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Impacts of the new land surface physics and vegetation dynamics on the GFDL AGCM simulation of climate

S. Malyshev[1], E. Shevliakova[1], P. C. D. Milly[2], and S. W. Pacala[1]
[1]Dept. of Ecology and Evolutionary Biology, Princeton University [2]United States Geological Survey

Introduction. We compare two simulations performed with the same atmospheric general circulation model but with different land surface schemes. The new land model component LM3V is designed to simulate an integrated set of biogeochemical, biophysical, and bio-geographic processes, as well as exchanges of energy and mass between land surface and the atmosphere. This work primarily focuses on the physical interaction between land surface and the atmosphere, and on the impact that the new land surface scheme has on the simulated climate, compared to the traditionally used LM2 (Milly and Shmakin, 2002).

Models. Atmospheric general circulation model GFDL AM2 (Anderson et al., 2004, Delworth et al., 2006) includes a new finite-volume dynamical core, a multi-species three-dimensional aerosol climatology, a fully prognostic cloud scheme, and a moist turbulent scheme. The horizontal resolution of the model is about 2 by 2.5 degree, there are 24 levels in vertical with effective model top at about 40 km.

Land model LM2 (Milly and Shmakin, 2002) incorporates soil sensible and latent heat storage, groundwater storage, prescribed stomatal control of transpiration, and prescribed soil- and plant-dependent parameters. This is the land model that is traditionally used with AM2.

LM3V represents processes operating on time scales from minutes to decades. The dynamic vegetation and soil carbon model operates on medium and long time scale ranging from days to years and includes models predicting carbon allocation, vegetation growth, disturbance and biogeography. The land surface model operates on fast time scales ranging from minutes to hours and includes canopy biophysics, ecosystem CO_2 exchange, soil/snow thermodynamics and water balance, and radiation exchange. The soil and hydrological components of the model are similar to those of LM2.

Both LM2 and LM3V operate on the same horizontal resolution as the atmospheric model. No attempt to re-tune the atmospheric model to improve state of the simulated climate was done in the experiment with LM3V .

Experiments. The control run was done with AM2/LM2, using prescribed observed inter-annually varying sea surface temperature (SST) over the period 1950-2000. The distribution of land surface properties was specified according to Matthews potential vegetation map.

Since LM3V simulates land surface and vegetation properties on the time scales from minutes to centuries, initial spin-up of the land model to the state consistent with the climate produced by the atmospheric component is important. To achieve this goal, the high-frequency output surface fields of precipitation, downward radiation fluxes, atmospheric temperature, and wind speed from the control AM2/LM2 run were recorded and used to spin-up LM3V in the stand-alone mode. The spin-up run began from the land model state corresponding to the observed climate. Then the 50-year time series of AM2/LM2-generated forcings was used repeatedly for a total of 150 years. The 150th year of the stand-alone was used as initial land condition to start the 50-year AM2/LM3V experiment with the same prescribed inter-annually varying SST as in the control run.

