Impacts of sea surface temperature gradients and surface roughness changes on the motion of surface oil: A simple idealized study

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Outline

- **Why do it**?
- **How to do it**?

  (1) Method: The Univ. of Washington Planetary Boundary Layer (UWPBL) model embedded with a revised surface roughness scheme

  (2) Experimental setup
- **What do we get**?

  Key Results: Changes in atmospheric PBL features with different SST gradients, particularly in the transition zones:

  1) Changes in Surface winds, surface wind divergence;

  2) Ekman transport and its dependence on SST gradients;
- **Summary**

Why do it: Because of some shortcomings in most oil trajectory forecast models:

- Treat oil as a passive tracer (virtual particles);
- Underestimate influence of SST gradient on near-surface winds on small spatial scales;
- Physical processes owing to surface roughness discrepancy between seawater and oil may not be fully considered

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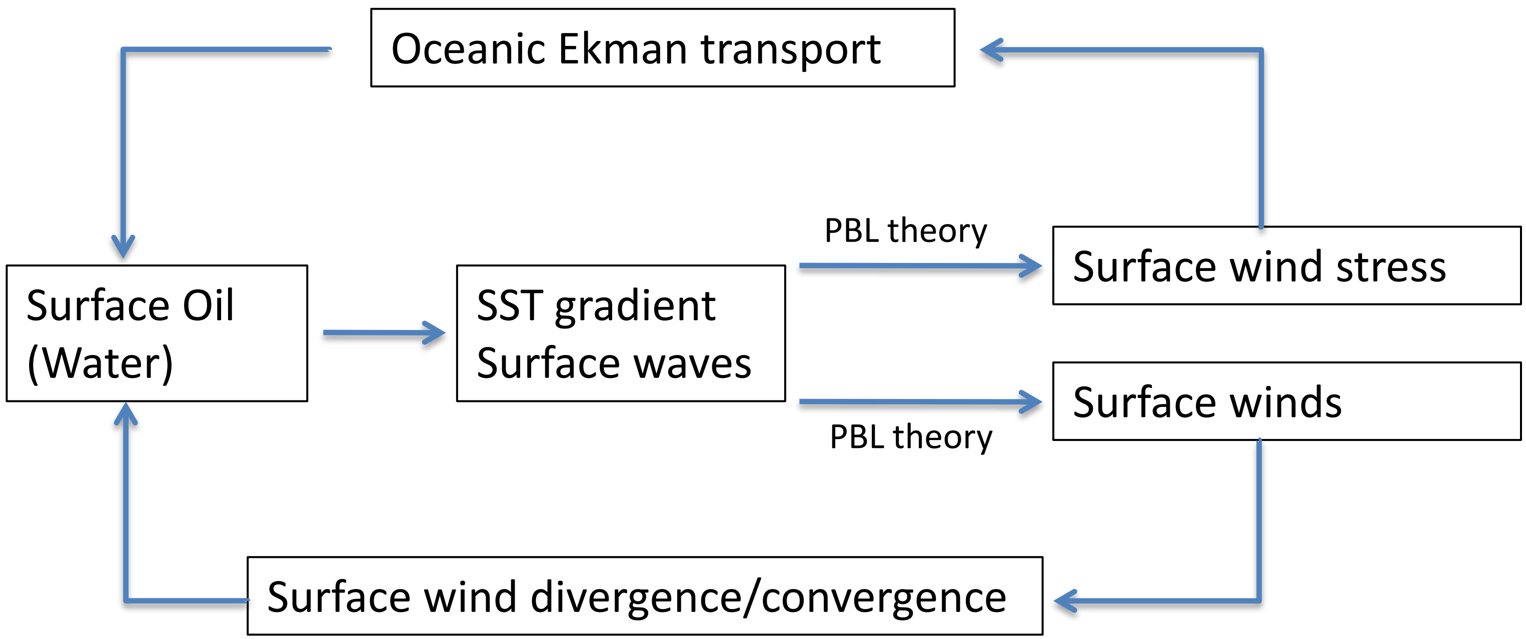
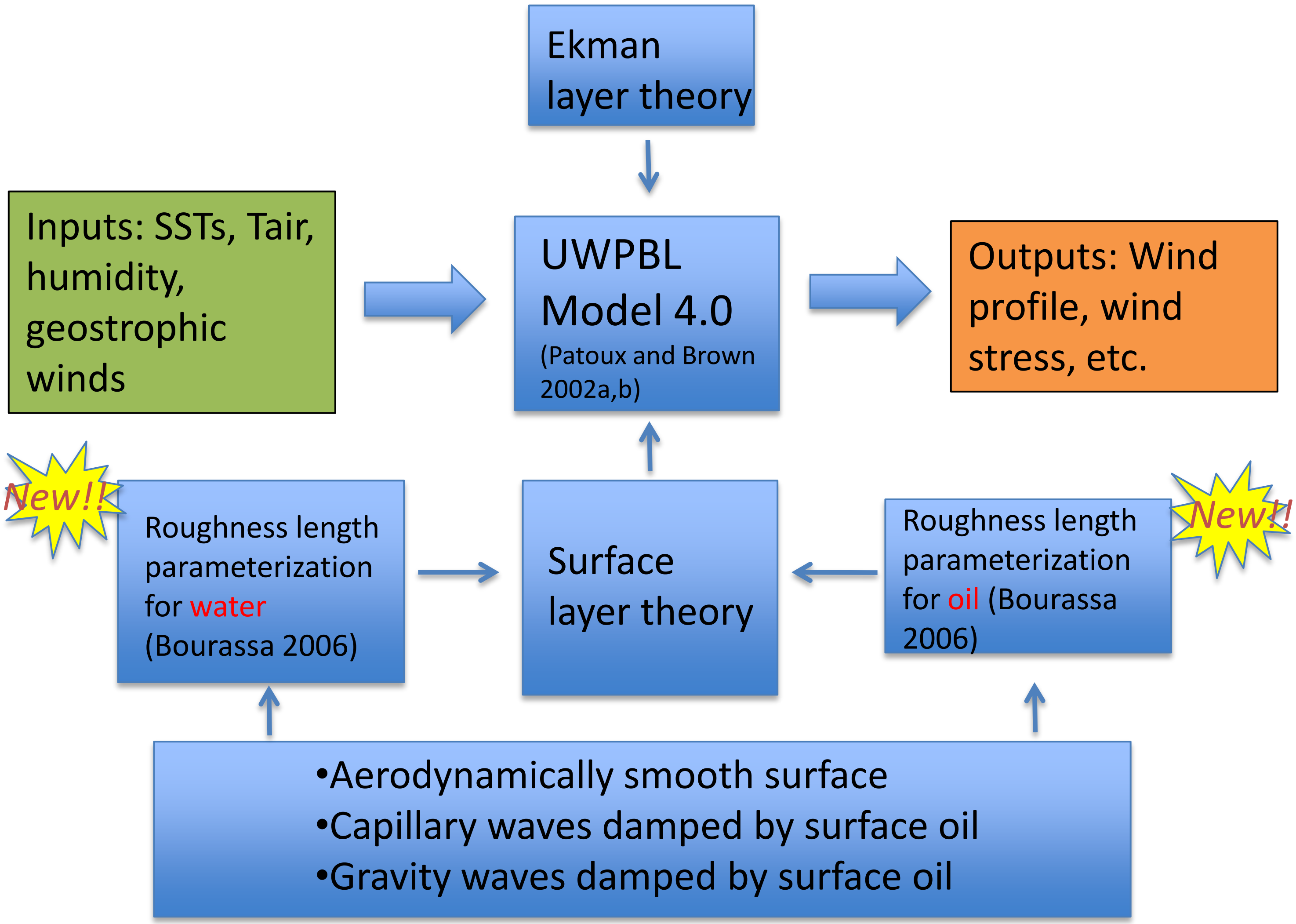
Hypothesis of potential feedback



