Interactive comment on "Temperature trends at the Mauna Loa Observatory, Hawaii" by B.D. Malamud, D.L. Turcotte, C.S.B. Grimmond

B.D. Malamud *et al.*

bruce.malamud@kcl.ac.uk

Reply to Referee and Editor Comments

We thank the two anonymous referees and the editor, Volker Rath, for their stimulating and helpful comments on the manuscript cpd-6-1685-2010 (Malamud *et al*, 2010). We have done further analyses to address some of the concerns raised, along with expanding the text in certain locations and correcting some typos; we believe the result is a substantially improved paper. We have divided our response below into responding to the editor and each anonymous referee separately. Any page numbers referred to below are the original cpd manuscript submitted.

I. EDITOR COMMENTS AND AUTHOR RESPONSE

[Editor]: "Dear Authors, having received two favourable reviews in the open discussion period, I would like to ask you to carefully answer these comments, and to invite you to submit a revised manuscript to CP, incorporating the reviewers suggestions and answering their questions. In particular I would ask you to discuss the possible use and impact of your results in climate science."

[Author Response] Thank you for drawing our attention to highlighting the use of our paper in climate science. To address this in a concise manner, we propose adding the following sentence to the end of the paper "These trends are consistent with the observed increases in the concentrations of CO_2 and its role as a greenhouse gas, and indicate the possible relevance of the Mauna Loa temperature measurements to global warming." This is reproduced from the original manuscript abstract, but was not highlighted enough in the actual paper itself, particularly as a conclusion. In addition, we have added a couple sentences (response 'a2' to Reviewer 2, Section III below) of the relevance of our studies.

II. ANONYMOUS REFEREE #1 COMMENTS AND AUTHOR RESPONSE

(a) [Referee 1, Comment 1] "Article is well written and technically sound."

(b1) [Referee 1, Comment 2] "The only point, which the authors may wish to address is the fact that a key result of the study finds a strong agreement between the changes in temperature at Mauna Loa and the local radiative forcing from the enhanced GHG."

(b2) [Author Response] We thank the referee for drawing our attention to the fact we have not highlighted this key result enough. In the last sentence of the original manuscript's abstract we will add the words "(demonstrated here by first-order radiative forcing calculations)" to become "These trends are consistent with the observed increases in the concentrations of CO_2 and its role as a greenhouse gas (demonstrated here by first-order radiative forcing calculations)…"

(c1) [Referee 1, Comment 3] "The authors do point out that large-scale climate modes such as the PDO influence the behaviour of the temperature field at this site, but since the agreement with the radiative forcing appears quite strong, it begs the question of what the quantitative influence of changes in SST patterns in the region of Hawaii may have been."

(c2) [Author Response] To explore one aspect of this comment, we examined NCEP monthly reanalysis data (Kanamitsu *et al.*, 1996; NOAA ESRL, 2010) for Sea Surface Temperature (SST) for a region of 18.1 to 21.9 °N and 153.8 to 157.5 °W, and for the period 1977–2006. This 3.8° x 3.7° region contains the Mauna Loa Observatory (MLO) site in Hawaii, and reflects the temporal pattern of SST in the region of Hawaii. The resultant trend (see **Fig. S1**, this reply) of SST as a function of year, gives a gradient over the 30 year period of 0.018 °C y^{-1}, which is the same value we report in our cpd manuscript for that found by the IPCC (2007) for 1980–2005 worldwide (p. 1690, lines 1−2). We believe that adding these new results (without the figure), just after the first sentence of p. 1689, line 25, will strengthen our overall presentation of temperature trends, going from one single instrumental station (micro-climate), to a regional area surrounding the station, and finally to the global results.

