Effects of submesoscale physical processes on the marine ecosystem: Upward nutrient flux and loggerhead sea turtles migration

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A few words about my research

- Physical Oceanography background
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- Theory of deep equatorial zonal currents
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Mean zonal velocity at 1000 m from ARGO floats

Ascani et al.'10
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- Multidisciplinary studies
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- Numerical models
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- Numerical models
- Analysis of various datasets
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- Physical Oceanography background
- Theory of deep equatorial zonal currents
- Multidisciplinary studies
- Numerical models
- Analysis of various datasets
- Experience at sea and with instruments
Outline

Examples of impact of physical processes on the marine ecosystem

Why should we care about submesoscale processes?

Impact of submesoscale processes on the vertical flux of nitrate around Hawaii

Impact of submesoscale processes on the eastward migration of loggerhead sea turtles in the North Pacific

Conclusions and future projects
Impacts of physical processes on the marine ecosystem

Adapted from D. Chelton
Effects of vertical mixing on phytoplankton

- Nutrient and light availability

Margalef's Mandala

- diatoms
  - Thalassiosira
- Chaetoceros
- Rhizosolenia
- Coccolithus
- Ornithocercus
dinoflagellates

nutrients
turbulence
Effects of vertical mixing on phytoplankton

- Nutrient and light availability
- Vertical migration

Margalef's Mandala

- Diatoms
  - *Thalassiosira*
- Chaetoceros
- Rhizosolenia
- Coccolithus
- Ornithocercus

- DINoflagellates
- Turbulence
Effects of vertical mixing on phytoplankton

- Nutrient and light availability
- Vertical migration
- Competition and diversity
Effects of mesoscale eddies on phytoplankton

- Nutrient and light availability

Inside a cyclonic eddy in the lee of Big Island

Nencioli et al.'08
Effects of mesoscale eddies on phytoplankton

- Nutrient and light availability
- Horizontal dynamical barriers

Nencioli et al.'08
Effects of mesoscale eddies on phytoplankton

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- Horizontal dynamical barriers
- Competition and diversity

Nencioli et al.'08
Effects of climate variability

- Affect mixing, temperature, circulation, etc
Effects of climate variability

- Affect mixing, temperature, circulation, etc
- Whole food web
Effects of climate variability

- Affect mixing, temperature, circulation, etc
- Whole food web
- Example: *Pacific Decadal Oscillation (PDO) on sea turtle population*
Impacts of physical processes on the marine ecosystem

Adapted from D. Chelton
Example of why discoveries are made with “new glasses”
Why should we care about submesoscale processes?

- Example of why discoveries are made with “new glasses”
- Higher resolution numerical models (1/30 to 1/60th of a degree)
Why should we care about submesoscale processes?

- Example of why discoveries are made with “new glasses”
- Higher resolution numerical models (1/30 to 1/60\textsuperscript{th} of a degree)
- New autonomous platforms
Up/downwelling induced by submesoscale processes
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Thomas et al.'07
Up/downwelling induced by submesoscale processes

- Surface density
- Surface biological productivity
- Cross-front density
- Cross-front nitrate

Thomas et al.'07
Up/downwelling induced by submesoscale processes

**cross-front vertical vel.**

**cross-front biological prod.**

**cross-front density**

**cross-front nitrate**

Thomas et al.'07
Up/downwelling induced by submesoscale processes

- Mixed layer
- Nitrate contours cross density contours
Up/downwelling induced by submesoscale processes

- Literature on “oceanic submesoscale processes” has exploded over the last ~15 years

- High impact on physics and biology

- Mostly from idealized numerical simulations
Up/downwelling induced by submesoscale processes

- Literature on “oceanic submesoscale processes” has exploded over the last ~15 years
- High impact on physics and biology
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Are they relevant for the regime around Hawaii, especially around Station ALOHA?

Do they impact the behavior of top predators, such as loggerhead sea turtles?
Impact of submesoscale processes around Hawaii

Johnson et al.'10
Up to 60% of nitrate required to sustain local primary productivity

Johnson et al.'10
Characterization of nitrate events

(1) density anomalies
(2) horizontal scale < 0.3 deg.
(3) down to 600 m depth
(4) no seasonality

Ascani et al.'13

depth of $\sigma=25 \text{ kg/m}^3$
Nitrate events are below the mixed layer

- Density anomalies
- Horizontal scale < 0.3 deg.
- Down to 600 m depth
- No seasonality

Ascani et al.'13
Submesoscale processes in a realistic numerical model of the circulation around Hawaii

Rossby number > 0.3
Vertical velocity > 10 m/day

Ascani et al.'13
Upwelling events can appear due to the float's sampling the mesoscale eddy field.
Impact of submesoscale processes on migration of loggerhead (*Caretta caretta*) sea turtles.

2002-2006 mean surface ocean currents (white streamlines) and eddy kinetic energy (colored areas).
Impact of submesoscale processes on migration of loggerhead (*Caretta caretta*) sea turtles.
Impact of submesoscale processes on migration of loggerhead (*Caretta caretta*) sea turtles
Impact of submesoscale processes on migration of loggerhead (*Caretta caretta*) sea turtles

Probability distributions of submesoscale index

- **null hypothesis**
- **turtles**

Outside filaments

Inside filaments
Impact of submesoscale processes on migration of loggerhead (*Caretta caretta*) sea turtles

![Probability distributions of submesoscale index](image)

- **Outside filaments**
- **Inside filaments**

Probability distributions of submesoscale index

- **Drifters**
- **Turtles**

0.0 0.1 0.2 0.3 0.4 (1/day)
Conclusions

Loggerhead sea turtles along the Kuroshio Extension
- Swim to reach nearby submesoscale filaments
- Try to stay inside filaments
- Submesoscale filaments as biological “hotspots” that attract top predators
- Fine-tuning of ecosystem management tools

Submesoscale activity around Hawaii and Station ALOHA
- Submesoscale processes active only in late winter and early spring with little impact on nutrient flux
- Need high-resolution observations for this period
Collaborative projects with UH Hilo faculty and students: Bridges between ocean physics and biogeochemistry

- Effect of vertical mixing on vertically-migrating phytoplankton species observed around Hawaii
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Modulation of loggerhead sea turtles by the Pacific Decadal Oscillation

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- Study of dynamics of pCO$_2$ and pH in Hilo Bay from a Waveglider
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Thank you for your attention
Theory of deep equatorial currents

Ascani et al.'10
Characterization of nitrate events

(a) $d_N(t; d_0)$ and $d^{\text{meso}}_N(t; d_0)$ (float #1)

(b) $d^{\text{epis}}_N(t; d_0)$ (all floats)
Characterization of nitrate events
Up/downwelling induced by submesoscale processes

50% tracer input outside eddy cores

Lapeyre and Klein'06
Submesoscale processes and submesoscale index

Vertical velocity at 20 m and submesoscale index on Jan. 15, 2010

Vertical velocity > 10 m/day

Submesoscale index associated with density fronts and surface chlorophyll maxima (e.g. Lehahn et al.'07; Calil et al.'10)
Effect of vertical mixing on phytoplankton

Intermediate Disturbance Hypothesis

Shannon-Weaver diversity index

Vertical diffusivity coefficient (m$^2$/s)

Perruche et al.'10
Effects of mesoscale eddies on phytoplankton

- Nutrient and light availability
- Competition and diversity

numerical simulation of a simple marine ecosystem model embedded in a mesoscale eddy field

Perruche et al.'11