My air-sea coupling study at Scripps under the influence of Art

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Multi-modal Oscillation in Ocean Basin
Scripps Institution of Oceanography
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Came to Scripps in 2002 to study air-sea coupling… & met my advisors

John, the RSM guy

Art, the ROMS guy
Dove right into modeling!!

Predictors and prediction!

- **SCOAR**
- **ECPC RSM**
  - **Flux**
  - **SST**
- **ROMS**

Santa Ana wind event, Feb. 2002

- **Fire weather index (FWI), San Diego**
- **SST in SCB**

Wind stress Feb 9, 1pm LT

Santa Ana wind

Climatology

Santa Ana

Climatological time series, in collaboration with international partners
The model sort of worked... But now what??
And then we saw these papers....

Xie et al. 1998

Chelton et al. 2001
Ugh… wind varies over the scale of eddy…?

Can the SCOAR simulate it?

Is this atmospheric response important?
The SCOAR reproduced the observed coupling!

![Image of SST and wind stress fields with plots comparing SCOAR and Satellite data.]

- **SST**: SST fields with seasonal variations shown.
- **Wind stress divergence**: Fields indicating areas of stress divergence.
- **Wind stress curl**: Fields showing areas of stress curl.

**Plot Analysis**:

- **Satellite**:
  - \( \nabla \cdot \tau \text{ vs } \nabla_0 T \)
  - \( \nabla \times \tau \text{ vs } \nabla_0 T \)
  - \( S = 1.35 \)
  - \( S = 0.75 \)

- **SCOAR**:
  - \( \nabla \cdot \tau \text{ vs } \nabla_0 T \)
  - \( \nabla \times \tau \text{ vs } \nabla_0 T \)
  - \( S = 1.47 \)
  - \( S = 0.89 \)
The Scripps Coupled Ocean–Atmosphere Regional (SCOAR) Model, with Applications in the Eastern Pacific Sector

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ABSTRACT

A coupled ocean–atmosphere model is introduced. It is designed to admit the air–sea feedbacks arising in the presence of an oceanic mesoscale eddy field. It consists of the Regional Ocean Modeling System (ROMS) and the Regional Spectral Model (RSM). Large-scale forcing is provided by NCEP/DOE reanalysis fields, which have physics consistent with the RSM. Coupling allows the sea surface temperature (SST) to influence the stability of the atmospheric boundary layer and, hence, the surface wind stress and heat flux fields. The system is denominated the Scripps Coupled Ocean–Atmosphere Regional (SCOAR) Model.

The model is tested in three scenarios in the eastern Pacific Ocean sector: tropical instability waves of the eastern tropical Pacific, mesoscale eddies and fronts of the California Current System, and gap winds of the Central American coast. Recent observational evidence suggests air–sea interactions involving the oceanic mesoscale in these three regions. Evolving SST fronts are shown to drive an unambiguous response of the atmospheric boundary layer in the coupled model. This results in significant model anomalies of wind stress curl, wind stress divergence, surface heat flux, and precipitation that resemble the observations and substantiate the importance of ocean–atmosphere feedbacks involving the oceanic mesoscale.
Then met Markus and Ragu…

… Got me into the Atlantic… and also the habit of heavy drinking…

Energetics of the TIWs
Jochum et al. 2004

Legeckis and Reverdin (1987) and Steger and Carton (1991). The analysis of ship drift and drifter data confirms the satellite based observations (Richardson and Reverdin, 1987); moreover the analysis by Richardson and Philander (1987) demonstrates that the TIWs are strongest away from the eastern or western boundary, in the center of the basin.

The subsurface structure and the frequency domain of TIWs have been studied with current meter moorings by Weisberg (1984) and Weisberg and Weingartner (1988, WW from here on). The mooring records show that their potential energy is negligible and that their kinetic energy has a central periodicity of approximately 25 days. The energy reaches a maximum of 1600 cm$^2$/s$^2$ at the surface and the center of the basin along the equator and decays rapidly below 50 m depth or east of 15$^\circ$W. Still, signals of TIWs were found as deep as 800 m (Boebel et al., 1999) and as far east as 4$^\circ$W (Weisberg et al., 1979).

