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USING A REGIONAL CLIMATE MODEL TO DIAGNOSE CLIMATOLOGICAL AND METEOROLOGICAL CONTROLS OF WILDFIRE IN THE WESTERN UNITED STATES

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1. INTRODUCTION

We are applying a retrospective approach for studying the climatic controls of fire in the western United States that involves examining jointly past observed and simulated records of weather and climate, along with historical records of fire, using a variety of data-analytical procedures employed in climate-diagnostic studies. The historical fire data set we are focusing on initially spans the period 1986-96 and is analyzed in detail by Bartlein et al. (2003), and references therein. Climate data are derived from two sources: 1) the National Center for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) Reanalysis Project (Kistler et al. 2001), on a nominal grid spacing of a few degrees, and 2) a contemporaneous, high-resolution data set (on a 45 km grid) we have generated using NCEP/NCAR reanalysis data to force a regional or limited-area atmospheric model.

Here we demonstrate the regional climate modeling component of our approach by presenting two case studies in which we analyze the temporal features of atmospheric circulation, surface weather, and fire-start records 1) on a monthly time scale for the fire season of 1994, and 2) on a daily time scale for the period 10-16 August, 1996, when a large number of fires broke out over the Sierra Nevada, the Pacific Northwest, and the Northern Rockies.

2. METHODOLOGY

Global atmospheric and surface climate fields for the period 1948-2003 have been produced by the NCEP using a sophisticated assimilation technique to incorporate a large number of observed data sets (e.g., atmospheric soundings, sea-surface temperature) into the a global atmospheric model (Kistler et al. 2001). The NCEP model has a nominal horizontal grid spacing of 2.5 degrees (about 250 km on a side) and is capable of simulating large-scale synoptic climate features and regional climate variations. The relatively coarse spatial scale of the model, however, limits the degree to which regional climate details are resolved over the topographically complex region of Western America. To provide access to higher resolution climate data, we have produced a continuous, high resolution (45 km horizontal grid, ~0.4 degree) simulation for the period 1957-2002 using a modified version of the NCAR RegCM2 regional climate model (Giorgi et al, 1993). The RegCM is derived from the MM4 meteorological model and is thus related to the MM5. The simulation is driven by temporally varying lateral (vertical profiles of temperature, wind, humidity) and surface (pressure and sea surface temperature) boundary conditions derived from the 6-hr NCEP reanalysis history files. A 150-sec model time step was used for the RegCM simulations, which allows archiving hourly values of the model fields for analysis and plotting.

The model domain covers the western U.S. and adjacent areas of Canada and Mexico; there are 3510 terrestrial grid points. At a 45-km grid spacing climatically important physiographic features such as coastlines and the basin and range topography that dominates the West are resolved (Fig. 1). Our configuration of the RegCM is fully coupled at the boundary layer with a sophisticated surface model, LSX (Land Surface Exchange model, Thompson and Pollard, 1995), that computes the exchange of energy and mass based on specified vegetation and soil properties. LSX includes a 6-layer, dynamic soil model that calculates soil temperature and the frozen and liquid water content in the top 4.5m of the soil.

The quality of the coupling between the NCEP and RegCM models is illustrated in Figure 2 with inset maps of 500 mb heights and sea level pressure. Together, the atmospheric models provide internally consistent climate information from the surface to the upper atmosphere over a wide range of spatial scales on temporal scales ranging from hourly to decadal.

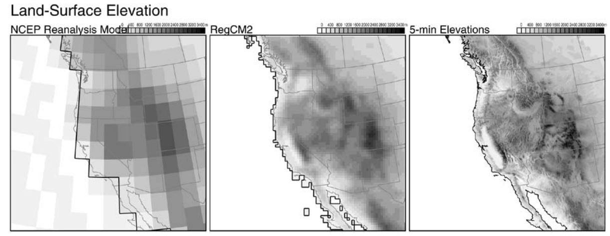

Figure 1: Topography as represented (left to right) in the NCEP GCM, the RegCM, and a 5-minute DEM.

