

An Evaluation of Satellite-Based and Reanalysis Long-Term Radiation Budget Datasets Using CERES EBAF Products

Shashi K. Gupta¹, Paul W. Stackhouse, Jr.²,
J. Colleen Mikovitz¹, Stephen J. Cox¹, and Taiping Zhang¹

¹Science Systems and Applications, Inc.

²Science Directorate, NASA Langley Research Center
Hampton, Virginia

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Presentation Outline

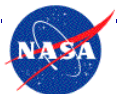
1. Introduce datasets used.
2. Objectives of the evaluation.
3. List evaluated parameters.
4. Discuss methodology used in the evaluation.
5. Present results and conclusions.

Datasets Used

- Reference Datasets:
CERES EBAF
- Evaluated Datasets:
NASA-GEWEX SRB
ISCCP-FD
MERRA
ERA-Interim

Objective of Evaluation

- Evaluate geographical distributions of radiation budget parameters relative to the reference fields.

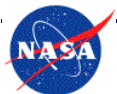


Parameters Evaluated

- TOA Outgoing Longwave Radiation (OLR)
- TOA Reflected Shortwave Radiation (RSR)
- Surface Downward Longwave Flux (DLF)
- Surface Downward Shortwave Flux (DSF)

Reference Datasets

- **CERES EBAF** (Energy Balanced and Filled)
TOA Fluxes Ed.-2.8 - Loeb *et al.* (2009): *J. Climate*, **22**, 748-766.
Surface Fluxes Ed.-2.7 – Kato *et al.* (2013): *J. Climate*, **26**, 2719-2740.
- CERES measured TOA fluxes balanced with ocean heat storage values by adjusting measurements to within retrieval uncertainties.
- Model-derived surface fluxes constrained by TOA fluxes. Obtained by adjusting model inputs within their uncertainties.
- Produced to meet the needs of climate modeling community.



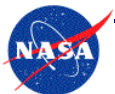
Evaluated Satellite-Based Datasets

1. **GEWEX SRB Release-3 Dataset** (produced at NASA LaRC)

- Surface and TOA radiative fluxes ($1^\circ \times 1^\circ$; 3-hourly; 24.5 years)
Input data: Cloud properties from ISCCP-DX data
Meteorological profiles from GEOS-4
Column ozone from TOMS, TOVS, and SMOBA
- Available at: eosweb.larc.nasa.gov/PRODOCS/srb/table_srb.html
- Reference: Stackhouse et al. (2011): *GEWEX News*, 21, Feb. 2011.

2. **ISCCP-FD Dataset** (produced at NASA GISS)

- Radiative fluxes at surface, TOA and at 3 level (280 km grid; 3-hourly; 21.5 years)
Input data: Meteorology mostly from TOVS
Ozone from TOMS
- Available at: isccp.giss.nasa.gov/projects/flux.html
- Reference: Zhang et al. (2004): *J. Geophys. Res.*, 109, D19105, (doi: 10.1029/2003JD004457)



Evaluated Reanalysis Datasets

1. MERRA

Modern Era Retrospective-analysis for Research and Applications.

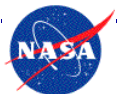
Reanalysis product from GMAO

Rienecker, M. M., and co-authors, (2011): *J. Climate*, 24, 3624-3648.
(doi: 10.1175/JCLI-D-11-00015.1)

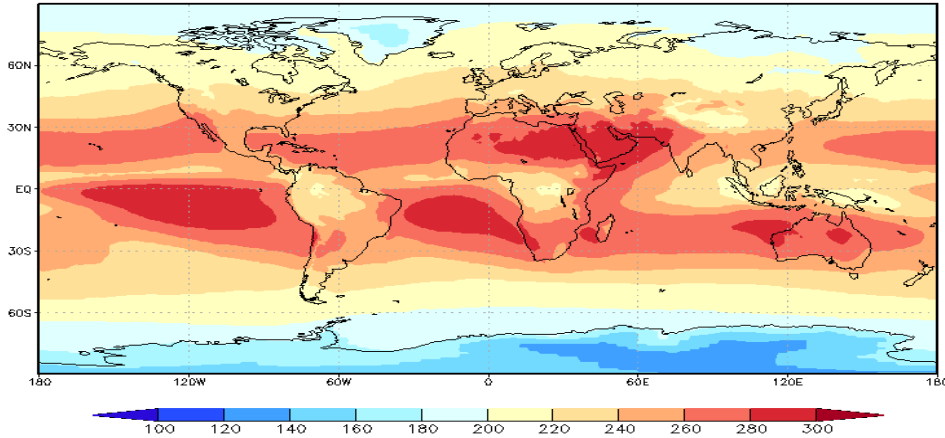
2. ERA-Interim

Latest reanalysis from ECMWF; preparatory to new ERA-40.

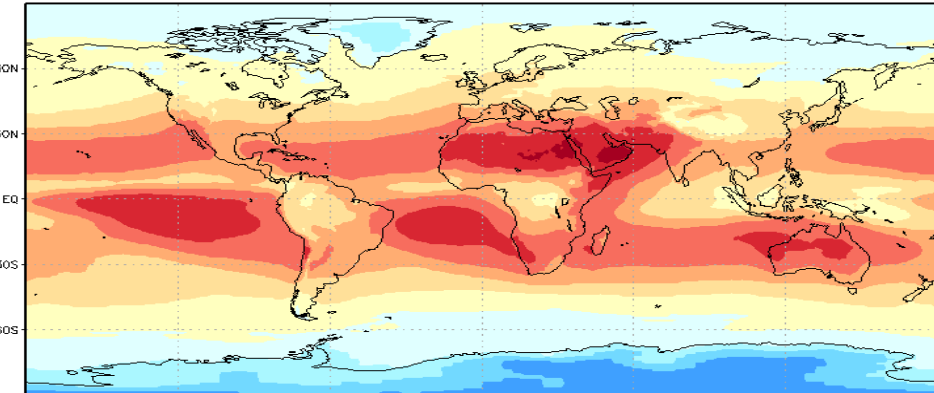
Dee, D. P., and co-authors, (2011): *Q. J. R. Meteorol. Soc.*, 137, 553-597. (doi: 10.1002/qj.828)



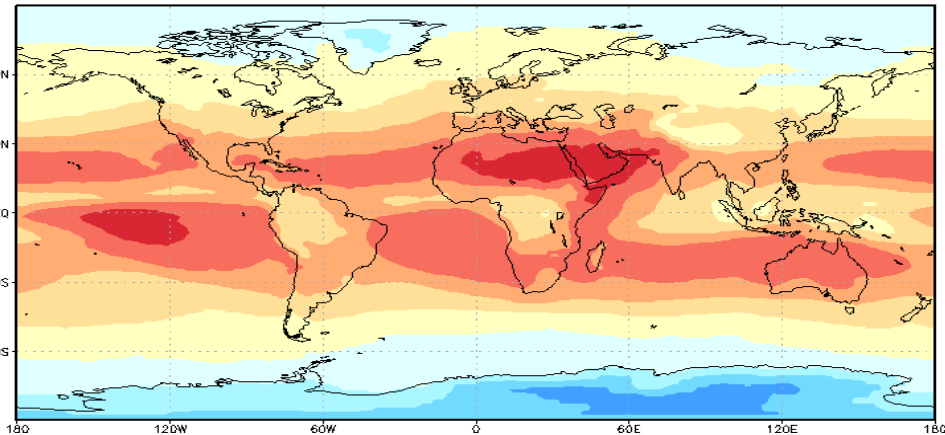
EBAF-2.8 OLR (W/m²) - 7-Year Avg. (2001-2007)



GEWEX-SRB OLR (W/m²) - 7-Year Avg. (2001-2007)



