

ECMWF physics in HIRLAM

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Introduction

In contribution to the HIRLAM-5 project work has been initiated to port the ECMWF parameterization package of physical processes into the HIRLAM forecast component. The outline of the work is described in Chapter 3 of the HIRLAM-5 Scientific Plan. The motivation to set up such a system has multiple elements. First of all, it will provide a platform in which the HIRLAM community can more easily and more directly benefit from research and development at the ECMWF. It also offers the possibility to objectively compare the physics components of HIRLAM and ECMWF operated in a LAM oriented framework. The interest of the Atmospheric Research division at the KNMI Climate Research and Seismology department is to modernize its platform for regional climate modeling. Its current atmospheric model RACMO carries the physics package of the ECHAM GCM and dates from 1995. It is based on a rather old version of HIRLAM, i.e. version 2.3. In that perspective, modernization offers the opportunity to catch up with developments within HIRLAM over the past 6 to 7 years, involving the dynamics, the climate generation package, the source code management, and the use of the Unix scripting system to prepare and control a numerical experiment. The choice of the ECMWF physics package is motivated by an already existing cooperation between KNMI Atmospheric Research and ECMWF. Adopting a model system built from the HIRLAM system as the baseline model for research is also expected to strengthen the collaboration between KNMI Atmospheric Research and the HIRLAM community in general, and the HIRLAM group at KNMI in particular.

The ECMWF package of physical parameterizations

A schematic representation of the physical processes accounted for in the ECMWF Integrating Forecast System is shown in Figure 1. Here, the various components are very briefly summarized.

Radiation

A full radiation calculation is based on all model information available. It delivers vertical profiles of SW transmissivities and LW emissivities. In view of the computational expenses full radiation is done at a lower frequency than the model time step. In the ECMWF model it is also done on a coarser horizontal grid, but this option has not (yet) been implemented in the LAM version. Radiative fluxes are updated every time step on the basis of the results. In the quick update, the SW fluxes are based on the actual solar zenith angle, while the LW fluxes are inferred from the LW emissivities with actual temperature profiles.