Early analytical studies by Philander (1976, 1978) demonstrate that the equatorial zonal currents are barotropically unstable and preferentially generate waves with wavelengths and periods of the observed TIWs. A series of highly idealized numerical studies corroborated these findings but showed that baroclinic (Cox, 1980), frontal (Yu et al., 1995) and Kelvin–Helmholtz instabilities (Proehl, 1996) can contribute as well. Cox (1980) pointed out that what is simply referred to as TIWs is a superposition of unstable waves and their projection on the set of free equatorial waves. The latest and most thorough study on TIWs and their energetics is provided by Masina and Philander (1999) and Masina et al. (1999). With an idealized numerical model of the Pacific Ocean they show that localized studies of the energy budget might be misleading, the whole equatorial domain has to be analyzed before a definite conclusion about the energy sources and sinks of the TIWs can be reached. This study emphasizes that TIWs cannot be analyzed in general or in isolation, but that the generation, structure and decay of TIWs depends on the particular generation region.

A detailed understanding of the TIWs is necessary because of their potential importance for climate. WW estimate that the equatorward heat flux of the TIWs in the upper 50 m is ap-

Fig. 1. TIWs as seen by SeaWiFS (courtesy of M. Uz). Note the cusps in ocean color along 4$^\circ$S and 4$^\circ$N.

But it lacked atmospheric coupling..
Eddy wind work?
A surprisingly important EKE sink term that no climate models can represent…

\[
\mathbf{U} \cdot \nabla K_e + \mathbf{u}' \cdot \nabla K_e = -\nabla \cdot (\mathbf{u}' \mathbf{p}') - g \rho' \mathbf{w}' + \rho_o (\mathbf{u}' \cdot \nabla \mathbf{U}) + \rho_o \mathbf{A}_h \mathbf{u}' \cdot \nabla^2 \mathbf{u}' + \rho_o \mathbf{u}' \cdot (\mathbf{A}_v \mathbf{u}') + \mathbf{u}'_{sfc} \cdot \mathbf{\tau}'
\]

Masina et al. 1999

Feedback of Tropical Instability-Wave-Induced Atmospheric Variability onto the Ocean

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ABSTRACT

The effects of atmospheric feedbacks on tropical instability waves (TIWs) in the equatorial Atlantic Ocean are examined using a regional high-resolution coupled climate model. The analysis from a 6-yr hindcast from 1999 to 2004 reveals a negative correlation between TIW-induced wind perturbations and TIW-induced ocean currents, which implies damping of the TIWs. On the other hand, the feedback effect from the modification of Ekman pumping velocity by TIWs is small compared to the contribution to TIW growth by baroclinic instability. Overall, the atmosphere reduces the growth of TIWs by adjusting its wind response to the evolving TIWs. The analysis also shows that including ocean current (mean TIWs) in the wind stress parameterization reduces the surface stress estimate by 15%–20% over the region of the South Equatorial Current. Moreover, TIW-induced perturbation ocean currents can significantly alter surface stress estimations from scatterometers, especially at TIW frequencies. Finally, the rectification effect from the atmospheric response to TIWs on latent heat flux is small compared to the mean latent heat flux.
Concluding my air-sea research at Scripps…

commencement 2008

my mom & dad, Art & John
2007 summer
Many questions remain unanswered:
How different are the effects by eddy SST-wind coupling vs current-wind coupling?

$$\tau=\rho_a C_D (W-U)|W-U|$$

T_e-τ coupling

anticyclonic eddy

U_e-τ coupling

upwelling

downwelling

Dipolar \( W_e \):
Max. \( W_e \) over \( \nabla T \)

Chelton 2013

Monopole \( W_e \):
Max. \( W_e \) over Min. \( \nabla T \)
Isolating mesoscale coupled ocean–atmosphere interactions in the Kuroshio Extension region

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Original

Smooothered
First-time demonstration of distinctive EKE response to two types of mesoscale O-A coupling

One mechanism based on induced Ekman Pumping velocity

Online smoothing separately applied to SST and surface current

Seo, Miller, Norris 2016, JPO
Does SST-wind coupling *really* shift the eddy position?

SSH 15cm: GW

Yes!!!!

About 1° downstream shift of the Great Whirl when eddy-SST-wind coupling is suppressed.

Seo 2017 JCLI
Ocean mesoscale air-sea coupling is an *active* area of research now!

It is NOT a high-wavenumber noise, but forms a fundamental part of the coupled system.

It is natural to ask how important it is, how to best measure, simulate, and interpret.

With *insights*, *opportunities*, and many *unconditional supports* by Art, I am extremely fortunate to be trained to become part of the community leading this sort of research!
Thank you, Art!!

Happy Birthday!

Thank you, Team Miller!