A Climate Model with a Mixed Layer based on NEMO v3.2

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Coupled models including a mixed layer ocean are now widely used in the community for several kind of studies (specially when a full ocean model remains too expensive regarding to CPU consumption).

To be able to easily switch from a conventional ocean-atmosphere coupled model (exhaustive but still significantly slanted) to a configuration using a mixed layer ocean, let's simply transform the NEMO code from an existing coupled configuration (here ARPEGE-NEMO).

Parts of the code like the NEMO advection scheme are bypassed and some instructions are added using a new namelist parameter (nn_cmxl) set to:

* 0 in normal mode,
* 1 during the correction calculation and
* 2 to use the mixed layer configuration applying the flux correction.

To switch from standard ocean to our configuration, we test the value of the nn_cmxl variable within fortran “IF” conditions. This strategy (instead of pre-processor operation) should allow us to separately activate this configuration on AGRIF zoom areas.

Mixed layer configuration

No horizontal exchange should be represented: NEMO avoid to calculate and integrate slope of lateral mixing (ldf_slp), advection and diffusion at the bottom layer (tra_bbl), horizontal and vertical advection (tra_adv, dyn_adv), lateral mixing (tra_ldf, dyn_ldf), horizontal gradient of hydrostatic pressure (dyn_hpg) and surface pressure gradient (dyn_spg).

The momentum trend is updated with the planetary vorticity trend only (dynvor). Ice dynamics and transports are switched off (sbcice_lim_2 and ln_limdyn=.false.)

A damping is necessary to avoid systematic drifts:

* ice thickness is restored (limdmp_2) to climatological values

* temperature and salinity are damped everywhere (nn_hdmp=-1) but only under the mixed layer (nn_zdmp=2). The restoring coefficient varies like an exponent of minus depth. Bottom and surface time scales are set to 30 days, with a transition depth of 800 meters. The salinity restoring coefficient is 10 times greater than the temperature one. This damping is activated during both correction calculation and application

stages.

Damping must only concern deep vertical levels: it is disabled at the surface (sbcmod).

Two new coupling fields of flux correction (heat and water) are received (sbccpl) from a toy model via OASIS. Calculated as described below, the daily climatological value of the heat (water) flux correction is added to non solar heat flux (total E-P balance). An adjustment of the heat flux correction (set to zero) is done wherever sea ice lies (limsbc_2) in the model.

The atmosphere model ARPEGE always calculates its own surface albedo and its own ice temperature (namelist values LMCC02 = .T. and LALBEDO=.F.)

Correction calculation

At the beginning of the time step loop (and not at the end, as usual in a coupled model), the Levitus temperature (even under ice) and observed corresponding sea ice fraction are sent to atmosphere (sbccpl). LIM model is disabled and ice cover is forced to observed quantities (sbcice_if). Ice fraction initialization has to be done before coupling (restart reading or calculation regarding Levitus). Fluxes are received after one coupling step of the atmosphere model (sequential coupling).

At the end of active tracer update routines, but before density (eos) and tendencies (tranxt) calculations, at each end of a simulated day, tb,tn and sb,sn values are re-initialized (in the mixed layer only) with daily Levitus temperature and salinity interpolated at the day following the current day (dtasal, dtatem). Those variables are re-initialized again after tendencies calculations.

At the same stage, the flux corrections are calculated, estimating the difference between total amount of energy (water) brought by the atmosphere during the one day coupling time step and the necessary energy (water) to drive the model to the Levitus state of the next day. The difference of temperature (salinity) between integrated variable tn (sn) and the Levitus value of the next day is multiplied by rau0.rcp (rau0) and accumulated on the total depth of the mixed layer (rho criteria only).

Heat and water flux correction could be saved using the old IOIPSL output procedure (diawri) or with the new IO module (tranxt). Atmosphere always sees the Levitus sea surface temperature, so it could be useful to save all the received coupling fields to be able to replay the oceanic simulation on a forced mode (sbccpl).

Then, we could process offline a 365 days climatology using the last 40 years of a 45 years long simulation (clmDayTLL NCL routine), removing the seasonal harmonics (smthClmDayTLL NCL routine).