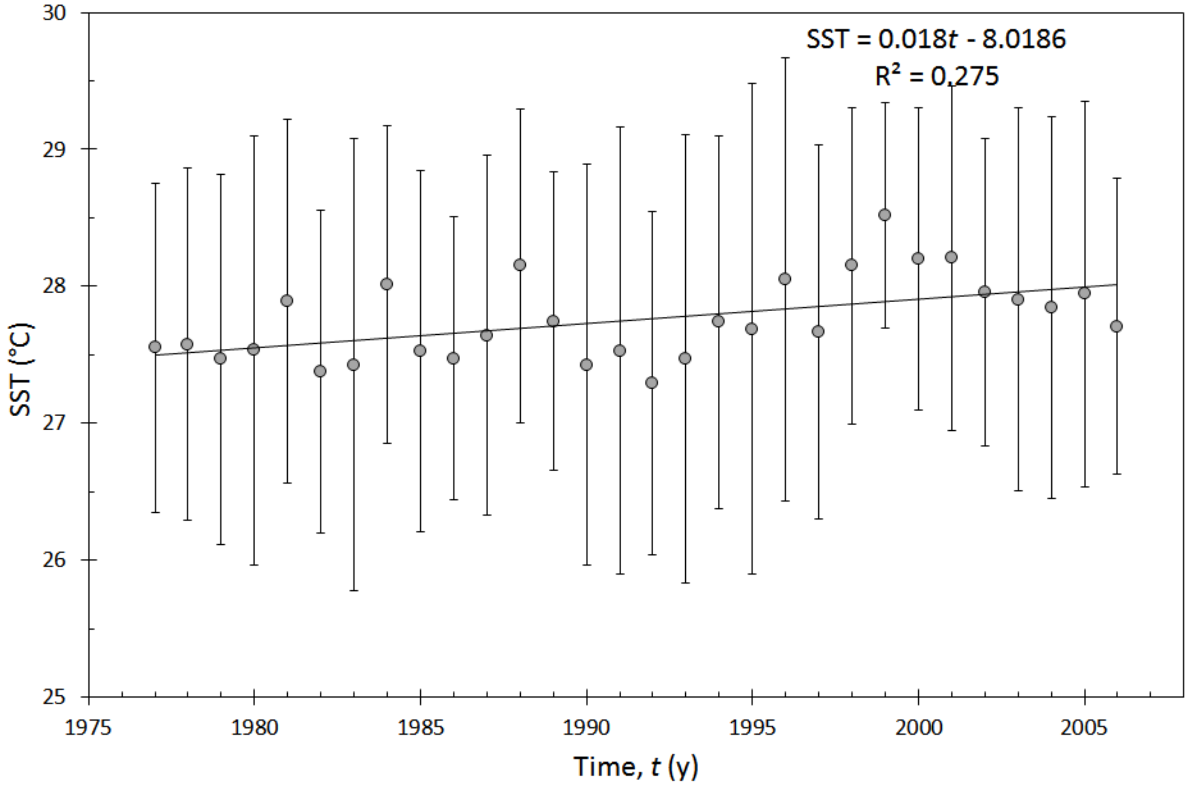

Fig. S1. NCEP monthly reanalysis data (Kanamitsu *et al*., 1996; NOAA ESRL, 2010) for Sea Surface Temperature (SST) for a region 18.1–21.9 °N and 153.8–157.5 °W, 1977–2006. Circles represent the mean of the monthly SST values for a given year, with error bars ±1 standard deviation of the 12 monthly SST values. Also include is the best-fit linear trend for the mean yearly SST values as a function of time, *t*.

III. ANONYMOUS REFEREE #2 COMMENTS AND AUTHOR RESPONSE

(a1) [Referee 2, General Comments] "The study analyzes long-term trends of the hourly temperatures and the DTR at the Mauna Loa observatory. This location best represents an open area with no anthropogenic influence. The nocturnal warming and the decrease of the DTR found in Mauna Loa strengthens some previous studies arguing that regional and global warming are not a reflection of urban heat island (UHI, e.g., Parker 2006, 2010). Thus, the study can contribute to the scientific discussion on global warming and deserves publication, subjected to a major revision based on the following comments."

(a2) [Author Response] Thank you. Based on these general comments we propose adding the following: "This site provides another example of an area with minimally-varying site characteristics, such as found in (often old) cities (Parker, 2006, 2010; Jones and Lister, 2009), which have been used to detect regional to global warming trends. The micro-scale temporal consistency of the surroundings of the site, allows detection of macro-scale (i.e., regional to global) warming trends."

(b1) [Referee 2, Specific Comment 1] "Measurements of CO_2 concentrations at Mauna Loa observatory have been widely taken as representative of global average values (IPCC, 2007). However, temperature trends widely differ among regions. While there is a global warming, there are large variations in its rate among various parts of the world and in some regions there is even cooling. Moreover, trends can be

different and even opposite between the seasons and the annual temperature trend does not reflect this complexity. The authors should stress the difference between global and regional temperature trends, unlike CO_2 *concentrations, and present the regional temperature trends for the study region including the differences between the seasons."*

(b2) [Author response] We thank the reviewer for this comment, and will address it with the following responses:

(i) We will better stress the difference between global and regional temperature trends in the text.