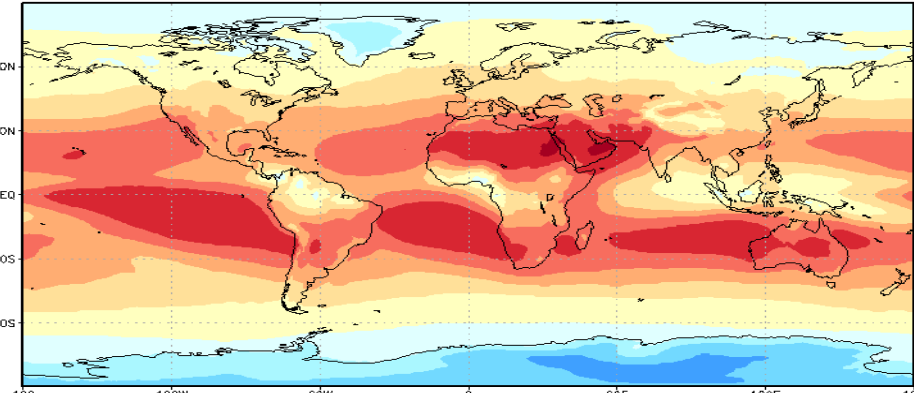
ISCCP-FD OLR (W/m²) - 7-Year Avg. (2001-2007)



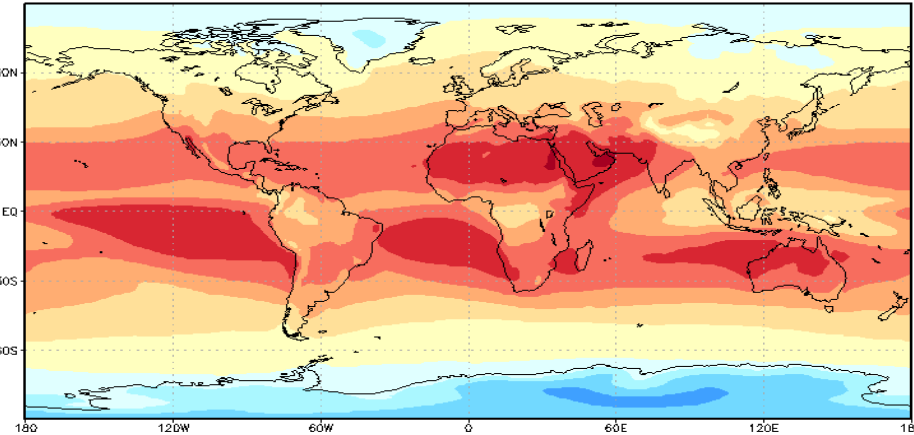
Comparison of 7-Year Average OLR Fields

Objective: Quantify agreement between the spatial patterns of test fields and the reference field.

MERRA OLR (W/m²) - 7-Year Avg. (2001-2007)

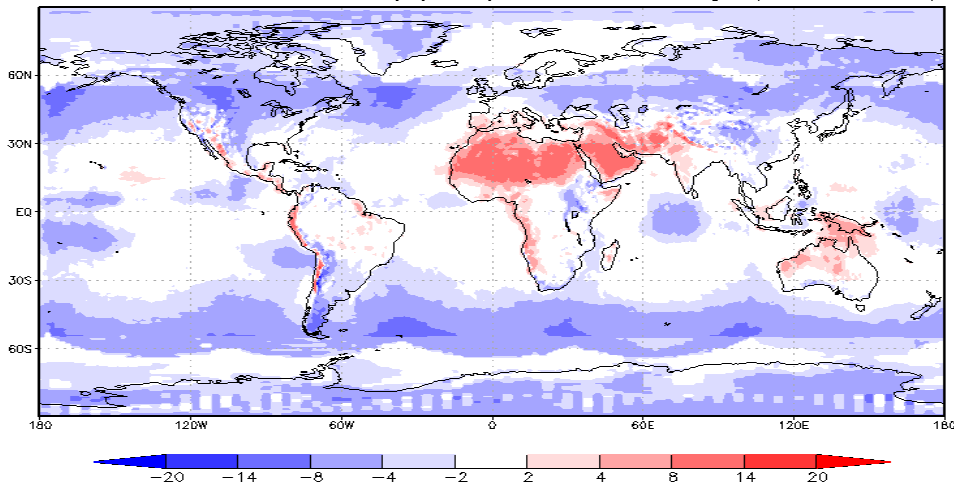


ERA-Interim OLR (W/m²) - 7-Year Avg. (2001-2007)



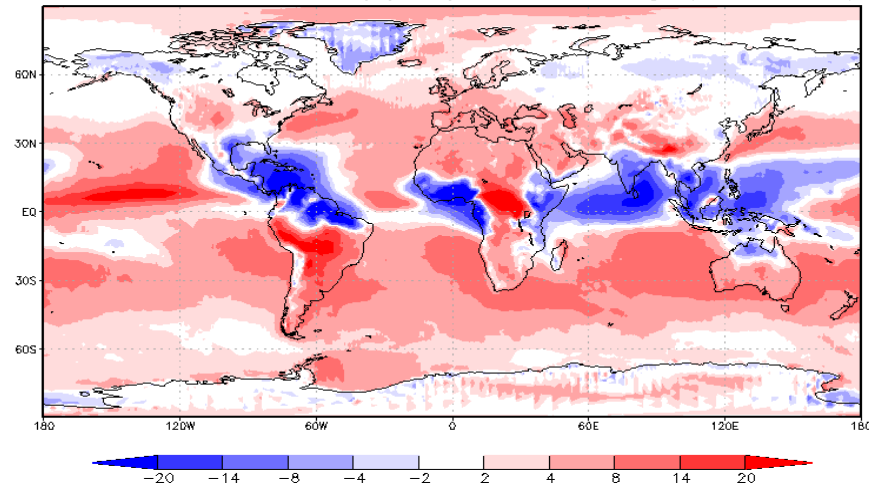
Difference Fields

GEWEX-EBAF OLR Diff. (W/m^2) - 7-Year Avg. (2001-2007)



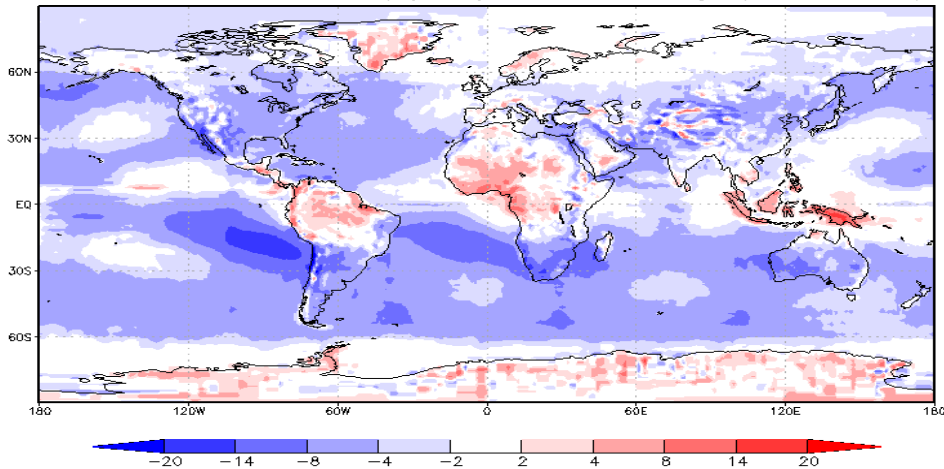
Global Average = -1.8

MERRA-EBAF OLR Diff. (W/m^2) - 7-Year Avg. (2001-2007)



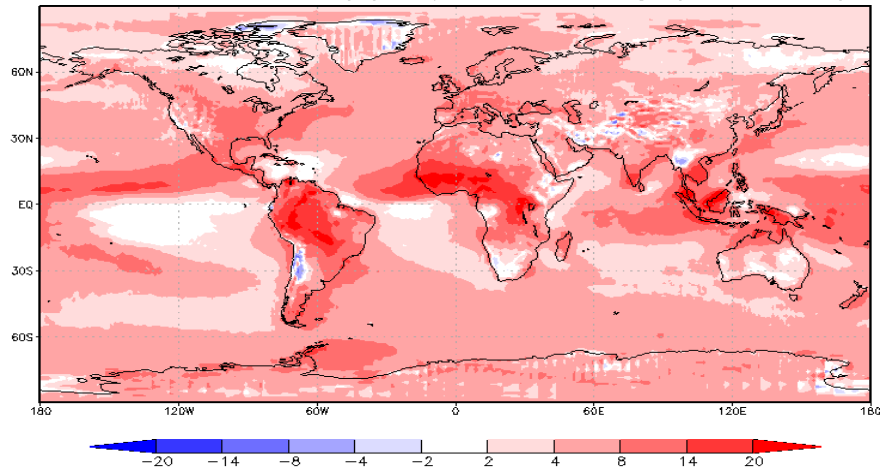
Global Average = 2.6

ISCCP-EBAF OLR Diff. (W/m^2) - 7-Year Avg. (2001-2007)



