The NWP system at DWD, Migration from IBM to NEC SX-9 and recent developments of the NWP system

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Abstract

The NWP-model suite of the DWD consists of three models with different resolutions: GME (40 km), COSMO-EU (7 km) and COSMO-DE (2.8 km). All models are running with their own data assimilation scheme. The COSMO-DE model is started every three hours. High resolution radar data are assimilated. The forecasts are available one hour after observation time.

Recently the new compute-server of the DWD - a NEC SX-9 - replaced the old IBM Power 5 system.

This presentation gives a short overview of the migration process from IBM to NEC. The NEC SX-9 allows a significant improvement of the NWP forecast systems. The new version of the global model GME with a horizontal resolution of 30km and the new ensemble system, based on COSMO-DE, are presented.

The new computer system at DWD

In the year 2008 the DWD moved into his new Headquarter in Offenbach. With this move, the new computer system delivered from NEC, went into production.

The new system is separated into two parts (called East- and West-side) with identical computing resources, to run NWP models. One part is only used for operational purposes, the other for research. If the operational part of the computing centre is not available, all operational runs can be switched to the research part, without any influence on speed and products. Research runs will be suspended in this case.

The main compute servers are NEC-SX9 vector computers, on every side 14 nodes with 16 vector processors. This system has a peak performance of about 23 Teraflop/s. The sustained performance is about 4.5 Teraflop/s. Every compute server is connected to a SUN fire x4600 cluster, consisting of 14 nodes with 8 AMD Opteron quad core CPUs and SuSE Linux SLES 10 SP2 as operational system. These clusters are used as a front-end system of the NEC SX-9 and for pre- and post-processing.. As a global file system NECs GFS is used. The central data handling system consists of two SGI Altix 4700 nodes with 92 Intel Itanium dual core CPUs. On these servers Oracle databases are running to handle observations and model fields. Archiving is done on two SUN STK SL8500 silos with a planned storage capacity up to 40 Petabyte in 2012.

The migration of the complete DWD production suite from the old IBM Power4 and Power5 systems to the new ones consists of three separate migrations:

- IBM Power5 / AIX / MPI ➔ NEC SX-9 / Super UX / MPI

NWP models GME, COSMO, WAVE, LPDM

- IBM Power5 / AIX /MPI ➔ SUN Fire / Linux / MPI
    - non-vectorizing parallel programs
    - serial programs
    - parallel execution of serial programs and shell scripts via MPI
    - data transfer from and to Oracle databases (grib, bufr, ...)
- IBM Power4 / AIX ➔ SGI Altix / Linux
    - Oracle databases
    - database interfaces
    - archive software

Due to problems of NEC to supply the SX-9 vector nodes in time the migration of the NWP models had to be separated into two separate steps:

- IBM Power5 ➔ NEC SX-8R
- NEC SX-8R ➔ NEC SX-9

During this sophisticated process we had to learn, that not only the pure migration of the applications can make problems but also the differences between the old and new system environment can lead to a large delay within the migration process. Some of those problems we detected were:

- initially quite instable SUN servers due to a bug in the kernel of Novell SLES10 operational system

- slow metadata retrieval on SGI database servers when accessing millions of files - a new configuration of the disks was necessary
- several MPI-bugs on NEC SX-9 occurred, a new version of the MPI library of September 2009 (one year after migrating the NWP model suite to the SX-8R) solved the main problems.

Finally it took almost one year to fully migrate the operational NWP suite to the new computer system.

Operational NWP-model suite

Since spring 2007, the operational NWP-model suite of DWD consists of three different NWP-models, the global model GME and the regional models COSMO-EU and COSMO-DE. Fig. 1 is showing all three models with their forecast areas. In addition to the NWP-models there are three wave models - the global wave model (GSM), the local wave model covering the Baltic Sea and parts of North Sea (LSM) and the Mediterranean wave model (MSM).

