Air-Sea Process in the Indian Ocean and the Intraseasonal Oscillation

J.P. Duvel (LMD)

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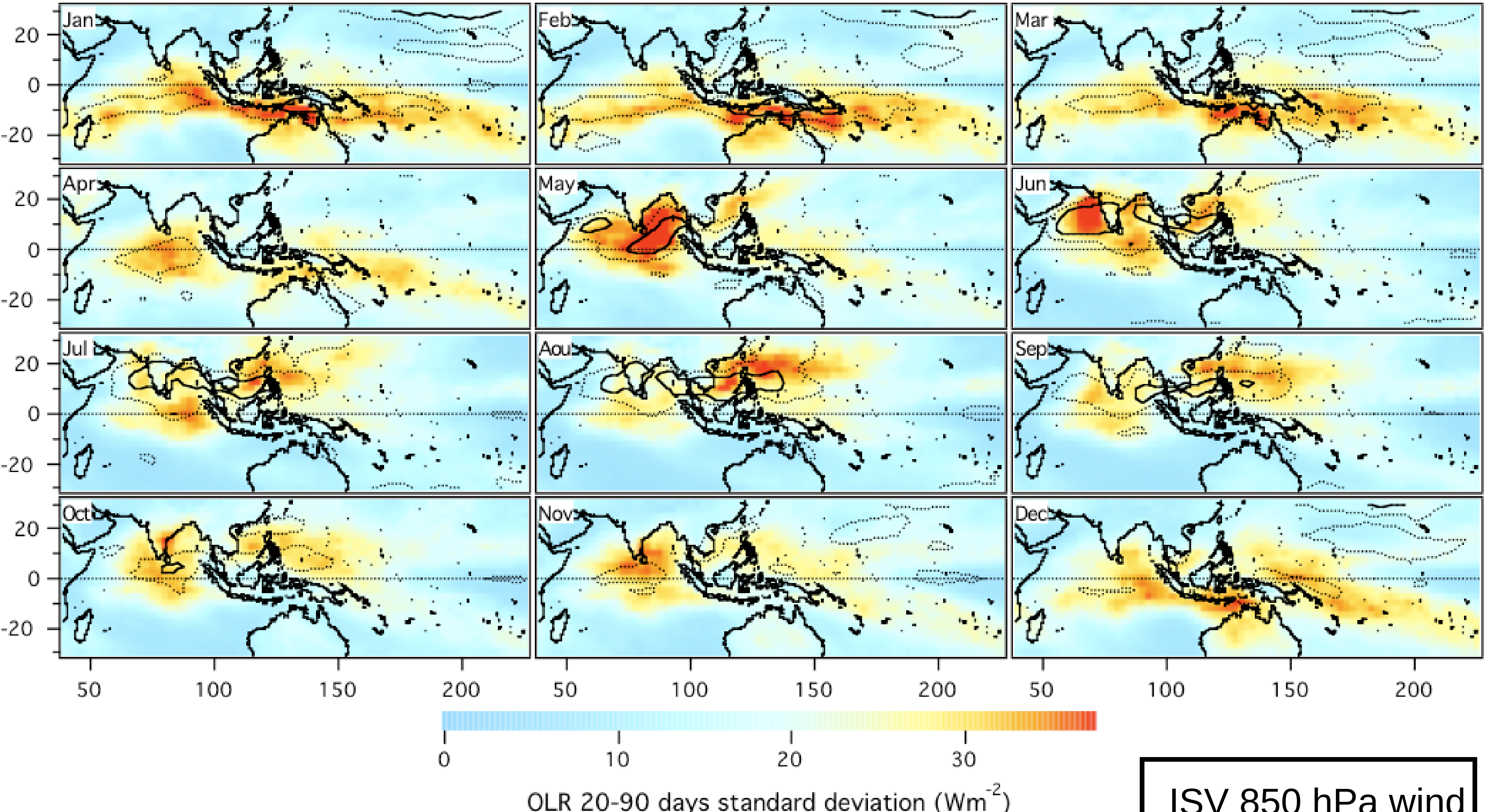
F. Doblas Reyes

Origin of the intraseasonal variability (ISV) of the convection?

- Response of the atmospheric deep convection to planetary waves?
  - The interaction with the ocean may have a marginal contribution
- Large-scale dynamical response to organized deep convection?
  - Interaction with the ocean is of primary importance
    - Organization of the convective perturbation (DWL,…)
    - Structure of the mixed layer (depth) may control the timing of the convective events (duration, time until the next event)

Seasonal cycle of the ISV



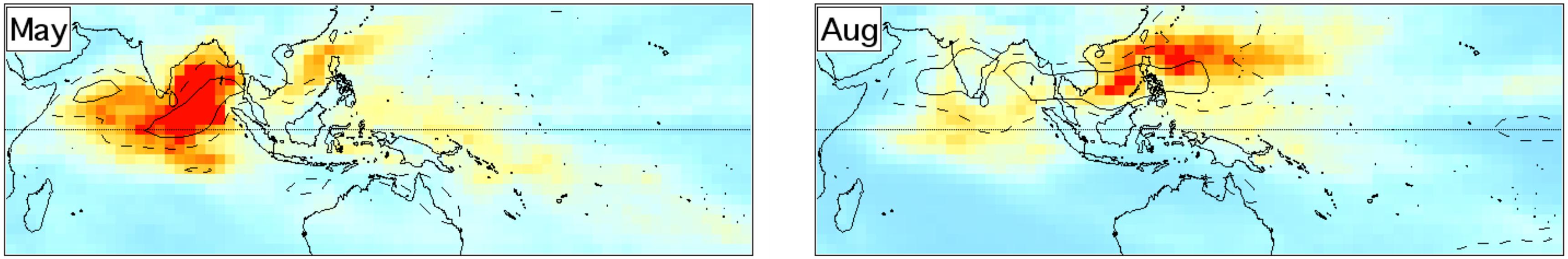
ISV 850 hPa wind

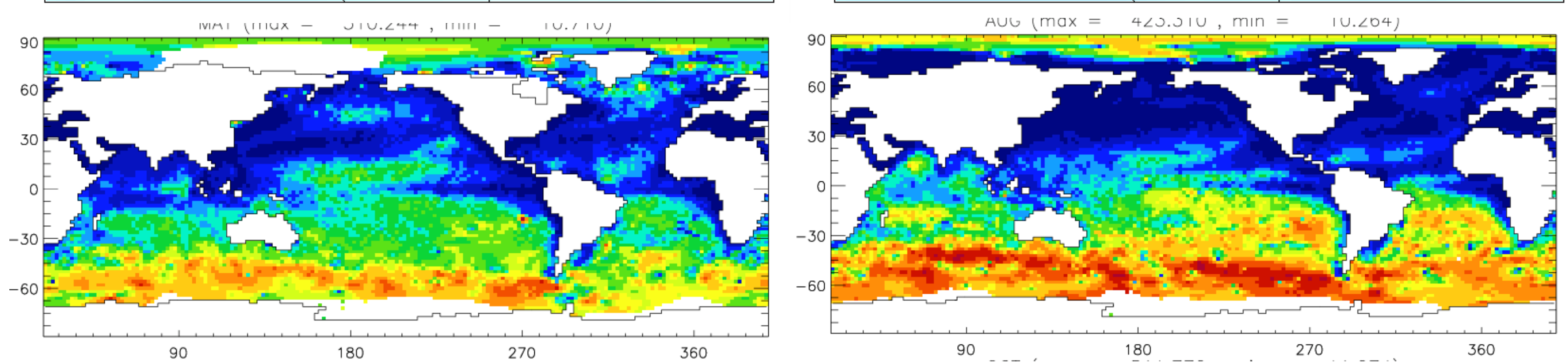
- dotted line: 2.5 m/s
- solid line: 3.5 m/s

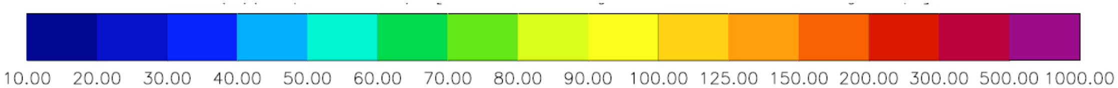
Bellenger and Duvel, 2007

Relation between the ISV and the MLD

- Larger ISV over regions with a thin ocean Mixed Layer?
- Must take also into account the deepening of the mixed layer due to wind IS perturbations







MLD from de Boyer Montégut et al, 2004

Impact of the MLD

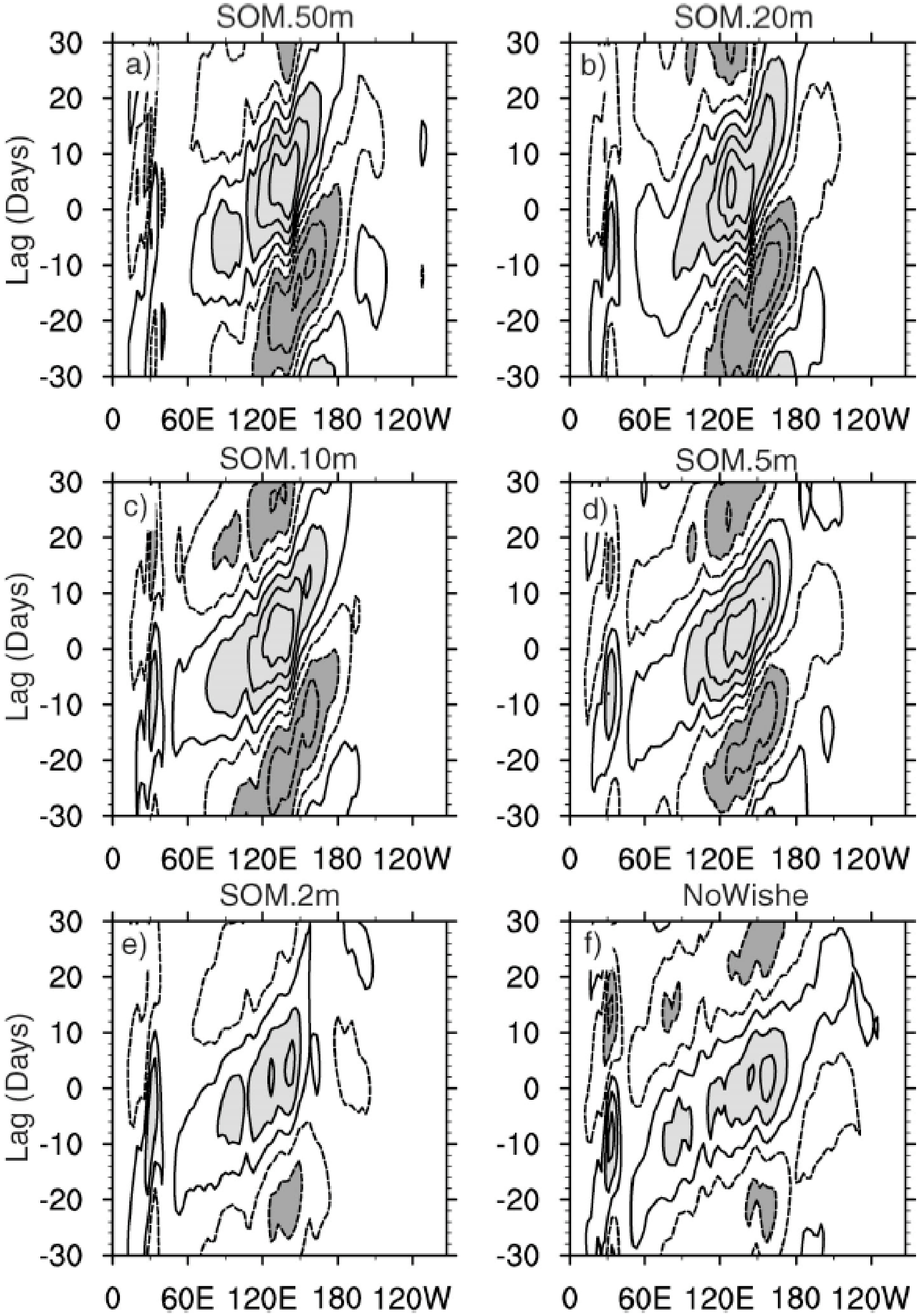
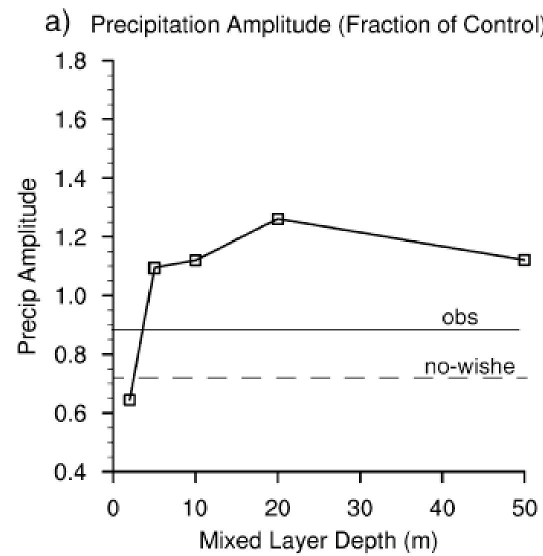


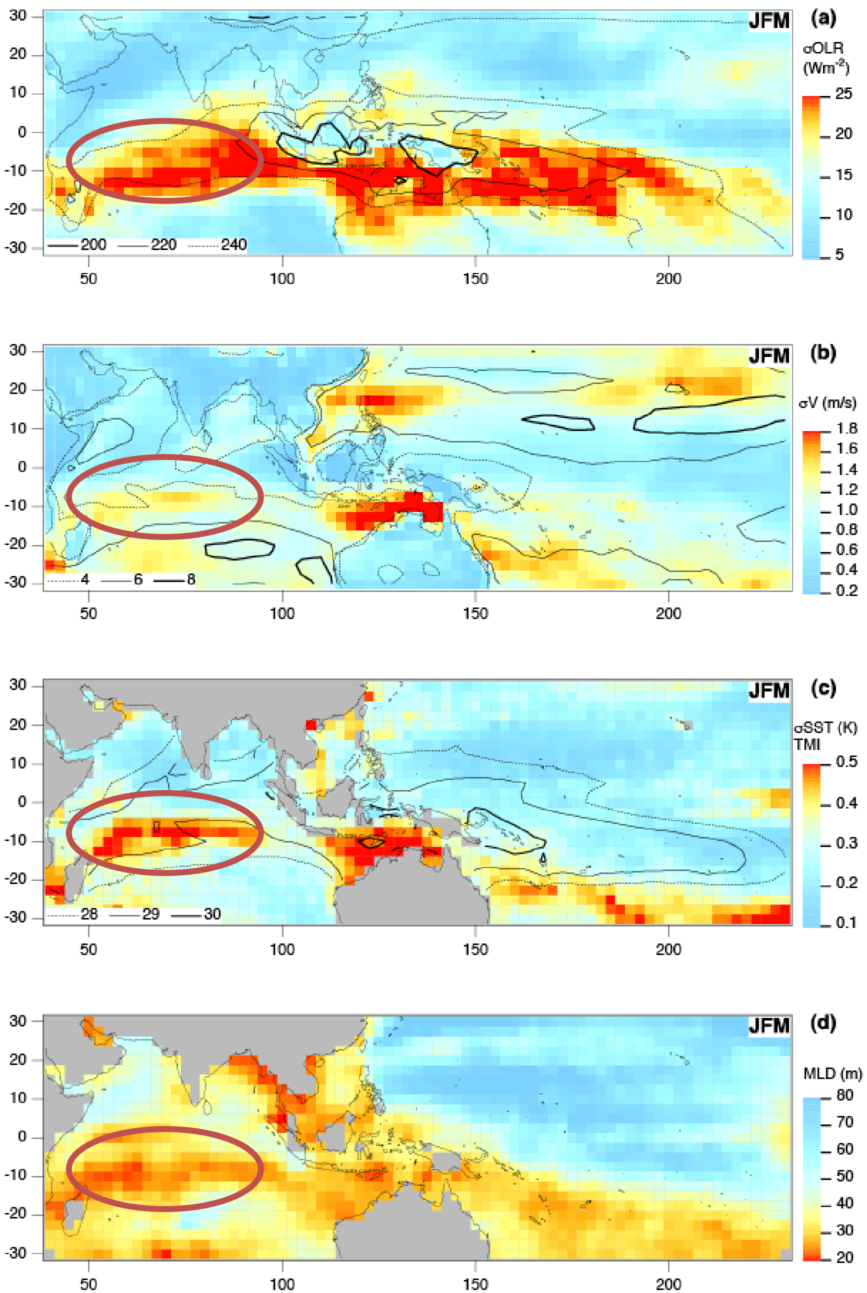
FIG. 2. As in Fig. 1b except for the (a) 50-m (b) 20-m (c) 10-m (d) 5-m and (e) 2-m SOM and (f) No-WISHE simulation.

