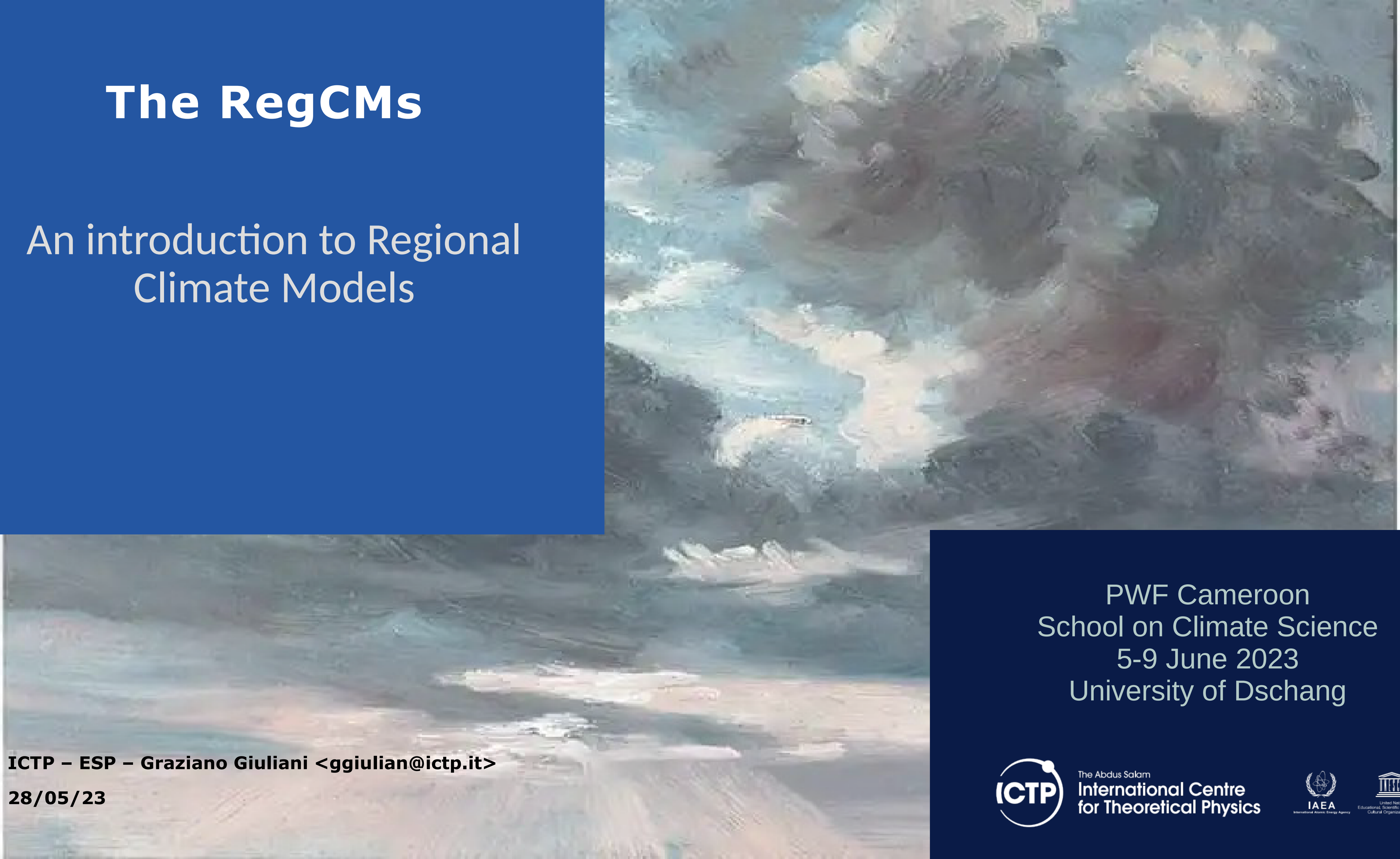
The RegCMs

An introduction to Regional Climate Models



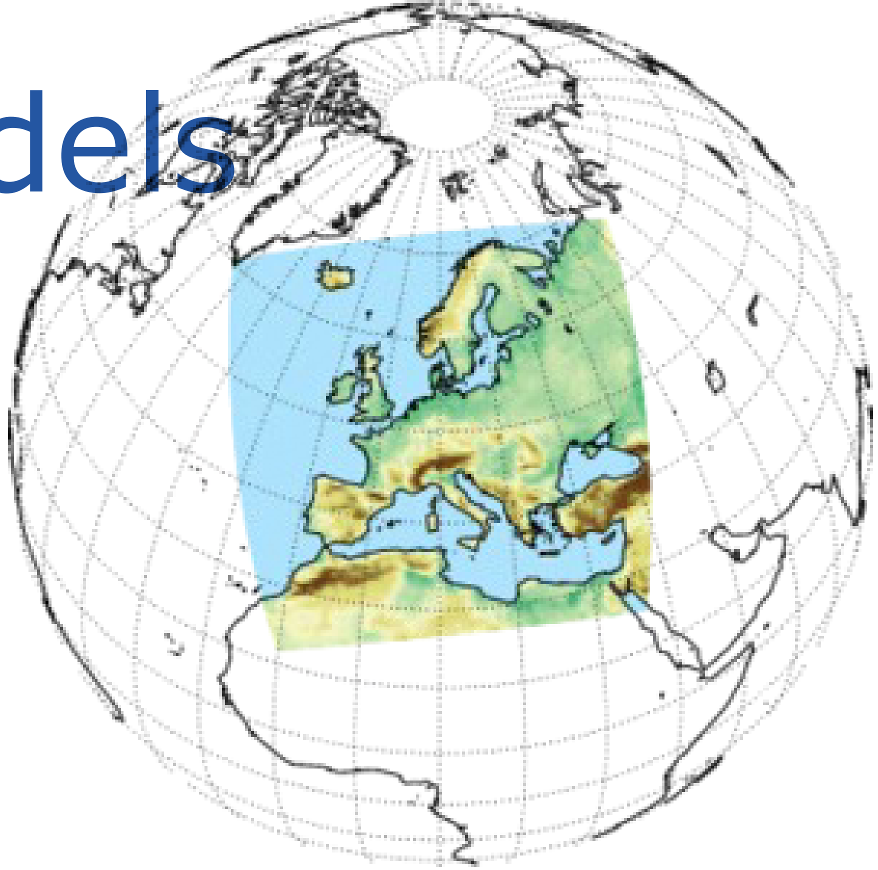
PWF Cameroon
School on Climate Science
5-9 June 2023
University of Dschang

ICTP – ESP – Graziano Giuliani <ggiulian@ictp.it>

28/05/23

The Abdus Salam International Centre for Theoretical Physics

Regional Climate Models

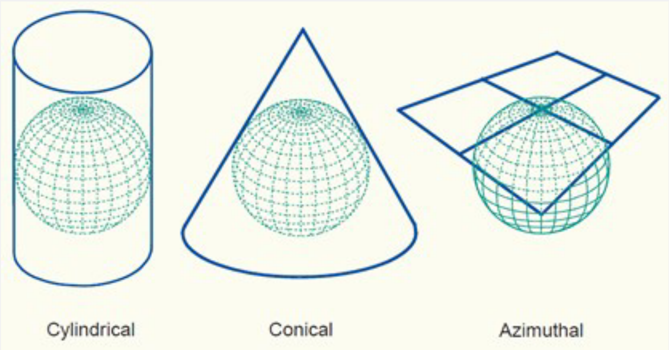


- Computer programs performing a physical down-scaling over a limited domain region of the Earth
- Numerical discretized equations solved in a full 3D flattened box domain
- Use same radiation boundary conditions as GCM
- Performances evaluated by comparing results obtained when using Reanalysis data as BC
- Future scenario predicted using CMIP GCMs as BC

