CERES Overview

Bruce A. Wielicki

Joint CERES/ARM/GCSS Session
Williamsburg, VA
November 3, 2004

CERES Science Team: Phase I
(phase II started in 2004)

Bruce A. Wielicki, Principal Investigator

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J. A. Coakley - OSU
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V. Ramanathan - Scripps
M. D. King - GSFC
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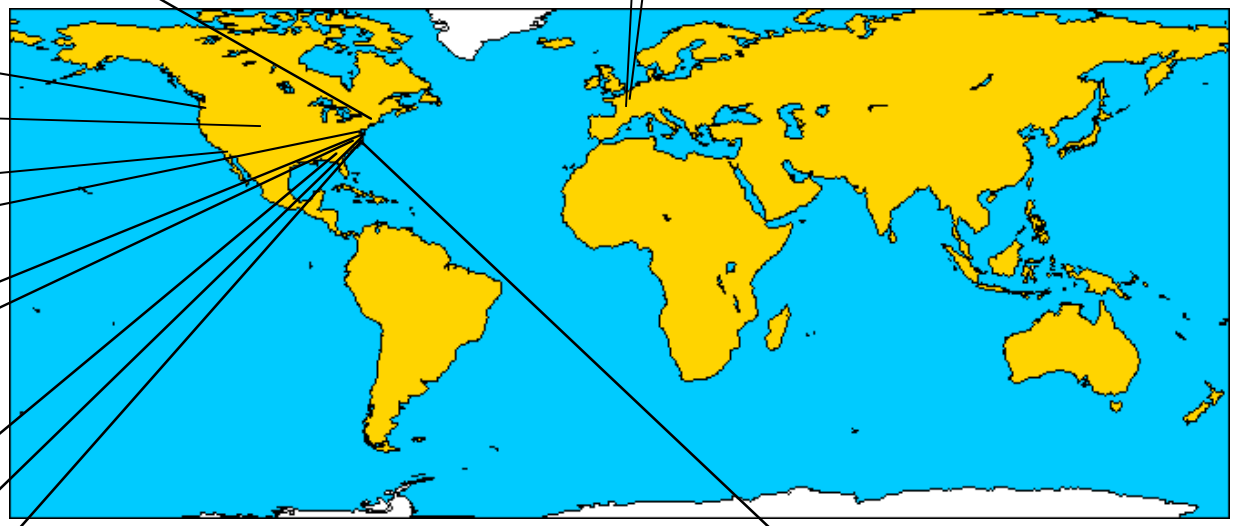
L. J. Donner - NOAA/GFDL
N. G. Loeb - HU

M. Viollier - CNRS
S. Dewitte - RMIB



LaRC

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CERES: Integrated Data for Radiation/Cloud/Aerosol

- 2 to 10 times ERBE accuracy: moving from 5 W/m^2 toward 1 W/m^2

- TOA, surface and atmosphere fluxes

- A radiative 4-D assimilation: integration of surface/ cloud/aerosol/atmosphere constrained to TOA flux

Input Data

- CERES Crosstrack Broadband
- CERES Hemispheric Scan ADMs
- MODIS Cloud/Aerosol/Snow&Ice
- Microwave Sea-Ice
- MATCH Aerosol Assimilation
- GEOS 4-D Assimilation Weather (fixed climate assimilation system)
- Geostationary 3-hourly Cloud
- Consistent Intercalibration

Output Data

ERBE-Like TOA Fluxes (20km fov, 2.5 deg grid)

CERES Instantaneous TOA/Sfc/Atmosphere Flux
- 20km field of view (SSF, CRS products)
- 1 degree grid (SFC, FSW products)
- Fluxes, cloud & aerosol properties

CERES Time Averaged TOA/Sfc/Atmosphere
- 3-hourly, daily, monthly
- 1 degree grid (SRBAVG, AVG, ZAVG products)
- Fluxes, cloud and aerosol properties

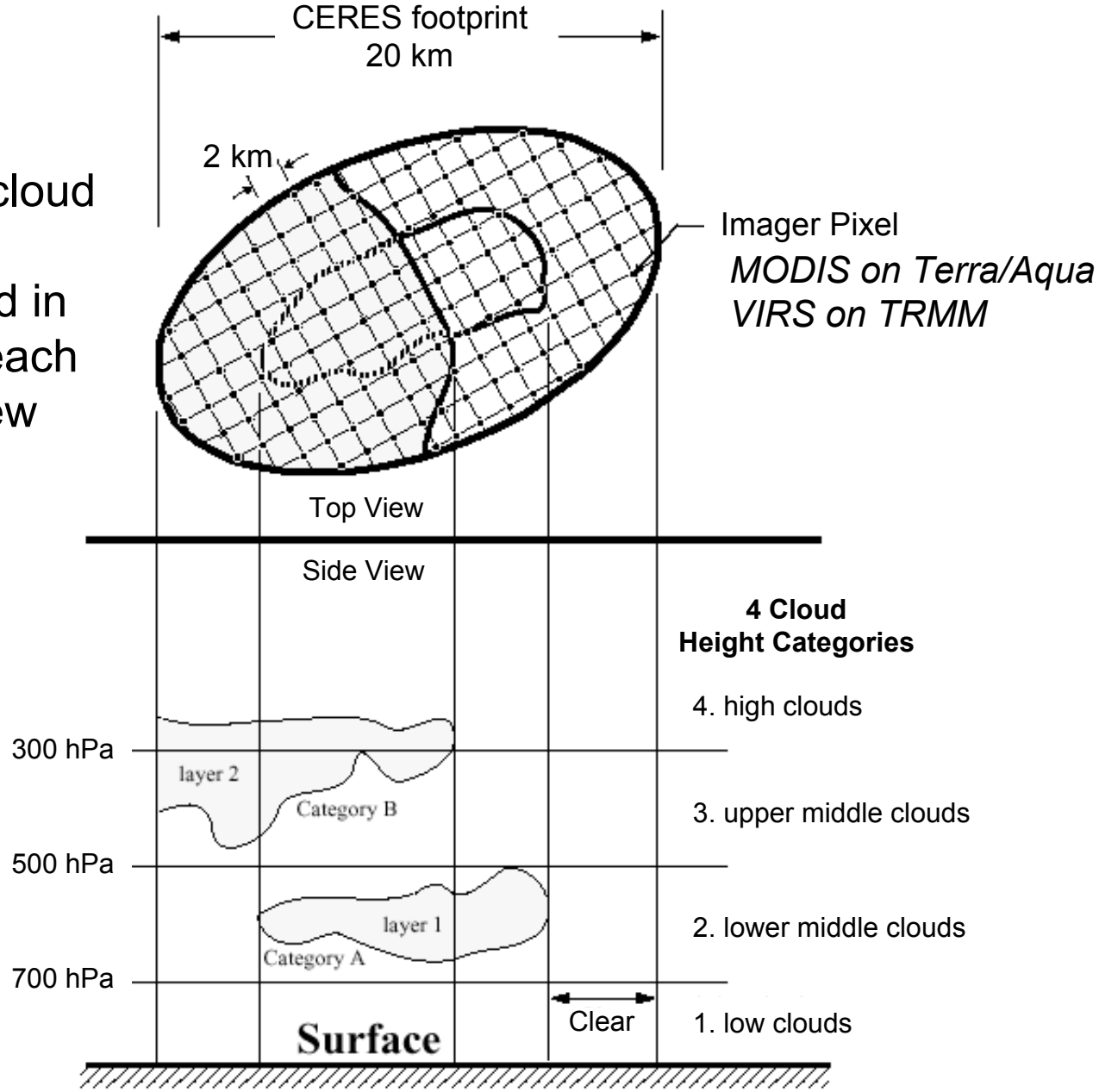
Summary of CERES Advances

• Calibration	Offsets, active cavity calib., spectral char.
• Angle Sampling	Hemispheric scans, merge with imager matched surface and cloud properties new class of angular, directional models
• Time Sampling	CERES calibration + 3-hourly geo samples new 3-hourly and daily mean fluxes
• Clear-sky Fluxes	Imager cloud mask, 10-20km FOV
• Surface/Atm Fluxes	Constrain to CERES TOA, Fu-Liou, ECMWF imager cloud, aerosol, surface properties
• Cloud Properties	Same 5-channel algorithm on VIRS,MODIS night-time thin cirrus, check cal vs CERES
• Tests of Models	Take beyond monthly mean TOA fluxes to a range of scales, variables, pdfs
• ISCCP/SRB/ERBE	overlap to improve tie to 80s/90s data.
• CALIPSO/Cloudsat	Merge in 2005 with vertical aerosol/cloud

Move toward unscrambling climate system energy components

CERES Angular Distribution Models: imager scene properties in CERES hemispheric scanning instrument fields of view

Surface, aerosol, cloud and atmosphere properties matched in Space/Time with each CERES field of view



Cloud Properties:

Fraction
Height
Temperature
Optical Thickness
Emissivity
Particle Phase
Particle Size

What time/space scale data products?

- **Level 2 Instantaneous Data**
  - 20km nadir fov, 2000km swath
  - 10:30am and 10:30pm local time sunsynchronous orbit
  - Global coverage twice per day
  - SSF: Cloud, Aerosol, Surface prop, TOA fluxes, Simple Sfc Fluxes
  - CRS: Full 3-D Radiative assimilation:
    consistent Cloud, Aerosol, Surface prop., Fluxes for TOA, Atm, Sfc
- **Level 3 Instantaneous 1 degree gridded data**
  - SFC: gridded version of SSF
  - FSW: gridded version of CRS
- **Level 3 Monthly 1 degree gridded data**
  - SRBAVG: gridded monthly mean, CERES only, CERES+3-hrly Geo available in Dec 2004 for 4 years of Terra (3/00 on),
    add daily average in spring 05: add Pc/Tau frequency distns?
  - SYN, AVG: gridded 3-hourly, daily, monthly CERES only and CERES + 3-hourly geo: available mid-2005.

What CERES Data is Currently Available?

- Validated Products (science ready, data quality summary avail.)
- Beta Products (typically available but not validated/science ready)

Product *Time Period*	TRMM *1/98-8/98 and 3/00*	Terra *3/00 forward*	Aqua *7/02 forward*
Instantaneous Field of View Products			
ERBE-Like ES-8	9 months	4 years	1.5 years
ADMs	yes	yes	spring 05
SSF: (TOA/Sfc/Cld/Aer)	9 months	3.8 years	fall 04
CRS (TOA/Sfc/Atm/Cld/Aer)	9 months	1.9 years	fall 04
(note: 1 degree gridded SSF is SFC, and gridded CRS is FSW product)			
1 Degree Gridded Monthly Products			
ERBE-Like ES-4/9	9 months	3.8 years	1.5 years
SRBAVG (SSF + geo)	9 months	fall, 04	spring 05
AVG (CRS + geo)	spring 05	summer 05	fall 05

Where do I get the CERES data?

