# Surface Atmosphere Radiation Budget (SARB) working group update

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CERES Science team meeting
Sep. 1-3, 2015
Seattle, WA

# SARB working group

- Provides surface and within-atmosphere irradiances using a 1D radiative transfer model initialized with multiple data sources
- Data products
  - EBAF-surface (monthly 1°×1° grids, available through Feb. 2015)
  - SYN1deg (3hourly, daily, and monthly 1°×1°, TOA, surface, 500 hPa, 200 hPa, and 70 hPa)
  - C3M (Level 2 with CALIPSO, CloudSat, CERES, and MODIS data, irradiance profile)
- Inputs for computing surface irradiances
  - Cloud properties derived from imager (MODIS, GEOs)
  - Temperature and humidity profile from GMAO reanalysis (GEOS)
  - Albedo history maps (land only. Derived from clear-sky CERES observations)
  - Daily snow and ice maps
  - MODIS aerosol optical thickness (through an aerosol transport model, MATCH)
  - CALIPSO/CloudSat derived cloud properties and AIRS derived upper tropospheric relative humidity (indirectly), as well as temperature and humidity profiles.

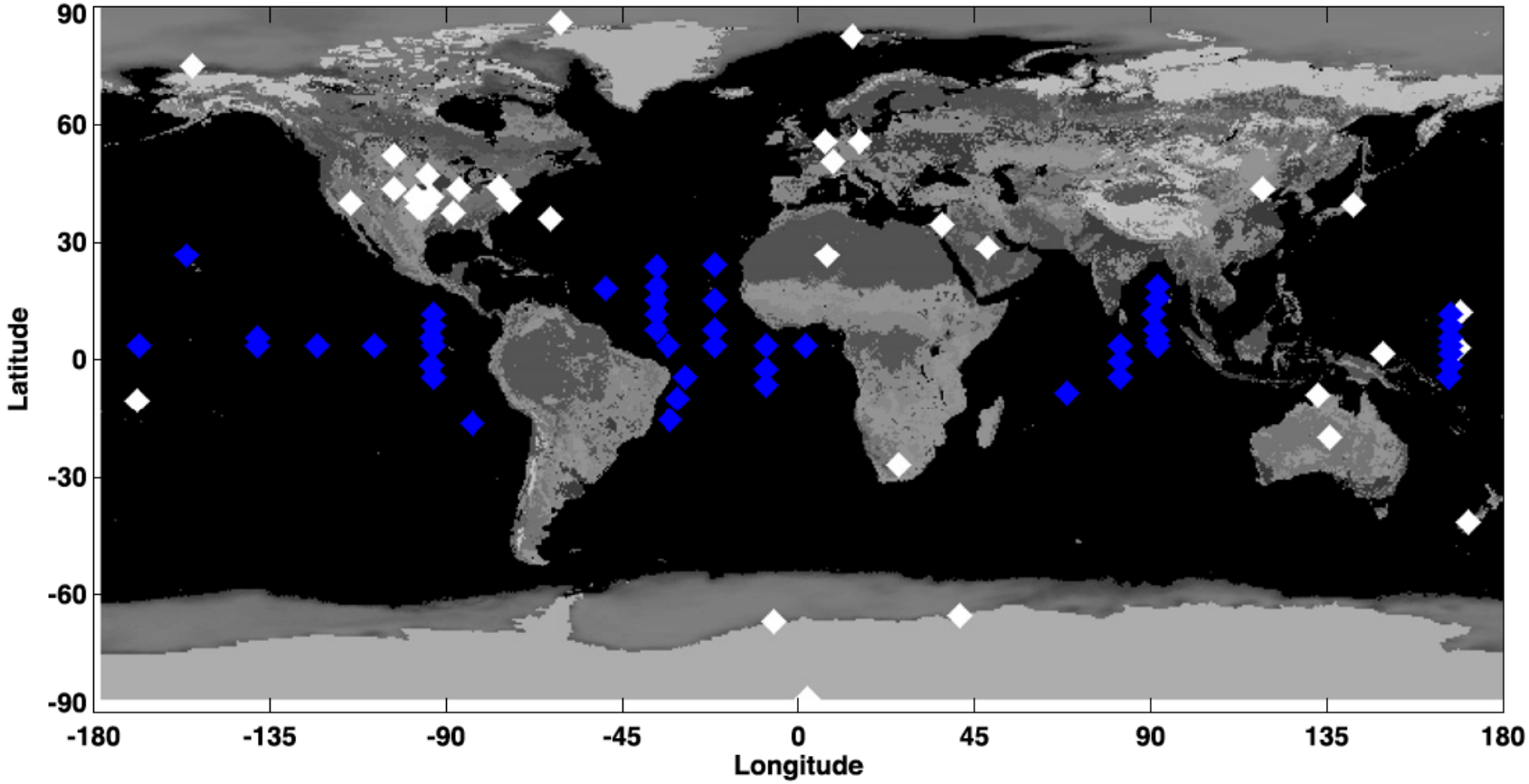
# Outline of this talk (and current SARB activities)

- Evaluation of surface irradiance (Ed3 SYN and EBAF)
  - New web-based tool
  - Comparisons with ship data
  - Surface observation uncertainty
  - MERRA surface irradiance evaluation
- Comparison of spectral radiances over Dome-C
- Evaluation of multi-layer cloud algorithm
- Preliminary result of Ed4 SYN (by Fred Rose)
- Ed4 EBAF-surface algorithm (separate talk)
  - Spectral information (irradiance)
  - Spectral finger printing (temperature and humidity correction)
- Ed4 C3M
  - Include Ed4 codes and new version of CALIPSO /CloudSat products
- Atmospheric energy budget (assessing the consistency with precipitation and atmospheric divergence)
  - Toward closing observation-based energy imbalance
  - Energy balance in ERA-Interim and MERRA
- Aerosol radiative effect and sensitivity studies with C3M
  - Working with the CALIPSO science team

# Evaluation of surface irradiance

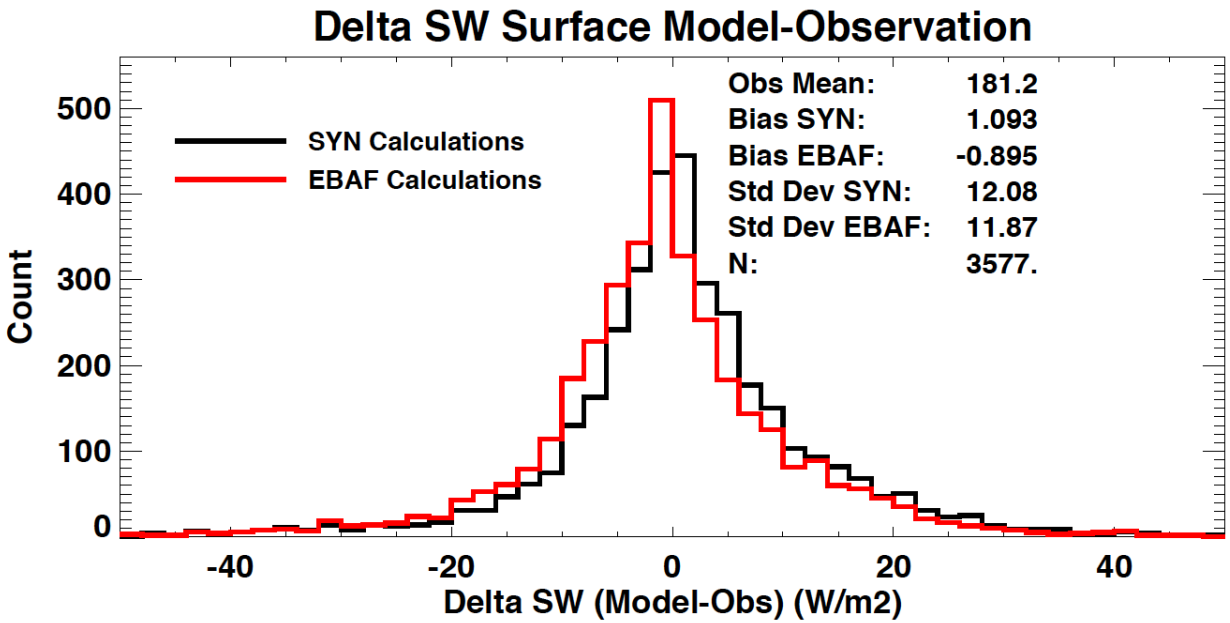
- 37 land sites
- 48 Ocean buoys
- Field campaign data
  - ARISE (Arctic)
  - MAGIC and other measurements from ships
- Two regions we need to focus on are polar regions and ocean (especially shallow cumulus regions)

