Downscaling of Climate Predictions : Methods and Challenges

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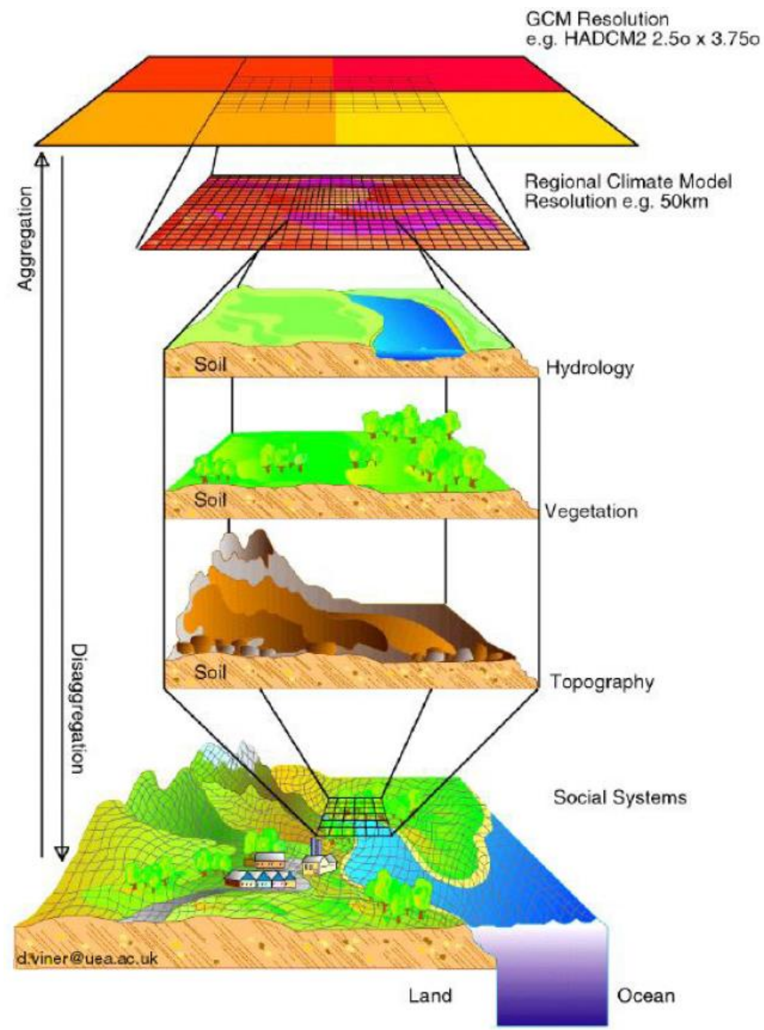
The Downscaling problem

- **Relevant Scales**
  - Mesh of the GCM ~ 200 km,
    3 month averaged information
    (*or month by month*)
  - Scales of applications ~ 1m to 10 km,
    Day, 10 days, month,

  - Climate parameters (RR, Tn, Tx, Number of days …),
  - Parameters from the application domain (Agriculture, Water resources, Health, …),



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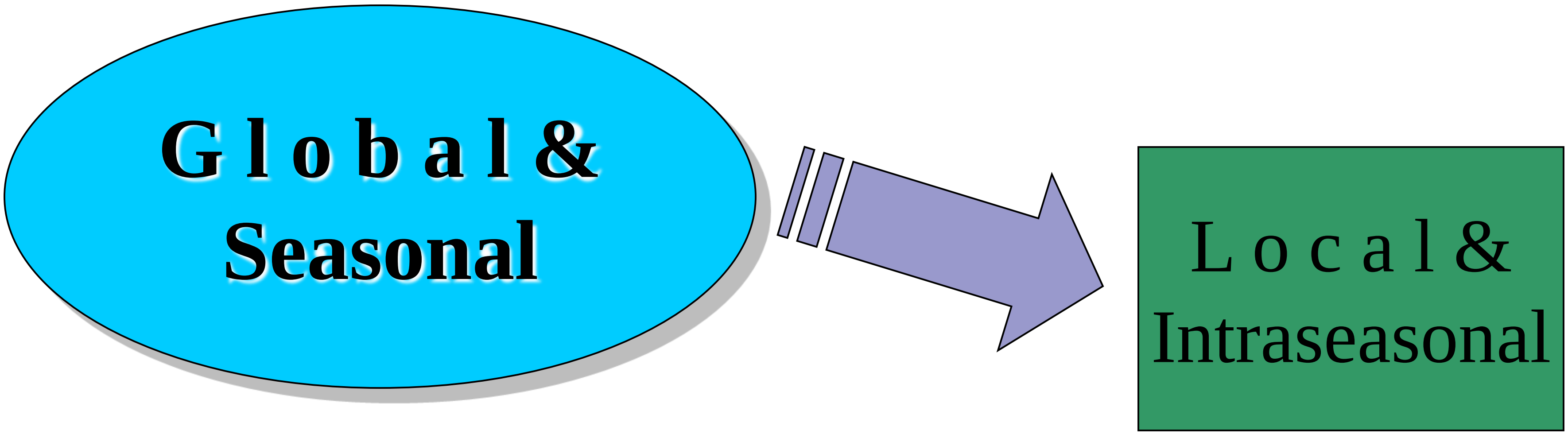
The Downscaling problem

- **Seasonal predictability and associated scales ⇒ usefull information for the user (scale adaptation)**



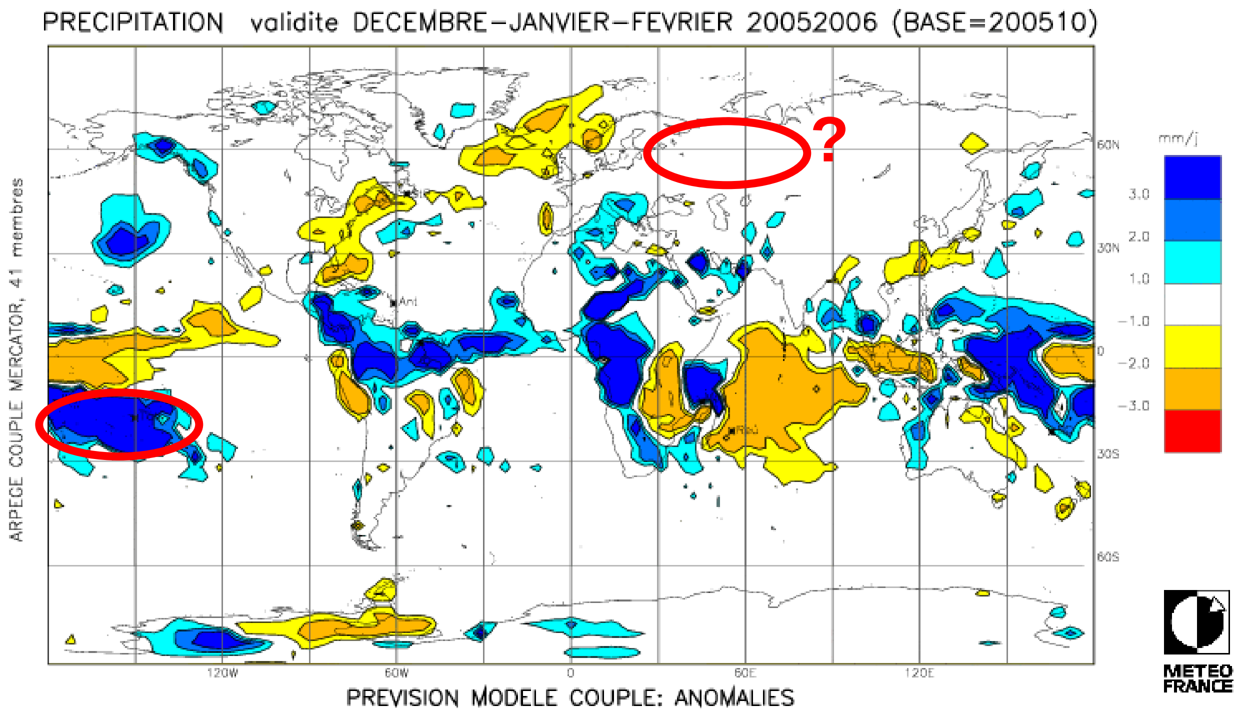
- **key questions**
  - Until which scales one can expect to downscale the large scale information ?
  - How the best compromise between the limits of seasonal predictability and the needs for applications ?

The Downscaling bases

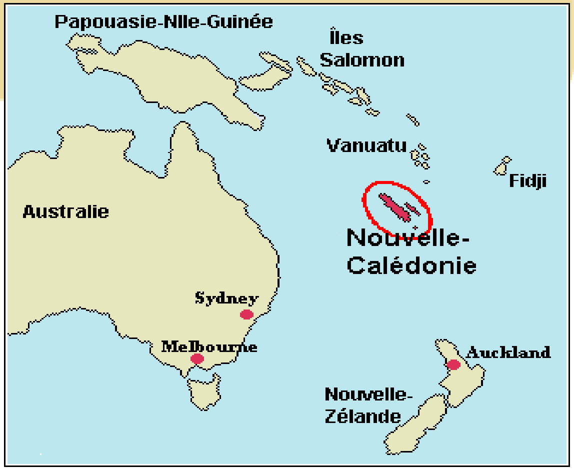
- **Main goal of the downscaling is**
  - To take into acount mean local effects of the large scale forcing
  - To adapt the seasonal forcasting information to the relevant scale for the user (at least to get better resolution generally needed both in space and time)
- **The downscaling should**
  - Reflect the mean effect of sub-grid processes
  - Take into account physical processes at the « local » scales
  - Bring more than a simple linear interpolation
- **The downscaling brings**
  - some artificial increase in the resolution
  - uncertainty which must be evaluated
  - Information which is part of the ensemble/probabilistic forecast

The Downscaling bases

- **Large scale forcing**
  - One has chance some to succeed **IF** the smaller scales are significantly forced by the large scale signal.

