Ministero della Transizione Ecologica

Institute of Atmospheric Pollution Research
National Research Council of Italy

ISPRA
Istituto Superiore per la Protezione e la Ricerca Ambientale

Sistema Nazionale per la Protezione dell'Ambiente

ALPENKONVENTION
CONVENTION ALPINE
ALPSKA KONVENCIJA
CONVENZIONE DELLE ALPI

EU GREEN WEEK 2021 - PARTNER EVENT:
An Alpine approach to improving air quality

4 June 2021

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Atmospheric Pollutants and Processes in the Alps

Air Quality in the Alps - FACTORS AND PROCESSES

Geography & Orography

Climatic regions of the Alps

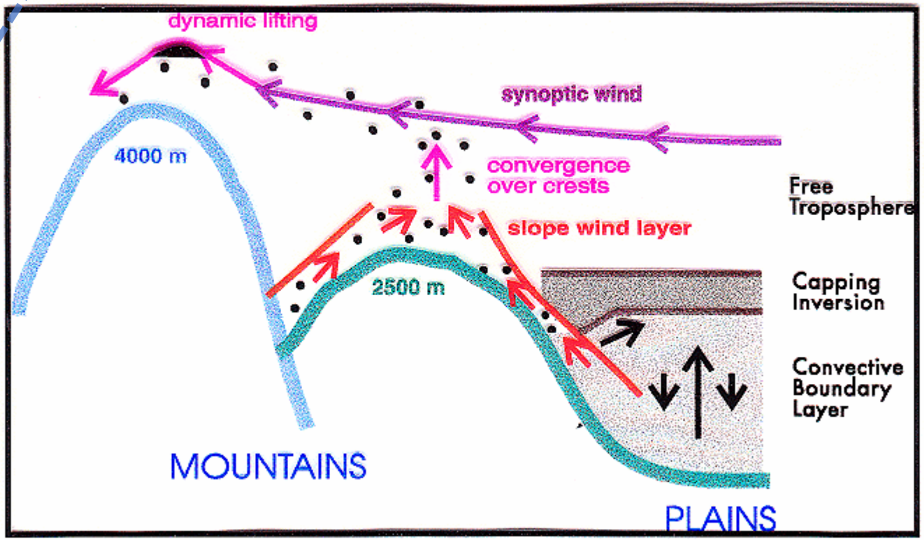
Regimes of synoptic and local

Valley width, slope, altitude *asl*, vertical profiles

Meteorology (RH, T, solar irradiance,...)

height of the boundary layer
vertical mixing of ambient air,
Dispersion/dilution efficiency of air pollutants

AIR QUALITY IN THE ALPS



Schematic view of the processes transporting boundary layer air from adjacent plains and valleys up to the level of the highest Alpine peaks. (Courtesy of Seibert, P. et al. 1996)

Climate Change effects

Regional-scale transport of air masses

mitting sources (anthropogenic, natural)

mospheric chemistry (formation, depletion)

Mass contribution

gaseous, liquid, particulate chemical compounds
in the ambient air

CLIMATIC REGIONS WITHIN THE ALPS

Csa = Hot-summer Mediterranean climate
(coldest month above -3 or 0; at least 1 month above 22 (°C))
Precipitations: winter >> summer

Csb = Warm-summer Mediterranean climate
(coldest month above -3 or 0; all months average below 22 (°C))
Precipitations: winter >> summer

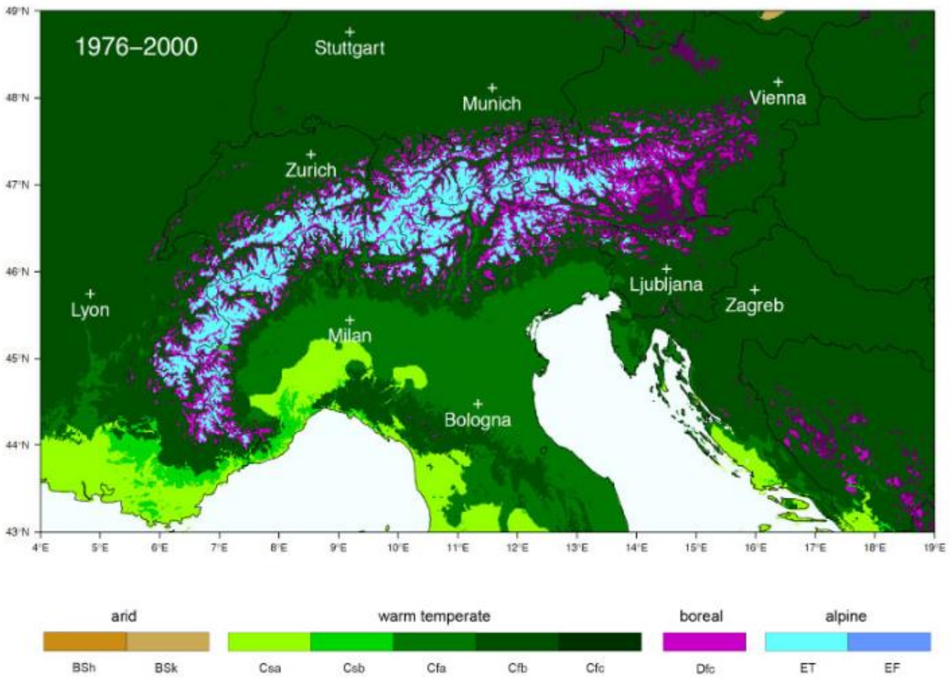
Cfa = Humid subtropical climate
(coldest month above -3 or 0; at least 1 month above 22 (°C))
Precipitations: no season differences