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3. RESULTS AND DISCUSSION

3.1 The 1994 Fire Season

The 1994 fire season was fairly typical of years when fires are relatively frequent throughout the West. Lightening-started fires were prevalent in the Southwest (SW) and Southern Rocky Mountains (SRM) in June. During July, the incidence of lightning-started fires remained high over the SW and SRM and increased over the Pacific Northwest (PNW) and the Northern Rocky Mountains (NRM). Numerous lightening-started fires occurred along the length of the Rockies during August, while anomalously few new fires were reported on the Pacific slopes of the PNW.

The specific weather and climate conditions that influenced the 1994 fire season originated in the fall of 1993 when a ridge of high pressure developed over the PNW that blocked the usual progression of storms from the Pacific. With the exception of a few months in which limited areas received above-normal precipitation, this dry pattern persisted over the PNW and NRM until June of 1994. (This sustained pattern of blocking during winters preceding active fire seasons is common, and was a factor, for example, in the 2002 Biscuit fire.) In contrast to the PNW and NRM, the arid SW received above-normal moisture from February through early June.

Much of the West therefore was experiencing long-term precipitation deficiency by June of 1994; the deficiency increased during July and August (Fig. 2). Precipitation in June and July was again suppressed by a blocking ridge that developed over the West along a southwest to northeast axis (Fig. 2). The center of the ridge migrated from the SW to over the PNW during July. Large-scale subsidence associated with the ridge suppressed precipitation. Strong diabatic heating produced lower-than-normal (1981-2000 RegCM normal period) sea level pressure and above normal surface air temperatures over much of the region.

Widespread soil-moisture deficits were evident as a result of persistent dry conditions (Fig 2.). We evaluate the departure of soil moisture from normal using a new standardized soil moisture index (SSMI) that is analogous to the standardized precipitation index (SPI, McKee et al. 1993, 1995) that is used as an indicator of drought (Hayes et al. 1999). We calculated the SSMI with the 30 years (1971-2000) of monthly average soil moisture simulated by the RegCM using the methods for calculating the SPI. Following the SPI classification scheme (McKee et al. 1993), values between +1 and -1 are considered normal (the long term mean SSMI is 0.), whereas values greater than +1.5 indicate very wet to extremely wet conditions and values less than -1.5 indicate severe to extreme dryness.

Our working hypothesis is that the moisture content of the larger size-classes of live and dead woody fuels integrate precipitation in a manner similar to soil moisture, while grasses and fine fuels have a more immediate response (Swetnam Betancourt, 1998). A reasonable, climatically based assumption for conditions at the beginning of the 1994 fire season is that grass production was high in the arid SW from above normal spring precipitation, while moisture levels in woody fuels were low throughout the much of the West, and over the NRM in particular.