NCAR CAM with relaxed Arakawa–Schubert convection, coupled to a slab ocean model



Maloney and Sobel 2004

Winter ISO



OLR

10m Wind

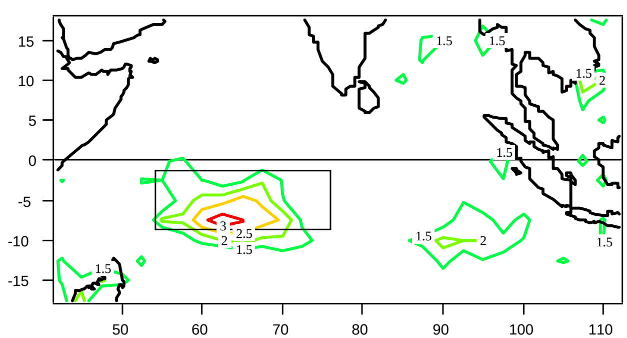
SST TMI (K)

MLD (m)

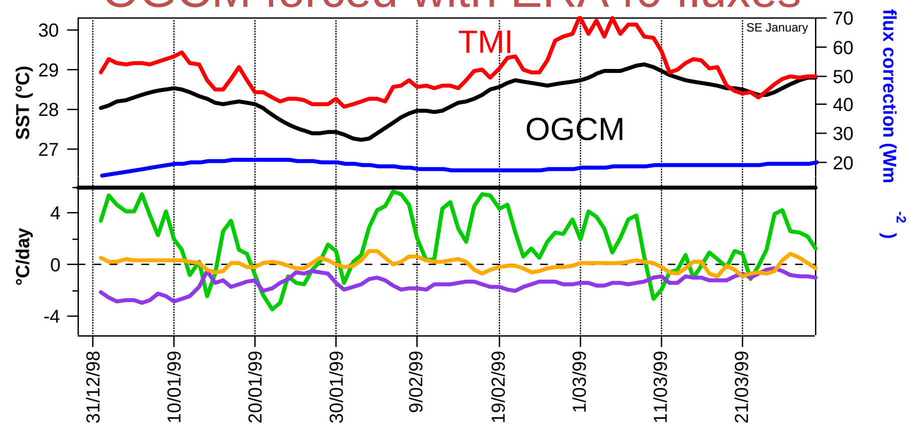
- Recent studies indicate the coupled nature of the ISV
  - Sengupta & Ravichandran, 2001; Harrison and Vecchi 2001; Duvel et al. 2004; Duvel and Vialard, 2007; etc…
- Large ISV of the SST South of the equator in the Indian Ocean during NH winter
  - Related to small mixed layer depth
  - Physical origin of this large SST variability ?

Physical origin of the intraseasonal SST variability

- Two simulations to leave intraseasonal variability unconstrained
  - Long (1990-2000) with relaxation to observed SST
  - Short (1999) with low-pass filtered relaxation term for heat and fresh water fluxes
- SST largely driven by surface heat fluxes



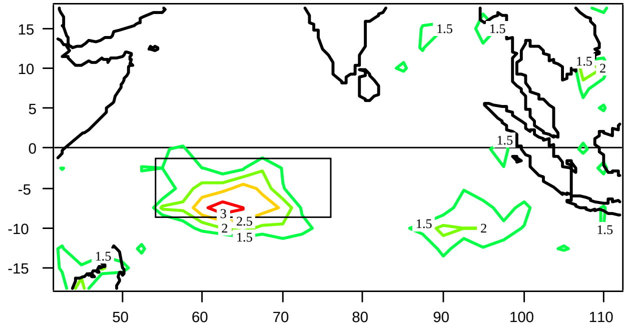
OGCM forced with ERA40 fluxes



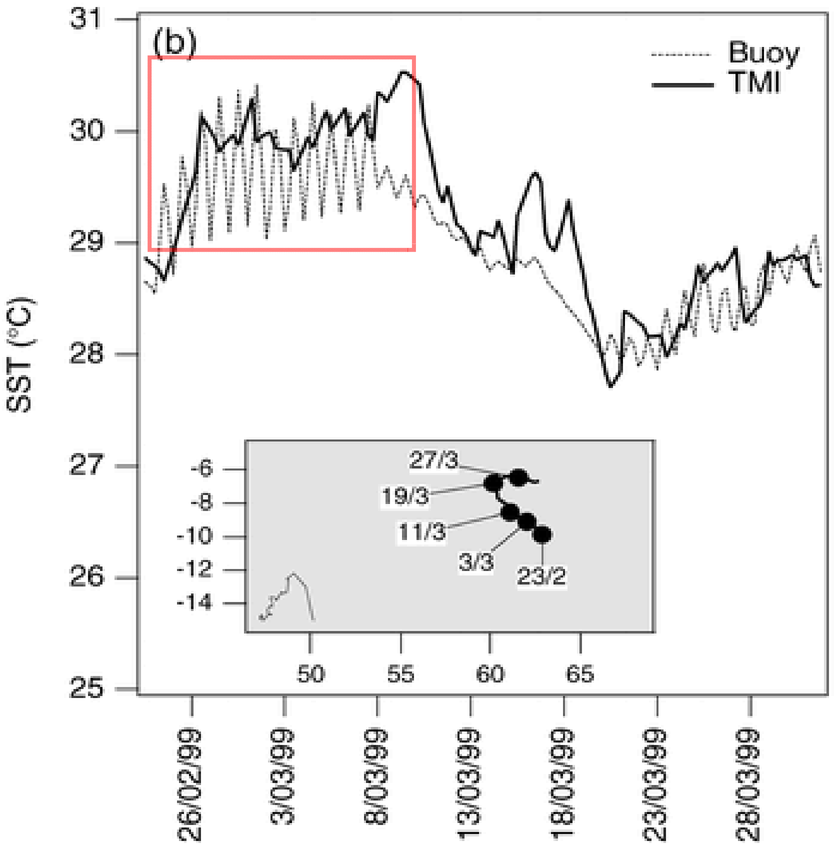
$$\partial_t T = \frac{Q_S\left(1-f(H)\right)}{\rho_0 C_P H} + \frac{Q^*}{\rho_0 C_P H} + \frac{\overline{w'T'}(-H) + \left(w(-H) - dH/dt\right)\left(T(-H) - T\right)}{H} + A$$

Physical origin of the intraseasonal SST variability

- Diurnal Warm Layer formation



Duvel et al. (2004)



Influence of air-sea coupling in the simulation of the MJO

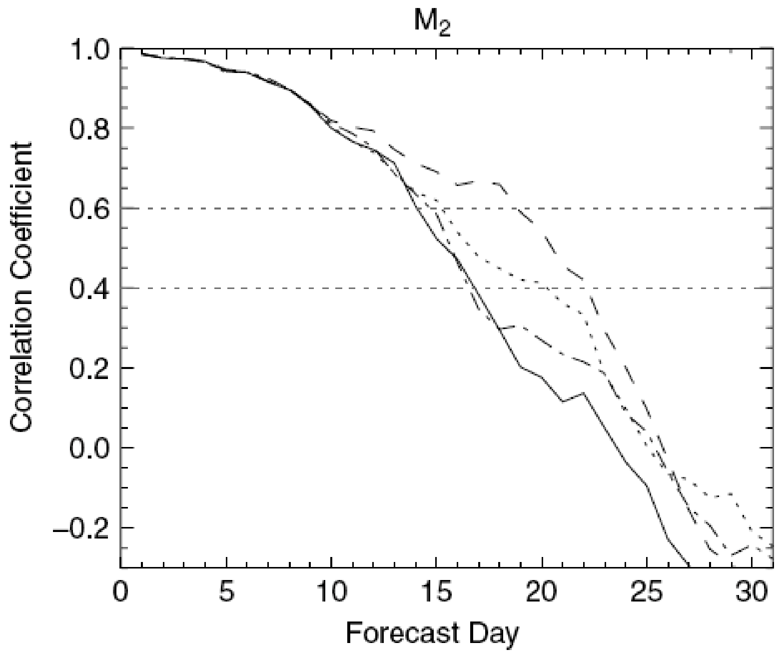


Figure 10. Correlation coefficients of observed M_2 time series with the ensemble mean forecast time series from the CONT (solid), ML (dashed), ML10m (dot-dashed), and ML24hr (dotted) experiments.

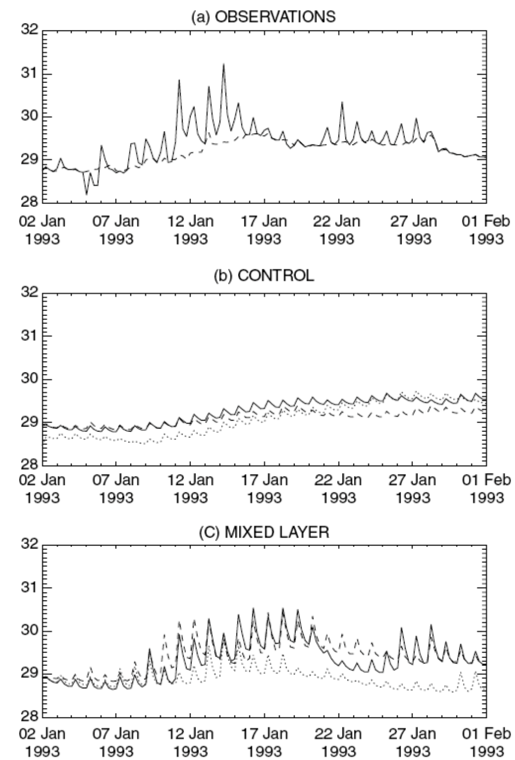
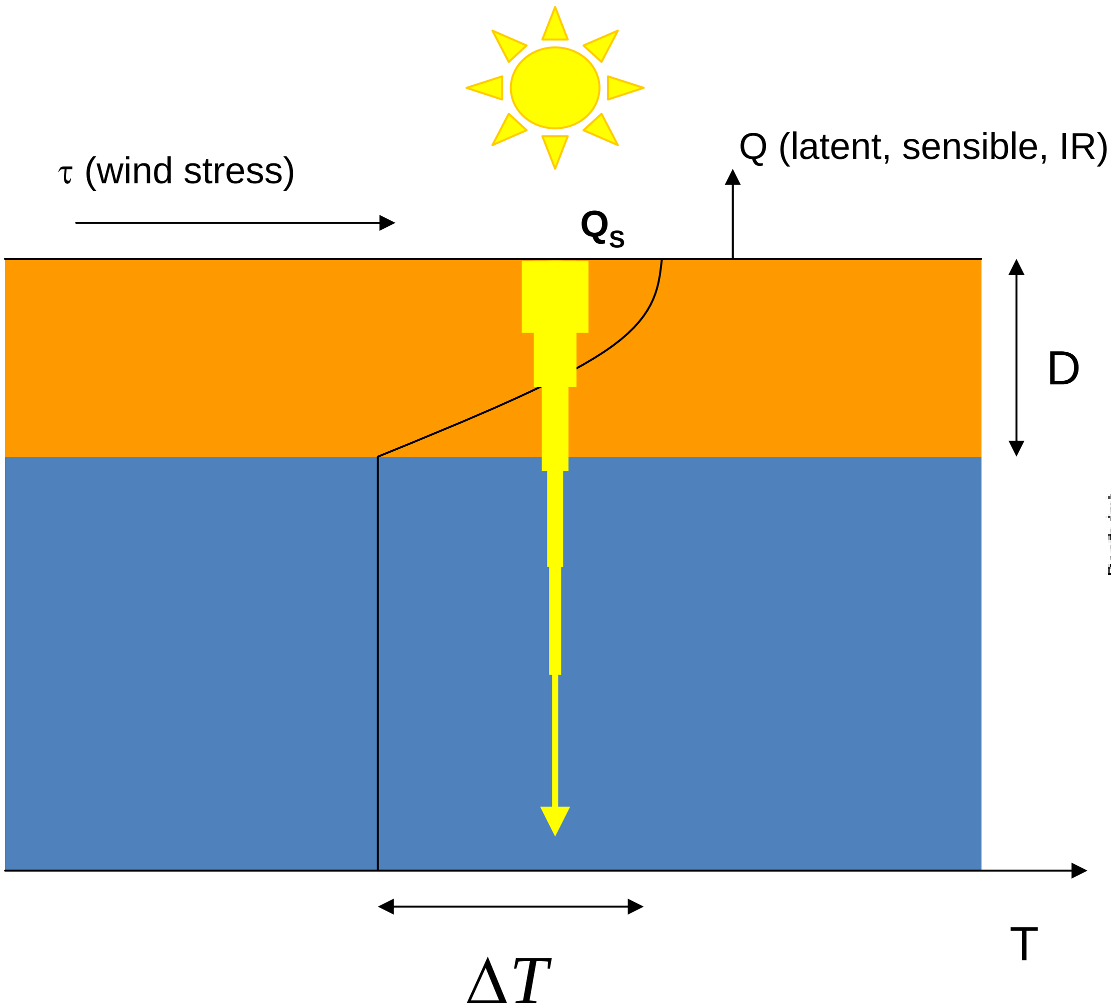


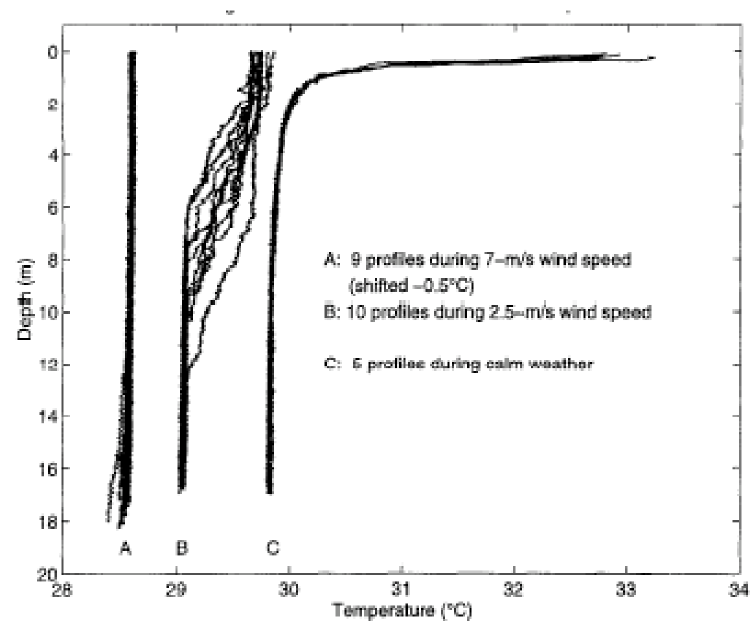
Figure 9. (a) Observed SST (solid line) and 10 m temperature (dashed line) from the WHOI mooring during TOGA-COARE. (b) SST evolution from three members of the CONT forecast experiments for a forecast beginning on 2 January 1993. (c) SST evolution from three members of the ML forecast experiments for a forecast beginning on 2 January 1993.

