An introduction into atmospheric boundary layers

Chiel van Heerwaarden

EWED Training Event, 21 October 2025



Martorell fire (2021, CFRS Bombers)

Three tutorials on the atmospheric boundary layer and wildfire plumes

- **Today morning (Chiel):** Introduction into the atmospheric boundary layers and plumes
- **Today afternoon (Jordi):** The fireless atmospheric boundary layer
- **Tomorrow morning (Martin):** Rising wildfire plumes



Atmospheric boundary layer



Martorell wildfire plume (2021, picture by CFRS)

Program for this morning: 21 October 2025

- 9.15-10:30: The atmospheric boundary layer: introduction into the concepts
- 10:30-11:00 Coffee break
- 11:00-12.30: The atmospheric boundary layer: the vertical structure
  - Interpretation of profiles and introduction into CLASS
- 12:30-13:30 Lunch break

If there is a question or a problem, please reach out!

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Part 1.1: *The atmospheric boundary layer: introduction into the concepts*




daytime convective boundary layer
(~ 1 - 2 km deep)


?
?
daytime convective boundary layer
(~ 1 - 2 km deep)
?




daytime convective boundary layer
(~ 1 - 2 km deep)

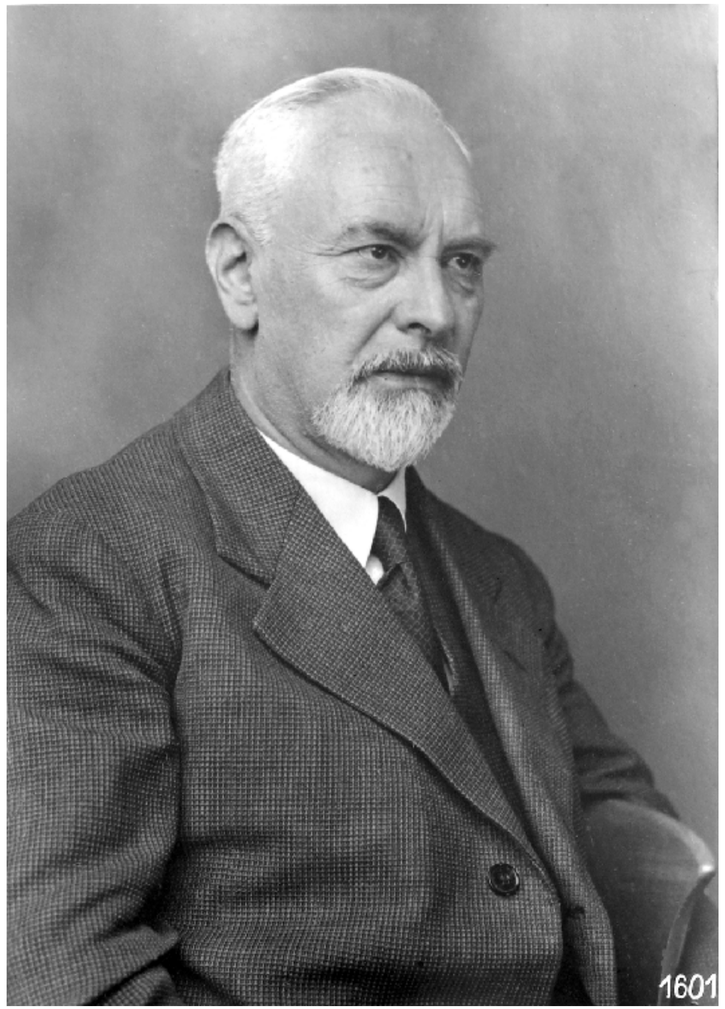
From **reality** to a **model**: the daytime convective boundary layer as a shoe box



daytime convective boundary layer
(~ 1 - 2 km deep)



Who discovered the boundary layer?



Ludwig Prandtl presented the boundary layer in his famous 1904 paper: ***Über Flüssigkeitsbewegung bei sehr kleiner Reibung****.*

According to the APS, it is the most revolutionary idea that never won a Nobel Prize

Wind over the surface generates turbulence: more wind, more turbulence

strong wind above the surface

atmospheric surface layer (~ 100 m)



no wind at the surface

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atmospheric surface layer (~ 100 m)

