GFDL IPCC Climate Models: Changes in Model Physics between TAR and AR 4

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Atmospheric Model

Radiation The shortwave radiation algorithm used in TAR had two-spectral bands (Lacis and Hansen, 1974) including gaseous absorption and parameterized Rayleigh scattering. The algorithm in AR4 was a multi-band, delta-Eddington scheme (Freidenreich and Ramaswamy, 1999) including scattering and absorption from clouds, aerosols and gases. TAR calculations assumed diurnally-averaged, seasonally varying but annually invariant insolation; AR4 calculations included diurnal variation and monthly changes in spectral solar irradiance.

The infrared scheme in TAR employed a random model for water vapor using transmissivities computed at multi-day intervals; AR4 used the Simplified Exchange Approximation (Schwarzkopf and Ramaswamy, 1999) computed at 3-hour intervals.

In TAR, an effective carbon dioxide amount was used to represent radiative contributions from all well-mixed gases; AR4 included radiative effects of methane, nitrous oxide, and halocarbons explicitly. Aerosol effects were parameterized as changes in surface albedo in TAR but were computed using a three-dimensional chemical transport model (Horowitz et al., 2003) in AR4. TAR used specified cloud radiative properties; AR4 used absorption and scattering coefficients that depended on the model's prognostic microphysical properties.

For more on AR 4, see GFDL Global Atmosphere Model Development Team (2004) and Delworth et al. (2005).

Planetary Boundary Layer and Diffusion TAR used specified surface drag and diffusion coefficients. For AR4, surface and stratocumulus convective layers were represented by a K-profile scheme with prescribed entrainment rates (Lock et al., 2000); surface fluxes were from Monin-Obukhov similarity theory; gustiness enhancement to wind speed was used in surface-flux calculations (Beljaars, 1995); enhanced near-surface mixing was employed in stable conditions; and orographic roughness was included. For more on AR4, see GFDL Global Atmosphere Model Development Team (2004).

Clouds TAR assumed clouds formed when relative humidity exceeded threshold values, with specified absorption and reflection. In AR4, cloud liquid, cloud ice, and cloud fraction are prognosed, using Rotstayn's (1997) microphysics and Tiedtke's (1993) macrophysics. For more on AR 4, see GFDL Global Atmosphere Model Development Team (2004).

Convection TAR used saturated adiabatic adjustment. AR4 used the relaxed Arakawa-Schubert parameterization (Moorthi and Suarez, 1992), built around an ensemble of entraining plumes whose mass fluxes relaxed cloud work functions to threshold values. The plumes detrained cloud liquid, ice, and fraction into stratiform clouds. A lower bound was imposed on lateral entrainment rates for deep convective updrafts (Tokioka et al., 1988), and convective momentum transport was represented by vertical diffusion proportional to the cumulus mass flux. For more on AR4, see GFDL Global Atmosphere Model Development Team (2004).

Gravity wave drag No gravity wave drag was used in the R15 GFDL models in TAR. The AR 4 models included orographic gravity wave drag from Stern and Pierrehumbert (1988), and a similar parameterization for gravity wave drag was used in the TAR R30 model (Broccoli and Manabe, 1992).

Numerics TAR used a spectral transform method in the horizontal (Gordon and Stern, 1982) and finite differences in the vertical. In AR 4, models with B-grid (Arakawa and Lamb, 1977) and finite-volume (Lin, 2004) dynamical cores were used.

Ocean Model

A description of the ocean model used in AR4 and a comparison with the TAR model can be found in Griffies et al. (2005). Flux adjustments for heat and salt were applied to the ocean TAR. No heat or salt flux adjustments were applied in AR4.

Vertical coordinate TAR and AR4 both use geopotential; AR4 also incorporates free surface and partial bottom cells.

Barotropic solver TAR used rigid lid; AR4 used explicit free surface.

Time stepping TAR and AR4 both used forward for lateral dissipative, implicit for vertical dissipative, and semi-implicit for Coriolis. TAR used leap frog for inviscid, while AR4 used predictor-corrector with 3rd-order Adams-Bashforth for inviscid.

Salt and water fluxes TAR used virtual salt fluxes and did not supply water fluxes from precipitation, evaporation, run-off. AR4 did not use virtual salt fluxes and did use real water fluxes.

Tracer advection TAR used 2nd-order centered; AR4 used a 3rd-order monotone flux limiter.

Tracer lateral sub-grid diffusion TAR used neutral diffusion and background horizontal diffusion. AR4 used neutral diffusion and Gent-McWilliams skew diffusion.

Tracer vertical sub-grid diffusion TAR used Bryan-Lewis diffusivity with a 50-m upper "mixed-layer" box. AR4 used a KPP mixed layer with Bryan-Lewis background diffusivity and parameterized tidal mixing on shelves.

Horizontal friction TAR used Laplacian friction with globally constant viscosity. AR4 used Laplacian friction with anisotropic viscosity in the tropics and isotropic Smagorinsky viscosity at higher latitudes with additional latitudinally dependent background friction at higher latitudes.

Vertical friction Globally constant in TAR; KPP in AR4.

Grid TAR used a spherical grid with polar filtering; AR4 used a tripolar grid with no polar filtering.

Topography Full steps were used in TAR; partial steps in AR4.

Equation of state Approximate UNESCO in TAR; state-of-science UNESCO-like in AR4.

Land Model

The TAR land model is described in Manabe et al. (1969). The AR4 land model is based on Milly and Shmakin (2002), with implementation details in GFDL Global Atmosphere Model Development Team (2004) and Delworth et al. (2005).

Soil TAR used a globally uniform "bucket." AR4 used regionally varying soil textures and associated physical properties.

Vegetation TAR's globally uniform "bucket" implied globally uniform rooting depth. AR4 used regionally varying (but temporally invariant) vegetation types and associated rooting depths and snow-free albedos.

Soil physics TAR ignored soil heat capacity. AR4 assigned soil thermal properties based on soil texture with multiple layers.

Vegetation physics Non-water-stressed bulk stomatal resistance was effectively zero in TAR but became a function of vegetation type in AR4.

Albedo TAR specified regionally varying snow-free albedo. AR4's albedo was a function of vegetation type.

Sea-Ice Model

TAR used a single-layer sea-ice model with zero heat capacity. The layer moved with the surface current until reaching a critical thickness (Delworth et al., 2002). AR4's sea-ice model has full dynamics with elastic-viscous-plastic internal ice forces. The single-layer of TAR was replaced in AR4 by two ice layers, both with sensible heat capacity and with latent heat capacity via brine in the upper layer, and a snow layer. The AR4 model has 5 ice thickness categories and open water (leads) (Delworth et al., 2005).

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