Mixed layer model (1st level 1.4 m)
OGCM (1st level 10 m)

Woolnough et al. 2007

Diurnal Warm Layer models





Toga-Coare
Soloviev and Lukas (1997).

Diurnal Warm layers

- Role of the Diurnal Warm Layers (DWL) in the intraseasonal SST perturbations?
  - DWLs increase the heat transfer from the ocean to the lower atmosphere.
  - DWLs enhance the boundary layer temperature contrast between regions and may modify the atmospheric circulation.
  - DWLs can trigger convective events organized at large scale?

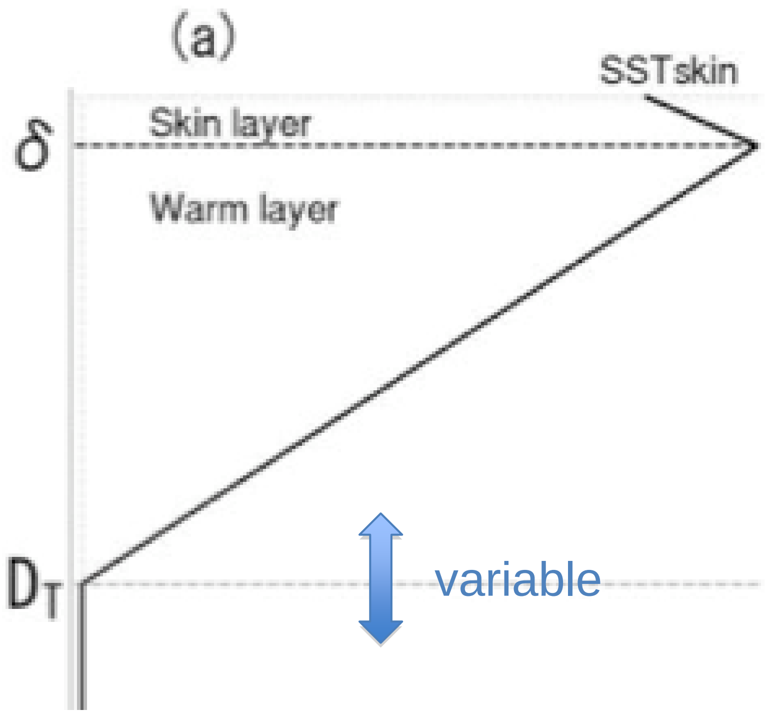
DWL diagnostic

- Single approach used to:
  - Diagnose the main characteristics of the DWL from homogeneous surface meteorological field over the whole tropical zone and;
  - Compute the perturbation of the surface fluxes related to the presence of DWL in AGCM.
- The approach is based on simple DWL models forced by large-scale surface meteorological field.
  - Two DWL models forced by hourly-interpolated surface parameters given by the ECMWF Re-Analysis (ERA40) product.
  - More precise than DWL diagnosed from empirical relation based on daily statistics.

Fairall et al, 1996	*Zeng & Beljaars, 2005*

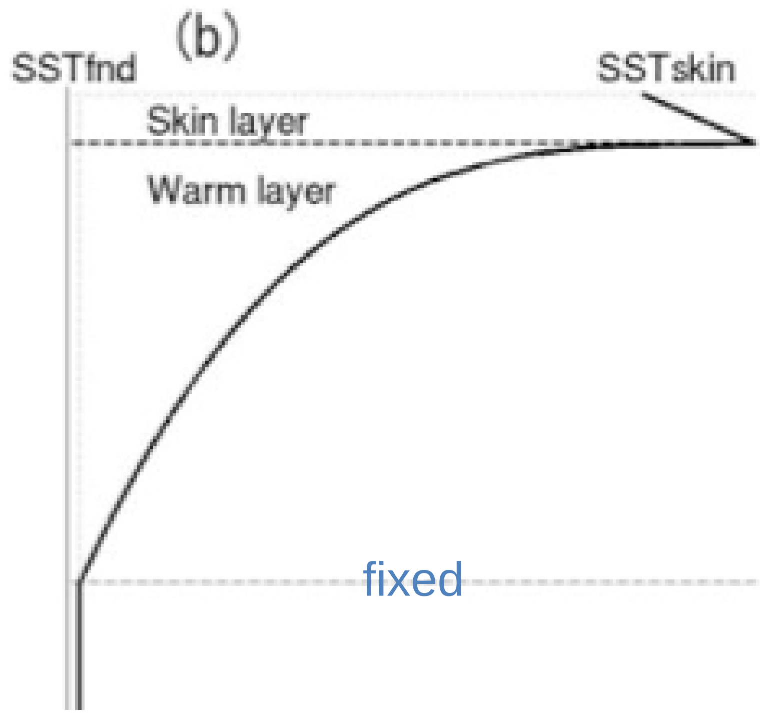
$$Ri_c \propto \frac{\int_t (Q_S - Q)dt * D}{\int_t \tau dt} \quad \Delta T \propto \frac{\int_t (Q_S - Q)dt}{D}$$

T(z) linear in the DWL
D computed



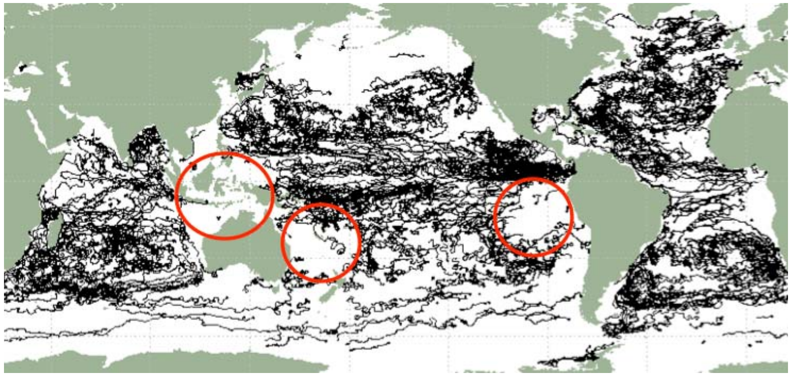
$$\frac{\partial}{\partial t}\int_{-d}^{-\delta} T dz = \frac{Q + R_s - R(-d)}{\rho_w c_w} - K_w \frac{\partial T}{\partial z}\Big|_{z=-d}$$

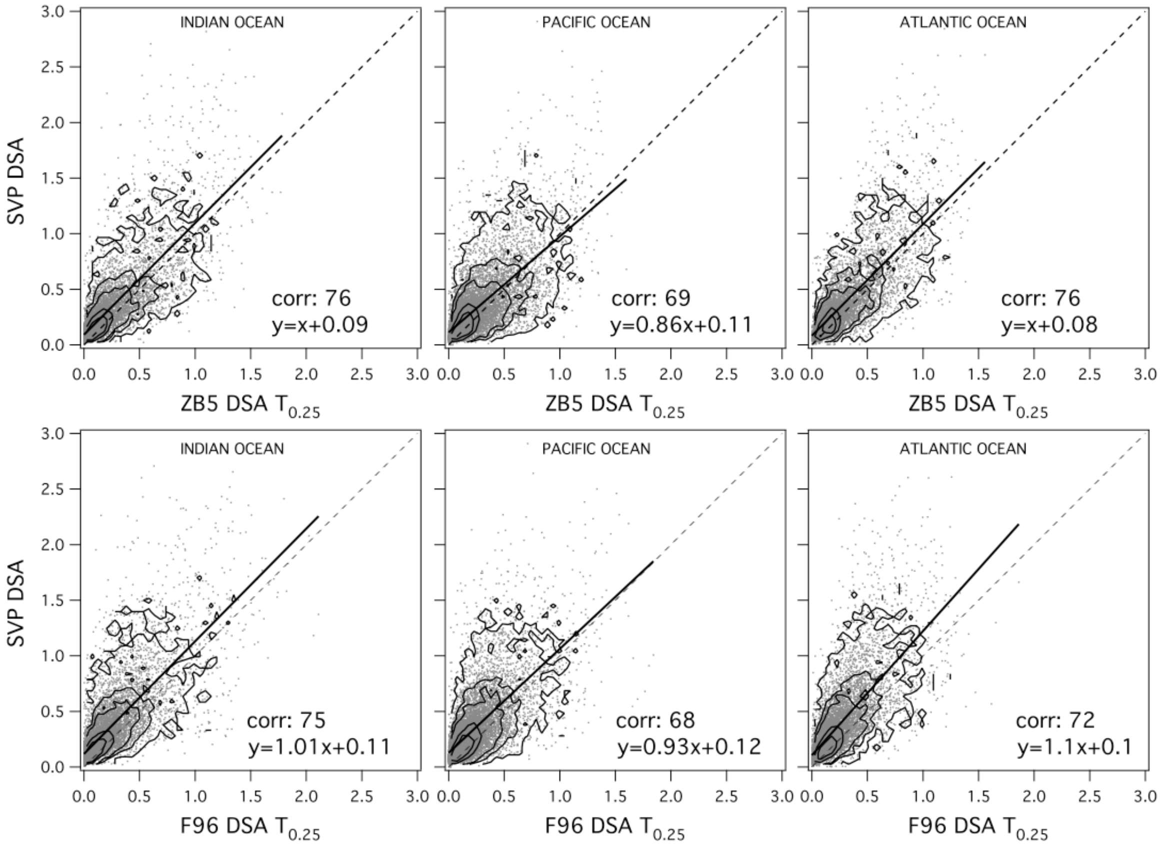
T(z) imposed shape and depth -d
K_w computed using MO



Validation with SVP buoys

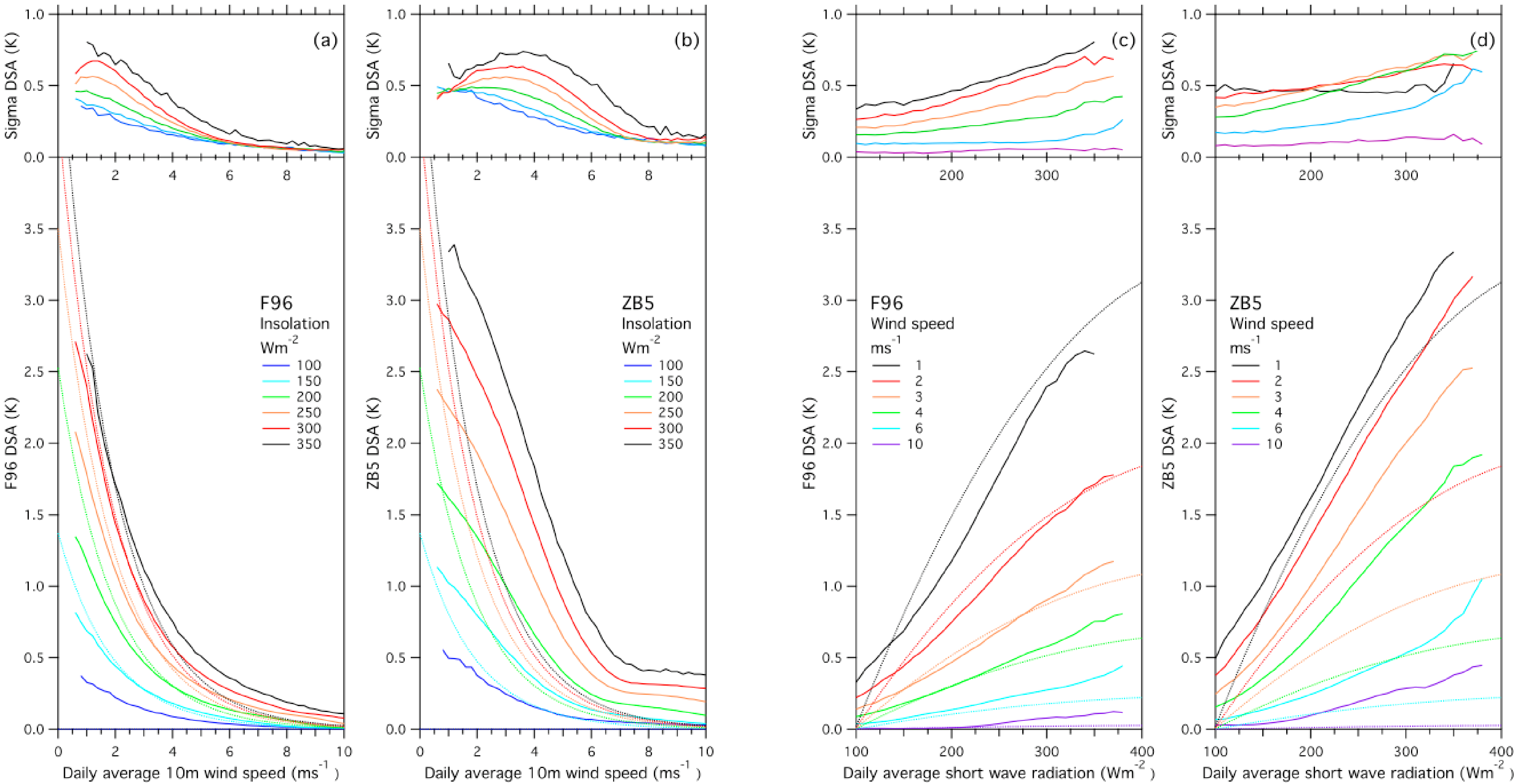
- Validation using SVP buoys
  - 50000 values of daily SST amplitude
  - Comparison of diurnal SST amplitudes





