Ocean Current Gradients Modify the Atmosphere

Mark A. Bourassa[1,2] and Jackie C. May[1,2,3]
1. Department of Earth, Ocean and Atmospheric Science, Florida State University, Tallahassee, FL 32306
2. Center for Ocean-Atmospheric Prediction Studies, Florida State University, Tallahassee, FL, 32310
3. NRL Stennis

Motivation and objectives

Motivation

Coupled Ocean/Atmosphere and Ocean/Wave/Atmosphere models, run at high resolution, indicate that there is a strong feedback between winds and currents. This feedback substantially changes currents, ocean mixed layer temperature and vertical motion, atmospheric boundary-layer winds, temperature and humidity if the resolution is sufficient to capture the feedbacks.

- Impacts are substantial
- Particularly strong near stronger current gradients
- Models greatly disagree on the strength of this current/wind feedback, but all models indicate that it is strong
- The example below is a monthly average of the curl missing

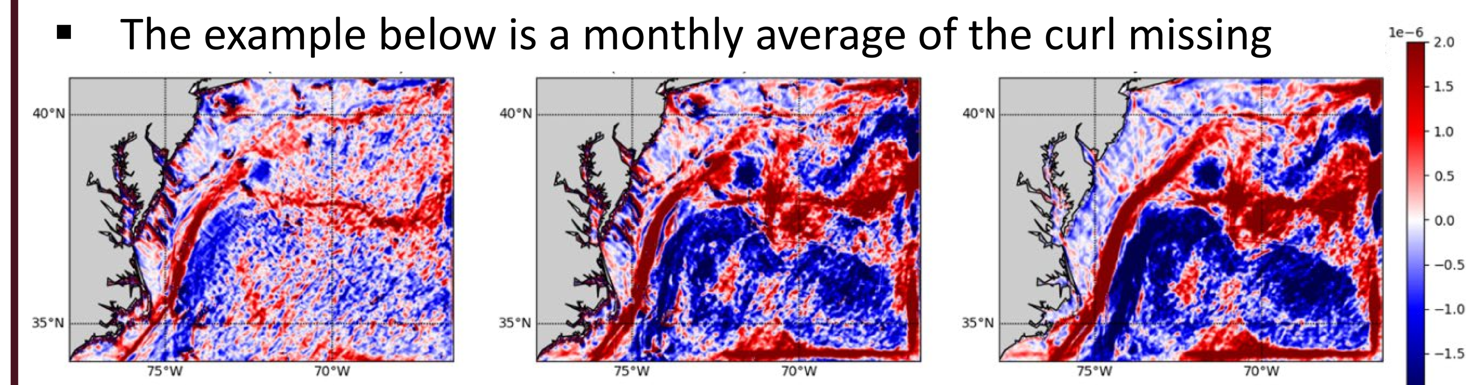


Fig. 1. Missing curl of stress associated with one-way coupling (left), additional missing curl with two-way feedback (middle) and the total missing curl (right). The atmospheric response is needed to modify the currents.

Objectives

- Explain the coupling in the atmosphere
  - Explain why the winds are simply adjusting to the currents
  - Link what is happening in the atmosphere to what is happening in the ocean
- Show an extreme example related to an atmospheric front