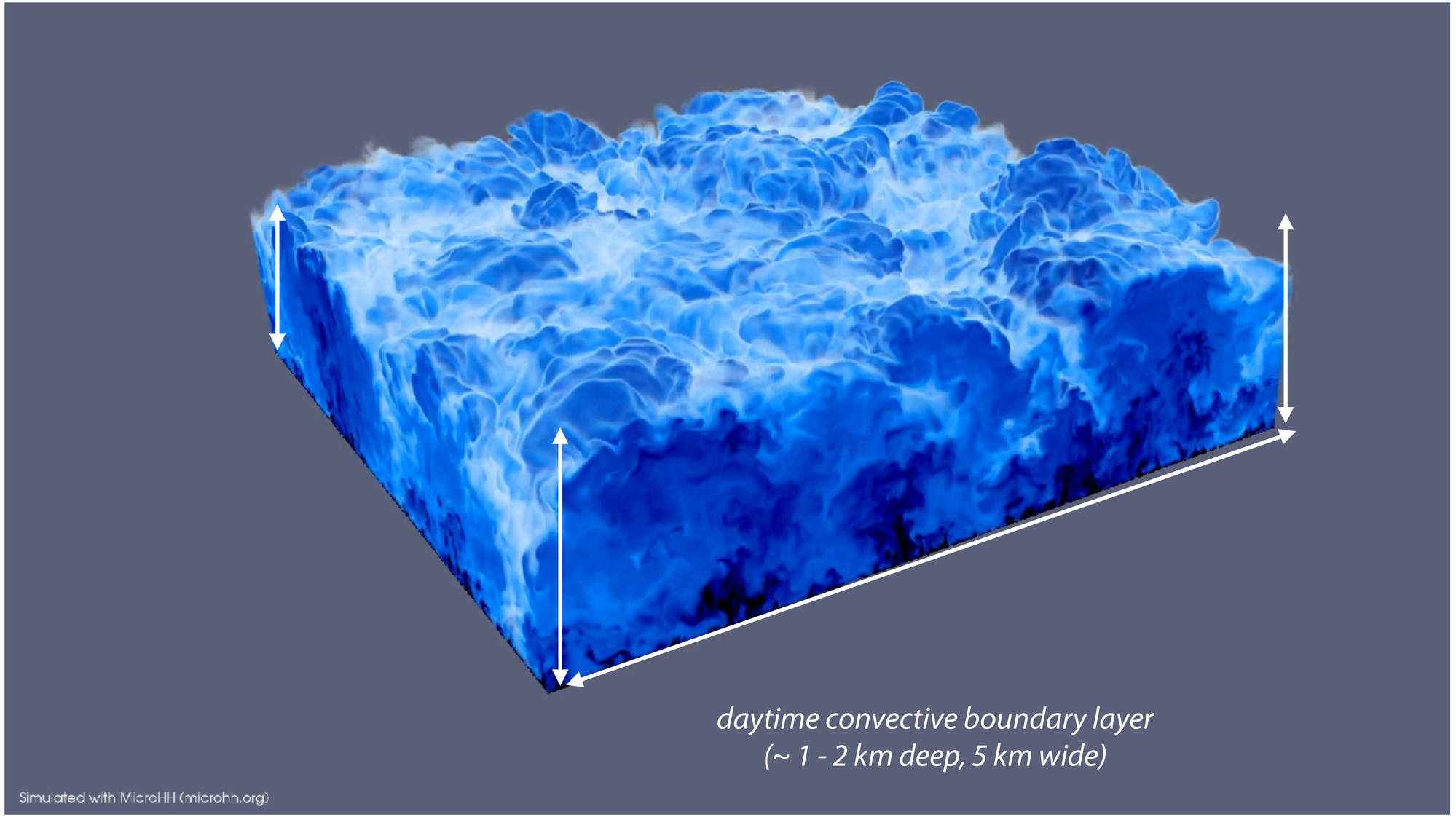


no wind at the surface



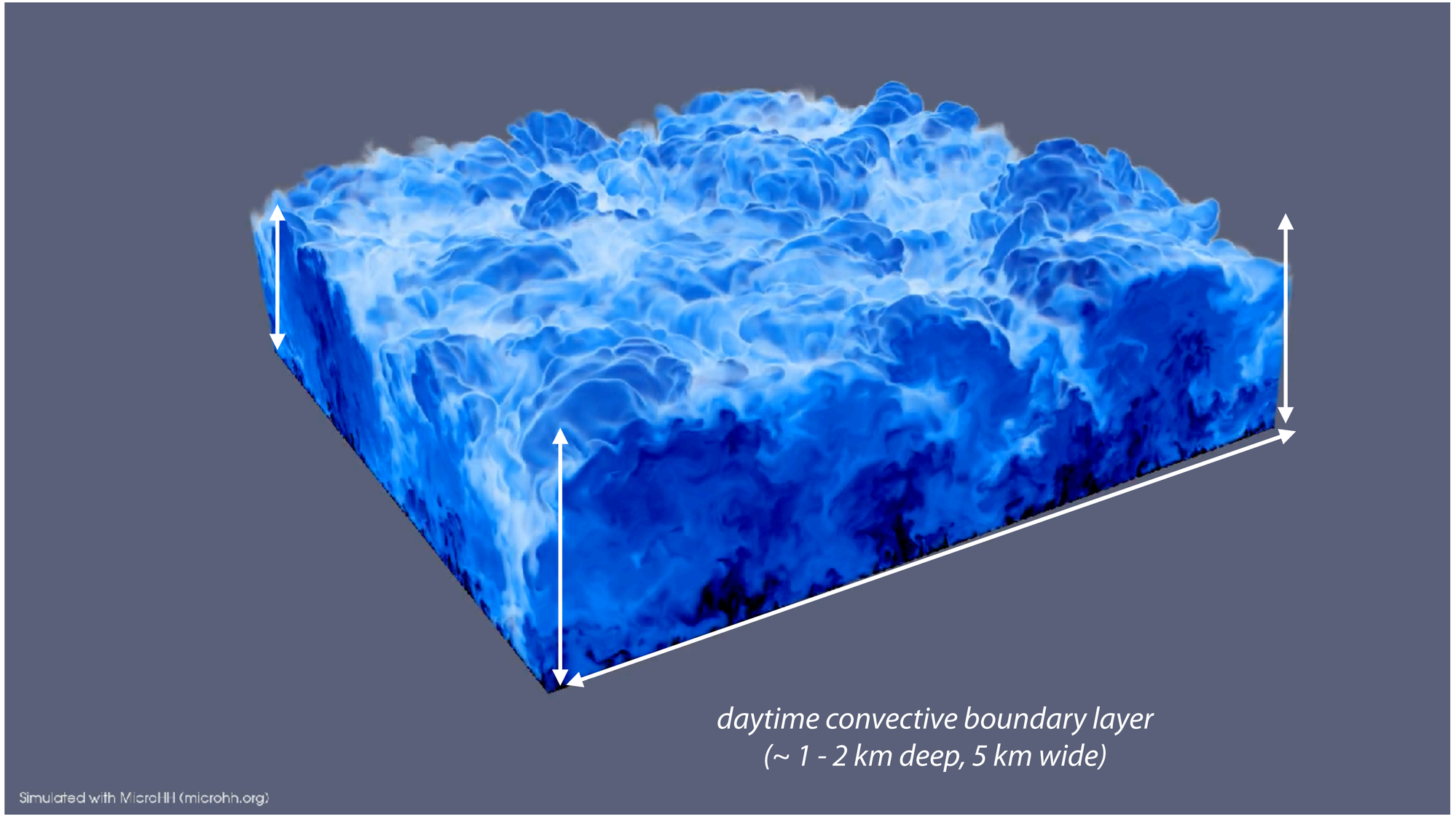
The blue marble taken from Apollo 17 in 1972

Surface warming drives the daytime atmospheric convective boundary layer



Visualization shows heat added from the surface

Surface warming drives the daytime atmospheric convective boundary layer



Visualization shows heat added from the surface

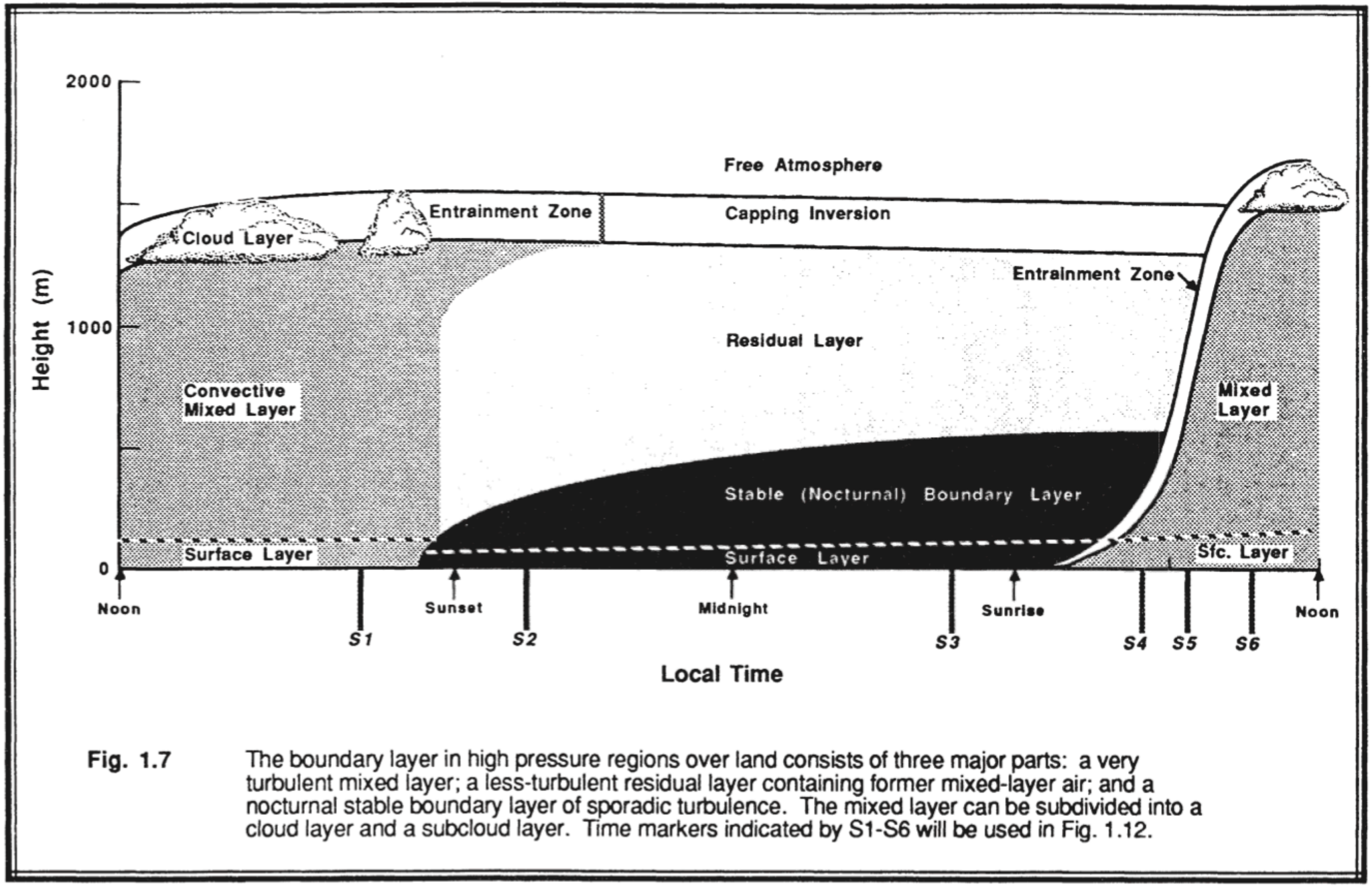


Fig. 1.7 The boundary layer in high pressure regions over land consists of three major parts: a very turbulent mixed layer; a less-turbulent residual layer containing former mixed-layer air; and a nocturnal stable boundary layer of sporadic turbulence. The mixed layer can be subdivided into a cloud layer and a subcloud layer. Time markers indicated by S1-S6 will be used in Fig. 1.12.

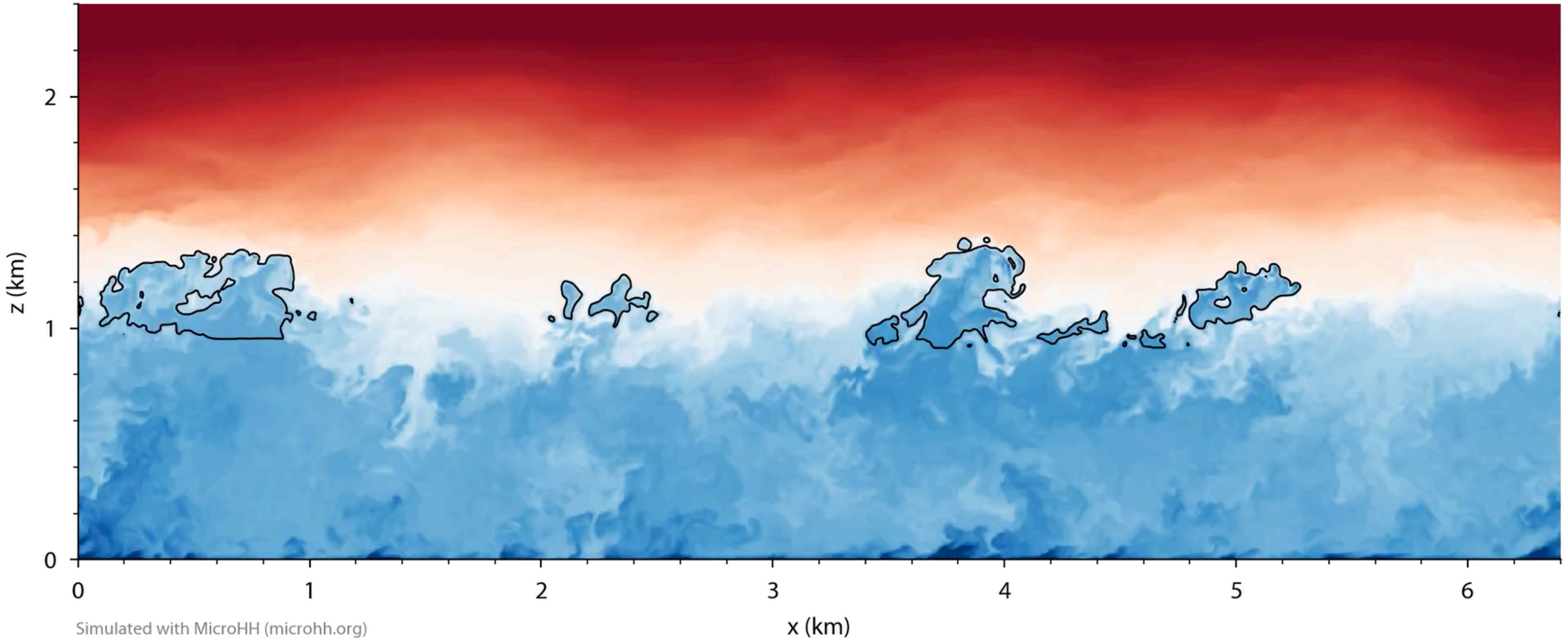
Probably the most famous conceptual sketch of boundary layer meteorology by Stull