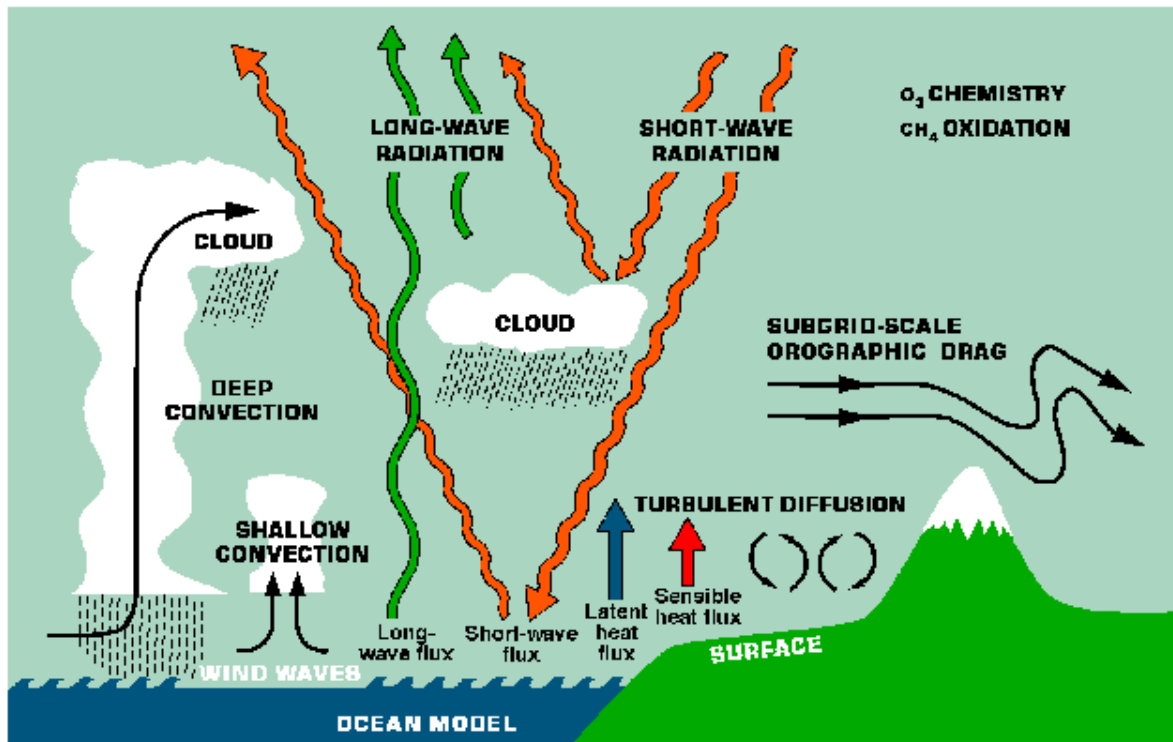


Figure 1: Schematic diagram of the various physical processes represented in the forecast model

Boundary Layer Mixing

Surface fluxes are derived using Monin-Obukhov similarity. The stable boundary layer is based on a Richardson number dependent closure. The unstable BL uses first-order K-closure, so it does not employ a TKE variable. The boundary layer scheme is formulated in terms of dry variables. Surface exchanges are calculated in this module and used as constraints in the surface-soil module.

Orographic Wave Drag

It parameterizes the effect of low-level blocking due to sub-grid scale orography, and the vertical transport of sub-grid scale gravity waves.

Moist Convection

Based on the mass-flux approach, originated by Tiedtke (1989) with extensions from others. The deep convection is controlled by the adjustment of CAPE at a prescribed rate. Mid-level convection is related to the resolved vertical velocity. Shallow convection is determined from an assumed steady-state of the moist static energy in the sub-cloud layer.

Condensation and large-scale precipitation.

Better known as the ECMWF prognostic cloud scheme, originated by Tiedtke (1993). The scheme solves the prognostic equations of cloud liquid water, cloud ice, and cloud fraction. It calculates the sources and sinks of cloud parameters in a process oriented approach, e.g. it requires the detrainment of liquid water generated in moist convection as a source term. This is in contrast to the integrated approach in which the cloud parameters are related to the (changes of the) thermodynamics of the model state.

Surface-soil processes.

Since August 2000, the surface-soil processes in the operational ECMWF model are accounted for by TESSEL, the Tiled ECMWF Surface Scheme of Exchange processes at the Land surface. In the current formulation, the surface characteristics of a grid box is composed from a weighted average of eight different tiles: bare soil, low vegetation, high vegetation (including trees), interception reservoir, snow on ground and low vegetation, snow on high vegetation, open sea, and sea-ice. The scheme employs four temperature and soil water layers in the soil, and four temperature layers in the sea-ice. Moreover, the surface temperature is represented by a prognostic skin temperature which governs the exchange of heat and moist between the surface and the atmosphere.

Strategy of Implementation

In interfacing the ECMWF physics package a definite strategy has been pursued.

1. To keep the components of the ECMWF physics package (physics routines, modules, setup routines) untouched in order to facilitate the implementation of future releases (which are expected to appear quite frequently).
2. To embed ECMWF variables in the HIRLAM code in a transparent way.
3. To construct a separate interface routine which relates the analogons of PHTASK and PHYS.

Implementation

The building blocks consisted of HIRLAM version 4.9.0 and the ECMWF physics components of Cycle 22, release 3. The ECMWF package of physics routines could indeed be kept untouched with the exception of a few changes in CALLPAR (the analogon of PHYS):

- To invoke the full radiation from the physics on the entire model grid.
- To prevent operating the boundary layer scheme at a higher frequency than the model time step (in the ECMWF model this is required by the interactive coupling to the wave model)

An interface routine PRE_CALLPAR links the HIRLAM code (PHTASK) with the ECMWF physics (CALLPAR).

