Response to RC #1

The authors would like to thank the anonymous referee for providing comments on this manuscript. Our responses are in blue, just below the referee comments.

This is an exceptionally well-written manuscript which introduces a new version of the CFMIP Observational Simulator Package (COSP). The manuscript clearly described the design of COSPv2 and its software improvements compared to the COSPv1. The reorganization of the COSP architecture allows for increased efficiency, helps to make the diagnostics consistent with radiation calculations of the host model more easily, and makes it easier to add new simulators and diagnostics. Given the wide use of the COSP in the global climate modeling community, this article should be able to provide helpful guidance to users.

Comment 1: It will be better if the author can quantitatively estimate the improved efficiency of the new COSP version compared with the old one in section 3.

In the text, we refer to "modest" increases in performance as a result of removing memory copies and redundant calculations in COSP2. Unfortunately, it's not feasible to compare COSP1 and COSP2 timing results on such a granular level, since the codes are organized very differently. With that being said, we're confident to say that computing a field once instead of three times is computationally more efficient.

From our experiences running COSP2 inline with a GCM (CAM), we observe roughly a ~65% speedup in COSP2 runtime when compared to COSP1. However, since we only tested this implementation in one model, we are reluctant to say that this performance increase is robust across a range of architectures and testing COSP2 across a range of models is beyond the scope of this work.

Comment 2a: Since COSPv1.4.1 is the production version for CFMIP3 and CMIP6, will the new COSPv2 diagnostics be different?

The diagnostics from COSPv1.4.1 are scientifically equivalent to the diagnostics produced by COSPv2.

Comment 2b: It was also mentioned in the summary that there is an optional layer in COSPv2 to provide compatibility with COSPv1.4.1. Is this option recommended for recent efforts of model evaluation?

Provided with COSP2 is an interface designed to be a "drop-in" replacement for COSP1.4.1. This is intended for modeling centers to implement COSP2 in their models without having to make code modifications. However, if you are new to using COSP for model validation/evaluation, we suggest starting directly with COSP2, as the 1.4.1 interface is more or less intended for legacy COSP1 users to use as a "bridge" between COSP1 and COSP2.

Comment 3: Page 3, Line 10, "ISSCP" should be "ISCCP".

Changed in manuscript.

Response to RC #2

The authors would like to thank Bastian Kern for providing comments on this manuscript. Our responses are in blue, just below the referee comments.

The manuscript describes version 2 of the CFMIP Observational Simulator Package (COSP). Especially enhancements in the software structure to disentangle the diag-nostic modules, the coupling interface and the host model.

The manuscript is well written and easy to follow. The developments of the software to enhance modularisation is appreciated and should facilitate integration of the diagnostics in numerical models, as well as the integration of novel diagnostic modules in COSP itself. As a technical paper, describing developments of a novel version of the COSP, it fits in the scope of the journal and should be published, subject to few minor comments.

Focusing on the novel interface is a good choice and keeps the manuscript at reasonable length. I assume measurements of computational demands vary over a wide range, depending on the complexity of the simulator package, and thus would not be very beneficial. Details of COSP and on the simulator modules can be found in a previous paper on version 1, this may be stressed a bit more (yes, I know it is cited on p.2 l.14).

We added a sentence into the text guiding readers to the COSP1 paper for more information on the diagnostics available in COSP1/COSP2.

There are several acronyms of satellite platforms and sensors (especially p.2 ll.4ff.). All the references are given and the acronyms are well known (at least in parts of the community), but maybe you could include the acronyms "decryption" (in-line, table, or list of acronyms?).

Very good point. In the text (see p.2. l.5-14) we added the acronym definitions for the various instruments.

Specific comments

I have only one specific comment, the second part is more a suggestion on how to support developers integrating the COSP in their numerical models (and is a bit beyond the publication of the paper).

