Training package
Providing Regional Climates for Impacts Studies - PRECIS

Modelling the Climate System and Climate Change

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CGE Hands-on training Workshop on V & A, Asuncion, Paraguay, 14th – 18th August 2006

The Climate System

- Goal of this session:
  - Brief introduction to the climate system, its drivers, ways to model the system, its variability, ways to predict future changes and the impacts of these changes on the natural and human systems.

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Session contents

- Introduction
- The Greenhouse Effect
- Climate Variability
- Climate of the 20th Century
- Climate Models
- Predicting Climate Change
- Impacts of Climate

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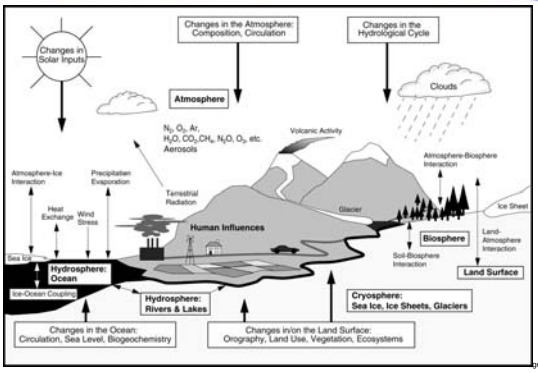
The Climate System

Introduction

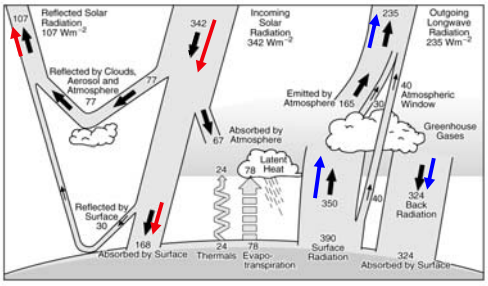
What is the Climate System?

- The complicated system consisting of various components, including the dynamics and composition of the atmosphere, the ocean, the ice and snow cover, the land surface and its features, the many mutual interactions between them, and the large variety of physical, chemical and biological processes taking place in and among these components.
- Climate refers to the state of the climate system as a whole, including a statistical description of its variations.

Components of the climate system



What drives the Climate?



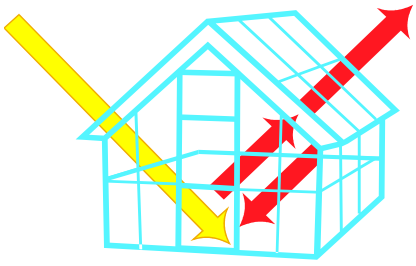
Earth's annual and global mean energy balance

The Greenhouse Effect

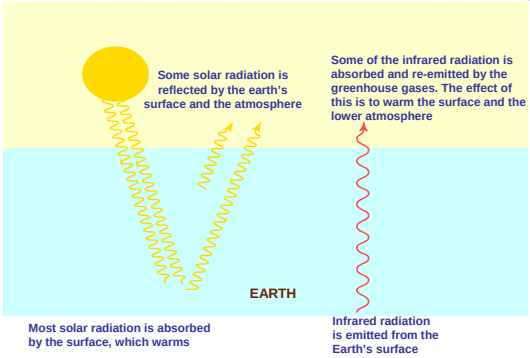
The Greenhouse Effect

Visible energy from the sun passes through the glass and heats the ground

Infra-red heat energy from the ground is partly reflected by the glass, and some is trapped inside the greenhouse



The Greenhouse Effect



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Climate Variability

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The concept of radiative forcing

- Changes in certain components of the climate system perturb the radiative energy budget of system, i.e. provide a radiative forcing. Examples include:
  - the concentration of radiatively active species
  - solar irradiance
  - changes affecting radiation absorbed by the surface
- Human induced perturbations include
  - composition of the atmospheric gases
  - increases in atmospheric aerosols
  - land-use change (agriculture, deforestation, reforestation, afforestation, urbanisation, traffic, …)

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Natural variability of climate

- ***External forcings:***
  - **solar radiation**
  - **volcanic eruptions - aerosols source into the atmosphere**
- ***Internal climate variability:***
  - **ENSO**
  - **NAO and other leading modes of variability**

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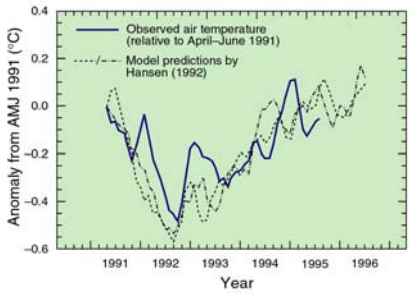
The effect of the Mt. Pinatubo eruption (June 1991) on global temperature