The setup routines dedicated to the various physics routines could be copied unchanged. Some setup-routines related to the model “administration” required modifications. An interface routine SETUP_PHECMWF is called from GEMINI.

The modifications which had to be applied to HIRLAM were more involved.

- To anticipate the presence of three cloud prognostic parameters the passive scalar element SY(KLON, KLAT, KLEV) (Y=M, Z, P, X) is extended by one dimension and converted into a cloud parameter element CLVARY(KLON, KLAT, KLEV, KCLVAR) (Y=M, Z, P, X; KCLVAR=1..MCLVAR), With MCLVAR=1 (HIRLAM) or 3 (ECMWF).
- Far more cumbersome is the presence of many more prognostic surface/soil variables in the ECMWF physics (different number of layers, different meaning of variables, etc.) Here things are separated by means of a compiler directive (PH_ECMWF and PH_HIRLAM, respectively)
- Postprocessing: ECMWF physics generates lots of output fields, including vertical flux-profiles of a variety of designated processes. So far, only fields with obvious HIRLAM analogons are retained and stored.

The HIRLAM Forecast component is coded in Fortran 77, utilizing pre-F90 features like dynamic array allocation. The ECMWF forecast component is coded in Fortran 90 (free format), using typical F90 features like Modules and also the Kind function, which do not exist in Fortran 77. Compilation of the full code with a F90 compiler is straightforward, but the use of the Kind-function requires some care. The KIND function enables to select the type of reals/integers from a pre-specified user-requested accuracy. To achieve a platform-independent code, it was found necessary to copy F77 variables and F90 variables back and forth within the interface routine, which had to be coded in Fortran 90.

On the level of UNIX scripts and makefiles a few modifications need to be implemented

- *Preps* generating a different set of climate fields
- *ExtractBDfromMARS* extraction of additional soil fields
- *Vineta* copying a different set of climate fields
- *Bries* interpolation of soil fields (if imported through *ExtractBDfromMARS*)
- *Forecast* to specify namelists related to ECMWF-physics
- *PrepareLibs* to specify number of cloud variables MCLVAR
- *Makefile* to specify ECMWF physics compilation directive
- *Makefile_x* to add the ECMWF physics library *phys_ec.a*
- *Env_expdesc* selecting the physics package

Generation of extra climate fields

The ECMWF physics requires a couple of additional fields to be specified by *ctopo*.

- The land surface scheme requires four fields on degree and type of high and low vegetation. These fields can already be generated by *ctopo*.
- The orographic wave drag scheme requires topographic information on
 - the variance of the terrain height (already available from *ctopo*)
 - anisotropy, mean slope, direction of the largest gradient (not yet available)

Initialization of surface/soil fields

The ECMWF surface/soil scheme utilizes prognostic variables for

- temperature (TSA) in the soil (4 layers)
- soil water (WSA) in the soil layer (4 layers)
- skin temperature (TL)
- skin reservoir content (WL)
- snow mass per unit surface (SNS)
- snow temperature (TSN)
- snow density (RSN)
- snow albedo (ASN)
- temperature (TIA) in the sea-ice (4 layers)

In the present implementation initial values must be provided for TSA, WSA, and SNS, while the remaining variables can be initialized from other information within the model, or simply be prescribed. In forecast cycling, an obvious choice would be to initialize all surface/soil fields from the first guess fields of the previous forecast. At a latter stage some of the fields

may be subjected to some form of data-assimilation, but this has not yet been considered. In the case of a cold start the fields TSA, WSA, and SNS can be extracted from MARS and subsequently be projected on the limited area domain by means of a suitable interpolation.

