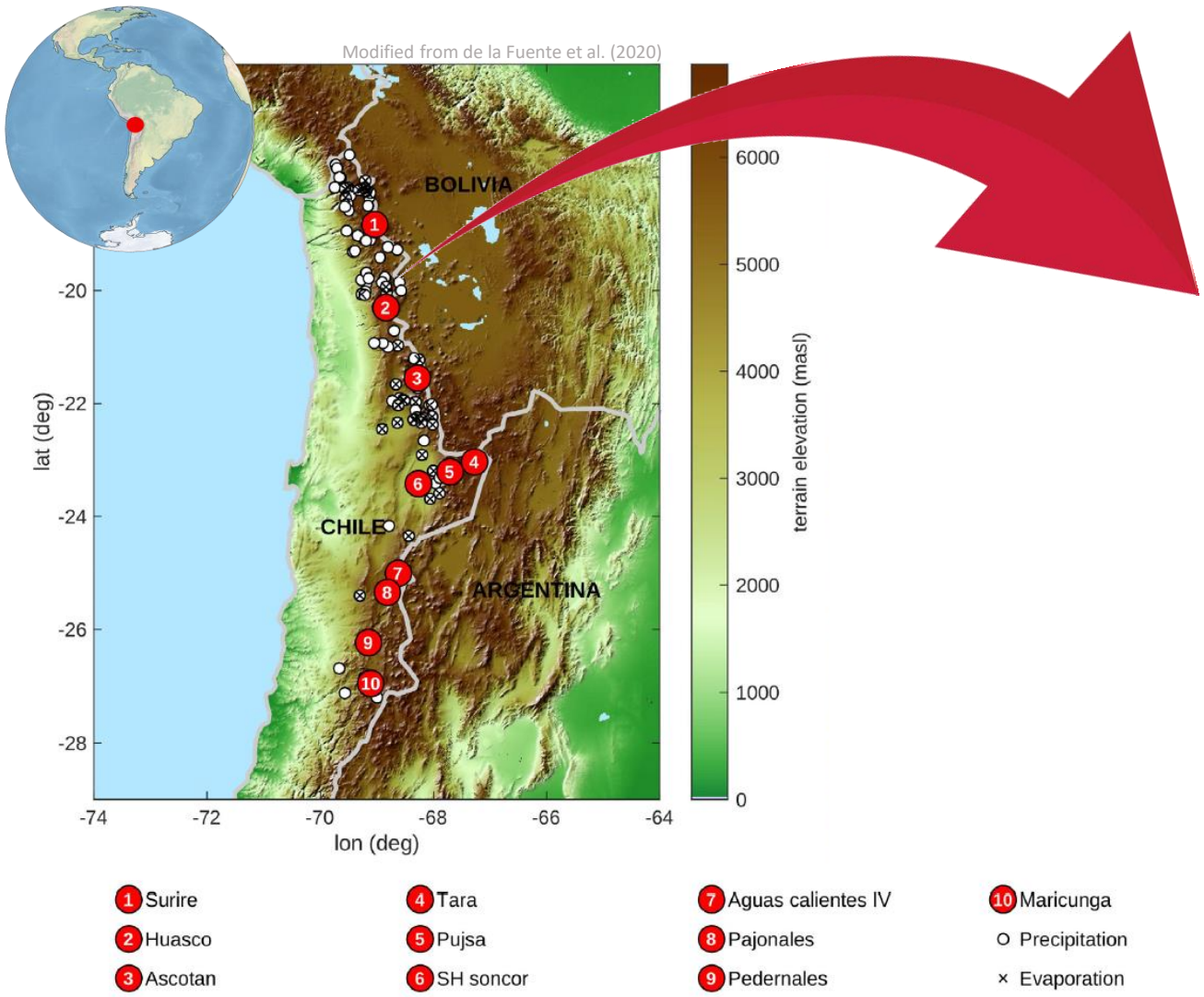
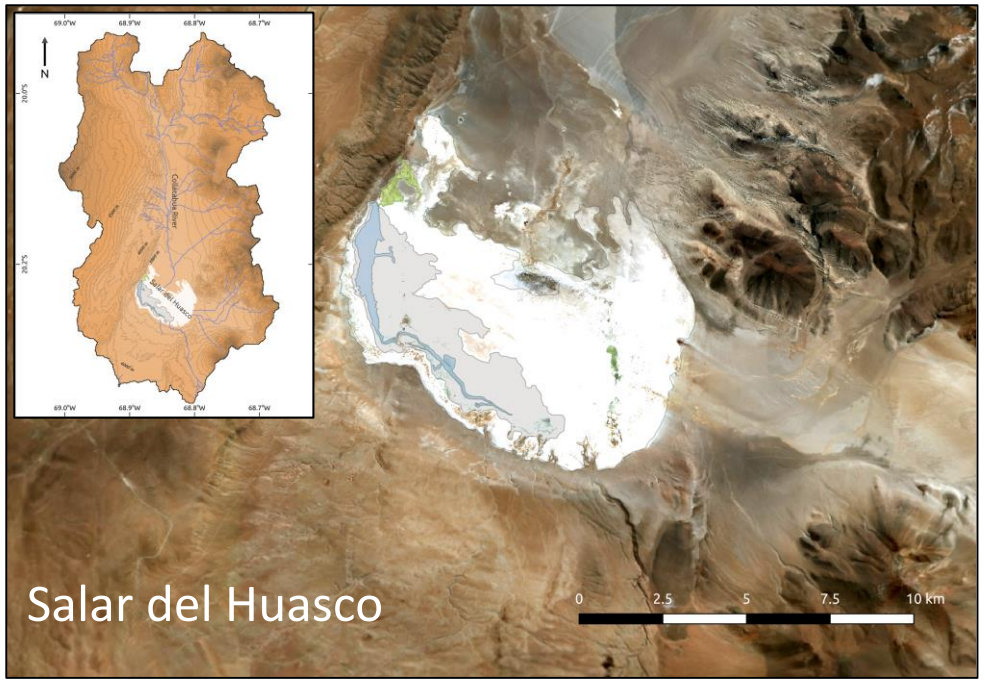
Evaporation driven by atmospheric boundary layer processes over a shallow salt-water lagoon in the Altiplano Desert

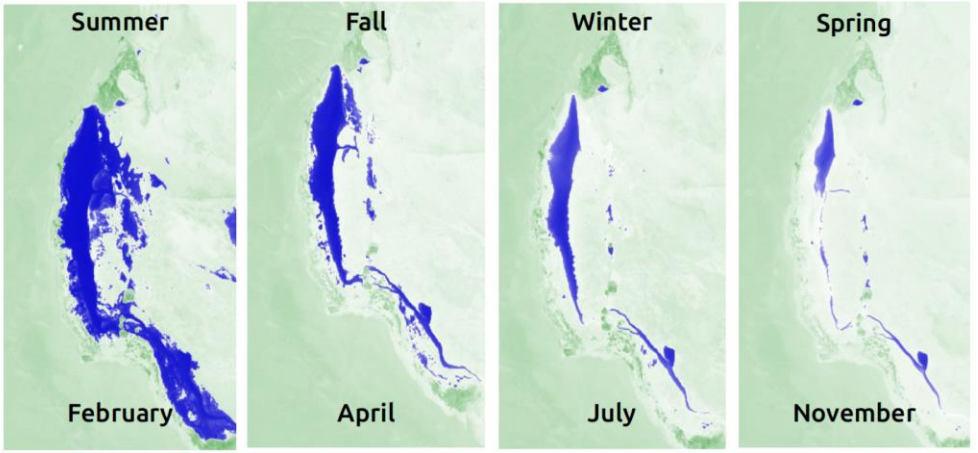
Francisca Aguirre-Correa*, Jordi Vilà-Guerau de Arellano, Reinder Ronda, Felipe Lobos-Roco, Francisco Suárez, and Oscar Hartogensis

Credits to Oscar Hartogensis

In the Altiplano (~1500 km) water is evaporated from highly localized environments (~10 km)

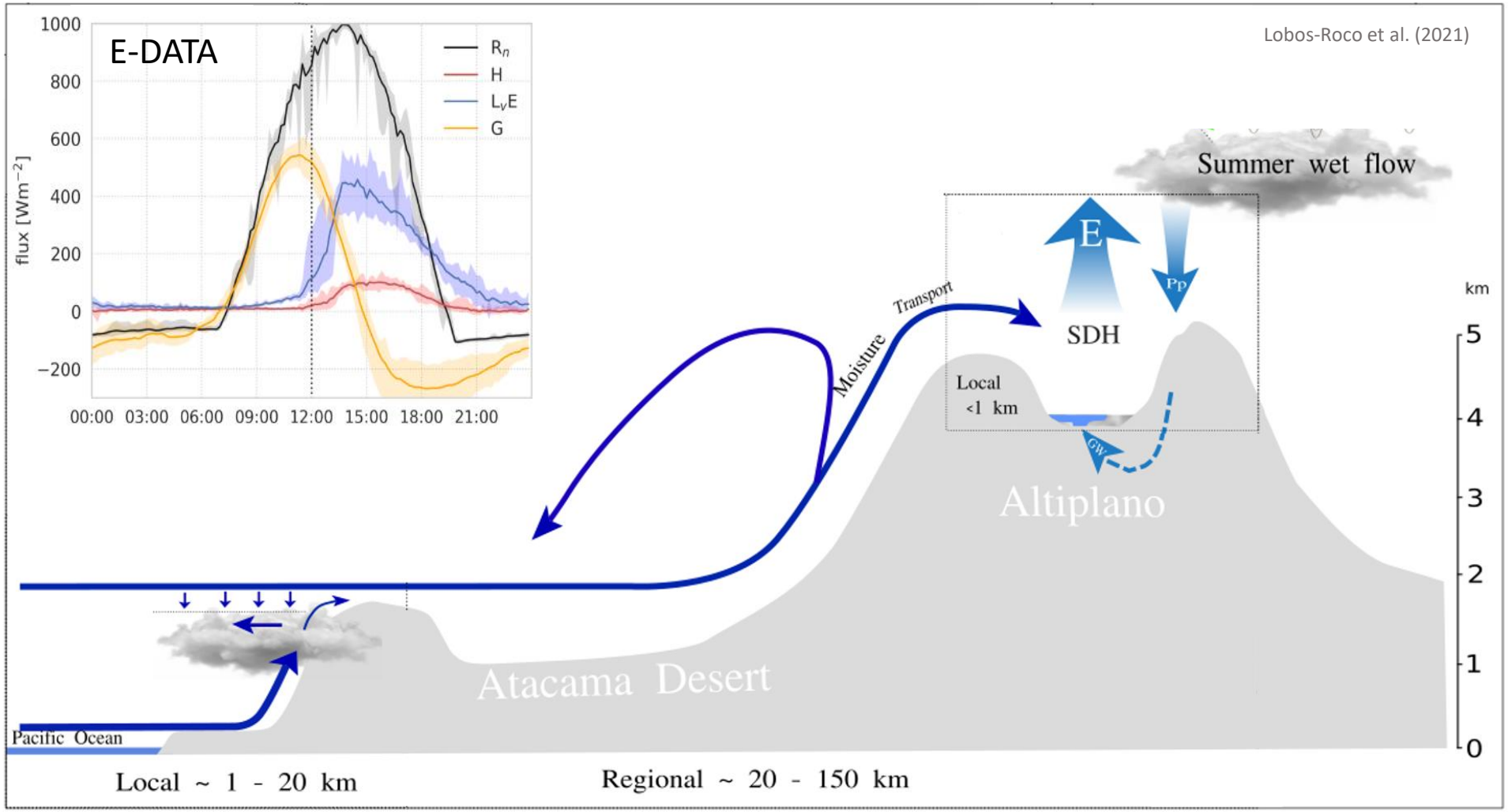






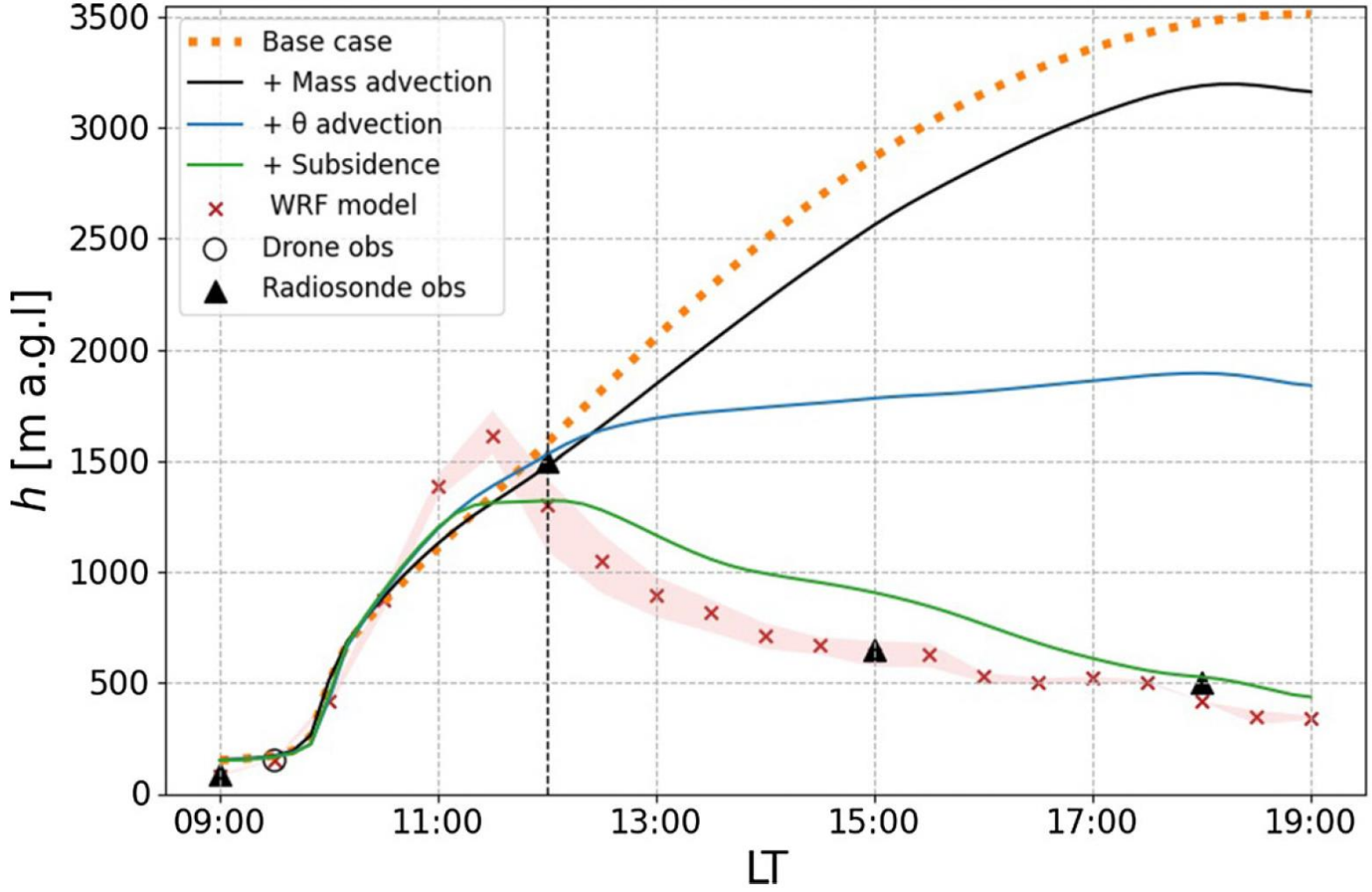
Lobos-Roco et al. (2021)

Local E is controlled by interactions with large-scale forcing driven by the steep topography and the Pacific Ocean



What role does the atmospheric boundary layer play in all of this?

Desert surface: Aguirre-Correa et al. (2023) in Boundary Layer Meteorology



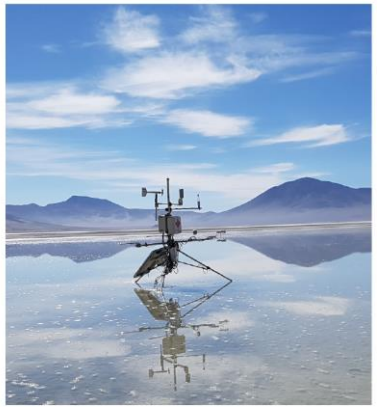
We use an Adapted Penman equation to salt-water conditions as a diagnostic tool for E

Radiative contribution

Aerodynamic contribution

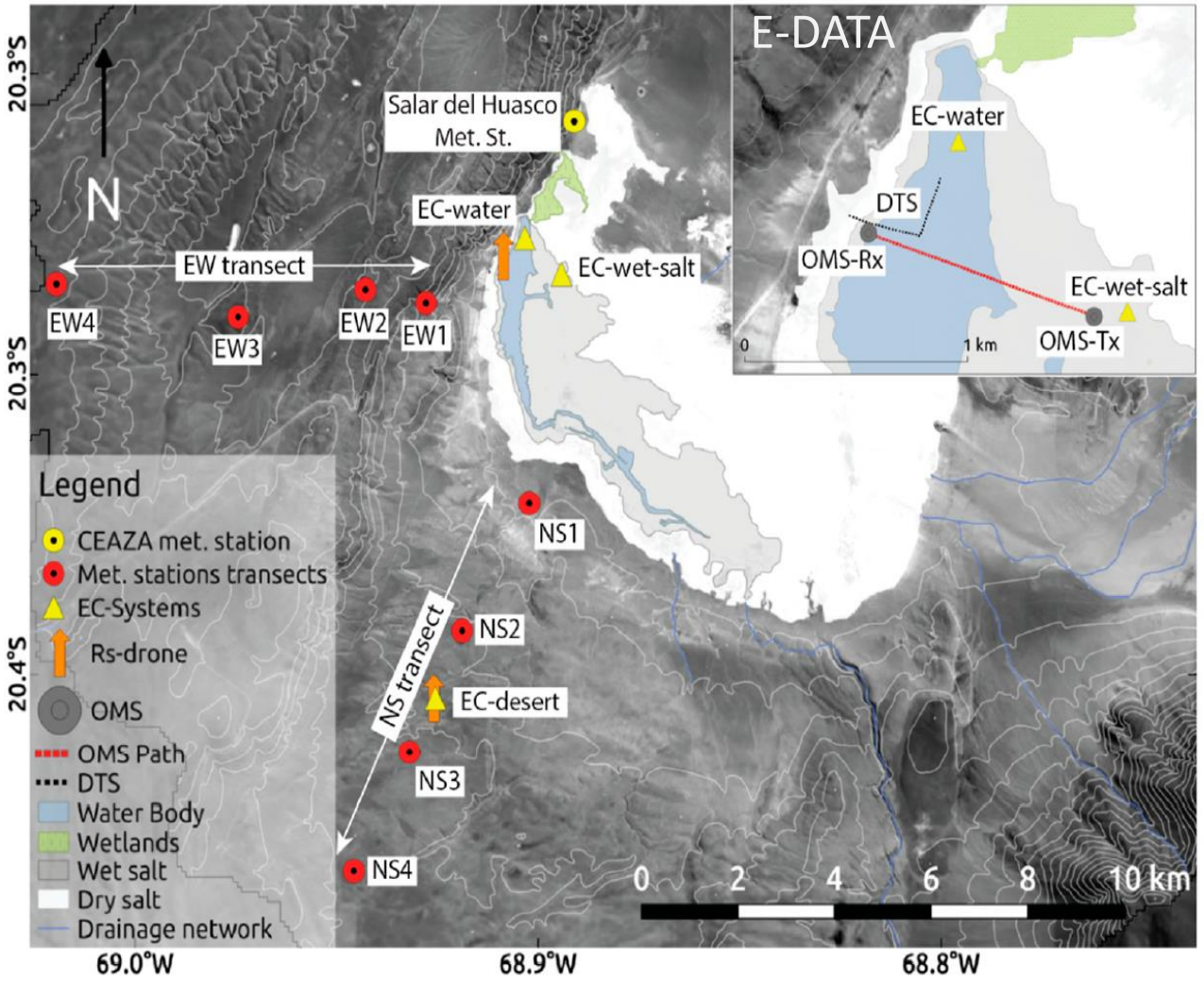
$$LE = \frac{s(RN - G) + \frac{\rho c_p}{r_a + r_{salt}}\left(q_{sat} - \frac{q}{a_w}\right)}{s + \frac{\gamma}{a_w}}$$

Calder and Neal (1984)