Impact on the wind stress and its curl

- These examples are from COAMPS model runs by Jackie May

The patterns of wind curl and stress curl mirror the current curl pattern

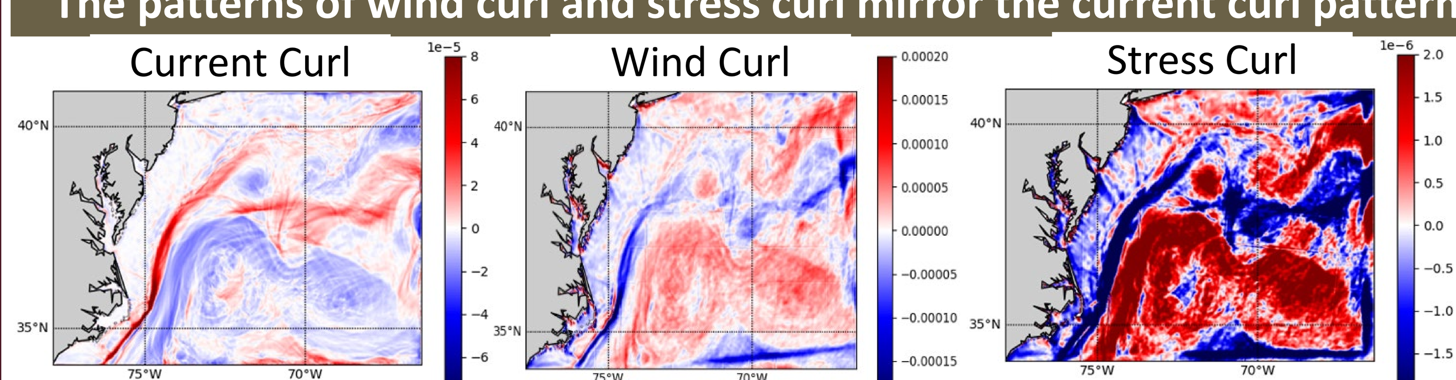


Fig. 2. Curl of modeled currents, earth-relative winds, and stress.

- The current clearly is tightly linked to the wind and stress.
  - Stress wind decrease when winds move with currents and increase when opposed by currents
    - The stress curl pattern would have the opposite sign as the current curl pattern
  - If the only the current were responsible, winds moving with the current would speed up and they would slow when opposed by the current.
    - The wind curl pattern would have the came sign as the current curl pattern.
    - Since this is clearly not the case, something else is making a larger contribution to the wind curl.

