Atmospheric response to oceanic sub-mesoscale SST fronts

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Summary

- Context
- Simulations setup
- Results
- Conclusion/futur work

Large scale relations

- 2 main mechanisms :

Downward Mixing Momentum : $\nabla \cdot \vec{u} = \alpha_{DMM} \nabla SST$

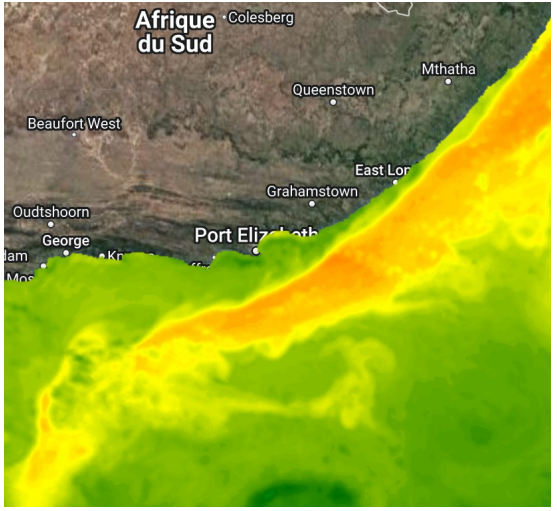
Pressure Adjustement : $\nabla \cdot \vec{u} = \alpha_{PA} \Delta SST$

See : Ayet and Redelsperger 2019, O'Neill et al. 2005

Small scale

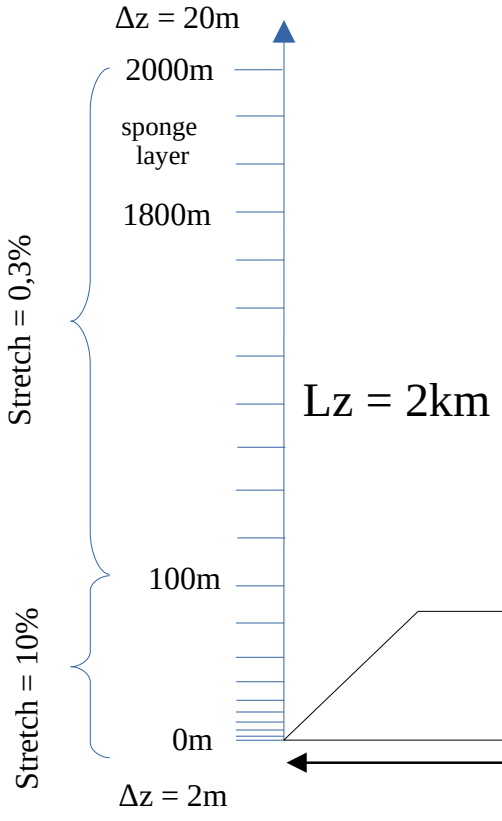
- GCM/CRM Subgrid scale physics
- Non linear response, up to ABL top
- Cloud formation ?

See : Sullivan et al. 2020 and 2021, Lambaerts et al. 2013

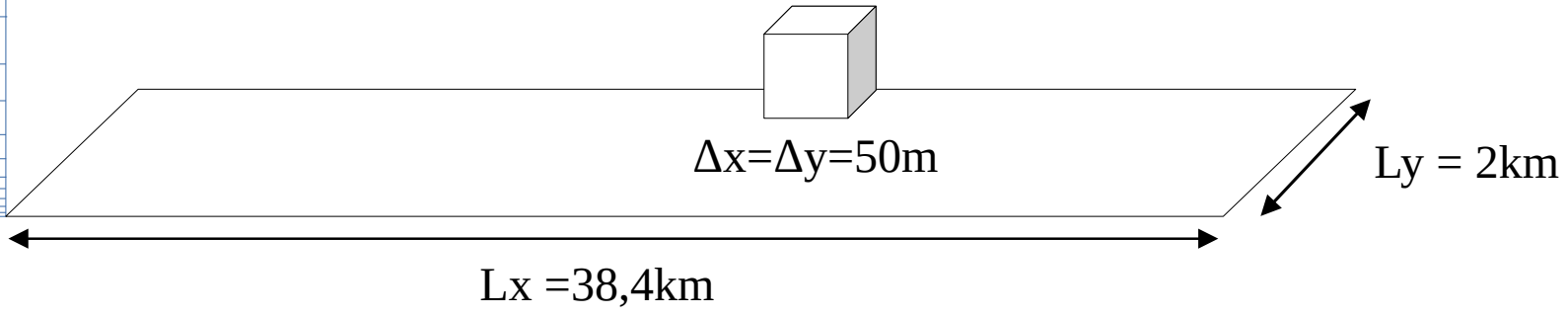


Agulhas current
SST Odyssea L4 (Ifremer) on 10/12/2015

Numerical experiment :

