DYNAMICS OF SEA-SURFACE TEMPERATURE ANOMALIES IN THE SOUTHERN OCEAN DIAGNOSED FROM A 2-D MIXED LAYER MODEL

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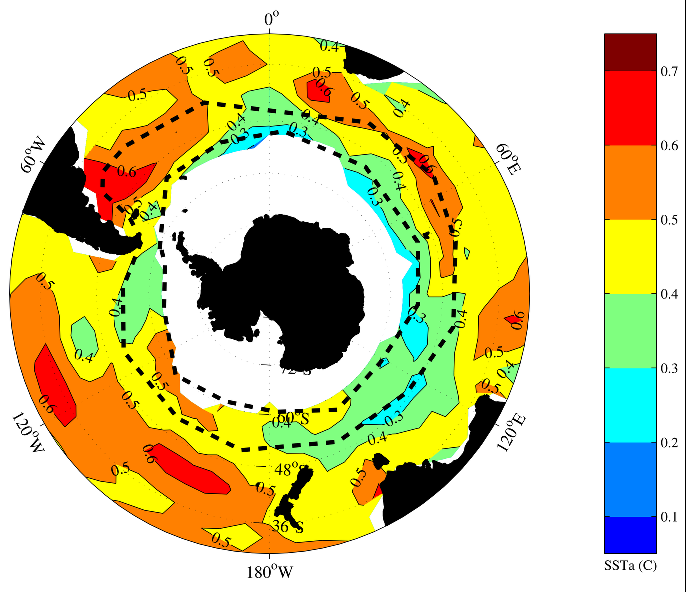
1- INTRODUCTION: The Southern Ocean is a crucial exchange window between the atmosphere and ocean (storage of heat, CO_2,...). The formation rate and properties of mode water are determined through ocean mixed layer processes, hence the high motivation to understand the mixed layer heat budget. During the last decade, substantial large-scale nonseasonal fluctuations have been identified in both the upper ocean and the atmosphere of the Southern Ocean. Some of these modes exhibit concomitant variations in both fluids, but the role of the ocean in these regional climate variations is still debated.

Objectives:
1) Diagnose mechanisms responsible for the generation and evolution of nonseasonal SST anomalies (SSTa) observed during a decade (1992-2002), with a simple model relying in as much as possible on observations (satellite, hydrography).
2) Examine how SST anomalies relate to dominant climate modes of the Southern Hemisphere (SAM and remote ENSO response).



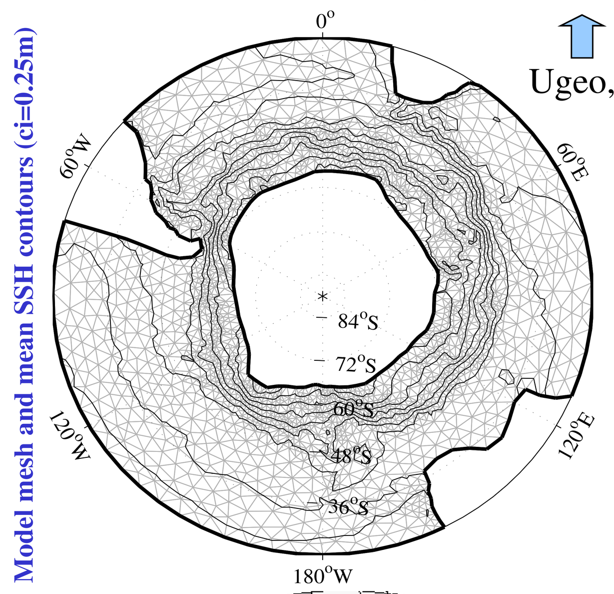
RMS variance of SST anomalies (°C)

