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ICON Grid Documentation

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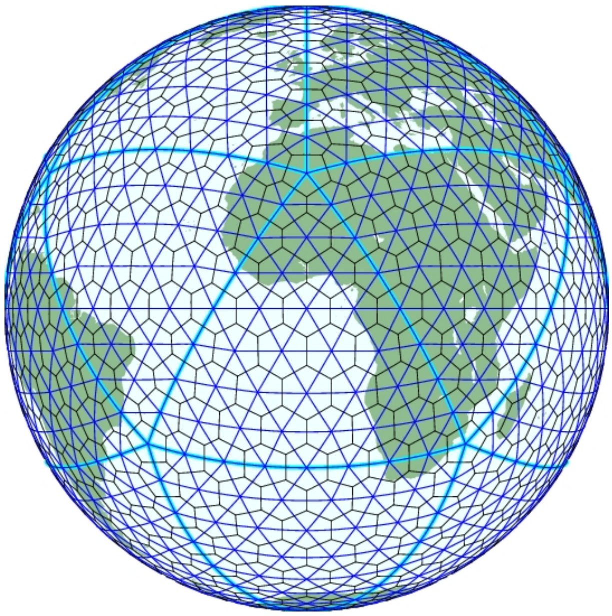

Figure 1: The ICON horizontal sphere grid. The light blue lines represent the projection of the original icosahedron edges. The dark blue lines depict the triangle grid after three edge bisections (R2B02). The black lines depict the dual hexagonal grid. No optimization is applied.

The ICON $3D$ spherical grid consists of two "orthogonal" components: the horizontal grid, and the vertical grid. The horizontal grid discretizes the sphere surface, it is a triangular or a hexagonal grid, and it is described in Section 1.1. The vertical dimension along the sphere radius is discretized in by a set of horizontal layers, and is described in Section 1.2.

Notation Notes: We distinguish between the physical (spatial) dimensions of a variable, which we denote by nD, and the array dimensions that the variable is coded in, denoted by kD_a. Variables that reside on a surface (the xy coordinates) are $2D$ variables, while variables on the 3 space (xyz coordinates) are $3D$. In ICON the two types of dimensions nD and kD_a are not the same.

Coordinate systems: CG is an abbreviation for the *geographical coordinates* (longitude - latitude). The associated data type is t_geographical_coordinates, defined in src/shared/mo_math_utilities.f90 with members %lon and %lat.

CC is an abbreviation for the $3D$ *Cartesian coordinates.* In these coordinates the sphere is considered to be the unit sphere. Unit tangent vectors on the sphere are invariant of the sphere radius length. The associated data type is t_Cartesian_coordinates, defined in src/shared/mo_math_utilities.f90, with members %x(3).

LC denotes the *local zonal-meridional coordinate system.* A $2D$ local coordinate system is associated with each point P on the sphere surface , which spans the tangent plane at P. The coordinates axes are aligned along the longitude and latitude curves through P.The associated data type is t_tangent_vectors, defined in src/shr_horizontal/mo_model_domain.f90, with members %v1 and %v2.

Other Abbreviation Notes: ICON in some cases uses a specific *orientation* convention in accessing the components or neigbors of the grid cells, edges and vertices. The orientation in most cases is counter clockwise, denoted by ccw. Clockwise orientation is denoted by cw.

1.1. The ICON horizontal spherical grid

The ICON horizontal spherical grid is based on the projection of the icosahedron on the sphere. The initial icosahedron grid is refined by n-secting the edges, and further refinement is obtained by iteratively bisecting the created edges (see Fig. 1). In each iteration a grid optimization procedure can be applied. The naming convention for the ICON horizontal grid is RnBk_*optimization*, where n is the number of initial divisions of the icosahedron edges, k is the number of bisecting iterations, and *optimization* denotes the applied optimization.

Geometry: All lines in the ICON horizontal spherical grid are arcs of great circles. Note that the normal and tangent vector at the edges form a left-handed coordinate system (see Table 4).

