# JOINT WMO TECHNICAL PROGRESS REPORT ON THE GLOBAL DATA PROCESSING AND FORECASTING SYSTEM AND NUMERICAL WEATHER PREDICTION RESEARCH ACTIVITIES FOR 2016

# BRAZIL - INMET/RSMC BRASILIA

## 1. Summary of highlights

The Regional Specialized Meteorological Center Brasilia (RSMC BRASILIA) has been running a local area modeling system since 1999 under close collaboration with the German Meteorological Service – DWD (DeutcherWetterdienst). Besides the use of the HRM, the RSMC Brasilia has began the implementation of the COSMO model operationally over Brazil with a grid space of 7 km (South America) and 2.8 km (three regions over Brazil).

All the improvements of DWD's modelling suite were include in the daily operations.

## 2. Equipment in use

### 2.1. Processing (HPC Cluster QDR/FDR Infiniband - 55.6Teraflops) with:

1) SGI Altix XE 1300 with:
    - Intel® Xeon® Processor X5560 (8M Cache, 2.80 GHz, 6.40 GT/s Intel® QPI)
    - 44 nodes
    - 352 cores
    - 4 Teraflops
    - SuSE Linux Enterprise Server 11.3

2) SGIAltix ICE 8400 with:
    - Intel® Xeon® Processor X5650 (12M Cache, 2.66 GHz, 6.40 GT/s Intel® QPI)
    - 58 nodes
    - 696 cores
    - 7.4 Teraflops
    - SuSE Linux Enterprise Server 11.3

3) SGI Altix ICE X with:
    - Intel® Xeon® Processor E5-2630 (15M Cache, 2.30 GHz, 7.20 GT/s Intel® QPI)
    - 134 nodes
    - 1608 cores
    - 29.5 Teraflops
    - SuSE Linux Enterprise Server 11.3

4) SGI UV 2000 with:
    - Intel® Xeon® Processor E5-4640 (20M Cache, 2.40 GHz, 8.00 GT/s Intel® QPI)
    - 768 cores
    - 14.7 Teraflops
    - SuSE Linux Enterprise Server 11.3

5) Service Nodes:
   - 2 x Login Nodes SGI XE-500 (2x Intel Xeon CPU X5690 @ 3.47GHz)
   - 4 x Storage Nodes SGI ISS3500 (43TB SAS, 180TB SATA)

## 2.2. Pos-Processing with:

1) Processing: HP Blade System
   - Processor Nehalem
   - 7 blades BL460 G5 (X8)
   - 8 cores per blade
   - Red Hat Enterprise Linux 5.5

2) Storage NetAPP
   - Cluster NetAPP with 4 x V3270
   - 8 ports 10Gbits Ethernet
   - 8 ports 1Gbits Ethernet
   - 8 ports 8Gbits SAN
   - ~ 0.8 Pbytes SSD/SAS/SATA disks

3) Storage: CAS System
   - Software CASTOR (CARINGO), with search engine.
   - 5 redundant nodes
   - 80 Tbytes

4) Pos-processing: Dell PowerEdge R710
   - 2 quad-core processor Intel Xeon 5520
   - 16 cores
   - 48 Gbytes RAM
   - 5 SAS HD 300 Gbytes @ 1500 rpm
   - Red Hat Enterprise Linux 6.0

Other peripheral equipment and systems are used for database purposes.

## 2.3. Network

The LAN network infrastructure at INMET is totally interconnected via Gigabit Ethernet. There are IPS/IDS systems installed, firewall, anti-virus and anti-spam.

## 2.4. Special systems

### 2.4.1. RTH Brasilia Telecommunication Systems

The Message Switching System (MSS) in Brasilia is acting as RTH on the MTN within the WMO GTS. The MSS software is a commercial software package called MovingWeather delivered by IBL Software Engineering. It runs on a dual HP Proliant DL380 GS servers:

1) Message Switching: Dell PowerEdge R710
   - 2 dual-core processor Intel Xeon E5320 AT 1.8 GHz, x86-64
   - 4 Gbytes RAM
   - HD 320 Gbytes
   - Red Hat Enterprise Linux 6.0

2) Virtualization: Dell Blade Servers PowerEdge M100e
   - 2 PEM 710 blades
   - Red Hat Enterprise Linux 6.0

3) Storage: NetApp FAS2040
   - 6 Tbytes capacity,
   - 1 fiber switch BROCADE 300
   - 1 SATA expansion cabinet with 20 Tbytes.

4) Tape Unit: Quantum Scalar i500
   - 40 LT0-5 tapes capacity
   - 3 Tbyte per tape

The Automatic File Distributor- AFD system, developed by DWD (http://www.dwd.de/AFD) is also used to deliver data and products to users.

### 2.4.2. Satellite Receiving System

Terascan 4.0 System for satellite image acquisition and processing used for NOAA, GOES and METEOSAT series (http://www.seaspace.com)

- 2 x Dell Precision 390
- Processor Intel Core 2 dual
- 4 Gbytes RAM
- 1 Tbyte HD
- CentOS 5.4

- HP COMPAC 6005 Phenon-II
- Two processor AMD Core 2 dual
- 2 Gbytes RAM
- 1 Tbyte HD
- CentOS 5.4

- 2 x SeaSpace box
- Processor Intel Core 2 dual
- 2 Gbytes RAM
- 250 GTbyte HD
- CentOS 5.4

EUMETCastreceiving system

- 2 x Dell Precision Optplex 745
- Intel Core 2 dual
- 2 Gbytes RAM
- 250 GBytes HD
- Fedora Core Linux and Windows XP

Software:

- AAPP – ATOVS and AVHRR Pre-processing package from MetOffice http://metoffice.gov.uk).
- ArcGIS version 10 from ESRI (http://www.esri.com).
- ENVI version 4.8 and IDL version 8.01 from ITT Vis (http://ittvis.com).

### 2.4.3. Graphical System

The Visualization System is a commercial software package called VisualWeather delivered by IBL Software Engineering. It runs on Dell PowerEdge R710 servers:

- 2 quad-core processor Intel Xeon 5520
- 16 cores
- 48 Gbytes RAM
- 5 SAS HD 300 Gbytes @ 1500 rpm
- Red Hat Enterprise Linux 6.0

## 3. Data and Products from GTS in use

- Alphanumerical data: SYNOP, BUOY, TEMP, PILOT
- Binary data: SYNOP, BUOY, ATOVS, AWS
- GRIB products

Model outputs in GRIB formats are not inserted into the GTS.

## 4. Forecasting system

### 4.1. System run schedule and forecast ranges

Non-hydrostatic COSMO model (00 and 12 UTC) for 174 hours and (06 and 18 UTC) for 72h - (7 km of horizontal resolution) over South America;

Non-hydrostatic COSMO model (00, 06, 12 and 18 UTC) for 27 hours – (2.8 km of horizontal resolution) over 3 regions of Brazil (Northeast, Southeast and South).

### 4.2. Medium range forecasting system (4-10 days)

#### 4.2.1. Data assimilation, objective analysis and initialization

#### 4.2.1.1. In operation

#### 4.2.1.2. Research performed in this field

None

#### 4.2.2. Model

#### 4.2.2.1. In operation

COSMO model 7km horizontal resolution. Domain (South America) - Mesh size: 0.0625° ~ 7 km:

| | | |
|---|---|---|
| startlon | = | -95.0 |
| endlon | = | -20.0 |
| startlat | = | -60.0 |
| endlat | = | 15.0 |
| ie | = | 1201 |
| je | = | 1201 |
| ke | = | 60 |

pollon = -180.0
pollat = 90.0
nrbmap = 305

Products: All analysis products are given on the 1201 x 1201 grid and available at hourly intervals.

a) On the 60 layers
Variables: p, T, u, v, w, qv, qc, qi, qrain, qsnow, TKE

b) On 10 pressure levels (1000, 950, 850, 700, 500, ..., 200 hPa)
Variables: pmsl, $\Phi$, T, u, v, $\omega$, Relative Humidity

c) On 4 constant height levels (1000, 2000, 3000, 5000 m)
Variables: p, T, u, v, w, Relative Humidity.

Assimilation scheme: none
Initialization: Runge-Kutta 3$^{rd}$ integration

**Short overview of the Non-hydrostatic COSMO model:**
***Dynamics***

- **Model Equations**: Nonhydrostatic, full compressible hydro-thermodynamical equations in advection form. Subtraction of a hydrostatic base state at rest.
- **Prognostic Variables**: Horizontal and vertical Cartesian wind components, pressure perturbation, temperature, specific humidity, cloud water content. Optionally: cloud ice content, turbulent kinetic energy, specific water content of rain, snow and graupel.
- **Diagnostic Variables**: Total air density, precipitation fluxes of rain and snow.
- **Coordinate System**: Generalized terrain-following height coordinated with rotated geographical coordinates and user defined grid stretching in the vertical. Options for (i) base-state pressure based height coordinate, (ii) Gal-Chen height coordinate and (iii) exponential height coordinate (SLEVE) according to Schär et al. (2002).

***Numerics***

- **Grid Structure**: Arakawa C-grid, Lorenz vertical grid staggering.
- **Spatial Discretization**: Second-order finite differences. For the two time-level scheme also 1st and 3rd to 6th order horizontal advection (default: 5th order). Option for explicit higher order vertical advection.
- **Time Integration**: Second-order leapfrog HE-VI (horizontally explicit, vertically implicit) time-split integration scheme by default, including extensions proposed by Skamarock and Klemp (1992). Option for a three time-level 3-d semi-implicit scheme (Thomas et al. (2000)). Several Options for two time-level 2nd and 3rd order Runge-Kutta split-explicit scheme after Wicker and Skamarock (2002) and a TVD-variant (Total Variation Diminishing) of a 3rd order Runge-Kutta split-explicit scheme.
- **Numerical Smoothing**: 4th-order linear horizontal diffusion with option for a monotonic version including an orographic limiter. Rayleigh damping in upper layers. 2-d divergence damping and off-centering in the vertical in split time steps.

