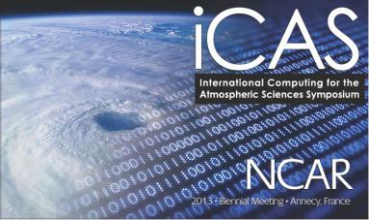

The Impacts of Climate Extremes on Ocean Ecosystems

Joan Kleypas
Climate & Global Dynamics
Integrated Science Program
NCAR

NCAR is sponsored by the National Science Foundation

Acknowledgments

Small team: Fred Castruccio (NCAR), Enrique Curchitser (Rutgers), Zack Powell (UC-Berkeley), Lizzie McLeod (TNC)

Special thanks to:

Rich Loft

Siddhartha Ghosh

Peter Backlund

NSF

Janus computational resources were provided by NSF-MRI Grant CNS-0821794, MRI-Consortium: Acquisition of a Supercomputer by the Front Range Computing Consortium (FRCC), with additional support from the University of Colorado and NSF sponsorship of NCAR, as well as the Texas Advanced Computing Center (TACC)

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Special thanks to: **HPC scientists like you**

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The Impacts of Climate Extremes on Ocean Ecosystems

1. Climate extremes
2. Climate extremes in the marine environment
3. How climate extremes affect marine ecosystems
4. How we use high performance computing to understand and plan for climate impacts on marine ecosystems

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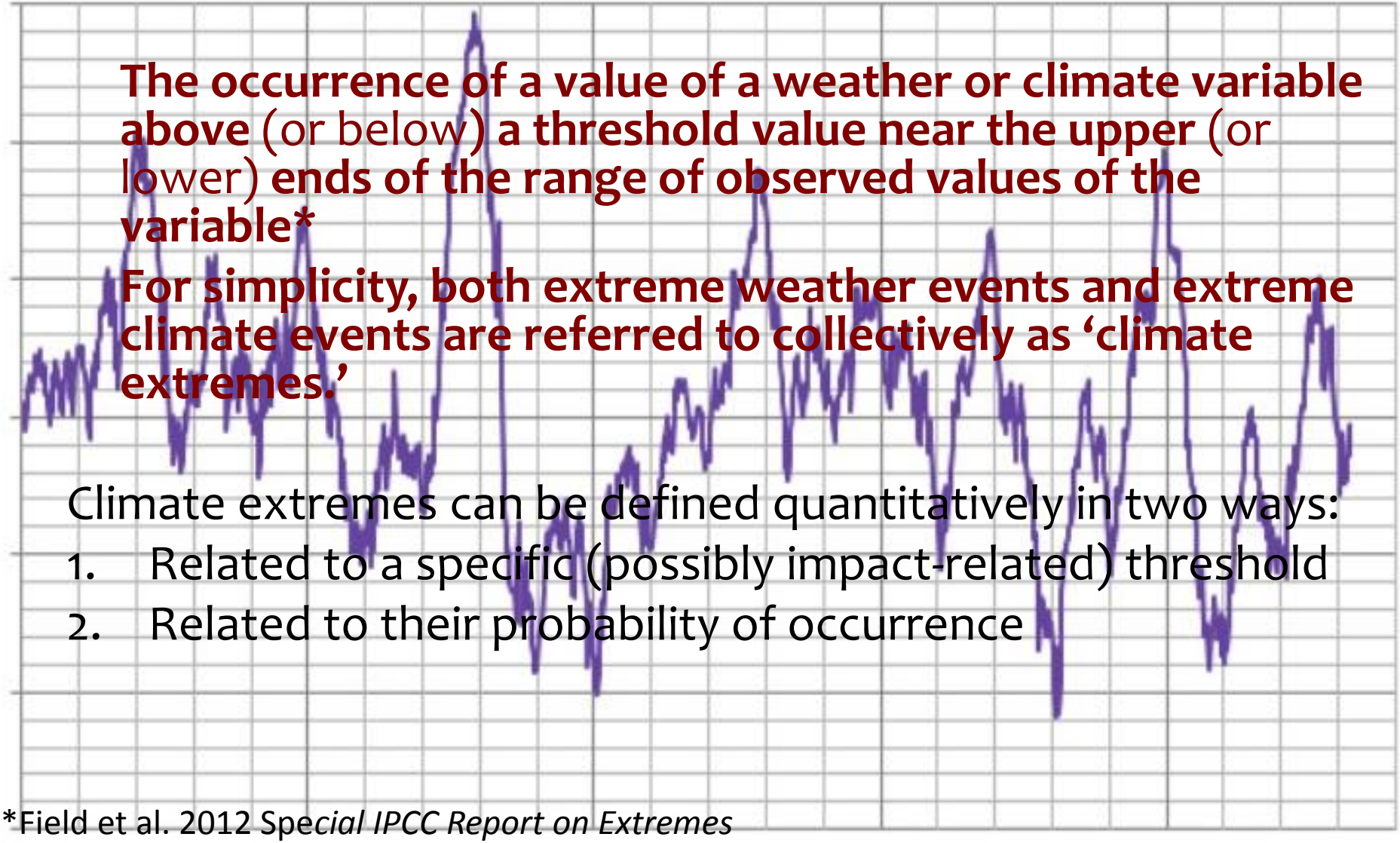
The Impacts of Climate Extremes on Ocean Ecosystems

1. **Climate extremes**
   - Temperature
   - Precipitation
   - Droughts
   - Floods
   - Storms

cli·mate ex·treme

(extreme weather or climate event)



The occurrence of a value of a weather or climate variable above (or below) **a threshold value near the upper** (or lower) **ends of the range of observed values of the variable***

For simplicity, both extreme weather events and extreme climate events are referred to collectively as 'climate extremes.'

Climate extremes can be defined quantitatively in two ways:

1. Related to a specific (possibly impact-related) threshold
2. Related to their probability of occurrence

*Field et al. 2012 Spe*cial IPCC Report on Extremes*

Climate Extremes

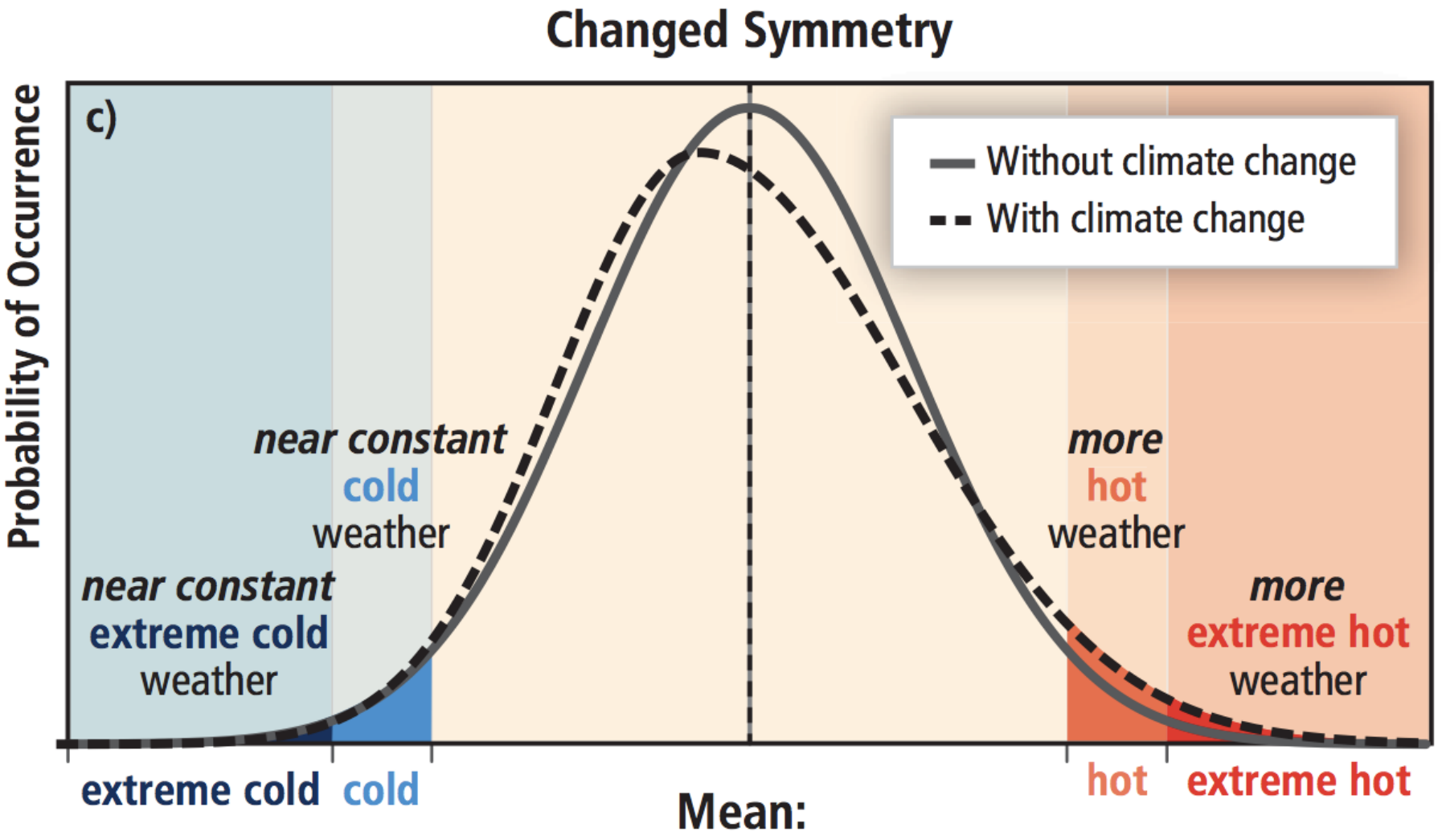
Absolute threshold: usually in reference to a particular place

Relative threshold: < 10, 5, 1%, or even lower chance of occurrence for a given time of the year (day, month, season, whole year) during a specified *reference* period (generally 1961-1990) are often used

Accumulation: e.g. droughts and floods - the accumulation itself is the extreme.

Compound: two or more events occurring simultaneously, can lead to high impacts, even if the two single events are not extreme per se

Climate Extremes



*Field et al. 2012 Spe*cial IPCC Report on Extremes*

Climate Extremes on Land

Slide courtesy of Kevin Trenberth

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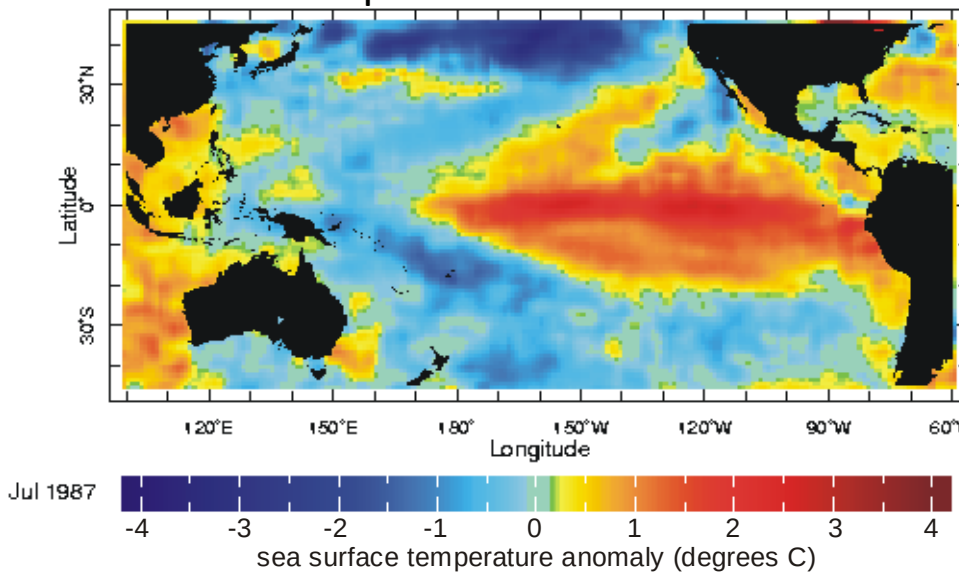
The Impacts of Climate Extremes on Ocean Ecosystems

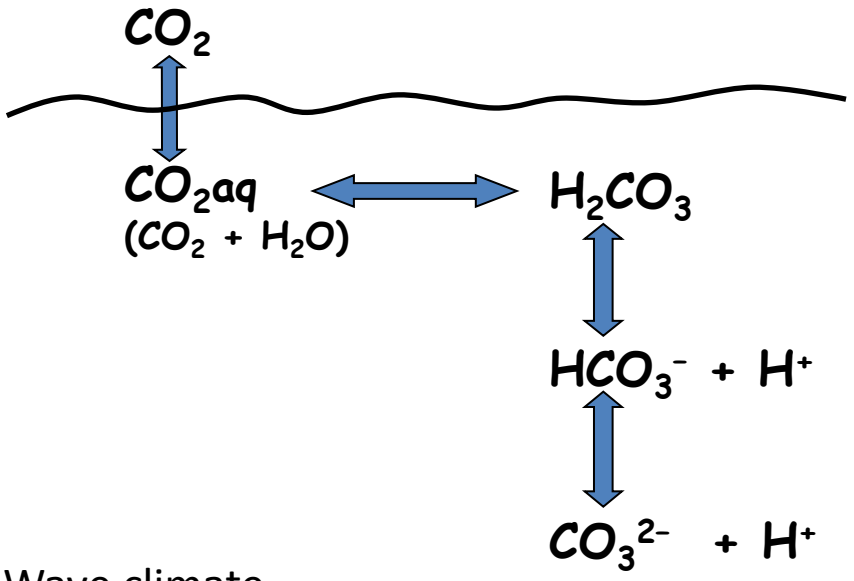
1. Climate extremes
2. **Climate extremes in the marine environment**
   - Temperature
   - Storms
   - Wave climate
   - Ocean acidification
   - Dust aerosols
   - Salinity, circulation patterns, etc.