Picture by Wouter Mol

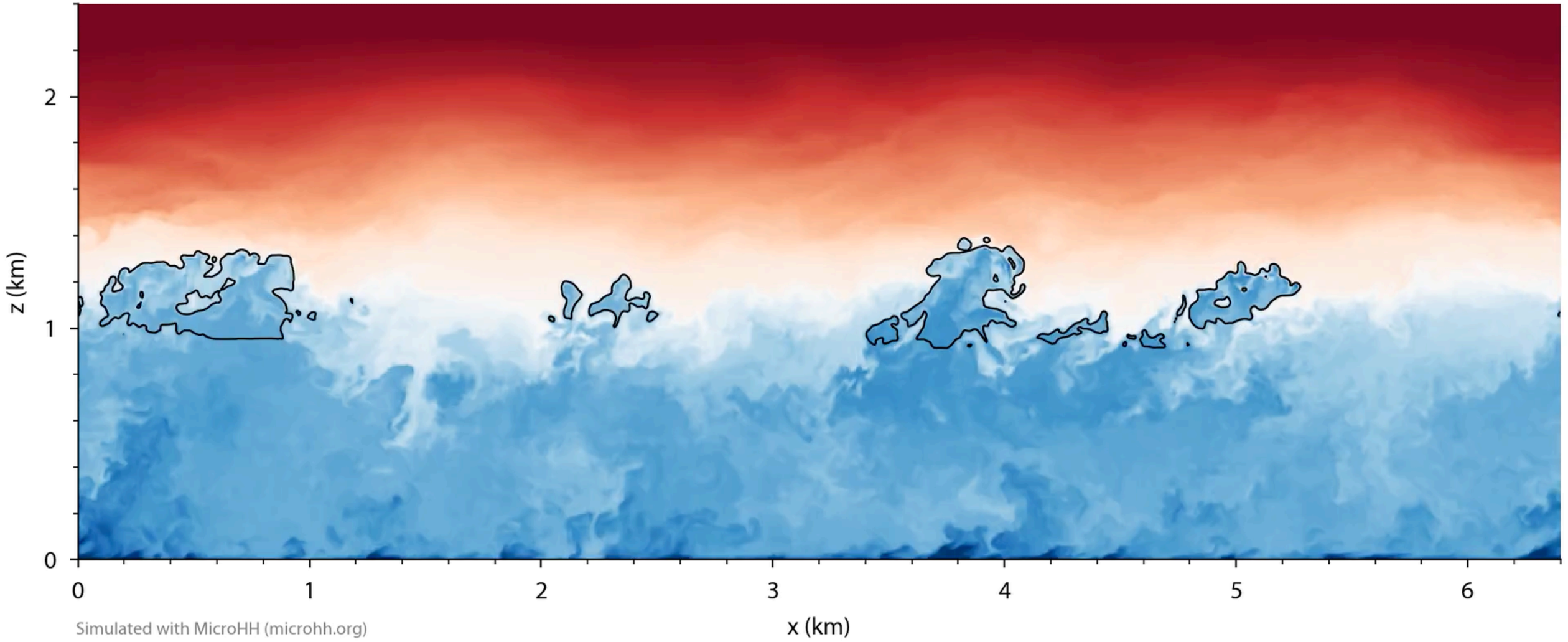


How long does it take for surface heating to reach the top of the convective boundary layer?

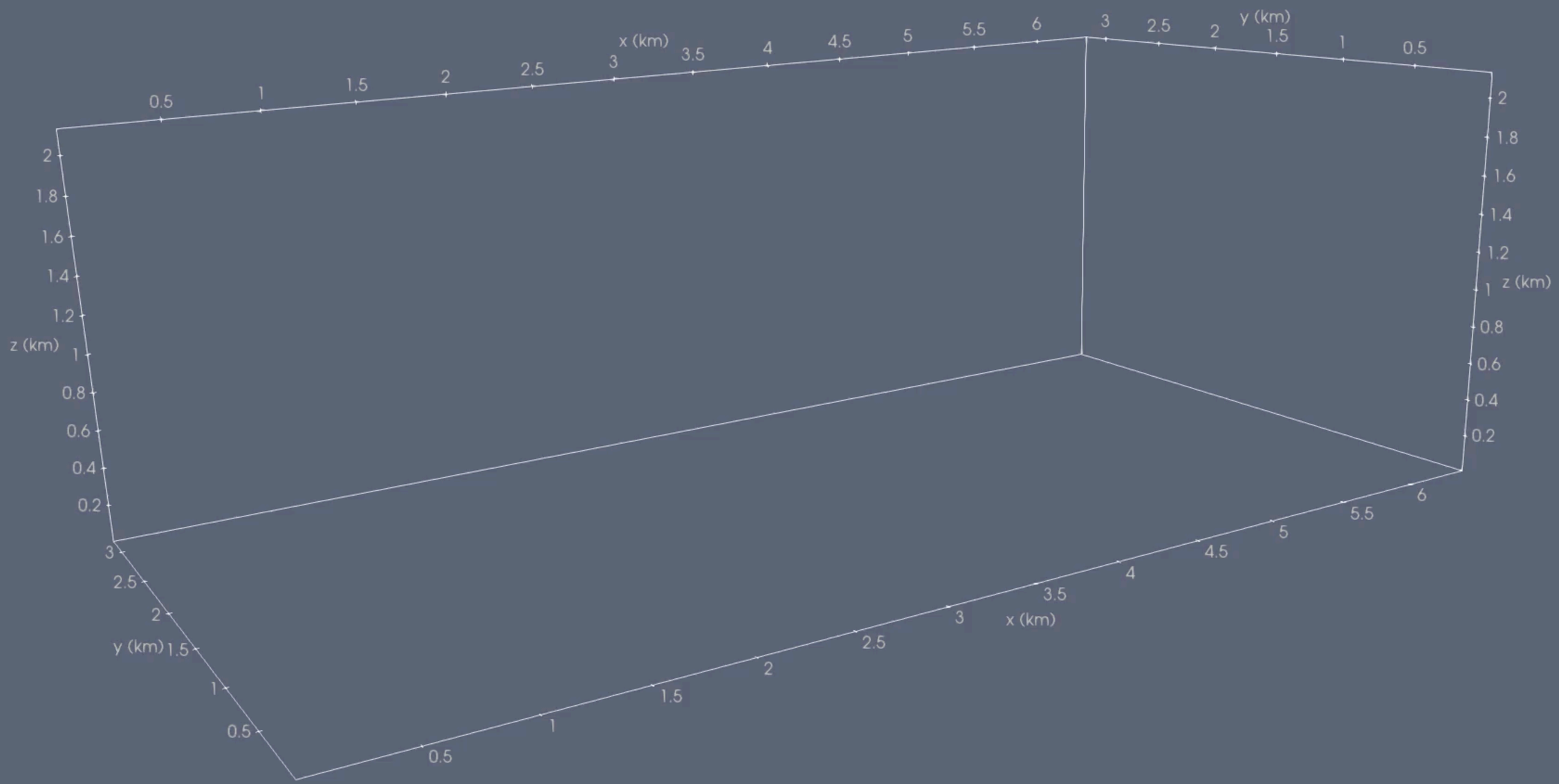


*Blue is moist air, red is dry air. Clouds contoured in **black**. A simulation second is 3 min in reality.*

