

Sea ice prediction environment: Documentation

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1 Abstract

An operational sea ice model requires significant support codes in the form of boundary conditions, initial conditions, forcing fields, model analysis, as well as the model itself. This document describes the sea ice prediction environment developed for NCEP use, for the ice prediction model to be run in an off-line mode with information provided by the weather model. This form of the model should also be useful for research purposes.

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2 Introduction

A number of programs have been developed at NCEP to support sea ice modelling. The guiding principle in developing these programs has been to design an efficient environment to conduct studies on sea ice modelling, and to generate sea ice forecast products on a routine basis. In order to meet those goals, the different elements have been developed on the concept of 'plug compatibility'. The classical elements for a forecast model are: derivation of boundary conditions, derivation of initial conditions, construction of model forcing, model analysis, and the model itself. These have been implemented as separate programs in such a way that each element may be improved without requiring modification in the others. Further, the design is such that the model domain and resolutions may be changed without searching through the several thousand lines of code for the relevant parameters. The mechanism for implementing that ability are "include" files. While not standard Fortran-77, they are part of the Fortran-90 standard, and are quite common in Fortran-77 compilers. A further note is that certain parts of the environment have been written in C, though most is in Fortran.

The environment descriptions are written separately. There is a final section which describes working within the environment as a whole (i.e., doing some real work). Along the way, storage, execution memory, and cpu requirements are discussed.

3 General Comments

All grids are assumed to be polar stereographic, true at 60 degrees (north or south), with 80 W at the bottom of the page in the Northern Hemisphere, and the top in the Southern Hemisphere, in accordance with the NCEP standards. Grids are written out with the convention that 1,1 is the lower left corner. The current working resolution is 127 km (at 60 degrees). The model is written so that the resolution can be change easily to any multiple of 25.4 km (1/15 Bedient), so that future resolutions will be 101.6, 76.2, 50.8, and 25.4 km. Different grids may be developed by more extensive modification of the icegrid include files. The minimum resolution is set by the SSMI sensor, for which the highest resolution from the NASA Team algorithm is approximately 25 km. The model domains are shown in figures 1a and 1b.

The grid specifications are given in table 1:

Variable	North	South
L	77*127	59*127
M	93*127	61*127
dx	127 km	127 km
dy	127 km	127 km
Pole - I	38 * 127 km	30 * 127 km
Pole - J	46 * 127 km	36 * 127 km
Standard Latitude	60 N	60 S
Standard Longitude	80 W	+100 E

where L and M specify the width of the domain in the x and y directions, respectively, and pole-i, pole-j specify the location of the pole (it need not be on the map), and the standard longitude is referenced to having 90 W at the bottom of the page.

4 Boundary Conditions

The boundary conditions to the sea ice model are the ocean mixed layer temperature and salinity, the temperature and salinity at a depth below the seasonal thermocline, the land mask, and the depth of the ocean. The present version of the model includes the oceanic fields in the restart file, so they are only taken from the boundary condition file for a cold start.

4.1 Land Mask

The land mask is derived first. The required information is the location of the pole, nominal grid spacing, size of the grid, and rotation of the grid (if any) with respect to 90 W. These parameters are declared in include files `icegrid.north` and `icegrid.south`. Other domains, for example the Great Lakes, may be studied by creating `icegrid.glk`, say. The original land mask is currently the `zmask 1x1` grid from Joe Sela. As this is a one degree gridded field, the resolution is not sufficient for high resolution regional modelling. Parameter values for the northern and southern hemisphere grid are given in table 1.

The program which creates the land mask is 'masker' which calls `terp`, `w3ft01`, `mapxy`, and `mclean`. `Terp` produces the first guess interpolation field. The values are real numbers due to the interpolation, rather than the integers which are needed by the models. `Mapxy` and `w3ft01` are called by `terp`. `Mapxy` converts `i,j` coordinates to latitude and longitude on a polar stereographic grid. `W3ft01` is an NCEP library routine which does fairly general interpolations. `Mclean` first rounds these numbers to 0 or 1, whichever is closer. Then `Mclean` cleans up the grid by removing water points which are surrounded by land at points $(i+1,j)$, $(i-1,j)$, $(i,j+1)$, $(i,j-1)$ – the cardinal directions in grid space. The ice model uses a staggered grid. For the inner grid, if two or more of the four nearest neighbors are ocean points, the inner grid value is set to ocean. The land masks are given in figures 2a and 2b.