Validation

Table 1 shows heat flux correction values for winter and summer seasons. Strong values are observed when compensating intense oceanic horizontal heat transports (Gulf Stream, Kuroshio). Our method also corrects atmospheric biases (regional heating eastward Peru and Guinea gulf, insufficient wind driven exchanges at southern high latitudes).

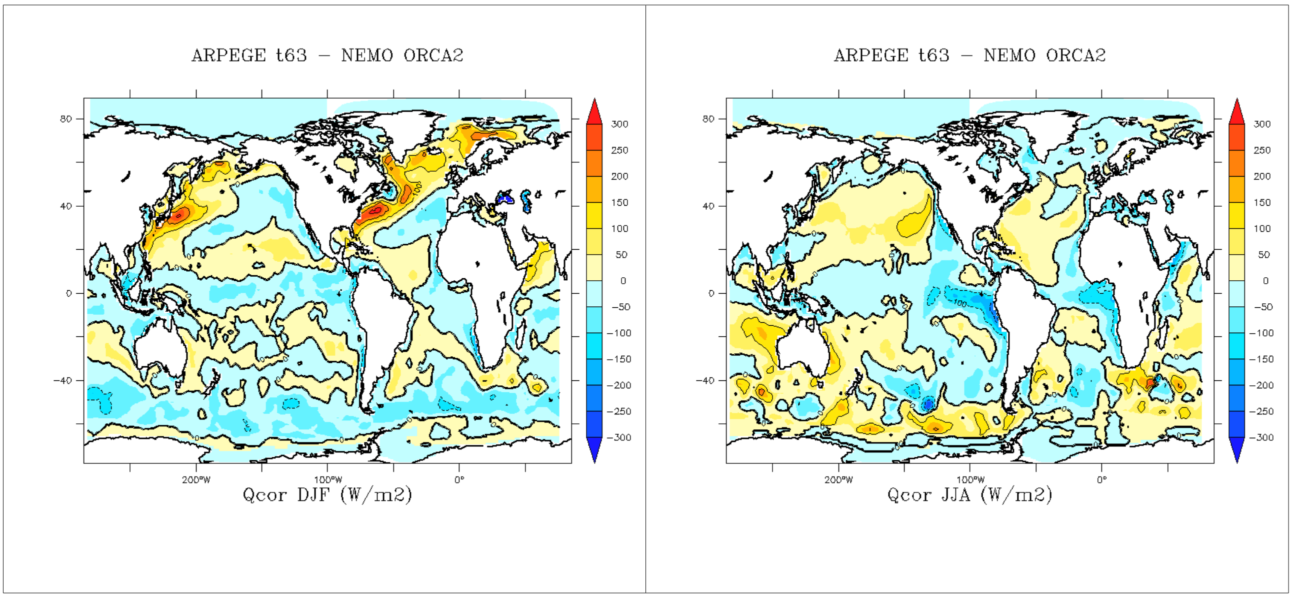

Table 1: Winter (fig 1) and summer (fig 2) values of heat flux correction (W/m2) using ARPEGE-NEMO low resolution model

Applying those corrections during a 35 years long coupled simulation,
mean state differences with Levitus (for both SST and SSS) appear extremely reduced compared to usual climate models (table 2). Global drifts in surface keep reasonable values, even for long term experiments (35 years, figure 5).

The strong damping to ocean climatology inhibits interannual variability in regions such Tropical Pacific where it is driven by ocean current variations: Figure 6 shows that nino3 region spectra power remains weak, without significant frequency peak.

At the opposite, regions where atmosphere strongly influences oceanic variability at interannual time scales (like mid-latitudes and particularly Northern Atlantic), variations of mixed layer depth is observed in the model and correlative atmospheric patterns in surface pressure anomalies better fit observations (figure 7).

