Multiple Stresses,Thresholds, and Ocean Acidification

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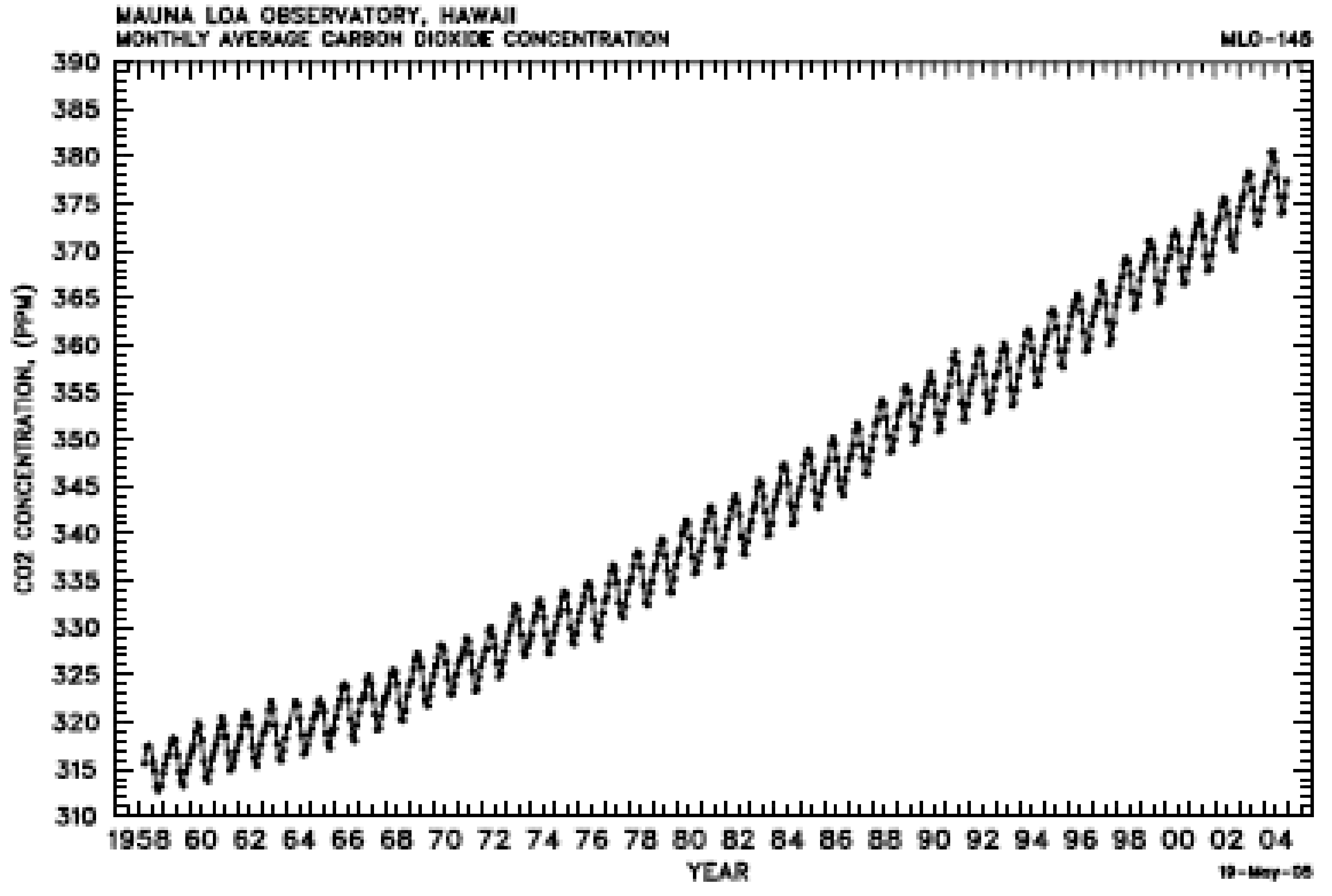


