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SMR.1303 - 2

Advanced Course:
CLIMATE CHANGE IN THE MEDITERRANEAN REGION
PART I: PHYSICAL ASPECTS
(12 - 16 March 2001)

"Representation of Climate Variability in General Circulation Models (GCMs)"

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These are preliminary lecture notes, intended only for distribution to participants

Representation of climate variability in GCMs

Jean-François Royer
(Meteo-France, Centre National de Recherches Météorologiques, Toulouse)

Introduction

- The climate system
- The hierarchy of climate models
- History of the development of GCMs

What is inside a GCM?

- Conservation equations (dynamics)
- Subgrid-scale processes (physics)
- Numerical methods

How to run a climate simulation?

- Boundary conditions
- Initial conditions
- Time integration
- Statistical processing
- Coupled simulations

Applications of GCMs

- Validation experiments
- Sensitivity studies
- seasonal forecasting
- paleoclimate reconstructions
- climate scenarios

Perspectives

- Regional modeling

The climate system

Outer Space

- electromagnetic radiations *(photons)*
    - solar radiation
    - terrestrial radiation
- gravitation (earth's orbit, lunar and solar tides)
- particles (solar wind, cosmic rays, meteorites, hydrogen escape)

Atmosphere

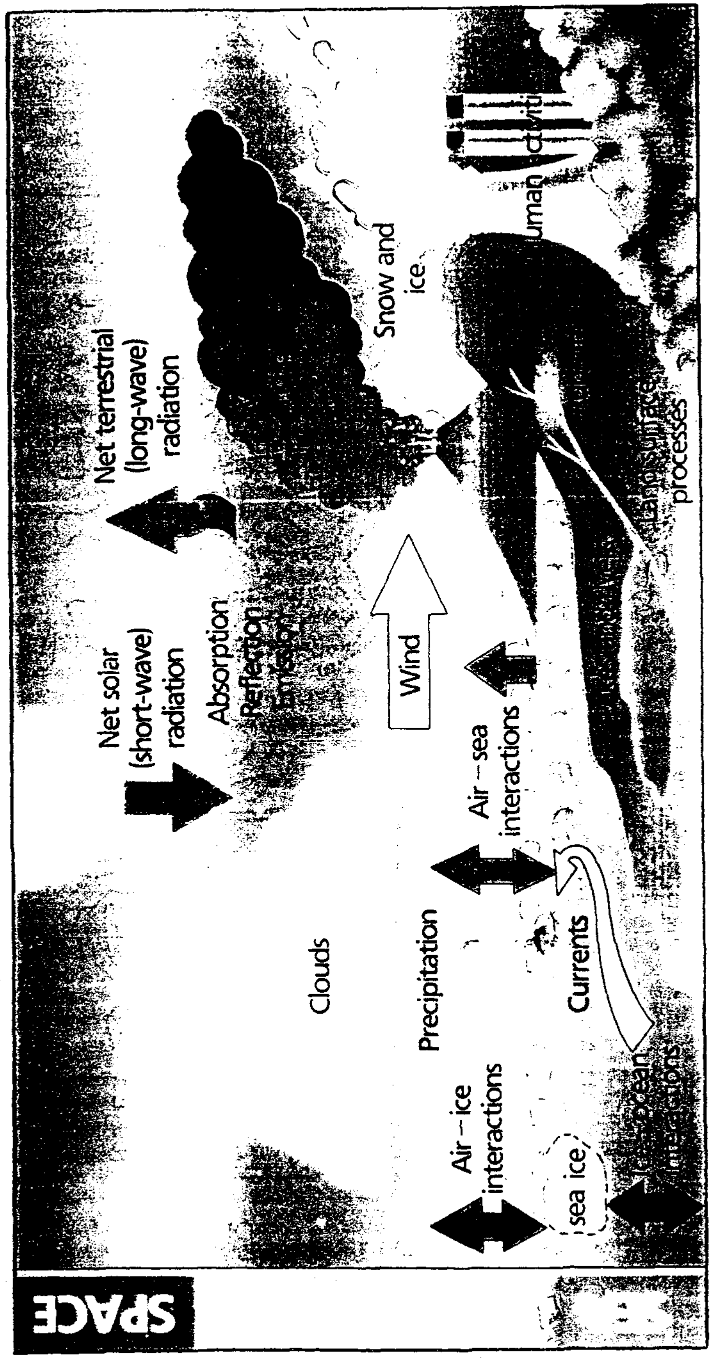
(importance of vertical stratification and horizontal variations, and transport)

- (thermosphere, ionosphere, mesosphere)
- stratosphere *(ozone, aerosols)*
- troposphere
    - gases
    - aerosols
    - clouds *(stratiform and convective)*
    - precipitation *(solid, liquid)*
- Boundary layer *(turbulence)*

Earth'surface

- ocean
- continents
    - orography
    - soils
    - land cover
    - continental hydrology
- ice
    - sea-ice
    - permanent land-ice *(inlandsis, glaciers, permafrost)*
    - snow cover

- biosphere
    - vegetation cover
    - marine biosphere *(ocean color)*



The Climate System

The hierarchy of climate models

- process studies/ simulations
- stationary / time evolution
- explicit/ parameterized transports
- number of degrees of freedom

Main type of model (spatial dimensions)
Physical and dynamical processes

Energy balance models (0-D)

- *thermodynamics (energy conservation)*
  - 1-D: latitude: (Budyko, Sellers)
  - 2-D: latitude-longitude (Adem)

Vertical column models (1-D)

- *radiative transfer + convective adjustment*

Zonal models altitude/latitude (2-D)

- *radiation + diffusion + chemistry*

General circulation models (3-D)

- *dynamics + physics + land surface*
  - *(+chemistry)*

Coupled models

- *atmosphere + ocean + sea-ice*
  - *(+ surface hydrology +biosphere + chemistry + land ice)*
  - *Integrated models (+ economy + industry)*

Short history of GCMs development

The precursors:
- V Bjerknes
- Richardson
- von Neumann
- Charney, Phillips

First phase of GCM modeling (1955-65)
- GFDL (Smagorinsky, Manabe, Miyakoda)
- UCLA (Mintz, Arakawa)
- NCAR (Kasahara, Washington)

Spread of GCMs (1965-75)
- RAND, GISS
- Australian NMRC
- UKMO
- LMD

Maturation of GCMs (1975-85)

- ECMWF, MPI
- Meteo France
- NCAR CCMs
- Other groups: NMC, OSU, CSU, LLNL

Large-scale applications of GCMs (1990-2001)
- Model intercomparison: AMIP (+ PMIP, CMIP, ...)
- Seasonal forecasts
- Climate scenarios and IPCC assessments

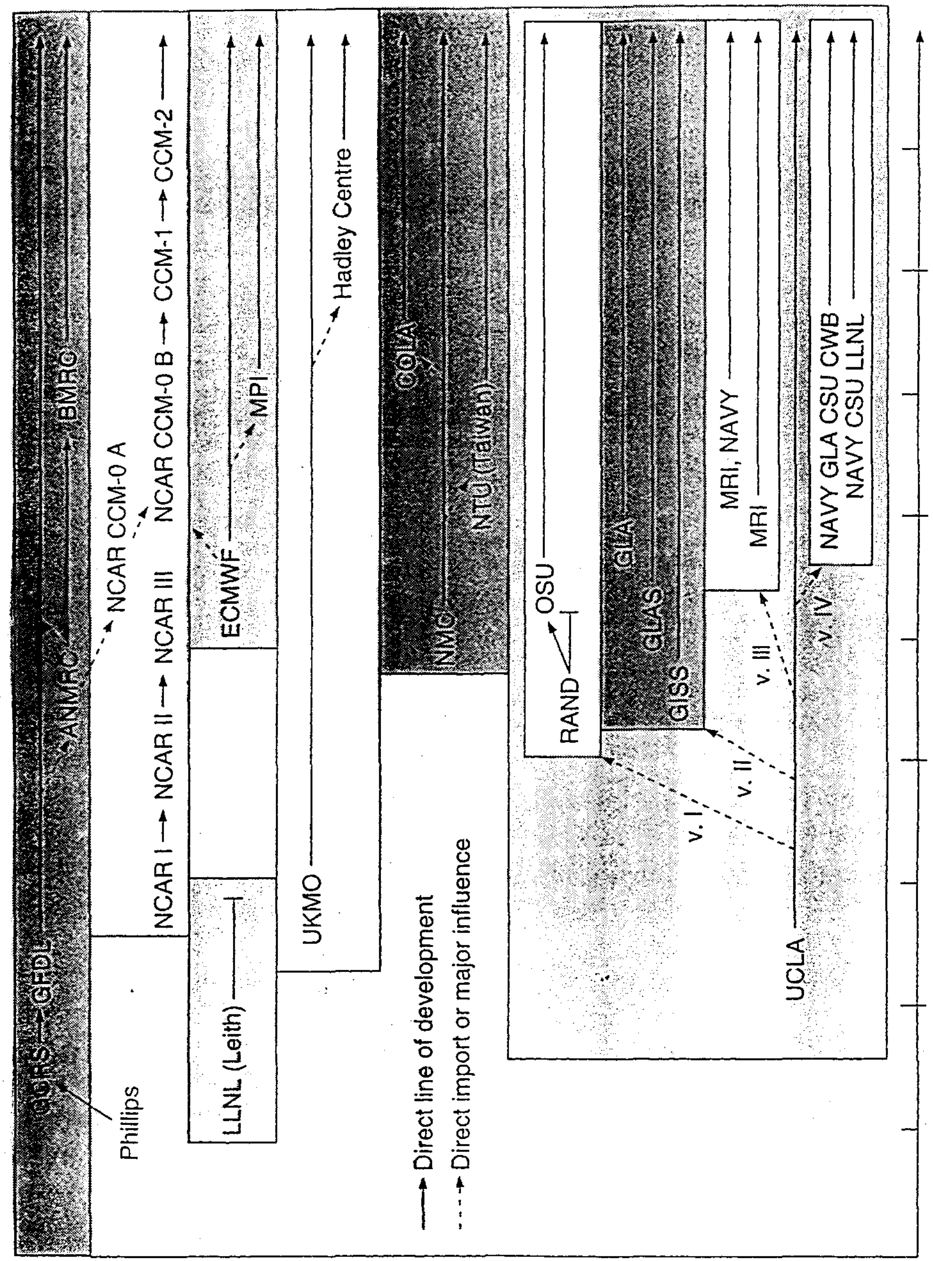


Figure 1 The GCM Family Tree. (P.N. Edwards, 2000)

Theoretical basis

Atmospheric dynamics

Navier-Stokes equations of compressible fluid dynamics

Particularities of the atmospheric fluid

Rotating coordinate frame

Presence of different phases of water

Hydrostatic approximation

Nonhydrostatic effects may be important for scales < 10 km (regional models)

Physical processes

Radiative transfer

Phase changes

Molecular diffusion

The primitive hydrostatic equations

1. conservation of momentum

$$\frac{D\mathbf{v}}{Dt} = -2\boldsymbol{\Omega} \times \mathbf{v} - \rho^{-1}\nabla p + \mathbf{g} + \mathbf{F}$$

2. conservation of mass

$$\frac{D\rho}{Dt} = -\rho\nabla \cdot \mathbf{v} + C - E$$

3 conservation of energy

$$\frac{DI}{Dt} = -p\,\frac{d\rho^{-1}}{dt} + Q$$

4. ideal gas law

$$p = \rho RT$$

where $\mathbf{v}$ = velocity relative to the rotating Earth,
t = time,

$\frac{D}{Dt}$ = total time derivative $\left[= \frac{\partial}{\partial t} + \mathbf{v} \cdot \nabla\right]$

$\boldsymbol{\Omega}$ = angular velocity vector of the Earth,
ρ = atmospheric density,
$\mathbf{g}$ = apparent gravitational acceleration,
p = atmospheric pressure,
$\mathbf{F}$ = force per unit mass,
C = rate of creation of atmospheric constituents,
E = rate of destruction of atmospheric constituents,
I = internal energy per unit mass $[= c_v T]$,
Q = heating rate per unit mass,
R = gas constant,
T = temperature,
c_v = specific heat of air at constant volume.

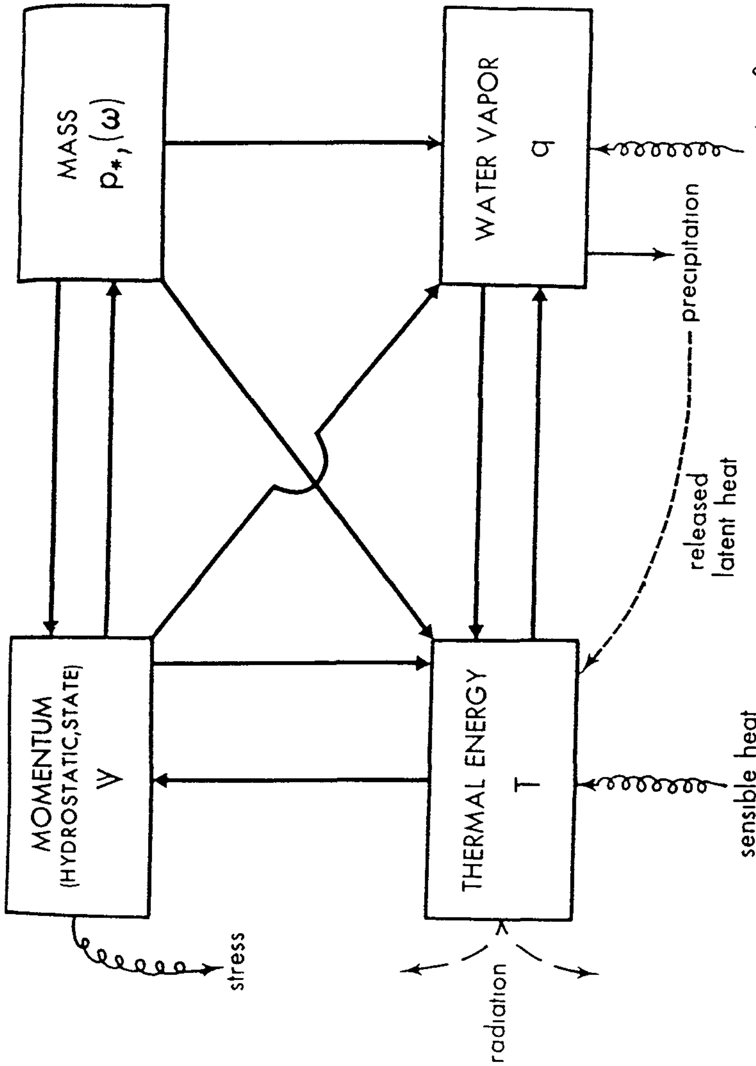


Fig 15 4 A schematic diagram of the relationship of the physical conservation laws which together define the variations of the primary macroscale variables in a quasi-hydrostatic system Also shown are external sources and sinks of momentum, heat, and water vapour (based on Smagorinsky, 1974)

Subgrid-scale processes (physics)

Unresolved scales (from the molecular scale to the grid size)

Radiative transfer
- Solar radiation
- Terrestrial radiation

Phase changes of water:
- Large-scale saturation
- Evaporation
- Ice

Cloud formation and evolution
- Stratiform
- convective
- liquid and solid precipitation