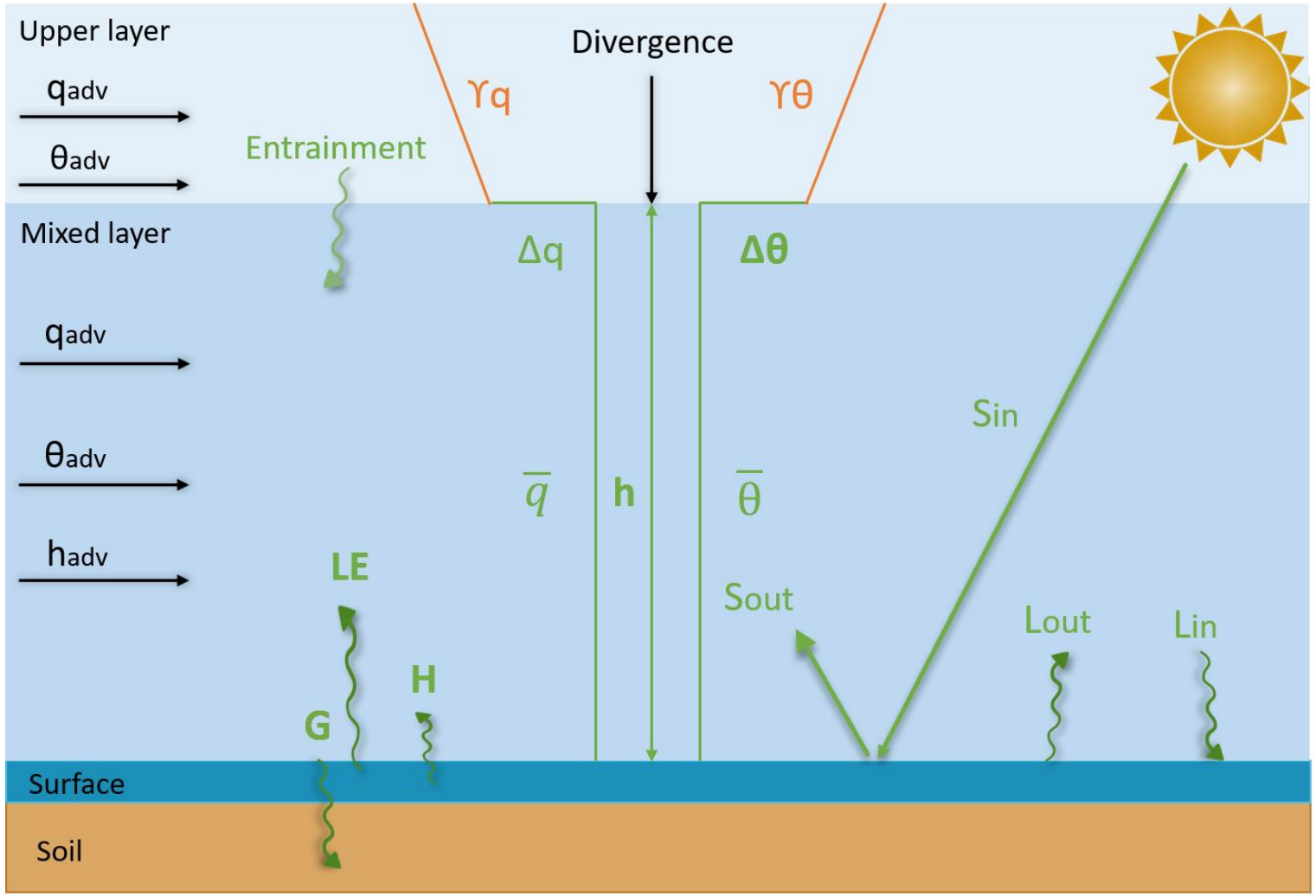


Credits to Oscar Hartogensis

Suárez et al. (2020)



We use a land-atmosphere conceptual model to analyse the drivers of evaporation

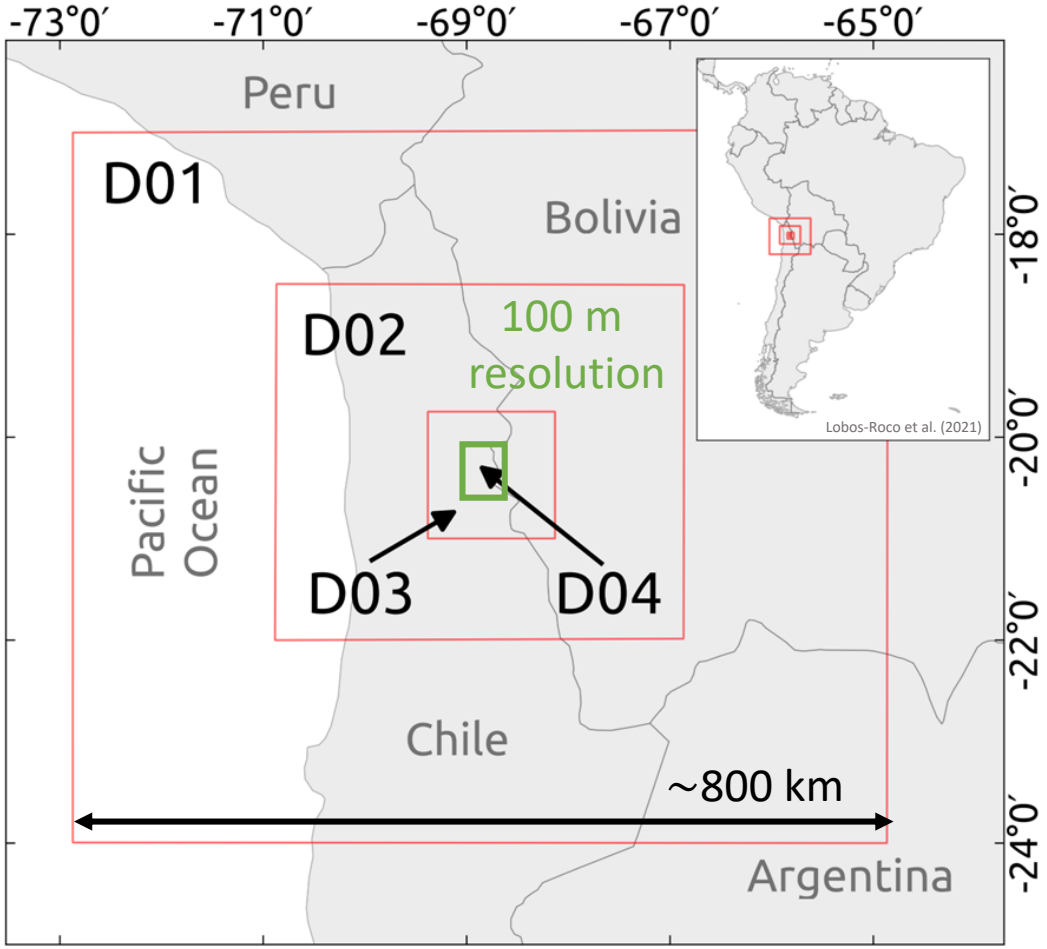


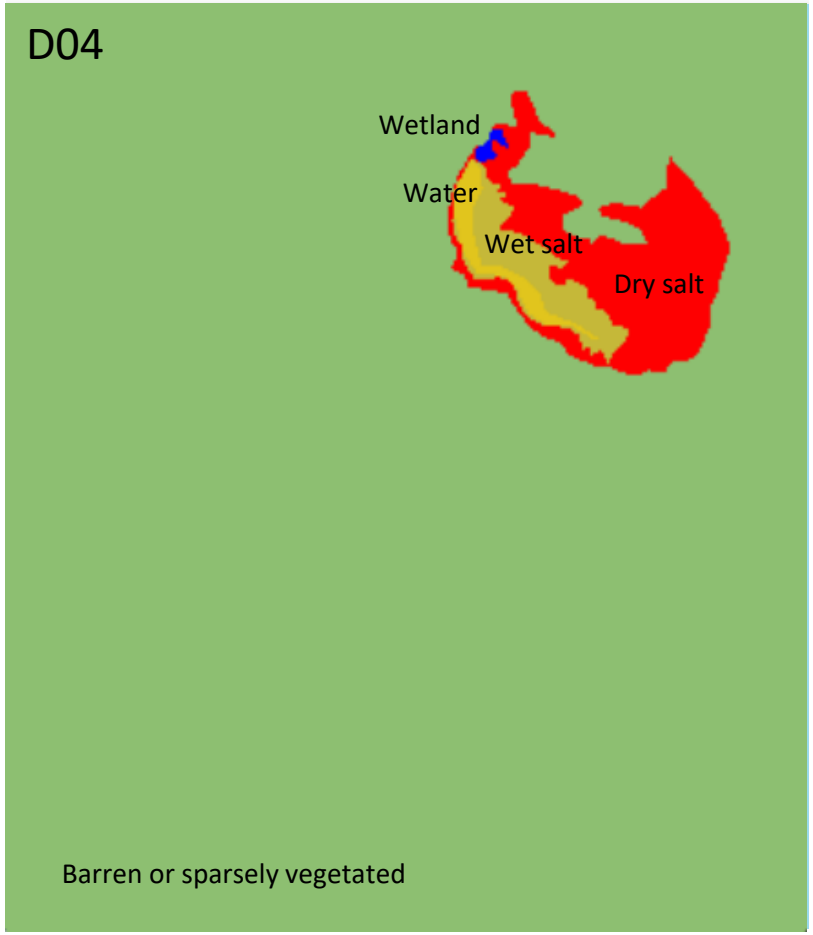
$$\frac{\delta \bar{q}}{\delta t} = \frac{\frac{LE}{\rho L_v} + w_e \Delta q}{h} + q_{adv}$$

$$\frac{\delta \bar{\theta}}{\delta t} = \frac{\frac{H}{\rho c_p} + w_e \Delta \theta}{h} + \theta_{adv}$$

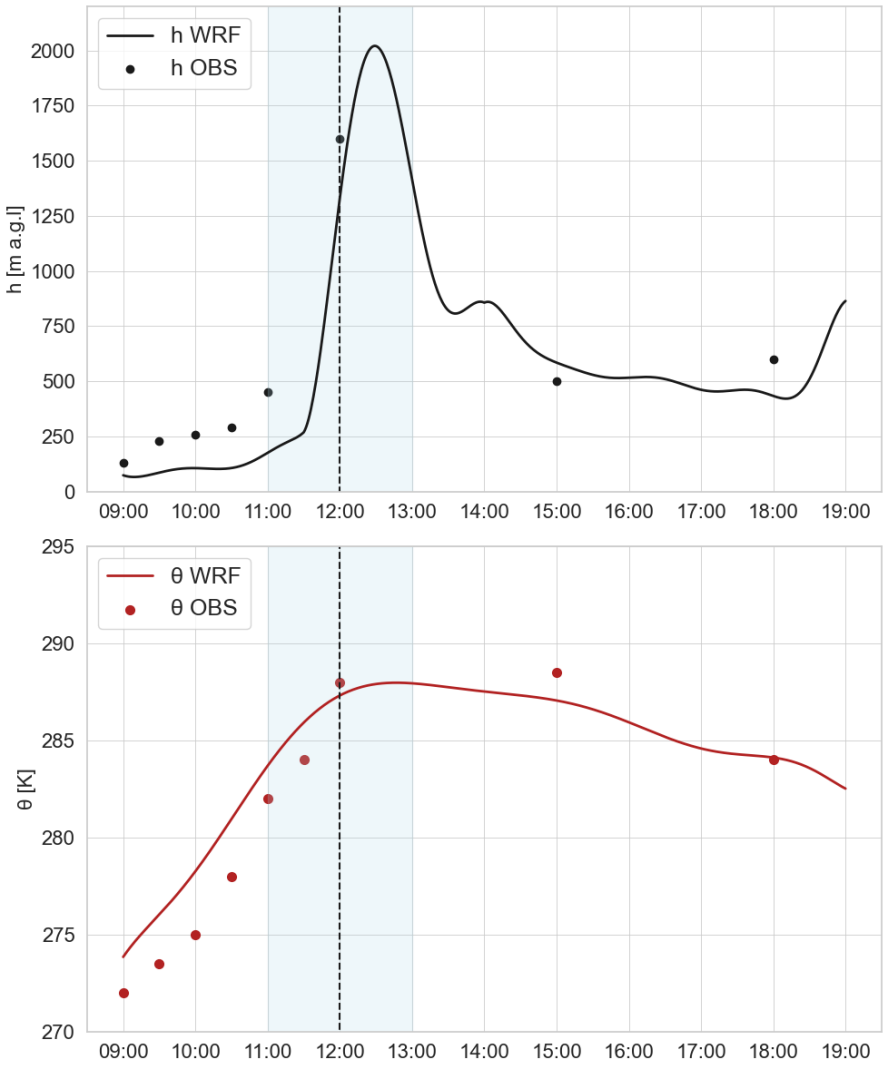
$$\frac{\delta h}{\delta t} = w_e + Div\left(\overrightarrow{U_h}\right) h + h_{adv}$$

We use WRF-LES model to characterize the regional transport and better represent the local atmosphere





Understanding the atmospheric boundary layer dynamics



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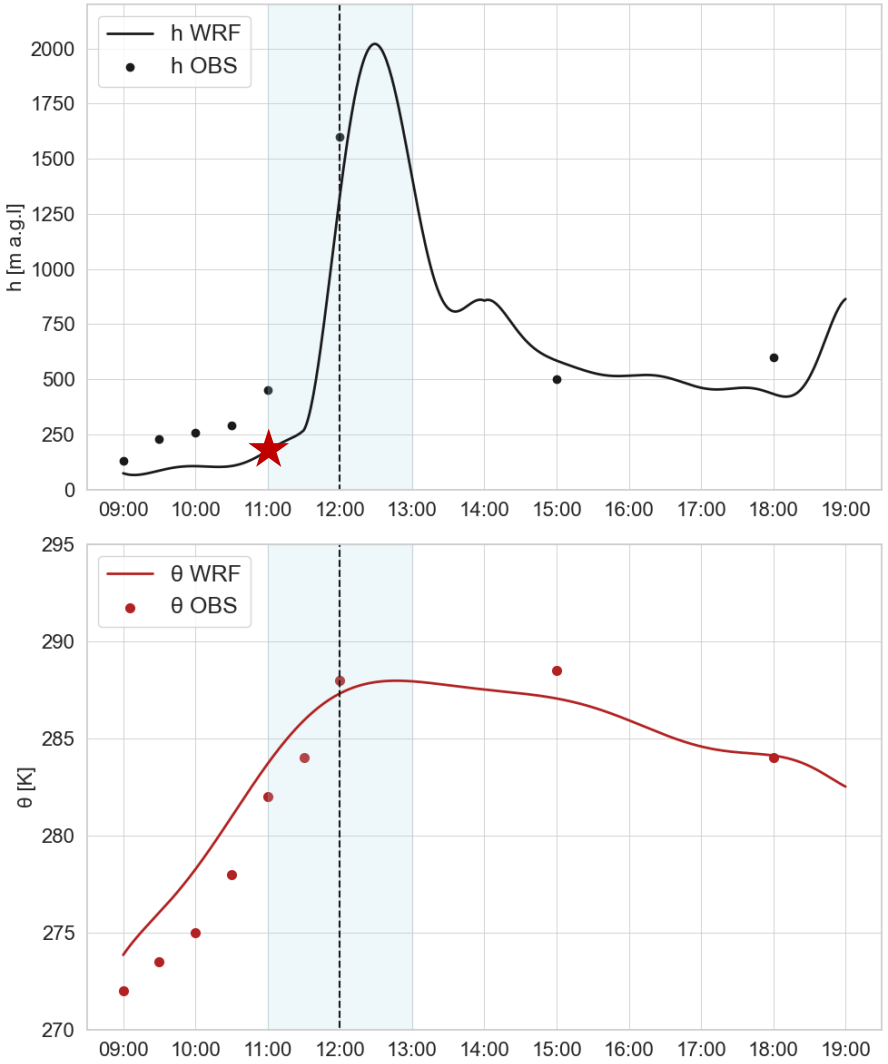

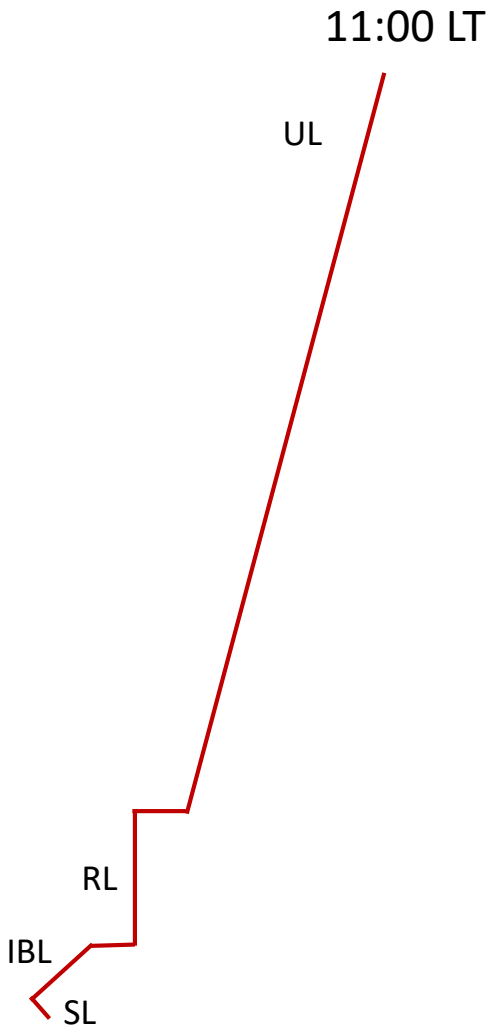

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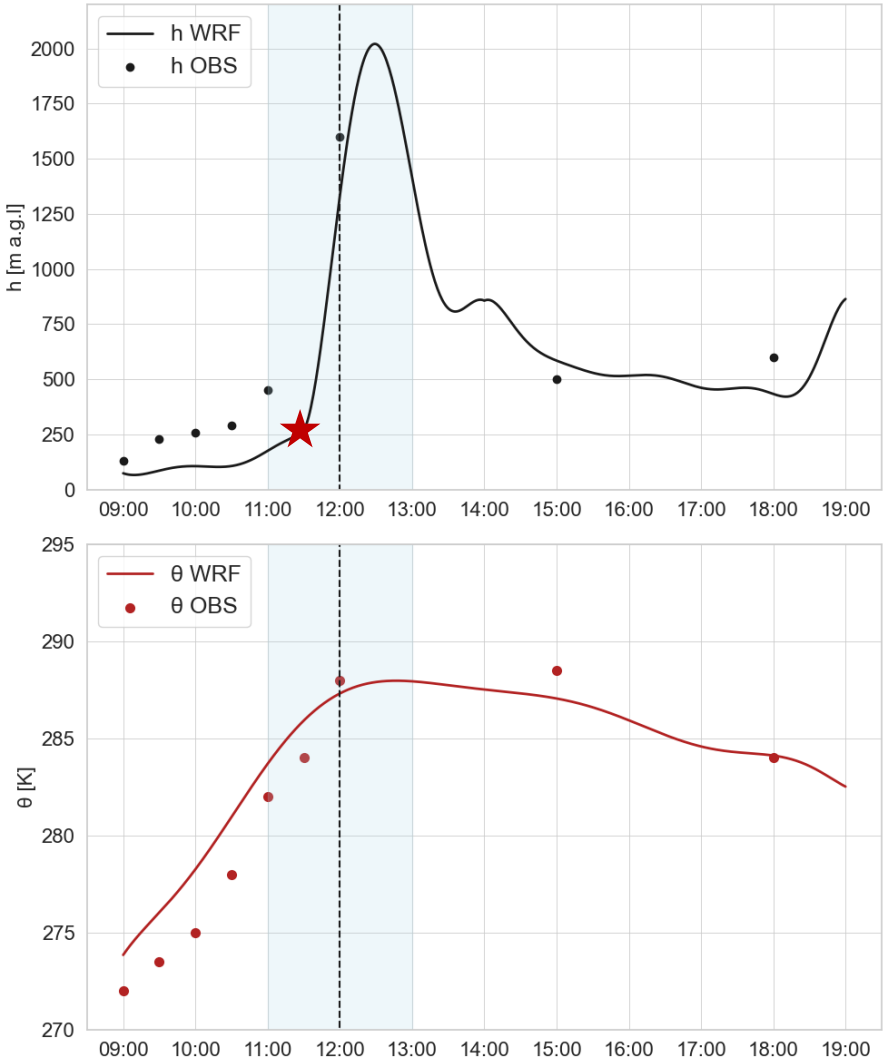

