7.13 COMPARISON OF THE MULTI-SCALE MODELING FRAMEWORK AND THE NCAR COMMUNITY ATMOSPHERIC MODEL (CAM) WITH ISCCP AND CERES RETRIEVALS

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1. INTRODUCTION

Recently, a new computational approach that couples cloud-scale dynamics with larger scale dynamics in global climate models (GCMs) has been developed. In this approach, called a Multiscale Modeling Framework (MMF) or superparameterization, all the cloud-related parameterizations are removed from a traditional GCM and, in each GCM grid cell, replaced with a 2D or a small 3D cloud resolving model (CRM) [Khairoutdinov and Randall, 2001; Randall et al., 2003]. A CRM explicitly calculates cloud properties from physical equations at a scale consistent with cloud dynamics, thereby removing the need for the most problematic GCM cloud parameterizations. This approach has the potential to produce a more accurate representation of cloud and ideally an improved climate simulation.

High resolution CRM output from an initial global MMF simulation (of 500 days) along with output from the parent (parameterized) GCM has been compared against data obtained from the U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) Program sites [Ovtchinnikov et al., 2004]. Results of this comparison showed that the MMF simulation produced improvement in the representation of clouds and precipitation in the tropical Pacific but not in the Southern Great Plains (SGP) of the United States.

In this article, we extend the previous studies by Khairoutdinov and Randall [2001] and Ovtchinnikov et al. [2004] in comparing MMF and standard CAM climate model output with top of atmosphere fluxes retrieved from the NASA Clouds and Earth's Radiant Energy System (CERES) instrument [Wielicki et al. 1996] and cloud properties retrieved by the International Satellite Cloud Climatology Project (ISCCP) [Rossow and Schiffer 1999]. We use the ISCCP D1 data (in which all cloudy pixels in a grid-box are placed in one of 42 cloud optical thickness-cloud top pressure types) and compare this data to model output using an ISCCP-simulator following the approach of Webb et al. [2001].

As in the previously mentioned studies, we show output from two NCAR CAM model (Version 3) runs performed for the same period, as well as initialized and forced by the same sea surface temperature values. In one run we use the standard CAM cloud parameterizations, which we will refer to as the "CAM" result. In the second run, which we refer to as the "MMF" result, the CAM cloud parameterizations are replaced with output from the embedded cloud resolving model, as described by Khairoutdinov and Randall [2001] and Ackerman et al. [2005; this conference];

The CAM and MMF runs are independent simulations, each producing its own climate. To examine what the conventional CAM cloud parameterizations would produce for the large scale fields as simulated in the MMF run, we apply the conventional parameterizations of cloud fraction, cumulus convection, and stratiform cloud microphysical and radiative properties to the grid-cell mean temperature and humidity distributions predicted by the MMF. We will refer to these results as "CAM-like".

2. RESULTS

We begin with a comparison of outgoing top of atmosphere fluxes. Fig. 1 shows the monthly averaged outgoing longwave flux for June 1998. The upper left panel is the CERES retrieval from the TRMM satellite. This satellite is in an equatorial orbit, and observations are restricted to a band roughly 40 degrees each side of the equator. The remaining three panels show the CAM output (upper right), the MMF output (lower right), and the CAM-like output (lower left). All three simulations produce a result which is broadly similar to the observations with large amounts of outgoing longwave radiation in the subtropical regions and regions of lower outgoing flux near the equator, most notably near Central America and India. While the overall pattern is similar, all three models show lower values than the retrievals in the tropical region, especially between Central Africa and Indonesia. Examination of outgoing shortwave fluxes (not shown due to space considerations) shows this same region to have too large an outgoing shortwave flux.

Fig. 2 shows the zonal mean outgoing longwave and shortwave flux. All three models significantly overestimate the outgoing shortwave (left panel) and underestimate the outgoing longwave (right panel) in the tropics (approximately 20 to 25 degrees north or south of the equator). Fig. 3 shows that the total outgoing flux (i.e., outgoing longwave + outgoing shortwave) is overestimated in all three model configurations. This overestimate appears to be primarily due to clouds.