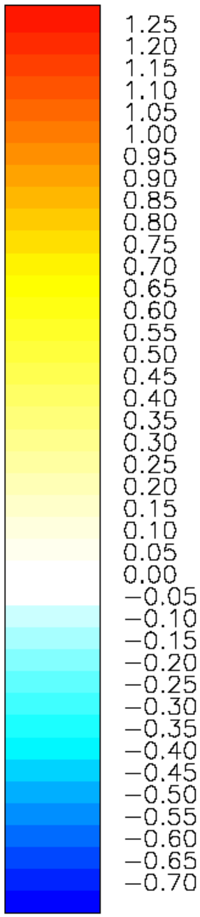


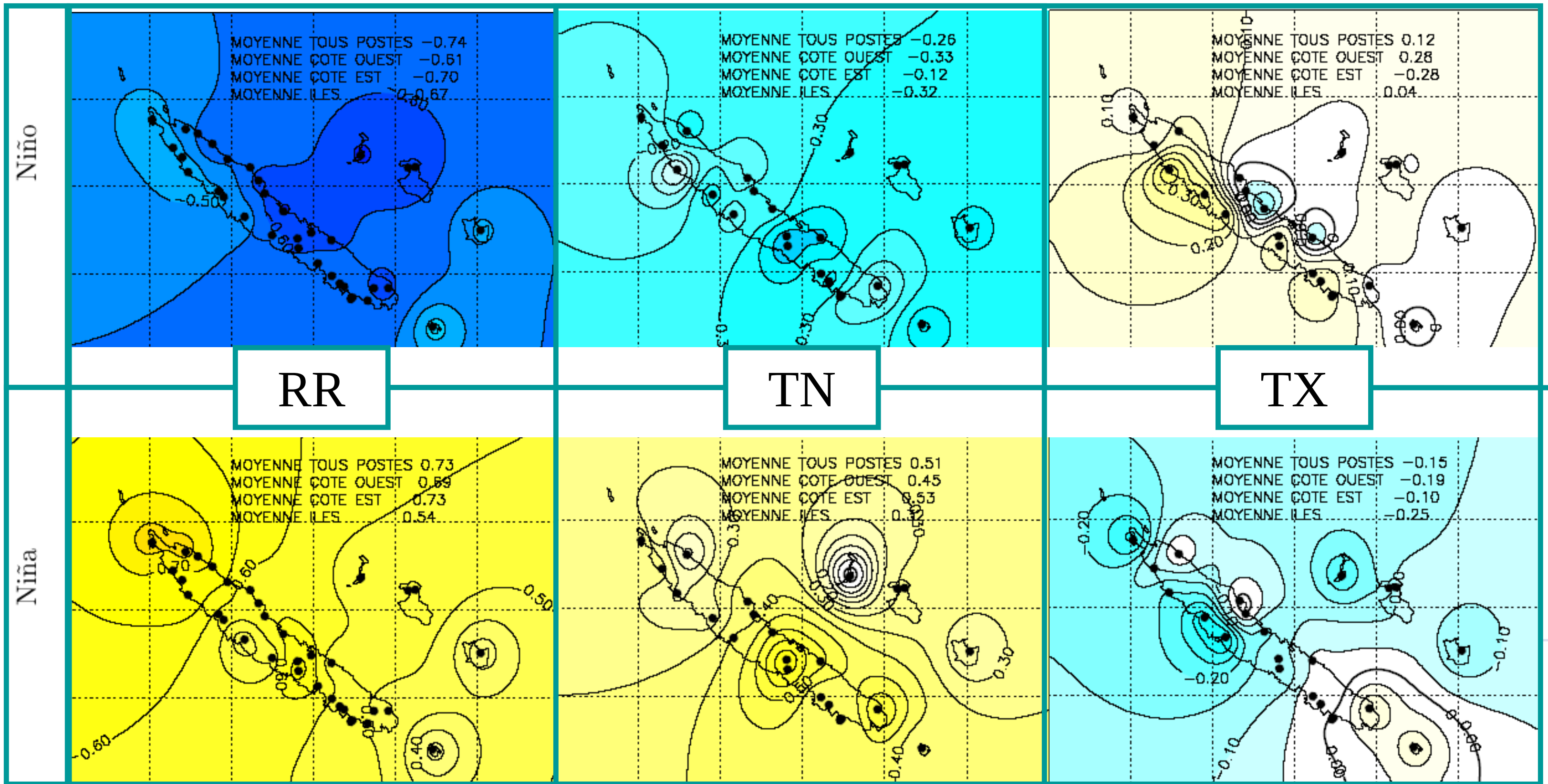
The Downscaling bases



- **Large scale forcing**
  - New-Caledonia

Standardized anomaly in JFM vs ENSO phases (1958-2001)

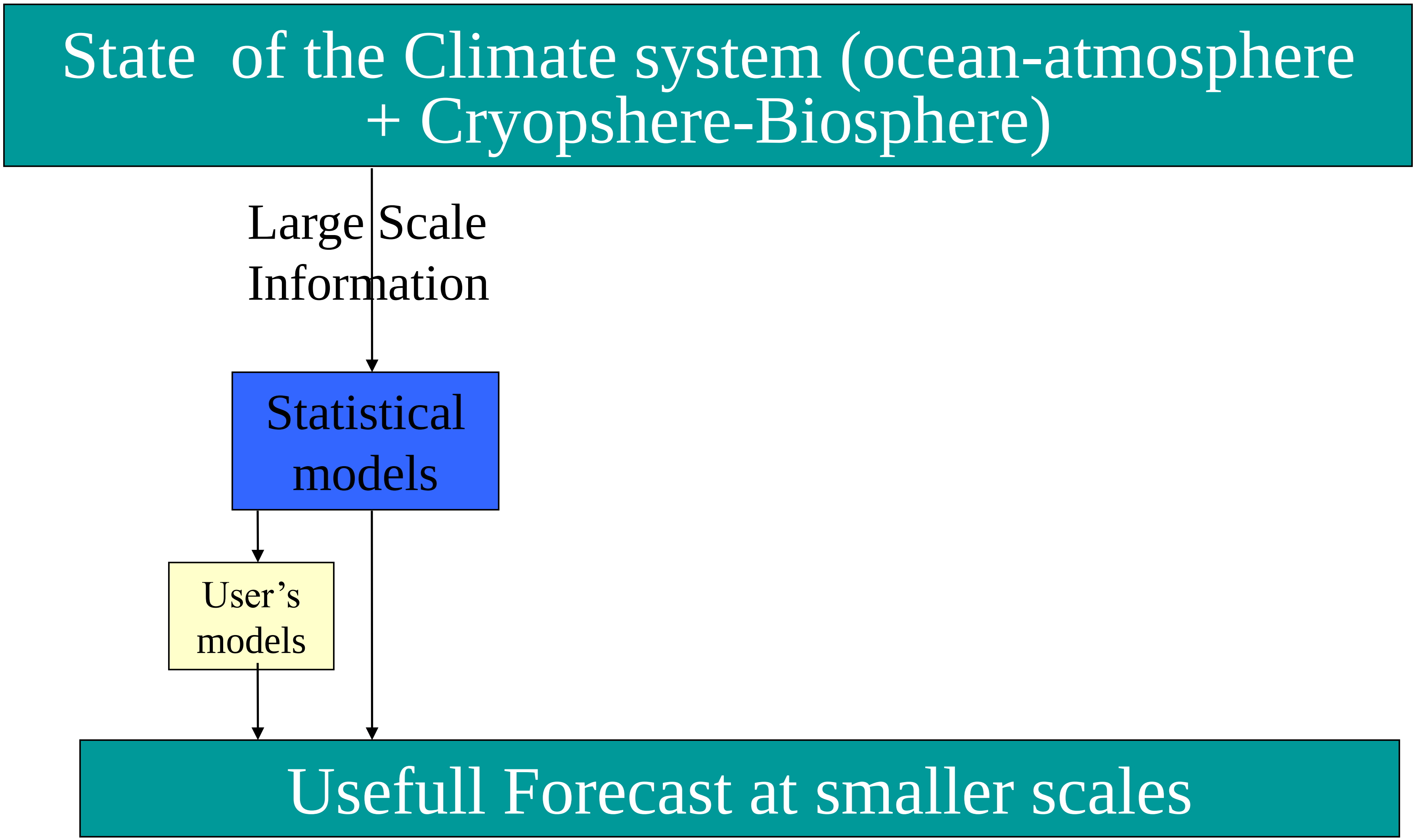




The Downscaling bases

- **Impact of the large scale forcing at « local » scales**
  - Methods to assess this impact
    - Composite analysis,
    - CCA, SVD,
    - Clustering
    - …
  - Diagnosis related to Downscaling
    - Space gradients, …
    - Homogeneous zones, …
  - Description of « local » signal and associated database
    - Data quality,
    - Network density,
    - Spatialization (***be carefull with GIS !***),

Methods of Downscaling



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Downscaling Methods

- **Purely Statistical methods**
  - Analysis of Large Scale Conditions (e.g. SST, SOI, …)
  - Asumption : LSC have a slow evolution and a significant influence on the « local » climate,
  - Statistical tools (mostly linear) including AR models
  - Common approach in RCOFs

\+ low computing cost,

\+ easy to implement operationally,

\- possible artificial scores,

\- weak representation of interactions within the climate system

\- difficult to use with complex relationship

\- need regular recalibration (multidecadal variability,

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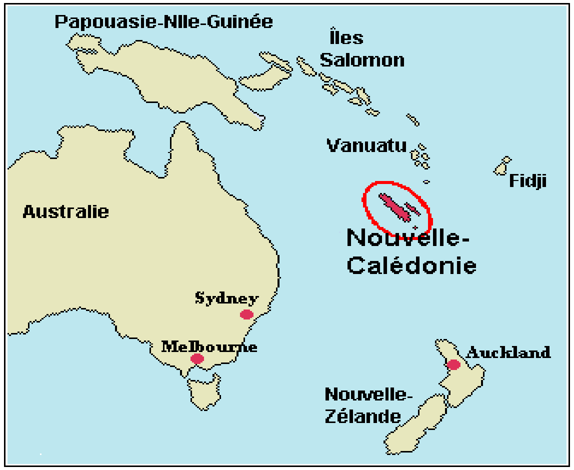
Downscaling Methods

- SCOPIC (Seasonal Climate Outlook for Pacific Island Countries)– BOM contribution
- Linear Discriminante Analysis

New-Caledonia

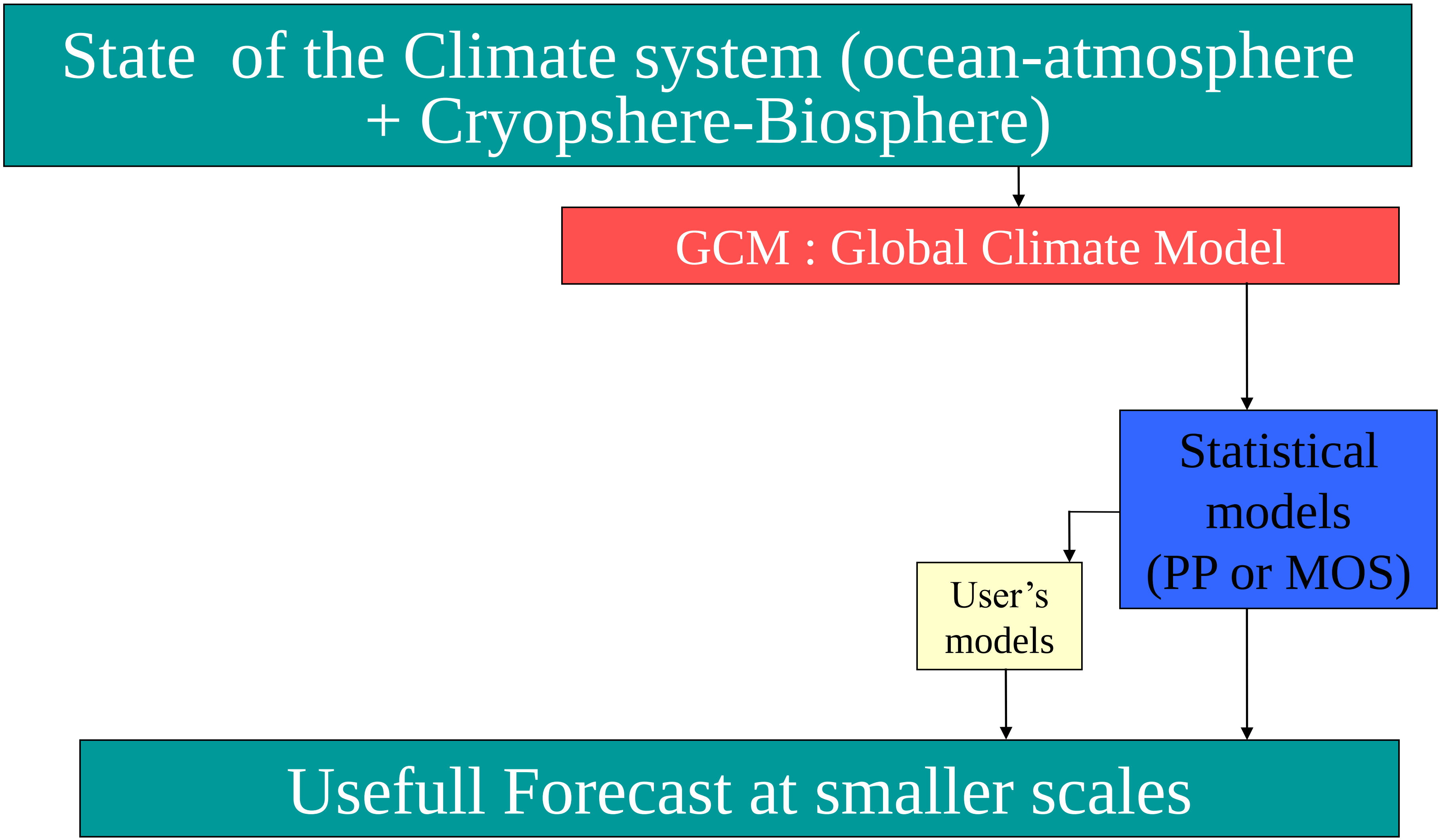


Prévisions statistiques pour la période : novembre 2005 à jar

Prévisions de précipitations réalisées

METEO FRANCE	Prévisions de novembre 2005 à janvier 2006				
	Prévisions probabilistes			Scores des vérifications	
	Prob T1	Prob T2	Prob T3	LEPS	HR
Postes	en %	en %	en %	en %	en %
Koumac	28.5%	34.3%	37.3%	15.3%	50.9%
Gomen	28.4%	34.1%	37.5%	19.3%	50.9%
Voh	29.4%	32.0%	38.6%	16.0%	47.2%
Koné	28.2%	34.2%	37.6%	23.4%	49.1%
Puembout	32.5%	29.0%	38.5%	15.6%	52.4%
Poya	24.8%	37.6%	37.6%	16.1%	50.0%
Bourail	27.1%	35.3%	37.6%	21.0%	56.6%
La Foa	23.3%	38.6%	38.1%	23.1%	58.5%
Boulouparis	27.9%	33.9%	38.3%	16.2%	48.9%
Tontouta	26.4%	36.1%	37.4%	13.8%	58.5%
Païta	23.7%	38.2%	38.1%	18.0%	62.3%
Nouméa	23.3%	38.4%	38.3%	13.1%	52.8%
Plum	26.2%	36.6%	37.2%	12.1%	53.8%
Pouébo	25.0%	37.5%	37.5%	6.5%	29.2%
Galarino	27.5%	35.7%	36.8%	4.4%	42.2%
Hienghène	31.0%	32.9%	36.2%	3.7%	41.2%
Touho	23.6%	38.2%	38.2%	11.0%	38.5%