(ii) We have presented regional temperature trends (on a yearly basis) in our response to referee 1 and **Fig. S1**.

(iii) We have defined four seasons and repeated our analyses, originally presented in **Fig. 2** (original manuscript). In **Fig. S2a**, we find that d*T*/d*t* for summer is very similar to all months considered together, but other seasons are systematically higher or lower. We further quantify and visualize the difference between the seasons by examining the mean number of hours per day that d*T*/d*t* is in a 'given' d*T*/d*t* range (**Figs. S2b** and **S2c**).We will discuss these results in our revised manuscript, as they highlight the clear systematic changes in number of hours d*T*/d*t* is in a given range, going from spring, summer, fall, to winter.

(iv) We then use winter and summer from **Fig. S2**, and repeat our analyses of **Fig. 3** (original manuscript), with results given in **Fig. S3**. We find that the gradients in **Fig. S3b**, d(DTR)/d*t*, are very similar whether examining 'all months', summer or winter.

We believe the addition of these two figures (with minor formatting changes to clean them up) to our original manuscript will strengthen the overall quality of the manuscript, so thank the reviewer for encouraging us to do this.

(c1) [Referee 2, Specific Comment 2] "Different causes can explain the slight cooling trend in the maximum temperature against the nocturnal (and average) warming, and thus the decrease in the DTR. The authors should discuss potential causes for the trends found, such as changes in wind velocity, cloud cover and variations in the occurrences and intensity of the regional synoptic systems. It is recommended, if possible, to analyze long-term trends of these factors and correlate them with the temperature and DTR trends."

(c2) [Author Response] We agree with the reviewer there are various potential causes for the trends found, and these will be mentioned in the manuscript. However, because of feedbacks, it is hard to separate cause from effect. We would expect changes in temperature to impact and be impacted by cloud cover, wind, etc., on the micro-scale and indeed all scales. For this locality and the 30 years of hourly records, we downloaded from NOAA (2011a) (hourly) wind, pressure (then the first difference, hourly pressure change, as a proxy for wind, as the wind data was missing multiple values), [temperature], and precipitation. We also examined hourly downwelling solar radiation (NOAA/ESRL/GMD radiation archive, 2011b). We performed a suite of 'first-order' correlation and trend analyses on hourly, and yearly means, by time of day (for an example of just 'one' of these analyses, see **Fig. S4**), but found that initial analyses of this data has not provided any clear explanation between variables. Doing an authoritative study and discussion for separating cause and effect is very difficult in this case and would require a significant physically-based modelling study, which we believe is outside the scope of what we originally intended for this paper.

(d1) [Referee 2, Specific Comment 3] "Table 1 presents temperature trends for different locations and study periods. The discussion on the results presented in this table should be extended beyond the explanations suggested by the authors (the continental location or anthropogenic effects) and consider also potential regional and local causes, as specified above."

(d2) [Author Response] This suggests that it is worth investigating the role of micro, regional and global scale processes (e.g. cloud cover, wind, synoptic regional patterns). We will extend the discussion and mention these different factors.