4.2 Ocean Temperature and Salinity

The ocean boundary conditions are derived from the Levitus [1982] ocean atlas of climatological values for temperature and salinity at the surface and at a depth below the seasonal thermocline in the region. The mechanism is to interpolate from the latitude-longitude grid of those data (1 by 1 degree, with values at the half-integer locations) to the model grid. Since the land mask used in the atlas may not (in fact, does not) correspond to the land mask derived in the sea ice environment, a scheme is necessary to obtain values for T, S at those points where the ice model has ocean and the atlas has land. The mechanism used is to construct a weighted average of all points in the atlas within 220 km of the ice model point. The weight is proportional to $\exp(-4 x^2 / R^2)$, where x is the distance between the ice point and the atlas point, and R is the radius of 220 km. If there are no data points within that radius, the temperature is set to -1.66 (slightly above the freezing point of sea water), and the salinity is set to 34.7 psu (mean ocean salinity). This is unsatisfactory for the Great Lakes and Caspian Sea. For that reason, these areas are not considered part of the operational grid, though they do appear on the map.

The equation of state for sea water used by the sea ice - ocean mixed layer model is a linear function, rather than the full equation of state. To ensure that the model ocean initial condition is stable, the buoyancy period is required to be no slower than 1800 seconds. If the stability fails this criterion, the surface layer salinity is adjusted to bring that degree of stability.

The depth of the lower layer read from the atlas depends on the hemisphere, and is set in the icegrid.* files (variable HMLREF) and the north.oin and south.oin files (by reference to the level in the Levitus [1982] atlas). Currently, the northern hemisphere lower layer is at 75 m depth. The southern hemisphere is at 500 m. The depths are different owing to differing typical depths of the ocean (the Arctic having extensive shallow shelves) and depths of the mixed layer (the Arctic being much shallower than the Antarctic). The specific values chosen are somewhat arbitrary. To change the reference depth, you must modify the icegrid.north/south files, *and* the south/north.oin files. For the latter change, you need Table 1 from Levitus [1982] as it is the mandatory level, rather than depth which is passed to the ocean initialization program.

Figures 3a-6b illustrate the surface temperature and salinity for both hemispheres, and the deep temperature and salinity.

4.3 Ocean - Bathymetry

Experimentation with the model revealed consistent biases in the shallow water regions. The model was unable in many of the shallow-water areas (Bering Sea, parts of the Canadian Archipelago, parts of the Great Lakes) to form an ice cover. The failure was due to the mixed layer being unaware that it had reached the bottom, and therefore that there was no more heat source. Consequently, ocean (and lake) bathymetry has been added to the data requirements and the relevant physics have been incorporated into the sea ice model. These corrections do cure the problem.

The bathymetry for the oceans (but not inland water) is derived from the Navy etopo5 data set via a two step process. The first step is programs by Hendrik Tolman which generate a global bathymetry on a regular latitude-longitude grid from the etopo5 data set. The second step is to apply the general lat-long to polar stereographic interpolater and make a consistency check that all points which the land mask says are ocean have a non-zero depth (set to 1 meter if the bathymetry has a zero or positive elevation). Sample bathymetry is shown in figures 7a and 7b.

5 Initial Conditions

Sea ice initial conditions are not fully-provided by any mechanism. Remote sensing can provide ice concentration accurate to a few percent, the precision depending on season and area [Cavalieri, 1992a]. Ice thickness is unobserved on hemispheric scales. Work is in progress on a data assimilation method which will derive ice thickness from ice concentration, but this is not currently operational. The procedures used to specify required initial conditions are described below.

5.1 Ice Concentrations

Regardless of whether an assimilation process is used, the satellite ice concentrations are needed for model initialization. Two operational data sources are available at NCEP, the EDR master map data products, and the SDR orbit by orbit products from the SSMI instruments on DMSP F-11 and F-13. The master map product includes the sea ice concentration as determined using the Navy's preferred algorithm and from orbits selected by the Navy. Given that the NCEP use of sea ice information (in particular the development of data assimilation techniques) will have different requirements than the Navy's, the orbit by orbit data are used. This has the feature that the sea ice concentration must be computed locally as well. The details of the ice concentration computation are described in Grumbine [1996]. The concentration algorithm used is the NASA-Team [Cavalieri, 1992b].

The ice concentrations are computed by the program `ssmi`, which also reads in the SSMI orbit file. `ssmi` is written in C because of the relative ease of writing decoders in that language. The output is unformatted, and readable by Fortran programs using `-s unblocked` on an assign statement (C90). Other computers do not require this step.

