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

1. Summary of highlights

In 2014, a test stage for AMDAR (Aircraft Meteorological DAta Relay) was initiated in cooperation with LATAM Airlines, including basic software on board. In December 2015, the new system started to systematically send messages at the sampling interval set by WMO. Format quality control was performed by SMN. Since July 2016, messages have been transmitted in real time (BUFR code) to the WMO Global Telecommunications System with IUAG header (Figure 1). They are currently being tested in several data assimilation systems at global centers.

The Regional Specialized Meteorological Center Buenos Aires (RSMC BUENOS AIRES) has been producing forecasts based on the numerical model ETA SMN since January 2003 with various changes along the years. A non-hydrostatic version is operational since January 2006 with changes in domain since then. All models run for the 00 and 12 UTC cycles. A full output is available for the NMC associated to the RSMC.

Austral-WWIII is the SHN/SMN operational implementation of the NOAA / NCEP WAVEWATCH III® 3.14 multiscale wave model, result of a joint effort with the Naval Hydrographic Service. It is a global multigrid mosaic aimed to provide numerical wave forecasts for the Southern Oceans and South Atlantic, driven by the NCEP GFS forecasts. A storm surge model is driven by the resulting total surface stress.

A lagrangian dispersion model (HYSPLIT) is operational for volcanic ash hazards since 2009 as well as the eulerian FALL3D model.

The computing capacity has increased significantly with the installation of a new cluster. The WRF-ARW model is executed in a pre-operational phase with a horizontal resolution of 4 km, in a domain that covers the whole country. Four simulations are carried out daily for a forecast range 48 hours.

In the area of research, progress has been made in the development of a data assimilation system with the LETKF methodology. Different techniques of nowcasting are also being developed from the use of information from remote sensors.

2. Equipment in use

Function	Computer	CPUs/ Processor	Memory	Disk Storage
Oracle Data base and quality control system	HP Proliant ML350G4 Server	2 Intel Xeon 3.4 GHZ, 1mb cache	DDR ECC 2GB	

ETA SMN model Nested ETA model	SG ALTIX 3700	32 CPUS GenuineIntel IA-64, Itanium 2 1500MHz	134GB	600GB
WRF-ARW (parallel)	CPUs: 720 cores (HT), 15 hosts, Infiniband FDR 56GbE	Intel(R) Xeon(R) CPU E5-2680 v3 @ 2.50GHz	944GB	55TB NAS + 5TB front end
ARPE Model (legacy)	SG* O^2	1 R10000 175MHz	128MB	36 GB system disk External 2 x 9 GB SCSI disk
Hysplit model FALL3D model	SG* ORIGIN 2004 (BACKUP for ETA models)	4 R10000 500 MHz 8 R10000 250 MHz 4 R10000 300 MHz	3338MB	9 GB system disk 36 GB External SCSI disk
Uruguay River Monitoring Program (WRF-ARW forecast)	2 (two) HP cluster composed by 5 nodes	4 (four) Intel Xeon E5620 (four cores per processor) And 1 (one) Intel XEON X3220 4 (four) Intel XEON e5405 (four cores per processor)	36GB	2 x 450GB 2 x 300GB 2 x 1TB

3. Data and Products from GTS in use

Data received, sent and used operationally include: SYNOP, SYNOP BUFR, TEMP, SATOB, SATEM, BUOY, AIREP, AMDAR, AMDAR BUFR, METAR, SHIP, SIGMET, TAF, PRONAREA. Data is stored after consistency checks.

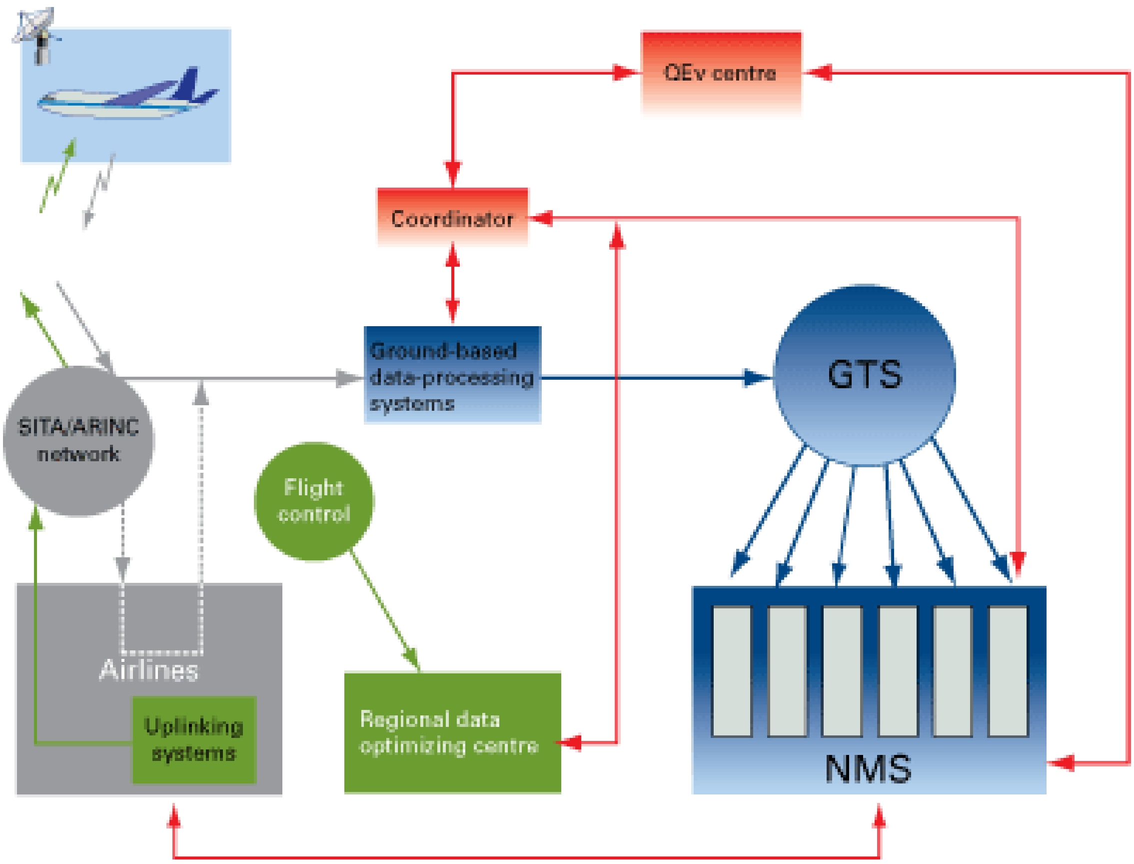

Figure 1. The new AMDAR data flow

4. Forecasting system

4.1 System run schedule and forecast ranges

The regional ETA model is initialized with the analysis fields from the GFS model (NCEP). Boundary conditions are updated every six hours and are taken from the GFS model from the same cycle. The 00 (12) UTC cycle starts its integration at 01 (13) UTC approximately and performs a 168 (132) hours forecast in 25min. Graphic outputs are generated simultaneously.

The nested high resolution and non hydrostatic ETA model starts its integration after the parent model. It performs at 48 hours forecast in 1 hour and 30 minutes.

Enriched real time 3 hour analysis are produced for MSLP based on ETA model forecasts and consistent observed data (Synop, Buoy, and SATOB).

A full analysis/forecast cycle of the legacy primitive equation model (ARPE) is run for the 00 and 12 UTC cycles (at 3 UTC and 15 UTC). The forecast range is 36 hours and the run time is 15 minutes. This model is used for analysis charts only.

The pre-operational system based on WRF-ARW model 48-hour forecasts run for 00 UTC, 06 UTC, 12 UTC and 18 UTC from NCEP/GFS analyses and forecasts. At its current horizontal resolution of 4 km, the forecast performs in 3 hours for the whole country (continental) domain.

4.2 Medium range forecasting system (4-10 days)

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

4.2.1.1 In operation

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4.2.1.2 Research performed in this field

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4.2.2 Model

4.2.2.1 In operation

<u>ETA SMN model</u>

The development of this model began in 1972 by Fedor Mesinger and Zaviša Janjic at the University of Belgrade and the Federal Hydrometeorological Institute of Yugoslavia. Major developments and improvements have been done at the National Centers of Environmental Prediction (NCEP), and since 2005, at CPTEC.

Equations: Primitive hydrostatic equations
Grid: Arakawa E-grid in horizontal, Philips grid in the vertical.
Resolution: 25km on the horizontal and 38 layers on the vertical.
Solution technique: Split-explicit time differencing, Arakawa-type in space.
Coordinate system: rotated spherical coordinates in horizontal; eta (step mountain) coordinate in vertical.
Physical processes: surface fluxes over land and water; land surface schemes; multilayer soil/vegetation/snow-pack land surface model; subgrid mixing; cumulus parameterizations; radiation parameterization; grid scale precipitation parameterization.
Data used: GFS model obtained at the NCEP ftp server. Data boundaries are updated every 6 hours. Sea surface temperature, ice/snow coverage and snow depth information is updated daily and are included in the ETA SMN model initial conditions.
Forecast range: 168 hours

4.2.2.2 Research performed in this field

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4.2.3 Operationally available Numerical Weather Prediction Products

<u>ETA SMN model</u>

Analyses and 3 hour forecasts of mean sea level pressure and 1000/500hPa thickness; 2-m temperature and humidity; 10m winds; 850hPa geopotential and dew point; 500hPa geopotential and temperature; 250hPa geopotential and wind speed; tropopause height in flight level references; freezing level in flight level heights; low, medium, high and total cloud

coverage; 24 hour accumulated precipitation fields (convective and large scale); meteograms for selected cities (approximately 100); clear air turbulence forecast of selected flight levels; fog; frost potential, are available on the Intranet network. Horizontal and vertical interpolations are made to obtain analyzed horizontal wind components and temperature fields every two degrees of latitude and longitude and forecasted fields every six hours at the seven flight levels used in our region are updated twice a day. Some selected fields and meteograms are available in the Internet as well. Forecasts are updated every 12 hours.
A complete set of variables every 3 hours and accumulated ones up to 168 hours of forecast are available for the forecast office of the National Meteorological Service through a web server Apache 2.2.3/PHP 5.2.0. Mean fields at all levels are obtained, analyzed on monthly and quarterly basis.

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

4.2.4.1 In operation

Analogs technique has been applied to GEFS model output using its retrospective forecasts database Version 1 (V1) (Hamill, 2006) for generating daily precipitation forecasts (Aldeco, 2011). The reforecast system Version 2 (V2) was built with the GFS-NCEP version that was operational in 2012. This version runs with resolution of 1° and provides up to 15-days forecasts from 1984 to present (Hamill et al, 2013). It was proved that the improve in resolution from V1 to V2 reforecast database resulted in an improve of the forecasts skill (Aldeco et al, 2015). Using the V2 reforecast database the technique has been applied to surface stations which are part of the National Meteorological Service precipitation data set. Part of the results are the operational generation of:

- Daily precipitation probabilistic forecast up to 14 days for different thresholds (operational since July 2012)
- Weekly forecast and weekly anomalies of accumulated precipitation for days 1 to 7 (week one) and for days 8 to 14 (week two). (Operational since February 2016).

4.2.4.2 Research performed in this field

2-m temperature from the same retrospective forecasts database will be used to generate:

- Daily temperature probabilistic forecast up to 14 days for different thresholds.
- Weekly forecast and weekly anomalies of mean temperature for days 1 to 7 (week one) and for days 8 to 14 (week two).

