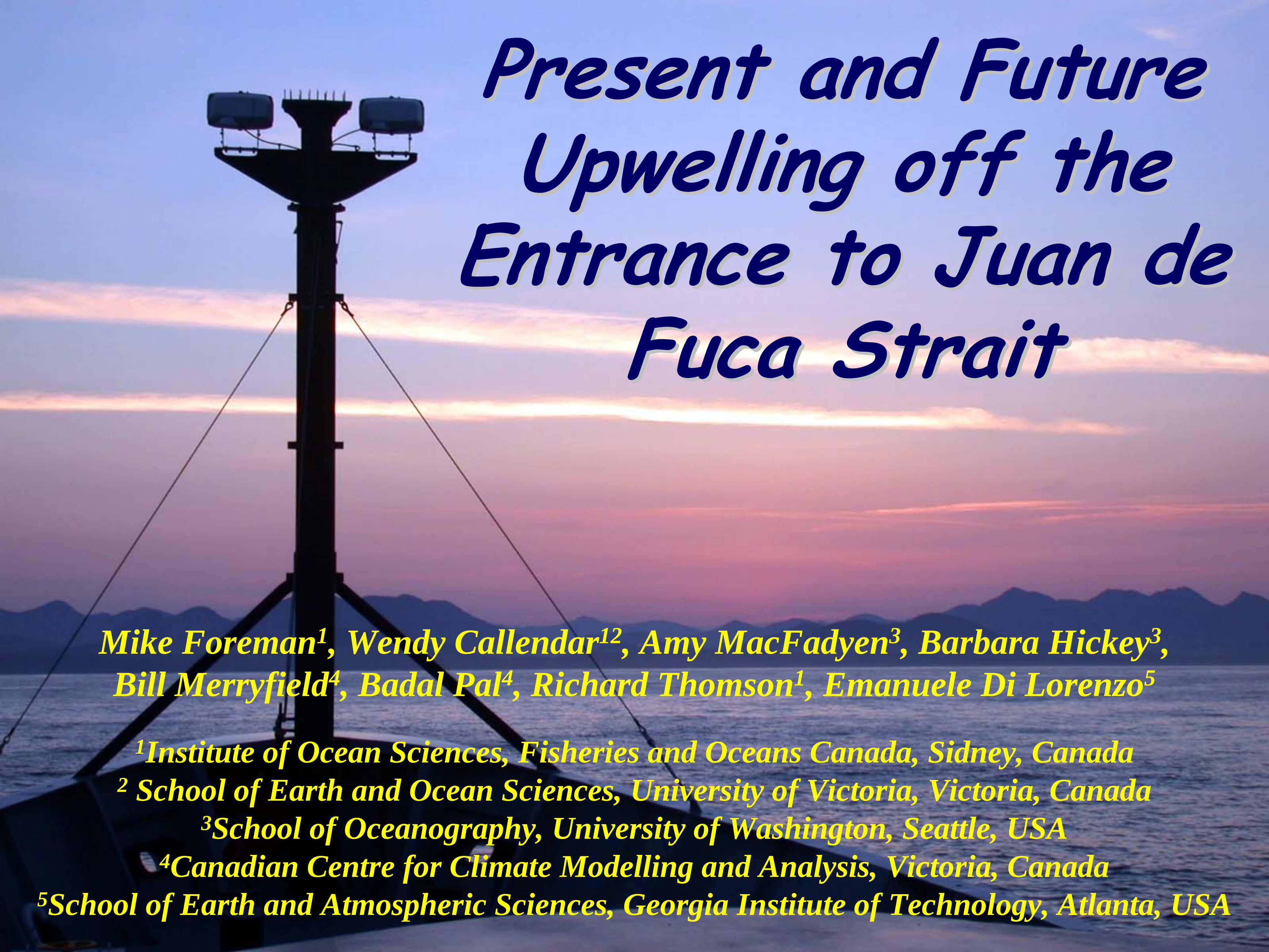

Present and Future Upwelling off the Entrance to Juan de Fuca Strait

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[3]School of Oceanography, University of Washington, Seattle, USA
[4]Canadian Centre for Climate Modelling and Analysis, Victoria, Canada
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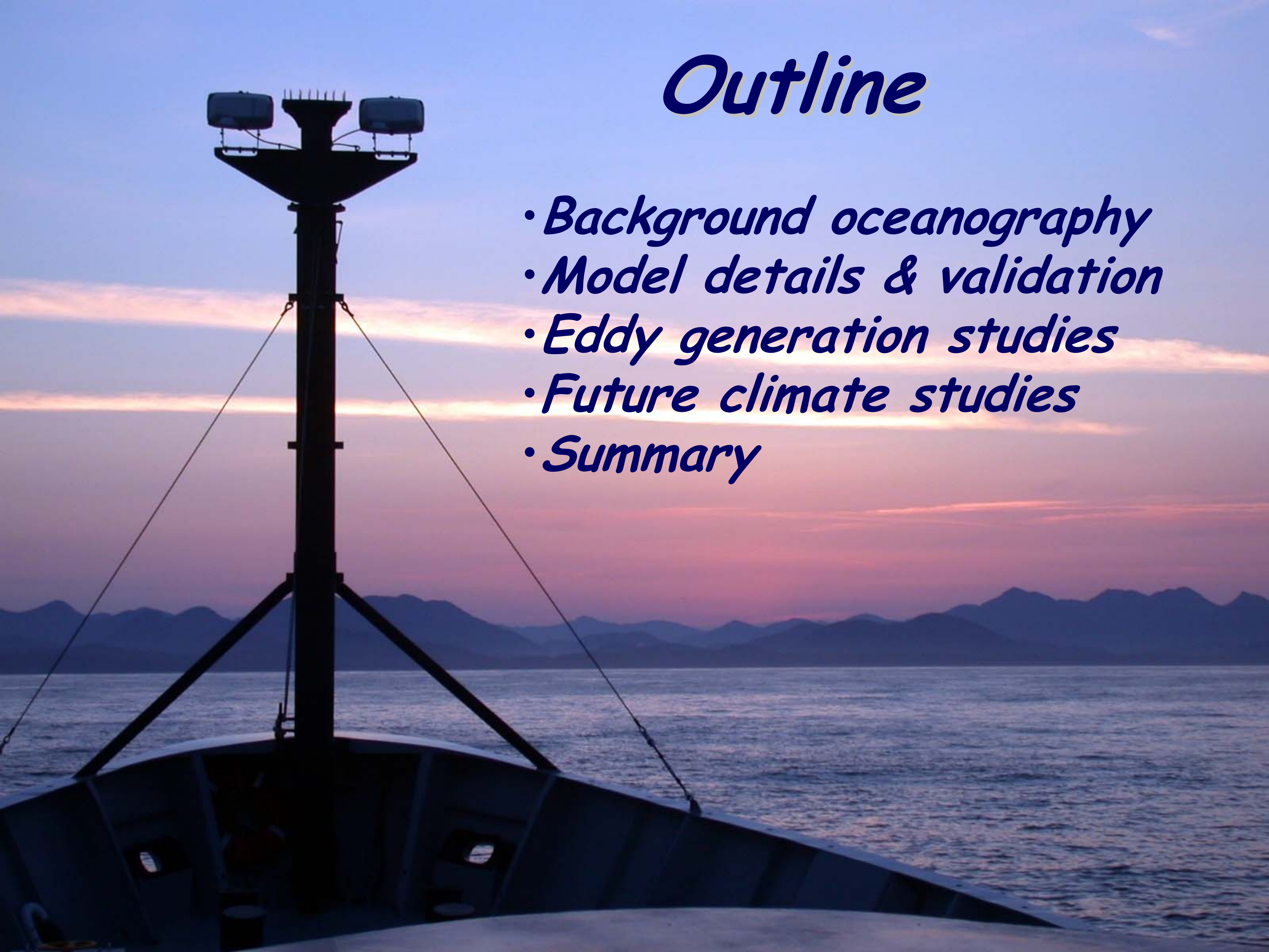
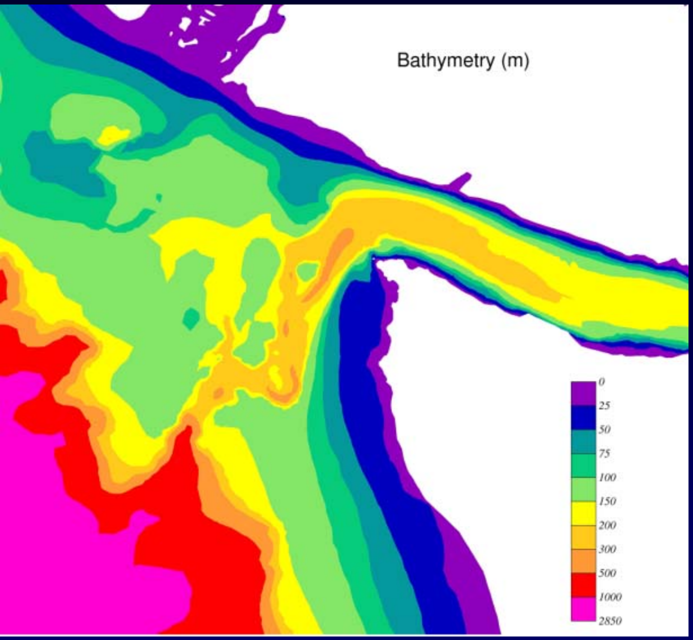
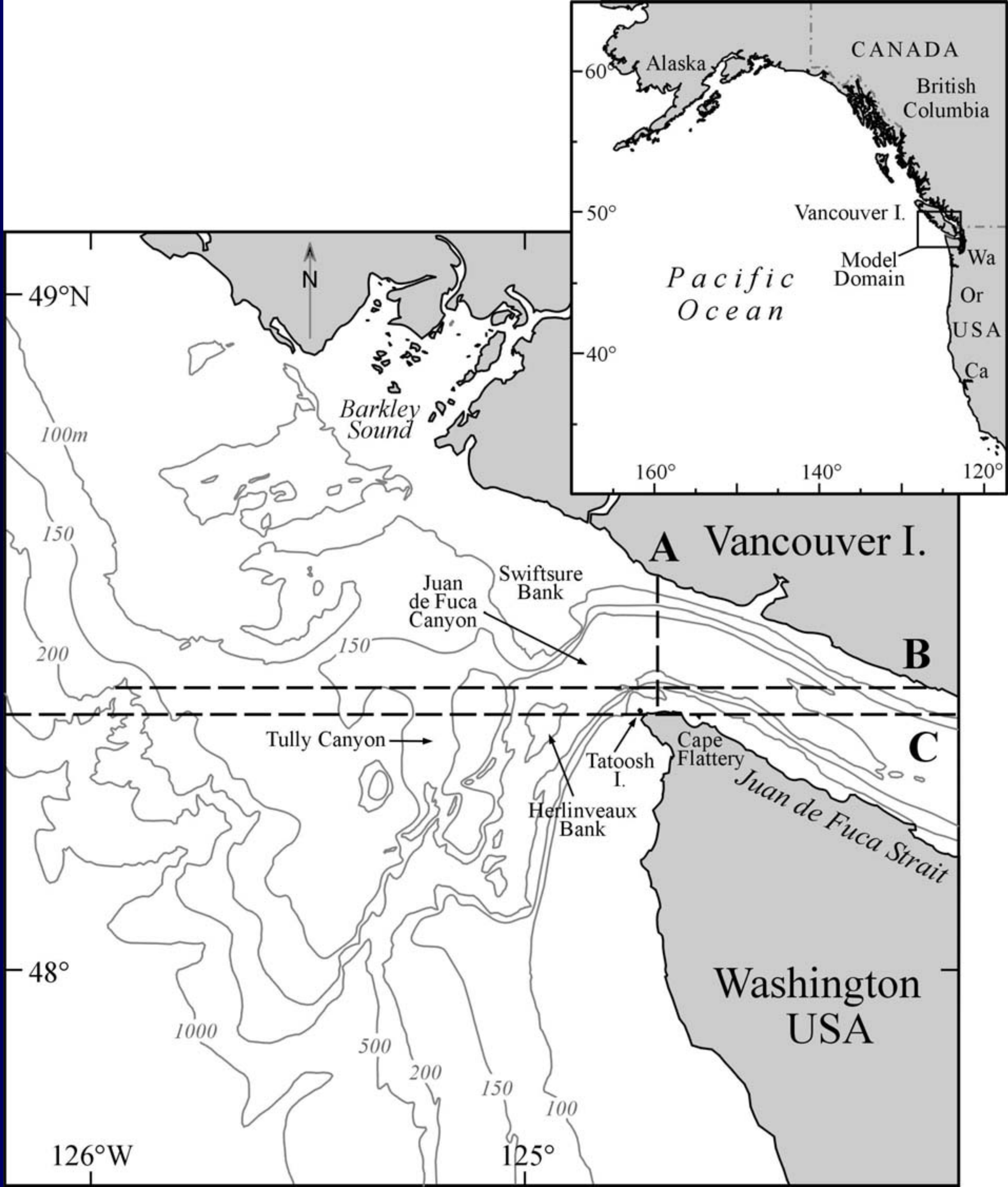