How to do it?



Ekman layer theory
Inputs: SSTs, Tair, humidity, geostrophic winds
UWPBL Model 4.0 (Patoux and Brown 2002a,b)
Outputs: Wind profile, wind stress, etc.
New!!
Roughness length parameterization for water (Bourassa 2006)
Surface layer theory
Roughness length parameterization for oil (Bourassa 2006)
New!!
•Aerodynamically smooth surface
•Capillary waves damped by surface oil
•Gravity waves damped by surface oil

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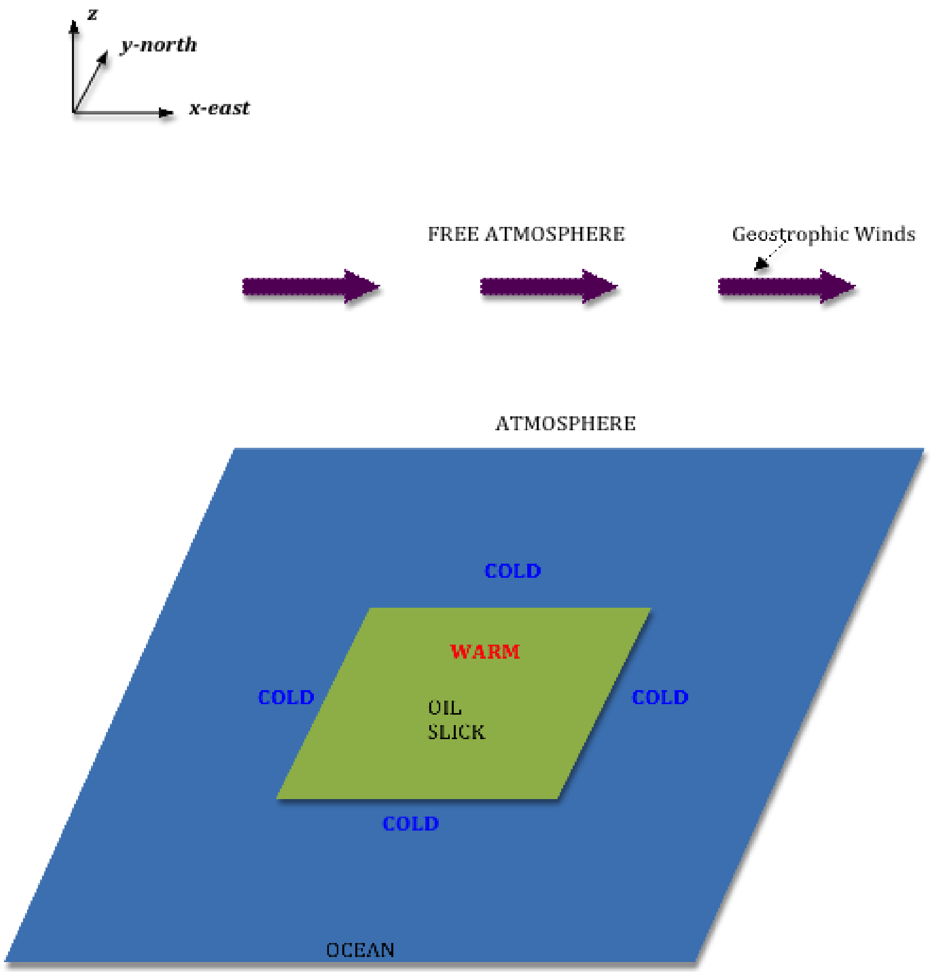
3-D schematic diagram for experimental setup



