Two-sided turbulent boundary layer parameterizations for assessing ocean – atmosphere fluxes

F. Lemarié [1] **C. Pelletier [1,2]** E. Blayo [1] M.-N. Bouin [3] J.-L. Redelsperger [4]

EGU2020: Sharing Geosciences Online, May 2020

[1] Univ. Grenoble Alpes, Inria, LJK, Grenoble, France

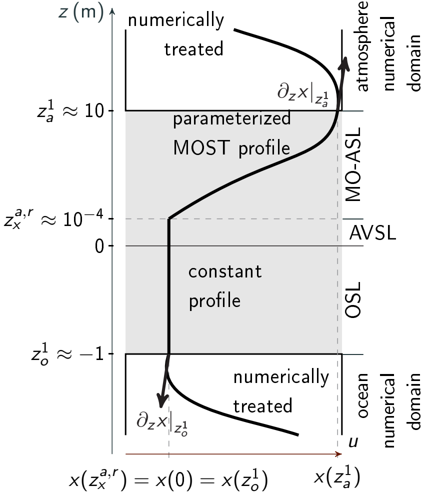
[2] ELIC/TECLIM, UCLouvain, Louvain-la-Neuve, Belgium

[3] Centre de Météo Marine, Météo-France, Brest, France

[4] CNRS, LOPS, IRD, Univ. Brest Occidentale, IFREMER, Brest, France

ANR COCOA (French national research agency), grant ANR-16-CE01-0007.

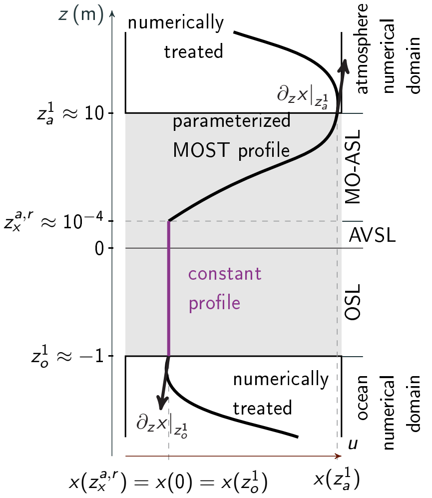
Motivations



MOST: Monin-Obukhov similarity theory. SL: surface layer. MO-ASL: MOST atmosphere layer. MO-OSL: MOST ocean layer. VSL: viscous sublayer.

Turbulent air-sea fluxes are determined from atmosphere, MOST-derived bulk formulae, which:

Motivations

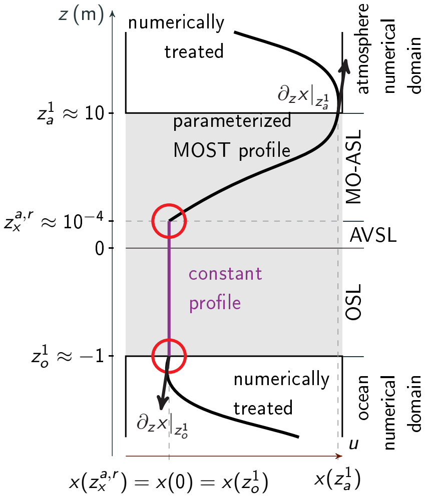


MOST: Monin-Obukhov similarity theory. SL: surface layer. MO-ASL: MOST atmosphere layer. MO-OSL: MOST ocean layer. VSL: viscous sublayer.

Turbulent air-sea fluxes are determined from atmosphere, MOST-derived bulk formulae, which:

- **Neglect** the ocean and viscous parts of the SL.

Motivations

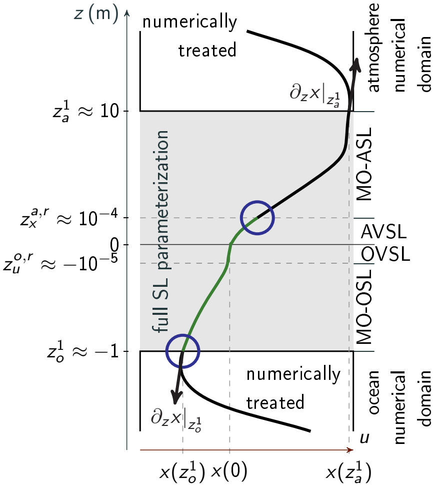


MOST: Monin-Obukhov similarity theory. SL: surface layer. MO-ASL: MOST atmosphere layer. MO-OSL: MOST ocean layer. VSL: viscous sublayer.