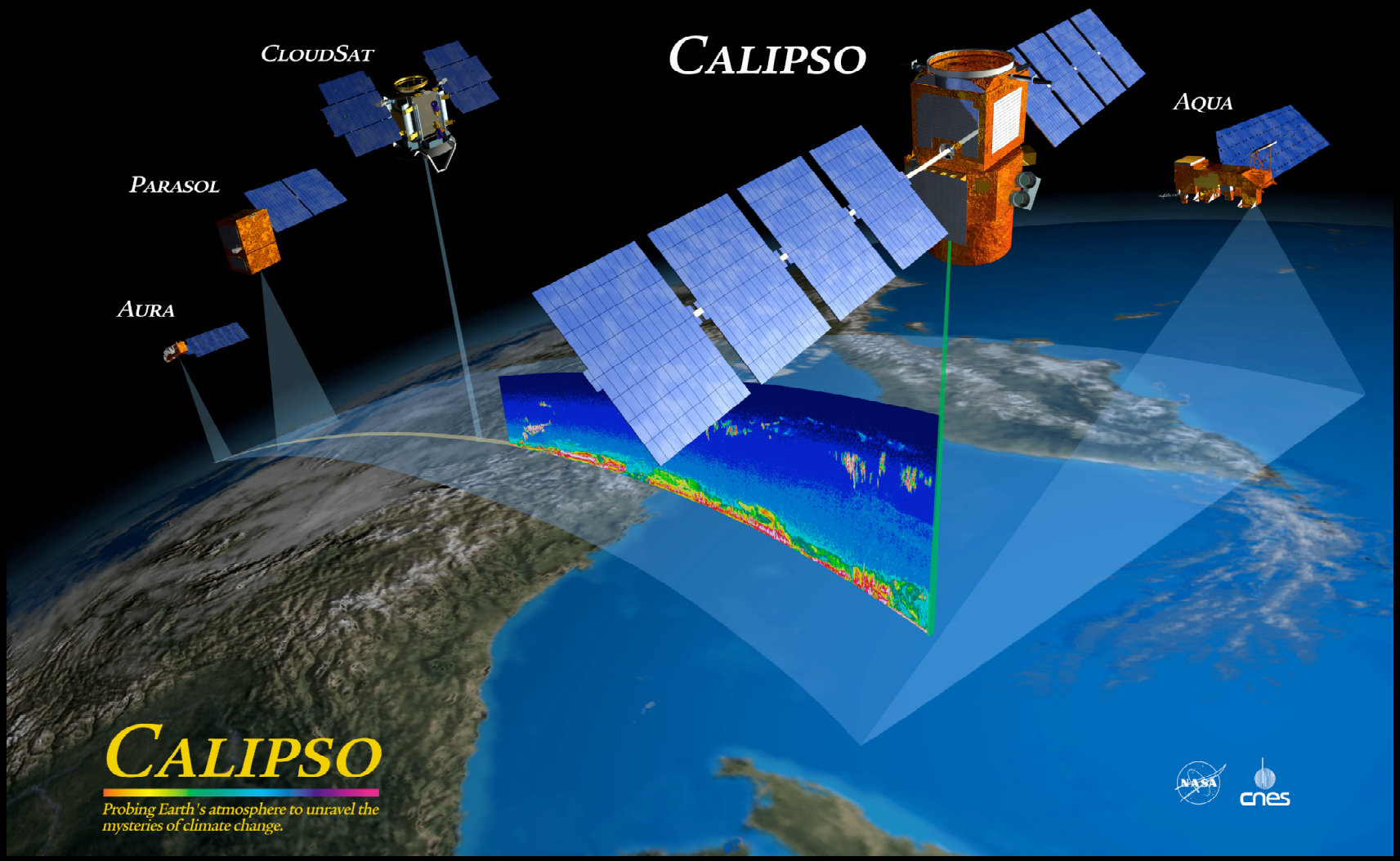
- CERES Data Can be Ordered on-line through the Atmospheric Sciences Data Center at NASA Langley Research Center (URL: http://eosweb.larc.nasa.gov/)

- Each Data Product has a Data Quality Summary: dynamic summary of current understanding of accuracy and limitations (journals are too slow).

- All Data Are in HDF Format and Can be Viewed using CERES ViewHDF Software (works on Mac, PC, SGI, Sun)

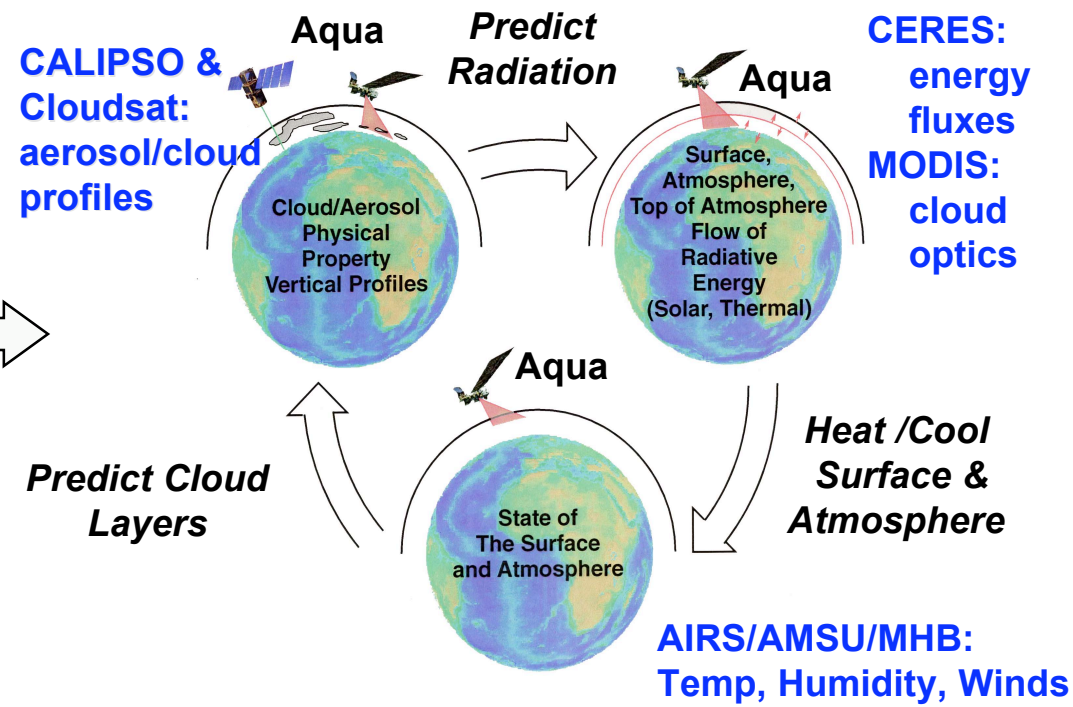
- Documentation Can be Found at the CERES Website (URL: http://asd-www.larc.nasa.gov/ceres/ASDceres.html)

"A-Train" Formation for Aerosol and Cloud Vertical Profiles
Atmospheric State => Aerosol/Cloud => Radiative Heating

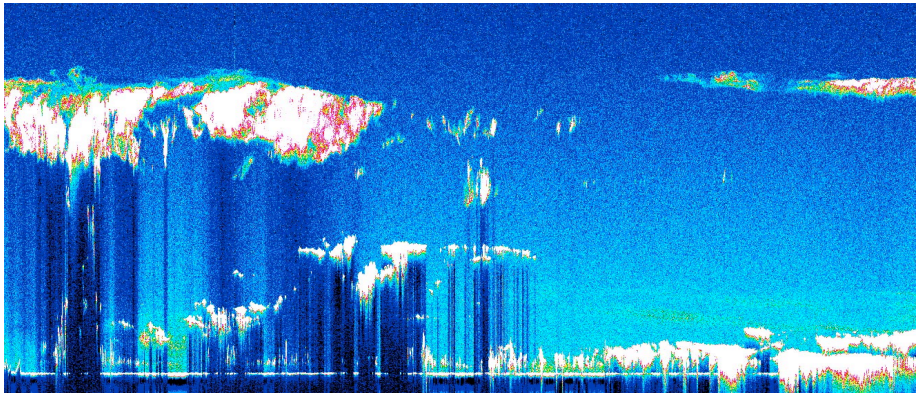


A-train: New Cloud and Climate Observations

Cloud/Radiation Feedback



Cloud Monitoring



- Lidar Cloud Fraction/Height
- Self calibrating 532nm backscatter
- Nadir only sampling noise: 0.3 Wm^{-2} LW zonal annual average
- UKMO zonal climate noise: 0.3 Wm^{-2}
- Greenhouse forcing: 0.6 Wm^{-2}/decade

CERES vs. ERBE TOA Error Budgets

Error Source	Monthly Avg 1σ (~ 250 km)		Monthly Zon Avg Difference Error (Eqtr to Pole)		Global and Zonal Trends (10yrs)	
SW Radiation	**ERBE**	**CERES**	**ERBE**	**CERES**	**ERBE**	**CERES**
angle sampling	3	< 1	10	< 1	< 1	< 0.2
time sampling	4	1 - 3	3	1	< 1	< 0.2
calibration (abs)	2	1	2	1	n/a	n/a
calibration (stab)	1	< 1	1	< 1	1	< 1
UKMO climate model natural variability				0.8		0.3
LW Radiation	**ERBE**	**CERES**	**ERBE**	**CERES**	**ERBE**	**CERES**
angle sampling	1.5	< 0.5	2.5	< 1	< 0.2	< 0.1
time sampling	4	1.5	3	1	< 0.3	< 0.1
calibration (abs)	2	1	2	1	n/a	n/a
calibration (stabi)	1	< 0.5	1	< 0.5	1	< 0.5
UKMO climate model natural variability				0.8		0.2

notes:

CERES data uses new angular models (200) by surface and cloud type (ERBE used 12).

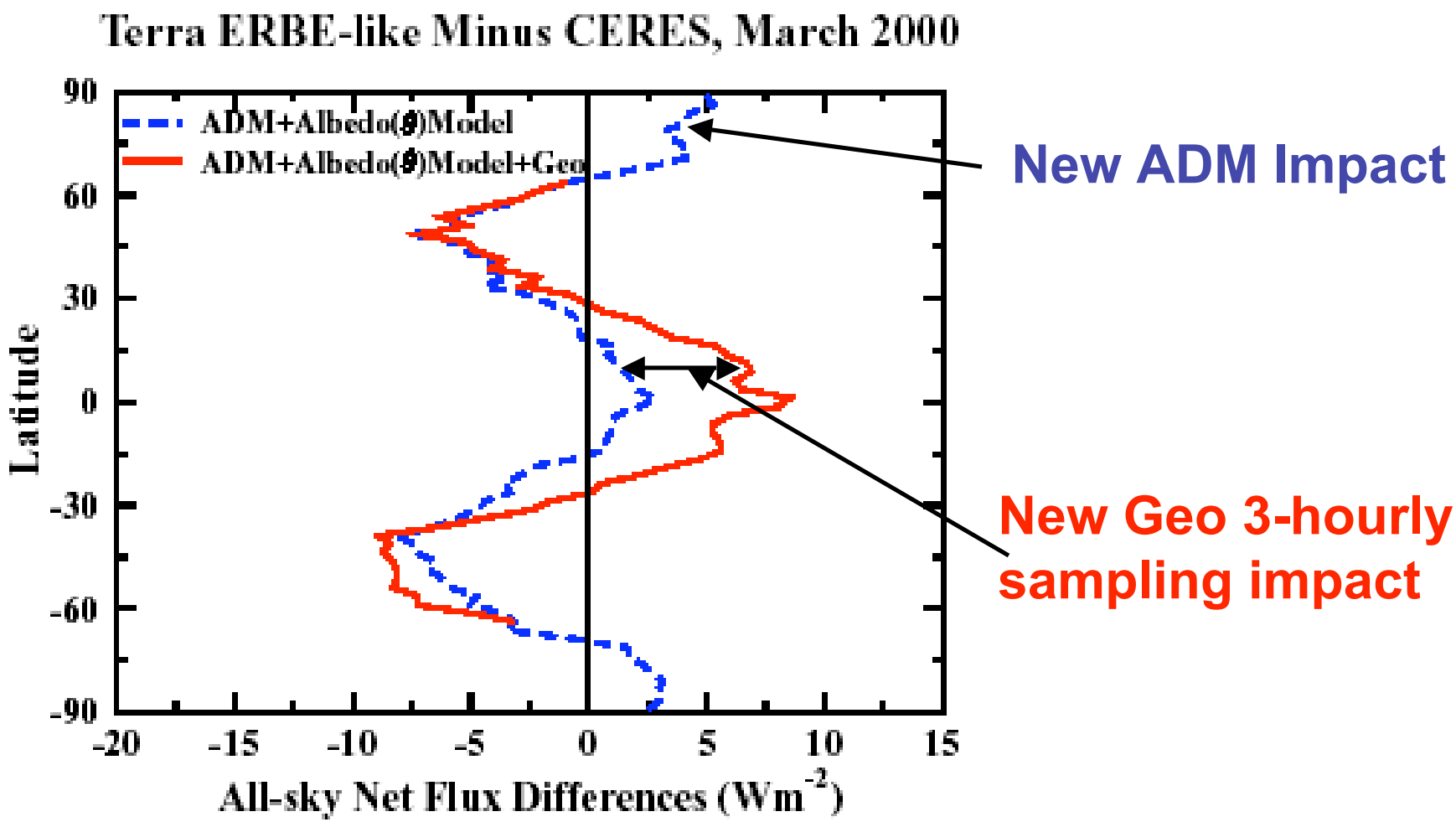
CERES data uses 3-hourly geo narrowband data to augment time sampling (ERBE no geo)

CERES calibration, characterization roughly a factor of 2 better than ERBE

CERES stability based on 3 instruments (TRMM,Terra) and assumes that only 80% of any gain changes during orbit and from ground to orbit can be removed by using on-board sources.