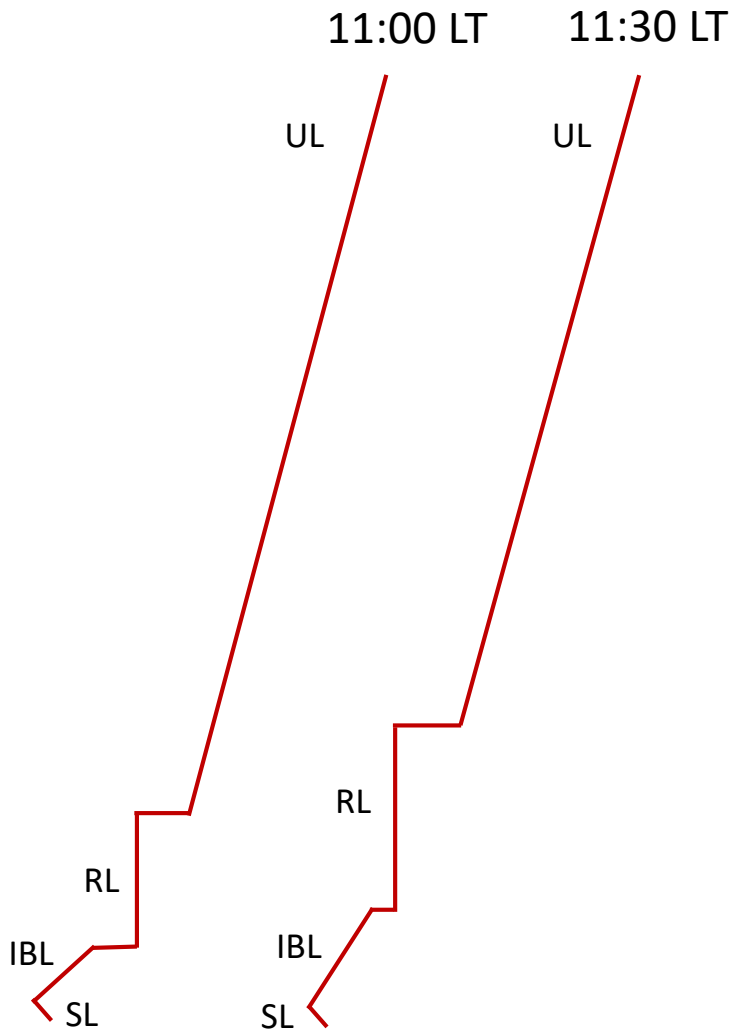

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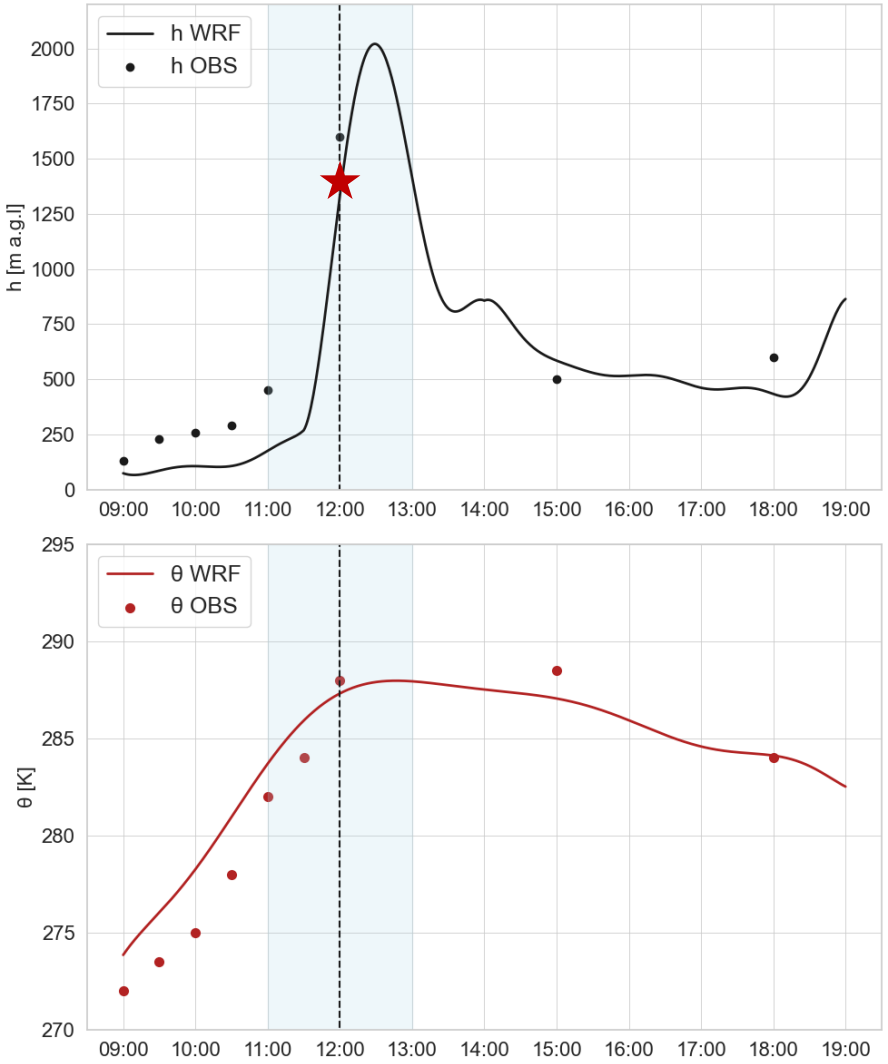
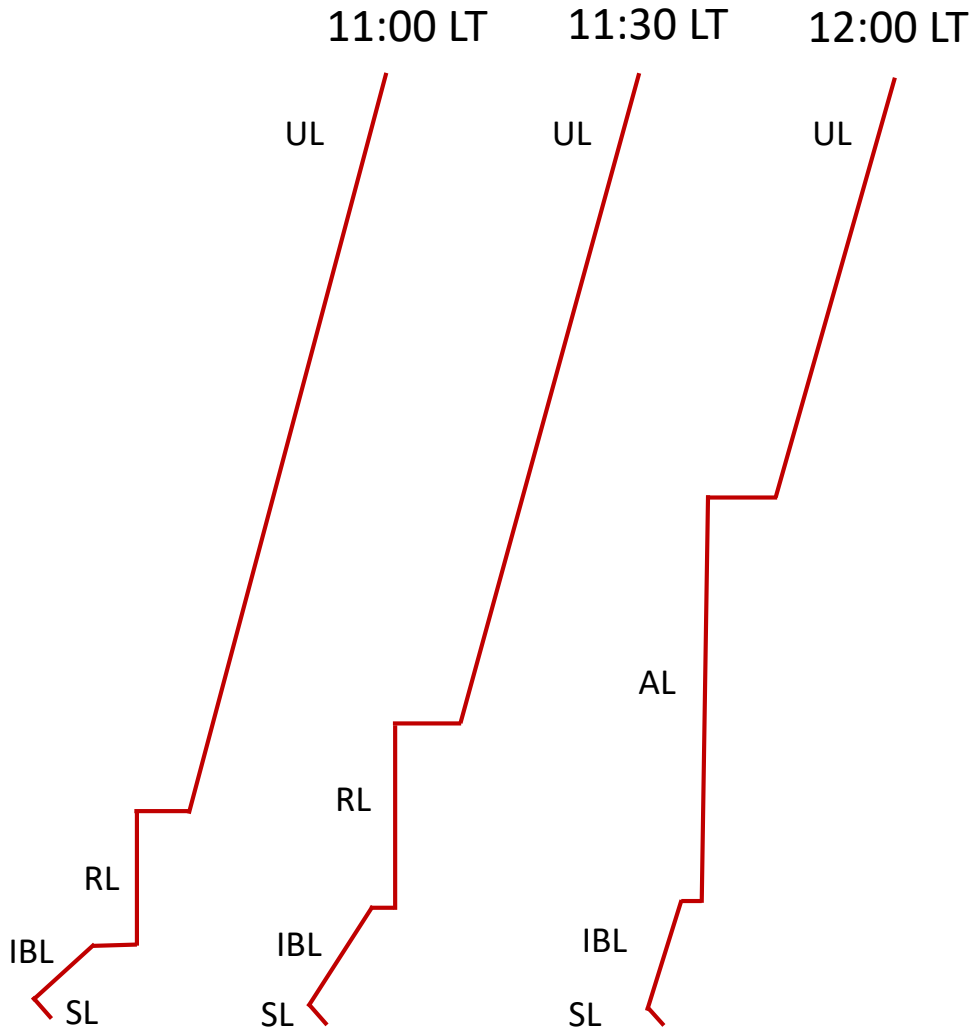
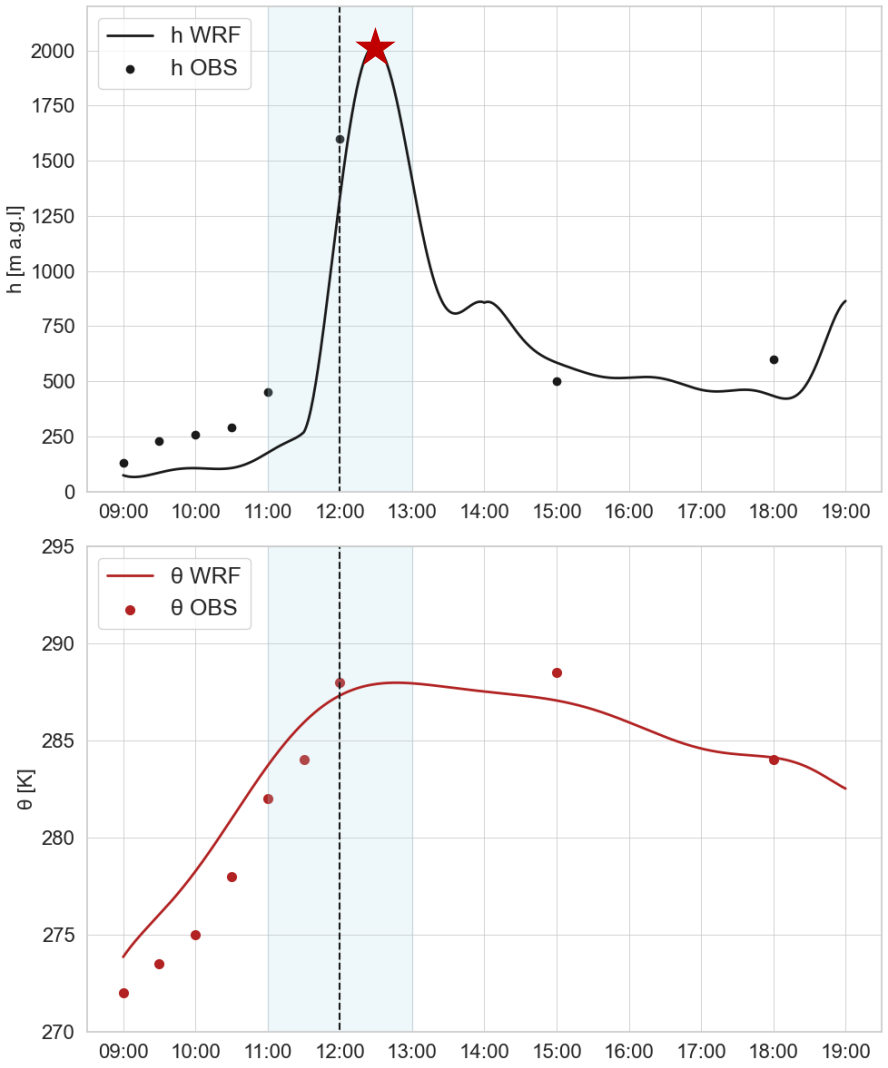
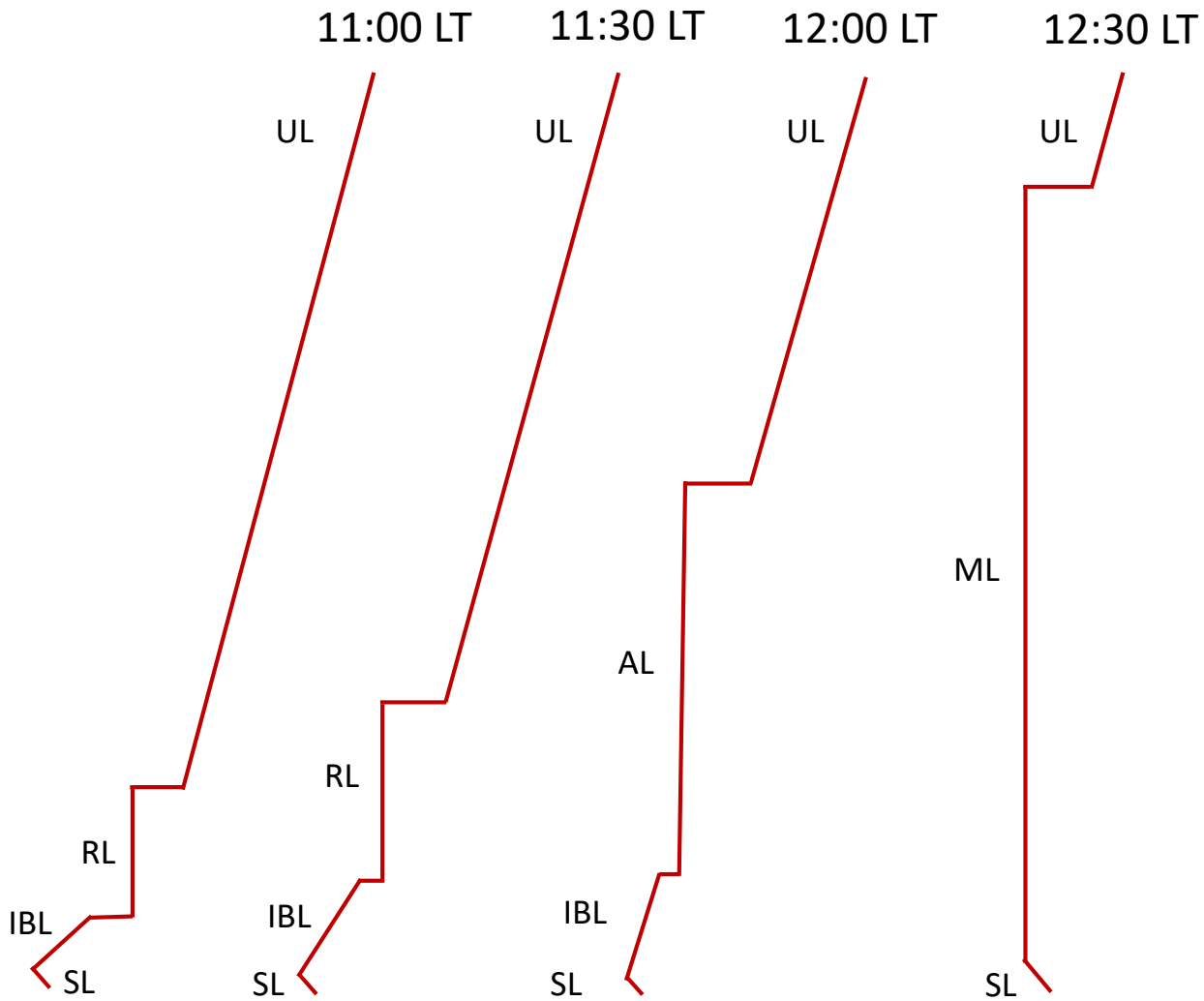


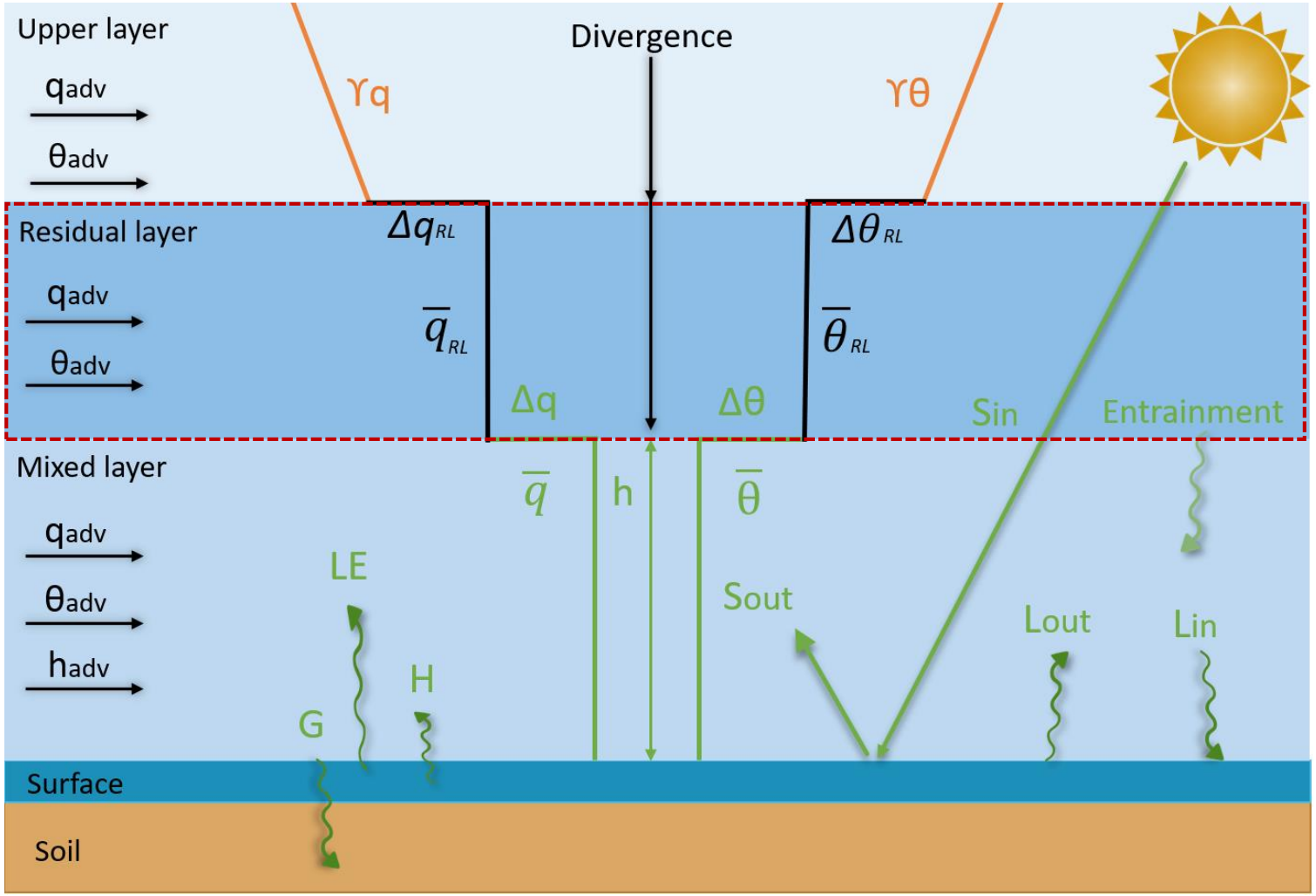


Understanding the atmospheric boundary layer dynamics





We use a land-atmosphere conceptual model to analyse the drivers of evaporation



$$\frac{\delta \bar{q}}{\delta t} = \frac{\frac{LE}{\rho L_v} + w_e \Delta q}{h} + q_{adv}$$

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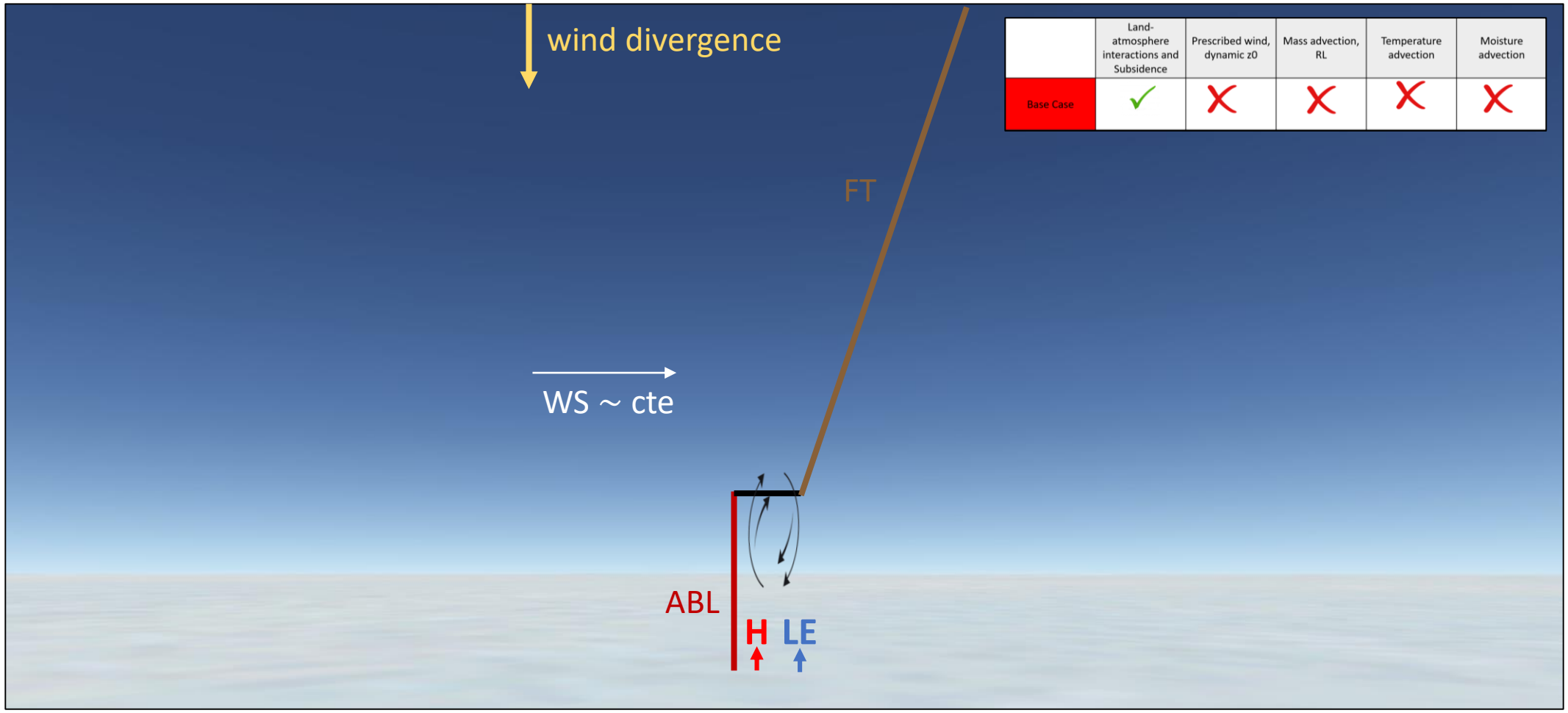
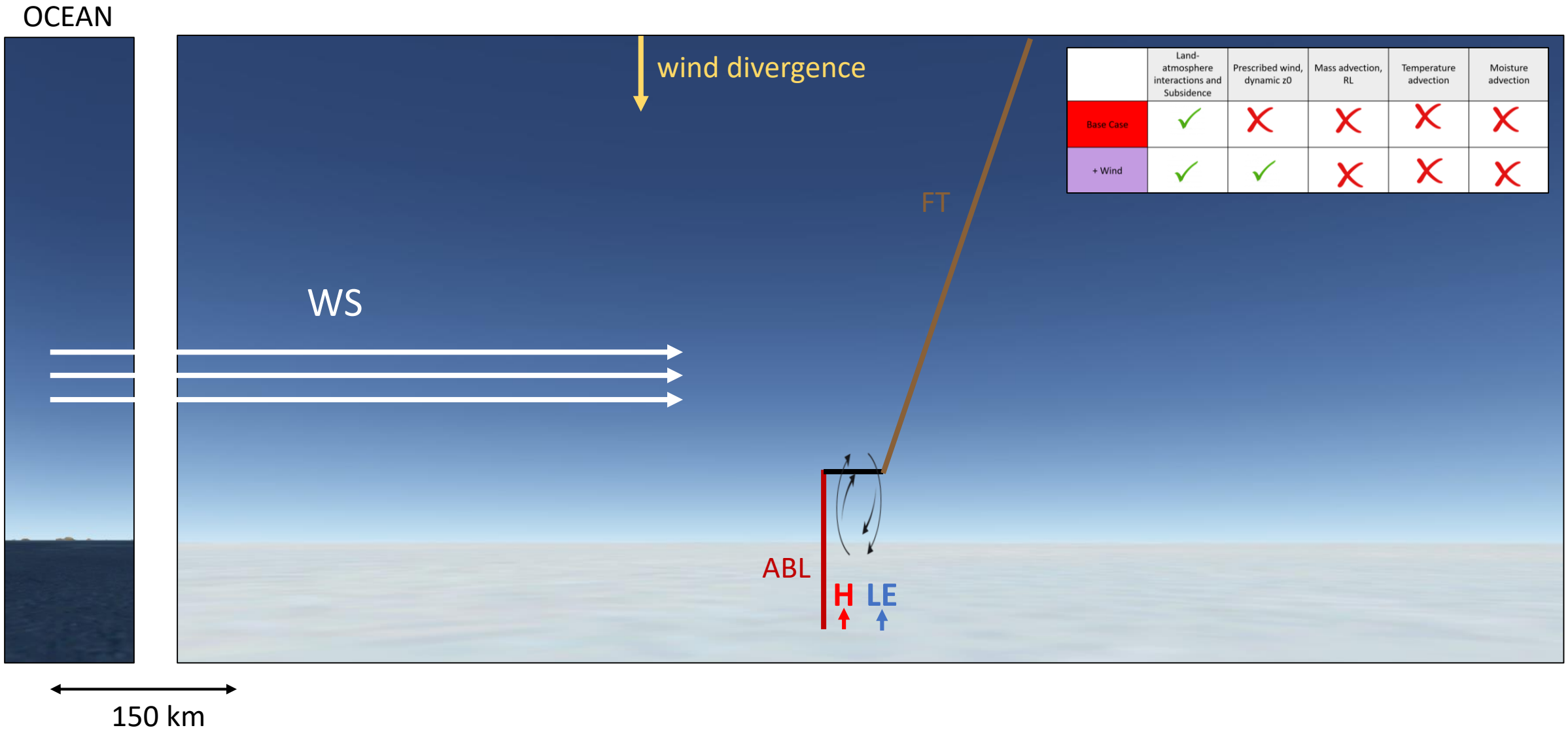
$$\frac{\delta h}{\delta t} = w_e + Div\left(\overrightarrow{U_h}\right) h + h_{adv}$$