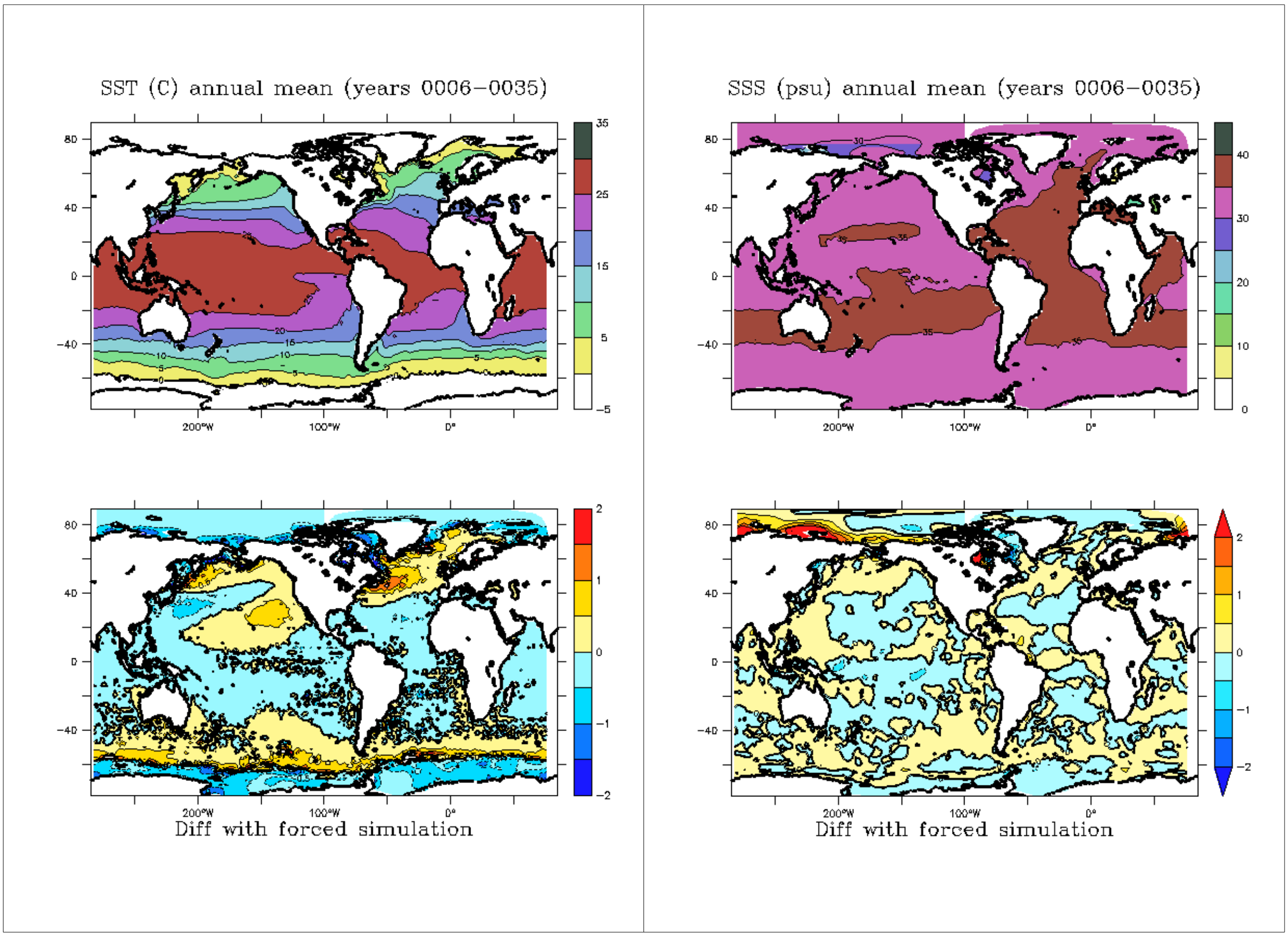

Table 2: Annual mean and difference with Levitus for SST (C, fig 3) and SSS (psu, fig 4)

