Interactions of Global-Warming and Urban-Climate in Different Climate Zones

Extended Abstract 68

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INTRODUCTION

This paper is organized around the following five interrelated themes: Global climate-change is here; Global climate change is a function of time and location; A review of Köppen global climate-classification; Urban-areas create their own climate;, and Urban & global climate-changes interact, for good or bad.

GLOBAL CLIMATE CHANGE

The physics behind the atmospheric greenhouse effect is that incoming short-wave solar energy mostly passes-thru the atmosphere, but outgoing terrestrial long-wave infra-red (IR) radiation is mostly-absorbed by atmospheric greenhouse gases (GHGs), the most important of which are carbon dioxide (CO_2) and water vapor (H_2O). This absorbed radiation is then re-emitted back to both space and the surface, and this latter energy then results the earth having an equilibrium temperature that is about 40°C warmer than it would be without an atmosphere. This effect was first described by Jean-Baptiste Fourier in 1827. As global industrialization has resulted in increased CO_2 emissions, and thus in increased atmospheric concentrations of CO_2, this equilibrium has been upset and the earth has been warming in recent decades.

The IPCC (2007) report, at IPCC_Report.htm, provides the best summary of global warming, both of its observations and of the attempts to model both past (observed) and future (projected) trends. The IPCC models generally reproduce past warming trends, including the observed global cooling from about 1940-70, during which aerosol induced cooling was stronger than GHG induced warming. They also show that the largest warming rates have occurred since 1970. The models are not perfect, however, with the largest areas of uncertainty as the interacttions between aerosols, clouds, and radiation.

SPATIAL AND TEMPORAL VARIATIONS

The IPCC temperature changes also show that changes since 1970 due to human-activities are greater than those due to natural causes, and that both are non-uniform over globe, when viewed on continental scales. They also show that the changes in temperature over land areas are greater than those over the ocean, and that seasonal variations exist in all areas, with certain areas even showing cooling. Changes in global precipitation patterns likewise show the same variations.

Impacts from climate-change include higher sea surface temperatures (SSTs), which result in reduced land and sea ice-coverage, increased sea-levels, and thus coastal flooding. Other adverse impacts include increased numbers of severe-storms; pole-ward movement of tropical insect-borne diseases; higher-rates of heat stress, summer energy-use (Lebassi *et al.* 2010), surface ozone, wildfires (especially if areas are also drier); droughts and reduced water-supplies. Crop-growth areas will move upslope (with mountain-tops as a limit) and pole-ward. This last movement will produce winner (on this issue, at least) and loser countries. Beneficial impacts include fewer frost-days and lower-rates of winter energy-use. All of these impacts will increase human migration, producing conflicts and security issues.

A "meteorology view" of climate-change physics, is that GHGs cause redistributions in the earth-energy system, which changes large-scale atmospheric and ocean flow-patterns, which changes the movements of warm and cold air masses and storms, which produces areas with more or less: heat/cold waves and droughts/floods. Evaluation of true local-magnitudes of climate-change requires segmented trend-analyses on correct-scales, both temporal (i.e., which years, seasons, time of day) and spatial (i.e., latitudinal/longitudinal area, altitude, distance from sea, and urban vs. rural areas).

One example of a local climate impact investigated by our current research group involves the work by Lebassi *et al.* (2009) who evaluated 1950-2005 summer (June, July, August; JJA) 2-m level mean-monthly max air-temperatures for two California air basins: San Francisco Bay Area (SFBA) and South Coast Air Basin (SoCAB). They focused on the rapid post-1970 warming period. Results for all 159 sites together showed: increased (0.23^{o}C decade^{-1}) T_{ave}-values; and asymmetric warming, as T_{min}-values increased faster than T_{max}-values (0.27 vs. 0.04^{o}C decade^{-1}). The spatial distribution of SoCAB (Figure 1) and SFBA T_{max}-values exhibited a complex pattern, with cooling (-0.30^{o}C decade^{-1}) in low-elevation coastal-areas open to marine air penetration and warming (0.32^{o}C decade^{-1}) at inland areas and at higher elevation coastal sites. They thus hypothesized that the coastal JJA T_{max}-cooling was due to (as a "reverse reaction") global-warming of inland areas, which resulted in increased sea breeze flow activity.