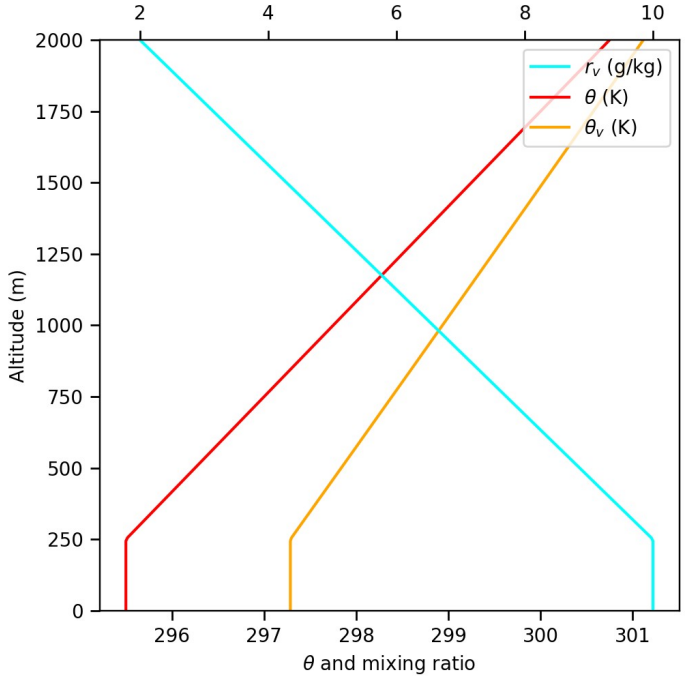


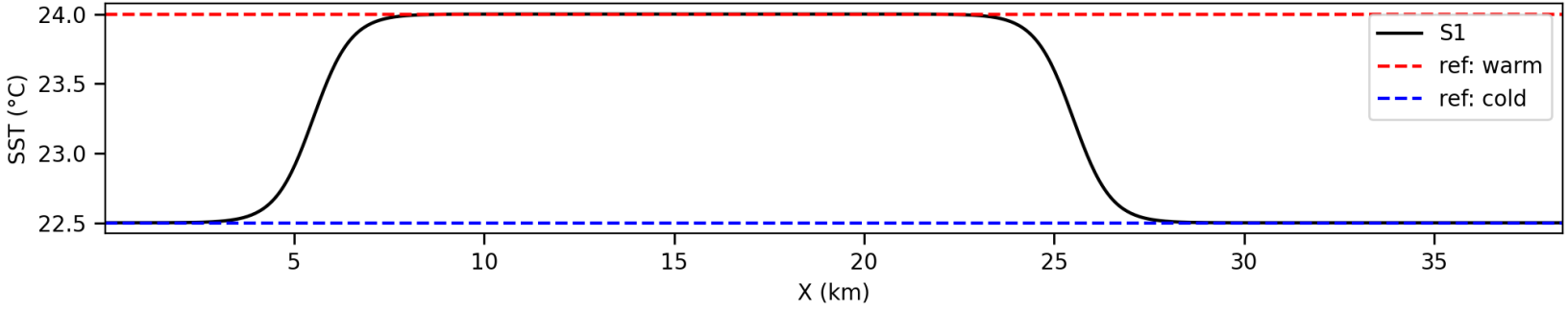
- MesoNH 5.6.0 in LES configuration
- 1.5 order closure from Cuxart et al. (2000)
- Pseudo-incompressible from Durran (1989)
- Mixing length = DEAR = max(ΔxΔyΔz, $l = l_s = 0.76\bar{E}^{1/2}\left(\frac{g}{\theta_0}\frac{\partial\bar{\theta}_l}{\partial z}\right)^{-1/2}$)



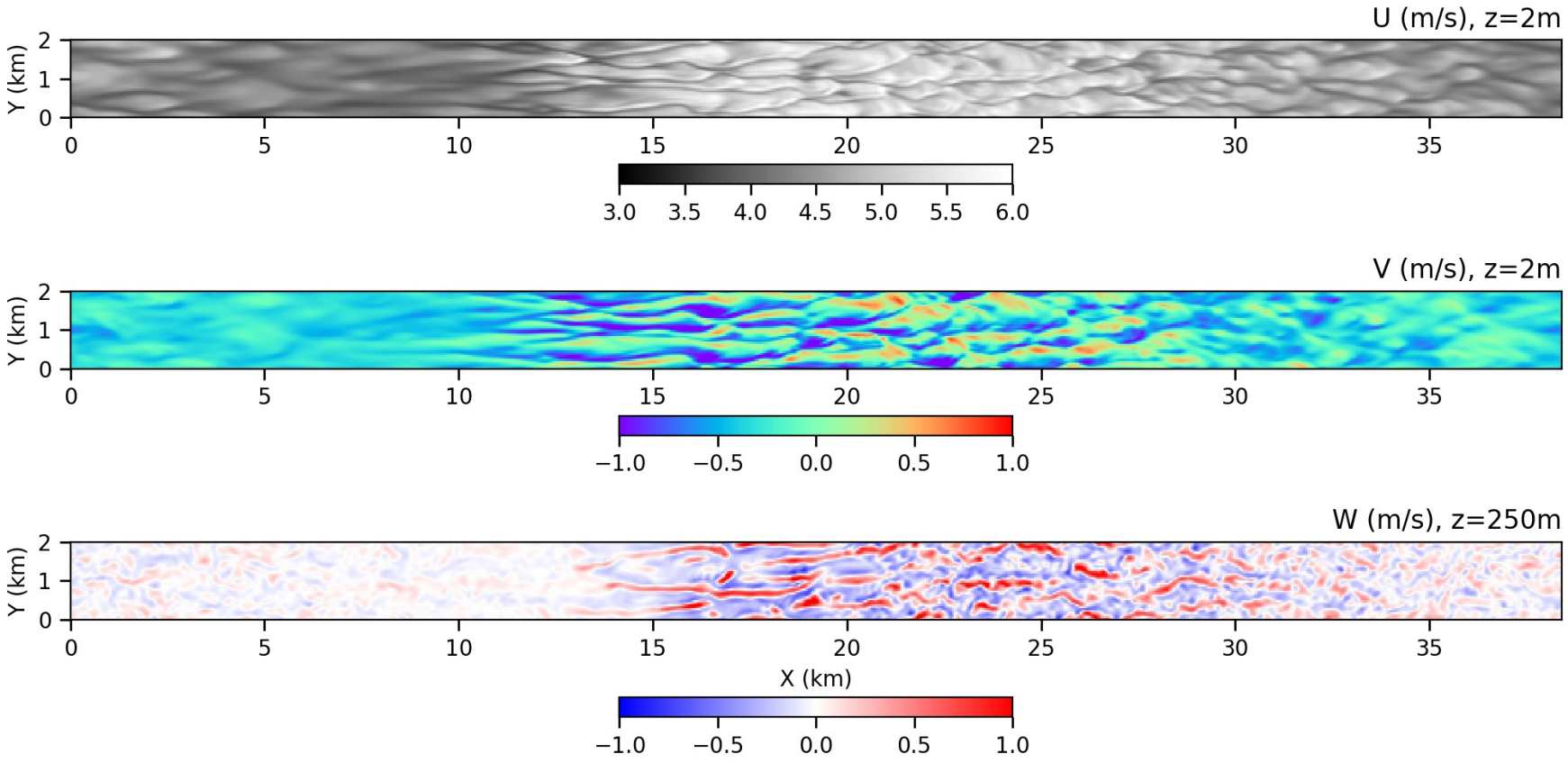
Initial conditions

- **U** = **Ug =** (7.5, 0) m/s
- SST(x) from t=0s
- Reference state = initial conditions after anelastic correction
- Clouds can form : ICE3
- Surface scheme : COARE3
- No radiation

