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APPLICATION OF IMPROVED ECOSYSTEM AERODYNAMICS IN REGIONAL WEATHER FORECASTS

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Abstract. This paper reports the impact of applying improved representation of the area-average aerodynamic properties of South American ecosystems on 7-d weather forecasts made with the Brazilian regional forecast model (Eta-SSiB). Two pairs of 7-d forecasts were made, each pair starting from the same initial conditions on 1 January 1999 and on 24 June 1999, respectively. In one run, the aerodynamic properties of the ecosystem used for each modeled grid square were those of the most common vegetation present. In the second, the grid-average aerodynamic properties of the vegetation were calculated using aggregation rules in combination with a high-resolution land-cover data set. There are marked differences in the aerodynamic properties of the underlying ecosystems in these two runs in some regions, notably around the Amazon River basin, in regions where there has been land-cover change, and in portions of southern Brazil. The 7-d average, predicted ecosystem–surface exchanges, near-surface temperature, and precipitation for the two pairs of runs were compared. There were differences between the forecasts that were most noticeable in regions where the ecosystem's aerodynamic properties were most dissimilar, but also elsewhere. Given the limited nature of the experiments reported, these preliminary results should be treated with care. Nonetheless, they suggest the need for more systematic study of the significance of ecosystems on regional weather forecasts in South America.

Key words: aerodynamic roughness; aggregation; regional weather forecasts.

Introduction

Over the last decade, substantial progress has been made in understanding how best to represent heterogeneous ecosystems in meteorological models. Meanwhile, there has been progress in providing the remotely sensed land-cover data to apply that understanding. Research has established the value, usefulness, and feasibility of applying remotely sensed land-cover classes when describing heterogeneous ecosystems in meteorological models used for free-running seasonal, interannual, and longer-term climate prediction (e.g., Burke et al. 2000). However, no attempt has been made to date to apply present-day theory and methods for realistically representing ecosystems in medium-range weather forecast models to improve their prediction of meteorological and hydrological variables and to aid their ability to calculate model-calculated data fields using four-dimensional data assimilation (4DDA). The CPTEC-Eta (Centro de Previsão de Tempo e Estudos Climáticos) mesoscale model is routinely used to make weather forecasts for South America. Here, we describe the early results of an initial study to investigate the impact of incorporating improved representation of heterogeneous ecosystems on short- to medium-term weather predictions made with the CPTEC-Eta model. In practice, because forecasts are made for 7 d in the present study, toward the end of the modeled period, the forecast fields may have acquired some features of climate rather than weather.

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Models and Methods

Eta weather forecast model

The Eta model calculates prognostic variables (i.e., temperature, specific humidity, horizontal wind components, surface pressure, turbulent kinetic energy, and cloud water) on an 80-km semistaggered Arakawa E grid that covers most of South America. Step-mountain (or Eta) vertical coordinates (Mesinger 1984) are used, with 28 vertical layers and the top of the atmosphere at 5000 Pa. The vertical resolution is higher in the lower layers (the first layer is ∼20 m deep) and near the tropopause. A forward-backward scheme (Janjic 1979) is used. The model uses a horizontal advection scheme to control the cascade of energy towards smaller scales. This scheme was specifically developed for the Eta grid by Janjic (1984) and is a modified Euler-backward time-differencing scheme. A split-explicit approach (Gadd 1978) is used during model integration.

The lateral boundaries of the modeled domain are specified from forecasts from a six-hourly CPTEC (Centro de Previsão de Tempo e Estudos Climáticos) global model (a derivative of the COLA model). The initial atmospheric and soil moisture conditions in both the CPTEC global model and the CPTEC regional model are taken from NCEP (National Center for Environmental Prediction, part of the national Oceanic and Atmospheric Administration [NOAA], USA) analyses. Atmospheric initiation and boundary conditions are input to the CPTEC Eta model in the form of spectral coefficients with T62 triangular truncation (equivalent to 1.825° resolution) in both meridional and zonal directions. Observed weekly average sea-surface temperatures are used, along with land-surface albedo taken from a seasonal climatology. Both grid-scale (Zhao and Carr 1997) and convective precipitation (Betts and Miller 1986, Janjic 1994) are calculated. The turbulent exchange in the free atmosphere is modeled using the Mellor-Yamada Level 2.5 scheme, while the exchange between the Earth's surface and the lowest model layer is calculated using the Mellor-Yamada Level 2 scheme (Janjic 1994, 1996*a, b*). The radiation package was developed at the Geophysical Fluid Dynamics Laboratory (Geophysical Fluid Dynamics Laboratory, NOAA, Princeton, New Jersey, USA): the short-wave radiation computation scheme is that of Lacis and Hansen (1974), and the long-wave scheme is that of Fels and Schwarztkopf (1975).

