Basics of numerical coupled modelling

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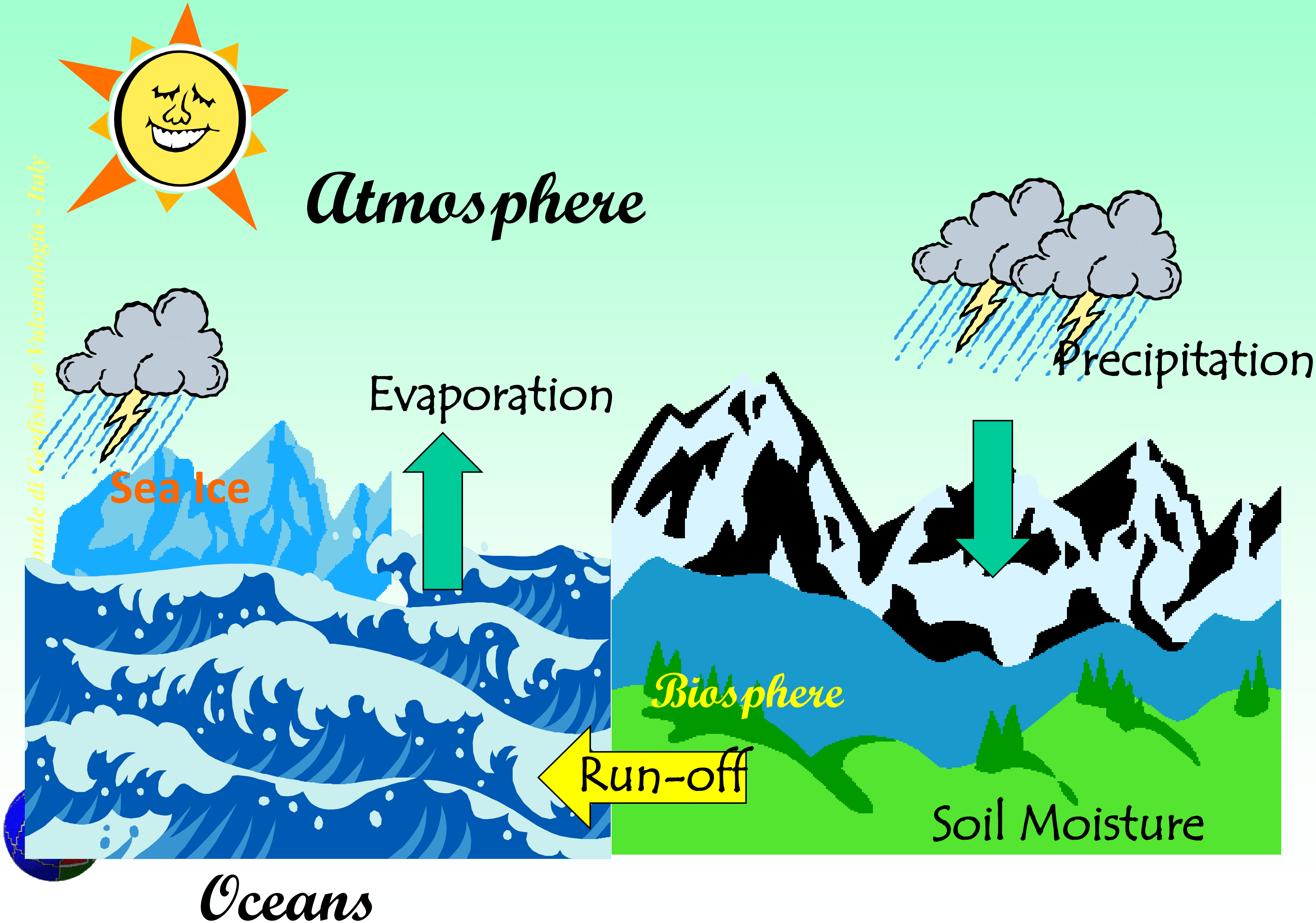
Lecture 5

The Climate System



Coupled Phenomena

Why is there a need for considering coupled models ?
There are at least two major reasons why it is clear that realistic description of climate cannot be done without considering the atmosphere and ocean at the same time

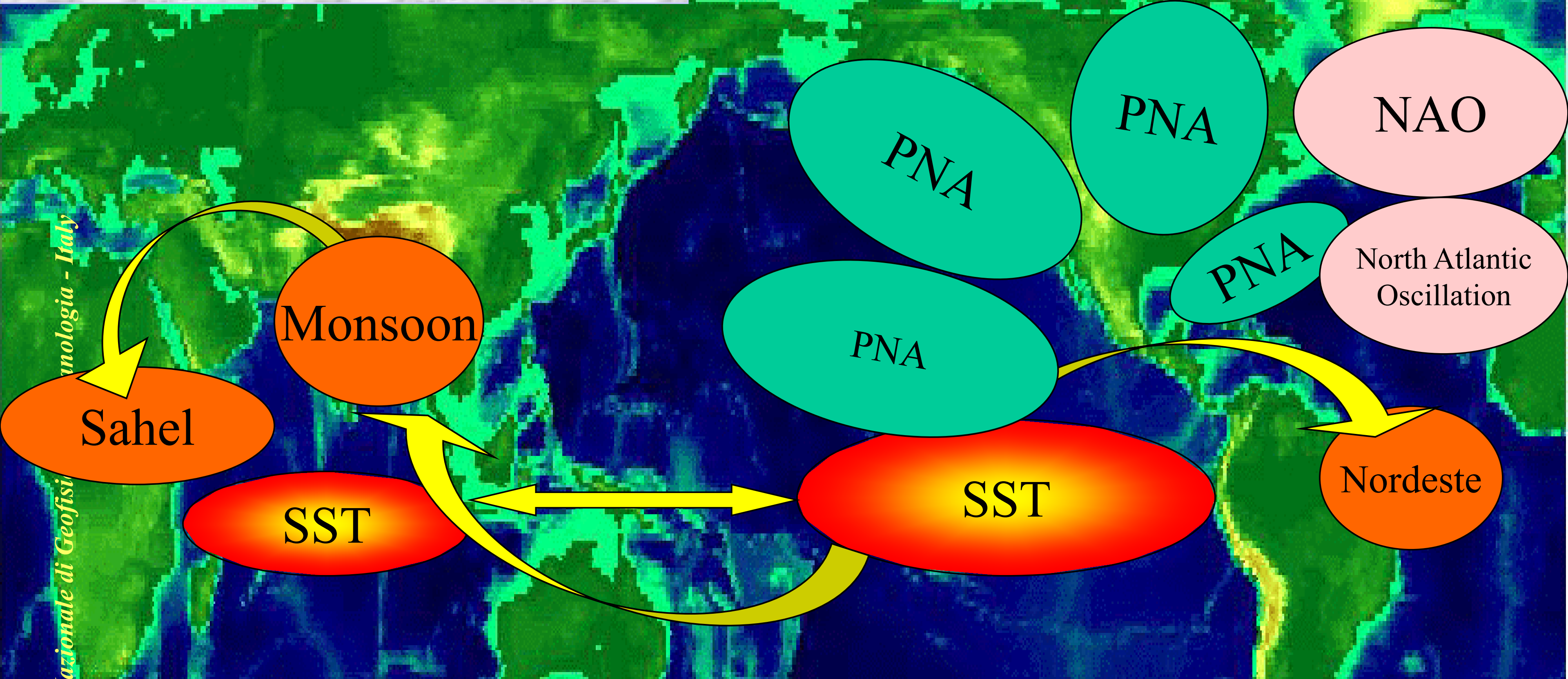
Teleconnections

The interactions between atmosphere and oceans in the tropics dominate the variability at interannual scales. The Sea Surface Temperature affects the atmosphere generating giant patterns that extend over the planet

Thermohaline Circulation

The deep oceanic circulations is driven by fluxes of heat and fresh water that change temperature and salinity of the water. Dense water (cold and saline) sink deep down creating a worldwide circulation as light water (fresh and warm) upwells through the world ocean, affecting the global sea surface temperatures, which in turn change the dominant mode of climate variability through the teleconnections.

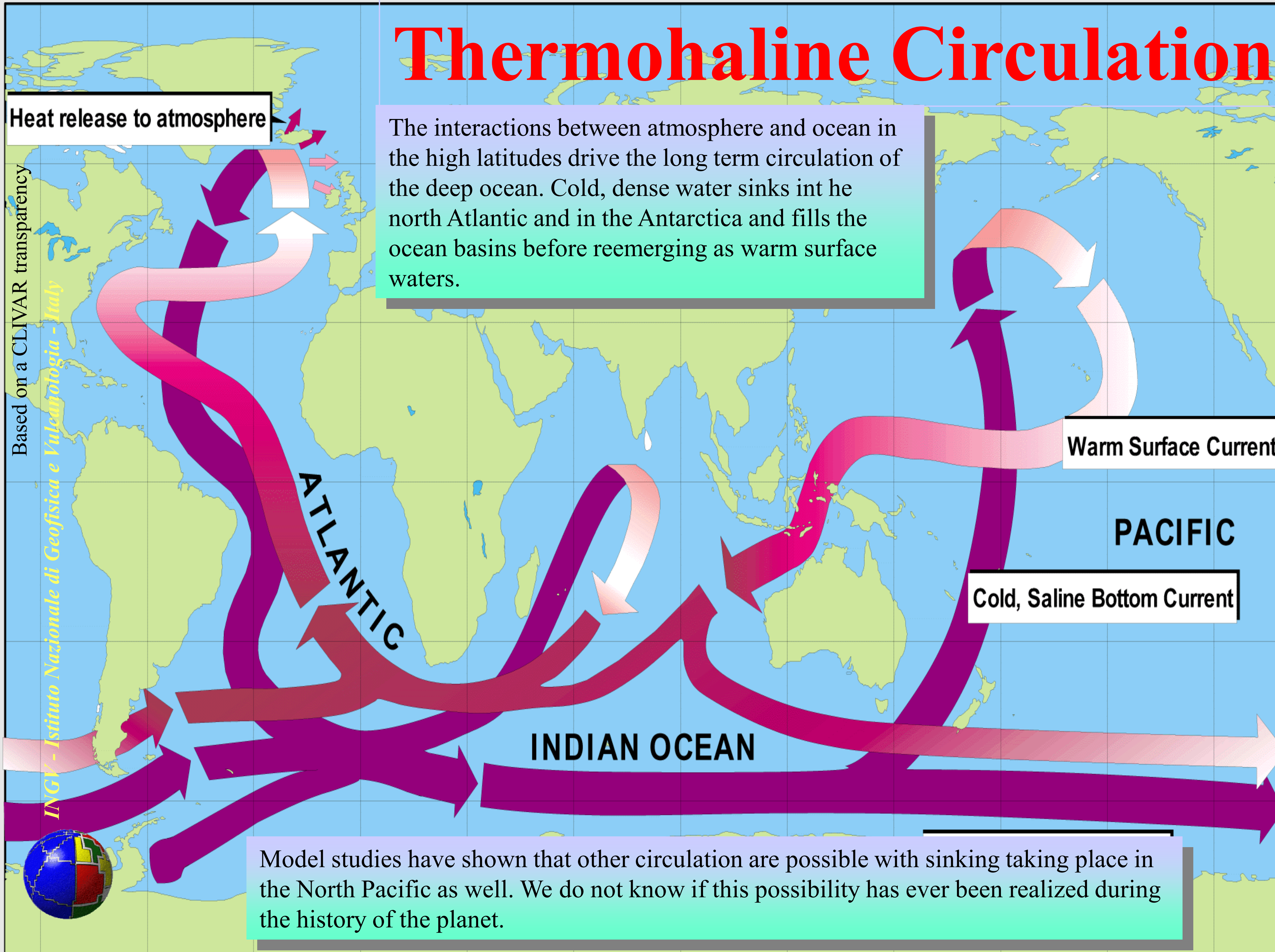
Teleconnections



The interactions between atmosphere and oceans in the tropics dominate the variability at interannual scales. The main player is the variability in the equatorial Pacific. Wavetrains of anomaly stem from the region into the mid-latitudes, as the Pacific North American Pattern (PNA). The tropics are connected through the Pacific SST influence on the Indian Ocean SST and the monsoon, Sahel and Nordeste precipitation. It has been proposed that in certain years the circle is closed and and a full chain of teleconnections goes all around the tropics. Also shown is the North Atlantic Oscillation a major mode of variability in the Euro-Atlantic sector whose coupled nature is still under investigation.

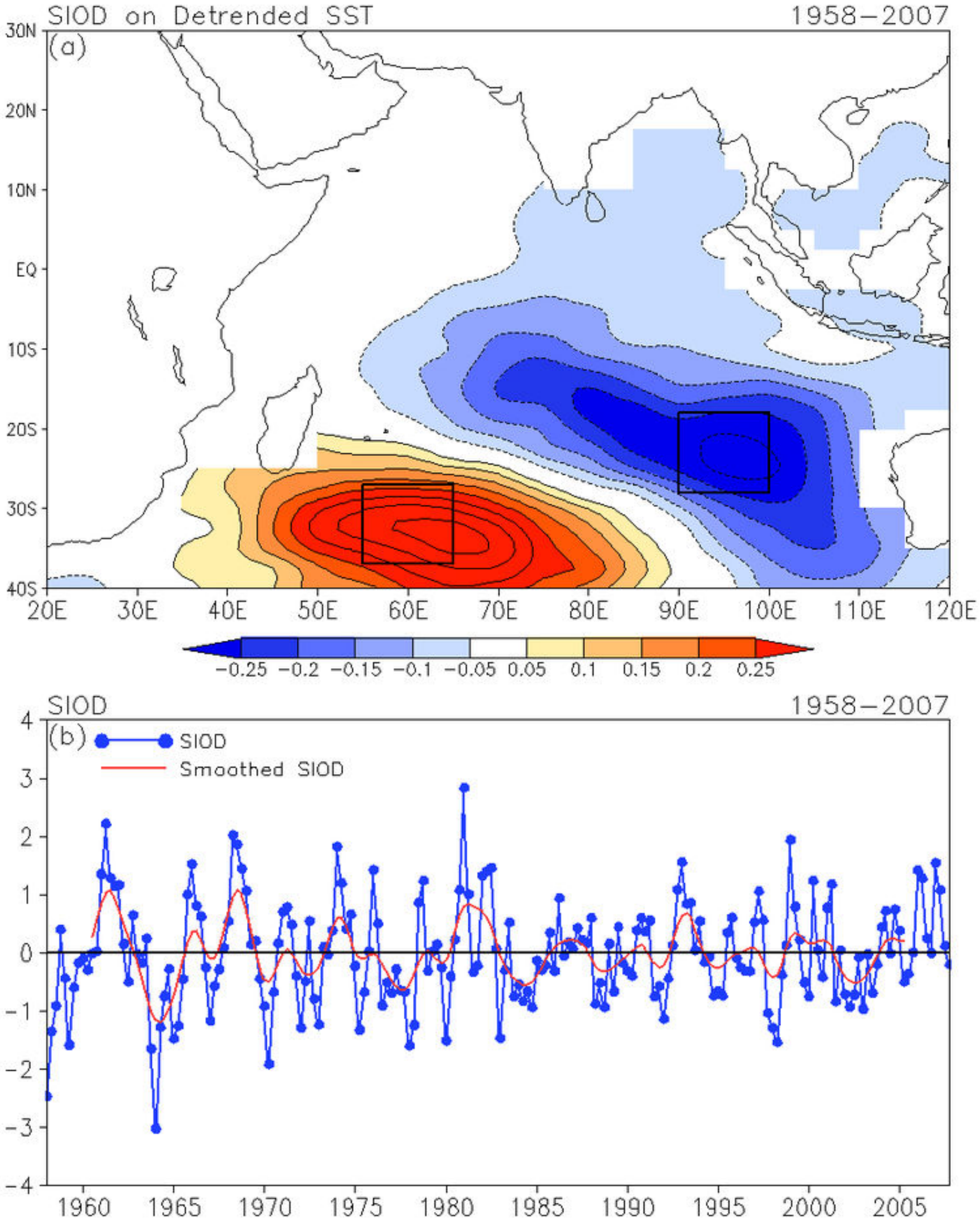
Thermohaline Circulation

The interactions between atmosphere and ocean in the high latitudes drive the long term circulation of the deep ocean. Cold, dense water sinks int he north Atlantic and in the Antarctica and fills the ocean basins before reemerging as warm surface waters.

