METR/ENVS 113

Lecture 8: Ground-level Ozone

SJSU Spring Semester 2020

Module 3: Outdoor Air Pollution (Ozone and PM2.5)

Frank R. Freedman (Course Instructor)

Lecture 8: Ground-Level Ozone (Outline)

- **Overview**
  - Health Effects
  - Historical Perspective
  - Ozone through the Atmosphere: Stratospheric vs. Ground-Level Ozone
- **Formation Mechanism**
  - Ground-Level Ozone: A secondary pollutant
  - Precursors: NOx and VOCs
  - Photochemical Formation Reactions
- **Regulatory Efforts and Emission Controls**
  - Briefly … more on Practice Quiz 3 (Short Answer)

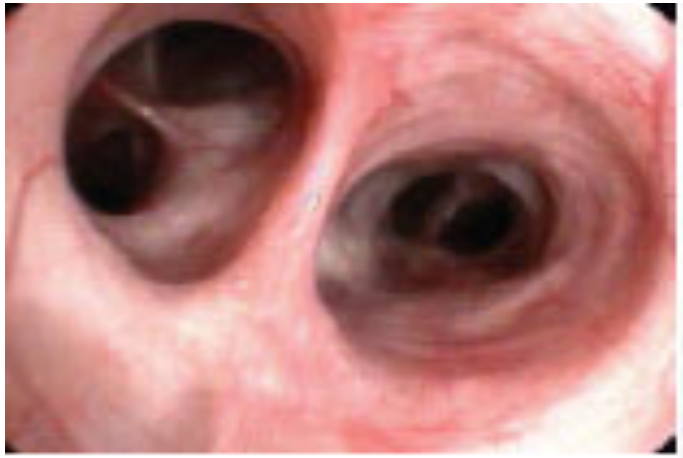
Ground-Level Ozone (Overview)

Ozone (O_3): Adverse Health Effects from Inhalation

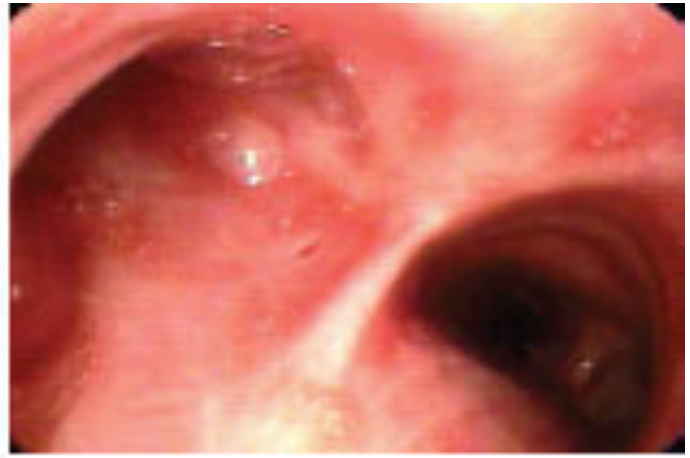
Ozone can cause the muscles in the airways to constrict, trapping air in the alveoli. This leads to wheezing and shortness of breath.

Key Points: Health Effects of Ozone Inhalation

- A lung irritant, inflames lung airway passages. Air becomes trapped in alveoli.
- Mainly short-term, episodic, acute effects.
- Shortness of breath, asthma exacerbation, increases susceptibility to respiratory illness.
- See next slide



Normal lung airway



Inflamed lung airway due to ozone exposure

https://www.epa.gov/ground-level-ozone-pollution/health-effects-ozone-pollution

https://www.epa.gov/ozone-pollution-and-your-patients-health/health-effects-ozone-general-population

What health problems can ozone cause?

Ozone can cause the muscles in the airways to constrict, trapping air in the alveoli. This leads to wheezing and shortness of breath.

Ozone can:

- Make it more difficult to breathe deeply and vigorously.
- Cause shortness of breath, and pain when taking a deep breath.
- Cause coughing and sore or scratchy throat.
- Inflame and damage the airways.
- Aggravate lung diseases such as asthma, emphysema, and chronic bronchitis.
- Increase the frequency of asthma attacks.
- Make the lungs more susceptible to infection.
- Continue to damage the lungs even when the symptoms have disappeared.
- Cause chronic obstructive pulmonary disease (COPD).

Ozone can cause the muscles in the airways to constrict, trapping air in the alveoli. This leads to wheezing and shortness of breath.

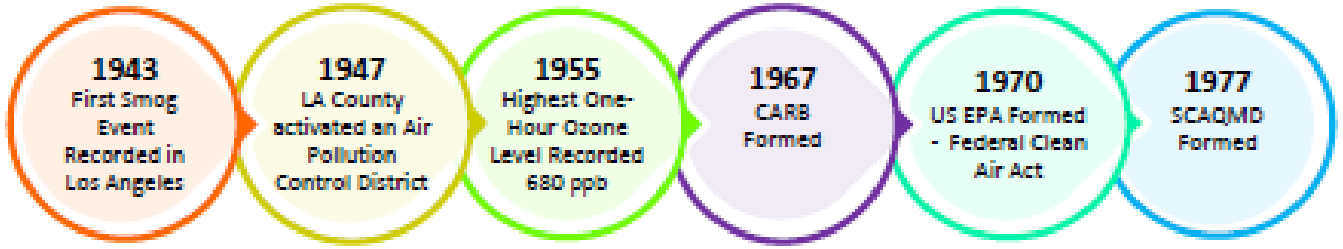
https://www.epa.gov/ozone-pollution-and-your-patients-health/health-effects-ozone-general-population

Historical Perspective: Los Angeles (1950s, 1960s)

Hollywood Citizens News Collection, Los Angeles Public Library

CARB Formed (California agency)

US EPA Clean Air Act (1970)



1-hr ozone = 680 ppb in 1955
Highest ever recorded
(Current standard = 90 ppb)

