CERES Validation Summary

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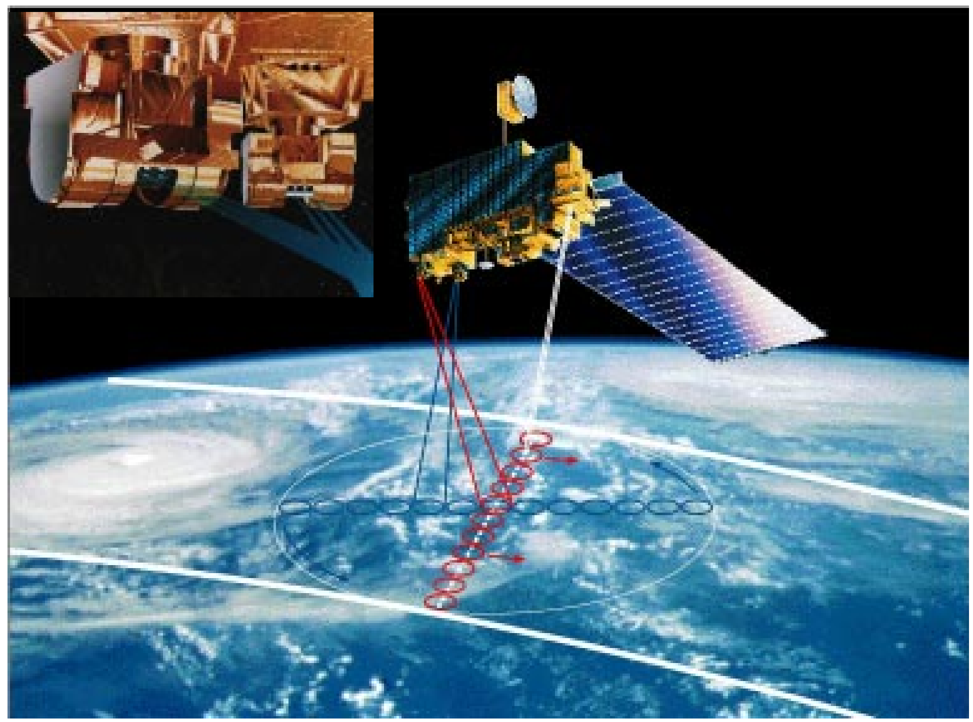


CERES Measurements

CERES Features

¥5 Instruments on 3 Satellites (TRMM, Terra, Aqua) for diurnal and angular sampling

¥3 Channels per instrument:

- ¥Shortwave (0.2-4.0µm) — Reflected solar radiation
- ¥Total (0.2-100µm) — Earth emitted radiation by subtracting SW
- ¥Window (8-12µm) — Thermal infrared emission

¥Coincident Cloud and Aerosol Properties from MODIS/VIRS

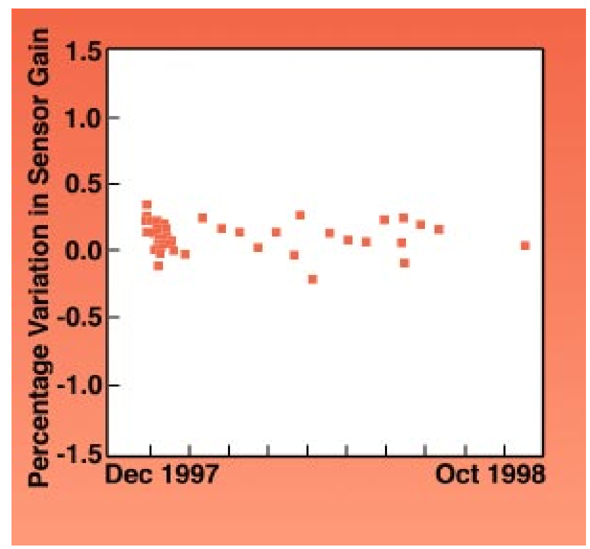
¥Will fly in Formation with ESSP3-CENA and CloudSat

Unprecedented Calibration Accuracy and Stability

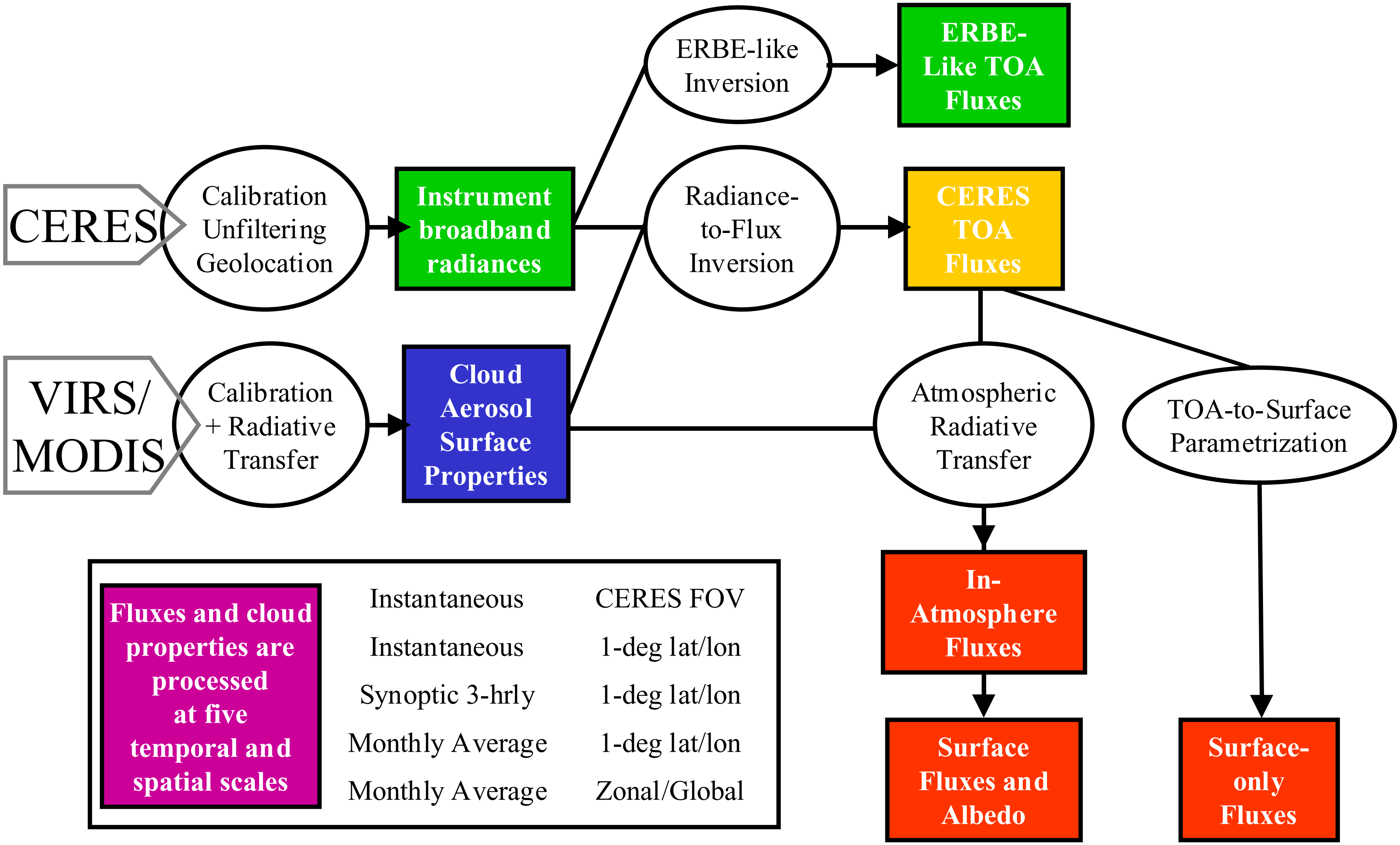
0.25% Consistency with Ground Calibration

Instrument Stability Better than 0.2%

SW Channels 10X Better than NB Radiometers



CERES Data Products

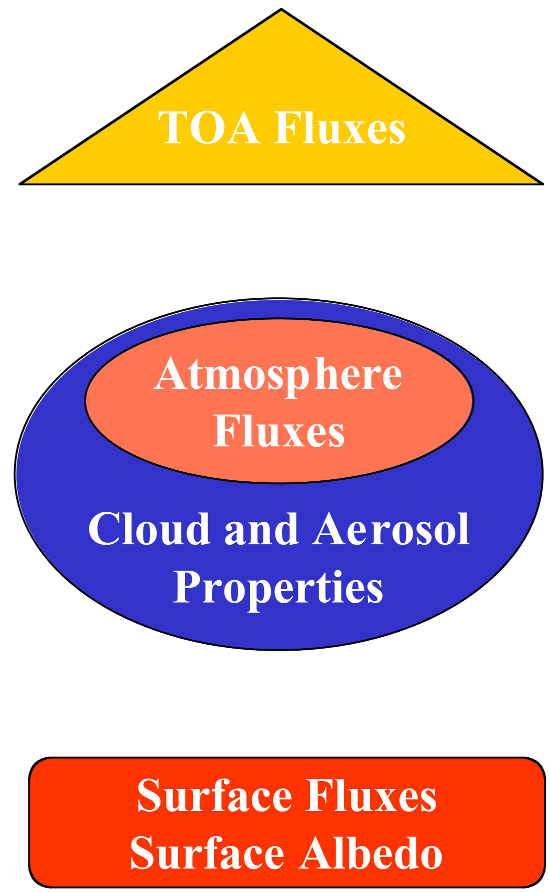


CERES Products Address ESE Science Questions

NASA ESE Science Questions

- How are global precipitation, evaporation and water cycle changing?
- What trends in atmospheric constituents and solar radiation drive the climate?
- What are the changes in land cover and use, their causes and consequences?
- What are the effects of clouds and surface hydrologic processes on climate?
- How are local weather and climate related?
- How can weather forecast be improved by space-based observations?
- How well can long-term climatic variations and trends be assessed and predicted?

CERES Products



Context and Vision of CERES Validation

§ Absolute radiometric calibration is essential to all CERES products

§ CERES approach to radiation measurement based on extended temporal, spatial and angular sampling

§ Validation of satellite remote sensing data against surface, aircraft, balloon in-situ data driven by sampling requirements:

- ¥Single case studies provide little validation
- ¥Field campaigns test hypotheses (limited statistical significance)
- ¥ Long-term observations at fixed sites provide the best means to validate CERES cloud and radiation data (e.g. ARM cloud, BSRN surface fluxes)

§ Inter-comparison of EOS algorithms and measurements critical to identify coding and logical data processing errors

§ Knowledge of accuracy of CERES data will improve with longer time series of validation data: 1% climate accuracy requires very large numbers of independent samples.

Validation Strategy of CERES Data Products

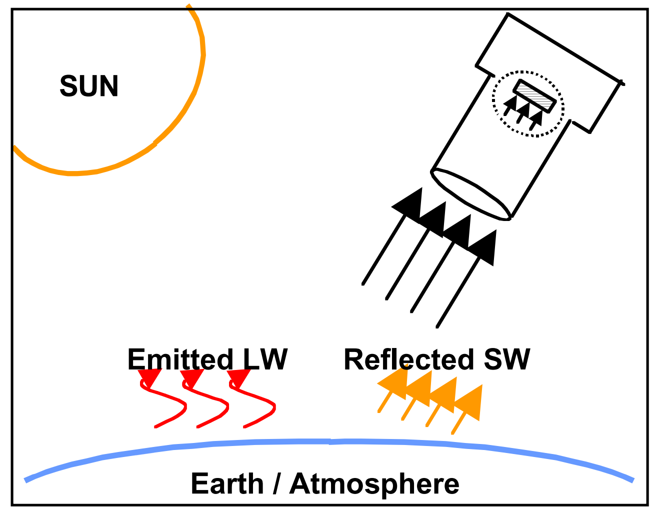
● Critical ◍ Important ○ Useful	TOA Radiance	TOA Radiant Flux	In Atmosphere Flux	Surface Flux & Albedo	Cloud Properties
On-board Calibration (ground + in-orbit)	Critical	Critical	Critical	Critical	Critical
Theoretical Sensitivity (radiative transfer model)	Important	Useful	Important	Useful	Important
Surrogate Data (existing comparable satellite data)	Useful	Important	Useful	Important	Important
Internal Consistency (check products for trends)	Critical	Critical	Important	Useful	Important
Surface Site data (ARM, BSRN, COVE, AERONET)			Critical	Critical	Critical
Satellite Data (ESSP3-CENA, Cloudsat, POLDER, MISR)	Useful	Important	Critical	Critical	Critical
Field Campaigns (CRYSTAL, CLAMS, SHEBA, ARESE,É)			Important	Important	Important

CERES TOA Radiances

Geo-located and Calibrated TOA Radiances

Interpretation of CERES measurements

¥Convert raw counts to filtered radiances ($Wm^{-2}sr^{-1}$)
¥Geo-locate footprints on the ground
¥Derive SW, LW and WN radiances from spectral unfiltering
¥Preserve radiometric scale across multiple instruments/missions

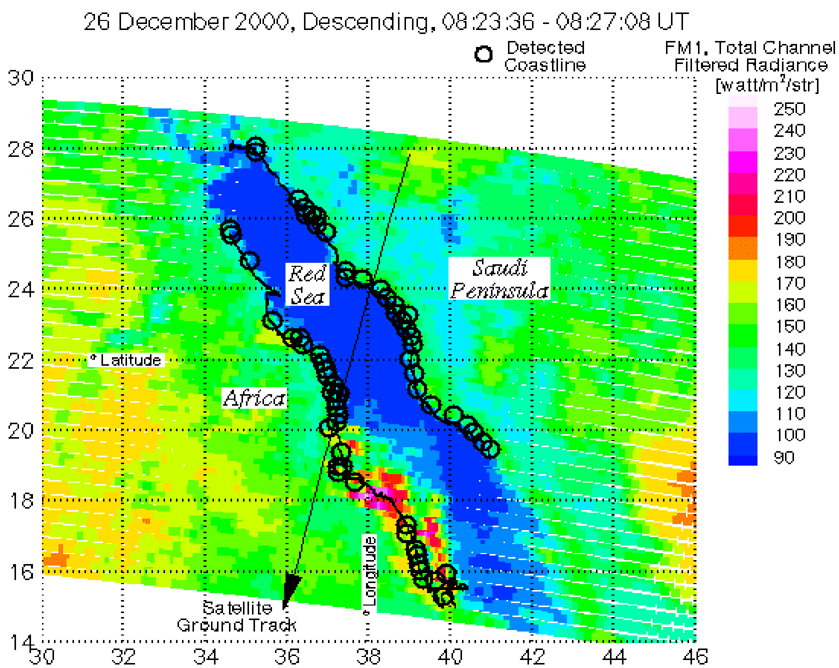


Validation Protocol:

¥Comprehensive ground calibration/characterization program
¥Theoretical instrument models
¥LW and SW on-board calibration facilities
¥Comparison of measurements to theoretical radiative transfer models
¥Vicarious calibration sources including Tropical Deep Convective Clouds
¥Characterizing specific geo targets for inter instrument/platform consistency checks

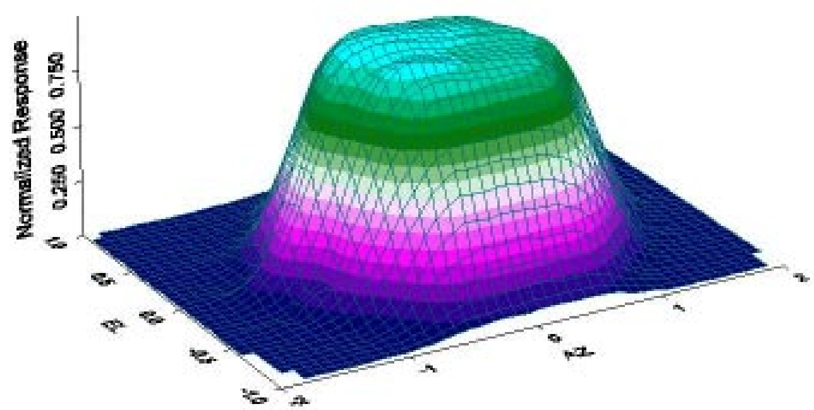
Validation of Geo-location

Navigation Accuracy: Locate known Earth surface feature using clear-sky sharp contrast and compare to coastline digital map.



O detected coastline

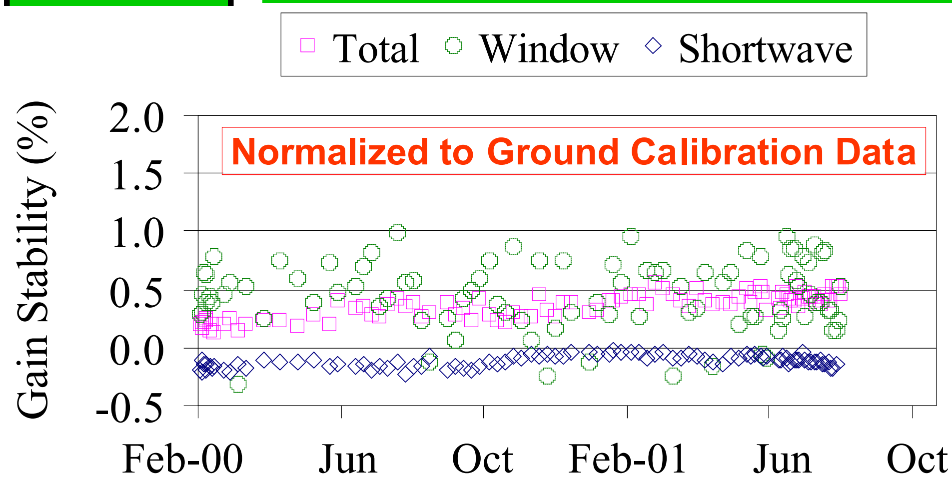
Lunar Scanning: Utilize moon as a source point to quantify azimuth/elevation errors and spatial uniformity of optics/detector physics and time response.



Optical Point Spread Function from lunar scanning

CERES TOA Radiances

Validation of Calibration



Lifetime Radiometric Stability

¥6 of 9 sensors launched to date demonstrate radiometric stabilities of better than 0.1%/year, 2 < 0.25% and 1 < 0.5%.

¥Internal calibration module: Blackbodies for the TOT and WN sensors, Quartz-halogen tungsten lamp for the SW sensors

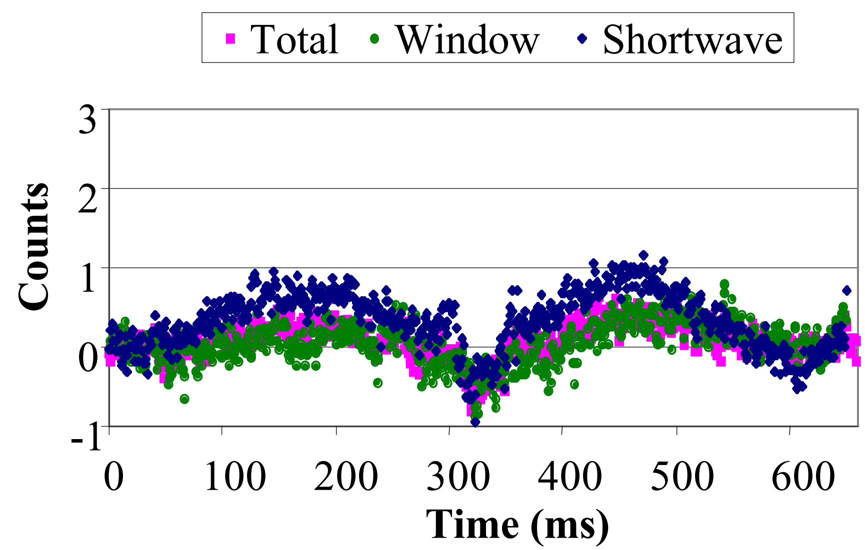
¥Mirror Attenuator Mosaic: Solar diffuser plate which attenuates direct solar view, provides relative calibrations for the SW sensor and the SW portion of the TOT sensor

Electronic noise due to scan elevation

¥Electronically induced instrument biases depend on azimuth and elevation position of the sensors

¥Determined using:

- ¥Deep space pitch-over maneuver (TRMM only)
- ¥Ground calibration facility: zero-g environment simulated by horizontal scan (TRMM, Terra, Aqua)



CERES TOA Radiances

Validation by Vicarious Calibration

Use of Tropical Deep Convective Clouds (DCC's)

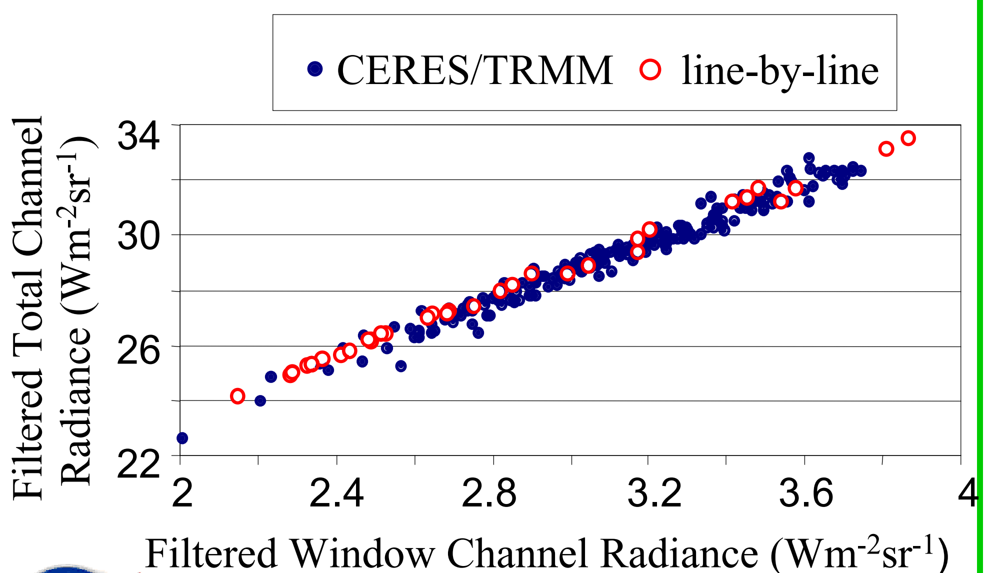
Cold (<205K), Optically thick, 15+ Km altitude

Line-by-Line radiative transfer calculations

¥DCC are near blackbody source

¥Broadband LW (TOT sensor at night) predicted from narrowband WN channel

¥Excellent agreement between theory and measurements

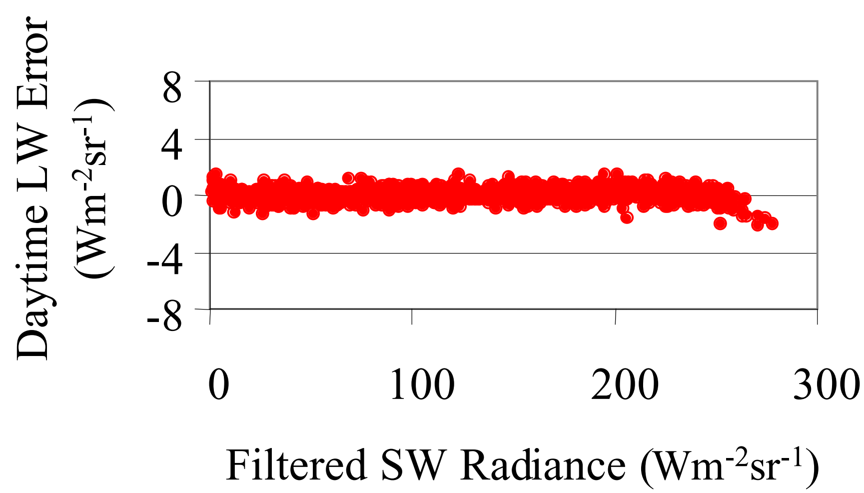


3-Channel Inter-comparison

¥Estimate LW from WN radiance (LW1)

¥Estimate LW from TOT — SW (LW2)

¥(LW2-LW1) vs SW shows consistency between SW sensor and SW portion of the TOT sensor.



CERES
TOA
Radiances

Validation by Vicarious Calibration

Use of Tropical Deep Convective Cloud (DCC) Albedo: SW checks

¥Deep convective clouds approach the optically thick limit of albedo:
i.e. albedo becomes insensitive to cloud optical depth changes.

¥ Being optically thick, these clouds are the most lambertian targets available for accurate correction of radiance to flux. Studies using CERES Rotating Azimuth Plane TRMM data suggest a 1 sigma noise in radiance to flux conversion of less than 3%: approaching values reached for clear ocean.

¥DCC are extensive in area and typically much larger than a CERES 10 km or 20 km nadir field of view, minimizing spatial inhomogeneity problems.

¥DCC are composed of fresh and relatively small ice crystals thereby avoiding the problems over snow and ice surfaces of aging snow surfaces with both changing grain size (near infrared absorption changes) and soot contamination (albedo drops).

¥DCC are sufficiently high that most tropospheric gaseous absorption is eliminated, particularily water vapor. Ozone and cloud particle absorption dominate.

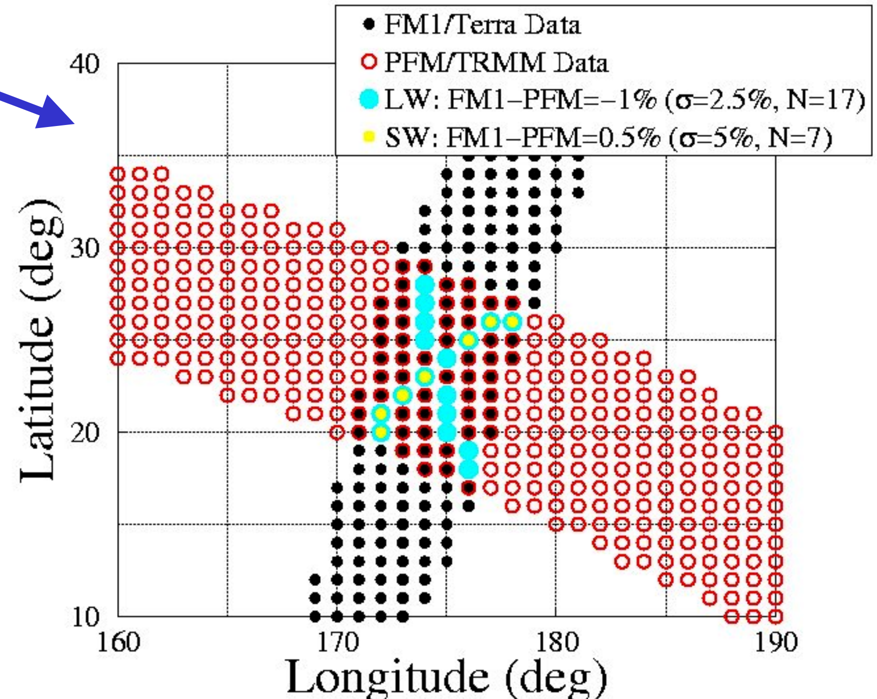
¥DCC at very cold temperatures (Tb < 205K) have a narrow and near normal distribution of albedo: 1 sigma of about 3% for individual CERES fields of view, and stability over large ensembles of data to ~ 0.5%.

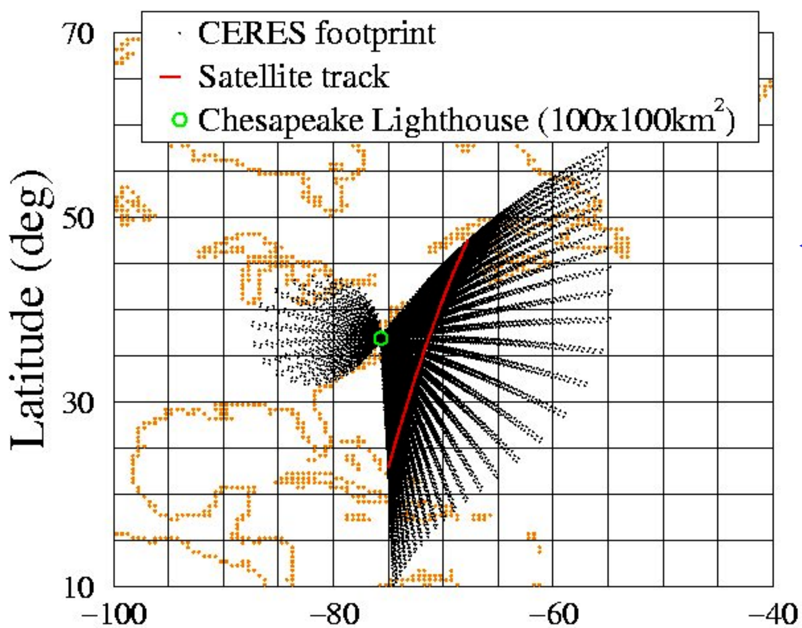
¥Comparisons of CERES TRMM, and Terra instrument DCC albedos agree to within about 0.5% or better.