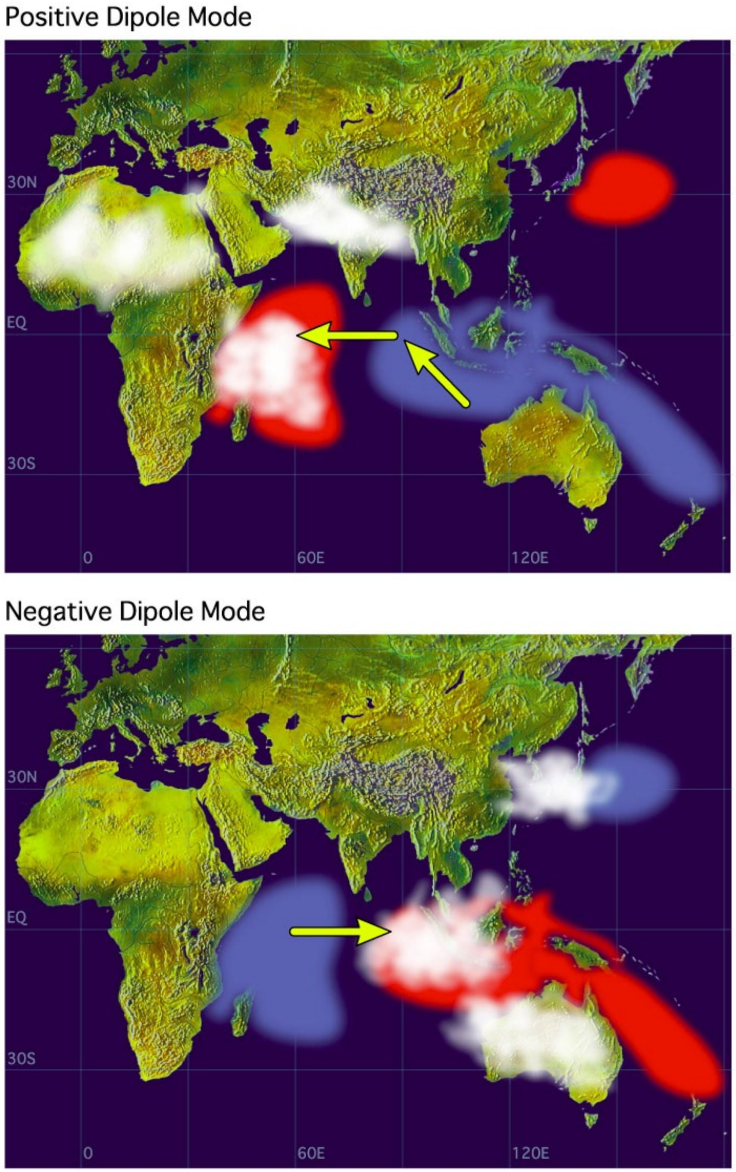


Model studies have shown that other circulation are possible with sinking taking place in the North Pacific as well. We do not know if this possibility has ever been realized during the history of the planet.

Subtropical Indian Ocean Dipole



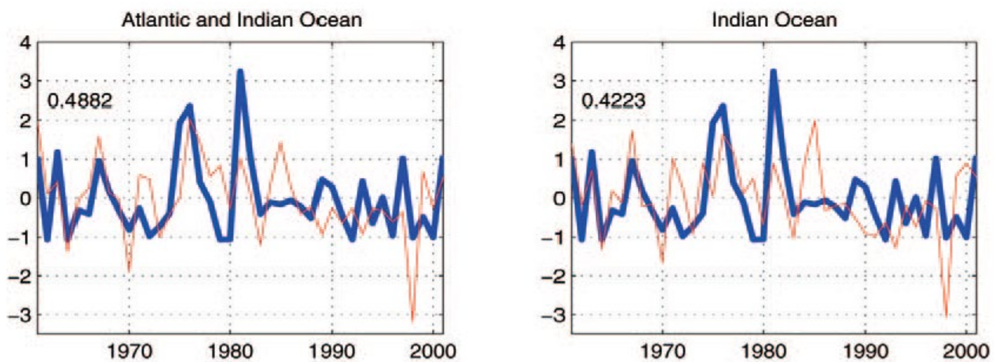
Indian Ocean Dipole



Seasonal to Decadal Prediction of Southern African Climate and Its Links with Variability of the Atlantic Ocean

BY C. J. C. REASON, W. LANDMAN, AND W. TENNANT

Improved climate prediction for southern Africa requires a better understanding of the oceanic influences, particularly the South Atlantic which has not been extensively studied.



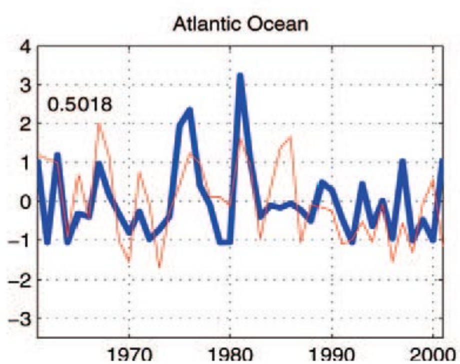


FIG. 6. MOS-simulated rainfall-normalized anomalies (thin line) of MAM rainfall for the |Ai-|Ais/Richtersveld Transfrontier National Park vs observed MAM-normalized anomalies (thick line). Results from using three different regions in the MOS domain are shown (southeast Atlantic and southwest Indian Oceans, southwest Indian Ocean only, southeast Atlantic Ocean only). The correlation between the 3-year-out cross-validated simulations and the observed time series is shown top left.

Numerical Models

The only hope we have to be able to understand and possibly predict some of these changes is to use numerical models to investigate the dynamics of atmosphere-ocean coupling.
Atmospheric and ocean numerical models can be put together (coupled) and numerically integrated for hundreds or thousands of years, depending on the realism of the models involved

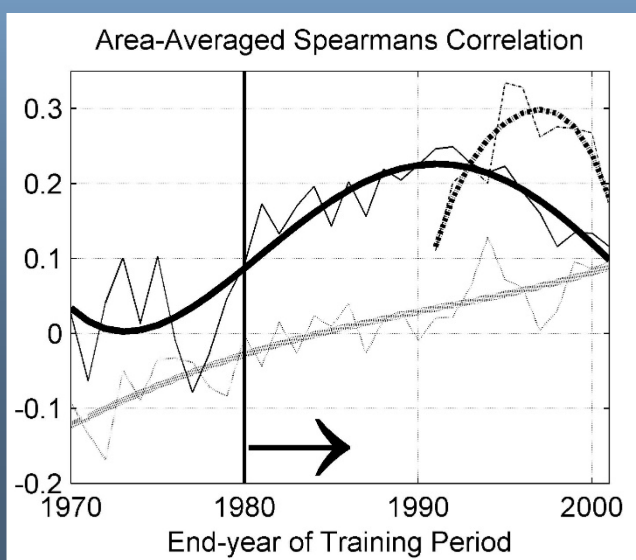


Figure 2. Variation in cross-validation forecast skill predicting DJF rainfall over southern Africa as reflected by area-averaged Spearman's correlation values. The thick black solid line (4th-order polynomial) and associated thin black solid line show the MMcca multi-model's performance as a function of cross-validation training period, while the thick black dotted and thin black dotted lines represent the ECHAM4.5-MOM3-DC2 coupled model. The remaining gray lines represent the statistical model that uses equatorial Pacific Ocean SST as predictor. The arrow indicates where the retroactive test period starts.

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RMetS
Royal Meteorological Society

Multi-model forecast skill for mid-summer rainfall over southern Africa

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[c] *South African Weather Service, Pretoria, South Africa*

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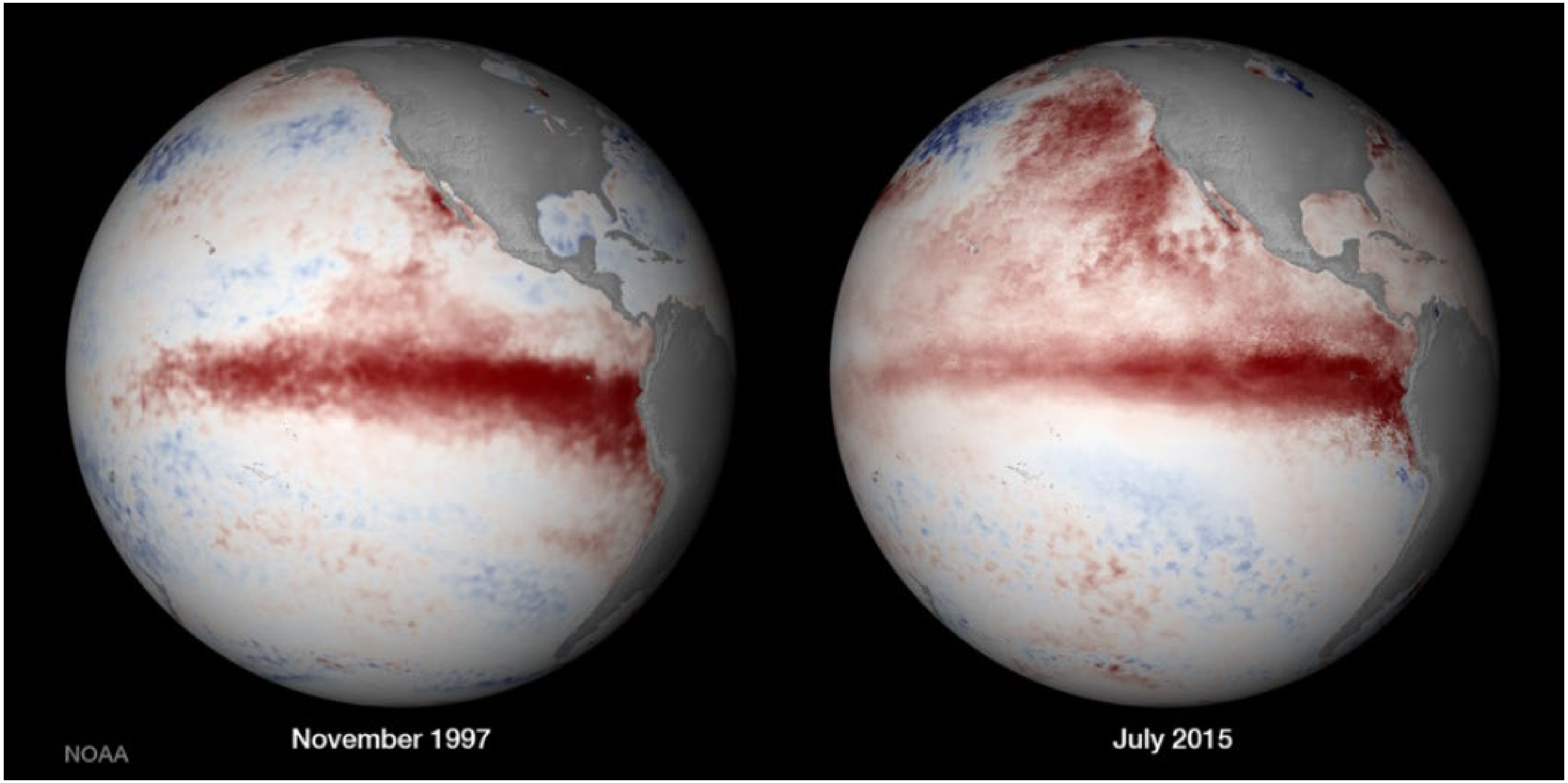
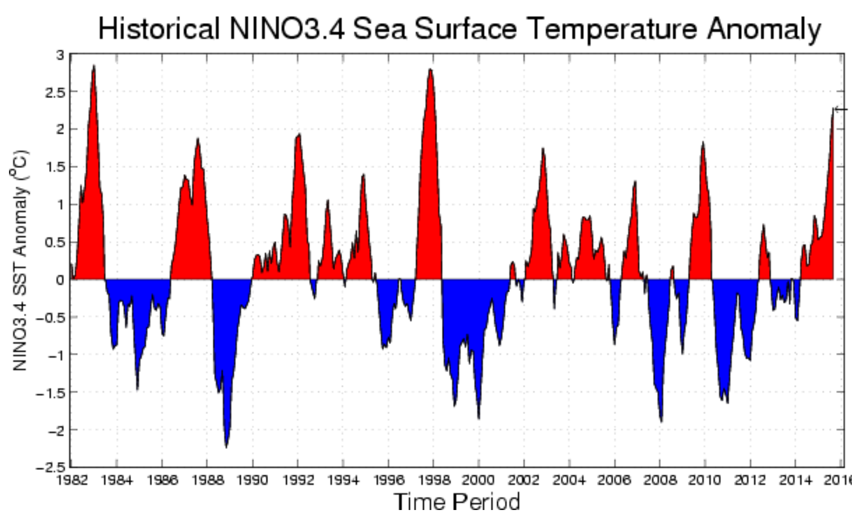
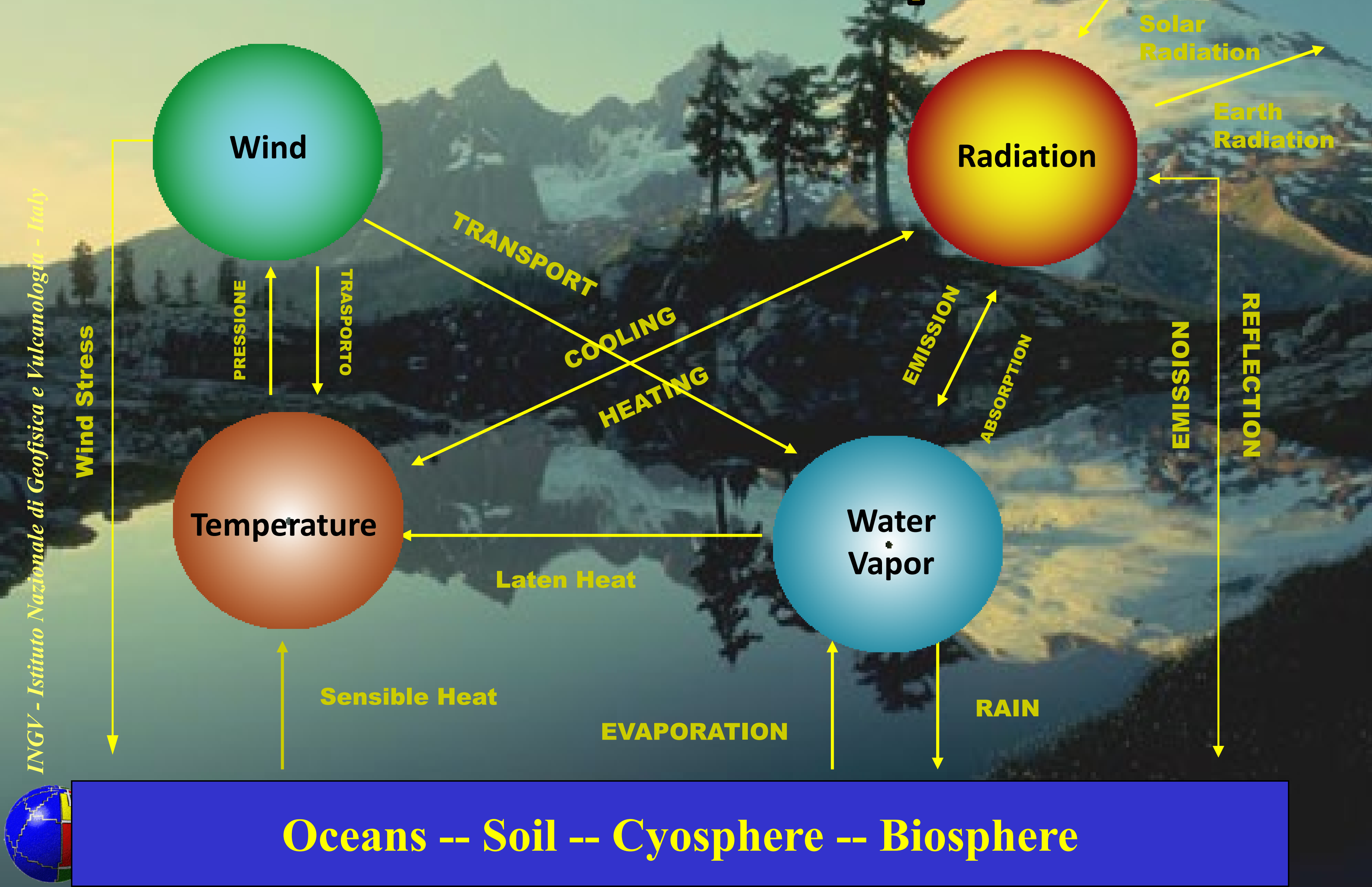


