Vertical Cross-Sections of Model Output

Lecture 7

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Lecture Objective and Learning Outcomes

Lecture objective

To teach how to build and interpret vertical cross-sections of WRF output, including the terrain, wind components and isentropes.

Learning outcomes

By the end of this lecture, students will be able to:

1. explain what a vertical cross-section shows in comparison with a map and a profile;
2. choose the line of a cross-section according to the scientific question;
3. build a cross-section with vertcross and add the terrain with interpline;
4. calculate and interpret the along-section wind component;
5. read isentropes as a measure of stability and take vertical exaggeration into account.

Three Ways to Look at the Model Atmosphere

Map (Lecture 5)

A horizontal slice: the level is fixed

axes: x – y

Profile (Lecture 6)

One column: the point is fixed

axes: z

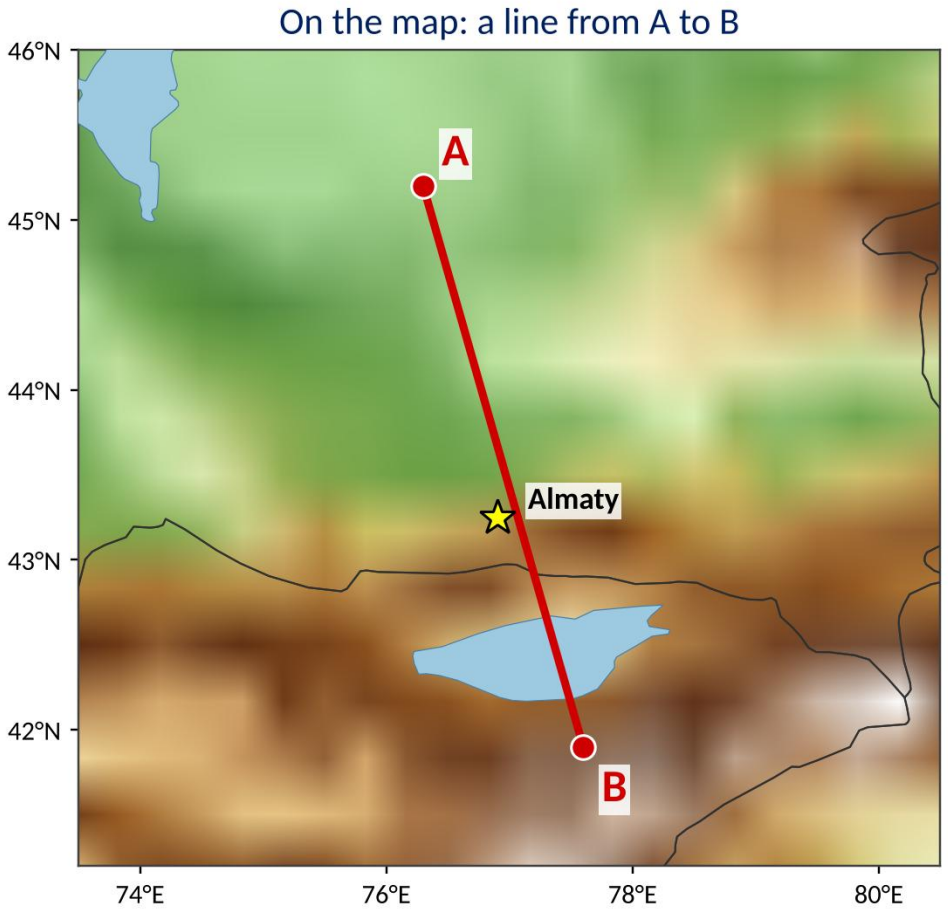
Cross-section (today)