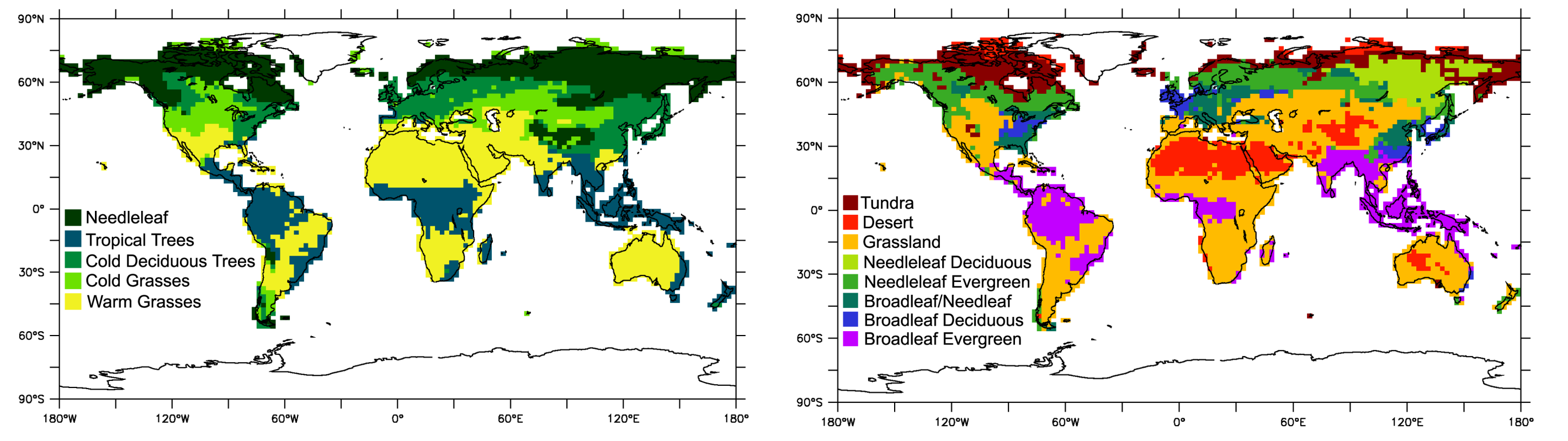

Fig. 1. Distribution of species simulated by AM2/LM3V (left), compared to Matthews (1983) land cover types (right), interpolated to model resolution.

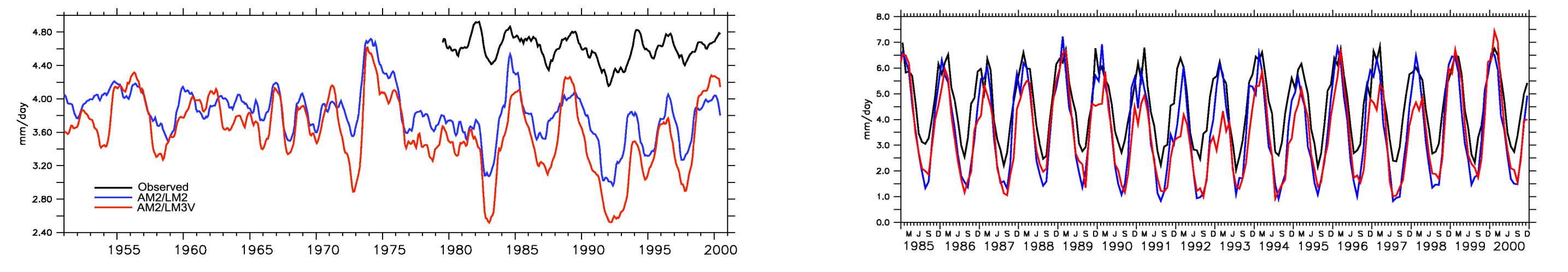

Fig.2. Precipitation averaged over Amazon region (85°W to 30°W, 30°S to 15°N), land only. Left: 12-month running average for the entire integration period. Right: 1985-2000 monthly averages. Observed values are from Nijssen et al., 2001.

