EVALUATION OF SURFACE FLUXES AND PRECIPITATION IN WRF METEOROLOGICAL SIMULATIONS OF THE AMAZON BASIN

Megan M. Bela[1*], Karla M. Longo[1], Saulo R. Freitas[2], Veronika Beck[3]

[1]Centro de Ciência do Sistema Terrestre (CCST), Instituto Nacional de Pesquisas Espaciais (INPE), São José dos Campos, SP, Brasil. Corresponding e-mail: meganbela@gmail.com

[2]Centro de Previsão de Tempo e Estudos Climáticos (CPTEC), Instituto Nacional de Pesquisas Espaciais (INPE), Cachoeira Paulista, SP, Brasil.

[3]Max Planck Institute for Biogeochemistry, Jena, Germany.

ABSTRACT: In this work, surface fluxes and precipitation simulated by the Weather Research and Forecasting (WRF) model are evaluated for the 2008 dry-to-wet transition in the Amazon region. WRF land use is updated with PROVEG data for the Amazon region, and albedo and greenness fraction are estimated from MODIS NDVI satellite data. Soil moisture is initialized from the GPNR product, based on assimilation of TRMM precipitation data in an offline hydrological model. Simulations using original (BM) and updated (ND) data were performed for Nov. – Dec. 2008 using a 30/10km nested grid configuration covering South America and the Amazon Basin, respectively.

LBA flux tower data from forest and pasture sites in Rondônia were used to evaluate the average diurnal cycle of surface radiation and heat fluxes. Both simulations were in agreement with observed sensible heat (H) fluxes, but overestimated surface latent heat (LH) fluxes at both sites, although the ND simulation showed some improvement in LH. Incoming shortwave and net radiation fluxes were also higher than observed for both simulations at both sites, but the ND case showed reduced fluxes at the pasture site.

3-hr TRMM 3B42 precipitation data were used to evaluate average hourly precipitation for the 10km domain and the average diurnal cycle of precipitation for 5° x 5° sub-domains. Both simulations overestimated peak rainfall rate and average hourly precipitation compared to TRMM, particularly in the southern Amazon, although the ND case showed some improvement. The timing of peak precipitation (14 LT/18 UTC) was in agreement with TRMM.

Keywords: Atmospheric modeling, Amazon, LBA, precipitation, TRMM, surface fluxes

1. INTRODUCTION

Major uncertainties remain in characterizing emissions, photochemical processes and pollutant transport in the Amazon basin, due in part to lack of observations. The LBA/BARCA campaign collected Amazon basin-wide aircraft measurements of trace gases and aerosols during the dry-to-wet transition of 2008, with the aims of analyzing budgets and evaluating atmospheric chemistry models for the Amazon. In this work, land surface data in the WRF (Weather Research and Forecasting) model is updated for the Amazon, and surface fluxes and precipitation are evaluated for the BARCA region and period using ground-based and satellite observations. In future BARCA studies, WRF will be coupled with chemistry (WRF-Chem) and biospheric (WRF-VPRM) models.