SSiB land-surface scheme

The simplified simple biosphere land-surface scheme (SSiB; Xue et al. 1991) used in the CPTEC-Eta model is a simplified version of the simple biosphere model (SiB; Sellers et al. 1986). It explicitly simulates some of the more important biophysical processes in vegetation. The SSiB scheme has three soil layers and one canopy layer with eight prognostic variables (i.e., soil wetness in three soil layers, the temperatures of the canopy, ground surface, and deep soil layers, and the liquid water stored on the canopy and snow stored on the ground). Vertical eddy flux transfer is calculated using the Mellor-Yamada second-order closure scheme (Mellor and Yamada 1982). Three aerodynamic resistances are specified, namely r_d, the resistance between the soil surface and the canopy air space; r_b, the resistance between the canopy and the canopy air space; and r_a, the resistance between the canopy air space and the reference height. The SSiB forcing variables (taken from the lowest modeled level of the Eta model) are precipitation, downward short-wave radiation, downward long-wave radiation, temperature, humidity, and wind speed. The output variables are surface albedo, the sensible heat flux, latent heat flux (transpiration and evaporation from intercepted water and the soil), momentum flux, ground heat fluxes, skin temperature, surface runoff, groundwater runoff, carbon dioxide flux, and net photosynthesis rate. SSiB requires the specification of 23 parameters for 13 ecosystems (i.e., broadleaf-evergreen trees, broadleaf deciduous trees, mixed forest, needle-leaf evergreen trees, needle-leaf deciduous trees, savanna, perennial grassland, broadleaf shrubs with ground cover, broadleaf shrubs with bare soil, tundra, desert, crops, and permanent ice). In the present study, the default values of the 23 parameters given by Xue et al. (1991) for each ecosystem were used.

Studies have been made with SSiB coupled to general circulation models (GCMs) to investigate the impact of land-surface changes on the Sahel (Xue and Shukla 1993, 1996) and to study the influence of seasonal variations in crop parameters within the USA. (Xue et al. 1996*b*, Fennessy and Xue 1997). These studies involve changing the land-cover parameters used in SSiB and suggest that the resulting changes in the surface energy budget and hydrological cycle can have a significant impact on regional climate simulations (Xue et al. 1996*a*). Our study extends these investigations to the South American continent and at the weather forecast time scale.

Burke et al. (2000) showed that using area-average values for the aerodynamic properties of vegetation in a climate simulation had a very similar effect to using area-average values for all of the parameters used to represent the vegetation cover. Consequently, in this preliminary study using the Eta-SSiB model, we investigate the effect on simulated weather of changing only the aerodynamic properties of the vegetation represented by SSiB in each model grid square from those of the most common vegetation class present to values that better represent the actual heterogeneous vegetation present.

Model runs and analyses

Two pairs of 7-d forecasts were made using the Eta-SSiB model; each pair starting from the same initial atmospheric conditions on 1 January 1999 and on 24 June 1999, respectively. A 1-km-grid vegetation cover map for South America (De Fries et al. 1998, Hansen et al. 2000) was used to specify the ecosystem-related parameters in SSiB in these two runs. In the control run, all of the ecosystem-related parameters used were those corresponding to the most common vegetation class present in each (80-km) grid square. In the second run, the parameters that describe the aerodynamic interaction of vegetation were altered, to better represent the actual heterogeneous vegetation present in each grid. The SSiB model uses two parameters to specify the aerodynamic properties of vegetation. The first, displacement height, *d*, is related to the height of the vegetation, while the second, the aerodynamic roughness length, z_0, is a measure of how rough the top of the canopy is and its effectiveness in retarding the flow of the overlying air. In the second run, the grid-average values of these two parameters for (perhaps heterogeneous) vegetation were calculated using aggregation rules following Shuttleworth (1998); thus,