Cfb = Temperate oceanic climate
(coldest month above -3 or 0; 4 months above 10 (°C))
Precipitations: no season differences

Cfc = Subpolar oceanic climate
(coldest month above -3 or 0; 1-3 months above 10 (°C))
Precipitations: no season differences

Dfc = Subarctic climate
(coldest month below -3 or 0; 1-3 months above 10 (°C))
Precipitations: no season differences

ET = Tundra climate
(warmest month 0-10 °C)



Rubel, F., K. Brugger, K. Haslinger, and I. Auer, 2017: The climate of the European Alps: Shift of very high resolution Köppen-Geiger climate zones 1800-2100. *Meteorol. Z.*, 26, 115-125.

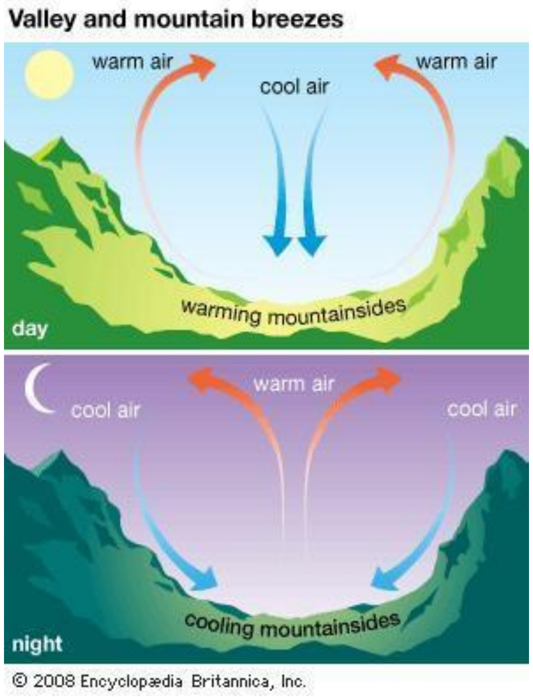
SYNOPTIC WINDS REACHING THE ALPS

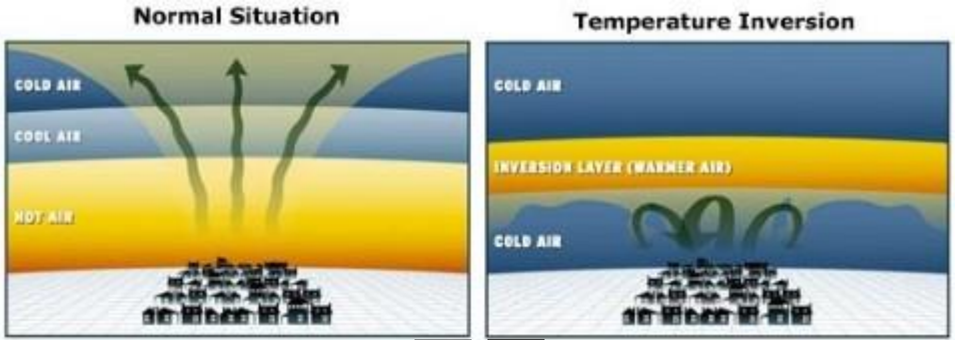
The <u>horn-shaped barrier of the Alps</u> contributes to generating three different cold wind systems:

- the Mistral in the western Rhone valley
- the Bise between the Jura and the Alps on the North
- The Bora on the Adriatic coast ESE of the Alps

Tibaldi S., Buzzi A., Speranza A. (1990). Orographic Cyclogenesis. In: Newton C.W., Holopainen E.O. (eds) Extratropical Cyclones. American Meteorological Society, Boston, MA. https://doi.org/10.1007/978-1- 944970-33-8_7.