On p.4 l.10ff:

It seems clear to me, that for a coarse resolution general circulation model, one has to sample some kind of subcolumns, to reach a horizontal resolution compatible with the simulator modules. What, if using a high resolution model (1km or smaller)? Can columns be passed directly and *"column-scale" properties have to be aggregated to a resolution suitable for the simulators (ISCCP)? Of course, you write, "it is the host model's responsibility to generate subcolumns and map physical to optical properties consistent with model formulation". So, it should be the responsibility of the developer integrating the interface in a numerical model to provide the proper input fields, but maybe you could add some hints on that.*

Just as in previous versions, when using a high-resolution model, model-columns can (and should) be passed directly to into COSP. This was something we did not stress in the text, but should have, as it's in the COSP1 paper. We added a few sentences (see p.4 l.31) in the text explaining this.

It may be beneficial to have more details on the interface routines and the in- and output fields, which have to be used in the host model. If you do not want to bore the reader with too technical description, maybe you could think about a user's manual in the repository or as a supplement to the paper.

That leads me to an additional comment, which is not crucial for publication of the pa- per:

I also retrieved the code from github and managed to compile it and run the provided test routines. This was more or less straightforward (it took me some time, because I had to compile CMOR2 first).

However, there are some minor inconsistencies in the README(.txt) files (some changed filenames, cosp_interface_v1p5.f90 mentioned in README not available).

We've updated all of the README files throughout COSP.

It is very good, that you include examples and testing routines in the repository. With the README files and the code examples, I think, I might be able to include the interface in a numerical model. For me it is fine to have the documentation in the README files and in the code. But maybe it would be more convenient to have an overview of the interface routines and details of in- and output fields in one place. So, you may think about a small user's manual as pdf in the repository or as supplement to the paper (there seems to be one for COSP 1.3.1) also including more technical details on the interface routines. It might ease the integration of COSP in numerical models.

Technical corrections

p.1, l.20:

Please include the acronym CMIP here, as it is used later in the text.

Corrected in text.

p.2, l.16:

Please update the reference Webb et al., 2016 to Webb et al., 2017 (see also below) p.6, l.19:

Corrected in text.

Please include the section: Code availability

Added new section to text. Previously the code was described in the summary section and not in its own section.

p.7, l.18:

Please change Geosci. Model Dev. Disc. to Geosci. Model Dev.

Corrected in text.

p.8, ll.20ff.:

The final revised version of this article is published:

Webb, M. J., Andrews, T., Bodas-Salcedo, A., Bony, S., Bretherton, C. S., Chadwick, R., Chepfer, H., Douville, H., Good, P., Kay, J. E., Klein, S. A., Marchand, R., Medeiros, B., Siebesma, A. P., Skinner, C. B., Stevens, B., Tselioudis, G., Tsushima, Y., and Watanabe, M.: The Cloud Feedback Model Intercomparison Project (CFMIP) contribution to CMIP6, Geosci. Model Dev., 10, 359-384, doi:10.5194/gmd-10-359-2017, 2017.

Corrected in text.

The Cloud Feedback Model Intercomparison Project Observational Simulator Package: Version 2

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Abstract. The Cloud Feedback Model Intercomparison Project Observational Simulator Package (COSP) gathers together a collection of observation proxies or "satellite simulators" that translate model-simulated cloud properties to synthetic observations as would be obtained by a range of satellite observing systems. This paper introduces COSP 2, an evolution focusing on more explicit and consistent separation between host model, coupling infrastructure, and individual observing proxies. Revisions also enhance flexibility by allowing for model-specific representation of sub-grid scale cloudiness, provide greater clarity by clearly separating tasks, support greater use of shared code and data including shared inputs across simulators, and follow more uniform software standards to simplify implementation across a wide range of platforms. The complete package including a testing suite is freely available.

1 A common language for clouds

The most recent revision to the protocols for the Coupled Model Intercomparision Project (CMIP, see Eyring et al., 2016) includes a set of four experiments for the Diagnosis, Evaluation, and Characterization of Klima (Climate). As the name implies one intent of these experiments is to evaluate model fields against observations, especially in simulations in which sea-surface temperatures are prescribed to follow historical observations. Such an evaluation is particularly important for clouds since these are a primary control on the Earth's radiation budget.