2. MATERIAL AND METHODS

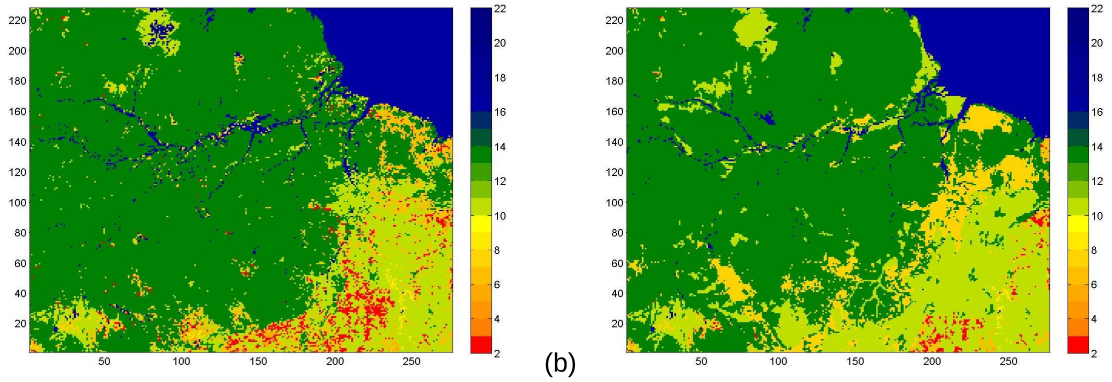
2.1 WRF Model

The Weather Research and Forecasting (WRF) model (Skamarock and Klemp, 2007) is a non-hydrostatic atmospheric model in use for research and weather prediction. In this study, WRF simulations were conducted with a 30/10 km two-way nested grid configuration. The 30km grid extends from approximately 80° W - 20° W and 40° S - 15° N, covering most of South America, and the 10km grid extends from 70°W - 46°W and 15°S - 5°N, covering the Amazon region. Both grids have 41 vertical eta levels up to approximately 20km altitude, with vertical resolution ranging from approximately 40m near the surface to a maximum of 1km. Initial and boundary conditions are taken from the ECMWF T799L91 operational model with horizontal resolution of approximately 25km, and the model is integrated from 1 Nov. - 31 Dec. 2008.

The cloud microphysics is the WRF Single-Moment 5-class scheme, which includes mixed-phase processes and super-cooled water (Hong et al., 2004), and the planetary boundary layer is parameterized with the Mellor-Yamada-Janjic scheme (Janjic, 2002). A new version of the Rapid Radiative Transfer Model (Mlawer et al. 2007), which utilizes the MCICA technique for random cloud overlap, is used for short- and longwave radiation. The Noah Land Surface Model, based on the OSU LSM described in Chen and Dudhia (2002), predicts soil temperature and moisture in 4 layers to a depth of 2m. Deep convection is parameterized on the 30km grid with the Grell-Devenyi ensemble scheme (Grell and Devenyi, 2002), and on the 10km grid with the Grell 3 scheme, which includes the effects of subsidence in neighboring columns.

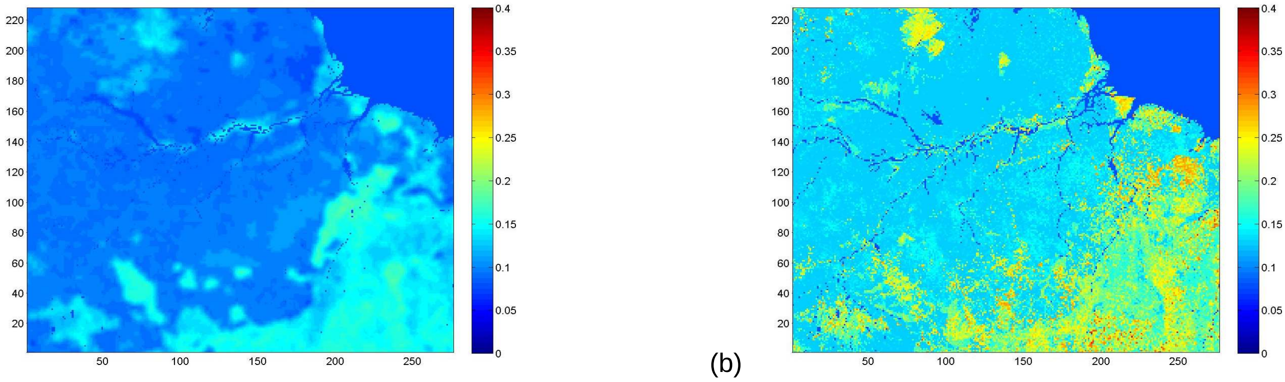
2.2 Land Surface Data

In this study, the 1km USGS Version 2 Global Land Cover Characteristics dataset (http://edc2.usgs.gov/glcc/glcc.php), based on 1km AVHRR data from Apr. 1992 – Mar. 1993, was updated with the PROVEG dataset (http://proveg.cptec.inpe.br/), which classifies Amazonian land use into four classes (forest, pasture, savanna, water) based on data from Landsat TM and PRODES (http://www.obt.inpe.br/prodes/). As shown in Figure 1, PROVEG (a) shows a marked reduction in broadleaf evergreen forest cover (dark green) in the southern and eastern Amazon region and corresponding increase in the area of grassland/pasture (yellow) and savanna (light green) relative to the USGS dataset (b).



(a) (b)
Figure 1 - Vegetation type on 10km WRF grid from (a) USGS and (b) USGS/PROVEG.