Conceptual Model of Wind and Current Feedbacks

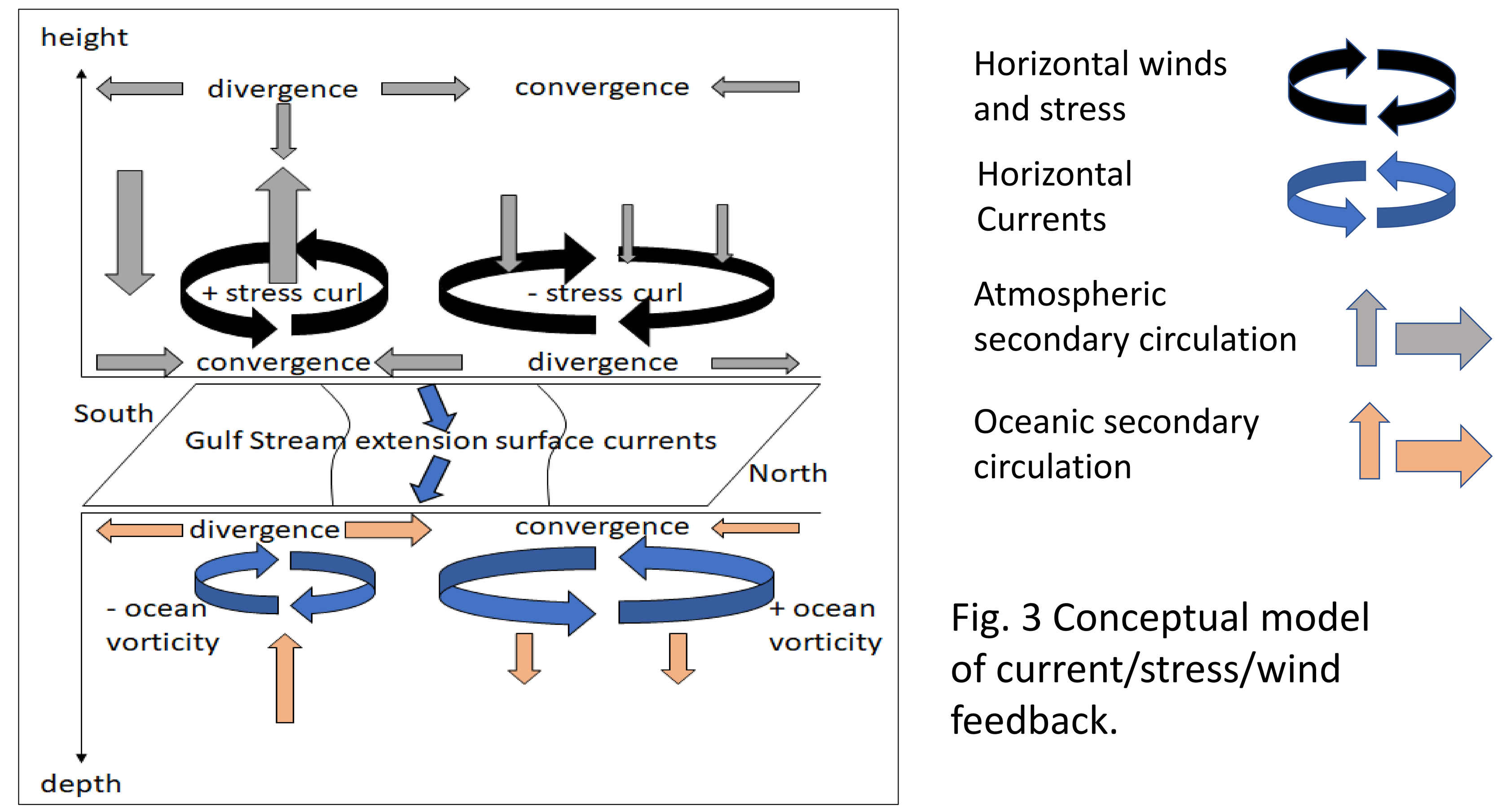
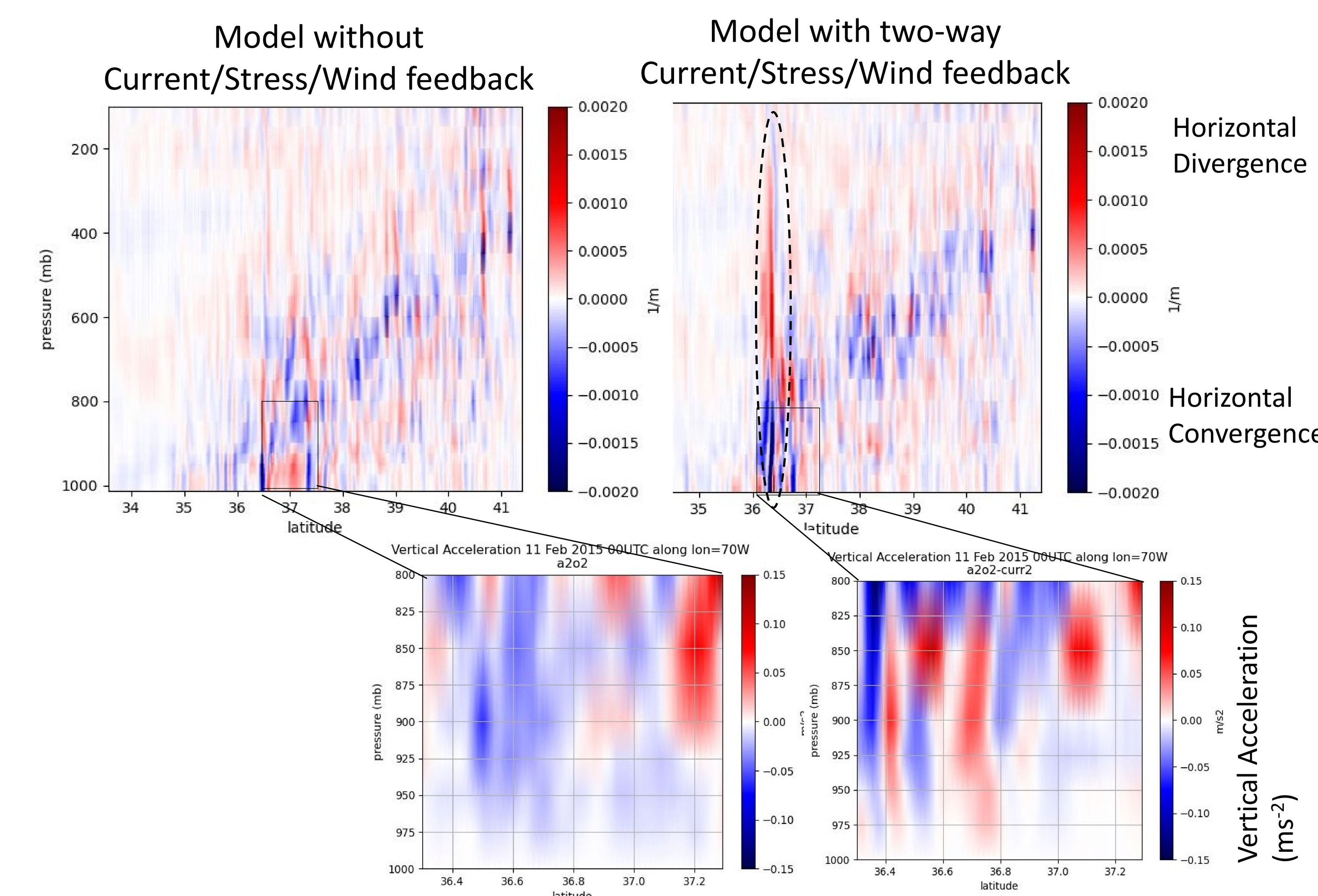