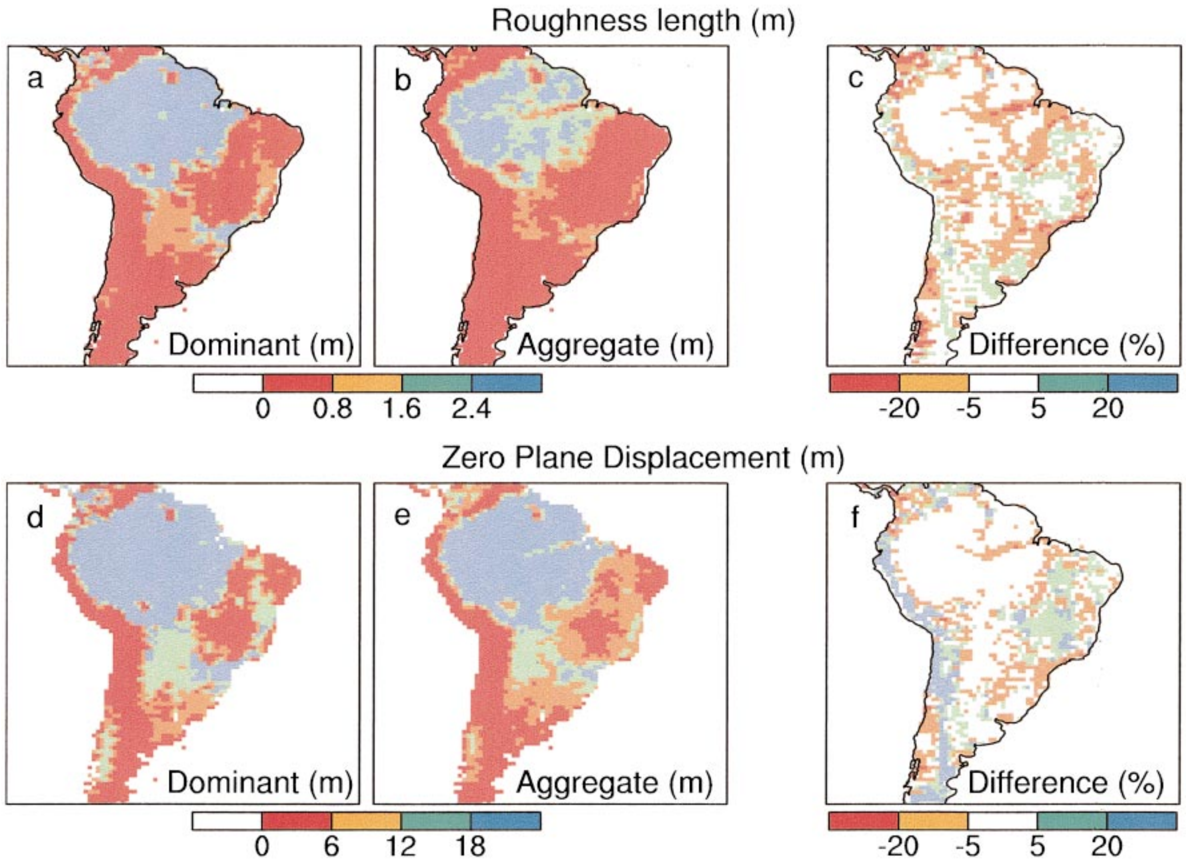

FIG. 1. (a) Aerodynamic roughness (a measure of how rough the top of the canopy is and its effectiveness in retarding the flow of the overlying air) of the dominant vegetation cover in each grid square used in the control run; (b) grid-average aerodynamic roughness derived using Eq. 2; (c) difference between the grid-average aerodynamic roughness and the aerodynamic roughness of the dominant vegetation cover in each grid square. Panels (d), (e), and (f) are as (a), (b), and (c), respectively, but are for zero-plane displacement.