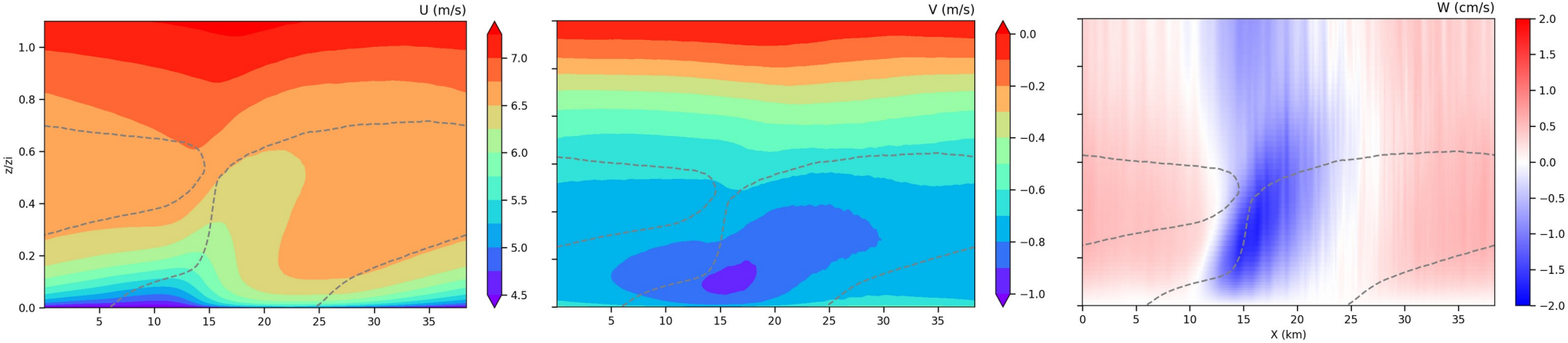




Last instant (t=+6h)



Mean fields



< > =

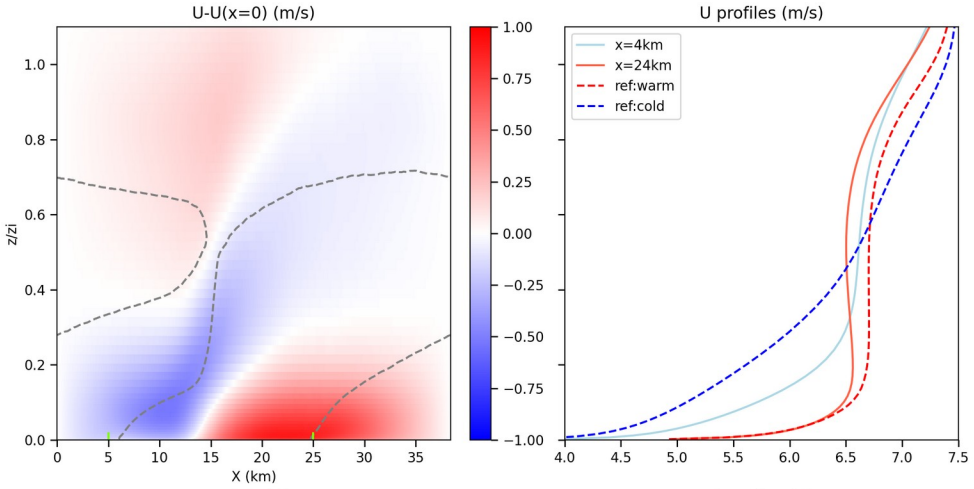
- Temporal mean from +2h to +6h
- Y mean from Y=0 to Y=2km
- X running average with window of 2km

