Adjoint sensitivities to local and remote forcing in the Central California region

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Introduction

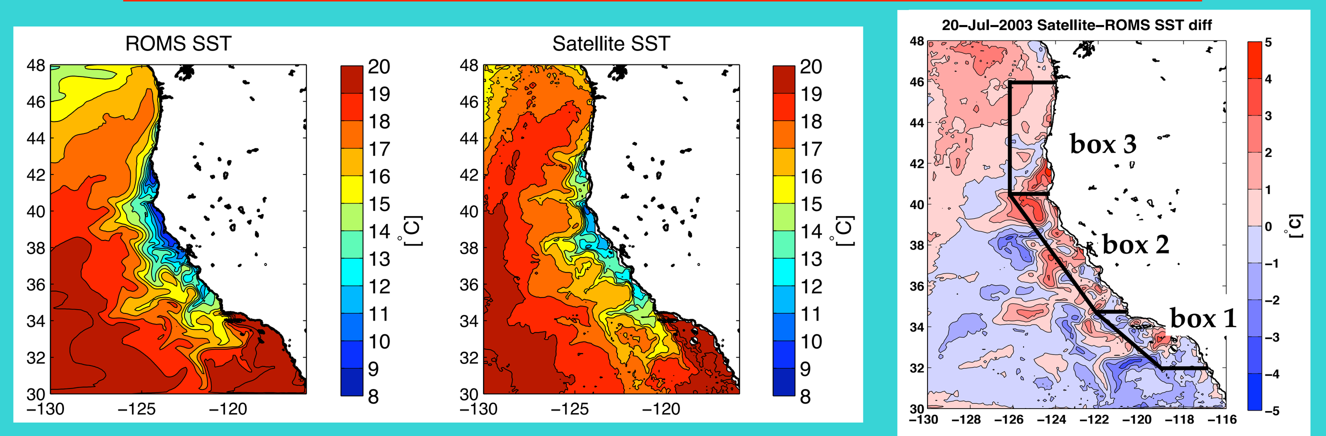
The Central California coastal circulation is characterized by complex dynamics driven both by internal instability processes and by external and boundary factors such as wind forcing, open boundary conditions, steep bathymetry and coastline shape. Understanding the relative contribution of these factors is relevant not only for theoretical reasons, but also for planning observational efforts and for data assimilation purposes.

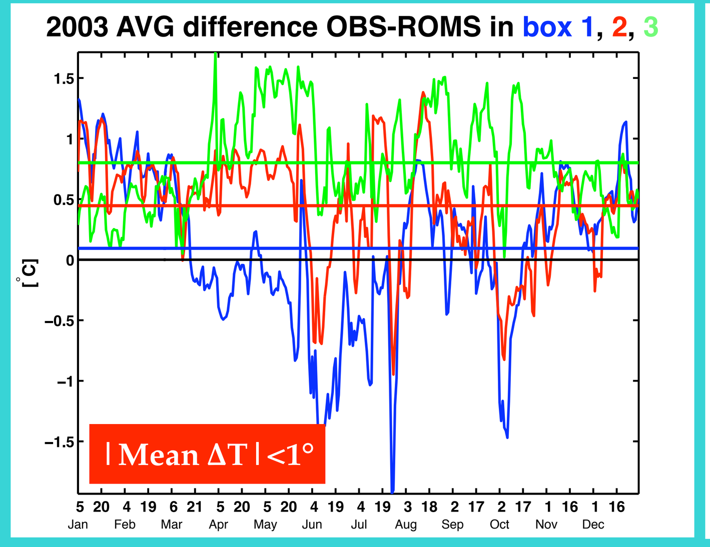
We use the Regional Ocean Modeling System (ROMS) to model the California Current System, and its associated adjoint model to study the sensitivity of the circulation to different driving mechanisms. The adjoint model approach is extremely suitable for sensitivity analyses because it allows one to determine how a certain metric - representative of a physical aspect of interest - evolves due to linear variations of the system variables, the external forcing, the initial state, and the open boundary conditions.