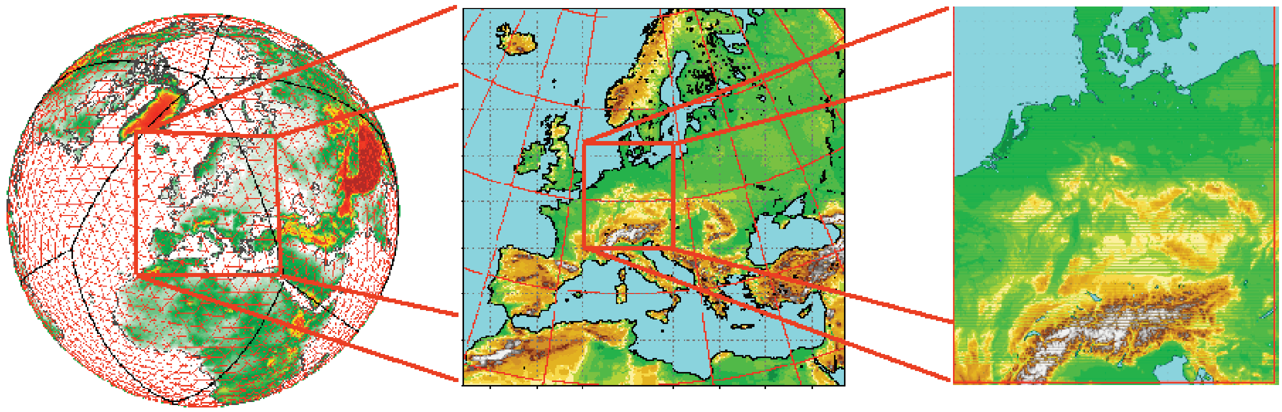


Fig. 1 GME, COSMO-EU and COSMO-DE with data dependencies

The GME [1] is a global hydrostatic forecast model based on a horizontal triangular grid. One of the large advantages of this grid is the absence of singular points at the North and South Pole. The horizontal resolution is about 40 km and the grid cell area has a size of about 1384 km_. The number of vertical levels is 40. This model version is running since 27. September 2004. Some additional features of the GME model are:

- 7-layer soil model including freezing/melting of soil water
- sea ice model
- seasonal variation of plant cover based on NDVI data.
- "Targeted Smoothing" of water vapour fields
- aerosol climatology

The data assimilation cycle of the GME is running eight times a day. A 3-dimensional data assimilation scheme, a sea surface temperature analysis (only 00 UTC) and an analysis of snow (density, depth, temperature) is executed. During the analysis of atmospheric fields several satellite data are incorporated using a 1DVAR approach. The implementation of the 3DVAR scheme allowed the DWD to switch off the use of the so called "pseudo temps" above the Atlantic and Pacific Ocean.

The regional model COSMO-EU is used operationally since 28. September 2005 and is covering Europe with a grid distance of about 7 km. This model has 40 vertical levels (like GME), but with a different vertical distribution. Important properties of the COSMO-EU are [2]:

- non-hydrostatic, fully compressible Euler equations
- parametrized convection
- 7-layer soil model including freezing/melting of soil water
- prognostic variables are p, u, v, w, T, qv, qc, qi, qr, qs, TKE
- sub-grid scale orography (SSO) scheme (Lott and Miller 1997)

Boundary data are interpolated from the GME at hourly intervals. The COSMO-EU has an own data assimilation suite. It is performing a continuous data assimilation (nudging scheme) which is started eight times a day for three hour assimilation periods. At 00 UTC an analysis of sea surface temperature and of the surface moisture is done.

The surface moisture is determined with an variational approach. At 00, 06, 12 and 18 UTC a separate analysis of snow (density, depth, temperature) is executed.

The high resolution model COSMO-DE is used operationally since 16. April 2007. The goals of developing this model were to provide a model-based NWP-system for very short range forecasts (until 21 hours) of severe weather events on the meso-γ scale, especially those related to

- deep moist convection (super- and multi-cell thunderstorms, squall-lines, MCCs, rainbands,...)
- interactions with fine-scale topography (severe downslope winds, föhn-storms, flash floodings, fog, ...)

The COSMO-DE model has a horizontal resolution of about 2.8 km and 50 vertical layers. The main properties of COSMO-DE are [5,6,9,10]:

- non-hydrostatic, fully compressible Euler equations
- resolved deep convection
- 7-layer soil model including freezing/melting of soil water
- prognostic variables are p, u, v, w, T, qv, qc, qi, qr, qs, qg (graupel), TKE
- radar data assimilation based on Latent Heat Nudging [3,7,8]

Boundary data are interpolated from the COSMO-EU model hourly. Radar data are available as a 2 dimensional composite every 5 minutes and are derived from a radar composite (reflectivity) of 16 stations with a spatial resolution of 1 x 1 km. The use of these data gives a better precipitation forecast until forecast hours 4 to 5.

