Detecting a Greenhouse Gas Warming Signal Using Only Maximum Daily Temperatures

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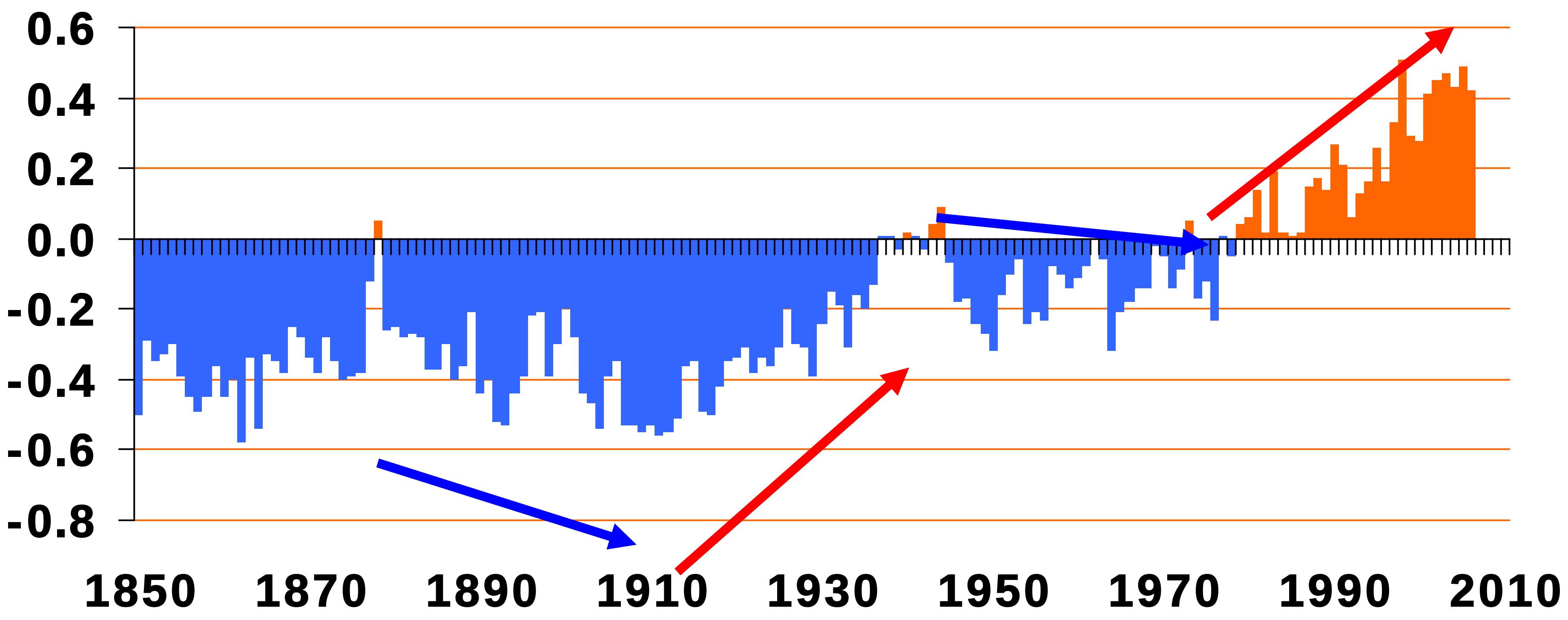
The essence of concern in anthropogenic greenhouse gas (AGHG) warming is the accumulation of heat in the atmosphere and ocean. Such accumulation is thought to possibly impact climate and climate regimes.

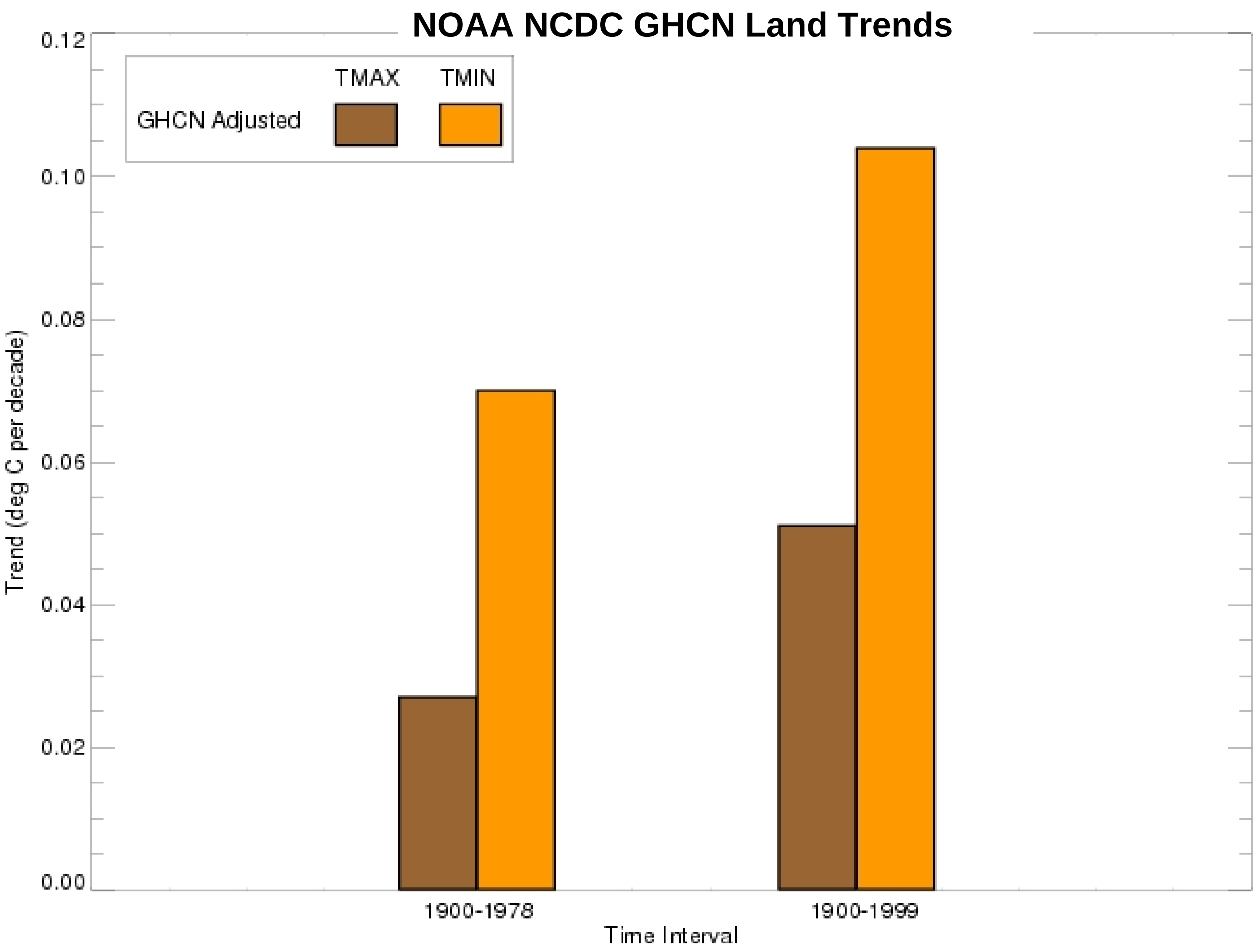
Past models and theory suggest that AGHG accumulated warming should be largest in the mid-upper troposphere

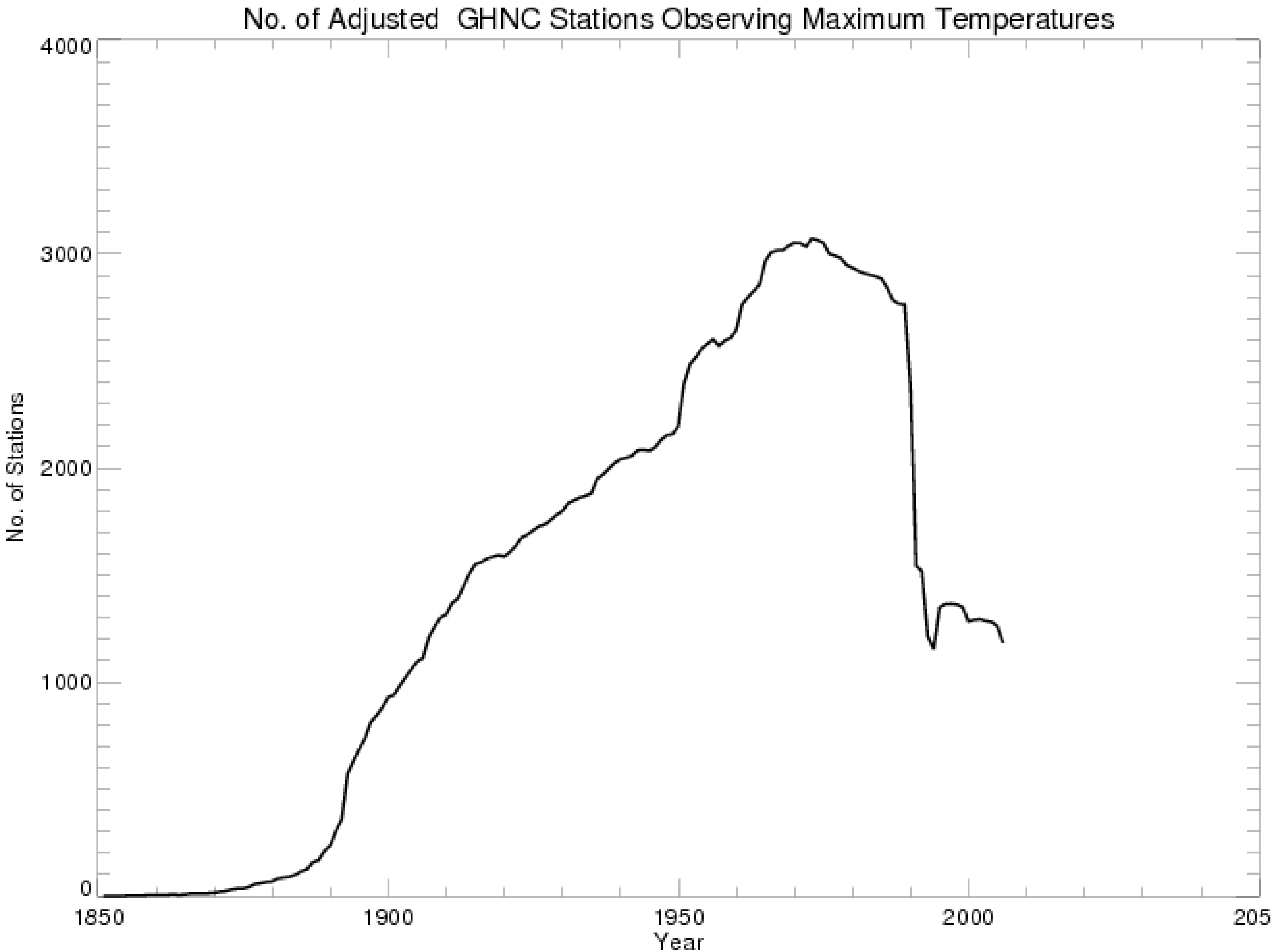
Most global data sets constructed to attempt to detect this warming use a mean daily surface temperature (average of Tmin and Tmax).

