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Instrument: Integrated Project

Thematic Priority: Global Change and Ecosystems

D5.27 Provision of diagnostics to assess model performances with an emphasis on the tropical regions

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Version 1

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Dissemination Level		
PU	Public	✓
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the Consortium (including the Commission Services)	

1. Introduction

A specific attention was put on model evaluation in WP5.2 with the aim to identify and understand model biases and to provide diagnoses and metrics that help to evaluate aspects of climate models that are critical to assess the model response to the anthropogenic forcing. This was done on the one hand by developing diagnoses that were applied to ensemble stream 1 simulations of climate change, and on the other hand by deriving sensitivity experiments in the different groups that serve either to develop new diagnoses or to test the role of particular aspects of model formulation such as clouds, surface fluxes, or vertical and horizontal resolution. This document summarized some of the diagnoses. Additional information can be found in the different deliverables. The diagnoses developed are those for which new development have been performed during the course of the ENSEMBLES project.

2. Regime sorted analyses to analyze climate sensitivity and clouds.

Objective : used satellite observations and meteorological reanalyses (1) to investigate the sensitivity of the tropical cloud radiative forcing (CRF) to interannual changes in sea surface temperature under different dynamical conditions and (2) to evaluate the ability of climate models to simulate this sensitivity and to point out systematic errors in this sensitivity.

Methodology : In the tropics, the relative occurrence of the different cloud types strongly depends on the large-scale atmospheric circulation. By using the monthly-mean mid-tropospheric (500 hPa) vertical pressure velocity ω_{500} as a proxy for large-scale rising ($\omega_{500} < 0$) or sinking deep ($\omega_{500} <0$) and shallow ($\omega_{500} >0$) motions, we decompose the large-scale tropical circulation as a series of dynamical regimes defined from ω_{500} (bins of 5 hPa/d), and we compute composites of climate variables in these regimes (Bony et al. 2004). To a first approximation, this methodology allows us to segregate regimes of deep convection and upper-level cloud tops from regimes of shallow convection and low-level cloud tops. For each dynamical regime (defined either from ERA-40 or NCEP2 reanalyses, we compute 17-year (1984-2000) time-series of monthly interannual anomalies of CRF and SST derived from ISCCP-FD and Reynolds dataset respectively. Then, the interannual sensitivity of the CRF to SST changes is computed from these timeseries as a linear regression coefficient. A similar procedure can be applied to 20th century simulations of coupled ocean-atmosphere models.

Example and reference: Deliverable 5.16 provides examples for the analyses of the AR4 simulations.

Bony, S., J. Dufresne, H. Le Treut, J. Morcrette, and C. Senior, 2004: On dynamic and thermodynamic components of cloud changes. *CLIMATE DYNAMICS*, **22,** 71-86.

Bony, S. and J. Dufresne, 2005: Marine boundary layer clouds at the heart of tropical cloud feedback uncertainties in climate models. *GEOPHYSICAL RESEARCH LETTERS*, **32, -**.

3. Using the regime-sorting approach to analyse tropical biases in coupled GCMs.

Objective : inspection of the precipitation fields in the vertical circulation regimes to highlight the origin of the biases in particular regions. Application to the double ITCZ bias.

Method : Based on the results outlined in D5.25 ("Understanding the double-ITCZ in the eastern Pacific") we recommend to extend the use of the regime-sorting approach to the analysis of tropical biases affecting state-of-the-art coupled GCMs. In this case the compositing methodology is used to inspect [1] precipitation fields in the vertical circulation regime space (as represented by the 500 hPa vertical velocity ω_{500} dynamical proxy), Pr(ω) and [2] mid-troposphere vertical circulation ω_{500} in the sea surface temperature space, ω(SST).

The use of diagnostic [1] allows the partition of total precipitation into deep (ω_{500} <0) and shallow (ω_{500} >0) convective components, thus providing additional dynamical informations compared to more standard averaging in the space-time domain. The Pr(ω) composite field needs to be complemented by the normalized frequency of occurrence (PDF (ω)) of the single ω_{500} regimes, in order to associate a relative weight to the precipitation rate corresponding to each vertical circulation regime. The split of the total precipitation into Pr(ω) and PDF (ω) makes possible to decouple the error on the magnitude of precipitation associated with individual convective events, from the error affecting the frequency of occurrence of convective regimes.

