5.6 OBSERVED LONG-TERM CALIFORNIA TEMPERATURE-TRENDS: COASTAL COOLING AND INLAND WARMING

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1. INTRODUCTION

Several studies have reported asymmetric warming attributed to historical land cover conversations by humans on regional (Chase et al. 2000) and global scales (Mintz, 1984; Zheng et al. 1997). It has been attributed a temperature decreased of 1-2°C (Betts 2001; Chase et al. 2000) in mid latitudes agricultural regions, and increases of 1-2°C (Defries et al. 2002; Sitch et al. 2004; Pielke et al. 2000) in deforested areas with possible extratropical impacts due to teleconnections.

Coastal areas represent an interesting case in which global, regional and local effects converge. In this study we report changes in regional and local climate, which may be attributed to the combined effects of local land cover conversions reflected in climatological maximum land surface temperatures and in global warming reflected mostly in increases of sea surface temperatures. The focus area of this study is Central and Southern California for which both cooling and warming trends were observed. We report maximum temperature increases inland and in certain coastal areas, while maximum temperature decreases along certain coastal areas. We attributed these asymmetric thermal trends to modifications in sea breeze flows driven by excessive warming of land masses over the sea surface temperatures. Earlier studies have reported asymmetric global warming attributed to increases in SSTs and in cloud cover (Karl et al. 1993; Nemani 2001).

We hypothesize here that asymmetric regional warming may be a consequence of changes in intrusion marine flows in coastal areas due to the combined effects of global warming and local land use.

Studies on impacts of local land cover conversions can be classified in urbanization or deforestation where the former is referred as urban heat islands (UHI).

The CEC, DOE, NASA, and NSF have initiated recent climate modeling studies to understand regional climate impacts in CA from modeled global change simulations through application of statistical downscaling techniques on scales down to about 10 km horizontal resolution. These efforts are useful to estimate resulting impacts on water resources, health, and air quality (Refs).

The current observational study reports on analyses of 2 m land and sea-surface temperatures from about 300 sites throughout CA for the last 60 years. Results for all of CA showed daily min temperatures with a significant upward trend, but corresponding max values with a smaller upward trend. Sub-area analyses showed these same results at inland Central Valley (CV) sites, but while coastal-plain areas in the San Francisco Bay Area (SFBA) and South Coast Air Basin (SCAB) generally also showed increasing min values, they showed decreasing max temperatures (Fig. 1).

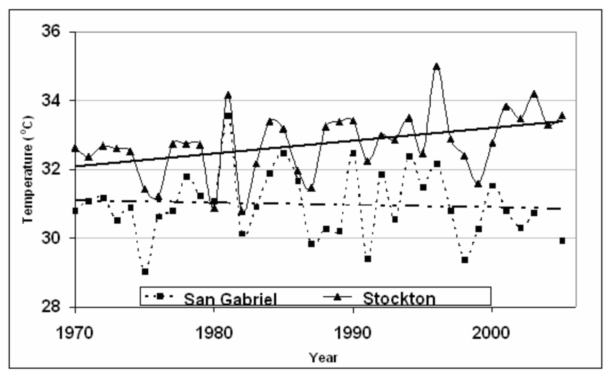

Fig. 1 Inland (__Stockton (SFBA)) and Coastal (San Gabriel - - - (SCAB)) temperature trends.

The current observational analysis has thus shown that global warming at inland CV sites have increased summer daytime horizontal temperature gradients across the state, which has increased the strength and frequency of cool summer marine sea-breeze flows into heavily populated and highly polluted CA coastal plains. These results will thus provide increased understanding of past and present trends in summer time ozone levels, as well as of the global and mesoscale (e.g., marine, land use, and topographic) physical processes causing these trends.

2. RAMS OVERVIEW

We used a mesoscale RAMS model to prove our hypothesis. This is a highly versatile non-hydrostatic numerical model developed at Colorado State University. It solves the Reynolds-averaged primitive equations, which are described by Tripoli and Cotton (1986). The model uses a quasi-Boussin-esq approximation, and “time-split” time differencing (Pielke 1984). The mesoscale model we use is the RAMS model. RAMS uses the Arakawa C staggered grid in which thermodynamic and moisture variables are defined at the grid volume center, and velocity components are defined at half grid points (Mesinger and Arakawa 1976). A Polar stereographic map projection is used for the horizontal grid domain, and a terrain-following sigma coordinate system with variable grid spacing is used in the vertical in order to increase the resolution near the surface The RAMS model can be initialized as variable field model initialization, where the four dimensional data assimilation (4DDA) uses time series of gridded variables of horizontal wind, potential temperature, and relative humidity values that are analyzed from either observations or large-scale model forecasts (e.g. NCEP, ETA).

