Where satellite observations meet climate models (in the atmosphere)

Robert Pincus
University of Colorado

What do satellite observations have to do with climate?

CCI and similar efforts stress measurements of

important physical quantities (ECV) that are

consistent over time (CDR)

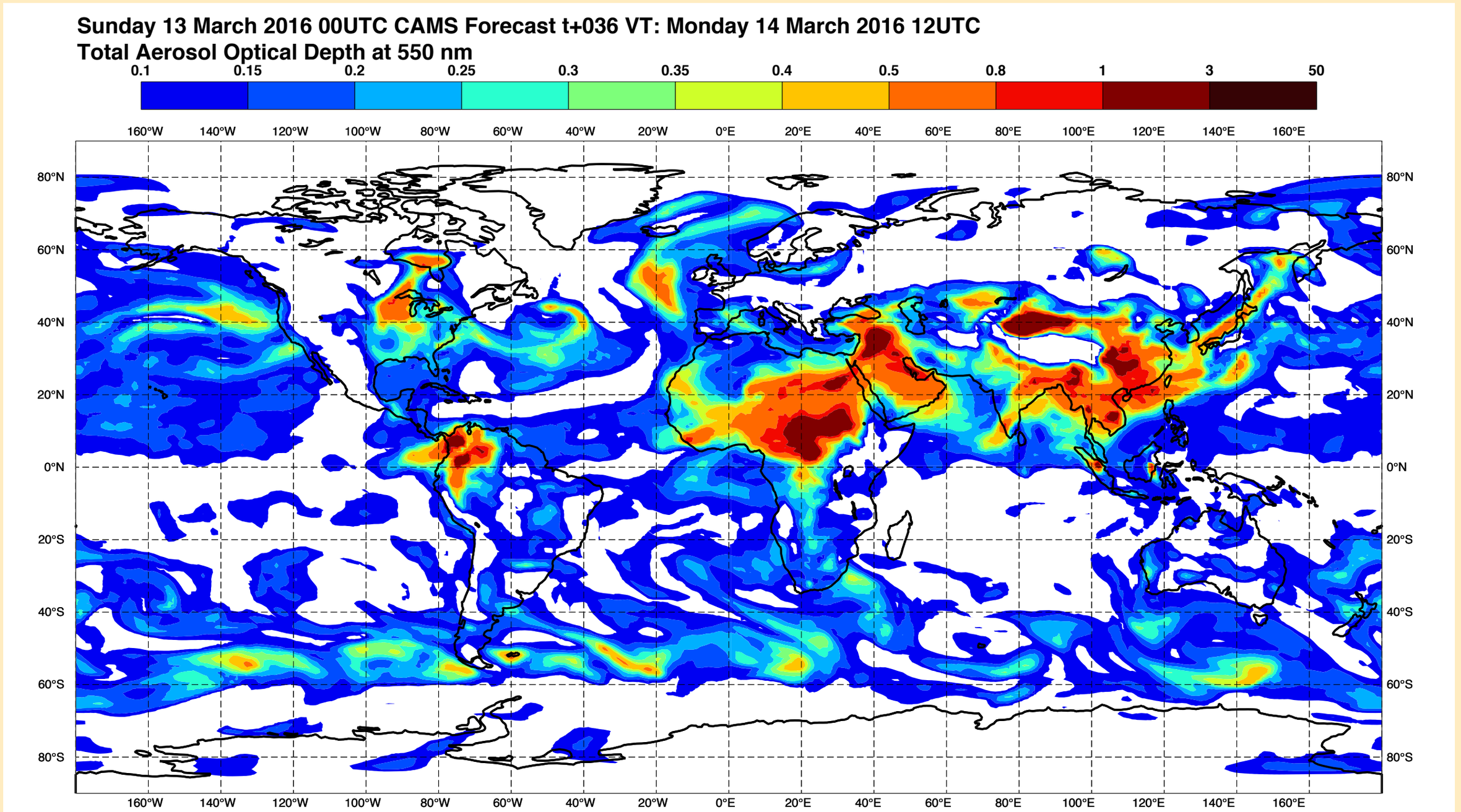
The working assumption is that retrievals of physical quantities are more useful than raw measurements

For clouds and aerosols (and likely composition) this is certainly true.

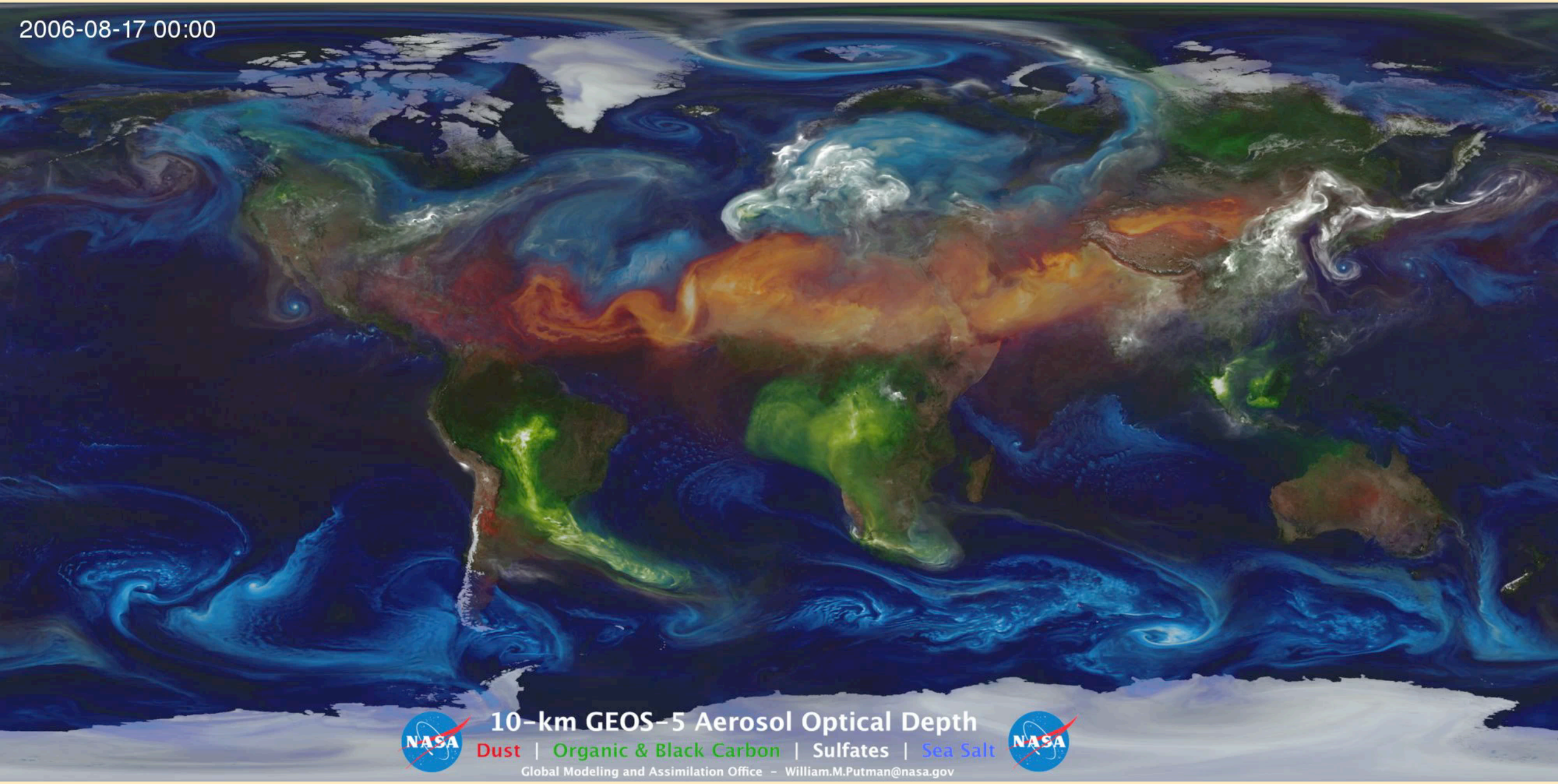
How are these data being used, and what interesting opportunities are there?

Satellite observations and climate state estimation

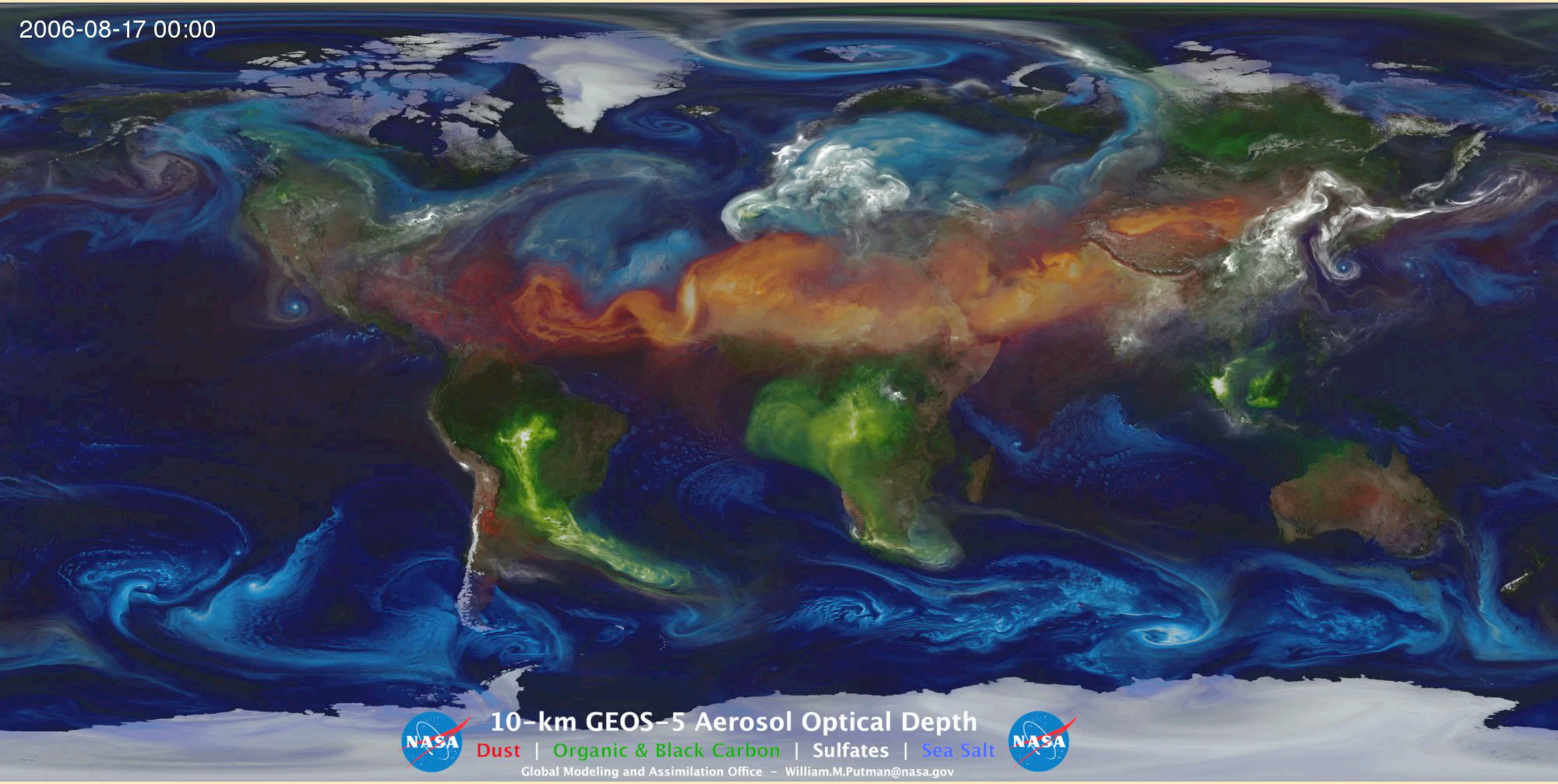
Operational aerosol forecasts are now routine



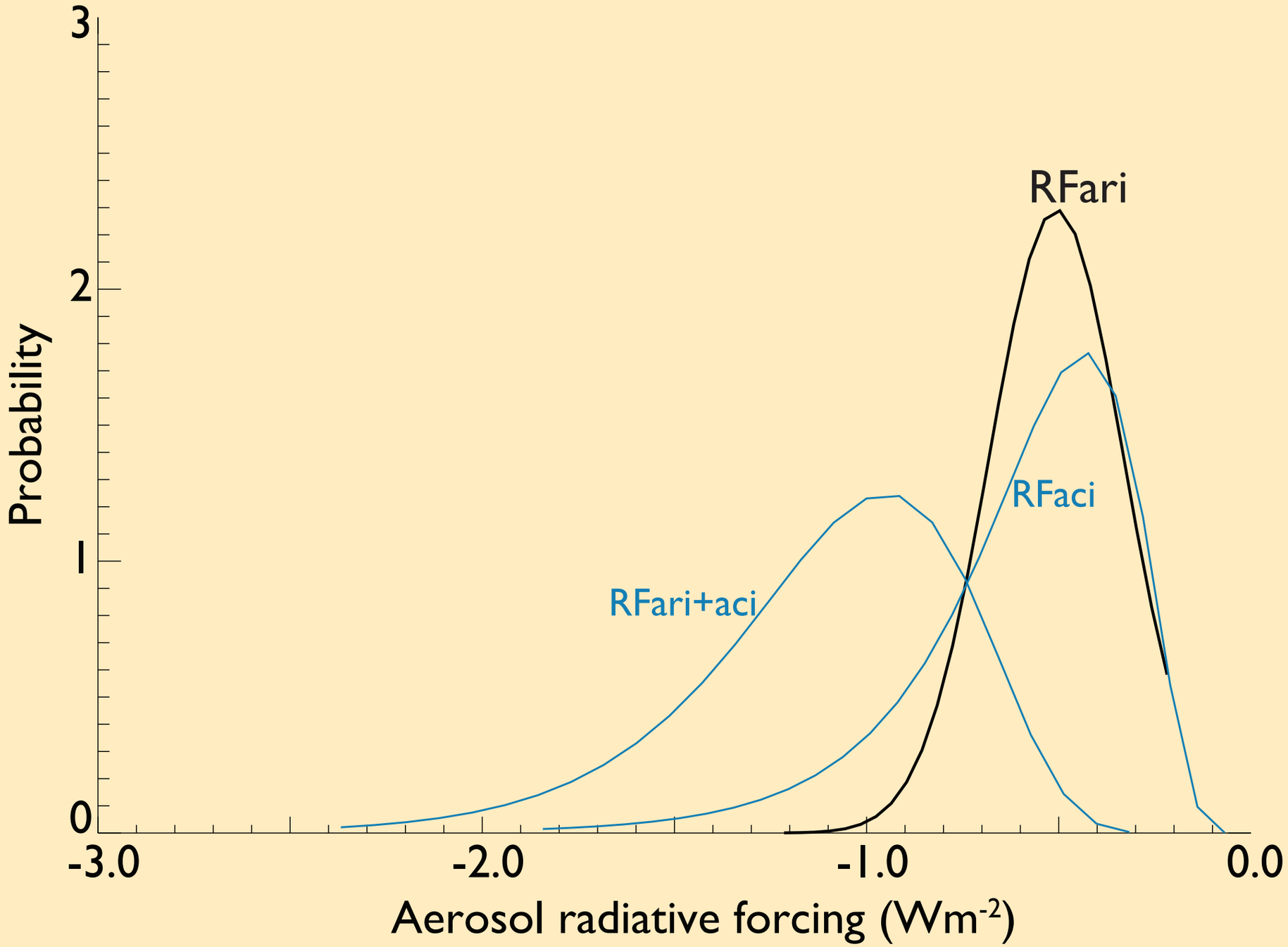
Satellite observations and climate state estimation