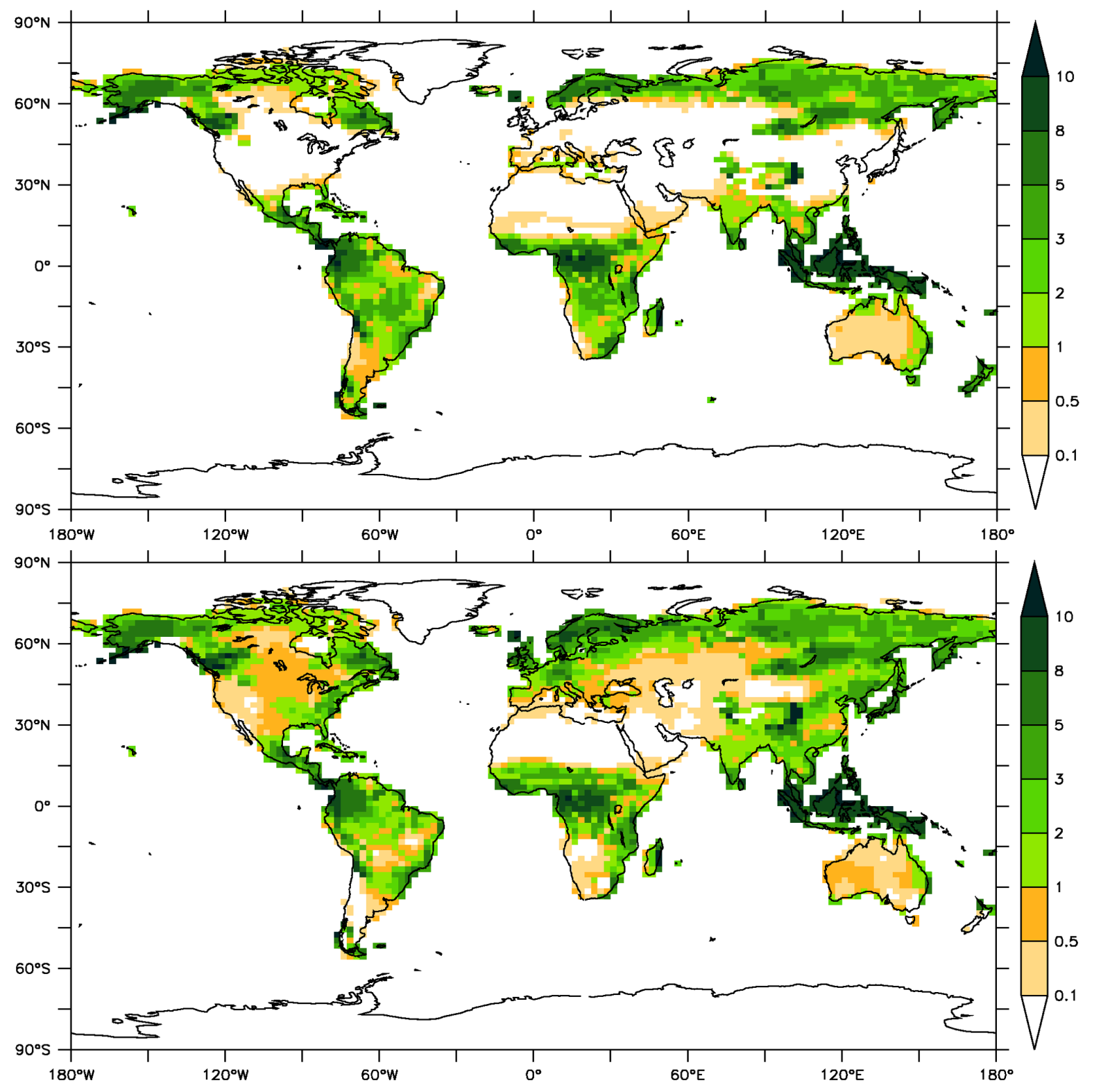

Fig.3. AM2/LM3V simulated leaf area index (LAI, m^2/m^2) for January (top) and July (bottom)