Downscaling Methods



Downscaling Methods

- **Dynamical / Statistical methods**
  - Forecasted Large Scale Conditions (from GCM)
  - Asumption : LSC which have a significant influence on the « local » climate are « well » represented in the GCM
  - Perfect Prog (PP) or Model Output Statistics (MOS)

+ Reasonable computing cost for the downscaling,
+ Complexity of the climate system represented in the LSC (GCM)
+ Potential predictors physically based (and numerous)
+ Correction of systematic bias of the GCM behaviour (MOS only)
+ Uncertainty sampling (ensemble forecast, multi-model, …)
+ Quite easy to implement operationally (GCM ouput access ?)

\- GCM limitations and bias,

Methods of Downscaling

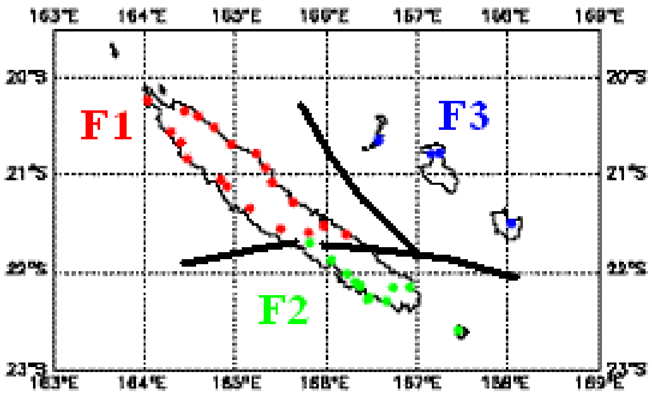
The different methods

- Linear methods
  - Regression (Multiple, …)
  - Discriminant Analysis (Linear, FDA, …)
  - CCA, SVD, …
  - Modes of Variability (model vs « observed » modes),
  - …
- Non Linear methods
  - Neural networks (optimisation of the network),
  - Analogues / Anti-analogues (optimisation of the distance and choice of the number of analogues)
  - Circulation regimes / weather types (Model vs « observed »),
  - Regression trees,
  - …
- Methods for Robustness evaluation
  - Overfitting
  - Multidecadal variability,
  - MOS vs PP

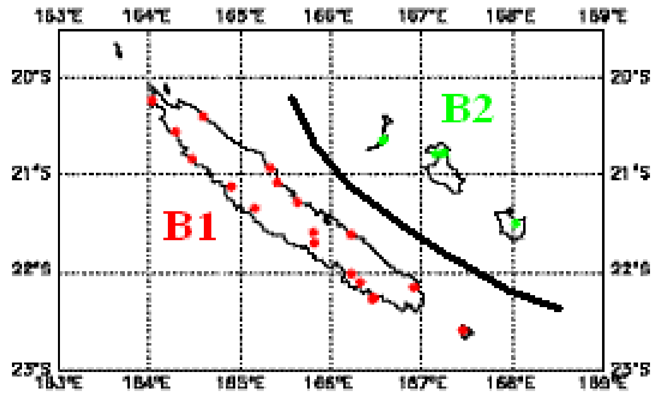
Downscaling

- Downscaling in Space - Zoning

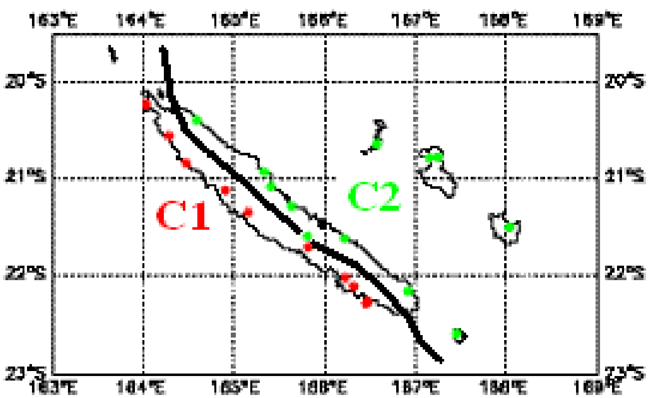
a)

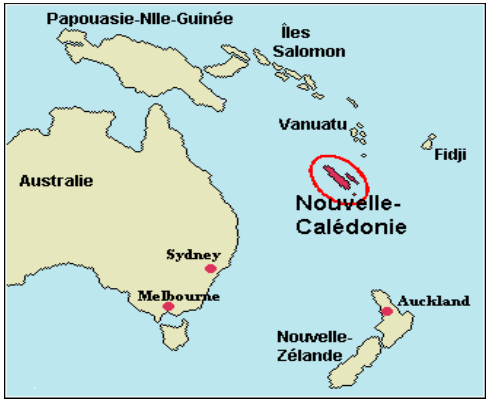


b)



c)





a) **Rainfall**

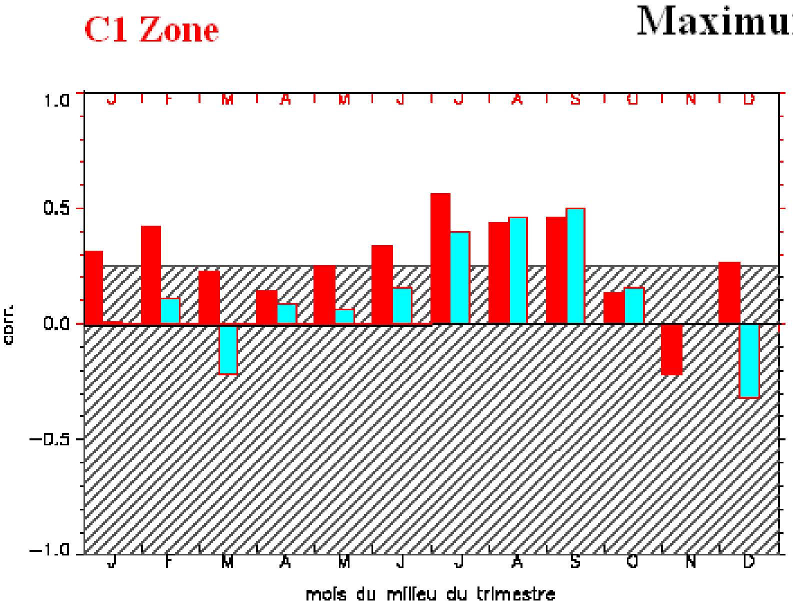
b) **Minimum Temperature**

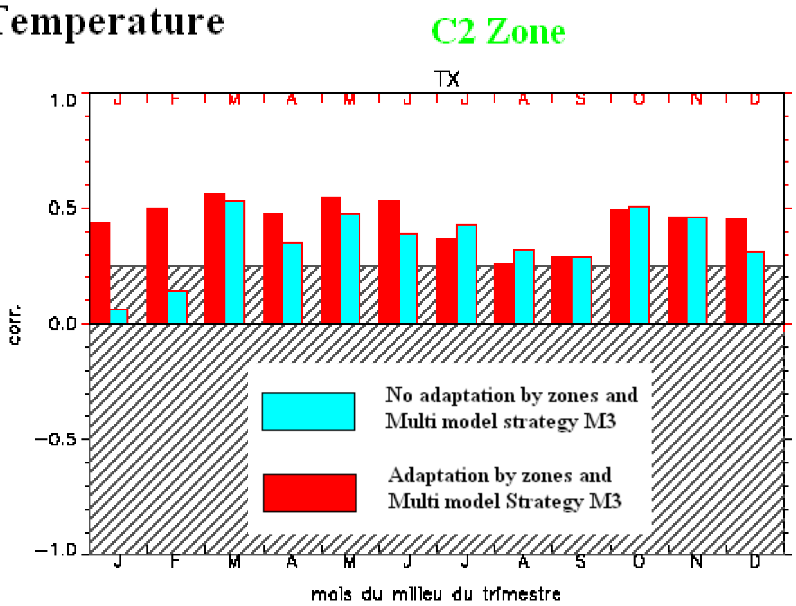
c) **Maximum Temperature**

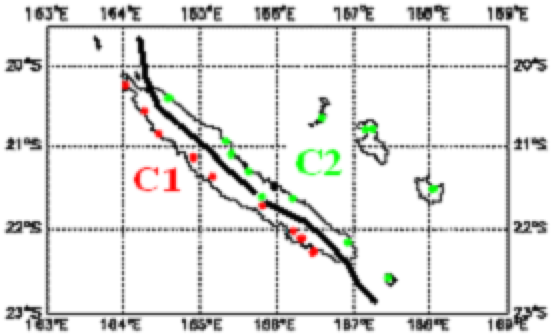
Downscaling

- Additional information brought by downscaling

Maximum Temperature





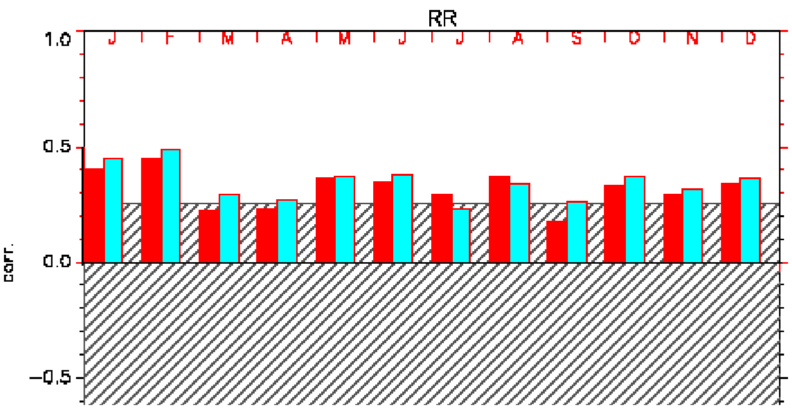


Downscaling

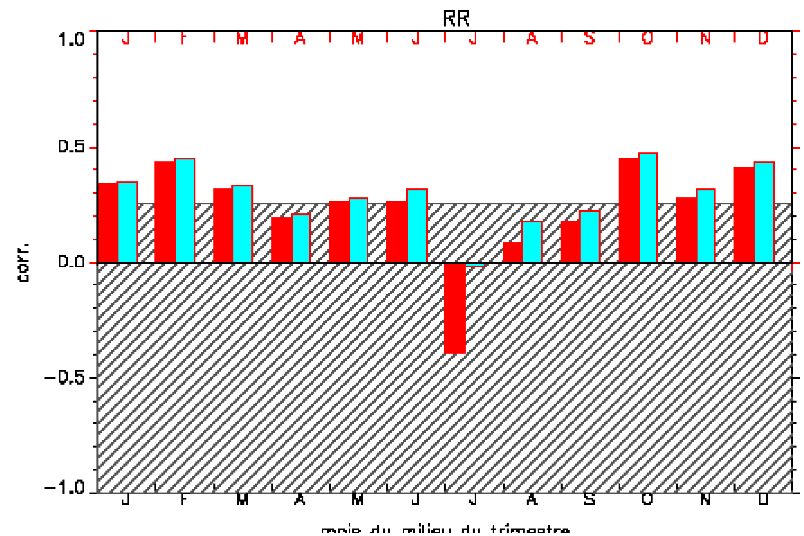
- Additional information brought by downscaling