Climate Extremes in the Ocean

Ocean Temperature



Ocean acidification



Tropical storms

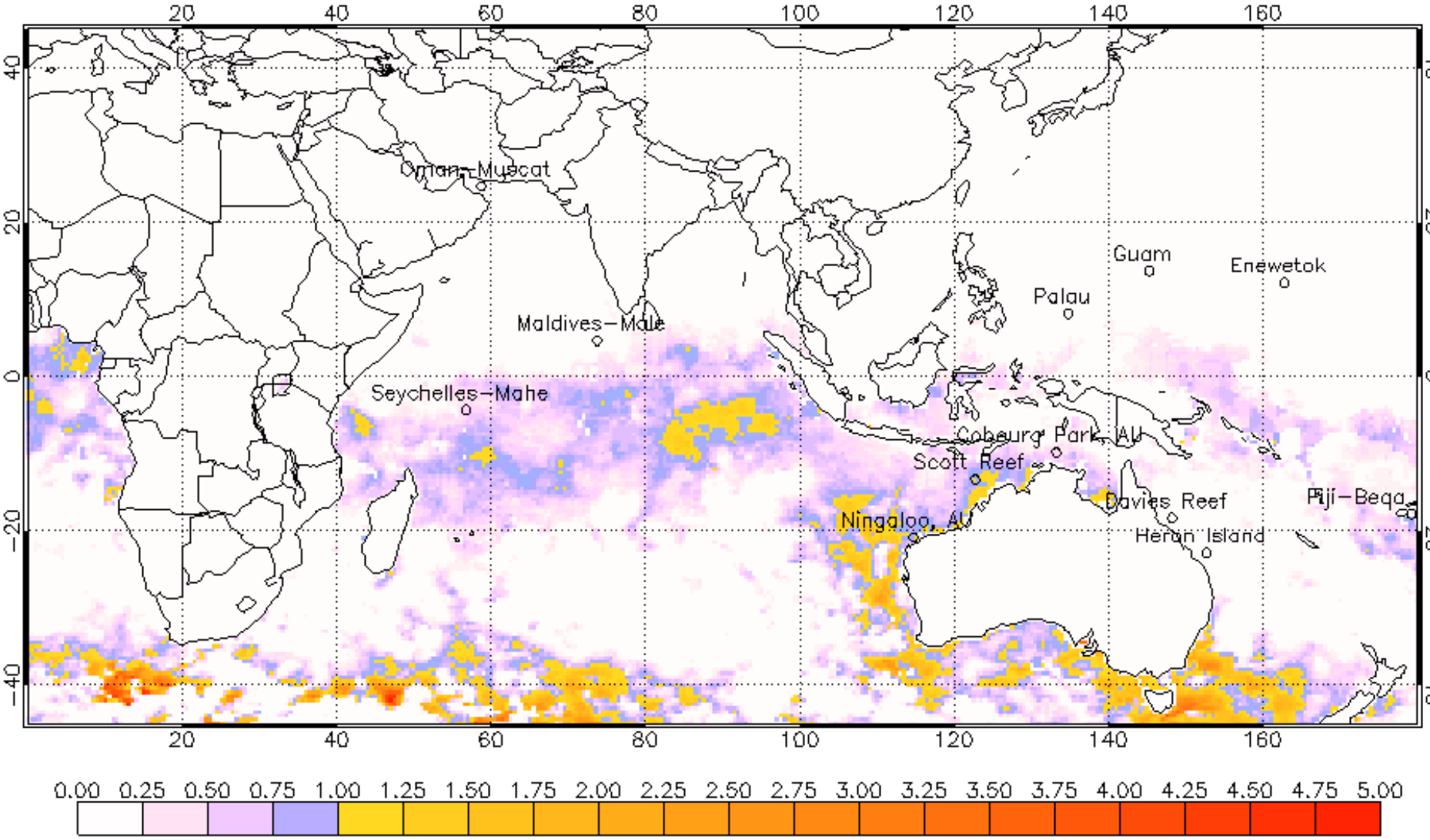
Wave climate

http://www.ospo.noaa.gov/Products/ocean/cb/hotspots/index.html

Ocean Temperature Hot Spots

Weekly SST Anomalies relative to 1961-1990

3/25/2013



Thermal Stress

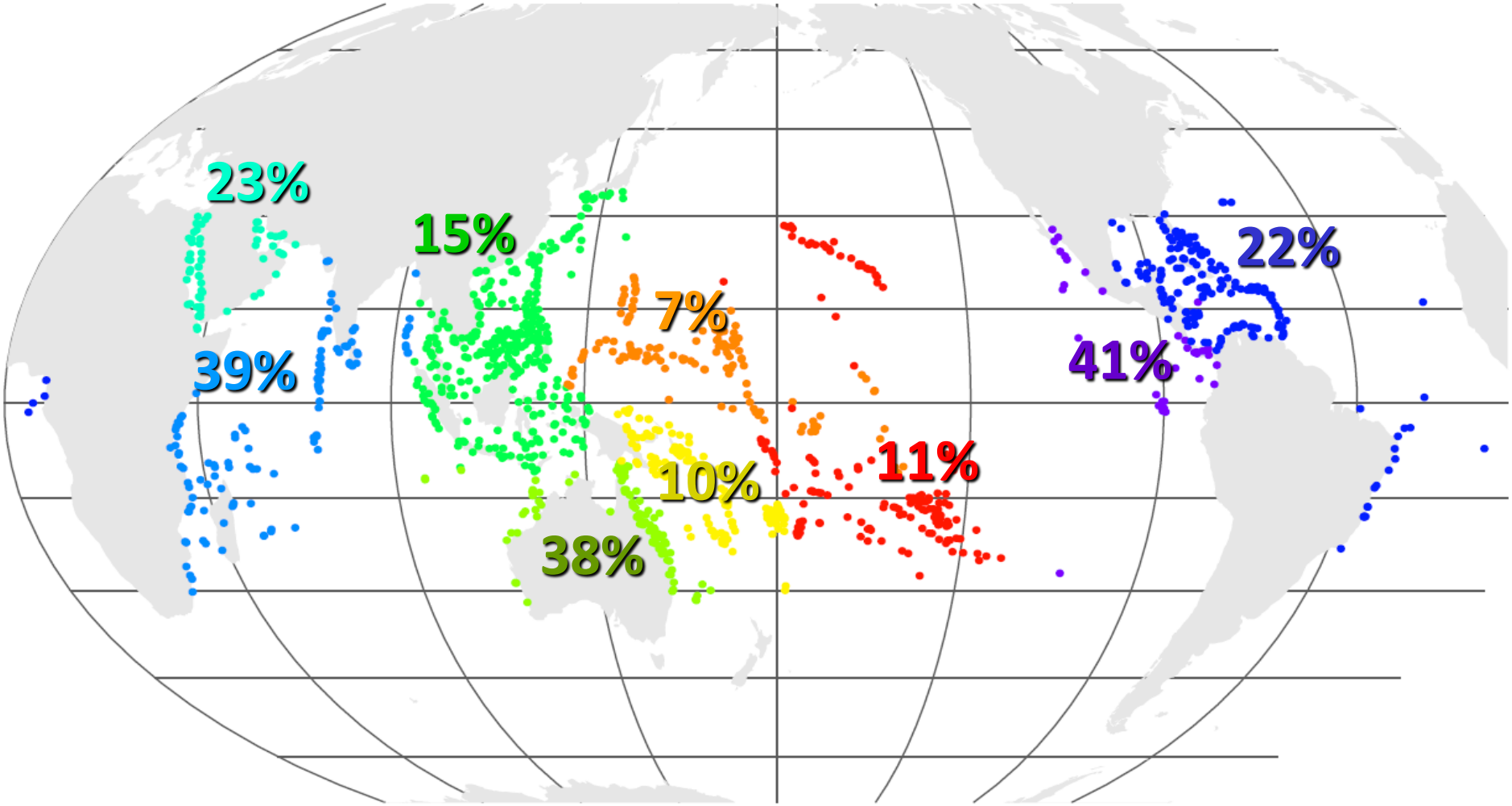
Degree Heating Week (DHW)

- Cumulative thermal stress over a rolling 12-week period for a given location

- Accumulation of excess heat when SST ≥ 1°C of climatological maximum SST

	°C above max	DHW
Week 1	1.0	1.0
Week 2	2.0	3.0
Week 3	0.8	3.0
Week 4	1.2	4.2
…	…	…
Week 12	0.0	4.2

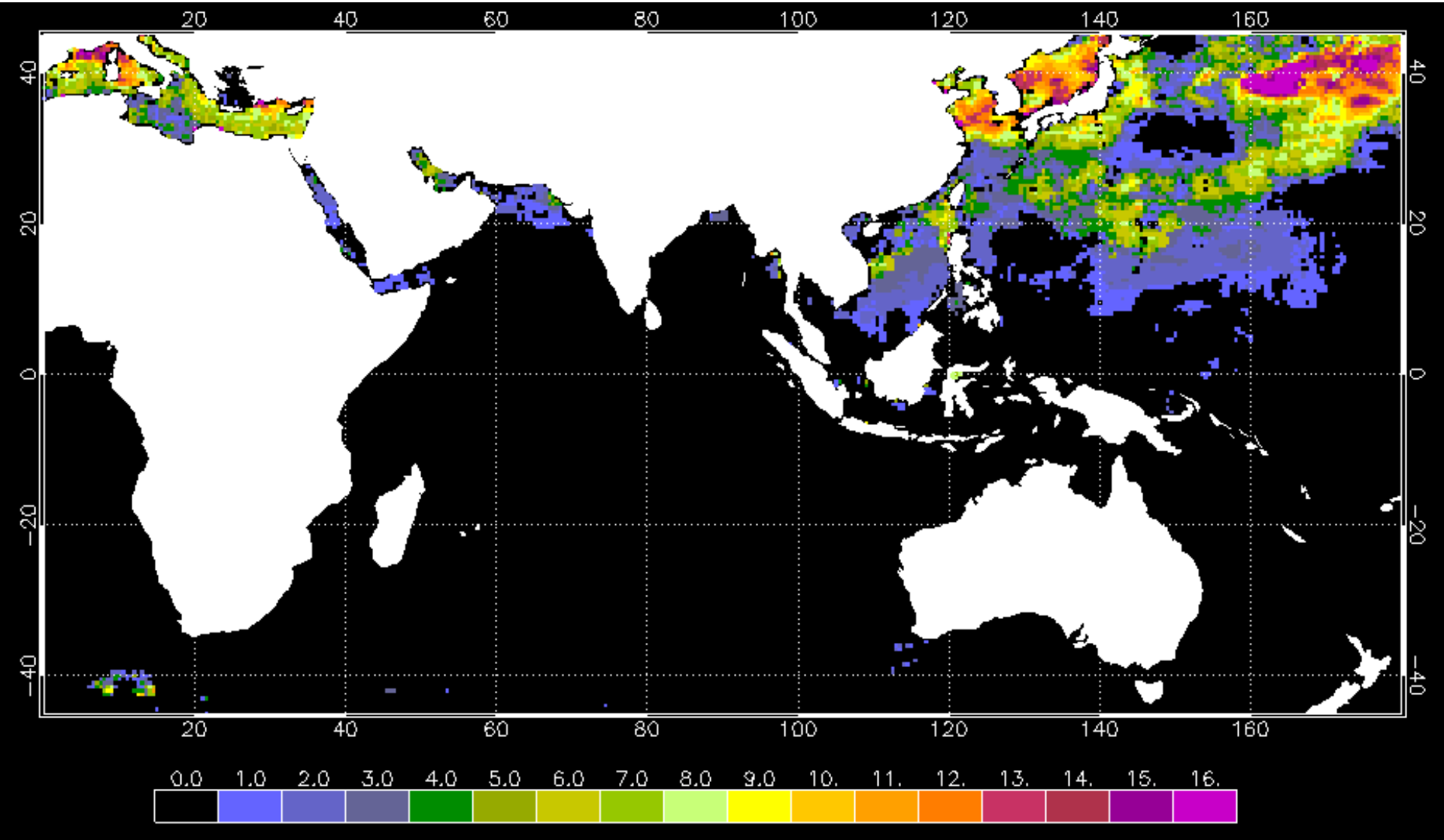
% of Reefs That Have Experienced Severe Bleaching