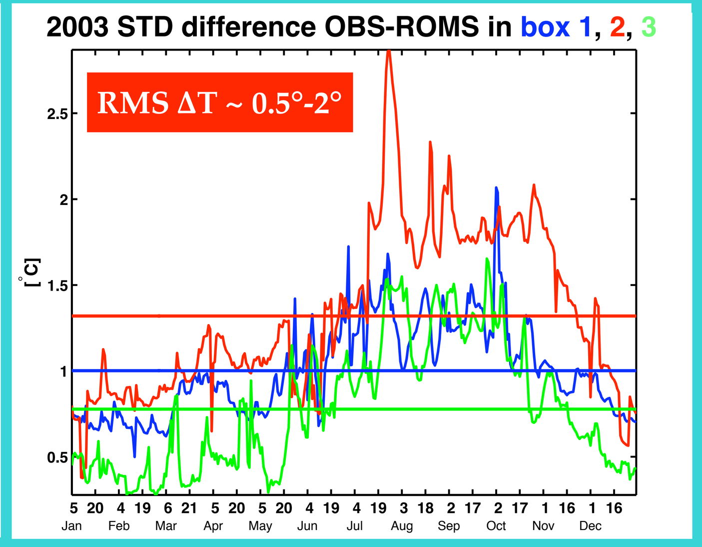
Model

The model domain covers the US west coast with a 1/10° horizontal resolution and 42 vertical layers. The circulation is driven by realistic surface fluxes provided by the high-resolution Coupled Ocean Atmosphere Mesoscale Prediction Model (COAMPS), covering a 6-year time period from 1999 to 2004. Monthly data from the global ECCO-GODAE (MIT) ocean model has been adopted at the three open boundaries of our domain.

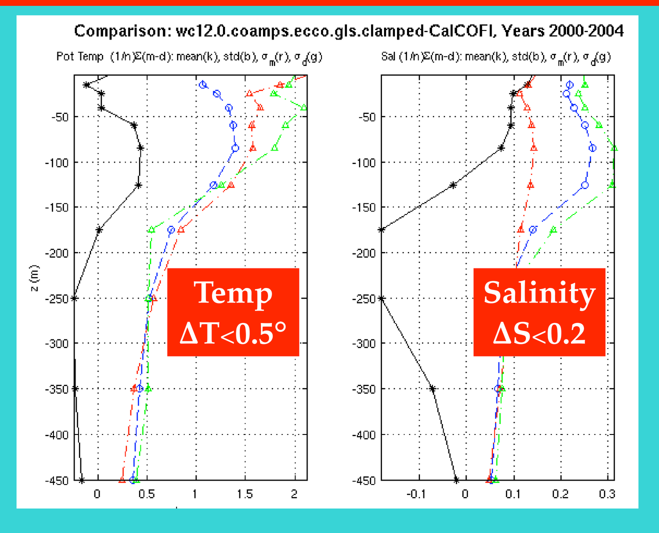
Comparison with SST blended satellite product



