Numerical Simulations in Climate Modeling : Requirements and Challenges

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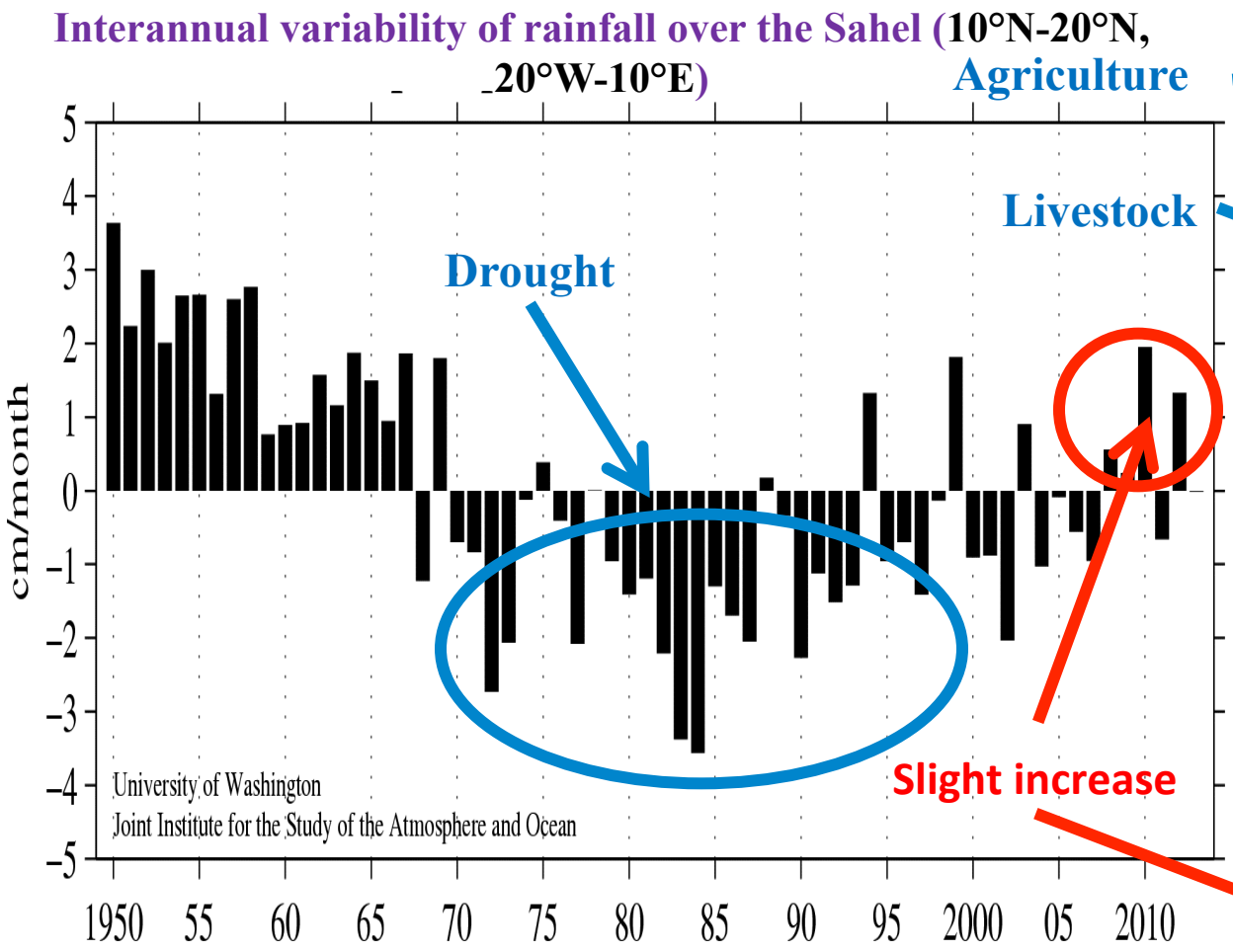
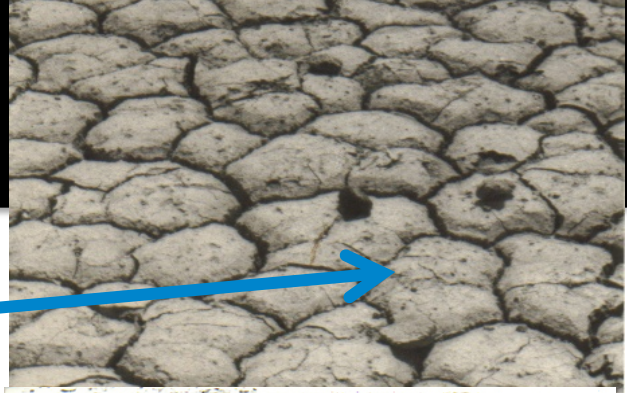
Background