Turbulent air-sea fluxes are determined from atmosphere, MOST-derived bulk formulae, which:

- **Neglect** the ocean and viscous parts of the SL.
- Lead to **numerical irregularities** inbetween subparts of the SL.

Motivations



MOST: Monin-Obukhov similarity theory. SL: surface layer. MO-ASL: MOST atmosphere layer. MO-OSL: MOST ocean layer. VSL: viscous sublayer.

Turbulent air-sea fluxes are determined from atmosphere, MOST-derived bulk formulae, which:

- **Neglect** the ocean and viscous parts of the SL.
- Lead to **numerical irregularities** inbetween subparts of the SL.

Introducing an **idealized framework** for extending existing formulae to **two-sided versions**, ensuring:

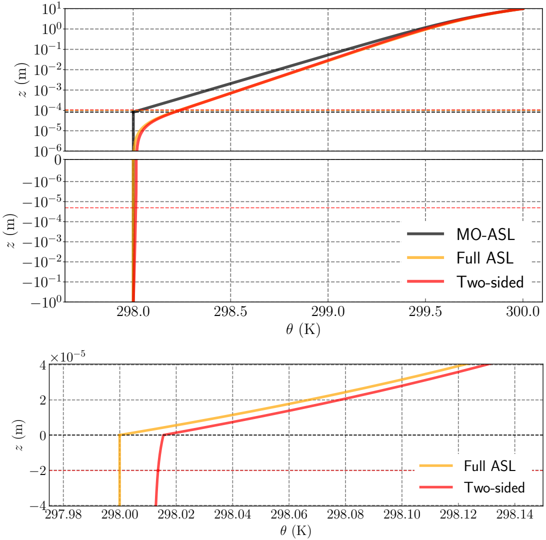
- **regularity**;
- **comprehensiveness**.

Comprehensive surface layer parameterization

SL-comprehensive $\mathbf{u}_h$ and θ_v profiles are derived from:

1. turbulent flux conservation;
2. a choice of roughness length parameterization and viscous profiles;
3. transmission conditions (e.g., viscous stress) at $z = 0$;

Regularity is ensured **by design**, except at $z = 0$, which is a **physical interface**.



Top: θ surface layer profiles resulting from different closure types; bottom: zoom around $z = 0$.

Impact on air-sea fluxes

Impact on turbulent fluxes via (u_a^*, θ_a^*), from **integrating $\mathbf{u_h}$** and θ_v profiles on the SL.

$$\frac{\kappa \Delta\theta}{\theta_a^*} = \ln\left(\frac{z_a^1}{z_\theta^{a,r}\left(\mathbf{x}_a^*\right)}\right) - \psi_h\left(\frac{z_a^1}{L_O^a\left(\mathbf{x}_a^*\right)}\right)$$

Analogous for $\|\mathbf{u_h}\|$. ψ_h: stability function; L_O^a: atm. Obukhov length

Impact on air-sea fluxes

Impact on turbulent fluxes via (u_a^*, θ_a^*), from **integrating $\mathbf{u_h}$** and θ_v profiles on the SL.

New contributions from the **viscous sublayers**

$$\frac{\kappa \Delta\theta}{\theta_a^*} = \ln\left(\frac{z_a^1}{z_\theta^{a,r}(\mathbf{x}_a^*)}\right) - \psi_h\left(\frac{z_a^1}{L_O^a(\mathbf{x}_a^*)}\right) + (1+\lambda_\theta)(\mathrm{e}-1)$$

Analogous for $\|\mathbf{u_h}\|$. ψ_h: stability function; L_O^a: atm. Obukhov length; $\lambda_\theta = \frac{\sqrt{\rho_a} c_p^a}{\sqrt{\rho_o} c_p^o}$

Impact on air-sea fluxes

Impact on turbulent fluxes via (u_a^*, θ_a^*), from **integrating $\mathbf{u_h}$** and θ_v profiles on the SL.

