Simulating Helium Isotopes in the CESM Ocean Component

or

Estimating the Rate of Continental Drift with an Ocean GCM

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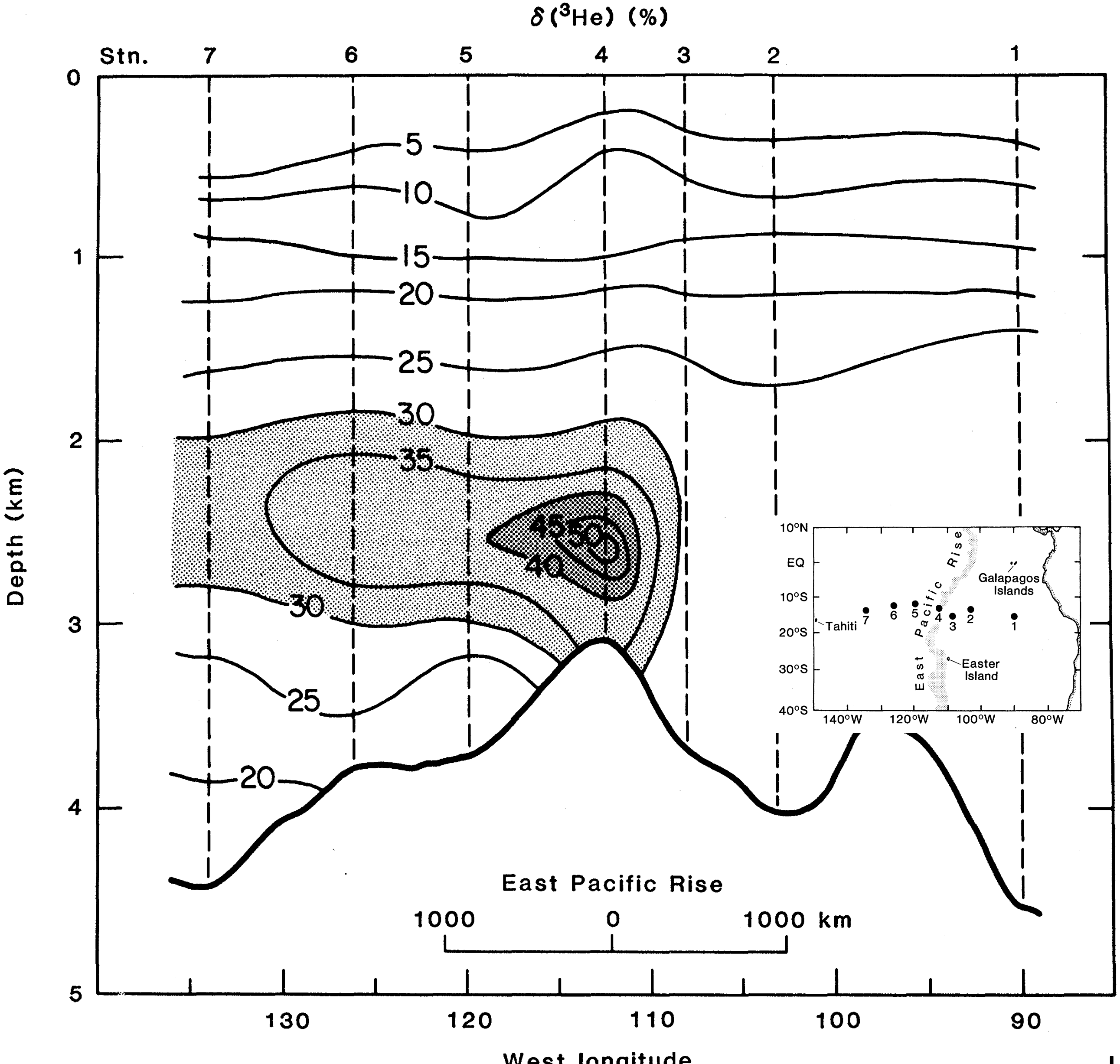
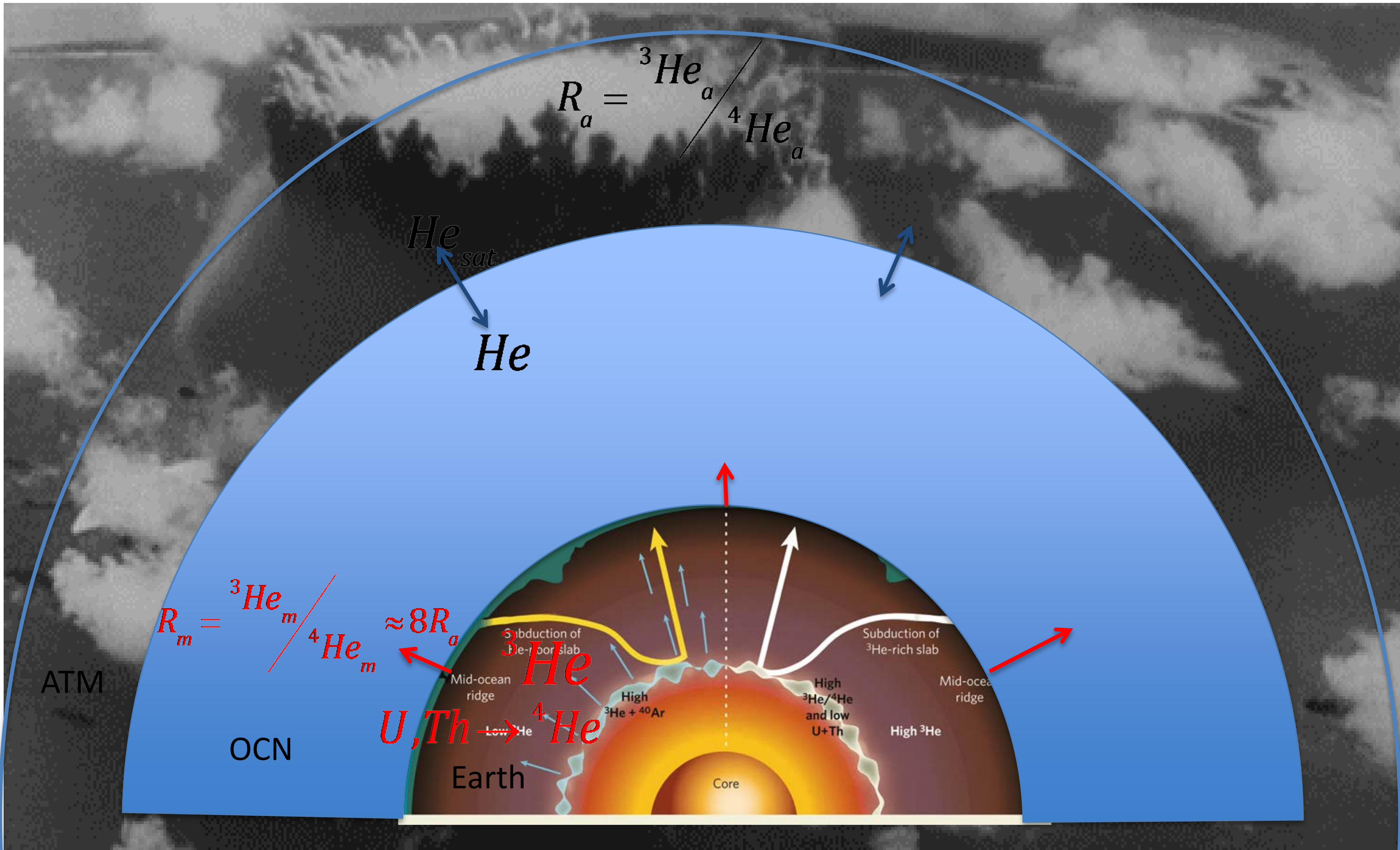