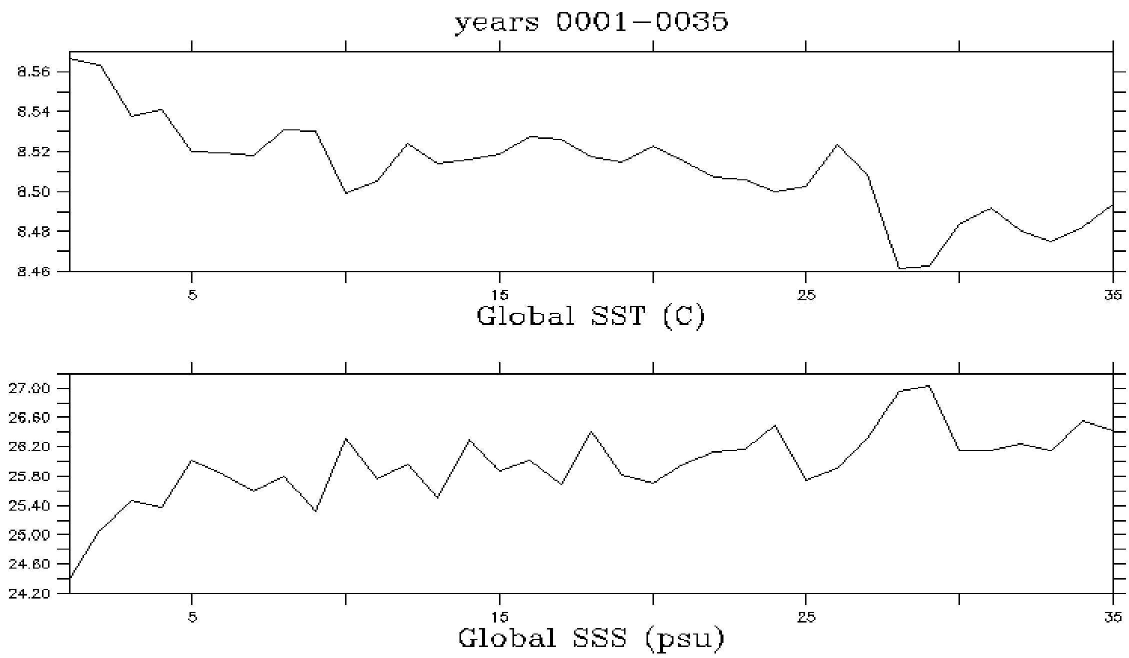

Figure 5: Global drifts for SST and SSS (C, annual means)

