Implications of Changing Ocean Chemistry II

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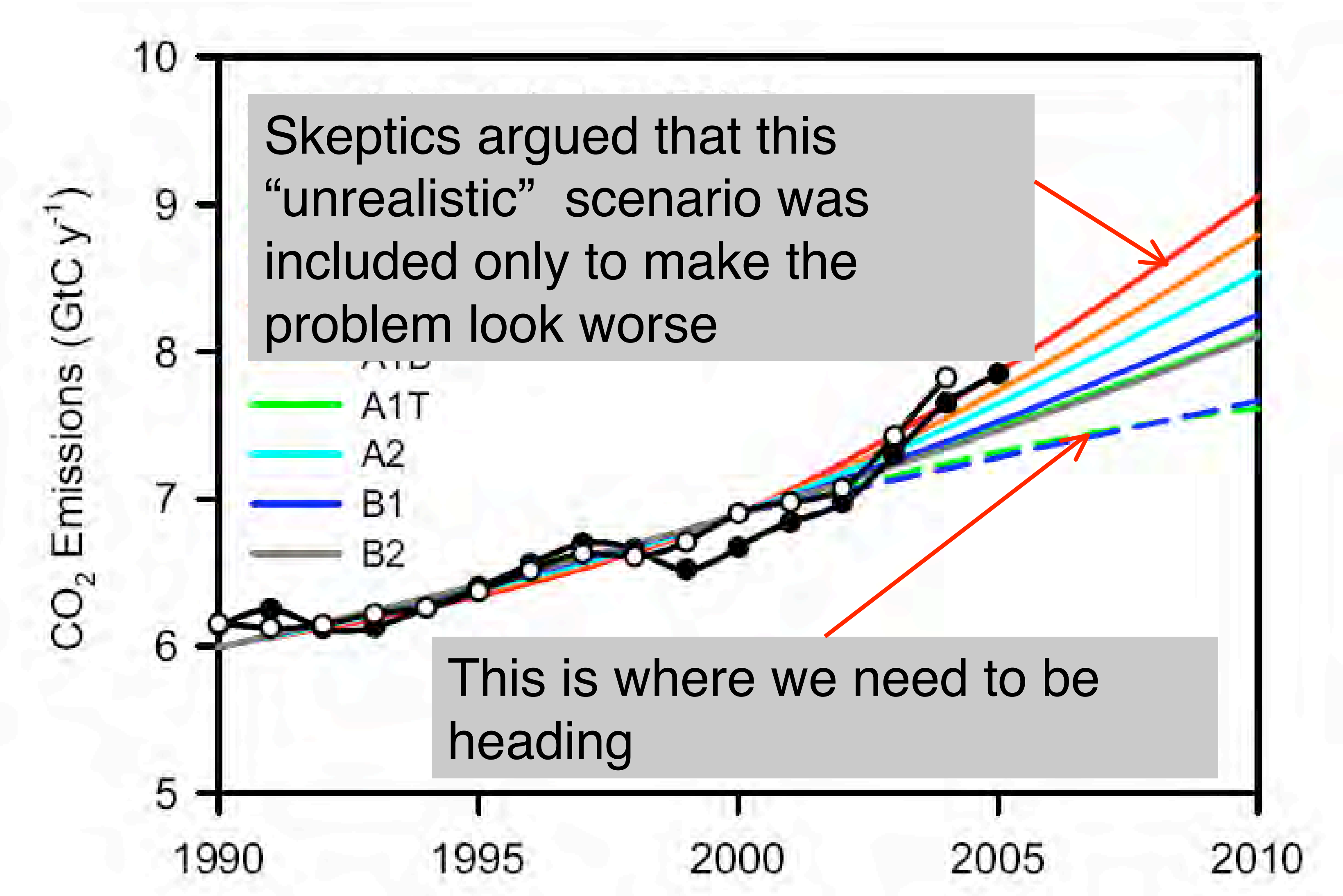
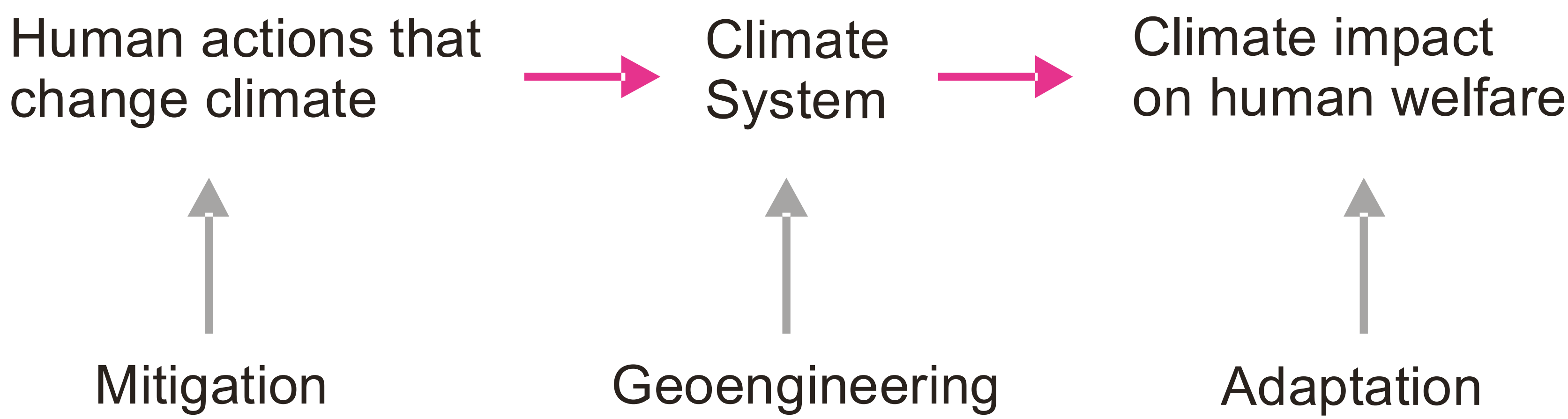
Outline

