SST and Mixed Layer Depth Variability in Upwelling Regions

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Objective: synthesis of global-ocean and sea-ice data that covers the full ocean depth and that permits eddies. 
Motivation: improved estimates and models of ocean carbon cycle, understand recent evolution of polar oceans, monitor time-evolving term balances within and between different components of Earth system, etc.

Forward model:
- MITgcm
- cubed-sphere configuration
- 18-km horizontal grid
- 50 vertical levels
- modified Leith viscosity
- KPP vertical mixing
- dynamic-thermodynamic sea ice

Velocity (m/s) At 15 m depth
Standard deviation of model-data difference for 2004-2005

- σ (model-data)
- σ explained by bias
- σ explained by diurnal
- σ explained bias + diurnal
Data error specification for cost function

σ (model-data)

AMSRE standard error on 1 Jan 04

AMSRE standard error on 1 Jul 04

AMSRE max standard error
Eddying, global-ocean, and sea ice solution obtained using the adjoint method to adjust $\sim 10^9$ control parameters

Cost functions reduction during first 22 forward-adjoint iterations

- Baseline solution derived from optimized Green’s function solution and OCCA (Forget 2010) climatology
- Optimization period is beginning of ARGO-rich period (January 2004 to April 2005)
- Huge computation: $\sim 1$ week per forward-adjoint iteration on 900 CPUs and 3.6 TB of RAM
- 41% overall cost function reduction after 22 forward-adjoint iterations
Reduction of root-mean-square model-data residual

\[
\text{rms(Optimized – AMSRE SST) – rms(Baseline – AMSRE SST)}
\]

\[
\text{rms(Optimized – ENVISAT SSH) – rms(Baseline – ENVISAT SSH)}
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<th>AMSR-E</th>
<th>Baseline</th>
<th>Optimized</th>
<th>AMSR-Base</th>
<th>AMSR-Optim</th>
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<tbody>
<tr>
<td>JAN to MAR</td>
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2004 Sea Surface Temperature

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[Image of temperature maps for different months and years]
Temperature profiles in Benguela Upwelling Zone
Benguela Upwelling Zone

**Ekman pumping**

\[ \omega_e = -\nabla \times \tau / \rho f \]

- \( \tau \): wind stress
- \( \rho \): water density
- \( f \): Coriolis parameter

**Coastal upwelling**

\[ \omega_c = -c\tau_y e^{-y/a} / \rho g' H \]

- \( c \): internal wave speed
- \( \tau_y \): longshore stress
- \( g' \): reduced gravity
- \( H \): mixed layer depth
- \( a \): Rossby radius
2004 wind stress curl

QuikSCAT          Baseline            Optimized          QSCAT-Base      QSCAT-Optim

JAN to MAR

APR to JUN

SEP to NOV

-5 x 10^-7  5 x 10^-7  N/m^3

-3 x 10^-7  3 x 10^-7  N/m^3
2004 Meridional wind stress

QuikSCAT | Baseline | Optimized | QSCAT-Base | QSCAT-Optim

JAN to MAR

APR to JUN

SEP to NOV

-0.08 | 0 | 0.08

N/m**2

-0.05 | 0 | 0.05

N/m**2
Benguela Region Upwelling

Ekman pumping

\[\dot{w}_e = -\nabla \times \tau / \rho f\]

(within 200 km of coastline)

Coastal upwelling

\[\dot{w}_c = -c \tau_y e^{-y/a} / \rho g' H\]

\((a = 26 \text{ km})\)
Summary and concluding remarks

- GHRSSST AMSR-E data were used to evaluate and constrain ECCO2 eddying ocean state estimates using the adjoint method.

- Significant negative biases (AMSR-E colder than ECCO2) are observed in areas of known upwelling.

- Estimated wind stress curl and longshore winds in Benguela Upwelling Zone are within 20% of QuikSCAT retrievals.

- Wind stress curl contributes ~1/3 of total upwelling.

- Cold temperature bias in baseline and optimized ECCO2 solutions results in part from weak (~1/2 theoretical value) upwelling.

- Aim to improve representation of coastal upwelling in global GCMs.