In the modern record of El Niños not a single El Niño event tracked like another El Niño event

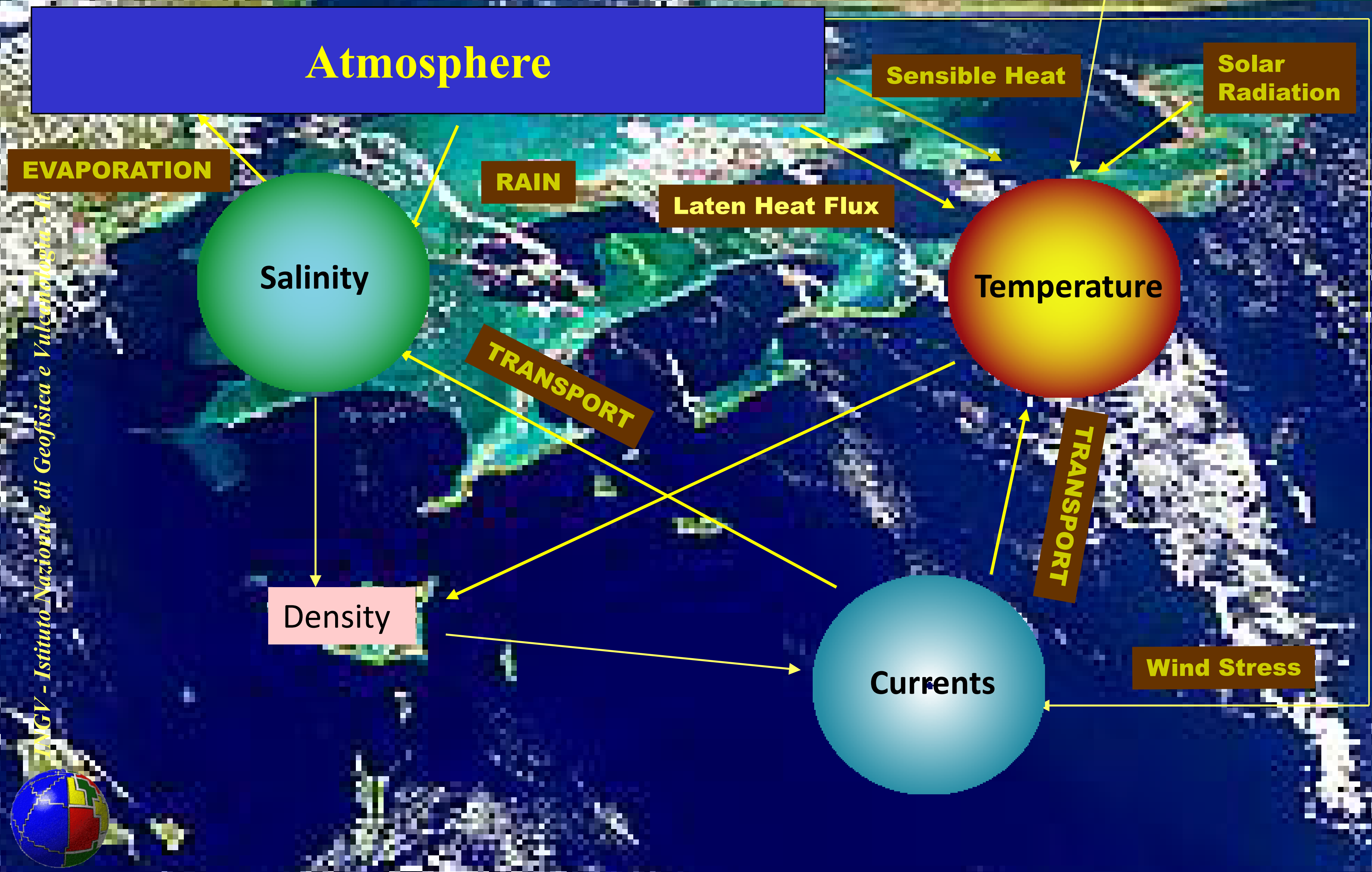


There is no guarantee that the impacts of one El Niño will be just like that of a previous one, even if they look broadly similar

Numerical Models:Atmosphere



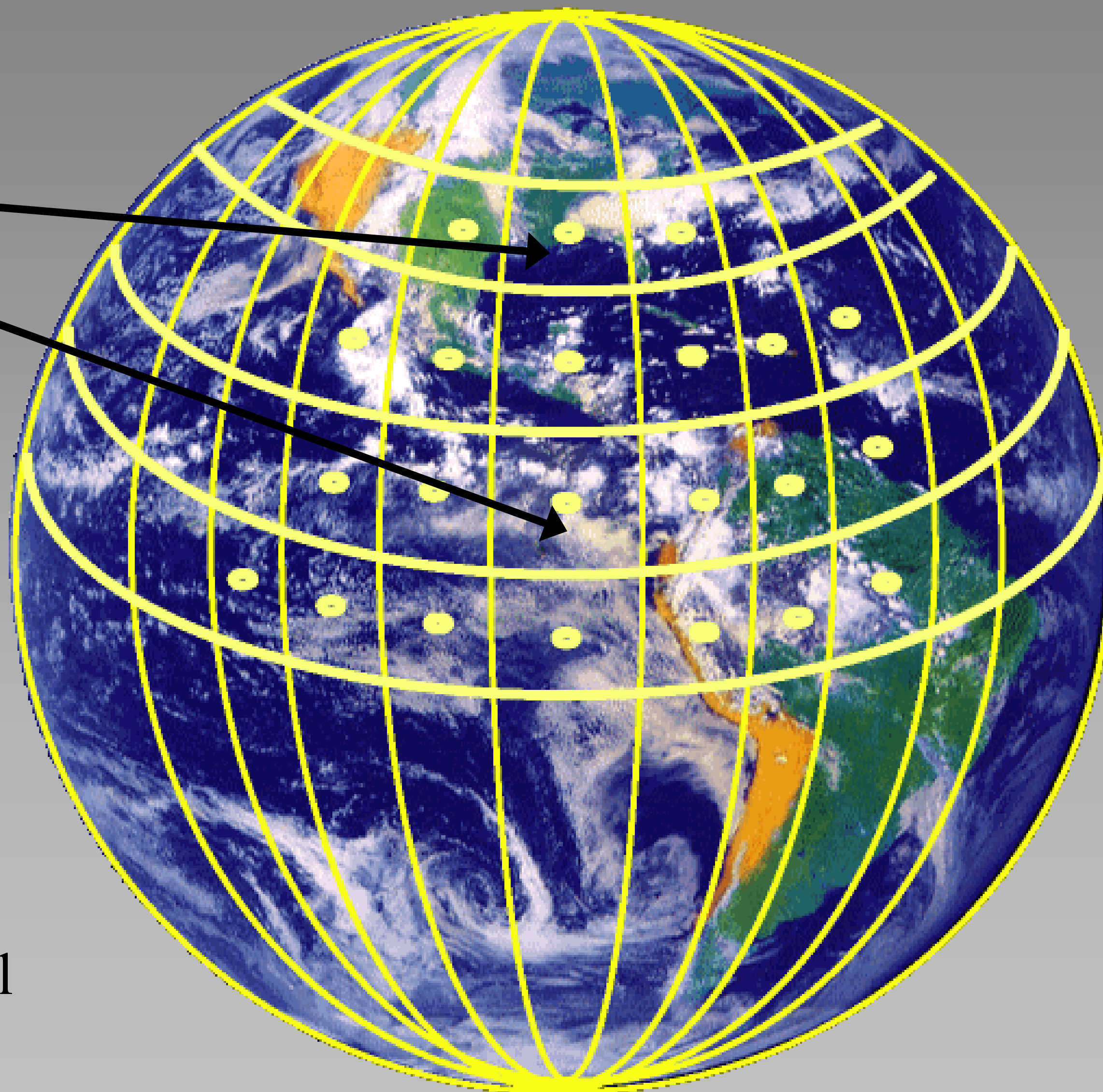
Numerical Models:Oceans



Discretization Methods

The atmosphere and the ocean are divided in computational cells: (Temperature, Wind, Rain, Sea Ice, SST, Salinity, …) both horizontally and vertically.

The dimensions of the cell are usually not the same in the atmosphere and ocean component because of the different dynamics.



Dimension of the cell (resolution) 200-300 km

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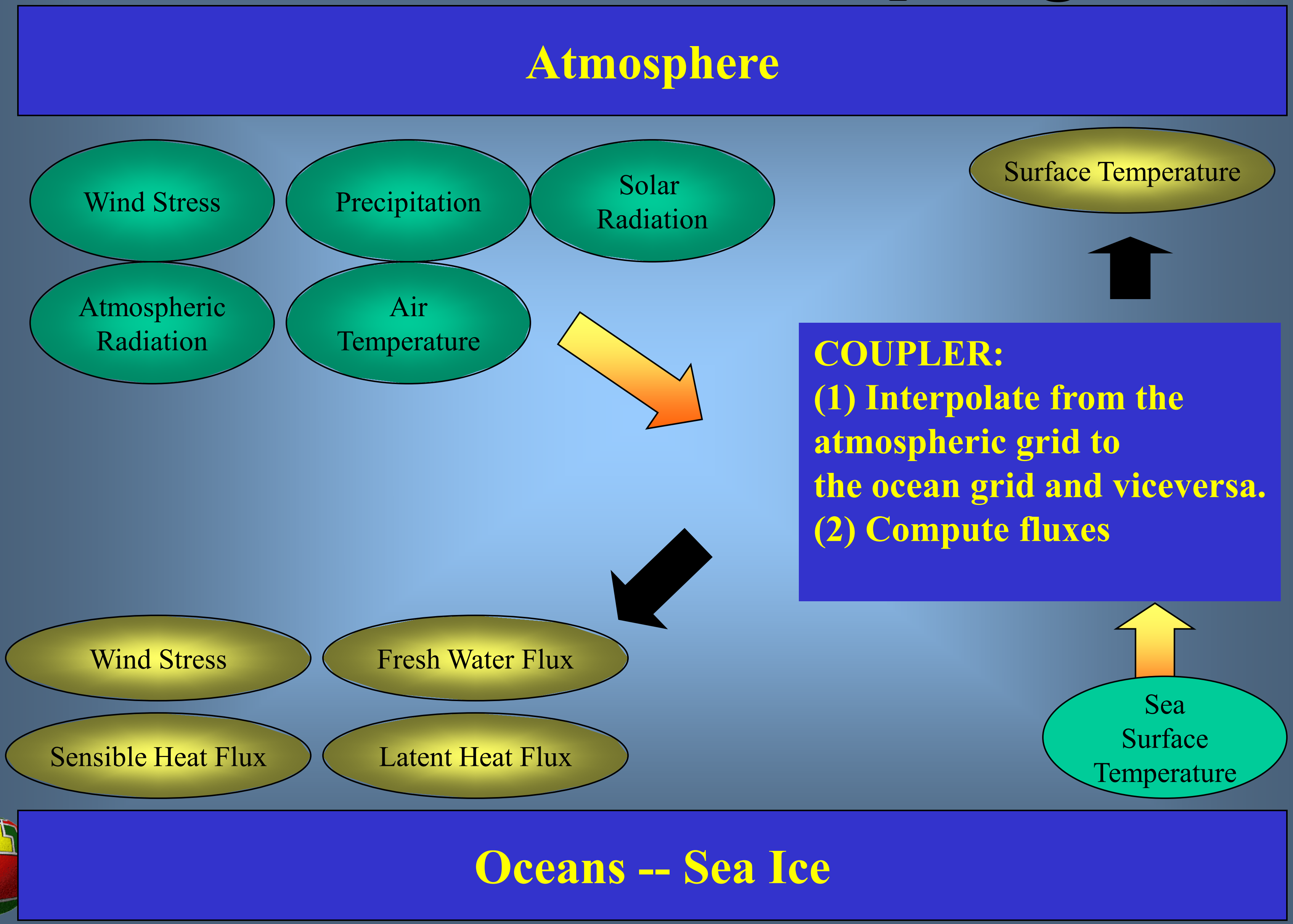
Numerical Models:Coupling



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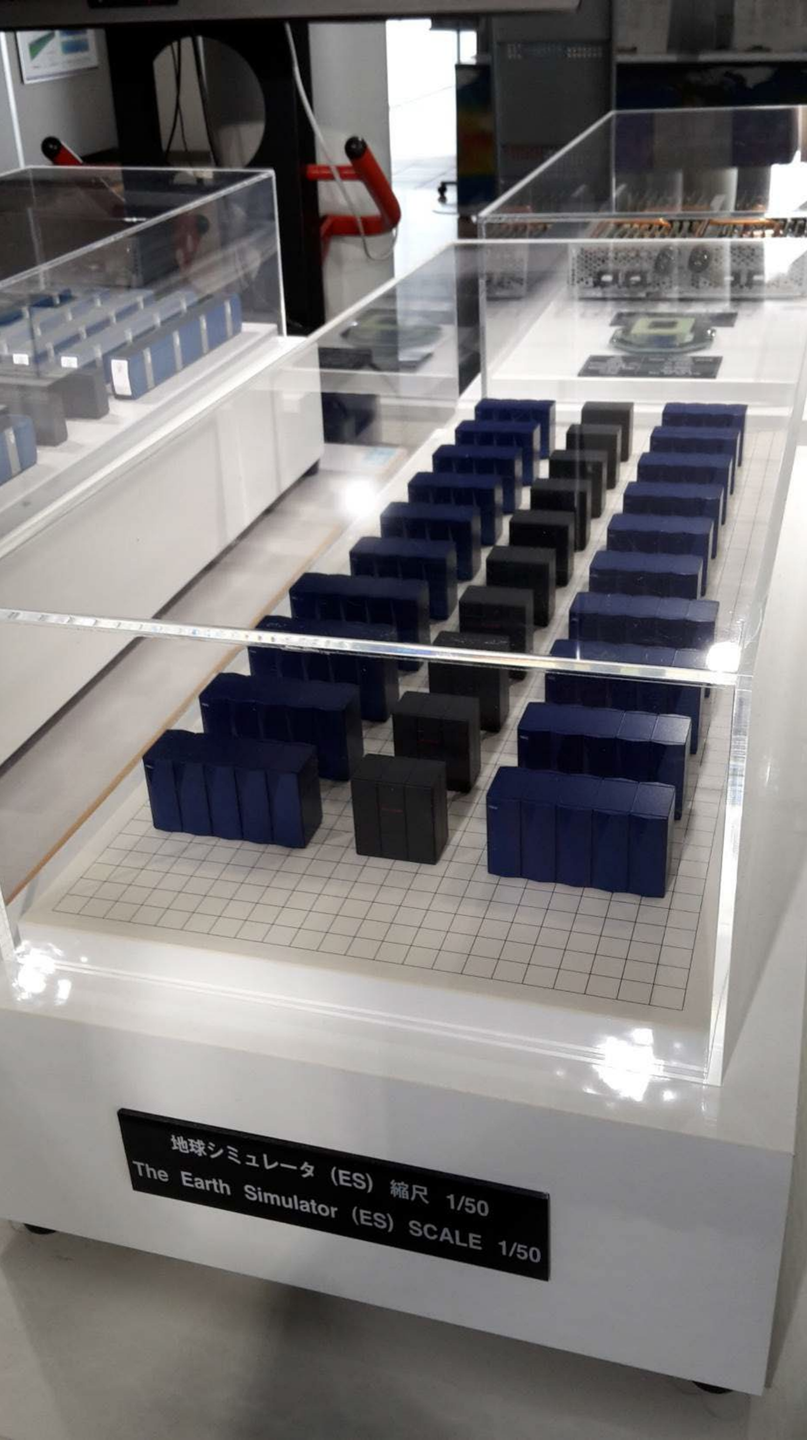
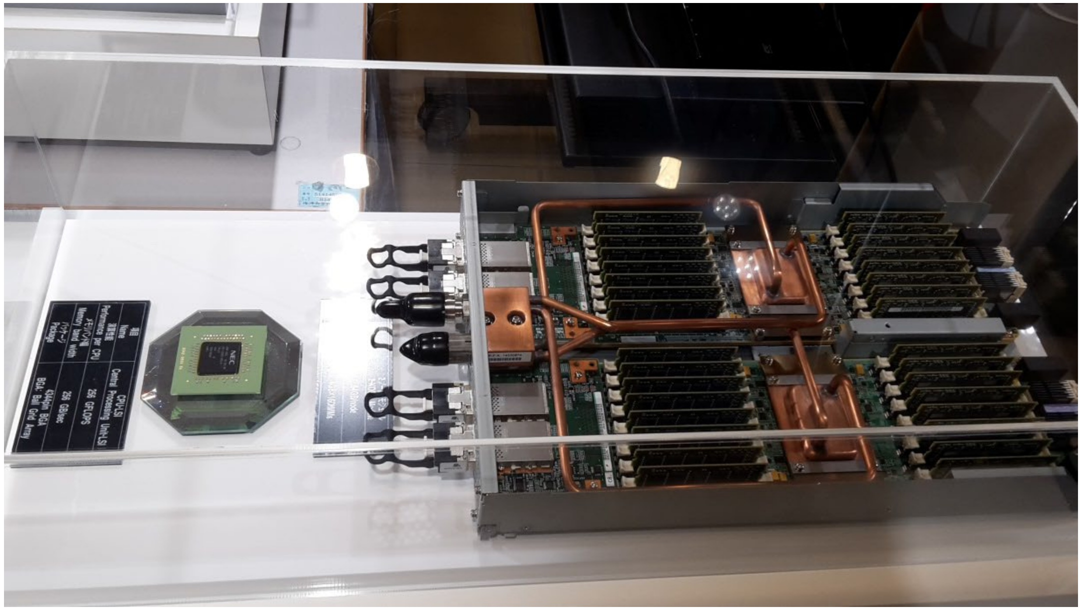
Very Large Computers are needed