- 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

Mechanism	Land Surface	Ocean	Geosphere
Biological	Enhancing carbon content of soils Afforestation	Fertilization to accelerate biological pump	Use of anaerobic biological reactions to reduce CO_2 to CH4 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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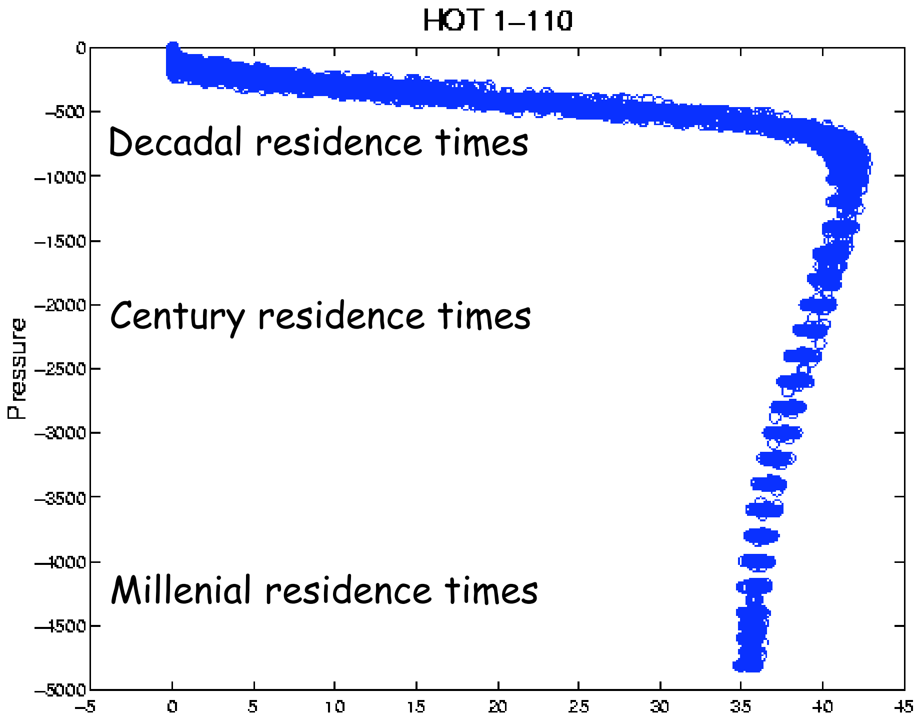
Carbon Storage in the Sea - Biogeochemical Mechanisms

- 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

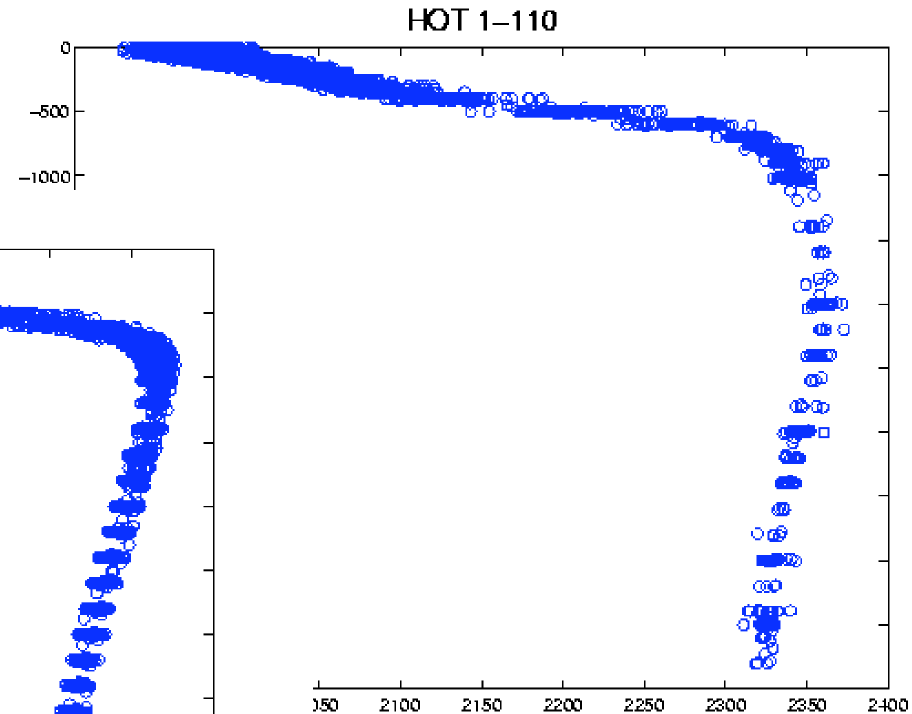
All of these are
Time-Shifting

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:



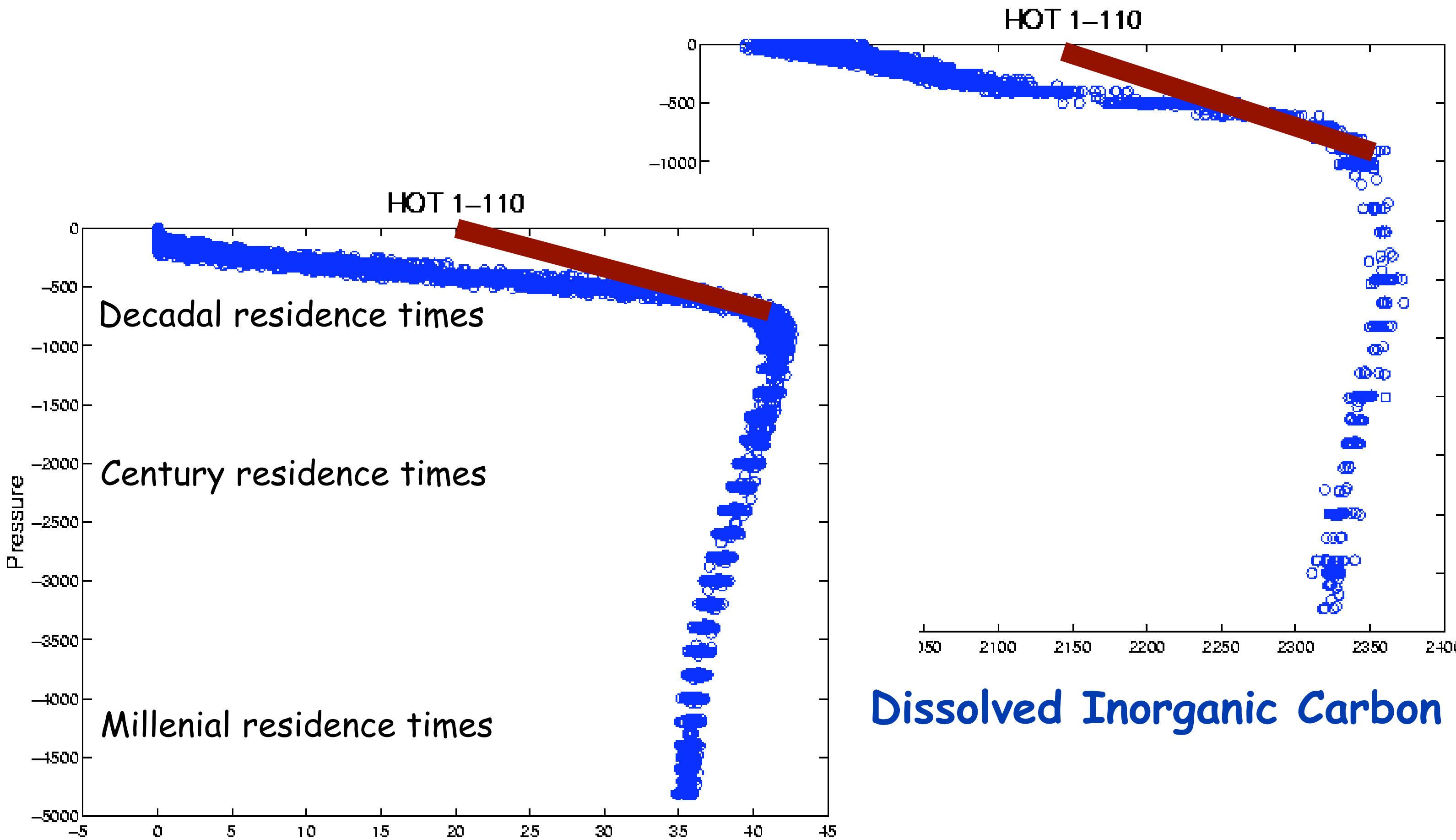
Nitrate+Nitrite



Dissolved Inorganic Carbon

Incomplete Nutrient Utilization in the Surface Waters (HNLC)

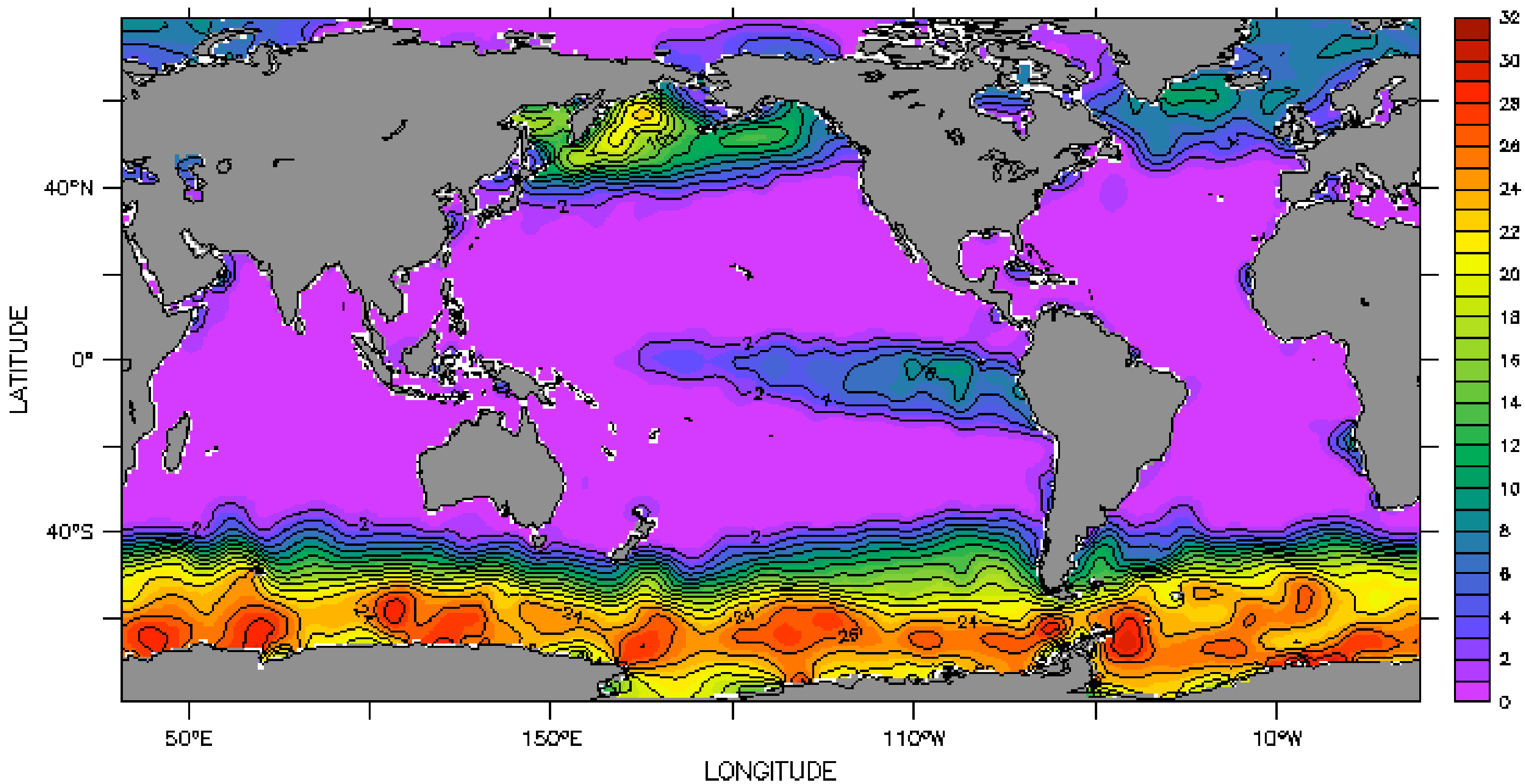
(Leaves un-used DIC in the surface and more CO2 in the atmosphere)