Satellite observations and climate state estimation



Models used for state estimation are used in other contexts

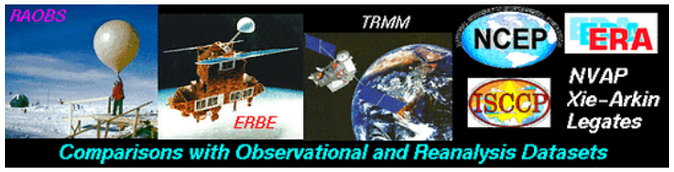


Nicolas Bellouin, Reading; update to Bellouin et al. 2013, 10.5194/acp-13-2045-2013

Comparison to models including evaluation

AMWG Diagnostics Package

gpci_cam5.1_cosp_1d_001



Plots Created
Tue Aug 5 12:01:48 MDT 2014

Set Description

1 Tables of ANN, DJF, JJA, global and regional means and RMSE.
2 Line plots of annual implied northward transports.
3 Line plots of DJF, JJA and ANN zonal means
4 Vertical contour plots of DJF, JJA and ANN zonal means
4a Vertical (XZ) contour plots of DJF, JJA and ANN meridional means
5 Horizontal contour plots of DJF, JJA and ANN means
6 Horizontal vector plots of DJF, JJA and ANN means
7 Polar contour and vector plots of DJF, JJA and ANN means
8 Annual cycle contour plots of zonal means
9 Horizontal contour plots of DJF-JJA differences
10 Annual cycle line plots of global means
11 Pacific annual cycle, Scatter plot plots
12 Vertical profile plots from 17 selected stations
13 Cloud simulators plots
14 Taylor Diagram plots
15 Annual Cycle at Select Stations plots
16 Budget Terms at Select Stations plots

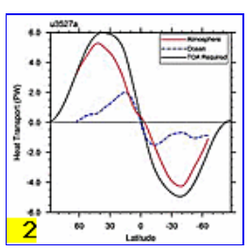
WACCM Set Description

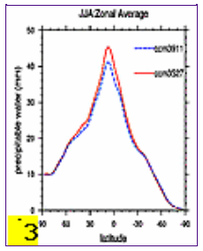
1 Vertical contour plots of DJF, MAM, JJA, SON and ANN zonal means (vertical log scale)

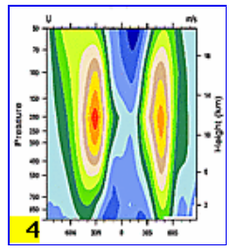
Chemistry Set Description

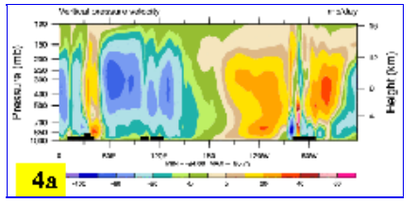
1 Tables / Chemistry of ANN global budgets
2 Vertical Contour Plots contour plots of DJF, MAM, JJA, SON and ANN zonal means
3 Ozone Climatology Comparisons Profiles, Seasonal Cycle and Taylor Diagram
4 Column O3 and CO lon/lat Comparisons to satellite data
5 Vertical Profile Profiles Comparisons to NOAA Aircraft observations
6 Vertical Profile Profiles Comparisons to Emmons Aircraft climatology
7 Surface observation Scatter Plot Comparisons to IMROVE