In the remainder of this section, we compare ISCCP cloud retrievals with ISCCP-simulated retrievals for our two model runs. Fig. 4 shows the monthly average total column cloud fraction for June 1998. In this figure, we include only those clouds with an optical depth greater than 0.3. Clouds with optical depths less than this are not likely to be detected by ISCCP. As was the case for the longwave flux, the pattern of the model output is broadly similar to the satellite-retrieved data. However, all of the models show significantly less cloud over most continental regions. This is consistent with a systematically lower cloud fraction predicted by the models for the SGP region as was diagnosed in the earlier study by Ovtchinnikov et al. [2004] using ground-based ARM observations. In oceanic areas with persistent low clouds, such as occur off the coast of California, the model runs also shows less cloudiness, especially in the MMF run. Fig. 5 shows the zonal averaged cloud fraction, with and without the optical depth threshold of 0.3. This figure shows a strong underestimate in the model cloud fraction relative to the retrieval data in the subtropical regions regardless of threshold. Further, the right panel shows that the MMF CAM-like run is producing large amounts of thin cloud compared to the CAM run. Fig 3 of Ackerman et al. [2005; this conference] show that this increase in (high and thin) cloud cover is associated with high levels of relative humidity in the upper troposphere in the MMF run.

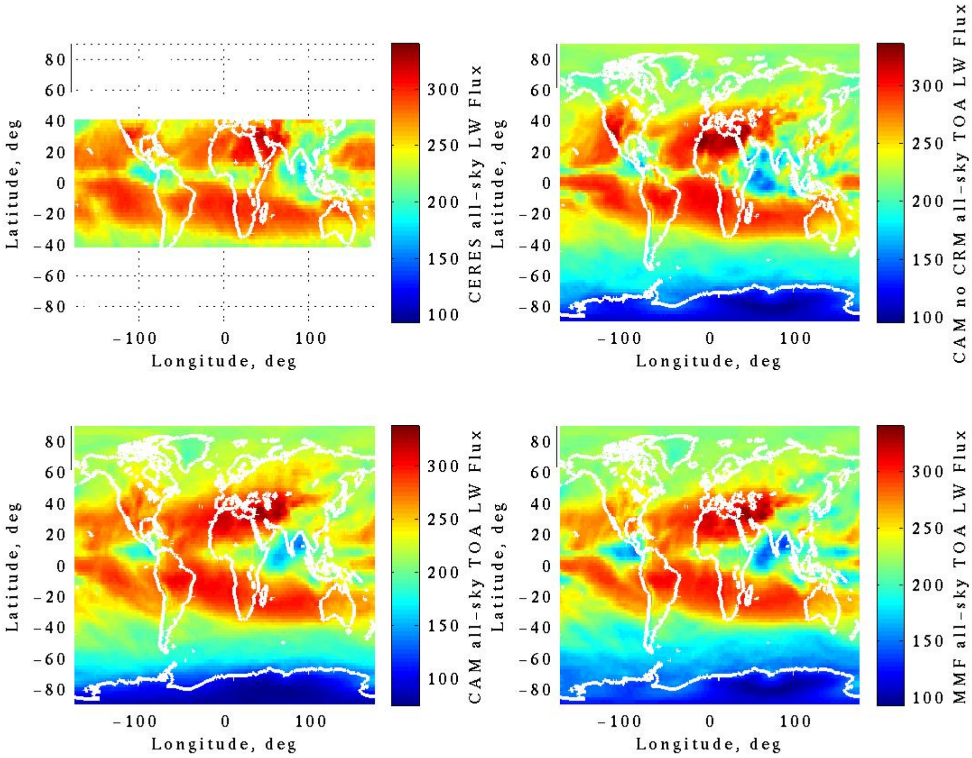

Figure 1. Top of Atmosphere Outgoing Longwave Flux for June 1998. (upper left panel) CERES (ES9) retrievals, (upper right panel) CAM simulation, (lower right panel) MMF simulation, (lower left panel) CAM-like result.

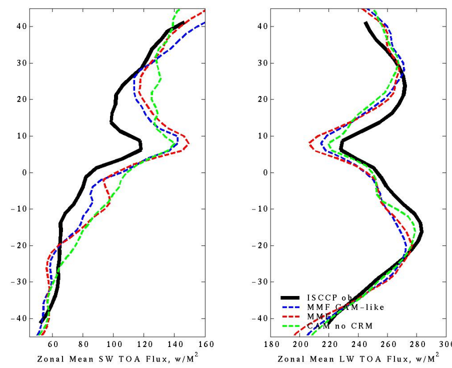

Figure 2. Zonal mean outgoing flux for June 1998. The vertical axis is latitude. (left) longwave, (right) shortwave.