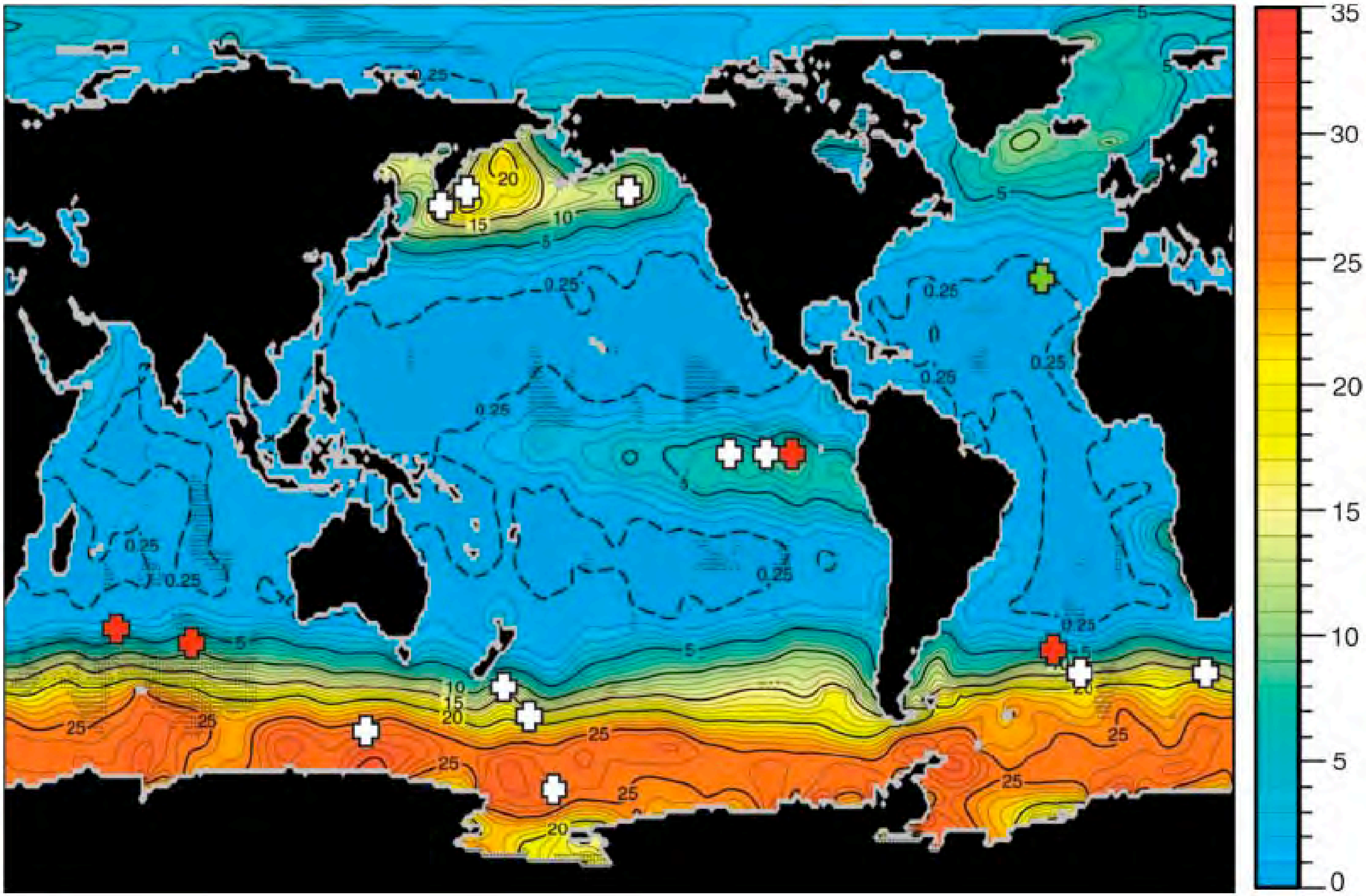
Dissolved Inorganic Carbon

Nitrate+Nitrite

Most of the ocean shows near-complete nutrient utilization



Surface Nitrate (µmoles/kg)



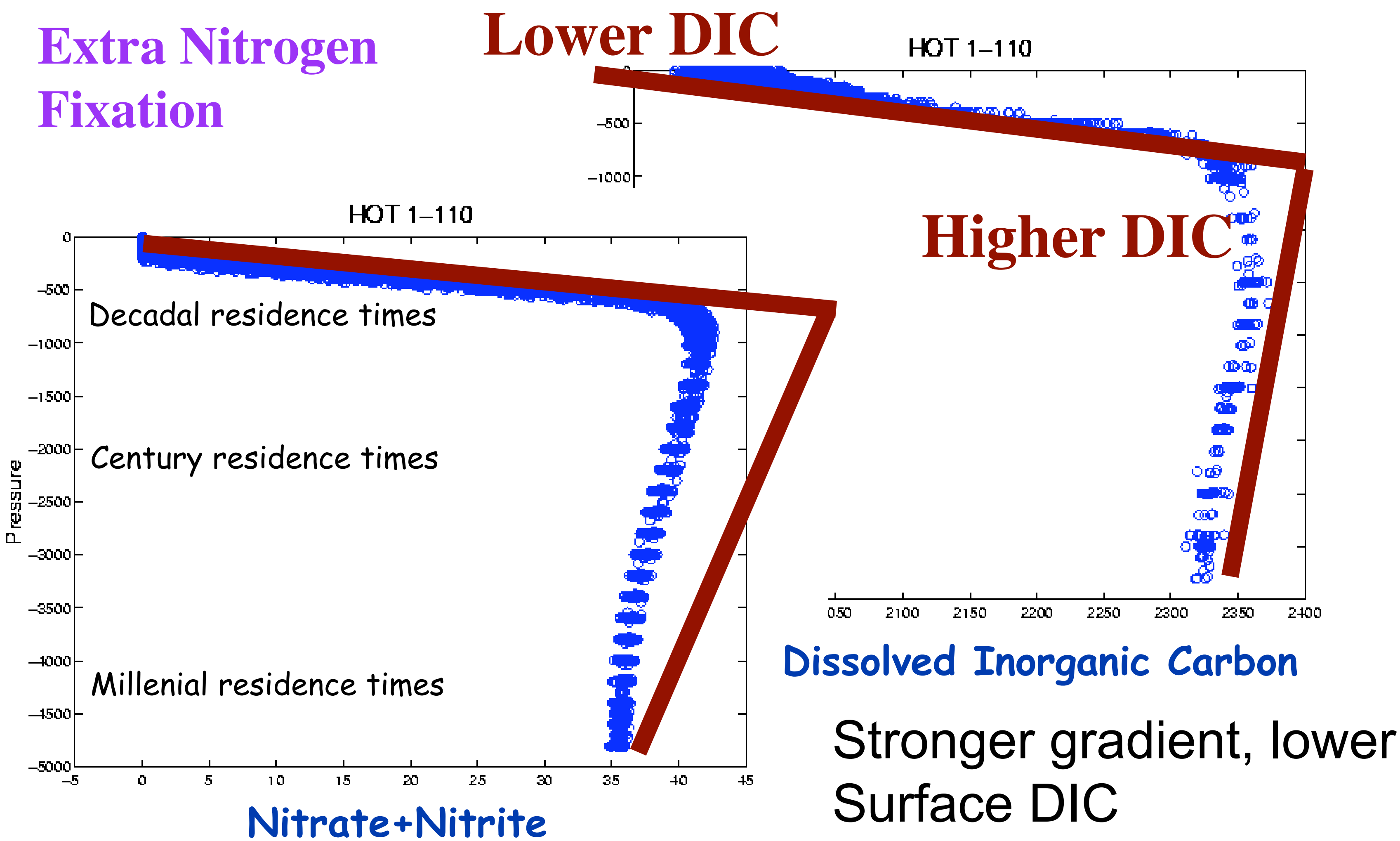
Boyd et al., 2007

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 (μmol quanta m^{-2} 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)
delDIC	6	26	17	14	58	21	13		36		nc	<1
δDMS (μmol 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	*Cyanobacteria Prochlorococcus*
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.

