University of BRISTOL

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 Ridgwell[1] & Erica Hendy[2,3]

University of Bristol: [1]Geographical Sciences, [2]Earth Sciences, & [3]Biological 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?).

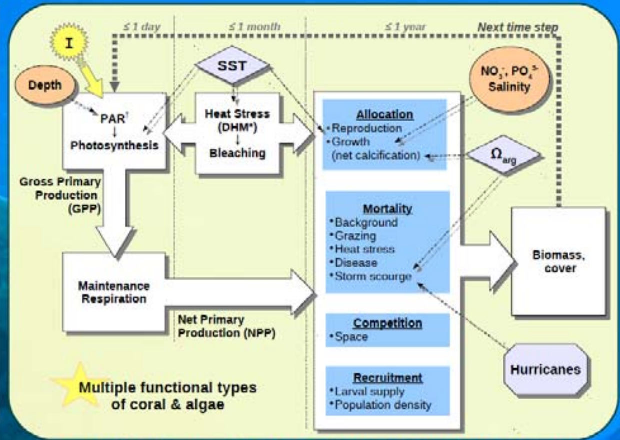


Figure 1: Coral Reef Ecosystem Model (CREM), model architecture adapted from the LPJ dynamic vegetation model (Bonan et al., 2003; Sitch et al., 2003). Climate change simulated with increasing sea surface temperature (SST), reduced aragonite saturation (Ω_{arg}) & increased hurricane frequency. Dashed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

† *PAR: Photosynthetically Available Radiation, and * 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°C-month (Donner, 2009)
- During bleaching:
  - no photosynthesis,
  - increased mortality (heat stress & disease).

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.

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

Figure 4: Cyclone damage in the Great Barrier Reef.

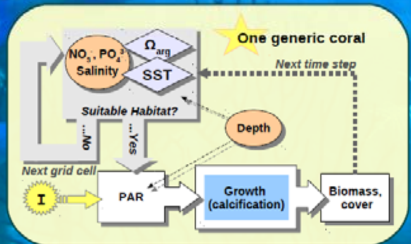


Figure 2: Simple calcification model based on the ReefHab model used for predicting suitable reef habitat & $CaCO_3$ production (Kleypas, 1997).

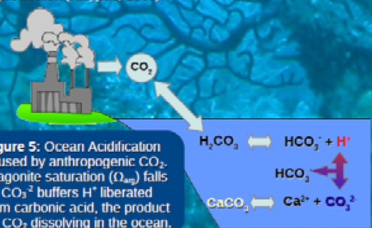


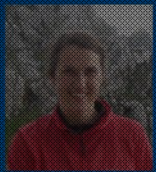
Figure 5: Ocean Acidification caused by anthropogenic CO_2. Aragonite saturation (Ω_{arg}) falls as CO_3^{-2} buffers H^+ liberated from carbonic acid, the product of CO_2 dissolving in the ocean.

References

- BONAN, G. B. *et al.* (2003) Global Change Biology, **9**: 1543-1566
- CAO, L. & 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**: 533-545
- 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.bris.ac.uk/
Coral Reef Research @ Bristol (CR@B)
http://www.bristol.ac.uk/biology/people/group/lab/2430

