

Modelling Coral Reefs in a Changing Climate



AXA
Research Fund
Through research protection

Nancy Jones, Andy Ridgwell & Erica Hendy

Modelling Coral Reefs in a Changing Climate



Nancy Jones^{1,2,3} nancy.jones@bristol.ac.uk

Andy Ridgwell¹ & Erica Hendy^{2,3}

University of Bristol: ¹Geographical Sciences, ²Earth Sciences, & ³Biological Sciences



Project Objective

To develop a novel model capable of making future predictions of coral distributions, reef community composition and live coral cover globally in response to climate change by adapting ideas from terrestrial vegetation models (figure 1).

The Model

- Increase complexity, starting with simple calcification model (figure 2), progressively develop a more biologically realistic model (figure 1).
- Shallow water mask (~500m).
- Constrain growth with light, temperature (SST), aragonite saturation (Ω_{arg}), nutrients & salinity.
- Increase number of functional groups.

Research Questions

How will climate change affect:

- global coral distributions (shifts in latitudinal range & biodiversity patterns?).
- reef community composition (macroalgal dominance?).
- different reefs (resilient reefs, refugia?).

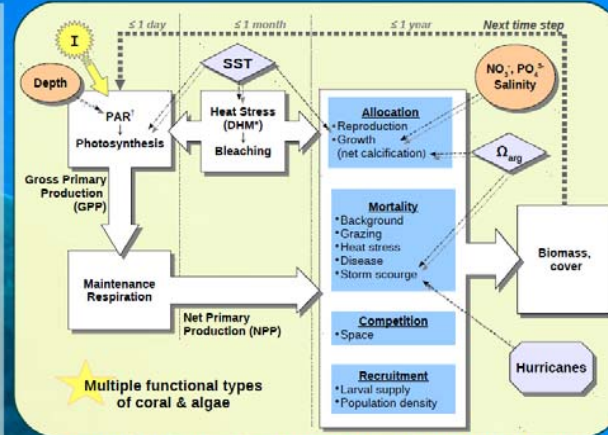


Figure 1: Coral Reef Ecosystem Model (CREM), model architecture adapted from the LPJ dynamic vegetation model (Bonan et al., 2003; Sitch et al., 2003). Climate change simulated with increasing sea surface temperature (SST), reduced aragonite saturation (Ω_{arg}) & increased hurricane frequency. Dashed lines indicate a variable's influence.

¹ PAR: Photosynthetically Available Radiation, and ² DHM: Degree Heating Months.

Reefs & Climate Change

Coral reefs are in decline around the world. Climate change, caused by anthropogenic CO_2 , is likely to worsen this decline and could lead the collapse of many reefs (Hoegh-Guldberg et al., 2007).

Temperature & Bleaching

- Heat stress response making corals appear white (figure 3).
- Calculate degree heating months (DHM) (figure 1), trigger bleaching at $2^\circ\text{C}\cdot\text{month}$ (Donner, 2009)
- During bleaching:
 - no photosynthesis,
 - increased mortality (heat stress & disease).



Figure 3: Bleached colonies of *Acropora cervicornis*. Bleaching caused by corals losing their symbiotic dinoflagellates (*Symbiodinium*) in response to elevated sea temperatures.

Hurricanes & Cyclones

- Hurricanes & cyclones damage reefs by removing fragile corals – storm scour (figure 4).
- Model periodic mortality events; timing & intensity from hurricane records (Edwards et al., 2011).
- Increase frequency of future events.



Figure 4: Cyclone damage in the Great Barrier Reef.

Ocean Acidification

- At 450ppm CO_2 , reefs in tolerable Ω_{arg} will have fallen to 8% (Cao & Caldeira, 2008) due to ocean acidification (figure 5).
- Calcification rate decreases with decreasing Ω_{arg} (Kleypas & Yates, 2009).
- Simulate growth as a function of Ω_{arg} .
- Trade-off between growth rate & skeletal density in low Ω_{arg} (Hoegh-Guldberg et al., 2007).
- Simulate increased susceptibility to storm scour after prolonged low Ω_{arg} .