***Initial and Boundary Conditions***

- **Initial Conditions**: Interpolated initial data from various coarse-grid driving models (GME, ECMWF, COSMO-Model) or from the continuous data assimilation stream (see below). Option for user-specified idealized initial fields.
- **Lateral Boundary Conditions**: 1-way nesting by Davies-type lateral boundary formulation. Data from several coarse-grid models can be processed (GME, IFS, COSMO-Model). Option for periodic boundary conditions.
- **Top Boundary Conditions**: Options for rigid lid condition and Rayleigh damping layer.
- **Initialization**: Digital-filter initialization of unbalanced initial states (Lynch et al. (1997)) with options for adiabatic and diabatic initialization.

### *Physical Parameterizations*

- **Subgrid-Scale Turbulence**: Prognostic turbulent kinetic energy closure at level 2.5 including effects from subgrid-scale condensation and from thermal circulations. Option for a diagnostic second order K-closure of hierarchy level 2 for vertical turbulent fluxes.Preliminary option for calculation of horizontal turbulent dffusion in terrain following coordinates (3D Turbulence).
- **Surface Layer Parameterization**: A Surface layer scheme (based on turbulent kinetic energy) including a laminar-turbulent roughness layer. Option for a stability-dependent draglaw formulation of momentum, heat and moisture fluxes according to similarity theory (Louis (1979)).
- **Grid-Scale Clouds and Precipitation**: Cloud water condensation and evaporation by saturation adjustment. Precipitation formation by a bulk microphysics parameterization including water vapour, cloud water, cloud ice, rain and snow with 3D transport for the precipitating phases. Option for a new bulk scheme including graupel.Option for a simpler column equilibrium scheme.
- **Subgrid-Scale Clouds**: Subgrid-scale cloudiness is interpreted by an empirical function depending on relative humidity and height. A corresponding cloud water content is also interpreted. Option for a statistical subgrid-scale cloud diagnostic for turbulence.
- **Moist Convection**: Tiedtke (1989) mass-flux convection scheme with equilibrium closure based on moisture convergence. Option for the Kain-Fritsch (Kain and Fritsch (1993)) convection scheme with non-equilibrium CAPE-type closure.
- **Shallow Convection**: Reduced Tiedtke scheme for shallow convection only.
- **Radiation**: δ-two-stream radiation scheme after Ritter and Geleyn (1992) short and longwave fluxes (employing eight spectral intervals); full cloud-radiation feedback.
- **Soil Model**: Multi-layer version of the former two-layer soil model after Jacobsen and Heise (1982) based on the direct numerical solution of the heat conduction equation. Snow and interception storage are included. Option for the (old) two-layer soil model employing the extended force-restore method still included.
- **Terrain and Surface Data**: All external parameters of the model are available at various resolutions for a pre-defined region covering Europe. For other regions or grid-spacings, the external parameter file can be generated by a preprocessor program using high-resolution global data sets.

### *Data Assimilation*

- **Basic Method**: Continuous four-dimensional data assimilation based on observation nudging (Schraff (1996), Schraff (1997)), with lateral spreading of upper-air observation increments along horizontal surfaces. Explicit balancing by a hydrostatic temperature correction for surface pressure updates, a geostrophic wind correction, and a hydrostatic upper-air pressure correction.
- **Assimilated Atmospheric Observations**: Radiosonde (wind, temperature, humidity), aircraft (wind, temperature), wind profiler (wind), and surface-level data (SYNOP, SHIP, BUOY: pressure, wind, humidity). Optionally RASS (temperature), radar VAD wind, and ground-based GPS (integrated water vapour) data. Surface-level temperature is used for the soil moisture analysis only.
- **Radar derived rain rates**: Assimilation of near surface rain rates based on latent heat nudging (Stephan et al. (2008)). It locally adjusts the three-dimensional thermodynamical field of the model in such a way that the modelled precipitation rates should resemble the observed ones.
- **Surface and Soil Fields**: Additional two-dimensional intermittent analysis:
- **Soil Moisture Analysis**: Daily adjustment of soil moisture by a variational method (Hess (2001)) in order to improve 2-m temperature forecasts; use of a Kalman-Filter-like background weighting.
- **Sea Surface Temperature Analysis**: Daily Cressman-type correction, and blending with global analysis. Use of external sea ice cover analysis.
- **Snow Depth Analysis**: 6-hourly analysis by weighted averaging of snow depth observations, and use of snowfall data and predicted snow depth.

***Code and Parallelization***

- **Code Structure**: Modular code structure using standard Fortran constructs.
- **Parallelization**: The parallelization is done by horizontal domain decomposition using a soft-coded gridline halo (2 lines for Leapfrog, 3 for the Runge-Kutta scheme). The Message Passing Interface software (MPI) is used for message passing on distributed memory machines.
- **Compilation of the Code**: The compilation of all programs is performed by a Unix shell script invoking the Unix make command. All dependencies of the routines are automatically taken into account by the script.
- **Portability**: The model can be easily ported to various platforms; current applications are on conventional scalar machines (UNIX workstations, LINUX and Windows-NT PCs), on vector computers (NEC SX series) and MPP machines (CRAY-XT3, IBM-SP series, SGI ALTIX series).
- **Model Geometry**: 3-d, 2-d and 1-d model configurations. Metrical terms can be adjusted to represent tangential Cartesian geometry with constant or zero Coriolis parameter.

#### 4.2.2.2. Research performed in this field

Assimilation system test on continuous four-dimensional data assimilation based on observation nudging.

### 4.2.3. Operationally available Numerical Weather Prediction Products

Products: All analysis products are given on the 751 x 751 grid and available at hourly intervals.

a) On the 60 layers
Variables: p, T, u, v, w, $q_v$, $q_c$, $q_i$, $q_{rain}$, $q_{snow}$, TKE

b) On 10 pressure levels (1000, 950, 850, 700, 500, ..., 200 hPa)

Variables: pmsl, Φ, T, u, v, ω, Relative Humidity.

c) On 4 constant height levels (1000, 2000, 3000, 5000 m)
Variables: p, T, u, v, w, Relative Humidity.

### 4.2.4. Operational techniques for application of NWP products (MOS, PPM, KF, Expert Systems, etc.).

#### 4.2.4.1. In operation

None

#### 4.2.4.2. Research performed in this field

We plan to continue the development of MOS and Kalman Filter by adding the forecast for the other variables.

### 4.2.5. Ensemble Prediction System (EPS)

**None**

#### 4.2.5.1. In operation

None

#### 4.2.5.2. Research performed in this field

Tests with 16 members (control + 15 members) for COSMO 11 km over South America.

#### 4.2.5.3. Operationally available EPS Products

None

## 4.3. Short-range forecasting system (0-72 hours)

### 4.3.1. Data assimilation, objective analysis and initialization

#### 4.3.1.1. In operation

#### 4.3.1.2. Research performed in this field

Assimilation system test on continuous four-dimensional data assimilation based on observation nudging.

### 4.3.2. Model

#### 4.3.2.1. In operation

#### 4.3.3. Operationally available NWP products

##### 4.3.3.1. Research performed in this field

None

#### 4.3.4. Operational techniques for application of NWP products

##### 4.3.4.1. In operation

None

##### 4.3.4.2. Research performed in this field

None

#### 4.3.5. Ensemble Prediction System

##### 4.3.5.1. In operation

None

##### 4.3.5.2. Research performed in this field

None

##### 4.3.5.3. Operationally available EPS Products

None

### 4.4. Nowcasting and Very Short-range Forecasting Systems (0-6 hours)

#### 4.4.1. Nowcasting system

##### 4.4.1.1. In operation

Non-hydrostatic COSMO (Consortium for Small-scale Modeling), model Domain: Three regions over Brazil (Mesh size: 0.025° ~ 2.8 km) - (Lateral boundary conditions of COSMO 7km):

| | | | | | |
|---|---|---|---|---|---|
| **Northeast** | **lat** | -19 | 0 | **je** | 761 |
| | **lon** | -49 | -33 | **ie** | 641 |
| | | | | | |
| **Southeast** | **lat** | -26 | -13 | **je** | 521 |
| | **lon** | -54 | -38 | **ie** | 641 |
| | | | | | |
| **South** | **lat** | -35 | -22 | **je** | 521 |
| | **lon** | -59 | -47 | **ie** | 481 |

#### 4.4.1.2. Research performed in this field

Tests with COSMO model 2.8km horizontal resolution (Lateral boundary conditions of COSMO 7km). Domain (two regions over Brazil):
Two regions over Brazil (Mesh size: 0.025° ~ 2.8 km):

| | | | | | |
|---|---|---|---|---|---|
| 1 | **lat** | -14 | 6 | **je** | 801 |
| | **lon** | -75 | -56 | **ie** | 761 |
| **North** | | | | | |
| 2 | **lat** | -14 | 5 | **je** | 761 |
| | **lon** | -60 | -45 | **ie** | 601 |
| | | | | | |
| | | | | | |
| **Midwest** | **lat** | -25 | -7 | **je** | 721 |
| | **lon** | -62 | -45 | **ie** | 681 |

### 4.4.2. Models for Very Short-range Forecasting Systems

#### 4.4.2.1. In operation

None

#### 4.4.2.2. Research performed in this field

None

## 4.5. Specialized numerical predictions

None

### 4.5.1. Assimilation of specific data, analysis and initialization (where applicable)

#### 4.5.1.1. In operation

None

#### 4.5.1.2. Research performed in this field

None

### 4.5.2. Specific Models (as appropriate related to 4.5)

#### 4.5.2.1. In operation

None

#### 4.5.2.2. Research performed in this field

None

### 4.5.3. Specific products operationally available

None

### 4.5.4. Operational techniques for application of specialized numerical prediction products (MOS, PPM, KF, Expert Systems, etc.) (as appropriate related to 4.5).

#### 4.5.4.1. In operation

None

#### 4.5.4.2. Research performed in this field

None

### 4.5.5. Probabilistic predictions (where applicable)

#### 4.5.5.1. In operation

None

#### 4.5.5.2. Research performed in this field

None

#### 4.5.5.3. Operationally available probabilistic prediction products

None

## 4.6. Extended range forecasts (ERF) (10 days to 30 days)

### 4.6.1. Models

#### 4.6.1.1. In operation

None

#### 4.6.1.2. Research performed in this field

None

### 4.6.2. Operationally available NWP model and EPS ERF products

None

## 4.7. Long range forecasts (LRF) (30 days up to two years)

## 4.8. Models

The COSMO model in CLimate Mode (COSMO-CLM or CCLM) is a nonhydrostatic regional climate model developed from the Local Model (LM) of the German Meteorological Service by the CLM-Community. Since 2005 it is the Community-Model of the german climate research. The model has been used for simulations on time scales up to centuries and spatial resolutions between 1 and 50 km.

