APPLICATION OF THE ROMS INCREMENTAL STRONG 4D-VARIATIONAL DATA ASSIMILATION IN THE CALIFORNIA CURRENT SYSTEM

G. BROQUET[1], C. A. EDWARDS[1], A. M. MOORE[1], B. S. POWELL[1], M. VENEZIANI[1], J. D. DOYLE[2], H. G. ARRANGO[3] AND J. ZAVALA-GARAY[3]

1) University of California Santa Cruz – 2) NRL – 3) RUTGERS

CODAE Project

2008 ROMS/TOMS European Workshop, LJK Grenoble, 6 – 8 October 2008

Context

- Development of **4DVAR** data assimilation methods in **ROMS** (Regional Oceanic Modeling System):

  - **Tangent Linear** and **Adjoint models** (TLROMS/ADROMS): ***Moore et al., 2004***
  - **ROMS-IS4DVAR** in the Intra-America Sea for near real time experiments: ***Powell et al., 2008***
  - Ex of present developments in ROMS-IS4DVAR: **adjustment of model/forcing parameters**

- **CODAE** (Coastal Ocean Data Assimilation Experiment) project:

  → modeling and controllability (sensitivity to various forcing / driving mechanisms, observability) studies for the California central coast circulation

  - Evaluation of a **CCS realistic configuration**: ***Veneziani et al. 2008a***
  - Sensitivity studies with ADROMS: ***Veneziani et al. 2008b***

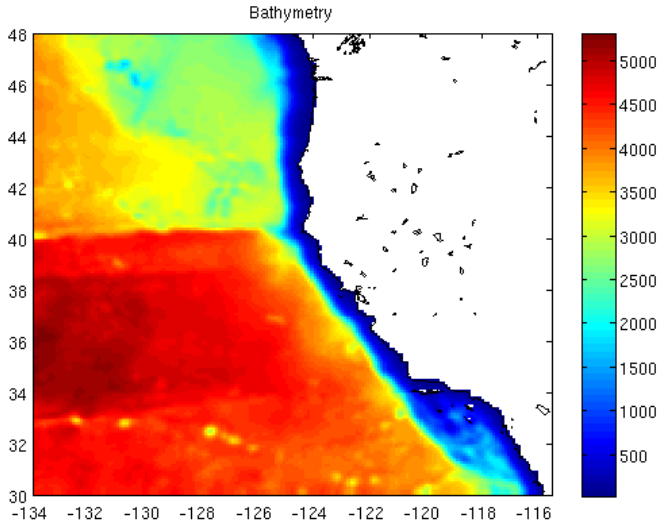
Objective: apply ROMS-IS4DVAR for the CCS to assess CODAE dynamical issues and improve an estimate of central California circulation

The ROMS West Coast configurations

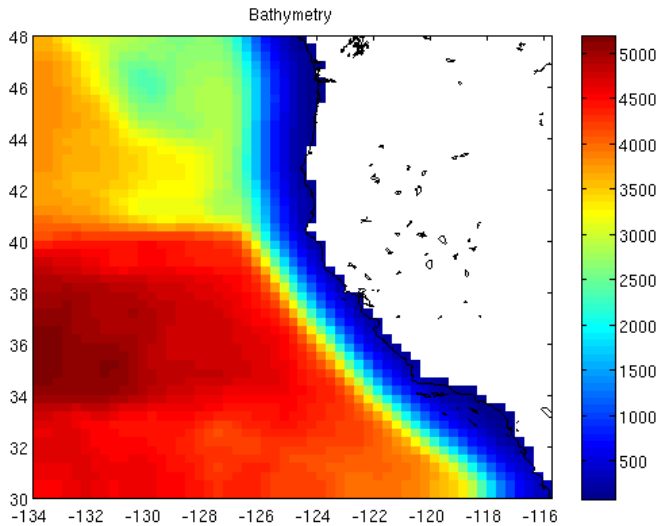
The two grids

WC10 : the configuration of ***Veneziani et al. 2008a-b***

WC3 : a coarse model to test at low cost the ROMS-IS4DVAR system



WC10 (bathymetry in m): res. 1/10° (~10 km) / 42 vertical levels



WC3 (bathymetry in m): res. 1/3° (~30 km) / 30 vertical levels

- Spin-up of 7 years → Initial condition for January 1, 1999, simulations over 1999-2004

Boundary Conditions

- Surface forcing
  - Formulation : Bulk fluxes computations or Imposed fluxes
  - Data : **COAMPS** (NRL)

- OBC
  - Formulation : clamped OBC for 3D fields / Flather+Chapman condition for barotropic fields
  - Data : **ECCO-GODAE**

ROMS-IS4DVAR

Adaptation in ROMS of the IS4DVAR method of ***Courtier et al. 1994 / Weaver et al. 2003*** (ECMWF-CERFACS)

- During each cycle of assimilation, adjustment of $\mathbf{s}=(\mathbf{x}_0,\mathbf{f}_1,\mathbf{f}_2\ldots\mathbf{f}_n)$ to minimize:

$$J(\delta \boldsymbol{s}^b)=\underbrace{\frac{1}{2}\delta \boldsymbol{s}^{bT}\boldsymbol{B}^{-1}\delta \boldsymbol{s}^b}_{J_b}+\underbrace{\frac{1}{2}\sum_i\left[\boldsymbol{G}_{t_0\rightarrow t_i}\delta \boldsymbol{s}^b-\boldsymbol{d}_i\right]^T\boldsymbol{R}_i^{-1}\left[\boldsymbol{G}_{t_0\rightarrow t_i}\delta \boldsymbol{s}^b-\boldsymbol{d}_i\right]^T}_{J_0}$$

where $\delta\boldsymbol{s}^b=\boldsymbol{s}-\boldsymbol{s}^b$, $\boldsymbol{d}_i=\boldsymbol{y}_i-H_i\boldsymbol{x}_i^b$

G : combination of the observation operator ***H*** and of Tangent Linear model ***M*** estimated from the trajectory $\boldsymbol{x}^b$ and **TLROMS**

R : observation error covariance matrix

B : background error covariance matrix

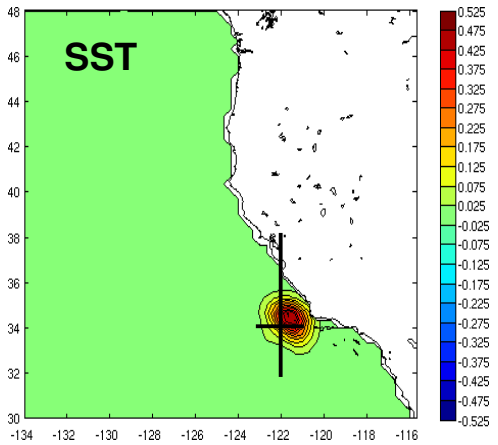
Minimization through CG algorithm inner loops : ∇J_0 **estimated from** G^T **(ADROMS)**

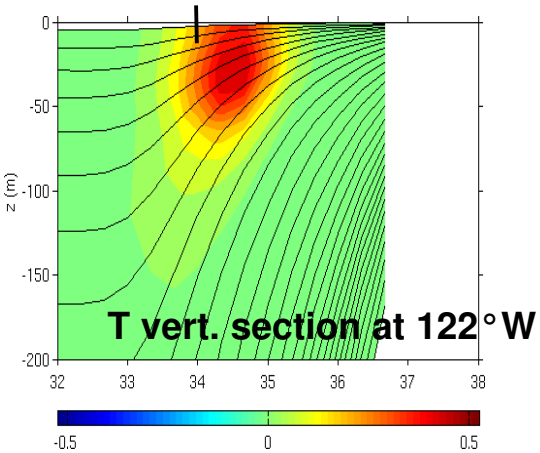
→ analysis solution of the form $\boldsymbol{s}^a=\boldsymbol{s}^b+\boldsymbol{B}\boldsymbol{G}^T$ *[correction in y-space]*

Typical Set up ROMS-IS4DVAR for the CCS (1)

- 14 day assimilation cycles (validity of the linear assumption)
- ***R*****:** diagonal matrix
- ***B***: univariate, with:
    - ➔ isotropic/homogeneous correlations (typical length scales: 50 km Hor. / 30 m Vert. / 100 km Hor. for surface wind stress)
    - ➔ standard deviations estimated from model own temporal variability

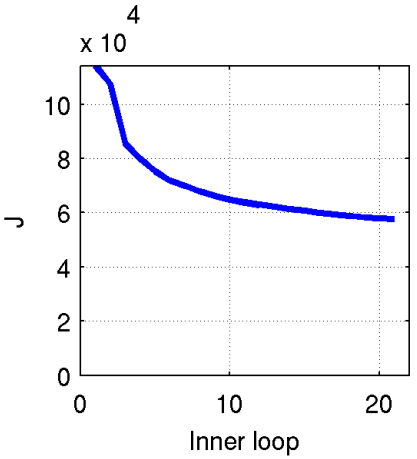
Adjustment of the initial condition from an innovation of 0.5° in SST(34°N,122°W) on Jan 15 2000 during cycle 1-15 Jan 2000 in WC3