Validation by Vicarious Calibration

TRMM/Terra/ScaRaB Inter-calibration

¥Modify CERES scanning azimuth to scan parallel to other instruments at orbital crossing times
¥Radiance measurements matched in time, space, and viewing geometry can be compared directly
¥100 independent samples (30-days) provide comparison with better than 0.1 and 0.4% uncertainty for LW and SW (95% confidence level)





CERES rotating azimuth capability

¥To provide multi-angle coverage of specific validation areas (e.g. CLAMS experiment) for BRDF validation
¥To scan particular geometries to enhance BRDF models (e.g. high angular sampling close to principal plane under Sun glint)
¥To inter-calibrate each 256 GERB detector with CERES. 0.5% confidence level for SW in 30 days.

CERES TOA Radiances

Radiance Calibration Summary

$^{+}$Jan-Aug Õ98
$^{++}$Mar 00-Jun01

	Ground to Flight Consistency (%)			On-orbit stability (%/year)			
	TOT	SW	WN	SW/TOT	LW/TOT	SW	WN
TRMM/PFM^{+}	**0.13**	**0.26**	**0.14**	**<0.1**	**<0.1**	**<0.1**	**0.22**
Terra/FM1^{++}	**0.20**	**<0.1**	**0.48**	**<0.1**	**0.2**	**<0.1**	**<0.1**
Terra/FM2^{++}	**0.12**	**<0.1**	**1.3**	**0.60**	**0.36**	**<0.1**	**<0.1**
Aqua/FM3	**TBD**						
Aqua/FM4							
FM5							

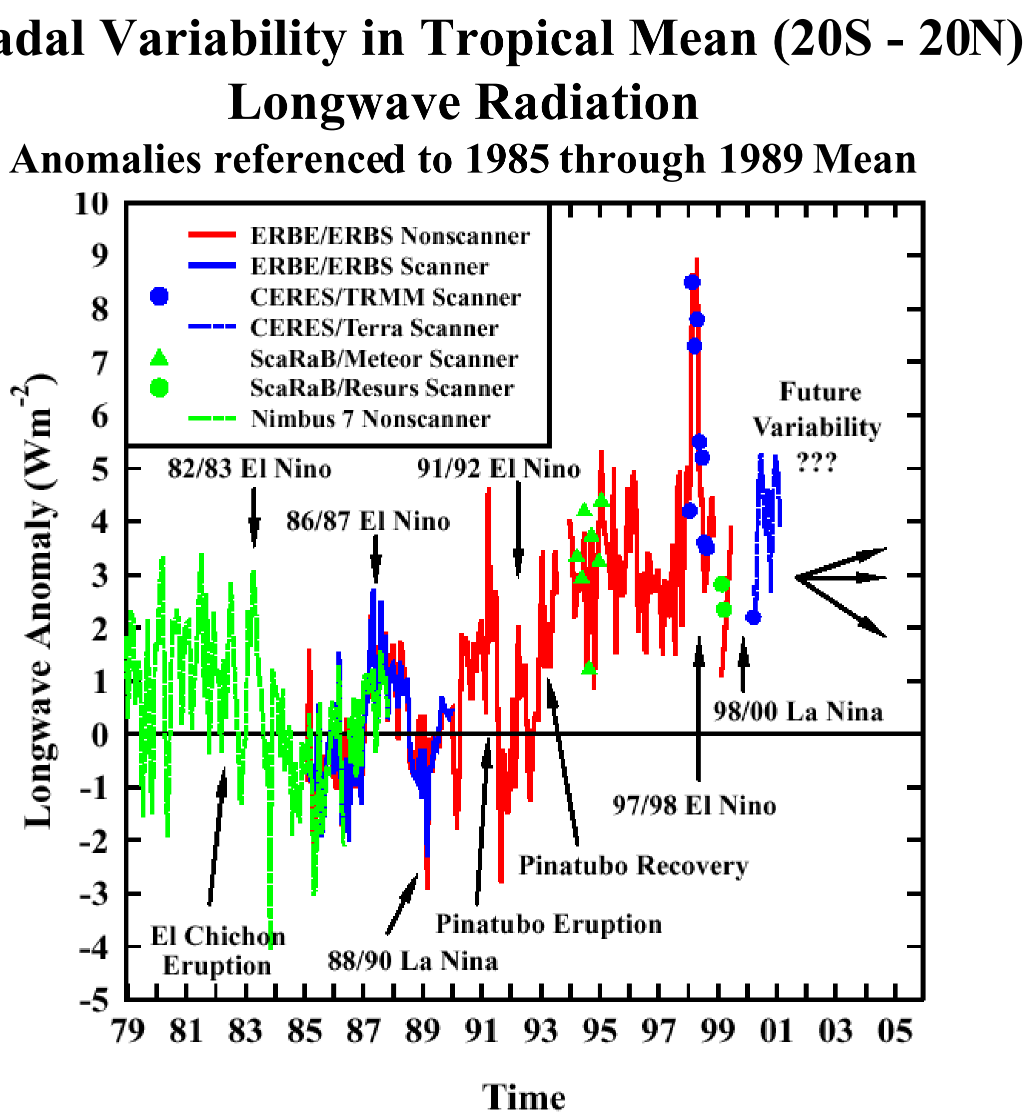
¥Validation protocols utilize data products across varying spatial, temporal, and spectral scales for robustness

¥Calibration of SW, LW and WN radiances validated by multiple tests with coherent results

ERBE-Like Fluxes

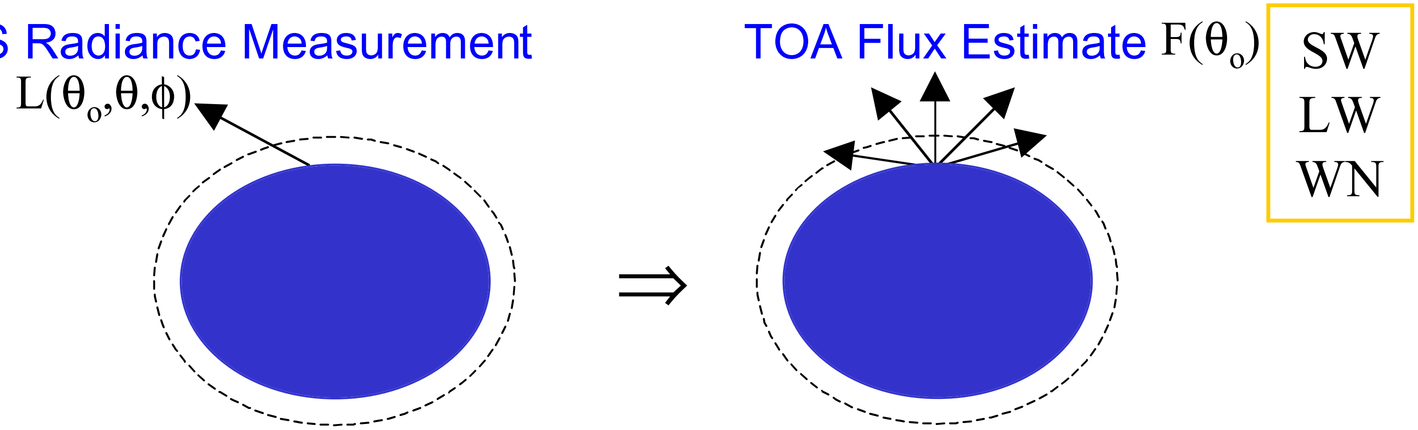
ERBE-Like TOA Flux Validation

- ¥CERES ERBE-Like TOA fluxes provide a product consistent with 15-year time series of ERB data
- ¥CERES/TRMM LW anomaly (Jan-JulÕ98 El Ni o) is consistent with ERBE wide field of view data
- ¥Monthly mean LW fluxes (20N-20S average) from CERES/TRMM and Terra are less than 1 Wm^{-2} apart



TOA Flux

Instantaneous Fluxes at TOA and Angular Distribution Models



TOA Flux is estimated from CERES radiance as:

$$F(\theta_o) = \frac{\pi L(\theta_o, \theta, \phi)}{R_j(\theta_o, \theta, \phi)}$$

where $R_j(\theta_o,\theta,\phi)$ is the Angular Distribution Model (ADM) for the Òj^{th}Ó scene type, and θ_o = solar zenith angle; θ = viewing zenith angle; ϕ = relative azimuth angle

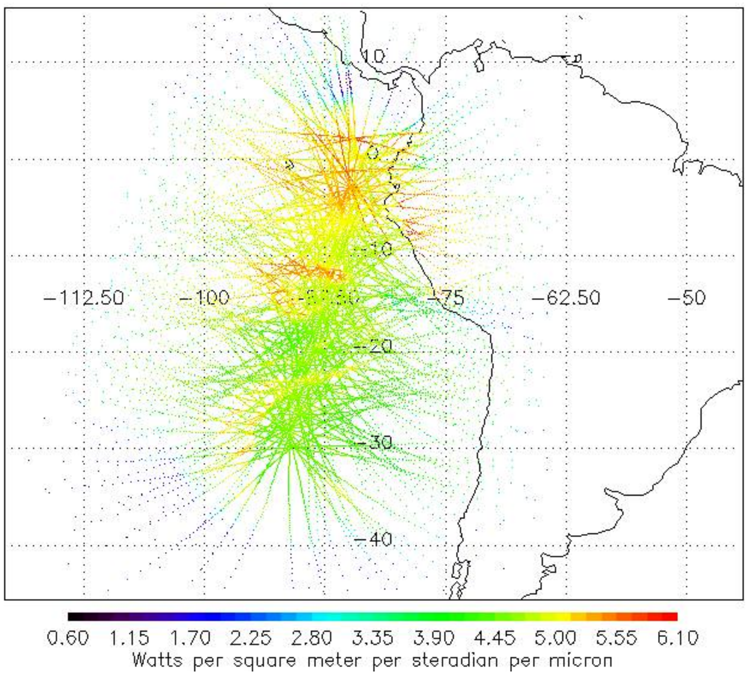
¥ ADMs are constructed empirically by compositing multi-angle radiance measurements by scene type and relating the mean radiances in different viewing geometries to the TOA flux inferred from the mean radiances

¥ Empirical approach avoids theoretical biases such as 3-D cloud effects and unknown ice crystal scattering and reduces dependence on absolute accuracy of cloud remote sensing such as cloud optical depth

Angular Distribution Models

¥Multi-angle radiance data are collected using the rotating azimuth plane scanning (RAPS) mode of CERES

¥One CERES instrument dedicated to RAPS observations on Terra and Aqua



¥Scene types are defined by clear and cloudy sky parameters that influence the anisotropy of the observed scenes. The CERES cloud product identifies several parameters used to define ADM scene types (e.g. cloud amount, phase, optical depth, emissivity)

¥ADMs are produced for 600 different scene types for TRMM, Terra and Aqua

Surface Type	Clear	Clouds		
		Fraction	Phase	Opt Depth
Ocean	5 ws*	12	2	14
Hi Tree/Shrub	1	5	2	6
Low Tree/Shrub	1	5	2	6
Dark Desert	1	5	2	6
Bright Desert	1	5	2	6

ws*: wind speed

TOA Flux

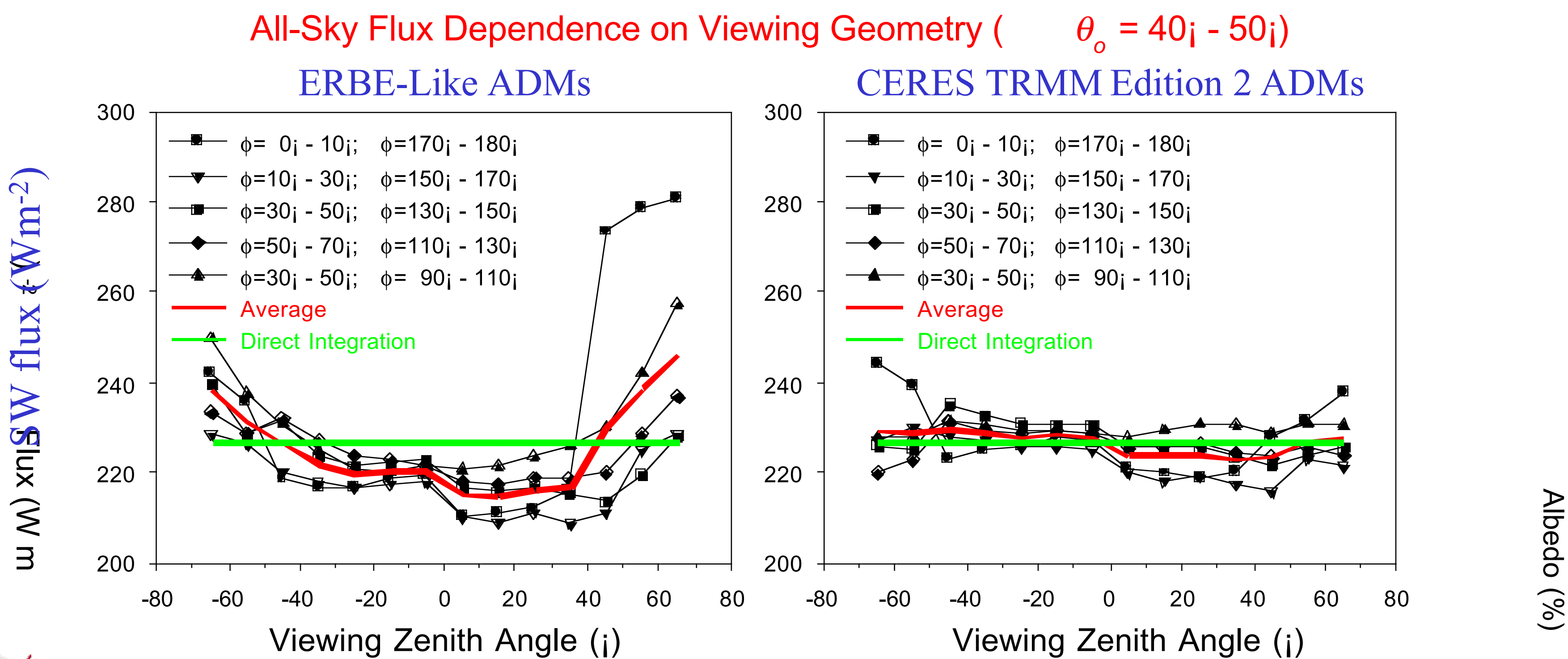
TOA Flux Validation

Flux Viewing Zenith Angle Dependence:

¥Does all-sky flux depend on viewing geometry?