Outline

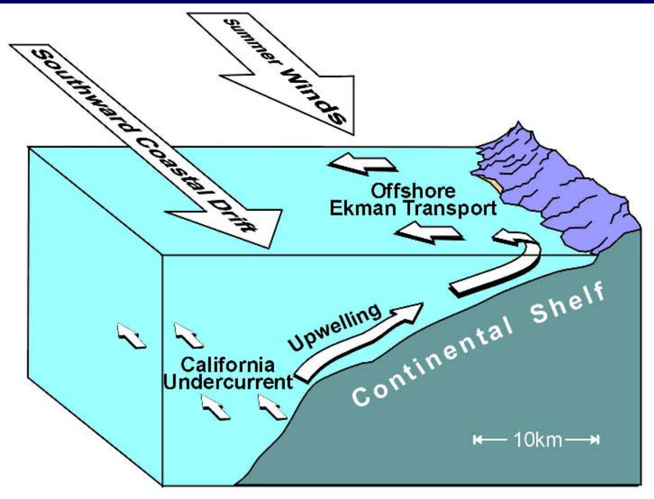
- Background oceanography
- Model details & validation
- Eddy generation studies
- Future climate studies
- Summary

The Region of Interest

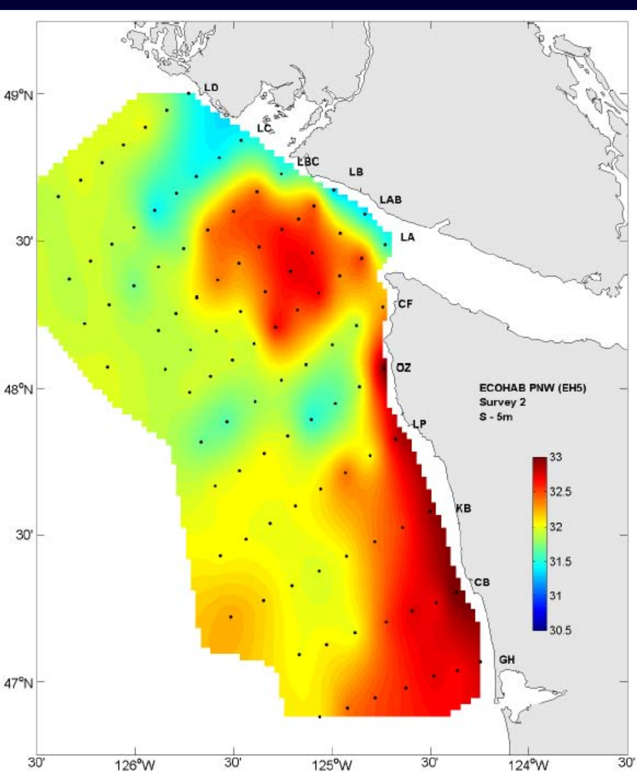




Juan de Fuca (Tully) Eddy

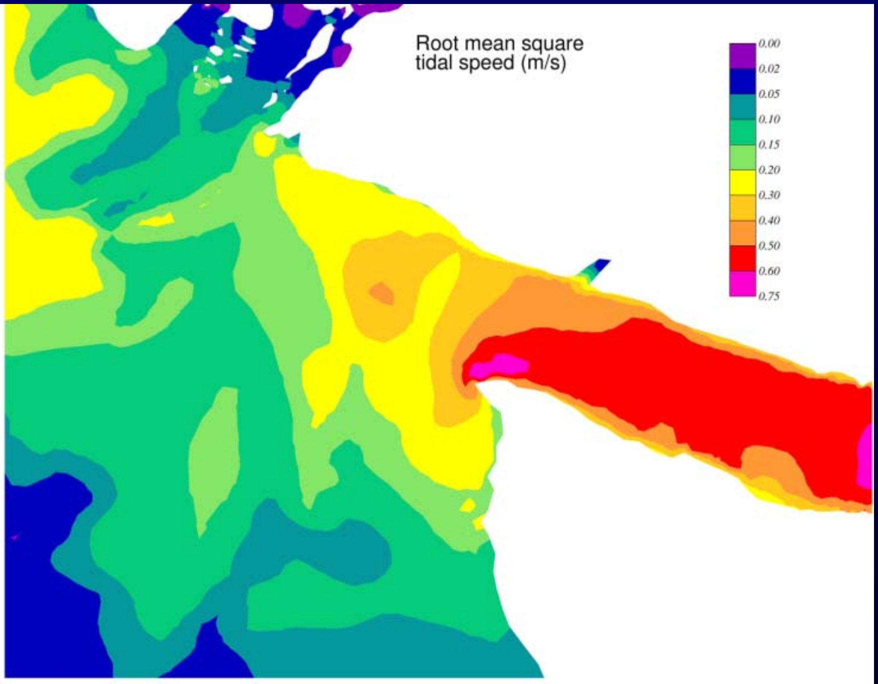


Courtesy of Rick Thomson



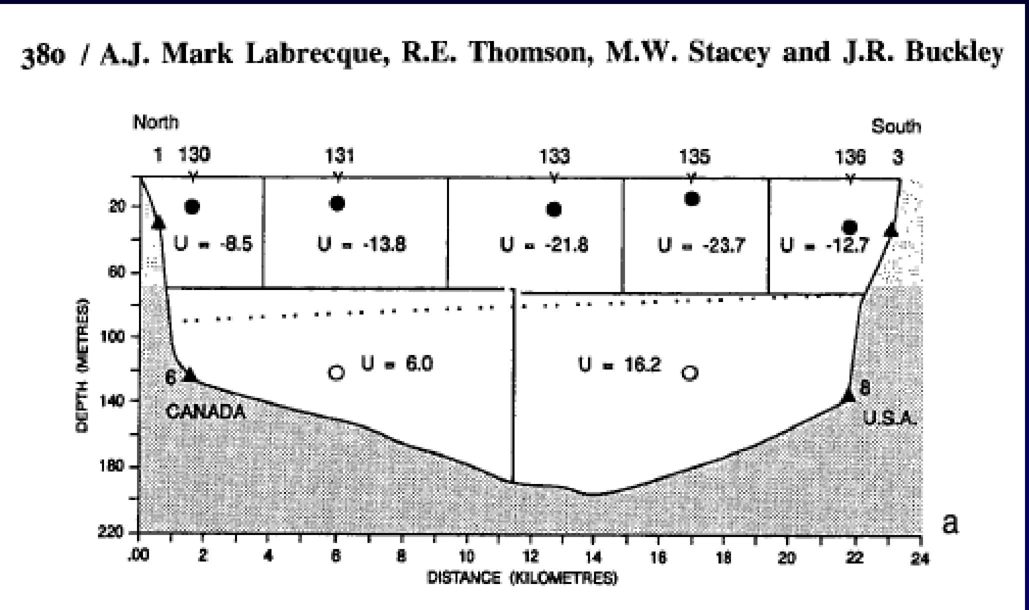
Sept 2005 salinity at 5m depth

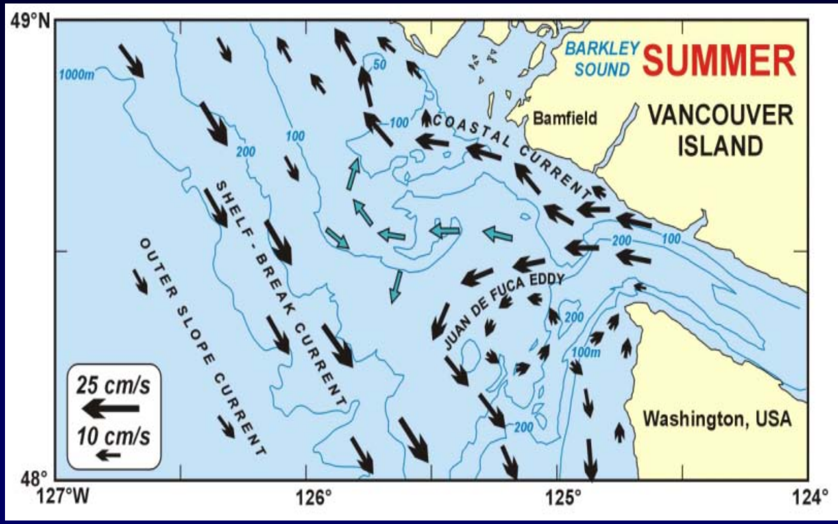
- *summer upwelling feature off the entrance to Juan de Fuca Strait*
- *Not classical upwelling, as off Washington, Oregon, California*
- *comprised of nutrient-rich California Undercurrent water (Freeland & Denman, 1982) that moves up the Juan de Fuca and Tully Canyons onto the shelf*
- *Makes the SW Vancouver Island & northern Washington shelves one of most productive fishing regions in the NE Pacific (Ware & Thomson, 2005)*



Background Physical Oceanography

- Strong tidal, estuarine, & wind-driven flows in Juan de Fuca Strait
- Estuarine flow primarily from Fraser River
- Summer upwelling winds