Project of the Earth Simulator Computer (Japan) :
objective, a global
coupled model with 5km resolution

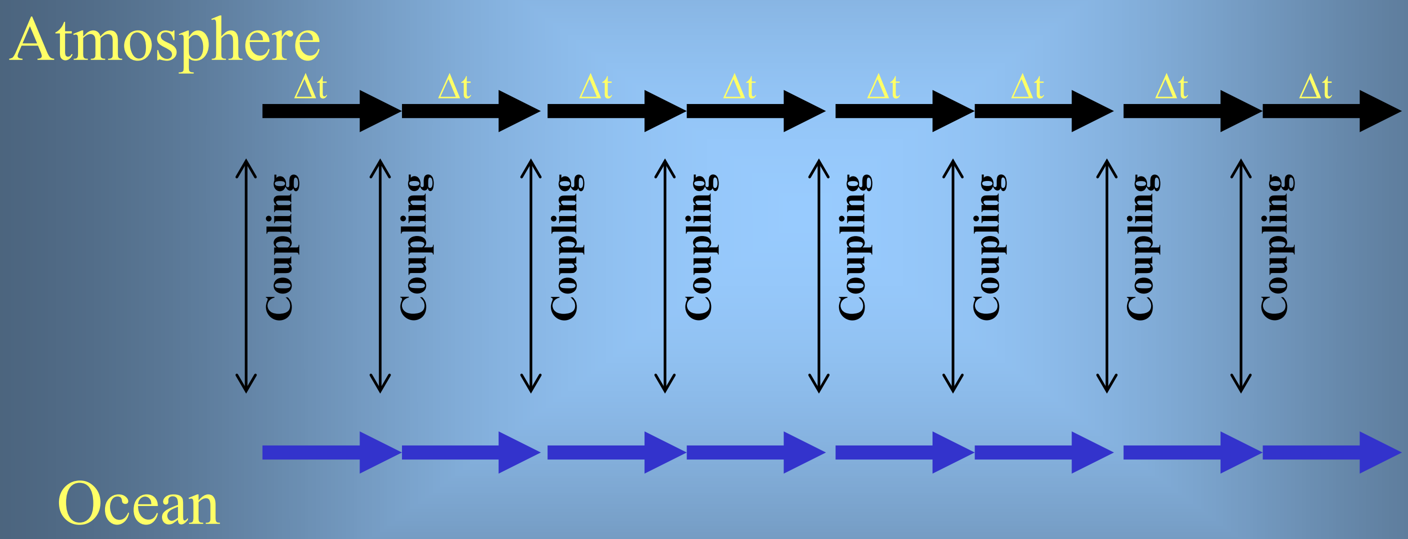

地球シミュレータ (ES) 縮尺 1/50
The Earth Simulator (ES) SCALE 1/50




Features of the Earth Simulator Building
Steel-frame construction.
Two-story 65m x 50m (71yd x 55yd)
17m (19yd) height
Lightning conductor isolated from building
Shielding by steel plates from electromagnetic waves
Air return duct
Rooms surrounding with steel nets
Power supply system
Air conditioning system
Seismic isolation system
(Insulation by 11 layered rubbers)
Lightning protection system
Seismic Isolation
Lighting: Light propagation
Earth Simulator Research Building 1F
JAMSTEC
Japan Agency for Marine-Earth Science and Technology

Experimental Strategy (1)

The main problem is how to synchronize the time evolution of the atmosphere with the evolution of the ocean. The most natural choice is to have a complete synchronization (synchronous coupling):

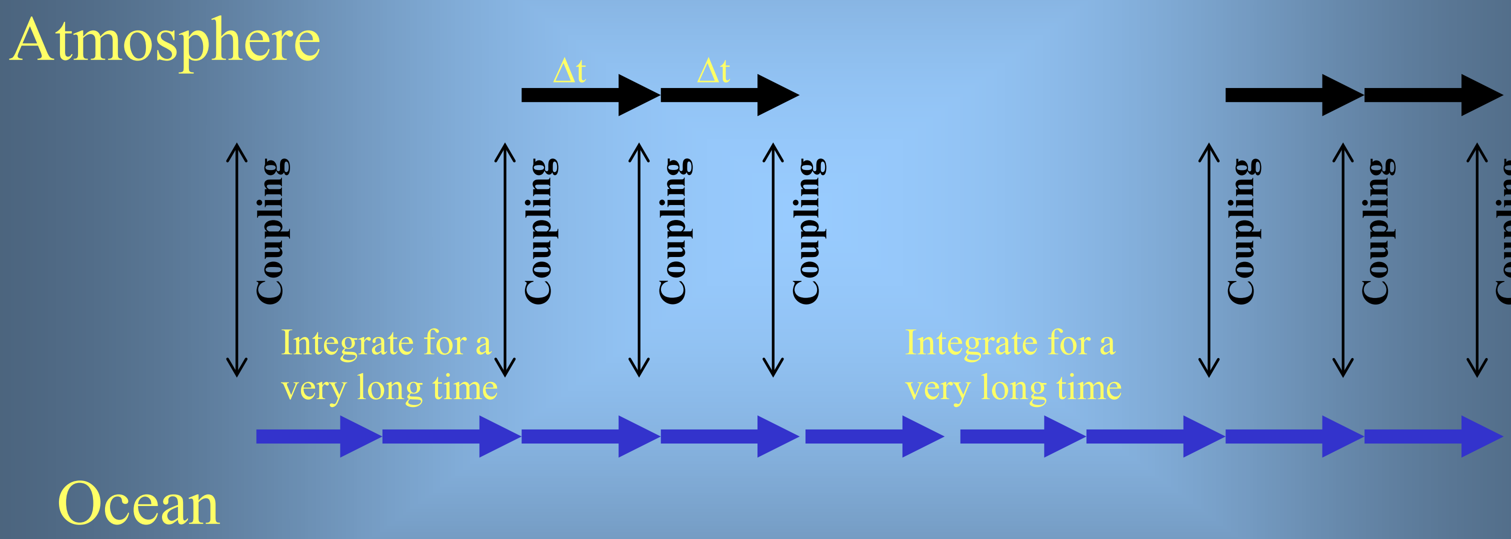


This choice would require to have similar time steps for both models, for instance 30min for the atmospheric model and 2 hours for the ocean model.

Computationally very expensive

Experimental Strategy (2)

Another possibility is to exploit the different time scales using the fact that the ocean changes much more slowly than the atmosphere (asynchronous coupling):



This choice save computational time at the expense of accuracy, but for very long simulations (thousands of years) may be the only choice.

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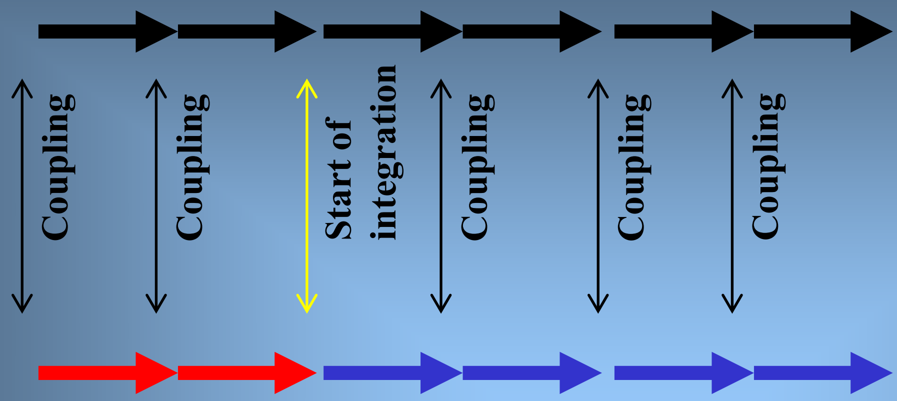
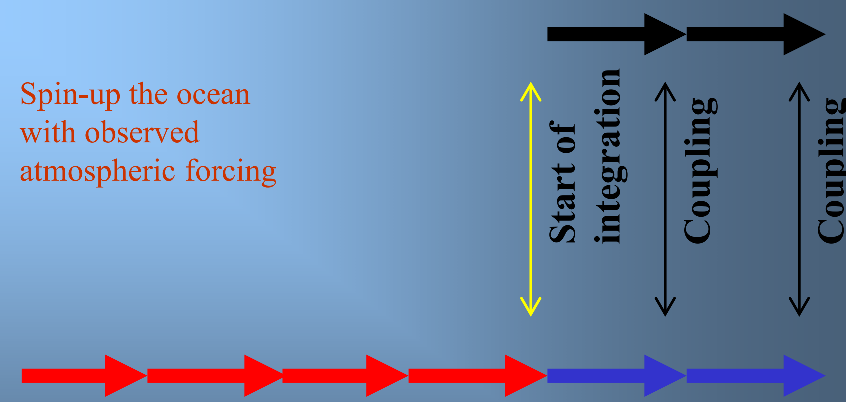
Initialization

Robust Diagnostic



Integrate the coupled model for
a period, e.g. two years, but
impose observed
surface temperature and salinity

Spin-up the ocean
with observed
atmospheric forcing



Spin-up

But sometimes the models are simply started from climatological conditions or, in the case of climate change experiments, the procedure may become much more sophisticated to account for effects from soil and ice.

Balancing the simulations

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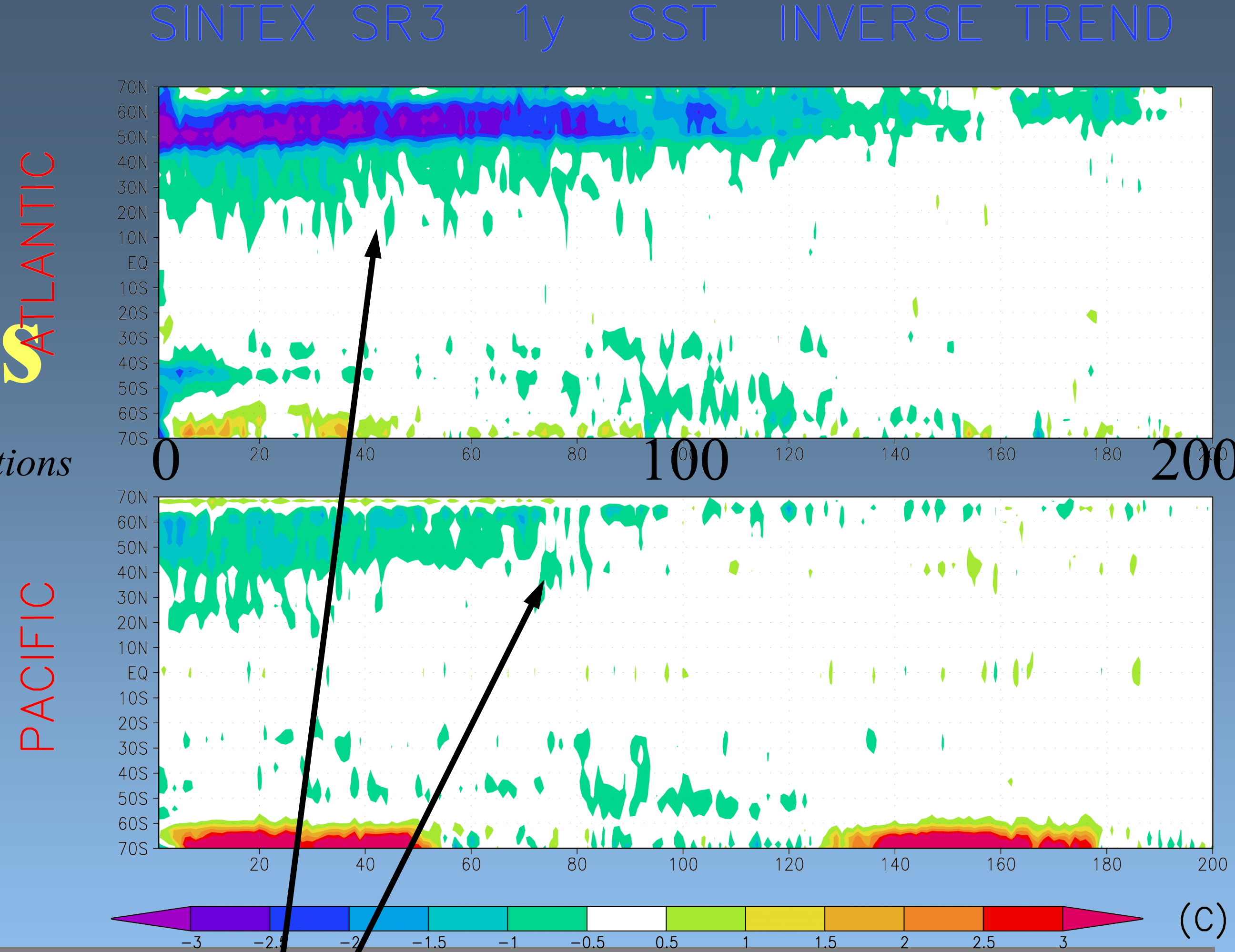


Years of Simulations

Coupled model are much more sensitive than either ocean or atmosphere model alone. There no constraints imposed, as the SST for the atmospheric simulations or the surface winds for the ocean, that can help in guiding the model toward a realistic climate state. The only forcing is given by the external solar radiation and the model must be capable of realizing its own balanced climate state. The <u>model drift from the initial condition</u> as it slowly reaches for its own equilibrium, if the model is realistic the final equilibrium will be very similar to the what we think is the present Earth climate, if the initial condition is well balanced the drift will be small and smooth.

