Atmospheric response to sea surface temperature mesoscale and submesoscale structures

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Outline

1- Context and motivation
2- Model setup
3- Reference simulation
4- Sensitivities
5- Discussion and conclusion
1- Context and motivation

Importance of SST features at scales of a WBC

Large-scale (O(300 km)) SST fronts impact the whole troposphere


Much idealized investigations of a frontal configuration:

Small et al 2008
1- Context and motivation

Large scale, mesoscales, submesoscales

Emphasis on the rôle of gradients of SST, not just SST anomalies

Now, $\nabla SST$ are strong at yet smaller scales:

Surface flow comprises numerous vortices and filaments at

Mesoscales ( $O(100 \text{ km})$ )
and sub-mesoscales ( $O(10 \text{ km})$ )

Impacts of SST anomalies at scales smaller than those of WBCs?

Klein et al 2008
1- Context and motivation

Mechanisms for the atmospheric response in the Boundary Layer (BL)

**Downward mixing mechanism**: $w$ proportional to the SST gradient

**Pressure adjustment mechanism**: $w$ proportional to the Laplacian of the SST

Different implications for the impact of **mesoscale and sub-mesoscale** SST anomalies

High-resolution ocean simulations indicate that SST spectrum has a slope in $k^{-2}$

Do SST anomalies at meso- and submesoscale impact the MABL? Is the pressure adjustment mechanism relevant to describe this impact?

**Aims of the present study**: Test the above and bring elements of answers, in **idealized simulations**, with **weak wind conditions**
2- Model setup

Weather Research and Forecast Model (WRF)  

Domain
Periodic in x, lateral wall in y
\( dx = 2 \text{ km} \)

Background flow
Uniform vertical shear:
\[
U(z) = U_H \frac{z}{H_{\text{top}}},
\]

\( U_H = 10 \text{ m/s}, \quad H = 12 \text{ km} \)
2- Model setup

Parameterizations

Yonsei University Scheme for the PBL
Monin-Obukov surface layer scheme
Dry simulations

SST

Homogeneous positive anomaly (3K)
Meridional gradient consistent with atmospheric shear
+ Anomalies
3- Reference simulation

3a: SST anomalies varying only in one direction

\[ f(y) = 0.75 \cos \left( \frac{2\pi}{L} y \right) + 0.25 \cos \left( \frac{3\pi}{L} y \right) \]

\textbf{SST} varying only in \( y \), i.e. \textbf{transverse to the wind}:

\( w \) at mid PBL (shown after 3h and 21h) responds like \(-\Delta \textbf{SST}\) consistent with pressure adjustment mechanism
3- Reference simulation

3a: SST anomalies varying only in one direction

Same SST, but varying in x, i.e. along the wind:

Again, remarkable agreement of $w$ with $-\Delta \text{SST}$

Effect of advection can be seen at 21 h
3- Reference simulation

3b: a full 2D spectrum of SST anomalies

Steep spectrum (k-4)
→ only mesoscale features (but not submesoscale)

Meridional gradient necessary for the thermal wind balance of the overlying atmospheric shear
3- Reference simulation

3b: a full 2D spectrum of SST anomalies

Steep spectrum (k-4) → mesoscale features

Differentiation → submesoscale features
3- Reference simulation

\( w \) at mid height of the PBL:

- \( t = 3 \) h
- \( t = 15 \) h

→ remarkable agreement with \(-\Delta \text{SST}\) (black contours)
3- Reference simulation

Quantifying the agreement:

Spatial correlation between $w$ and $-\Delta$ SST

Maximum height of the PBL
Mean height of the PBL
3- Reference simulation

At which scales?

Spectral correlations between $w$ (mid-PBL)

.. and $\Delta$ SST
3- Reference simulation

At which scales?

**Spectral correlations** between $w$ (mid-PBL)

.. and -Δ SST

.. and -Δ T (mid-PBL)

→ decorrelation at small scales (< 40 km) after ~12h due to decorrelation between T and SST

→ effect of advection (low-pass filter)
Outline

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4- Sensitivities

Sensitivity to the choice of BL parameterization:

**w at mid-PBL**

<table>
<thead>
<tr>
<th>Reference simulation</th>
<th>Mellor-Yamada-Nakanishi Niino scheme</th>
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<tbody>
<tr>
<td><img src="image1" alt="Reference simulation" /></td>
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</table>
4- Sensitivities

Sensitivity to the choice of BL parameterization:

Similar results despite significant differences between the schemes
4- Sensitivities

Sensitivity to the spatial scales in SST:

SST with a shallower spectrum (k-2)

SST anomaly

-Δ SST
4- Sensitivities

$\Delta\text{SST}$ at mid height of the PBL: $t = 3\ h$

$w$ at mid height of the PBL: $t = 3\ h$
4- Sensitivities

Sensitivity to the **background wind**:

Evolution with time of spatial correlations at different heights.

Doubling of the shear

1 m/s surface wind
### 4- Sensitivities – summary

Various diagnostics at t=15 h

<table>
<thead>
<tr>
<th>Case</th>
<th>Ref</th>
<th>2 × U</th>
<th>U + U₀</th>
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<th>$k^{-2.5}$ SST</th>
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<tr>
<td>$&lt;h_{PBL}&gt; (m)$</td>
<td>971</td>
<td>993</td>
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<td>$SST_{rms} (10^{-2}K)$</td>
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5- Conclusion and discussion

Do SST anomalies at meso- and submesoscale impact the MABL?

Yes, SST anomalies down to sub-mesoscale impact $w$ in the MABL

$w$ enhanced in the presence of a shallower spectrum of SST anomalies

Is the pressure adjustment mechanism relevant?

Yes, remarkable agreement between $w$ and $-\Delta$ SST in our experiments

Robust relative to the SST spectrum, to resolution and choice of parameterization

On the other hand, very sensitive to the surface wind.

An important limitation of our results is that they concern weak wind conditions.

Perspectives:

Stronger winds?
Moisture?
Impact above BL?
Thank you for your attention


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3- Atmospheric response to SST anomalies

Asymmetry between updrafts and downdrafts

PDF of $w$ in regions where

- $\Delta$ SST $> 0$ (- - -) : pronounced exponential tail for $w > 0$
- $\Delta$ SST $< 0$ (— —) : near Gaussian, significant negative mean
3- Atmospheric response to SST anomalies

At which scales?

Isotropic spectra

\( w \) (mid-PBL)

Laplacian of T (mid-PBL)

Laplacian of SST

Laplacian of surf. heat flux

\( E(k) \)

\( k \)
Spectral correlation between the Laplacian of SST and the surface heat flux for the reference simulation