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The Hamburg Atmosphere-Ocean Coupled Circulation Model E C H O-G

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ABSTRACT

ECHO-G is a global coupled atmosphere-ocean climate model whose component models are the ECHAM atmosphere general circulation model and a global version of the Hamburg Ocean Primitive Equation model, HOPE-G, which includes a dynamic-thermodynamic sea-ice model with snow cover.

ECHO-G can be used in numerical studies of natural variability of the world climate and of climate changes on time-scales ranging from the component models time steps to centuries.

In high latitudes, the interaction between ocean and atmosphere can be strongly affected by the sea-ice cover. In particular, the heat flux through ice and that through leads and polynyas can differ by an order of magnitude on horizontal scales much smaller than that of a gridcell in global climate models. ECHO-G accounts for these effects by a separate calculation of fluxes over ice and over water when a sub-grid-scale partial ice cover is present.

Since the component models are used in their stand-alone versions with only some subroutine calls added, and since the coupling interface, OASIS, is a flexible tool that allows to change the number of component models, of interpolation methods, and data exchange frequencies by keyword specification, it should be relatively easy to include other models, or change the coupling strategy.

This report describes the physical and technical aspects of a specific set-up that is in use at DKRZ.

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1 Summary

The coupled atmosphere-ocean climate model ECHO-G is set up from cycle 4 of the Hamburg atmosphere general circulation model, ECHAM, and the global version of the Hamburg Ocean Primitive Equation general circulation model, HOPE-G. The latter incorporates a dynamic-thermodynamic sea-ice model with snow cover.

The atmosphere model ECHAM is described in volume 6 of the DKRZ technical report series (DKRZ, 1993). It has been modified for ECHO-G in order to properly account for a sub-gridscale partial ice cover as described in Groetzner et al. (1996). With these modifications, heat, freshwater, and momentum fluxes are calculated separately for the ice-covered and the ice-free part of each gridcell in order to account for the strong nonlinear dependences of the fluxes on the surface conditions. The fluxes over ice and over water are passed separately to the ocean - sea-ice model.

The ocean model is only little changed from the version described in Wolff et al. (1997). The changes mainly concern the ice-growth routines which do not use heat-balance equations any more. Instead, fluxes as obtained from the atmosphere model areused for the computation of the thermodynamic ice growth.

The component models are coupled by use of the OASIS coupling software developed at CERFACS . It is described in Terray et al. (1998).

2 Model description

ECHO-G is a coupled climate model (CCM) that consists of two component models, an atmosphere general circulation model (AGCM) and an ocean-sea ice general circulation model (OGCM).

The AGCM, ECHAM, has been developed from the ECMWF weather forecast model. It has been extensively changed at the Meteorologisches Institut der Universität Hamburg and at the Max-Planck-Institut für Meteorologie in order to adjust the model for climate simulations. Cycle 3 of the model, ECHAM3, is described in the DKRZ technical report no. 6 (DKRZ, 1993). The performance of ECHAM4, which is used for ECHO-G, is presented in Chen and Roeckner (1996) and Roeckner et al. (1996). Modifications of the ECHAM4 component model in ECHO-G relative to the standard version at DKRZ concern the treatment of the net atmospheric freshwater flux on the continental glaciers (Greenland and Antarctica), the continental river-runoff, and the method of flux calculation which accounts for a partial ice cover.

For the CCM described herein we have used a version of ECHAM4 with 19 levels and a horizontal resolution of T30, corresponding to an approximate horizontal gridpoint distance of 3.75^o. It should, however, be relatively easy to set up a CCM with any of the other resolutions used at DKRZ (T21, T42, T63, T106). The performance of the T30/L19 version of ECHAM4 is described in Stendel and Roeckner (1998).

The HOPE-G model used in ECHO-G is formulated on a Gaussian T42 Arakawa-E grid (ca. 2.8^o) with grid refinement at low latitudes (acronym t42er). Approaching the equator, the meridional gridpoint distance becomes increasingly smaller, with the smallest separation between two lines of the same parity being 0.5^o. The vertical resolution is by 20 horizontal layers. This model is based on the code that is available from the DKRZ model pool and is described in Wolff et al. (1997). The simulated climate of the ocean model that was obtained in a spin-up integration with cyclically repeated daily forcing of a 15 year period is described in Legutke et al. (1999). The forcing data were produced in a stand-alone integration of ECHAM4 with a T42 resolution and climatological AMIP-SST prescribed at the lower boundary. As was already mentioned for the atmosphere, it should be relatively easy to set up a CCM with any of the resolutions for the ocean that are in use at DKRZ.

At a specified frequency, the atmosphere component model passes heat, fresh water, and momentum to the ocean and receives surface conditions. This frequency is the same for all exchange fields in the version described here and defines the lengths of a ’coupled time step’. The fields that are exchanged have been averaged over the last coupled time step.

The atmosphere-ocean fluxes are calculated in the atmosphere model. The atmosphere needs to know the mean sea-surface temperature (SST), $\bar{\theta}_1$, the mean sea-ice concentration (SIC), $\bar{A}_I$, the mean effective sea-ice thickness (SIT), $\bar{h}_{eff}$, and the mean snow depth (SNT), $\bar{h}_S$, of the last coupled time step. Fluxes are calculated separately over water and sea ice. The method used here to account for a sub-gridscale partial ice cover is described in Groetzner et al. (1996). It is based on the ’blending height concept’ which assumes that the atmospheric variables are horizontally homogeneous over each gridcell in a certain height, the blending height. The blending height is defined as the height where the atmospheric flow changes from equilibrium with the local surface conditions to independence of horizontal position in the cell. ECHAM is formulated on a hybrid vertical coordinate system where the lower levels use terrain-following σ – coordinates while the upper levels become surfaces of constant pressure. We take the lowest level of the atmosphere model to be the blending height which lies ca. 30 m above the bottom. The fluxes through the ice-covered and the ice-free part of each gridcell are calculated from the atmospheric variables at the blending height and the oceanic surface fields SST, SIT, SNT, and SIC.

The net atmospheric flux for an atmosphere gridcell is the horizontal average of the fluxes through the ice-free and ice-covered surface of the gridcell, weighted by the fractional areas of the respective surfaces. The mean total flux of a coupled time step that has to be applied to the ocean and sea ice is thus

$$\sum_{n=1,\,NTATMOS} (\bar{A}_I \cdot FL_n^{S/I} + (1-\bar{A}_I) \cdot FL_n^{W}) / NTATMOS,$$

where *NTATMOS* is the number of atmospheric time steps per coupled time step, and $FL_n^{S/I}$, FL_n^{W} stand for any of the atmospheric fluxes at time step n over the snow/ice and water surface, respectively. Overbars denote mean values of a coupled time step.

The fluxes through the ice-free and ice-covered surface of a gridcell are passed to the ocean as mean fluxes relative to the total gridcell surface (denoted by curved overbars):

$$\overset{\frown}{\overline{FL}}^{S/I} = \sum_{n=1,\,NTATMOS} \bar{A}_I \cdot FL_n^{S/I} / NTATMOS,$$

$$\overset{\frown}{\overline{FL}}^{W} = \sum_{n=1,\,NTATMOS} (1-\bar{A}_I) \cdot FL_n^{W} / NTATMOS.$$

Exceptions are the wind stress on the ice-covered area and the downwelling solar radiation.

To close the freshwater budget, a routing scheme for the freshwater fluxes over land (Sausen et al., 1994) is implemented to provide a continental runoff into the ocean. The net freshwater flux over glacier regions (namely Greenland and Antarctica) is accumulated each coupled time step and is distributed to the ocean cells neighboring the coast of the respective region. This is done instantaneously without accounting for a time lag between the net snow fall and the freshwater input near the coast. In the standard version of ECHAM4, the net precipitation in the glacier regions (mainly snow fall) is lost for the hydrological cycle, since melting of glaciers or glacier calving is not simulated.

The time integration is outlined in the diagram of Figure 2 on page 21. Solid arrows indicate the model flow, while dashed arrows indicate data I/O. There is no direct communication between the component models. All data exchange is via OASIS. The first run in an experiment with ECHO-G is initialized with

ocean surface variables only: if LRERUN=.false., initial surface fields SST, SIT, SIC, and SNT are written to the file sstocean which contains the exchange fields generated by the ocean. In Figure 2, NC is the number of coupled time steps of the run. JO and NO, and JA and NA, are the model time step and the number of model time steps per coupled time step of the ocean and the atmosphere, respectively. The corresponding variable names in the model source code are found in Table 7 on page 39.
Figure 2 does not include the I/O on named pipes by which the models are synchronized. The dashed arrows have to be interpreted in the sense that each process (HOPE, ECHAM4, and OASIS) that wants to read exchange data, has to wait until the data have been written to the file.

The models are coupled synchronously. The fields that are passed to the atmosphere, i.e. SST, SIT, SIC, and SNT are averages of a coupled time step as well. All exchanged fields are used without time interpolation.

2.1 Heat fluxes

The atmosphere-ocean mean heat flux $\overline{H}$ consists of the component through the air/water interface $\widehat{\overline{H}}^{W}$ and through the air/sea-ice interface $\widehat{\overline{H}}^{S/I}$. Positive values denote a flux into the ocean. For the description of the individual heat flux components we concentrate on the dependence on the variables delivered by the ocean model, i.e. sea surface temperature $\bar{\theta}_1$, sea-ice concentration $\overline{A}_I$, effective sea-ice thickness $\bar{h}_{eff}$, and snow depth $\overline{h_S}$. A scheme of the dependencies and of the exchange of coupling variables is displayed in Figure 1 on page 13.

The gridcell-mean net heat flux through the air/water interface $\widehat{\overline{H}}^{W}$ comprises the downwelling shortwave radiative heat flux, $\overline{H}^{W}_{dsw}$, the longwave radiative heat flux, $\overline{H}^{W}_{lw}$, and the turbulent fluxes of latent and sensible heat, $\overline{H}^{W}_{la}$ and $\overline{H}^{W}_{se}$:

$$\begin{aligned}\widehat{\overline{H}}^{W} &= (1-\overline{A}_I)\overline{H}^{W}\\ &= (1-\overline{A}_I)(\overline{H}^{W}_{dsw}+\overline{H}^{W}_{lw}+\overline{H}^{W}_{la}+\overline{H}^{W}_{se}).\end{aligned}$$

The corresponding heat flux through the air/sea-ice interface $\widehat{\overline{H}}^{S/I}$ consists of the downwelling shortwave radiative heat flux, $\overline{H}^{S/I}_{dsw}$, the longwave radiative heat flux, $\overline{H}^{S/I}_{lw}$, the turbulent fluxes of latent and sensible heat, $\overline{H}^{S/I}_{la}$ and $\overline{H}^{S/I}_{se}$, the conductive heat flux through the sea ice $\overline{H}_c$, and a residual heat flux $\overline{H}_{res}$ describing the surface melting of sea ice:

$$\begin{aligned}\widehat{\overline{H}}^{S/I} &= \overline{A}_I\overline{H}^{S/I}\\ &= \overline{A}_I(\overline{H}^{S/I}_{dsw}+\overline{H}^{S/I}_{lw}+\overline{H}^{S/I}_{la}+\overline{H}^{S/I}_{se}+\overline{H}_c+\overline{H}_{res}).\end{aligned}$$

The heat flux between air and sea-ice $\overset{\frown}{\overline{H}}^{S/I}$ determines the sea-ice skin temperature $T^{S/I}$, which represents a boundary condition for the sea-ice covered regions in ECHAM.

The downward component of the solar radiance $\overline{H}_{dsw}$ depends on the incoming shortwave radiation H_{sw}, and on the albedo of water α^W and of sea-ice $\alpha^{S/I}$. The latter is a function of the snow thickness $\bar{h}_S$. For snow-covered sea ice the albedo ranges from 0.75 to 0.85 and for snow-free ice from 0.66 to 0.75 depending on the surface temperature. For temperatures above T_{melt}, the freezing point of fresh water, the respective minimum albedo is chosen, and for temperatures below $(T_{melt} - 10K)$ the respective maximum albedo is applied. Between these values, the albedo is a linear function of the surface temperature.

$$
\begin{aligned}
\overline{H}_{dsw} &= \overset{\frown}{\overline{H}}{}^{W}_{dsw} + \overset{\frown}{\overline{H}}{}^{S/I}_{dsw} \\
&= (1-\overline{A}_I)\overline{(1-\alpha^W)H_{sw}} + \overline{A}_I\overline{(1-\alpha^{S/I}[\bar{h}_S])H_{sw}}
\end{aligned}
$$

The net longwave radiation is

$$
\begin{aligned}
\overline{H}_{lw} &= \overset{\frown}{\overline{H}}{}^{W}_{lw} + \overset{\frown}{\overline{H}}{}^{S/I}_{lw} \\
&= (1-\overline{A}_I)\overline{(L-\sigma\varepsilon\bar{\theta}_1^4)} + \overline{A}_I\overline{(L-\sigma\varepsilon(T^{S/I})^4)}.
\end{aligned}
$$

The downward longwave radiation L and the emissivity are the same over the ice-free and ice-covered parts of the gridcell. σ denotes the Stefan-Boltzman constant.

The turbulent fluxes of latent heat

$$
\begin{aligned}
\overline{H}_{la} &= \overset{\frown}{\overline{H}}{}^{W}_{la} + \overset{\frown}{\overline{H}}{}^{S/I}_{la} \\
&= (1-\overline{A}_I)\overline{D^W_{la}[\bar{\theta}_1]|\vec{v}_B|(q_B - q^W[\bar{\theta}_1])} + \overline{A}_I\overline{D^{S/I}_{la}|\vec{v}_B|(q_B - q^{S/I})}
\end{aligned}
$$

and sensible heat

$$
\begin{aligned}
\overline{H}_{se} &= \overset{\frown}{\overline{H}}{}^{W}_{se} + \overset{\frown}{\overline{H}}{}^{S/I}_{se} \\
&= (1-\overline{A}_I)\overline{D^W_{se}[\bar{\theta}_1]|\vec{v}_B|(\theta_B - \bar{\theta}_1)} + \overline{A}_I\overline{D^{S/I}_{se}|\vec{v}_B|(\theta_B - T^{S/I})}
\end{aligned}
$$

are calculated with bulk formulas. $\vec{v}_B$ is the air velocity, θ_B the air temperature, and q_B the specific humidity at the blending height. In ECHAM the values of the lowest model level are used as blending height variables. These variables are identical over the ice-covered and ice-free part of a gridcell. The latent heat flux is proportional to the difference of the specific humidity at the blending height and at the surface. The specific humidity at the surface is calculated by means of the SST $\bar{\theta}_1$ for open water and by means of the skin temperature $T^{S/I}$ for sea-ice regions. These surface temperatures are also used to determine the sensible heat flux, which is proportional to the temperature difference between blending height and surface. The exchange coefficients D^W_{la}, $D^{S/I}_{la}$, D^W_{se}, and $D^{S/I}_{se}$ are dependent on the roughness length and the bulk Richardson number *Ri*. This stability parameter is computed separately for open water and ice-covered regions and depends on the surface temperature, roughness length z_o and the blending height values of temperature and wind:

$$Ri^W = Ri^W \; [\bar{\theta}_1, \theta_B, \hat{v}_B, z_o^W]$$
$$Ri^{S/I} = Ri^{S/I}[T^{S/I}, \theta_B, \hat{v}_B, z_o^{S/I}]$$

A more detailed description of the turbulent surface fluxes is given in Roeckner et al. (1996).

