Using Satellite Observations of Cloud Vertical Distribution to Improve Global Model Estimates of Cloud Radiative Effect on Key Tropospheric Oxidants

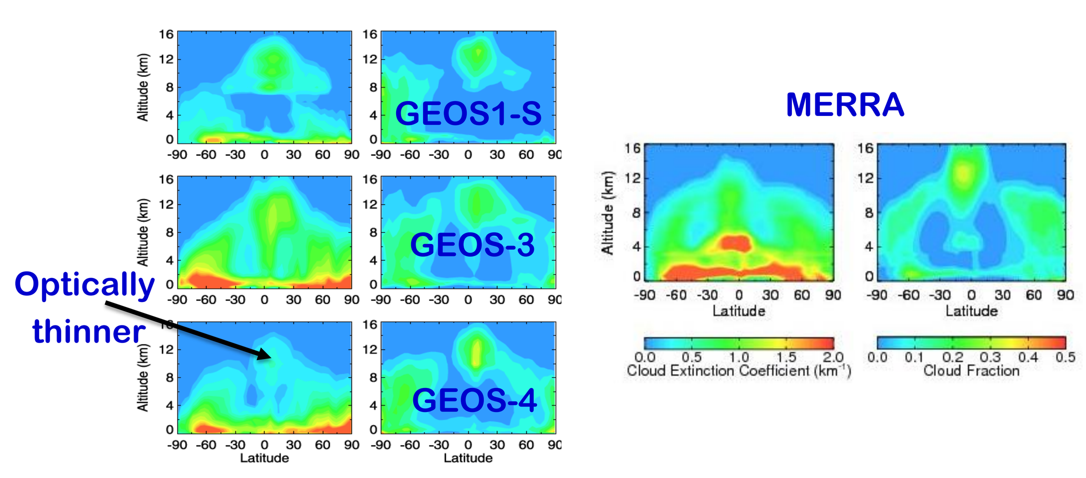
Hongyu Liu[1], James Crawford[2], Seung-Hee Ham[3], Bo Zhang[1], Seiji Kato[2], Apostolos Voulgarakis[4], Gao Chen[2], Duncan Fairlie[2], Bryan Duncan[5], and Robert Yantosca[6]

[1]National Institute of Aerospace, Hampton, VA [2]NASA Langley Research Center, Hampton, VA [3]SSAI, Hampton, VA
[4]Imperial College London, UK [5]NASA Goddard Space Flight Center, Greenbelt, MD [6]Harvard University, Cambridge, MA

Introduction

- Clouds directly affect tropospheric photochemistry through modification of solar radiation that determines photolysis frequencies. This effect is an important component of global tropospheric chemistry-climate interaction, and its understanding is thus essential for predicting the feedback of climate change on tropospheric chemistry.
- Cloud vertical distributions and optical depths in the meteorological data sets used to drive tropospheric chemistry simulations often vary from model to model, contributing substantially to intermodel discrepancies in key tropospheric oxidants, especially hydroxyl radical (OH), which largely defines the oxidizing capacity of the atmosphere.
- Objectives: (1). To evaluate GEOS-Chem/MERRA model clouds and their vertical distribution with A-Train satellite observations. (2). To quantify the impact of model biases in cloud optical depths and spatial distributions on the simulated key tropospheric oxidants.

Large Differences in Cloud Distribution Among Models



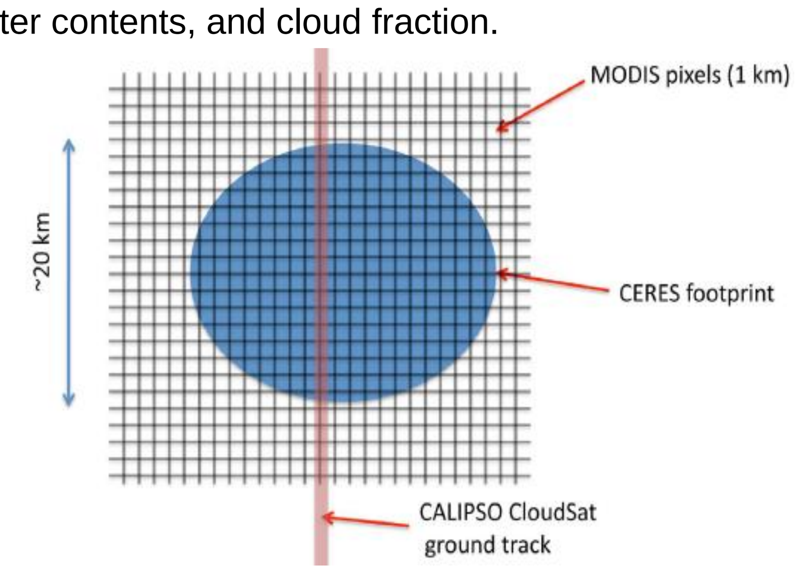
Cloud Ext. Coefficient Cloud Fraction (June)