Agriculture



Livestock

Slight increase

http://www.esrl.noaa.gov/psd/data/climateindices/list/

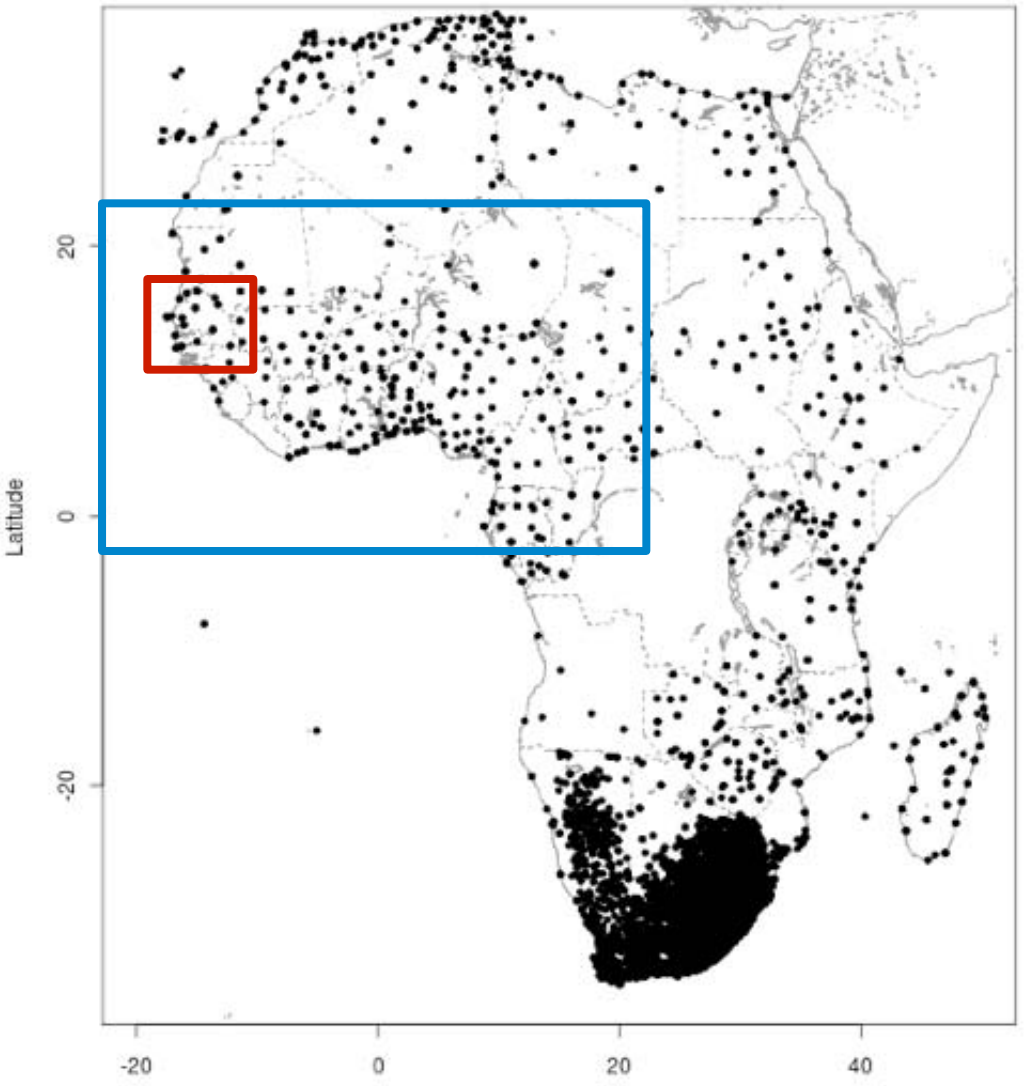
Background

West Africa (WA)

↓

Sparse compared to South Africa

Low density of gauge station across Senegal



Courtesy from Chris Lennard

Climate models

Climate Models are numerical representations of the fundamental equations that describe the behavior of the climate system and the interactions across its components *(atmosphere, ocean, cryosphere, biosphere, chemosphere)*

Global Climate Models (GCMs)

- Coupled Atmosphere-Ocean General Circulation Models (AOGCMs) are the most advanced tools today available for climate simulation.

- However, their resolution (100 – 300 km) is still too coarse to provide fine scale regional climate information useful for impact studies

Five layers of Numerical Modeling (1)

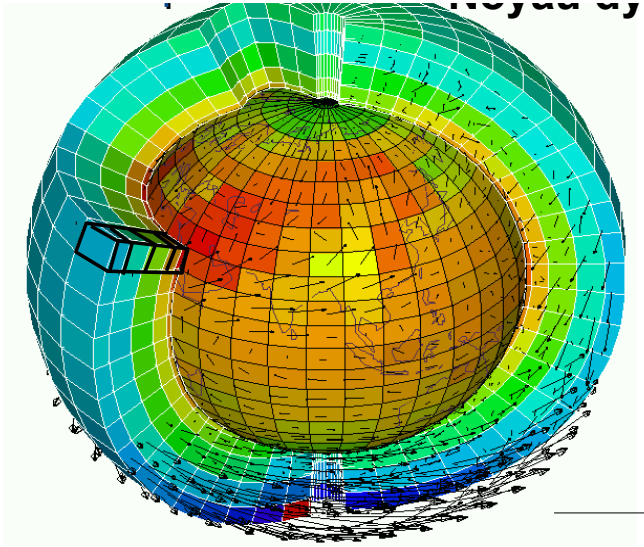
Appearences	Meteorology Atmopsheric composition Global warming ……
Theories (Physic, Chemistry, Biology, Economy)	**Fluid Mechanic** **Radiation-matter Interaction** **Chemistry**
Mathematic	**Navier-Stokes equations** **Thermodynamic Laws** **Radiative transfer**
Numerical Calculation	**Grid points discretization** **Finite differences and finite volumes**
Informatic	Fortran/Linux High Performance Computing Modularity Flexiblity/Multi-configuration

(1) Numerical modeling concerns all of these five layers

(2) Mathematics is a common language of these five layers

(3) Modeling : always try to highlight the links with the upper layers

Principes of Numerical Modeling (2)



- Conservation de la masse

  $D\rho/Dt + \rho\, \mathrm{div}\underline{U} = 0$

- Conservation de la température potentielle

  $D\theta / Dt = Q / Cp \ (p_0/p)^{\kappa}$

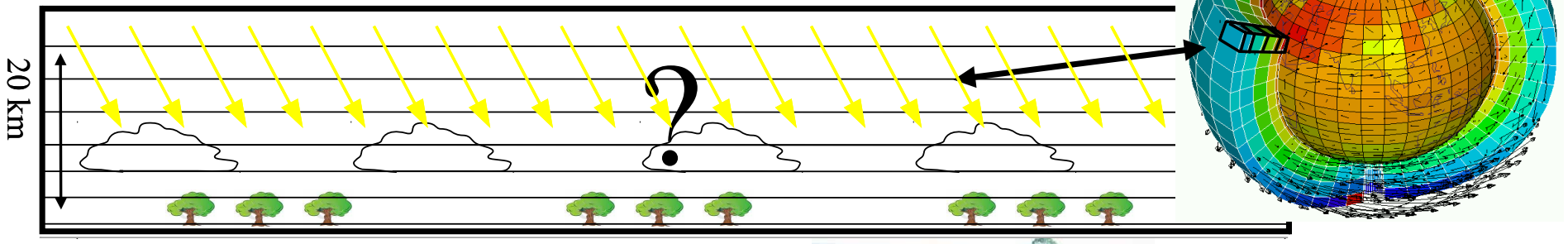
- Conservation de la quantité de mouvement

