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ESO Weather_Watch: an Automated Service for Observatory Operation

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Abstract. ESO visiting astronomers, telescope operation and observatory maintenance teams have now access to a new service which should improve observing efficiency as well as safety of operation. A *Weather Watch* mailing list has been created which allows subscribers to receive emails each time a change is forecasted in the observing conditions of the next 48 hour at La Silla and Paranal Observatories.

The messages are generated at ESO headquarters on the basis of the outcome of ECMWF meteorological forecasts, after adjustment to local conditions by Kalman filtering, and of satellite based cloud cover analysis.

The data fusion process in operation is briefly described and the selection criteria for issuing warnings are discussed.

1. Introduction

ESO has been conducting a wide survey of existing and potential forecasting techniques and several feasibility studies were initiated from 1992 onwards, both internally and externally. Their results, summarized during the 1997 workshop on *Forecasting Astronomical Observing Conditions* (Sarazin, 1997), allowed to select the most promising techniques for the operational services to be developed for the ESO observatories in Chile. These tools were progressively installed, reaching completion in the course of 1999. Following a description of the operational package, we present an estimate of the performance after one year of operation.

2. Data Ingestion

2.1. Medium Range Forecasts

The numerical meteorological forecast model data is obtained from ECMWF and consists of daily model output runs initialized with the 00UT and 12UT data. The forecasted fields (wind, temperature and geopotential height) are respectively available at about 06UT and 03UT (on the following day). The 00UT run output covers every 6 hours out to 48 hours and the 12UT run output includes, additionally, 12-hourly forecasted fields from 48 hours to 8 days ahead. The area of interest is shown in Figure 1: the ECMWF data is on a 3^ox3^o latitude/longitude grid covering (10S to 43S)-(65W to 110W) and also on a

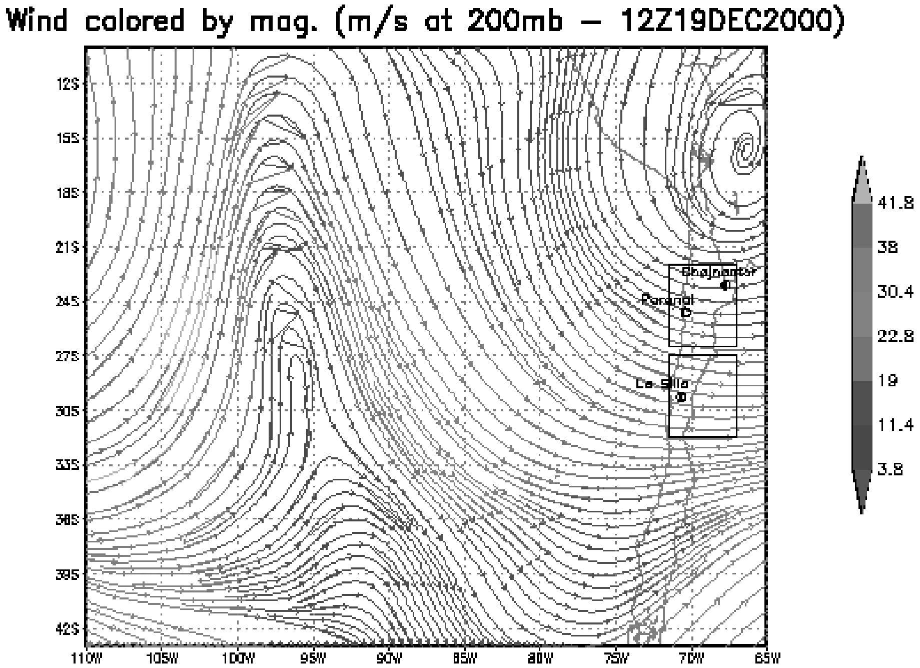

Figure 1. Horizontal projection of the data cubes delivered to ESO by ECMWF

0.5^ox0.5^o grid for the 4.5^ox4.5^o block covering the two sites, (22S to 26.5S)-(67W to 71.5W) for Paranal and (27S to 31.5S)-(67W to 71.5W) for La Silla.