$$d = \sum_{i}^{N} w_i d_i \tag{1}$$

$$\left\{\ln\left[\frac{(z_b - d)}{z_0}\right]\right\}^{-2} = \sum_{i}^{N} w_i \left\{\ln\left[\frac{(z_b - d_i)}{z_{0,i}}\right]\right\}^{-2} \tag{2}$$

where d_i is the zero plane displacement, $z_{0,i}$ is the aerodynamic roughness length for each class of vegetation, i, present in the grid, w_i is the fraction of each class, and z_b is an assumed ''blending height'' in the atmosphere, which was arbitrarily set equal to 50 m in this study.

RESULTS

Aggregate parameters

Fig. 1 shows contour maps of the values of the aerodynamic roughness and zero plane displacement in the two Eta model runs, i.e., the values for the most common (dominant) ecosystem and the area-average (aggregate) values for the heterogeneous ecosystem, together with the differences between these two. In some regions, there are significant differences between the dominant and area-average aerodynamic roughness length and zero plane displacement used in the two runs. The differences are most marked (and of order several meters) around the Amazon River itself, where there has been land-cover change along the southern and western edges of the Amazon River basin, and in portions of southern Brazil.

Model output

The 7-d average difference in the modeled values of latent and sensible heat, temperature, and precipitation for the South American continent at 0600 and 1800 hours Greenwich mean time (GMT) in January and July, respectively, are shown in Fig. 2. In both cases, the modeled fields are consistent with observations within natural variability and observational errors. In general, there is a noticeable difference in all of these modeled fields. Not surprisingly, because of energy conservation, in the case of the latent and sensible heat fluxes, the mean differences tend to be complementary, with noteworthy differences between the two runs (~20 W/m^2, or ~20%) during the day (at 1800 hours GMT)