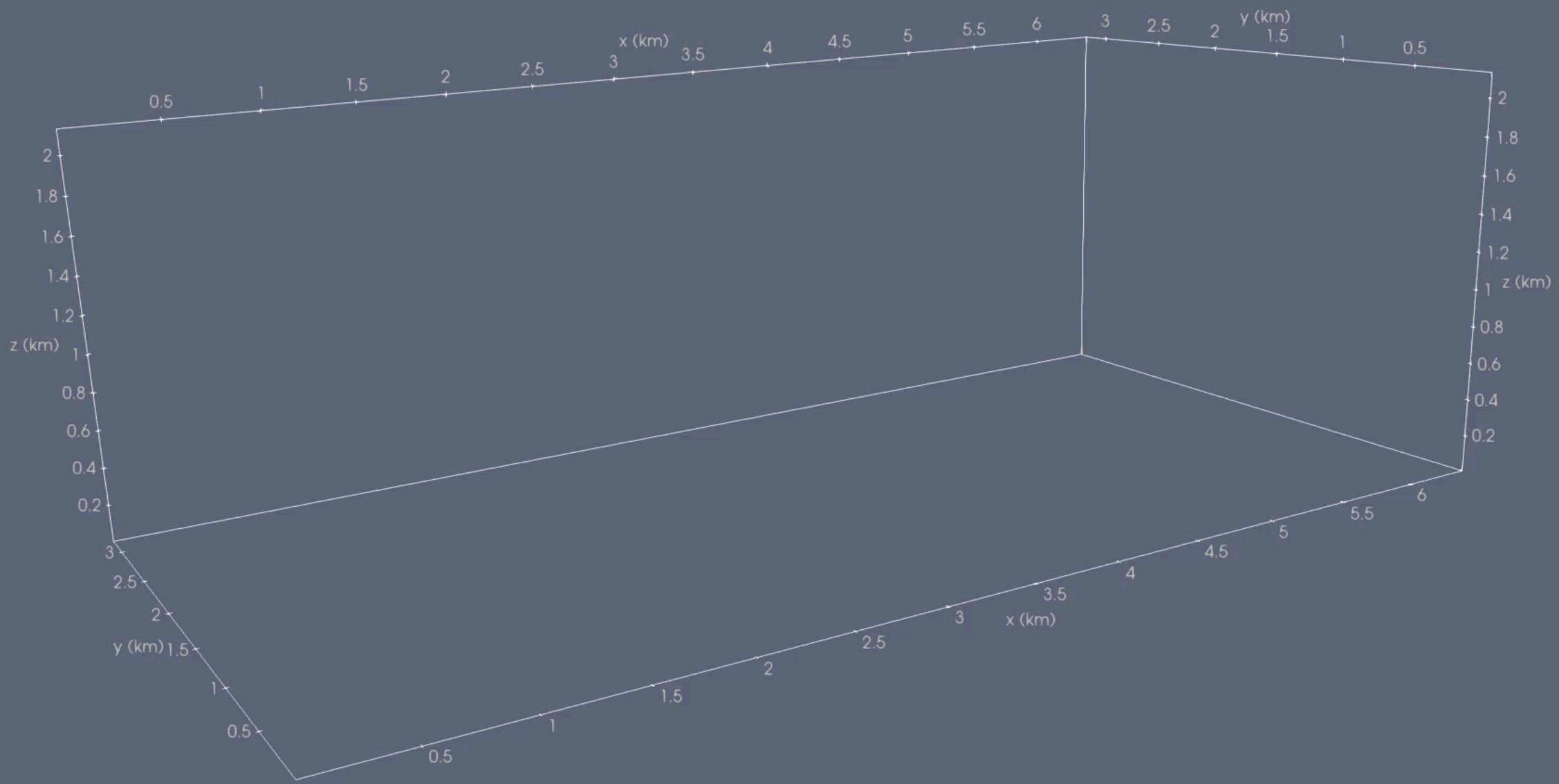
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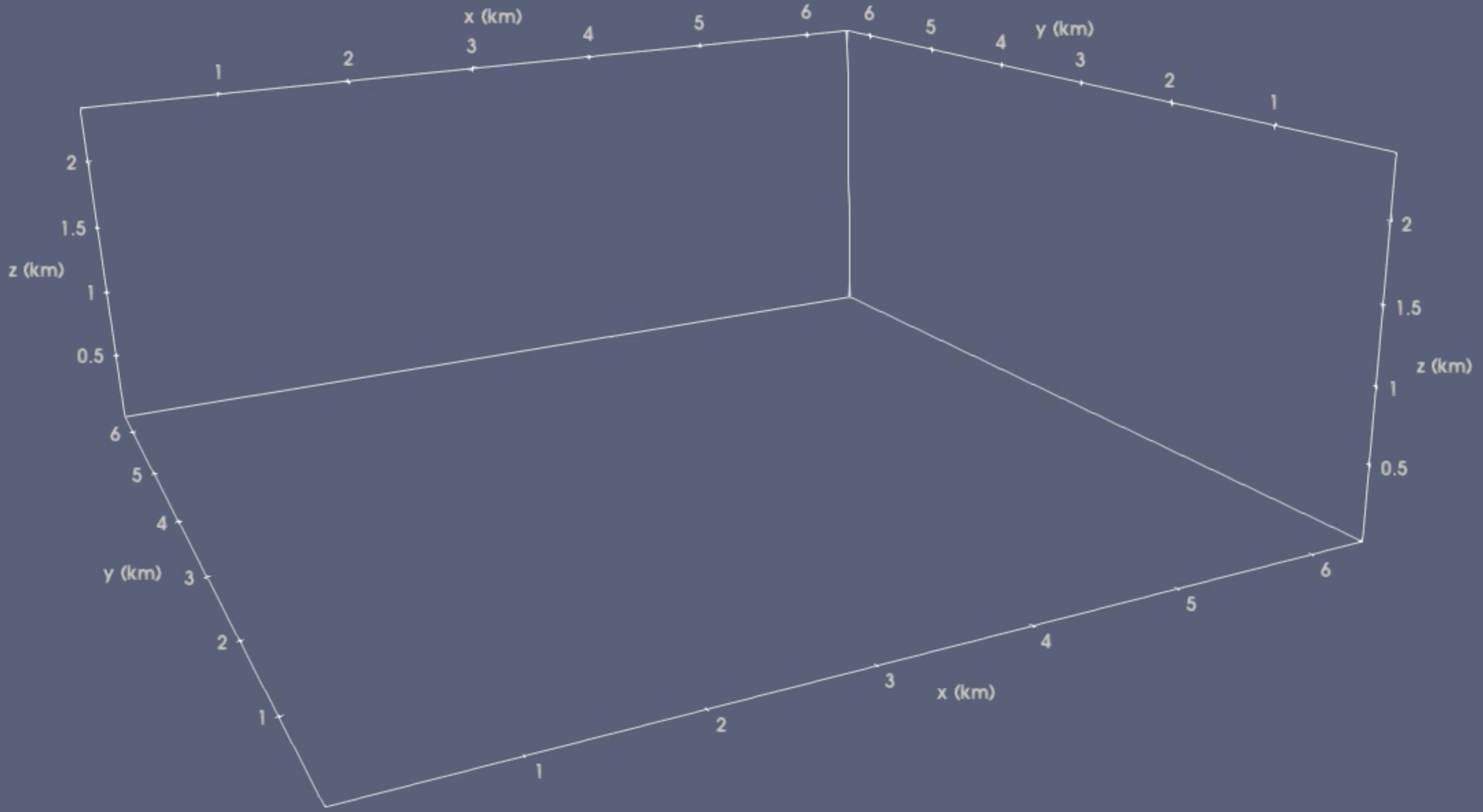
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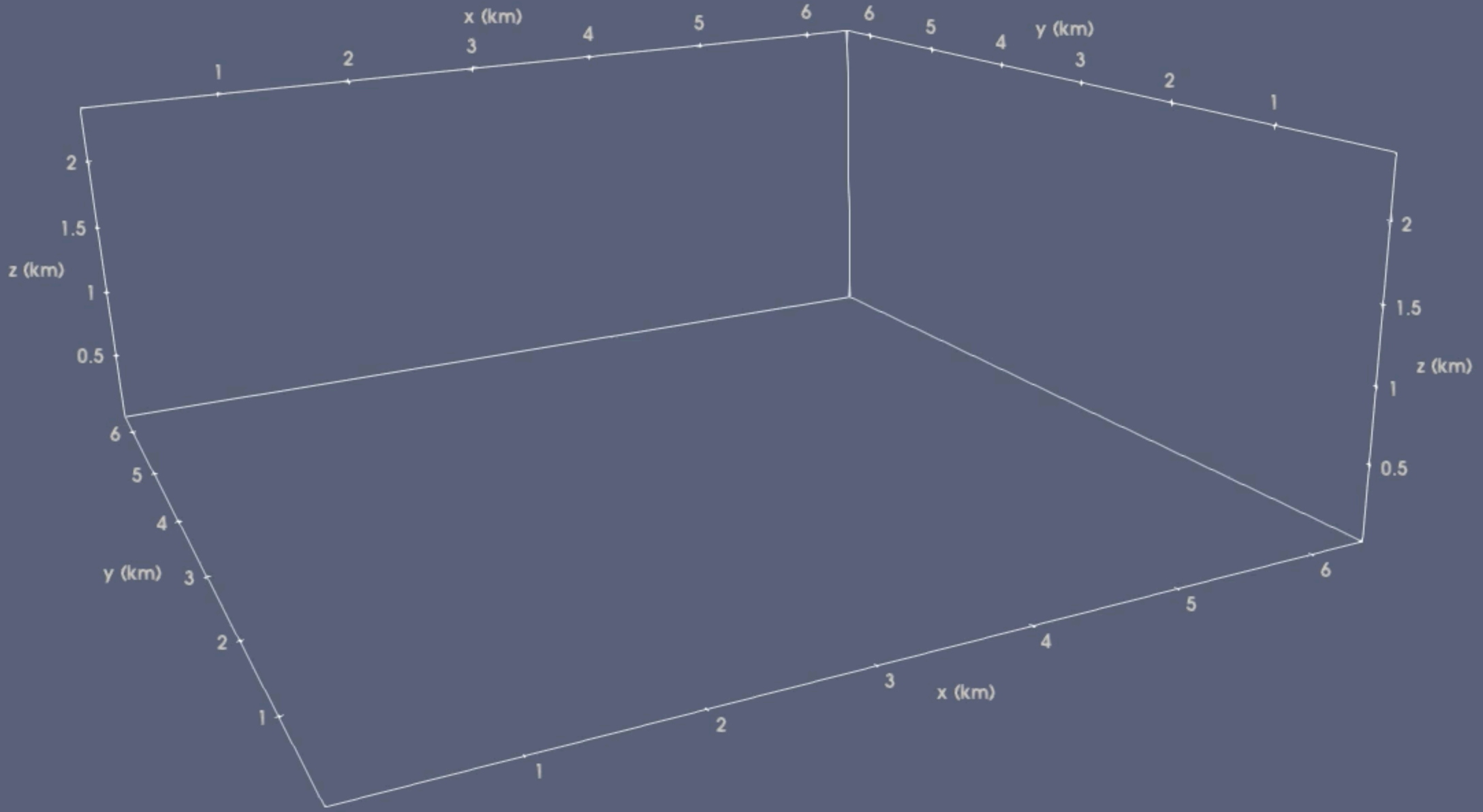
Simulated with MicroHH (microhh.org)