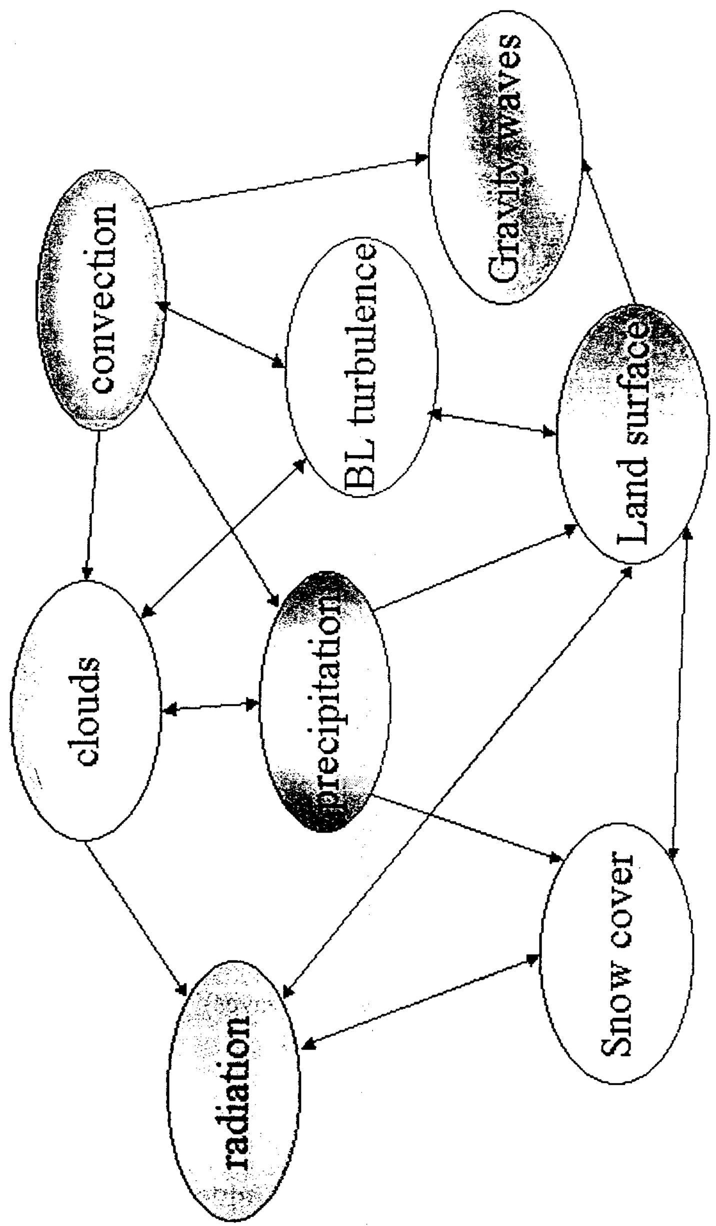
Turbulent motions
- Surface exchanges of momentum, heat and water
- Vertical fluxes in the boundary layer

Organized motions
- Boundary-layer convection (shallow convection)
- Deep convection
- Gravity waves (orography, convection)
- Large-scale horizontal diffusion

Subrid-scale heterogeneities
- Land surface processes
- Cloud formation
- Precipitation

Interactions between different processes
- Positive of negative feedback loops

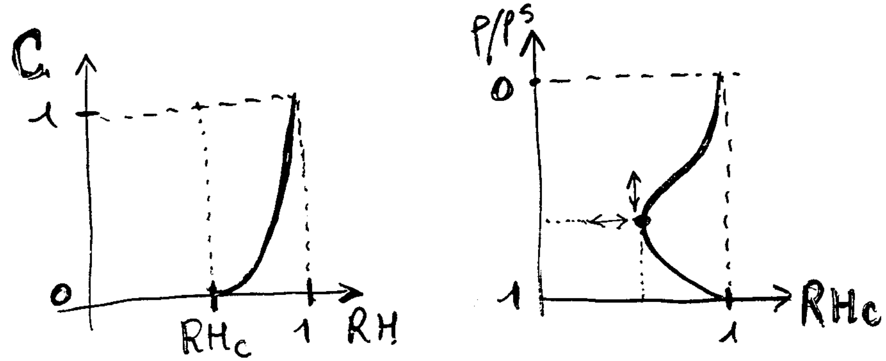
Physical parameterizations



Cloud parameterization schemes in GCMs

1) **Diagnostic schemes** (empirical)

e.g. Arpège model: Critical relative humidity (Slingo, Geleyn)



cloud cover $C = f(RH - RH_c)$

liquid water $q_e = g(\Gamma_w)$ — Hashwarden — {Sommeria, Remes

stability $Ri^* = f(Ri, \frac{d\,\overline{q}-\overline{q}_s}{dz})$ eg: Geleyn (87) Shallow convect

2). **Prognostic cloud schemes**

(evolution equation for cloud water)

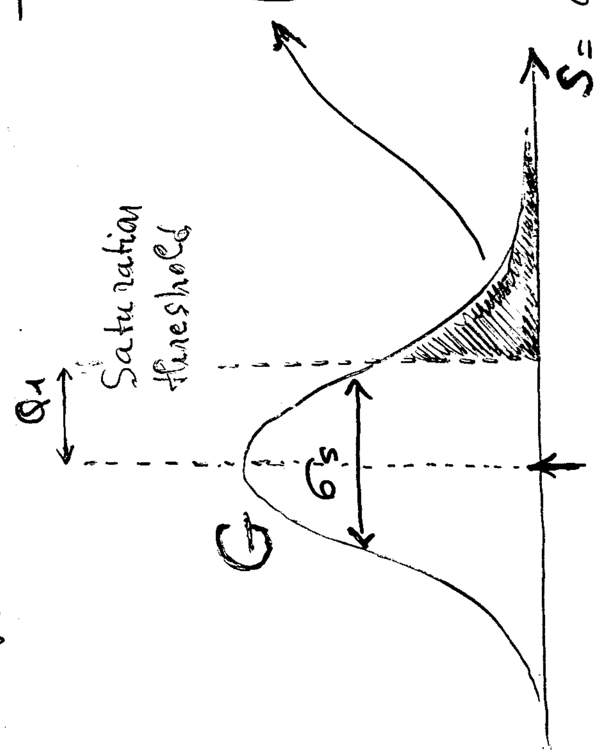
$$\frac{dq_e}{dt} = V.\nabla q_e + S(q_e)$$

$$C = C(q_e)$$

eg: Sundquist, Roeckner, Ti[illegible], [illegible] Randall.

Statistical cloud schemes

Sasamori - Henze and Heise,
Sommeria and Deardorff (1975)
Bougeault (1982)



$\bar q_w = \bar q_v + q_e$

$\bar\Theta_e = \bar\Theta - \frac{L}{c_p} q_e$

large-scale variables

Normalized saturation deficit

$$Q_1 = \frac{a\,\Delta \bar q}{2\sigma_s}$$

→ cloud cover:

$$C = \int_{-Q_1}^{\infty} G(\tilde s)\, d\tilde s = F_0(Q_1)$$

$$q_e \sim \int_{-Q_1}^{\infty} \tilde s\, G(\tilde s)\, d\tilde s = F_1(Q_1)$$

$$\frac{R_i - R_{iH}}{R_{iC}} = \int_{-Q_1}^{\infty} \tilde s^2 G(\tilde s)\, ds = F_2(Q_1)$$

Closure hypotheses

- distribution shape $G =$
- Distribution width σ_s

Land Surface Model (LSM):

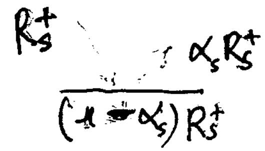
tasks:
provide correct feedback to the atmospheric model

fluxes of:

✔ *radiation,*
✔ *momentum,*
✔ *heat,*
✔ *moisture*

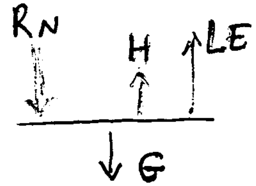
partitioning of incoming solar radiation:

- absorbed
- reflected



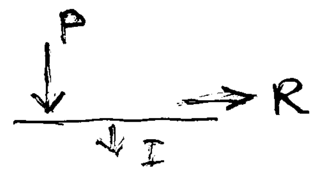
partitioning of the net radiation balance: R_N

- sensible heat flux, H
- latent heat flux LE
- soil heat flux G



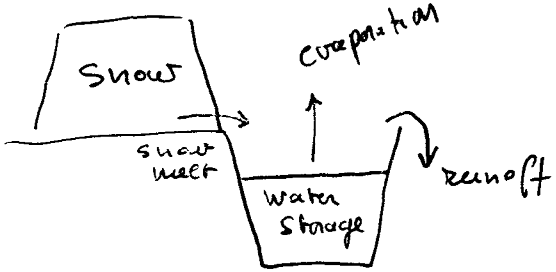
partitioning of precipitation:

- runoff R
- storage I

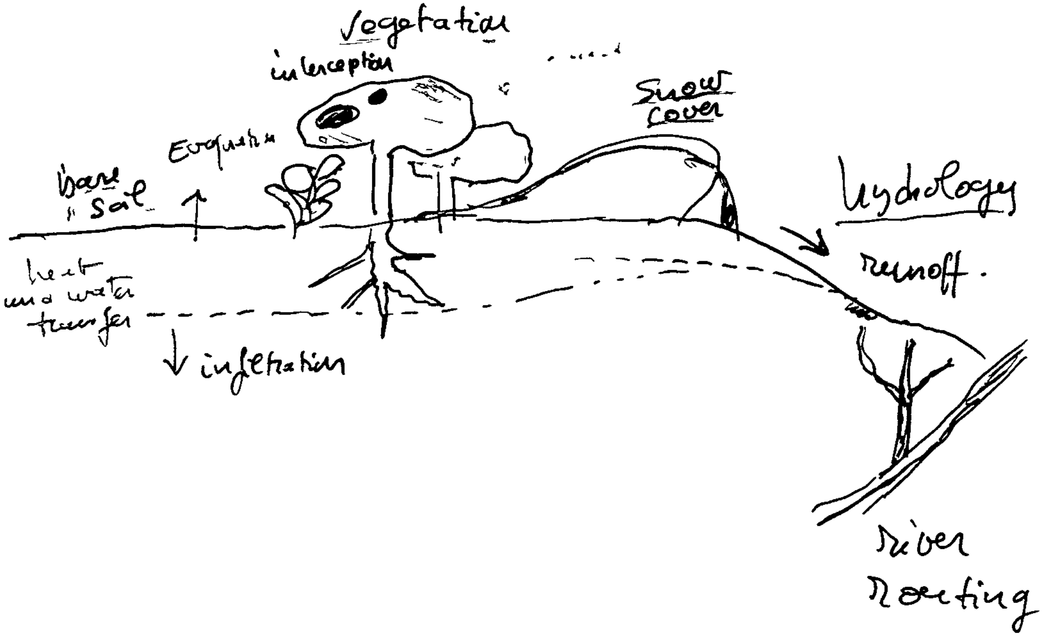


Bucket model

(heat and water ~~balance~~ budget)



Soil-Vegetation-Atmosphere-Transfer (SVAT)



Numerical methods

(Discrete approximations for solving continuous partial differential equations)

Finite difference methods

- Vertical differentiation
- Grid point models Arakawa grids

Spectral methods

- Fourier series
- Spherical harmonics
- Spectral transform method
  - Spectral Truncation
  - Associated grid

Time integration schemes

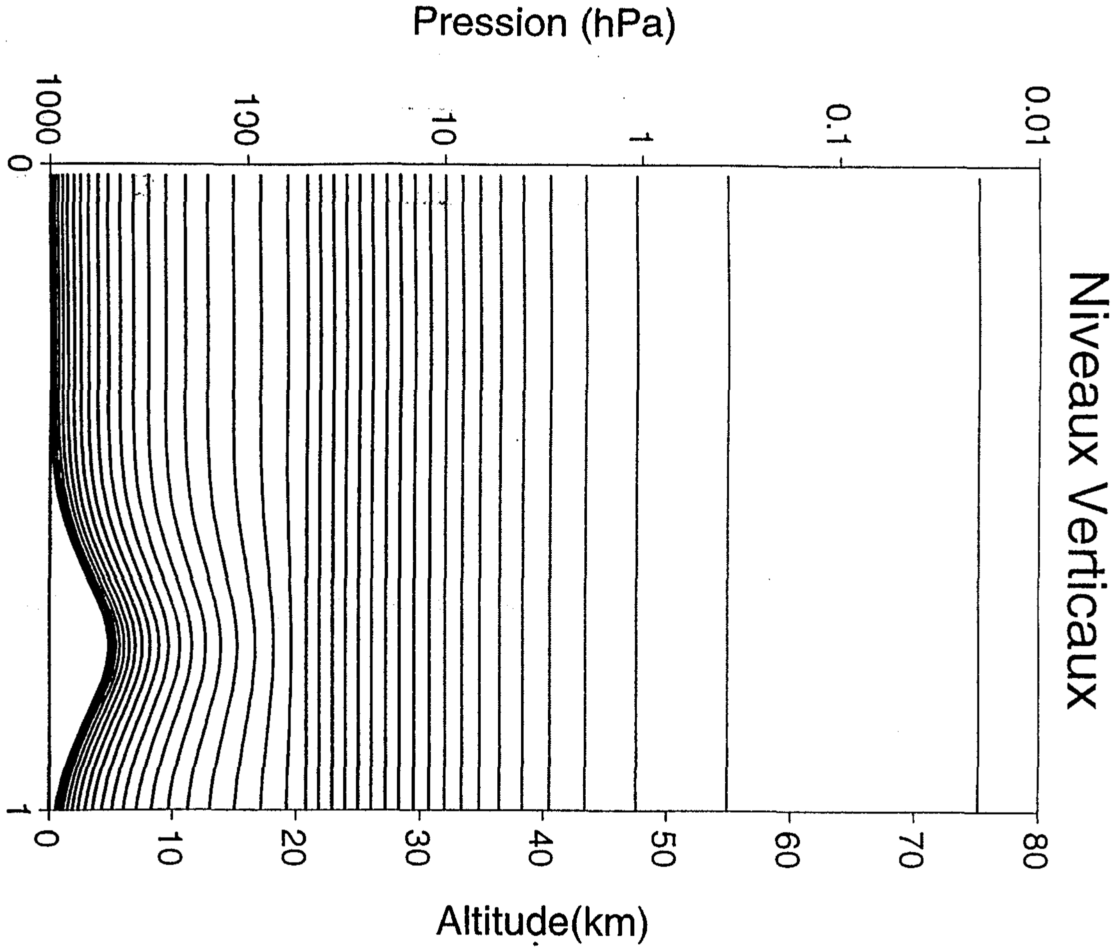
- Classical Eulerian methods
  - Leap-frog
  - Semi-implicit schemes

- Semi-Lagrangian methods

Constraints:

(computer limitations)

- spatial resolution
- duration of simulation



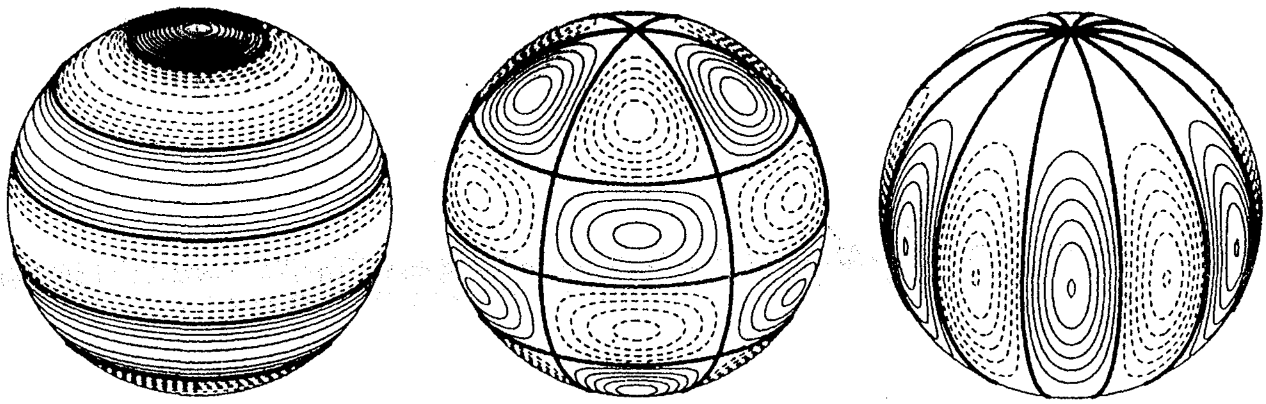


Figure 3.3. Spherical harmonics (left to right) (m,n) = (0,6), (3,6) and (6,6), indicated by 1, 2 and 3 in Figure 3.2.