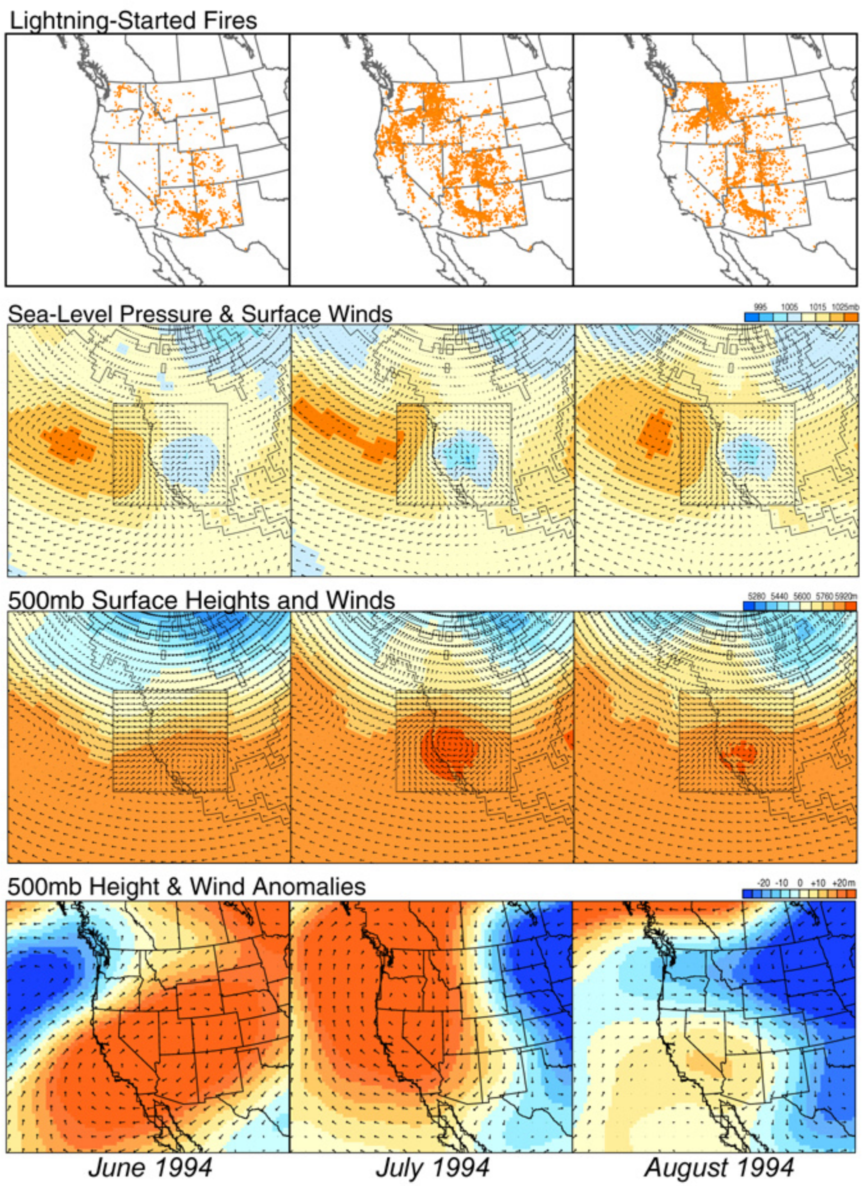
The anomalies of the 700-500 mb lapse rate (figures not shown), suggest that abundant convection was present throughout the 1994 fire season to ignite numerous fires, especially along the southern border of Arizona and New Mexico. Migration of the ridge to the PNW in July triggered convection over the PNW and NRM, moved the area of active convection over the SW northward, and extended anomalously high convective activity eastward over Utah and Colorado. As indicated by the precipitation anomalies, this pattern effectively blocked the Southwest monsoon. A substantial number of ignitions were reported over the affected regions in July.

During August, the strong blocking ridge over the PNW was replaced by a more meridional circulation pattern which produced onshore flow, while the remnants of the ridge persisted over the SW. Although continued dry surface conditions favored fires over the Pacific slopes of the PNW, the onshore flow suppressed convection and thus new fires there, but at the same time contributed to instability that induced convection over the NRM where numerous fires were ignited. High numbers of new fires also continued to occur over the SW and SRM under the influence of the ridge which supplied a warm, dry air mass at the surface, and suppressed the supply of moisture off the Gulf of Mexico for the generally wetter convective storms of the Southwest monsoon.

3.2 The August, 1996 Fire Outbreak

During August,1996 there was a particularly high incidence of fires in the West. Atmospheric circulation patterns led to a progression of lightning-caused fires that began over the central Sierras on 10 August and proceeded north through California, central and eastern Oregon and on into Idaho on 13 through 15 August (Fig 3, bottom row). (This is a relatively common circulation pattern for August; it occurred most recently beginning 20 August 2003).

Between 7 and 11 August 1996 a weak upper-level trough developed in the Gulf of Alaska and migrated eastward. At the same time, the subtropical ridge axis along the west coast strengthened and moved inland over the Great Basin. (Fig 3, top row). At the surface, the thermal low, also centered over the Great Basin (Fig. 3, row 2), strengthened, so that by 11 August a combination of atmospheric conditions existed that favored the outbreak of fire across the region. These conditions included large-scale rising motions [negative (blue) vertical velocity (omega) values, Fig. 3, row 4], and onshore flow of moisture in the middle and lower atmosphere, which in turn favored development of relatively steep environmental lapse rates (Fig. 3 row 3) and abundant dry and wet convection.