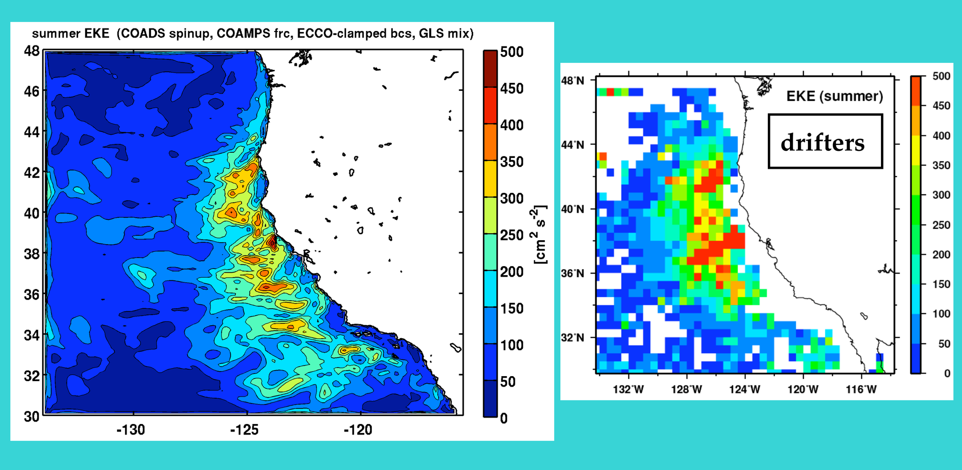




Comparison with CALCOFI profile



Comparison with EKE (summer) from in-situ surface drifters



Adjoint sensitivity studies

If Φ is a vector containing all the system state variables (momentum, free surface, temperature, salinity, etc.), its non-linear evolution can be described through the Navier-Stokes equations:

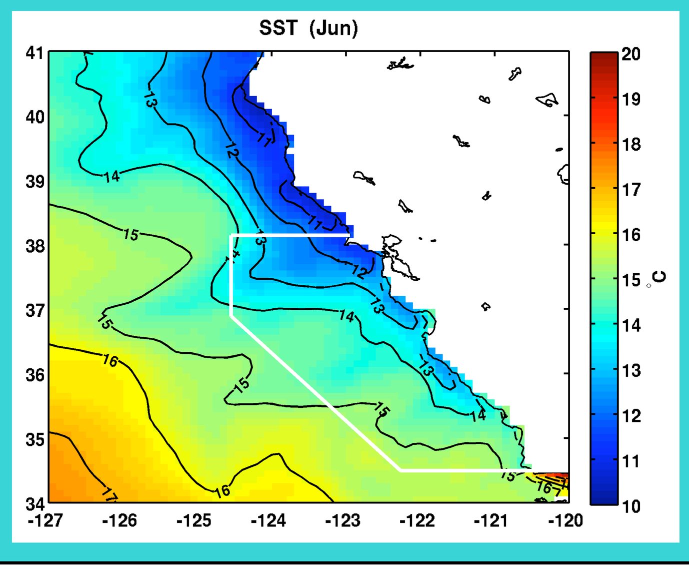
$$\partial\Phi/\partial t = N(\Phi) + F \qquad (1)$$

where N is the non-linear operator and F is the external forcing.

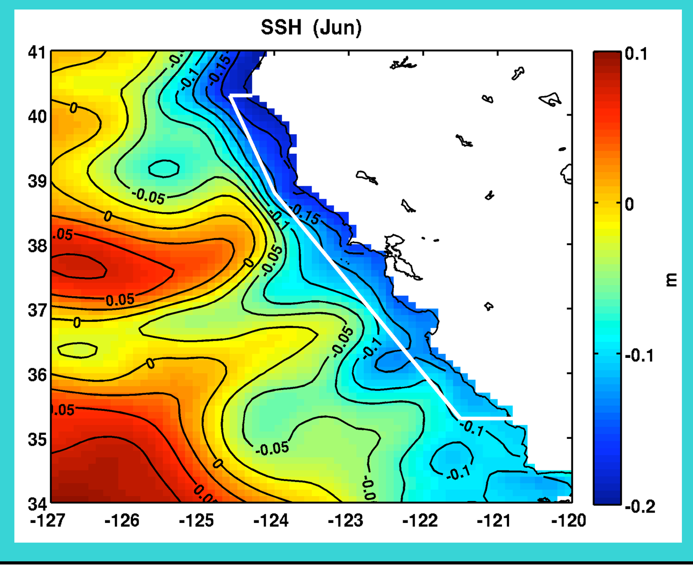
In the adjoint sensitivity studies, we define a metric J as a function of the state vector, G(Φ), characterizing some aspect of the circulation we want to focus on. By assuming that J evolves linearly over a certain period of time due to "small" perturbations in the state initial condition, $\delta\Phi_0$, boundary conditions, $\delta\Phi_\Omega$, and external forcing, δF, the sensitivities of J to such perturbations are given by the results of the adjoint model associated with (1).