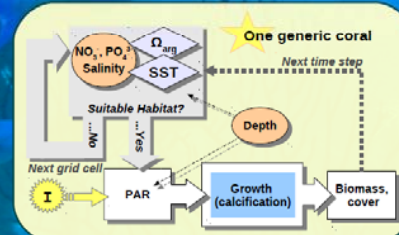
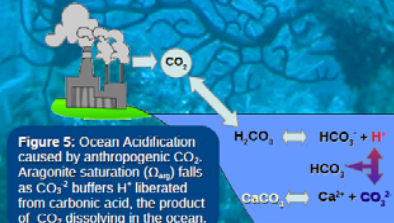


Figure 2: Simple calcification model based on the ReefLab model used for predicting suitable reef habitat & CaCO_3 production (Kleypas, 1997).



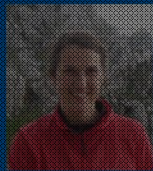
References

- BONAN, G. B. et al. (2009) *Global Change Biology*, 19: 1549-1566
- CAO, J. & CALDEIRA, K. (2008) *Geophysical Research Letters*, 35: doi:10.1029/2008GL035072
- DONNER, S. (2009) *PLOS ONE*, 4: e5712
- EDWARDS, H. et al. (2011) *Global Change Biology*, 17: 2033-2048
- HOEGH-GULDBERG, O. et al. (2007) *Science*, 318: 1737-1742
- KLEYPAS, J. (1997) *Paleoceanography*, 12: 533-546
- KLEYPAS, J. & YATES, K. (2009) *Oceanography*, 22: 109-117
- SITCH, S. et al. (2003) *Global Change Biology*, 9: 161-185

Research groups affiliation:
Bristol Research Initiative for a Dynamic Global Environment (BRIDGE)
<http://www.bridge.bristol.ac.uk/>
Coral Reef Research @ Bristol (CR@B)
<http://www.bristol.ac.uk/biology/bocppl/group/lab2430>



Modelling Coral Reefs in a Changing Climate



Nancy Jones^{1,2,3} nancy.jones@bristol.ac.uk

Andy Ridgwell¹ & Erica Hendy^{2,3}

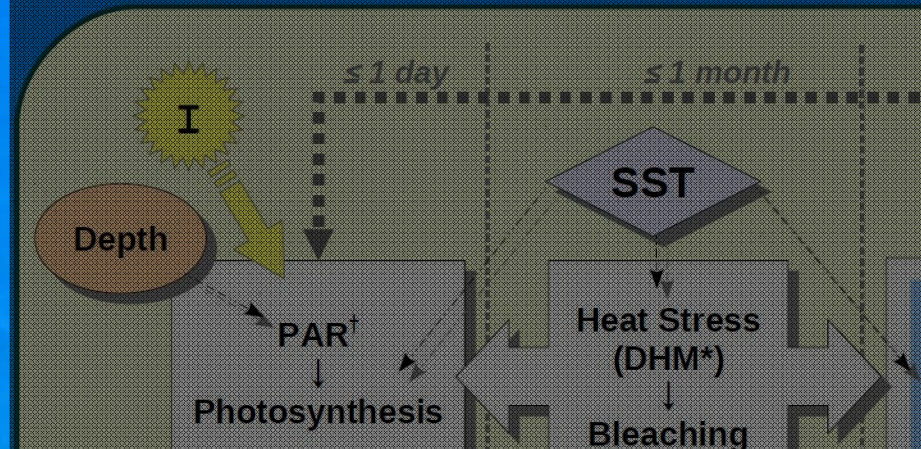
University of Bristol: ¹Geographical Sciences, ²Earth Sciences, & ³Biological Sciences



AXA
Research Fund
Through research, protection

Project Objective

To develop a novel model capable of making future predictions of coral distributions, reef community composition and live coral cover globally in response to climate change by adapting ideas from terrestrial vegetation models (**figure 1**).



Modelling Coral Reefs in a Changing Climate

University of BRISTOL

Project Objective
To develop a novel model capable of making future predictions of coral distributions, reef community composition and live coral cover globally in response to climate change by adapting ideas from terrestrial vegetation models (Figure 1).