The COSMO-DE is running eight times a day for an 21 hour forecast. This rapid update cycle gives the forecasters the possibility to use several consecutive forecasts as an LAF-ensemble. The very short observation cut off time of about 40 minutes allows it to provide the complete forecast 1 hour after analysis time within the database. The model output frequency of several meteorological fields is 15 minutes. So it is possible to evaluate the development of high resolution meteorological phenomena with a life cycle up to 2 hours. The data assimilation cycle is similar to that of the COSMO-EU, but without surface moisture analysis. The assimilation of radar data with the Latent Heat Nudging is executed during data assimilation. Since spring 2008 an important product of the COSMO-DE are 1- and 6-hourly probabilities of severe events.

Figure 2 shows the operational schedule of all NWP models of the DWD. This schedule is mainly based on the requirement to provide the COSMO-DE forecasts eight times a day one hour after analysis time within the database.

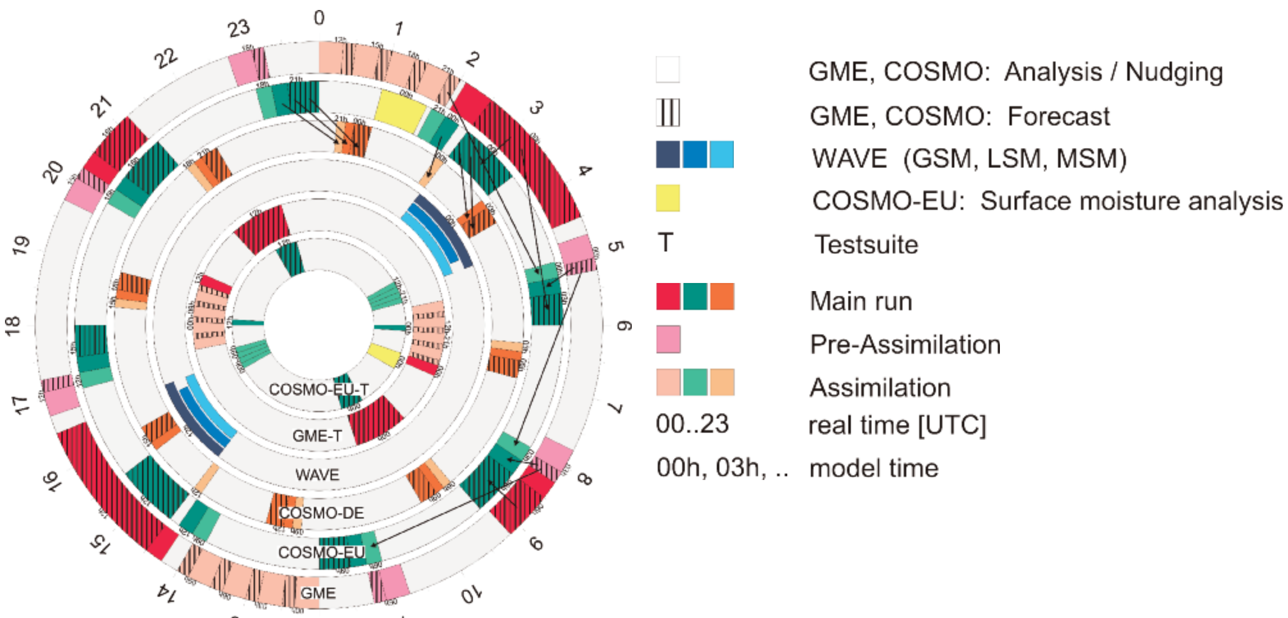


Fig. 2 Operational schedule

The picture shows a 24 hour clock, every circle corresponds to one NWP-model. The dark areas characterize the production runs, the brighter areas of a model circle the data assimilation. Each model run consists of an analysis and a forecast run (dashed area). Every running COSMO-DE gets boundary fields of a COSMO-EU run with an analysis time of X-3 hours. To provide all COSMO-EU runs with proper boundary data a so called GME-pre-assimilation is implemented. The arrows at the picture show the boundary data transfer between the different NWP-models; the two inner circles are indicating the schedule of the pre-operational test suites of GME and COSMO-EU.

Table 1 shows the differences between the data assimilation schemes of GME, COSMO-EU and COSMO-DE.