Modelling Coral Reefs in a Changing Climate

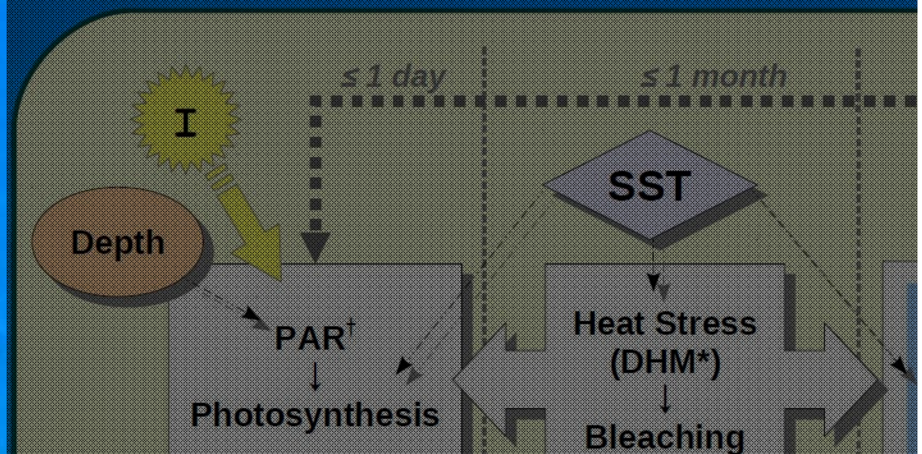


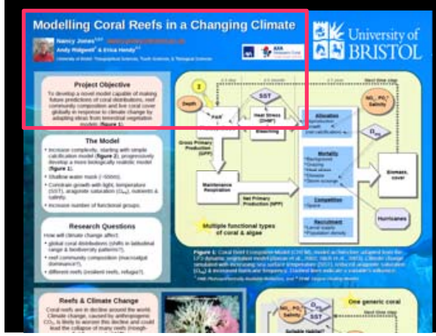
Nancy Jones[1,2,3] nancy.jones@bristol.ac.uk
Andy Ridgwell[1] & Erica Hendy[2,3]
University of Bristol: [1]Geographical Sciences, [2]Earth Sciences, & [3]Biological Sciences

AXA Research Fund

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**).





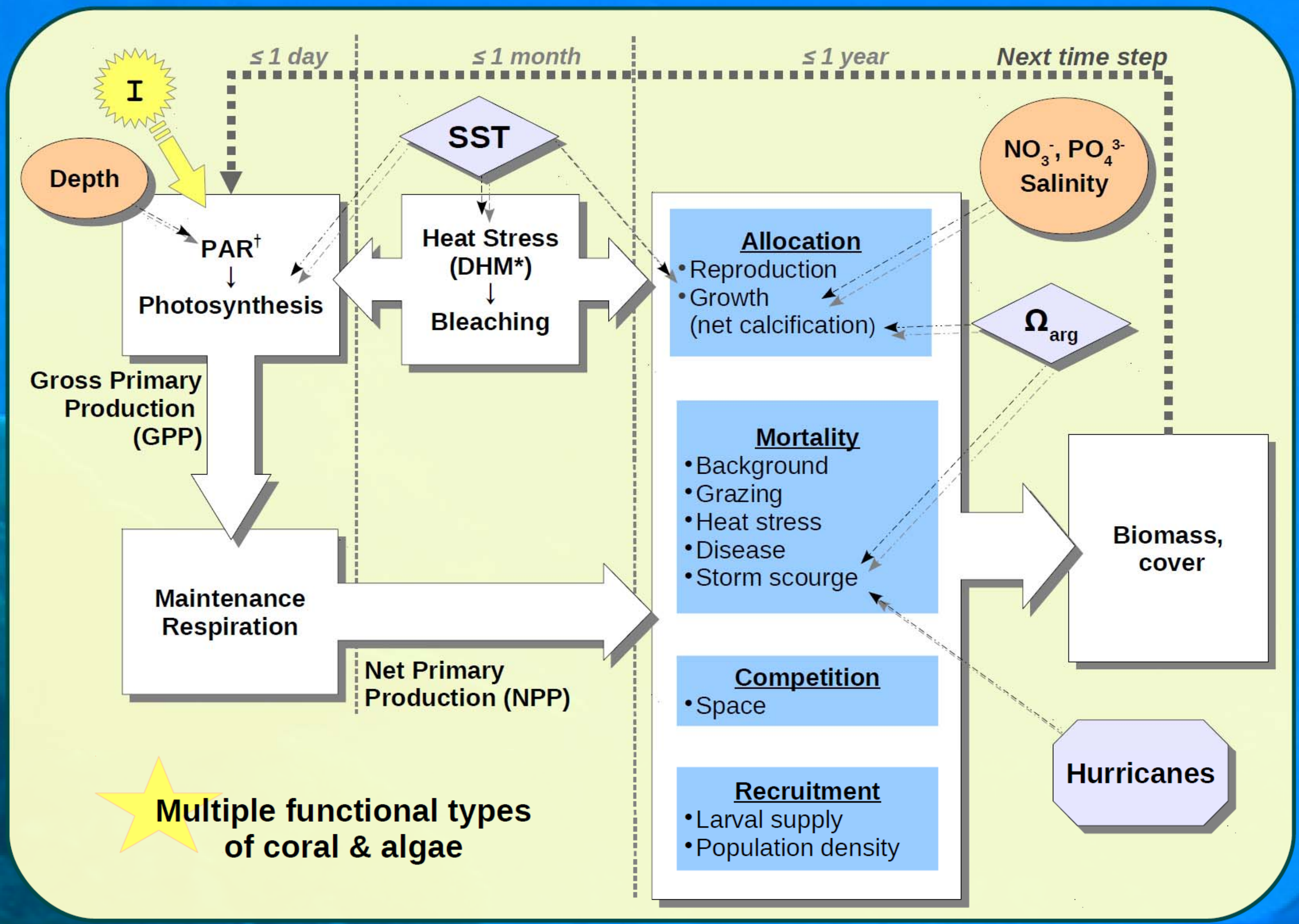
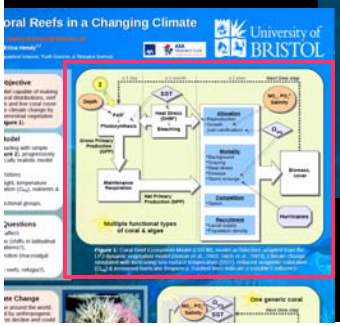