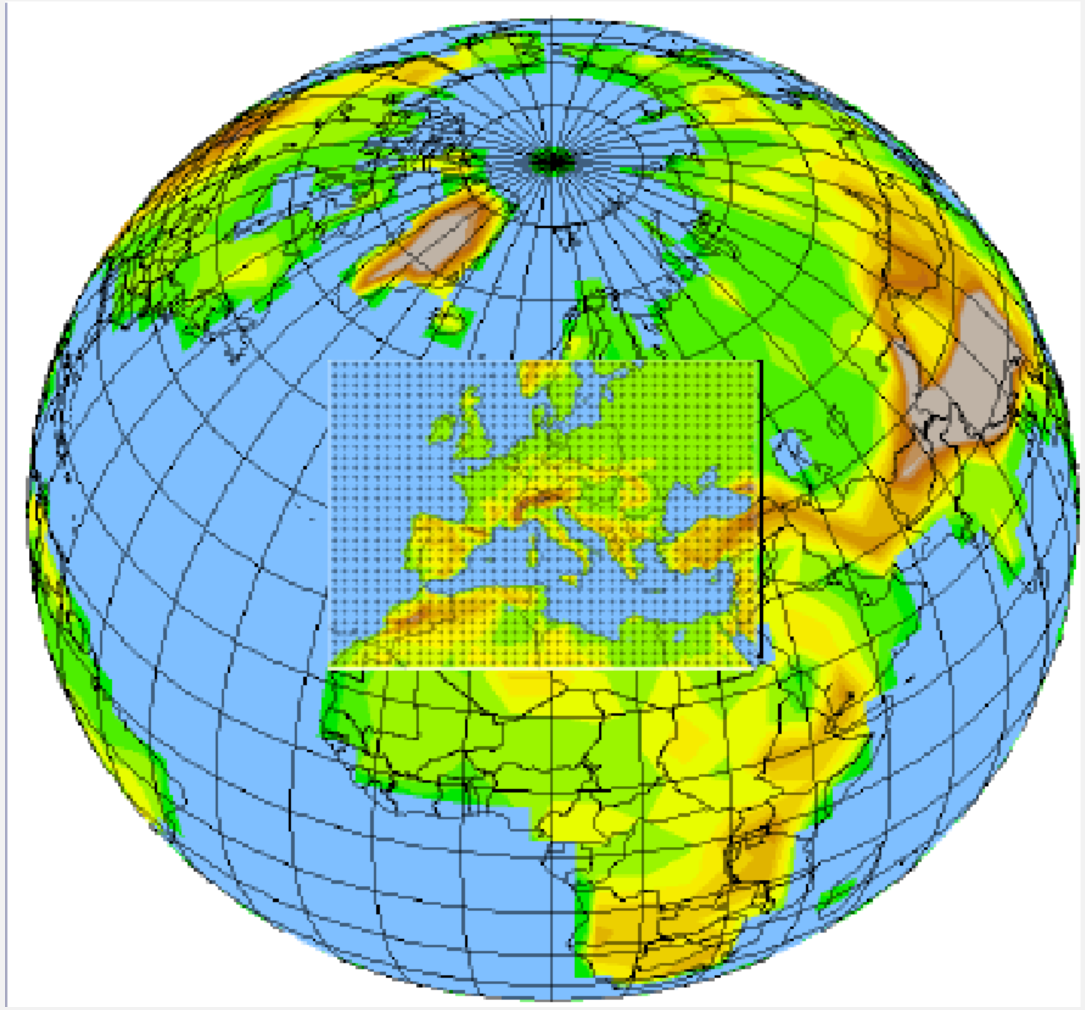
Projection – flattening the earth

- A map projection is a set of transformations used to represent the curved two-dimensional surface of a globe on a plane.
- All projections distort the surface in some way and to some extent.
- Different map projections exist in order to preserve some properties of the sphere-like body at the expense of other properties.

Mathematically, a sphere has not null Gaussian curvature, while a plane, a cylinder or a cone have zero Gaussian curvature and are developable surfaces. This mean You can construct them from a sheet of paper. You cannot create a spherical shape from a single sheet of paper.



GCM resolution



Motivation: The resolution of GCMs is still too coarse to capture regional and local climate processes.

Technique: Regional Climate Model (RCM) is one way nested within a GCM in order to locallyincrease the model resolution.

- Atmospheric Initial conditions (IC) and lateral boundary conditions (LBC) for the RCM are obtained from the GCM (Climate projection) or Reanalysis (perfect LBC Hindcast).
- Climate boundary conditions are the same of the driving GCM : the RCPs in CMIP Strategy: The GCM simulates the response of the general circulation to the large scale forcings, the RCM simulates the effect of sub-GCM-grid scale forcings and provides fine scale regional information

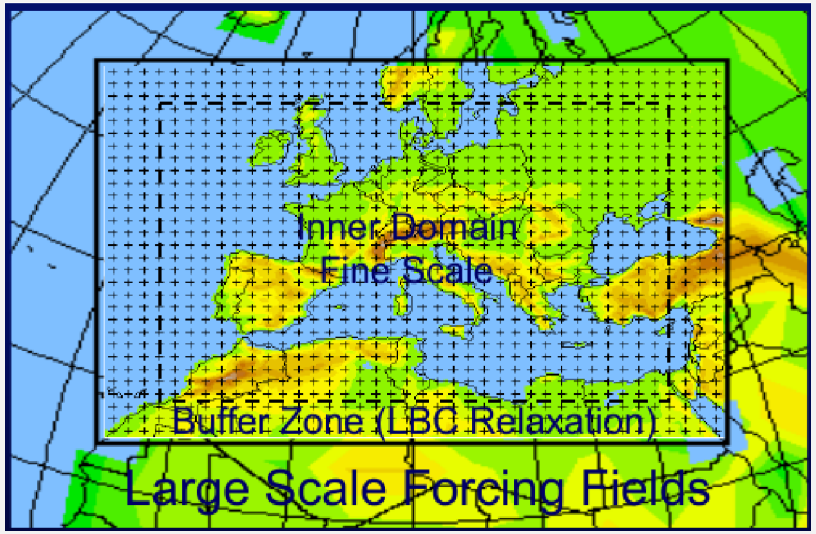
Technique borrowed from NWP

Boundary condition

$$\frac{\partial \alpha}{\partial t} = F(n) F_1 (\alpha_{LBC} - \alpha_{mod}) - F(n) F_2 \Delta_2 (\alpha_{LBC} - \alpha_{mod})$$

The Regional model receives the physical boundary conditions from a Global model

- Past : Reanalysis experiments
  - ECMWF : ERA (EIN)
  - NCEP – NCAR : NNRP
  - JMA : JRA
- Future : CMIP GCM
  - CMIP3
  - CMIP5
  - CMIP6