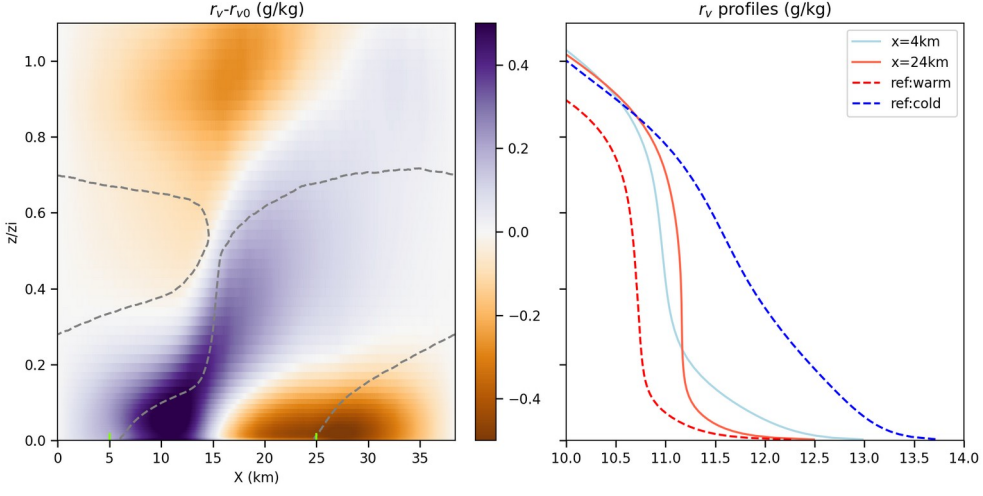
zi = 450m

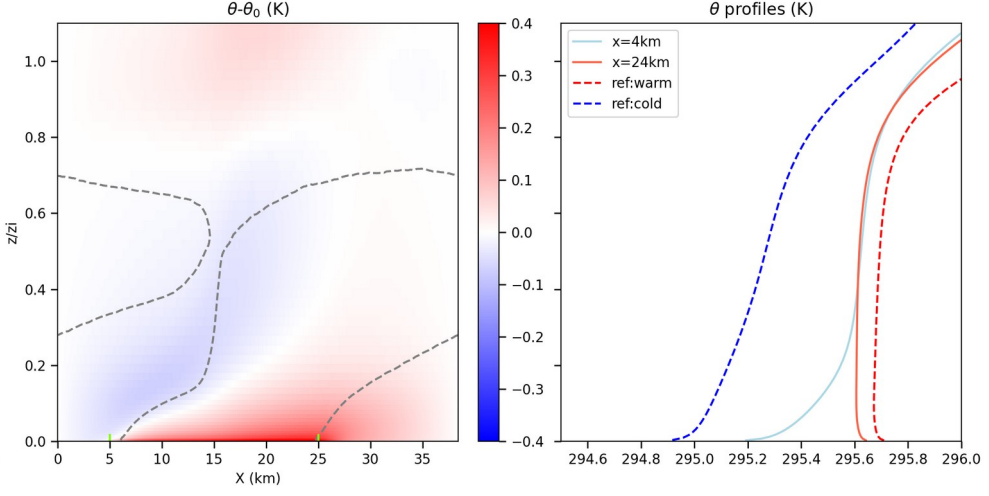
IBL criteria : dθ/dz = 5e-4 K/m

Mean fields

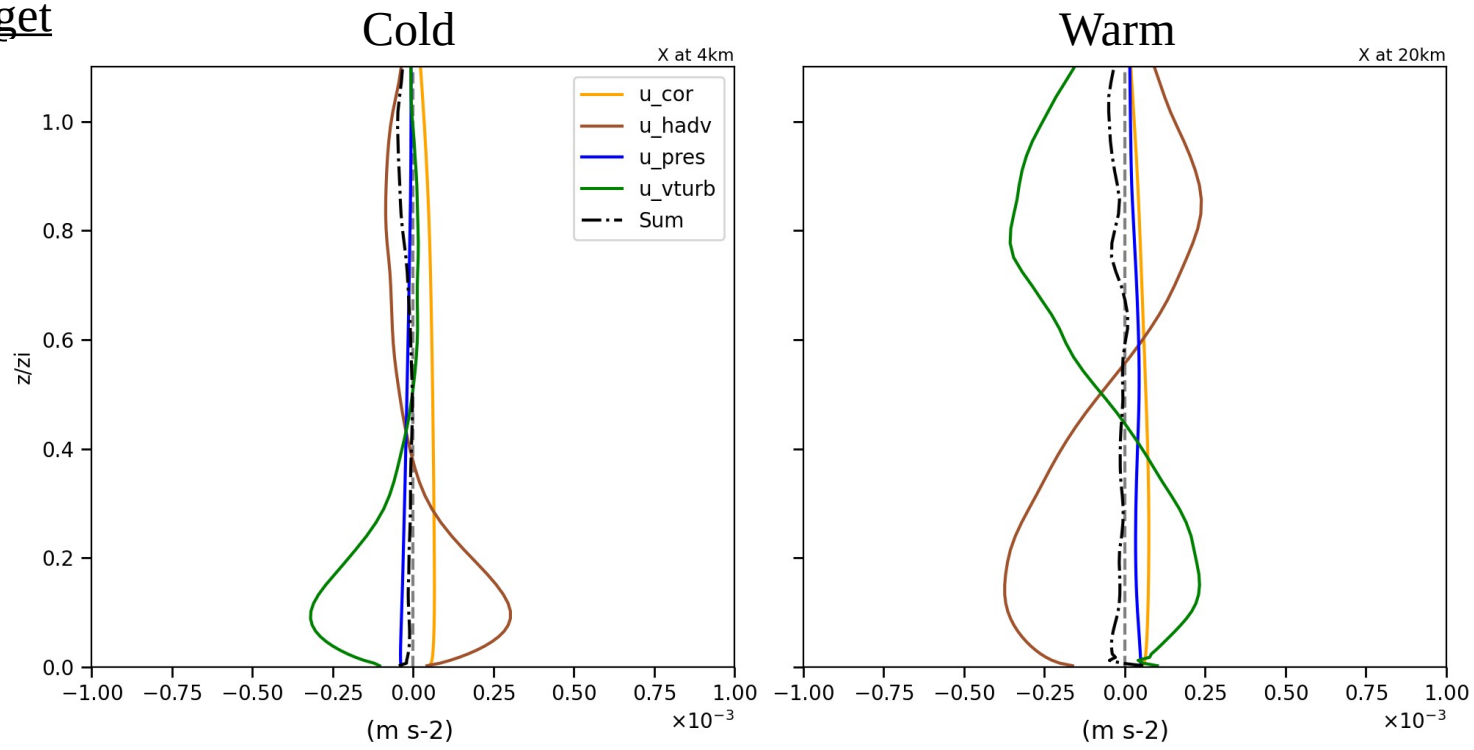
- U increases on warm SST
- 10km delay in U,Rv
- IBLs form





