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USING RE-ANALYSIS MODEL DATA TO ANALYSE CLIMATE TRENDS RELATED TO THE ASTROCLIMATOLOGY OF PARANAL AND LA SILLA

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RESUMEN

Este trabajo consiste en un resumen de los resultados de dos ejercicios de investigación separados. En la primera parte, se examinó la correlación entre magnitudes estadísticas de tiempos de observación astronómica nocturna (*seeing y fracción fotométrica nocturna*) para los observatorios Paranal y la Silla de ESO y 35 variables de reanálisis de ERA-40 y NCEP-NCAR (disponibles con el software FriOWL), usando la información de los reanálisis desde la coordenadas más cercana a los observatorios. Los resultados confirman que los datos de fracción fotométrica nocturna en ambos observatorios están mejor descritos que los datos de seeing. La relación más fuerte se encontró en La Silla, debido a su localización baroclínica más hacia el sur. Los datos de emisión de radiación de onda larga (OLR) se desempeñan tan bien o mejor que los datos equivalentes de cubierta nubosa en los reanálisis ERA-40. En la segunda parte del estudio, la herramienta FriOWL se usó en un análisis de la climatología del Norte de Chile para determinar las causas del deterioro en las condiciones astronómicas de seeing en Paranal desde 1998. Los resultados muestran que ha ocurrido un gran incremento en la altura geopotencial de 1000 hPa al Sureste de Paranal en el período 1998–2007, cuando se comparó con los nueve años anteriores. Este incremento, sin embargo, no se observa en los niveles de 700, 500 y 200 hPa. En el mismo período también ocurrió un corrimiento hacia el sur en el eje de altura geopotencial cercana a superficie desde 21°S a 25–27°S. Además, parece que existe un vínculo entre los cambios de fase de la oscilación interdecadal del Pacífico y anomalías de circulación atmosféricas sobre la región del Pacífico.

ABSTRACT

This paper consists of a summary of the results of two separate research exercises. In the first part, the relationship between astronomical night-time viewing statistics (*Seeing* and *Photometric Night Fraction*) from ESO Paranal-La Silla observatories and thirty-five ERA-40 and NCEP-NCEP re-analyses variables (available with the FriOWL software) were examined for correlation, using data from the re-analysis model gridpoint closest to the two observatories. The results confirm that the photometric night fraction datasets of both observatories are better described than are the seeing datasets. The strongest relationships are found at La Silla due to its more southerly, baroclinic location. Interestingly, the NOAA outgoing longwave radiation (OLR) dataset performs equally well, or better than its equivalent ERA40 re-analyses cloud cover dataset. In second part of this study, the FriOWL tool was used in an analysis of the climatology of northern Chile region, to help determine the cause of a deterioration in astronomical seeing conditions at Paranal from 1998 onwards. The results show that an exceptional increase in 1000hPa geopotential height has occurred to the south-east of Paranal over the 1998–2007 period, when compared to the previous nine-year period. This increase is not replicated at the 700, 500 or 200 hPa levels, however. A shift south in the axis of near-surface geopotential heights from 21°S to 25–27°S has also occurred over the same period. Furthermore, there appears to be a link between phase shifts of the Interdecadal Pacific Oscillation, and atmospheric circulation anomalies over the Pacific region.

Key Words: atmospheric effects — methods: data analysis — site testing

1. INTRODUCTION

This paper presents the results of two separate applied studies using FriOWL (Graham et al. 2005, 2008; Graham 2008a,b) climate re-analysis datasets. In the first study, over fifteen years of FriOWL data are compared to the long-term monthly mean Paranal and La Silla astroclimatological statistics (*Seeing* and *Photometric night fraction* data). The

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second study uses a selection of FriOWL climate maps to analyse whether changes in atmospheric circulation in the northern Chile region are linked to perturbations in the Paranal monthly mean seeing record (Beniston et al. 2002; Graham 2008b).

2. PART I: SIMPLE AND MULTIPLE LINEAR REGRESSION ANALYSES

Simple and multiple linear regression analyses were carried out between fifteen years of mean monthly re-analysis data (for 35 different atmospheric variables; see full list in Graham 2008b, p. 7) and the monthly mean Paranal and La Silla Seeing and Photometric night fraction data series (available on the European Southern Observatory website at `http://www.eso.org/gen-fac/pubs/astclim/` Accessed 8 March 2011). The climatological data was taken from the gridpoint (pixel) closest to each observatory.