Backup Slides

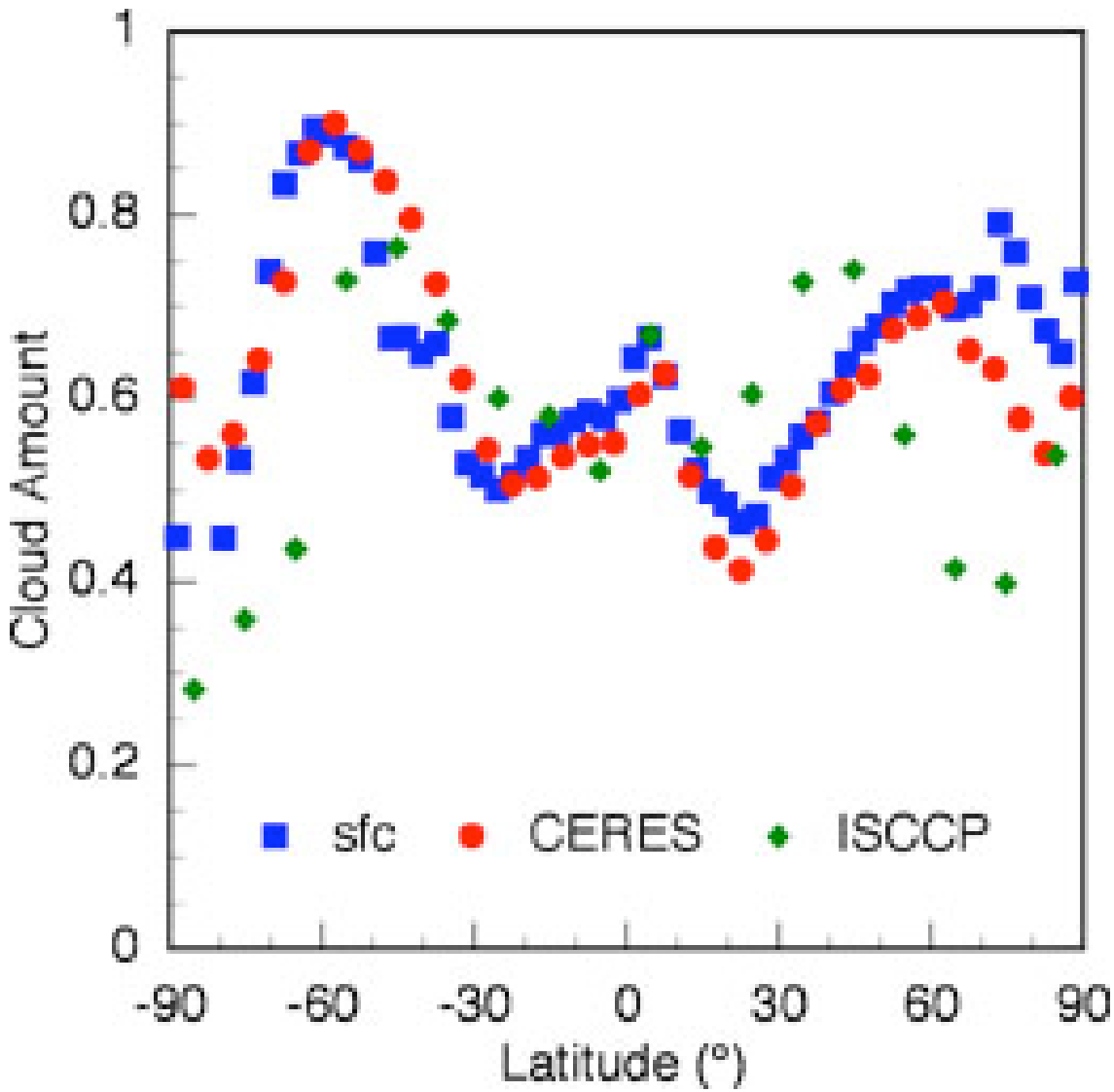
Differences of new CERES SW fluxes from ERBE-Like zonal means for March 2000. Differences up to 8 Wm^{-2}.
Will impact equator to pole transport, surface flux constraints with ARGO on ocean mixing processes, climate model validation



What are key CERES Issues?

- Completing CERES constraint of geo shortwave diurnal cycles
  - 3 Wm^{-2} noise from time/angle differences in 1 degree monthly grid box
- Closing the global net energy budget to from 3 Wm^{-2} to 1 Wm^{-2}
- Determining source of shortwave 2 Wm^{-2} decrease over 2000 - 2004
  - calibration drift? lamps claim stable to better than 0.2% or 0.2 Wm^{-2}
  - coding error in production software?
  - electronics issue that affects only lamps and SW channels?
  - no obvious change in MODIS cloud properties
  - clear-sky ocean, desert, all-sky dropping 2%
  - deep convective cloud (<205K) drop 1% but MODIS claims increase in particle size explains the 1%.
  - use 4 years of CRS untuned calculated - observed to look at changes and tie down versus cloud fraction, phase, surface type, latitude, etc.
- Completing 3-hourly synoptic and monthly avg.
- Adding daily average data products to 3-hourly and monthly
- Validation against GERB diurnal cycles and CALIPSO/Cloudsat

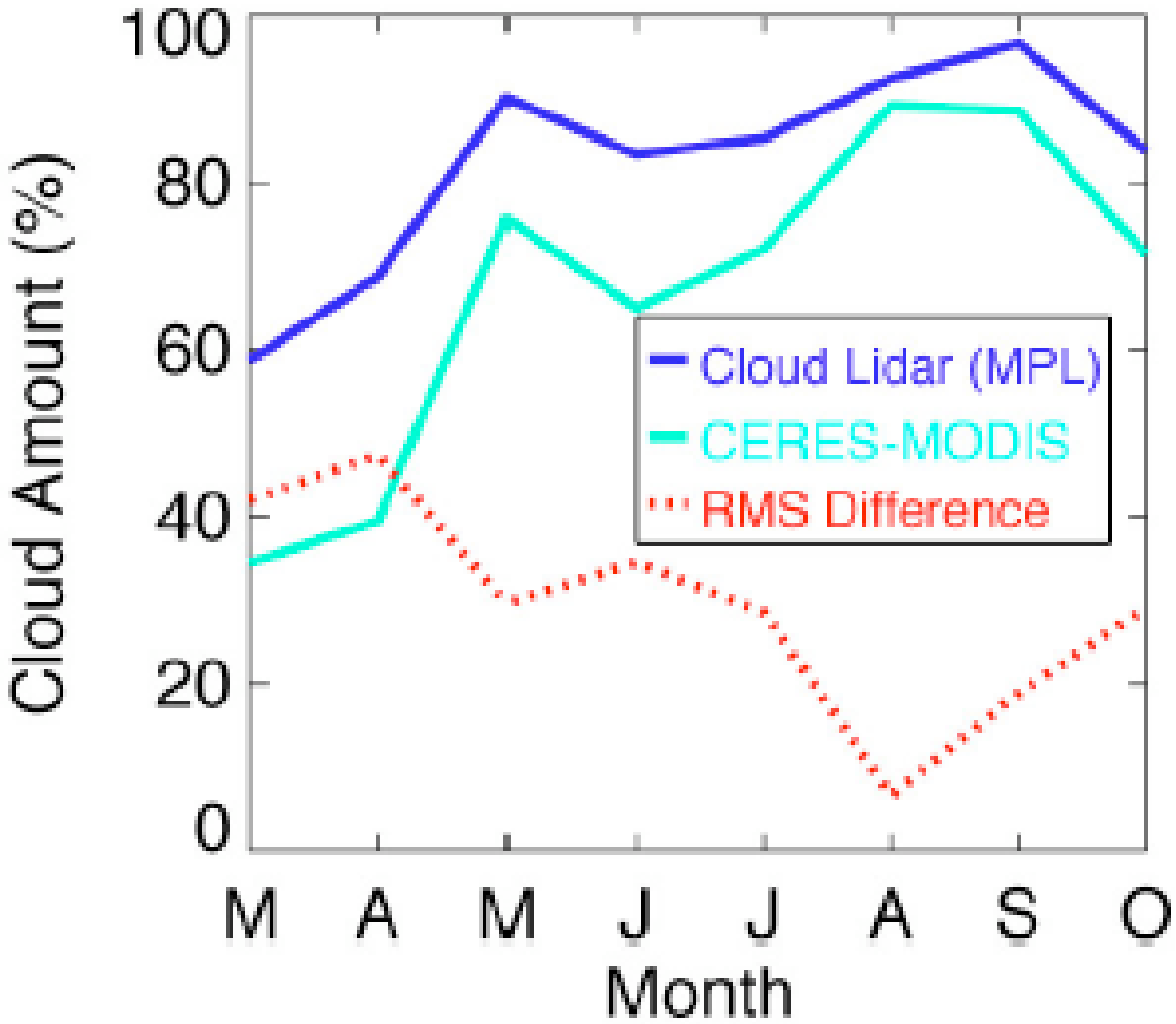
CERES Terra MODIS Cloud Fraction



Surface Observations (71-96)

CERES Terra MODIS (00-03)

ISCCP D (83-01)



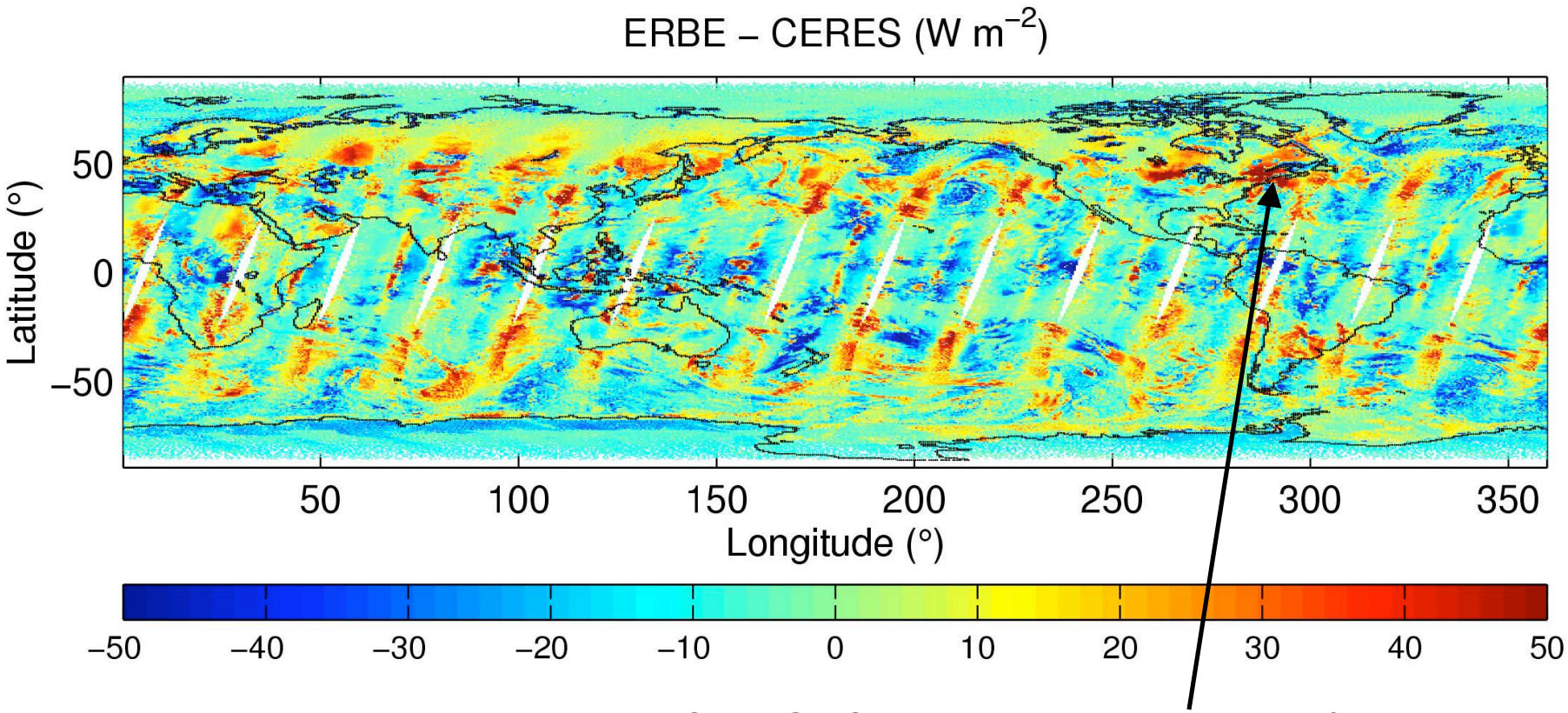
CERES MODIS Cloud Amount versus
Barrow ARM site surface lidar (uses monthly means)
March 2000 to April 2002

