

Implications of Changing Ocean Chemistry II

October 17, 2007

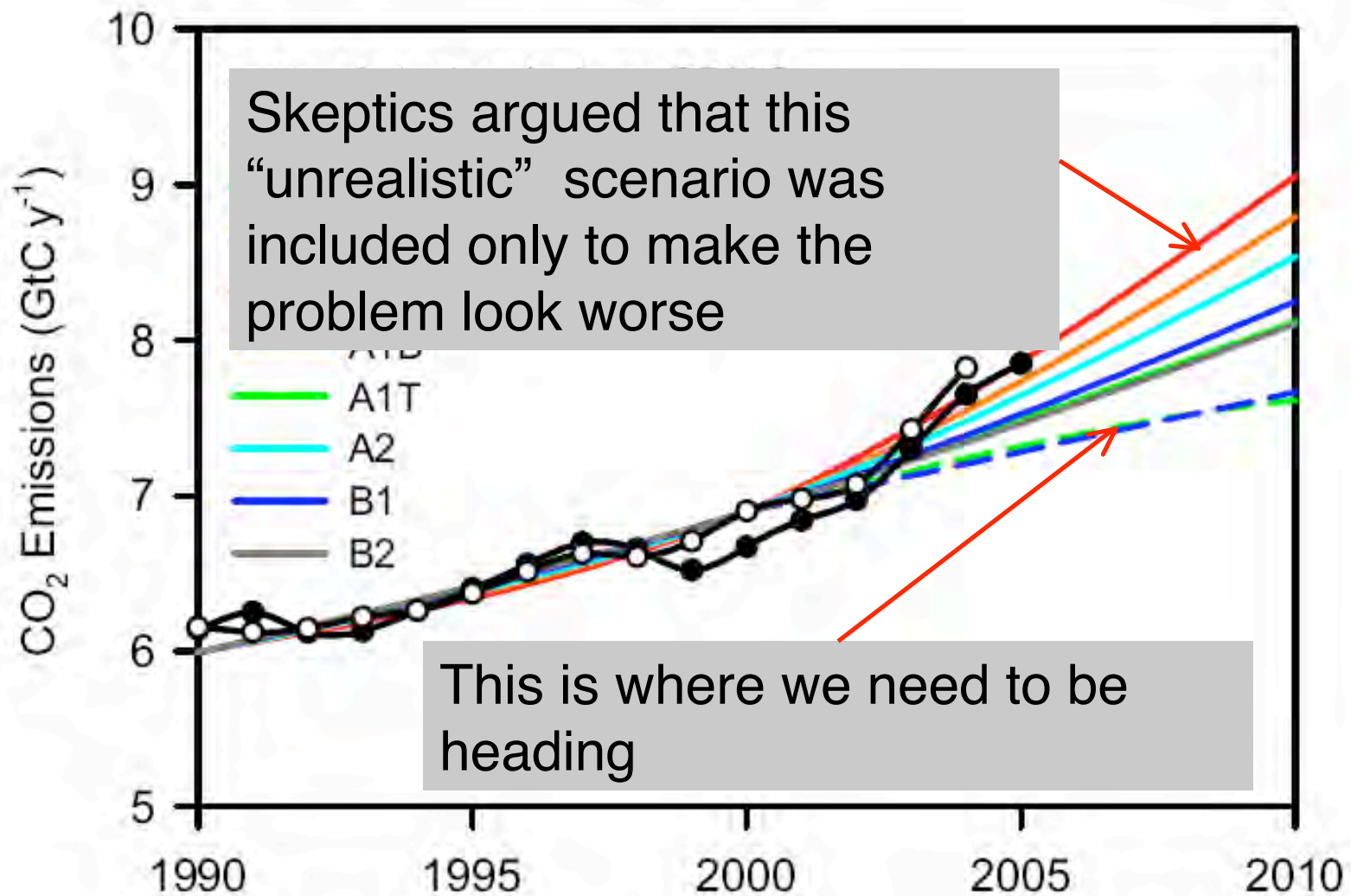
Anthony Michaels

Wrigley Institute for Environmental Studies
University of Southern California

Outline

- Carbon Management Context
- Carbon Storage in the Sea
- Markets and Verification Issues
- Scientific Infrastructure Needs

Emissions are rising faster than expected



Human actions that
change climate



Climate
System



Climate impact
on human welfare

Human actions that
change climate



Climate
System



Climate impact
on human welfare



Mitigation



Geoengineering



Adaptation

AB 32

- California leads the way
- State-wide cap on emissions
- Mix of regulatory and market approaches
- May need a mix of emission reductions and carbon sinks to reach goals
- Model for nation

Key point - cap and trade as much about stimulating innovation as controlling carbon

Carbon Management

		Location		
		Land Surface	Ocean	Geosphere
Mechanism	Biological	Enhancing carbon content of soils Afforestation	Fertilization to accelerate biological pump	Use of anaerobic biological reactions to reduce CO ₂ to CH ₄ in strongly reducing environments.
	Chemical	Industrial production of stable carbonates	Acceleration of CaCO ₃ dissolution Addition of alkalinity	Subsurface dissolution of carbonates or silicates by brines acidified by injected CO ₂ .
	Physical		Formation of 'lakes' of liquid CO ₂ .	Physical confinement of gas phase CO ₂ in underground formations.