Figure 1: Coral Reef Ecosystem Model (CREM), model architecture adapted from the LPJ dynamic vegetation model (Bonan et al., 2003; Sitch et al., 2003). Climate change simulated with increasing sea surface temperature (SST), reduced aragonite saturation (Ω_{arg}) & increased hurricane frequency. Dashed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

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



The Model

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

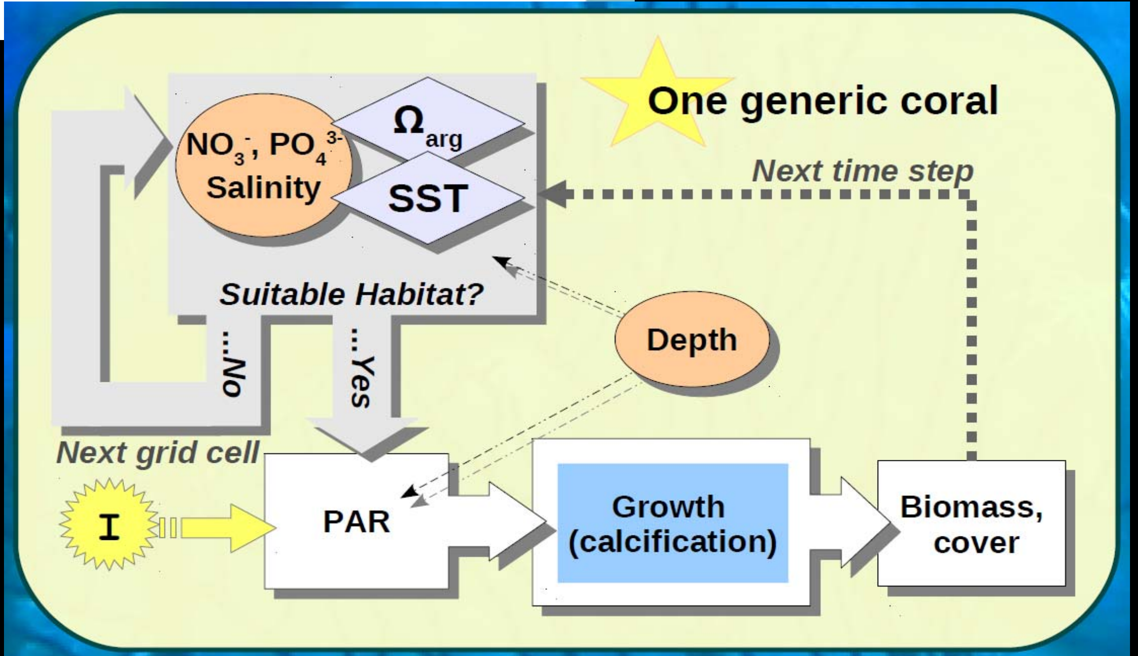
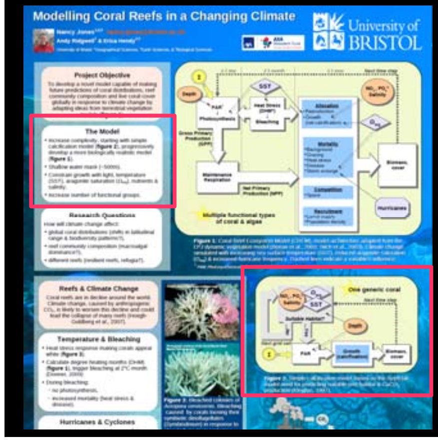
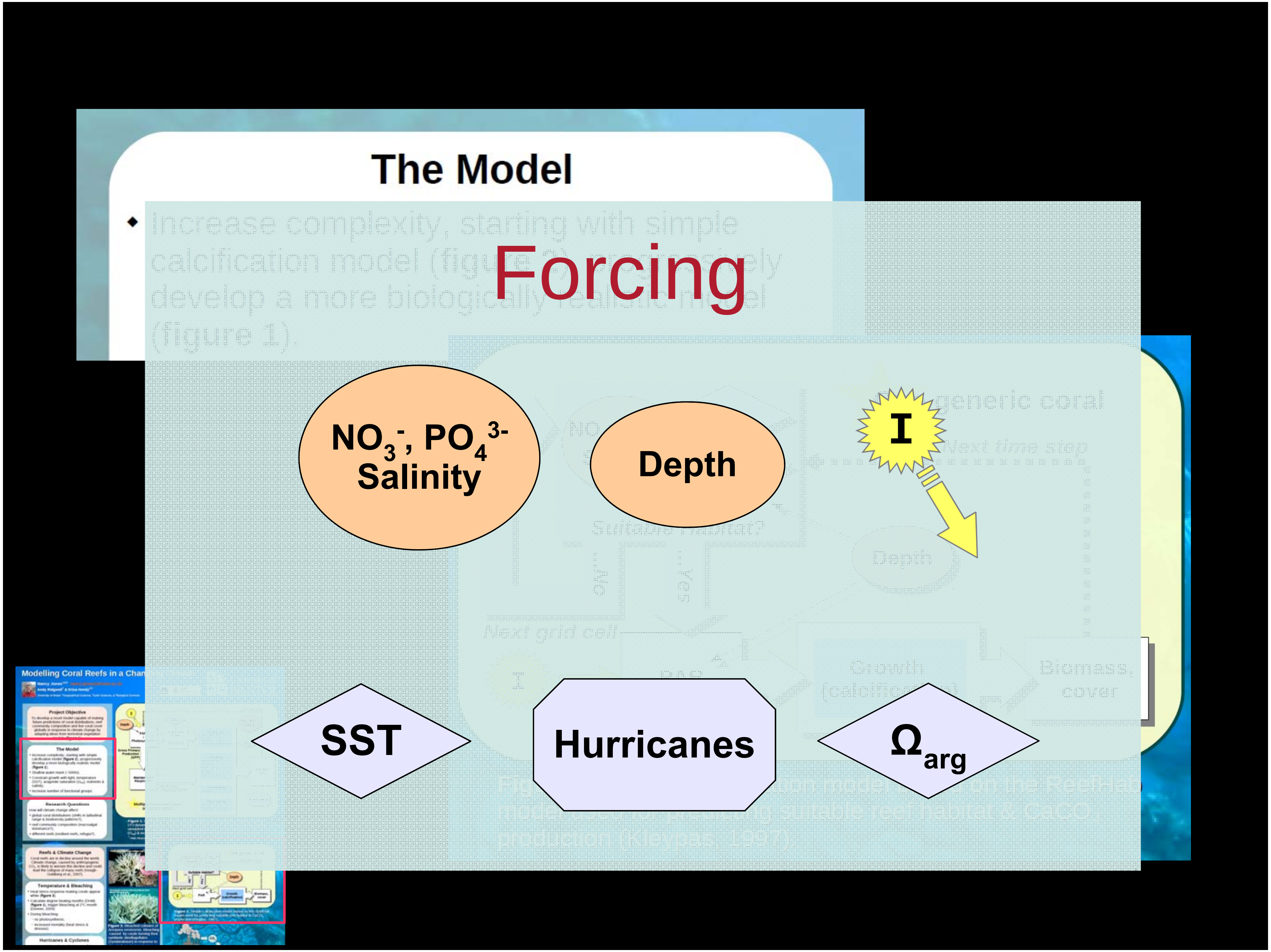