Model resolution and input variables:

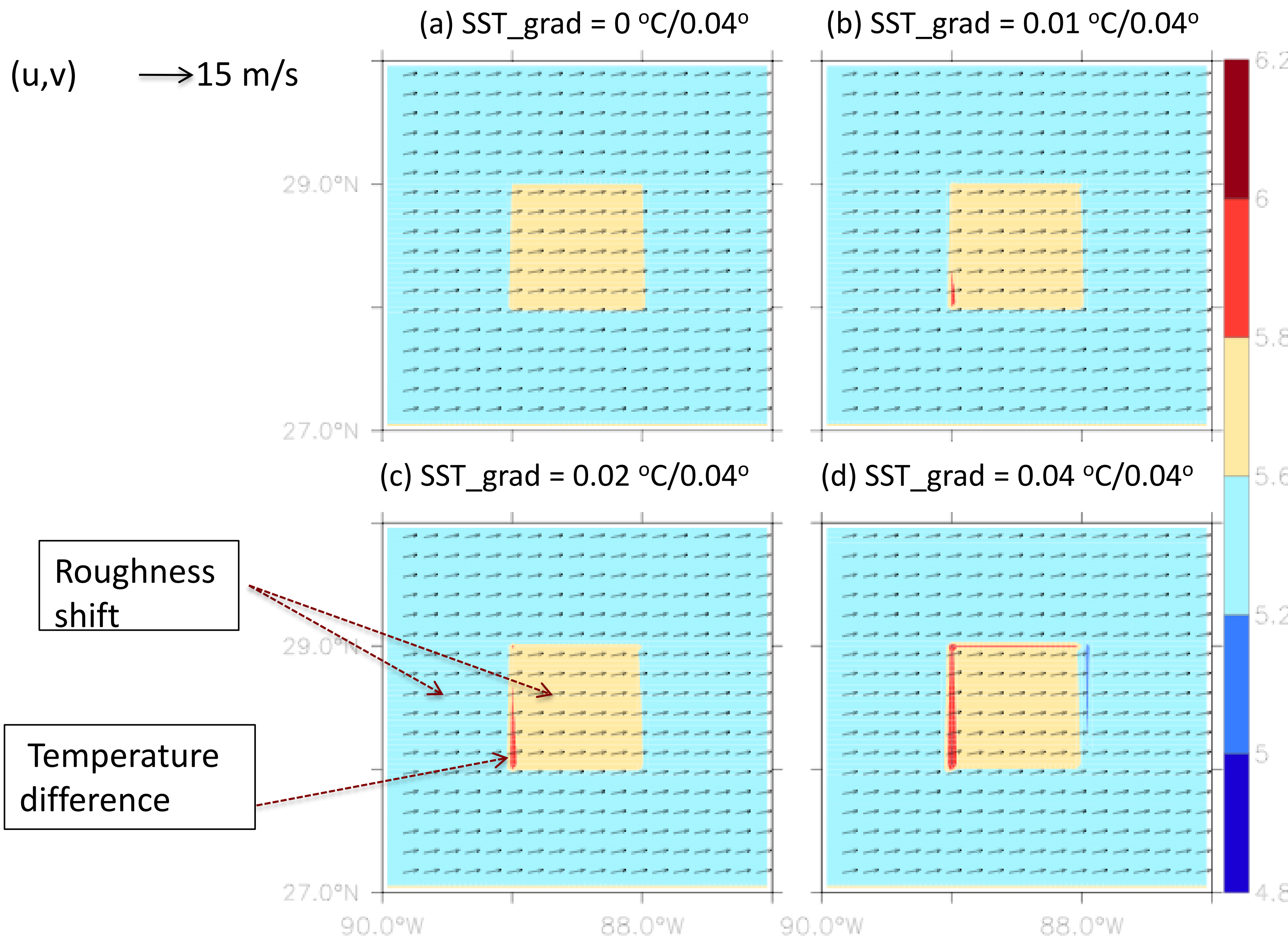
- Model domain: 90W-87W, 27N-30N
- Oil domain: 89W-88W, 28N-29N
- Resolution: deltaX by deltaY = 0.04 deg° X 0.04°
- Ugeo is about 8 m/s
- Air humidity = 0.02 kg/kg
- SST = 25°C for water;
  = 25°C + deltaT for oil
- Tair = 24.5°C for water;
  = 24.5°C + deltaT for oil
- deltaT = 0.001, 0.002, ..., 0.04°C
- Temperature gradient = deltaT/deltaX in unit of °C per 0.04°.

Note: Assumption of SST gradient between oil and seawater is supported by satellite observations (Svejkovsky et al. 2012)

What do we get?