Topology: The connectivity is defined explicitly and can represent a general unstructured grid. For each grid entity a list of adjacent entities is stored. Most of these lists are ordered in a counter clockwise orientation. See Tables 3 to 5 for more details.

1.2. The ICON vertical grid

The vertical grid consists of a set of vertical layers. Each of these layers carries the horizontal $2D$ grid structure, thus forming the $3D$ structure of the grid. The vertical coordinates have a terrain-following hybrid structure. The hydrostatic dynamical core uses pressure-based vertical coordinates, while the non-hydrostatic has height-based vertical coordinates. Details for the calculation of the vertical coordinates can be found in Hui Wan's Phd thesis [1].

2. ICON grid data and loop structures

The major ICON variables are mapped on the grid entities, namely on the grid cell centers, edge centers and vertices. Details on the the staggering scheme can be found in Section 3. In this section the data and loop structures are described.

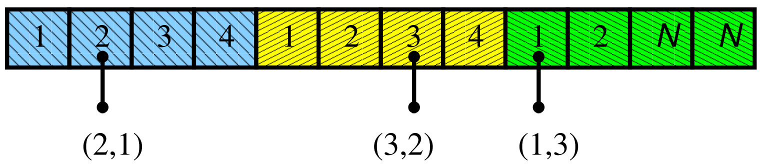

Figure 2: Horizontal array structure with blocking factor $nproma = 4$. The first index indicates the position inside the block, while the second index indicates the block. The last block contains 2 elements, the last two positions are not used. The total memory size is 12, while the total number of elements is 10.

The horizontal grid data structure is designed to represent an unstructured grid and is mapped to one dimension. This single dimension is organized into blocks of *nproma* size, resulting a two dimensional structure, with indices (index_in_block, block_number), see Fig. 2. *nproma* is

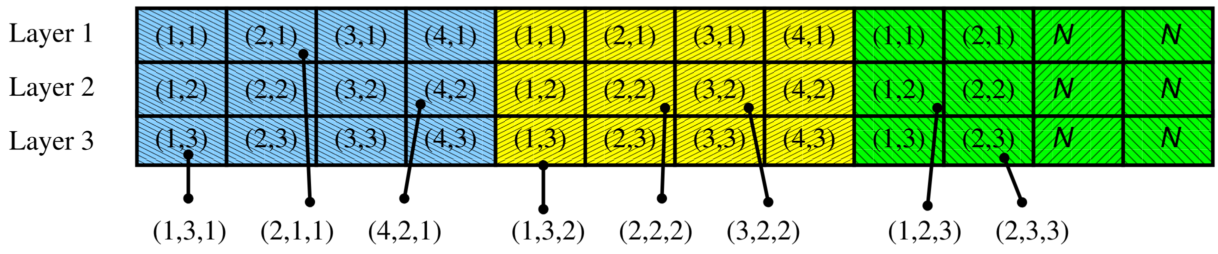

Figure 3: 3*D* array structure with blocking factor *nproma* = 4 and three vertical layers. The first index indicates the position inside the block, the second the vertical layer, the third index indicates the block. Each block occupies a continuous chunk of memory. The last block contains 6 elements. The total memory size is 36, while the total number of elements is 30.

a constant, defined during runtime (see the ICON namelist description). The block size may be different though on the array "boundaries". This structure are designed to accommodate both vector and cache based architectures. A block of *nproma* size can be processed as one vector by vector machines, or by one thread in a threaded environment.

3*D* variables include an additional dimension representing the vertical layer to which they belong, while maintaining the blocking structure in the horizontal dimension. The indexing has the form (index_in_block, vertical_layer, block_number), see Fig. 3. A typical 3*D* loop has the following structure.

```
DO jb = start_block, end_block
   CALL get_block_indices(p_patch, jb, start_block, end_block, &
                          i_startidx, i_endidx)
   DO jk = 1, vertical_layers
      DO je = i_startidx, i_endidx
         A(je,jk,jb) = ....
      ENDDO
  ENDDO
ENDDO
```

3. ICON triangular staggering scheme

In ICON a C-staggering is applied to the triangular cells. Figure 4 and 5 show the location of all prognostic and the most important diagnostic variables in both horizontal and vertical directions. Table 1 provides a brief description of those variables, together with the variable names which are used in the code.