4.2.5 Ensemble Prediction System (EPS)

4.2.5.1 In operation

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4.2.5.2 Research performed in this field

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4.2.5.3 Operationally available EPS Products

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4.3 Short-range forecasting system (0-72 hrs)

4.3.1 Data assimilation, objective analysis and initialization

4.3.1.1 In operation

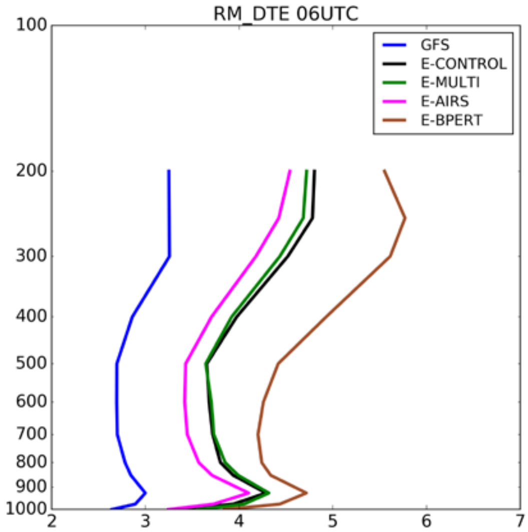
Objective analysis (legacy): Cressman successive correction method. The analyzed variables are geopotential heights, temperature, humidity and wind components for ten pressure levels (1000, 850, 700, 500, 400, 300, 250, 200, 150 and 100 hPa); temperature, pressure and humidity at surface and tropopause pressure level.
Data assimilation: performed every twelve hours. The first guess field is generally the twelve hours one predicted by the ARPE model in the previous run and in case of model divergence, the climatological field for that month.
Data used: SYNOP, TEMP, BUOYS, SATEM, SATOB and GRID (global model)

Enriched 3-hour fields with Barnes method are produced for mean sea level pressure, while standard levels analysis fields are produced experimentally with Barnes analysis method and ETA SMN model forecasts as initial field.

4.3.1.2 Research performed in this field

Many efforts have been carried out to reduce the uncertainty in the initial conditions. The regional Local Ensemble Transform Kalman Filter coupled with the Weather Research and Forecasting model (LETKF-WRF) system implemented at the SMN is evaluated during a two month period (November-December 2012). The domain covers most of Southern South America with an horizontal resolution of 40 km. A 40 member ensemble is used to assimilate conventional and satellite observations (Dillon et al., 2016, Dillon, 2017). A verification of 6, 24 and 48-hour ensemble forecasts initialized from the LETKF-WRF system is carried out for the experiments described below.

Two different ensemble generation strategies are evaluated: a single model ensemble and a multi physics ensemble that includes different choices for the cumulus and planetary boundary layer parameterizations. This experiment shows that, overall, the multi physics approach produce better results. The inclusion of boundary perturbations has also been explored although, it does not produce a significant impact in the current experimental settings. Finally we explore the sensitivity to the assimilation of the Atmospheric Infrared Sounder (AIRS) temperature and moisture retrievals. The results indicate that the inclusion of these retrievals is a valuable alternative to deal with the scarcity of radiosondes observations in Southern South America (Dillon et al, 2017). The intense precipitation event of 6th December 2012 has been selected to evaluate the impact in the numerical forecasts of using different initial conditions.



E-CONTROL: Control run

E-MULTI: A multi-scheme configuration is used in order to better represent the ensemble spread. Cumulus and PBL parameterizations are combined.

E-AIRS: same configuration of E-CONTROL assimilating also the vertical profiles of temperature and humidity from AIRS, using a thinning technique.

E-BPERT: The same configuration of E-CONTROL but including perturbed B.C., which are generated with a similar technique of that applied to I.C., using consecutive dates for each ensemble member.

$$DTE = 0.5(u'^2 + v'^2 + \frac{C_{pd}}{T_{ref}} T'^2) \qquad RM_{DTE} = \sqrt{\frac{1}{N}\sum DTE}$$

Figure 2. Root mean square difference of energy for different experiments and compare to GFS, 6-hour forecasts (ref: ERA-I)

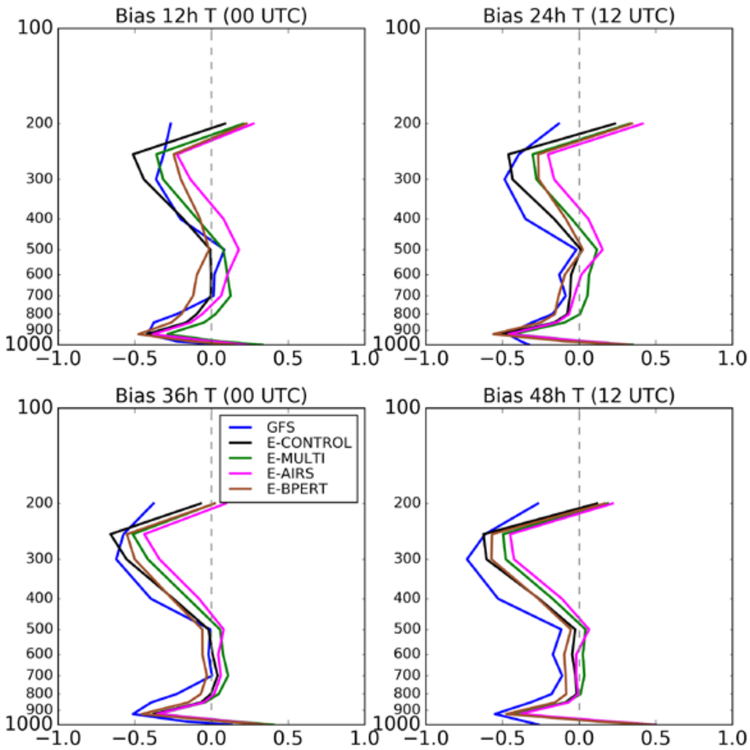


Figure 3. Bias for 12, 24, 36 and 48 hours temperature forecasts initialized at 12 UTC (ref: ERA-I)

4.3.2 Model

4.3.2.1 In operation

Nested ETA SMN model
A 48 hours forecast is performed on every run. Domain is shown in Figure 4
Equations: Primitive non-hydrostatic equations.
Resolution: 10km on the horizontal and 38 layers on the vertical.
Data used: Forecast from the ETA SMN model from the same cycle. Data boundaries are updated every 3 hours. Sea surface temperature, ice/snow coverage and snow depth information is updated daily and are included in the ETA SMN model initial conditions.
Forecast range: 48 hours

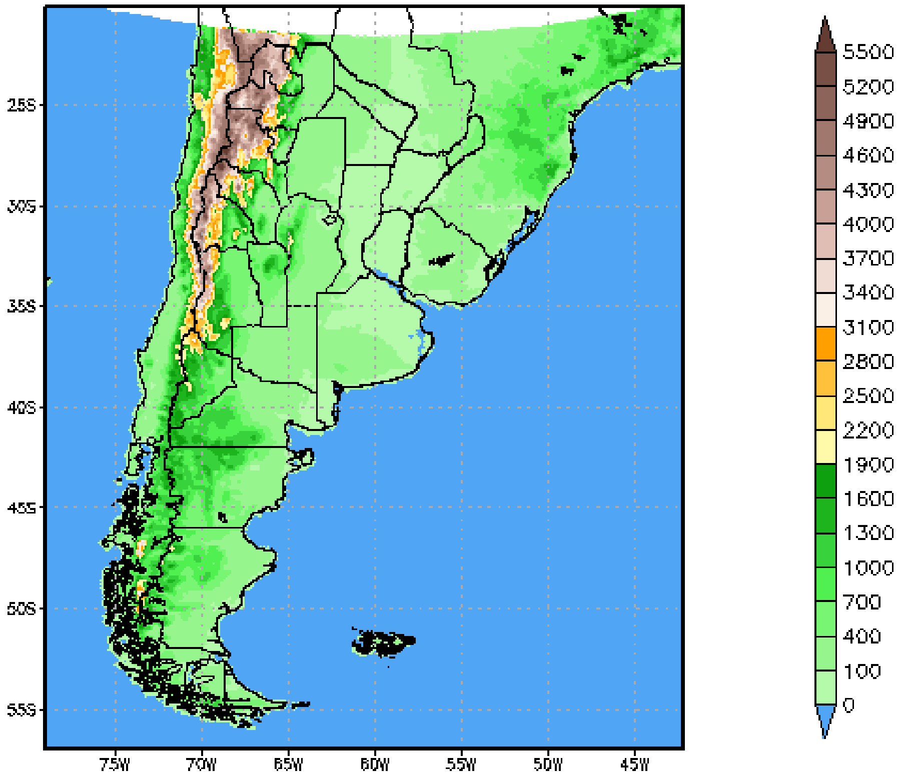


Figure 4. Nested ETA High resolution domain

4.3.2.2 Research performed in this field

Heavy rainfall and other severe phenomena related to deep convection and their forecast is a major problem in different geographical regions. Subtropical South America is particularly affected by large and intense mesoscale convective systems (MCSs) within which severe events develop specially during the warm season. Research in this area is focused on design and implement a high resolution forecast in order to progress in the forecast of these intense events.

Numerical forecasts of different cases studies were performed using WRF-ARW reaching a horizontal resolution of around 4km. Model forecast performance was evaluated against measurements from weather radar, rainfall estimates from satellite and surface observations available in the region. The sensitivity to different initial conditions, horizontal and vertical resolution and settings on cloud microphysics scheme are addressed and discussed in order to maximize the WRF-ARW forecast potential for particular cases. An evaluation of a period was shown by Matsudo et al., 2015.

WRF-ARW model (Skamarock et al., 2008) 48-hr forecasts were initialized twice a day (at 00 and 1200 UTC) at the NMS-Argentina from December 2012 to December 2016, for central Northeast of Argentina. Since January 2017, four forecasts cycles are performed (00,06,12,and 18UTC) for the whole country. For both cases, the main features include 4 km grid spacing, 38 vertical sigma-p levels, 1-hour temporal resolution and convection explicitly resolved. Model parameterizations includes Mellor, Yamada, Janjic (MYJ) planetary boundary layer (PBL) scheme (Hong et al., 2006) and the WRF single- moment (WSM), particularly, the WSM6 microphysics scheme (Hong and Lim, 2006) while surface processes are modeled using the 4-layer NOAH LSM (Chen and Dudhia, 2001). WSM6 microphysics scheme is appropriate for examining heavy rainfall events by including graupel as another prognostic variable in addition to rain and snow. Regarding the soil model, the NOAH scheme is a four-layer model that forecasts soil moisture and temperature which includes a time-varying green vegetation fraction, soil type and snow cover with up to two vertical layers. Similar configurations, as the one chosen from this experiments, are widely used in different institutions around the globe running the WRF model in a real-time basis. As an example, the WRF model with a similar configuration provided useful information on high-resolution weather phenomena over U.S. (Schwartz et al., 2010).

4.3.3 Operationally available NWP products

Analysis and 3 hour forecasts of mean sea level pressure and 1000/500hPa thickness; 2m temperature and humidity; 10m winds; 850hPa geopotential and dew point; convective and total cloud coverage; 36 hour accumulated precipitation fields (rain and snow); fog; frost potential; CAPE-convection inhibition; SWEAT Index; TOTAL_TOTAL Index, are available on the Intranet network.

Forecasts are updated every 12 hours.

A complete set of that variables are available for the forecast office of the National Meteorological Service through a web server Apache 2.2.3/PHP 5.2.0.

4.3.4 Operational techniques for application of NWP products

4.3.4.1 In operation

(MOS, PPM, KF, Expert Systems, etc..)

Calibrated extreme temperatures are produced for 12 and 00 UTC cycles of GFS model forecasts for the following 4 days.

Calibrated extreme temperatures are produced for 00 UTC cycle of Ensemble GFS model forecasts for the following 7 days. Calibration is applied to the mean maximum and minimum forecast temperatures and expanded later to all ensemble members

Correction of maximum and minimum temperatures based on the 12 UTC cycle from the ETA SMN model valid for the following day is performed on selected locations. The information of the previous years of the model performance is used to correct the actual forecast values by a constant or linear/quadratic equation. Equations are updated on monthly basis

Model forecast is used along with Normal Statistics of long time series of observed data for extreme weather forecast guidance of maximum/minimum temperature, daily precipitation and wind in Argentina.