  $D\underline{U}/Dt + (1/\rho)\ \underline{\mathrm{grad}}p - \underline{g} + 2\ \underline{\Omega} \wedge \underline{U} = \underline{F}$

- Conservation des composants secondaires

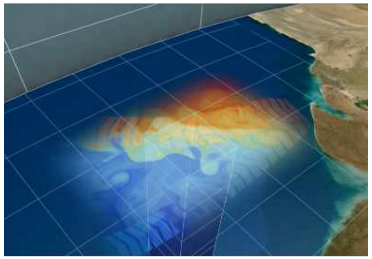
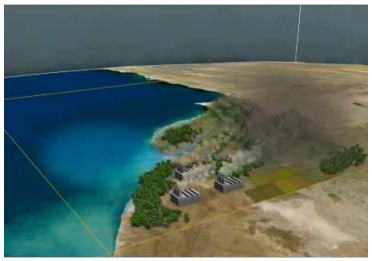
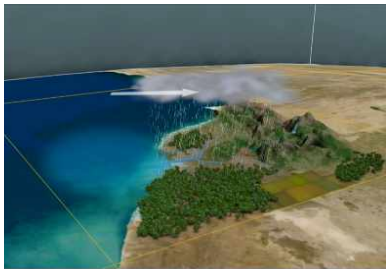
  $Dq/Dt = Sq$

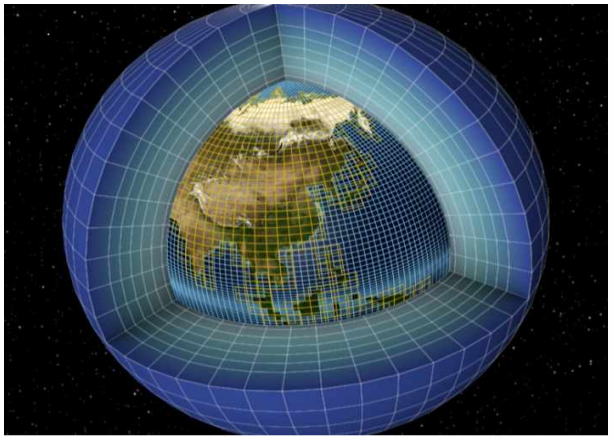
Dans une colonne du modèle ...

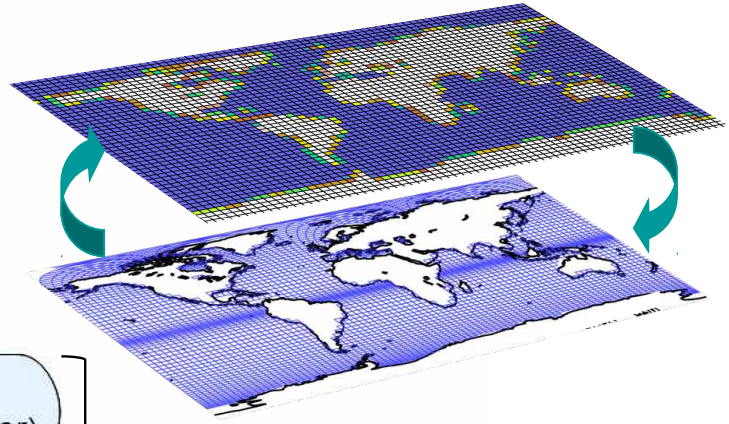


Principes of Numerical Modeling (3)