2.2. Satellite Products

GOES-8 satellite data consist of infra-red window (10.7 μm) and water vapour (6.7 μm) image rectangular sectors (top left corner at 10^oS, 115^oW and bottom right corner at 45^oS, 60^oW) taken every 3 hours starting at 02h45 UT and made available by the provider (CIRA, Co, USA) about 1.5 hour after scan time. The operational version of the forecast programme currently in use only processes the 6.7 μm image, but an upgraded version that uses both 10.7 μm and 6.7 μm imagery is planned in 2001. The spatial resolution of GOES-8 imagery at 6.7 μm is 8 km x 8 km and the radiometric resolution is 10 bit. The count value is converted to a radiance, then to upper tropospheric humidity (UTH) corresponding to the relative humidity in the layer extending approximately from 550 mb to 300 mb.

2.3. Local Meteorology

The observatories are logging the data from automated meteorological stations once a minute. The main parameters are sent in real time to the archive database at the ESO headquarters. The forecast model can query the database and extract wind speed, pressure, temperature and humidity which are then used to adjust the long range forecasts as well as to anchor the default vertical profiles for the satellite PWV estimates.

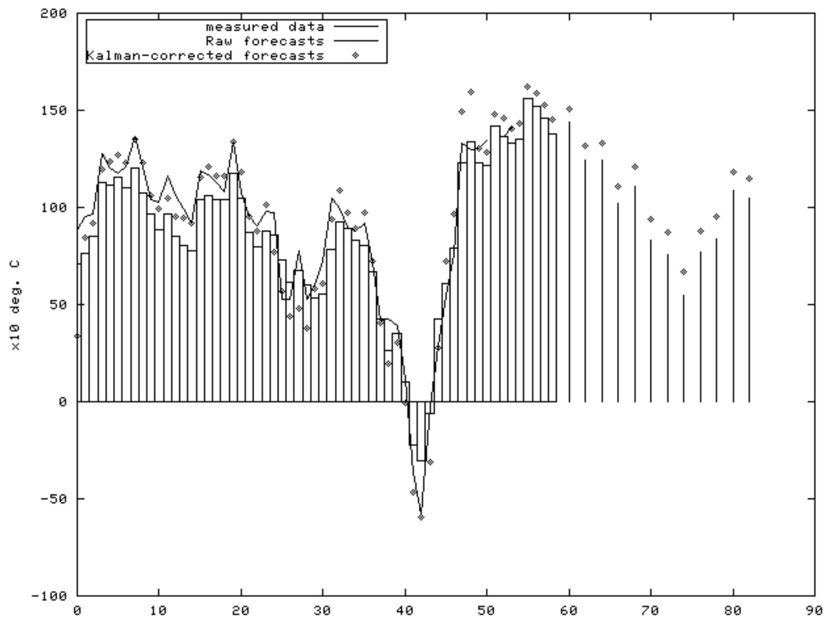

Figure 2. Paranal temperature measured locally (line) and forecasted by ECMWF 12 hours earlier with (dots) and without (bars) Kalman filtering. The x axis is in time units of 6 hour: a new forecast is issued at x=54, using the previous two weeks as a training database for the Kalman filter, the forecast covers the next day in 6 hours steps, then with 12 hours steps for the remaining 7 days. Negative temperature (associated to snowfall) occurring at x=42 had been correctly forecasted within better than 1 celsius.

3. Data Fusion

3.1. Forecasting local meteorology

The forecasting algorithms were implemented at ESO by (Labit, 1998) following the recommendations of a feasibility study conducted at CRS4, Italy (Benzi, 1996). The pressure, temperature and wind speed vertical profiles above each observatory are extracted from the ECMWF forecast using a bilinear interpolation: the four points of the ECMWF grid nearest to the site are isolated and the vertical profile is computed with respect to the distance between the site and the four points. The surface parameters at the altitude of the site is computed from ECMWF the standards levels using a cubic spline interpolation. This simple approach has the disadvantage that soil effects are not taken into account. For that reason, a Kalman filter previously trained on a data set composed of the last two weeks of surface meteorological records, is applied on the forecasts. The efficiency of this method is illustrated in Figure 2 for the short term temperature offsets, and Figure 3 for the seasonal pressure/altitude biases.