Here, we show the adjoint sensitivity studies for two coastal metrics: an upwelling index, given by the squared SST spatially averaged over an area centered around Monterey Bay, and a measure of mean sea level averaged over a more elongated coastal area (white contours in figures below). The two J's are time averaged over the duration of each adjoint run.

$$J_{SST} = \frac{1}{T}\frac{1}{A}\int_t\int_A SST^2\, dA\, dt$$

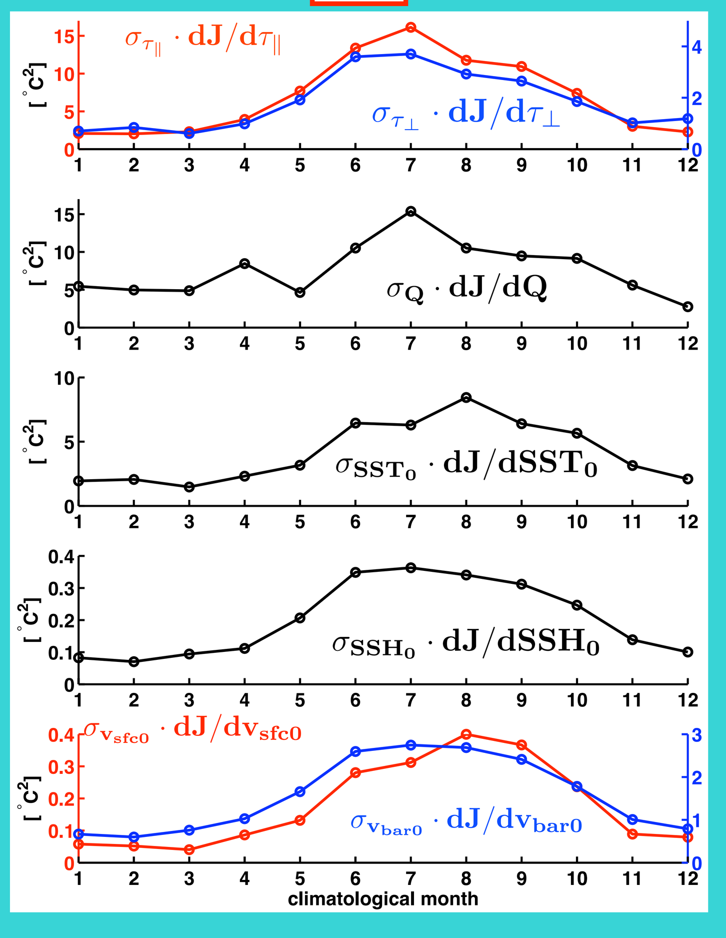


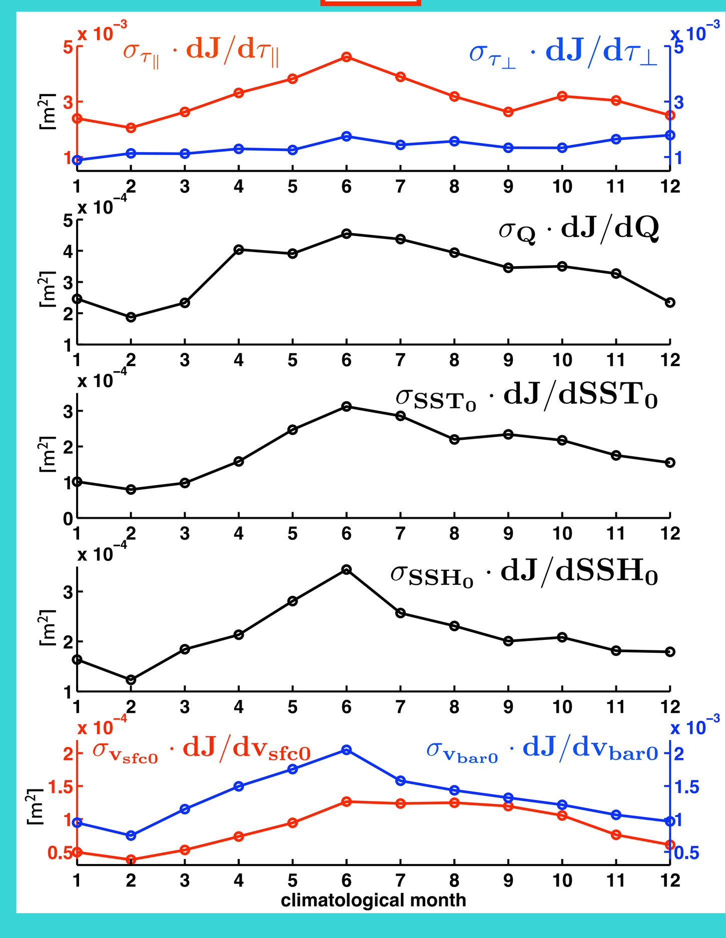
$$J_{SSH} = \frac{1}{T}\frac{1}{A}\int_t\int_A SSH^2\, dA\, dt$$