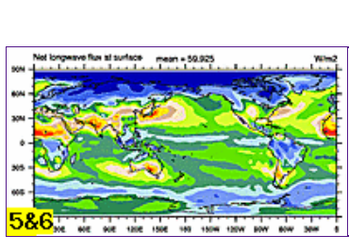
Click on Plot Type

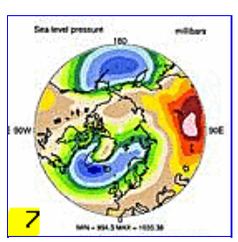


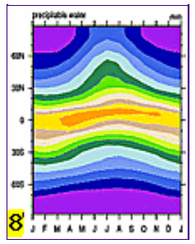


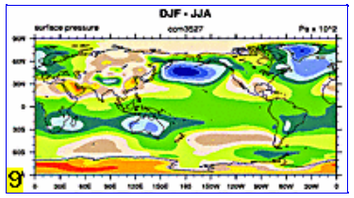


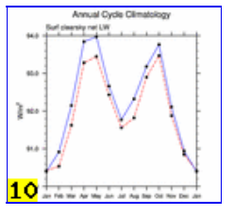


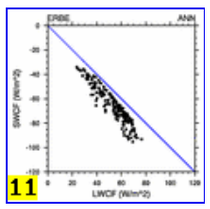


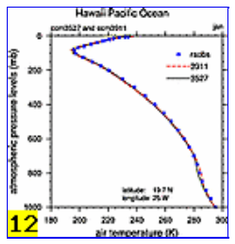


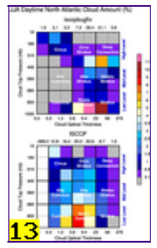


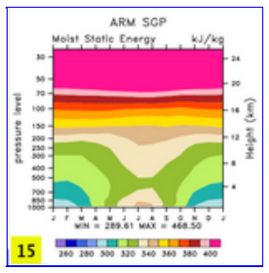


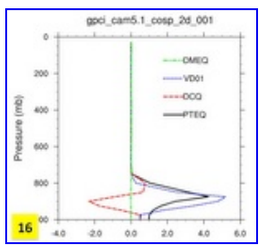


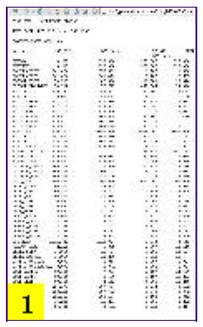




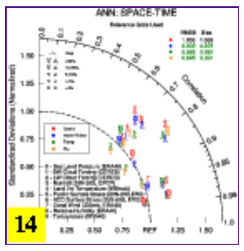






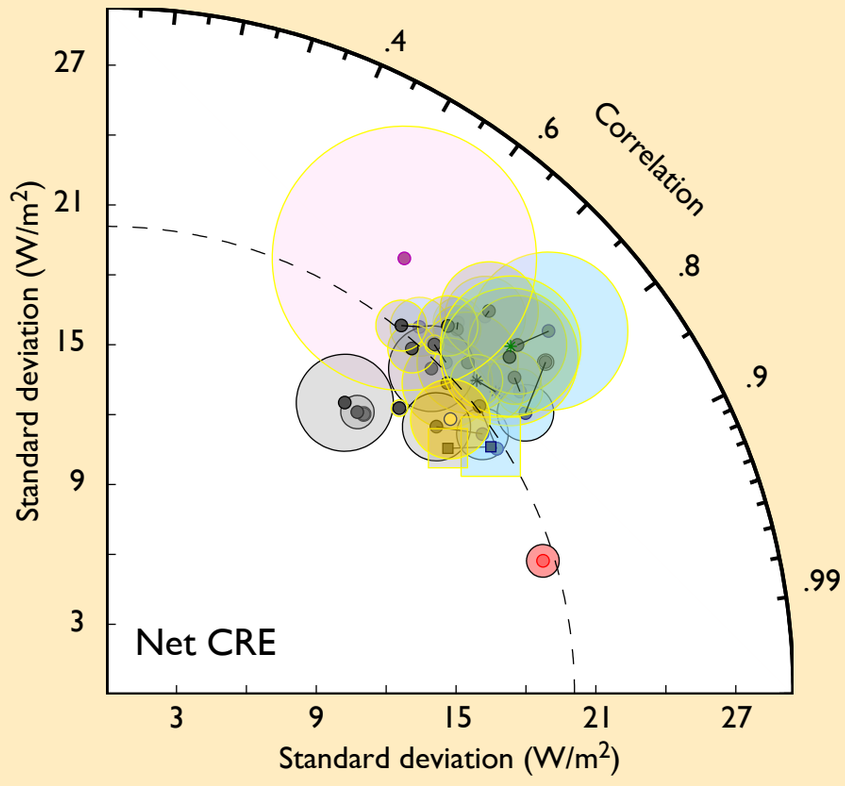


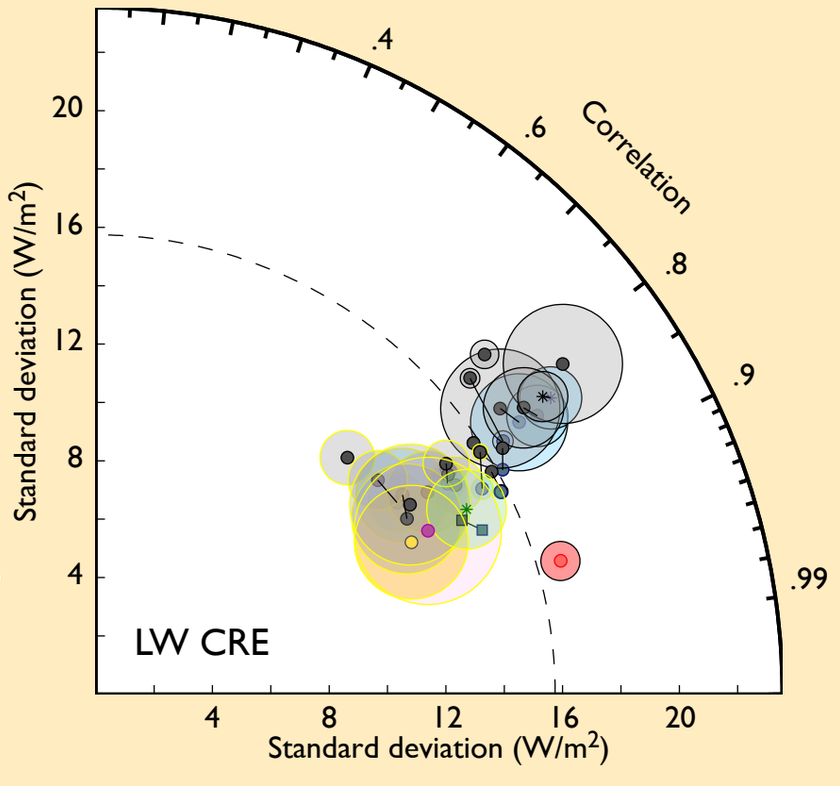
TABLES

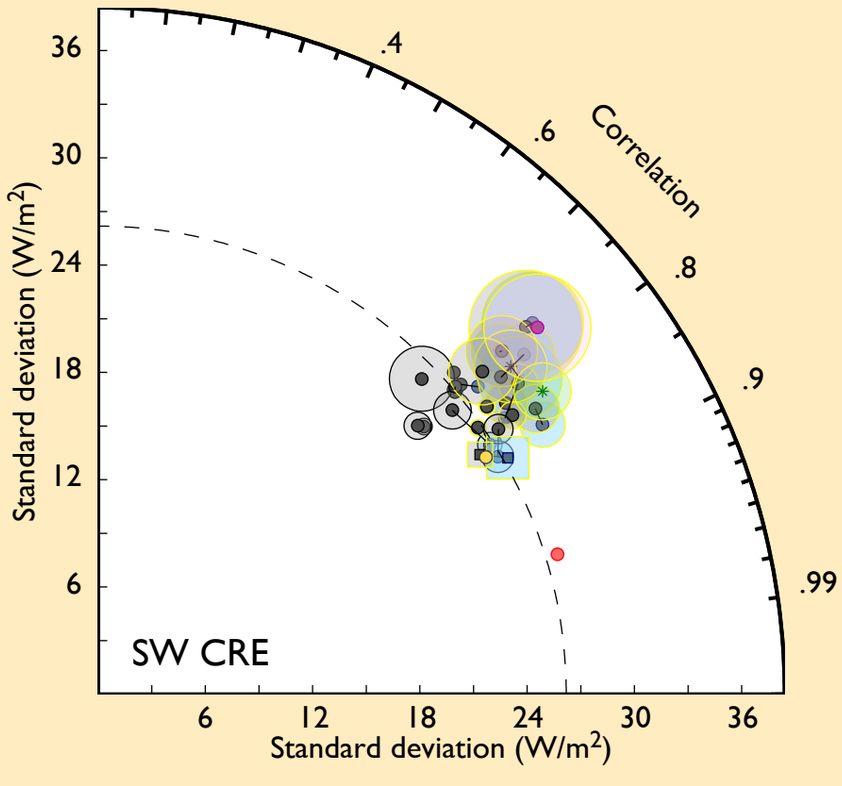


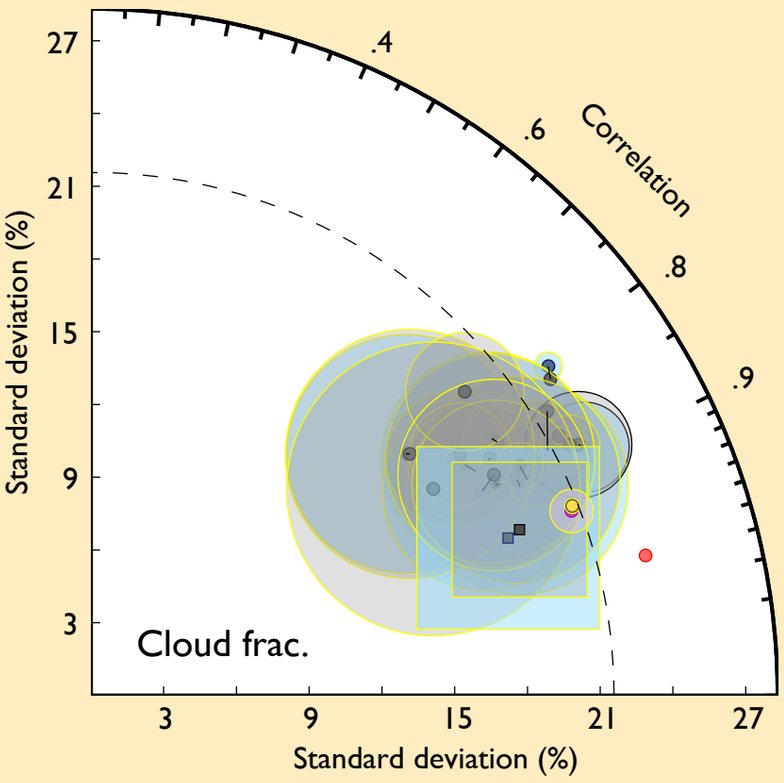
METRICS

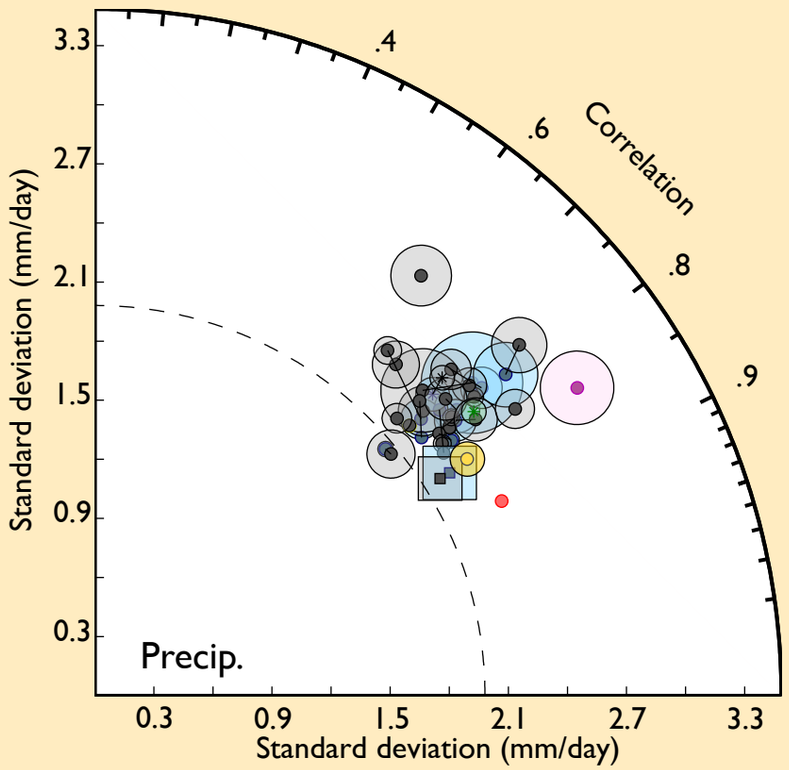
Evaluation including "metrics" became common for CMIP3

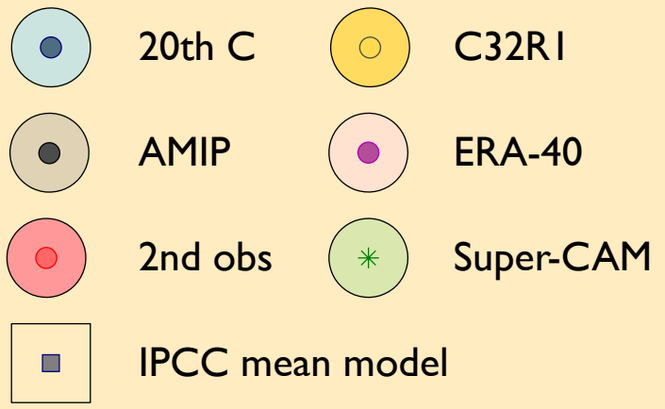












Pincus et al. 2008, 10.1029/2007jd009334

Routine evaluation becomes routine…

Geosci. Model Dev. Discuss., 8, 7541–7661, 2015
www.geosci-model-dev-discuss.net/8/7541/2015/
doi:10.5194/gmdd-8-7541-2015

Geoscientific Model Development Discussions
Open Access

ESMValTool (v1.0) – a community diagnostic and performance metrics tool for routine evaluation of Earth System Models in CMIP

V. Eyring[1], M. Righi[1], M. Evaldsson[2], A. Lauer[1], S. Wenzel[1], C. Jones[3,4], A. Anav[5], O. Andrews[6], I. Cionni[7], E. L. Davin[8], C. Deser[9], C. Ehbrecht[10], P. Friedlingstein[5], P. Gleckler[11], K.-D. Gottschaldt[1], S. Hagemann[12], M. Juckes[13], S. Kindermann[10], J. Krasting[14], D. Kunert[1], R. Levine[4], A. Loew[15,12], J. Mäkelä[16], G. Martin[4], E. Mason[14,17], A. Phillips[9], S. Read[18], C. Rio[19], R. Roehrig[20], D. Senftleben[1], A. Sterl[21], L. H. van Ulft[21], J. Walton[4], S. Wang[2], and K. D. Williams[4]

[1]Deutsches Zentrum für Luft- und Raumfahrt (DLR), Institut für Physik der Atmosphäre, Oberpfaffenhofen, Germany
[2]Swedish Meteorological and Hydrological Institute (SMHI), 60176 Norrköping, Sweden
[3]University of Leeds, Leeds, UK
[4]Met Office Hadley Centre, Exeter, UK
[5]University of Exeter, Exeter, UK

… but can be misleading

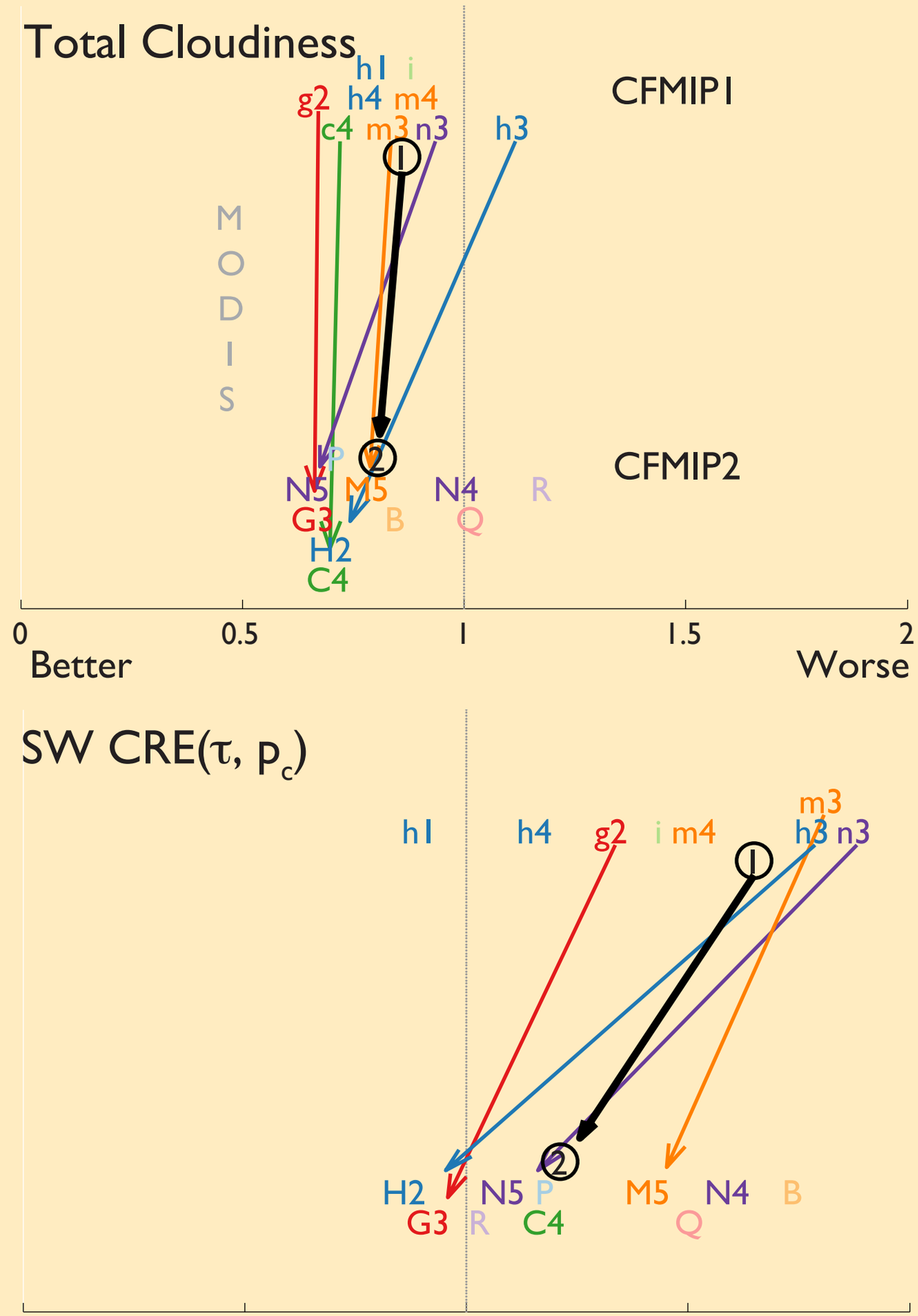
"Here the progress that has been made in recent years is measured by comparing .. cloud properties [cloud amount, liquid water path, and cloud radiative forcing] … from the CMIP5 models with satellite observations and with results from comparable CMIP3 experiments. …the differences in the simulated cloud climatology from CMIP3 and CMIP5 are generally small, and there is very little to no improvement apparent in the tropical and subtropical regions in CMIP5."

Lauer and Hamilton 2013, 10.1175/JCLI-D-12-00451.1

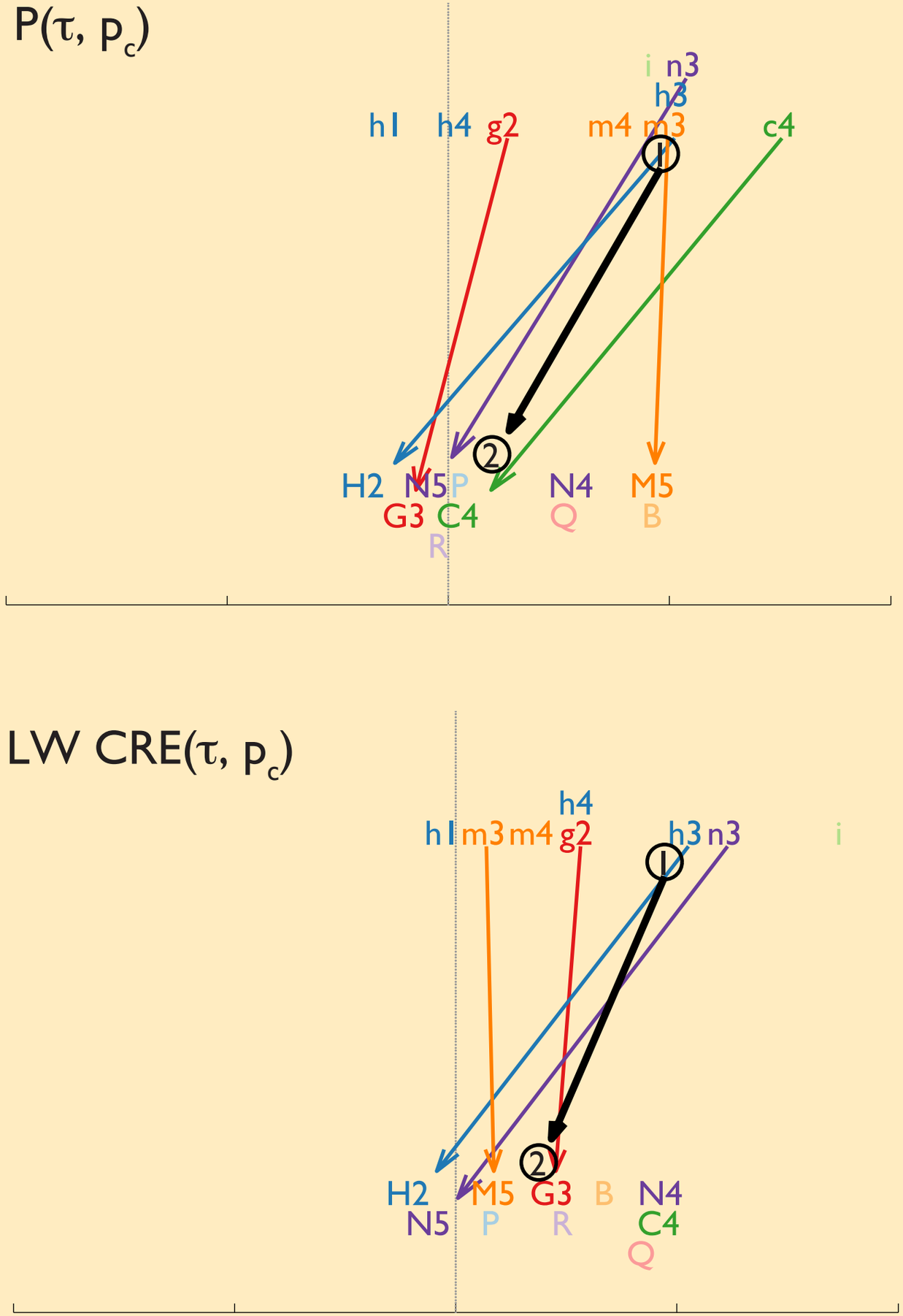
"… based on these biases in the annual mean, Taylor diagram metrics, and RMSE, there is virtually no progress in the simulation fidelity of [outgoing TOA radiation and surface solar] fluxes from CMIP3 to CMIP5. ..We hypothesize that at least a part of these persistent biases stem from the common global climate model practice of ignoring the effects of precipitating and/or convective core ice and liquid in their radiation calculations."