Lebassi *et al.* (2011) used the mesoscale meteorological RAMS numerical model, with a smallest horizontal grid-resolution of 4 km, to reproduce the SoCAB observational T_{max}-trends in Lebassi *et al.*[2] Results showed (a) 1400 LST coastal cooling up to -1.0°C; almost the exact magnitude as the observed trend of up to -1.05°C and (b) sea breeze accelerations of up to 1.5 m s^{-1} at the general location found in the observational study.

Coastal cooling may thus be an example of a regional "reverse-reaction" to global warming, and that significant societal impacts may result from this effect. For example, agricultural production could increase or decrease, e.g., wine grape production will increase in the cooling valleys north of San Francisco. Beneficial effects due to reduced summer T_{max}-values in coastal areas could include decreased max O_3 levels, which will occur due to resulting reduced: fossil-fuel usage for cooling, natural hydro-carbon production, and photochemical photolysis rates. Human thermal-stress rates and mortality would also decrease. Additional analyses and simulations are needed to evaluate T_{max} cumulative frequency distributions to see if heat wave frequency is increasing at given sites, even as average T_{max}-values decrease.

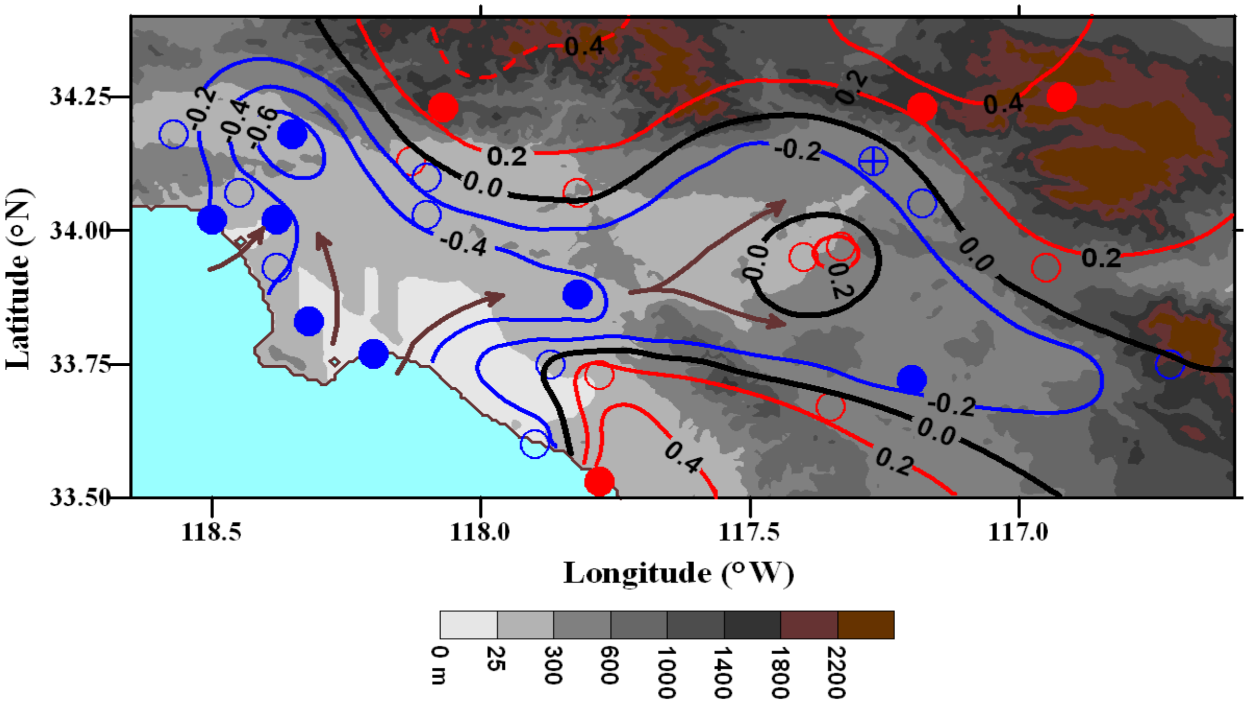

Fig. 1: SoCAB 1970-2005 summer 2-m T_{max} warming/cooling trends (^{0}C dec^{-1}), where solid, crossed, and open circles show statistical p-values of < 0.01, 0.01 to 0.05, and > 0.05, respectively (from Lebassi et al. 2009).