The Model
• Develop a novel model capable of making future predictions of coral distributions, reef community composition and live coral cover globally in response to climate change by adapting ideas from terrestrial vegetation models (Figure 1).
• Develop a novel model capable of making future predictions of coral distributions, reef community composition and live coral cover globally in response to climate change by adapting ideas from terrestrial vegetation models (Figure 1).
• Develop a novel model capable of making future predictions of coral distributions, reef community composition and live coral cover globally in response to climate change by adapting ideas from terrestrial vegetation models (Figure 1).

Research Questions
How will climate change affect:
• Global coral distributions (depth, latitude, longitude)?
• Reef community composition (diversity, abundance)?
• Live coral cover (percent cover, rugosity)?

Reefs & Climate Change
Coral reefs are in decline around the world. Climate change, caused by anthropogenic CO₂, is likely to exacerbate this decline and could lead to the collapse of these iconic ecosystems.

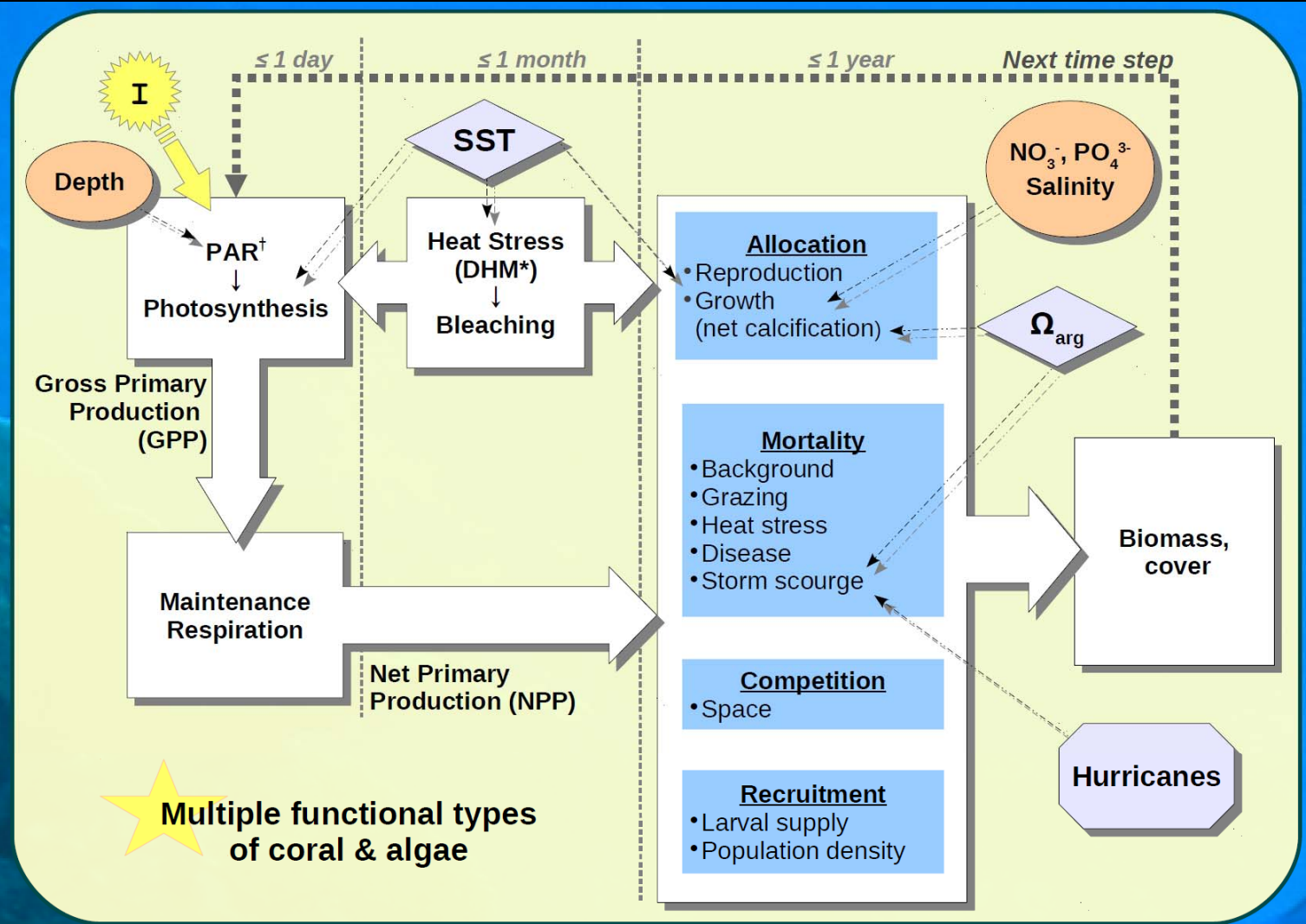