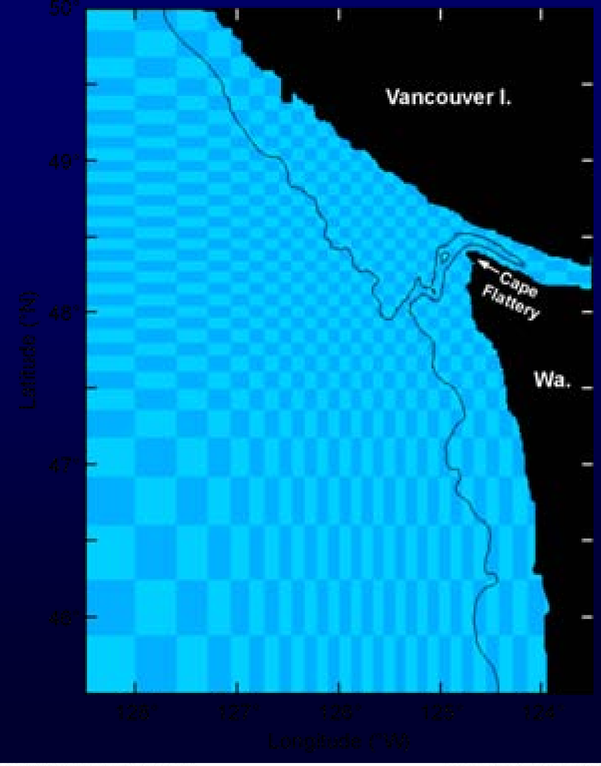


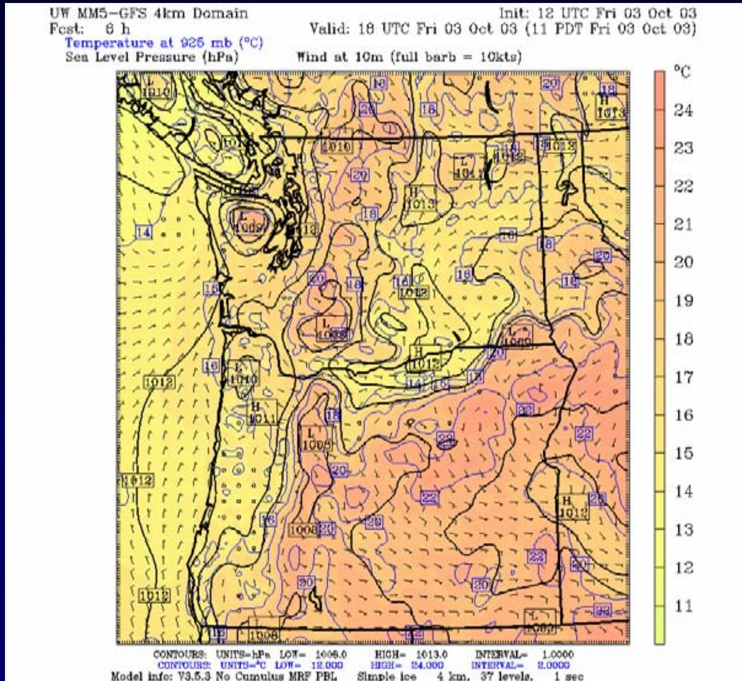
Courtesy of Rick Thomson

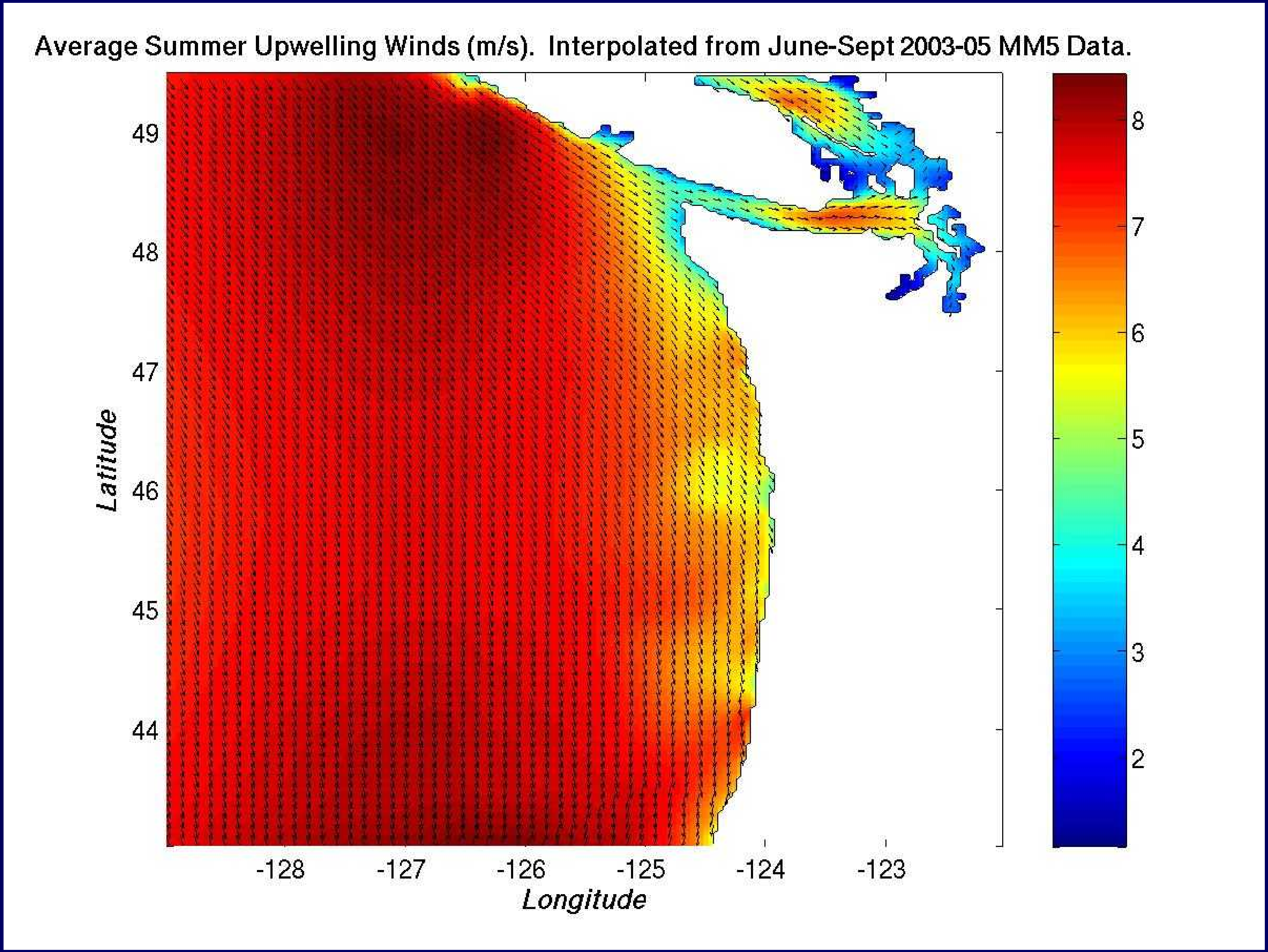
Physical Modelling (ROMS)

- ***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***







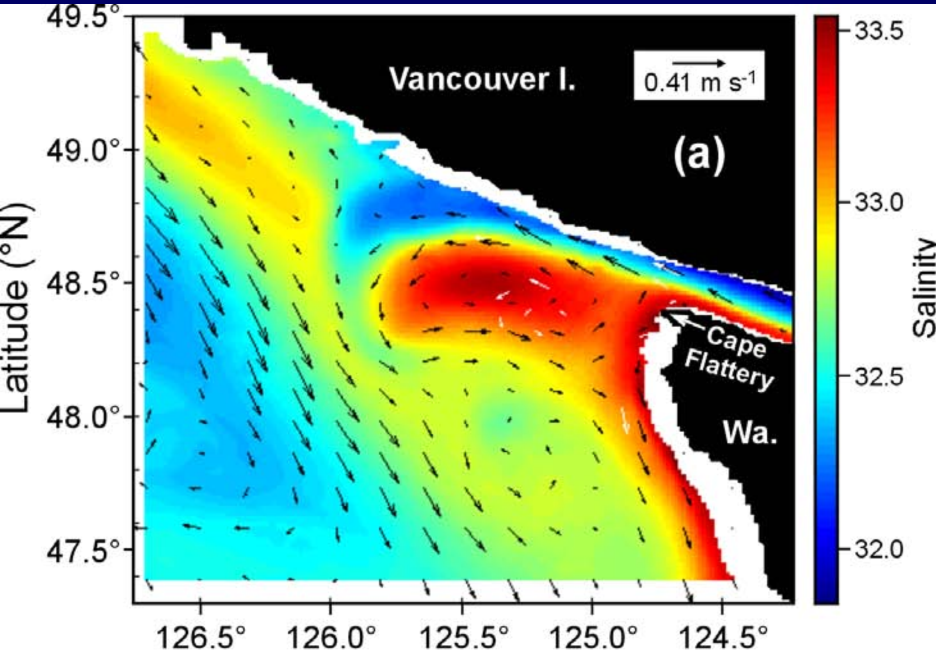
Tinis et al. (2006) verified MM5 winds with offshore buoy data

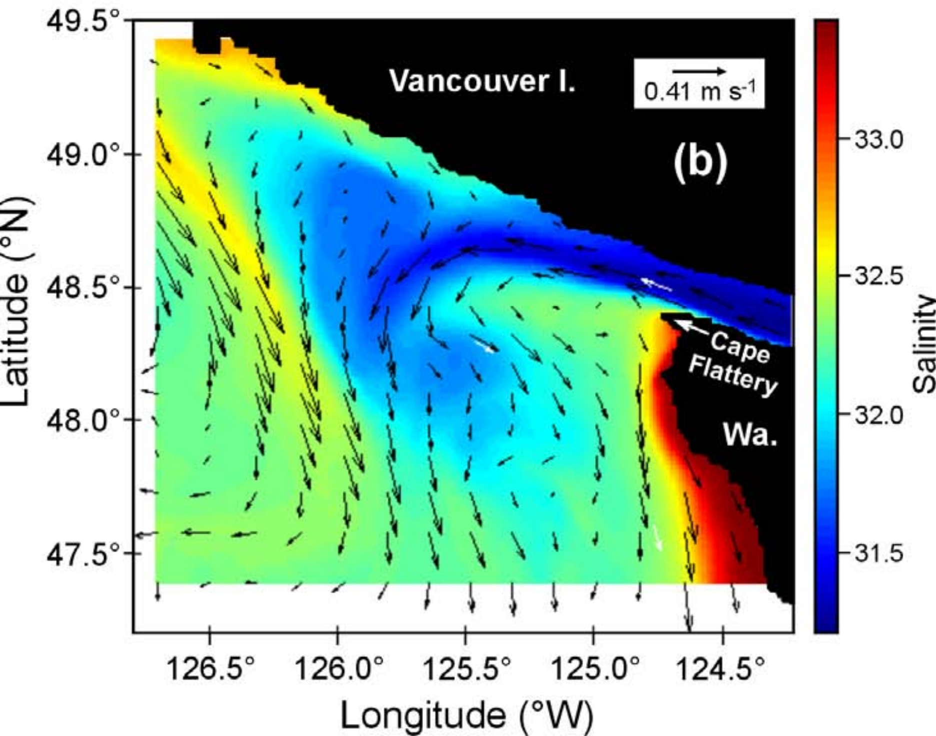
Model Experiments

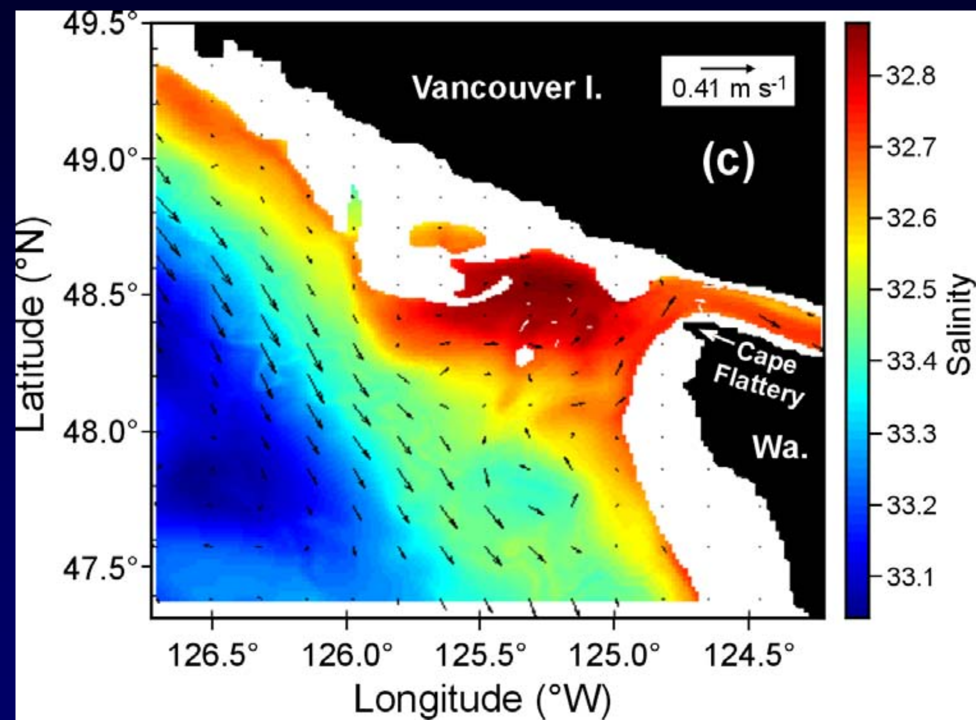
Experiment	Objective	Initial Conditions	Tides	Estuarine Flow	Winds	Duration
A	Baseline run	Summer climatology	yes	yes	yes	60 days
B	Role of winds	Summer climatology	no	yes	yes	60 days
C	Role of tides	Summer climatology	yes	yes	no	60 days
D	Role of estuarine flow	T and S profiles	yes	no	yes	60 days

