CLIMATE CHANGE AND WATER RESOURCES

by Ali UYUMAZ

TURKISH WATER FOUNDATION

- İstanbul Technical University

Turkish Water Foundation

TURKISH WATER FOUNDATION (TWF)

WERDEC

RERDEC

CERDEC

Kent State University

University of Khartum

Sandia Laboratories (USA)

University of California
Cooperation agreement

World Water Council
Registered member

Saudi Geological Survey

etc.

www.suvakfi.org.tr

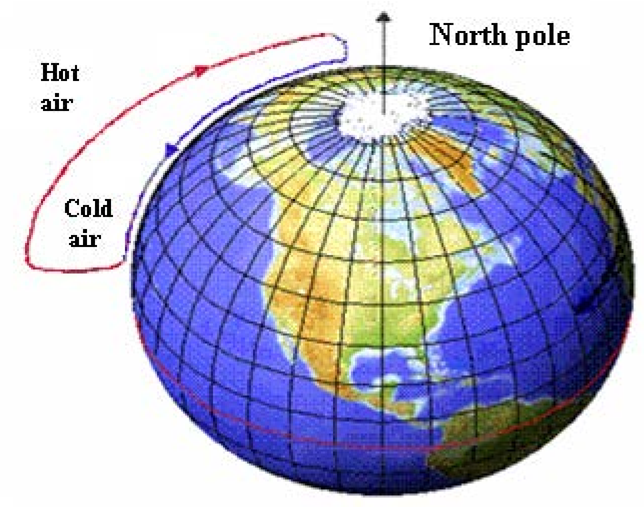
www.turkwater.org.tr

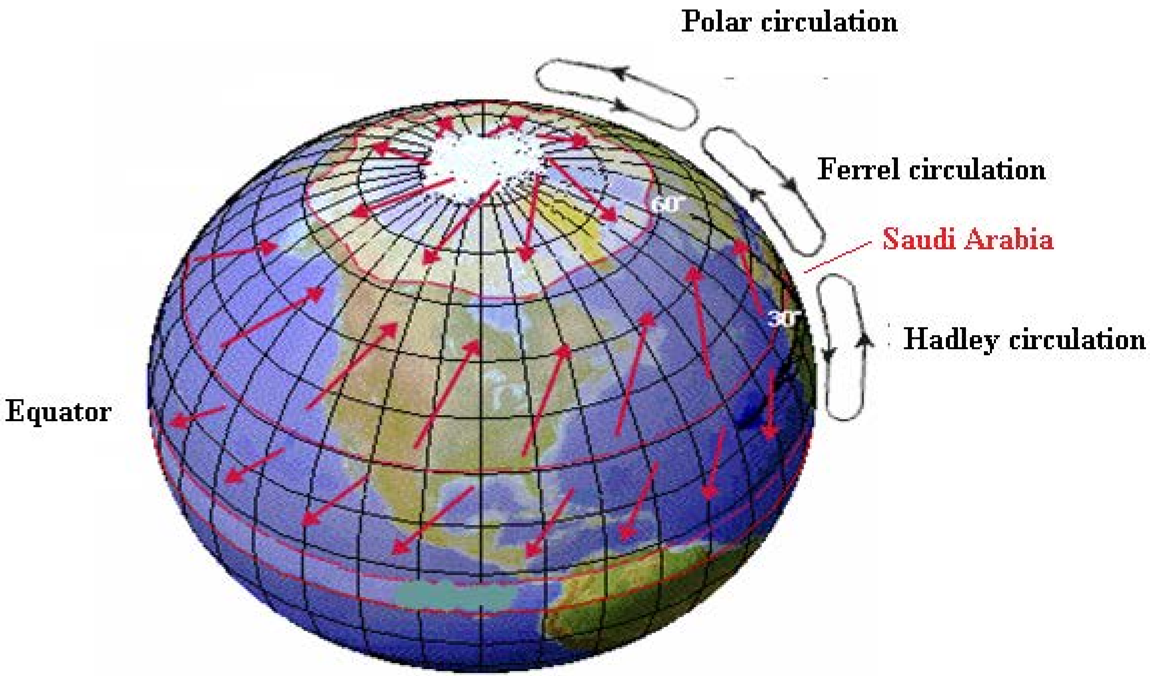
www.werdec.org.tr

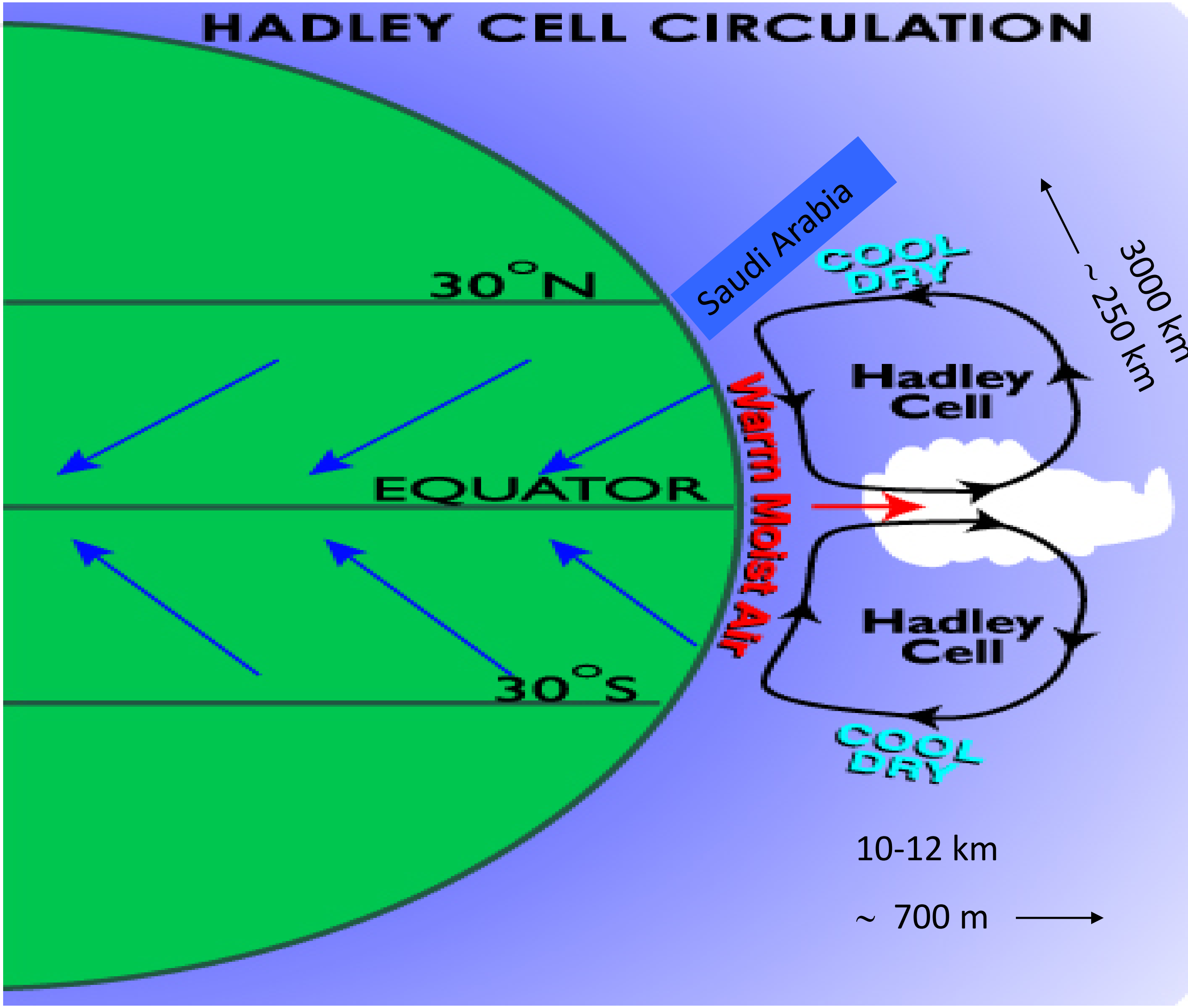
www.rerdec.org.tr

www.dunyasugunu.org.tr

Turkish Water Foundation


North pole
Hot
air
Cold
air


Polar circulation
Ferrel circulation
60°
Saudi Arabia
30°
Hadley circulation
Equator