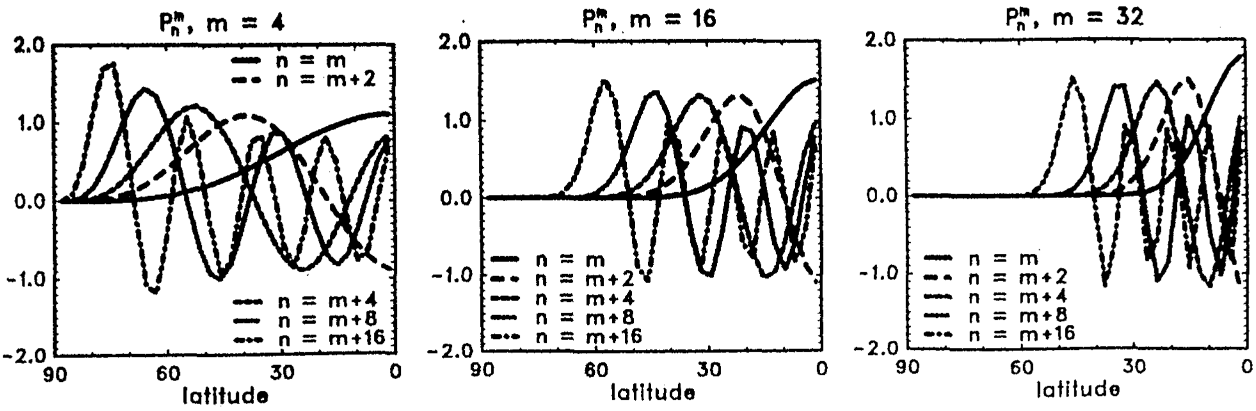


Figure 3.4. Latitudinal structure of selected $P_n^k(\mu)$. Williamson and Laprise (20

The model as a dynamical system

A set of coupled differential equations

Phase space

Enormous number of degrees of freedom

$> 10^6$ in current NWP models

Trajectory in phase space

convergence to a lower dimensional manifold

Attractor

Balance relations (geostrophism)

climate simulation

use the NWP models as a tool for the simulation of climate

Systematic errors (model drift)

Differences between atmospheric and model attractors

Successive steps in a GCM simulation

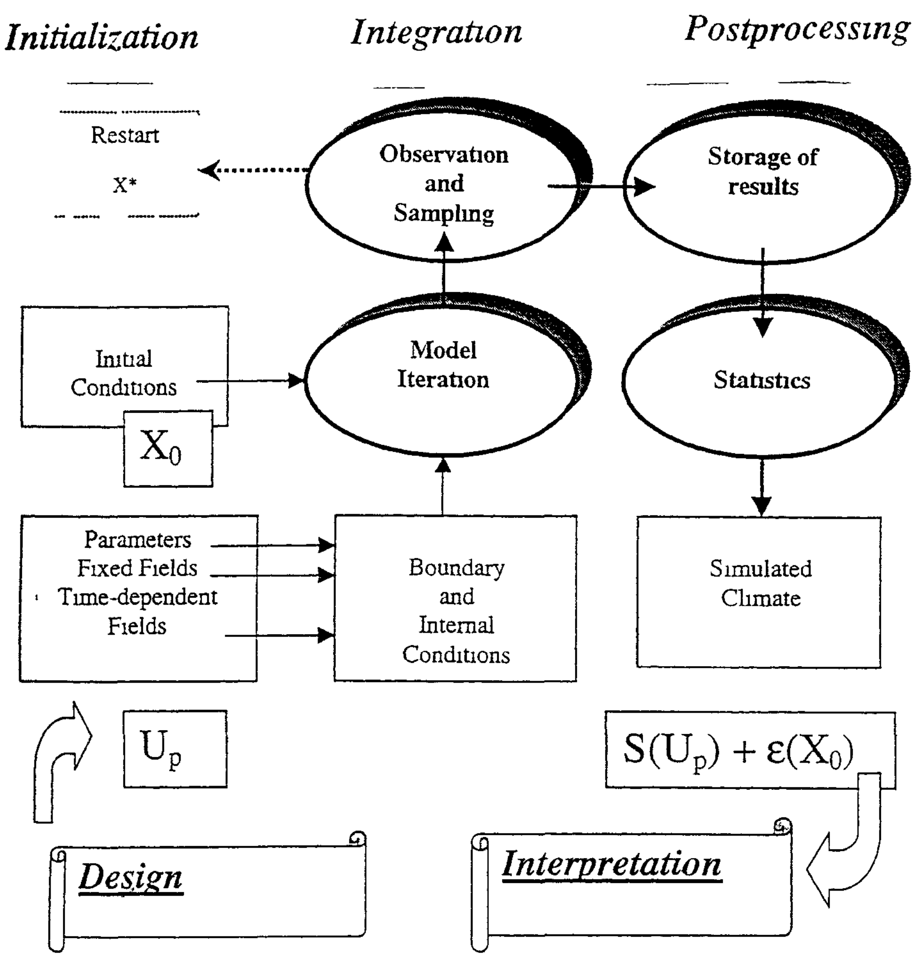
Design of the experiment
- Purpose of the simulation

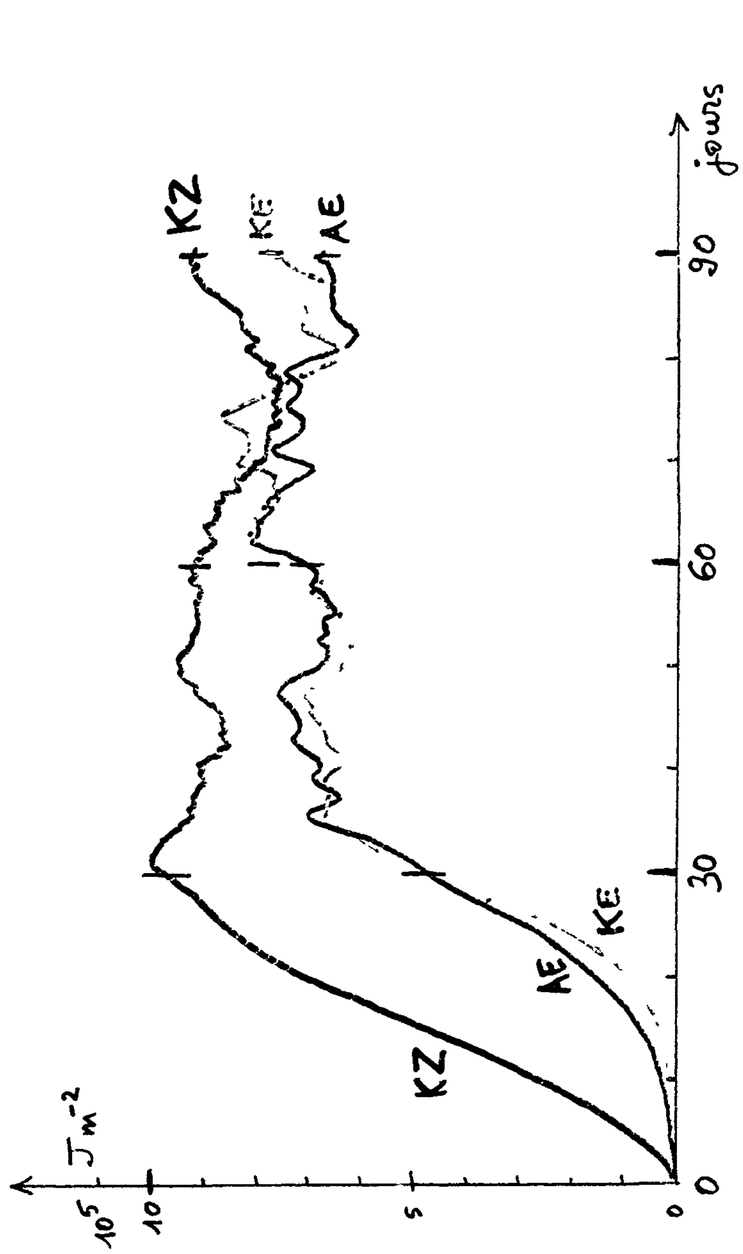
Initialization
- Model setup
- Specification of boundary conditions

Integration
- Time-stepping
- Storage of the results

Post-processing
- Retrieval of archived fields
- Computation of statistics (model climate)
    - Spatio-temporal averages
    - Variance and higher moments (spectra)
    - Multidimensional statistics (EOF, PCA, SSA)
- Visualization

Interpretation
- Validation
- Sensitivity experiments
- Applications (forecasting, scenarios)





- Evolution des énergies d'un modèle partant du repos -
KZ : énergie cinétique zonale
AE : Énergie potentielle utilisable turbulente

Surface Boundary conditions

Land-sea mask
- Continent fraction

Orography
- Mean height
    - o Standard deviation
    - o Anisotropy tensor

Soil properties
- Dominant soil type
- Bare soil albedo and emissivity
- Thermal properties
- Hydraulic properties

Vegetation cover
- Vegetation fraction
- Roughness length
- Albedo
- Leaf Area Index (LAI)
- Minimum stomatal resistance
- Root depth

Ocean surface
- Temperature
    - o Sea state (swell and waves)
    - o Ocean color (albedo)

Sea-ice
- Fractional cover
    - o Physical properties (aldedo, roughness)

9 The different steps in running a GCM experiment

9.1 Design

basic and crucial choices:

- choice of model version (vertical and horizontal resolution)
- choice among different parameterizations (if available)
- precise definition of the initial and boundary conditions

material constraints (computer resources, time span available)

reasonable balance between the scientific interest of the simulation, and its overall cost (human and computer time).

9.2 Preparation

files necessary for model integration

- setup files (model parameters)

  recompilation (changes in model source code)

- files for boundary conditions

  "restart" file (initial condition)

- files and storage space for model output.

check as far as possible the prepared input fields

(printing, plotting or more elaborate graphical outputs)

possible initial setup errors

Short runs:

verify that all is operating smoothly and generating meaningful

results.

9.3 Integration

basic run (limited number of days)

manual or automatic repetition of the basic run

Pay attention to the expected duration of the whole simulation

(shared resources)

sample and check regularly some of the model results

9.4 Postprocessing

processing tools

standard statistics

- temporal means (over an month, a season or a year)
- spatial means (zonal, areal or global averages)

plotting utilities

More elaborate statistical analysis procedures

9.5 Interpretation

- critical examination of the different plots

- comparison with other published or unpublished experiments

- attempts to provide a rational explication, with the help of relevant theoretical support

- writing an adequate descriptive report

8 The different categories of climate simulations

8.1 Validation experiments

realistic simulation of the present climate

Observed boundary condtions:

- The land-sea mask
- The mean height of the orography
- properties of the land surface (surface albedo, roughness height, vegetation type and fractional coverage, type and depth of the active soil layer, thermal and hydric properties, variance of subgrid orography, ...)
- The sea surface temperature (SST) field, and sea-ice limits.

- fixed fields :
  - land-sea mask
  - orography
  - soil type
- Seasonal and interannual variations:

  (SSTs, vegetation growth)

  - climatological SSTs
  - Observed SSTs (AMIP)
  - seasonal variation (albedo, leaf area index)

Validation is important for the credibility of a model

(objective statistical techniques should be used)

8.2 Sensitivity experiments

Influence of specified modifications in the parameters or boundary conditions on the model

at least two simulations:

- A "control" (or reference) simulation
- One or (hopefully) several "perturbed" (or modified) simulations

Sensitivity experiments can have different goals

- Process studies

  role and feedback of a particular physical process

  - radiative processes
  - cloud processes
  - convection
  - land surface processes
  - model resolution

- potential impact of external forcings

  - orography
  - insolation intensity or distribution
  - rotation rate of the earth
  - atmospheric composition
  - aerosols
  - volcanic eruptions
  - sea surface temperatures
  - sea ice and snow cover
  - albedo and other land-surface properties
  - vegetation distribution

3 Climate simulations

- palaeoclimatic reconstructions

  - astronomical parameters
  - reconstructed SST patterns
  - height of the ice caps
  - vegetation distribution

  (Ice Age)

Coupled ocean-atmosphere simulations

Consistency of simulated climate with palaeoclimatic data

modification of hypotheses

framework to interpret the palaeoclimatic data

- Future climate scenarios

hypotheses on the evolution of

- composition of the atmosphere
- land-surface cover

forecast the response of ocean temperatures

coupled atmosphere-ocean models

evaluation of future climate changes by the IPPC

flux correction' methods

control and increasing CO2 simulations without flux correction

"time-slice" (or "snapshot") simulations

Ensembles of simulations

higher resolution models to refine the regional aspects

correction of ocean drift

AMIP

World Climate Research Programme
Working Group on Numerical Experimentation

Atmospheric Model Intercomparison Project

Website locations: USA, Europe and Australia

What is AMIP?	**Newsletters**
AMIP I (1990-96)	**Abstract archive**
Model output access	**Model documentation**

CMIP and other climate model intercomparisons

AMIP II

- **Guidelines**
- **Experimental design details**
- **Standard model output** and **WGNE diagnostics**