http://www.ospo.noaa.gov/Products/ocean/cb/dhw/index.html

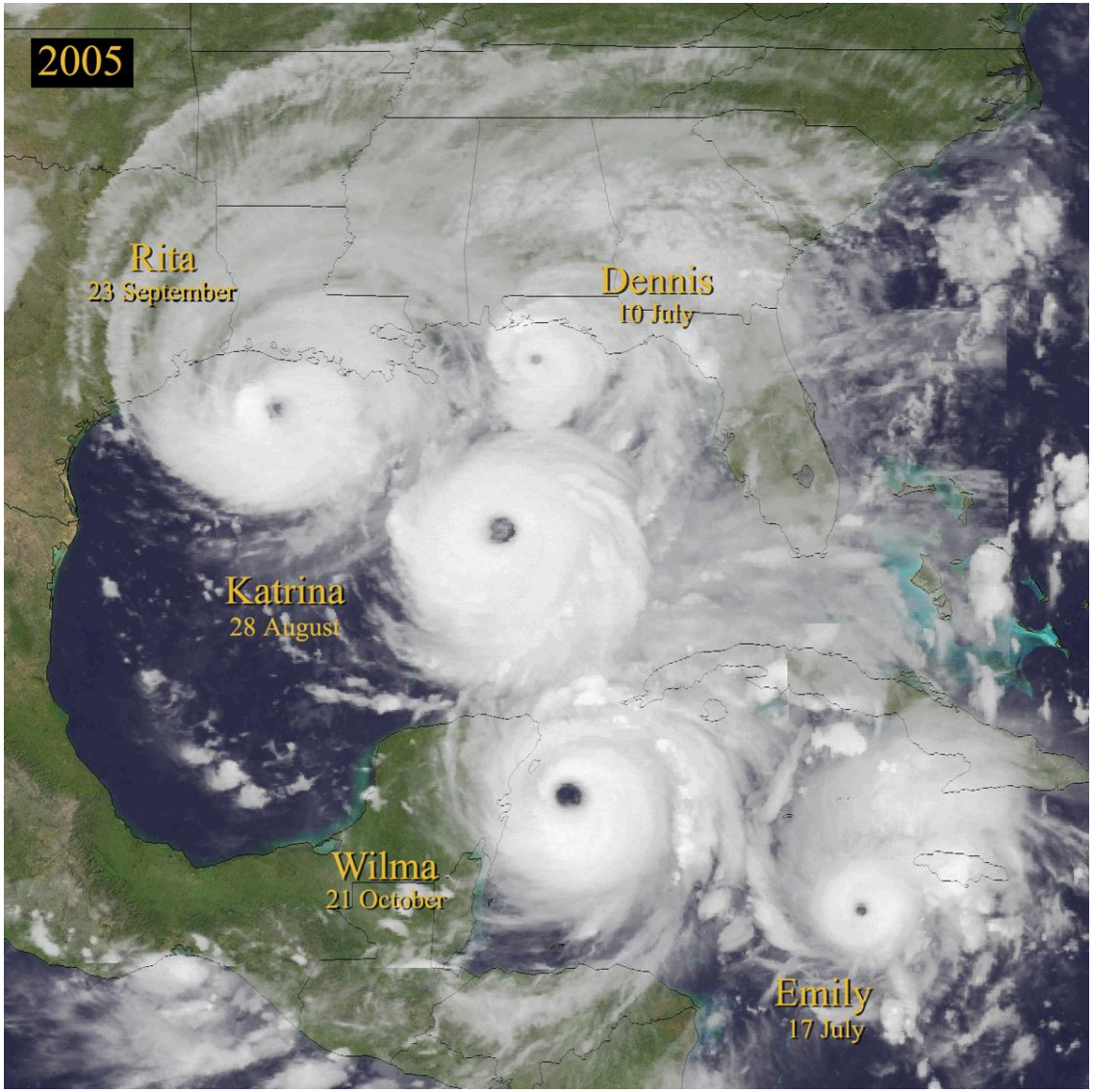
Heat Stress – Degree Heating Weeks

DHW – 12 weeks ending on 09/09/2013



Increases in storm frequency

Increases in storm frequency



2005 Composite:

Dennis, Emily, Katrina, Rita and Wilma

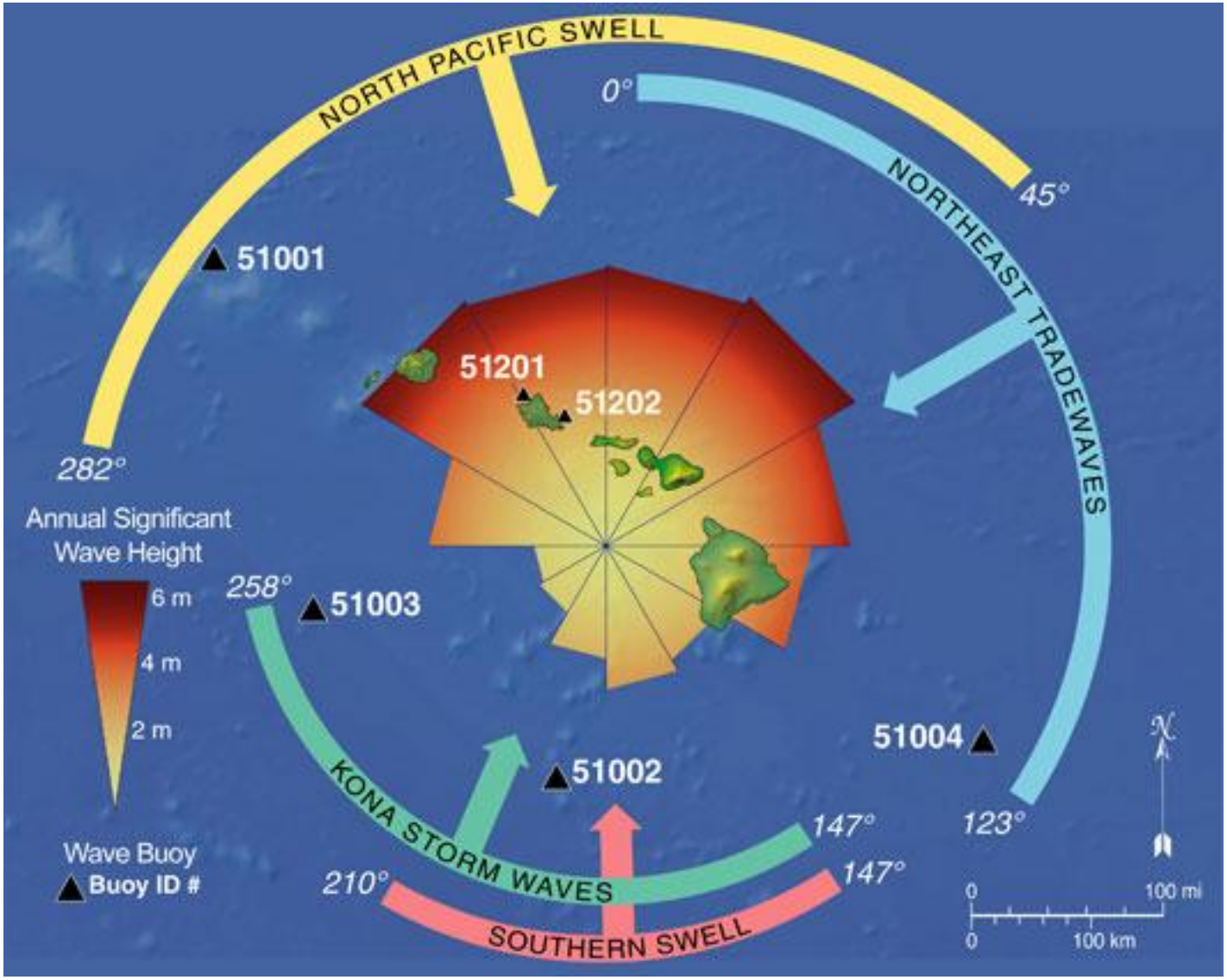
Tropical storms often damage shallow-water ecosystems.

Occasional disturbance tends to promote biodiversity, but when disturbances are too frequent, ecosystems can't recover.