4.3.4.2 Research performed in this field

An adaptative regression based on a Kalman Filter approach is being tested to correct maximum and minimum temperatures based on the 00 UTC cycle from GFS model valid for the day. Satisfactory results were reached. Figure 4 shows the root mean square error for maximum and minimum temperatures considering the observations in the whole country during a year.

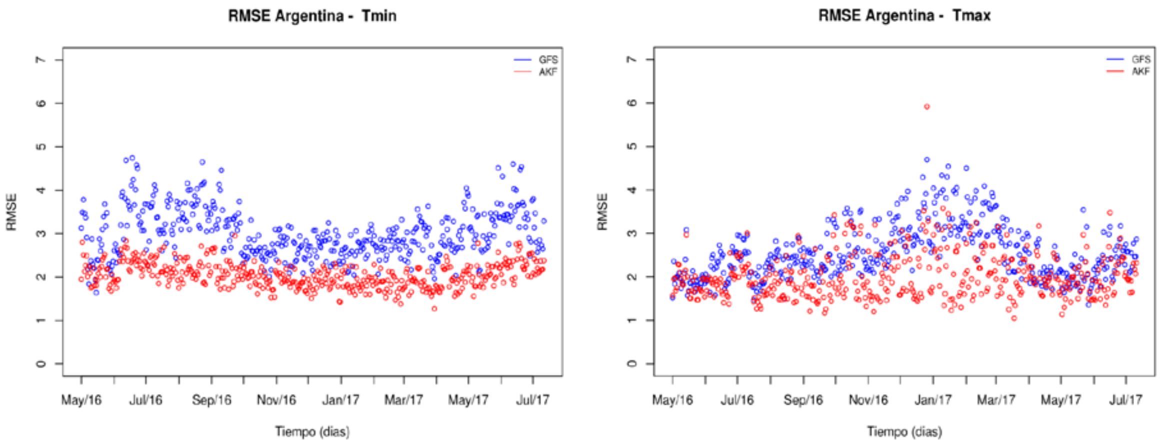


Figure 5. Root mean square error GFS (blue), Corrected (red) for minimum temperature (left) and maximum temperature (right).

4.3.5 Ensemble Prediction System

4.3.5.1 In operation

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4.3.5.2 Research performed in this field

In order to address the uncertainty associated with high resolution, ensemble forecast experiments were performed for central Northeast of Argentina. Given the fact that forecast uncertainty is highly dependent on the meteorological situation and model configuration it is important to implement methods to estimate it. Based on the experience and results derived from the deterministic scheme, the 4-km resolution WRF model is used to develop the ensemble system. Different Ensemble Prediction System (EPS) versions are explored considering different physical parameterization schemes with focus on evaluating microphysics and planetary boundary layer options up to 48h lead time using GFS ensemble data as initial and boundary conditions.

A preliminary evaluation of the EPS system is conducted using a case study from the 2015--2016 warm season in which HIWEs have been reported. The EPS skill and performance are evaluated against surface conventional observations and remote sensing information.

4.3.5.3 Operationally available EPS Products

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4.4 Nowcasting and Very Short-range Forecasting Systems (0-12 hrs)

4.4.1 Nowcasting system

4.4.1.1 In operation

Very short-range forecasts are based on direct observation of operational weather radar products, satellite imagery, and lightning information. No specific numerical models running at this temporal scale or automated algorithms are used.

The process consists of a first general diagnosis based on GOES satellite information (especially, water vapor imagery). When storms begin to develop, the information provided by the weather radar network is analyzed. These data are supplemented with satellite information, in order to identify severe weather signatures (i.e., overshooting tops, enhanced-V), and lightning data (i.e., jumps detection in the flash rate associated to the storm cell). A subjective extrapolation of stormy areas is applied by the forecaster with the aim of producing a very short warning lasting 3 hours.

In order to gain further information about the weather activity related to the detected storms, forecasters make use of information published on social networks (Twitter) and focus on the Tweetdeck Tool (by applying a series of filters based on keywords such as hail or flood). Real-time data collected by automatic meteorological stations belonging to other institutions are also analyzed.

4.4.1.2 Research performed in this field

Satellite cloud tracking and forecast:
Forecasts and Tracking the evolution of Cloud Clusters (FORTRACC) technique was implemented in an experimental phase as a result of a collaboration with CPTEC, INPE (Brazil). FORTRACC identifies a convective cloud delimiting an area associated with deep convection using IR geostationary satellite data. A cold threshold of GOES IR brightness temperatures (221K) and a minimum area (90 pixels) is used, and statistical parameters are calculated. Displacement of the convective system and the area expansion and evolution of the minimum brightness temperature of the convective system is estimated.

Radar storm tracking and forecast:

A method for the extrapolation of radar reflectivity field based on the determination of the motions vectors between successive fields was implemented. The use of a semi-lagrangian advective scheme and a sensitivity study of the reflectivity forecast to the different parameters used for the calculation of motion vectors was evaluated. The analysis was carried out through idealized experiments, where the radar observations are simulated in a synthetic way based on a high-resolution simulation performed with a numerical model.

Hydrometeor identification based on radar data:

A hydrometeor classification scheme based on polarimetric variables from the city of Anguil (Province of La Pampa) INTA C-band weather radar was tested in two case studies in order to identify hail close to the ground (Vidal et al., 2015). Dual-polarized weather radars may offer the opportunity to detect and identify different classes of hydrometeors present in convective storms. In particular, hydrometeor classification helps to detect hail shafts within storms, thus providing valuable information for nowcasting applications, flight assistance, among others. Currently, new case studies observed by the newly installed RMA (Radar Meteorologico Argentino) dual-pol Doppler weather radars are being analyzed.

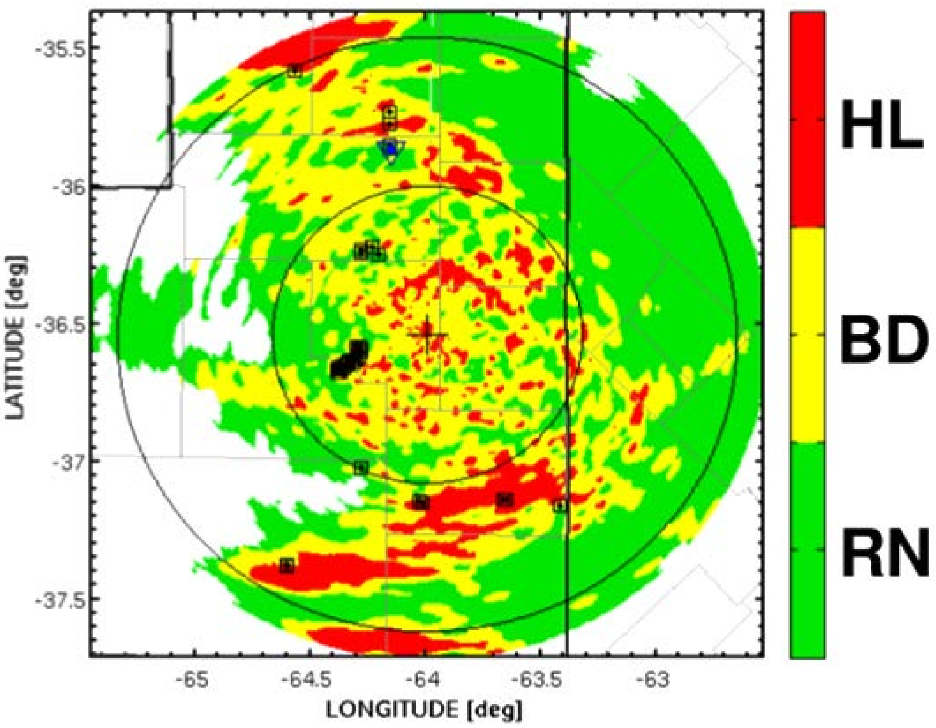

Figure 6: Hydrometeor identification algorithm (HID) map from hailstorm occurred in January 13, 2011. Hail damage reports during the studied day are indicated with black squares. Tornado report is indicated with blue triangle. HID categories (HL: hail; BD: big drops; RN: rain) from lowest PPI (0.5°) are integrated from 17:10 UTC to 23:50 UTC.

Combined radar and lightning data:

The weather radar network operated in Argentina does not yet span the entire territory. For this reason it is planned to take advantage as much as possible of other sources of information related to severe weather, such as those describing lightning activity. In particular, a proxy of radar reflectivity is under development based on total lightning data. This technique relates the total lightning flash rates (IC+CG) from Vaisala GLD360 network with the maximum radar reflectivity derived from the Argentinian weather radar network, through the implementation of novel techniques of machine learning. Since information associated with total lightning is mostly limited to the convective region of the storms, it functions as a good indicator of the most active zones of the mesoscale convective systems that very frequently affect our region. The use of extrapolation techniques on this information will allow the generation of very short-range forecasts in order to improve severe weather warnings.

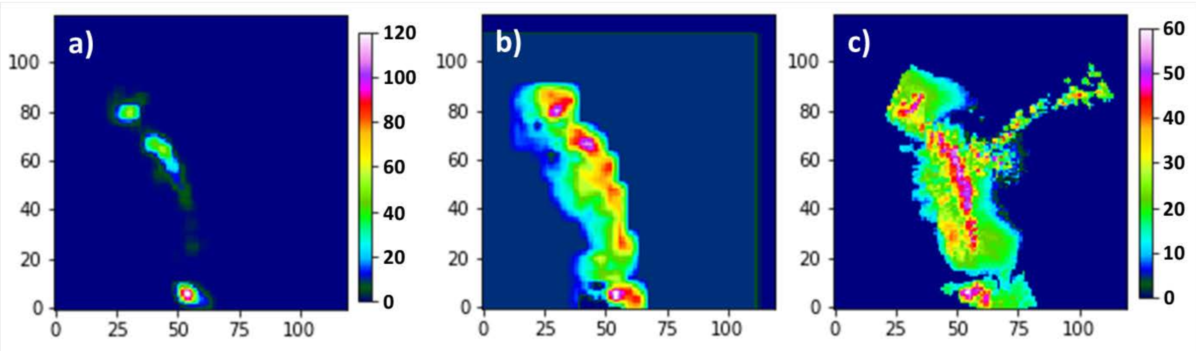

Figure 7: Example of radar reflectivity proxy (b, dBZ), observed maximum column reflectivity for the same time (c, dBZ) and observed density flash rate (a, flashes min^{-1}).

Radar reflectivity calibration with disdrometers:

The SMN has incorporated a total of 10 OTT Parsivel^2 laser disdrometers to be used for the calibration of radar reflectivity of the national weather radar operative network. Some preliminary analysis have been performed over case studies of different storms using two disdrometers located in the metropolitan area of Buenos Aires. Raindrop size distributions, radar reflectivity, rainfall rate, and Z-R relationship variability have been analyzed in order to improve the QPE from radar data.