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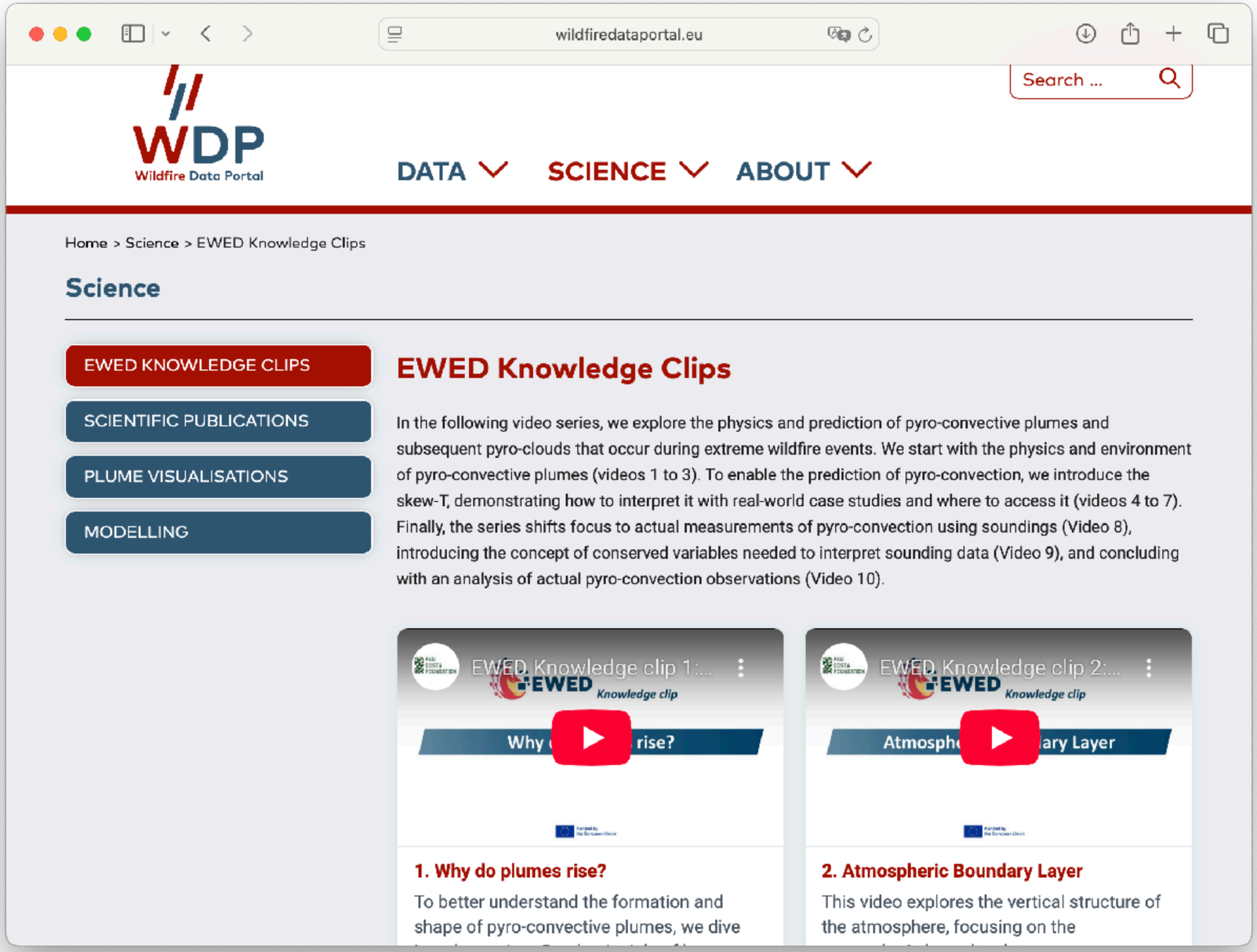


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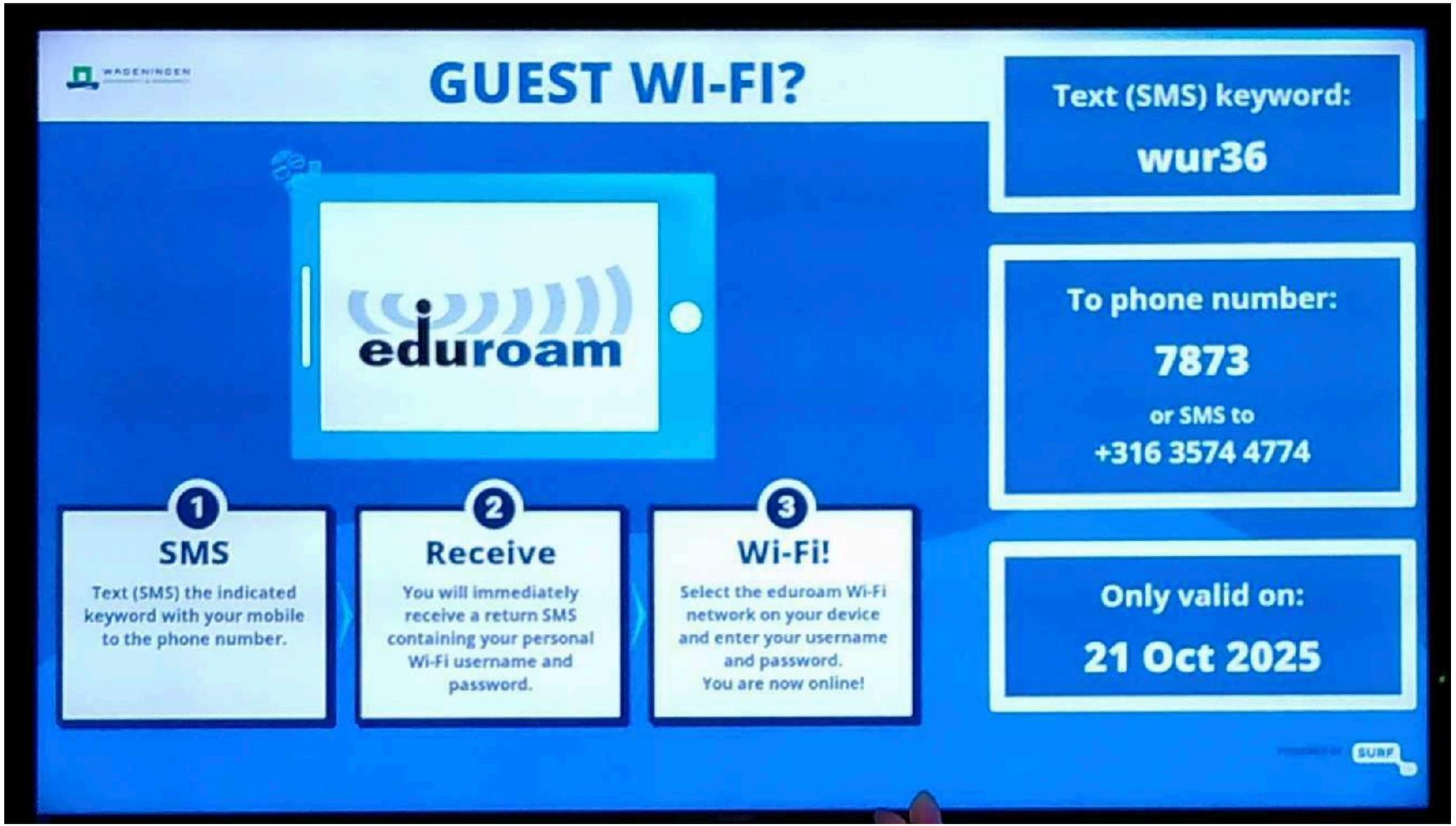


Simulated with MicroHH (microhh.org)

Extra explanation on wildfiredataportal.eu/science/ewed-knowledge-clips/



Access to internet



Part 1.2

The atmospheric boundary layer:
the vertical structure

Daytime convective boundary layer is box that grows because of **surface heating**



daytime convective boundary layer
(~ 1 - 2 km deep)

