Physics

Cause and effect…

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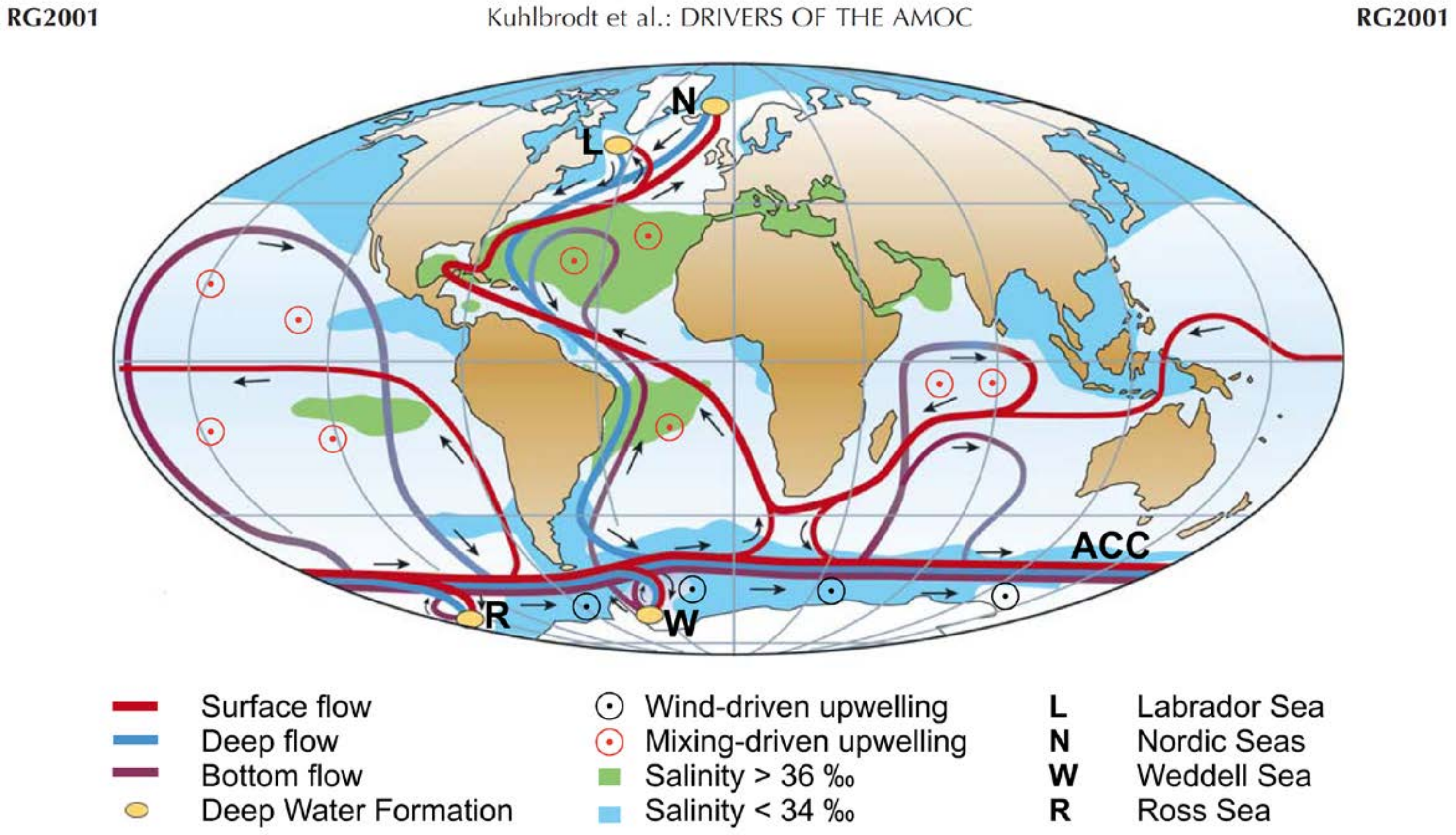
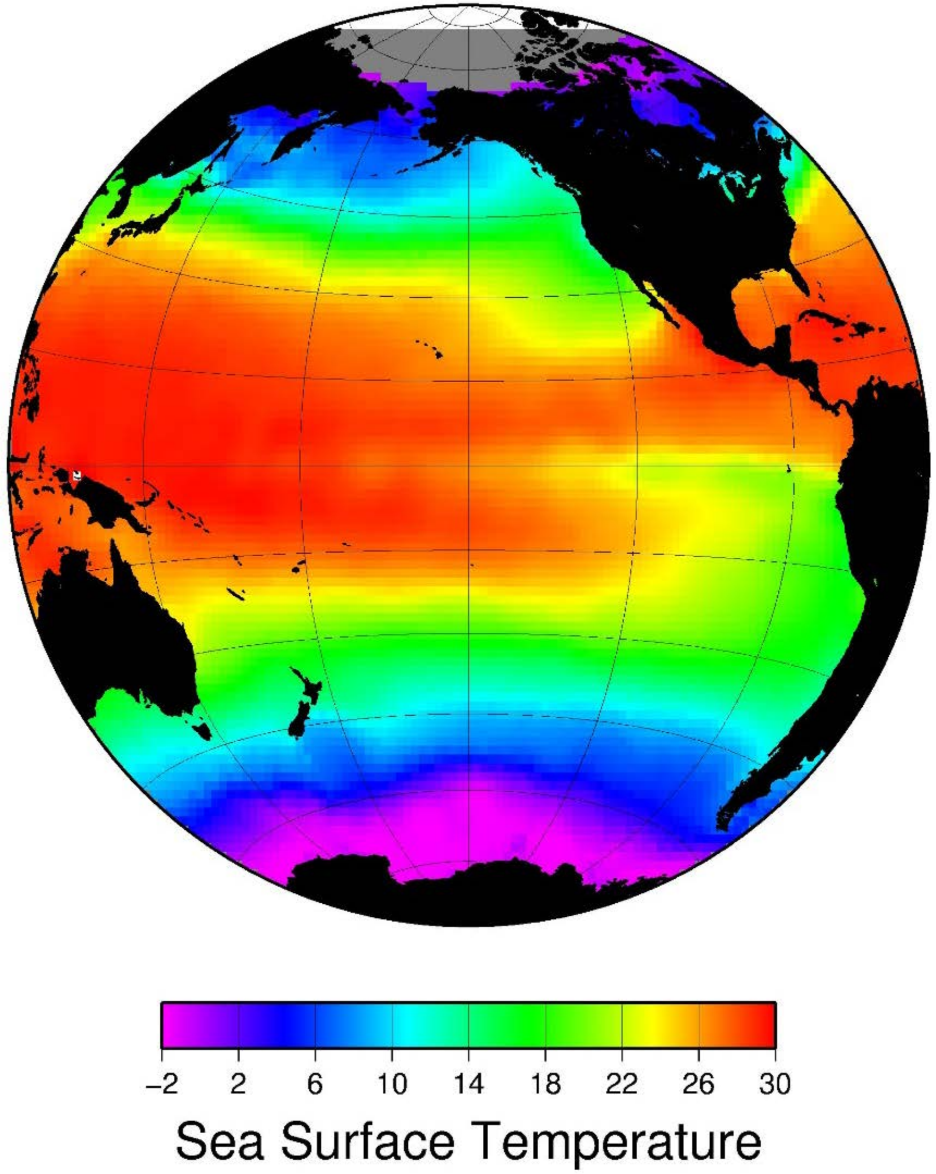
Physics: Cause and effect…

- Large scale distributions of nutrients are driven by ocean circulation patterns
  - Biotic feedback important as well





Physics: Cause and effect…

1. Diagnosing rates and processes from observations
   - Underlying assumptions & limitations
2. Proposing a strategy
   - Lowering expectations and regional scale schematic models
3. Specific examples: the ETPZ
   - Abyssal hydrothermal plume evolution
   - Upwelling