Experiments: Base Case



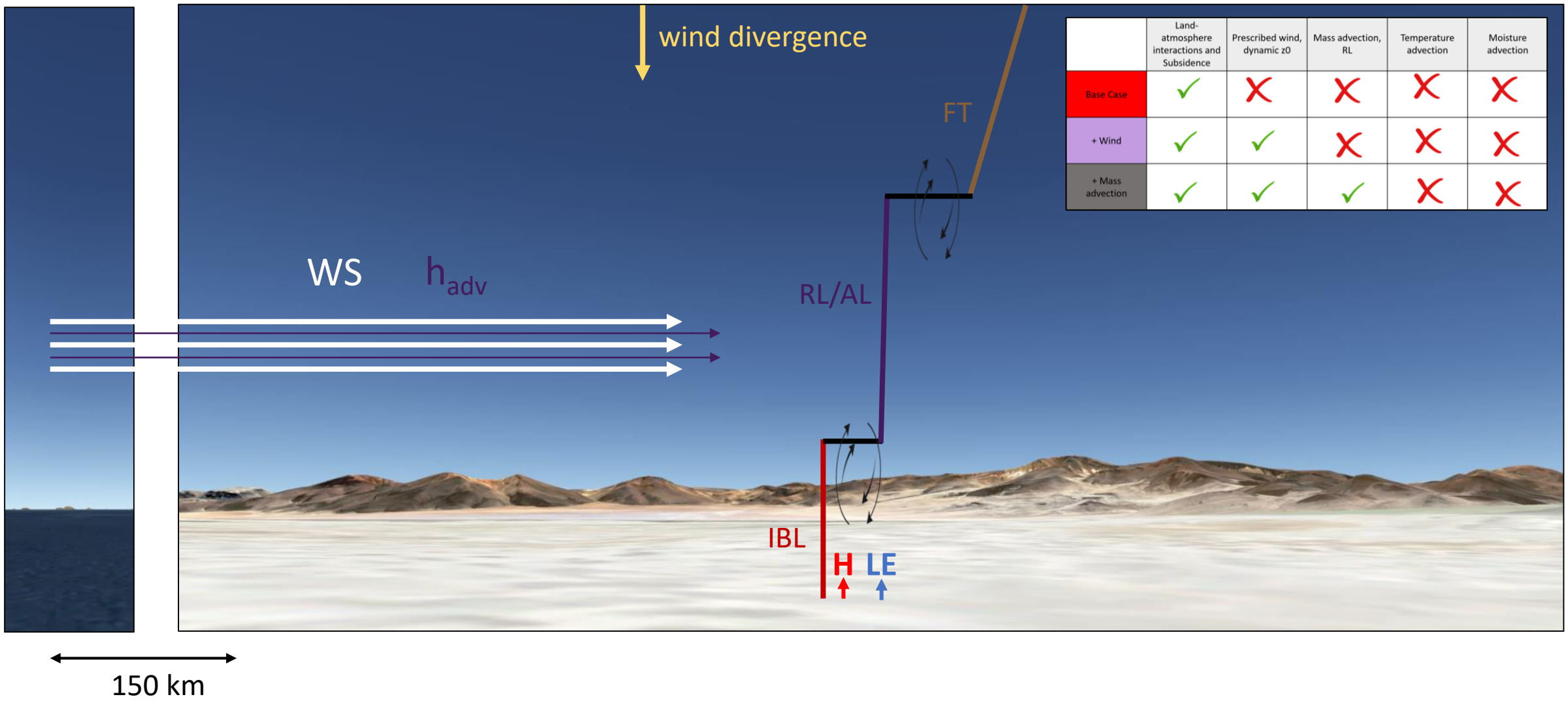
	Land-atmosphere interactions and Subsidence	Prescribed wind, dynamic z0	Mass advection, RL	Temperature advection	Moisture advection
Base Case	✓	✗	✗	✗	✗

Experiments: + Wind



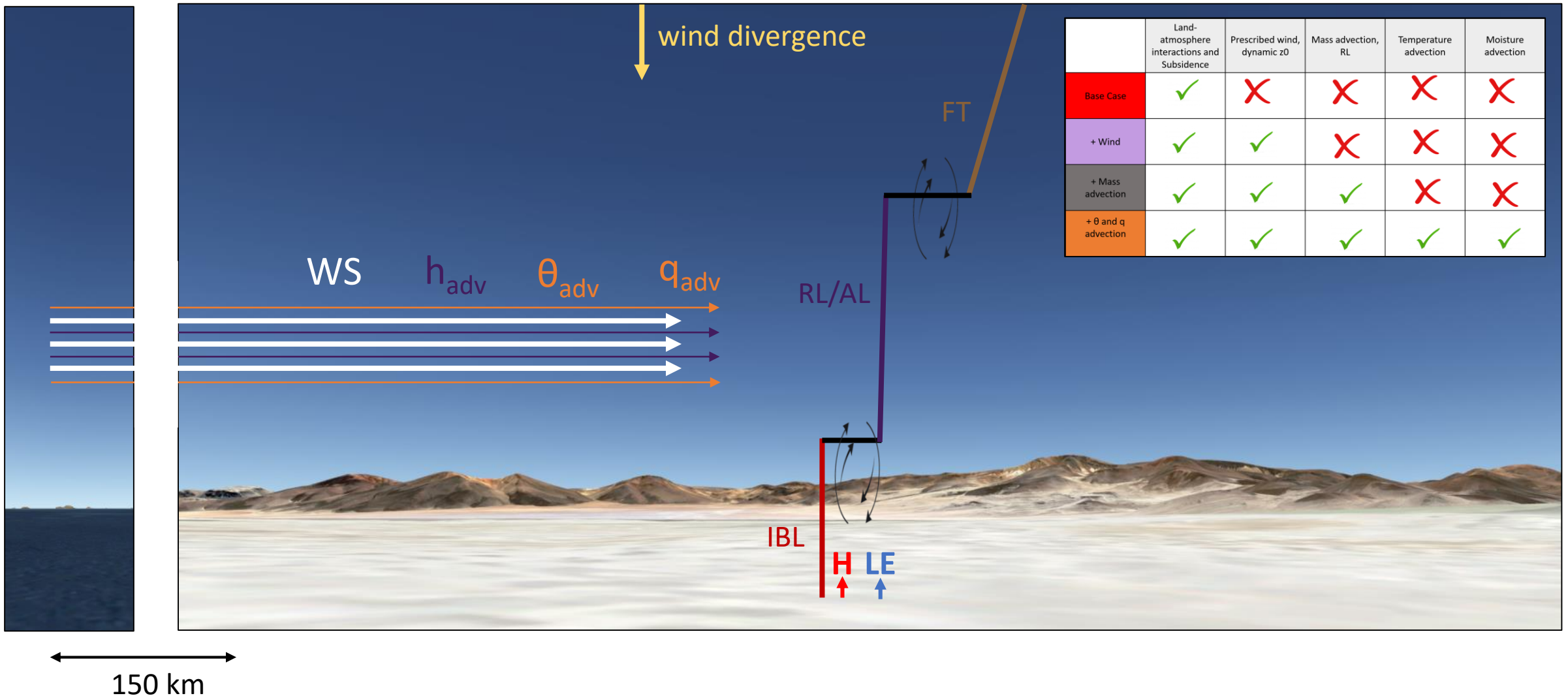
	Land-atmosphere interactions and Subsidence	Prescribed wind, dynamic z0	Mass advection, RL	Temperature advection	Moisture advection
Base Case	✓	✗	✗	✗	✗
+ Wind	✓	✓	✗	✗	✗

Experiments: + Mass advection



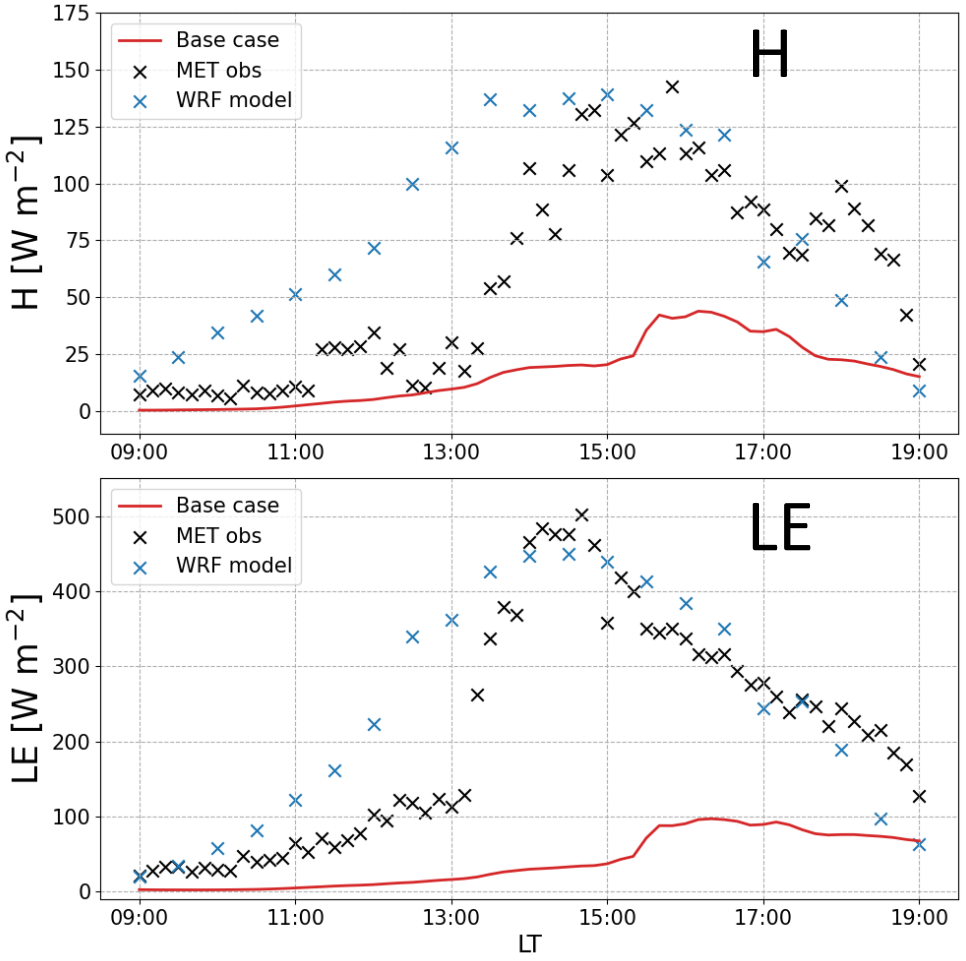
	Land-atmosphere interactions and Subsidence	Prescribed wind, dynamic z0	Mass advection, RL	Temperature advection	Moisture advection
Base Case	✓	✗	✗	✗	✗
+ Wind	✓	✓	✗	✗	✗
+ Mass advection	✓	✓	✓	✗	✗

Experiments: + θ and q advection



	Land-atmosphere interactions and Subsidence	Prescribed wind, dynamic z0	Mass advection, RL	Temperature advection	Moisture advection
Base Case	✓	✗	✗	✗	✗
+ Wind	✓	✓	✗	✗	✗
+ Mass advection	✓	✓	✓	✗	✗
+ θ and q advection	✓	✓	✓	✓	✓

Base Case: small surface fluxes

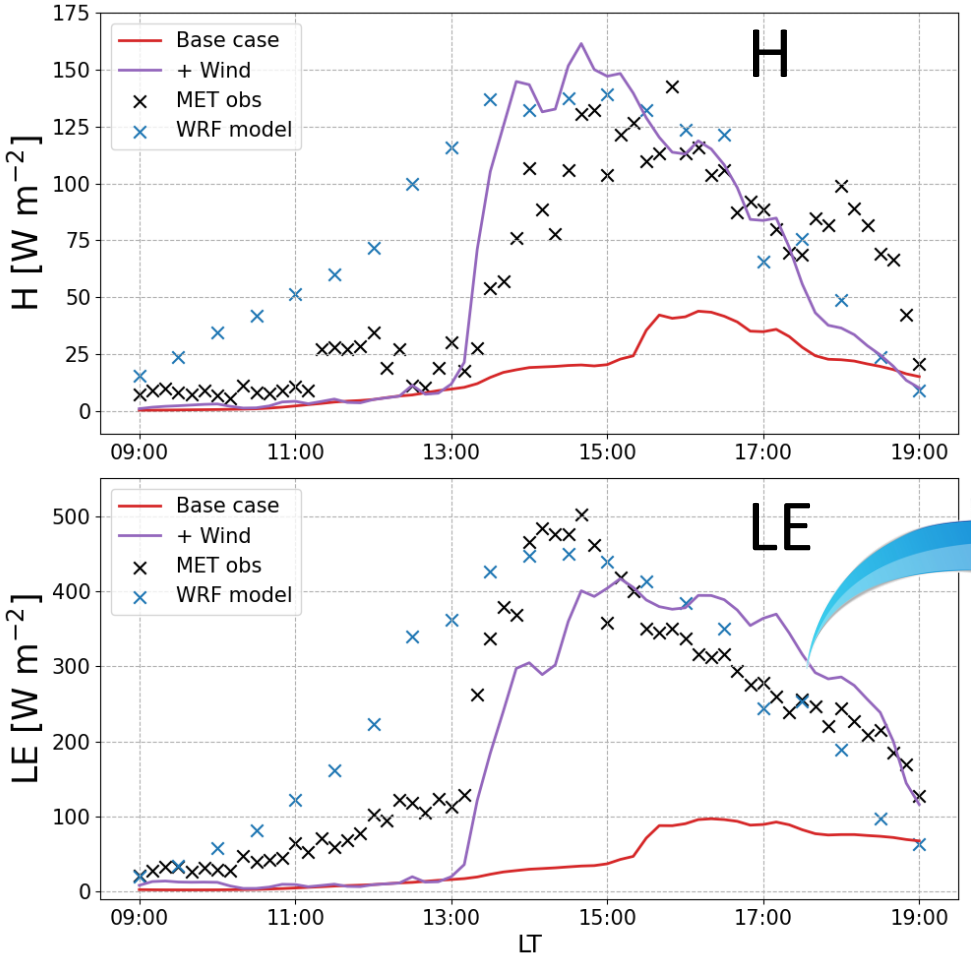


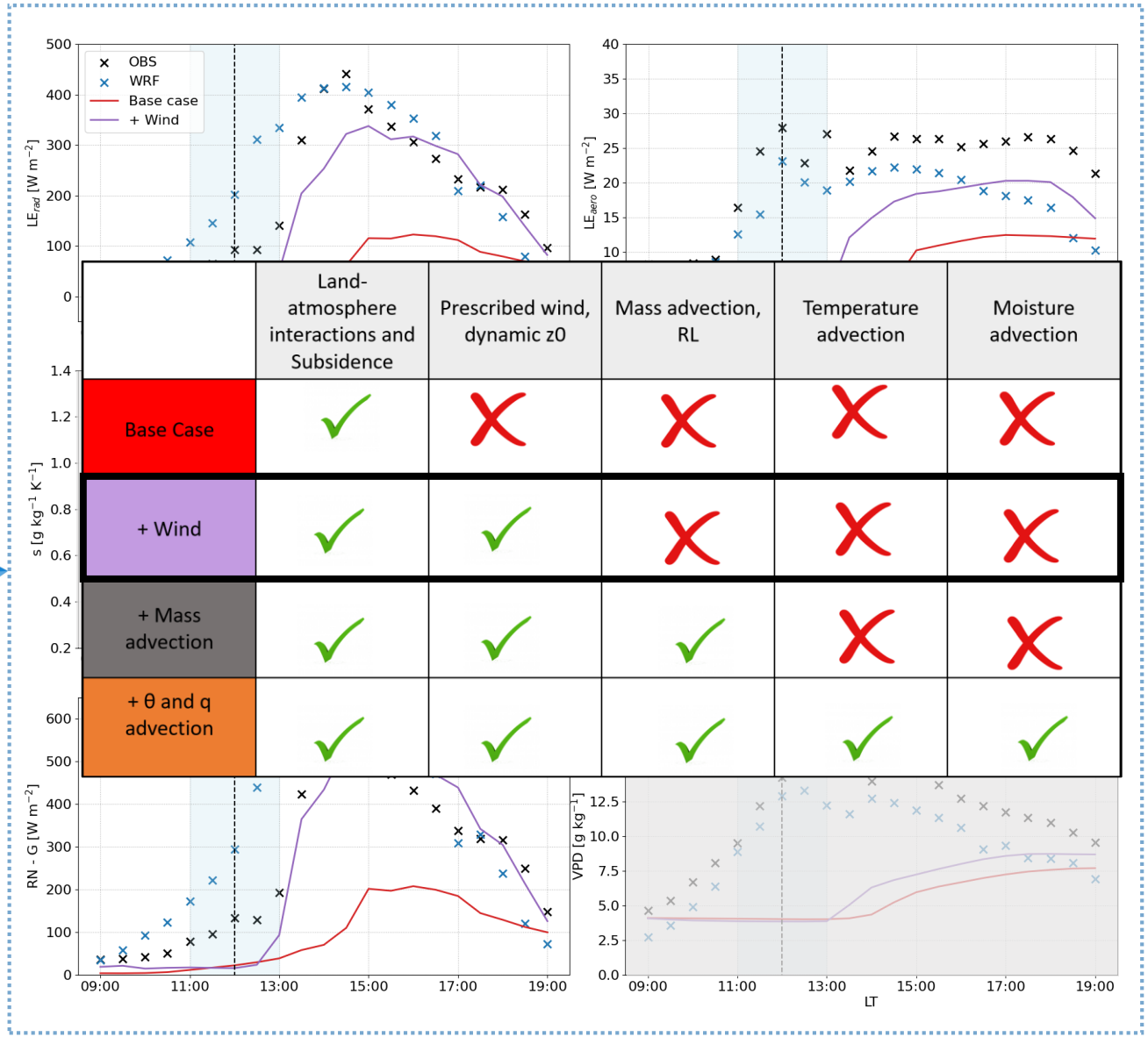
	Land-atmosphere interactions and Subsidence	Prescribed wind, dynamic z0	Mass advection, RL	Temperature advection	Moisture advection
Base Case	✓	✗	✗	✗	✗
+ Wind	✓	✓	✗	✗	✗
+ Mass advection	✓	✓	✓	✗	✗
+ θ and q advection	✓	✓	✓	✓	✓