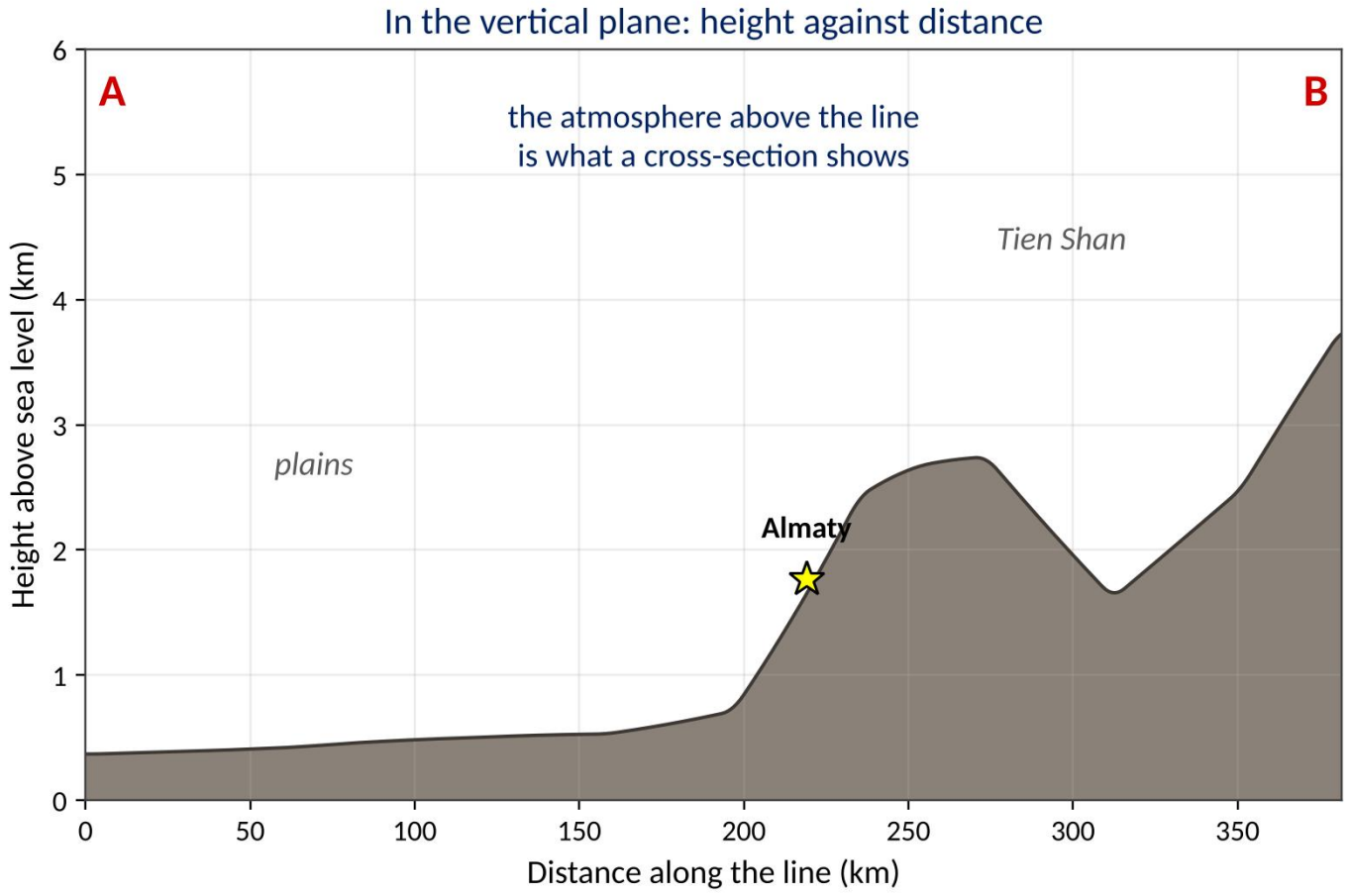
A vertical slice along a line on the map

axes: distance – z

- A cross-section puts all the model columns along a line next to each other
- It shows flow over mountains, valley winds and the rise of pollution along a slope
- For a city at the foot of high mountains it is one of the most informative figures

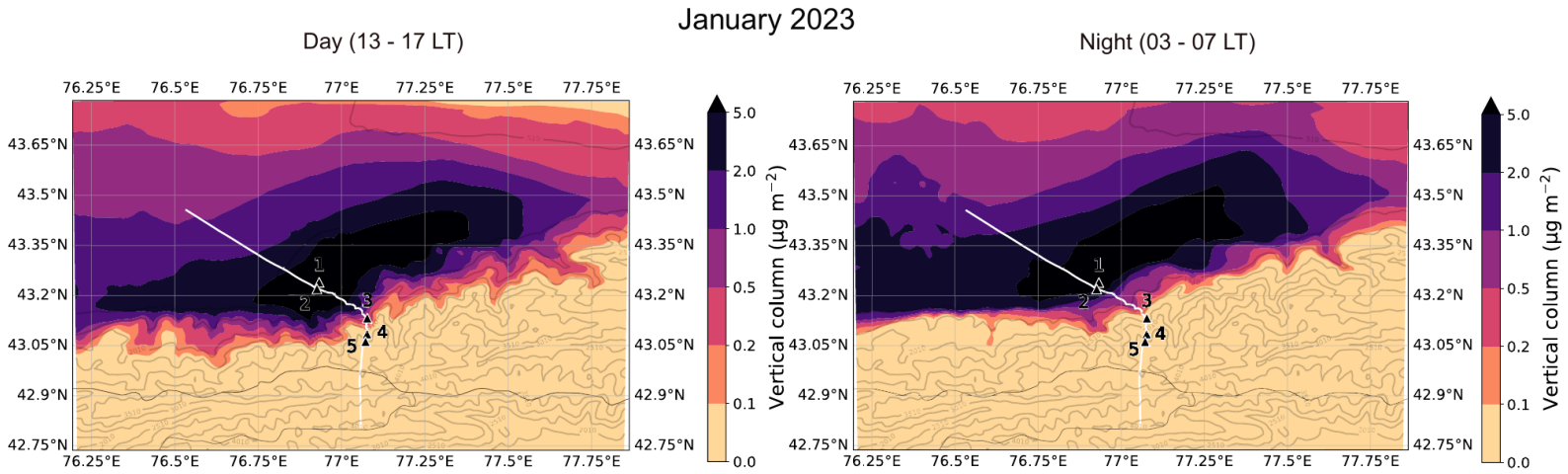
What Is a Vertical Cross-Section?