$$R = {}^{3}He / {}^{4}He$$

$$\delta^{3}He = 100\left(\frac{R_{ocn}}{R_{atm}} - 1\right)$$

Lupton and Craig (1981)

Helium Isotope Cycle



Decomposition of Mantel and Atmospheric Helium

- He has very similar to behavior as Ne – can separate out atmospheric component of He by using Ne as proxy (Roether 1998)
- Can separate explicitly in model using separate tracers and linearly recombining for total

$$He = He^{atm} + He^{man}$$

$$\mathrm{T}\left(He^{atm} + He^{man}\right) = K\left(He^{sat} - He^{atm} - He^{man}\right) + S$$

$$\mathrm{T}\left(He^{atm}\right) = K\left(He^{sat} - He^{atm}\right)$$

$$\mathrm{T}\left(He^{man}\right) = -K \cdot He^{man} + S$$

T = $\partial_t + \mathcal{A} - \mathcal{D}$

K = surface flux

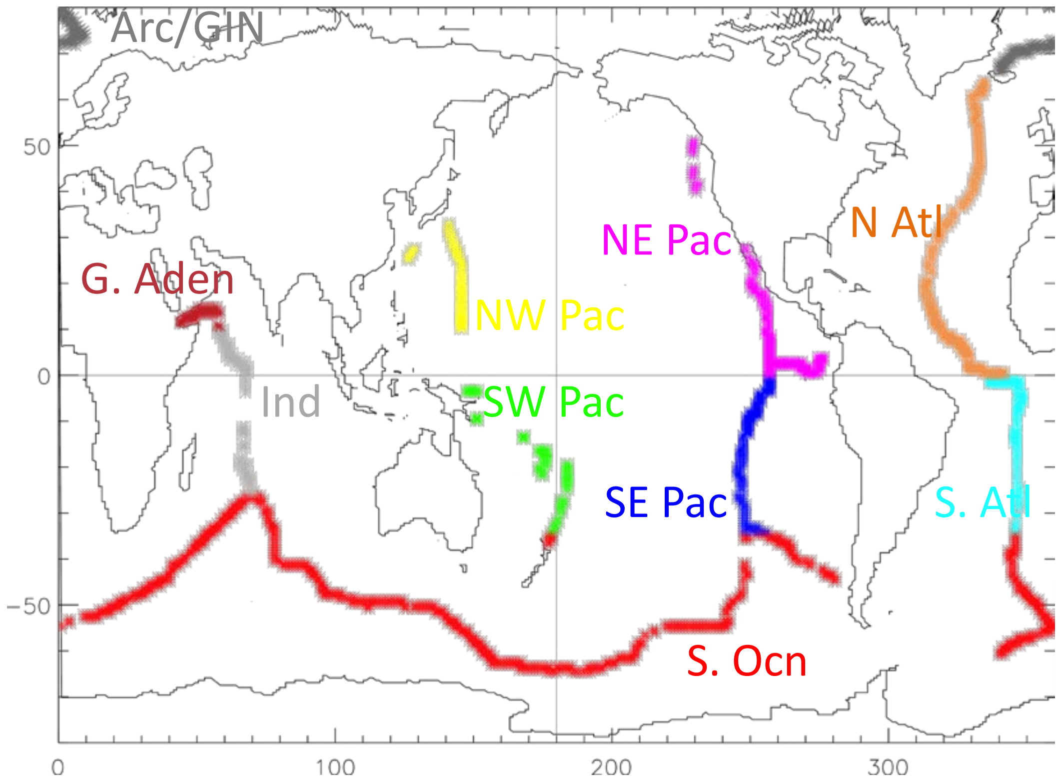
S = source

Regional Helium Sources

$$S = \sum_{n=1}^{N} S_n^{man} \qquad He = \sum_{n=1}^{N} He_n^{man}$$

$$\mathrm{T}\left(He_n^{man}\right) = -K \cdot He_n^{man} + S_n^{man}$$

N=10



Model Configuration

- Codebase is CESM 1.2
- Normal Year Forcing, x1 grid
- Active Ice Model
- Physics spun up for 100 years
- OCMIP He protocols
  - implementation by D. Tsumune
  - regional tracer implementation by F. Bryan
- Spin up ^{3}He and ^{4}He wrt model year 0101
  - Natural He (no ^{3}He bomb signal)
- He spun up using Newton-Krylov solver
  - brute force spin up would take 1000's of years
  - NK solver is orders of magnitude faster

Source-to-Sink Fluxes

	SRC	Sink									
		ACC	SW PAC	SE PAC	NW PAC	NE PAC	S ATL	N ATL	ARC	IND	ARAB
ACC	133.9	98.1	0.2	4.6	5.9	10.8	1.8	7.6	0.0	4.2	0.5
SW PAC	14.2	6.6	2.1	1.7	0.6	2.0	0.1	0.5	0.0	0.6	0.0
SE PAC	52.0	31.5	0.2	3.6	3.6	7.4	0.6	2.6	0.0	2.3	0.2
NW PAC	8.1	2.5	0.0	0.6	2.4	1.8	0.1	0.25	0.0	0.4	0.0
NE PAC	34.8	15.4	0.1	3.2	3.7	8.7	0.4	1.4	0.0	1.7	0.1
S ATL	13.6	10.3	0.0	0.4	0.5	0.9	0.2	1.0	0.0	0.4	0.1
N ATL	16.6	9.9	0.0	0.3	0.5	0.9	0.2	1.0	0.0	0.4	0.1
ARC	6.7	3.9	0.0	0.1	0.2	0.3	0.1	1.0	0.9	0.1	0.0
IND	14.0	9.3	0.0	0.2	0.3	0.6	0.5	1.7	0.0	1.1	0.3
ARAB	5.3	2.3	0.0	0.0	0.1	0.1	0.2	0.6	0.0	1.0	1.0
ALL	299	190.0	2.7	14.7	17.7	33.4	4.1	21.1	1.0	12.3	2.3

Optimizing Source Strength

- Source of ^{3}He proportional to rate of formation of new crust at mid-ocean ridges (and thus also to heat flux)
- Poorly observationally constrained globally
- Given a “trusted” circulation estimate (data-constrained or verified with other tracers) we can provide additional constraints on source strength by optimizing the sources to minimize the error in ^{3}He (or δ^3He) against observations.
- We optimize our regional source strengths with local scale factors α

$$E\left(\overrightarrow{\alpha}\right)=\sum_i\left[He_i^{obs}-He_i^{atm}-\sum_{n=1}^{N}\alpha_n S_n\right]^2$$

Optimized Source Strengths

Region	α
ACC	1.20048
SW PAC	1.41611
SE PAC	0.737304
NW PAC	8.33495
NE PAC	1.05112
S ATL	0.186655
N ATL	2.90742
ARC	-0.0632658
IND	0.955885
ARAB	0.380839

Summary

- He isotopes have been implemented in CESM 1.2
  - fast spin up is essential for tracers to be of practical use
  - moving forward should port to CESM 2

- Regional He tracers provide insight on deep ocean circulation and how deep waters return to the surface

- Non-physical optimized source strength is indicative of issues in model circulation
  - unknown if this is specific to NY forcing?