The LM has been developed by the German Weather Service (DWD) for operational weather forecast. Meanwhile it is used and further developed by several other weather services organized in the COnsortium for Small-scale MOdelling (COSMO). In this sense the COSMO-CLM model system is a unified model system for Numerical Weather Prediction and Regional Climate Modeling.

#### 4.8.1.1. In operation

None

#### 4.8.1.2. Research performed in this field

For the treatment of the data to be used by the model in operational mode, the global data of ECMWF - S2S – CY43R1 (sub-seasonal to seasonal forecast) , based on 51 members, were updated twice a week (Monday and Thursday at 00Z) Until day 46, with a resolution of 0.5 every 06 hours. For the external data used by the model (topography, albedo, type and soil levels, etc.), a grid of 25 km was established to be used as boundary to verify the simulations generated by the model.

The research is in the phase of data acquisition to verify the best calibration of the climate model, in operational mode, on a sub-seasonal scale forecast to 45 days.

#### 4.8.2. Operationally available EPS LRF products

None

## 5. Verification of prognostic products

### 5.1 Research performed in this field

Since 2012 INMET has been using the COSMO numerical weather prediction model. Whereas we are aware that many users have already started using the model, we have investigated some statistics of the forecast products.

The statistics are calculated from the numerical forecasts and of the observations data like bias and RMS, and the Brier skill score from the numerical weather prediction files from COSMO model (7km).

An alternative methodology has been used in INMET to evaluate the quality of NWP models, especially those regarding to point forecasting, gathered either as result of interpolation on model grid. The key aspect is the use of Brier scores and its components. Although these scores are mostly applied to categorical outputs, we have tested a straightforward methodology for applying it to continuous variables, such as temperature, rainfall, pressure and others.

Brier Skill Score constitutes a measure of effectiveness of the predictor model that includes the COSMO and all other processes to run, post-processing and verification, thus becoming the index of system performance predictor.

### 5.2 Research performed in this field

Calculate the statistics verification of numerical forecasts INMET forward the analysis and observations, bias and RMS, and the Brier scores from the numerical weather prediction files from COSMO model (2,8 km) and others statistics products.

## 6. Plans for the future (next 4 years)

### 6.1. Development of the GDPFS

#### 6.1.1. major changes in the Operational DPFS which are envisaged within the next year

It is planned to expand the storage capacity from 100 Tbytes to 0,5Pbytes.

### 6.1.2. major changes in the Operational DPFS which are envisaged within the next 4 years

We have started studies to verify the adoption of the GPU or MIC technology for processing the numerical models.

## 6.2. Planned research Activities in NWP, Nowcasting, Long-range Forecasting and Specialized Numerical Predictions

### 6.2.1. Planned Research Activities in NWP

Run the non-hydrostatic COSMO model with horizontal resolution of 7km for the South America to 174 hours of forecast (00 and 12 UTC) and 120 hours of forecast (06 and 18 UTC).

### 6.2.2. Planned Research Activities in Nowcasting

Runthenon-hydrostaticCOSMO model with horizontal resolution of2.8Km over regionsofBrazil(North and Midwest) to27 hours of forecast(00, 06, 12 and 18 UTC).

### 6.2.3. Planned Research Activities in Long-range Forecasting

None

### 6.2.4. Planned Research Activities in Specialized Numerical Predictions

None

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# BRAZIL - CHM RIO DE JANEIRO

## 1. Summary of highlights

The Brazilian Hidrography Navy Center (CHM) that operates the Marine Meteorological Service is responsible for the weather forecasts and severe weather warnings issues over Metarea V on South Atlantic Ocean. CHM has been running local area modeling system since 1999 under close collaboration with German Meteorological Service – DWD (DeutcherWetterdienst). Besides the use of the HRM, CHM has started the implementation of the COSMO model operationally over Brazil and METAREA V with a grid space of 10 km.

## 2. Equipment in use

### 2.1. Processing (HPC Cluster QDR/FDR Infiniband – 16 Teraflops) with:

1) SGI Altix ICE 8400 with:
   - Intel® Xeon® Processor E5472 (12Mb Cache, 3.00 GHz, 6.40 GT/s Intel® QPI)
   - Intel® Xeon® Processor X5650 (12Mb Cache, 2.67 GHz, 6.40 GT/s Intel® QPI)
   - 48 nodes
   - 640 cores
   - 7.1 Teraflops
   - SuSE Linux Enterprise Server 11.1

2) SGI Altix ICE X with:
   - Intel® Xeon® Processor E5-2630 (15Mb Cache, 2.30 GHz, 7.20 GT/s Intel® QPI)
   - 25 nodes
   - 300 cores
   - 5.5 Teraflops
   - SuSE Linux Enterprise Server 11.2

3) SGI UV 100 with:
   - Intel® Xeon® Processor E7-8837 (24Mb Cache, 2.67 GHz, 6.40 GT/s Intel® QPI)
   - 320 cores
   - 3.4 Teraflops
   - SuSE Linux Enterprise Server 11.1

4) Service Nodes:
   - 1 x Login Nodes SGI C2108-RP2 (6 x Intel Xeon CPU E5-2630 @ 2.30GHz)
   - 1 x Login Nodes SGI XE250 (4 x Intel Xeon CPU E5420 @ 2.50GHz)
   - 1 Storage Node SGI Infinity Store Server 3500 (60TB SATA)
   - 1 Storage Node SGI Nexis 9000 (54TB SATA)

5) 2 SGI Altix 450 with:
   - Intel ® Dual-Core ® Itanium ®
   - 132 cores
   - 844 Gigaflops

## 2.2. Pos-Processing with:

1) 1 Dell Power Edge 2950
   - Intel® Xeon® Processor E5430 @2.66 GHz
   - 2 processors Quad core
   - VMware ESXi 4.0.0

2) 2 Dell Power Edge 1950
   - Intel® Xeon® Processor E5430 @2.66 GHz
   - 2 processors Quad core
   - VMware ESXi 4.0.0

3) 8 Dell Power Edge R-410
   - Intel® Xeon® Processor E5620 @2.40 GHz
   - 1 processor Quad core
   - XenServer 6.1 (Redhat based system)

4) 1 Dell Powe Edge R720
   - Intel® Xeon® Processor E5-2650 @2.00 GHz
   - 2 processors Oct core
   - CentOS 6.2

Other peripheral equipment and systems are used for database purposes.

## 2.3. Network

The LAN network infrastructure at CHM is partially interconnected via Gigabit Ethernet. The part of LAN interconnected trough fast communication has been migrating to Gigabit.

## 2.4. Special systems

### 2.4.1. Dedicated Internet Access

The internet access is provided by GVT Company through a dedicated link with 40 Mbps bandwidth.

### 2.4.2. Satellite Receiving System

EUMETCast receiving system
2 x Workstations
Intel Core 2 dual and Intel Quad Core
4 Gbytes RAM each
500 GBytes HD and 320 GBytes HD
Ubuntu Linux and Windows XP

Software: XRIT2PIC -HRIT/LRIT data broadcasted by Eumetcast and NOAA from Rob Alblas (http://www.alblas.demon.nl/wsat/software).
ImageMagick version 6.7.7-9 2012-06-25 Q16 from ImageMagick Studio LLC (http://www.imagemagick.org/)

#### 2.4.3. **Internet Data Distribution (IDD)**

The IDD system has been made available through internet connection with the Center for Weather Forecasting and Climate Research (CPTEC). The IDD is applied by a set of requested data as conventional observations, GOES satellite images, numerical models that are received as soon as they are available on the observation system.

#### 2.4.4. **Graphical System**

The Visualization System is based upon two free software packages, Grid Analysis and Display System (GrADS) and General Meteorology PAcKage (GEMPAK).

## 3. Data and Products from GTS in use

- Alphanumerical data: SYNOP, SHIP, BUOY
- Binary data: SYNOP, BUOY
- GRIB products

Model outputs in GRIB formats are not inserted into the GTS.

## 4. Forecasting system

### 4.1. System run schedule and forecast ranges

HRM model (00 and 12 UTC) for 120 hours - (10 km of horizontal resolution and 60 vertical levels) over part of South America and adjacent South Atlantic Ocean that corresponds to METAREA V;

HRM model (00 and 12 UTC) for 120 hours - (15 km of horizontal resolution and 60 vertical levels) over Antarctic Peninsula, Drake Passage and extreme south of South America;

Non-hydrostatic COSMO model (00 and 12 UTC) for 78 hours - (10 km of horizontal resolution and 60 vertical levels) over the same domain of HRM model.