KÖPPEN CLIMATE TYPES

The original Köppen global climate classification system was based on the requirements for certain plant-types to grow, as estimated by local monthly-average temperature and precipitation values. The modified (with the addition of the H-climate type, as explained below) global distribution of Köppen climate types (Figure 2) shows the following main regions: cold high-altitude H-climates (shown on this older map as E, defined below) in Tibet and the Andes; mid-latitude dry B-climates in the Sahara and on the west-side of the continents; hot tropical A-climates at the equator; middle-latitude mild-winter C-climates; cold snowy-winter high-latitude D-climates in most of Canada and Siberia; and cold polar E-climates in Antarctica, Greenland, and the northern reaches of Canada and Asia.

Sub-divisions of interest to the current study include: wet (f) warm (a) summer Cfa Mediterranean C-climates on the east-side of the continents; and cool (b) dry (s) summer Csb Marine

Mediterranean C-climates on the west-side of the continents; the current study area on the west coast of California has this climate, and coastal-cooling is most likely in these climates, as their summer on-shore flows move over cold southward-moving coastal ocean-cur-rents.

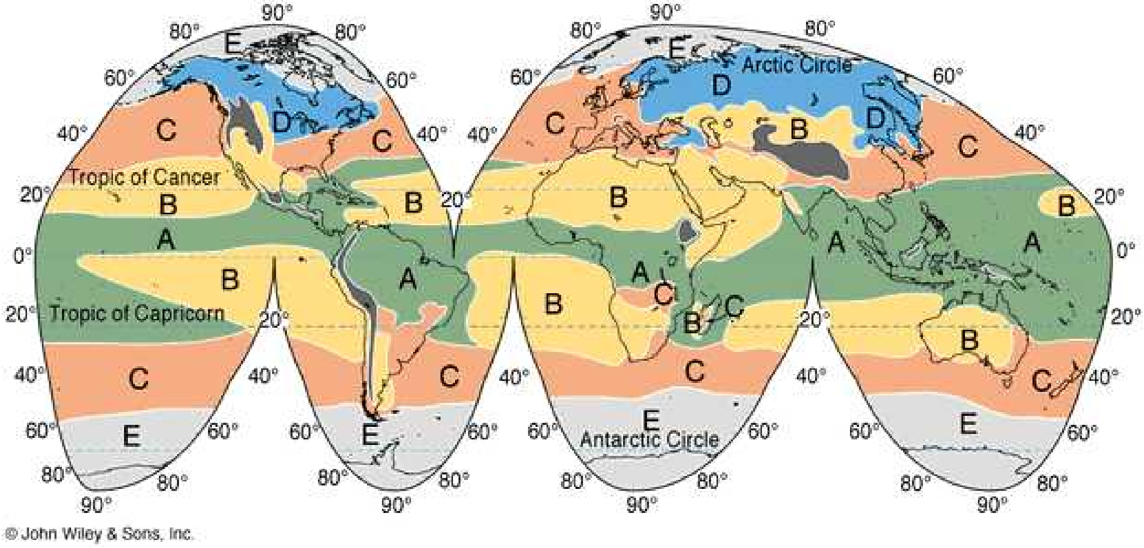

Fig. 2: Köppen global-climate classification system; see text for definition of symbols.