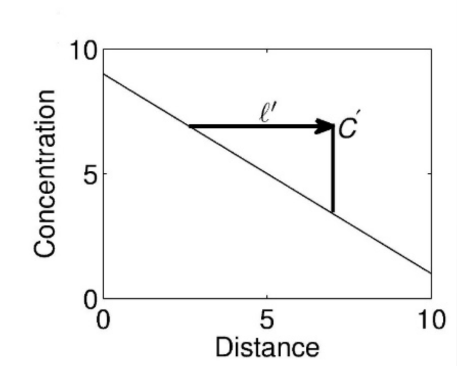
Diagnosing rates and processes from observations

1. Lagrangian conservation: $$\frac{dC}{dt} = J$$

   J hides a large number of processes: including *In situ* consumption/production, sorption/desorption, *etc.*

2. Eulerian framework: $$\frac{\partial C}{\partial T} + \nabla\left(\vec{u}C\right) = J + \nabla\left(D_m \nabla C\right)$$

3. Reynolds decomposition: $$\vec{u} = \overline{\vec{u}} + \vec{u}' \qquad \overline{\vec{u}} \equiv \int \vec{u} \quad \Rightarrow \quad \int \vec{u}' = 0$$ $$C = \overline{C} + C' \qquad \overline{C} \equiv \int C \quad \Rightarrow \quad \int C' = 0$$



4. Scale length assumption: $$C' \approx -\ell' \nabla \overline{C} \quad \text{so} \quad \int\left(\vec{u}'C'\right) \Rightarrow -\int\left(\vec{u}'\ell'\right)\nabla\overline{C} \Rightarrow -\mathrm{K}\nabla\overline{C}$$

5. Eddy mixing formulation: $$\frac{\partial C}{\partial T} + \nabla\left(\overline{\vec{u}}\,\overline{C}\right) = \nabla\left(\mathrm{K}\nabla C\right) + J + \nabla\left(D_m \nabla C\right)$$

$$\begin{pmatrix} \mathrm{K}_{xx} & \mathrm{K}_{xy} & \mathrm{K}_{xz} \\ \mathrm{K}_{yx} & \mathrm{K}_{yy} & \mathrm{K}_{yz} \\ \mathrm{K}_{zx} & \mathrm{K}_{zy} & \mathrm{K}_{zz} \end{pmatrix}$$

K is the turbulent diffusivity tensor

- Will have off-diagonal elements in Cartesian coordinate systems
  - Problematic since $\mathrm{K}_{zz} \ll \mathrm{K}_{xx}$ or K_{yy} (off diagonal elements of z are grossly contaminated)
- Preferred coordinate system is isopycnal (~isoneutral) where K is diagonal
  - in two isopycnal and one diapycnal directions
  - So with some assumptions…

$$\begin{pmatrix} \mathrm{K}_{x} & 0 & 0 \\ 0 & \mathrm{K}_{y} & 0 \\ 0 & 0 & D \end{pmatrix}$$

$$\frac{\partial C}{\partial t} = \vec{u} \cdot \nabla C - \kappa \cdot \left(\nabla^2 C + 2 \frac{\nabla h \cdot \nabla C}{h} \right) - D \rho_z^2 \frac{\partial^2 C}{\partial \rho^2} + J$$

where $\kappa = \begin{pmatrix} \mathrm{K}_x & 0 \\ 0 & \mathrm{K}_y \end{pmatrix}$ and $D = \mathrm{K}_z$

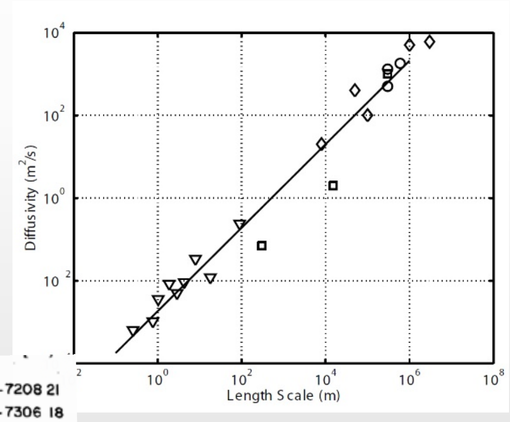
Note missing "*w*" assuming linear EOS

Assumed *C* and potential vorticity mix the same

Caveat Emptor on turbulent diffusivities

- Assumes separation of scales, subsumes “sub-gridscale” processes
- Relies on normal distributions
- There is a scale dependence:
  - Horizontally
  - Vertically

Depends on scales of motion interacting with property gradients: *e.g.*, lakes vs ocean gyres



Scales with density gradient

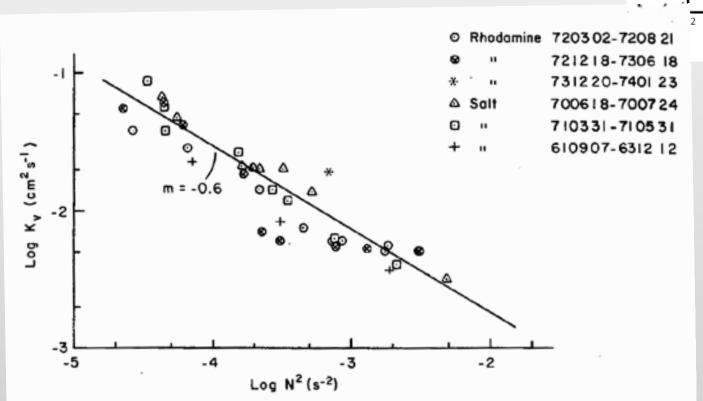
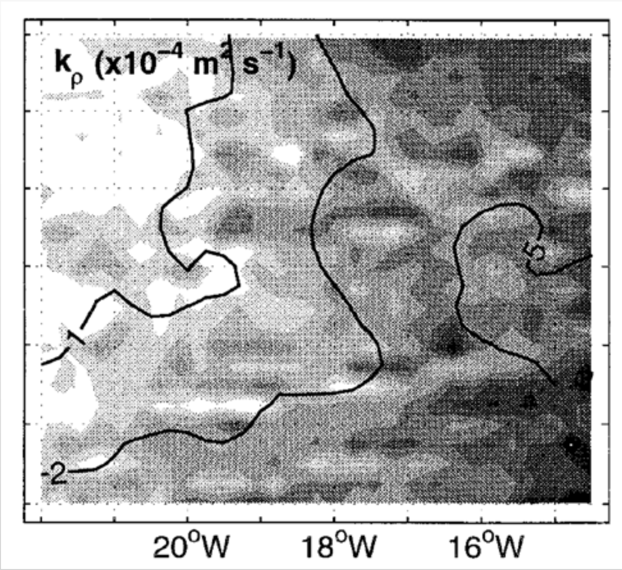


Figure 1. Vertical (diapycnal) “eddy” diffusivity K_v as a function of N^2. From Svensson (1979), who determined K_v from budgets of the ...

$$Ri = \frac{g'\nabla\rho}{\rho\left(\nabla u\right)^2}$$

And in the abyssal ocean there’s rough topography:



The sampling problem

- Cruises are typically two dimensional, non-synoptic, non-eddy resolving, may or may not close off a volume
  - - ship logistics, station time, methodological conflicts, cost of measurements
- Flow is largely 3 dimensional (not to mention the 4^{th} dimension…)
- Boundary conditions may not be well known

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3. Specific examples: the ETPZ
   - Abyssal hydrothermal plume evolution
   - Upwelling

2. Proposing a Strategy

- The long term solutions lie in the large scale, sophisticated prognostic models to be discussed by Alessandro
- A shorter term approach may be to develop a series of regional (experiment scale) schematic models that are
  - "as simple as possible but no simpler"
    - Incorporate the basic circulation and only those processes that dominate distributions
  - With prescribed empirical boundary conditions
  - Calibrate the model with observed tracers constraints
  - Can be run with limited computing power allowing …
    - Experimentation and exploration
    - Access by many experimentalists with many different "tracers"
- Recognizing that the results have limited global applicability
  - But can give a "first order" estimate of process rates

A silk purse from a sow's ear?