The resulting (25.4 km) sea ice grids are made available to global SST (sea surface temperature) analyses (1 degree and 1/2 degree), wave forecast models, global atmospheric weather forecast model, and the National Ice Center, as well as the sea ice forecast model. A sample is shown in figures 8a and 8b.

5.2 Ice Thickness

The sea ice model currently incorporates the observations using an *ad hoc* scheme following that of Preller and Posey [1989]. The program used is `restart`, which requires that a model restart file exist. The first step is to update the sea surface temperature field using the SST analysis if one exists. If none exists, simple bounds checking is done: ensure that the model mixed layer temperature is above freezing and not more than 10 C above the climatological mean temperature. When there is an SST analysis, the analysis grid point nearest the model grid point is used for the SST comparison in the model. If the SST is above freezing and no more than 10 degrees away from the climatology, a weighted average of the model and analysis SST replaces the model sst. The weight is currently 0.4. This is selected so that at the end of a week, the model would converge to the SST analysis, which is performed weekly. A higher weight could be used, but that would tend to prevent ice from advancing in the fall and winter, when marginal ice zone ocean temperatures fall rapidly.

If an ice concentration analysis field exists, the ice analysis resolution is reduced to that of the model grid by averaging the analyzed ice concentrations in program `reducer`. If the analyzed and modelled concentrations disagree, the concentration is set to a weighted average of the observation and model. The weight is set in the control script, and is currently 0.75. This is a highly simplified data assimilation scheme, where the observations are considered to be about three times more reliable than the model. The restart program may be modified to provide a better assimilation method as one is determined. If the observations show ice where the model has none, 10 cm thick ice is placed at that point.

6 Model Forcing

Since this is to be an operational ice forecasting environment, the model forcing is derived from the weather forecast model's fields. The fields used are q_2 , T_2 , U_{10} , $LW\downarrow$, $LW\uparrow$, $SW\downarrow$, low cloud fraction, and surface pressure for forecast hours 12 through 168. The flux files represent averages over the preceding 12 hours, so 12 hours is the appropriate starting field to use to advance the ice model for the next 12 hour step. These data are included in the MRF surface flux files, which are saved as `/com/mrf/prod/mrf.yymmdd/drfmr.T00Z.SFLUXGrbFxx` on the C-90, where `xx` is the forecast time. The flux files are also available at `nic.fb4.noaa.gov`, in directory `pub/mrf`, with the same file naming convention. The flux files are in GRIB format. Information about and source code for decoding GRIB files is in directory `pub/info` on the nic server.

The grids used by the weather and ice forecast models are different. The conversion from the weather model grid is done by converting from the flux file grid (gaussian points) to a regular latitude-longitude grid, then from there to the model's grid. The conversion routines are `terp`, `mapxy`, and `w3ft01`. The program converts each step's forcing to the model grid, and writes out the fields as unformatted binary. A one week forecast then consists of 14 repetitions of the interpolate to model grid – forecast cycle.

7 Model Analysis

The principal analysis program currently is `mapcont` (`.north`, `.south`), which overlays a contour map (concentration, thickness, etc.) on a geographic map of the appropriate hemisphere. This program depends on the NCAR graphics library. The corner point locations for the mapping routine are given by program corners. The program constructs a meta file which can be viewed directly by `idt`, or translated to postscript by `ftrans`.

For viewing maps in `IMDISP` or `NCSA Imagetool`, program `image` will read in the unformatted binary file (say concentration) and write out a raster (8 bit) file for the grid. `mag` will magnify this file by repeating each grid value into an $N \times N$ pixel box. Where N is chosen to make the y dimension no greater than 480 pixels. The 480 is specified in a parameter statement in file `mapim.f`, and may be changed to suit the resolution of your screen.

8 Model

The sea ice forecast model itself is documented in a separate publication [Grumbine, 1996]. The model is derived from the Max Planck Institut für Meteorologie sea ice model, as documented by Stössel [1991]. Ice dynamics are treated as a non-Newtonian fluid, according to the rheology of Hibler [1979]. The thermodynamics of the ice itself follow Parkinson and Washington [1979] as implemented by Hibler [1980]. Ocean-ice heat flux is derived from a mixed-layer ocean model, developed by Lemke [1987] and coupled to a version of this sea ice model [Lemke et al., 1990]. The air-ice heat fluxes are derived from either bulk aerodynamics or a surface layer model based on Louis [1979, as implemented by Koch [1988]]. The bulk aerodynamic formulation is presently used.