- Surface winds
- Surface wind divergence/convergence
- Oceanic Ekman transport

surface wind speed



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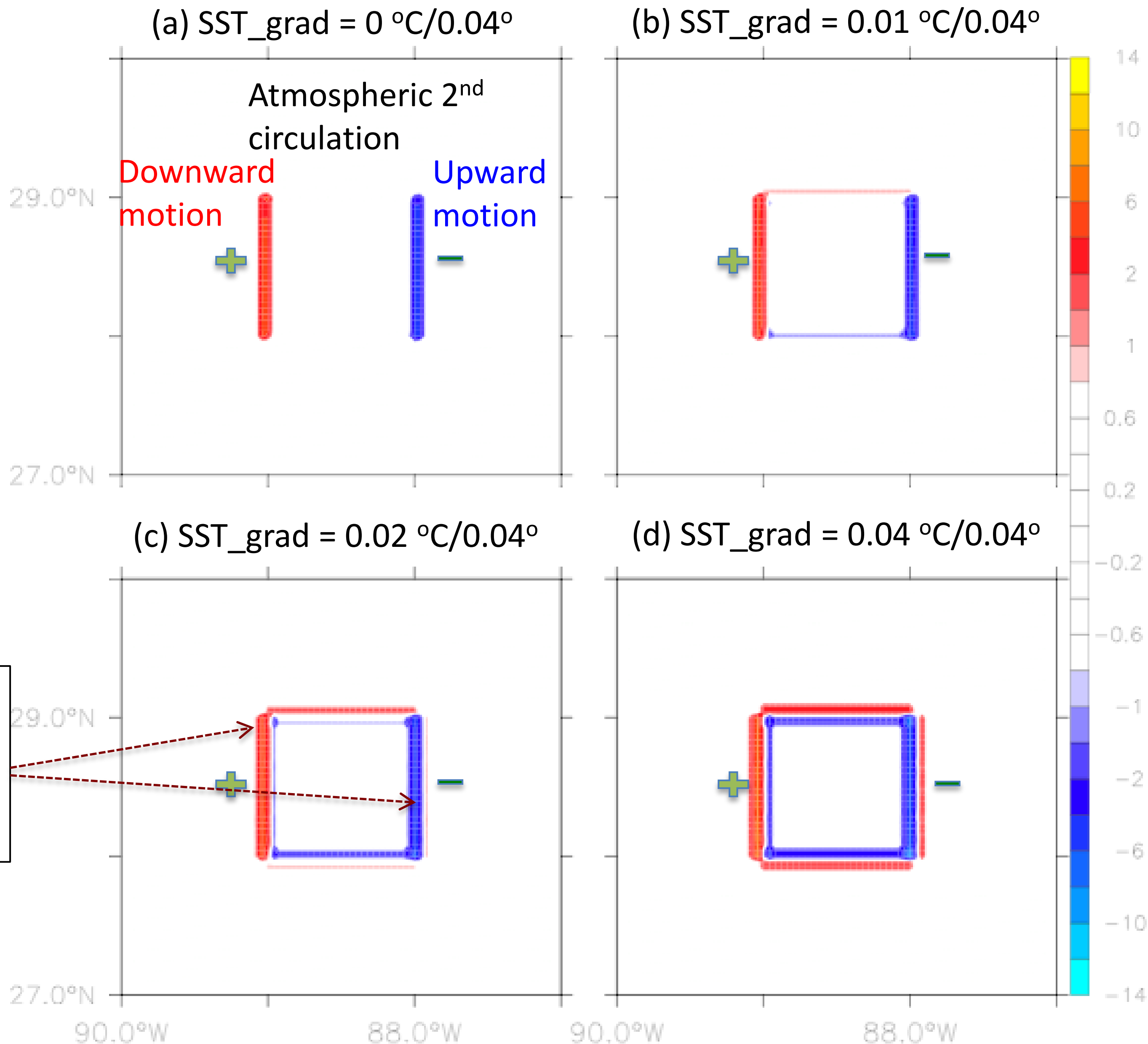
Surface wind divergence (x 10^5 s^{-1})