¥Flux vs cloud property dependencies: do we get consistent results from different viewing geometries?

¥Fluxes based on ADMs are compared to true fluxes from direct integration



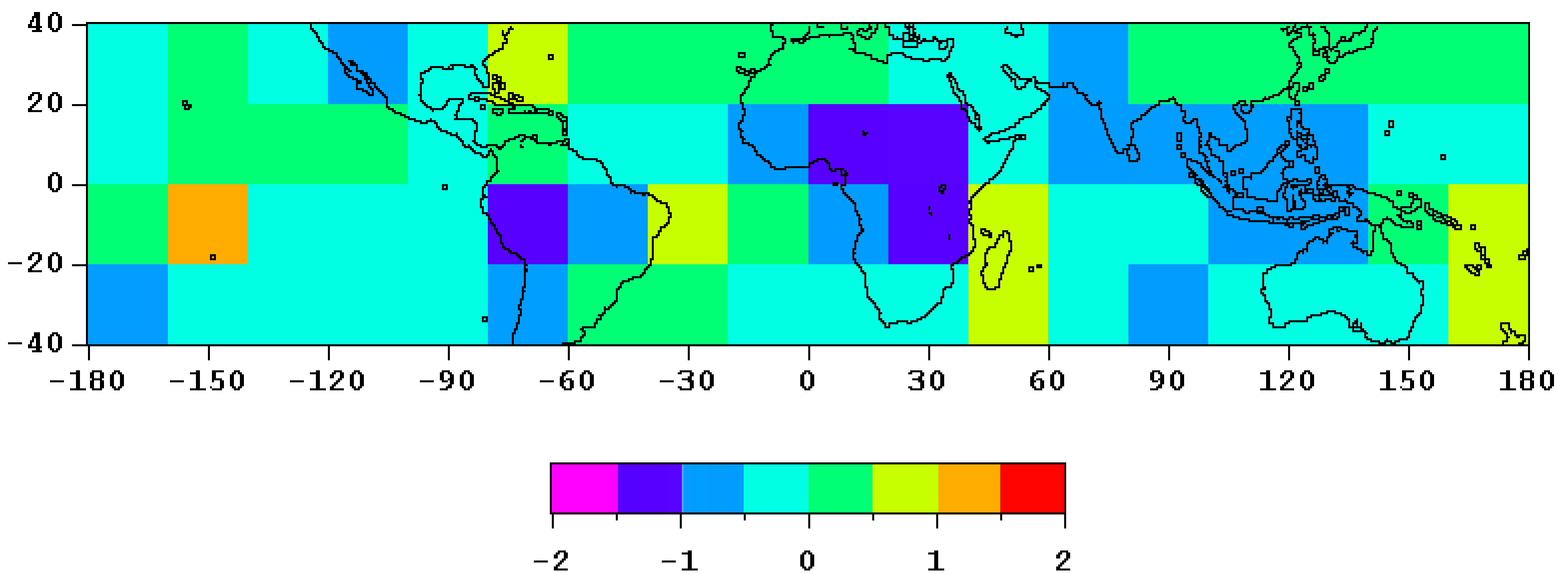
TOA
Flux

TOA Flux Validation

Regional Direct Integration (DI) Checks:

¥Are all-sky regional mean fluxes from ADMs consistent with fluxes inferred by direct integration of mean radiances?

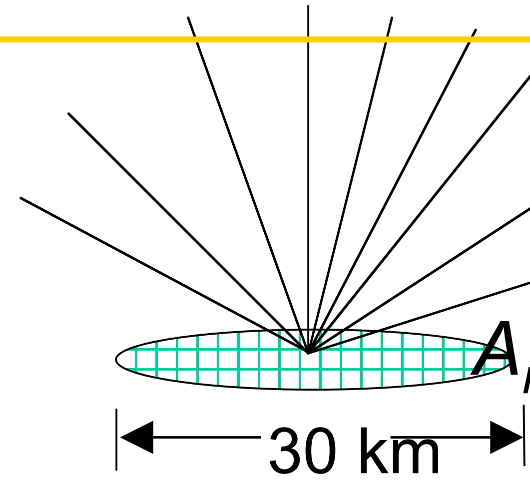
¥ADM-DI flux difference (1σ) is 0.5 W m^{-2} in the tropics for TRMM.



ADM monthly mean flux biases (W m^{-2}) over 20¡×20¡ regions from CERES/TRMM SSF Edition 2 SW TOA fluxes.

TOA Flux

TOA Flux Validation



Along-Track Albedo Consistency Checks:

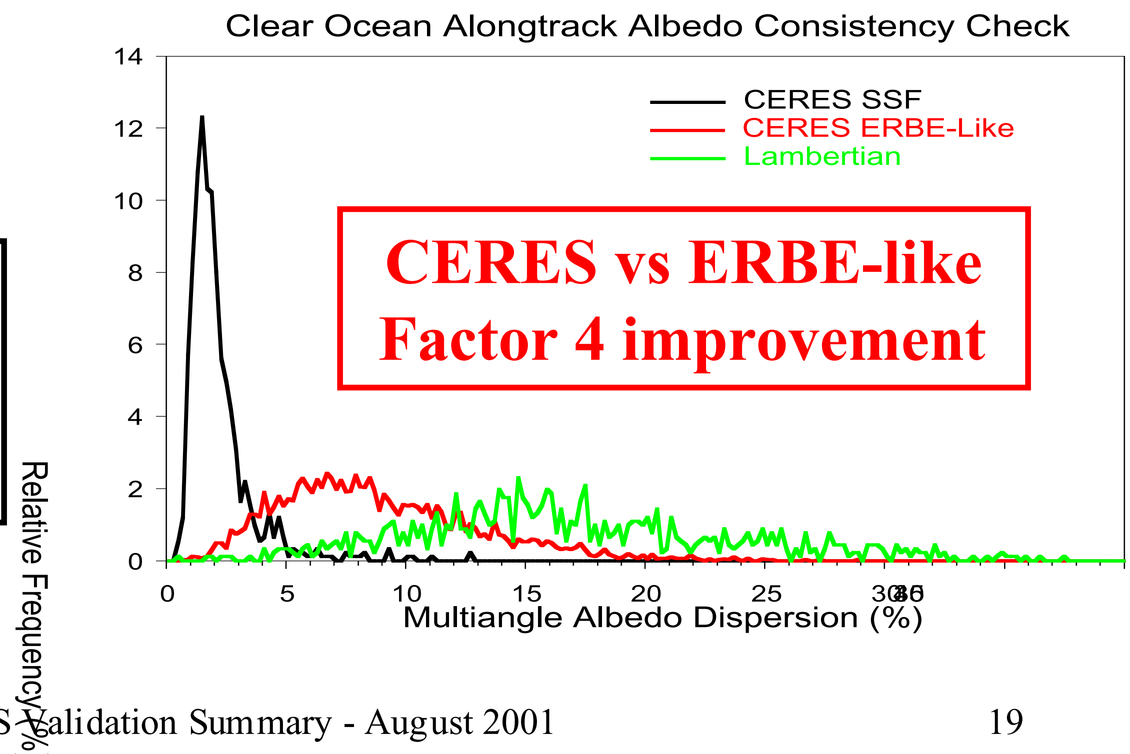
¥ Are instantaneous clear-sky albedo consistent from different viewing geometries?

¥ Infer albedo from simultaneous measurements over 30-km regions at multiple angles.

¥Compute albedo dispersion parameter:

$$D = \frac{\sigma_A}{\bar{A}} \times 100\%$$

Average Dispersion (%)
CERES SSF = 2.2
CERES ERBE-Like = 8.8
Lambertian = 16.9



TOA Flux

TOA Flux Validation Summary

CERES/TRMM TOA Flux Uncertainties Due to ADM Errors

($W\ m^{-2}$)	Monthly Global Average Bias		Monthly Regional Average (20 deg) 1 σ		Instantaneous	
	TRMM	Goal	TRMM	Goal	TRMM	Goal
Shortwave (Edition 2)	-0.2	0	0.5	1	7 *	12
Longwave (Beta 2)	0.1	0	0.6	0.5	TBD	4

* For clear ocean/land/desert and overcast cloud only. Errors for broken cloud await orbital crossing multi-angle data from Terra and Aqua spacecraft with CERES/MODIS.

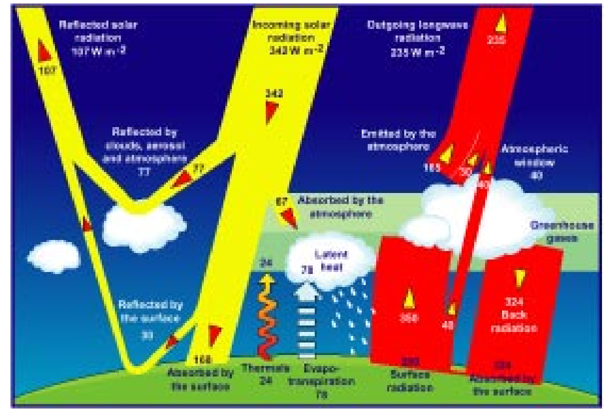
Future Work and Concerns/Challenges:

¥Validate CERES/TRMM LW and WN fluxes

¥Study influence of cloud property dependencies on viewing geometry

¥Develop and validate Terra and Aqua ADMs at 1 degree regional scale

CERES Cloud Products



¥ Used by CERES for:

- ¥**Relating cloud properties to the radiation budget**
- ¥**Developing new bidirectional reflectance models**
- ¥**Deriving surface and atmospheric radiation fluxes**

¥Cloud Retrieval Input

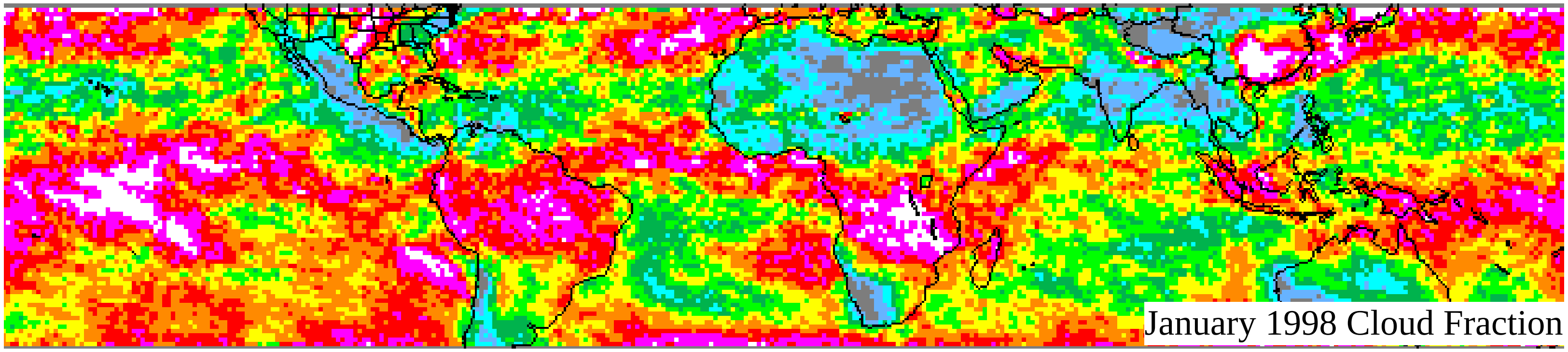
- ¥**Imager data from onboard imagers (VIRS and MODIS)**
- ¥**Channels: 0.65, 1.6, 3.7, 10.8, and 12-µm**
- ¥**Temperature & humidity profiles**


MODIS

¥Methodology

- ¥**Cloud mask uses all 5 channels & a priori clear-sky information**
- ¥**Properties derived from 4-channel model-matching method**
- ¥**Objective phase determination based on 4-channel consistency tests**
- ¥**5 channel retrieval includes emissivity for non-black clouds at night.**

Cloud Property Validation



January 1998 Cloud Fraction

Derived Properties to be Validated

Macrophysical:	Fractional coverage, Height, Radiating Temperature, Pressure
Microphysical:	Phase, optical depth, particle size, water path
Clear Area:	Albedo, Skin Temperature, Aerosol optical depth, Emissivity

Validation Strategy

¥ Monitor imager calibration

¥ Compare zonal and global statistics with existing data sets

¥ Test results for retrieval biases

¥ Perform large ensemble comparisons to regional surface sites (ARM) and global ESSP3-CENA lidar and Cloudsat flying in formation with Aqua