Recall from Lecture 5

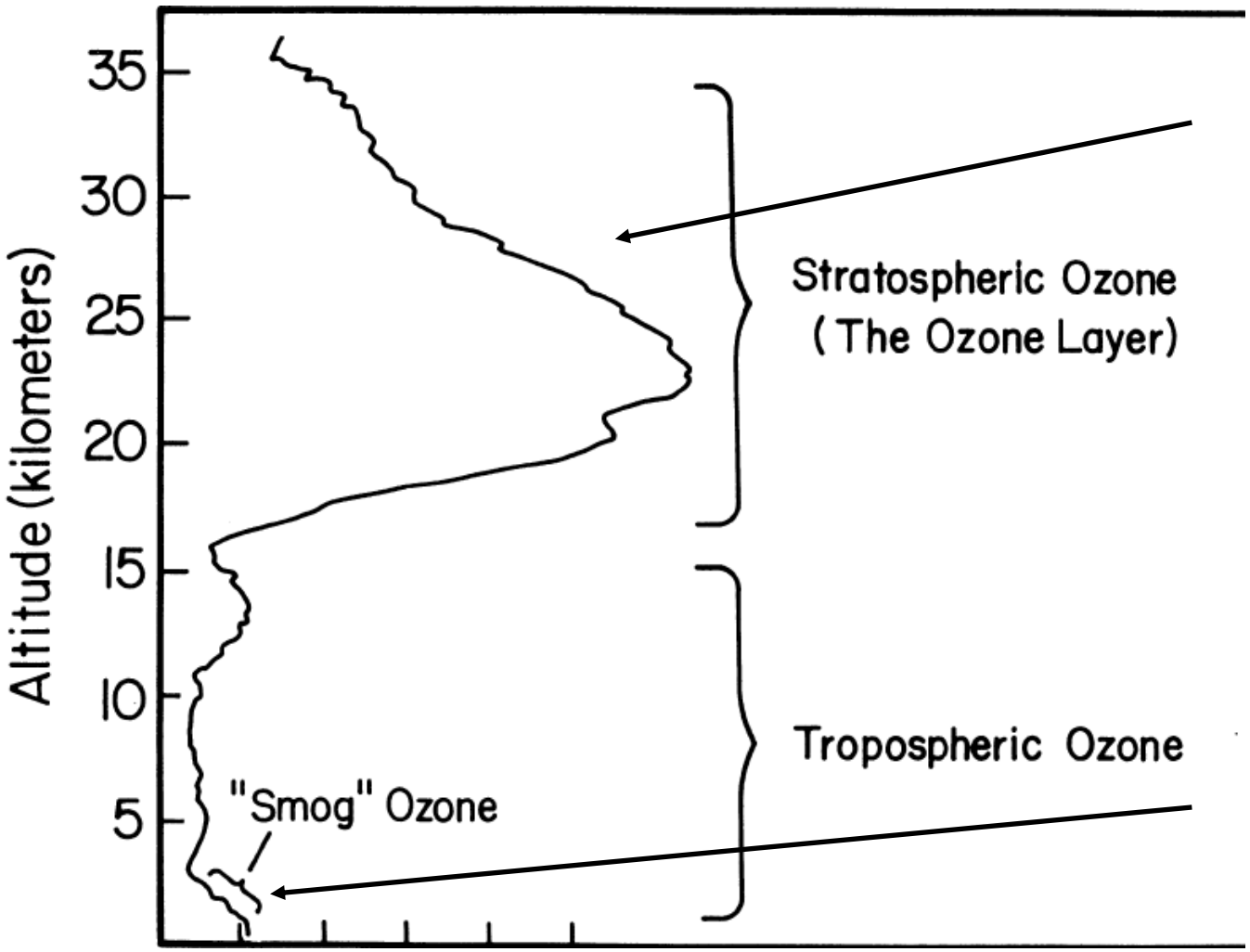
Ambient Air Quality Standards

	California**	Federal*
Ozone		
1-hour average	90 ppbv	--
8-hour average	70 ppbv	70 ppbv
CO		
1-hour average	20 ppmv	35 ppmv
8-hour average	9.0 ppmv	9.0 ppmv
NO_2		
1-hour average	180 ppbv	100 ppbv
annual average	30 ppbv	53 ppbv
SO_2		
1-hour average	250 ppbv	75 ppbv
24-hour average	40 ppbv	140 ppbv

* Federal standards are set by Environmental Protection Agency (EPA) as "NAAQS" (National Ambient Air Quality Standards).

** California standards are set by the California Air Resources Board.

Ozone (O_3) Concentration vs. Height (Troposphere & Stratosphere)



Stratospheric Ozone ("good ozone")

- *Where ultraviolet sunlight is absorbed.*
- *Beneficial effect to surface life.*
- *See Lecture 2*

Ground-Level Ozone ("bad ozone")

- *Forms in urban areas, typically summertime*
- *A "secondary pollutant" – not emitted, but formed in the atmosphere due to chemical reactions involving sunlight ("photochemical reactions")*
- *Also called photochemical smog*
- *Ozone emission precursors: NOx and VOCs*

Ozone Air Pollution: Summary

- Primary Pollutant: Emitted from a source
- Secondary Pollutant: Formed from chemical reactions in atmosphere
- Ozone is a secondary pollutant.
  - Formed from chemical reactions between NOx and VOCs, which are emitted.
  - Chemical reactions to form ozone require sunlight … i.e. the reactions are “photochemical reactions”
  - Hence, the term “photochemical smog” is synonymous.
  - Nox and VOCs are called “ozone precursors” …

Ground-Level Ozone (Formation Mechanism)

Chemical Reactions: Tropospheric Ozone

$2NO + O_2 \rightarrow 2NO_2$ ← Formation of NO2

$NO_2 + sunlight \rightarrow NO + O$ ← Dissociation of NO2 to free oxygen through absorbing sunlight

$O_2 + O \rightarrow O_3$ ← Creates ozone

$NO + O_3 \rightarrow NO2 + O_2$ ← Destroys ozone

- Equilibrium btw creation and destruction of ozone
- Roughly constant background tropospheric ozone concentrations from 10 – 40 ppb.
- Lower at night since sunlight goes away to create free oxygen.

Chemical Reactions: Ground-Level Ozone

$2NO + O_2 \rightarrow 2NO_2$ ← Formation of NO2

$NO + VOC \rightarrow NO_2$

(complicated set of reactions btw NO & VOCs. Result is to create additional NO_2)