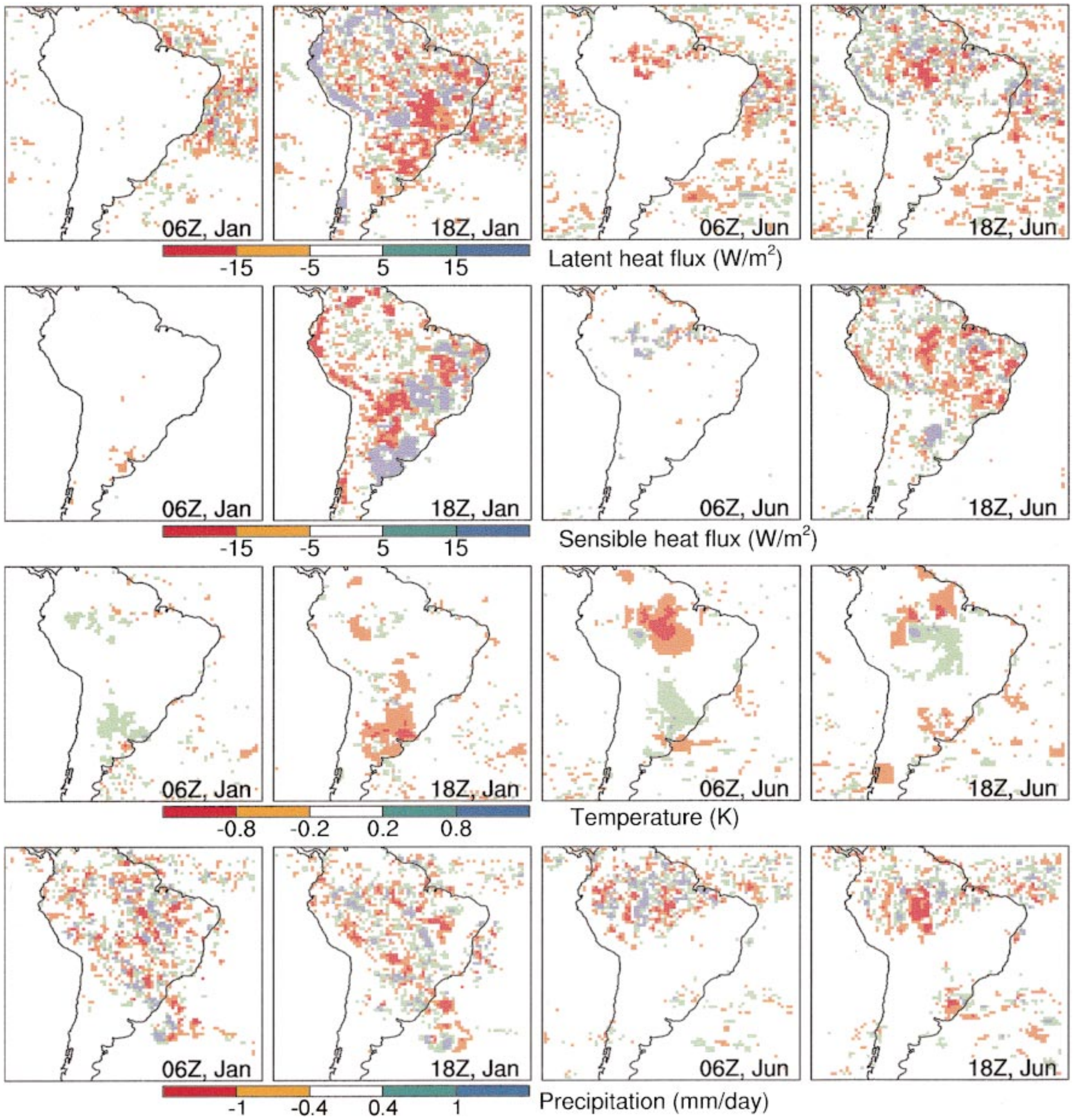

FIG. 2. Seven-day average differences in the modeled values of latent and sensible heat, temperature, and precipitation given by the CPTEC model for the South American continent with the modified aerodynamic parameters shown in Fig. 1. Columns correspond to modeled values at 0600 hours and 1800 hours Greenwich mean time in January and June 1999, respectively. Rows correspond to latent heat, sensible heat, temperature at the lowest model level, and precipitation, respectively.

in both January and July and at night (at 0600 hours GMT) in January in regions where the difference in aerodynamic parameters is large.

As might be expected, there is some evidence of correlation between the spatial patterns of sensible heat flux and modeled near-surface temperature where the two model simulations differ. However, modeled precipitation fields show little local response to the modified aerodynamic properties of the underlying ecosystem. In this preliminary study, changes in the aerodynamics of the underlying vegetation appear instead to generate a remote relocation in the location of bands of convective precipitation within the central Amazon region in June and for a southwesterly movement of several hundred kilometers in bands of precipitation across large areas of South America in the January simulations. Clearly, it is not possible to say on the basis of this initial study whether these are truly a remote response to the modified ecosystem aerodynamics, but more rigorous investigation of this possibility does seem merited.

Summary and Conclusions

This initial study of the effect of applying improved representation of ecosystems in short-to-medium-term weather forecasts made with the CPTEC Eta model shows expected evidence of sensitivity in surface heat fluxes and some response in near-surface weather variables. Not surprisingly, some of the more noticeable changes occur in locations where ecosystem change has resulted in heterogeneous mixes of ecosystems. There is some suggestion of possible systematic changes in the location of seasonal patterns of precipitating weather systems within the South America continent, but the evidence for these is still preliminary. Our conclusion is that weather forecasts are sensitive to the improved specification of the heterogeneous vegetation in ecosystems in forecast models certainly, particularly at the locations where these improvements in representation are made. Clearly, this topic merits more detailed study, which will be greatly facilitated by the improved availability of relevant validation data from the Large-scale Biosphere–Atmosphere (LBA) Experiment.

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Literature Cited

Betts, A. K., and M. J. Miller. 1986. A new convective adjustment scheme. Part II: single column model tests using GATE wave, BOMEX and Arctic air-mass data sets. Quarterly Journal of the Royal Meteorological Society **112**:693–709.

Burke, E. J., W. J. Shuttleworth, Z. L. Yang, S. L. Mullen, and M. A. Arain. 2000. The impact of the parameterization of heterogeneous vegetation on the modeled large-scale circulation in CCM3-BATS. Geophysical Research Letters **27**:397–400.