An application of this methodology to the AR models, in the eastern Pacific, is displayed in figures 1 and 2.

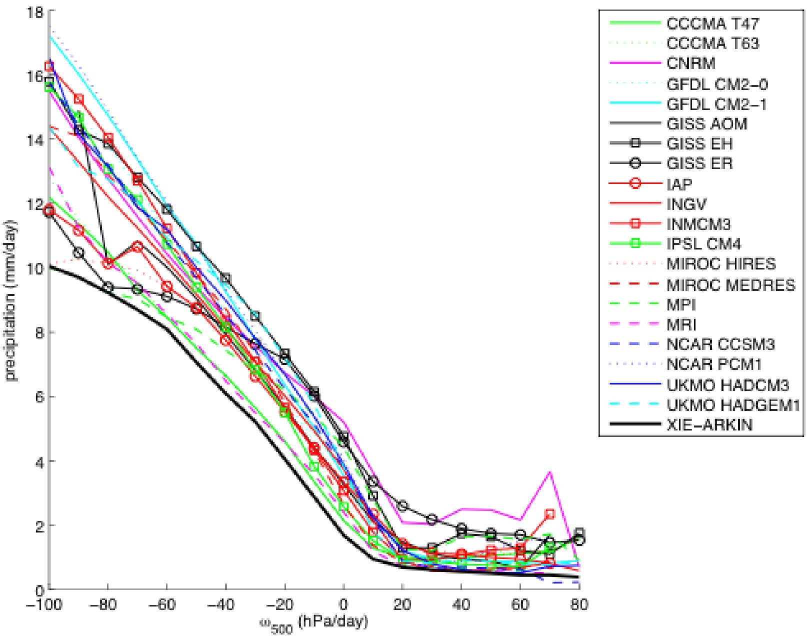

Fig. 1: Composite of precipitation (mm/day) for different vertical circulation regimes identified by ω_{500} in [150W-100W,20S-0] for AR4 20C3M simulations and Xie-Arkin data set (*after B09*).

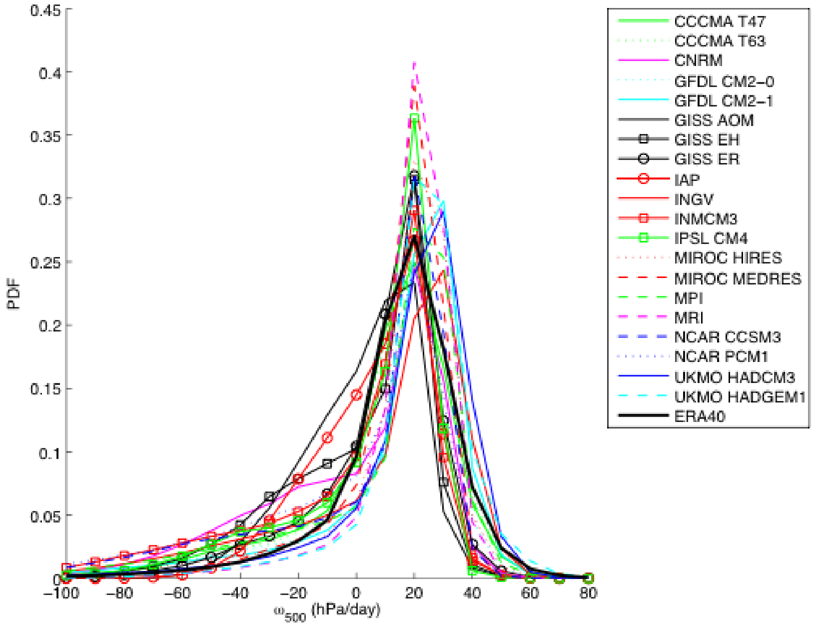

Fig. 2: Probability density function of ω_{500} in [150W-100W,20S-0] for AR4 models and observations (ERA-40). Model PDFs are computed from monthly outputs from the 1960-2000 period of IPCC 20C3M simulations.