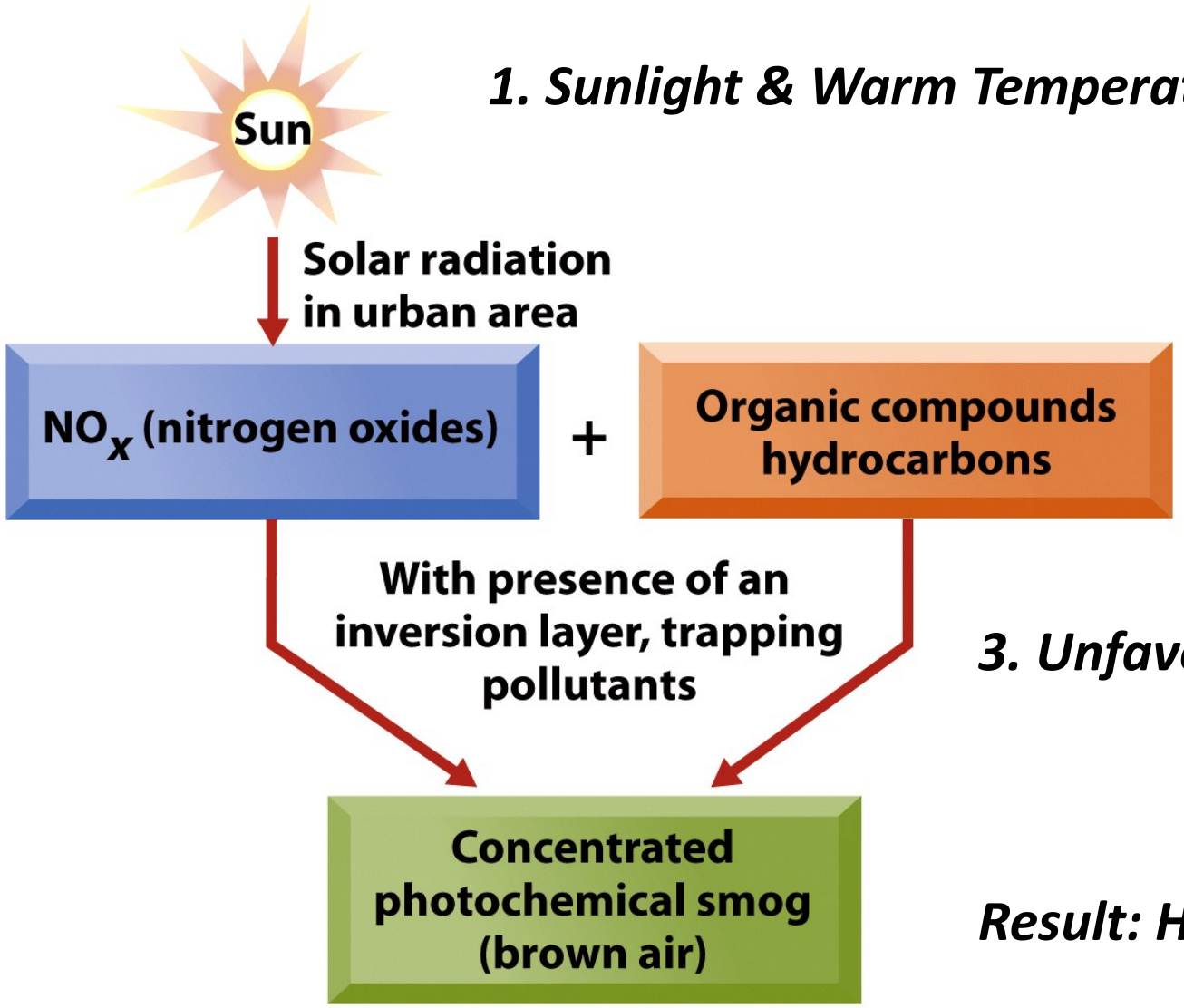
$NO_2 + sunlight \rightarrow NO + O$ ← Dissociation of NO2 to free oxygen through absorbing sunlight

$O_2 + O \rightarrow O_3$ ← Creates ozone

$NO + O_3 \rightarrow NO2 + O_2$ ← Destroys ozone

- Equilibrium btw creation and destruction of ozone
- More NO2 to create free oxygen due to urban emissions of extra NO_X and VOCs.
- Ground-level ozone concentrations in urban air is higher … can reach ~ 100 ppb or higher.