URBAN CLIMATES

The weather, climate, and climate-change within cities results from battles between conflicting urban-induced impacts on the earth-surface and atmosphere. These changes result: when grass and soil are replaced by concrete and buildings, which alters surface heat and moisture fluxes to and from the atmosphere; from fossil-fuel consumption (especially in high latitude cities), which produces atmospheric pollution and heat; and as atmospheric aerosols and building-walls decrease both incoming solar and outgoing IR radiation. One net effect of these processes is that, during periods with low regional wind speeds, low-latitude cities lose their stored solar energy more slowly at night than do nearby rural areas. They thus remain warmer at night, forming a nocturnal urban heat island (UHI), a localized analogy to global warming.

Some resulting parameter-changes are generally in one direction within urban areas (relative to values in surrounding rural areas), i.e.: visibility is decreased due to increased urban aerosol levels; and turbulence is increased both due to mechanical (due to rough surfaces) and thermal (due to hot surfaces) effects. Other parameters, however, are increased or decreased (due to current local conditions): UHIs or urban cool islands (UCIs; discussed below) can form; flows can either convergence into a city (into the low pressure area associated with an UHI) or divergence around the city (during non UHI periods) like water around a rock; and wind speeds can either decrease due to surface roughness effects or increased due to UHI-related accelerations.

Imamura (1992) related UHI-formation to the thermal inertia (TI) of adjacent urban and rural surfaces. TI is defined as the square root of the product of subsurface heat conductivity and heat capacity. Literature values show that wet rural soils have higher TI values than urban concrete and building materials, which in turn have higher values than dry rural soils. On the diurnal and annual time cycles, wet rural soils thus heat up and cool-down most-slowly, while the converse is true for dry rural soils; urban rates are intermediate.

Use of this UHI formation theory in conjunction with the Köppen climate-types thus makes it possible to generalize when UHIs will be strongest in a given city, based on the seasonal distribution of its regional precipitation, as follows:

- warm or hot (low latitude) cities surrounded by wet rural-soils (e.g., in A-climates and in Cfa-climates, on the east side of the continents) should have: daytime and wet-season maximum UHIs; and nighttime and dry-season UCIs
- warm-cities within dry rural-soils (e.g., in B-climates and in Csb-climates, on the west-side of continents) should show reverse UHI and UCI diurnal patterns
- cold (high-altitude H- and high-latitude D- and E-climates) cities, whose UHIs form mainly from anthropogenic heat-fluxes should show: winter and nighttime maximum-UHIs; and summer and daytime minimum-UHIs.

These city-scale UCIs are larger-scale (and form by different physical processes) than those behind daytime shaded-buildings.

The survey of UHI-values from around the globe by Imamura (1992) generally verifies the above generalizations, as do her observations in the following cities on three continents (whose populations range from a few thousand to a few hundred thousand): Shimozuma, Japan; Sacramento, California; and four Brazilian cities (Figure 3). Her results show all nighttime and nighttime UHIs proportional to population (in different non-linear rates), and while all nighttime UHI-values fall on the same curve, daytime values in cities in wet rural-soils have larger UHIs than those in dry rural-soils, for the same population.

GLOBAL-URBAN INTERACTIONS

It is thus possible to conclude that, as it affects human thermal-stress values:

- daytime-UHIs reinforce global-warming in: cool cities, a good (in terms of human thermal-stress levels) result; and warm-cities in wet rural-soil areas in A- and Cfa-climates, a bad result.
- nighttime-UHIs reinforce global-warming in: cool-cities, a good result; and warm-cities in dry rural-soil areas in B-climates and in Csb-climates, a bad result
- nighttime-UCIs counter global-warming in warm-cities in wet rural-soil areas in A- and Cfa-climates, a good result

