Annexe

The work "A 52-year climatological study using NCEP/NCAR reanalysis data for the Paranal area", of Bustos [1] uses reanalysis data for the closest grid point, located 60 Km south-east of Paranal and a geopotential height (D-class variable) of 1,843 m.a.s.l. The results obtained in [1] were done for this grid point.

To study the NCEP/NCAR data for Paranal, an altitude correction is needed. The following figures are the same as in the previous work [1], but the data is corrected in the same method than the used in the work of Bustos et al [2] for Chajnantor.

In this case, the altitude difference between the NCEP/NCAR grid point (1,843 m) and Paranal (2,635 m) is 792 m.

1. PWV correction

Considering that the NCEP/NCAR reanalysis is giving the PWV for a grid point at 1,843 m and the Paranal site is at 2,635 m, a correction to the PWV for the height difference is needed. Here, only the height difference is corrected and other differences based on the geographical locations are not considered. If water vapour density is exponentially distributed in altitude [3], then

$$\rho(h) = \rho_0 e^{-h/h_0} \qquad \text{Eq. 1}$$

with ρ_0 the water vapor density at the ground (reference level) and h_0 the scale height factor for this distribution. For Chajnantor (5,050 m.a.s.l.), h_0 is 1,500 m [4]. For Paranal, h_0 can be considered to be 2,000 m. This value needs to be contrasted with the observed values at Paranal.

PWV is obtained integrating $\rho(h)$ over the entire atmospheric column from ground to an altitude h:

$$PWV = \int_0^h \rho_0 e^{-h/h_0} dh = \rho_0 h_0 \cdot \left(1 - e^{-h/h_0}\right) \qquad \text{Eq. 2}$$

when h is sufficiently large:

$$PWV \approx \rho_0 \cdot h_0 \qquad \text{Eq. 3}$$

The NCEP/NCAR data used here gives the value of PWV at a point at 1,843 [m], thus we can estimate the water vapor density at this surface by:

$$\rho_0 = \frac{PWV_{1843}}{h_0} \qquad \text{Eq. 4}$$

Considering an altitude of 2,635 [m] for Paranal and using Eq.1 and Eq. 4, then the water vapour density at 2,635 [m], 792 [m] above the grid point surface, will be given by

$$\rho(2635) = \frac{PWV_{1843}}{h_0} \cdot e^{-792/h_0} \qquad \text{Eq. 5}$$

Replacing ρ(2,635) in Eq. 3, the PWV at 2,635 [m] can be calculated as:

$$PWV_{2635} = PWV_{1843} \cdot e^{-792/h_0} \qquad \text{Eq. 6}$$

Replacing h_0=2000 [m] into Eq. 6 we obtain

$$PWV_{2635} = 0.6730 \cdot PWV_{1843} \qquad \text{Eq. 7}$$

From Eq. 7 we have that the PWV data from NCEP/NCAR reanalysis has to be multiplied by an altitude correction factor of 0.6730 in order to correct it for Paranal.

2. Temperature correction

The temperature of a dry air parcel decreases with its altitude at the *dry adiabatic lapse rate* $\mathbf{\Gamma_d}$ = 9.8 [ºC/Km]. Under saturated conditions, the saturated parcel's temperature decreases with altitude at the *saturated adiabatic lapse rate* $\mathbf{\Gamma_s} \cong 6.5$ [ºC/Km] [5]. Studying different radiosonde data at Chajnantor, variable lapse rates were found between 7 and 9.3 [ºC/Km]. If we consider an average lapse rate for Chajnantor of 8 [ºC/Km] to be similar for Paranal, the average temperature difference between the grid point and Paranal should be 6.34 [ºC]. This value also needs to be compared with radiosonde observations made at Paranal.

3. Pressure correction

For the case of pressure, an exponential decay with a scale factor H_0 is assumed:

$$p(h) = P_0 e^{-\int_0^h \frac{1}{H(h)} dh}$$

$$H(h) = \frac{RT(h)}{M_d g}$$

Where P_0 is the pressure at the ground level [mb], R is the molar gas constant, M_d is the molecular waight of "dry" air, and g the gravitational constant. Using an H_0 value of 8 km [5], the correction factor obtained using an altitude difference of 792 m is 0.9057.