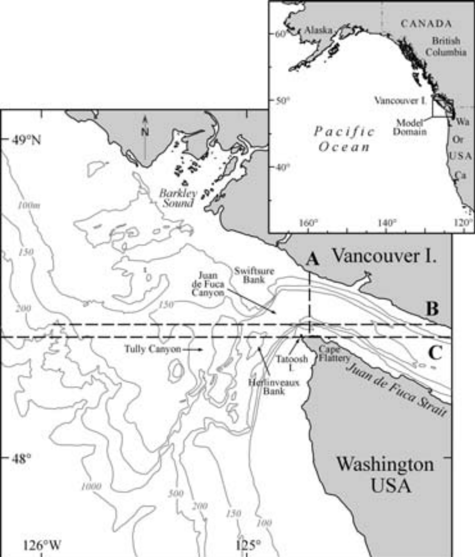
Baseline Run: Validation

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



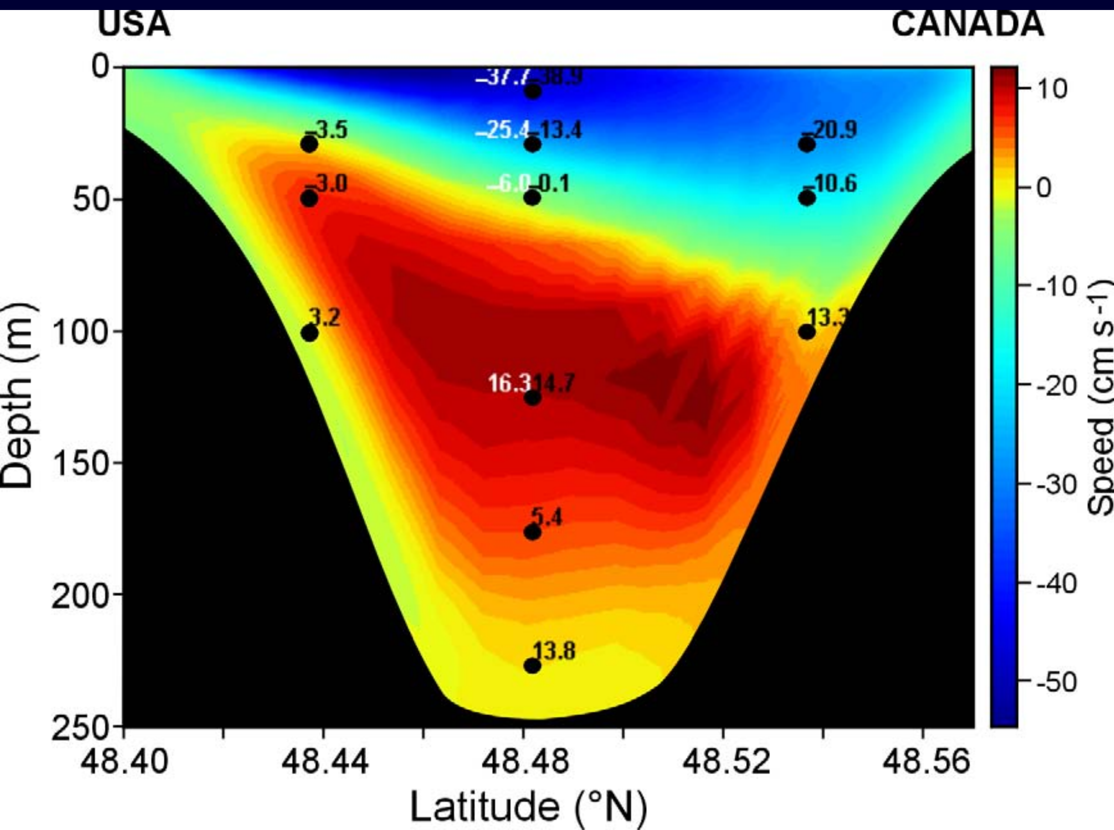


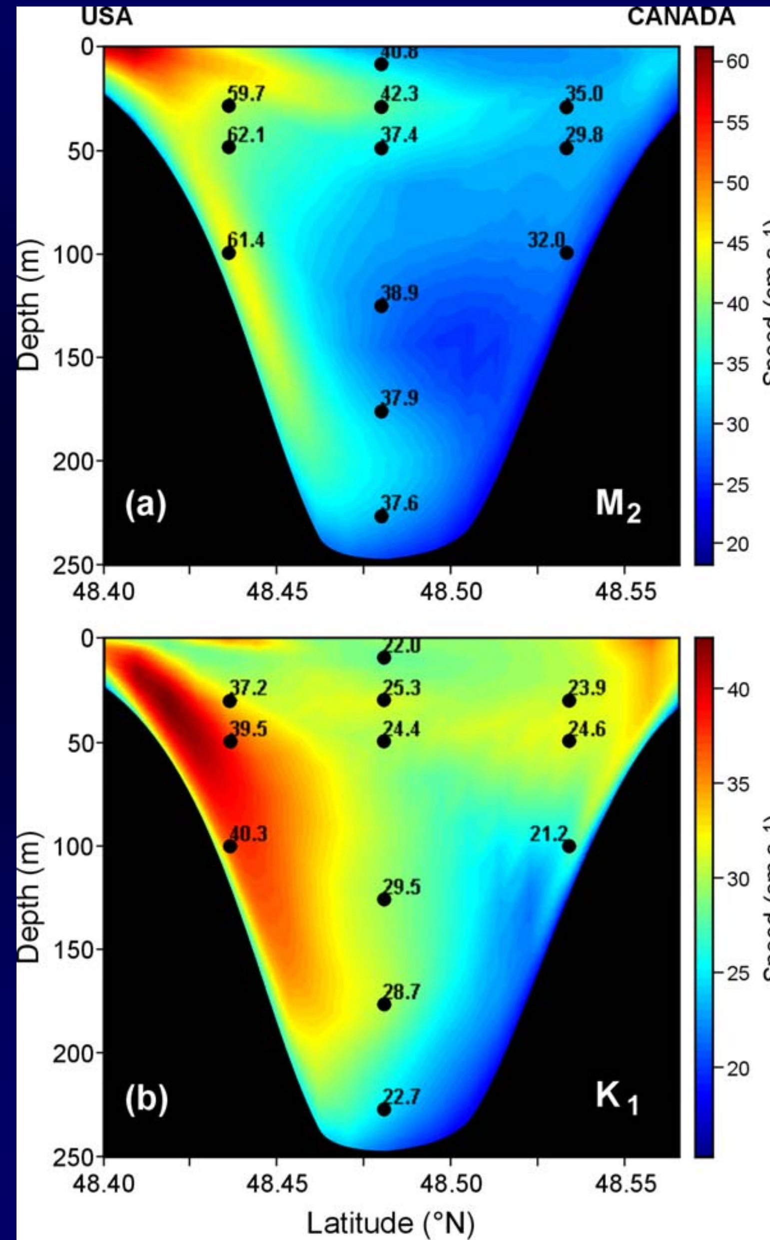


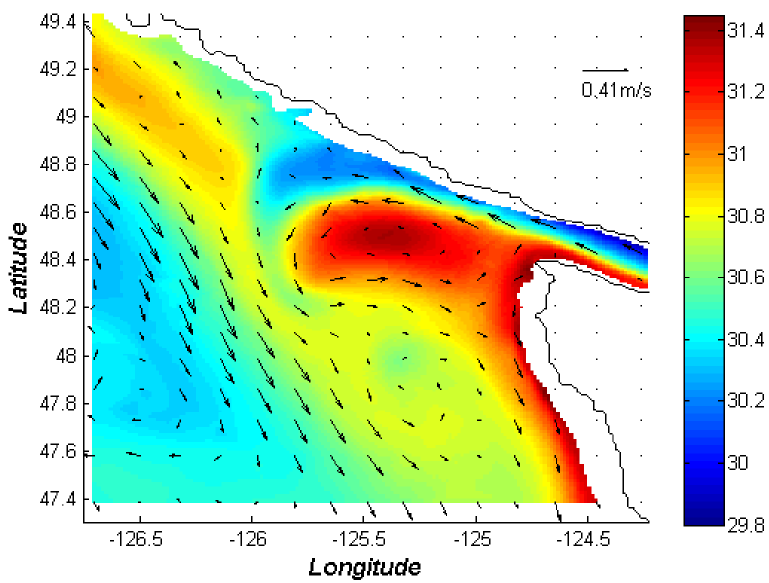


Baseline Run: Validation

Mean flows & tides across Juan de Fuca Strait

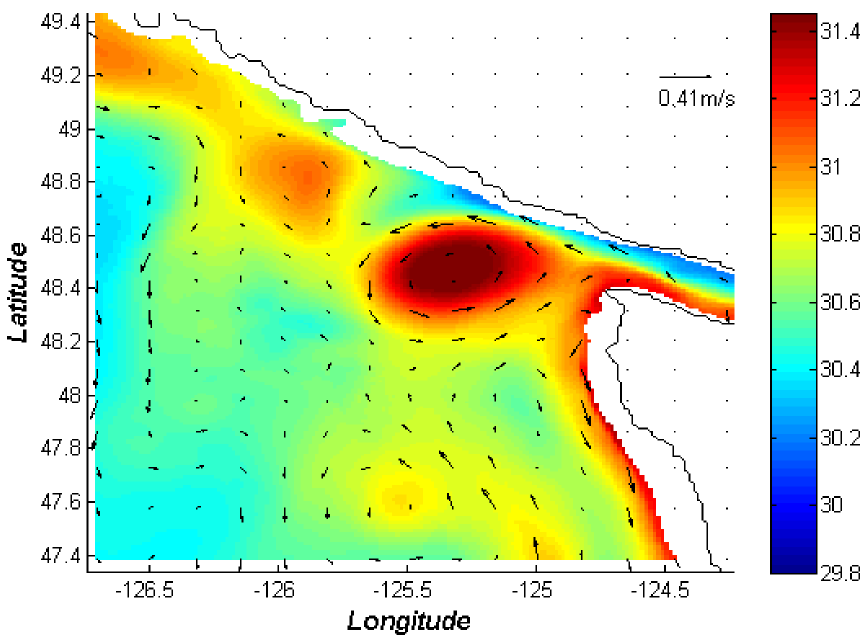


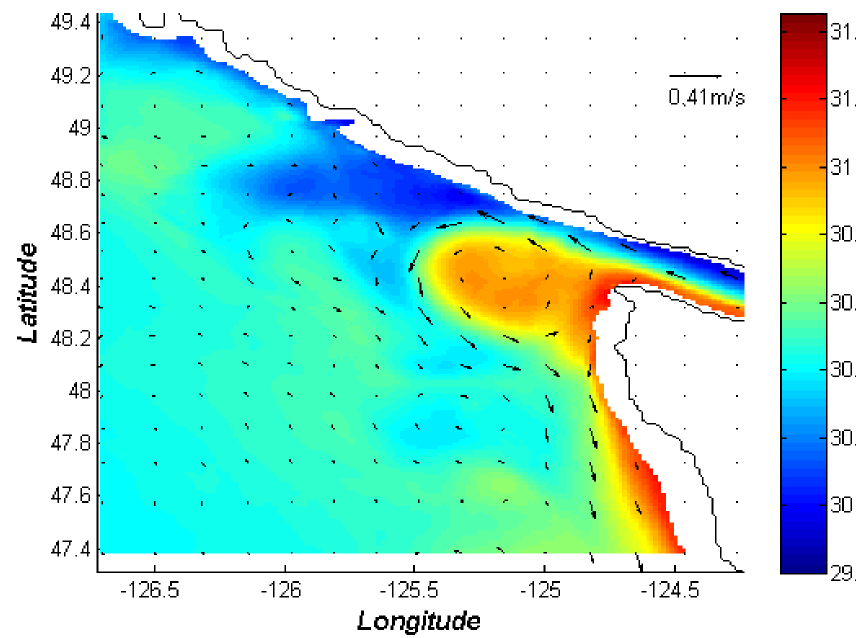




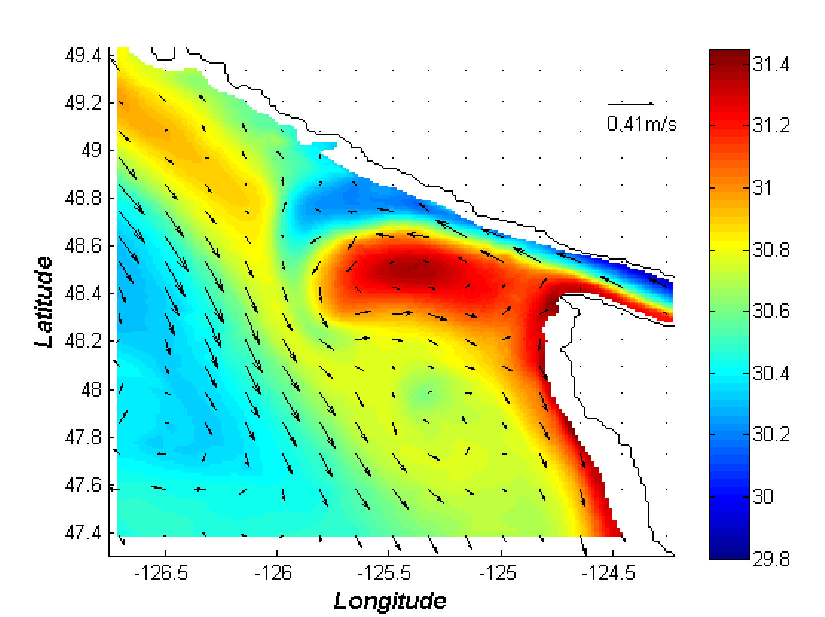
Baseline
vs
Winds but no Tides
vs
Tides but no Winds