Figure 1: Coral Reef Ecosystem Model (CREM), model architecture adapted from the LPJ dynamic vegetation model (Bonan et al., 2003; Sitch et al., 2003). Climate change simulated with increasing sea surface temperature (SST), reduced aragonite saturation (Ω_{arg}) & increased hurricane frequency. Dashed lines indicate a variable's influence.

† PAR: Photosynthetically Available Radiation, and * DHM: Degree Heating Months

Coral Reefs in a Changing Climate

University of BRISTOL

Objective
 Realistic simulation of coral reef dynamics under future climate change scenarios, including the impact of ocean acidification and sea level rise.

Model
 Using the Coral Reef Ecosystem Model (CREM) to simulate coral reef dynamics under future climate change scenarios.

Model
 Using the Coral Reef Ecosystem Model (CREM) to simulate coral reef dynamics under future climate change scenarios.

Questions
 How will coral reef dynamics change under future climate change scenarios? What are the key drivers of coral reef decline?

Key Change
 Increased sea surface temperature (SST) and ocean acidification (OA) are the primary drivers of coral reef decline.

The Model

- ◆ Increase complexity, starting with simple calcification model (**figure 2**), progressively develop a more biologically realistic model (**figure 1**).

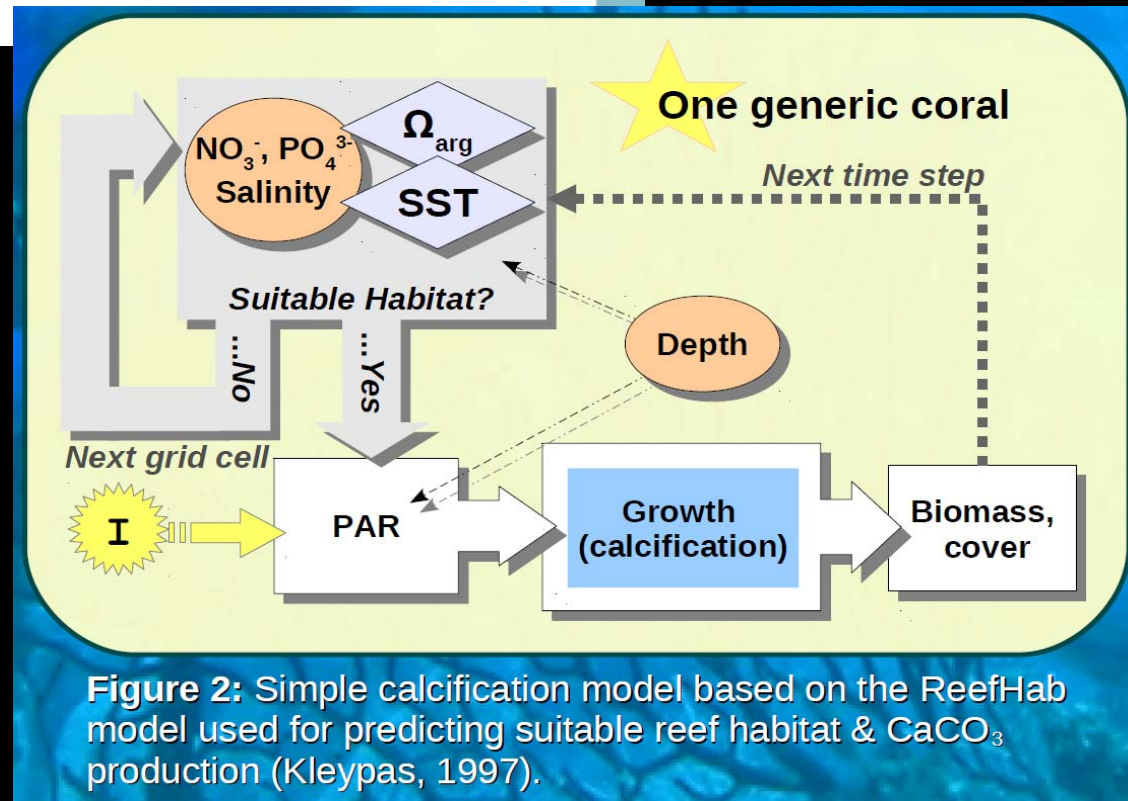
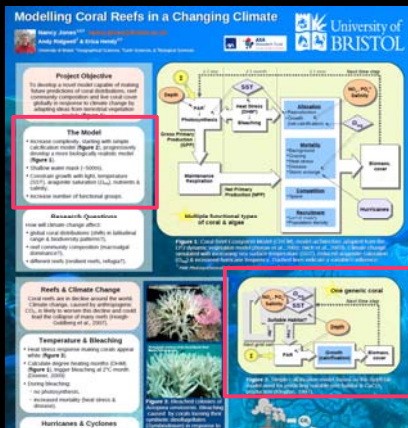


