Tutorial 1: Explanation of CPP Options, ocean.in, and i4dvar.in

I4D-Var Tutorial Wiki Page

WC13 C-preprocessing Options

(Basic Configuration)

Momentum Equations Options:

```
#define UV_ADV              including advection terms
#define UV_COR              including Coriolis term
#define DJ_GRADPS           splines density Jacobian PGF
#define UV_QDRAG            quadratic bottom friction
#define UV_VIS2             harmonic horizontal mixing
#define MIX_S_UV            mixing along s-levels
```

Tracers Equations Options:

```
#define TS_U3HADVECTION     3rd-order Upstream H. advection
#define TS_C4VADVECTION     4th-order Centered V. advection
#define TS_DIF2             harmonic horizontal mixing
#define MIX_GEO_TS          mixing along geo-potentials
#define SALINITY            including salinity
#define NONLIN_EOS          nonlinear equation of state

#define ANA_BTFLUX          analytical bottom Temp flux
#define ANA_BSFLUX          analytical bottom Salt flux
```

Vertical Turbulent Mixing Parameterization:

```
#define GLS_MIXING          Generic Length Scale Mixing
#ifdef GLS_MIXING                  (K-omega)
# define N2S2_HORAVG        smoothing of buoyancy/shear
# define KANTHA_CLAYSON     stability function
#endif
```

Atmospheric Boundary Layer Parameterization:

```
#define BULK_FLUXES         Air/sea COARE bulk fluxes

#define DIURNAL_SRFLUX      imposing local diurnal cycle
#define SOLAR_SOURCE        solar radiation source term
#define LONGWAVE_OUT        compute outgoing long wave rad
#define EMINUSP             compute E-P
```

Model Configuration Options:

```
#define SOLVE3D             solve 3D primitive equations
#define CURVGRID            curvilinear grid
#define MASKING             land/sea masking
#define SPHERICAL           spherical grid
#define PROFILE             time profiling

#define SPLINES             parabolic splines
                              reconstruction
```

Lateral Boundary Conditions:

```
#define EASTERN_WALL        closed eastern wall condition

#define WEST_FSCHAPMAN      free-surface, Chapman
#define WEST_M2FLATHER      2D momentum, Flather
#define WEST_M3CLAMPED      3D momentum, clamped
#define WEST_TCLAMPED       tracers, clamped condition

#define NORTH_FSCHAPMAN     free-surface, Chapman
#define NORTH_M2FLATHER     2D momentum, Flather
#define NORTH_M3CLAMPED     3D momentum, clamped
#define NORTH_TCLAMPED      tracers, clamped

#define SOUTH_FSCHAPMAN     free-surface, Chapman
#define SOUTH_M2FLATHER     2D momentum, Flather
#define SOUTH_M3CLAMPED     3D momentum, clamped
#define SOUTH_TCLAMPED      tracer, clamped

#define SPONGE              enhanced viscosity/diffusion
                              areas
```

WC13 C-preprocessing Options
(I4D-Var Configuration)

Algorithm:

```
#define IS4DVAR              primal form of incremental strong constraint 4D-Var
```

Control Vector:

```
#define ADJUST_BOUNDARY      open boundary conditions increments
#define ADJUST_STFLUX        surface tracer flux increments
#define ADJUST_WSTRESS       surface wind stress increments
```

Error Covariance Modeling:

```
#define VcONVOLUTION         Vertical correlation modeling
#define IMPLICIT_VCON        Implicit vertical diffusion operator
#define BALANCE_OPERATOR     Multivariate balance constraint
#ifdef BALANCE_OPERATOR
# define ZETA_ELLIPTIC       SSH elliptic equation method
#endif
```

Prior:

```
#define FORWARD_READ         read basic state linearization in TLM and ADM files
#define FORWARD_WRITE        writing basic state by the NLM
#define FORWARD_MIXING       processing basic state vertical mixing coefficients
#define NL_BULK_FLUXES       surface kinematic fluxes from nonlinear model
```

I/O :

```
#define OUT_DOUBLE           double precision data in output NLM, TLM, and ADM
```