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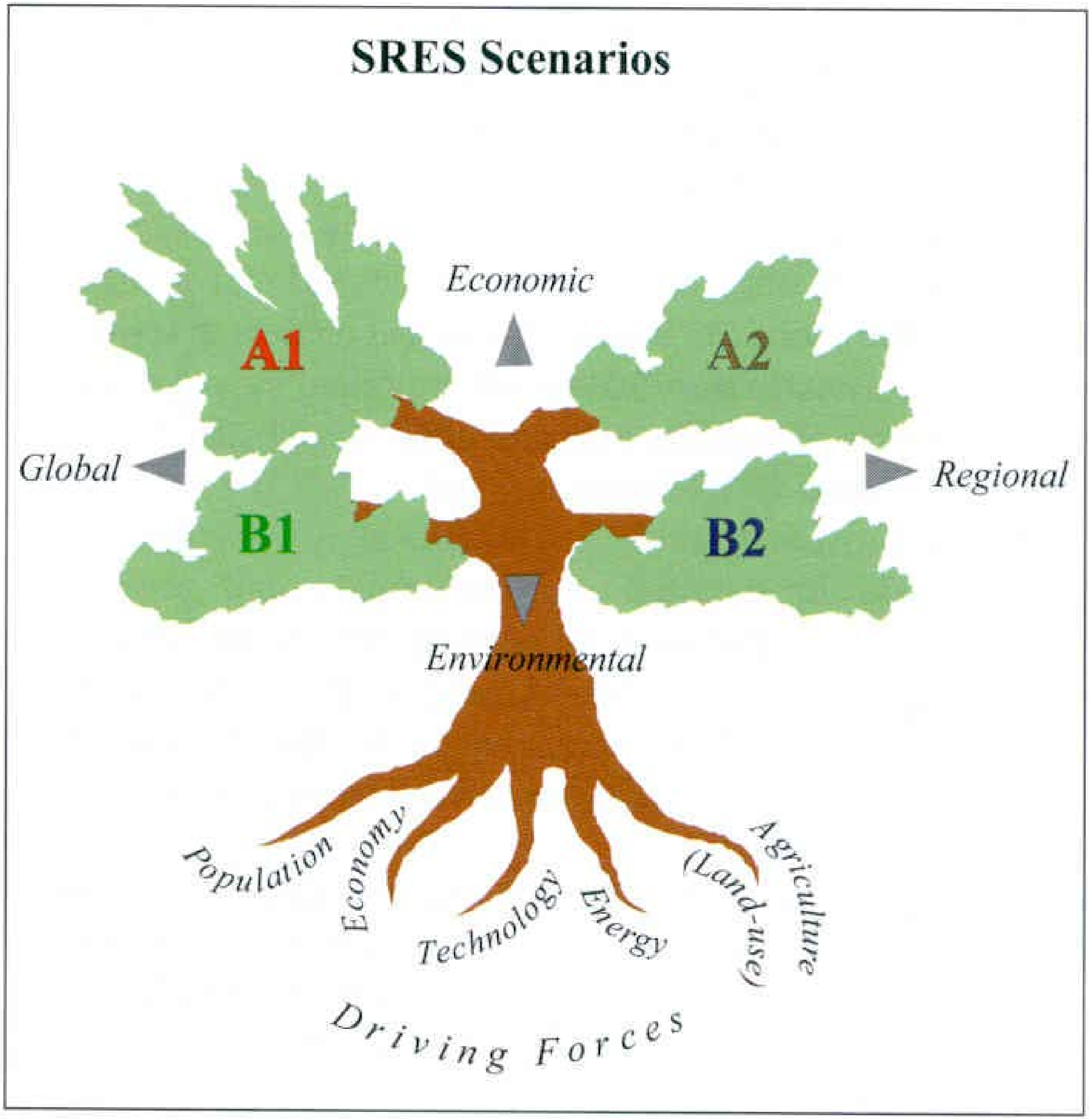
1 degree increase in the global average temperature


SRES Scenarios
Economic
A1
A2
Global
Regional
B1
B2
Environmental
Population
Economy
Technology
Energy
Agriculture (Land-use)
Driving Forces

SRES SCENARIOS FROM INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC) REPORT

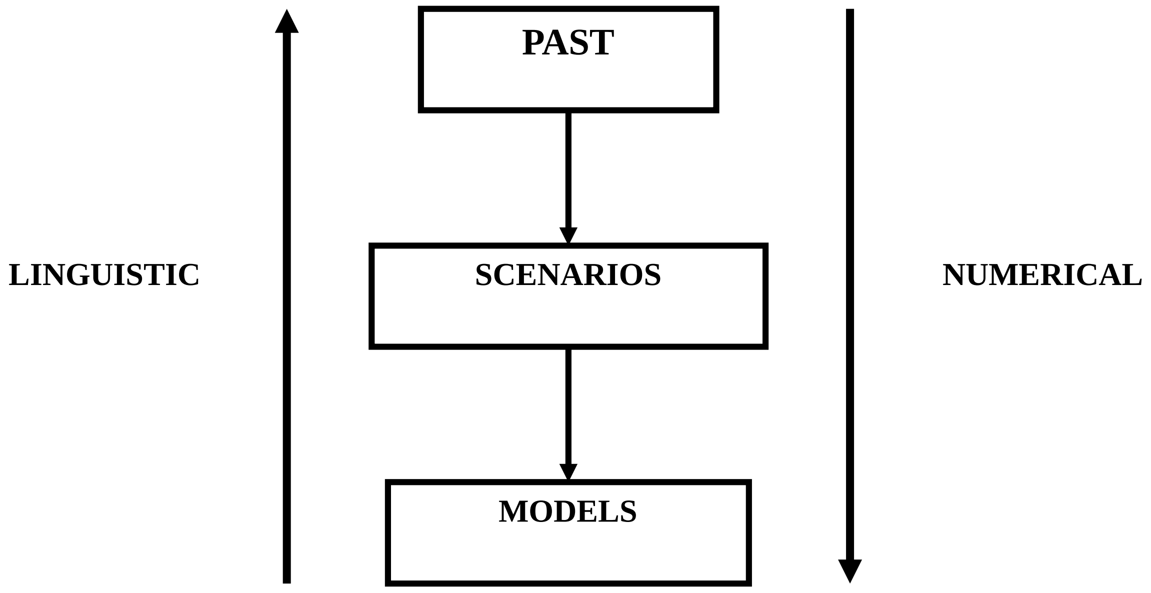
A1 storyline describes a world of very rapid economic growth, low population growth, and rapid introduction of new and more efficient technologies.

A2 storyline describes a heterogeneous world; population growth is high and economic growth and technological change are slower than in other storylines.

B1 storyline describes a world with low population growth, rapid change to an information and service economy, corresponding to cleaner technology and less reliance on natural resources.

B2 storyline describes a world reliant on local solutions to global problems; population growth is moderate, intermediate levels of economic development exist and there is more diverse technological change in the A1 or B1 storylines.

Note : CO_2 emissions in the A2 scenario are higher than CO_2 emissions in B2 scenario.



Past:Historical information, NATIONAL AND LOCAL
Scenario: Present end future times plans INTERNATIONAL, SRES
Model: Numerical prediction of future with scientific, economic, energy, social status, etc deductions INTERNATIONAL+NATIONAL

SCENARIO GENERATION

DYNAMIC MODEL

Global Model

Atmospheric Global Climate Models (GCM)

Coupled Atmospheric-Ocean Global Climate Models (AOGCM)

Smallest scale ~ 300 km

Regional models (smaller scale ~ 50 km)

- Dynamic: Equations of Physics,
- Chemistry, Ocean-land-atmosphere interaction
- Input current temp., press, rel. humidity, winds
- Output: Many atmospheric parameters (including temp, precipitation) stepped forward in time

UNCERTAINTIES OF DYNAMIC MODELS

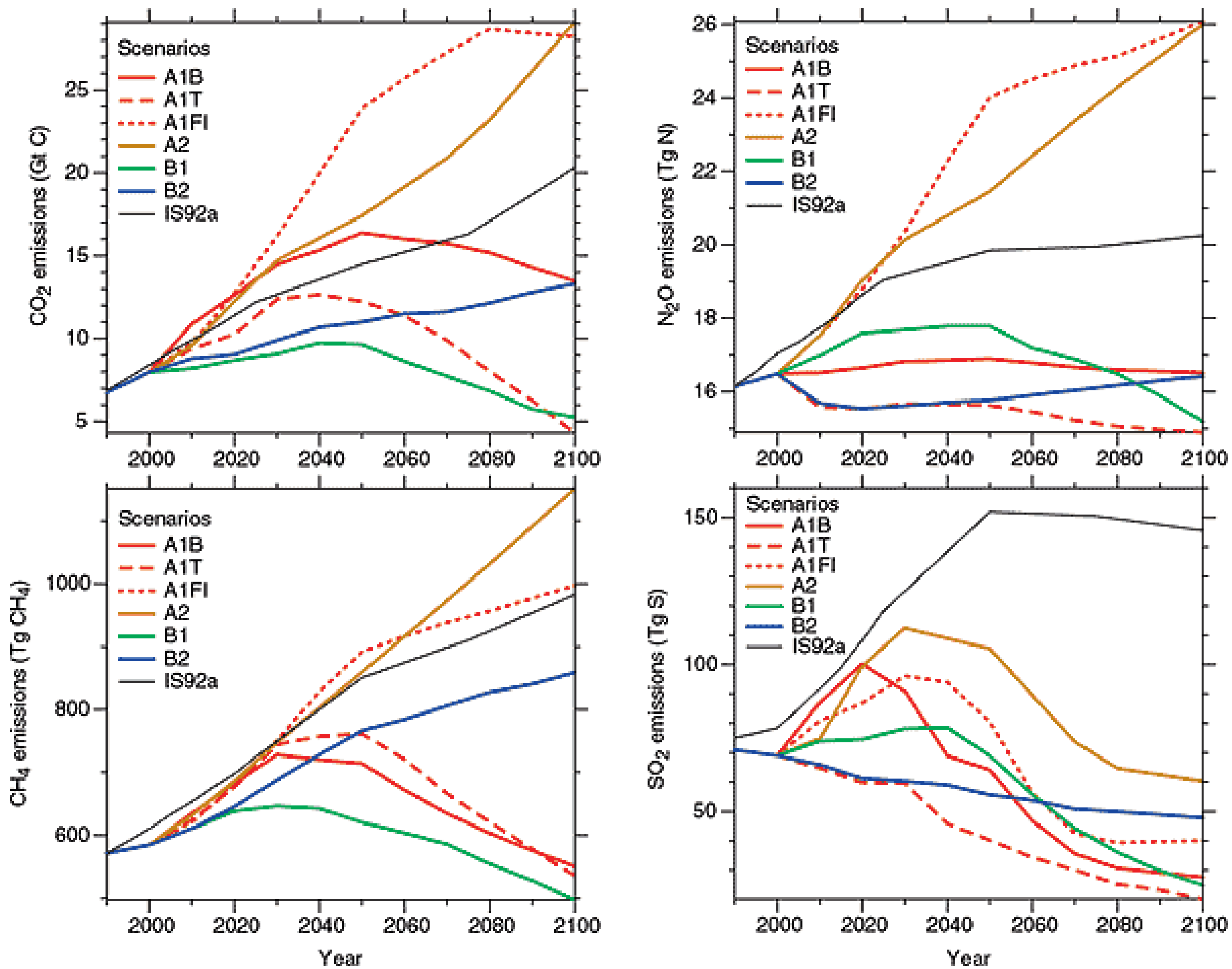
- Many variables to work with (Some derived empirically)