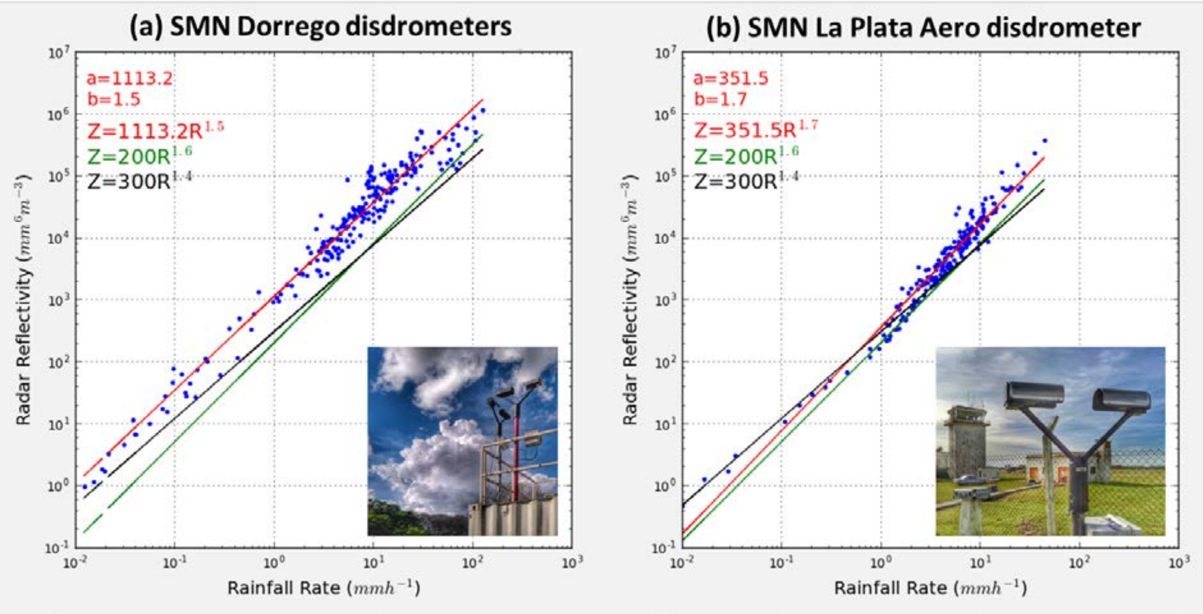

Figure 8: Example of a case study of Z-R relationship parameters related to the passage of a squall line on October 1, 2017 over the northeastern Buenos Aires province.

Dealing with radar interferences

Until recently weather radars enjoyed very strict rules protecting their operating frequencies from contamination from other radio frequency sources. During the last decade, new players -mostly related with wireless technology- have started to demand new bands in a radio-frequency spectrum that is now almost fully occupied with a great variety of users. Unfortunately, frequencies reserved for weather radars are now been used by licensed and unlicensed transmitters affecting most radars near urban centers, crippling their performances, and affecting the quality of derived products.

At the SMN we have been working at several levels to deal with the growing number of interferences affecting the radar network. Our activities in this matter concentrate mainly on two fronts: 1) develop simple techniques such as filtering to minimize the visual impact of interferences , and 2) to track approximate location, time of appearance and potential owner of source of interference to later engage those implicated for possible solutions to problem.

4.4.2 Models for Very Short-range Forecasting Systems

4.4.2.1 In operation

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4.4.2.2 Research performed in this field

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4.5 Specialized numerical predictions

[Specialized NP on sea waves, storm surge, sea ice, marine pollution transport and weathering, tropical cyclones, air pollution transport and dispersion, solar ultraviolet (UV) radiation, air quality forecasting, smoke, sand and dust, etc.]

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

4.5.1.1 In operation

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4.5.1.2 Research performed in this field

<u>Volcanic Ash:</u>

When a volcanic eruption occurs, source term quantification is the main factor of uncertainty in volcanic ash cloud forecasts. Ensemble forecast combined with data assimilation is one of the best ways to deal with these uncertainties. In order to perform data assimilation we coupled the Ensemble Transform Kalman Filter (ETKF) method (Hunt et al., 2007) with FALL3D (Costa et al., 2006, Folch et al., 2014) ash dispersion model, named ETKF-FALL3D (Osores et al., 2016, Osores et al.2017, Osores 2017). We have performed a sensitivity analysis of the ETKF-FALL3D system using different observing system simulation experiments (OSSE) in which synthetic observations of ash cloud mass loading were generated and assimilated every 6 hours in a small domain close to the volcano (Osores et al., 2016, Osores et al.2017, Osores 2017). These synthetic observations mimic quantitative ash mass loading retrievals from satellite data. In these experiments, the ETKF-FALL3D was used to estimate the 3D distribution of ash within the domain, the eruptive column height and the shape of the vertical mass flow rate distribution at the vent location. Results showed that the ETKF-FALL3D system might be adequate to produce an on-line optimization of the uncertain volcanological parameters as well as to objectively correct the 3-dimensional distribution of volcanic ash concentrations.

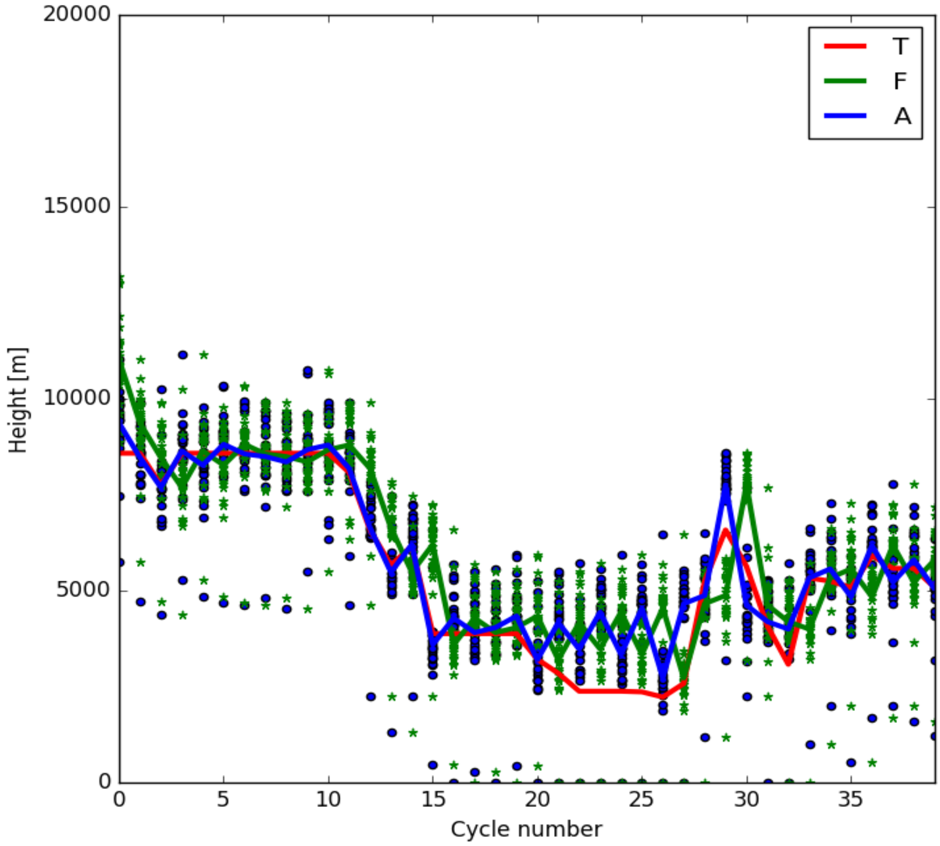


Figure 9: Column height ETKF-FALL3D optimization time serie. True Value (red), Forecast (green) and Analysis (blue) (Osores et al., 2016).

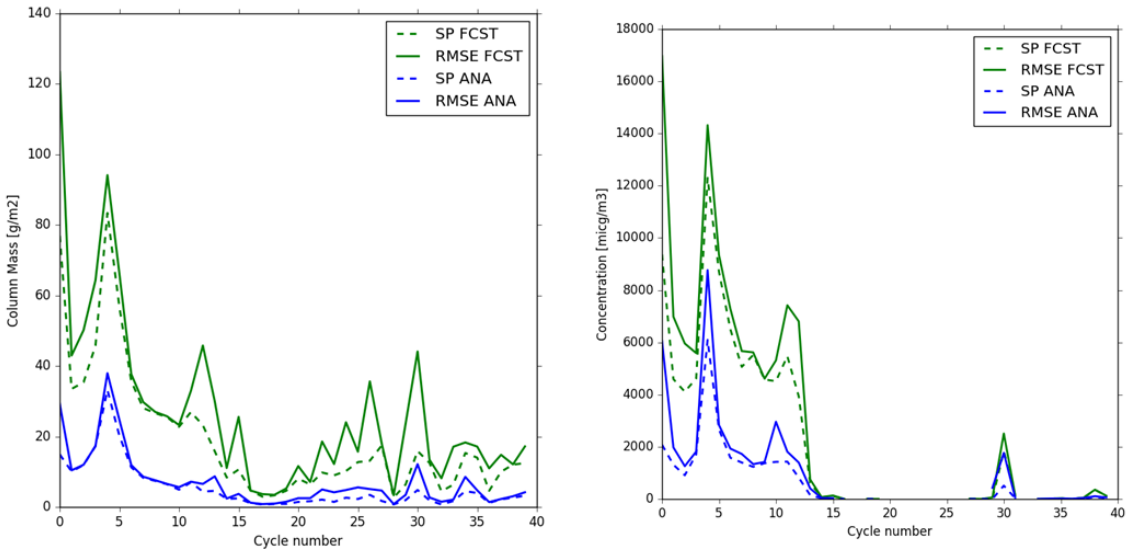


Figure 10: Mean SP and RMSE time series of (a) Fine ash mass loading and (b) ash concentration at Flight level (FL) 300. Ensemble Forecast (green) and Ensemble Analysis (blue), (Osores et al., 2016).

Ocean Waves:

An advanced method for the assimilation of significant wave height and wind data into the ocean wave model, based on a 4D Local Ensemble Transform Kalman Filter technique was introduced in Etala and Echevarría (2013). The joint use of wind and wave observations allowed us to avoid some assumptions usually made in the wave spectra retrieval, by means of the consideration of the analysed wind, beyond the multivariate analysis of wind and wind waves.

Storm Surge:

The propagation time of the surge in the extensive and shallow continental shelf (see Fig. 3) allows the detection of sea-level anomalies based on observations from several hours up to the order of a day prior to a surge event that can lead to flooding of the most populated coasts. A 4-D Local Ensemble Transform Kalman Filter (4D-LETKF) initializes an ensemble in a 6-h cycle, assimilating the very few tide gauge observations available along the northern coast and satellite altimeter data. The 4D-LETKF evolving covariance of the ensemble perturbations provides realistic cross-track analysis increments. Improvements on the forecast ensemble mean show the potential of an effective use of the sparse satellite altimeter and tidal gauges observations (Etala, Saraceno and Echevarría, 2015).

4.5.2 Specific Models (as appropriate related to 4.5)

4.5.2.1 In operation

Dispersion Model

HYSPLIT model

To accomplish with our responsibilities as a Volcanic Ash Advisory Center (Buenos Aires VAAC), we make use of HYSPLIT model to produce volcanic ash dispersion plots and related VAA messages (Volcanic Ash Advisory messages) whenever a volcanic event occurs in our area of responsibility. The HYSPLIT (HYbrid Single-Particle Lagrangian Integrated Trajectory) model is the newest version of a complete system for computing simple air parcel trajectories to complex dispersion and deposition simulations. As a result of a joint effort between NOAA and Australia's Bureau of Meteorology, the model has recently been upgraded. HYSPLIT can compute the advection of a single pollutant particle, or simply its trajectory. The dispersion of a pollutant is calculated by assuming either puff or particle dispersion. The model's default configuration assumes a puff distribution in the horizontal and particle dispersion in the vertical direction.

The model can be run with the ETA SMN model forecasts which give more adaptability, for larger domains GFS forecasts are used. The model runs locally or through the web page of NOAA ARL

FALL3D model

FALL3D is a multipurpose and multiscale model for the dispersion of atmospheric particles bases on an Eulerian formulation of the advection-diffusion-sedimentation equation. Time-dependent 3D wind fields and atmospheric variables are furnished by coupling off-line the model with prognostic, diagnostic or re-analysis meteorological data. Depending on the considered resolution, coupling can be with global (e.q. GFS) or mesoscale (WRF, ETA) meteorological models or with local-scale mass-consistent interpolators. Different options exist for describing source term (volcanic column), including a numerical solution of the equations based on the buoyant plume theory that allows for estimating the eruption rate from the observed eruption column height. The model can deal simultaneously with a wide spectrum of particle sizes and inert gas aerosol. Aggregation of fine ash during the transport, due to the presence of both ice and liquid water, can be also considered. Model outputs include ground load (deposit thickness), airborne concentration, ash concentration at selected flight levels, column mass and AOD. Model outputs are written in NetCDF format

Puff model (Puff-Volcanic Ash Tracking Model)

Used through the Geophysical Institute, University of Alaska Fairbanks web page. Forecasts of ash dispersion is compared with other forecasts for final VA advisories

Mesoscale meteorological modeling in support of atmospheric dispersion forecasts

WRF-ARW model

WRF-ARW is run on daily basis for the 00UTC cycle, initialized every 24 hours up to 84 forecast hours, on a 16-core HP cluster. The model domain over southeastern South America is depicted in Figure 11, with the inner domain reaching 5 km horizontal resolution over the La Plata River region. The model outputs are used to initialize the HIRHYLTAD/MBLM dispersion model in support of the Uruguay River Monitoring Program, carried on by agreement with the Secretary of Environment and Sustainable Development of Argentina.