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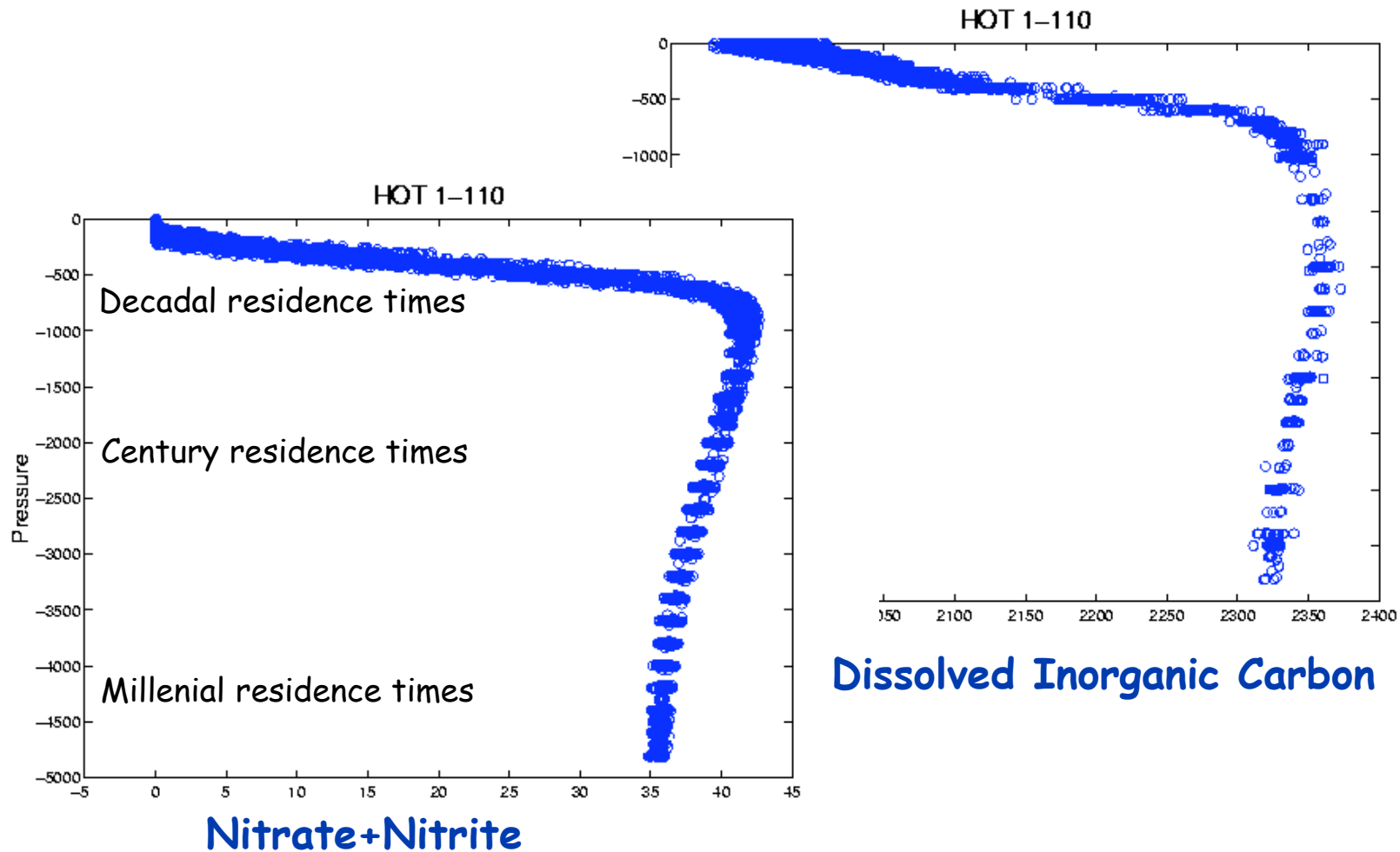
Carbon Storage in the Sea - Biogeochemical Mechanisms

- Relative use of surface macronutrients
 - Residual Nitrate (HNLC)
 - Residual Phosphate in the absence of NO_3
- Changes in C:N:P of export
- Changes in remineralization length-scale
- Changes in PIC rain rate ratios with POC

All of these are
Time-Shifting

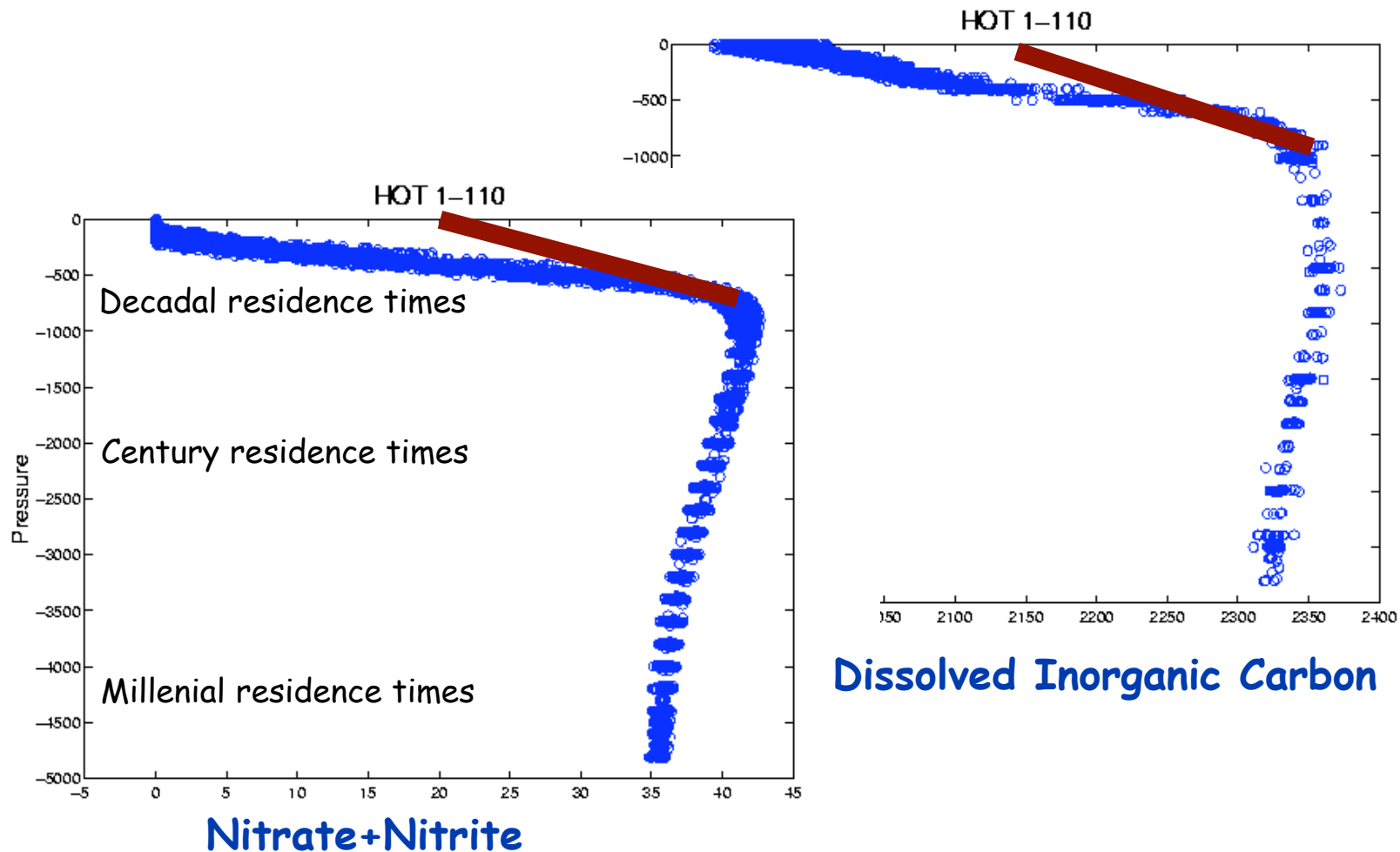
Most are Sensitive to the
Addition of Trace Amounts
of Iron

Ocean biology maintains a vertical DIC gradient - ocean biology is limited by the supply of nutrients:

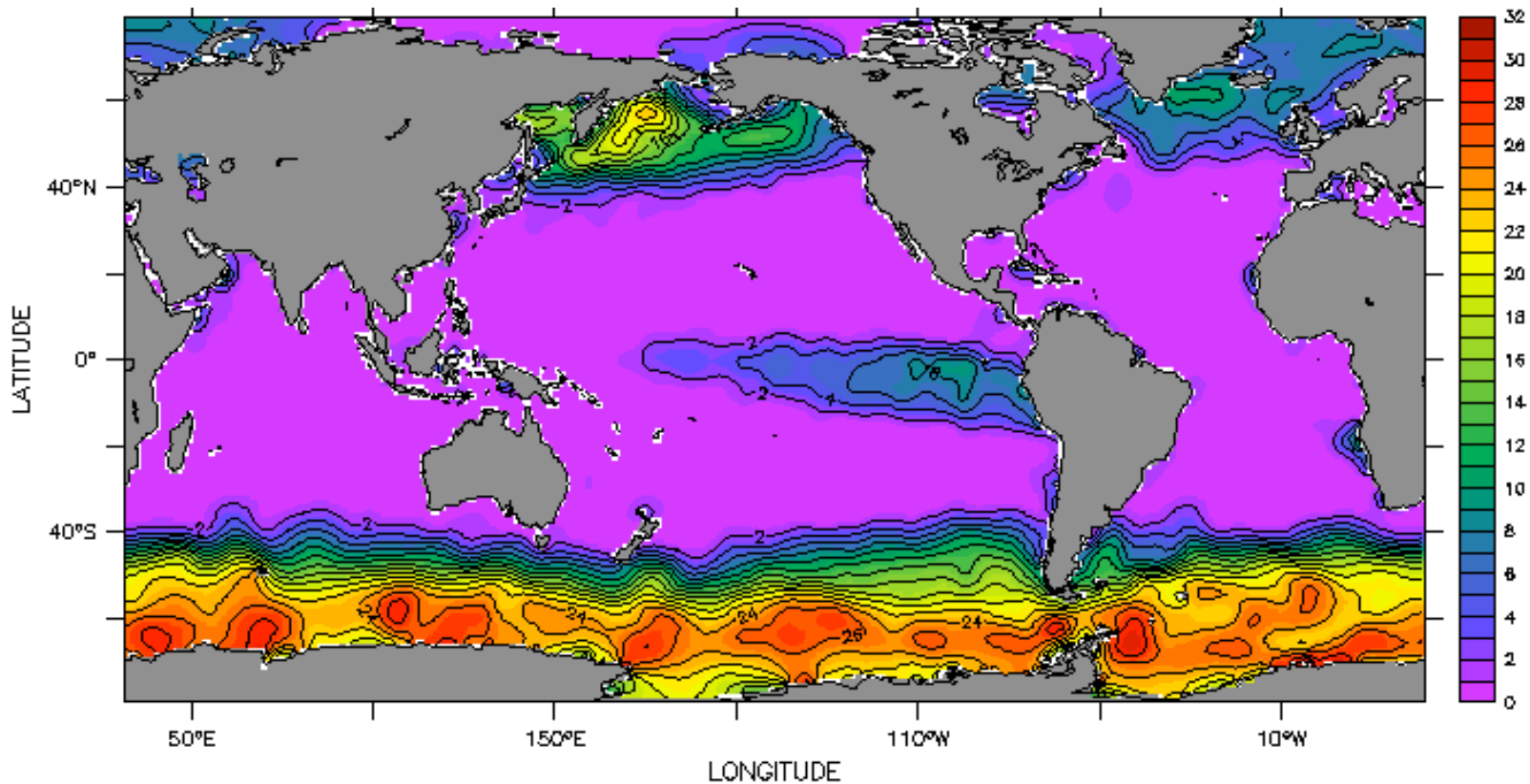


Incomplete Nutrient Utilization in the Surface Waters (HNLC)

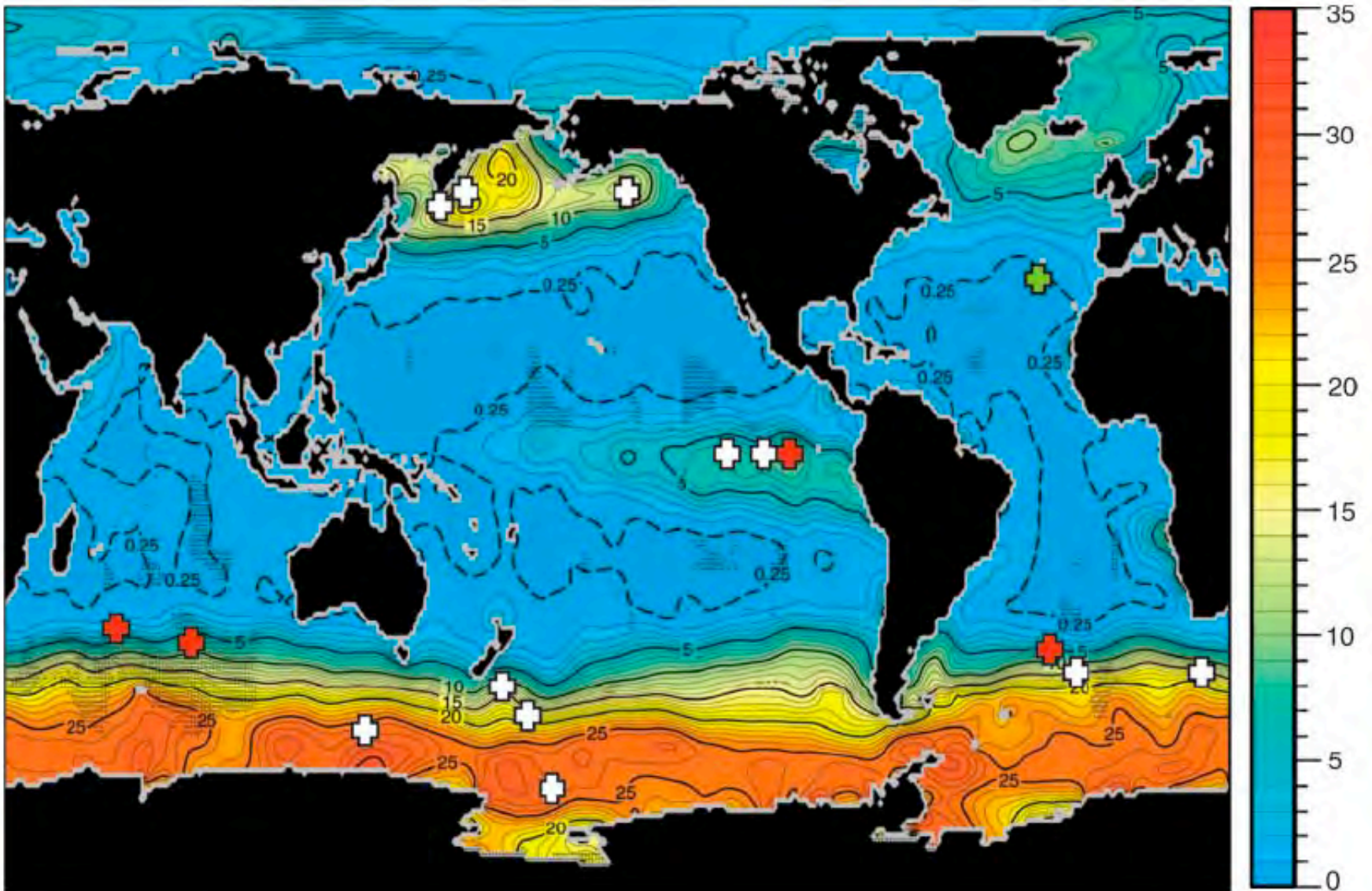
(Leaves un-used DIC in the surface and more CO₂ in the atmosphere)