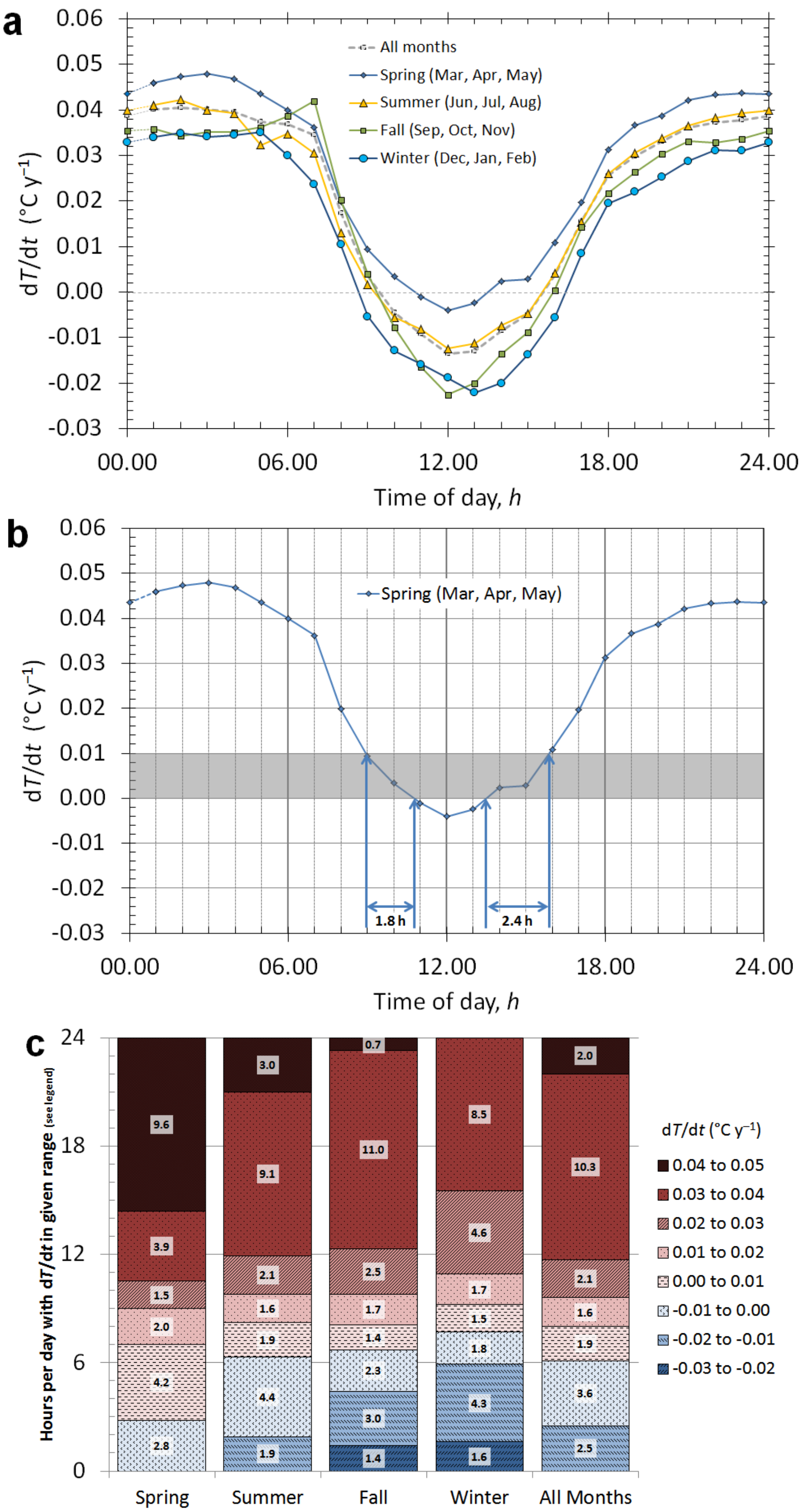

Fig. S2. Best-fit trend-line slopes, d*T*/d*t*, for the 30-year Mauna Loa data (NOAA, 2011a) as a function of time of day, *h*, as a function of season and all months together: **(a)** Annual mean rates of warming (cooling) d*T*/d*t* are given for 'all months' (dashed line here, same as **Fig. 2b**, original manuscript), and four seasons, spring (March–May), summer (June–August), fall (September–November), winter (December–February). **(b)** Example of calculating the mean number of hours that d*T*/d*t* is in a given range of values, here done for $0.00 \leq dT/dt < 0.01$ °C y^{-1} and spring, i.e. 4.2 h (light pink cross hatch, **Fig. S2c**). **(c)** Number of hours per day d*T*/d*t* is in a given 'range' (see legend) going from 'cooling' (blue) to warming (pink/red), as a function of four seasons and all months together.