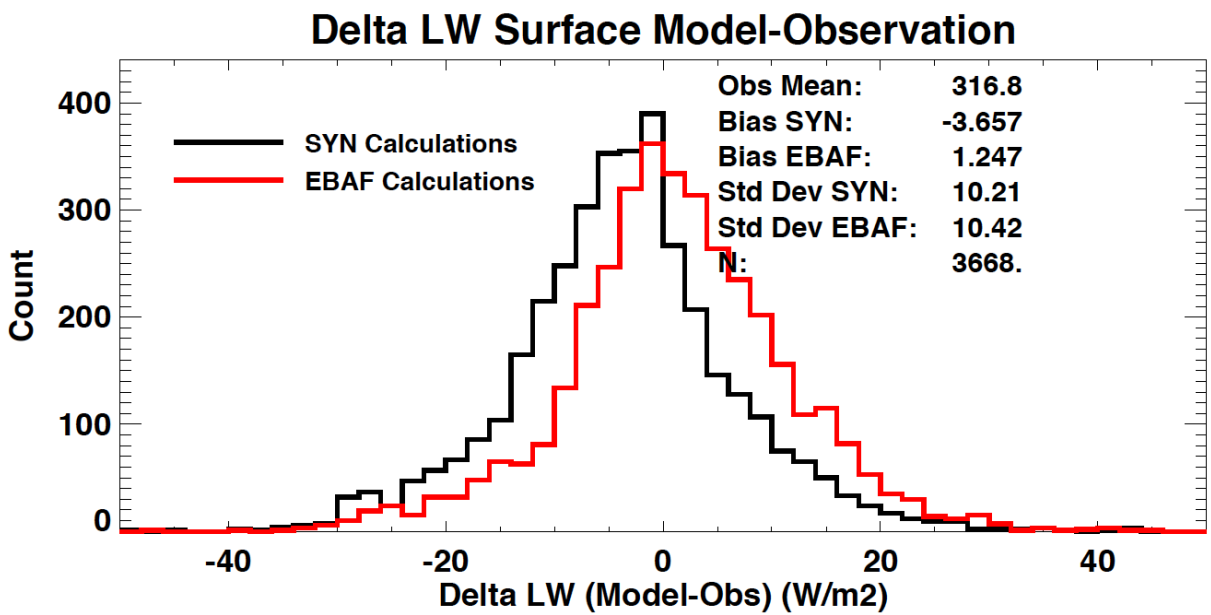
# Evaluation with surface observations



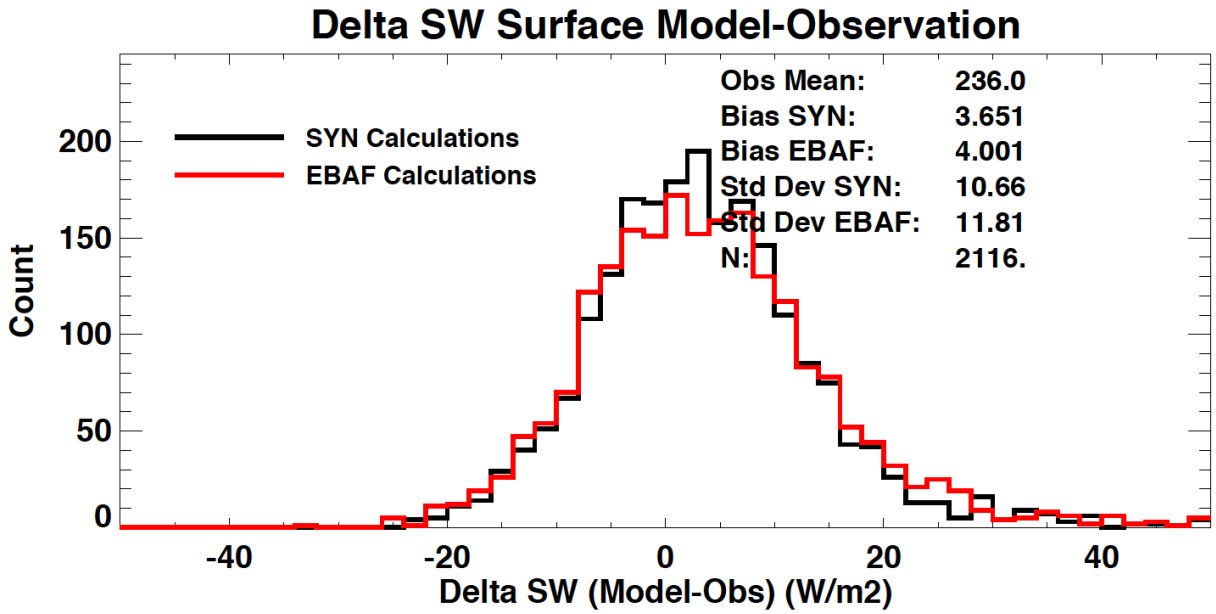

Surface validation sites used in the CERES project
37 land sites
48 ocean buoys

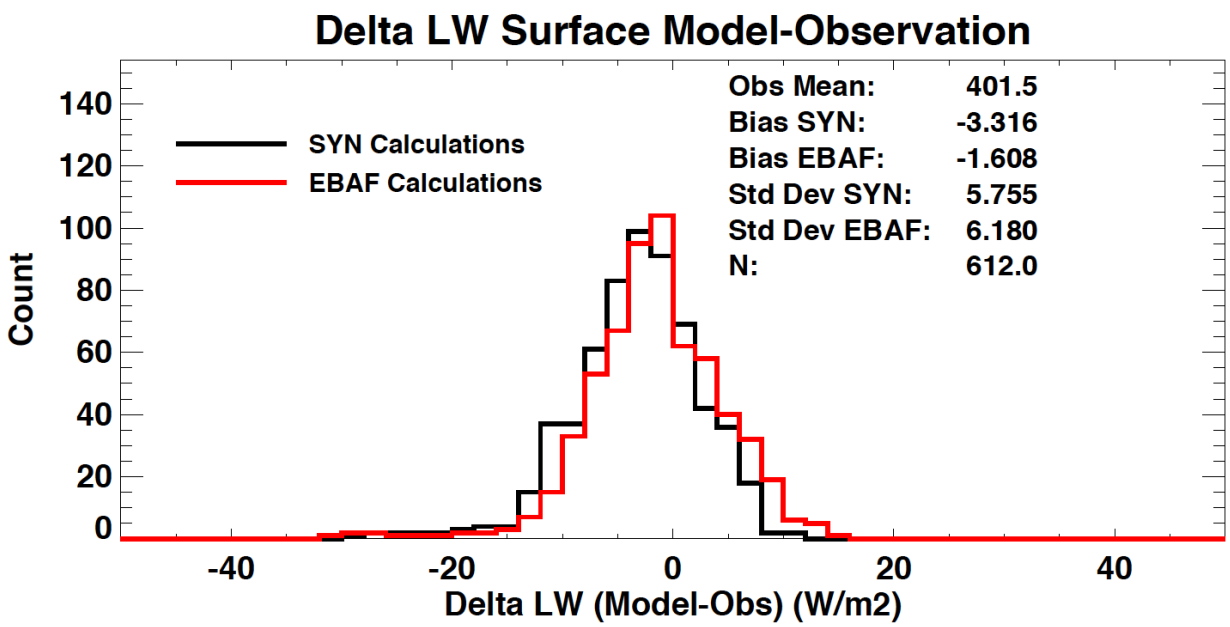
# Over Land (Ed3 SYN and EBAF)



# Over ocean (Ed 3 SYN and EBAF)



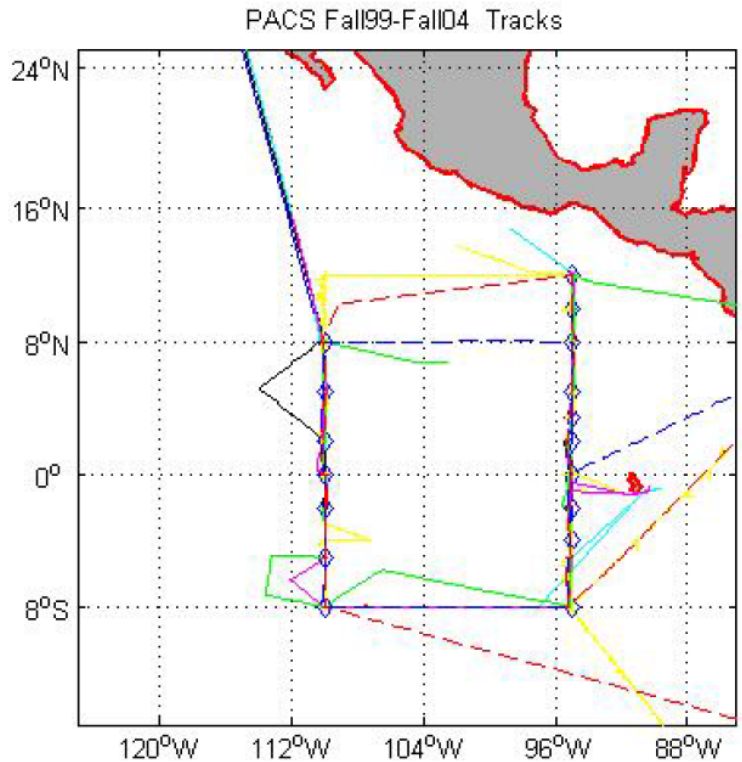




The reason for the SW positive bias is unknown, but Ed 4 SYN has more low-level clouds.

We are investigating low-level clouds (e.g. S. Ham's talk) over ocean (their effect is larger on SW and not so large on LW).

We need to investigate how GEO detect boundary layer clouds.

# East Pacific Investigation of Climate (EPIC) data



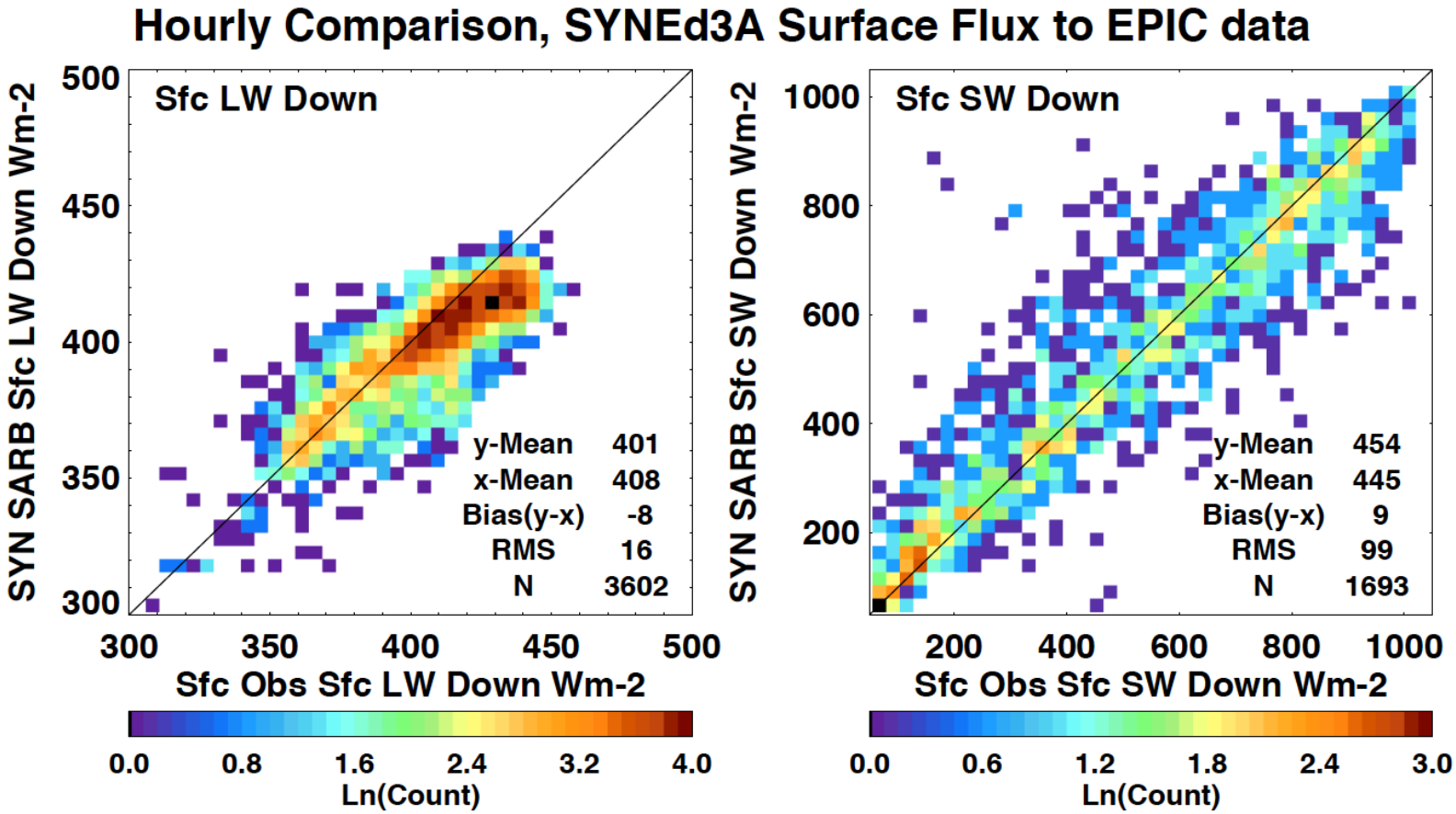

We only compare hourly mean over a grid box with ship observations

(Fairall et al. 2008)

**Figure 1.** Cruise tracks for 10 PSD projects from 1999 through 2004. Lines are as follows: F99 – solid blue; S00 – solid red; F00 – solid black; S01 – solid cyan; Epic01 & F01– solid yellow; S02 – solid magenta; F02 – solid green; F03 – dashed blue; F04 – dashed red. The circles denote TAO buoys on the 95 W and 110 W lines. The jogs off the buoy lines are usually to collect buoys that have broken loose or to visit the Galapagos Islands.

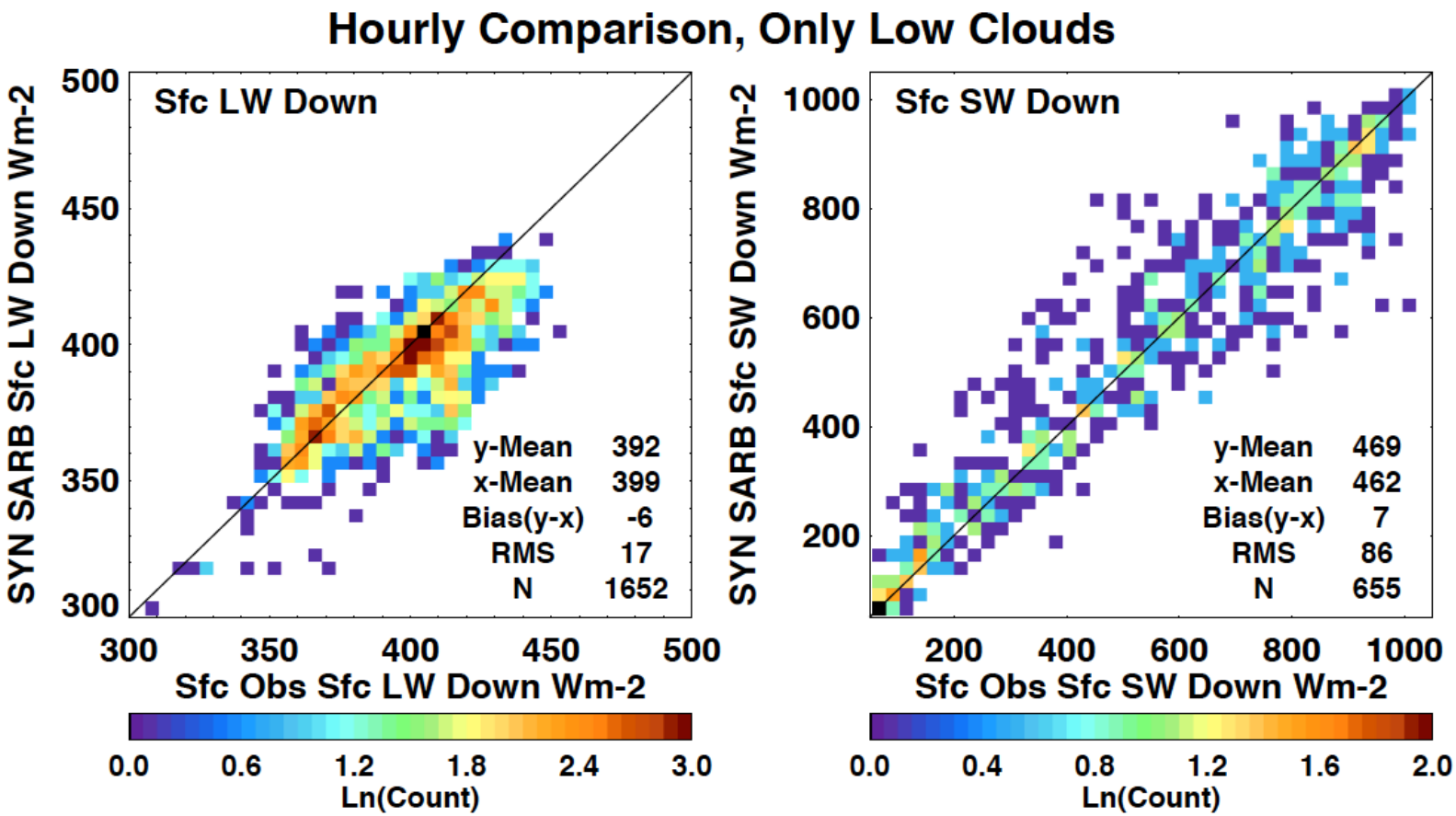
A cruise to the southeast Pacific Ocean examines how turbulence, drizzle, aerosols, and Andes combine to regulate the albedo (Bretherton et al. BAMS 2004, EPIC 2001 stratocumulus study)