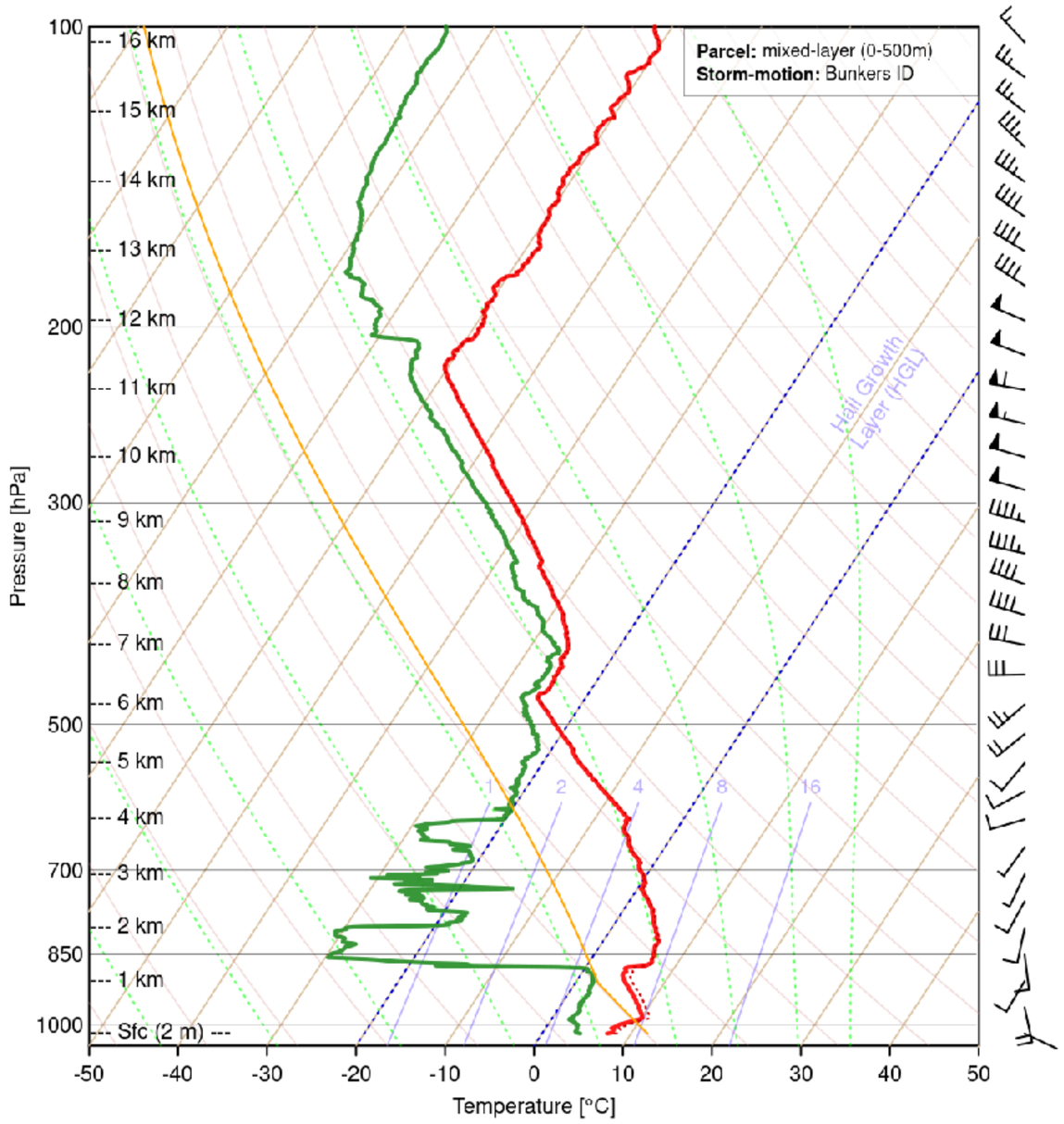


We measure the vertical structure of the atmosphere with radiosoundings



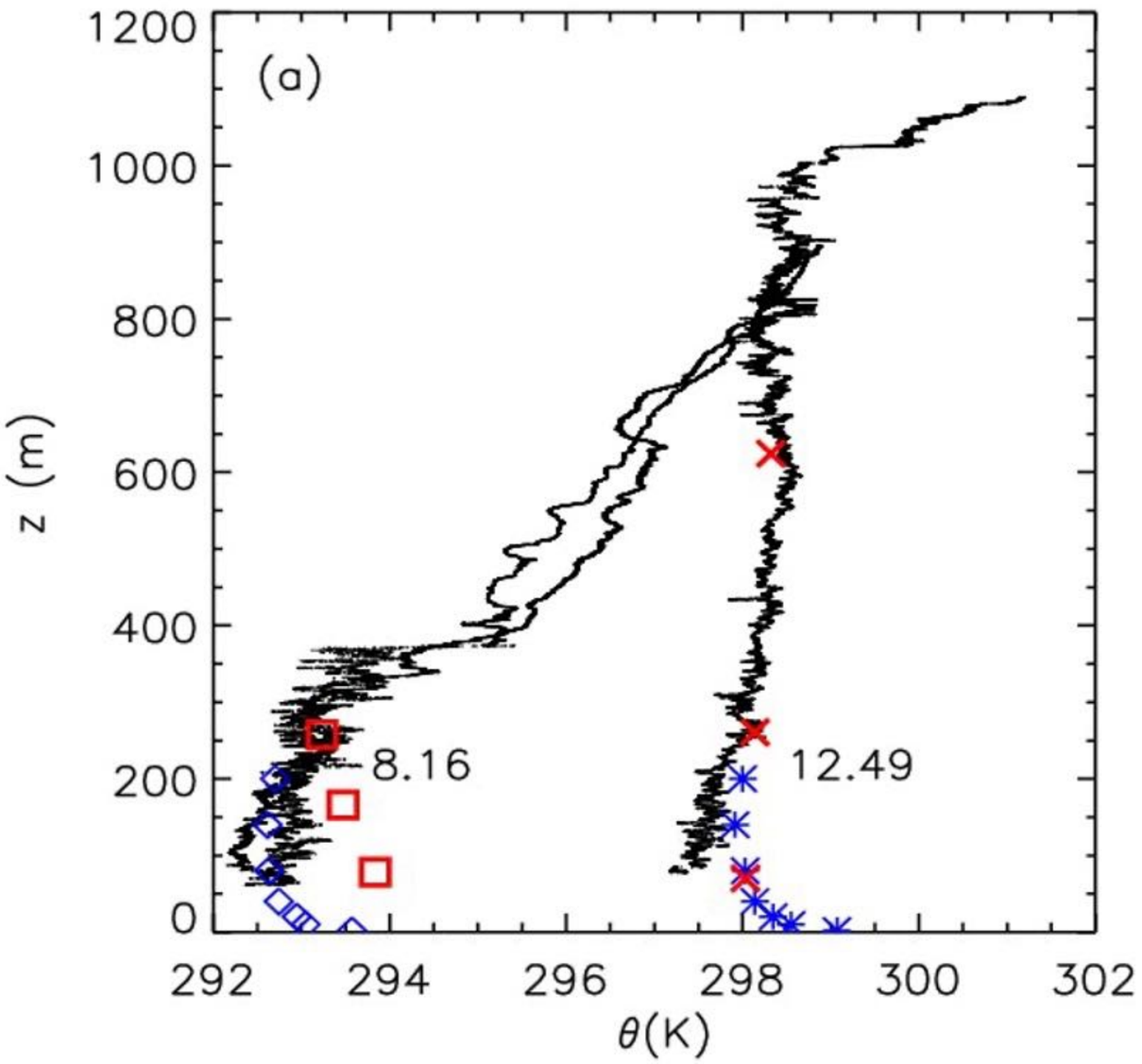


The Skew-T log-p diagrams are often used, but requires a high level of expertise





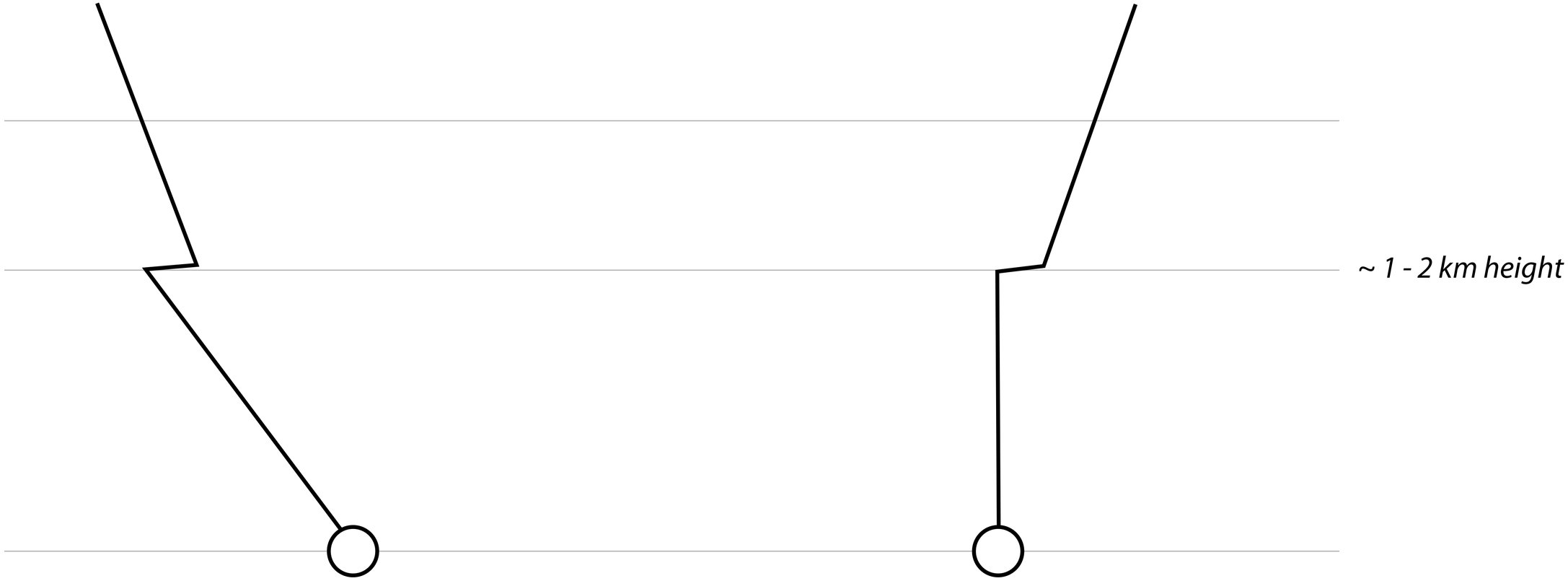
Potential temperature (θ) makes the interpretation a lot easier