For a depth of 0.25m

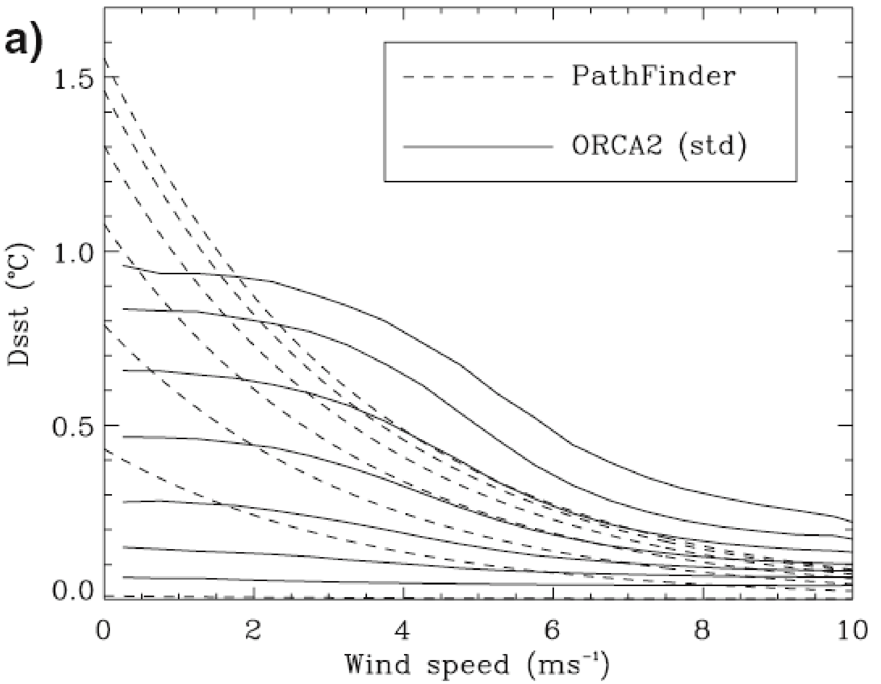
Validation with TMI empirical relations

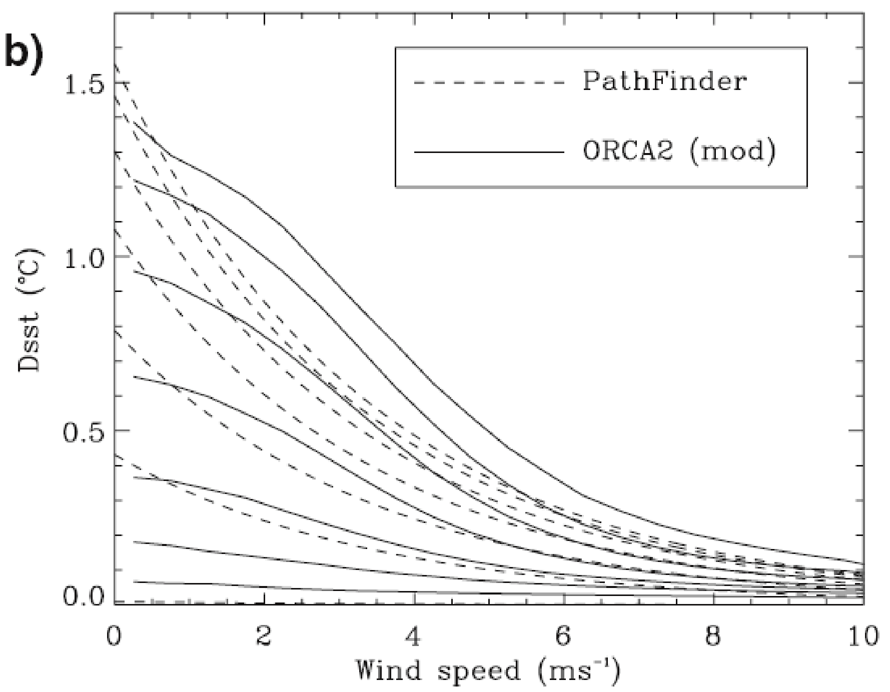


Empirical relation adapted from Gentemann et al. (2003)

Approximation for clear sky: $SW_{surf} = 0.75*SW_{TOA}$

For $T_{subskin}$





DWL in OGCM

Potential interest of the parameterization, even for a high resolution GCM

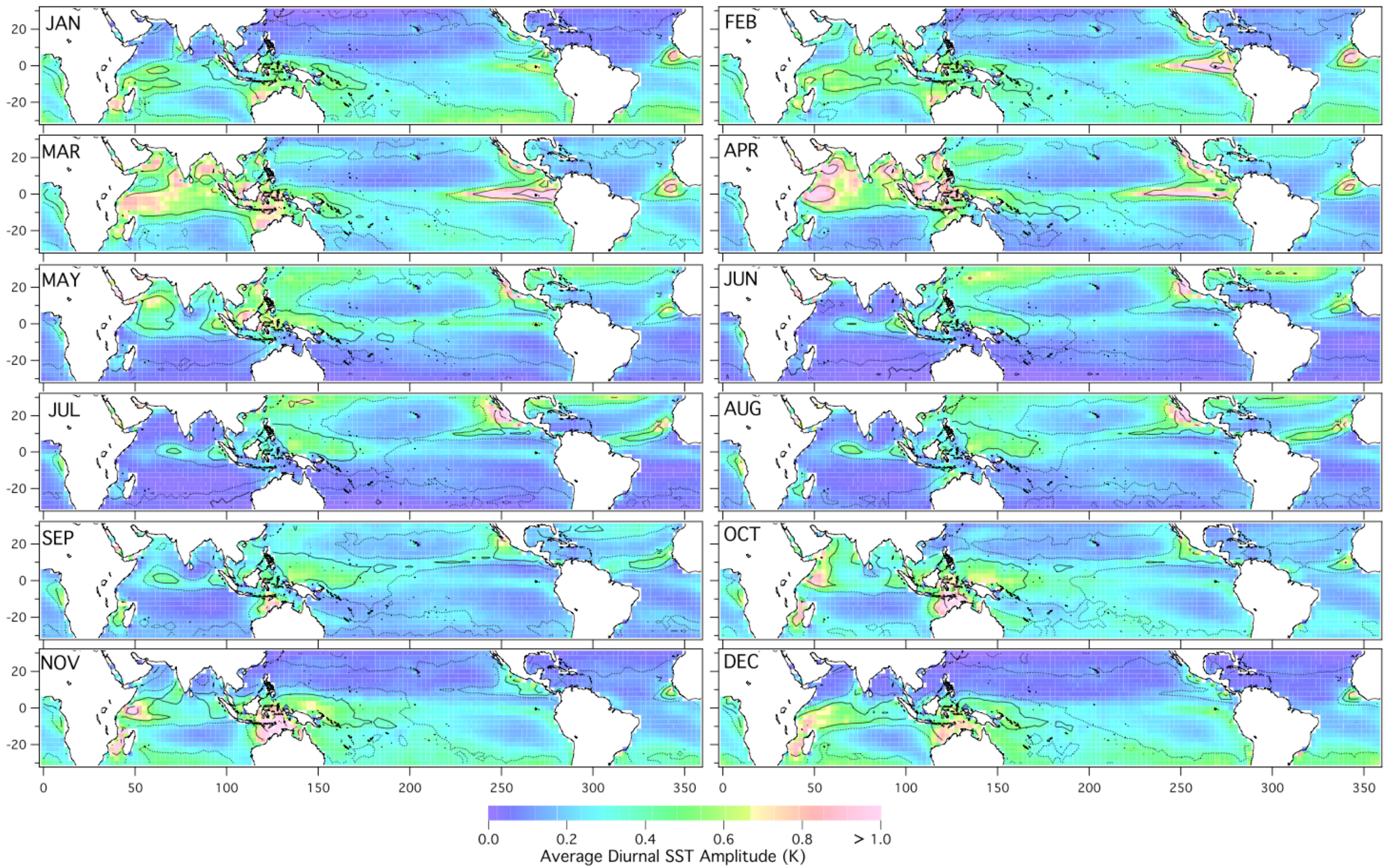
Here, ORCA (301 levels) with a first layer of 1m

Adjustement of the model mixing scheme to increase the mixing at high wind speed and decrease it at low wind speed

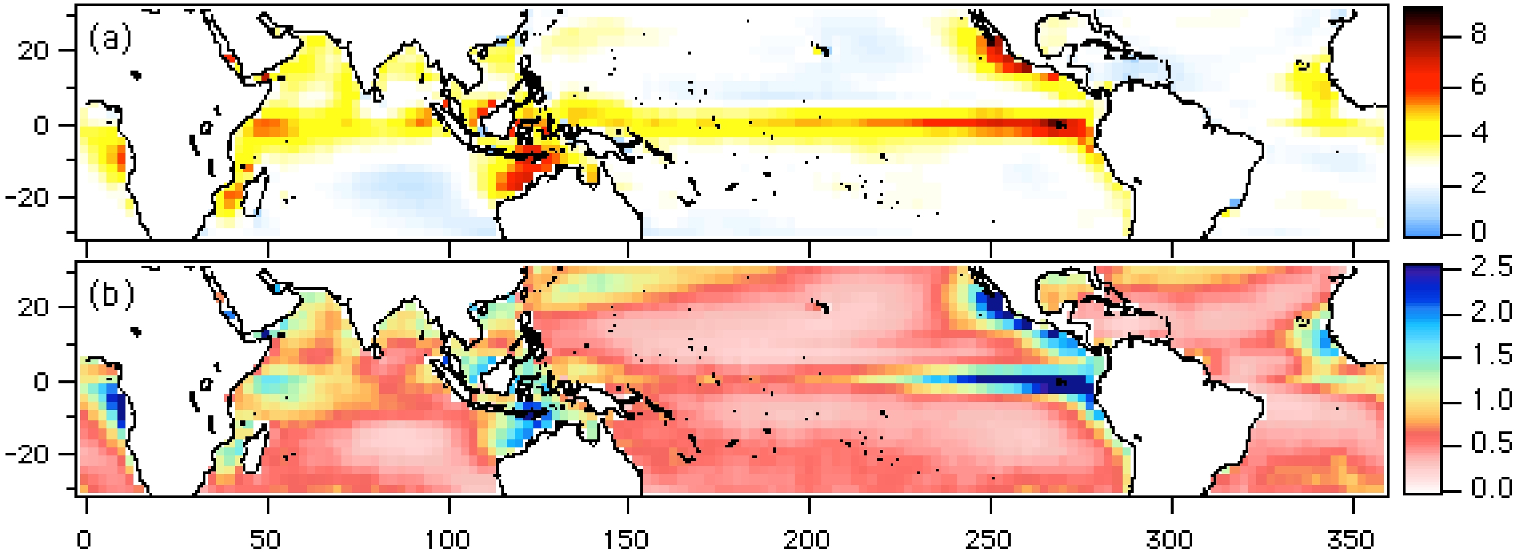
Still underestimate DSA at low wind speed compared to TMI results (twice the PF Dsst)

Bernie et al, 2007

Monthly mean Diurnal amplitude



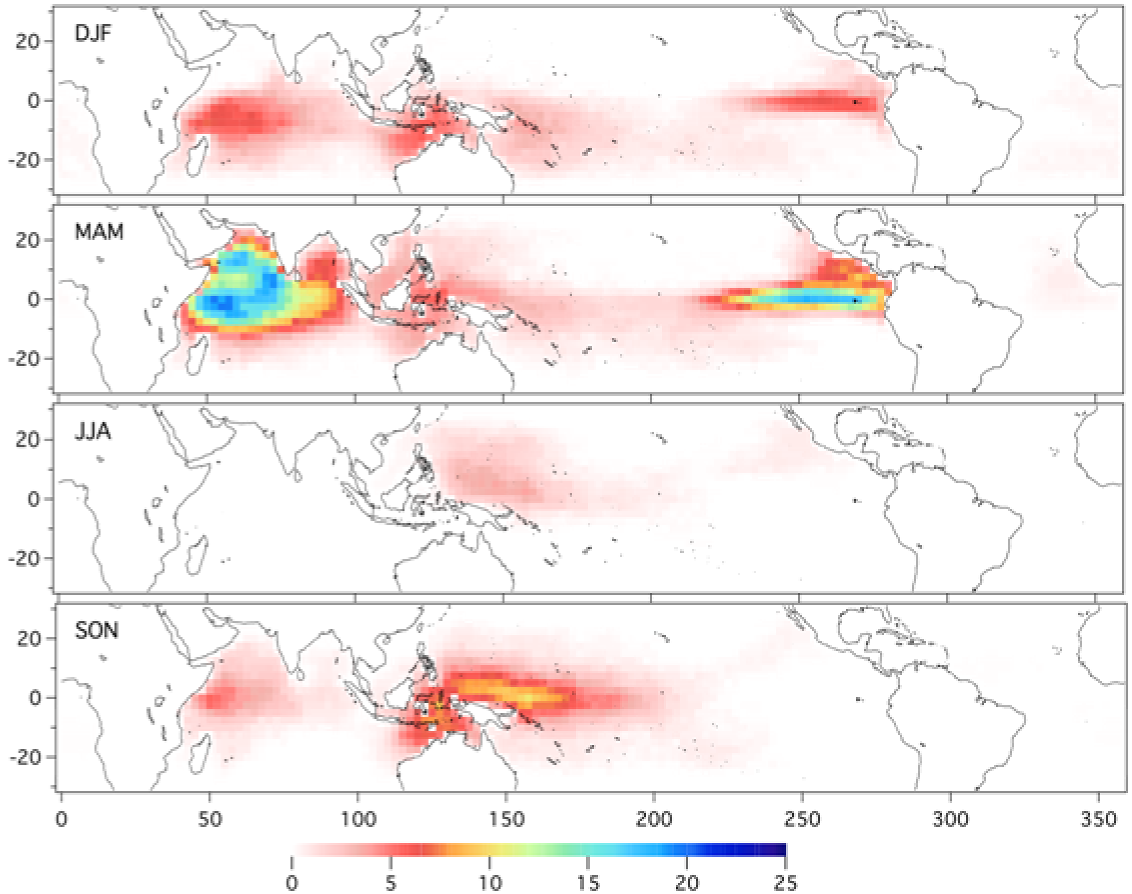
Surface flux and ML temperature perturbations due to DWL



(a) Annual mean surface flux perturbation (surface cooling in Wm-2) due to DWL
(b) Corresponding annual mean cooling of the ocean mixed layer (K/year).

Regionally:
- 0.5K/month over the northwest Australia in October
- 0.8K/month over the eastern Pacific in March

Size of the DWL



Occurrence (% of day)

DWLs with equivalent radius larger than 1000 km appears :

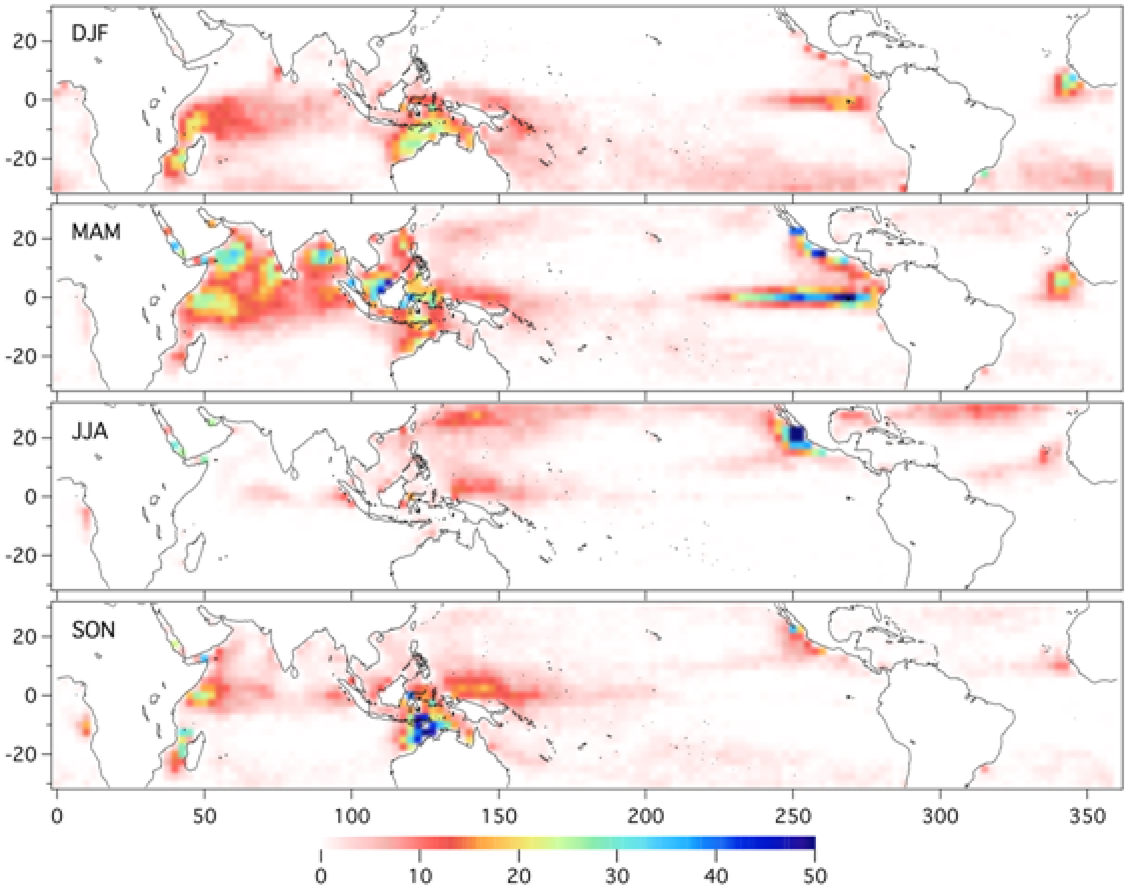
- 2 and 3 times by year for a DSA threshold of 1.4K

- 2 and 3 times by week for a DSA threshold of 0.7 K.