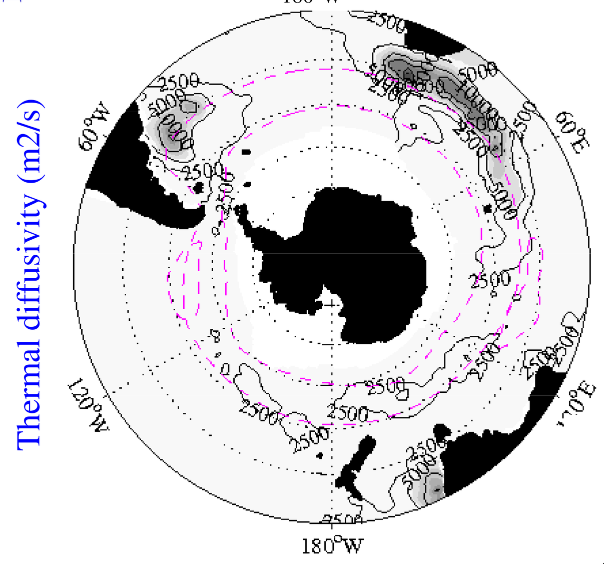
2- METHODS

A simple diagnostic model for SST anomalies. We use an advection-diffusion equation for the SST anomaly T', forced by anomalous air-sea (FQ) and Ekman (FEk) heat flux, anomalous geostrophic advection (Fgeo). Ignored physics (eg vertical ocean processes) and forcing errors are accounted for by a Newtonian damping term (Fdamp).

$$\partial_t T' + \overline{v} \cdot \nabla T' - \nabla \cdot \kappa_h \nabla T' = Q'/\rho c_p \overline{h} - \boldsymbol{v}' \cdot \nabla \overline{T} - \gamma T'/\rho c_p \overline{h} + \ldots$$

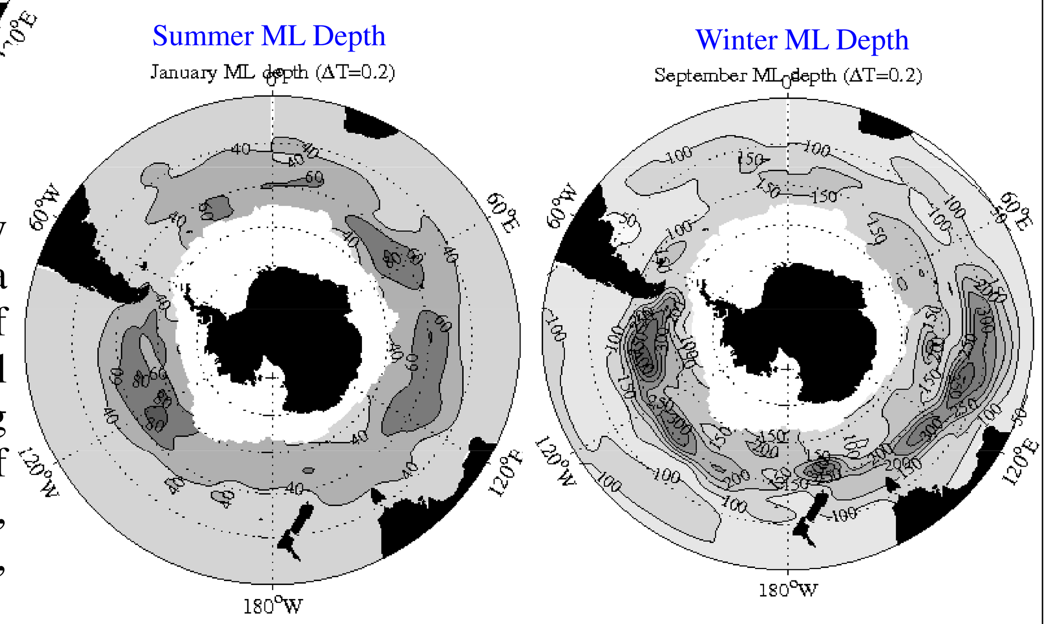
Ugeo, UEk — Diff — FQ — FEk, Fgeo — Fdamp