# Comparison with ship data



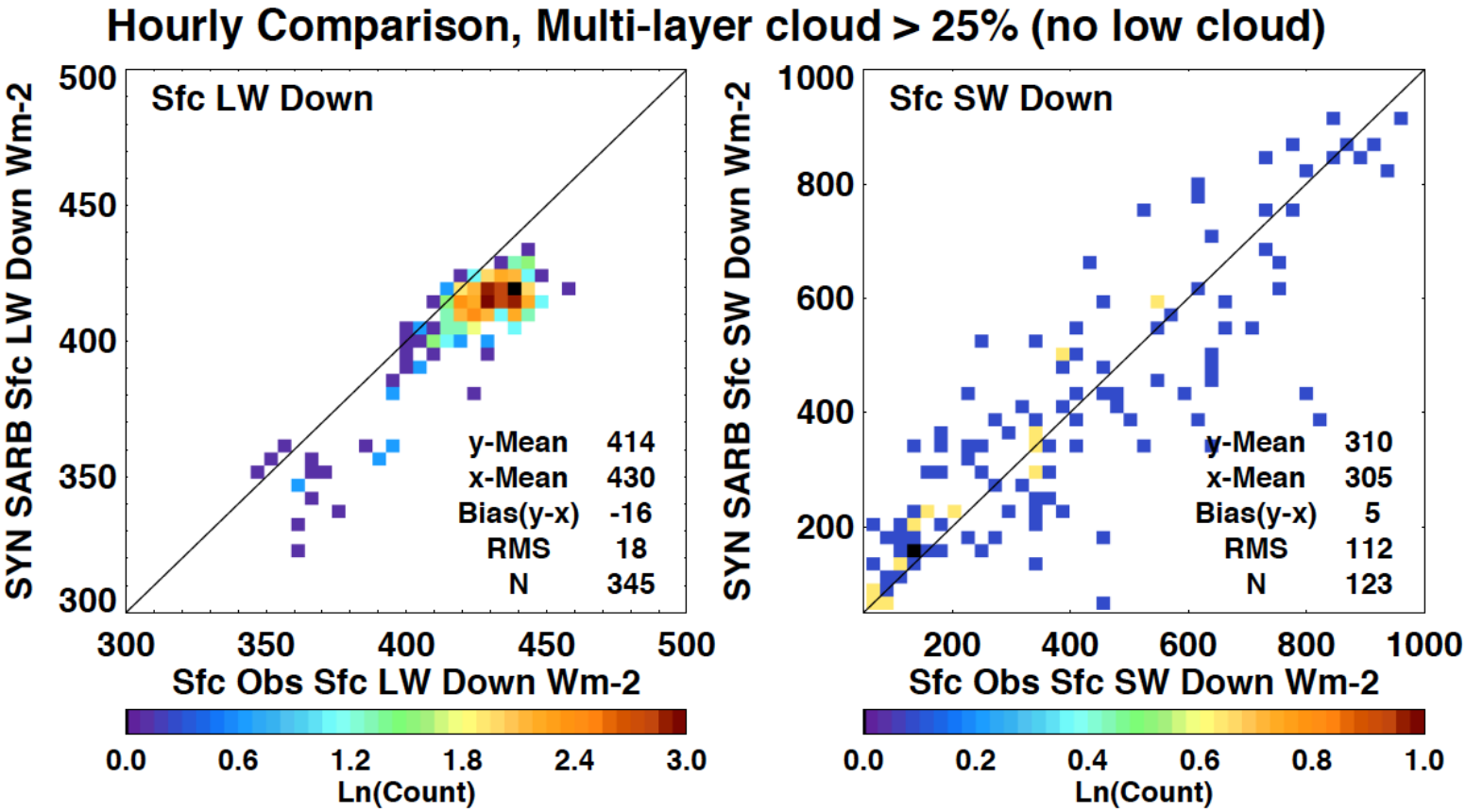

A positive bias is consistent with buoy data, but LW down is biased low

# Hour-boxes with Low-level (sfc-700 hPa)clouds only




Ed 4 has more low-level clouds, which increases LW down and decreases SW down (F. Rose's talk)

# Hour-boxes with multiple layers




- Low-level clouds (sfc-700 hPa) = 0, the sum of mid-low (700 – 500 hPa), mid-high (500-300 hPa), and high (300 hPa and higher) > 0.25 in an hour-box
- Ed4 treads cloud overlap, which increases LW down

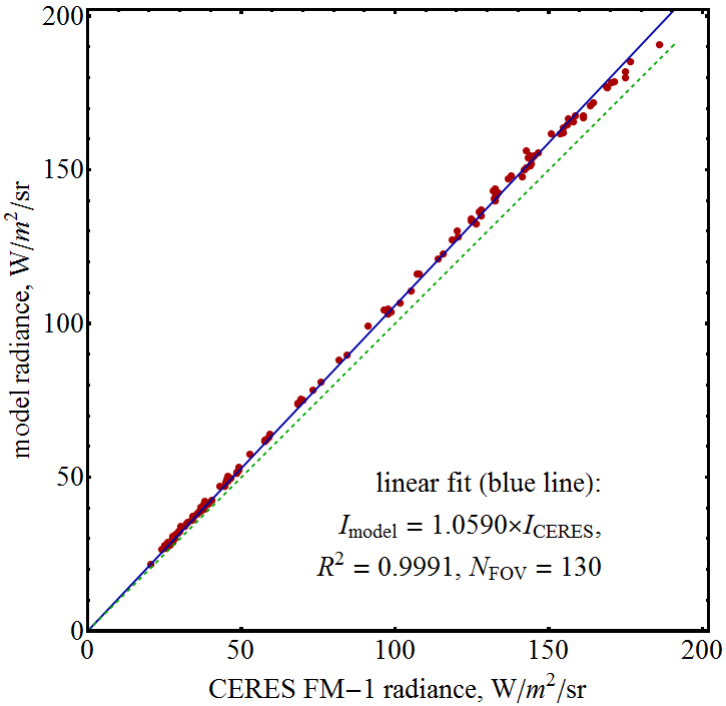
# Model-CERES comparisons over dome-C

(Extending work by Hudson et al. 2006)

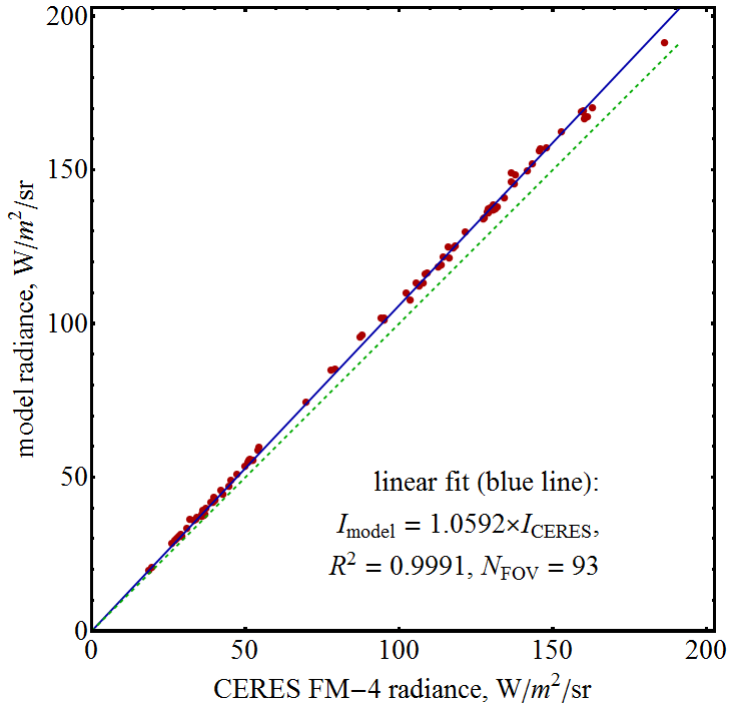
- Revised the spectral snow surface BRDF model
- Start comparing modeled spectral radiances with SCIAMACHY observations
- Will perform sensitivity studies and try to separate effects due to microscopic (snow grain size) and macroscopic (surface topography)

# Modeling CERES SW radiance

FM-1




FM-4




New snowpack model makes RT modeling brighter: previous snowpack model yield 4.62% overestimation for FM-1 and 4.68% overestimation for FM-4.

# Comparison of the new snowpack model on SCIAMACHY data

| band | central wavelength, um | Slope: model radiance vs observation | | mean SCIAMACHY solar constant, W/m$^2$ |
|---|---|---|---|---|
| | | Old snowpack | new snowpack | |
| 1 | 0.2563 | 0.5418 | 0.5430 | 3.679 |
| 2 | 0.2779 | 0.9663 | 0.9690 | 2.010 |
| 3 | 0.2951 | 0.9394 | 0.9304 | 10.743 |
| 4 | 0.3173 | 0.8403 | 0.8400 | 14.785 |
| 5 | 0.3451 | 1.0568 | 1.0535 | 32.750 |
| 6 | 0.3850 | 1.0117 | 1.0111 | 52.654 |
| 7 | 0.4298 | 1.0193 | 1.0181 | 77.269 |
| 8 | 0.4849 | 1.0177 | 1.0151 | 127.622 |
| 9 | 0.5288 | 1.0199 | 1.0190 | 41.728 |
| 10 | 0.5448 | 1.0276 | 1.0267 | 17.782 |
| 11 | 0.5581 | 1.0264 | 1.0260 | 31.636 |
| 12 | 0.5858 | 1.0514 | 1.0488 | 69.102 |
| 13 | 0.6150 | 1.0286 | 1.0290 | 33.658 |
| 14 | 0.6459 | 1.0299 | 1.0302 | 66.361 |
| 15 | 0.6754 | 1.0185 | 1.0189 | 26.683 |
| 16 | 0.6943 | 1.0022 | 1.0160 | 29.466 |
| 17 | 0.7235 | 1.0392 | 1.0398 | 51.975 |
| 18 | 0.7670 | 1.0005 | 1.0444 | 60.410 |
| 19 | 0.8180 | 1.0360 | 1.0280 | 58.275 |
| 20 | 0.8667 | 1.0333 | 1.0326 | 43.599 |
| 21 | 0.9319 | 1.0484 | 1.0524 | 74.233 |
| 22 | 1.0103 | 1.0330 | 1.0247 | 51.898 |
| 23 | 1.1200 | 1.0427 | 1.0400 | 85.551 |
| 24 | 1.3551 | 0.7289 | 1.0488 | 122.195 |
| 25 | 1.5647 | 1.4104 | 0.8794 | 25.296 |
| All 25 | | 1.0155 | 1.0292 | 1211.356 |

# Multi-layer cloud algorithm

(T. Viudez-Mora's presentation in the SARB WG meeting)

