Surfex, sea-ice, sea-ice schemes and Gelato

Stephane Sénési – 2 october 2014 - Glt_Sfx_Report_V6

This document is part of Surfex V8 release notes. It reports on introducing in Surfex :

- handling the turbulent fluxes at the sea-ice/atmosphere interface as dedicated fields (besides open -or ambiguous- sea fluxes fields); so allowing to handle both open-sea an sea-ice in each grid mesh
- handling sea-ice concentration, for computing mixed fluxes over mixed sea and sea-ice
- allowing for forcing sea-ice concentration and for nudging sea-ice concentration and/or thickness
- handling of sea surface salinity (including external fields) [this handling was later one sensibly moved to another Surfex module (coupling_seaflux), before release of V8]
- handling sea-ice schemes,
- and specifically handling sea-ice model Gelato

It addresses the following aspects :

- changes occurring in physics and outputs
- tests which have been conducted
- current shortcomings
- implementation details, which are relevant mainly for Surfex and Gelato maintainers
- hints for implementing alternate sea-ice schemes

It is not a user's guide for using sea-ice schemes in Surfex. Such a user's guide must be looked for in the relevant section of Surfex user's guide. We assume that the reader is familiar with that section of the user's guide.

Changes

In 2014, the handling of sea-ice concentration fractional values and of sea-ice prognostic schemes was introduced in Surfex V8.0, and applied to embedding the 1-dimensional version of sea-ice model Gelato V6.0.47

In this version, the handling of sea-ice concentration fractional values is activated when one of these conditions occur :
   - a sea-ice scheme is activated (e.g. CSEAICE_SCHEME='GELATO') , or
   - a sea-ice concentration forcing field is provided (CINTERPOL_SIC /= 'NONE') (in that case, for the computation of fluxes, the SST field is also interpreted as sea-ice temperature where sea-ice concentration is not zero, and sea-ice albedo is set to a constant)

In those cases, the provided sea surface diagnostics are linearly weighted averages of diagnostics computed separately over open sea and sea-ice (except for Z0, for which weighting is logarithmic); this contrast with the previous setting where each diagnostic field included either a sea-ice or an open sea value depending on a binary decision about sea-ice occurrence, and where sea-ice was actually managed only through external coupling (i.e. with flag LCPL_ESM set to 'true'). The weights are based on the sea-ice concentration fraction. For each diagnostic on the mixed surface, a sea-ice-only diagnostic is also provided

Also, fields fed back to the atmosphere by routine coupling_seaflux are then linearly weighted averages over both surfaces for all variables except for the radiative temperature; the latter is computed in order to be consistent with the linearly weighted averages of emissivity and of upward long wave radiative flux; this latter change applies also for the ESM configuration, except if flag LREPROD_OPER is set (this flag, described elsewhere, allows to ensure backward compatibility to some older version of Surfex).

Gelato sea-ice scheme is fed with atmospheric fields computed using the same routine as for the coupling to external ocean and sea-ice models in the ESM configuration; this ensures consistency between both configurations for this direction of the coupling (except of course that the internal sea-ice scheme is 1-d only)

Gelato sea-ice scheme is fed with oceanic fields (Sea Surface Temperature and Salinity) handled by the existing Surfex mechanism based on daily interpolation of monthly fields (or constant fields, or even uniform values, or, for the SST only, by the oceanic mixed layer scheme included in Surfex if activated); it can also be fed with a nudging Sea Ice concentration field, which is provided in the same way (external fields or uniform value) or derived from the SST field. This SST field used by Gelato is however forced to be lower than salinity-dependant freezing point temperature on locations showing some sea-ice

