Surface Curl and Ekman Upwelling Modification by Wind Response to SSTs

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1. Motivation

- Modification of surface winds within the Marine Atmospheric Boundary Layer by sea surface temperature gradients has been observed in many locations.
- These changes in winds and SSTs can modify near-surface stability, surface stress, and latent and sensible heat fluxes.
- In general, these processes are poorly modeled in Numerical Weather Prediction (NWP) and climate models.
- Failure to account for these air-sea interactions produces inaccurate values of turbulent fluxes, and therefore a misrepresentation of ocean forcing.

2. Methodology

- The winds are calculated from the ERA-Int perssure fields and Reynolds daily OKSSTs using the University of Washington Planetary Boundary-Layer Model (UWPBL)
- Run for two cases:
  - Ignoring SST gradients
  - Considering thermal wind like changes in surface wind
  - Stratification is assumed to be neutral.
- This approach accounts for most of the SST-induced wind speed variability.

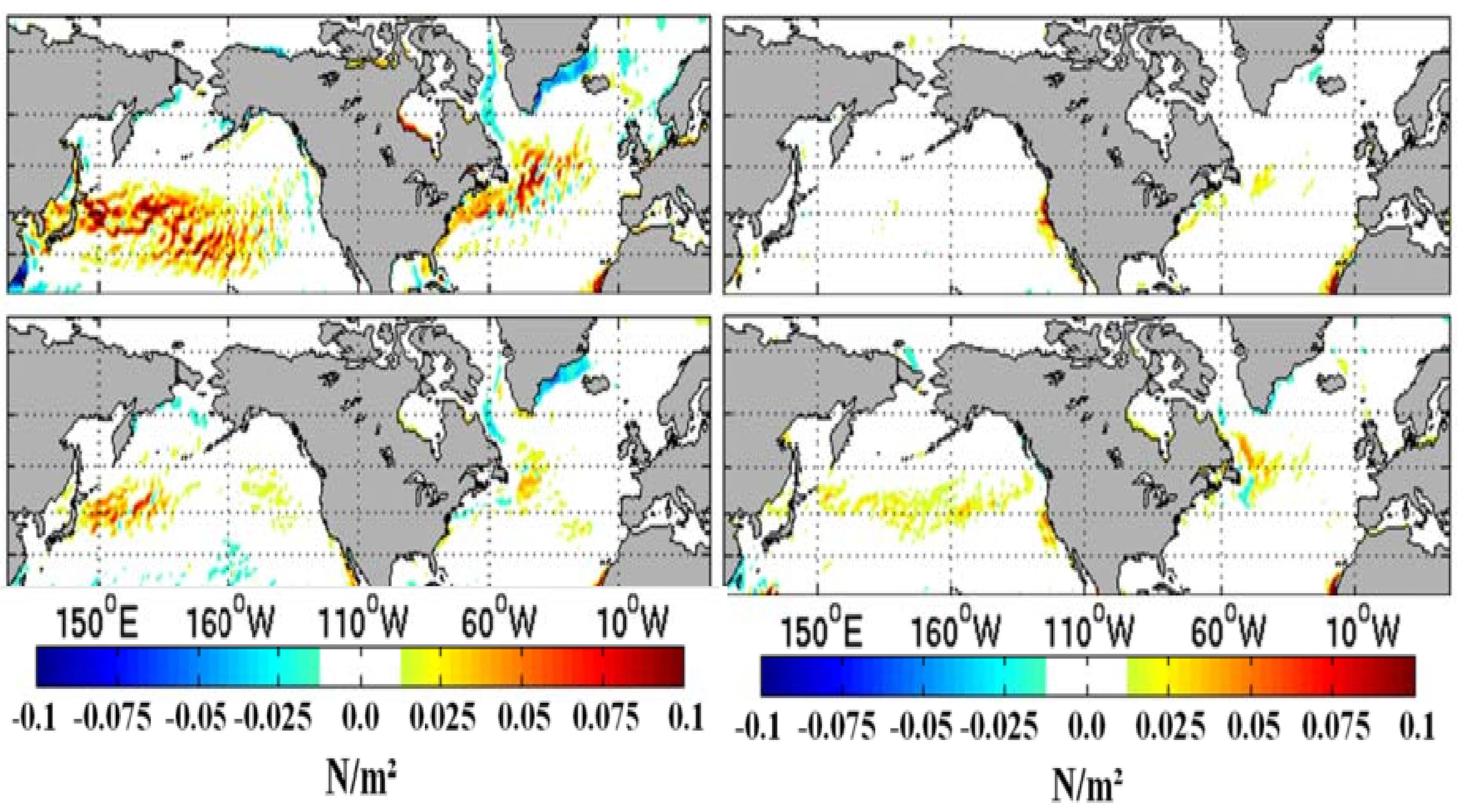

Fig. 1. Change in surface stress (Nm-2) due to SST-related modification of surface winds for (a) January, (b) April, (c) July, and (d) October 2003. Each image represents a The changes in stress are much greater in the Winter, and are smallest in the Summer.

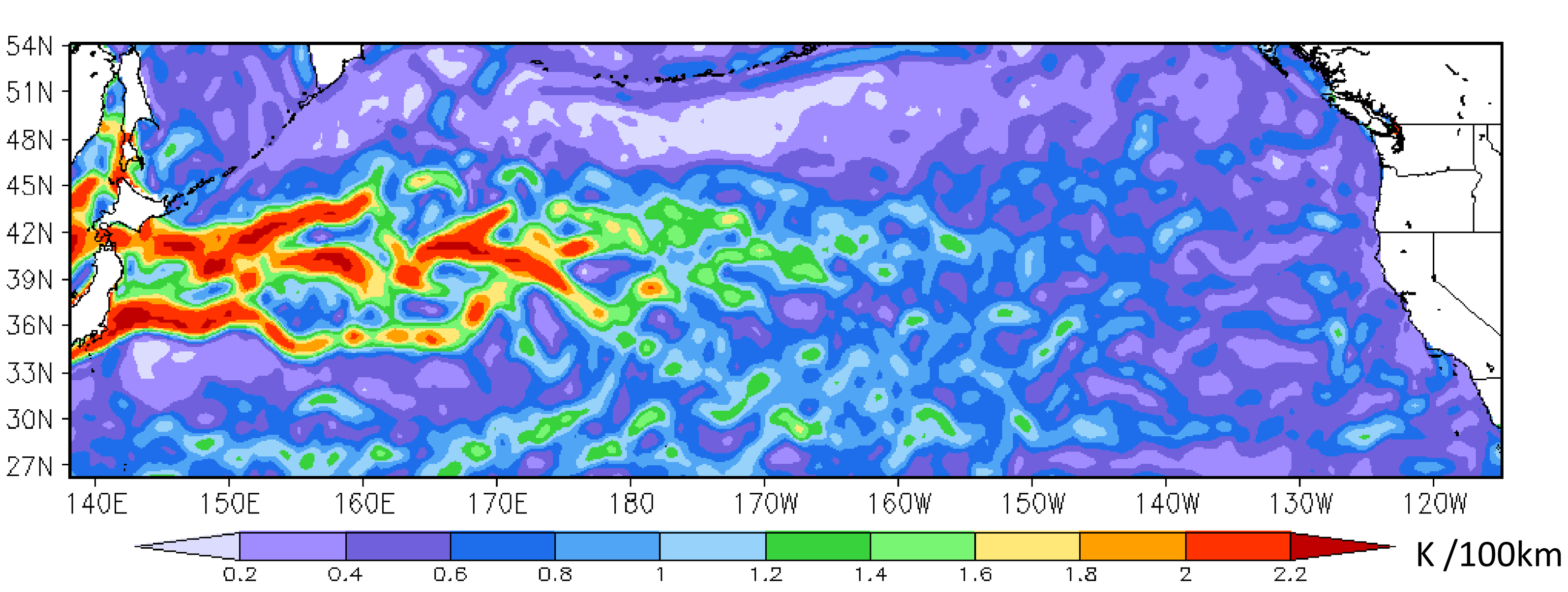

Fig. 2. SST gradient for a daily snap shot in winter 2003. SSTs are from the Reynolds daily OI.

3. Calculation of Ekman Upwelling

Stress was calculated using the Bourassa (2006) parameterization. The spatially averaged curl of the stress was calculated using a Greens function (Bourassa and McBeth, 2010). The diameter of the averaging area is 100km. These calculations make the assumption that there has been sufficient time for the upper ocean to adjust to the wind forcing.