COUPLED MODEL FROM IPSL : IPSL-CM5A ou IPSL-CM5B

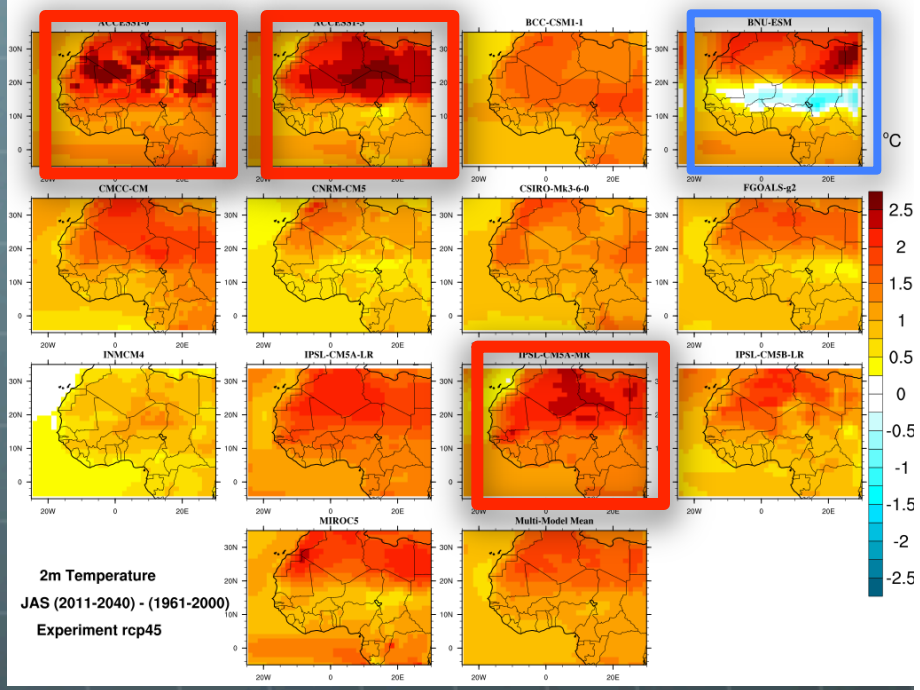





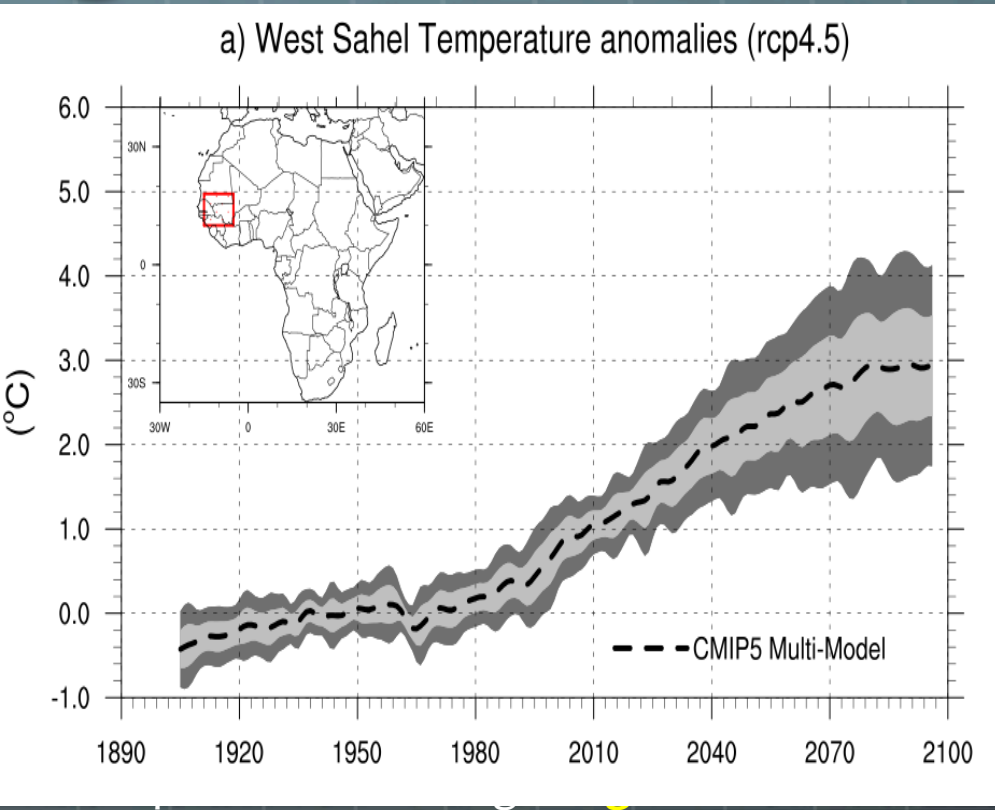




Temperature change in West-Africa

Temperature : near future /optimistic scenario





- **Differential warming** : warmer at North than at South
- At north: warmer at East than at West
- **BNU-ESM** (blue rec.) **only model predicting cooling temperatures**

at West

- Warming about 1°C in 2010, **2°C in 2040** and 3°C en 2100
- beyond 2070: temperature range variation **1.8°-4.0°C**

Regional Climate Modeling

- **Regional Climate Models (RCMs) can be "nested" within a GCM or reanalyses**

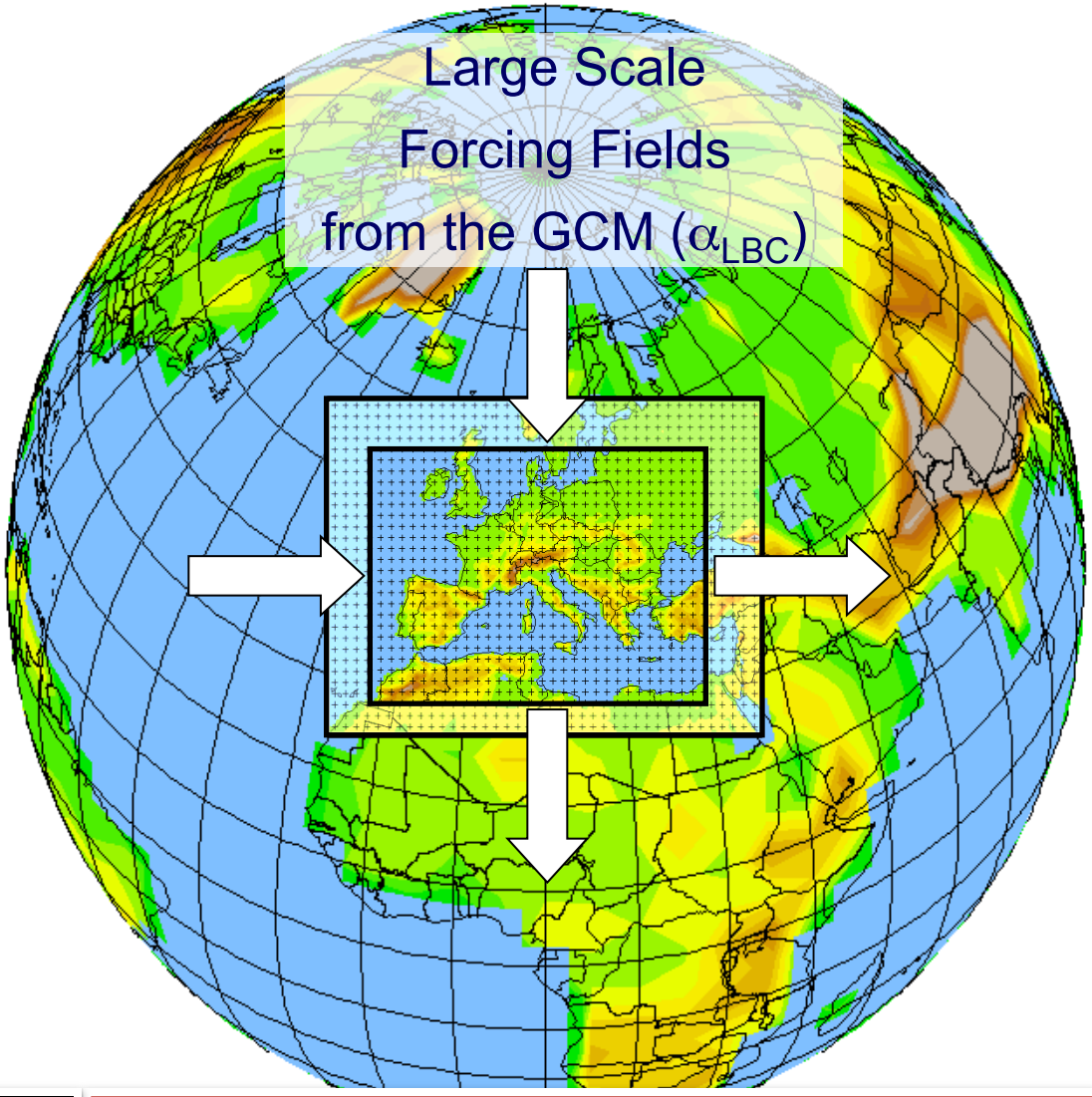
-Increase resolution to 10s km.