Particular changes made for use at NCEP include: use weather model-derived shortwave radiation fluxes, change to polar stereographic grid, use for both hemispheres rather than only the southern, addition of bathymetry, mixed layer maximum depth is bounded by the bathymetry, freezing point as a function of salinity rather than fixed, equation of state for sea water as a quadratic function of temperature rather than linear, albedo extracted as a separate function, and i/o changes required to make the model more modular (suitable for the forecast environment).

9 Information for Other Users

Rather than require other users of sea ice information (wave modellers, atmospheric modellers, etc.) to learn the details of how the sea ice model grids its output, a special directory is set up with the required information. The background information is the land mask (mask.north, mask.south), and the latitudes and longitudes of the grid points (latlong.north, latlong.south). The mask files are ascii, with 1 denoting ocean and 0 denoting land. The latitude/longitude files are unformatted binary, with the longitude and latitude written as an unformatted real arrays, longitude first. Other users do need to know the sizes of the arrays. The information is given in a file (created manually at this time) called grids. Program masker, mentioned in the boundary condition section, creates the land mask for use by others as well. Program listpts, also in the boundary condition directory, creates the latitude/longitude files.

10 Creating and Working In the Environment

The sea ice environment is archived for transfer in a single large 'tar' file. There are two versions, icenv.all.tar.Z and icenv.lt.tar.Z. The first version includes the Levitus [1982] climatological atlas data files. The second does not. In the archive as well is the script 'travel'. The script can be downloaded via ascii ftp, but the ice environment requires a binary transfer. Chmod 777 travel, modify those elements which are specific to your system (noted in the script). The scripts, travel, build, and those that build calls, presume that you are in the Bourne shell. If you are not, or aren't sure, enter /bin/sh. Then execute travel unpack all -> for the full environment travel unpack light -> for the environment less the atlas.

The environment has been created so that building the entire suite of programs and required files can be done by executing a single script and modifying two input files. Although the code itself has been written for machine independence, the scripts (mainly through the use of assign statements) assume a Cray environment. The master script is build. This script invokes the scripts to build the northern and southern hemisphere versions of the ice model, create the land mask and ocean initial conditions (bc.jcl), and make the static files for other users. build uses Makefiles to recreate only programs for which some change has been made.

The change from a northern hemisphere forecast to southern hemisphere, or changes to the grid domain within a hemisphere can be made by only changing the icegrid.inc file. This is the single most important file as it is used by almost all the source code files. It has been previously described in section 3.

The other include files are mgrid.inc – specify the meteorological input file, physical.inc – specify physical parameters for the ice and atmosphere (used by many source files), oml.inc

– specify parameters for the ocean mixed layer, rheology.inc – specify parameters for the sea ice rheology. The include files are saved in directory mpi.source.

The scripts are:

```
travel
build
bc.jcl
ic.jcl
analy.jcl
fullfore.jcl
```

Substitute scripts can be used, though some care needs to be taken that all the required programs (even if in changed form) get executed.

Source code is split between directories bc, ic, meteo, analy, and mpi.source. The makefile for each element is saved with the source code.

The total icenv.tar file encompasses on the order of 250 files. These occupy approximately 1200 Kb of space, not including the land mask file, and certainly not including the 17 Mb of the Levitus atlas files. The executables total approximately 20 Mb on the NCEP Cray C-90. The input files which are generated occupy 11 Mb (meteorological input for both hemispheres, for a week), and 300 Kb for data files (model land masks, ocean t, s). Output for a seven day forecast, with thickness, velocity, air and sea heat fluxes, mixed layer parameters, and the restart file, saved daily is another 30 Mb. Not counting the ocean atlas, the space requirement is on the order of 60 Mb. Obvious steps can be taken to reduce this. The forecast execution time on the C-90 is under a minute for a one week forecast, including generation of the forcing files. Execution memory requirement is under 2 Mb.

11 Concluding Comments

The original version of this document was written on 9 April 1996. As it is documenting something which is continually changing, the version you are currently reading should not be considered up to date. Current documentation is a series of LaTeX files which are updated individually as that section of the environment is changed. The master copy of documentation is located on the C90 in /wd2/wd21/wd21rg/icemodel/doc as a set of LaTeX files. A copy is also maintained on <http://polar.wwb.noaa.gov/seaice/Models.html>. Every effort is being made to maintain that documentation. Please write me at wd21rg on the C90, or as wd21rg@hp20.wwb.noaa.gov if you have questions or comments.

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