Include File: wc13.h

```
/*
** svn $Id: wc13.h 476 2010-06-26 20:25:30Z arango $
*******************************************************************************
** Copyright (c) 2002-2010 The ROMS/TOMS Group                               **
**   Licensed under a MIT/X style license                                    **
**   See License_ROMS.txt                                                    **
*******************************************************************************
**
** Options for the California Current System, 1/3 degree resolution.
**
** Application flag:   WC13
** Input script:       ocean_wc13.in
**                     s4dvar.in
**
** Available Drivers options: choose only one and activate it in the
**                            build.sh script (MY_CPP_FLAGS definition)
**
**  AD_SENSITIVITY            Adjoint Sensitivity Driver
**  AFT_EIGENMODES            Adjoint Finite Time Eigenmodes
**  ARRAY_MODES               Stabilized representer matrix array modes
**  CLIPPING                  Stabilized representer matrix clipped analysis
**  CORRELATION               Background-error Correlation Check
**  GRADIENT_CHECK            TLM/ADM Gradient Check
**  FORCING_SV                Forcing Singular Vectors
**  FT_EIGENMODES             Finite Time Eigenmodes
**  IS4DVAR                   Incremental, strong constraint 4DVAR
**  NLM_DRIVER                Nonlinear Basic State trajectory
**  OPT_PERTURBATION          Optimal perturbations
**  PICARD_TEST               Picard Iterations Test
**  R_SYMMETRY                Representer Matrix Symmetry Test
**  SANITY_CHECK              Sanity Check
**  SO_SEMI                   Stochastic Optimals: Semi-norm
```

ROMS Standard Input Parameters

```
   NtileI == 2           ! I-direction partition
   NtileJ == 2           ! J-direction partition
. . .
   NTIMES == 192         ! Number of time-steps (4 days)
       DT == 1800.0d0    ! Number of time-steps (48 steps per day)
. . .
   Nouter =  1           ! Number of 4D-Var outer loops
   Ninner =  50          ! Number of 4D-Var inner loops
. . .
  LDEFOUT == T           ! Switch to create new history files
     NHIS == 48          ! Steps between writing of NLM data (daily)
  NDEFHIS == 0           ! Steps between creation of new NLM files
. . .
LcycleTLM == F           ! Switch to recycle records in TLM file
     NTLM == 48          ! Steps between writing of TLM data (daily)
  NDEFTLM == 0           ! Steps between creation of new TLM files
LcycleADJ == T           ! Switch to recycle records in ADM file
     NADJ == 192         ! Steps between writing of ADM data (strong constraint)
  NDEFADJ == 0           ! Steps between creation of new ADM files
     NSFF == 48          ! Steps between adjustment of surface fluxes (daily)
     NOBC == 48          ! Steps between adjustment of open boundary (daily)
. .
  APARNAM =  i4dvar.in   ! I4D-Var standard input parameters
```

Standard Input File: ocean_wc13.in

```
!
!  ROMS/TOMS Standard Input parameters.
!
!svn $Id: ocean_wc13.in 476 2010-06-26 20:25:30Z arango $
!========================================================= Hernan G. Arango ===
!  Copyright (c) 2002-2010 The ROMS/TOMS Group                                 !
!    Licensed under a MIT/X style license                                      !
!    See License_ROMS.txt                                                      !
!==============================================================================
!                                                                              !
! Input parameters can be entered in ANY order, provided that the parameter   !
! KEYWORD (usually, upper case) is typed correctly followed by "="  or "=="   !
! symbols. Any comment lines are allowed and must begin with an exclamation   !
! mark (!) in column one.  Comments may  appear to the right of a parameter   !
! specification to improve documentation.  Comments will be ignored  during   !
! reading.  Blank lines are also allowed and ignored. Continuation lines in   !
! a parameter specification are allowed and must be preceded by a backslash   !
! (\).  In some instances, more than one value is required for a parameter.   !
! If fewer values are provided, the  last value  is assigned for the entire   !
! parameter array.  The multiplication symbol (*),  without blank spaces in   !
! between, is allowed for a parameter specification.  For example, in a two   !
! grids nested application:                                                    !
!                                                                              !
!    AKT_BAK == 2*1.0d-6  2*5.0d-6              ! m2/s                         !
!                                                                              !
! indicates that the first two entries of array AKT_BAK,  in fortran column-  !
! major order, will have the same value of "1.0d-6" for grid 1,  whereas the  !
! next two entries will have the same value of "5.0d-6" for grid 2.            !
!                                                                              !
! In multiple levels of nesting and/or multiple connected domains  step-ups,  !
! "Ngrids" entries are expected for some of these parameters.  In such case,  !
! the order of the entries for a parameter is extremely important.  It  must  !
```