Making Angular Distribution Models

- 2 years of matched CERES, surface, aerosol, cloud, atmosphere global data (TRMM, Terra, Aqua done individually)
- Use Rotating Azimuth Plane (RAP) CERES scanner for hemispheric viewing
- Sort by:
  - Solar zenith angle
  - Viewing zenith angle
  - Viewing azimuth angle
  - Cloud properties (fraction, phase, optical depth, emissivity, height)
  - Surface properties (surface wind, vegetation type, skin temp)
  - Aerosol loading (optical depth)
  - Atmosphere state (temperature lapse rate, column water vapor)
- Determine SW, LW, Window anisotropy by angle and property
- ADMs provide instantaneous radiance to flux conversion

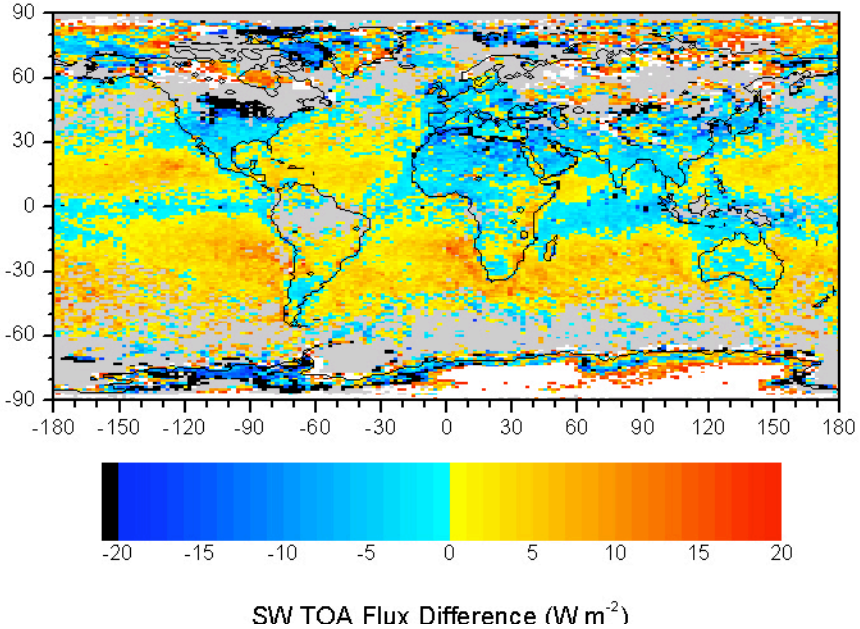
New CERES ADMs greatly improve instantaneous fluxes

Key to constraining more accurate surface fluxes
Key to accurate cloud fluxes by cloud type
Key to accurate matched satellite/surface fluxes for aerosol absorption

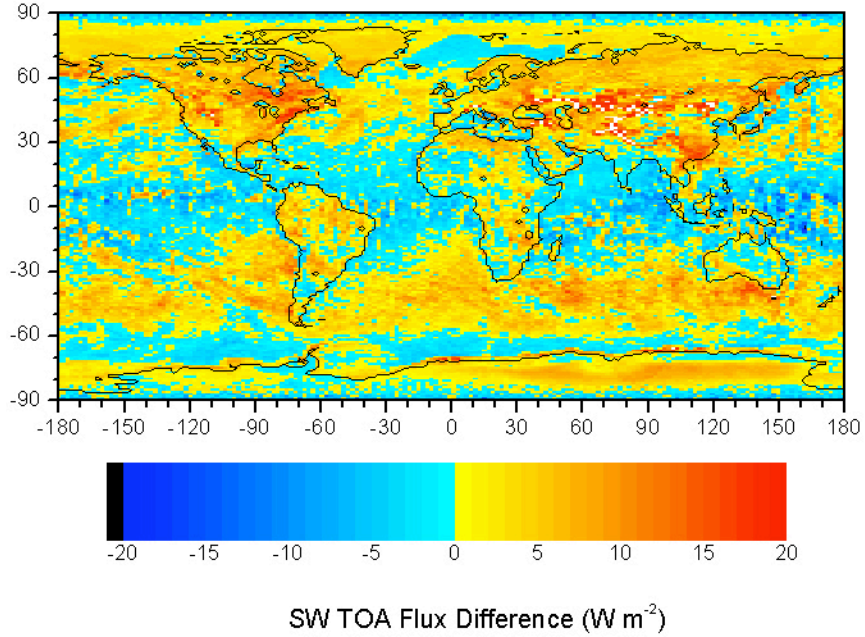


CERES TOA instantaneous shortwave fluxes differ from ERBE by +/- 50 Wm^{-2} with a strong dependence on scene type & viewing angle

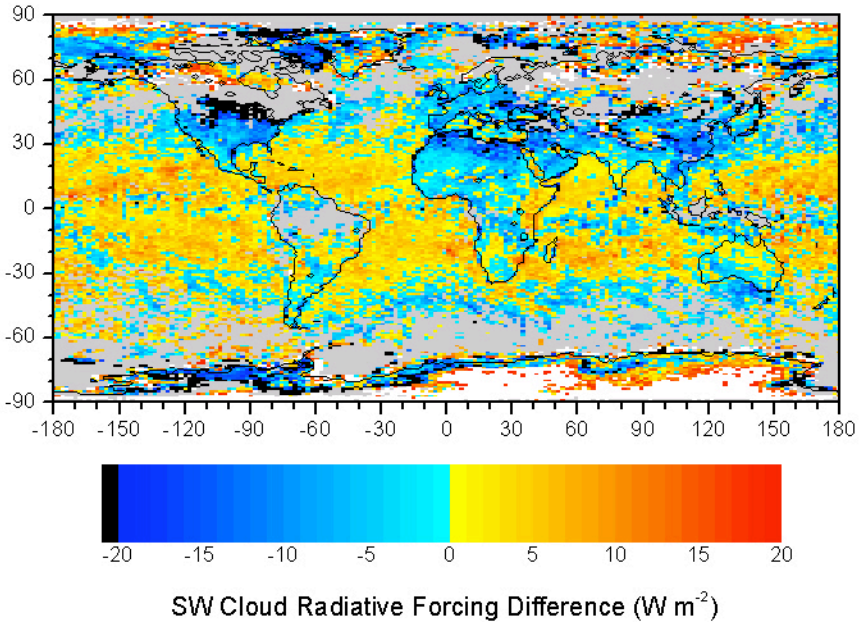
Clear-sky SW TOA Flux (March 2003)



All-sky SW TOA Flux (March 2003)



SW TOA Cld. Rad. Forcing (March 2003)



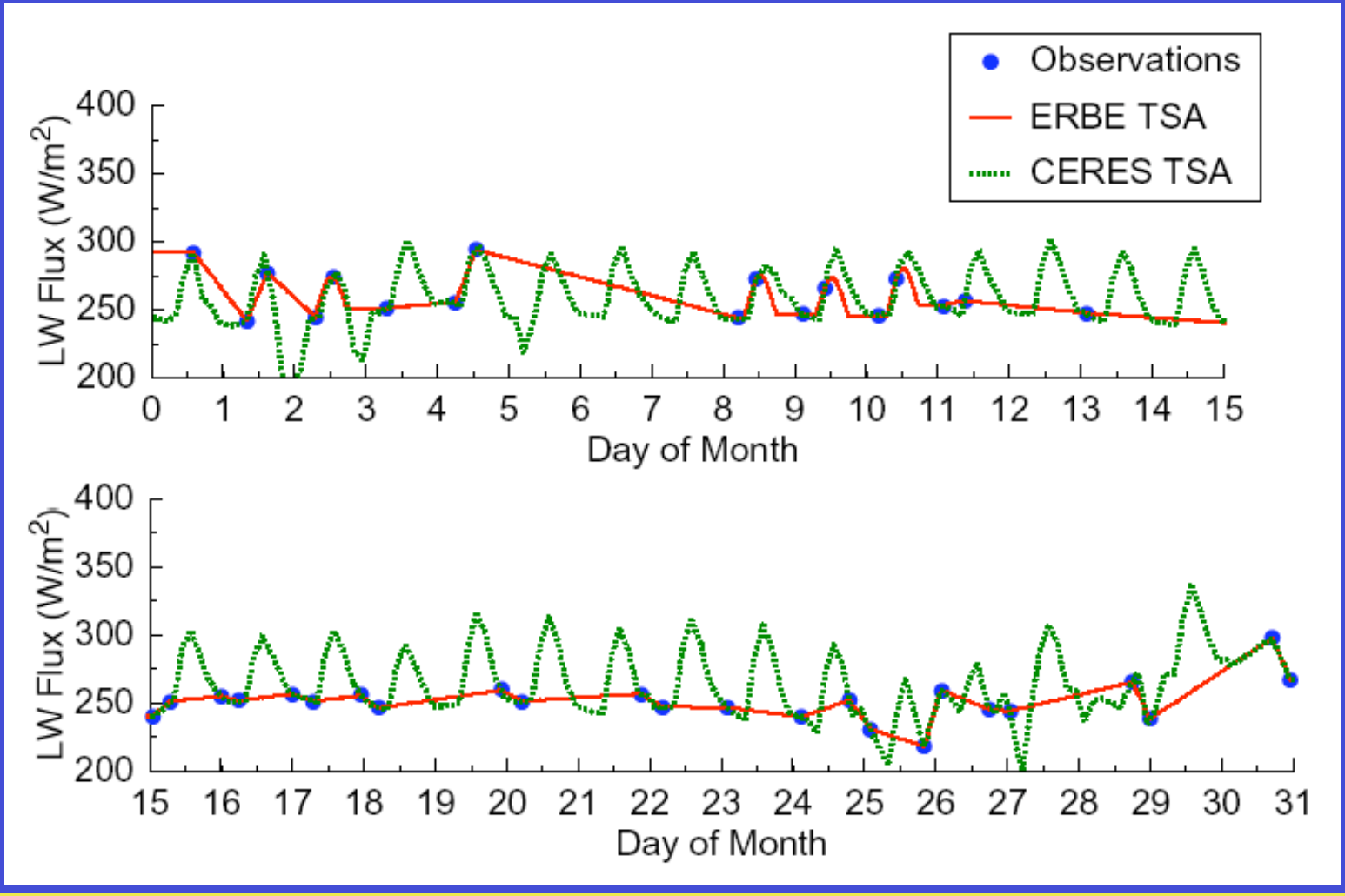
Effect of new CERES ADMs:

ERBE-Like TOA Flux (ES-8)
minus
New ADM TOA Flux (SSF)

(all SW fluxes are 24-hour average)

Temporal Interpolation of TOA LW Flux

January 1998 E. Sahara 24.5N 20.5E

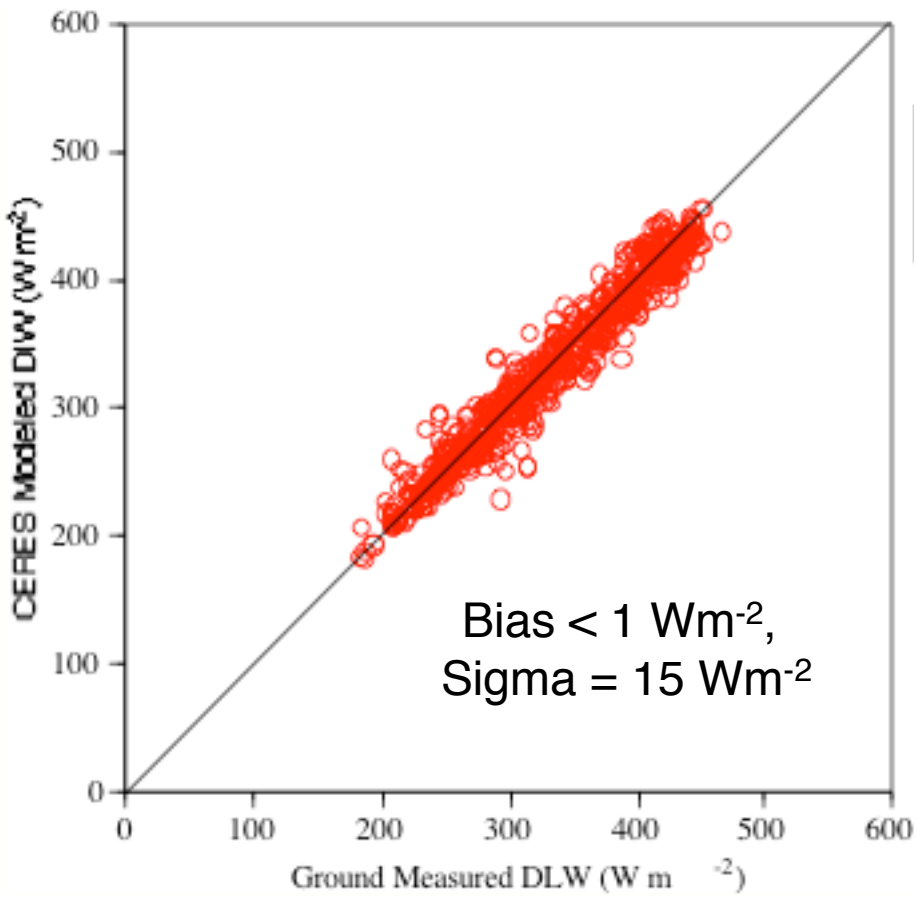


CERES Surface and Atmosphere Fluxes

- Simple Surface Fluxes on SSF, SFC, SRBAVG Products
  - Algorithms similar to Darnell et al., GEWEX SRB product
  - Use improved CERES TOA fluxes
  - Minimize use of radiative models or other model input

- 4-D Radiative Assimilation on CRS, FSW, and AVG Products
  - Use full radiative transfer (Fu-Liou with gamma function tau distn)
  - Input CERES fov matched cloud properties derived from MODIS
  - Input MODIS team aerosol data (MOD04)
  - Input NCAR MATCH 4-D aerosol assimilation of MODIS aerosol (used for composition and vertical layering)
  - Input GSFC GEOS 4.0.3 4-D weather assimilation data
  - Constrain solution to CERES fov TOA fluxes: SW, LW, 8-12um
  - Adjust least certain input for each surface/cloud/atmosphere state

ARM Central Facility, Downward LW Fluxes
CERES estimate (y-axis) vs ARM Surface Measurement (x-axis)
All-sky, 715 CERES Overflights within 1 minute,
Day and Night Overpasses, Nov 00 to Sep 01



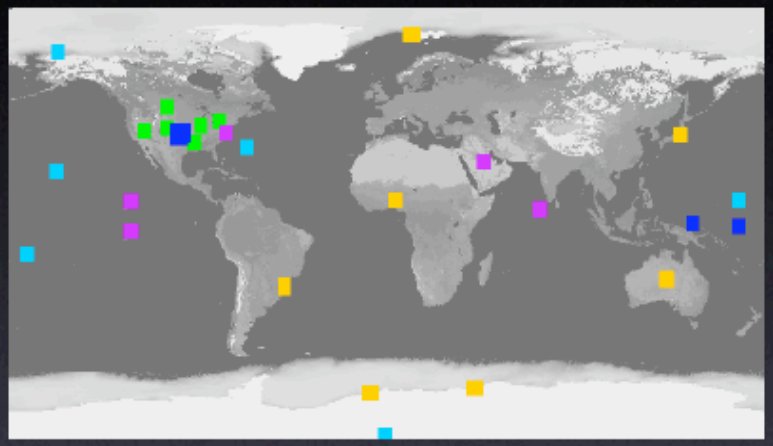
For BSRN sites
equator to pole
Bias < 5 Wm^{-2}
Instantaneous
sigma 15 to 25 Wm^{-2}

Total of 60,000
comparisons

New Terra CERES CRS Data Product
Instantaneous Match Surface Flux Accuracy

Surface Flux	Bias (24 hr Average)*	Aerosol Forcing (24 hr)	Sigma (24 hr Average)*	Samples
SW Down All-sky	3	-	27	3900
LW Down All-sky	- 5	-	22	7700
SW Down Clear-sky	0	- 8	8	1600
LW Down Clear-sky	- 9	2	15	800

Tested against 40 BSRN, ARM SURFRAD, COVE surface sites

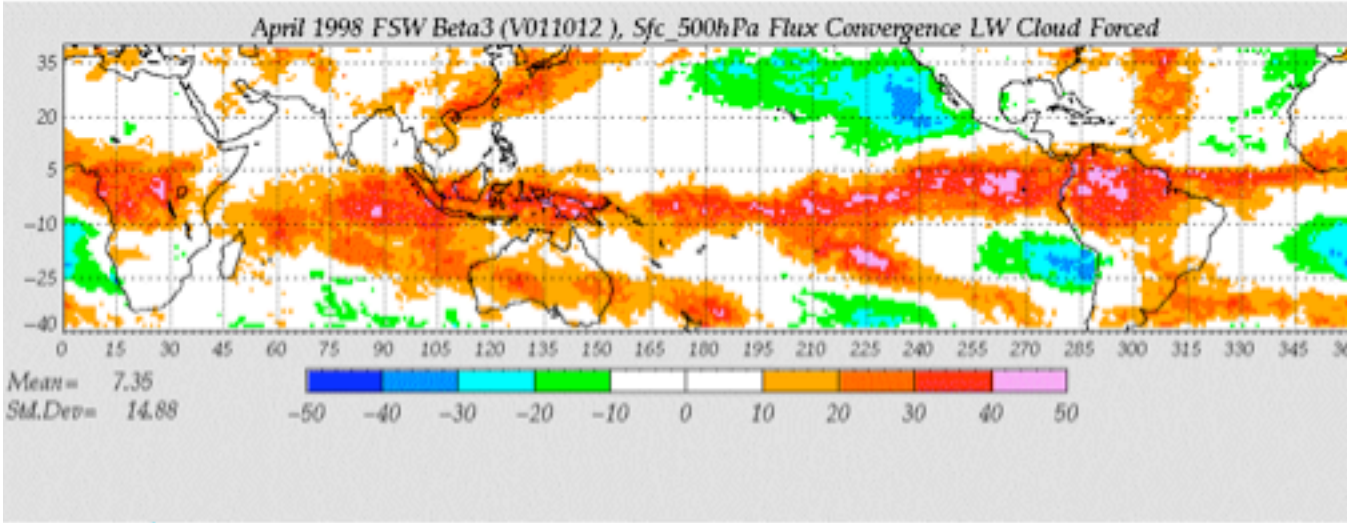


- Surface Data Averaged over 30 minutes
- Uses closest CERES 20-km field of view
- MODIS clear-sky aerosols
- NCAR MATCH aerosol assimilation of MODIS for cloudy sky aerosol
- GSFC GEOS-4 assimilation atmosphere
- New gamma distribution Fu-Liou model
- No surface data used in satellite retrieval

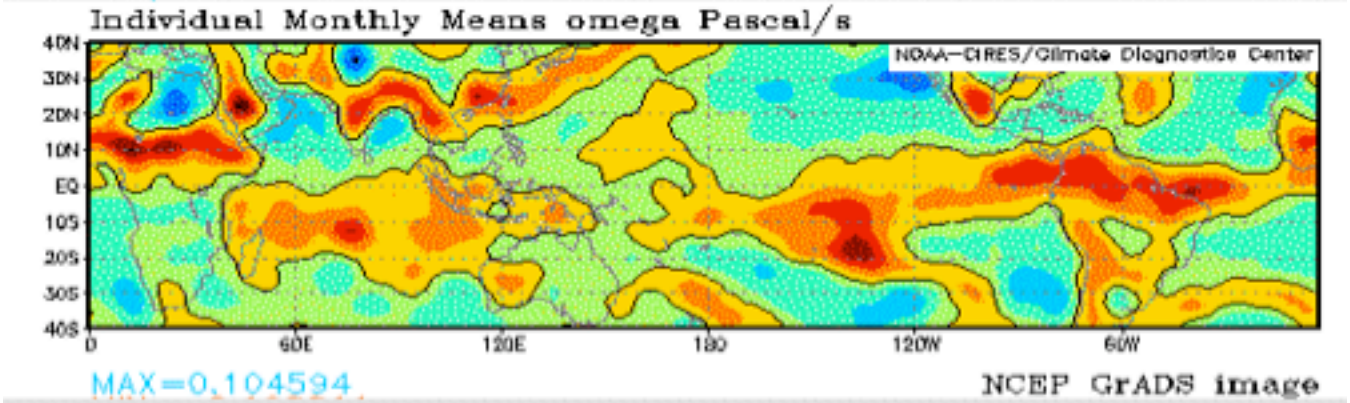
* SW fluxes are scaled to 24-hour average insolation (1/3 typical Terra 10:30 am values)
LW fluxes include both daytime and night-time validation results

CERES April 1998 Atmosphere Fluxes

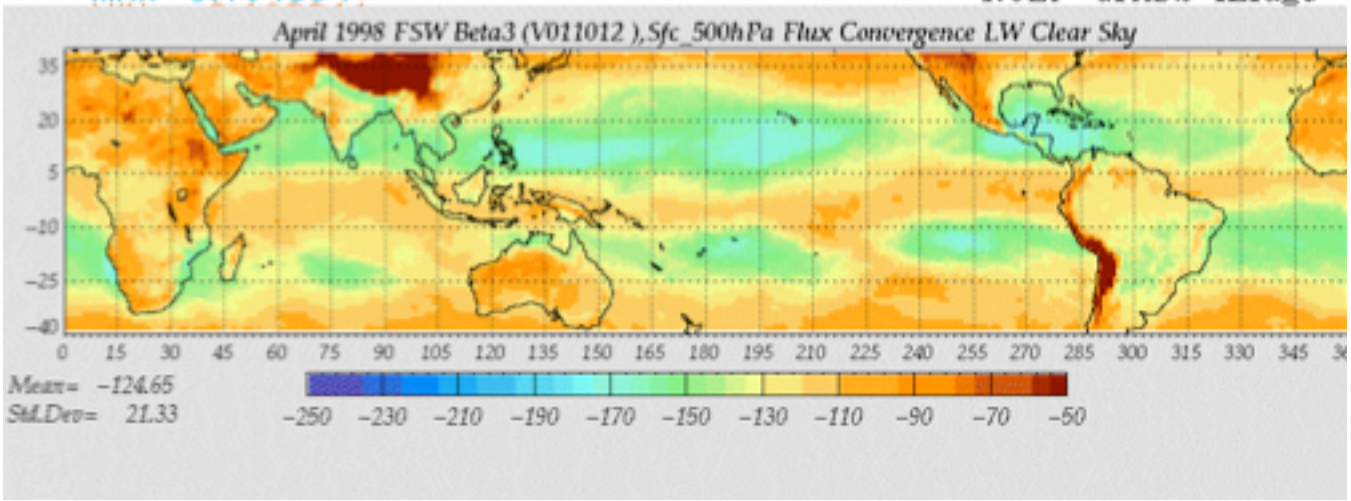
Cloud Forcing
LW Convergence
Sfc to 500 hPa
-50 to +50 Wm^{-2}