Proposing a Strategy

Models are *abstractions* of reality

- Incomplete physics and chemistry
- Simplified boundary conditions and domain

"Calibration" is necessary

- Constraints/parameterization need to reflect objectives
- There are plenty of "ventilation tracers"*
  - the more the merrier: CFCs, ^{3}H, ^{7}Be, ^{14}C, ^{129}I, etc.
- There are fewer "nutrient-like tracers"**
  - volcanic ^{3}He, tritiugenic ^{3}He, noble gases, ^{228}Ra (partly)
- "Age tracers" may be valuable for local (not global) modeling

*Tracing *entry* paths into the ocean

**Tracing *return* paths back to the surface

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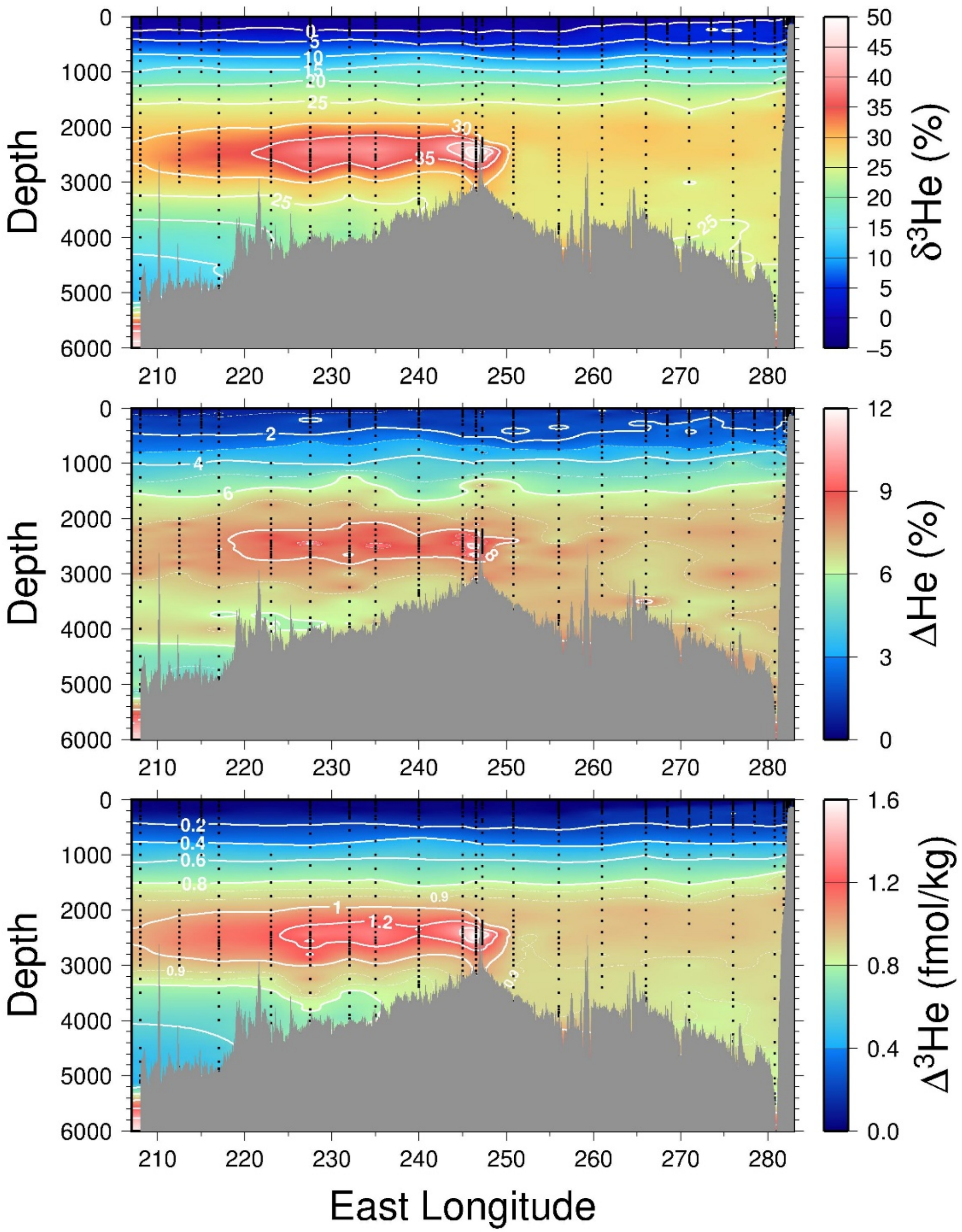
Example 1: The EPZT Hydrothermal plume



Stommel (1982)

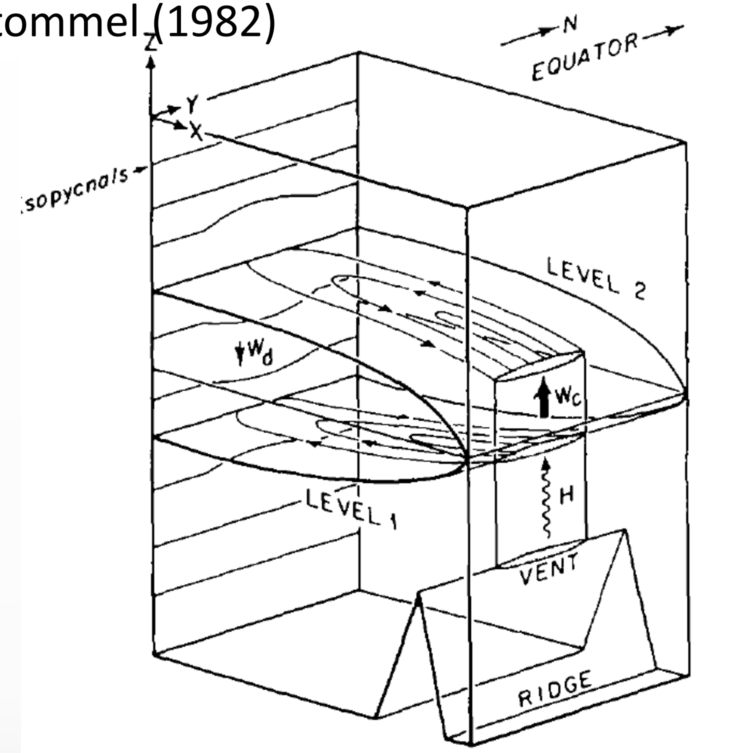
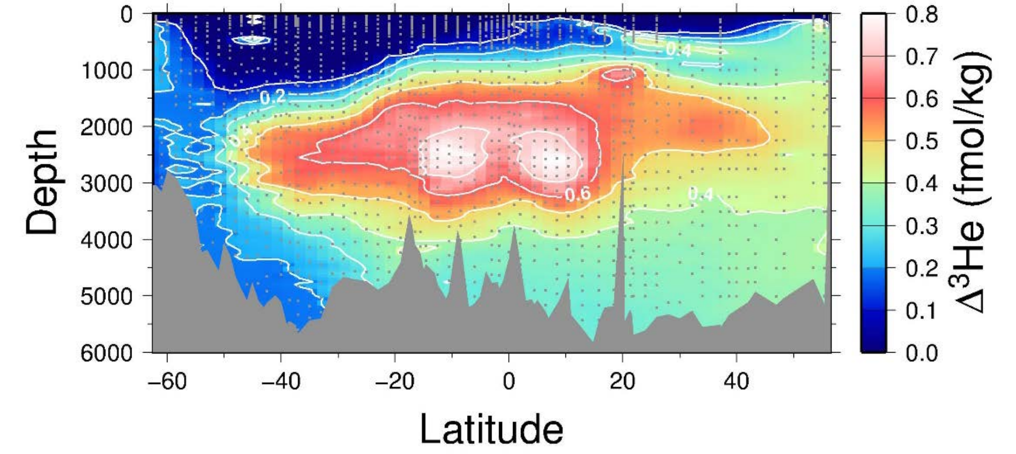


