Mixed layer heat budget in the Eastern Equatorial Atlantic as inferred using ARGO floats

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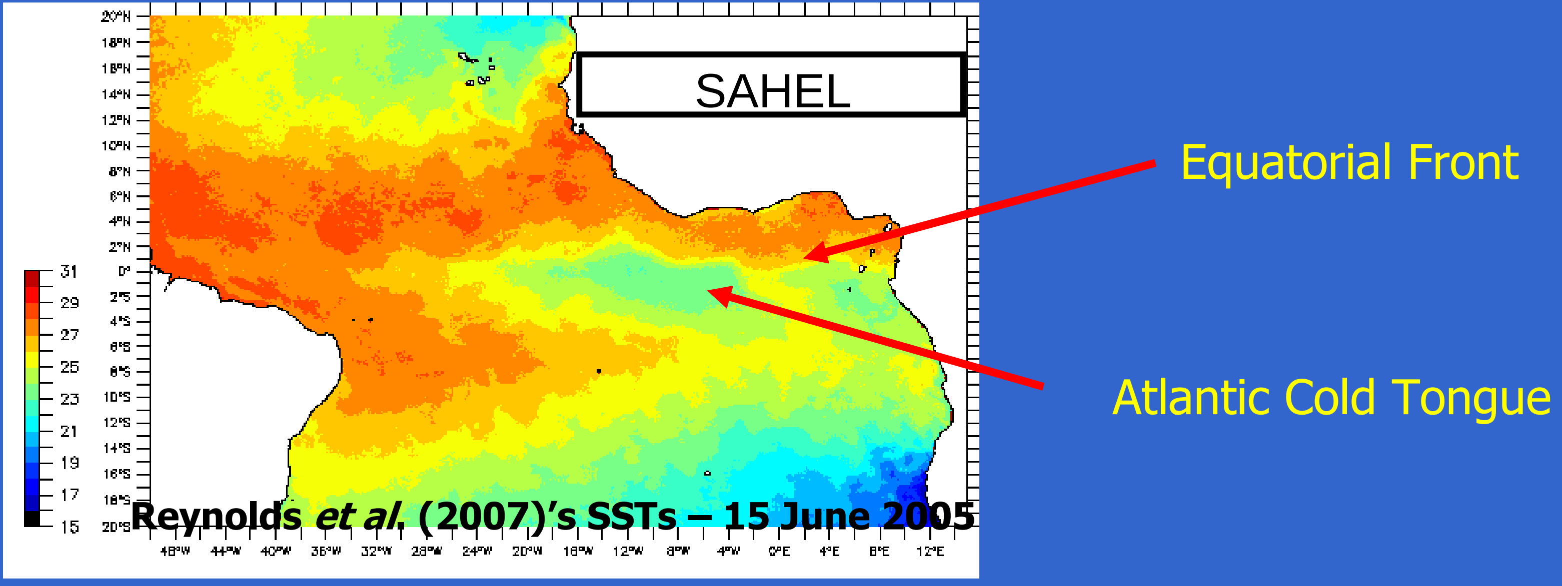
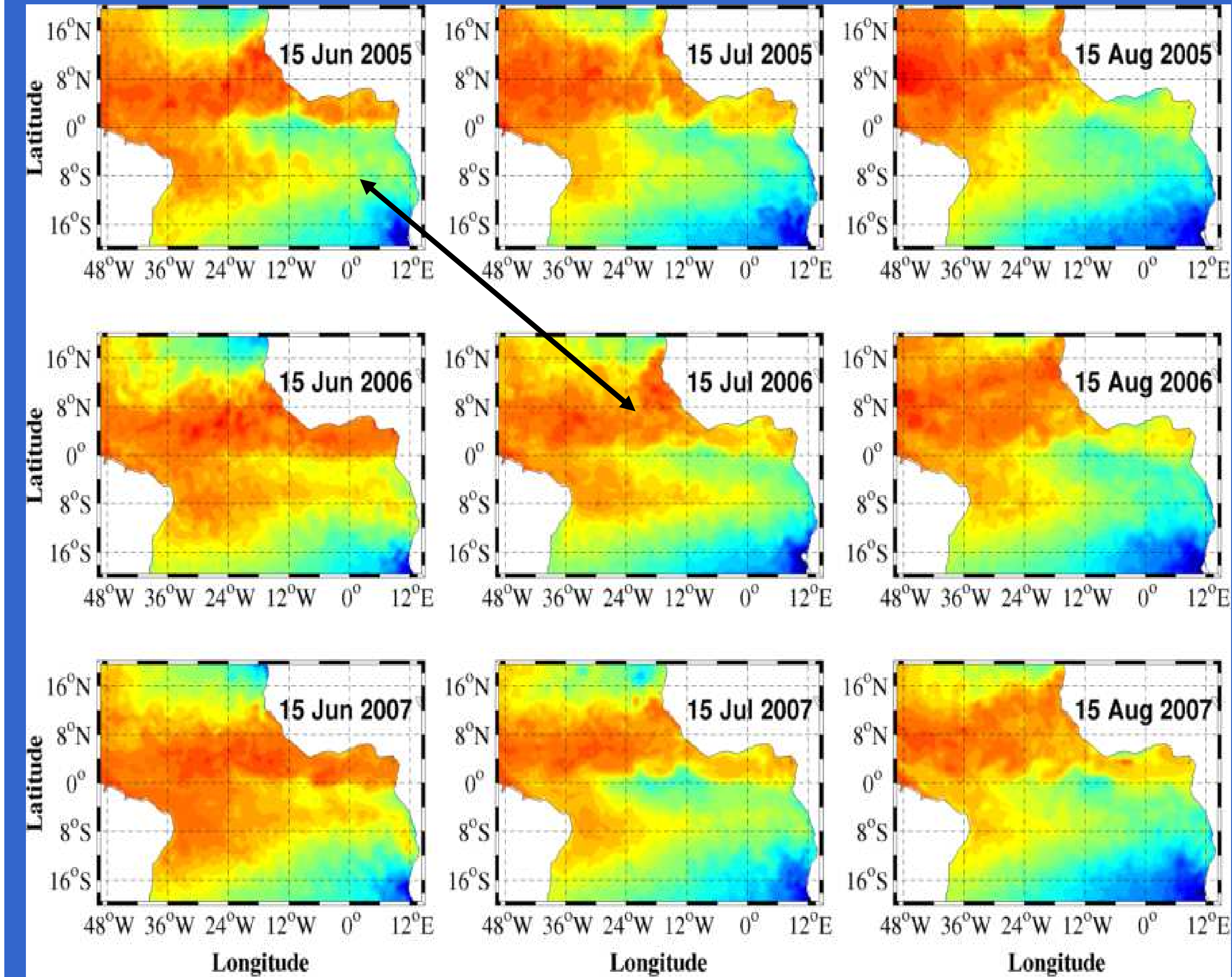
Introduction

1. SST anomalies in the Eastern Equatorial Atlantic (EEA) have a strong impact on precipitation over the West African continent (e.g., Vizy and Cook, 2002);
2. There is an interaction between the Atlantic Cold Tongue and the West African Monsoon (e.g., Okumura and Xie, 2004; Gu and Adler, 2004; Hagos and Cook, 2009);
3. Need to understand the physical processes affecting SSTs in the EEA.



Introduction

SSTs comparison between 2005, 2006 and 2007



Early and intense cooling in May-June 2005 than in May-June 2006 and 2007

One month shift of the cooling in 2005 and 2006

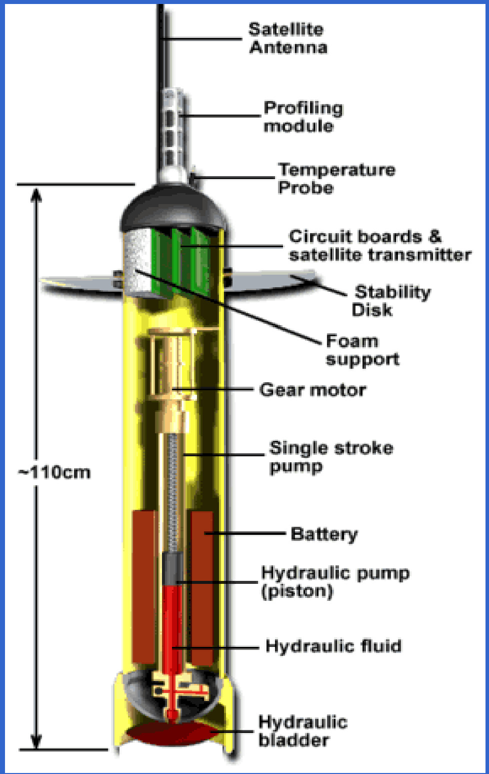
Nearly the same SST pattern in late boreal summer