Vertical Velocity
at 700hPa
red = ascent

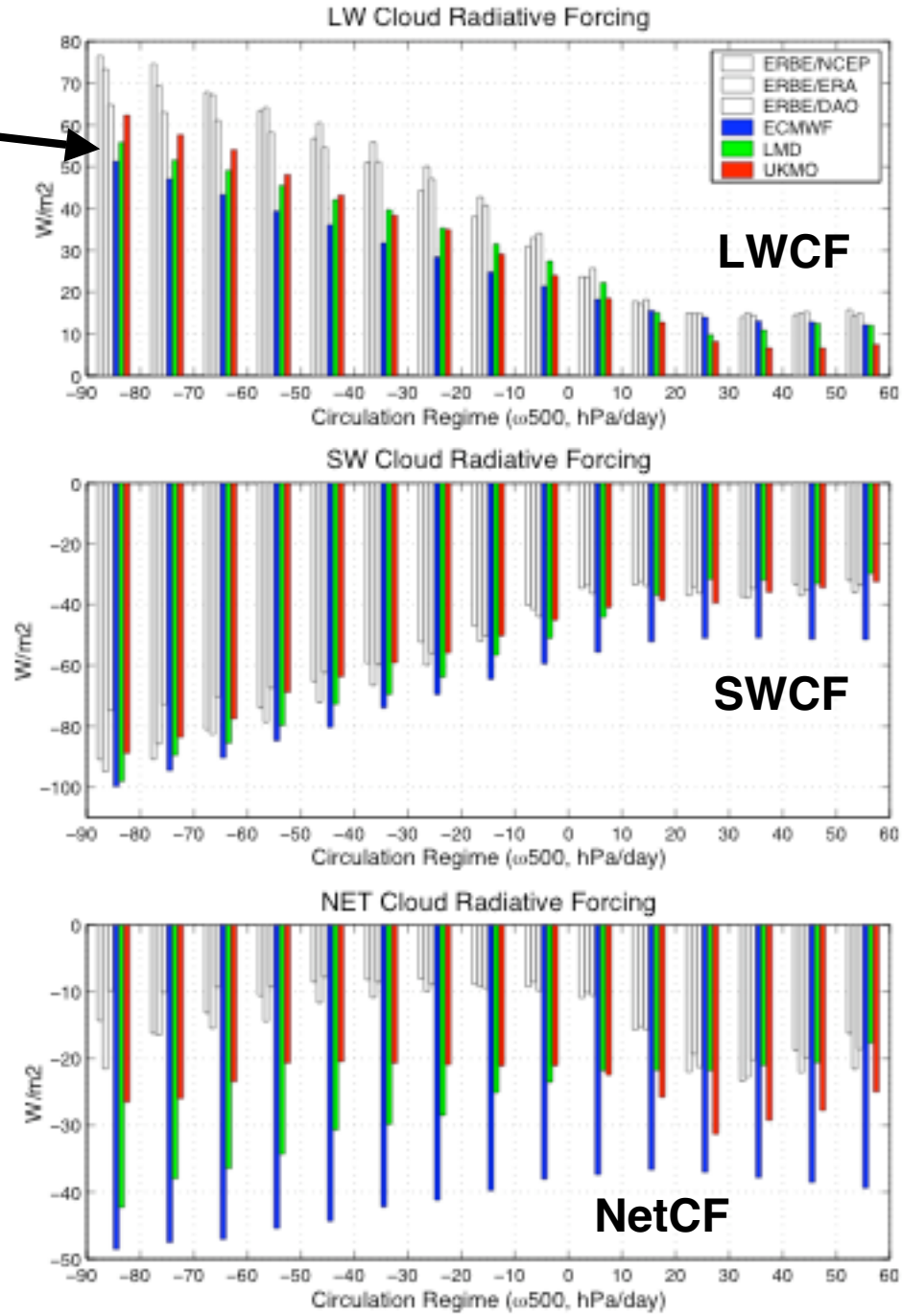


Clear Sky
LW Convergence
Sfc to 500 hPa
-250 to -50 Wm^{-2}



How do we take advantage of the greatly improved accuracy & integration of the CERES data?

white: ERBE/NCEP, ERA, DAO
blue: ECMWF
green: LMD
red: UKMO



Model vs Data Intercomparisons by Dynamic Regime:

Vertical Velocity

(Bony et al., 2003)

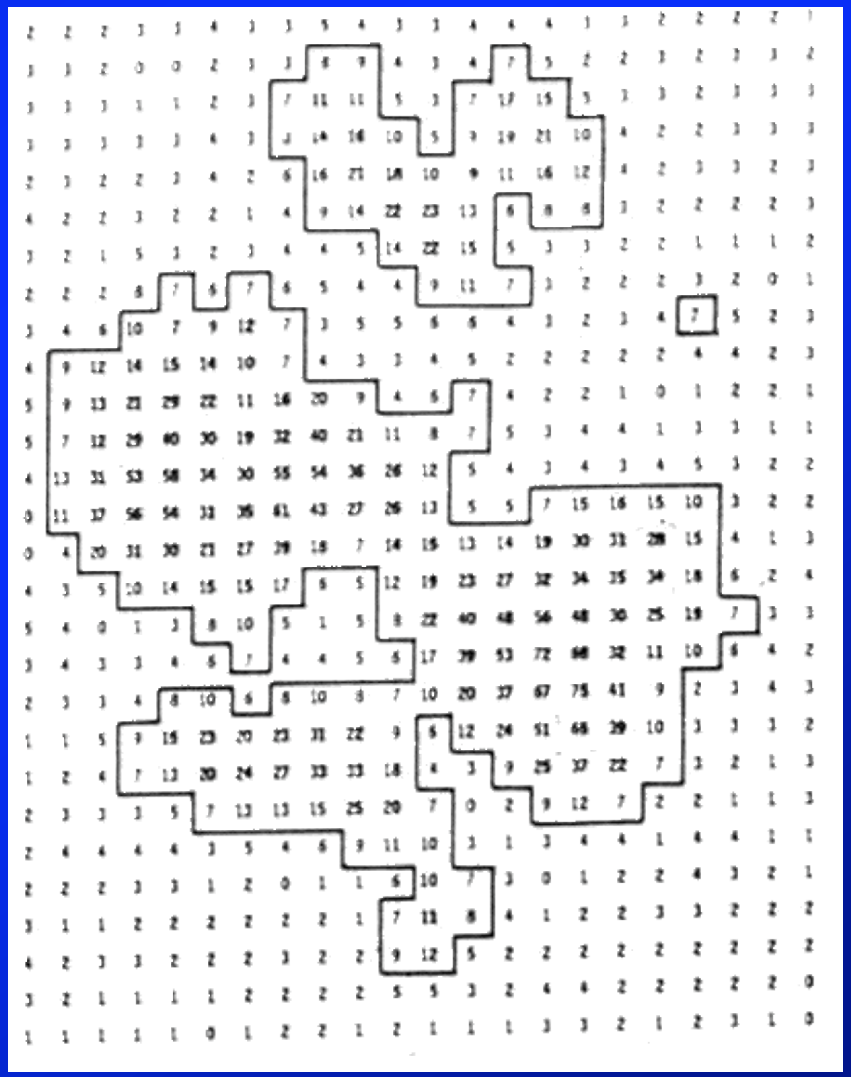
Need to redo with CERES fluxes since ERBE much less accurate by dynamic state

How do we study clouds at the short time/space scales of cloud physics, yet at climate accuracy?

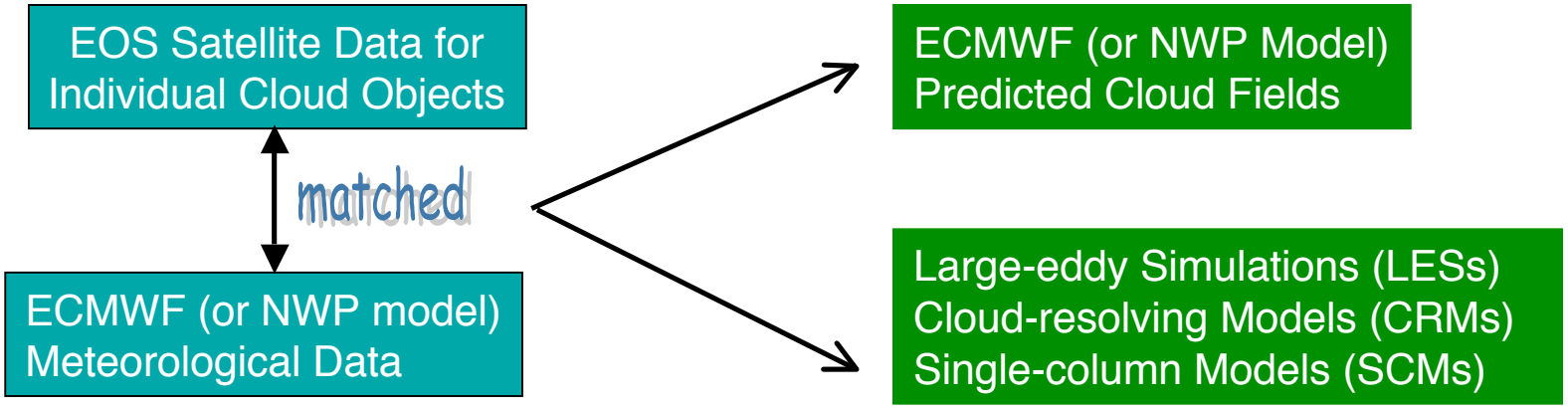
Objectively Define Cloud Systems

- ♣ Define a cloud system as a contiguous region of the Earth with a single dominant cloud type (e.g. stratocumulus, stratus, and deep convection)

- ♣ Determine the shapes and sizes of the cloud systems by the satellite data and by the cloud property selection criteria (Wielicki and Welch 1986)