During the testing, it appeared that the earlier choice regarding the computation of turbulent exchange coefficients on sea-ice (it was then only done in ESM mode) was sub-optimal : it involves using routine SURFACE_AERO_COND with a Cd coefficient based on sea-ice temperature, which actually leads to instabilities of ice surface temperature under strong temperature advections and is not consistent with the proposals of a number of authors. So, provision has been made to set Cd, Ch and Ce for sea-ice to a fixed value through a namelist parameter, and the recommended choice si 0.0015; this has however not been set as the default behaviour; for reproducing the earlier behaviour, XCD_ICE_CST should not be set (the default value, 0., is interpreted by the code as 'compute as before')

Note : Gelato sea-ice scheme cannot work yet in OpenMP multi-threading mode

Tests undertaken

Tests on a Linux PC and on a single point have been conducted for three different locations, namely the North Pole and two places showing significant intra-annual sea-ice concentration variability, one between Greeland and Newfoundland (71.5N/56.5W), and one in the Southern Ocean (65.5S/5.5W). They used ERA-Interim and HadISST forcings, over the period 1980-1999. Sea surface salinity was constant at 33 psu. Surface and Gelato time step were set to 3h. The simulated mean state and variability of sea-ice temperature, concentration and thickness are realistic, and so is the snow depth over sea-ice. The fields fed back to the atmosphere also show realistic values, which are significantly improved thanks to a sea-ice surface temperature which responds to the atmospheric forcing. The namelist used is reproduced below. When nudged with the sea-ice concentration deduced from HadISST values (namely with SIC=1 where SST <= -1.8°C), Gelato also responds reasonably at the chosen North-Atlantic location, i.e. the sea-ice concentration is much more sensitive to the SST reaching the freezing level. See appendix B

A 2D test has been conducted using the global Arpege T127 reduced Grid, and GPCC forcing, for year 1980. The mean spatial extent and thickness of sea-ice and their variability are realistic sea-ice. For this test, the 'updcli' tool was adapted to Surfex-only PREP.fa update

A non-regression test was conducted, based on the 2d test configuration above. Original and modified versions of Surfex produced, for a one month run, the same output values (either on sea only or for aggregated values)

Nudging the sea-ice concentration has been tested both in 0d mode (see appendix B)

Nudging the sea-ice thickness has been tested in T127 mode. This implied improving updcli and building some tools for feeding the PREP.fa file with SIT (or SSS, or SIC) fields. The impact of such a constraint has been assessed only through the change in the Northern hemisphere total ice volume (from TBD to TBD thousands of km**3, when using an e-folding time of 0.2 days on a three-day long run starting without sea-ice constrained with a COMBINE historical simulation results from 19800101)

MPI : a T127 run on PC, with one or two MPI tasks, produces the same results, as tested on the difference on sea-ice diagnostics (sea-ice concentration, thickness, temperature and albedo)

Surfex embedded in Arpege : a series of AMIP-like experiments were conducted,
the first one aimed at verifying that, when Gelato is not activated, former results are reproduced using the Gelato-enabled version of the code
the second one documents the impact of setting turbulent exchange coefficients to a fixed value
the third one documents the impact of activating Gelato
the fourth one activates the nudging of sea-ice cover using AMIP-provided forcing data

Later on, Matthieu Chevallier undertook some tests, still in Arpege embedded mode on T127 grid : nudging sea-ice cover and/or sea-ice thickness with various data sources on 20-year long runs, and providing Surfex with varying SSS (from ORAS4 dataset)

CPU cost : it was assessed on the 2d global test described above; a one month simulation treating only the sea, without any output field, on a CNRM Linux server, in mono-processor mono-thread mode, lasts for 2'27" with Gelato (with one ice category) and 1'01" without it. This additional cost is however small with respect to the cost of the continental scheme

Machines and compilers : tests on PC were run using gfortran; tests the BullX 'beaufix' computer used Intel fortran (ifort)