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Human-induced climate variations

- **Perturbations of the atmospheric composition - the enhanced greenhouse effect**
- **Effect of aerosols:**
  - **direct effect (scattering of incoming solar radiation)**
  - **indirect effect (affecting the radiative properties of clouds)**
- **Land-use change (agriculture, deforestation, reforestation, afforestation, urbanisation, traffic, …)**

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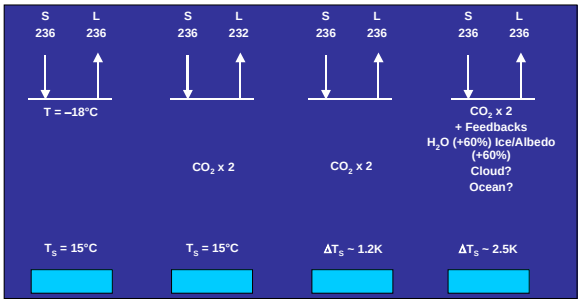
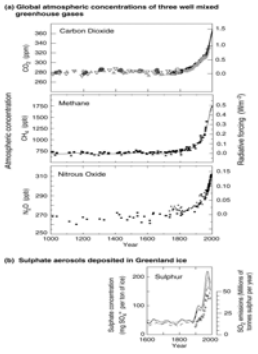
The Enhanced Greenhouse Effect

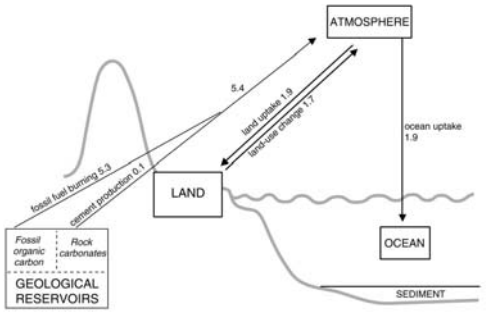
Solar (S) and longwave (L) radiation in Wm-2 at the top of the atmosphere



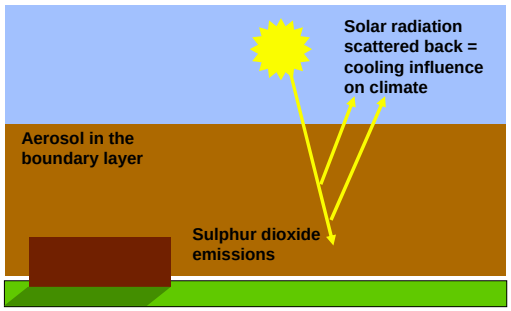


Indicators of the human influence on the atmosphere during the industrial era

Human Perturbation of the Carbon Cycle



The effect of aerosol on climate



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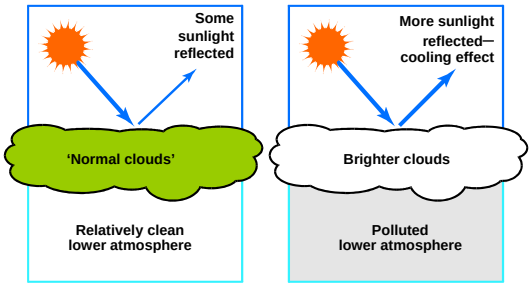
The indirect effect of aerosol



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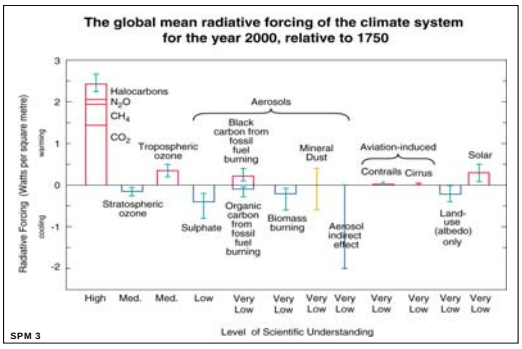

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How do we quantify the response of the climate?