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

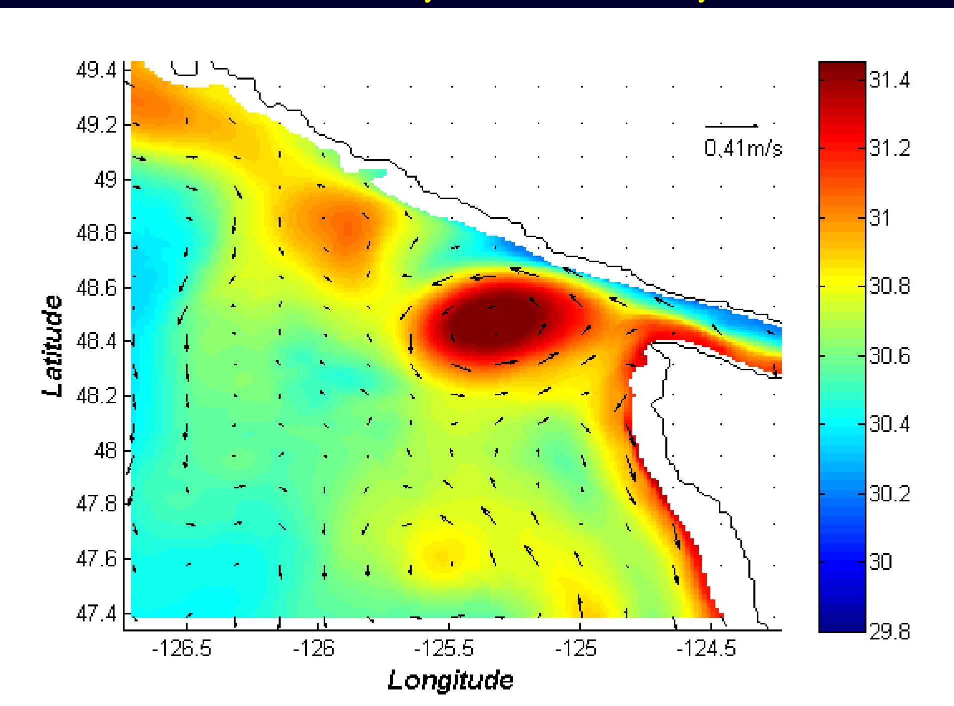


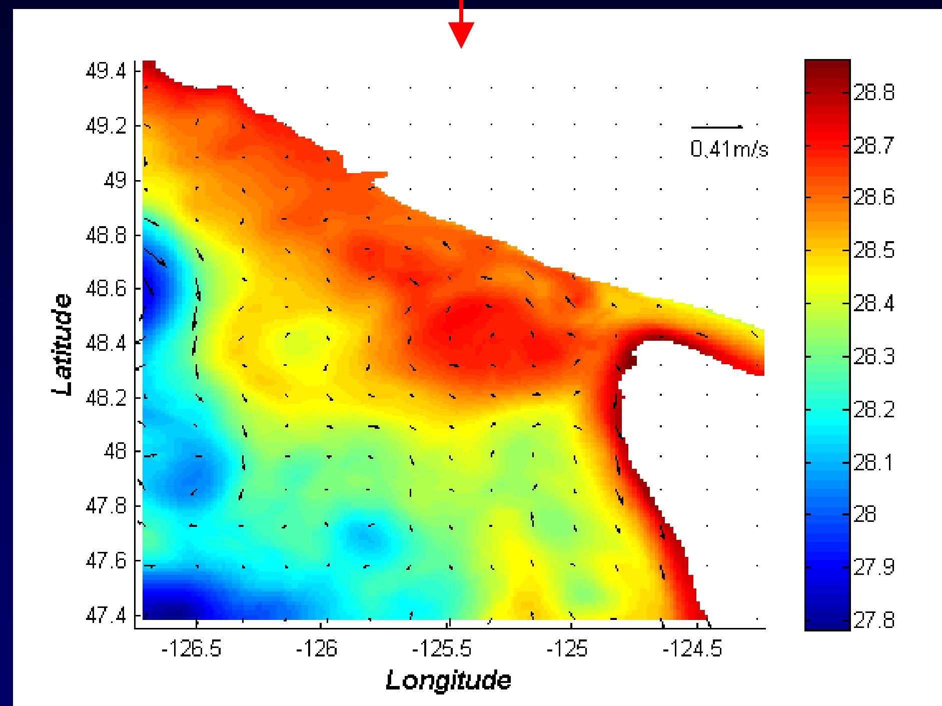


Baseline vs Winds but no Tides vs Winds & Tides but no Estuarine Flow

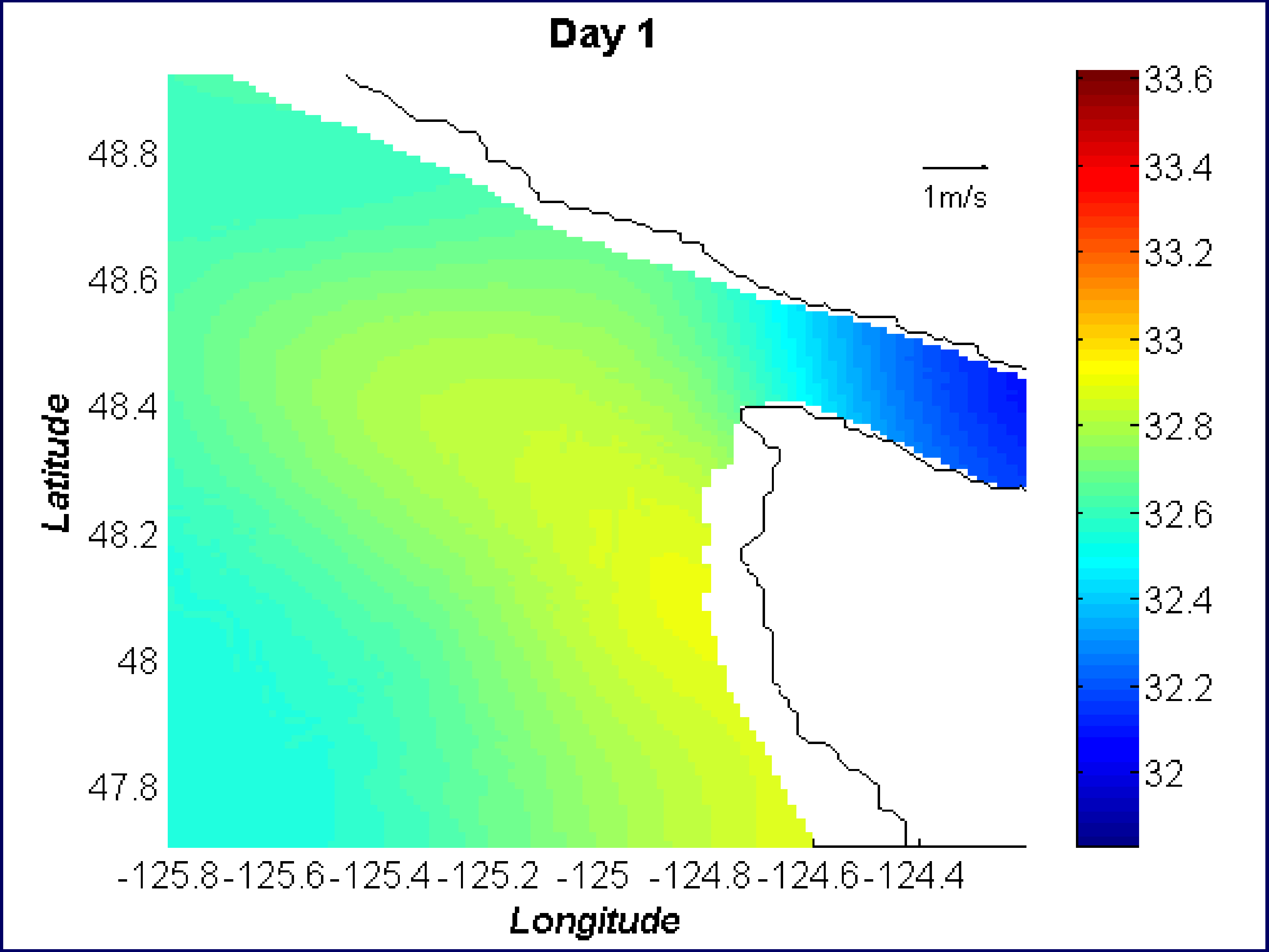


Average (days 46-60) flows & salinity at 35 m depth



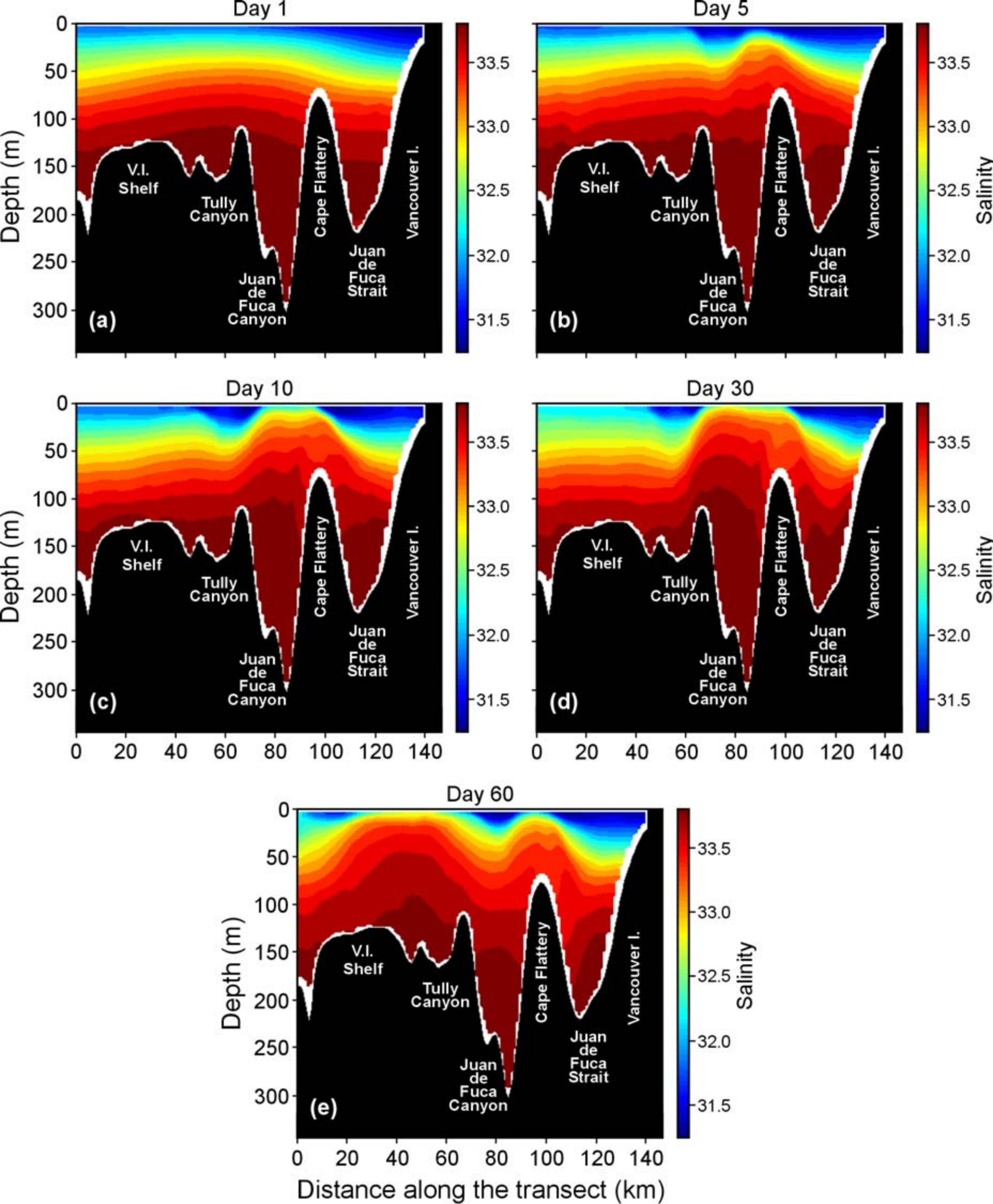


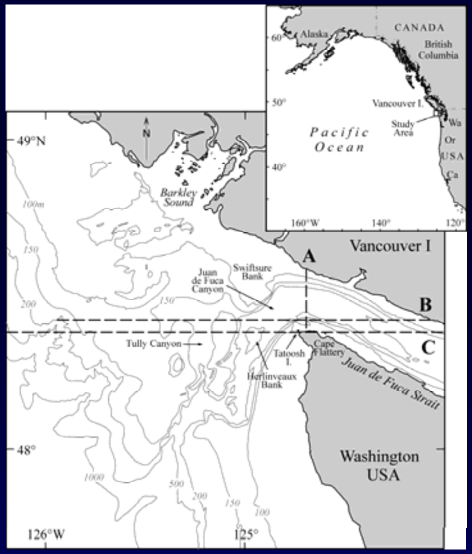
Eddy Development: Winds but no Tides



Daily 35m salinity and velocity