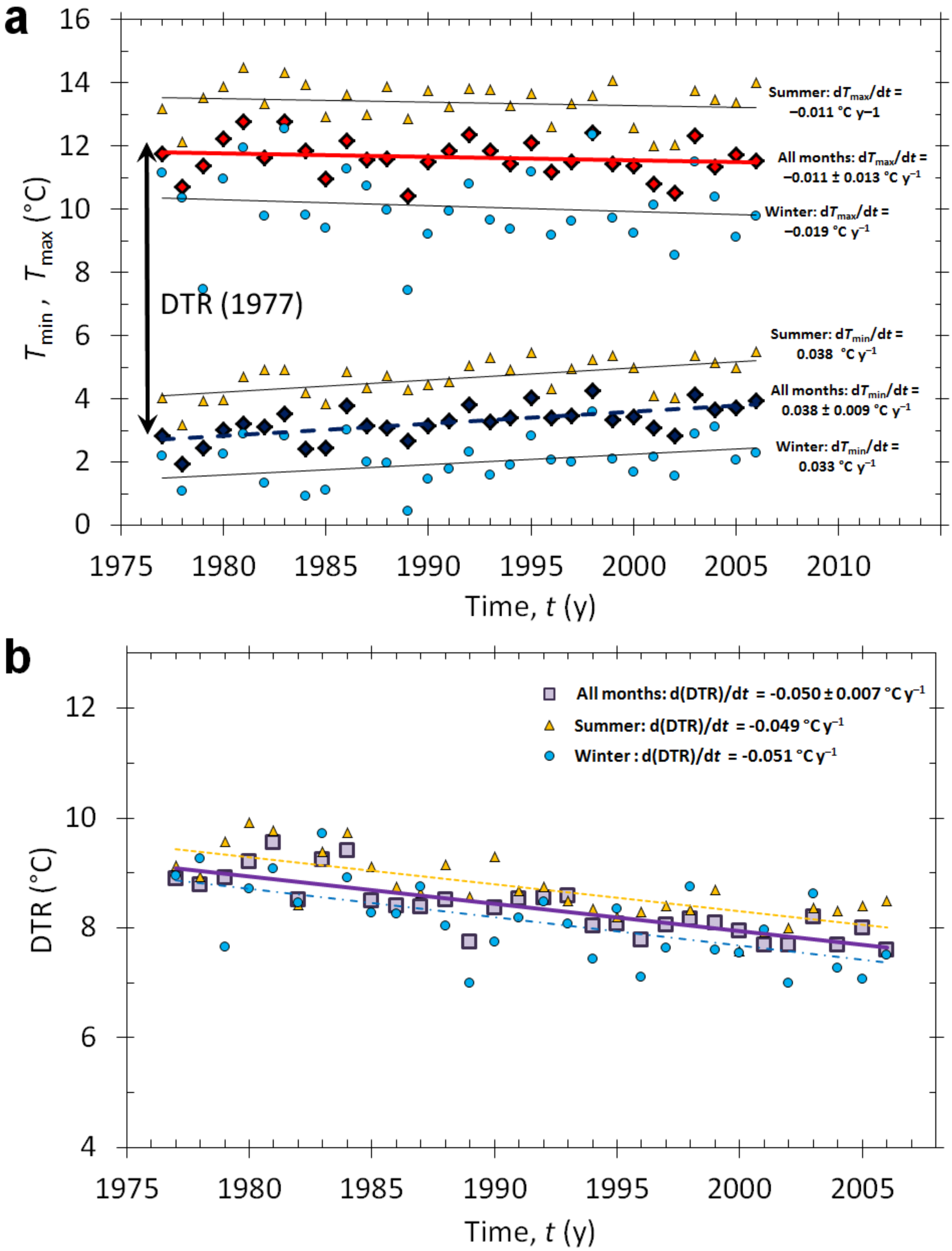

Fig. S3. Mean annual maximum and minimum temperatures, and diurnal temperature ranges (DTR) for the 30-year Mauna Loa data (NOAA, 2011a), given for all months during the year, summer (June-August) and winter (December-February). **(a)** The sequence of annual mean maximum temperatures T_{max} and minimum temperatures T_{min} are given as a function of time *t* for 1977–2006, for all months considered together (diamonds, same as **Fig. 3a**, original manuscript), summer (triangles) and winter (circles). The best-fit linear trends of the annual values are shown along with their slopes (±1 s.e. of the slope, for "all months"). **(b)** The annual mean values of DTR are given as a function of time *t*, for all months considered together (squares, same as **Fig. 3b**, original manuscript), summer (triangles) and winter (circles). The best-fit linear trend (solid lines) of the annual values are shown along with their slopes (±1 s.e. of the slope for "all months"). [Note: Notation and legibility will be improved for the final manuscript].