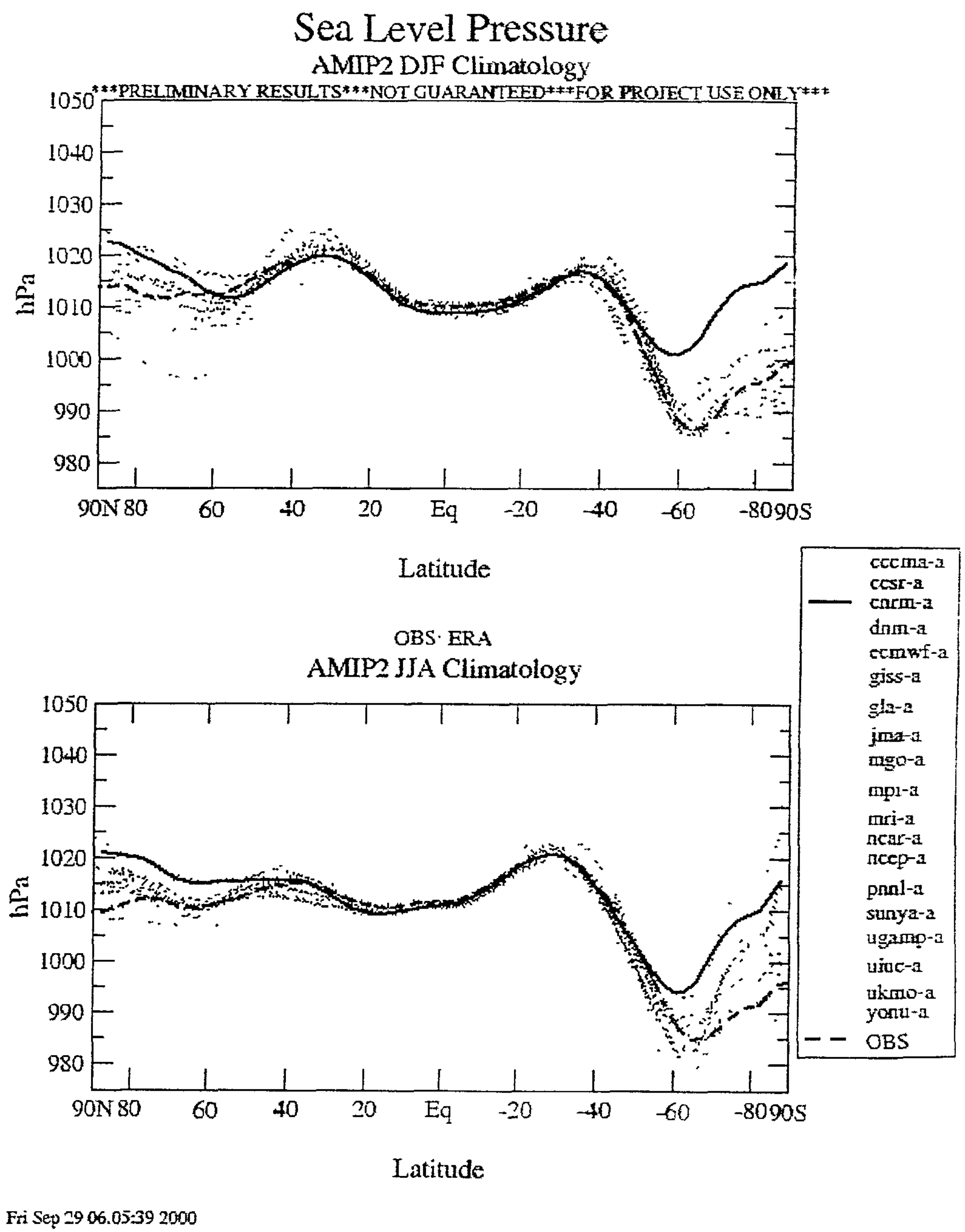
- **Evolving Quality Control: *Zonal Means*** **(updated frequently)**
- **Simulation status** **(updated frequently)**
- **Diagnostic subprojects** (updated October 2000)
- **Experimental subprojects**

- **AMIP data transmission standards**
- **Model documentation template** and **work in progress**
- **Call for diagnostic subproject proposals**
- **Additional resources**

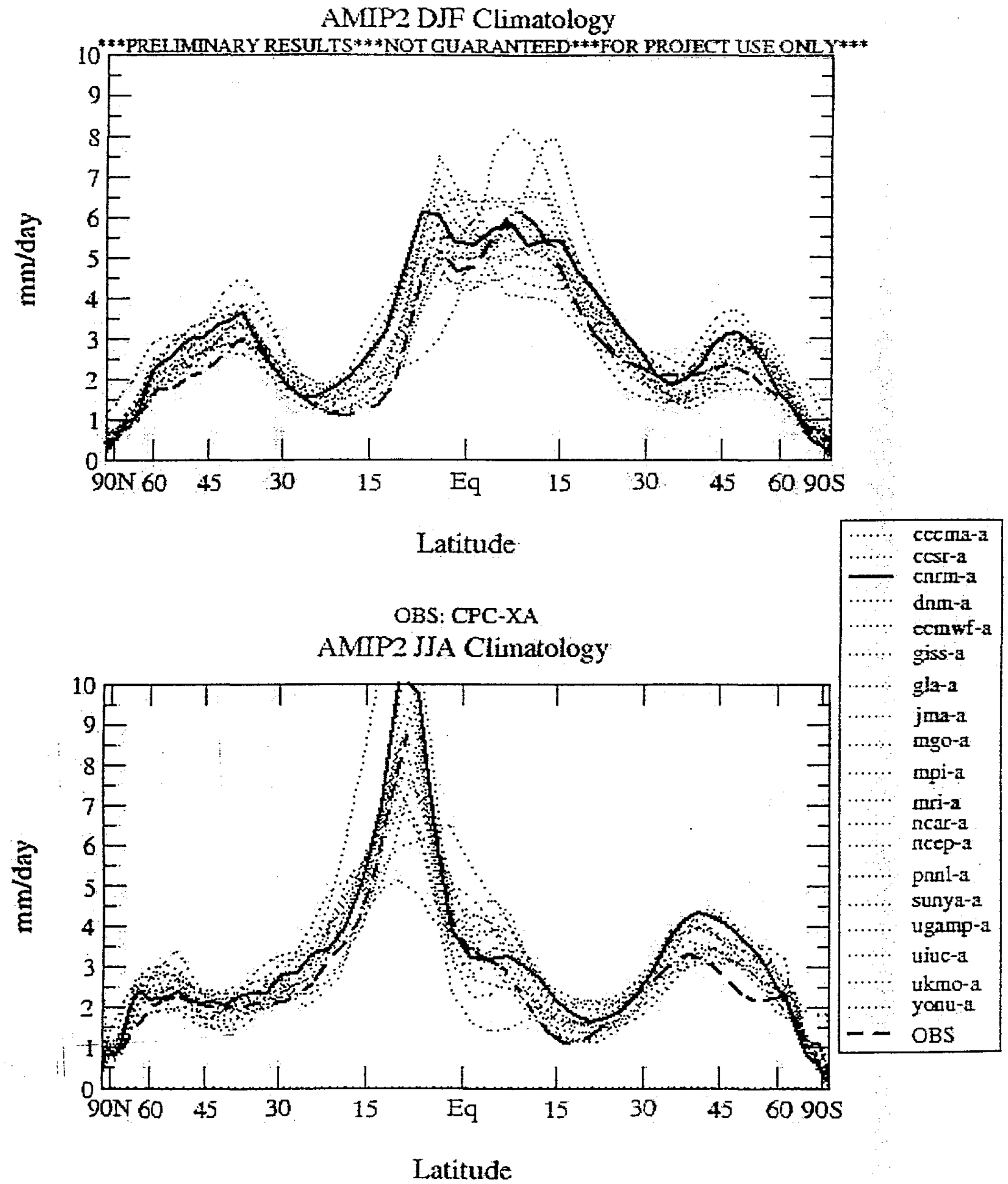
Return to PCMDI home page

AMIP Models and Output Status

Group	Contact(s)	Model Version	Resolution
BMRC	McAvaney	BMRC 2 3	R31 L9
CCC	Boer	GCM II	T32 L10
CNRM	Déqué	EMERAUDE	T42 L30
COLA	Straus	COLA 1.1	R40 L18
CSIRO	Hunt	CSIRO 9 Mark 1	R21 L9
CSU	Randall	CSU 91	4x5 L17
DERF	Miyakoda	GFDL SM392.2	T42 L18
DNM	Galin	A5407.VI	4x5 L7
ECMWF	Ferranti	ECMWF Cy36	T42 L19
GFDL	Wetherald	CDG 1	R30 L14
GISS	Lo/Del Genio	MODEL II Prime	4x5 L9
GLA	Lau	GCM-01 0 AMIP-01	4x5 L17
GSFC	Park	GEOS-1	4x5 L20
IAP	Wang/Zeng	IAP-2L	4x5 L2
JMA	Sato	GSM 8911	T42 L21
LMD	Le Treut	LMD 5	3 6x5 6 L11
MGO	Meleshko	AMIP 92	T30 L14
MPI	Dümenil/Schlese	ECHAM 3	T42 L19
MRI	Kitoh	GCM-II	4x5 L15
NCAR	Williamson	CCM2	T42 L18
NMC	van den Dool	MRF	T40 L18
NRL	Rosmond	NOGAPS 3.2	T47 L18
RPN	Ritchie	NWP-D40P29	T63 L23
SUNYA	Wang	CCM1-TG	R15 L12
SUNYA/NCAR	Wang/Thompson	GENESIS 1.5	T31 L18
UCLA	Mechoso	AGCM 6.4	4x5 L15
UGAMP	Blackburn/Slingo	UGCM 1.3	T42 L19
UIUC	Schlesinger	MLAM-AMIP	4x5 L7
UKMO	Hall	UM-CLIMATE1	2.5x3.75 L19
YONU	Oh	Tr 5.1	4x5 L5



Total precipitation rate



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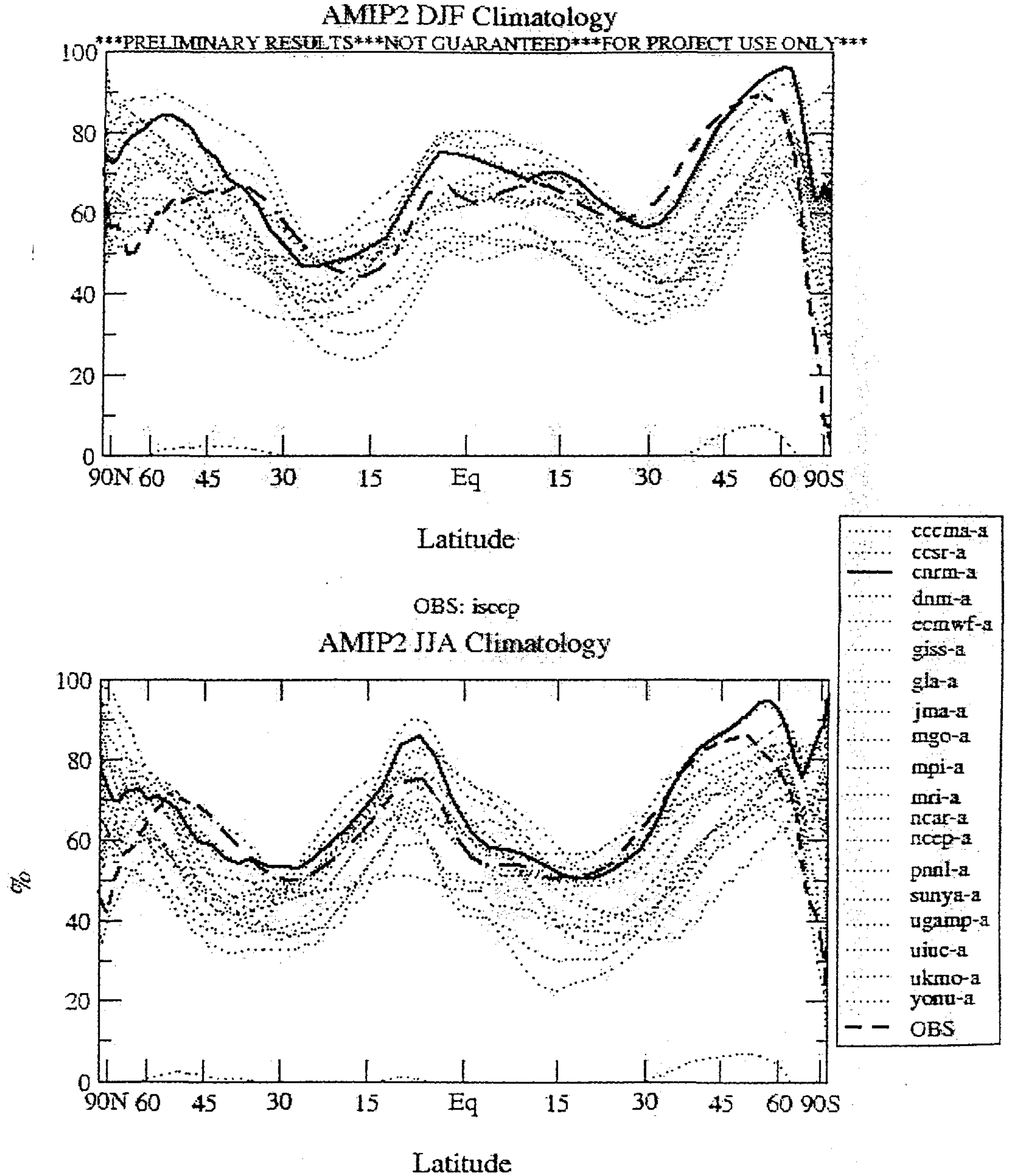
Total cloud amount



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Other climate model intercomparisons and related projects

- Atmospheric Tracer Transport Model Intercomparison Project (**TRANSCOM**)
- General - **CLIVAR** intercomparison projects
- The Coupled Model Intercomparison Project (**CMIP**)
- Dynamical cores intercomparison
- ENSO Intercomparison Project (**ENSIP**)
- GCM-Reality Intercomparison Project for SPARC (**GRIPS**)
- Ocean Carbon-Cycle Model Intercomparison Project (**OCMIP**)
- Project for Intercomparison of Landsurface Parameterization Schemes (**PILPS**)
  - PILPS Phase 3 (PILPS in the AMIP)
- Paleoclimate Model Intercomparison Project (**PMIP**)
- Project to Intercompare Regional Climate Simulations (**PIRCS**)
- Sea-ice Model Intercomparison Project (**SIMIP**)
- Seasonal Model Intercomparison Project (**SMIP**)
- Single Column modeling (**SCM**, Atmospheric Radiation Measurement Program)
- Study of Tropical Oceans in Coupled Models (**STOIC**)

Reanalysis Projects:

- NCEP/NCAR
- DAO
- ECMWF

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 95, NO. D10, PAGES 16,601–16,615, SEPTEMBER 20, 1990

Intercomparison and Interpretation of Climate Feedback Processes in 19 Atmospheric General Circulation Models

R. D. Cess,[1] G. L. Potter,[2] J. P. Blanchet,[3] G. J. Boer,[3] A. D. Del Genio,[4] M. Déqué,[5] V. Dymnikov,[6] V. Galin,[6] W. L. Gates,[2] S. J. Ghan,[2] J. T. Kiehl,[7] A. A. Lacis,[4] H. Le Treut,[8] Z.-X. Li,[8] X.-Z. Liang,[9] B. J. McAvaney,[10] V. P. Meleshko,[11] J. F. B. Mitchell,[12] J.-J. Morcrette,[13] D. A. Randall,[14] L. Rikus,[10] E. Roeckner,[15] J. F. Royer,[5] U. Schlese,[15] D. A. Sheinin,[11] A. Slingo,[7] A. P. Sokolov,[11] K. E. Taylor,[2] W. M. Washington,[7] R. T. Wetherald,[16] I. Yagai,[17] and M.-H. Zhang[9]