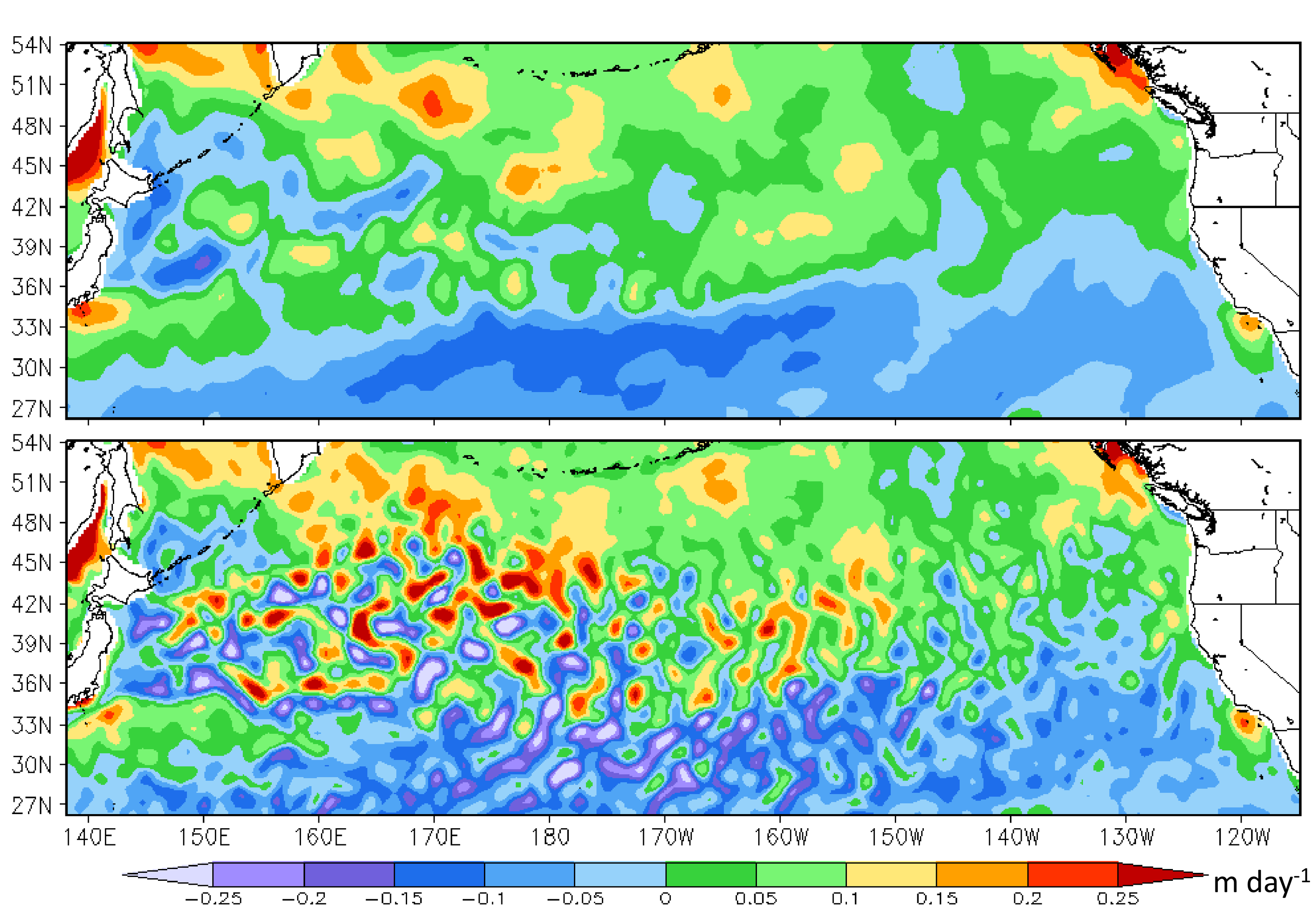

Fig. 3. Ekman upwelling examples for the same wind pressure fields without (top) wind perturbations due to SSTs, and with (bottom) wind perturbations due to SST induced baroclinic flow. These are from one six hour period, using bulk flux input data from the ERA-int product. The SST gradients are from Fig. 2. SSTs clearly add a great deal of small scale information.

