Air Pollution Modeling

Air Pollution Modeling

- Why Air Pollution Modeling?
- Scale of Modeling
- Air Quality Forecasting Techniques
- Grid-based Eulerian Air Pollution Modeling

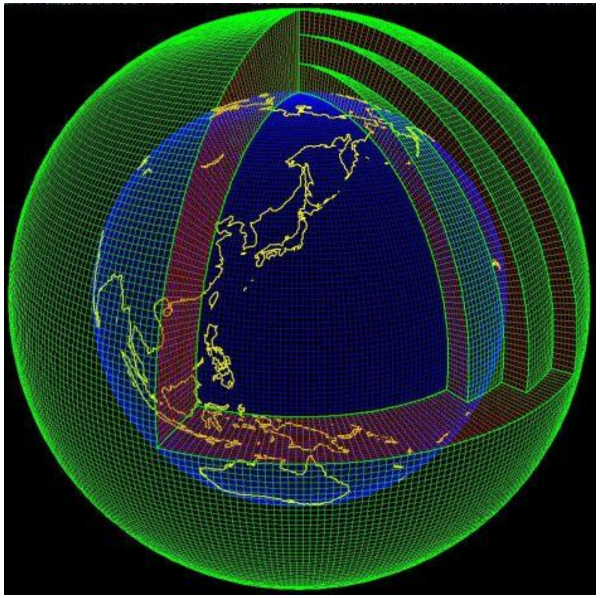
Why Air Pollution Modeling?

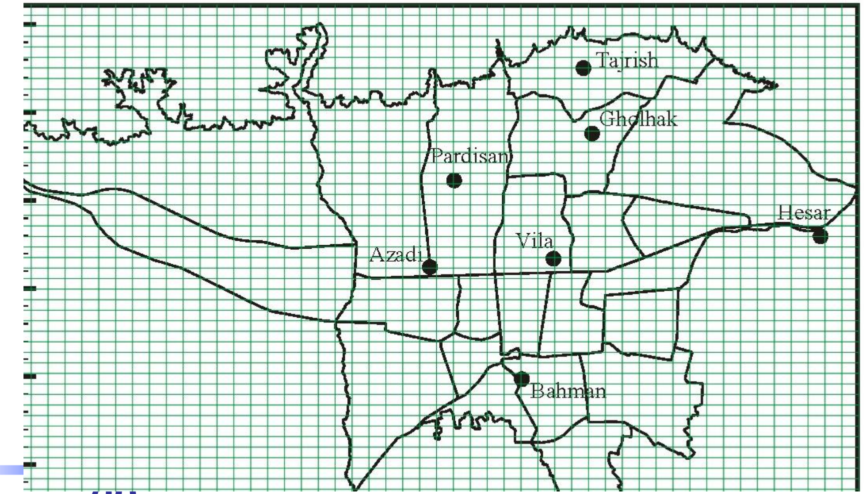
- Increasing awareness of the health aspects of air pollution exposure, especially by subpopulations most sensitive such as children and the elderly
- Models provide a cause-effect link between emissions into the air and the resulting ambient concentrations.
- models can be used to predict the future concentration of a particular pollutant after the implementation of a new pollution control program.
- The results of the modeling are then used to estimate the effectiveness of the control program
- In some countries the air quality forecasts have been routinely featured on television as well as weather forecasts
- Investigation of the effect of different condition (land-use, topography and …) on air pollution using a model