Global Average = -3.5

ERA-EBAF OLR Diff. (W/m^2) - 7-Year Avg. (2001-2007)



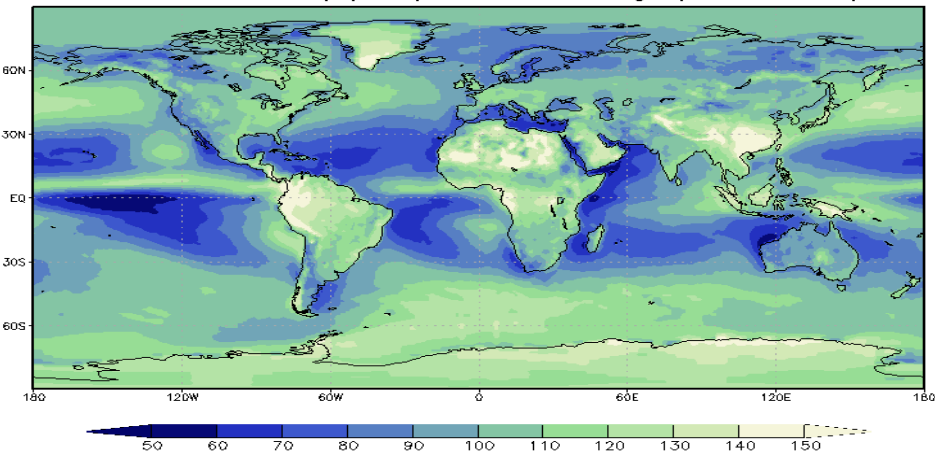
Global Average = 6.2



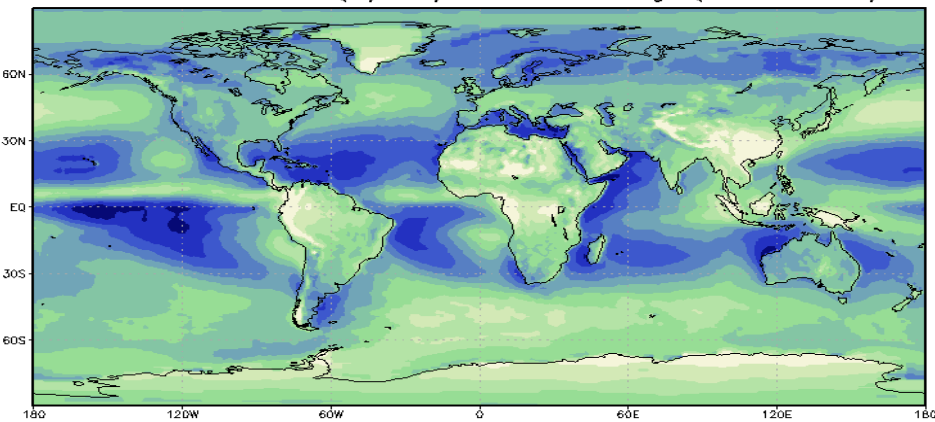
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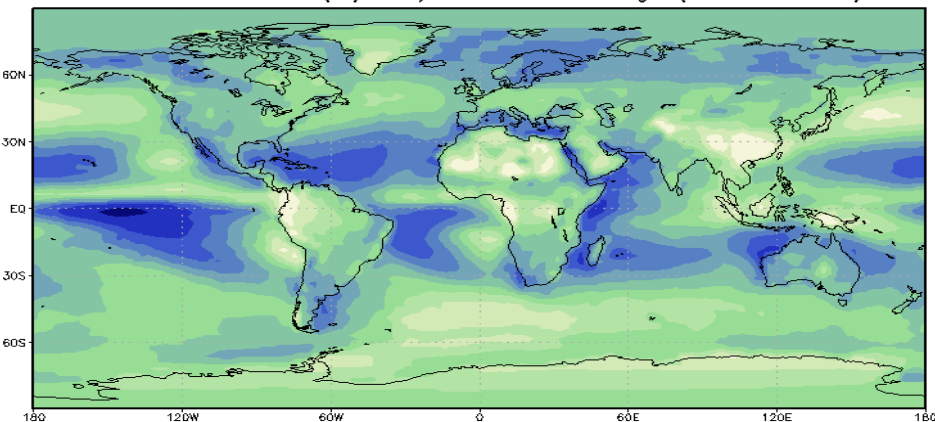
EBAF-2.8 RSR (W/m^2) - 7-Year Avg. (2001-2007)



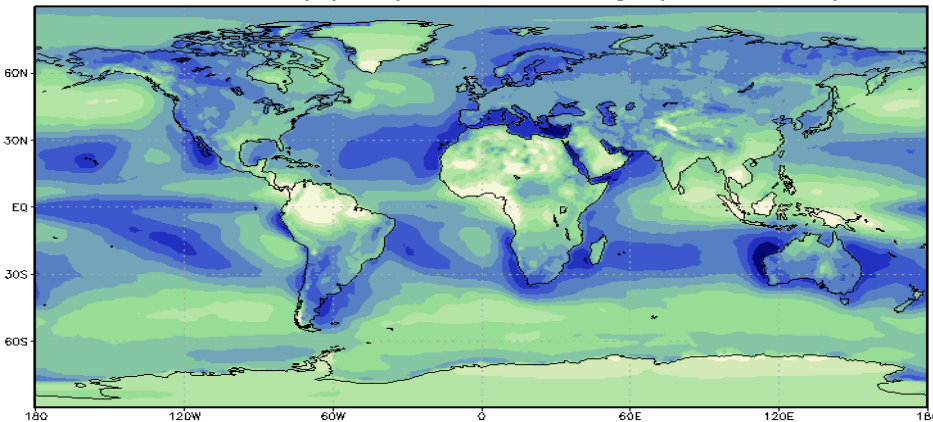
GEWEX-SRB RSR (W/m^2) - 7-Year Avg. (2001-2007)



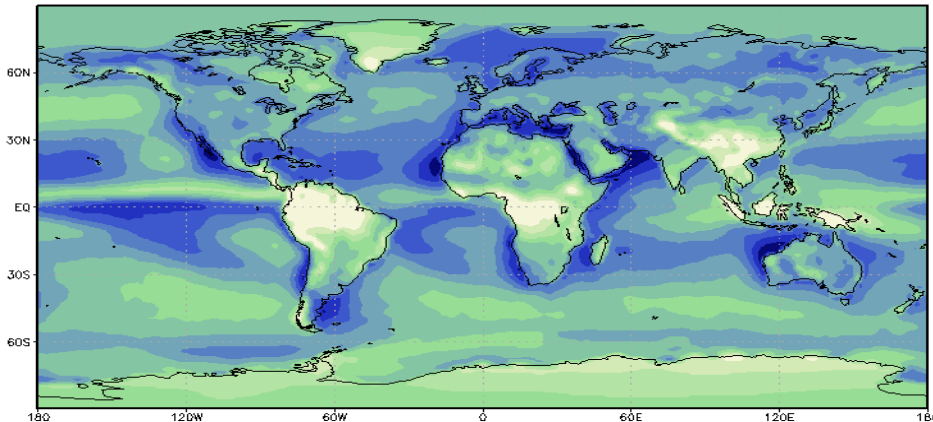
ISCCP-FD RSR (W/m^2) - 7-Year Avg. (2001-2007)



MERRA RSR (W/m^2) - 7-Year Avg. (2001-2007)