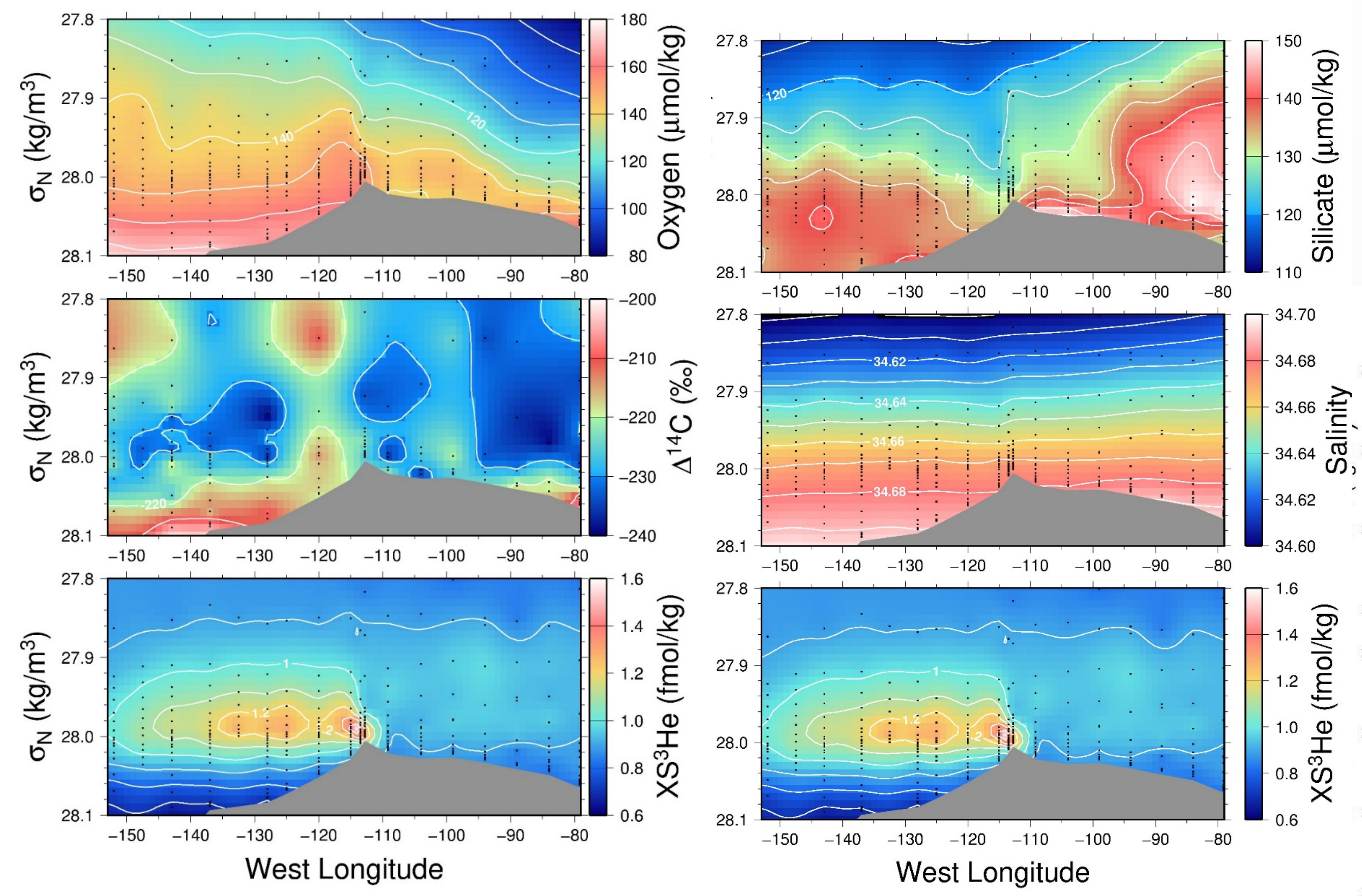
Fig. 1. Two oppositely rotating superposed gyres at mid-depth driven by large volume, w_c, of water entrained into hot vent water, H, at the lower level and released at higher level. Due to beta-effect the gyres extend westward from the crest of the

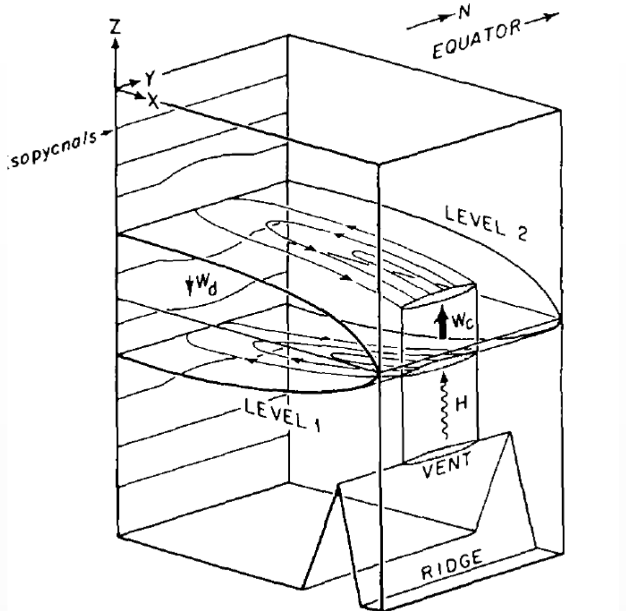
Superimpose this on a large scale circulation?