Wave Climate

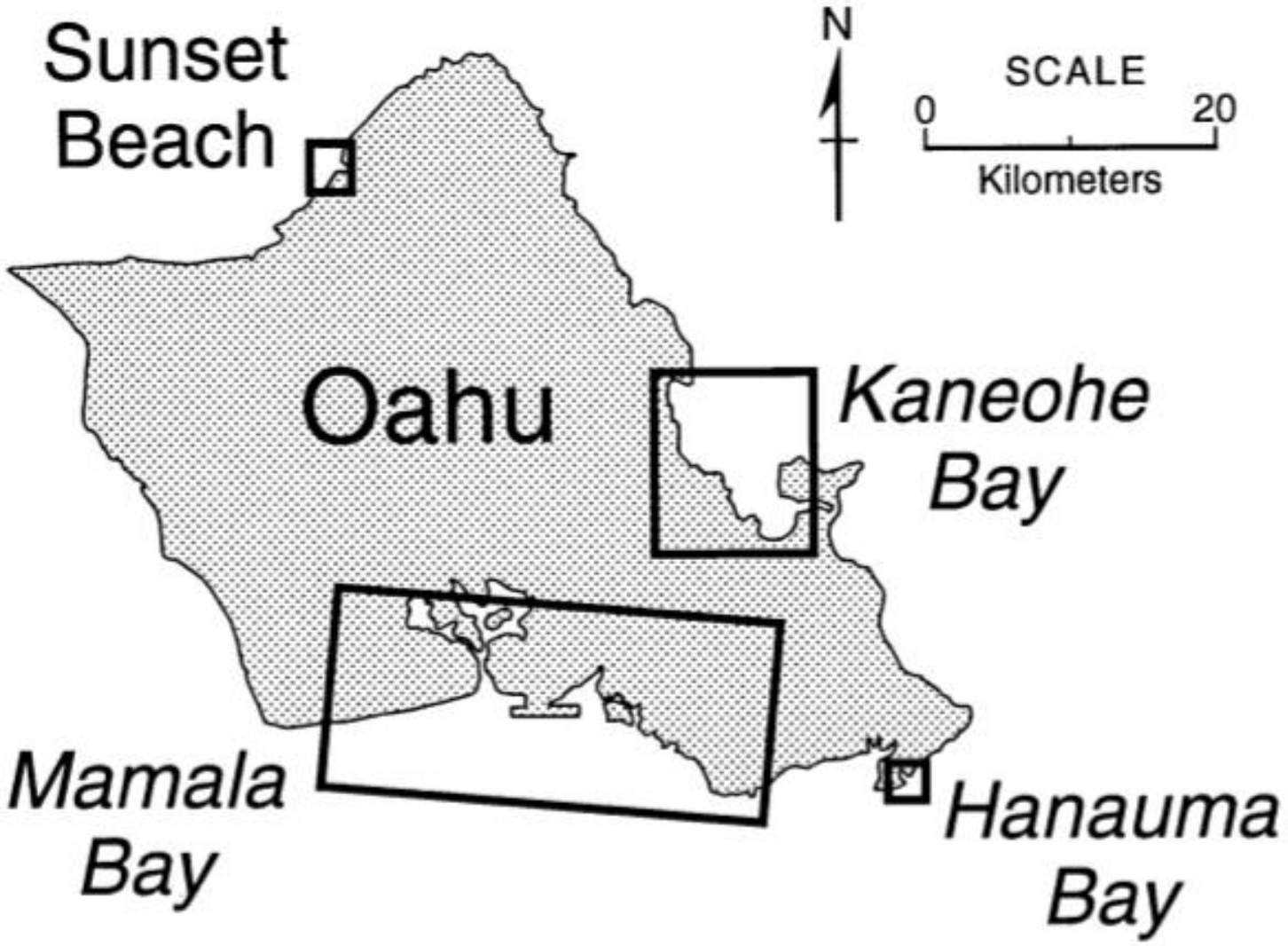
Sean O'Flaherty

Wave Climate



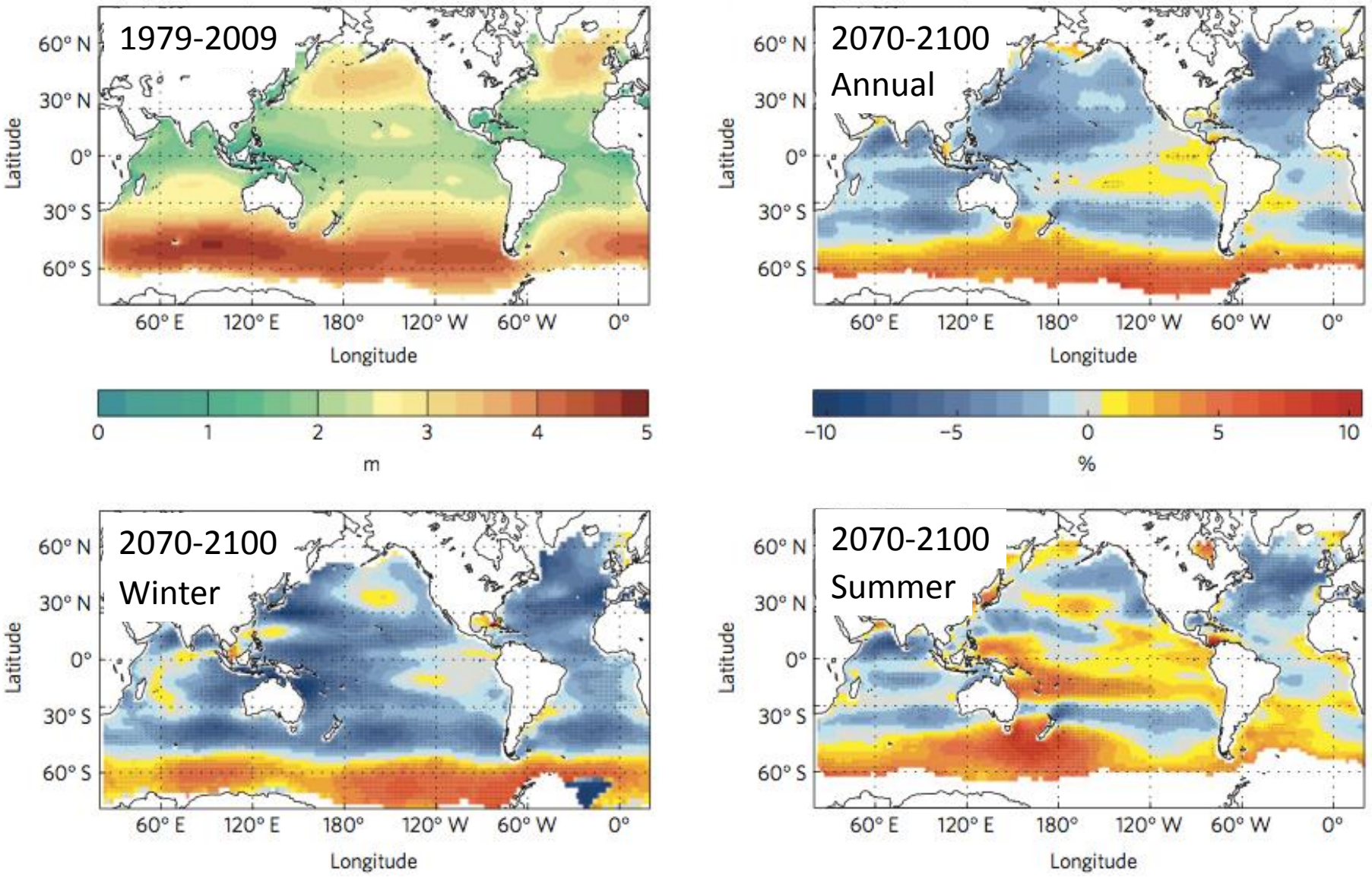
Vitousek & Fletcher 2008 *Pacific Science*

Wave Climate



Grigg 1998 *Coral Reefs*

Significant Wave Height



Heller et al. 2013 *Nature Climate Change*

The Impacts of Climate Extremes on Ocean Ecosystems

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The Impacts of Climate Extremes on Ocean Ecosystems

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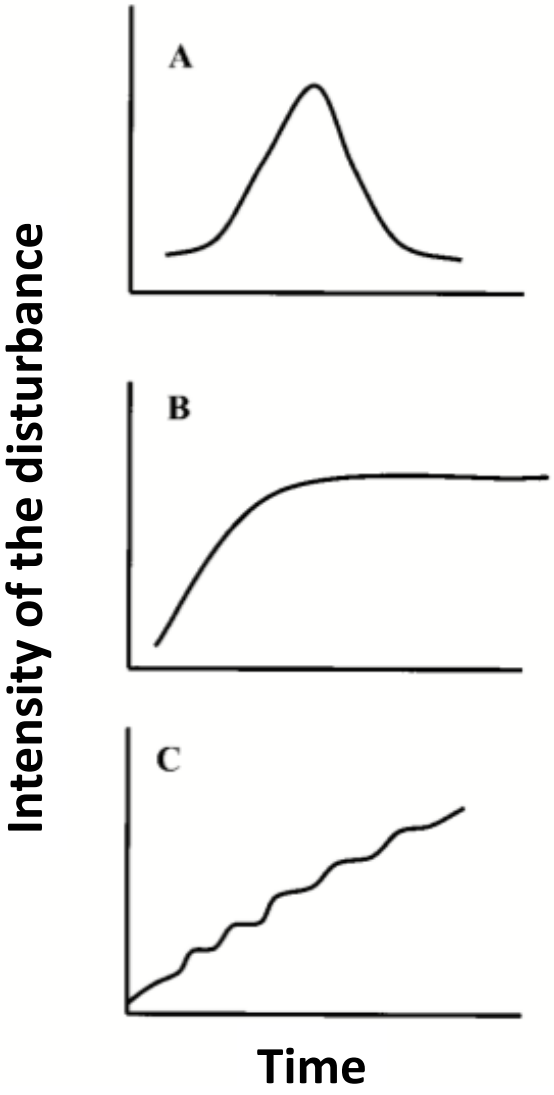
3. **How climate extremes affect marine ecosystems**
   - Temperature: Coral bleaching events
   - Storm frequency: Kelp bed destruction
   - Wave climate: Ecosystem construction
   - Compound effects: Harmful algal blooms
   - Ocean acidification: Multiple impacts
   - Dust aerosols: Nutrients, toxins, pathogens