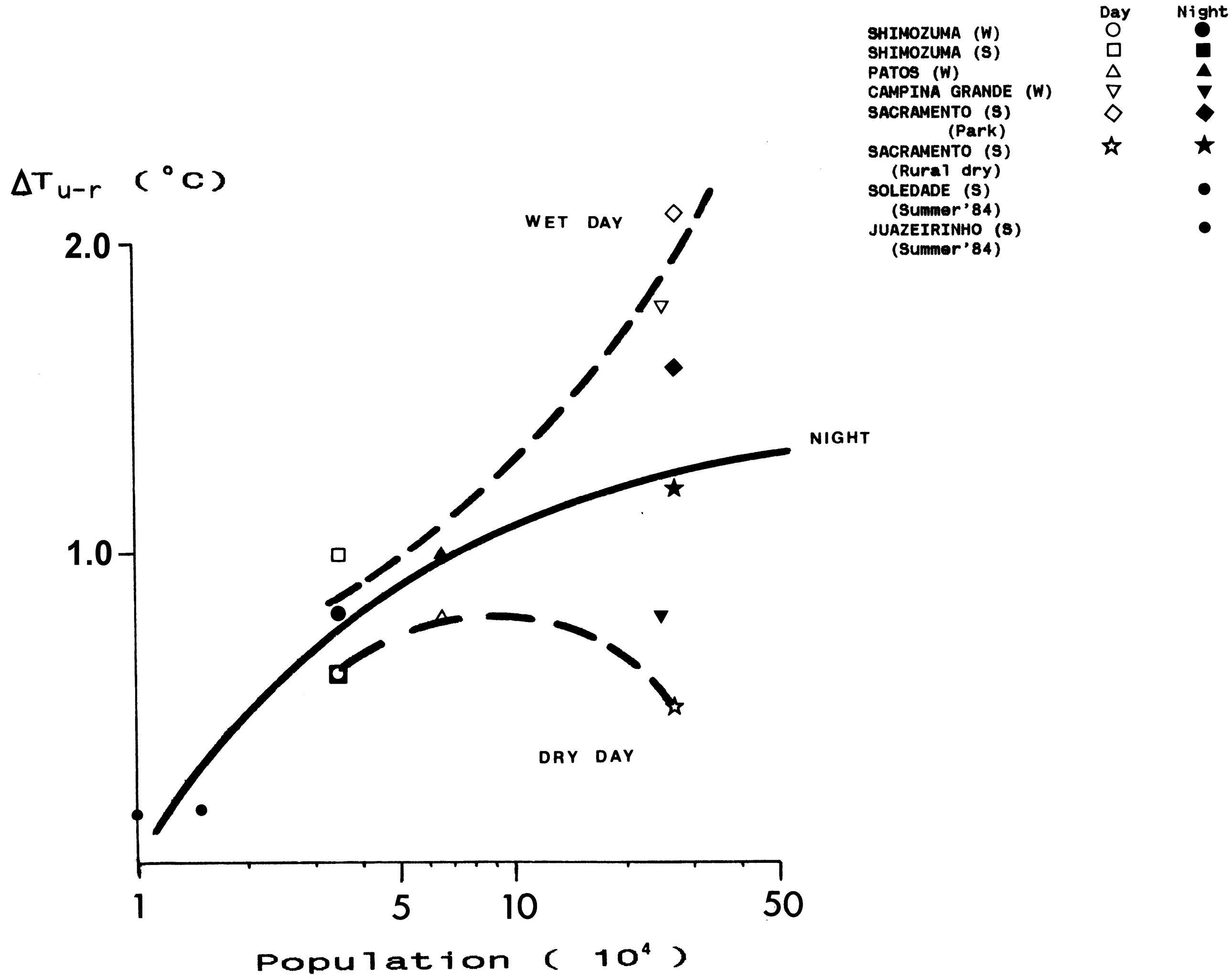

Fig. 3: Daytime and nighttime UHI-magnitudes (^{0}C) as a function of population for a variety of cities, as a function of nearby rural soil moisture.