What coupled models can do

The first coupled models had large drifts to an unrealistic climate state. It was then proposed to include a correction to partially correct for the poor fluxes that were exchanged between the models. This correction, known as “flux-adjustment” allowed early experiments, but is becoming less necessary in modern models.

The following slides will show some of the results from an integration of a coupled model, developed at our institution in collaboration with LODYC in Paris, within the context of a project sponsored by the European Union, SINTEX. The results are however pretty typical of the behaviour of coupled models.

The SINTEX coupled model

Atmosphere
ECHAM-4

Coupler
OASIS

Ocean
OPA

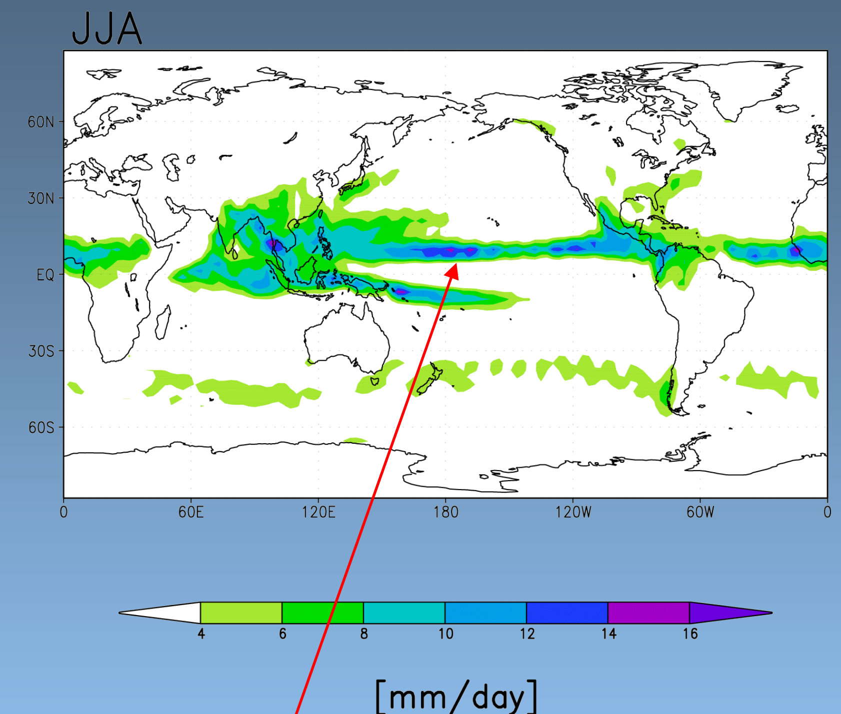
ECHAM-4:
Max-Planxk -Institute,
Hamburg
Roeckner et al., 1996)
Global
Spectral T30 (3.75 x 3.75 deg)
19 Vertical levels

OPA 8.1:
LODYC, Paris,
Madec et al., 1998)
Global
2 deg longitude
0.5 - 2 deg latitude
31 Vertical Levels
Climatological Sea Ice

Coupling every 3 Hours

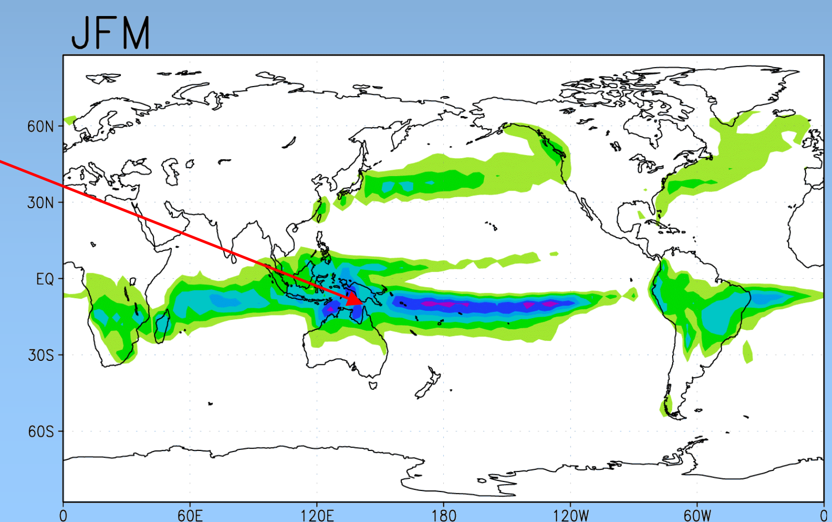
No Flux Adjustment

Precipitation



Coupled models can reproduce precipitation pretty well on a global scale, including the tropical ITCZ and monsoon circulation, but the pattern follow too much the seasonal oscillation of the sun

The rain is too much concentrated in the summer hemisphere and the South Pacific Convergence Zone does not have the right shape



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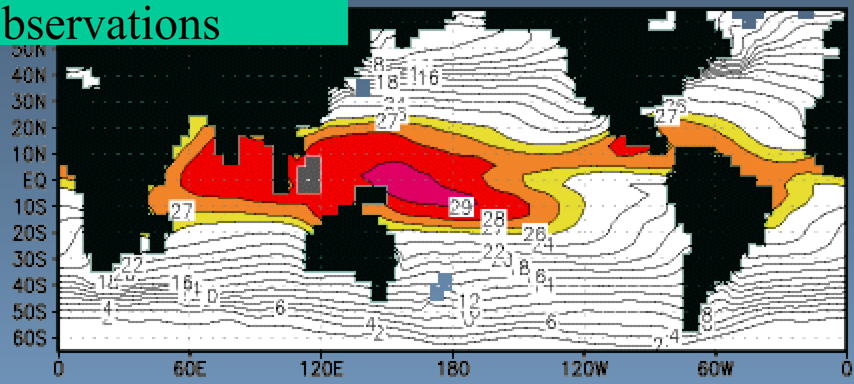
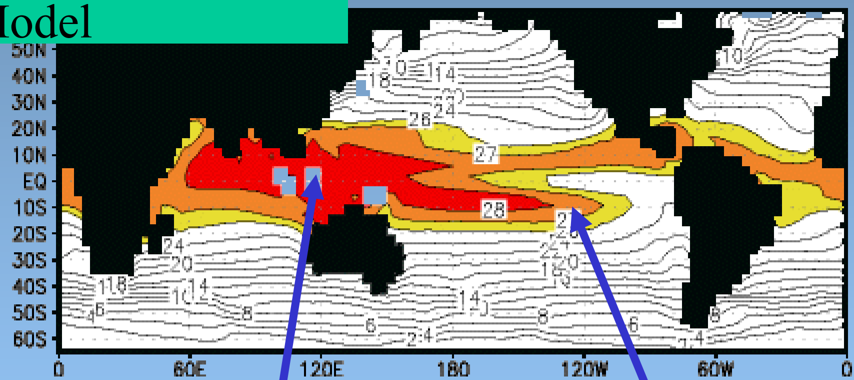
Sea Surface Temperature

Observations

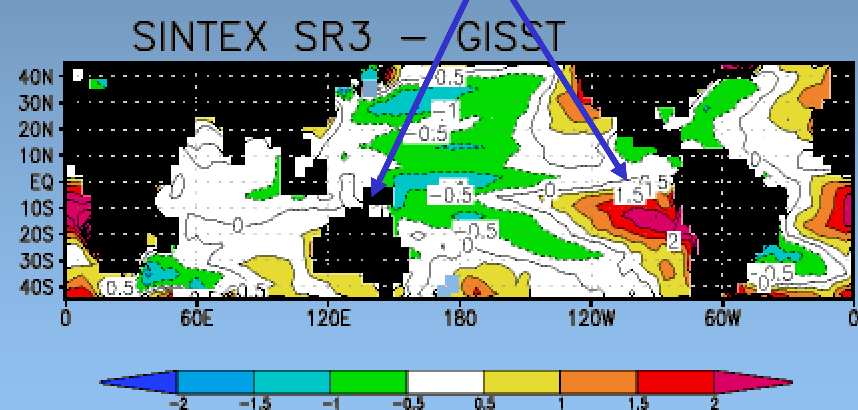


Model



Marine Temperature in the <u>model</u> are too narrowly confined to the equator, the observations are wider

Coupled models can reproduce the over-all pattern, but they tend to be warmer than observations in the eastern oceans and colder in the western portions of the oceans



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Southern Oscillation

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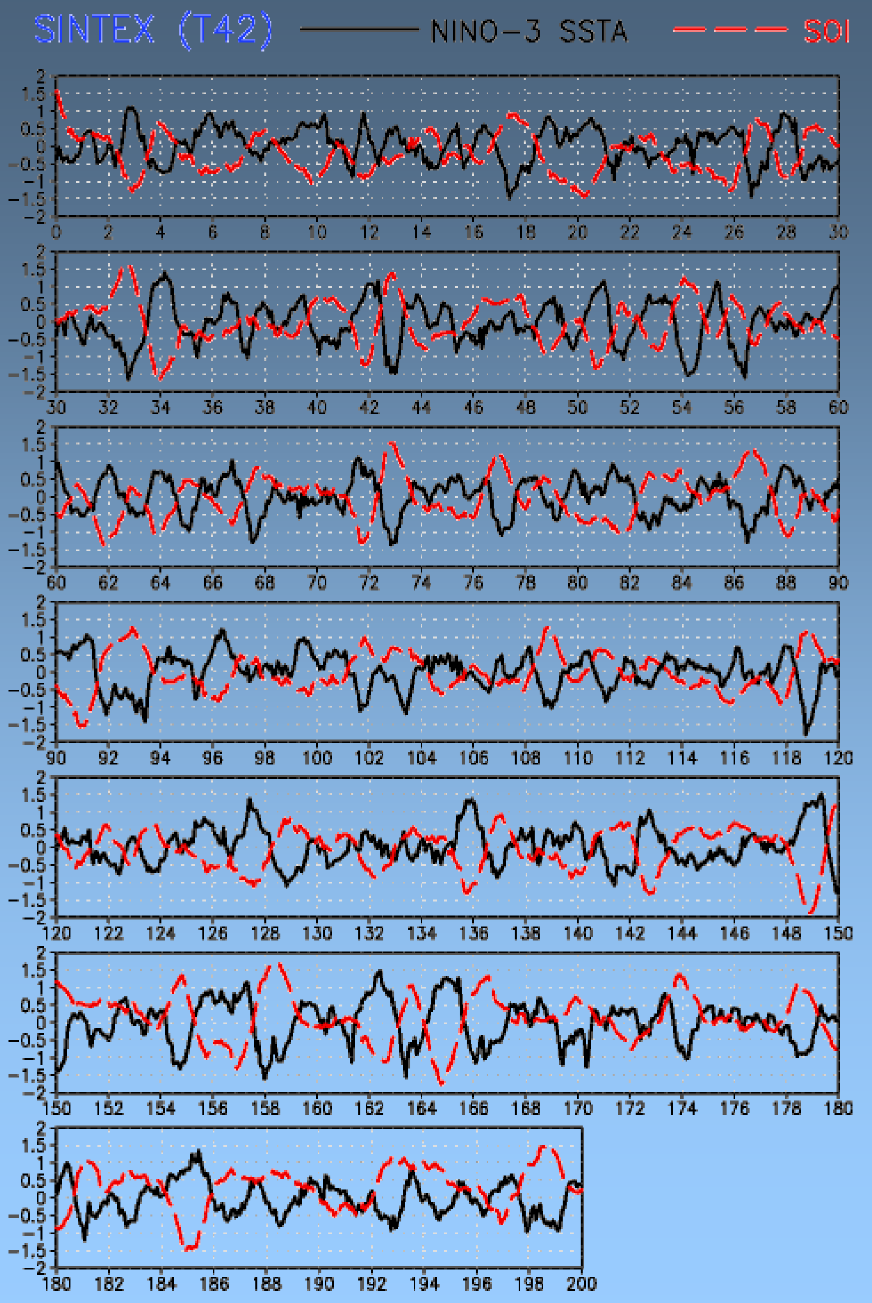
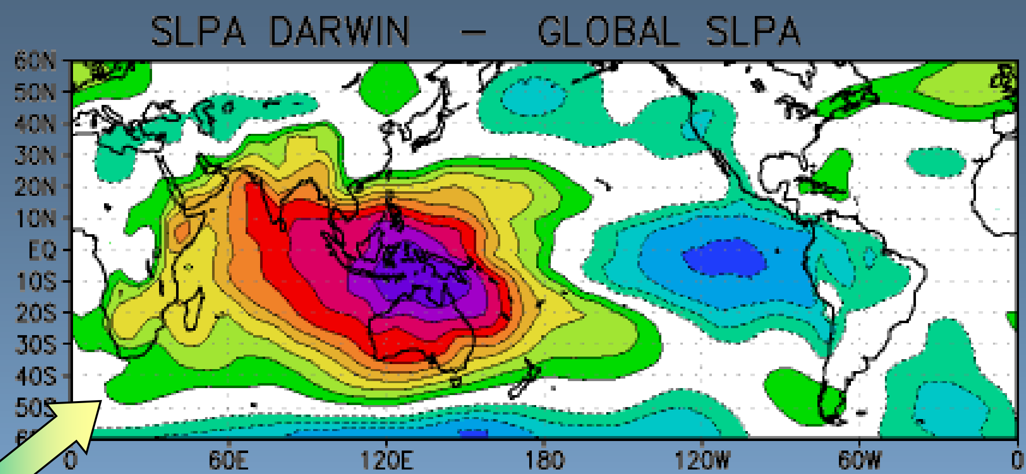
Coupled models can reproduce the strong coupling between Sea Level Pressure and Sea Surface Temperature as it is shown in this 200 years time series of the Southern Oscillation Index (SOI) and of the SST in the NINO3 area from a simulation. The anticorrelation is pretty clear and the model displays a realistic interannual variability

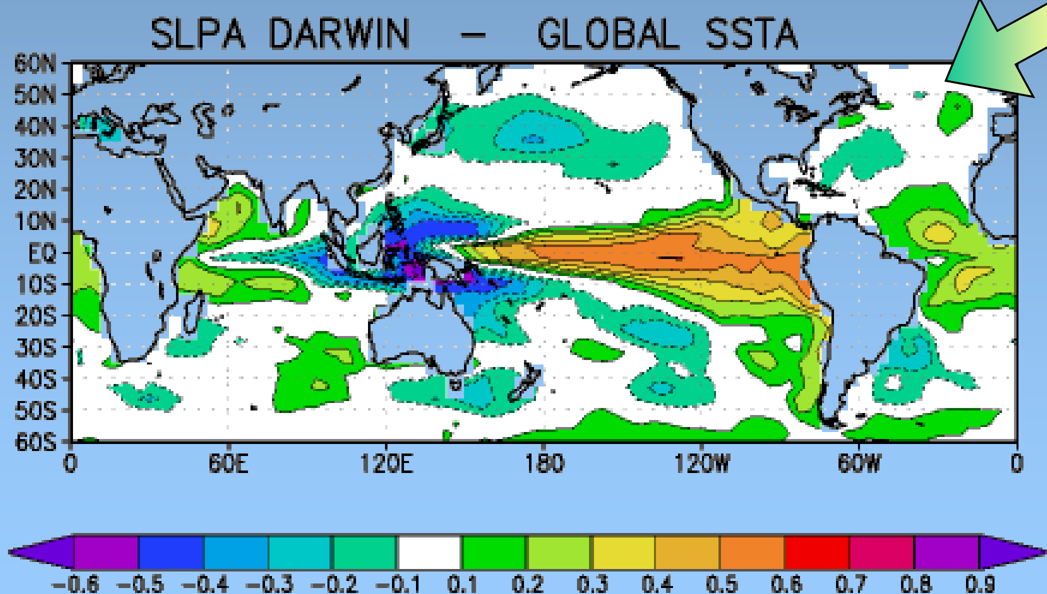


Teleconnections

Correlations between the Sea Level Pressure in Darwin and global SLP in the coupled model. The correlations are very realistic



Correlations between the Sea Level Pressure in Darwin and global SST in the coupled model. Also in this case the basic teleconnections are there, but the quality is barely satisfactory.