¥ Test consistency of measured and modeled TOA fluxes

Cloud Aerosol Properties

Cloud Property Validation: Imager Calibration

Multiple Imager Comparisons

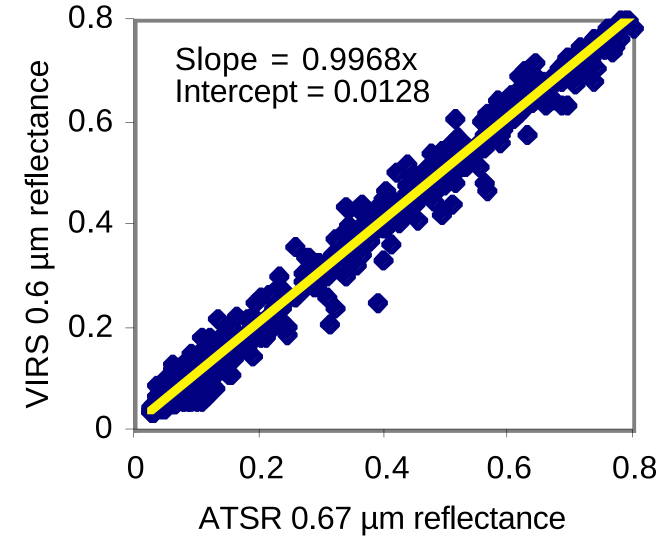
Method: Compare coincident MODIS, VIRS, AVHRR, and ATSR-2 radiances

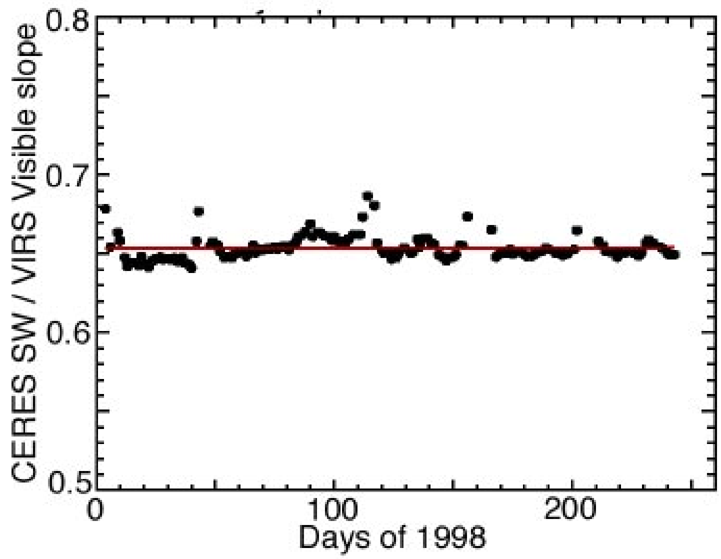
Results:

VIRS / ATSR VIS and IR channels agree to 3%

VIRS 1.6 µm channel shows 17% bias

MODIS / VIRS channels agree to within 2%





Stability Checks

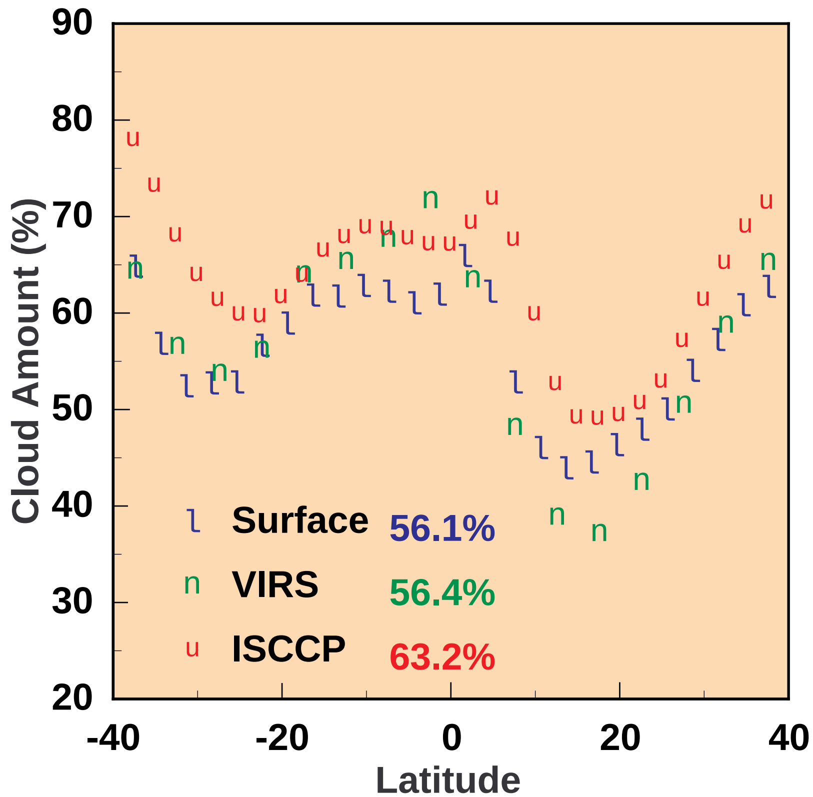
Method: Monitor time series of MODIS and VIRS narrowband channels with well-calibrated CERES broadband

Results: All VIRS channels show < 1% drift relative to CERES from 1998-2000

Cloud Property Validation: Global Statistics

Global/Zonal Comparisons

- ISCCP climatological optical depth and fraction
- Surface-based climatological fraction
- MODIS cloud properties
- AVHRR particle sizes
- Land/Ocean consistency checks
- Seasonal consistency checks



Objective

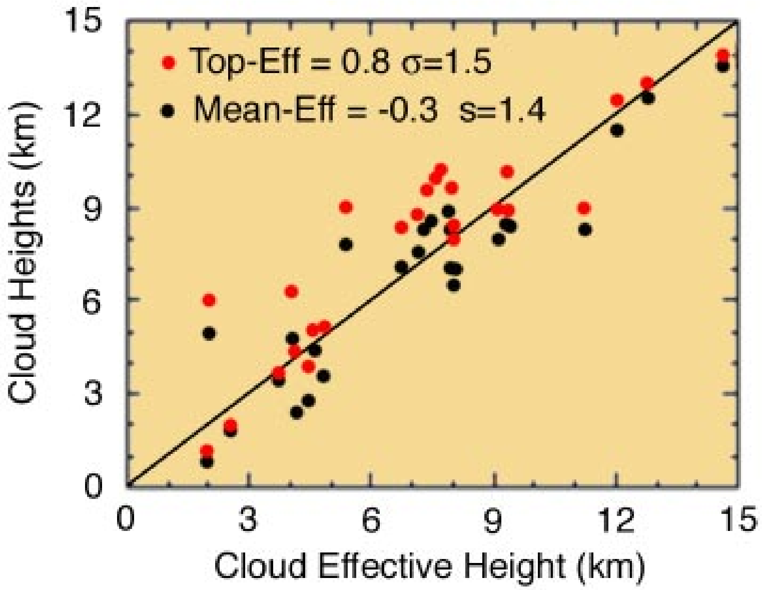
¥ Provides initial quality control test of monthly processed data
¥ Used to quantify agreement with climatology
¥ MODIS/AVHRR comparisons test coincident data for angular biases
¥ Consistency checks necessary to evaluate robustness of algorithm

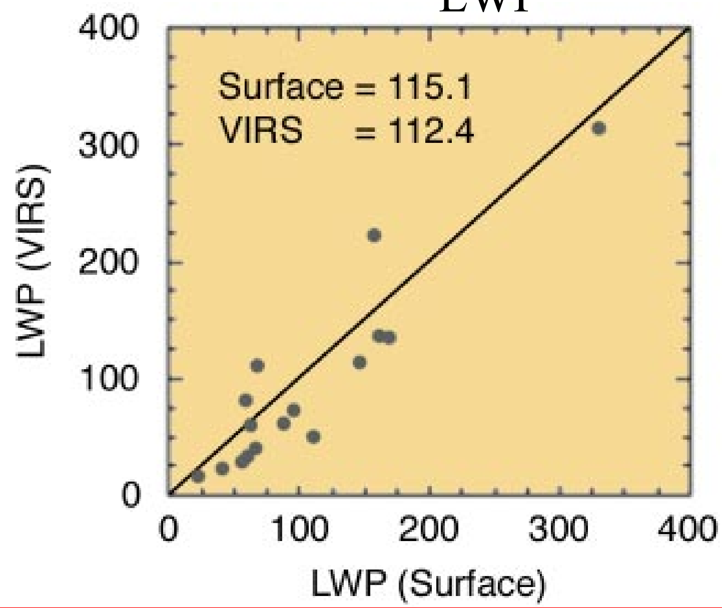
Cloud Aerosol Properties

Cloud Property Validation: Comparisons with Surface-Based Data

Radar: Height/Pressure
Thickness
Multi-level cloud detection

Radar+Radiometer: Optical Depth
Particle Size
LWP



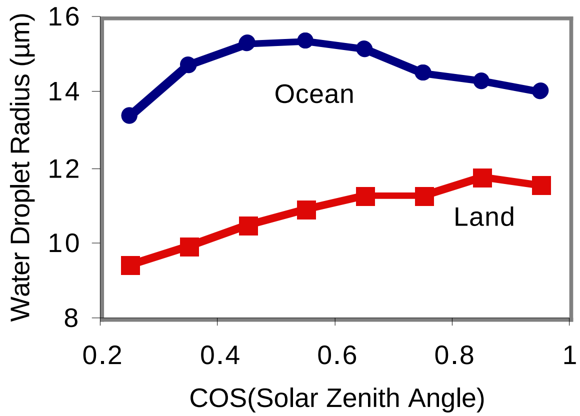


Challenges / Concerns

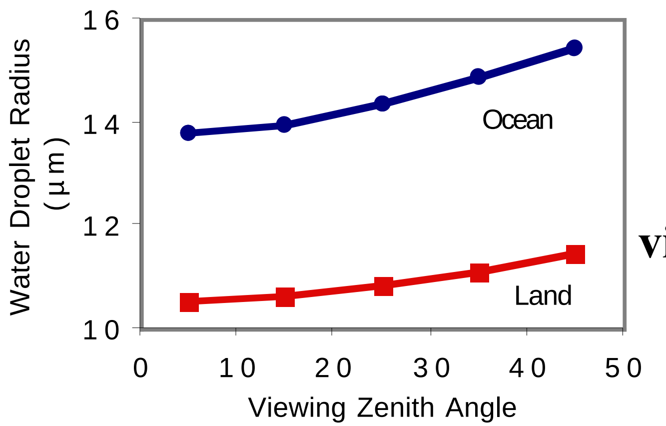
¥ Current validation data primarily from 3 ARM sites
¥ Global comparisons made possible by ESSP-3/Cloudsat
¥ Very limited number of samples, particularly for ice clouds
¥ Still need validation over other climate regimes
¥ CERES cloud retrievals applied to geostationary data to expand data volume

Cloud Aerosol Properties

Cloud Property Validation: Testing Retrievals for Biases

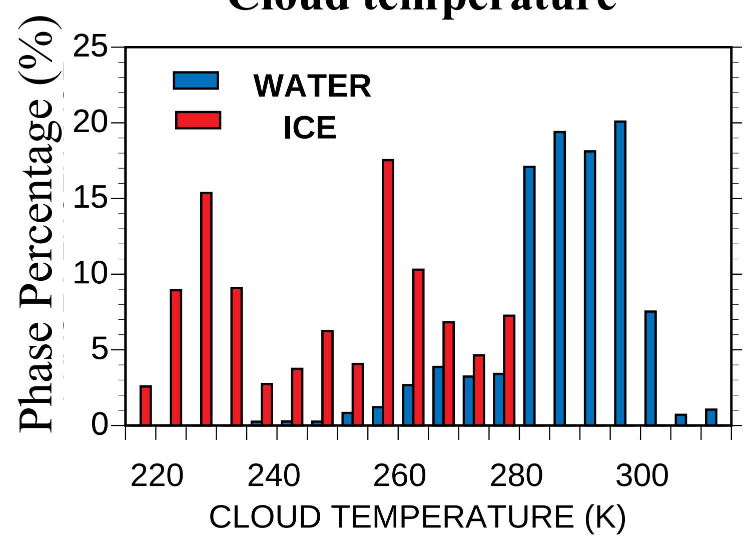


Droplet Size vs. solar zenith angle



Droplet Size vs. viewing zenith angle

Phase and Size vs. Cloud temperature



Objective: Test retrieved properties for unphysical functionalities with respect to

- Viewing geometry
- Surface type
- Geography and season

Calculating Surface-only Fluxes

¥Downwelling clear-sky and all-sky SW and LW surface fluxes are derived from relationships with TOA fluxes and atmospheric data.

¥Each component is computed from two parameterizations:

		Model A	Model B
SW	Clear	Li et al.	LPSA
	All-sky	-	LPSA
LW	Clear	Ramanathan and Inamdar	LPLA
	All-sky	-	LPLA

LPSA/LPLA:
Langley Parameterized
SW/LW Algorithm

Validation criteria:

¥–20 W m^{-2} for instantaneous CERES FOV

¥–10 W m^{-2} for monthly avg 1-deg

Surface-only Fluxes

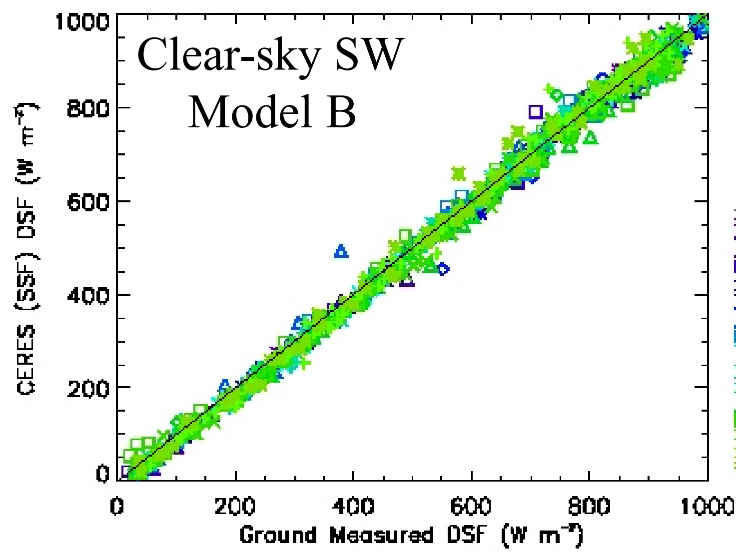
Surface-only Flux Validation

¥CERES surface —only fluxes are validated against surface measurements of SW and LW fluxes from surface observation sites (ARM, BSRN, CMDL).

¥Statistical comparisons are required to reduce the sampling noise induced by spatial and temporal mismatch between CERES flux and surface measurements.