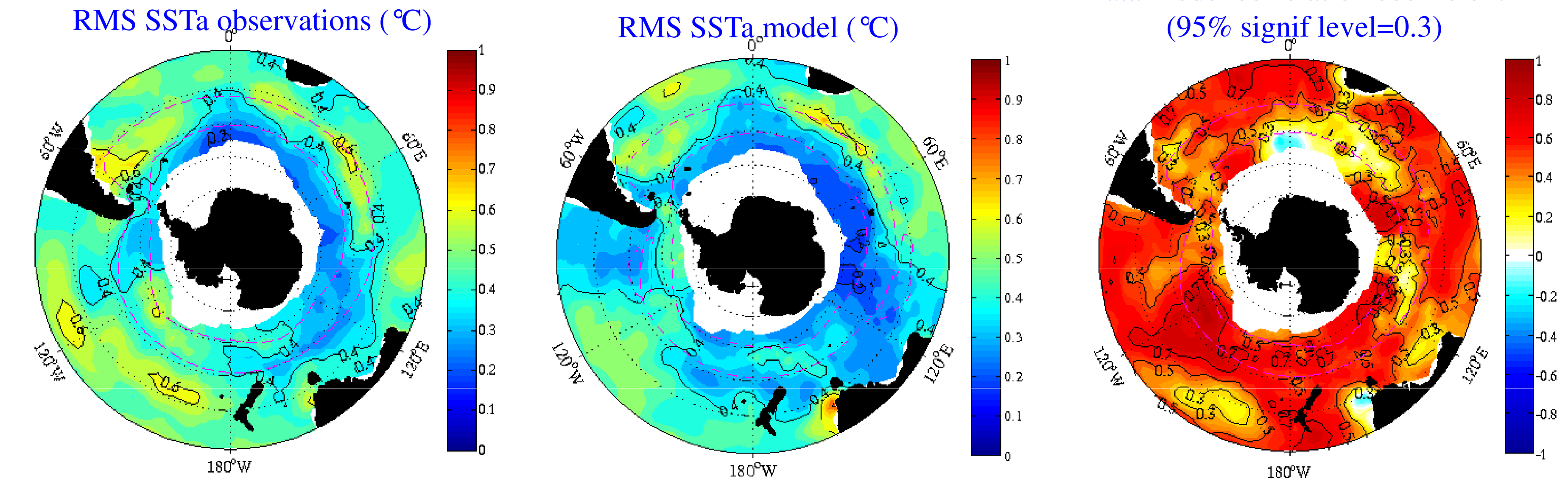
- The model is integrated over the decade 1992-2002
- Geostrophic advection is prescribed from altimetry (Aviso's Ssalto/Duacs maps + mean SSH Rio05)
- The domain is closed at 20S, zero flux boundary conditions are applied.
- The finite-element mesh is refined in frontal zones (resolution better than 1°)
- Forcings: OAflux for turbulent fluxes, ISCCP for shortwave radiations, ERA40 for wind stress.
- Newtonian damping: 20 W/m2/K (e-folding 8 months for a 100m thick anomaly).
- Horizontal diffusivity: using estimates based on float statistics: 2000-20000m2/s (Sallée et al 2008)
- Mixed layer depth prescribed from a climatology

Mixed layer depth climatology was estimated based on a vertical temperature jump of 0.2°C from 400000 individual hydrographic profiles coming from a large database of observations (WOCE, WOD, Argo, GSTPP, Elephant Seals, AMT)