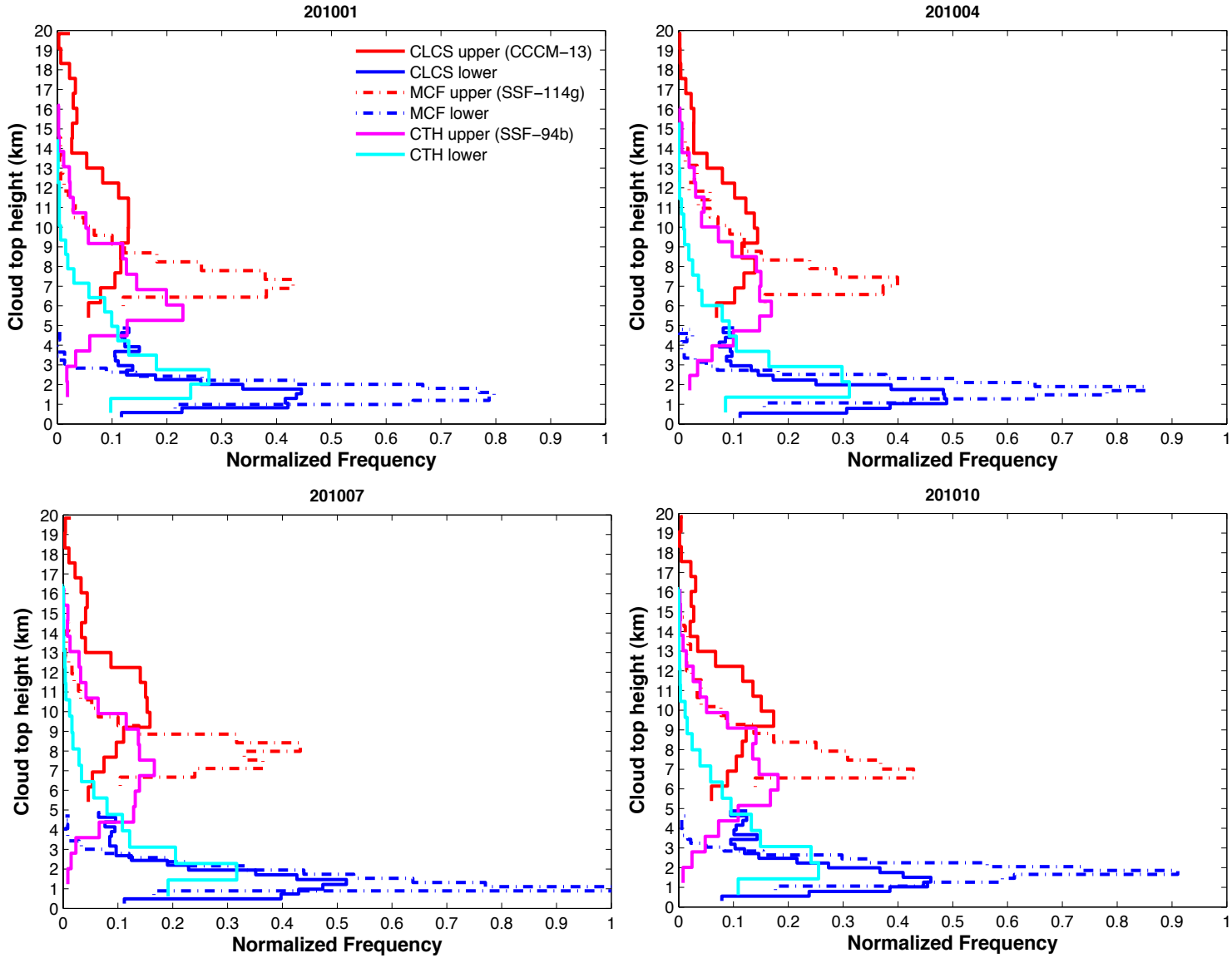
- According to CALIPSO/CloudSat, multi-layer clouds occur ~50%
- Multi-layer code retrieves multi-layer about 7% of all footprints.
- When the multi-layer code retrieves multi-layer, about 30% of them are single-layer clouds according to CALIPSO/CloudSat
- When clouds are very clean multi-layer clouds (daytime, according to CALIPSO/CloudSat, two-layer, upper CTH > 5 km and lower CTH < 5 km), which are only 1% of multi-layer clouds, the multi-layer code identify multi-layer clouds about 20% of all clean cases.

# Frequency of cloud overlap occurrence over matched footprints
## Daytime

| MCF / CLCS | January | April | July | October | Mean | |
|---|---|---|---|---|---|---|
| **SL / SL** | 12.5 | 10.0 | 11.4 | 11.8 | **11.4** | |
| **SL / ML** | 2.8 | 4.2 | 3.0 | 3.8 | **3.5** | |
| **SL / SLML** | 15.2 | 19.8 | 17.8 | 17.8 | **17.7** | **Total single** |
| **SL / clear** | 0.8 | 0.7 | 0.7 | 1.2 | **0.9** | **33.4** |
| **ML / SL** | 0.3 | 0.1 | 0.1 | 0.1 | **0.2** | |
| **ML / ML** | 0.4 | 0.4 | 0.4 | 0.4 | **0.4** | |
| **ML / SLML** | 0.8 | 0.5 | 0.6 | 0.5 | **0.6** | **Total multilayer** |
| **ML / clear** | 0.0 | 0.0 | 0.0 | 0.0 | **0.0** | **1.2** |
| **SLML / SL** | 0.7 | 0.5 | 0.6 | 0.6 | **0.6** | |
| **SLML / ML** | 1.3 | 1.5 | 1.8 | 1.4 | **1.5** | |
| **SLML / SLML** | 3.2 | 3.1 | 4.1 | 3.3 | **3.4** | **Total single-multilayer** |
| **SLML / clear** | 0.0 | 0.0 | 0.0 | 0.0 | **0.0** | **5.3** |
| **Clear / SL** | 3.0 | 3.6 | 3.2 | 3.3 | **3.3** | |
| **Clear / ML** | 0.7 | 0.9 | 1.0 | 0.7 | **0.8** | |
| **Clear / SLML** | 2.1 | 2.7 | 2.7 | 2.0 | **2.4** | **Total clear** |
| **Clear / Clear** | 6.8 | 2.4 | 2.5 | 3.2 | **3.7** | **10.2** |

SL: single layer ML: multilayer SLML: single and multilayer

# CTH vertical distribution for ideal multilayer case.
# CLCS and MCF matched footprints during daytime



# Ed3 and Ed4 SYN comparison
by Fred Rose

# Ed4_SYN1deg_Month
# First Look at the Operational Product

Seiji Kato, David Doelling, Pat Minnis,
Fred Rose, David Rutan, Alex Radkevich, Seung-Hee Ham
Tom Caldwell, Cathy Nguyen, Raja Raju, Dennis Keyes,
Rabi Palikonda, Qing Trepte, Sarah Bedka, Michelle Nordeen,
Pam Mlynczak, Cristian Mitrescu …
(And really the entire CERES group!)

CERES Science Team Meeting

UW Seattle

September 1st-3rd 2015

# CERES ED4_SYNI Product Changes

GMAO Atmosphere

- Switch to Geos5.4.1 for entire record
  - Ed3a had G4/G5.2 discontinuity (Jan2008)

## Clouds

- Random Overlap: four most significant cloud vertical profiles created from random overlap assumption normalized to cloud fractions as viewed from space.
- Incorporate cloud groups lapse rate for lower atmosphere temperature
- Fu-Liou based cloud optical depth -> LWP/IWP relation
- Decrease cloud 1.24um optical depth over daytime snow : ln(tau)Fix = ln(tau) -1.0

## Aerosols

- Ed4 Hourly Match data (~700Mb /day)
- Include troposphere SO4, stratospheric SO4 Ammonium sulfate, and volcanic ash in addition to small dust, large dust, sulfate, sea-salt, black carbon, soluble, and insoluble
- Collection 5 MODIS used in MATCH

## Surface Albedo

- Ed4 Surface history map (CERES Clear Sky and Partly Cloudy Fov using clear-sky albedo derived from clear pixel MODIS radiances)
- Surface albedo spectral shape from MODIS MCD43C product over land and snow
- Ocean surface albedo LUT (Z. Jin) dependent on SZA, wind speed, optical depth as in Ed3a

## Radiative Transfer Code

- 18 SW band Fu-Liou
- Hybrid SW solver:
  - FU 4-STREAM (Homogeneous Cloudy SF>10)
  - GWTSA (Inhomogeneous SF<10 Cloudy)
  - Fu 4-stream (Clear)

## Tuning

- Tightened sigma's at GEO times

## TSI Product

- Hourly Cloud properties: 5-channel GEO, MODIS Terra (10:30) / Aqua(1:30)
- Improved NB-BB LW irradiance ( M. Sun)
- Include cloud group retrievals cloud (Top/Base) (Pressure/Temperature) pairs
- Include MODIS and GEO Clear Sky skin temperature retrievals

## Snow/Ice Map Product

- EICE and ESNOW 1/8$^{th}$ mesh, Plus sea ice from CWG Clear Sky albedo threshold.

New Output Variables

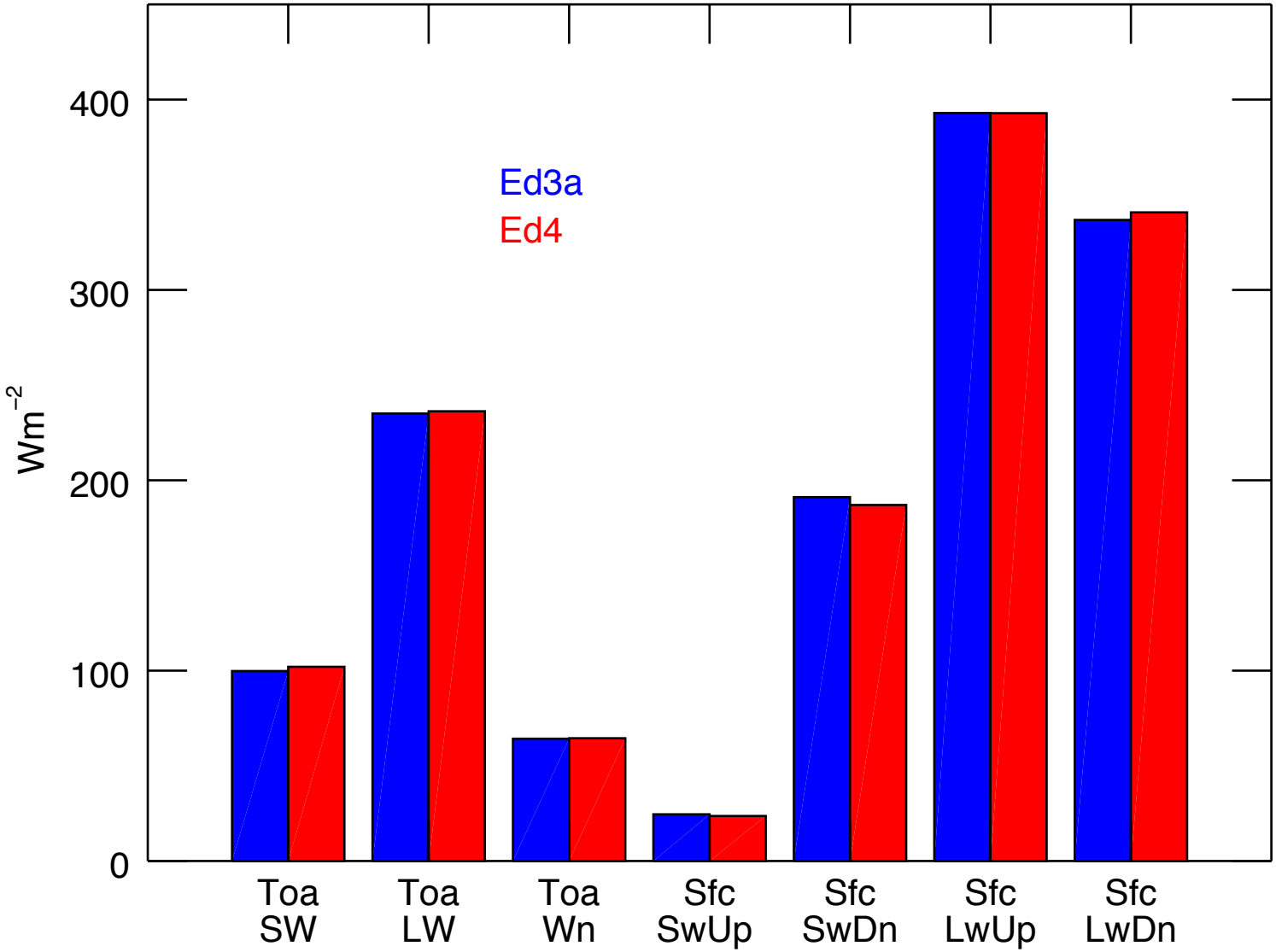
- Revised Ed4 SYNI output structure
- Entropy related outputs

Deleted SYNS Validation subset file output.