Most of the ocean shows
near-complete nutrient utilization



Surface Nitrate ($\mu\text{moles/kg}$)



Property	IronEX I (6)	IronEX II (30)	SOIREE (49)	EisenEx (56)	SEEDS I (57)	SOFEX-S (54, 58)	SOFEX-N (58)	EIFEX (46)	SERIES (17)	SEEDS II (59)	SAGE (59)	FeeP (59)
Fe added (kg)	450	450	1750	2350	350	1300	1700	2820	490	480	1100	1840
Temperature (°C)	23	25	2	3 to 4	11	-1	5	4 to 5	13	9 to 12	11.8	21
Season	Fall	Summer	Summer	Spring	Summer	Summer	Summer	Summer	Summer	Summer	Fall	Spring
Light climate ($\mu\text{mol quanta m}^{-2} \text{ s}^{-1}$)	254 (max) to 230 (min)	216 to 108	59 to 33	82 to 40	178 to 39	103 to 62	125 to 74		173 to 73		59 to 52	
Dilution rate (day^{-1})	0.27	0.18	0.07	0.04 to 0.43	0.05	0.08	0.1		0.07 to 0.16			0.4
Chlorophyll, $t = 0$ (mg m^{-3})	0.2	0.2	0.2	0.5	0.9	0.2	0.3	0.6	0.4	0.8	0.6	0.04
Chlorophyll, maximum (mg m^{-3})	0.6	3.3	2.3	2.8	23.0	2.5	2.4	3.0	5.5	2.4	1.3	0.07
MLD (m)	35	40*	65*	80*	13	35	45	100	30*	30	70*	30*
Bloom phase (duration, days)	Evolving (5) subducted	Decline (17)	Evolving (13)	Evolving (21)	Evolving (10)	Evolving (28)	Evolving (27) subducted	Partial decline, evolving	Decline (25)	Evolving (25)	No bloom (17)	No bloom (7)
deIDIC	6	26	17	14	58	21	13		36		nc	<1
δDMS ($\mu\text{mol m}^{-3}$)	0.8	1.8	2.9	1.3, then to 0†	nc	nc	Increased		8.5, then to -5.7†	nc	nc	nc
Dominant phytoplankton	Mixed	Diatom	Diatom	Diatom	Diatom	Diatom	Mixed	Diatom	Diatom	Mixed	Mixed	<i>Cyanobacteria</i> <i>Prochlorococcus</i>
Export	nc	increase	nc	nc	nc	Increase	Increase§	Increase	Increase	nc	nc	
Mesozooplankton stocks	Increase‡	Increase	nc	nc	nc	nc	nc	Increase	Increase	Increase	nc	nc
Primary production (max/min ratio)	4	6	9	4	4	6	10	2	10		2	1.7

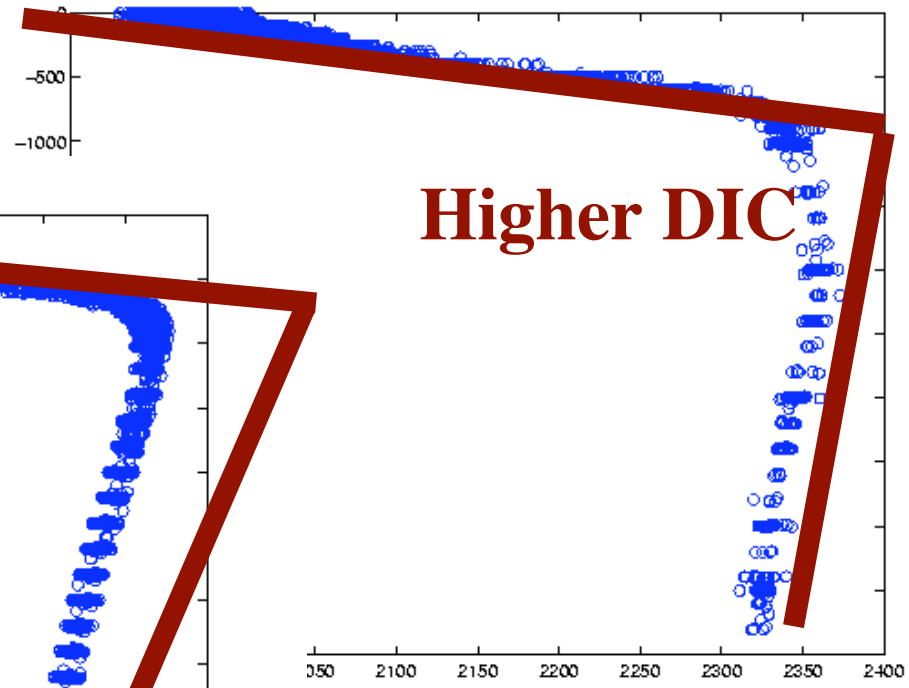
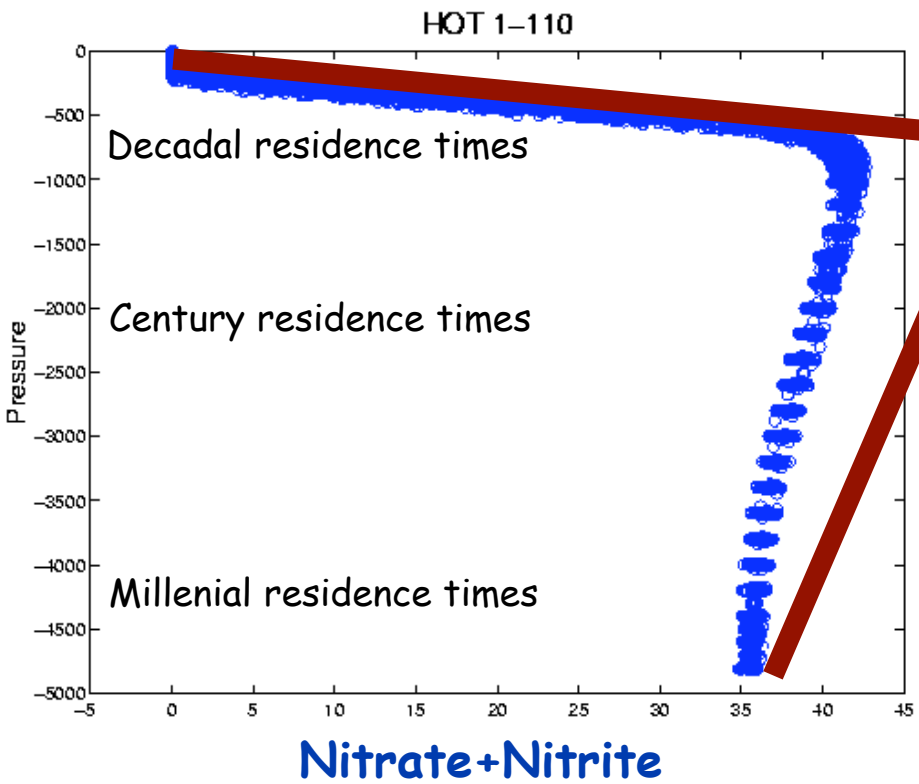
*Changes in MLD were observed during the study; the maximum MLD is shown (for initial MLD, see table S1). †An initial increase in DMS concentration followed by a decline by the end of the study. ‡Based on anecdotal evidence. §Increased export was mainly associated with a subduction event.

