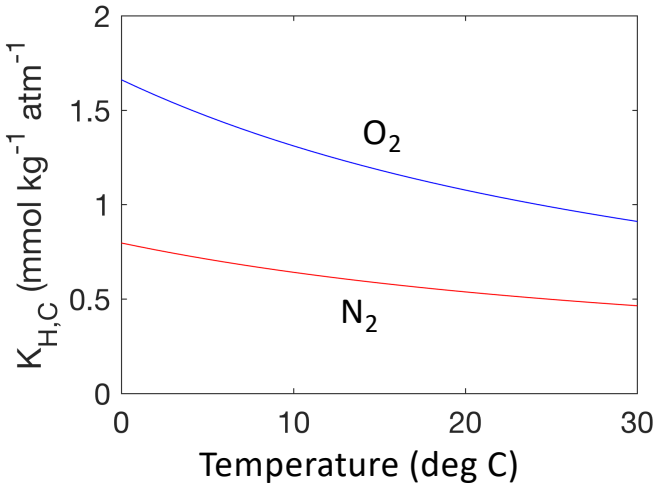




Solubility vs. partial pressure: O_2 and N_2

- Oxygen: ~20 % of the atmosphere
  Partial pressure = 0.209
- Nitrogen: ~78 % of the atmosphere
  Partial pressure = 0.781

Solubility vs. Temperature



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  Partial pressure (pO_2=fO_2) = 0.209
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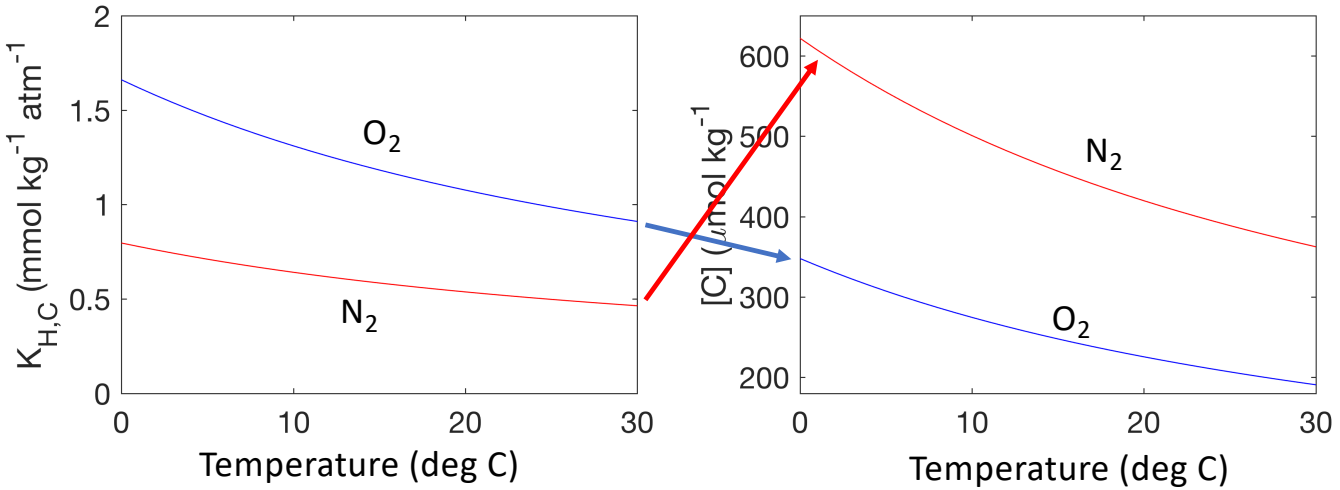
N_2 is 4x more plentiful in the atmosphere, but only half as soluble as oxygen, so saturation concentration is ~2x oxygen

Solubility vs. Temperature



What affects gas exchange in the ocean?

Mechanisms?