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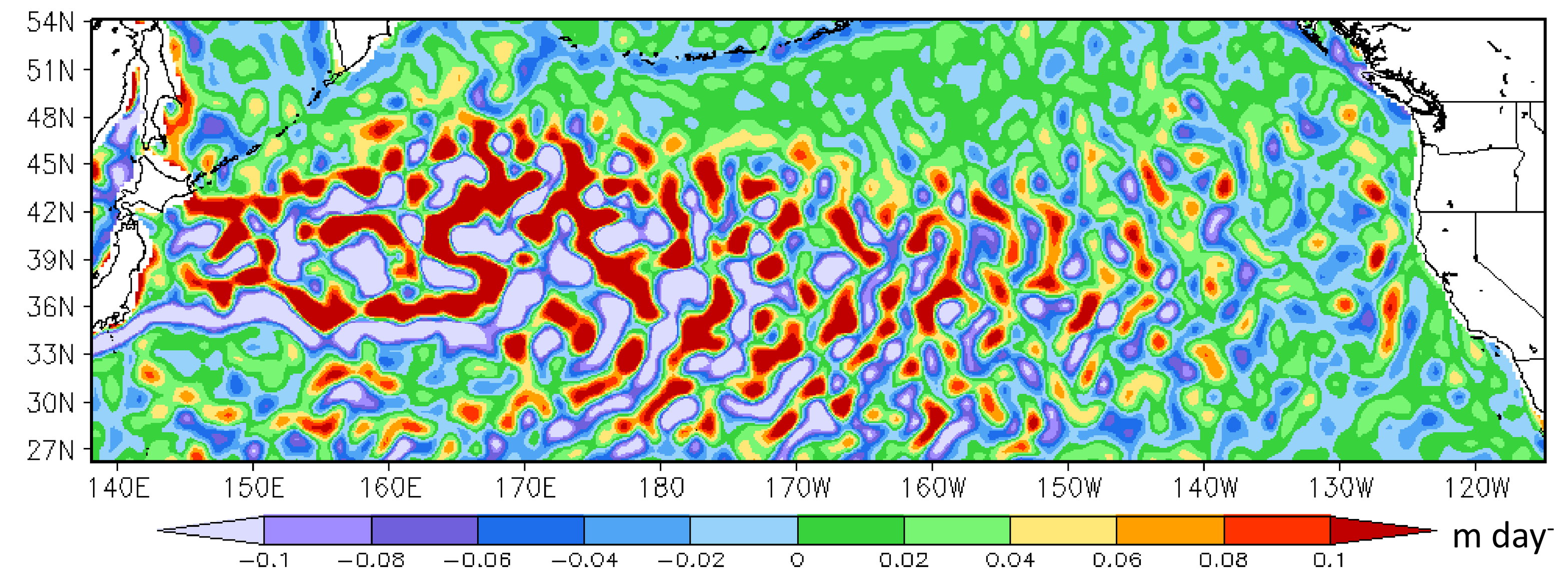

Fig. 4. Difference of the two images in Figure. 3: the changes in surface stress due to considering thermal wind-like impacts of SST gradients. Note that these changes are almost as large as the values in the wind field that did not included SST-related variability.

4. Band-Pass Filtering of the Upwelling

- The upwelling can be calculated with any area: we use roughly circular shapes
- The variability at any range of spatial scales can be isolated by
  - Calculating the upwelling at two spatial scales
  - Each scale includes variability at that scale and larger scales
  - The upwelling for the larger scale is subtracted from the upwelling for the smaller scale
- This process results in a band pass filter, passing the variability between the two spatial scales.