Terrain: ETOPO global relief model (20 arc-minutes), so the mountain ranges are smoothed

Choosing the Line



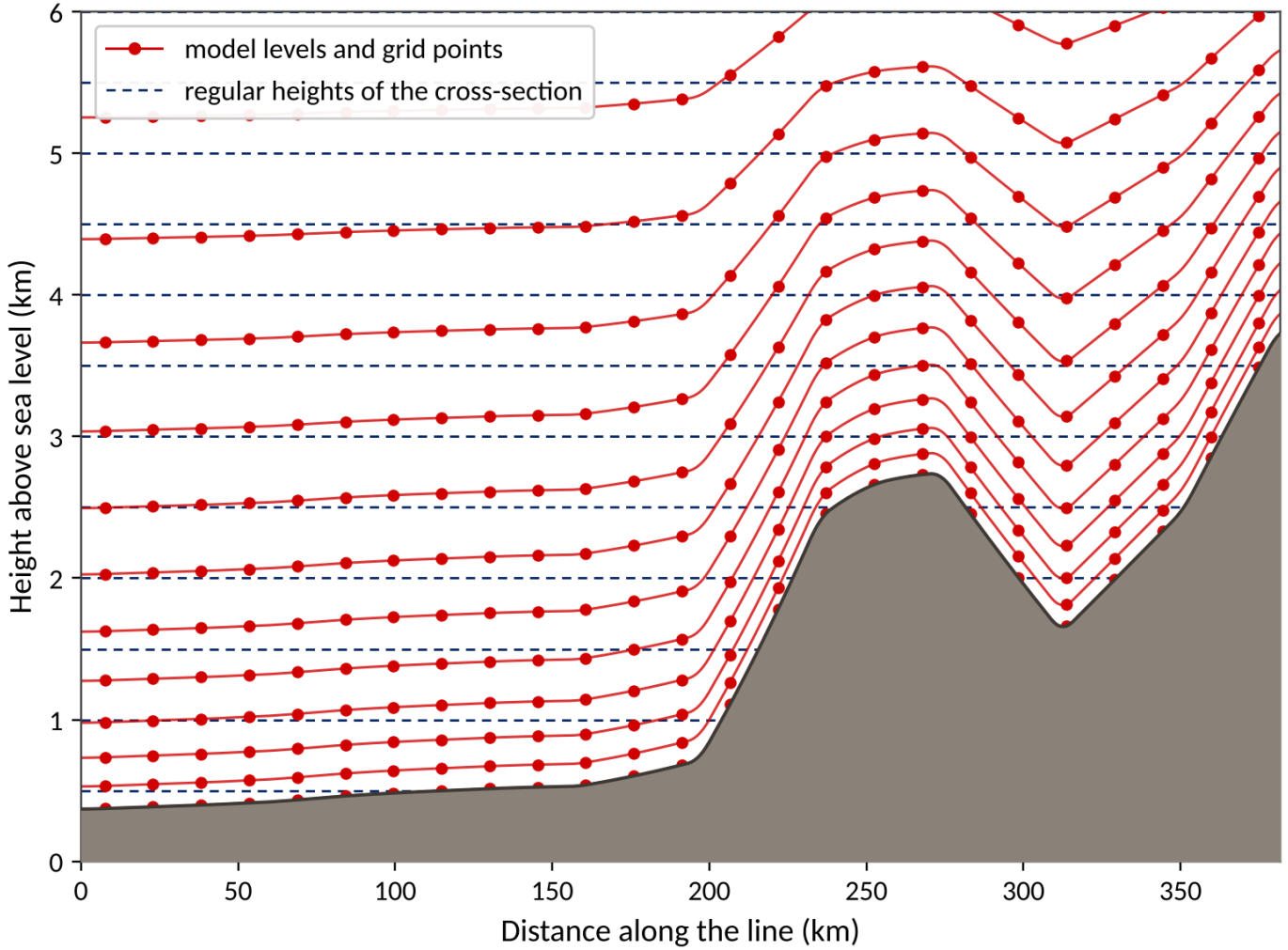
Source: Tursumbayeva et al. (2026), Meteorological Applications, 33, e70183

- Across a mountain range: flow over the mountains
- Along a valley: valley and slope winds
- Through stations: comparison with observations
- White line: from Almaty along the Kishi Almaty valley to the glaciers, through five stations