### 4.2. Medium range forecasting system (4-10 days)

#### 4.2.1. **Data assimilation, objective analysis and initialization**

##### 4.2.1.1. **In operation**

None

##### 4.2.1.2. **Research performed in this field**

None

## 4.2.2. Model

### 4.2.2.1. In operation

**H**igh resolution **R**egional **M**odel (HRM), model Domain:

First model domain for part of South America and METAREA V (mesh size 0.09 degrees ~ 10 km):

| | | |
|---|---|---|
| Startlon | = | -72.0 |
| endlon | = | -18.0 |
| startlat | = | -49.9 |
| endlat | = | 14.9 |
| ie | = | 601 |
| je | = | 721 |
| ke | = | 60 |
| pollon | = | -180.0 |
| pollat | = | 90.0 |
| nrbmap | = | 401 |

Second model domain for Antarctic (mesh size 0.15 degrees ~ 15 km):

| | | |
|---|---|---|
| Startlon | = | -22.5 |
| endlon | = | 22.5 |
| startlat | = | -18.75 |
| endlat | = | 18.75 |
| ie | = | 301 |
| je | = | 251 |
| ke | = | 60 |
| pollon | = | 104.0 |
| pollat | = | 157.0 |
| nrbmap | = | 409 |

**Short overview of the hydrostatic High resolution Regional Model HRM:**

**Prognostic variables**

- Surface pressure $p_s$
- Temperature $T$
- Water vapour $q_v$
- Cloud water $q_c$
- Cloud ice $q_i$
- Ozone (optional) $o_3$
- Horizontal wind $u, v$

*Several surface/soil parameters*

**Diagnostic variables**

- Vertical velocity $\omega$
- Geopotential $\phi$
- Cloud cover clc
- Diffusion coefficients tkvm/h

**Numerics of HRM**

- Regular or rotated latitude/longitude grid
- Mesh sizes between 0.25° and 0.05° (~ 28 to 6 km)
- Arakawa C-grid, second order centered differencing
- Hybrid vertical coordinates, 30 to 60 layers (Simmons and Burridge, 1981)
- Split semi-implicit time stepping (Burridge, 1975); $\Delta t$ = 150s at $\Delta$ = 0.25°
- Helmholtz equation solved by a direct method (FFT and Gauss solver)
- Lateral boundary formulation due to Davies (1976)
- Radiative upper boundary condition as an option (Herzog, 1995)
- Linear fourth-order horizontal diffusion, slope correction for temperature
- Adiabatic implicit nonlinear normal mode initialization (INMI, Temperton, 1991) or diabatic (incremental) digital filter initialization (DFI, Lynch, 1997)

**Physical parameterizations of HRM**

- $\delta$-two stream *radiation* scheme (Ritter and Geleyn, 1992) including long- and shortwave fluxes in the atmosphere and at the surface; full cloud - radiation feedback; diagnostic derivation of partial cloud cover (rel. hum. and convection)
- Grid-scale *precipitation* scheme including parameterized cloud microphysics (Doms and Schättler, 2003)
- Mass flux *convection* scheme (Tiedtke, 1989) differentiating between deep, shallow and mid-level convection or (alternatively) Bechtold (2001) convection scheme
- Level-2 scheme (Mellor and Yamada, 1974) of *vertical diffusion* in the atmosphere, similarity theory (Louis, 1979) at the surface
- *Subgrid scale orographic* (SSO) effects (blocking and wave breaking) due to unresolved orography (Lott and Miller, 1997)
- Seven-layer *soil model* including snow and interception storage (Heise and Schrodin, 2002)
- Sea ice model (*Mironov and Ritter, 2003; Mironov and Ritter, 2004*)

**Programming issues**

- Coded in Fortran95; some C subroutines for GRIB encoding/decoding
- Parallelization based on OpenMP for shared memory multi-processors and on MPI for distributed memory systems

4.2.2.2. **Research performed in this field**

None

### 4.2.3. Operationally available Numerical Weather Prediction Products

Products: All analysis products are given on the 601 x 721 grid (METAREA V) and 301 x 251 grid (Antarctic) available at every 3 hours intervals.

a) On the 60 layers
Variables: p, T, u, v, w, qv, qc, qi, qrain, qsnow, TKE

b) On 10 pressure levels (1000, 950, 850, 700, 500, ..., 200 hPa)
Variables: pmsl, Φ, T, u, v, ω, Relative. Humidity.

### 4.2.4. Operational techniques for application of NWP products (MOS, PPM, KF, Expert Systems, etc.)

#### 4.2.4.1. In operation

None

#### 4.2.4.2. Research performed in this field

We plan to implement a Model Output Calibration (MOC) which allows to downscale predicted variables as temperature, humidity based on the linear regression between the forecast error and model output variables. One feature of the scheme is the use of short training period.

We are developing a weather forecast editor based on cluster analysis that will support the meteorologists on the task of grouping geographic areas with similar weather regimes during the forecast period.

### 4.2.5. Ensemble Prediction System (EPS)

#### 4.2.5.1. In operation

None

#### 4.2.5.2. Research performed in this field

None

#### 4.2.5.3. Operationally available EPS Products

None

## 4.3. Short-range forecasting system (0-72 hours)

### 4.3.1. Data assimilation, objective analysis and initialisation

#### 4.3.1.1. In operation

None

#### 4.3.1.2. Research performed in this field

None

## 4.3.2. Model

### 4.3.2.1. In operation

Non-hydrostatic COSMO (Consortium for Small-scale Modelling), model Domain:

Model domain for part of South America and METAREA V (mesh size 0.09 degrees ~ 10 km):

| | | |
|---|---|---|
| Startlon | = | -72.0 |
| endlon | = | -18.0 |
| startlat | = | -49.9 |
| endlat | = | 14.9 |
| ie | = | 601 |
| je | = | 721 |
| ke | = | 60 |
| pollon | = | -180.0 |
| pollat | = | 90.0 |
| nrbmap | = | 401 |

**Short overview of the Non-hydrostatic COSMO model:**
***Dynamics***

- **Model Equations**: Nonhydrostatic, full compressible hydro-thermodynamical equations in advection form. Subtraction of a hydrostatic base state at rest.
- **Prognostic Variables**: Horizontal and vertical Cartesian wind components, pressure perturbation, temperature, specific humidity, cloud water content. Optionally: cloud ice content, turbulent kinetic energy, specific water content of rain, snow and graupel.
- **Diagnostic Variables**: Total air density, precipitation fluxes of rain and snow.
- **Coordinate System**: Generalized terrain-following height coordinate with rotated geographical coordinates and user defined grid stretching in the vertical. Options for (i) base-state pressure based height coordinate, (ii) Gal-Chen height coordinate and (iii) exponential height coordinate (SLEVE) according to Schär et al. (2002).

***Numerics***

- **Grid Structure**: Arakawa C-grid, Lorenz vertical grid staggering.
- **Spatial Discretization**: Second-order finite differences. For the two time-level scheme also 1st and 3rd to 6th order horizontal advection (default: 5th order). Option for explicit higher order vertical advection.
- **Time Integration**: Second-order leapfrog HE-VI (horizontally explicit, vertically implicit) time-split integration scheme by default, including extensions proposed by Skamarock and Klemp (1992). Option for a three time-level 3-d semi-implicit scheme (Thomas et al. (2000)). Several Options for two time-level 2nd and 3rd order Runge-Kutta split-explicit scheme after Wicker and Skamarock (2002) and a TVD-variant (Total Variation Diminishing) of a 3rd order Runge-Kutta split-explicit scheme.
- **Numerical Smoothing**: 4th-order linear horizontal diffusion with option for a monotonic version including an orographic limiter. Rayleigh damping in upper

layers. 2-d divergence damping and off-centering in the vertical in split time steps.

*Initial and Boundary Conditions*

- **Initial Conditions**: Interpolated initial data from various coarse-grid driving models (GME, ECMWF, COSMO-Model) or from the continuous data assimilation stream (see below). Option for user-specified idealized initial fields.
- **Lateral Boundary Conditions**: 1-way nesting by Davies-type lateral boundary formulation. Data from several coarse-grid models can be processed (GME, IFS, COSMO-Model). Option for periodic boundary conditions.
- **Top Boundary Conditions**: Options for rigid lid condition and Rayleigh damping layer.
- **Initialization**: Digital-filter initialization of unbalanced initial states (Lynch et al. (1997)) with options for adiabatic and diabatic initialization.

*Physical Parameterizations*

- **Subgrid-Scale Turbulence**: Prognostic turbulent kinetic energy closure at level 2.5 including effects from subgrid-scale condensation and from thermal circulations. Option for a diagnostic second order K-closure of hierarchy level 2 for vertical turbulent fluxes.Preliminary option for calculation of horizontal turbulent dffusion in terrain following coordinates (3D Turbulence).
- **Surface Layer Parameterization**: A Surface layer scheme (based on turbulent kinetic energy) including a laminar-turbulent roughness layer. Option for a stability-dependent draglaw formulation of momentum, heat and moisture fluxes according to similarity theory (Louis (1979)).
- **Grid-Scale Clouds and Precipitation**: Cloud water condensation and evaporation by saturation adjustment. Precipitation formation by a bulk microphysics parameterization including water vapour, cloud water, cloud ice, rain and snow with 3D transport for the precipitating phases. Option for a new bulk scheme including graupel.Option for a simpler column equilibrium scheme.
- **Subgrid-Scale Clouds**: Subgrid-scale cloudiness is interpreted by an empirical function depending on relative humidity and height. A corresponding cloud water content is also interpreted. Option for a statistical subgrid-scale cloud diagnostic for turbulence.
- **Moist Convection**: Tiedtke (1989) mass-flux convection scheme with equilibrium closure based on moisture convergence. Option for the Kain-Fritsch (Kain and Fritsch (1993)) convection scheme with non-equilibrium CAPE-type closure.
- **Shallow Convection**: Reduced Tiedtke scheme for shallow convection only.
- **Radiation**: δ-two-stream radiation scheme after Ritter and Geleyn (1992) short and longwave fluxes (employing eight spectral intervals); full cloud-radiation feedback.
- **Soil Model**: Multi-layer version of the former two-layer soil model after Jacobsen and Heise (1982) based on the direct numerical solution of the heat conduction equation. Snow and interception storage are included. Option for the (old) two-layer soil model employing the extended force-restore method still included.
- **Terrain and Surface Data**: All external parameters of the model are available at various resolutions for a pre-defined region covering Europe. For other regions or grid-spacings, the external parameter file can be

generated by a preprocessor program using high-resolution global data sets.

***Data Assimilation***

- **Basic Method**: Continuous four-dimensional data assimilation based on observation nudging (Schraff (1996), Schraff (1997)), with lateral spreading of upper-air observation increments along horizontal surfaces. Explicit balancing by a hydrostatic temperature correction for surface pressure updates, a geostrophic wind correction, and a hydrostatic upper-air pressure correction.
- **Assimilated Atmospheric Observations**: Radiosonde (wind, temperature, humidity), aircraft (wind, temperature), wind profiler (wind), and surface-level data (SYNOP, SHIP, BUOY: pressure, wind, humidity). Optionally RASS (temperature), radar VAD wind, and ground-based GPS (integrated water vapour) data. Surface-level temperature is used for the soil moisture analysis only.
- **Radar derived rain rates**: Assimilation of near surface rain rates based on latent heat nudging (Stephan et al. (2008)). It locally adjusts the three-dimensional thermodynamical field of the model in such a way that the modelled precipitation rates should resemble the observed ones.
- **Surface and Soil Fields**: Additional two-dimensional intermittent analysis:
- **Soil Moisture Analysis**: Daily adjustment of soil moisture by a variational method (Hess (2001)) in order to improve 2-m temperature forecasts; use of a Kalman-Filter-like background weighting.
- **Sea Surface Temperature Analysis**: Daily Cressman-type correction, and blending with global analysis. Use of external sea ice cover analysis.
- **Snow Depth Analysis**: 6-hourly analysis by weighted averaging of snow depth observations, and use of snowfall data and predicted snow depth.