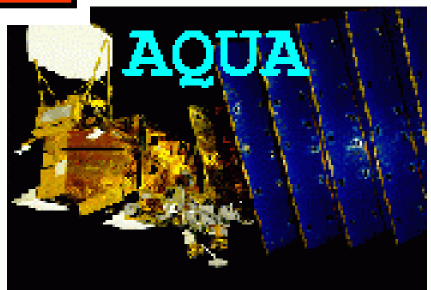
Validation criteria of –20 W m^{-2} met for clear-sky SW and all-sky LW surface fluxes using Model B

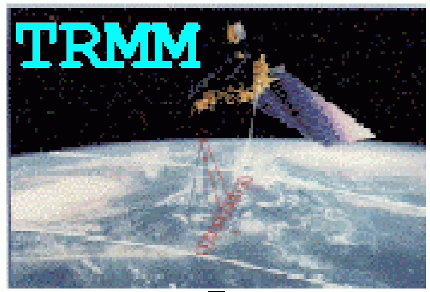
W/m^2		Model A		Model B	
		Bias	σ	Bias	σ
SW	Clear	31.6	28.2	-6.3	20.4
	All-sky	-	-	TBD	TBD
LW	Clear	TBD	TBD	TBD	TBD
	All-sky	-	-	1.1	21.6

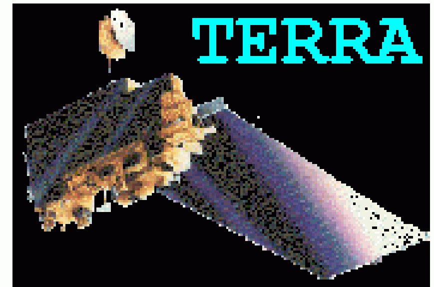


Surface &Atmo Fluxes

Surface & Atmospheric Radiation Budget (SARB)







Calibrated

Top of Atmosphere Broadband Radiation

Collocated

SARB Goal →

Closure for Net Atmospheric Radiation

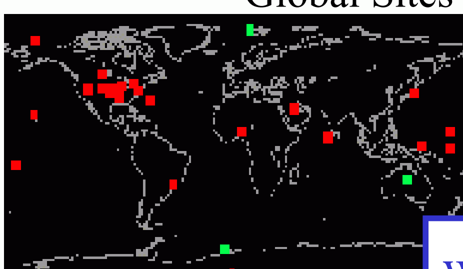
Radiation Transfer Model

Continuous

Observed Surface Broadband Radiation

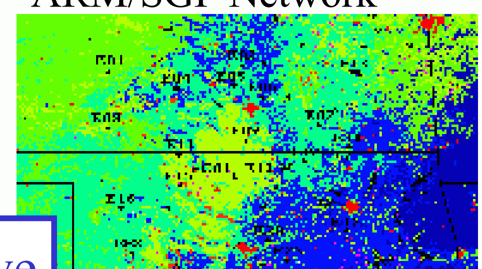
Long Term

Global Sites



Validation at Surface

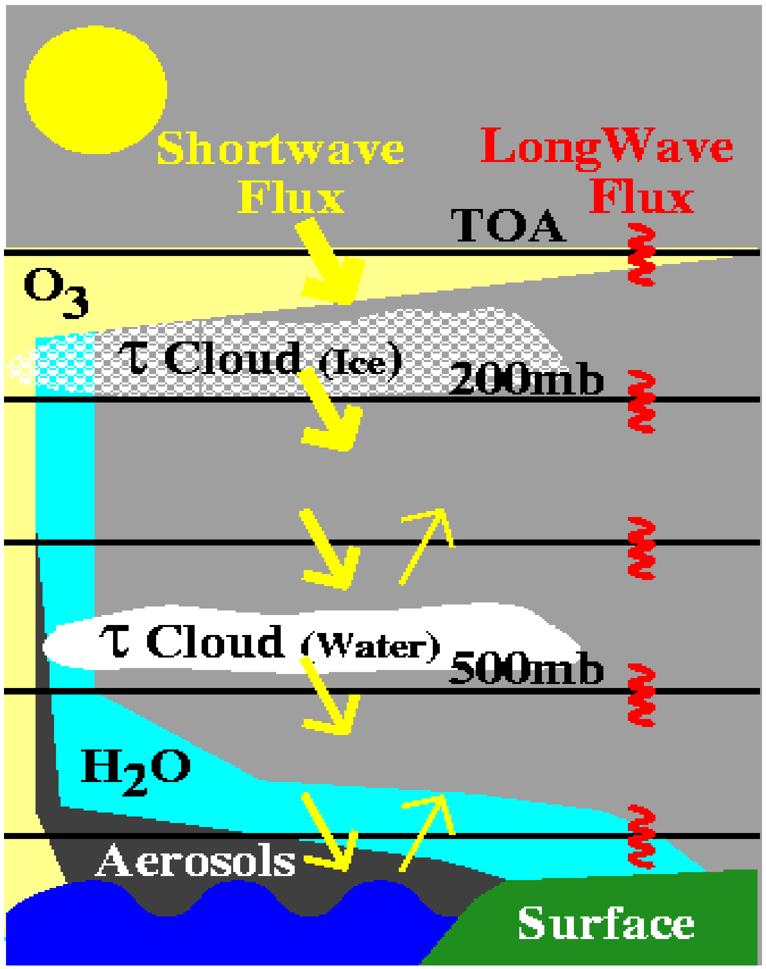
ARM/SGP Network



www-cave.larc.nasa.gov/cave

Surface
&Atmo
Fluxes

SARB Calculations



SARB Calculations of Radiative Flux Profiles

¥Collect Inputs

- ¥Water vapor profiles
- ¥Temperature profiles
- ¥Ozone profiles
- ¥Cloud properties
- ¥Aerosol properties
- ¥Surface properties

¥Compute Fluxes

- ¥Fast radiative transfer code (Fu & Liou)

¥Compare With CERES TOA Fluxes

¥Adjust Appropriate Inputs

¥Re-Compute Flux Profiles

srbsun.larc.nasa.gov/flp0300

Surface &Atmo Fluxes

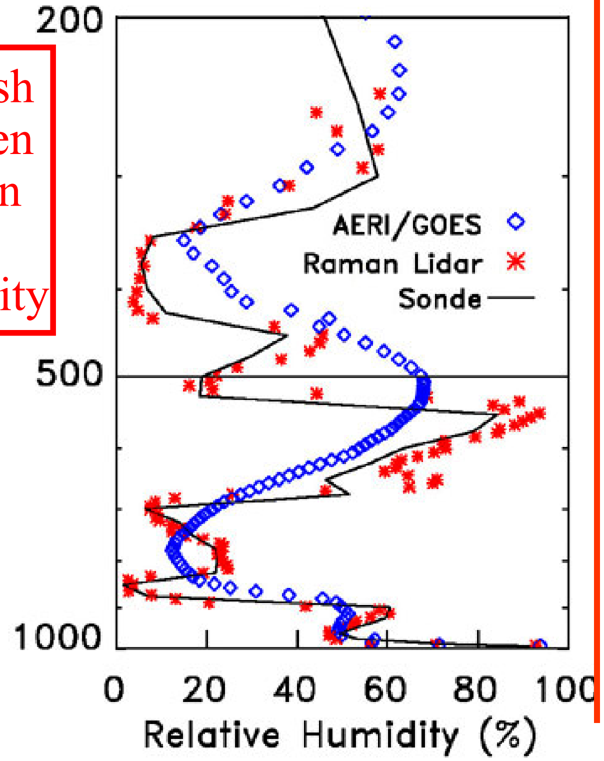
SARB Validation of Model Input

Observed fluxes at altitude are rare, but are influenced by atmospheric conditions.

Validate Atmospheric Profiles

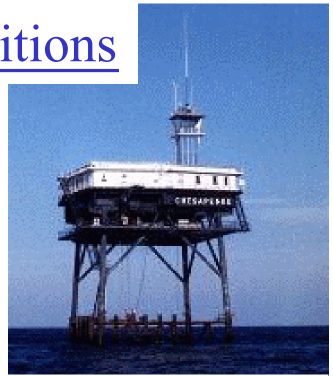
Compare CERES LW and WN clear-sky fluxes to calculated fluxes based on ECMWF/DAO

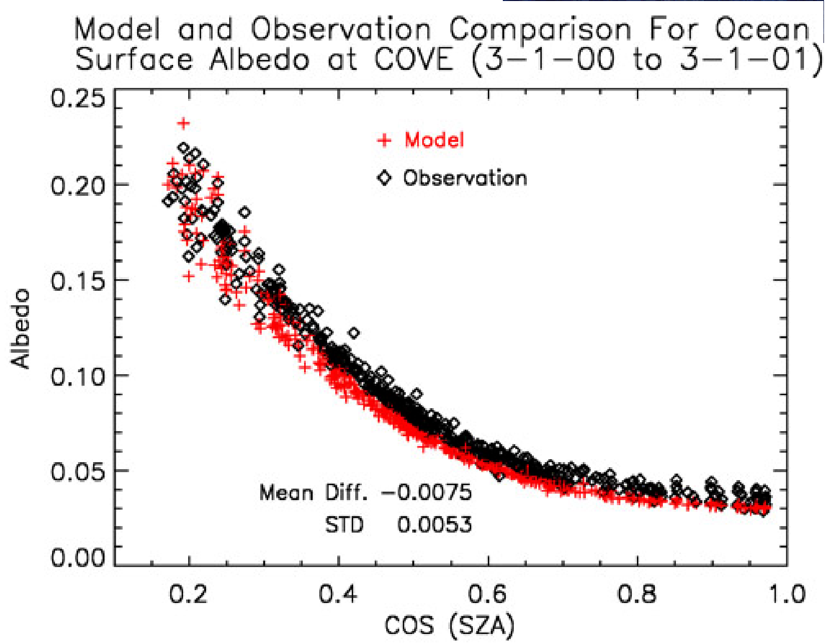
Difficult to establish consistency between different validation data for upper tropospheric humidity



Validate Boundary Conditions

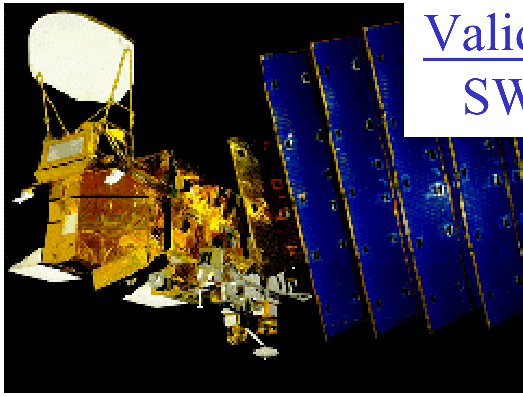
Sea Surface Albedo





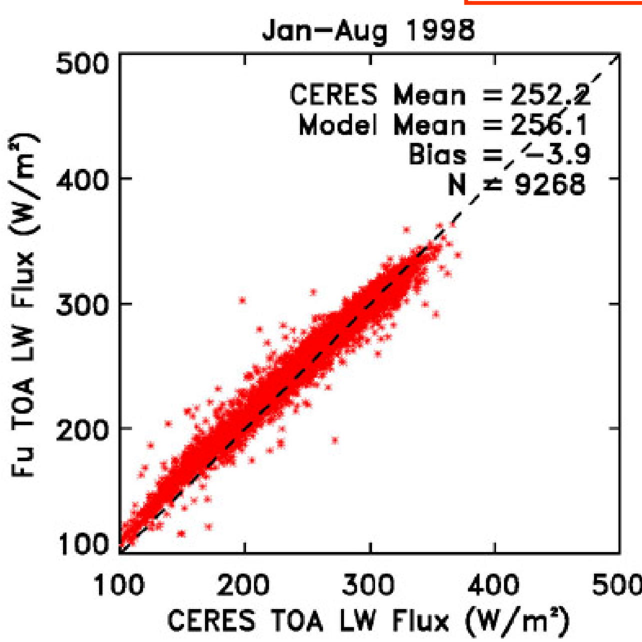
Surface &Atmo Fluxes

SARB Validation of TOA & Surface Fluxes

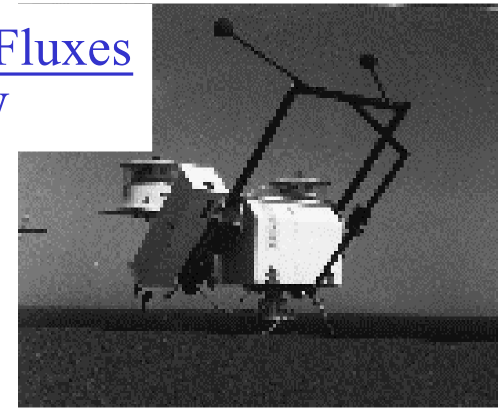


Validate TOA Fluxes
SW, LW and WN

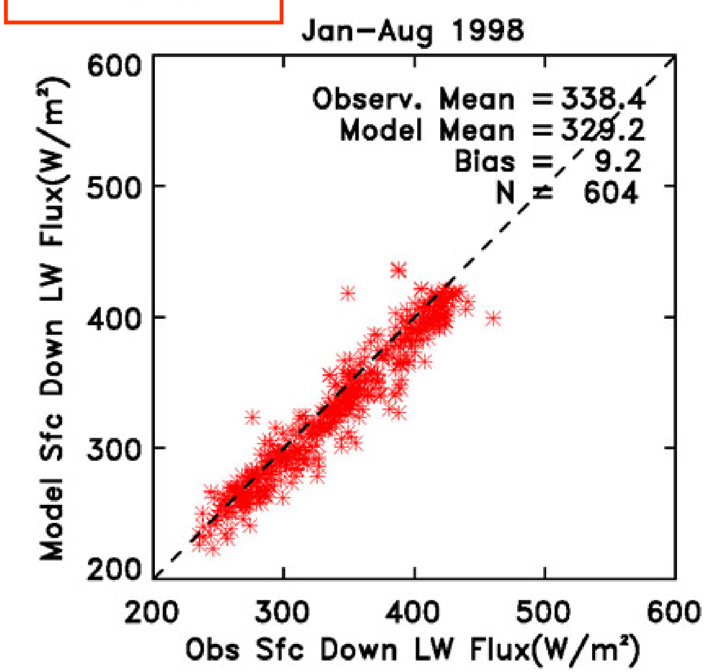
All-sky TOA LW Fluxes



Validate Surface Fluxes
SW and LW

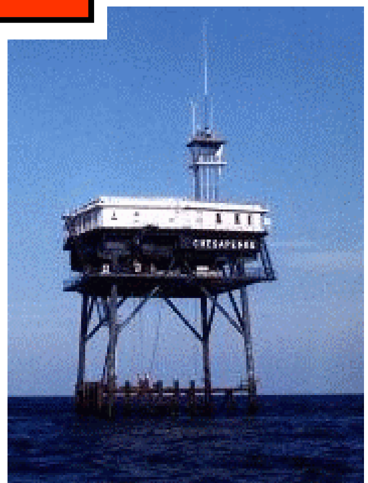


Clear-sky Surface LW Fluxes



Surface &Atmo Fluxes

SARB Validation Site
CERES Ocean Validation Experiment (COVE)