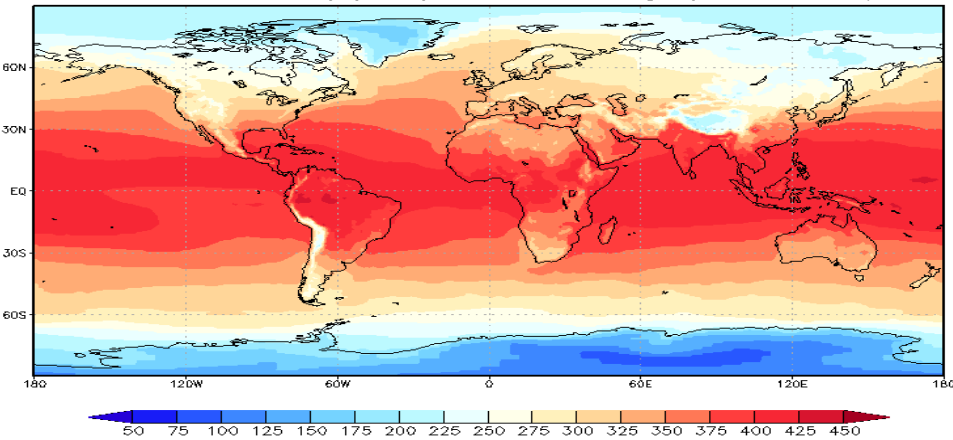


ERA-Interim RSR (W/m^2) - 7-Year Avg. (2001-2007)



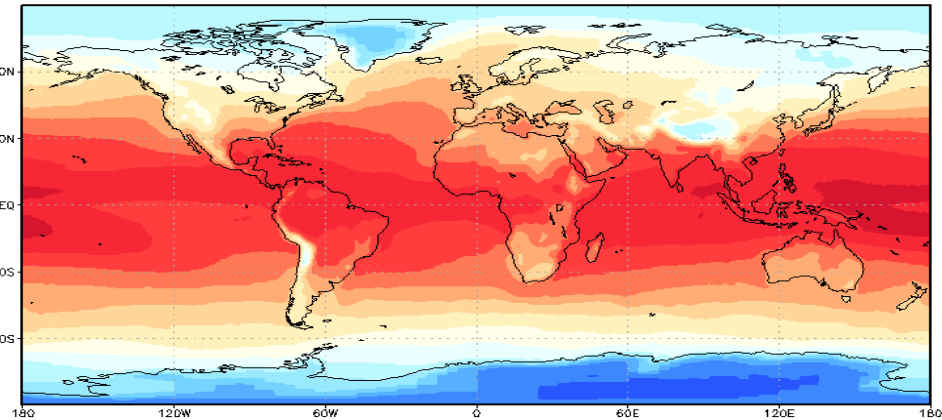
Comparison of 7-Year
Average RSR Fields.
Similar analysis was done
for the other 3 parameters

EBAF-2.7 DLF (W/m²) - 7-Year Avg. (2001-2007)

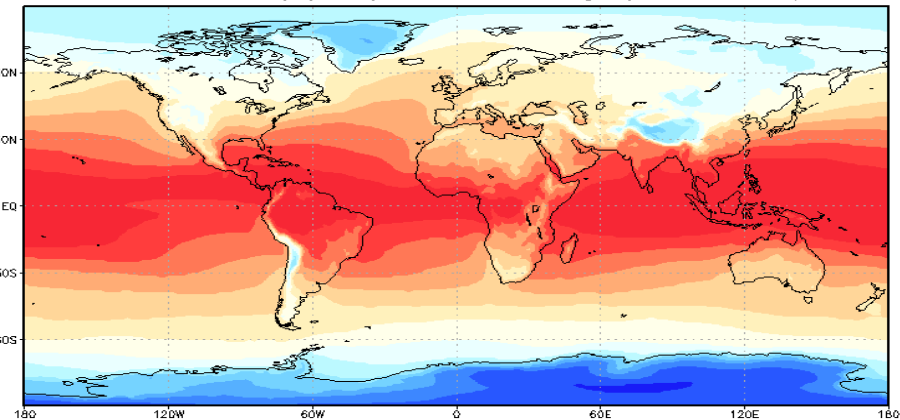


Comparison of 7-Year Average DLF Fields

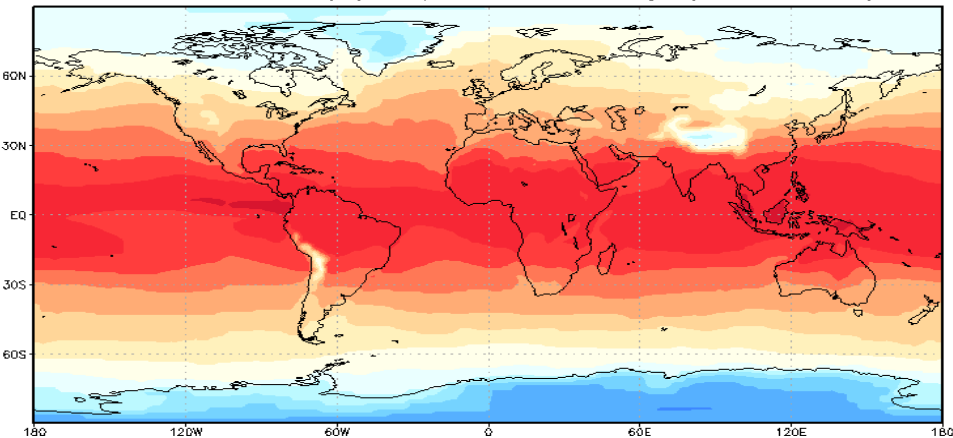
GEWEX-SRB DLF (W/m²) - 7-Year Avg. (2001-2007)



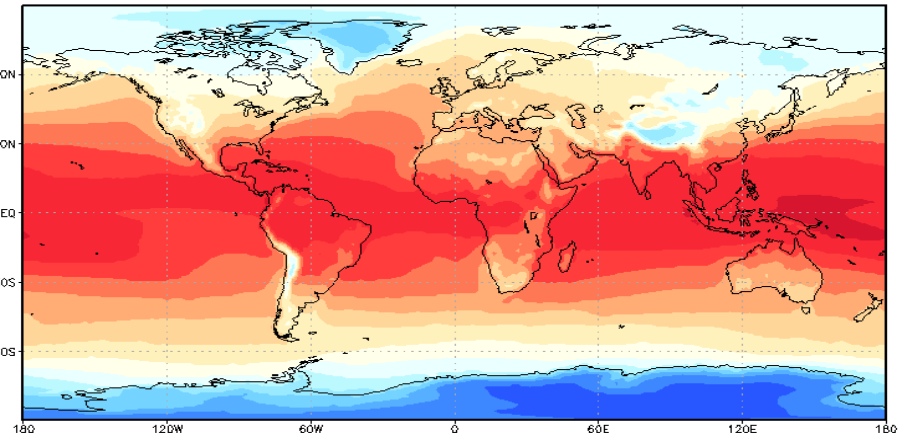
MERRA DLF (W/m²) - 7-Year Avg. (2001-2007)



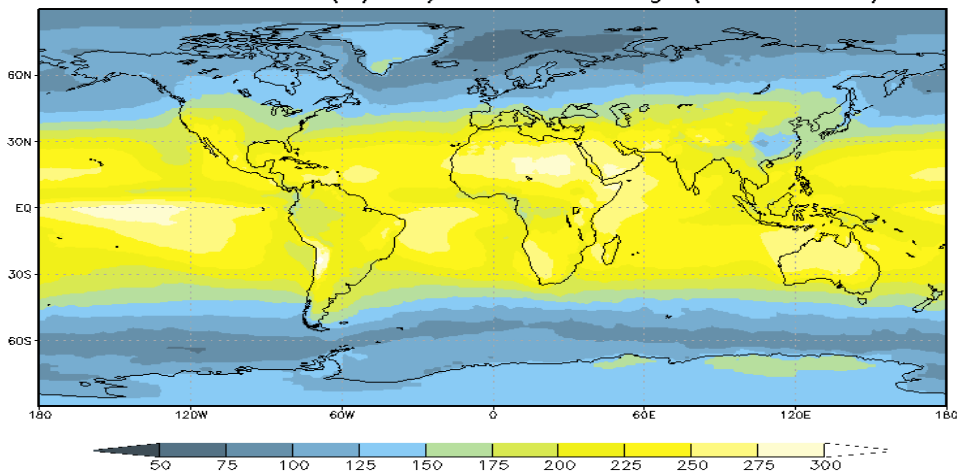
ISCCP-FD DLF (W/m²) - 7-Year Avg. (2001-2007)



ERA-Interim DLF (W/m²) - 7-Year Avg. (2001-2007)