Li et al. 2013, 10.1002/jgrd.50378

Total Cloudiness



$P(\tau, p_c)$



SW CRE(τ, p_c)

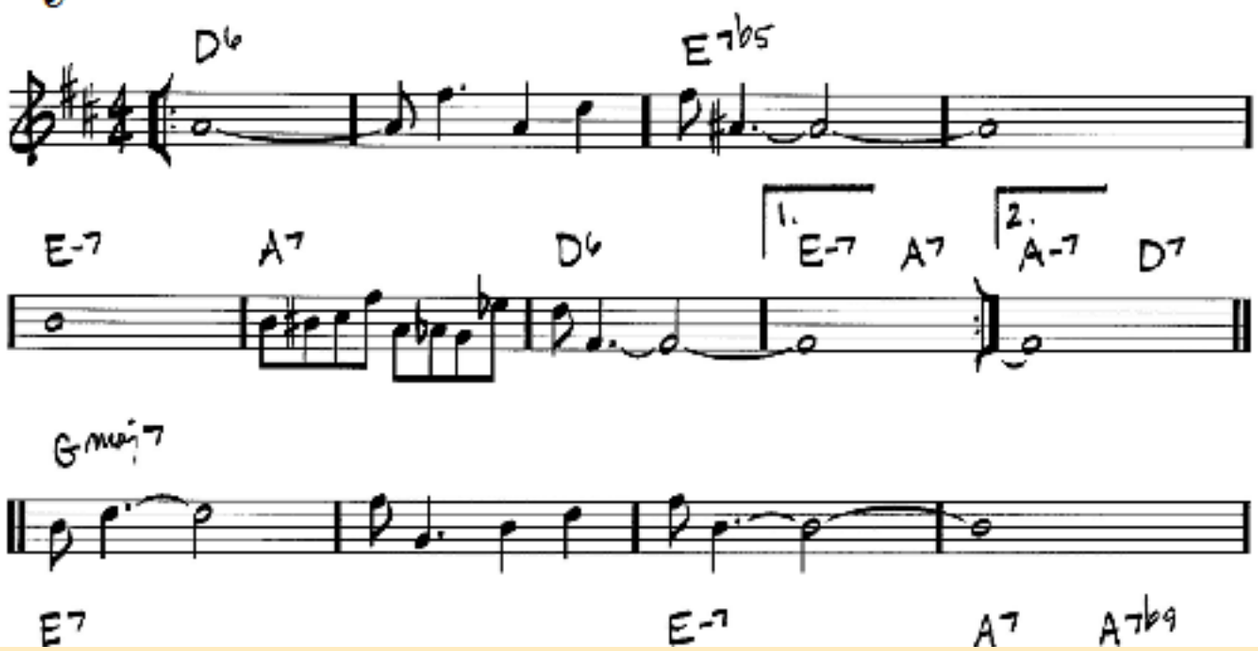
LW CRE(τ, p_c)

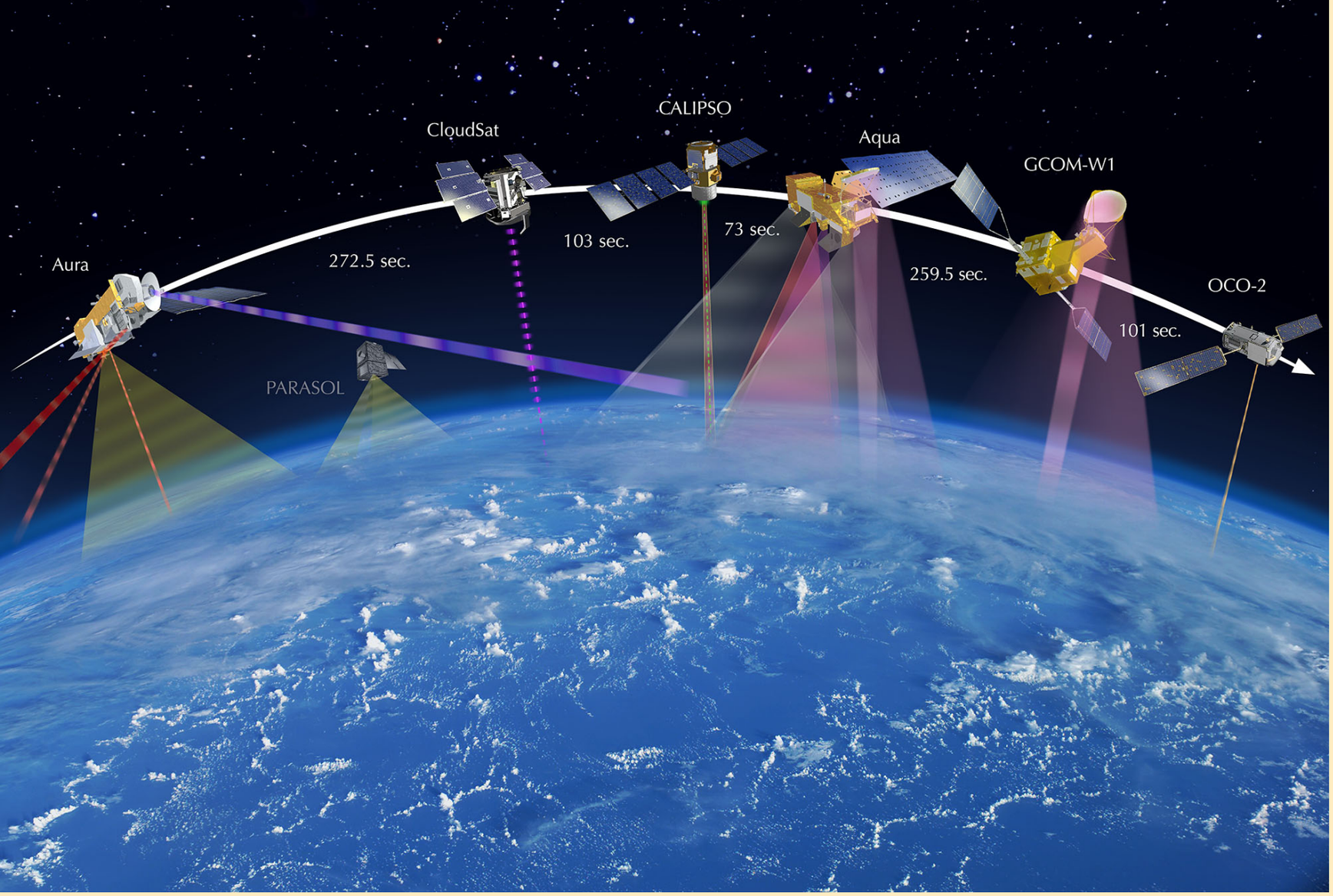
Klein et al. 2013, 10.1002/jgrd.50141

Two big changes in the last decade

TAKE THE "A" TRAIN

– Billy Strayhorn




CALIPSO
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OCO-2
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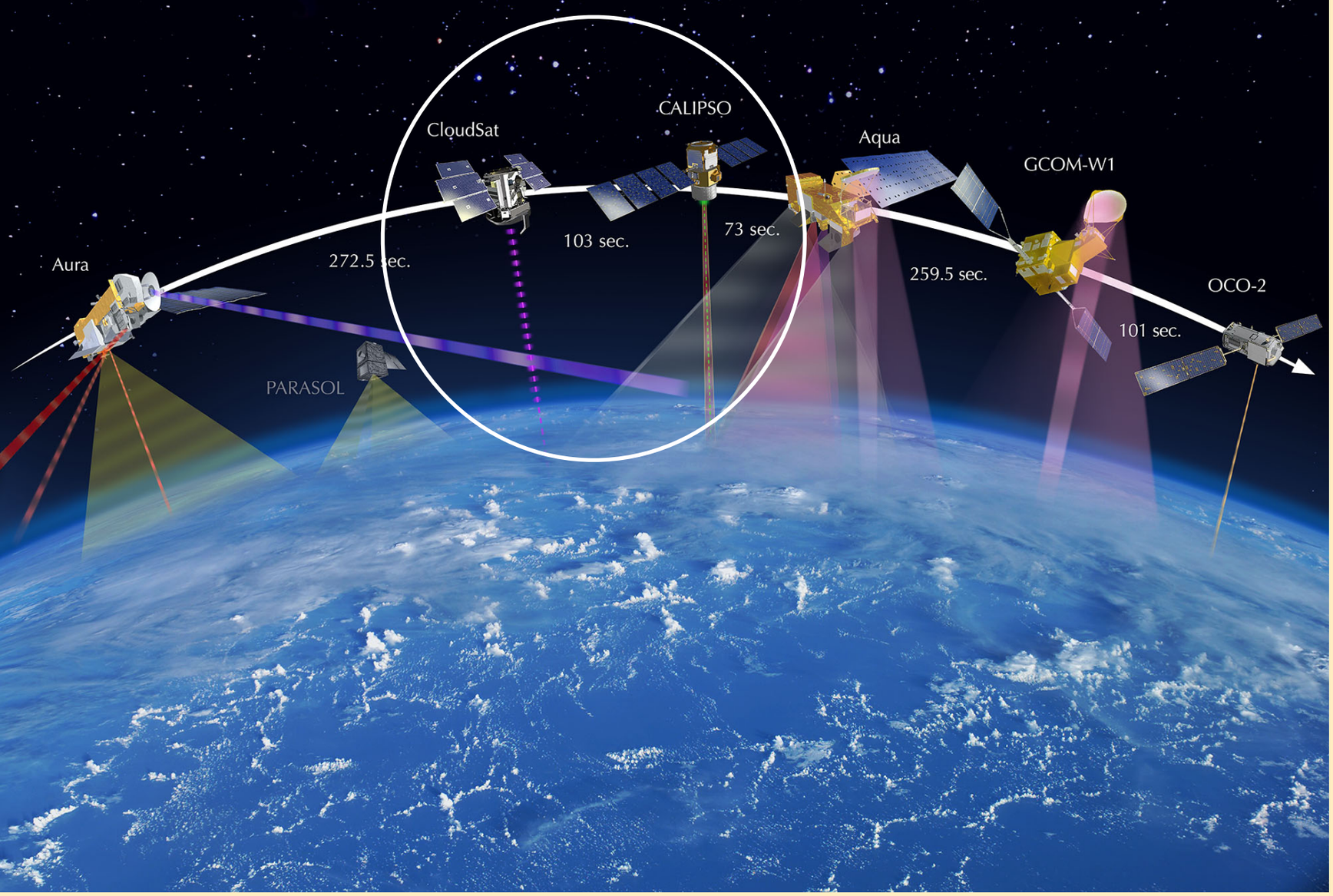
PARASOL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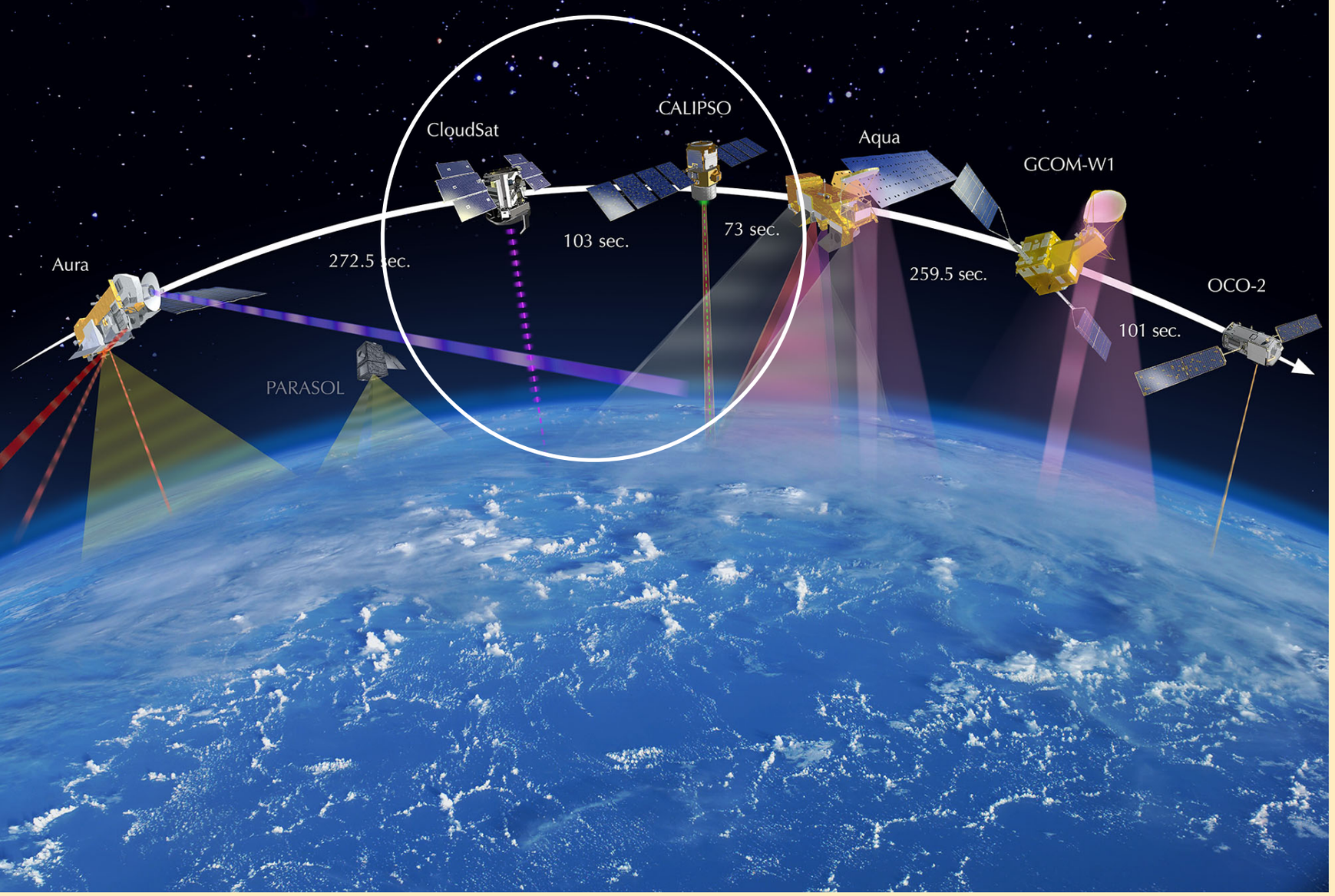
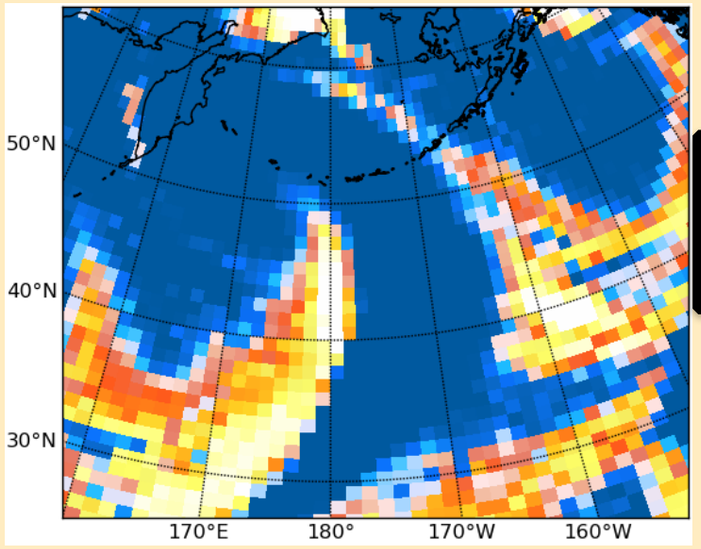
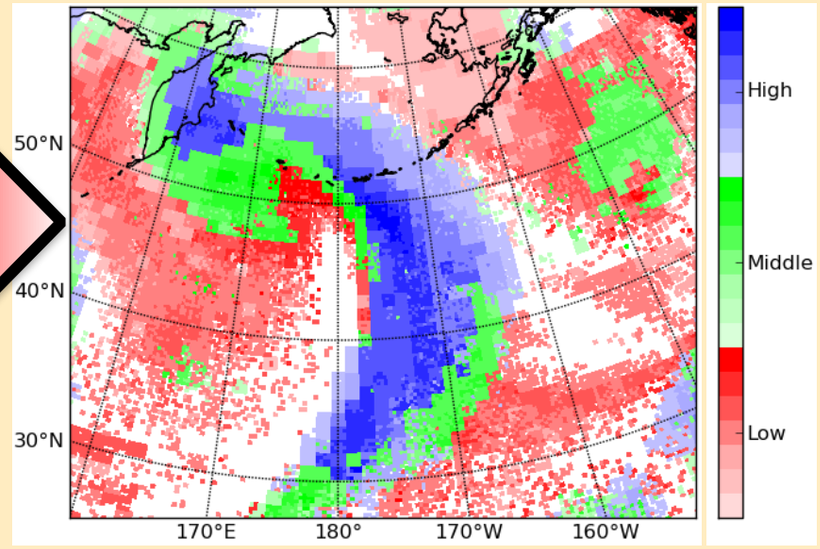


