Coral Reef Hydrodynamics & BGC
NREM 665
I. Hydrodynamics

A. Geometric complexity of CRs leads to varying fluid dynamics from mm - km scales
1. **Fine scale** (0 – 1 m) example: *Branching corals*

   a. Flow approaching branching corals diverted over & around coral
      
      i. corals w/ dense branching → divert more flow to exterior

      ii. corals w/ sparse branching → allow more flow through interior

   b. Corals respond to flow in complex ways that can alter their physical structure

      i. branch orientation that optimizes
The shape of a coral may also be a product of millions of years of evolution acting to form a physical structure that is highly adapted to take advantage of its physical environment.

Coral colonies are thought to use their shapes to assist in sediment shedding, protection from predation and to compete with adjacent neighbors. Another intriguing idea is that the shape of some corals may increase the residence time of the water passing directly adjacent to the coral colony. This would allow increased time for suspension feeding as portions of passing water spend longer amounts of time in contact with specific sections of coral tissue. Another view would be that by breaking up a colony’s surface into branches, corals are maximizing the amount of surface area exposed to the flow of water (and therefore suspended food).

(Gulko 1998)
Fine Scale Hydrodynamics Con’t.

Strong water motion and the unstable nature of the convex shape serves to tilt the skeleton upwards.

Once the skeleton is upright, it presents a much greater cross-section to the prevailing water currents which facilitate it being turned over the rest of the way.

Once righted, the coral’s upright shape is very stable. The septa (skeletal ridges) on the skeleton may serve to slow down water passing over the skeleton. The water is then channeled by the septa towards the center and the polyp’s mouth, assisting in feeding.

(Gulko 1998)
Stylophora pistillata as seen by X-ray tomography (Monismith 2007)
Flow inside *Stylophora* as measured by Magnetic Resonance Velocimetry (Monismith 2007)
2. **Intermediate scale** (1-10 m) example: *Reef Slope*

   a. Reef slope

   i. Spurs alternating w/ grooves allow waves to dissipate energy by surging up grooves

   ii. As H$_2$O washes back, it carries sediment that accentuates grooves by erosion
Intermediate Scale Hydrodynamics

Spurs & Grooves on an atoll

(Mann 2000)
Spurs & grooves on an outer bank reef
Aerial photo of spurs & grooves at Looe Key NMS, FL, USA
Spur & groove structure & associated species on the South Shore of Moloka‘i

a: *Porites compressa* (vertical fingers)

b: *Montipora capitata* (horizontal plates)

c: *Pocillopora meandrina* (cauliflower)

(Field et al. 2007)
3. **Large scales** (10 m – kms) Ex: roughness, waves on reef, ocean currents

   a. Physical feature of reefs = **roughness**

      i. high drag coefficients: CR drag $10X >$ muddy or sandy sea beds (Monismith 2007)

   b. Waves breaking on reef

      i. When depth above reef **small**, waves weak b.c. strong friction

      ii. When depth above reef **large**, waves weak b.c. of limited breaking & small *radiation stress gradients* (Monismith 2007)

      iii. *Where do largest waves occur?*
c. Wave-driven flow thru reef & lagoon

   i. Waves break on fore reef, create pressure gradient over reef flat & lagoon, drive current that exits lagoon thru gaps in reef (Hearn 1999)

   ii. Flow over reef, thru lagoon shapes community distribution & production by controlling nutrient supply & turbulence
Intermediate/Larger Scale Hydrodynamics: Coral dislodgement during disturbance events

CSF =

Figure 3 | Annual probabilities of colony dislodgement predicted from the 37-yr history of water velocity on the study reef. a, Yearly dislodgement estimates as a function of distance from the reef crest for six CSF values (10, 25, 50, 100, 250 and 500) that span the realistic range of values for a wave-exposed reef platform b. Images of colonies of the three species with CSF values approximately equal to five of those represented in the upper panel (no colonies at the study site were near CSF = 500).

(Madin & Connolly 2006)
Figure 8.35. Mean percent coral cover on hard bottom habitats in various wave exposure regimes in the MHI. Exposures with the same letter designation are not significantly different (Tukey's HSD multiple unplanned comparisons test, α=0.05). Wave exposure codes for each site were based on methods described in Friedlander et al. (2003). Error bars are standard error of the mean. Sources: CRAMP/DAR, PIFSC-CRED, FHUS, WHAP.

(Friedlander et al. 2008)
Large Scale Hydrodynamics: Wave flow over reef flat & through lagoon

d. Regional currents (100s of km) impact GBR, reefs of FL, Pacific & Japan

i. Coral bleaching: important to understand how warm $H_2O$ migrates onto, away from CRs

ex: Warm $H_2O$ masses can be blocked @ cont shelf edges
Monitoring Coral Reefs
II. CR Biogeochemistry

A. Calcification

1. \( \frac{1}{2} \) Ca that enters sea each year is taken up & temp. bound into CRs

   a. w/ each atom of Ca a molecule of \( \text{CO}_2 \) is also deposited, resulting in gross \( \text{CO}_2 \) fixation of 700 billion kg C yr\(^{-1}\) (Mann 2004)

2. Coral polyps deposit \( \text{CaCO}_3 \) on underside of their soft tissue @ interface w/ reef surface

   a. Calcif. controlled by?
3. Carbonate Buffering System & Calcification Rxn

\[
\begin{align*}
\text{CO}_2 + \text{H}_2\text{O} & \rightleftharpoons \text{H}_2\text{CO}_3 \rightleftharpoons \text{H}^+ + \text{HCO}_3^- \rightleftharpoons 2\text{H}^+ + \text{CO}_3^{2-} \\
\text{Ca}^{2+} + 2\text{HCO}_3^- & \rightleftharpoons \text{Ca(HCO}_3)_2 \rightleftharpoons \text{CaCO}_3 + \text{H}_2\text{CO}_3
\end{align*}
\]
4. Dissolving CO₂ in seawater increases H⁺ conc., ↓ ocean pH.

   a. ↓ 0.1 units since IR, predicted ↓ 0.1-0.5 by 2100

   a. ↓ calcification rates of corals, diatoms; dissolve existing coral?
B. N Cycling

1. Primary producers take up NO$_3^-$ & NH$_3$ from reef waters
   
a. Uptake controlled by diffusion of H$_2$O thru low-nutrient boundary layers adjacent to organisms (polyp, algae surfaces), $f$(water velocity)

2. Consumers commonly excrete large quantities of NH$_3$

   
a. Flats →
   
b. Lagoons →
4. **E value** = (24 hr net community production) = Community PSN – Community Resp.

   a. Atolls: isolated CRs (recycling of nutrients) $E \approx$

   b. barrier reefs (upwelling, land-based nutr. inputs) $E >$

   c. fringing reefs - intermediate Es

C. **Paradox:** High productivity of CRs in low-nutrient waters. *Why?*