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Impact of wind speed on nighttime temperature increase due to higher atmospheric carbon dioxide*

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Research motivation

Observations show a faster increase in 2 m temperature at night than during the day (Fig. 1). Also the observed diurnal temperature range seems to have decreased in the recent decades (Fig. 2).

By exploring routine 2m temperature records, Parker (2004) found no differences in temperature rise between calm and windy nights (Fig. 3). He concluded that global warming is not urban, since that would imply a larger increase in calmer than in windy nights.

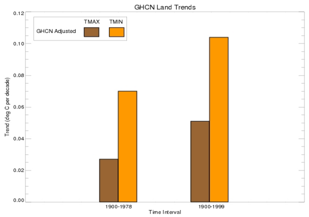


Figure 1: Global maximum and minimum temperature rise (McNider et al).

However, basic boundary-layer physics suggests that its vertical structure should depend on wind speed. Based on these findings, we formulate our research question:

To what extent is the temperature rise due to enhanced CO_2 a function of height and wind speed in the nighttime boundary layer?

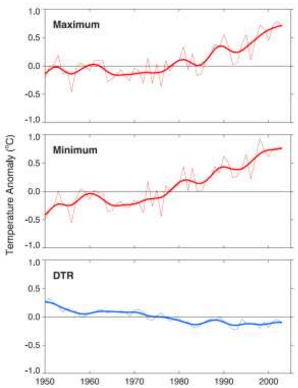


Figure 2: Global trends in maximum and minimum temperature, and diurnal temperature range (Vose, 2005)

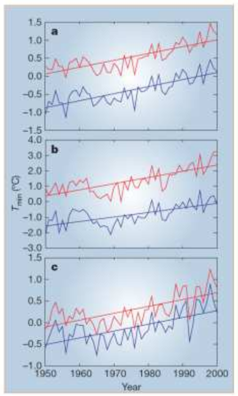
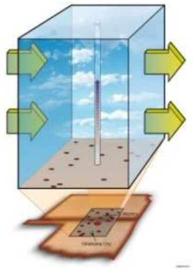


Figure 3: Trends in minimum temperature for all cases (a), winter (b), and summer cases (c), Red= upper wind speed tercile, lowest wind speed tercile (Parker, 2004).

Research strategy

In this research we utilize a validated atmospheric column model (Duynkerke, 1991; Steeneveld et al 2006; see box 1) and run a clear sky diurnal cycle initial conditions inspired from observations of the CASES-99 experimental campaign (Kansas, USA). This run is repeated for a range of geostrophic wind speeds (U_g) between 2 till 20 m/s. In a first set of runs we use pCO_2 = 330 ppm, and in the second set pCO_2 is increased by 40%. Next we investigate the temperature rise in the (z, U_g)-space.



Results

The vertical structure of the CO_2 induced temperature rise reveals ~0.55 K warming close to the ground and a decreasing rise aloft. Hence temperature rise is height dependent. For small U_g the warming decreases faster with height than for larger U_g. Also, for most levels temperature rise depends on U_g. **However, close to the surface a relatively large range of winds show a constant temperature rise**. Independent column model results by the Univ. of Alabama confirmed the general model behavior for a range of surface roughness length and surface emissivity.

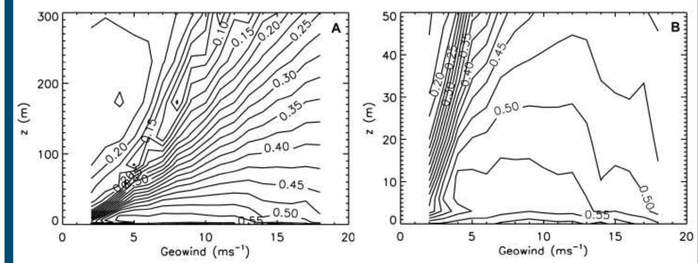


Figure 4: Modelled temperature increase as function of height and geostrophic wind speed, at 0600 LT (a). Panel (b): zoom in of panel (a).

Box 1: detailed model settings
z_{0m}=3 cm, z_{0h} =z_{0m}/10. Land-atmosphere coupling Λ=5 W/m2/K.
Vertical: 10 km, 91 levels. Increase CO_2 by 40%. Time step 10 sec
Initialisation @19.00 UTC (close to local noon).

Implications for 2 meter temperature.

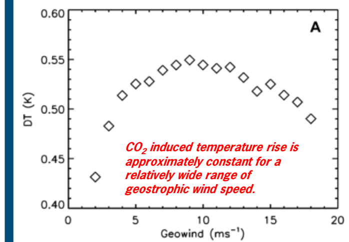


Figure 5: Modeled 2m temperature rise as function of Geowind.

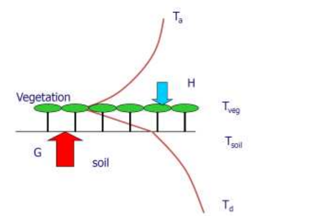


Figure 6: Sketch of land surface coupling at night.

Explanation

For U_g > 15 m/s, the more intense turbulence deepens the boundary layer. Thus, CO_2 induced warming is distributed over a deeper layer, resulting in a smaller increase close to the ground. For small U_g turbulence is weak and warming cannot be distributed efficiently aloft. In that case part of the extra warming will be stored in the soil.

The stable boundary layer has two regimes (Fig 7 and 8))
A: For windy conditions increased stratification (surface cooling) enhances the sensible heat flux *H*, *compensating the increased cooling* from the atmosphere to the surface
B: For calm and very stable conditions, increased stratification inhibits turbulence, and limits the sensible heat flux, *enhancing the increased cooling.*

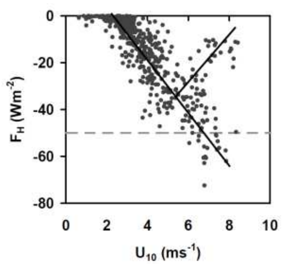


Figure 7: Two regimes of sensible heat flux as function of 10 m wind for Cabauw observations.

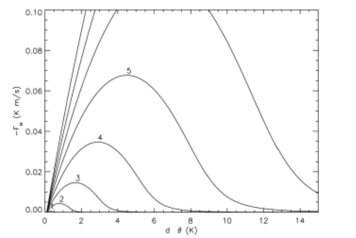


Figure 8: Sensible heat flux as function of wind speed stratification, based on surface layer similarity theory

Conclusion

Two meter temperature rise due to enhanced atmospheric CO_2 is rather constant for a wide range of Geostrophic wind speeds due to land surface feedbacks but above 2 m there is a clear height dependence.

Duynkerke, P.G., 1991: Radiation fog: A comparison of model simulation with detailed observations, *Mon. Wea. Rev.*, **119**, 324-341.
Parker, D.E., 2004: Large Scale warming is not urban, *Nature*, **432**, 290.
Steeneveld, G.J., B.J.H. van de Wiel and A.A.M. Holtslag, 2006: Modeling the Evolution of the Atmospheric Boundary Layer Coupled to the Land Surface for Three Contrasting Nights in CASES-99, *J. Atmos. Sci.*, **63**, 920-935.
*Steeneveld, G.J., A.A.M. Holtslag, R.T. McNider, and R.A. Pielke Sr. (2011), Screen level temperature increase due to higher atmospheric carbon dioxide in calm and windy nights revisited, *J. Geophys. Res.*, ***116***, D02122, doi:10.1029/2010JD014612.