Cannot represent sub-grid scale accurately, e.g. clouds are much less than grid scale

Uncertainty in greenhouse gas emissions

CLIMATE CHANGE MODELS

In addition, CC models include possible changes in greenhouse gases: A1, A2, B1, B2 scenarios of CO_2 and other emissions



SCENARIO GENERATION

STATISTICAL MODEL

- Statistical Downscaling Models

Regression equation relating predictands (such as temp and rainfall) and predictors (such as wind, pressure, humidity),

Equations can apply to varying size scale kilometers, from Jeddah to Riyadh, or to a point, e.g. Riyadh Airport

Uses output from GCM (Smallest area ~ 300 km) and downscale to a smaller area such as Riyadh Airport (a point)

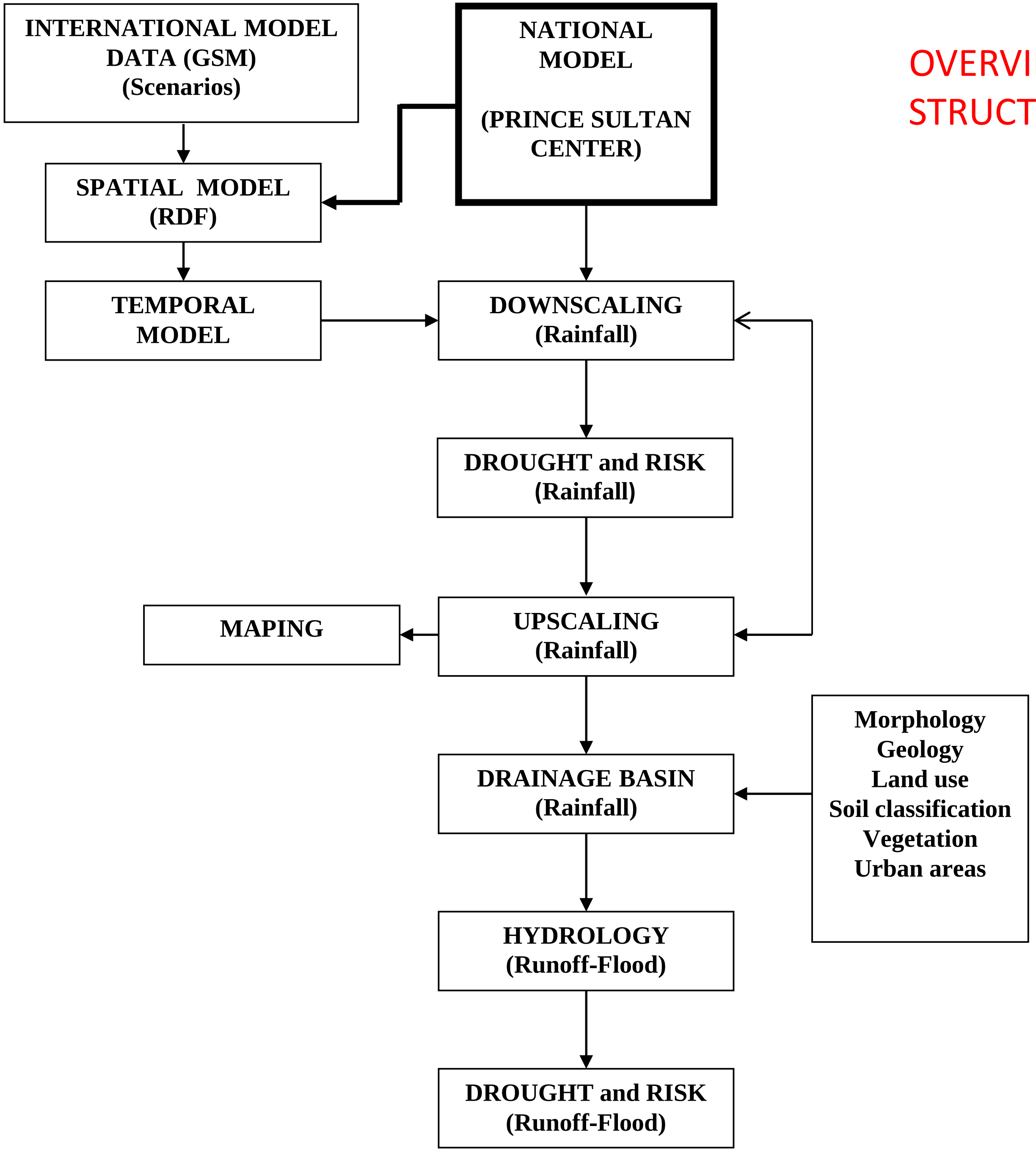
METHOD USED TO GENERATE CLIMATE SCENARIOS
FOR
THE ARABIAN PENINSULA

Statistical downscaling

WHITE MARKOV process for scenario-past observation matching between predictands (temp and rainfall) and predictors, (within 10 % error limits)

Assume that WHITE MARKOV process holds also in the future

OVERVIEW OF SDSM STRUCTURE VERSION



KEY STEPS IN THE SDSM.

Data Reliability Control and transformations

Downscale Predictors Selection

Model Calibration

Data Analysis

Graphing Monthly Statistics

Scenario Generation up to 2100

Advantages and Disadvantages of the Statistical Downscaling

Use of specific scenarios, depending on how the climate system is changing. (Site or locality specific).

Cheap, computationally undemanding

Requires high quality data for model calibration (30 years of historic data) based on empirical relationships which may change.

PROBLEMS WITH CLIMATE SCENARIOS

Problem 1. <u>Models are not accurate</u> ….
Climate model data cannot be used directly in environmental or social simulation model

Problem 2. **<u>Different climate models give different results …</u>**
It is difficult to decide which climate model (s) to use

PROBLEMS WITH CREATING CLIMATE SCENARIOS

Problem 3. **<u>It is expensive to run many (global/regional) climate model experiments for many future emissions</u>**
It is necessary to make choices about which emissions scenarios to use

Problem 4. **<u>Climate models give results at "undesirable" spatial scale</u>**
It is necassry to develop and apply one or more downscaling methods.

Problem 5. **<u>The magnitude of future emissions changes</u>**
It is not know how emissions of greenhouse gases will increase in the future.

LIMITATIONS

Uncertainty in GCM projections

Assumption are regression equations may not be correct

Precipitation values difficult to predict

Much greater confidence in temperature scenarios

Incomplete station data.

Derivative of a vector in a rotating system

For a whatever vector $\vec{A}$,

$$\frac{d_a\vec{A}}{dt} = \frac{d\vec{A}}{dt} + \vec{\Omega} \times \vec{A}$$

where $\vec{\Omega}$ is the angular vector of the rotating system. $d_a\vec{A}/dt$ iis the derivative of the vector $\vec{A}$ in the inertial system. and $d\vec{A}/dt$ is the derivative of the vector $\vec{A}$ in the relative system.

The general relationship can be thus expressed as:

$$\frac{d_a}{dt} = \frac{d}{dt} + \vec{\Omega}\times$$

Expression of the acceleration term in rotating coordinates

By applying the general relationship to the position vector $\vec{r}$ (defined as a vector from the Earth's centre to the considered point at the Earth's surface), we obtain the equation relating the absolute velocity and the relative velocity:

$$\frac{d_a\vec{r}}{dt} = \frac{d\vec{r}}{dt} + \vec{\Omega} \times \vec{r}$$

That is:

$$\vec{V}_a = \vec{V} + \vec{\Omega} \times \vec{r}$$

where $\vec{\Omega} \times \vec{r}$ is the associated velocity due to the rotation of the Earth.

The general derivative operator can be applied to the velocity vector itself $\vec{V}_a$:

$$\frac{d_a\vec{V}_a}{dt} = \frac{d\vec{V}_a}{dt} + \vec{\Omega} \times \vec{V}_a$$

Equations governing the atmosphere

- Equation of motion, momentum conservation
- Continuity equation, mass conservation
- Thermodynamic energy equation, energy conservation
- Equation of state for an ideal gas

Equation of motion

For a particle of air of unit mass with ρ as the density, different forces can be identified, either "real" or "apparent".

- The pressure gradient force $\vec{F} = -\frac{1}{\rho}\nabla p$.
- The viscous force $\vec{N} = \nu\nabla^2\vec{V}$ where ν is the viscosity coefficient.
- The gravitational force $\vec{g} = -\frac{GM}{r^3}\vec{r}$ where G is the gravitational constant.
- The centrifugal force $\Omega^2\vec{R}$
- The Coriolis force $-2\vec{\Omega}\times\vec{V}$
- The gravity force $\vec{g} = -\frac{GM}{r^3}\vec{r} + \Omega^2\vec{R} = -\nabla\Phi$. In practice, $|\vec{g}|$ changes only about 1% at maximum around the constant m/s^2.