The Keeling Curve

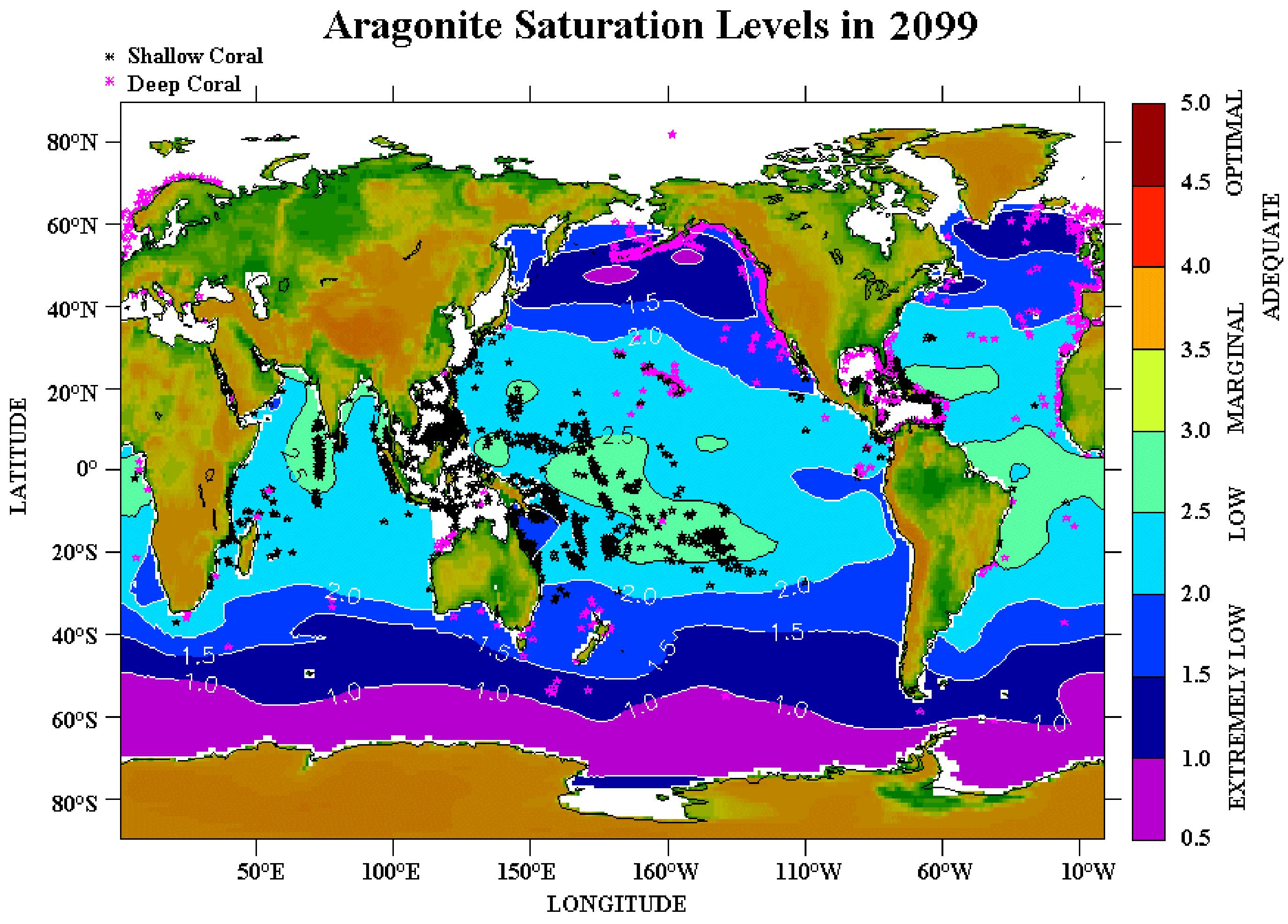
New “Grand Challenges” in Protecting the Web of Life in the World Ocean