New contributions from the **viscous sublayers** and the **ocean SL**:

$$\frac{\kappa \Delta\theta}{\theta_a^*} = \ln\left(\frac{z_a^1}{z_\theta^{a,r}(\mathbf{x}_a^*)}\right) - \psi_h\left(\frac{z_a^1}{L_O^a(\mathbf{x}_a^*)}\right) + (1+\lambda_\theta)(\mathrm{e}-1) + \lambda_\theta \ln\left(\frac{z_o^1}{z_\theta^{o,r}(\mathbf{x}_a^*)}\right) - \lambda_\theta \psi_h\left(\frac{-z_o^1}{L_O^o(\mathbf{x}_o^*)}\right)$$

Analogous for $\|\mathbf{u_h}\|$. ψ_h: stability function; L_O^a: atm. Obukhov length; $\lambda_\theta = \frac{\sqrt{\rho_a} c_p^a}{\sqrt{\rho_o} c_p^o}$; L_O^o: ocean Obukhov length.

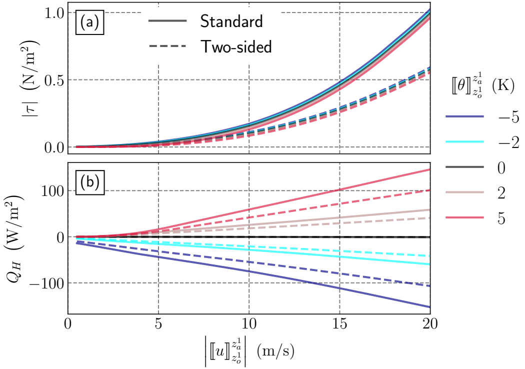
Impact on air-sea fluxes

Impact on turbulent fluxes via (u_a^*, θ_a^*), from **integrating $\mathbf{u_h}$** and θ_v profiles on the SL.

New contributions from the **viscous sublayers** and the **ocean SL**:

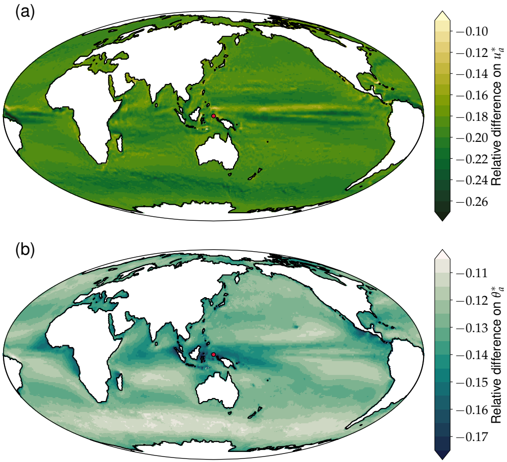
$$\frac{\kappa\Delta\theta}{\theta_a^*} = \ln\left(\frac{z_a^1}{z_\theta^{a,r}(\mathbf{x}_a^*)}\right) - \psi_h\left(\frac{z_a^1}{L_O^a(\mathbf{x}_a^*)}\right) + (1+\lambda_\theta)(\mathrm{e}-1) + \lambda_\theta \ln\left(\frac{z_o^1}{z_\theta^{o,r}(\mathbf{x}_a^*)}\right) - \lambda_\theta\psi_h\left(\frac{-z_o^1}{L_O^o(\mathbf{x}_o^*)}\right)$$

Analogous for $\|\mathbf{u_h}\|$. ψ_h: stability function; L_O^a: atm. Obukhov length; $\lambda_\theta = \frac{\sqrt{\rho_a}c_p^a}{\sqrt{\rho_o}c_p^o}$; L_O^o: ocean Obukhov length.



- Two-sided closures lead to **dampened fluxes**.
- Results from using **one-sided roughness parameterizations** in a two-sided context.
- Calls for **calibrating bulk formulae anew**, taking into account the two-sided closure above.

Conclusions



Time-averaged (year 2006) relative difference on turbulent scales arising from using two-sided bulk closures, using ERA-Interim (atmosphere) and GLORYS2v4 (ocean) near-surface data.

- Introduced an idealized framework for extending existing bulk formulae to **two-sided** versions.
- Adapted to **coupled ocean-atmosphere numerical simulations**, which use $\theta(z = -1\text{m})$ as ocean temperature, **yet** with bulk closures derived from **surface measurements**.
- Considerable room for enhancement through **retuning** and **new physics** (e.g. radiation penetration, wave-induced surface deformation).