The line follows the scientific question

Here: the path of polluted air from the city to the mountains

The Problem: Model Levels Are Not Horizontal



- Model levels follow the terrain
- A picture needs regular heights
- Two interpolations:
  - horizontal: grid points → points of the line
  - vertical: model levels → regular heights
- Below the ground: no value

Code: vertcross

```
from wrf import getvar, vertcross, CoordPair, to_np

th = getvar(nc, "theta")    # field to show, K
z  = getvar(nc, "z")        # height of levels, m

start = CoordPair(lat=43.40, lon=76.90)
end   = CoordPair(lat=43.00, lon=77.10)

th_x = vertcross(th, z, wrfin=nc,
                 start_point=start, end_point=end,
                 latlon=True, meta=True)

print(th_x.dims)    # ('vertical', 'cross_line_idx')
```

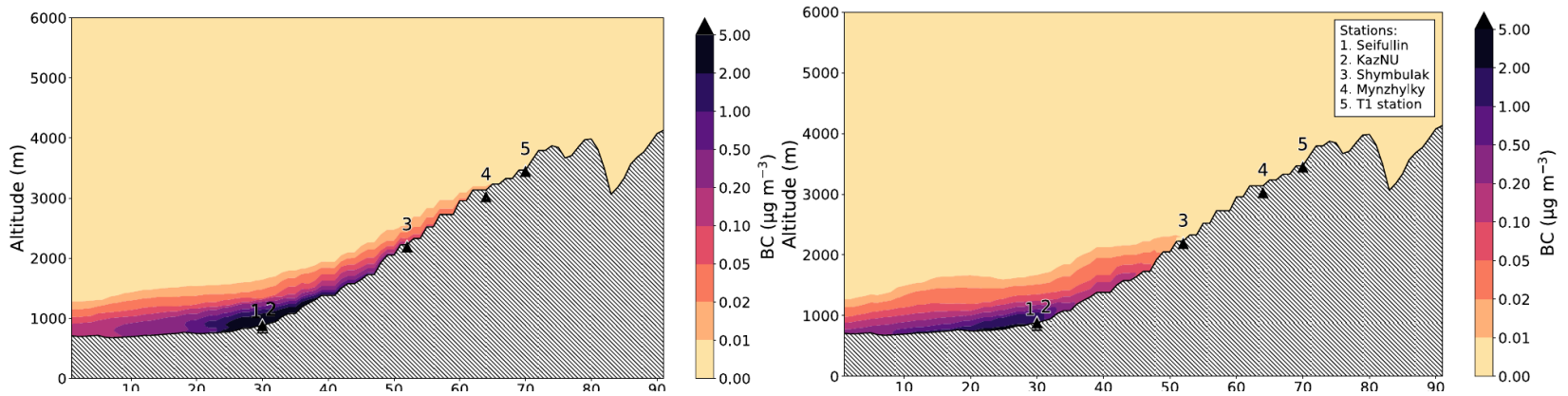
- CoordPair: the two ends of the line
- vertcross: both interpolations in one call
- Result: a 2-D array, height × position along the line
- Missing values below the ground
- Give pressure instead of z for a pressure axis

Code: Drawing the Section and the Terrain

```
from wrf import interpline

ter = getvar(nc, "ter")
ter_line = interpline(ter, wrfin=nc,
                      start_point=start, end_point=end)

xs = np.arange(th_x.shape[-1])
ys = to_np(th_x.coords["vertical"])

cf = ax.contourf(xs, ys, to_np(th_x), levels=20)
ax.fill_between(xs, 0, to_np(ter_line), color="saddlebrown")

plt.colorbar(cf, label="Potential temperature (K)")
ax.set_ylabel("Height above sea level (m)")
```

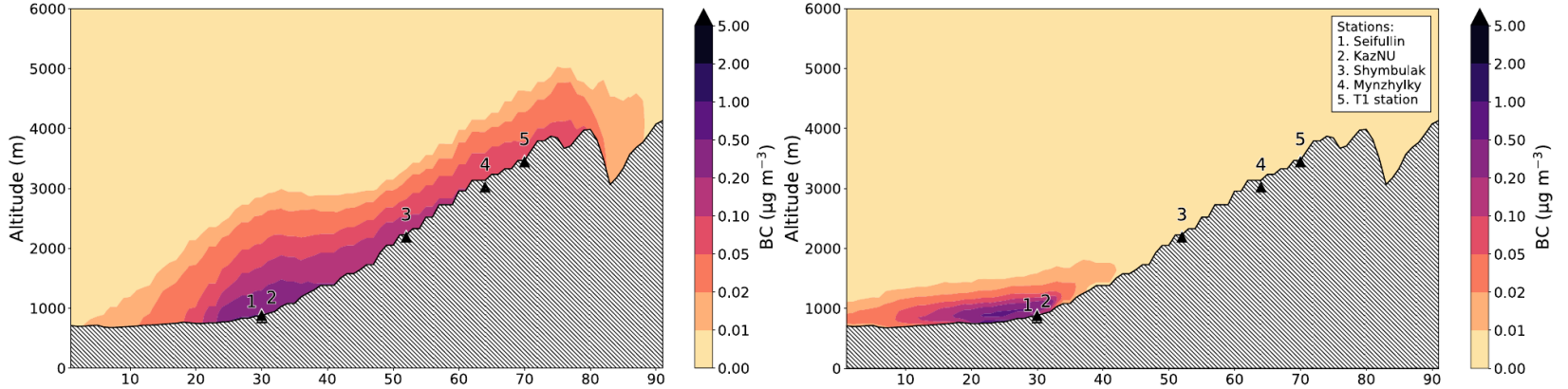
- contourf, as for a map
- x: position along the line; y: the coordinate “vertical”
- interpline: terrain height along the same line
- fill_between: the terrain as a solid shape
- Colour bar with units, labels on both axes