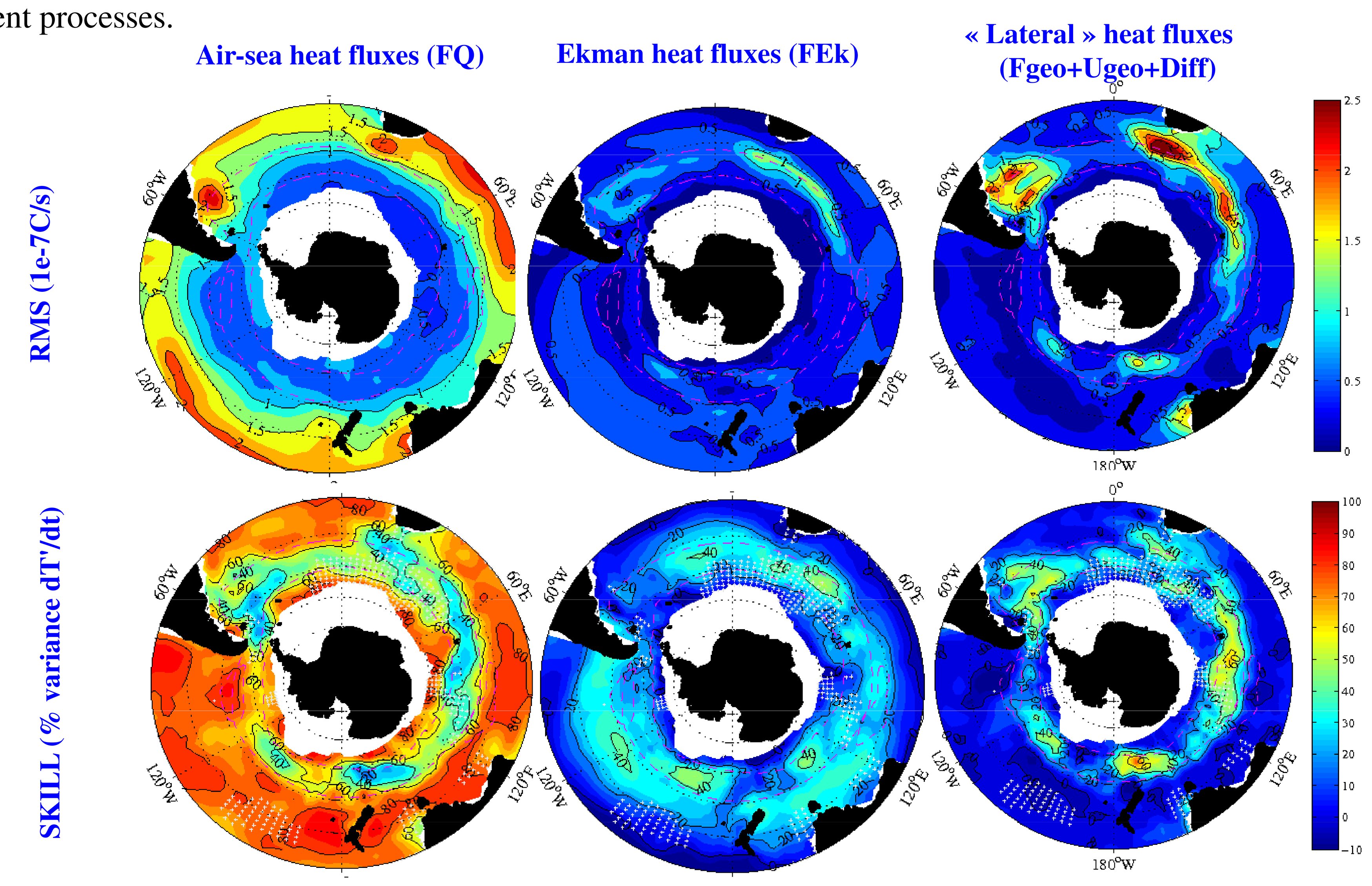
3- MODEL-DATA COMPARISONS

This simple model performs overall well in reproducing observed SST anomalies. The RMS variance of the model is close to the observed SST variance. It is slightly underestimated (owing to the missing physics) except in the East Australian Current where it is overestimated (missing upstream boundary conditions). Observed and modeled SSTa are significantly correlated over most of the domain.



4- HEAT BUDGET.