LOCAL WINDS IN THE ALPS





Stelvio Pass, Italy, Jan. 2013; a: 11 a.m., b: 4 p.m. (different days). Credit: A. Pietrodangelo

Thermally generated local winds (mountain venting) play a key role on air vertical mixing and pollutants dilution in valleys

Summer: mixing layer evolves rapidly during the day, due to strong insolation. Good vertical mixing. Pollutants dilution is efficient

Winter: calm wind events lead to diurnal atmospheric stability and temperature inversion. Mixing layer height evolves slowly. Poor vertical mixing. Pollutants dilution is not efficient due to air stagnancy

EXCHANGE PROCESSES IN THE DAYTIME BOUNDARY LAYER

CBL convective (daytime) boundary layer
(grey shading in the figure)

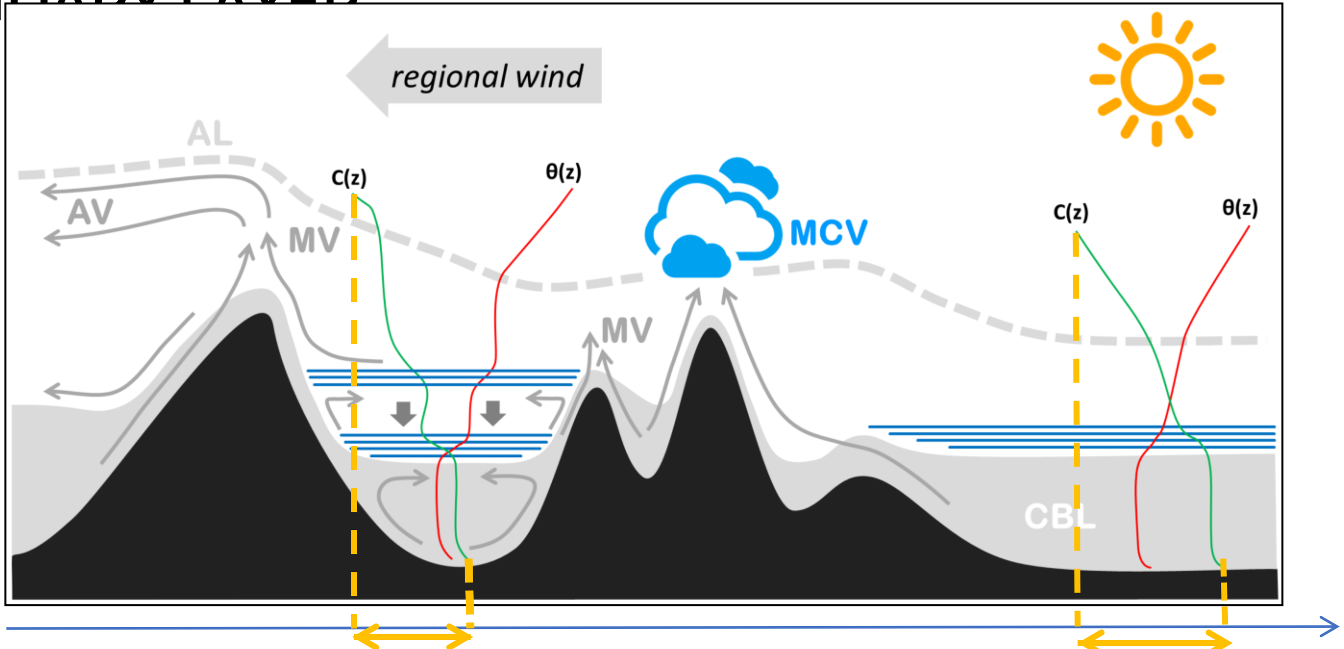
MV mountain venting

AV advective venting

MCV mountain-cloud venting

C(z) pollutant concentration profile

Θ(z) potential temperature profile

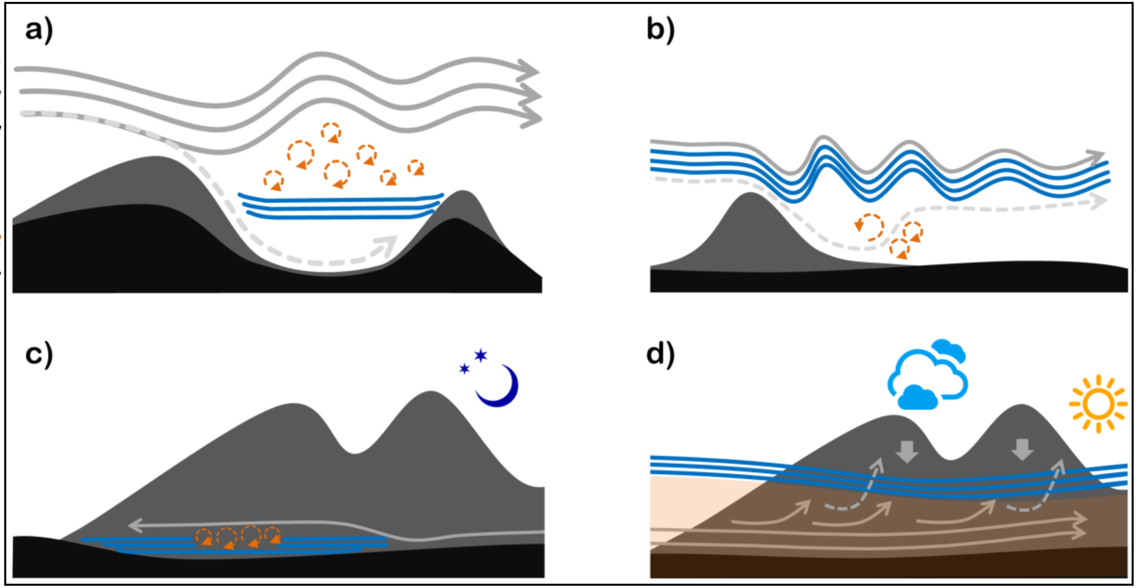


Exchange processes in the daytime boundary layer over mountainous terrain (Serafin S., et al., 2018, Atmosphere)