***Code and Parallelization***

- **Code Structure**: Modular code structure using standard FORTRAN constructs.
- **Parallelization**: The parallelization is done by horizontal domain decomposition using a soft-coded gridline halo (2 lines for Leapfrog, 3 for the Runge-Kutta scheme). The Message Passing Interface software (MPI) is used for message passing on distributed memory machines.
- **Compilation of the Code**: The compilation of all programs is performed by a UNIX shell script invoking the UNIX make command. All dependencies of the routines are automatically taken into account by the script.
- **Portability**: The model can be easily ported to various platforms; current applications are on conventional scalar machines (UNIX workstations, LINUX and Windows-NT PCs), on vector computers (NEC SX series) and MPP machines (CRAY-XT3, IBM-SP series, SGI ALTIX series).
- **Model Geometry**: 3-d, 2-d and 1-d model configurations. Metrical terms can be adjusted to represent tangential Cartesian geometry with constant or zero Coriolis parameter.

### 4.3.2.2. **Research performed in this field**

None

### 4.3.3. **Operationally available NWP products**

Products: All analysis products are given on the 601 x 721 grid and available at every 3 hours intervals.

a) On the 60 layers
Variables: p, T, u, v, w, qv, qc, qi, qrain, qsnow, TKE

b) On 10 pressure levels (1000, 950, 850, 700, 500, ..., 200 hPa)
Variables: pmsl, □, T, u, v, □, Relative Humidity

c) On 6 constant height levels (500, 1000, 1500, 2000, 3000, 5000m)
Variables: p, T, u, v, w, Relative Humidity.

### 4.3.4. Operational techniques for application of NWP products

#### 4.3.4.1. In operation

None

#### 4.3.4.2. Research performed in this field

None

### 4.3.5. Ensemble Prediction System

#### 4.3.5.1. In operation

None

#### 4.3.5.2. Research performed in this field

None

#### 4.3.5.3. Operationally available EPS Products

None

## 4.4. Nowcasting and Very Short-range Forecasting Systems (0-6 hours)

### 4.4.1. Nowcasting system

#### 4.4.1.1. In operation

None

#### 4.4.1.2. Research performed in this field

None

### 4.4.2. Models for Very Short-range Forecasting Systems

#### 4.4.2.1. In operation

None

#### 4.4.2.2. Research performed in this field

None

## 4.5. Specialized numerical predictions

SEA WAVES FORESCASTING SYSTEM

CHM is responsible for operating the Brazilian Marine Meteorological Service (SMM) that issues specific weather bulletins for mariners, called METEOROMARINHA, and severe weather warnings. In order to provide wave information and elaborate the METEOMARINHA, CHM runs operationally two wave models: WAM and WAVEWATCH III™.

OCEAN FORESCASTING SYSTEM

A specific Brazilian effort on operational short-range Ocean Forecasting started in 2008 under the Oceanographic Modelling and Observation Network (REMO). REMO's member are CHM, Federal University of Bahia (UFBA), Federal University of Rio de Janeiro (UFRJ), University of São Paulo (USP) and Petrobras Research and Development Center LeopoldoAméricoMiguez de Mello (CENPES). The general goals of REMO are to research the field of physical oceanography and to develop operational ocean forecasting systems over the tropical Atlantic and the South Atlantic Ocean for a broad range of users of oceanographic information, including the off-shore petroleum industry.

### 4.5.1. Assimilation of specific data, analysis and initialization

#### 4.5.1.1. In operation

OCEAN FORESCASTING SYSTEM

An optimal interpolation scheme (OI) into HYCOM with fixed model error covariance matrix is used for the METAREA V and the S-SE domains in operational mode. The system produces synthetic data of temperature and salinity from given SSH and SST fields as in Ezer and Mellor (1997). SSH and SST are taken from the HYCOM+NCODA 1/12º global analysis. The OI analysis is done in both grids each 5 days. For the large-scale domain that covers most of the Atlantic Ocean, only the Cooper and Haines (1996) scheme is applied to constrain the model ocean SSH. In this grid, there is a relaxation scheme of SST to climatology.

### 4.5.1.2. Research performed in this field

OCEAN FORESCASTING SYSTEM

A multivariate Ensemble Optimal Interpolation (EnOI) scheme is under construction to run in all HYCOM domains.

## 4.5.2. Specific Models (as appropriate related to 4.5)

### 4.5.2.1. In operation

SEA WAVE FORESCASTING SYSTEM

WAVEWATCH III™ basin model (00 and 12 UTC) for 168 hours (100 km of horizontal resolution) over IAP (Indian, Atlantic and Pacific Oceans);
WAVEWATCH III™ regional model (00 and 12 UTC) for 120 hours (30 km of horizontal resolution) over METAREA V;
WAVEWATCH III™ regional model (00 and 12 UTC) for 120 hours (10 km of horizontal resolution) over South/SouthEast Brazilian Coast;
WAVEWATCH III™ regional model (00 and 12 UTC) for 168 hours (60 km of horizontal resolution) over Antarctica;
WAM basin model (00 and 12 UTC) for 168h (100 km of horizontal resolution) over Atlantic Ocean;
WAM regional model (00 and 12 UTC) for 78 hours (10 km of horizontal resolution) over METAREA V;
WAM regional model (00 and 12 UTC) for 78 hours (60 km of horizontal resolution) over Antarctica;

**WAVEWATCH III™**

WAVEWATCH III™ (Tolman 1997, 1999a, 2009) is a third generation wave model developed at NOAA/NCEP in the spirit of the WAM model (WAMDIG 1988, Komen et al. 1994). It is a further development of the model WAVEWATCH, as developed at Delft University of Technology (Tolman 1989, 1991a) and WAVEWATCH II, developed at NASA, Goddard Space Flight Center (e.g., Tolman 1992). WAVEWATCH III™, however, differs from its predecessors in many important points such as the governing equations, the model structure, the numerical methods and the physical parameterizations. Furthermore, with model version 3.14, WAVEWATCH III™ is evolving from a wave model into a wave modeling framework, which allows for easy development of additional physical and numerical approaches to wave modeling.

WAVEWATCH III™ solves the random phase spectral action density balance equation for wavenumber-direction spectra. The implicit assumption of this equation is that properties of medium (water depth and current) as well as the wave field itself vary on time and space scales that are much larger than the variation scales of a single wave. With version 3.14 some source term options for extremely shallow water (surf zone) have been included, as well as wetting and drying of grid points. Whereas the surf-zone physics implemented so far are still fairly rudimentary, it does imply that the wave model can now be applied to arbitrary shallow water.

IAP grid configuration:
- Limits: 80,5°S, 60,8°N, 180°W, 79,2°E

- Horizontal grid: 1° x 1° (approximately 100 km)
- Forcing: GFS and GME

METAREA V grid configuration:
- Limits: 50°S, 15°N, 72°W, 18°W
- Horizontal grid: 0.3° x 0.3° (approximately 30 km)
- Forcing: GFS and HRM

South/SouthEast Brazilian Coast grid configuration:
- Limits: 34.9°S, 18.1°S, 54.9°W, 38.1°W
- Horizontal grid: 0.1° x 0.1° (approximately 10 km)
- Forcing: GFS and HRM

Antarctica grid configuration:
- Limits: 78.7°S, 51°S, 115°W, 45°W
- Horizontal grid: 0.15° x 0.15° (approximately 15 km)
- Forcing: GME and GFS

**Wam Model**

The Wave Model (WAM) is a third generation wave forecast model, developed at Max-Planck Institute for Meteorology (Max-Planck-InstitutfürMeteorologie) in Hamburg (Germany), by K. Hasselmann and others researchers. It has been widely used by several international institutions for research and operational applications.

The model determines the evolution of the bi-dimensional ocean wave spectrum through the integration of the energy transport equation. It can be used in regional or global grids, for shallow or deep waters, with the inclusion of the refraction effect or without it. It allows the input of a topography dataset previously established. The source terms and the propagation are computed with different methods and time steps. A sub-grid can run in a nested mode, or either, the spectrum information generated by the bigger grid run is incorporated as initial and boundary conditions for the smaller one.

The following parameters can be prognosticated: significant wave height, mean wave direction and wave period.

Operationally, WAM is used on the prediction of the Atlantic Ocean, forced by the 10-meter wind from the German global model GME, of METAREA V and Antarctica, both forced by the 10-meter wind from the regional model HRM applied to these areas. The prediction of METAREA V is nested to the prediction applied to the Atlantic Ocean. Additionally, the model is set for high resolution on a near shore region on the South/Southeast of the country, nested to the METAREA V region grid.

The forecasts are generated twice daily referred to 00 and 12 GMT.

Atlantic grid configuration:
- Limits: 80,5°S, 60,8°N, 115°W, 79,2°E
- Horizontal grid: 1° x 1° (approximately 100 km)
- Forcing: GME

METAREA V grid configuration:
- Limits: 50°S, 15°N, 72°W, 18°W
- Horizontal grid: 0.3° x 0.3° (approximately 30 km)
- Forcing: GFS and HRM

South/SouthEast Brazilian Coast grid configuration:
- Limits: 34.9°S, 18.1°S, 54.9°W, 38.1°W
- Horizontal grid: 0.1° x 0.1° (approximately 10 km)
- Forcing: GFS and HRM

Antarctica grid configuration:
- Limits: 78.7°S, 51°S, 115°W, 45°W
- Horizontal grid: 0.15° x 0.15° (approximately 15 km)
- Forcing: GME

OCEAN FORESCASTING SYSTEM

The Hybrid Coordinate Ocean Model (HYCOM) version 2.2.14 has been used in the operational system hosted by CHM.

The operational system in CHM today is based on HYCOM. Three different domains are employed using a nesting strategy:

(i) a large-scale configuration with 1/4º of horizontal resolution and 21 vertical layers that covers almost the whole Atlantic Ocean, from Antarctica to 50º N and from 100º W to 20º E, except the Pacific;

(ii) an eddy resolving configuration with 1/12º of horizontal resolution and 21 vertical layers for the METAREA V; and

(iii) ameso-scale configuration with 1/24 º of horizontal resolution and 21 vertical layers for the region off the Brazilian southeast coast, from the continent to 35º W, and from 35ºS to 12ºS. Constant barotropic mass fluxes and relaxation of temperature and salinity for climatology are imposed as lateral boundary conditions for the large-scale grid.