Model	GME	COSMO-EU	COSMO-DE
Assimilation interval	3 hourly	3 hourly	3 hourly
Assimilation type	3+1DVar + 3 hour forecast	cont. data assimilation (nudging)	cont. data assimilation (nudging)
Sea surface temperature	00 UTC	00 UTC	00 UTC
Snow (density, depth, temperature	3 hourly	6 hourly	6 hourly
Surface moisture	(planed)	00 UTC	–
Surface moisture	–	–	LHN (radar data)

Table 1 Differences between data assimilation schemes

Within Table 2 we see the forecast time and the observational cut off- and the ready-times of all production runs of the three NWP-models. Ready-time means that the forecast has finished and all data are available for further use. All forecast data are stored already during the model run into the field database. So every post-processing application has immediately access to these data.

	type	time [UTC] / interval	forecast time [h]	cut off time X + ??	ready time X + ??
GME	main forecast	00, 12 06, 18	174 48	+ 2:14 + 2:15	+ 4:20 + 3:05
	pre-assimilation	3 hourly	3	+ 4:45	+ 5:15
	assimilation	00, 12 03, 15 06, 18 09, 21	3 3 3 3	+ 12:00 + 9:30 + 7:00 + 4:30	+ 12:30 + 10:00 + 7:30 + 5:00
COSMO-EU	main forecast	00, 12 06, 18 03, 09, 15, 21	78 48 24	+ 2:30 + 2:30 + 2:30	+ 3:30 + 3:10 + 2:50
	assimilation	3 hourly	3 (cont.)	+ 4:50 (.. 7:50)	+ 5:00
COSMO-DE	main forecast	3 hourly	21	+ 0:40	+ 1:00
	assimilation	3 hourly	3 (cont.)	+ 3:20 (.. 6:20)	+ 3:30

Table 2 NWP-model with forecast time, observation cut off- and ready-times

Recent developments

GME 30L60

A new version of the DWD global model will be operationally on 02. February 2010. The main changes in comparison to the actual 40 km versions are:

- reduction of the mesh width from 40 km (ni=192) to 30 km (ni=256)
- increase the number of model layers from 40 to 60

  higher resolution within boundary layer and tropopause region
  model top increases from 10 hPa to 5 hPa
  lowest model level of 10 m unchanged
- new cloud microphysics scheme (Fig. 3) with prognostic rain and snow content QR and QS (QR and QS are interpolated to COSMO-EU as boundary data)

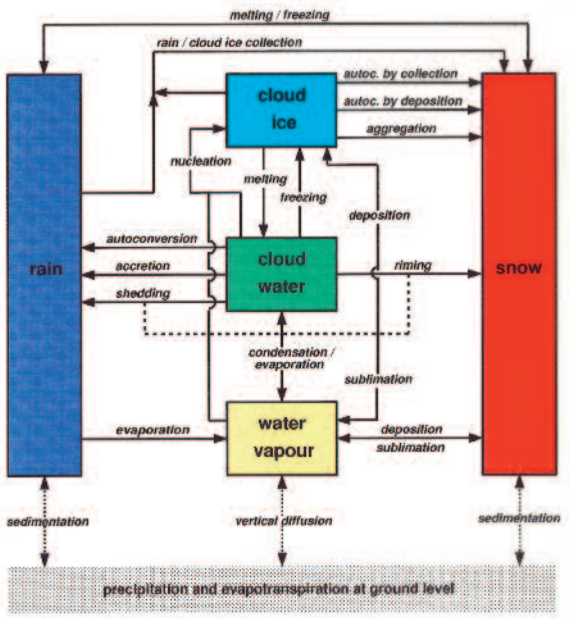


Fig. 3 Processes of the cloud microphysics scheme of GME30L60 (grid scale)

Soil moisture data assimilation

At the moment the soil moisture with the GME data assimilation scheme is running free. The soil moisture determines on clear / partially cloudy days the maximum temperature, the atmospheric boundary layer depth, low level clouds as well as the initiation of convection to a large extend. If the soil moisture is too high, the model will develop a cold bia. If it is too low, a warm bias will result. The goal of developing a soil moisture assimilation scheme is to minimize the screen level forecast error. The displayed cost function considers deviations from initial soil moisture and screen level observations.

$$J=(w-w_b)^T B^{-1}(w-w_b)+(T_{2m}-T_{2m^{obs}})^T O^{-1}(T_{2m}-T_{2m^{obs}})$$

Figure 4. shows the soil moisture increments based on the T2m forecast error. We can see large increments of soil moisture in regions with high T2m bias.