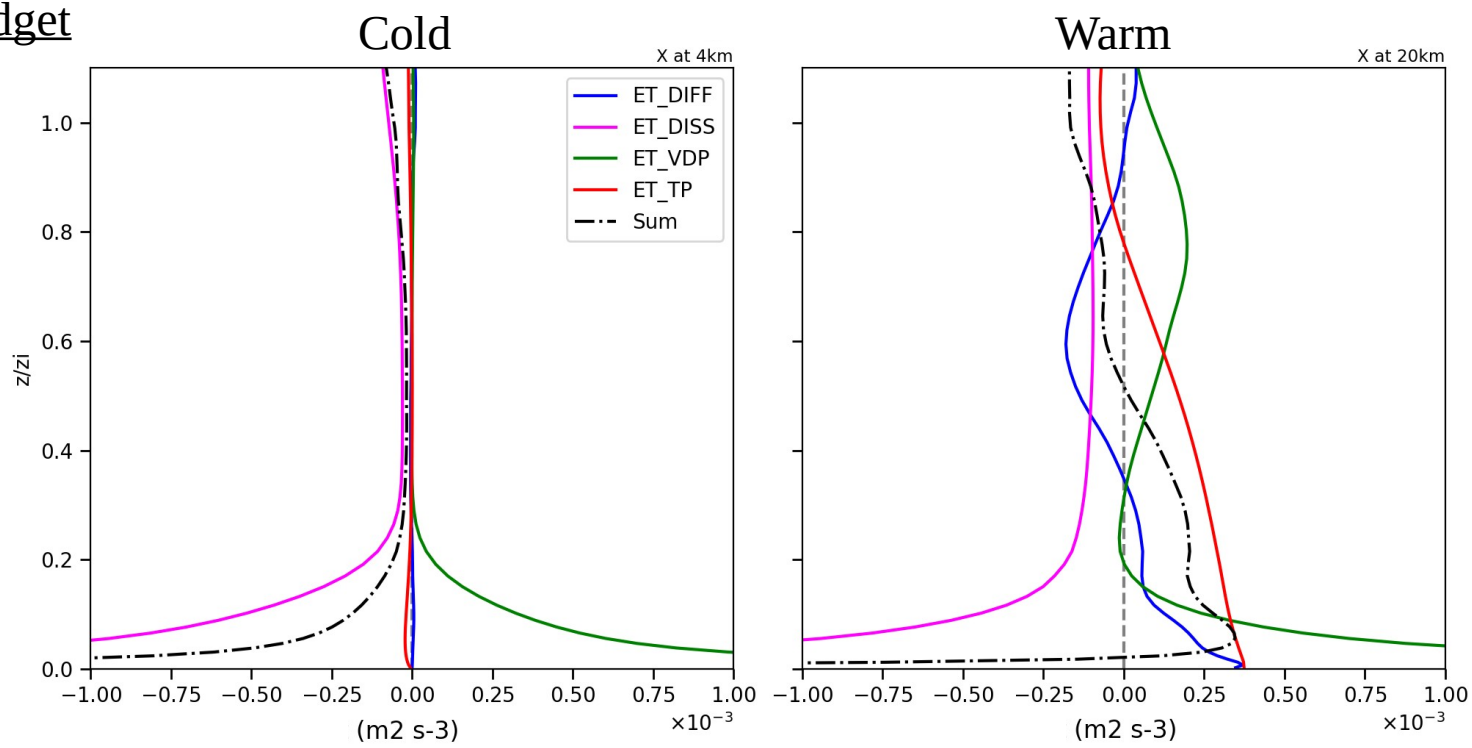


U Budget



$$\frac{\partial U}{\partial t} = -U\frac{\partial U}{\partial x} - \frac{1}{\rho_0}\frac{\partial < P' >}{\partial x} + fV - \frac{\partial < uw >}{\partial z}$$

ET Budget



$$\frac{\partial < E >}{\partial t} = -U_i \frac{\partial < E >}{\partial x_i} - < u_i u_j > \frac{\partial U_i}{\partial x_i} - (\frac{\partial < u_j E >}{\partial x_j} + \frac{1}{\rho_0} < u_i \frac{\partial p}{\partial x_i} >) + \frac{g}{\Theta_v} < w\theta_v > - < \varepsilon > + ...$$

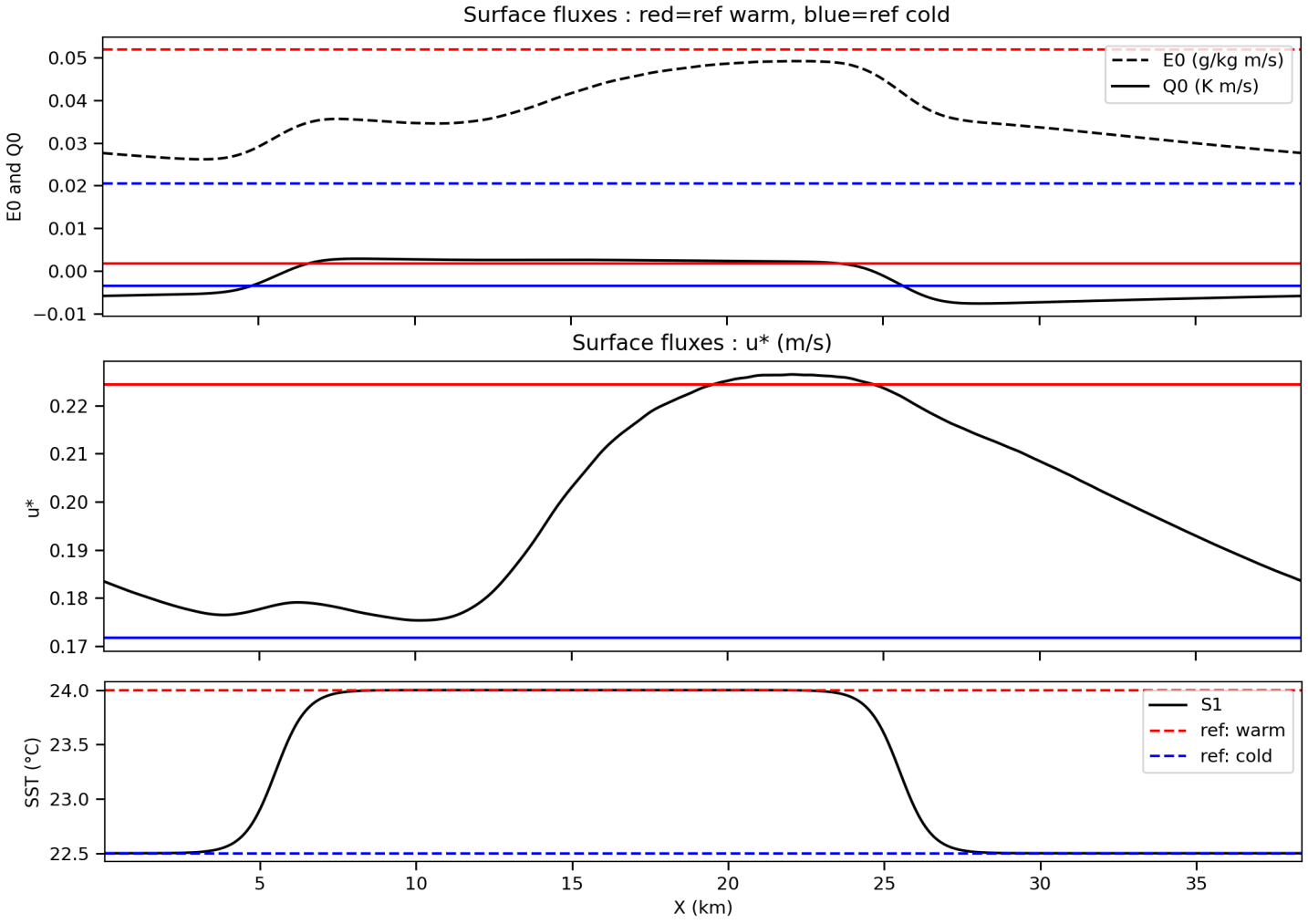
Conclusion

- ABL’s responses is far downwind
- Delay between wind and temperature fields
- DMM is the main mechanism