The large-scale domain is forced by the NOAA/NCEP Global Forecast System (GFS) 0.5º atmospheric fields each 3 hour. The other domains are forced by the DeutscherWetterdienst (DWD) atmospheric model HRM with 0.1 º of horizontal resolution that runs in an operational daily basis in CHM.

#### 4.5.2.2. **Research performed in this field**

SEA WAVE FORESCASTING SYSTEM

Development of WAVEWATCH III™ two-way nesting between IAP and METAREA V grids, and between IAP and Antarctica grids.

OCEAN FORESCASTING SYSTEM

A method to include tide forcing in the 1/24º grid was developed in 2012, and is now fully operational.

#### 4.5.2.3. **Specific products operationally available**

SEA WAVES FORESCASTING SYSTEM

Only figures of the models (WAM and WAVEWATCH III™) initial condition and the forecasts are available at CHM´s web page (http://www.mar.mil.br/dhn/chm/meteo/prev/modelos/modelagem.htm), such as maps of significant wave height, direction and period.

OCEAN FORESCASTING SYSTEM

Only figures of the model initial condition and the forecasts are available at CHM´s web page (http://www.mar.mil.br/dhn/chm/meteo/prev/modelos/hycom-v.htm) and at REMO´s web page (http://www.rederemo.org) for specific fields, such as SST, SSH, surface currents and vertical sections of temperature, zonal current and meridional current at specific latitudes and longitudes

### 4.5.3. **Operational techniques for application of specialized numerical prediction products (MOS, PPM, KF, Expert Systems, etc.)**

#### 4.5.3.1. **In operation**

None

#### 4.5.3.2. **Research performed in this field**

None

### 4.5.4. **Probabilistic predictions**

#### 4.5.4.1. **In operation**

None

#### 4.5.4.2. **Research performed in this field**

None

#### 4.5.4.3. **Operationally available probabilistic prediction products**

None

## 4.6. Extended range forecasts (ERF) (10 days to 30 days)

### 4.6.1. In operation

None

### 4.6.2. Research performed in this field

None

### 4.6.3. Operationally available NWP model and EPS ERF products

None

## 4.7. Long range forecasts (LRF) (30 days up to two years)

### 4.7.1. In operation

None

### 4.7.2. Research performed in this field

None

### 4.7.3. Operationally available products

None

# 5. Verification of prognostic products

The verification process was implemented at CHM in 2009. Since then it has been performed every three months an operational calculation of standard verification scores comparing gridded model data to point-based observations using a free package called R Graphics System. R scripts has been used to consult and feed the database. All products such as graphics, tables and statistics are produced by R scripts as well. All process are executed periodically at a set time on Linux. The final products are available to the forecaster in a server or the Internet.

CHM is able to evaluate the quality of NWP models using a low-cost operational forecast verification system that uses only free and open-source software.

The graph below illustrates a type of analysis where forecasts of 4 models are evaluated.

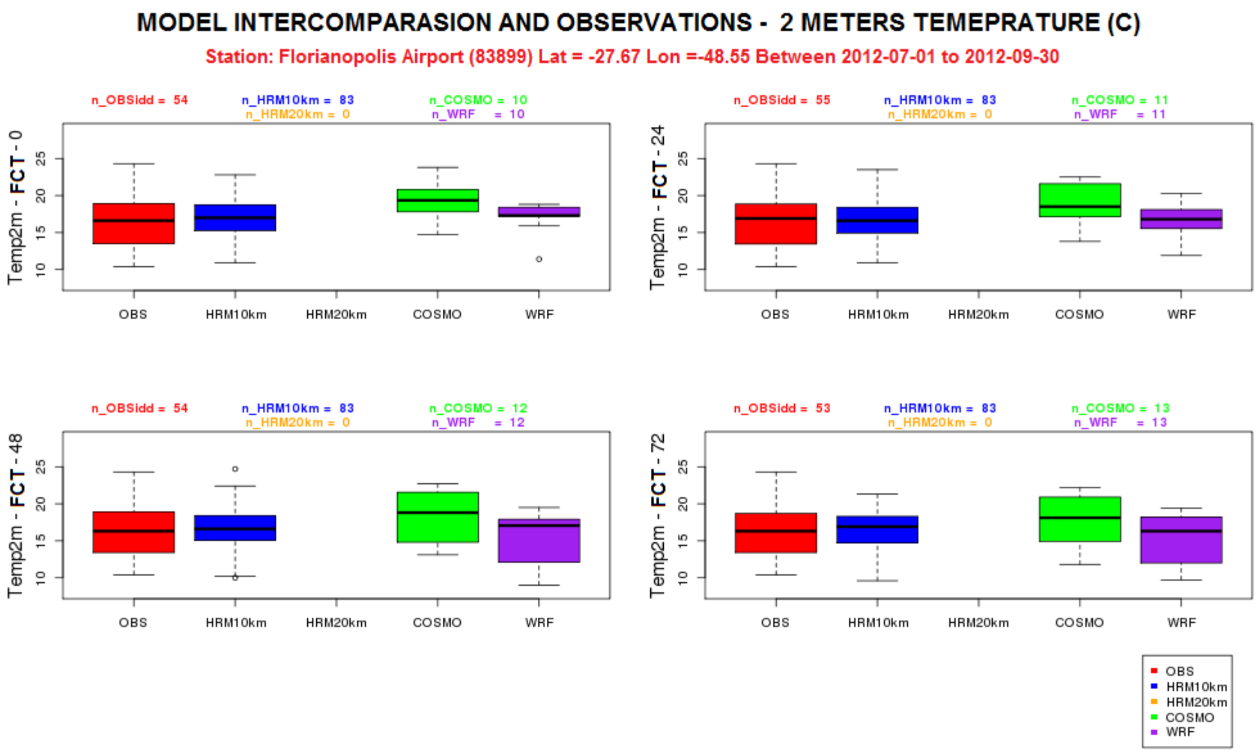


Figure 1 – Box plot - evaluating NWP from 4 different models

## 6. Plans for the future

## 6.1. Development of the GDPFS

### 6.1.1. Major changes in the Operational DPFS which are envisaged within the next year

It is planned to expand the storage capacity and processing power at 20% per year. It means that, in every 5 years, CHM will have doubled its computational base.

### 6.1.2. Major changes in the Operational DPFS which are envisaged within the next 4 years

It is expected to run atmospheric model only in distributed memory machines instead of currently utilized shared memory machines.

## 6.2. Planned research Activities in NWP, Nowcasting, Long-range Forecasting and Specialized Numerical Predictions

None

### 6.2.1. Planned Research Activities in NWP

Additionally, runthenon-hydrostaticWRF model withhorizontalresolutionof at least 10kmfor the South America and METAREA Vto 120hours of forecast(00and12UTC).

### 6.2.2. Planned Research Activities in Nowcasting

None

### 6.2.3. Planned Research Activities in Long-range Forecasting

None

### 6.2.4. Planned Research Activities in Specialized Numerical Predictions

None

### 6.2.5. Consortium

Not appropriate.

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# BRAZIL – Brazilian Air Force - Department of Air Space Control

## 1. Summary of highlights

To the Brazilian Air Force, forecast of meteorological phenomena is important due to aeronautical and airspace activities, such as air traffic management and rocket launching. In Brazil, the Department of Air Space Control (Departamento de Controle do EspaçoAéreo, DECEA) is responsible for providing information and meteorological forecasting to the aviation. Through the DECEA Ordinance 009/SDAD, of October 6th, 2008, the Working Group (WG) of Weather Numerical Modeling Program (Programa de ModelagemNumérica do Tempo, PMNT). The WG participants come from different units of Brazilian Airspace Control System (Sistema de Controle do EspaçoAéreoBrasileiro, SISCEAB); they are meteorological experts, mostly with postgraduate degree (master's and doctoral level) or possess specific knowledge in the Information Technology (IT) field. WNMP aims to provide high resolution forecasts to the heaviest flow areas of the national air navigation, which enables an increase of meteorological information detailing and weather forecast quality to SISCEAB. In 2002, the first simulations with the 5th generation of the Mesoscale Model (MM5) initiated both for operational purposes and for scientific research and development, developed jointly by Pennsylvania State University (PSU) and National Center for Atmospheric Research (NCAR). Currently, MM5 has been used by the following institutions: Institute of Aeronautics and Space (Instituto de Aeronáutica e Espaço, IAE), Airspace Control Institute (Instituto de Controle do EspaçoAéreo, ICEA) e National Center for Aeronautics Meteorology (Centro Nacional de MeteorologiaAeronáutica, CNMA). The forecasts generated by MM5 are available on the ICEA and the Brazilian Air Force Meteorological Network (Rede de Meteorologia do Comando da Aeronáutica, REDEMET) website. The high resolution numerical model, designed as PNTAR/Rio, was devised in 2007 and formalized by means of the agreement 001/CISCEA/2007. It was signed by CISCEA and UFRJ. The agreement foresaw that the university would develop a high resolution model which would be assigned to the CNMA. The purpose is to assist weather forecasters in preparing the aerodrome and area forecasting (e.g. TAF and GAMET reports) that are issued by SISCEAB meteorological centers. In 2011, the development of the Weather Research and Forecasting Model (WRF) started in ICEA. WRF is the latest generation of weather forecast numerical modeling which will support both the operational meteorological centers as for atmospheric researches. With efforts directed to the WRF development, its use has been increased. In Brazil, for example, it is used in researches in the most prestigious academic institutions as National Institute for Space Research (InstitutoNacional de PesquisasEspaciais, INPE), Federal University of Rio de Janeiro (Universidade Federal do Rio de Janeiro, UFRJ) and University of São Paulo (Universidade de São Paulo, USP).