Ground-Level Ozone Formation: Conditions for Bad Episodes



1. Sunlight & Warm Temperatures

2. High Precursor Emissions (NO_x and VOCs)

3. Unfavorable geography and meteorology

Result: High Ozone (O_3) & Photochemical Smog

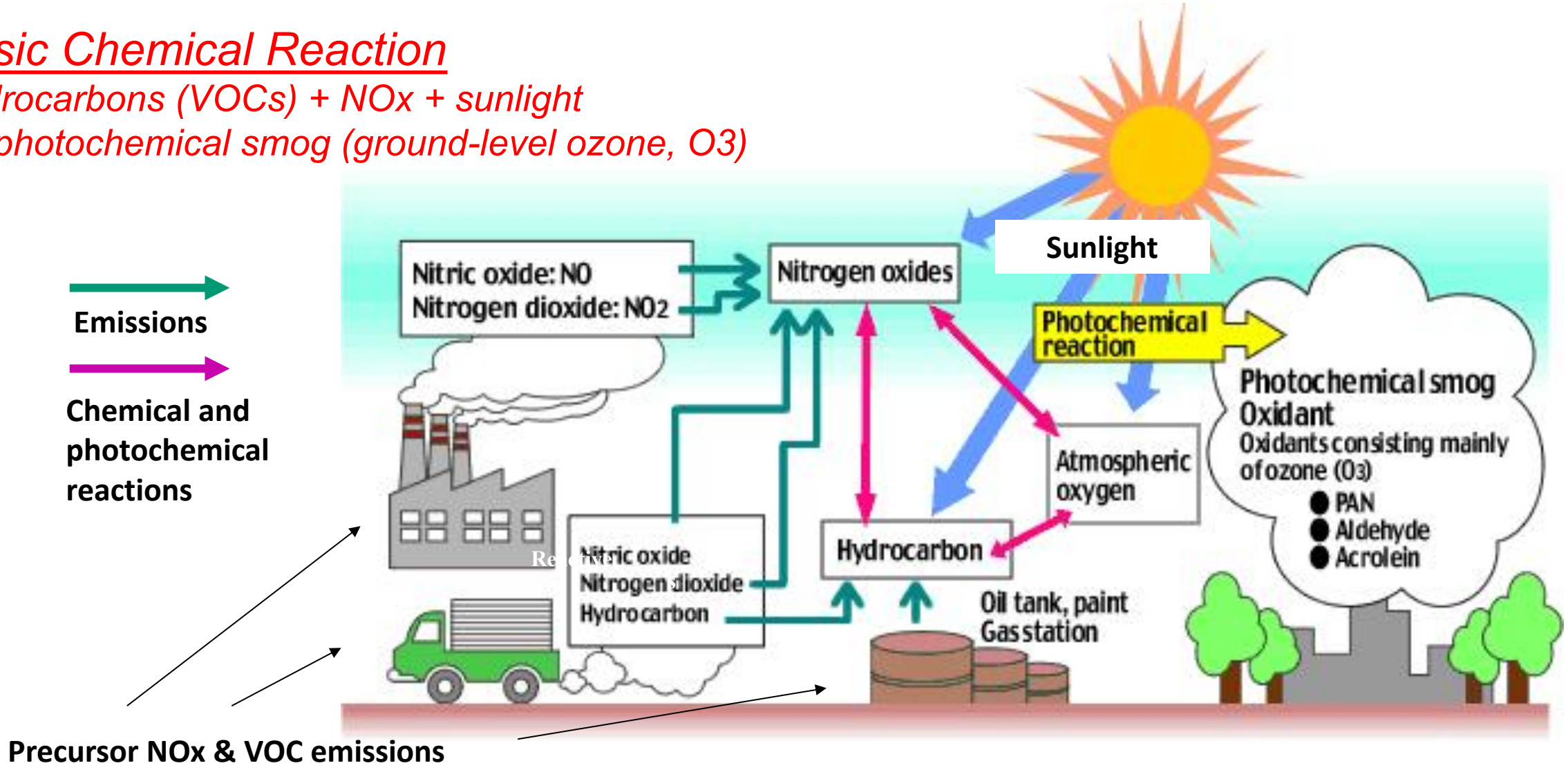
Photochemical Urban Smog

(Pictorial summary highlighting emission sources & chemical reactions)

Basic Chemical Reaction

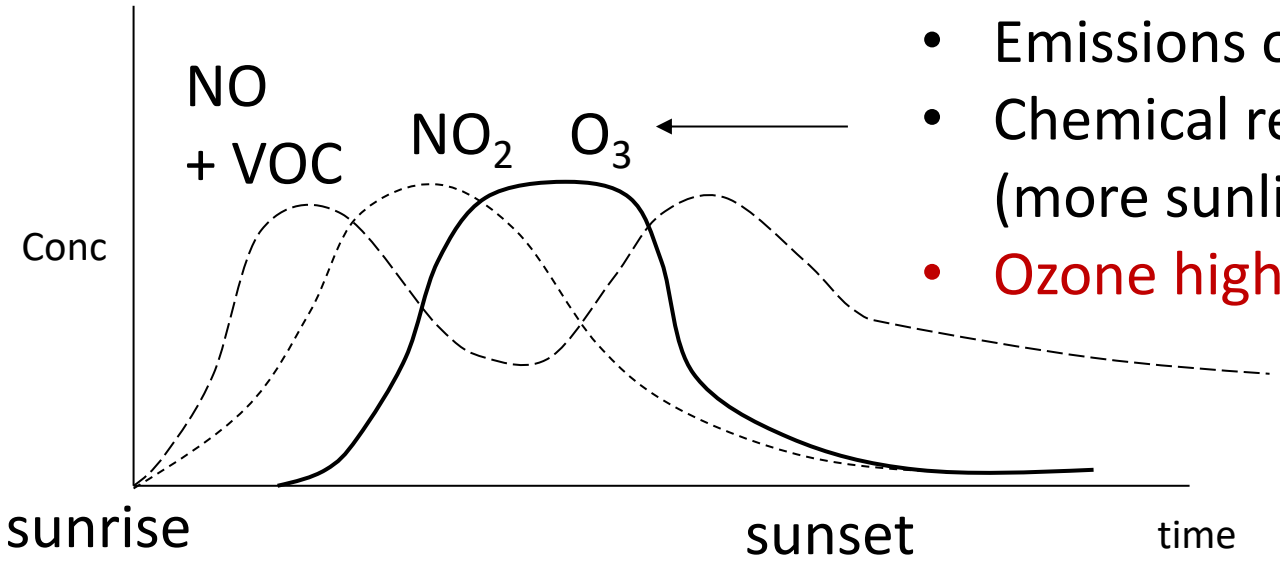
Hydrocarbons (VOCs) + NOx + sunlight

→ photochemical smog (ground-level ozone, O3)



Ground-Levels Ozone Formation: Typical Diurnal Cycles

Diurnal variation of emissions of NO & VOC (cars & industry)
+ Diurnal variation of sunlight …



- Emissions of NO and VOCs highest in morning
- Chemical reactions more active as day proceeds (more sunlight and higher temperatures)
- Ozone highest in mid-late afternoon

Case Study: Los Angeles
(Summertime ground-level ozone)
(non-attainment area for O3)