- **Radiative impact of clouds on global photolysis frequencies and OH is more sensitive to the vertical distribution of clouds than to the magnitude of column CODs [Liu, H. et al., JGR 2006, 2009].**

C3M – a Merged Cloud Data Product @ NASA Langley

Merged cloud vertical profiles from multiple A-Train satellite (CALIPSO, CloudSat, CERES, and MODIS) observations (Kato et al., JGR 2010, 2011)

- Collocation of 333-m CALIPSO and 1-km CloudSat mask profiles to 1-km MODIS pixel.
- The merged cloud profiles are further collocated & grouped within a 20-km CERES footprint.
- 3-D structures of cloud boundary, cloud extinction, ice/liquid water contents, and cloud fraction.



GEOS-Chem Global CTM (v9.2, http://geos-chem.org/)

- Driven by the MERRA reanalysis from NASA GMAO
- Horizontal resolution 2°×2.5°, 47 levels in vertical
- Ozone-NO_x-CO-VOC coupled to aerosol (sulfate-nitrate-ammonium and carbonaceous) chemistry [Bey et al., JGR 2001; Park et al., JGR 2004]
- Photolysis rate calculation: Fast-J [Wild et al., JAC 2000] with MERRA surface albedo, 3-D cloud optical depth, and cloud fraction
- Simulation period: Sept. 2007 – Dec. 2008

Model Representations of Cloud Vertical Coherence

- Linear Assumption

$\tau_c' = \tau_c \cdot f$

grid-scale OD in-cloud OD cloud fraction

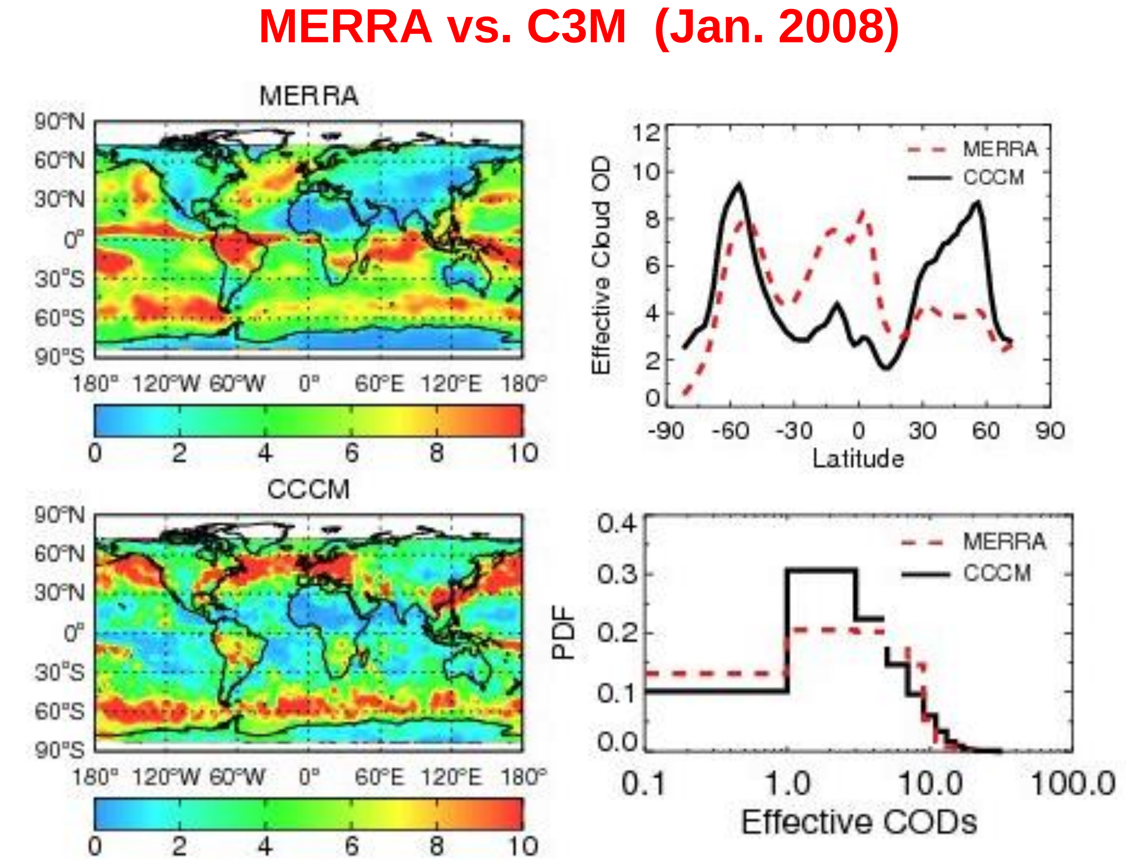
- Approximate Random Overlap [Briegleb, 1992]