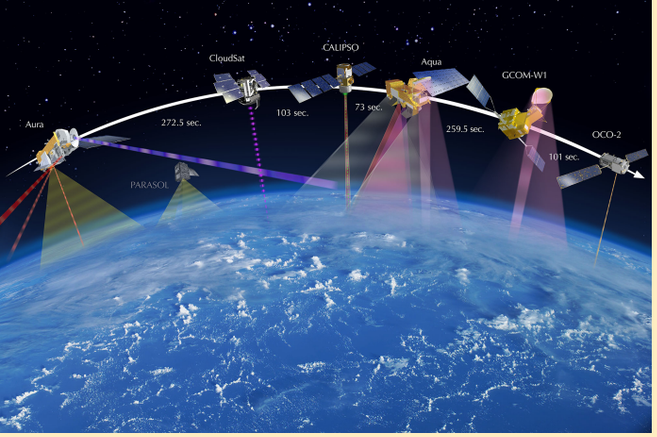
Climate Model Clouds



COSP Processing

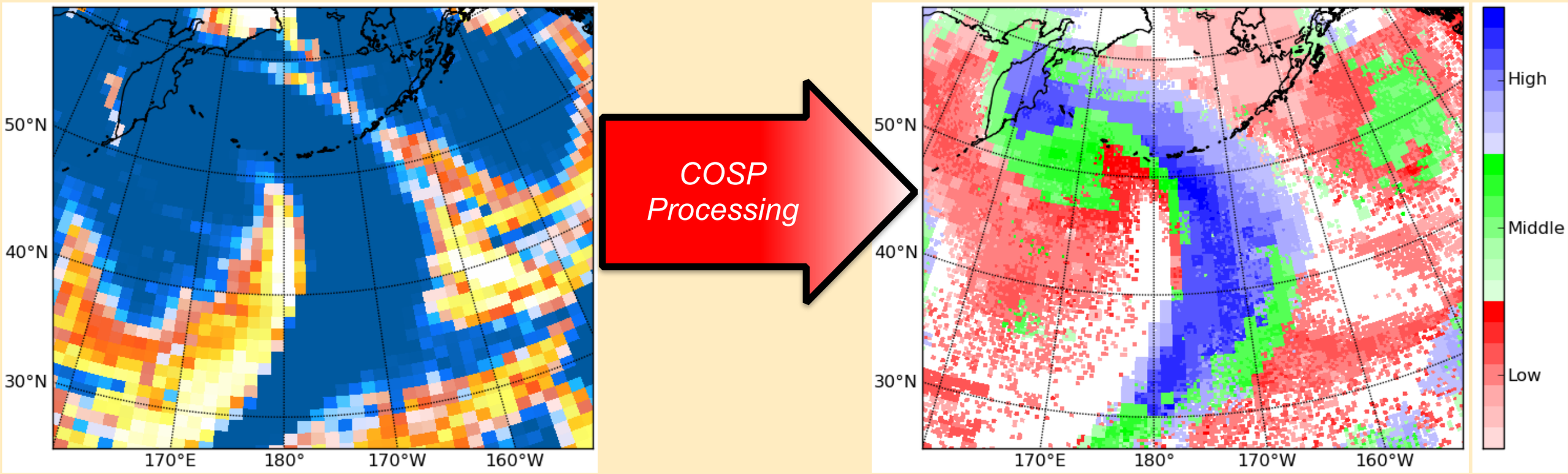
Pseudo-Satellite Observations



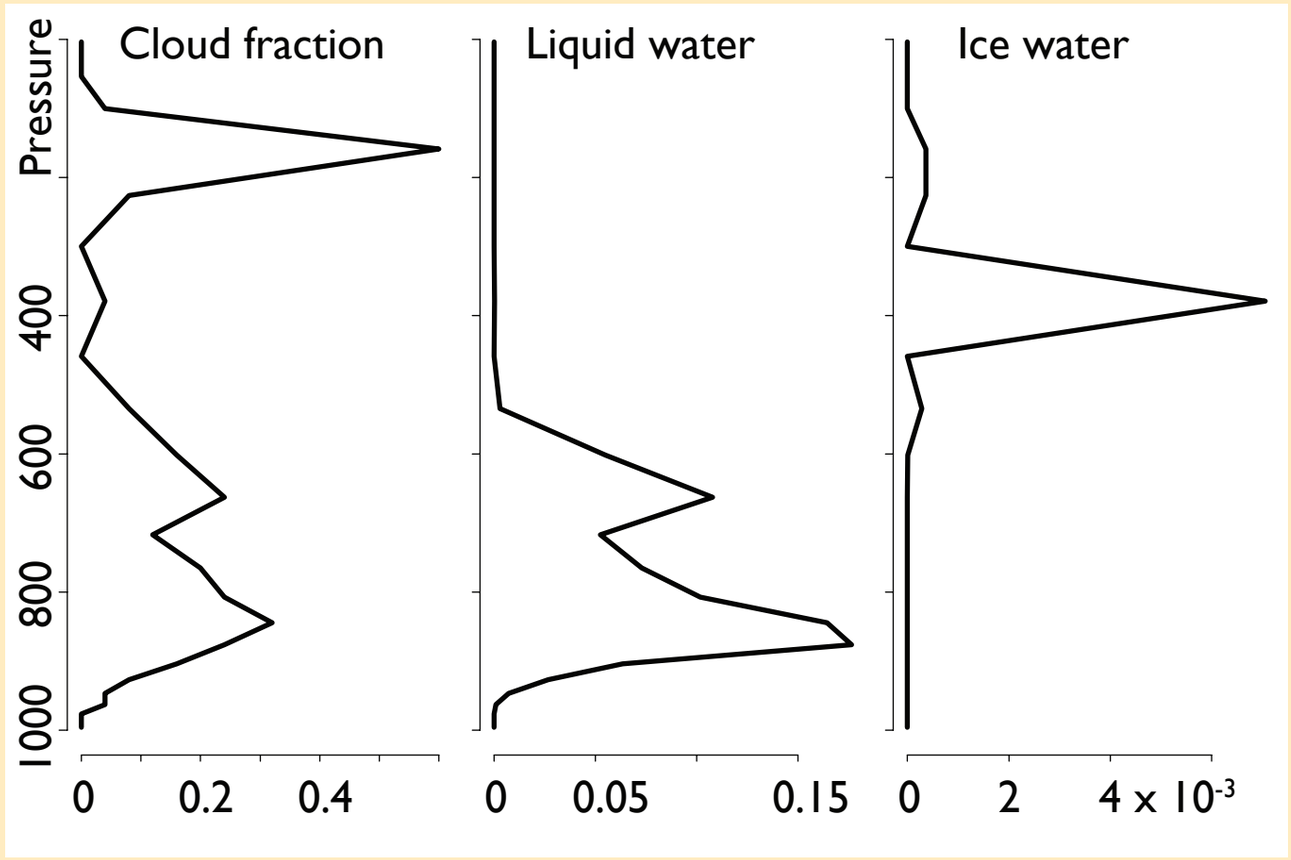


Climate Model Clouds

Pseudo-Satellite Observations

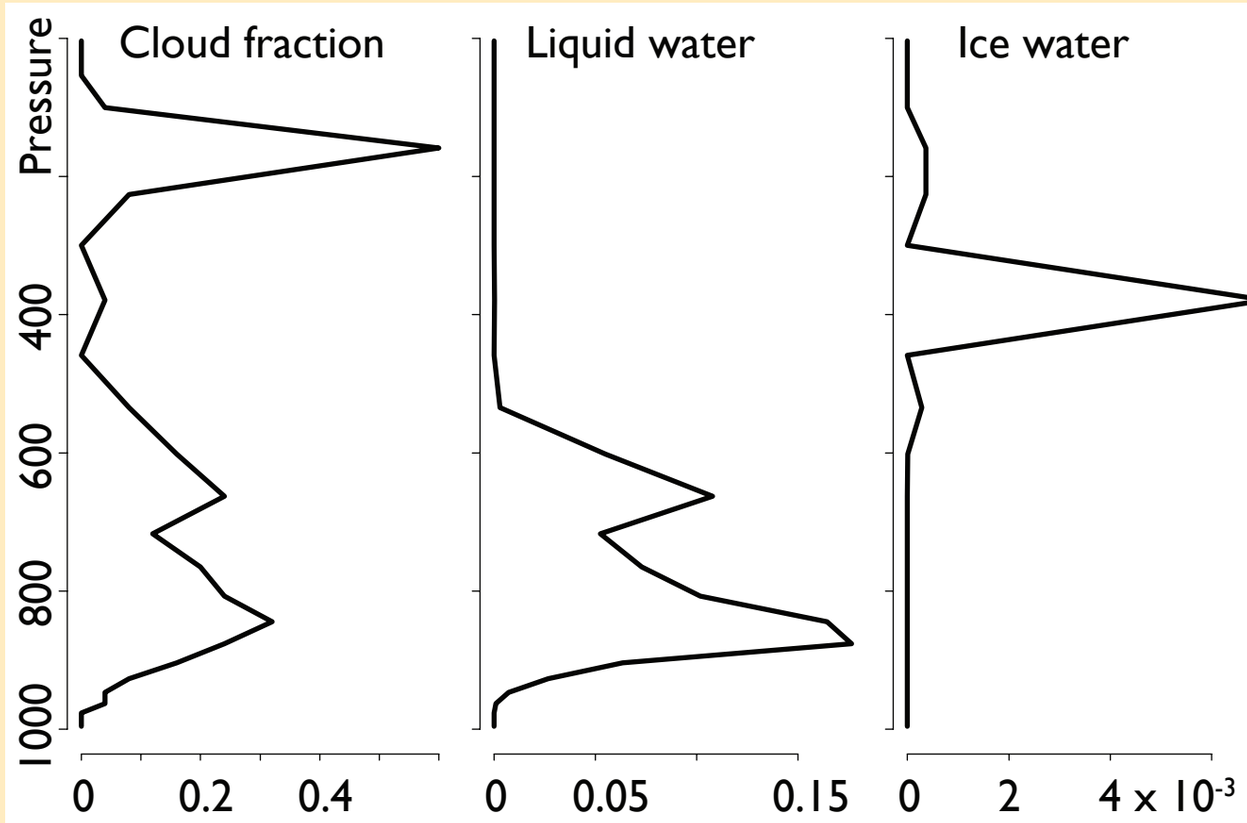


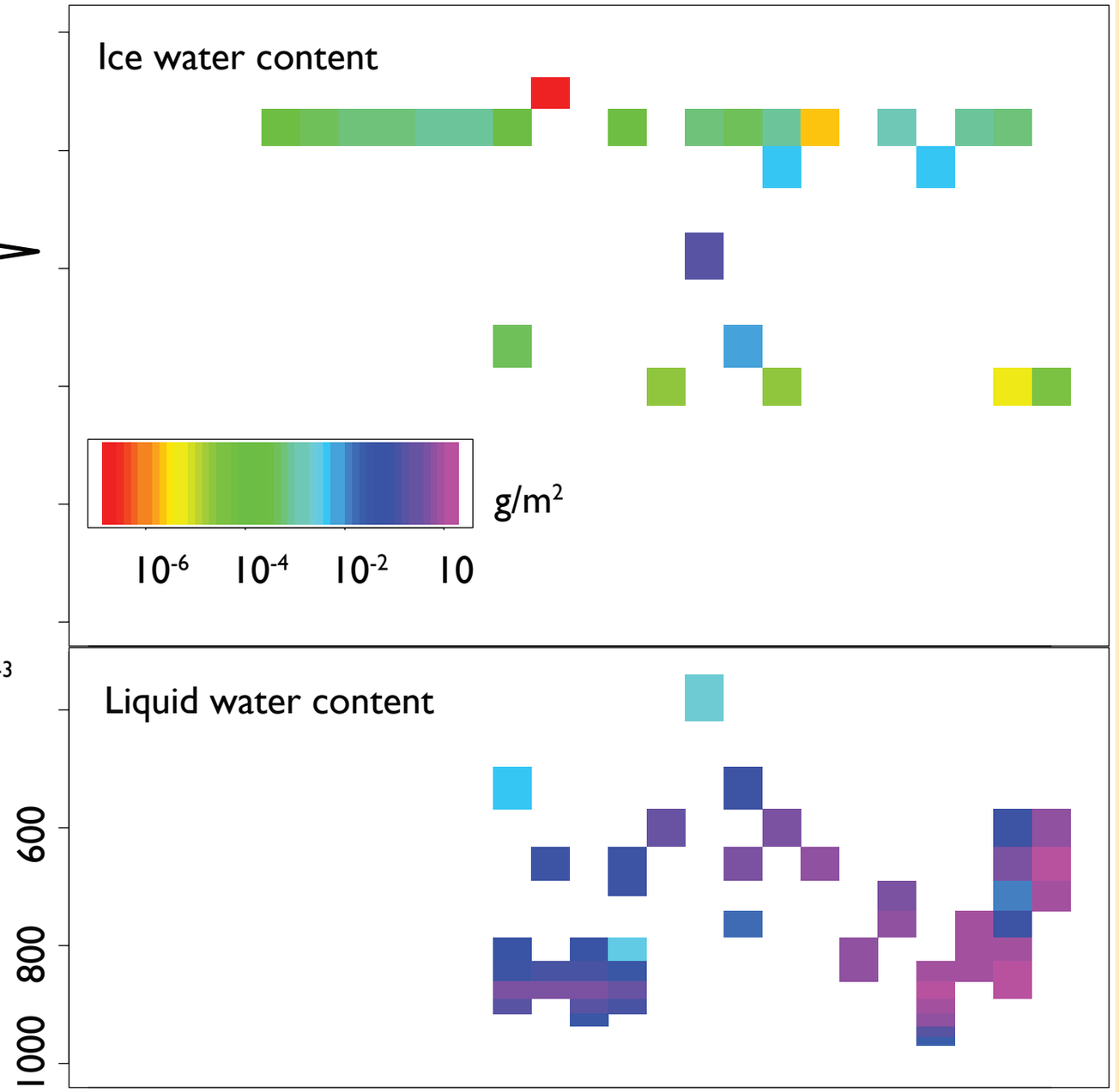
Observational proxies(i) — matching scales