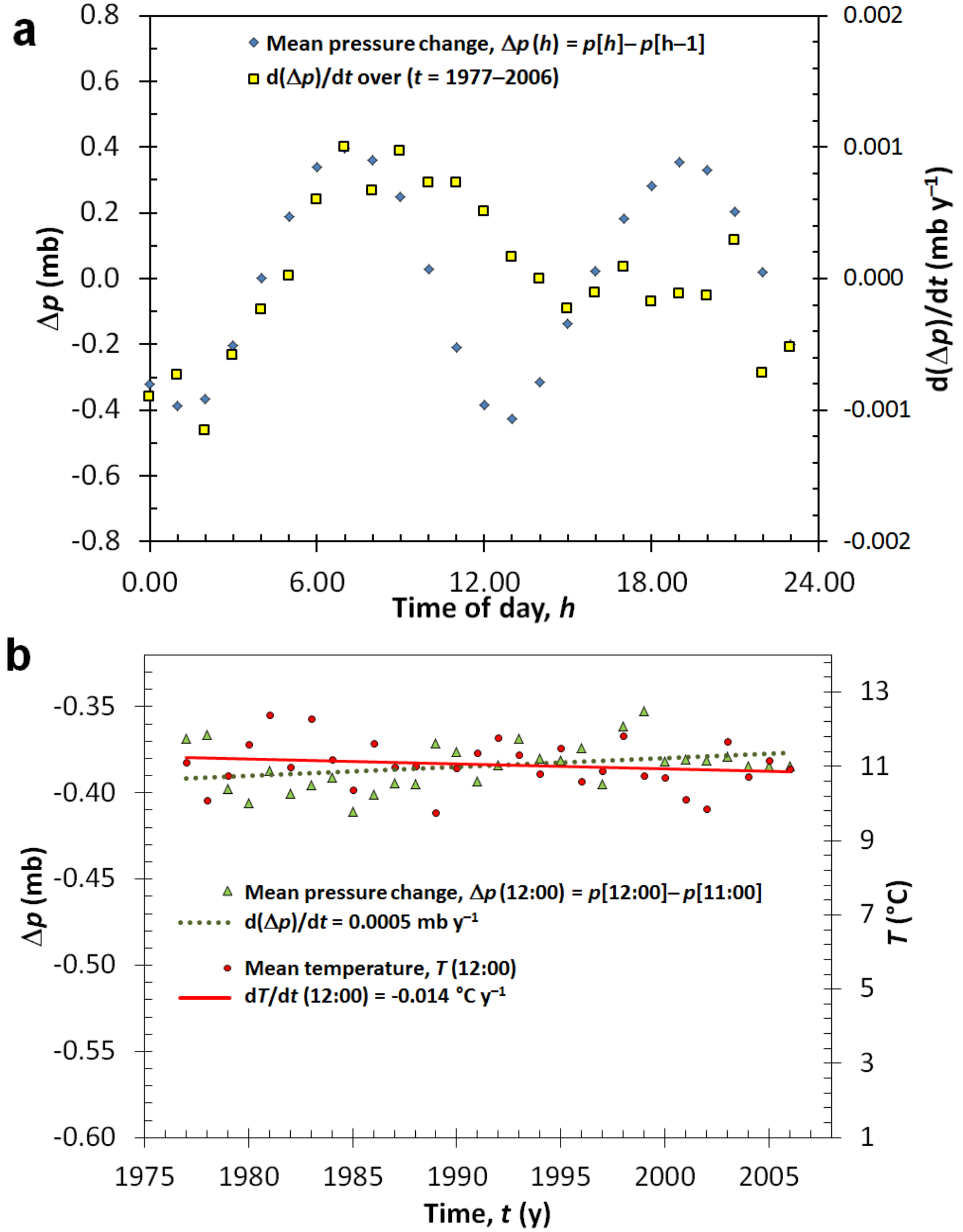

Fig. S4. **(a)** Mean hourly pressure changes (Δp) and best-fit trend lines for the 30-year Mauna Loa Observatory, Hawaii (NOAA, 2011a) as a function of time of day, h. Change in pressure is measured at a given hour h minus the previous hour, $\Delta p = p(h)–p(h–1)$, as a proxy for changes in wind speeds. The mean of all Δp at a specified time of day, h, are averaged for years t = 1977–2006 (filled diamonds). Annual mean rates of change, $d(\Delta p)/dt$, (yellow squares) are also given as a function of time of day, h. **(b)** For h = 12:00 (noon, LST), annual mean temperatures T (red circles) and mean hourly pressure changes Δp (green triangles), both based on hourly data at the Mauna Loa Observatory, Hawaii (NOAA, 2011a) are given as a function of year t = 1977–2006. Also shown are the least-squares best-fit lines, and slopes, for dT/dt (red solid line) and $d(\Delta p)/dt$ (dotted green line), both as a function of t.