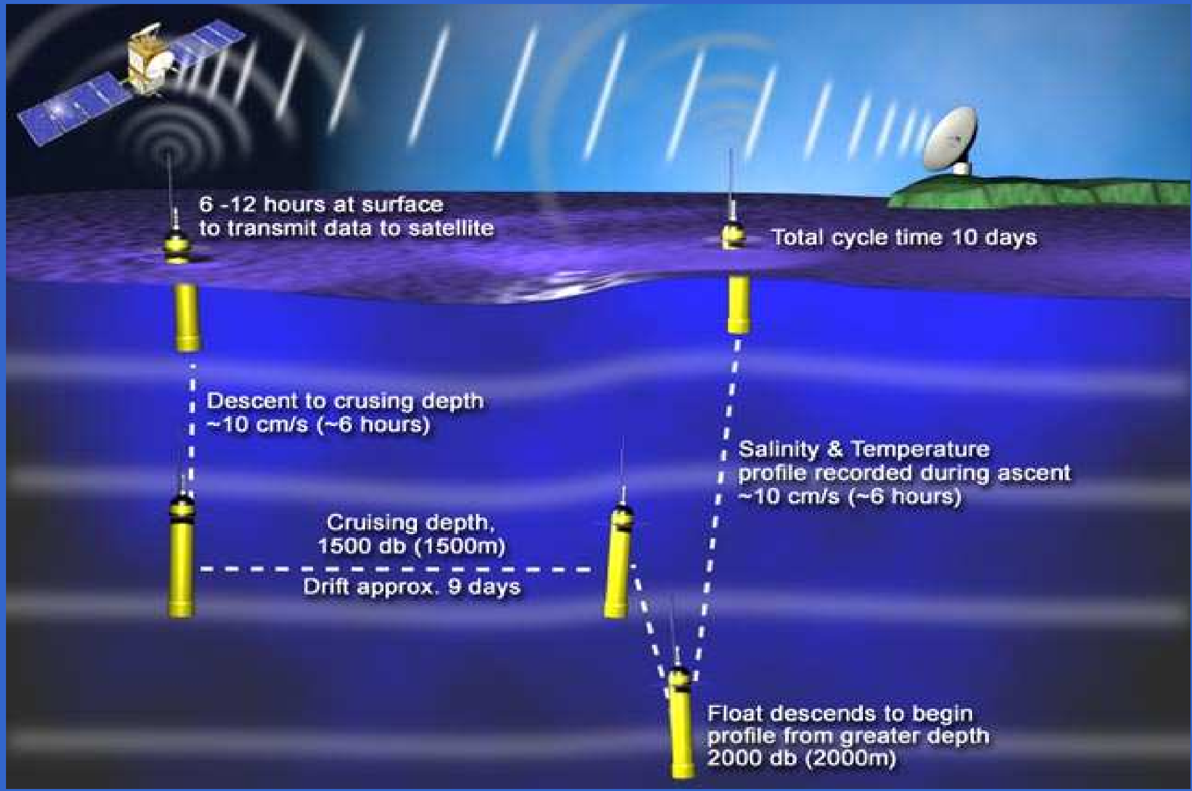
Introduction

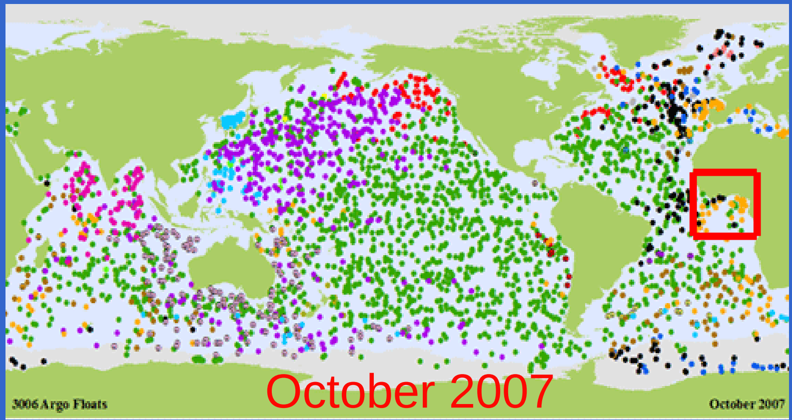
1. Observation (e.g., Merle *et al.*, 1980; Foltz *et al.*, 2003) and modeling studies (Philander and Pacanowski, 1986; Yu *et al.*, 2006; Peter *et al.*, 2006) suggest that subsurface processes are at the origin of upper temperature decrease in the ACT;
2. Further south, near surface temperatures are largely dominated by surface heat fluxes;
3. Observations fail to close heat budgets within 150 Wm^{-2} in the EEA (Foltz *et al.*, 2003).

Here, we present an original oceanic mixed layer heat budget from operational plateforms (ARGO floats and PIRATA buoys) and outputs from atmospheric NWP models.

The ARGO Floats







Nowadays more than 3000 ARGO floats are sampling the world ocean

Quality Control Test on vertical profiles

Download data from coriolis website

↓

Visual Inspection of température profiles (erroneous profiles, Spike, temperature inversion, etc…)

↓

Specific treatments of profiles taking into account the shallow mixed layer in the Gulf of Guinea
(First temperature profiles values ⟷ comparaison with independent data)

Method

$$\rho_0 c_p h \partial_t \langle T\rangle = \rho_0 c_p \left[-h\langle U\rangle.\nabla\langle T\rangle - \nabla\int_{-h}^{0}\tilde{U}.\tilde{T}dz - (\langle T\rangle - T(-h))w_e(-h) + \overline{w'T'}(-h) + hA_H\nabla^2\langle T\rangle \right]$$

$$+F_{sol}[1-I(-h)] + F_{nsol}$$

Caniaux and Planton (1998)

with

$$w_e(-h) = w(-h) + \partial_t h + U(-h)\nabla h - A_H\nabla^2 h$$

$$w(-h) = \frac{\partial_t T(-h)}{\partial_z T(-h)}$$

$$I(-h) = I_0\left[Re^{-\frac{h}{D_1}} + (1-R)e^{-\frac{h}{D_2}} \right]$$

Paulson and Simpson (1977)

$$\langle U\rangle \approx U^{surface}_{Ekman} + U^{surface}_{geostroph}$$

Oscar data set (Bonjean and Lagerloef, 2002)

$$\langle\alpha\rangle = \frac{1}{h}\int_{-h}^{0}\alpha dz$$

$$\tilde{\alpha} = \alpha - \langle\alpha\rangle$$

$$\overline{\alpha} = \frac{1}{\tau}\int_{0}^{\tau}\alpha dt$$

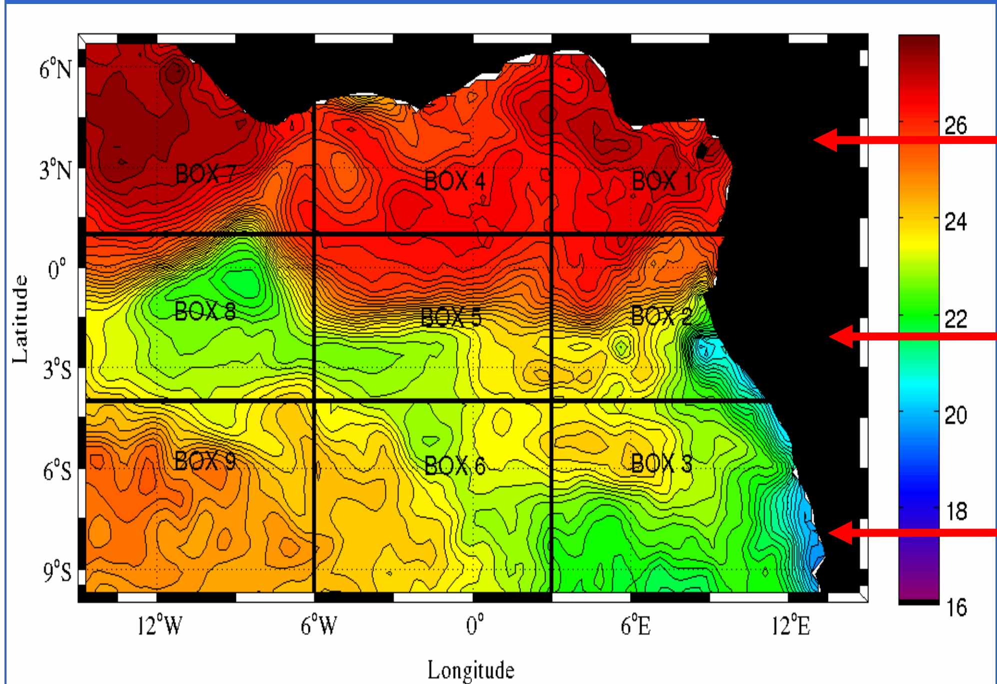
$$\alpha' = \alpha - \overline{\alpha}$$

so that:

$$\rho_0 c_p h \partial_t \langle T\rangle = \rho_0 c_p \left[-h\overline{U}.\overline{\nabla SST} - (\langle T\rangle - T(-h))w_e(-h) \right] + F_{sol}(1-I(-h)) + F_{nsol}$$