4D-Var Parameters: Normalization

```
Nmethod  == 0                   ! normalization method
Nrandom  == 5000                ! randomization iterations
. . .
LdefNRM  == F F F F             ! Create a new normalization files
LwrtNRM  == F F F F             ! Compute and write normalization
. . .
CnormI(isFsur) =  T             ! 2D variable at RHO-points
CnormI(isUbar) =  T             ! 2D variable at U-points
CnormI(isVbar) =  T             ! 2D variable at V-points
CnormI(isUvel) =  T             ! 3D variable at U-points
CnormI(isVvel) =  T             ! 3D variable at V-points
CnormI(isTvar) =  T T           ! NT tracers
. . .
CnormB(isFsur) =  T             ! 2D variable at RHO-points
CnormB(isUbar) =  T             ! 2D variable at U-points
CnormB(isVbar) =  T             ! 2D variable at V-points
CnormB(isUvel) =  T             ! 3D variable at U-points
CnormB(isVvel) =  T             ! 3D variable at V-points
CnormB(isTvar) =  T T           ! NT tracers
. . .
CnormF(isUstr) =  T             ! surface U-momentum stress
CnormF(isVstr) =  T             ! surface V-momentum stress
CnormF(isTsur) =  T T           ! NT surface tracers flux
. . .
NRMnameM == wc13_nrm_m.nc       ! model error (weak constraint)
NRMnameI == wc13_nrm_i.nc       ! initial conditions
NRMnameB == wc13_nrm_b.nc       ! open boundary conditions
NRMnameF == wc13_nrm_f.nc       ! surface forcing (wind stress and net heat flux)
```

4D-Var Parameters: Decorrelation Scales

```
Horizontal and vertical stability and accuracy factors (< 1):

!                  IC       Model    OBC      Sur For

        Hgamma =  0.5      0.5      0.5      0.5        ! horizontal operator
        Vgamma =  0.0005   0.0005   0.0005   0.0005     ! vertical operator

Initial conditions correlations (m):

HdecayI(isFsur) ==  50.0d+3                              ! free-surface
HdecayI(isUbar) ==  50.0d+3                              ! 2D U-momentum
HdecayI(isVbar) ==  50.0d+3                              ! 2D V-momentum
HdecayI(isUvel) ==  50.0d+3                              ! 3D U-momentum
HdecayI(isVvel) ==  50.0d+3                              ! 3D V-momentum
HdecayI(isTvar) ==  50.0d+3   50.0d+3                    ! 1:NT tracers

VdecayI(isUvel) ==  30.0d0                               ! 3D U-momentum
VdecayI(isVvel) ==  30.0d0                               ! 3D V-momentum
VdecayI(isTvar) ==  30.0d0    30.0d0                     ! 1:NT tracers

Surface forcing correlations (m):

HdecayF(isUstr) == 100.0d+3                        ! surface U-momentum stress
HdecayF(isVstr) == 100.0d+3                        ! surface V-momentum stress
HdecayF(isTsur) == 100.0d+3  100.0d+3              ! 1:NT surface tracer flux
```

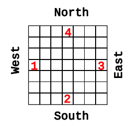
4D-Var Parameters: Decorrelation Scales

Open boundary conditions correlations (m):

```
!                   1: west  2: south  3: east  4: north

HdecayB(isFsur) == 100.0d+3 100.0d+3 100.0d+3 100.0d+3    ! free-surface
HdecayB(isUbar) == 100.0d+3 100.0d+3 100.0d+3 100.0d+3    ! 2D U-momentum
HdecayB(isVbar) == 100.0d+3 100.0d+3 100.0d+3 100.0d+3    ! 2D V-momentum
HdecayB(isUvel) == 100.0d+3 100.0d+3 100.0d+3 100.0d+3    ! 3D U-momentum
HdecayB(isVvel) == 100.0d+3 100.0d+3 100.0d+3 100.0d+3    ! 3D V-momentum
HdecayB(isTvar) == 4*100.0d+3  4*100.0d+3                 ! 1:NT tracers

VdecayB(isUvel) ==  30.0d0   30.0d0   30.0d0   30.0d0     ! 3D U-momentum
VdecayB(isVvel) ==  30.0d0   30.0d0   30.0d0   30.0d0     ! 3D V-momentum
VdecayB(isTvar) == 4*30.d0  4*30.d0                       ! 1:NT tracers
```