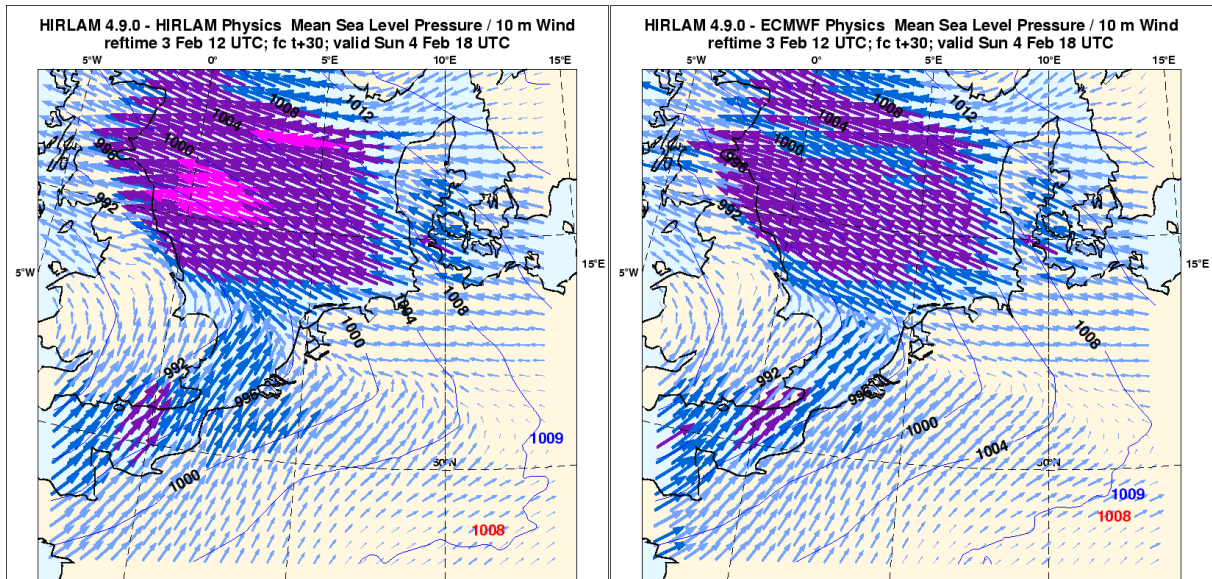


Figure 2: Mean Sea Level Pressure and 10 m wind for t+30 forecast HIRLAM reference (left panel) and HIRLAM+ECMWF physics (right panel). The analysis reference time is 3 February 2001 UTC, the verification time is 4 February 2001 18 UTC.

Test Integration

A single forecast is made for a small test-domain with 66x66 points at 18 km horizontal resolution. Number of vertical layers is 31. The run with HIRLAM physics is carried out with the reference system, including Semi-Lagrangian transport, the CBR boundary layer scheme, and the STRACO condensation. The time step size was chosen 450 s. The results for the mean sea level pressure and 10-m wind, for liquid water column, and for the 6-hour precipitation