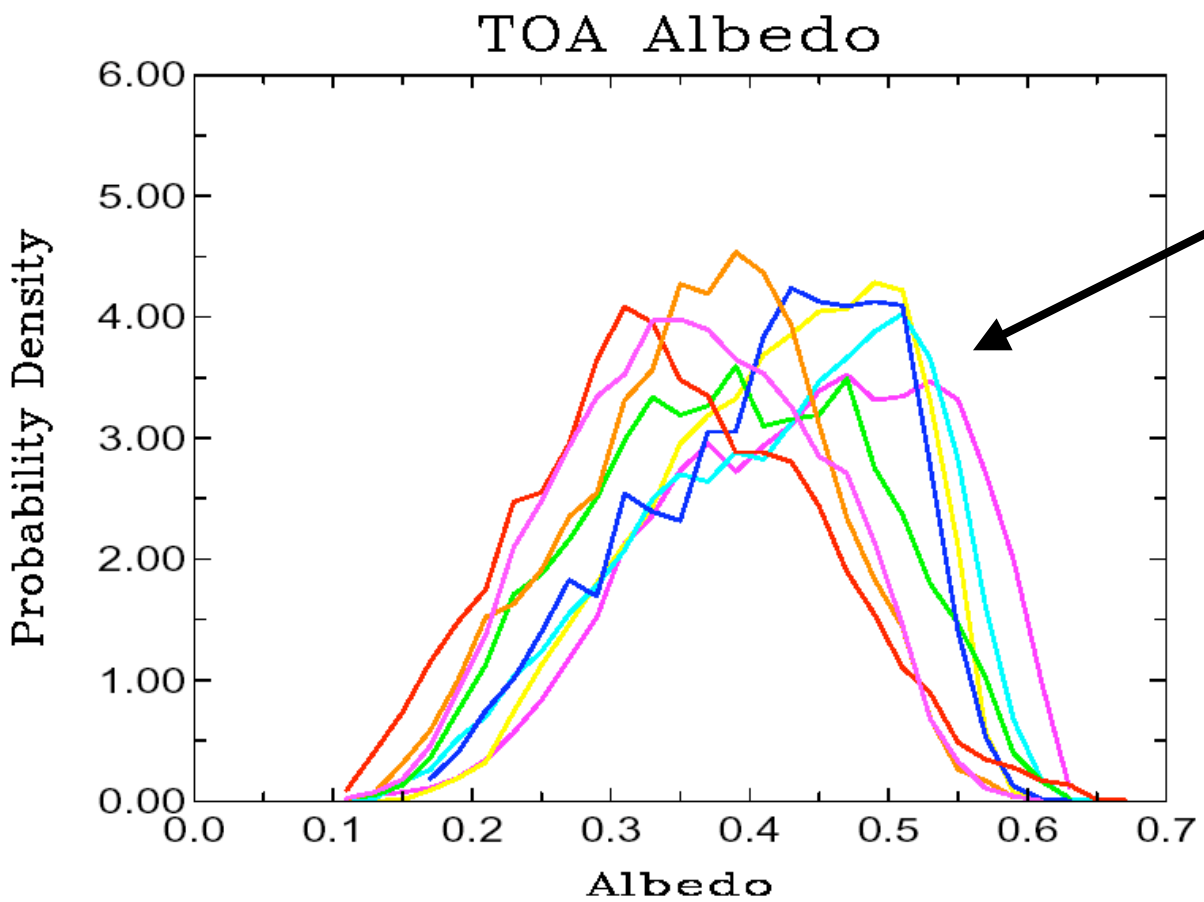


Using satellite cloud system data for evaluating and improving CRMs and cloud parameterizations



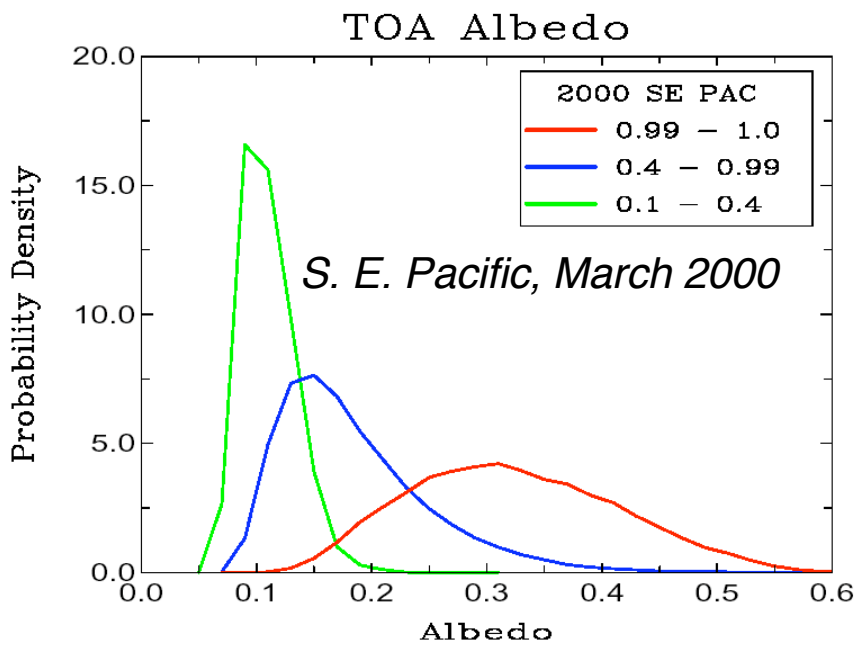
- Analyze the statistics of subgrid characteristics (PDFs) of satellite-observed cloud objects, *not* GCM gridbox means
- Match the CERES SSF (Single Scanner Footprint) cloud and radiation data with ECMWF meteorological data (T, q, u, v and advective tendencies)
- Perform cloud model simulations driven by ECMWF advective tendencies; an iterative process of improvement and evaluation of cloud models
- Also evaluate the ECMWF parameterization using its predicted cloud fields

Overcast Boundary Layer: Observed CERES Cloud Object Pdfs for March, 1998

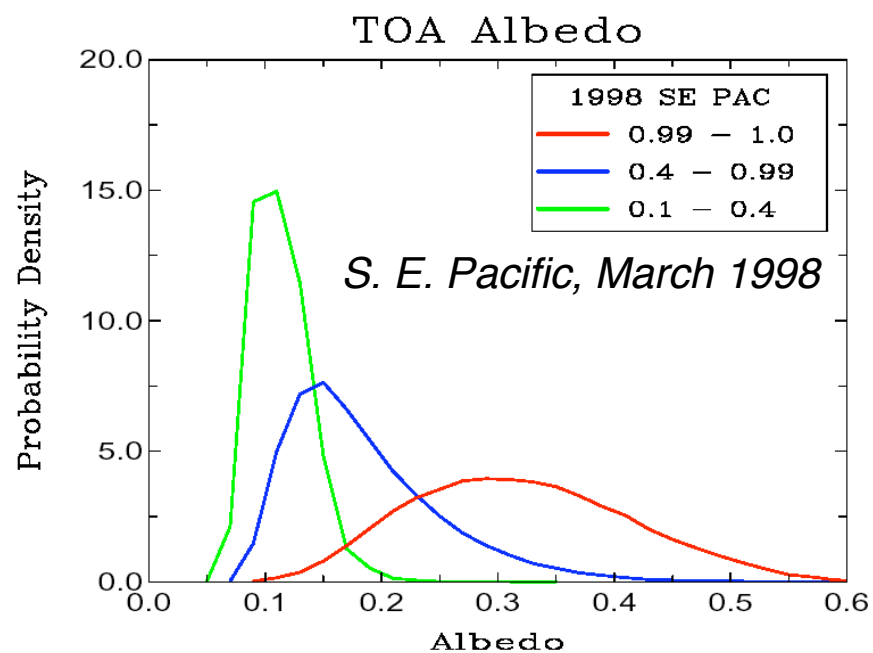


Sample individual pdfs for just 8 of the stratus cloud systems (CERES SSF TOA albedo)

Boundary Layer: Observed CERES TOA Albedo Pdfs for March, 2000 vs March, 1998

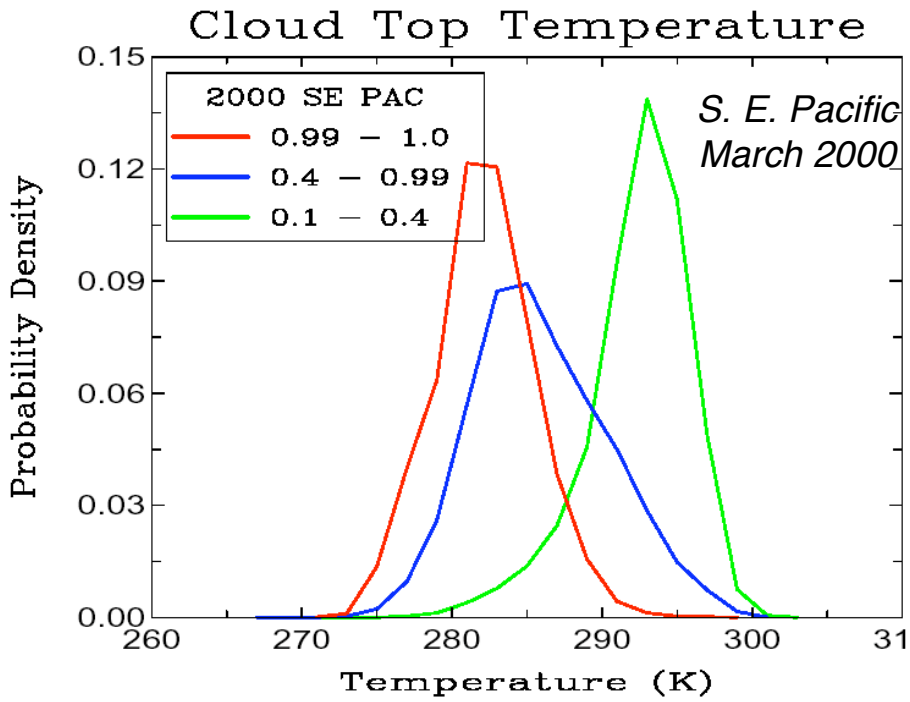


No apparent difference in the S.E. Pacific, even though the Walker Cell strength reduced, Hadley cell strengthened...

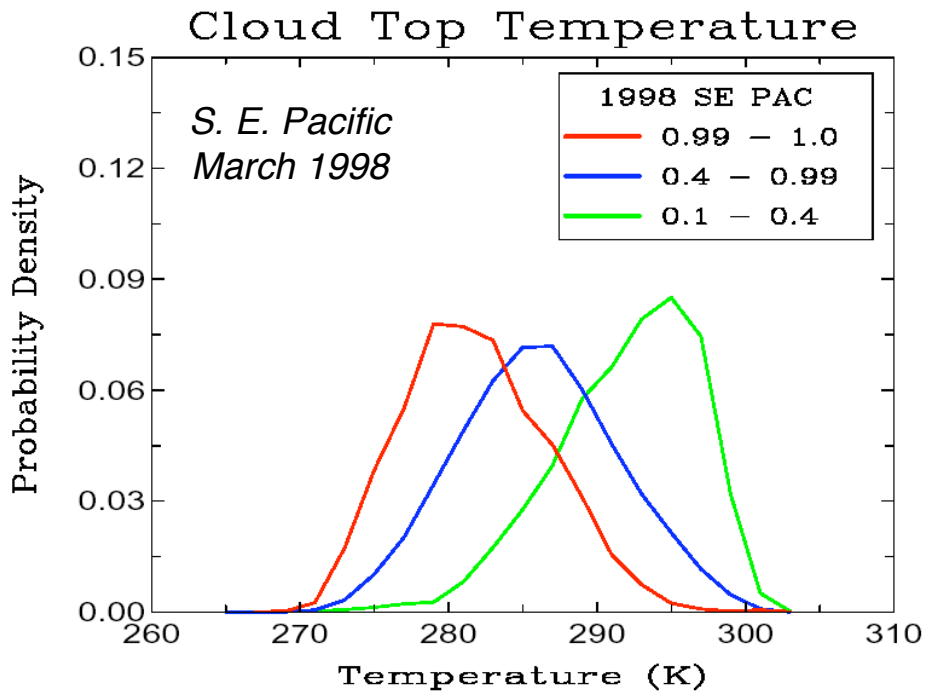


Suggests stable properties by cloud type: next step to quantify how stable....