"Global" Surface Temperature

Are Mean Surface Temperatures a Proper Metric for Detecting Tropospheric Heat Accumulation




NOAA NCDC GHCN Land Trends
TMAX
TMIN
GHCN Adjusted
0.12
0.10
0.08
0.06
0.04
0.02
0.00
Trend (deg C per decade)
1900-1978
1900-1999
Time Interval



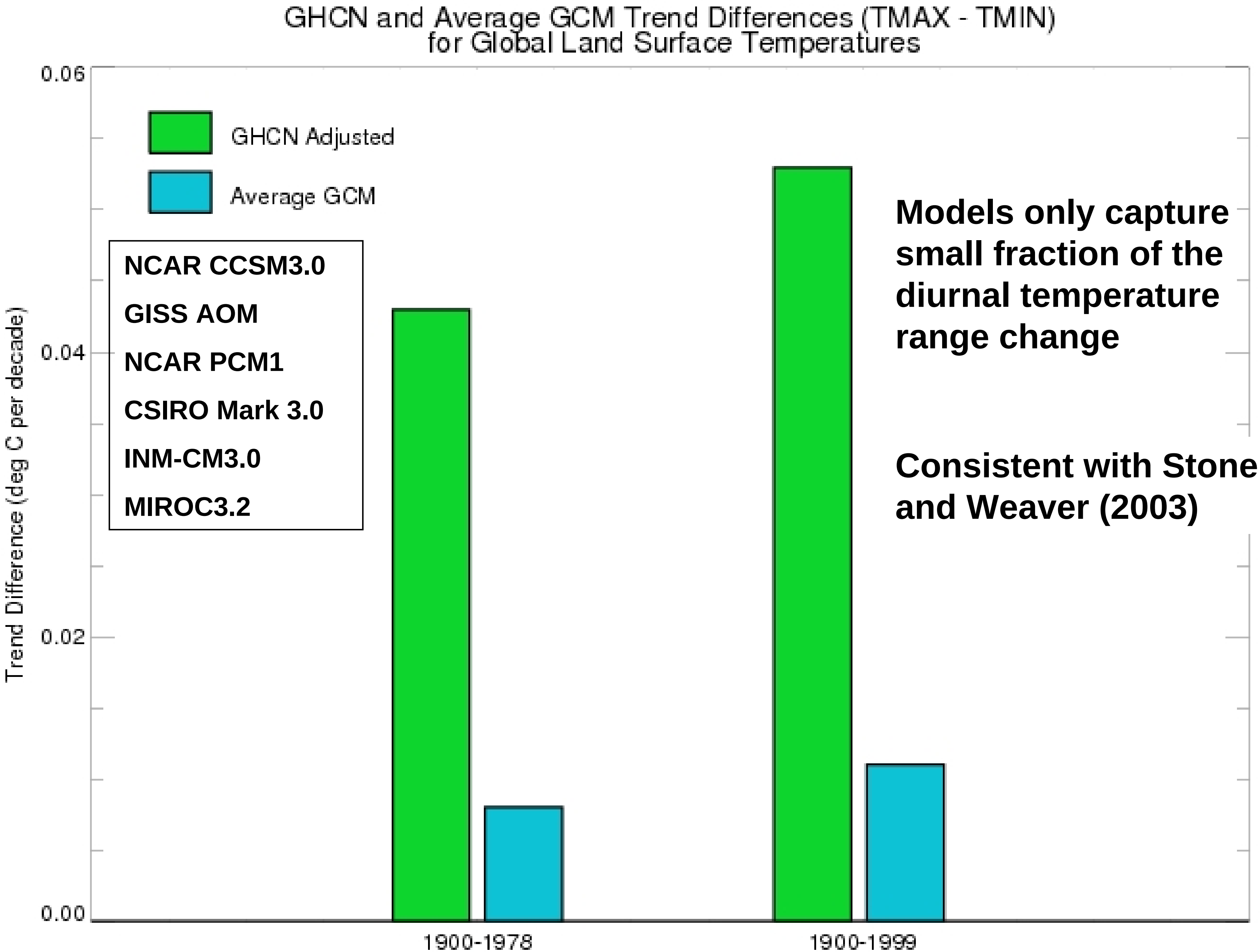
No. of Adjusted GHNC Stations Observing Maximum Temperatures
4000
3000
2000
1000
0
No. of Stations
1850
1900
1950
2000
2050
Year

This asymmetry in warming is one of the most significant signals in the observed climate record

The reasons for this asymmetrical rise have been subject to considerable debate

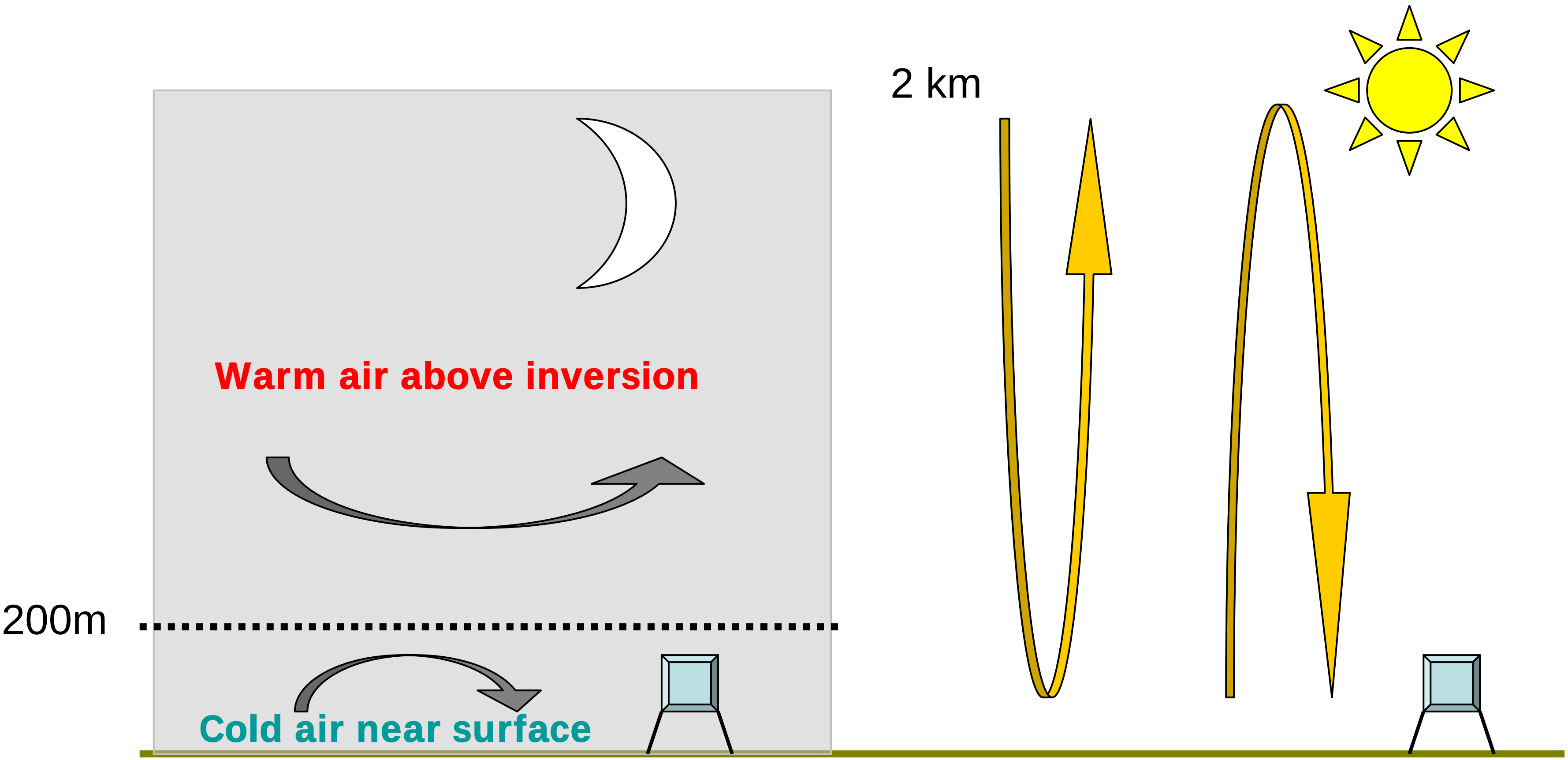
1. **Increased cloudiness (Dai et al.1999)**
2. **Urbanization (Balling and Idso, 2002, Gallo et al. 1999)**
3. **Surface moisture/irrigation (Durre and Wallace, 2001, Christy et al. 2006)**
4. **Greenhouse gases (Cao et al. 1992, Stone and Weaver 2003)**
5. **Aerosols (Charlson et al. 1992, Dai et al. 1997)**
6. **Contrails (Travis et al. 2004)**
7. **Stable boundary layer dynamics Walters et al. 2007**

While the reasons for the night time warming are subject to debate it makes up a significant part of the warming in the surface instrumental record that has been part of the call for greenhouse gas reductions.



GHCN and Average GCM Trend Differences (TMAX - TMIN)
for Global Land Surface Temperatures
GHCN Adjusted
Average GCM
NCAR CCSM3.0
GISS AOM
NCAR PCM1
CSIRO Mark 3.0
INM-CM3.0
MIROC3.2
Models only capture small fraction of the diurnal temperature range change
Consistent with Stone and Weaver (2003)
Trend Difference (deg C per decade)
0.06
0.04
0.02
0.00
1900-1978
1900-1999

Day vs. Night Surface Temp



Nighttime - disconnected shallow layer/inversion. Temperature affected by land-use changes, buildings, farming, etc.

Daytime - deep layer mixing, connected with levels impacted by enhanced greenhouse effect. Larger wind speeds increase footprint of measurements.

Is this night time warming really a signal of the accumulation of heat due to anthropogenic greenhouse gases (AGHG)?

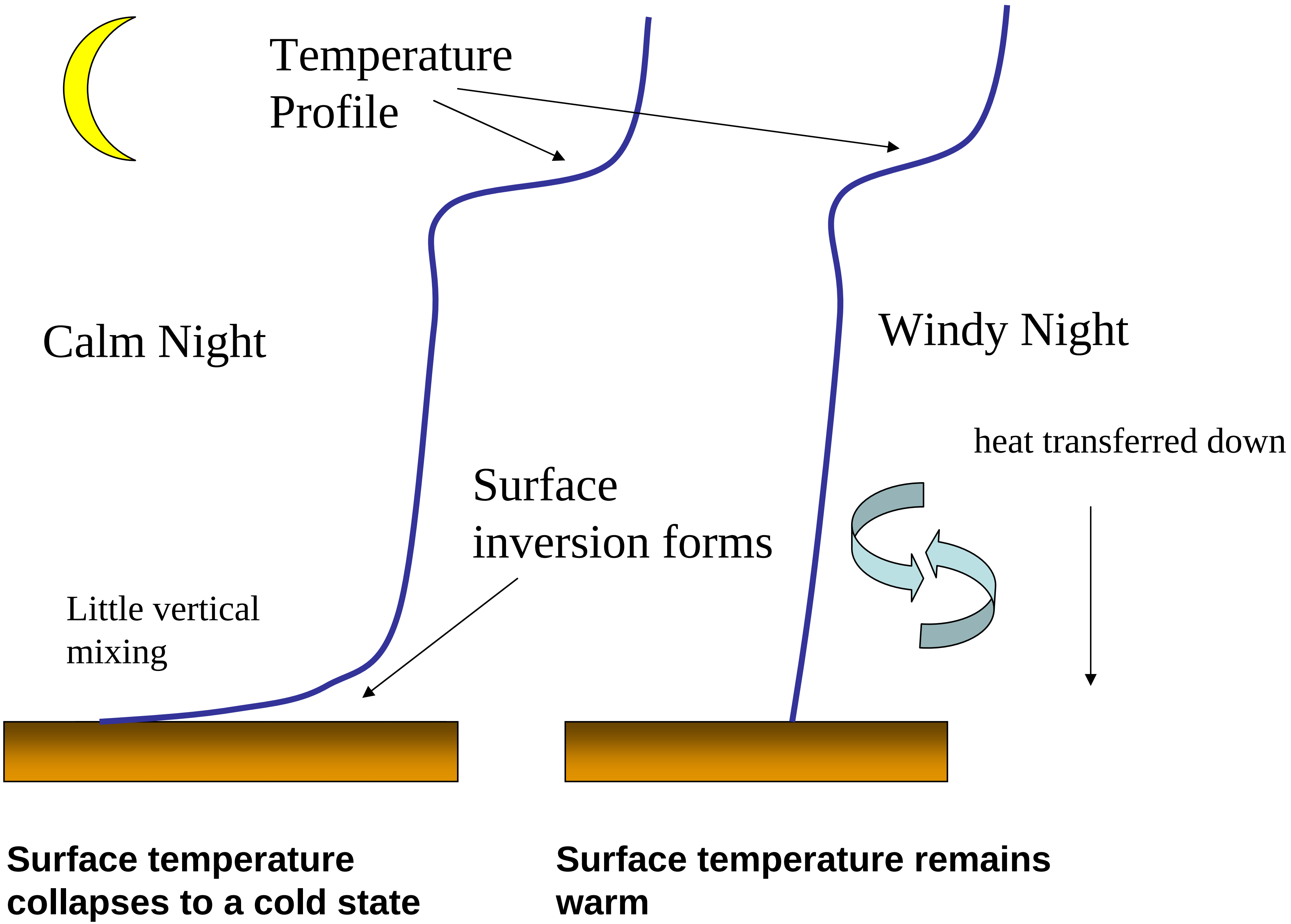
Is the night time boundary layer a good place to detect the accumulation of heat in the atmosphere due to anthropogenic greenhouse gases (AGHG)?

Nighttime Temperatures Are Extremely Sensitive to Land Use Change

Nighttime stable boundary layers are quite shallow, usually less than 500 m and often less than 200m. Their very existence signals a decoupling between the surface and the atmosphere above.

Runnals and Oke (2006) concluded that nighttime temperatures and/or the amount of stabilization are highly sensitive to surface land characteristics .