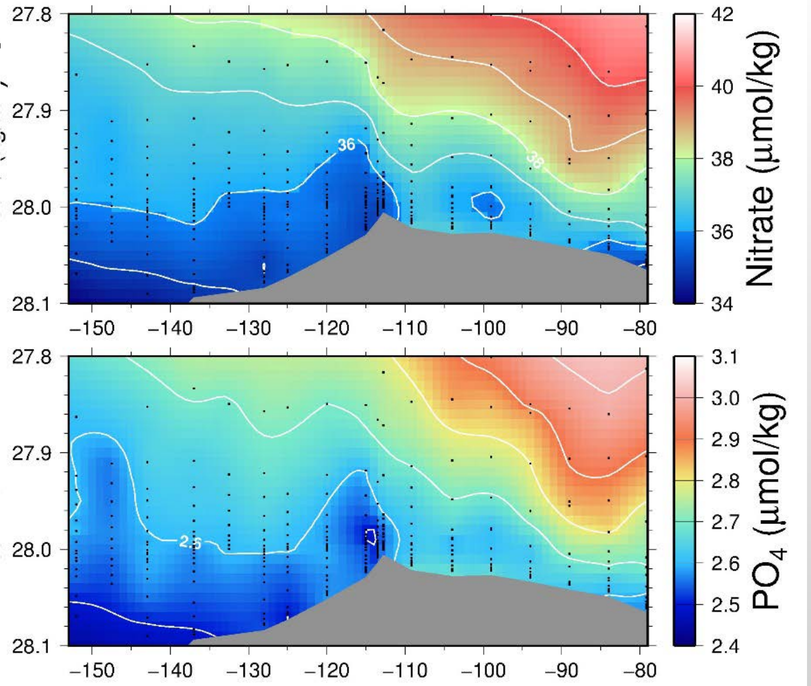
^3He section along 150^o W



The EPZT Hydrothermal Plume

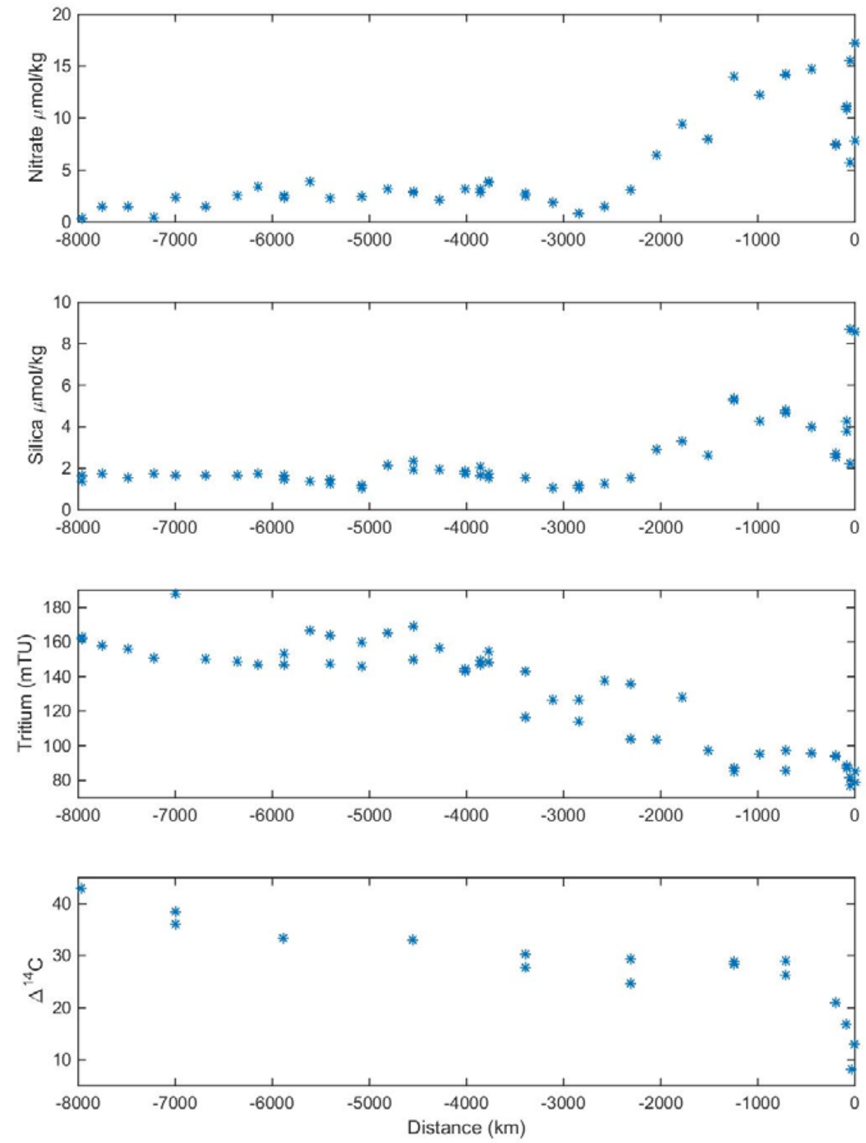


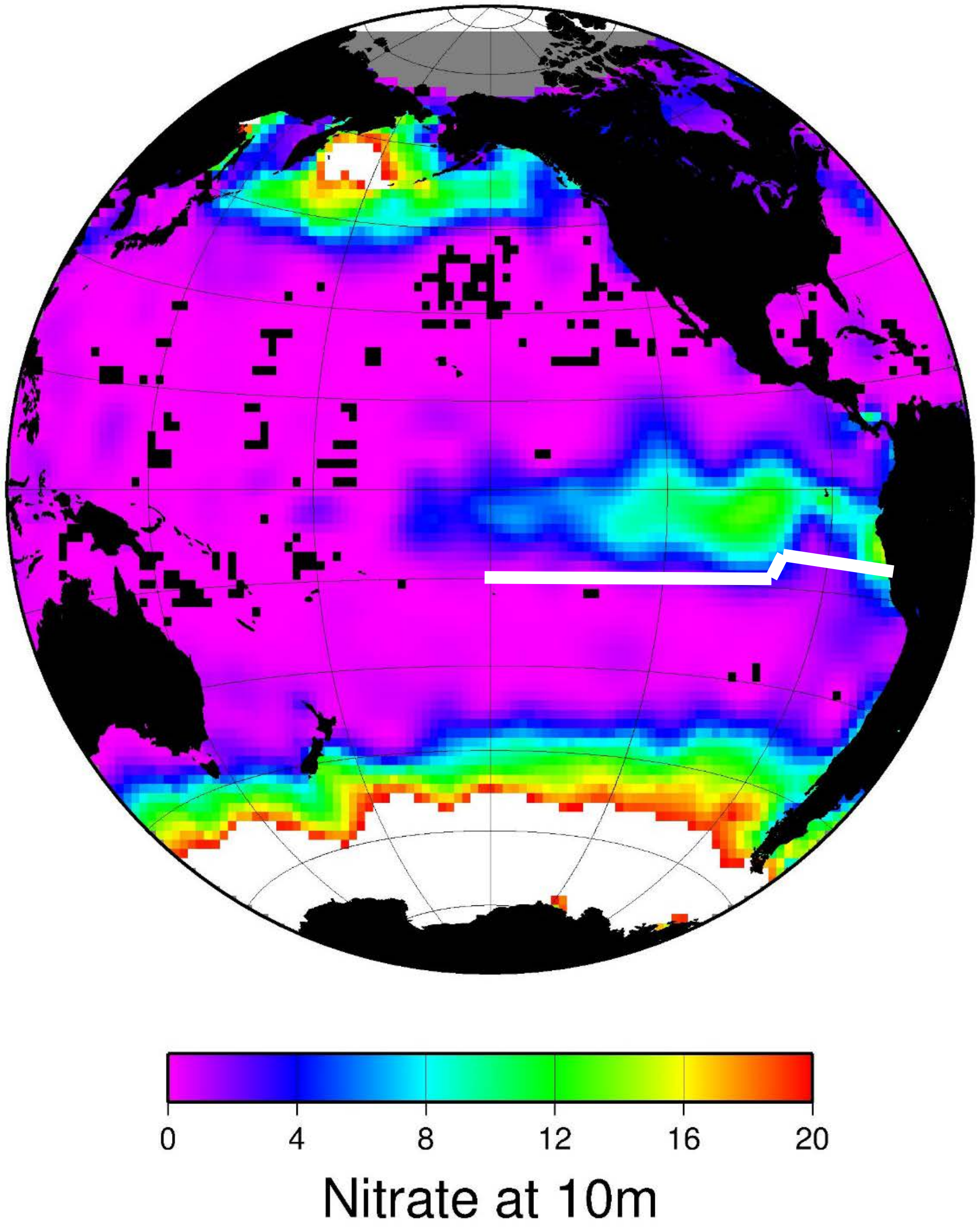


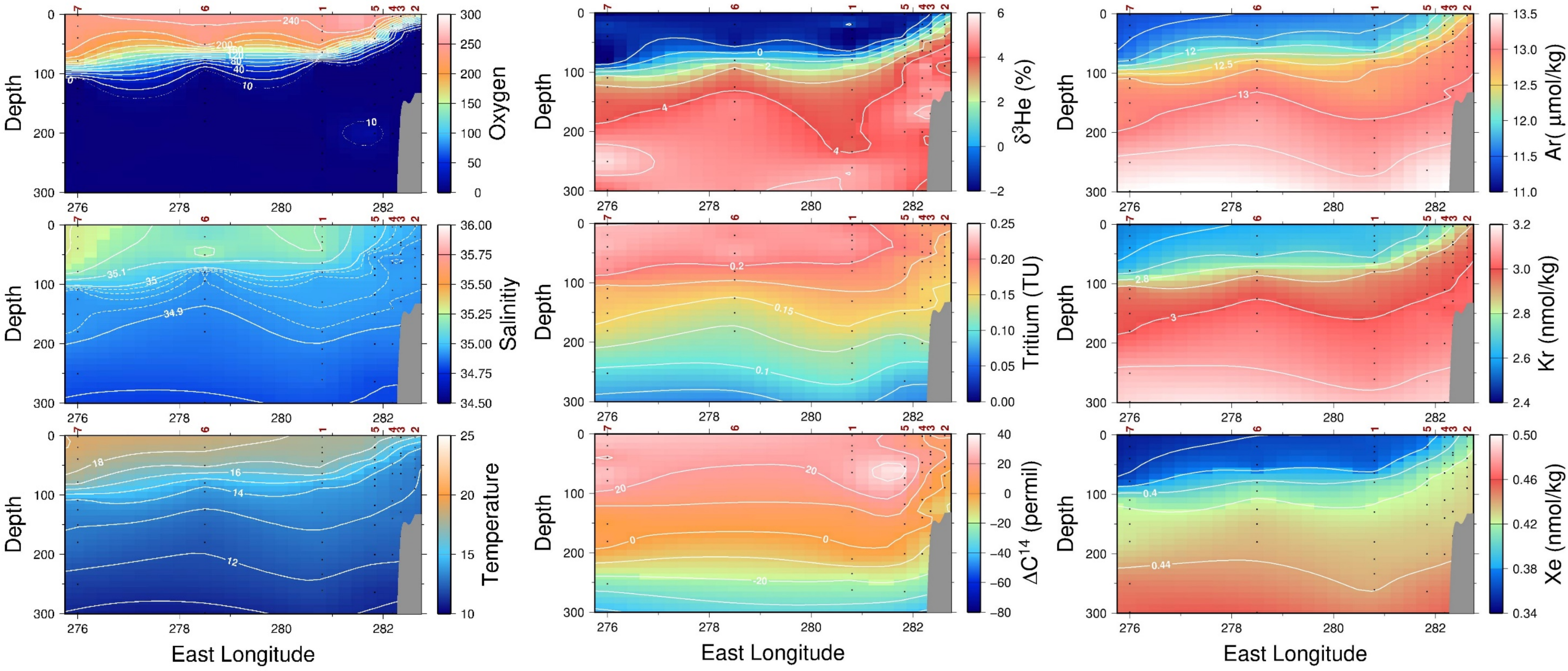


Example 2: The EPZT Upwelling Region