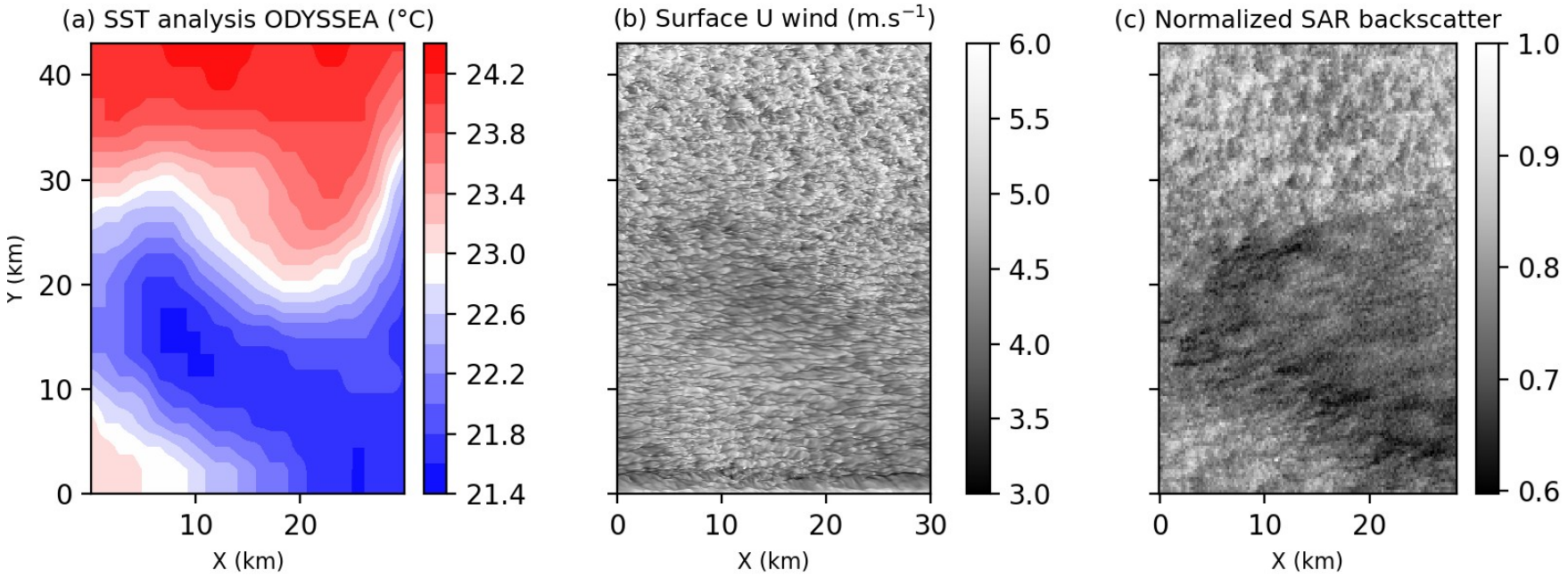
Next work

- Explore parameter space : stability, strength of the front, wind speed/direction, initial humidity and temperature
- Real case : Agulhas current at Δx=50m from Odyssea SST analysis

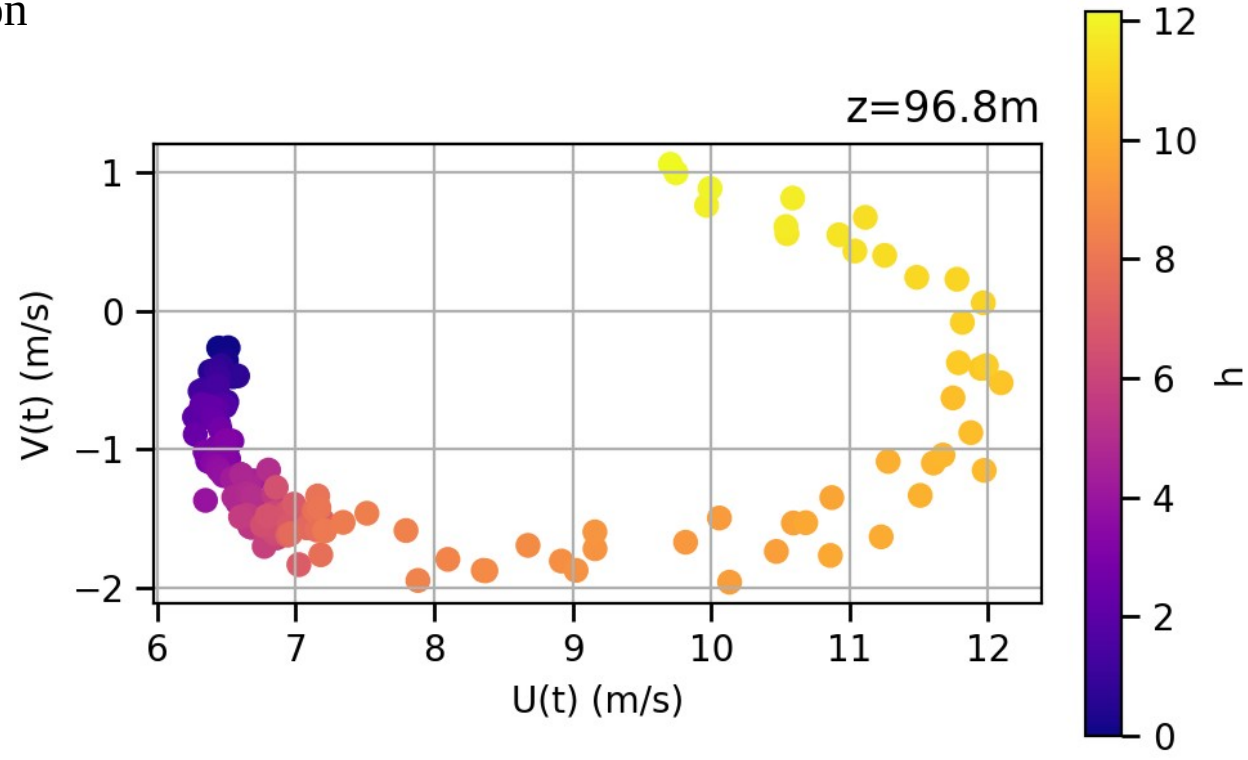
Surface fluxes of across front simulation