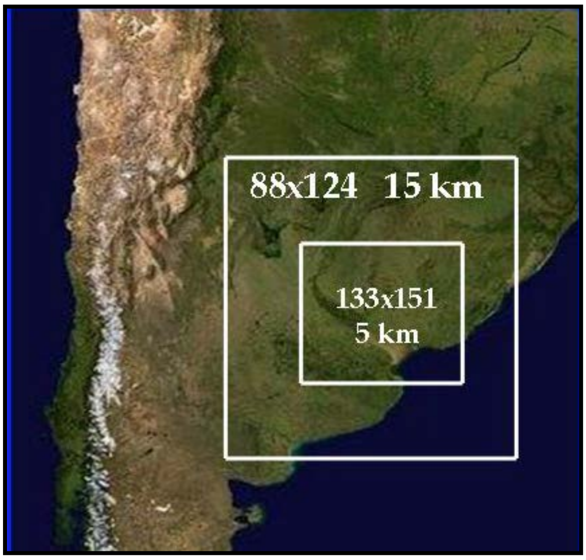


Figure 11: South American domain of the WRF-ARW model daily runs in support of the Uruguay River Monitoring Program.

Boundary layer and atmospheric dispersion forecast models

MBLM model

The Mesoscale Atmospheric Boundary Layer Model (MBLM) has been especially developed for forecasting the low-level wind field over coastal regions (Berri et al., 2010). It is dry and hydrostatic and its main attribute is the high horizontal resolution (0.01º) that allows an appropriate definition of the river-land temperature gradient. The model has been validated for short term predictions (Sraibman and Berri, 2009) as well as for climatological high resolution wind fields (Berri et al., 2011). The model runs coupled to Eta/SMN operative forecasts to produce high-resolution low-level wind fields in support of the Uruguay River Monitoring Program.

HIRHYLTAD model

The High-Resolution Hybrid Lagrangian Trajectory and Atmospheric Dispersion (HIRHYLTAD) model has been developed by Blanco and Berri (2011), and is routinely used in the daily activities of the Uruguay River Monitoring Program. It is a puff model in which each puff travels with the local wind vector and disperses horizontally and vertically according to Gaussian dispersion parameters calculated as a function of the atmospheric stability. HIRHYLTAD has two calculation modules, the first one determines smoke lines using lagrangian trajectories and the second one performs the dispersion calculation and determines concentrations. The accumulated concentration is estimated with the Gaussian dispersion equation after introducing all necessary modifications to adapt it to the model characteristics. The 3D plume is composed by successive puffs of material released by the source at a 5-minute rate.

Prognostic products

HIRHYLTAD was created to be used in conjunction with a MBLM, from which 3D wind fields are taken for the dispersion calculations. The MBLM model provides high resolution horizontal (1 km) and temporal (5 min.) outputs. In contrast with other dispersion models based on quasi-stationary conditions, the MBLM/HIRHYLTAD coupling is advantageous for representing atmospheric short-term variability. These two models produce daily 72-hour forecast of the area affected by the pollutant plume emitted from the UPM (ex-Botnia) pulp mill plant, in support of the Uruguay River Monitoring Program. Figure 12 shows an example of HIRHYLTAD/MBLM 12-hour accumulated plume forecast of the Uruguay River Monitoring Program, in the vicinity of the city of Gualeguaychú.

Smoke_Plume is an operational forecast system designed for an immediate response in the event of an accidental air pollution episode. The application resides in the servers of the Forecast Department and is ready to be used at any time. It provides successive images of the instantaneous smoke plume coming out from up to 4 different simultaneous sources, at a 1 hour frequency, and for up to 36 hours forecast. The region covered is a 500 km square centered on the La Plata River of South America. This system is based on HIRHYLTAD model, described above, which consists of a lagrangian trajectory and atmospheric dispersion puff model in which each puff travels with the local wind vector and dilutes horizontally and vertically according to Gaussian dispersion parameters calculated as a function of the atmospheric stability. Smoke_Plume uses the 3D forecasts of the meteorological MBLM model (5 km horizontal resolution, 5 min time resolution) updated daily and available FTP from the National Weather Service servers. Since the system is intended to provide a quick answer in the case of an accidental air pollution event, when emission rates as well as other physical characteristics of the source are normally not available, it considers a constant emission rate equal to 1 and presents results in a percentage scale with respect to the position of the maximum concentration. It is possible to choose the height of emission and the level at which the concentrations are to be calculated. Figure 12 provides an example of the model output.

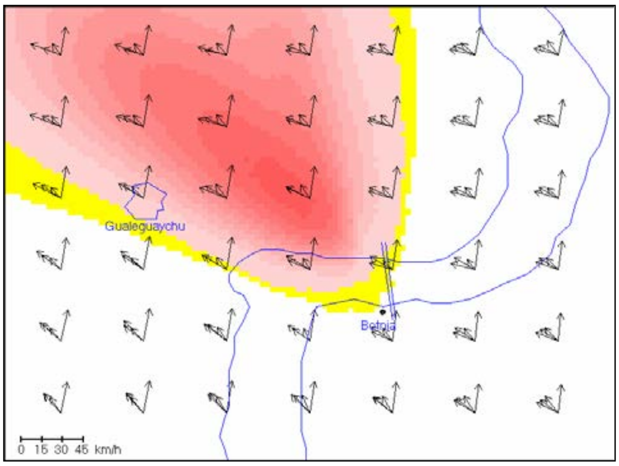


Figure 12: Example of HIRHYLTAD/MBLM 12-hour accumulated plume forecast of the Uruguay River Monitoring Program, in the vicinity of the city of Gualeguaychú

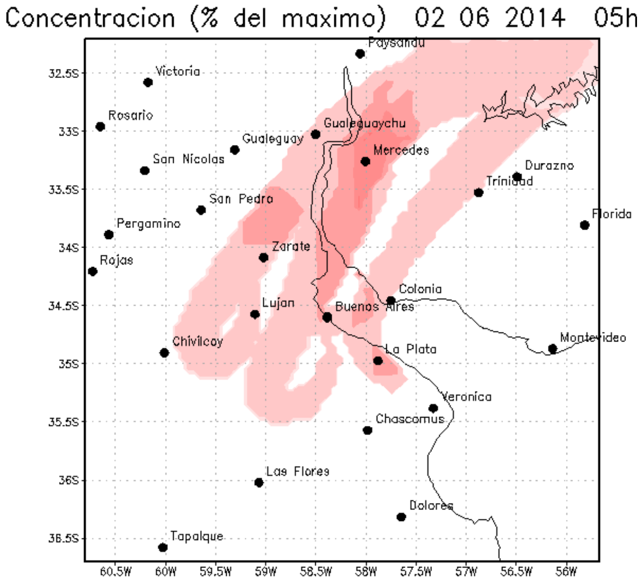


Figure 13: Example of a 36 hr forecast of 4 smoke plumes released from imaginary sources in the vicinity of the city of Buenos Aires. The graph shows the disposition of the instantaneous plumes at 0500 local time of 2 June 2014

Observation Network in support to MBLM modeling system

The Uruguay River Environmental Monitoring Program established a network of automatic meteorological stations in the Gualeguaychú area. The network has a total of 5 stations, including 3 meteorological towers with two measuring levels at 10 and 42 meters. All meteorological stations record data simultaneously every 10 minutes, since October 2009. The data include temperature, relative humidity, precipitation and solar radiation at the surface; and wind and temperature at 10 meters and 42 meters The data archive allows analysis of the wind direction frequency distribution and mean wind mean speed by sector, and is also used to calibrate the MBLM model and validate the plume forecasts.

Ocean Waves

Austral-WWIII is a multiscale wave model, based on NOAA / NCEP WAVEWATCH III® (Tolman, 2009). It provides 4-day numerical wave forecasts 4 times daily in a global multigrid mosaic with focus on the Southern Oceans and South Atlantic. The model is driven by the

NCEP GFS wind forecasts, including air-sea temperature contrast. Sea ice is updated daily with the 00 GMT cycle.

Storm surge

The SMARA storm surge model is a 2D depth-averaged model applied on the shelf and Rio de la Plata estuary (Etala, 2009a, b), and it is one-way coupled to the wave model through the surface wind/wave stress.

UV RADIATION MODEL (ISUV-ISUVn).

The principle parameters to influence the erythemal irradiance at clearsky conditions are the solar elevation, the Sun-Earth distance, the total ozone amount, the altitude of the place, the aerosol loading and the surface albedo. Furthermore, there are some minor corrections due to the exact composition of the atmosphere, e.g. the vertical ozone, pressure and temperature profiles.

With these assumptions, the irradiance can be calculated e.g. with the radiative transfer model using time, latitude, longitude and altitude as only remaining independent input parameters. As in spite of the increased velocity of computers, radiative transfer models still consume too much time to use them in this kind of software, an approximation of the radiative transfer solutions was used for the ISUV-ISUVn model.

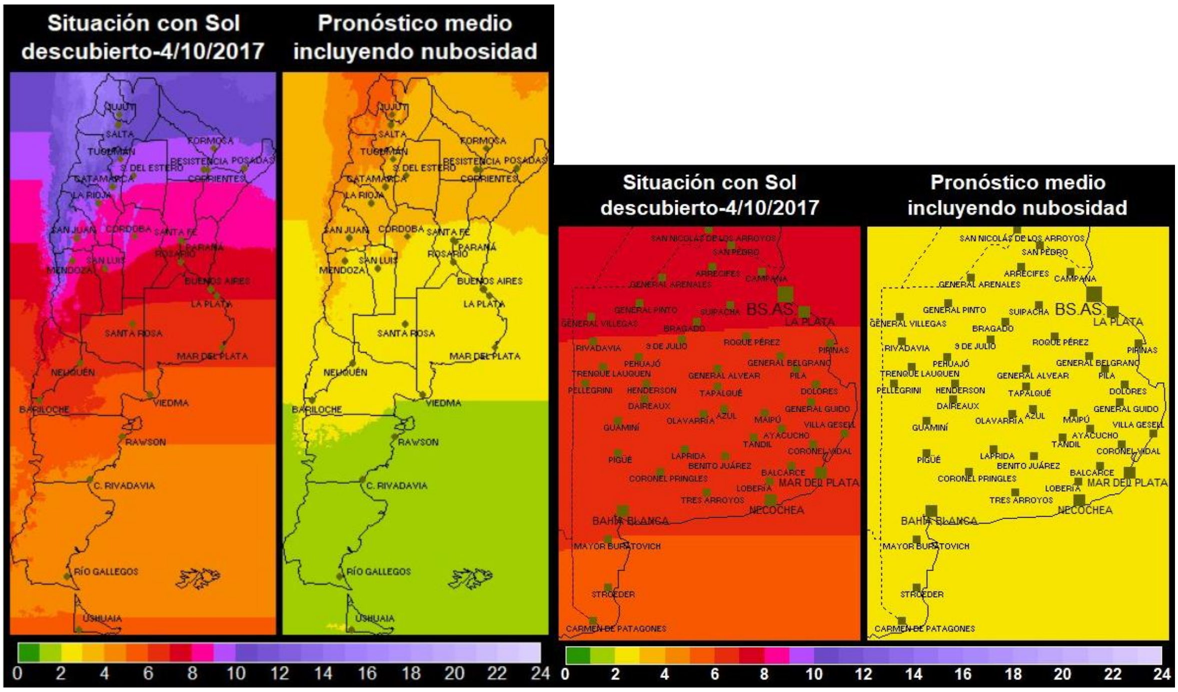
The ISUV-ISUVn model is written in the language Delphi 4 for Windows 95 and newer.