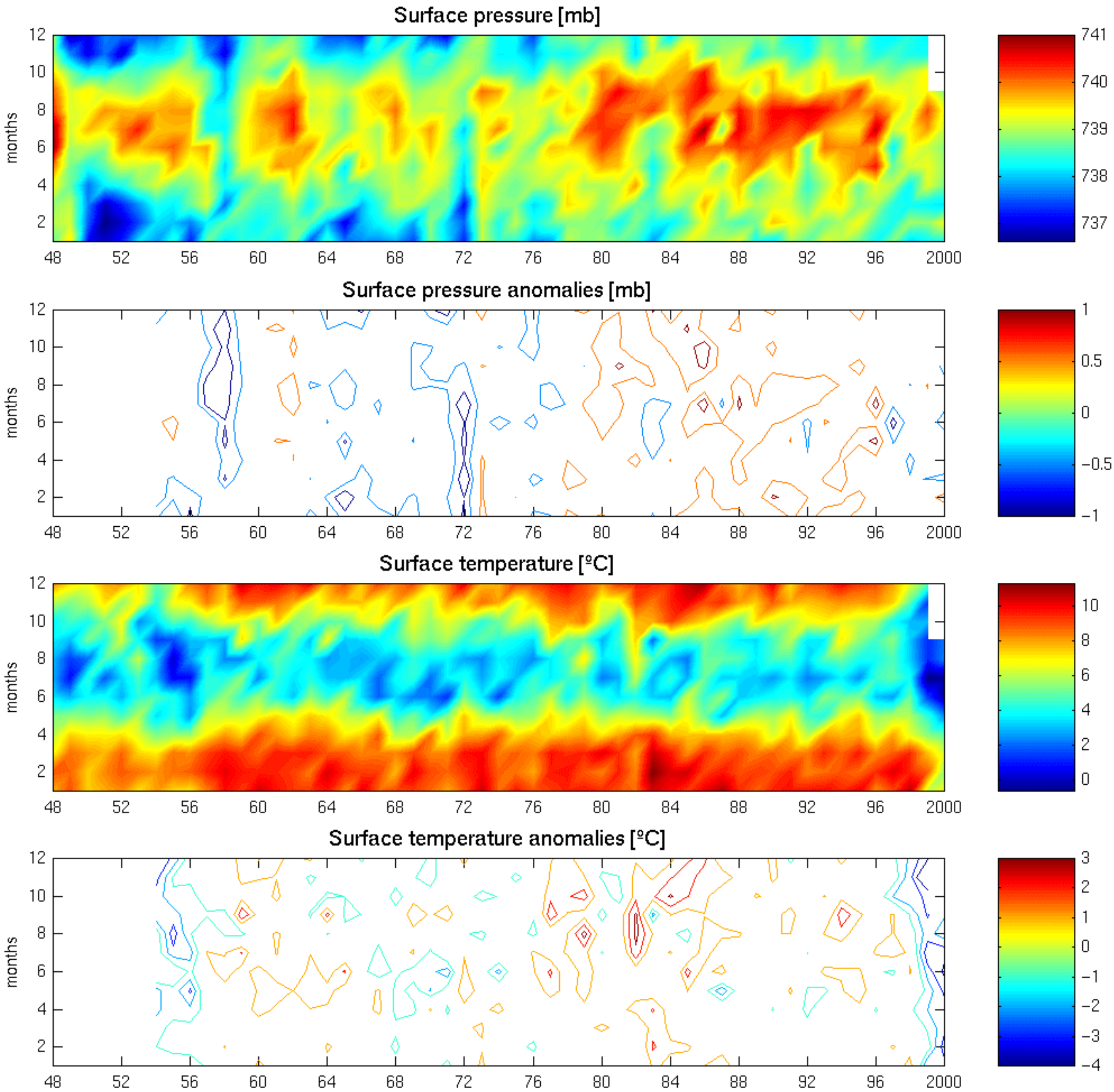

Surface pressure [mb]
months
741
740
739
738
737
Surface pressure anomalies [mb]
months
1
0.5
0
−0.5
−1
Surface temperature [ºC]
months
10
8
6
4
2
0
Surface temperature anomalies [ºC]
months
3
2
1
0
−1
−2
−3
−4
12
10
8
6
4
2
48
52
56
60
64
68
72
76
80
84
88
92
96
2000