(e1) [Referee 2, Specific Comment 4] "In order to present the complicated connections between the long-term trends of the temperature (minimum, maximum and DTR) and the CO2 concentrations, consider adding a graph of their variations along the study period and the problematic in deriving the correlation between them."

(e2) [Author Response] To examine these connections, we first compiled for each year, *t*, the following: T_t (mean annual temperature), $T_{t[\max]}$ (mean annual maximum temperature), $T_{t[\min]}$ (mean annual minimum temperature), DTR ($T_{t[\max]} - T_{t[\min]}$), and C_t (mean annual CO_2 in ppmv). We then combine Eqs (1) and (2) of our original manuscript to give us:

$$(T_t - T_0) = 5.35\lambda \ln(C_t / C_0) \qquad \text{(Eq. S1)}$$

where for a given year *t*, T_t and C_t are the mean annual temperature (°C) and CO_2 concentrations (ppmv), T_0 and C_0 the respective 'reference values' (1977 in our original manuscript), and λ is the equilibrium climate sensitivity. Further manipulation of Eq. (S1) and using the reference year 1977 (we use here for clarity, T_{1977}, C_{1977}), gives the relationship:

$$\exp(T_t - T_{1977}) \propto (C_t / C_{1977}) \qquad \text{(Eq. S2)}$$

Therefore (Eq. S2), the exponential of the difference in temperature (between year *t* and 1977) should be roughly proportional to the CO_2 concentration ratios, C_t/C_{1977}. One can extend this rough proportionality to the other temperature variables $\exp(T_{t[\max]}–T_{1977[\max]})$, $\exp(T_{t[\min]}–T_{1977[\min]})$, $\exp(\mathrm{DTR}_t–\mathrm{DTR}_{1977})$ each as a function of C_t/C_{1977}. The best-fit linear relationship to $\exp(T_t–T_{1977})$ as a function of (C_t/C_{1977}), t = 1977 to 2006, and then doing the same for the other temperature variables $T_{t[\max]}$, $T_{t[\max]}$, DTR_t, gives the following relationships:

$$\exp(T_t - T_{1977}) = 5.1(C_t / C_{1977}) - 4.1,\ r^2 = 0.08 \qquad \text{(Eq. S3)}$$

$$\exp(T_{t[\max]} - T_{1977[\max]}) = -3.3(C_t / C_{1977}) + 4.6,\ r^2 = 0.05 \qquad \text{(Eq. S4)}$$

$$\exp(T_{t[\min]} - T_{1977[\min]}) = 12.3(C_t / C_{1977}) - 11.4,\ r^2 = 0.34 \qquad \text{(Eq. S5)}$$

$$\exp(\mathrm{DTR}_t - \mathrm{DTR}_{1977}) = -7.2(C_t / C_{1977}) + 8.3,\ r^2 = 0.51 \qquad \text{(Eq. S6)}$$

with r^2 the coefficient of determination. As the year *t* increases, the concentration of CO_2 (C_t) increases, and the ratio (C_t/C_{1977}) grows larger. From our original manuscript, for the 30 year record, $\mathrm{d}T/\mathrm{d}t$ = 0.021 °C y^{-1}, $\mathrm{d}T_{\max}/\mathrm{d}t$ = –0.011 °C y^{-1}, $\mathrm{d}T_{\min}/\mathrm{d}t$ = 0.038 °C y^{-1}, d(DTR)/d*t* = –0.050 °C y^{-1}, so we would expect the gradients in Eqs. (S3–S6) to roughly follow the same general trends. In each case, comparing the magnitude and sign of the gradients (e.g., $\mathrm{d}T/\mathrm{d}t$ = 0.021 °C y^{-1}, compared with 5.1 in Eq. S3) results in these gradient magnitudes and signs very roughly correlated, for each of the different variables examined. In addition, as the gradient increases for each of these relationships, the 'quality' of fit r^2 also increases, with the relationship of $\exp(\mathrm{DTR}_t–\mathrm{DTR}_{1977})$ vs (C_t/C_{1977}) having r^2 = 0.51. Therefore, certainly some of the change that we see in C_t at this local station (which is reflected globally) is being reflected in the change in DTR at this local station.