The gridcell-mean conductive heat flux through the snow/ice layer,

$$\widehat{\overline{H}}_c = \bar{A}_I \cdot \overline{H}_c$$
$$= \bar{A}_I \cdot \frac{\kappa_I}{\bar{h}_{eff}} \cdot (\overline{T}^{S/I} - \bar{\theta}_1),$$

is used for bottom ablation or accretion of sea ice. It is assumed that within a time step the temperature profile within the ice layer adjusts to the surface conditions and is thus linear. The effective ice thickness $\bar{h}_{eff} = (\kappa_I \cdot \bar{h}_S + \kappa_S \cdot \bar{h}_I)/(\kappa_S \cdot \bar{A}_I)$ is introduced to account for the different thermal conductivities of snow and ice. κ_I and κ_S are the heat conductivities of sea ice and snow, respectively. $\bar{h}_I$ and $\bar{h}_S$ are the gridcell-mean thicknesses of sea ice and snow, respectively.

The gridcell-mean residual heat flux,

$$\widehat{\overline{H}}_{res} = \bar{A}_I \cdot \overline{H}_{res},$$

causes surface melt of snow or ice.

For its computation, a preliminary new skin temperature $\tilde{T}_n^{S/I}$ of the snow/ice layer is calculated first by use of a heat-flux balance at the surface:

$$(\rho_I c_p)^{S/I} \cdot \Delta z_I \cdot \frac{(\tilde{T}_n^{S/I} - T_{n-1}^{S/I})}{\Delta t_a} + \frac{\kappa_I}{\bar{h}_{eff}} \cdot (\bar{\theta}_1 - \tilde{T}_n^{S/I}) - H_{-c}^{S/I}(T_{n-1}^{S/I}) = 0.$$

$(\rho_I c_p)^{S/I}$ is the specific heat of sea ice or snow, and Δt_a the time step of the atmosphere.
The surface heat fluxes are formulated with the skin temperature $T_{n-1}^{S/I}$ of the last time step, except for the conductive heat flux through the ice, which is formulated implicitly. $H_{-c}^{S/I}$ denotes the total surface flux excluding the conductive heat flux. For the formulation of the time derivative, it is assumed that the surface heat flux is absorbed in the upper Δz_I *=10 cm* of the snow/ice layer.

The skin temperature $\tilde{T}_n^{S/I}$ is not allowed to rise above T_{melt}, the freezing point of fresh water. If this happens, it is reset to T_{melt}, and the surface heat equation is solved once more, with the new (and final) skin temperature $T_n^{S/I} = Min(\tilde{T}_n^{S/I}, T_{melt})$:

$$(\rho_I c_p)^{S/I} \cdot \Delta z_I \cdot \frac{(T_n^{S/I} - T_{n-1}^{S/I})}{\Delta t_a} + \frac{\kappa_I}{\bar{h}_{eff}} \cdot (\bar{\theta}_1 - T_n^{S/I}) - H^{S/I}(T_{n-1}^{S/I}) = -H_{res}.$$

Of all the heat fluxes, only the residual heat flux $\widehat{\overline{H}}_{res}$, that is always positive, does not directly enter the ocean. It is first used to melt snow, then to melt ice. Only when all ice and snow is melted, the remaining heat is added to the total heat flux and enters the ocean.

The atmosphere passes four heat flux fields to the ocean: the net heat flux over open water $\widehat{\overline{H}}^W$, the conductive heat flux through the snow/ice cover $\widehat{\overline{H}}_c$, the residual heat flux at the snow/ice surface $\widehat{\overline{H}}_{res}$, and the downwelling solar heat flux $\overline{H}^W_{dsw}$. The latter is only used for penetration of solar radiation into deeper ocean layers. It is applied to the ice-free part of the gridcell, and just implies a vertical redistribution of heat within the ocean. Thus, heat conservation is no critical point for its transfer and it can be multiplied by the actual ice concentration in the ocean model. This field is transferred without the factor $(1 - \bar{A}_I)$.

The net heat flux $\widehat{\overline{H}}^W$ updates the upper ocean temperature. Depending on the value of the new ocean temperature relative to T_{freez}, the freezing point of sea water, and the direction of the total heat flux minus the surface residual heat flux (net plus conductive heat flux), the total heat is used to melt ice, increase or decrease θ_1, or increase the ice volume, or a combination of this.
If the net heat flux has the potential of creating new ice, that is, if the flux is upward and the new upper-level temperature is at the freezing point of sea water, the ice compactness will be updated by that part of the gridcell that will be covered by new ice (ice production due to net heat flux only) if this assumes a specified minimum thickness (see Wolff et al., 1997).

2.2 Freshwater fluxes

The only freshwater flux component, which directly depends on the variables provided by the ocean model, is the evaporation:

$$\begin{aligned}\bar{E} &= \widehat{\overline{E}}^W + \widehat{\overline{E}}^{S/I} \\ &= (1 - \bar{A}_I)\overline{D_e^W[\bar{\theta}_1]|\vec{v}_B|(q_B - q^W[\bar{\theta}_1])} + \bar{A}_I\overline{D_e^{S/I}|\vec{v}_B|(q_B - q^{S/I})}\end{aligned}$$

Evaporation strongly depends on the local stratification due to the dependence of the bulk transfer coefficients D_e^W and $D_e^{S/I}$ on the Richardson number Ri (see “Heat fluxes” on page 5). $q^{S/I}$ and q^W are the specific humidities at the ice/snow and water surface, respectively. q_B is the corresponding value at blending height. D_e^W and q^W depend on the SST $\bar{\theta}_1$, which is provided by the ocean model.

Two freshwater flux fields are passed to the ocean. The first is the gridcell-mean freshwater flux, which comprises precipitation $\bar{P}$ and evaporation $\bar{E}^W$ over water, continental runoff $\bar{R}$, and liquid precipitation (rain) over ice $\bar{P}_R^{S/I}$:

$$\begin{aligned}\bar{F}^W &= (1-\bar{A}_I)\cdot(\bar{P}-\bar{E}^W)\\ &\quad+\bar{R}\\ &\quad+\bar{A}_I\cdot\bar{P}_R^{S/I}.\end{aligned}$$

The precipitation calculated in the atmosphere does not depend on the surface type.
The second freshwater flux field, the gridcell-mean solid freshwater flux over ice, includes the sublimation of snow or ice $\bar{E}^{S/I}$ and the snow fall $\bar{P}_S^{S/I}$:

$$\begin{aligned}\overset{\frown}{\bar{F}}{}^{S/I} &= \bar{A}_I\cdot\bar{F}^{S/I}\\ &= \bar{A}_I\cdot(\bar{P}_S^{S/I}-\bar{E}^{S/I}).\end{aligned}$$

The solid freshwater flux, $\overset{\frown}{\bar{F}}{}^{S/I}$, is used to update the snow depth. Upward solid freshwater fluxes are used for sublimation of snow, and, if all snow is consumed, the remaining flux is used to sublimate sea ice, and then to evaporate water. The formulation conserves mass but not heat.

The sum of both freshwater fluxes is used to update the ocean surface elevation, which is a prognostic variable. In this way, the influence of the snow cover is accounted for in the barotropic pressure gradient that is calculated by use of the sea-surface elevation only. Consequently, a change of ice thickness does not influence the sea-surface elevation. Its effect on the thickness of the upper ocean layer is, however, taken into account in the calculation of the upper ocean salinity and the vertical mixing parameterizations.

Since the sea-surface elevation is a prognostic variable, there is no need to specify salt fluxes through the surface. Instead, all freshwater fluxes can be transformed directly into changes of the sea-surface elevation. The salinity is then adjusted to the new upper layer thickness with the total salt content being conserved. Accordingly, if sea ice is created or melted, this implies an upward or downward freshwater flux respectively for the computation of the upper-layer salinity and a corresponding salt flux of the same direction depending on the sea-ice salinity and the ice volume change. Since the sea-ice salinity is smaller than the upper-ocean salinity, melting of sea ice is associated with a freshening of the upper ocean.

2.3 Momentum fluxes

The momentum fluxes for the atmosphere/water interface $\overset{\frown}{\bar{M}}{}_j^W$ and the atmosphere/sea-ice interface $\overset{\frown}{\bar{M}}{}_j^{S/I}$ are calculated with bulk formulas in the atmosphere model:

$$\begin{aligned}\bar{M}_j &= \overset{\frown}{\bar{M}}{}_j^W + \overset{\frown}{\bar{M}}{}_j^{S/I}\\ &= (1-\bar{A}_I)\overline{D_m^W[\bar{\theta}_1]\left|\vec{v}_B\right|(v_{Bj}-v_j^W)} + \bar{A}_I\overline{D_m^{S/I}\left|\vec{v}_B\right|(v_{Bj}-v_j^{S/I})}\end{aligned}$$

The index *j=1,2* stands for the zonal and meridional vector component respectively.

The exchange coefficients D_m^W and $D_m^{S/I}$ depend on the stability (Richardson number, see “Heat fluxes” on page 5) and especially $D_m^{S/I}$ on the SST $\bar{\theta}_1$, which is passed over from the ocean model. The water velocity $\vec{v}_1$ and the sea-ice velocity $\vec{v}_I$ are not passed over from the ocean in the present version of the coupled model. Both velocities are set to zero in the atmospheric model.

Momentum fluxes are also passed in two fields, the gridcell-mean wind stress acting on the water surface, $\widehat{M}_j^W$, and the stress acting on the snow/ice surface, $\overline{M}_j^{S/I}$. The wind stress on ice is passed to the ocean without averaging over the gridcell area. It will be used in the sea-ice momentum equation (see Wolff et al., 1997). The momentum flux into the ice/ocean system derived from the air/ice stress is $A_I \overline{M}_j^{S/I}$. From the ice velocity, the water-ice stress $\vec{\tau}_I$ is calculated with a quadratic stress law (see Wolff et al., 1997). In order to account for sea-ice concentration changes in a gridcell during a coupled time step, the air/water momentum flux is corrected by the mismatch of the momentum flux in the atmosphere and the ice/ocean. The momentum flux applied to the ocean is thus

$$\overline{M}_j = (1 - \overline{A}_I) \cdot \overline{M}_j^W + (\overline{A}_I - A_I) \cdot \overline{M}_j^{S/I} + A_I \cdot \vec{\tau}_I .$$

A summary of the fields that are exchanged by ECHO-G and the variables that directly depend on these fields is displayed in Figure 1 on page 13.
Besides the dependencies listed in Figure 1, there are additional indirect dependencies, and dependencies which occur only if conservation of heat or mass could not be guaranteed otherwise. The symbols used in the formulas are explained in Table 8 on page 45.

2.4 Flux corrections

Corrections to the heat and freshwater fluxes can be done by either applying heat and freshwater fluxes which correspond to a relaxation of the SST and SSS to specified temperature or salinity fields (e.g. climatologies), or by reading and applying time-constant fields of heat and freshwater fluxes that have been generated before.
Relaxation-related fluxes can be calculated only in the ocean model. Their calculation is activated by specific FORTRAN preprocessor switches (gpp options; see Table 5 on page 35). Note that the salinity-relaxation fluxes are set to 0 at gridcells where the specified (climatological) surface temperature is below the freezing point plus a specified temperature offset T_+. Thus, there is no SSS relaxation within a ‘climatological ice region’ which is defined through the specified temperature field and the offset. The SST-relaxation related fluxes are applied in all cells. They do not depend on the ice concentration.
The time-constant fields of heat and freshwater flux corrections that are supplied with the model (see Table 1 on page 18) have been calculated in a 100-year coupled run of ECHO-G where monthly climatological AMIP-SSTs were used for the calculation the SST-relaxation fluxes. AMIP-SSTs that were colder than freezing point were set to freezing point before the calculation of the relaxation fluxes.

2.5 Interpolation between atmosphere and ocean grids

The interpolation from the atmospheric grid to the ocean grids and vice versa is done with the OASIS software developed at CERFACS (Terray et al., 1998). With this software, the interpolation method can be chosen by keyword specification in the OASIS control file ‘namcouple’ (Table 1 on page 18). All interpolation schemes use only the sea-cell values to interpolate between the grids (Note that the continental runoff is projected on sea cells as well.). Total fluxes through the sea surfaces of the component models are conserved.

With a T30 resolution for the atmosphere and a T42er resolution for the ocean, the horizontal grid of the ocean is much finer than that of the atmosphere, in particular in the tropics. There are as much as 40 ocean gridcells underlying one atmosphere cell. In order to avoid aliasing effect which could occur with point-interpolation methods, ECHO-G uses an area-averaging scheme for the interpolation of the SST, SIT, SIC, and SNT. The value transferred to an atmosphere gridpoint is the spatial average of the oceanic values of those gridcells that are overlapped by the atmosphere cell, weighted by the relative areas that are taken up by the ocean gridcells.

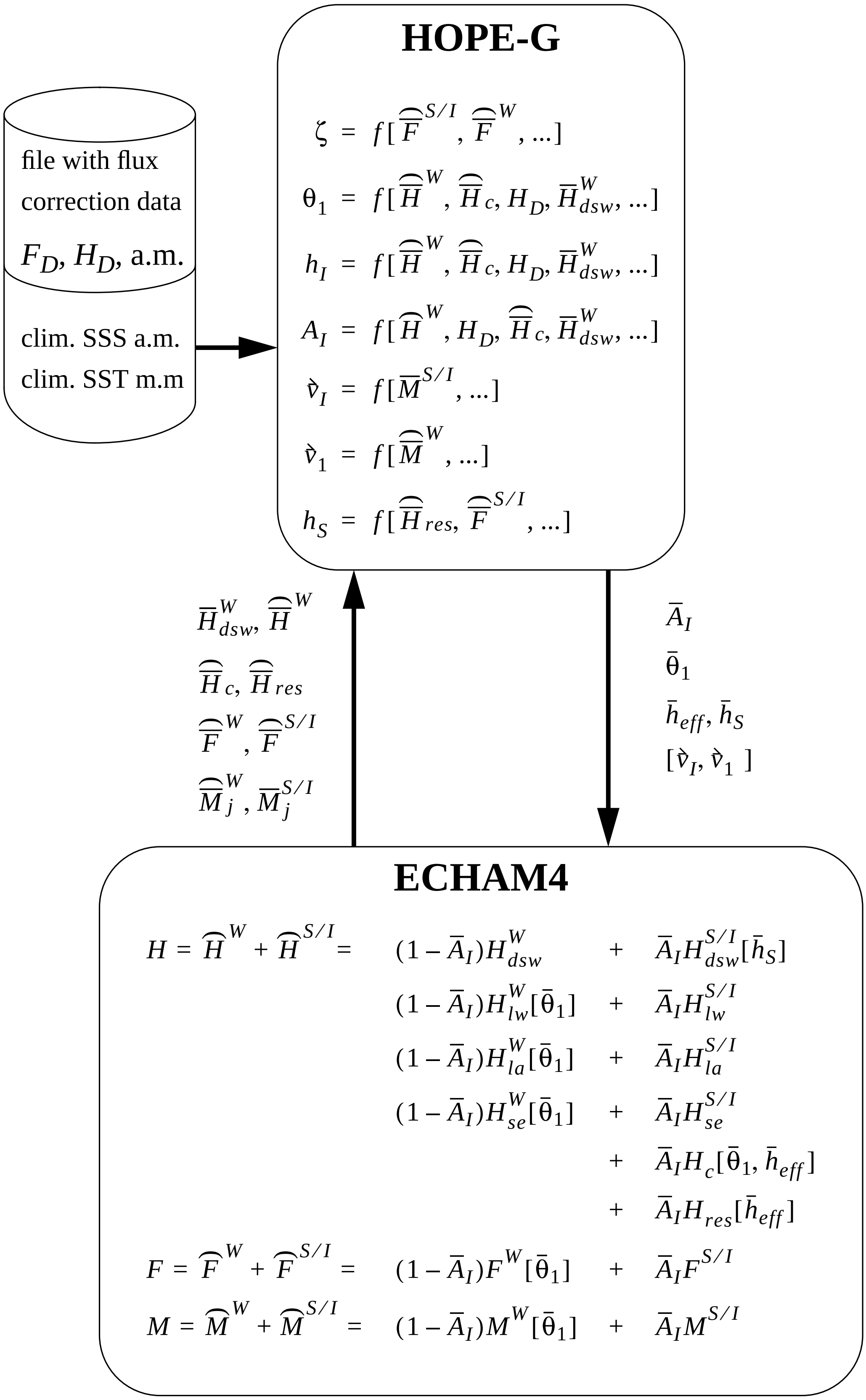
The interpolation from the atmosphere to the ocean is from the coarser to the finer grids.