- Anthropogenic fossil fuel emissions since 1850 increasing atmospheric CO_2 concentrations by c. 100ppm, higher than any experienced on earth for at least last 650K years. Oceans taking up ~30% of CO_2 emissions.
- Ocean pH reduced by 0.1 pH unit (c.10%), but much more implied in future as result of total commitment of GHG to atmosphere & timescale of exchanges between ocean & atmosphere.
- Ocean acidification directly affects all calcareous life forms in ocean & indirectly affects web of life as changes felt up the food chain & interfere with predator-prey relations.
- Significant increases in surface & subsurface heat in world ocean which produces large scale biogeographic shifts in distribution of most important species targeted by global commercial fisheries, on which humans depend as source of animal protein intake.
- Significantly increased melt rates of polar ice sheets in summer as result of unexpected feedbacks between sub-surface heat increases & sub-surface ice--increased probability of stratification in water column ⇒ lower productivity.

Changing Ocean Thermal Structure (Levitus et al 2005 Results)

- Between 1955 – 1998, world ocean heat content between 0 – 3000 m increased 14.5 x 10^{22} J = mean T. increase of 0.037° C at rate of 0.20 Wm^{-2}.
- Large part of change occurring in upper 700 m of world ocean. Substantial regional variability observed.
- Note that increase of 0.037° C a very large increase, since a 0.1° C increase roughly = mean T. change of 100° C of global atmosphere if all heat instantaneously transferred.

Past, Present and Future Aragonite Saturation Levels



Saturation levels provided by Orr et. al. Submitted

From R. Feely: *Global Warming: A Threat to Biodiversity*
Northwestern University October 22, 2005

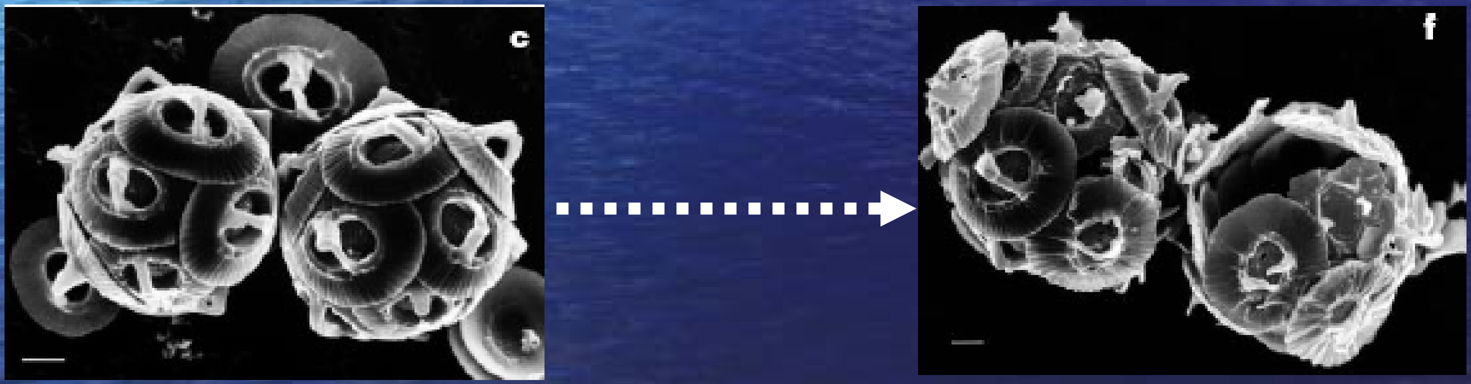
Coccolithophores

$p\mathrm{CO_2}$ 280-380 ppmv **$p\mathrm{CO_2}$ 780-850 ppmv**

Emiliania huxleyi

Calcification decreased

- 9 to 18%



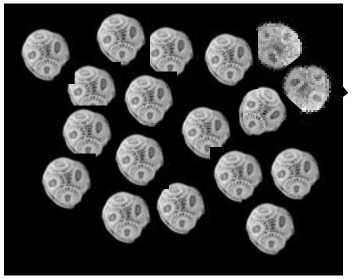
Gephyrocapsa oceanica

- 45%

Manipulation of $\mathrm{CO_2}$ system by addition of HCl or NaOH

Riebesell et al.(2000); Zondervan et al.(2001).