In fact they concluded that differences in climate temperature trends at night between closely space stations is evidence of changes in land use. They showed that the nighttime temperatures are much more sensitive to urbanization/land use change than daytime temperatures.


Temperature
Profile
Calm Night
Windy Night
heat transferred down
Surface
inversion forms
Little vertical
mixing
Surface temperature
collapses to a cold state
Surface temperature remains
warm

Use of Nonlinear Analysis to Explore Climate Sensitivity

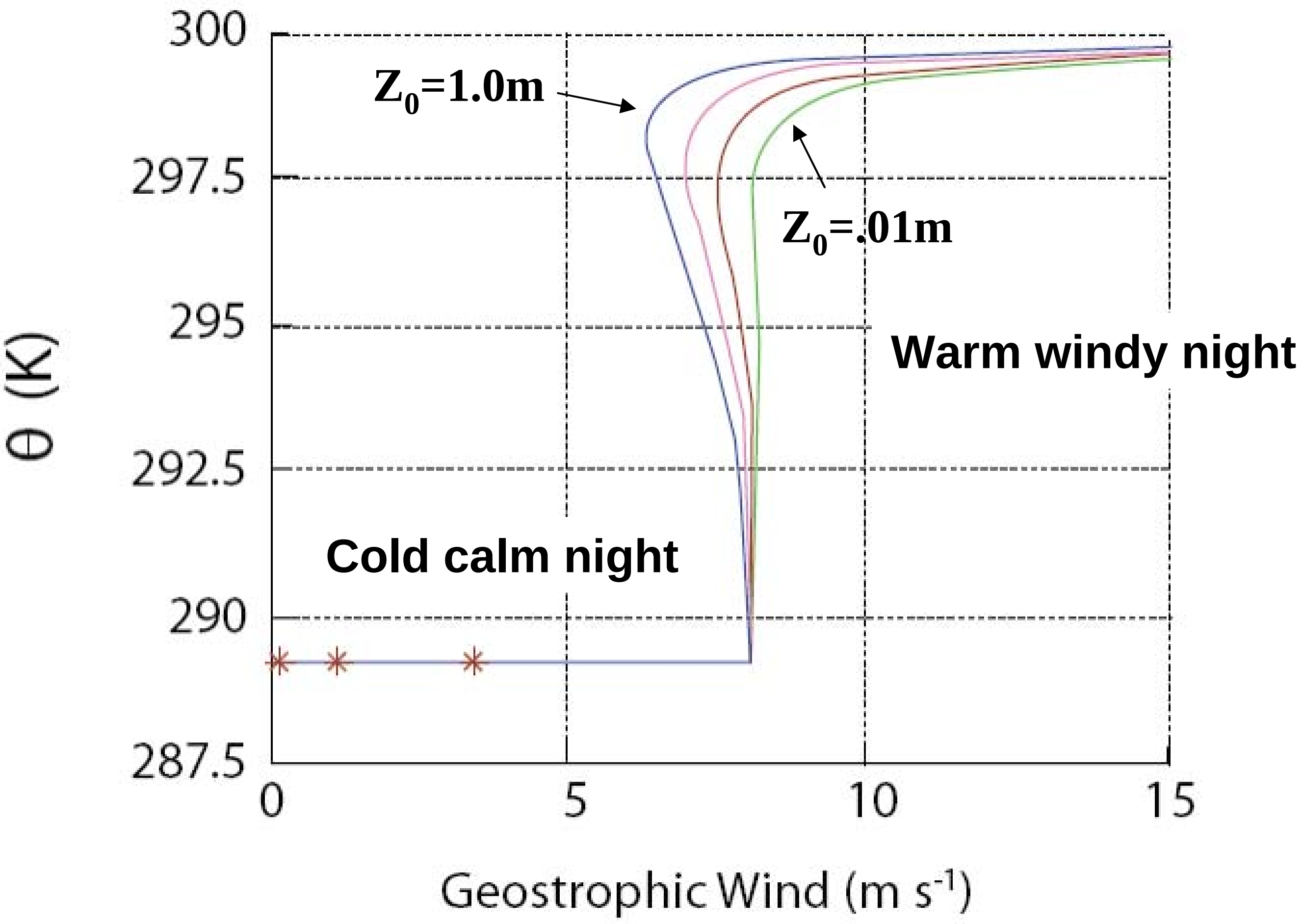
Rather than integrating the ODEs numerically we employ some recent tools in nonlinear analysis to explore the behavior of the system of equations. The primary tools are numerical continuation that can trace out the equilibrium bifurcation diagram, determine special bifurcation points and compute the eigenvalues of the system as a function of the bifurcation parameters.

McNider, R.T., D.E. England, M.J. Friedman, and X. Shi. 1995. On the predictability of the stable boundary layer. J. Atmos. Sci. 52(10):1602–1614.

Shi, X., R.T. McNider, D.E. England, M.J. Friedman, W.Lapenta, and B. Norris. 2005. On the behavior of the stable boundary layer and role of initial conditions. Pure Appl. Geophys. 162: 1811–1829.

Walters, J., R. McNider, X.Shi, W. Norris, and J. Christy. 2007. Positive surface temperature feedback in the stable boundary layer. Geophys. Res. Lett. 34:L12709.

Bifurcation Diagrams



Layer 1 temperature versus geostrophic wind U_g

Parameters Impacting Surface Temperature Trends

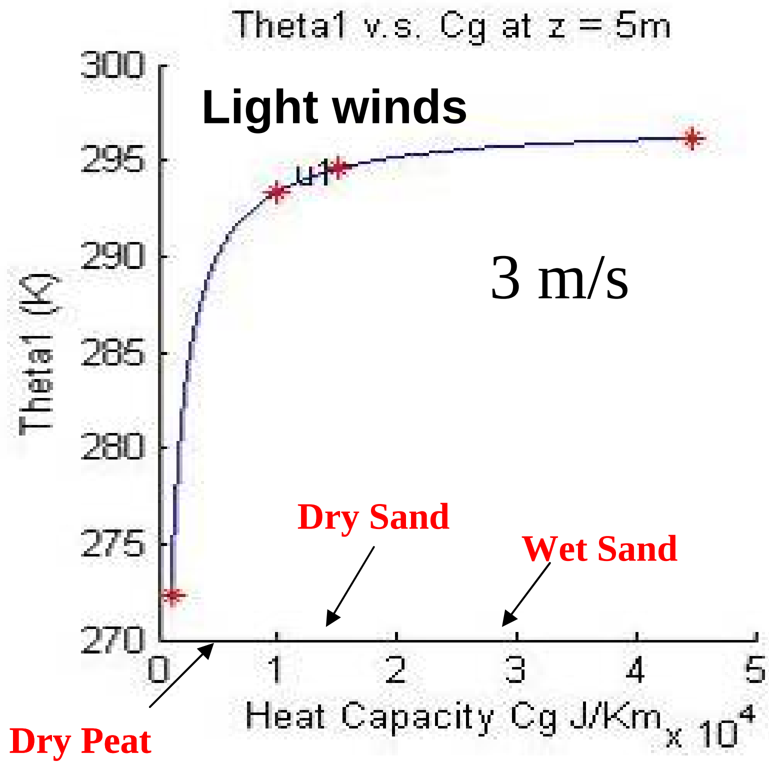
Heat Capacity

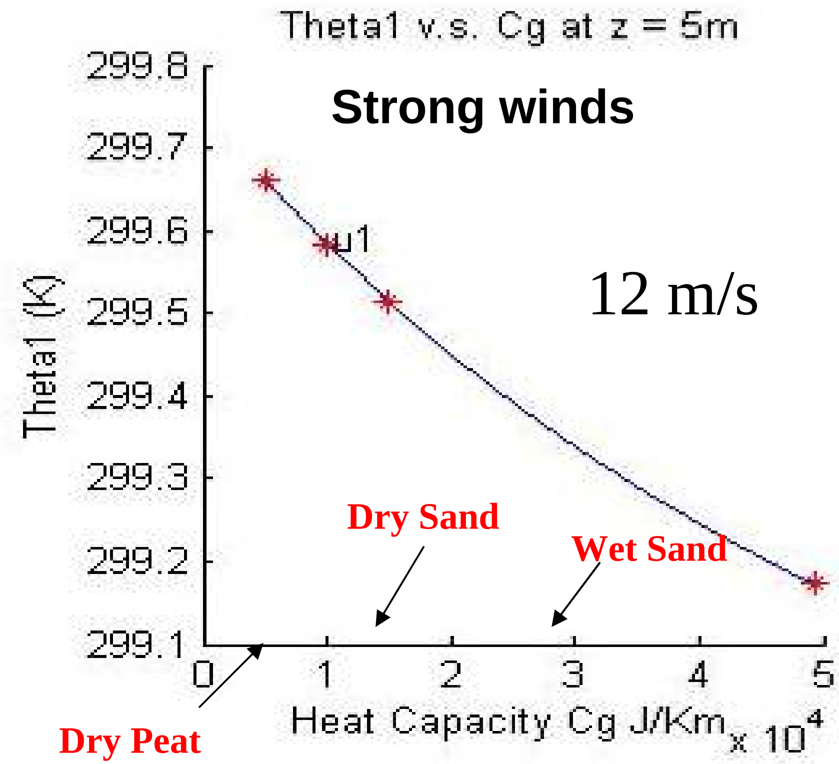
Heat capacity of the surface in a grid model is highly uncertain and in fact is more a model heuristic than a fundamental physical parameter. (McNider et al. 2005)

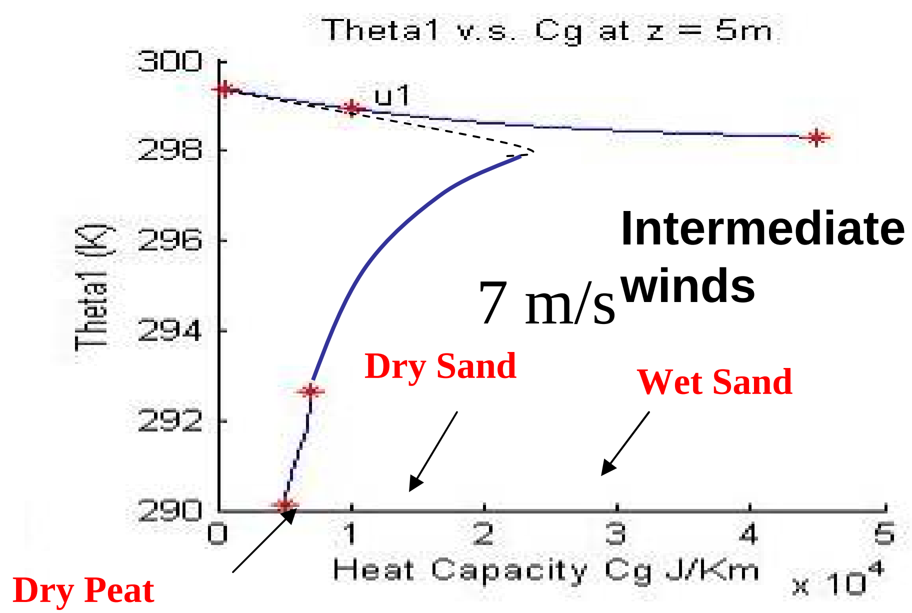
Surface heat capacity increases with moisture and vegetative fraction.

Irrigation increases heat capacity.

Urbanization can increase heat capacity and conductivity.