The wind stress over water and that over ice or snow are interpolated with a bicubic interpolation scheme which guarantees smooth spatial derivatives.

The heat and freshwater fluxes are also interpolated with a bicubic scheme. An exception is the residual heat flux which is positive by definition and is interpolated linearly.

Near the equator, the meridional scale of the ocean grid and the scale of natural SST patterns are much finer than that of the atmosphere grid. At least the heat flux between ocean and atmosphere should respond to these patterns. This, however, is not possible if the fluxes are calculated in the atmosphere using the mean upper-layer ocean temperature averaged over the atmosphere gridcells. In order to partly correct this, we redistribute the net atmospheric heat flux that enters the ocean cell group that underlies a single atmosphere cell in a manner that the total heat flux through the cell-group surface is conserved and that the heat through each cell of a group is proportional to the difference between the local ocean SST and an ‘effective’ atmosphere near-surface temperature. This ‘effective’ atmosphere near-surface temperature is calculated by assuming that the net heat flux is proportional to the ‘effective’ atmosphere near-surface temperature with a proportionality constant of $40\ W/(Km^2)$. This ‘subgrid’ correction is done in the tropics only where the meridional scale differences of the ocean and atmosphere grids are largest. It can be (de)activated by specification of symbolic names for conditional compiling (gpp options).

Figure 1 Fields exchanged between the component models of ECHO-G



3 System description

When ECHO-G is started, one process is created for each component model, ECHAM4 and HOPE, and an additional process is created for OASIS. The OASIS process and the model processes are in a (UNIX) parent-child relationship. All communication between the models is via OASIS, there is no direct communication between the models themselves.
The synchronization of the field exchange is done by OASIS. With the 'PIPE concept' which is used for ECHO-G, this synchronization is done by I/O on named pipes (FIFOs). For each exchange field that is passed to OASIS or received from OASIS, a corresponding FIFO has to be defined in the models. When a model or OASIS is ready to pass a field, it first writes the data on a file and then writes its time step number to the pipe that corresponds to that field. When OASIS or the model is ready to read the field, it first tries to read the corresponding pipe. Since this reading is on FIFOs, it will wait until the time step message has been written to the pipe. Only then the fields will be read from the file.
This synchronization can be done in a mode where the integration of the component models over one coupled time step is sequential or parallel. For more details on the OASIS concept see Terray et al. (1998).

ECHO-G is initialised with the ocean surface conditions only (file sstocean) in the first run of each experiment. Continuation runs are initialised with both, the ocean surface conditions and the atmospheric fluxes (file flxatmos) of the last coupled time step. A flow chart of the time stepping of ECHO-G is displayed in Figure 2 on page 21 (see “Model description” on page 3).

3.1 Flow chart of HOPE-G

A more detailed flow chart of the HOPE-G component model is shown in Figure 3 on page 23. It includes only those aspects of the model flow that are relevant for the coupled version. For the HOPE model-flow charts see Wolff et al. (1997).

The main program of HOPE in its component model version is OCE_MAIN.

OCE_MAIN first calls OCEINI to initialise HOPE (reading of topography, restart files or initial stratification, specification of model parameters, etc.) as in the standard stand-alone version. Only some parts of the code that are associated with the reading of forcing data are not included in OCEINI. The model standard output is redirected to an extra file named ‘oceout’, in order to have separate standard output files for all component models and OASIS.

Then HOPE reads the CCM control data from NAMELIST KONTCTL.

In subroutine OCE_PIPE_DEF the FIFOs are defined. There are 4 writing FIFOs associated with the surface conditions, 10 FIFOS for the reading of the atmospheric fluxes (see Figure 1 on page 13), and two additional pipes through which the communication between HOPE and OASIS is initialised.

At the beginning of a coupled experiment (LRERUN=.F.), i.e. if no OASIS restart files are available, initial ocean surface conditions are written to file ’sstocean’ and timestep information to the corresponding pipes by calling OCE_INI_WRTE. The component model with model number 1 (ECHAM4, specified in the namcouple file) then starts the first coupled time step and the other model, HOPE, waits until the first fluxes calculated in the first coupled time step are available. HOPE then starts its first coupled time step, parallel to the second coupled time step of ECHAM4, which reuses the surface conditions provided by the HOPE initialisation.

At the beginning of a coupled time step (MOD(JO,NO)=1), OCE_READ is called to read the pipes corresponding to the atmospheric flux fields and then to read the fluxes from file ’flxocean’. (NO and NC are the number of ocean time steps per coupled time step and the number of coupled time steps respectively. JO is the HOPE time-step counter.)

Then the exchange fields generated by HOPE are initialised in subroutine OSSTINI. HOPE is advanced by 1 ocean time step in subroutine OCESTEP, the same subroutine that is used in the stand-alone standard version. In OCESTEP, subroutine OSSTACC is called to accumulate the surface conditions.

At the end of each coupled time step (MOD(JO,NO)=0), HOPE normalises the mean surface condition fields and calls subroutine OCE_WRTE to writes them to file ’sstocean’ and the time step to the corresponding pipes.

3.2 Flow chart of ECHAM4

In Figure 4 on page 25 the flow chart of the ECHAM4 routines relevant for coupling are shown. A detailed description of the model flow is given in DKRZ (1993). The main program of ECHAM is MAIN (different to the ECHAM4 standard version). MAIN calls ATMINI and ATMSTP. ATMINI, which is based on the standard ECHAM routine CONTROL, initialises the atmospheric model.
In READ_KONTCTL, which is called by ATMINI, the namelist KONTCTL is read. KONTCTL contains the coupling parameters and is also read by HOPE. Thereafter, the named pipes (FIFOs) for data exchange with OASIS are initialised in ATM_PIPE_DEF. 10 FIFOs are used for writing the atmosphere-to-ocean flux fields, 4 FIFOs are defined for reading the surface conditions, and 2 FIFOs are used to initialise the communication between ECHAM4 and OASIS. Since the initial conditions are created by HOPE if no OASIS restart files are available in a first run, there is no subroutine corresponding to OCE_INI_WRTE.

ATMSTP is based on the standard ECHAM routine DRIVE. The routine STEPON, called by ATMSTP, advances the model by one atmosphere model time step. At the beginning of each coupled time step (MOD(JA,NA)=1), ATM_READ is called in STEPON. This routine reads the pipes corresponding to the oceanic surface condition fields and then, from file ‘sstatmos’, the oceanic surface conditions (SST, sea-ice thickness and coverage, and snow thickness over sea-ice) provided by HOPE via OASIS.

In order to perform an atmospheric time step, several routines are called in STEPON (for details see DKRZ (1993)). Among other routines COLLECT is called (via SCAN1, GPC, and PHYSC). COLLECT accumulates the atmosphere-ocean flux components which are transferred to HOPE via OASIS. At the end of a coupled time step (MOD(JA,NA)=0) these flux components are averaged in ATM_AVRG and written to file ‘flxatmos’ in ATM_WRTE. Both routines are called in STEPON. The atmospheric time step is written to the corresponding FIFOs in ATM_WRTE as well. This is the signal for OASIS that the flux fields are available now and can be read and interpolated to the ocean grid.

In order to have separate output files for all component models and OASIS, the model standard output of ECHAM4 is redirected to file ‘atmout’.

3.3 Input files

The coupled model needs some additional input files which are listed in Table 1 on page 18. Table 1 contains only those files which are relevant for the coupled model. Each component model also requires input files which are needed in stand-alone runs as well. These are described in the respective manuals.

The first four files of Table 1 are needed by OASIS for the interpolation. These are named ’grids’, ’masks’, ’areas’, and ’mweights’. They all have the OASIS file format (as do the next two), that is, they must be unformatted with sequential access mode. For each array, they contain one record with an 8-byte character locator and one record with the array data. The locator of the OASIS files are summarized in Table 4 on page 34. Section 4.4, “Generating the grid-information files” on page 33, describes how these files are generated. For the specific set-up of the coupled model provided by the DKRZ, these files are provided as well and need not be generated as long as the model is run on a machine with binary compatibility to the CRAY C90.

The ’grids’ file contains the latitudes and longitudes, ’masks’ the land/sea mask (0 for land / 1 for sea), and ’areas’ the surface areas of the grid cells of each grid of all component models.
For the interpolation from the (finer) ocean grid to the (coarser) atmosphere grid, we use an area-averaging method (activated by the keyword ’SURFMESH’ in the OASIS control file ’namcouple’). This method uses the file ’mweights’ which, for each atmosphere cell, contains the weights of the values of ocean cells used for the calculation of the values for the atmosphere cell. This file can be generated by OASIS. Its generation is quite CPU-time consuming. It can be saved, however, after the first run and used in the following integrations.

The file ’sstocean’ contains the (initial) ocean surface conditions for an experiment. It can be generated in subroutine OCEINI or provided by the user. This file has to be in the OASIS format as well, i.e. for each exchange field, it contains one record with the locator followed by one record with the field data. The locator used by ECHO-G for the exchange fields are summarized in Table 6 on page 38.

In a continuation run, ECHO-G reads initial data also from file ’flxatmos’. This file as well as the actual ’sstocean’ has been saved by ECHO-G at the end of the preceding run of the experiment.

The NAMELIST KONTCTL contains the control variables for the time looping of ECHO-G. It is read by the ocean as well as by the atmosphere in subroutine READ_KONTCTL. This subroutine checks whether the component models restart files are synchronised.

The file ’PATEMP’ contains monthly climatological SST. It is used in HOPE for the computation of the flux correction data by relaxation of ocean SST to climatological SST. Annual mean fresh-water and heat flux correction data can be read from file FWFCORR and HTFCORR. The use of SST/SSS relaxation or flux corrections or none of them, and thus the use of these files is activated by gpp options at compile time of the ocean (Table 5 on page 35) or by setting switches in the ocean which control the ocean model flow .

The last file named ’namcouple’ contains the control information for OASIS. It contains information about the general set-up of the coupled model (no. of models, sequential or parallel integration, interpolation methods etc.) and is described in detail in Section 4.7, “The ‘namcouple’ file” on page 36.
Table 1 also lists the variable names of logical units and the subroutines were the units are set. Each unit number is used in one component model or in OASIS only. Thus the units used in the previous DKRZ pool version of HOPE have been changed. Units used by ECHAM4 are not changed except for the redirection of the standard output.

Table 1 ECHO-G input files

Unit / set in..	Alias file name	Description	Comment
nulgr=71 SBR inilun	grids	latitudes and longitudes of all component model gridpoints	section 4.4 used by OASIS only
nulma=72 SBR inilun	masks	land/sea masks of all component model grids	"
nulsu=73 SBR inilun	areas	cell areas of all component model grids	"
nulcc=76 SBR inilun	mweights	weights for interpolation with SURFMESH	section 4.7 written/read by OASIS
kunitow=92 SBR READ_KONTCTL	sstocean	ocean surface conditions on the ocean grid	written by HOPE, read by OASIS
kunitaw=95 SBR READ_KONTCTL	flxatmos	atmospheric fluxes on the atmosphere grid	written by ECHAM4, read by OASIS
nlunkon=51 SBR OCEINI	KONTCTL	ECHO-G control variables	NAMELIST; read by HOPE and ECHAM4

Table 1 ECHO-G input files

Unit / set in..	Alias file name	Description	Comment
nlunpat=57 SBR OCEINI	PATEMP	monthly climatological SST	read by HOPE
lunfwf SBR PBOPEN	FWFCORR	a. m. fresh-water flux correc-tion	"
lunfwf SBR PBOPEN	HTFCORR	a. m. heat flux correction	"
nulin = 4 Program COUPLE	namcouple	OASIS control variables	read by OASIS

3.4 Output files

The standard output of HOPE, ECHAM4, and OASIS is directed to the files ’oceout’, ’atmout’, and ’cplout’ respectively. The logical units are set in subroutine inilun for OASIS, in MAKESD for ECHAM4, and in OCEINI for HOPE.

Table 2 ECHO-G output files

Unit/ set in ..	Alias file name	Description	Comment
nout=6 SBR MAKESD	atmout	ECHAM4 std output	
nulou=79 program COUPLE	cplout	OASIS std output	
nlunout=7 SBR OCEINI	oceout	HOPE std output	
nulcc=76 SBR inilun	mweights	weights for interpolation with SURFMESH	see section 3.3 and section 4.7

3.5 Internal files

Table 3 lists additional files which are used internally by ECHO-G and contain the ocean surface conditions interpolated to the atmospheric grids, 'sstatmos', and the atmospheric fluxes interpolated to the ocean grids 'flxocean'.