- Cooling/heating
- Mixing with deeper waters
- Breaking waves
- Winds
- wind speed
- wave height
- wave shape
- breaking vs. non-breaking (bubbles)
- spray
- relative direction of wind and waves

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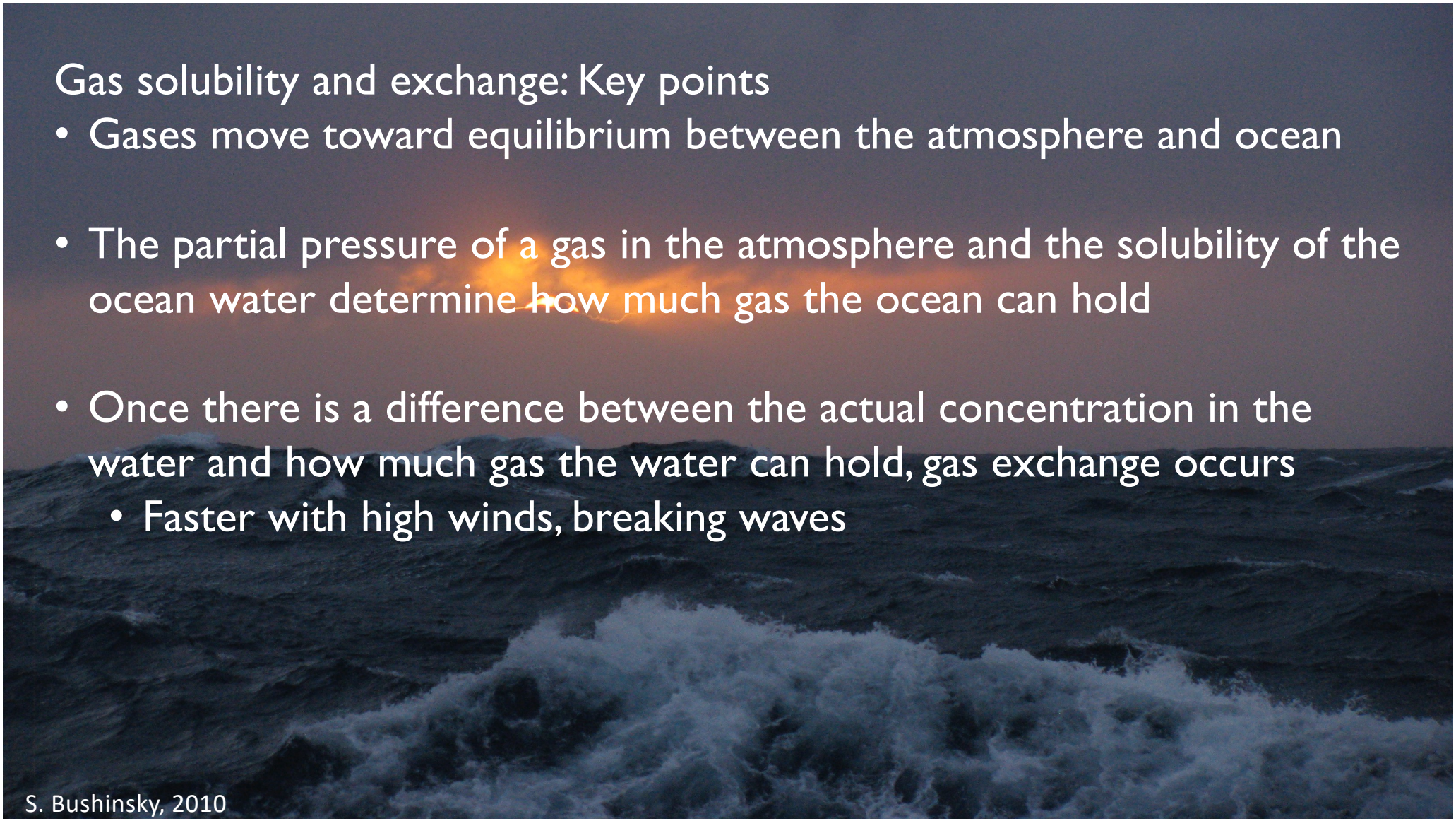

Gas solubility and exchange: Key points

- Gases move toward equilibrium between the atmosphere and ocean
- The partial pressure of a gas in the atmosphere and the solubility of the ocean water determine how much gas the ocean can hold
- Once there is a difference between the actual concentration in the water and how much gas the water can hold, gas exchange occurs
  - Faster with high winds, breaking waves

S. Bushinsky, 2010