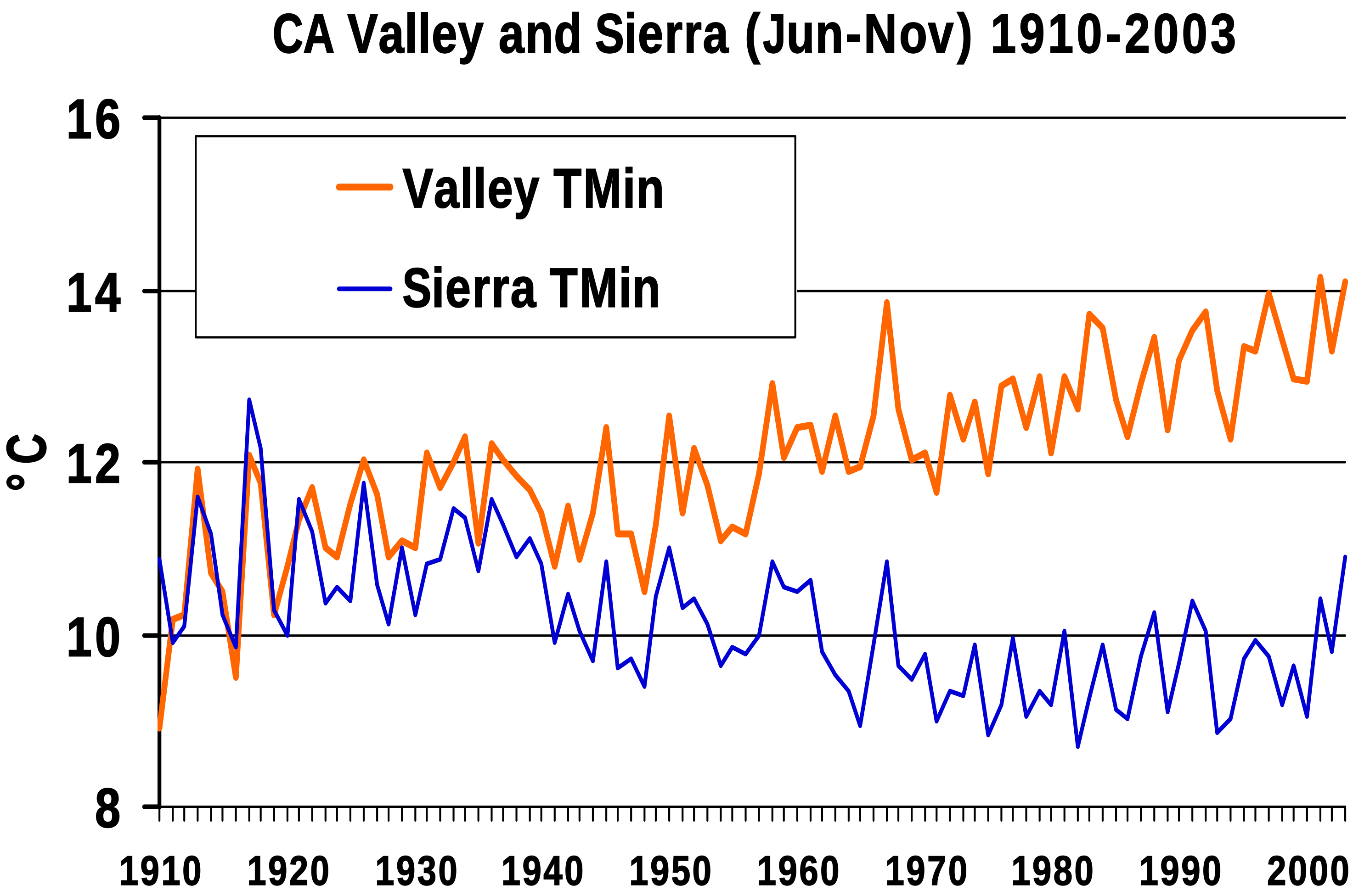

Theta1 v.s. Cg at z = 5m
Light winds
3 m/s
u1
Theta1 (K)
300
295
290
285
280
275
270
0
1
2
3
4
5
Heat Capacity Cg J/Km
x 10^4
Dry Sand
Wet Sand
Dry Peat


Theta1 v.s. Cg at z = 5m
Strong winds
12 m/s
u1
Theta1 (K)
299.8
299.7
299.6
299.5
299.4
299.3
299.2
299.1
0
1
2
3
4
5
Heat Capacity Cg J/Km
x 10^4
Dry Sand
Wet Sand
Dry Peat


Theta1 v.s. Cg at z = 5m
Intermediate winds
7 m/s
u1
Theta1 (K)
300
298
296
294
292
290
0
1
2
3
4
5
Heat Capacity Cg J/Km
x 10^4
Dry Sand
Wet Sand
Dry Peat

MODIS
21 Jul 2002

Jacques Descloitres
MODIS
Land Rapid Response Team
NASA GSFC



Christy et al. 2006

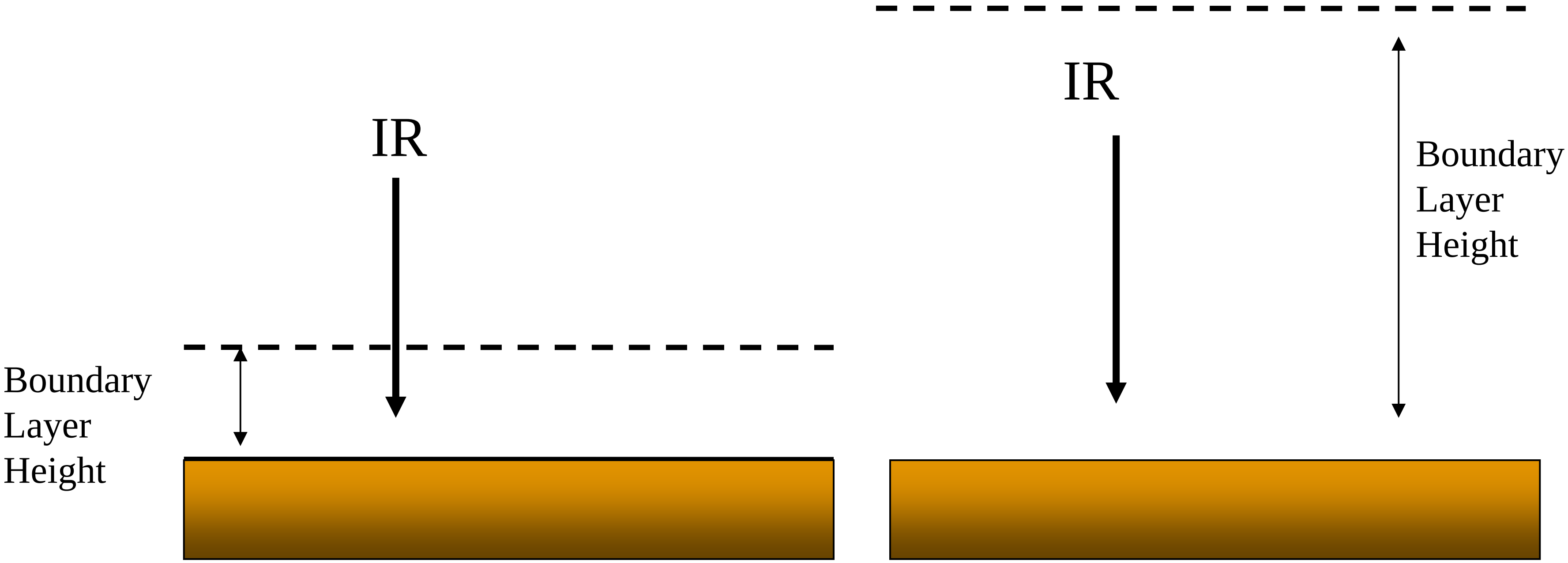
Parameters Impacting Surface Temperature Trends

Increased Downward Longwave Radiation

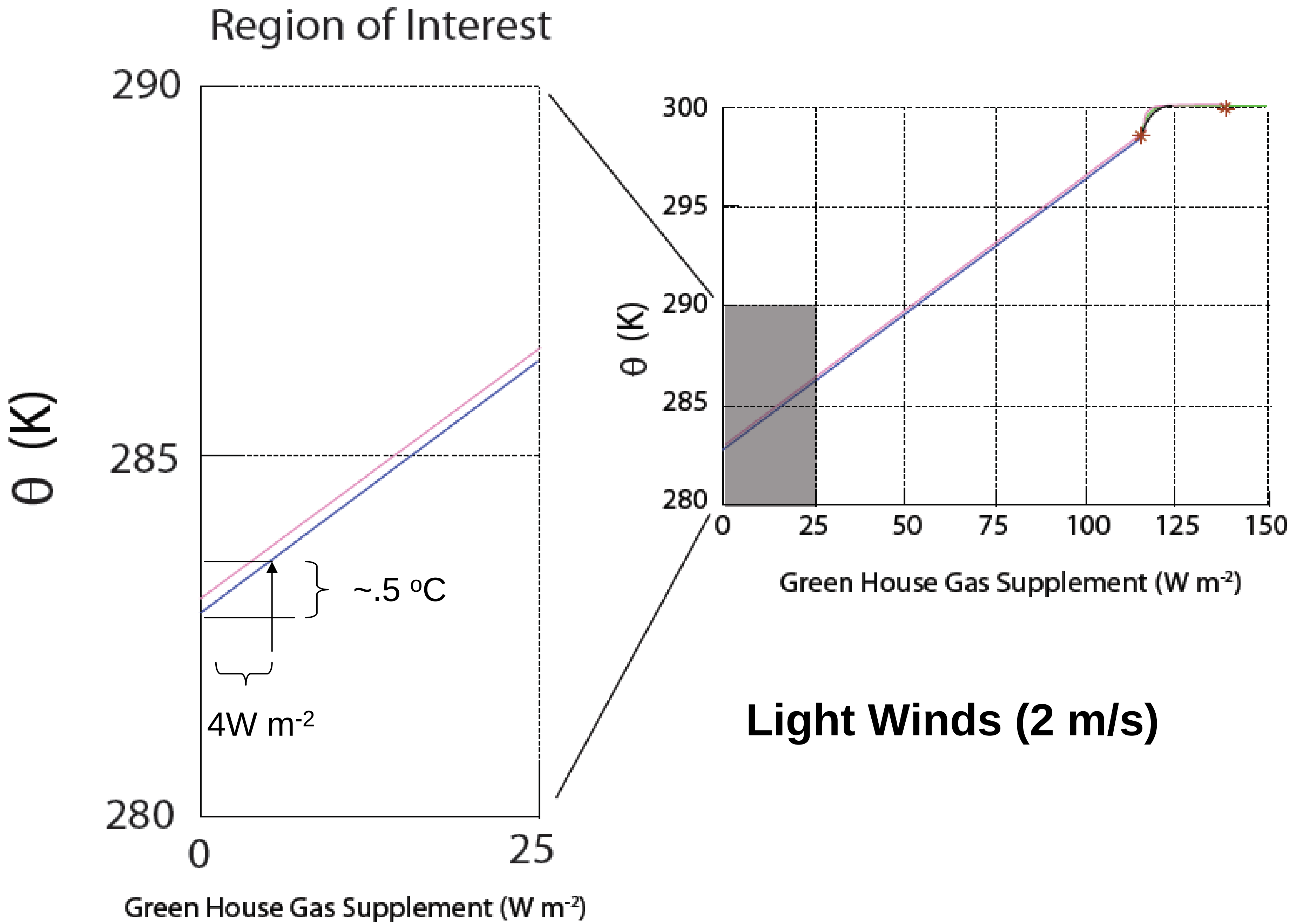
Greenhouse gases have increased downward radiation 2–4 watts/sq meter (Walters et al. 2007)

Cloud cover also implicated in nighttime warming

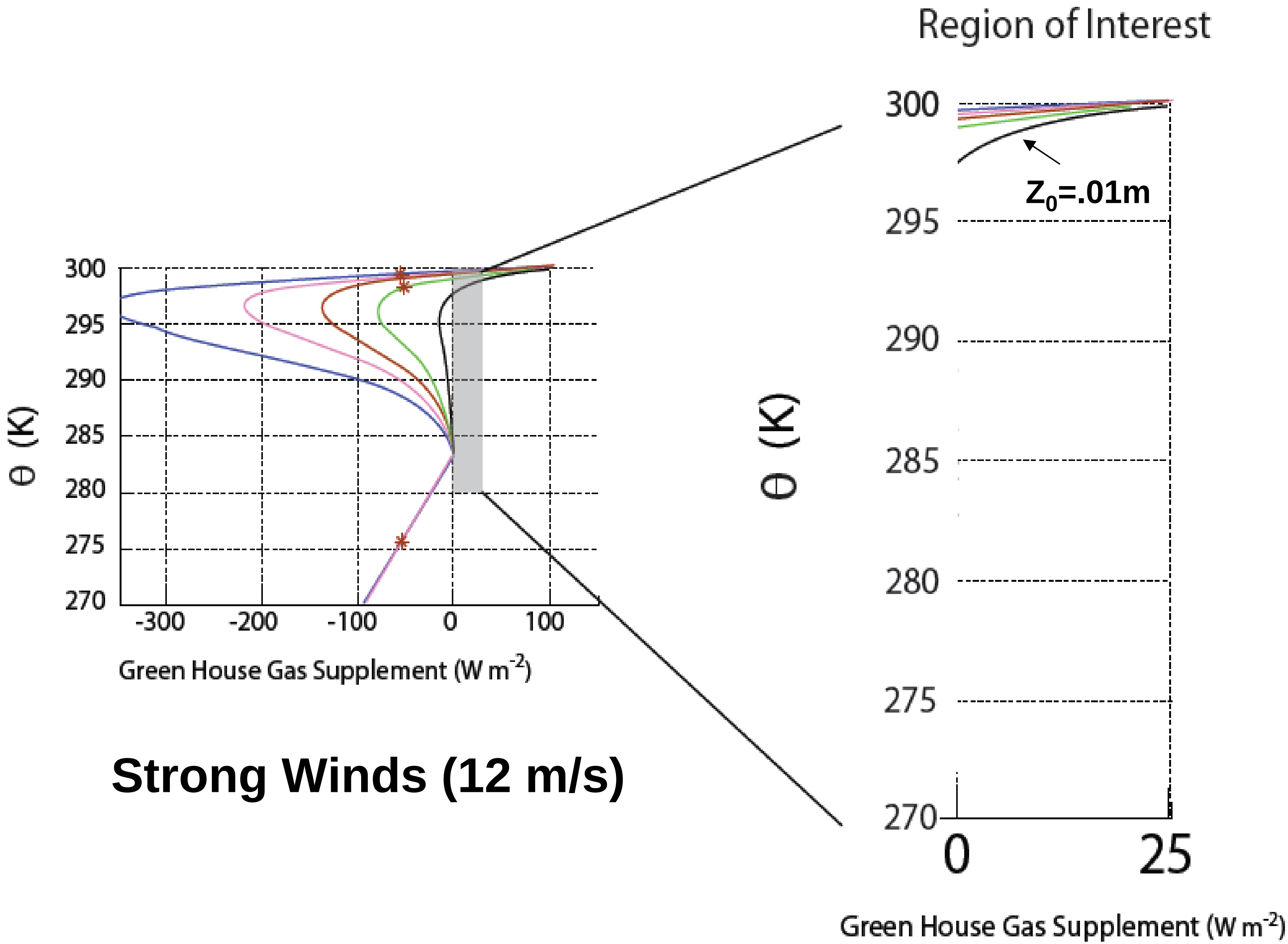
To first order temperature response to IR forcing will depend on boundary layer height



