Estimating the annual mean screen temperature empirically

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With 9 Figures

Received March 6, 2001
Revised July 30, 2001

Summary

We have examined station data from around the world to study the separate effects of the latitude (between 60° N–40° S), elevation and distance inland, on the annual-mean screen temperature. In the first 200–400 km from some west coasts, screen temperatures (after adjustment for elevation) rise inland, reaching a maximum called the ‘thermal-ridge temperature’ Tr. The rise of temperature within this littoral fringe (of width F) depends mainly on the difference between the sea-surface temperature off the west coast and the zonal mean. Further inland than such a fringe, adjusted temperatures generally decline eastwards, approximately linearly, at a rate C. The rate is related to hemisphere and latitude.

Empirical relationships between latitude and the observed coastal sea-surface temperature, the near-shore screen temperature, Tr, C and F for each continent are used to estimate annual mean temperatures on land. Independent estimates of this kind for 48 places, using a look-up table, differ overall by only 0.7 K from the actual long-term average annual mean temperatures. This is less than half the error resulting from an assumption of zonal-mean temperatures. Basing estimates on coastal sea-surface temperatures, instead of the look-up table, results in an average error of 1.0 K for the 48 places. The errors are comparable with the standard deviation of annual mean temperatures during 30 years or so.

1. Introduction

There are several reasons for estimating features of the climate of a place by assuming the relevance of available measurements from geographically similar locations. Firstly, no measurements may have been made at the place in question. Secondly, measurements can be compared with an estimate, as a check on any eccentricity of the observations, provided we know that the estimate is commonly of useful accuracy. Significant difference between estimate and measurement signals some regional or local peculiarity, which may warrant investigation. Errors in estimating based on only three geographic factors (viz. latitude, elevation and distance from the sea) indicate the degree to which more local factors govern the climate. Thirdly, being able to deduce climate from geographic features implies the reverse, an ability to identify places with known climates, e.g. homoclines. Lastly, and importantly in teaching climatology, quantitative empirical associations of numerical values of climate elements (with each other and with geographic factors) provide clues to the relative magnitudes of the mechanisms responsible, and represent an advance on the merely qualitative generalisations customary in textbooks.

The question to be answered is this – how accurately can we estimate the annual mean temperature at screen level at a locality on land, from our present knowledge of the effects of large-scale geographical features? This is not answered properly by available multiple-regression studies, involving merely statistical interpolation between
observations, e.g. Zheng and Basher (1996). That approach ignores physical processes involving the distance from the sea and the sea breezes, for example. Instead, we will attempt to disentangle the large-scale factors affecting annual mean temperatures generally. We consider only latitudes between 40° S–60° N, where most people live and temperatures are little affected by the high albedo and latent heat of ice.

We begin by considering the effect of elevation on annual mean temperatures, in order to ‘adjust’ observed temperatures to their sea-level equivalents, thus allowing a common basis for comparisons. The second variable to be considered is the latitude, to permit ‘correcting’ observations from places of similar latitude to the equivalents at a selected common latitude nearby. On removal of the dominant effects of elevation and latitude, we can examine the effect of eastward distance from the ocean. Then we can use the information to estimate the temperature at each of numerous selected places, for comparison with the observed values.

Much of the evidence comes from the book by Linacre and Geerts (1997), hereafter referred to as LG97, secondly from Linacre (1992), i.e. L92, and thirdly from Linacre and Hobbs (1977), i.e. LH77. Some climate data come from Pearce and Smith (1990), based on ‘Tables of Temperature, Relative Humidity and Precipitation of the World’ (Met. 617, Her Majesty’s Stationery Office, London, 1958 et seq.). However, most of the climate-station data used here have been extracted from the International Station Meteorological Climate Summary v 4.0 (1996), available on a CD-ROM from the US National Climate Data Center (www.ncdc.noaa.gov). Also, we make considerable use of the NCAR/NCEP global reanalysis data set (at a resolution of 2.5 degrees), which is based on weather station, buoy, ship, upper-air and satellite data (Kalnay et al., 1996). These data were mined on-line at the web-site of the US Climate Diagnostics Center, http://www.cdc.noaa.gov) using monthly-mean values for the period 1968–1996.

2. The effect of elevation on the annual mean temperature

Average temperatures fall with elevation, both in the free atmosphere and on rising ground. The International Civil Aviation Organization’s Standard Atmosphere lapse rate is 6.5 K/km in free air in the troposphere. (Note that temperature differences are here expressed in units Kelvin, whereas temperatures themselves are in Celsius units.) But lapse rates of screen temperatures in mountainous terrain are affected by heat transferred to and from the ground surface, and by topographically induced winds. The air near the ground is generally warmer than free air at the same level, in warm latitudes and seasons.

Various ground-level lapse rates have been reported in the literature. Data from 34 places between 0–34° S in Africa (LG97, p. 370) lead to a relationship between the annual mean temperature (here taken as the average of observed January and July mean temperatures), the latitude and the elevation, implying a lapse rate of 3.8 K/km. Temperatures from places in South America show a ground-level lapse rates of about 4.2 K/km (LG97, p. 58), 4.9 K/km (LG97, p. 68) and 5.0–6.1 K/km (Safford, 1999). In addition, we have found that lapse rates at a spacing of 5-degrees latitude on the east of the Andes range from 3.4–7.6 K/km, with an average of 5.3 K/km. (Rates on the west of the Andes are scattered around only 2.9 K/km, but that is explained by mid-level inversions due to cold coastal seas – see Note 11.E in LG97.) Likewise, data from 18 places on the east of the Himalayas (between 28–33 degrees of latitude and 93–104 longitude) indicate an overall value of 5.0 K/km.

These various lapse rates have a median of 5 K/km and that figure will be used in what follows. Applying it to a value of ground-level temperature at a given height provides the sea-level equivalent, which we call the ‘adjusted’ temperature. Adjusted temperatures allow comparison of conditions independently of elevation.

Fortunately, the choice of the lapse-rate value is not critical in estimating the annual mean temperature at a place, because of the procedure adopted. This involves initial ‘adjustment’ of observed values, to derive relationships with temperatures at sea level, and hence an estimate of the adjusted temperature for a particular place. This is subsequently adjusted using the same lapse rate, but in reverse, to obtain the estimate of the actual temperature at the height of that place. In other words, there is some cancellation of the effect of the lapse rate.