ECMWF

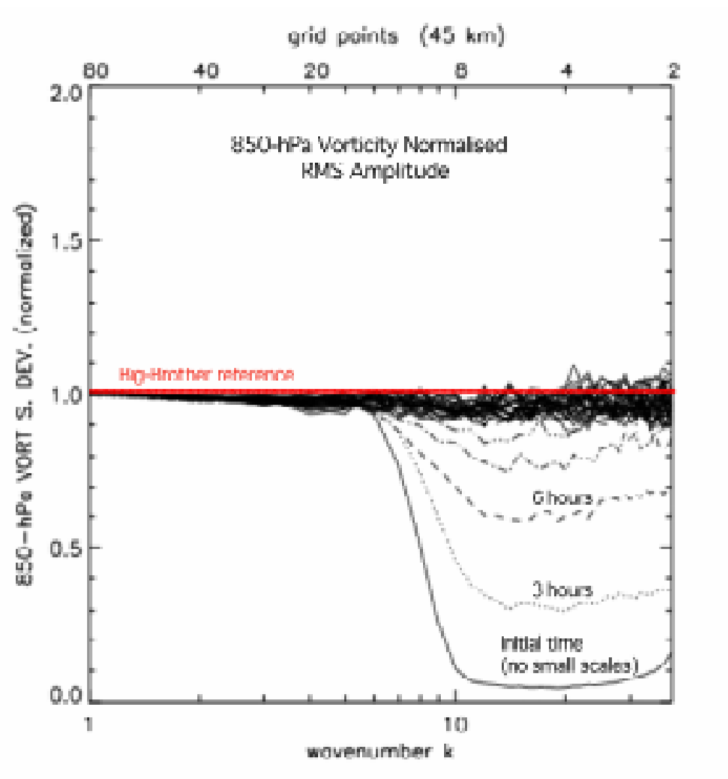
NCEP

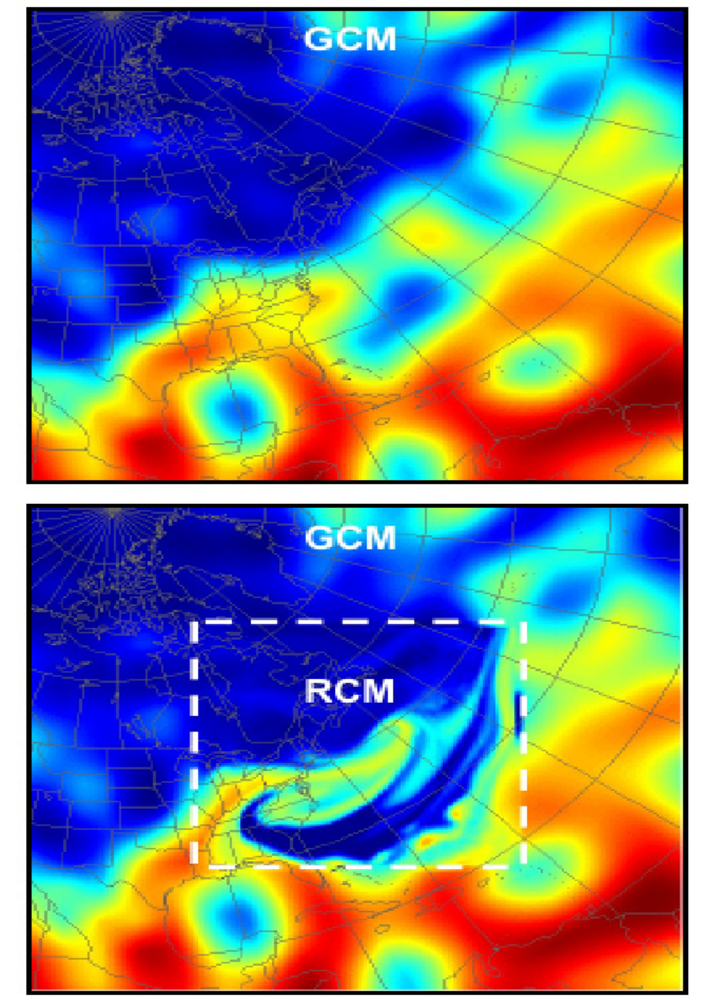
JRA

WCRP World Climate Research Programme

Down-scaling results

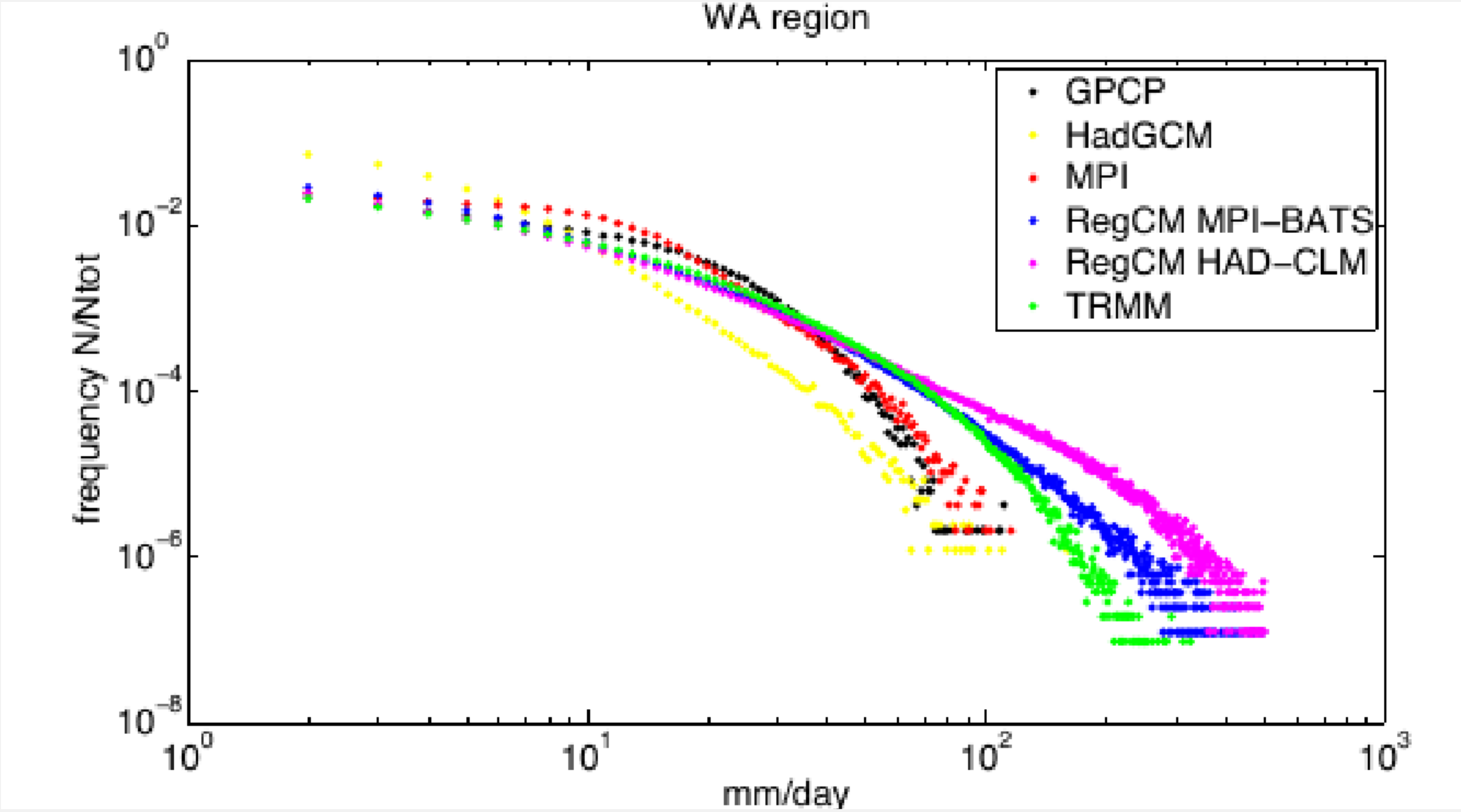
Dynamical Downscaling: Generation of small scales by a high-resolution RCM driven by low-resolution GCM data (See 900 hPa specific humidity right) (From R. Laprise)





Extreme description

The GCM is close to the coarse resolution data, the RCMs to the high resolution data
This is what we expect from a downscaling exercise



Regional Climate Model

Pros

- Physically based down-scaling
  - Comprehensive climate modeling system
- Wide variety of applications
  - Process studies
  - Paleo-climate
  - Climate change
  - Seasonal prediction
- High resolution through multiple nesting
  - currently 3 to 50 km grid interval

Cons

- One-way nesting
  - No regional-to-global feedbacks
- Technical issues in the nesting technique
  - Domain, LBC procedure, physics, etc.
- Not intended to correct systematic errors in the large scale forcing fields
  - ***Always analyze first the forcing fields***
- Computationally demanding

COMPONENTS

Dynamical Core

Solve one form or another of the Navier-Stokes equations for the motion of fluids.