NOx Emissions

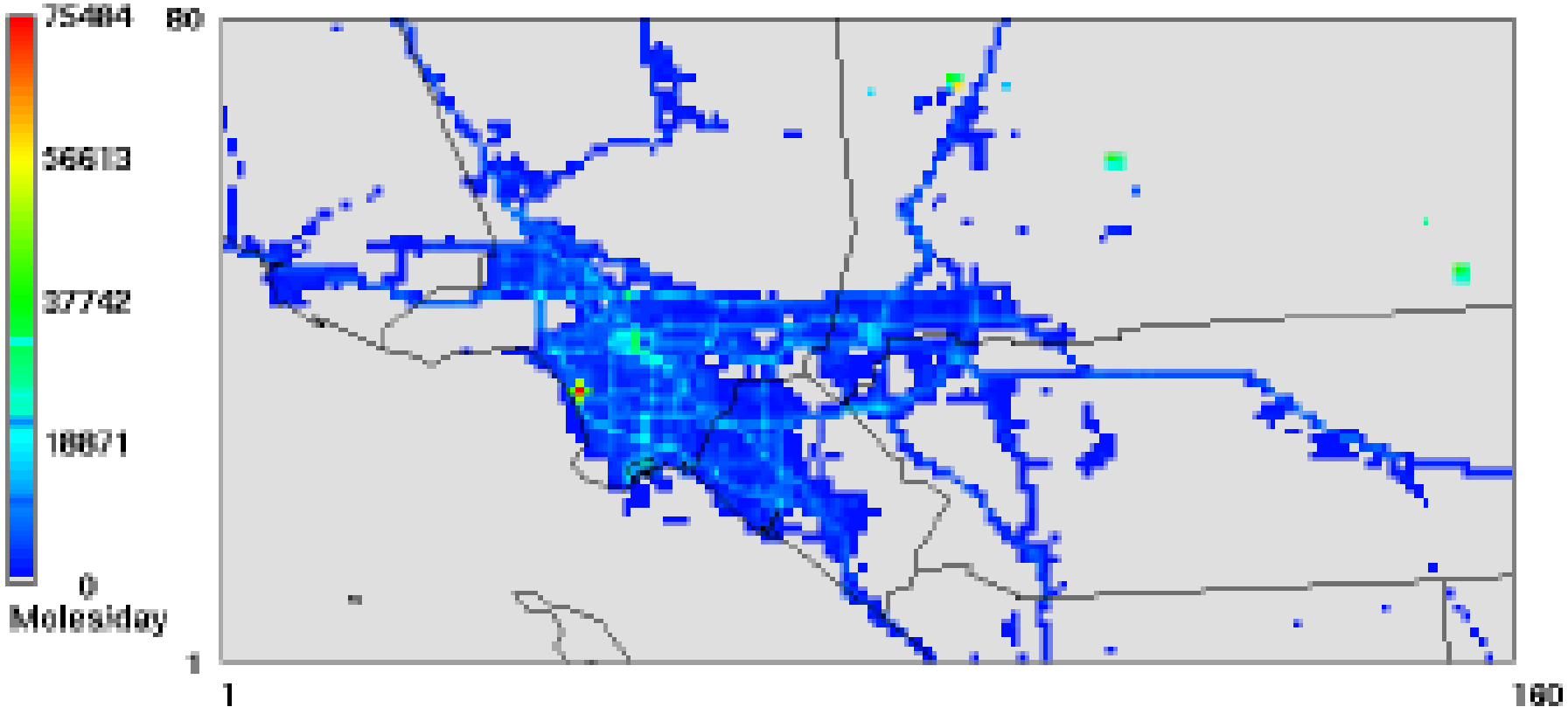


Figure IX-8i
Weekday average NOx emissions pattern.

NOx emissions highest in LA City Center (“western LA Basin”)
(Emissions spread across basin, but centered on major roadways since NOx is dominated by motor vehicle emissions)