Heat storage **Mean h. advec.** **Entrainment** **Solar heat flux** **Non-solar heat flux**

Subdivision of the EEA

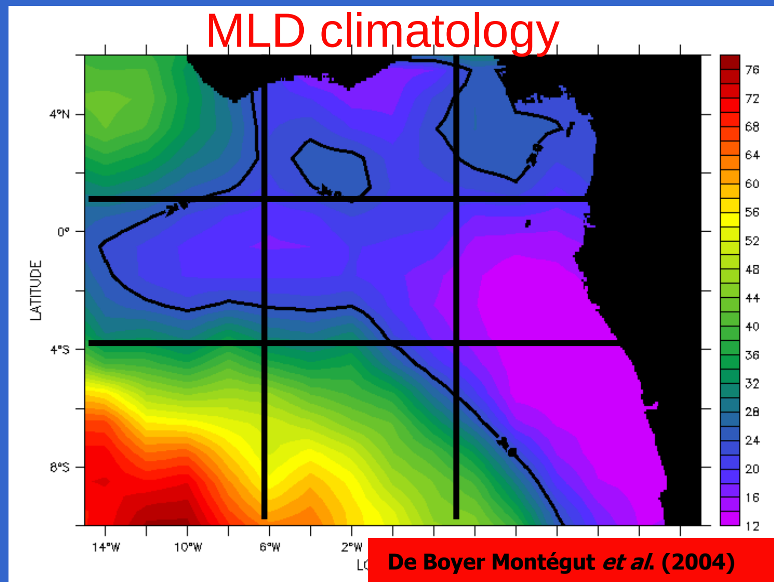


Northern boxes (warmer SSTs, Guinea Current, heavy precipitation)

ACT boxes (SEC and EUC)

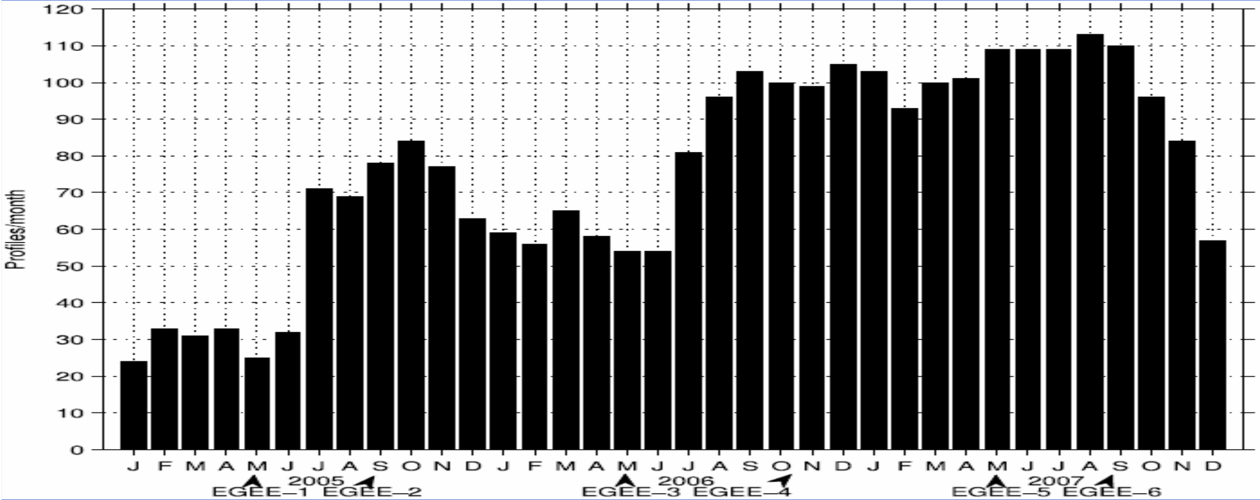
Southern boxes (SECC, Angola dome)

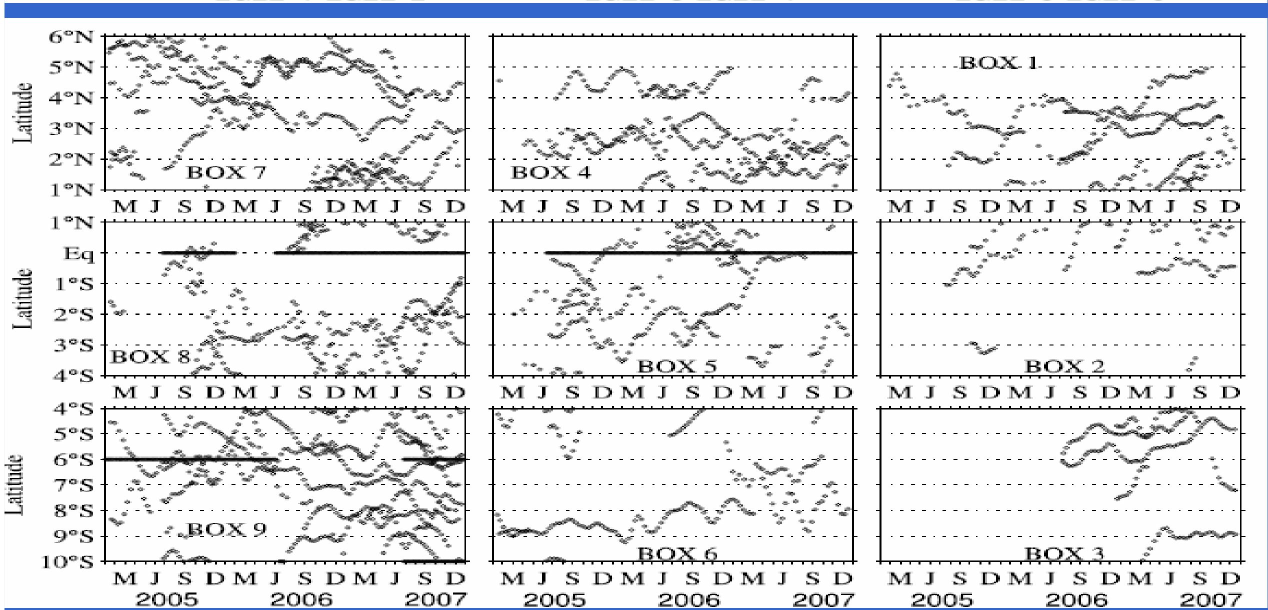
9 boxes of nearly equal surface area, reflecting the regional characteristics of the dynamics and thermodynamics in the EEA



De Boyer Montégut *et al.* (2004)