3.2. Forecasting precipitable water vapour

Precipitable water vapour (PWV) is computed from the atmospheric infrared emission counts measured on the satellite 6.7 μm images as described in (Erasmus & Peterson 1997). The forecast periods are each 3 hours in length, extending up to 24 hour ahead of the analysis time. For each forecast period, a semi-conically shaped area traces out the portion of the satellite image predicted to move over the site during that period. The most likely path is defined by a motion vector estimated from the wind at 500 mb forecasted by ECMWF using a dedicated algorithm.

3.3. Forecasting cloudiness

The shape of the analysis area is a 8 pixels wide circle, which represents the sky area as observed from the ground at the observatory down to 70 degree zenith distance for cirrus clouds traveling at about 12 km above see level. The cloud motion is then derived as for PWV.

The presence of cold cirrus clouds between the satellite and the water vapour layer increases UTH values of the 6.7 μm image. Threshold UTH values have been empirically defined to classify the pixels into as clear or having transparent or opaque cirrus. In the present release (Erasmus & Maartens 1999), a sky transparency index (TI$\in [0,1]$) is computed using the UTH of the transparent pixels when less than 10% of the pixels are opaque. The correspondence between this definition and the terminology of the tool used by astronomers for preparing the proposals (P2PP), and sky transparency as measured from the ground is shown in Table 1.

Table 1. Sky Quality Conditions from best to worse: table of correspondence for satellite based Weather_Watch (Table 2), P2PP terminology and the line of sight sky variability measured from the ground.

W_W	LowPWV	Nominal	HighPWV	Variable	Clouds	Overcast
P2PP		Photometric		Clear	Cirrus	N/A
Rms (%)		< 1		$1 < . < 10$	> 10	

4. Forecast Dissemination

Any individual can subscribe to the weather_watch mailing list sending an e-mail to majordomo@eso.org the body of which contains: *subscribe weather_watch-list* $<$ *myemail* $>$. Everytime a change of the forecasted situation is detected, an e-mail is then received which contains the forecasted event (see protocol on Table 2) along with the expected date and time of occurrence. As a check that weather_watch is alive and online, a message is sent every day at 13h35 UT in all circumstances. Following the "*no news is good news*" principle, new messages are sent in the intervals only when noticeable changes are forecasted. As 3-hourly satellite and 6-hourly meteo data assimilation and processing are not synchronized, a maximum of up to 12 messages per day can be issued when conditions are very variable.

Additional graphic displays are available on the ESO web at http://www.eso.org/gen-fac/pubs/astclim/forecast/meteo/ along with a direct access to forecasted data as original ascii files or via a java interface.

Table 2. Weather_Watch Message Protocol: definition of the limit conditions triggering the issuance of an updated e-mail bulletin.

Protocol	Terminology
Clouds	5% to 80% Cloudy Sky in a 3-hourly mean
HighPWV	Precipitable Water Vapour > 10 mm H2O
LowPWV	Precipitable Water Vapour < 1 mm H2O
LowPressure	Incoming Weather Front (±12 hours)
NegativeTemperature	Air Temperature < 0 Celcius (±1 C)
Nominal	Nominal Observing Conditions
Overcast	> 80% Cloudy Sky in a 3-hourly mean
StrongWind	Wind Speed at Ground Level > 15 m/s
VariableExtinction	< 5% Cloudy Sky and (> 25% Transparent Cirrus or Transparency Index< 0.9)

5. Forecast Verification

5.1. Surface Meteorology

The statistics of the forecast of surface meteorological parameters are given in tables 3, 4 and 5. With 12-hour forecast rms errors of the order of one Celcius and one mb respectively, temperature and pressure forecast skills with kalman filtering are considered satisfactory for the observatory purposes. On the other hand, because local winds in mountain areas are strongly influenced by mesoscale effects, wind velocity forecasts are not accurate enough due to the limited resolution (0.5^o) of the ECMWF terrain model. As can be expected Kalman filtering does not improve the performances in this case.

As illustrated in Figure 4, the timing accuracy of the forecast is not better than 12 hours in case of short scale rapidly moving weather features. The users are thus advised to account for a ±12 hours margin in time of arrival when low pressure is forecasted.