Comment [RP1]: RC2: TC1

But such a comparison is not straightforward. The most comprehensive views of clouds are provided by satellite remote sensing observations. Comparisons to these observations are hampered by the large discrepancy between the model representation, as profiles of bulk macro- and microphysical cloud properties, and the information available in the observations which may, for example, be sensitive only to column-integrated properties or be subject to sampling issues caused by limited measurement sensitivity or signal attenuation. To make comparisons more robust the Cloud Feedback

Model Intercomparison Project (CFMIP, https://www.earthsystemcog.org/projects/cfmip/) has led efforts to apply observation proxies or "instrument simulators" to climate model simulations made in support of the (CMIP) and CFMIP.

Comment [DJS2]: RC2: TC1

Instrument simulators are diagnostic tools that map the model state into synthetic observations. The ISCCP (International Satellite Cloud Climatology Project) simulator (Klein and Jakob, 1999; Webb et al., 2001), for example, maps a specific representation of cloudiness to aggregated estimates of cloud-top pressure and optical thickness as would be provided by a particular satellite observing program, accounting for sampling artifacts such as the masking of high clouds by low clouds and providing statistical summaries computed in precise analogy to the observational datasets. Subsequent efforts have produced simulators for other passive instruments include MISR (the Multi-angle Imaging SpectroRadiometer: Marchand and Ackerman, 2010 describe this simulator) and MODIS (Moderate Resolution Imaging Spectroradiometer; Pincus et al., 2012) and for the active platforms CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation; Chepfer et al., 2008) and CloudSat (Haynes et al., 2007).

Comment [DJS3]: RC2: Defined acronyms inline.

Some climate models participating in the initial phase of CFMIP provided results from the ISCCP simulator. To ease the way for adoption of multiple simulators CFMIP organized the development of the Observation Simulator Package (COSP; Bodas-Salcedo et al., 2011). A complete list of the instrument simulator diagnostics available in COSP1 and COSP2, can be found in Bodas-Salcedo et al., 2011. The initial implementation, hereafter COSP1, supported more widespread and thorough diagnostic output requested as part of the second phase of CFMIP associated with CMIP5 (Taylor et al., 2012). Similar but somewhat broader requests are made as part of CFMIP3 (Webb et al., 2017) and CMIP6 (Eyring et al., 2016).

Comment [DJS4]: RC2: Added reference to COSP1 paper.

Comment [DJS5]: RC2: TC #2

The view of model clouds enabled by COSP has enabled important advances. Results from COSP have been useful in identifying biases in the distribution of model-simulated clouds within individual models (Kay et al., 2012; Nam and Quaas, 2012), across the collection of models participating in coordinated experiments (Nam et al., 2012), and across model generations (Klein et al., 2013). Combined results from active and passive sensors have highlighted tensions between process fidelity and the ability of models to reproduce historical warming (Suzuki et al., 2013), while synthetic observations from the CALIPSO simulator have demonstrated how changes in vertical structure may provide the most robust measure of climate change on clouds (Chepfer et al., 2014). Results from the ISCCP simulator have been used to estimate cloud feedbacks and adjustments (Zelinka et al., 2013) through the use of radiative kernels (Zelinka et al., 2012).

COSP1 simplified the implementation of multiple simulators within climate models but treated many components, especially the underlying simulators contributed by a range of collaborators, as inviolate. After most of a decade this approach was showing its age, as we detail in the next section. Section 3 describes details the conceptual model underlying a new implementation of COSP and a design that addresses these issues. Section 4 provides some details regarding implementation. Section 5 contains a summary of COSP2 and provides information about obtaining and building the software.

2 Barriers to consistency, efficiency, and extensibility

Especially in the context of cloud feedbacks, diagnostic information about clouds is most helpful when it is consistent with the radiative fluxes with which the model state co-evolves. COSP2 primarily seeks to address a range of difficulties that arose in maintaining this consistency in COSP1 as the package became used in an increasingly wide range of models. For example, as COSP1 was implemented in a handful of models, it became clear that differing cloud microphysics across models would often require substantial code changes to maintain consistency between COSP1 and the host model.