Figure 1

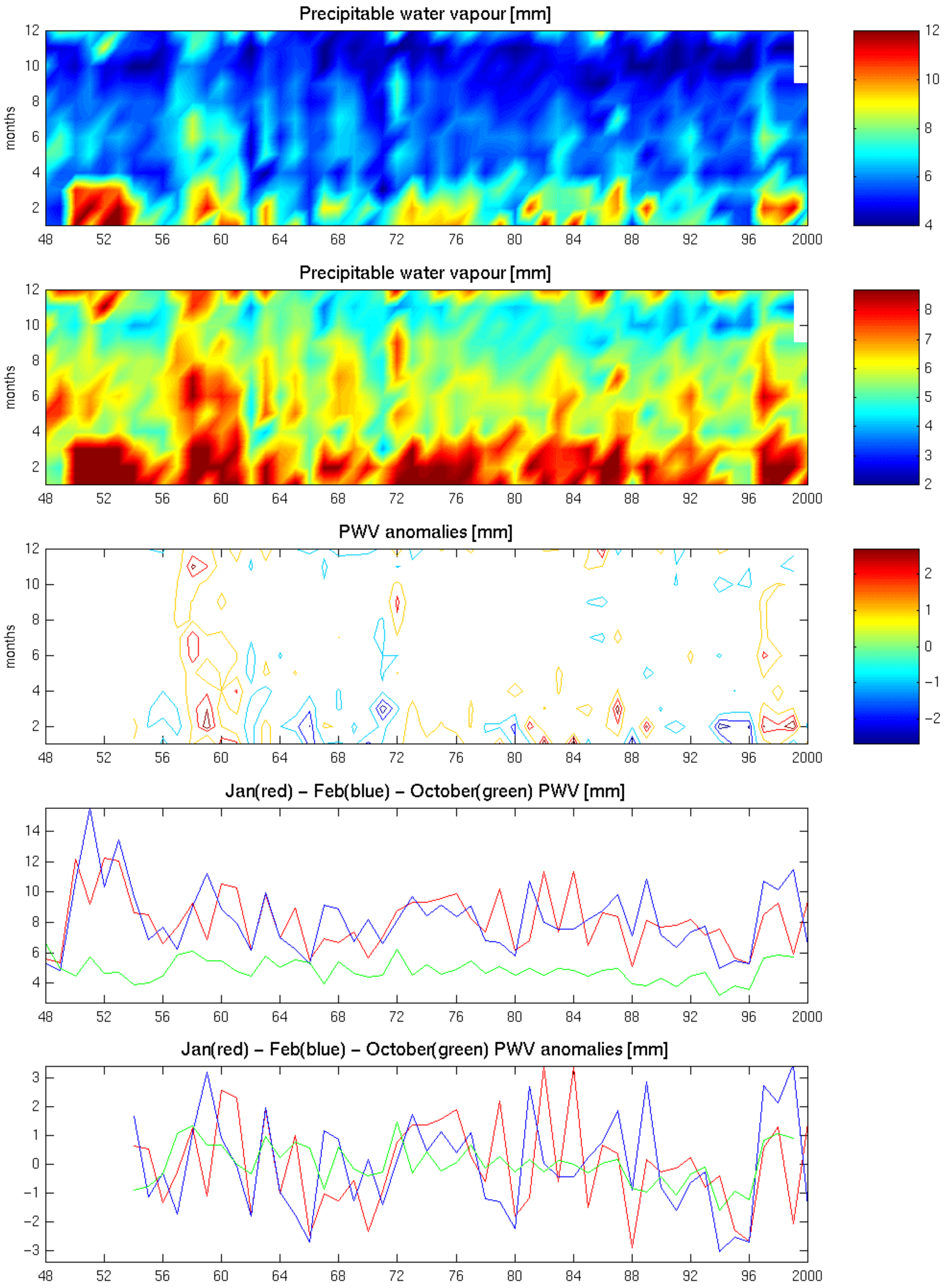
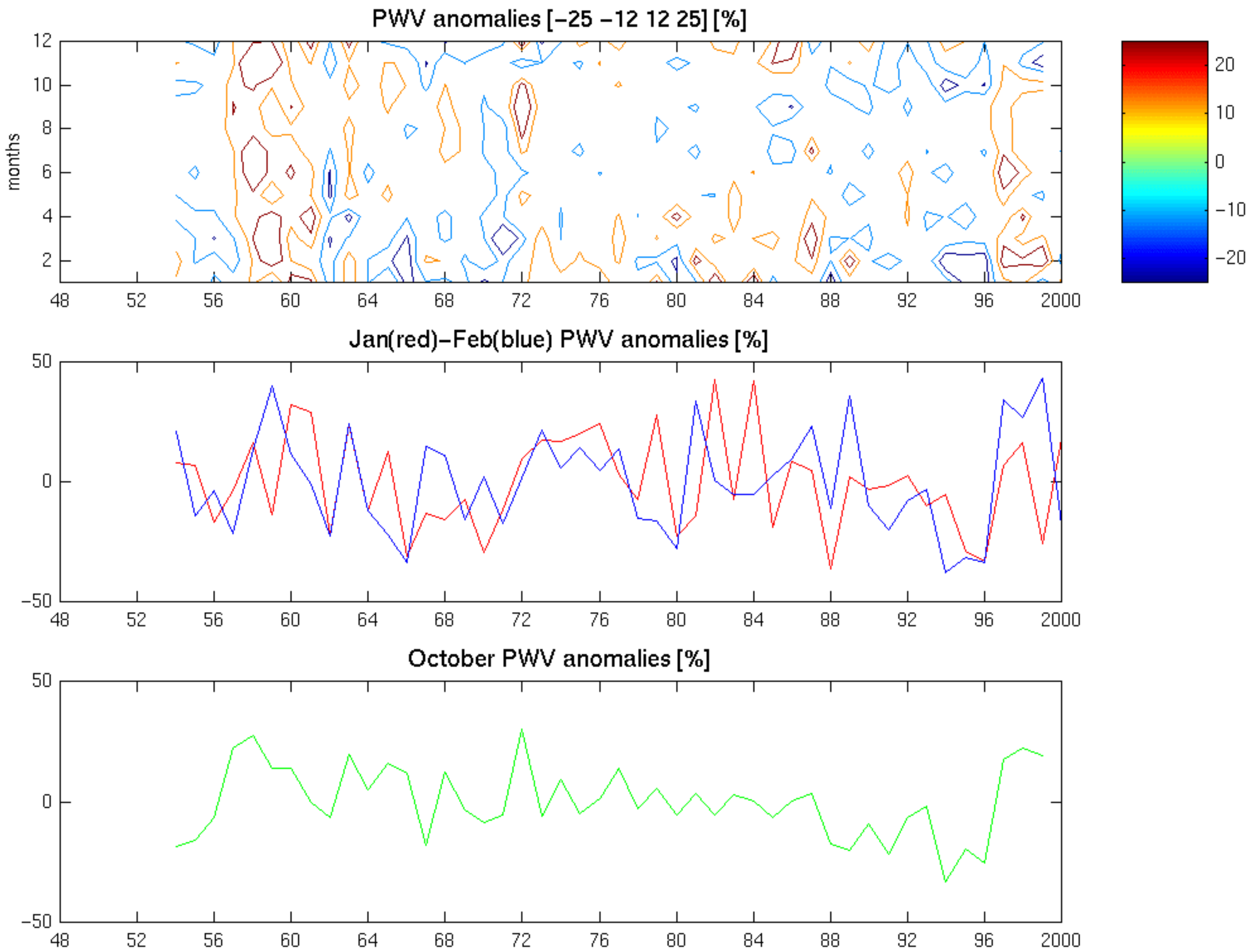