Table 3 ECHO-G internal files

Unit / set in ...	File	Description	Comment
kunitar=96 SBR READ_KONTCTL	sstatmos	ocean surface conditions on the atmospheric grid	written by OASIS read by ECHAM4
kunitor=91 SBR READ_KONTCTL	flxocean	atmospheric fluxes on the ocean grids	written by OASIS read by HOPE

Figure 2 Scheme of the time integration of ECHO-G

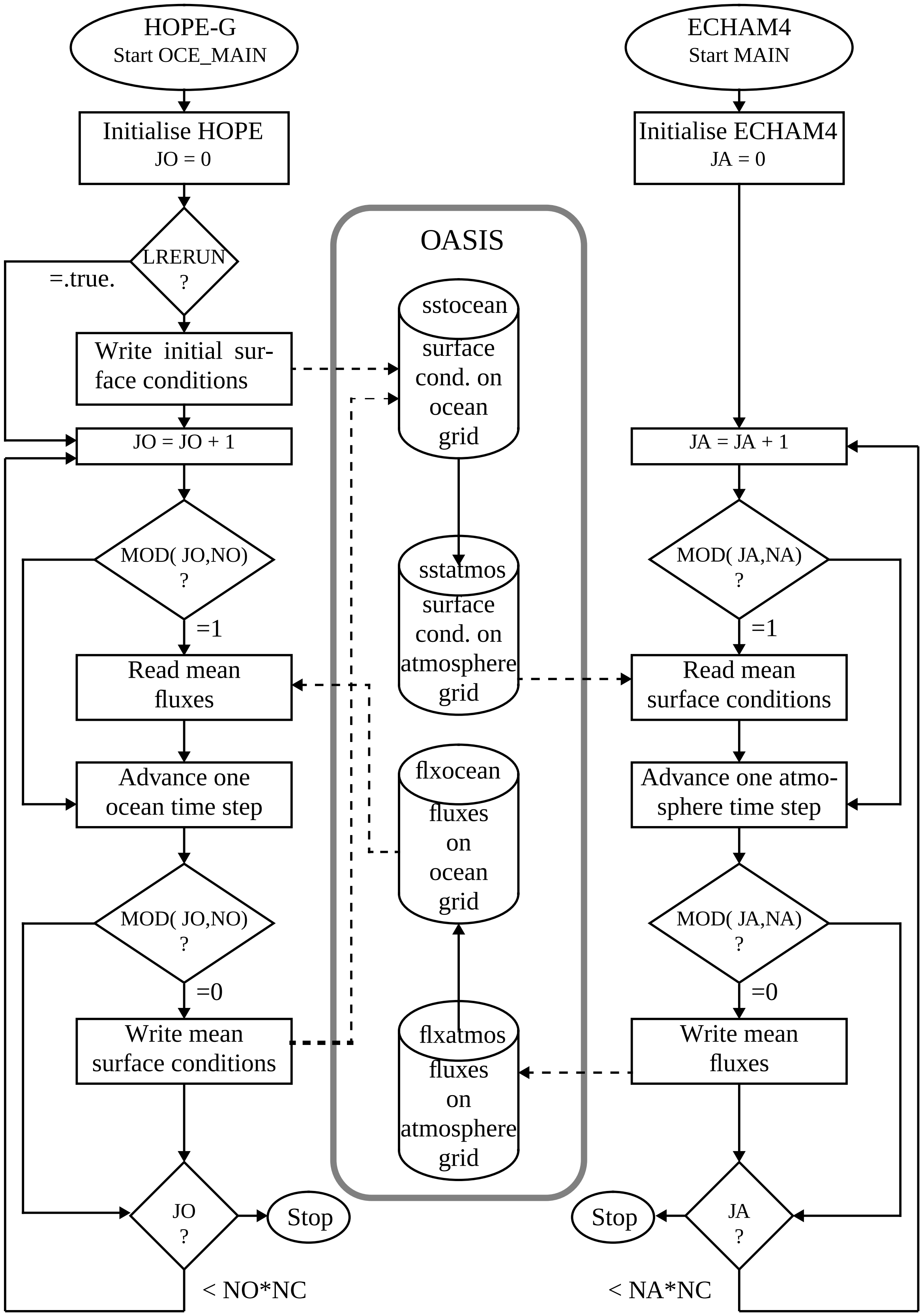


Figure 3   Flow chart of component model HOPE-G

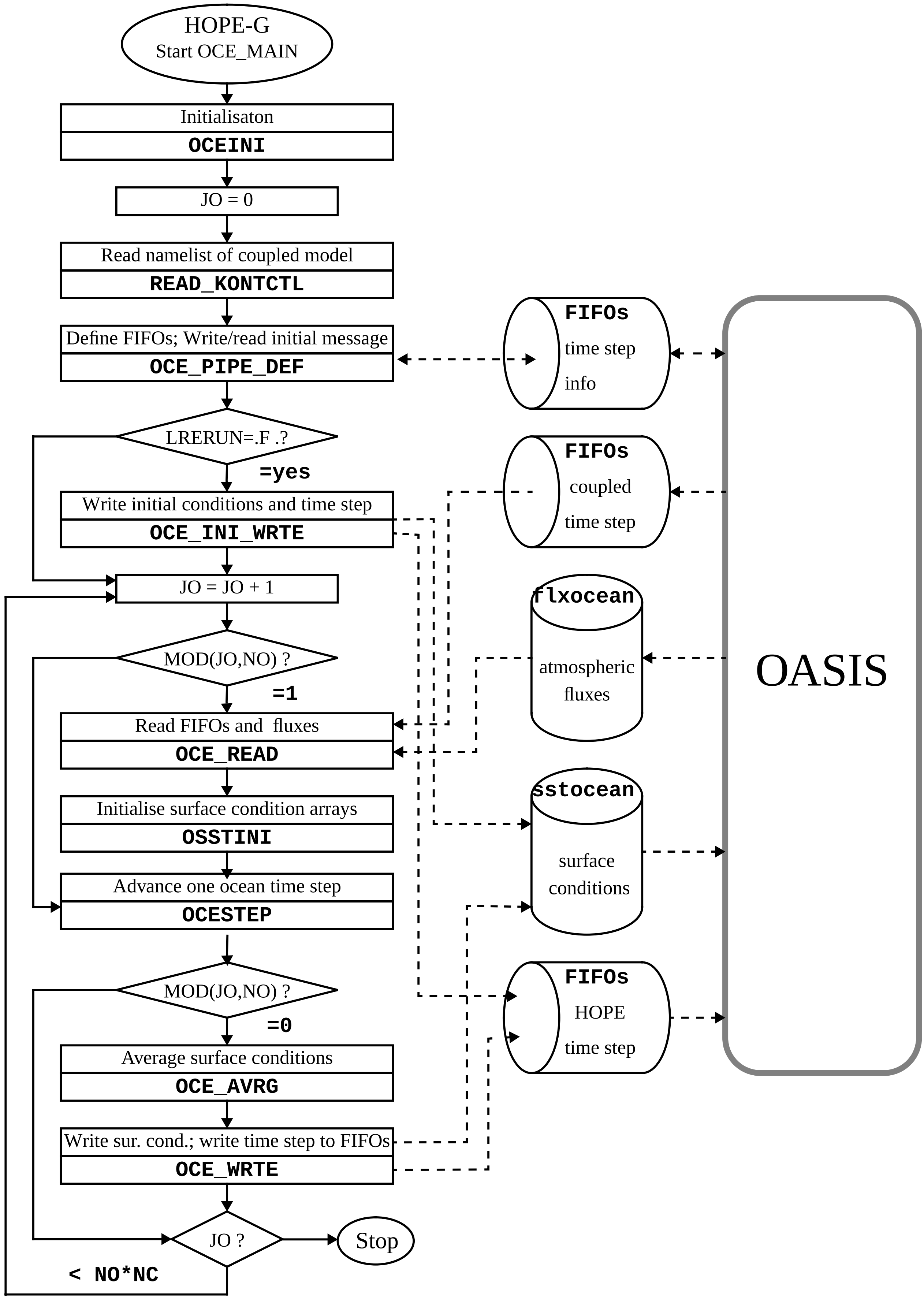
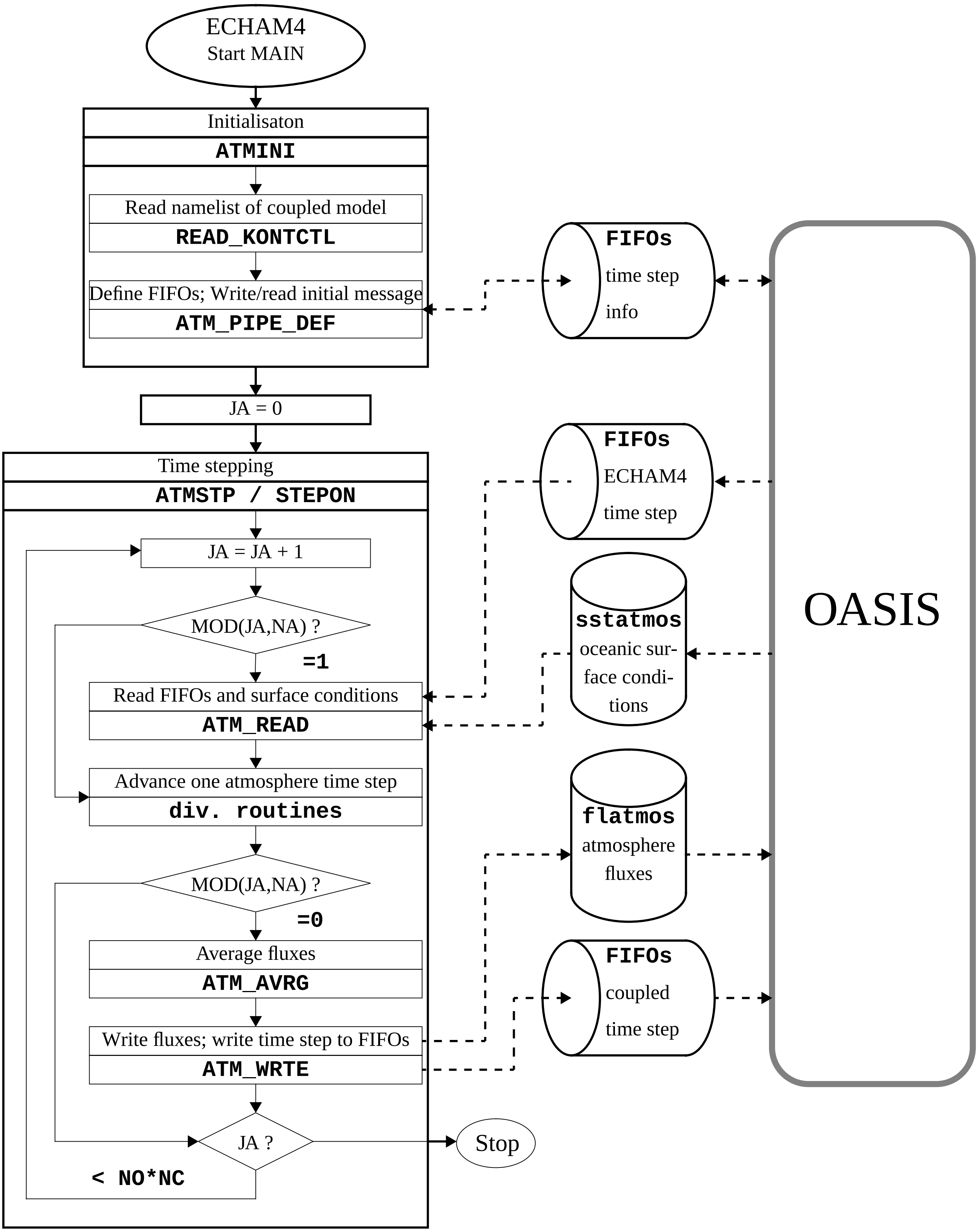


Figure 4 Flow chart of component model ECHAM4



3.6 Subroutines needed to set up the component model HOPE-G

The component model HOPE differs from the stand-alone model by only a small number of additional subroutine calls which concern the data exchange with OASIS, and some minor other changes of the code. The latter are related to the use of the atmospheric forcing fields which is different from that of the stand-alone version. The thermodynamic ice-growth routine GROWTH now exclusively uses atmospheric fluxes, while the stand-alone version uses near-surface atmospheric fields in ice-regions. The coupled model is set up by specifying the gpp options -DPFLUXES and -DPOASIS in the HOPE compile script. If -DPFLUXES is not specified but -DPOASIS, a stand-alone version of HOPE is set up that uses the same forcing data as does the version alreay in the DKRZ model pool, however, the reading of the data and the interpolation to the ocean grid is done by OASIS.

The subroutines that are needed to set up the ocean component model ready to be used with OASIS can be found in directory oasis/sbrs_oasis.F, the other subroutines needed for the compilation of HOPE reside in directory sbrs.F and sbrs_t42er.F. The latter directory contains subroutines that are specific for the particular resolution of the ocean model.

3.6.1 Main program OCE_MAIN

In the HOPE pool version, the main program that controls the ocean model integration is OCEMAST. Since this program also reads the forcing data and calls an interface that interpolates the data between the atmosphere and ocean grids it has been replaced. The main program of the component HOPE version is called OCE_MAIN. It controls the ocean integration and the reading and writing of exchange fields as depicted in Figure 3 on page 23.

3.6.2 Subroutine READ_KONTCTL

Subroutine READ_KONTCTL sets defaults for the ECHO-G control variables and reads the NAMELIST KONTCTL. This namelist, which overwrites the control variables, is also read in ECHAM4 with the same routine. READ_KONTCTL checks the synchronization of the restart files of the component models.

3.6.3 Subroutine OCE_PIPE_DEF

OCE_PIPE_DEF initialises the communication between OASIS and HOPE. It defines 2 named pipes (FIFOs) for the initial information exchange with OASIS, one pipe for writing to OASIS named RDhopt42 and one pipe for reading named WThopt42. HOPE writes the total number of time steps, the number of time steps per coupled time step, the length of its time step and its process ID to RDhopt42. OASIS uses this information from all component models to define its own time step and check the consistency between the time stepping and exchange frequency of the different models. The corresponding information of OASIS is read by HOPE from WThopt42. OCE_PIPE_DEF also defines the pipes for synchronization of field exchange, one reading pipe for each of the 10 flux fields received from the atmo-

sphere and one writing pipe for each of the 4 surface condition fields sent to the atmosphere.
It is recommended to compile this routine without any optimisation or multitasking.

3.6.4 Subroutine OCE_INI_WRTE

Subroutine OCE_INI_WRTE is called at the beginning of an experiment if no OASIS restart files (‘sst-ocean’, ‘flxatmos’) are available (LRERUN=.false.). It writes the ocean initial surface conditions to ’sst-ocean’ and time step information to the corresponding pipes.
It is recommended to compile this routine without any optimisation or multitasking.

3.6.5 Subroutine OCE_READ

OCE_READ reads the pipes related to the atmospheric flux fields and then the corresponding exchange fields that are passed by OASIS from the atmosphere to file ’flxocean’.
It is recommended to compile this routine without any optimisation or multitasking.

3.6.6 Subroutine OSSTINI

At the beginning of each coupled time step, subroutine OSSTINI resets the arrays where the surface conditions are accumulated.

3.6.7 Subroutine OCE_AVRG

At the end of each coupled time step, the accumulated surface conditions are normalised in subroutine OCE_AVRG and the effective ice thickness is calculated from the gridcell-mean ice thickness and snow depth (see “Heat fluxes” on page 5). The mean sea-ice concentration is interpolated from the scalar to the vector grid for later use in the sea ice-ocean surface-stress calculation in subroutine OCWIND.

3.6.8 Subroutine OCE_WRTE

OCE_WRTE writes the mean surface condition fields to file ’sstocean’ and the ocean time step is written to the corresponding pipes.

3.6.9 Subroutine PIPE_DEF

Auxiliary subroutine to define a FIFO.

3.6.10 Subroutine locread.

This OASIS subroutine performs a localized read on the file containing the exchange fields (for details see Terray et al., 1998).