DWL amplitude > 0.7 K
Equivalent radius > 1000 km

Bellenger and Duvel, 2008

Duration of the DWL



Occurrence (% of day)

Most persistent DWL:

- 90 days for DSA larger than 0.7 K

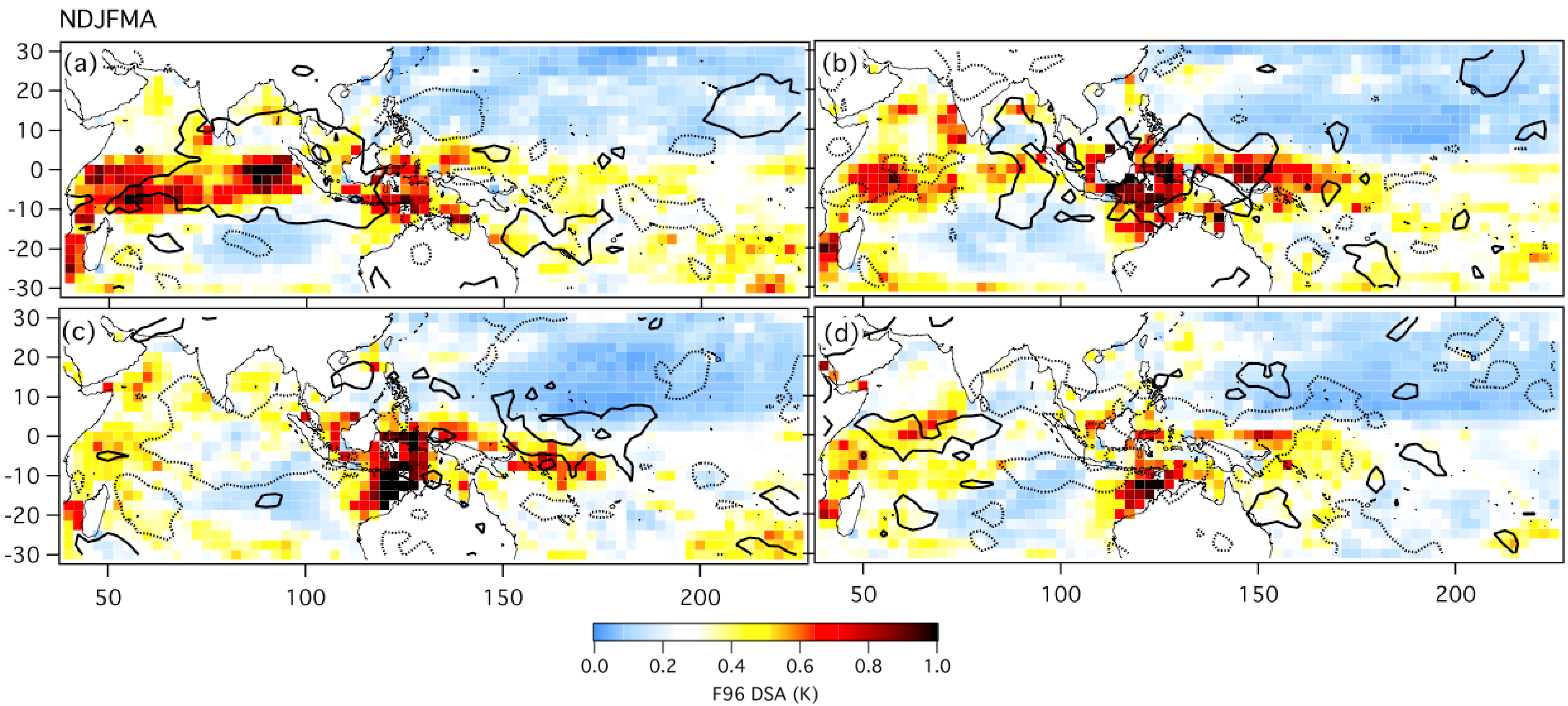
- 40 days for DSA larger than 1.4 K.

DWL amplitude > 0.7 K
Duration > 5 days

Bellenger and Duvel, 2008

Intraseasonal perturbation of the DWL

- DWL develop during the suppressed phase
- DWL may help to trigger large-scale organized convection

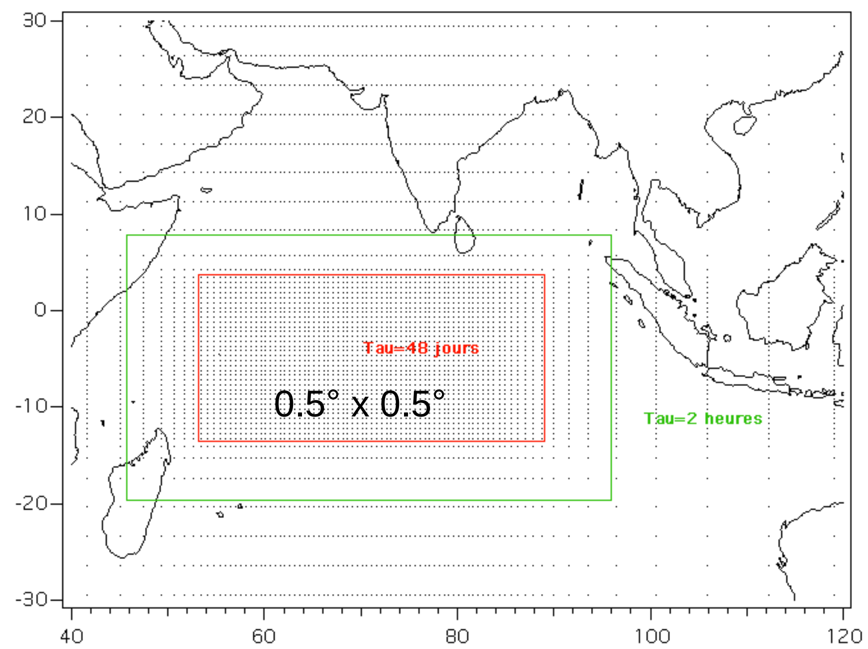


Role of the DWL in the ISV of the SST

- DWLs increase the ISV of the SST
  - Double the intraseasonal SST amplitude for some regions
- Region of strong DWL are also regions of strong ISV
  - Long duration (d > 5days) and large (r > 1000km) DWL
  - DWL can trigger large-scale organized convective event?
- Test the Impact of the DWL on simulated ISV in the LMD-Z AGCM

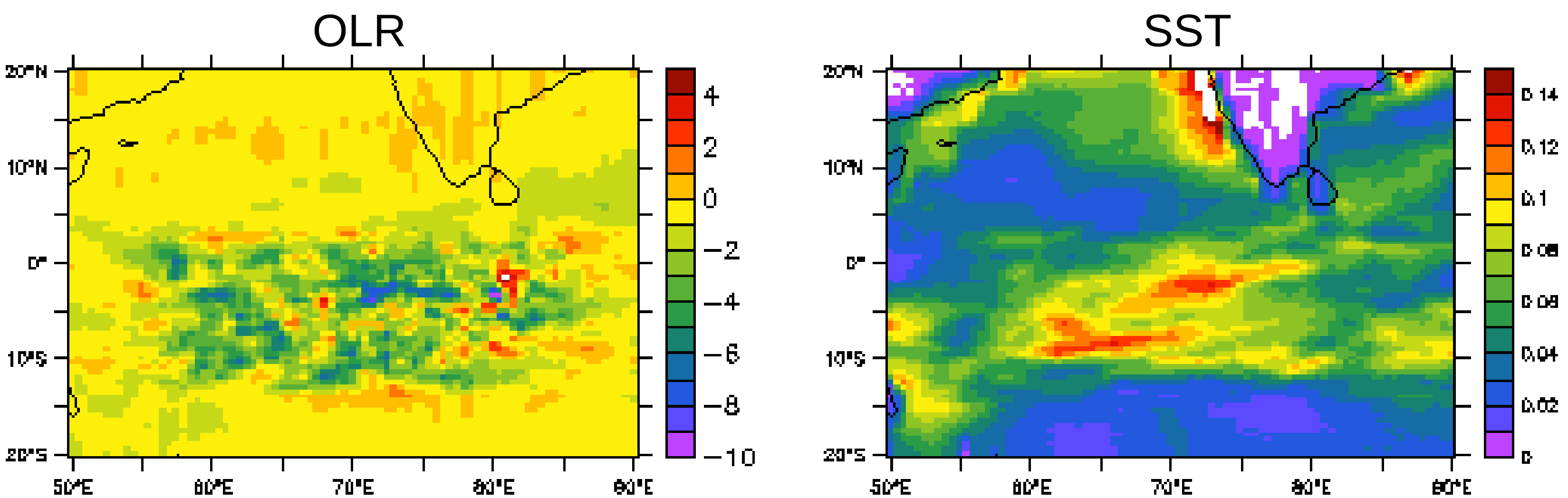
Preliminary DWL simulations with LMD-Z

- LMD-Z forced and guided 3-month (JFM 99) simulations
  - 1 with the cool skin and DWL parameterization
  - 1 without
- Relaxation toward ERA-40 reanalyses (P, T, Q, U) with a relaxation time of:
  - 2 hours outside the green region (i.e. ≈ ERA40)
  - 48 days in the red region (i.e. ≈ LMDZ)



LMD AGCM sensitivity test

- The SST ISV amplitude increases
- The OLR ISV amplitude decreases
  - The diurnal variation of the SST triggers convection even during “suppressed” phases.

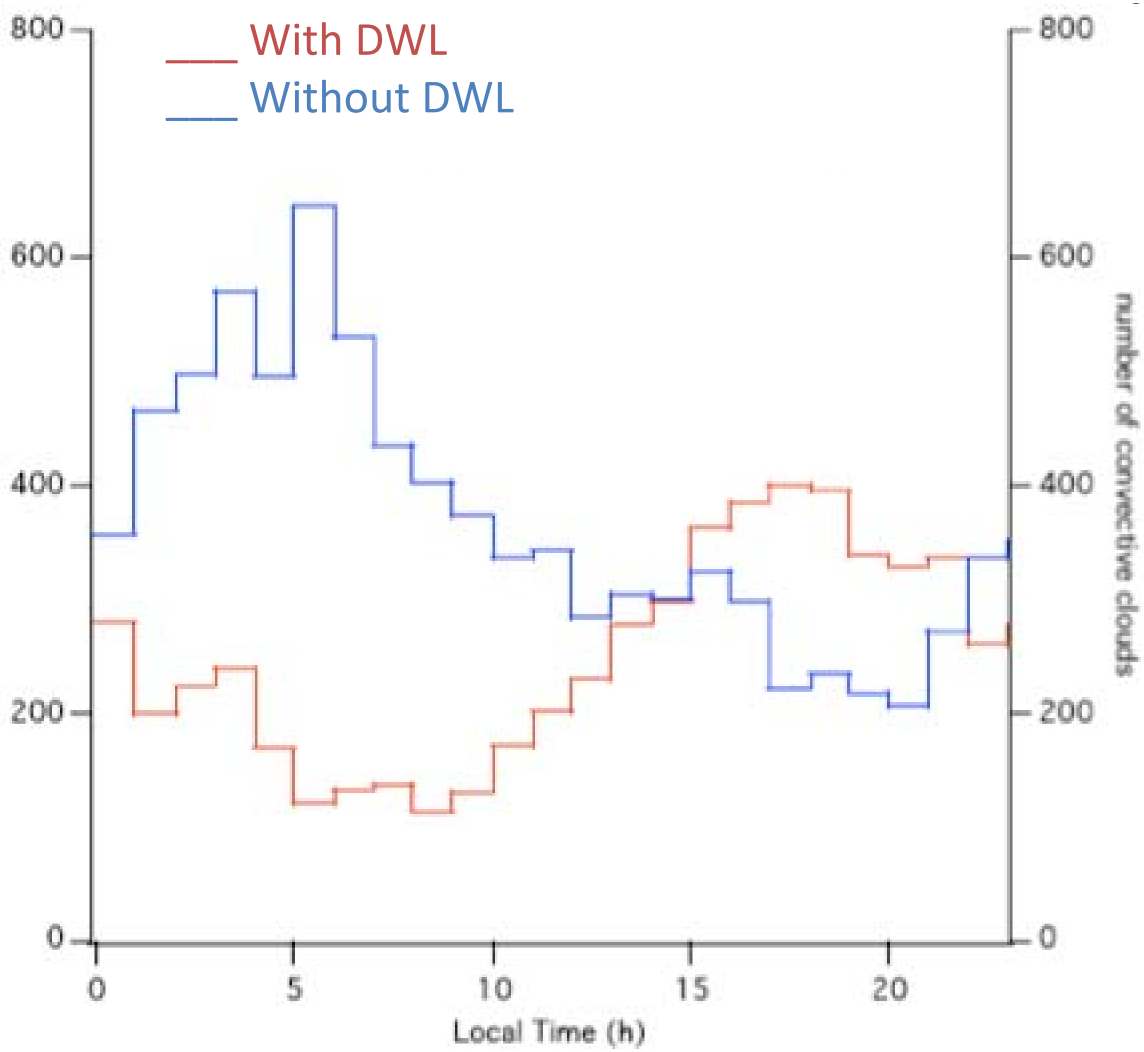


Difference in the ISV amplitude due to the DWL Parameterization

Parameterization of the DWL in the LMD-Z AGCM

- Ambiguous role of the DWL in the ISV of the convection
  - Increase the ISV of the SST
  - Diurnal release of the convective instability decreases the ISV of the convection
    - Analogy with a continental regions (DWL = a continent that disappears as soon as the wind increases…)
    - Exaggerated in the GCM because of triggering criteria in the convective parameterization?
  - Improvements needed to trigger large-scale organized convective perturbations by DWLs?