Mass conservation equation

Mass divergence form:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{V}) = 0$$

Or velocity divergence form:

$$\frac{d\rho}{dt} + \rho \nabla \cdot \vec{V} = 0$$

Equation of state

The thermodynamic state of the atmosphere at any point is determined by the values of pressure, temperature, and density (or specific volume) at that point. These field variables are related to each other by the equation of state for ideal gas.

$$p = \rho R T$$

Energy conservation equation

If the heating rate of a particle of air is Q (J kg^{-1}s^{-1}), the internal energy has to change $C_v\frac{dT}{dt}$ and the particle works through compression or expansion by $p\frac{d}{dt}(\frac{1}{\rho})$. The enrgy conservation equation is thus:

$$C_v\frac{dT}{dt} + p\frac{d}{dt}(\frac{1}{\rho}) = Q$$

By using the equation of state, we can obtain:

$$p\frac{d}{dt}(1/\rho) = R\frac{dT}{dt} - \frac{1}{\rho}\frac{dp}{dt}$$

The energy conservation equation can thus be expressed in another form:

$$C_p\frac{dT}{dt} - \frac{1}{\rho}\frac{dp}{dt} = Q$$

where $C_p = C_v + R$ is the specific heat at constant pressure.

Potential temperature

For an ideal gas undergoing an adiabatic process (i.e., a reversible process in which no heat is exchanged with the surroundings, $Q = 0$) the energy conservation equation can be written in the form

$$C_p d \ln T - R d \ln p = 0$$

Integrating this expression from a state at pressure p and temperature T to a state in which the pressure is p_0 and the temperature is θ, we obtain after taking the antilogarithm

$$\theta = T \left(\frac{p_0}{p} \right)^{R/C_p}$$

This relationship is referred to as Poisson's equation, and the temperature θ thus defined is called the potential temperature.

The spherical coordinates

The three primative directions over the Earth are the longitude λ, latitude ϕ and the radial distance r from the center of the Earth. In practice, the third direction uses z, the distance from the sea level. Suppose that the radius of the Earth (a) is constant, one can obtain $r = a+z$ and $dr = dz$.

By using u, v and w to represent the three components of the velocity vector, we can have:

$$u = r\cos\phi\frac{d\lambda}{dt}$$

$$v = r\frac{d\phi}{dt}$$

$$w = \frac{dr}{dt}$$

Equation of motion in spherical coordinates

For purpose of theoretical analysis and numerical prediction, it is necessary to expand the vectorial equation of motion into its scalar components:

$$\frac{du}{dt} = \frac{uv\tan\phi}{r} - \frac{uw}{r} - \frac{1}{\rho r\cos\phi}\frac{\partial p}{\partial\lambda} + fv - \hat{f}w + N_\lambda$$

$$\frac{dv}{dt} = -\frac{u^2\tan\phi}{r} - \frac{vw}{r} - \frac{1}{\rho r}\frac{\partial p}{\partial\phi} - fu + N_\phi$$

$$\frac{dw}{dt} = \frac{u^2 + v^2}{r} - \frac{1}{\rho}\frac{\partial p}{\partial r} - g + \hat{f}u + N_z$$

The terms proportional to $1/r$ are called the curvature terms, owing to the curvature of the earth. $f = 2\Omega\sin\phi$ is the Coriolis parameter and $\hat{f} = 2\Omega\cos\phi$. Considering $r = a + z$ with $a \gg z$, one can replace r by a and dr by dz in the above equations.

Scale analysis of the equations of motion

For synoptic-scale circulations, one can have:

$\frac{du}{dt}$	$=$	$\frac{uv\tan\phi}{a}$	$-\frac{uw}{a}$	$-\frac{1}{\rho a\cos\phi}\frac{\partial p}{\partial\lambda}$	$+fv$	$-\hat{f}w$	$+N_\lambda$
10^{-4}		10^{-5}	10^{-8}	10^{-3}	10^{-3}	10^{-6}	10^{-5}

$\frac{dv}{dt}$	$=$	$-\frac{u^2\tan\phi}{a}$	$-\frac{vw}{a}$	$-\frac{1}{\rho a}\frac{\partial p}{\partial\phi}$	$-fu$	$+N_\phi$
10^{-4}		10^{-5}	10^{-8}	10^{-3}	10^{-3}	10^{-5}

$\frac{dw}{dt}$	$=$	$\frac{u^2v^2}{a}$	$-\frac{1}{\rho}\frac{\partial p}{\partial z}$	$-g$	$+\hat{f}u$	$+N_z$
10^{-7}		10^{-5}	10	10	10^{-3}	10^{-7}

Hydrostatic Approximation:

$$\frac{\partial p}{\partial z} = -\rho g$$

Geostropic Approximation: the pressure gradient force is approximatively in equilibrium with the Coriolis force:

$$f v_g = \frac{1}{\rho a \cos\phi} \frac{\partial p}{\partial \lambda}$$

$$f u_g = -\frac{1}{\rho a} \frac{\partial p}{\partial \phi}$$

Or in vector form:

$$\vec{v}_g = \frac{1}{\rho f} \vec{k} \times \nabla p$$

One can see that the geostrophic balance is a diagnostic expression that gives the approximative relationship between the pressure field and horizontal velocity in large-scale extratropical systems. The geostrophic approximation is verified when the wind acceleration is much smaller than the Coriolis force.

Thermal wind

This is an important notion to understand the general circulation of the atmosphere. The thermal wind ($\vec{V}_T$) is defined as the vertical variation of the geostrophic wind:

$$\vec{V}_T = \frac{\partial \vec{V}_g}{\partial z} = \frac{R}{f}\vec{k} \times \nabla T$$

A horizontal temperature gradient can thus induce a wind vector that is parallel to the iso-temperature lines.

Primitive Equation

The geostrophic equation is a diagnostic relation, since it does contain any terms of temporal derivative. One needs to take other terms with smaller values to obtain a **prognostic equation**:

$$\frac{du}{dt} = fv - \frac{1}{\rho a \cos\phi}\frac{\partial p}{\partial \lambda} + N_\lambda$$

$$\frac{dv}{dt} = -fu - \frac{1}{\rho a}\frac{\partial p}{\partial \phi} + N_\phi$$

For phenomena with a spatial extension comparable to the radius of the Earth, such as stationary planetary waves, the Hadley cell, one needs also to take into consideration the terms in relation with the curvature of the Earth.

$$\frac{du}{dt} = \frac{uv}{a}\tan\phi + fv - \frac{1}{\rho a \cos\phi}\frac{\partial p}{\partial \lambda} + N_\lambda$$

$$\frac{dv}{dt} = \frac{u^2}{a}\tan\phi - fu - \frac{1}{\rho a}\frac{\partial p}{\partial \phi} + N_\phi$$

FREQUENTLY ASKED QUESTIONS ABOUT CLIMATE CHANGE

Is it true that the world is becoming warmer ?

Is the warming anthropogenic or not ?

Is it similar to past climate changes ?

What is the precipitation and atmospheric moisture balance and change ?

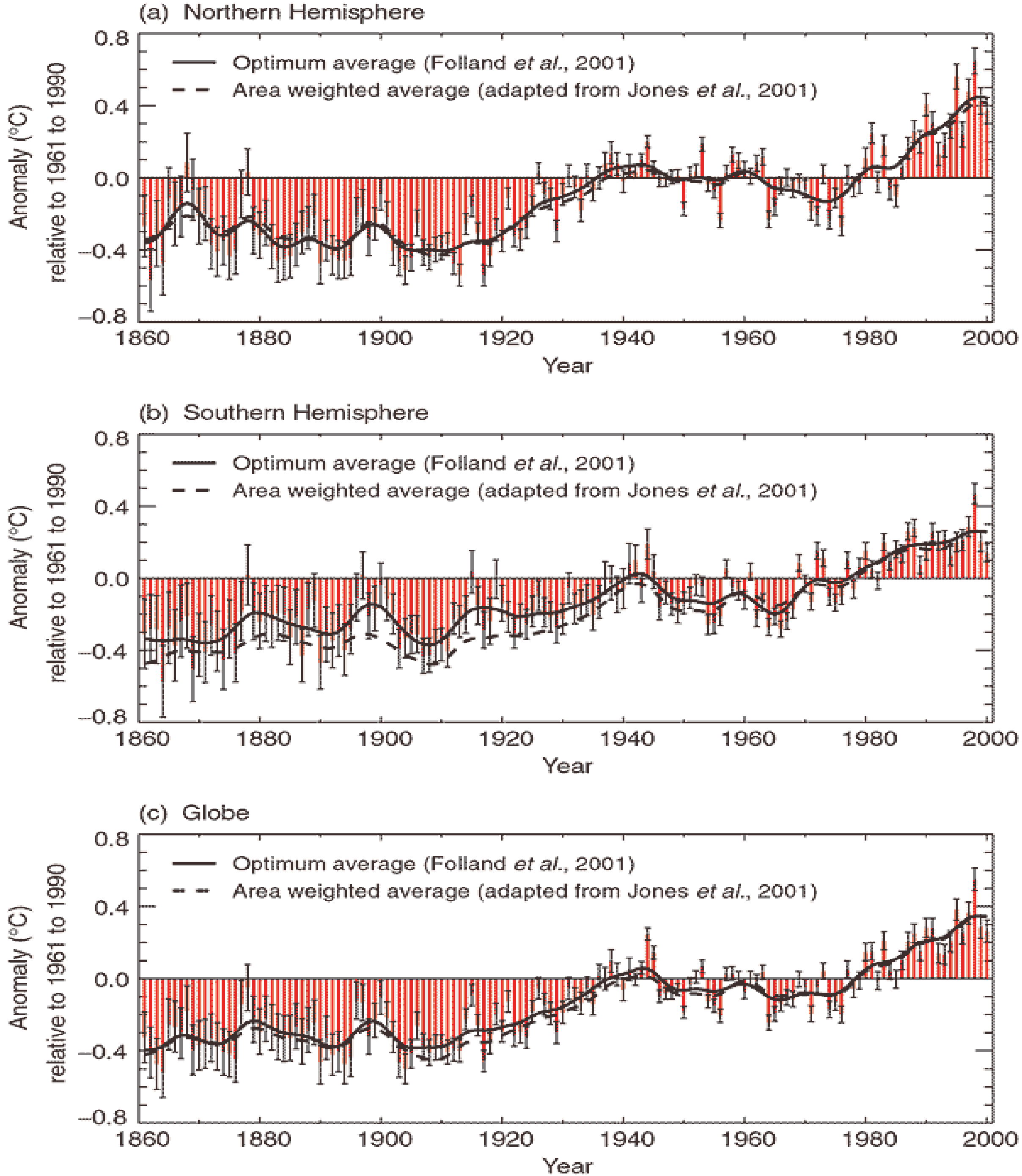
Has climate variability, or have climate extremes, changed ?