The object of the ISUV is to give an estimation of the clearsky UV Index (basically for all situations when the direct sun is uncovered at the place) in Argentina on the one hand and of the average UV Index for the expected weather situation in Argentina on the other hand. Both are predictions for solar noon of the next day, the latter one is also called ISUVn with ‘n’ for ‘nublado’ (cloudy).

The ozone prediction is in general not based on the total ozone climatology, but on measurements of the day before. First, the ground measurements in the Argentine ozone stations are extrapolated for the whole country in the following way: each station’s measurement is assumed to be valid for the whole region of ±5° latitude around the location for the whole Argentine longitude range. An altitude correction of the total ozone is additionally applied. In the areas, where two extrapolated measurements are overlapping, the smaller value is taken. For areas, which are not covered by this extrapolation, the TOMS/Earth Probe Level 3 data are taken. Finally, when there are still uncovered regions (e.g. when TOMS is not measuring), the ozone climatology as used the ‘low ozone’ mode.

For the ISUVn, a cloud prediction for the next day is made by the meteorologists of the Argentine National Weather Service. They divide the country in regions with different cloud indices. The cloud index is an integer value from 1 to 5 and is depending on the predicted cloud type and cloud coverage. A cloud transmittance belongs to each cloud index and finally the ISUV is multiplied with the cloud transmittance to give the ISUVn for each pixel. The relation of cloud coverage, cloud types, cloud index and cloud transmittance used for the first version of the ISUV-ISUVn.

The UV index colors were currently modified and adapted to those recommended by the World Health Organization (WHO) and World Meteorological Organization (WMO).



4.5.2.2 Research performed in this field

<u>FALL3D model version 7.1</u>

FALL3D is a multipurpose and multiscale model for the dispersion of atmospheric particles bases on an Eulerian formulation of the advection-diffusion-sedimentation equation. Time-dependent 3D wind fields and atmospheric variables are furnished by coupling off-line the model with prognostic, diagnostic or re-analysis meteorological data. Depending on the considered resolution, coupling can be with global (e.q. GFS) or mesoscale (WRF, ETA) meteorological models or with local-scale mass-consistent interpolators. This model can simulate the dispersion and deposition related to volcanic eruptions and remobilized ash or dust from ground surface. The model can deal simultaneously with a wide spectrum of particle sizes and SO2. Dry and wet sedimentation of ash during the transport can also be consider. Model outputs include ground load and deposit thickness, airborne concentration, ash concentration at selected flight levels, column mass loading and AOD. Model outputs are written in NetCDF format.

4.5.3 Specific products operationally available

Significant wave height and peak direction fields, wind wave and primary swell height and mean direction hourly fields for a 6-hour hindcast and 96-hour forecast. The cycle is updated 4 times daily at 00, 06, 12 and 18 GMT. Web products are available at approximately H+4.5 hours. Text bulletins (in Spanish) for 11 selected points approximately 100 nm off-shore contain hourly significant wave height and height, period and direction of the main wave trains for the complete hindcast and forecast period. http://www.smn.gov.ar/?mod=archolas&id=16

Storm surge level and total depth-averaged current fields on the continental shelf and Río de la Plata. 96-hour forecasts are updated twice daily at 00 and 12 GMT. Web products are available at approximately H+4.5 hours at http://www.smn.gov.ar/?mod=pron&id=44

The outputs of the ISUV-ISUVn model are two images jpg format for Argentina (clear and cloudy skies), and and 46 images for each province (clear and cloudy skies) . Also, the individual value of UV Index with text format for 5138 localities of the Argentina (clear and cloudy skies). The UV Index is calculated for the mid solar day . The projections are to only one day.. http://www.smn.gov.ar/#

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
"[brief description of automated (formalized) procedures in use for interpretation of specialized NP output]"
-

4.5.4.2 Research performed in this field
-

4.5.5 Probabilistic predictions (where applicable)

4.5.5.1 In operation
"[Number of runs, initial state perturbation method etc.]" *(Describe also: time range, number of members and number of models used: their resolution, main physics used etc.)*
-

4.5.5.2 Research performed in this field

To develop efficient ensemble-based ash dispersion forecasts, a sensitivity analysis of the FALL3D model has been performed to identify the sources of uncertainty that produce the largest impact.
The sensitivity analysis considered eruption column height, vertical distribution of mass flow rate, grain size distribution, particles density, processes of aggregation and meteorological fields. This evaluation revealed that the eruption source parameters that determine the emission profile were the most sensitive (Osores et al., 2017, Osores, 2017). In order to produce a finite ensemble forecast we have selected the parameters that impact the most and considered them as the parameters to be optimize at the data assimilation processes. The ensemble consists in 25 members, with 0.25° horizontal resolution.

4.5.5.3 Operationally available probabilistic prediction products

"[brief description of variables which are outputs from probabilistic prediction techniques]"
-

4.6 Extended range forecasts (ERF) *(10 days to 30 days)*

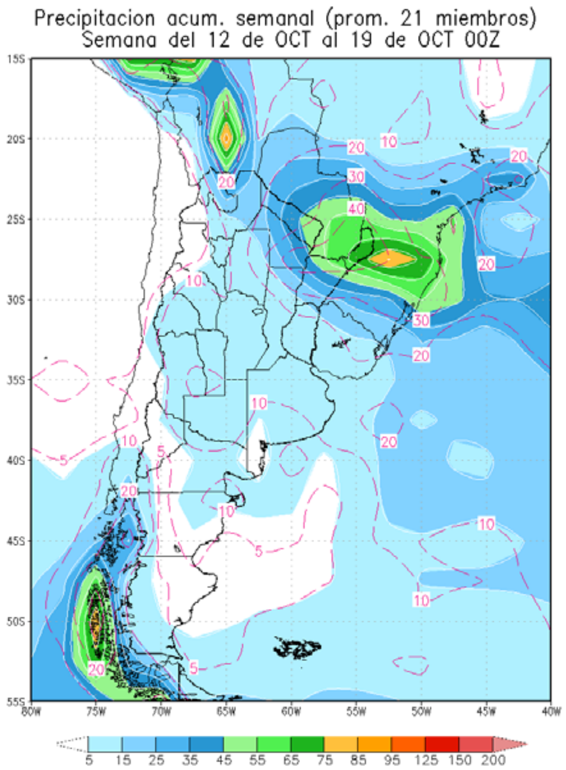
4.6.1 Models

4.6.1.1 In operation
-

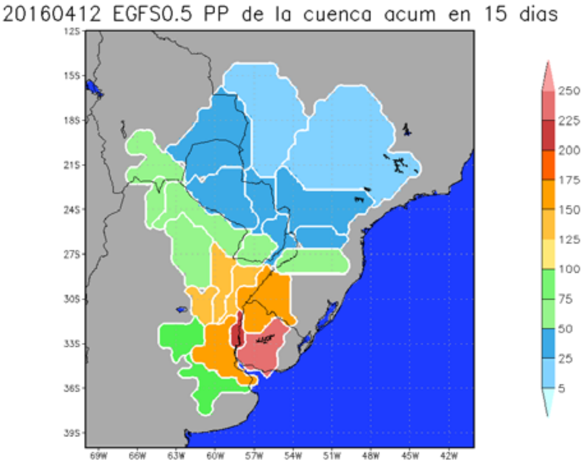
4.6.1.2 Research performed in this field
-

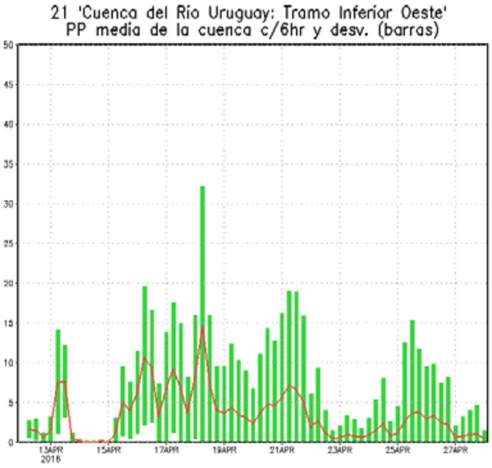
4.6.2 Operationally available NWP model and EPS ERF products

EPS products for Weekly Outlook Forecasting (Week 1 and 2) based on GFS ensemble Forecast: Weekly total precipitation for the ensemble's mean and its standard deviation, weekly spaghetti for total precipitation (based on Bias corrected 24-hour precipitation products produced by NCEP every day at 00Z.)

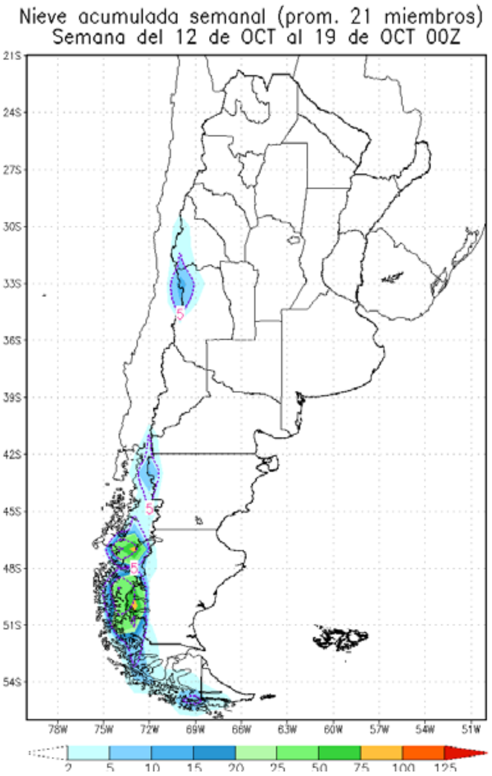


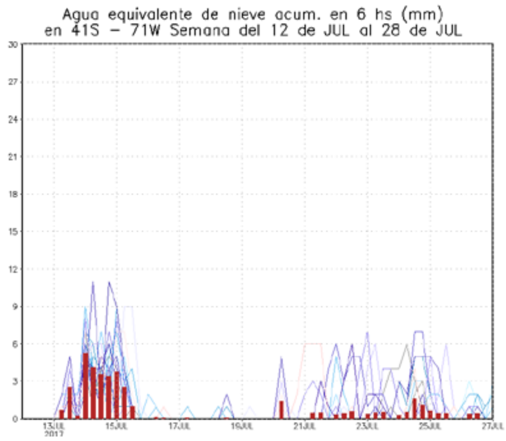
Biweekly mean total precipitation in La Plata basin, (based on ensemble GFS, 0.5° horizontal resolution) and meteograms of precipitation in each basin up to 15 days.



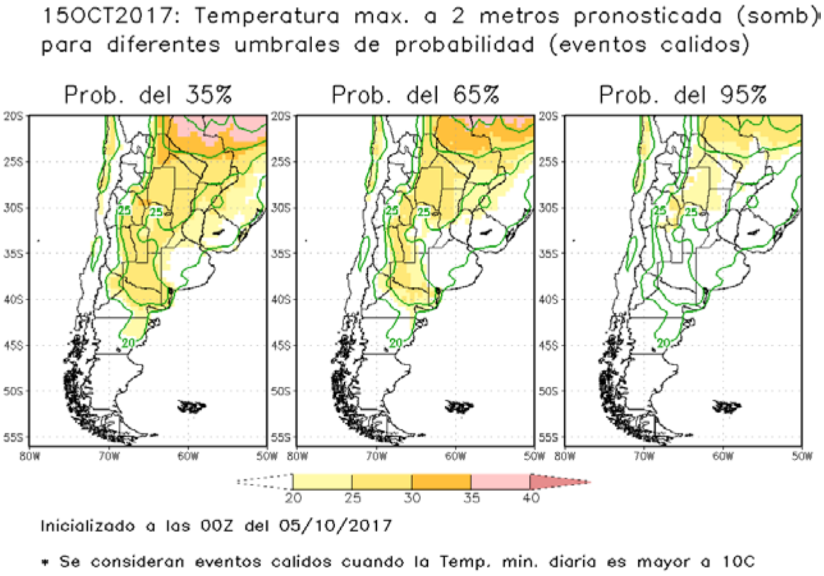


Mean and standard deviation for weekly Water Equivalent of Accumulated Snow (based on ensemble GFS, 1° horizontal resolution) and meteograms of snow rate.