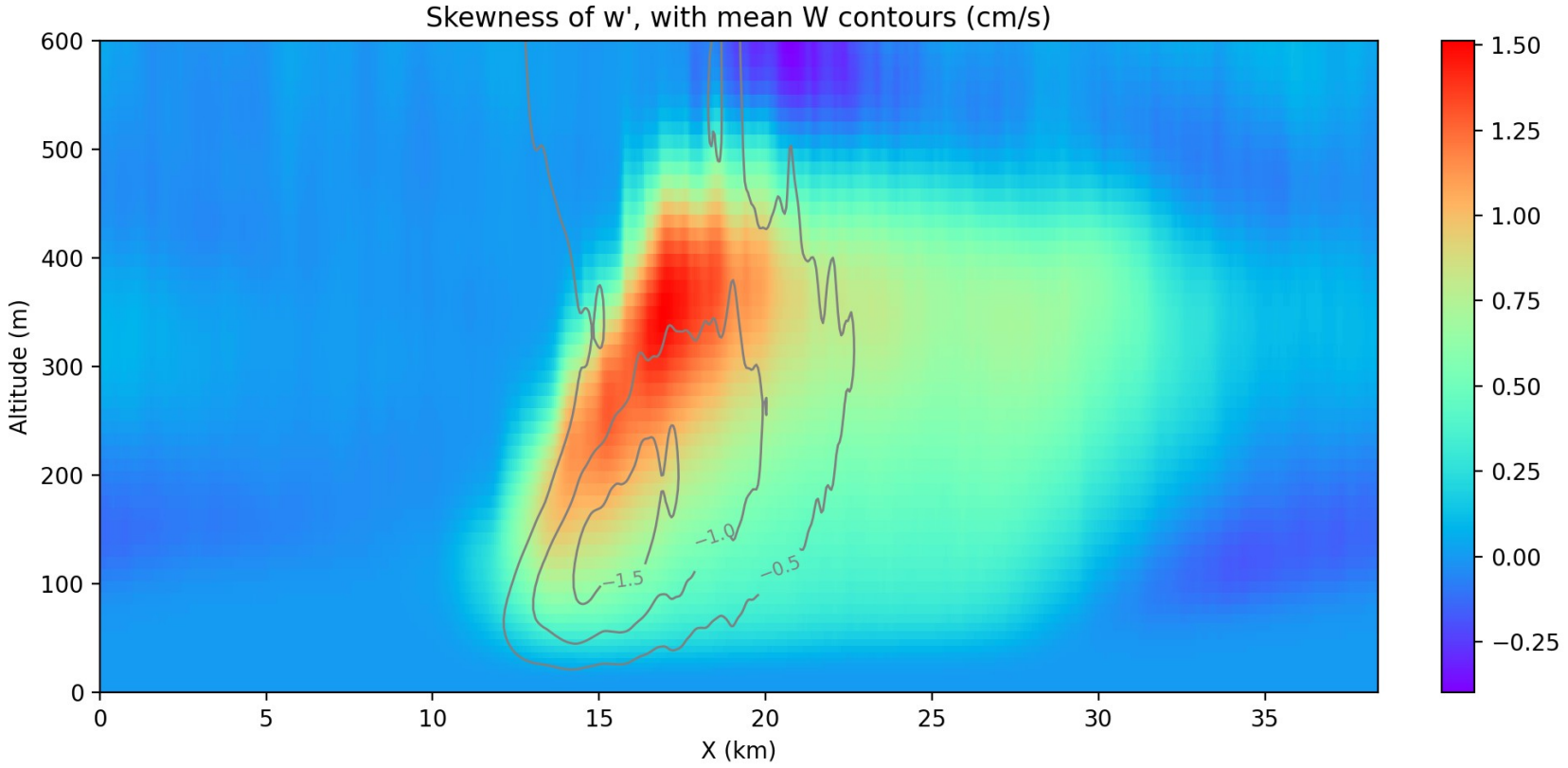
Simulation Agulhas current



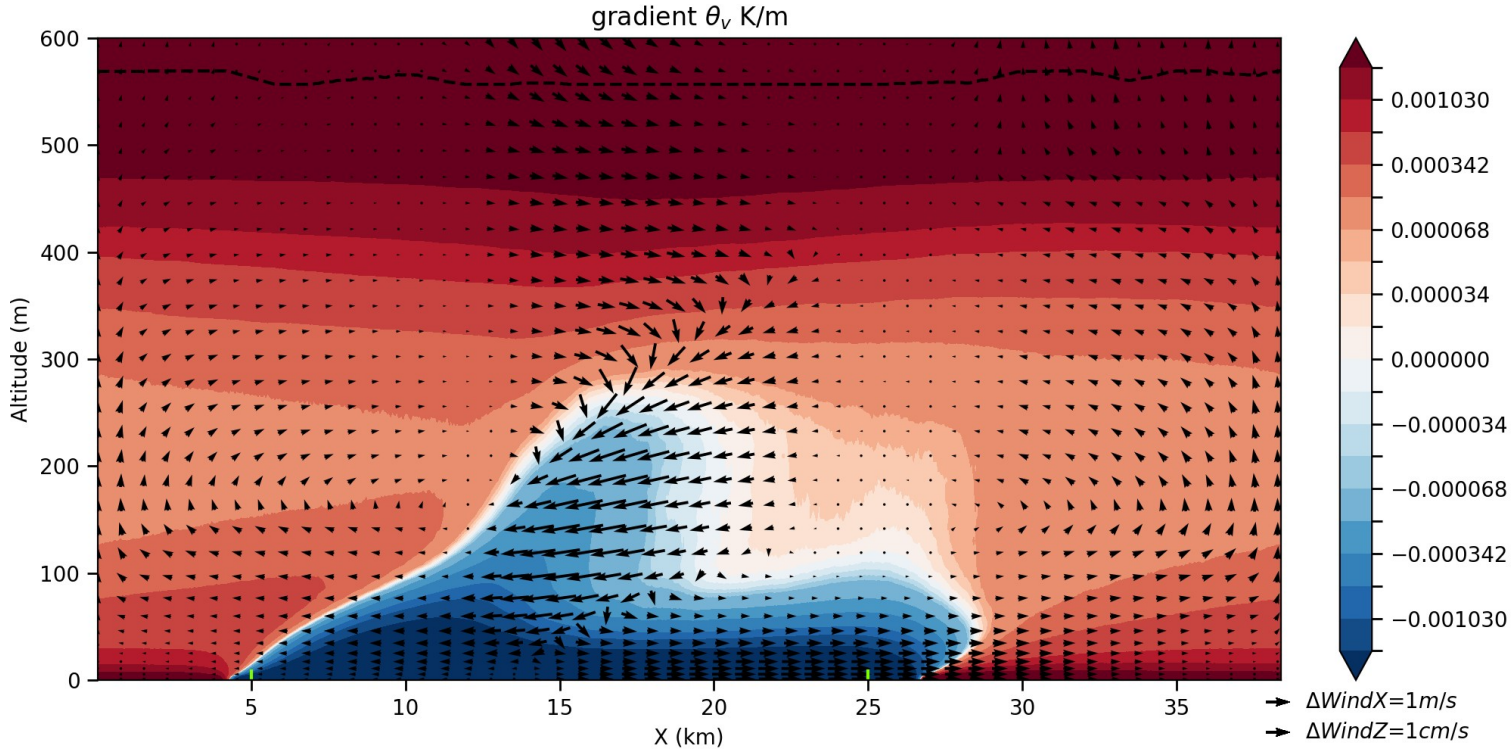
Inertial oscillation of across front simulation