Rainfall

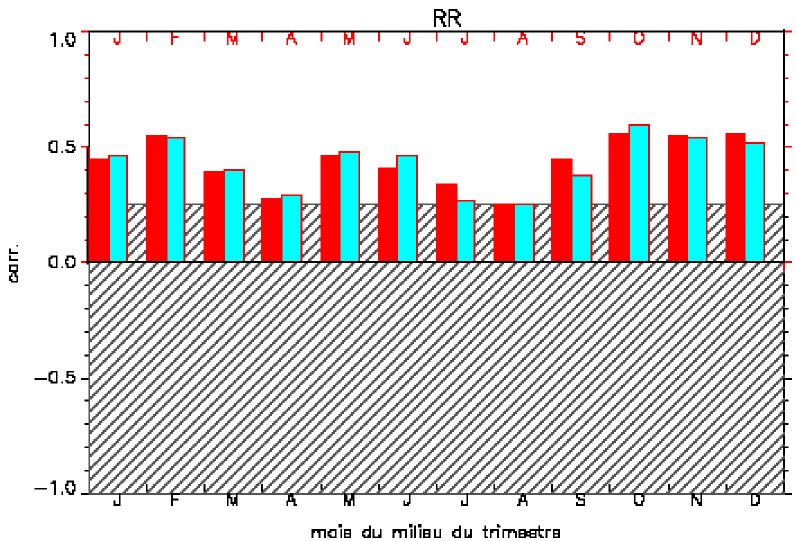
F1 Zone

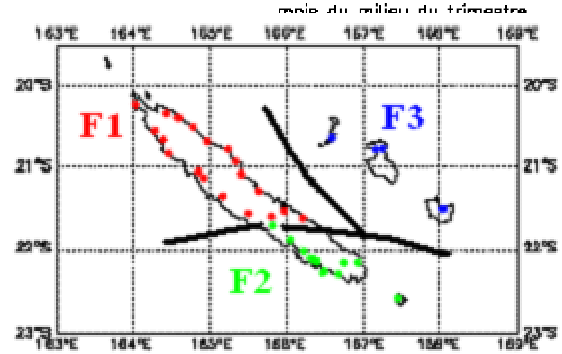


F2 Zone



F3 Zone





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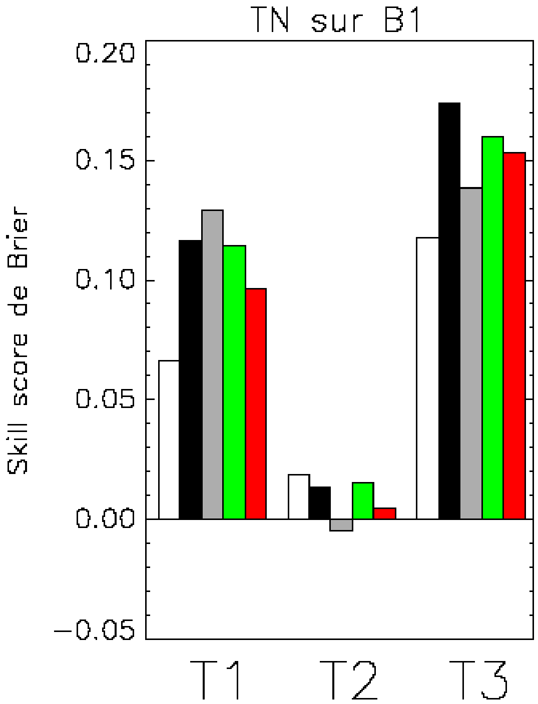
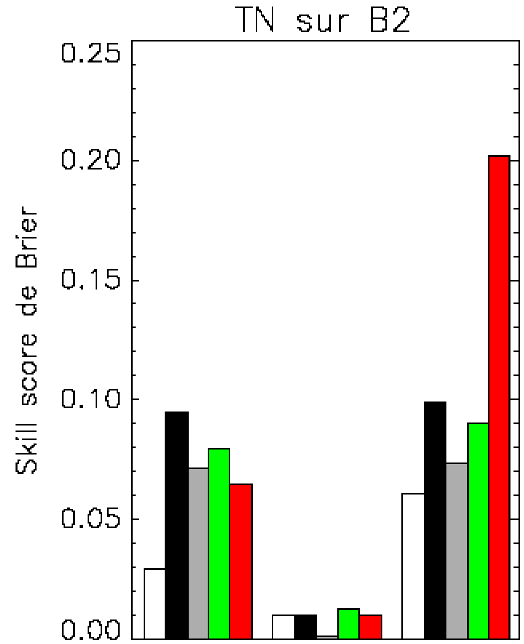
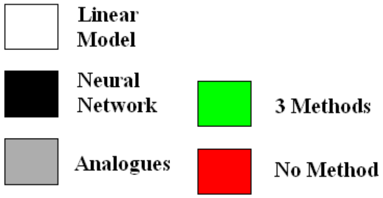
Downscaling

- Model Choice
- Robustness problems



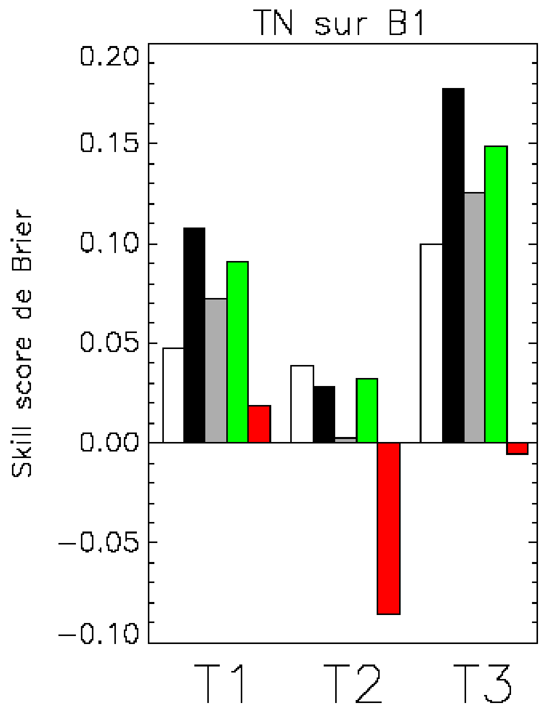


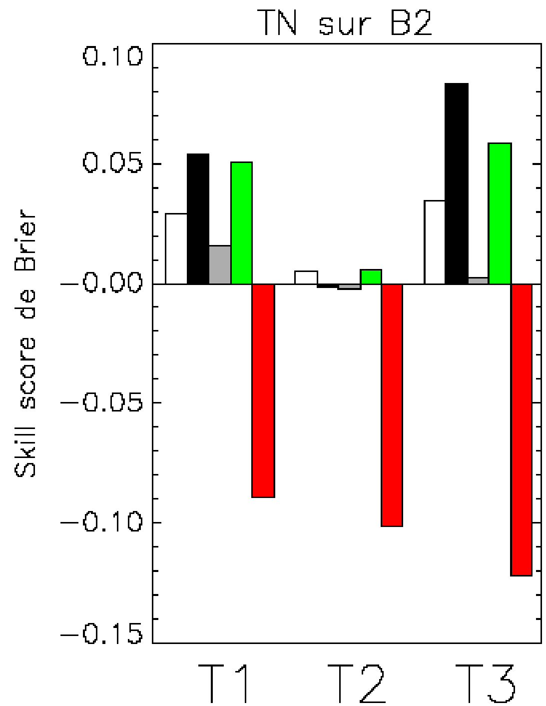


Test on 1980-2002

Minimum Temperature

Test on 1958-1979

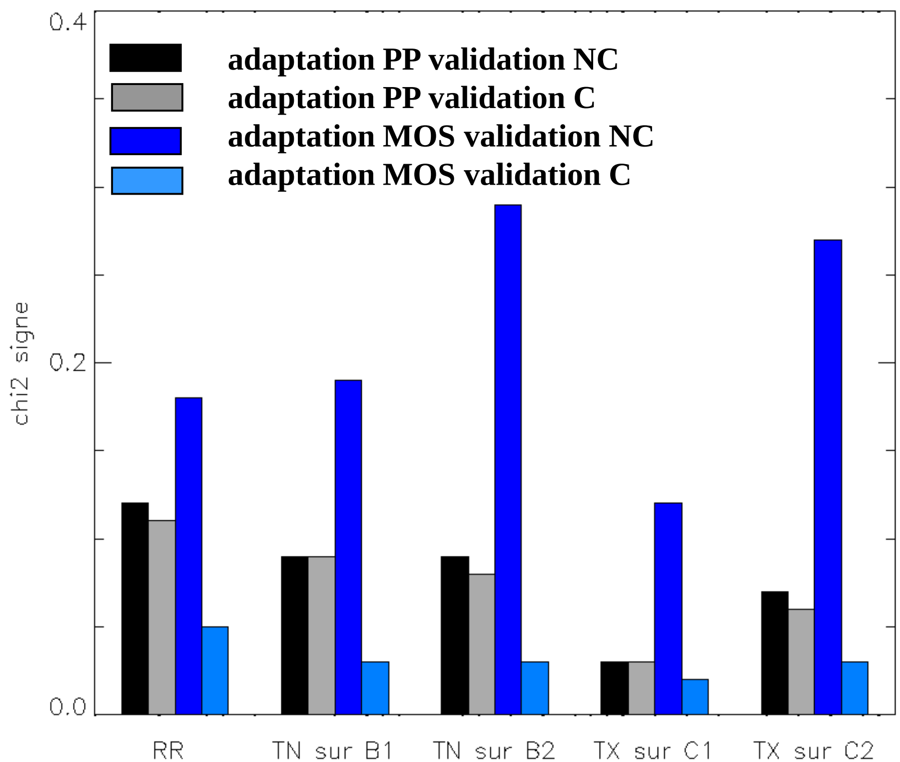




Downscaling

- Comparison of MOS adaptation using a 15-year climatology with a Perfect Prog adaptation using reanalysis (or longer hindcasts ?)

« Arithmetic Chi2 »



	T1	T2	T3
T1	1/9	1/9	1/9
T2	1/9	1/9.	1/9
T3	1/9	1/9	1/9

Arithmetic Chi2 of the tercile forecasts in validation modes : NC on learning file C cross vaildation For Perfect Prog mode (PP) and MOS mode (MOS) over a 15-year period.