Temperature decreases with height, but that makes our analysis complex

change in temperature = *work done by the system* + *heat added to the system*



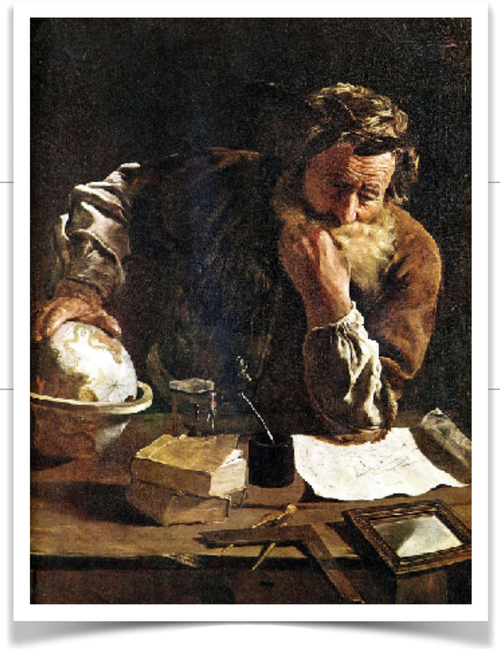
Temperature (T)
temperature we measure
used in Skew T - log P diagrams

Potential temperature (θ)
temperature of air parcel if we bring it to the surface
so-called "conserved variable"

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adding heat creates ***buoyancy***



~ 1 - 2 km height

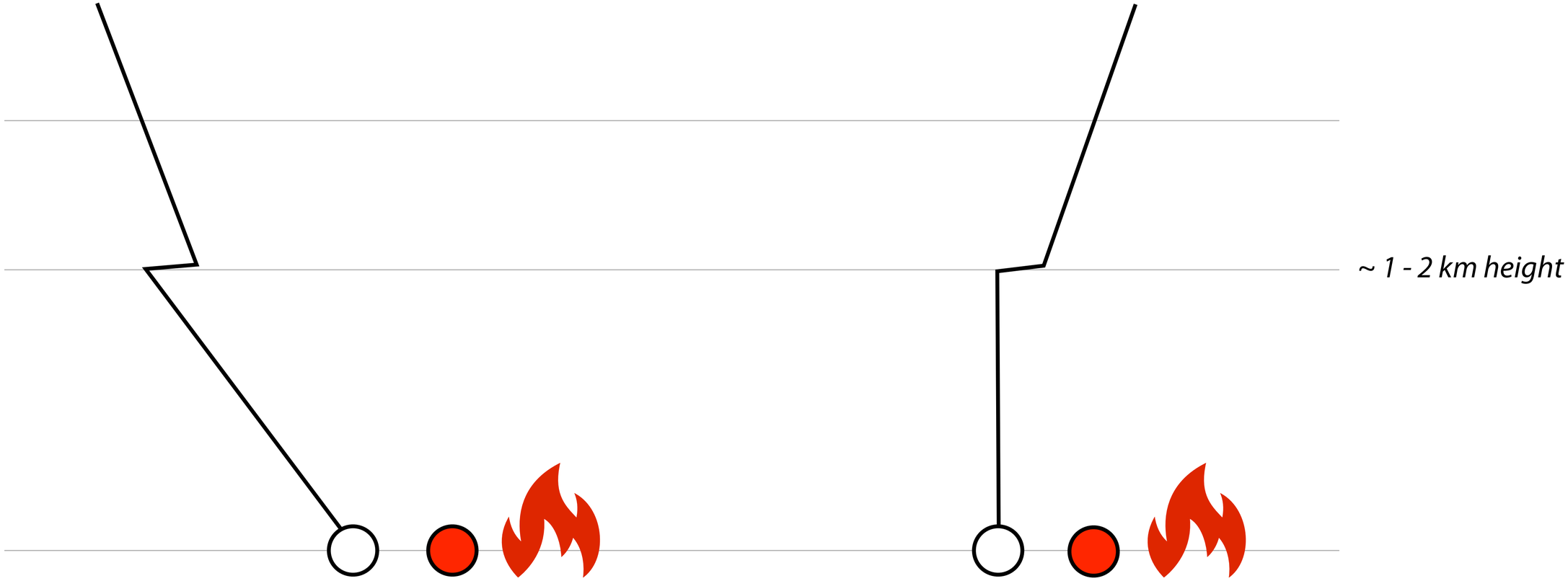
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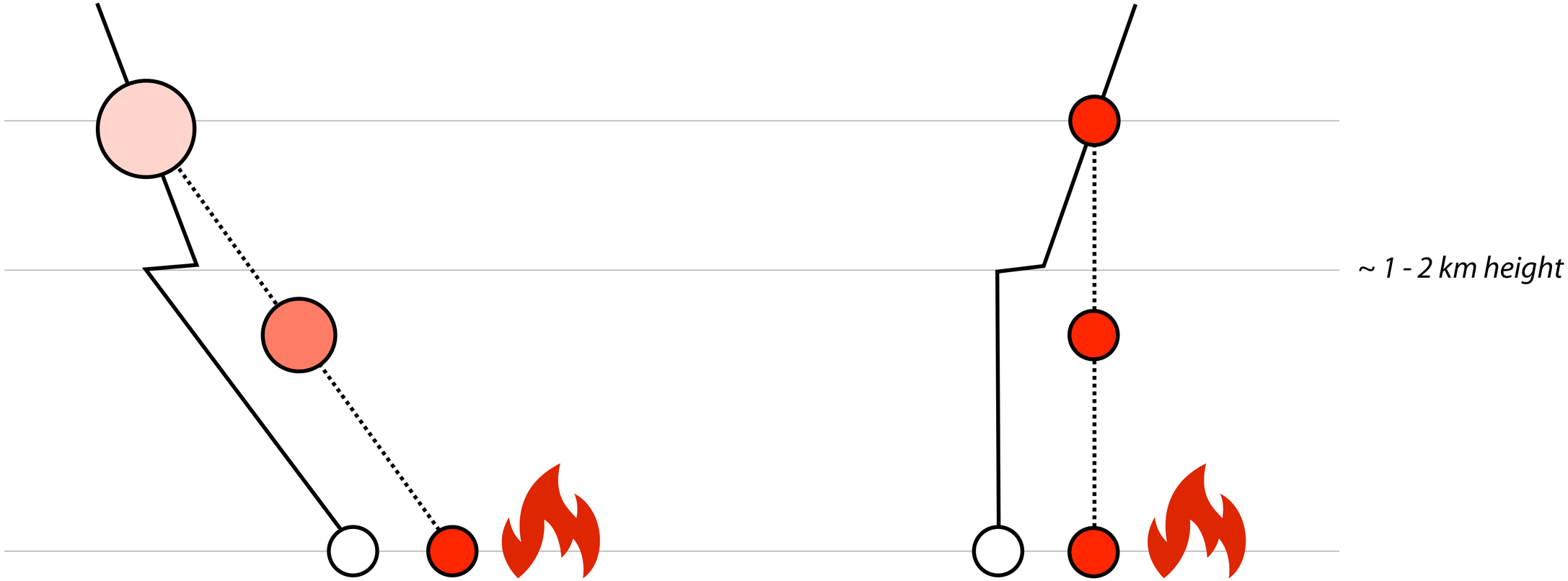
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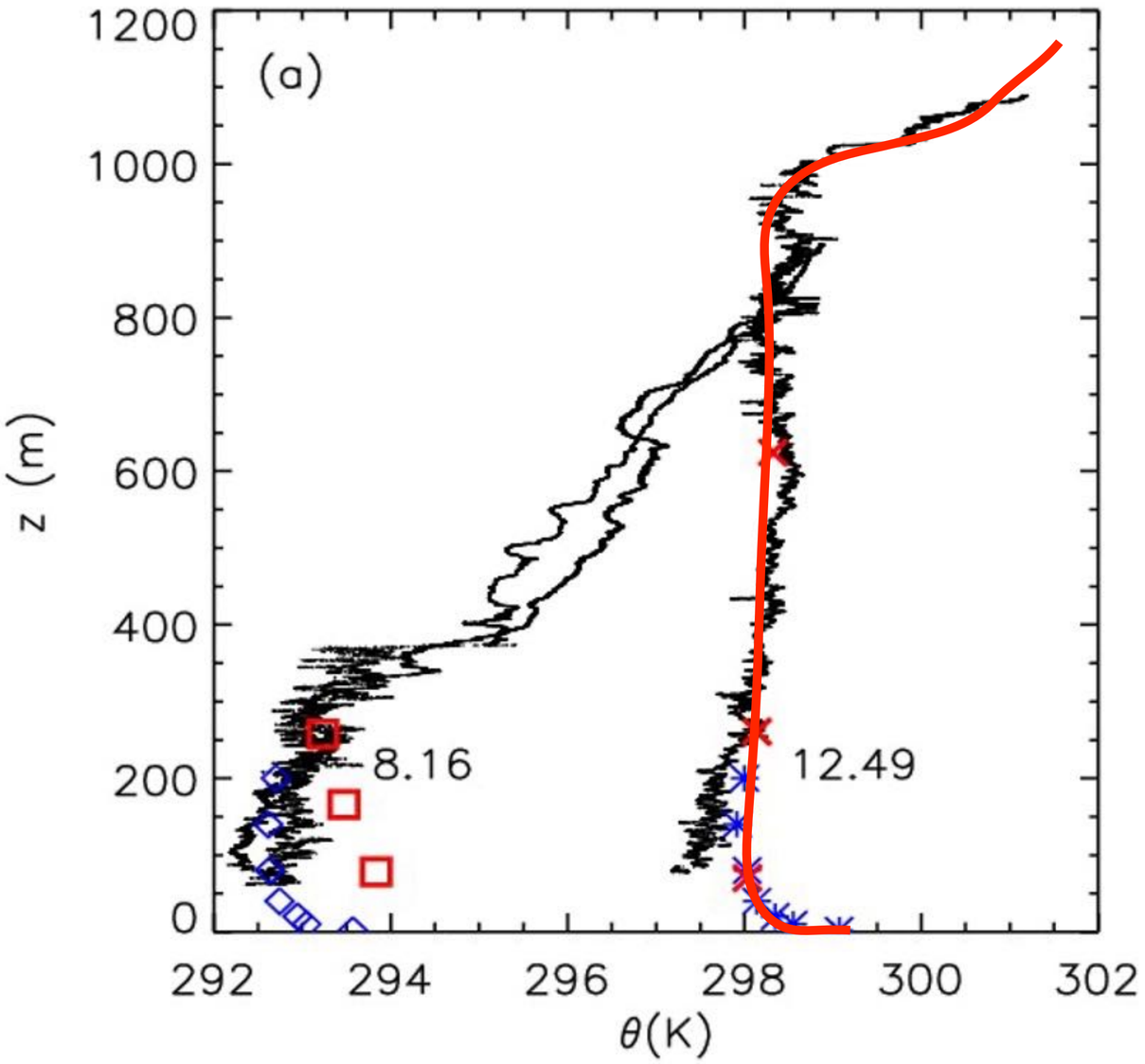
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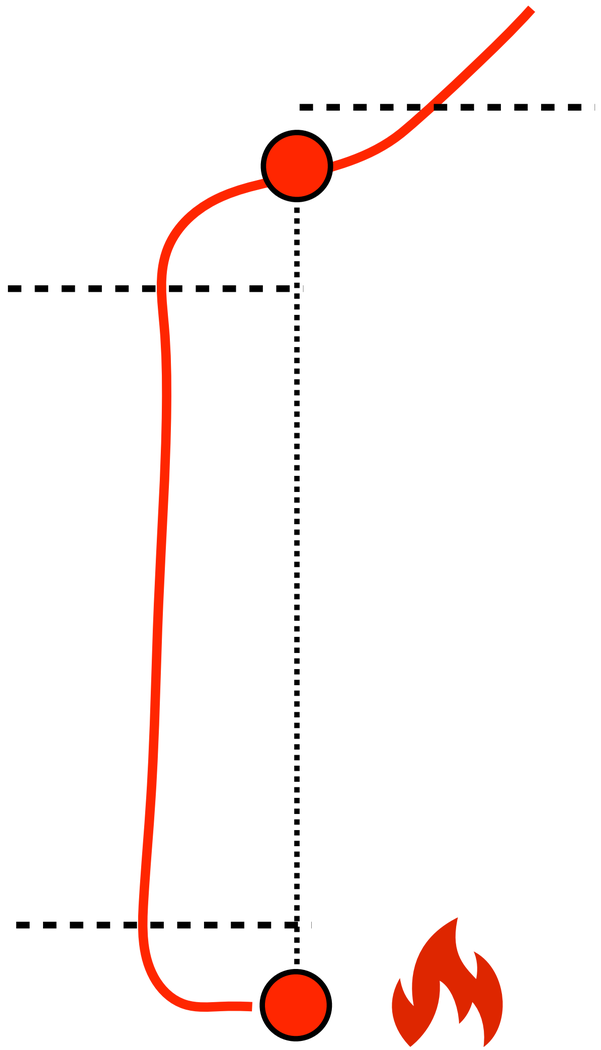