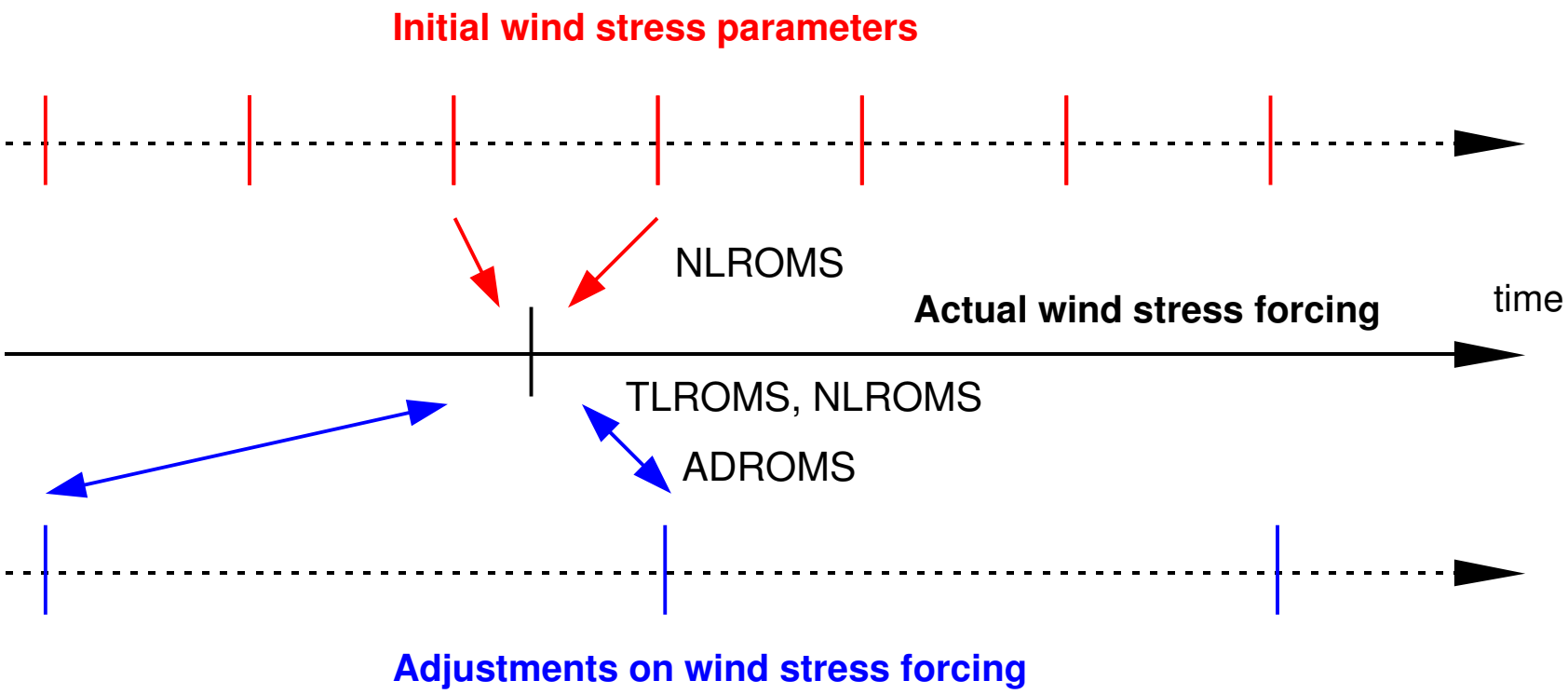
- 10/20 inner loops (convergence of the CG algorithm)

Assimilation of SSH/SST/CalCOFI/GLOBEC in WC3: evolution of the cost function during the 35th assimilation cycle (Apr 22nd- Mar. 6th 2000).



Typical Set up ROMS-IS4DVAR for the CCS (2)

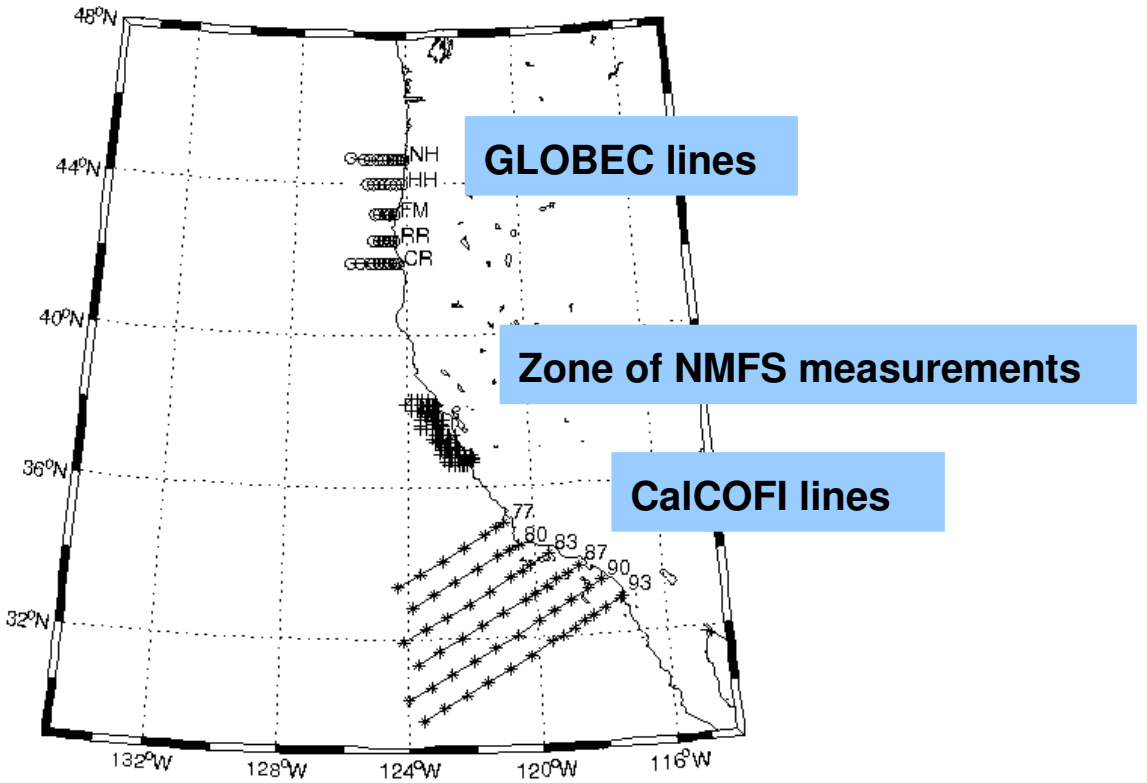
Frequency of adjustment for surface wind stress



- standard deviations of the background error covariance have to be adapted to the frequency
- best results obtained with frequency of adjustment for surface wind stress = 1 day = frequency of available (COAMPS) data

Observations

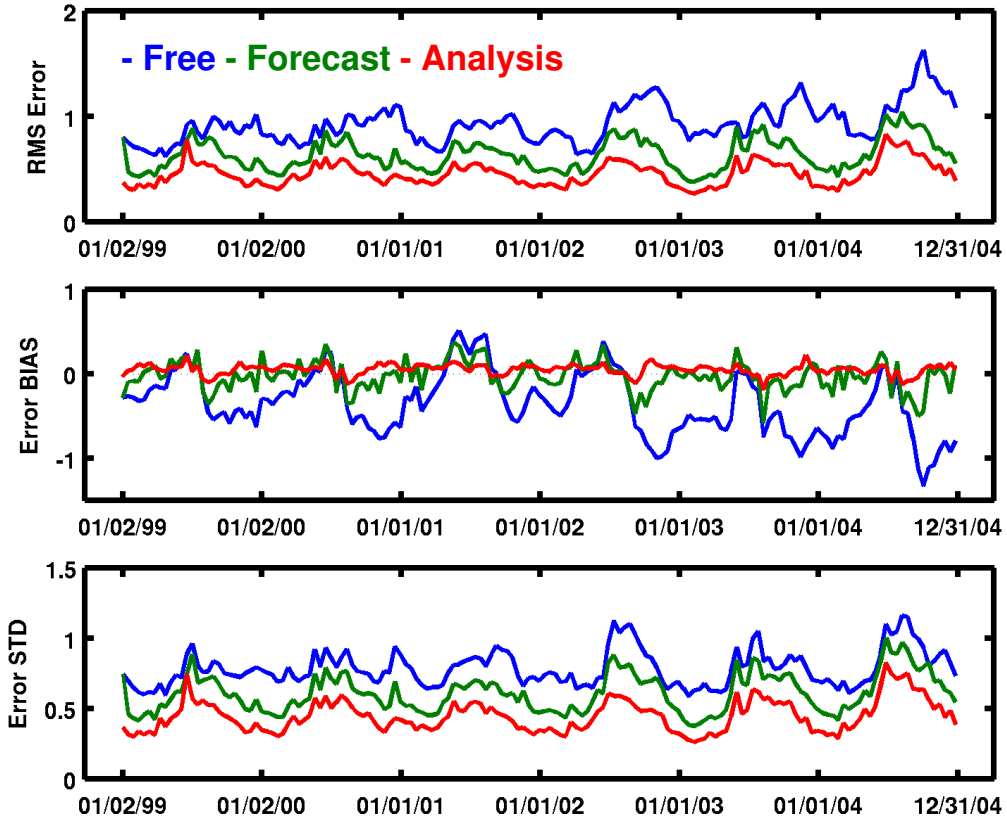
- **SSH AVISO** (Ssalto-Duacs data) – obs err : $r_{SSH}=(0.02\text{m})^2$
- **SST COAMPS** – obs err : $r_{SST}=(0.4°)^2$
- In Situ T-S profiles from **CalCOFI** - **GLOBEC** (NEP/CCS) and **NMFS** (NOAA) cruises
  – obs err : $r_S=(0.01)^2$; $r_T=(0.1)^2$



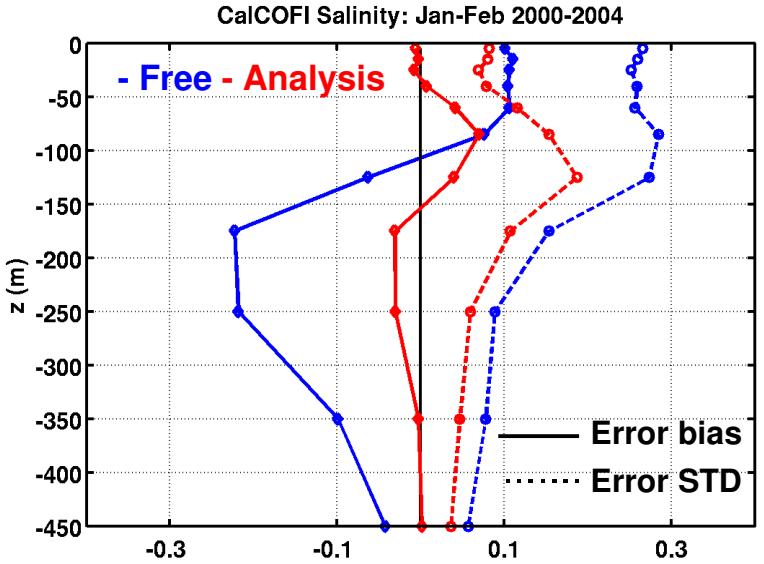
→ assimilation of surface and in situ data despite potential competitions (weight in cost function, opposed effects through model and system limitations)