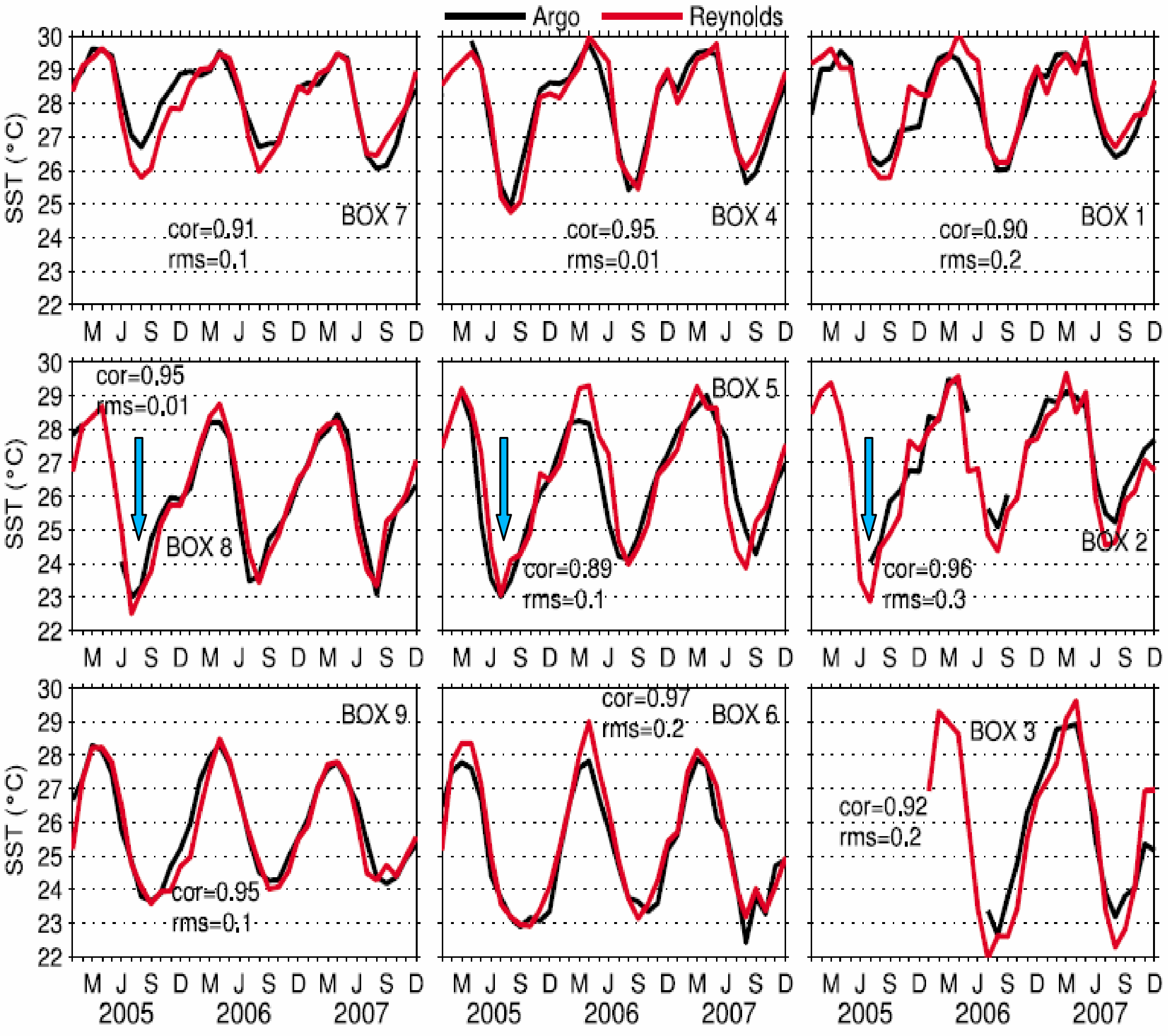
Spatial and Temporal Distributions of Profiles





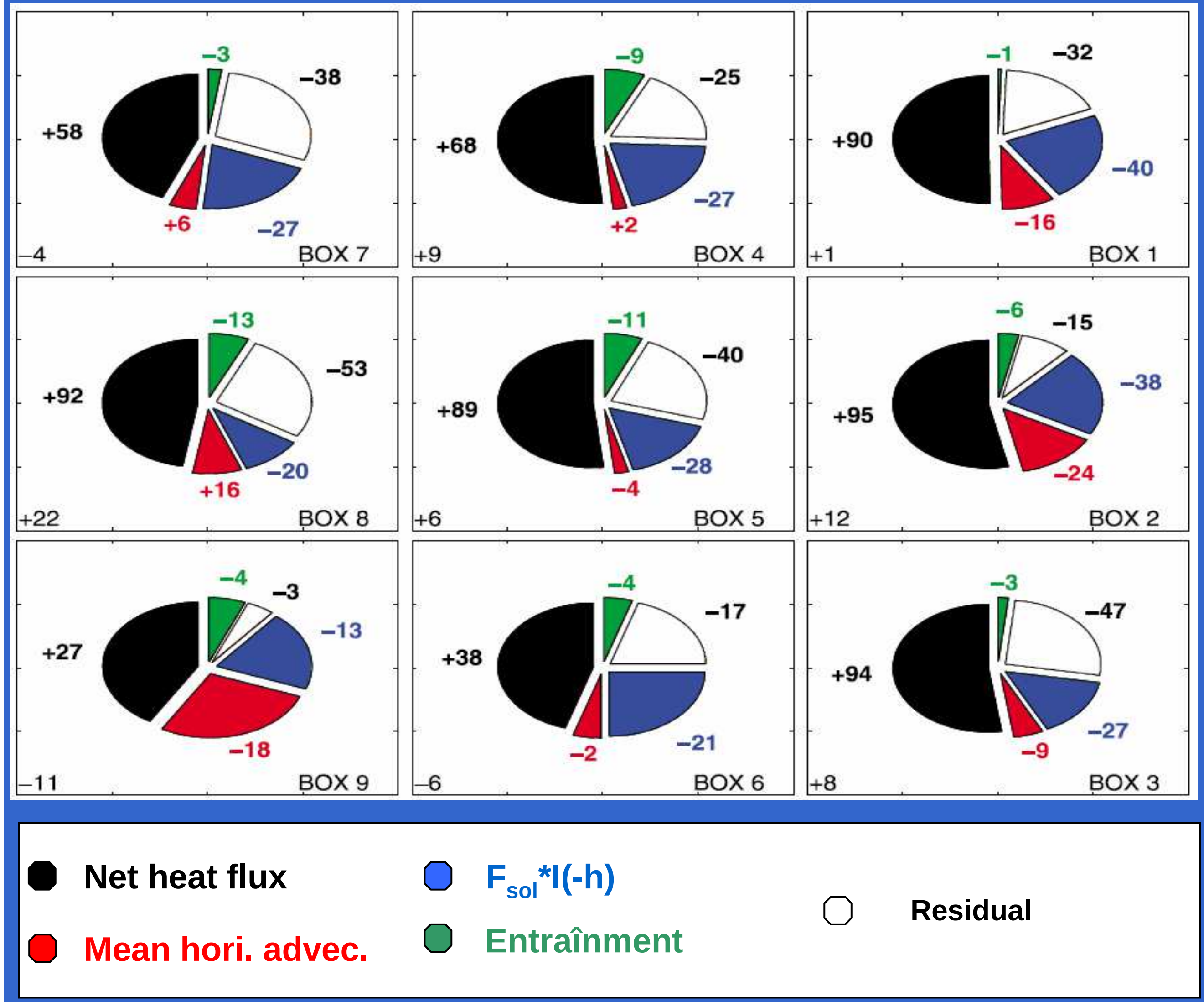
1. 2400 profiles over 3 years (2005-2007);
2. The number of floats increased during the EGEE cruises;
3. 20 profiles/mon. in January 2005 and 100 profiles/mon. in January 2007;
4. Lower number of floats (4-9) and profiles in boxes 2, 3, 6 than in the other boxes (11-18);
5. 4 PIRATA buoys are included.