The indexing of 2*D*, 3*D* and 4*D* variables (fields) is as follows: For 2D fields, the second index (jb) relates to the block number and the first index (jc, je or jv) relates to the position within the block. The label for the first index depends on whether the variable is defined at the cell center (jc), cell edge (je), or cell vertex (jv). For 3*D* fields, the block number (jb) is shifted to the third dimension. The second dimension (jk) now relates to the vertical level, where '1' is the top-most full (or half) level and 'nlev' ('nlev+1') is the lowest full (or half) level. For 4D fields (tracers), the first and second dimension are, again, the position within a block and the vertical level, respectively. The block number (jb) is shifted to the fourth dimension, while the third dimension (jt) relates to the tracer number.

Based on the above said, a specific value of a 2*D*, 3*D*, or 4*D* field at position (jc) of block (jb)

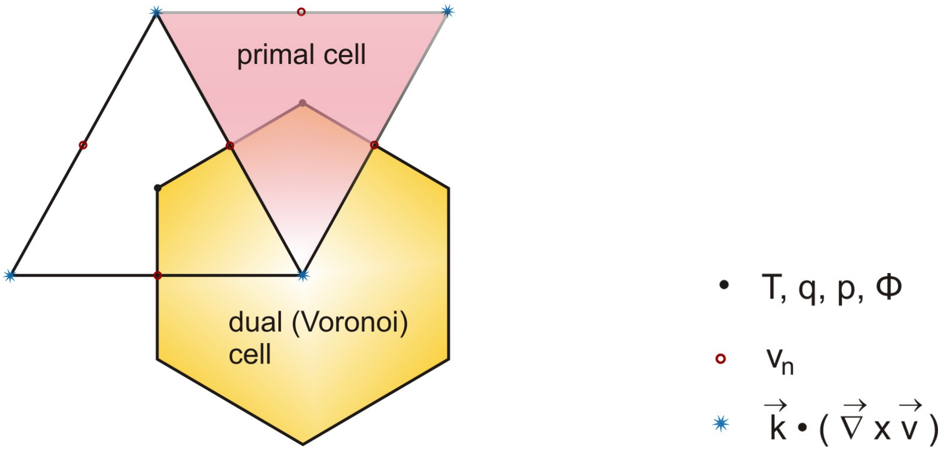

Figure 4: (a) Horizontal grid with primal cell (triangular) and dual cell (hexagonal). Note that the dual edges are orthogonal to and bisect the primal edges.

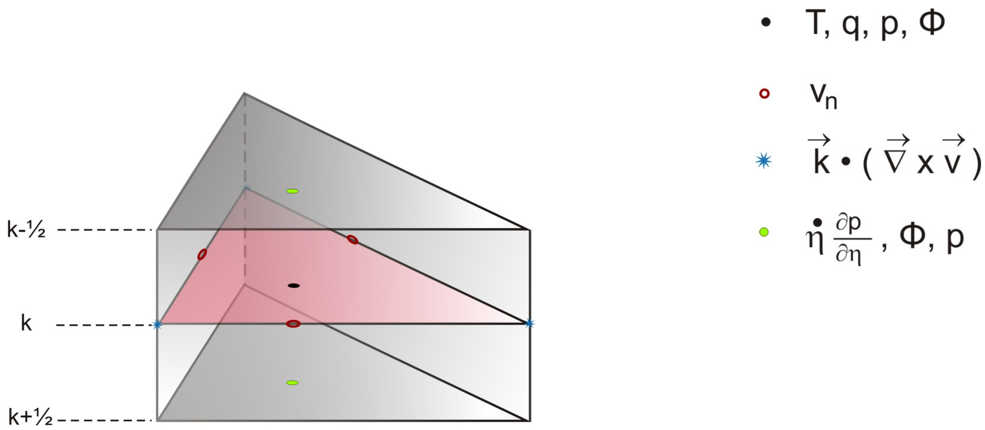

Figure 5: Vertical structure of primal grid. The half levels ($k \pm 1/2$) correspond to η levels.