The stresses ecosystems feel

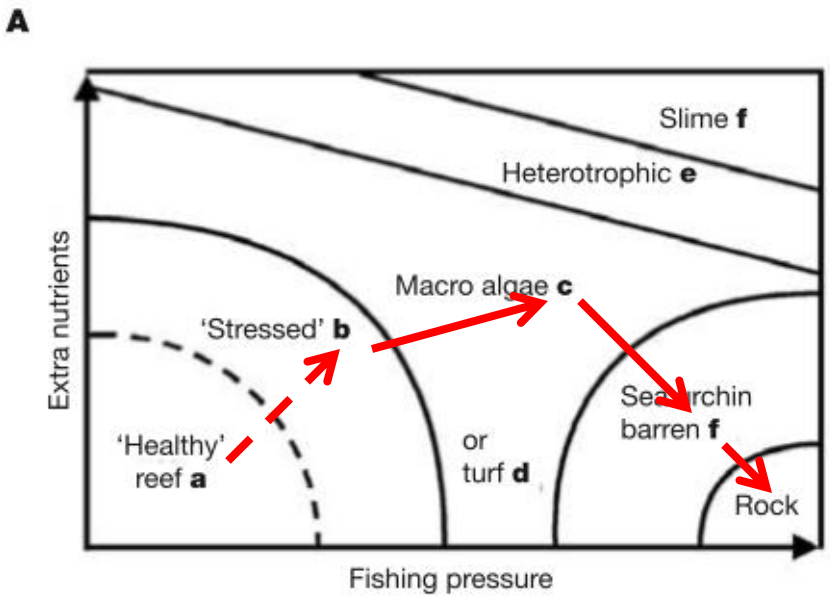


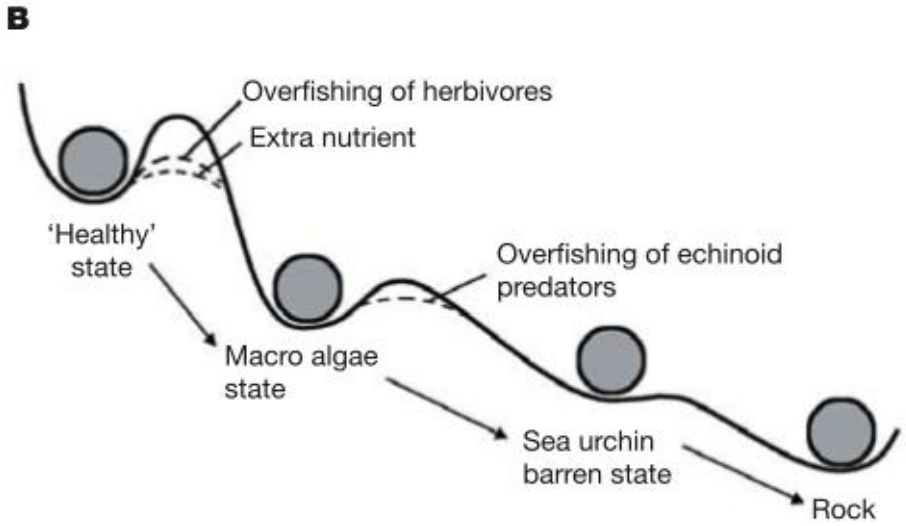
"Pulse" disturbance storms

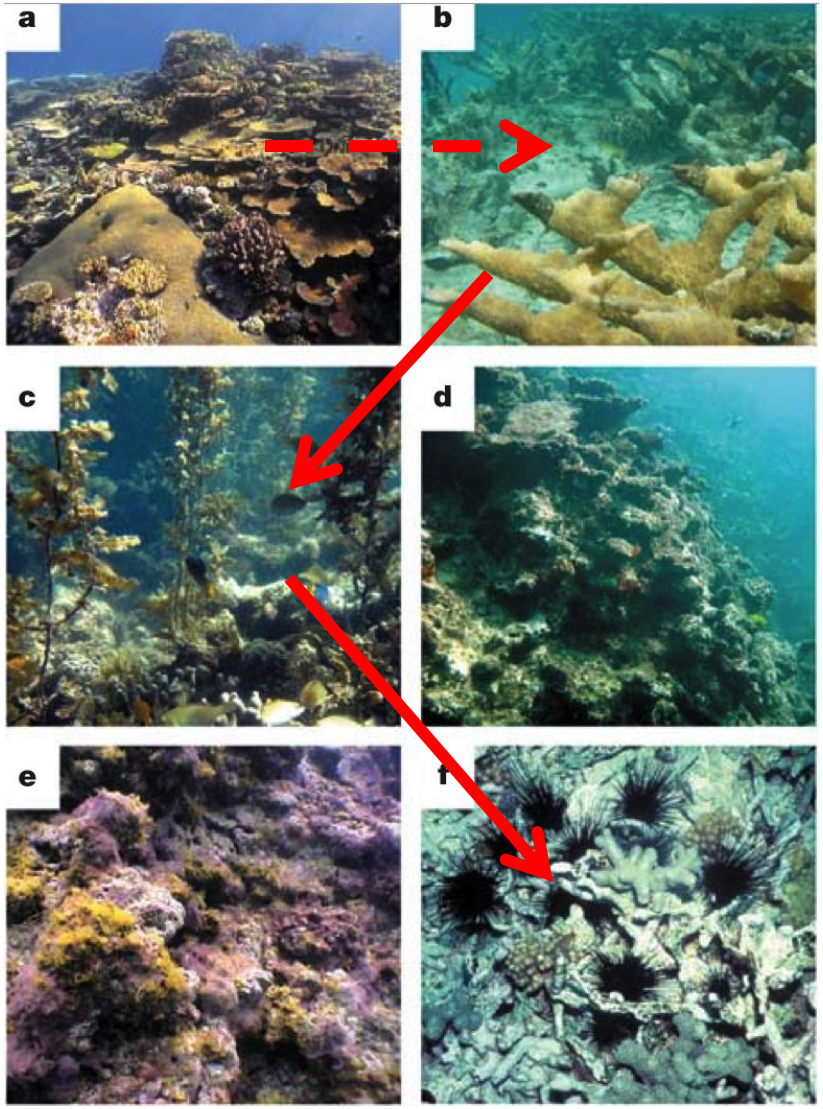
"Press" disturbance PDO

"Ramp" disturbance acidification
warming

Alternative Stable States







Bellwood et al. (2008)
Nature

The Impacts of Climate Extremes on Ocean Ecosystems

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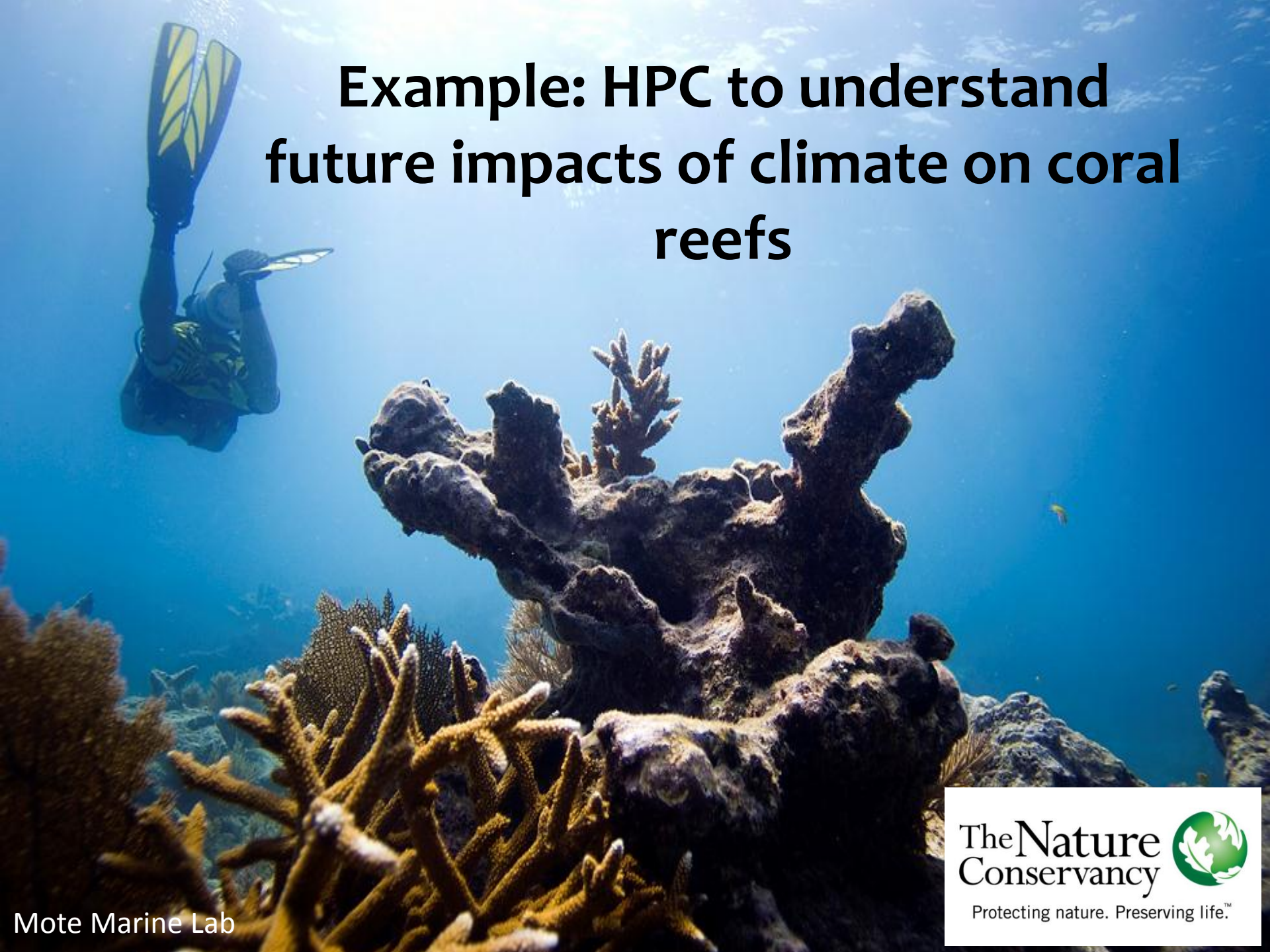
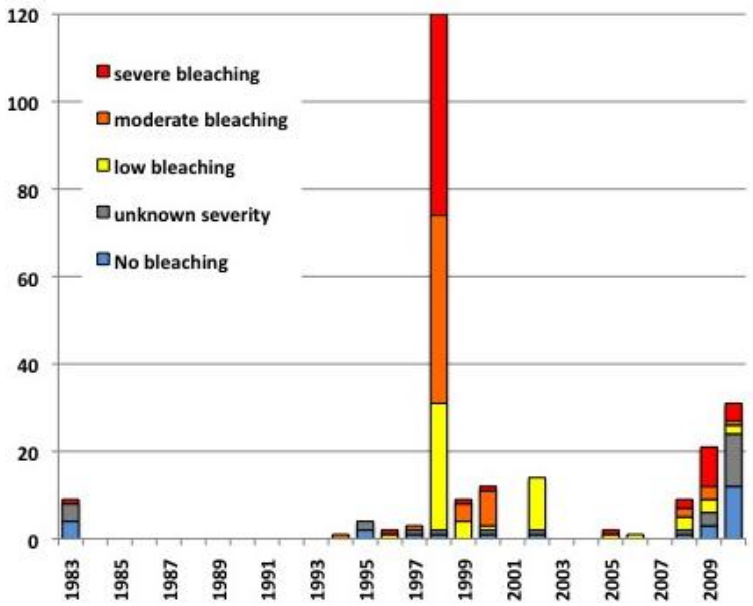
Example: HPC to understand future impacts of climate on coral reefs

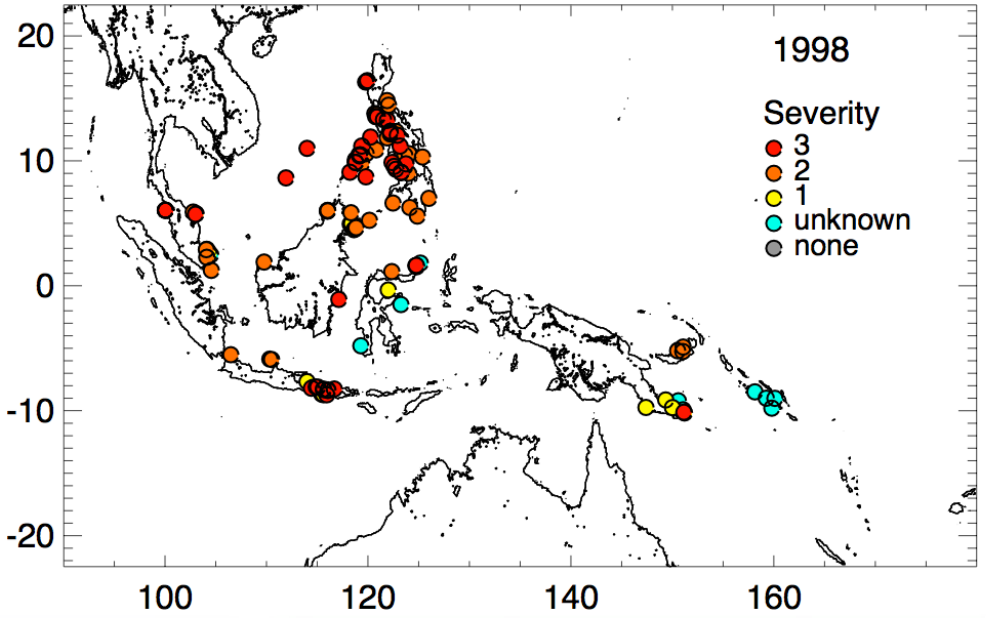


Mote Marine Lab

The Nature Conservancy
Protecting nature. Preserving life.™

Coral bleaching in the Coral Triangle





Photos: Ray Berkelmans

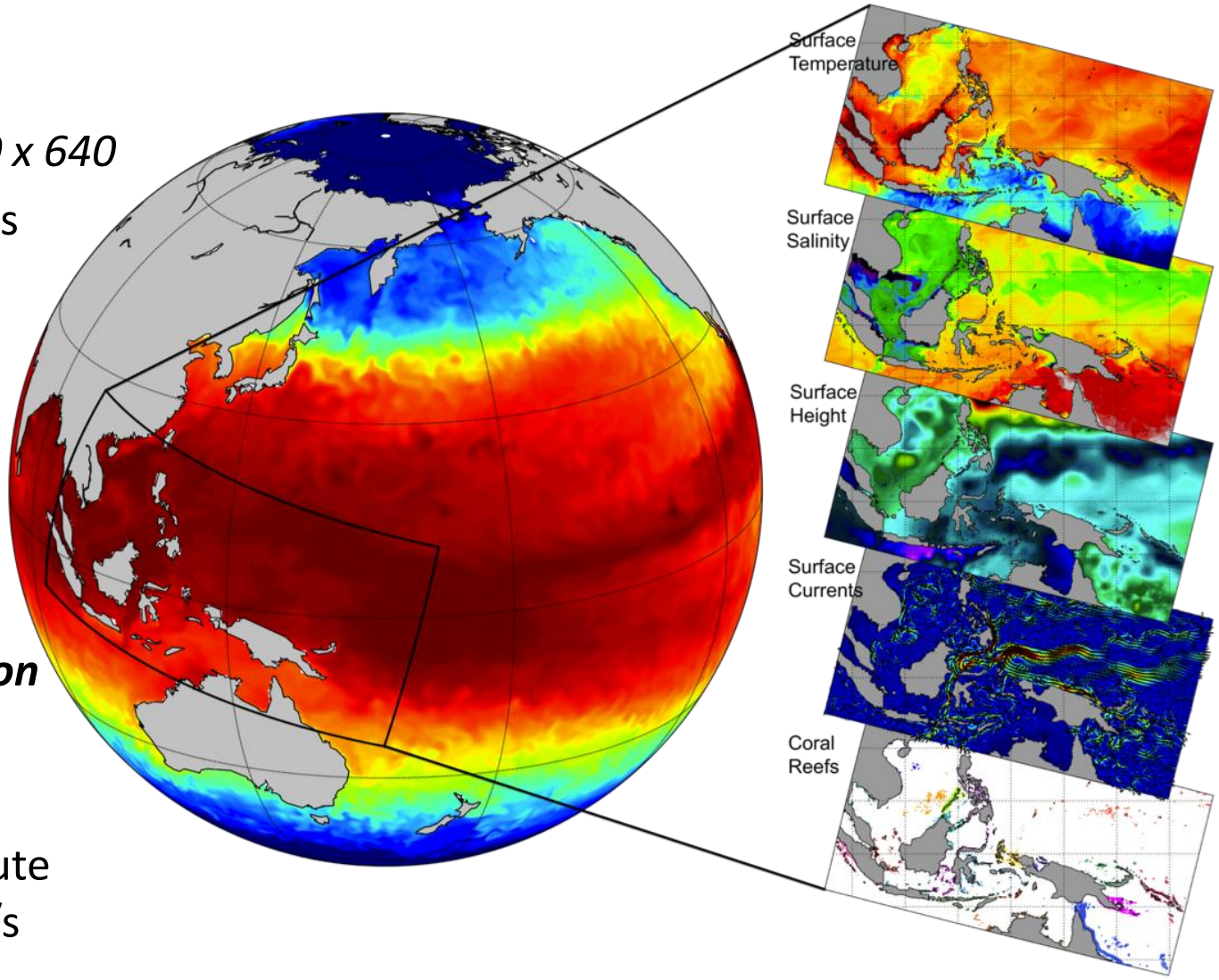
Regional Ocean Model System

"Coral Triangle" Implementation

Horizontal res.: *1280 x 640*

Vertical res.: 50 levels

Time step: 90 sec



Computational cost on Janus:

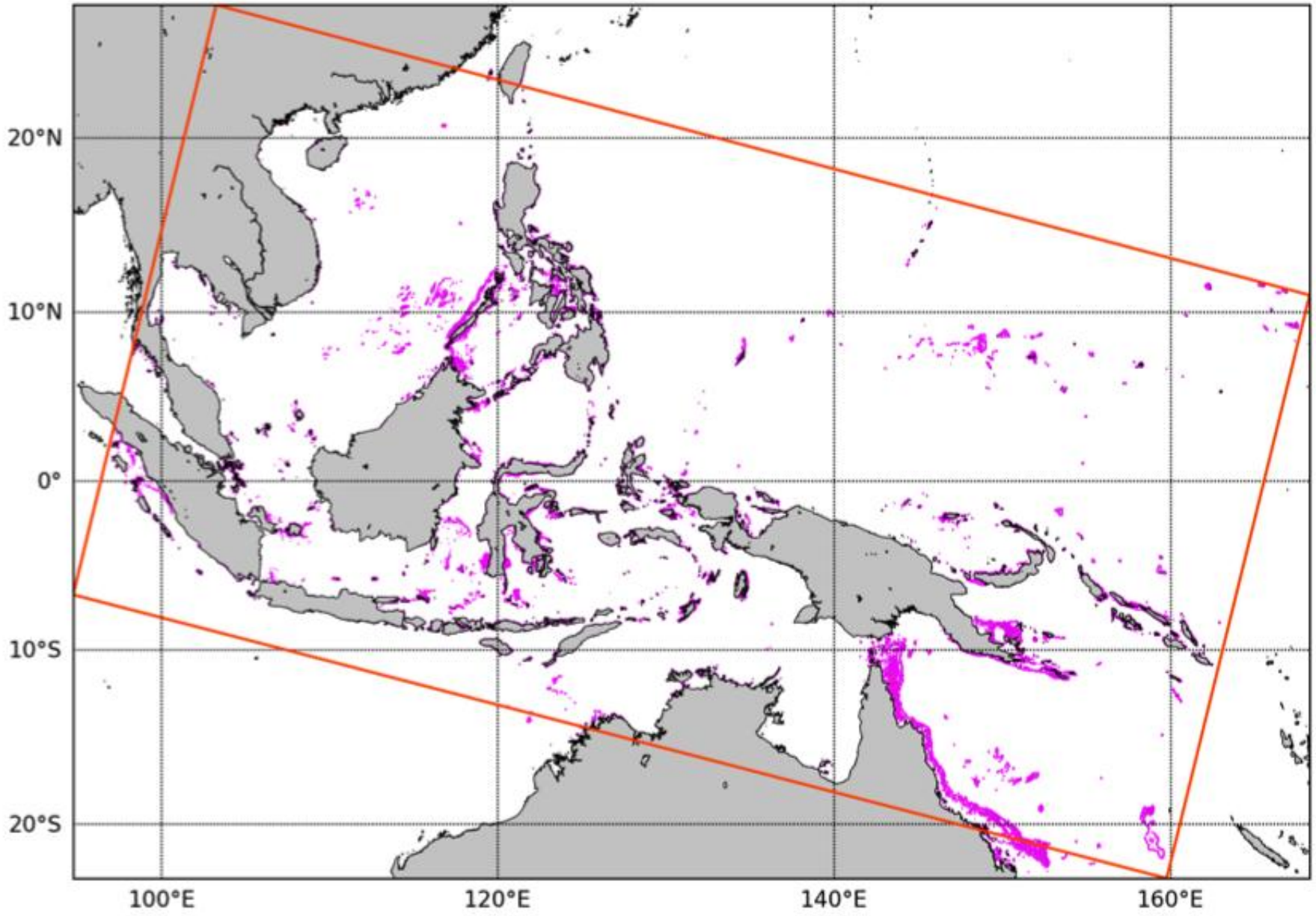
~ 40,000 SU/yr

- 1368 12-way compute nodes @ 134 Gflops/s

Data storage: 600 GB/yr (daily averages)

Illustration: F Castruccio

Region of Greatest Marine Biodiversity



CT-ROMS 2004-2006

Bathymetry: global SRTM30_PLUS product with 30-sec resolution [Becker et al., 2009]

Vertical resolution: 50 terrain-following levels

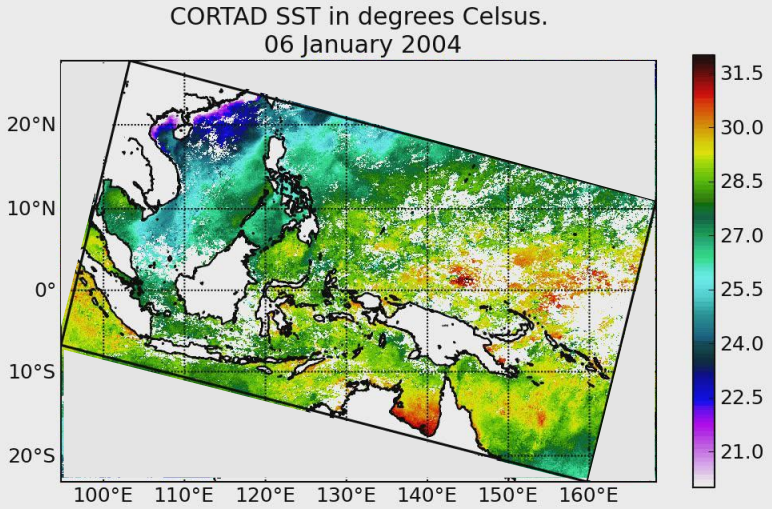
Atmospheric forcing: Modern Era-Retrospective Analysis for Research and Applications (MERRA, Rienecker et al., 2011)

Boundaries and initial conditions: Simple Ocean Data Assimilation (SODA, Carton et al., 2000)

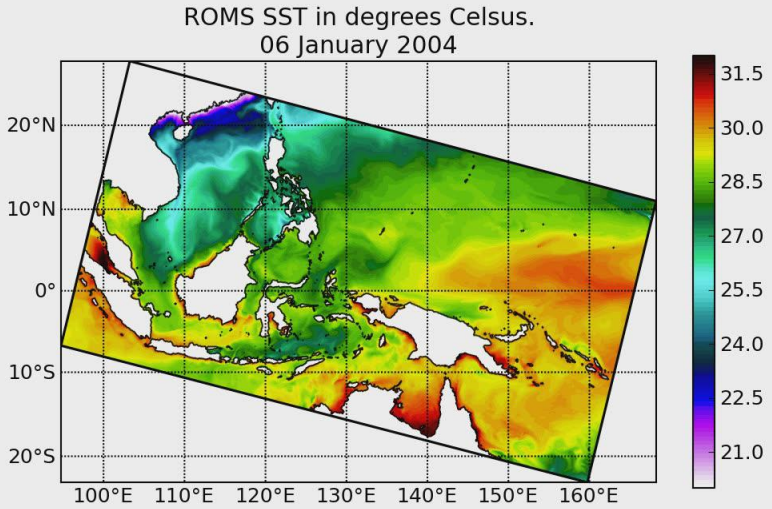
Tidal boundary conditions: global model of ocean tides TPXO 7.2 (Egbert and Erofeeva, 2002)