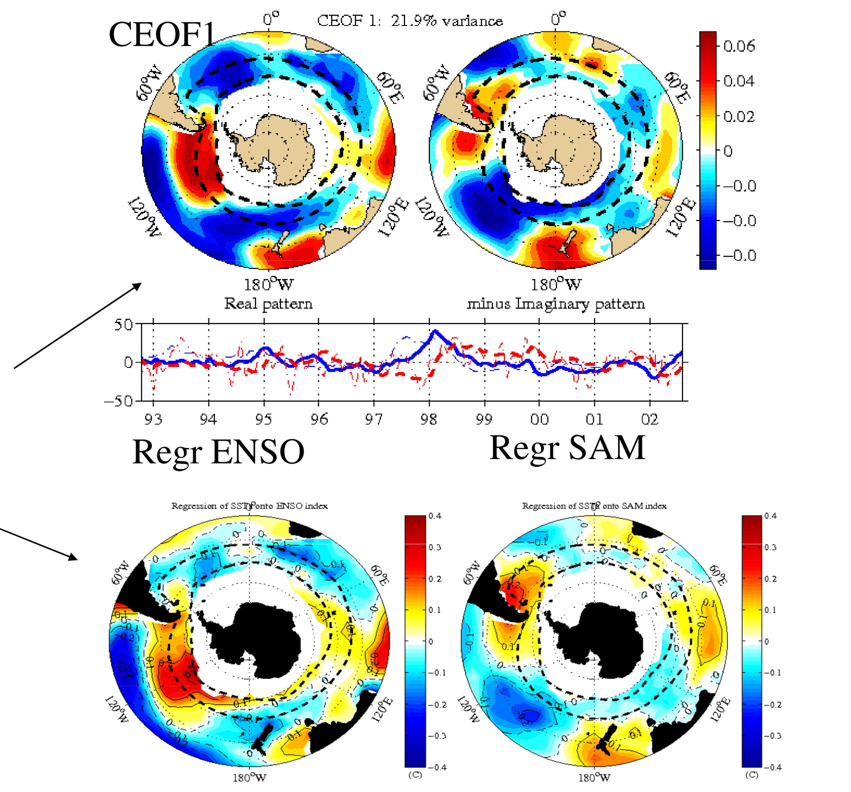
We examine the fraction of the temperature tendency variance accounted for by the different processes.



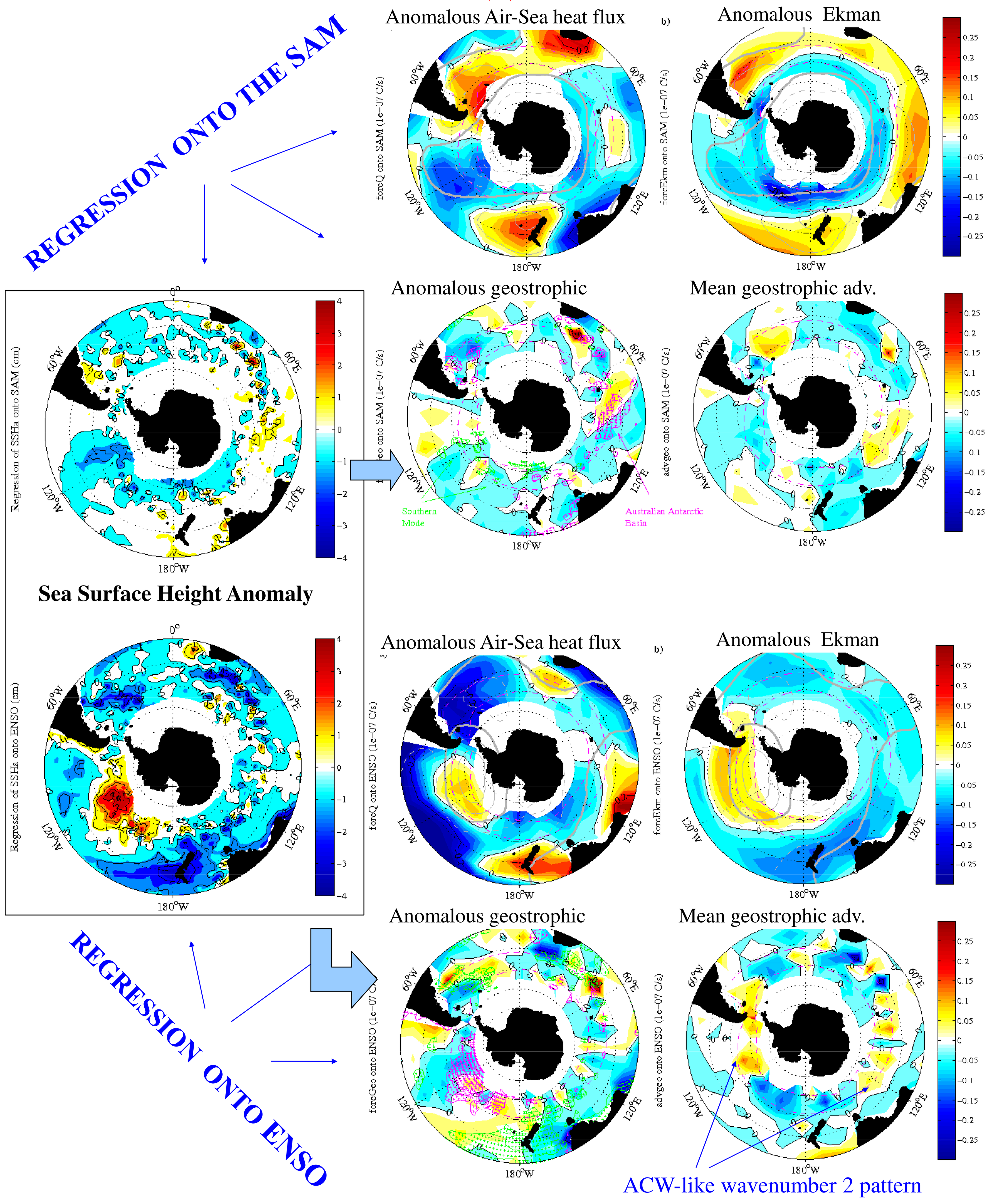
- Anomalous air-sea and Ekman heat fluxes are responsible for a large fraction of the SSTa variance over the Southern Ocean
- Anomalous geostrophic currents are the dominant forcing mechanism along the ACC pathway, downtream of topographic features (Macquarie ridge, Eltanin Fracture Zone, Drake Passage, Kerguelen), where eddy activity and frontal migrations are important.