Boundary edges to adjust (logical switches):

```
!                    1   2   3   4

   Lobc(isFsur) ==   T   T   F   T          ! free-surface
   Lobc(isUbar) ==   T   T   F   T          ! 2D U-momentum
   Lobc(isVbar) ==   T   T   F   T          ! 2D V-momentum
   Lobc(isUvel) ==   T   T   F   T          ! 3D U-momentum
   Lobc(isVvel) ==   T   T   F   T          ! 3D V-momentum

   Lobc(isTvar) ==   T   T   F   T  \
                     T   T   F   T
```



4D-Var Parameters: Balance Operator

SSH, elliptic solver:

```
        Nbico == 200                       ! biconjugate gradient iterarion
```

SSH, integration of hydrostatic equation:

```
      LNM_depth == 1000.0d0                ! level of no motion (m, positive)

      LNM_flag  =  1                       ! Integration flag

                                             [0] integrate from bottom to surface
                                             [1] integrate from LNM to surface or
                                                 from local depth, if shallower
```

Balanced salinity empirical T-S relationship:

```
       dTdz_min == 0.001d0                 ! minimun dT/dz (Celsius/m)
       ml_depth == 100.0d0                 ! mixed-layer depth (m; positive)
```

State Variables switches:

```
balance(isSalt) =  T                       ! salinity
balance(isFsur) =  T                       ! free-sruface
balance(isVbar) =  F                       ! 2D momentum (ubar, vbar)
balance(isVvel) =  T                       ! 3D momentum (u, v)
```

Other 4D-Var Parameters

Lanczos algorithm parameters:

```
        GradErr = 1.0d-4               ! Upper bound on the relative error of the
                                         gradient

       HevecErr = 1.0d-1               ! Maximum error bound on Hessian eigenvectors

     LhessianEV = T                    ! Compute approximated hessian eigen pairs
```

Preconditioning:

```
       Lprecond = F                    ! Limitted-Memory Preconditioner: Spectral

          Lritz = T                    ! Limitted-Memory Preconditioner: Ritz

        NritzEV = 0                    ! If preconditioning, number of eigenvectors
                                         if NritzEV = 0, use HevecErr
```

Weak constraint:

```
      LhotStart = T                    ! Hot start in subsequent outer loops

         NpostI = 50                   ! Posterior error analysis Lanczos iterations

           Nvct = 50                   ! Stabilized representer matrix eigenvector
                                         to process

      tl_M2diff == 0.0d0               ! RPM relaxation (m2/s), 2D momentum
      tl_M3diff == 0.0d0               ! RPM relaxation (m2/s), 3D momentum

       tl_Tdiff == 0.0d0  0.0d0        ! RPM relaxation (m2/s), tracers
```