De Fries, R., M. Hansen, J. R. G. Townshend, and R. Sohlberg. 1998. Global land cover classifications at 8 km spatial resolution: the use of training data derived from Landsat imagery in decision tree classifiers. International Journal of Remote Sensing **19**:3141–3168.

Fels, S. B., and M. D. Schwartzkopf. 1975. The simplified exchange approximation: a new method for radiative transfer calculations. Journal of Atmospheric Science **32**:1475–1488.

Fennessy, M. J., and Y. Xue. 1997. Impact of USGS vegetation map on GCM simulations over the United States. Ecological Applications **7**:22–33.

Gadd, J. 1978. A split-explicit integration scheme for numerical weather prediction. Quarterly Journal of the Royal Meteorological Society **104**:569–582.

Hansen, M., R. DeFries, J. R. G. Townshend, and R. Sohlberg. 2000. Global land cover classification at 1 km resolution using a decision tree classifier. International Journal of Remote Sensing **21**:1331–1365.

Janjic, Z. I. 1979. Forward-backward scheme modified to prevent two-grid-interval noise and its application in sigma coordinate models. Contributions to Atmospheric Physics **52**:69–84.

Janjic, Z. I. 1984. Non-linear advection schemes and energy cascade on semi-staggered grids. Monthly Weather Review **112**:1234–1245.

Janjic, Z. I. 1994. The step-mountain eta coordinate model: further developments of the convection, viscous sublayer and turbulence closure schemes. Monthly Weather Review **122**:927–945.

Janjic, Z. I. 1996*a*. The Mellor-Yamada level 2. 5 scheme in the NCEP Eta model. Pages 333–334 *in* Preprint, Eleventh Conference on Numerical Weather Prediction, Norfolk, Virginia. American Meteorological Society, Boston, Massachusetts, USA.

Janjic, Z. I. 1996*b*. The surface layer in the NCEP Eta model. Pages 354–355 *in* Preprint, Eleventh Conference on Numerical Weather Prediction, Norfolk, Virginia. American Meteorological Society, Boston, Massachusetts, USA.

Lacis, A. A., and J. E. Hansen. 1974. A parameterization of the absorption of solar radiation in the Earth's atmosphere. Journal of Atmospheric Science **31**:118–133.

Mellor, G. L., and T. Yamada. 1982. Development of a turbulence closure-model for geophysical fluid problems. Reviews of Geophysics **20**:851–875.

Mesinger, F. 1984. A blocking technique for representation of mountains in atmospheric models. Rivista di Meteorologia Aeronautica **44**:195–202.

Sellers, P. J., Y. Mintz, Y. C. Sud, and A. Dalcher. 1986. A simple biosphere model (SiB) for use within general circulation models. Journal of Atmospheric Science **43**:505–531.

Shuttleworth, W. J. 1998. Combining remotely sensed data using aggregation algorithms. Hydrology and Earth System Science **2**:149–158.

Xue, Y., N. Bastable, P. J. Dirmeyer, and P. J. Sellers. 1996*a*. Sensitivity of simulated surface fluxes to changes in land surface parameterization—a study using ABRACOS data. Journal of Applied Meteorology **35**:386–400.

Xue, Y., M. J. Fennessy, and P. J. Sellers. 1996*b*. Impact of vegetation properties on U. S. summer weather prediction. Journal of Geophysical Research **101**:7419–7430.

Xue, Y., P. J. Sellers, J. Kinter, and J. Shukla. 1991. A simplified biosphere model for global climates studies. Journal of Climate **4**:354–364.

Xue, Y., and J. Shukla. 1993. The influence of land surface properties on Sahel climate. Part I: desertification. Journal of Climate **6**:2232–2245.

Xue, Y., and J. Shukla. 1996. The influence of land surface properties on Sahel climate. Part I: afforestation. Journal of Climate **9**:3260–3275.

Zhao, Q., and F. H. Carr. 1997. A prognostic cloud scheme for operational NWP models. Monthly Weather Review **125**:1931–1953.