Potential Effects on Open Ocean Food Webs



Coccolithophores

ARCOD@ims.uaf.edu

Copepods

Vicki Fabry

Pteropods

Barrie Kovish

Pacific Salmon

Effects of Acidification on Corals (Langdon, 2007)

- On average, coral calcification changes 23% for each unit change in saturation state. (Threshold when $\Omega < 1$)
- Most reefs now exist in areas only adequate to growth--severe pressures from multiple stresses.
- As atmospheric concentration of CO_2 exceeds 550ppmv, net accretion of reef structures may not be sustainable.
- Reefs may be able to adapt fast enough to prevent extinction, but not fast enough to avoid degradation.
- Inability of reefs to develop into coral communities would have larger habitat implications.

How Does Climate Affect Marine Ecosystems?

- Ecosystem responses to ocean climate most quickly detected in lower trophic levels, i.e., phytoplankton, zooplankton, and invertebrates--rapid reproduction rates reveals fluctuations in abundance over short periods of time (PICES, 2004, Edwards and Richardson, 2004).
- It is the bottom-up process that cascades all the way up the food chain(Field, 2004; Ware and Thomson, 2005). Must think about planktonic ecosystems and community structure and interactions across multiple trophic levels(Ruhl and Smith,Jr., 2004).

Framing the Problem: The NRC Workshop Report on Multiple Stresses (2007)

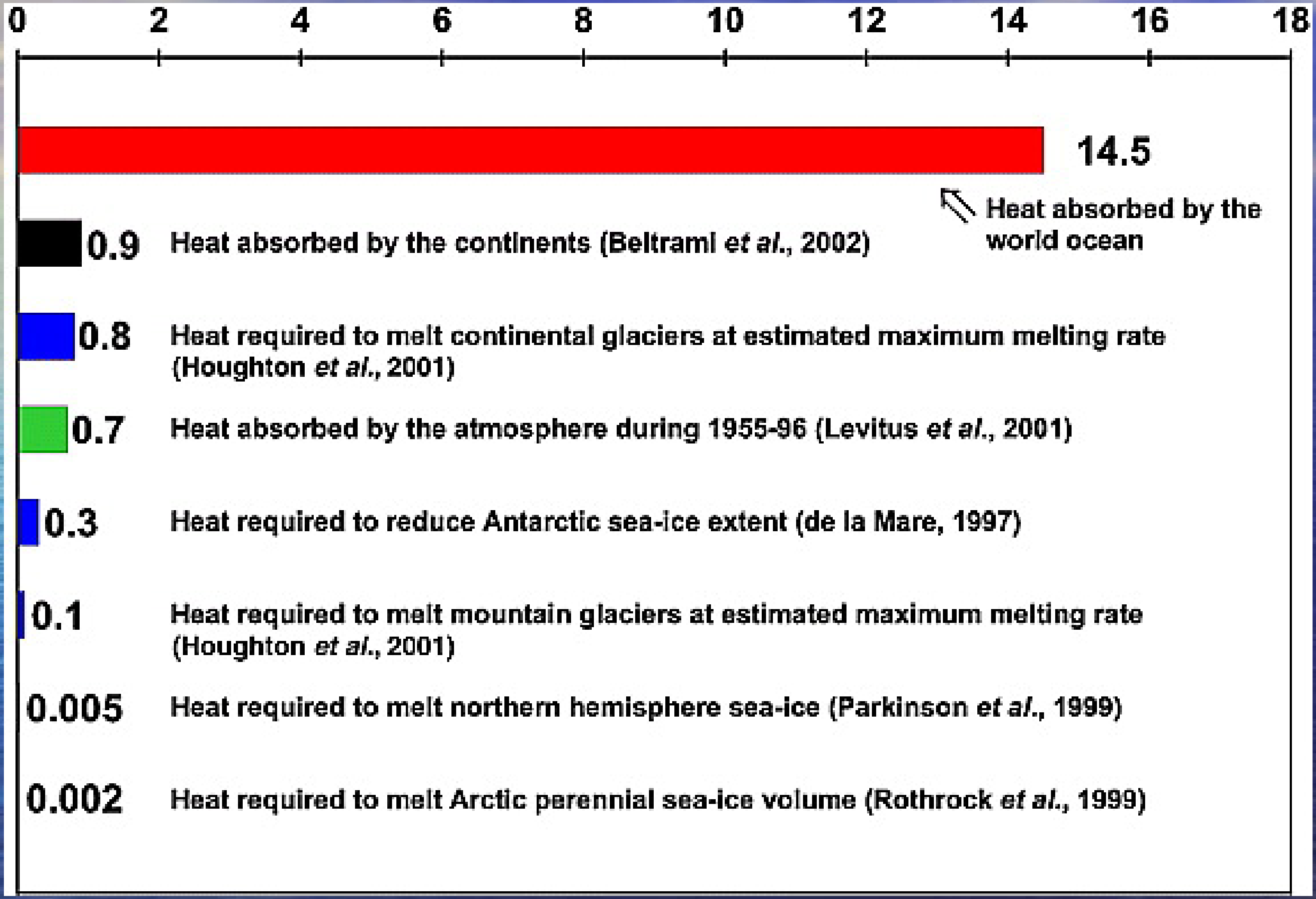
- The Puzzle:
- Both ecosystems & humans often face suites of multiple environmental stresses generated by a combination of external physical forcing & internal forcing. Multiple environmental stresses produce more than additive effects. They create synergies through interaction and produce quantitatively & qualitatively different outcomes from single influences.
- Outcomes are derived from nonlinear processes operating on multiple spatiotemporal scales which lead to critical thresholds or points at which either rates of change shift dramatically and/or the system shifts into a different state.
- However, many (most?) nonlinearities are unknown and gaps in understanding these phenomena lead to gaps in knowing how to respond to them in terms of design of policy & management approaches.