Figure 2: Simple calcification model based on the ReefHab model used for predicting suitable reef habitat & $CaCO_3$ production (Kleypas, 1997).





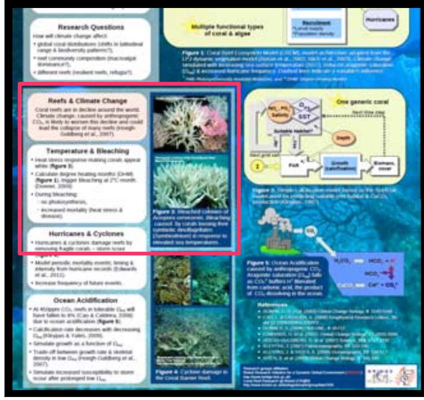
The Model
Forcing
NO_3^-, PO_4^{3-}
Salinity
Depth
I
SST
Hurricanes
Ω_{arg}

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).

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



SST

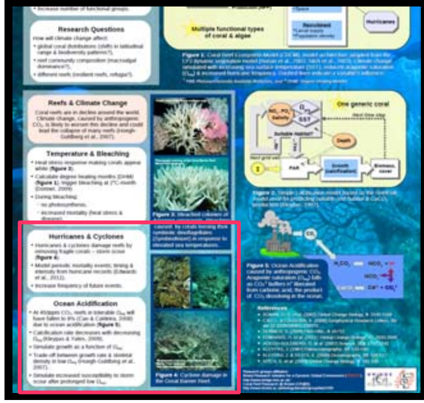
Hurricanes

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.

Figure 4: Cyclone damage in the Great Barrier Reef.



SST

Hurricanes

Ω_{arg}

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}.

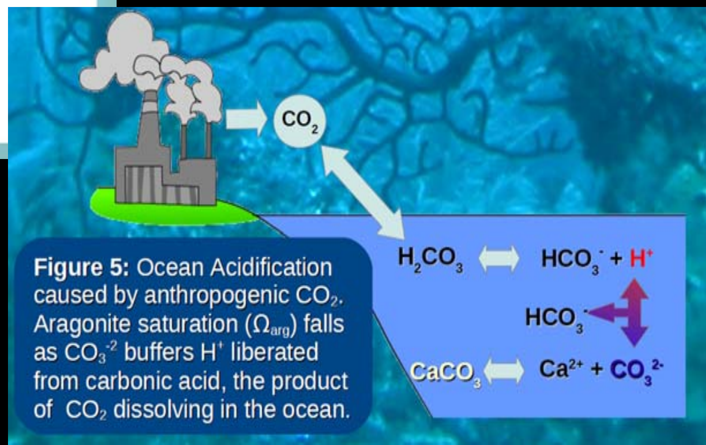
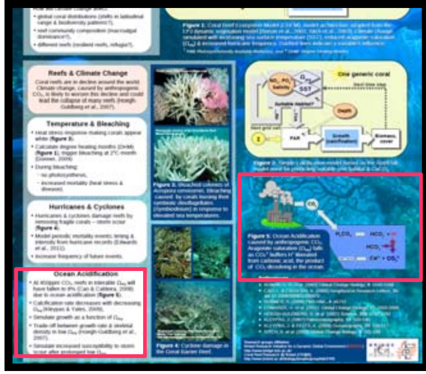