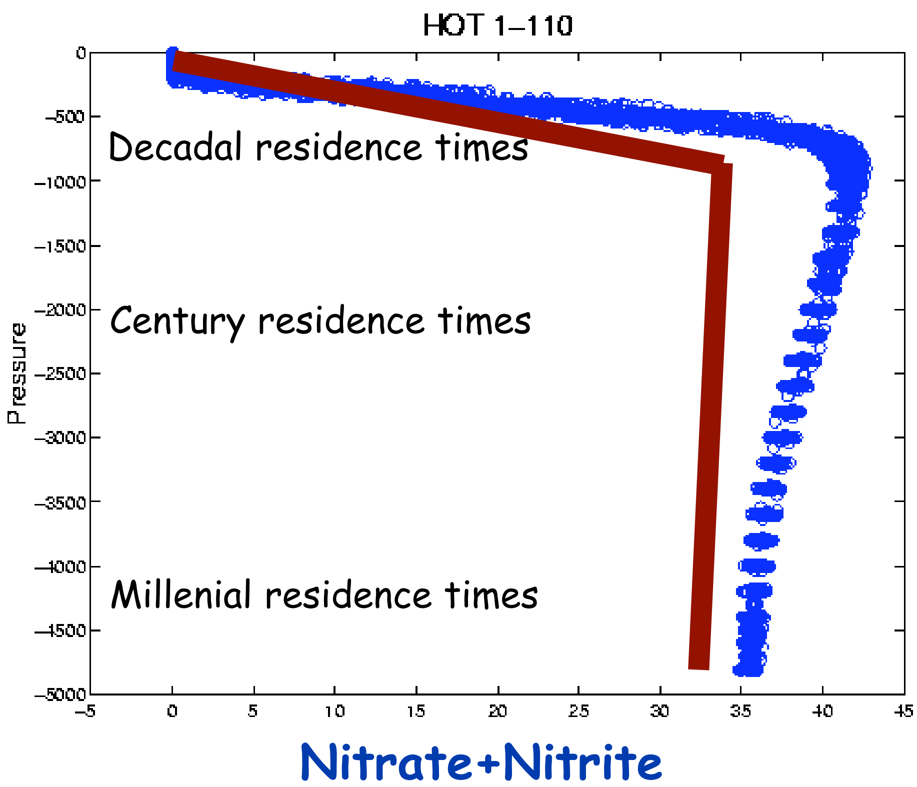
Boyd et al., 2007

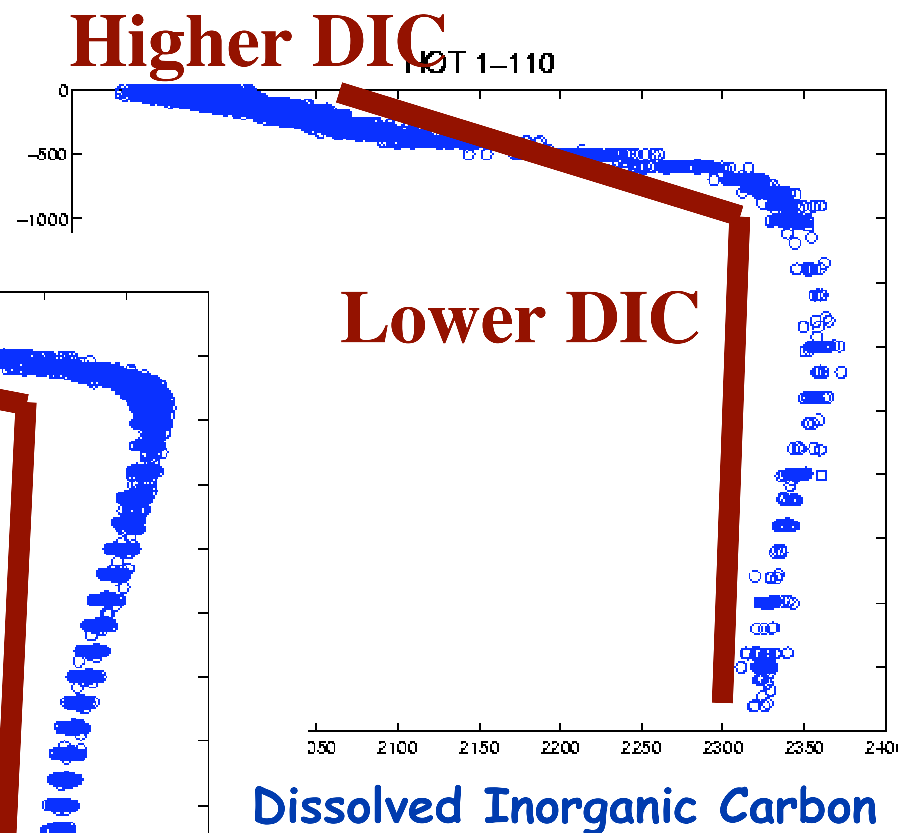
Changes in Total Nitrate Stock
Nitrogen Fixation - Denitrification Balance