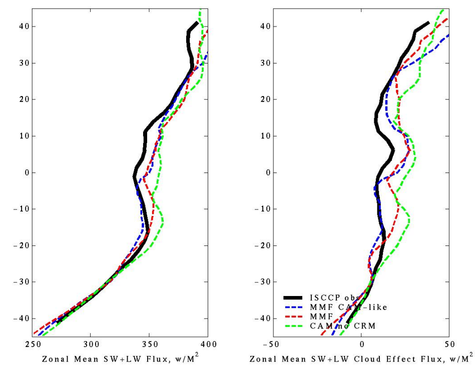

Figure 3. Zonal means of (left) total outgoing flux (shortwave + longwave) and (right) net cloud effect (mean all sky – mean clear sky) for June 1998.

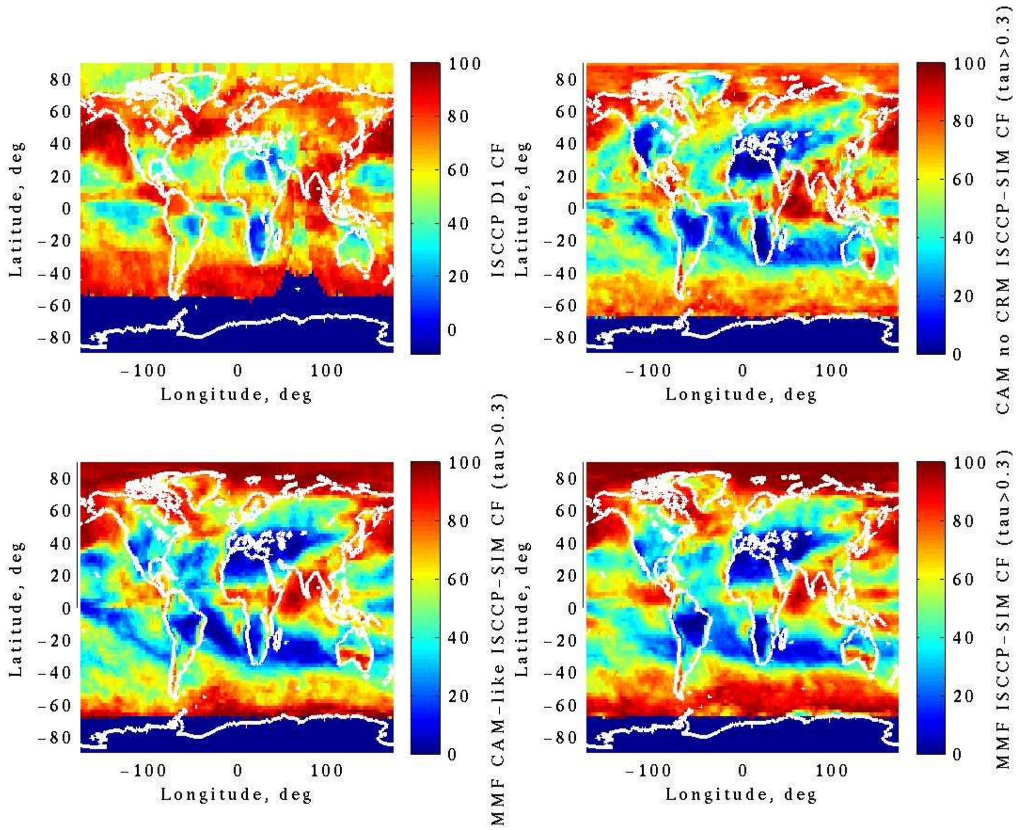

Figure 4. Monthly average total column cloud fraction for June 1998. (upper left panel) ISCCP D1 data, (upper right panel) CAM simulation, (lower right panel) MMF simulation, (lower left panel) CAM-like result.