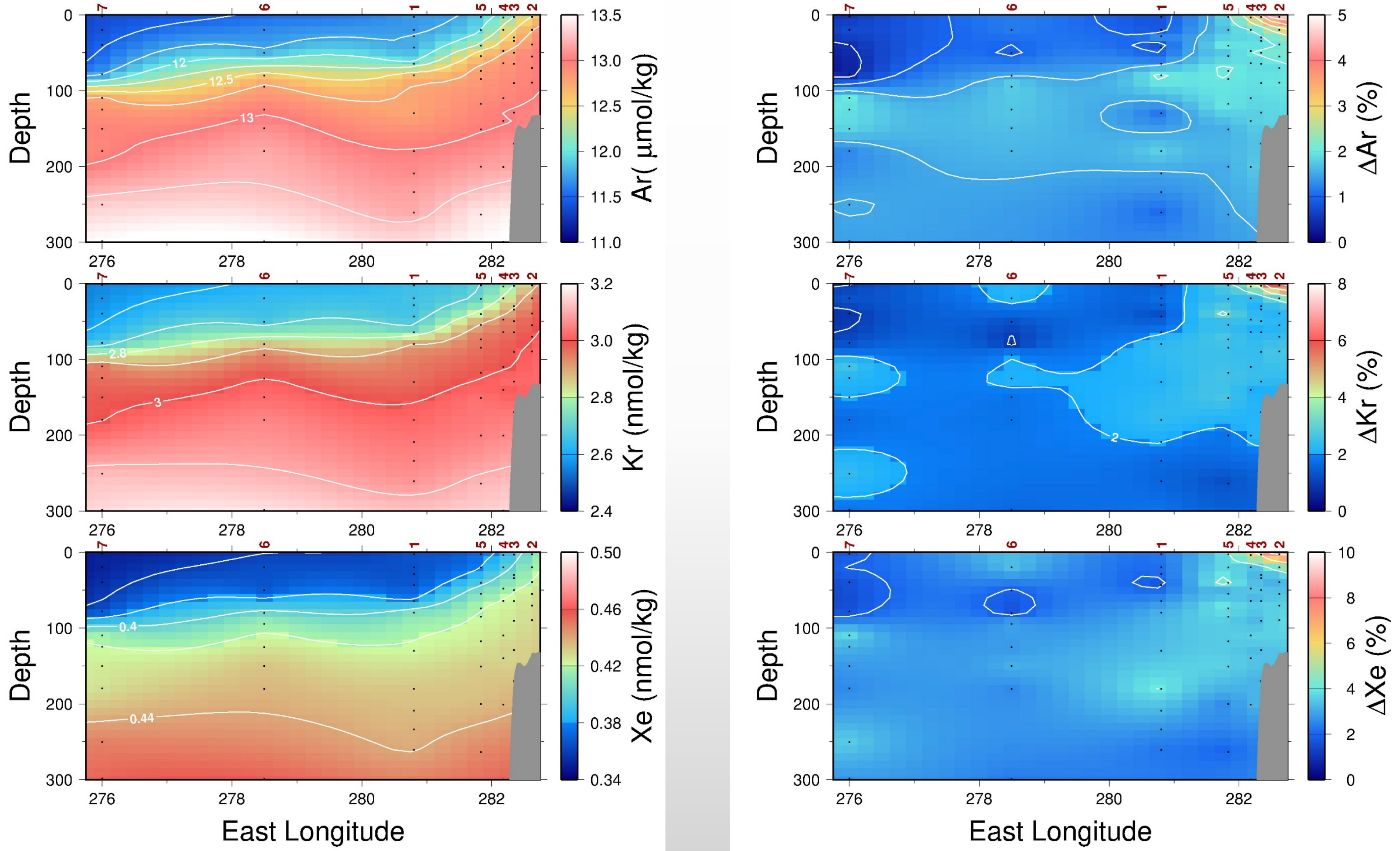
- A quasi-zonal section off Peru at ~12°S







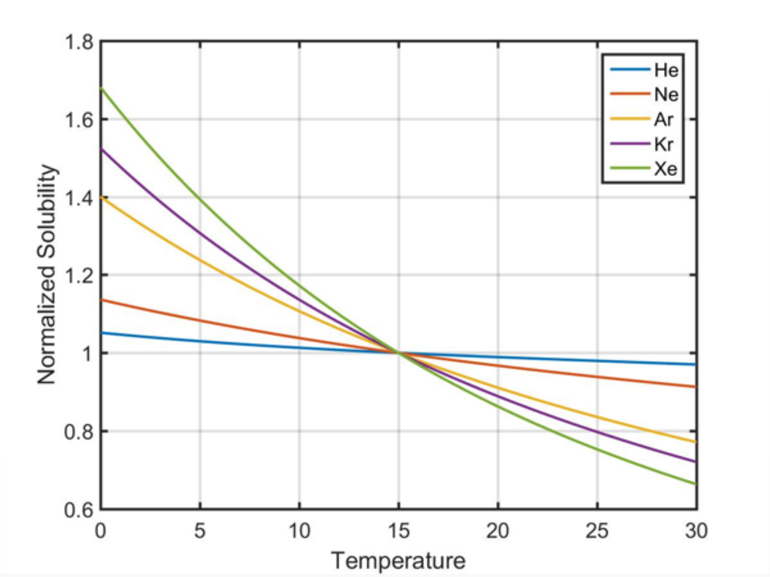
Depth
Oxygen
Salinitiy
Temperature
δ3He (%)
Tritium (TU)
ΔC14 (permil)
Ar(µmol/kg)
Kr (nmol/kg)
Xe (nmol/kg)
East Longitude