$\tau_c' = \tau_c \cdot f^{3/2}$ → Effective COD

(default & used in this work)

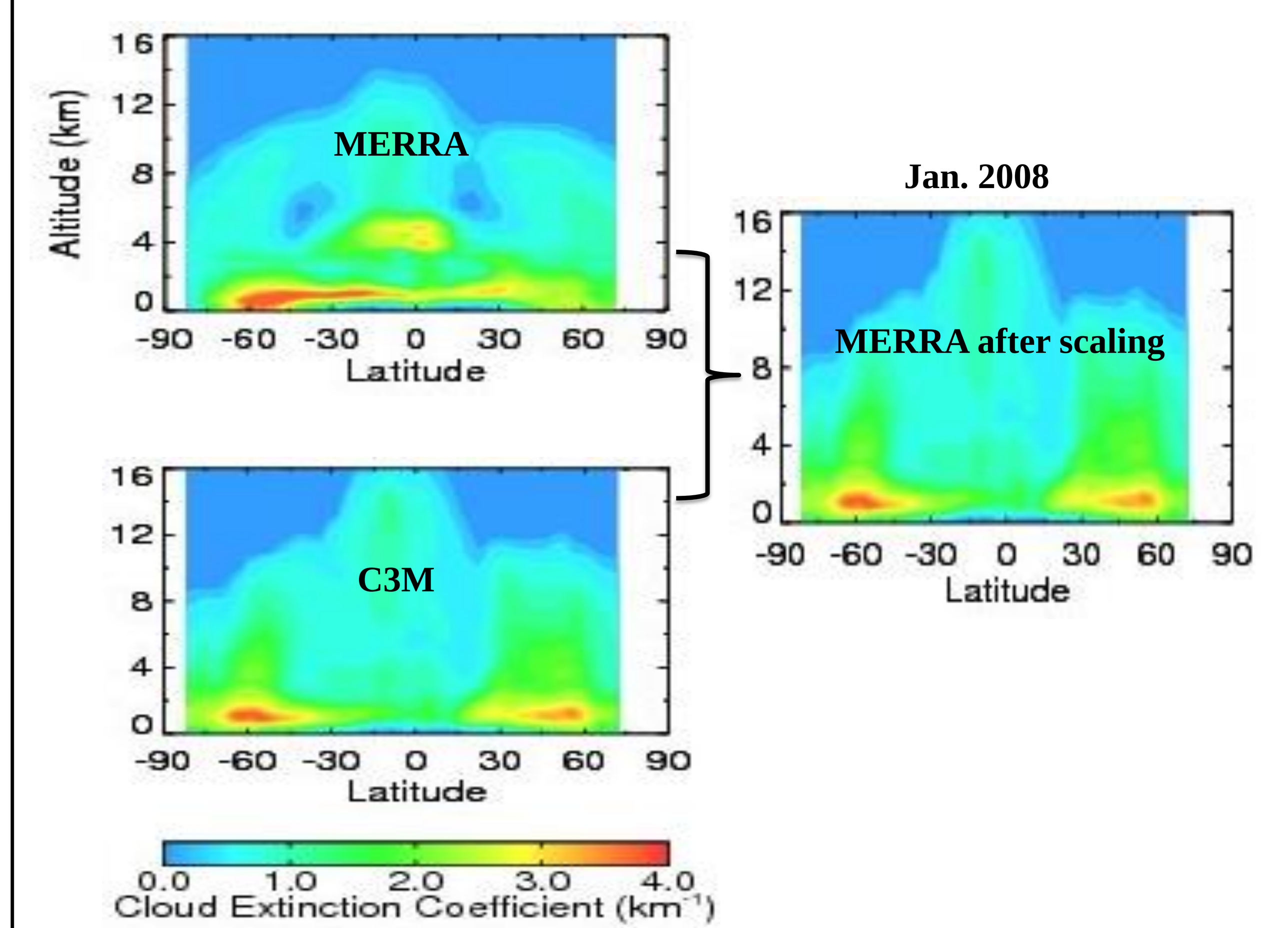
- Maximum-Random Overlap [Stubenrauch et al., 1997]
  - clouds in adjacent layers (a cloud block) are maximally overlapped; cloud blocks are randomly overlapped.