Horizontal blue lines represent layers with enhanced static stability, **which favour the separation of up-slope flows from the ground**. Down-pointing arrows represent valley-core subsidence. The dashed line indicates the top of the regional aerosol layer (AL). **Pollutants concentration (C(z)) decrease along vertical profile is slowed down in the static stability layers.**

EXCHANGE PROCESSES - INFLUENCE OF STABLE LAYERS

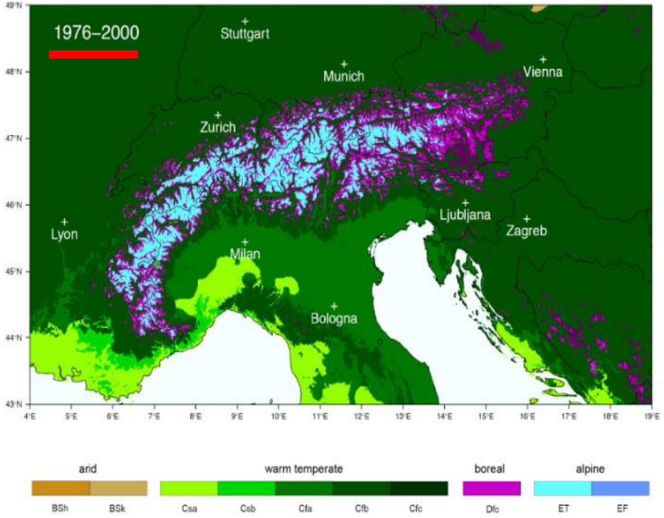
(a) Airflow over a valley, with (continuous grey lines) or without (dashed grey line) a stable layer below the mountain-top level, results, respectively, in elevated turbulence (orange whirls) and small-amplitude waves, or in valley flushing and large-amplitude waves



Role of stable layers (blue lines) in controlling multi-scale interactions (Serafin S., et al., 2018, Atmosphere)

(d) Foehn wind
Confinement of moist air (orange shading) beneath a stable layer during daytime, possibly destabilizing the atmosphere. Thermally driven breezes advect air from the plain and upwards along the slopes (grey lines). Part of the upslope flow pierces the stable layer and causes mountain venting (dashed grey lines). Valley-core subsidence (down-pointing arrows) displaces the stable layer downwards.

CLIMATE CHANGE EFFECTS – Climatic regions



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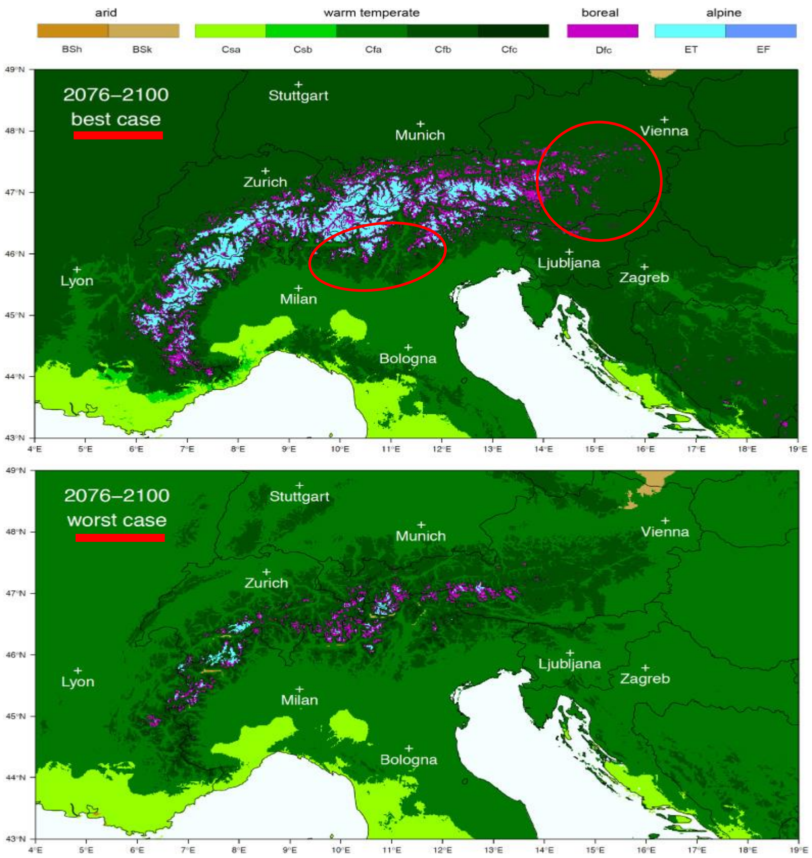
Climate change effects on climatic regions of Alps modelled scenarios for 2076-2100

Ongoing research....