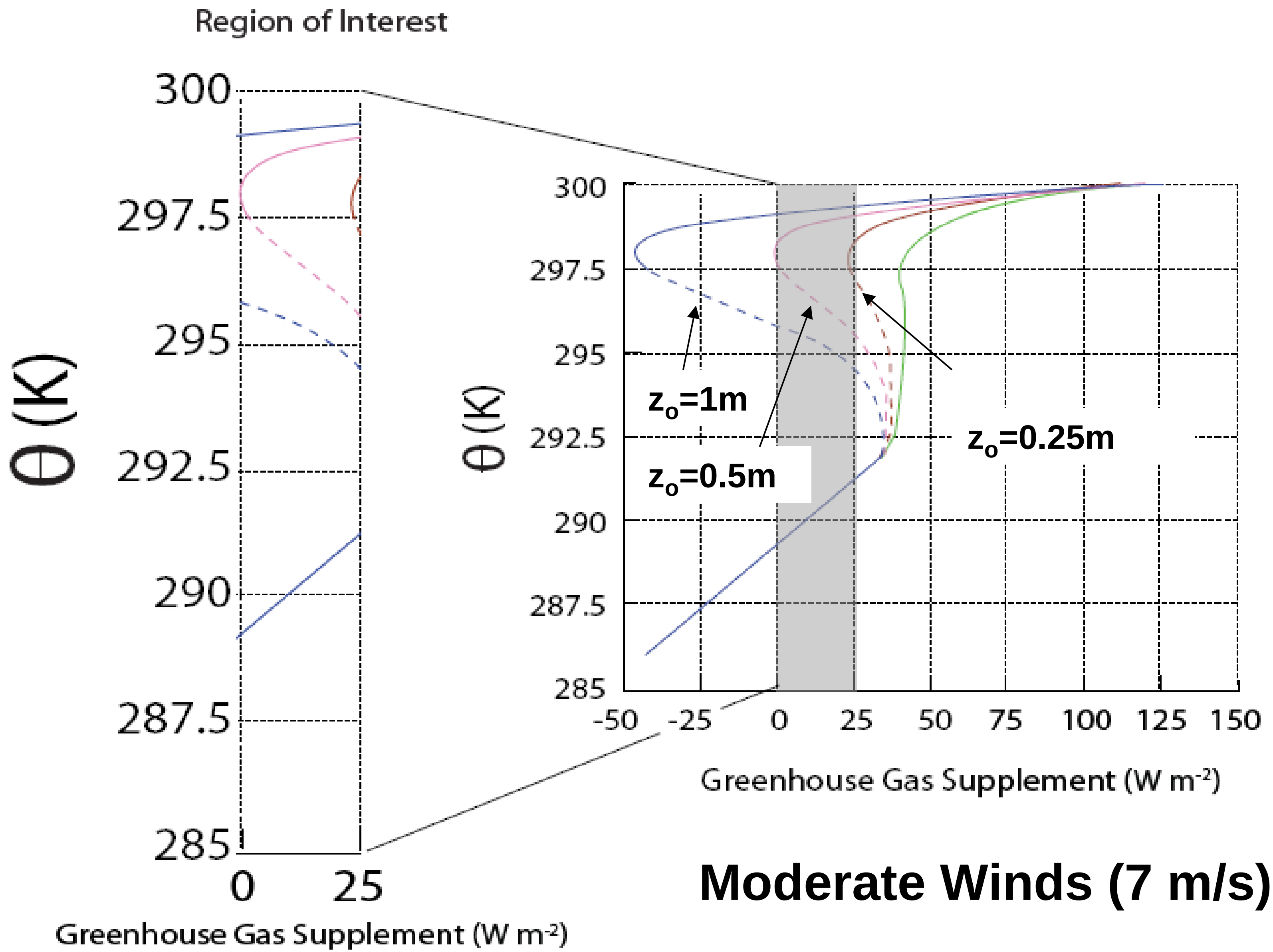
For a given IR forcing, warming will depend inversely (but perhaps not linearly) on boundary layer depth. Thus, temperature response will be greater at night than day (Eastman et al. 2001)



Light Winds (2 m/s)

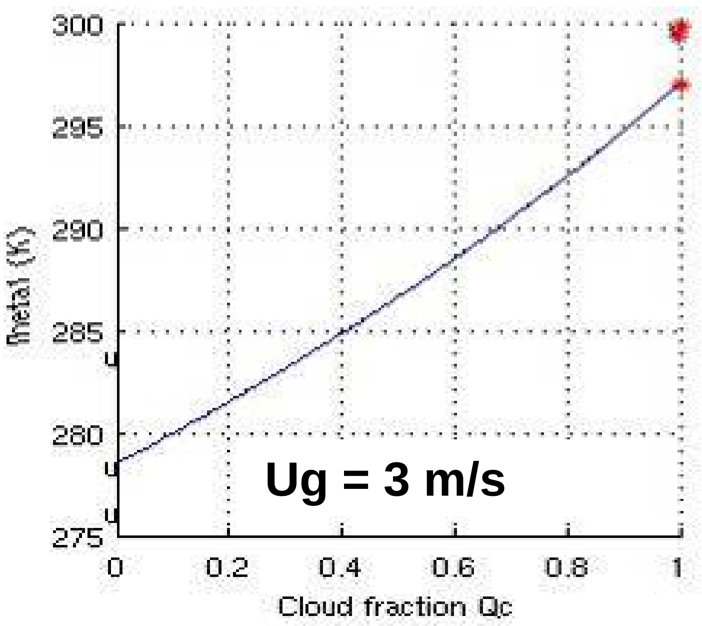


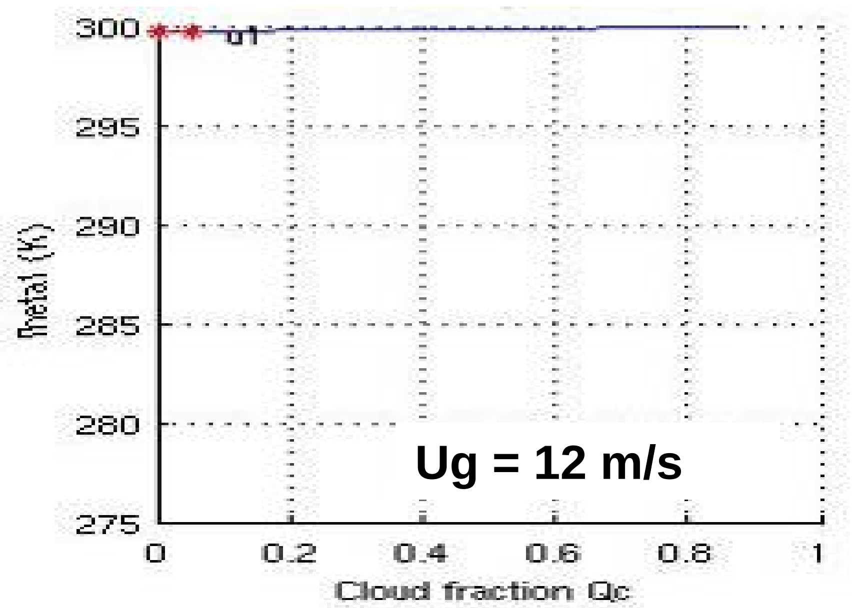
Strong Winds (12 m/s)

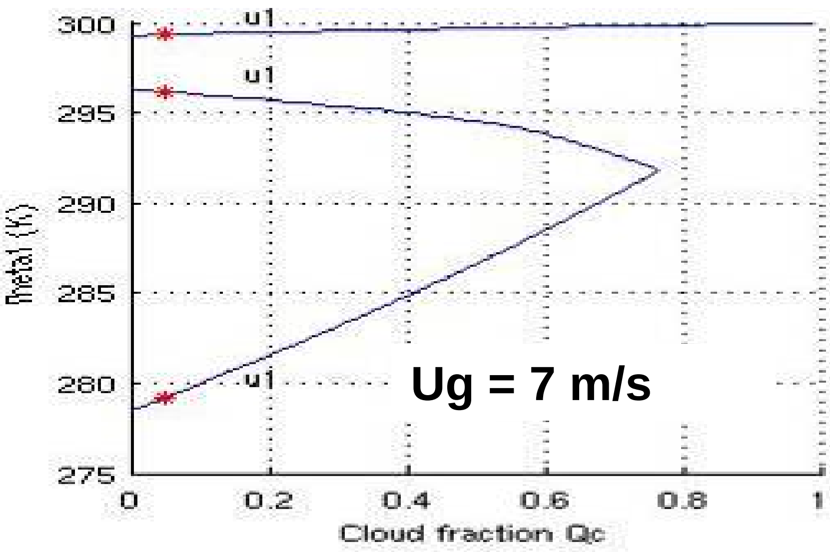


Moderate Winds (7 m/s)

Additional longwave heating from clouds vs air temperature (5 m)