Bias T2m, avg (12, 15 UTC), 20080824
Mean: –0.02 std: 1.09 min: –4.72 max: 8.58

SMA Inkrement layer 4-5 (9–81 cm), 20080824
Mean: 0.70 std: 4.29 min: –25.5 max: 41.09

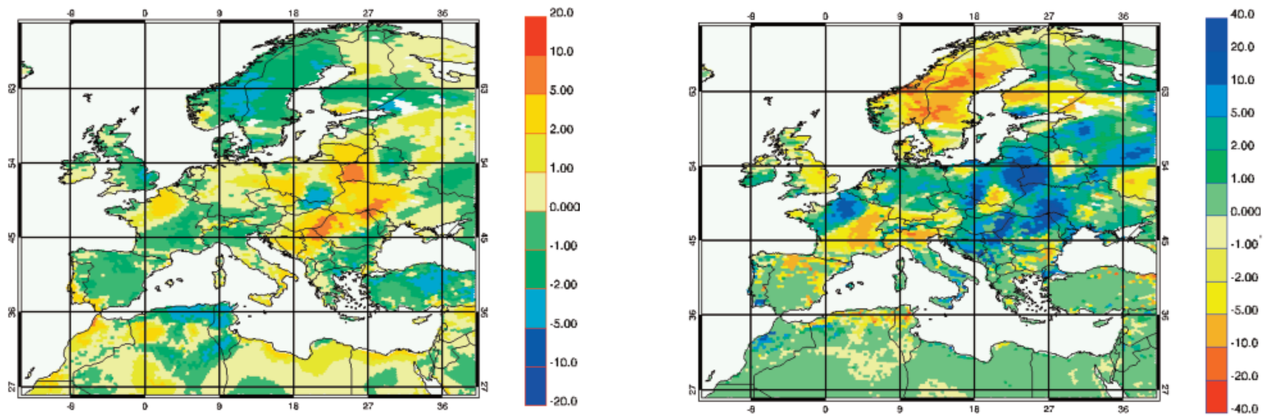


Fig. 4 Soil moisture increments based on T2m forecast error

COSMO-DE Ensemble Prediction System

The local model COSMO-DE can capture extreme events with it's forecasts and the synoptic structures can look more realistic than forecasts of the COSMO-EU. But to expect, that a single forecast can catch those events on the right place at the right time, is unrealistic. The DWD develops an ensemble prediction system on the convective scale based on the COSMO-DE. Pre-operational runs of this EPS system with 20 member are planned for the first quarter 2010. To increase the efficiency of the COSMO-DE EPS system three types of perturbations are put into the ensemble runs.

- Initial conditions

Currently the analysis fields of the COSMO-DE assimilation cycle are perturbed in a simple way. Later on a data assimilation based on an Ensemble Transform Kalman Filter (EnTKF) is planned.

- Boundary conditions

Currently the results of the "Multimodel-Multiboundary-Ensemble System SREPS" of INM are taken to drive a COSMO-SREPS ensemble (10 km resolution) running at ECMWF. The forecasts of the COSMO-SREPS will be interpolated and used as boundary data of the COSMO-DE EPS.

- Perturbations of the model physics

Currently these perturbations are realized by perturbed parameters in physical parameterizations. A possible alternative could be the implementation of stochastic physics into the COSMO-DE.

The properties of the pre-operational COSMO-DE EPS will be the following:

- EPS runs per day 8
- EPS members 20
- forecast time 21 hours
- observation cut off time X + 0:45 hours
- ready time the EPS X + 1:15 hours
- data amount of one EPS run 766 Gbyte (full) or 300 Gbyte (reduced output fields)
- data transfer rate into database 3.4 Gbit/s (full= or 1.4Gbit/s (reduced)

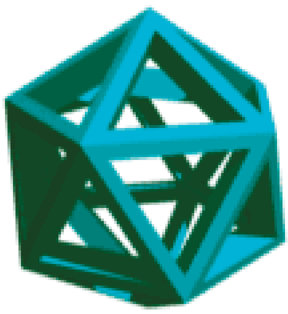
ICON – ICOsahedral Nonhydrostatic Model

The ICON will be the next generation global model at DWD and the Max-Planck-Institute (MPI-M) in Hamburg. The goal is to develop a non-hydrostatic global model with static local zooming option. A first operational NWP model version will be ready by 2011.

At DWD the ICON will replace the global model GME and the regional model COSMO-EU by running a high-resolution window over Europe. With the development of ICON we want to establish a library of scale-adaptive physical parameterization schemes to be used with ICON and COSMO-DE.

The MPI-M wants to use ICON as dynamical core of an Earth System Model (COSMOS). ICON will replace the regional climate model REMO. The MPI-M also develops an ocean model based on ICON grid structures and operators.