- **Lateral boundary conditions are obtained from the GCM or reanalyses.**

-"Relaxed" in via the buffer zone.

- **Intended to enhance the GCM simulation.**

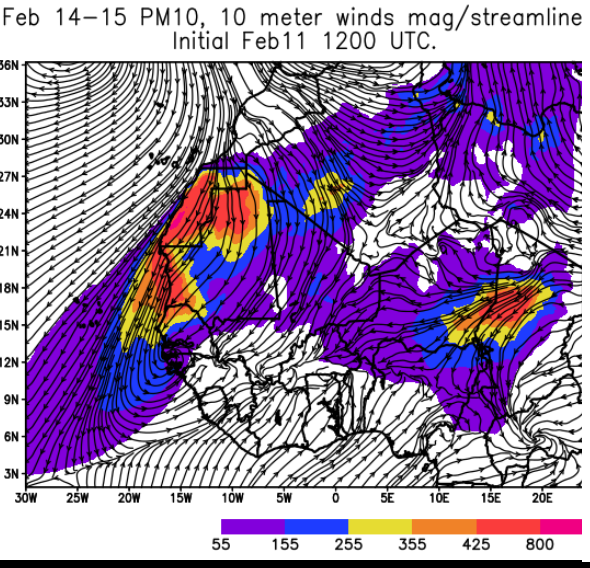
-Garbage in, garbage out.

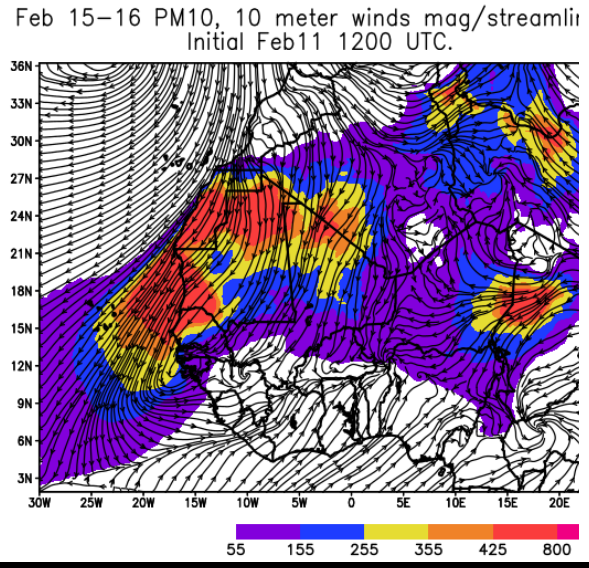


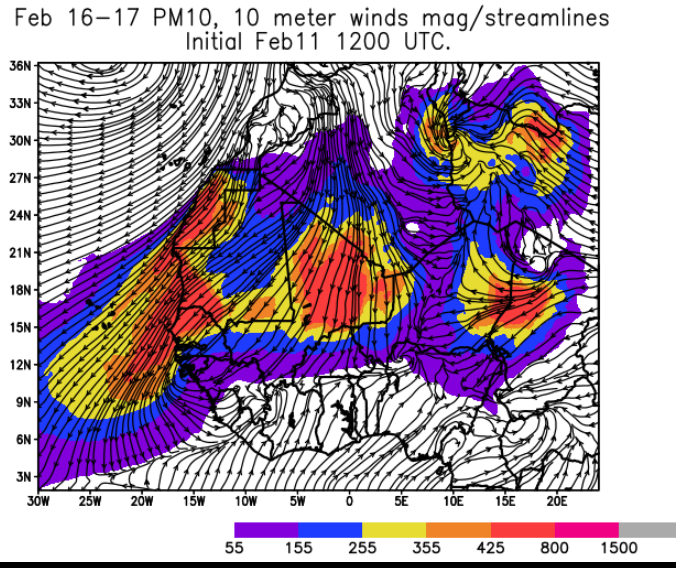
Regional Climate models (RCMs)