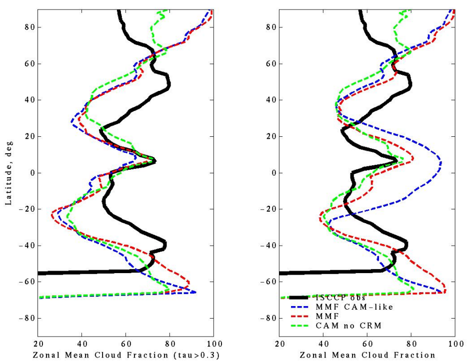

Figure 5. Zonal mean cloud fraction, (left) clouds optical depth > 0.3, (right) all clouds.

Next, we examine the full ISCCP histogram of cloud occurrence as a function of cloud top pressure and cloud optical thickness for three regions in the Pacific which have been the focus of previous studies. First, following Webb et al. [2001], fig. 6 shows the frequency of cloud occurrence for the California Stratocumulus region, defined as the region between 220^o -250^o East longitude and 15^o-35^o North latitude. As in previous figures the upper left panel is the satellite-retrieval, the upper right panel is the CAM output, the lower right panel for is the MMF run, and the lower left panel is the CAM-like result obtained by applying the standard CAM cloud diagnostics to the grid-mean MMF output. The same scale is used in each panel. Note, a dark-red color indicates an absolute occurrence of 10% OR greater, not just 10%.

The total column cloud fraction for each model configuration is listed in the panel title. In fig. 6, we see that all three model configurations underestimate the total cloud amount, as one would anticipate from the results in figs. 4 and 5. The model ISCCP-simulated clouds also appear to be more optically thick and lower than the ISCCP-retrievals. Similar to the results shown here, Webb et al. [2001] found that the Hadley Centre (HADAM4), ECMWF (Cycle 16r2), and the LMD (LMDZ 2.0) models produced cloud which were lower than the ISCCP-retrievals indicates. The ISCCP cloud top pressures seem to be low relative to field measurements and must be viewed with some skepticism.

Our simulation results differ from those presented by Webb et al., however, in that our simulations appear to be producing clouds which are optically thicker than ISCCP, whereas Webb et al. found them to be optically thinner in the models they evaluated.

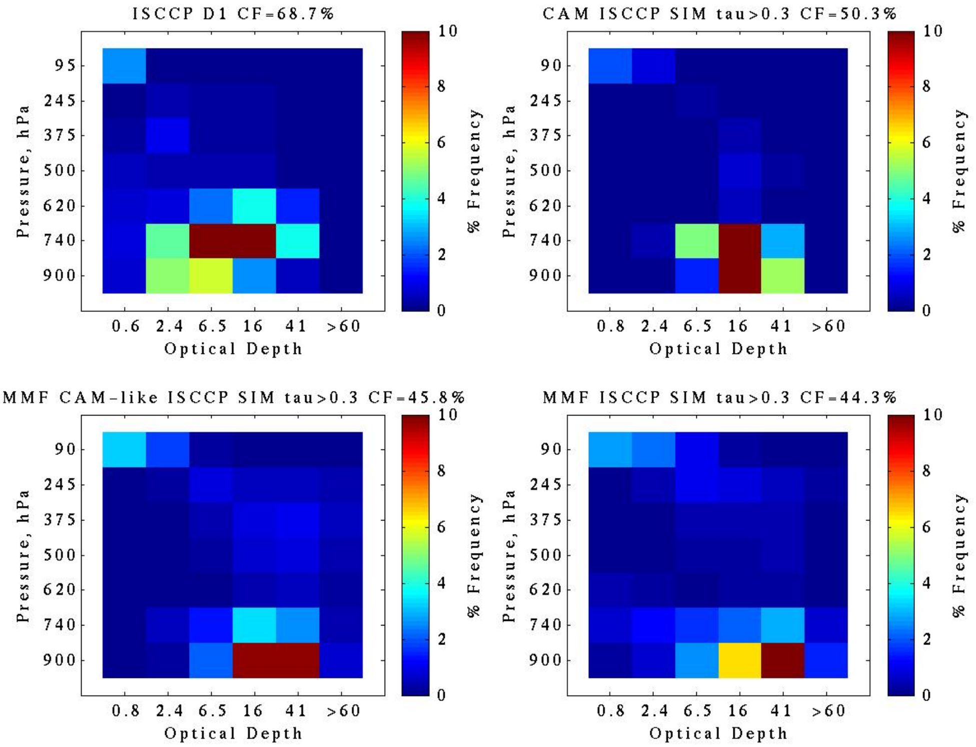

Figure 6. Histogram of cloud occurrence by cloud top pressure and optical depth for California Stratus.