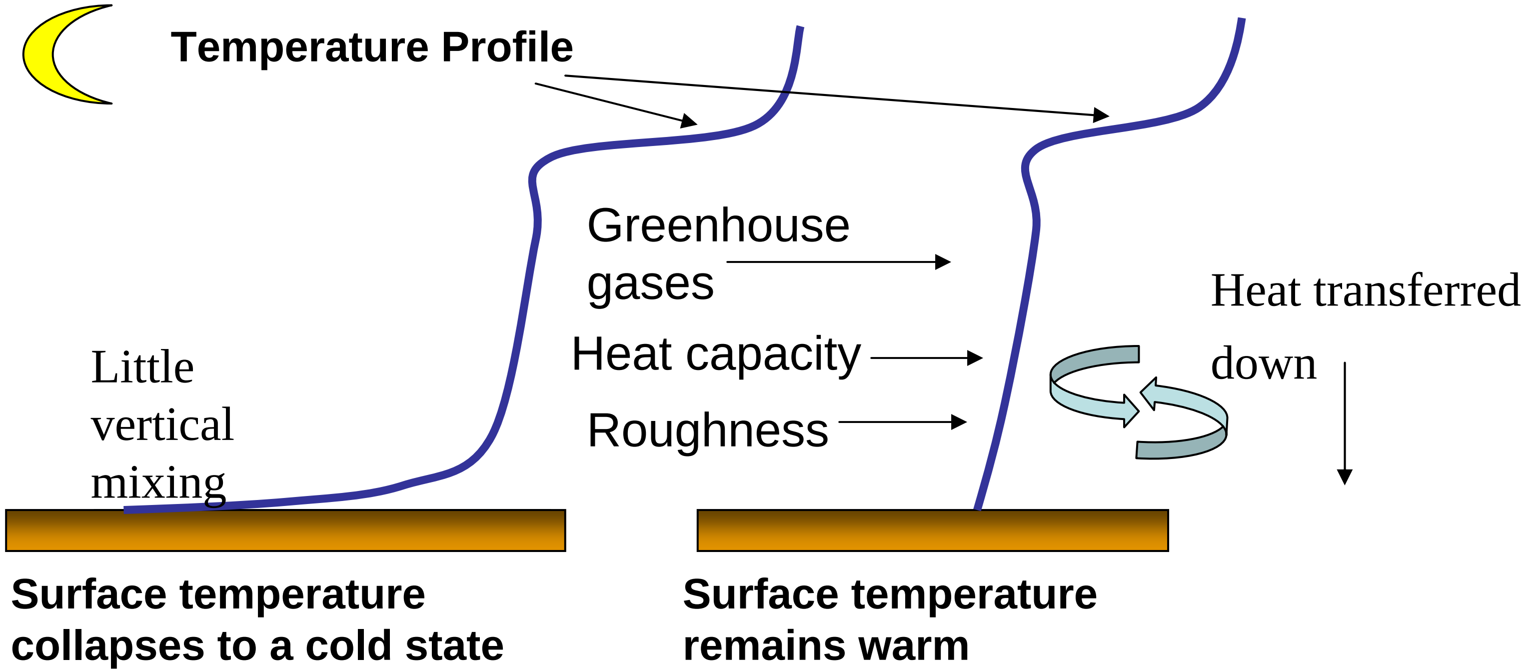






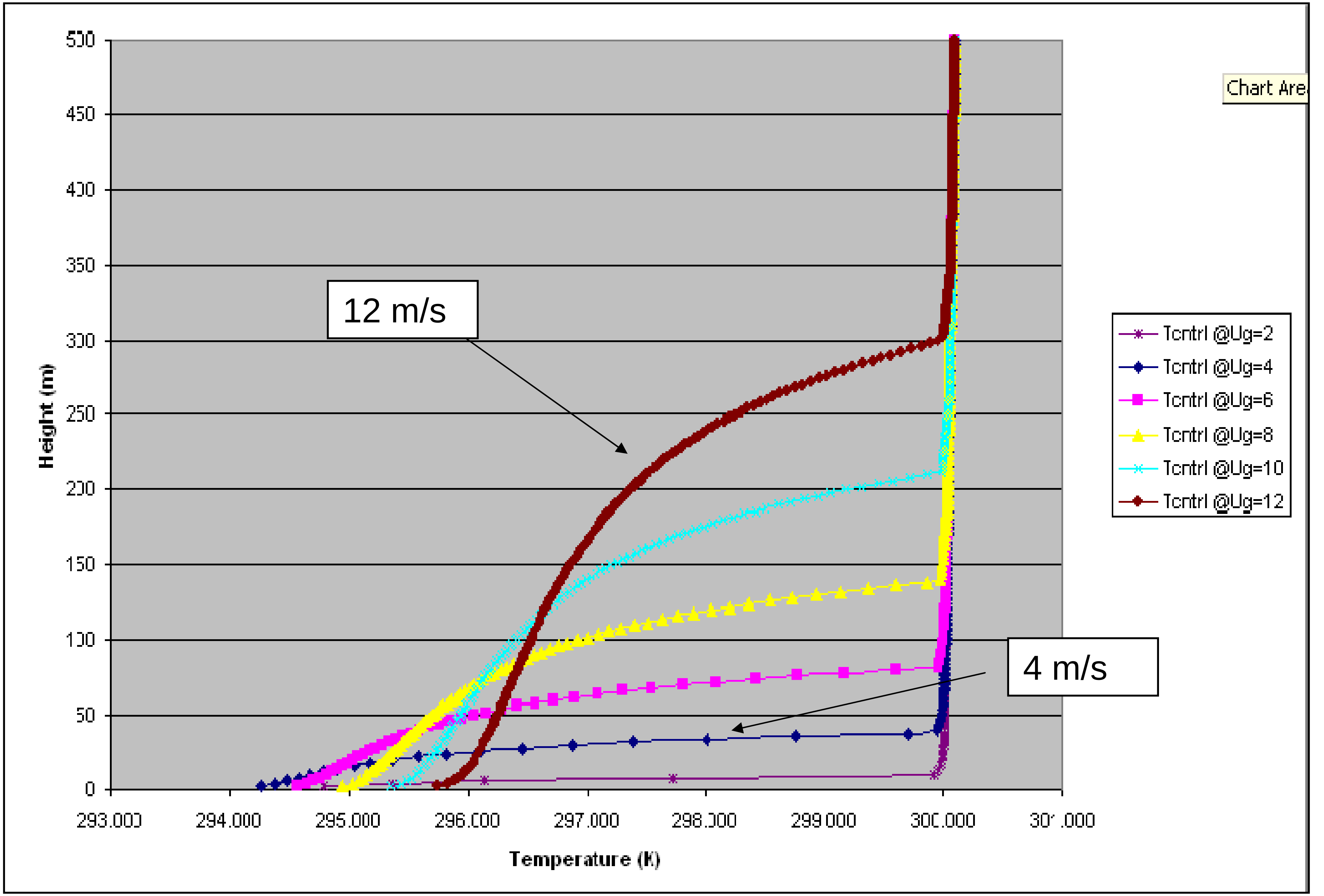
Increases in downward radiation and/or increases in surface heat capacity or roughness act to make the stable boundary less stable

This decreased stability in certain parameter spaces causes the surface to be more connected with the air aloft leading to enhanced warming

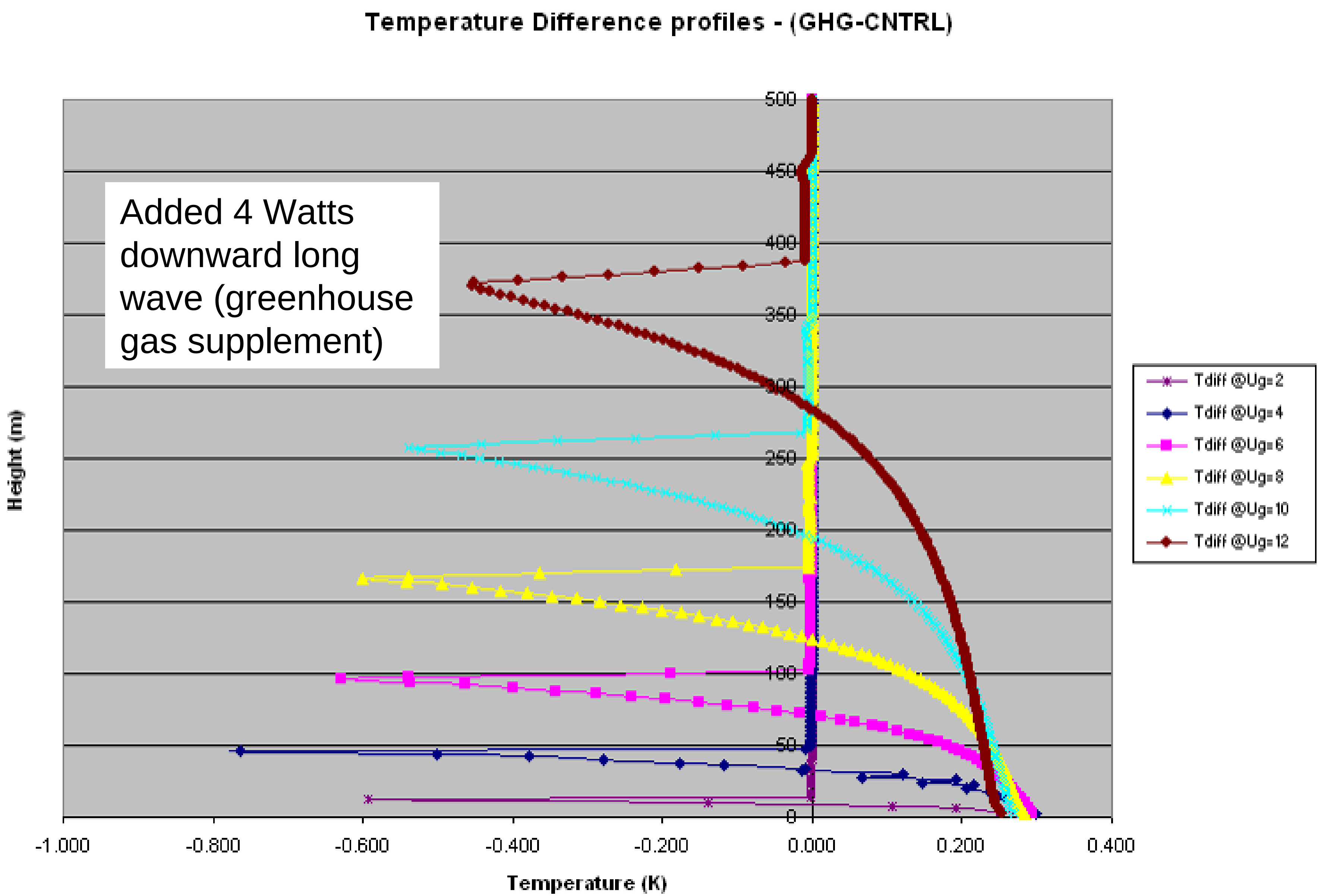


Thus, this acts as a positive climate feedback in that slight changes in parameters can lead to large changes in temperature.

However, it is not a net energetic increase but only a redistribution of heat !

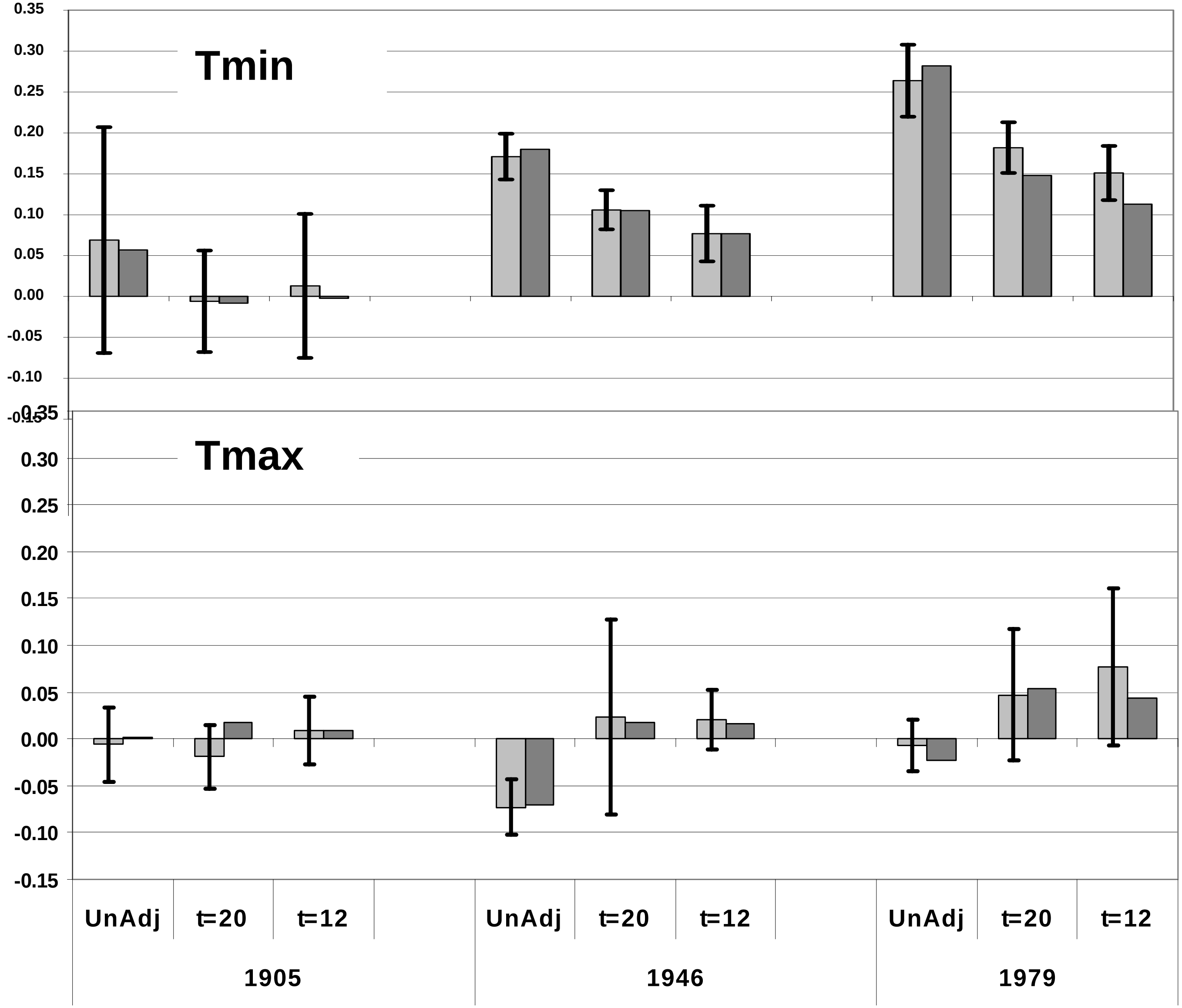


12 m/s
4 m/s
Height (m)
Temperature (K)
Tcntrl @Ug=2
Tcntrl @Ug=4
Tcntrl @Ug=6
Tcntrl @Ug=8
Tcntrl @Ug=10
Tcntrl @Ug=12



Temperature Difference profiles - (GHG-CNTRL)
Added 4 Watts downward long wave (greenhouse gas supplement)
Height (m)
Temperature (K)
500
450
400
350
300
250
200
150
100
50
0
-1.000
-0.800
-0.600
-0.400
-0.200
0.000
0.200
0.400
Tdiff @Ug=2
Tdiff @Ug=4
Tdiff @Ug=6
Tdiff @Ug=8
Tdiff @Ug=10
Tdiff @Ug=12

East Africa Temperature Trends



How well do GCM handle these processes?