- **The response of the climate system to this forcing agents is complicated by:**
  - **feedbacks**
  - **the non-linearity of many processes**
  - **different response times of the different components to a given perturbation**
- **The only means available to calculate the response is by using numerical models of the climate system.**

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The Climate of the 20th Century

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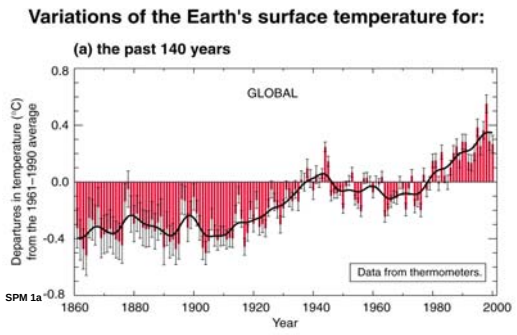
Variations of the Earth's surface temperature for the past 140 years



SPM 1a

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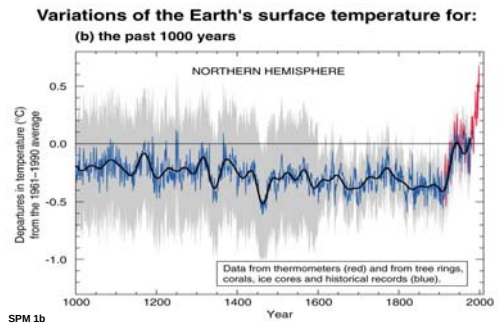
Variations of the Earth's surface temperature for the past 1,000 years



SPM 1b

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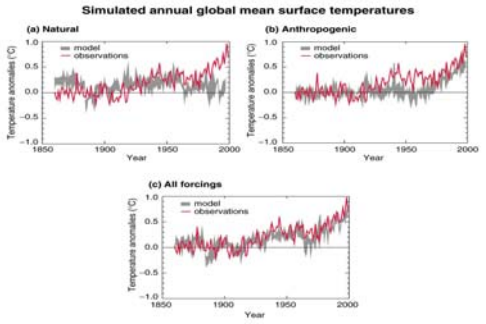
Simulated annual global mean surface temperatures



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Climate Models

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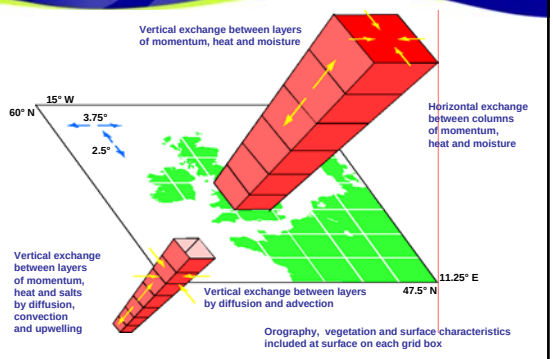
Modelling Global Climate



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Modelling climate

- Representation at finite resolution and timestep
  - grid point and spectral methods
- Solve (integrate) governing differential equations
- *Prognostic* variables
  - take information from timestep to timestep
- Other quantities diagnosed – *diagnostic* variables
- Sub-model coupling or prescribed boundary conditions

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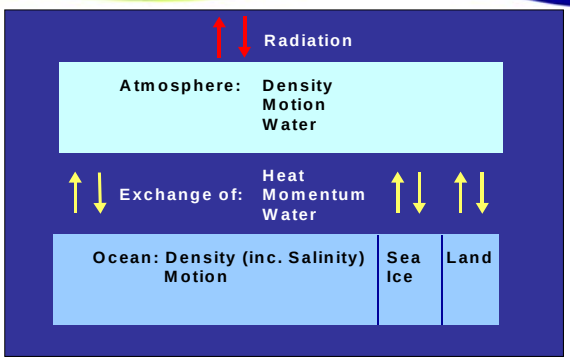
Coupled atmosphere / ocean climate model



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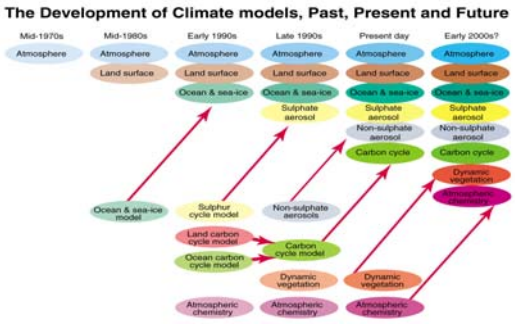
Development of climate models