Pincus et al. 2006, 10.1175/MWR3257.1

Observational proxies(i) — matching scales





Pincus et al. 2006, 10.1175/MWR3257.1

Observational proxies(ii) — a satellite's-eye view

Simulators map the model description of clouds

$$r_{e(l,i)}(z), \tau_{(l,i)}(z) \text{ or } q_{(l,i)}(z)$$

into synthetic pixel-scale observations using rough approximations

$$p_c = \int_{\text{TOA}}^{\tau=1} p(z)\sigma_c(z)dz \quad P = \int_{\text{TOA}}^{\tau=1} P(z)\sigma_c(z)dz$$

$$\tau = \int_{\text{TOA}}^{\text{sfc}} \sigma_c(z)dz \qquad r_e = F^{-1}(F(r_e(z)))$$

and aggregate these in space and time as per the observational data sets

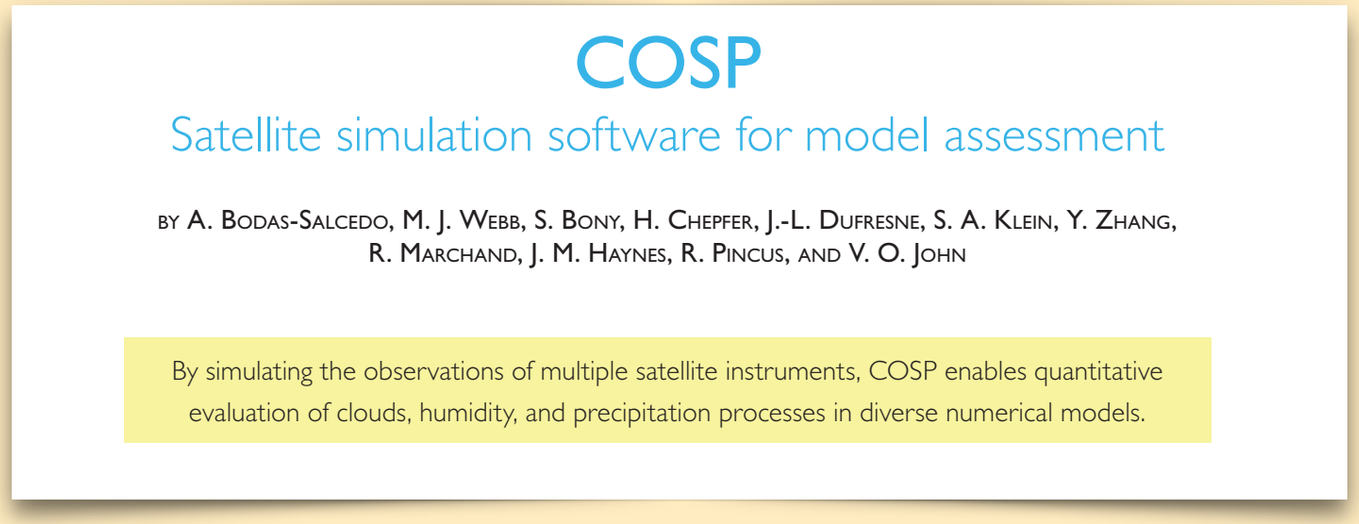
Most climate models have observation proxies for clouds

Diagnostics from the CFMIP Observation Simulator Package were requested for CFMIP2/CMIP5 and have been revised for CFMIP3/CMIP6.

COSP facilitates the mapping of model state information to observations from passive (MISR, MODIS, ISCCP) and active (CloudSat, CALIPSO) platforms

Observations are produced for each data stream

Can be extended by adding new sensors (e.g. CLARA), analyses…



COSP

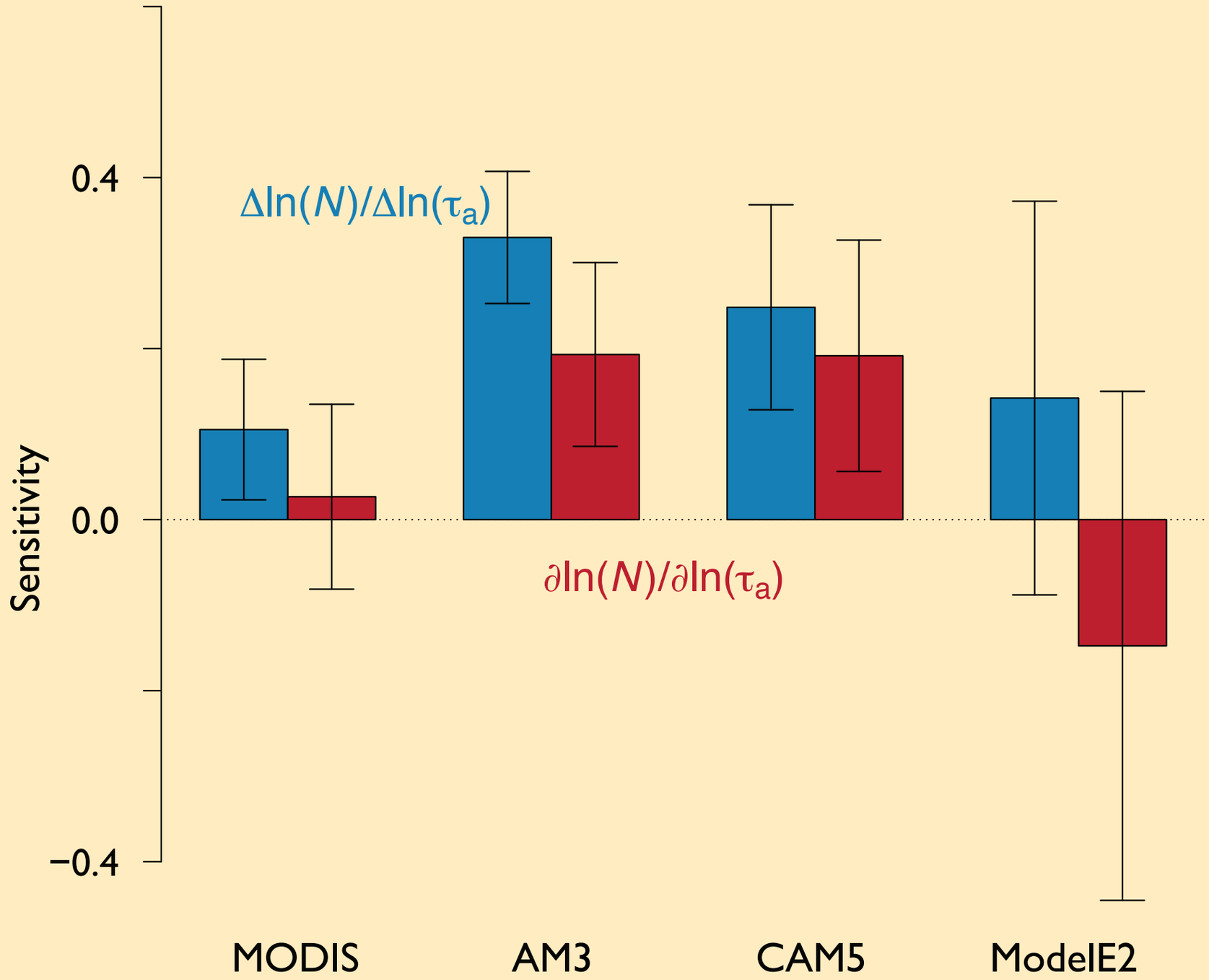
Satellite simulation software for model assessment

BY A. BODAS-SALCEDO, M. J. WEBB, S. BONY, H. CHEPFER, J.-L. DUFRESNE, S. A. KLEIN, Y. ZHANG, R. MARCHAND, J. M. HAYNES, R. PINCUS, AND V. O. JOHN

By simulating the observations of multiple satellite instruments, COSP enables quantitative evaluation of clouds, humidity, and precipitation processes in diverse numerical models.

Bodas-Salcedo et al. 2011, 10.1175/2011BAMS2856.1

Using proxies to pick apart correlations between aerosols and clouds



after Ban-Weiss et al. 2014, 10.1002/2014JD021722

But there's a lot the proxies can't do…

We understand the sensitivity of our instruments

See, for example: GEWEX cloud assessment (10.1175/BAMS-D-12-00117.1)

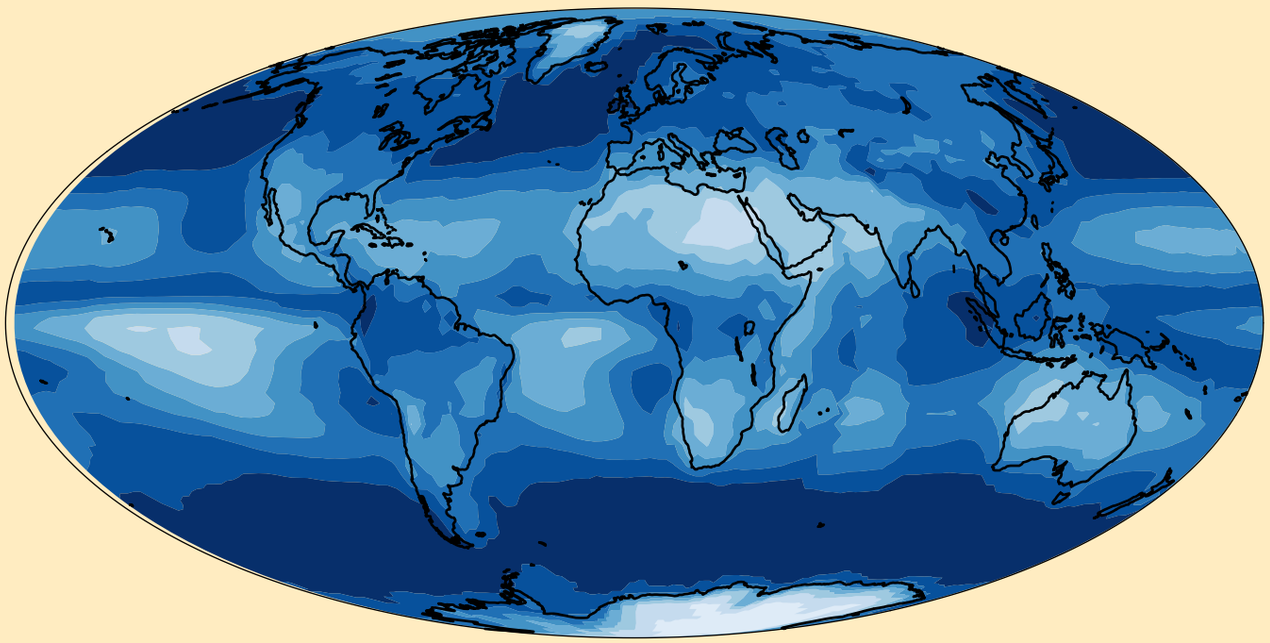
Every observation has a model attached to it.

Our models for interpreting reflectance measurements use

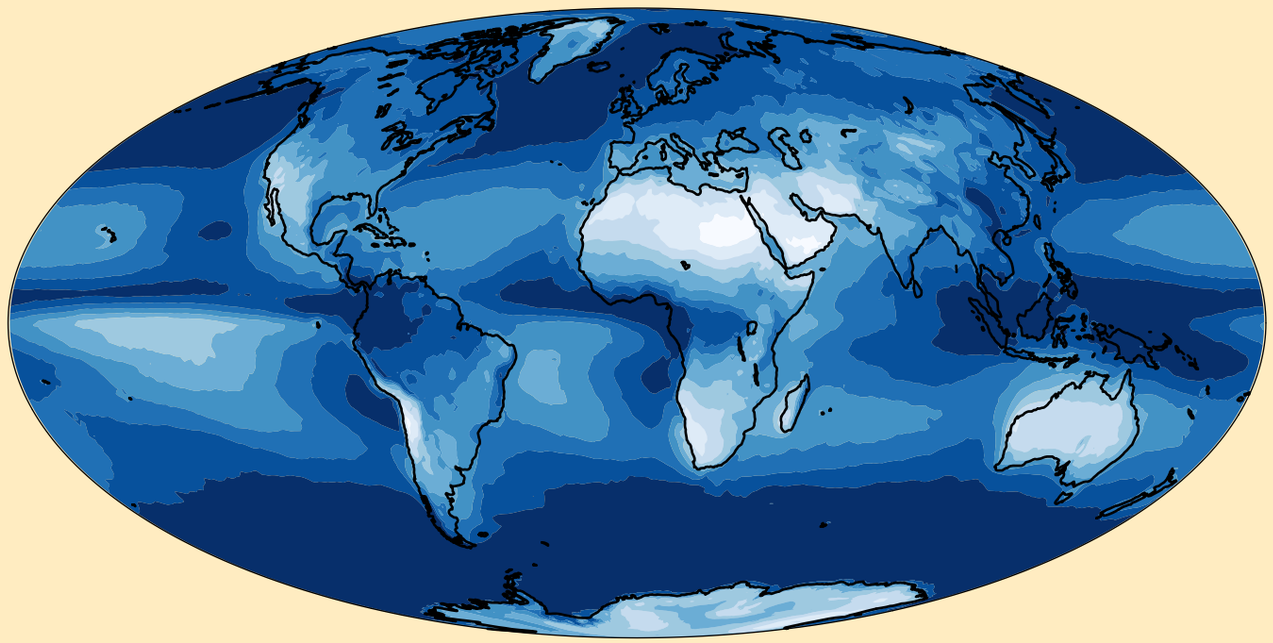
simple forward models (e.g. one-dimensional radiative transfer) operating on highly parameterized representations of clouds

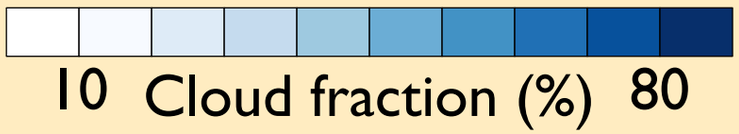
A simple question. How much of the planet is cloudy?