Probabilistic temperature forecast for daily warm and cold events for thresholds of 35% 65% and 95% over a period of 15 days. This experimental product is a complement for the detection of cold and heat waves.



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

4.7.1 In operation

-

4.7.2 Research performed in this field

-

4.7.2 Operationally available EPS LRF products

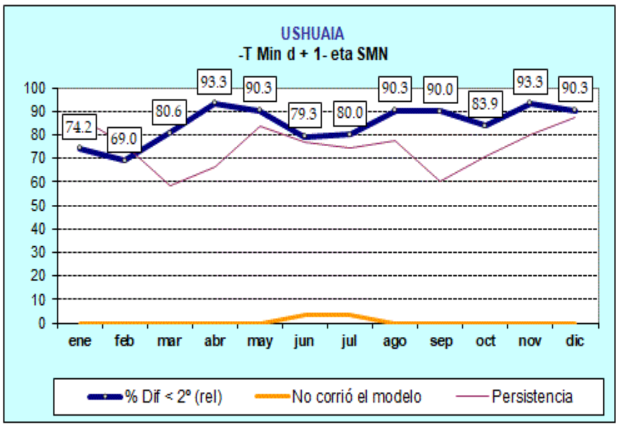
-

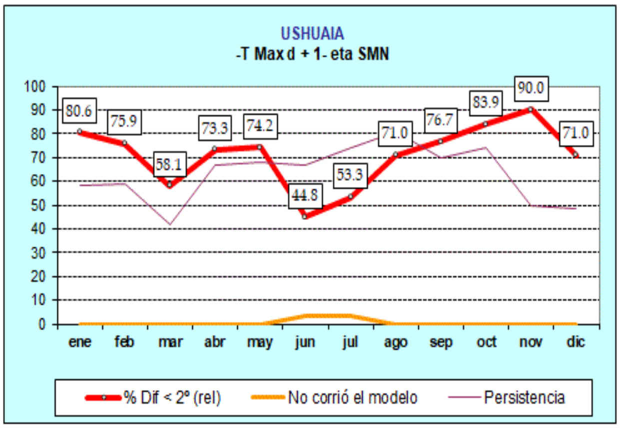
5. Verification of prognostic products

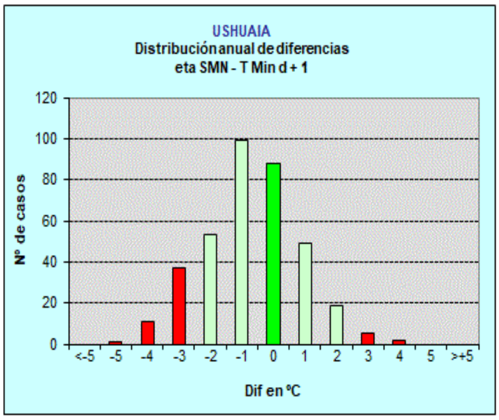
5.1 "annual verification summary"

Maps of observed precipitations and maximum/minimum temperatures are available on daily basis for comparison with the respective ETA model forecasts for the same period and all the possible forecast ranges.

Verifications of maximum and minimum temperature and precipitation of selected cities forecasted by the ETA SMN model are performed on monthly basis. Statistics of the official forecasts are included as well. Corrected temperatures forecast evaluation is also monthly obtained and then updated for the following year.

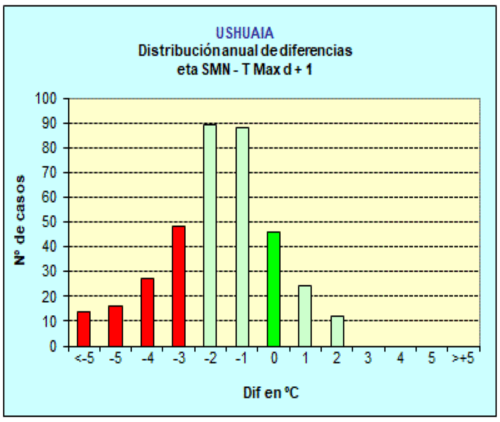






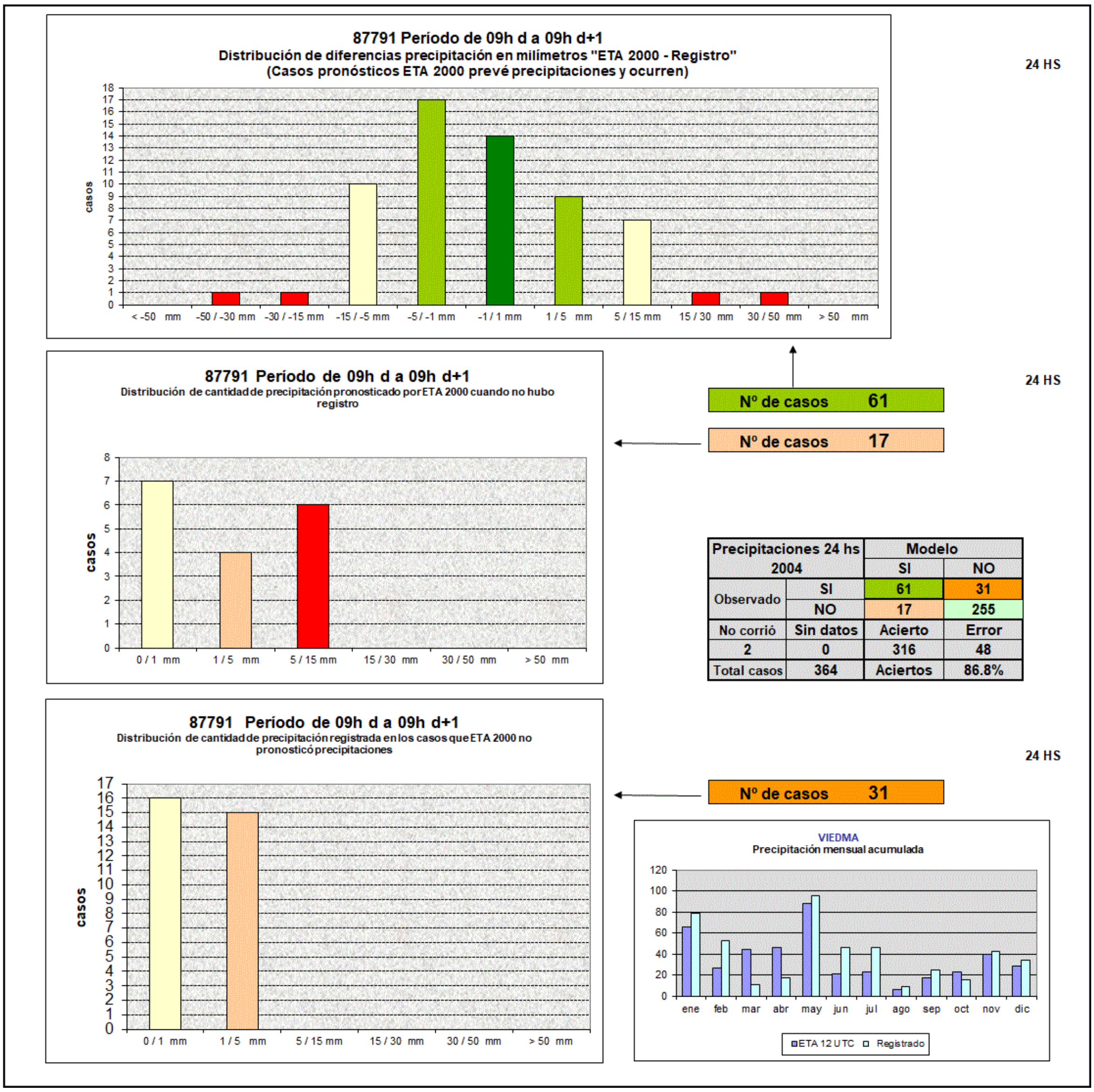
% DIF < 2 (rel)

84.6



% DIF < 2 (rel)

71.2



Precipitaciones 24 hs 2004		Modelo	
		SI	NO
Observado	SI	61	31
	NO	17	255
No corrió	Sin datos	Acierto	Error
2	0	316	48
Total casos	364	Aciertos	86.8%

Example of the verification of temperatures and precipitation forecasts in Ushuaia and Viedma.

GFS temperatures forecasts and calibrated GFS temperatures forecasts are verified on daily/monthly basis.

Since August 2011 the wave forecasts are verified within the JCOMM Wave Forecast Verification Project framework and from buoy data time series available from the project.

Storm surge predictions are validated against the tidal gauge network available from the Naval Hydrographic Service on daily and monthly basis.

The operational MBLM forecast winds over the Uruguay River are compared with the wind observations at all the available stations, on yearly basis. The analysis uses contingency tables for wind direction vector, and root-mean-square-error for the horizontal wind components as well as wind speed. Seasonal differences are also analyzed. The root-mean-square-error for the horizontal wind components has a better fit for surface observation compared to the 42 meters wind data. The results reveal that the error is minimum in winter and maximum in spring. The mean hit rate for 8-sector wind direction is 71%, the average of RMSE of the horizontal wind components is 3.6 m/seg and for the horizontal wind speed is 2.3 m/seg.

A validation of smoke plume forecasts over the Uruguay River obtained with the HIRHYLTAD/MBLM model is also performed on a yearly basis. Observed winds are horizontally interpolated to generate wind fields over the whole domain. The comparison between forecast plumes and calculated plumes with observations during 12-hour periods is carried out by defining a Plume Matching Area Error (PMAE). Results show a good agreement particularly in the first 12 hours of forecast, with an average of 40% for PMAE, and only 10 out of 365 cases with complete mismatch (PMAE =100%).

5.2 Research performed in this field

Forecast verification scheme is being implemented, different statistics are calculated for temperature at 12 and 18 UTC and 24 hours accumulated precipitation. Some examples are shown where differents models are compared. Figure 14 shows the probability distribution of precipitation volumes (PDF, Amitai et al., 2012) for January, February and March 2016. Also the ratio between forecast and observed total precipitation volume is included in Figure 14. Different statistics for temperature at 18UTC are presented for December 2016. Results show a better performance of WRF over the other models, which motivates its future operational implementation.