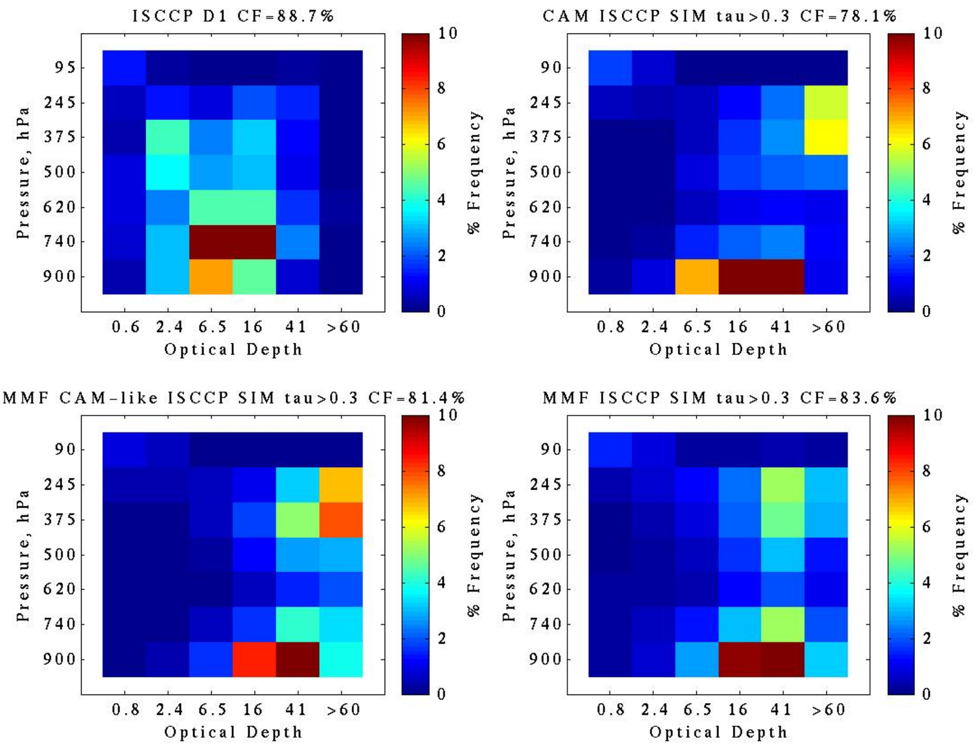

Figure 7. Same as Fig. 6 except for Northern Pacific Ocean.