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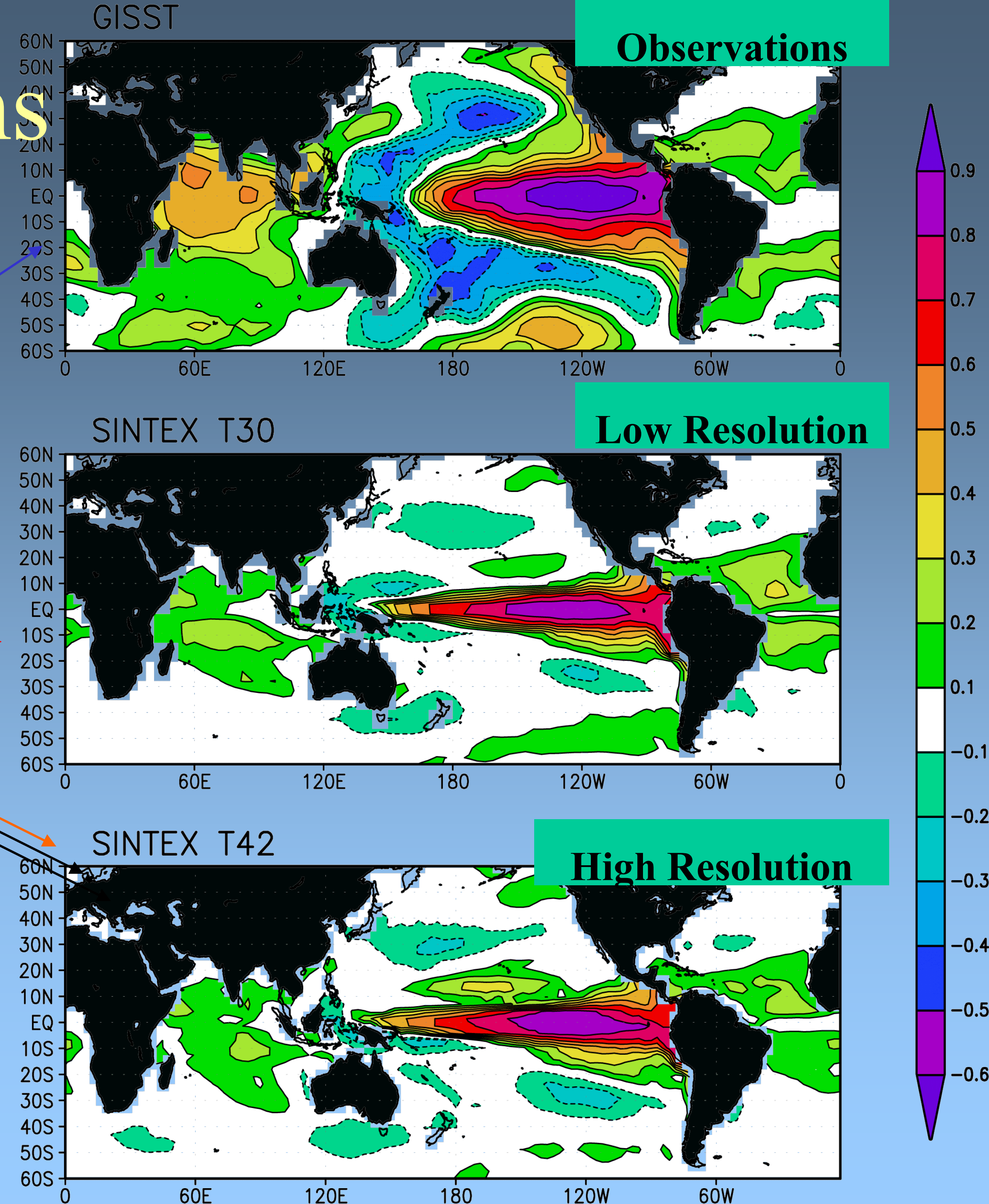
Teleconnections

Correlations between the Sea Surface Temperature in the equatorial Pacific (NINO3) and global SST. Results from observations and two 200 years simulations of coupled model are shown, at lower resolution and at a higher resolution . The models reproduce global patterns, but the propagation of the teleconnections into the midlatitude is still poorly represented.



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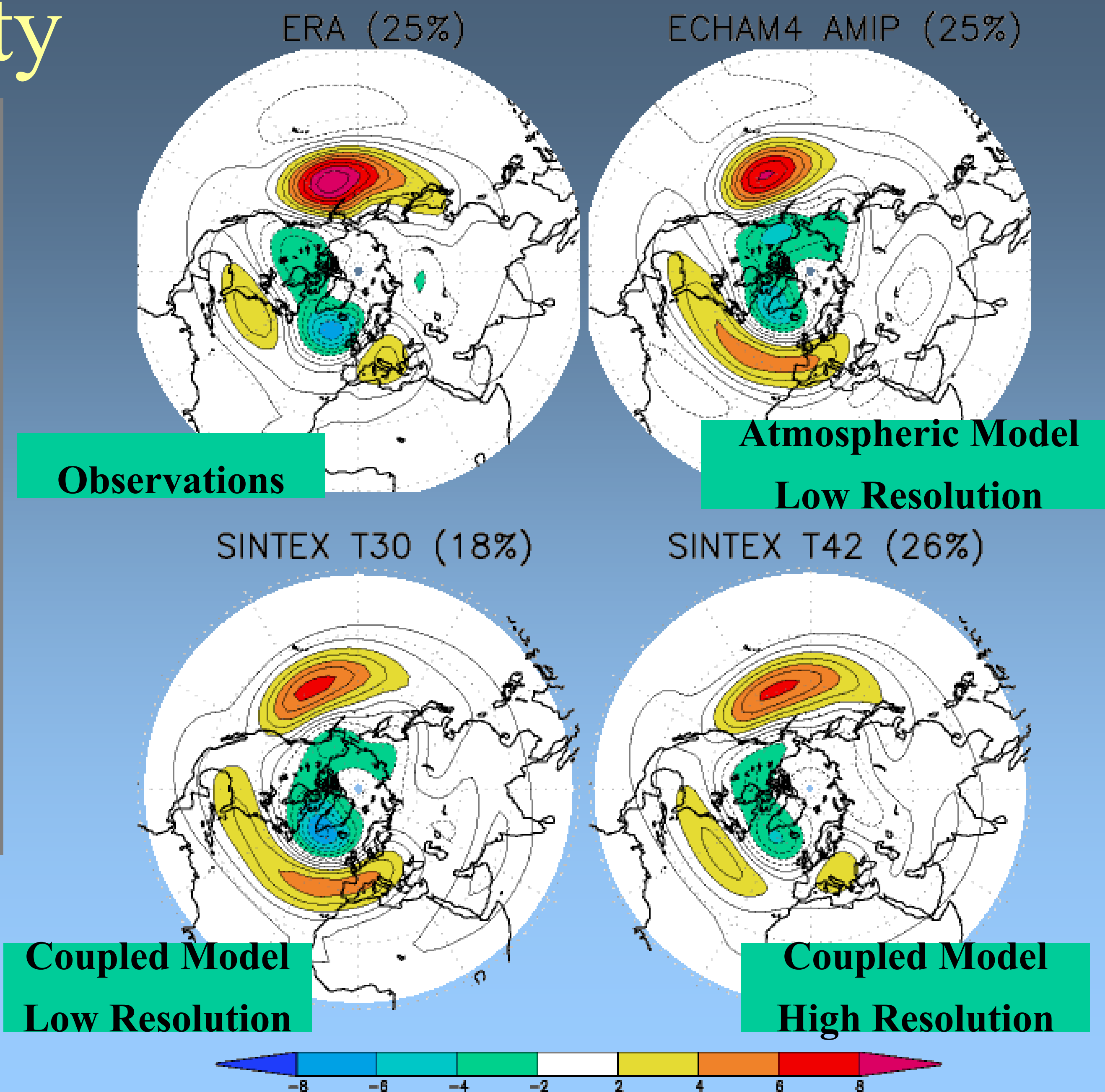
Variability

Empirical Orthogonal Patterns from coupled models, atmospheric-only models and observations. It is here shown the first EOF for Winter (JFM) Z500 . The models, especially the high resolution coupled model, shows a good resemblance with observations, indicating that the modes of variability of the model are close to the real one.



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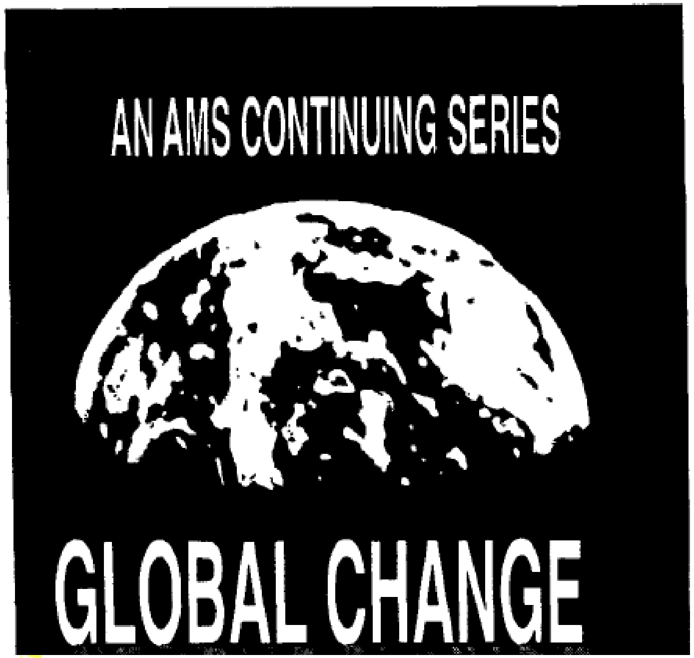

AMIP: The Atmospheric Model Intercomparison Project

W. Lawrence Gates
Program for Climate Model Diagnosis and Intercomparison,
Lawrence Livermore National Laboratory,
Livermore, California

An Overview of the Results of the Atmospheric Model Intercomparison Project (AMIP I)

W. Lawrence Gates, James S. Boyle, Curt Covey, Clyde G. Dease, Charles M. Doutriaux, Robert S. Drach, Michael Fiorino, Peter J. Gleckler, Justin J. Hnilo, Susan M. Marlais, Thomas J. Phillips, Gerald L. Potter, Benjamin D. Santer, Kenneth R. Sperber, Karl E. Taylor, and Dean N. Williams
Program for Climate Model Diagnosis and Intercomparison,
Lawrence Livermore National Laboratory, Livermore, California

Seasonal Rainfall Prediction Skill over South Africa: One- versus Two-Tiered Forecasting Systems

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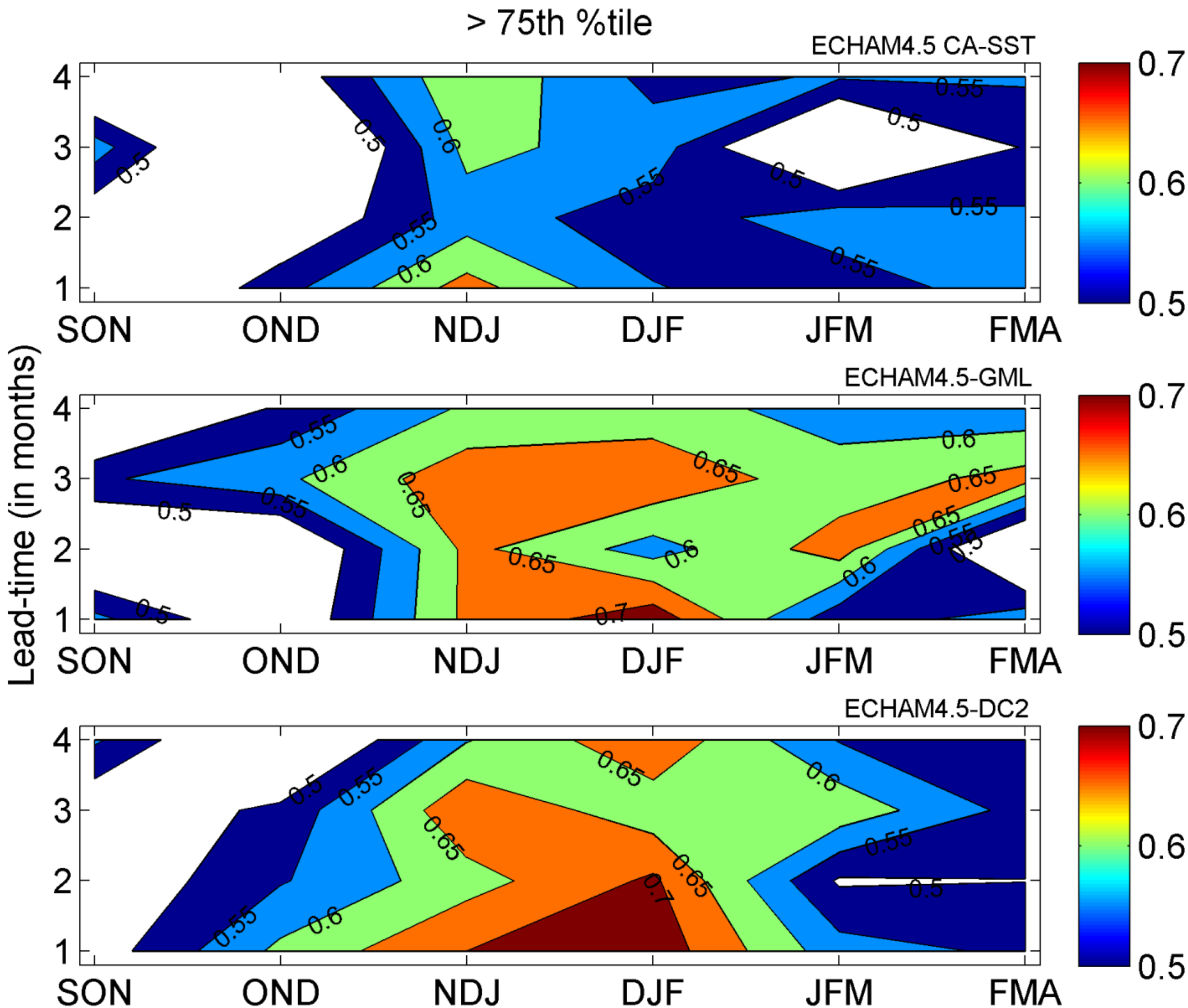
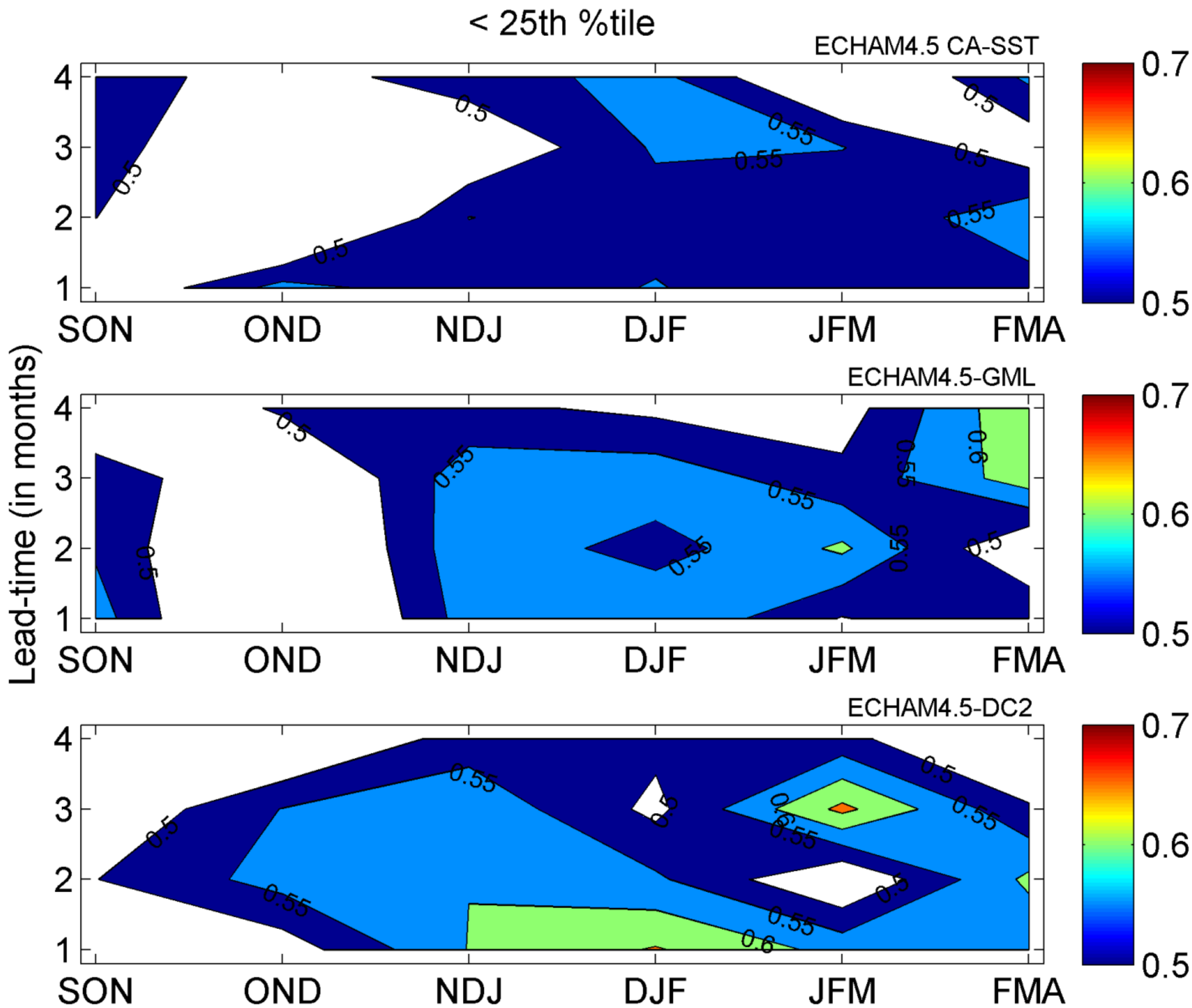
(Manuscript received 30 May 2011, in final form 15 September 2011)