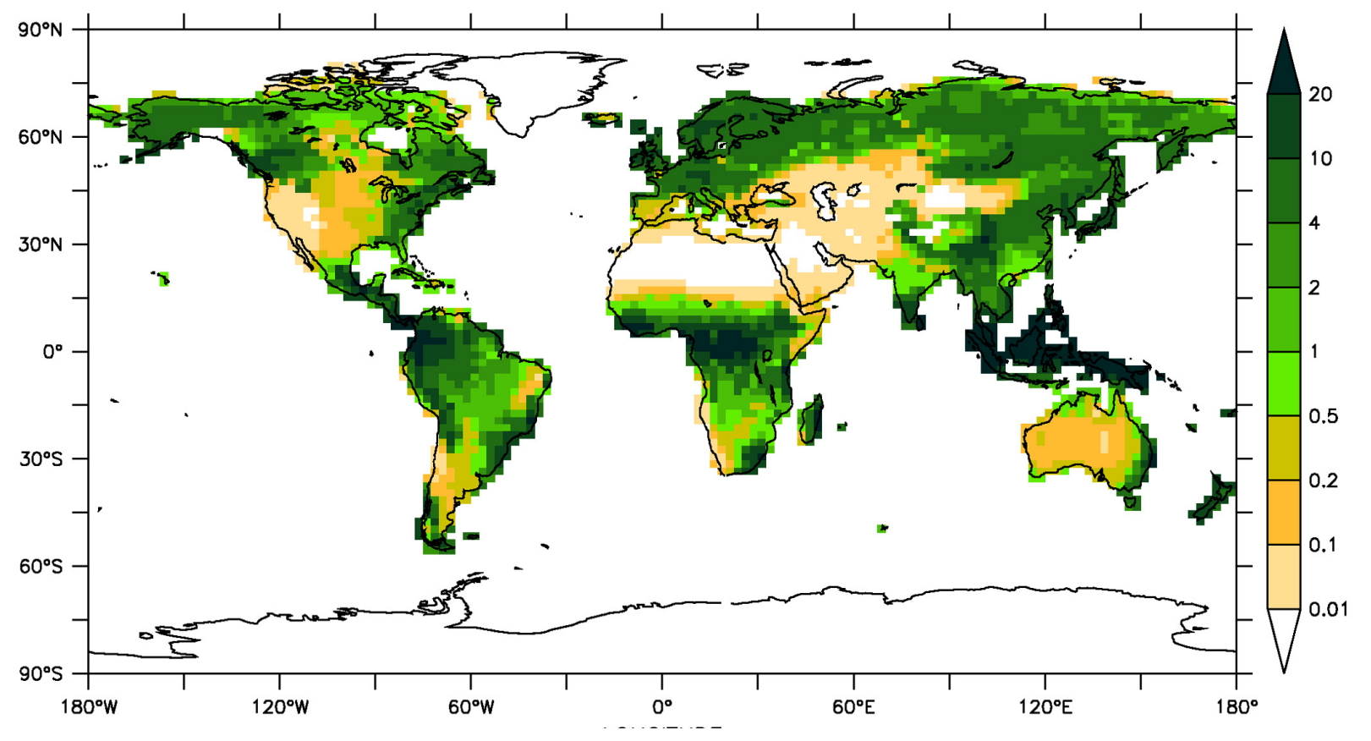

Fig. 4. AM2/LM3V simulated total biomass, kg C/m^2

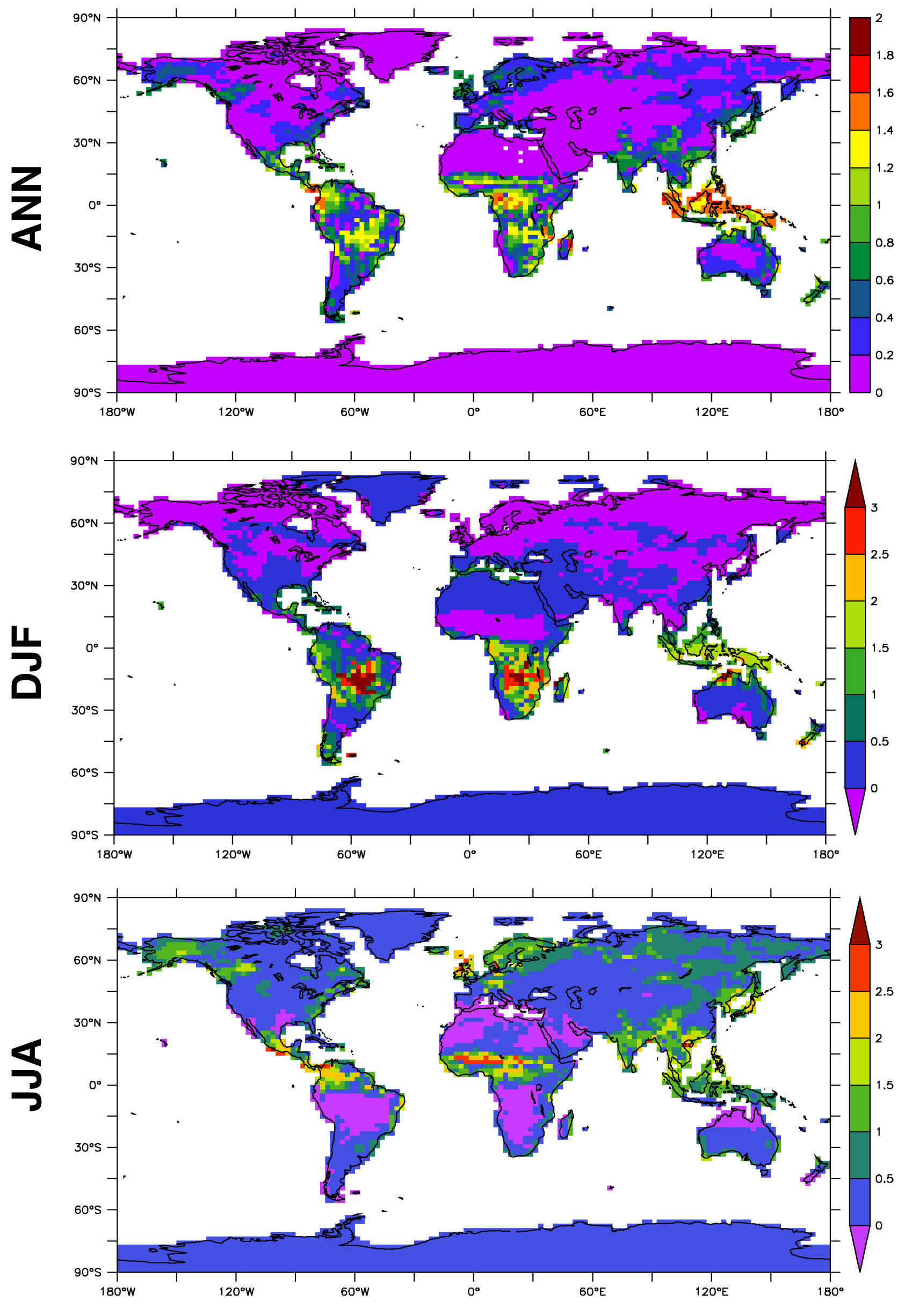

Fig. 5. AM2/LM3V simulated net primary productivity (NPP, kg C m^{-2} $year^{-1}$) . Top is annual-mean, middle is December-January-February, bottom is June-July-August

Results. The resulting distribution of the species dominant over the 50-year integration period is shown in Fig.1. Note that LM3V "species" represent broader categories than traditional plant functional types (PFTs). For example, depending on available water the LM3V tropical trees can be evergreen, representing tropical rainforest, or they can drop leaves during dry season, representing drought-deciduous forests. Similarly, cold deciduous and coniferous trees with low wood biomass and leaf area index (LAI) roughly correspond to the traditional shrub-land PFTs; any species with zero biomass can correspond to desert type.

The simulated species, LAI (Fig. 3), total biomass (Fig. 4), and net primary productivity (NPP, Fig.5) distributions are quite realistic, except several regional features of the simulated distribution. For example, the range of coniferous trees is noticeably shifted north in both Eurasia and North America. The primary reason for this shift is a warm seasonal bias in high latitudes in the AM2-generated climate.

The model also tends to simulate smaller extent, biomass and LAI of the Amazon tropical forest compared to observations. Fig.2 illustrates possible cause: the model precipitation over this region is underestimated, and therefore it cannot sustain the realistic forest functioning. However, Fig. 2 also shows that the model precipitation reproduces the phase of the inter-annual variability in this region remarkably well, albeit significantly exaggerating the amplitude. It is also noticeable that LM3V, introducing additional degrees of freedom and feedbacks associated with changing vegetation, results in further increase of variability.

As illustrated in Fig. 6, the response of the atmosphere to the new land surface scheme is mostly confined to the near-surface levels: the zonal mean values don't differ much between the two numerical experiments.

Fig. 7 shows the response of the simulated near-surface climate to the change of land surface scheme. The major feature of the model -model difference is rather large increase of annual-mean near-surface temperature over the continental high-latitudes in the AM2/LM3V run. It can be attributed to the transitional seasons (spring and fall), while changes in summer and winter are not so significant. We hypothesize that the warming can be associated with the positive vegetation-albedo feedback.