5- RELATIONS WITH CLIMATE MODES (I)

- Previous studies have shown that a significant fraction of the SSTa variance is consistent with a response to SAM and/or ENSO related atmospheric forcing *[eg, Hall & Visbeck, 02; Park et al 04; Verdy et al,06; Maze et al, 06; Ciasto & Thompson, 07]*
- The leading mode of a CEOF analysis suggests eastward advection of SST anomalies by the ACC, especially in the Southeast Pacific.
- However, closer examination of this leading CEOF mode shows that it associates ENSO and SAM regression patterns into one complex mode.
- Is there illusion of propagation of SST anomalies? What is the role of advection for SAM and ENSO related SST variability? We examine the mixed layer heat budget regressed onto these two climate indices.



6- RELATIONS WITH CLIMATE MODES (II)



ACW-like wavenumber 2 pattern

7- CONCLUSIONS

- Simple 2D diagnostic model has good skills in reproducing observed SST anomalies.
- Heat budget:
  - Anomalous air-sea and Ekman heat fluxes are responsible for a large fraction of the SSTa variance over the Southern Ocean
  - Anomalous geostrophic currents are the dominant forcing mechanism along the ACC pathway, downtream of topographic features (Macquarie ridge, Eltanin Fracture Zone, Drake Passage, Kerguelen).
  - Consistent with in situ observations from repeat transects (eg Sokolov & Rintoul, 2003 south of Tasmania): geostrophic heat flux associated with eddies (short periods) and frontal migrations for longer time scales.
- Relation with climate modes:
  - Anomalous atmospheric fluxes (air-sea and Ekman) overall team-up to imprint ENSO and SAM variability to the SST (with regional exceptions)
  - Anomalous geostrophic currents are as importantas atmospheric heat fluxes for the ENSO related heat budget (strong ENSO-locked SSH response). Distinct pattern from atmospheric forcing. Of lesser importance for SAM-locked budget
  - ENSO related forcings (atmospheric and oceanic) generate a wavenumber-2 zonal SST gradient along the ACC: advection of anomalies consistent with ACW pattern (this pattern is likely obscured by SAM-related variability)
- Perspective: influence of vertical ocean processes, especially in mode water formation regions (AAIW and SAMW) ? Examine winter mixed layer heat budget in these regions.

Acknowledgments. Hydrographic observations come from several national and international programs (Argo, WOCE, CNES Elephant seals,AMT).The altimeter products were produced by Ssalto/Duacs as part of the Environment and Climate EU Enact project (EVK2-CT2001-00117) and distributed by Aviso, with support from CNES. We thank CNES (OST/ST) and CNRS for their support. **Reference:** Vivier, F, D Iudicone, F Busdraghi, Y-H Park, Dynamics of SST anomalies in the Southern Ocean diagnosed from a 2D mixed layer model, Climate Dynamics 2008