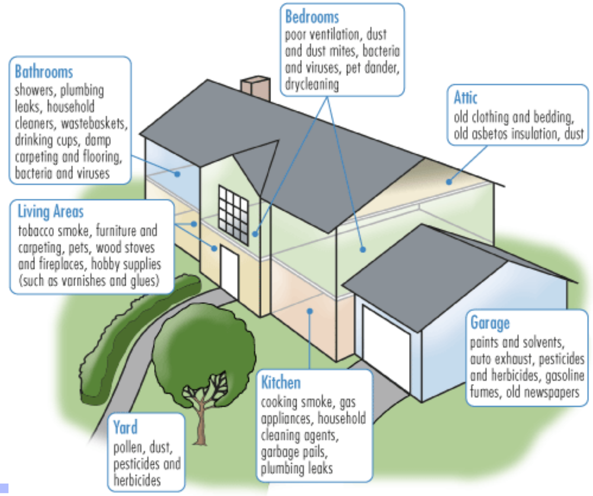
Scale of Modeling

Type of Problem		Horizontal Scale	Vertical Scale	Temporal Scale	Type of Organization
I	Indoor	10^{-2}–10^{-1} km	Up to 10^{-1} km	10^{-1}–10^{0} hr	Family/business
	Local	10^{-1}–10 km	Up to 3 km	10^{-1}–10 hr	Municipality/county
	Urban	10–10^{2} km	Up to 3 km	10^{0}–10^{2} hr	Municipality/county
II	Regional	10^{2}–10^{3} km	Up to 15 km	10–10^{3} hr	State/country
	Continental	10^{3}–10^{4} km	Up to 30 km	10^{2}–10^{4} hr	Country/world
III	Hemispheric	10^{4}–2×10^{4} km	Up to 50 km	10^{3}–10^{5} hr	World
	Global	4×10^{4} km	Up to 50 km	10^{3}–10^{6} hr	World