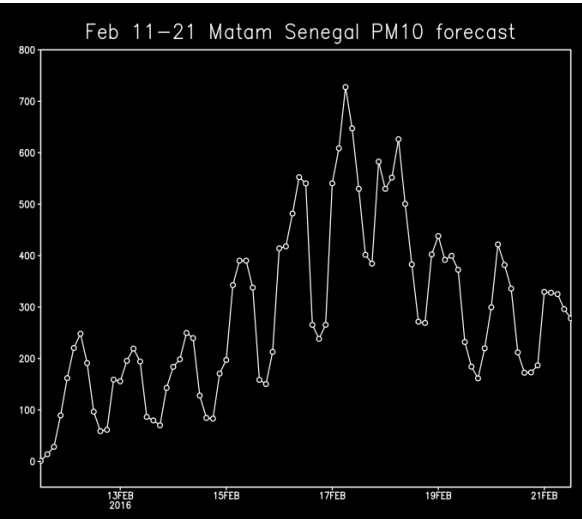
- Improved resolution of coastlines and topography
- Improved simulation of mesoscale systems
- Improved simulation of extreme events
  (e.g. floods, wind storms, heat waves)
- Improved resolution for Impacts models
  (e.g. agriculture, hydrology, air quality, storm surge)
- Can be used for process studies to understand mechanisms
  (e.g. land-surface, sea surface temperatures, glacial/snow albedo)
- Can include additional processes not included by the GCM simulations.
  (e.g. land cover changes, aerosols, lake effects, glacial melting)
- Can be used on PCs.

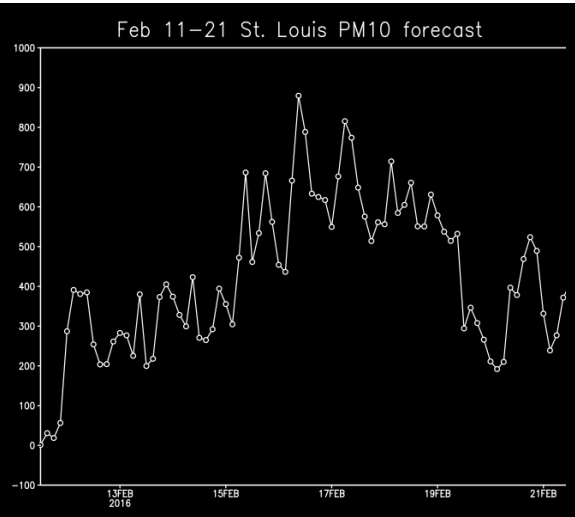
Regional Climate models: Application to dust outbreak simulations through West Africa

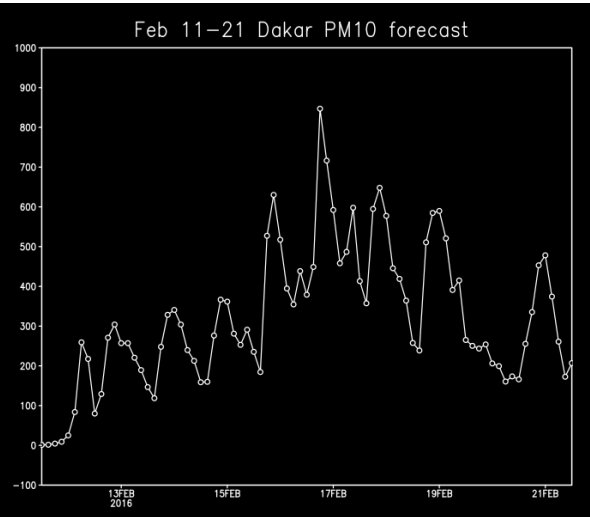












GrADS: IGES/COLA

Challenges and Requirements (1)

CICLAD (**C**alcul **I**ntensif for **Cl**imat, **A**tmospher and **D**ynamic) platform

- Venue : University Pierre & Marie-Curie (Paris VI/Jussieu) at Paris

- Big storage space (> 1 Peta Byte)
- Cluster (640 AMD core 2.4GHz) 24 nodes
- One virtualization Infrastructure for data distribution
- High speed network with low latency between nodes (40 Gb/s InfiniBand)

- Access: ssh user@ciclad-ng.ipsl.jussieu.fr

- /home 20Go for each user with backup
- /home did not used for input data and computation results in jobs

Challenges and Requirements (2)

Storage Infrastructure

- 15 I/O nodes (Infiniband interconnexion)
- 14 disk rack (more than 700 hard disks)
- 5 Lustre parallel file system
  - ✧ more than 2Gb/s write for /data filesystem
  - ✧ if problems on filesystems, I/O are blocked and jobs continue to run after the filesystem is restarted
  - ✧ Good feature in batch mode, less in interactive mode

Challenges and Requirements (3)

Compute nodes

- 24 nodes (640 AMD core 64 bit 2.4 GHz)
  - ✧ Computer with 8, 12, 32 or 64 core
  - ✧ 4GB Ram memory by core on any node
  - ✧ Infiniband inter-connexion between node
  - ✧ 3 external access nodes by ssh with key (ciclad-ng, ciclad1 and ciclad2)
- batch system (torque-maui)
- many Scientific Software and Compiler

Challenges and Requirements (4)

Software Configuration

- Scientific Linux 6.6 on all nodes
- LUSTRE filesystem
- Batch System torque with maui scheduler
- idl, matlab & scilab
- commercial fortran compiler: pgf95, ifort, nagfor
- Free fortran compiler: gfortran
- Parallelism: openmpi
- Others: ferret, gmt, netcdf, cdo, nco, ncl, epd python

Challenges and Requirements (5)