Are the observed trends continuous consistently ?

What are the effects on WATER RESOURCES ?

What are the SCIENTIFIC information

and knowledge predictions for future?


(a) Northern Hemisphere
Optimum average (Folland et al., 2001)
Area weighted average (adapted from Jones et al., 2001)
Anomaly (°C) relative to 1961 to 1990
0.8
0.4
0.0
−0.4
−0.8
1860
1880
1900
1920
1940
1960
1980
2000
Year
(b) Southern Hemisphere
Optimum average (Folland et al., 2001)
Area weighted average (adapted from Jones et al., 2001)
Anomaly (°C) relative to 1961 to 1990
Year
(c) Globe
Optimum average (Folland et al., 2001)
Area weighted average (adapted from Jones et al., 2001)
Anomaly (°C) relative to 1961 to 1990
Year

BASIC EVENTS

1) ARIDITY: It is a permanent natural condition and a stable climatic feature of a region,

2) DROUGHT: It refers to a temporary feature of the climate or to regular but unpredictable climatic changes,

3) WATER SHORTAGE: It is understood mostly as a man-made phenomenon reflecting the concern with temporary and small area water deficiencies, and

4) DESERTIFICATION: It is a part of an alteration process in the ecological regime often associated with aridity and/or drought but principally brought about by human-made activities which change the surrounding environment to a significant degree.

CLIMATE CHANGE and HYDROLOGICAL CYCLE

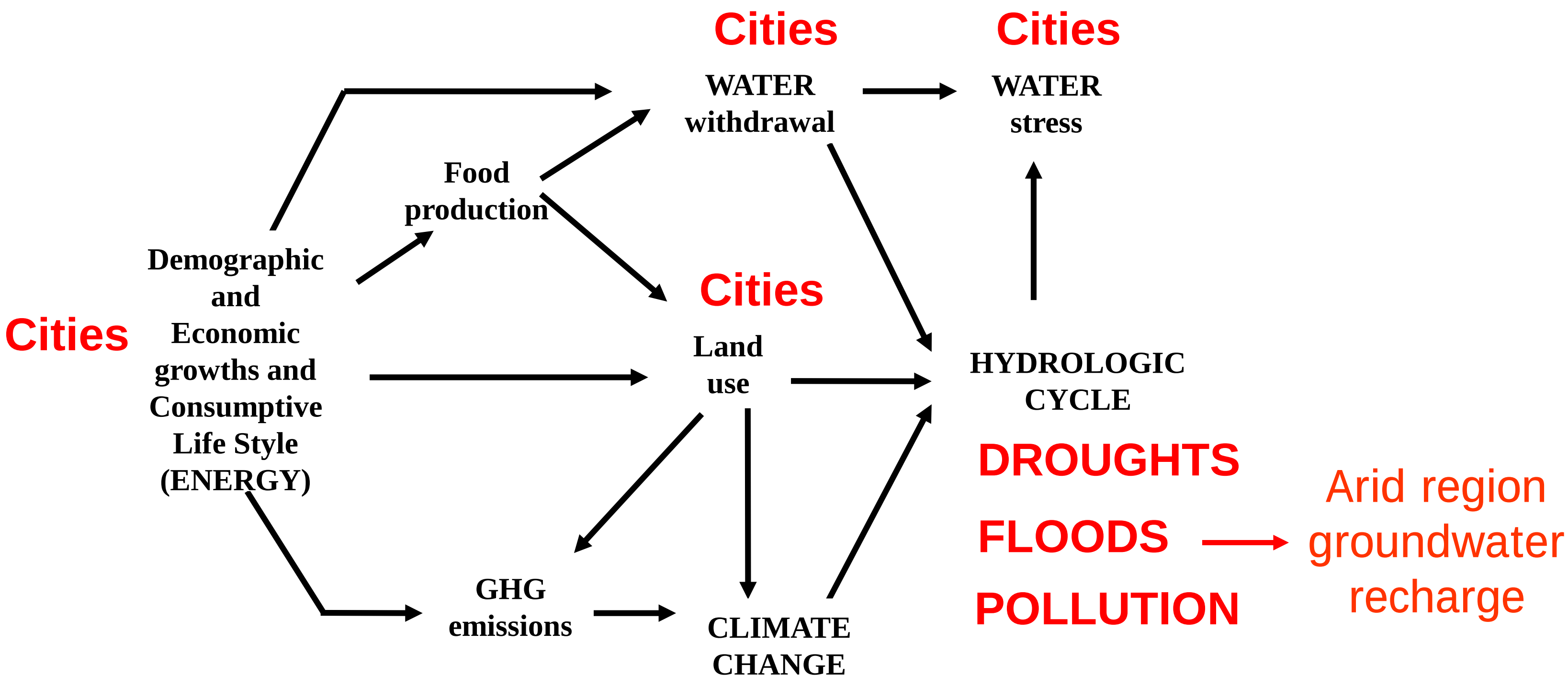


Diagram illustrating major pathways of changes. Demographic and economic growth, and increasingly consumptive life style, drive the changes in hydrological cycles and freshwater resources through changes in land use, water withdrawals, and climate related to food production and the emission of the greenhouse gases (GHGs). (Modified from Oki, 2005 by Şen, 2008).

SRES SCENARIOS FROM INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC) REPORT

A1 STORYLINE: The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of few and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1F1), non-fossil energy sources (A1T), or a balance across all sources (A1B).

A2 STORYLINE: The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than in other storylines. (3-4 0C).

B1 STORYLINE: The B1 storyline and scenario family describes a convergent world with the same global population that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solution to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives. (2 0C)

B2 STORYLINE: The B2 storyline and scenario family describes a world in which the emphasis is on local solution to economic, social and environmental sustainability. It is a world with continuously increasing global population at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented toward environmental protection and social equity; it focuses on local and regional levels.

Note : CO_2 emissions in the A2 scenario are higher than CO_2 emissions in B2 scenario.

GLOBAL AND REGIONAL MODEL

DYNAMIC MODEL

GLOBAL MODEL (Smallest scale ~ 300 km)

Atmospheric Global Climate (Circulation) Models (GCM)

Coupled Atmospheric-Ocean Global Climate Models (AOGCM)

REGIONAL MODELS (smaller scale ~ 50 km)

- Dynamic: Equations of Physics,
- Chemistry, Ocean-land-atmosphere interaction
- Input current temp., press, rel. humidity, winds
- Output: Many atmospheric parameters (including temp, precipitation) stepped forward in time