Research Example: Black Carbon up the Slope



January (top): day and night

BC in a thin layer below about 1500 m; mountain stations in clean air

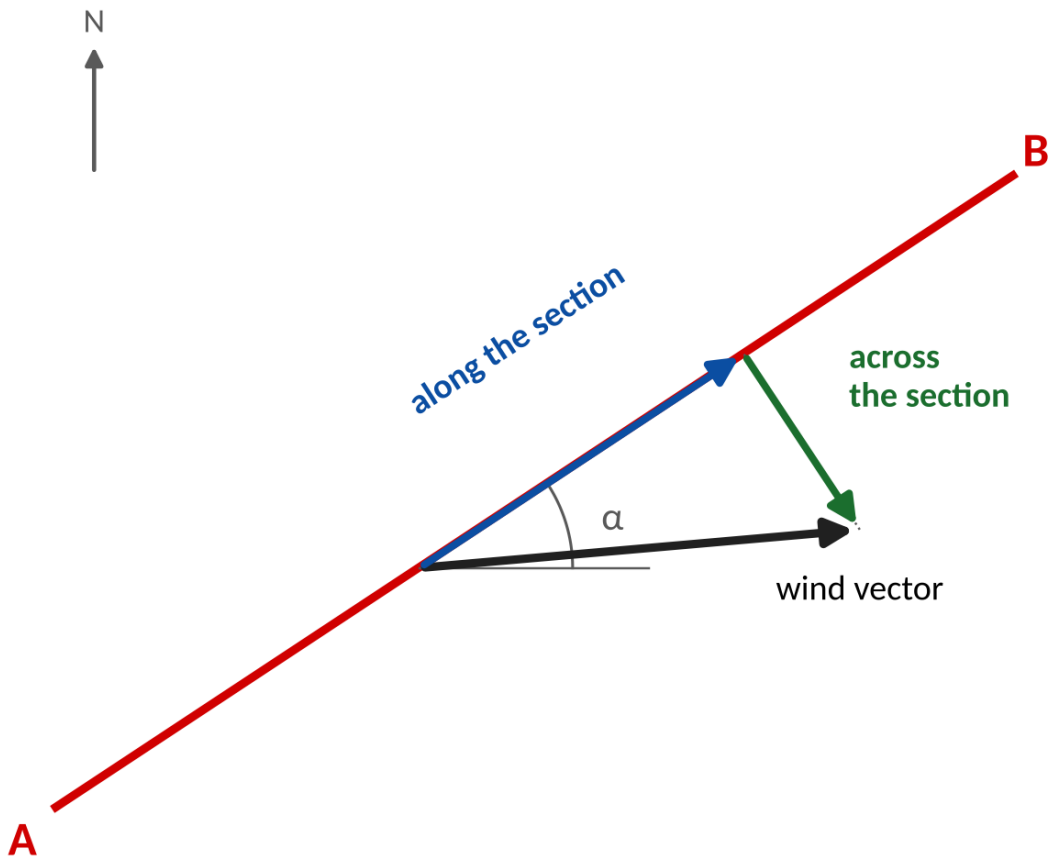


July (bottom): day and night

Daytime: BC along the slope up to about 4000 m, reaching the glaciers

1–2: urban sites, 3: Shymbulak, 4: Mynzhylky, 5: T1. WRF-CHIMERE, 1 km. Source: Tursumbayeva et al. (2026), Meteorological Applications, 33, e70183

Wind in a Cross-Section: Which Component?