Comparison ARGO-Reynolds' SSTs



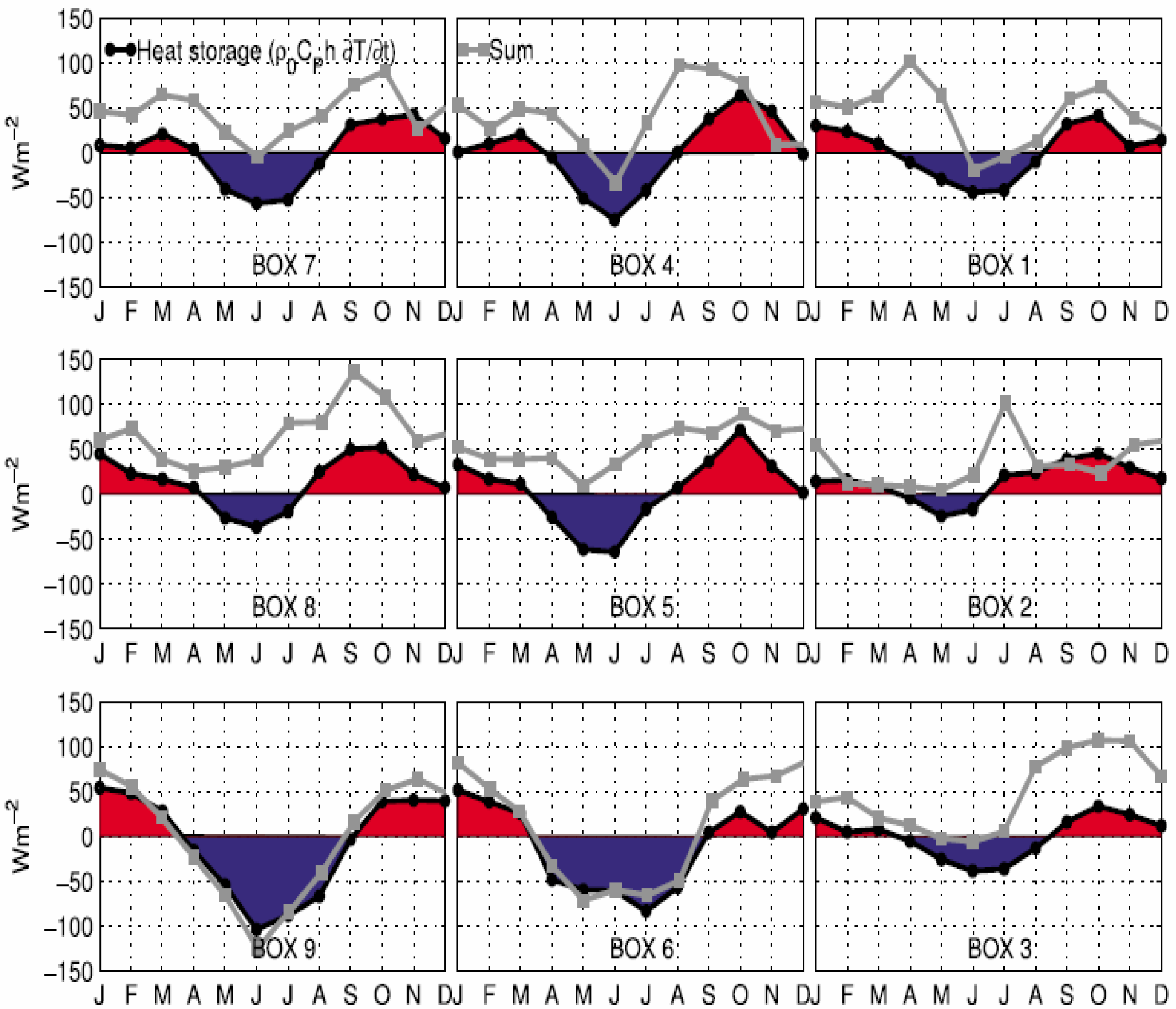
1. **Good agreement between ARGO and Reynolds' SSTs after quality control and despite limited sampling;**
2. **Important seasonal cycle in each box, weaker north (3°C-4°C) than south (4°C-6°C) of the equator, with north-south SST gradients;**
3. **2005 was a year with anormally cold SSTs in the ACT (boxes 2, 5, 8).**

Mean Annual ML Heat Budgets (Wm^{-2})



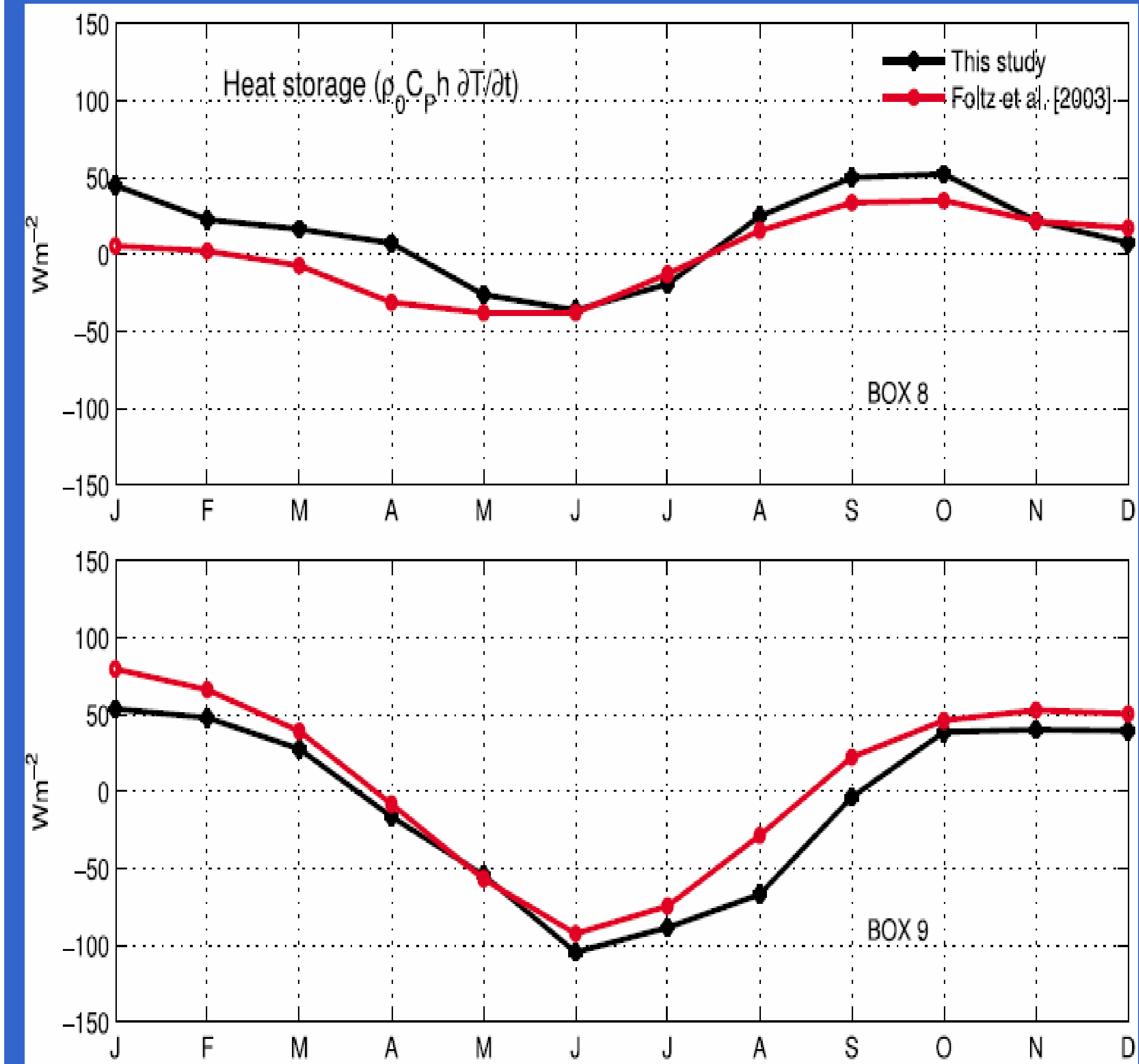
1. Mean budgets are positive except in boxes 4, 6, 9;
2. Surface heat fluxes dominate;
3. A significant part of solar heat flux goes out of the ML base;
4. Mean horizontal advection important in boxes 1, 2, 9;
5. Weak contribution of entrainment;
6. The residuals are strong, meaning that one or several terms are missing.

Seasonal Cycle (Wm^{-2})



1. Amplitude of cooling/warming: -100 Wm^{-2} to +50 Wm^{-2};
2. Cooling from April to July, weaker in the ACT;
3. Warming the remainder of the year with a short cold season in November-December;
4. The sum of the calculated terms of the heat budget is greater than the storage term (except in box 9): the missing term has a negative contribution.