Diurnal convection and DWL



MISMO campaign

– Radar measurement of convective rain
– Number of convective cells

– Mostly shallow to mid-level convection during DWL episodes

Bellenger et al. (2008) (CCSR-JAMSTEC)

Questions

- The control of the representation of the ISV in GCMs is still a challenge
  - What are the main physical processes at the origin of the intraseasonal variability (ISV) of the convection ?
- Role of air-sea coupling in the triggering and the evolution of intraseasonal events?
  - Structure of the mixed layer (depth) may control the timing of the convective events (duration, time until the next event);
  - Role of Diurnal Warm layers in triggering large-scale organized convective event.

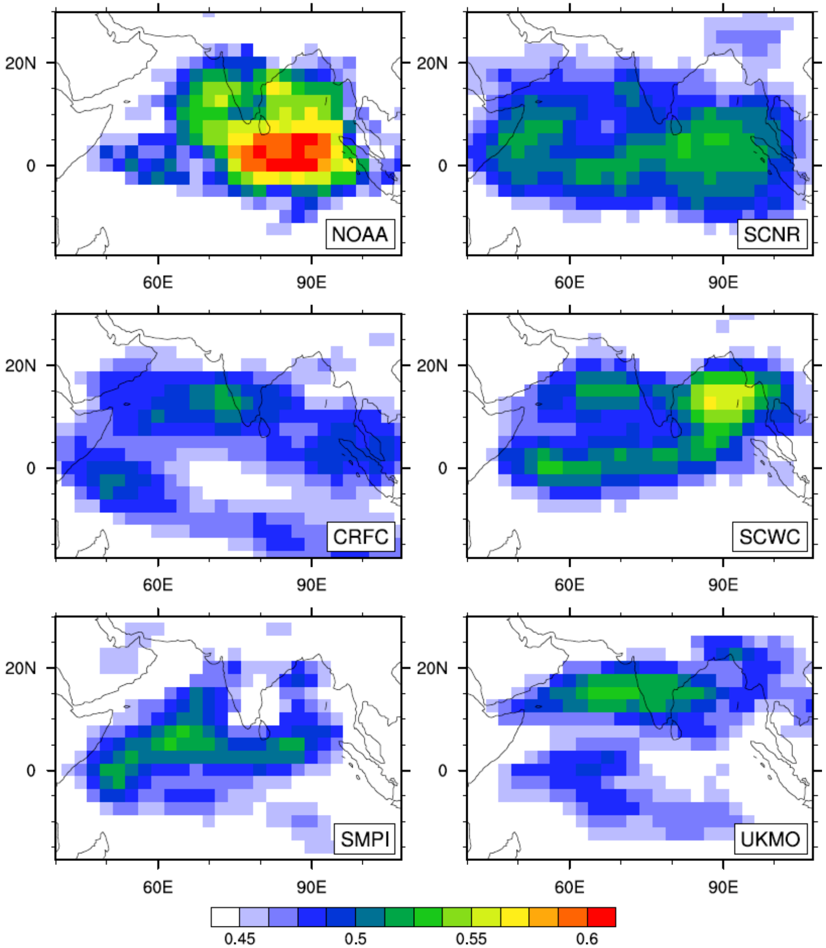
Questions

- Incorporate DWL parameterization in AGCMs?
  - Improve/adapt existing DWL simplified models
- Adaptation of the Convective scheme necessary?
  - More stringent triggering criterion of the deep convection?
    - Known to improve the ISV (e.g. Wang & Schlesinger 1996, Vitart et al 2003)
    - Other processes necessary (cloud/radiation)?
  - How to represent also shallow and mid-level convection in convectively suppressed conditions?

Method for event-wise evaluation of the ISV in GCMs

- Local Mode Analysis gives:
  - Perturbation pattern, period, amplitude for each ISV event;
  - Corresponding perturbations for SST and surface winds (multivariate analysis).
- Application for model evaluation
  - Compare distributions of ISV events
  - Test whether an average pattern is similar to actual ISV patterns.

Large-scale organisation of Intraseasonal convective perturbations

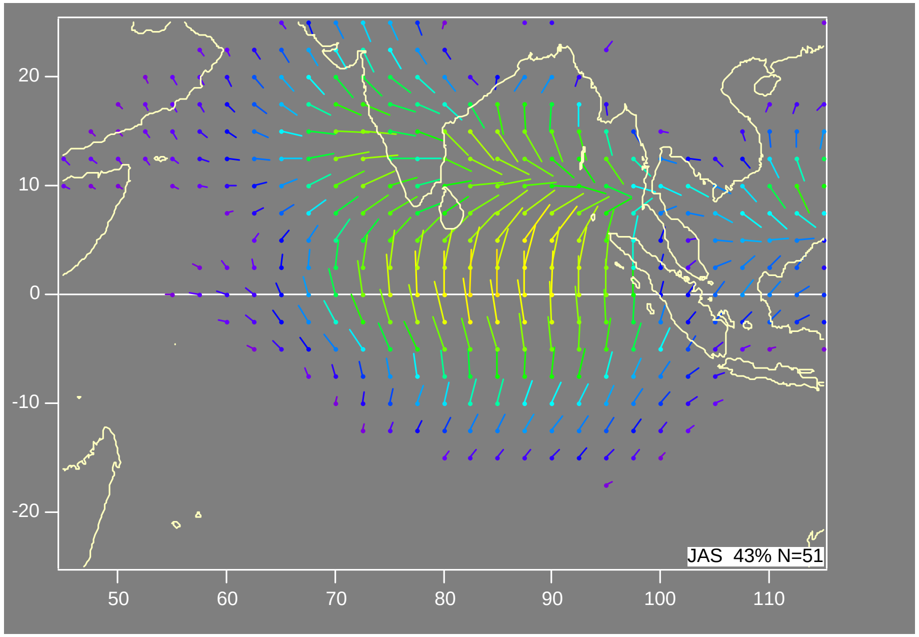


Xavier et al. J Clim 2008

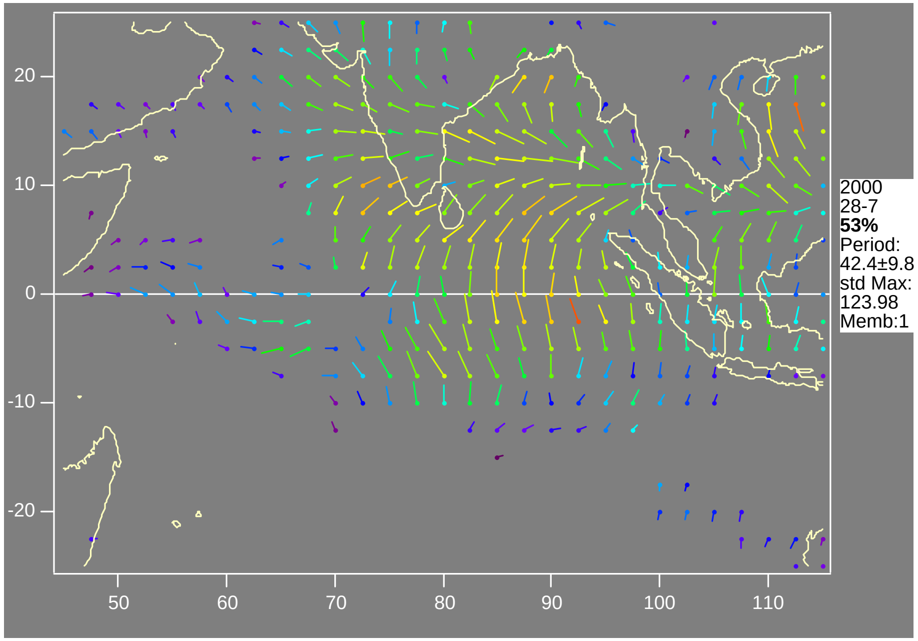
- Demeter coupled GCMs for JJAS.
- Percentage of ISV variance of the OLR due to large-scale perturbation:
  - Demeter CGCMs tend to underestimate the role of large-scale organized ISV events;
  - CGCMs also have a wrong spatial distribution of this percentage.

Reproducibility of the Patterns

- Average JAS pattern well representative of the July-August 2000 pattern.
  - Computation of a normalised distance between patterns to study the reproducibility of the perturbations
    - Distance between two complex vectors



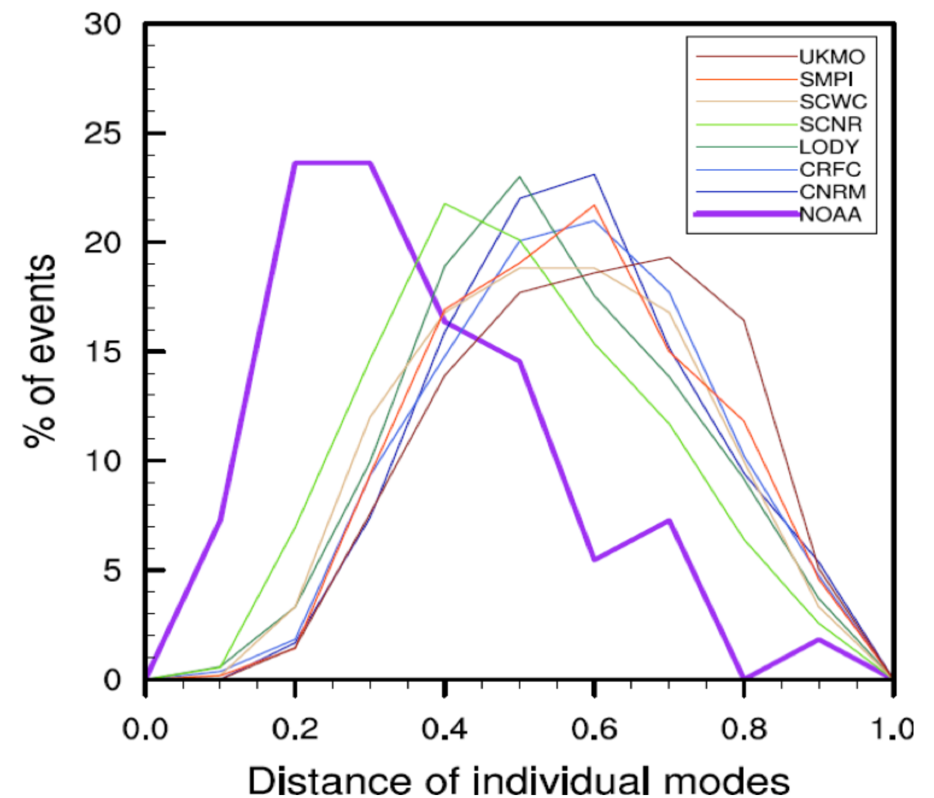
1979-2004



2000

Reproducibility of spatial patterns of Intraseasonal convective perturbations

- Distance between the average ISV pattern and the pattern for each ISV event (MJJAS):
  - In observations (OLR), the perturbation pattern is well reproducible and the average ISV pattern is thus well representative of the phenomenon;
  - This is not true for the Demeter CGCMs.