3. METHODOLOGY

3.1 Methodology Overview

In this research historical surface temperature data analyses consist of long-term data records, from 300 locations in California, to trace the temperature changes on the coast and inland regions of the local climate in California. Primary sources of such data include the cooperative network, first order National Weather Service stations, and military weather stations. Here we used data from 300 cooperative stations with more than 100 stations in the northern Central Valley (CV) of California, each with 40 to 60 years of monthly average, minimum, and maximum temperature data records, in which about 100 of the stations are in central California and 30 of the stations are on the south coast air basin coasts of California. These stations were used for the identifications of long-term temperature trends and current spatial temperature deviation from 35 years back in time. Summertime June, July and August (JJA) maximum and minimum temperatures had been analyzed for the recording period of 1970 to 2004. The average temperature record is the average of the maximum and minimum temperature not the 24 hour average value. As a result, the max and min temperatures were the focus of this research. The daily temperature values from the NCDC data were averaged in to a monthly average min and max temperatures. Months with above five days missing values were disregarded from the analysis and were not filled or interpolated. The method used in this research study is calculations of the slope of the temperature trends from all stations in California. Then, the statistically significant temperature trend slope values were plotted in two dimensions (2D) to identify cooling and warming regions. No interpolations are used in the 2D mapping for the reason that the topographic influence in the surface weather parameters is large in California as it will be discuss later in the paper. Two coastal regions are the focus for this study; the southern coast air basin and the central California region. These places had been selected because both are highly populated regions of California and it would be crucial to further studies of long term changes in surface temperatures, which has high impact in health, air pollution and energy use.

Simulations with RAMS (version 4.4) have been performed for the research study in this paper. For all cases, a four day simulation period was chosen based on the Naval Postgraduate School (NPS) wind profiler data from Fort Ord. All simulations cover the period 0000 UTC 16-19 June 2005. These two cases were chosen so that the simulations would be comparable to the most detailed available observational climatological study of the San Francisco Bay and South Coast air basin by Lebassi *et al.* (draft for submission to science). RAMS simulations of the two cases were conducted, and model results were validated against and compare to observational data. The results were then examined for the existence sea breeze increases in the SFB.

3.2 Case Description

The summertime months of June, July and August (JJA) long-term 1970-2004 mean-monthly 2m air temperature data were analyzed for the stations in the specified regions experienced a significant warming inland and significant cooling in on the coast. The temperature changes may to be due to a combination of effects including the sea breeze, mountain topology, and changes in land use.

Firstly, the 35 year time series temperature slope was calculated for all the stations in California for the minimum, maximum, and average temperatures. These slopes were then plotted against the above parameters to see if there is a significant correlation. The plot of the slope vs. elevation showed no correlation. The temperature slope versus distance from the coast was plotted for the Stations in southern coast, which showed coastal cooling and inland warming. For the zonal plot, there was no significant variation near the Central California, but temperature slope decreased as we go from northern to southern California. It was also observed that the minimum temperature slope had been dominated by warming, while the maximum had cooling over the coast. The SST of the California coast was also plotted for the long-term time series and trend slope was generated from the data. The data used was a mean monthly gridded data set with 2 degrees resolution. The extended reconstructed sea surface temperature (ERSST) was constructed using the most recently available International Comprehensive Ocean-Atmosphere Data Set (ICOADS) SST data and improved statistical methods that allow stable reconstruction using sparse data. This monthly analysis begins January 1854, but because of sparse data the analyzed signal is heavily damped before 1880. Afterwards the strength of the signal is more consistent over time. The ERSST analysis will be updated as new data become available (Smith et. al. 2003).

Finally, four days RAMS modeling had been set up for a potential land use and current land use, for which difference in the flow patterns had been calculated.

3.3 Model Setup

The RAMS simulations focused on the analysis of the changes in the flow pattern of the northern California Central Valley. For this purpose, a nested-grid configuration was implemented. The outer model domain was extended eastward to include most of the western United States, and westward a considerable distance seaward (Fig. 2). Finer nested grids were applied over the area of interest in order to obtain meteorological fields at high resolution.