SST gradients affect surface wind divergence in the boundary

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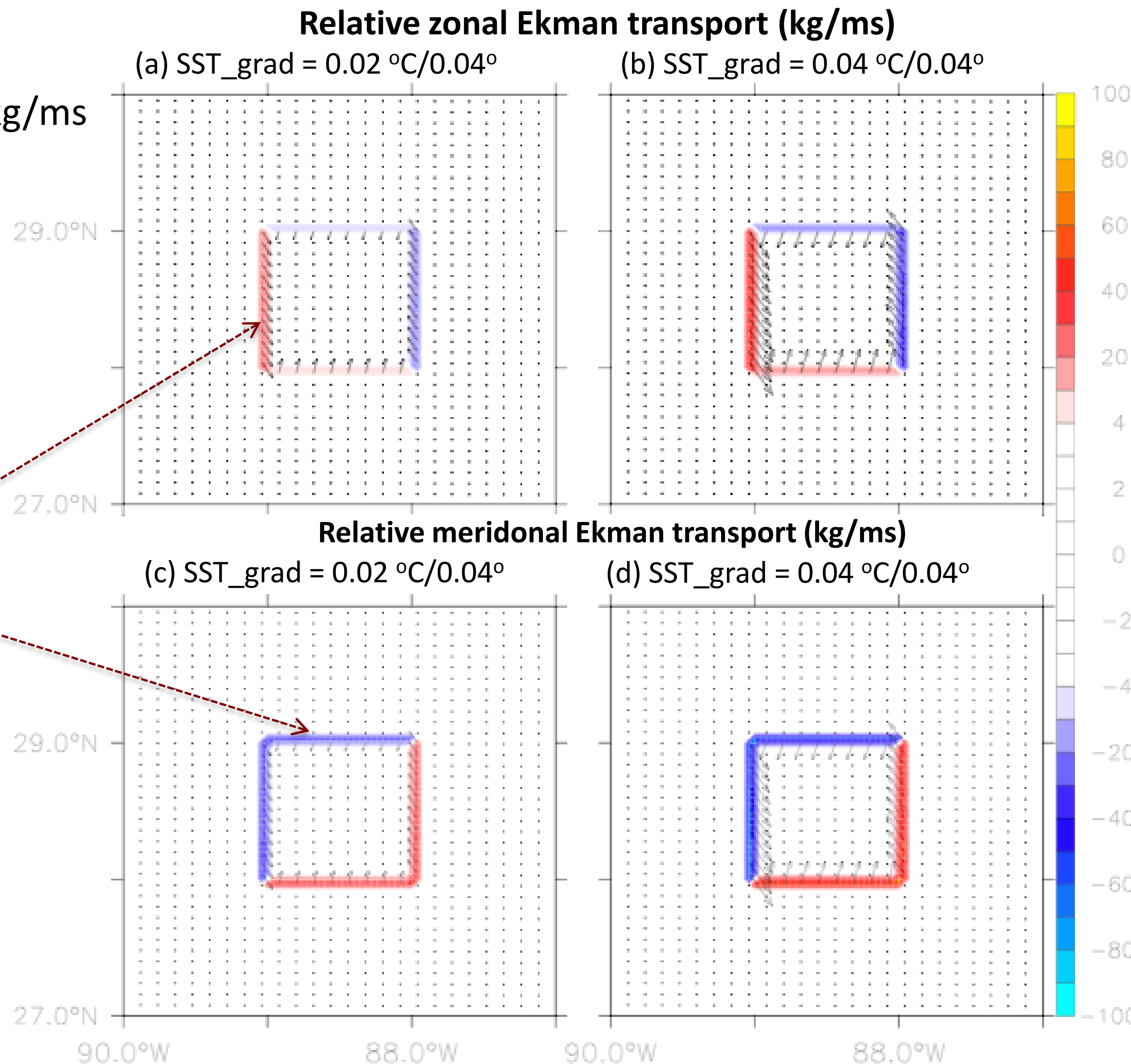
(mx,my) ⟶ 100kg/ms

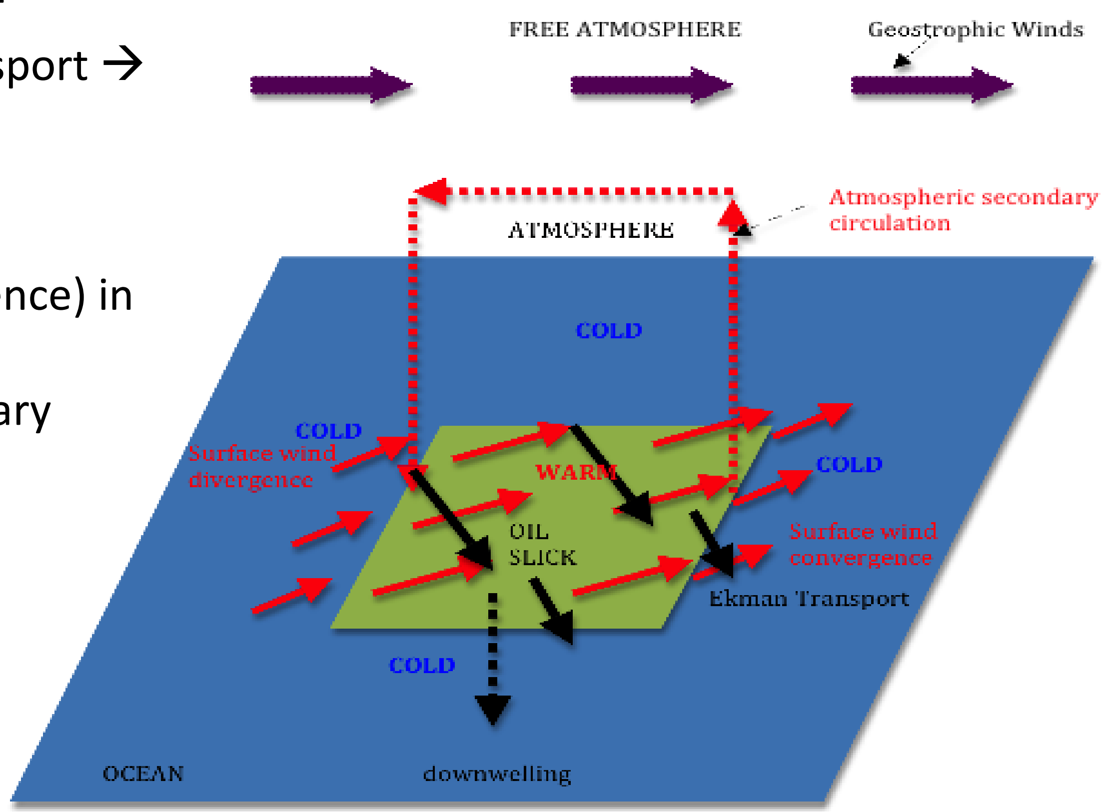
SST gradients affect Ekman transport in the boundary