Changes in Total Nitrate Stock
Nitrogen Fixation - Denitrification Balance

Extra Denitrification

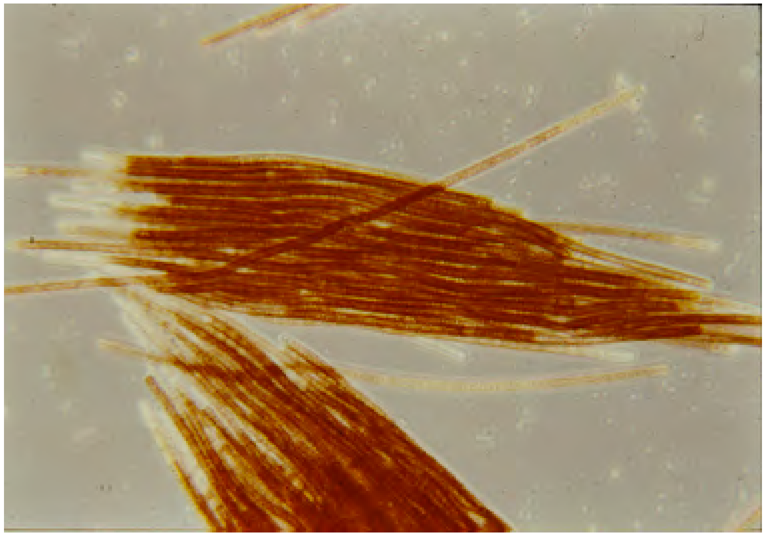


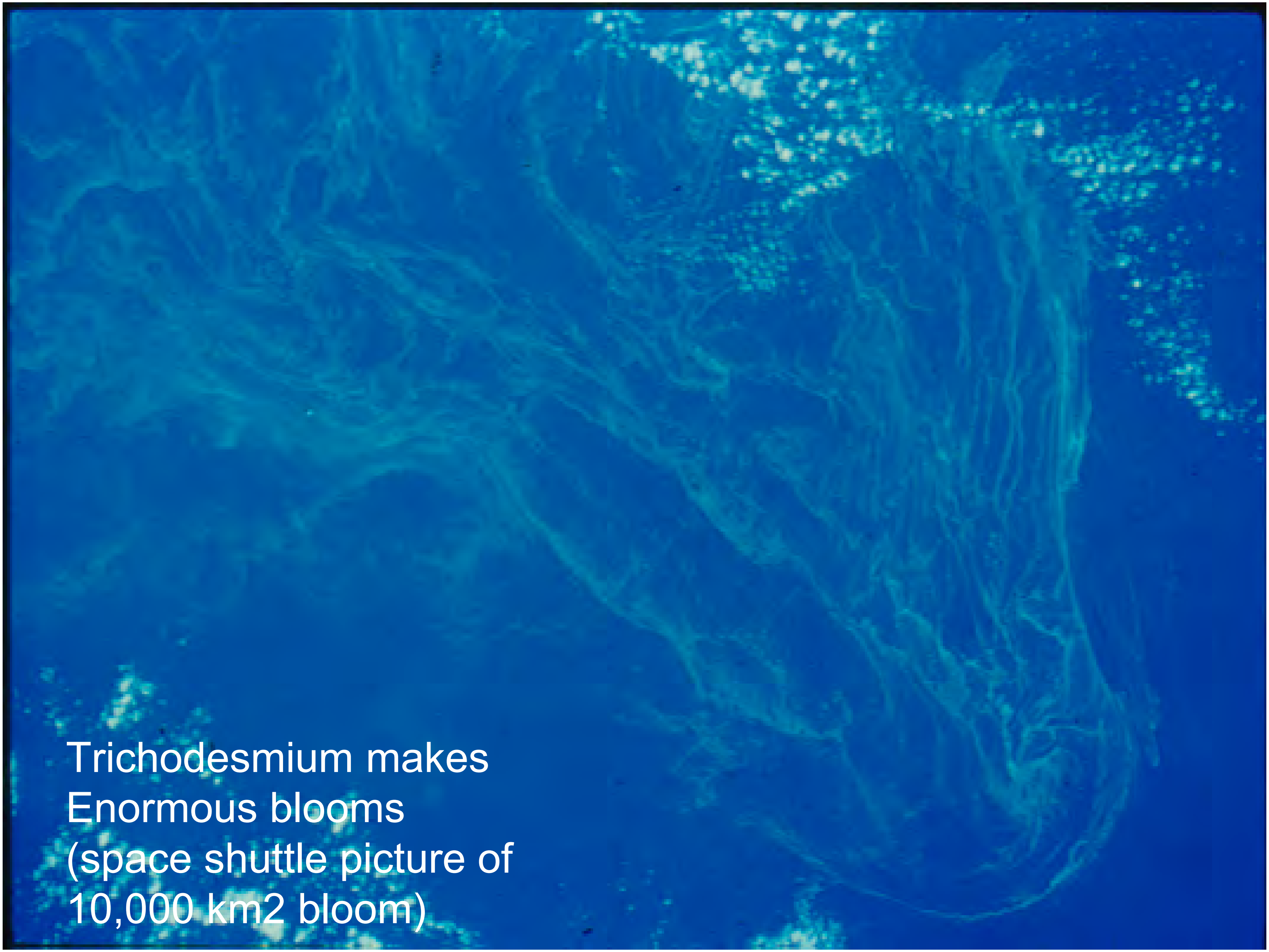


Weaker gradient, higher Surface DIC

Trichodesmium spp.