3.7 Subroutines needed to set up the uncoupled ECHAM4

Two steps are needed to get the coupled version from the standard ECHAM4:

- improved description of the atmosphere-ocean interaction, which can also be used with the uncoupled model.
- technical changes, which are needed for the exchange of information with OASIS.

The modifications of the uncoupled ECHAM4 are described in the following and the coupling routines are presented in Section 3.8.

3.7.1 Subgrid-scale atmosphere-ocean fluxes

The physical changes concern the atmosphere-ocean fluxes of partly sea-ice covered gridcells. In contrast to the standard ECHAM4, the fluxes of a gridcell over open water and sea-ice are calculated separately. This method has been developed by Groetzner et al. (1996) for the ECHAM3. To implement this method, the routines VDIFF (calculation of turbulent fluxes of the boundary layer), SKINTEM (calculation of the sea-ice skin temperature), RADINT and RADHEAT (calculation of shortwave and longwave radiation) have to be updated. An additional diagnostic heat flux component which describes the surface melting of sea-ice by atmosphere fluxes (QRES) is calculated in SKINTEM. Due to the separate computation of the fluxes for land, open water, and sea-ice, additional field codes for the ECHAM4 output are introduced. These additional output variables contain the individual subgrid-scale fluxes. A list of these variables is given in Table 9 on page 48.

3.7.2 Continental runoff

To ensure a closed hydrological cycle for the coupled system, a scheme for the continental river runoff and a scheme for the calculation of freshwater input to the ocean from glaciers (Greenland and Antarctica) are added to the standard version of ECHAM4. Both schemes are only diagnostic tools for the uncoupled ECHAM4, whereas the treatment of the subgrid-scale atmosphere-ocean fluxes always affects the model climate, in a stand-alone as well as in a coupled integration.

The applied runoff scheme has been developed by Sausen et al. (1994). The update for ECHAM4 contains a set of additional routines to save restart fields (HISTRUN), to initialise (INIROP, INIRUNO), and to run the scheme (RUNO, COLRUN, DISRUN). Beside the unit for the restart fields (81), three additional units are needed for the boundary conditions of the runoff scheme (82, 83, 84).

In the standard ECHAM4, runoff from continental ice sheets is not considered. Due to a positive net freshwater flux onto both glacier regions of the model (Greenland and Antarctica) these regions normally constitute a sink for the hydrological cycle. To close the freshwater budget for the coupled system, the freshwater flux is accumulated separately over both glacier regions and distributed along the respective coast lines. The corresponding input due to latent heat of fusion is added to the heat flux. In subroutine INIGLAC a mask is read from unit 18 which defines the glacier cells of the atmosphere grid where the ’glacier runoff’ is accumulated and the ocean cells of the atmosphere grid where fresh water is distributed.

3.8 Subroutines needed to set up the component model ECHAM4

3.8.1 Subroutine READ_KONTCTL

see “Subroutine READ_KONTCTL” on page 27

3.8.2 Subroutine ATM_PIPE_DEF

ATM_PIPE_DEF initialises the communication between OASIS and ECHAM4. It defines two named pipes (FIFOs) for the initial information exchange, one pipe for writing to OASIS named RDpsech4 and one pipe for reading named WTpsech4. ECHAM4 writes the total number of time steps, the number of time steps per coupled time step, the length of its time step and its process ID to RDpsech4. OASIS uses this information from all component models to define its own time step and check the consistency between the time stepping of the different models. The corresponding information of OASIS is read from WTpsech4. ATM_PIPE_DEF also defines the pipes for synchronization of field exchange, one reading pipe for each of the 4 oceanic surface condition fields and one writing pipe for each of the 10 atmosphere-ocean flux fields sent to the ocean.
It is recommended to compile this routine without any optimisation or multitasking.

3.8.3 Subroutine ATM_READ

ATM_READ reads the pipes related to the oceanic surface-condition fields and then the corresponding exchange fields that are passed from the ocean to file ’sstatmos’ by OASIS.
It is recommended to compile this routine without any optimisation or multitasking.

3.8.4 Subroutine COLLECT

This routine accumulates the atmosphere-ocean flux fields used for coupling.

3.8.5 Subroutine ATM_AVRG

Subroutine ATM_AVRG normalises the accumulated fields, distributes the accumulated net fresh-water flux of the glaciers to the coastal sea cells, and calculates the latent heat of fusion for the glacier runoff.

3.8.6 Subroutine ATM_WRTE

ATM_WRTE opens the file ’flxatmos’ to which the atmosphere-ocean fluxes are written. The normalised fields are written to the file and the atmospheric time step is written to the corresponding pipes.

3.8.7 Subroutine PIPE_DEF and subroutine locread

see “Subroutines needed to set up the component model HOPE-G” on page 27.

4 User's manual

This section describes how the standard version of ECHO-G is set up and run on a CRAY machine of the DKRZ. n.n is the release number, 1.0i is taken to be the actual version-no. of ECHAM and HOPE, 45 is the user ID used to identify the user of ECHO-G, 003_c03 gives a serial number for the actual experiment of which the last three letters only are used by HOPE and OASIS. The OASIS release-no. is 2.2
All source code necessary to set up this version of ECHO-G is contained in the tar-file ECHO-G_n.n_source_cray.tar and all data input files are contained in ECHO-G_n.n_data_cray.tar. Results of two runs of one month length are found in ECHO-G_n.n_result_cray.tar. These tar-files, as well as a postscript version (ECHO-G_tech_rep_n.n.ps) of this manual, are available on the DKRZ file server in directory /pool/modelle/echo-g.
Figure 5 on page 41 and Figure 6 on page 43 show the directory trees which are created by the source and data tar-files respectively when they are expanded. Directories at the end of dashed lines will not be created by expanding one of the tar-files but during the execution of one of the scripts contained in the tar-files.
Section 4.1 and Section 4.2 gives a summary of the contents of the directories. Note that the source and data directory trees contain identical paths. Thus the source and data files must be expanded in different directories (e.g. /pf/... and /mf/...).
Before any of the scripts is started, do not forget to change the path names above the directories that are set up by the tar-files (the home and working directories) to the directories where the tar-files have been expanded.

4.1 Contents of directories: source code

sbrs.F: source code of HOPE that is used for all grid resolutions

sbrs_t42er.F: source code of HOPE which depends on the model grid

.scripts: scripts to generate ECHO-G integration scripts

oasis: all source code and programs related to OASIS

oasis/sbrs_oasis.F: source code needed to set up HOPE as a component model of ECHO-G

oasis/oasis_version2.2: source code of OASIS; for more details on OASIS see Terray et al. (1998)

oasis/oasis_version2.2/...local: local DKRZ versions of OASIS subroutines

oasis/oasis2.2_dkrz: scripts to generate the OASIS executable and the OASIS grid-information files

hope_t42er: script to compile the HOPE-G ocean model *hope_t42er/sbrs_hope_1.0i.f:* source code of HOPE after FORTRAN preprocessing

echam4_t30: scripts to compile the ECHAM4 atmosphere component model of ECHO-G

echam4_t30/anselm: update file to account for partial ice cover in ECHAM4

echam4_t30/updcoup_t30_t42er: update files to set up ECHAM4 as a component model of ECHO-G

echam4_t30/45003_c03: scripts to run ECHO-G.

4.2 Contents of directories: data

forcing: flux correction data

forcing/echam4_clim: land/sea mask of ECHAM4/T30

oasis/cpl/lib: OASIS binaries and libraries after compilation

hope_t42er: input files for HOPE (bathymetry, barotropic-system matrix)

hope_t42er/c03: HOPE output of experiment 45003_c03

hope_t42er/c03/abend: HOPE output of experiment 45003_c03 if an abnormal end occurred

hope_t42er/c03/output: HOPE output files

hope_t42er/c03/restart: HOPE restart files

hope_t42er/oasis/cpl/data: grid-information data for OASIS

echam4_t30/initial: input files for ECHAM4

echam4_t30/45003_c03: standard output files of all component models and OASIS

echam4_t30/45003_c03/abend: ECHAM4 output of experiment 45003_c03 if an abnormal end occurred

echam4_t30/45003_c03/output: ECHAM4 output files

echam4_t30/45003_c03/restart: ECHAM4 and OASIS restart files

execs: executables

bin... : binaries of the component models

4.3 Generating the OASIS executable

We use release 2.2 of the OASIS software of CERFACS (Terray et al.,1998). A compile script is provided with oasis/oasis2.2_dkrz/COMP_OASIS.job. It can be specified whether all libraries, only the local modifications, or the interpolation libraries shall be created, or a combination of these. All libraries must be recreated if any of the include COMMON blocks are changed. All directories that will be used but do not exist at execution-time will be created. The OASIS executable will reside in directory ‘execs’ after compilation.

We keep the OASIS source directory tree organization as it is provided by CERFACS (below directory oasis_version2.2). Local versions of the subroutines in directory ’src’ reside in directory ’srclocal’ at the same directory level. Local versions of the include files of directory ’include’ reside in directory ’includelocal’, etc.

4.4 Generating the grid-information files

The OASIS grid-information files (see Table 1 on page 18) are provided in directory hope_t42er/oasis/cpl/data of the data tar-file. A script that generates these files can be found in oasis/oasis2.2_dkrz/Create_gridinf.job and the program is compiled with Comp_gridinf.job of the same directory.

For the standard DKRZ version of ECHO-G, the resolution of the ocean and the atmosphere horizontal grids are specified as res_oce=_t42er (T42 plus equator refinement) for HOPE-G and res_atm=_t30 (T30 triangular truncation) for ECHAM4 in both scripts. The other values for res_oce and res_atm given in the scripts relate to other resolutions of the component models used at DKRZ.

Note, that the HOPE arrays have additional columns used for the specification of zonal cyclic boundary conditions. These columns are not included in the grid-information files.

The script may try to access directories of the DKRZ file-server. This is the case if any of the files are not found on the working directory specified in the scripts. These files are also needed for the HOPE-G standalone pool version and are described in the HOPE manual (Wolff et al., 1997).

The grid-information files will be saved with the ocean model and atmosphere model resolutions appended to their names. Their content together with the locator (see “Input files” on page 17) are listed in Table 4 on page 34. The appendices of the locators are defined in oasis/oasis_version2.2/srclocal/blkdata.f. The first part of the locator names is set in oasis/sbrs_oasis.F/GRIDINF.F.

The home and working directories have to be changed in the script to the directories where the tar-files have been expanded. All directories that will be used but do not exist at execution-time will be created.

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Table 4 Grid-information files for OASIS

File	Unit	Content	Locator
grids	71	atmosphere longitudes	atmo.lon
		atmosphere latitudes	atmo.lat
		ocean scalar-grid longitudes	oces.lon
		ocean vector-grid longitudes	ocev.lon
		ocean scalar-grid latitudes	oces.lat
		ocean vector-grid latitudes	ocev.lat
masks	72	atmosphere land/sea (1/0) mask	atmo.msk
		ocean land/sea (1/0) scalar-grid mask	oces.msk
		ocean land/sea (1/0) vector-grid mask	ocev.msk
areas	73	atmospheric gridcell surfaces	atmos.srf
		ocean scalar-grid cell surfaces	oces.srf
		ocean vector-grid cell surfaces	ocev.srf

4.5 Generating the HOPE executable

The HOPE executable will reside in directory ‘execs’ after compilation with the script hope_t42er/ COMP_HOPE_t42er_1.0i. The script uses the make utility. Make only compiles those subroutines that have been changed since the last compilation or that depend on code that has been changed since the last compilation. It is thus important that the specified dependencies are correct and complete. This was strived for, however is not guaranteed. If preprocessor specifications for conditional compilation (gpp options) are changed, the whole code should be recompiled by activating the line that deletes all binaries.

In addition to the horizontal resolution, one can specify the vertical resolution, which is blank for the standard version (20 layers). The parameter ‘icelevs’, which sets the number of ice thickness classes for the heat flux calculation must have the value 1 for the ECHO-G component model. Parameter OCVERS gives the model-version appendix and has to be the same as that specified in the input file (‘45003_c03’) for the script PREPCCM.45003_c03 that generates the ECHO-G integration-scripts (e.g.1.0i).
Some FORTRAN preprocessor options can be activated in the compile script. -DMATR -DOASIS, and -DPFLUXES are required for the component model HOPE version. The other preprocessor options for HOPE are listed in Table 5 on page 35. Those that appear in the model code but are not listed in Table 5

should be used with care if at all. We also warn the user of HOPE-G that of course not all gpp combinations could be tested.

Table 5 Fortran preprocessor (gpp) options for conditional compilation of HOPE-G

Option name	Description
PCFL	call of subroutine *CFL* that checks the CFL criterion each time step
PDCONADJ	diagnosis of convective adjustment
PDIFKOE	diagnosis of effective horizontal diffusion coefficients
PDVISCO	diagnosis of effective horizontal viscosity coefficients
PELIMI	direct solution of barotropic system with Gauss elimination
PFLUXES	forcing with fluxes only (required for the coupled version)
PHTFCORR	use of annual-mean heat flux correction fields
PFWFCORR	use of annual-mean fresh-water flux correction fields
PHTMERID	diagnosis of meridional heat transport (advective and diffusive)
PMATR	reading the barotropic-system matrix from disk
POASIS	set up for coupling with OASIS (required for the coupled version)
PTSADUP	upwind advection for tracers (temp./sal.)
PPATEMP	activates SST relaxation in the ocean
PSBGRD	sub-grid scale redistribution of net atmospheric heat flux
PSHFLUX	diagnosis of heat budget under ice
PSYNOUT	additional output of time stepping-messages
PTRIAN	calculation of the barotropic-system matrix
PVTURKOE	diagnosis of effective vertical diffusion/viscosity coefficients

4.6 Generating the ECHAM4 executable

The atmosphere component model executable of ECHO-G, ECHAM4, is generated by successively running COMP_ECHAM4_t30_1.0a, then COMP_ECHAM4_t30_1.0b, and COMP_ECHAM4_t30_1.0i which are found in directory echam4_t30.
These scripts use the nupdate facility. If the model is compiled on the J90 (lake), the preprocessor option V64 must be activated.
The update file for COMP_ECHAM4_t30_1.0a is found in directory anselm. By this update, ECHAM4

is enabled to separately calculate fluxes through different surface types of inhomogenous gridcell surfaces (partial ice cover).
The update files for COMP_ECHAM4_t30_1.0b and COMP_ECHAM4_t30_1.0i are found in directory updcoup_t30_t42er. By the first update, the standard output of ECHAM4 is redirected to file 'atmout'. This is useful in order to have separate output files for the component models. The second update file introduces additional code that is needed to set up ECHAM as a component model of ECHO-G.

4.7 The 'namcouple' file

The OASIS control file 'namcouple' contains all general information about the set-up of the coupled model. The same 'namcouple' file can be used for all experiments, runs and all grid resolutions. To adapt the files to the particular run, it will be edited in the integration script before it is read by OASIS.
Changes (e.g. exchange frequency) have to be applied to hope_t42er/c03/PREPCCM.45003_c03 (see "Generating scripts for the integration of ECHO-G" on page 39) in order that they are introduced to all scripts of the experiment.
ECHO-G uses the version 'namcouple_fluxes' of the files in directory oasis/oasis2.2_dkrz. The other version is used if the ocean model is forced with fluxes in low- and mid-latitudes but with surface fields in high latitudes (HOPE must then be compiled without specification of the gpp parameter DPFLUXES). The file is listed in Section , "The OASIS control file 'namcouple'" on page 49.