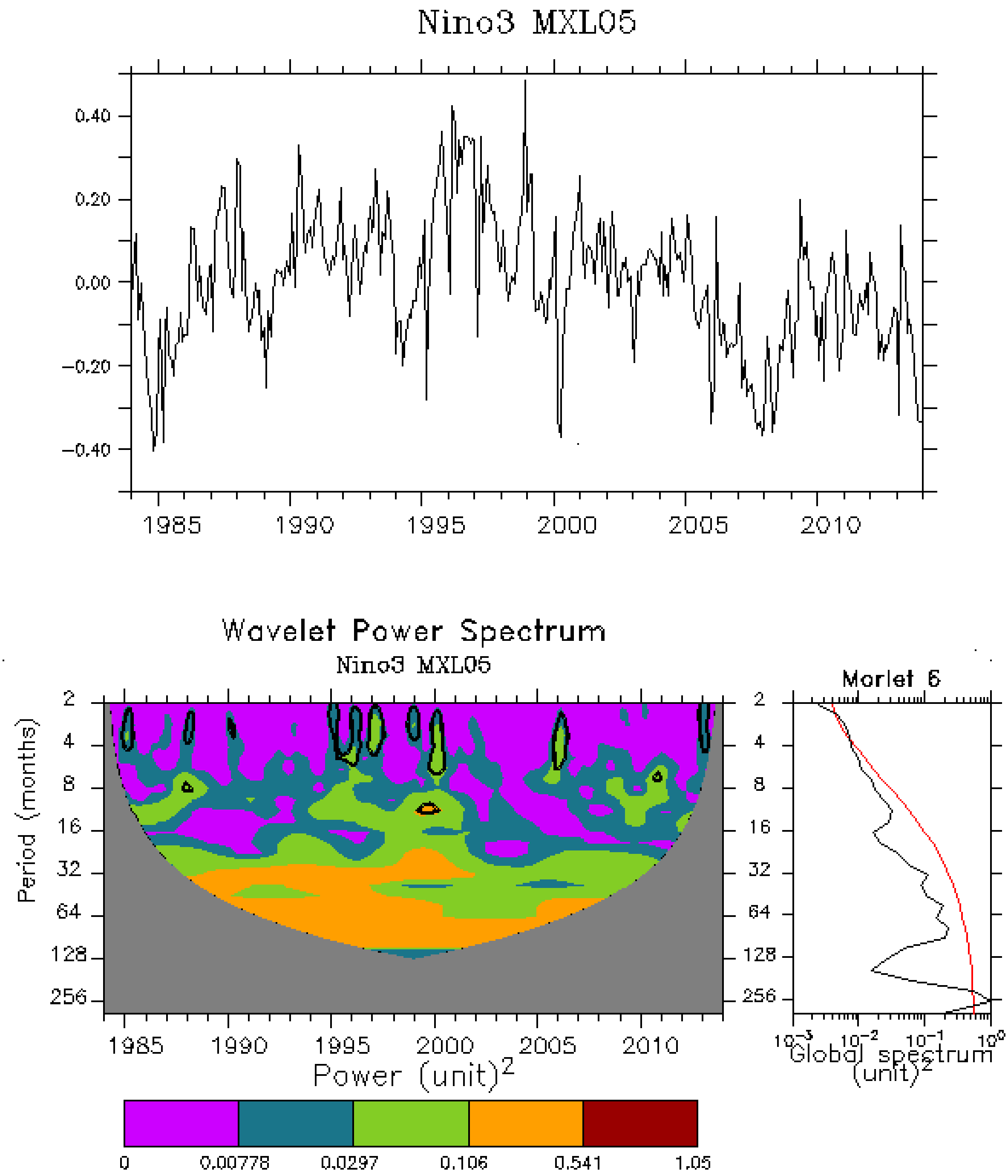

Figure 6: nino3 region SST anomalies (C) and wavelet analysis (monthly means)

