Examining the Wind Forced Velocity Structure of the California Current System Using Observations Derived from Satellite Remote Sensing

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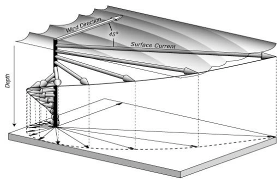
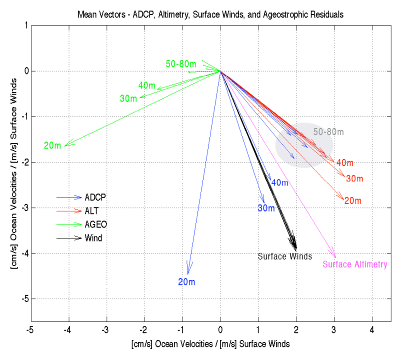
Background - Wind-driven Ocean Currents

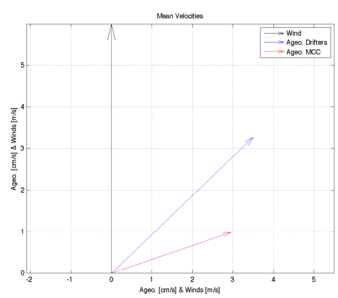
•Modern theory for wind-driven ocean circulation originated from Nasen's qualitative argument explaining why icebergs in the Artic drift to the right of the wind
•This led to Ekman's [1905] paper describing the effect of wind and the Earth's rotation on the upper ocean
•Ekman acknowledged that wind-stress induces vertical mixing in the upper ocean through turbulent processes
•The model for the momentum balance of a steady wind driven current leads to the solutions (deemed the Ekman spiral)



Overview - Methodology

•Methodology is derived to observe mesoscale time-dependent wind-driven ocean velocities
–Procedure involves removal of a geostrophic signal from "total flow" observations
•Potential total flow data sets are investigated by statistical analysis
–Theoretical characteristic signals of wind-driven flow are found in drifting buoy data, acoustic Doppler current profiler data (ADCP) data, and velocity data extracted from satellite imagery using the maximum cross-correlation technique (MCC)
•Methodology is then developed to combine CTD (conductivity, depth, temperature) data with altimetry data to provide estimates of geostrophic current at depth
•For MCC derived observations to be used in this analysis the depth of this product required consideration
–Statistical comparison with coincident ADPC and drifter velocity observations suggest MCC derived velocities are characteristics of ocean currents at ~30 m depth
–Assumptions
–That near surface velocity fields can be decomposed into their geostrophic and ageostrophic components
–Resulting ageostrophic residual velocities are wind-driven
–MCC derived velocities are representative current at 30 m



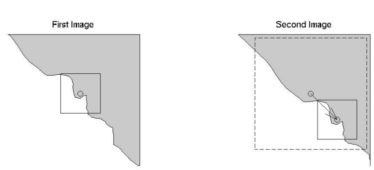


Velocity Data

•12-year time series 1994-2006
•Total Flow Observations
–Global Drifter Program - Drifting Buoys (provided by NOAA/AOML)
–ADCP data (distributed by JASADCP)
–MCC method applied to AVHRR BT images
•Geostrophic Observations
–Altimetry (AVISO MADT) combined w/ CTD data
•Winds
–Scatterometry (ERS 1 & 2, Quikscat - distributed by cerssat/ifremer)
•Seven day mean velocity fields
–Altimetry and wind data used are distributed in weekly fields
–Rio and Hernandez [2003] found that wind-driven current observations most coherent with wind stress at periods of ~10 days
–Drifter, MCC, and ADCP velocity observations are composited to 7-day mean fields that coincide with altimetry and wind products