Global Distribution of Effective Cloud Optical Depth MERRA vs. C3M (Jan. 2008)



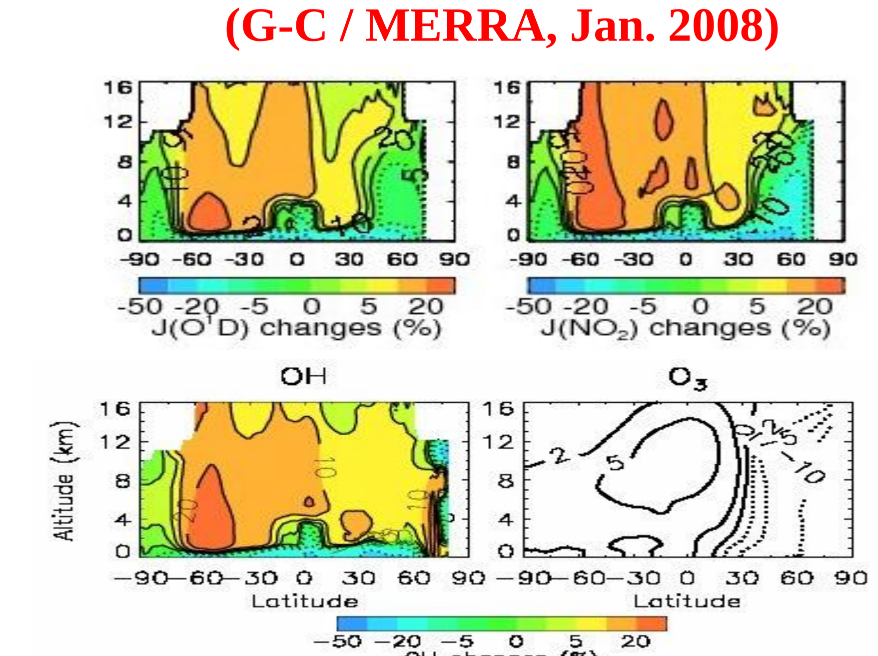
- MERRA daily 1:30pm LT clouds sampled along satellite orbit track.
- MERRA overestimates tropical cloud OD, but underestimates at NH mid-lat.

Scale MERRA 3-D Effective Cloud ODs to Those of C3M on a Monthly Mean Basis



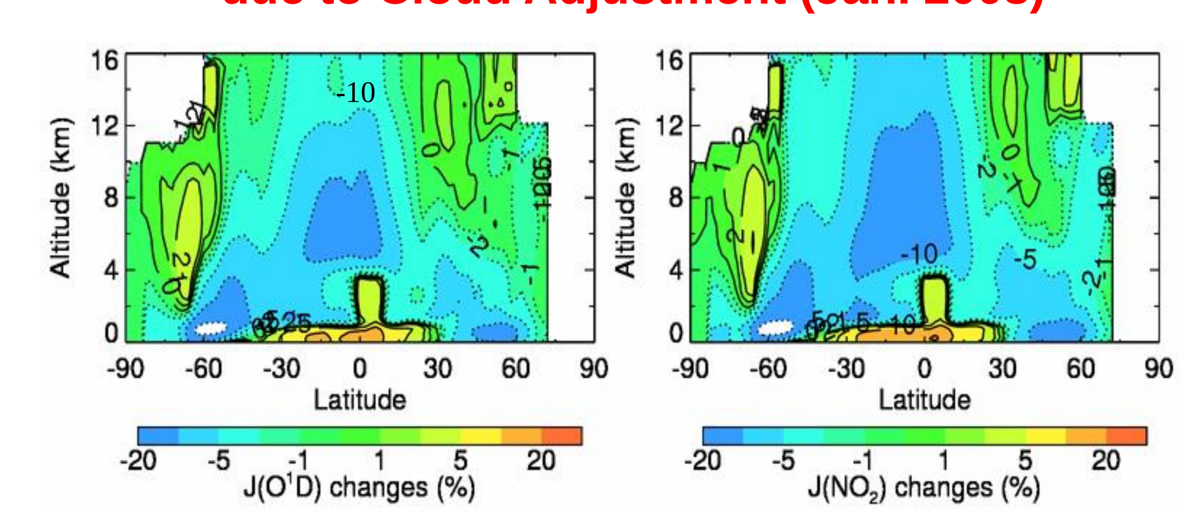
- Monthly 3-D scale factors are applied to model instantaneous effective ODs for that month.