Diagnostic [2] allows to establish a relation between the onset of deep convection and the thermal conditions of the surface ocean. The ω(SST) composite helps in identifying the SST-threshold beyond which the system undergoes a transition from subsidence to deep convection conditions. The threshold can be easily identified as the zero-crossing SST, i.e. the surface temperature for which the mid-troposphere vertical velocity undergoes a change of sign, indicating a switch in the vertical circulation regime. In B09 the AR4 intra-model dependency of this critical SST in the eastern Pacific is analysed (figure 3). Combining this information with the knowledge of mean SST conditions, for a certain area, discriminates between models which are most likely in an unstable conditions (i.e., $SST_{crit} - \overline{SST}<0$), from those which are most of the time in stable conditions (i.e., $SST_{crit} - \overline{SST}>0$). This has been proved particularly useful in explaining the large model-to-model spread in the double-ITCZ bias, displayed by AR4 climate models (B09).

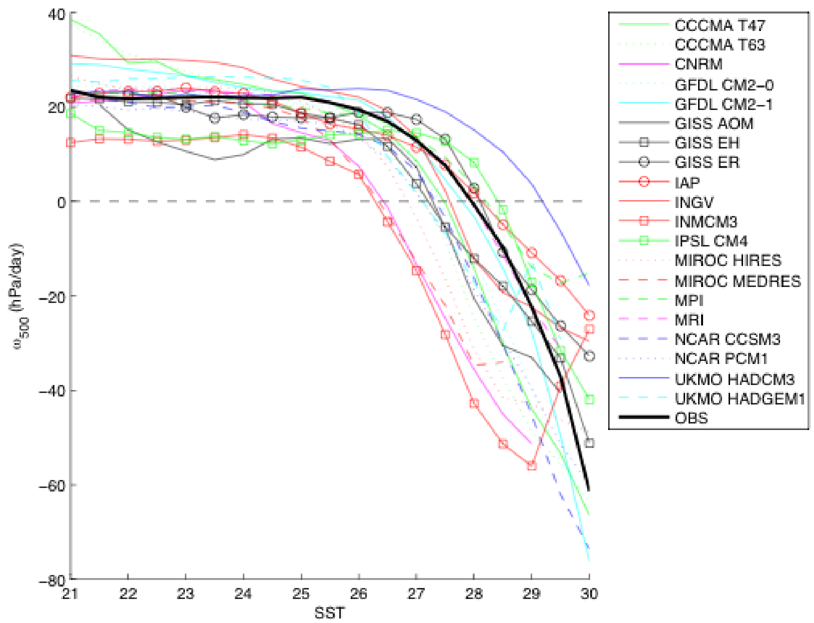

Fig. 3: Composite of ω_{500} (hPa/day) sorted by surface temperature regimes (^{o}C) in AR4 20C3M simulations and observations (*after B09*).

The regime sorting compositing procedure is rather straightforward, and does not require a particularly sophisticated software.

References

Bellucci A., S. Gualdi and A. Navarra, 2009: The double-ITCZ syndrome in coupled general circulation models: the role of large-scale vertical circulation regimes, *submitted to the J. Climate.*

Bony S.,J.L. Dufresne, H. Le Treut, J.J. Morcrette, and C. Senior, 2004: On dynamic and thermo-dynamic components of cloud changes. *Clim. Dyn.*, **22,** 71-86.

4. Development of a metric to relate the characteristics of ENSO variability to the strength of the coupling between the ocean and the atmosphere.

Objective : Quantifying the dynamical Bjerknes feedback and the heat flux feedback in the tropical Pacific to understand the diversity of simulated changes in ENSO characteristics in future climate projections.