Fig. 3 Conceptual model of current/stress/wind feedback.

- The current gradient imparts vorticity the ocean on each side of the current.
- Stress is related to surface relative winds, decreasing when wind move with currents and increasing when winds move against currents, giving the curl of the stress the opposite sign as the winds.
  - The current gradient in the cross-wind direction is related to the change in the curl of stress.
  - This stress induces Ekman currents, with the curl of stress inducing Ekman upwelling and down welling.
  - The Ekman current moves perpendicular the main current, and largely cancels in other directions, apparently tightening the gradient on one side of the surface current.
- Winds at the water surface move with the currents, but this adjustment must change as the height above the surface increases.
  - Decreased stress causes less friction
    - Which increases wind speeds near the surface, again causing a curl with a sign like that of the currents
    - More importantly, the decrease in stress transports less momentum down from the top of the atmospheric boundary-layer, and areas with increases stress have more momentum transported downward.
      - From a log-height perspective, a 10 m wind is much closer to the top of the boundary-layer than the ocean surface
      - At a height of 10 m above the ocean surface, the transport of momentum downward plays a bigger role than the currents in directly modifying the winds.
        - Therefore the 10 m wind pattern matches the stress pattern
        - This feedback on winds further changes the near surface wind shear, making it greater and causing a positive feedback! This feedback is what causes the large increase in current feedback seen in the middle image of Fig. 1
- The atmospheric rotation anomaly induced by currents also has an Ekman behavior, with horizontal flow being altered from geostrophic flow to move towards lower pressure. This causes flow into areas with positive curl and upward motion.
  - Vortex stretching could also contribute the asymmetry in response across the current.
- Several models show that in the mean these atmospheric impacts are felt strongly in the boundary-layer, and that they extend through the free atmosphere.
  - Further research is needed to better understand the key processes in transferring boundary-layer characteristics into the free atmosphere.

Extreme Atmospheric Example

Fig. 4 Example of extreme current/stress/wind feedback associated with an atmospheric front passing over an ocean front. Right images are from an atmospheric model without this feedback, left images from a two-way coupled model to capture the full feedback. The top images show horizontal convergence. The bottom images show vertical acceleration.



- Both model runs show that properties from the atmospheric boundary-layer are being exchanged with the free atmosphere, as is expected with an atmospheric front.
- Atmospheric waves can be seen propagating upward and northward (to the upper right in the images)
- The horizontal convergence & divergence and the vertical acceleration are much strong in the area of the ocean front in the model run with current/stress/wind feedback.
- In at least the mid-latitudes this could be a key missing detail in modeling how the boundary-layer interacts with the free atmosphere.
  - A mechanism that is tied to ocean currents and their interaction with the atmospheric boundary-layer.
  - This mechanism could also be very important for vertical transport of marine aerosols and sea spray.

Acknowledgements

- Some of what is described here is built upon prior research by Peter Gaube et al. and Hyodae Seo et al., Lionel Renault et al., and much earlier work in the atmosphere and ocean related to Ekman transport.
- We thank Sarah Gille and Larry O'Neill (who's student has a related talk) for insightful discussion about parts of this coupling process.
- We thank ONR for largely funding this work, and support for MAB from NASA and NOAA.