¥Observations are long term, continuous, & well calibrated

  ¥Upwelling & downwelling broadband fluxes (BSRN)

  ¥Directional scans for upwelling SW spectral radiance

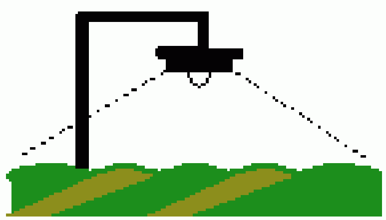
  ¥Aerosol (Aeronet), wind & waves (NOAA)

¥Tighten closure for column absorption/net radiation (i.e. aerosol forcing to atmospheric heating)

¥Validation for ocean boundary in a wide range of sea states

U(large FOV(land)) ≠ U(radiometer FOV)

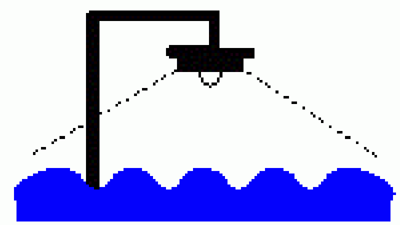
$$\frac{\int UdA}{\int dA} \neq \frac{\int Udt}{\int dt}$$



Inhomogeneous

U(large FOV(ocean)) ≈ U(COVE radiation)

$$\frac{\int UdA}{\int dA} \approx \frac{\int Udt}{\int dt}$$



Quasi-homogeneity

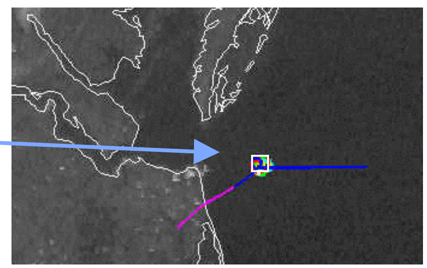
U - Upwelling radiation at the surface, t - time, A -Area(FOV)

Surface &Atmo Fluxes

CERES goal in CLAMS:

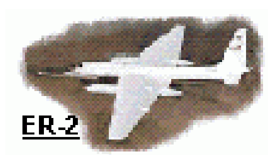
Learn how well point measurements at COVE platform represent the broader ocean

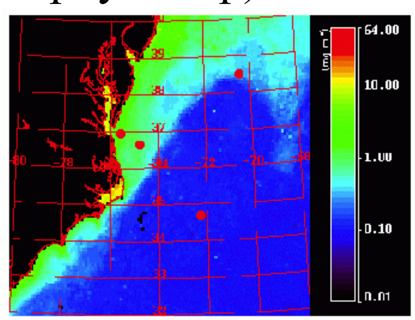
Do the steel legs and shadow (see photo above) spoil observations at COVE? Radiometers flown on the OV-10 near COVE to find out.



¥2km X 4km flight pattern of OV-10 at 200m altitude
¥spectral + broadband instruments at COVE and on OV-10

Target buoys far to sea (SeaWiFS Chlorophyll map) as well as COVE at the Chesapeake Lighthouse:





¥CV-580 near surface BRDF & aerosols
¥ER-2 at 20 km AirMISR & MAS
¥Target buoys observing wind & waves

Surface &Atmo Fluxes

SARB Accuracy Target and Current Estimates

TOA Upward Flux Jan-Aug 1998
(CERES — Calculations)

Wm^{-2}	Clear Sky		All Sky	
	Bias	σ	Bias	σ
LW	-0.1	3.4	3.0	6.5
Target	1.0	-	1.0	-
SW	-0.6	2.8	0.4	15.3
Target	1.0	-	1.0	

Surface Downward Flux Jan-Aug 1998
(1/2 hour average of surface observation — collocated calculations)

Wm^{-2}	Clear Sky		All Sky	
	Bias	σ	Bias	σ
LW	2.9	17.9	-1.7	31.9
Target	5.0	-	5.0	-
SW	-56.5	67.1	-47.7	91.2
Target	20.0	-	20.0	

The large bias in surface SW is partially due to:

¥Satellite cloud screening (Error reduces to —37 Wm^{2} with ground based cloud screening)
¥$\tau_{aerosol}$ optical input from assimilation data is less than from ground based photometers
¥Quality of surface observations (Insolation observed in 1998 at the SGP is ~20 Wm^{-2} less than in 1999. Mean bias of clear-sky calculations is only 1 Wm^{-2} in 2000.)

TISA

Temporal Interpolation and Spatial Averaging (TISA)

¥ **Objective**

— Interpolate radiative fluxes and cloud/aerosol/surface properties between times of measurements to produce accurate temporal averages

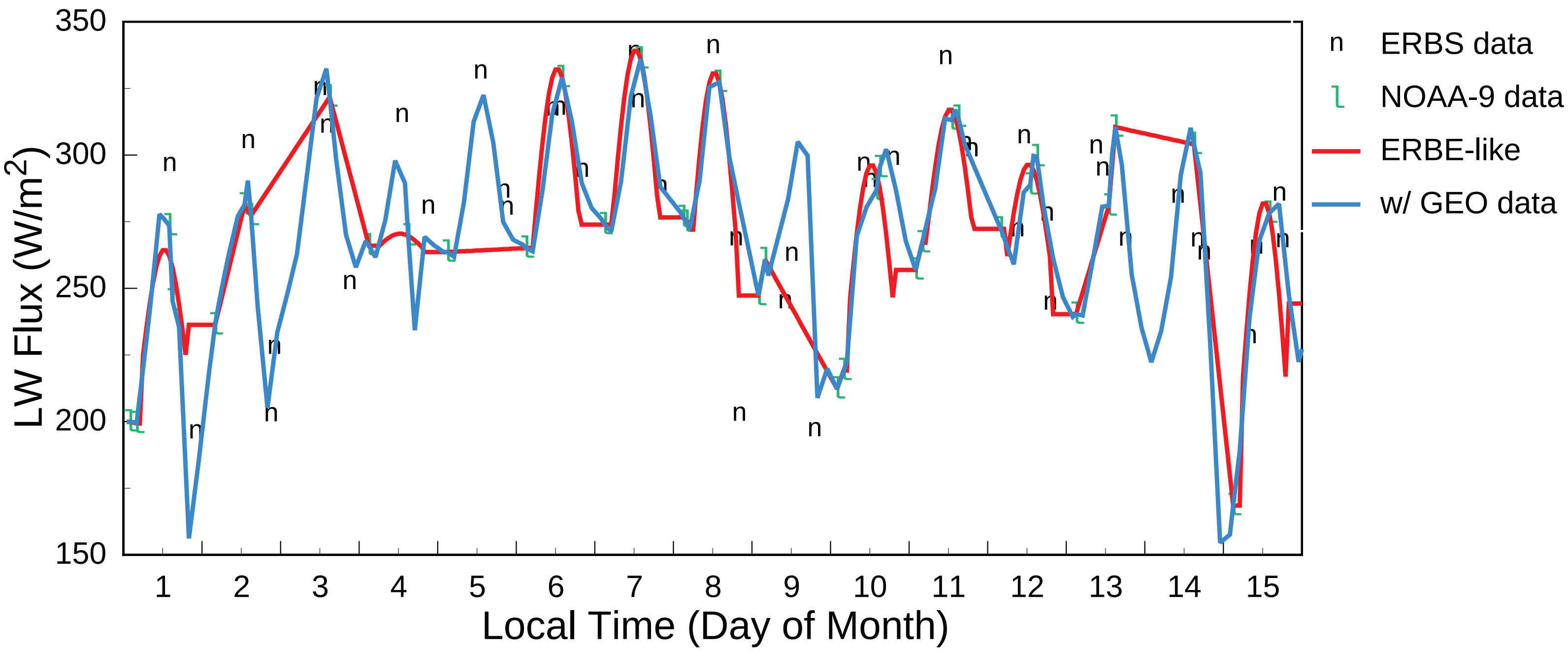
¥ **Approach**

— Model diurnal cycles between CERES observations using geostationary (GEO) data

— Produce daily and monthly mean surface and atmospheric fluxes

— Produce synoptic products from time-sampled data

— Method evaluated using ERBE data. Instantaneous flux errors reduced by 50%.

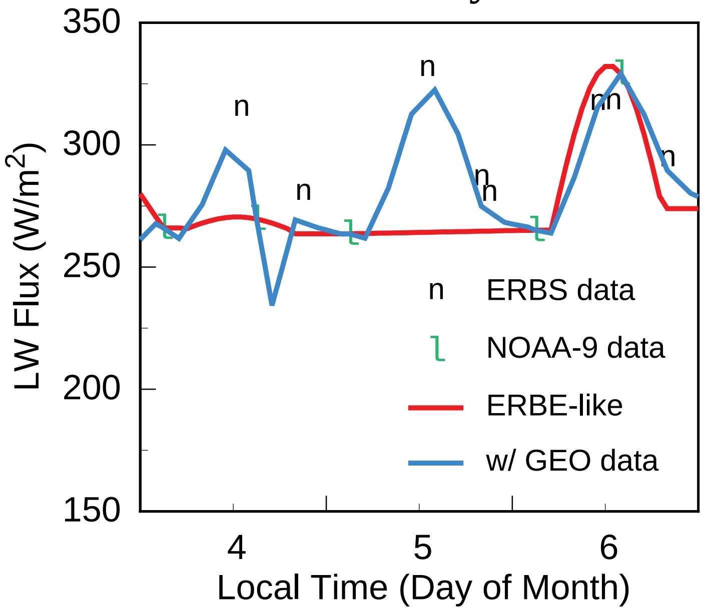


TISA

Temporal Scales of TISA Validation

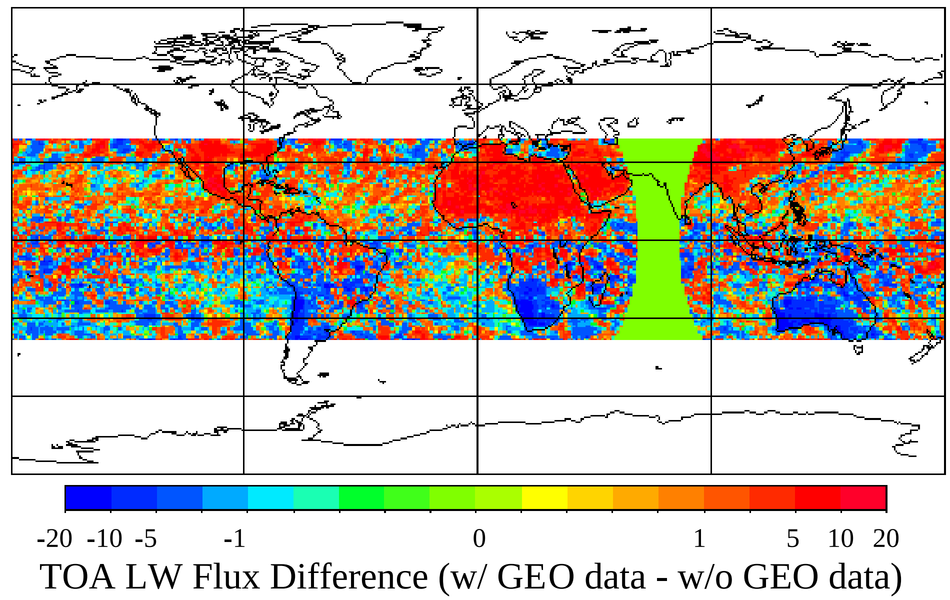
Instantaneous:

GEO Data Resolve Diurnal Cycle



Monthly Means

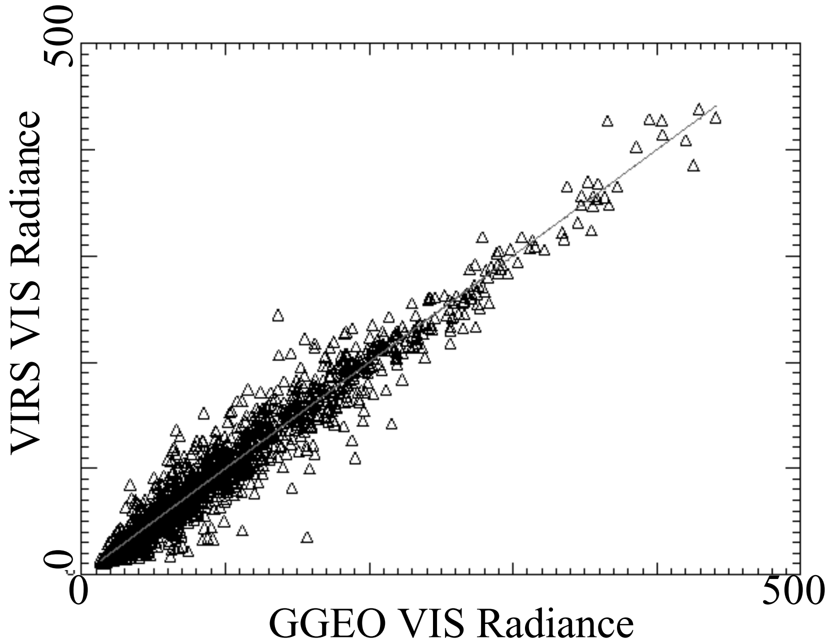
Improved Diurnal Modeling Removes Temporal Sampling Biases