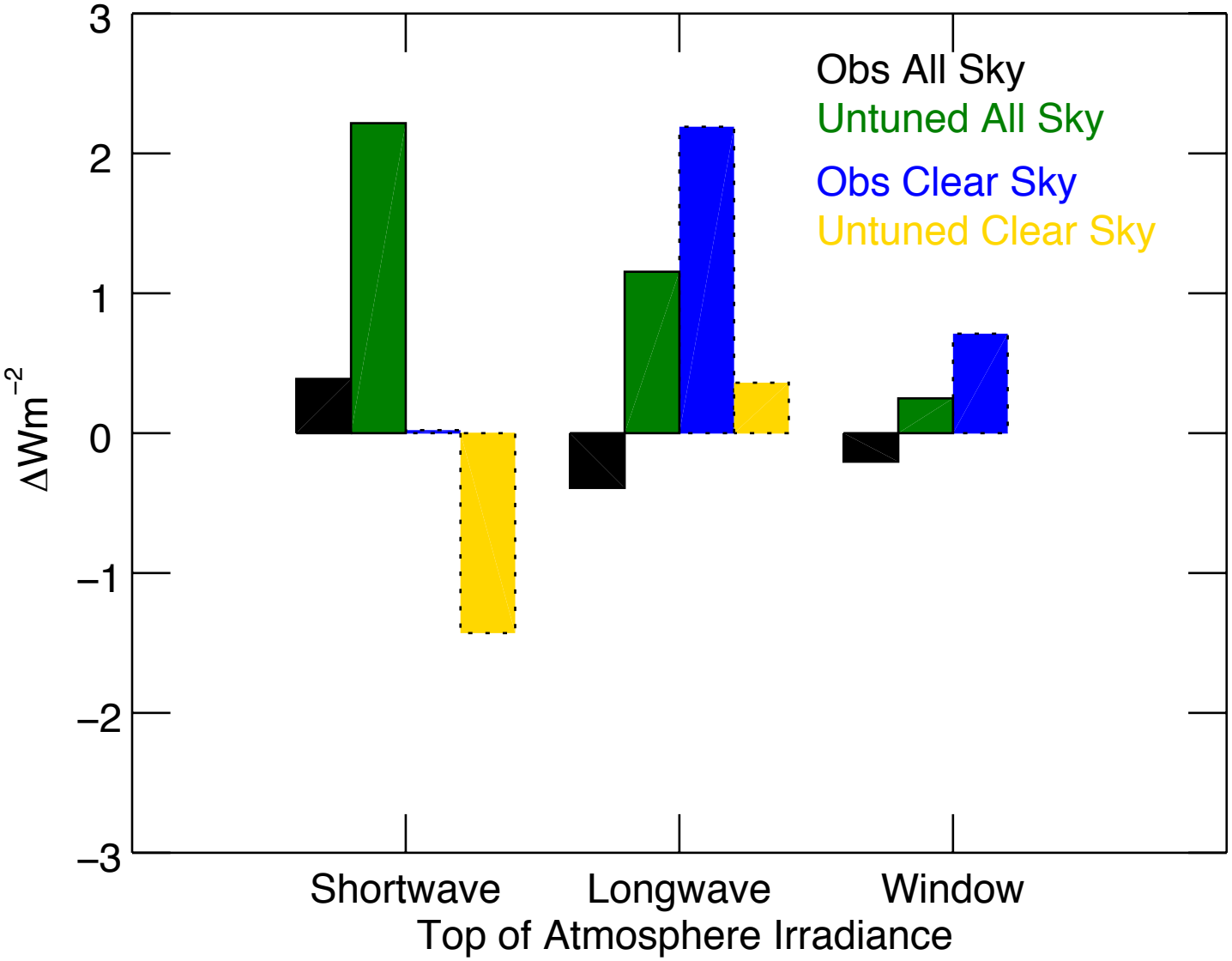
# Data

- Five Months ( Jan-May 2008)
- CER_SYN1deg_Month monthy average of hourly gridded computations
  - Ed3a
  - Ed4
    - Formally processed last week of Aug 2015 at LaRC DAAC

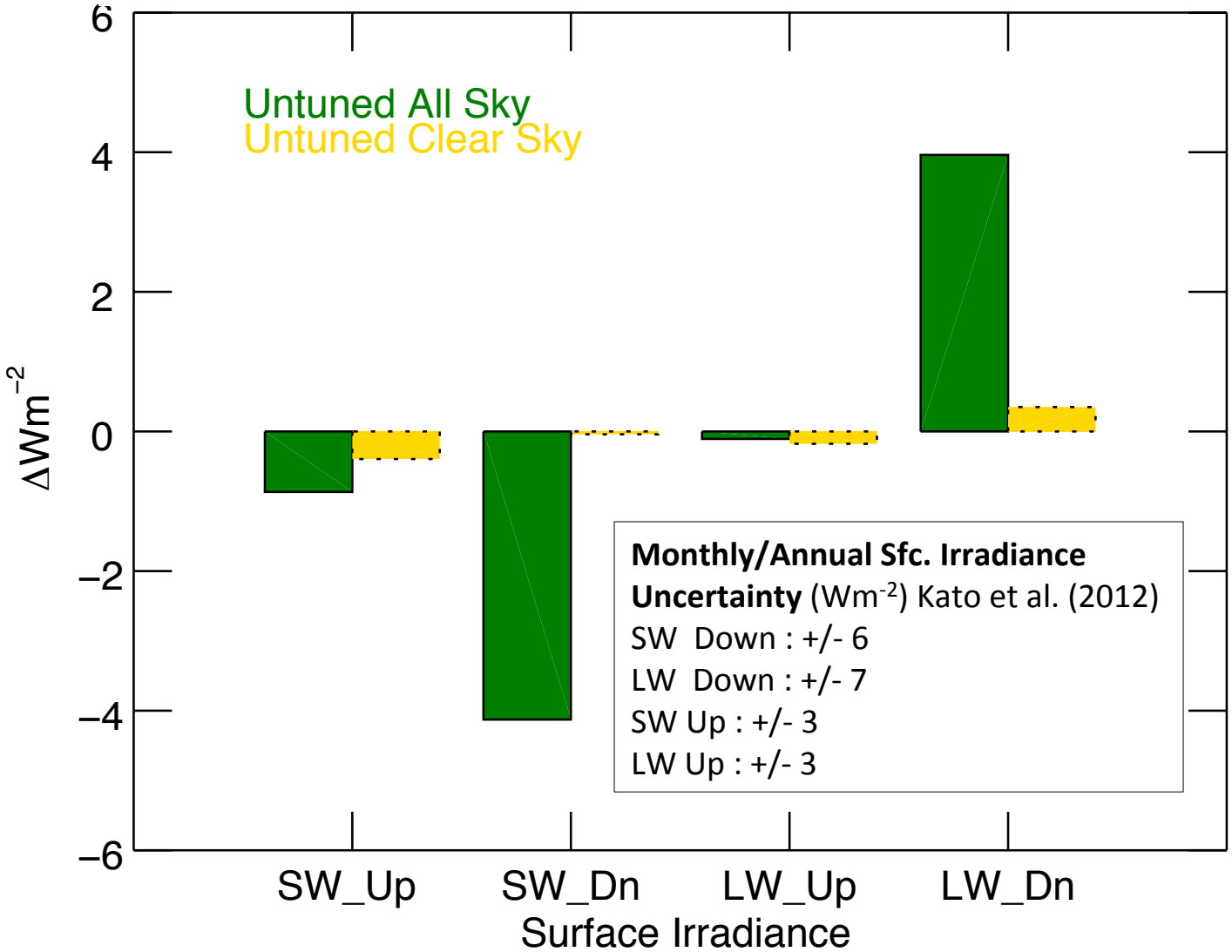
# Ed4 & Ed3a SYN TOA & Surface Untuned Model Irradiance