Shortcomings of the current implementation

- Gelato native restarts cannot be used in the PREP phase (i.e. as initial state)
- the sensible heat exchange between sea-ice and ocean is computed by Gelato using a simplified scheme (while the ocean mixed layer scheme could be modified to compute it more precisely)
- more generally, there is no coupling with the ocean mixed layer scheme (which, by the way, does not yet compute Sea Surface Salinity evolution); this will be implemented in a later Surfex version
- multiple ice categories can be activated in Gelato (through the 'wizzard' mode) but are not handled separately for flux computation in Surfex (same as for ESM in Surfex V7 : a sea-ice temperature averaged over sea-ice categories is sent by Gelato to Surfex, and Gelato uses a single tunable value of the derivative of flux w.r.t. to sea-ice temperature for deriving fluxes over each category); implementing full mulit-catgeory fluxes will be done in a later version

Details of implementation and provided changes - overarching assumption

An overarching assumption used in the development is that, in order to allow for sensible long-term maintenance, there should be only one version of Gelato sources for all host models (i.e. Nemo, Surfex and stand-alone Gelato driver); it implied that, beyond a necessary upgrade of Gelato that allowed it to inherit its domain-distribution from the host model, and that applied to Surfex and Nemo, there has been only minor changes to the Gelato source codes for Surfex, the changes were designed to be compatible with running Gelato in Nemo. This has forbidden us, for instance, to modify Gelato to work on native 1D fields like Surfex works, and forced us to use the data structure proposed by Gelato for interfacing with the host model. Further details are given below.

Details of implementation and provided changes, from the Surfex and Arpege perspective

The source code used for this development is derived from Surfex release number 1889, and was tested in Arpege 6.0 using a version based on that release and provided in March 2014 on computer beaufix as ~colinj/rootpack/arp601_export.00.IMPI411IFC1301.2cx

In directory src/SURFEX, 45 surfex modules have been modified, and 7 modules named *sea-ice* have been created. This does not include any 'modd_sea-ice' nor 'init_sea-ice' nor 'diag_sea-ice' module, for which the corresponding '*seaflux*' modules have been modified instead.

In src/OFFLIN, modules 'offline' and 'init_outfn_sean' have been modified. Module 'offline' calls Gelato routines OPNDIA and CLSDIA, for allowing expert Gelato users to output Gelato native diags in Gelato formats, by the master processor; no I/O is done by these calls in case of standard Gelato use; this calls do not occur when running in Arpege

The 98 relevant Gelato source code modules (from Gelato V6.0.47) have been included in the Surfex distribution tree as directory src/LIB/GELATO. This does not include all Gelato sources (e.g. dynamics is not included). This set of modules is released under the CeCILL-C licence. Some of these modules had to be instrumented with a cpp_key labeled 'in_surfex' (and also with the Surfex 'NOMPI' cpp key for also allowing Surfex non-MPI compilation and runs). For compilation in Surfex, Makefile.SURFEX.mk has been changed accordingly.

The Surfex 'Makefile' has been modified in order to avoid compiling Emacs auto-save files (whose name begins with '#.')

The Surfex 'Makefile.SURFEX.mk' has been modified in order to trigger the compilation of Gelato sources; it sets CPP flag 'in_surfex' for this compilation

The Arpege 'gmkfile' has been modified to introduce a CPP key 'in_arpege' for Surfex compilation, which allows for disabling some MPI communication when running in Arpege (see below); it also sets CPP key 'in_surfex'.

Regarding MPI communication and Gelato global diagnostics :

- when ran outside of Arpege, the Gelato interface calls the Gelato function mpp_sum twice, which actually calls MPI_ALLREDUCE, in an OMP_SINGLE region. Other MPI communications are done when Gelato is used in expert mode and calls for writing additional diagnostics in its own way; in that case, we use the Surfex function GATHER_AND_WRITE_MPI (which actually does not write anything);

– when ran in Arpege : because Arpege loops sequentially on NPROMA blocks, reducing a scalar among all blocks cannot be done using MPI communication only and would require a significant re-engineering of Gelato code; hence, for now, all printed global diagnostics show dummy values

A single namelist, NAM_SEAICE, has been added. And namelist NAM_PREP_SEAFLUX is used for a few sea-ice parameters