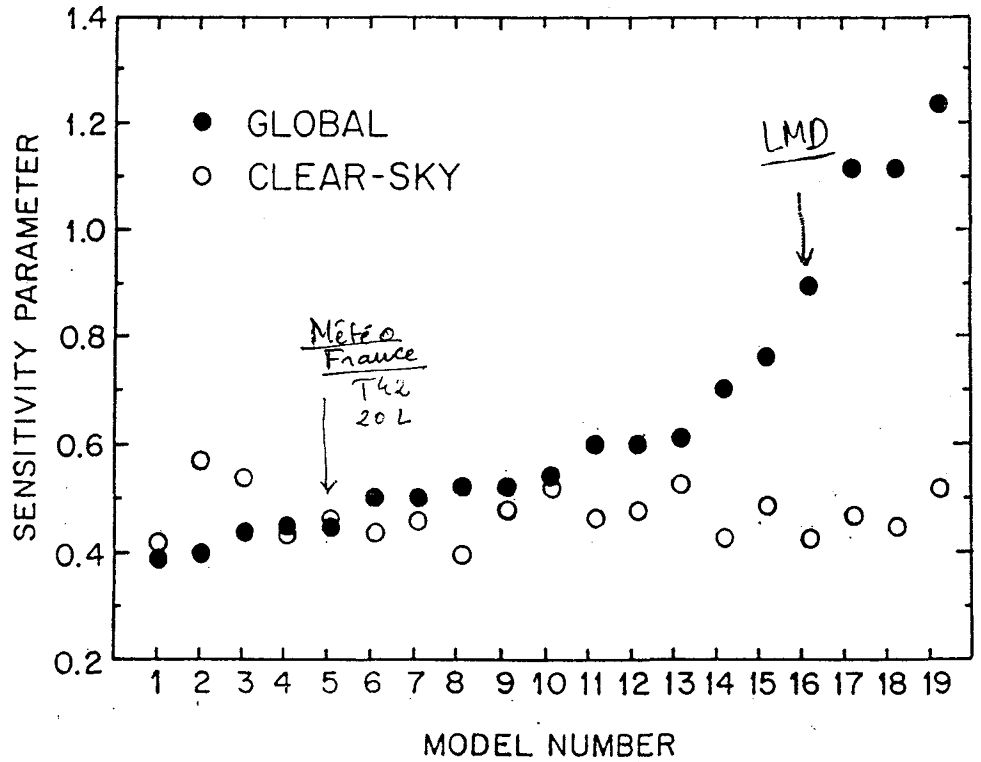


Fig. 1. Clear-sky and global sensitivity parameters (K m^2 W^{-1}) λ for the 19 GCMs. The model numbers correspond to the ordering in Table 9.

$$\lambda = \frac{\Delta T}{\Delta G}$$ ← Température ← Flux radiatif

Applications of GCMs

Paleoclimate reconstructions

- PMIP
  - (Paleoclimatic Model Intercomparison Experiment)
- Last Glacial Maximum (-20 k yr B.P.)
- Holocene Climate optimum (-6 k B.P.)
- Last Interglacial (-125 k, -115 k BP)
- Cretaceous climates
- Continental drift

Climate forecasts

- Long-range weather forecasting
  - Ensemble forecasts
- Statistical adaptations
- Atmosphere-ocean coupled forecasts
  - ENSO forecasting
- International projects
  - PROVOST
  - DEMETER

Climate scenarios

- IPCC assessments
- Climate of the 21-st century
  - Scenarios of GHG emissions
  - Aerosols
- Integrated assessment models

THE ARPEGE-IFS MODEL

The Stretched And Tilted-Pole Version

Method : write the model equations on the sphere with a new system of coordinates

Conformal transform *Courtier Geleyn*, QJRMS, 1988

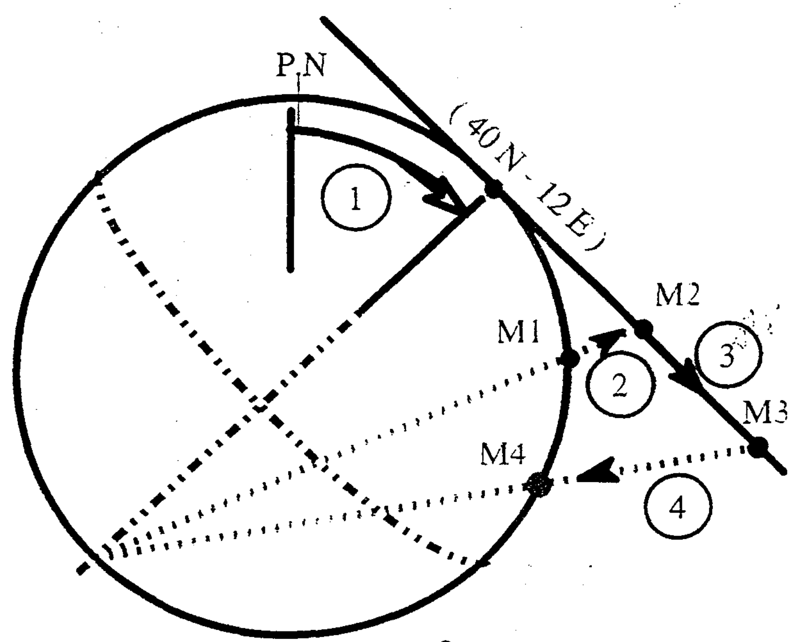
1 • shifting North pole to the point (40°N, 12°E)

2 • polar stereographic projection (M1 -> M2)

3 • homothetic transform in the tangent plane (factor c=3.5) (M2 -> M3)

4 • inverse polar stereographic projection (M3 -> M4)

PROPERTIES : isotropic ($\Delta x = \Delta y$) ; spectral compatible



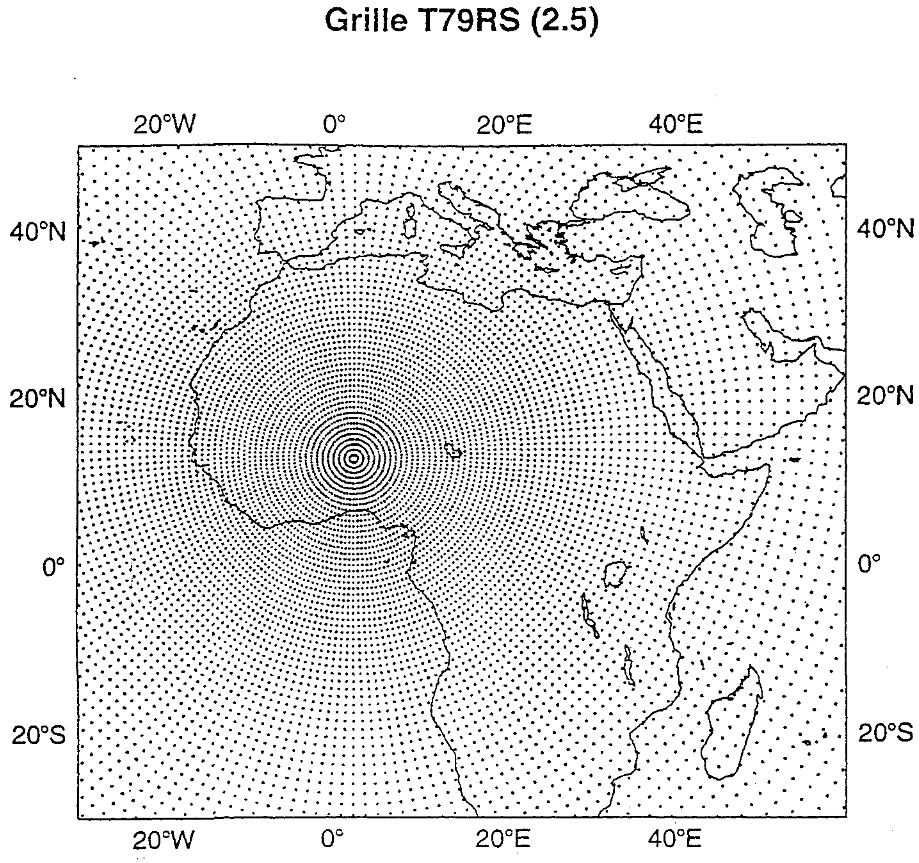
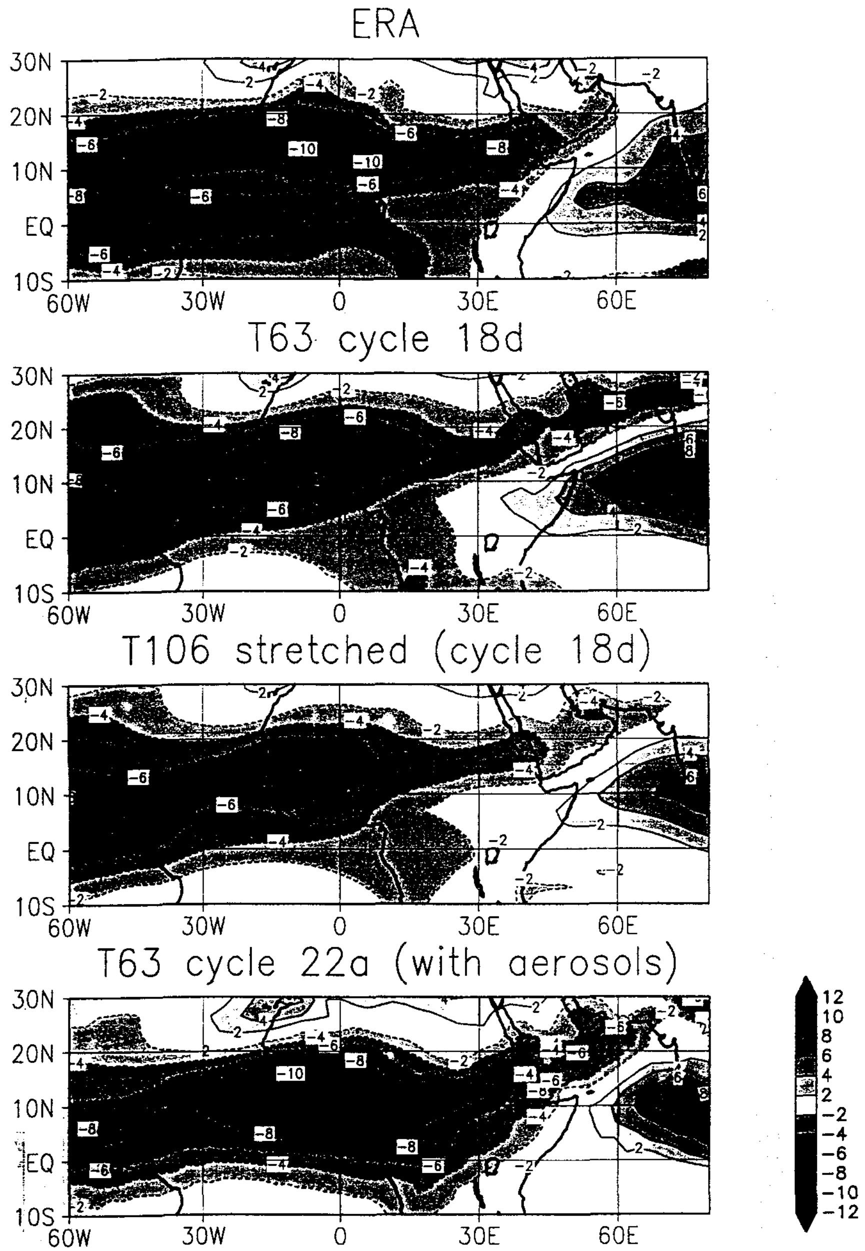
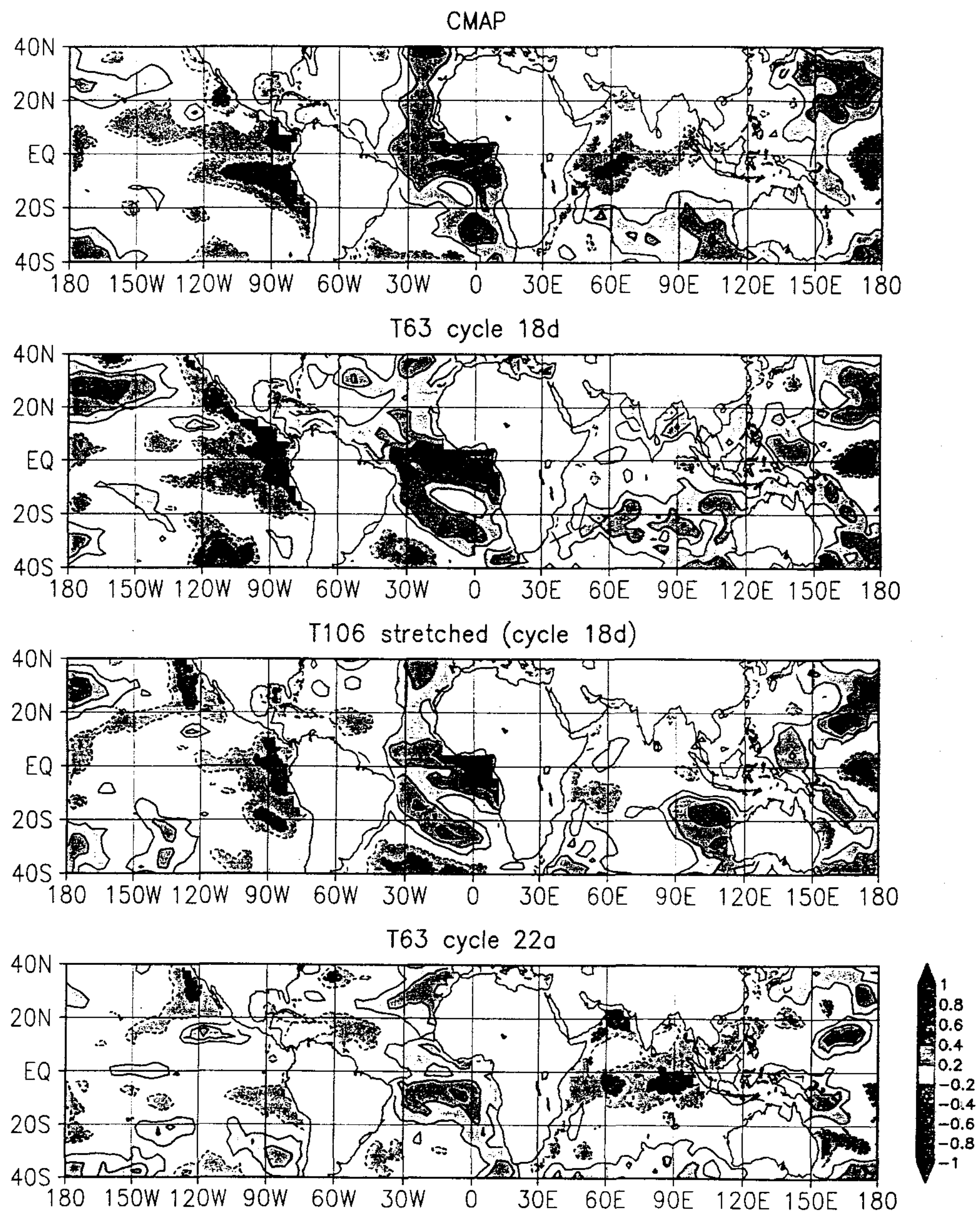


Figure 1: Geographical distribution of the gridpoints on the Gaussian grid of the T79 Arpege-Climat model with a stretching factor of 2.5 and a pole at 12.5 N, 2.5 E used for the WAMP simulation.