Changes in Total Nitrate Stock Nitrogen Fixation - Denitrification Balance

Extra Nitrogen
Fixation

Lower DIC

HOT 1-110

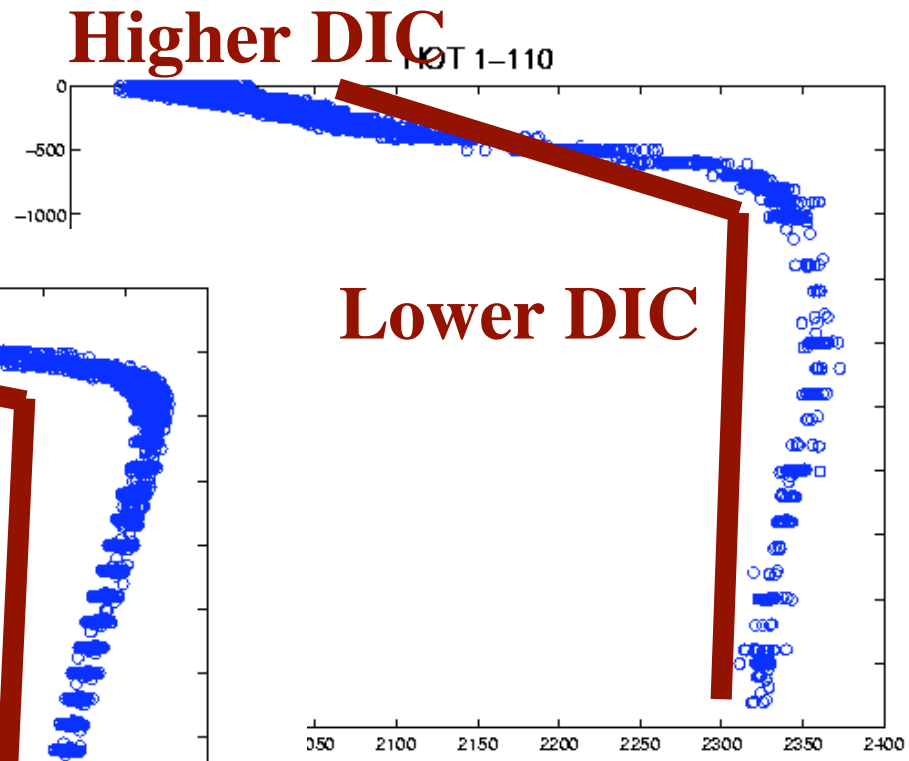
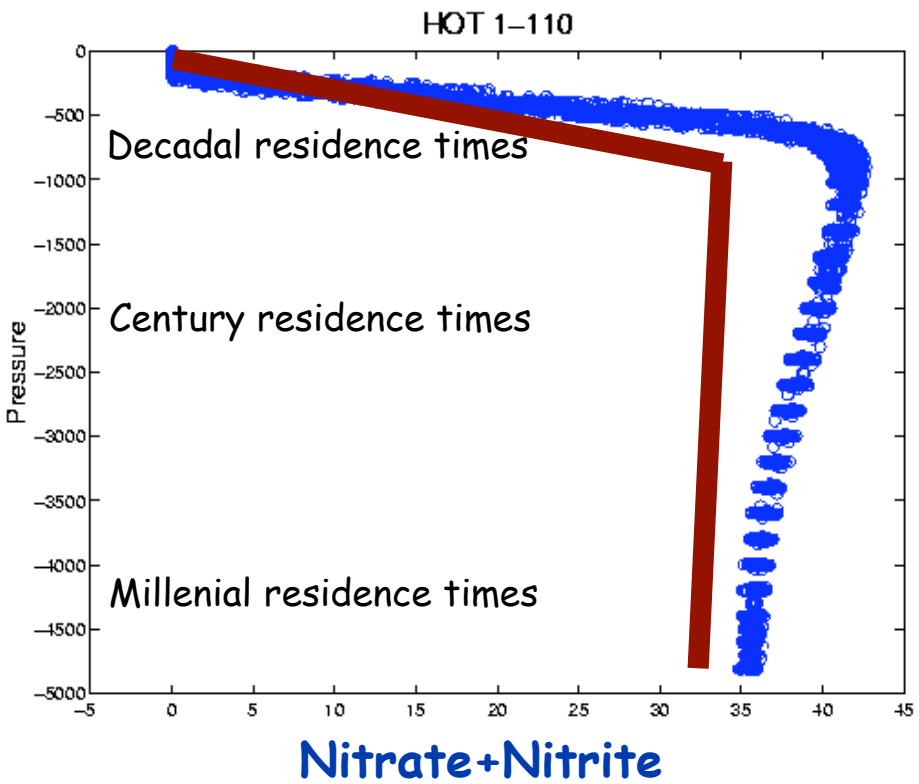