In case of separate sea-ice fluxes, the computation of fluxes on sea-ice is done, on any grid point showing some sea-ice, whatever the seaflux scheme used (and in that case, it is no more done in 'ecume_seaflux' nor in 'coare30_seaflux' routines)

The standard configuration of the embedded Gelato uses only one ice category, and computing fluxes for more than one ice category was not implemented at that stage

A current assumption is that the time step set for the sea-ice model is less than, and a divisor of, the seaflux scheme timestep. If the sea-ice model proves to be too costly, revisiting this assumption could be quite easy (the usual value of this time step in CNRM climate coupled model is one day)

Details of implementation and provided changes, from the Gelato perspective

Changes in Gelato sources are managed as the 'master' branch of git repository /cnrm/aster/data3/aster/senesi/gltsfx/gitglt. The script SCRIPTS/to_surfex.sh is designed for managing the export of Gelato codes to a Surfex distribution tree, and its main tasks are : maintaining the list of Gelato sources that must not be delivered, maintaining a timestamp for identifying thoses changes in Gelato sources that are not yet delivered, commenting out the interface declaration section of modules with name matching modi_*, and (temporarily) adding a CeCILL licence banner in the delivered codes.

Main changes in Gelato sources are :

- adding a new parameter (dttave) which is the length (in days) for Gelato's own diagnostics averaging period; if set to a value longer than the run length, diagnostics will be averaged over the run length
- allowing for an empty list of snapshot diagnostics (cinsfld parameter)
- no printout at all when nprinto=0 (except for a printout of gltpar if applicable)
- modifiy mpp_sum, mpp_min ... to work in Surfex (see above)
- renaming a few modules from modi_xx to mode_xx : glt_dia*, glt_init, gltools_temper_r
- adapt namelist reading routine readnam, which actually also make some init, to work without a 'gltpar' file
- fix the handling of SIC constraint
- deactivate calls to gltools_bound when in surfex
- Change style of declaration of functions strlower & strsplit
- Gelato types do not declare arrays for the dynamics when in Surfex

The content of the Gelato 'gltpar' file had to be duplicated in Surfex routine diag_default_sea-ice, WHICH IS AN ISSUE REGARDING THE MAINTENANCE. This was done with as few changes as possible in order to allow for code comparison.

The wizzard use of Gelato involves providing it with a Gelato-propretary-format namelist, named 'gltpar'; such a namelist is not mandatory for 'normal' use, for which Surfex NAM_PREP_SEAICE and NAM_SEAICE namelists provide enough flexibility. These latter namelists have a higher priority than the values in 'gltpar'

The most important Gelato parameters for which a default value is hard-coded in Surfex are : one ice thickness category only, no advection nor dynamics, cflxin='double' (only one heat flux for sea-ice, and one flux for water), heat exchange with the ocean is computed by Gelato, no damping on the surface temperature of sea-ice, no I/O for restarts, 9 ice layers and one snow layer, output logical unit (noutlu) set to Surfex's one; the latitudes, longitudes and mesh areas are inherited from Surfex; Gelato 2D arrays are degenerated to fit Surfex 1D arrays (second dimension is set to 1); for a full list, see module default_seaice

Gelato parameters which are set by a Surfex NAM_SEAICE namelist parameter are : the time step (default is to use the same value as the 'SEA' scheme), the SIC and SIT e-folding damping time constant (default is 0, for no damping, otherwise the scheme used are MONO for SIC and MONO_ADD for SIT), and the derivative of surface flux w.r.t. temperature (default is -20 W m-2 K-1)

Gelato's own diagnostics fields can be generated in wizard mode, except when running in Arpege (see above); they could be used in Arpege with little code changes, for cases when the number of procs and NPROMA value used ensure that there is only one NPROMA block per MPI task.