Scale of Modeling



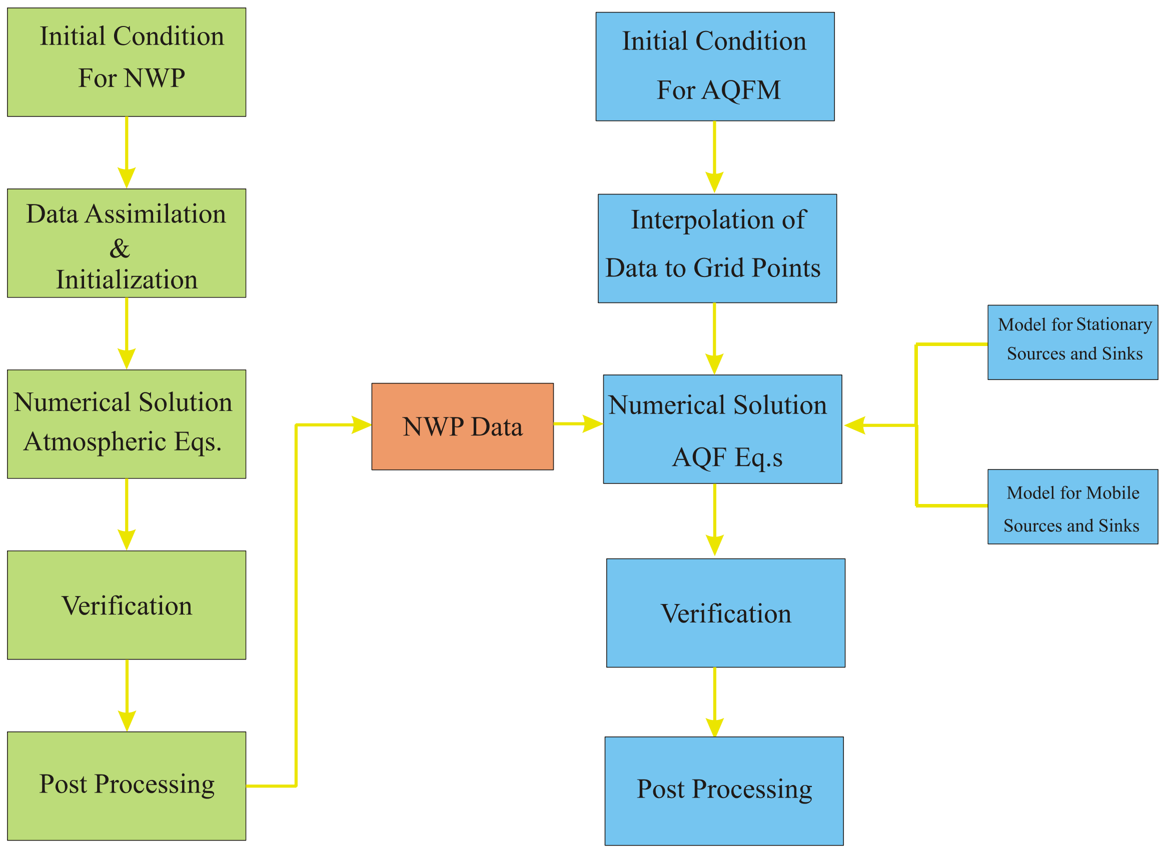




Air Quality Forecasting Techniques

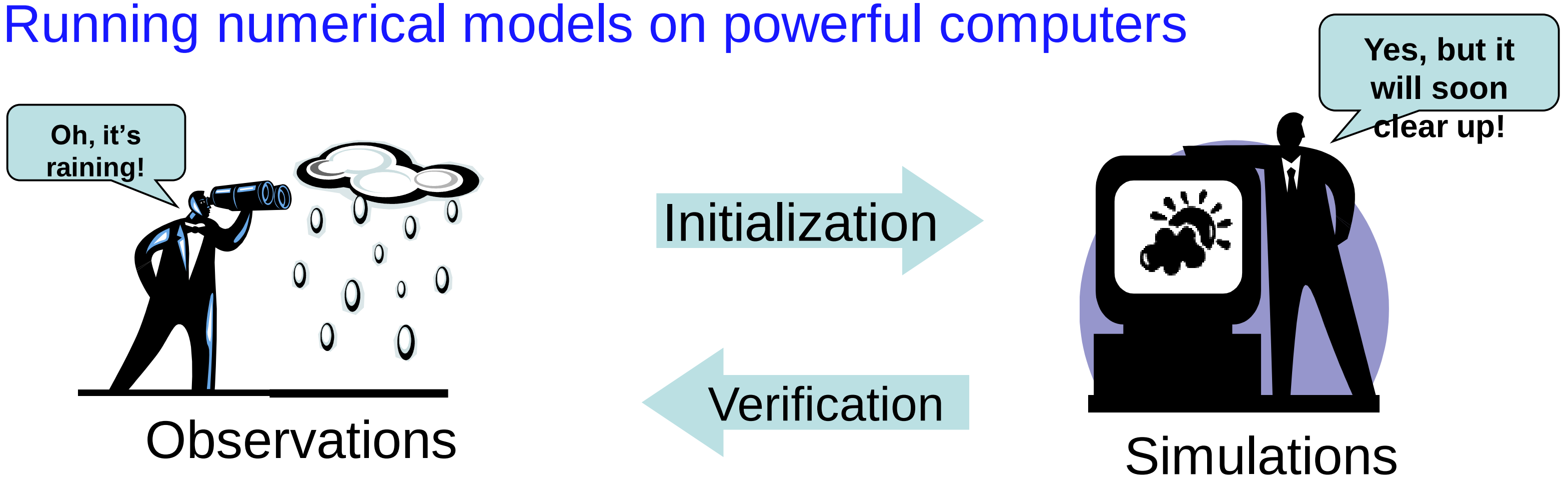
- Criteria schemes
- Parametric Methods
  - Statistical
  - Neural Networks
  - Fuzzy logic
- Deterministic Methods
  - Gaussian method
  - Lagrangian method
  - Eulerian method (Our goal)
  - Hybrid Eulerian-Lagrangian method

Development of a Grid-based Eulerian Air Pollution Modeling



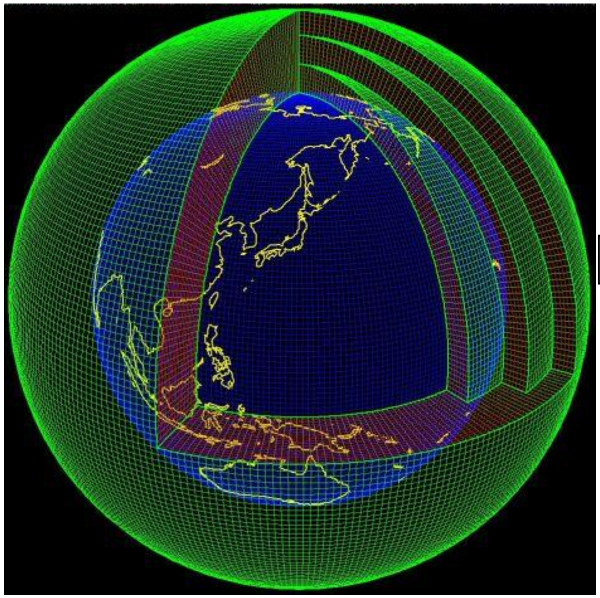
Numerical Weather Prediction (NWP)