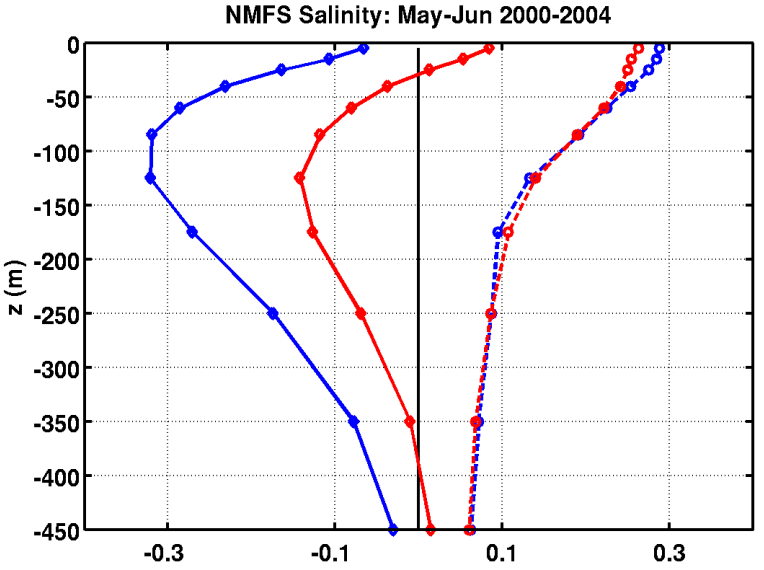
WC10: assimilation of SSH/SST/CalCOFI/GLOBEC

Diagnostics towards observations



Error statistics for COAMPS SST for each 14d assimilation cycles



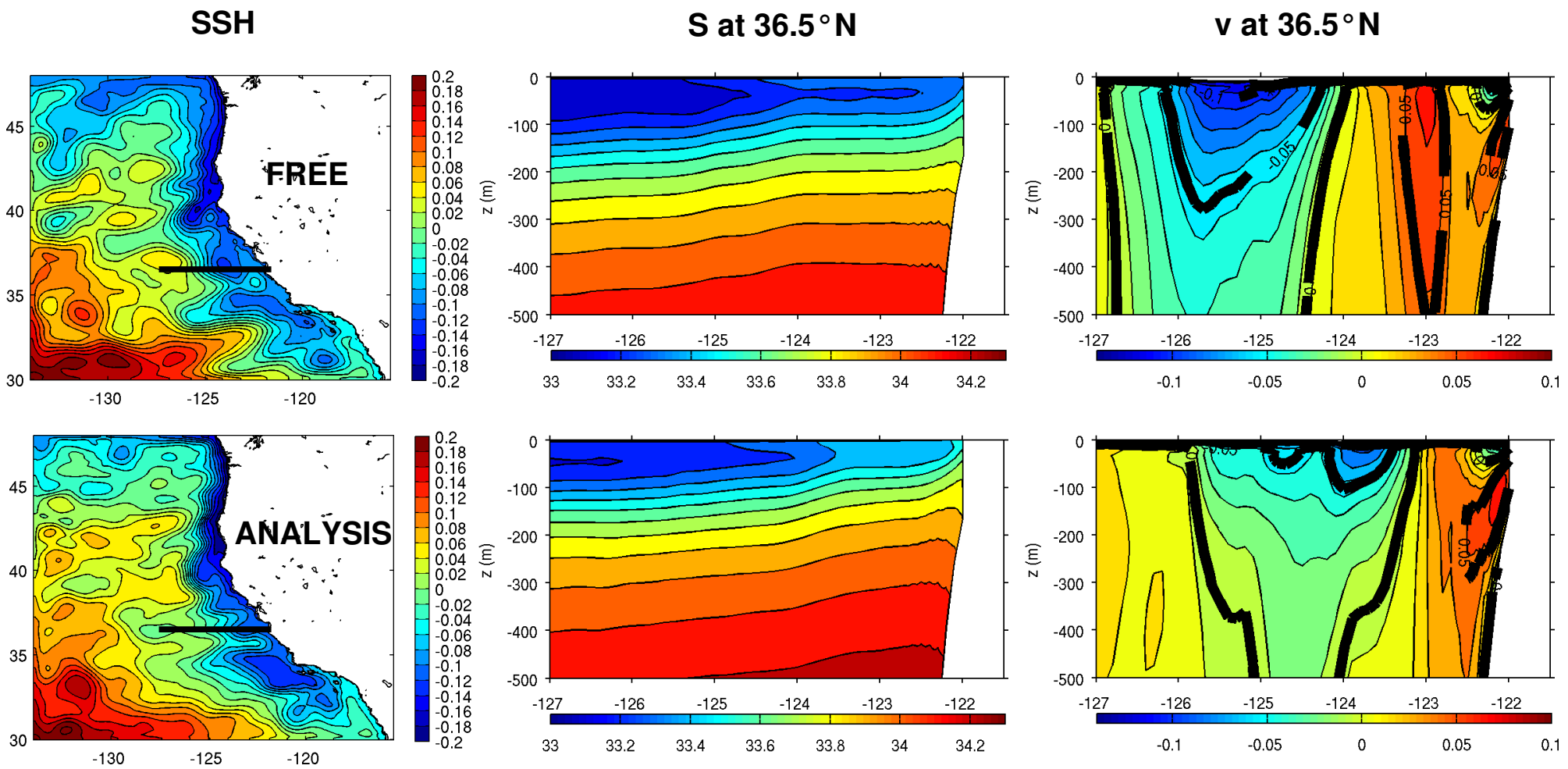


Error statistics for in situ salinity data during 2000-2004

- $(\text{RMS Error})^2 = (\text{Error bias})^2 + (\text{Error STD})^2$
- correction of all components of error
- forecasts still show improvements
- sensible corrections on the non observed part of the state

WC10: assimilation of SSH/SST/CalCOFI/GLOBEC

Influence on the regional circulation



Mean summer fields: FREE (Top) and ANALYSIS (Bottom)

Important adjustments in SSH + sensitive changes in the T/S/density gradients even far from observations

➔ currents are strongly modified in the whole CCS

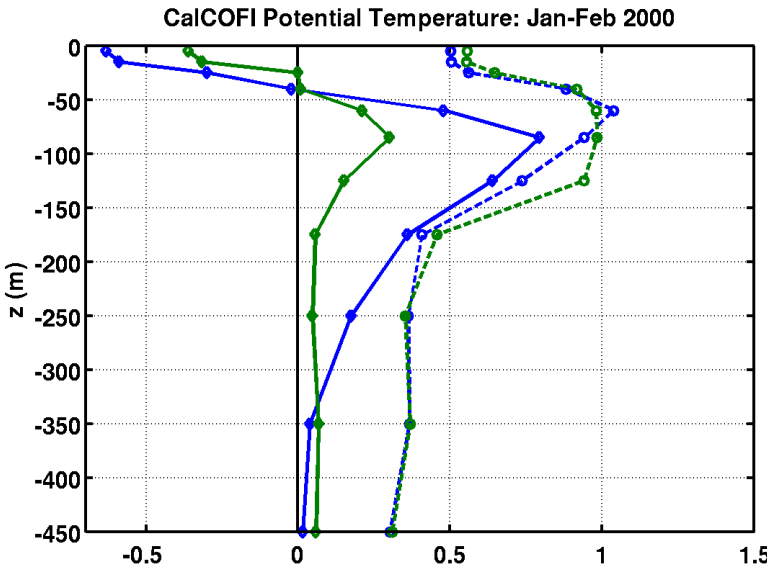
WC3: Assimilation of LEVITUS climatology

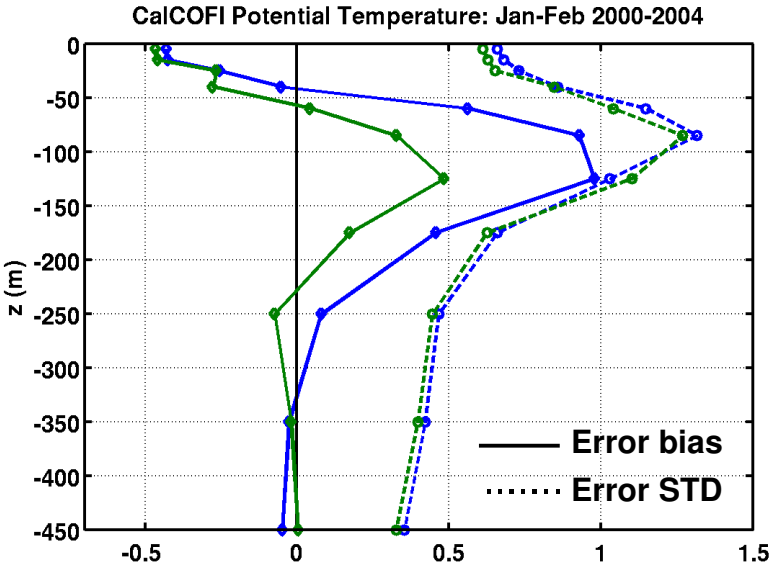
- Importance of bias in the error (+ preliminary to the application of a multivariate balance operator for ***B***)
  - ➔ assimilation of LEVITUS climatology at the beginning of every seasons