at level (jk) can be accessed as follows:

2D: [hydro_prog]%pres_sfc(jc, jb)
3D: [hydro_prog]%vn(jc, jk, jb)
4D: [hydro_prog]%tracer(jc, jk, jt, jb)

In Figure 6 the variables describing the grid topology and geometry are defined. In Table 2 these variables are briefly described and the names which are used in the code are listed.

variable	description	position	name within code	unit
v_n	normal velocity component	edge midpoints of primal grid (full level)	[hydro_prog]%vn(:,:,:)	$m\,s^{-1}$
T	temperature	circumcenters of primal grid (full level)	[hydro_prog]%temp(:,:,:)	K
θ	potential temperature	circumcenters of primal grid (full level)	[hydro_prog]%theta(:,:,:)	K
p_s	surface pressure	circumcenters of primal grid (half level)	[hydro_prog]%pres_sfc(:,:)	Pa
q	scalar (i.e. mixing ratios)	circumcenters of primal grid (full level)	[hydro_prog]%tracer(:,:,:,:)	$kg\,kg^{-1}$
ζ	vertical component of relative vorticity	vertices of primal grid (full level)	[hydro_diag]%rel_vort_v(:,:,:)	s^{-1}
Φ	geopotential	circumcenters of primal grid (full and half level)	[hydro_diag]%geo_mc(:,:,:)	$m^2 s^{-2}$
$\dot{\eta}\frac{\partial p}{\partial \eta}$	vertical velocity (η coord.)	circumcenters of primal grid (half level)	[hydro_diag]%weta(:,:,:)	$Ps\,s^{-1}$
ω	vertical velocity (pressure coord.)	circumcenters of primal grid (half level)	[hydro_diag]%wpres(:,:,:)	$Pa\,s^{-1}$
u	zonal velocity component	circumcenters of primal grid (full level)	[hydro_diag]%u(:,:,:)	$m\,s^{-1}$
v	meridional velocity component	circumcenters of primal grid (full level)	[hydro_diag]%v(:,:,:)	$m\,s^{-1}$

Table 1: Overview of all prognostic and some diagnostic variables for the hydrostatic model. Prognostic variables are highlighted in red. Note: Only the most important diagnostic variables are listed here. For a complete list, see `src/hydro_atmos/mo_hydro_state.f90`. The brackets in column 3 indicate, that the prefix is a structure of type [...].

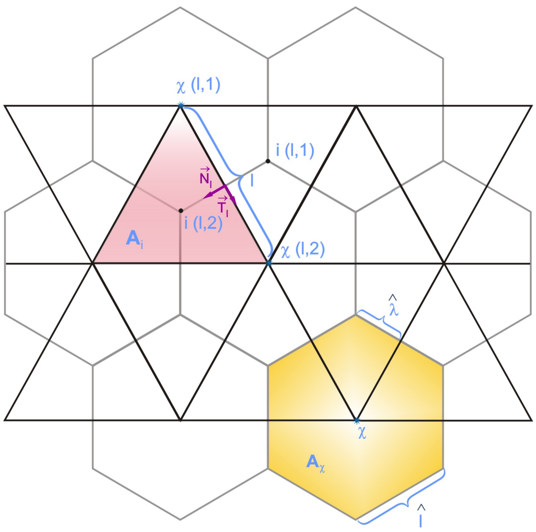

Figure 6: Notation for the horizontal grid. See Table 2 for a description.

variable	**description**	**name within code**
i	triangular cell and its center	[patch]%cells%idx(:,:)
χ	vertex of triangle and center of dual cell	[patch]%verts%idx(:,:)
l	edge of triangular cell and its length	[patch]%edges%primal_edge_length(:,:)
$\hat{l}$	edge of dual cell and its length	[patch]%edges%dual_edge_length(:,:)
$\hat{\lambda}_{i,l}$	distance between mass point i and edge l	[patch]%edges%edge_cell_length(:,:,:)
A_i	Area of primal cell i	[patch]%cells%area(:,:)
A_χ	Area of dual cell χ	[patch]%verts%dual_area(:,:)
N_l	Normal unit vector at edge l	[patch]%edges%primal_normal(:,:)
T_l	Tangential unit vector at edge l	[patch]%edges%dual_normal(:,:)
$i(l,1), i(l,2)$	the two neighboring triangles sharing edge l	[patch]%edges%cell_idx(:,:,:)
$\chi(l,1), \chi(l,2)$	the two ends of edge l	[patch]%edges%vertex_idx(:,:,:)