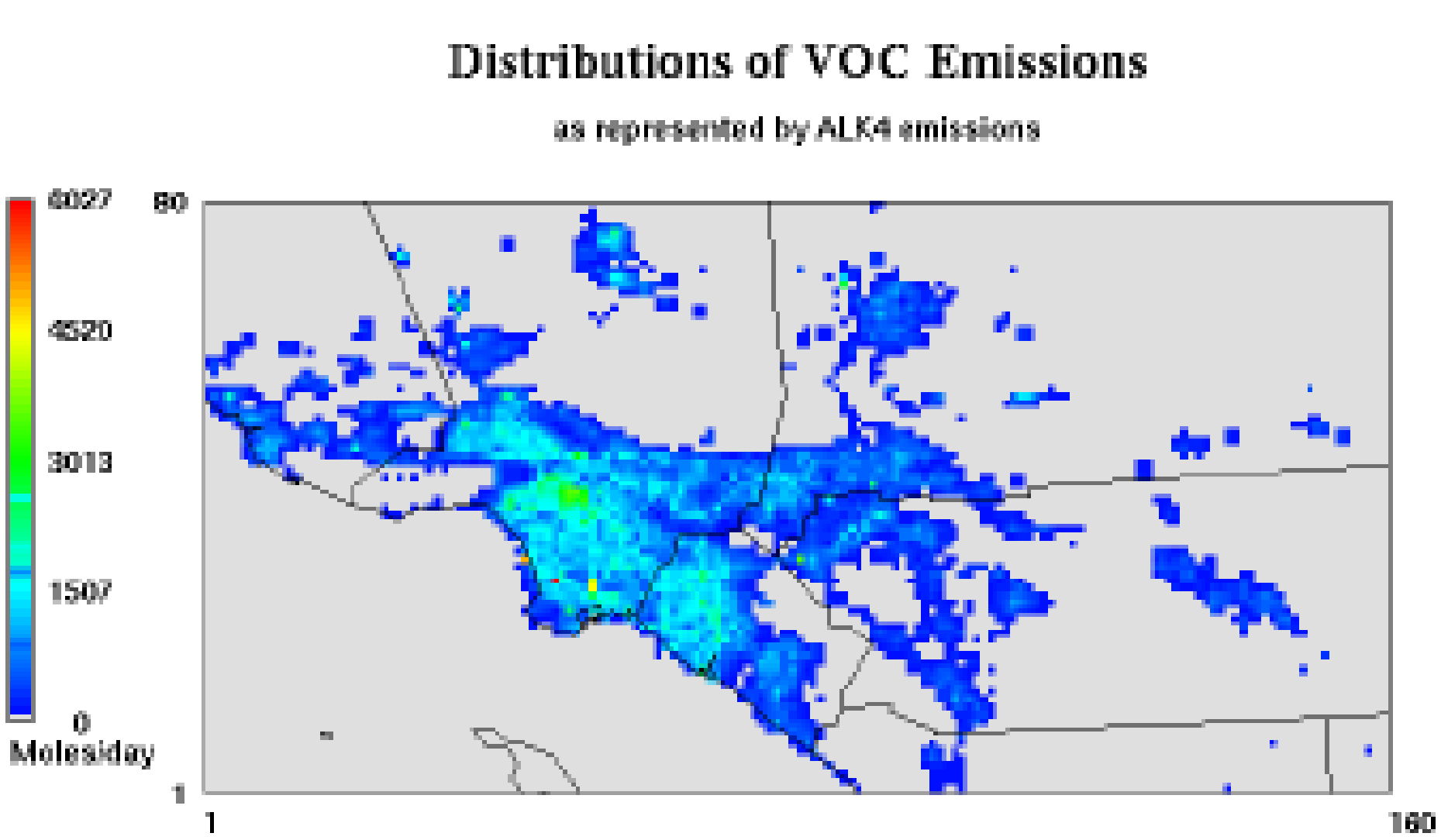


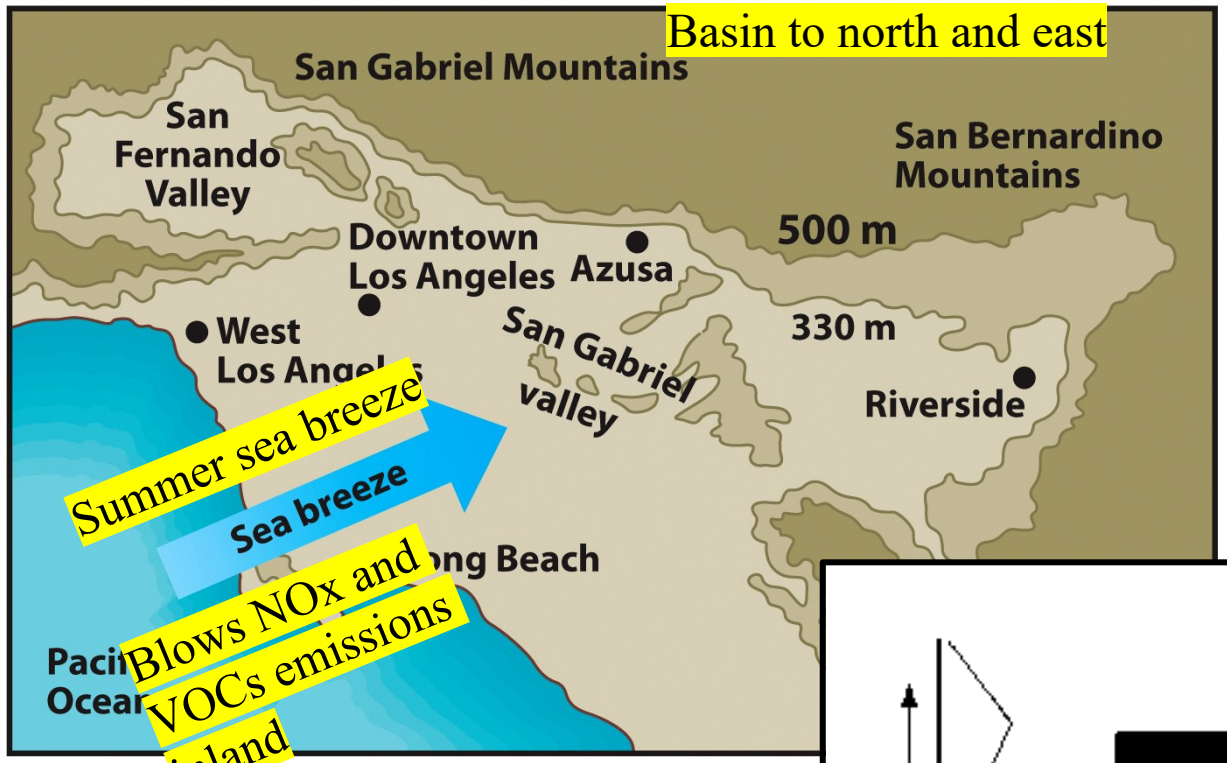
Figure IX-8h
Weekday average VOC emissions pattern.

VOC emissions highest in LA City Center (“western LA Basin”)

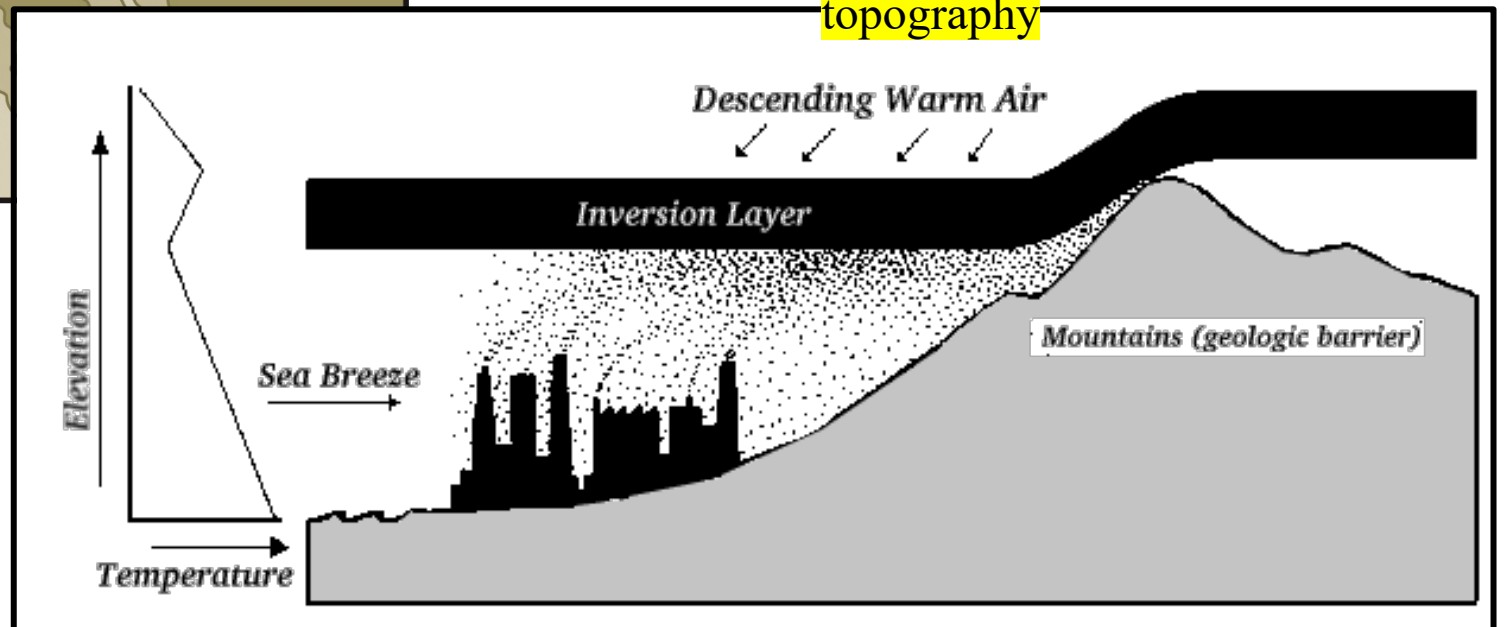
(A bit more uniform across basin compared to NOx – sources more varied, less centered on motor vehicles)

Typical Summertime Daytime Wind Pattern (Los Angeles area)