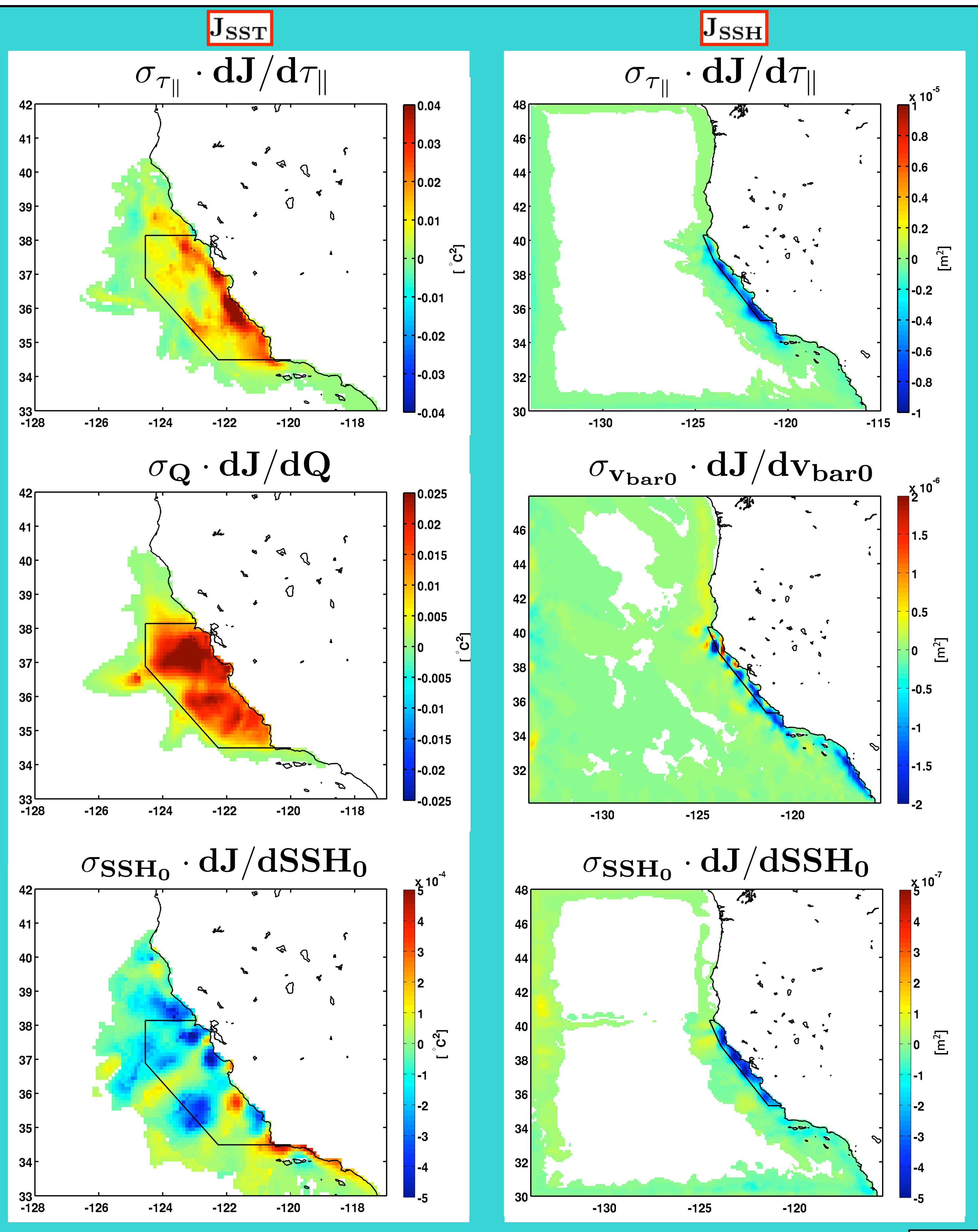
We have conducted 14-day subsequent adjoint simulations over the time period 2000-2004, and looked at the results in terms of sensitivity to the state variable initial condition, $dJ/d\Phi_0$, and to the 14-day averaged external forcing, $dJ/d\underline{F}$. Furthermore, the adjoint results have been weighted by the typical variability, σ, of the particular Φ_0 or $\underline{F}$ field with respect to which we are considering the sensitivity.