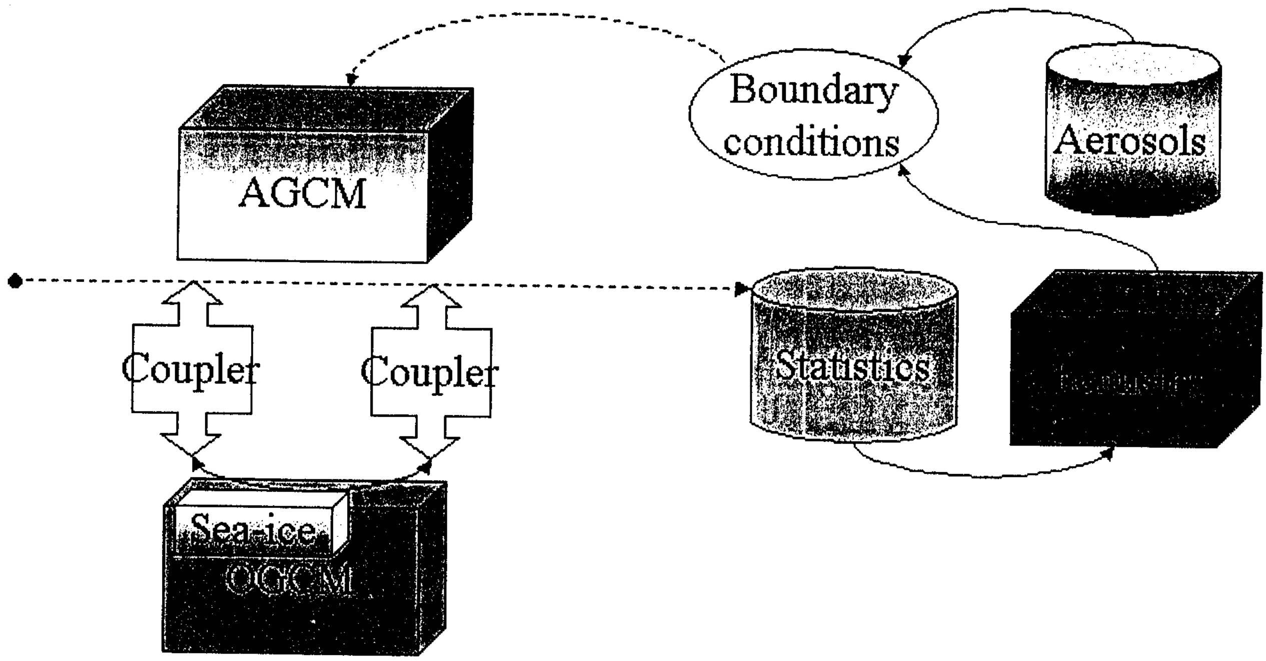
JAS Model 600 hPa WIND vs ERA (1979–93)

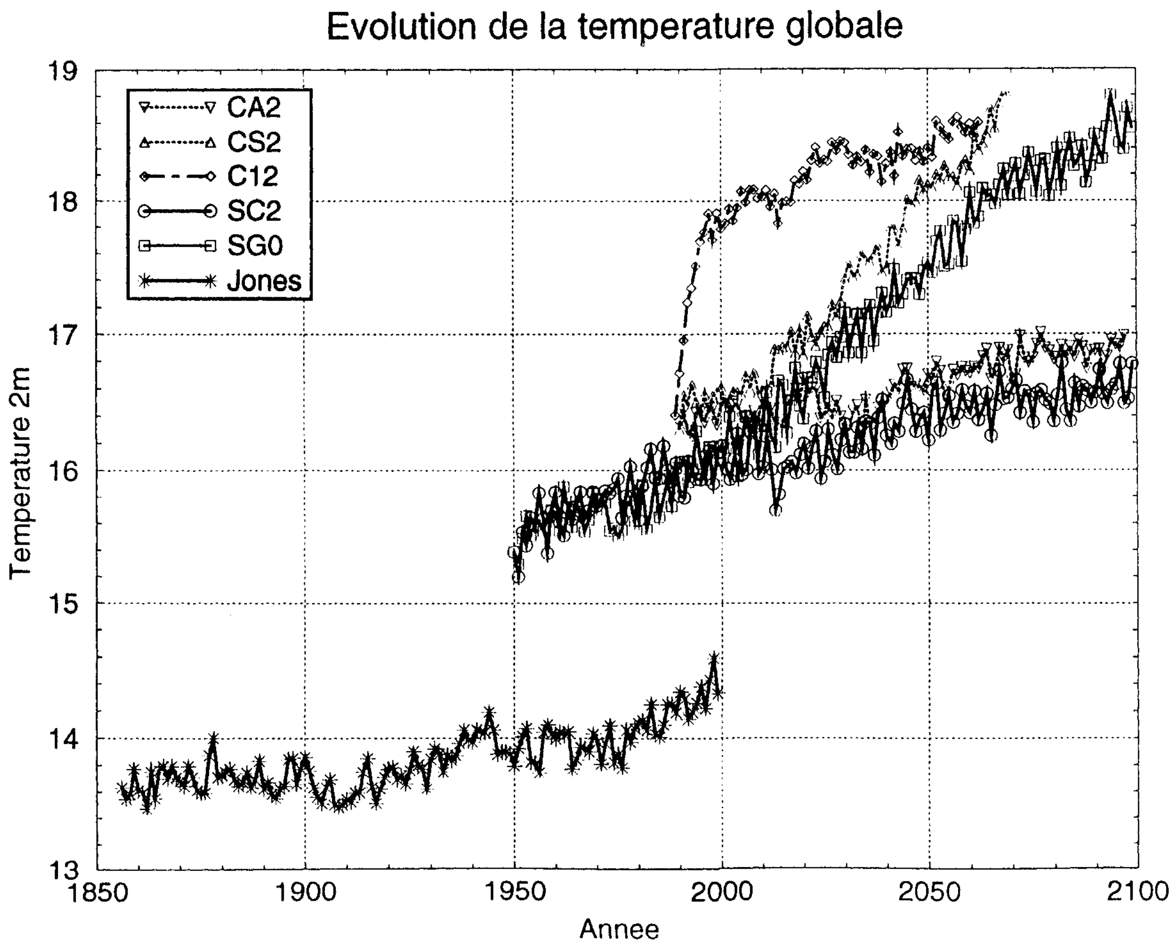


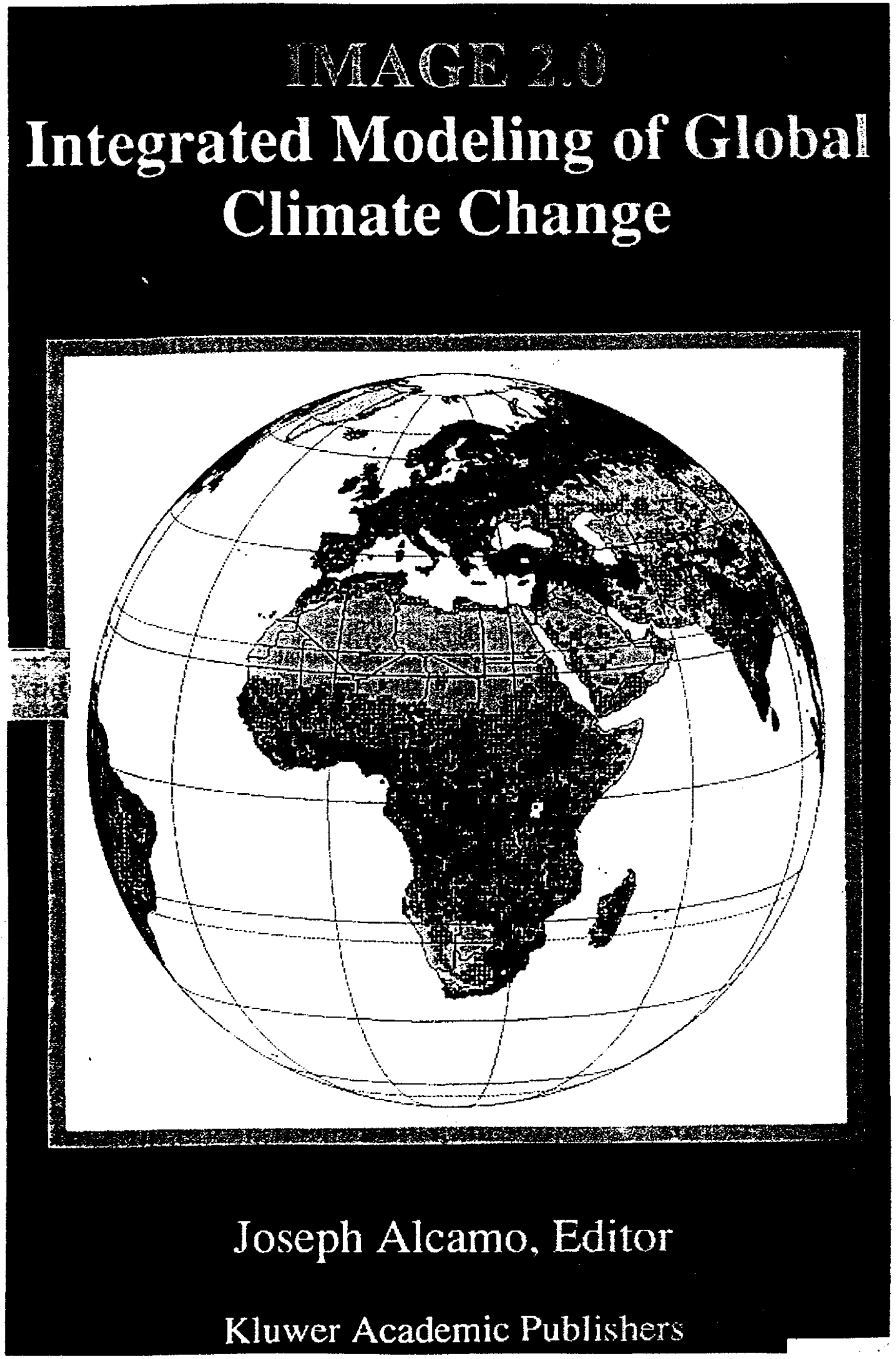
JAS correlation: guinea PREC. with SST



Coupling methodology

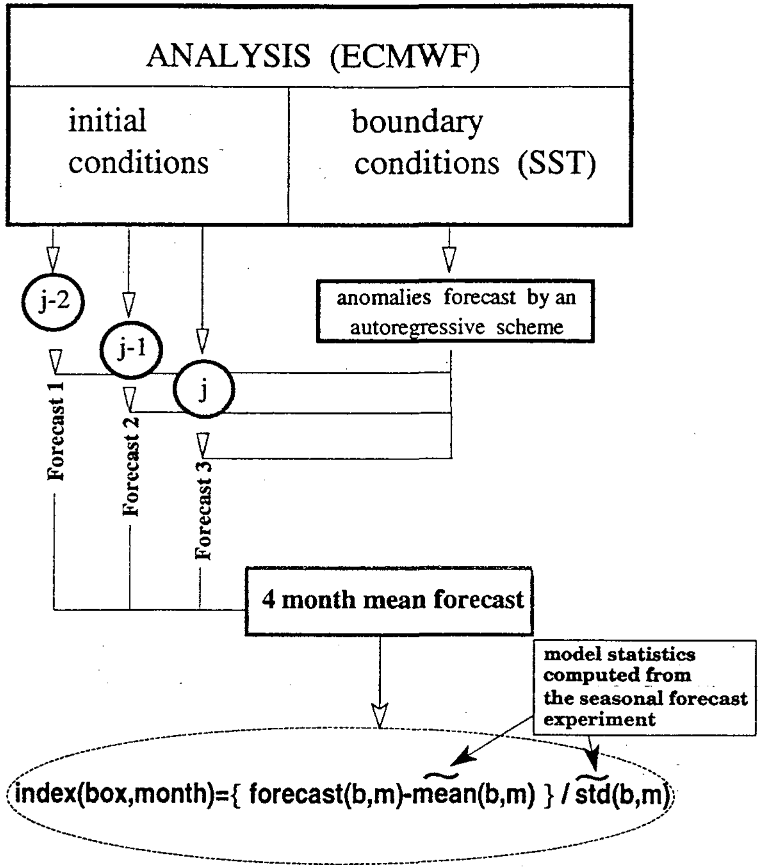






ELMASIFA * numerical seasonal forecast

Météo-France/CNRM M. Déqué, JPh. Piedelievre



	month 1	month 2	month 3	month 4
box 1	i11	i12	i13	i14
box 2	i21	i22	i23	i24
box 3	i31	i32	i33	i34
box 4	i41	i42	i43	i44

* EUC PROGRAMME : AVICENNE, PROJECT : AVI-CT93-0010

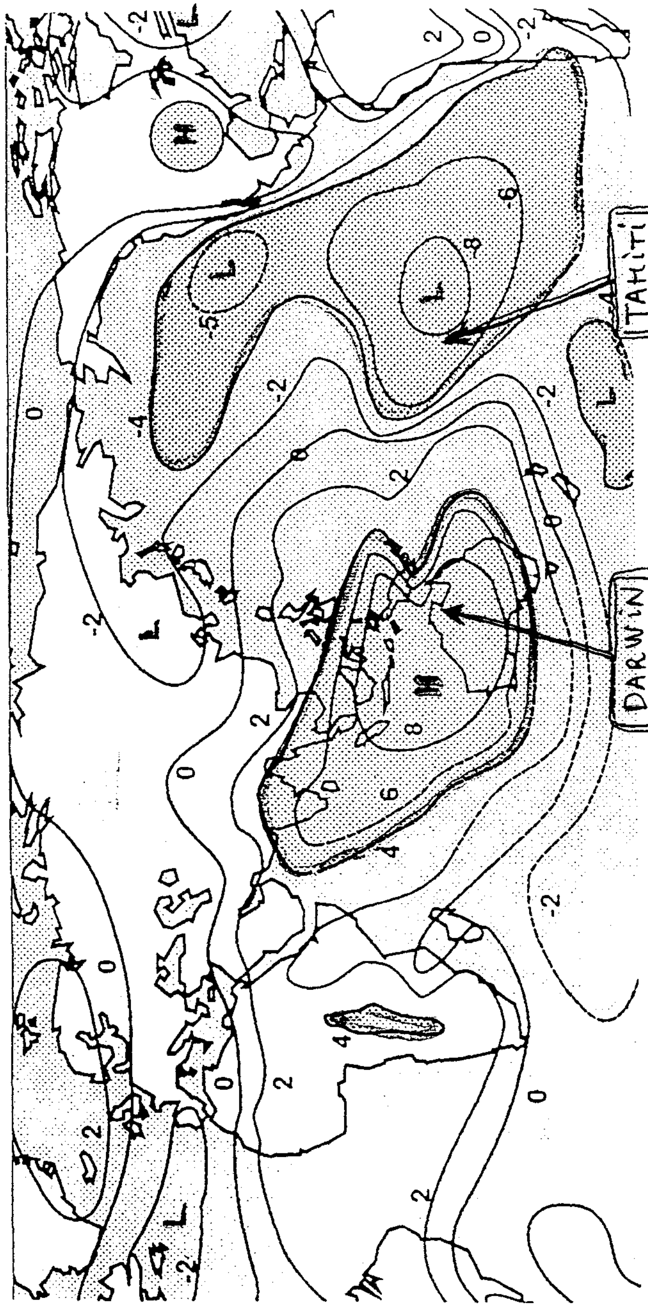


Figure 2 — Carte des corrélations entre la pression en surface et la pression à Darwin, Australie. Cette carte montre l'énorme échelle spatiale de l'ENSO : lorsque la pression est élevée dans le Pacifique Ouest, elle est basse dans le Pacifique Est. Bien qu'il y ait des relations avec les latitudes moyennes, celles-ci sont moins fortes (*tiré de Trenberth et Shea, 1987*)

Stephenson and Royer (1994)