Methodology : The dynamical (μ) and heat flux feedback (α) in the east Pacifi are estimate by regressing the corresponding interannual anomalies the Niño 3 SST anomalies (see Figs. 9 and 10 of Guilyardi et al. 2009 reported below). The slope of the linear regression measures the intensity of the feedback. For μ [measured here as the Niño 4 zonal wind stress anomaly regressed onto the Niño3 SST anomaly, both regions being the maximum variability zone for the corresponding fields, according to Gill (1980); not shown], the reference values are 8.6 x 10^{-3} N m^{-2} C^{-1} for NCEP-2 and 12.8 x 10^{-3} N m^{-2} C^{-1} for ERA-40 (Figs. 9a and The average total heat flux feedback (a) in the Niño3 region is 219 W m^{-2} C^{-1} in ERA-40 and 217 W m^{-2} C^{-1} in OAFlux.

Example and references: The method has been applied to compare the performances of two version of the IPSL couple model differing only by the convection scheme.

Guilyardi, E., P. Braconnot, F. F. Jin, S. T. Kim, M. Kolasinski, T. Li, and I. Musat, 2009: Atmosphere Feedbacks during ENSO in a Coupled GCM with a Modified Atmospheric Convection Scheme. *Journal of Climate*, **22,** 5698-5718.

Braconnot, P., F. Hourdin, S. Bony, J. L. Dufresne, J. Y. Grandpeix, and O. Marti, 2007: Impact of different convective cloud schemes on the simulation of the tropical seasonal cycle in a coupled ocean-atmosphere model. *Climate Dynamics*, **29,** 501-520.