Three nested grids were chosen to select important physical features of the meteorology. The domain for the outer grid was set to be large enough to capture the synoptic high pressure systems important for our two simulation cases. The second grid was selected to capture the Sierra Nevada mountain range and its influence on the dynamics, and the third grid was chosen to resolve the details of the coastal mountains of the central valley (Fig. 2)

The detailed configuration that was selected and applied to the specified periods of simulation is summarized on table 1. Concerning the vertical structure, the grids were identical. In detail, 50 vertical layers with grids above the first level increase by a grid stretch ratio of 1.2 and 10m initial resolution had been used. The vertical resolution was dense in the lower levels, and became increasingly coarse toward the top of the domain, which was set at 30 km.

Table 1: Model Grid Configuration

Grid	NX	NY	NZ	Δx, Δy	Δz	Δt
1	80	80	30	60 km	30 m	10 s
2	82	82	30	15 km	30 m	5 s
3	70	70	30	3.75 km	30 m	2.5 s

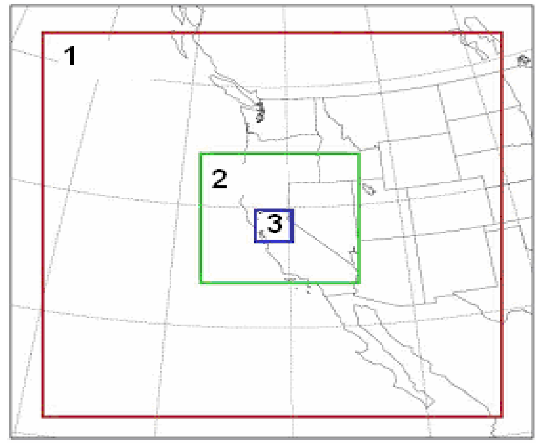

Fig. 2 Nested grid configuration of the modeled region. (grid 1: red, grid 2: green, gird 3: blue)

3.4 Initialization and Input Data

Initialization of the RAMS simulations requires four types of input data: (1) topographic data that characterizes the elevation of the land surfaces; (2) sea surface temperature data that provides the temperature of the sea surface over the Pacific Ocean; (3) vegetation data that characterizes land surface characteristics; and (4) meteorological data that characterizes meteo-rological fields at the initial time, at the boundaries, and at synoptic distance scales. We describe each of these inputs in turn.

3.5 Land use

Two simulation Cases had been conducted for this research study, based on two land use scenarios. The first case is with a California potential land use with was reconstructed for the pre-urban era (Fig. 3). The second case used land use of the current time.

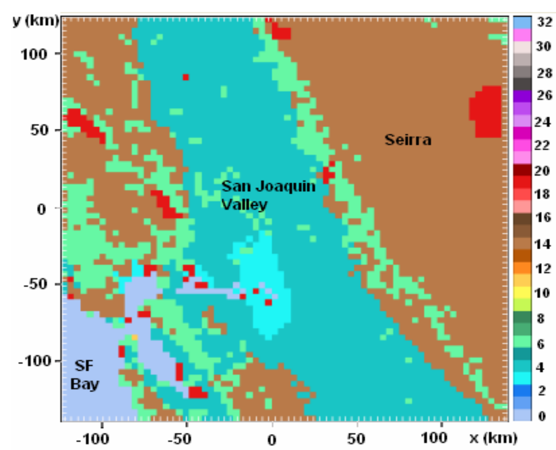

Fig. 3 Potential Land use of San Francisco of the pre urban case of the modeling simulation (0 ocean, 30 urban)

4. RESULTS

4.1 *Observational Results*

For the SF Bay regions (Fig. 4), the summertime months of JJA long-term 1970-2004 mean-monthly 2m air temperature data were analyzed.

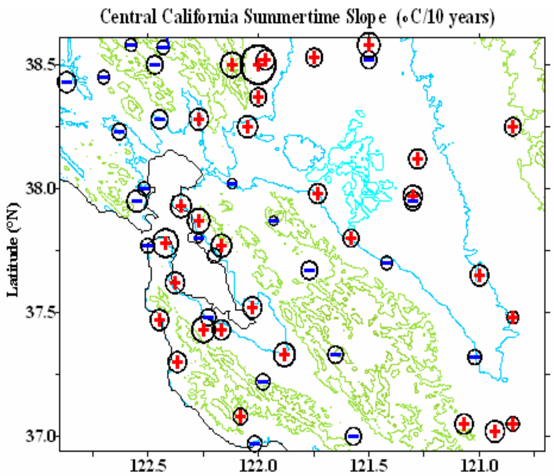

Fig. 4 1970-2005 Central California 2D temperature trends slope.