> 75th %tile
ECHAM4.5 CA-SST
ECHAM4.5-GML
ECHAM4.5-DC2
Lead-time (in months)
SON
OND
NDJ
DJF
JFM
FMA
0.5
0.55
0.6
0.65
0.7



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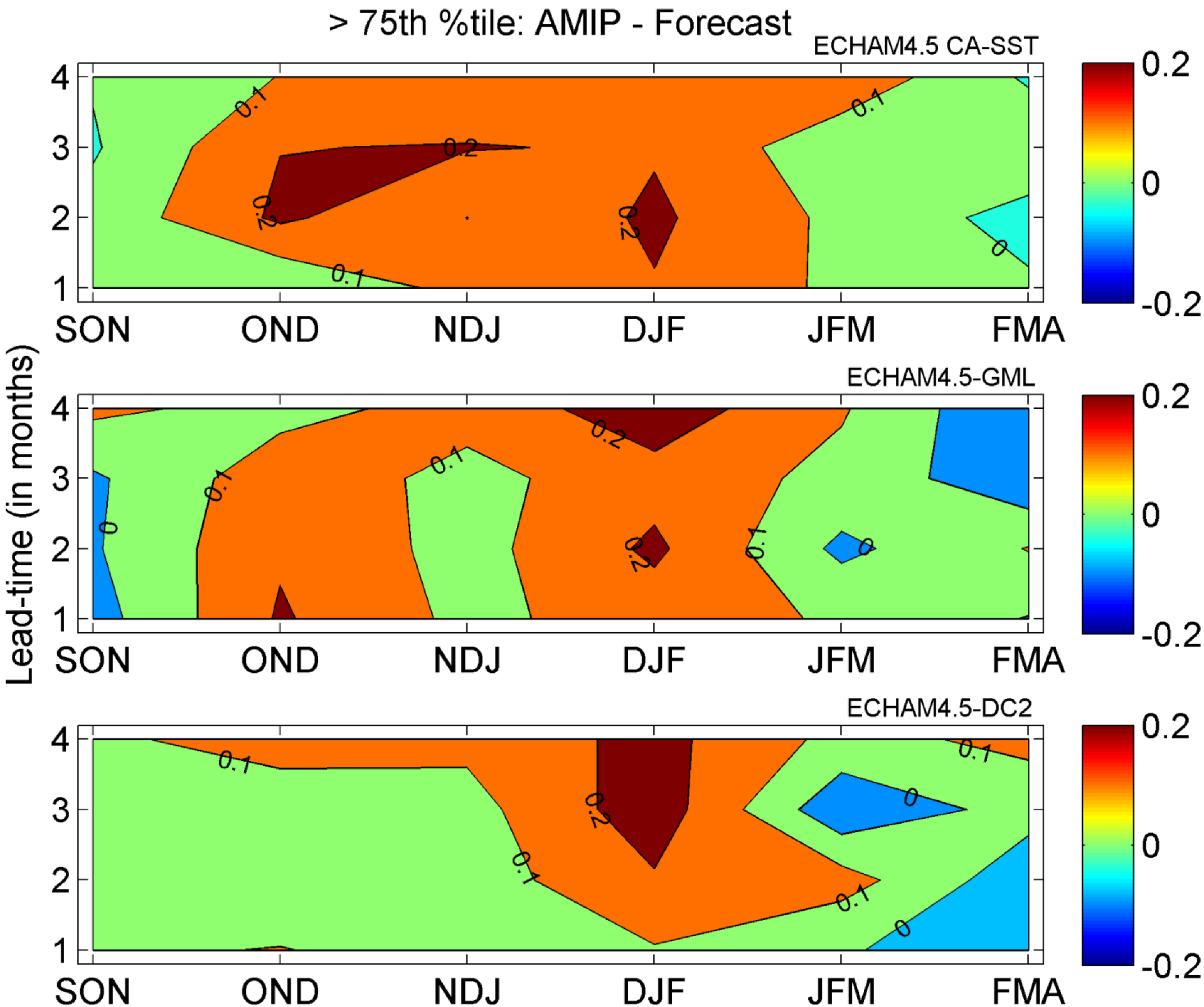
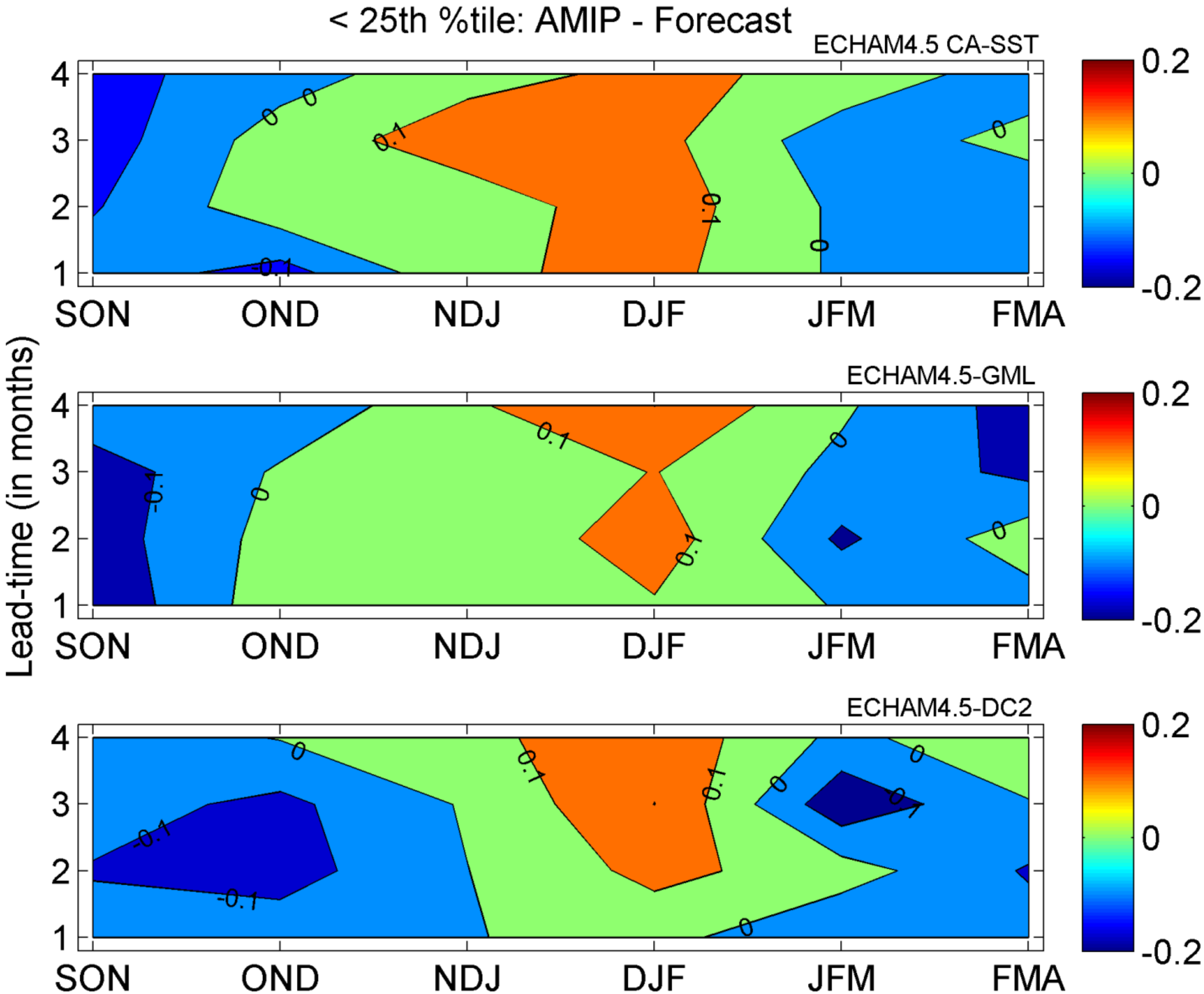
ECHAM4.5 CA-SST
ECHAM4.5-GML
ECHAM4.5-DC2
Lead-time (in months)
SON
OND
NDJ
DJF
JFM
FMA
1
2
3
4
0.5
0.55
0.6
0.7



> 75th %tile: AMIP - Forecast
ECHAM4.5 CA-SST
ECHAM4.5-GML
ECHAM4.5-DC2
Lead-time (in months)
SON
OND
NDJ
DJF
JFM
FMA
0.2
0
-0.2


< 25th %tile: AMIP - Forecast
ECHAM4.5 CA-SST
ECHAM4.5-GML
ECHAM4.5-DC2
Lead-time (in months)
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JFM
FMA
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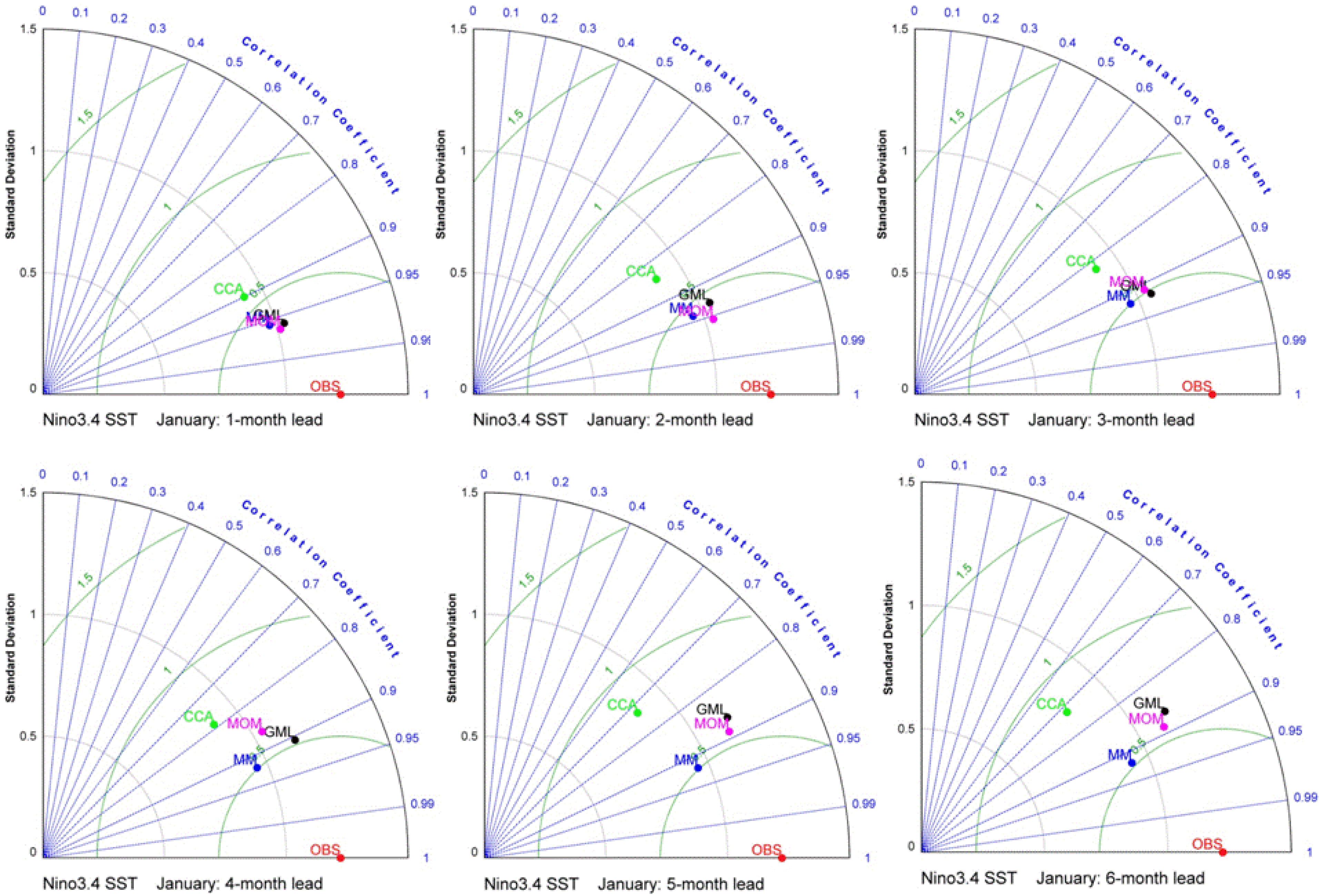
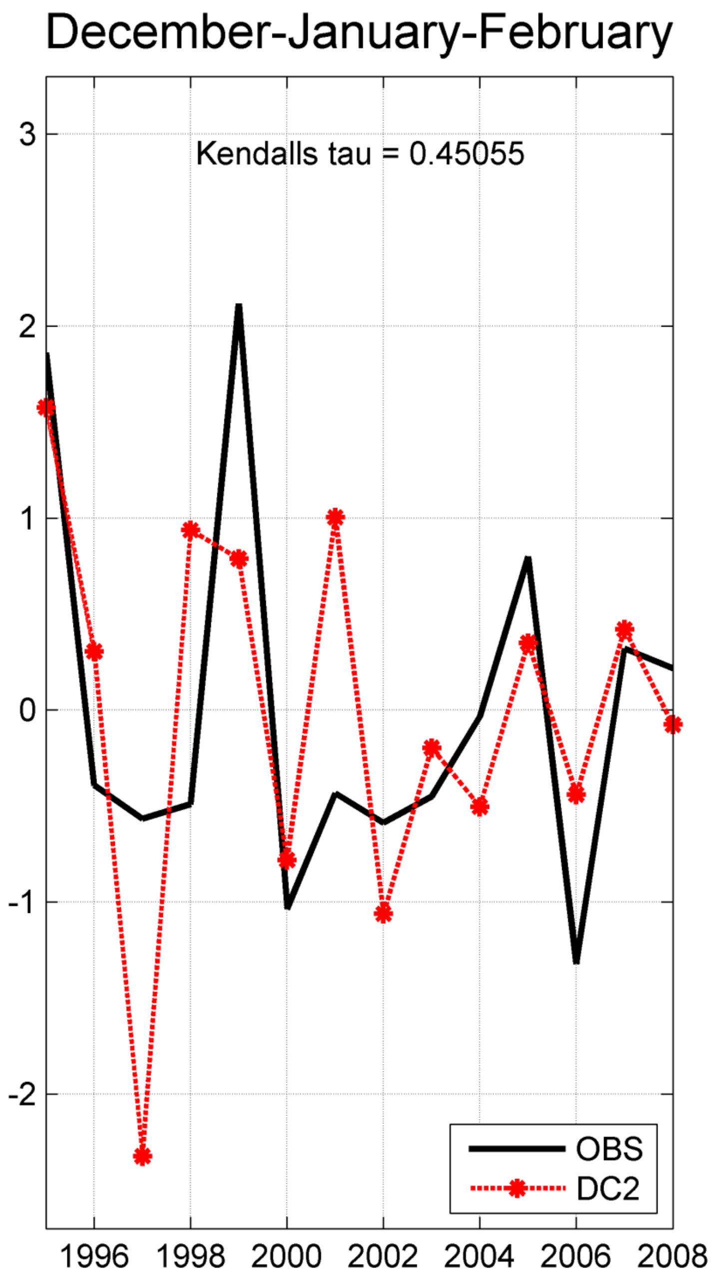
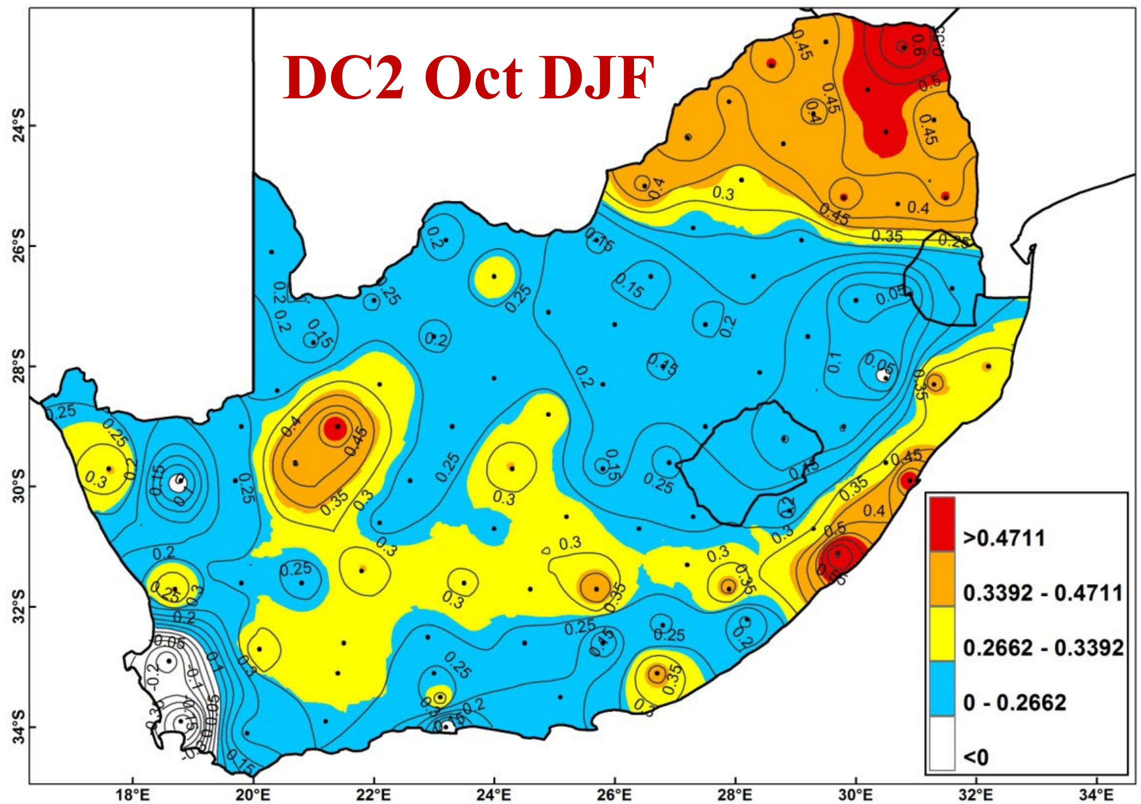
0
-0.2
0.1
-0.1