Navier–Stokes Equations
3 – dimensional – unsteady

Glenn Research Center

Coordinates: (x,y,z)
Velocity Components: (u,v,w)

Time : t
Density: ρ
Total Energy: Et

Pressure: p
Stress: τ

Heat Flux: q
Reynolds Number: Re
Prandtl Number: Pr

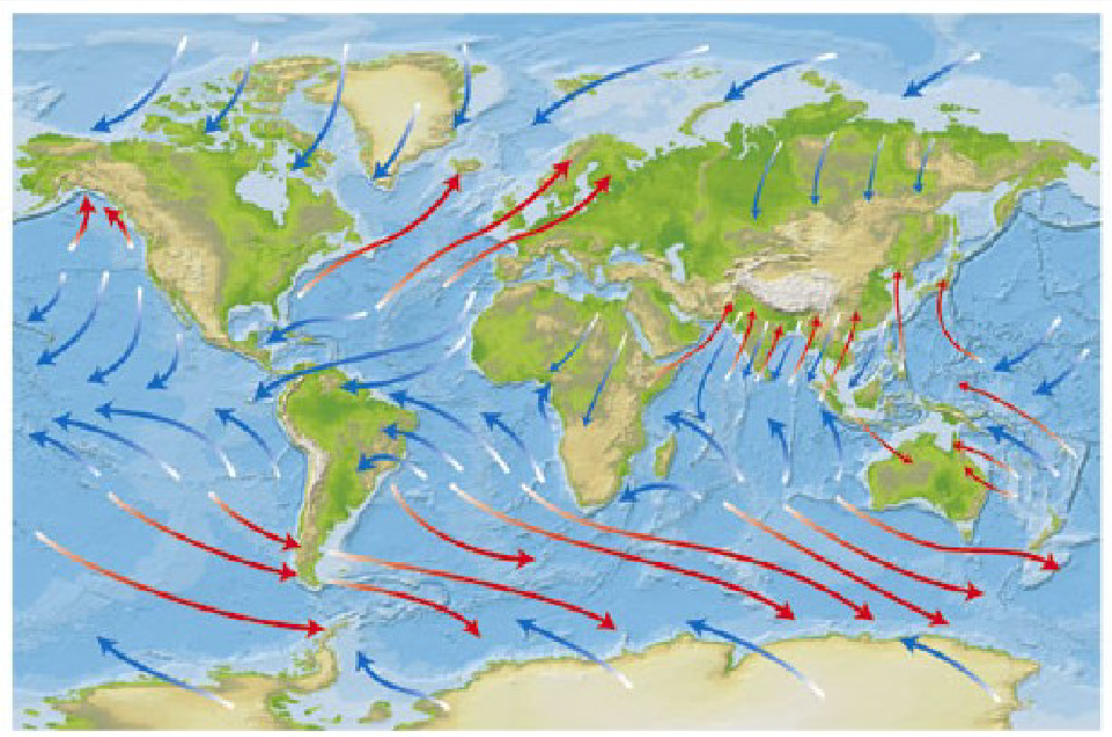
Continuity:
$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} + \frac{\partial(\rho w)}{\partial z} = 0$$

X – Momentum:
$$\frac{\partial(\rho u)}{\partial t} + \frac{\partial(\rho u^2)}{\partial x} + \frac{\partial(\rho uv)}{\partial y} + \frac{\partial(\rho uw)}{\partial z} = -\frac{\partial p}{\partial x} + \frac{1}{Re_r}\left[\frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{xy}}{\partial y} + \frac{\partial \tau_{xz}}{\partial z}\right]$$

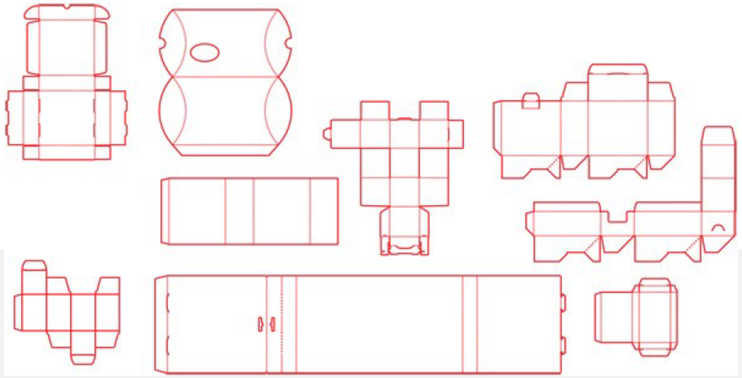
Y – Momentum:
$$\frac{\partial(\rho v)}{\partial t} + \frac{\partial(\rho uv)}{\partial x} + \frac{\partial(\rho v^2)}{\partial y} + \frac{\partial(\rho vw)}{\partial z} = -\frac{\partial p}{\partial y} + \frac{1}{Re_r}\left[\frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \tau_{yy}}{\partial y} + \frac{\partial \tau_{yz}}{\partial z}\right]$$

Z – Momentum
$$\frac{\partial(\rho w)}{\partial t} + \frac{\partial(\rho uw)}{\partial x} + \frac{\partial(\rho vw)}{\partial y} + \frac{\partial(\rho w^2)}{\partial z} = -\frac{\partial p}{\partial z} + \frac{1}{Re_r}\left[\frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial \tau_{zz}}{\partial z}\right]$$

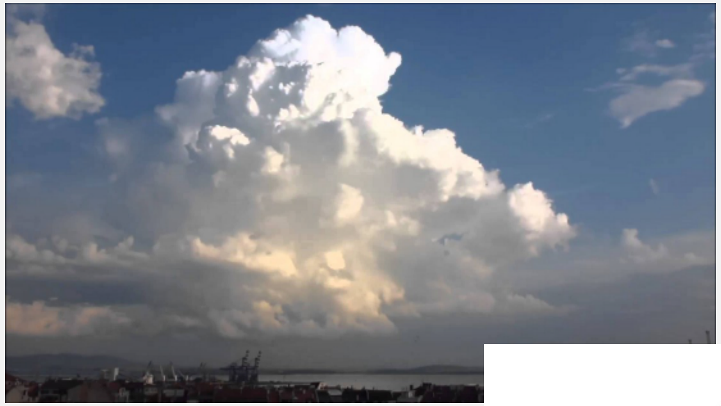
Energy:
$$\frac{\partial(E_T)}{\partial t} + \frac{\partial(uE_T)}{\partial x} + \frac{\partial(vE_T)}{\partial y} + \frac{\partial(wE_T)}{\partial z} = -\frac{\partial(up)}{\partial x} - \frac{\partial(vp)}{\partial y} - \frac{\partial(wp)}{\partial z} - \frac{1}{Re_r Pr_r}\left[\frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y} + \frac{\partial q_z}{\partial z}\right]$$
$$+ \frac{1}{Re_r}\left[\frac{\partial}{\partial x}(u\,\tau_{xx} + v\,\tau_{xy} + w\,\tau_{xz}) + \frac{\partial}{\partial y}(u\,\tau_{xy} + v\,\tau_{yy} + w\,\tau_{yz}) + \frac{\partial}{\partial z}(u\,\tau_{xz} + v\,\tau_{yz} + w\,\tau_{zz})\right]$$