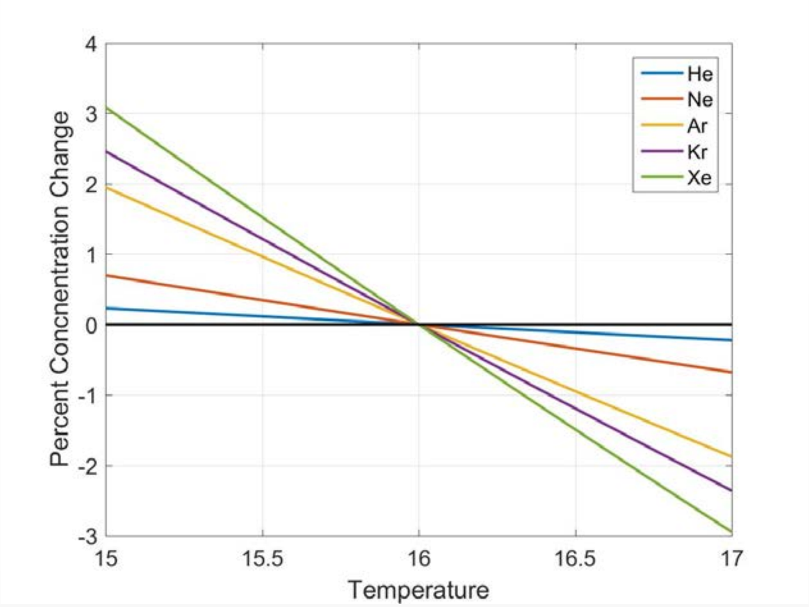
Depth
Ar(µmol/kg)
ΔAr (%)
Kr (nmol/kg)
ΔKr (%)
Xe (nmol/kg)
ΔXe (%)
East Longitude

Noble gas properties

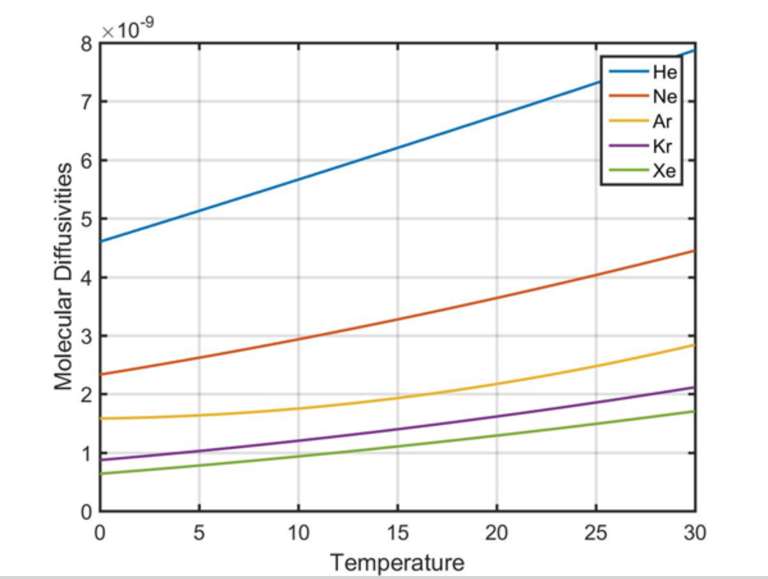
Have a range of solubilities and temperature depencies



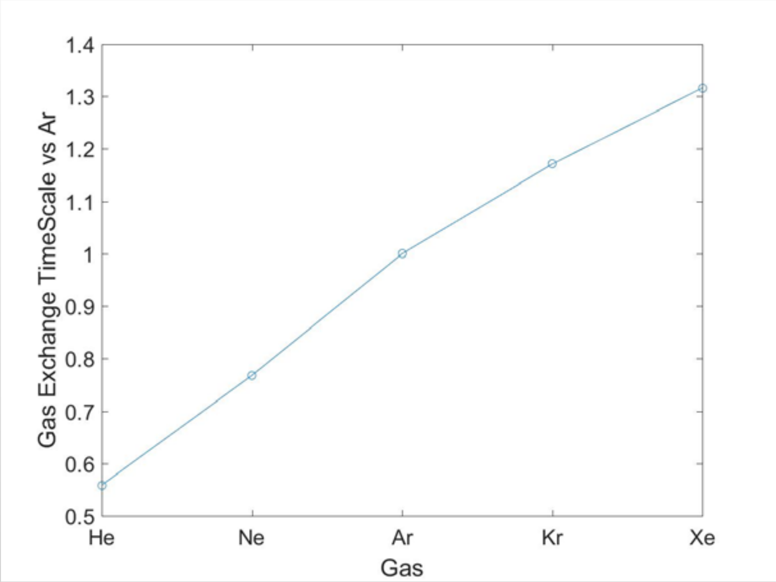
Responses to temperature change ranges from 0.2 to 3%/degree