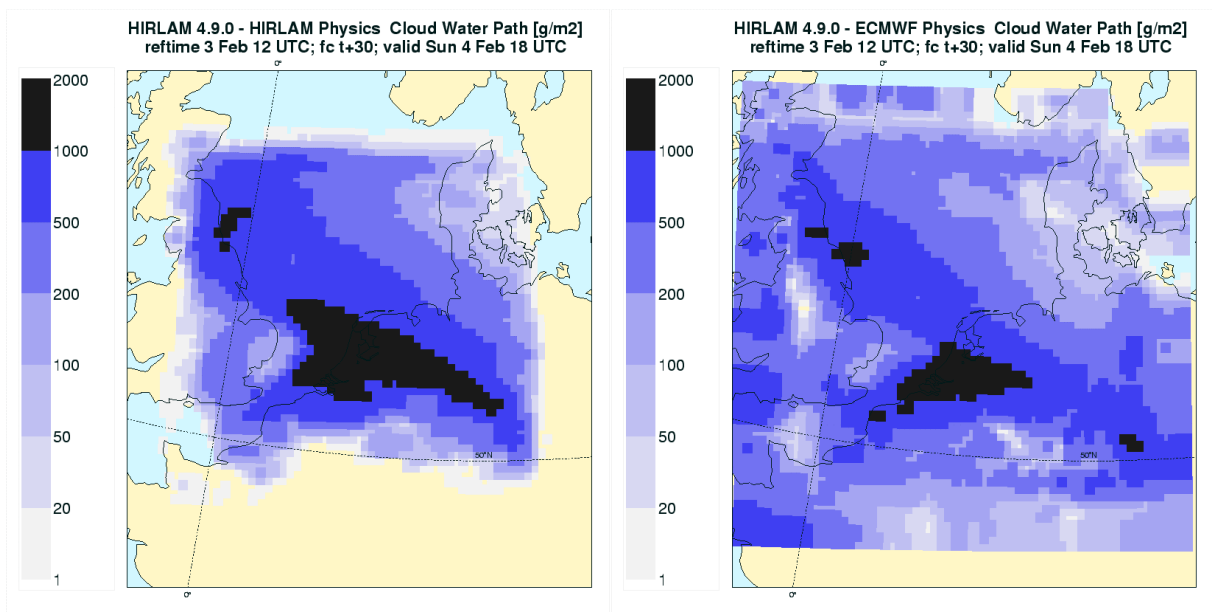


Figure 3 Like Figure 2 for grid-box mean vertically integrated cloud water content

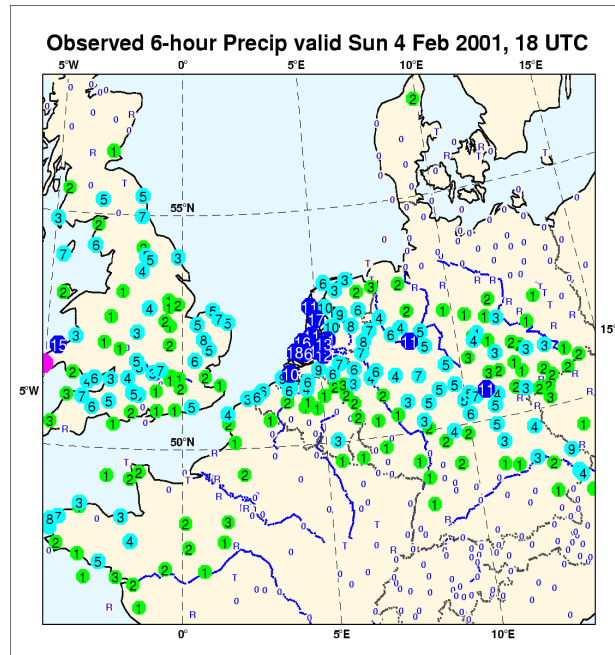
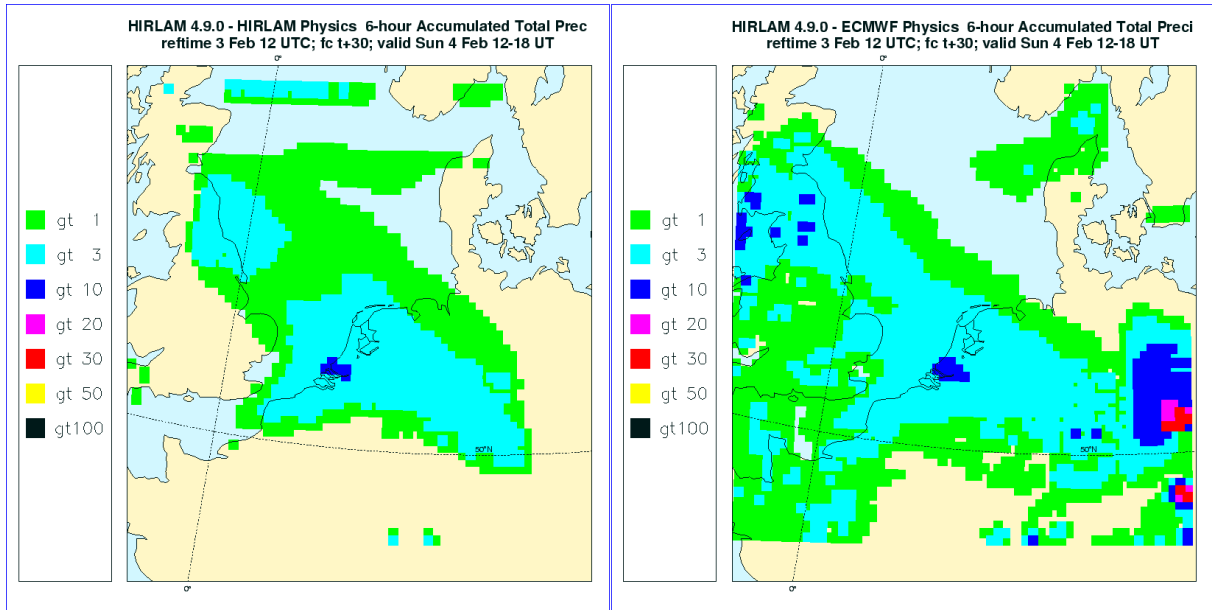