3-D Schematic diagram

- Net convergence of Oceanic Ekman transport → downwelling

- Surface wind divergence(convergence) in the boundary → atmospheric secondary circulation



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Summary

- There are significant changes in surface winds, wind speed, wind divergence, and oceanic Ekman transport in the transition zones between water and oil, which in turn may play a role in influencing the surface oil motion. Both the strong SST gradient and roughness change in the transition zones play an important role in these changes;
- An atmospheric secondary circulation can be induced as a consequence of strong wind divergence in the transition zones, which in turn affects the surface oil motion.
- A net convergence of oceanic Ekman transport tends to push the oil downward to the subsurface. The orientation of oceanic Ekman transport owing to air surface temperature gradient and roughness change tends to spin the surface oil and deform the surface oil.

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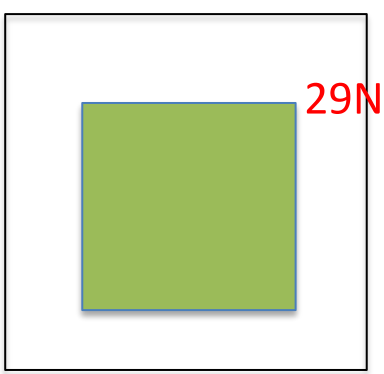
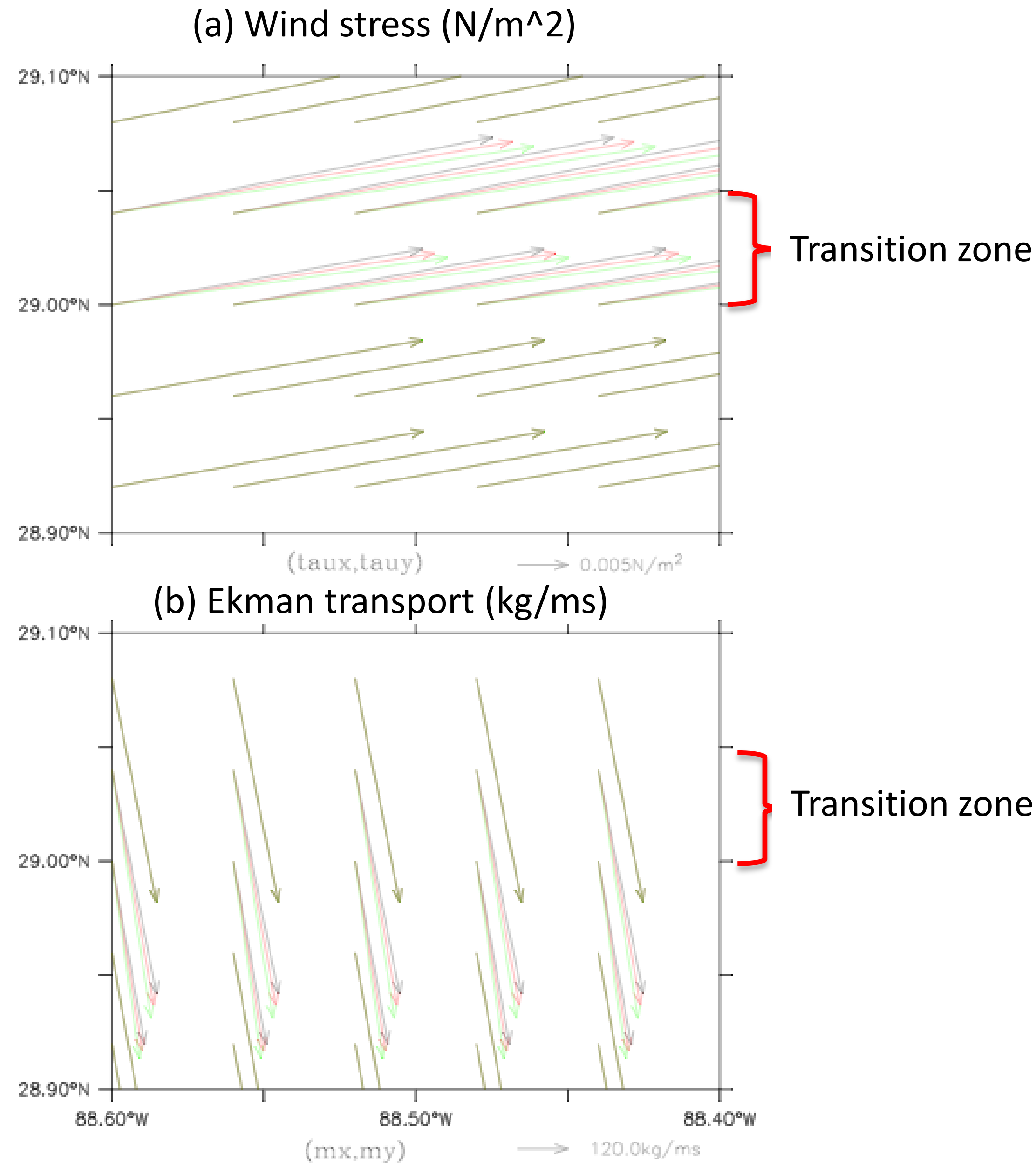
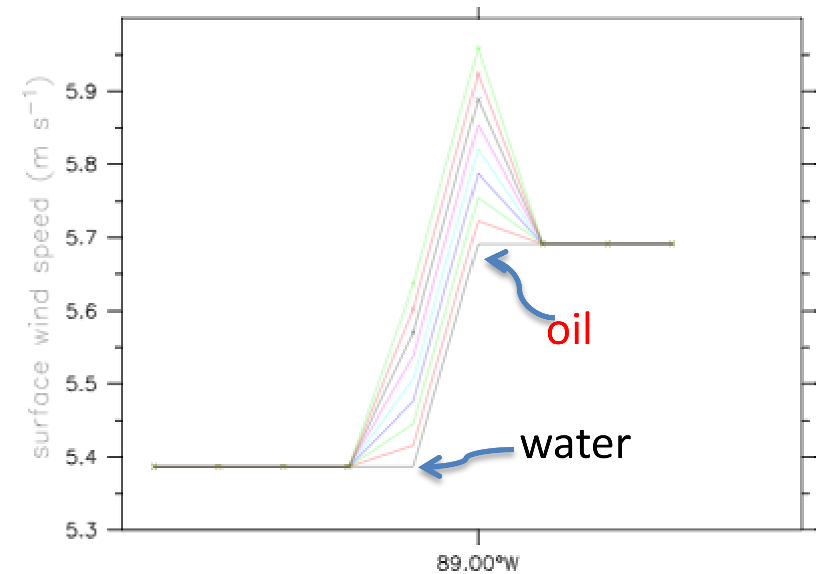
Changes in magnitude and directions of wind stress and Ekman transport in response to SST gradients