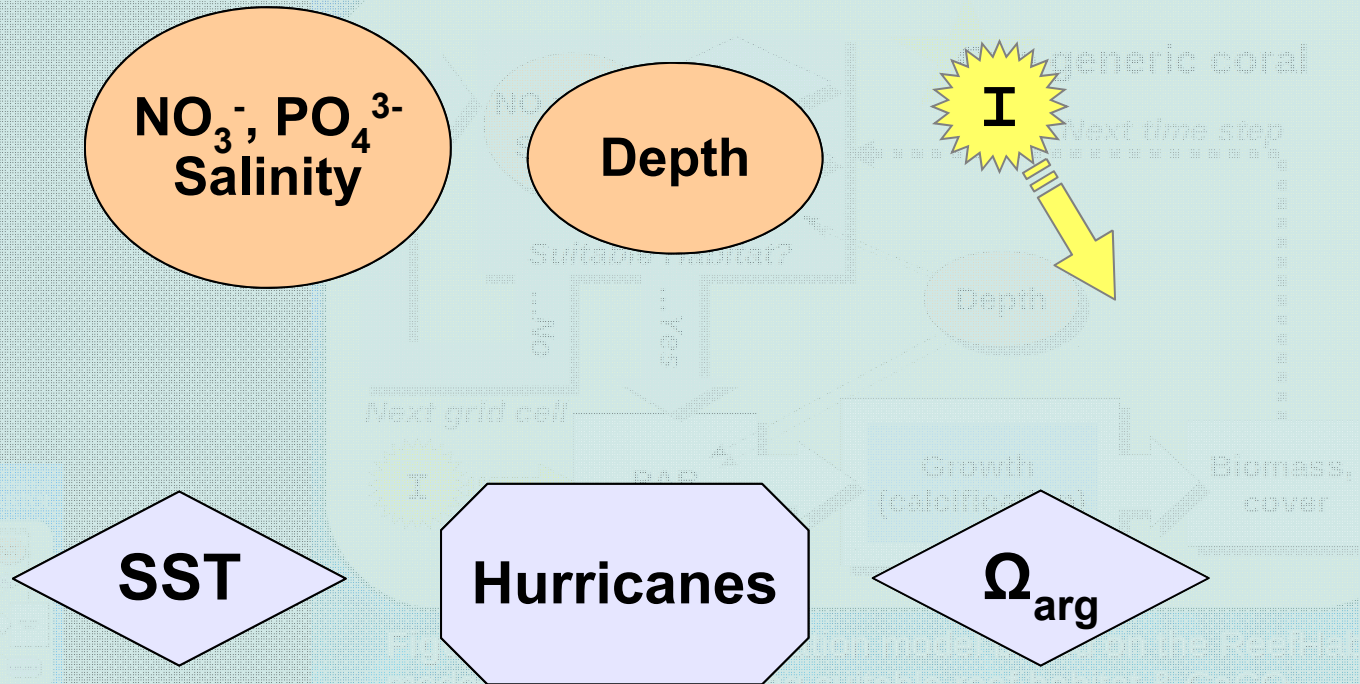
Figure 2: Simple calcification model based on the ReefHab model used for predicting suitable reef habitat & CaCO_3 production (Kleyvas, 1997).