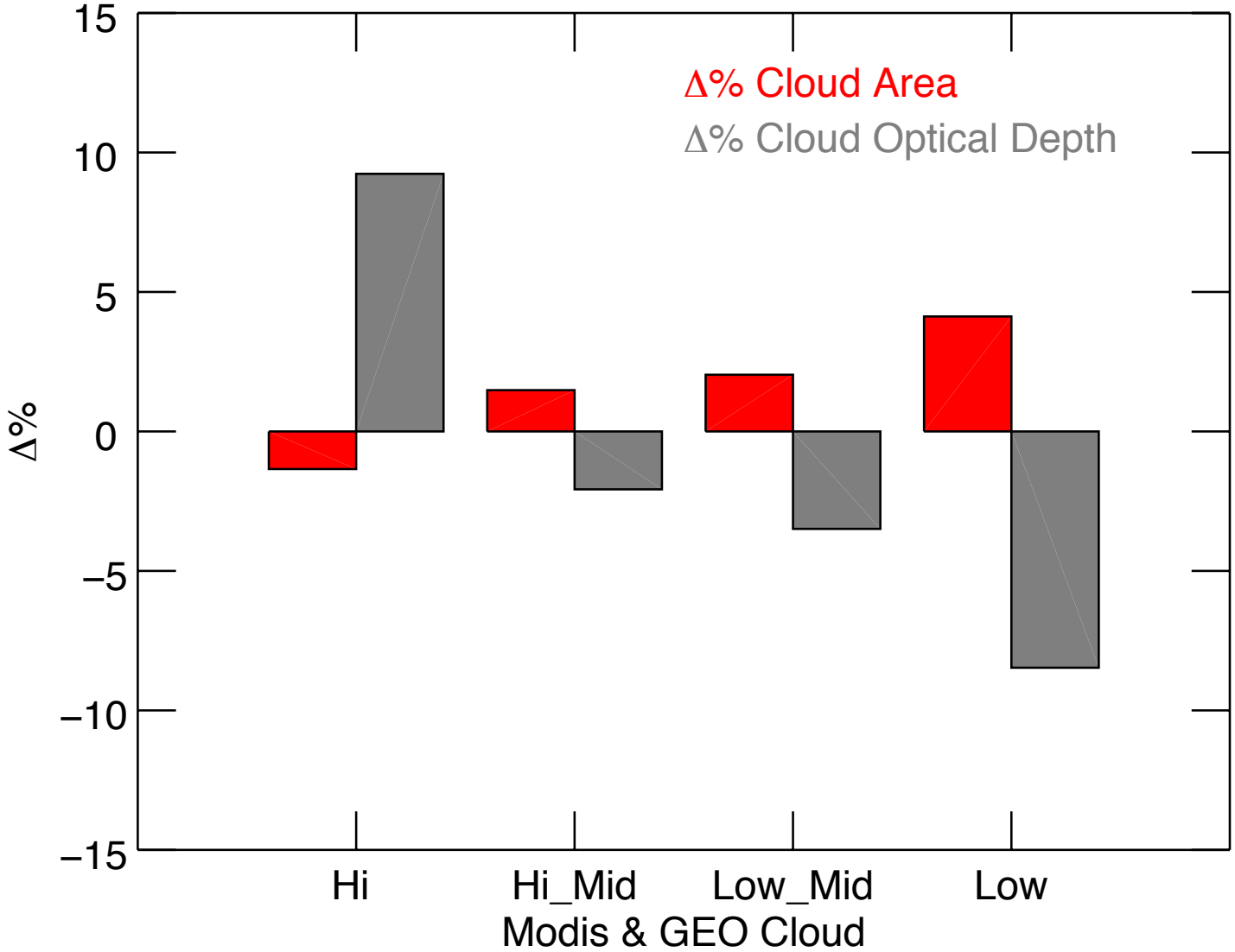
# Ed4 *minus* Ed3a
# Toa Irradiance



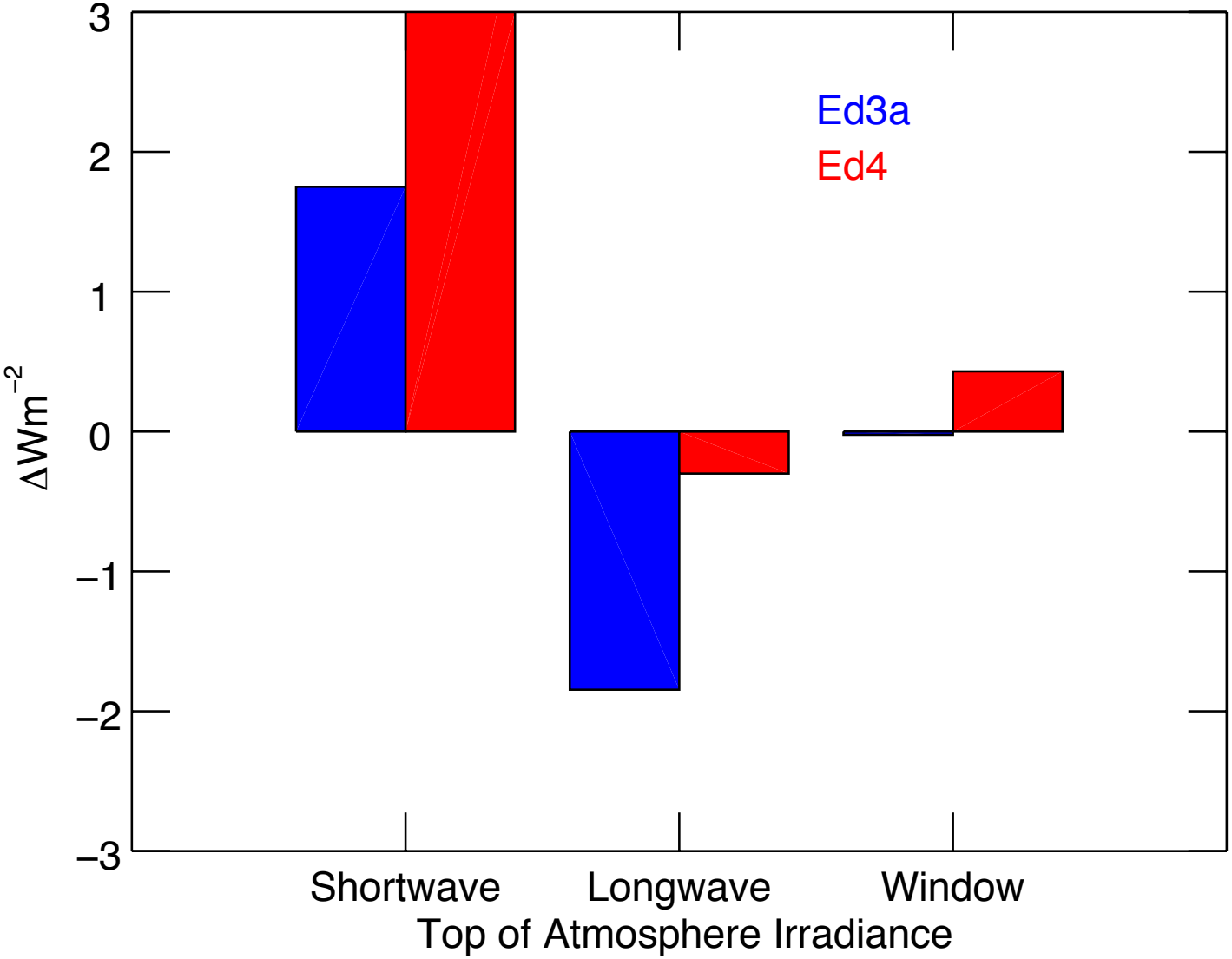
# Ed4 *minus* Ed3a
# Surface Irradiance



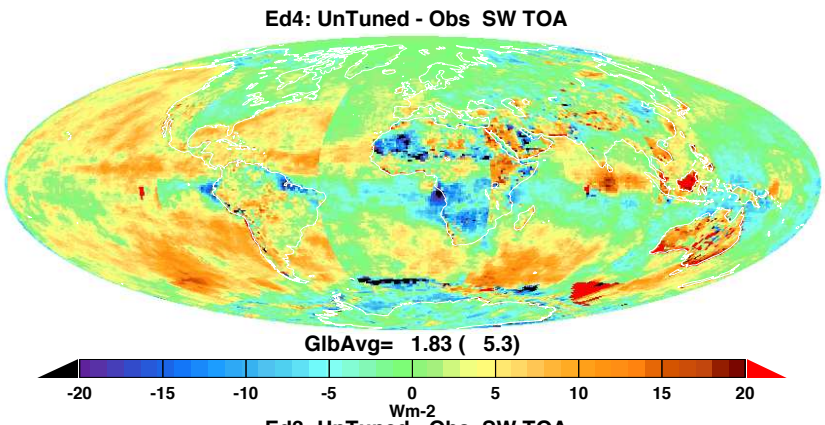
# Ed4 *minus* Ed3a
# Cloud Area and Optical Depth

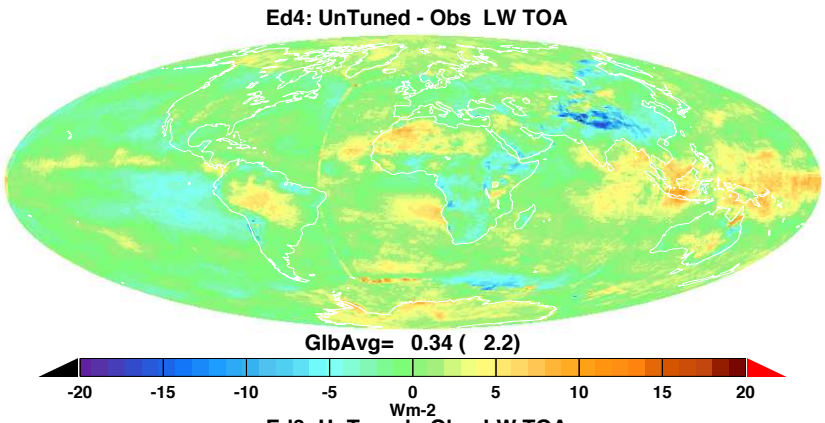


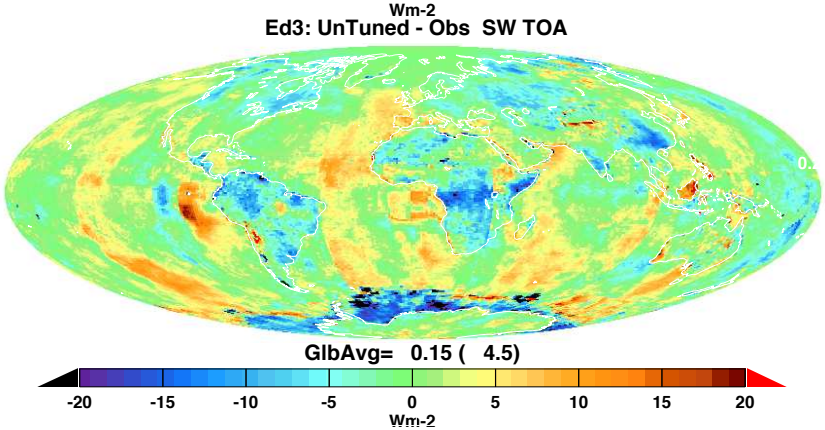
# Model Untuned *minus* Observed : Ed4 & Ed3a TOA Irradiances

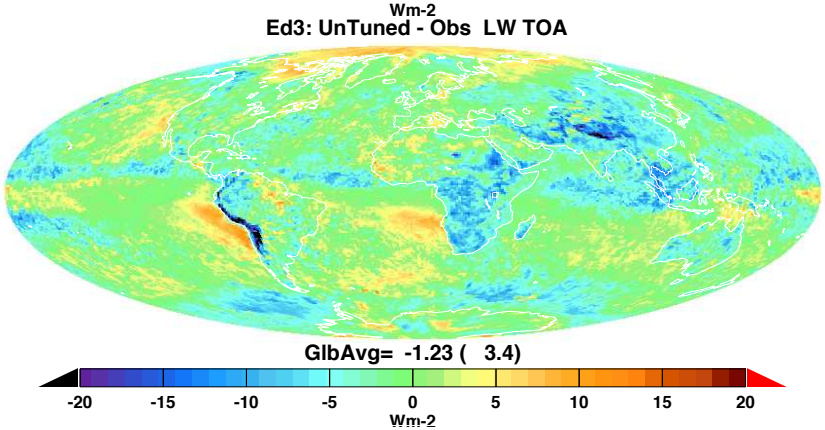


# Model Untuned *minus* Observed TOA Irradiance (October 2010)



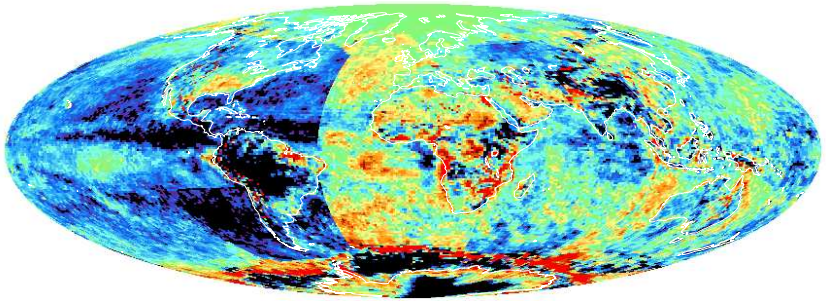



# Ed4 *minus* Ed3 : SW Surface Irradiance (October 2010)

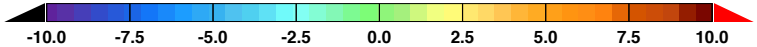
Ed4 : CER_SYN1deg-Month_Terra-MODIS_ValR1-X86_400403.200110
Ed3 : CER_SYN1deg-Month_Terra-MODIS_Edition3A_303301.200110

Ed4 : CER_SYN1deg-Month_Terra-MODIS_ValR1-X86_400403.200110
Ed3 : CER_SYN1deg-Month_Terra-MODIS_Edition3A_303301.200110

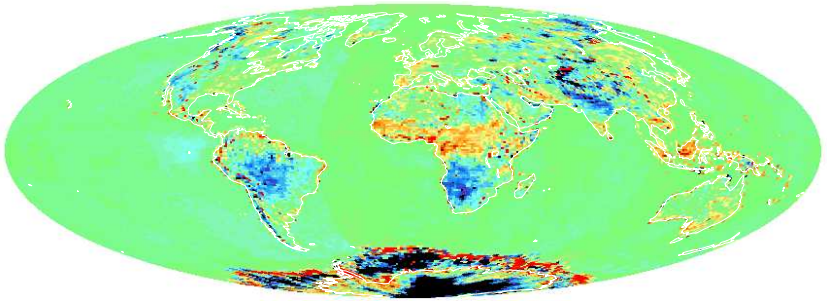
Ed4 - Ed3 : SW SFC Down Model Untuned



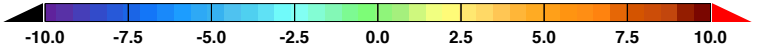
GlbAvg= -3.04 ( 6.3)



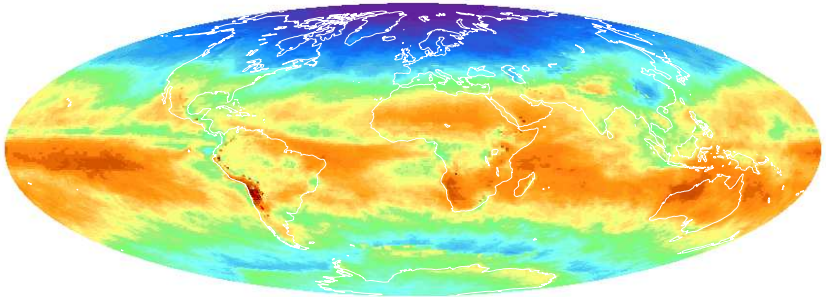

Ed4 - Ed3 : SW SFC UP Model Untuned



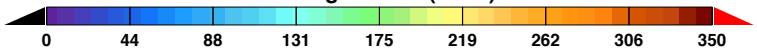
GlbAvg= -0.62 ( 3.0)



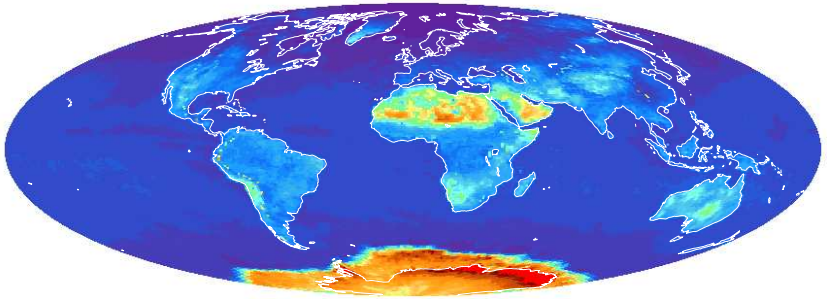

Ed4: SW SFC Down Model Untuned



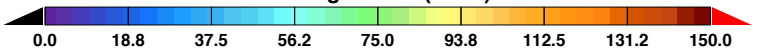
GlbAvg= 185.00 ( 23.3)



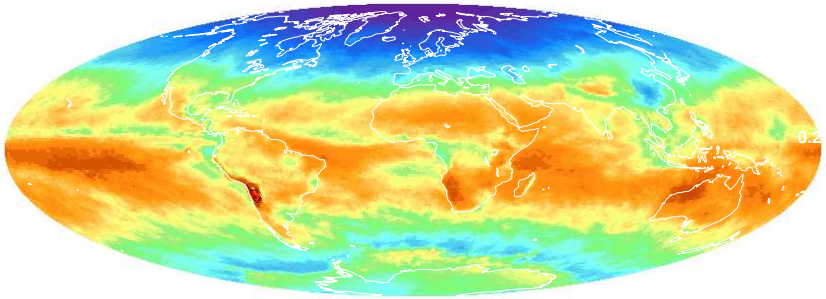

Ed4: SW SFC UP Model Untuned



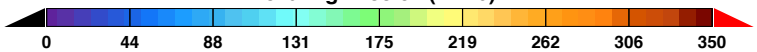
GlbAvg= 22.34 ( 13.6)



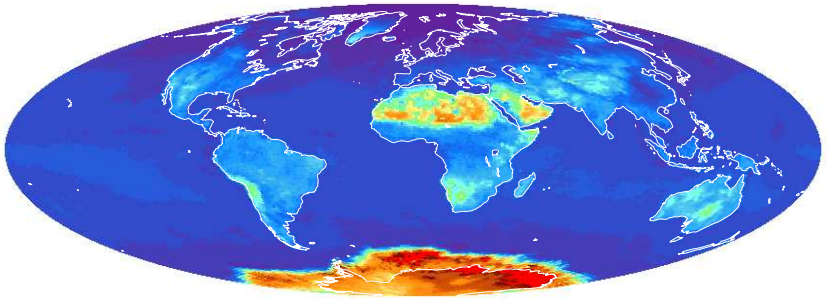

Ed3: SW SFC Down Model Untuned



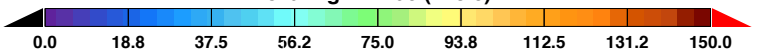
GlbAvg= 188.04 ( 22.9)




Ed3: SW SFC UP Model Untuned



GlbAvg= 22.96 ( 13.6)