Boundary Layer: Observed CERES Cloud Top Temperature Pdfs for March, 2000 vs March, 1998



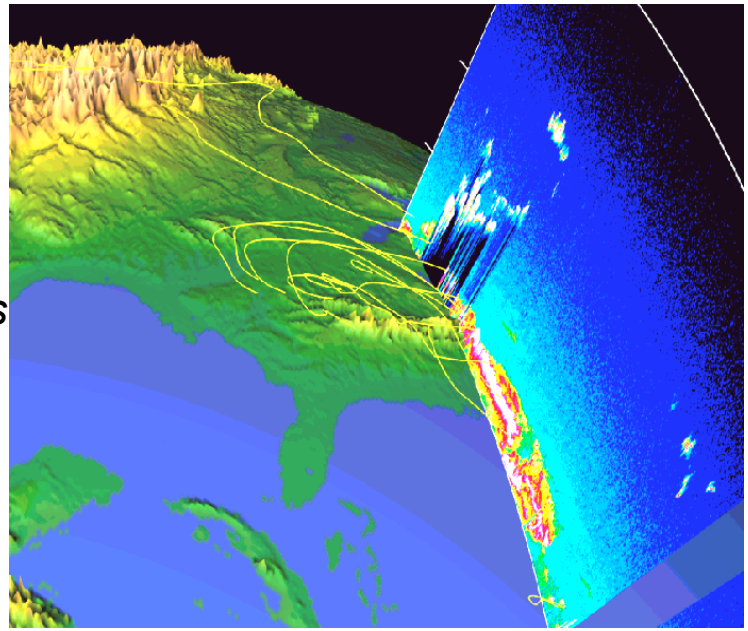
March 2000: Colder SST (La Nina) & Colder Cloud Top Temperature, but Narrower Frequency Distribution

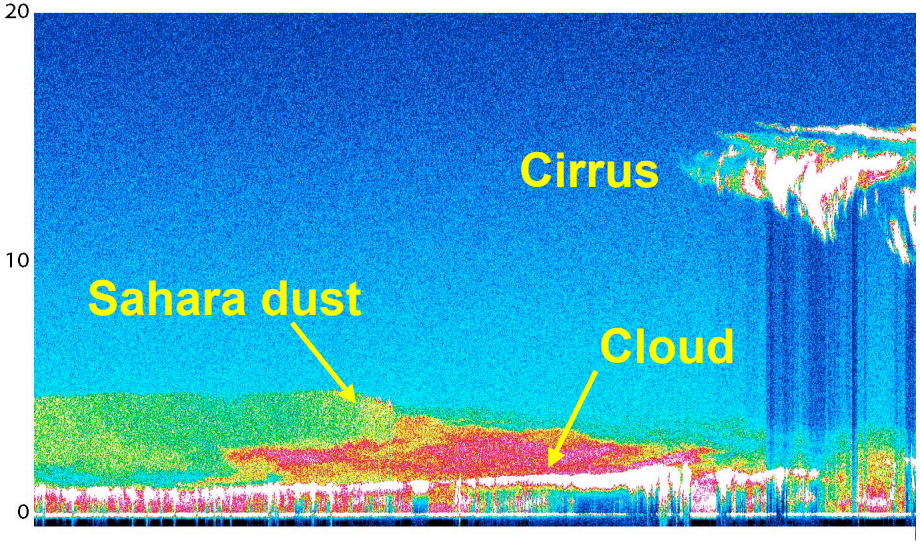


The Vertical: CALIPSO Aerosol

Aerosol Direct Radiative Forcing

- λ CALIPSO aerosol profiles
  - *enable back-trajectories to aerosol sources*
- λ 4-D assimilation of aerosol profiles
  - *constrains uncertainties in source/transport models*
  - *partitioning of natural, anthropogenic forcings*
- λ A-train: CALIPSO + MODIS + CERES
  - *improved surface SW fluxes*



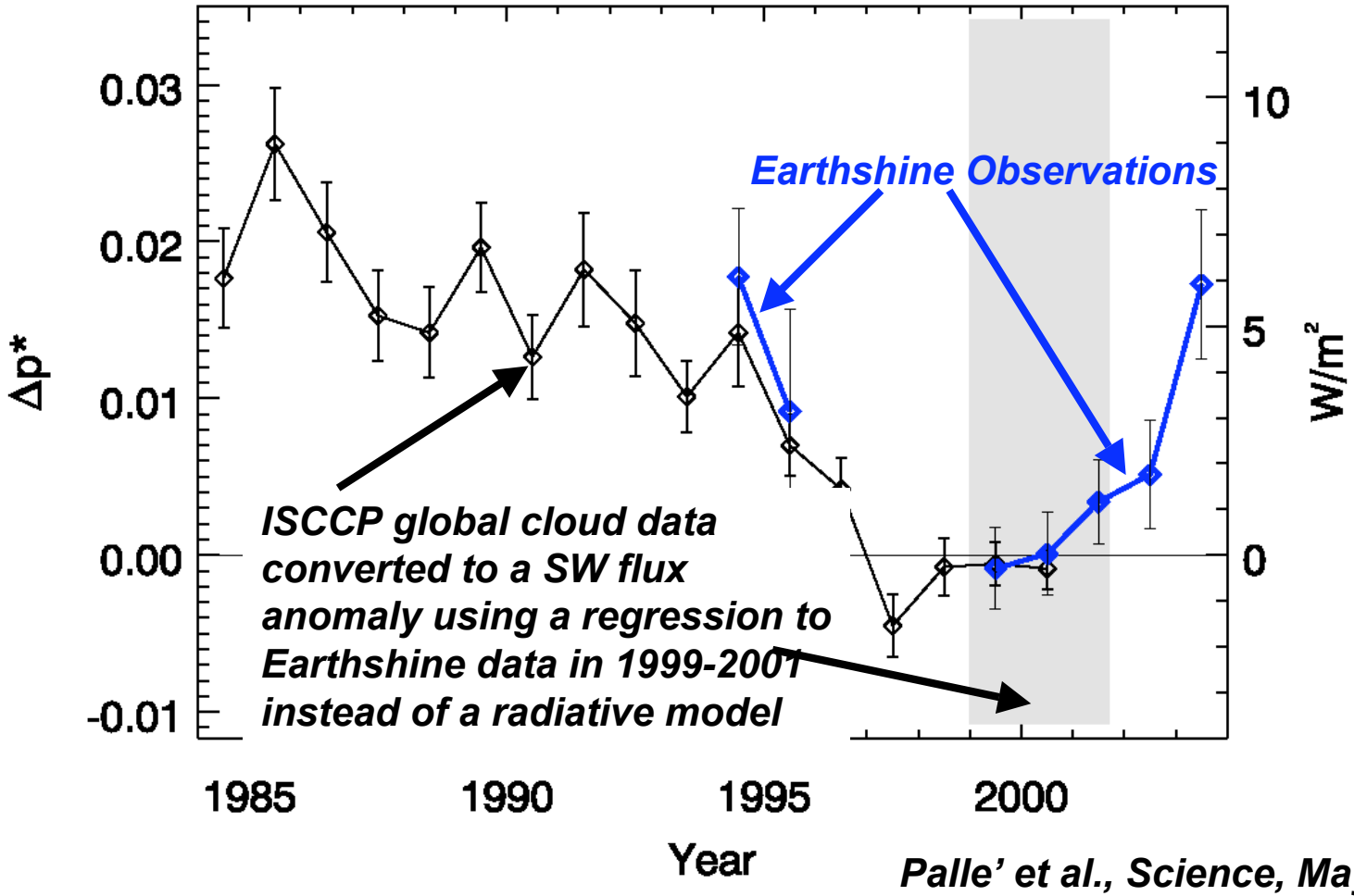


Aerosol Indirect Radiative Forcing

- CALIPSO cloud and aerosol profiles
  - unique ability to determine if cloud and aerosol are in the same layer.
- A-train: add MODIS + CERES
  - cloud microphysics, optics, radiation
- A-train: add AMSR, Cloudsat radar
  - adds rain, LWP plus drizzle.

Aerosol Forcing and Cloud Feedback Approaches

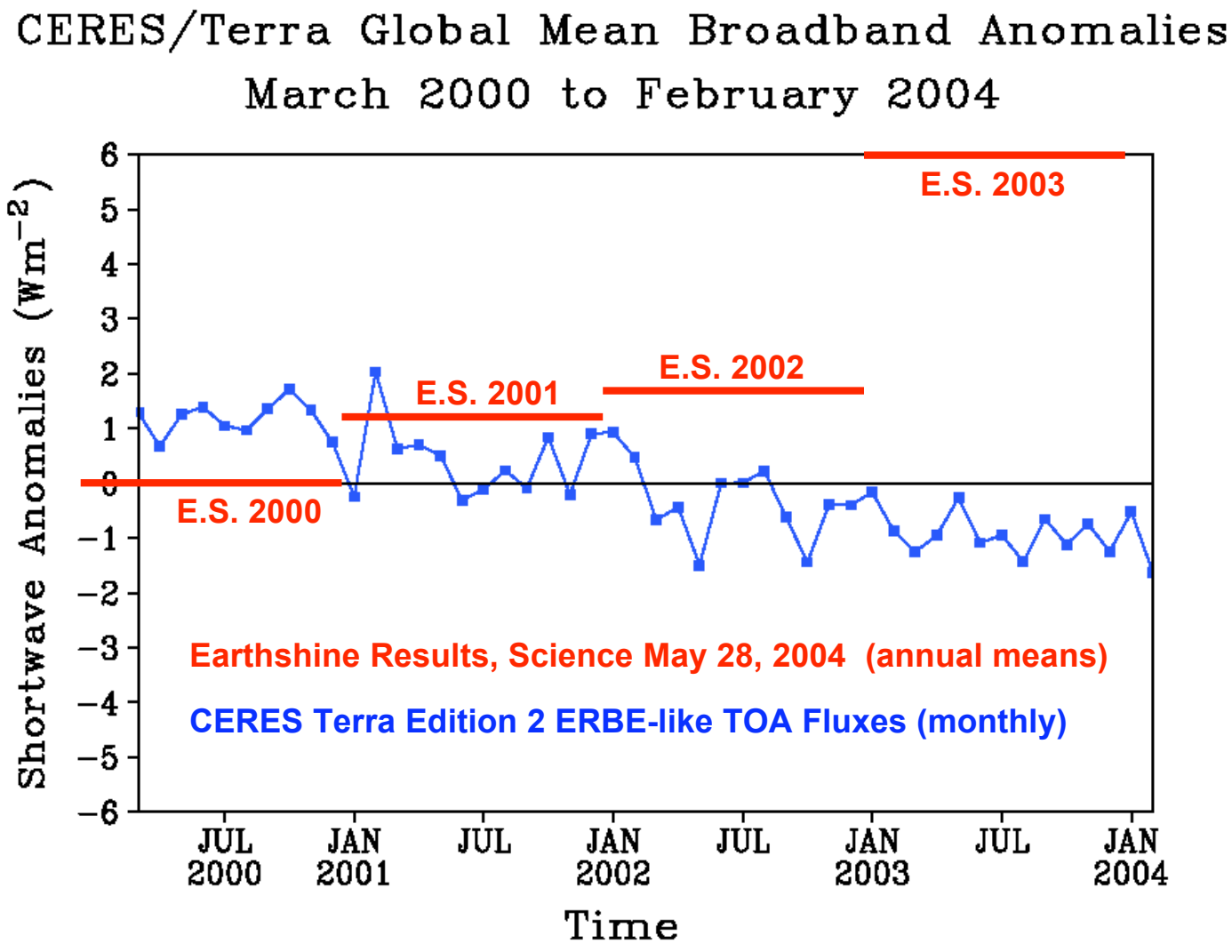
- **Cloud Feedback**
- **Atmosphere => Cloud => Radiation => Atmosphere**
- **Aerosol Direct Radiative Forcing**
- **Aerosol Source => Advection => Sinks => Radiation => Atmosphere**
- **Aerosol Indirect Radiative Forcing**
- **Aerosol Source => Advection => Sinks => Atmosphere => Cloud => Radiation => Atmosphere**
- ***Aerosol Chemistry must be tracked by source region***
- ***Aerosol indirect effect must be sorted by atmosphere dynamic state which dominates cloud properties***



Palle' et al., Science, May 2004

Key earthshine concerns:

- ***observation is near direct backscatter peak, angle varies with lunar libration***
- ***only 1/3 of the earth viewed***
- ***varying CCD detectors used depending on libration: gain aliasing***
- ***visible albedo, but interpreted as if broadband: exaggerates cloud change***
- ***albedo and earthshine not uniquely related: can change one without the other: just spatially redistribute cloud within the large earthshine viewing region***



Conclusion: CERES and Earthshine show no agreement on global albedo