Temperature (T)
temperature we measure
used in Skew T - log P diagrams

Potential temperature (θ)
temperature of air parcel if we bring it to the surface
so-called "conserved variable"

Four layers that are **unstable**, **neutral** or **stable**





free atmosphere

$$\frac{\Delta\theta}{\Delta z} > 0 \,(\text{stable})$$

entrainment zone

$$\frac{\Delta\theta}{\Delta z} \gg 0 \,(\text{stable})$$

mixed layer

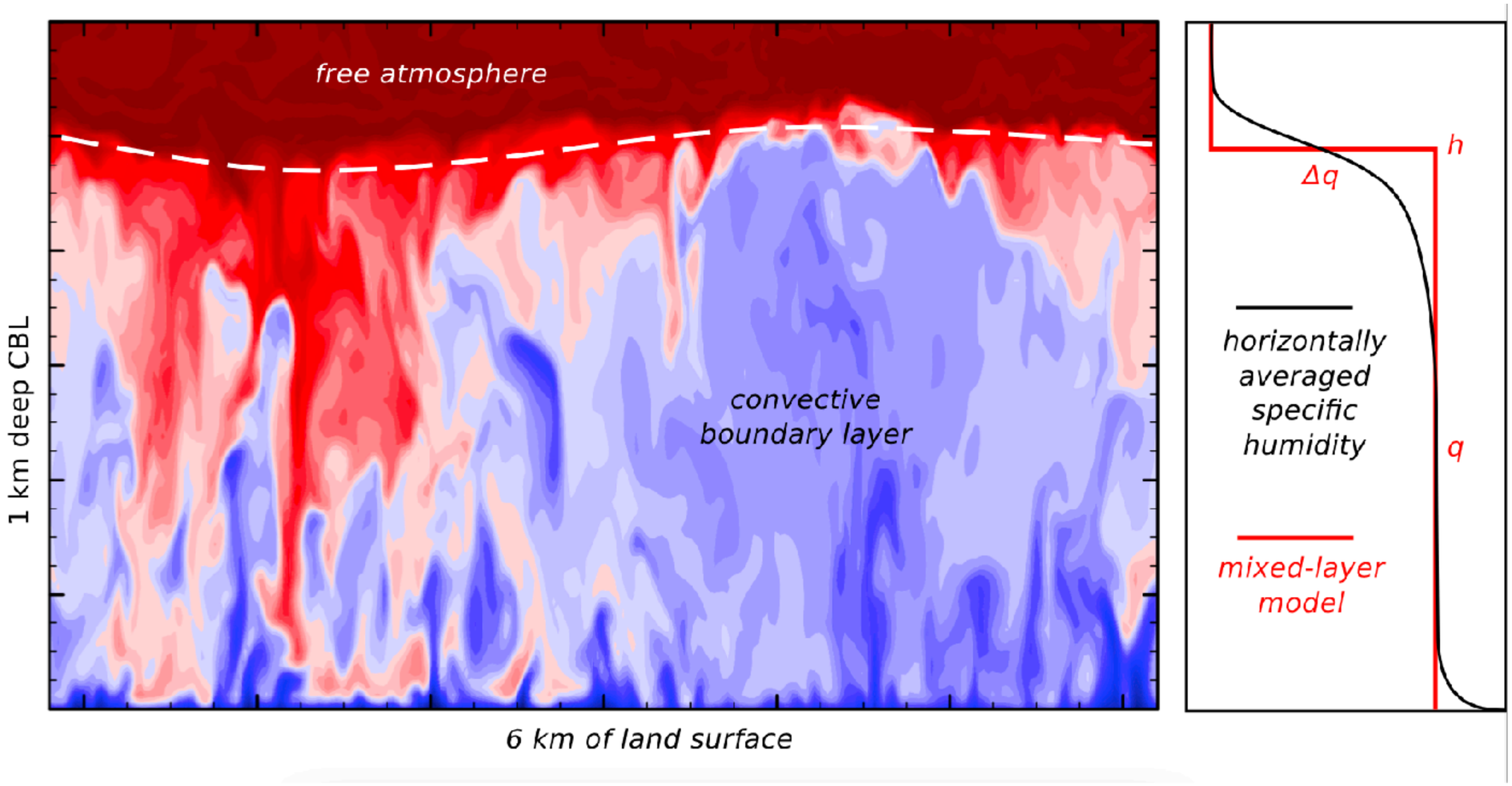
$$\frac{\Delta\theta}{\Delta z} \approx 0 \,(\text{neutral})$$

surface layer

$$\frac{\Delta\theta}{\Delta z} < 0 \,(\text{unstable})$$

The structure of the daytime convective boundary layer

- Moisture also shows the same structure as potential temperature



The tools of the EWED Training event (tools are in testing phase, we need feedback)

- The EWED Wildfire Data Portal



wildfiredataportal.eu

wildfiredataportal.eu/science/modelling

- The Chemistry Land Atmosphere Soil Slab (CLASS) model

classmodel.github.io

The case of today and tomorrow: (an idealized version of) the Martorell wildfire

- Martorell, Catalonia, 13 July 2021
- What happened? (Expert in the room)
- Why this case?
  - Excellent example daytime boundary layer
  - Good sounding observations
  - Pyrocumulus formation
  - All aspects of the training available



Photo by CFRS (wildfiredataportal.eu)

What to do now?

- Open the case via the link below

- Check the evolution of the profiles by moving the slider
  - Temperature (T)
  - Potential temperature (θ)
  - Specific humidity (q)
  - Relative humidity (RH)

- Check the time series
  - Boundary-layer height (h)
  - Potential temperature (θ)
  - Specific humidity (q)

wildfiredataportal.eu/science/modelling