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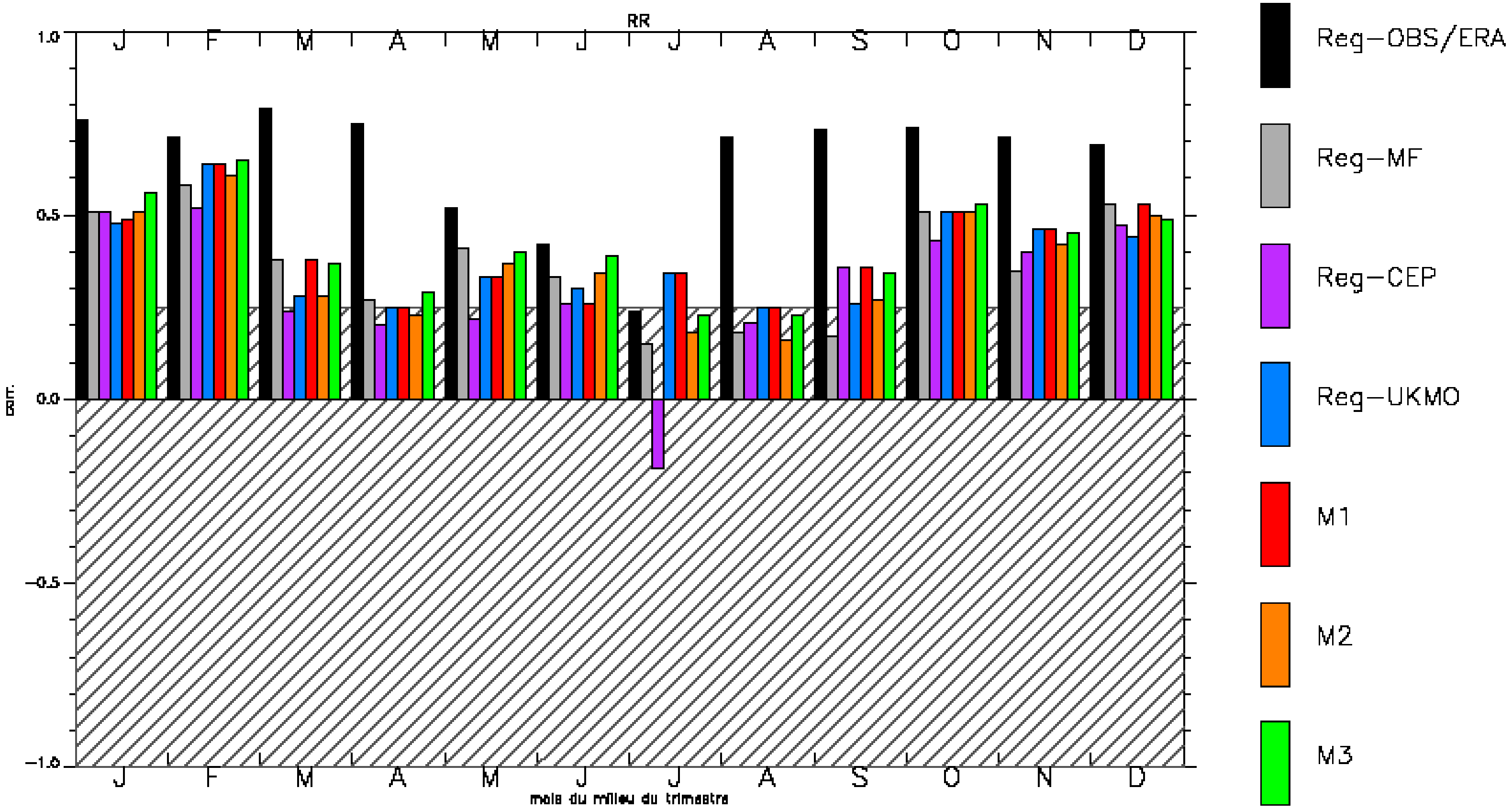
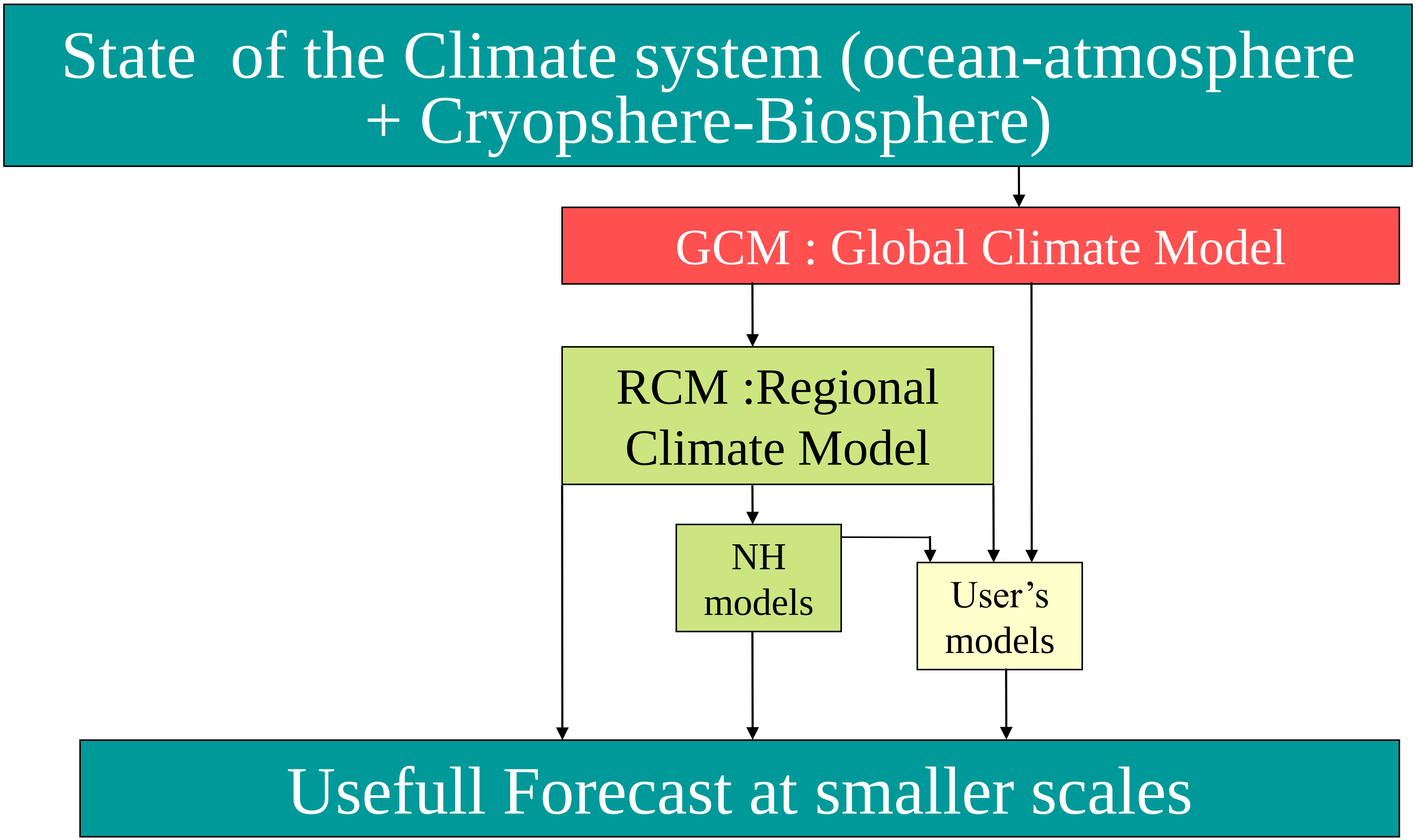
Downscaling (MME issues)

- **Adaptations of GCM's output over New-Caledonia**



Rainfall

Downscaling Methods



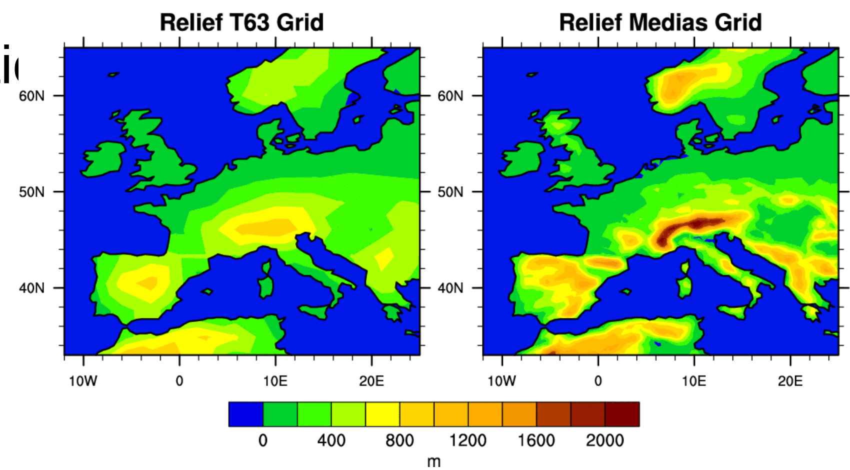
Downscaling Methods

- **Dynamical methods**
  - Limited Area Model coupled with the GCM
  - Asumption : The LSC force the « local » climate which is better represented in a LAM
  - *Model Output Statistics can be added*

+ No needs of observations over the region of interest,
+ Complexity of the climate system represented in the LSC and the LAM
+ Better extreme events forecasts
+ Uncertainty sampling (ensemble forecast, multi-model, …)
+ Difficult to implement operationally (GCM coupling files)
- GCM limitation and bias,
- Huge computing resources
- Boundary effects
- LAM limitation and error propagation

Downscaling Methods

- **Dynamical downscaling**
  - Available RCM models
    - MM 5
    - PRECIS,
    - ALADIN
    - HIRLAM,
    - …. ,
  - Hight Resolution Global Circulati
    - Full HR GCM
    - Stretched Grid



  - Available models (HR GCM)
    - Earth Simulator (~10 km - Research),
    - ECMWF (T159 L62 / N80 for the physics - operational - ~125 km)

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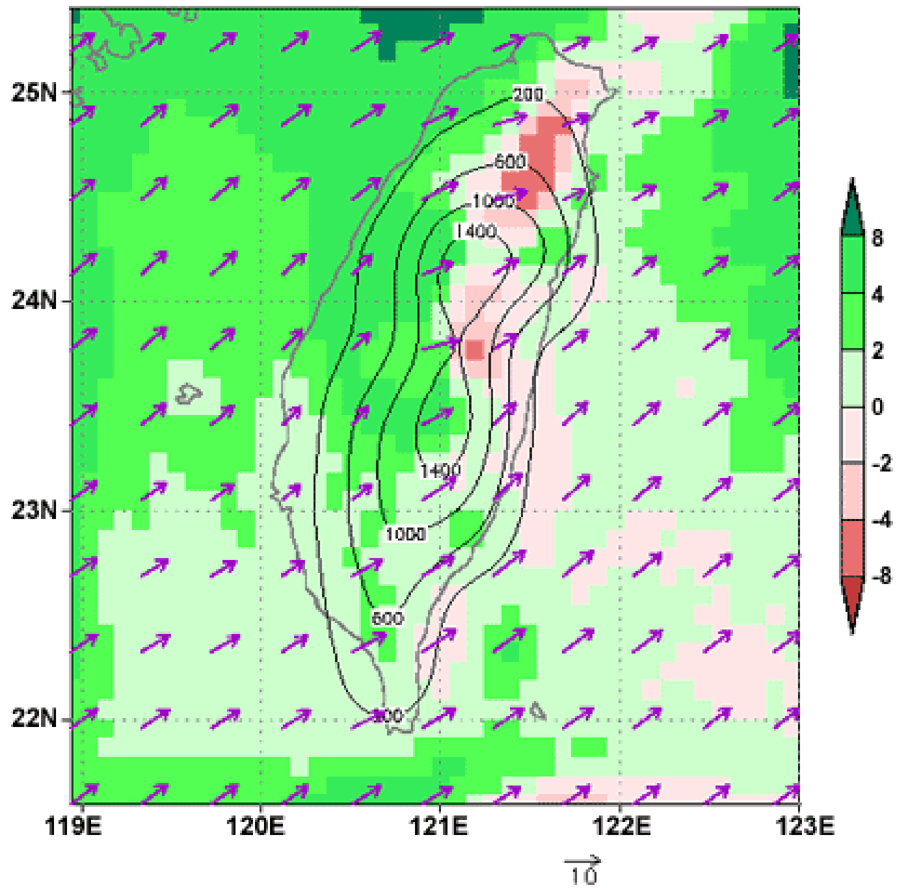
Downscaling Methods

- **Large scale forecast : Above Normal forecast**
  - Taïwan

FMA wind and rainfall for case study 1983-1971.