Execution on CICLAD platform: how I do in practice

```
pc2:aide-memo abdoulayedeme$ ssh deme@ciclad-ng.ipsl.jussieu.fr
Last login: Fri Mar  4 18:34:50 2016 from 41.82.212.193
*******************************************************************************
WARNING THERE IS NO BACKUP on /data
output of your jobs must be on /data
source program on your home  ( with backup )
in case of problems mailto:svp-ciclad@ipsl.jussieu.fr
FAQ on http://ciclad-web.ipsl.jussieu.fr/faq
documentation on http://ciclad-web.ipsl.jussieu.fr/Documentations
-------------------------------------------------------------------------------
Ciclad-NG Cluster Usage : cpu used 281/1120 (25.09%)
Jobs Total: 54 Active: 41 Idle: 0 Blocked: 13
Ciclad Cluster Usage : cpu used 0/0 (0.00%)
Jobs Total: 0 Active: 0 Idle: 0 Blocked: 0
ciclad interactive  usage
 ciclad1   : users (  2 ) cpu (0%)
 ciclad-ng : users ( 79 ) cpu (0.375%)
 ciclad2   : users (  0 ) cpu (2%)
-------------------------------------------------------------------------------
Warning : on ciclad-ng, ciclad1 and ciclad2 interactive jobs are now limited to :
          - 1 Hour CPU
          - 8 Gb Ram
-------------------------------------------------------------------------------

Quota for user deme
on /home:          I use 7.588GB/20.000GB   and 854/300000 files
on /data:          I use 1428.747GB/2000.000GB   and 40357/300000 files
on /loceanfs:      I use 624.543GB/0GB   and 478/0 files
on /backupfs:      I use 7.587GB/0GB   and 854/0 files
UUID                          bytes         Used    Available Use% Mounted on
filesystem summary:          539.6T       338.5T       195.7T  63% /data
bashrc_profile
[deme@ciclad-ng ~]$
```

login on CICLAD

general informations on CICLAD

specific informations to me

Challenges and Requirements (6)

Execution on CICLAD platform: how I do in practice

```
aide-memo — deme@ciclad-ng:~ — ssh — 96×34
[deme@ciclad-ng ~]$ pwd
/home/deme
[deme@ciclad-ng ~]$ ls
bug_exctarc_amipGFDL-CM3.txt      lpaosfDem-new.sh.source          quantile.ncl
CMIP5                             mgaetani                         script-exec
ESCAPE                            onset_map_modelCMIP5_rcp85.ncl   script-output
lpaosfDem-nco_CCetmaps.sh.source  out_essai_nco.dat                scripts
[deme@ciclad-ng ~]$ du -sh *
4,0K    bug_exctarc_amipGFDL-CM3.txt
183M    CMIP5
56K     ESCAPE
8,0K    lpaosfDem-nco_CCetmaps.sh.source
8,0K    lpaosfDem-new.sh.source
28K     mgaetani
12K     onset_map_modelCMIP5_rcp85.ncl
260K    out_essai_nco.dat
8,0K    quantile.ncl
7,5G    script-exec
968K    script-output
416K    scripts
[deme@ciclad-ng ~]$
```

my home: /deme
only for scripts which are daily saved

```
aide-memo — deme@ciclad-ng:/data/deme — ssh — 96×34
[deme@ciclad-ng ~]$
[deme@ciclad-ng ~]$ cd /data/deme/
[deme@ciclad-ng deme]$ pwd
/data/deme
[deme@ciclad-ng deme]$ du -sh *
0       adlmd
1,4T    CMIP5-bis
26G     CMIP5-nco
3,4G    ESCAPE
[deme@ciclad-ng deme]$
[deme@ciclad-ng deme]$
[deme@ciclad-ng deme]$
[deme@ciclad-ng deme]$ date
dim. mars  6 00:06:44 CET 2016
[deme@ciclad-ng deme]$
```

my home-data: /data/deme
relative big capacity for storage
some essential data

Challenges and Requirements (7)