The first step to create the ICON grid is to inscribe an icosahedron into the unit sphere. The 12 vertices touching the surface define the basic mesh, consisting of 20 spherical triangles. Further mesh refinements by one "root division" followed by successive bisections (connect midpoints of the edges for each triangle by great circle arcs). The result will be a dual grid, consisting of triangles and hexagons (+ 12 pentagons at the icosahedron vertices).



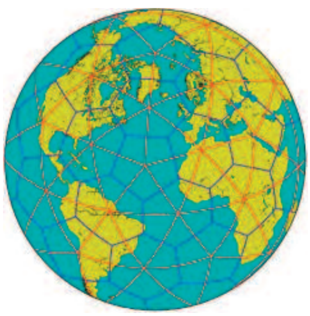
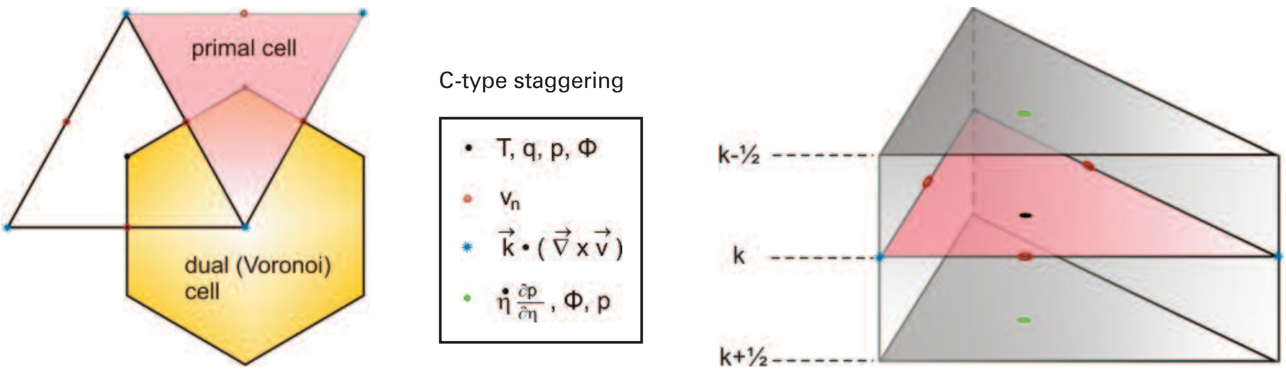


Fig. 5 Grid topology and geometry of ICON

Figure 6. shows the 3D arrangement of the discrete variables within the ICON grid. The cell center is the center of triangle circumcircle.



Horizontal

Vertical

Fig. 6 3D arrangement of discrete variables

The grid refinement of the ICON grid necessary to replace COSMO-EU is done at three refinement levels. It is possible to create latitude-longitude or circular windows (Fig.7). One-way and two-way nesting is possible.

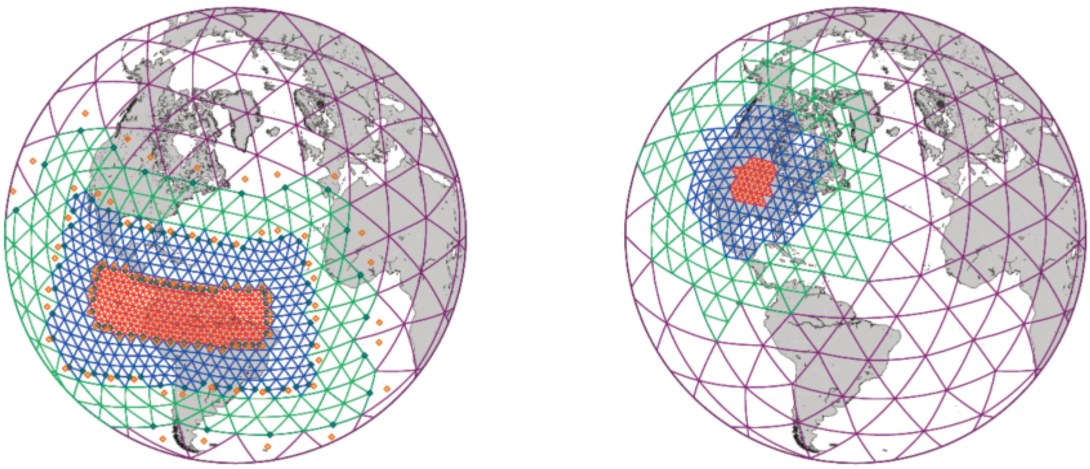


Fig. 7 Latitude-longitude and circular window