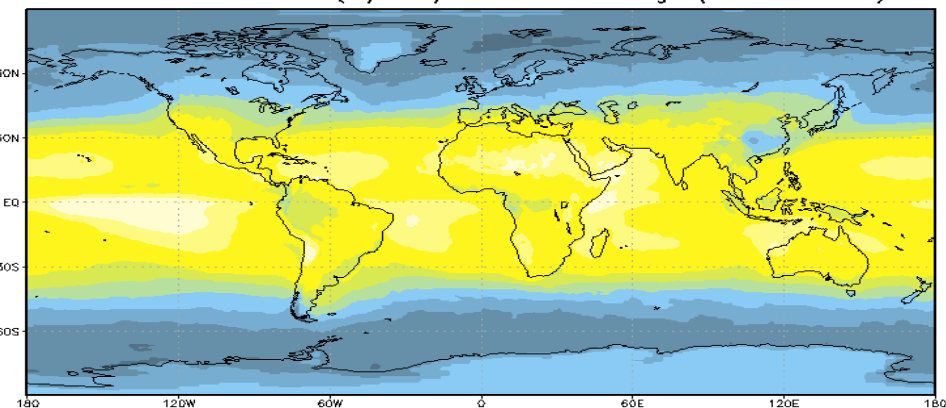


EBAF-2.7 DSF (W/m²) - 7-Year Avg. (2001-2007)

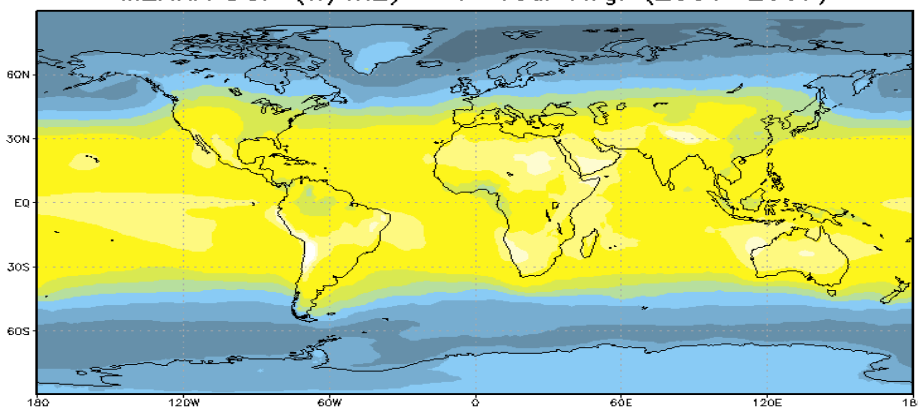


Comparison of 7-Year Average DSF Fields

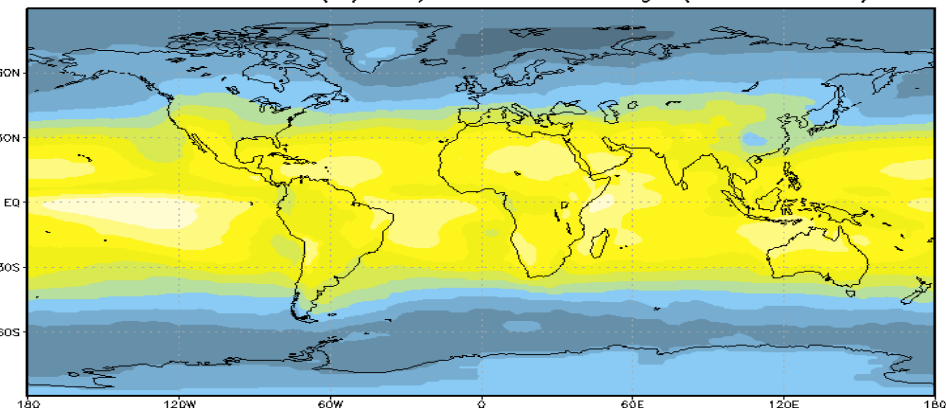
GEWEX-SRB DSF (W/m²) - 7-Year Avg. (2001-2007)



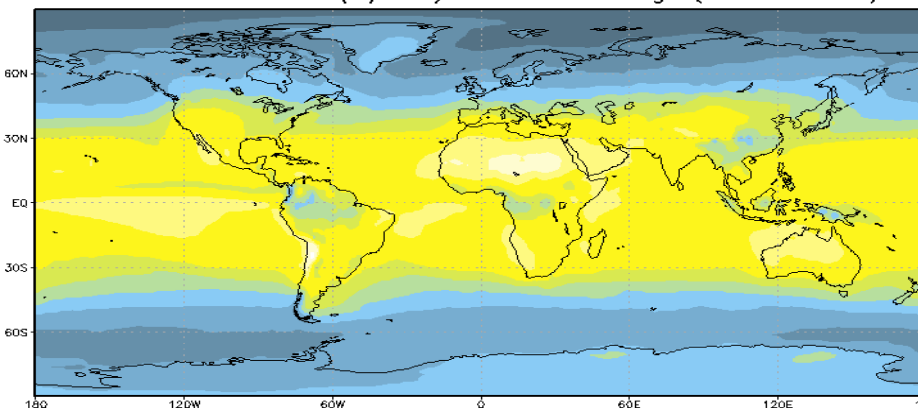
MERRA DSF (W/m²) - 7-Year Avg. (2001-2007)



ISCCP-FD DSF (W/m²) - 7-Year Avg. (2001-2007)



ERA-Interim DSF (W/m²) - 7-Year Avg. (2001-2007)



Methodology – Taylor Diagram

- Comparison of Three Statistical Parameters:
(Taylor, K. E. (2001): *JGR*, **106**, 7183-7193.)

1. Correlation Coefficient (R) between the fields:

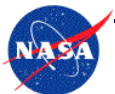
$$R = \frac{1}{N} \frac{\sum (f_n - \bar{f})(r_n - \bar{r})}{s_f s_r}$$

where f represents the test variable and r the reference variable. σ_f and σ_r are their standard deviations. High correlation coeff. demonstrates a correspondence between the spatial patterns.

2. Standard Deviations (σ) of the two fields:

$$s_f^2 = \frac{1}{N} \sum (f_n - \bar{f})^2 \quad \text{and} \quad s_r^2 = \frac{1}{N} \sum (r_n - \bar{r})^2$$

comparable values of standard deviations indicates that range of values in the two fields are comparable.



Methodology (contd.)

3. RMS Difference (E):

$$E^2 = \frac{1}{N} \sum (f_n - r_n)^2$$

quantifies the difference between the corresponding values in the two fields but includes the bias between them.

Centered RMS Difference (E'):

$$E'^2 = \frac{1}{N} \sum [(f_n - \bar{f}) - (r_n - \bar{r})]^2$$

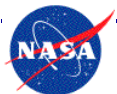
centered RMS removes the effect of mean bias from the RMS. An accurate measure of the difference between the patterns.

