

## Climate Model Report Card

**Model Name:** Geophysical Fluid Dynamics Laboratory Climate Model version 3

**Developers:** National Oceanic and Atmospheric Administration's (NOAA) Geophysical Fluid Dynamics Laboratory (GFDL)

**Data Portal:** <https://cera-www.dkrz.de>, <https://esgf-node.llnl.gov>

**Spatial Resolution:** 2.00° x 2.50°

**Temporal Resolution:** 3 hr, daily, monthly

**Historical Run(s):** 1860-2005 (daily, monthly), 1970-2005 (3 hr)

**Future Scenario(s):** RCP2.6, RCP4.5, RCP6.0, RCP8.5

**Future Time Period(s):** 2006-2100 (3 hr for RCP8.5; daily for RCP2.6, RCP4.5, RCP6.0, RCP8.5; monthly for RCP2.6, RCP4.5, RCP8.5), 2006-2300 (3 hr for RCP4.5)

## LAKE COMPONENT

**Name:** Lake model within Land Model, version 3 (LM3)

**Reference:** <sup>1</sup>Milly, P. C., Malyshev, S. L., Shevliakova, E., Dunne, K. A., Findell, K. L., Gleeson, T., ... & Swenson, S. (2014). An enhanced model of land water and energy for global hydrologic and earth-system studies. *Journal of Hydrometeorology*, 15(5), 1739-1761.

**Description:** Lake temperature calculations follow Henderson-Sellers (1985) and Hostetler & Bartlein (1990), accounting for vertical heat transfer within a column by eddy diffusion and convective mixing. Lakes and lake ice receive water from melting snowpack above lake ice, precipitation, and river inflows. Soil beneath the lakes is impermeable but receives geothermal heat flux. Lakes are defined by USGS's Global Land Cover Characteristics database under "IGBP Water Bodies."<sup>1</sup>

**Vertical Layers | Depths:** The documentation cites that "lakes are characterized by changing depth," and the study discretizes it into 20 dynamic layers with a maximum depth of 50m. It is unclear to GLISA if this is the same set-up used in CMIP5.<sup>1</sup>

**Vertical Mixing (y/n):** Yes

**Horizontal Mixing (y/n):** Yes, a variable  $K_x$  is added to Henderson-Sellers (1985)'s and Hostetler & Bartlein (1990)'s work to account for three-dimensional mixing in large, deep lakes, and the LM3 documentation specifies horizontal lake calculations are performed at a different time-step than vertical lake calculations.<sup>1</sup>

**Lake Ice:** Lakes have vertical profiles that consist of water and ice, with ice always above liquid water.<sup>1</sup>

## LAND COMPONENT

**Name:** Land Model, version 3 (LM3)

**Reference:** <sup>1</sup>Milly, P. C., Malyshev, S. L., Shevliakova, E., Dunne, K. A., Findell, K. L., Gleeson, T., ... & Swenson, S. (2014). An enhanced model of land water and energy for global hydrologic and earth-system studies. *Journal of Hydrometeorology*, 15(5), 1739-1761.

**# Land Cover Types:** 3 land covers types (soil, lake, or glacier), and 5 soil vegetation types (C3 grass, C4 grass, temperate deciduous tree, tropical tree, or cold evergreen tree)<sup>1</sup>

**# Soil Layers:** 20 layers (+5 for snow) with a total depth of 10m

**Soil Moisture:** Water flux at the surface is calculated by adding rainfall, snowmelt, the canopy interception store and subtracting evaporation.<sup>1</sup>

**Runoff:** Rainfall that cannot enter the soil column because it is too saturated with no available macropores present becomes surface runoff. Runoff is then combined with nearby water flowing into a upstream river and lake, if present. LM3 uses a TOPMODEL approach.<sup>1</sup>

**Sub-Grid Lakes (y/n):** Yes, grid cells are made up of many tiles, where tiles are either 100% lake, glacier, or soil.<sup>1</sup>

**Carbon Fluxes:** Carbon and vegetation dynamics follow Shevliakova et al. (2009), where carbon is tracked in leaves, fine roots, heartwood, sapwood, and labile and is affected by weather, climate, atmospheric CO<sub>2</sub> concentration, soil state, and disturbances (anthropogenic and natural).<sup>1</sup>

**Land Use Change:** Each grid cell is defined by a combination of four land-use types: undisturbed lands, croplands, pastures, and lands previously used in agriculture or harvested.<sup>3</sup> LM3 is largely based on LM3V (Shevliakova et al., 2009) and the LaD model (Milly & Shmakin, 2002), where the former is designed to address land use and land management changes. In LM3's documentation, the spin-up period neglected land use change while the historical phase used land use scenarios of Hurtt et al. (2011),<sup>1</sup> but it is unclear to GLISA if this is the same set-up used in CMIP5.

**Groundwater:** Groundwater is all water below the "water table" (which has a depth of 10m), and is steady-state with uniform recharge. A zero water flux and a constant geothermal heat flux are given at the bottom of the soil-bedrock layers.<sup>1</sup>

## ATMOSPHERE COMPONENT

**Name:** Atmospheric Model, version 3 (AM3)

**Reference:** <sup>2</sup>Donner, L. J., Wyman, B. L., Hemler, R. S., Horowitz, L. W., Ming, Y., Zhao, M., ... & Zeng, F. (2011). The dynamical core, physical parameterizations, and basic simulation characteristics of the atmospheric component AM3 of the GFDL global coupled model CM3. *Journal of Climate*, 24(13), 3484-3519.

**Physical Parameterizations:** Shortwave and longwave radiation (Freidenreich & Ramaswamy, 1999) and (Schwarzkopf & Ramaswamy, 1999) modified by (Anderson et al., 2004), cloud radiative transfer and overlap (Pincus et al., 2003), orographic gravity wave drag (Stern & Pierrehumbert, 1988), stratiform clouds (Tiedtke, 1993) with modifications by (Anderson et al., 2004), deep cumulus convection (Donner, 1993; Donner et al., 2001; Wilcox & Donner, 2007), microphysical processes (Rotstain, 1997) and (Rotstain et al., 2000), shallow cumulus scheme (Bretherton et al., 2004), modified by (Zhao et al., 2009)<sup>2</sup>

**Chemistry:** Historical concentrations of carbon dioxide, nitrous oxide, methane, and four halocarbons are considered. Sulfur dioxide emissions from volcanoes, sulfate, black carbon, dust, and sea salt are modeled. AM3 includes interactive simulation of aerosols from emissions, while previous versions used specified concentrations. AM3 merges chemistry models for the troposphere (Horowitz et al., 2003) and stratosphere (Austin & Wilson, 2006).<sup>2</sup>

### Additional References

<sup>3</sup>Dunne, J. P., John, J. G., Shevliakova, E., Stouffer, R. J., Krasting, J. P., Malyshev, S. L., ... & Zadeh, N. (2013). GFDL's ESM2 Global Coupled Climate-Carbon Earth System Models. Part II: Carbon System Formulation and Baseline Simulation Characteristics, *Journal of Climate*, 26(7), 2247-2267.