Temporal Sampling Accuracy Goals (W/m^2)		
Daily Average Regional 1σ	Monthly Average Regional 1σ	Monthly Average Global Bias
8.0	2.5	1.0

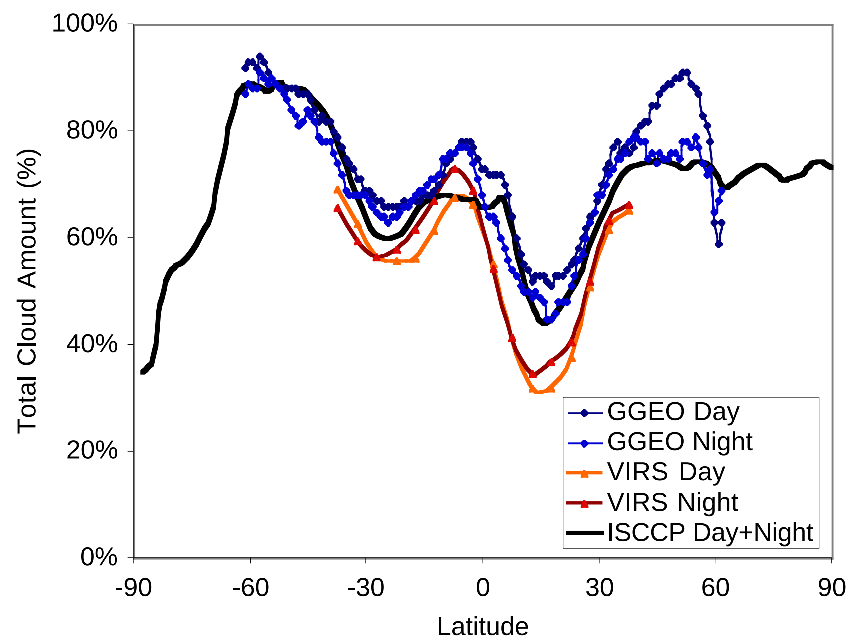
Geostationary Data Quality Control

TISA



Calibration:
- Monthly VIRS/GEO inter-calibrations
- Scene-type dependent narrowband-to-broadband relations derived monthly
- Data screened for bad scan lines

Cloud Property Comparisons
- VIRS/GGEO cloud properties compared on instantaneous and zonal mean basis
- Comparisons with ISCCP climatology



TISA

TISA Validation: Evaluating Interpolated Fluxes

Surface Flux Validation

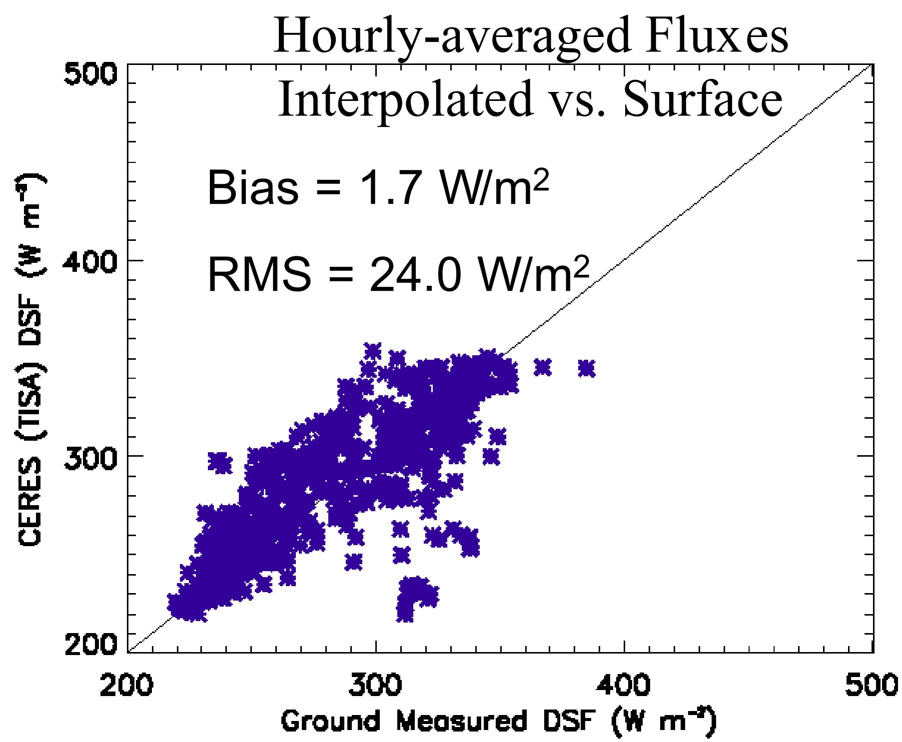
¥ Use GEO-interpolated 1¡x1¡ gridded fluxes

¥ TOA flux interpolated to all hours of month

¥ Surface fluxes computed using CERES TOA-surface algorithms

¥ Match with hourly averaged data from ARM Central Facility

¥ Compare bias and rms of interpolated comparison with instantaneous results to determine interpolation error



¥ Surface fluxes from continuous ground site time series provide the best available data for evaluating temporal interpolation

¥ Surface flux errors represent composite of interpolation errors of CERES TOA flux and cloud properties

¥ TOA flux interpolation will be evaluated separately using GERB data

TISA

TISA Validation: Evaluating Monthly Mean Fluxes

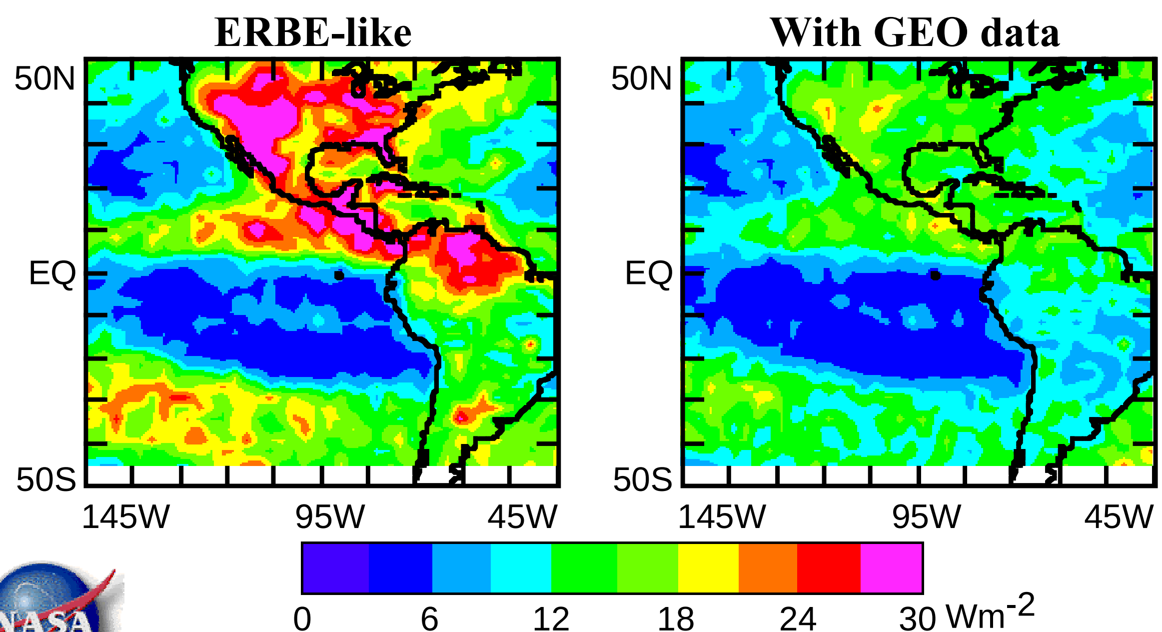
Monthly Error Components

¥ Spatial gridding error
¥ Temporal sampling effects
¥ GEO Narrowband calibration
¥ Narrowband/Broadband conversion
¥ Fixed GEO viewing geometry effect

Monthly Mean Flux Validation

¥ Comparison with ERBE-like
¥ Multiple satellite comparisons
¥ Regional comparisons using monthly averaged surface data
¥ Regional comparisons with monthly averaged GERB data

Regional Instantaneous LW Flux Temporal Sampling Error



W/m^2	ERBE-like	With GEO data
LW Flux Error	13	6
SW Flux Error	43	16

Status of CERES Validation

- The CERES instruments on TRMM and Terra demonstrated unprecedented radiometric stability (better than 0.1%/yr for most channels).
- Inter-channel and inter-instrument comparisons demonstrate radiometric consistency on the order of 0.2% to 0.5% in LW and SW, respectively.
- Using 3 months of overlapping CERES rotating scan plane data for Terra and Aqua, radiance inter-calibration can achieve 0.05% LW and Window channels, 0.25% SW channels (95% confidence): a level of 0.1 Wm^{-2} in LW, and 0.2 Wm^{-2} in SW TOA flux.
- CERES/TRMM ERBE-like fluxes consistent with contemporary ERBE/ERBS, CERES/Terra and ScaRaB/Resurs fluxes.
- New TRMM angular dependence models are in final validation; results show major reduction in angular bias compared to ERBE models. Because of limited TRMM sampling (9 months, 40S to 40N only) Terra/Aqua will be more accurate, global, and allow accuracy testing for broken cloudiness.
- Completing evaluation of ECMWF versus DAO GEOS 3.3.x 4-D assimilation data input. Temperature, humidity profile accuracy comparable. Evaluating Tskin.

Status of CERES Validation

- Initial cloud property validation indicates very good agreement with surface-based measurements. Full validation requires study of other cloud types, climate regimes and much larger statistical sampling to verify climate accuracy versus cloud type.
- First validated CERES angular models from TRMM and matched cloud/aerosol/radiation SSF data product expected to receive approval at the 9/01 CERES Science Team meeting,with release in Oct. 2001.
- In-atmosphere and surface flux validation is limited by spatial and temporal matching of the satellite and surface-based fluxes. Future work will focus on improving the validation datasets and inputs to the model, and on improved time/space matching. TRMM validated data products expected to be in production by Feb. 2002.
- TISA error budget modeled using high temporal resolution data sets. In depth validation of diurnal cycle modeling will use time series of surface fluxes and Geostationary Earth Radiation Budget (GERB) data.

Validation Challenges

§ Getting sufficient high quality validation data at surface sites:

- ¥ BSRN funding limited, data archive inoperable the last year, data quality control needs improvement.
- ¥ ARM tropical west pacific sites difficult to maintain, so no surface cloud radar/lidar data overlapping with Terra MODIS ÒB-sideÓ data. Will slow cloud validation work in the tropics.
- ¥ ARM cloud data itself requires further validation of microphysical retrievals using aircraft in-situ data: in progress.
- ¥ ARM cloud data still evolving to be able to handle all cloud types, initial validation only on single layer water and thin ice clouds.
- ¥ ARM/BSRN sites over ocean are few, missing many climate regions.
- ¥ Will rely on ESSP-3/Cloudsat merged with MODIS and CERES to validate global cloud structure and 3-D radiation and anisotropy effects.
- ¥ Still need BSRN/Aeronet observations merged for resolution of aerosol absorption effect on surface fluxes. Also need more BSRN/Aeronet type observations on ships covering all oceans over time.

Validation Challenges

- Data staging and sub-sampling difficulties at DAACs slow validation progress.
  - Especially true for CERES which requires multiple years of matched surface/satellite observation pairs at a large number of surface sites.
  - Working with LaRC DAAC to use hard disk staging of key data sets to speed validation turnaround.
  - Working with GSFC DAAC to get MODIS 5-minute granules processed for data over ARM sites in March 2000 through October 2000 (A-side electronics data which is lower priority for MODIS reprocessing)
  - Finalizing with GSFC DAAC to spatially and spectrally sub-sample MODIS by a factor of 10 to greatly speed staging and processing.
- Continued efforts at ARM and BSRN to improve surface flux data, especially for SW fluxes.
- Systematic viewing angle biases in cloud properties need further work: expect ESSP-3 lidar to precess across the Aqua MODIS/CERES scan swath to verify cloud and aerosol angular dependence.

Validated Product Delivery Schedule

- ¥ TRMM (Jan-Aug 1998, March 2000)
  - — ERBE-Like TOA fluxes (ES-8/4/9) Available since 8/98
  - — TRMM Angular Dependence Models (ADMs) Sept, 2001
  - — TRMM SSF Ed 2 cloud/ADM/TOA/Sfc flux early Oct, 2001
  - — TRMM CRS Ed 2 TOA/Sfc/Atmosphere flux Feb, 2002
  - — TRMM SRBAVG TOA/Sfc Flux, geo time interp. Feb, 2002
  - — TRMM AVG TOA/Sfc/Atmosphere flux, geo Aug, 2002
- ¥ Terra (March 2000 to current)
  - — ERBE-Like TOA fluxes (ES-8/4/9) Available since 12/00
  - — Terra Edition 1 cloud + TRMM ADMs Jan, 2002
  - — Terra Angular Dependence Models (2 yrs data) Nov, 2002
  - — Terra SSF Ed 2 cloud/ADM/TOA/Sfc flux Dec, 2002
  - — Terra CRS Ed 2 TOA/Sfc/Atmosphere flux June, 2003
  - — Terra SRBAVG TOA/Sfc Flux, geo time interp. June, 2003
  - — Terra AVG TOA/Sfc/Atmosphere flux, geo Dec, 2003

Validated Product Delivery Schedule

- Aqua (Launch between Jan and June, 2002)

— ERBE-Like TOA fluxes (ES-8/4/9)	Launch + 7 months
— Aqua Edition 1 cloud + Terra ADMs	Launch + 18 mo.
— Aqua Angular Dependence Models (2 yrs data)	Launch + 30 mo.
— Aqua SSF Ed 2 cloud/ADM/TOA/Sfc flux	Launch + 31 mo.
— Aqua CRS Ed 2 TOA/Sfc/Atmosphere flux	Launch + 34 mo.
— Aqua SRBAVG TOA/Sfc Flux, geo time interp.	Launch + 34 mo.
— Aqua AVG TOA/Sfc/Atmosphere flux, geo	Launch + 37 mo.

- *ES-8, SSF, and CRS CERES data products are instantaneous field of view data, while ES-4, ES-9, SRBAVG, and AVG are gridded daily through monthly time averages.*