The satellite observations COSP emulates are derived from individual observations made on spatial scales of order kilometres (for active sensors, tens of meters) and statistically summarized at ~100 km scales commensurate with model predictions and aggregated observational data streams. To represent this scale-bridging the ISSCP simulator introduced the idea of subcolumns – discrete, homogenous samples constructed so that a large ensemble reproduces the profile of bulk cloud properties within a model grid column and any overlap assumptions made about vertical structure. COSP1 inherited the specific methods for generating subcolumns from the ISCCP simulator including a fixed set of inputs (convective and stratiform cloud fractions, visible-wavelength optical thickness for ice and liquid, mid-infrared emissivity) describing the distribution of cloudiness. Host models for which this description wasn't appropriate, for example a model in which more than one category of ice was considered in the radiation calculation (Kay et al., 2012), had to make extensive changes to COSP if the diagnostics were to be informative.

The fixed set of inputs limited models' ability to remain consistent with the radiation calculations. Many global models now use the Monte Carlo Independent Column Approximation (Pincus et al., 2003) to represent subgrid-scale cloud variability in radiation calculations. Inspired by the ISCCP simulator, McICA randomly assigns subcolumns to spectral intervals, replacing a two-dimensional integral over cloud state and wavelength with a Monte Carlo sample. Models using McICA for radiation calculations must implement methods for generating subcolumns, and the inability to share these calculations between radiation and diagnostic calculations was neither efficient nor self-consistent.

COSP1 was effective in packaging together a set of simulators developed independently and without coordination but this had its costs. COSP1 contains three independent routines for computing joint histograms, for example. Simulators required inputs, some closely related (relative and specific humidity, for example) and produced arbitrary mixes of outputs at the column and subcolumn scale, making multi-sensor analyses difficult.

3 A conceptual model and the resulting design

Though the division was not always apparent in COSP1, all satellite simulators perform four discrete tasks within each column:

1. Sampling of cloud properties to create homogenous subcolumns
2. Mapping of cloud physical properties (e.g. condensate concentrations and particle sizes) to relevant optical properties (optical depth, single scattering albedo, radar reflectivity, etc.)
3. Synthetic retrievals of individual observations (e.g. profiles of attenuated lidar backscatter or cloud-top pressure/column optical thickness pairs)
4. Statistical summarization (e.g. appropriate averaging or computation of histograms)

The first two steps require detailed knowledge as to how a host model represents cloud physical properties; the last two steps mimic the observational process. This first step is not invoked for models with high spatial resolution, as we describe more fully below.

The design of COSP2 reflects this conceptual model. The primary inputs to COSP2 are subcolumns of optical properties (i.e. the result of step 2 above), and it is the host model's responsibility to generate subcolumns and map physical to optical properties consistent with model formulation. This choice allows models to leverage infrastructure for radiation codes using McICA, making radiation and diagnostic calculations consistent with one another. COSP2 also requires as input a small set of column-scale quantities including surface properties and thermodynamic profiles. These are used, for example, by the ISCCP simulator to mimic the retrieval of cloud-top pressure from infrared brightness temperature. In COSP 2 the instrument simulator components have no dependencies on the host model including the underlying spatial scale.

Comment [DJS6]: RC1: Changed from ISSCP to ISCCP

Comment [DJS7]: RC2: This should have been in there from the beginning.

Simulators within COSP2 are explicitly divided into two components (Figure 1). The subcolumn simulators, shown as lenses with colors representing the sensor being mimicked, take a range of column inputs (ovals) and subcolumn inputs (circles, with stacks representing multiple samples) and produce synthetic retrievals on the subcolumn scale, shown as stacks of squares. Column simulators, drawn as funnels, reduce these subcolumn synthetic retrievals to statistical summaries (hexagons). Column simulators may summarize information from a single observing system, as indicated by shared colors. Other column simulators may synthesize subcolumn retrievals from multiple sources, as suggested by the black funnel.