To explain the mechanism, we must recall that the albedo of forests is typically lower than that of the grasslands; moreover the albedo of evergreen coniferous forests in high latitudes tend to be rather significantly lower that that of any other vegetation type during the cold time of year when the land is snow-covered. Therefore, as the coniferous forest region expands northward, the albedo of this region decreases, resulting in increase of near-surface temperature.

A different manifestation of the same effect is the cooling in the Great Lakes region, where the forest retreated north, lowering overall albedo, and therefore temperatures.

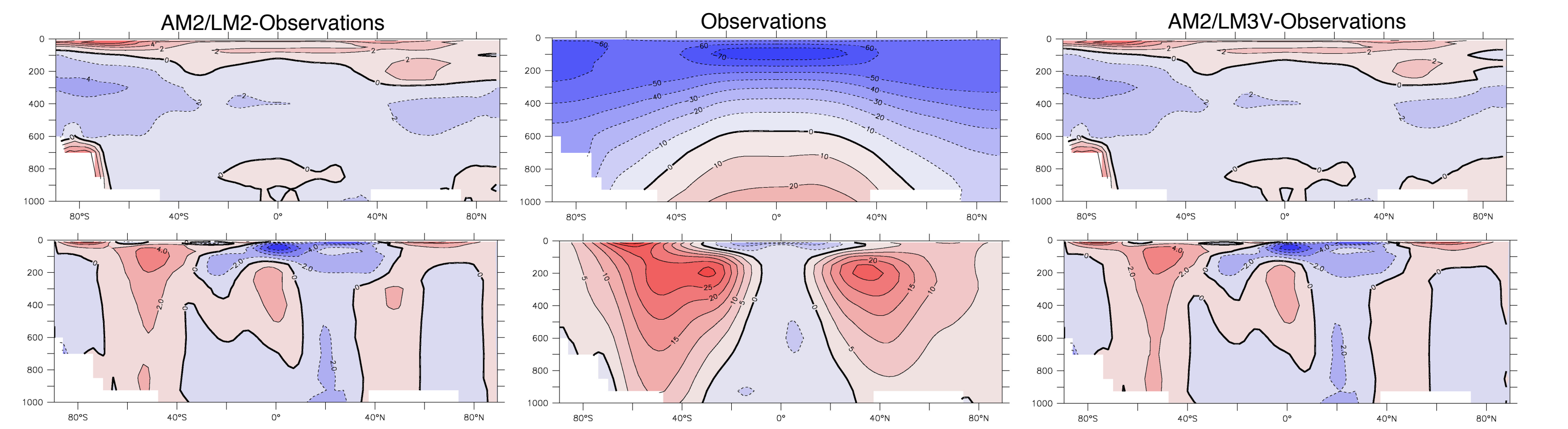

Fig.7. Annual-average zonal-mean differences with observations (middle) obtained in control run (left) and in simulation with LM3V (right). Top: air temperature, degrees K; bottom: zonal wind, m/s.

Changes in precipitation over mid-latitude land are consistent with summer-time differences in temperature. Overall, it appears that in tropics the feedbacks introduced by dynamic vegetation work to increase the pre-existing model biases, such as dryness of the Amazon.

Conclusions. Vegetation model, either forced by AM2/LM2 climate or coupled to the atmospheric model, produces generally realistic vegetation distribution, reflecting however the biases of the model climate. New land surface scheme coupled with the atmospheric model produces reasonable near-surface climate, with little effect on the simulation of the dynamics of the atmosphere. The biases in the surface climate produced by the atmospheric model explain biases in predicted vegetation characteristics, which in term amplify the errors in the AM2/LM3V-simulated surface climate in some regions. This indicates that improvement of the atmospheric model performance is required in some regions, specifically in South American tropics and in high latitudes.