Hadley Centre Global Climate Model
FORTRAN program code

```
CALL SUBROUTINE LSP_FOCWWIL
! Purpose: Calculate from temperature the Fraction Of Cloud Water Which
! Is Liquid. Operates within range 0 to -9 deg.C based upon
! MRF observational analysis.

*CALL C_0_DG_C
      REAL
     & TSTART                 ! Temperature at which ROCWWIL reaches 1.
     &,TRANGE                 ! Temperature range over which 0 < ROCWWIL < 1.
      PARAMETER(TSTART=TM, TRANGE=9.0)
      DO  I = 1, POINTS
            TFOC = T(I)
! Calculate fraction cloud water which is liquid (FL)as in eq. P26.50.
            IF (TFOC .LE. (TSTART - TRANGE)) THEN
! Low temperatures, cloud water all frozen----------------------
                  ROCWWIL(I) = 0.0
            ELSE IF (TFOC .LT. TSTART) THEN
! Intermediate temperatures-------------------------------------
                  ROCWWIL(I) = (TFOC - TSTART + TRANGE) / TRANGE
            ELSE
! High temperatures, cloud water all liquid---------------------
                  ROCWWIL(I) = 1.0
            END IF
      END DO                   ! Loop over points
      RETURN
      END
*ENDIF
```


Climate processes and Feedbacks

- **Water vapour**
- **Clouds**
- **Ocean processes**
- **Cryosphere**
- **Land surface**
- **Carbon cycle**

Parametrizations

- **In climate models, this term refers to the technique of representing processes, that cannot be explicitly resolved at the spatial or temporal resolution of the model (sub-grid scale processes), by relationships between the area or time averaged effect of sub-grid scale processes and the large scale flow.**

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Predicting Climate Change

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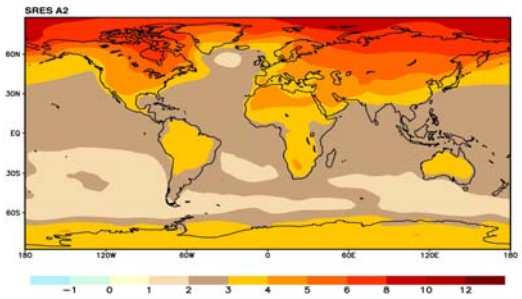
Land areas are projected to warm more than the oceans with the greatest warming at high latitudes



Annual mean temperature change, 2071 to 2100 relative to 1990:
Global Average in 2085 = 3.1ºC

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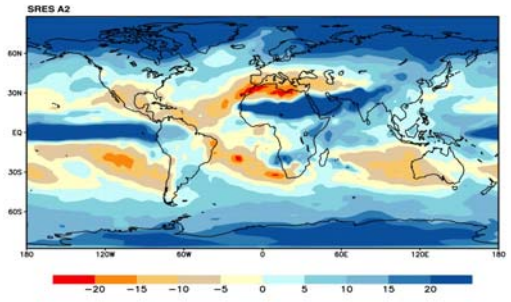
Some areas are projected to become wetter, others drier with an overall increase projected



Annual mean precipitation change: 2071 to 2100 Relative to 1990

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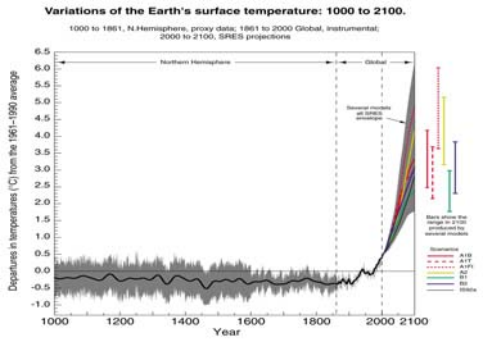

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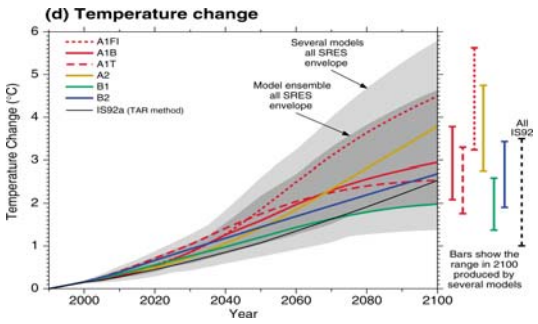

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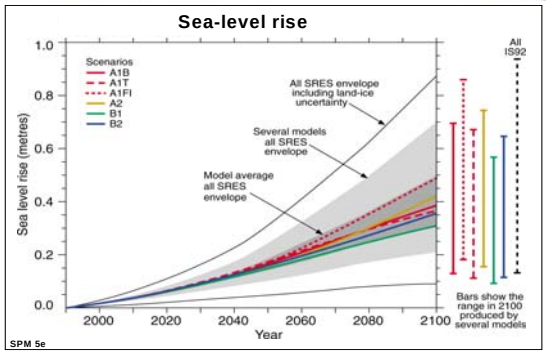