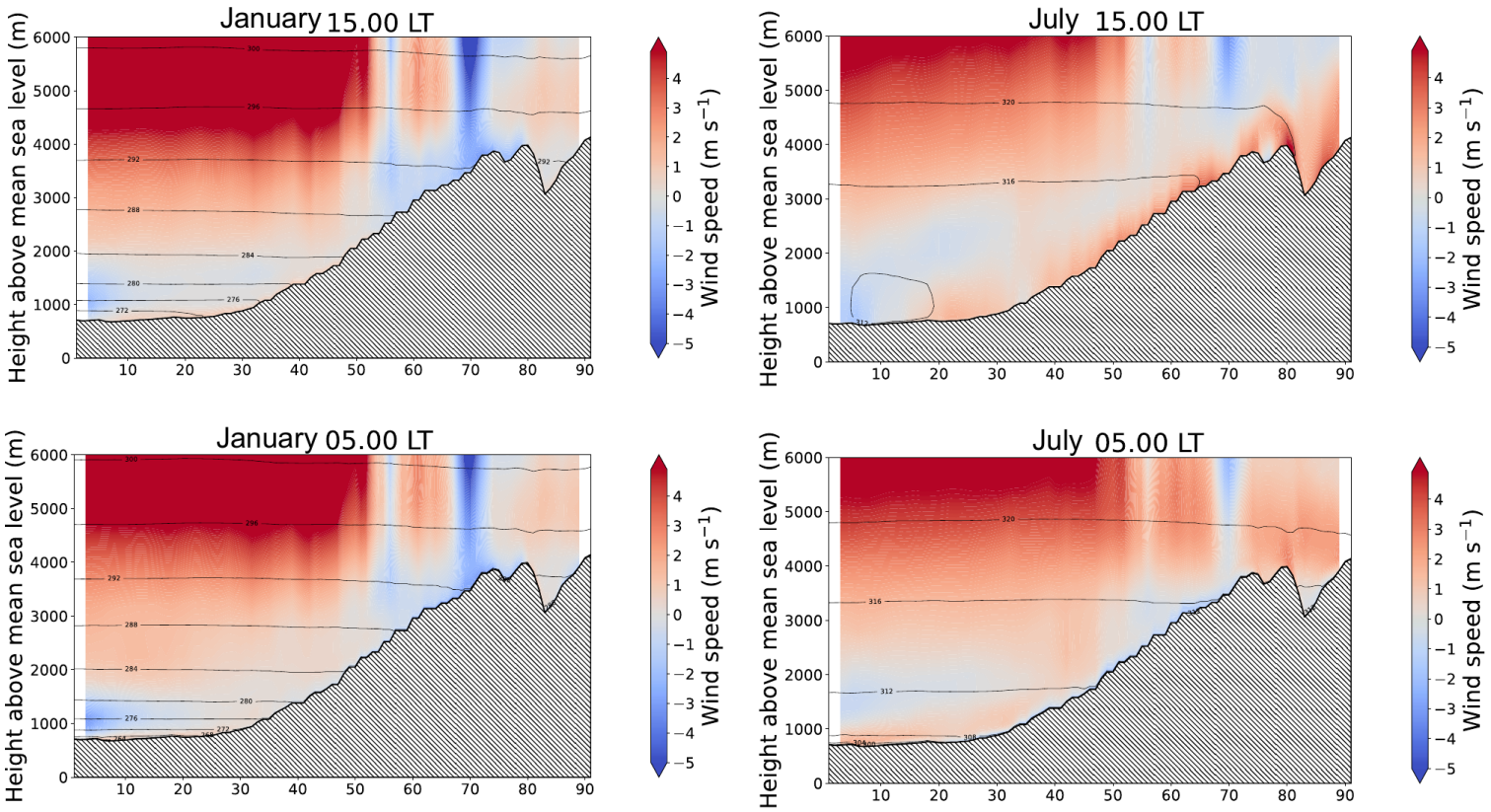


$$V_{along} = u \cdot \cos\alpha + v \cdot \sin\alpha$$

  - α: the angle of the line, counted from east

- Along the section: air moving from A towards B, or back
- Across the section: flow through the plane of the picture
- Valley winds: show the along-valley component
- Always say which component and which sign