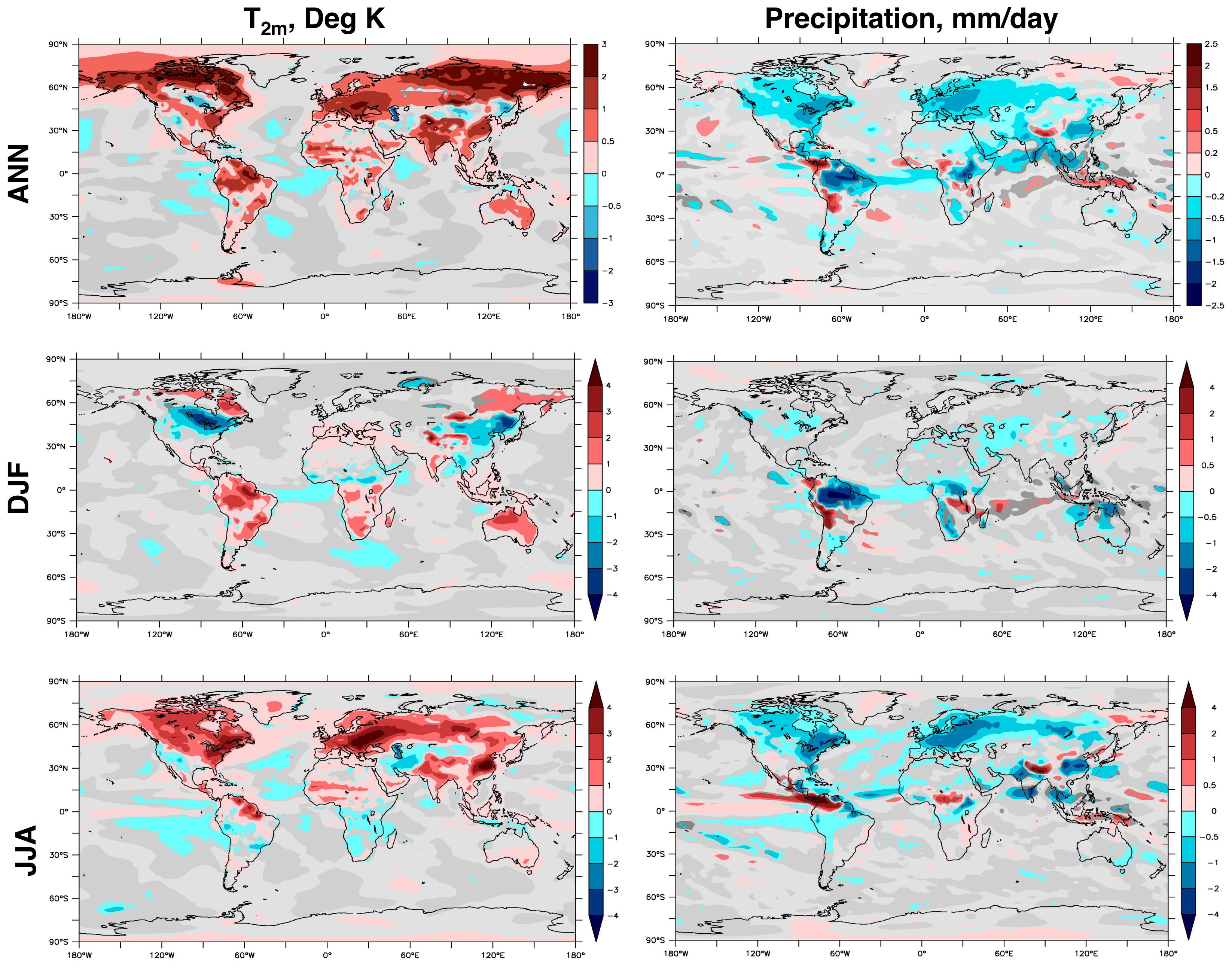

Fig.7. Difference in near-surface temperature (deg K, left) and precipitation (mm/day, right) between AM2/LM3V run and AM2/LM2 run. Top is annual-mean, middle is December-January-February, and the bottom is June-July-August. All values are 50-year averages; regions where differences were not statistically significant at 5% level according to paired-difference test are grayed out.

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Address for correspondence: Dr. Sergey Malyshev, GFDL, Princeton University Forrestal Campus, US Route 1, Princeton, NJ, 08542 E-mail: malyshev@princeton.edu