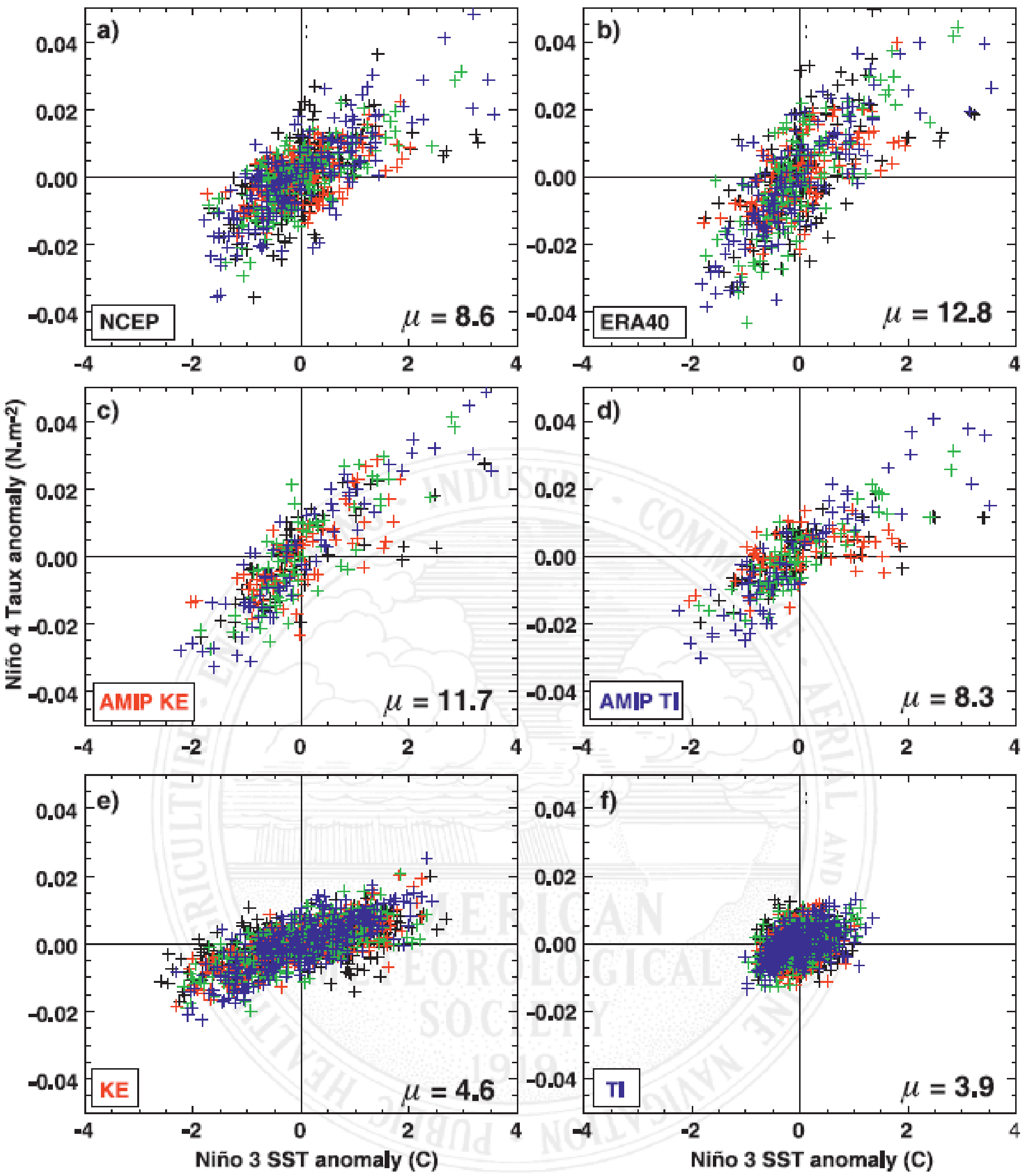

FIG. 9. Scatterplot of monthly Niño-4 zonal wind stress anomaly as a function of monthly Niño-3 SSTA for (a) NCEP2, (b) ERA40, (c) AMIP-KE, (d) AMIP-TI, (e) KE, and (f) TI. The slope of the linear regression measures the coupling strength μ, as indicated in units of 10^{-3} N m^{-2} C^{-1}. Colors indicate different seasons: Dec–Feb (black), Mar–May (blue), Jun–Aug (red), and Sep–Nov (green).