High mountains bounding LA Basin to north and east

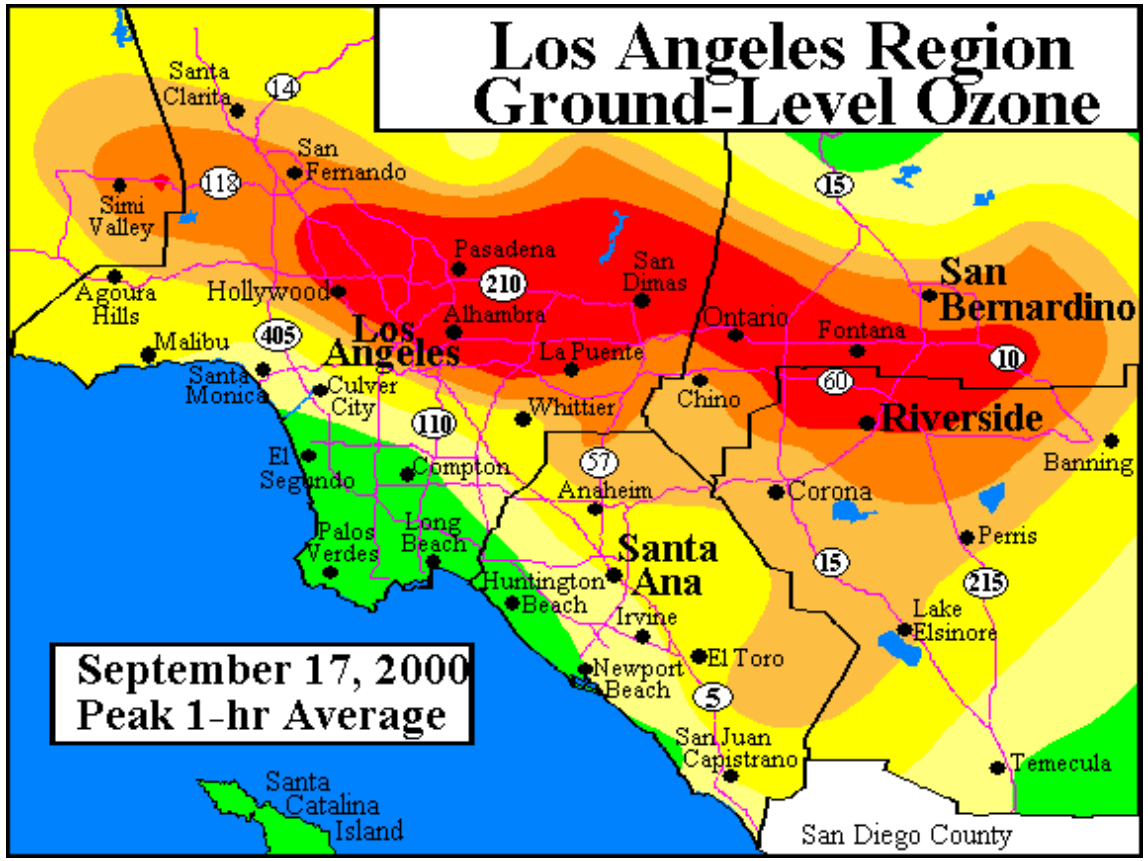


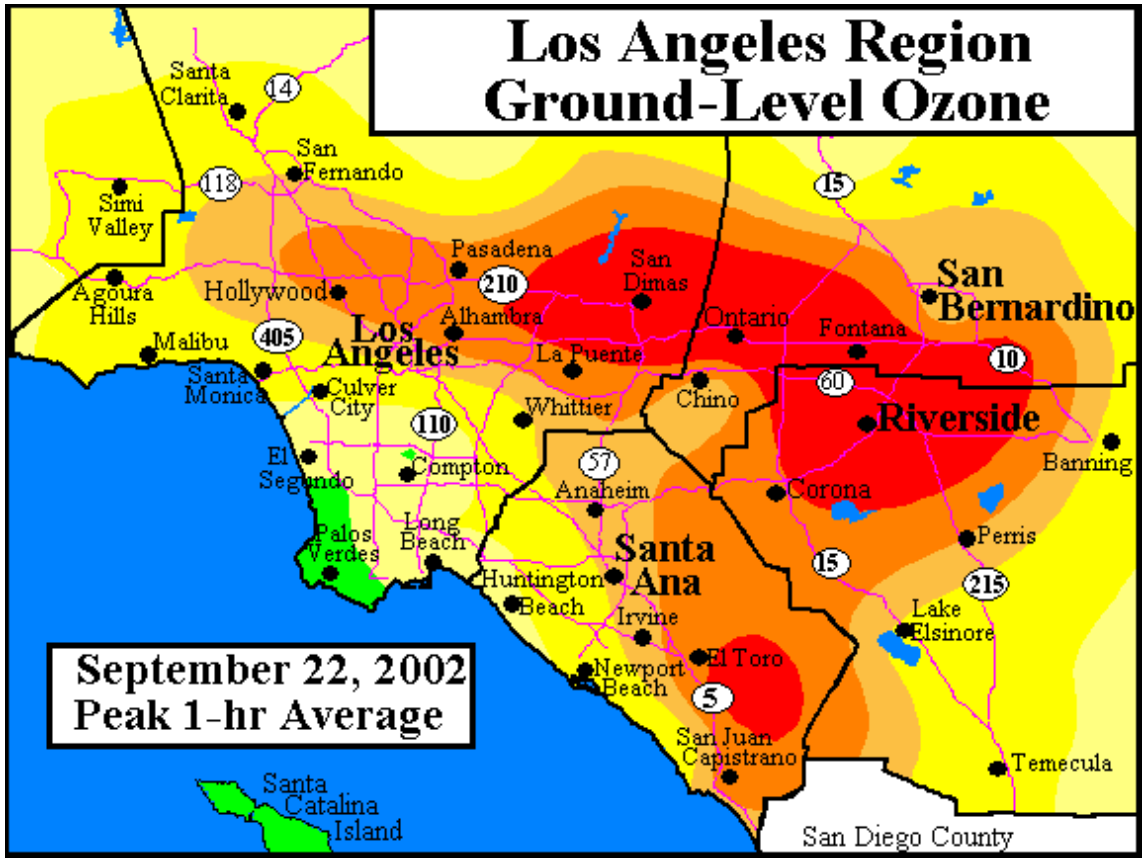
Pollution blows inland and is bounded atop by subsidence inversion layer & on sides by topography