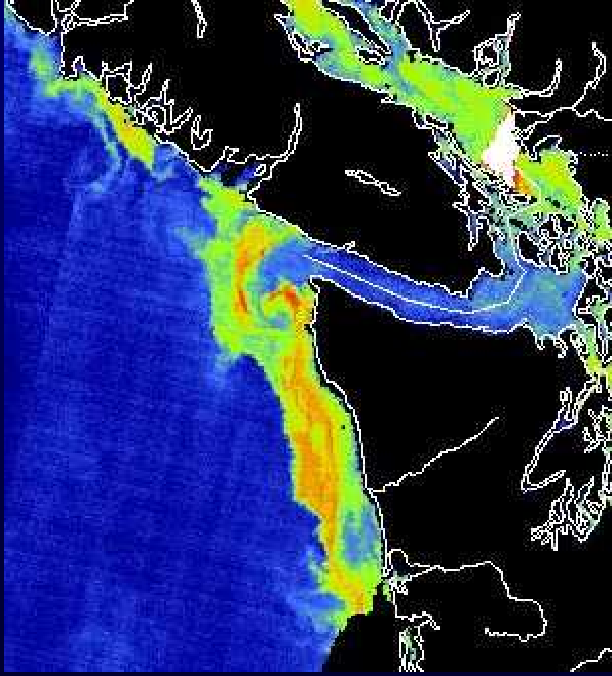
Eddy Development: Winds but no Tides



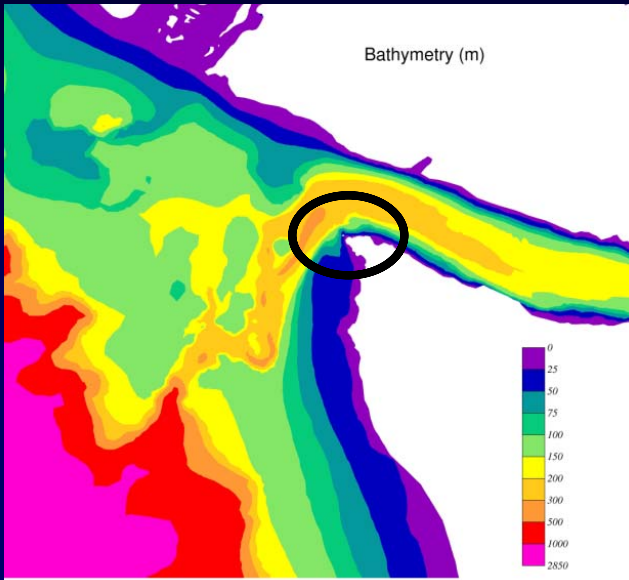


Summary of Present-day Eddy

- 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

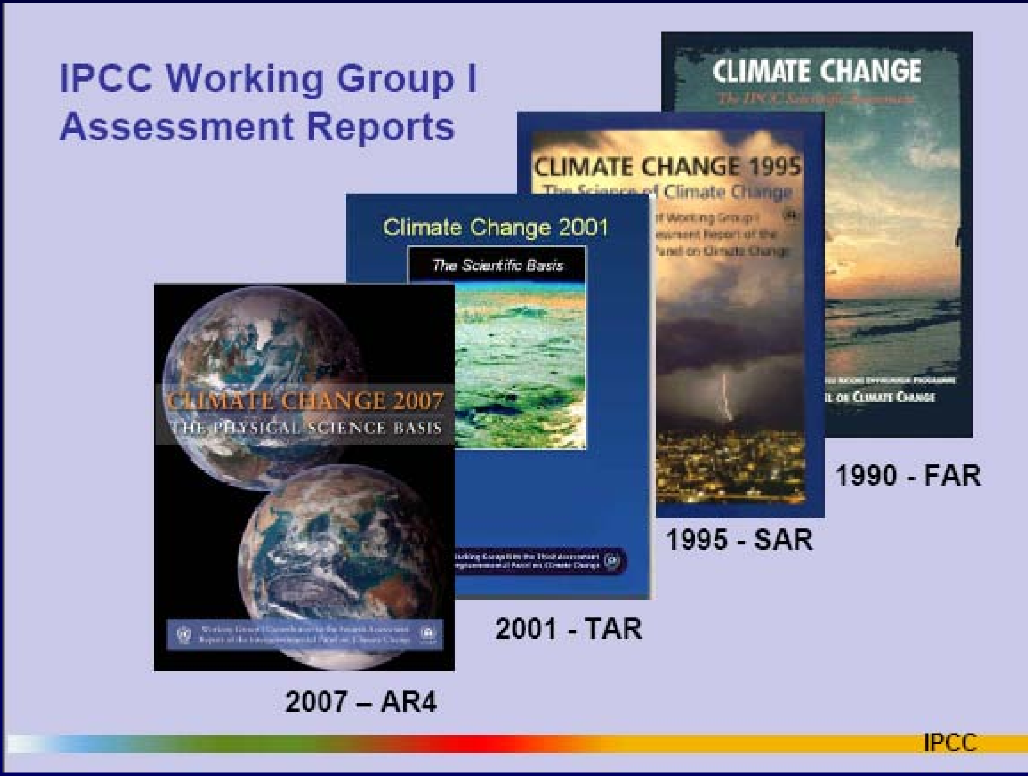


MERIS chlorophyll image: June 3, 2003
Courtesy of Jim Gower & Steph King



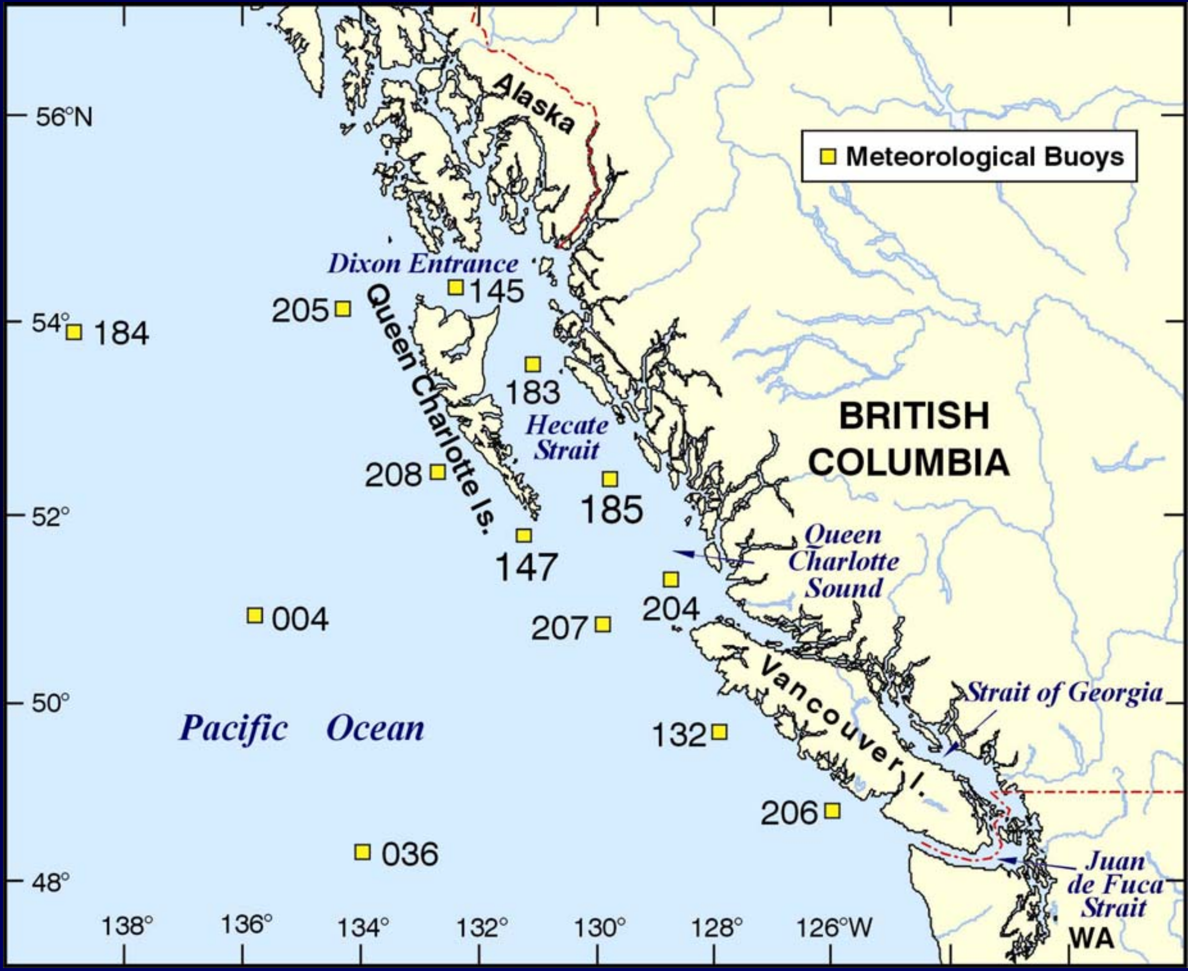
What is the Future of the Juan de Fuca Eddy under Climate Change?