This division mirrors the processing of satellite observations by space agencies. At NASA, for example, these processing steps correspond to the production of Level 2 and Level 3 data, respectively. Implementation required the restructuring of many of the component simulators from COSP1. This allowed for modest code simplification by using common routines to make statistical calculations.

Models with spatial resolution roughly commensurate with individual satellite observations might apply the subcolumn simulators directly to model columns, then report statistics at some reduced spatial resolution. The scale separation is also illustrated by COSP implementations in multi-scale modeling frameworks (e.g. Marchand and Ackerman, 2010), in which the subcolumn simulators are applied to individual high-resolution cloud-scale columns and statistical summaries are reported on the low-resolution global grid.

Separating the computation of optical properties from the description of individual simulators allows for modestly increased efficiency because inputs shared across simulators, for example the 0.67 µm optical depth required by the ISCCP, MODIS, and MISR simulators, do not need to be recomputed or copied. The division also allowed us to make some simulators more generic. In particular, the CloudSat simulator used by COSP is based on the Quickbeam package (Haynes et al., 2007). Quickbeam is quite generic with respect to radar frequency and the location of a sensor but this flexibility was lost in COSP1. COSP2 exposes the generic nature of the underlying subcolumn lidar and radar simulators and introduces configuration variables that provide instrument-specific information to the subcolumn calculation.

4 Implementation

4.1 Interface and control flow

The simplest call to COSP now makes use of three Fortran derived types representing the column and subcolumn inputs and the desired outputs. The components of these types are `PUBLIC` (that is, accessible by user code) and are, with few exceptions, pointers to appropriately-dimensioned arrays. COSP determines which subcolumn and column simulators are to be run based on the allocation status of these arrays, as described below. All required subcolumn simulators are invoked, followed by all column simulators. Optional arguments can be provided to restrict work to a subset of the provided domain (set of columns) to limit memory use.

COSP2 has no explicit way of controlling which simulators are to be invoked. Instead, column simulators are invoked if space for one or more outputs is allocated – that is, if one or more of output variables (themselves components of the output derived type) is associated with array memory of the correct shape. The set of column simulators determines which subcolumn simulators are to be run. Not providing the inputs to these subcolumn simulators is an error.

The use of derived types allows COSP's capabilities to be expanded incrementally. Adding a new simulator, for example, requires adding new components to the derived type representing inputs and outputs but codes referring to existing components of those types need not be changed. This functionality is already in use – the output fields available in COSP2 extend COSP1's capabilities to include the joint histograms of optical thickness and effective radius requested as part of CFMIP 3.

4.2 Enhancing portability

COSP2 also includes a range of changes aimed at providing more robust, portable, and/or flexible code, many of which were suggested by one or more modeling centers using COSP. These include

1. Robust error checking, implemented as a single routine which validates array shapes and physical bounds on values.
2. Error reporting standardized to return strings, where non-null values indicates failure.
3. Parameterized precision for all `REAL` variables `(KIND=wp)` where the value of `wp` can be set in a single location to correspond to 32 or 64 byte real values.
4. Explicit `INTENT` for all subroutine arguments.
5. Standardization of vertical ordering for arrays in which the top of the domain is index 1.
6. Conformance with Fortran 2003 standards.

COSP2 must also be explicitly initialized before use. The initialization routine calls routines for each simulator in turn. This allows for more flexible updating of ancillary data such as lookup tables.

5. Summary

Version 2 of the CFMIP Observational Simulator Package, COSP2, represents a substantial revision of the COSP platform. The primary goal was to allow a more flexible and representation of clouds, so that the diagnostics produced by COSP can be fully consistent with radiation calculations made by the host model, even in the face of increasingly complex descriptions of cloud macro- and microphysical properties. Consistency requires that host models generate subcolumns and compute optical properties, so that the interface to the host model is entirely revised relative to COSP1.

As an example and a bridge to past efforts, COSP2 includes an optional layer that provides compatibility with COSP 1.4.1, accepting the same inputs and implementing sampling and optical property calculations in the same way. COSP2, either via this COSP 1.4.1. interface or via mode direct implementations, may be used to provide CMIP6/CFMIP3 output.