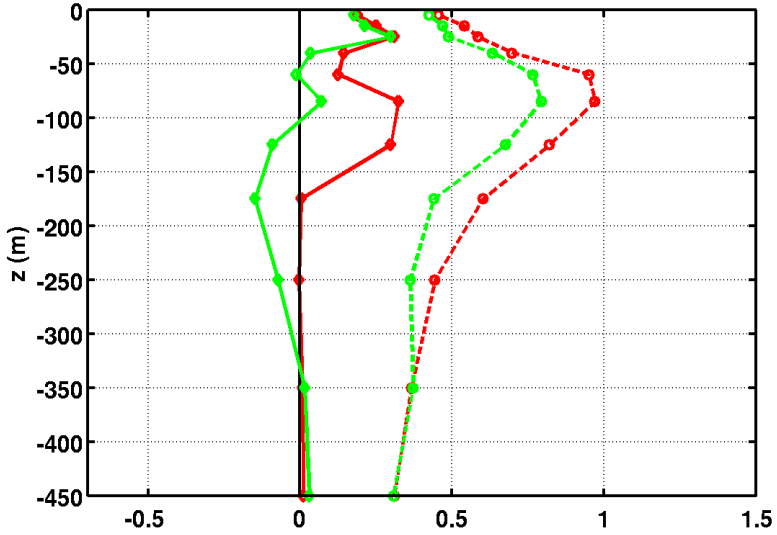
- Free
- Assim climato

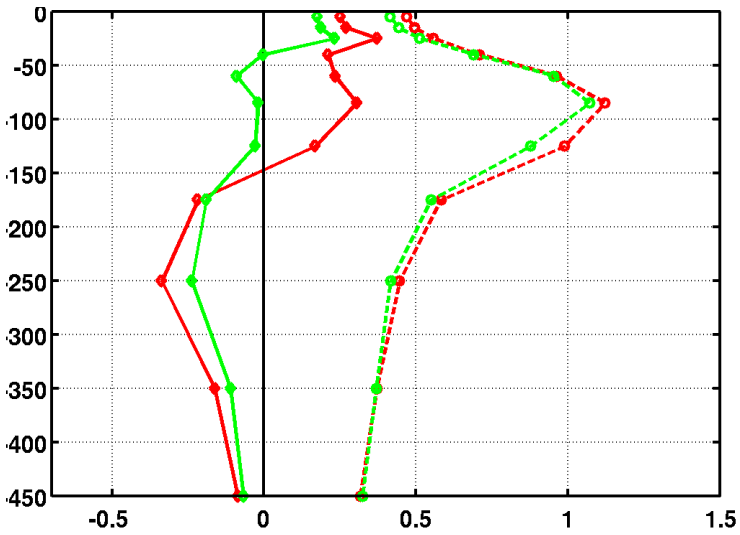
Error statistics for winter CalCOFI temperature data during 2000 (left) and 2000-2004 (right)

- Assim SSH/SST/C/G
- Assim SSH/SST/C/G and climato



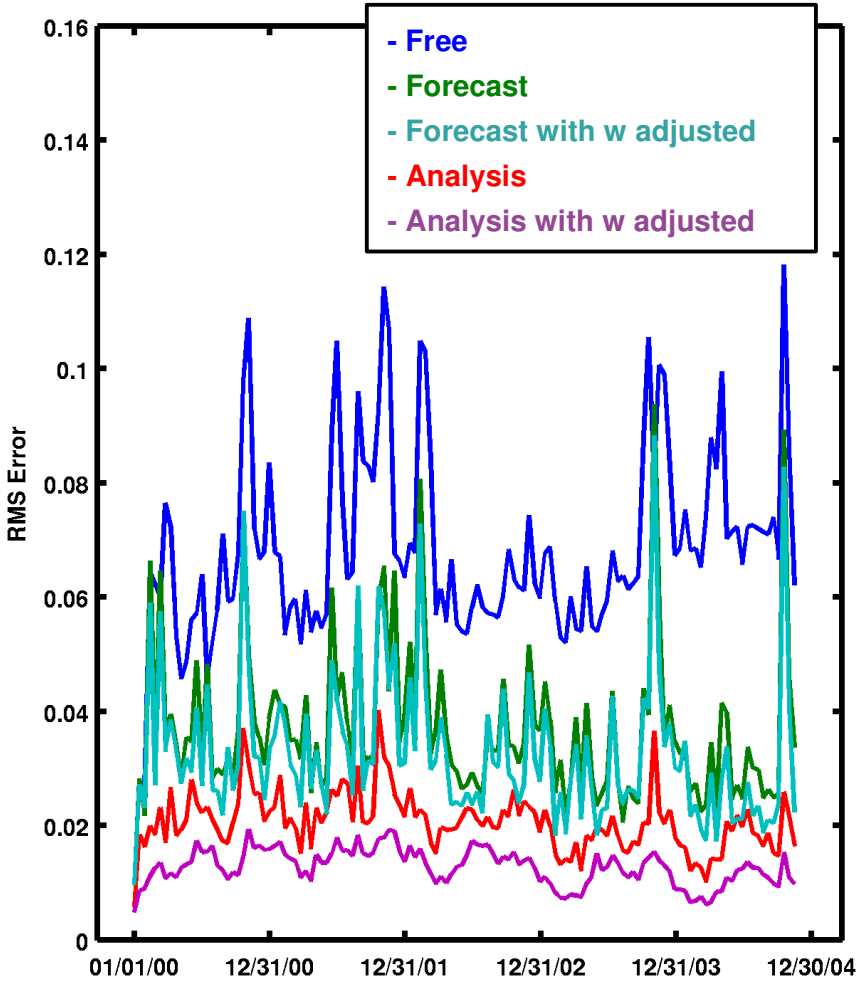






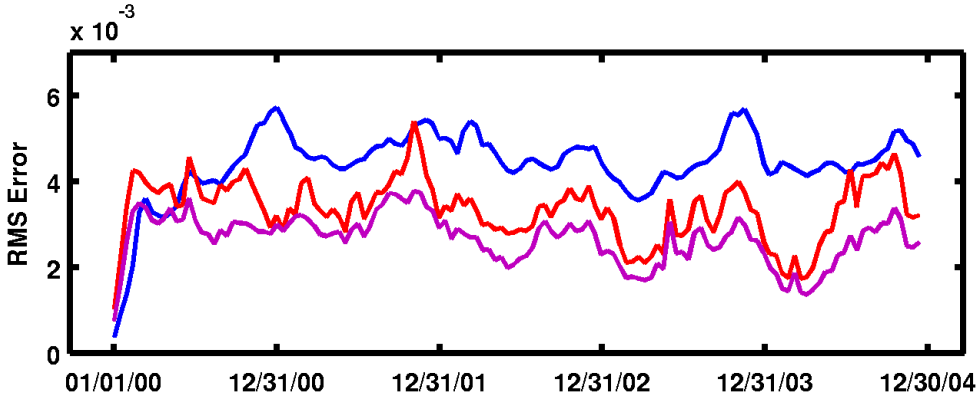
- Improvement (not systematic), less sensitivity after the first year (less sensitive on NMFS data)

WC3: test of the adjustment of wind stress forcing with twin experiments (1)



RMS error for SSH for each 14d cycles

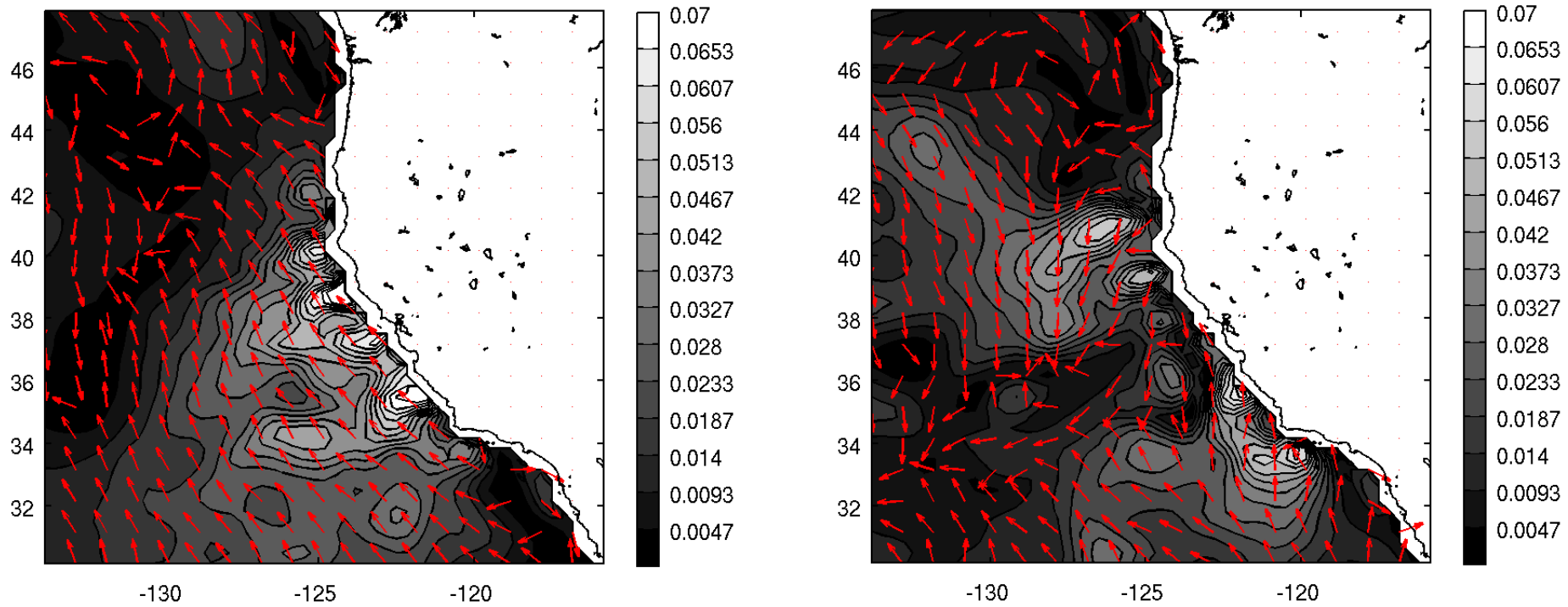
- Free model with right w parameters → truth
- Simulations are conducted with a delay of 1 year in w parameters and with assimilation of the equivalent of SSH/SST/CalCOFI/GLOBEC from the truth