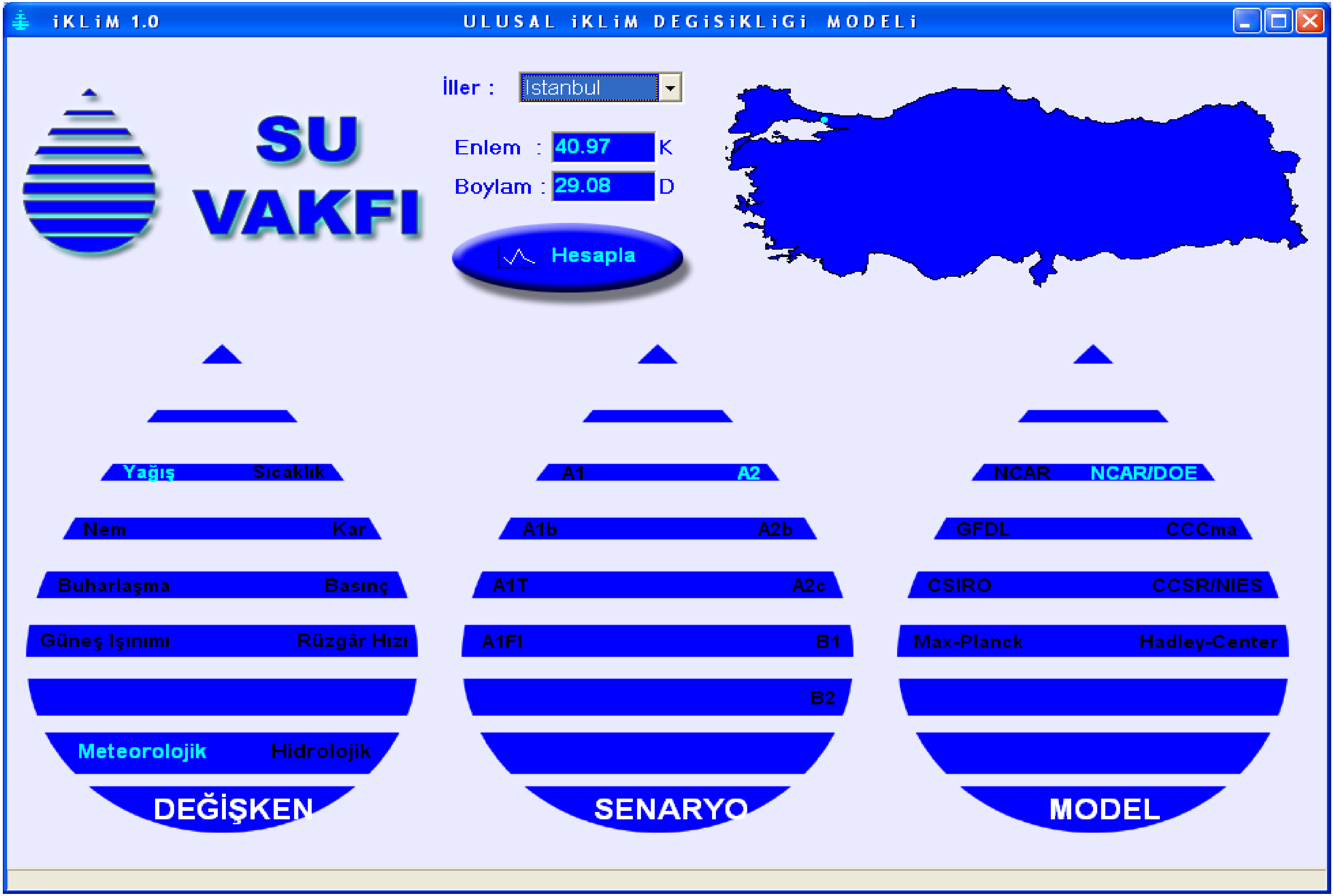
UNCERTAINTIES OF DYNAMIC MODELS

- Many variables to work with (Some derived empirically)

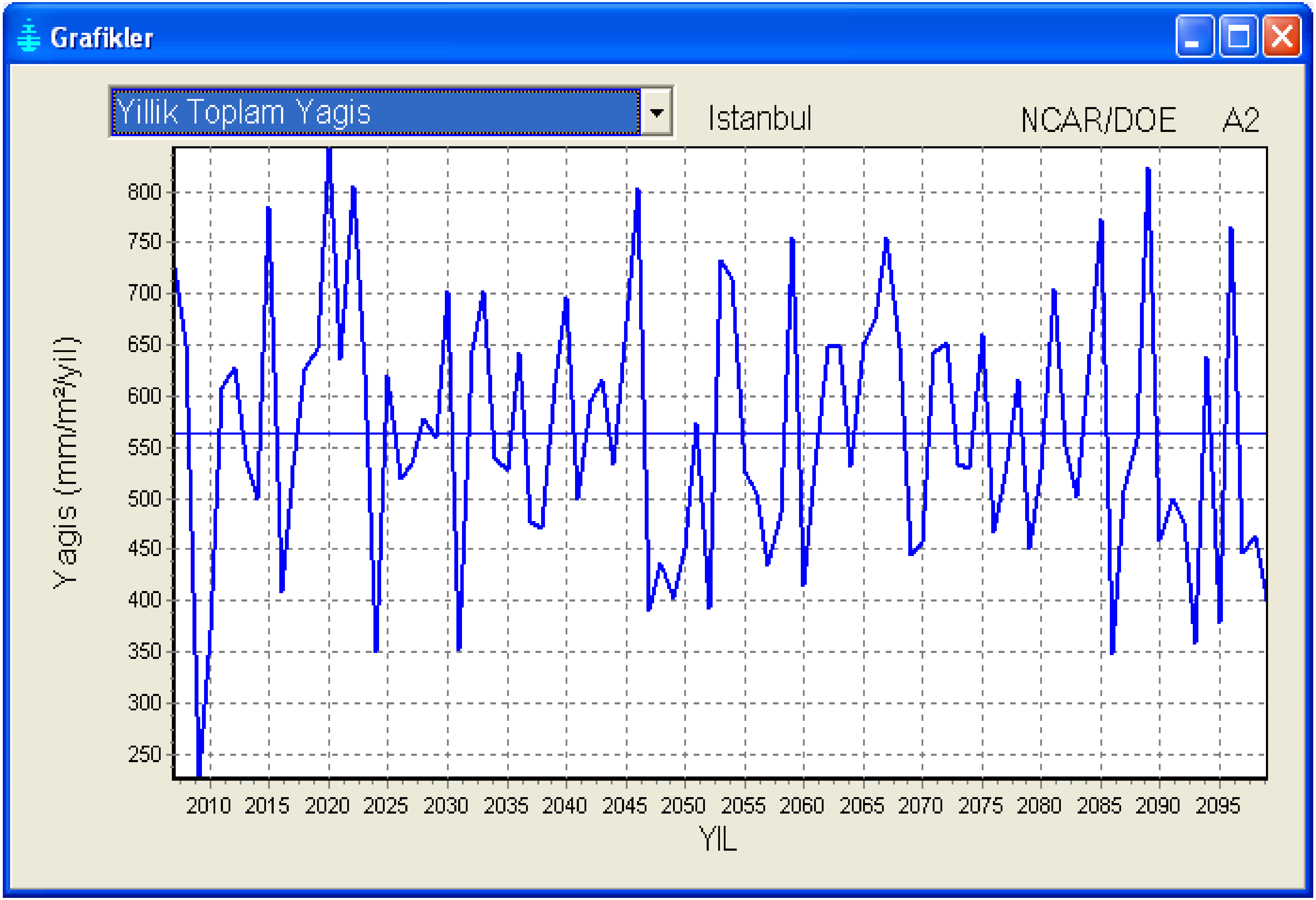
Cannot represent sub-grid scale accurately, e.g. clouds are much less than grid scale

Uncertainty in greenhouse gas emissions

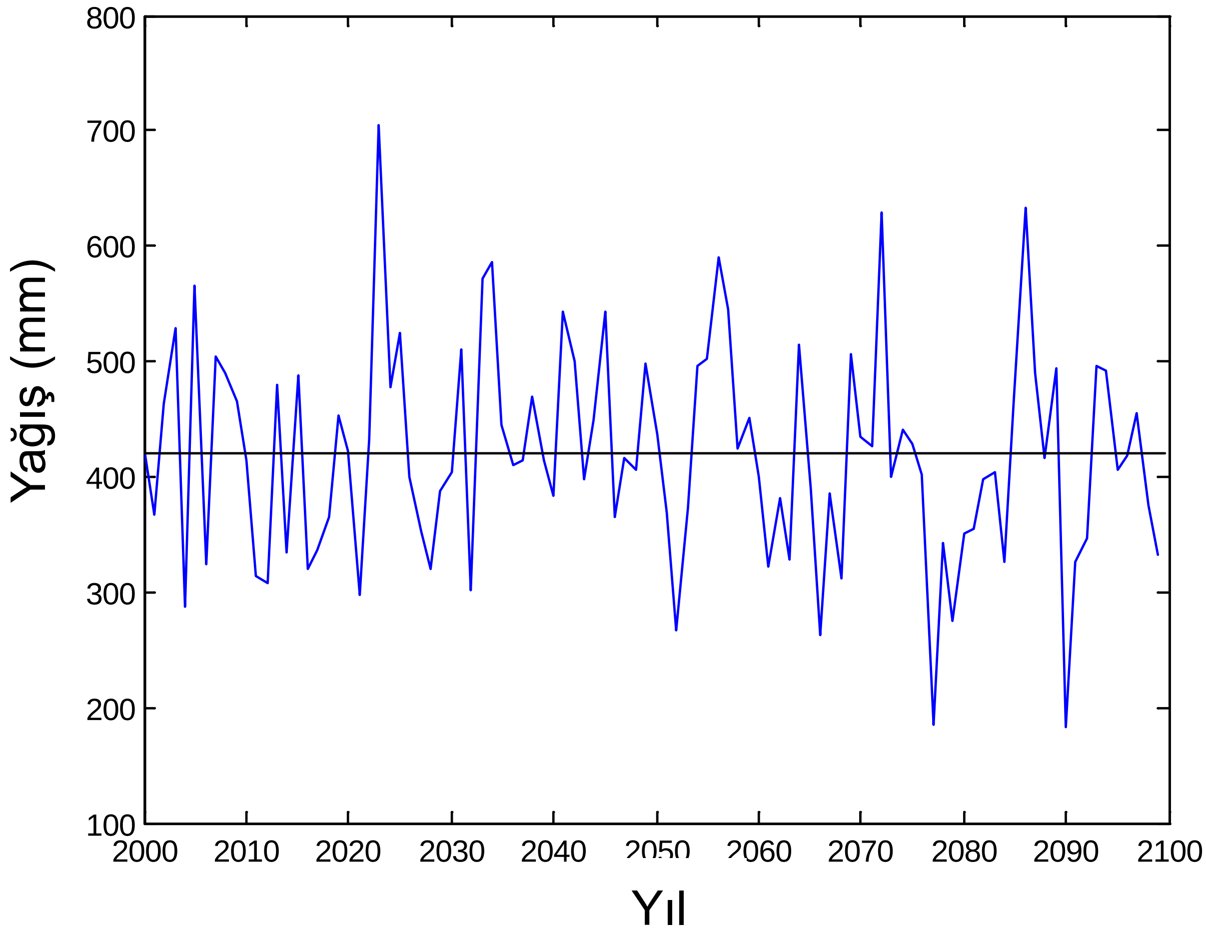
NATIONAL CLIMATE CHANGE MODEL (ISTANBUL METROPOLITAN)