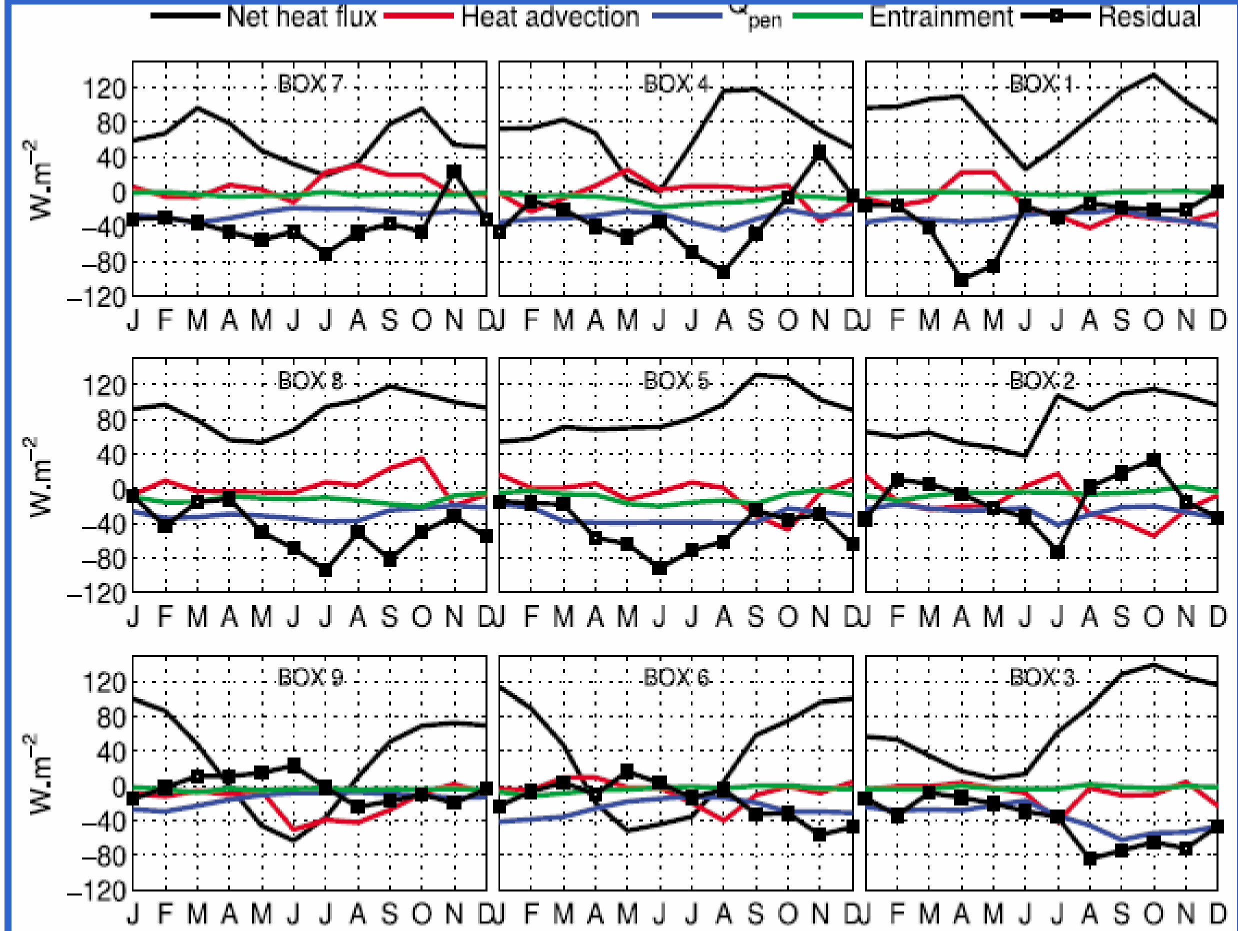
Seasonal Cycle (Wm^{-2}): Compariosn with Foltz et al. 2003



1. Our findings are in agreement with Foltz et al 2003 in terms of phase and amplitude of the seasonal cycle despite the different data set we use.

2. In agrement also with Merle et al. 1980 and Peter et al. 2006 results

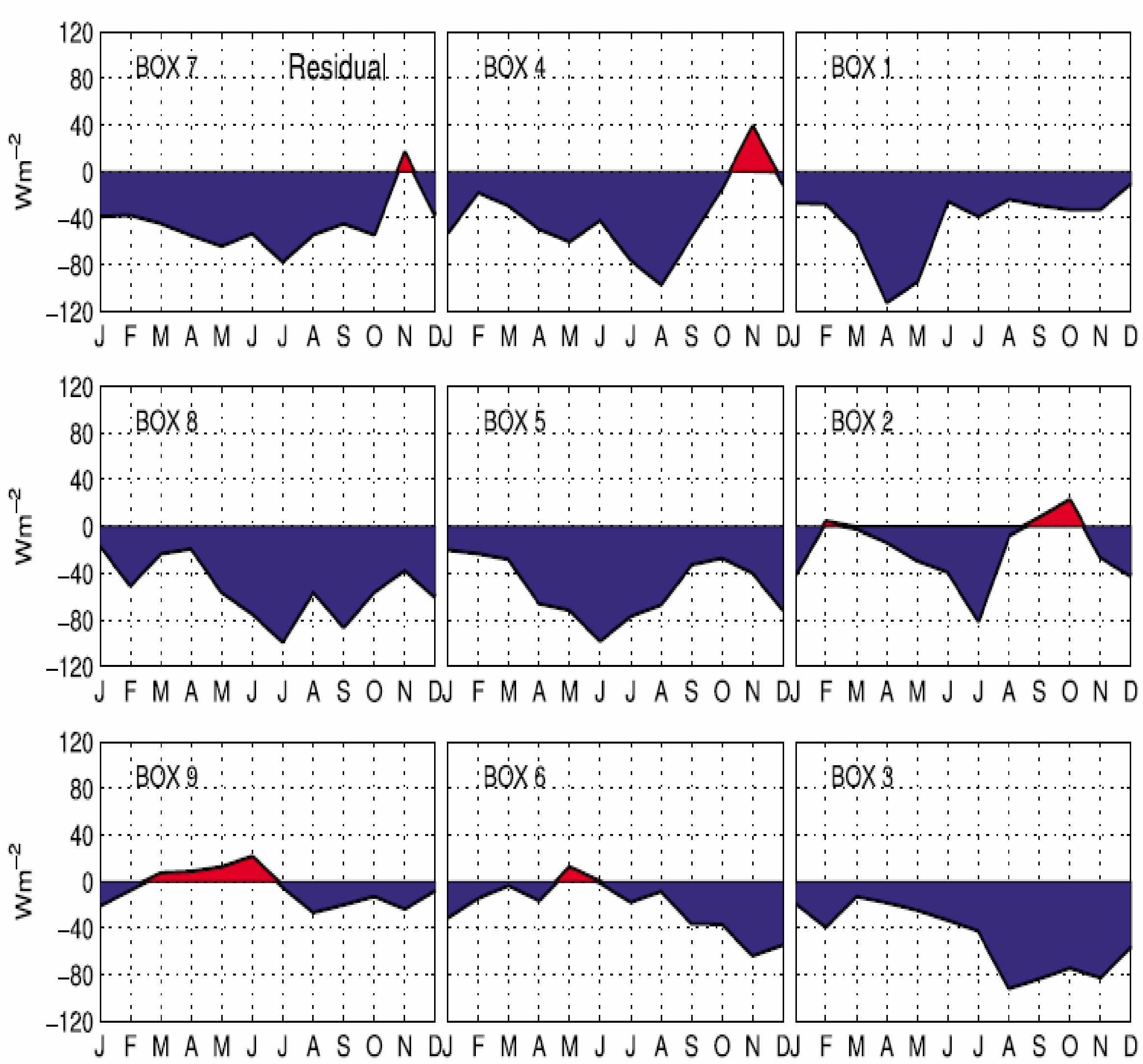
Seasonal Cycle (Wm^{-2})



1. **The seasonal cycle of heat storage is mainly due to the seasonal cycle of the surface heat fluxes; weak seasonality of advection;**
2. **The surface heat fluxes have always a positive contribution, except in austral winter in boxes 6 and 9;**
3. **Entrainment is insignificant throughout the year.**