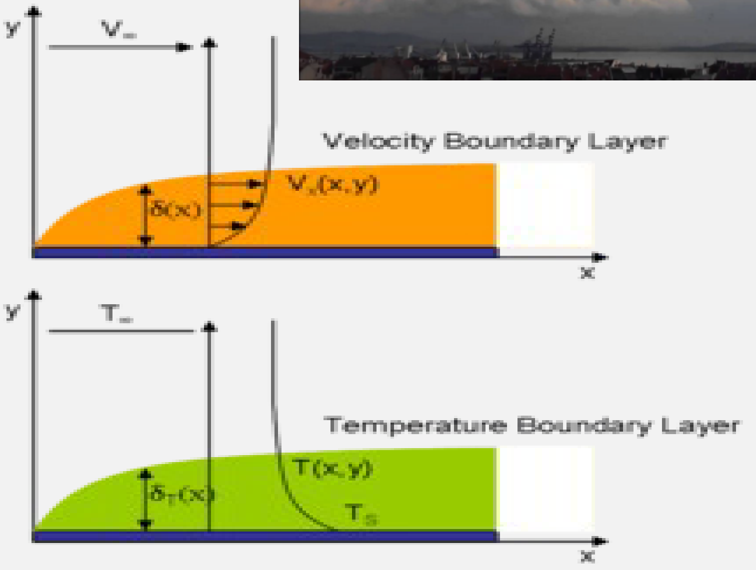


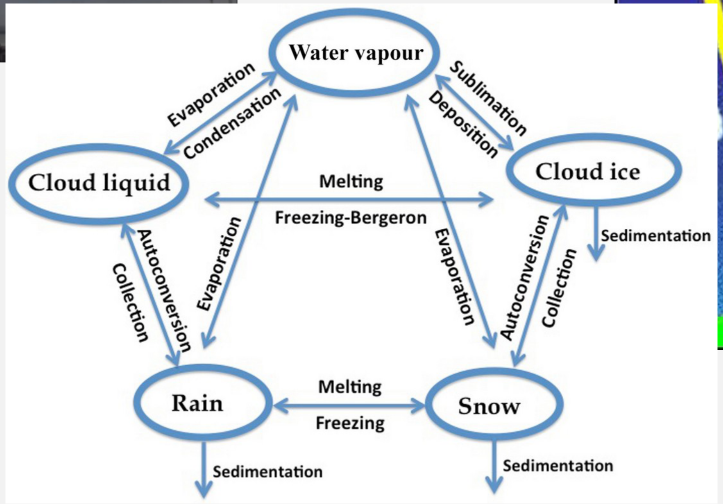
Physics packages

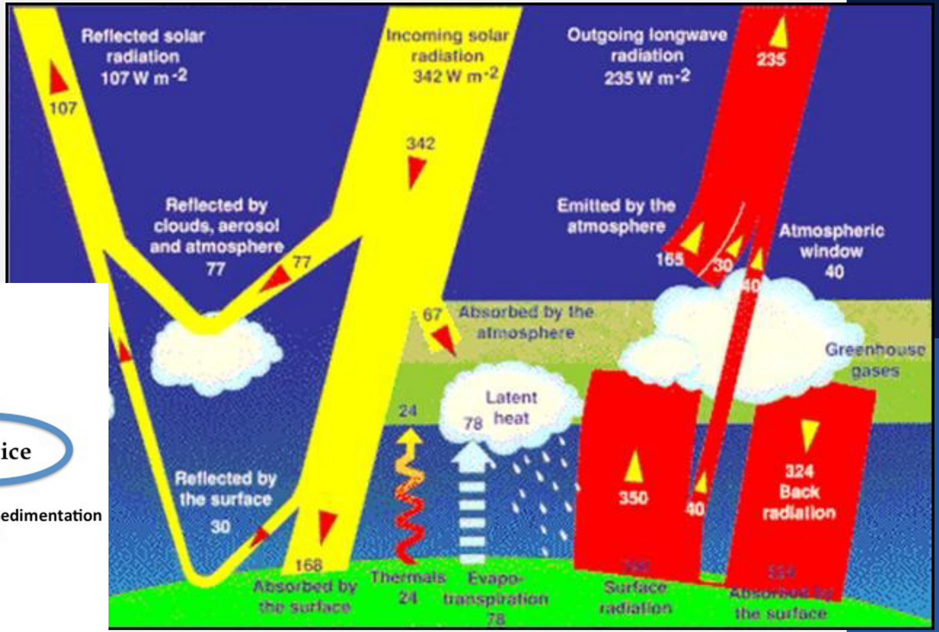


Parameterized solvers for sub-grid scale
non resolved physical processes

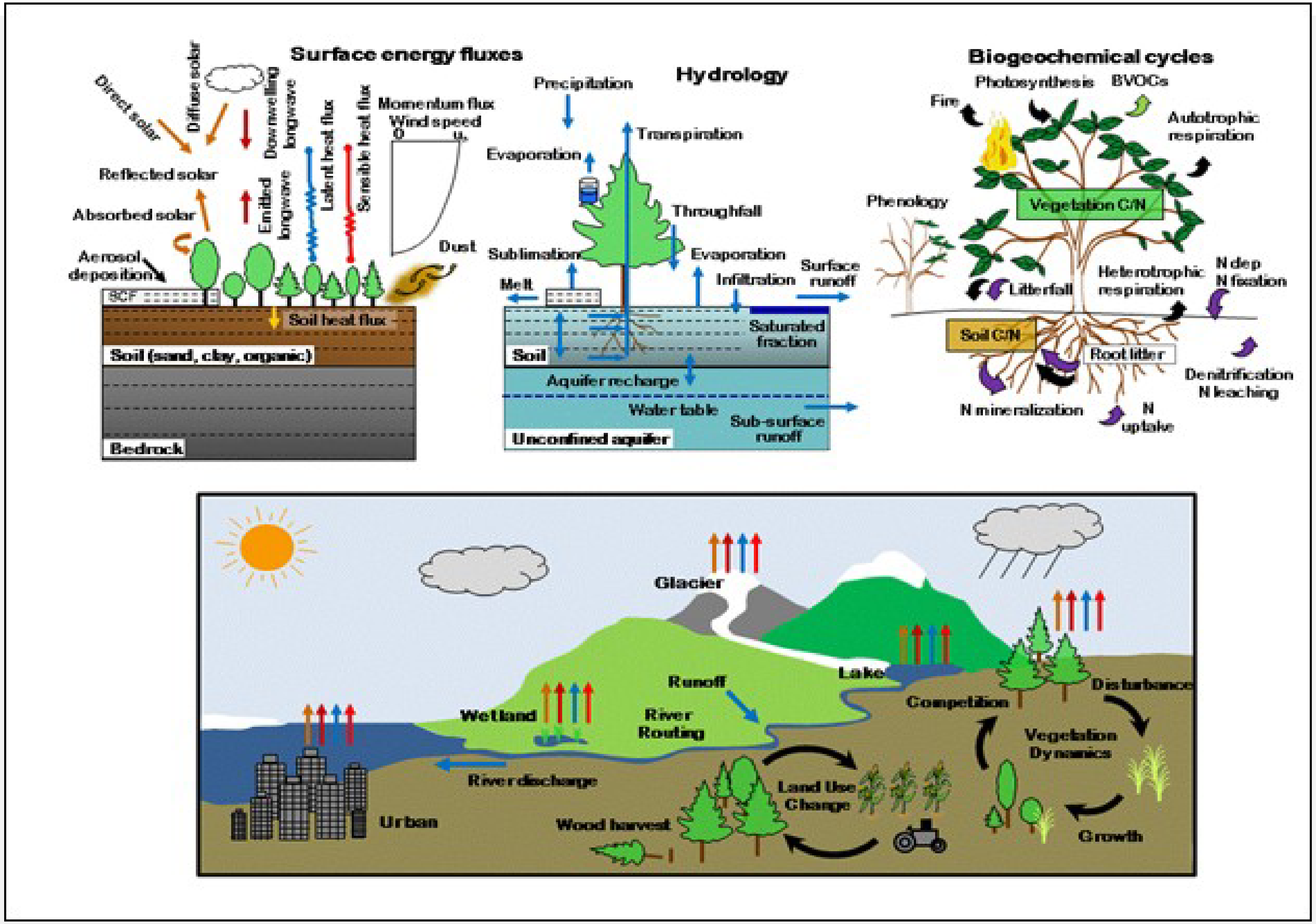