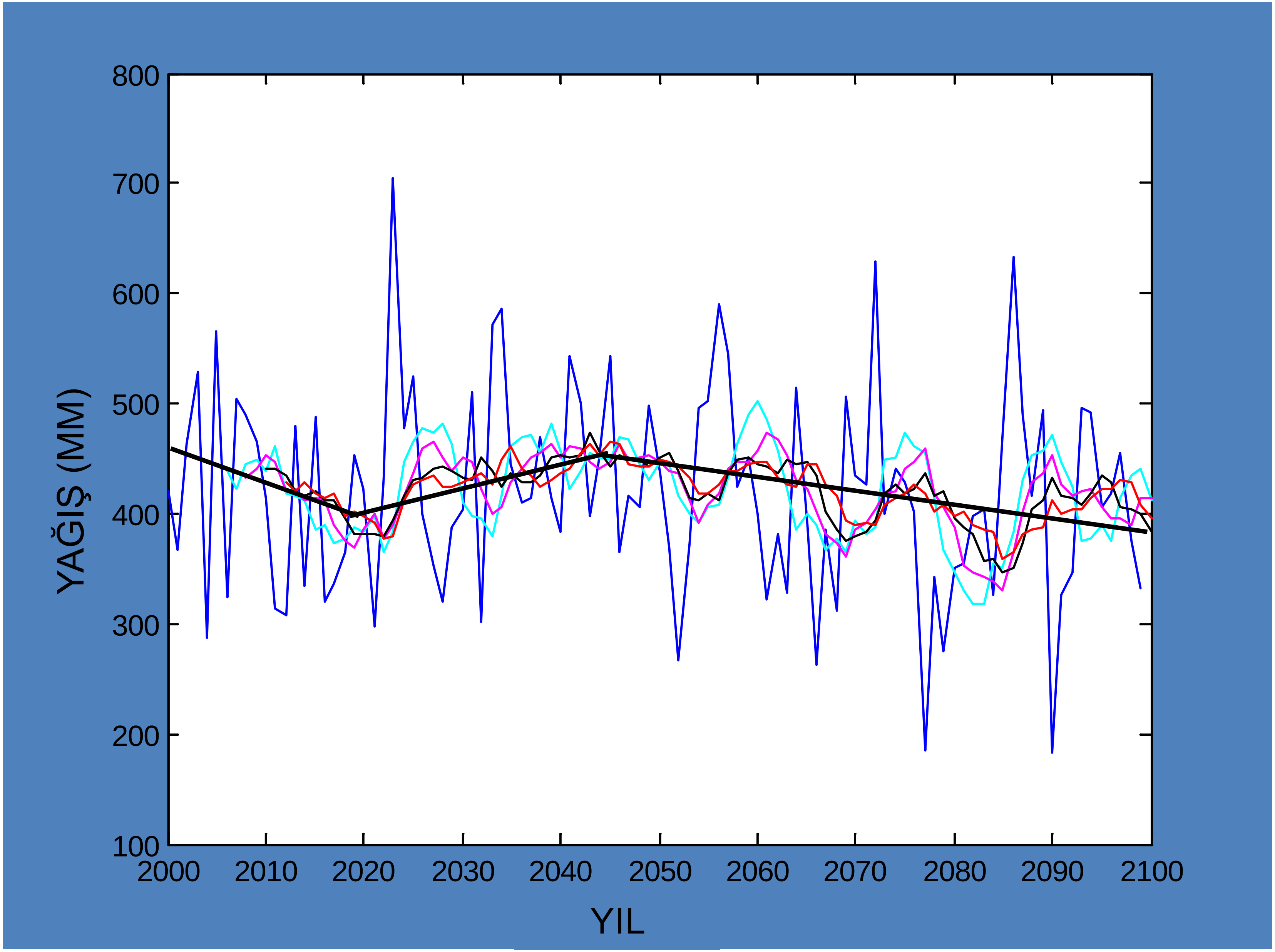


TOPLAM YAĞIŞ MİKTARLARI(2000-2100)



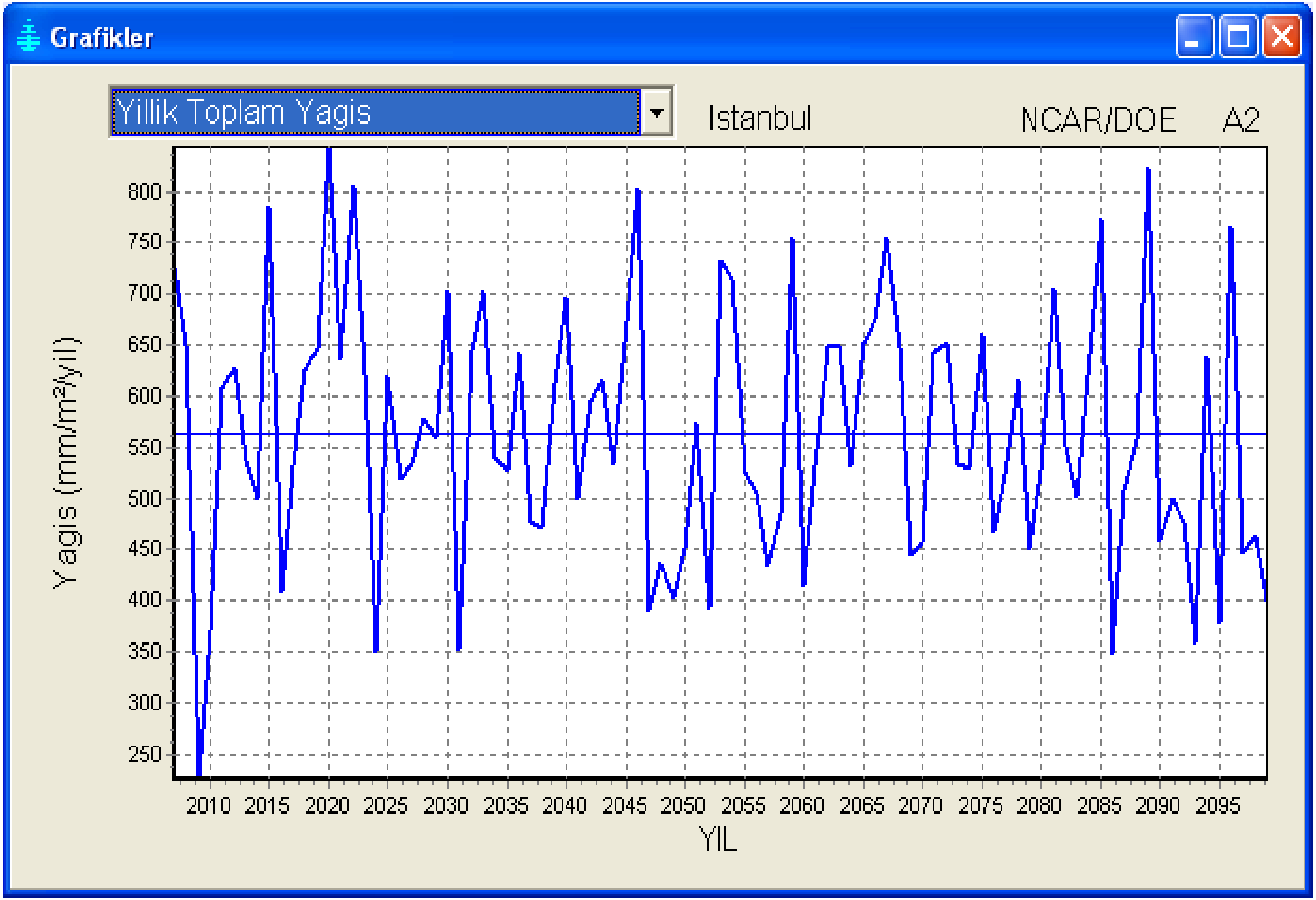
Bu asırda Istanbul yağışları (mm)