- *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

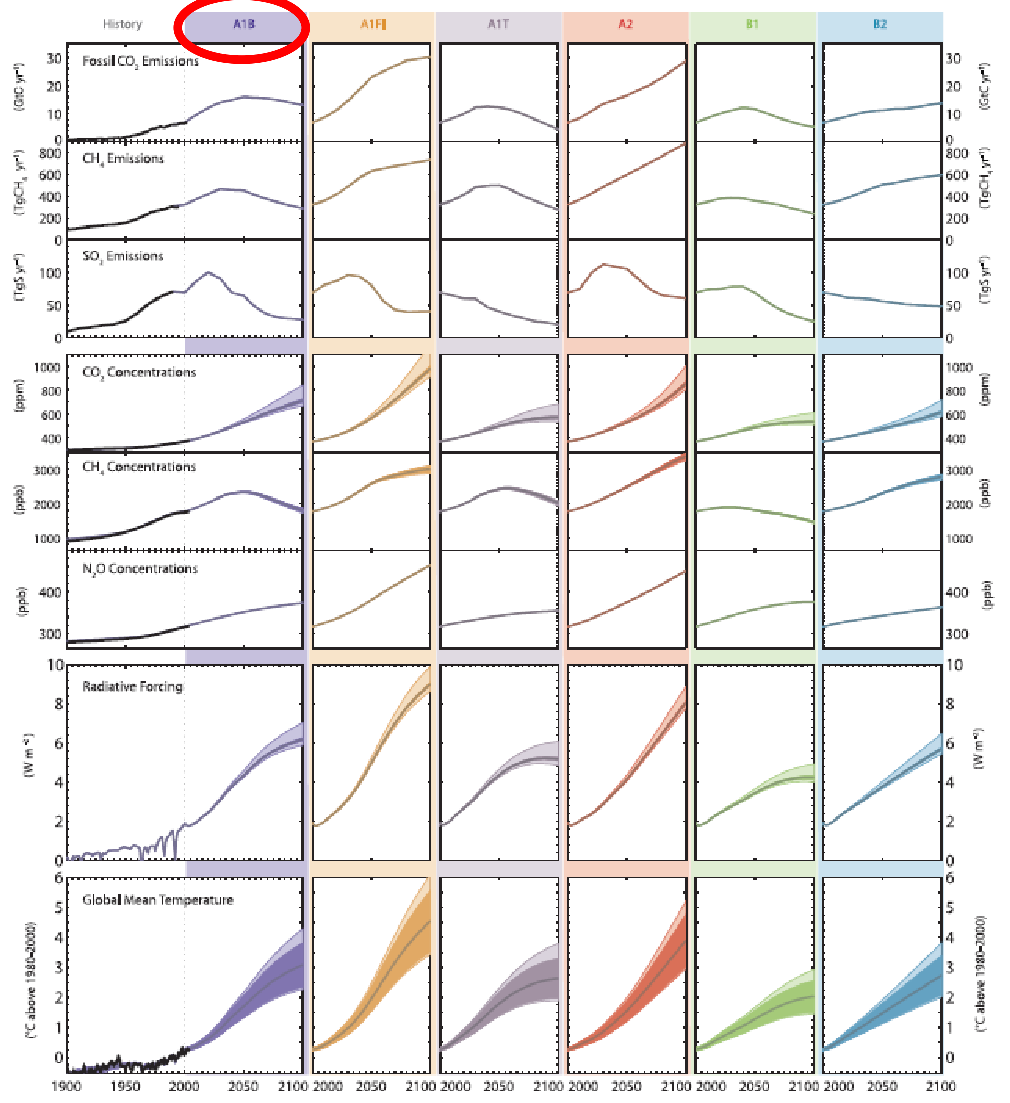
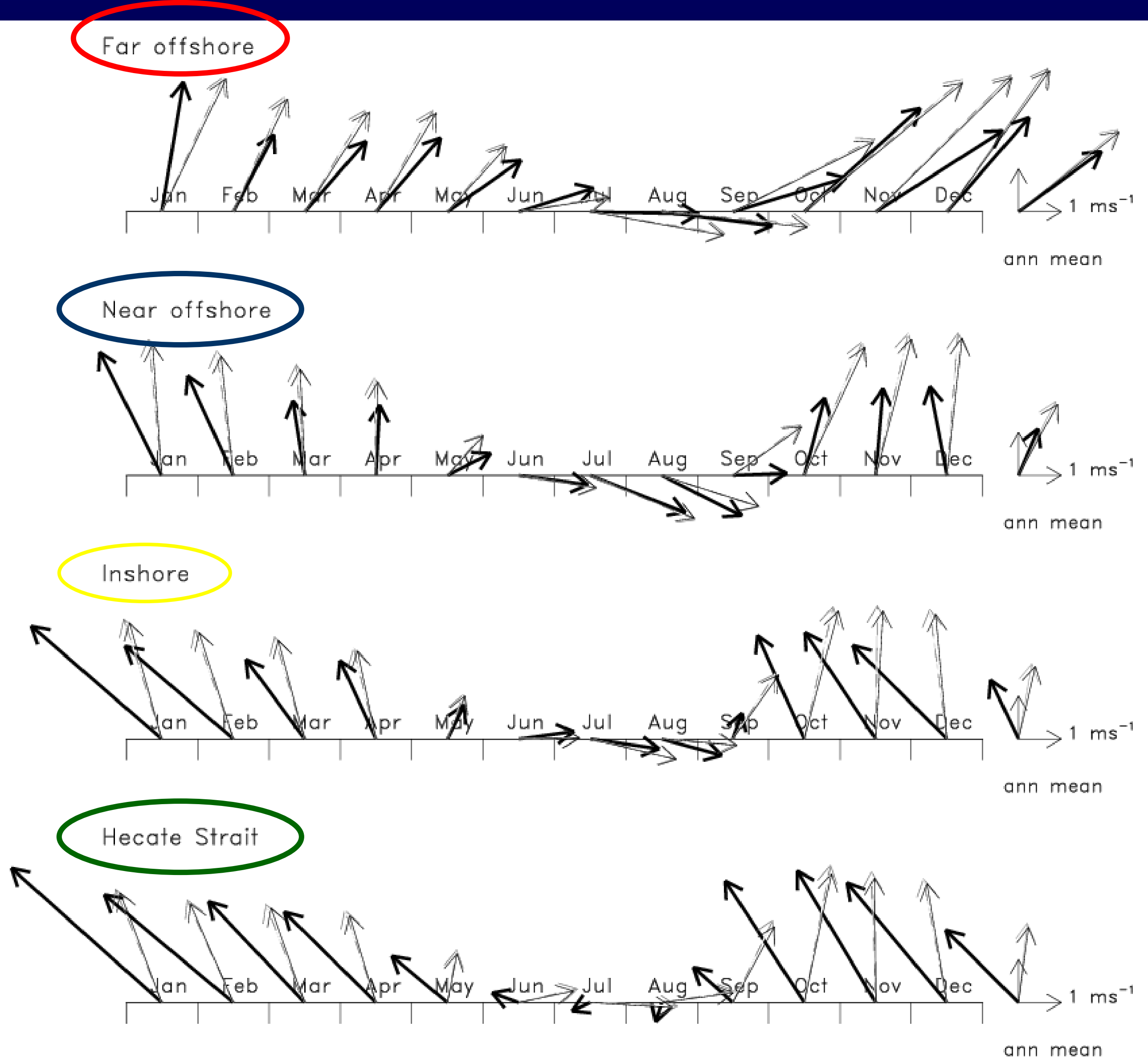
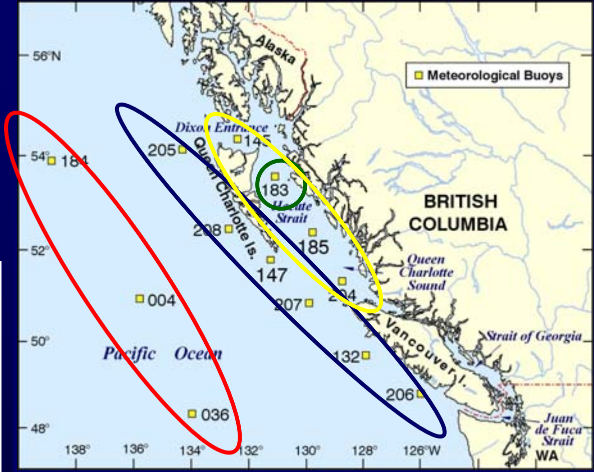


Figure 10.26. *Fossil CO_2, CH_4 and SO_2 emissions for six illustrative SRES non-mitigation emission scenarios, their corresponding CO_2, CH_4 and N_2O concentrations, radiative forcing and global mean temperature projections based on an SCM tuned to 19 AOGCMs. The dark shaded areas in the bottom temperature panel represent the mean ±1 standard deviation for the 19 model tunings. The lighter shaded areas depict the change in this uncertainty range, if carbon cycle feedbacks are assumed to be lower or higher than in the medium setting. Mean projections for mid-range carbon cycle assumptions for the six illustrative SRES scenarios are shown as thick coloured lines. Historical emissions (black lines) are shown for fossil and industrial CO_2 (Marland et al., 2005), for SO_2 (van Aardenne et al., 2001) and for CH_4 (van Aardenne et al., 2001, adjusted to Olivier and Berdowski, 2001). Observed CO_2, CH_4 and N_2O concentrations (black lines) are as presented in Chapter 6. Global mean temperature results from the SCM for anthropogenic and natural forcing compare favourably with 20th-century observations (black line) as shown in the lower left panel (Folland et al., 2001; Jones et al., 2001; Jones and Moberg, 2003).*

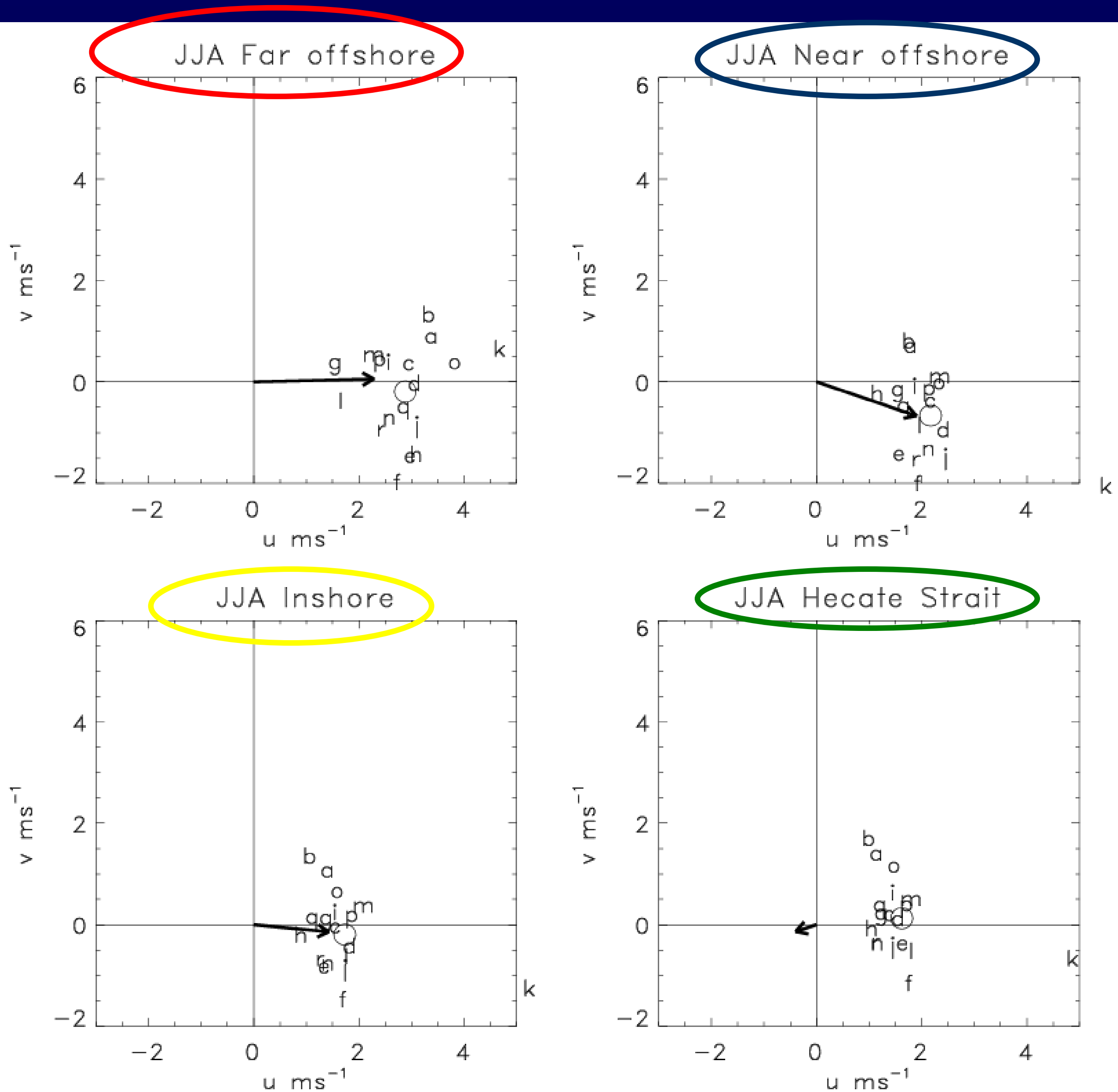
1976-95 Evaluation of Ensemble Monthly Averages





- *Seasonal direction changes captured reasonably well*
- *Near offshore summer upwelling winds captured reasonably well*

1976-95 Summer Evaluation of Individual Models



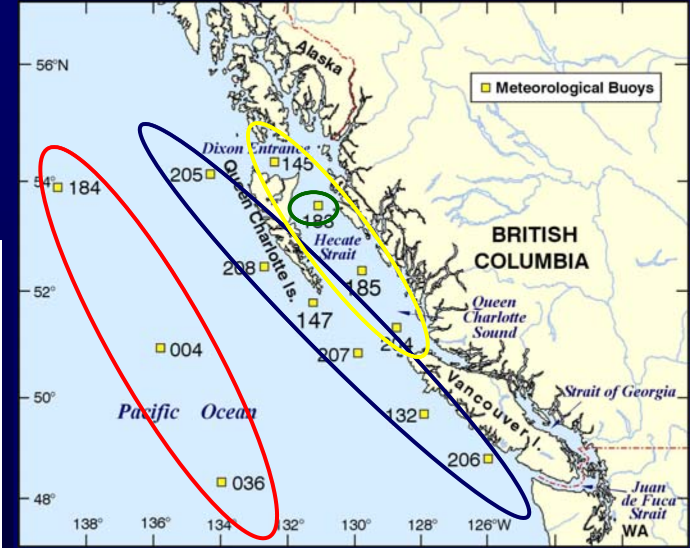
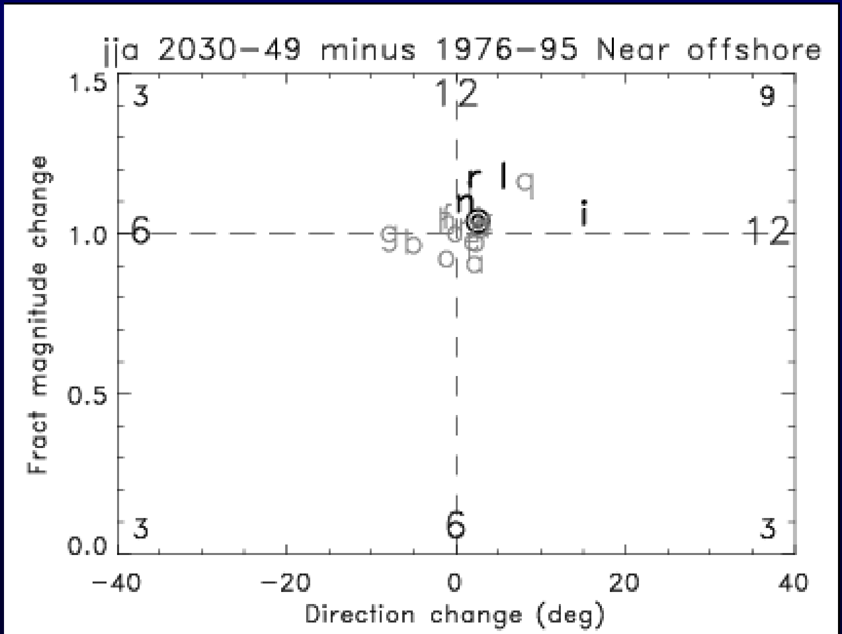