As the re-analyses data for each observatory are gridpoint values, this part of the study was comprised of using 1-dimensional values extended through time, and comparing these to the 1-dimensional times series of the astroclimatological parameters. Thus, the use of simple and linear regression analyses in this exercise are only valid in terms of the absolute value of the climate variables, and not on the relative value of each variable compared to its neighbours (this is relevant for e.g. wind, which depends on the pressure gradient [*rate of change of pressure*] across several pixels, and not on the absolute value of pressure at any one pixel point). So, insofar as linear regression between point values can be justified, the following results were found (a more detailed summary can be found in Graham 2008b):

- At Paranal, 42% of total variation of monthly mean photometric night fraction can be explained by NOAA outgoing longwave radiation (OLR), which performs better than the ERA40 high cloud cover fraction. It is thought that this is because the NOAA OLR dataset is a direct measurement of radiance; the ERA40 values are model parameterisations, which are generally poor for clouds. Furthermore, 55% of the total variation of Paranal mean monthly seeing can be explained by a combination of NCEP-NCAR 1000 hPa geopotential height, surface relative humidity and ERA40 surface wind.

- At La Silla, only 40% of total variation of La Silla monthly seeing can be explained by a combination of ERA40 windspeed at 500 hPa, NCEP-NCAR surface relative humidity and 1000 hPa geopotential. However, up to 66% of total variation of mean monthly photometric night fraction is explained by combination of NOAA outgoing longwave radiation (OLR), ERA40 high cloud cover and integrated water vapour at 500 hPa.

- Overall, only around 50% of variability of mean monthly seeing and photometric night fractions are described by the re-analysis data at both observatories. The strongest relationships occur during the spring and autumn seasons and during baroclinic weather conditions (most common at La Silla).

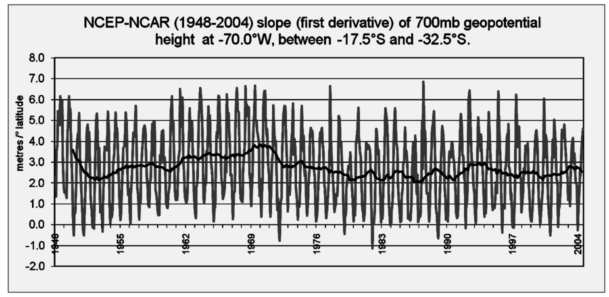

Fig. 1. Monthly time series of the first derivative (gradient) of the slope of 700 hPa surface at 70.0°W, from $-32.5°$ to $-17.5°$S, using FriOWL NCEP/NCAR data (1948–2004). There is a strong seasonal variation with highest values during the southern winter, and occasional negative values during the summer indicating an occasional reversal of westerly winds to easterlies. Also plotted is the long-term mean (thick black line).

3. PART II: CLIMATE CHANGE CIRCULATION STUDIES

As the first part of this study showed, only moderate relationships between the monthly mean FriOWL climatological data and the astronomical viewing statistics for Paranal and La Silla were discovered. In an effort to establish stronger links between atmospheric circulation values and perturbations in the Paranal seeing record, the geopotential height of various pressure levels were examined in detail. The slope of geopotential height of a certain pressure level strongly controls the windspeed and wind direction at that height.

Figure 1 presents the first derivative (gradient) of the slope of 700 hPa surface fixed at 70.0°W, from $-32.5°$ to $-17.5°$S, as determined from the FriOWL NCEP-NCAR data (1948–2004). In other words, this graph shows the temporal variation of the strength of the westerly/easterly component of the 700 hPa geostrophic winds. There is a strong seasonal variation in the slope with highest values during the winter, and occasional negative values during the summer – implying occasional easterly

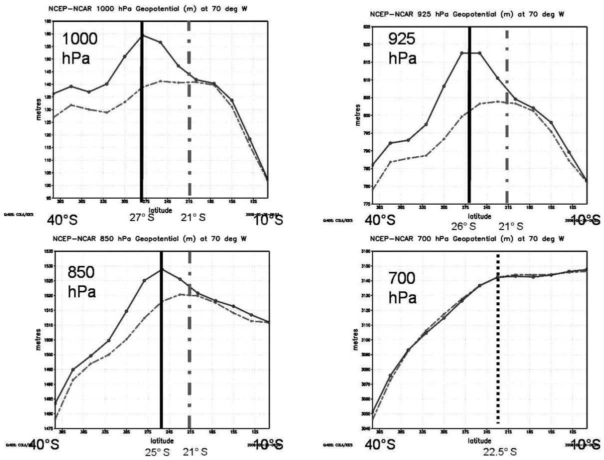

Fig. 2. The shift south of the axis of highest NCEP/NCAR geopotential heights (solid black vertical line) at 1000 hPa (top left), 925 hPa (top right), 850 hPa (bottom left) and 700 hPa (bottom right), from 10° to 40°S, for 1987–1998 (grey dashed line) and 1998–2007 (solid black line) at 70°W.