From Guilyardi et al. 2009

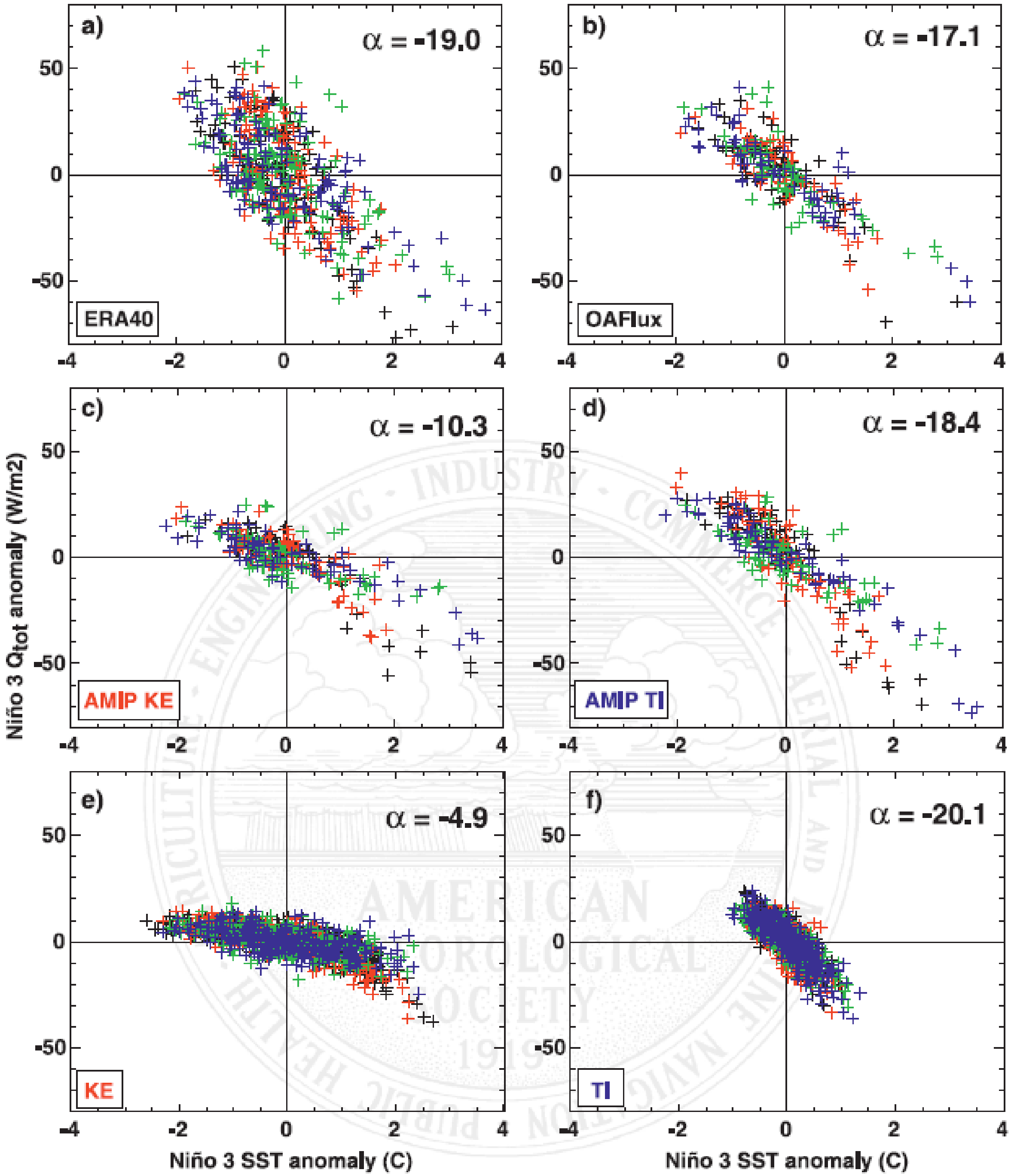

FIG. 10. As in Fig. 9 but for the monthly Niño-3 total heat flux anomaly as a function of the Niño-3 SST anomaly. The slope of the linear regression measures the heat flux feedback α, as indicated in units of W m^{-2} C^{-1}. (a) ERA40, (b) OAFlux/HadISST1.1, (c) AMIP-KE, (d) AMIP-TI, (e) KE, and (f) TI.

From Guyliardi et al. 2009

5. Development of metrics to characterize and assess the performance of ENSO and Pacific simulations

Objective : The latest multi-model approach, derived from the IPCC AR4, allows, to an unprecedented scale, latest generation coupled GCMs to be analyzed together and compared. Associated analysis shows that El Niño is now an emergent mode of variability in complex models. However, the diversity of their simulations of El Niño contributes to a large uncertainty in projections of future tropical climate and the associated teleconnections and impacts. Part of this uncertainty is due to the model shortcomings and it is key to document them in a common way.

Methodology : It is important to assess ENSO characteristics in terms of theoretical/mechanistic understanding of the phenomena, not just looking at local statistics (e.g. Niño 3 SST anomalies), which may have the correct value for the wrong reasons (i.e. as a result of bias compensation). Moreover, multi-model analyses should rely upon common diagnostics. The definition of a set of “metrics” to assess a phenomenon can have great value to the wider community engaged in model development and/or analysis. Metrics, such as the one presented in section 3, are now under discussion in preparation for future CMIPs (Gleckler et al. 2008, Guilyardi et al. 2009), and the CLIVAR Pacific Panel is charged with devising metrics for ENSO and for the wider tropical Pacific climate. Here we use the term “metric” as a measure of the “distance” of the model to some observational reference, usually computed as a single scalar value (Gleckler et al. 2008) while other more complex or qualitative analyses where observations do not provide an easy reference are called “diagnostics”. This activity will extend the part of the work done in the ENSEMBLES project.

The analysis presented here builds on community discussion that led to a proposal presented at the Perth March 2009 Pacific Panel meeting (see associated *mindmap*).

In devising such metrics, several goals are pursued:

- **Document** the performance of ENSO and tropical Pacific simulation in CMIP coupled models.
- Help **better understanding** of processes in models and identify new mechanisms
- Establish **guidance** for multi-model ensembles means (rejection of inadequate models, weighting, etc.)

Example and references : The text above and the descrition of the metrics are from the ENSO metric website : http://www.locean-ipsl.upmc.fr/~ENSO_metrics/index.html.

The work was initiated during the ENSEMBLES project in collaboration with other projects and international initiatives.