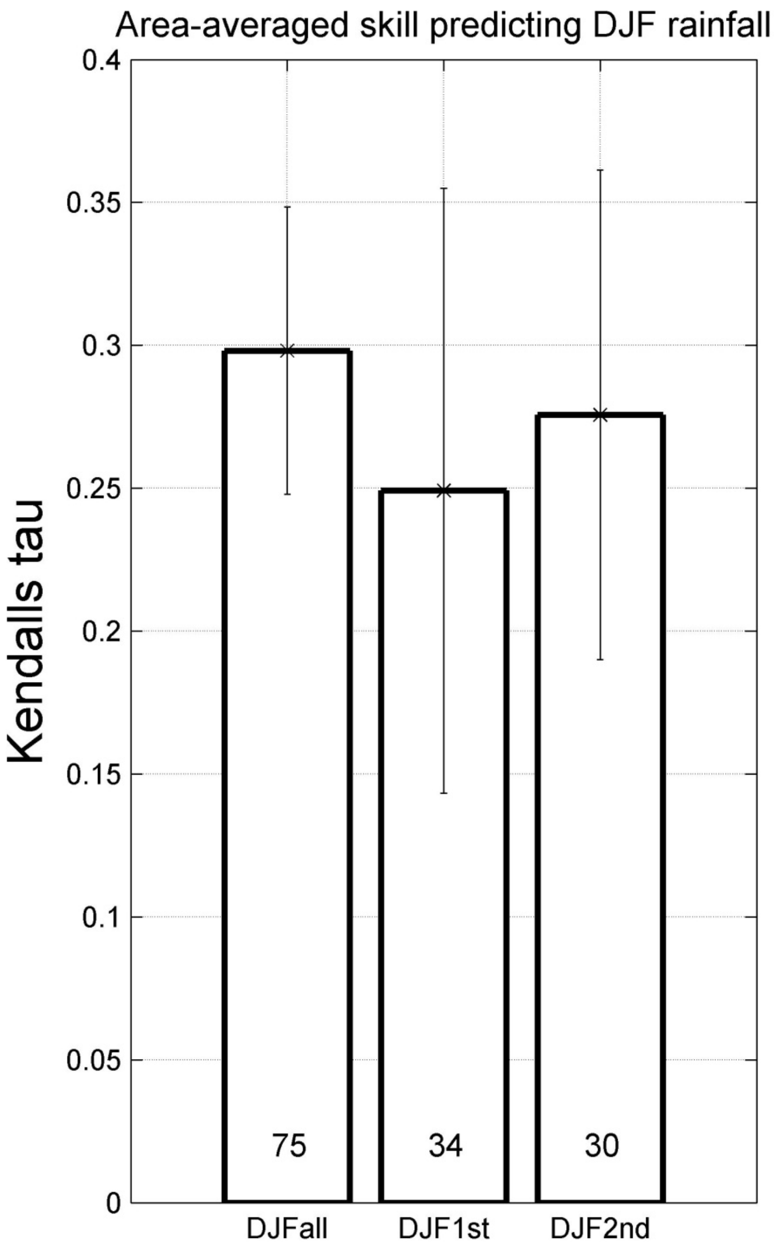
Taylor diagrammes



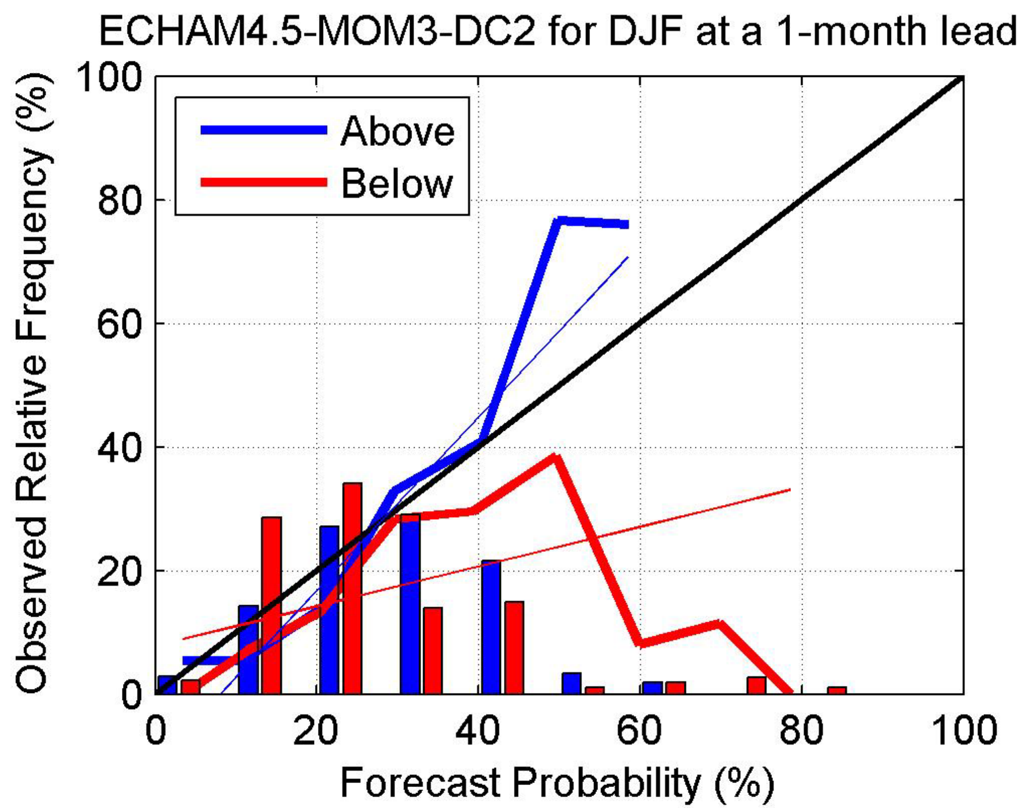
December-January-February
Kendalls tau = 0.45055
3
2
1
0
-1
-2
1996
1998
2000
2002
2004
2006
2008
OBS
DC2



DC2 Oct DJF
24°S
26°S
28°S
30°S
32°S
34°S
18°E
20°E
22°E
24°E
26°E
28°E
30°E
32°E
34°E
>0.4711
0.3392 - 0.4711
0.2662 - 0.3392
0 - 0.2662
<0



Area-averaged skill predicting DJF rainfall
Kendalls tau
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
75
34
30
DJFall
DJF1st
DJF2nd



ECHAM4.5-MOM3-DC2 for DJF at a 1-month lead
Above
Below
Observed Relative Frequency (%)
Forecast Probability (%)
0
20
40
60
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Dynamical Seasonal Climate Prediction Using an Ocean–Atmosphere Coupled Climate Model Developed in Partnership between South Africa and the IRI

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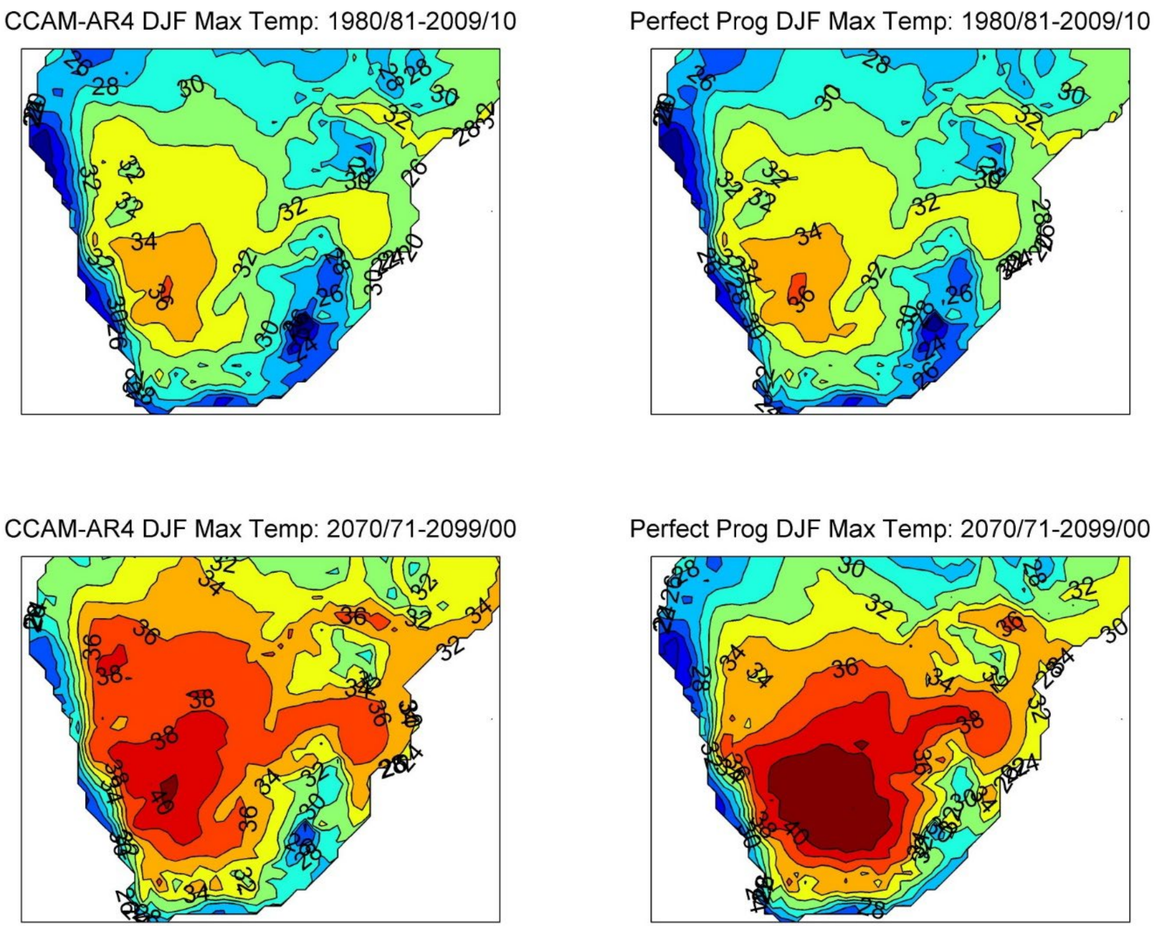
ABSTRACT

The recent increase in availability of high-performance computing (HPC) resources in South Africa allowed the development of an ocean–atmosphere coupled general circulation model (OAGCM). The ECHAM4.5-South African Weather Service (SAWS) Modular Oceanic Model version 3 (MOM3-SA) is the first OAGCM to be developed in Africa for seasonal climate prediction. This model employs an initialization strategy that is different from previous versions of the model that coupled the same atmosphere and ocean models. Evaluation of hindcasts performed with the model revealed that the OAGCM is successful in capturing the development and maturity of El Niño and La Niña episodes up to 8 months ahead. A model intercomparison also indicated that the ECHAM4.5-MOM3-SA has skill levels for the Niño-3.4 region SST comparable with other coupled models administered by international centers. Further analysis of the coupled model revealed that La Niña events are more skillfully discriminated than El Niño events. However, as is typical for OAGCM, the model skill was generally found to decay faster during the spring barrier.

The analysis also showed that the coupled model has useful skill up to several-months lead time when predicting the equatorial Indian Ocean dipole (IOD) during the period spanning between the middle of austral spring and the start of the summer seasons, which reaches its peak in November. The weakness of the model in other seasons was mainly caused by the western segment of the dipole, which eventually contaminates the dipole mode index (DMI). The model is also able to forecast the anomalous upper air circulations, particularly in the equatorial belt, and surface air temperature in the Southern African region as opposed to precipitation.

Climate Change 2007, the **Fourth Assessment Report** (**AR4**) of the United Nations Intergovernmental Panel on Climate Change (IPCC), is the fourth in a series of reports intended to assess scientific, technical and socio-economic information concerning climate change, its potential effects, and options for adaptation and mitigation.



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