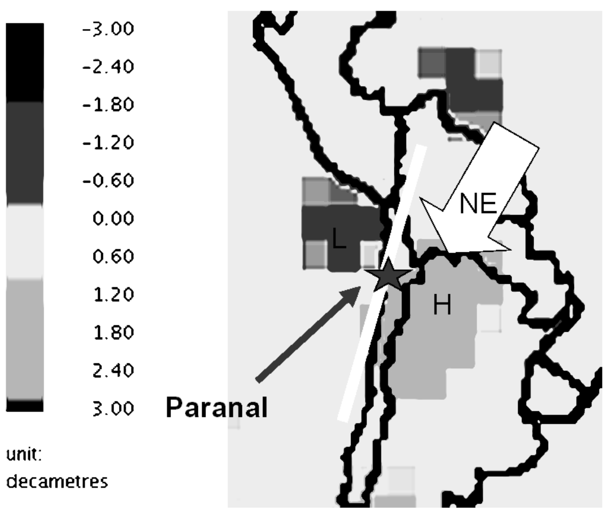

Fig. 3. FriOWL map of the difference in the geopotential height of the 1000hPa surface (in tens of metres) between 1998–2007 and 1987–1998. A large increase ("H") has occurred to the south-east of Paranal, whereas a decrease in height ("L") has occurred to the north-west. The resultant anomalous geostrophic wind direction is therefore north-easterly (indicated by large arrow "NE").

winds. There does not appear to be any long-term trend in the dataset, however.

Meanwhile, Figure 2 shows that the axis of the highest geopotential heights at 1000 hPa, 925 hPa, 850 hPa has shifted southwards by 4° to 7° latitude over the period 1998–2007, when compared to the earlier 1987–1998 period. No change is apparent at the 700 hPa level, however. This means that an easterly (offshore) component of wind has become more common in northern Chile in the lower levels of the atmosphere.

At the same time, Figure 3 presents a FriOWL map showing the difference in geopotential height of the 1000 hPa surface (in tens of metres) between 1998–2007 and 1987–1998. A large increase ("H") has occurred to the south-east of Paranal, whereas a decrease in height ("L") has occurred to the northwest. The resultant anomalous geostrophic wind direction is therefore north-easterly (indicated by large arrow "NE"), which had been shown to be the direction from which the poorest seeing conditions at Paranal arise (Naverette 2005). For further information, please see Graham (2008b). Furthermore, there appears to be a link between phase shifts of the Interdecadal Pacific Oscillation (IPO) and atmospheric circulation anomalies over the Pacific region, and this is possibly responsible for change of wind directions and increased seeing at Paranal since 1998 (Graham 2008b). If these occurrences are real, they may have strong implications for Chilean astroclimatology. Further research is encouraged, however. As also described in Graham (2008b), a new atmospheric circulation index (known as "PAR"), based on differences of 1000 hPa heights at 30°S over Chile and the near-Pacific region, captures well the post-1998 variability of Paranal seeing.

4. SUMMARY AND CONCLUSIONS

The astronomical night-time viewing statistics (Seeing and Photometric Night Fraction) of ESO Paranal and La Silla observatories were examined and compared to 22 years of thirty-five ERA-40 and NCEP-NCEP climate model re-analyses variables, available on the FriOWL website. The results show that the mean monthly astroclimatological statistics of both observatories are only moderately explained by time series of FriOWL data; the strongest relationships are found at La Silla due to its more southerly, baroclinic location where this is a stronger seasonal variation in weather than at Paranal. The Photometric Night Fraction datasets of both observatories correlate better with the NOAA outgoing longwave radiation (OLR) dataset than with the ERA40 cloud cover variables – presumably because the ERA40 data are based on parameterisations, whilst the NOAA data are direct measurements. Paranal seeing is mostly closely related to the NCEP-NCAR reanalysis geopotential height at 1000 hPa.

The FriOWL tool was used in an analysis of the temporal variations of atmospheric circulations over the northern Chile region, to help determine the cause of a deterioration in astronomical seeing conditions at Paranal from 1998 onwards. An exceptional increase in 1000hPa geopotential height has occurred to the south-east of Paranal over the 1998–2007 period, when compared to the previous 1989–1998 period, but this increase is not replicated at the 700, 500 or 200 hPa levels. A shift south in the axis of near-surface geopotential heights from 21°S to 25–27°S has also occurred during this time. Furthermore, there appears to be a link between phase shifts of the Interdecadal Pacific Oscillation (IPO) and atmospheric circulation anomalies over the Pacific region; further research is encouraged.

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