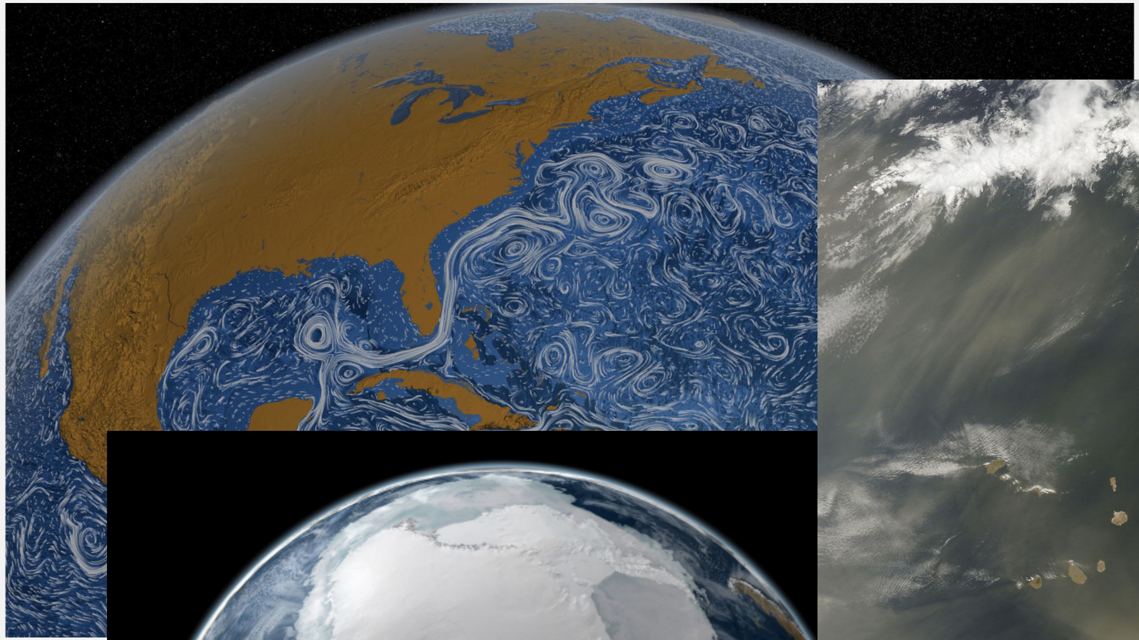


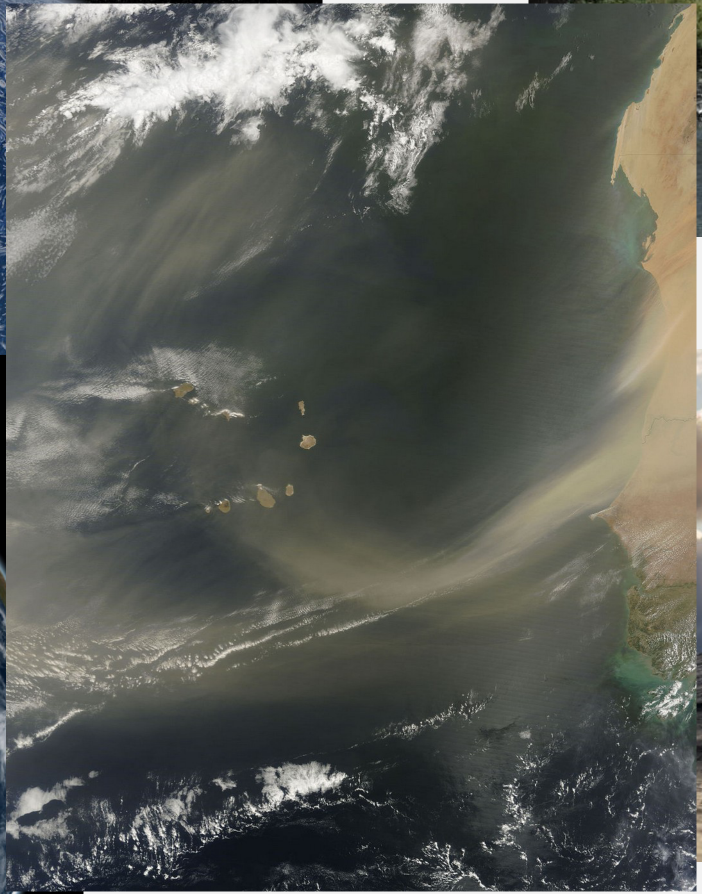


Required coupling



Optional coupling

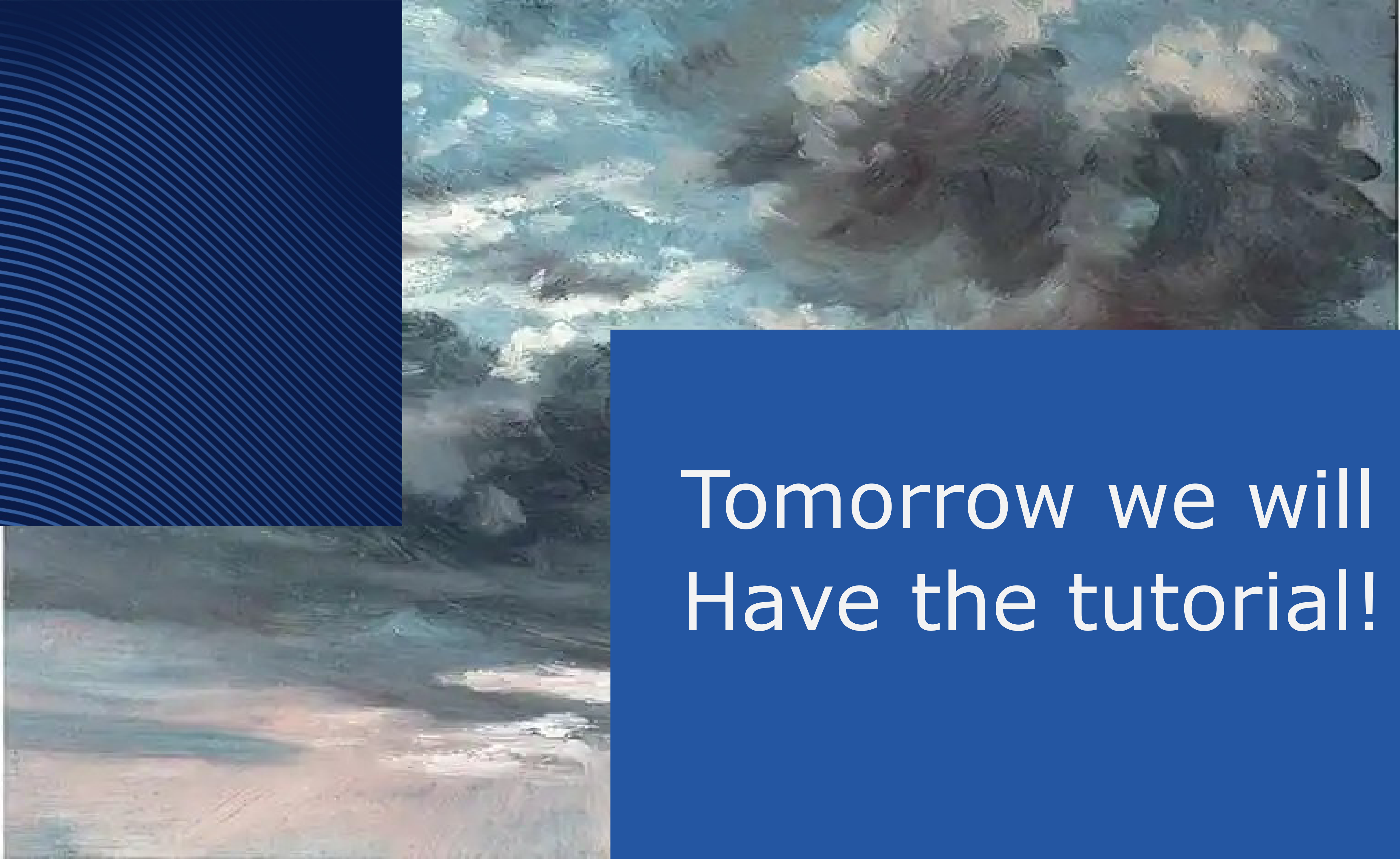




Community Experiment

WCRP CORDEX

Coordinated Regional Climate Downscaling Experiment



Tomorrow we will
Have the tutorial!