## 2. Equipment in use

At ICEA, the main hardware requirements are: 4 (four) servers HP Proliant (DL360 G7), with 1 (one) processor Quad-core 2.4 GHz (per core), 6 (six) GB of RAM; 2 to 4 Hard Drives (HD) of 146 GB and 256 MB of cache memory. The multiprocessing system is used to run the model and enables multiple flows of simultaneous execution. The CNMA uses a system comprised of four computers to operate the model PNTAR/Rio. Each one of them contains four processing cores, defined as “processing knots”, as well as a computer that contains two processing cores, defined as “accessing knot and visualization”. The computers are networked via switch Ethernet, 1 Gbps port.

## 3. Data and Products from GTS in use

# 4. Forecasting system

## 4.1. System run schedule and forecast ranges

The ICEA utilizes the WRF and MM5 models in a non-hydrostatic mode with two-way nesting. The domains extent and horizontal resolutions to both models are similar. Currently, the real-time system generates 72 h forecast, initializing four times per day (00Z, 06Z, 12Z e 18Z). The models output are saved in three hour intervals. Prognostics are generated for four different domains, each one with a nested grid. Thus, there are two different grids for the same region of interest. The domain named NORTH is centered at 5° South latitude and 64° West longitude and it shows two grids with horizontal resolution of 36 and 12 km. The domain named NORTHEAST is centered at 8° South latitude and 38° West longitude and grids with horizontal resolution of 45 and 15 km. The SOUTHEAST centered at 23,43° South latitude and 46,47° West longitude and grids of 36 and 12 km. Finally, the domain named ALCÂNTARA focuses the region of Alcântara Launch Center (Centro de Lançamento de Alcântara, CLA) and it is centered at 02,40° South latitude and 44,44° West longitude, with two grids of horizontal resolution of 18 and 6 km. The choice of domains is related to the Brazilian Air Force project that aims at the research and development of numerical modeling for aeronautical and airspace purposes. Next, a summary of coordinates (in degrees) of each grid are given in Table 1.

Table 1 – Domain extent (in degrees) for WRF and MM5 models.

| DOMAIN | Horizontal resolution (km) | Domain extent (in degrees) |
|---|---|---|
| **NORTH** | **36** | 80 - 48ºW/21ºS - 12ºN |
| | **12** | 66 - 55ºW/09ºS - 02ºN |
| **NORTHEAST** | **45** | 56 - 20ºW/24ºS - 09ºN |
| | **15** | 39 - 30ºW/12ºS - 03ºN |
| **SOUTHEAST** | **36** | 60 - 32ºW/35 - 10ºS |
| | **12** | 49,5 - 44ºW/26.5 - 20ºS |
| **ALCÂNTARA** | **18** | 55 - 34ºW/12.5ºS - 08ºN |
| | **06** | 47.5 - 41.5ºW/5.5ºS - 0.5ºN |

The initial and boundary conditions come from the global model analysis Global Forecast System (GFS) in NCEP format. The initial and boundary conditions used in the model are in format of second version of General Regularly-distributed Information in Binary (GRIB2) code, with horizontal resolution of 0.5°; temporal resolution of 6 hours, and 64 vertical levels. The geophysical input was derived using 5', 2' and 30'' USGS terrain and land use, divided in 24 categories (USGS 24-category data). The products are available on the ICEA and REDEMET website (http://www.icea.intraer/climatologia/index.html and http://www.redemet.aer.mil.br).

The PNTAR/Rio real-time system is performed twice a day. The domain is centered approximately at the Rio de Janeiro city, whose grids (three grids) represent the terminal area in Rio. Data provided by NCEP, in GRIB2 format and a six-hour temporal resolution is used for boundary conditions. Such model corresponds to a MM5 version, adapted to operational requirements. Besides that, the CNMA produces NWP fields, which are considered relevant for air navigation, based on data from the model ETA/Ensemble40x40km, provided by the CPTEC. These products are also available on line, on the REDEMET website at http://www.redemet.aer.mil.br/cptec/prognostico.

## 4.2. Short-range forecasting system (0-72 hours)

### 4.2.1. Data assimilation, objective analysis and initialization

#### 4.2.1.1. In operation

**WRF Model**

WRF is the latest generation of weather forecast numerical modeling which will support both the atmospheric research and operational forecasting needs. It was developed in collaborative partnership among several agencies such as the National Center for Atmospheric Research (NCAR), the National Oceanic and Atmospheric Administration (NOAA), the Air Force Weather Agency (FAWA), the Naval Research Laboratory, the Federal Aviation Administration (FAA) and other agencies of research and development. Further information is available on http://www.wrf-model.org.

Most prominent model characteristics are: dynamic multiple cores, changeable system of three-dimensional data assimilation, and a software architecture allowing for parallel computation and system extensibility. It can be installed in a large number of computational platforms (e.g. Linux), it is portable, flexible, in the public domain and freely distributed. The model can be applied both for real data (observations, analyses) or idealized atmospheric conditions, in a broad range of applications across scales ranging from thousands of kilometers to a few meters.

WRF modeling system is a set of several components (for more details, see ARW V3 Modeling System User´s Guide, 2011). The principal components are: in the preprocessing, WRF Preprocessing System (WPS); WRF initialization (real); WRF operation and post-processing (ARWpost). WPS is a set of three subsystems which prepares the input data for simulation: geogrid, ungrib and metgrid. Geogrid defines the model domain and interpolates the static geographical data to the grids. Ungrib extracts the meteorological fields from GRIB (V1 and V2) format files. Metgrid horizontally interpolates the meteorological fields extracted by ungrib to the model grids defined by geogrid. The work of vertically interpolating meteorological fields to WRF eta levels is performed within the real program. WRF is responsible for implementing the model itself. Finally, ARWpost is used to convert model outputs into formats which can be viewed for graphic applications (e.g. GrADs).

The vertical resolution used is 28 levels, with pressure on atmosphere top of 50 hPa. The physical parameterizations used in the models are: WSM3 (HONG, DUDHIA; CHEN, 2004) for microphysics (explicit convection); RRTM (MLAWER ET AL., 1997) for long-wave radiation; Dudhia (DUDHIA, 1989) for short-wave radiation; MM5 similarity (PAULSON; DYER; HICKS; WEBB, 1970) for surface layer; Noah-LSM (CHEN; DUBHIA, 2001) for surface process; Yonsei University Scheme (HONG; NOH; DUDHIA, 2006); and Kain-Fritsch (KAIN; FRITSCH, 1990; 1993) for shallow and deep convection. The choice of physical parameterizations follows the default values from the installation (Tab.2).

Table 2 – Definitions adopted for initial simulations.

| Parameter or physical process | Value or parameterization | |
|---|---|---|
| microphysics (explicit convection) | WSM3 | (Hong; Dudhia; Chen, 2004) |
| long-wave radiation | RRTM | (Malawer et al., 1997) |
| short-wave radiation | Dudhia | (Dudhia, 1989) |

| Parameter or physical process | Value or parameterization |
|---|---|
| surface layer | MM5 similarity (Paulson et al., 1970) |
| surface process | Noah-LSM (Chen e Dudhia, 2001) |
| planetary boundary layer | Yonsei University (Hong; Noh; Dudhia, 2006) |
| shallow and deep convection | Kain-Fritsch (Kain; Fritsch, 1990; 1993) |

The timestep used for outermost grid (nested grid) is 180 s (60 s). For WRF it is recommended carrying out integrations with timestep equivalent to six times the grid spacing value ($\Delta$x, in km, ARW V3 *Modeling System User´s Guide*, 2011).

### 4.2.1.2. Research performed in this field

***None***

## 4.2.2. Model

### 4.2.2.1. In operation

**MM5 Model**

The 5th generation of the mesoscale model system developed jointly by Pennsylvania State University (PSU) and National Center for Atmospheric Research (NCAR) is known as MM5 (Mesoscale Model 5th Generation). First generation dates back to the 70s; however, from 1993, its applicability has been extended to finer grids (1-5 km), eliminating the hydrostatic approach. Since then, MM5 has been extensively used for both research and operational purposes. MM5 web site is http://box.mmm.ucar.edu/mm5.

MM5 has the following general characteristics: it is freely distributed; it is portable (the system has been installed on multiple platforms under Unix and Linux operating systems), with a sigma coordinated vertical system and its B grid from Arakawa-Lamb it can run in high resolutions; it allows grid nesting and four-dimensional data assimilation. It also has different parameterization schemes of physical processes available (7 options for deep convection, 6 for cloud microphysics, 4 for radiation, 7 for planetary boundary layer and 3 for surface).

The model is supported by a series of pre and post-processing programs, which together are referred to as MM5 modeling system. These modules are divided according to their specificities and were developed to facilitate the data preparation for simulations to be performed with MM5, and during result post-processing (for more details see Dudhia et al., 2002). During pre-processing, the function of module TERRAIN is to interpolate horizontally information of topography and terrain usage to the module grid; the function of module REGRID is to interpolate horizontally the analysis and forecast to the grid, and the function of module INTERPF is to interpolate vertically the pressure coordinates for sigma and fields of initial and boundary conditions. When running, the module generates outputs which are converted into GrADS format during post-processing (MM5toGrADS).

The vertical resolution used is 23 levels, with pressure on atmosphere top of 100 hPa. The physical parameterizations used in the models are: “simple ice” (DUDHIA, 1989) for microphysics (explicit convection); cloud radiation scheme for radiation; MRF-PBL (Hong e Pan, 1996) for planetary boundary layer; multi layer for surface process; Grell (Grell, 1995) for deep convection (implicit convection). The timestep used is 90s, except ALCANTARA grid that uses 45s. The choice of physical parameterizations follows the default values from the installation version (Tab.3).

Table 3– Physical parameterizations used in MM5 simulations

| Physical process | Parameterization |
|---|---|
| deep convection | GRELL (Grell, 1995) |

| Physical process | Parameterization |
|---|---|
| microphysics (explicit convection) | “simple ice” (DUDHIA, 1989) |
| land-surface | Multi layer (CHEN; DUDHIA, 2001) |
| Boundary layer | MRF PBL (HONG-PAN, 1996) |
| radiation: | Cloud radiation (MLAWER ET AL., 1997) |

**PNTAR - Rio System**

The PNTAR/Rio system was devised by the Federal University of Rio de Janeiro and made operational at CNMA. Its main objective is to provide specific PNT products for aviation. It is an updated version of the MM5 system, adapted to operational requirements. The PNTAR system was implemented in a computing environment, compatible with the operational needs required and based on the application of a mesoscale of numerical model and using a two-way nested configuration. The domain is centered approximately over Rio de Janeiro city. The SST data used are obtained from NOAA and have a horizontal resolution (temporal) of 1º (7 days). All three grids share these resolutions: 20 km, 07 km e 02 km. The physical parameterizations used in the model are shown in Table 4.