Table 1: Climate models used in this study and their atmospheric resolutions

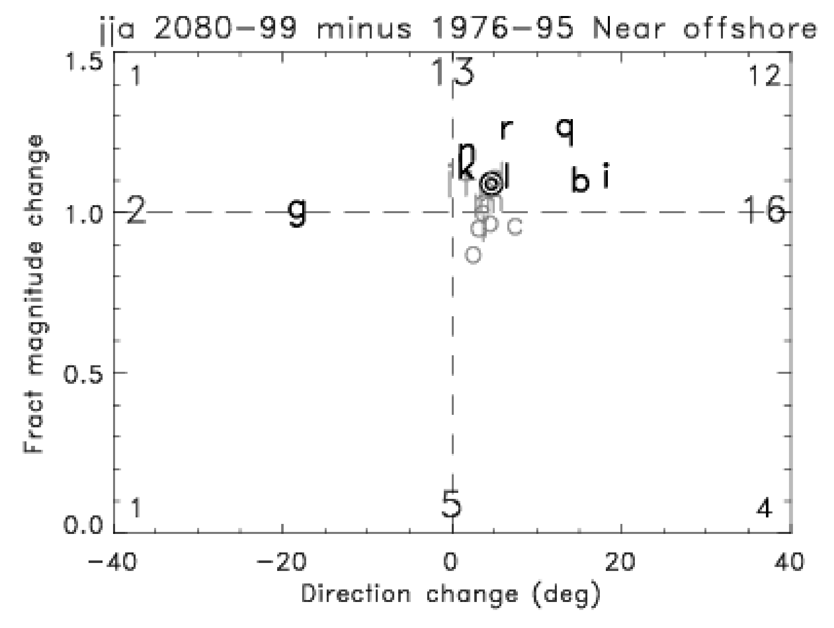
Symbol	Institution/Model	Atmospheric resolution	Horiz grid dimensions lon × lat
a	BCCR/BCM2.0	T63L31	128 x 64
b	CCCMA/CGCM3.1(T47)	T47L31	96 x 48
c	CCCMA/CGCM3.1(T63)	T63L31	128 x 64
d	CCSR/MIROC3.2(med)	T42L20	128 x 64
e	CNRM/CM3	T63L45	128 x 64
f	CSIRO/Mk3.5	T63L18	192 x 96
g	GFDL/CM2.0	2.5° × 2°L2	144 x 90
h	GFDL/CM2.1	2.5° × 2°L24	144 x 90
i	GISS/AOM	4° × 3°L12	90 x 60
j	GISS/EH	5° × 4°L20	72 x 46
k	GISS/ER	5° × 4°L20	72 x 46
l	INM/CM3.0	5° × 4°L21	72 x 45
m	IPSL/CM4	2.5° × 3.75°L19	96 x 72
n	MIUB/ECHO-G	T30L19	96 x 48
o	MPI/ECHAM5	T63L31	192 x 96
p	MRI/CGCM2.3.2	T42L30	128 x 64
q	UKMO/HadCM3	3.75° × 2.5°L19	96 x 72
r	UKMO/HadGEM1	1.875° × 1.25°L38	192 x 144

Projected Changes at Near offshore Buoys

2030-49



2080-99

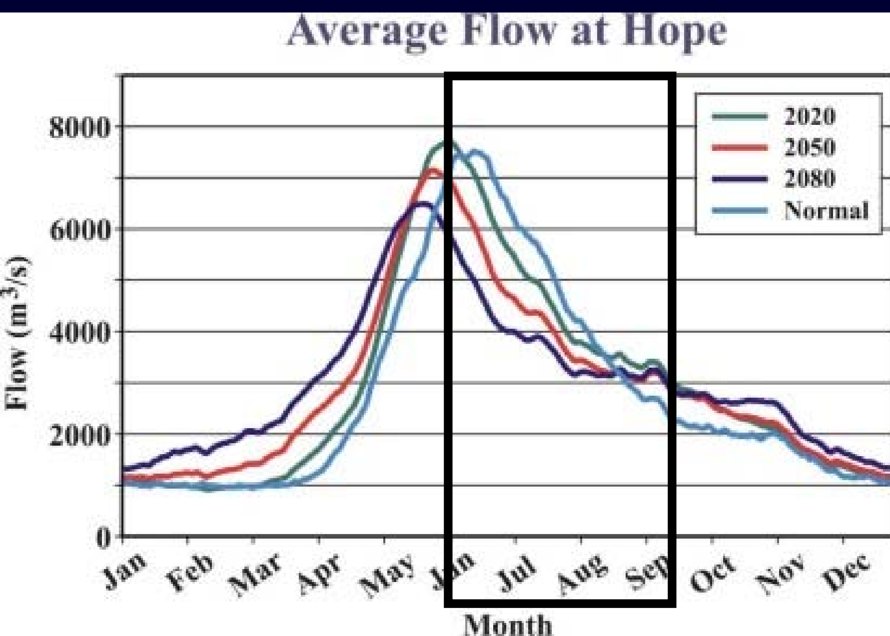


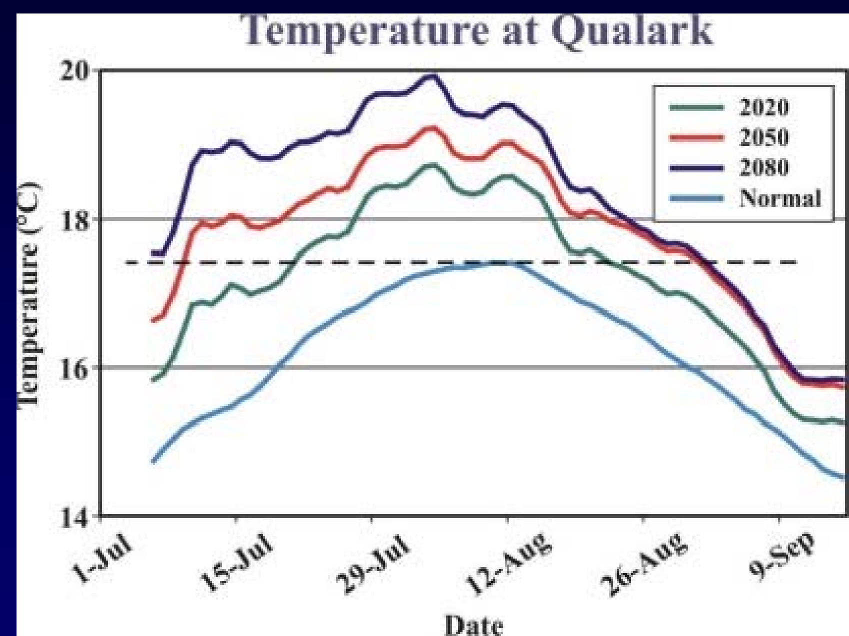
Conclusion:

- 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

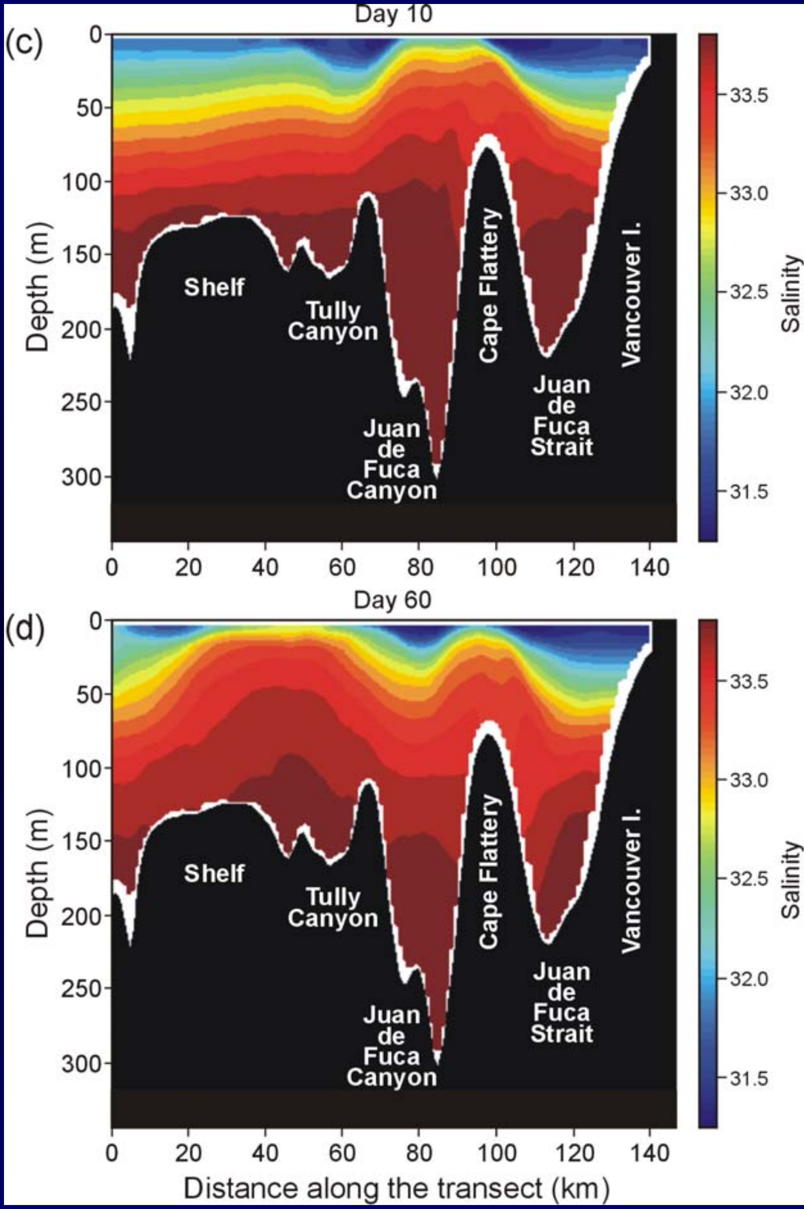




Summary:

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



No tides simulation

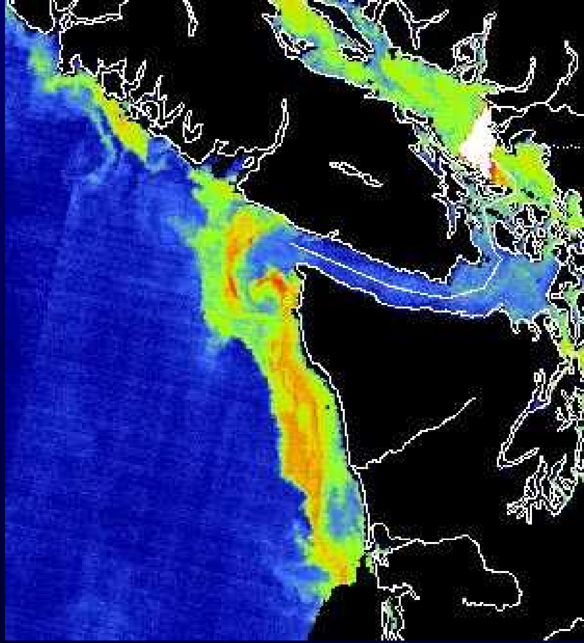
Summary

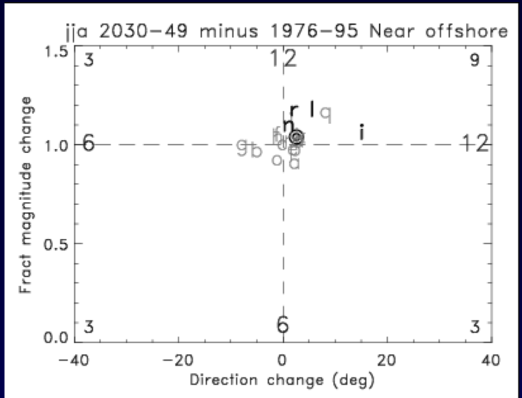
Future Upwelling

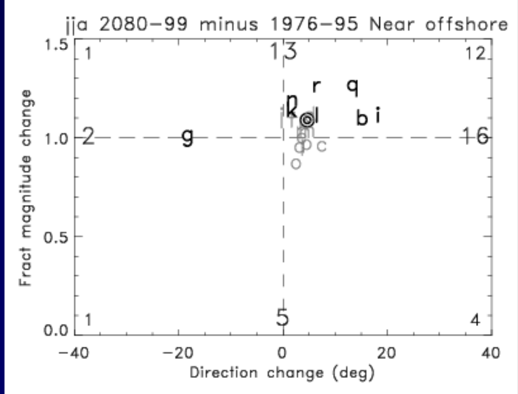
- *Tides won't change*
- *Summer upwelling winds slightly stronger*
- *Estuarine flow might be weaker ?*
- *Juan de Fuca Eddy should remain but may be weaker*

More details in

- *Foreman et al., 2008, JGR 113, doi:10.1092/2006JC004082*
- *Merryfield et al., 2008, submitted to JGR*








Thanks for your interest!