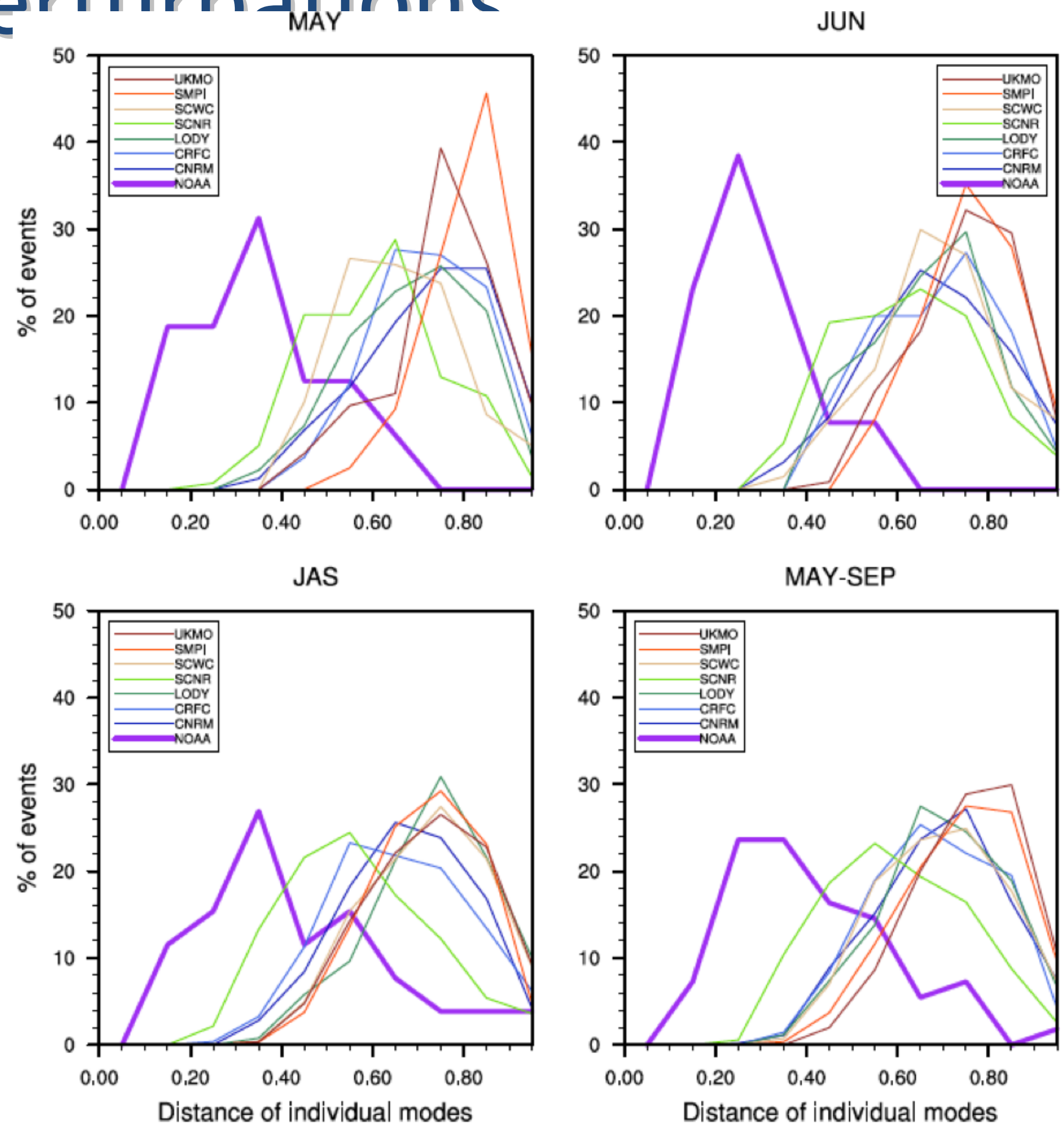


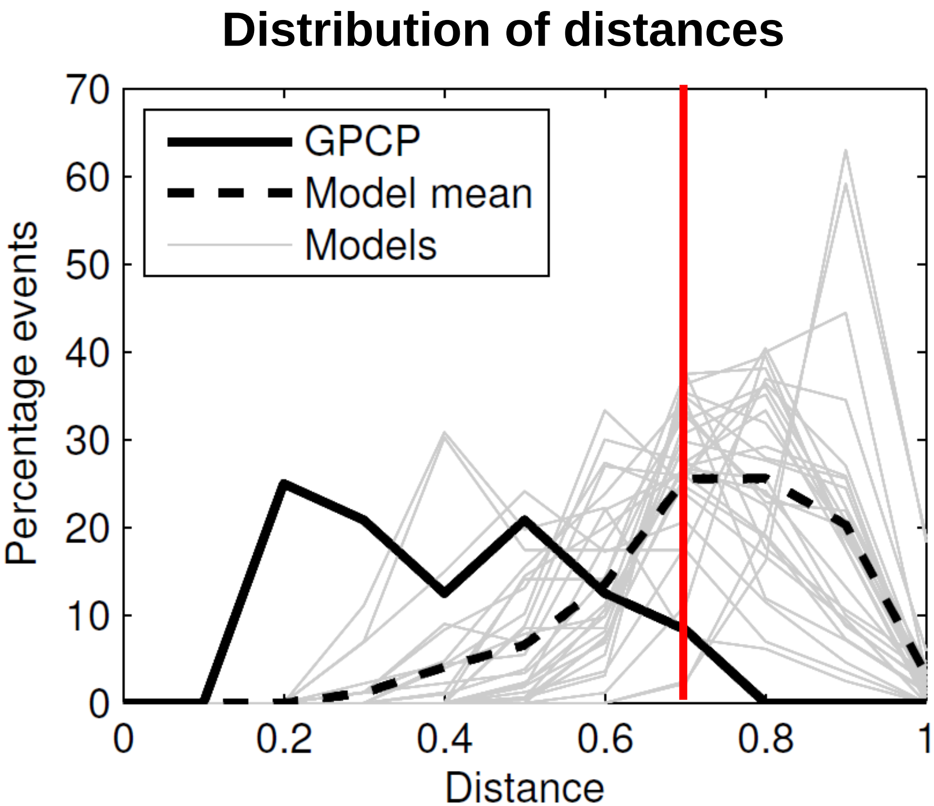
Distance = 0 for identical patterns

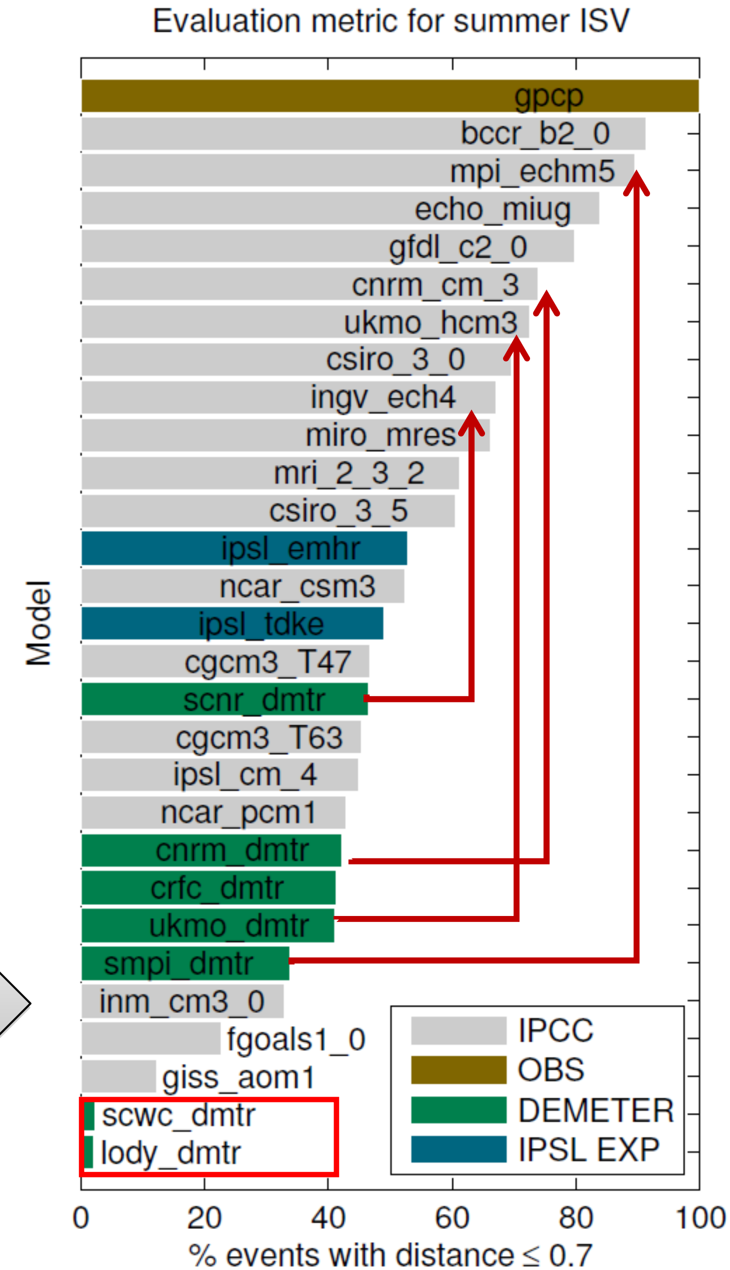
Xavier et al. J Clim 2008

Reproducibility of spatial patterns of Intraseasonal convective perturbations

Distance between the average OBSERVED ISV pattern and the pattern for each ISV event.



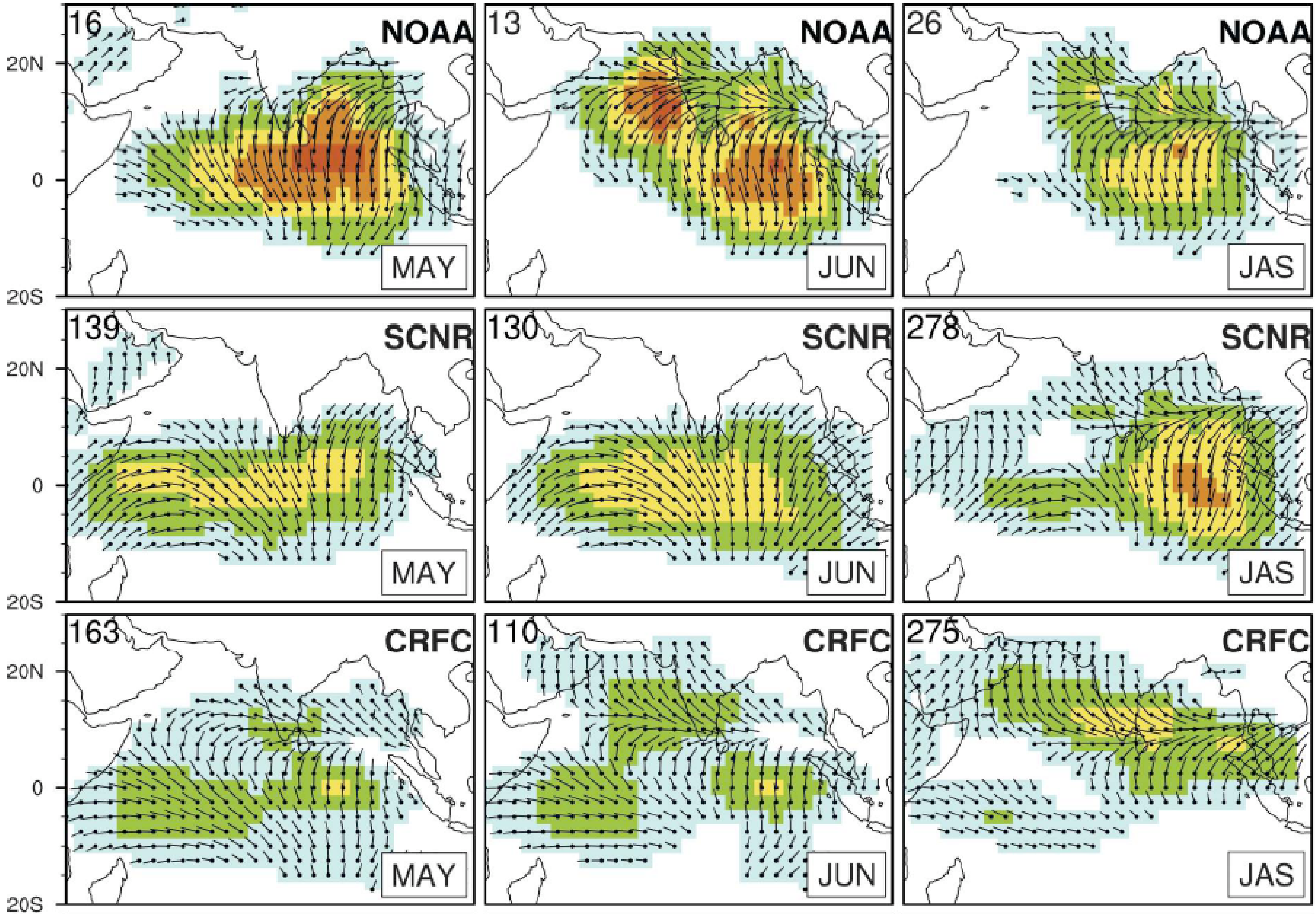




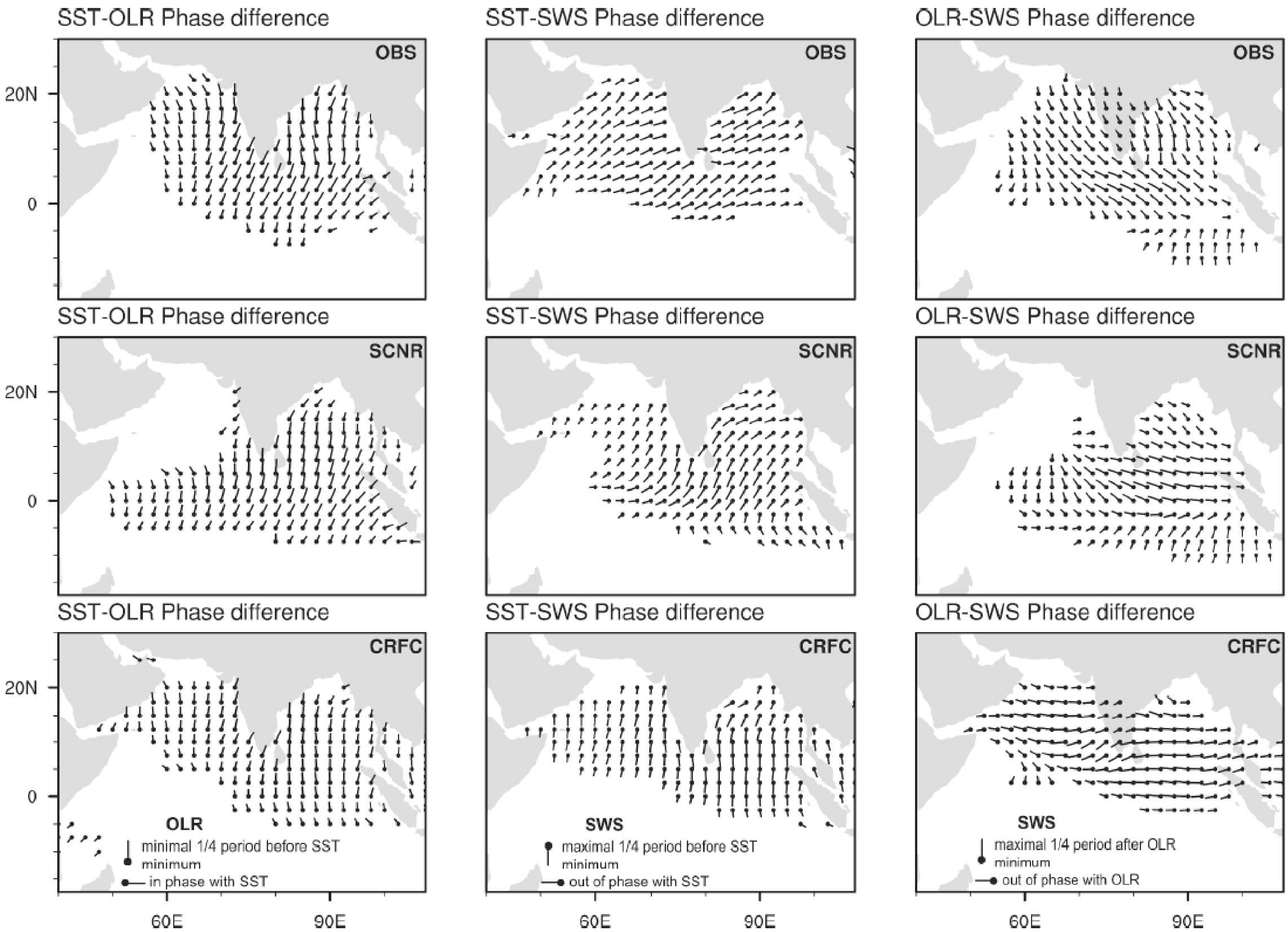
Metric = % of events with distance ≤ 0.7

Xavier, Duvel, Braconnot (under review)

Seasonal dependence of the ISV



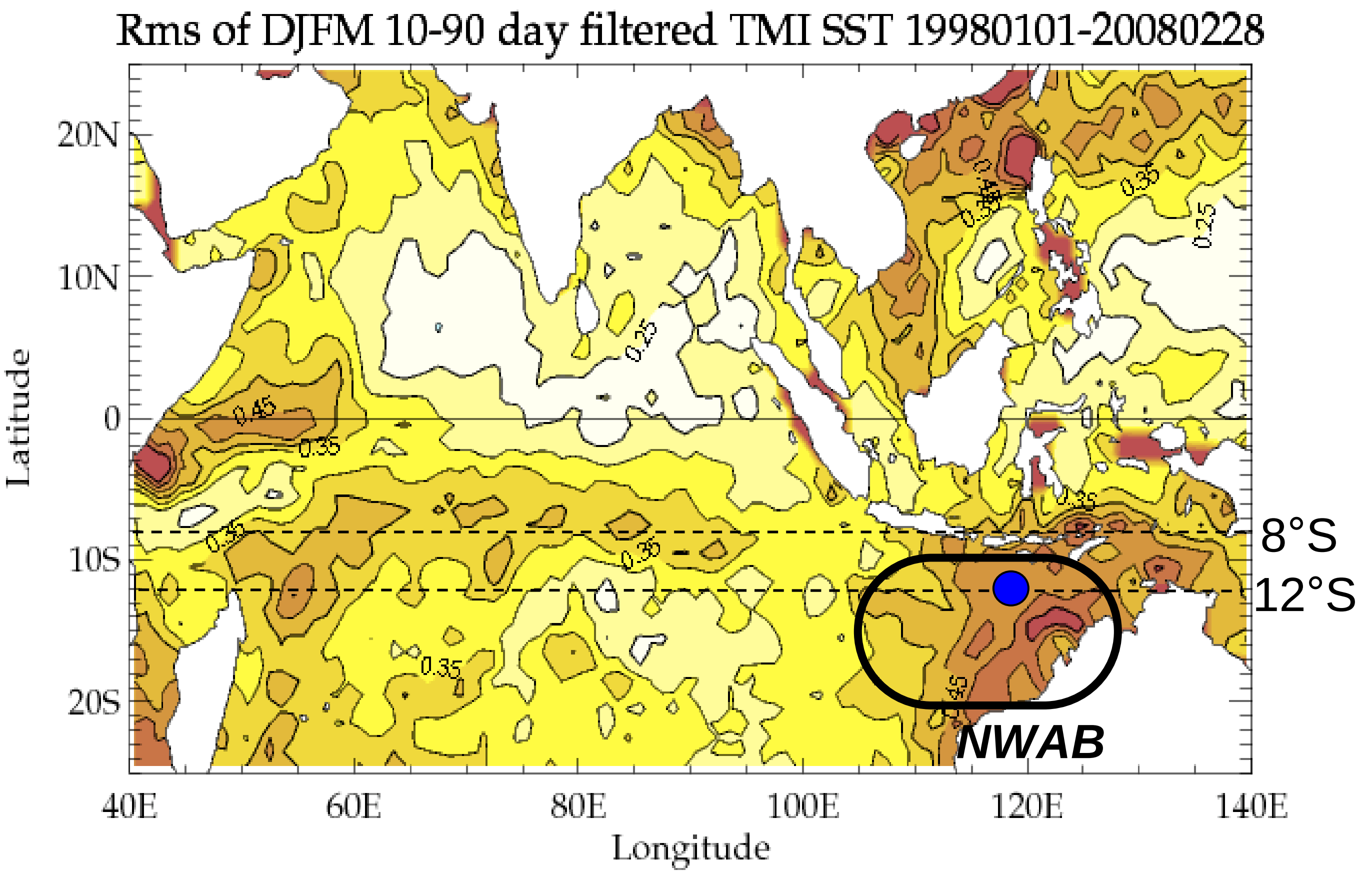
Air-sea processes



Some scientific objectives for the TRIO experiment (2011)

- Measurements in regions of large ISV:
  - Surface fluxes perturbations and the ocean mixed layer structure;
  - Atmospheric boundary layer perturbation (impact of DWL and of ML temperature) and the convective instability;
  - Shallow and mid-level convection, the moisture in the free troposphere and the convective instability;
  - Mid-troposphere moisture (dry intrusion,…) and the convective inhibition.