The Model

- ◆ Increase complexity, starting with simple calcification model (figure 2), progressively develop a more biologically realistic model (figure 1).

Forcing



Modelling Coral Reefs in a Changing Ocean

Project Objective

- Develop a novel model capable of simulating future production of coral distributions, coral community composition and the coral reef globally in response to three change by 2100: sea level rise, ocean acidification and warming.

The Model

- Simulate coral reef growth with various coral species and depth profiles (Figure 1).
- Simulate reef growth (1-1000yr).
- Simulate reef growth with light, temperature, CO₂, nutrient saturation (NO₃⁻, PO₄³⁻), and salinity.
- Simulate reef growth with various coral species.

Research Questions

- How will coral reef change globally?
- Global coral reef distributions (depth, latitude, longitude) in 2100?
- Global coral reef community composition (species diversity, biomass) in 2100?
- Global coral reef production (GPP) in 2100?

Reefs & Climate Change

- Coral reefs are in decline around the world.
- Climate change, caused by anthropogenic CO₂, is likely to worsen this decline and could lead to collapse of many reefs (Hoegh-Guldberg et al., 2007).

Temperature & Bleaching

- Coral reef temperature is rising globally (Figure 2).
- Global coral reef bleaching events (Diaz et al., 2007) are increasing at 2°C decade.
- Bleaching events are increasing globally (Figure 3).
- Bleaching events are increasing globally (Figure 3).

Hurricanes & Cyclones

- Hurricanes and cyclones are increasing globally (Figure 4).
- Hurricanes and cyclones are increasing globally (Figure 4).

SST

Hurricanes

Ω_{arg}

Temperature & Bleaching

- ♦ Heat stress response making corals appear white (**figure 3**).
- ♦ Calculate degree heating months (DHM) (**figure 1**), trigger bleaching at 2°C-month (Donner, 2009)
- ♦ During bleaching:
 - no photosynthesis,
 - increased mortality (heat stress & disease).



Photograph courtesy of the Great Barrier Reef Marine Park Authority



Figure 3: Bleached colonies of *Acropora cervicornis*. Bleaching caused by corals losing their symbiotic dinoflagellates (*Symbiodinium*) in response to elevated sea temperatures.

Research Questions
How will climate change affect coral reefs?
What are the potential risks to coral reefs?
How can we manage coral reefs to reduce the risk of collapse?
What are the potential benefits of coral reefs?

Multiple functional types of coral & algae
Figure 1. Coral Reef Community Model (CRM) model structure. The CRM is a conceptual model of the coral reef community structure and function. It is based on the idea that coral reefs are composed of multiple functional types (FTs) that interact with each other and with the environment. The CRM is a dynamic model that can be used to predict the future of coral reefs under different scenarios of climate change.

One genetic coral
Figure 2. Genetic diversity of coral reefs. The CRM is a dynamic model that can be used to predict the future of coral reefs under different scenarios of climate change.

Bleeds & Climate Change
Coral reefs are in decline around the world. Climate change is a major driver of coral reef decline. The CRM is a dynamic model that can be used to predict the future of coral reefs under different scenarios of climate change.

Temperature & Bleaching
Heat stress is a major driver of coral reef decline. The CRM is a dynamic model that can be used to predict the future of coral reefs under different scenarios of climate change.

Hurricanes & Cyclones
Hurricanes and cyclones are a major driver of coral reef decline. The CRM is a dynamic model that can be used to predict the future of coral reefs under different scenarios of climate change.

Ocean Acidification
Ocean acidification is a major driver of coral reef decline. The CRM is a dynamic model that can be used to predict the future of coral reefs under different scenarios of climate change.

SST

Hurricanes

Ω_{arg}

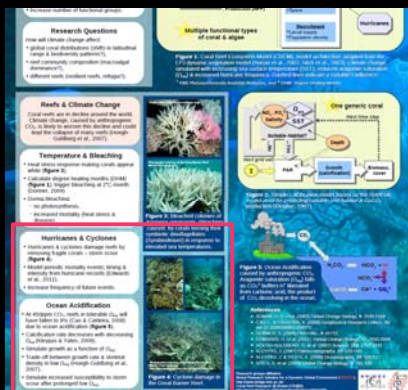
Hurricanes & Cyclones

- ♦ Hurricanes & cyclones damage reefs by removing fragile corals – storm scour (figure 4).
- ♦ Model periodic mortality events; timing & intensity from hurricane records (Edwards *et al.*, 2011).
- ♦ Increase frequency of future events.