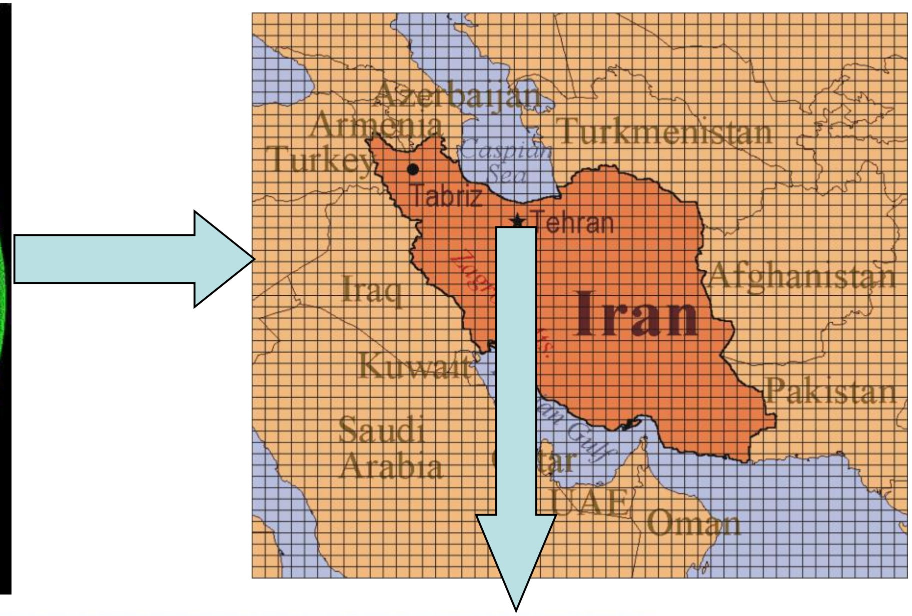
- Observing the atmosphere
- Running numerical models on powerful computers

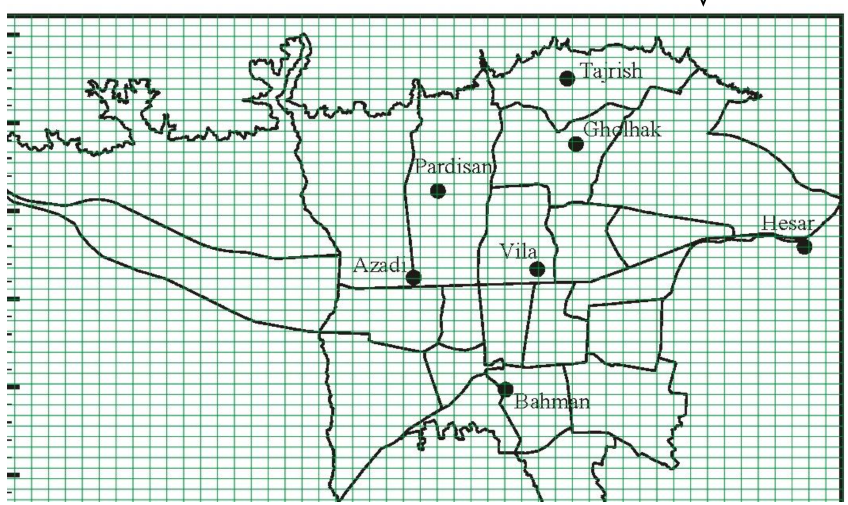


- We solve a set of nonlinear equations which describe the motion of the atmospheric fluid as well as process such as precipitation
- The nonlinearity requires a numerical treatment on "big" computers
- Observations are needed to initialize and verify the model forecast