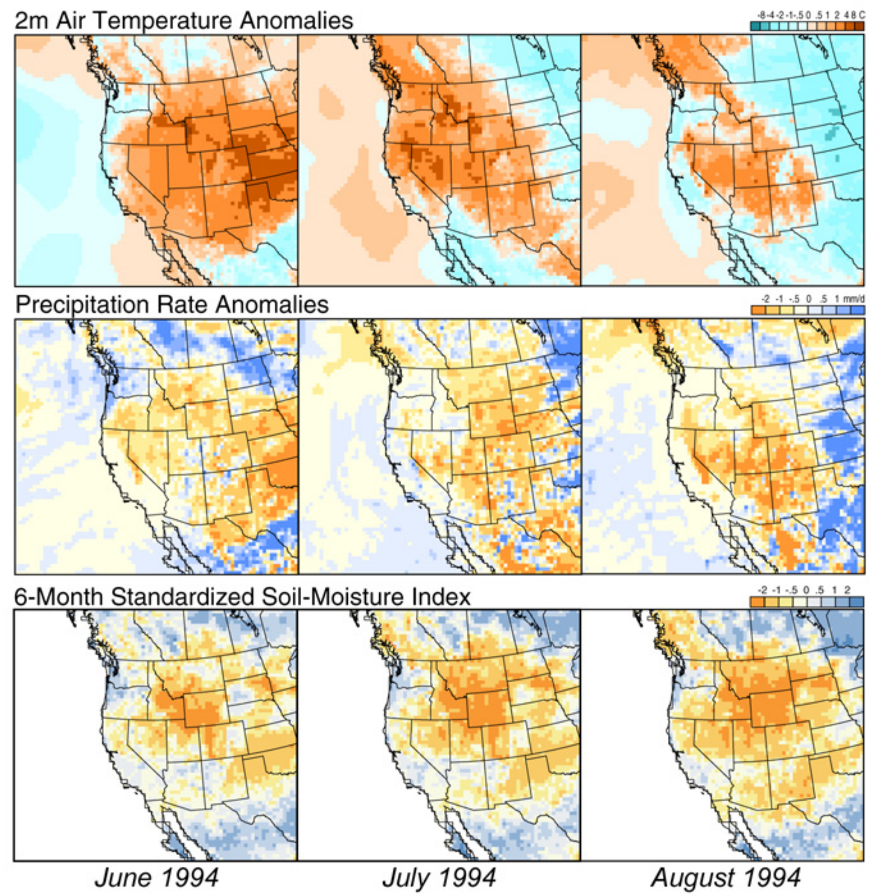


Figure 2. June through August 1994 fire starts (Hardy et al, 2001), atmospheric variables, and standardized soil moisture index (SSMI, see text). Sea-level pressure and 500 mb heights display the continuity of the nested RegCM (box) within the NCEP driving fields. 6-hr NCEP fields are interpolated horizontally and vertically to the boundary of the RegCM where they are introduced to the RegCM through an 8 grid-point relaxation technique. Anomalies for 500 mb heights, 2-m air temperature, and precipitation rate are relative to the 1981-2000 RegCM normals; SSMI departures are relative to the 1971-2000 Regcm normals.