ISCCP: 66%



MODIS mask: 67%

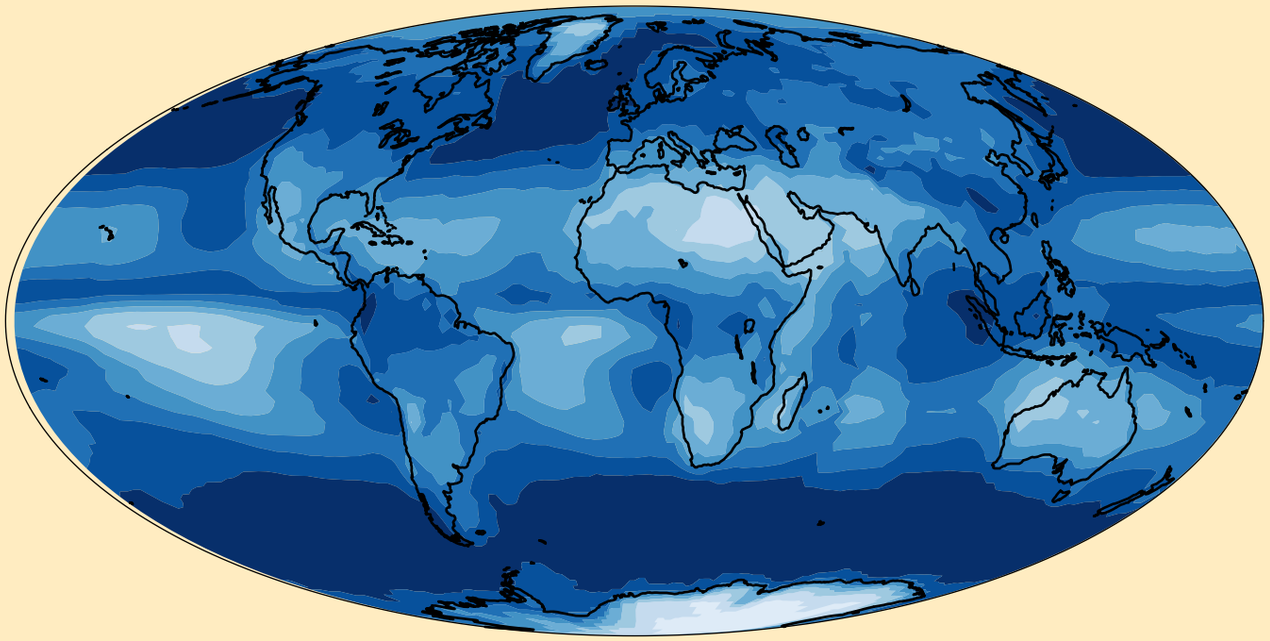




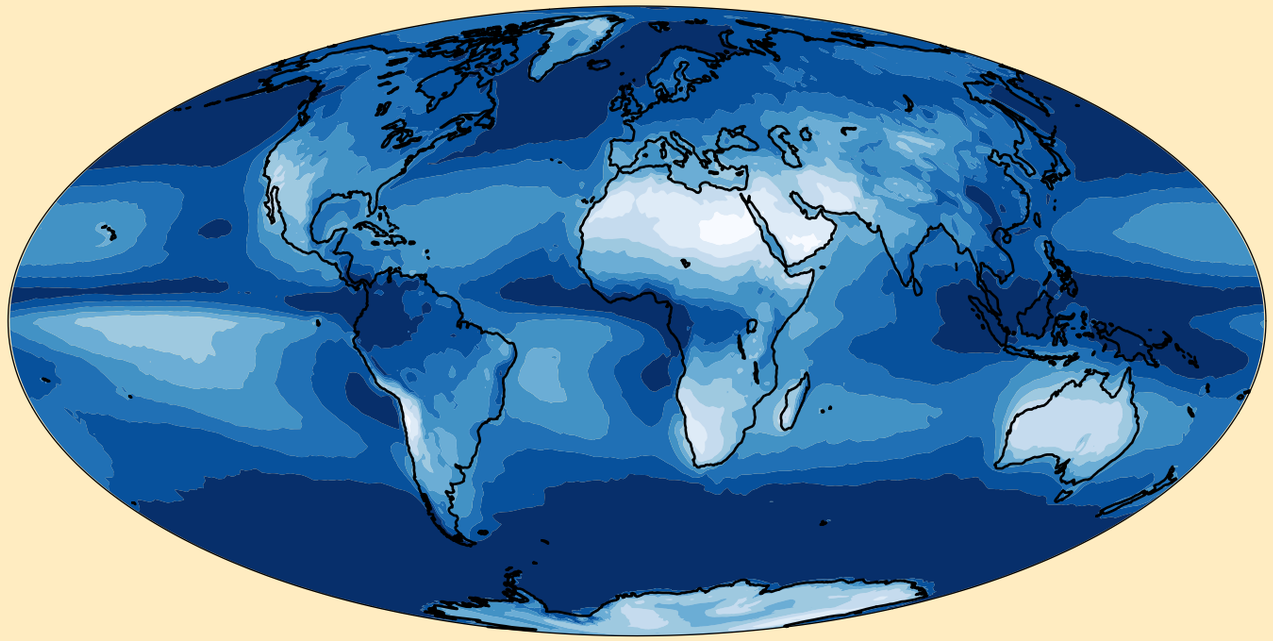
Pincus et al. 2012, 10.1175/JCLI-D-11-00267.1

A simple question. How much of the planet is cloudy?

ISCCP: 66%

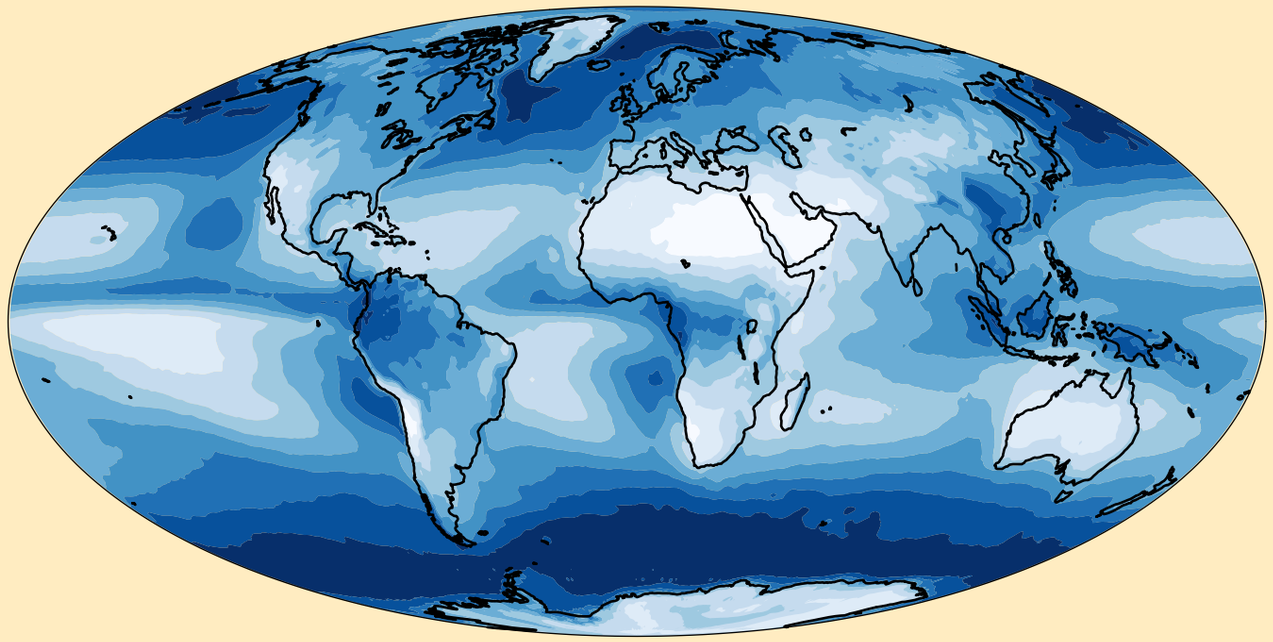


MODIS mask: 67%



10 Cloud fraction (%) 80

MODIS retrievals: 50%



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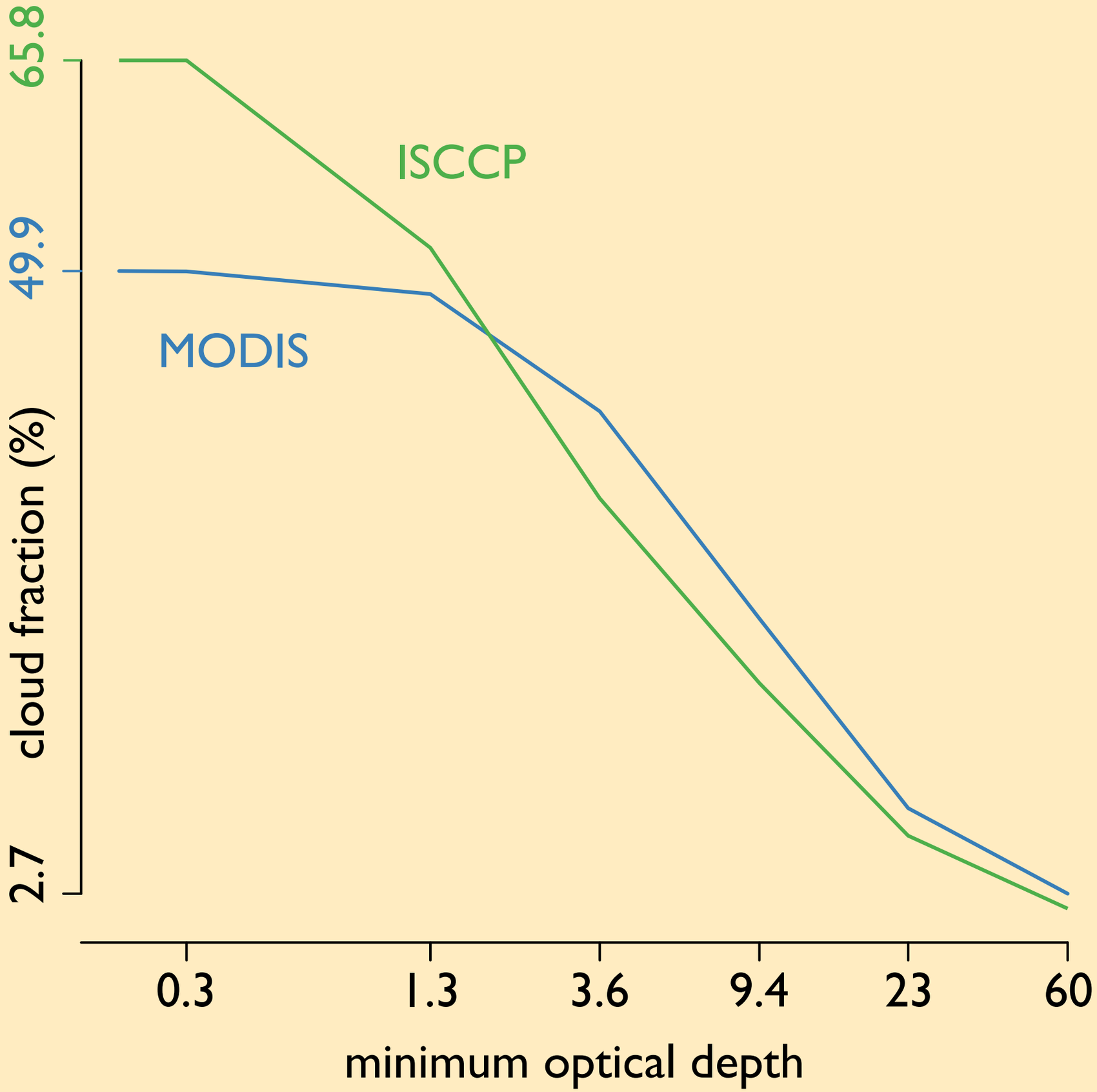