Best Known Planktonic Diazotroph




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

Scale

- Potential scale: 10 - 500 million tons CO_2 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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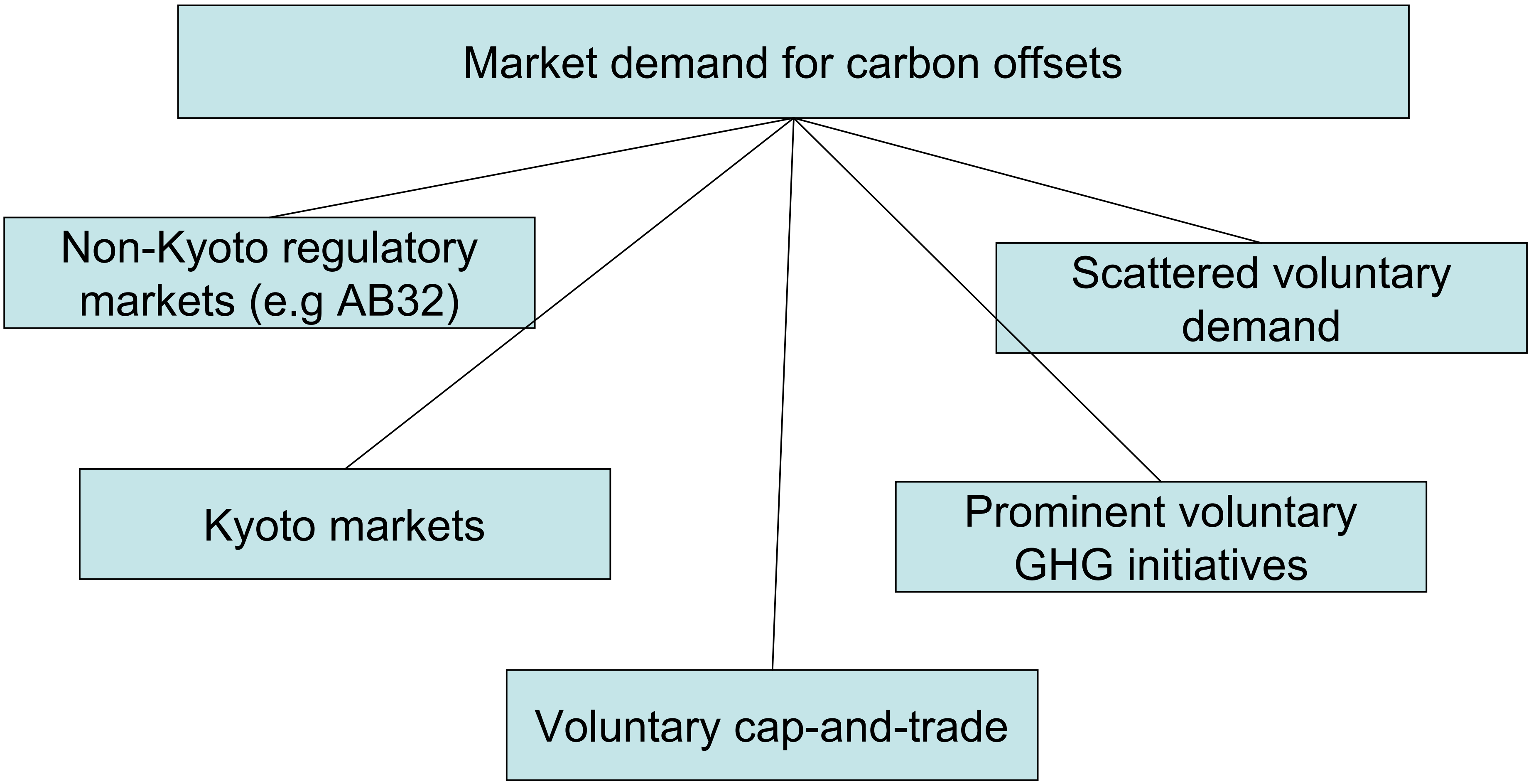
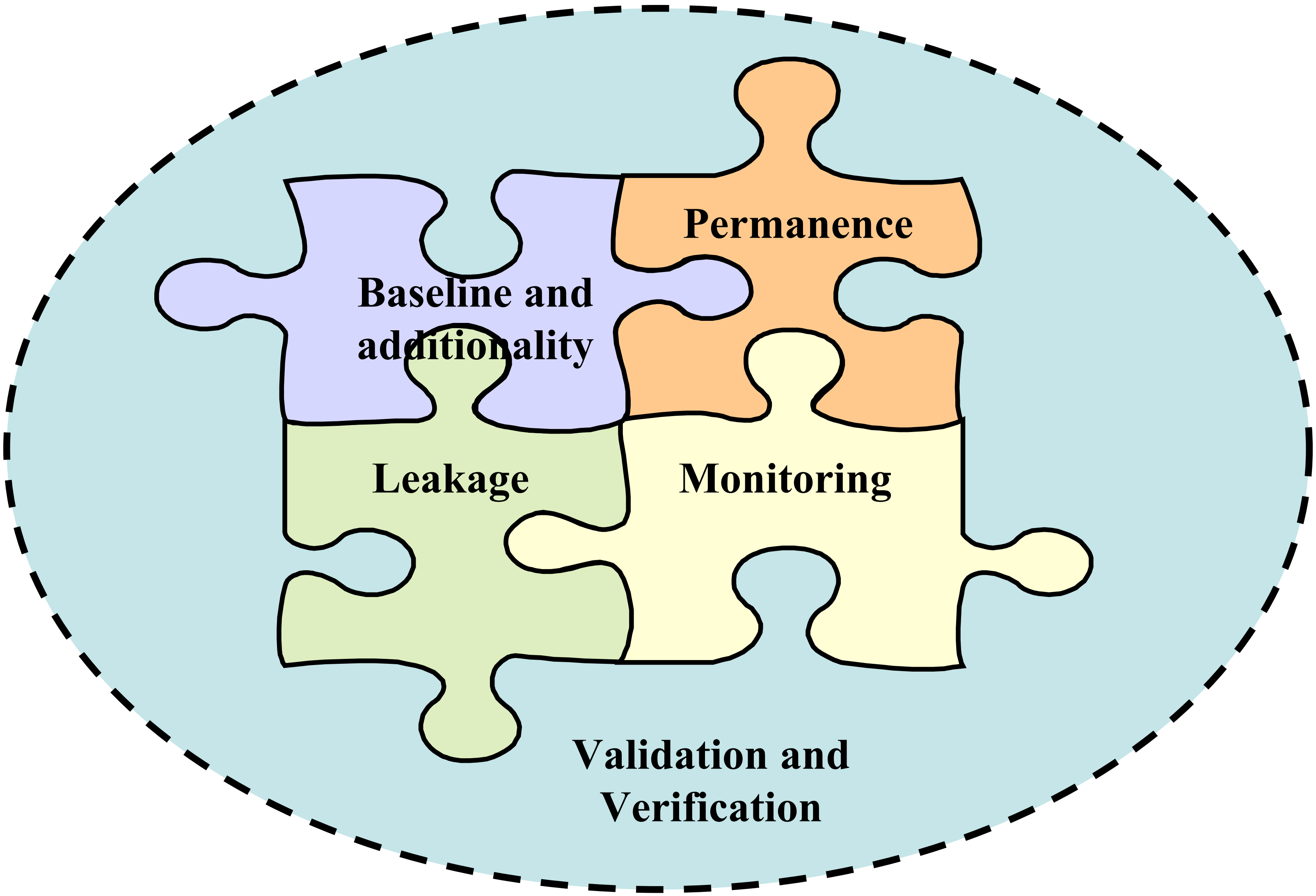
The market context