Directions for implementing an alternate sea-ice scheme

The relevant places to look at for implementing an alternate sea-ice scheme are mainly : the modules named "*sea-ice*", and modules modd_seaflux, init_seaflux, diag_inline_seaflux and of course coupling_seaflux. Module 'sea-ice_gelato1dn' should be mimicked for calling an alternate scheme. Strings "SEAICE_SCHEME" and "HANDLE_SIC" are good anchors for identifying all places involving the sea-ice scheme and the handling of separate fluxes for sea-ice.

The sea-ice scheme must return sea-ice concentration, temperature and albedo; the scheme should accept being provided with a sea-ice concentration constraint field (and a damping e-folding time), and a time step; the returned sea-ice concentration field may use only binary values (0. and 1.) but will anyway be processed as if it were a really fractional field

```
&NAM_FRAC            LECOCLIMAP   = F ,
                     XUNIF_NATURE = 0.0
                     XUNIF_SEA    = 1.0
                     XUNIF_TOWN   = 0.0
                     XUNIF_WATER  = 0.0
/
&NAM_PGD_GRID         CGRID     = 'LONLATVAL'
/
&NAM_LONLATVAL        NPOINTS =   1      ,
                     XX = 0.25,
                     XY = 89.75,
                     XDX     =   1.0    ,
                     XDY     =   1.0
/
&NAM_PGD_SCHEMES      CNATURE = 'NONE  '    ,
                     CSEA    = 'SEAFLX'    ,
                     CTOWN   = 'NONE  '    ,
                     CWATER  = 'NONE  '
/
&NAM_COVER            XUNIF_COVER = 1.0
/
&NAM_ZS               XUNIF_ZS    = 0.0
/
&NAM_PREP_SURF_ATM    NYEAR = 1980,
                     NMONTH = 01,
                     NDAY   = 01,
                     XTIME  = 0.
/
&NAM_PREP_SEAFLUX     XSST_UNIF = 271.15      ,
                     CSEAICE_SCHEME='GELATO'
                     XSSS_UNIF =  33.        ,
                     XSIC_UNIF = 1.0,
/
&NAM_SURF_ATM         XVZ0CM      = 1.E-5   ,
                     XVCHRNK      = 0.015   ,
                     XRIMAX       = 0.20    ,
                     LNOSOF       = T       ,
                     LVERTSHIFT   = F       ,
/
&NAM_SURF_CSTS        XEMISSN       = 0.99  ,
                     XALBCOEF_TA96 = 0.036 ,
                     XALBSCA_WAT   = 0.065 ,
                     XALBWAT       = 0.065 ,
                     XEMISWAT      = 0.96  ,
                     XALBWATICE    = 0.60  ,
                     XEMISWATICE   = 0.97  ,
                     XZ0SN         = 0.03  ,
                     XZ0HSN        = 0.003 ,
                     XWSNV         = 2.0
/
```

```
&NAM_SEAFLUXn         CSEA_FLUX    = 'DIRECT',
                   CSEA_ALB     = 'TA96'  ,
                   CINTERPOL_SST= 'MONTH ',
                   XICHCE       = 1.0
/
&NAM_SEABATHY         XUNIF_SEABATHY= -300.,
/
&NAM_SSOn           CROUGH       = 'NONE'
/
&NAM_DIAG_SURF_ATMn    LFRAC        = F
/
&NAM_DIAG_SURFn       N2M          = 0      ,
                   LSURF_BUDGET   = T      ,
                   LCOEF          = F      ,
                   LRAD_BUDGET    = F      ,
                   LSURF_VARS     = T      ,
                   LSURF_BUDGETC  = T      ,
                   LRESET_BUDGETC = T
/
&NAM_IO_OFFLINE       LPRINT             = F       ,
                   CFORCING_FILETYPE    = 'NETCDF',
                   CSURF_FILETYPE       = 'ASCII ',
                   CTIMESERIES_FILETYPE = 'NETCDF',
                   XTSTEP_SURF          = 10800.  ,
                   XTSTEP_OUTPUT        = 21600.  ,
                   LLIMIT_QAIR          = T       ,
                   LSET_FORC_ZS         = F       ,
                   XLIMIT_DELTAZ        = 2200.   ,
                   LRESTART             = T       ,
                   LPRINT               = T       ,
                   LOUT_TIMENAME        = T       ,
                   NB_READ_FORC         = 0
/
&NAM_WRITE_DIAG_SURFn  LPROVAR_TO_DIAG   = T ,
                   LSELECT          = F ,
                   CSELECT(1)       = 'SIT', 'SIC', 'SND', 'TSICE','IALB'
/
&NAM_SEAICEn      LDIAG_SEAICE      = T ,
                     CINTERPOL_SSS      = 'NONE  ',
                     CINTERPOL_SIC      = 'NONE  ',
                     CINTERPOL_SIT      = 'NONE  ',
                     XFREEZING_SST      = -1.8    ,
                     XSIC_EFOLDING_TIME = 0,
                     XSIT_EFOLDING_TIME = 0,
                     XSEAICE_TSTEP = 10800.,
                    XCD_ICE_CST       = 0.0015  ,
                    XSI_FLX_DRV         = -20.
/
```