The spatial climatology of mean monthly maximum temperature plots show cooling over the coast and warming inland in the Central Valley, urban centers, and the Sierra Nevada. The temperature changes may be due to a combination of effects including the marine air penetration, mountain topology, and changes in land use. Analysis of the Southern coastal air basin (Fig. 5) also showed similar trends. There is coastal cooling, inland warming, and additional warming in urban centers. Offshore marine penetration cools the coastal areas and penetrates east passing around Chino and then veers south easterly towards the valleys of Lakeview and Estelle. It also penetrates north towards the San Fernando Valley. These regions had experienced cooling trends over the specified period of time. On the other hand, inland regions, which include the San Gabriel and San Bernandino mountains in the north and Santa Ana Mountains on the south, had experienced warming trends. These also match to the cold marine air penetration in the region.

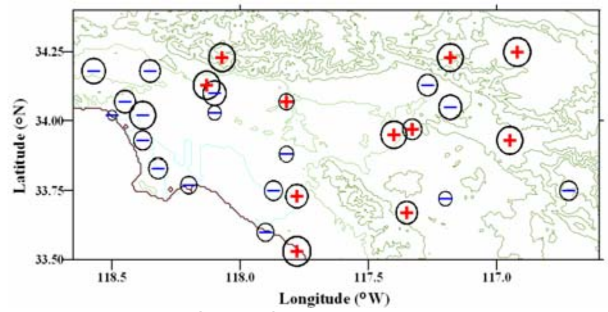

Fig. 5 1970-2005 South Coast Air Basin 2D temperature trends slope.

4.2 Modeling Results

RAMS simulations were executed to improve the understanding of the flow patterns in the SF Bay Basin and the investigation of possible changes in coastal flow intensities as function of land use. The three-day average for the 3 PM wind direction for the Present case (fig. 6) combined with the 3 PM average difference in wind magnitude for the two land use cases investigated (Present and PNV). Results are shown for the high resolution grid (grid 3) reflecting an increase in wind magnitude of more than 2 m/s in coastal areas, Napa Valley, and in the low Sierra Nevada south of Sacramento. Reductions in the flow magnitude are clearly observed in the urban areas (San Francisco, San José, and Sacramento), and in parts of the Central Valley. The reduction in wind speed in urban areas is in general expected as increases in hydrological drag can be associated with growing urban canopies. Wind speed reductions in parts of the Central Valley are less obvious and may be attributed to modulations in the thermal state of the low lands caused by variations in the amount of moisture in the soil or by the additional penetrating marine coastal flow.

The flow pattern shows an accelerating and penetrating marine flow intrusion through the Carquinez Strait towards the South San Francisco Bay and Central Valley, with modulations by topography and urban areas, particularly San Francisco and Sacramento (shown in the figure). We suspect that heat from the valley and cities is being advected towards the western side of the Sierras. The net increase in the winds is 1- 3 m/s and the increase in temperatures are 0.5 to 1^0C (not shown here). In general, the simulated flow patterns resemble those observed (not shown).