Figure 5: Ocean Acidification caused by anthropogenic CO_2. Aragonite saturation (Ω_{arg}) falls as CO_3^{-2} buffers H^+ liberated from carbonic acid, the product of CO_2 dissolving in the ocean.



Modelling Coral Reefs in a Changing Climate

Nancy Jones[1,2,3] nancy.jones@bristol.ac.uk
Andy Ridgwell[1] & Erica Hendy[2,3]
University of Bristol: [1]Geographical Sciences, [2]Earth Sciences, & [3]Biological 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?).

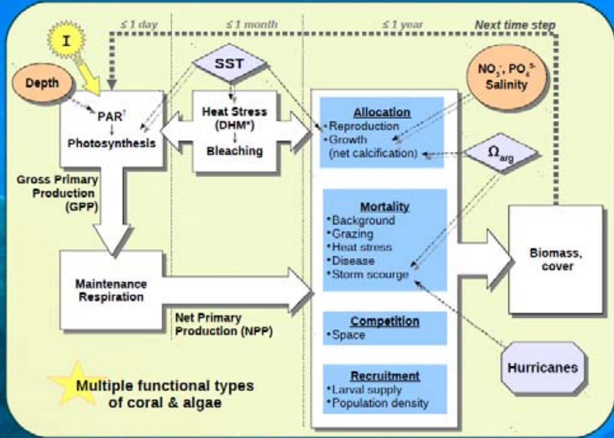


Figure 1: Coral Reef Ecosystem Model (CREM), model architecture adapted from the LPJ dynamic vegetation model (Bonan et al., 2003; Sitch et al., 2003). Climate change simulated with increasing sea surface temperature (SST), reduced aragonite saturation (Ω_{arg}) & increased hurricane frequency. Dashed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

† *PAR: Photosynthetically Available Radiation, and* * *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°C-month (Donner, 2009)
- During bleaching:
  - no photosynthesis,
  - increased mortality (heat stress & disease).

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.

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

Figure 4: Cyclone damage in the Great Barrier Reef.

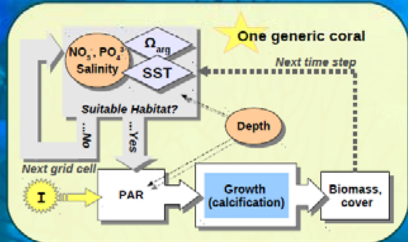


Figure 2: Simple calcification model based on the ReefHab model used for predicting suitable reef habitat & $CaCO_3$ production (Kleypas, 1997).

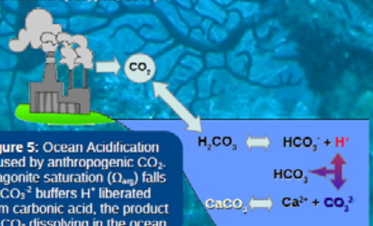


Figure 5: Ocean Acidification caused by anthropogenic CO_2. Aragonite saturation (Ω_{arg}) falls as CO_3^{-2} buffers H^+ liberated from carbonic acid, the product of CO_2 dissolving in the ocean.

References

- BONAN, G. B. *et al.* (2003) Global Change Biology, **9**: 1543-1566
- CAO, L. & 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**: 533-545
- 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.bris.ac.uk/
Coral Reef Research @ Bristol (CR@B)
http://www.bristol.ac.uk/biology/people/group/lab/2430