Dissolved Inorganic Carbon

Stronger gradient, lower
Surface DIC

Changes in Total Nitrate Stock Nitrogen Fixation - Denitrification Balance

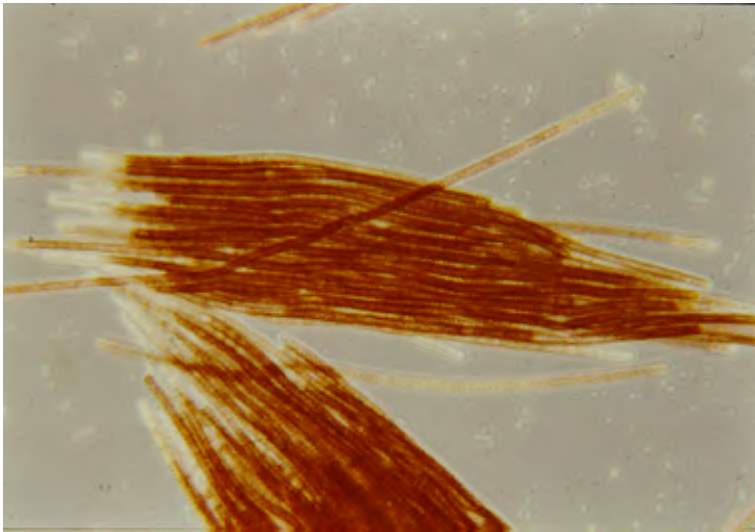
Extra
Denitrification

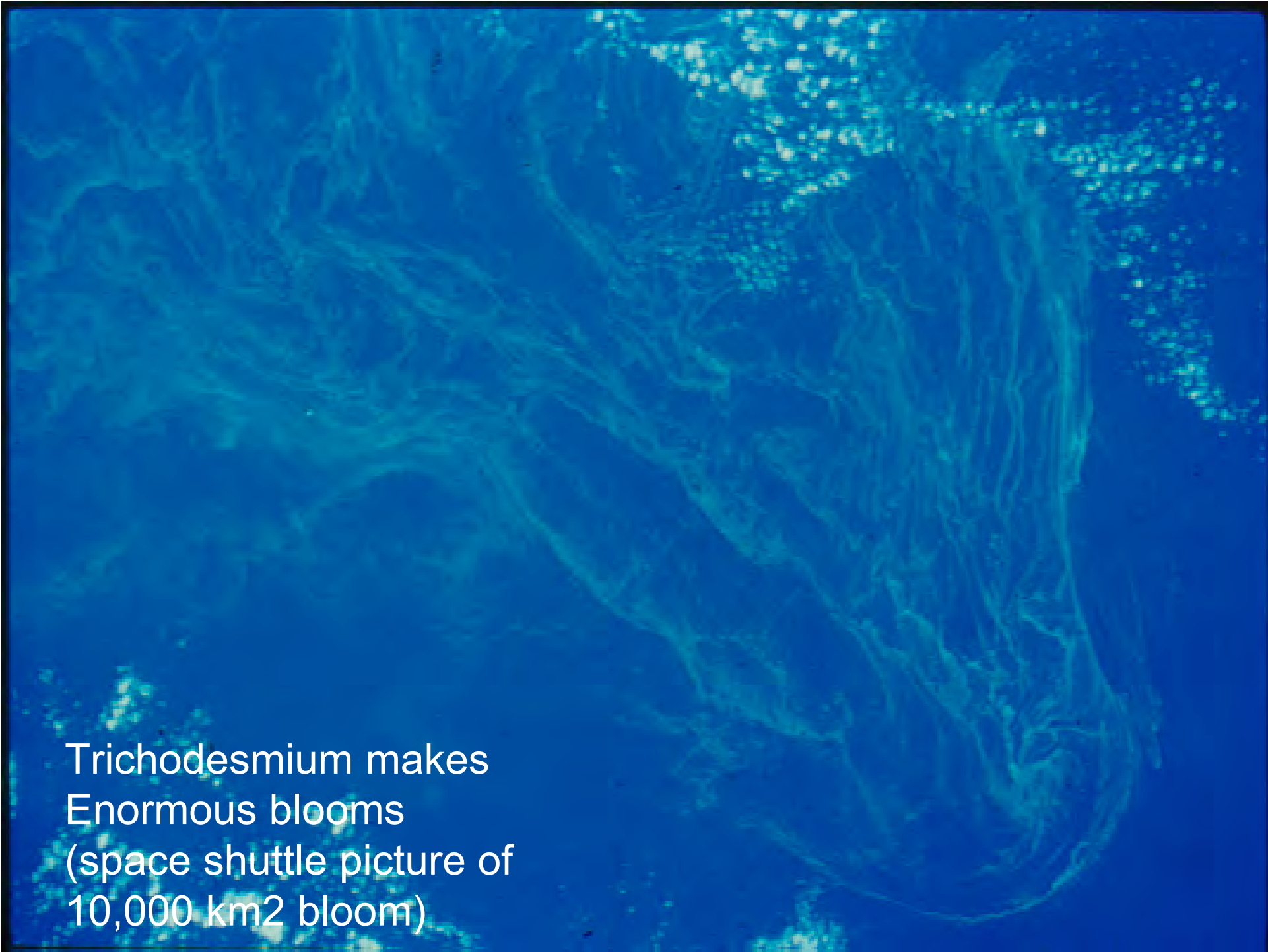


Dissolved Inorganic Carbon

Weaker gradient, higher
Surface DIC

Trichodesmium spp.
Best Known Planktonic Diazotroph



A satellite photograph of a massive, swirling oceanic bloom of Trichodesmium. The bloom is a large, intricate, light-colored pattern against the darker blue of the surrounding ocean. The pattern consists of numerous smaller, interconnected swirls and eddies, creating a complex, fractal-like appearance. The bloom is centered in the upper right portion of the image, with its edges extending towards the center and bottom. The overall color palette is dominated by various shades of blue, from deep navy to bright cyan, with the bloom itself appearing as a lighter, almost white, textured mass.

Trichodesmium makes
Enormous blooms
(space shuttle picture of
10,000 km² bloom)