Photographs courtesy of the Great Barrier Reef Marine Park Authority:
<http://gbrmpa.lookat.me.com.au/site/welcome.me>

Figure 4: Cyclone damage in the Great Barrier Reef.



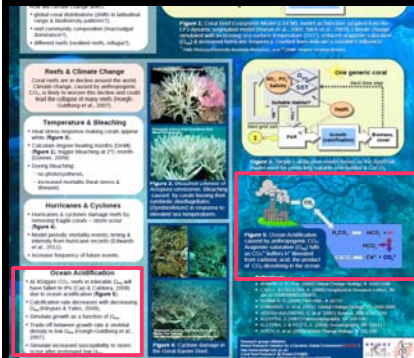
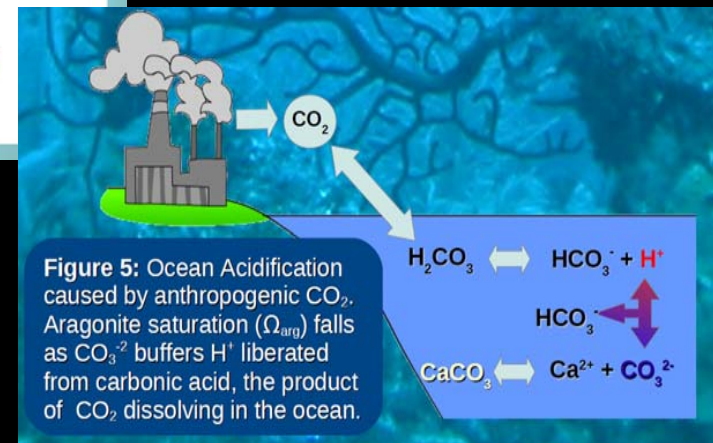
SST

Hurricanes

Ω_{arg}

Ocean Acidification

- At 450ppm CO₂, reefs in tolerable Ω_{arg} will have fallen to 8% (Cao & Caldeira, 2008) due to ocean acidification (**figure 5**).
- Calcification rate decreases with decreasing Ω_{arg} (Kleypas & Yates, 2009).
- Simulate growth as a function of Ω_{arg} .
- Trade-off between growth rate & skeletal density in low Ω_{arg} (Hoegh-Guldberg *et al.*, 2007).
- Simulate increased susceptibility to storm scour after prolonged low Ω_{arg} .



Modelling Coral Reefs in a Changing Climate



Nancy Jones^{1,2,3} nancy.jones@bristol.ac.uk

Andy Ridgwell¹ & Erica Hendy^{2,3}

University of Bristol: ¹Geographical Sciences, ²Earth Sciences, & ³Biological Sciences



Project Objective

To develop a novel model capable of making future predictions of coral distributions, reef community composition and live coral cover globally in response to climate change by adapting ideas from terrestrial vegetation models (figure 1).

The Model

- Increase complexity, starting with simple calcification model (figure 2), progressively develop a more biologically realistic model (figure 1).
- Shallow water mask (~500m).
- Constrain growth with light, temperature (SST), aragonite saturation (Ω_{arg}), nutrients & salinity.
- Increase number of functional groups.

Research Questions

How will climate change affect:

- global coral distributions (shifts in latitudinal range & biodiversity patterns?).
- reef community composition (macroalgal dominance?).
- different reefs (resilient reefs, refugia?).