Thanks to IRI

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Downscaling Methods

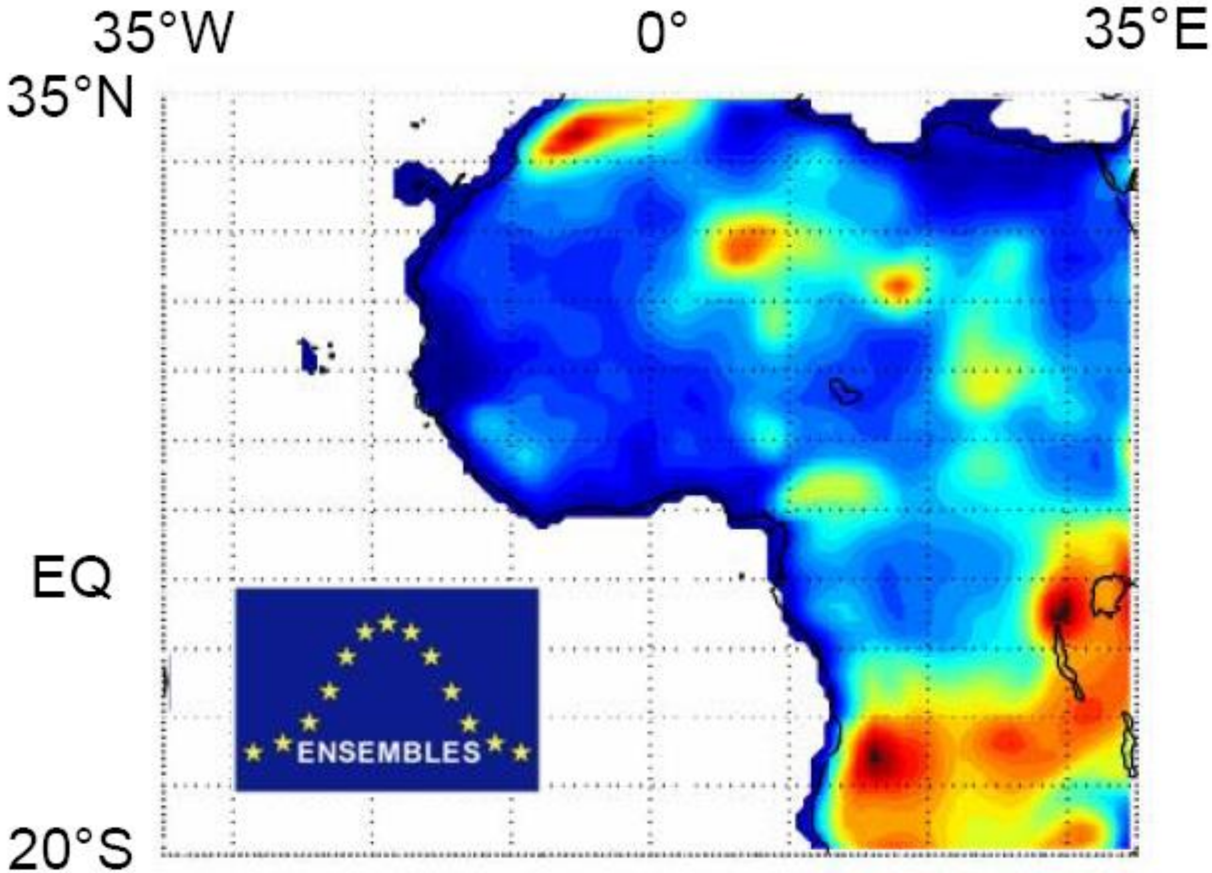
- **Dynamical downscaling**
  - General Circulation Model
    - Quality of Mean climate and variability and assessment of GCM bias
    - Quality of the Large Scale Forecast
    - Provision of coupling files,
    - Provision of hindcast,
  - Regional Climate Model
    - Quality of Mean climate and variability and assessment of LAM bias (LAM forced by Reanalysis)
    - Reference experiment (LAM forced by GCM hindcast),
    - Evaluation of Forecast quality
    - Verification of added value to the Large Scale Forecast
    - Operational coupling,

Downscaling Methods

- **Other Points of interest :**
  - Global Circulation Models
    - Influence of resolution on the quality of the Large Scale Signal (mean climat, bias, forecast)
    - Influence of resolution on the efficiency of dynamical downscaling
    - Parametrizations
    - Coupled Climate Components
    - …
  - RCM
    - One way versus Two way nesting,
    - Relevant LAM resolution with respect to GCM resolution,
    - Choice of simulated area,
    - Parametrizations,
    - Coupled vs Uncoupled RCM,
    - Influence of large water bodies,
    - Extreme event forecasts,
    - How to cope with GCM bias ?
    - …

Downscaling Methods

- **Domain choice :**



ENSEMBLES project

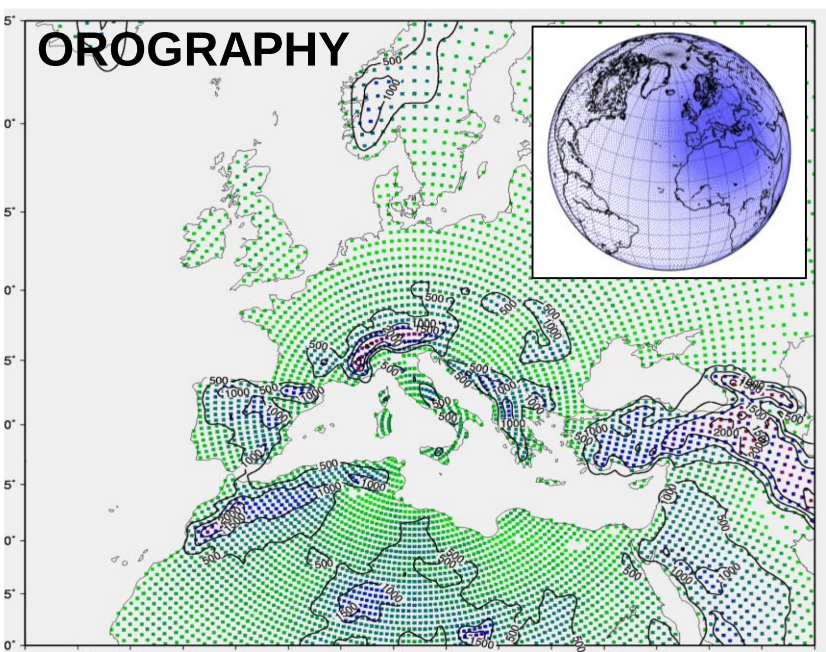
http://ensembles-eu.metoffice.com/

Mediterranean AORCM

Atmosphere: ARPEGE-Climate

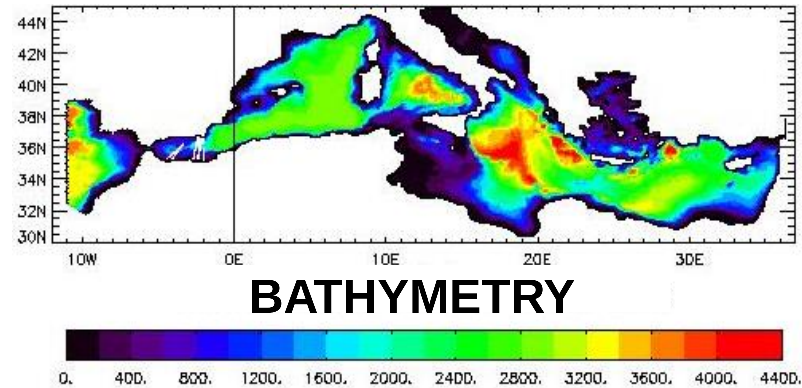
(Gibelin and Déqué 2003)

- Global and spectral AGCM
- 31 vertical levels
- Stretched Grid
- Zoom over the Med Sea
- Resolution : 0.5° (50 km)



Ocean: OPAMED8

(Somot et al. 2006)



- Horiz. resol.: $\Delta x \sim 1/8° \sim 10km$
- 43 vertical z-levels
- Atlantic buffer zone (3D-relaxation for S and T)
- Explicit river runoff fluxes (UNESCO database + Black Sea)
- MedAtlas-II initial conditions
- 10-year spin-up

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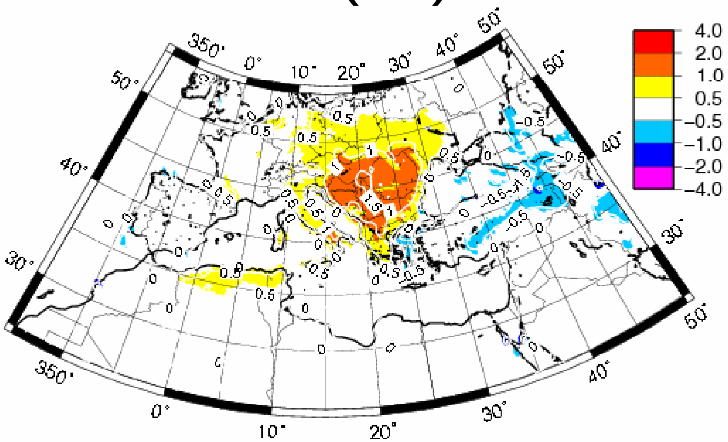
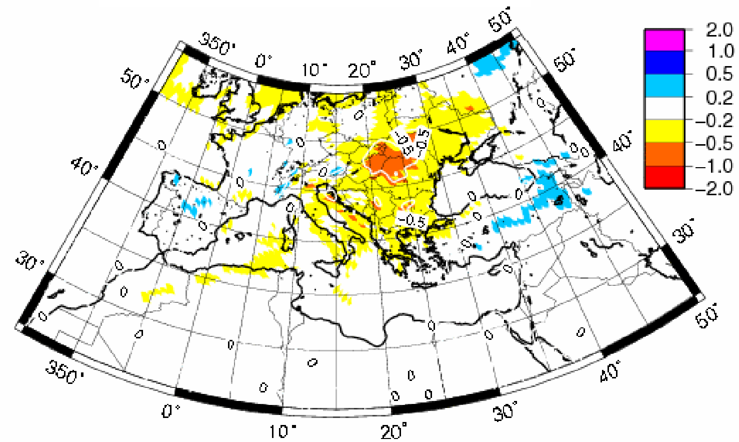
Coupling impact in Summer: Δ(AORCM) - Δ(ARCM)

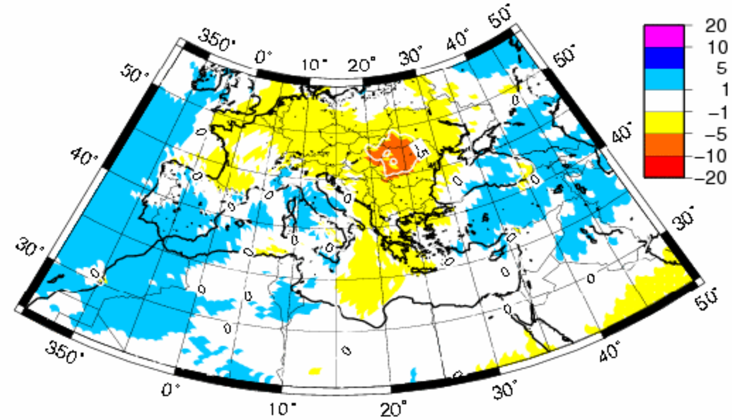
T2m (°C)



Prec (mm/j)



- AORCM: drier and warmer
- SST : less warming in the AORCM (-0.5°C, Aegean Sea, 99% signif.)
- Increase in land-sea temperature contrast
- Decrease in relative humidity over land (« Rowell and Jones, 2006 » effect)
- Positive feedbacks (soil water, nebulosity)



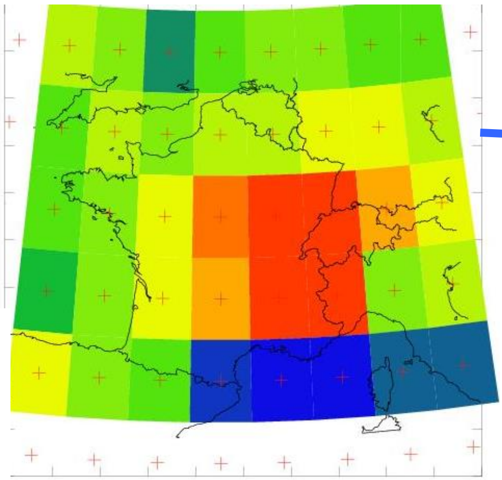
Nebulosity (%)