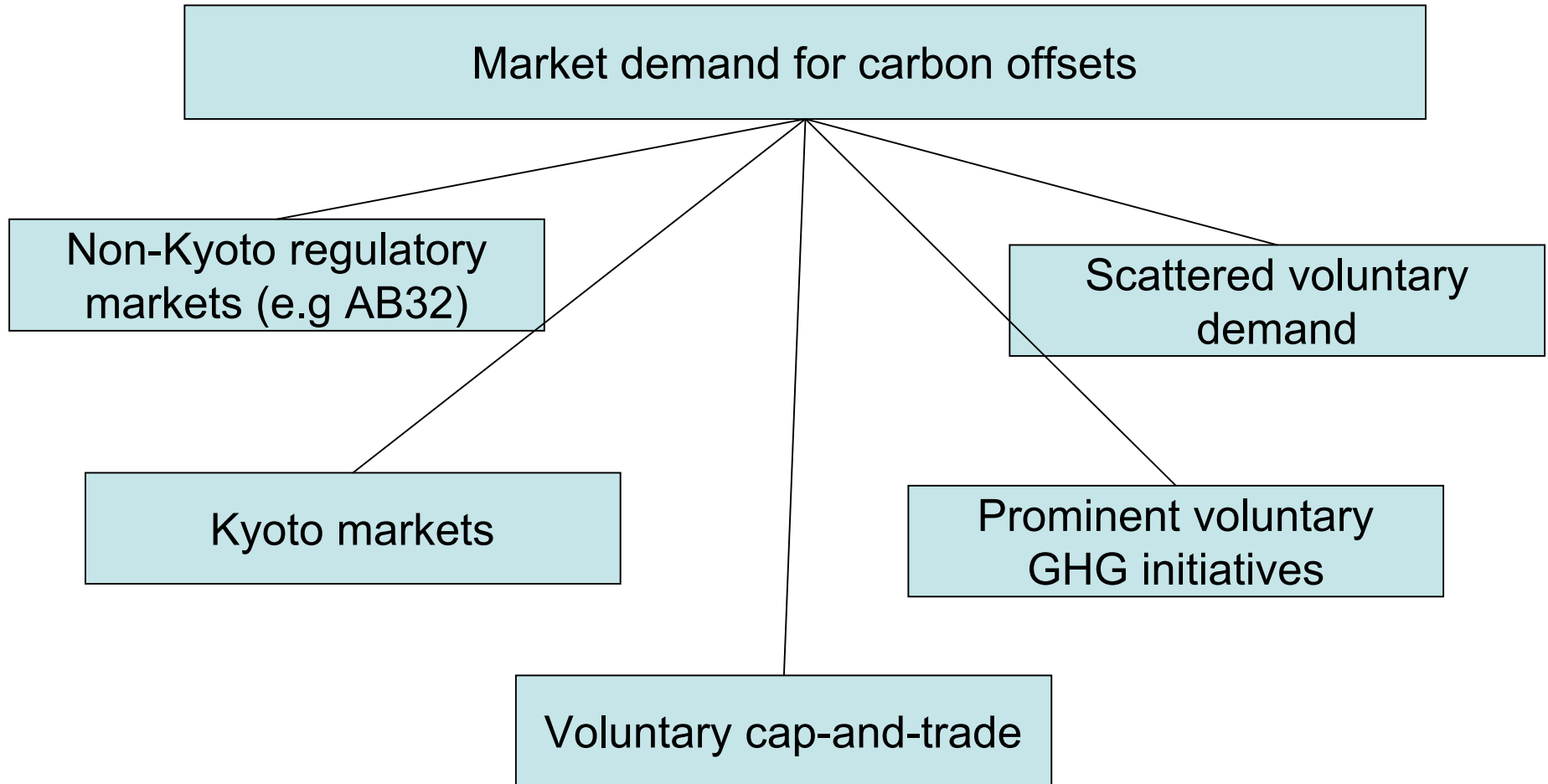
Scale

- Potential scale: 10 - 500 million tons CO₂ per year, maybe more
- Potential cost: \$2-6 per ton
- Critical limitations
 - Offsetting negative environmental impacts
 - Predictability and duration of carbon storage
 - Society's choices

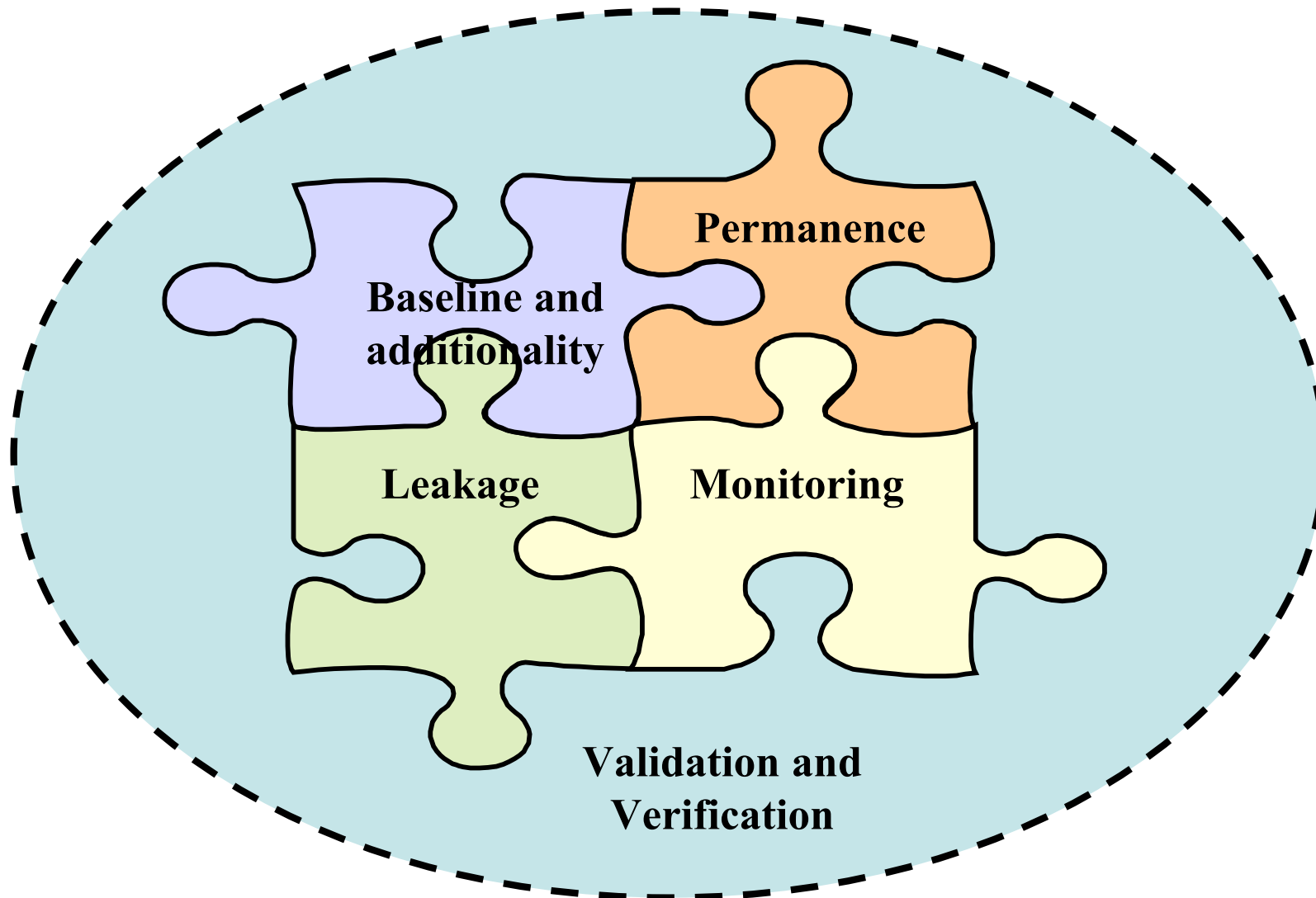
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The market context