The two are related as

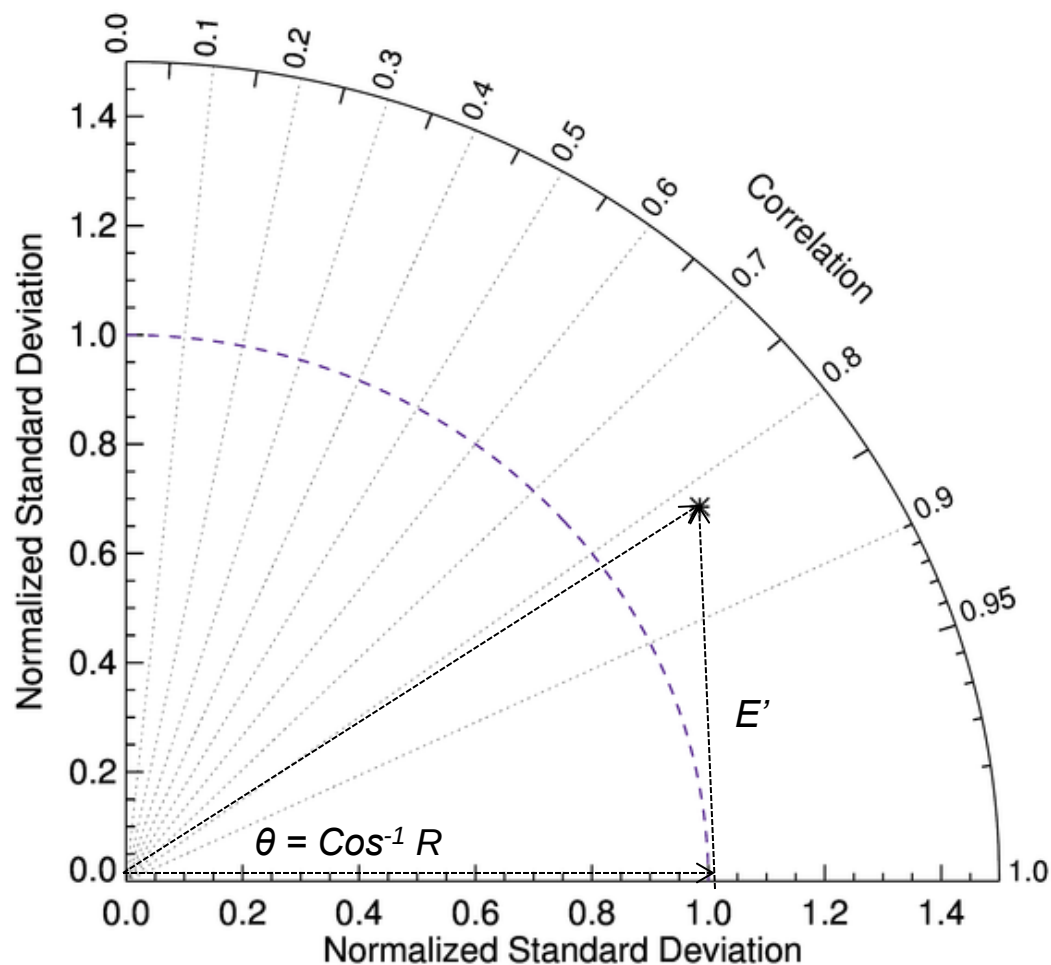
$$E'^2 = E^2 - \bar{E}^2 \quad \text{where} \quad \bar{E} = (\bar{f} - \bar{r}) \quad \text{mean bias of the test field.}$$

These 3 parameters are related as:

$$E'^2 = s_f^2 + s_r^2 - 2s_f s_r R$$



Example Taylor Diagram



$$E'^2 = s_f^2 + s_r^2 - 2s_f s_r R$$

On this 2-D diagram,
a single point represents
all 3 statistical parameters.

The 3 parameters are related
by the law of cosines:

$$c^2 = a^2 + b^2 - 2ab \cos \theta$$

Standard deviations and E' are normalized by the standard
deviation for the reference field.

Taylor Diagrams

The diagram for each parameter, a 2-D plot, shows all 3 measures of agreement between the field patterns. These diagrams allow a visual judgment of the of the agreement.

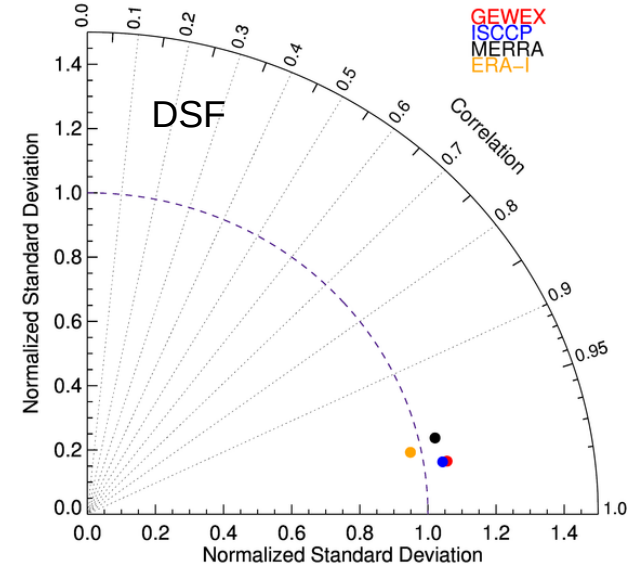
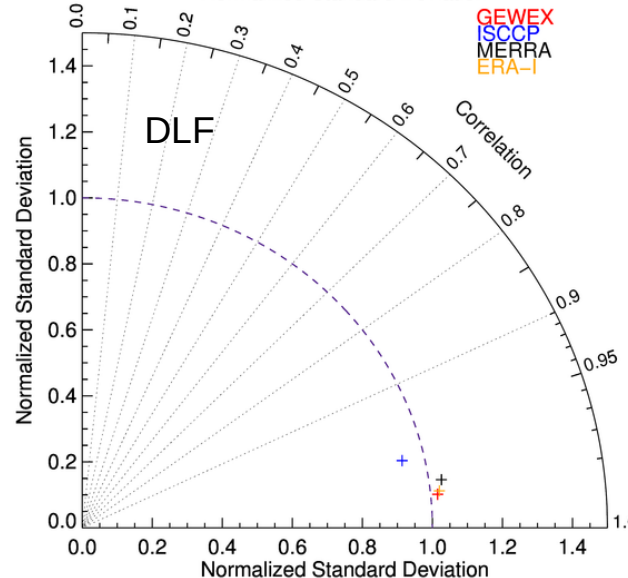
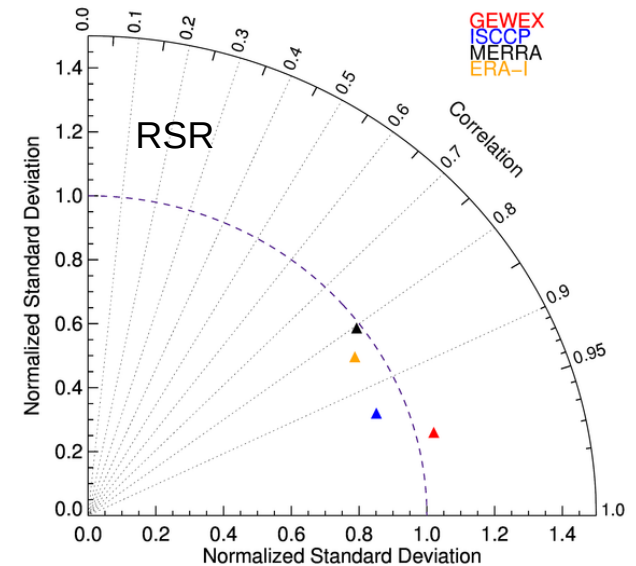
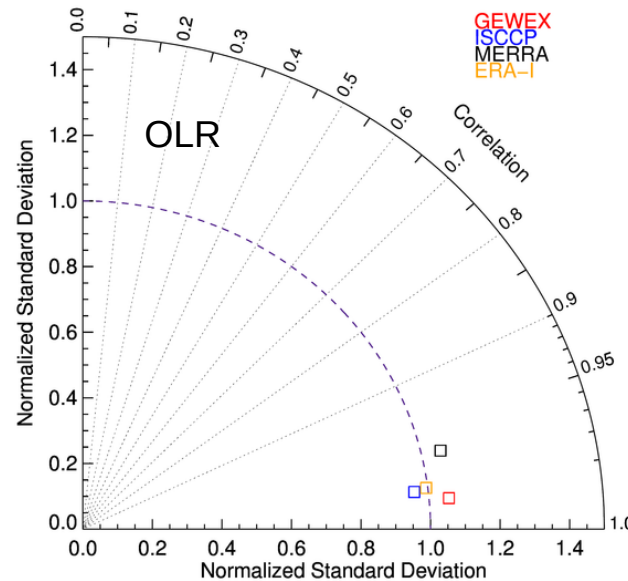
Best Agreement:

OLR: ERA-I

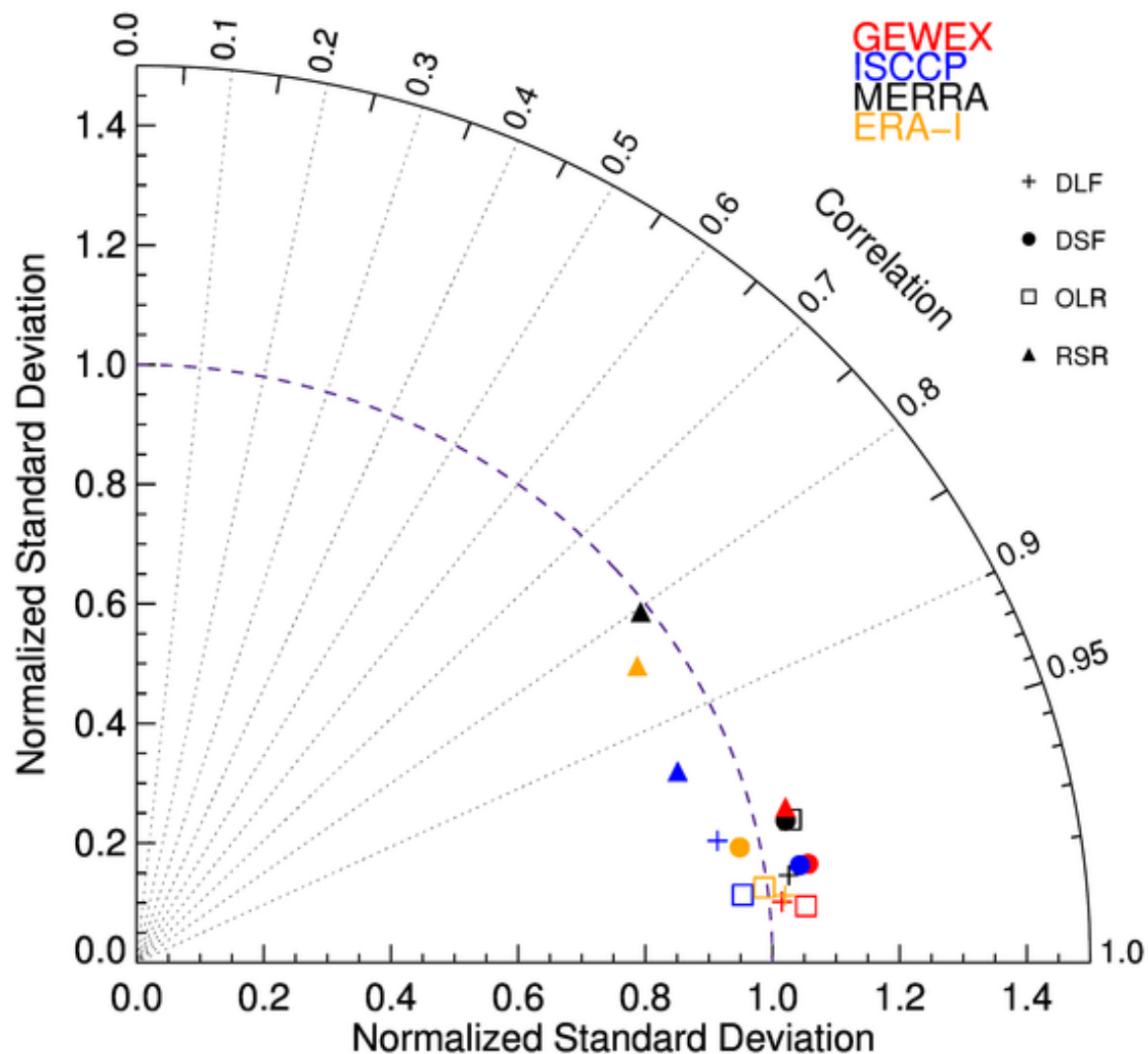
RSR: GEWEX

DLF: GEWEX

DSF: ISCCP



Combined Taylor Diagram



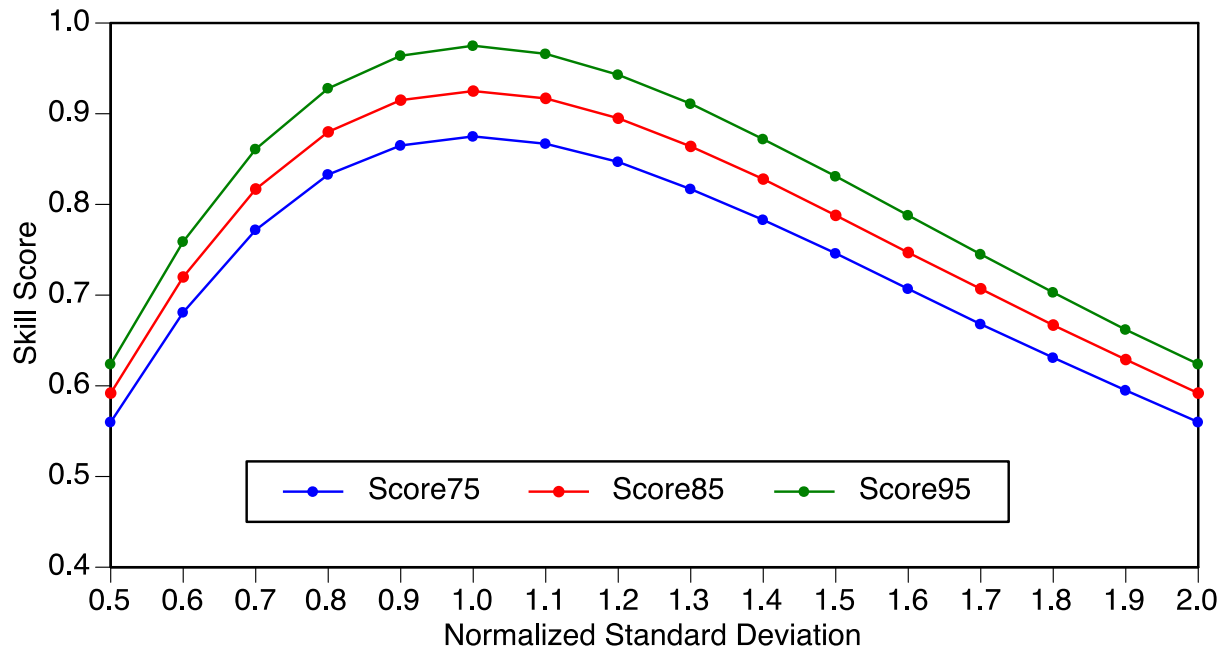
Many models and many parameters can be put on a single diagram.

Skill Score

- Skill Score (SS) defined as:

$$SS = \frac{2(1 + R)}{(\rho_f + 1/\rho_f)^2}$$

R – Correlation Coefficient and $\rho_f = \sigma_f / \sigma_r$, the normalized standard deviation of the test field. SS defined above does not take the effect of bias into account, though bias degrades the skill of the model. Hence, we developed a modified SS.



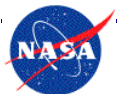
Multiyear Global Averages and Biases

Flux Model	OLR	RSR	DLF	DSF
EBAF (2.8/2.7)	239.81	99.60	345.27	186.68
GEWEX-SRB	238.03	101.99	344.29	186.93
Bias	-1.78	2.39	-0.98	0.24
Rel. Bias (%)	-0.74	2.40	-0.28	0.13
ISCCP-FD	236.30	105.51	346.25	186.61
Bias	-3.51	5.91	0.98	-0.07
Rel. Bias (%)	-1.46	5.92	0.28	-0.04
MERRA	242.39	99.56	330.88	191.66
Bias	2.58	-0.04	-14.39	4.98
Rel. Bias (%)	1.08	-0.04	-4.17	2.67
ERA-Interim	245.95	98.59	341.84	186.07
Bias	6.14	-1.01	-3.43	-0.61
Rel. Bias (%)	2.56	-1.01	-0.99	-0.33

Bias = Test Value – Reference Value

Relative Bias = Bias/Reference Value

Relative Bias (%) = Relative Bias x 100



Modified Skill Score (*ESS*)

