Present and Future Upwelling off the Entrance to Juan de Fuca Strait

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Outline

• Background oceanography
• Model details & validation
• Eddy generation studies
• Future climate studies
• Summary
The Region of Interest
Juan de Fuca (Tully) Eddy

- **summer** upwelling feature off the entrance to Juan de Fuca Strait

- Not classical upwelling, as off Washington, Oregon, California

- comprised of nutrient-rich California Undercurrent water (Freeland & Denman, 1982) that moves up the Juan de Fuca and Tully Canyons onto the shelf

- Makes the SW Vancouver Island & northern Washington shelves one of most productive fishing regions in the NE Pacific (Ware & Thomson, 2005)

*Courtesy of Rick Thomson*

*Sept 2005 salinity at 5m depth*
Background Physical Oceanography

- Strong tidal, estuarine, & wind-driven flows in Juan de Fuca Strait
- Estuarine flow primarily from Fraser River
- Summer upwelling winds
Objective:
- What forcing causes eddy generation & what are the specific dynamics?

Model details:
- Stretched grid: 1 to 5 km
- Temperature & salinity initial conditions from summer climatology
- Average summer winds from UW MM5 atmospheric model (http://www.atmos.washington.edu/mm5rt/)
- $M_2$, $S_2$, $K_1$, $O_1$ tidal forcing
- Strong TS nudging at JdF boundary to maintain estuarine flows
- Radiation &/or nudging conditions on N, S, W boundaries
- No Columbia River discharge
Tinis et al. (2006) verified MM5 winds with offshore buoy data.
<table>
<thead>
<tr>
<th>Experiment</th>
<th>Objective</th>
<th>Initial Conditions</th>
<th>Tides</th>
<th>Estuarine Flow</th>
<th>Winds</th>
<th>Duration</th>
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<tbody>
<tr>
<td>A</td>
<td>Baseline run</td>
<td>Summer climatology</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>60 days</td>
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<td>B</td>
<td>Role of winds</td>
<td>Summer climatology</td>
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<td>Role of tides</td>
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<td>yes</td>
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<td>60 days</td>
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Baseline Run: Validation

Average (days 46-60) flows & salinity at 0, 35, 100 m depths
Baseline Run: Validation

Mean flows & tides across Juan de Fuca Strait
Baseline vs Winds but no Tides vs Tides but no Winds

Average (days 46-60) flows & salinity at 35 m depth
Average (days 46-60) flows & salinity at 35 m depth

Baseline vs Winds but no Tides vs Winds & Tides but no Estuarine Flow
Eddy Development: Winds but no Tides
Summary of Present-day Eddy

- Good agreement between summer observations & model
  - Confidence in model dynamics

- Model suggests eddy is generated by enhanced upwelling off Cape Flattery
  - Migrates westward to lie over Tully Canyon

- Eddy generation requires estuarine flow & upwelling winds and/or tides
  - Key = proximity of dense bottom water off Cape Flattery
    - 200m depth contour only 4km away

MERIS chlorophyll image: June 3, 2003
Courtesy of Jim Gower & Steph King
What is the Future of the Juan de Fuca Eddy under Climate Change?

- Eddy is forced by a combination of winds, tides & estuarine flow

- How will each of them be affected?
  - Tides – no change
  - Upwelling winds?
  - Estuarine flow?
Changes to the Upwelling Winds

- network of 13 offshore buoys with re-analysis winds back to 1958 (Faucher et al., 1999)

i. Can evaluate climate model winds over observation period

ii. Then look at climate model projections
Methodology

• 10m winds from 18 global climate model simulations

  • PCMDI web site
  • A1B emission scenario

• Interpolate, or take nearest value, to buoy locations

• compare monthly & seasonal averages over period 1976–95

• look at projections for 2030–49 and 2080–99

Figure 10.25. Global CO₂, CH₄, and NO₂ concentrations for six representative SRES fossil fuel/industrial emissions scenarios, their corresponding CO₂, CH₄, and NO₂ concentrations, relative radiative forcing, and annual temperature projections, assuming an RCM tuned to 1976–2005. The solid simulation lines in the bottom temperature panel represent the mean ± 1 standard deviation for the 18 model runs. The higher asserted areas depict the changes in this uncertainty range. Carbon dioxide feedbacks are assumed to be lower or higher than in the reference setting. Lower projections for mid-range carbon dioxide scenarios for the six RCP greenhouse gas scenarios are shown in thin colored lines. Global warming (above line) and annual temperature changes relative to pre-industrial warming (below line) are shown. The temperature changes are shown in the right panel for the 6 greenhouse gas scenarios and relative forcing compared sequentially with 20th-century observations (black line), as shown in the upper left-panel (Polonsky et al., 2001; Jones et al., 2001; Jones and Lough, 2004).
1976–95 Evaluation of Ensemble Monthly Averages

- Seasonal direction changes captured reasonably well
- Near offshore summer upwelling winds captured reasonably well
1976-95 Summer Evaluation of Individual Models

Table 1: Climate models used in this study and their atmospheric resolutions

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Institution/Model</th>
<th>Atmospheric resolution</th>
<th>Lon x Lat</th>
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</table>
Projected Changes at Near offshore Buoys

Conclusion:

- Slight changes in upwelling winds
- Magnitude increase
- Clockwise rotation
Changes to the Estuarine Flow

- Driven mainly by the Fraser River

- Future projections based on CCCMa IPCC AR3 output:
  - Morrison et al., J. Hydrology, 2002

- Summer discharge will be weaker but temperature will be warmer
  - Still an estuarine flow in JdF Strait
  - More study required with regional climate model
Summary:

Present Upwelling

- Good agreement between summer observations & model
- Model suggests eddy is generated by enhanced upwelling off Cape Flattery
- Requirements = estuarine flow + upwelling winds and/or tides
  - Key = proximity of dense bottom water off Cape Flattery
Summary

Future Upwelling

- Tides won’t change
- Summer upwelling winds slightly stronger
- Estuarine flow might be weaker
- Juan de Fuca Eddy should remain but may be weaker

More details in

- Merryfield et al., 2008, submitted to JGR
Thanks for your interest!