As the reviewer has mentioned, the relationship between these variables is complex, further confounded by near zero gradients in quantifying r^2. However, we hope that briefly mentioning these additional analyses with some discussion in our revised manuscript, will go part-way to answering Reviewer 2's Comment 4.

*(f1) [Referee 2, Specific Comment 5] "*Suggestion for additional references:" (Easterling *et al.*, 1997; Leathers *et al.*, 1998; Parker, 2006, 2010; Scheitlin and Dixon, 2010).

(f2) [Author Response] We have added the references for Parker (2006, 2010) in our reply to 'a2' this section. We believe that Vose *et al.* (2005) is preferable to Easterling *et al.* (1997), as it has been updated considerably over the original paper. We will consider appropriate locations for Leathers *et al.* (1998) and Scheitlin and Dixon (2010).

(g1) [Referee 2, Technical Correction 1] "Add the geographic location of Mauna Loa, i.e., 19°28'N 155°36'W"

(g2) [Author Response] We will add the exact location of the MLO to the first sentence of Section 2 "…(altitude 3397 m a.s.l; 19.54°N, 155.58°W)". This latitude and longitude is slightly different than that given by the referee, as we have chosen the location of the actual observatory.

(h1) [Referee 2, Technical Correction 2] "Page 2, line 20: Change CO2 to CO_2"

(h2) [Author Response] We checked throughout the entire paper, and were unable to find any instances of CO2 (vs. CO_2).

(i1) [Referee 2, Technical Correction 3] "Page 6, line 4: the difference between the maximum and minimum annual trends is +0.054°C y^{-1} and not −0.054°C y^{-1}. Delete the minus before the value."

(i2) [Author Response] Thank you for spotting this typo. We will change the wording of the sentence (p. 1691, line 17) from "This is very close to the difference between the maximum and minimum annual trends (−0.054°C y^{-1}) given in Fig. 2…" to "This absolute value of d(*DTR*)/d*T* is very close to the difference between the maximum and minimum annual trends (0.054°C y^{-1}) given in Fig. 2…"

(j1) [Referee 2, Technical Correction 4] "Page 6, line 8: since the separate trends for each 15-year period are not presented in Fig. 3b, change the sentence: ". . . we divided the annual DTR data in Fig. 3b into…" to: "… we divided the annual DTR data (presented in Fig. 3b) into. . . ."

(j2) [Author Response] We agree (p. 1691, line 23) and have changed the manuscript.

(k1) [Referee 2, Technical Correction 5] "Page 8, lines 9-11: since the study indicates strong nocturnal warming in Mauna Loa, located on relatively low latitudes (the border of the tropics), consider deleting the last sentence "Relatively strong nocturnal warming can qualitatively explain 'why' global warming appears to be concentrated in the high-latitude Arctic (IPCC, 2007)" or refer also to lower latitudes."

(k2) [Author Response] We agree (p. 1694, lines 4–5) and have changed the manuscript.

(l1) [Referee 2, Technical Correction 6] "Page 13, line 8 (caption of Fig. 2): the mean rate of warming. . . . is +0.021°C y^{-1} and not -0.021°C y^{-1}. Delete the minus before the value."

(l2) [Author Response] We agree (p. 1698, last line of Fig. 2 caption) and have changed the manuscript.

IV. OTHER CHANGES MADE BY AUTHORS

(a) We noticed that we made a typo on p. 1690, line 15, and will change "…*C*=392 ppmv for 2006" to "…*C*=382 ppmv for 2006". Subsequent calculations had been made on the value of 382 ppmv (not the typo of 392 ppmv).

(b) p. 1690 (lines 23-24). Change "very close to the results we obtain for the Mauna Loa Observatory, d*T*/d*t* =…" to "very close to the mean rate of warming results we obtain for the Mauna Loa Observatory (Fig. 2b), d*T*/d*t* =…"

(c) Various locations. Other minor changes for clarity from the original manuscript.

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