Nested Grids in NWP

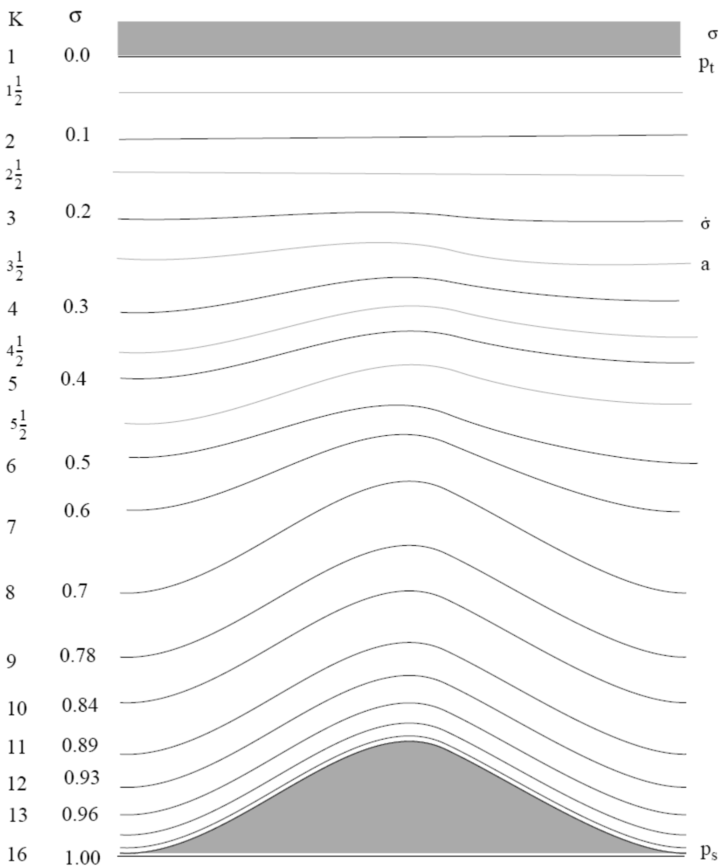






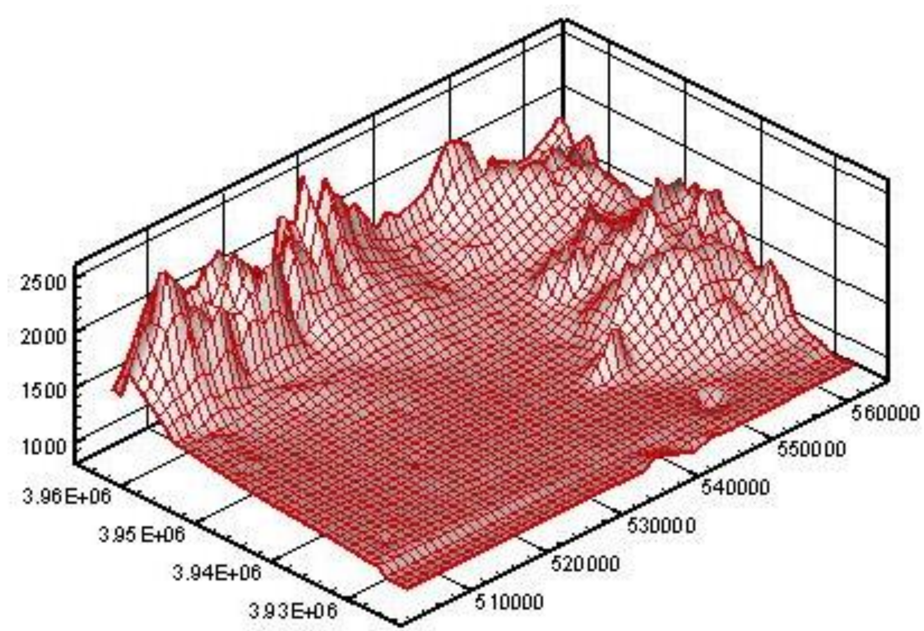
Numerical Weather Prediction (cont.)

- Vertical descretization



$$\sigma = (p - p_t)/(p_s - p_t)$$

- Topography of Tehran



Numerical Weather Prediction

- Three equations of motion
- One thermodynamic equation
- Several continuity equations for water species
- One mass continuity equation
- Local tendencies are derived base on
  - Advection
  - Pressure gradient
  - Coriolis force
  - Gravit. acceleration
  - Turbulent diffusion
  - Radiation
  - Divergence

Equations of motion:

$$\frac{\partial u}{\partial t} = -u\frac{\partial u}{\partial x} - v\frac{\partial u}{\partial y} - w\frac{\partial u}{\partial z} - \theta\frac{\partial \pi'}{\partial x} + fv + \frac{\partial}{\partial x}\left(K_m\frac{\partial u}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_m\frac{\partial u}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_m\frac{\partial u}{\partial z}\right)$$

$$\frac{\partial v}{\partial t} = -u\frac{\partial v}{\partial x} - v\frac{\partial v}{\partial y} - w\frac{\partial v}{\partial z} - \theta\frac{\partial \pi'}{\partial y} - fu + \frac{\partial}{\partial x}\left(K_m\frac{\partial v}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_m\frac{\partial v}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_m\frac{\partial v}{\partial z}\right)$$

$$\frac{\partial w}{\partial t} = -u\frac{\partial w}{\partial x} - v\frac{\partial w}{\partial y} - w\frac{\partial w}{\partial z} - \theta\frac{\partial \pi'}{\partial z} - \frac{g\theta_v'}{\theta_0} + \frac{\partial}{\partial x}\left(K_m\frac{\partial w}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_m\frac{\partial w}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_m\frac{\partial w}{\partial z}\right)$$

Thermodynamic equation:

$$\frac{\partial \theta_{il}}{\partial t} = -u\frac{\partial \theta_{il}}{\partial x} - v\frac{\partial \theta_{il}}{\partial y} - w\frac{\partial \theta_{il}}{\partial z} + \frac{\partial}{\partial x}\left(K_h\frac{\partial \theta_{il}}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_h\frac{\partial \theta_{il}}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_h\frac{\partial \theta_{il}}{\partial z}\right) + \left(\frac{\partial \theta_{il}}{\partial t}\right)_{rad}$$