Appendix B - Comparing a constrained and a free simulation

The figures below are monthy averages for Sea Ice Fraction (0-1, 1 means that 100 % of the grid cell is concentrationed with sea-ice) and Sea Ice Thickness on a North Atlantic location for 1981-1985 winters. 'sicc' and 'sitc' stand for the constrained simulation, which damping e-folding time is 5 days. 'sicl' and 'sitl' stand for the free simulation. Seaice disappears more quickly in the constrained simulation when SST rises above -1.8°C (and sea-ice thickness is smaller), while sea-ice formation is occurring at the same pace. Note that SST is interpolated daily, so, for instance, March 1985 includes both ice formation and ice melt phases.

	SST	sicc	sicl	sitc	sitl
1981-01	-0.92	0.00	0.00	0.00	0.00
1981-02	-1.80	0.69	0.69	0.31	0.30
1981-03	-1.58	0.11	0.99	0.06	0.48
1981-04	-1.71	0.66	0.99	0.26	0.39
1981-05	+0.04	0.02	0.08	0.26	0.01
1981-06	+2.33	0.00	0.00	0.00	0.00
....					
1982-01	-0.46	0.00	0.00	0.00	0.00
1982-02	-1.80	0.65	0.63	0.31	0.29
1982-03	-1.80	1.00	1.00	0.80	0.78
1982-04	-1.80	0.90	1.00	0.84	0.95
1982-05	-1.60	0.63	1.00	0.23	0.86
1982-06	+1.06	0.00	0.07	0.00	0.01
1982-07	+4.10	0.00	0.00	0.00	0.00
...					
1982-12	-0.35	0.00	0.00	0.00	0.00
1983-01	-1.80	0.66	0.65	0.35	0.34
1983-02	-1.80	1.00	1.00	0.93	0.93
1983-03	-1.80	1.00	1.00	1.15	1.15
1983-04	-1.80	0.84	1.00	1.08	1.29
1983-05	-1.05	0.03	0.90	0.03	0.77
1983-06	+2.24	0.00	0.00	0.00	0.00
...					
1983-12	-1.15	0.00	0.00	0.00	0.00
1984-01	-1.80	0.70	0.70	0.36	0.36
1984-02	-1.80	1.00	1.00	0.95	0.95
1984-03	-1.80	1.00	1.00	1.28	1.30
1984-04	-1.80	1.00	1.00	1.43	1.45
1984-05	-1.80	0.81	1.00	1.21	1.49
1984-06	+0.55	0.02	0.33	0.01	0.21
1984-07	+3.25	0.00	0.00	0.00	0.00
...					
1985-02	-1.24	0.00	0.00	0.00	0.00
1985-03	-1.80	0.74	0.78	0.27	0.29
1985-04	-1.47	0.54	0.93	0.19	0.37
1985-05	+1.34	0.00	0.00	0.00	0.00