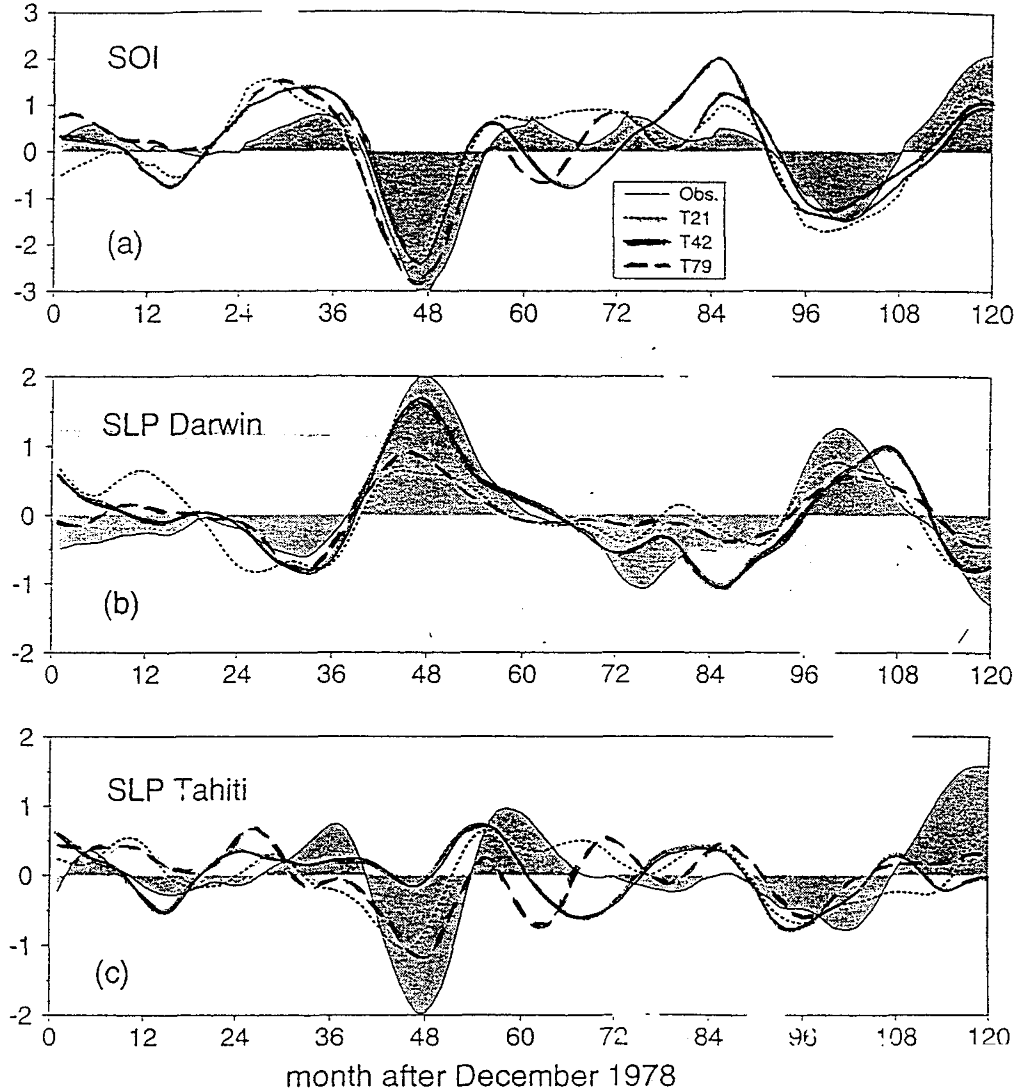
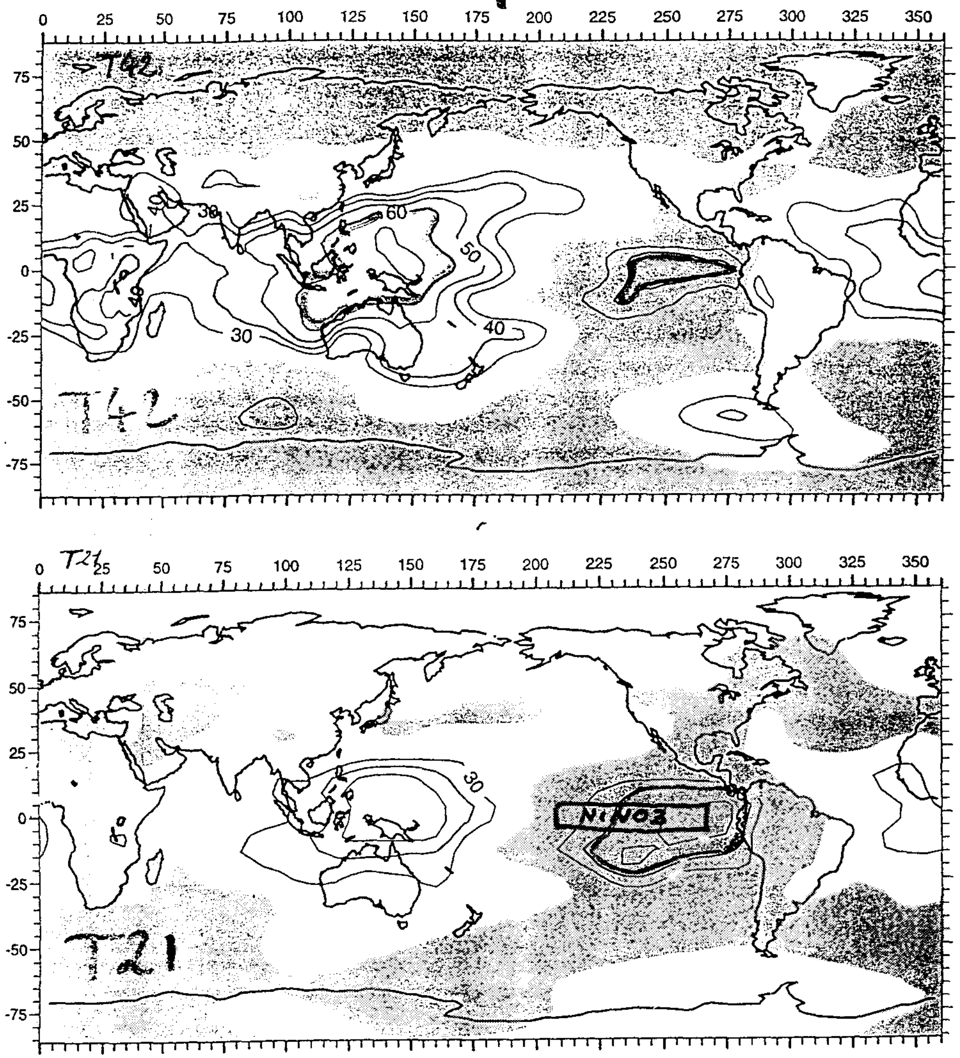


Fig. 2 Low-pass filtered (a) SOI, (b) Darwin SLP in hPa and (c) Tahiti SLP in hPa. Filled grey curve shows the CRU observations.

Sea level pressure

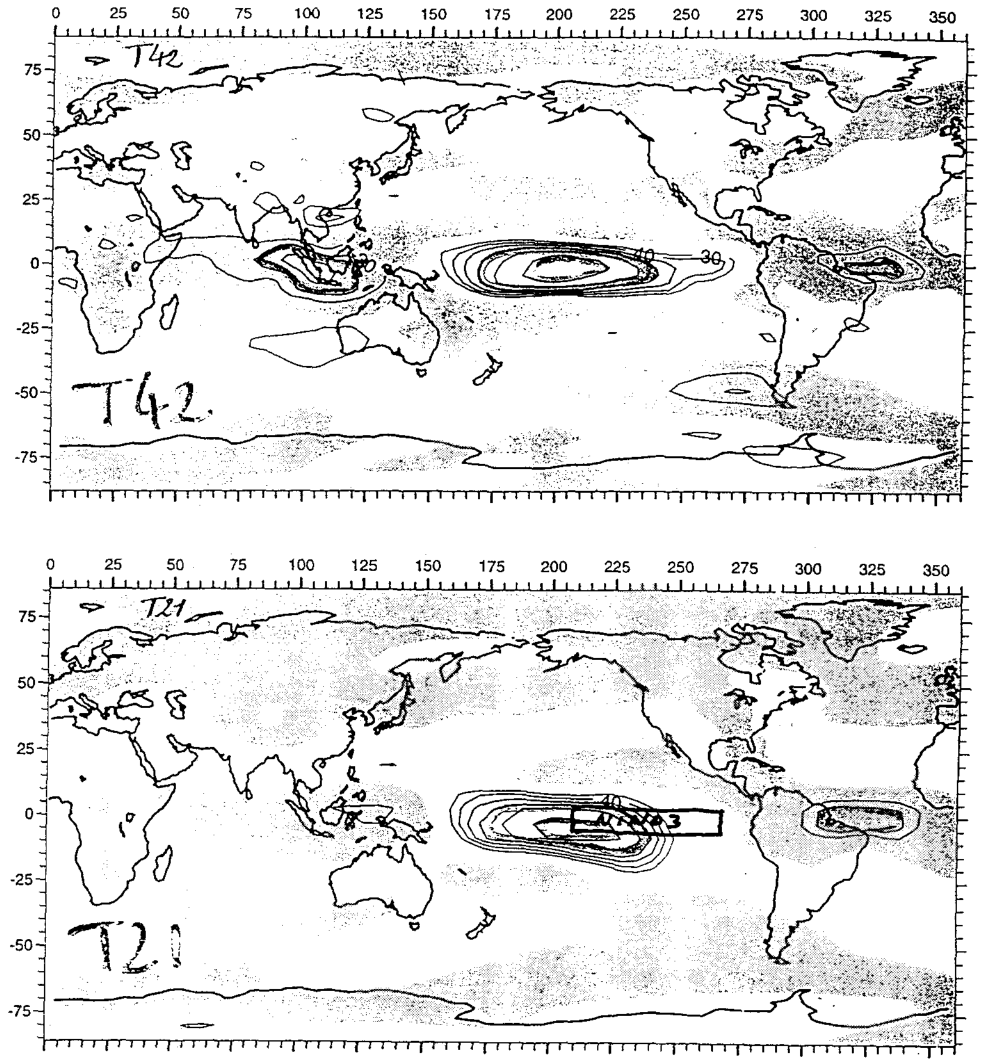


MSLP
Monthly Mean Correlations
min -52.68 max 59.97, shaded .00
col 1, ****** -30.00 10.00
col 1, 30.00 100.00 10.00

SLP

Correlation with Nino 3 SST

850 hPa zonal wind (U850)

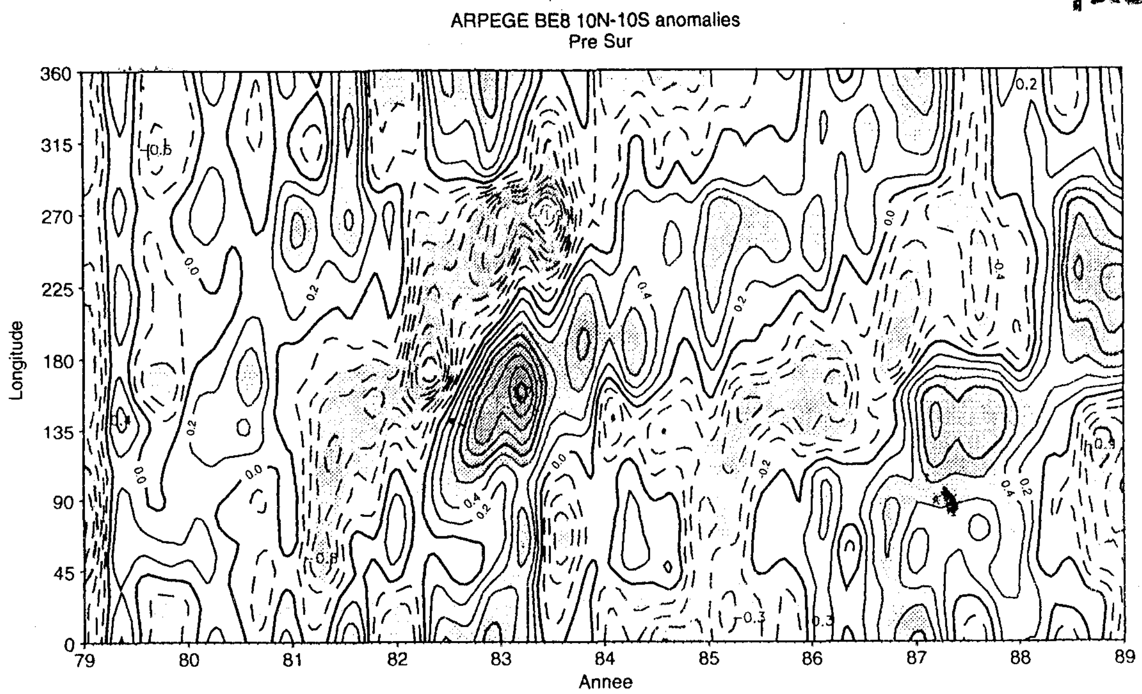


U850
Monthly Mean Correlations
min -50.80 max 84.54, shaded .00
col 1, ****** -30.00 10.00
col 1, 30.00 100.00 10.00

U850

Correlation with Nino 3 SST

T106



Surface pressure

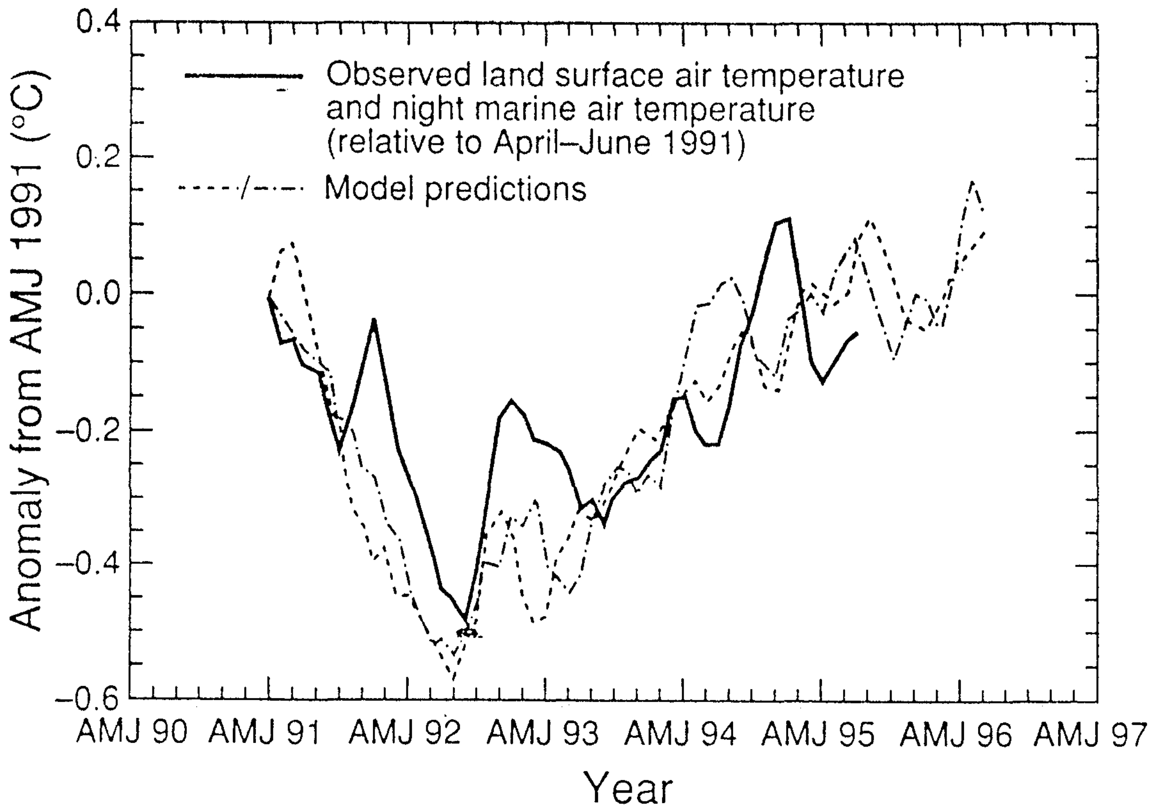


Figure 14: Predicted and observed changes in global land and ocean surface air temperature after the eruption of Mt. Pinatubo.