Methods of Downscaling

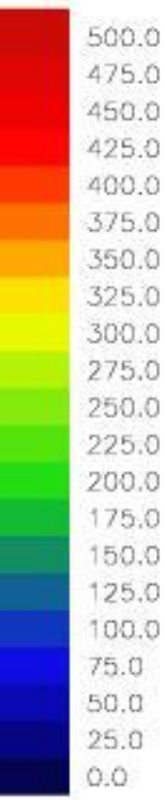
- **Other methods**
  - Conditional dynamical simulations (e.g. by circulation regimes / Weather types),
  - Interpolation and local corrections (e.g. vertical gradients, quantiles/quantiles corrections)
  - Weather generators,

Methods of Downscaling

- Simple interpolation method (ROUSSET-REGIMBEAU,2007)

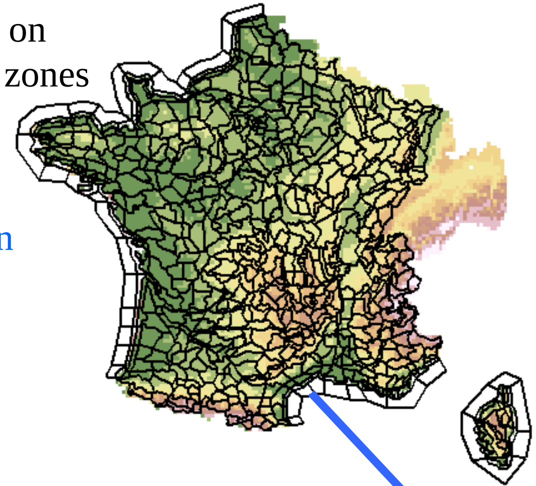


DEMETER Precipitation



Interpolation on SYMPOSIUM zones

Interpolation 1/r² Distance

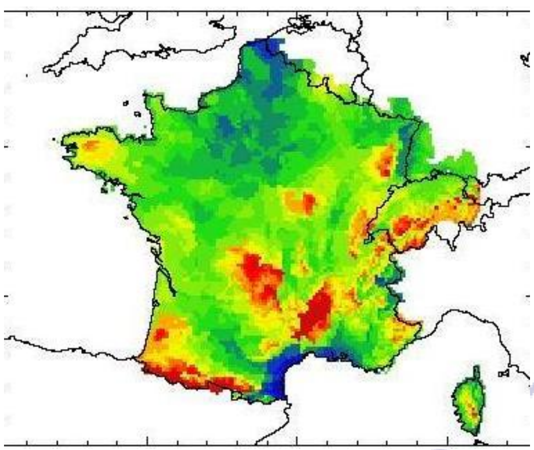


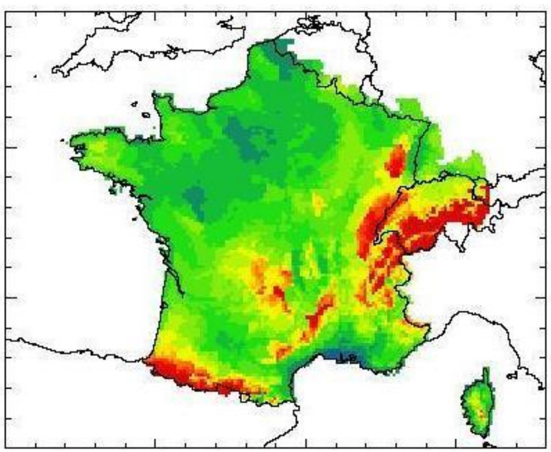
Vertical Gradient (Simulation 1)
T : -0.65 °K/100m
Rain : + 0.7 à 2 mm/year/1m

Cumulated rain in mm over March-April-May 1998

Interpolation on ISBA mesh - 8km

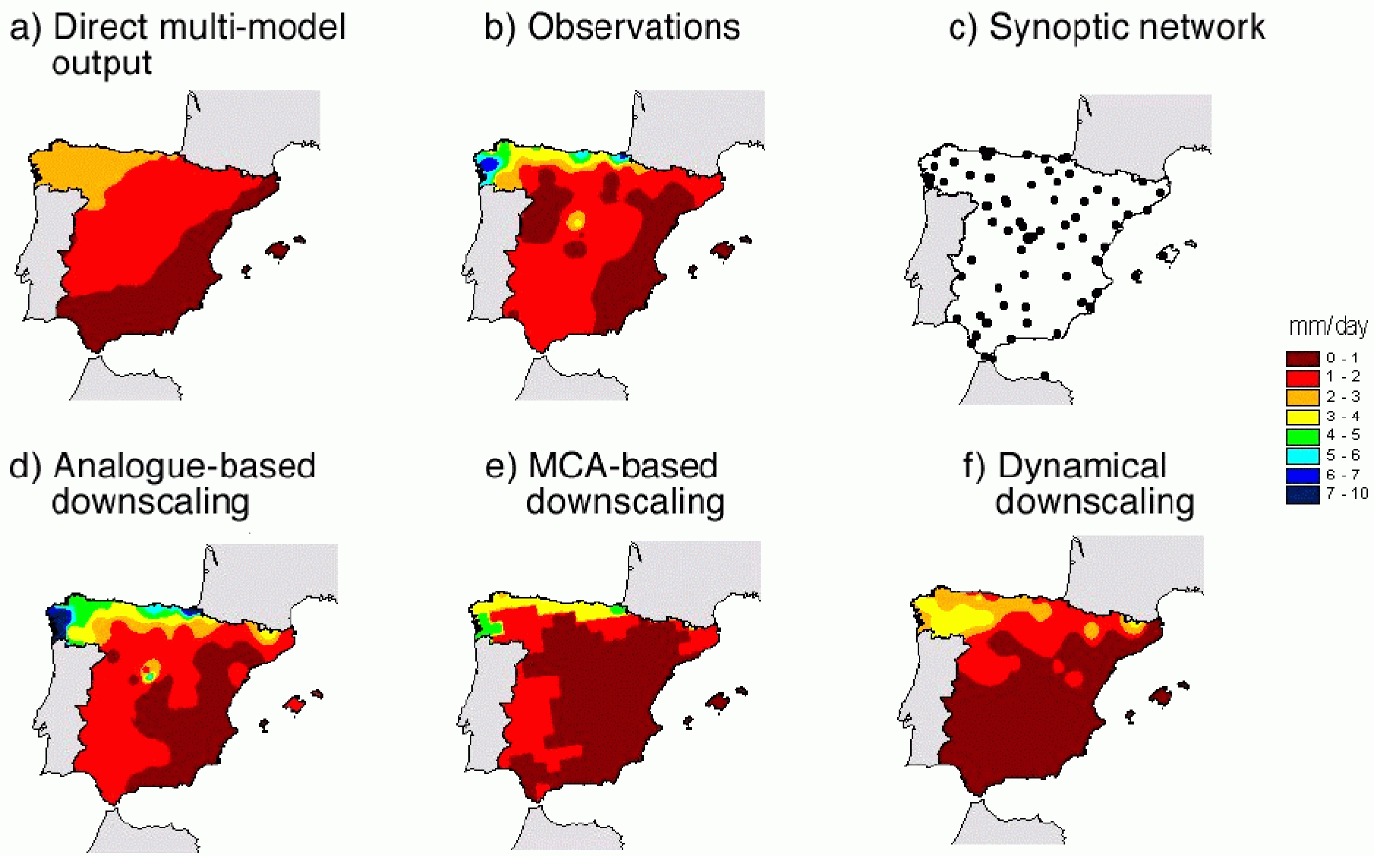
SAFRAN Reference





Methods comparison

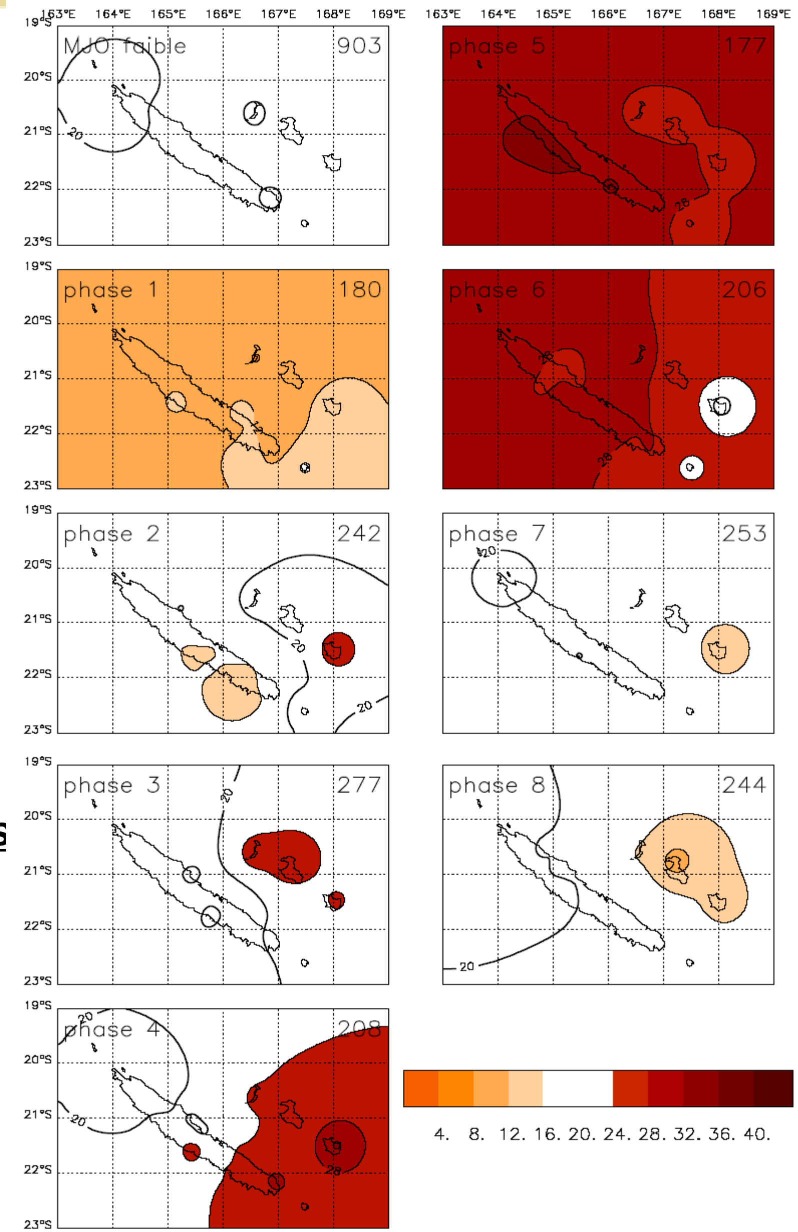
- Purely Dynamical and Statistical/Dynamical methods give quite comparable results



Palmer and all, 2004, BAMS (Demeter paper)