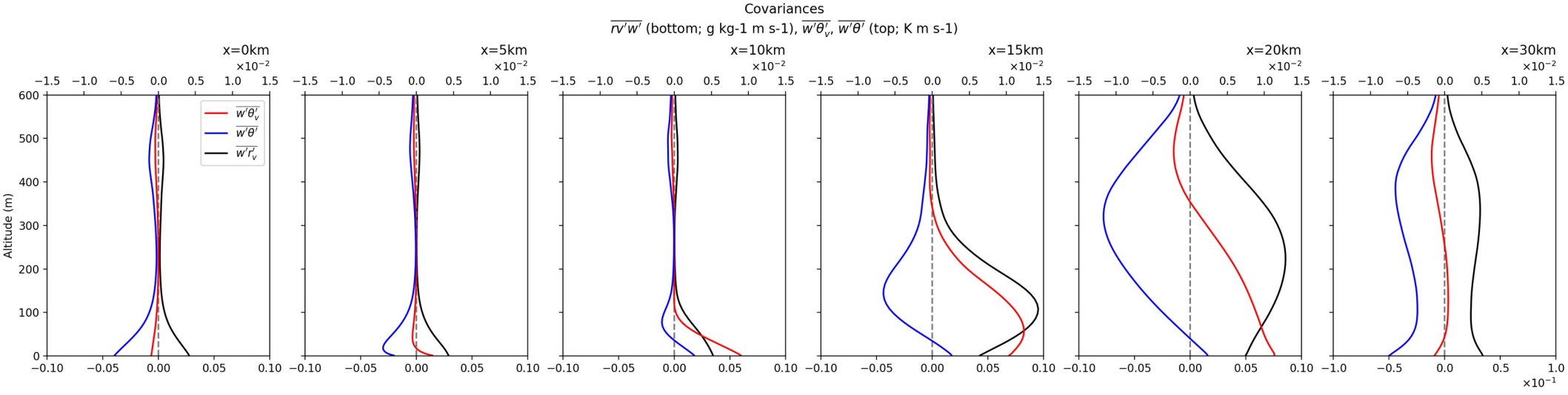
Skewness of w’ of across front simulation



Buoyancy and secondary circulation
of across front simulation



Fluxes profiles of across front simulation



Large scale

Ayet, A, Redelsperger, J-L. An analytical study of the atmospheric boundary-layer flow and divergence over an SST front. Q J R Meteorol Soc. 2019; 145: 2549–2567.https://doi.org/10.1002/qj.3578

O'Neill, L. W., D. B. Chelton, S. K. Esbensen, and F. J. Wentz, 2005: High-Resolution Satellite Measurements of the Atmospheric Boundary Layer Response to SST Variations along the Agulhas Return Current. J. Climate, 18, 2706–2723, https://doi.org/10.1175/JCLI3415.1

Wallace, J. M., T. P. Mitchell, and C. Deser, 1989: The Influence of Sea-Surface Temperature on Surface Wind in the Eastern Equatorial Pacific: Seasonal and Interannual Variability. J. Climate, 2, 1492–1499, https://doi.org/10.1175/1520-0442(1989)002<1492:TIOSST>2.0.CO;2

Spall, M. A., 2007: Midlatitude Wind Stress–Sea Surface Temperature Coupling in the Vicinity of Oceanic Fronts. J. Climate, 20, 3785–3801, https://doi.org/10.1175/JCLI4234.1.

Kilpatrick, T., N. Schneider, and B. Qiu, 2014: Boundary Layer Convergence Induced by Strong Winds across a Midlatitude SST Front. J. Climate, 27, 1698–1718, https://doi.org/10.1175/JCLI-D-13-00101.1.

Perlin, N., S. P. de Szoeke, D. B. Chelton, R. M. Samelson, E. D. Skyllingstad, and L. W. O'Neill, 2014: Modeling the Atmospheric Boundary Layer Wind Response to Mesoscale Sea Surface Temperature Perturbations. Mon. Wea. Rev., 142, 4284–4307, https://doi.org/10.1175/MWR-D-13-00332.1.

Submesoscale

Sullivan, P. P., J. C. McWilliams, J. C. Weil, E. G. Patton, and H. J. S. Fernando, 2020: Marine Boundary Layers above Heterogeneous SST: Across-Front Winds. J. Atmos. Sci., 77, 4251–4275, https://doi.org/10.1175/JAS-D-20-0062.1.

Samelson, R. M., E. D. Skyllingstad, D. B. Chelton, S. K. Esbensen, L. W. O'Neill, and N. Thum, 2006: On the Coupling of Wind Stress and Sea Surface Temperature. J. Climate, 19, 1557–1566, https://doi.org/10.1175/JCLI3682.1.

Skyllingstad, E.D., Vickers, D., Mahrt, L. et al. Effects of mesoscale sea-surface temperature fronts on the marine atmospheric boundary layer. Boundary-Layer Meteorol 123, 219–237 (2007). https://doi.org/10.1007/s10546-006-9127-8

Wenegrat, J. O., & Arthur, R. S. (2018). Response of the atmospheric boundary layer to submesoscale sea surface temperature fronts. Geophysical Research Letters, 45, 13,505–13,512. https://doi.org/10.1029/2018GL081034

Lambaerts, J., Lapeyre, G., Plougonven, R., and Klein, P. (2013), Atmospheric response to sea surface temperature mesoscale structures, J. Geophys. Res. Atmos., 118, 9611–9621, doi:10.1002/jgrd.50769.

Redelsperger, J-L, Bouin, M-N, Pianezze, J, Garnier, V, Marié, L. Impact of a sharp, small-scale SST front on the marine atmospheric boundary layer on the Iroise Sea: Analysis from a hectometric simulation. Q J R Meteorol Soc. 2019; 145: 3692–3714. https://doi.org/10.1002/qj.3650