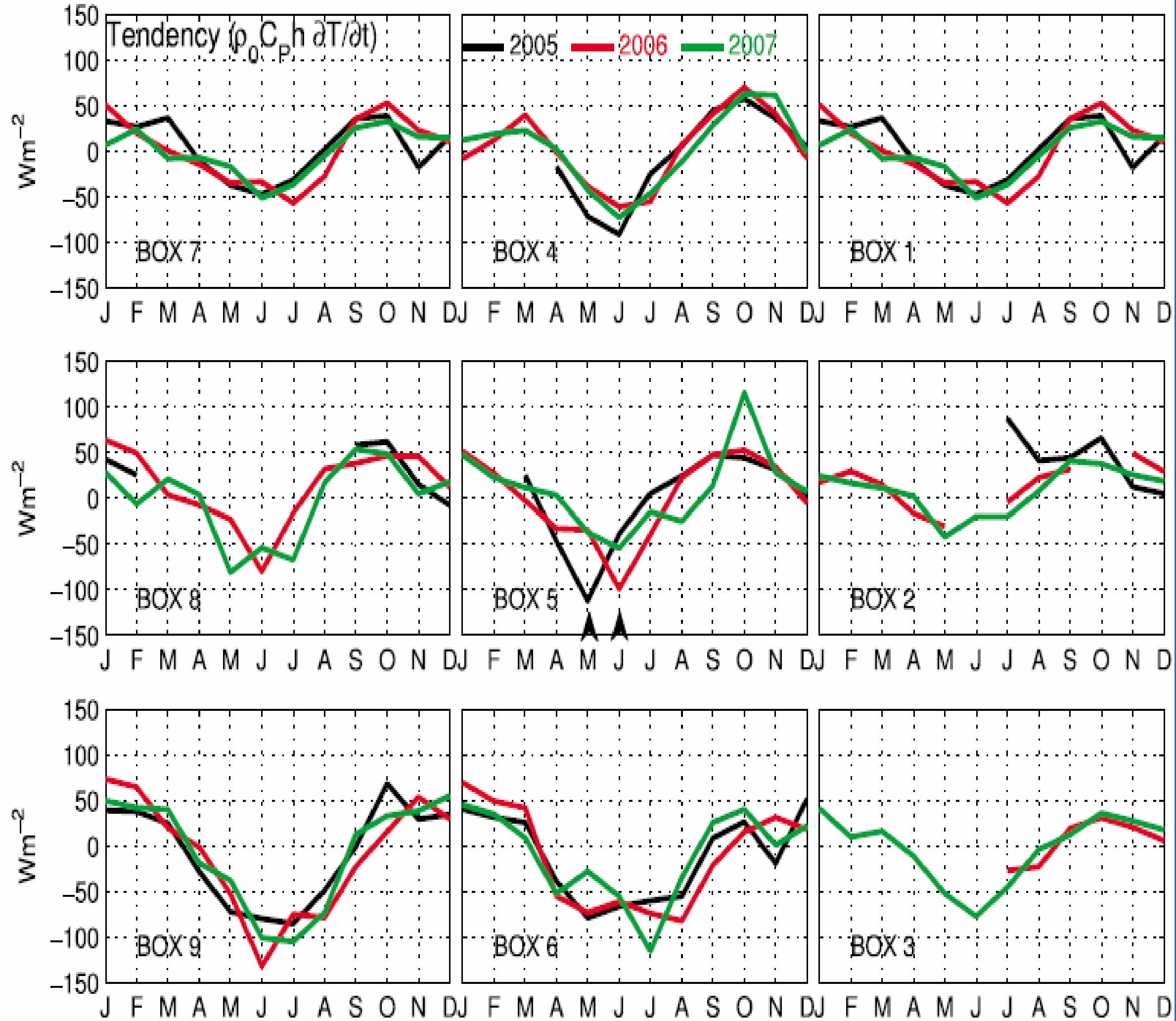
Net heat flux | **Mean hori. advec.** | F_{sol}***I(-h)** | **Entraînment** | **Residual**

Seasonal Cycle of the Residuals (Wm^{-2})



1. **Large negative residuals (down to -120 Wm^{-2}) in boxes 1, 4, 5, 7, 8;**
2. **Weak residuals in the southernmost boxes;**
3. **These residuals are due to errors and missing terms;**
4. **Turbulence data collected during AMMA/EGEE (Dengler *et al.*, 2010) and other studies (Rhein *et al.*, 2010) compare well with our residuals (phase, amplitude, spatial repartition);**
5. **This suggests that vertical mixing is probably the missing term.**

Seasonal Cycle (Wm^{-2}): Comparison of 2005, 2006 and 2007

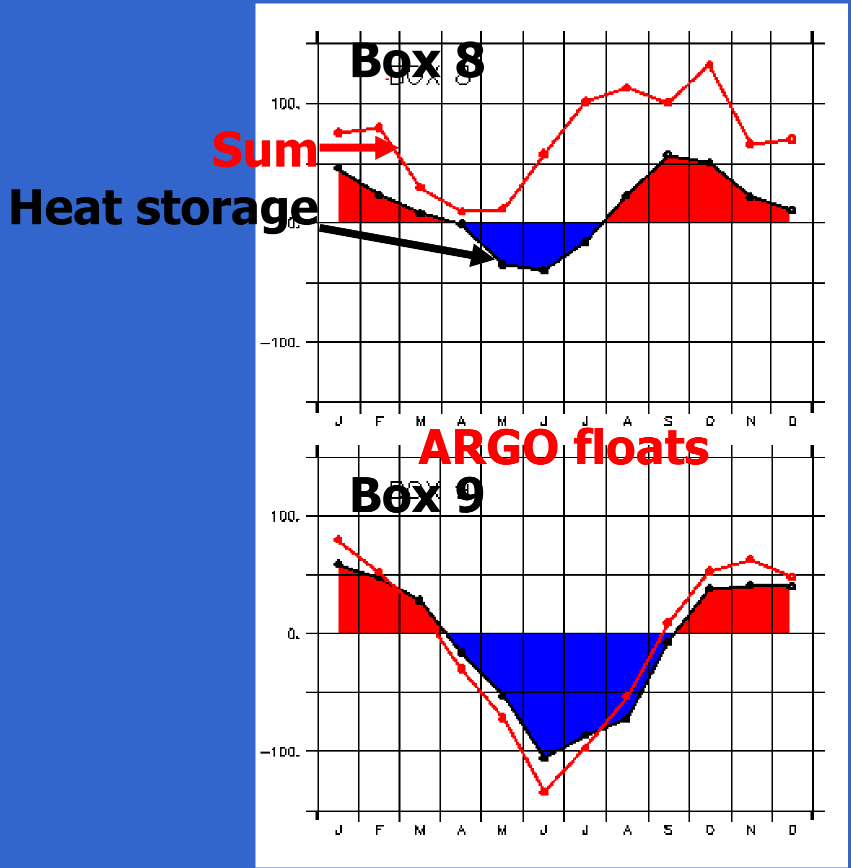


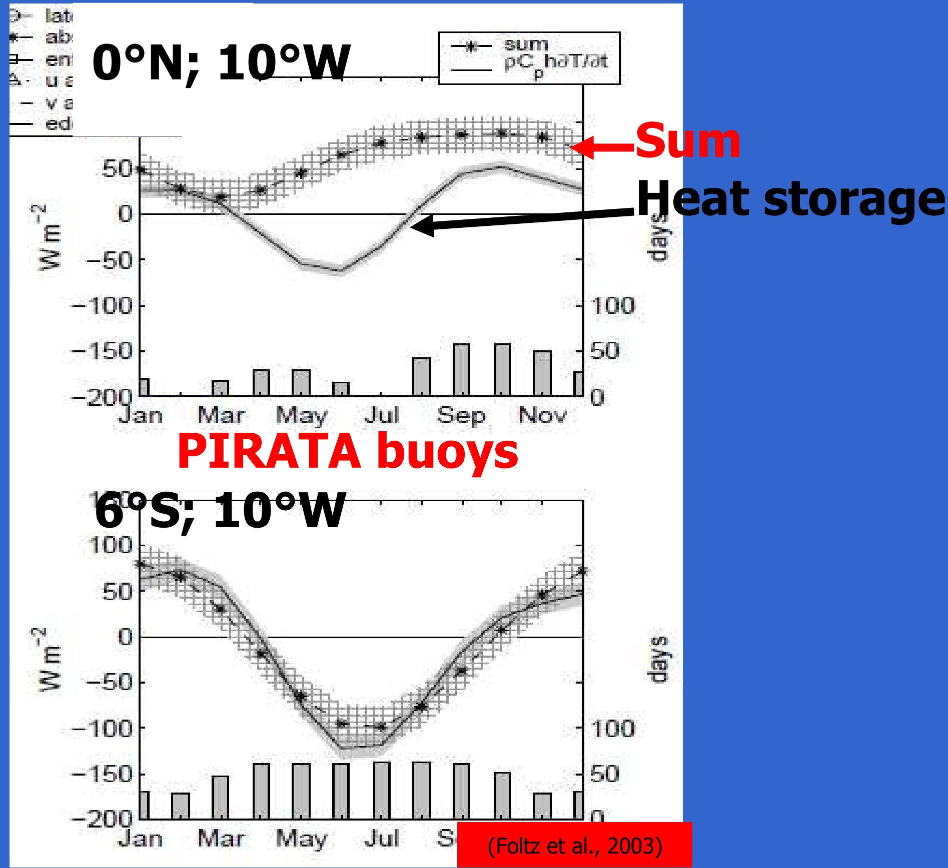
1. As shown previously, a one month shift of the cooling between 2005 and 2006 in the ACT;
2. But same conditions in late boreal summer;

Conclusions

1. **ARGO floats are able to provide realistic ML budgets in the EEA at seasonal time scales;**
2. **Cooling in April-July and warming the remainder of the year, with a short cold season;**
3. **The cooling rate in the Atlantic cold tongue is weaker and shorter than elsewhere (shallow MLDs along the equator);**
4. **Important residuals suggest that vertical diffusion is the most important process during the cold tongue setup (strong vertical shear between the SEC and the EUC).**