The RegCMs

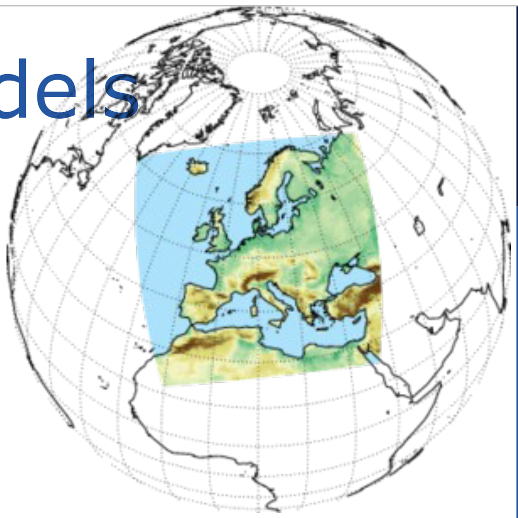
An introduction to Regional Climate Models

ICTP – ESP – Graziano Giuliani <ggiulian@ictp.it>
28/05/23

PWF Cameroon
School on Climate Scienc
5-9 June 2023
University of Dschang

The Abdus Salam International Centre for Theoretical Physics
IAEA

Regional Climate Models

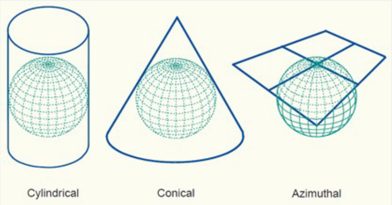


- Computer programs performing a physical down-scaling over a limited domain region of the Earth
- Numerical discretized equations solved in a full 3D flattened box domain
- Use same radiation boundary conditions as GCM
- Performances evaluated by comparing results obtained when using Reanalysis data as BC
- Future scenario predicted using CMIP GCMs as BC

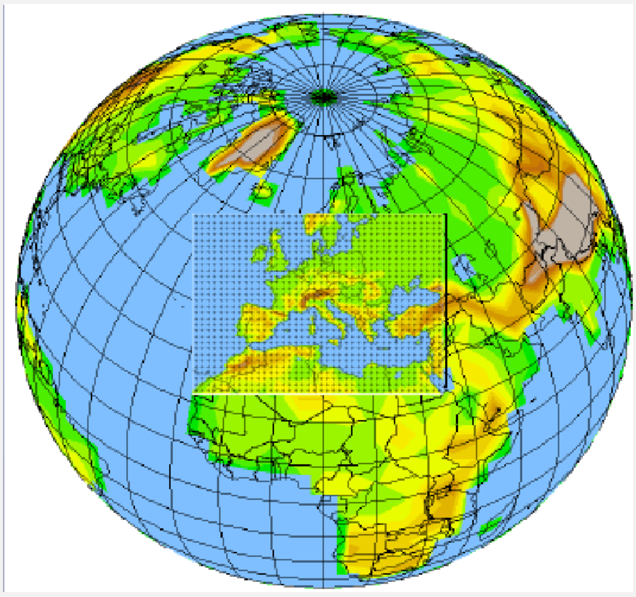
Projection – flattening the earth

- A map projection is a set of transformations used to represent the curved two-dimensional surface of a globe on a plane.
- All projections distort the surface in some way and to some extent.
- Different map projections exist in order to preserve some properties of the sphere-like body at the expense of other properties.

Mathematically, a sphere has not null Gaussian curvature, while a plane, a cylinder or a cone have zero Gaussian curvature and are developable surfaces. This mean You can construct them from a sheet of paper. You cannot create a spherical shape from a single sheet of paper.



GCM resolution



Motivation: The resolution of GCMs is still too coarse to capture regional and local climate processes.

Technique: Regional Climate Model (RCM) is one way nested within a GCM in order to locallyincrease the model resolution.

- Atmospheric Initial conditions (IC) and lateral boundary conditions (LBC) for the RCM are obtained from the GCM (Climate projection) or Reanalysis (perfect LBC Hindcast).
- Climate boundary conditions are the same of the driving GCM : the RCPs in CMIP Strategy: The GCM simulates the response of the general circulation to the large scale forcings, the RCM simulates the effect of sub-GCM-grid scale forcings and provides fine scale regional information

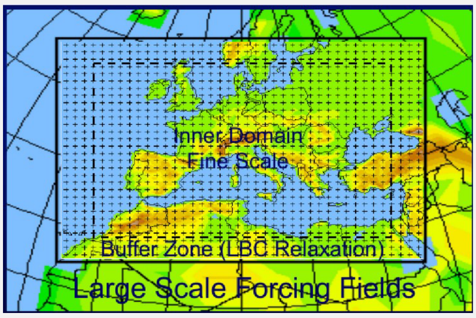
Technique borrowed from NWP

Boundary condition

$$\frac{\partial \alpha}{\partial t} = F(n) F_1 (\alpha_{LBC} - \alpha_{mod}) - F(n) F_2 \Delta_2 (\alpha_{LBC} - \alpha_{mod})$$

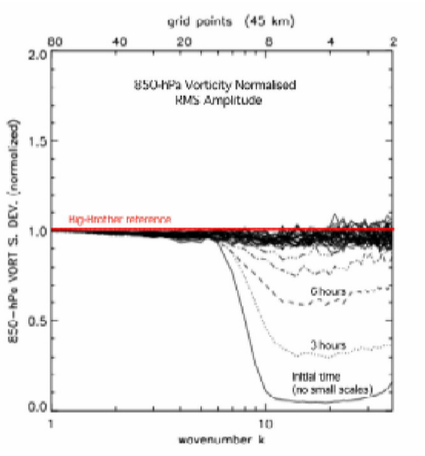
The Regional model receives the physical boundary conditions from a Global model

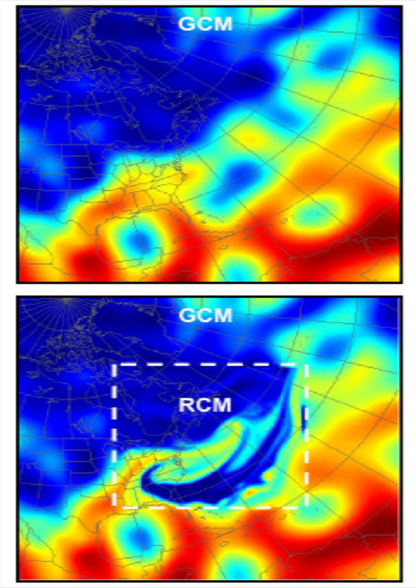
- Past : Reanalysis experiments
  - ECMWF : ERA (EIN)
  - NCEP – NCAR : NNRP
  - JMA : JRA
- Future : CMIP GCM
  - CMIP3
  - CMIP5
  - CMIP6



Down-scaling results

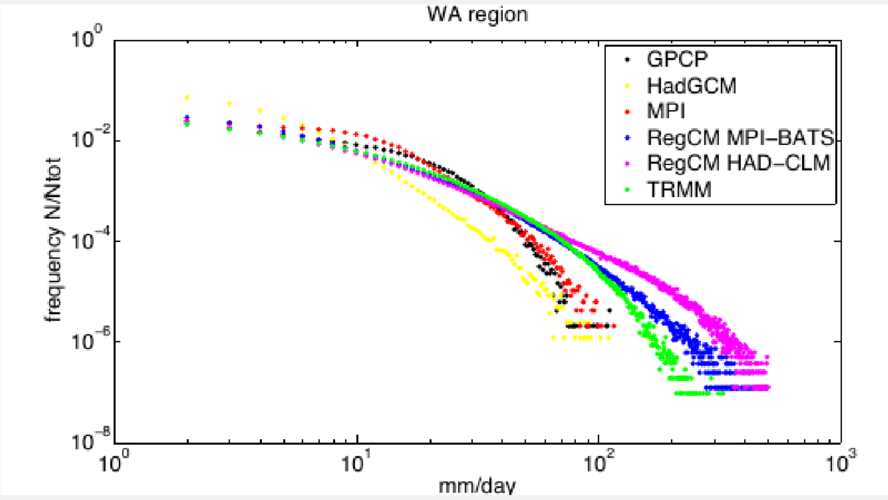
Dynamical Downscaling: Generation of small scales by a high-resolution RCM driven by low-resolution GCM data (See 900 hPa specific humidity right) (From R. Laprise)





Extreme description

The GCM is close to the coarse resolution data, the RCMs to the high resolution data
This is what we expect from a downscaling exercise



Regional Climate Model

Pros

- Physically based down-scaling
  - Comprehensive climate modeling system
- Wide variety of applications
  - Process studies
  - Paleo-climate
  - Climate change
  - Seasonal prediction
- High resolution through multiple nesting
  - currently 3 to 50 km grid interval

Cons

- One-way nesting
  - No regional-to-global feedbacks
- Technical issues in the nesting technique
  - Domain, LBC procedure, physics, etc.
- Not intended to correct systematic errors in the large scale forcing fields
  - ***Always analyze first the forcing fields***
- Computationally demanding

COMPONENTS

Dynamical Core

Solve one form or another of the Navier-Stokes equations for the motion of fluids.