Key components of methodologies for GHG projects



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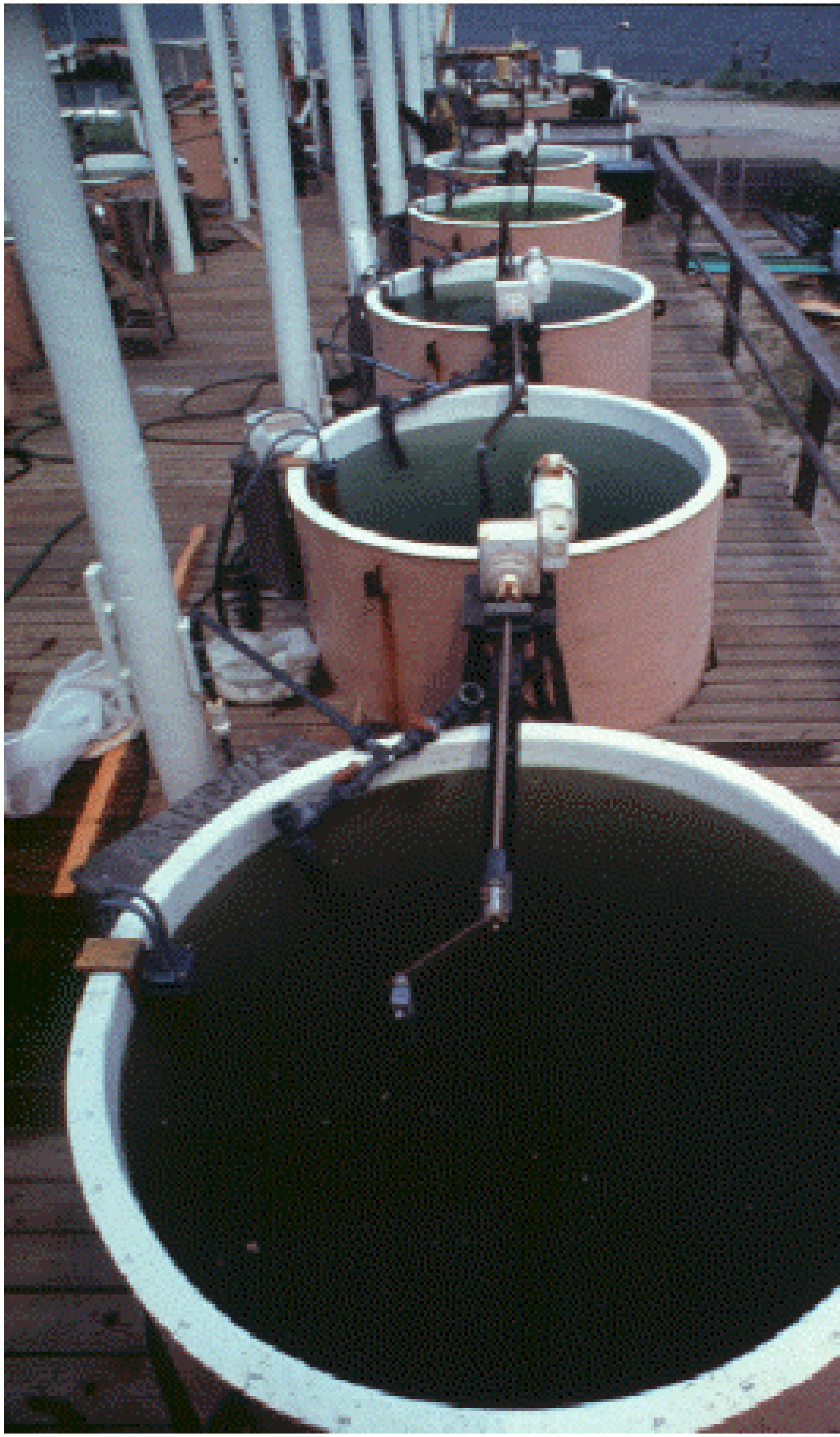
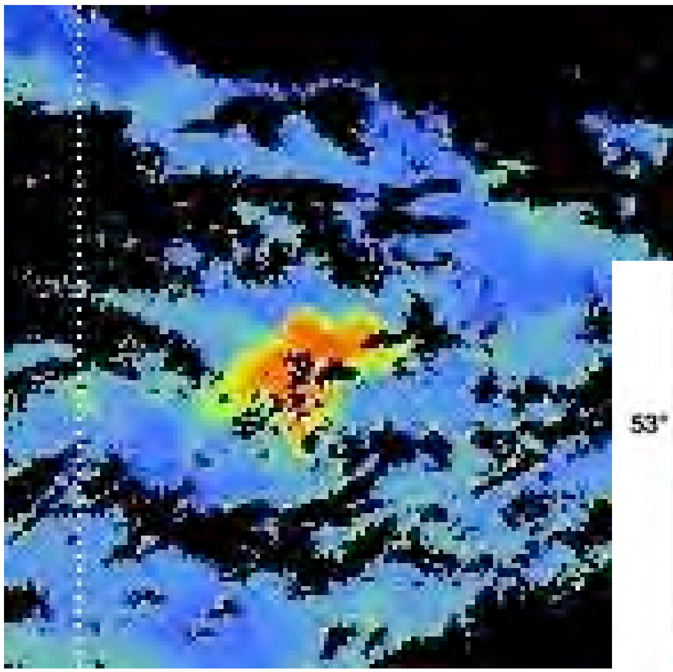
Ecosystem Scale Experimental Manipulations

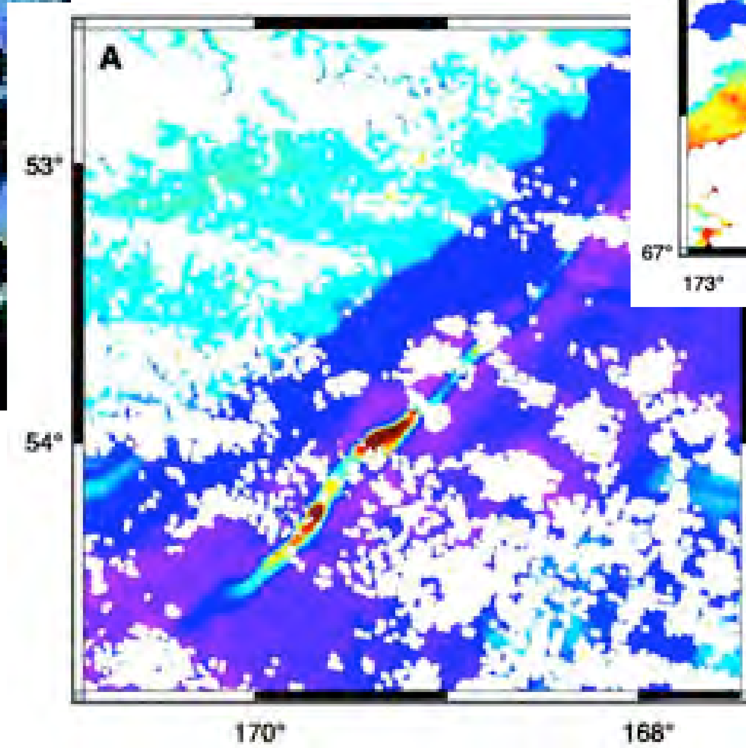
- Critical need to manipulate systems to understand dynamics and test ability to predict system behavior

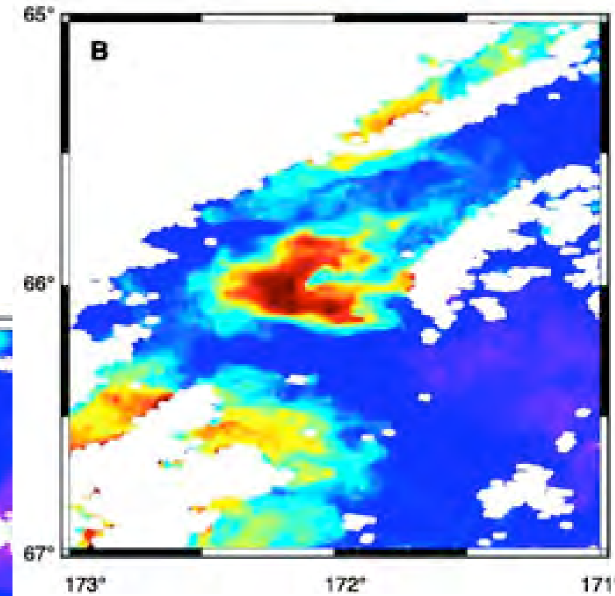
- MERL on steroids
- Iron Fertilization
- Impacts of ocean acidification




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?