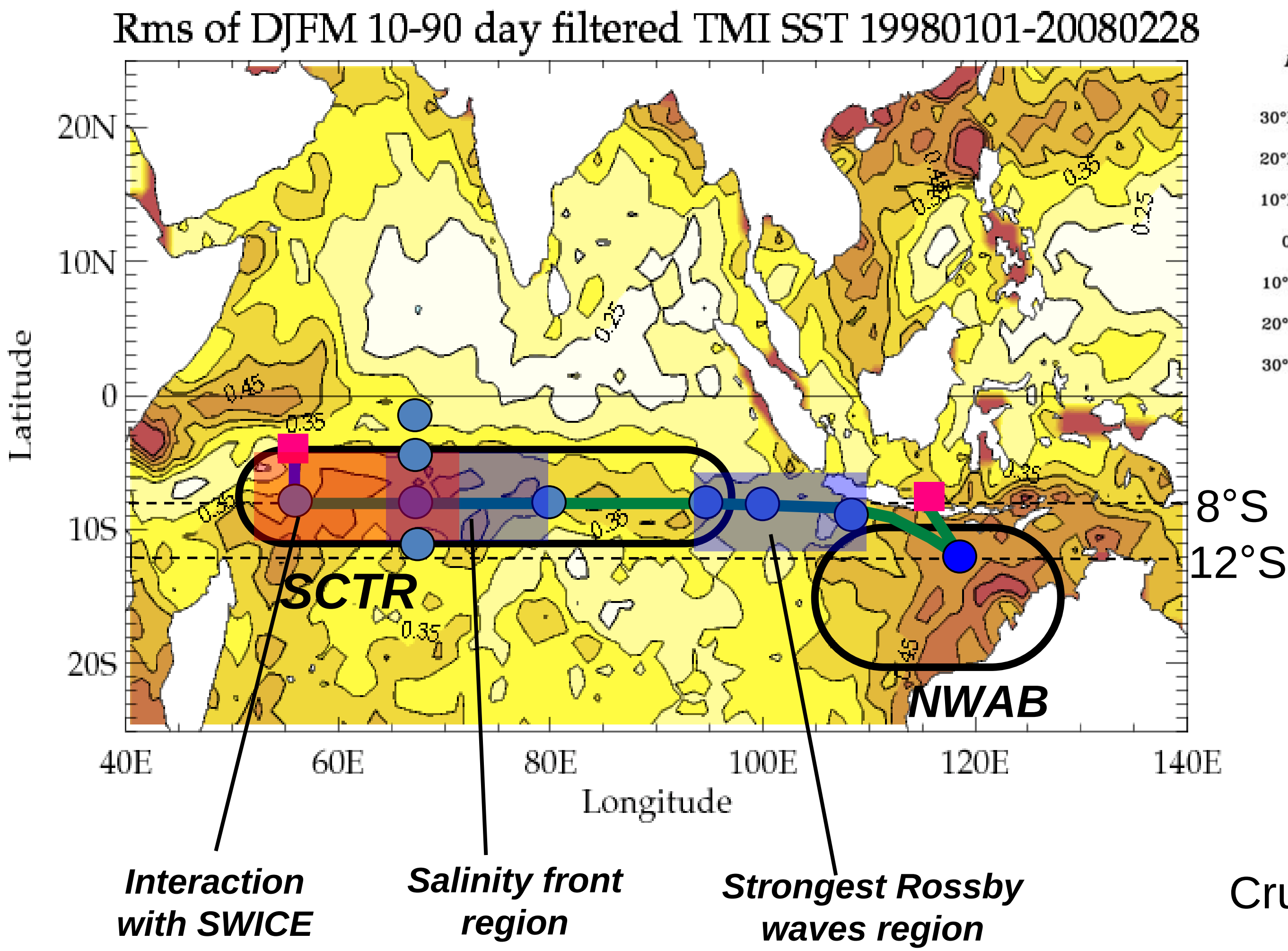
A mooring in North Western Australian Shelf

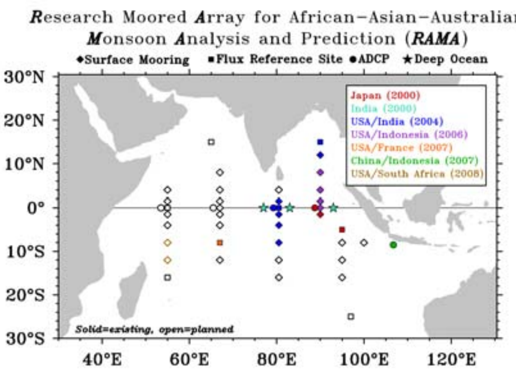


Region of strong MJO air-sea interactions, strong diurnal cycle, strong baroclinic tides

Mooring as part of process experiment (~1-2 years) and then seek blessing of IOP (easily accessible: Australia, Indonesia)

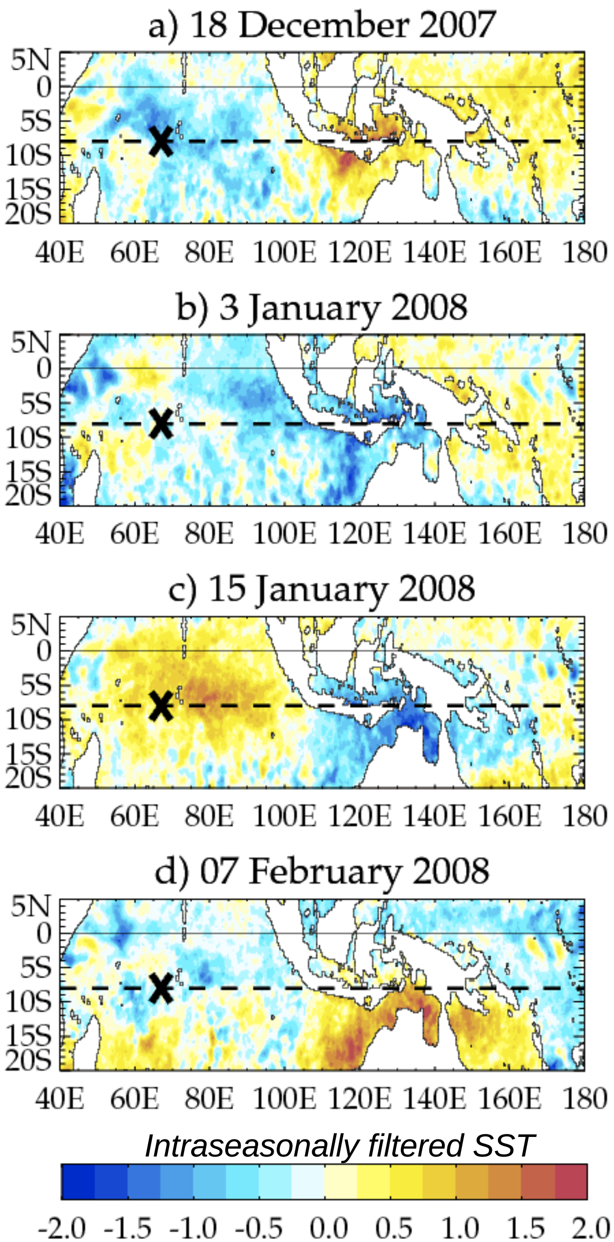
TRIO: overview & contribution to RAMA

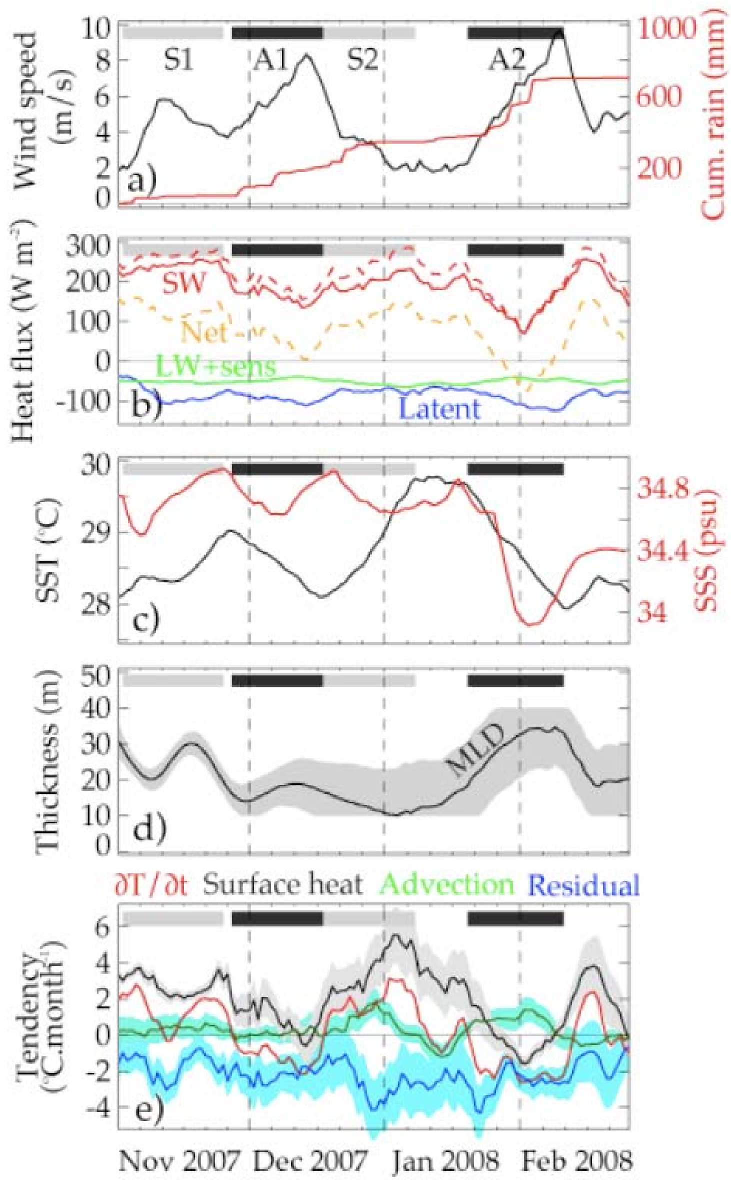




Cruise duration: ~46 days

Observed SST signature of MJO



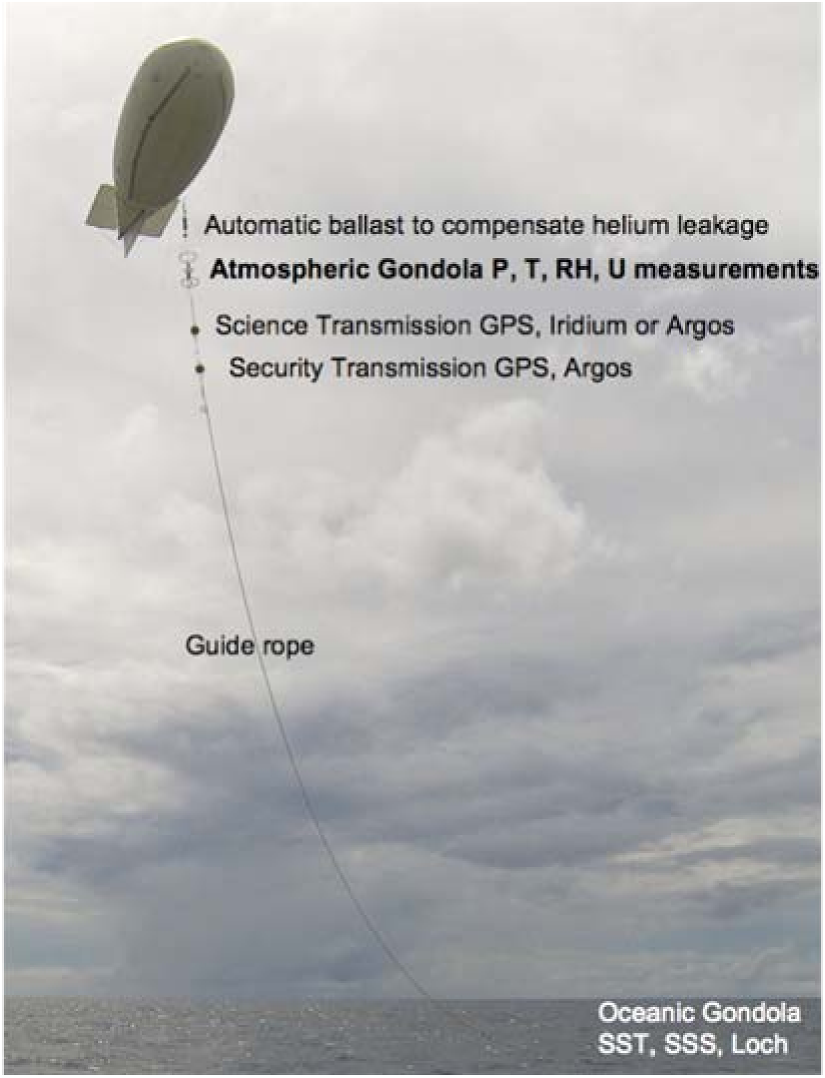


Cirene/RAMA buoy provided insights in the processes of the upper ocean response, but many questions remain unanswered.

(Vialard et al. 2008)
(GRL, in press)

Aeroclippers

- Measurements at the air-sea interface over open oceans (30 days).
- Determination of turbulent fluxes:
  - Small perturbation of the measurements due to the mechanical structure compared to buoys or ships.
- Converge toward organized convective systems:
  - Optimize the sampling around the convective systems.



Duvel et al. BAMS 2008

Aeroclippers for Trio and Swice

- Flux perturbations related to organized deep convection:
  - Large-scale perturbations (Westerly Wind Events);
  - Statistics on surface flux perturbations associated to organized convection.
- In situ experiment dedicated to Cyclones in the IO:
  - Study of the surface dynamics in cyclones;
  - Now-casting of the cyclone evolution;
  - Continuous measurement of the surface pressure in the eye.