Table 2: List of symbols used for describing the horizontal grid. The brackets in column 3 indicate, that the prefix is a structure of type *patch*.

A. Grid Variables

ICON grid cell variables			
NETCDF variable name	name in the code [patch%grid_cells%]	description	(units,type, orientation)
neighbor_cell_ index	neighbor_[blk,idx](:,:,:)	Index list of the neighbor cells	ccw
edge_of_cell	edge_[blk,idx](:,:,:)	Index list of the cell edges	ccw
vertex_of_cell	vertex_[blk,idx](:,:,:)	Index list of the cell vertices	ccw
orientation_of_normal	edge_orientation(:,:,:)	The orientation of the edge normal vector (the variable primal_normal in the edges table) for the cell according to Gauss formula. It is equal to +1 if the normal to the edge is outwards from the cell, otherwise is -1. The same is true for the tangent vectors and the Stokes formula for a left-handed normal-tangent system (used in ICON).	-1,+1,ccw
lon_cell_centre, lat_cell_centre	center(:,:)	lon, lat of cell centers	CG
cell_area_p	area(:,:)	Area of cell	m^2

Table 3: Grid cell variables.

ICON grid edge variables			
NETCDF variable name	name in the code [patch%grid_edges%]	description	(units,type, orientation)
edge_vertices	vertex_[blk,idx](:,:,:)	Index list of the two edge vertices	
adjacent_cell_of_edge	cell_[blk,idx](:,:,:)	Index list of the two adjacent cells	
edge_system_ orientation	system_orientation(:,:)	+1 if the vector from vertex(1) to vertex(2) has the same orientation as the tangent vector (dual_normal). -1 otherwise.	-1,+1
lon_edge_centre, lat_edge_centre	center(:,:)	lon, lat of the edge center	CG
zonal_normal_primal_ edge meridional_normal_ primal_ edge	primal_normal(:,:)	The normal (unit) vector to the edge in local coordinates (on the tangent plane to the sphere). It always points from cell(1) to cell(2).	LC
	primal_cart_normal	The normal vector to the edge as above in Cartesian coordinates	CC
zonal_normal_dual_ edge meridional_normal_ dual_ edge	dual_normal(:,:)	The tangent unit vector to the edge in local coordinates (on the tangent plane to the sphere). The primal_normal, dual_normal forms a left-handed coordinate system	LC
	dual_cart_normal	The tangent unit vector to the edge, as above, in Cartesian coordinates	CC

Table 4: Grid edge variables.

ICON grid vertex variables			
NETCDF variable name	name in the code [patch%grid_vertices%]	description	(units,type, orientation)
vertices_of_vertex	neighbor_[blk,idx](:,:,:)	Index list of the neighbor vertices	(ccw)
cells_of_vertex	cell_[blk,idx](:,:,:)	Index list of the cells containing this vertex	(ccw)
edges_of_vertex	edge_[blk,idx](:,:,:)	Index list of the edges containing this vertex	(ccw)
edge_orientation	edge_orientation(:,:,:)	+1 when the vector from this to the neighbor vertex has the same orientation as the tangent unit vector of the connecting edge. -1 otherwise.	-1,+1
longitude_vertices, longitude_vertices	vertex(:,:)	lon, lat of the vertex	CG
dual_area_p	dual_area(:,:)	Area of the dual cell	m^2

Table 5: Grid vertex variables.

References

[1] Wan Hui, *Developing and testing a hydrostatic atmospheric dynamical core on triangular grids*, PhD thesis, Max Planck Institute for Meteorology, Hamburg, Germany, 2009.