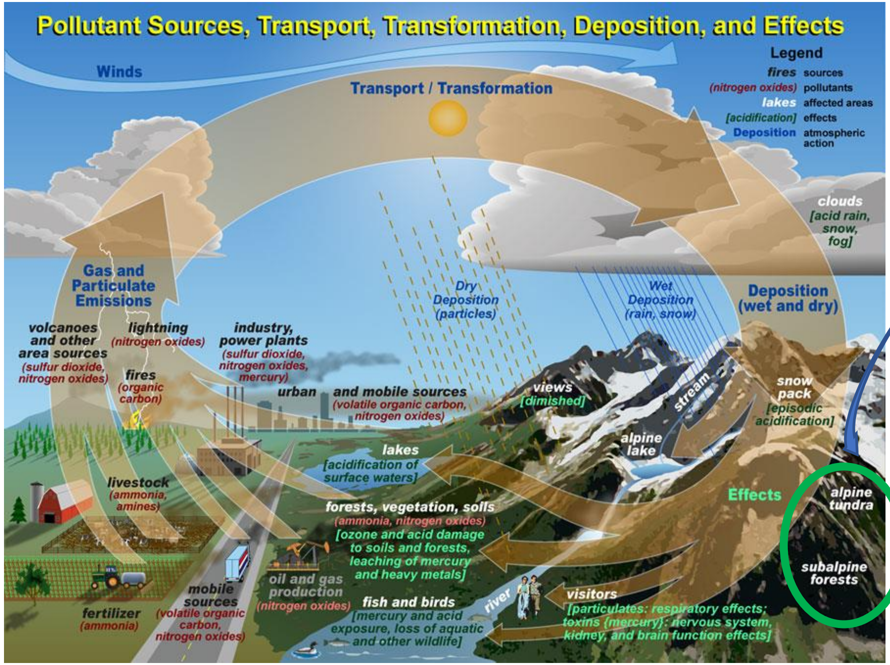


Rubel, F., K. Brugger, K. Haslinger, and I. Auer, 2017: The climate of the European Alps: Shift of very high resolution Köppen-Geiger climate zones 1800-2100. *Meteorol. Z.*, 26, 115-125.

CLIMATE CHANGE EFFECTS – possible impacts on atmosphere

CC — regional changes → mesoscale (LRT) circulation dynamics of air masses — local changes → climatic regions, weather (temperature profile, relative humidity, mountain venting dynamics,.....) — frequency, intensity, balance changes →

- ventilation of valleys
- temperature inversion
- vertical mixing
- cloud cover, precipitations
- solar irradiance, heat waves



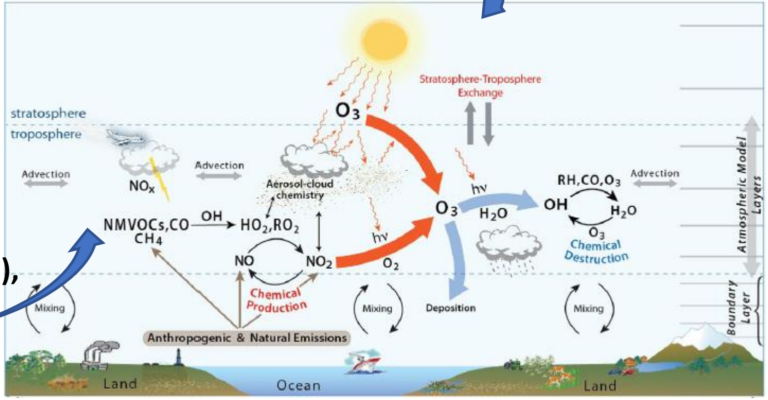
Credit: ***U.S. Fish and Wildlife Service***

forests/vegetation

- distribution among species,
- stomatal resistance to deposition,
- biogenic VOCs emission rates

atmospheric physics

VOCs, PM, (O_3), atmospheric chemistry



Schematic of chemical and physical processes responsible for tropospheric ozone (Adapted from: Young, PJ, et al. 2018)

REGIONAL-SCALE TRANSPORT OF AIR MASSES

Air pollutants conveyed by long-range transported (LRT) air masses to the Alps undergo increased condensation in alpine cool regions (cold trapping), and are transported to lakes, soil and vegetation by deposition.
The Alps act as sink of LRT air pollutants.

EU FP5 CARBOSOL (2002-2004)

Schauinsland (Germany, 1205 m. asl),
Puy de Dôme (France, 1450 m. asl),
Sonnblick Observatory (Austria, 3106 m. asl)

PM10 and PM2.5 chemical speciation & source apportionment, focused on carbonaceous aerosol

EU INTERREG IIIB Alpine Space Programme MONARPOP (2005-2008)

40 monitoring sites (Austria, Germany, Italy, Slovenia, Switzerland)

Persistent Organic Pollutants (POPs) in air, depositions, humic top soil, mineral soil and needles samples;
focused on POP spatial distribution & vertical profiles

FOEN (Switzerland), (2005-2013) StMUV (Bavaria) and BMNT (Austria) (2005- ; PureAlps (2016-2020))