Gleckler, P. J., K. E. Taylor, and C. Doutriaux, 2008: Performance metrics for climate models. *Journal of Geophysical Research-Atmospheres,* **113,** -.

Guilyardi, E., A. Wittenberg, A. Fedorov, M. Collins, C. Z. Wang, A. Capotondi, G. J. van Oldenborgh, and T. Stockdale, 2009: Understanding El Nino in Ocean-Atmosphere General Circulation Models Progress and Challenges. *Bulletin of the American Meteorological Society,* **90,** 325-+.

6. Metric to assess the representation of intrasaisonnal variability in climate models

Objective : The objective is to evaluate two major aspects of the intermittent Intra Seasonal Variability(ISV) namely i) the reproducibility of the pattern of ISV events and ii) their degree of realism. Based on these diagnostics an evaluation metric is defined which can objectively evaluate the role of different model physics on the representation of ISV.

Methodology: The complete method is described in deliverable D5.26. Spatial patterns and temporal characteristics of the intraseasonal convective events are determined using the Local Mode Analysis (LMA ; Goulet and Duvel 2000). The LMA makes it possible to detect and characterize in a simple mathematical form the main events of an intermittent phenomenon such as the ISV, that succeed one another in time. It gives a pattern and statistics (amplitude, degree of organization, period, propagation features, etc) for each intraseasonal event and itallows us to compare different events in models and observations.

Example and references : Examples are provided in deliverable D.5.26. This work was done in close collaboration with workpackage WP5.3 to address both the Demeter and the IPCC class models. Figure 8.4 of ENSEMBLES final report summarized the results (see figure below). The metric bears significant relationship with the high frequency variability and the accuracy of the simulated summer monsoon climate. This implies that a correct representation of internal atmospheric processes such as the synoptic weather variability and ISV is required to reduce uncertainties in monsoon climate projections (Xavier et al., submitted)

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Goulet L, Duvel JP, 2000. A new approach to detect and characterize intermittent atmospheric oscillations: Application to the intraseasonal oscillation. Journal of the Atmospheric Sciences 57, 2397-2416.

Xavier, P., J.-P. Duvel, P. Braconnot, and F. Doblas-Reyes, submitted: An evaluation metric for intraseasonal variability in climate models. *journal of climate*

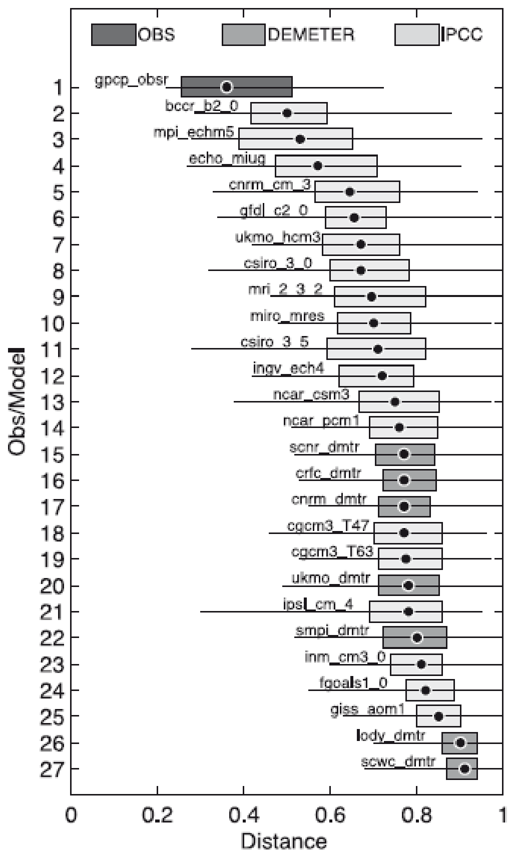

Figure 8.4: Distribution of distances between individual intraseasonal variability (ISV) events to the observed average summer ISV pattern in the observations and models. The bars range from the 25th percentile to the 75th percentile value. The line represents the range of values. The median (50th percentile) values are denoted by the black dots. Models are arranged according to the median distance.