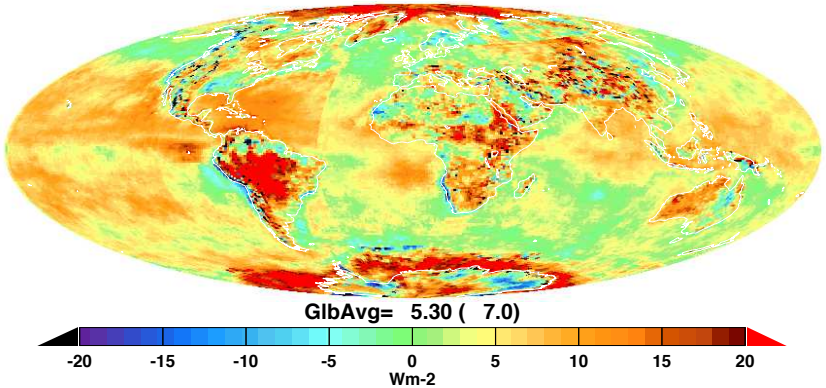


# Ed4 *minus* Ed3 : LW Surface Irradiance (October 2010)

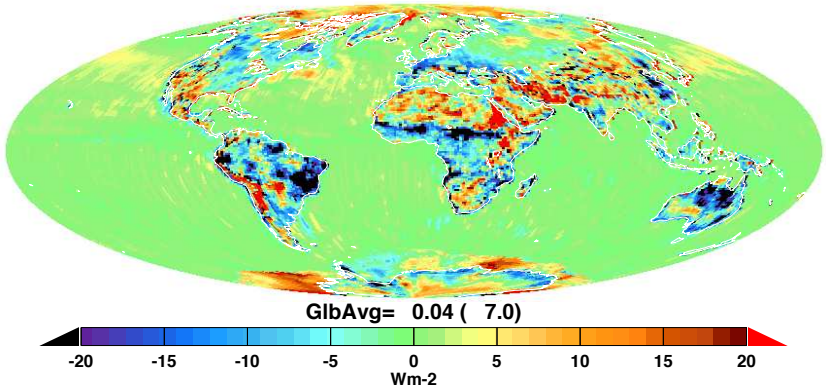
Ed4 : CER_SYN1deg-Month_Terra-MODIS_ValR1-X86_400403.200110
Ed3 : CER_SYN1deg-Month_Terra-MODIS_Edition3A_303301.200110

Ed4 : CER_SYN1deg-Month_Terra-MODIS_ValR1-X86_400403.200110
Ed3 : CER_SYN1deg-Month_Terra-MODIS_Edition3A_303301.200110

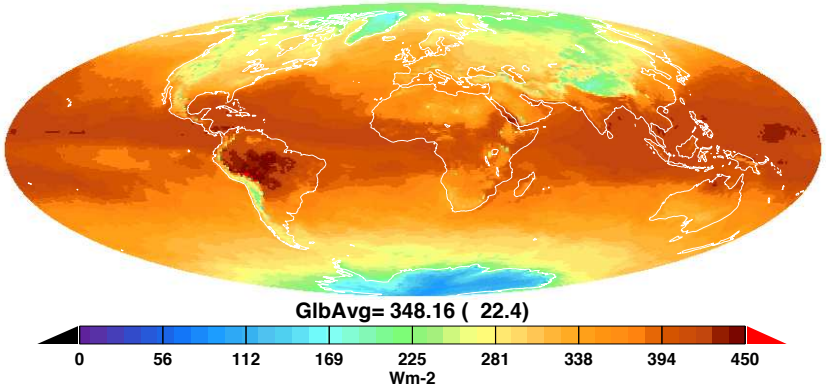
Ed4 - Ed3 : LW SFC Down Model Untuned



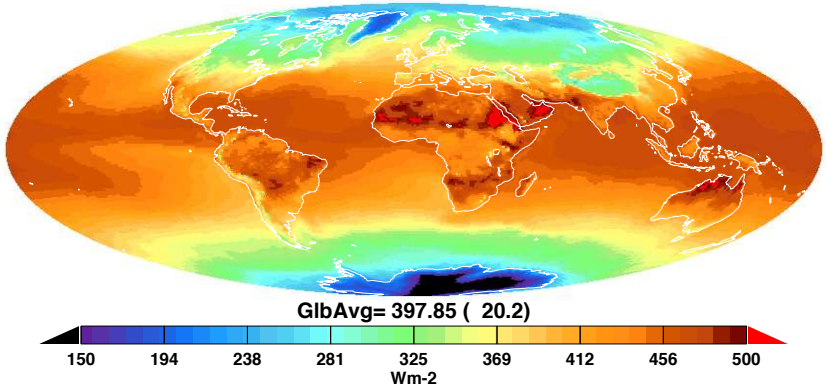

Ed4 - Ed3 : LW SFC Up Model Untuned



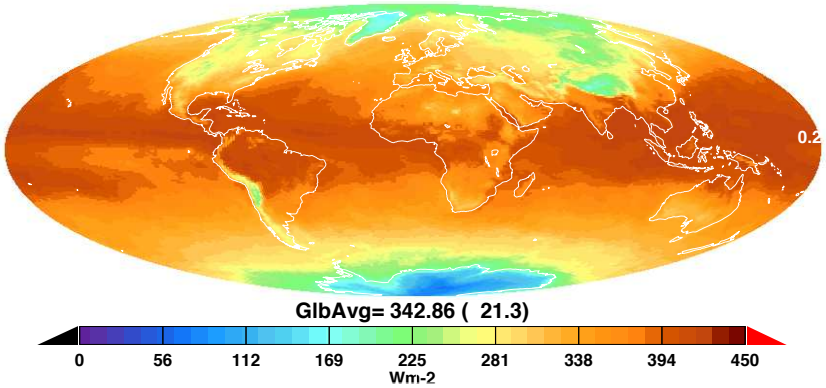

Ed4: LW SFC Down Model Untuned



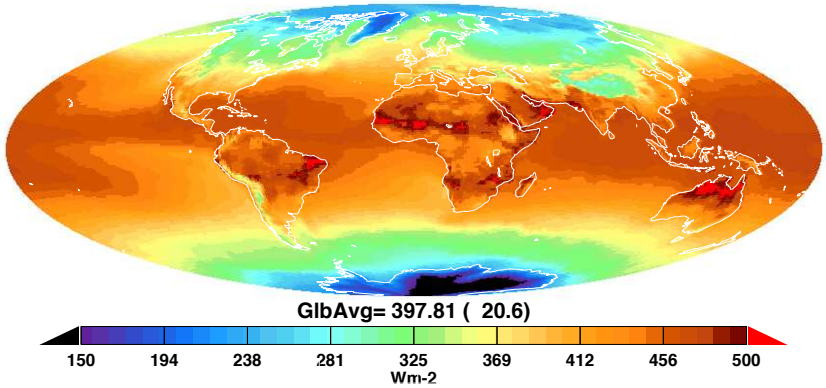

Ed4: LW SFC Up Model Untuned




Ed3: LW SFC Down Model Untuned




Ed3: LW SFC Up Model Untuned

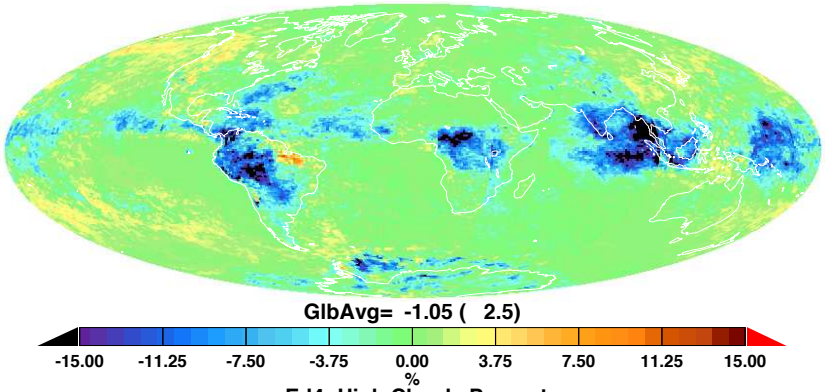


# Ed4 *minus* Ed3 : Cloud Area (October 2010)

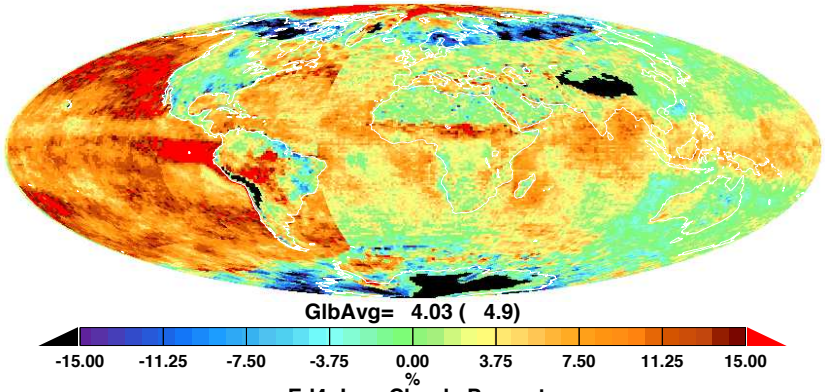
Ed4 : CER_SYN1deg-Month_Terra-MODIS_ValR1-X86_400403.200110
Ed3 : CER_SYN1deg-Month_Terra-MODIS_Edition3A_303301.200110

Ed4 : CER_SYN1deg-Month_Terra-MODIS_ValR1-X86_400403.200110
Ed3 : CER_SYN1deg-Month_Terra-MODIS_Edition3A_303301.200110