RMS error for T(100m) for each 14d cycles

- Improvement of statistical check to the assimilated observations and to the whole state space

WC3: test of the adjustment of wind stress forcing with twin experiments (2)

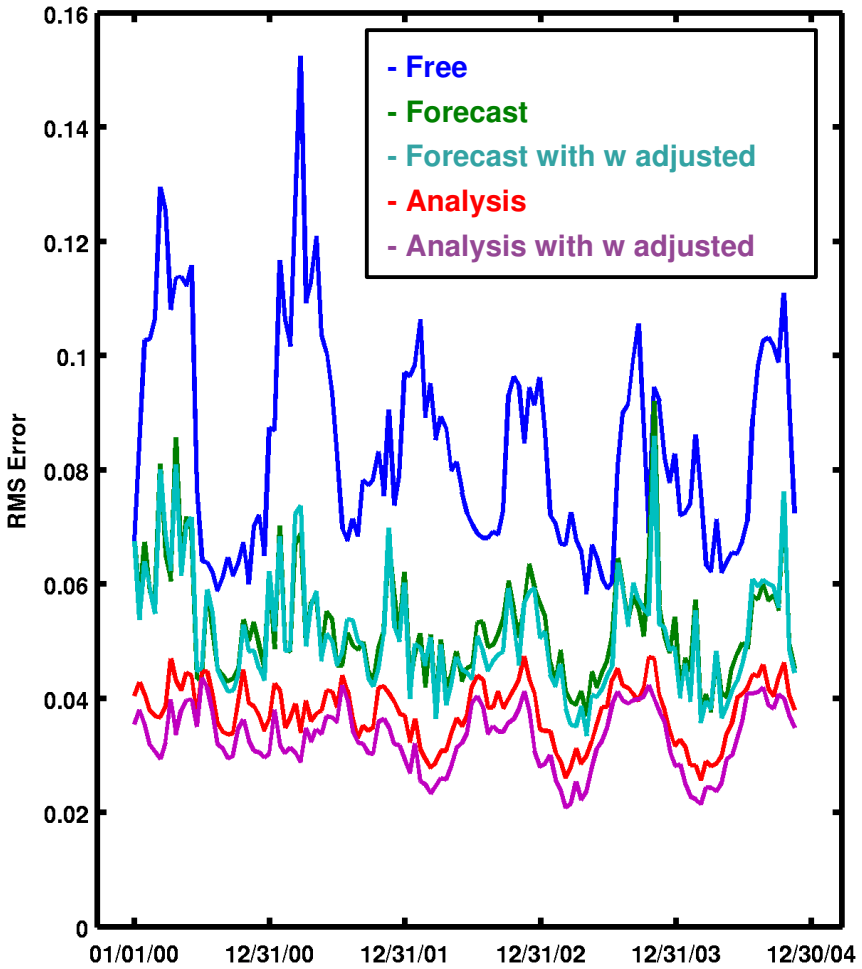


June 2000 mean error on the wind stress forcing: FREE and ANALYSIS (left); ANALYSIS with W adjusted (right)

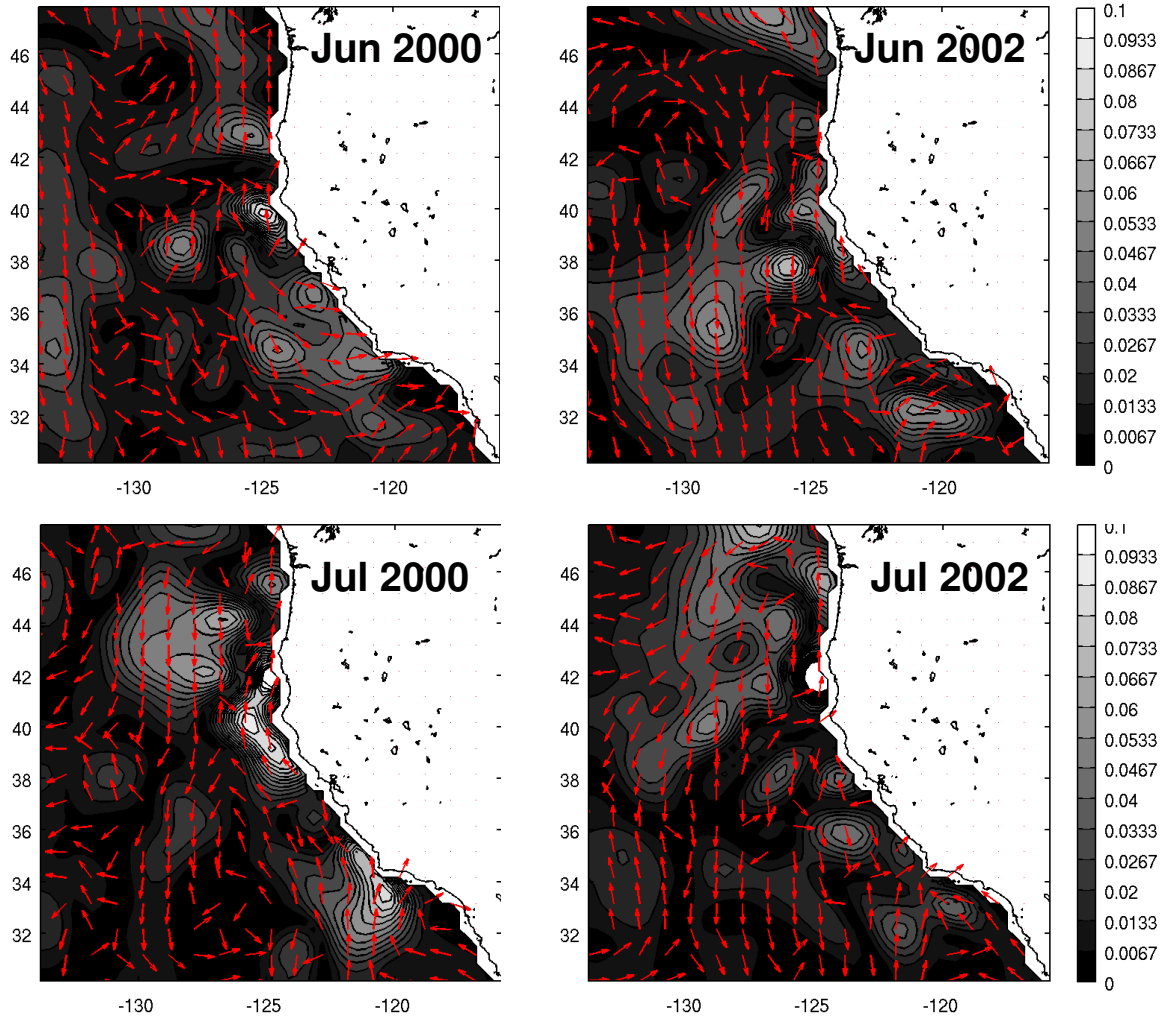
- Adjusted w parameters are closer to the “true” ones over the central California shelf but often further to the “true” ones offshore.

➔ Systematic but slight decrease in the overall mean errors on w (corrections more compatible with observations than with the true forcing)

WC3: assimilation of SSH/SST/CalCOFI/GLOBEC and adjustment of wind stress forcing (1)



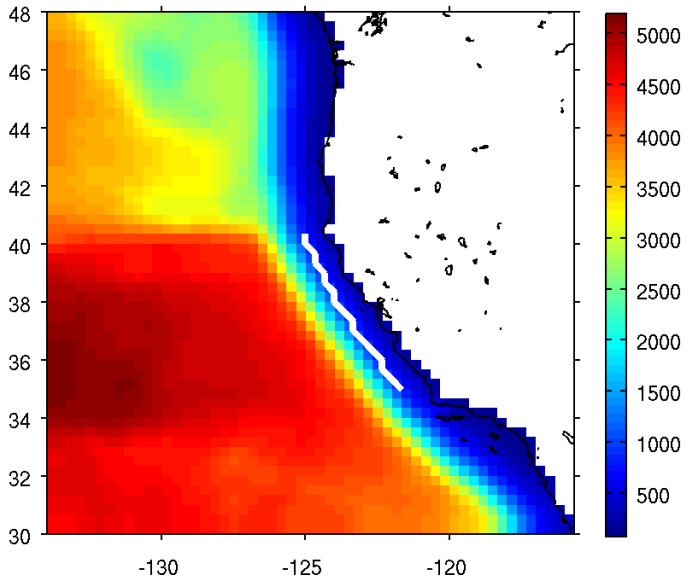
RMS error for SSH for each 14d cycles



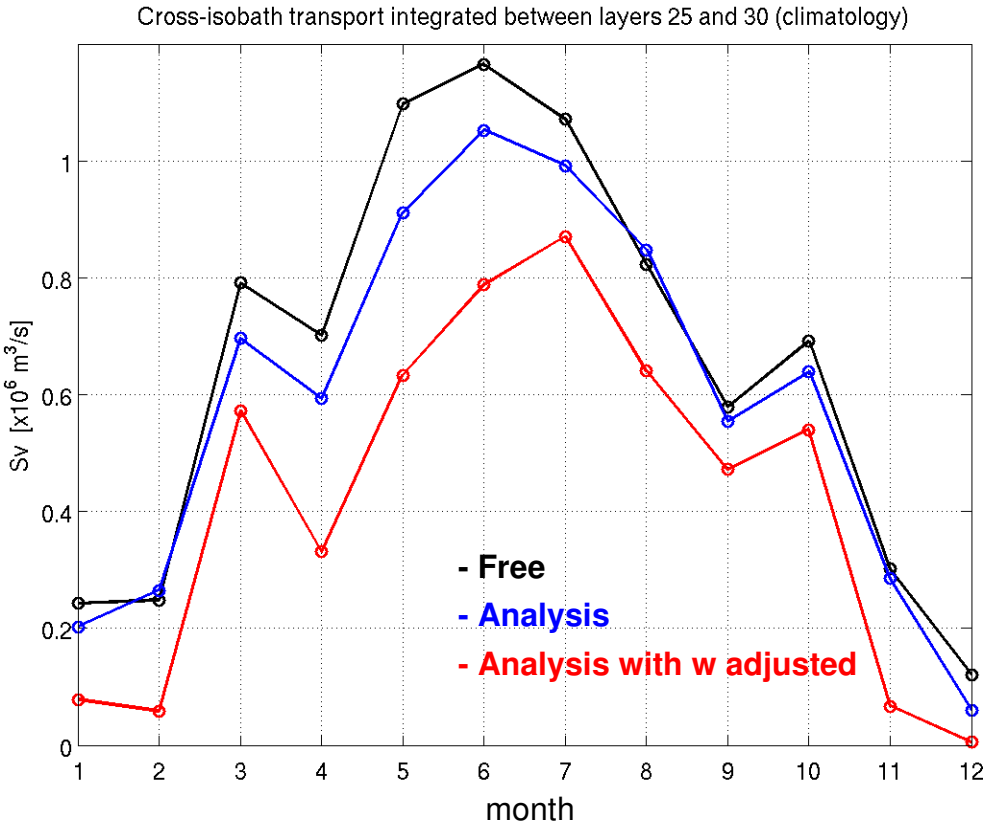
Monthly mean correction to the wind stress forcing