+ Wind: mechanical turbulence triggers surface fluxes

Radiative contribution — Aerodynamic contribution

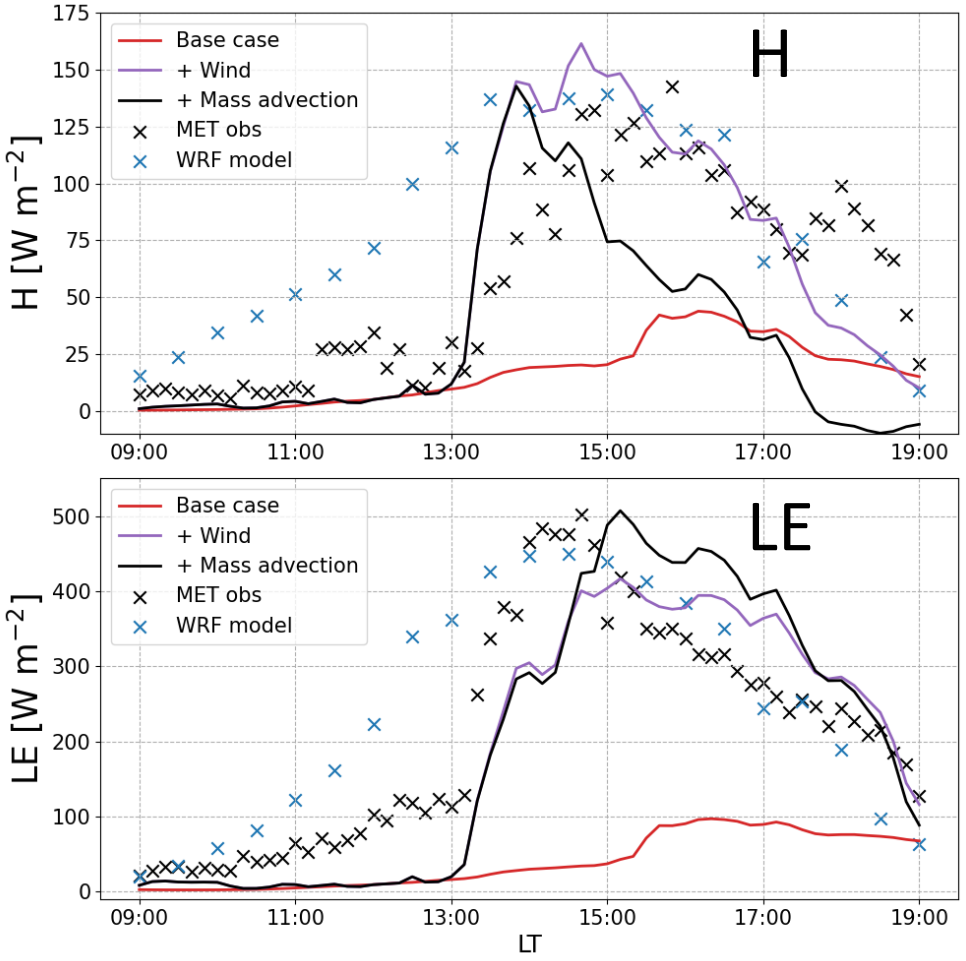
$$LE = \frac{s(RN - G) + \frac{\rho c_p}{r_a + r_{salt}}\left(q_{sat} - \frac{q}{a_w}\right)}{s + \frac{\gamma}{a_w}}$$





	Land-atmosphere interactions and Subsidence	Prescribed wind, dynamic z0	Mass advection, RL	Temperature advection	Moisture advection
Base Case	✓	✗	✗	✗	✗
+ Wind	✓	✓	✗	✗	✗
+ Mass advection	✓	✓	✓	✗	✗
+ θ and q advection	✓	✓	✓	✓	✓

+ Mass advection: intermediate step

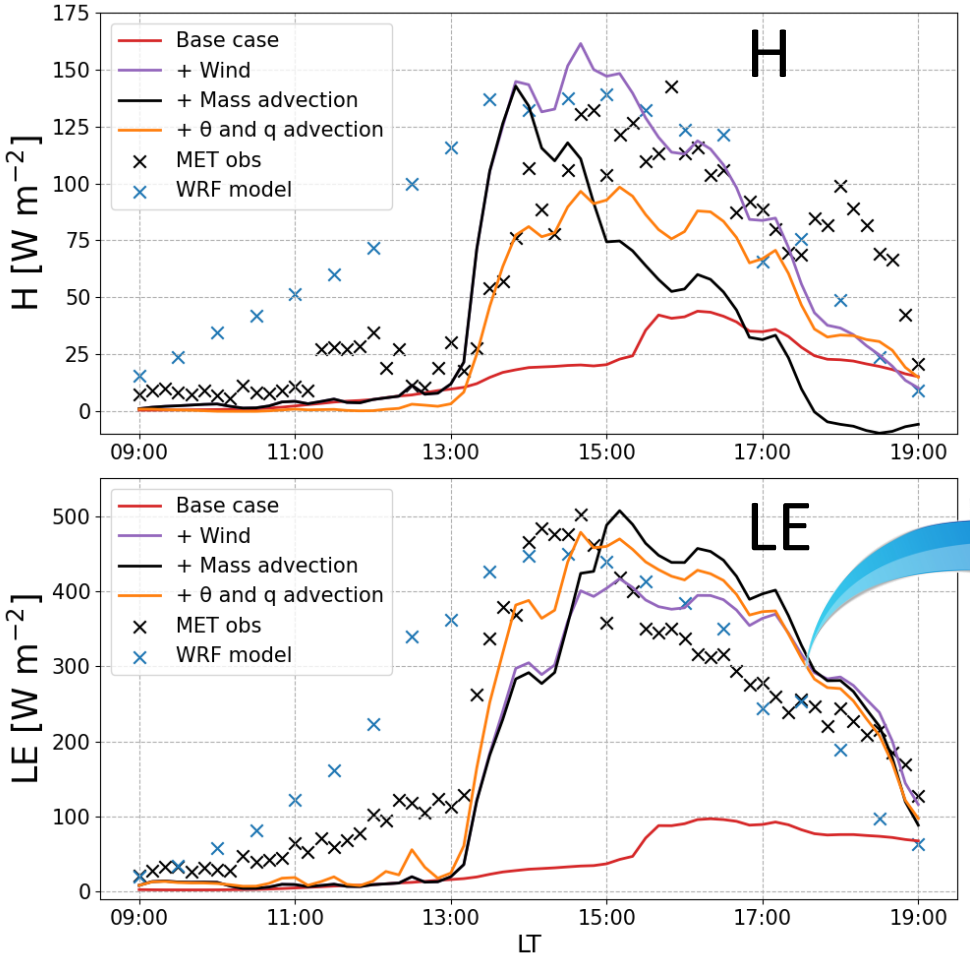


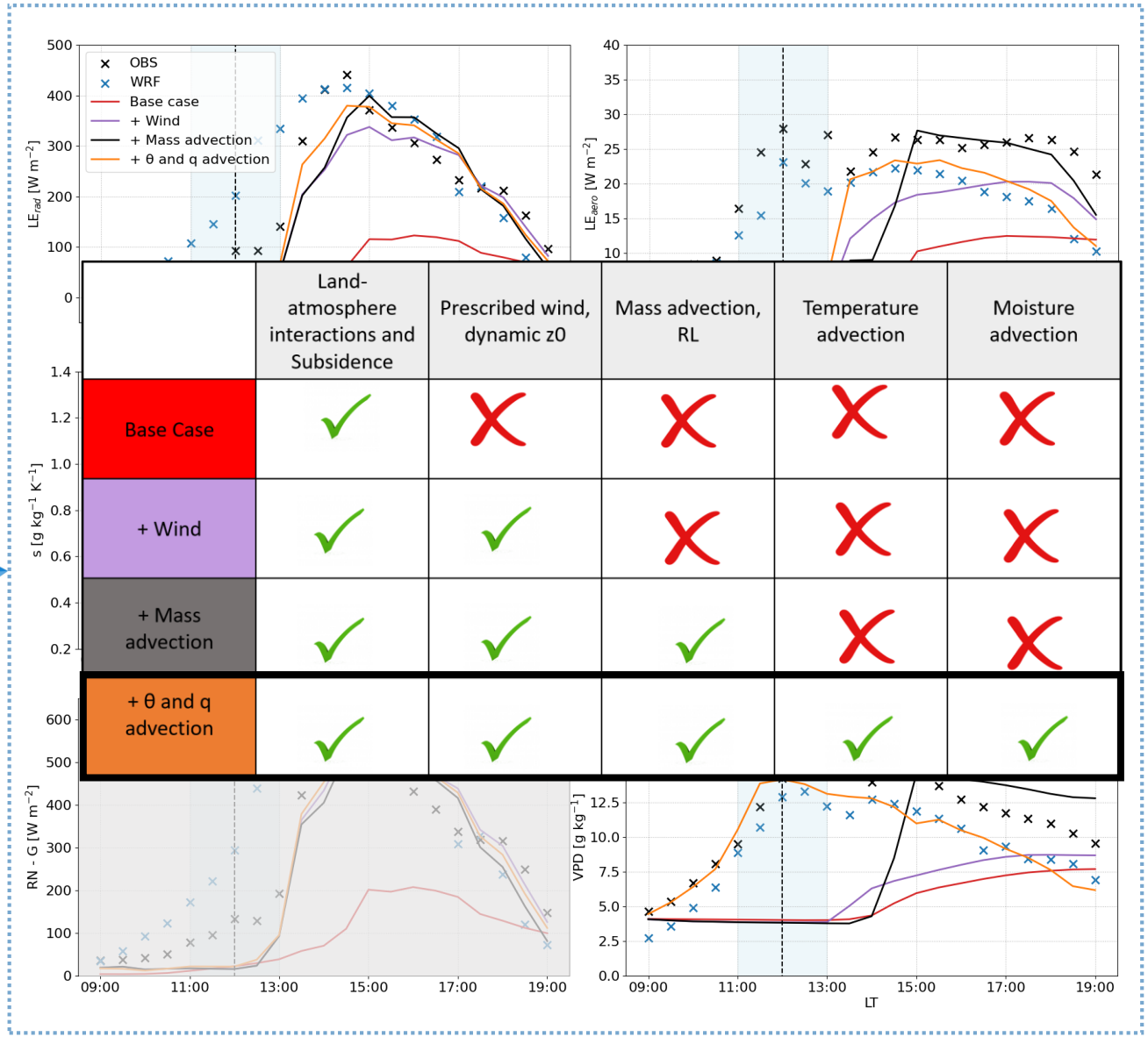
	Land-atmosphere interactions and Subsidence	Prescribed wind, dynamic z0	Mass advection, RL	Temperature advection	Moisture advection
Base Case	✓	✗	✗	✗	✗
+ Wind	✓	✓	✗	✗	✗
+ Mass advection	✓	✓	✓	✗	✗
+ θ and q advection	✓	✓	✓	✓	✓

+ θ and q advection: dynamic behaviour is better represented

Radiative contribution — Aerodynamic contribution

$$LE = \frac{s(RN - G) + \frac{\rho c_p}{r_a + r_{salt}}\left(q_{sat} - \frac{q}{a_w}\right)}{s + \frac{\gamma}{a_w}}$$





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Base Case	✓	✗	✗	✗	✗
+ Wind	✓	✓	✗	✗	✗
+ Mass advection	✓	✓	✓	✗	✗
+ θ and q advection	✓	✓	✓	✓	✓

Remarks

- The **atmospheric boundary layer** is mainly driven by **advection**
- **Evaporation** is mainly triggered by **turbulence** when the regional flow arrives
- **Evaporation** is also driven by the interaction with the ABL:
  - **Mass advection** of a deeper boundary layer from the surrounding desert
  - **Cold and dry air advection** that allows to describe the dynamic behaviour

The understanding of
the ABL dynamics is key to understand evaporation regimes in the Altiplano!

ACKNOWLEDGEMENTS

ATE/ 220005 - FSEQ/210018 - FONDECYT/ 1210221
BECAS/ DOCTORADO NACIONAL/ 21211730

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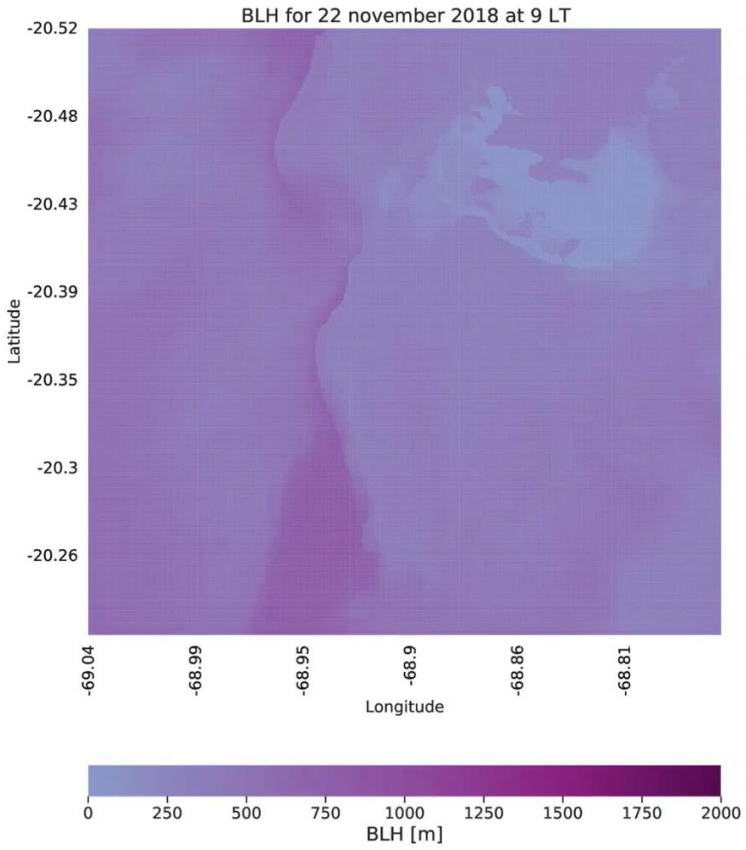
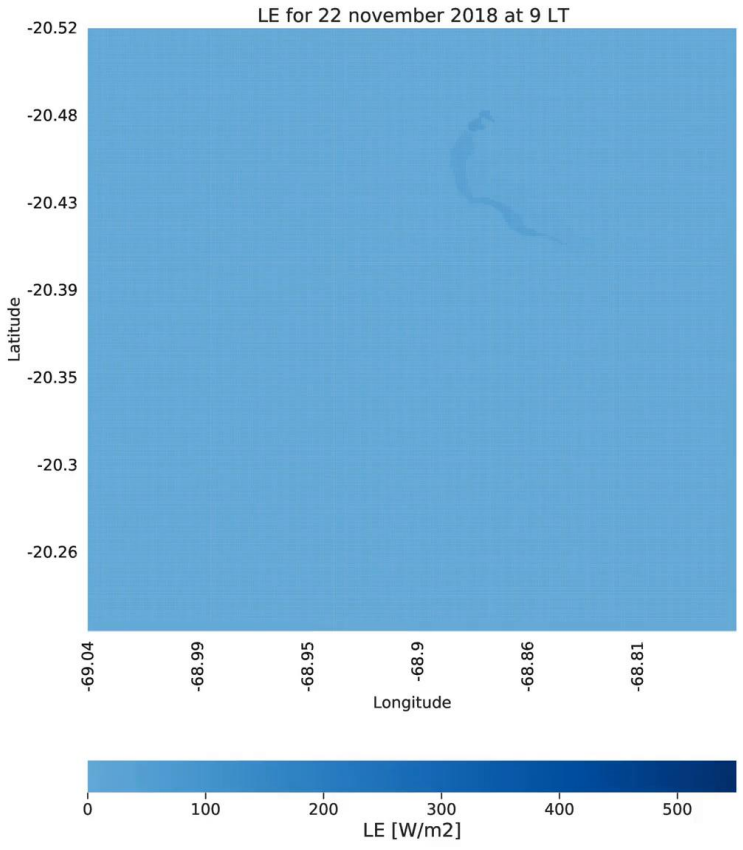
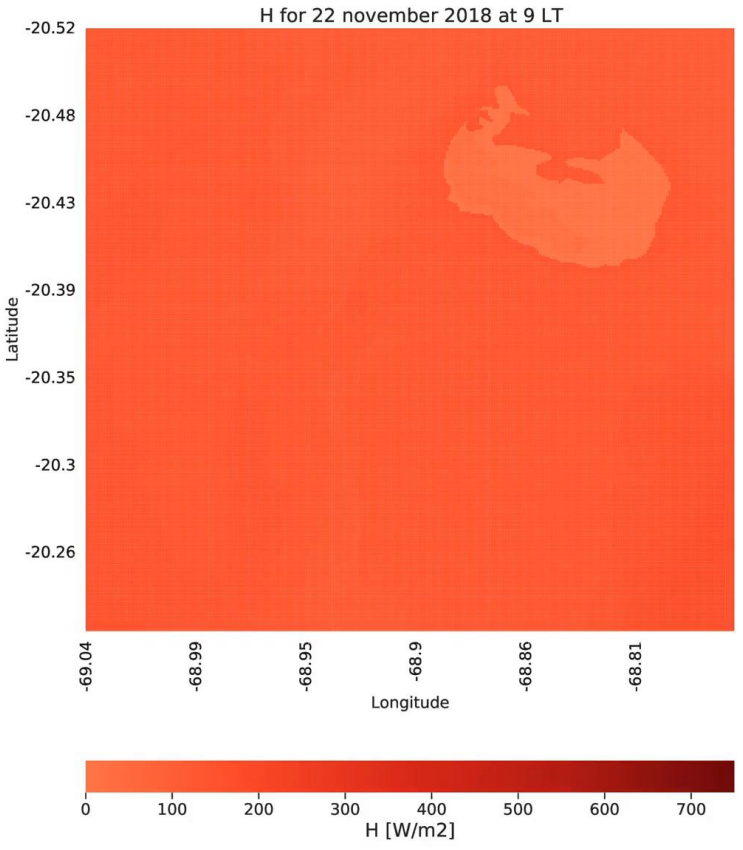
✉ faguirre2@uc.cl