Where We Ended: The Melillo/Miles Research Agenda for the Heinz Center/Nature Conservancy Thresholds Initiative

- What are thresholds?
- Do thresholds operate in ecological & social systems? Can we predict the likelihood of a threshold happening? (What indices? What tools?)
- Can we manage systems to reverse or halt their movement toward thresholds?
- What are the consequences of crossing thresholds? How do we manage to minimize negatives & maximize positives? (Deal with multiple stresses & scale).
- Are there management impediments to optimal responses?
- What kind of partnership between environment & social services is needed?

Research Agenda for Policy Making (Janetos, 2007)

- Suggests that most important knowledge to get as quickly as possible is information about potential end-points and lag-times
- What are potential magnitudes of important end-points?
- Are there thresholds we must worry about?
- To what degree is there sufficient ecological “buffering” to guard against cascading effects?
- What are the implications for atmospheric greenhouse gas concentrations and therefore emissions and mitigation costs



Levitus et al. 2005.

Classifying Multiple Stressors

- Whatever the physical forcing (triggers), real effort should be focused on detecting & analyzing the primary, secondary, & tertiary stressors and their impacts.
- Primary stressors:factors directly affecting ecosystem change across range of scales.
- Secondary stressors: create conditions that abet vulnerability to some indicator.
- Tertiary stressors: inhibit resiliency or adaptive capacity.

(Generalizing from Easterling in NRC 2007)

Methodological Tensions as result of Differences in Approach

- Is prediction to be the primary objective??
- Rial et al.(2005) & Pittock (2006): There are far more nonlinearities in the climate system than we can understand. Need to move away from prediction to integrated assessment of vulnerability with focus on risk assessment & disaster prevention. Do it quantitatively to derive insight into relative importance of climate vis-à-vis other environmental influences. Yes, try to understand as much as possible about nonlinearities and thresholds & use that knowledge as best we can.