Water species mixing ratio continuity equation:

$$\frac{\partial r_n}{\partial t} = -u\frac{\partial r_n}{\partial x} - v\frac{\partial r_n}{\partial y} - w\frac{\partial r_n}{\partial z} + \frac{\partial}{\partial x}\left(K_h\frac{\partial r_n}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_h\frac{\partial r_n}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_h\frac{\partial r_n}{\partial z}\right)$$

Mass continuity equation:

$$\frac{\partial \pi'}{\partial t} = -\frac{R\pi_0}{c_v\rho_0\theta_0}\left(\frac{\partial \rho_0\theta_0 u}{\partial x} + \frac{\partial \rho_0\theta_0 v}{\partial y} + \frac{\partial \rho_0\theta_0 w}{\partial z}\right)$$

Air Quality Modeling

$$\frac{\partial c_i}{\partial t} + \nabla \cdot (\overline{U}\ c_i) = \nabla \rho\ D_i \nabla \left(\frac{c_i}{\rho} \right) + R_i (c_1, c_2, \ldots, c_n, T, t) + S_i (\overline{x}, t)$$

$$i = 1, 2, 3, \ldots, n$$

c_i : concentration of species i.

$\overline{U}$: wind velocity vector

D_i : molecular diffusivity of species i

R_i : rate of concentration change of species i by chemical reaction

S_i : source/sink of i

ρ : air density

n : number of predicted species

Computer System for Model Running

- ~~Super Computer~~
- Parallel Processing System

Boundary Conditions

- **Physical parameterization of boundary layer**
  - Surface roughness and heat flux
  - Mixing height depth
  - Mean wind profile
  - Stability
  - Turbulence
- **Land use**
  - Urban
  - Industry
  - Forestry
  - Agriculture
- **Boundary condition from numerical weather prediction**

