This slide had an error in class and as posted earlier. The Lecture notes have been fixed. The error was as shown corrected below.

Dissociation of

$CaCO_3 <-> Ca^{2+} + CO_3^{2-}$

and the subsequent combination of ~~Ca~~ $^{2+}$ CO_3^{2-} with hydrogen ions lowers the saturation value of $CaCO_3$

With CO_2 at 550ppm, coral habitat shrinks somewhat owing to warming. But more critical is that this habitat will be in water where the saturation value of $CaCO_3$ is lower than where any corals lived prior to the industrial revolution

Particularly vulnerable: Central Pacific and the Great Barrier Reef

Summary of Oceans

Mean sea level rise (MSLR) during the 20th century was on average 1.2 to 2.2 mm/yr and presently is a little over 3.1 +/- 0.4 mm/yr.

The TOPEX/Poseidon satellite and its predecessors (1993-present) measure MSLR using radar altimetry, which has good spacial coverage and an accuracy of 3-4 mm for 10 day averages. Tide gauges were used prior to the satellite era. They are more accurate but only give point measurements along coast lines. There were few before 1950s.

The key controls on MSLR are ocean thermal expansion, water sources from land, tides, tsunamis, subsidence/uplift, converging currents, atmospheric pressure. The first two are directly influenced by global warming and affect global sea level.

Recent MSLR results from ocean thermal expansion (~60%), glaciers and ice caps (~25%) and Greenland and Antarctica (~15%). Estimates from these three sum to nearly the total measured MSLR. In the past, their sum was less than measured MSLR – giving rise to the so-called sea level enigma.

Summary of Oceans

Ocean temperature (and hence heat content) is well measured since 2000 by Argo floats. XBT have measured since 1962, but they can't measure as deep in the ocean. Ocean heat content rise averaged among models is in good agreement with observations, although the spread among models is too large.

IPCC 2007 projected MSLR by 2100 at 200-500 mm, but this ignored any increase in dynamic thinning. Recent reasonable estimates put this number as high as 2m, but more like 1 m.

Recent estimates of annual mass loss from the GRACE satellite are 237 Gt for Greenland and 192+/-92 Gy from Antarctica.

The Bangladesh, Tuvalu and the Maldives are among the countries most threatened by MSLR. Much of the Netherlands is already below sea level and they are planning to add to their sea walls.

Summary of Oceans

The Gulf Stream is mostly wind driven and is not likely to stop flowing. However, there is a ocean thermohaline circulation that is strongly influenced by buoyancy (or water density) in the northern North Atlantic water. It brings heat from the tropics towards the Arctic and western Europe. The water sinks in the north because the water cools. If the atmosphere warms, the water can't cool as efficiently and the sinking may weaken. Increased runoff of fresh water which has lower density than sea water is another way to weaken the circulation. Global warming does both. This circulation is likely to weaken in the future and therefore offset the warming in western Europe somewhat.

ENSO or El Nino/Southern Oscillation is a coupled ocean-atmosphere phenomena, with irregularly spaced El Ninos and La Ninos. El Ninos are associated with warming in the eastern tropical Pacific. El Nino can be considered an analogy for global warming in some regions. The impacts are many and include higher precipitation and reduced upwelling of cool, nutrient rich waters in the eastern Pacific.

Summary of Oceans

Phytoplankton are photosynthesizing organisms in the ocean. They have chlorophyll and are therefore colorful like leaves. They require sunlight, nutrients, and CO2 for life. They are most abundant where the ocean circulates nutrient rich waters from depth up to the surface.

Coral bleaching is caused by corals expelling their symbiont phytoplankton upon ocean warming, which become too productive for the corals tastes.

Ocean acidification results from ocean uptake of CO2 and its dissolution into hydrogen (and bicarbonate) ion. The hydrogen ion in turn combines with carbonate ions that otherwise would be available to increase calcium carbonate levels. Lowering calcium carbonate impairs shell and coral skeletal development.

pH measures the hydrogen ion concentration. It decreases with increasing H+ with a logarithmic scale and hence puny changes in pH mean huge changes in H+ concentration. pH has fallen by ~0.08 while H+ concentrations have increased by ~30%

Summary of Oceans

Ocean marine life sinks when it dies and decays at depth. Decomposition has the opposite chemical reaction as photosynthesis and hence it consumes oxygen and produces CO2. The ocean is low in oxygen below regions where the surface waters are rich in life. The water is also high in nutrients because from the sinking organic matter. Upwelling this water can be good or bad. If the oxygen level is too low, the water cannot support life and is known as a dead zone. If the oxygen level is high enough, the high nutrient content can benefit marine life.

Too much phytoplankton growth can be harmful too, as seen in red tides or harmful algal blooms.

Finally, non-native species may invade when the ocean conditions favor them.