The Maximum Cross-Correlation (MCC) Method

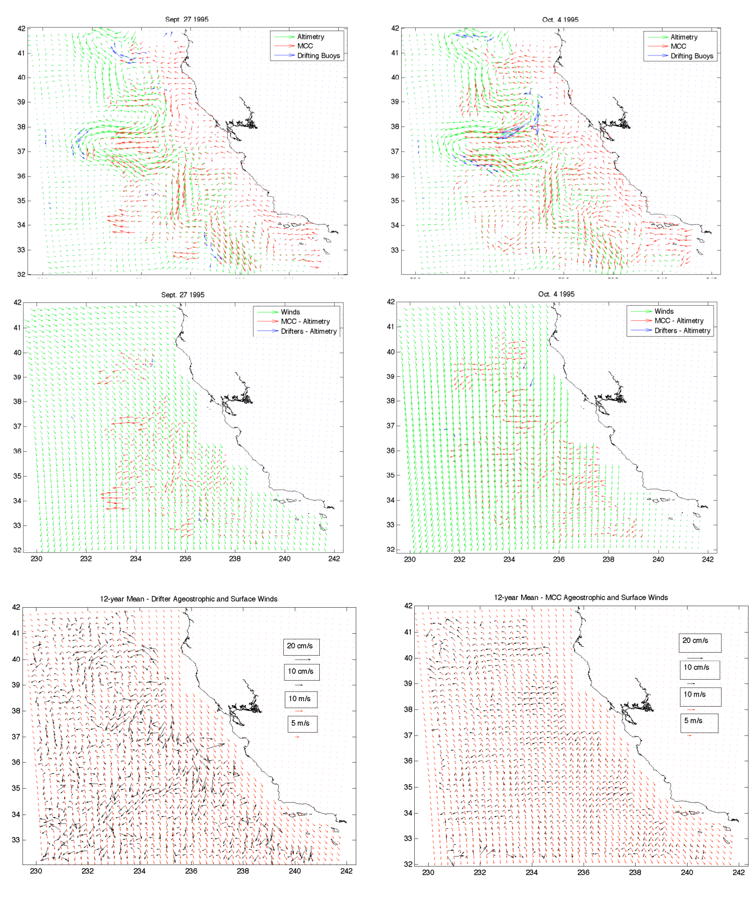
•Automated procedure that calculates the displacement of small regions of patterns from one image to another
•Method has seen variety of tracking applications
–Cloud motion [Leese et al., 1971]
–Ice flow [Ninnis et al., 1986]
–Ocean currents [Emery et al., 1986]
•Method cross-correlates template subwindow in initial image with subwindow of same size in the second image, searching for location, within specified range, that gives the maximum cross-correlation



Geostrophic Velocities Estimates at Depth

•Initial analysis suggested a need to account for vertical geostrophic shear before removing geostrophic signal from total flow products
•CTD data (provided by GTSPP) used to estimate geostrophic currents relative to surface current
•Made using any two CTD casts within 80 km and 7 days of each other
•Combining these geostrophic observations with directions from seasonal mean altimetric velocity fields, spatial mean estimates of geostrophic current at depth are created for each season
•This product is then applied to 7-day surface MADT velocity fields to produce time-dependent estimates of geostrophic current at specific depths

•If reduction and rotation of geostrophic current with depth are not accounted for, wind-driven estimates, from the ADCP and surface altimetry would be dominated by geostrophic shear present, and would fail to capture wind-driven signal
•Ageostrophic forcing should be negligible at deeper levels and similarity of depth dependent geostrophic estimates to deepest ADCP observations is a fair validation of methodology to produce these geostrophic estimates
•20 m current demonstrates the largest ageostrophic signal, rotated to right of wind, with a magnitude comparable to surface geostrophic flow
•Residual ageostrophic velocities from 30 to 80 m are all directed to right of wind, consistent with Ekman theory, signifying that these vectors are most likely wind-driven
•Spiral observed is similar to the Ekman spiral found by Chereskin [1995] that is quantitatively similar to theoretical Ekman spiral, though much flatter in shape
•Observations demonstrate magnitude and phase decay with depth
•If assumed MCC depth of 30 m is valid then methodology and observations are producing an Ekman-like response
•15 m drifters and assumed 30 m MCC ageostrophic currents show magnitude and phase decay with depth



Summery

•Methodology applied does produce observations of wind driven current
•Derived observations consistently displacement to right of wind
•Theoretical Ekman-spiral is evident in each of ageostrophic products - derived from ADCP, MCC, and drifters observations
•Mean wind-driven flow shows jet-like structure not associated with mean wind velocity patterns