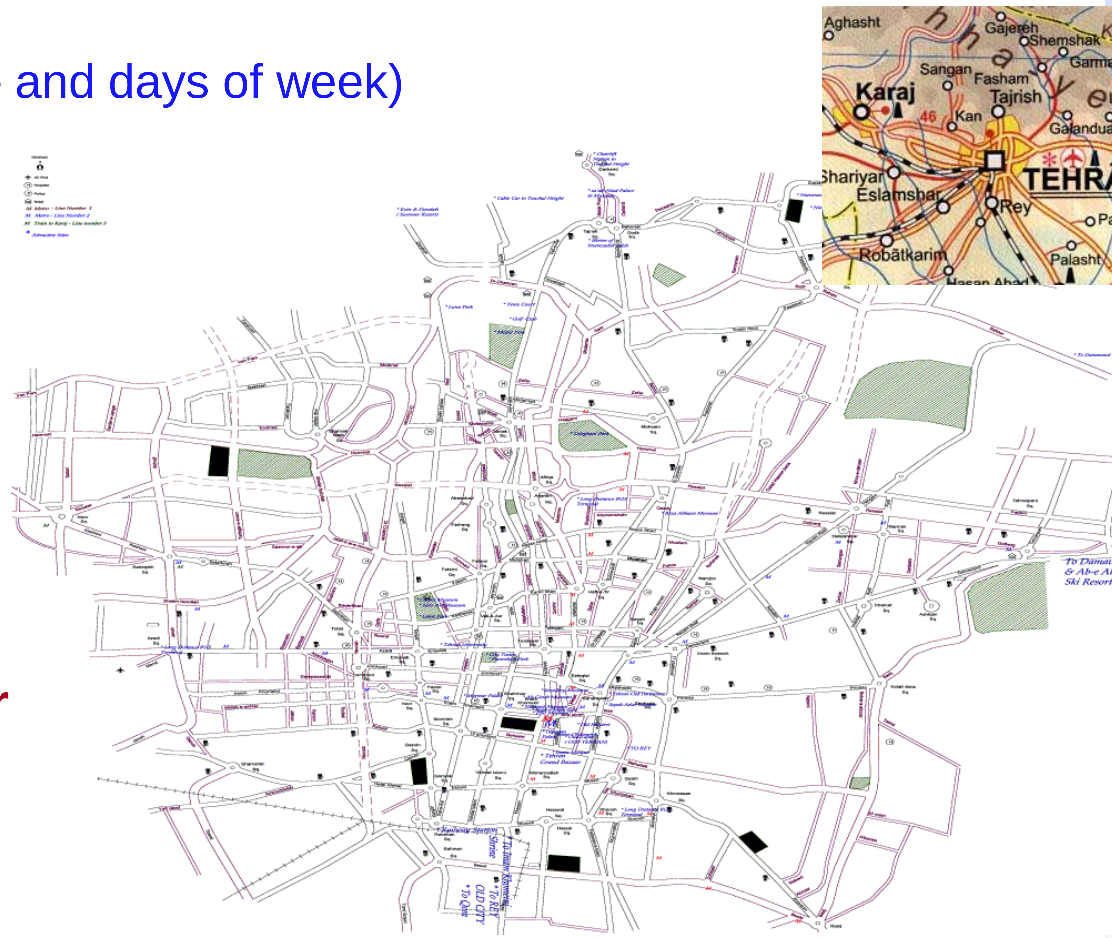
Sources and Sinks

- **Mobile Sources**
  - Road Traffic;
  - Rail Traffic;
  - River Traffic;
  - Aircraft.
- **Stationary Sources**
  - Large Industrial Processes;
  - Small Industrial Processes;
  - Large Boiler Plant.
  - Gas Combustion (domestic and commercial);
  - Oil Fuel Combustion (domestic and commercial);
  - Coal Combustion (domestic and commercial);
  - Agriculture and Nature;
  - Other.

Emission Sources

Mobile Sources

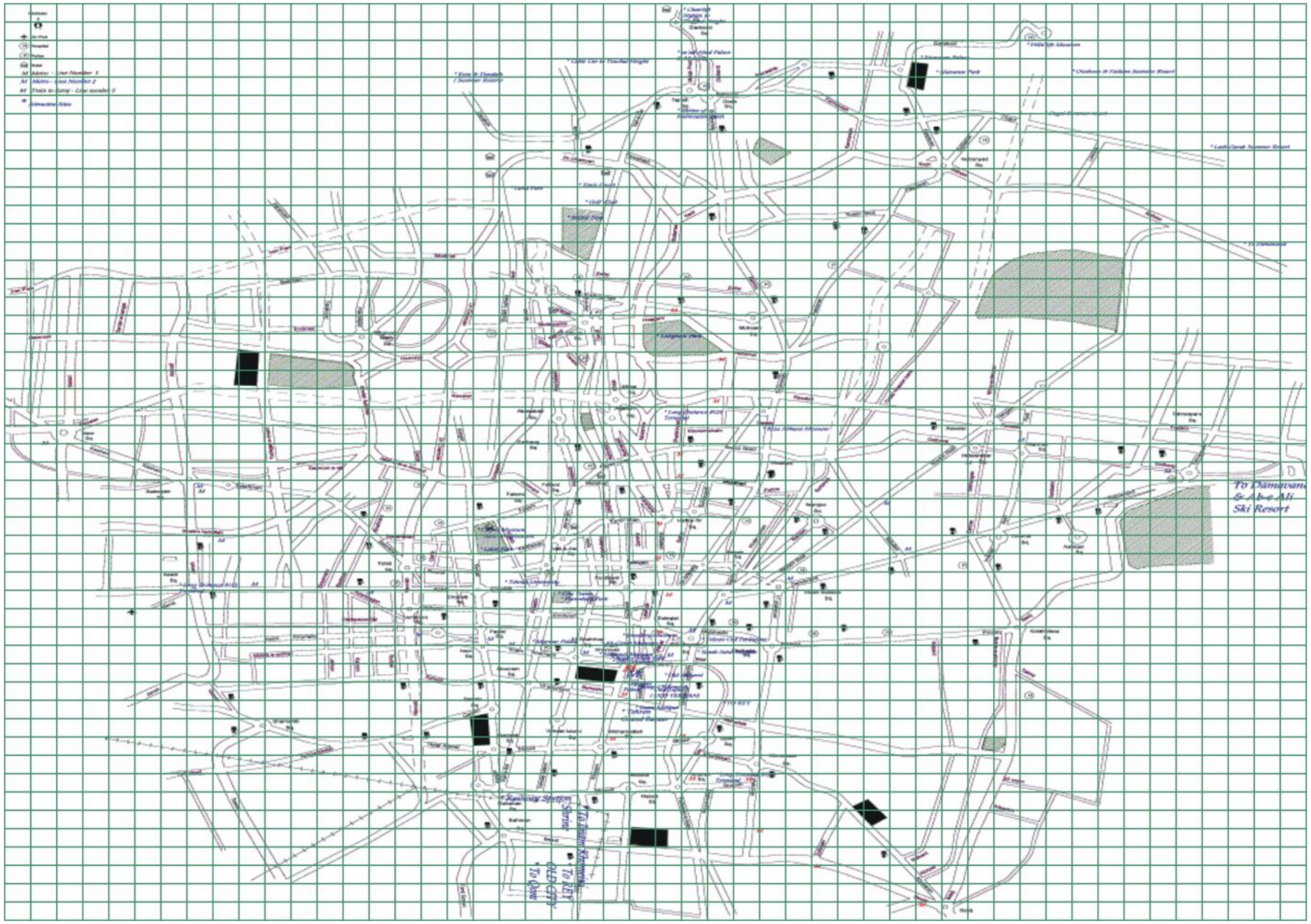
- **Traffic Volume**
  - Function of time (day time and days of week)
  - Function of space
- **Fleet Composition**
  - Light duty vehicles
  - Heavy duty vehicles
- **Average Vehicle Speed**
  - Function of time
  - Function of space
- **Vehicles Emission Factor**
  - Types of cars
  - Driving Cycles