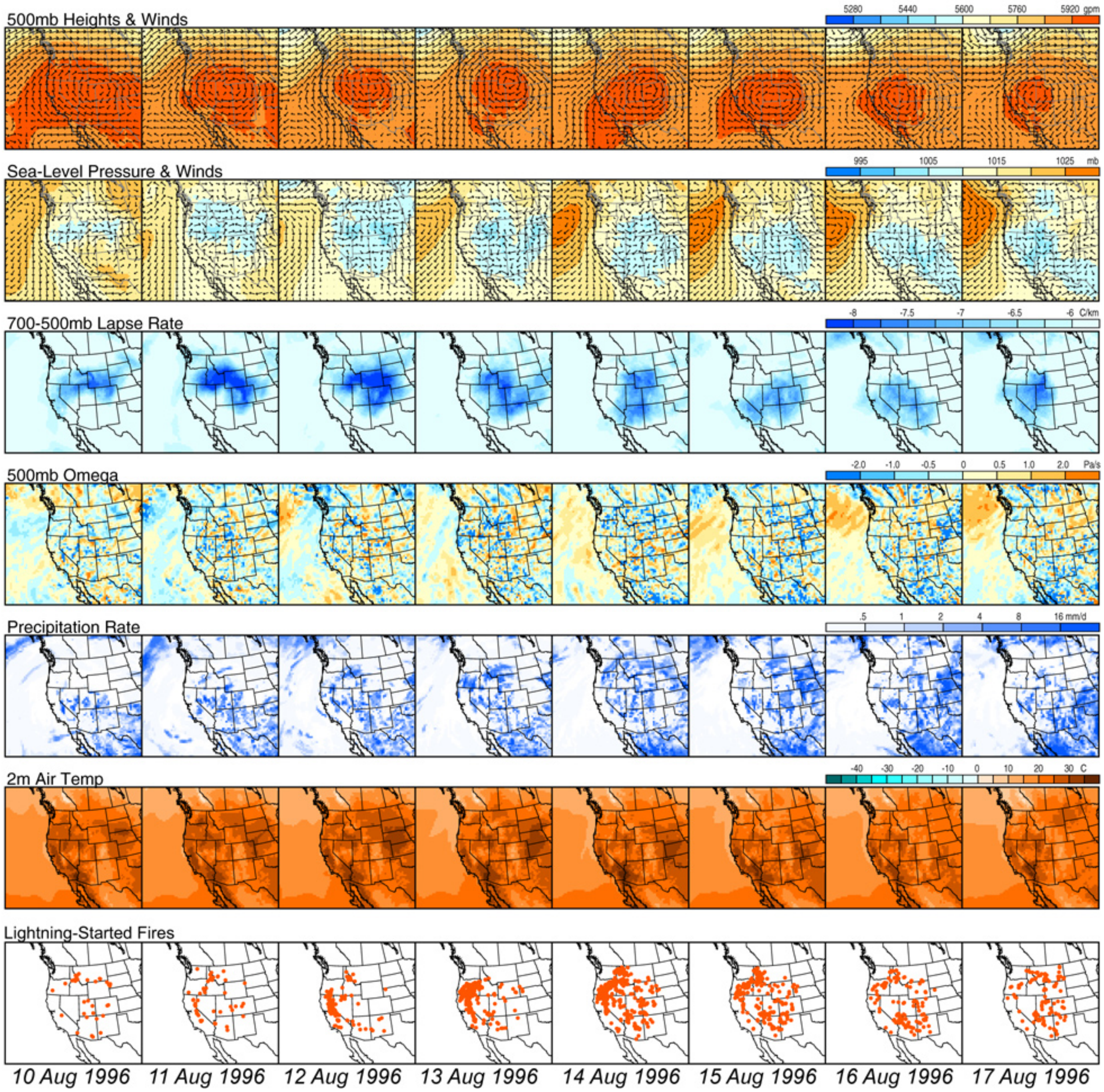


Figure 3. Atmospheric fields simulated by the RegCM, and daily fire starts for the period of 10-17 August, 1996. Precipitation over the continent is convective. We infer that low precipitation rates, particularly those of 4 mm/day and less, are indicative of dry convective events.

On 12 August, the surface and upper-level circulation produced southwesterly flow into the interior that triggered vigorous convective storms. This flow pattern draws marine air onshore at lower elevations, but is associated with very high fire danger at higher elevations in the Sierra Nevada and Siskiyou mountains. From 13 to 15 August, the subtropical ridge and thermal low continued to strengthen, resulting in more westerly flow across the northwest into the NRM. The daily average RegCM fields clearly capture the development of this pattern, along with intensification and migration of associated convective indices (700-500 mb lapse rates, and lifted index, not shown). Although there often can be lags between the actual time of a fire start and when the fire is reported, the temporal and spatial convective precipitation patterns from the RegCM are coherent with those of the fire-start data.