Key components of methodologies for GHG projects

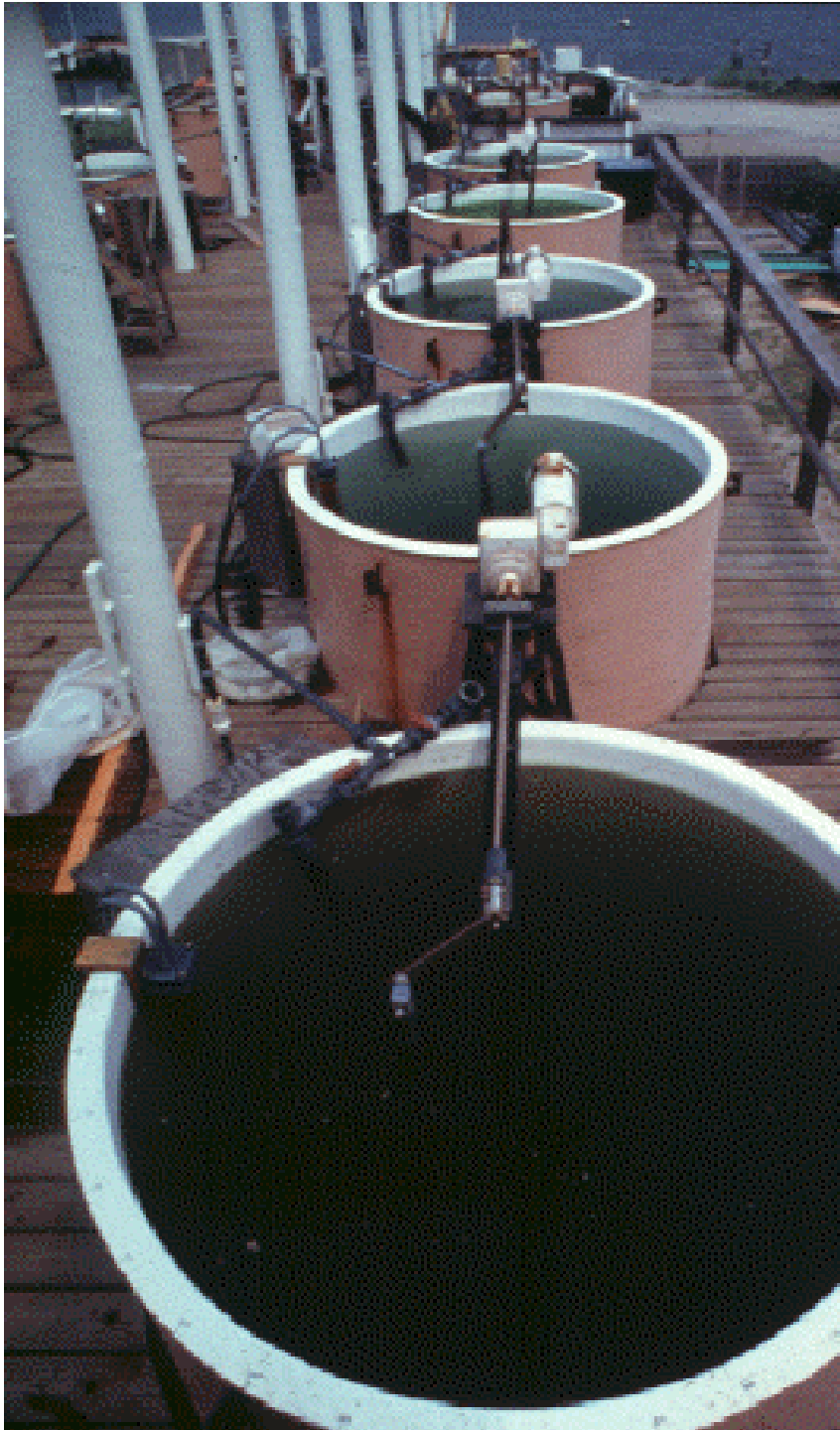


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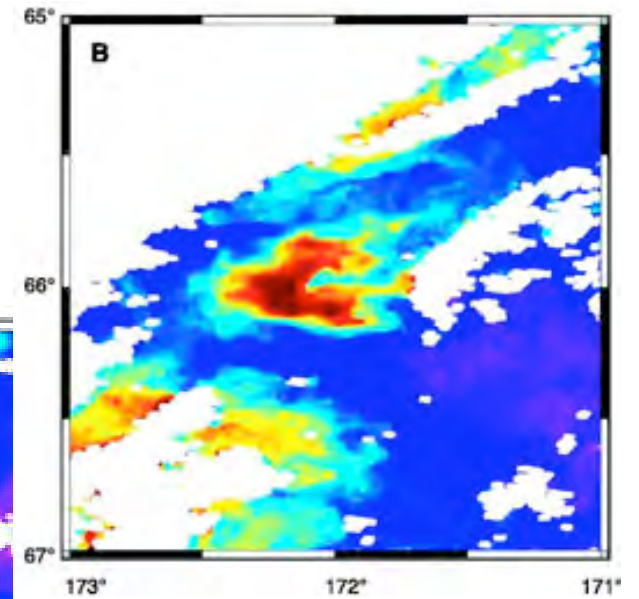
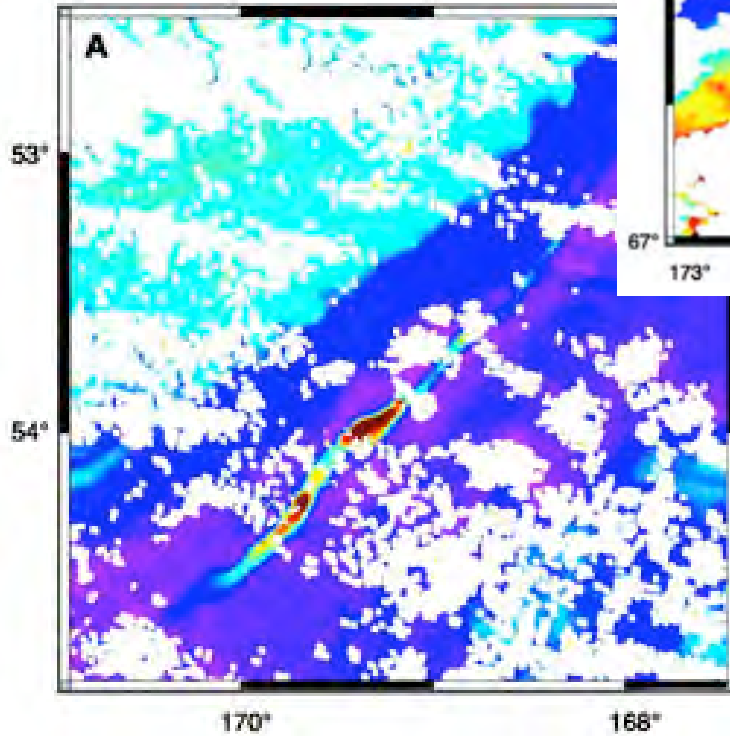
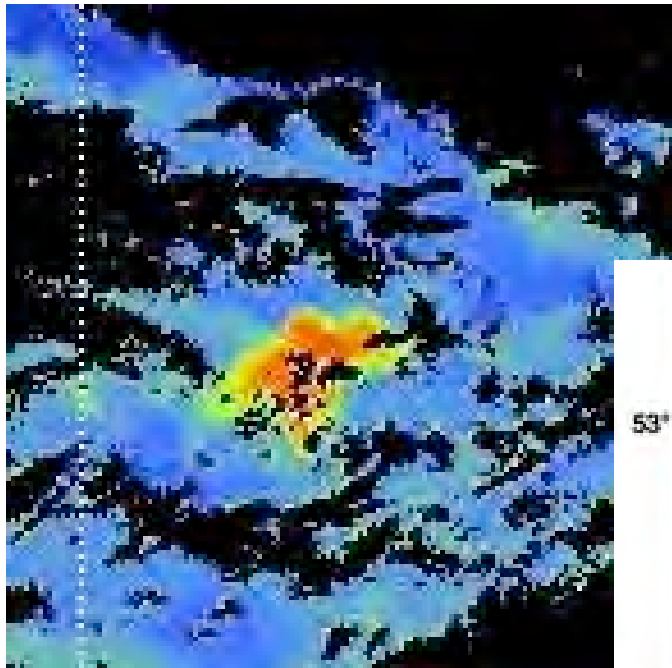
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Ecosystem Scale Experimental Manipulations

- Critical need to manipulate systems to understand dynamics and test ability to predict system behavior
- MERL on steroids
- Iron Fertilization
- Impacts of ocean acidification



Fe induced blooms





Why California?

- Excellent ocean science and scientists
- Leaders in ocean fertilization science
- Green-tech Entrepreneurs
- AB 32
- We can build the scientific infrastructure
- Someone has to lead --

Thank you

Questions?