Weißfluhjoch (Switzerland, 2663 m. asl)
Schneefernerhaus/Zugspitze (Germany, 2650 m. asl)
Sonnblick Observatory (Austria, 3106 m. asl)

Persistent-Bioaccumulating-Toxic (PBT) Substances (POPs and inorganic Hg) in air and depositions

Result from air mass-related measurement: Impact on the Alpine peaks from three dominating directions; as indicated, some directions show higher concentrations of PCB and OCP. (Courtesy of Freier, K.P. et al., 2019)

REGIONAL-SCALE TRANSPORT OF AIR MASSES

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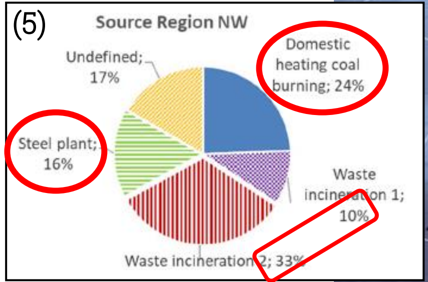
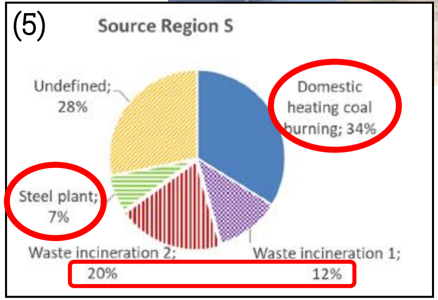
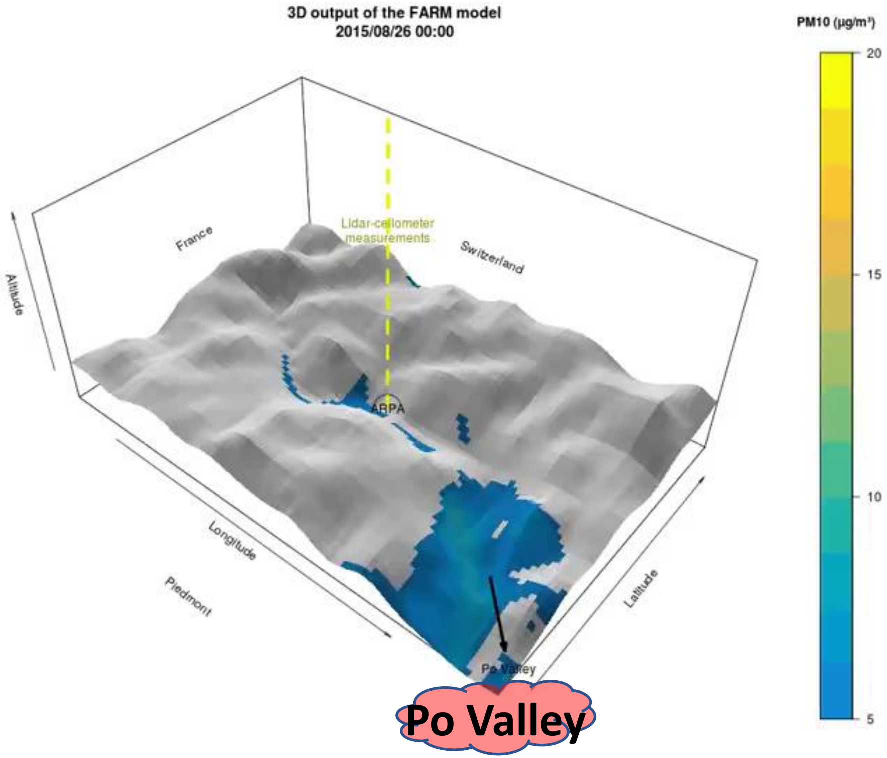




(1) Salvador et al., *Atm. Env.*,44, 2010
(2) Diemoz et al., *Atmos. Chem. Phys.*,19, 2019
(3) De Angelis and Gaudichet., *Tellus B*, 43:1,1991
(4) Di Mauro et al., *The Cryosphere*, 13, 2019
(5) Kirchner et al., *Atm. Env.*, 223, 2020

Transport of secondary aerosol from the Po Valley to Aosta (Italian Alps)

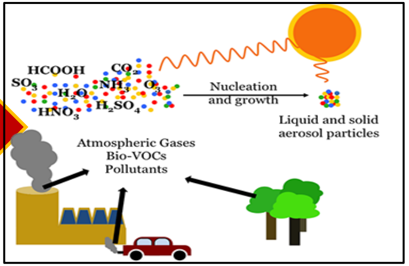


- Recurrent episodes of wind-driven aerosol layers from the Po Valley:
  - 50% of days
  - Cold season
  - Synoptic winds E – W
  - Advected particles in the accumulation mode
  - Increase in the inorganic secondary aerosol (nitrate, sulfate, ammonium)