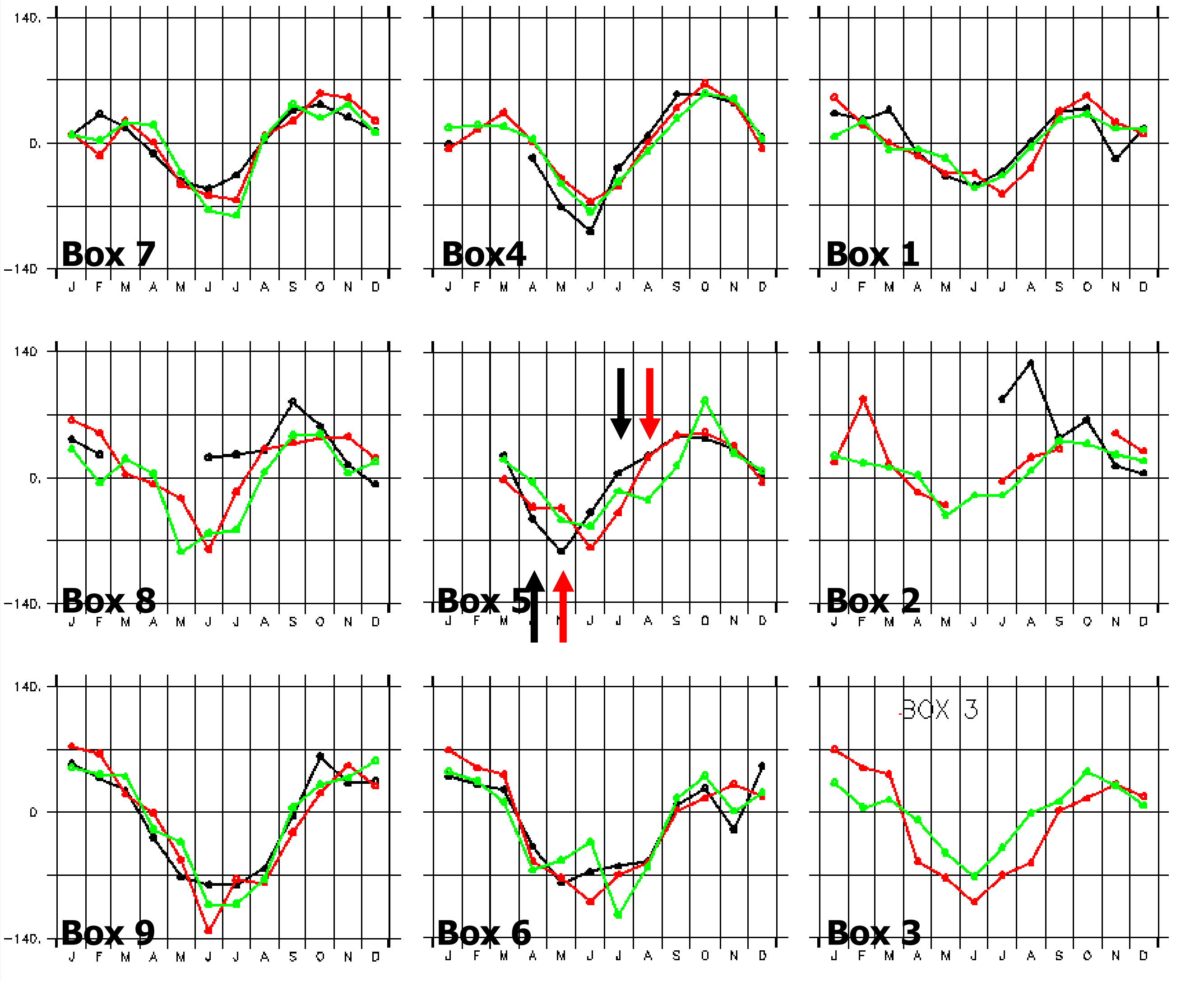
Comparison with Foltz *et al.* (2003)





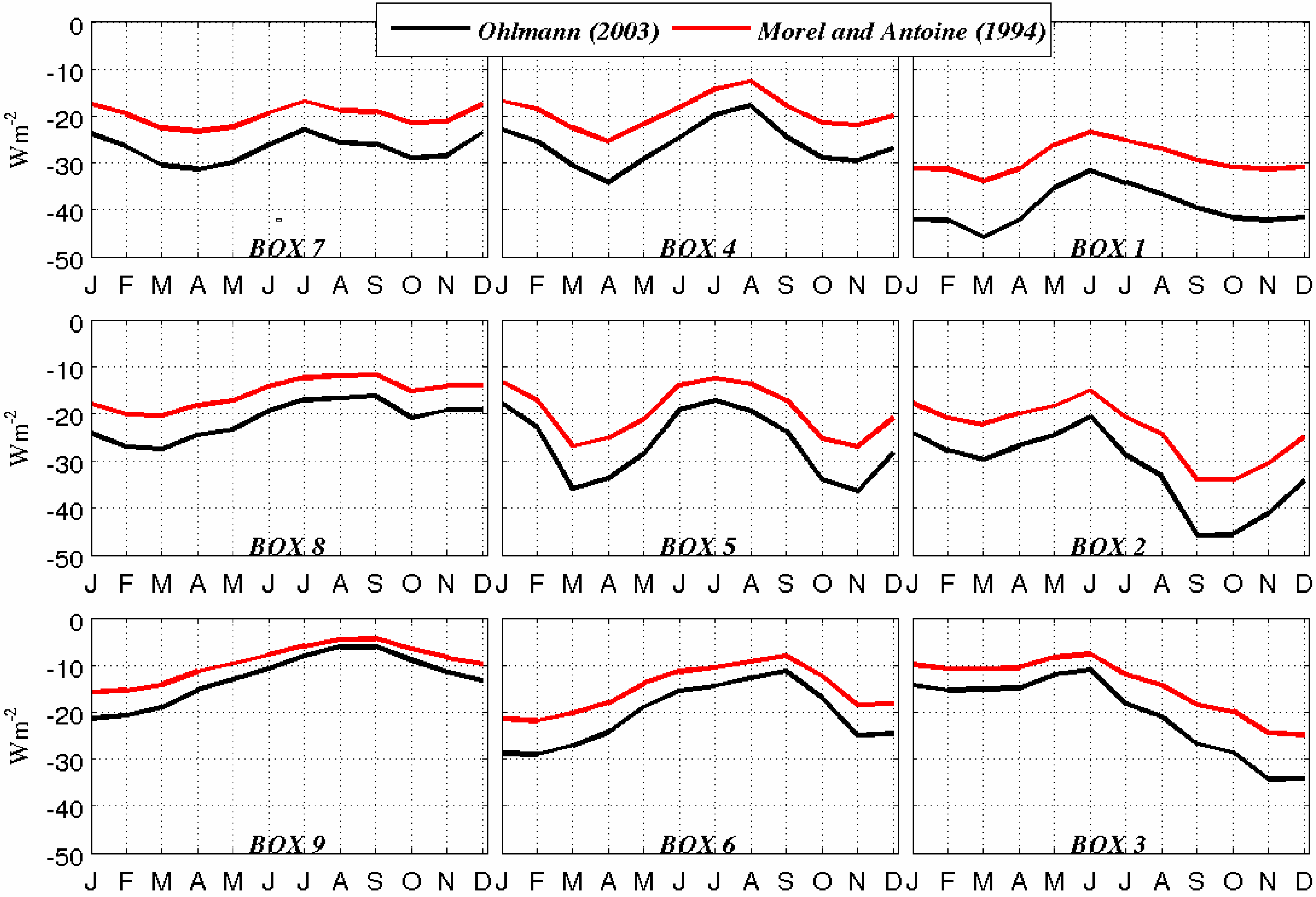
1. **Important differences of heat storage in the two boxes;**
2. **Similar heat budgets both in phase and amplitude;**
3. **Strong residuals in the cold tongue box and closed budget in the southernmost boxes.**

Interannual Variability



2005 2006 2007

1. **No systematic differences between years;**
2. **Except in box 5 between 2005-2006: one month time shift, lasting 4 months, with an earlier ACT in 2005 than in 2006;**
3. **In agreement with earlier ACT (Marin *et al.*, 2009) and earlier West African Monsoon (Janicot *et al.*, 2008).**


Ohlmann (2003)
Morel and Antoine (1994)
Wm-2
0
-10
-20
-30
-40
-50
J F M A M J J A S O N D
BOX 7
BOX 4
BOX 1
BOX 8
BOX 5
BOX 2
BOX 9
BOX 6
BOX 3