While most GCMs have some stability dependence in their surface layer schemes the parameterization is often crude and heavily engineered.

Higher resolution boundary layer models generally have a closure scheme dependent on turbulent kinetic energy (TKE) equations or Richardson Number analogues.

$$\frac{\partial(TKE)}{\partial t} \approx \underbrace{K_m\left(\frac{\partial}{\partial}\frac{V}{z}\right)^2}_{\text{shear generation}} + \underbrace{K_h\frac{g}{\vartheta}\frac{\partial\vartheta}{\partial z}}_{\text{buoyancy suppression}} + dissipation$$

Ratio of buoyancy term and shear generation term is the Richardson Number

$$Ri = \frac{g}{\vartheta}\frac{\partial\vartheta}{\partial z}/\left(\frac{\partial}{\partial}\frac{V}{z}\right)^2$$

The problem with implementing these closures in large scale models is that the closure is grid dependent

$$Ri = \frac{g}{\vartheta}\frac{\partial \vartheta}{\partial z} / \left(\frac{\partial}{\partial}\frac{V}{z}\right)^2$$

While the Richardson Number is dimensionless it is dependent on grid size

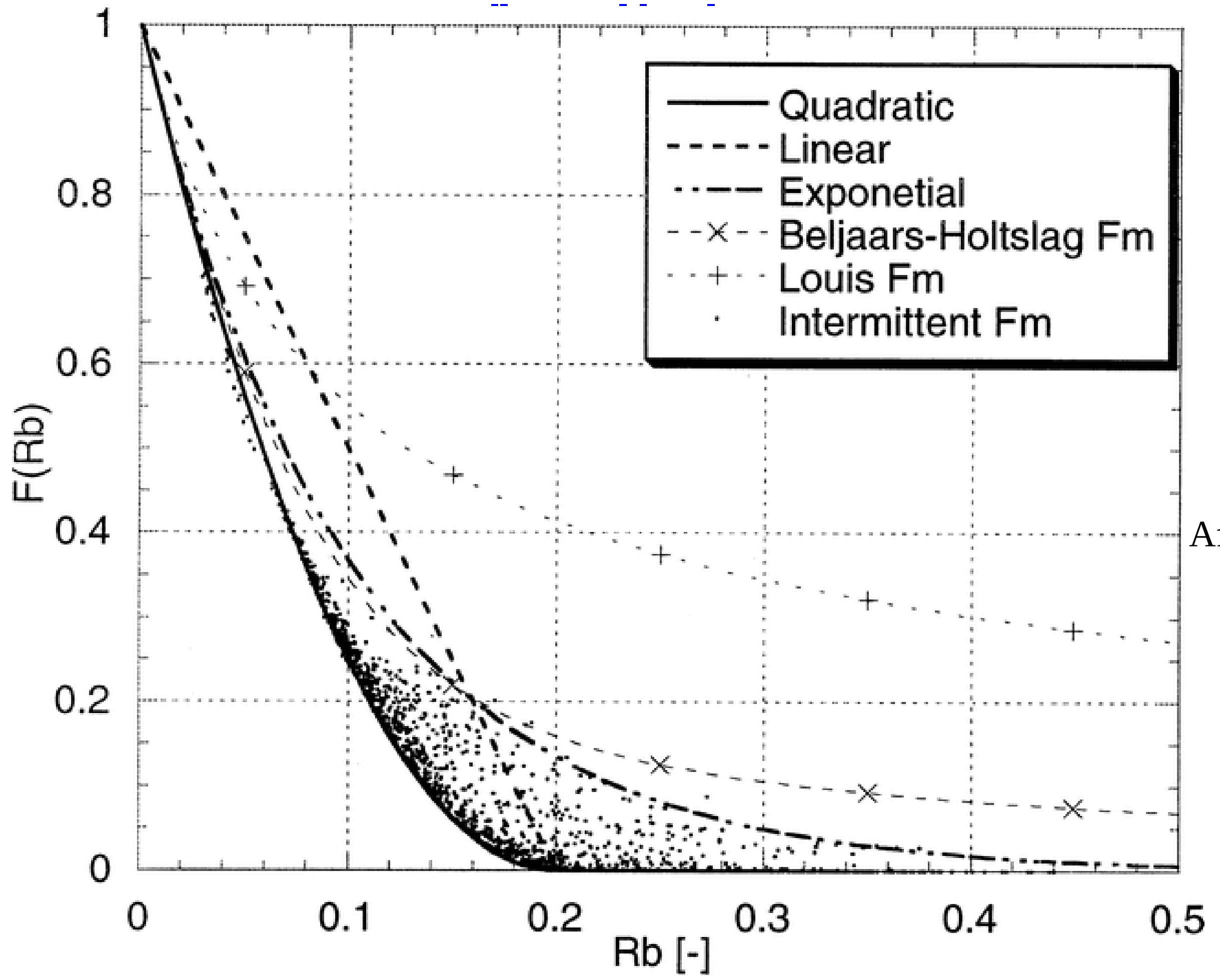
$$Ri = f(\Delta z)$$

As the vertical grid size increases Ri becomes larger. Thus, mixing becomes less.

Large scale models fight this tendency of too little mixing. In the stable boundary layer, the model nearly always wants to go to the cold solution (Beljaars and Vitirbo 1998, Steeneveld et al. 2006) and in fact to a runaway cooling.

Modelers engineer around this by adding more mixing or using stability functions with more mixing (Louis profiles)

GCM's lose their sensitivity to landuse change and downward radiation by having long-tailed stability functions



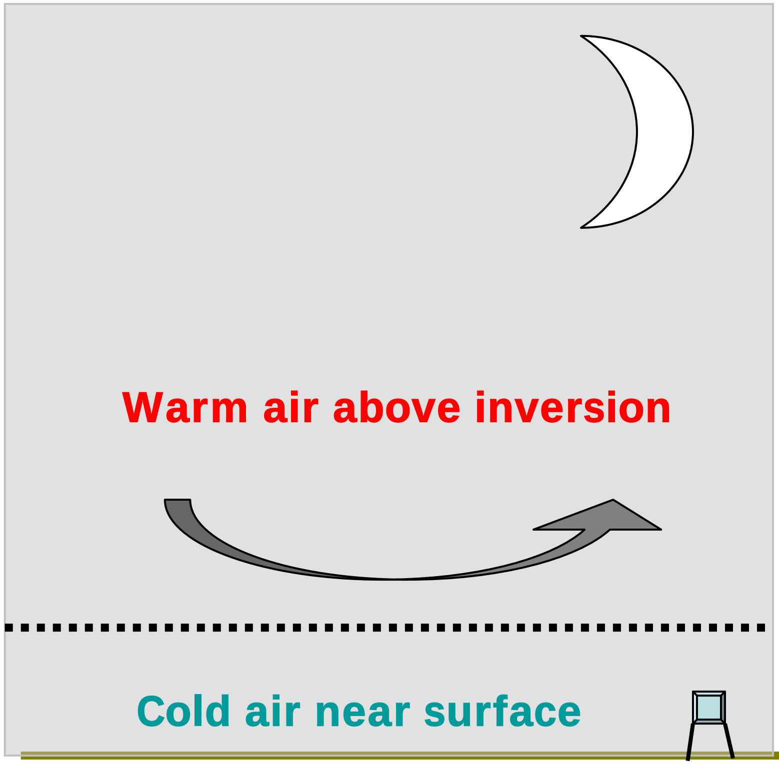
After Van de Weil 2002

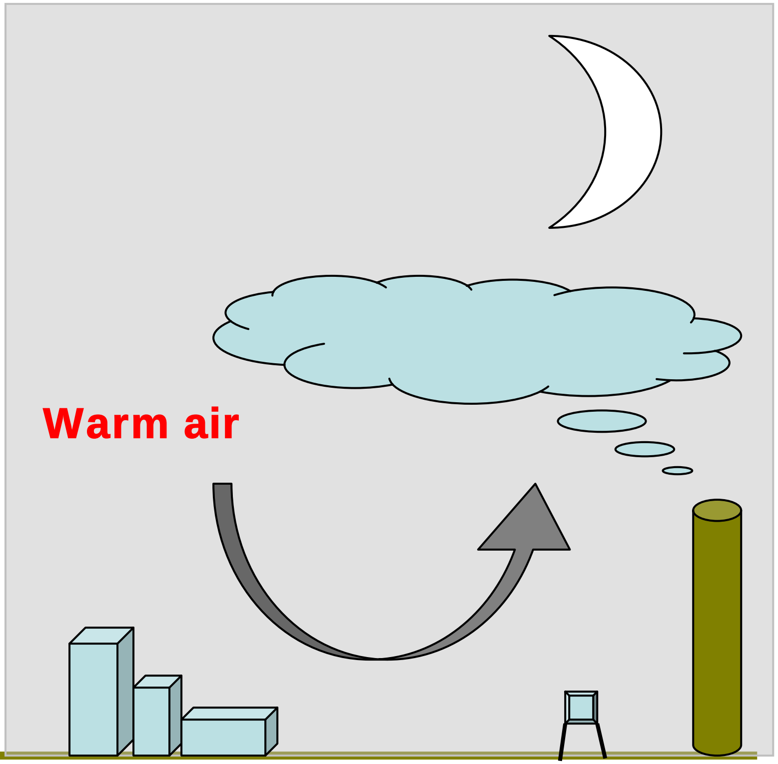
FIG. 7. Various stability functions for turbulent exchange as a function of the bulk Richardson number. The dots correspond to the *time-averaged* (30 min) values of the stability function during an intermittent run with the original quadratic stability function used in each time step

While engineering fixes keep the model within reasonable parameter spaces the, models lose much of their dynamic dependence on changes in stability.

Thus, GCMs in general would not capture the boundary layer climate feedback responses discussed here.

Night Surface Temp





Nighttime – disconnected shallow layer / inversion. But this situation can be sensitive to small changes such as roughness or heat sources.

Buildings, heat releasing surfaces, aerosols, greenhouse gases, etc. can disrupt the delicate inversion, mixing warm air downward - affecting TMin.