- daytime-UCIs counter global-warming in warm-cities in dry rural-soil areas in A-, B- and in Csb-climates, a good result.

The interaction of UHIs and global climate-changes in different climate zones around the world thus effects local-scale security issues, as: nighttime and daytime UCIs counter global-warming, and thus reduce thermal-stress events in any climate area; and heat-stress events are most-likely in wet rural-soil areas in A and Cfa climates.

Conclusion

The IPCC shows non-uniform global-warming rates over the last 35 years over the globe, on both the seasonal and diurnal time-scales. The spatial distribution of climate change is thus a function of latitude, longitude, altitude, urbanization, and distance from the sea.

The paper focused on trends in summer 2-m daily T_{max} values for 1970-2005 in the SoCAB California coastal urban air basin. Results showed a complex pattern, with cooling in low-elevation coastal-areas open to marine air penetration and warming at inland areas. The explanation for the coastal cooling was that the expected GHG-driven global warming of summer T_{max}-values in inland California produced enhanced coastal-inland pressure- and temperature-gradients, and hence increased cool-air sea breeze intrusions, producing a "reverse reaction" coastal-cooling to global warming. RAMS simulations for the SoCAB area reproduced the general spatial extent of the coastal cooling area, as well as its maximum magnitude of about 1.0 K dec^{-1}. Coastal-cooling is thus most likely in west-coast marine-Mediterranean climates, with their on-shore flows-over cold southward-moving coastal ocean-currents.

Coastal-cooling reverse-reactions to global-warming are expected in subtropical low-elevation west-coast marine-Mediterranean Csb climate areas (i.e., California, Chile, Australia, South Africa, and Portugal), in which sea breezes strongly influence regional climate. IPCC (2007) 1976-2001 annual temperature trends do, in fact, show such cooling (blue dots at west-coast areas in Figure 6) at all these sites, except Portugal. Falvey et al. (2009) observed cooling off the Chilean coast, while Oglesby et al. (2010) found the phenomenon with 4 km WRF simulations of the west coast of Central America.

Urban areas also produce their own climates due effects from concrete and buildings, fossil fuel consumption, and atmospheric pollutant layers. One composite-effect of these impacts is that cities cool less rapidly than their rural surroundings, i.e., they remain warmer at night, and thus nocturnal urban heat island (UHIs) form, as a localized global-warming analogy; urban cool islands (UCIs) also form under certain conditions. The magnitude of UHIs and other urban-induced weather and climate effects is dependent on geographic location, background large-scale weather- and climate-conditions, and rural soil-moisture content.

As wet rural soils have higher TI values than urban building materials, which in turn have higher values than dry rural soils. On the diurnal and annual time cycles, wet rural soils thus heat up and cool-down most-slowly, while the converse is true for dry rural soils; urban rates are thus intermediate. A generalization of when UHIs would be strongest in a given city, based on the seasonal distribution of its regional precipitation, follows: warm cities surrounded by wet rural-soils have daytime and wet-season maximum UHIs, as well as nighttime and dry-season UCIs; while cities within dry rural-soils have the reverse UHI and UCI diurnal patterns. Cold cities (whose UHIs form mainly from anthropogenic heat-fluxes) have maximum winter- and nighttime-UHIs, as well as minimum summer- and daytime-UHIs.

Daytime-UHIs reinforce global-warming in cool (high-latitude and high-elevation) cities and in warm-cities in wet rural-soil climates, while nighttime-UHIs reinforce global-warming in cool-cities and in warm-cities in dry rural-soil climates. Nighttime-UCIs counter global-warming in warm-cities in wet rural-soil climates, and daytime-UCIs counter global-warming in warm-cities in dry rural-soil climates. Heat-stress events are thus most-likely in wet rural-soil climates.