Figure 4: Like Figure 2 for 6-hour accumulated precipitation. Lower panel shows observed amounts.

valid after 30 hours of integration are shown in Figures 2, 3, and 4. Meteorological conditions were set by a warm frontal system very slowly moving across the Netherlands in NNO-direction giving rise to moderate, and occasionally, heavy rain, frozen rain, and snow, with 2m-temperatures varying between -5°C in the northern parts of the Netherlands to $+10^{\circ}\text{C}$ in the central and southern parts.

Figure 4 shows that the maximum in precipitation is well captured by both models. It also shows that there is a very large difference in predicted precipitation in the lateral boundary zone. The HIRLAM precipitation field is almost entirely suppressed in the boundary zone with the exception of strip along the northern edge. The HIRLAM+ECMWF precipitation, on the other hand, is quite widespread. Along the western boundary and in the southwestern

cornere this seems to be supported by observations, but along the eastern boundary there is huge overprediction. This is quite likely related to persistent conditions of outflow along the eastern edge, which are not handled properly. (Although the near surface wind shown in Fig.2 suggests otherwise, the column integrated vapour flow (not shown here) at the eastern boundary indeed has a significant outflow component across the edge.) The reason this does not occur in the HIRLAM reference run is probably due to the special treatment of the prognostic liquid water variable in the boundary zone within the STRACO scheme, which is relaxed towards a diagnosed quantity. The left panel of Figure 3 suggests that this diagnosed value is very low when compared with typical model values. In the current setup, any form of relaxation of the three cloud variables prognosed by the ECMWF physics is absent, and the parameters evolve just freely. This simple choice is probably not the optimal solution, and the issue requires attention in the near future.

CPU Performance

The ECMWF radiation module is extremely expensive. Even when the full radiation is only called every 8th time step like in the previous example (once an hour), the radiation consumes 35 to 40% of the CPU. Disregarding the radiation, the remainder of the ECMWF physics is about 1.5 to 2 times more expensive than the physics of the HIRLAM reference system. In this perspective it is probably very useful to study the performance of the HIRLAM model with ECMWF physics, but with HIRLAM radiation backsubstituted. It is also worthwhile investigating whether it is feasible and beneficial to operate the ECMWF radiation scheme on a coarser grid (like it is operated in the ECMW model) when HIRLAM is operated in longer climate-type integrations.

Status and Outlook

The interfacing of ECMWF physics in the HIRLAM forecast component is technically completed. The next phase will be to test the system on cases with a focus on specific physical processes, e.g.

- snow melt in the spring season
- vertical distribution of clouds
- the hydrological cycle
- boundary-layer winds evaluated with Cabauw data
- ...

A subsequent action involves an objective verification of HIRLAM + ECMWF physics in parallel with the HIRLAM reference system for 15-day integration periods in all four seasons. Details on the implementation phase and results of the evaluation phase will be reported on in the final stage. When the system has gone through the evaluation phase it will be made available to the HIRLAM community, but at this stage it is difficult to foresee when this will be implemented. For more information, please contact me through vanmeijg@knmi.nl