Simulators in COSP2 are divided into those that compute subcolumn (pixel) scale synthetic retrievals and those that compute column (grid) scale statistical summaries. This distinction, and the use of extensible derived types in the interface to the host model, are designed to make it easier to extend COSP's capabilities by adding new simulators at either scale, including analysis making use of observations from multiple sources.

6. Code availability

Comment [DJS8]: RC2: TC#3

The source code for COSP2, along with downloading and installation instructions, are available in a GitHub repository (https://github.com/CFMIP/COSPv2.0). This manuscript is based on commit 04df31a, which is also available at https://doi.org/10.5281/zenodo.1040332. Previous versions of COSP (e.g. v1.3.1, v1.3.2, v1.4.0 and v1.4.1) are available in a parallel repository (https://github.com/CFMIP/COSPv1). But these versions have reached the end of life, and COSP2 provides the basis for future development. Models updating or implementing COSP, or developers wishing to add new capabilities, are best served by starting with COSP2.

Acknowledgements

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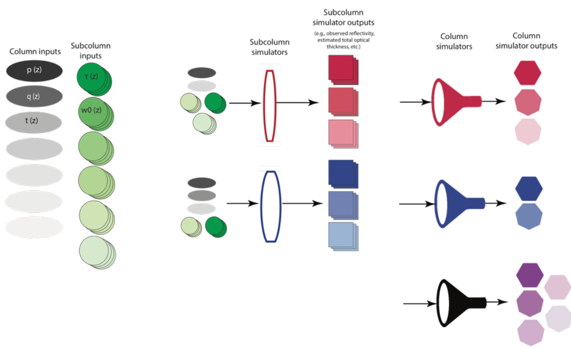

Figure 1. Organizational view of COSP2. Within each grid cell host models provide a range physical inputs at the grid scale (grey ovals, one profile per variable) and optical properties at the cloud scale (green circles, Nsubcol profiles per variable). Individual subcolumn simulators (lens shapes, colored to indicate simulator types) produce Nsubcol synthetic retrievals (squares) which are then summarized by aggregation routines (funnel shapes) taking input from one or more subcolum simulators.

References

Bodas-Salcedo, A., Webb, M. J., Bony, S., Chepfer, H., Dufrense, J. L., Klein, S. A., Zhang, Y., Marchand, R., Haynes, J.

M., Pincus, R. and John, V.: COSP: Satellite simulation software for model assessment, Bull. Amer. Meteor. Soc., 92(8), 1023–1043, doi:10.1175/2011BAMS2856.1, 2011.

Chepfer, H., Bony, S., Winker, D., Chiriaco, M., Dufresne, J.-L. and Seze, G.: Use of CALIPSO lidar observations to evaluate the cloudiness simulated by a climate model, Geophys. Res. Lett., 35(15), doi:10.1029/2008GL034207, 2008.

Chepfer, H., Noel, V., Winker, D. and Chiriaco, M.: Where and when will we observe cloud changes due to climate warming? Geophys. Res. Lett., 41(23), 8387–8395, doi:10.1002/2014GL061792, 2014.

Eyring, V., Bony, S., Meehl, G. A., Senior, C. A., Stevens, B., Stouffer, R. J. and Taylor, K. E.: Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6) experimental design and organization, Geosci. Model Dev., 9(5), 1937–1958, doi:10.5194/gmd-9-1937-2016, 2016.

Haynes, J. M., Marchand, R., Luo, Z., Bodas-Salcedo, A. and Stephens, G. L.: A multipurpose radar simulation package: QuickBeam, Bull. Amer. Meteor. Soc., 88(11), 1723+, doi:10.1175/BAMS-88-11-1723, 2007.

Kay, J. E., Hillman, B. R., Klein, S. A., Zhang, Y., Medeiros, B. P., Pincus, R., Gettelman, A., Eaton, B., Boyle, J., Marchand, R. and Ackerman, T. P.: Exposing global cloud biases in the Community Atmosphere Model (CAM) using satellite observations and their corresponding instrument simulators, J. Climate, 25, 5190–5207, doi:10.1175/JCLI-D-11-00469.1, 2012.