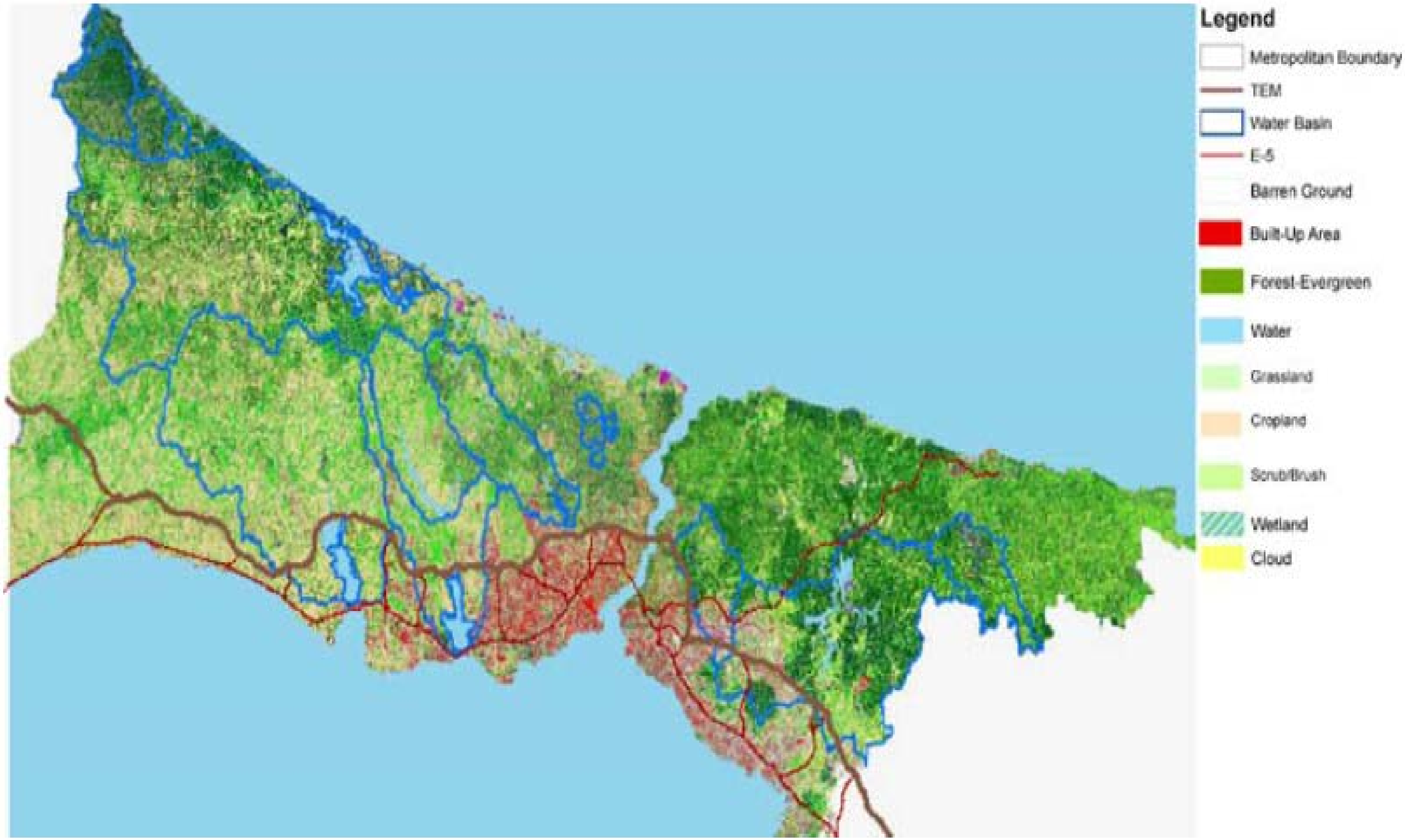


800
700
600
500
400
300
200
100
YAĞIŞ (MM)
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
YIL

TOTAL RAINFALL AMOUNT (2000-2100)



LAND USE CLASSIFICATION BY IKONOS 2005



CURRENT WATER SUPPLY BASINS IN And around ıstanbul

Code no.	Source name	Date of completion	Major rivers and lakes	Annual average capacity (m^3)	Ratio in total (%)
1	Elmalıdere Regülatörü	1997	Elmalıdere	11,600,000	1.1
2	Büyükdere Barajı	1995	Büyükdere	28,400,000	2.7
3	Kuzuludere Barajı	1995	Kuzuludere	11,300,000	1.1
4	Düzdere Barajı	1995	Düzdere	4,500,000	0.4
5	Terkos Barajı	1883	Terkos Gölü	162,000,000	15.6
6	Büyükçekmece Barajı	1989	B.Çekmece Gölü	120,000,000	11.6
7	Sazlıdere Barajı	1998	Sazlıdere	85,000,000	8.2
8	Alibeyköy Barajı	1972	Alibey Deresi	36,000,000	3.5
9	Küçükçekmece	–	–	–	–
10	Elmalı I ve II Barajları	1893–1950	Göksu	15,000,000	1.4
11	Ömerli Barajı	1972	Çayağzı Çayı	235,000,000	22.7
12	Darlık Barajı	1989	Darlık Deresi	97,000,000	9.4
–	Bentler ve Yeraltısuları	1453–1893	–	10,000,000	1.0
–	Yeşilvadi Çevirme Yapısı	1992	Yeşil Dere	10,000,000	1.0
–	Sultanbahçedere Barajı	1997	Sultanbahçe Dere	19,400,000	1.9
–	Kazandere Barajı	1997	Kazandere	100,000,000	9.7
–	Pabuçdere Barajı	2000	Nazlıdere	60,000,000	5.8
–	Şile Keson Kuyuları	1996		30,000,000	2.9
Total				1,035,200,000	100.0

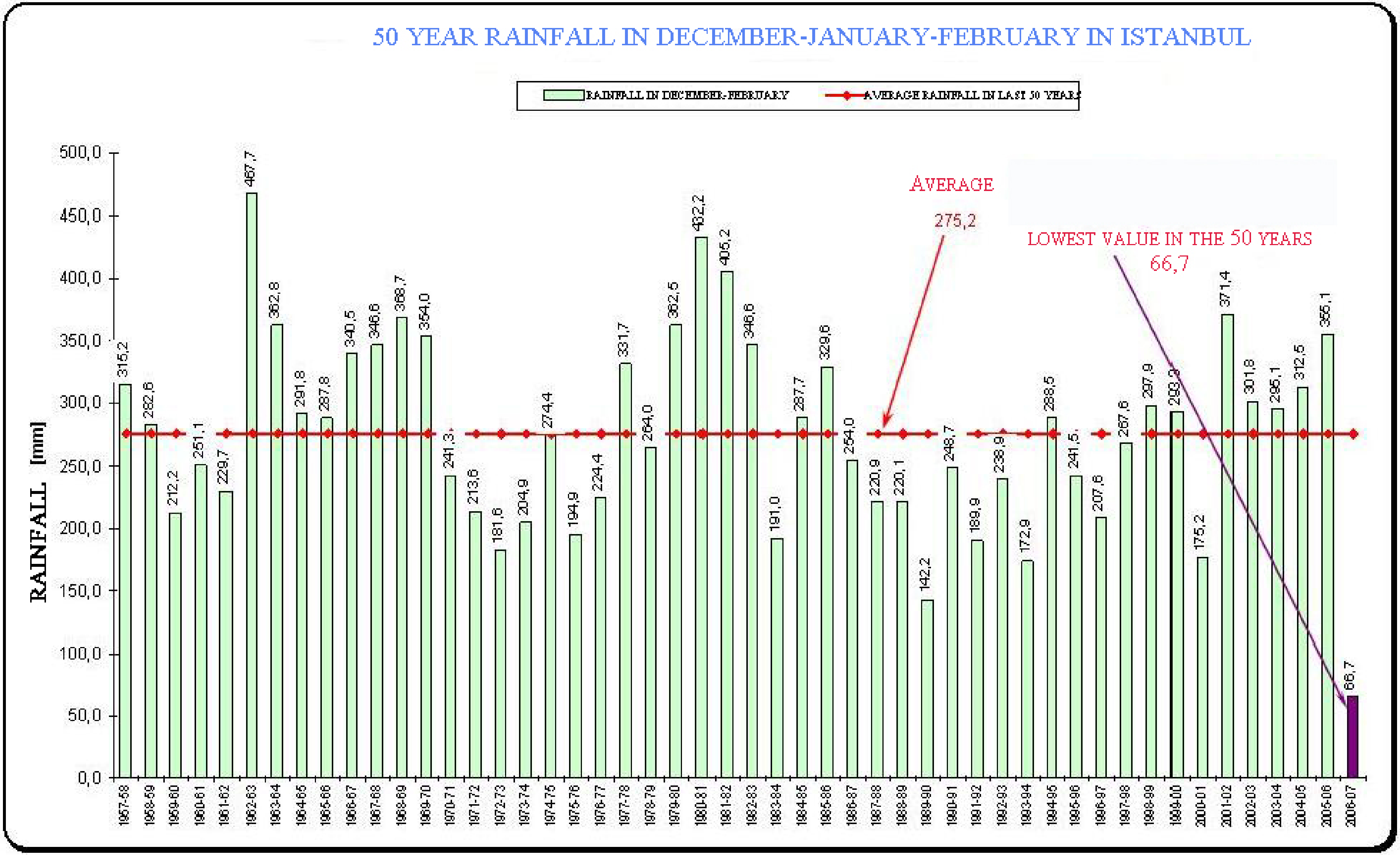
Years	Provincial population[a]	Annual rate of increase[b] (%)	Urban population[a]	Annual rate of increase[b,c] (%)
1950	1,166,477		1,002,085	
1955	1,533,822	5.6	1,297,372	5.3
1960	1,882,092	4.2	1,506,040	3.0
1965	2,293,823	4.0	1,792,071	3.5
1970	3,019,032	5.6	2,203,337	4.2
1975	3,904,588	5.3	2,648,006	3.7
1980	4,741,890	4.0	2,909,455	1.9
1985	5,842,985	4.3	5,560,908	13.8
1990	7,309,190	4.6	6,753,929	4.0
2000	10,018,735	3.2	9,085,599	3.0
Average		4.4		4.5

[a] Census 2000 by DIE (2000)

[b] The model for the rate calculation: $Y = Y_0(1 + r)^t$

[c] Between 1980 and 1985 some of the local administrative units and villages are incorporated into the urban counties.

WATER RESOURCES OF İSTANBUL


50 YEAR RAINFALL IN DECEMBER-JANUARY-FEBRUARY IN ISTANBUL
RAINFALL IN DECEMBER-FEBRUARY
AVERAGE RAINFALL IN LAST 50 YEARS
AVERAGE
275,2
LOWEST VALUE IN THE 50 YEARS
66,7
RAINFALL [mm]
500,0
450,0
400,0
350,0
300,0
250,0
200,0
150,0
100,0
50,0
0,0
315,2
282,6
212,2
251,1
229,7
467,7
362,8
291,8
287,8
340,5
346,6
368,7
354,0
241,3
213,6
181,6
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