Emitting sources of PM and SA







% mass contributions of sources to PM_{10} in alpine valleys

BB >> SA ≥ RTf

SA >> BB ≈ RTf

Year (season[a])	Site (Country)	Valley or area	Contribution to PM_{10} (in % of PM mass)			References
			Biomass burning %	Traffic %	Secondary aerosol %[b]	
2008 (w)	Erstfeld (CH)	Erstfeld	21 - 30	15 - 30	15 - 25	Ducret-Stich R. *et al.*, 2013a Project funded by the Swiss Federal Office for the Environment
2008 (s)			8 - 15	13 - 15	35 - 40	
2010 (y)	Lanslebourg (FR)	Maurienne	57	31	9	Projects Lanslebourg 2010-2014 (in: Favez O. *et al.*, 2017a; SOURCES Project Report)
2010 (y)	Lescheraines (FR)	Auvergne-Rhone-Alpes	58	6	n.a.	PARTICUL'AIR (in: Favez O. *et al.*, 2017a; SOURCES Project Report)
2010 (y)	Grenoble (FR)	Auvergne-Rhone-Alpes	42	10	n.a.	FORMES (in: Favez O. *et al.*, 2017a; SOURCES Project Report)
2013-14	Air RA (FR)	Auvergne-Rhone-Alpes	21	2	~ 20	AERA (in: Favez O. *et al.*, 2017a; SOURCES Project Report)
2013-14 (w)	Chamonix (FR)	Arve	70	5	15	Favez O. *et al.*, 2017a; SOURCES Project Report
2013-14 (s)			10	5	35	
2013-14 (w)	Marnaz (FR)	Arve	64 - 71	4 - 8	8 - 12	DECOMBIO (in: Favez O. *et al.*, 2017a; SOURCES Project Report)
2013-14 (s)			< 3	8	30 - 35	
2013-14 (w)	Passy (FR)	Arve	66 - 74	4 - 8	12 - 15	
2013-14 (s)			< 3	5 - 10	40 - 50	
2013-14 (w)	Chamonix (FR)	Arve	57 - 62	3 - 14	18 - 21	
2013-14 (s)			5 - 10	7 - 12	38 - 43	

Table 4: Contribution of biomass burning, traffic and secondary formation of aerosols to PM10 concentration in some Alpine valleys. (a) Winter = w; Summer = s; Annual = y. (b) SA is reported as the sum of all inorganic and organic omponents available from each study.
(RSA8 Air Quality in the Alps, 2021)

Main emitting **sources of primary PM** in the Alpine valleys: biomass burning (**BB**) and road traffic (**RTf**)

Main emitting **sources of chemical precursors forming Secondary Aerosol (SA)** in the troposphere:

- **BB** (CO, VOCs, SO_2, NOx,)
- **RTf** (CO, VOCs, NOx)
- **Domestic heating** (NOx, SO_2, CO)
- **Forests, vegetation** (VOCs)
- **Agriculture** (NH_3)

Emitting sources of PM and SA precursors– Biomass Burning and domestic heating

Emissions from biomass burning generally decreased in recent years in the Alps, but with differences among regions.

During last years, in most Alpine Countries specific measures were already in place in order to reduce emissions (lower limit values, best practices, bans and incentives for the use of lower emission appliances).

However, this sector is still the predominant source of carbonaceous aerosols during the cold season; reasons why need further investigations.

At European level stricter rules apply for this activity from 1st January 2020

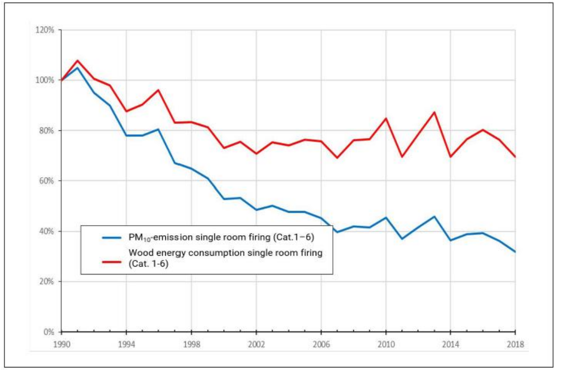


Figure 6: Evolution of the emissions of single room fire stoves in Switzerland. (RSA8 Air Quality in the Alps, 2021)

particle-bound organics: PAHs (BaP, ...), furans, ...

black carbon, brown carbon (HULIS), levoglucosan

metal particles

fine (PM2.5, PM1) and ultrafine (UFP: ≤ 100 nm) airborne PM

low-volatile NMVOCs

CO, SO_2, NOx (NO, NO_2)

Reasons of concern for health & ecosystems:

In the heating period, the contribution of wood combustion to PM10 mass increases in the evening (sometimes by more than 80%), just when pollutant dilution is inefficient due to nocturnal air stagnancy.
The two factors are combined enhancing pollutants levels in ambient air.

Alpine and sub-alpine sites where BB was chemically characterized (2005-2010):

Chamonix (FR), Lanslebourg (FR), Lescheraines (FR), Passy (FR), Grenoble (FR), Ebnat Kappel (CH), Magadino (CH), Moleno (CH), Roveredo (CH), Zagorje (SI), Sondrio (IT), Cantù (IT), Graz (AT), Ispra (IT), Milan (IT).