Credits to Oscar Hartogensis

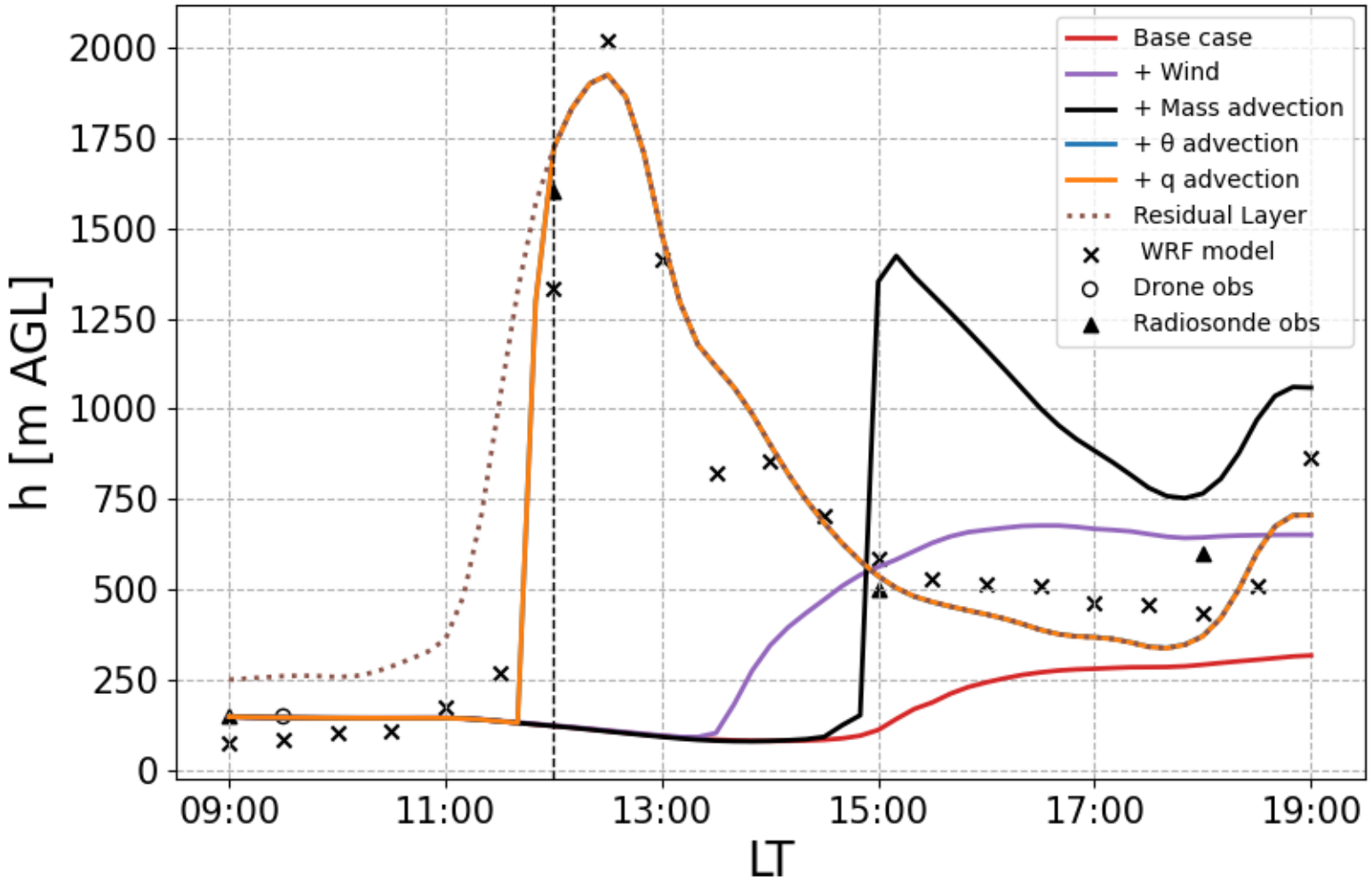
Appendix: WRF animations





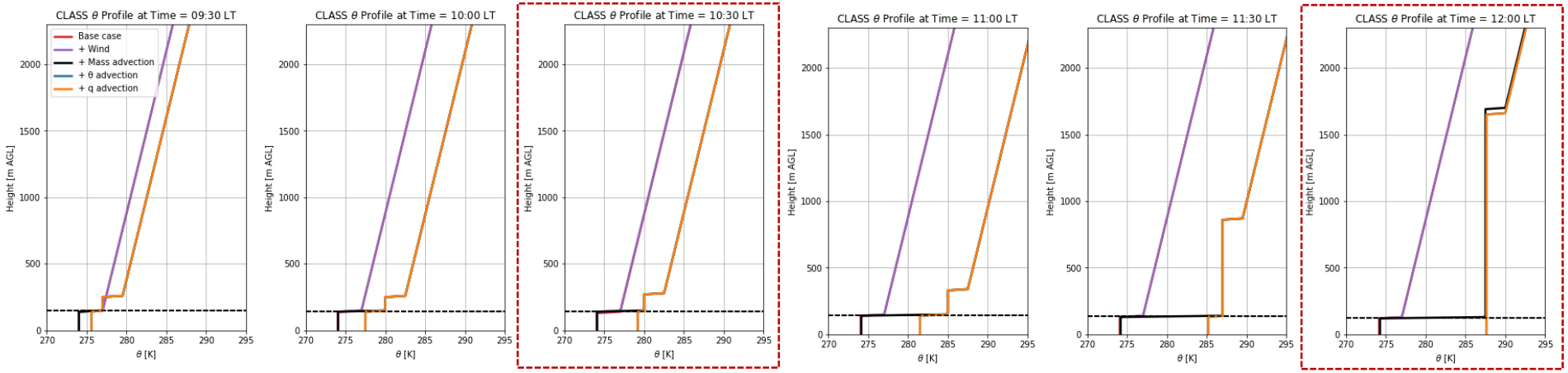


Appendix: CLASS h

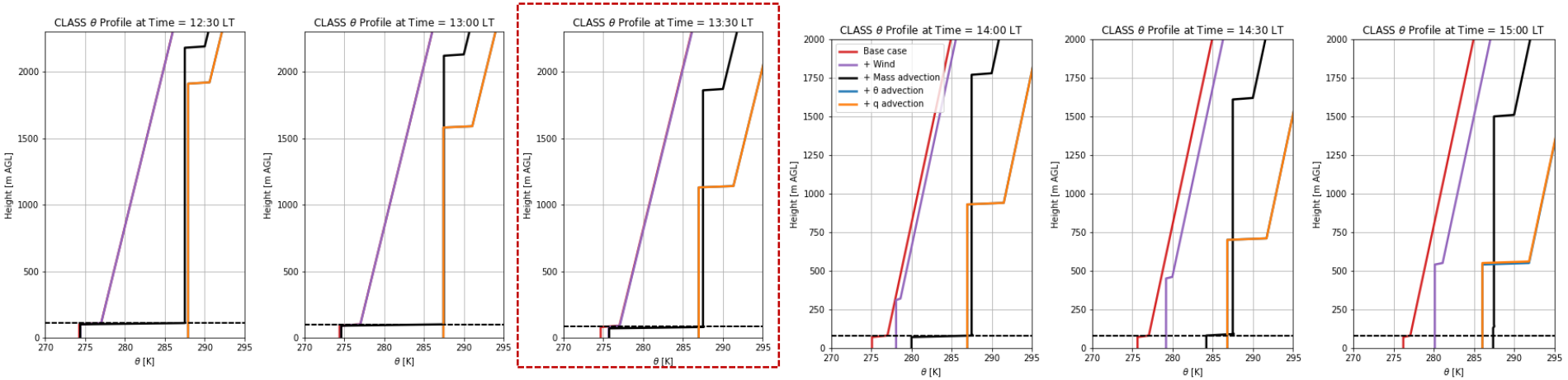


Appendix: CLASS profiles

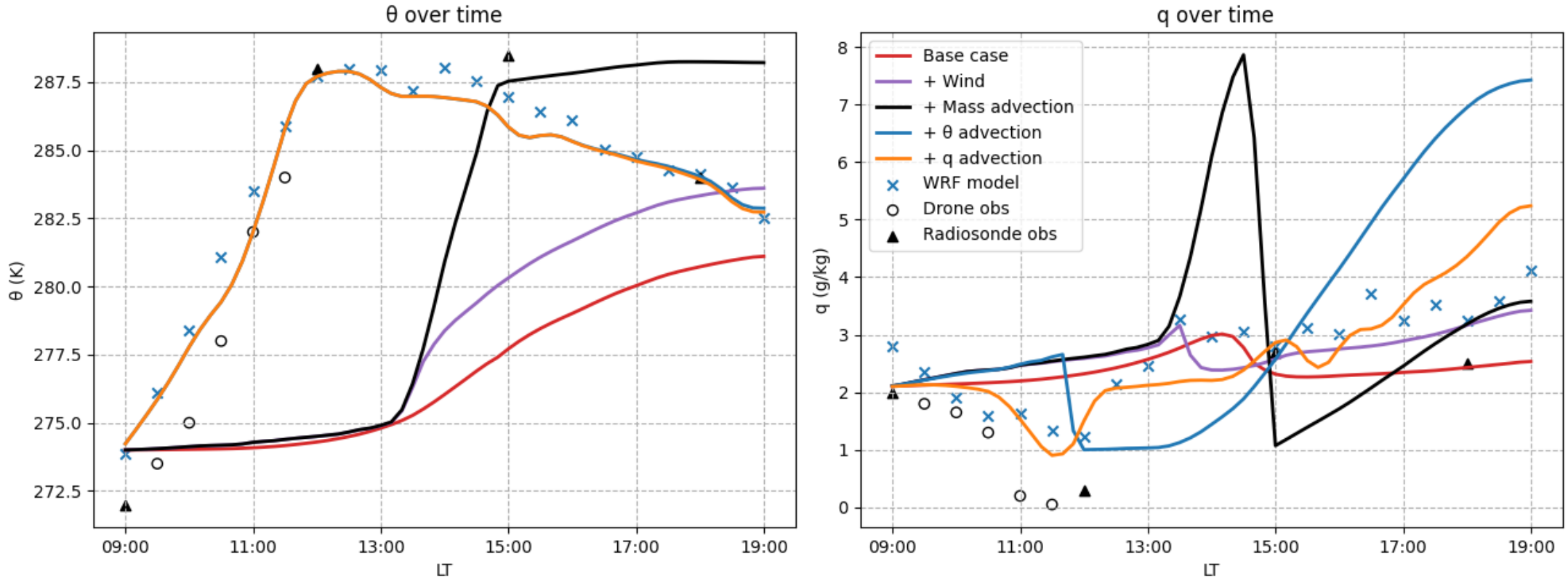
MORNING



AFTERNOON

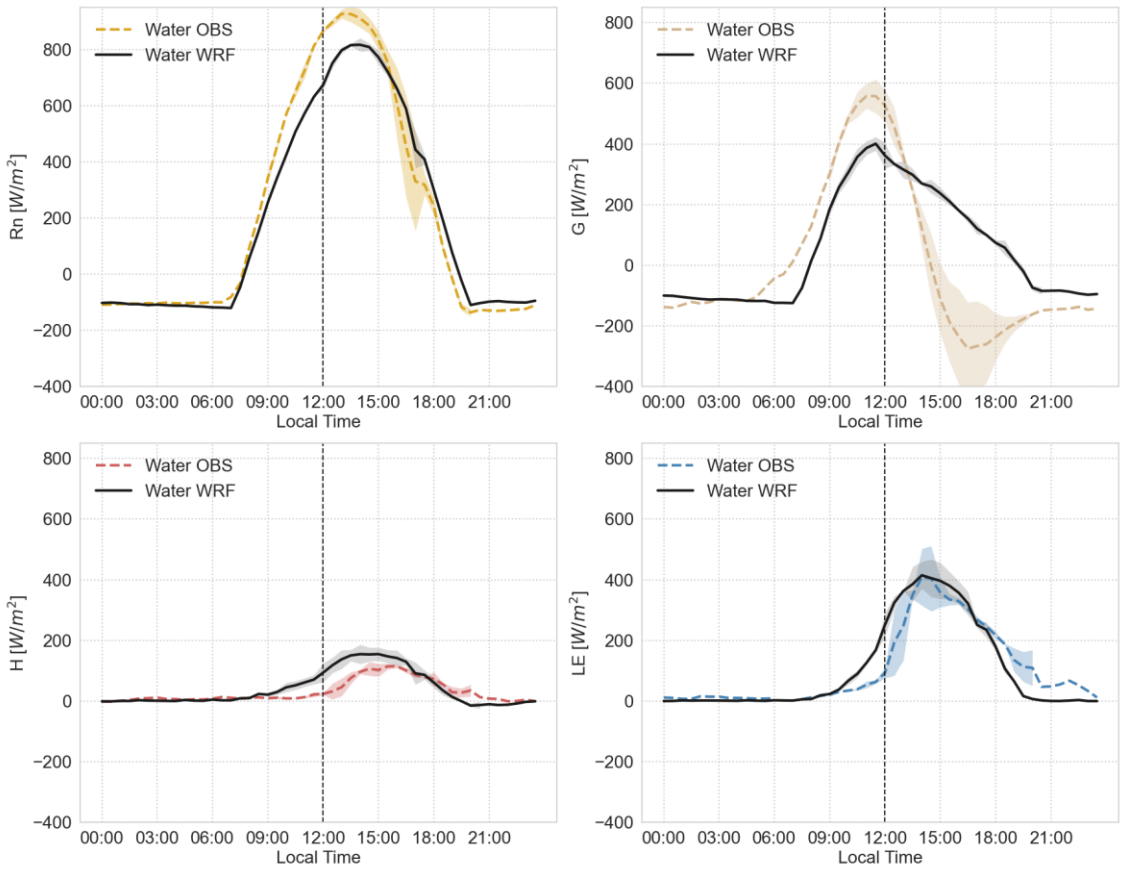


Appendix: CLASS temperature and moisture

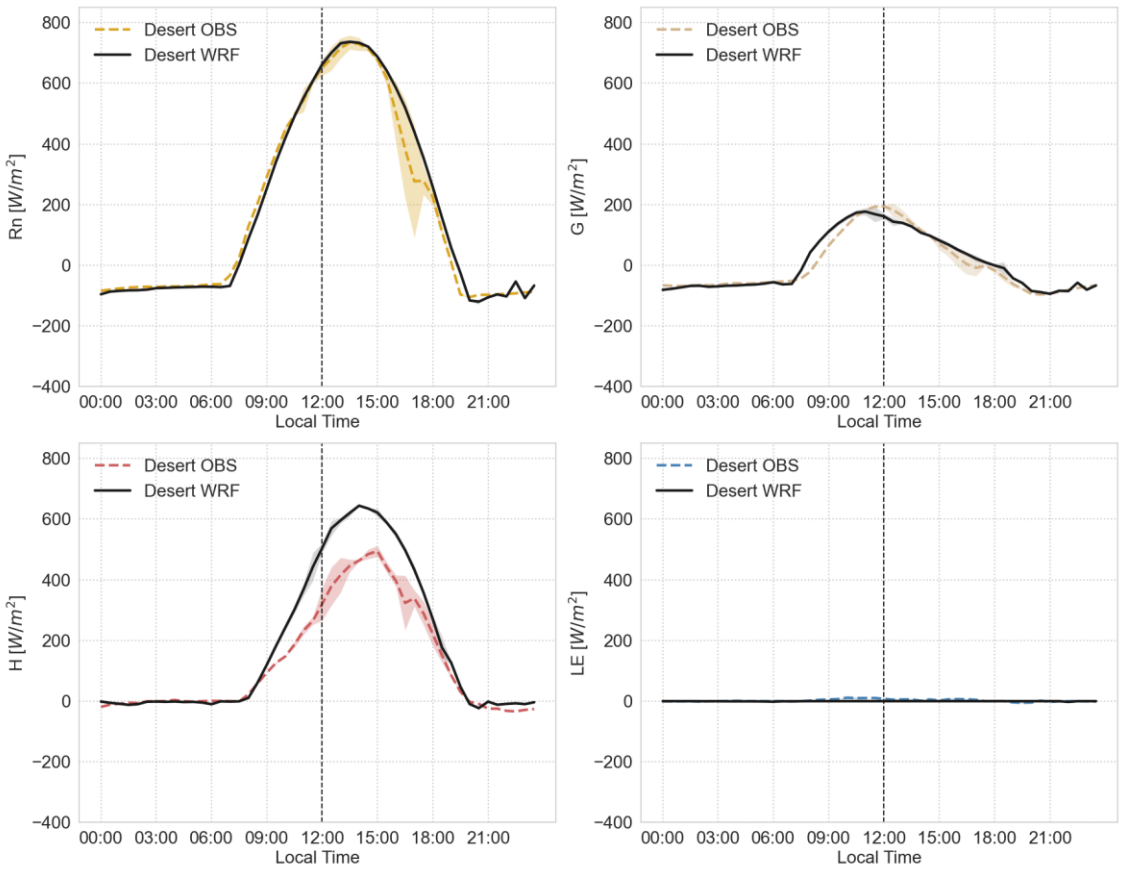


Appendix: WRF surface validation

Water



Desert



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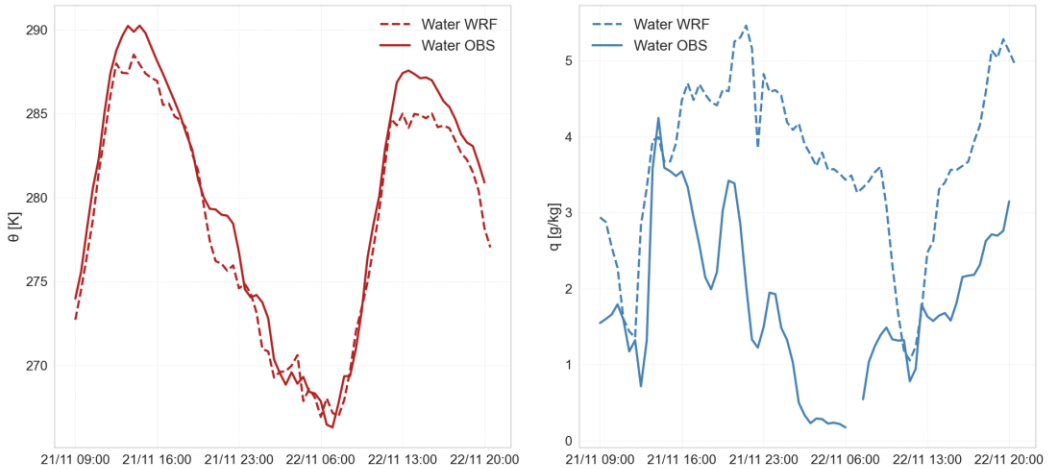
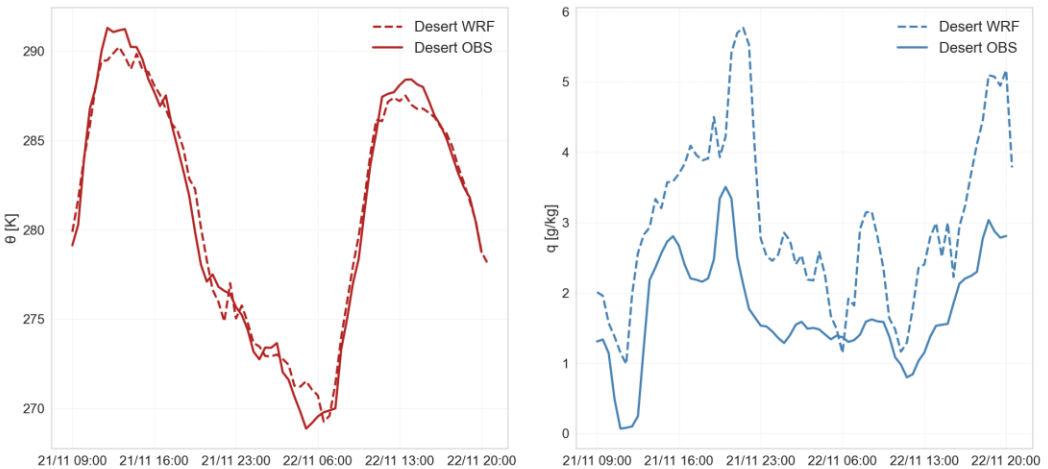
Water