After 15 August, the subtropical ridge and thermal low weakened and moved southwestward. The upper-level trough also weakened, ending the convection across the northern half of the region, but reinvigorating the flow of subtropical moisture into the SW, and increasing convection there.

4. CONCLUSIONS

Climate data from the NCEP reanalysis and the RegCM simulations provide a useful combination with which to diagnose the fire record on decadal, annual, monthly, and daily time periods. Because we have continuous, multi-decade data sets for a large number of atmospheric and surface variables, we are able to investigate both antecedent and immediate climatic conditions that are associated with given fire seasons. We are expanding our analysis of variables simulated by RegCM to include surface energy and mass balances, with the goal of understanding how to parsimoniously categorize and quantify the climatic controls of fires in the West. We are also using output from our climate simulations to drive vegetation models to investigate the potential role of climate in natural restoration and reduction of fuel loading.

5. ACKNOWLEDGEMENTS

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6. FURTHER INFORMATION

Further information, including high-resolution versions of the figures can be found at:
http://geography.uoregon.edu/fireclim/

7. REFERENCES

Bartlein, P.J., S.W. Hostetler, S.L. Shafer, J.O. Holman, and A.M. Solomon, 2003: The seasonal cycle of wildfire and climate in the western United States, *5th Symposium on Fire and Forest Meteorology*, American Meteorological Society, paper P3.9.

Giorgi, F., M. R. Marinucci, and G. T. Bates, 1993: Development of a second-generation regional climate model (RegCM2). Part I: Boundary-layer and radiative transfer processes. *Monthly Weather Review*, **121,** 2794-2813.

Hardy, C. C., K. M. Schmidt, J. P. Menakis, and R. N. Sampson, 2001: Spatial data for national fire planning and fuel management. *International Journal of Wildland Fire*, **10,** 353-372.

Hayes, M.J., M.D. Svoboda, D.A. Wilhite, and O.V. Vanyarkho, 1999: Monitoring the 1996 drought using the standardized precipitation index. *Bulletin of the American Meteorological Society*, **80**, 429-438.

Hostetler, S.W., P.J. Bartlein, J.O. Holman, S.L. Shafer, and A.M. Solomon, 2003: Using a regional climate model to diagnose climatological and meteorological controls of wildfire in the western United States. *5th Symposium on Fire and Forest Meteorology*, American Meteorological Society, paper P1.3.

Kistler, R., E. Kalnay, W. Collins, S. Saha, G. White, J. Woollen, M. Chelliah, W. Ebisuzaki, M. Kanamitsu, V. Kousky, H. van den Dool, R. Jenne, and M. Fiorino, 2001: The NCEP-NCAR 50-year reanalysis: Monthly means CD-ROM and documentation. *Bulletin of the American Meteorological Society*, **82,** 247-267.

McKee, T.B., N.J. Doesken and J. Kleist, 1993: The relationship of drought frequency and duration to time scales. Preprints, *Eighth Conf. on Applied Climatology*, Anaheim, CA, Amer. Meteor. Soc., 179-184.

McKee, T.B., N.J. Doesken and J. Kleist, 1995: Drought monitoring with multiple time scales. Preprints, *Ninth Conf. on Applied Climatology*, Dallas, TX, Amer. Meteor. Soc., 233-236.

Mitchell, T. D., T. R. Carter, P. D. Jones, M. Hulme, and M. New, 2003: A comprehensive set of high-resolution grids of monthly climate for Europe and the globe: the observed record (1901-2000) and 16 scenarios (2001-2100). *Journal of Climate*, submitted.

Swetnam, T. W. and J. L. Betancourt, 1998: Mesoscale disturbance and ecological response to decadal climatic variability in the American Southwest. *Journal of Climate*, **11,** 3128-3147.

Thompson, S. L. and D. Pollard, 1995: A global climate model (GENESIS) with a land-surface transfer scheme (LSX). Part I: present climate simulation. *Journal of Climate*, **8,** 732-761.