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Impacts of Climate Change

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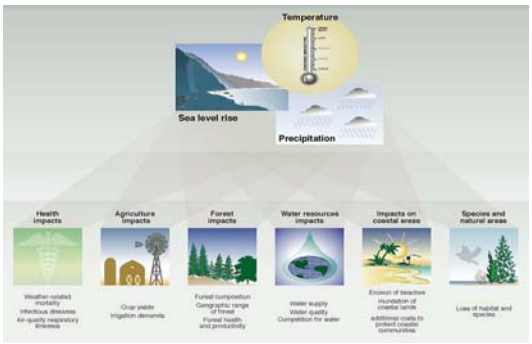
More adverse than beneficial impacts on ecological and socioeconomic systems are projected



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Human Health Impacts

- Expansion of the areas of potential transmission of malaria and dengue fever (medium-to-high confidence); roughly 300 million more people at risk of malaria
- Increased heat-related deaths and illness, affecting particularly the elderly, sick, and those without access to air conditioning
- Increased risks to human life, risk of infectious disease epidemics and many other health risks where floods, droughts or storms increase in frequency and/or intensity
- Decreased winter deaths in some temperate regions

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Ecosystem Impacts

- Coral death from exposure to 3-4 ºC higher seasonal maximum sea-surface temperatures for 6 months or more
- Substantial reduction in glacier and ice-cap volume; tropical glaciers particularly vulnerable to elimination
- Loss of unique vegetation systems and their endemic species (e.g. vegetation of Cape region of South Africa and some cloud forests)
- Extensive reduction in Arctic summer sea-ice extent with benefits for shipping but adverse effects on sea-ice dependent animals (e.g. polar bears, seals, walrus)
- Coastal wetland loss from sea level rise (up to 10% globally for 20 cm rise, higher percentages in some areas)
- Increased disturbances of ecosystems by fire and insect pests
- Increase net primary productivity of many mid- and high-latitude forests
- Extinction of some critically-endangered and endangered species

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Agriculture Impacts

- General decrease in cereal crop yields in mid-latitudes
- Decreased crop yields in areas of increased drought
- Food prices increase relative to projections that exclude climate change
- Decreased cereal crop yields in most tropical and subtropical regions
- Increased heat stress in livestock and crop damage from heat waves
- Decreased frost damage for some crops

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Water Resource Impacts

- Decreased water quantity and quality in some areas of increased drought
- Increased flood damage due to more intense precipitation events
- Decreased water supply in many water stressed countries (half-billion people in central Asia, southern Africa, and countries surrounding the Mediterranean affected)
- Increased water supply in some other water stressed countries (e.g. parts of Asia)

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Market Impacts

- Net market sector losses most regions and for global aggregate
- Increased insurance prices and reduced insurance availability in response to increased frequency and intensity of some extreme climate events
- Decreased energy demand for heating buildings in winter and increased energy demand for cooling buildings in summer
- Net market sector losses in many developing countries

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To summarise:...

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Predicting Climate Change

EMISSIONS — Scenarios from population, energy, economics models

CONCENTRATIONS CO_2, methane, etc. — Carbon cycle and chemistry models

HEATING EFFECT 'Climate Forcing'. — Gas properties

CLIMATE CHANGE Temp, rain, sea-level, etc. — Coupled climate models

IMPACTS Flooding, food supply, etc. — Impacts models

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Predicting Climate Change

EMISSIONS — Scenarios from population, energy, economics models

CONCENTRATIONS CO_2, methane, etc. — Carbon cycle and chemistry models

Feedbacks

HEATING EFFECT 'Climate Forcing'. — Gas properties

Feedbacks

CLIMATE CHANGE Temp, rain, sea-level, etc. — Coupled climate models

IMPACTS Flooding, food supply, etc. — Impacts models

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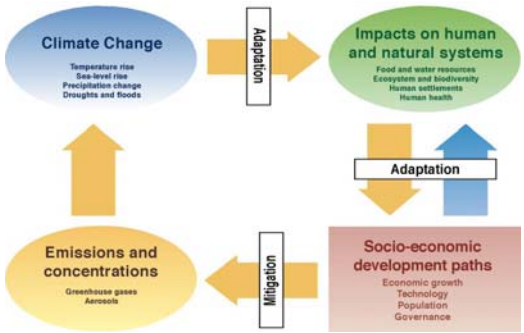
Climate Change – An integrated framework



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End of session

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Questions & Answers