- Improvement of statistical check to the observations
- Regular corrections close to the shelf

WC3: assimilation of SSH/SST/CalCOFI/GLOBEC and adjustment of wind stress forcing (2)



Portion of isobath -500m used for calculations



Monthly mean of cross-isobath -500m transport integrated in the 15 first meter depth during the period 2000-2003

- Reduction of the upwelling (a tendency in the correction rather linked to the limitation of the resolution on WC3 than to high resolution COAMPS fields ?)

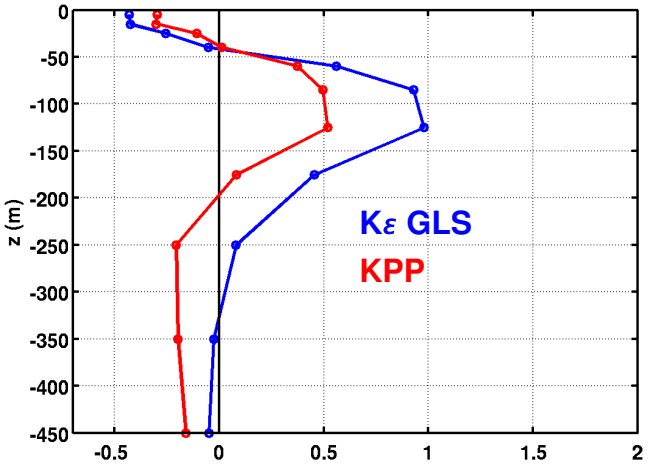
WC3: sensitivity study to improve the vertical extrapolation from surface data

- A typical problem of vertical extrapolation: increase of warm bias near the surface (centered at the thermocline) from surface data assimilation

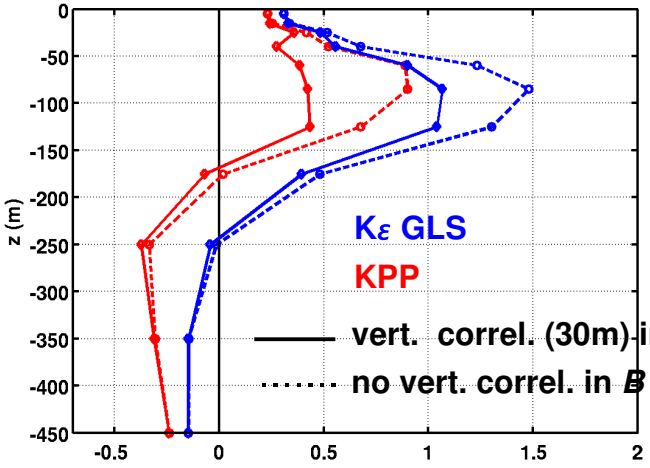
→ **modification of *B* vertical correlation length scales** (30m already weak, no vertical correlations ?)

→ **modification of ROMS/TLROMS/ADROMS vertical diffusion parameterization**

FREE (Bulk forc.)

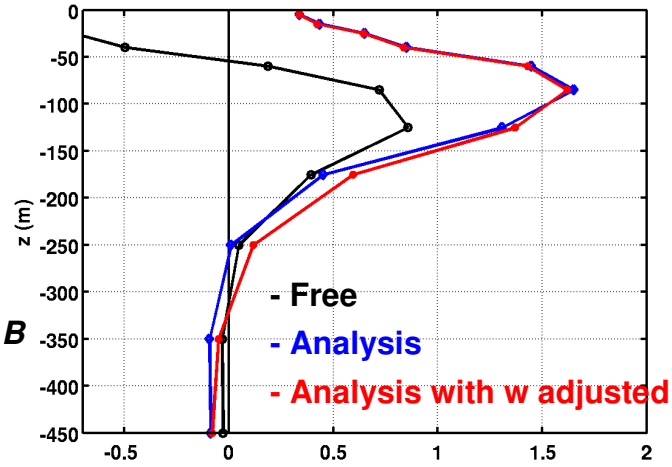


Assim. SSH/SST (Bulk forc.)



Imposed surface forcing - Kε GLS

FREE and Assim. SSH/SST



Temperature bias in WC3 for CalCOFI in winter during period 2000-2004

- Improvement from no vert. correl. in ***B***
- Better extrapolation from SST with KPP vertical mixing scheme
- Problem increased by use of imposed surface forcing: no real improvement from wind stress adjustment

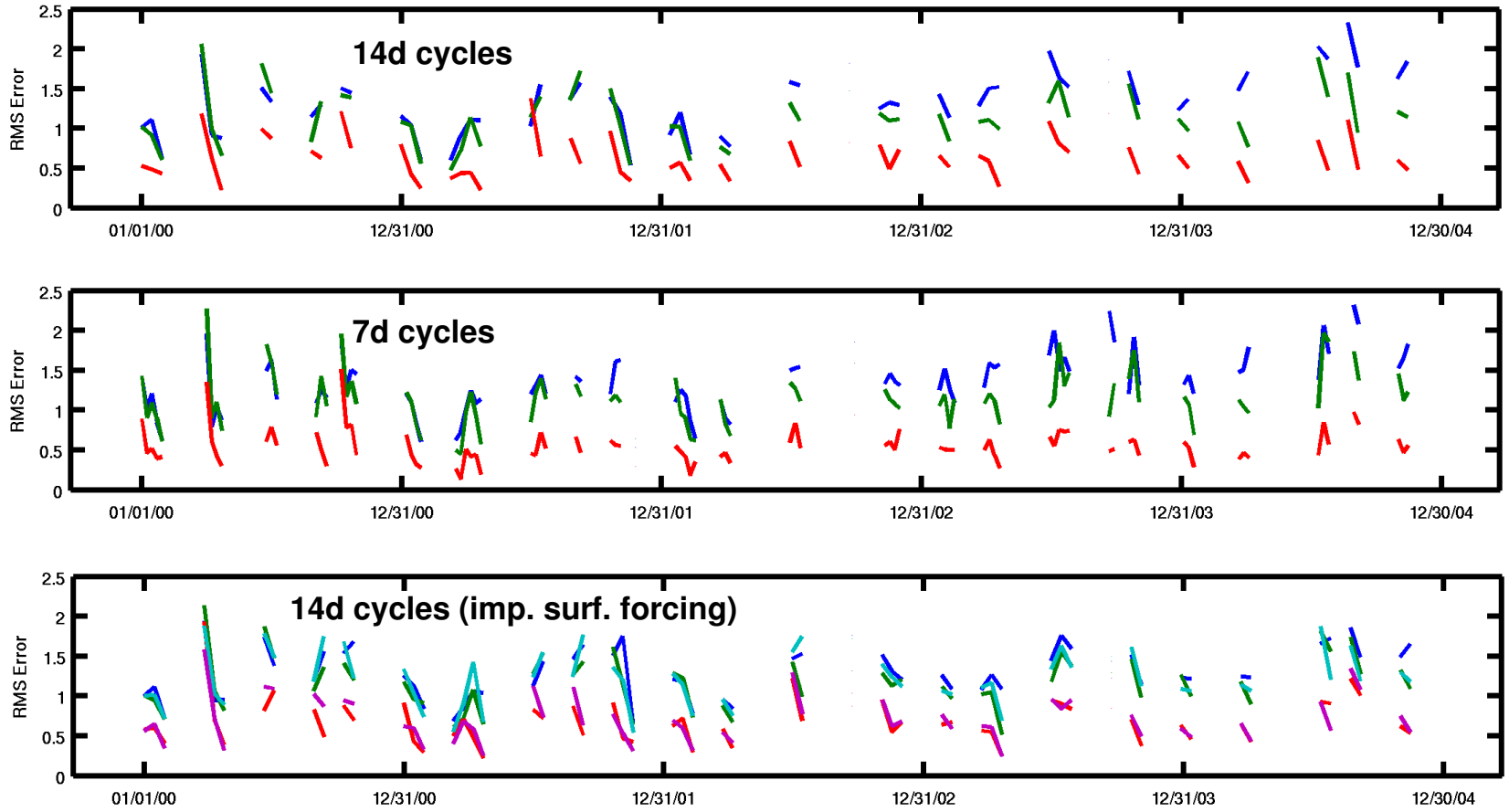
WC3: sensitivity study to improve the forecast at depth from in situ data assimilation

- Forecast degrade at depth: the assimilation cycle is too long ?

➔ No real impact when **reducing the cycle length**

- no impact from surface wind stress adjustment

- **Free**
- **Forecast**
- **Forecast with w adjusted**
- **Analysis**
- **Analysis with w adjusted**



RMS error for assimilated CalCOFI/GLOBEC T data for each assimilation cycle in WC3

Conclusion

- **Application of ROMS-IS4DVAR in the CCS successful:**

• **Reduction of differences between model and assimilated observations**, despite actual competition between different type of obs

• **Sensible extrapolation of the information from observations to the whole circulation and for forecasting**, despite limited sets of in situ data

• **The adjustment of surface wind stress improves results.**
Tendencies in the corrections (expected in WC10) → feedback to the atmospheric analysis.