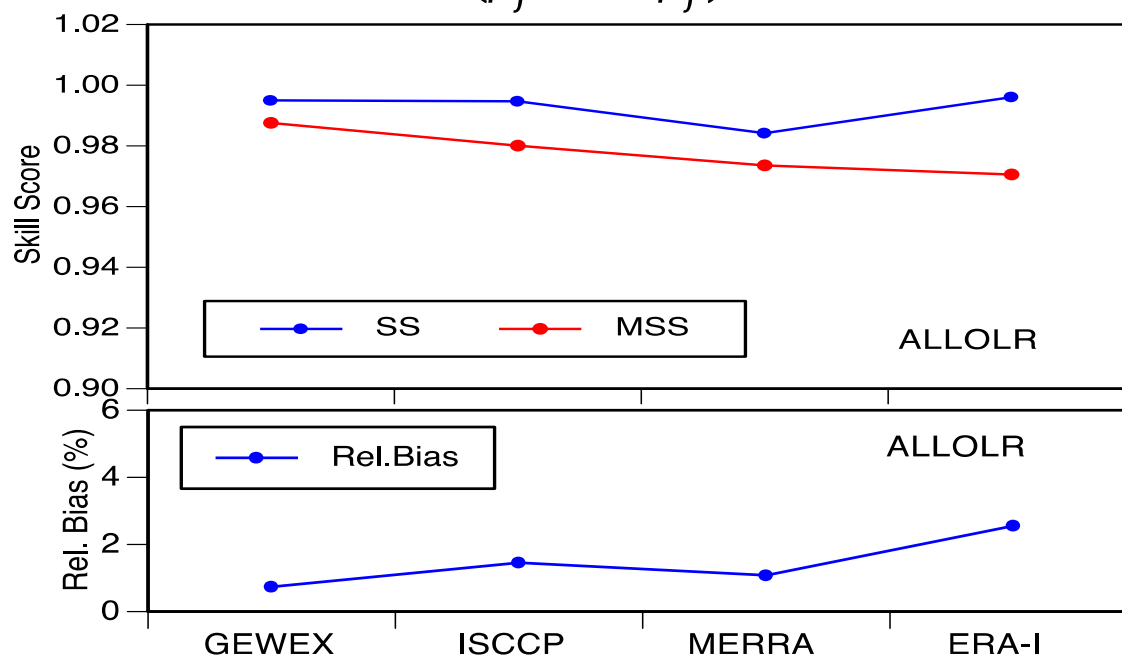
Defined Bias Factor (*BF*) as:

$$BF = \left(1 - \frac{|\bar{f} - \bar{r}|}{\bar{r}}\right) = \left(1 - \frac{|\bar{E}|}{\bar{r}}\right)$$

and defined a Modified Skill Score (*MSS*) as:

$$MSS = SS \times BF$$

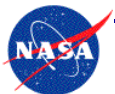
$$MSS = \left(\frac{2(1 + R)}{(\rho_f + 1/\rho_f)^2}\right) \left(1 - \frac{|\bar{E}|}{\bar{r}}\right)$$



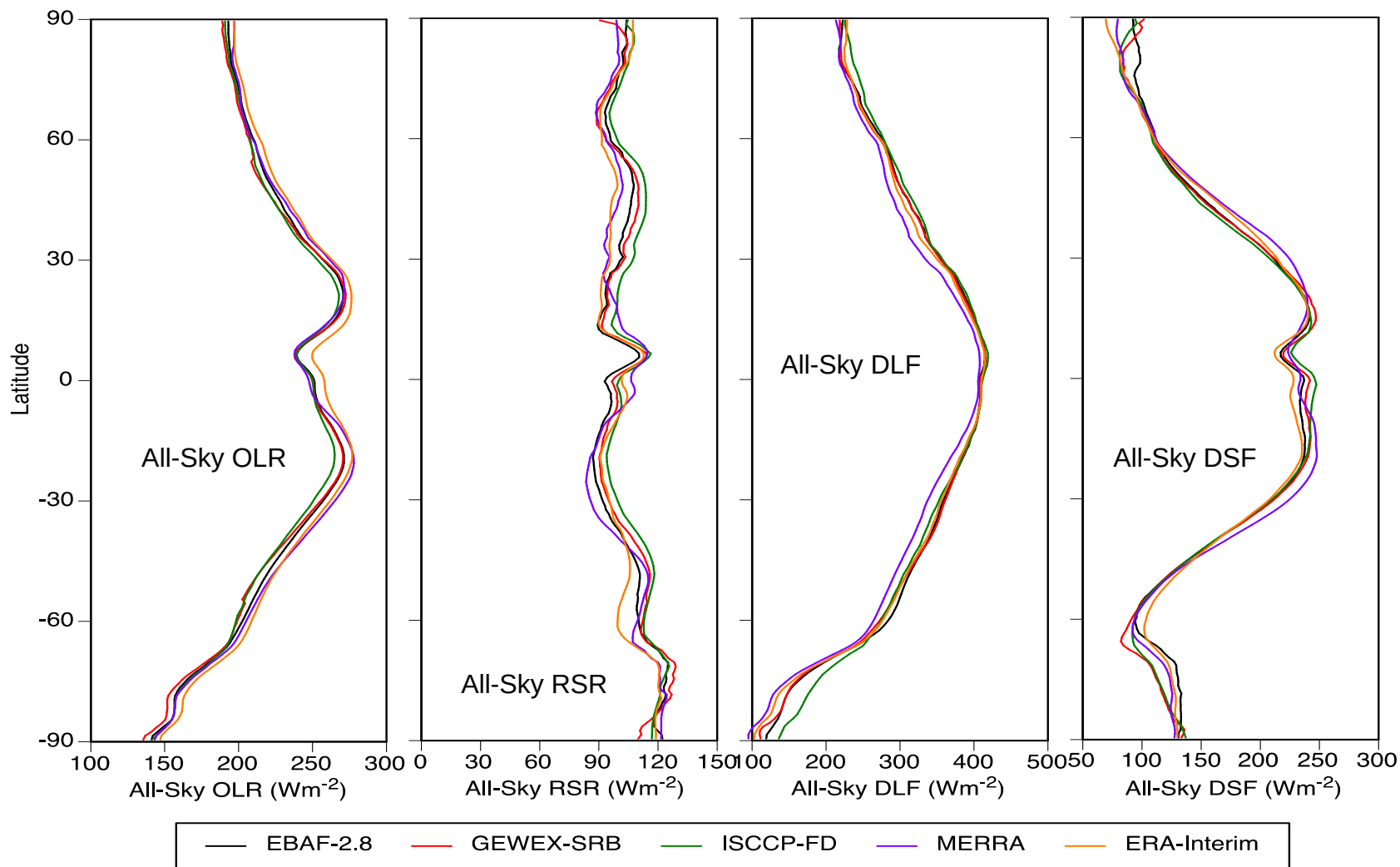
Skill Score and Modified Skill Score

Model	Stats	OLR	RSR	DLF	DSF
GEWEX-SRB	IRel. BiasI(%)	0.74	2.40	0.28	0.13
	SS	0.9950	0.9816	0.9969	0.9895
	MSS	0.9876	0.9581	0.9941	0.9882
ISCCP-FD	IRel. BiasI(%)	1.46	5.92	0.28	0.04
	SS	0.9947	0.9592	0.9839	0.9911
	MSS	0.9801	0.9024	0.9811	0.9908
MERRA	IRel. BiasI(%)	1.08	0.04	4.17	2.67
	SS	0.9842	0.9020	0.9940	0.9847
	MSS	0.9736	0.9016	0.9525	0.9584
ERA-Interim	IRel. BiasI(%)	2.56	1.01	0.99	0.33
	SS	0.9961	0.9182	0.9963	0.9890
	MSS	0.9706	0.9089	0.9864	0.9858

The second value in each box confirm the best agreements as indicated on the 4 Taylor diagrams. The first and the third values show that higher relative bias causes larger degradation of the skill score.



Multiyear Zonal Averages



This method can be applied equally well to zonal average distributions.



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Summary and Concluding Remarks

- All-sky LW and SW, TOA and surface fluxes from 4 sources were evaluated. Two were satellite-based: GEWEX-SRB Release-3, and ISCCP-FD; other two, re-analysis models: MERRA and ERA-Interim.
- Reference data came from CERES EBAF products. Edition-2.8 for TOA, and Edition-2.7 for surface.
- Applied Taylor Diagram method for evaluating agreement between geographical distribution of the fluxes.
- Taylor diagrams allow display of multiple measures of agreement on a 2-D plot and also a visual judgment of their quality.
- One model does not provides best agreement for all parameters. GEWEX for RSR and DLF; ERA-I for OLR and ISCCP for DSF.
- This method can also provide a numerical skill score for agreement, though that does not account for the biases between models.
- A modified skill score is proposed for taking account of biases between models. Demonstrated to exhibit desired characteristics.