Changes (%) in Daily Mean J, OH and O_3 due to Cloud (G-C / MERRA, Jan. 2008)



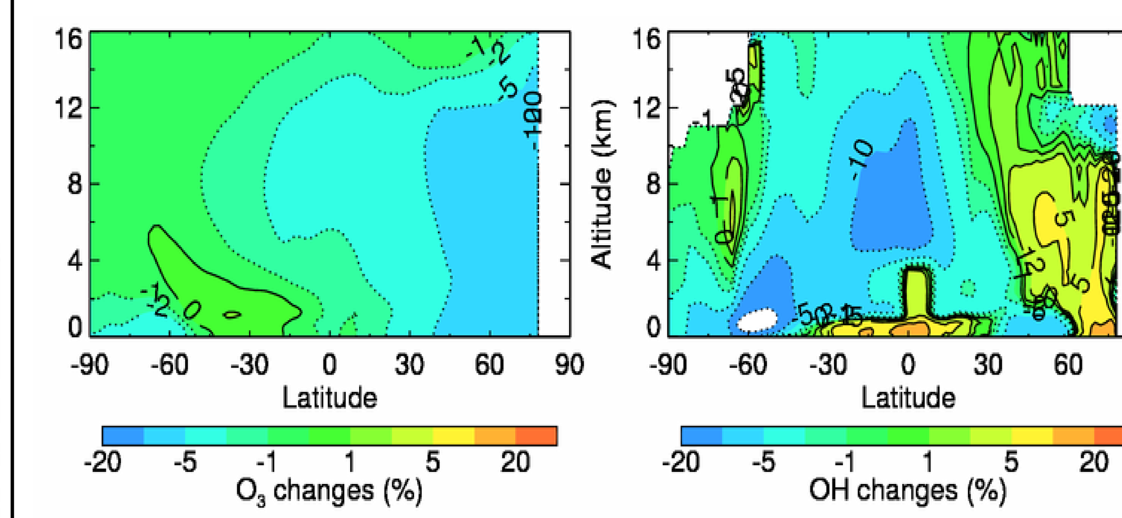
- Large increases in J-values and OH in tropical MT / UT and in SH marine stratiform cloud region.

Changes (%) in Daily Mean J-values due to Cloud Adjustment (Jan. 2008)



- Large decreases in J(O^1D) and J(NO_2) in tropical MT / UT and in SH marine stratiform cloud region.

Changes (%) in O_3 and OH due to Cloud Adjustment (Jan. 2008)



- Large decreases in OH in tropical MT / UT and in SH marine stratiform cloud region.

Impact of Cloud Adjustment on OH and Methylchloroform (MCF) & CH_4 Lifetimes

Annual Mean

			% changes
OH_{vw} (#/cm^3)	1.36×10^6	1.30×10^6	-4.1
OH_{mw} (#/cm^3)	1.32×10^6	1.27×10^6	-3.8
Lifetime (MCF, yr)	5.26	5.43	+3.2
Lifetime (CH_4, yr)	8.9	9.2	+3.1

- **Global multi-model mean OH concentration is overestimated by 5-10% [Naik, V. et al., ACP 2013].**
- **Here, using C3M to constrain the model clouds reduces the global mean OH concentration by ~4%.**

Summary and Conclusions

- **Cloud radiative effect (CRE) is one of the major factors that affect tropospheric OH. Large differences in cloud distributions among current models could contribute significantly to the wide model spread of tropospheric OH (ACCMIP activity; Voulgarakis et al., ACP 2013).**
- **CCCM, a 3-D cloud data product developed at NASA Langley and merged from multiple A-Train satellite observations, provides unprecedentedly strong constraints on the vertical distribution of clouds & thus reduces the model biases in simulated CRE on key oxidants.**
- **The approach presented here can be used in other CTM or CCM models (e.g., within the Chemistry-Climate Modeling Initiative) to reduce biases in model-simulated OH.**

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Contact: Hongyu Liu (Hongyu.Liu-1@nasa.gov)