In 'namcouple', the following parameters are set when the integration-scripts are generated or before execution of ECHO-G (change .scripts/PREPCCM.45003_c03 to modify them):

- 'Anzahl_der_sequentiellen_Modelle' replaced by $nmseq: nmseq=2/1 specifies whether the models are to be run sequentially or parallel
- 'exp-id' replaced by $ocexptid: e.g. c03
- 'Laufzeit' replaced by $runtime : length (in sec) of the present run
- 'Jahr_Monat_Tag' replaced by $YYYY${MONTH1}01 : YYYY is the year , MONTH1 the first runof the coupled experiment
- 'Seq_no' replaced by $iseq: sequential no. of the atmosphere mode (1 for parallel execution)
- 'Extra_step' replaced by $exstep: 1 if an extra OASIS step is to be done at the end of the run (to save data)
- 'Delay' replaced by $delay: n if the reading of the exchange fields by the model is to be delayed by n time steps.

nmseq, iseq, exstep, and delay depend on whether the component models are run parallel or sequential, and on whether surface conditions as well as fluxes are available at the start of the run. We use 2,2,0,0 respectively for a first run (no 'flxatmos' available; $RERUN is then .FALSE.), i.e. the component models run sequentially, and only the ocean exchange data (surface conditions) are provided by OASIS at the beginning of the first coupled time step. In continuation runs ($RERUN is then .TRUE., 'sstocean' and 'flxatmos' are available), the exchange fields of both component models are passed to the other model by OASIS at the beginning of the first coupled time step, and the models are integrated parallel.

- the grid dimensions of ocean and atmosphere :$lato, $lata, $lono, and $lona
- naismvoi replaced by $anaismax: the maximum number of ocean gridcells underlying an atmosphere grid cell
- niwtm replaced by $anaismwr: 1 indicates that the weight-file ‘mweights’ is generated by OASIS and written to disk; 0 indicates that it already exists.

This is coded in file ‘namcouple’ only, which is used for forced integrations of HOPE-G where the forcing data are read and interpolated by OASIS. We recommend that a new set-up (different grid resolutions) is tested first in an ocean or atmosphere stand-alone mode. A coupled integration can use the same file ‘mweights’.

For the other parameters of the ’namcouple’ file see the OASIS manual (Terray et al., 1998).

The first four exchange fields specified in ’namcouple_fluxes ’ are those generated by HOPE.

In the first line for each field, the first 2 entries are the locators in ‘sstocean’ and ‘sstatmos’ (see Table 6 on page 38). The third gives the serial number of the field description in array cfldlab which is defined in SBR oasis/oasis_version2.2/srclocal/blockdata.f. This is followed by the number of analyses (see third line), the alias names of the data-exchange files, and their logical unit numbers. The last parameter of this lines specifies that the field is to be passed to the other model.

In the second line for each field, the first 4 parameters gives the grid dimensions of the data-generating and -receiving model, and the first part of the locators in the grid-information files (Table 4 on page 34).

In the third line for each field, key words for the analyses to be performed with the fields are specified. With the T42 ocean grid including a meridional grid refinement near the equator (res_oce=t42er) and the T30 resolution for the atmosphere (res_atm=t30), the ocean grid is always finer than the atmosphere grid. To avoid aliasing effects we use the SURFMESH surface-averaging method to interpolate the fields from the ocean to the atmosphere grid. This method uses the file ’mweights’ which contains the weights of the ocean-grid values for interpolation. This file can be generated in a first run by OASIS with anaismwr=1 in the integration script. Since its generation is quite expensive, it should be saved and read from disk in subsequent runs (set anaismwr=0). For the standard DKRZ ECHO-G version, the file is provided in hope_t42er/oasis/cpl/data. If a new ’mweights’ file is generated, take care that the maximum number of overlapping cells (anaismax) is the same when the file is generated and used.

Accumulated values of the input and output fields of the global, sea, and land surfaces are calculated when CHECKIN and CHECKOUT are specified. All interpolation methods use only values from sea cells. Values on land cells are extrapolated from sea cells before the interpolation using 2 neighboring points (NINENN 2).

The OASIS ordering of arrays is from south to north and west to east. The ocean fields are written to file ’sstocean’ according to this convention. Before the fields are written to ’sstatmos’, their meridional direction will be reversed by specification of REVERSE, so that they will be written in the ECHAM4 order.

Similar argument apply to the specification of INVERT for the following 10 fields, the atmospheric fluxes. These field are transferred from the coarser to the finer grid, so we simply use the BICUBIC inter-

polation except for the residual heat flux which should always be positive.
The exchange fields and their locators are listed in Table 6 on page 38. The unit numbers are read from KONTCTL by SBR READ_KONTCTL and must be changed there and in ‘namcouple’ if at all.

Table 6 ECHO-G exchange fields

File/Unit	Content	Locator	Array name	Comment
sstocean / 92	sea surface temperatures	SSTOCEAN	$TH_{E/O}ACC$	on ocean scalar grid
	effective sea-ice thickness	SITOCEAN	$SIT_{E/O}ACC$	"
	sea-ice concentration	SICOCEAN	$SIC_{E/O}ACC$	"
	snow depth	SNTOCEAN	$SNT_{E/O}ACC$	"
sstatmos / 96	sea surface temperatures	SSTATMOS	ATEMP	on atmos-phere grid
	effective sea-ice thickness	SITATMOS	AICETH	"
	sea-ice concentration	SICATMOS	AICECO	"
	snow depth	SNTATMOS	ASNCOV	"
flxatmos / 95	zonal wind stress on water	TXWATMOS	AWUST	on atmos-phere grid
	meridional wind stress on water	TYWATMOS	AWVST	"
	zonal wind stress on ice	TXIATMOS	AIUST	"
	meridional wind stress on ice	TYIATMOS	AIVST	"
	solid fresh-water flux	FRIATMOS	AIFRE	"
	liquid fresh-water flux	FRWATMOS	AWFRE	"
	residual heat flux	RHIATMOS	AIQRE	
	conductive heat flux	CHIATMOS	AICON	
	net heat flux over water	NHWATMOS	AWHEA	
	downwelling solar heat flux	SHWATMOS	AWSOL	
flxocean / 91	zonal wind stress on water	TXWOCEAN	$AOFLTXW_{E/O}$	on ocean vector-grid
	meridional wind stress on water	TYWOCEAN	$AOFLTYW_{E/O}$	"
	zonal wind stress on ice	TXIOCEAN	$AOFLTXI_{E/O}$	"
	meridional wind stress on ice	TYIOCEAN	$AOFLTYI_{E/O}$	"

Table 6 ECHO-G exchange fields

File/Unit	Content	Locator	Array name	Comment
	solid fresh-water flux	FRIOCEAN	$AOFLFRI_{E/O}$	on ocean scalar-grid
	liquid fresh-water flux	FRWOCEAN	$AOFLFRW_{E/O}$	"
	residual heat flux	RHIOCEAN	$AOFLRHI_{E/O}$	"
	conductive heat flux	CHIOCEAN	$AOFLCHI_{E/O}$	"
	net heat flux over water	NHWOCEAN	$AOFLNHW_{E/O}$	"
	downwelling solar heat flux	SHWOCEAN	$AOFLSHW_{E/O}$	"

4.8 Generating scripts for the integration of ECHO-G

A script is provided with .scripts/PREPCCM.45003_c03 that creates scripts to run ECHO-G. Again the working and home directories have to be changed to the directory name where the data and source tar-files have been expanded. Also, the experiment ID (e.g.45003_c03) and the name of the machine where the model will be run have to be specified (e.g. lake). Before the script can be run, the program MAKELST_CCM.comp has to be compiled.

The minimum length of an integration is one month, the maximum length one year. All months of one scipt have to be of the same year. The first and last job number, and the length (in months) of the integration period of the scripts to be generated by PREPCCM.45003_c03 are specified with JOB1 and JOB2 and MANZ. PREPCCM.45003_c03 will then generate JOB2 - JOB1 + 1 scripts, each for the integration of MANZ months, where the first script starts at month (JOB1-1)*MANZ+1, and the last script ends at month JOB2*MANZ. The ECHO-G control variables in NAMELIST KONTCTL are provided with the integration scripts. They are listed in Table 7.

Table 7 ECHO-G control variables

Variable name	Description
NTAOSTOP	number of coupled time steps
NTOCEAN	number of ocean time steps per coupled time steps
NTATMOS	number of atmosphere time steps per coupled time steps
NATOFF	age (in model time steps) of atmosphere initial file
NOCOFF	age (in model time steps) of ocean initial file
NTSAVE	frequency for saving of ocean restart files

Table 7 ECHO-G control variables

Variable name	Description
NWINTER	frequency for saving of atmosphere restart files
NRESUMC	atmosphere time step at which the run is resumed
LRERUN	.true. for continuation runs (Table 7 on page 39)
NSTOPC	atmosphere time step at which the run is stopped
KUNITAR	unit where the atmosphere reads exchange data (file = sstatmos)
KUNITAW	unit where the atmosphere writes exchange data (file = flxatmos)
KUNITOR	unit where the ocean reads exchange data (file = flxocean)
KUNITOW	unit where the ocean writes exchange data (file = sstocean)

4.9 Integrating ECHO-G

When all component models and OASIS have been compiled successfully, and scripts for the integration have been generated, the experiment can be started by submitting the first integration script. When this script has been run successfully it will automatically submit the next script to integrate the next MANZ months, and so on, until all scripts provided for the experiment are executed.

Model output will be written to the directories as described in Section 4.2, “Contents of directories: data” on page 32.

With each ECHO-G integration script, a second script is generated which saves the model output on the file server. This script is submitted by the corresponding integration script when the latter has finished. If it is executed successfully, it removes itself, the corresponding integration script, and the data it saved including the standard output files. ECHAM4 output is saved every months, HOPE output once a year. The restart files are saved every MANZ months. Small files, as ZEITR and HTMERID are saved only at the end of a decade. Thus, at the end of each decade, the only trace on the compute server that is left by an experiment of which all aspect are run successfully is the standard output files of the data-saving scripts. These should be checked regularly in order to be sure that no problems occurred during the data saving process. If the data are not saved successfully, the data-saving script resubmits itself and retries to save the data two hours later.

Figure 5 Directory tree that is set up with file ECHO-G_n.n_source_cray.tar

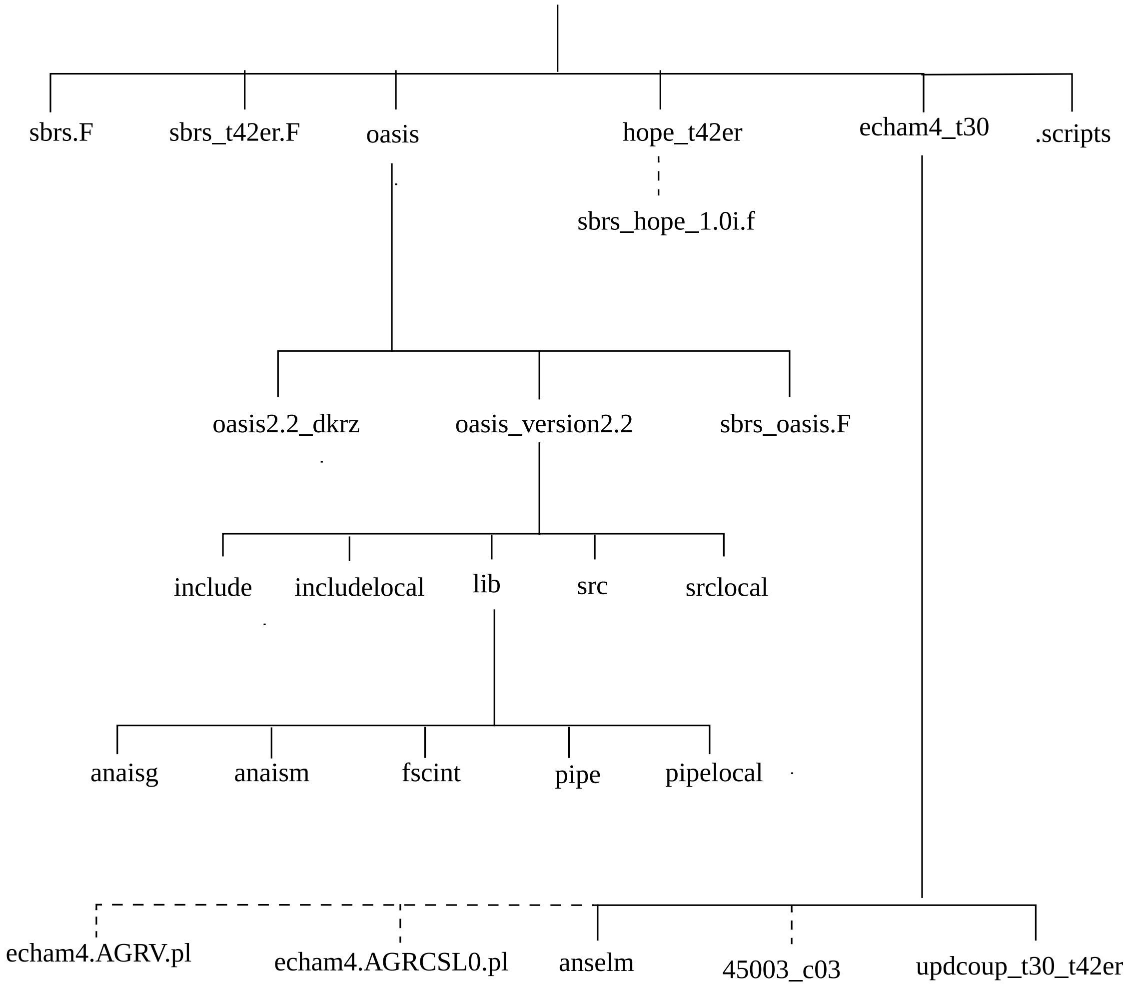
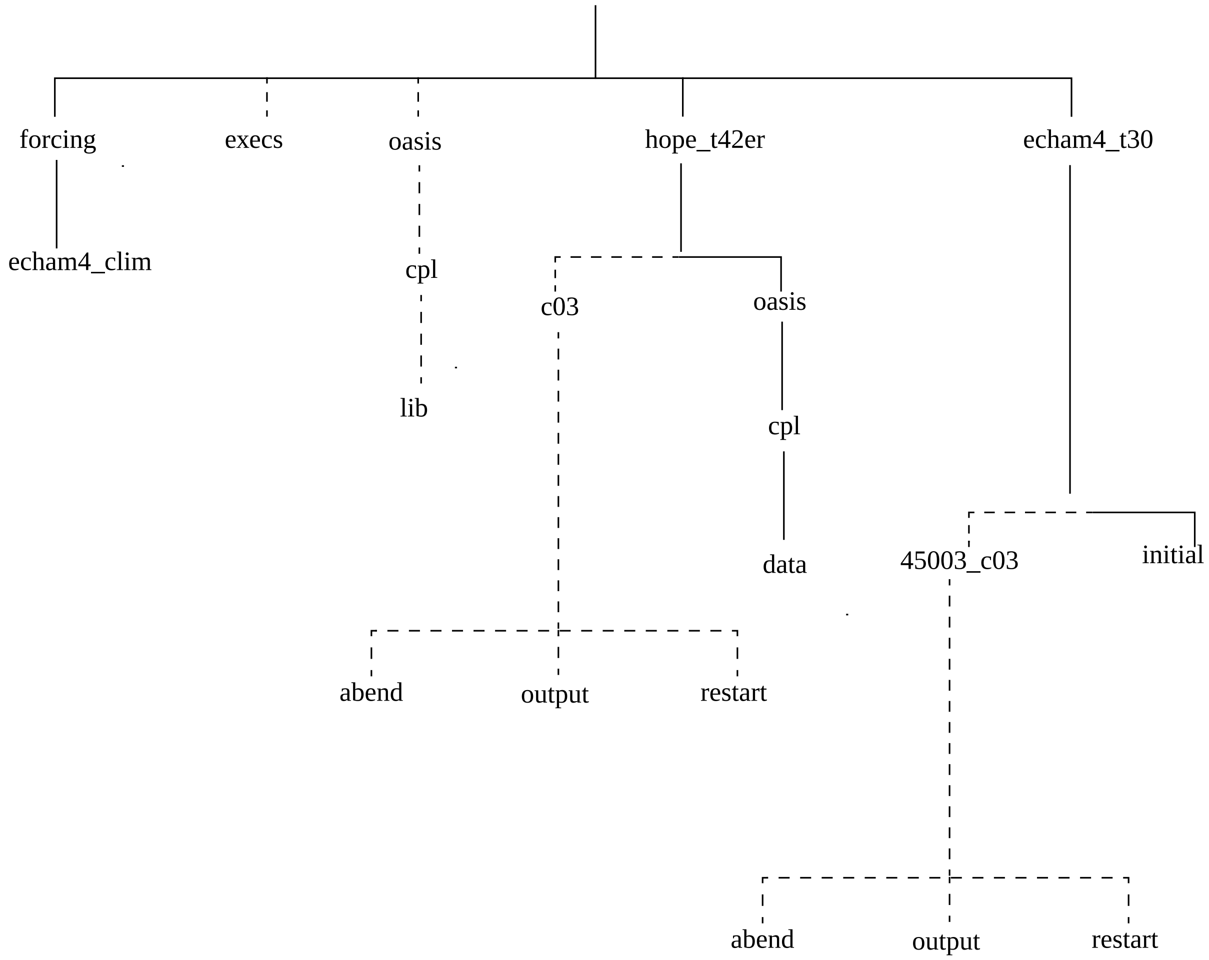