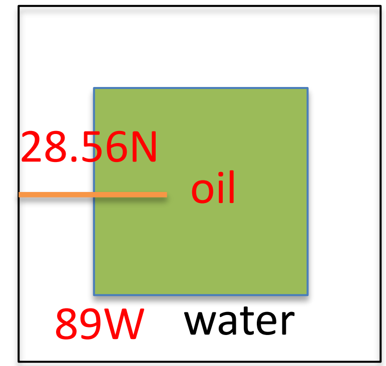
Black: 0 degC/0.04°
Red: 0.02 degC/0.04°
Green: 0.04 degC/0.04°



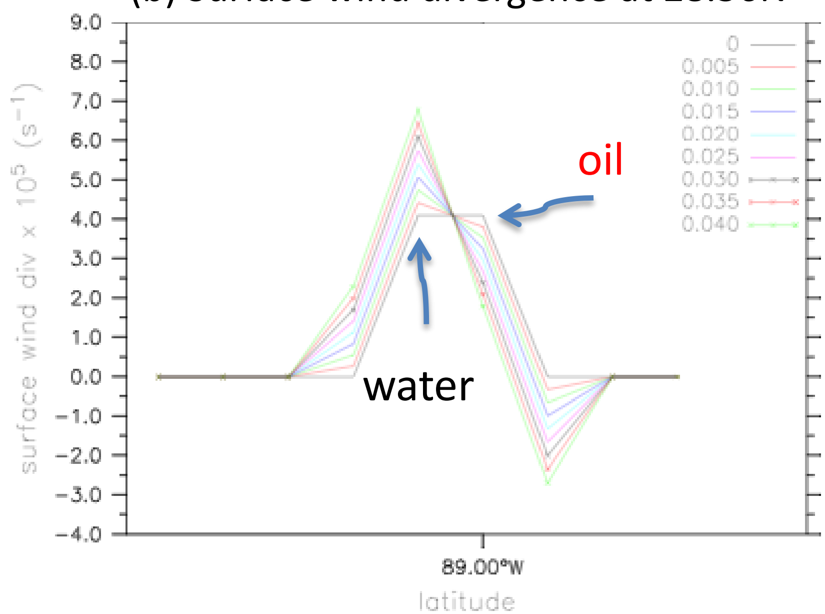


(a) Surface wind speed at 28.56N





(b) Surface wind divergence at 28.56N



The magnitudes of surface wind speed and divergence become greater as SST gradient (in $^{o}C/0.04^{o}$) increases