Below is the climatological seasonal cycle of a number of sensitivity results **(note the ranking)** for the two J's, obtained by integrating the fields in the spatial domain and interannual averaging over the 2000-2004 period.

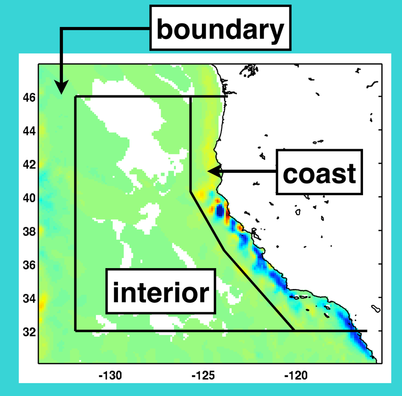




Spatial distribution of adjoint sensitivities (JUL)



Sensitivity to local and remote driving mechanisms



J_{SST}

var	$\sum \sigma_{var}\frac{dJ}{dvar}$	% from BDRY	% from INTERIOR	% from COAST
Q	7.65 °C²	0.1	11.8	88.1
$\tau_\parallel$	6.91	2.6	18.2	79.2
SST_0	4.12	0.2	22.7	77.1
v_{bar0}	1.56	7.3	29.7	63.0
SSH_0	0.20	13.1	24.7	62.2
v_{sfc0}	0.18	4.1	39.2	56.7
(E-P)	0.02	4.2	15.1	80.7

J_{SSH}

var	$\sum \sigma_{var}\frac{dJ}{dvar}$	% from BDRY	% from INTERIOR	% from COAST
$\tau_\parallel$	31×10^{-4} m²	38.8	1.9	59.3
v_{bar0}	13×10^{-4}	32.8	12.0	55.2
Q	3.3×10^{-4}	69.2	0.2	30.6
SSH_0	2.1×10^{-4}	39.4	8.8	51.8
SST_0	1.9×10^{-4}	88.0	0.9	11.1
v_{sfc0}	0.9×10^{-4}	75.9	3.3	20.8
(E-P)	0.5×10^{-4}	52.2	0.3	47.5

Conclusions

- The adjoint model allows us to obtain spatial and temporal distributions of sensitivities to average surface forcing and to state variable initial conditions.
- Both metrics are most sensitive to wind stress forcing, with surface heat flux and the initial distribution of SST, SSH, and velocity also playing an important role. The sensitivities to temperature and salinity increase when considering the contribution from subsurface layers.
- J_{SST} represents a mostly locally forced process, whereas contribution from the boundary area becomes sizable (30-80%) for the J_{SSH} metric.

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