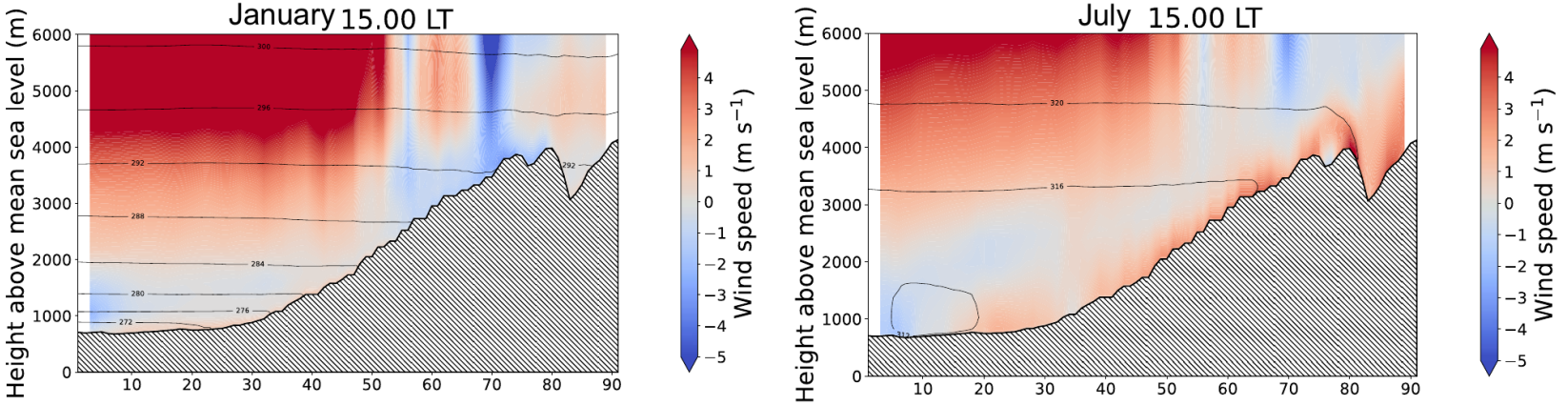
Research Example: Wind along the Valley



- Red: upslope (city → mountains). Blue: downslope
- January: weak flow near the surface, little difference between 15 and 05 LT
- July, 15 LT: upslope flow along the whole slope, up to about 4000 m
- July, 05 LT: weak downslope flow
- The valley wind carries BC to the mountains

Black lines: potential temperature. Source: Tursumbayeva et al. (2026), Meteorological Applications, 33, e70183

Reading Isentropes in a Cross-Section



Isentropes: lines of constant θ

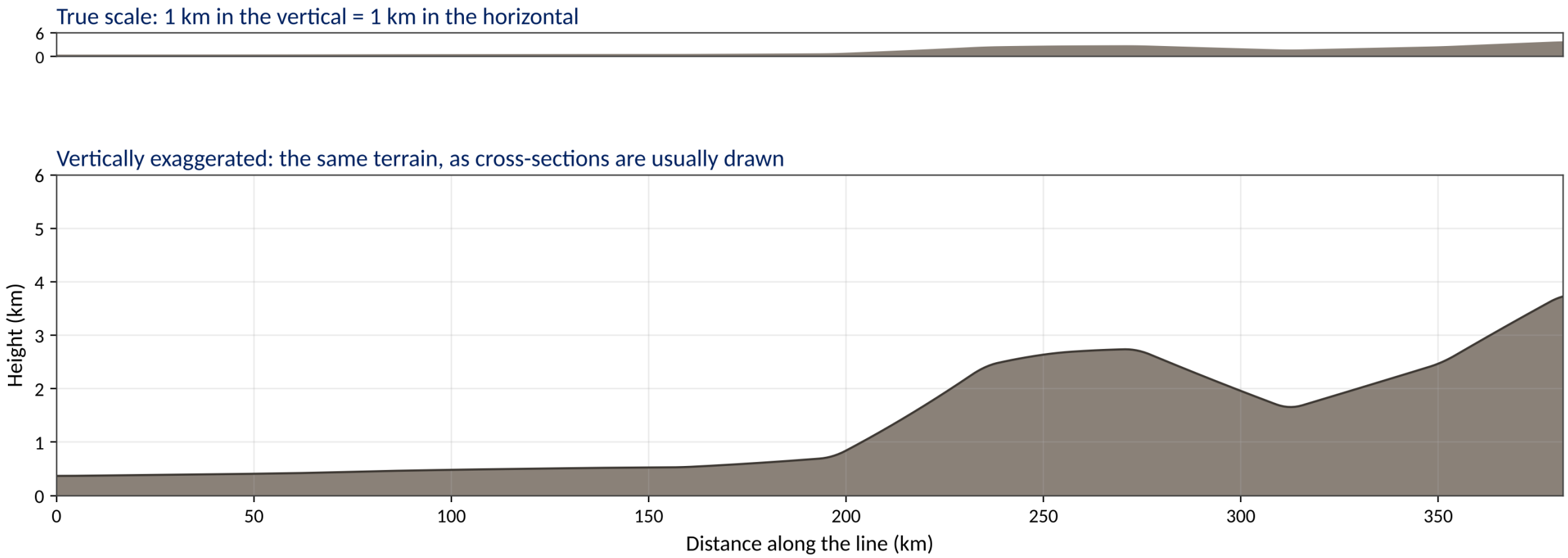
Close together = strong stability

Far apart = weak stability

- January: many lines between the surface and 5 km (272–296 K): strongly stratified air
- July: only two or three lines in the same layer (312–320 K): weak stability, air rises easily
- Filled field for the wind + contour lines for θ: the classical meteorological cross-section