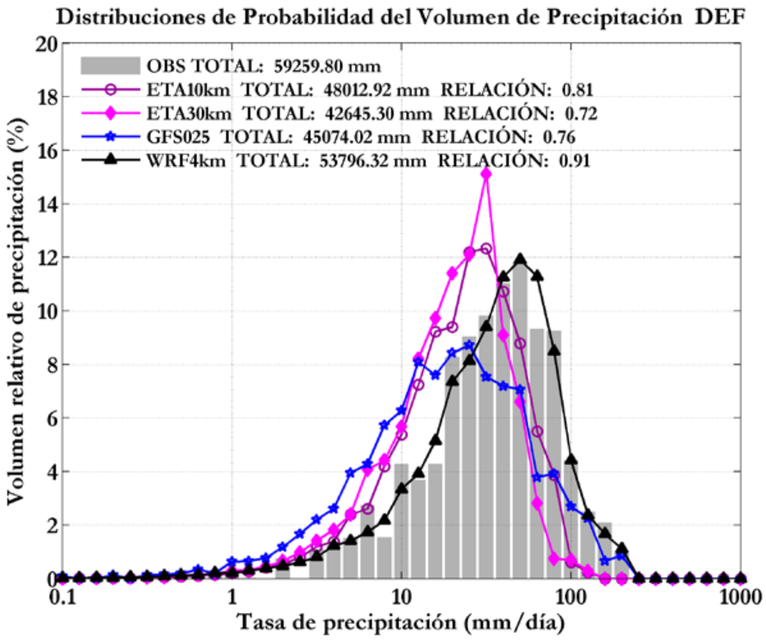


Figure 14. Probability distribution of precipitation volumes, January-February-March 2016

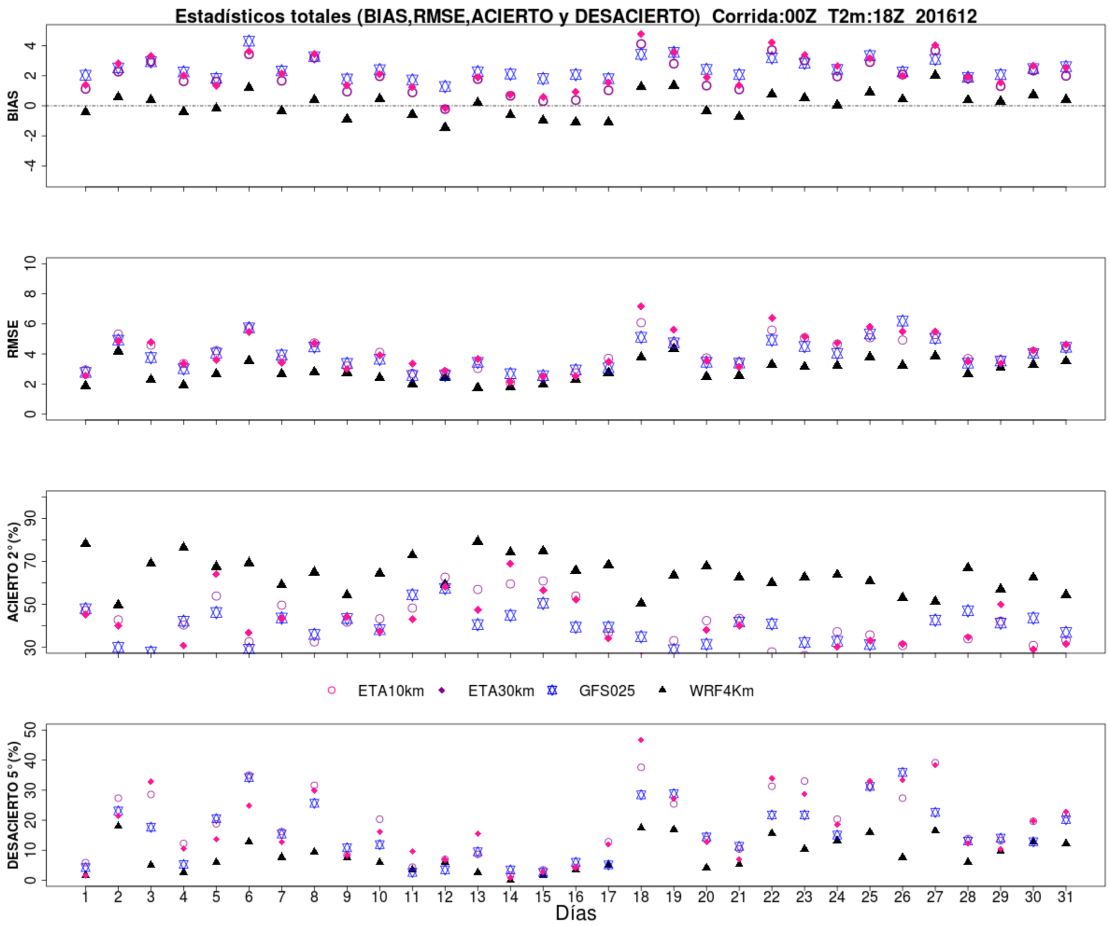


FIgure 15. BIAS, Root mean square error, percentage of success (error less than 2 degrees) and percentage of no success (error greater than 2 degrees) for temperature at 18UTC during december 2016 for ETA 10 and 30km, GFS and WRF.

Verification of weekly outlooks:

Once a month, the weekly forecast of precipitation is performed. Verification of weekly accumulated precipitation based on precipitation data from NWS rain gauge network compared to forecasts of weekly precipitation at 1 week and at 2 weeks is realized. The threshold of 10mm is used for categorical statistics. Also we include the probability distribution of precipitation volumes (PDF, Amitai et al., 2012), dispersion diagram, BIAS map, clasical statistics and the ratio between forecast and observed total precipitation volume.

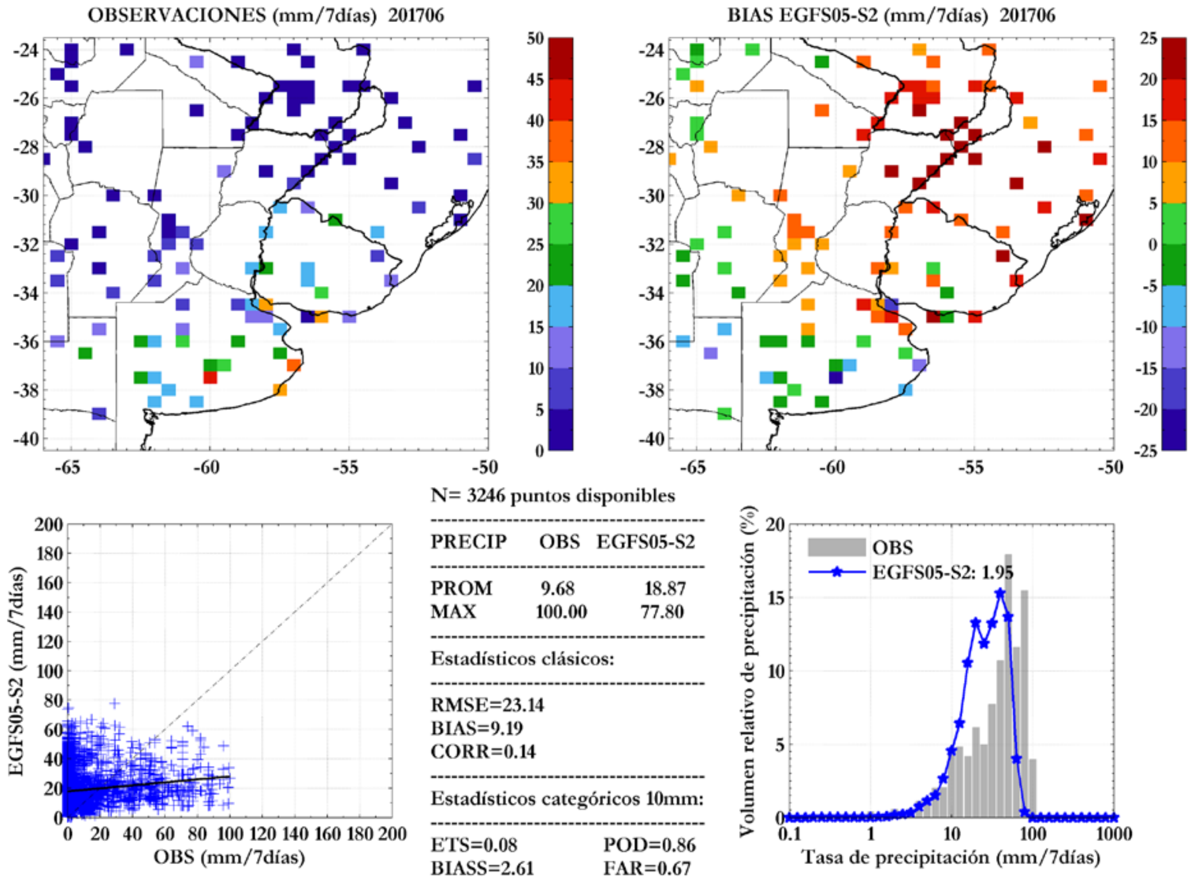


Figure 16. Verification of weekly outlooks

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 expected in the next year

WRF-ARW is expected to be implemented operationally in the coming year. Four forecasts cycles will be performed (00,06,12,and 18UTC) for the whole country and for a range of 48hs. The main features include 4 km horizontal resolution, 38 vertical sigma-p levels, 1-hour temporal resolution and convection explicitly resolved over the domain shown in Fig. 16.

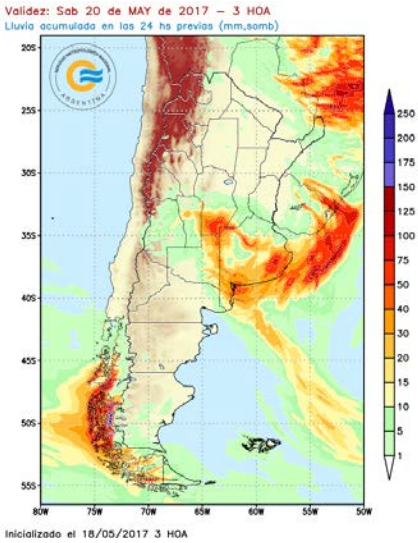


Figure 17. WRF-ARW model domain.

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

In the next 4 years it is planned to migrate to a new HPC system that will have a processing capacity of about 20 times higher than the current system. Once the new HPC is up and running, it is expected to implement a high resolution data assimilation system applying LETKF methodology with the ability to incorporate local observations. In addition the analyzes generated through the assimilation system will be used to generate an ensemble forecast with a horizontal resolution of at least 5km, for a range no longer than 24 hours.

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

6.2.1 Planned Research Activities in NWP

Research will be carried out in order to advance the development a high resolution data assimilation and ensemble forecast system. It is expected that from the use of local information in high resolution can improve the forecast of high-impact weather events. It is planned to continue using the LETKF methodology coupled with the WRF model. Numerous sensitivity experiments must be performed in order to design the system.

6.2.2 Planned Research Activities in Nowcasting

In order to improve the performance of the FORTRACC Technique in our region, a validation will be performed to calibrate thresholds. Differents adjustment will also be made in order to adapt its use to the information provided by the new satellite GOES-16.

In terms of radar tracking with motions vectors, this methodology will be applied to real radar observations. It is planned to combine this methodology with data assimilation techniques following Otsuka et al., 2016.

Related to the nowcasting system, and based on the combination of radar and lightning observation, it is planned to incorporate the new total lightning data provided by the GLM sensor onboard GOES-16 satellite.

Regarding the quality of radar-measured reflectivity, it is planned to continue advancing in two fronts: first through the use of disdrometer data to achieve better radar reflectivity calibration, and second by addressing those responsible of radar interference sources to manage a progressive cleaning of the radar frequency band.

The efforts discussed above are part of the objective of making a better use of the remote sensing available, to eventually introduce more objective/quantitative methods in forecasting operations.

6.2.3 Planned Research Activities in Long-range Forecasting

In order to improve the weekly forecasts, calibration of the GEFS (0.5 ° horizontal resolution) model in the region of La Plata basin will be performed. The model will be calibrated with the observed meteorological information for the period 2001-2010 for temperature, precipitation and snow variables. The forecast period will extend to 15 days. The quantification of the quality of the calibration will be carried out by calculating various statistics (correlation coefficients, root mean square error and others).

6.2.4 Planned Research Activities in Specialized Numerical Predictions

To assess the performance of FALL3D-ETKF ensemble based data assimilation system we plan to test it with real satellite data. Also, we plan to implement the localization of the observational error covariance matrix and explore the use of other complementary observations such as LIDAR and RADAR.

Future of the ISUV-ISUVn model.

We plan to update the ISUV-ISUVn model to a modern programming language, in a manner that would not require human intervention. That is, ingesting ozone data obtained from the Dobson Spectrophotometers, and outputs of the weather forecast model with cloudiness.

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