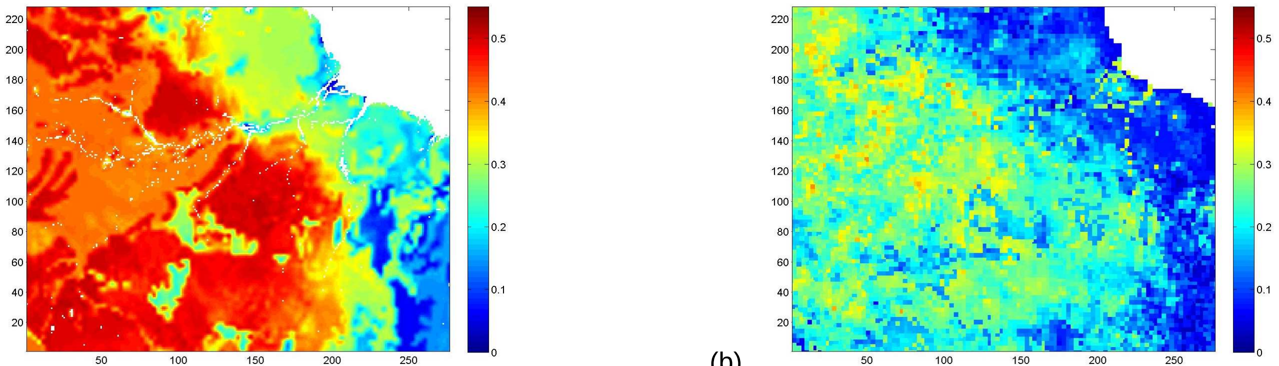
Albedo and greenness fraction were estimated from the USGS/PROVEG land use and a 2001-2002 1km MODIS NDVI product processed by the Terrestrial Biophysics and Remote Sensing Lab (http://tbrs.arizona.edu/cdrom/Index.html), using the Land Ecosystem-Atmosphere Feedback Version 3 (LEAF-3) parameterization (Walko et al., 2000). Albedo and greenness fraction from the NESDIS/NOAA 0.15° 5-year climatology (Csiszar and Gutman, 1999) are provided with the WRF model. Figure 2 shows November albedo on the 10km domain (a) from NESDIS/NOAA and (b) calculated from MODIS and USGS/PROVEG. The increased resolution better captures the surface heterogeneity and is in better agreement with observations by von Randow (2004): 0.1-0.15 for forest, and 0.18-0.22 for pasture/savanna.



(a) (b)
Figure 2 - WRF albedo on 10km grid (a) from NESDIS/NOAA 0.15° 5-year climatology for November and (b) calculated from 2001-2002 1km MODIS NDVI and USGS/PROVEG.

2.3 Soil Moisture Initialization

The twice daily 0.25° GPNR soil moisture product is derived from an offline hydrological model (Gevaerd and Freitas, 2006) which assimilates TRMM precipitation data. Figure 4 shows interpolated soil moisture for the top soil layer (0 – 0.1m depth) from (a) ECMWF and (b) GPNR. GPNR presents more spatially heterogeneous and realistic values: 0.3-0.4 for the Amazon basin and around 0.1 for the north and northeast regions, while ECMWF predicts values of approximately 0.45 and 0.1-0.3, respectively.



(a) (b)
Figure 3 - Top-layer (0 – 0.1m) soil moisture (mm^3mm^{-3}) initialization data (1 Nov 2008 00 UTC) on 10km grid from (a) ECMWF and (b) 0.25° GPNR product.

2.4 Surface Flux Evaluation

The surface heat and radiative flux balances are evaluated with flux tower data from two sites in the southern Amazon: the Jarú Biological Reserve, located in a rainforest area at 10°4.706'S and 61°56.027'W, and Fazenda Nossa Senhora, a deforested pasture area located at 10°45'S and 62°22'W (von Randow, et al., 2004). Half-hourly incoming and outgoing shortwave and longwave radiation and hourly latent and sensible heat flux measurements were averaged over the wet seasons of 1999 (Feb. – Mar.) and 2000 (Jan. – Mar.). Minutely simulated values from Nov. – Dec. 2008 of radiation and heat fluxes in the corresponding grid cell in the 10km domain were averaged into half-hourly and hourly bins, respectively.

2.5 Precipitation Evaluation

The simulated and TRMM average hourly precipitation rates from Nov. – Dec. 2008 on the 10km domain were compared. To evaluate the precipitation diurnal cycle, the grid was divided into sixteen 5° x 5° sub-domains and simulated and TRMM average hourly precipitation in each three hour time increment (0, 3, 6, 9, 12, 15, 18 UTC) were averaged over the sub-domain and simulation period.