Emitting sources of PM and SA precursors– Road Traffic

Motor vehicle traffic **affects the whole road infrastructure** in the Alpine region:

- **main transit routes of freight transport**
- **urban roads in the valleys**
- **peripheral routes connecting small villages**
- **off-road routes reaching semi-natural mountain areas at high altitudes**

+

The **most common form of passenger transport in these areas is the private car, it is expected to increase** in the near future in the Alpine region (Alpine Convention, 2007).

+

Tourism and freight transport traffic examples

particle-bound organics: PAHs (BaP, ...), furans, ...

black carbon

metal particles

resuspended road dust

(abrasion of brakes, tires, other mechanis, asphalt)

fine (PM2.5, PM1) and ultrafine (UFP: ≤ 100 nm) airborne PM

coarse (> 2.5 µm) airborne PM

low-volatile NMVOCs

CO, SO_2, NOx (NO, NO_2)

Street Canyon-like effect

The <u>complex topography of the Alps limits the transport infrastructure to only a small number of corridors</u> along valleys and across passes where traffic emissions are concentrated.

<u>In villages roads pass through adjoining buildings</u>.

<u>Both cases are comparable to U-shaped structures crossed by roads, that is, street canyons</u>, which trap pollutants and long-wave radiation (Singh N., et al., Urban Ecology, 2020)

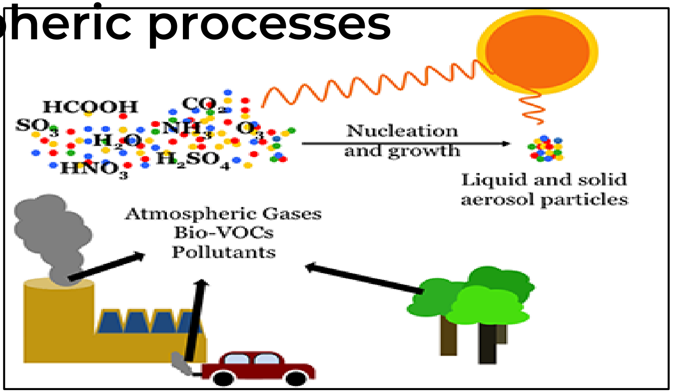
=

Reasons of concern for health & ecosystems:

- In villages, <u>roads are close to buildings</u> (street canyon-like effect)
- substantial concentrations <u>increase of traffic-related air pollutants</u> (NO_2, elemental carbon, PAHs, metals...) is observed <u>next to motorways or main roads in villages</u>
- off-road mountain routes often affected by <u>old diesel engine exhausts (inefficient combustion and poor exhaust trapping)</u>

Secondary Aerosol formation - Sources and atmospheric processes

Secondary aerosol (**SA**) is formed in the atmosphere by photochemical reactions of precursors (pollutants directly emitted)



Schematic relationships of primary pollutant- emitting sources and secondary pollutant formation in the atmosphere

SA is more enriched in organics or inorganic pollutants (nitrate, sulfate, ammonium), depending on **type of emitting sources** and **season** (weather-related T, winds regime, humidity, etc.).

SA air concentration is significant both in cold and warm seasons, but generally higher during summer, due to intense insulation aiding photochemical SA formation

COLD SEASON

Agriculture

BB and fossil fuels combustion

Ammonia (NH_3)

Volatile organics (VOCs), sulfur dioxide (SO_2),nitrogen oxides (NOx)

ammonium <u>nitrate</u>, oxygenated organics

WARM SEASON

Agriculture

Vegetation (biogenic) emissions and fossil fuels combustion

Ammonia (NH_3)

Volatile organics (VOCs), sulfur dioxide (SO_2),nitrogen oxides (NOx)

ammonium <u>sulfate</u>, oxygenated organics

FINAL REMARKS

1. Geography and orography-related atmospheric peculiarities of the Alps play a key role on air quality

2. Climate changes (CC) will possibly affect the complex Alpine ecosystems-atmosphere equilibria, however emissions reduction and deep understanding of CC mechanisms is critical to limit adverse impacts

3. Synergic and counter-synergic relationships between CC and physical – chemical processes of the atmosphere and their impact on atmospheric pollution needs further investigation

4. Air quality monitoring in the Alpine region should be carried on routinely, regardless of improved pollutant levels, in particular concerning precursors of secondary aerosol (SA), because of the complex mechanisms responsible of SA formation in the Alps

5. Emerging pollutants (PBT, microplastics) have been recently detected in non-negligible presence in the Alpine region. Research/monitoring programmes focused on these pollutants should be undertaken

6. Emitting sources most impacting on the air quality in the Alps are those related to combustion of wood-other biomass (domestic heating) and of fossil fuel (vehicle traffic exhausts). In addition, same sources, plus the wide vegetation cover of Alps and agriculture, are also responsible for high SA in PM_{10}.

Paolo Angelini, Head of Italian Delegation
Ministry of Ecological Transition

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Thanks for your attention !