- **Critical role of the dynamical inversion from ADROMS:** problem of the linearity assumption

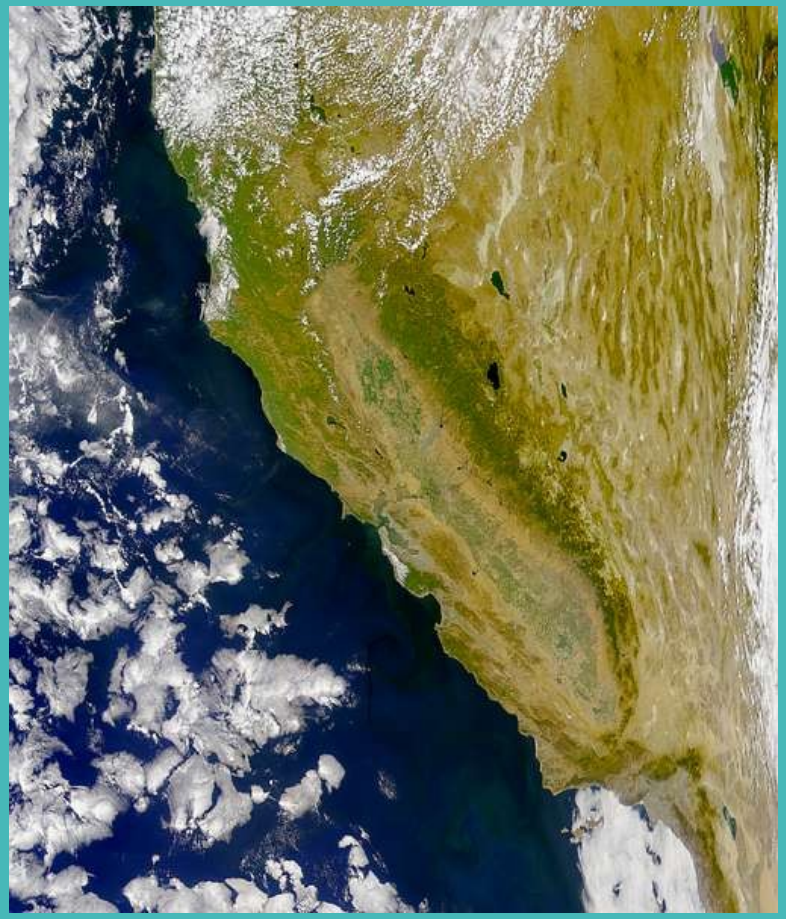
- **Present development for an improved application of ROMS-IS4DVAR in the CCS:**

• **Adjustment of surface heat and salinity fluxes**

• spatial extrapolation still imperfect, ***B*** covariances are idealized and univariate (problem of physical balances in the adjustments)

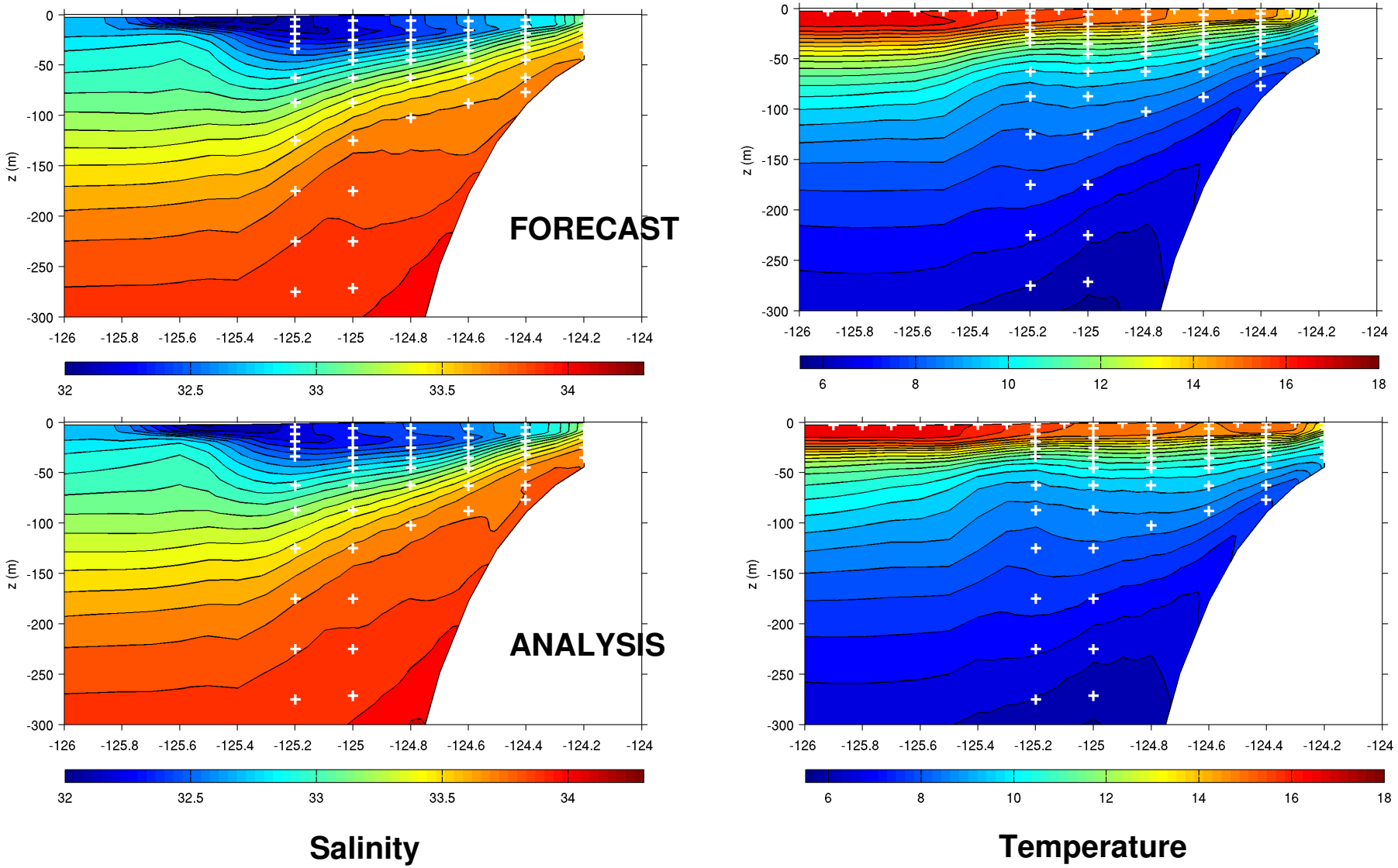
→ **Experiments with a multivariate operator applied to *B***

Thank you !



WC10: assimilation of SSH/SST/CalCOFI/GLOBEC

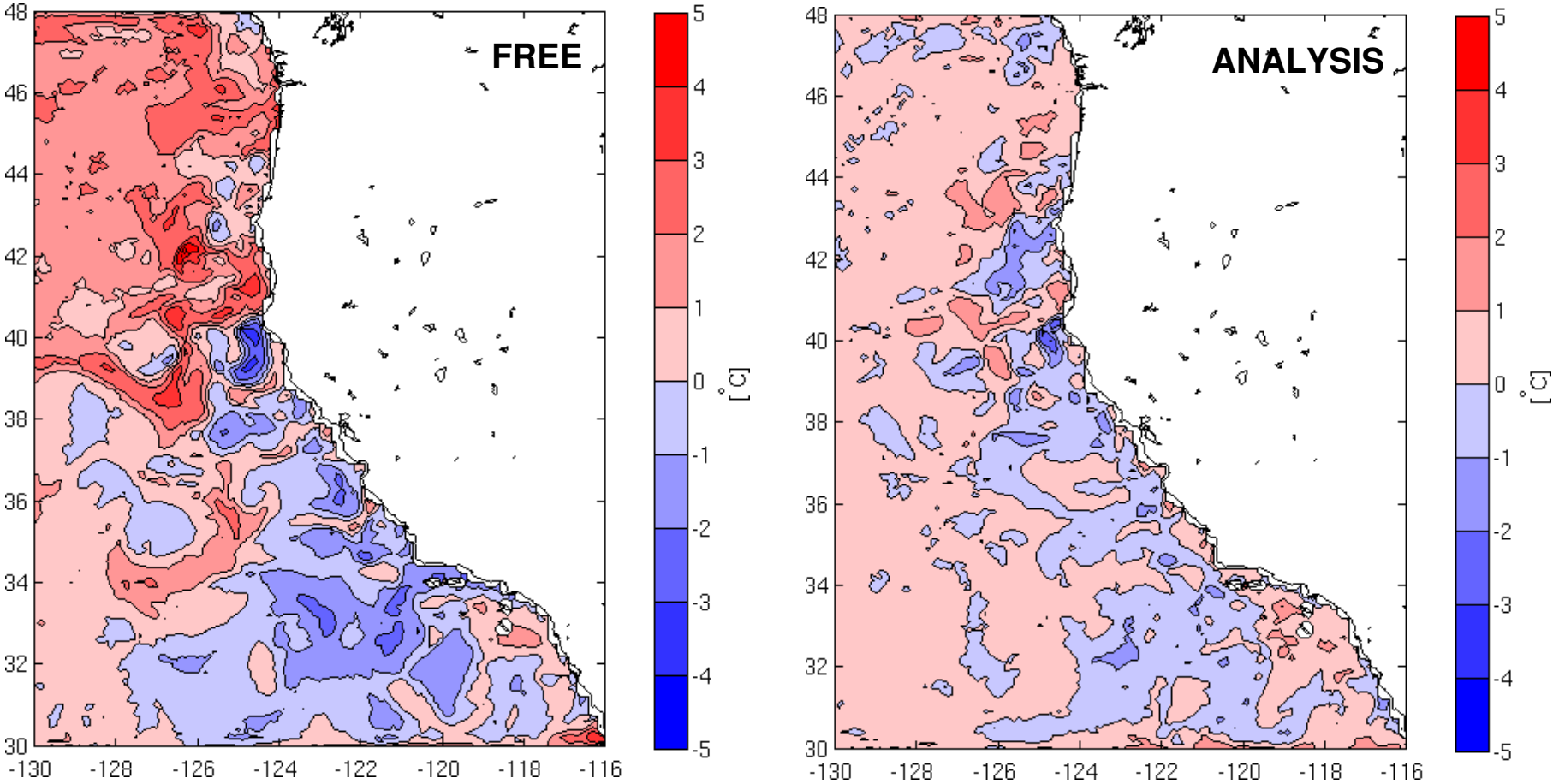
Adjustment of the initial condition for cycle: 8-22 September 2001



Temperature and salinity section at 44°N for the initial condition of cycle 8-22 Sep 2001. White points: Position of available GLOBEC and SST data during this cycle.