1. **Minimum temperature trends are easily influenced by land use change.**
2. **Minimum temperatures only measure a shallow layer.**
3. **Mimimum temperatures are very sensitive to radiative forcing from enhanced greenhouse gases, clouds and aerosols. But these temperature changes are largely due to a redistribution of heat.**
4. **Models don’t handle night-time boundary layers very well.**

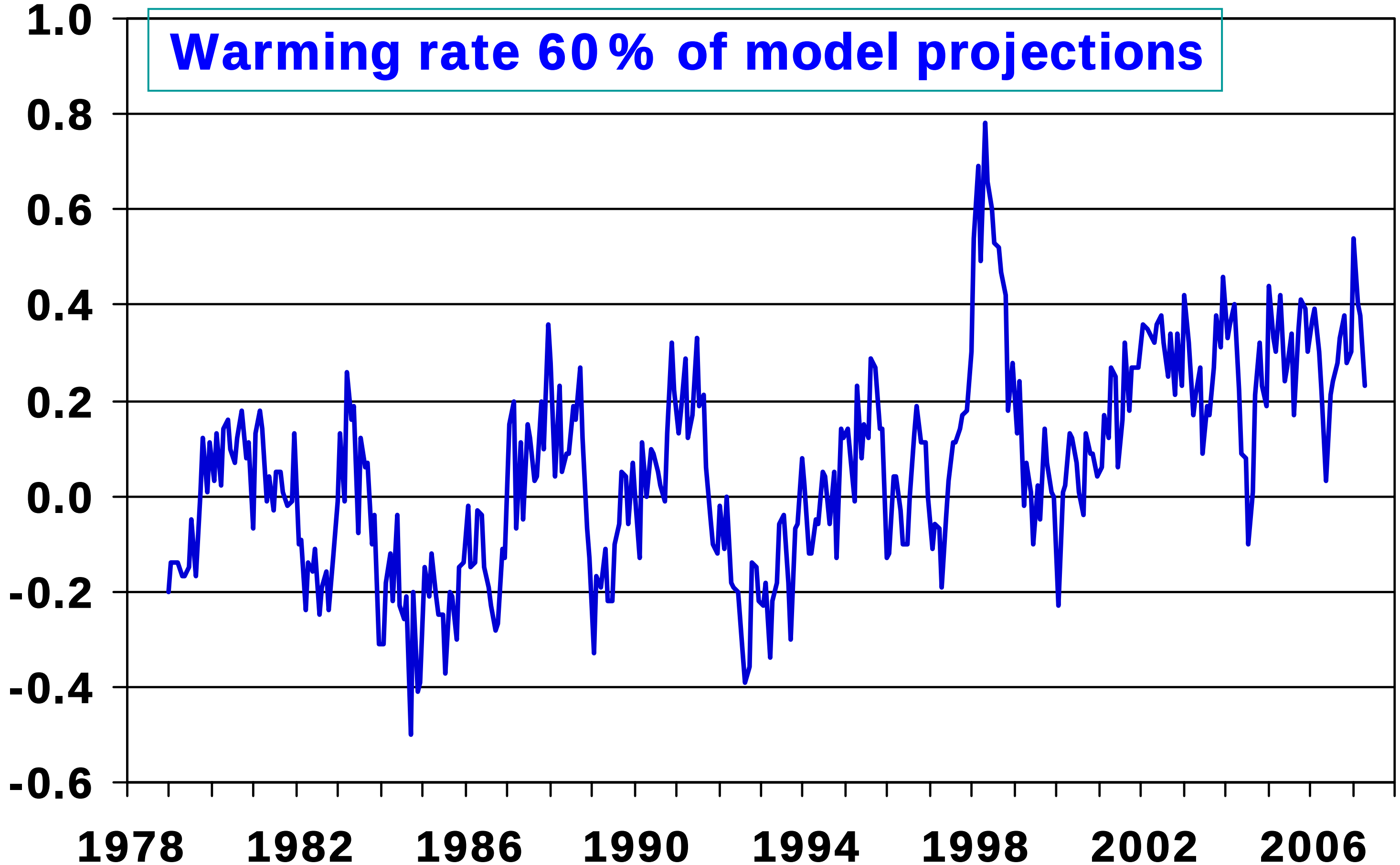
So why use night-time temperatures to detect accumulation of heat due to CO2 climate change?

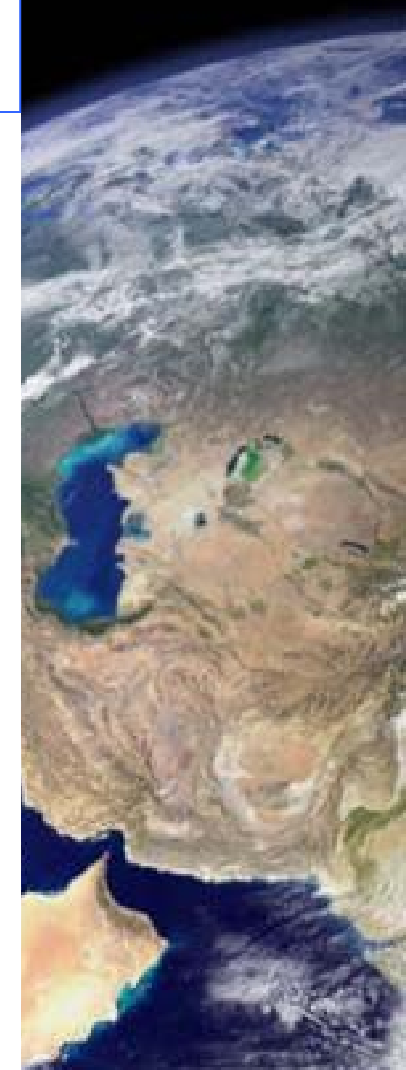
Better to use measurements of deep atmosphere- balloons or satellite or surface maximum temperatures.

True Color Earth

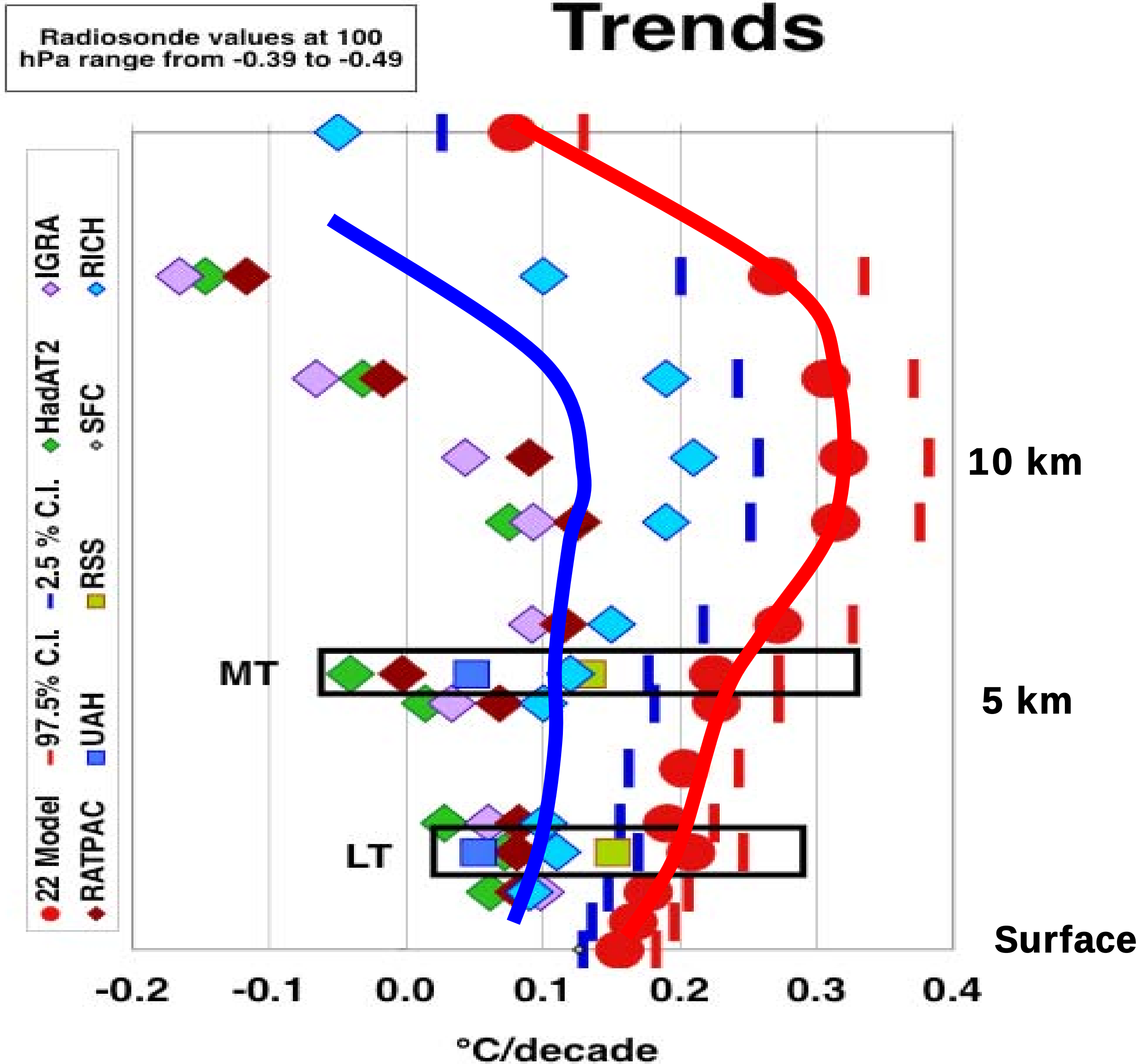
by WeatherStreet.com

Global Bulk Atmospheric Temperatures
UAH Satellite Data





Trends



Douglass et al. 2007

Conclusions

Above evidence suggests that Tmin is a terrible way to track the accumulation of heat from anthropogenic greenhouse gases in the deep atmosphere.

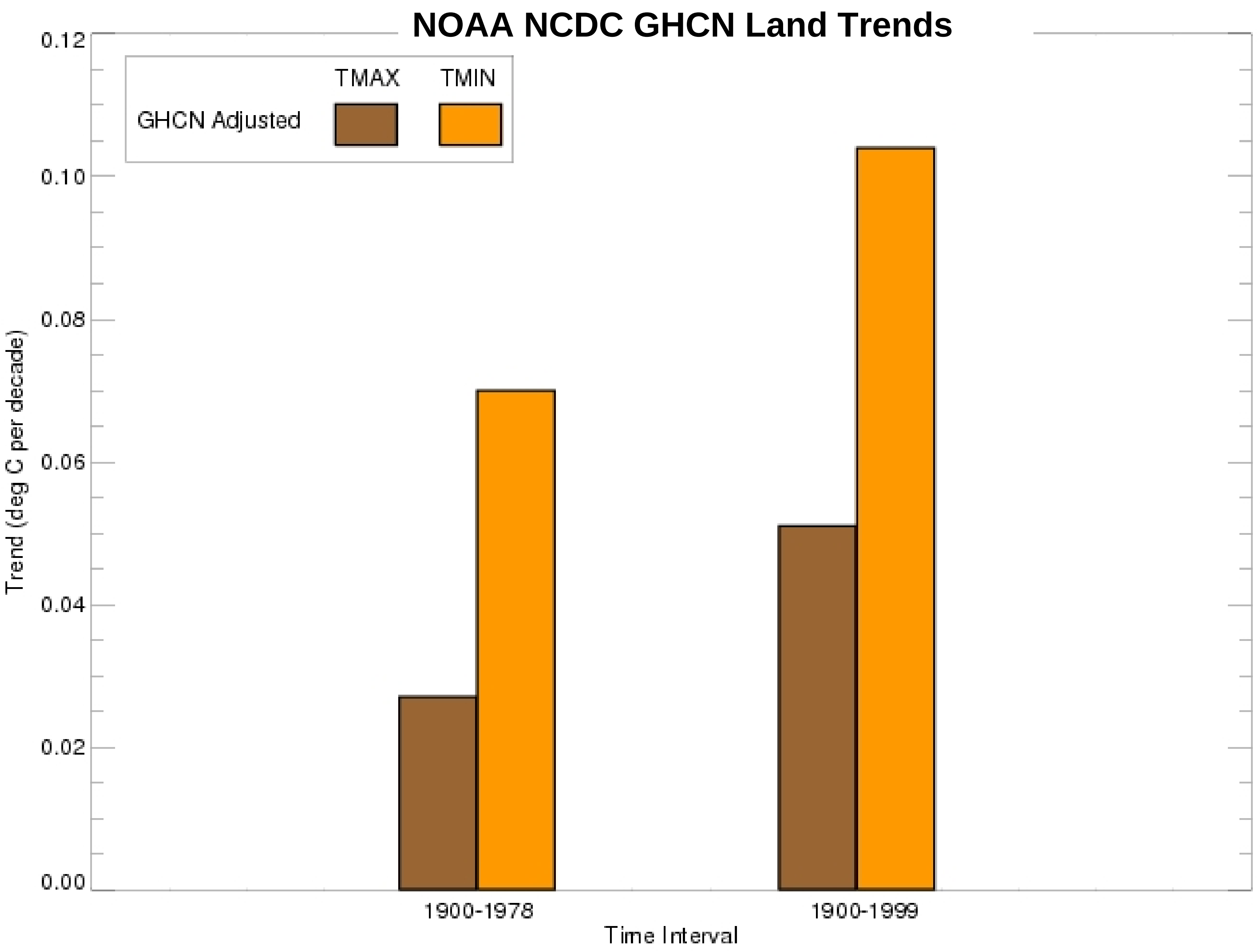
Maximum temperatures (Tmax) have a better chance of detecting heat accumulation in the deep atmosphere

A. Tmax usually represents a deep measure of temperature since daytime temperatures are generally well mixed up to 1 km or 2 km.

B. Larger average wind speeds means the horizontal foot prints of the measurements are larger and less sensitive to local land use change.

C. Tree rings which are a prime way to extend the past climate record beyond the instrumental era are evidently better correlated with maximum temperatures (Wilson and Luckman 2003)

Opinion: In general, surface temperature data sets as now constructed have numerous flaws. They are not sufficient to make key public policy decisions.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Trend (deg C per decade)
1900-1978
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