3 – RESULTS AND DISCUSSION

3.1 Surface Fluxes

The observed (upper and lower bounds) and simulated average surface latent (LH) and sensible (H) heat flux diurnal cycles are shown in Figure 5 for (a) Rebio Jarú and (b) Fazenda Nossa Senhora. Average observed latent (sensible) heat fluxes are higher (lower) at the forest (pasture) site, due to the higher (lower) evapotranspiration of forest (pasture) vegetation. The model overestimates peak (13 LT) latent heat fluxes by about 200 Wm^{-2} in the BM simulation and 100 Wm^{-2} in the ND simulation. The improvement in the ND simulation may be due to more accurate representation of land use at the observation site; the land use type in the grid cell containing FNS changed from forest to pasture, and the region around both towers shows increased deforestation in ND. The model shows reasonable agreement for sensible heat flux, with average hourly values falling within the observed bounds, except for the ND case at Rebio Jarú.

The observed and simulated average surface radiation diurnal cycle is shown in Figure 6 for (a) Rebio Jarú and (b) Fazenda Nossa Senhora. Both simulations overestimate peak incoming shortwave radiation (S_{in}) by approximately 300 Wm^{-2}, with minimal difference between the BM and ND cases. Excessive S_{in} is the primary contributor to the overestimation of net radiation (R_n) by approximately 200 Wm^{-2} at both sites, although at Fazenda Nossa Senhora the ND case shows a reduction relative to BM of approximately 50 Wm^{-2} at the peak.

(a) (b)

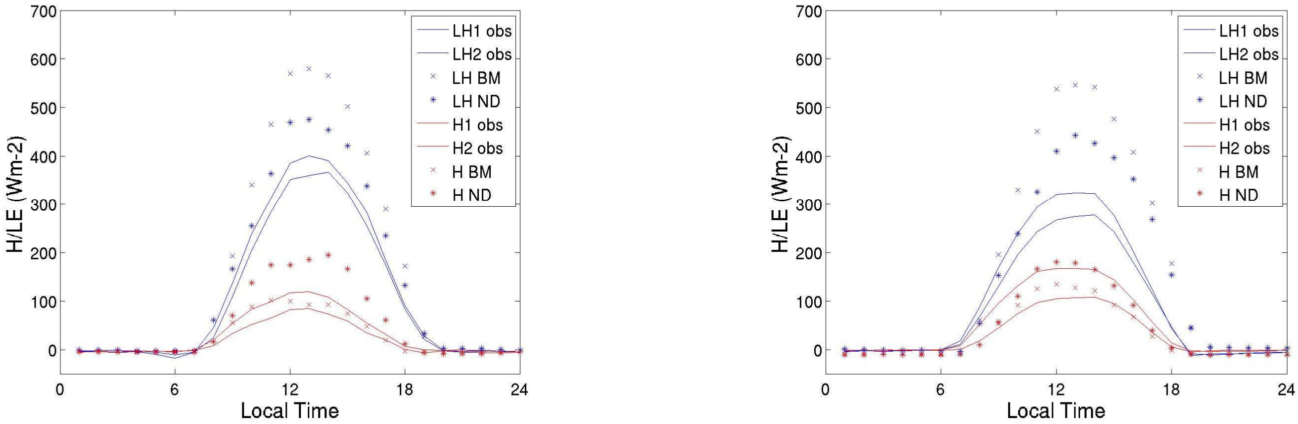


Figure 4 - Average diurnal surface heat fluxes at (a) Rebio Jarú (forest) and (b) FNS (pasture).

(a) (b)