WC10: assimilation of SSH/SST/CalCOFI/GLOBEC

Validation of COAMPS SST assimilation

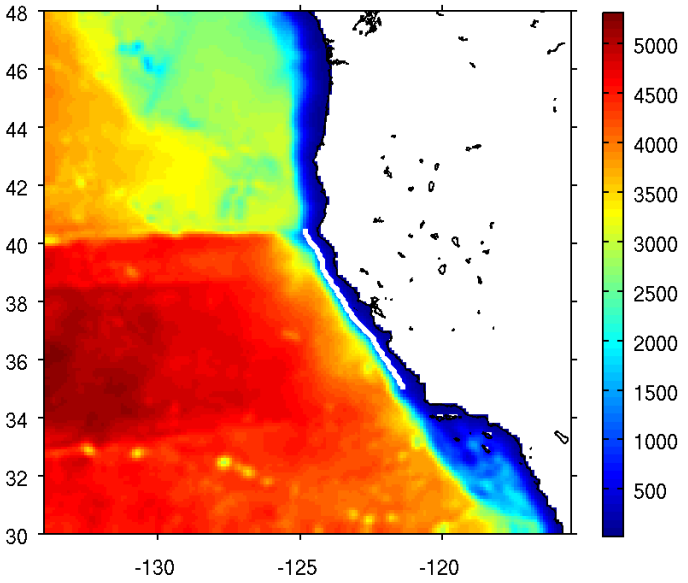


5 day difference between WC10 SST and NOAA satellite blended product on Sep. 10th 2002: FREE (left) ANALYSIS (right)

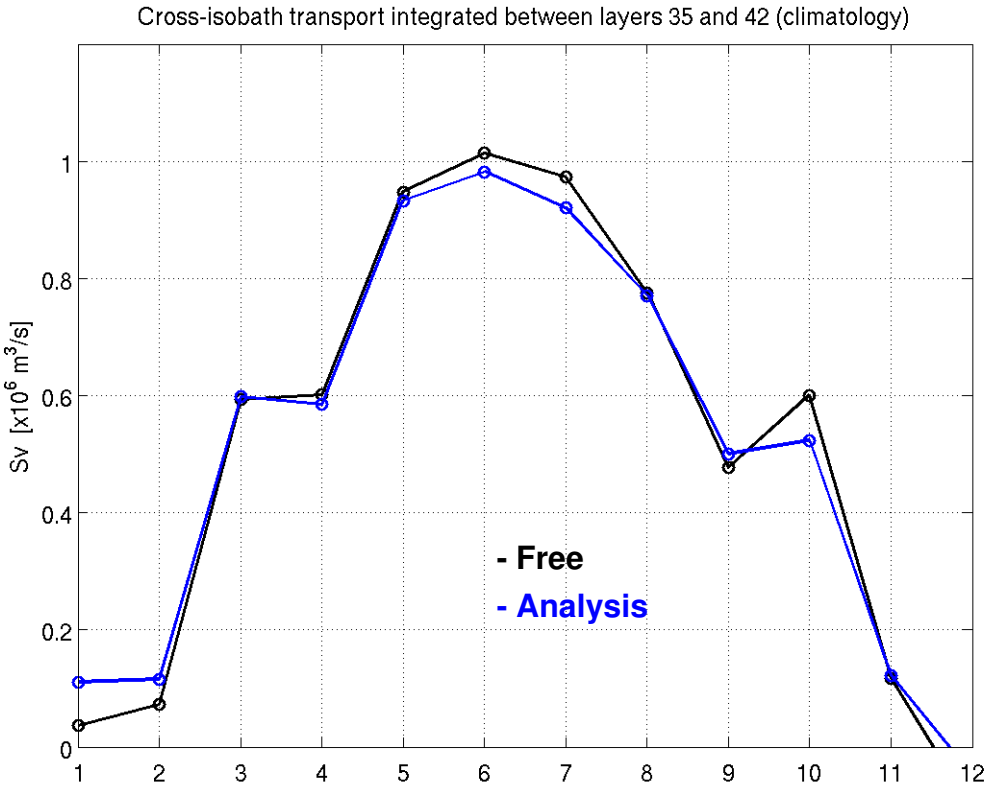
- Blended 5 days SST from multi sensors (MODIS, AVHRR, GOES, AMSR-E : D. Foley/NOAA)
- corrections at mesoscale

WC10: assimilation of SSH/SST/CalCOFI/GLOBEC

Influence on the cross-isobath -500m transport along the central California

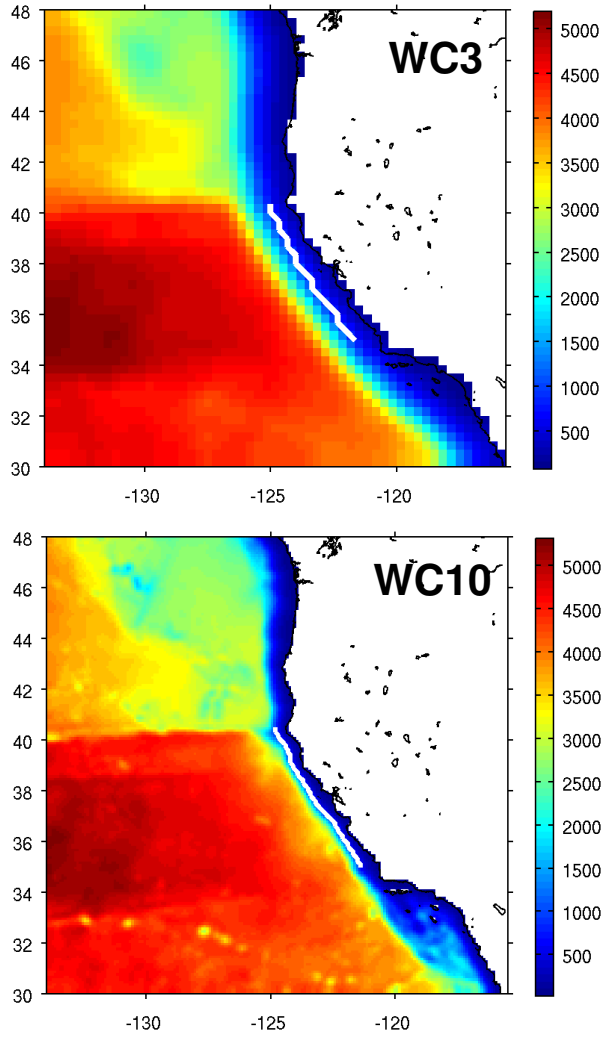


Portion of isobath -500m used for calculations

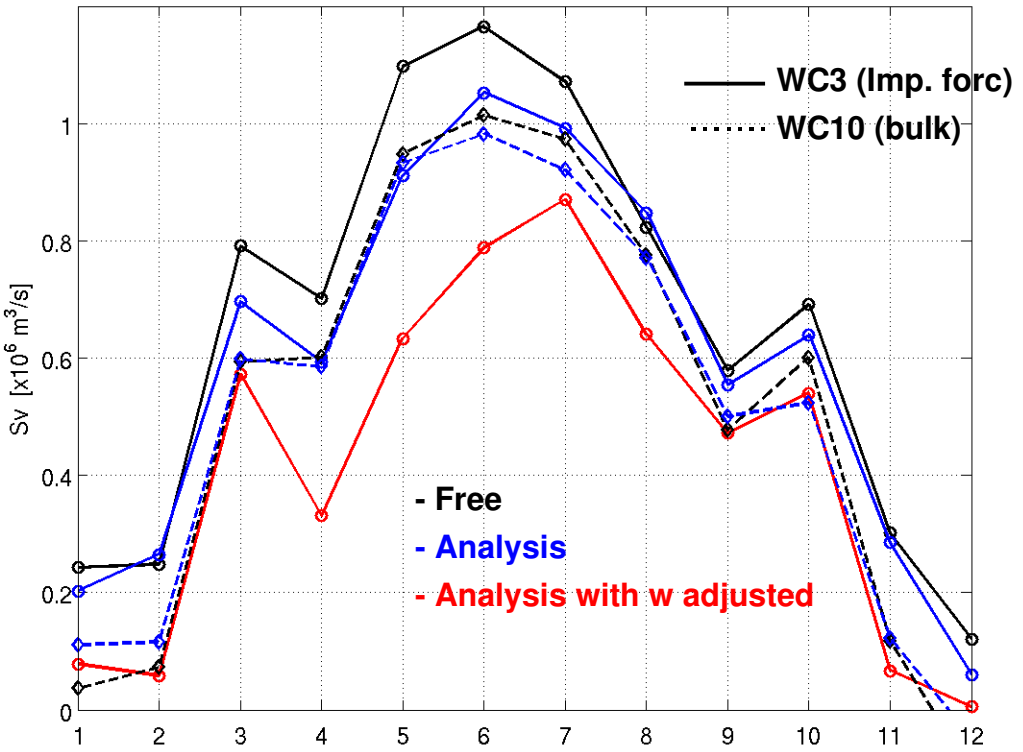


Monthly mean of cross-isobath -500m transport integrated in the 15 first meter depth during the period 2000-2003

Cross-isobath -500m transport along the central California



Portion of isobath -500m used for calculations



Monthly mean of cross-isobath -500m transport integrated in the 15 first meter depth during the period 2000-2003