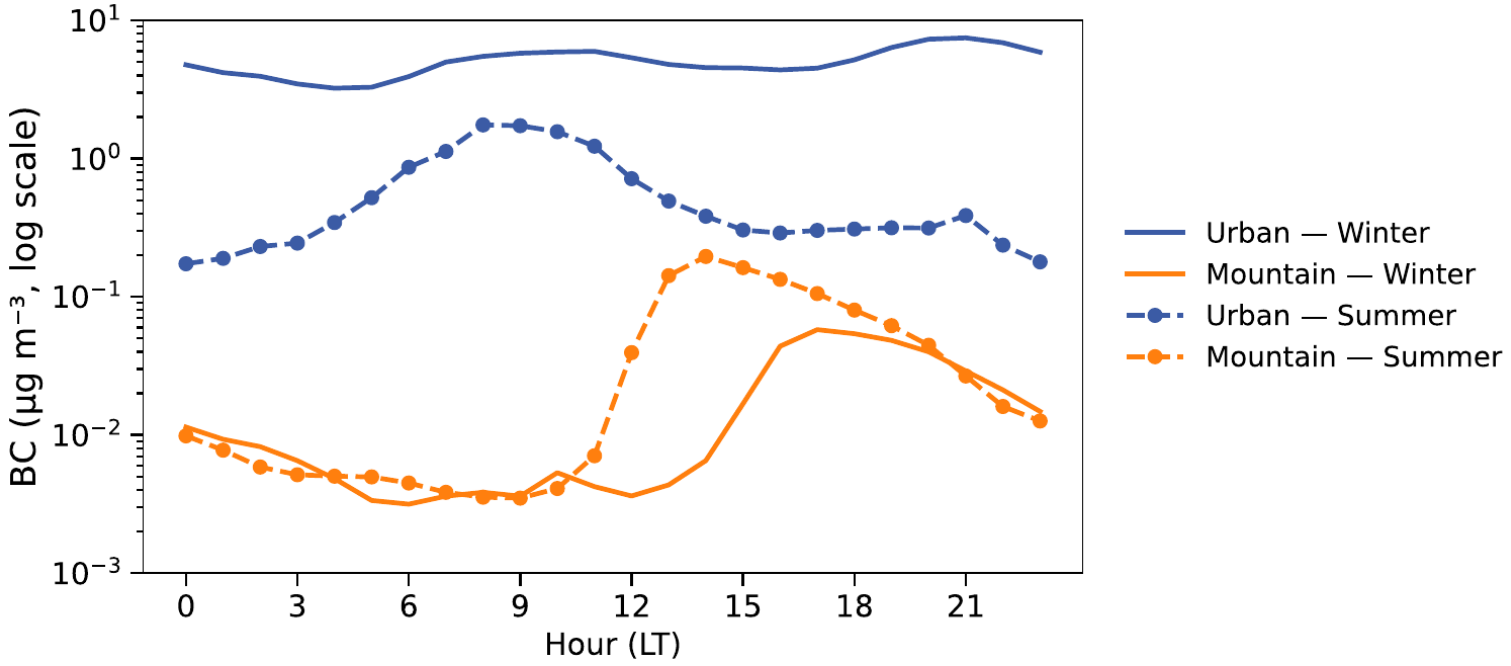
Source: Tursumbayeva et al. (2026), Meteorological Applications, 33, e70183

Vertical Exaggeration



Slopes look much steeper than they are; scale wind arrows in the same way as the axes

Adding Time: the Daily Cycle along the Section



- Urban stations: morning peak at about 9–10 LT
- Mountain stations: the peak comes later
- Delay: 5 hours in summer, 7 hours in winter
- The delay = travel time of polluted air up the valley

Modelled BC, logarithmic scale. Source: Tursumbayeva et al. (2026), Meteorological Applications, 33, e70183

A cross-section shows one moment or one average; time series at points along the line show how the pattern develops

Checklist for a Cross-Section

Terrain

Always shown; empty below the ground

Axes

Distance (km) and height (m), above sea level or not

Location

A small map with the line

Wind

Which component, which sign

Comparison

The same colour scale in all panels

Exaggeration

Remember it when describing slopes

Summary

Key points

- A cross-section: height against distance along a chosen line
- The line follows the scientific question
- vertcross interpolates from model levels to regular heights
- Always add the terrain; show the along-section wind
- Wind + isentropes reveal circulations and stability

Next lecture

Model validation

How well does the model agree with observations?

Thank you for your attention!

Self-Check Questions

1. How does a cross-section differ from a map and from a vertical profile?
2. How should the line of a cross-section be chosen?
3. Which two interpolations does vertcross perform, and why are they needed?
4. How is the along-section wind component calculated?
5. What does the spacing between isentropes show?
6. What is vertical exaggeration, and how does it affect the reading of slopes and wind arrows?

References

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6. Stull, R. B. (1988). An Introduction to Boundary Layer Meteorology. Kluwer Academic Publishers.
7. Figure data: NOAA NGDC ETOPO global relief model; Natural Earth.