Chaos Theory

Chaotic Processes: the dynamical evolution that is \textit{aperiodic} and \textit{sensitively dependent} on initial conditions.

• Can’t explain future behavior (more than a few steps in time) based on the existing state

• You CAN, however, put boundaries on it
Lagrangian Coherent Structures

Structures that separate dynamically distinct regions of fluid in a time-varying system.... Somewhat related to chaotic oscillations (can’t predict with any certainty the interactions of the fluid at small scales, but at larger scales LCS provides boundaries.
Thin Layers are prevalent in upwelling systems, and frequently concentrate harmful species....

McManus et al., in prep.
Upwelling relaxation: the wrong (common) view
2D upwelling relaxation: what really happens
No Alongshore Variation Allowed! day 0.00
Hurricanes and HABs

Hurricanes, similar to other large-scale events, can promote plankton blooms (including HABs) by opening and closing niches....
Cyclone Opal

Fig. 3. Diatom biomass in the DCM.
Fig. 3 HYCOM model simulation of anticyclone-induced current velocities at depth.
Figure 1: Mean frequency of sea surface temperature (SST) fronts off the Pacific coast of Central America, 1985-2005, detected by applying Cayula and Cornillon’s SIED algorithm\textsuperscript{1} to 15,340 twice-daily SST images from the NOAA NODC 4 km AVHRR Pathfinder 5.0 database\textsuperscript{2}. Pixels show the 5x5 cell focal mean of SST front frequency. Black outlines show the smoothed 0.025 frequency contours that enclose two zones of high frontal frequency.
Figure 3: Estimates of productivity and locations of marine mammal sightings for our region of interest. (a) Mean production of phytoplankton estimated by the Vertically Generalized Productivity Model (VGPM)$^{16}$ from SeaWiFS chlorophyll concentration and AVHRR SST, 1997-2007. (b, c) Mean production of microzooplankton and mesozooplankton estimated by the Pacific ROMS-CoSINE model$^{17}$, 1991-2007. (d, e, f) Sighting locations of common dolphins (Delphinus delphis), spotted dolphins (Stenella attenuata), and blue whales (Balaenoptera musculus) from research and tuna vessels in the NOAA/NMFS/SWFSC sightings database, 1971-1999$^{18}$. 
A unifying theory...

- Combining Lagrangian Coherent Structures, hotspots, and “paradox of the plankton” concepts may explain how small/medium scale variability relates to large-scale variability…
Ecological and physical (sub-)mesoscale structure from satellite data.
Identification and history of the fluid dynamical niches.
The concept of “steady state” and NPZD-type models are useful, but biological organisms don’t respond to the mean. Much of the interesting behavior is occurring at small- and medium-scales. Recent studies suggest that the large-scale patterns can be understood by thinking of them as aggregates or special cases of these smaller-scale interactions.