I4D-Var Parameters File: i4dvar.in

```
!  4DVar assimilation input parameters.
!
!svn $Id: s4dvar.in 1256 2010-06-12 21:59:26Z arango $
!========================================================= Hernan G. Arango ===
!  Copyright (c) 2002-2010 The ROMS/TOMS Group                                !
!    Licensed under a MIT/X style license                                     !
!    See License_ROMS.txt                                                     !
!==============================================================================
!                                                                             !
! Input parameters can be entered in ANY order, provided that the parameter   !
! KEYWORD (usually, upper case) is typed correctly followed by "="  or "=="   !
! symbols. Any comment lines are allowed and must begin with an exclamation   !
! mark (!) in column one.  Comments may  appear to the right of a parameter   !
! specification to improve documentation.  Comments will be ignored  during   !
! reading.  Blank lines are also allowed and ignored. Continuation lines in   !
! a parameter specification are allowed and must be preceded by a backslash   !
! (\).  In some instances, more than one value is required for a parameter.   !
! If fewer values are provided, the  last value  is assigned for the entire   !
! parameter array.  The multiplication symbol (*),  without blank spaces in   !
! between, is allowed for a parameter specification.  For example, in a two   !
! grids nested application:                                                   !
!                                                                             !
!    AKT_BAK == 2*1.0d-6  2*5.0d-6              ! m2/s                        !
!                                                                             !
! indicates that the first two entries of array AKT_BAK,  in fortran column-  !
! major order, will have the same value of "1.0d-6" for grid 1,  whereas the  !
! next two entries will have the same value of "5.0d-6" for grid 2.           !
!                                                                             !
! In multiple levels of nesting and/or multiple connected domains  step-ups,  !
! "Ngrids" entries are expected for some of these parameters.  In such case,  !
! the order of the entries for a parameter is extremely important.  It  must  !
! follow the same order (1:Ngrids) as in the state variable declaration. The  !
```

I4D-Var Job Script: job_i4dvar.sh

1. Set path definition to one directory up in the tree.

   ```
   set Dir = `dirname ${PWD}`
   ```

2. Set string manipulations perl script.

   ```
   set SUBSTITUTE = ${ROMS_ROOT}/ROMS/Bin/substitute
   ```

3. Copy nonlinear model initial conditions file.

   ```
   cp -p ${Dir}/Data/wc13_ini.nc wc13_ini.nc
   ```

4. Set initial conditions, boundary conditions and surface forcing error covariance standard deviations files.

   ```
   set STDnameI = ../Data/wc13_std_i.nc
   set STDnameB = ../Data/wc13_std_b.nc
   set STDnameF = ../Data/wc13_std_f.nc
   ```

5. Set initial conditions, boundary conditions and surface forcing error covariance normalization factors files.

   ```
   set NRMnameI = ../Data/wc13_nrm_i.nc
   set NRMnameB = ../Data/wc13_nrm_b.nc
   set NRMnameF = ../Data/wc13_nrm_f.nc
   ```

6. Set observations file.

   ```
   set OBSname = wc13_obs.nc
   ```

7. Get a clean copy of the observation file. This is really important since this file is modified.

   ```
   cp -p ${Dir}/Data/${OBSname} .
   ```

8. Modify 4D-Var template input script and specify above files.

   ```
   set I4DVAR = i4dvar.in
   if (-e $I4DVAR) then
     /bin/rm $I4DVAR
   endif
   cp s4dvar.in $I4DVAR

   $SUBSTITUTE $I4DVAR ocean_std_i.nc $STDnameI
   $SUBSTITUTE $I4DVAR ocean_std_b.nc $STDnameB
   $SUBSTITUTE $I4DVAR ocean_std_f.nc $STDnameF
   $SUBSTITUTE $I4DVAR ocean_nrm_i.nc $NRMnameI
   $SUBSTITUTE $I4DVAR ocean_nrm_b.nc $NRMnameB
   $SUBSTITUTE $I4DVAR ocean_nrm_f.nc $NRMnameF
   $SUBSTITUTE $I4DVAR ocean_obs.nc   $OBSname
   $SUBSTITUTE $I4DVAR ocean_hss.nc   wc13_hss.nc
   $SUBSTITUTE $I4DVAR ocean_lcz.nc   wc13_lcz.nc
   $SUBSTITUTE $I4DVAR ocean_mod.nc   wc13_mod.nc
   $SUBSTITUTE $I4DVAR ocean_err.nc   wc13_err.nc
   ```