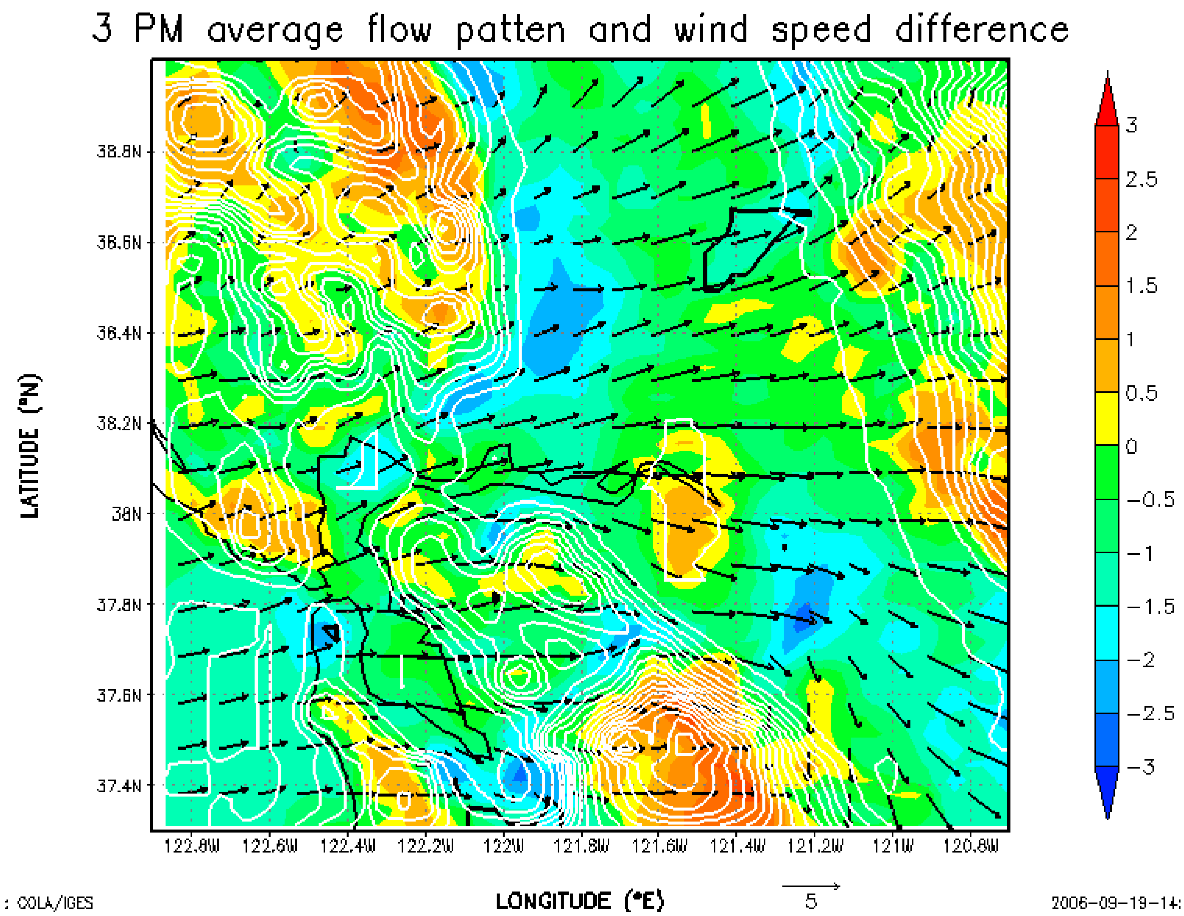

Fig. 6 RAMS simulations for the San Francisco Bay Area for three consecutive summer days (3pm PST 16-19 June 2005) showing flow patterns under a present land use (arrows), and wind speed differences for land use impact (Present-Natural) for same three summer days (background color).

5. SUMMARY

In this paper we have presented a modeling and observational study of climatological surface temperature analyses for Coastal California. It was found that regional minimum temperatures are strongly correlated with regional sea surface temperature increases, a result in agreement with claims of global warming due to green house gases. Further analysis of local maximum land surface temperatures revealed an asymmetric cooling and warming trend. Coastal areas in the San Francisco Bay area and in Los Angeles show a cooling trend, while inland and urban centers show an increasing trend. The cooling areas are strongly correlated with the sea breeze flows which suggest an increase of the cold marine air intrusion due to the increase regional sea breeze potential. Increases in maximum temperature inland and in urban centers are attributed to the combined effects of global warming and regional and local land surface modifications. The net result of additional air masses from the ocean is a warming of the eastern mountains, including the lower portions of the Sierra Nevada in Central California.

The impact and significance of these results are various. The combined effects of global warming and local land use may lead to asymmetric warming along the coasts and general warming in inland areas. This may be the case for areas where coastal waters are cooler than the land, such as the Northern Pacific. Additional air masses may also lead to air quality issues, as the larger air masses will be accumulated along the direction of the westerly flows as in the case of the Central Valley for the particular case reported here. The additional advected heat from the coastal areas and Central Valley is deposited in the eastern Sierras leading to warming of these areas. We hypothesized that similar asymmetric cooling/heating patterns are found in different parts of the planet.

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