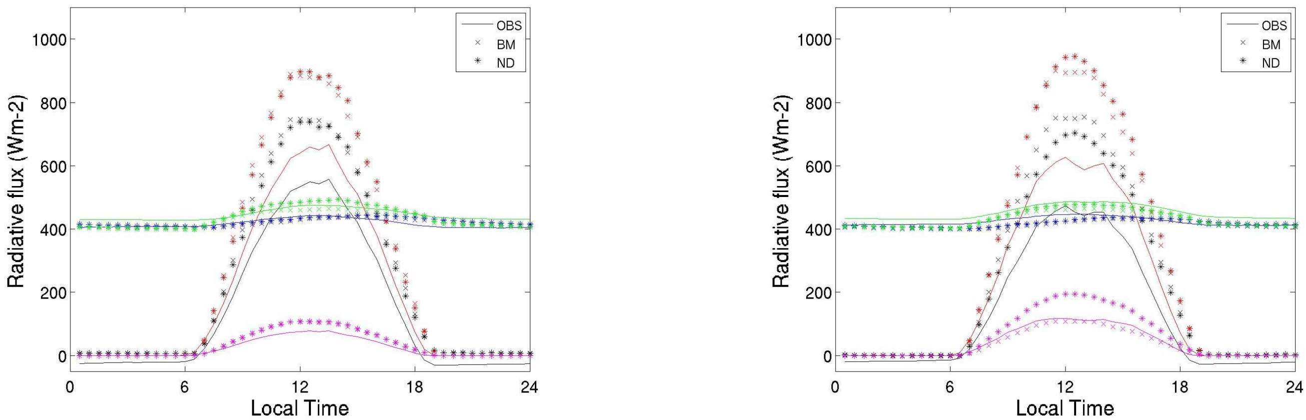


Figure 5 - Average diurnal surface radiation fluxes at (a) Rebio Jarú (forest) and (b) FNS (pasture).

3.2 Precipitation

Figure 6 shows average hourly precipitation (mm hr^{-1}) in the 10km domain from 1 Nov. – 31 Dec. 2008 for the (a) 3-hourly 0.25° TRMM product and (b) BM and (c) ND simulations. Both simulations overestimate the average precipitation rate in the southern Amazon, with the error increasing with southerly latitude, likely due in part to overestimation of surface latent heat fluxes and the lack of a shallow convective scheme. However, the ND run shows improvement in the geographical distribution, capturing the elevated precipitation in the NW of the domain and reduced precipitation in the predominantly pasture/savanna NE of the domain, possibly due to the improvement in representation of land surface properties.

Figure 7 shows average hourly precipitation (mm hr^{-1}) at 3 hour intervals for 5° x 5° boxes in the southeastern

Amazon (15°S – 10°S, 65°W – 60°W) for TRMM data and BM and ND simulations. The time of peak average precipitation rate (14 LT/18 UTC) is in agreement among simulations and TRMM; however, both simulations overestimate the peak average precipitation rate by approximately double, although the ND simulation shows a slight reduction relative to BM. At off-peak hours with lower precipitation rates, the model shows reasonable agreement with TRMM.

(a) (b) (c) (d)