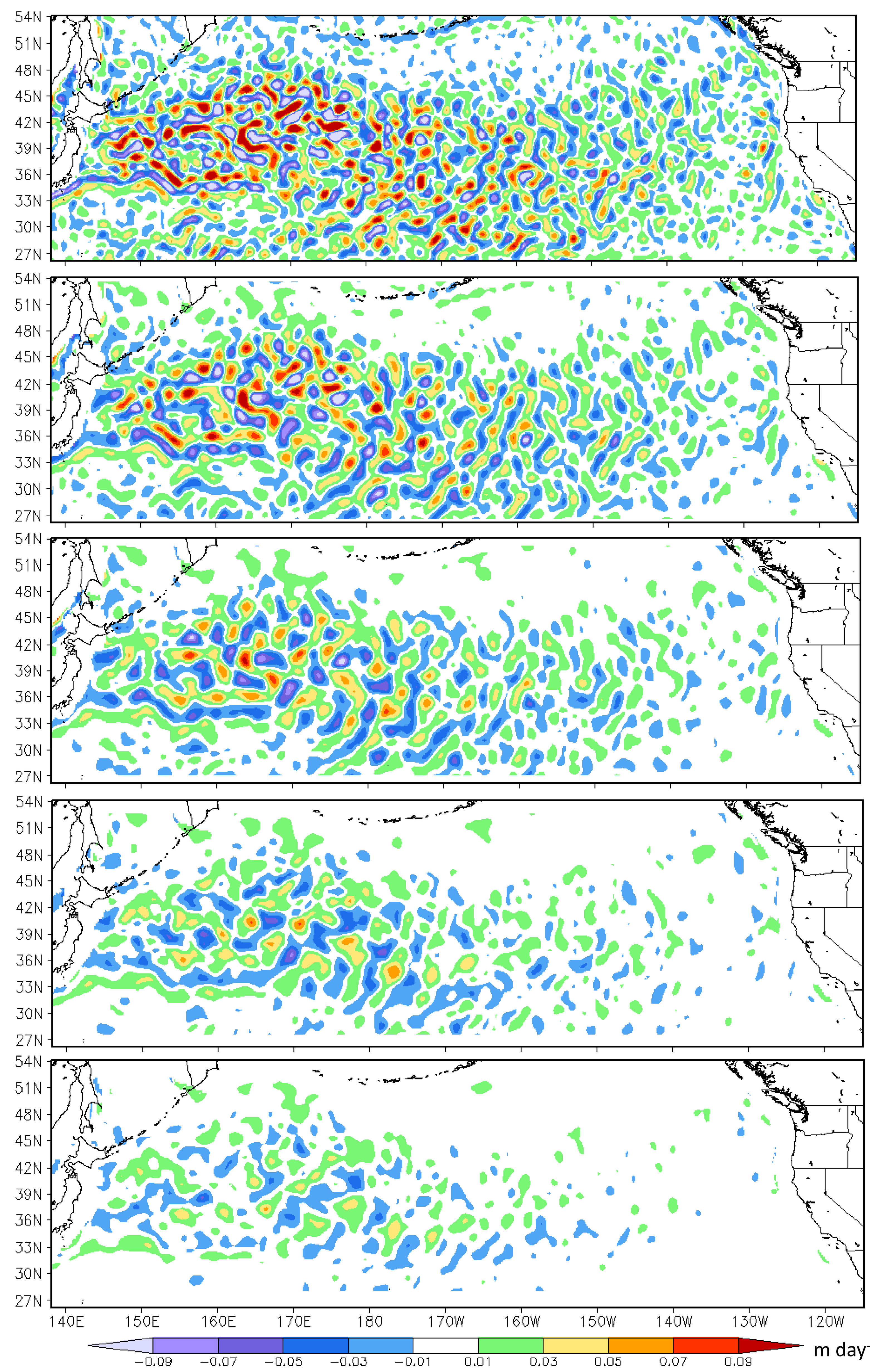

Fig. 5. Band passed Ekman upwelling differences from Fig. 4. From top to bottom, the images shows Ekman upwelling on the scales of 100 to 200km, 200 to 300km, 300 to 400km, 400 to 500km and 500 to 600km. The largest scale shows a relatively small impact. The smaller scales show substantial impact and are not well resolved in NWP, and none of these scales are resolved in most climate models.

5. Conclusions

The impacts of SST gradients on curl are of order(1). Consequently, the impacts on Ekman upwelling are also very large, given the assumption that the currents reach an Ekman balance. The wind and SST coupling is typically poorly modeled, underestimating the coupling by at least a factor of two. Furthermore, numerical models do not resolve ocean forcing on scales less than roughly 8 to 10 times the grid spacing. Therefore, this very important mixing is missing in most modeling.

The impact on Sverdrup flow is proportionately smaller (order 10%) because integration tends to combine nearly cancelling changes in the forcing.