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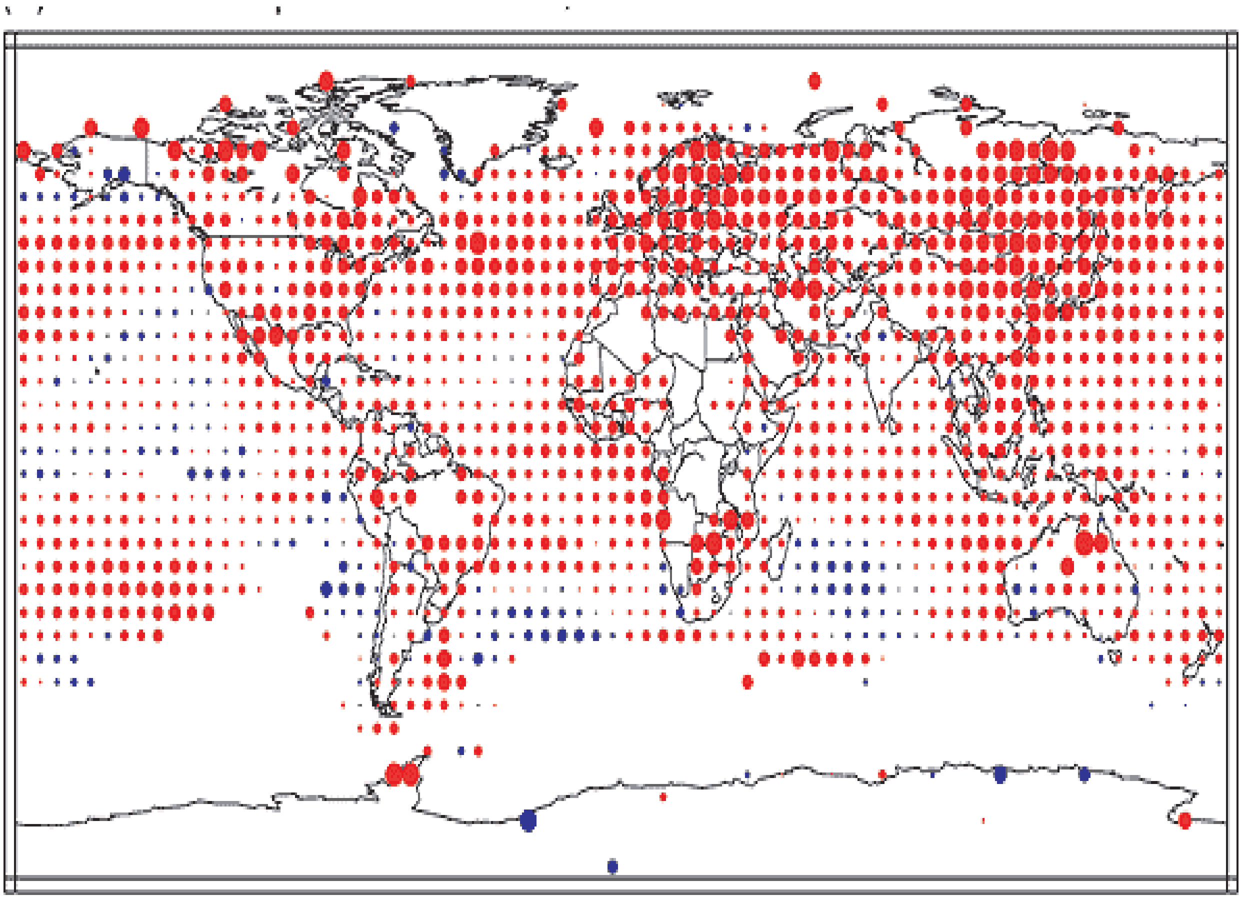

Fig. 4: Annual sea surface- and 2-m over-land air- temperature trends from 1970-2007, where red is warming and blue is cooling; and where circle-size is proportional to magnitude of change (from IPCC 2007).

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