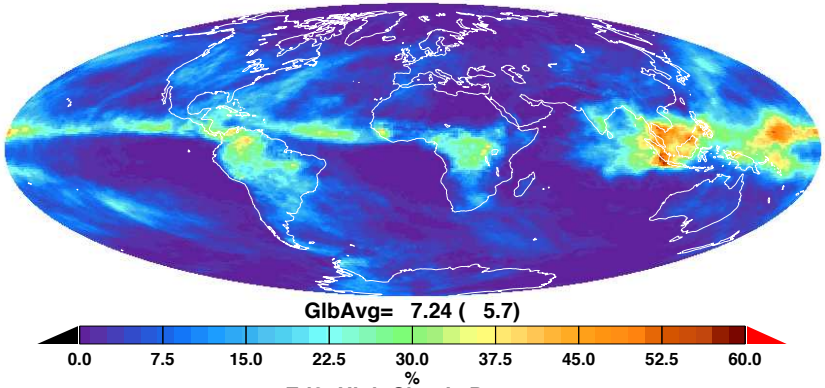
Ed4 - Ed3 : High Clouds Percent



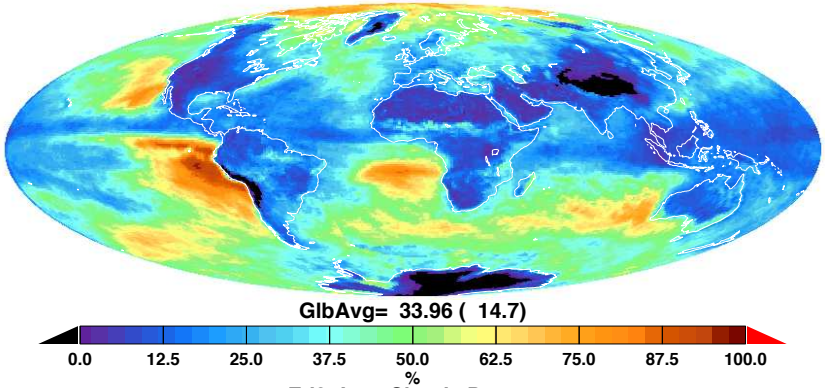

Ed4 - Ed3 : Low Clouds Percent



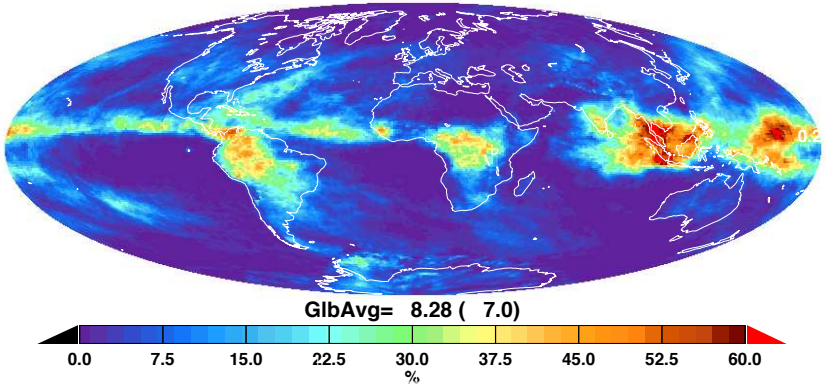

Ed4: High Clouds Percent



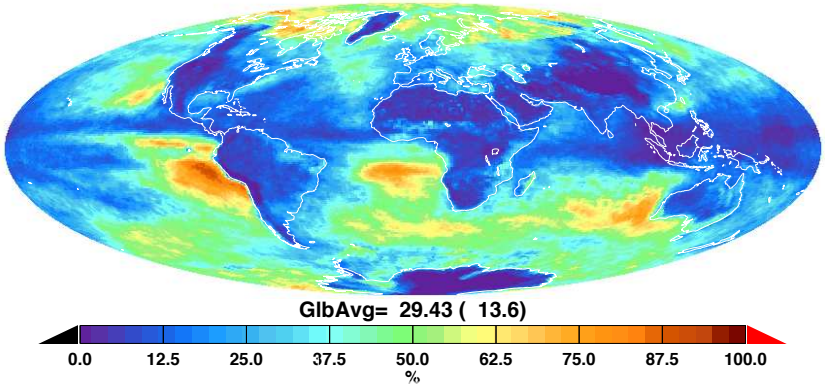

Ed4: Low Clouds Percent




Ed3: High Clouds Percent




Ed3: Low Clouds Percent



# Summary

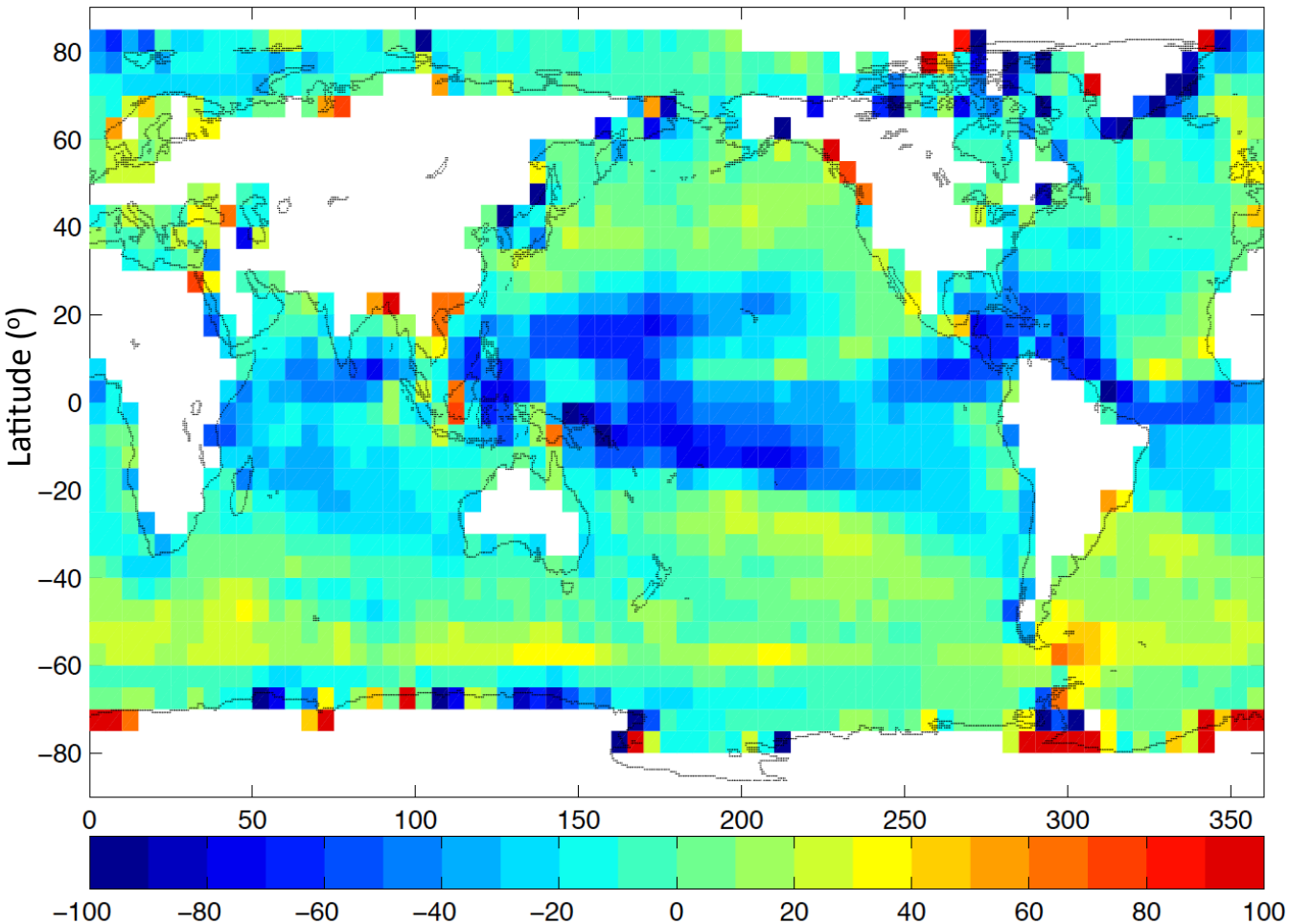
- Edition 4 TSI/SYNI/SYN code includes many data input and algorithm changes
- Impacts
  - More Low cloud area but Thinner optical depths
  - Less High cloud area but Thicker optical depths
  - Less SW surface Insolation
  - More LW downward flux

# Summary

- Ed4 SYN production started
- Use of ship data (e.g. MAGIC and EPIC) to validate surface irradiance over ocean
  - Focusing on clouds (e.g. boundary layer clouds and cloud overlap) to investigate downward SW and LW)
- Continue comparing computed SW spectral with SCIAMACHY and broadband with CERES
  - Analysis of spectral albedo of sea ice from ARISE
- Multi-layer cloud retrieval evaluation
  - Evaluation in terms of using retrieved properties in irradiance computations continue

# Back-ups

Sum of all energy terms for the atmospheric column in $Wm^{-2}$ (10 year average)




$Wm^{-2}$

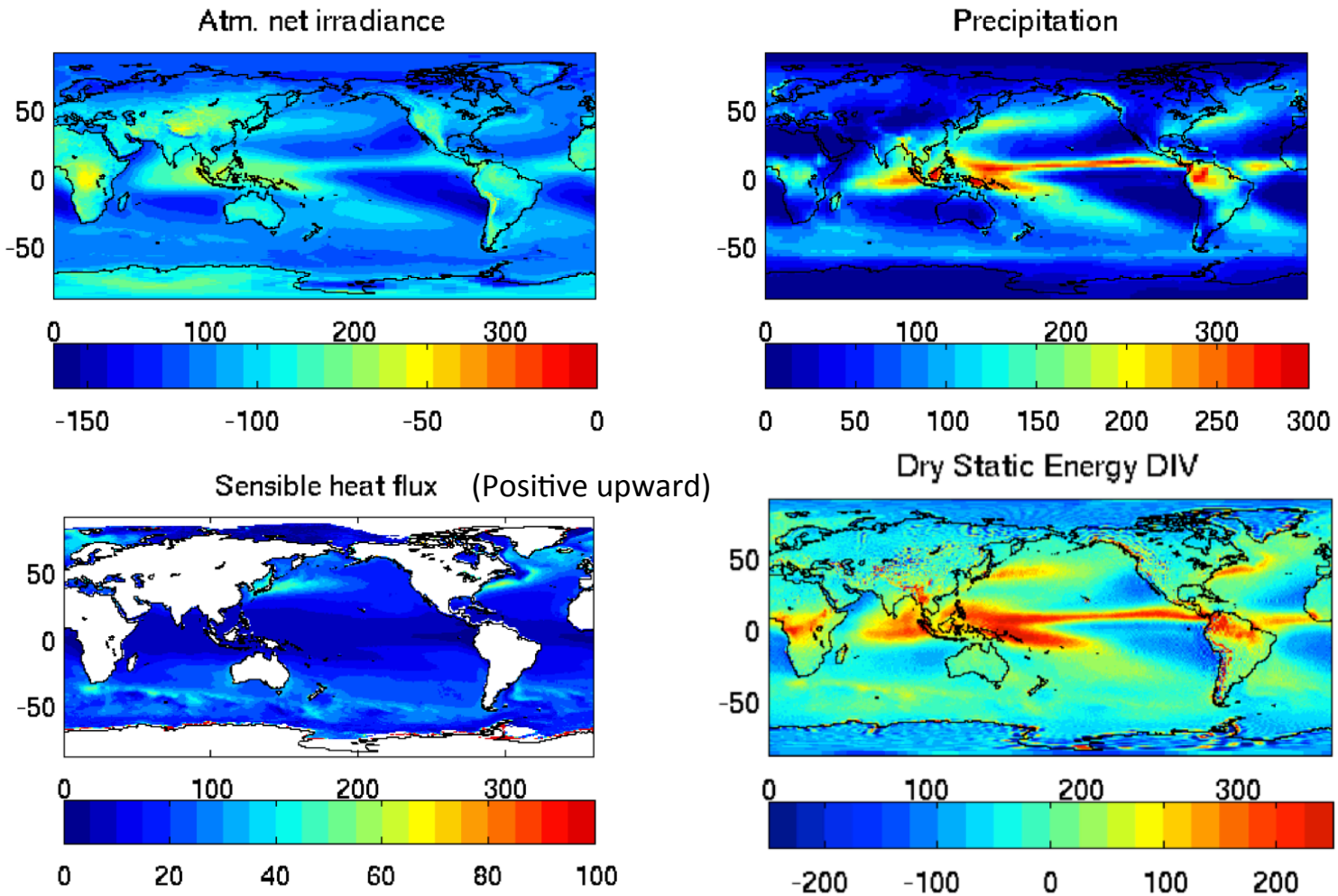
Negative area

- Precipitation is too small
- Divergence is too large
- Radiative cooling is too large (clouds are too low)

-Dry static and Kinetic energy tendency - divergence of dry static energy -divergence of kinetic energy + atmospheric net irradiance + precipitation - surface sensible heat flux (positive downward)

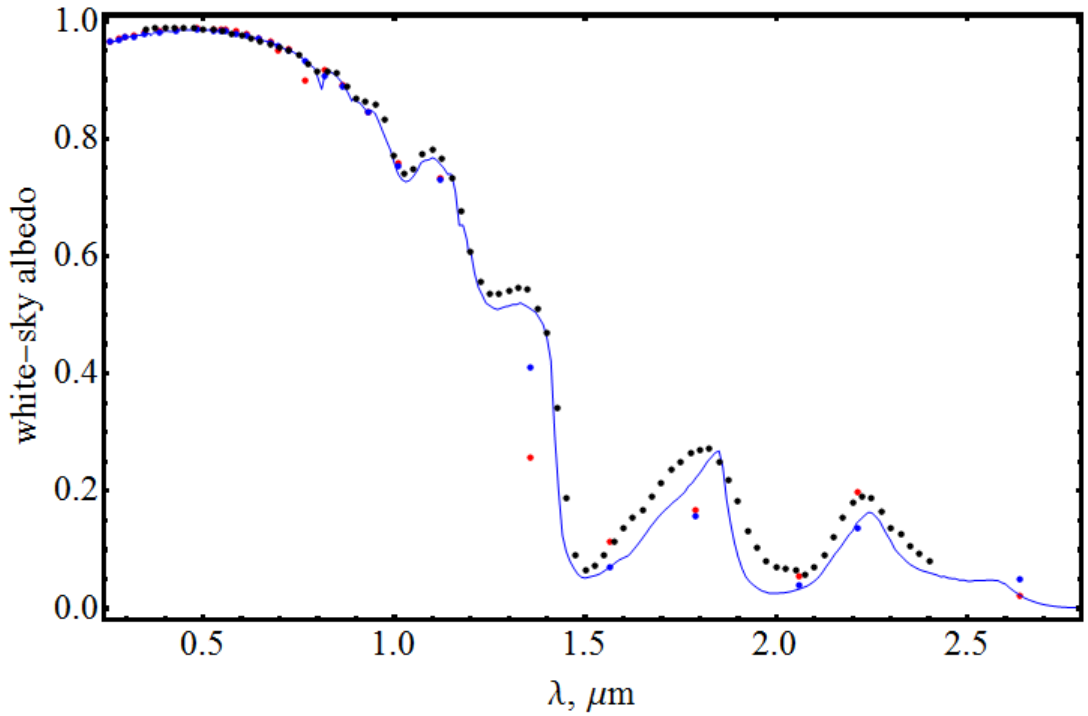
$$-\frac{\partial(K_E + S_H + \Phi_s)}{\partial t} - \nabla_p \cdot (\mathbf{F}_K + \mathbf{F}_{DE}) + (R_T - R_s) + LP - H_s = 0$$

# Atmospheric net irradiance, precipitation, and surface sensible heat flux




Three large terms are Atmospheric net irradiance, precipitation, and dry static energy divergence

# Spectral refinement of snowpack albedo model (Extending work by Hudson et al. 2006)




New snowpack albedo model vs old and measurements: blue line - new albedo at high spectral resolution, blue dots – weighted with solar spectrum into RT model spectral bands, red dots - old model, black dots - Hudson et al (2006).

Albedo refinement

1. Snow single scattering properties computed with 10 nm resolution (old model – only at the central wavelengths of the RT model bands);
2. Snowpack black- and white-sky albedo computed at the same set of wavelength;
3. Albedo is integrated within RT model bands with Thuillier solar spectrum as weighting function.