Figure 6 Directory tree that is set up with file ECHO-G_n.n_data_cray.tar



5 Appendix A

Table 8 Symbols

Symbol	Unit	Variable name		Description / Locator
		atmosphere	ocean	
$\bar{\ }$				time mean of one coupled time step
$\frown$				gridcell mean
$^{S/I}$				for sea-ice covered part of a grid cell
^{W}				for water covered part of a grid cell
$\bar{A}_I$	frac.	SEAICE	$SIC_{E/O}ACC$	sea-ice concentration
α^W	frac.	ALSOW	ALBW	surface albedo of water
$\alpha^{S/I}$	frac.	ALSOI	ALBSN(M) / ALBI(M)	surface albedo of (melting) snow surface albedo of (melting) sea ice
$c_p^{S/I}$	J/(kg·K)	ZCPICE	CLB	specific heat of snow/ice
D_{la}^W				turbulent exchange coefficient of latent heat over water
$D_{la}^{S/I}$				turbulent exchange coefficient of latent heat over snow / sea ice
D_{se}^W				turbulent exchange coefficient of sensible heat over water
$D_{se}^{S/I}$				turbulent exchange coefficient of sensible heat over sea ice
D_e^W				turbulent exchange coefficient of evaporation over water
$D_e^{S/I}$				turbulent exchange coefficient of evaporation over sea ice
D_m^W				turbulent exchange coefficient of momentum over water
$D_m^{S/I}$				turbulent exchange coefficient of momentum over sea ice
Δt_a	s	DTIME		time step of the atmosphere model
Δt_o	s		DT	time step of the ocean model
E	m/s	EVAP		evaporation

Table 8 Symbols

Symbol	Unit	Variable name		Description / Locator
		atmosphere	ocean	
$E^{S/I}$	m/s	EVAPI		sublimation of snow/ice
E^{W}	m/s	EVAPW		evaporation over water
ε				emissivity
$\overline{\widehat{F}}^{S/I}$	m/s	AIFRE	$AOFLFRI_{E/O}$	mean solid freshwater flux (gridcell average)
$\overline{\widehat{F}}^{W}$	m/s	AWFRE	$AOFLFRW_{E/O}$	mean liquid freshwater flux (gridcell average)
F_D	m/s		$FWFCORR_{E/O}$	fresh water flux due to SSS relaxation
FL_n				flux at time step n
$FL^{S/I}$				flux through air/snow/ice interface
FL^{W}				flux through air/water interface
H	W/m^2			atmosphere-ocean heat flux
H_{sw}	W/m^2			incoming shortwave radiative heat flux
$\overline{H}_{dsw}$	W/m^2	AWSOL	$AOFLSHW_{E/O}$	downward component of shortwave radiation
H_{lw}	W/m^2			longwave radiative heat flux
H_{la}	W/m^2	$AHFL_{W/I}$		latent heat flux
H_{se}	W/m^2	$AHFS_{W/I}$		sensible heat flux
$H_{-c}^{S/I}$	W/m^2			total surface heat flux over sea-ice excluding the conductive flux
$\overline{\widehat{H}}_{c}$	W/m^2	AICON	$AOFLCHI_{E/O}$	mean conductive heat flux through ice (gridcell average)
H_D	W/m^2		$AOFLDHW_{E/O}$	heat flux due to SST relaxation
$\overline{\widehat{H}}_{res}$	W/m^2	AIQRE	$AOFLRHI_{E/O}$	mean surface residual heat flux (gridcell average)
$\overline{\widehat{H}}^{W}$	W/m^2	AWHEA	$AOFLNHW_{E/O}$	mean heat flux through open water (gridcell average)
h_I	m		$SICTH_{E/O}$	sea-ice thickness (gridcell average)
$\bar{h}_S$	m	SNCOV	$SNT_{E/O}ACC$	mean snow depth (gridcell average)

Table 8 Symbols

Symbol	Unit	Variable name		Description / Locator
		atmosphere	ocean	
$\bar{h}_{eff}$	m	SICED	$SIT_{E/O}ACC$	mean effective ice thickness (including isolating effect of snow)
κ_I	W/(mK)	ZALPHA	CON	conductivity of ice
κ_S	W/(mK)	ZALPSN	CONSN	conductivity of snow
L	W/m^2			atmospheric long wave radiation
$\overline{\overline{M}}^{S/I}$	Pa	(AIUST, AIVST)	$AOFLTX/YI_{E/O}$	mean momentum flux through the snow/ice surface
$\widehat{\overline{M}}_j^{W}$	Pa	AWUST, j=1 AWVST, j=2	$AOFLTX/YW_{E/O}$	mean momentum flux on the water surface (gridcell average), j=1 zonal, j=2 meridional
P	m/s	APRL+APRC		precipitation
$P_R^{S/I}$	m/s			rain on sea ice
$P_S^{S/I}$	m/s			snow fall on sea ice
$q^{S/I}$				specific humidity at sea-ice/snow surface
q^W				specific humidity at water surface
q_B				specific humidity at the blending height
Ri^W				Richardson number over water
$Ri^{S/I}$				Richardson number over snow/ice
R	m/s			continental / river runoff
ρ_I	kg/m^3	ZRHOICE	RHOICE	density of sea ice
ρ_S	kg/m^3		RHOSNO	density of snow
ζ	m			sea level
σ	$W/(mK^4)$	STBO		Stefan-Bolzmann constant
$T_{freez,}$	[K] / [^oC]	CTFREEZ	TFREZ	freezing point of sea water
T_{melt}	K	TMELT	TMELT	freshwater melting temperature
$T_n^{S/I}$	K	TSI		final snow/ice skin temperature at step n
$\tilde{T}_n^{S/I}$	K			preliminary snow/ice skin temperature at step n

Table 8 Symbols

Symbol	Unit	Variable name		Description / Locator
		atmosphere	ocean	
$\vec{\vec{\tau}}_a^W$	Pa			air-water surface stress
$\vec{\vec{\tau}}_a^{S/I}$	Pa			air-ice surface stress
$\vec{\vec{\tau}}_I$	Pa			ice-water surface stress
T_+				defines ‘climatolgical’ ice region
θ_B	K			air temperature at blending height
$\bar{\theta}_1$	K	TSW	$SST_{E/O}ACC$	mean upper layer ocean temperature
$\vec{v}_B$	m/s			air velocity at the blending height
$\vec{v}_I$	m/s		$SICU/V_{E/O}$	sea ice velocity
$\vec{v}_1$	m/s		$U_{E/O}$	upper-layer ocean velocity
Δz_I	m	ZDICE		depth of upper snow/ice layer whose temperature is affected by the surface heat balance
z_0^W	m	AZ0W		roughness length over water
$z_0^{S/I}$	m	AZ0I		roughness length over snow/ice

Table 9 Additional codes for ECHAM4 output

Code	Acc.	Variable	Description
101	m	TEFFW	surface temperature of open water [K]
102		TSI	surface temperature of sea ice [K]
103		TSW	surface temperature of open water [K]
104	m	USTRI	zonal windstress over sea ice [Pa]
105	m	VSTRI	meridional windstress over sea ice [Pa]
106	m	USTRW	zonal windstress over open sea [Pa]
107	m	VSTRW	meridional windstress over open sea [Pa]
108	m	USTRL	zonal windstress over land [Pa]
109	m	VSTRL	meridional windstress over land [Pa]
110	m	AHFLI	latent heat flux over sea ice [W/m^2]

Table 9 Additional codes for ECHAM4 output

Code	Acc.	Variable	Description
111	m	AHFLW	latent heat flux over open sea [W/m^2]
112	m	AHFLL	latent heat flux over land [W/m^2]
113	m	EVAPI	evaporation over sea ice [m/s]
114	m	EVAPW	evaporation over open water [m/s]
115	m	EVAPL	evaporation over land [m/s]
116		AZ0I	roughness length over sea ice [m]
117		AZ0W	roughness length over open water [m]
118		AZ0L	roughness length over land [m]
119	m	AHFSI	sensible heat flux over sea ice [W/m^2]
120	m	AHFSW	sensible heat flux over open water [W/m^2]
121	m	AHFSL	sensible heat flux over land [W/m^2]
122		ALSOI	albedo of sea ice [frac.]
123		ALSOW	albedo of water [frac.]
124		ALSOL	albedo of land [frac.]
125	m	AHFICE	conductive heat flux [W/m^2]
126	m	QRES	residual heat flux for melting sea ice [W/m^2]