Castruccio et al. (in press) *JGR*

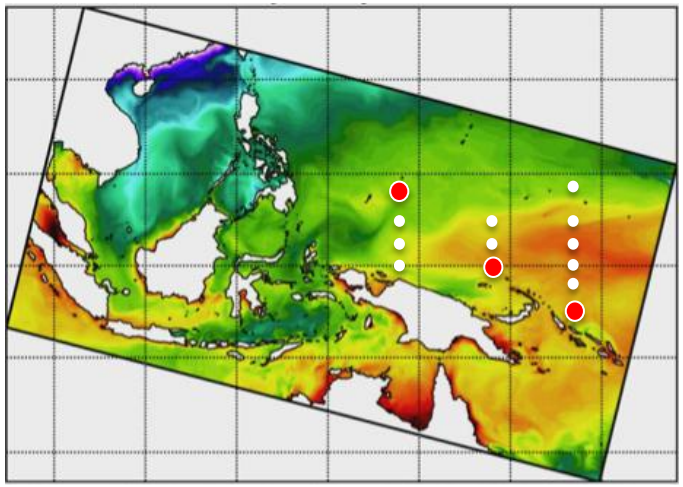
CoRTAD

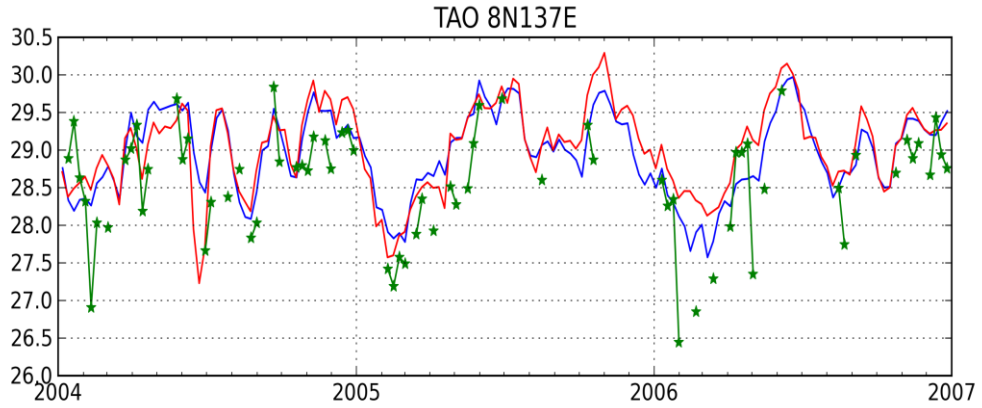


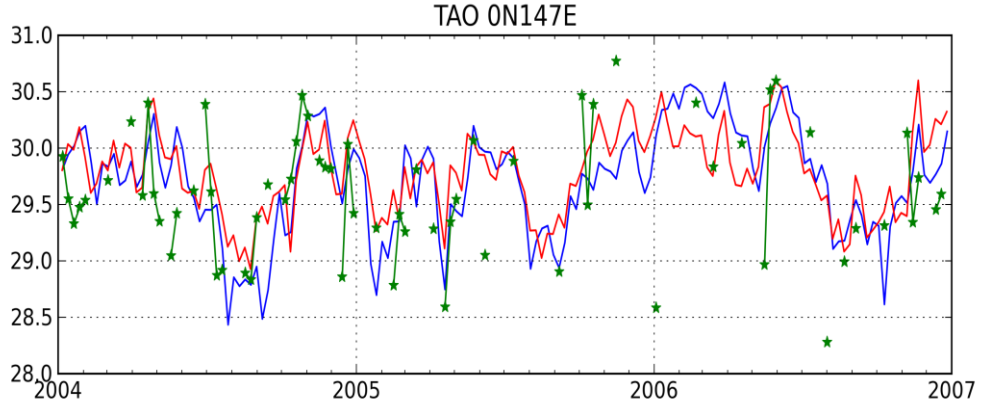
CT-ROMS

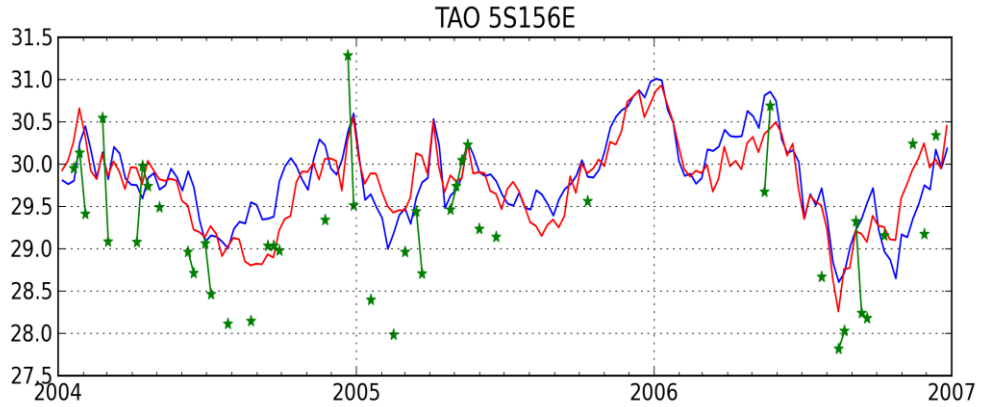


Sea surface temperature





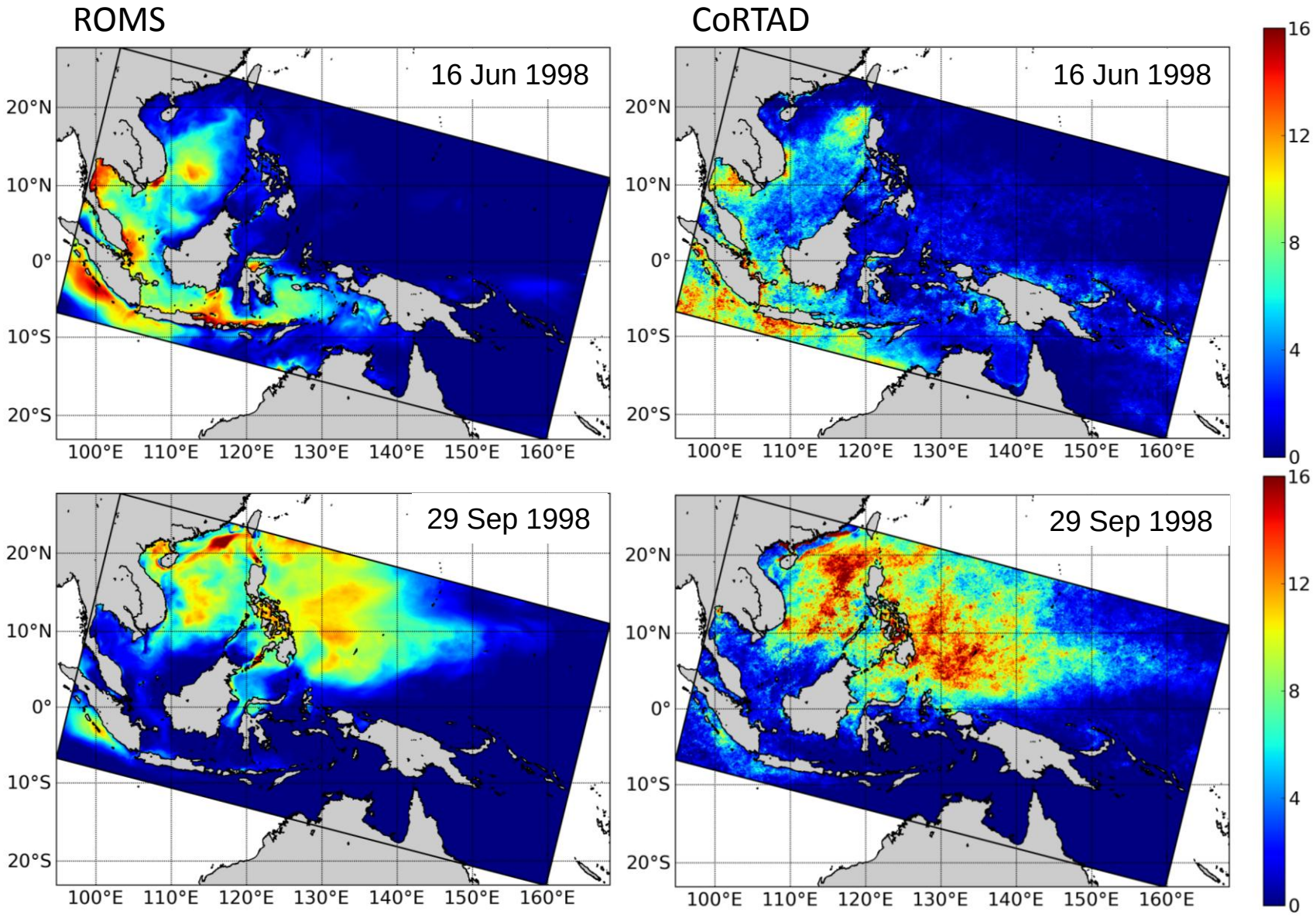




Castruccio et al. (in press) *JGR*

TAO **CT-ROMS** **CoRTAD**

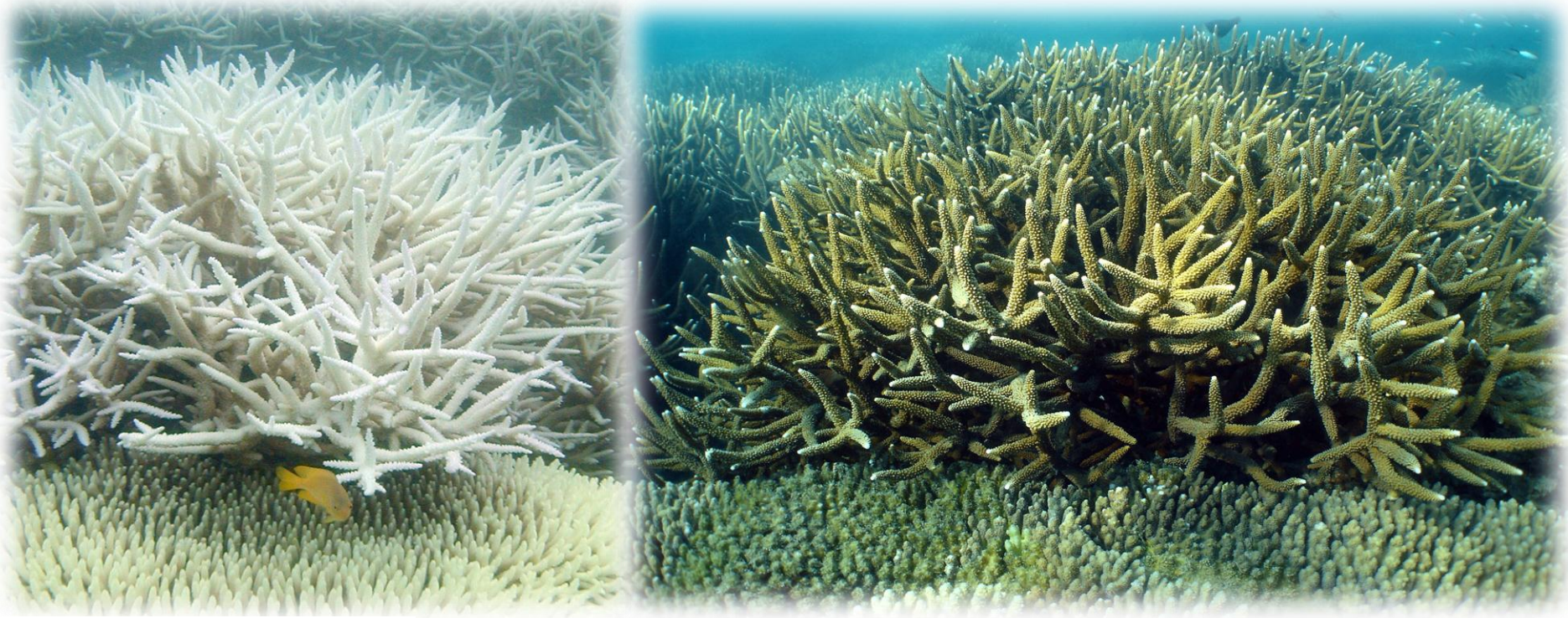
Comparison of Degree-Heating-Weeks



The Coral Triangle

Beyond Bleaching:

"Connectivity" between reefs



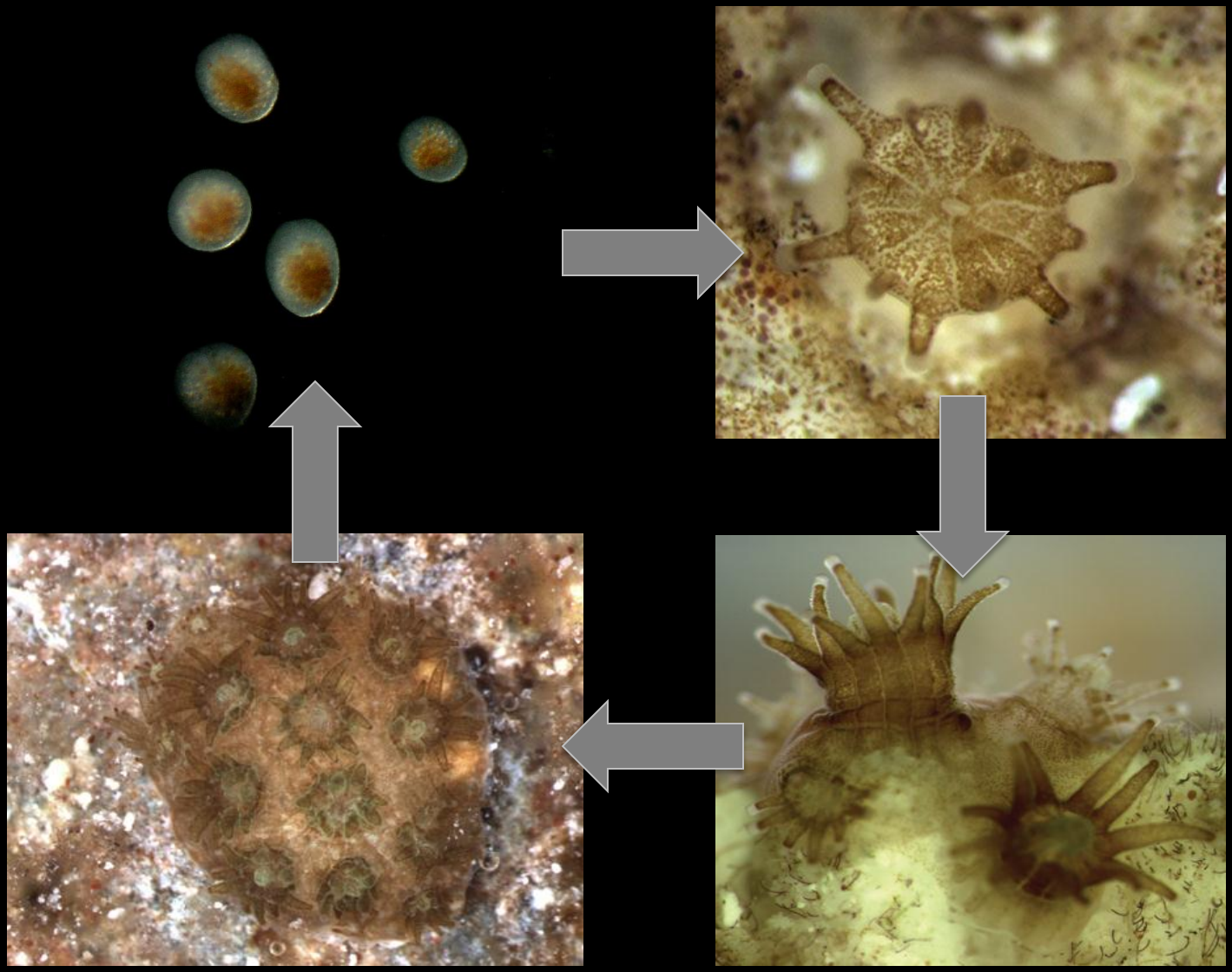
Photos: Ray Berkelmans

Coral Spawning Events

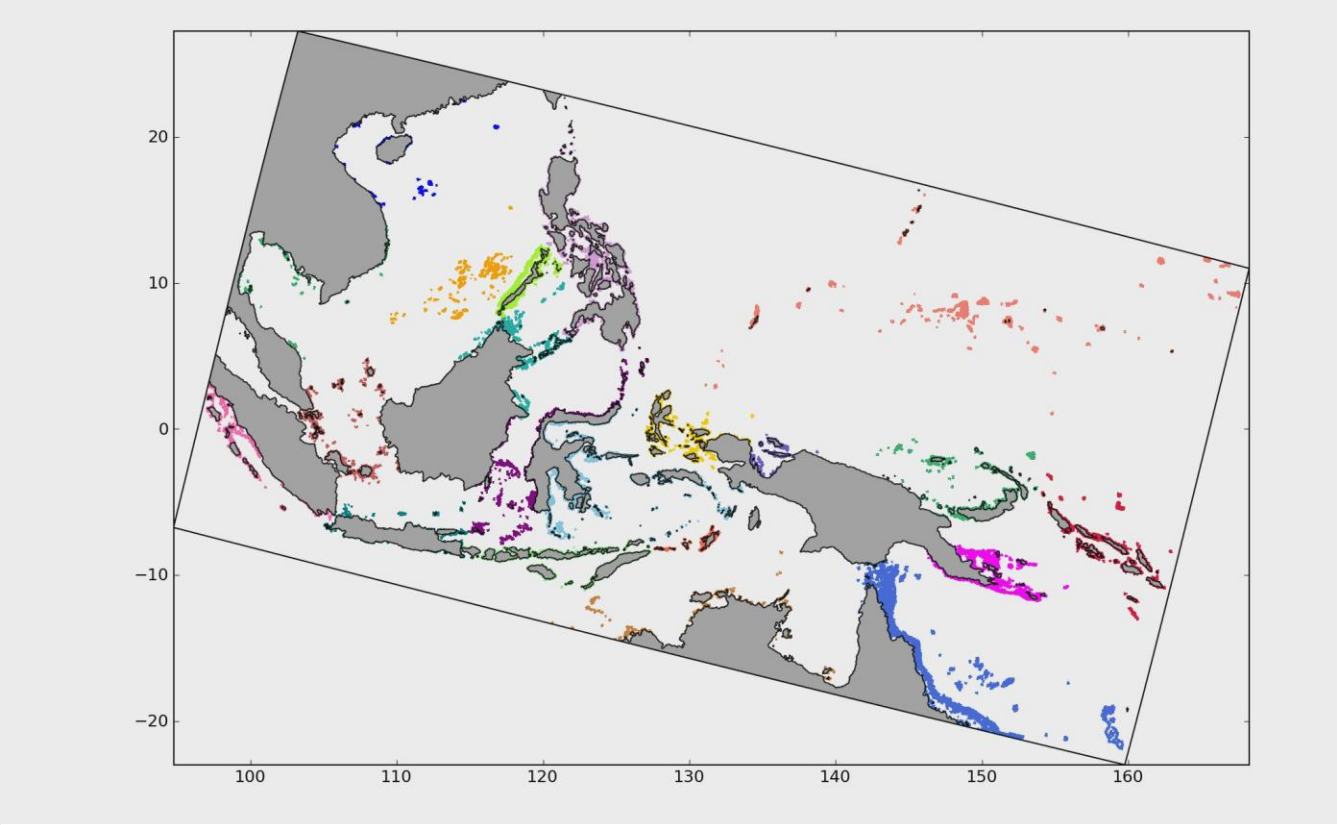
Video: NOAA Flower Garden Banks

Photo: Bette Willis

Coral Life Cycle



Connectivity

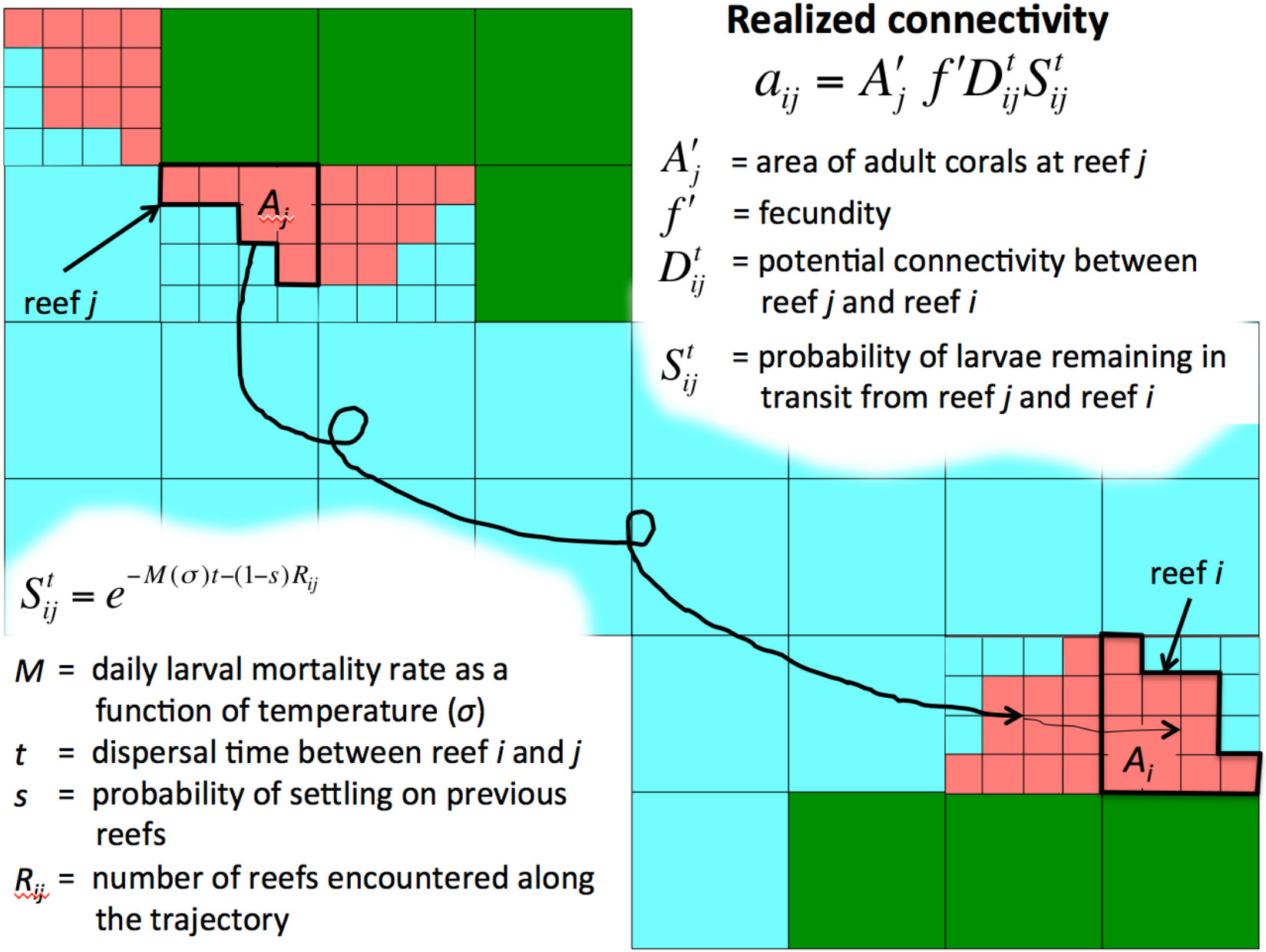


Holding it all together

Recovery depends on how well “connected” coral communities are in terms of the transport of larvae from one reef to another

If one reef gets hit, will it be reseeded with larvae from a healthy reef?

Connectivity



Realized connectivity

$$a_{ij} = A'_j \, f' D^t_{ij} S^t_{ij}$$

A'_j = area of adult corals at reef *j*

f' = fecundity

D^t_{ij} = potential connectivity between reef *j* and reef *i*

S^t_{ij} = probability of larvae remaining in transit from reef *j* and reef *i*

$$S^t_{ij} = e^{-M(\sigma)t-(1-s)R_{ij}}$$

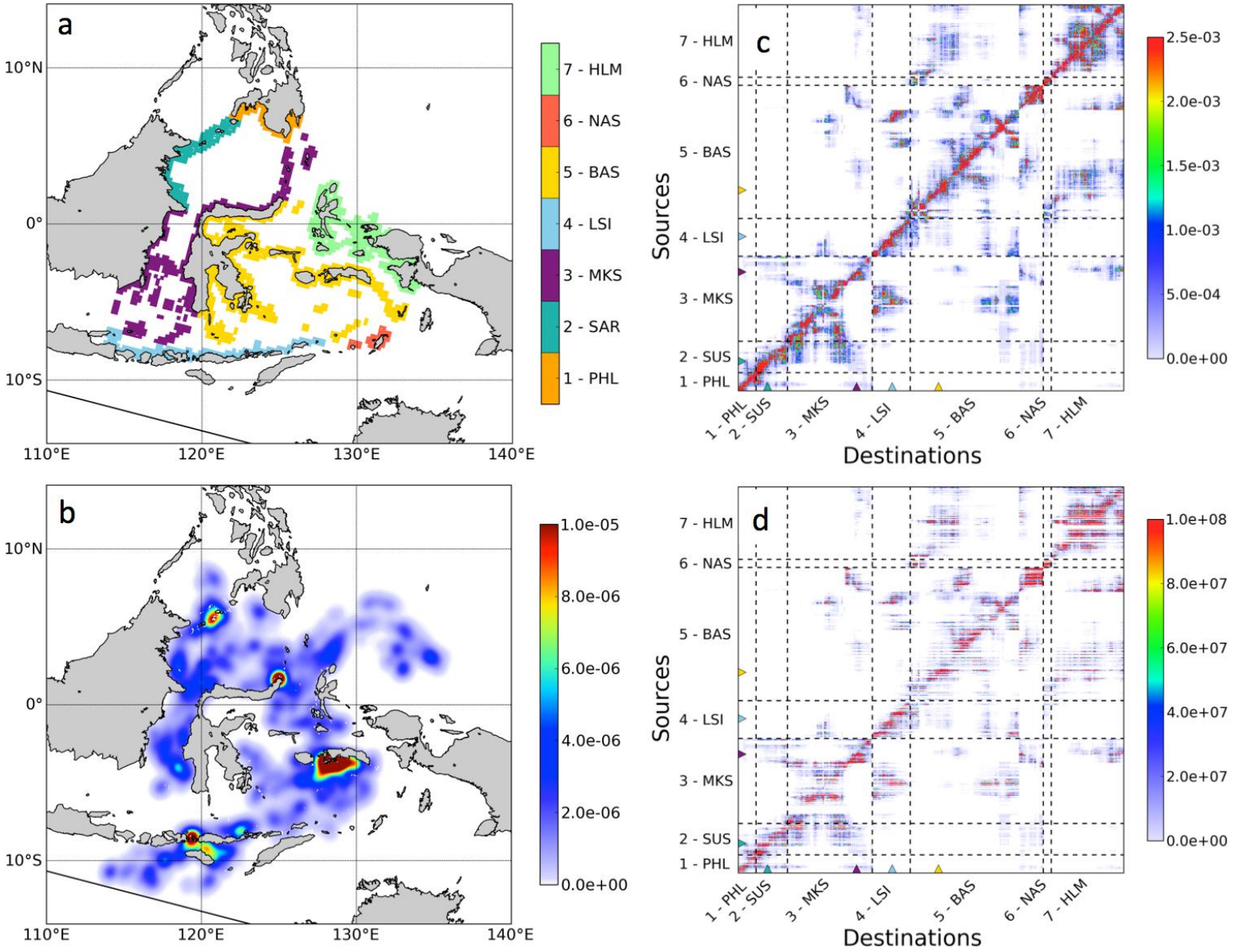
M = daily larval mortality rate as a function of temperature (σ)

t = dispersal time between reef *i* and *j*

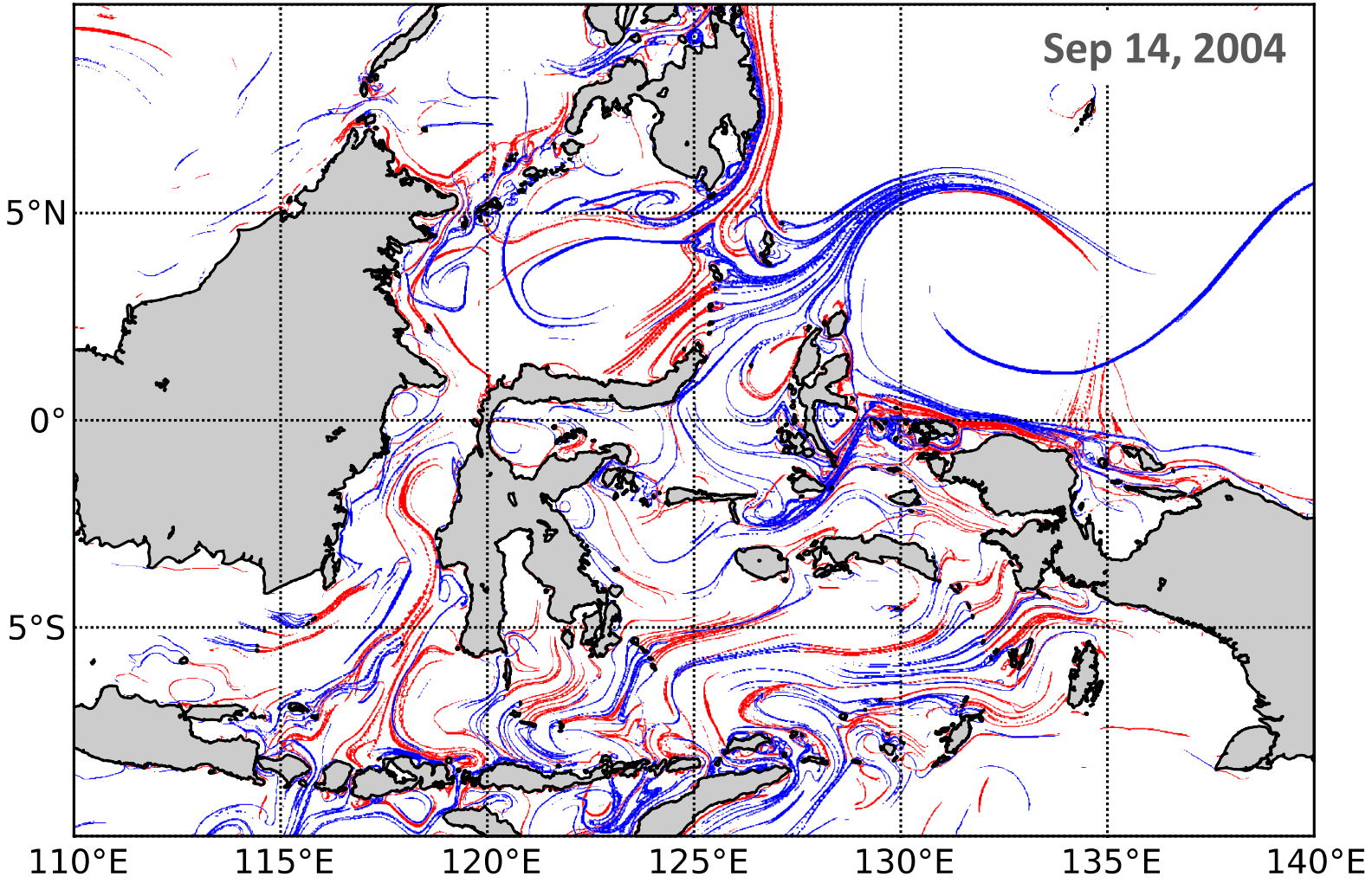
s = probability of settling on previous reefs

R_{ij} = number of reefs encountered along the trajectory

Connectivity



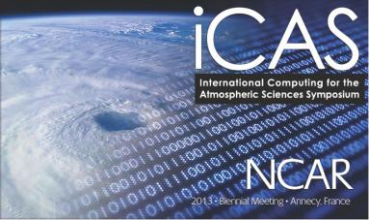
Lagrangian Coherent Structures



The Impacts of Climate Extremes on Ocean Ecosystems

Three Points

1. Climate extremes do affect the ocean
2. These extremes have significant impacts on ocean ecosystems
3. HPC is invaluable in designing ways to minimize those impacts



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THANK YOU

MERCI

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