Table 4– Physical parameterizations used in PNTAR / Rio system simulations

| Physical process | Parameterization |
|---|---|
| deep convection | Betts-Miller (BETTS-MILLER, 1993) |
| microphysics (explicit convection) | Schultz (Schultz, 1989) |
| land-surface | Noah Land |
| Boundary layer | MRF PBL (HONG-PAN, 1996) |
| Cumulus rasos | Shalow Cumulus |
| radiation: | CCM2 |

### 4.2.2.2. Research performed in this field

None

## 4.2.3. **Operationally available NWP products**

**Weather Numerical Forecast Products**

```
LU_INDEX       1  0  LAND USE CATEGORY (-)
U             19  0  x-wind component (m s-1)
V             19  0  y-wind component (m s-1)
W             19  0  z-wind component (m s-1)
PH            19  0  perturbation geopotential (m2 s-2)
PHB           19  0  base-state geopotential (m2 s-2)
T             19  0  perturbation potential temperature (theta-t0) (K)
MU             1  0  perturbation dry air mass in column (Pa)
MUB            1  0  base state dry air mass in column (Pa)
NEST_POS       1  0  - (-)
P             19  0  perturbation pressure (Pa)
PB            19  0  BASE STATE PRESSURE (Pa)
P_HYD         19  0  hydrostatic pressure (Pa)
Q2             1  0  QV at 2 M (kg kg-1)
T2             1  0  TEMP at 2 M (K)
TH2            1  0  POT TEMP at 2 M (K)
PSFC           1  0  SFC PRESSURE (Pa)
U10            1  0  U at 10 M (m s-1)
```

| | | | |
|---|---|---|---|
| V10 | 1 | 0 | V at 10 M (m s-1) |
| QVAPOR | 19 | 0 | Water vapor mixing ratio (kg kg-1) |
| QCLOUD | 19 | 0 | Cloud water mixing ratio (kg kg-1) |
| QRAIN | 19 | 0 | Rain water mixing ratio (kg kg-1) |
| LANDMASK | 1 | 0 | LAND MASK (1 FOR LAND, 0 FOR WATER) (-) |
| TSLB | 4 | 0 | SOIL TEMPERATURE (K) |
| SMOIS | 4 | 0 | SOIL MOISTURE (m3 m-3) |
| SH2O | 4 | 0 | SOIL LIQUID WATER (m3 m-3) |
| SMCREL | 4 | 0 | RELATIVE SOIL MOISTURE (-) |
| SEAICE | 1 | 0 | SEA ICE FLAG (-) |
| XICEM | 1 | 0 | SEA ICE FLAG (PREVIOUS STEP) (-) |
| SFROFF | 1 | 0 | SURFACE RUNOFF (mm) |
| UDROFF | 1 | 0 | UNDERGROUND RUNOFF (mm) |
| IVGTYP | 1 | 0 | DOMINANT VEGETATION CATEGORY (-) |
| ISLTYP | 1 | 0 | DOMINANT SOIL CATEGORY (-) |
| VEGFRA | 1 | 0 | VEGETATION FRACTION (-) |
| GRDFLX | 1 | 0 | GROUND HEAT FLUX (W m-2) |
| ACGRDFLX | 1 | 0 | ACCUMULATED GROUND HEAT FLUX (J m-2) |
| SNOW | 1 | 0 | SNOW WATER EQUIVALENT (kg m-2) |
| SNOWH | 1 | 0 | PHYSICAL SNOW DEPTH (m) |
| CANWAT | 1 | 0 | CANOPY WATER (kg m-2) |
| SST | 1 | 0 | SEA SURFACE TEMPERATURE (K) |
| SSTSK | 1 | 0 | SKIN SEA SURFACE TEMPERATURE (K) |
| LAI | 1 | 0 | Leaf area index (area/area) |
| MAPFAC_M | 1 | 0 | Map scale factor on mass grid (-) |
| MAPFAC_MX | 1 | 0 | Map scale factor on mass grid, x direction (-) |
| MAPFAC_MY | 1 | 0 | Map scale factor on mass grid, y direction (-) |
| MF_VX_INV | 1 | 0 | Inverse map scale factor on v-grid, x direction (-) |
| F | 1 | 0 | Coriolis sine latitude term (s-1) |
| E | 1 | 0 | Coriolis cosine latitude term (s-1) |
| SINALPHA | 1 | 0 | Local sine of map rotation (-) |
| COSALPHA | 1 | 0 | Local cosine of map rotation (-) |
| HGT | 1 | 0 | Terrain Height (m) |
| TSK | 1 | 0 | SURFACE SKIN TEMPERATURE (K) |
| RAINC | 1 | 0 | ACCUMULATED TOTAL CUMULUS PRECIPITATION (mm) |
| RAINNC | 1 | 0 | ACCUMULATED TOTAL GRID SCALE PRECIPITATION (mm) |
| SNOWNC | 1 | 0 | ACCUMULATED TOTAL GRID SCALE SNOW AND ICE (mm) |
| GRAUPELNC | 1 | 0 | ACCUMULATED TOTAL GRID SCALE GRAUPEL (mm) |
| HAILNC | 1 | 0 | ACCUMULATED TOTAL GRID SCALE HAIL (mm) |
| CLDFRA | 19 | 0 | CLOUD FRACTION (-) |
| SWDOWN | 1 | 0 | DOWNWARD SHORT WAVE FLUX AT GROUND SURFACE (W m-2) |
| GLW | 1 | 0 | DOWNWARD LONG WAVE FLUX AT GROUND SURFACE (W m-2) |
| OLR | 1 | 0 | TOA OUTGOING LONG WAVE (W m-2) |
| XLAT | 1 | 0 | LATITUDE, SOUTH IS NEGATIVE (degree_north) |
| XLONG | 1 | 0 | LONGITUDE, WEST IS NEGATIVE (degree_east) |
| ALBEDO | 1 | 0 | ALBEDO (-) |
| ALBBCK | 1 | 0 | BACKGROUND ALBEDO (-) |
| EMISS | 1 | 0 | SURFACE EMISSIVITY (-) |
| NOAHRES | 1 | 0 | RESIDUAL OF THE NOAH SURFACE ENERGY BUDGET (W m{-2}) |
| TMN | 1 | 0 | SOIL TEMPERATURE AT LOWER BOUNDARY (K) |
| XLAND | 1 | 0 | LAND MASK (1 FOR LAND, 2 FOR WATER) (-) |
| UST | 1 | 0 | U* IN SIMILARITY THEORY (m s-1) |
| PBLH | 1 | 0 | PBL HEIGHT (m) |
| HFX | 1 | 0 | UPWARD HEAT FLUX AT THE SURFACE (W m-2) |
| QFX | 1 | 0 | UPWARD MOISTURE FLUX AT THE SURFACE (kg m-2 s-1) |
| LH | 1 | 0 | LATENT HEAT FLUX AT THE SURFACE (W m-2) |
| ACHFX | 1 | 0 | ACCUMULATED UPWARD HEAT FLUX AT THE SURFACE (J m-2) |
| ACLHF | 1 | 0 | ACCUMULATED UPWARD LATENT HEAT FLUX AT SURFACE (J m-2) |
| SNOWC | 1 | 0 | FLAG INDICATING SNOW COVERAGE (1 FOR SNOW COVER) (-) |
| SR | 1 | 0 | fraction of frozen precipitation (-) |
| POTEVP | 1 | 0 | accumulated potential evaporation (W m-2) |
| SNOPCX | 1 | 0 | snow phase change heat flux (W m-2) |
| SOILTB | 1 | 0 | bottom soil temperature (K) |

```
pressure      19  0  Model pressure (hPa)
geopt         19  0  Geopotential (m2/s2)
height        19  0  Model height (km)
tc            19  0  Temperature (C)
theta         19  0  Potential Temperature (K)
td2            1  0  Dewpoint Temperature at 2m (C)
rh            19  0  Relative Humidity (%)
clflo          1  0  Low Cloud Fraction (%)
clfmi          1  0  Mid Cloud Fraction (%)
clfhi          1  0  High Cloud Fraction (%)
rh2            1  0  Relative Humidity at 2m (%)
wspd          19  0  Wind Speed (m s-1)
wdir          19  0  Wind Direction (Degrees)
ws10           1  0  Wind Speed at 10 M (m s-1)
wd10           1  0  Wind Direction at 10 M (Degrees)
umet         19  0  Rotated wind component (m s-1)
vmet          19  0  Rotated wind component (m s-1)
u10m           1  0  Rotated wind component (m s-1)
v10m           1  0  Rotated wind component (m s-1)
slp            1  0  Sea Levelp Pressure (hPa)
cape          19  0  CAPE (J/kg)
cin           19  0  CIN (J/kg)
mcin           1  0  MCIN (J/kg)
lcl            1  0  LCL (meters AGL)
lfc            1  0  LFC (meters AGL)
```

## 5. Verification of prognostic products

ICEA has used the following observational data sets for the evaluation of its regional models:

1. NCEP/NCAR reanalysis;
2. Daily total of GPCP precipitation for precipitation anomalies;
3. OLR data sets from NOAA; and
4. Observational data of wind, clouds, temperature, humidity, pressure and precipitation from ICEA Climatological database.

Measurements of model skill used at ICEA include (WILKS, 1995):

a) Anomaly correlation;
b) Bias score;
c) Root Mean Square Error (RMSE);
d) Willmott Index; and
e) Accuracy and performance measures (Hit rate, False alarm rate, Probability of detection, Heidke, Kuipers e Gilbert, etc).

## 6. Plans for the future (next 4 years)

- New products of numerical modeling: The generation of new products specifically for aviation is under consideration, such as clear air turbulence (CAT), aircraft icing and fog occurrence.
- Data assimilation in WRF model: Evaluation of data assimilation process in WRF model using observational and meteorological radar data.
- Model Evaluation: comparing model outputs with observational databases from ICEA.

- Cycle of rapid assimilation in weather numerical modeling, aiming to provide outputs with higher temporal frequency.

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