How to validate the forecasts ?

Skill measures

RMS error

Anomaly correlation coefficient

Synoptic usefulness criterion

ACC > 0.6

Improvement of model skill

Error growth

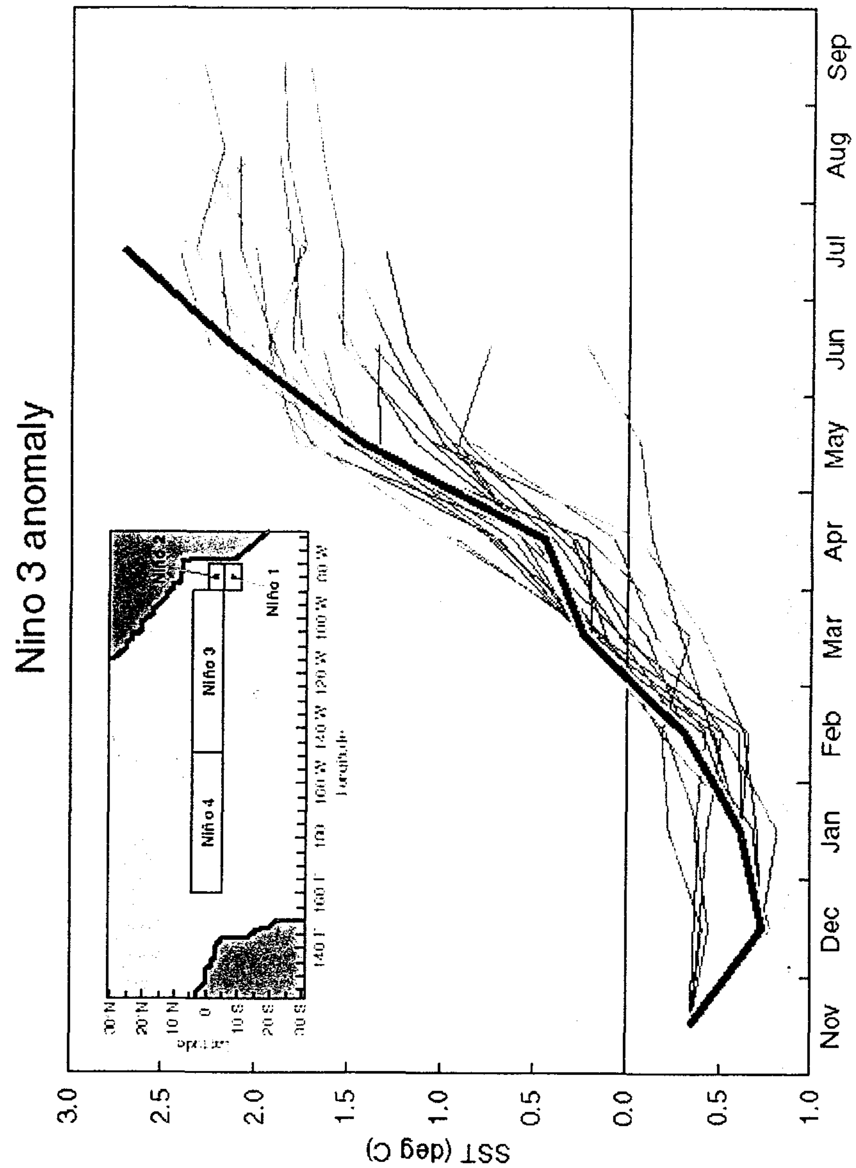
Sensitivity to initial conditions

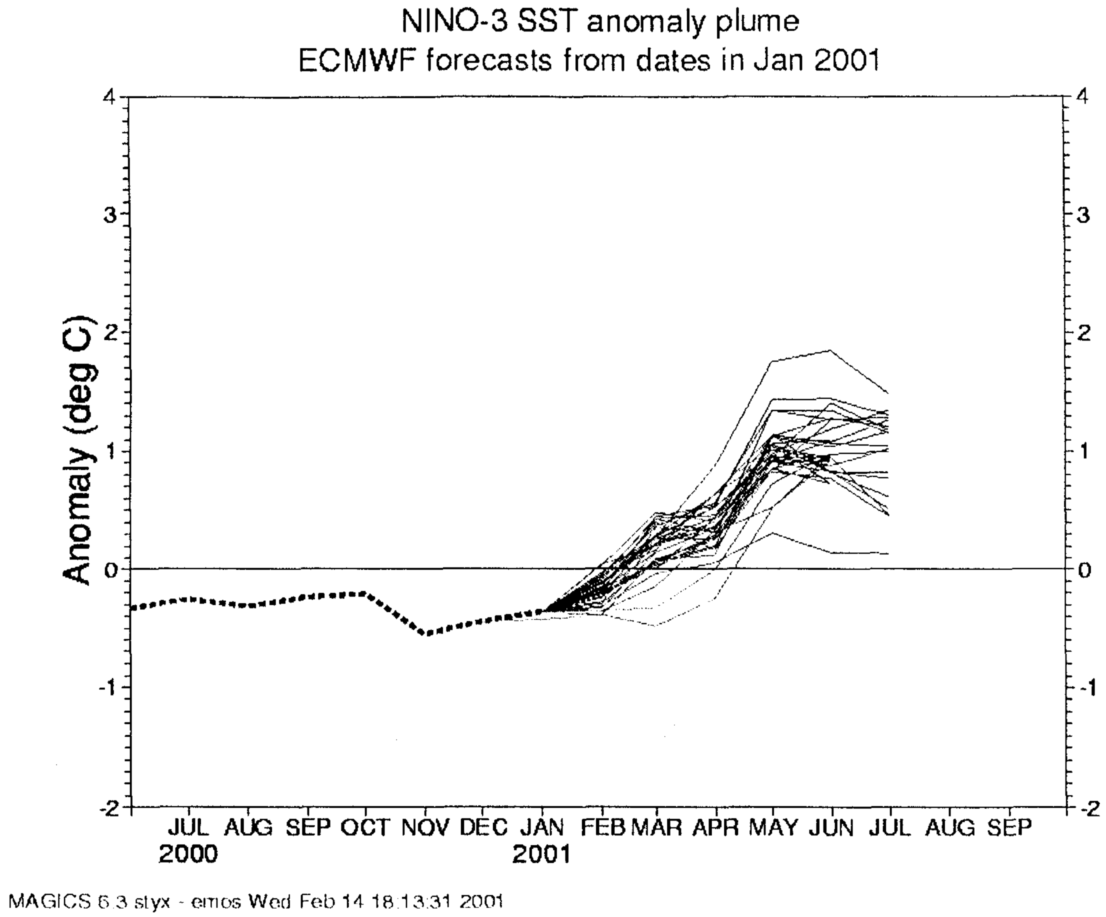
Thompson (1957)

Lorenz (1963, 1982)

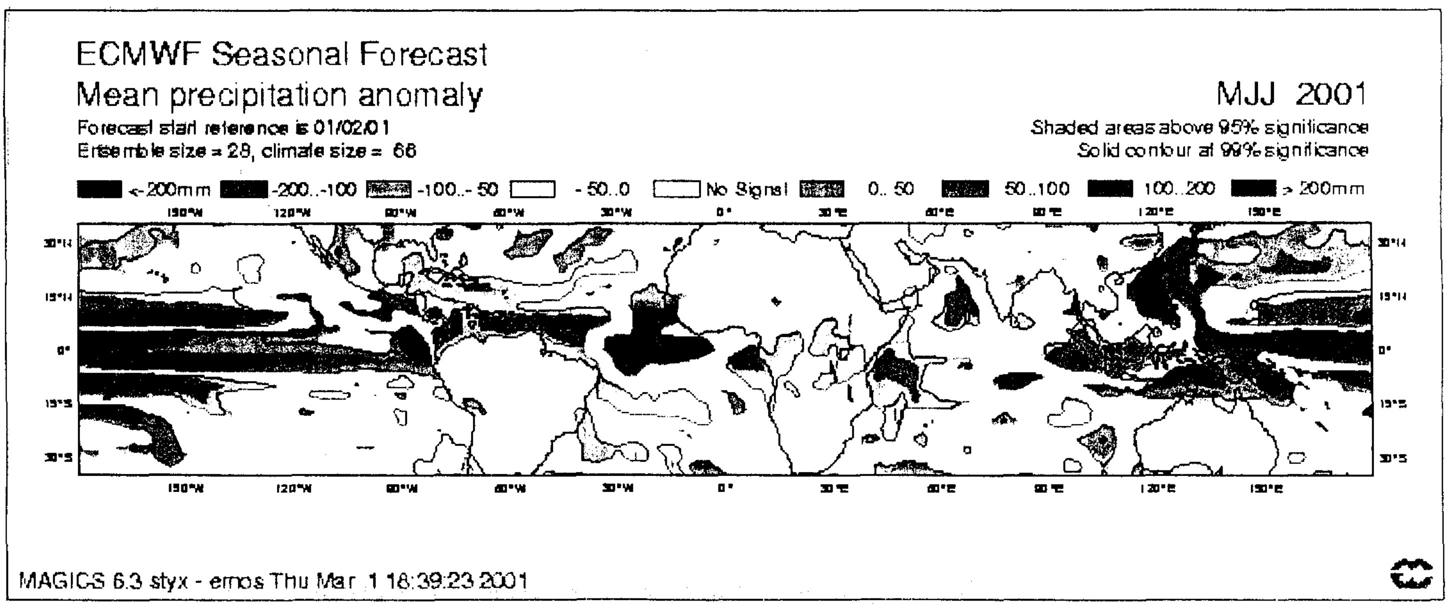
Flow dependence

Scale dependence




NINO-3 SST anomaly plume
ECMWF forecasts from dates in Jan 2001
Anomaly (deg C)
4
3
2
1
0
-1
-2
JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP
2000
2001
MAGICS 6.3 styx - emos Wed Feb 14 18:13:31 2001

31


ECMWF Seasonal Forecast
Mean precipitation anomaly
MJJ 2001
Forecast start reference is 01/02/01
Ensemble size = 28, climate size = 66
Shaded areas above 95% significance
Solid contour at 99% significance
<-200mm
-200..-100
-100..-50
-50..0
No Signal
0..50
50..100
100..200
> 200mm
150°W 120°W 90°W 60°W 30°W 0° 30°E 60°E 90°E 120°E 150°E
30°N
15°N
0°
15°S
30°S
MAGICS 6.3 styx - emos Thu Mar 1 18:39:23 2001

How to improve the forecasts ?

Improvement of the resolution

Mesoscale models

Non-hydrostatic models?

Variable resolution?

Improvement of the Physics

Cloud physics

Surface and boundary layer processes

Improvement of the initial conditions

New observing systems (satellites, radars)

4-dimensional (variational?) assimilation

Increase of the number of forecasts

Ensemble forecasting

Probabilistic forecasts

Perspectives

Regional simulations

- Limited aera models (LAM)
  - Lateral boundaries
- Variable resolution models
  - Mesh refinement
  - grid stretching methods
- Statistical downscaling methods

Improvement of physical parameterizations

- Cloud processes
- aerosols
- Boundary layer
- Convective systems
- Mesoscale circulations

Increase of computer power

- Improvement of model resolution
- Ensemble simulations
- Long-term variability
- Multicomponent coupled models
  - Vegetation
  - Hydrology
  - chemistry

Recommended books:

Mote, P and A O'Neill, Eds , 2000 Numerical Modeling of the Global Atmosphere in the Climate System (NATO Science Series, Vol C 550) Kluwer Academic Publishers, Dordrecht, 517 pp

Randall, D J , Ed , 2000 General Circulation Model Development - Past, Present and Future (Arakawa Festschrift) (International Geophysics Series, Volume 70). Academic Press, San Diego, FL, 807 pp

Jacobson, M Z., 1999 Fundamentals of Atmospheric Modeling Cambridge University Press, New York, 656 pp

Beniston, M., 1998. From Turbulence to Climate Numerical Investigations of the Atmosphere with a Hierarchy of Models Springer, Berlin, 328 pp

Krishnamurti, T N., H S Bedi and V Hardiker, 1998 An Introduction to Global Spectral Modeling Oxford University Press, New York, 253 pp.

McGuffie, K and A Henderson-Sellers, 1997 A Climate Modelling Primer, 2nd ed. John Wiley and Sons, Chichester, 253 pp

Krishnamurti, T.N. and L. Bounoua, 1996 An Introduction to Numerical Weather Prediction Techniques CRC Press, Boca Raton, FL, 293 pp

Trenberth, K E., Ed , 1992 Climate System Modelling Cambridge University Press, Cambridge, 788 pp

Schlesinger, M.E , Ed , 1988 Physically-Based Modelling and Simulation of Climate and Climatic Change Part 2 (NATO ASI Series - C Mathematical and Physical Sciences, 243). Kluwer Academic Publishers, Dordrecht, 625-1084 pp

Schlesinger, M E., Ed , 1988 Physically-Based Modelling and Simulation of Climate and Climatic Change Part I (NATO ASI Series - C Mathematical and Physical Sciences, 243) Kluwer Academic Publishers, Dordrecht, 624 pp

Washington, W M and C L Parkinson, 1986 An Introduction to Three-Dimensional Climate Modelling Oxford University Press, Oxford, 422 pp

Applications of GCM:

Houghton, J T , L G Meira Filho, B A Callander, N Harris, A Kattenberg and K Maskell, Eds , 1996 Climate Change 1995 The Science of Climate Change - Contribution of Working Group 1 to the Second Assessment Report of the Intergovernmental Panel on Climate Change Cambridge University Press, New York, 572 pp

Le Treut, H., Ed., 1996 Climate Sensitivity to Radiative Perturbations. Physical Mechanisms and their Validation (NATO ASI Series, I 34) Springer-Verlag, Berlin Heidelberg New York, 331 pp

Nesme-Ribes, E , Ed., 1994. The Solar Engine and its Influence on Terrestrial Atmosphere and Climate (NATO ASI Series - I· Global Environmental Change, I 25) Springer-Verlag, Berlin Heidelberg, 561 pp (Proceedings of the NATO Advanced Research Workshop on the Solar Engine and Its Influence on Terrestrial Atmosphere and Climate, held in Paris, France, October 25 - 29, 1993,)

Shukla, J., Ed , 1993 Prediction of Interannual Climate Variations (NATO ASI Series, I 6). Springer-Verlag, Berlin Heidelberg New York, 265 pp (Proceedings of the NATO Advanced Research Workshop on Prediction of Interannual Climate Variations held at Trieste, Italy, July 22-26, 1991,)

Internet links

ECMWF model description

- http://www ecmwf.int/research/ifsdocs/PHYSICS/index.html

Atmospheric Model Intercomparison Project (AMIP)

- http://www-pcmdi.llnl gov/amip/

NCAR CCSM: Community Climate System Model

- http://www cgd.ucar edu/csm/

IPCC Data Distribution Centre

- http://ipcc-ddc cru uea ac uk/