Precipitable water vapour [mm]
months
Precipitable water vapour [mm]
months
PWV anomalies [mm]
months
Jan(red) – Feb(blue) – October(green) PWV [mm]
Jan(red) – Feb(blue) – October(green) PWV anomalies [mm]
48
52
56
60
64
68
72
76
80
84
88
92
96
2000

Figure 2



PWV anomalies [−25 −12 12 25] [%]
months
Jan(red)−Feb(blue) PWV anomalies [%]
October PWV anomalies [%]

Figure 3

Conclusions

The data corrected in altitude presents differences only in absolute values for PWV, temperature, and pressure than the previous work of Bustos [1]. Variations, tendencies, and anomalies are the same for both sets of data.

During austral summer, the PWV monthly averages corrected for Paranal show values between 5 and 12 mm and the anomalies do not exceed more than ± 3.3 mm throughout the years (except for the 1949-1953 period, considered an overestimation of the reanalysis due to poor observational data).

The altitude correction factors for PWV, temperature, and pressure have to be compared with the observed at the Paranal site.

7.- References

[1] Bustos, R., 2000: "A 52-year climatological study using NCEP/NCAR reanalysis data for the Paranal area". Internal report, European Southern Observatory, Paranal Observatory.

[2] Bustos, R., Delgado, G., Nyman, L., and Radford, S., 2000: "52 years of climatological data for the Chajnantor area" ALMA Memo Series No. 333.

[3] Thompson, A., Moran, J., and Swenson, G., 1994: "Interferometry and Synthesis in Radio Astronomy". Krieger Publishing Company

[4] G. Delgado, A. Otárola, R. Booth, V. Belitsky, D. Urbain, R. Hills, and Y. Robson, "Phase Correction of Interferometer Data at Mauna Kea and Chajnantor," to be submitted to the ALMA Memo Series, 2000.

[5] Salby, M. L., 1996: "Fundamentals of Atmospheric Physics". Academic Press, San Diego.

Annexe

A 52-Year Climatological Study
For the Paranal Area
Using NCEP/NCAR Reanalysis Data

Ricardo Bustos Placencia
Civil Electrical Engineer
University of Chile
Email: rbustos@dgf.uchile.cl

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Paranal Observatory

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