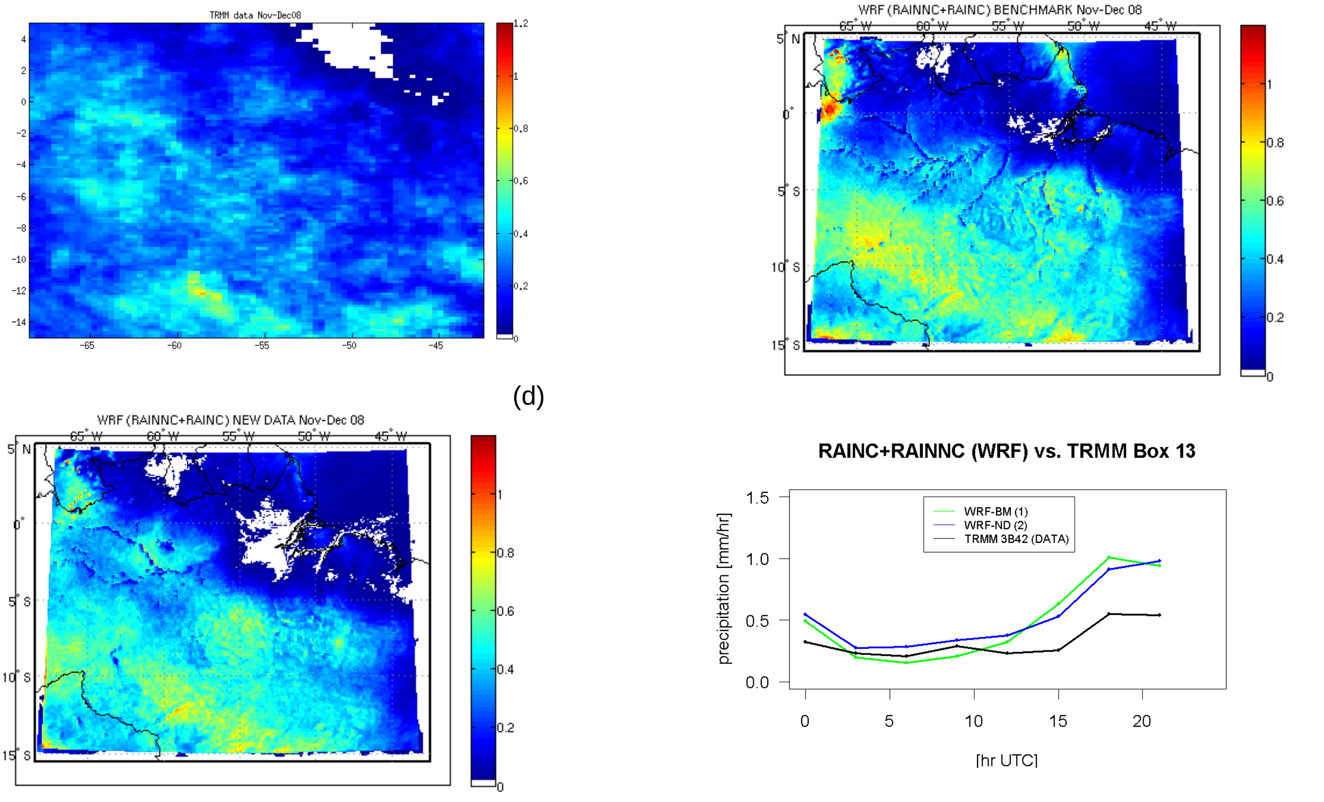


Figure 6 – Average hourly precipitation (mm hr^{-1}) in 10km domain for (a) 3-hourly 0.25° TRMM product and (b) BM and (c) ND simulations, and (d) average hourly precipitation (mm hr^{-1}) at 3 hour intervals for 15°S – 10°S, 65°W – 60°W.

4 – CONCLUSIONS

An evaluation of WRF model simulations of the Amazon basin showed reasonable agreement with observed surface fluxes and precipitation in forest and pasture areas for the dry-to-wet transition season, showing WRF's capacity to reproduce the impacts of different land surface regimes on boundary layer processes. More realistic land surface properties and soil moisture initialization improved performance. However, substantial challenges remain in accurately simulating tropical land surface and convective processes. The model is "too sunny," with excessive peak shortwave radiation at the surface possibly contributing to overestimated latent heat fluxes and precipitation. Additionally, the excessive precipitation is principally due to an overestimate of the peak precipitation rate in the late afternoon, suggesting that further improvements are necessary in the convective scheme. Since the surface energy balance strongly influences the development of the convective boundary layer and the precipitation regime, further improvements in land surface properties and convection will directly contribute to gains in accuracy of WRF coupled simulations with biospheric and chemistry models.

5 – REFERENCES

Chen, F., and J. Dudhia, 2001: Coupling an advanced land-surface/ hydrology model with the Penn State/ NCAR MM5 modeling system. Part I: Model description and implementation. Mon. Wea. Rev., 129, 569–585.

Csiszar, I., and Gutman, G, 1999: Mapping global land surface albedo from NOAA AVHRR. J. Geophys. Res., 104, 6215-6228.

Hong, S.-Y., J. Dudhia, and S.-H. Chen, 2004: A Revised Approach to Ice Microphysical Processes for the Bulk Parameterization of Clouds and Precipitation, Mon. Wea. Rev., 132, 103–120.

Gevaerd, R. and Freitas, S. R.: Estimativa operacional da umidade do solo para iniciaciação de modelos de previsão numérica da atmosfera. Parte I: Descricão da metodologia e validacão, Revista Brasileira de Meteorologia, 21, 3, 1–15, 2006.

Grell, G. A., and D. Devenyi, 2002: A generalized approach to parameterizing convection combining ensemble and data assimilation techniques. Geophys. Res. Lett., 29(14), Article 1693.

Janjic, Z. I., 2002: Nonsingular Implementation of the Mellor–Yamada Level 2.5 Scheme in the NCEP Meso model, NCEP Office Note, No. 437, 61 pp.

Mlawer, E. J., S. J. Taubman, P. D. Brown, M. J. Iacono, and S. A. Clough, 1997: Radiative transfer for inhomogeneous atmosphere: RRTM, a validated correlated-k model for the longwave. J. Geophys. Res., 102 (D14), 16663–16682.

Skamarock, W. C., J. B. Klemp, 2007: A time-split nonhydrostatic atmospheric model for research and NWP applications. J. Comp. Phys., special issue on environmental modeling. 3465-3485.

von Randow, C., et al., 2004: Comparative measurements and seasonal variations in energy and carbon exchange over forest and pasture in South West Amazonia. Theor. Appl. Climatol. 78, 5-26.