Klein, S. A. and Jakob, C.: Validation and sensitivities of frontal clouds simulated by the ECMWF model, Mon. Wea. Rev., 127, 2514–2531, doi:10.1175/1520-0493(1999)127<2514:VASOFC>2.0.CO;2, 1999.

Klein, S. A., Zhang, Y., Zelinka, M. D., Pincus, R., Boyle, J. and Gleckler, P. J.: Are climate model simulations of clouds improving? An evaluation using the ISCCP simulator, J. Geophys. Res., 118(3), 1329–1342, doi:10.1002/jgrd.50141, 2013.

Marchand, R. and Ackerman, T. P.: An Analysis of Cloud Cover in Multiscale Modeling Framework Global Climate Model Simulations using 4 and 1 km horizontal grids, J. Geophys. Res., 115, D16207, doi:10.1029/2009JD013423, 2010.

Nam, C. C. W. and Quaas, J.: Evaluation of clouds and precipitation in the ECHAM5 general circulation model using CALIPSO and CloudSat satellite data, J. Climate, doi:10.1175/JCLI-D-11-00347.1, 2012.

Nam, C., Bony, S., Dufresne, J.-L. and Chepfer, H.: The “too few, too bright” tropical low-cloud problem in CMIP5 models, Geophys. Res. Lett., 39(21), L21801, doi:10.1029/2012GL053421, 2012.

Pincus, R., Barker, H. W. and Morcrette, J.-J.: A fast, flexible, approximate technique for computing radiative transfer in inhomogeneous cloud fields, J. Geophys. Res., 108, 4376, doi:10.1029/2002JD003322, 2003.

Pincus, R., Platnick, S., Ackerman, S. A., Hemler, R. S. and Hofmann, R. J. P.: Reconciling simulated and observed views of clouds: MODIS, ISCCP, and the limits of instrument simulators, J. Climate, 25, 4699–4720, doi:10.1175/JCLI-D-11-00267.1, 2012.

Suzuki, K., Golaz, J.-C. and Stephens, G. L.: Evaluating cloud tuning in a climate model with satellite observations, Geophys. Res. Lett., 40(6), 4464–4468, doi:10.1002/grl.50874, 2013.

Taylor, K. E., Stouffer, R. J. and Meehl, G. A.: An Overview of CMIP5 and the Experiment Design, Bull. Amer. Meteor. Soc., 93(4), 485–498, doi:10.1175/BAMS-D-11-00094.1, 2012.

Webb, M. J., Andrews, T., Bodas-Salcedo, A., Bony, S., Bretherton, C. S., Chadwick, R., Chepfer, H., Douville, H., Good, P., Kay, J. E., Klein, S. A., Marchand, R., Medeiros, B., Siebesma, A. P., Skinner, C. B., Stevens, B., Tselioudis, G., Tsushima, Y. and Watanabe, M.: The Cloud Feedback Model Intercomparison Project (CFMIP) contribution to CMIP6, Geosci. Model Dev., 10, 359-384, doi:10.5194/gmd-10-359-2017, 2017.

Webb, M. J., Senior, C., Bony, S. and Morcrette, J.-J.: Combining ERBE and ISCCP data to assess clouds in the Hadley Centre, ECMWF and LMD atmospheric climate models, Climate Dyn., 17(12), 905–922, doi:10.1007/s003820100157, 2001.

Zelinka, M. D., Klein, S. A. and Hartmann, D. L.: Computing and Partitioning Cloud Feedbacks Using Cloud Property Histograms. Part I: Cloud Radiative Kernels, J. Climate, 25(11), 3715–3735, doi:10.1175/JCLI-D-11-00248.1, 2012.

Zelinka, M. D., Klein, S. A., Taylor, K. E., Andrews, T., Webb, M. J., Gregory, J. M. and Forster, P. M.: Contributions of Different Cloud Types to Feedbacks and Rapid Adjustments in CMIP5, J. Climate, 26(14), 5007–5027, doi:10.1175/JCLI-D-12-00555.1, 2013.