5.2. Clouds and Water Vapour

The PWV forecast verification tests presented on Table 6 have been made by comparison either with the subsequent satellite image, or with ground based infrared sky background measurements made with a dedicated monitor developed at Kitt Peak Observatory in the eighties. An rms error of the order of 1 mm H_2O has been obtained when anchoring the vertical mixing ratio profile to local temperature and humidity conditions recorded at the time of the analysis.

For the analysis of cloud forecast skill, four categories were defined as in Table 7. It is shown in Table 8 that only 50% of the cloudiness is correctly forecasted with the present release of the model. On the other hand the false alarm rate is much lower (8% and 11% yearly respectively at Paranal and La Silla to be compared to 20%, resp. 30%) than if clear sky was systematically forecasted.

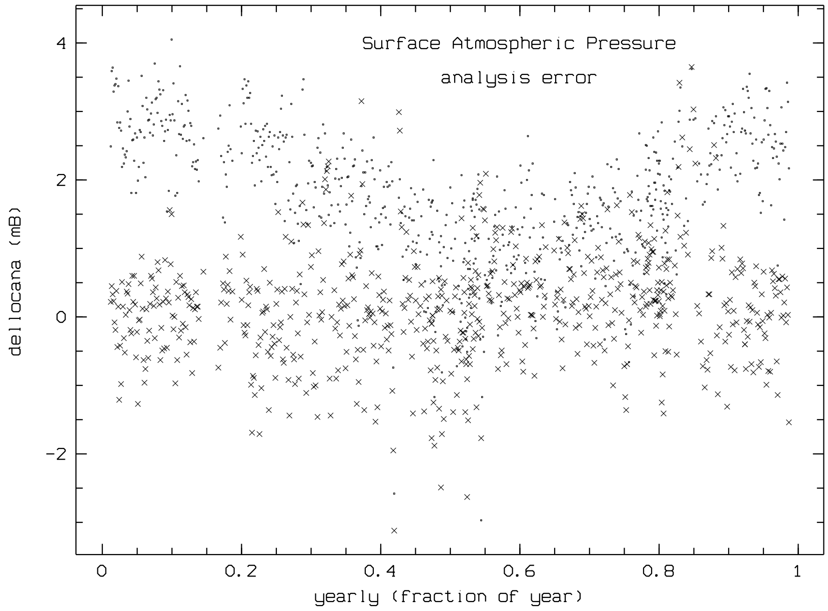

Figure 3. Yearly local pressure forecast error at Paranal with Kalman filtering (crosses) compared to raw forecasts (dots). Surface data is extracted by multiple interpolation as explained in § 3.1.

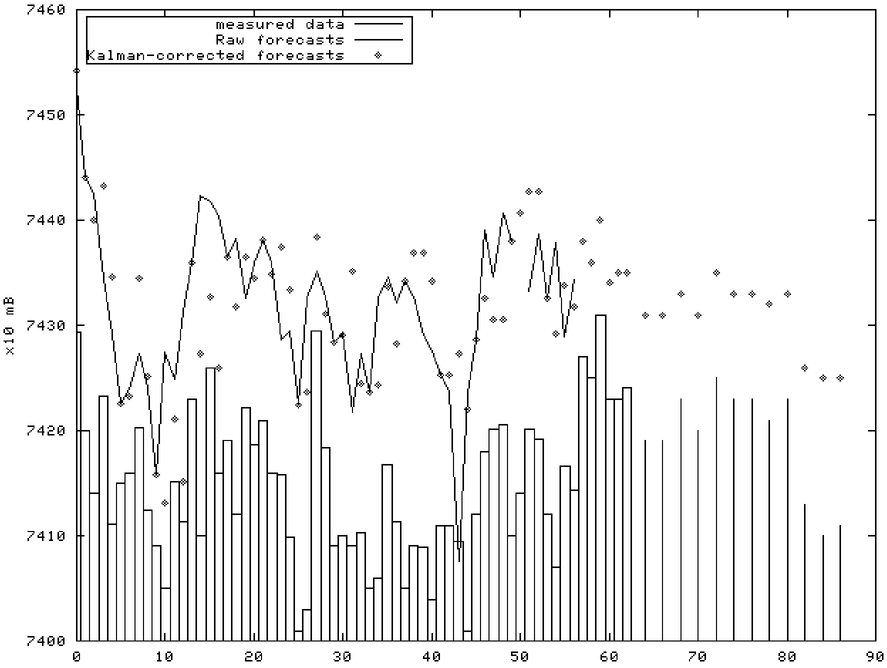

Figure 4. Mishap: atmospheric Pressure measured locally (line) and forecasted by ECMWF 12 hours before -unfiltered (bars) and with Kalman filtering (dots)- for 3 weeks by steps of 6 hours at Paranal. The low pressure forecasted at x=44 arrived indeed 6 hours in advance: rapidly rising fog forced the observatory to stop operation in some emergency.