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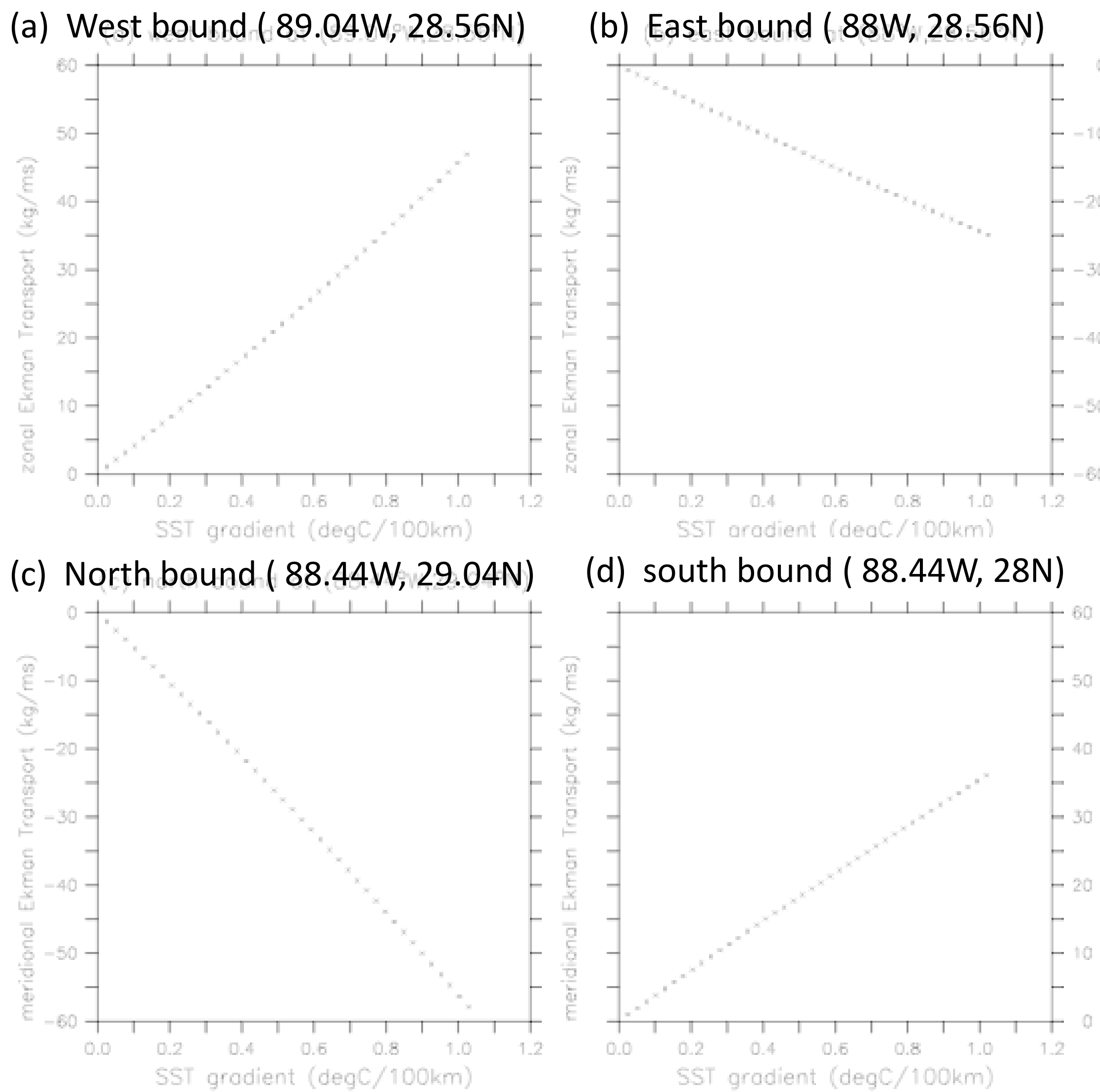
Ekman transport dependence on SST gradients

- Eastward transport at west (east) bound are linearly enhanced (weakened) in response to an SST gradient increase;
- There is a net **positive** zonal mass convergence in oil region because of the presence of SST gradients.

- Southward transport at north (south) bound are linearly enhanced (weakened) in response to an SST gradient increase;
- There is a net **positive** meridional mass convergence in oil region, caused by the presence of SST gradients.



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Surface momentum roughness length parameterization for seawater and oil

$$z_{0i} = \left[\beta_s \frac{0.11\nu}{|u_{*i}|} + \varepsilon \left[\left(\beta_c \frac{b\sigma}{\rho_w |\mathbf{u}_*| |\mathbf{u}_* \bullet \mathbf{e}_i|} \right)^2 + \left(\beta_g \frac{a |\mathbf{u}_*| |\mathbf{u}_* \bullet \mathbf{e}_i|}{g} \right)^2 \right]^{0.5} \right]$$

(1) Aerodynamical smooth surface (2) capillary waves (3) gravity waves

Parameters: β_s , β_c , β_g are weights for aerodynamically smooth surface, capillary waves, and gravity waves; ν : air molecular viscosity; b=0.019, a = 0.035, is Charnock's constant. σ : surface tension. $\varepsilon = 0.25$ for oil, represents the oil damping effects on capillary waves and short gravity waves; $\varepsilon = 1.0$ for seawater; $\mathbf{u}_*$: friction velocity.

Anisotropic: unit vectors parallel (e_1) and perpendicular (e_2) to the mean direction of wave motions.

References: (1) Nikuradse 1933; Kondo 1975
(2) Bourassa 1999; 2006
(3) Smith et al. 1992

Surface roughness length parameterization for seawater and oil (continued)

- Binary weights: $\beta_s = 1 - \beta_c$

For water surface: $\beta_c = 0, \beta_g = 0$ if $U_{eff} \le U_{\lim}, U_{\lim} = 1 m/s$

$$\beta_c = \tanh\left(0.4\left(U_{eff} - U_{\lim}\right)^3\right), \ \beta_g = \tanh\left(0.2\left(U_{eff} - U_{\lim}\right)^3\right) \quad \text{if} \quad U_{eff} > U_{\lim}$$

For oil surface: $\beta_c = 0, \beta_g = 0$ if $U_{eff} \le U_{\lim}, U_{\lim} = 7 m/s$

$$\beta_c = \tanh\left(0.4\left(U_{eff} - U_{\lim}\right)^3\right), \ \beta_g = \tanh\left(0.3\left(U_{eff} - U_{\lim}\right)^3\right)$$

$$U_{eff} = u_* \left[\ln\left(z/z_0 + 1\right) + \varphi\left(z, z_{0,} L\right)\right] / K_v$$