I4D-Var Job Script File: job_i4dvar.sh

```
#!/bin/csh -f
#
# svn $Id: job_i4dvar.sh 474 2010-06-25 20:19:44Z arango $
#######################################################################
# Copyright (c) 2002-2010 The ROMS/TOMS Group                         #
#   Licensed under a MIT/X style license                              #
#   See License_ROMS.txt                                              #
#######################################################################
#                                                                     #
# Incremental strong constraint I4D-Var job script:                   #
#                                                                     #
# This script NEEDS to be run before any run:                         #
#                                                                     #
#   (1) It copies a new clean nonlinear model initial conditions      #
#       file. The nonlinear model is initialized from the             #
#       background or reference state.                                #
#   (2) Specify initial conditions, boundary conditions, and surface  #
#       forcing error convariance input standard deviations files.    #
#   (3) Specify initial conditions, boundary conditions, and surface  #
#       forcing error convariance input/output normalization factors  #
#       files.                                                        #
#   (4) Copy a clean copy of the observations NetCDF file.            #
#   (5) Create 4D-Var input script "i4dvar.in" from template and      #
#       specify the error covariance standard deviation, error        #
#       covariance normalization factors, and observation files to    #
#       be used.                                                      #
#                                                                     #
#######################################################################

# Set path definition to one directory up in the tree.

 set Dir=`dirname ${PWD}`
```

Compile: build.sh

1. Set a local environmental variable to define the path to the directories where all this project's files are kept.

```
setenv MY_ROOT_DIR          /home/arango/ocean/toms/repository
setenv MY_PROJECT_DIR       ${PWD}
```

2. Location of your ROMS source code.

```
setenv MY_ROMS_SRC          ${MY_ROOT_DIR}/branches/arango
```

3. Buld script invoked CPP options.

```
setenv MY_CPP_FLAGS "-DIS4DVAR"
```

4. Compiler selection environment variables.

```
setenv USE_MPI             on
setenv USE_MPIF90          on
setenv FORT                pgi
```

5. Use custom library paths.

```
#setenv USE_MY_LIBS         on
```

Libraries for PGI

```
if ($?USE_MY_LIBS) then
  switch ($FORT)
    case "pgi"
      setenv ARPACK_LIBDIR      /opt/pgisoft/serial/ARPACK
      if ($?USE_MPI) then
        setenv PARPACK_LIBDIR   /opt/pgisoft/mpich/PARPACK
      endif

      if ($?USE_NETCDF4) then
        if ($?USE_MPI) then
          setenv NETCDF_INCDIR  /opt/pgisoft/mpich/netcdf4/include
          setenv NETCDF_LIBDIR  /opt/pgisoft/mpich/netcdf4/lib
          setenv HDF5_LIBDIR    /opt/pgisoft/mpich/hdf5/lib
        else
          setenv NETCDF_INCDIR  /opt/pgisoft/serial/netcdf4/include
          setenv NETCDF_LIBDIR  /opt/pgisoft/serial/netcdf4/lib
          setenv HDF5_LIBDIR    /opt/pgisoft/serial/hdf5/lib
        endif
      else
        setenv NETCDF_INCDIR    /opt/pgisoft/serial/netcdf3/include
        setenv NETCDF_LIBDIR    /opt/pgisoft/serial/netcdf3/lib
      endif
    breaksw
```

Build Script: build.sh

```
#!/bin/csh -f
#
# svn $Id: build.sh 474 2010-06-25 20:19:44Z arango $
#::::::::::::::::::::::::::::::::::::::::::::::::::::::::: John Wilkin :::
# Copyright (c) 2002-2010 The ROMS/TOMS Group                           :::
#   Licensed under a MIT/X style license                                :::
#   See License_ROMS.txt                                                :::
#:::::::::::::::::::::::::::::::::::::::::::::::::::::: Hernan G. Arango :::
#                                                                       :::
# ROMS/TOMS Compiling Script                                            :::
#                                                                       :::
# Script to compile an user application where the application-specific  :::
# files are kept separate from the ROMS source code.                    :::
#                                                                       :::
# Q: How/why does this script work?                                     :::
#                                                                       :::
# A: The ROMS makefile configures user-defined options with a set of    :::
#    flags such as ROMS_APPLICATION. Browse the makefile to see these.  :::
#    If an option in the makefile uses the syntax ?= in setting the     :::
#    default, this means that make will check whether an environment    :::
#    variable by that name is set in the shell that calls make. If so   :::
#    the environment variable value overrides the default (and the      :::
#    user need not maintain separate makefiles, or frequently edit      :::
#    the makefile, to run separate applications).                       :::
#                                                                       :::
# Usage:                                                                :::
#                                                                       :::
#    ./build.sh [options]                                               :::
#                                                                       :::
# Options:                                                              :::
#                                                                       :::
#    -j [N]      Compile in parallel using N CPUs                       :::
```