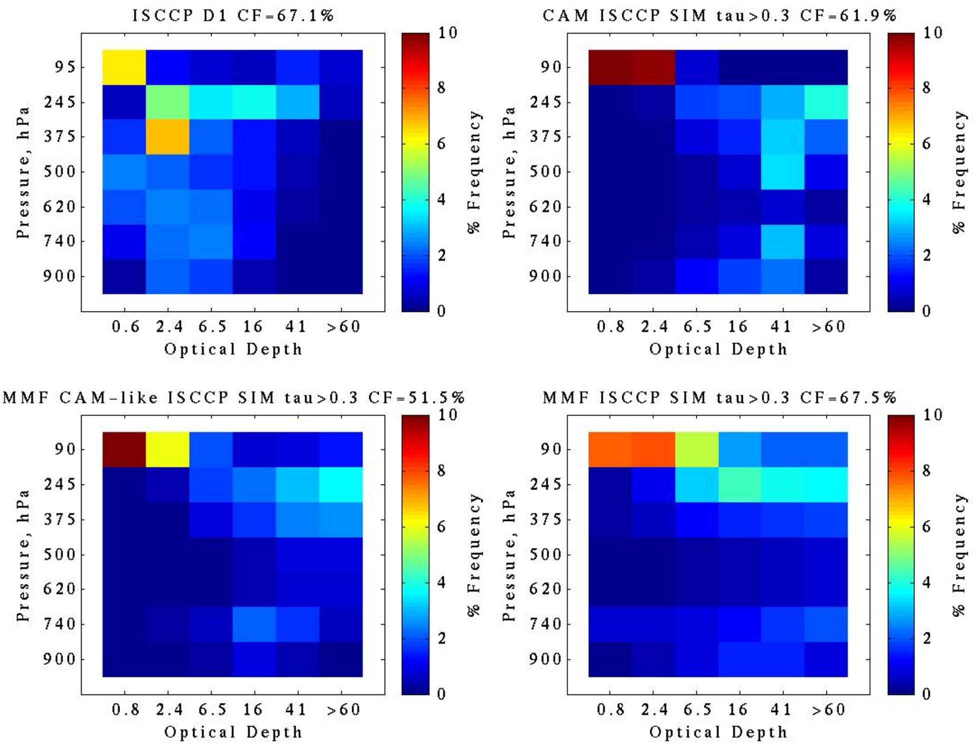

Figure 8. Same as Fig. 6 except for Tropical Western Pacific.

Turning our attention to the North Pacific region (defined here as the region between 160^o -220^o East longitude and 30^o-60^o North latitude), fig. 7 shows that the models and retrievals have similar total column cloud fractions. However, the distribution of these clouds between the retrieval and models is quite different. Both the CAM and the MMF run produce a bimodal distribution with one maximum suggesting the presence of a large number of high clouds with large optical depths and a second peak suggesting the presence of a large number of boundary layer cloud with moderate to large optical depths. These results are very similar to those presented by Norris et al. [2001], who compared summertime cloudiness over this same region for July 1986 using the NCAR CCM3 model. Norris et al. further composited their model results and ISCCP D1 data (via ECMWF analysis) according to the large scale vertical ascent at 500 hPa. They found two distinct cloud modes; one mode had a large scale ascent greater than 40 mb/day, where the model produced extensive frontal clouds which appear too high and too optically thick. The second mode occurred with 500 hPa ascents of less than –40 mb/day, where the model appeared to produce clouds which were too optically thick but too few, with the net result that the model underestimated the shortwave cloud effect in the low-cloud mode.

Norris et al. suggested that the overproduction of cloud in the ascent regime was likely due to the models inability to resolve the vertical motion. Nonetheless, this same result is observed here in the MMF run, using a 2D cloud resolving model with 4 km resolution.

Lastly, fig. 8 shows the monthly mean ISCCP and model ISCCP-simulator data for the Tropical Western Pacific, defined here as the region between 130^o - 190^o East longitude and 10^o North to 10^o South latitude. In this region, the CAM and the MMF simulations both produce total cloud fractions which are comparable to the ISCCP-retrievals. However, the CAM result has much more mid-level cloudiness and too few high clouds with moderate optical depths. The MMF run, on the other hand, has very-little mid-level cloudiness, and is dominated by high clouds at all optical depth ranges. For all model configurations, what low-level clouds are present appear more optically thick than the ISCCP-retrievals.

3. CONCLUSIONS

The results shown here are very preliminary. Nonetheless some conclusions can be reached even at this early stage of the analysis. First, the results we have examined thus far suggest that both the CAM and MMF models have too much cloud forcing (fig. 3) and yet are producing too little total cloud (fig. 5). As one might expect, this means that the clouds that are being produced by the model are too (optically) thick, which is confirmed in the three regional cloud distributions examined here (figs. 6-8). This trend has been reported for other climate models as well, including the GFDL model (personal communication Steve Klein).

Secondly, in almost every case we have examined so far, the CAM and MMF solutions more closely resemble each other than the observational datasets. Compared to the ISCCP retrievals, the model seems to predict boundary layer clouds which are optically thicker and lower in the atmosphere in all three oceanic regions examined in detail. It is not clear whether this is a true problem rather than a deficiency of the ISCCP-retrievals or ISCCP-simulator. We plan to examine this issue in more detail using U.S. Department of Energy Atmospheric Radiation Measurement program and other satellite datasets. In particular, we plan to examine cloud-top height from the NASA Multi-angle Imaging Spectro-Radiometer (MISR) which uses a stereo-imaging technique rather than an IR-based technique to determine cloud height (as used by ISCCP). MISR also views the Earth with a higher spatial resolution (~275 m at nadir) than the sensors used in connection with ISCCP and may provide insight on the optical depth distribution, as well.

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4. REFERENCES

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