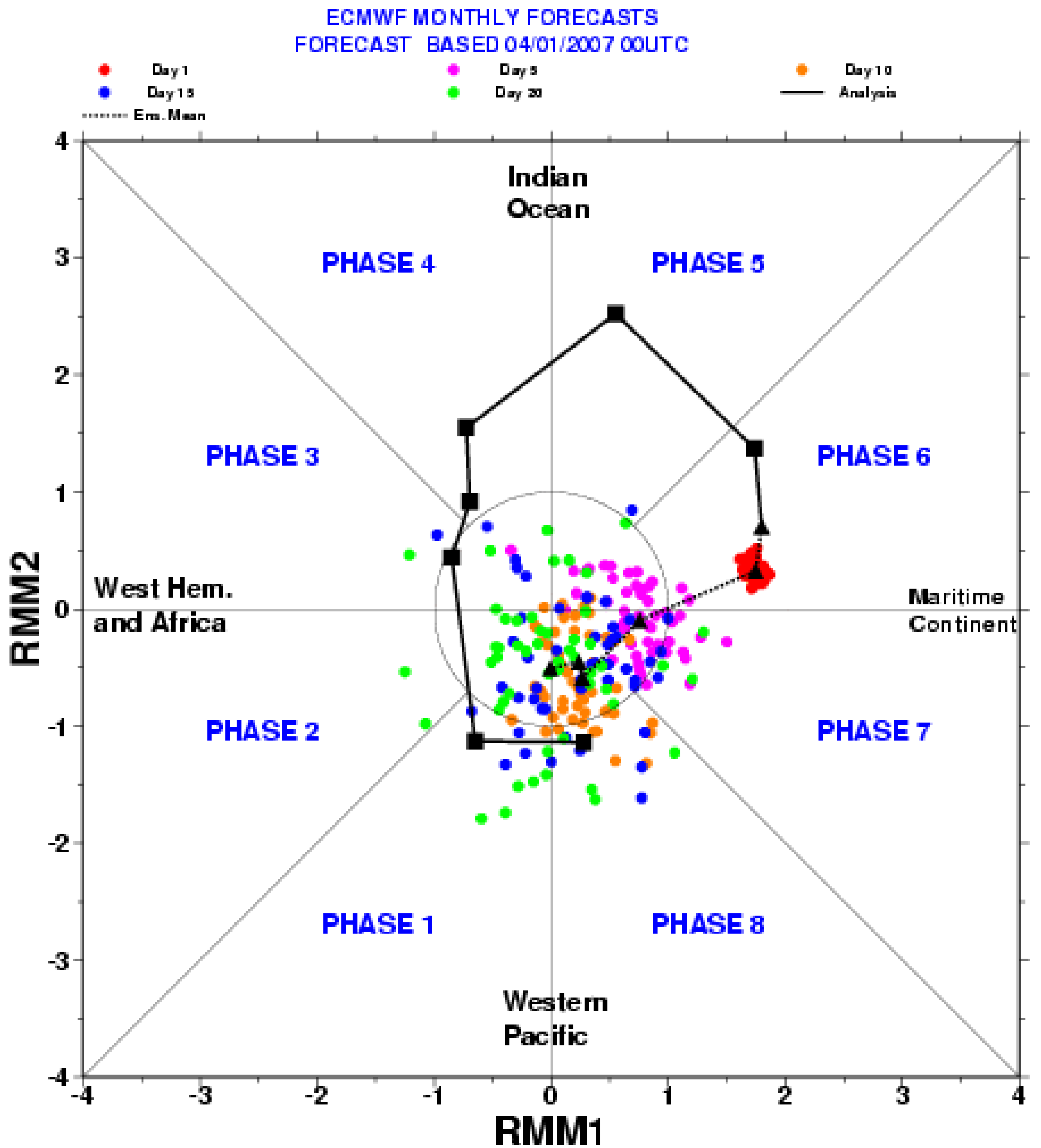
Downscaling in time

- **Intraseasonal variability**
  - Intraseasonal evolutions
  - Intraseasonal modulations
  - Significant intraseasonal forcing of the MJO on Tn, Tx and RR



Probabilities of rainfall above the upper quintile (strong rainfall) in JFM vs MJO phases (Real time MJO Multivariate Index – Wheeler & Hendon – MWR - 2004)

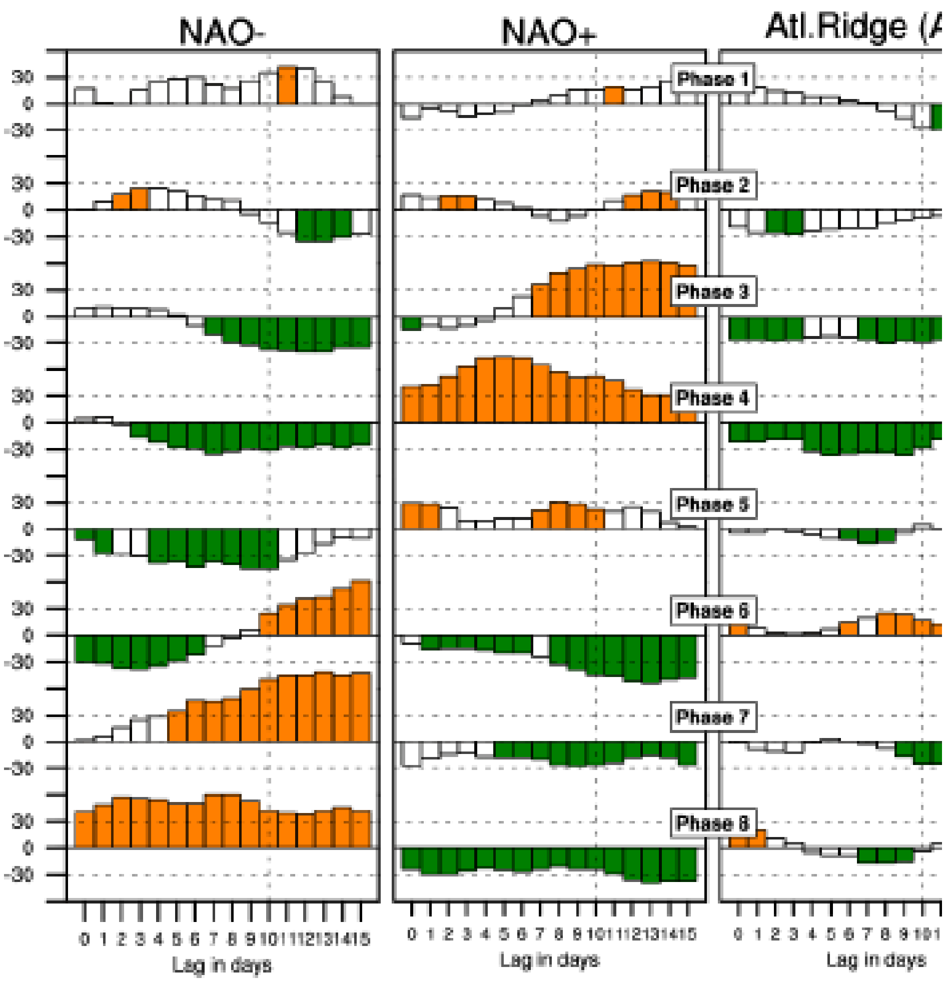
Downscaling in time

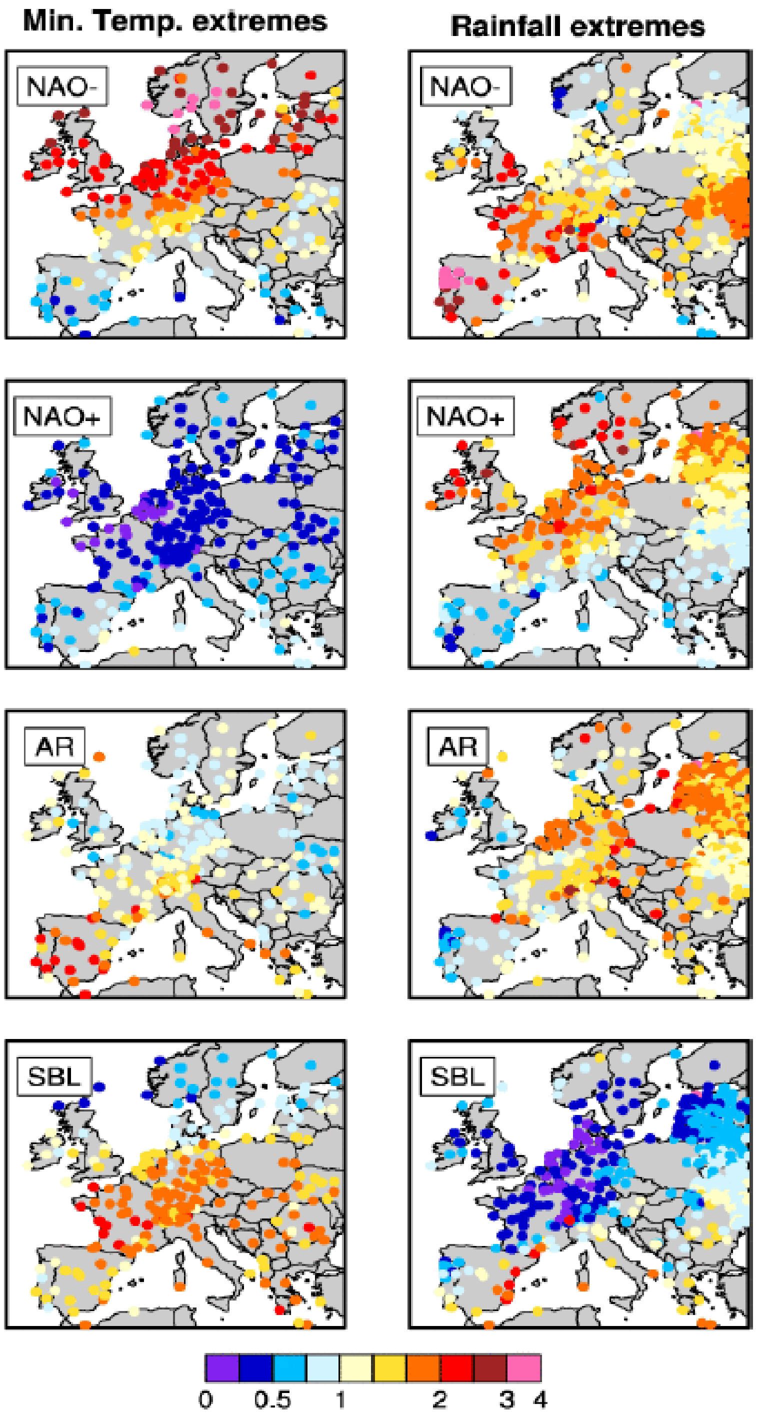


METEO FRANCE
Toujours un temps d'avance

Downscaling in time

- **MJO/NAO relationship**





Conclusion

- **Sucess in downscaling depends on :**
  - The predictability over the targeted region,
  - The « local » part of the signal which is large scale forced,
  - The parameter, the targeted gategories and the period ,
  - Good observations for calibration when needed (climate and users's domain),
  - The use of the information,

- **About downscaling models (MOS or PP) :**
  - A sufficient long period for training (notably when multidecadal variability is present),
  - Recalibration of the model on a regular basis (notably when one have a short training period),
  - Recalibration when the GCM changes (MOS),

Conclusion

- **About downscaling models (MOS or PP) :**
  - Verification of added value brought by the model,
  - Verification of the robustness of the model,
  - Robustness seems to depend on the category (terciles more robust than quintiles),
  - The merging of information coming from different GCM can be done quite easily (but is it better than single model downscaling ?),
  - For short training period, the Perfect Prog approach seems to be quite robust (use depends probably on predictability)
  - A lot of methods can be used,
  - The « best » choice can depend on the forcing, the period and the parameter,

Conclusion

- **About Dynamical downscaling :**
  - Verification of additional value brought by the RCM,
  - Challenge for extreme events,
  - Coupled version can improve the local representation of the local climate (depends on the link between local SSTs and local climate),
  - Challenges in initial states (e.g. Snow / Ice, soil moisture, …),
  - Fine mesh analysis (notably for surface parameters)
  - Resolution / Parametrizations / …
  - Multimodels issues

Conclusion

- **About Downscaling :**
  - Tools similar for both seasonal and climate change issues,
  - Capacity building useful for both seasonal and climate change issues,
  - Seasonal forecasts first step for CC adaptation,
  - Tailoring and Downscaling quite similar activities
  - Many softwares available for statistical downscaling
  - MOS (or PP when necessary) could be promoted notably in the frame of RCOFs activities and WMO framework
  - Some RCMs already widely disseminated – take care with operational aspects for seasonal forecasting
  - Difference between operational forecasting suites and « resarch » mode (more suitable for CC issues)

Thank you for attention