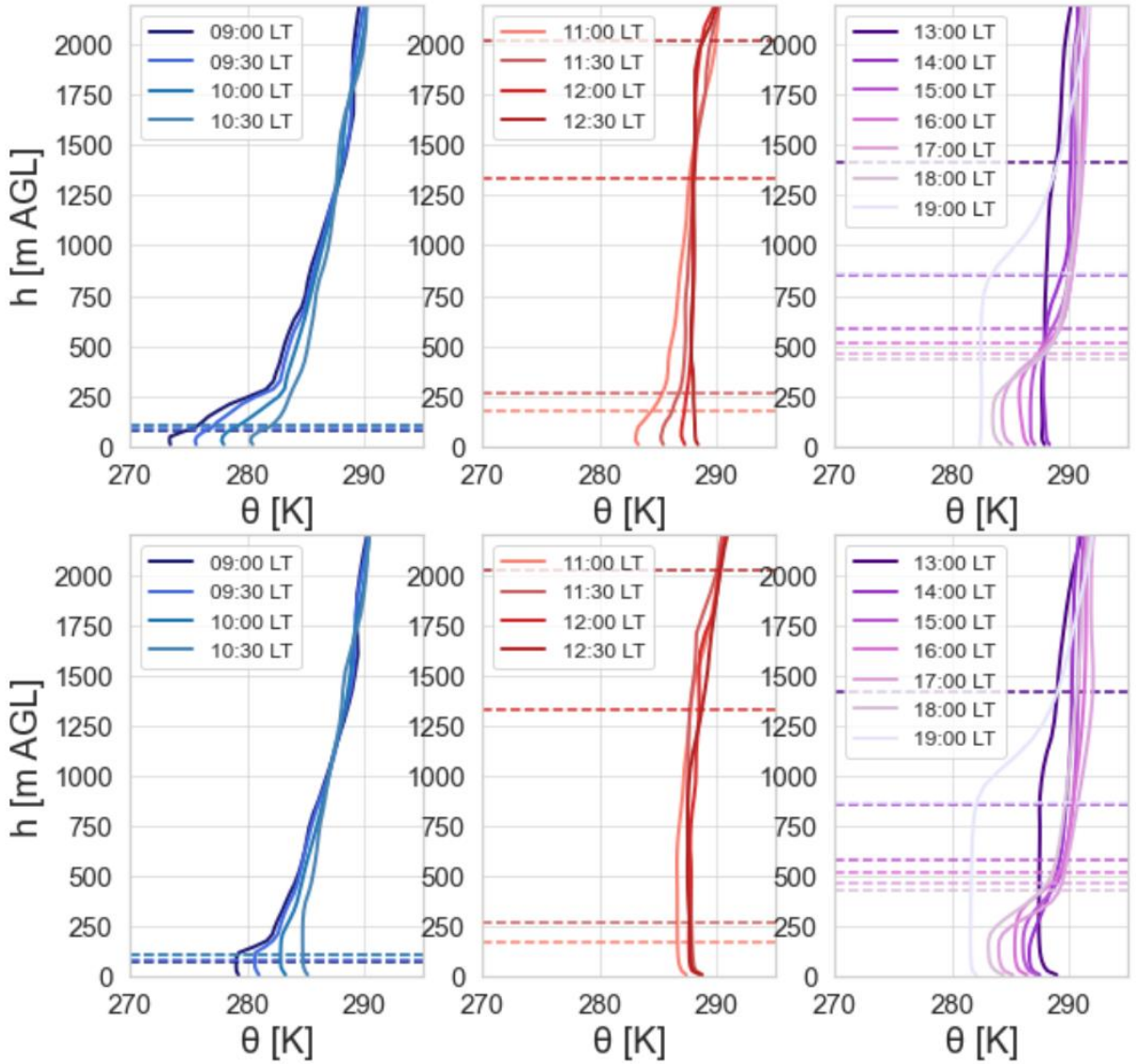
Desert



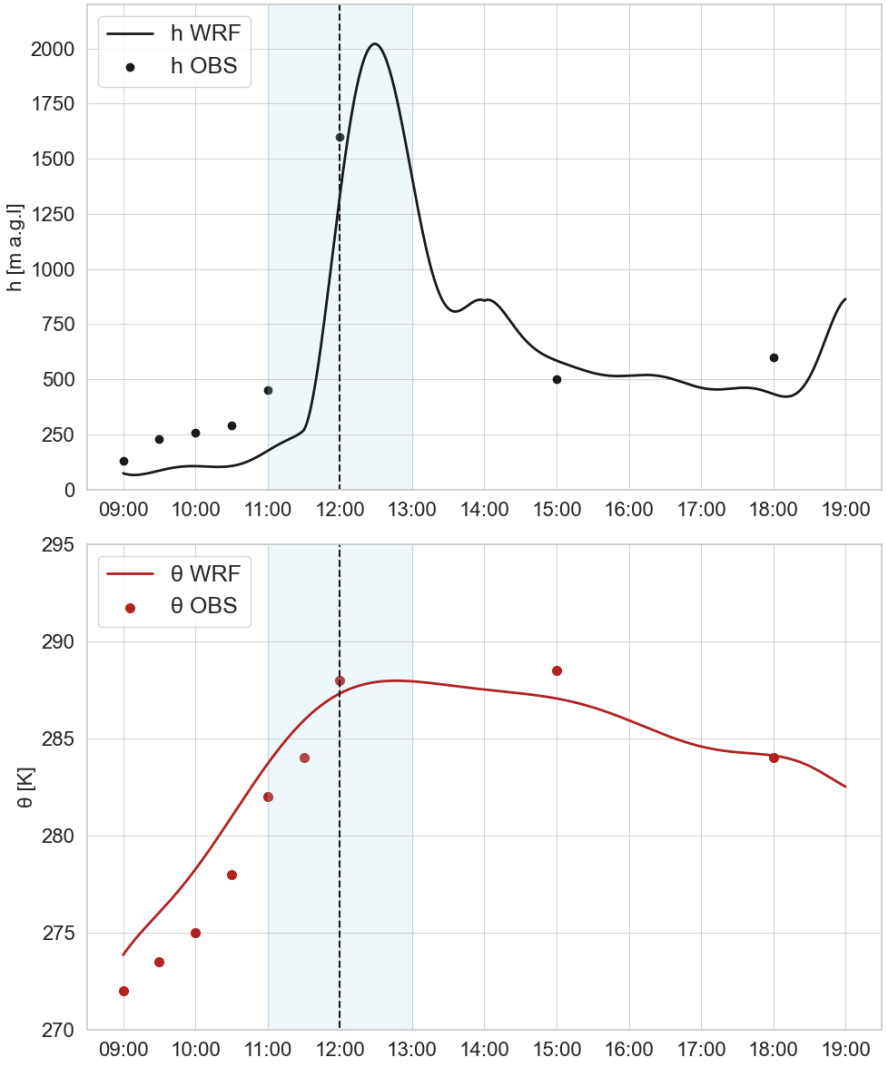
Appendix: WRF ABL validation

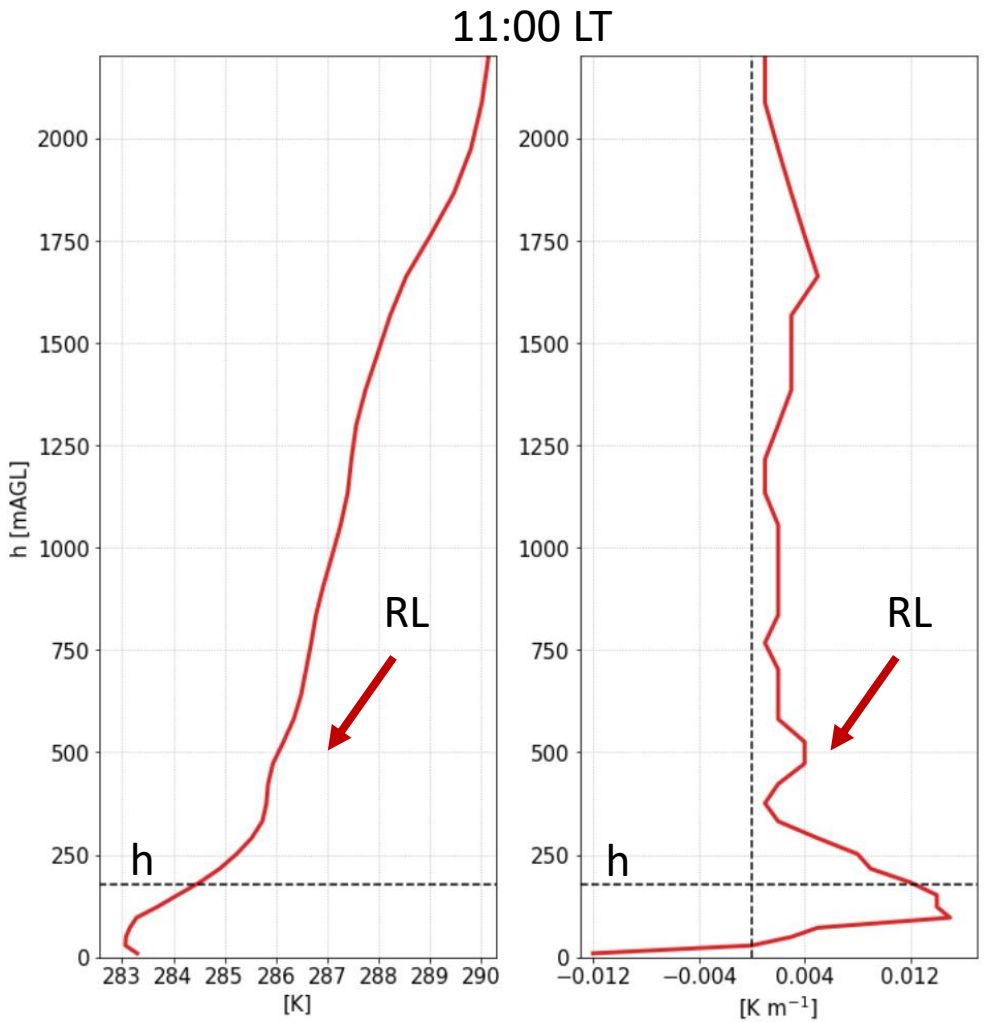
Water

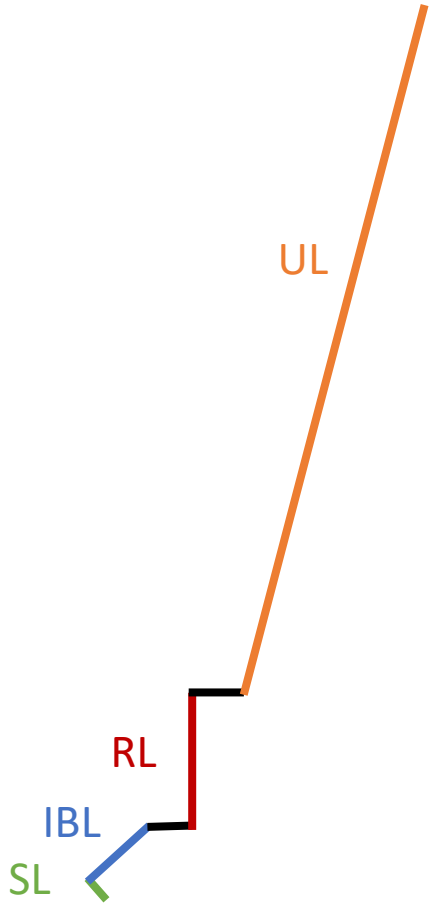
Desert



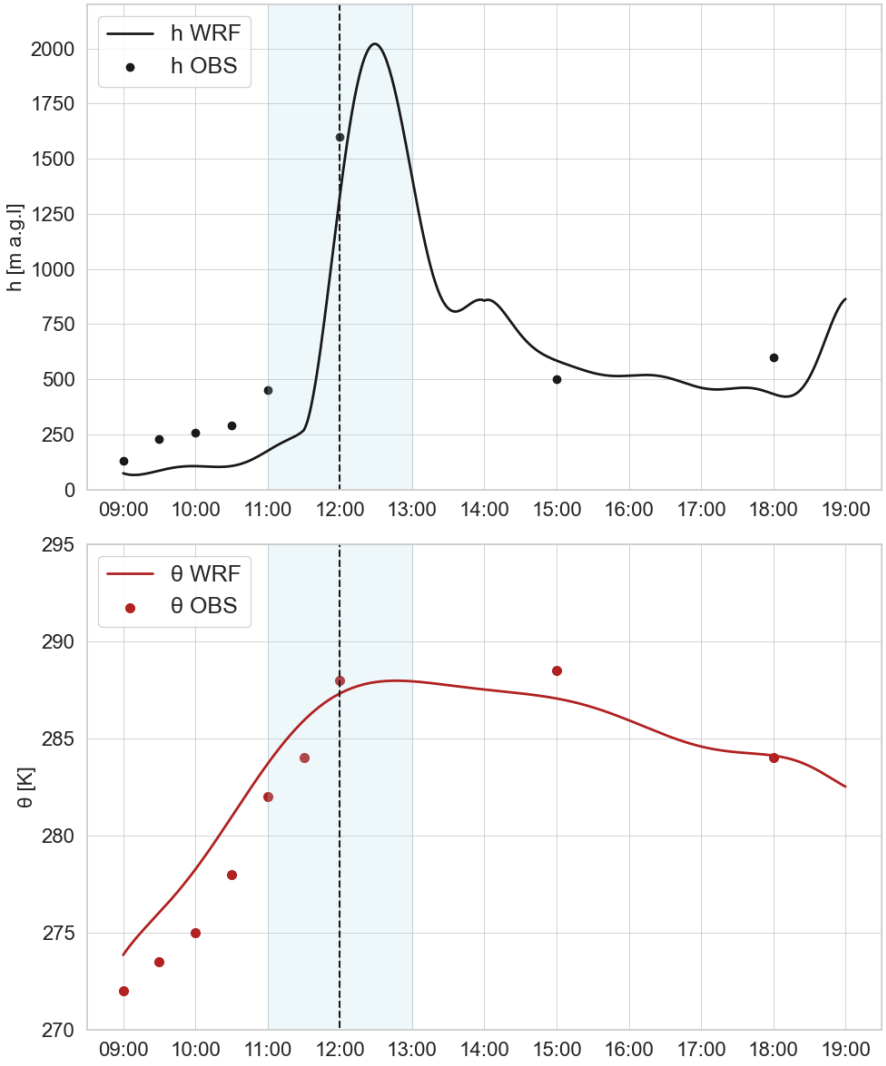
Understanding the atmospheric boundary layer dynamics

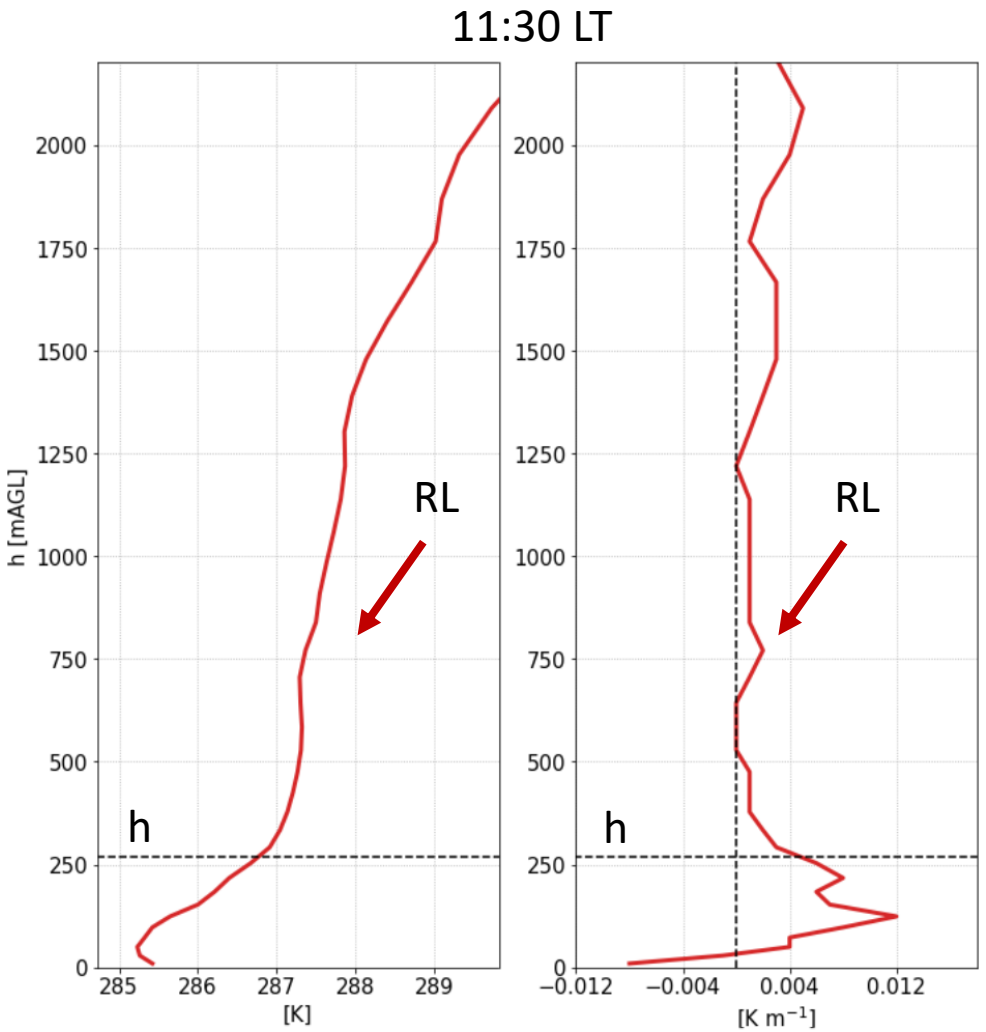


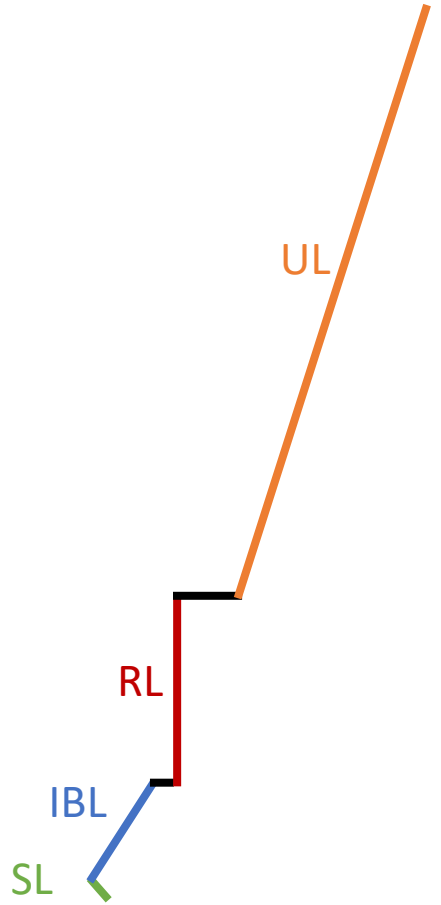




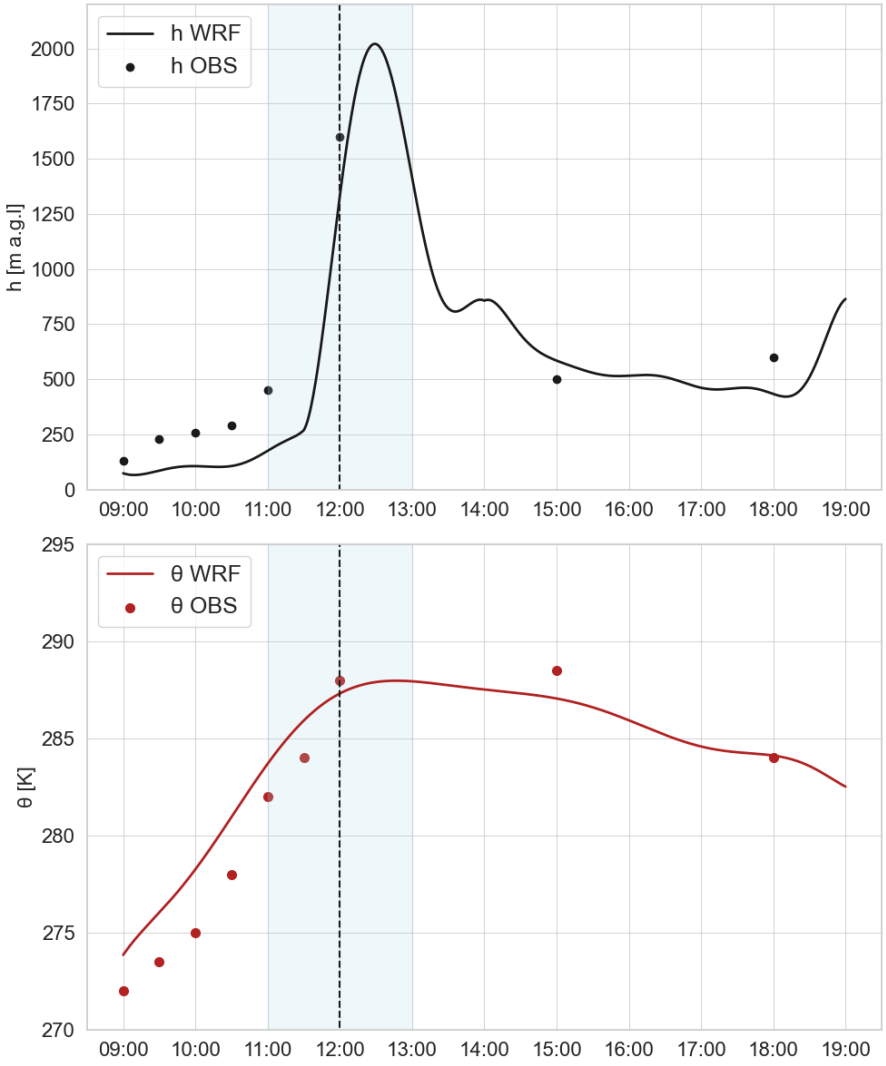
Understanding the atmospheric boundary layer dynamics

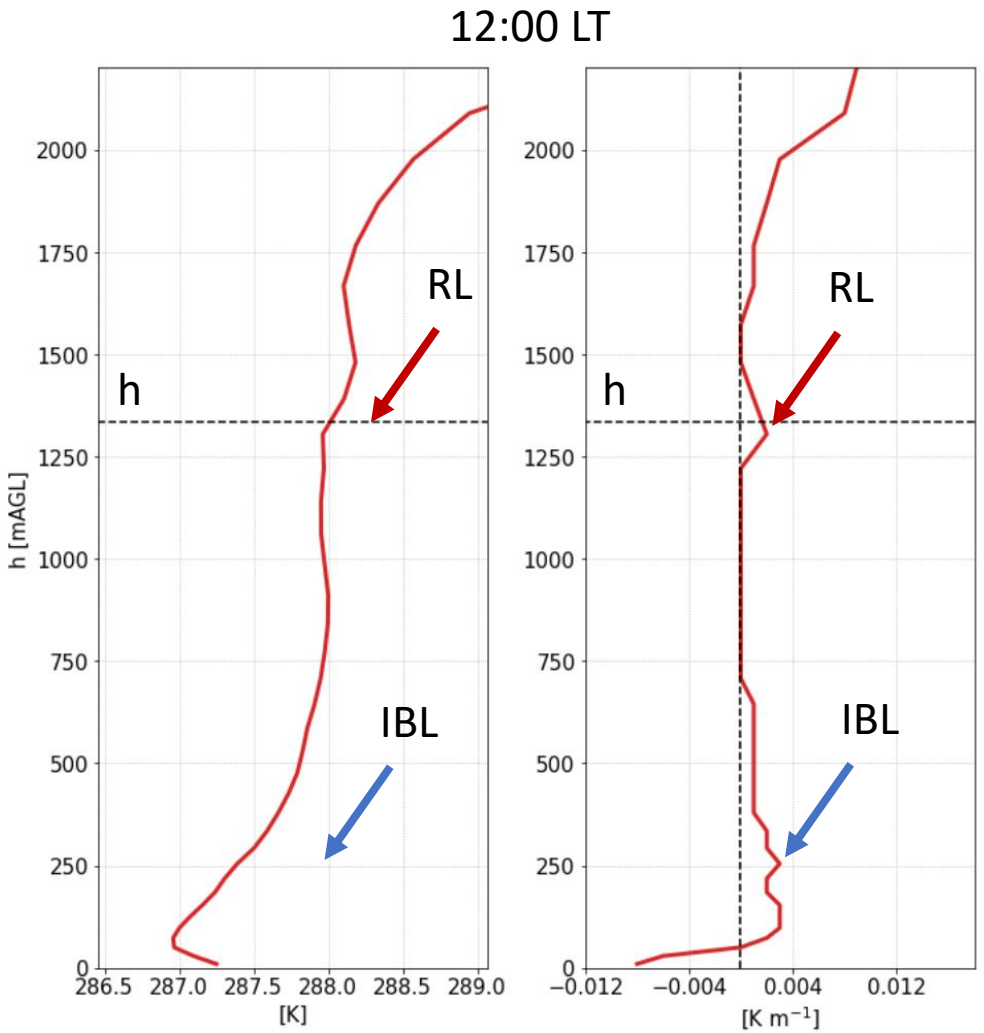


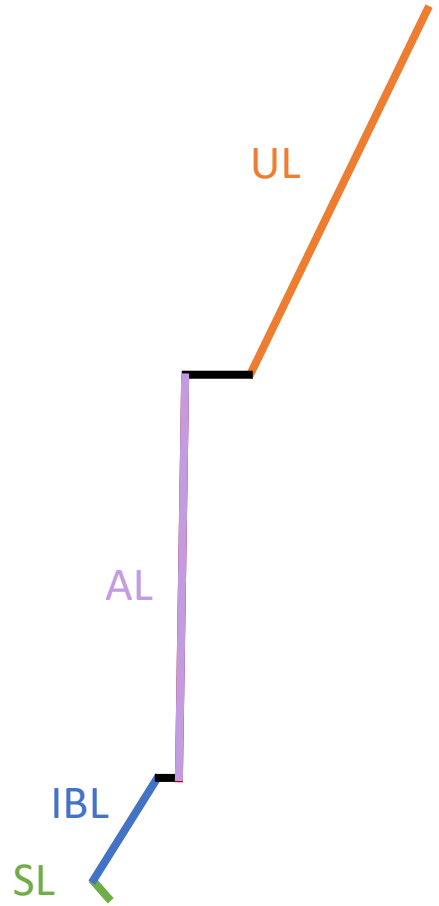




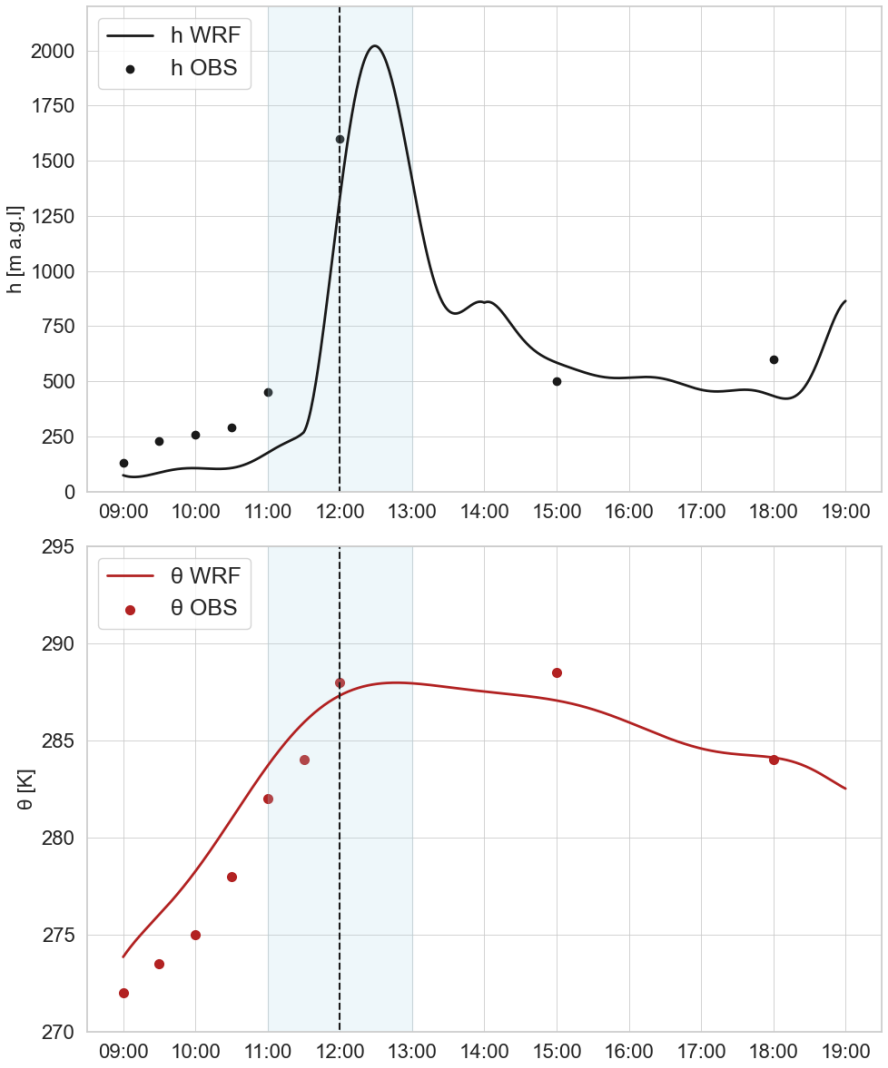
Understanding the atmospheric boundary layer dynamics