Ground-Level Ozone: Air Pollution Episodes in Los Angeles Basin

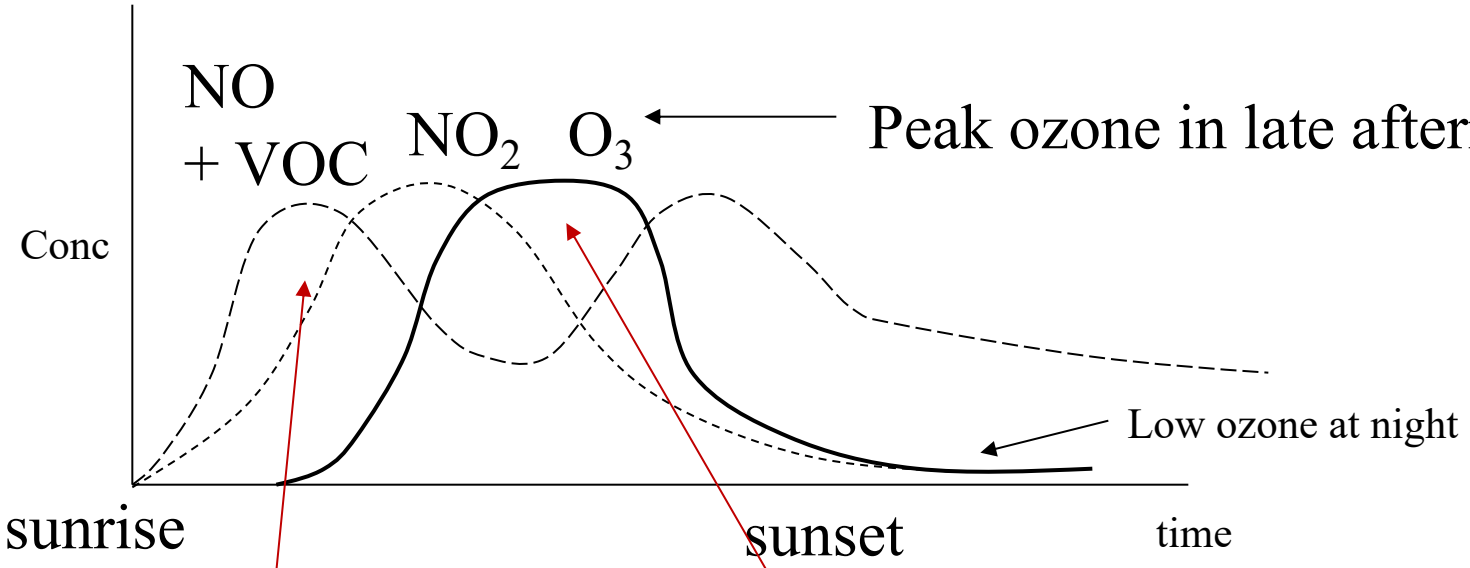
(peak 1-hour concentrations for two example days …)





≤ 60 ppb 60 - 125 ppb > 125 ppb

Ground-Levels Ozone Formation: Typical Diurnal Cycles



Western LA Basin
(where emissions of NO & VOC are highest)

Eastern LA Basin
(sea breeze winds blow precursor NO & VOC inland)
(chemical reactions occur during travel … form NO2 then O3)
(O3 highest inland … eastern LA Basin)

Ground-Level Ozone
(Regulatory Efforts & Emission Controls)

Number of Days per Year Exceeding 8-hour ozone standard

(Year 2015; Federal and State 8-hour ozone standard = 70 ppb)

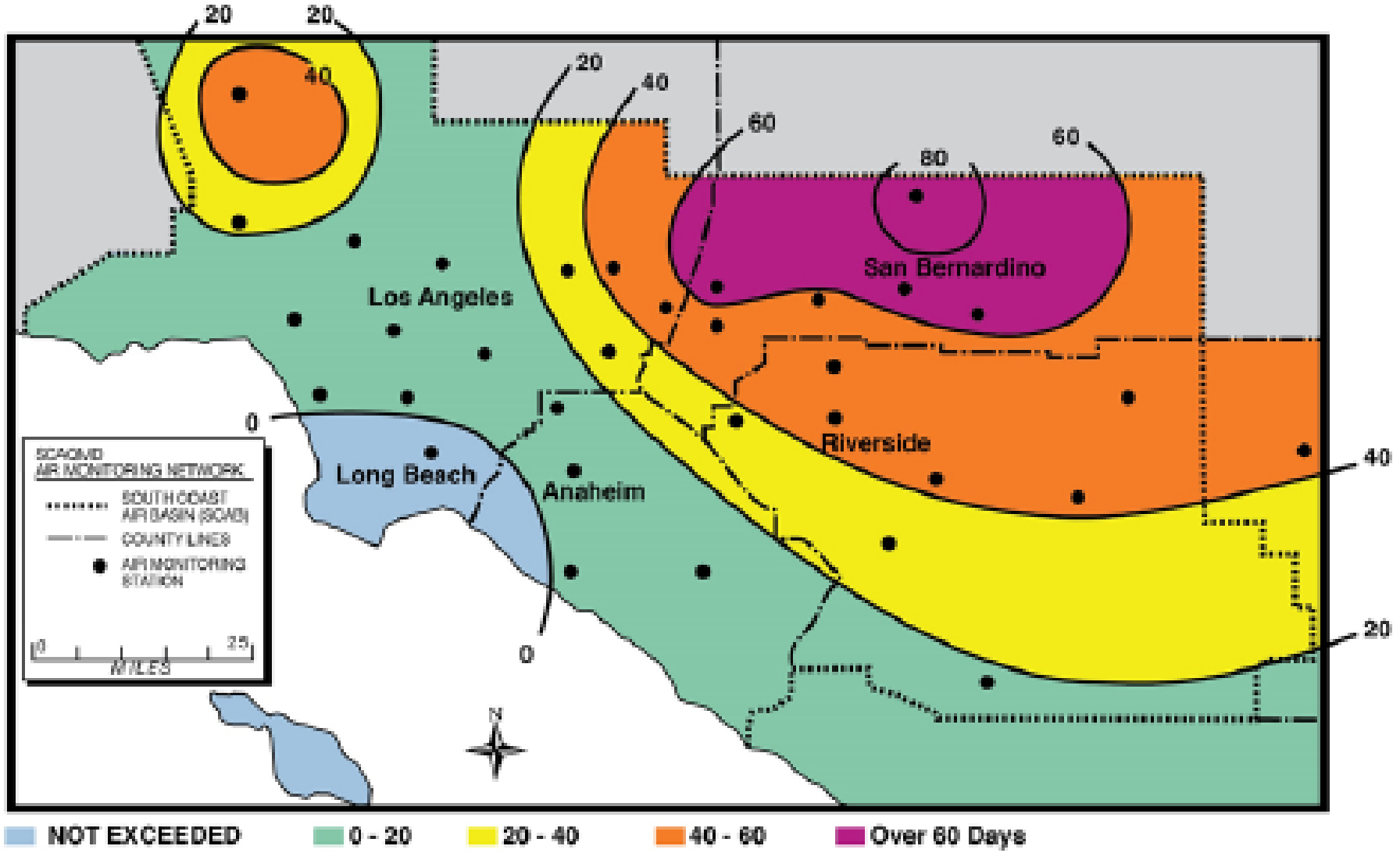


Figure 2-4 of http://www.aqmd.gov/home/air-quality/clean-air-plans/air-quality-mgt-plan/final-2016-aqmp

Implementation Plan

(South Coast Air Quality Management District, SCAQMD)

(http://www.aqmd.gov/home/air-quality/clean-air-plans/air-quality-mgt-plan/final-2016-aqmp)

- State Implementation Plans (SIP) are required from all air districts that are non-attainment areas for a particular criterial air pollutant and averaging time.

- The South Coast Air Basin is non-attainment with respect to both 1-hour and 8-hr ozone. SCAQMD therefore is required to submit a SIP for ozone.