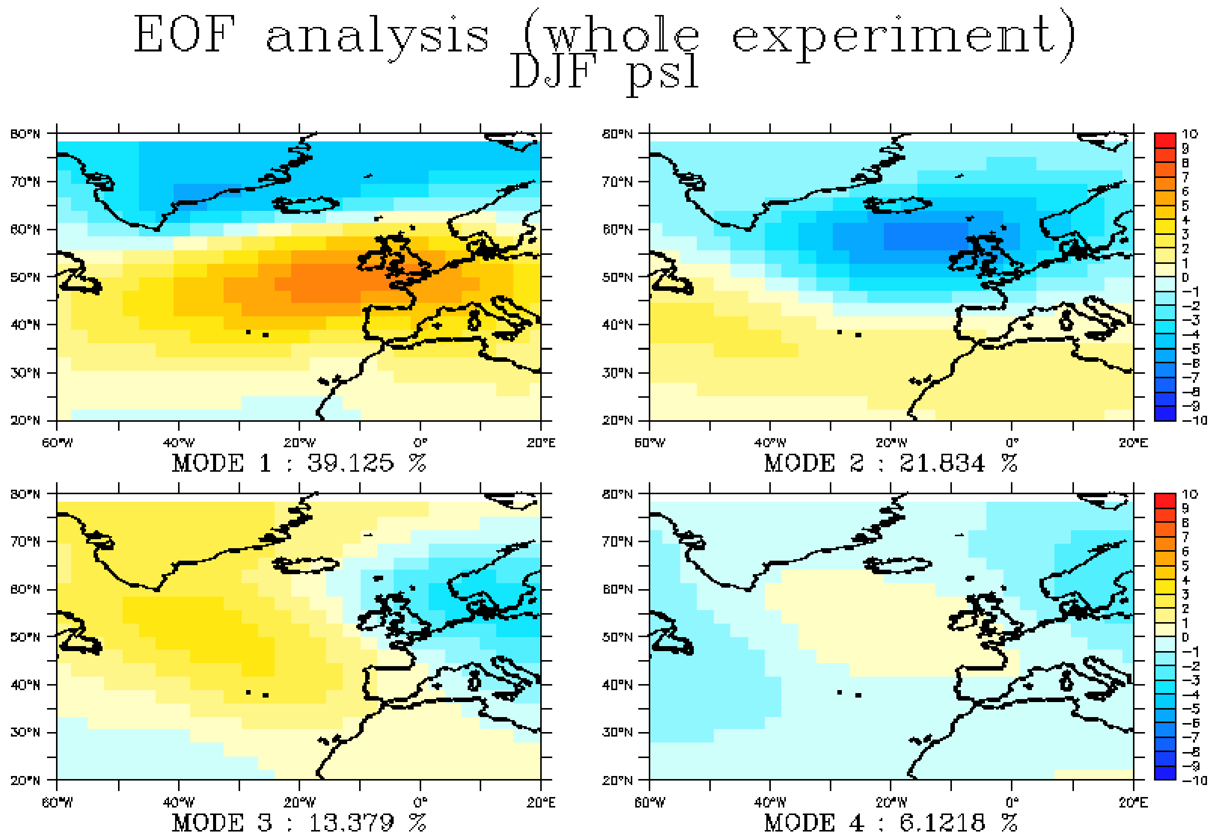

Figure 7: EOF and explained variance for winter monthly means surface pressure (hPa)

Current limitations

* Due to a lack of information on analyzed temperature or salinity at lower time scale, the coupling time step used to calculate our correction is set to one day.

* The mixed layer depth used for damping or correction processing is only calculated following the rho criteria

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Annex 1: detail of NEMO routine modifications

diawri.F90:
    add ioipsl calls for flux corrections output

dtasal.F90 et dtatem.F90:
    calculate day+1 Levitus SST and SSS
    read Levitus on several files at ORCA025 resolution

dynvor.F90:
    limit vorticity to planetary vorticity

limdmp_2.F90:
    99% damping only on ice thickness (no damping on ice extent)

limsbc_2.F90:
    add heat flux correction to qns non solar flux (no correction if ice)
    add water flux to emp and emps

limthd_zdf_2.F90:
    limit ice temperature (ARPEGE-ISBA only)

sbccpl.F90:
    add new coupling fields (received flux corrections)
    send Levitus SST (t_dta instead of tn) before receiving atmospheric fluxes (for flux correction calculation case only)
    anticipate ice cover initialization (for flux correction calculation case only)
    add iom calls for coupling fields outputs (ARPEGE-ISBA only)

sbcice_if.F90:
    force ice cover to observed values

sbcice_lim_2.F90:
    inhibit ice dynamics and transports
    don't do twice ice cover initialization (for flux correction calculation case only)

sbcmod.F90:
    inhibit surface damping

sbc_oce.F90:
    define heat and water flux arrays and nn_cmxl namelist option for Mixed Layer Configuration

sshwzv.F90:
    inhibit crossland advection option

step.F90:

inhibit lateral physics (zps_hde, ldf_slp), bottom diffusion/advection (tra_bbc, tra_bbl_dif, tra_bbl_adv), horizontal & vertical advection (tra_adv), lateral mixing (tra_ldf)

limit dynamics to Coriolis vorticity and vertical diffusion terms

add flux calculation and Levitus reset (for flux correction calculation case only)

inhibit coupling field send, done first in sbccpl (for flux correction calculation case only)

stpctl.F90:

do not print elliptic solver statistics (division by 0)

tradmp.F90:

special restoring for salinity (multiplied by 10)

special restoring below mixed layer only

add option to read restoring term in a file

add option to restore everywhere (from k=2 to k=jpk-1)

tranxt.F90:

add routine tra_mxlwrt for flux correction calculation and diagnostic

add routine tra_mxlini to reset temperature and salinity (tn,tb,sn,sb) to Levitus values (on mixed layer only, not below)

Annex 2: OASIS coupling fields (ARPEGE-NEMO case)

Part One: flux calculations

Coupling field	**NEMO naming rule**	**Sent by**
Levitus surface temperature	O_SSTSST	oce
Observed ice fraction	OIceFrac	oce
Surface stresses	O_OTaux1 , O_OTauy1 , O_OTauy2, O_OTaux2	atm
Total solid and liquid precipitation	OtotSnow , OTotRain	atm
Total evaporation	OTotEvap	atm
Sublimation	OIceEvap	atm
Mixed Ocean/Ice heat fluxes	O_QnsMix , O_QsrMix	atm
Non solar heat flux derivative	O_dQnsdT	atm
10 meter wind module (matches with additional tke source nn_etau= 1)	O_Wind10	atm

Part two: coupled mode with flux correction

Same coupling fields except:

Coupling field	**NEMO naming rule**	**Sent by**
Model SST	O_SSTSST	oce
Model ice fraction	OIceFrac	oce
Heat flux correction	OHeatCor	toy
Water flux correction	O_WatCor	toy