Navier–Stokes Equations
3 – dimensional – unsteady

Glenn Research Center

Coordinates: (x,y,z)
Velocity Components: (u,v,w)

Time : t
Density: ρ
Total Energy: Et

Pressure: p
Stress: τ

Heat Flux: q
Reynolds Number: Re
Prandtl Number: Pr

Continuity:

$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} + \frac{\partial(\rho w)}{\partial z} = 0$$

X – Momentum:

$$\frac{\partial(\rho u)}{\partial t} + \frac{\partial(\rho u^2)}{\partial x} + \frac{\partial(\rho uv)}{\partial y} + \frac{\partial(\rho uw)}{\partial z} = -\frac{\partial p}{\partial x} + \frac{1}{Re_r}\left[\frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{xy}}{\partial y} + \frac{\partial \tau_{xz}}{\partial z}\right]$$

Y – Momentum:

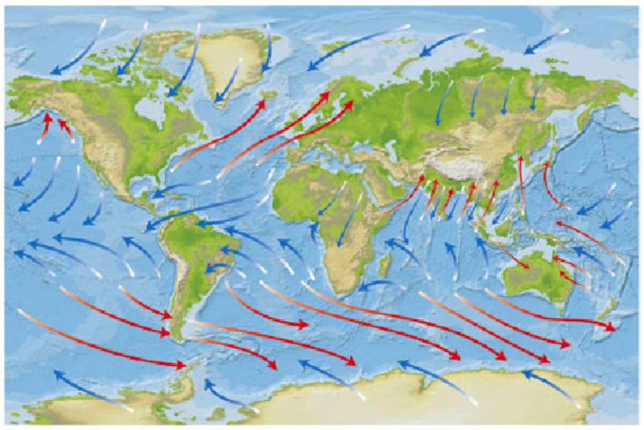
$$\frac{\partial(\rho v)}{\partial t} + \frac{\partial(\rho uv)}{\partial x} + \frac{\partial(\rho v^2)}{\partial y} + \frac{\partial(\rho vw)}{\partial z} = -\frac{\partial p}{\partial y} + \frac{1}{Re_r}\left[\frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \tau_{yy}}{\partial y} + \frac{\partial \tau_{yz}}{\partial z}\right]$$

Z – Momentum

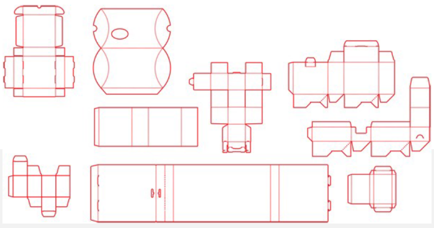
$$\frac{\partial(\rho w)}{\partial t} + \frac{\partial(\rho uw)}{\partial x} + \frac{\partial(\rho vw)}{\partial y} + \frac{\partial(\rho w^2)}{\partial z} = -\frac{\partial p}{\partial z} + \frac{1}{Re_r}\left[\frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial \tau_{zz}}{\partial z}\right]$$

Energy:

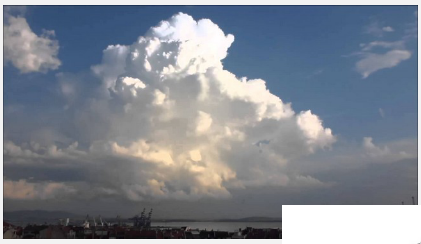
$$\frac{\partial(E_T)}{\partial t} + \frac{\partial(uE_T)}{\partial x} + \frac{\partial(vE_T)}{\partial y} + \frac{\partial(wE_T)}{\partial z} = -\frac{\partial(up)}{\partial x} - \frac{\partial(vp)}{\partial y} - \frac{\partial(wp)}{\partial z} - \frac{1}{Re_r Pr_r}\left[\frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y} + \frac{\partial q_z}{\partial z}\right]$$
$$+ \frac{1}{Re_r}\left[\frac{\partial}{\partial x}(u\,\tau_{xx} + v\,\tau_{xy} + w\,\tau_{xz}) + \frac{\partial}{\partial y}(u\,\tau_{xy} + v\,\tau_{yy} + w\,\tau_{yz}) + \frac{\partial}{\partial z}(u\,\tau_{xz} + v\,\tau_{yz} + w\,\tau_{zz})\right]$$

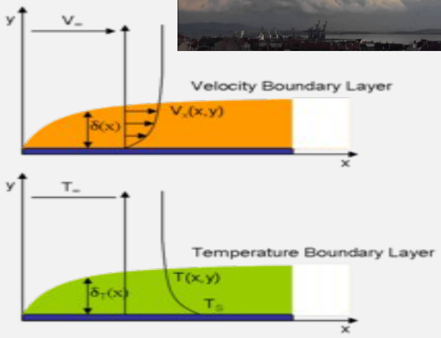


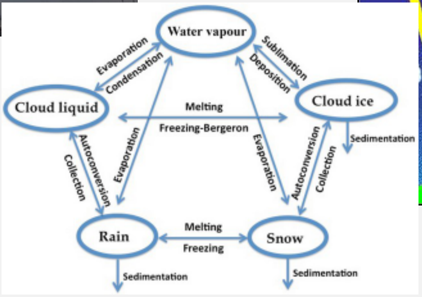
Physics packages

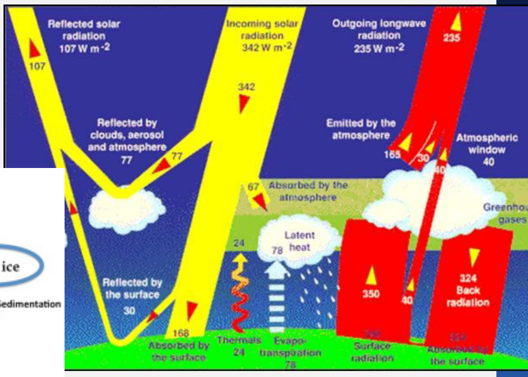


Parameterized solvers for sub-grid scale
non resolved physical processes

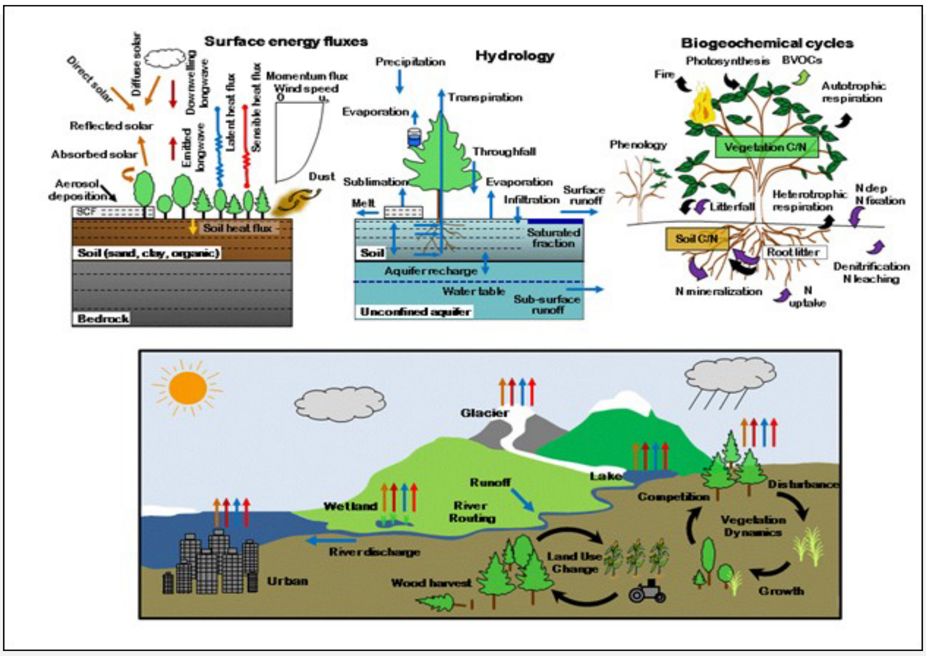








Required coupling



Optional coupling

Community Experiment

WCRP CORDEX

Coordinated Regional Climate Downscaling Experiment

Tomorrow we will
Have the tutorial!