’m’ denotes mean over output interval

The OASIS control file ’namcouple’

```
##########################################################################
#
#       Input file for OASIS 2.2.
#
#       This version is for use of ECHAM4 fluxes
#       and relaxation heat flux computation in the ocean.
#
#       The file will be edited in the run-script to update it for the
#       actual integration period and grid dimensions.
#
##########################################################################
#
#       The initial file ‘sstocean’ for the atmosphere
#       will be written in OCEINI for LRERUN=.F.
#       When the models are to be run parallel in the first run (SEQMODE = 1)
#       the exchange of the fields generated by the models with sequential
#       number larger than 1 have to be delayed. An extra oasis time step
```

```
#       is then required for these fields.
#
#########################################################################
#
#       Input delimiters have to occupy position 1 to 9 !
#       No blank lines allowed !
#       Length of input lines <= 80 !
#       If   number of exchanged fields                         or
#            field identifier
#       is changed
#   ==>  modify related OCE/ATM_PIPE_DEF subroutine accordingly !
#       If locators for latitudes/langitudes/masks/areas are changed
#   ==>  modify related GRID_WRTE subroutine accordingly !
#
########################################################################
#
# SEQMODE : 1        if all models run simultaneously
#           n        if  n  models run sequentially
#
 $SEQMODE
            Anzahl_der_sequentiellen_Modelle
 $END
#
########################################################################
#
# MACHINE : CRAY     if the coupled model is run on  a cray     (CHAR*4)
#           IEEE     "   "    "       "   "   "  "   a workstation
#
 $MACHINE
            CRAY
 $END
#
#########################################################################
#
# CHANNEL (CHAR*4)
#           PIPE     if named pipes + binary files are used
#                       for synchro and data respectively;
#           CLIM     if sockets are used for message passing both
#                       for synchro. and data (use of the Cerfacs library
#                                                      based on PVM3.3)
#
 $CHANNEL
            PIPE
 $END
#
#########################################################################
#
# NFIELDS : total number of fields being exchanged.
#
 $NFIELDS
            14
 $END
#
#########################################################################
#
# JOBNAME : acronym for the given simulation (CHAR*3)
#          the value will be set before the actual integration
#
```

```
 $JOBNAME
            exp-id
 $END
##########################################################################
#
# NBMODEL : number of models and their names (CHAR*6).
#
 $NBMODEL
            2  ECHAM4   HT42ER
 $END
#
###########################################################################
#
# RUNTIME (<I8)
#         total simulated time for the actual run in seconds
#         the value will be set before the actual integration
#
#
 $RUNTIME
              Laufzeit
 $END
#
###########################################################################
#
# INIDATE (I8)
#         initial date of the run (YYYYMMDD)
#
#
 $INIDATE
            Jahr_Monat_Tag
 $END
#
###########################################################################
# Indicates whether a header is encapsulated within the field (YES or NOT)
 $MODINFO
   NOT
 $END
#
#
###########################################################################
#
#
#
# Analyses:  n.m) is mth parameter of line n
#
# - MASK   : masking of a field, needed in the extrapolation step;
#             call before EXTRAP
#             1.1) mask value
#
# - EXTRAP : extrapolation, fills up land points with sea values
#             (to deal with different sea-land masks in the models);
#             1.1) extrapolation method
#                  NINENN only
#             2.1) number of neighbors used
#
# - BLASNEW: linear combination of fields after interpolation.
#
# - BLASOLD:    "        "       "   "    before     "
```

```
#                 e.g.:  fld1 = a1*fld1+a2*fld2+...an*fldn
#            1.1) multiplier of current field (a1)
#            2.1) number of fields to be combined with the current field (n-1)
#                 +n-1 lines: k=1,n-1
#            1.k) name       of additional field
#            2.k) multiplier “      “        “
#
# - REDGLO : go from a reduced gaussian grid to a global one;
#            has to be the last analysis
#            1.1) SEALAND sea values are extended to continental areas
#                             using the reduced grid sea-land mask
#                 LANDSEA the opposite is performed.
#                 NOEXTRAP no extrapolation is performed.
#
# - GLORED : go from a global gaussian grid to a reduced one
#                 has to be the first analysis
#
# - NOINTERP: no interpolation case; useful with identical grids;
#                 OASIS then does the synchronization task.
# - INVERT : go from the model array ordering to OASIS convention
#                                                (S-->N and W-->E)
#            1.1) NORSUD or SUDNOR
#            2.1) ESTWST or WSTEST
#
# - REVERSE: the opposite of the above
#
# - INTERP : interpolation from one grid to another
#            1.1) interpolation method
#                 (NNEIBOR,BILINEAR,BICUBIC,SURFMESH,GAUSSIAN)
#            2.1) source grid type
#                 L  uniform
#                 R  reduced gaussian
#                 G  gaussian
#                 Z  irregular
#                 U  unstructured  (not yet implemented)
#            3.1) periodicity of source grid
#                 true or false : T or F
#            4.1) periodicity of target grid
#            5.1) field type
#                 SCALAR or VECTOR
#            6.1) rank for interpolation data file
#                 (identifier for anaism/g relevant data in file
#                 mweights/gweights; GAUSSIAN or SURFMESH only;
#                 maximum no. of arrays must be specified in parameter.h)
#            7.1) maximum number of overlapped neighbors                “
#            8.1) flag for generation of weights (Compute/read : 1/0)    “
#            9.1) Variance of gaussian interpolation (GAUSSIAN only)
#
# - FILLING: complete a regional dataset with global data
#            1.1) file name for the global data set
#            2.1) logical unit
#            3.1) filling technique : XXXYYYZZ
#                 XXX : SMO or RAW
#                       (smoothing or no smoothing)
#                 YYY : SST or SIE
#                       (SST or sea ice extent)
#                  ZZ : MO or SE or AN
#                       (interanual monthly/climatlogical monthly/annual)
```

```
#            4.1) 1 or 0                             YYY=SST only
#                        (coastal correction / no coastal correction)
#            5.1) symbolic name for the array containing the difference
#                 between the initial SST and the SST modified by a smooth
#                 filling  XXX=SMO only
#            6.1) unit to write flux correction to    “   “   “
#                        (for 5) and 6) see CORRECT)
#
# - CONSERV: insure local or global flux conservation
#            1.1) GLOBAL or LOCAL  (LOCAL has no effect yet)
#
# - CORRECT: do field correction with external data (flux correction)
#            1.1) multiplier of current field
#            2.1) number of fields to be combined with the current field
#                 +n-1 lines: k=1,n-1
#            1.k) name       of additional field
#            2.k) multiplier “      “       “
#            3.k) file name  of additional field
#            4.k) logical unit
#
# - SUBGRID: restore subgrid variability in a field when the resolution
#            are very different.The idea here is to add a term proportional
#            to Delta(T)= Toce - Tatm and to conserve the fluxes. The added
#            has the spatial oceanic variability as it contains  Toce for
#            each oceanic mesh. This can be necessary for Pacific
#            simulation where the atmosphere never really feels the cold
#            tongue due to markedly different resolutions.
#            call with MOZAIC.
#            1.1) symbolic names for the 3 fields appearing in the first-order
#                 Taylor expansion.
#            2.1)
#            3.1)
# case a: used to interpolate the non solar heat flux with the following
# formula -->> Qo = Qa + (dQa/dTa)*(To -Ta) (linear approximation).
# This can be helpful if one wants to differentiate the non solar heat flux
# between two types of surface (ocean and ice) present in the OGCM grid
# squares underneath one AGCM grid square.
#
# case b: used to interpolate the solar heat flux with the following
# formula -->> QSo = QSa * (1 - Ao)/(1 - Aa) where Ax is the albedo for
# the appropriate grid square.
#
# Input parameters: the first four input parameters are identical to those
# previously described for the MOZAIC analysis. THE SAME WARNINGS APPLY
# REGARDING PARAMETERS jpnfs and jpsoa.
# The fifth one tells OASIS
# which one of the cases (a or b) is appropriate (NONSOLAR or SOLAR).
# If it is NONSOLAR, there are three more parameters giving the symbolic
# names of the fields which are going to be used in the above formula.
# (First: Ta, second: To and third: dQa/dTa)
# If it is SOLAR, there are two more parameters giving the symbolic
# names of the fields which are going to be used in the above formula.
# (First: Aa and second: Ao)
#
# - MOZAIC:   in contrast to SURFMESH where the weights might be calculated by
#             oasis or specified by the user, they must be specified by the
#             user for MOZAIC (bug in 2.0, attention). Weights on land points
#             can be non-zero.This can be useful for exemple for the runoff
```

```
which
#             is given on land points.
#            1.1) logical file name
#            2.1) logical unit
#           3.1) identifier for the mapping data set;used to complete the head-
ers
#                 which are used to read both weights and adresses.
#                 It is also used to locate these arrays
#                 in the macro arrays used within OASIS.
#                 (<jpnfp in  parameter.h !).
#            4.1) used to read initially the weights and adresses arrays
#                 ( < jpmoa in parameter.h !).
#
# - CHECKIN
#   CHECKOUT  can be used to follow precisely the field values
#             before and after interpolation. Extrema and  mean value are
#             calculated for the global earth, the sea and the land.
#             If the integral flag is 1, the field integrals are calculated
#             as well. All the results are printed in the OASIS output file.
#             Note that they have no input parameters (and no input lines !).
#
#
#
#############################################################################
 $STRINGS
#
# STRINGS  Line 1 :
# 1)     Locator of exchanged field on source grid.
# 2)     Locator of exchanged field on target grid.
# 3)     Label number for internal oasis output (see cfldlab() in blkdata.f)
# 4)     Exchange frequency for the field in seconds
# 5)     Number of analyses to be performed
# 6&8)   Source file name & unit numbers for data transfer
# 7&9)   Target   "    "     "
# 10)    Field status (EXPORTED or AUXILARY)
#        If EXPORTED, the field is both received and sent after interpolation.
#        If AUXILARY, the field is just received and used within OASIS. It is
not
#        given to the other model.
#
# STRINGS  Line 2 :
# 1)     Number of longitudes on source grid
# 2)       "    "  latitudes  "     "     "
# 3)       "    "  longitudes "  target    "
# 4)       "    "  latitudes  "     "     "
# 5&6)   Acronyms used to locate the data in the grid description files
# 7)     Sequential index of the data generating model
#        (e.g. if SEQMODE=2 and model 1/2 are atmosphere/ocean and the run
#              is to be initialized with ocean SST only,
#              then this parameter is 1 for the ocean meaning that the ocean
#              output is available first.)
#
# 8)     N (0/>0 ... do not/do delay of field exchange)
#        Flag used to delay the field exchange
#        by N coupled time steps in the case of parallel models (SEQMODE=1).
#        If SEQMODE>1 set N=0. N=0 for the input flux fields of the first
#        model if it is to receive the first flux fields via OASIS.
# 9)     Flag to compute an extra timestep (1 yes, 0 no)
```

```
#        This flag can be used if one wants to perform an additional exchange
#        for the current field.
# 10)    Flag to compute the field integral (1 yes, 0 no)
#        This flag tells OASIS to calculate the integral of the field. this
#        implies you have asked for analysis CHECKIN and CHECKOUT which
#        calculates other quantities (useful for debuging)
#
############################################################################
#
# Field 1 Ocean sea surface temperature [K;K]
#
#
SSTOCEAN SSTATMOS 1    86400   6  sstocean   sstatmos  92   96 EXPORTED
lono lato  lona lata  oces atmo    1  0          0         1
#Analysis:
   CHECKIN MASK     EXTRAP   INTERP CHECKOUT REVERSE
#
   9999.999999e+06
#
            NINENN 2
#
                     SURFMESH Z   T      T   SCALAR    1  naismvoi   0   0
#
                            NORSUD   WSTEST
#
############################################################################
#
# Field 2 Sea ice thickness  [m;m]
#
#
SITOCEAN SITATMOS 9    86400   6  sstocean   sstatmos  92   96 EXPORTED
lono lato  lona lata  oces atmo    1  0          0         1
#Analysis:
   CHECKIN MASK     EXTRAP   INTERP CHECKOUT REVERSE
#
           9999.999999e+06
#
                    NINENN 2
#
                     SURFMESH Z   T      T   SCALAR    1  naismvoi   0   0
#
                                             NORSUD   WSTEST
#
############################################################################
#
# Field 3 Sea ice concentration  [;]
#
#
SICOCEAN SICATMOS 8    86400   6  sstocean   sstatmos  92   96 EXPORTED
lono lato  lona lata  oces atmo    1  0          0         1
#Analysis:
   CHECKIN MASK     EXTRAP   INTERP CHECKOUT REVERSE
#
           9999.999999e+06
#
                    NINENN 2
#
                     SURFMESH Z   T      T   SCALAR    1  naismvoi   0   0
```

```
#
                                             NORSUD   WSTEST
#
############################################################################
#
# Field 4 Snow thickness  [m;m]
#
#
SNTOCEAN SNTATMOS 10   86400   6  sstocean   sstatmos  92   96 EXPORTED
lono lato  lona lata  oces atmo    1  0          0         1
#Analysis:
   CHECKIN MASK     EXTRAP   INTERP CHECKOUT REVERSE
#
           9999.999999e+06
#
                    NINENN 2
#
                     SURFMESH Z   T      T   SCALAR    1  naismvoi   0   0
#
                                             NORSUD   WSTEST
#
###########################################################################
#
# Field 5 Zonal wind stress over water [pa;pa]
#
TXWATMOS TXWOCEAN 23       86400  7   flxatmos  flxocean 95 91 EXPORTED
lona lata  lono lato  atmo ocev   Seq_no Delay Extra_step 1
#Analysis:
          INVERT   CHECKIN MASK     EXTRAP INTERP CONSERV CHECKOUT
#
          NORSUD   WSTEST
#
                   9999.999999e+06
#
                            NINENN 2
#
                                   BICUBIC G   T    T   VECTOR
#
                                                  GLOBAL
#
############################################################################
#
# Field 6 Meridional wind stress over water [pa;pa]
#
TYWATMOS TYWOCEAN 24       86400  7   flxatmos  flxocean 95 91 EXPORTED
lona lata  lono lato  atmo ocev   Seq_no Delay Extra_step 1
#Analysis:
          INVERT  CHECKIN MASK     EXTRAP INTERP CONSERV CHECKOUT
#
          NORSUD   WSTEST
#
                   9999.999999e+06
#
                            NINENN 2
#
                                   BICUBIC G   T    T   VECTOR
#
                                                  GLOBAL
```

```
#
###############################################################################
#
# Field 7 Zonal wind stress over ice [Pa;Pa]
#
TXIATMOS TXIOCEAN 3        86400  7   flxatmos  flxocean 95 91 EXPORTED
lona lata  lono lato  atmo ocev   Seq_no Delay Extra_step 1
#Analysis:
          INVERT   CHECKIN MASK     EXTRAP INTERP CONSERV CHECKOUT
#
          NORSUD   WSTEST
#
                   9999.999999e+06
#
                            NINENN 2
#
                                  BICUBIC G   T    T   VECTOR
#
                                                  GLOBAL
#
###############################################################################
#
# Field 8 Meridional wind stress over ice [pa;pa]
#
#
TYIATMOS TYIOCEAN 4        86400  7   flxatmos  flxocean 95 91 EXPORTED
lona lata  lono lato  atmo ocev   Seq_no Delay Extra_step 1
#Analysis:
          INVERT   CHECKIN MASK     EXTRAP INTERP CONSERV CHECKOUT
#
          NORSUD   WSTEST
#
                   9999.999999e+06
#
                            NINENN 2
#
                                   BICUBIC G   T    T   VECTOR
#
                                                  GLOBAL
#
###############################################################################
#
# Field 9 Solid freshwater flux [m/s;m/s]
#
#
FRIATMOS FRIOCEAN 28       86400  7   flxatmos  flxocean 95 91 EXPORTED
lona lata  lono lato  atmo oces   Seq_no Delay Extra_step 1
#Analysis:
          INVERT   CHECKIN MASK     EXTRAP INTERP CONSERV CHECKOUT
#
          NORSUD   WSTEST
#
                   9999.999999e+06
#
                            NINENN 2
#
                                   BICUBIC G   T      T   SCALAR
#
```

```
                                                   GLOBAL
#
##############################################################################
#
# Field 10 Liquid freshwater flux [m/s;m/s]
#
#
FRWATMOS FRWOCEAN 29       86400  7   flxatmos  flxocean 95 91 EXPORTED
lona lata  lono lato  atmo oces   Seq_no Delay Extra_step 1
#Analysis:
          INVERT   CHECKIN MASK     EXTRAP INTERP CONSERV CHECKOUT
#
          NORSUD   WSTEST
#
                   9999.999999e+06
#
                            NINENN 2
#
                                    BICUBIC G   T    T   SCALAR
#
                                                   GLOBAL
#
##############################################################################
#
# Field 11 Residual heat flux  [W/M^2;W/m^2]
#
#
RHIATMOS RHIOCEAN 12       86400  6   flxatmos  flxocean 95 91 EXPORTED
lona lata  lono lato  atmo oces   Seq_no Delay Extra_step 1
#Analysis:
          INVERT   CHECKIN MASK     EXTRAP INTERP  CHECKOUT
#
          NORSUD   WSTEST
#
                   9999.999999e+06
#
                            NINENN 2
#
                                   BILINEAR G   T      T   SCALAR
#
##############################################################################
#
# Field 12  Conductive heat flux [W/M^2;W/m^2]
#
#
CHIATMOS CHIOCEAN 16       86400  7   flxatmos  flxocean 95 91 EXPORTED
lona lata  lono lato  atmo oces   Seq_no Delay Extra_step 1
#Analysis:
          INVERT   CHECKIN MASK     EXTRAP INTERP CONSERV CHECKOUT
#
          NORSUD   WSTEST
#
                   9999.999999e+06
#
                            NINENN 2
#
                                    BICUBIC  G   T    T   SCALAR
#
```

```
                                                  GLOBAL
#
#############################################################################
#
# Field 13 Total heat flux over water [W/m**2;W/m**2]
#
#
NHWATMOS NHWOCEAN 5        86400  7   flxatmos  flxocean 95 91 EXPORTED
lona lata  lono lato  atmo oces   Seq_no Delay Extra_step 1
#Analysis:
          INVERT   CHECKIN MASK     EXTRAP INTERP CONSERV CHECKOUT
#
          NORSUD   WSTEST
#
                   9999.999999e+06
#
                            NINENN 2
#
                                   BICUBIC G   T      T   SCALAR
#
                                                  GLOBAL
#
#############################################################################
#
# Field 14 Downwelling solar heat flux [W/m**2;W/m**2]
#
#
SHWATMOS SHWOCEAN 7        86400  7   flxatmos  flxocean 95 91 EXPORTED
lona lata  lono lato   atmo oces   Seq_no Delay Extra_step 1
#Analysis:
          INVERT   CHECKIN MASK     EXTRAP INTERP CONSERV CHECKOUT
#
          NORSUD   WSTEST
#
                   9999.999999e+06
#
                            NINENN 2
#
                                   BICUBIC G   T      T   SCALAR
#
                                                  GLOBAL
#
############################################################################
 $END
```

6 References

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