Execution on CICLAD platform: how I do in practice

```
151717 # ls -lrt *.sh
151723 # cd
151725 # ls -lrt *.sh
151744 # cp extrac_domainAO_HF_guidage-30mn.sh extrac_domainAO_HF_guidage-12h.sh
151749 # vi extrac_domainAO_HF_guidage-12h.sh
151842 # cd /data/deme/CMIP5-bis/lmdz/amip/AMIPg3CM5Bs60Y/ATM/output/HF
151856 # ls -lrt ex*.sh
151857 # cd
151859 # ls -lrt ex*.sh
152112 # qsub -qday3 -lpmem=16gb -l pvmem=12gb extrac_domainAO_HF_guidage-03h.sh
152133 # qsub -qdays3 -lpmem=16gb -l pvmem=12gb extrac_domainAO_HF_guidage-03h.sh
152143 # qsub -qdays3 -lpmem=16gb -l pvmem=12gb extrac_domainAO_HF_guidage-30mn.sh
152153 # qsub -qdays3 -lpmem=16gb -l pvmem=12gb extrac_domainAO_HF_guidage-12h.sh
153031 # qstat
153452 # cd /data/deme/CMIP5-bis/lmdz/
153453 # ls
153455 # cd amip/
153456 # ls
153503 # cd AMIPgCM5Bs60Y
```

```
[deme@ciclad-ng ~]$ ls
bug_exctarc_amipGFDL-CM3.txt   lpaosfDem-nco_CCetmaps.sh.source   onset_map_modelCMIP5_rcp85.ncl
CMIP5                          lpaosfDem-new.sh.source           out_essai_nco.dat
ESCAPE                         mgaetani                          quantile.ncl
[deme@ciclad-ng ~]$ cd script-exec
[deme@ciclad-ng script-exec]$ ls
extrac_domainAO_DA_guidage-03h.sh.e93542   extrac_domainAO_DA_guidage-30mn.sh.e99086
extrac_domainAO_DA_guidage-03h.sh.e93557   extrac_domainAO_DA_guidage-30mn.sh.e99641
extrac_domainAO_DA_guidage-03h.sh.e97717   extrac_domainAO_HF_guidage-03h.sh.e93539
extrac_domainAO_DA_guidage-03h.sh.e99087   extrac_domainAO_HF_guidage-03h.sh.e99653
extrac_domainAO_DA_guidage-03h.sh.e99639   extrac_domainAO_HF_guidage-12h.sh.e93540
extrac_domainAO_DA_guidage-12h.sh.e93543   extrac_domainAO_HF_guidage-30mn.sh.e93538
extrac_domainAO_DA_guidage-12h.sh.e93558   extrac_domainAO_HF_guidage-30mn.sh.e99654
extrac_domainAO_DA_guidage-12h.sh.e97716   extrac_domainAO_MO_guidage-03h.sh.e93536
extrac_domainAO_DA_guidage-12h.sh.e99088   extrac_domainAO_MO_guidage-03h.sh.e93560
extrac_domainAO_DA_guidage-12h.sh.e99640   extrac_domainAO_MO_guidage-12h.sh.e93537
extrac_domainAO_DA_guidage-30mn.sh.e93541  extrac_domainAO_MO_guidage-12h.sh.e93561
extrac_domainAO_DA_guidage-30mn.sh.e93556  extrac_domainAO_MO_guidage-30mn.sh.e93531
extrac_domainAO_DA_guidage-30mn.sh.e97718  extrac_domainAO_MO_guidage-30mn.sh.e93559
script-exec]$
```

```
[deme@ciclad-ng script-exec]$ cd ../script-output/
[deme@ciclad-ng script-output]$
[deme@ciclad-ng script-output]$ ls
check_aggregate_boitel_escapeV0.amip.trop3x3.out.o77021  extrac_domainAO_DA_guidage-03h.sh.o99087
check_aggregate_boitel_new.amip.maps.out.source          extrac_domainAO_DA_guidage-03h.sh.o99639
check_aggregate_boitel_new.piControl.maps.out.source     extrac_domainAO_DA_guidage-12h.sh.o93543
check_aggregate_boitel_new.rcp45.GlobalCC.out.source     extrac_domainAO_DA_guidage-12h.sh.o93558
check_aggregate_boitel_new.rcp45.maps.out.old            extrac_domainAO_DA_guidage-12h.sh.o97716
check_aggregate_boitel_new.rcp60.GlobalCC.out.source     extrac_domainAO_DA_guidage-12h.sh.o99088
check_aggregate_boitel_new.rcp85.GlobalCC.out.source     extrac_domainAO_DA_guidage-12h.sh.o99640
do_it_extracfiles_dailyAMIP_trop3x3_EscapeV1.sh.o88019   extrac_domainAO_DA_guidage-30mn.sh.o93541
do_it_extracfiles_dailyAMIP_trop3x3_EscapeV1.sh.o88033   extrac_domainAO_DA_guidage-30mn.sh.o93556
do_it_extracfiles_dailyAMIP_trop3x3_EscapeV2.sh.o88023   extrac_domainAO_DA_guidage-30mn.sh.o97718
do_it_extracfiles_dailyAMIP_trop3x3_EscapeV2.sh.o88034   extrac_domainAO_DA_guidage-30mn.sh.o99086
do_it_extracfiles_dailyAMIP_trop3x3_EscapeV4.sh.o88025   extrac_domainAO_DA_guidage-30mn.sh.o99641
do_it_extracfiles_dailyRCP45_trop3x3_EscapeV1.sh.o78455  extrac_domainAO_daily_guidage-12h.sh.old
do_it_extracfiles_dailyRCP45_trop3x3_EscapeV2.sh.o78456  extrac_domainAO_HF_guidage-03h.sh.o88858
do_it_extracfiles_dailyRCP45_trop3x3_EscapeV3.sh.o78457  extrac_domainAO_HF_guidage-03h.sh.o89958
do_it_extracfiles_dailyRCP45_trop3x3_EscapeV4.sh.o78458  extrac_domainAO_HF_guidage-03h.sh.o93539
do_it_extracfiles_dailyRCP85_trop3x3_EscapeV1.sh.o78467  extrac_domainAO_HF_guidage-03h.sh.o99653
do_it_extracfiles_dailyRCP85_trop3x3_EscapeV2.sh.o78468  extrac_domainAO_HF_guidage-12h.sh.o88860
do_it_extracfiles_dailyRCP85_trop3x3_EscapeV3.sh.o78469  extrac_domainAO_HF_guidage-12h.sh.o89959
do_it_extracfiles_dailyRCP85_trop3x3_EscapeV4.sh.o78470  extrac_domainAO_HF_guidage-12h.sh.o93540
do_it_extracfiles_daily_trop3x3_EscapeV0.sh.o77037       extrac_domainAO_HF_guidage-12h.sh.old
do_it_extracfiles_daily_trop3x3_EscapeV1.sh.o76021       extrac_domainAO_HF_guidage-30mn.sh.o88859
do_it_extracfiles_daily_trop3x3_EscapeV1.sh.o77933       extrac_domainAO_HF_guidage-30mn.sh.o89957
do_it_extracfiles_daily_trop3x3_EscapeV2.sh.o76022       extrac_domainAO_HF_guidage-30mn.sh.o93538
do_it_extracfiles_daily_trop3x3_EscapeV3.sh.o76023       extrac_domainAO_HF_guidage-30mn.sh.o99654
do_it_extracfiles_daily_trop3x3_EscapeV4.sh.o76024       extrac_domainAO_HF_guidage-30mn.sh.old
```

job soumission

executable informations

output informations

Challenges and Requirements (8)

Easier access to my own data: (THREDDS + ERDDAP)/NAS

NAS = Network Attached Storage

2. **AMEO' (NAS),** pour évaluer localement (Jussieu) l'installation sur un NAS.

- **Choix du construteur (Synology) et du système (Disk Station Manager).**
- **Choix du facteur de forme (mini-tour),**
- **Choix du type de modèle : mini-tour, 2 baies, processeur dual core, puissant…**

Synology DS713+ →

- CPU Model
  Intel Atom, Dual Core 2.13 GHz, Floating Point
- System Memory
  1 GB DDR3 (mais on pourrait en rajouter…)
- Storage Drive Bay(s)
  2

CONCLUSIONS

1. Climate Modeling is deeply linked to **High Performance Computing** (HPC)
2. Grand Challenge of Climate Modeling: scientific and computational
3. System challenges : capacity, I/O performance etc...
4. Software challenges: s/w engineering, computational, optimisation
5. Cimate Modeling requires **Huge volume data** : distributed and archiving
6. Cimate Modeling requires **efficient data storage** models, data mining

THANK YOU FOR YOUR ATTENTION