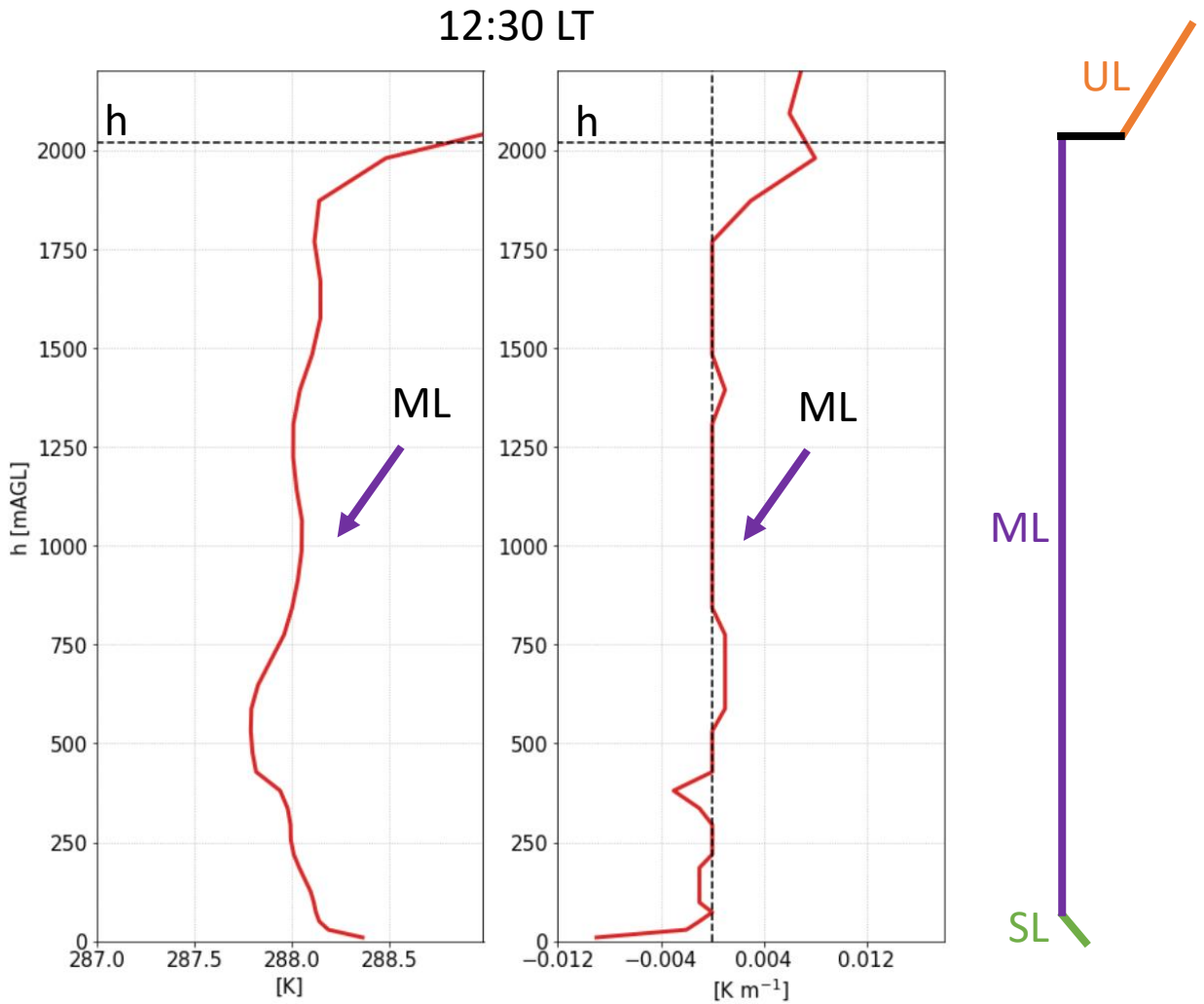




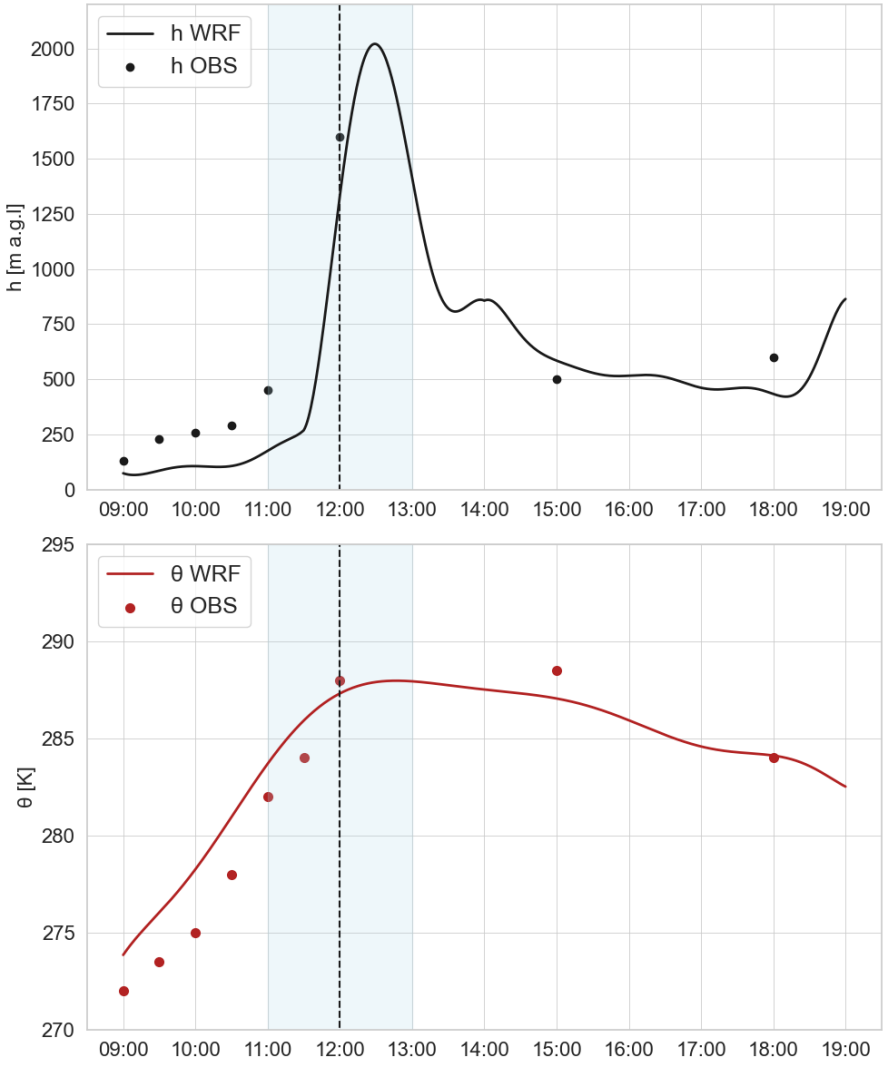


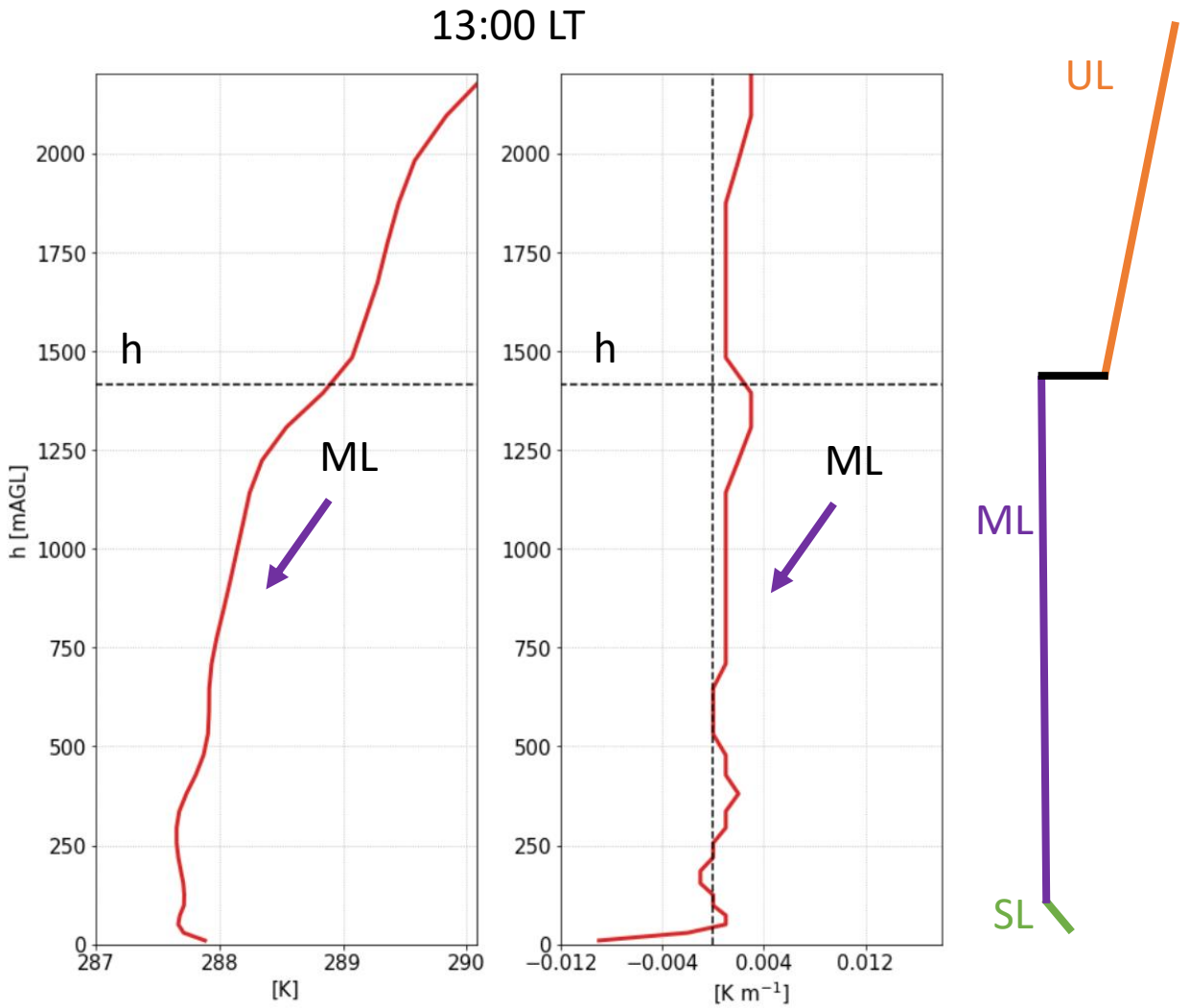
Understanding the atmospheric boundary layer dynamics



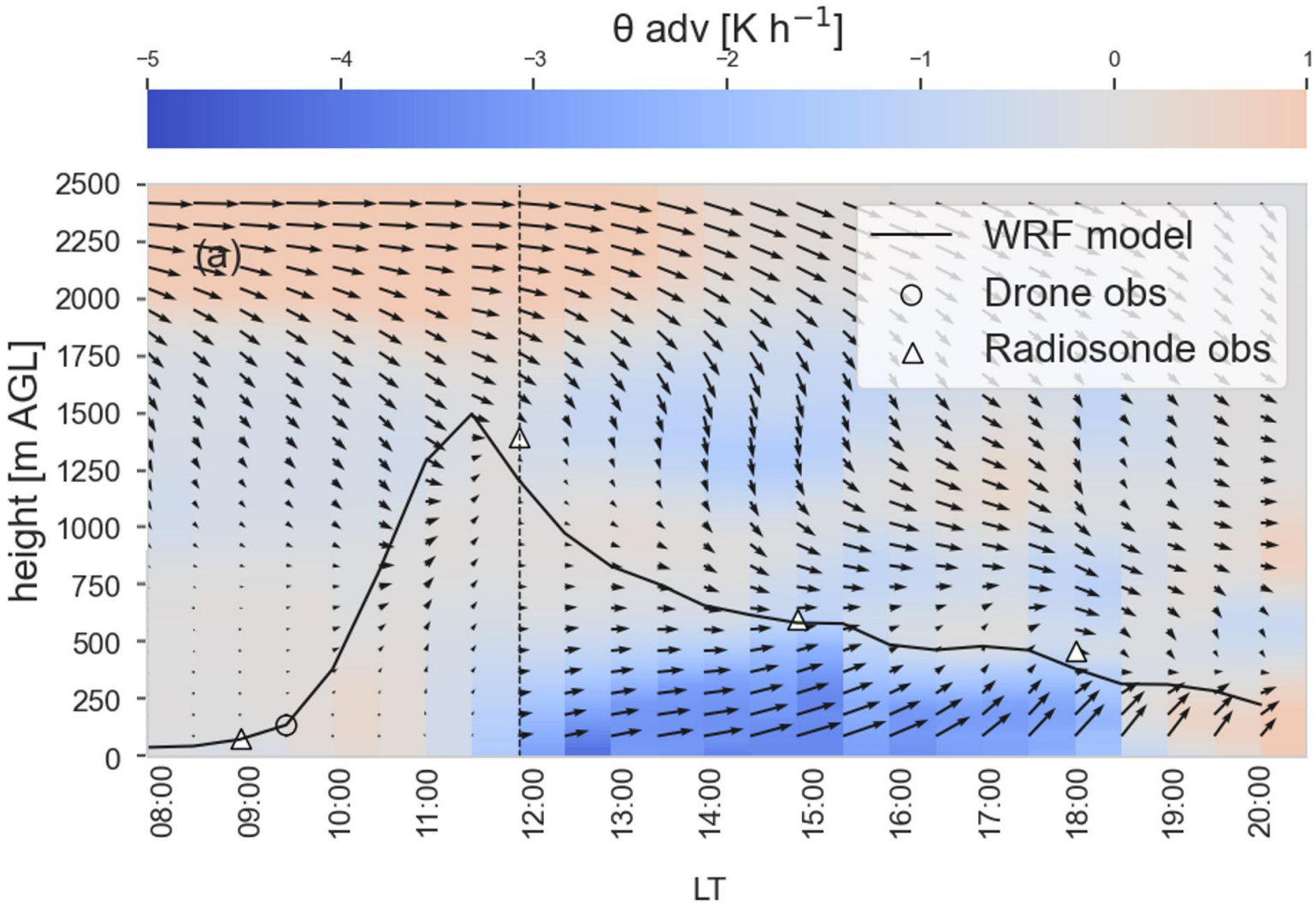


Understanding the atmospheric boundary layer dynamics

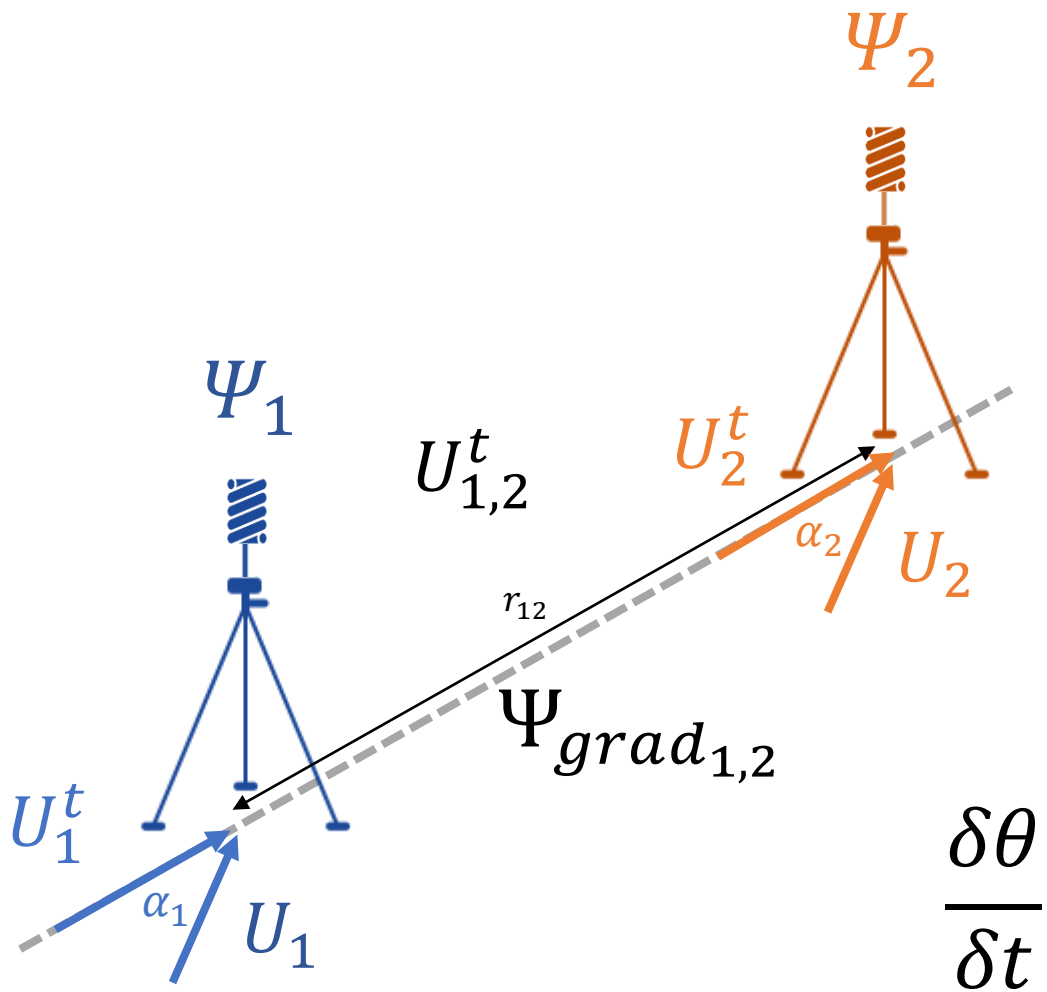




Appendix: desert



Advection approach



$$\Psi_{grad} = \frac{\Psi_2 - \Psi_1}{r_{12}}$$

$$U_1^t = -U_1 \cos(\alpha_1)$$

$$U_2^t = -U_2 \cos(\alpha_2)$$

$$\frac{\delta\theta}{\delta t} = \frac{\left(\overline{w'\theta'}\right)_s - \left(\overline{w'\theta'}\right)_e}{h} + \theta_{adv}$$

$$\theta_{adv} = \left(U_{1,2}^t\right) \Psi_{grad}$$