Pincus et al. 2012, 10.1175/JCLI-D-11-00267.1

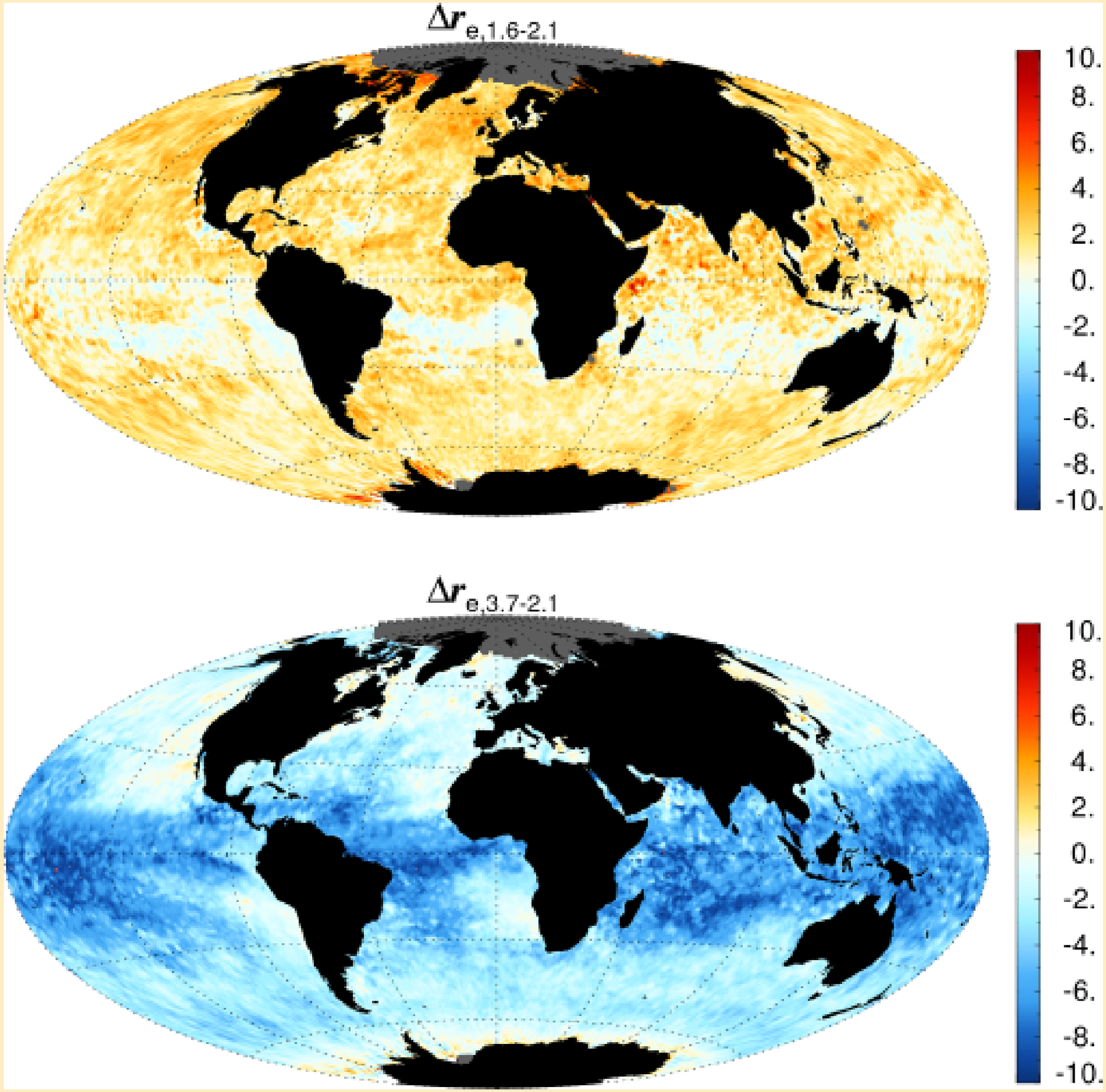
On the limits of instrument simulators (i): partly-cloudy pixels

The largest differences in estimates of cloud fraction between MODIS and other data streams stems from the treatment of partly-cloudy pixels

Most (~50-85%) optically thin pixels are in fact partly-cloudy

This sensitivity can not be represented in observation proxies because they don't produce cloudy pixels

But there are sensitivities we are only beginning to understand



Zhang and Platnick (2011), doi:10.1029/2011JD016216

On the limits of instrument simulators (ii): spectral dependence of r_e

On the limits of instrument simulators (ii): spectral dependence of r_e

Hints from observations

(optical thickness retrieved at different angles were rarely consistent;
Liang et al. 2009, doi:10.1029/2008GL037124)

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that led to understanding:

even fully cloudy pixels can be inhomogeneous
reflection is reduced in such pixels by an amount depending on wavelength
reduced reflection looks like absorption i.e. larger cloud drops

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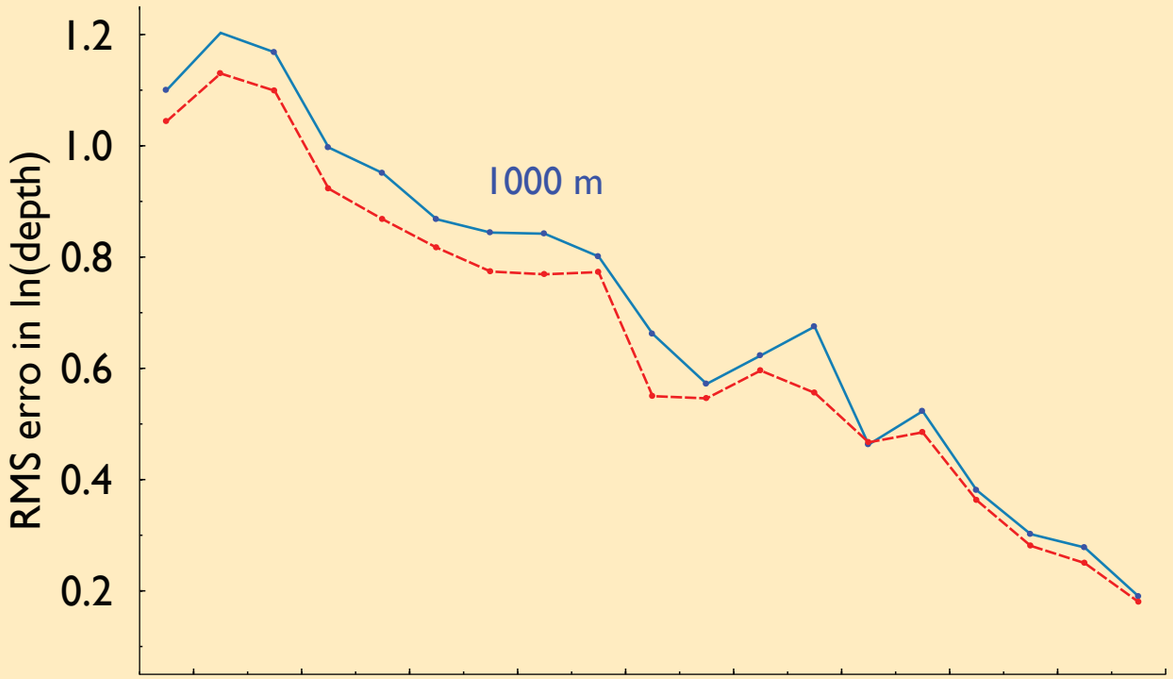
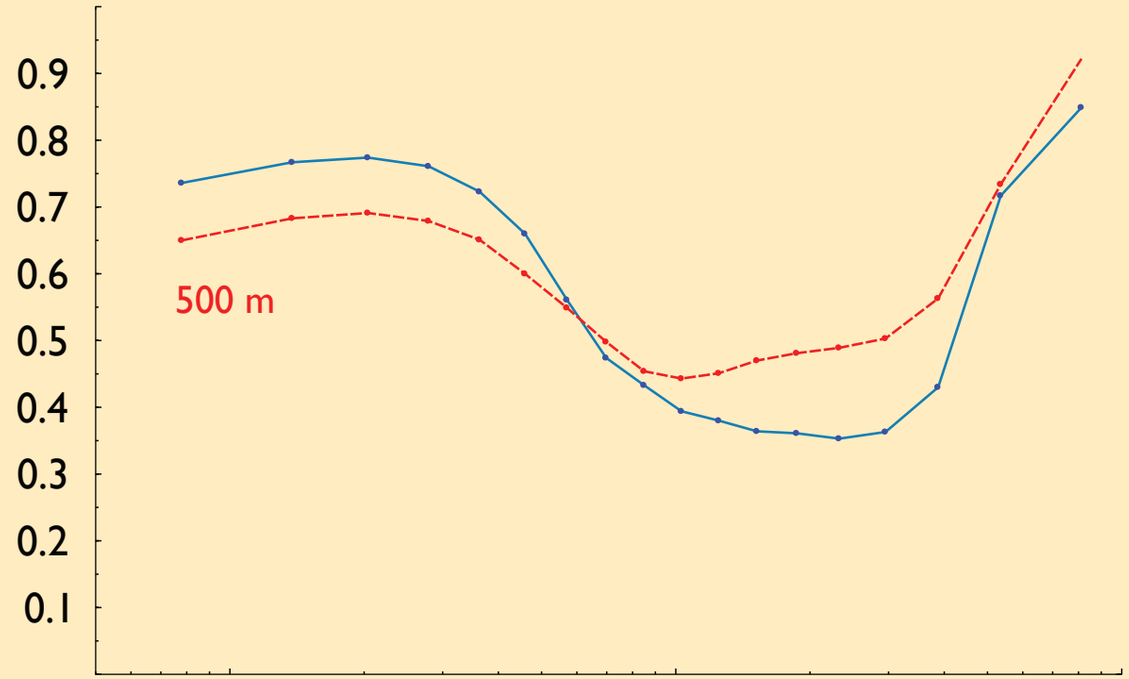
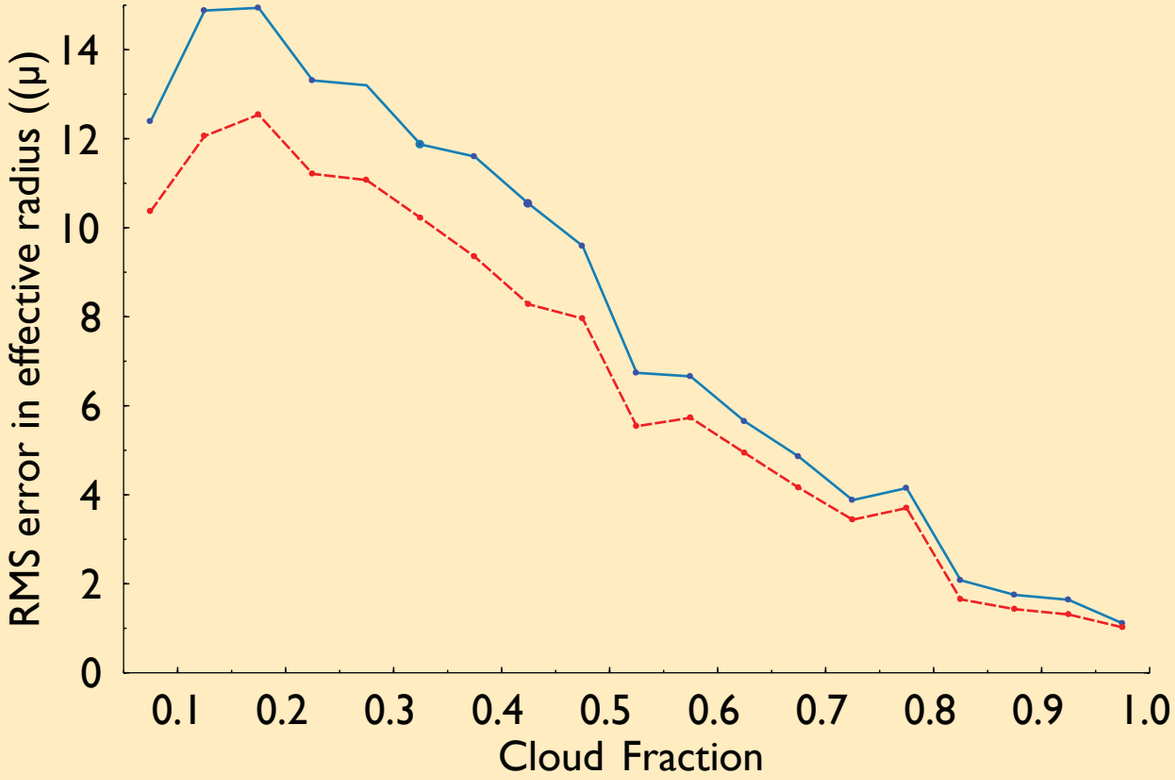
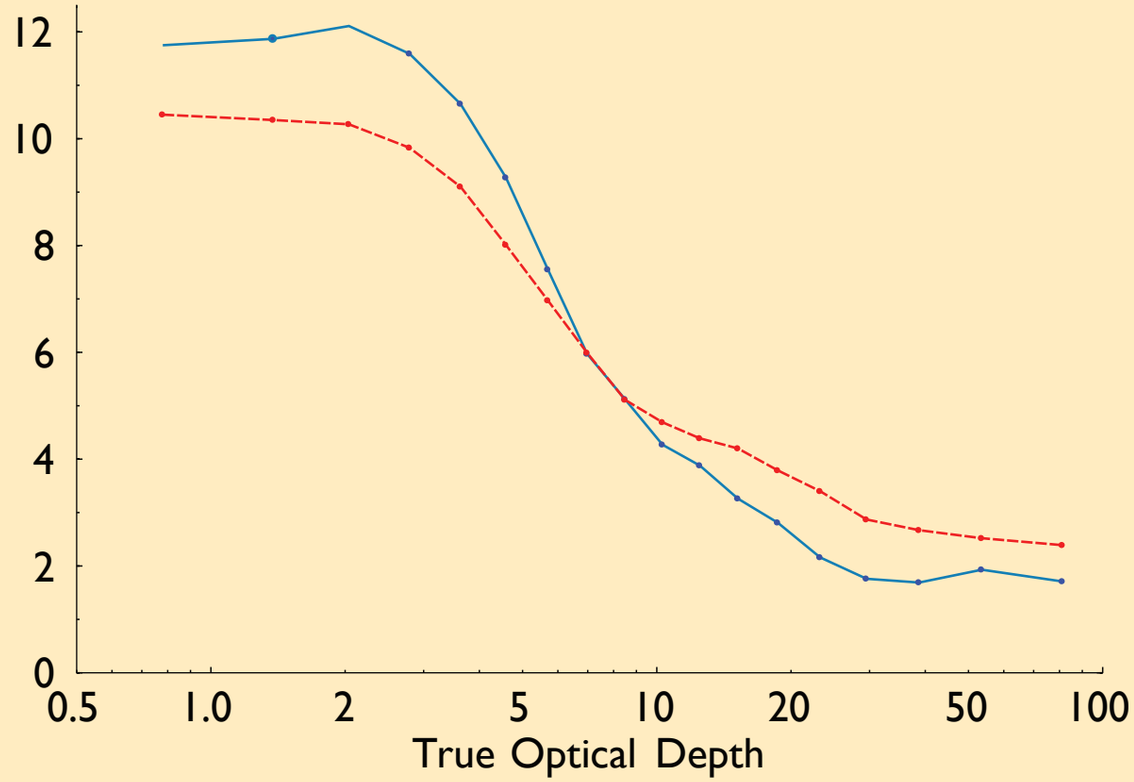
Like partly cloudy pixels, this isn't treated in observation proxies, making comparisons of modeled and observed size uninformative









pers. comm., Frank Evans, University of Colorado

Being careful what we wish for

Making relevant data more useful is a good thing

Finding common ground between retrievals and models is informing modeling

But too great an emphasis on success as "use by climate modelers" can deemphasize other valuable uses…

… and implies certainty in our data sets that we know isn't always warranted

Being careful what we do and say

Better than anyone the remote sensing community understands

the limits of the models we use and
how those limits impact our retrievals

We might be better served by devoting less energy to “products” and more to answering specific questions in context