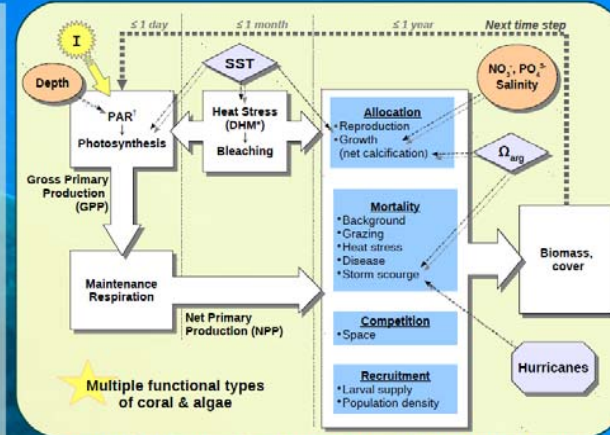


Figure 1: Coral Reef Ecosystem Model (CREM), model architecture adapted from the LPJ dynamic vegetation model (Bonan et al., 2003; Sitch et al., 2003). Climate change simulated with increasing sea surface temperature (SST), reduced aragonite saturation (Ω_{arg}) & increased hurricane frequency. Dashed lines indicate a variable's influence.

¹ PAR: Photosynthetically Available Radiation, and ² DHM: Degree Heating Months.

Reefs & Climate Change

Coral reefs are in decline around the world. Climate change, caused by anthropogenic CO_2 , is likely to worsen this decline and could lead the collapse of many reefs (Hoegh-Guldberg et al., 2007).

Temperature & Bleaching

- Heat stress response making corals appear white (figure 3).
- Calculate degree heating months (DHM) (figure 1), trigger bleaching at $2^\circ\text{C}\cdot\text{month}$ (Donner, 2009)
- During bleaching:
 - no photosynthesis,
 - increased mortality (heat stress & disease).



Figure 3: Bleached colonies of *Acropora cervicornis*. Bleaching caused by corals losing their symbiotic dinoflagellates (*Symbiodinium*) in response to elevated sea temperatures.

Hurricanes & Cyclones

- Hurricanes & cyclones damage reefs by removing fragile corals – storm scour (figure 4).
- Model periodic mortality events; timing & intensity from hurricane records (Edwards et al., 2011).
- Increase frequency of future events.



Figure 4: Cyclone damage in the Great Barrier Reef.

Ocean Acidification

- At 450ppm CO_2 , reefs in tolerable Ω_{arg} will have fallen to 8% (Cao & Caldeira, 2008) due to ocean acidification (figure 5).
- Calcification rate decreases with decreasing Ω_{arg} (Kleypas & Yates, 2009).
- Simulate growth as a function of Ω_{arg} .
- Trade-off between growth rate & skeletal density in low Ω_{arg} (Hoegh-Guldberg et al., 2007).
- Simulate increased susceptibility to storm scour after prolonged low Ω_{arg} .

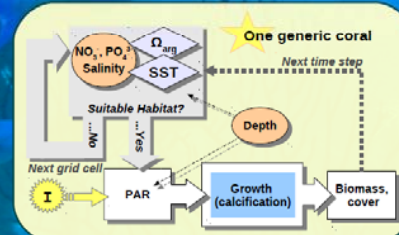
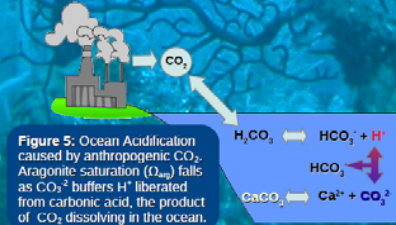


Figure 2: Simple calcification model based on the ReefLab model used for predicting suitable reef habitat & CaCO_3 production (Kleypas, 1997).



References

- BONAN, G. B. et al. (2009) *Global Change Biology*, 9: 1549-1566
- CAO, J. & CALDEIRA, K. (2008) *Geophysical Research Letters*, 35: doi:10.1029/2008GL035072
- DONNER, S. (2009) *PLOS ONE*, 4: e5712
- EDWARDS, H. et al. (2011) *Global Change Biology*, 17: 2033-2048
- HOEGH-GULDBERG, O. et al. (2007) *Science*, 318: 1737-1742
- KLEYPAS, J. (1997) *Paleoceanography*, 12: 533-546
- KLEYPAS, J. & YATES, K. (2009) *Oceanography*, 22: 109-117
- SITCH, S. et al. (2003) *Global Change Biology*, 9: 161-185

Research groups affiliation:
Bristol Research Initiative for a Dynamic Global Environment (BRIDGE)
<http://www.bridge.bristol.ac.uk/>
Coral Reef Research @ Bristol (CR@B)
<http://www.bristol.ac.uk/biology/bcep/our/groups/lab2430>