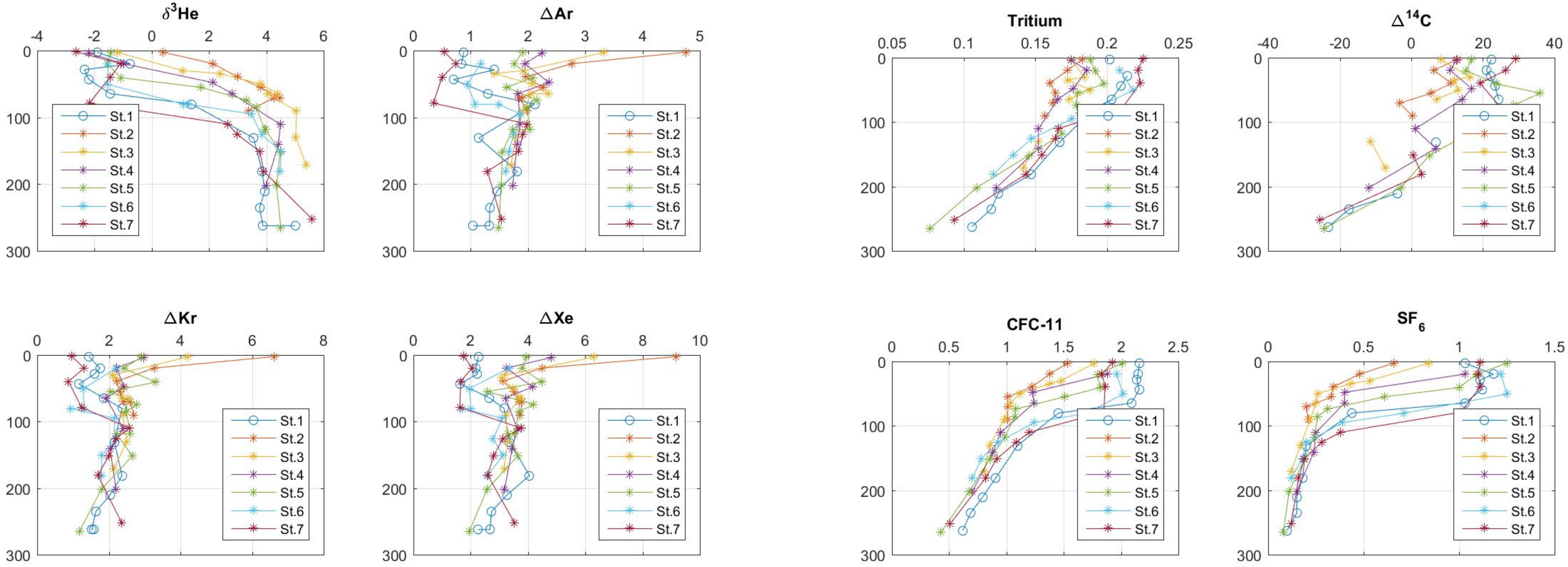


Have a range of molecular diffusivities



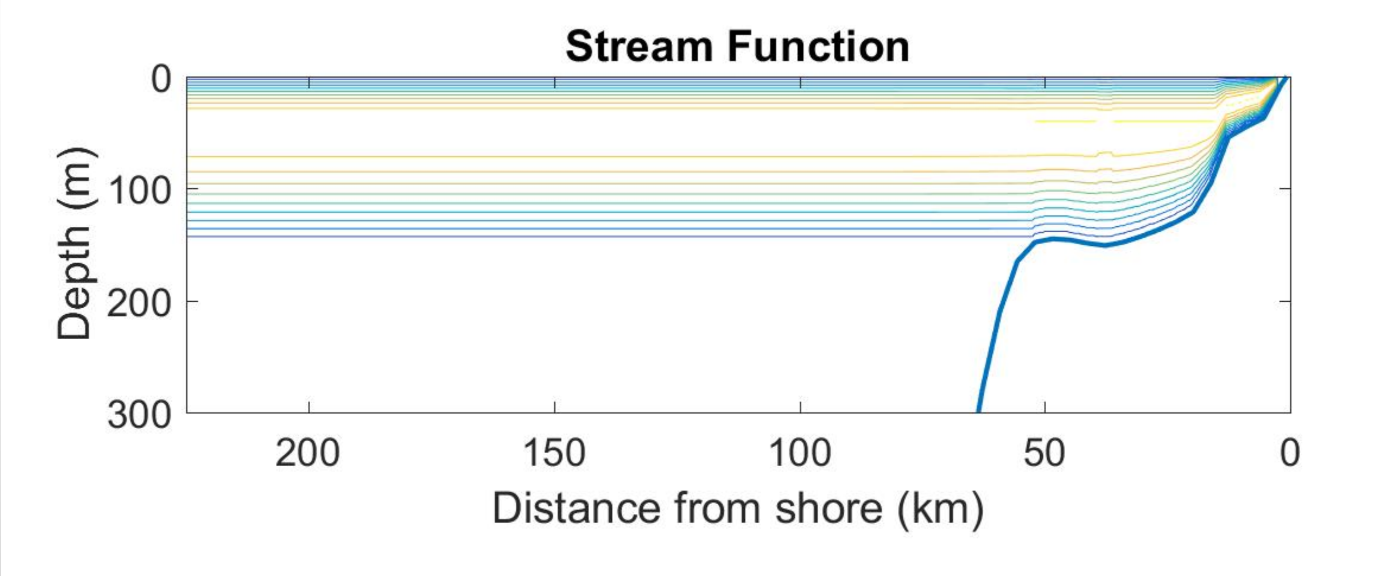
Gas exchange time-scale ranges over a factor of 2

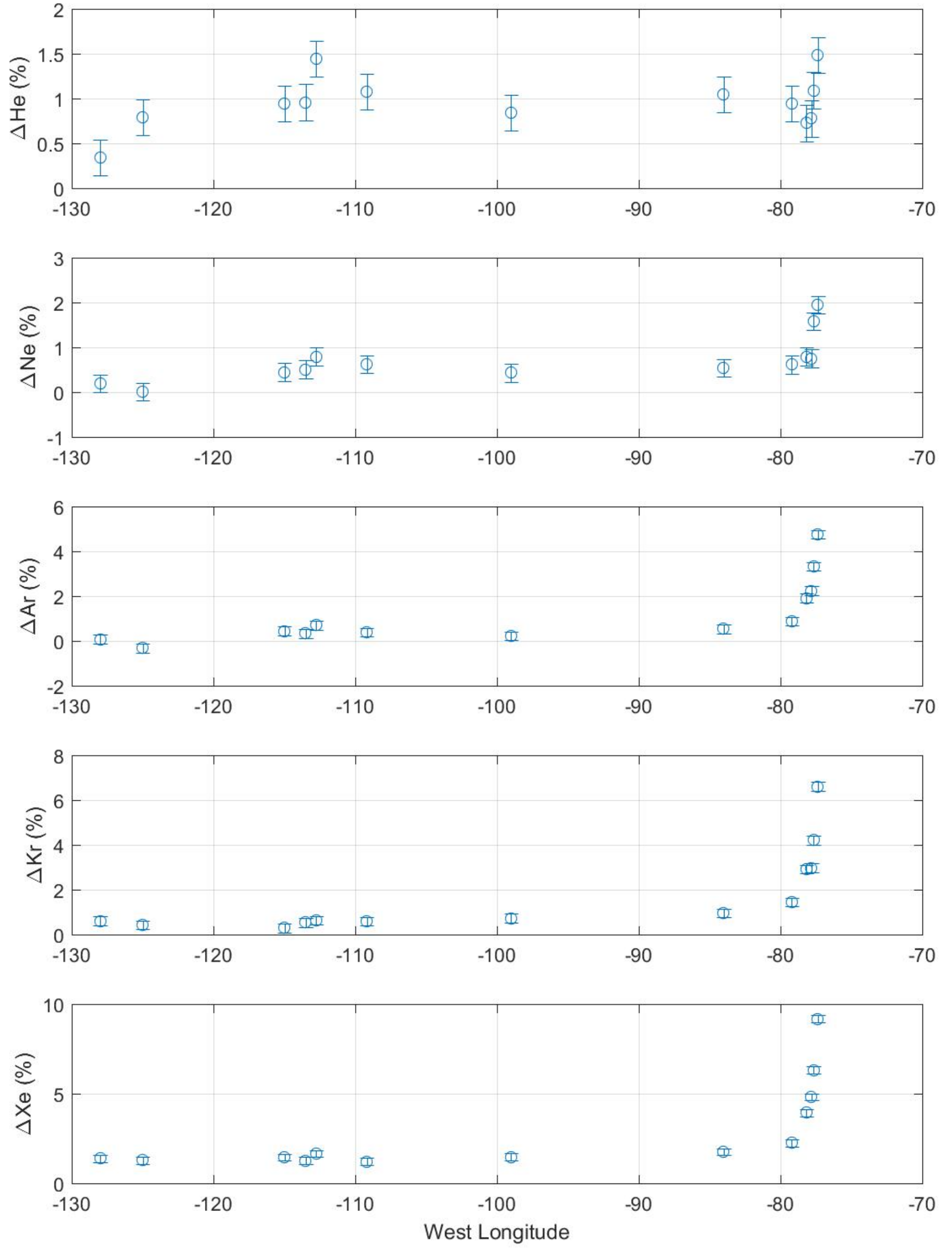



δ^3He
ΔAr
Tritium
Δ^{14}C
ΔKr
ΔXe
CFC-11
SF_6
St.1
St.2
St.3
St.4
St.5
St.6
St.7

Basic Approach:

- Employ a simple zonal overturning streamfunction
  - that reflects the net zonal overturning cell
  - and conserves mass
- Impose simple surface forcing (NCEP winds and HF)
  - and PWP mixed layer dynamics
- Calibrate overturning streamfunction against observed
  - tracer fields (NGs, T-^{3}He, ^{14}C, CFC/SF_6 and others
- Simulate/evaluate other non-conservative tracers using
  - consumption/production rates





Establish working teams around specific models?

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