Table 3. Statistics of surface temperature analysis and forecasting accuracy at Paranal Observatory during the period 01.05.99 to 25.10.2000. The twin numbers refer respectively to 00UT and 12UT ECMWF products (KF is for Kalman Filtered).

	Error in Celsius		
	mean	mean absolute	rms
Analysis	0.7/0.8	1.2/1.1	0.8/0.7
KF Analysis	-0.3,-0.3	1.2/0.8	1.1/0.7
KF t+12h forecast	0.2/0.5	1.0/1.1	0.7/0.8

Table 4. Statistics of surface pressure analysis and forecasting accuracy at Paranal Observatory during the period 01.05.99 to 25.10.2000. The twin numbers refer respectively to 00UT and 12UT ECMWF products (KF is for Kalman Filtered).

	Error in mB		
	mean	mean absolute	rms
Analysis	1.9/1.7	1.9/1.8	0.9/0.9
KF Analysis	0.1/0.2	0.7/0.5	0.6/0.5
KF t+12h Forecast	2.4/2.2	2.4/2.3	0.9/0.8

Table 5. Statistics of surface wind speed analysis and forecasting accuracy at Paranal Observatory during the period 01.05.99 to 25.10.2000. The twin numbers refer respectively to 00UT and 12UT ECMWF products (KF is for Kalman Filtered).

	Error in m/s		
	mean	mean absolute	rms
Analysis	3.4/4.0	3.8/4.2	2.8/3.0
KF Analysis	-0.4/0.5	2.9/2.6	2.4/2.0
KF t+12h Forecast	3.6/4.5	3.9/4.8	2.8/3.3

Table 6. Statistics of precipitable water vapour forecasting accuracy (mm H_2O) on all forecasts up to t+24 hours issued from 26.08.98 to 31.12.98, when comparing to ground based IR radiometer observations (Paranal only) and satellite based analyses, and when ground meteorology (local temperature and humidity) is available.

	Satellite Forecast		
Site	Paranal		LaSilla
Ground Meteorology	Yes	No	No
Ground Observed PWV	1.17	1.5	N/A
Satellite Observed PWV	0.98	1.58	1.23

Table 7. Cirrus cloud cover categories for testing forecast skill: when forecasted and satellite observed values are in the same category, a hit is counted. Neutral indicates values differ by one category and a miss by two or more categories.

Cloud Cover Category	% Total cirrus cloud	Fraction of sky that is clear
Clear	< 25	> 0.75
Mostly Clear	25-50	0.50-0.75
Mostly Cloudy	50-75	0.25-0.50
Cloudy	> 75	< 0.25

Table 8. Statistics of clouds forecasting accuracy (Table 7) on all forecasts up to t+24 hours issued from 26.08.98 to 31.12.98. Number in parenthesis are the results excluding clear days.

Site	Paranal	LaSilla
Hit	92.2 (55.5)	88.8 (51.6)
Neutral	3.7 (22.6)	4.1 (19.3)
Miss	4.0 (22.8)	7.1 (29.1)

6. Planned Improvements

Significant improvement in the forecast accuracy of low and middle altitude clouds, usually hidden by the water vapour layer in the 6.7μ m channel, may be expected with the planned inclusion of 10.7μ m satellite data as input to the forecast programme. While forecasts of clear and overcast sky are unequivocal for the end user, a scaling is also necessary for partially cloudy sky forecasts to be effectively used in astronomical queue scheduling. Attempts are made to derive a satellite transparency index (TI) which can be related to the rms of the atmospheric extinction measured from the ground with an optical telescope (Erasmus & Sarazin 2000).

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