Stationary Sources

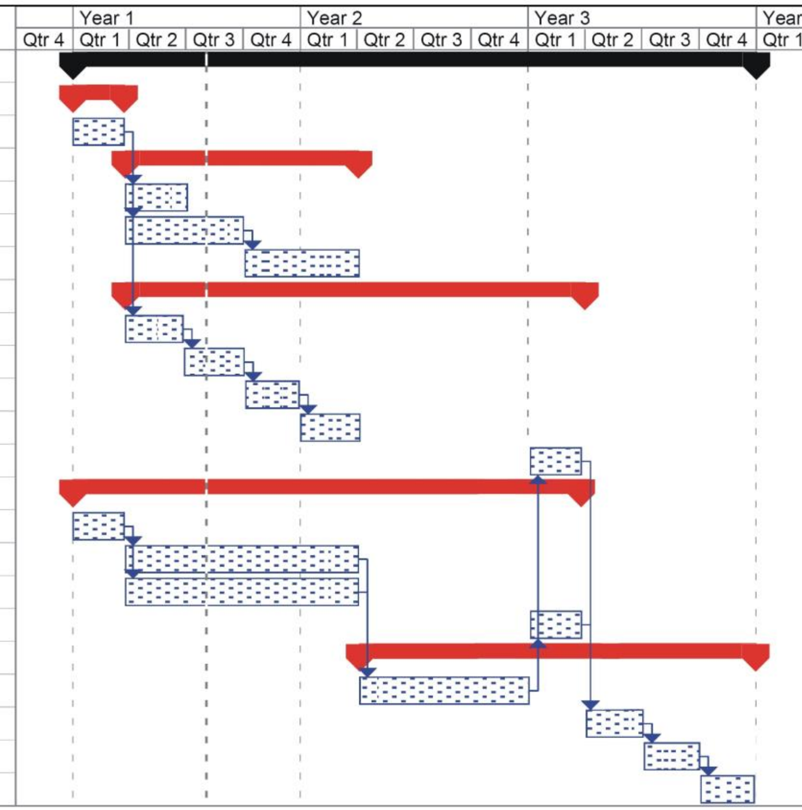
- Stake Parameters (height, diameter, flue gas velocity, temperature)
- Air Pollution Factors for Domestic and Commercial Areas
  - Energy consumption
  - Fuel types
- Air Pollution Factors for Agriculture and Nature Sources

Interpolation to Grids



Project Managment

ID	WBS	Task Name	Duration
1	**1**	**AIR QUALITY MODELLING**	**36 mons**
2	**1.1**	**Phase 00:**	**3 mons**
3	1.1.1	Preliminary Studies	3 mons
4	**1.2**	**Phase 01:**	**12 mons**
5	1.2.1	Selection of a Mesoscale Weather Model	3 mons
6	1.2.2	Governing Equation	6 mons
7	1.2.3	Selection of Proper Method of Discretization	6 mons
8	**1.3**	**Phase 02:**	**24 mons**
9	1.3.1	Running The Weather Prediction Model	3 mons
10	1.3.2	Parallel Running	3 mons
11	1.3.3	Weather Prediction Model Verification	3 mons
12	1.3.4	Providing Needed Data for Air Quality Model	3 mons
13	1.3.5	Linkage Between Weather Prediction Model and Air Quality Model	3 mons
14	**1.4**	**Phase 03:**	**27 mons**
15	1.4.1	Studies for Air Pollution Sources in Tehran	3 mons
16	1.4.2	Model Development for Stationary Sources	12 mons
17	1.4.3	Model Development for Mobile Sources	12 mons
18	1.4.4	Linkage Between Air Pollution Sources Model and Air Quality Model	3 mons
19	**1.5**	**Phase 04:**	**21 mons**
20	1.5.1	Air Quality Model Development	9 mons
21	1.5.2	Model Verification	3 mons
22	1.5.3	Post Processing	3 mons
23	1.5.4	Report Preparation	3 mons



Thank you