CERES Overview: Clouds and the Earth's Radiant Energy System

Bruce A. Wielicki
NASA Langley Research Center

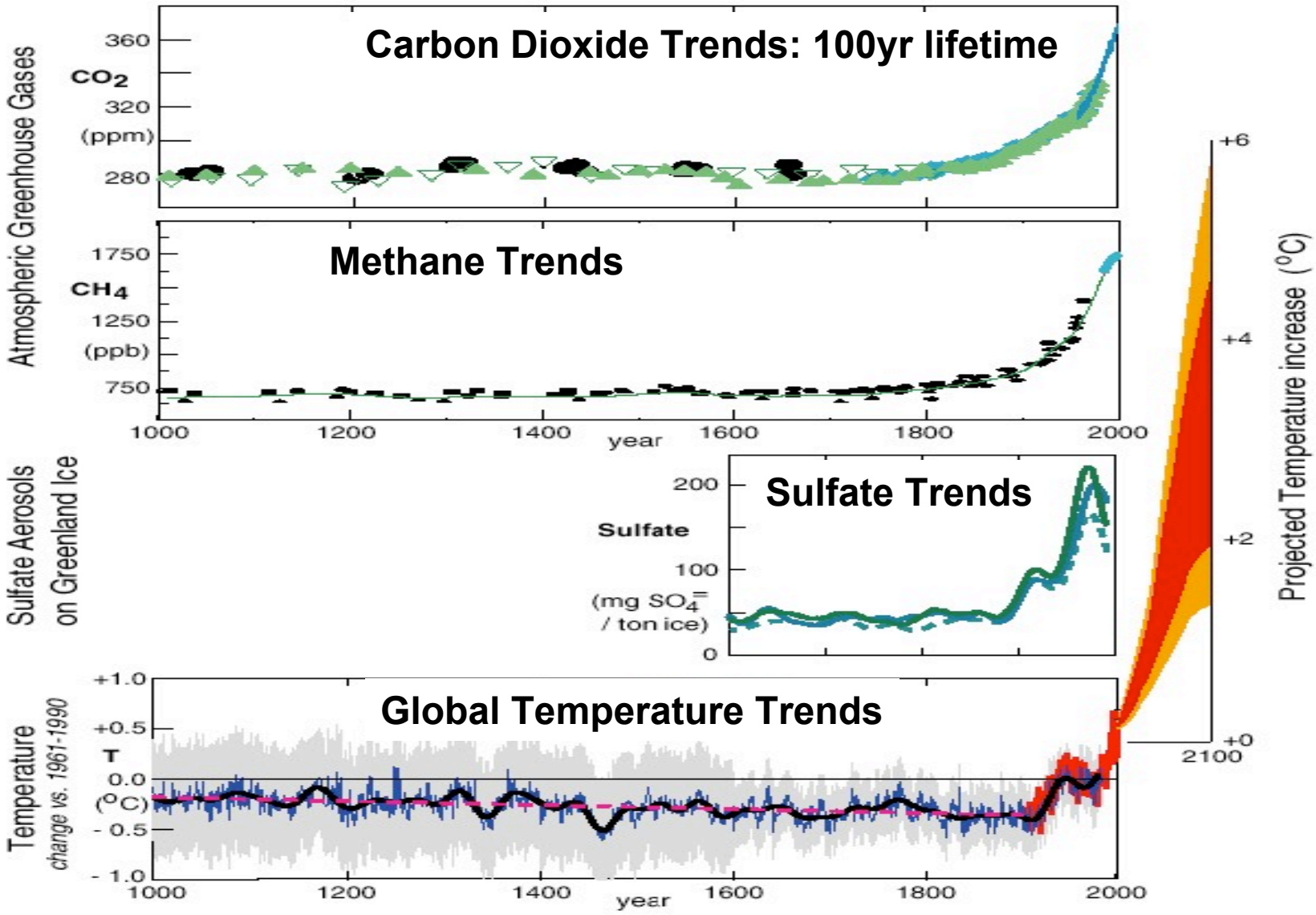
CERES Data Products Workshop
Norfolk, VA

January 29-30, 2003

Outline

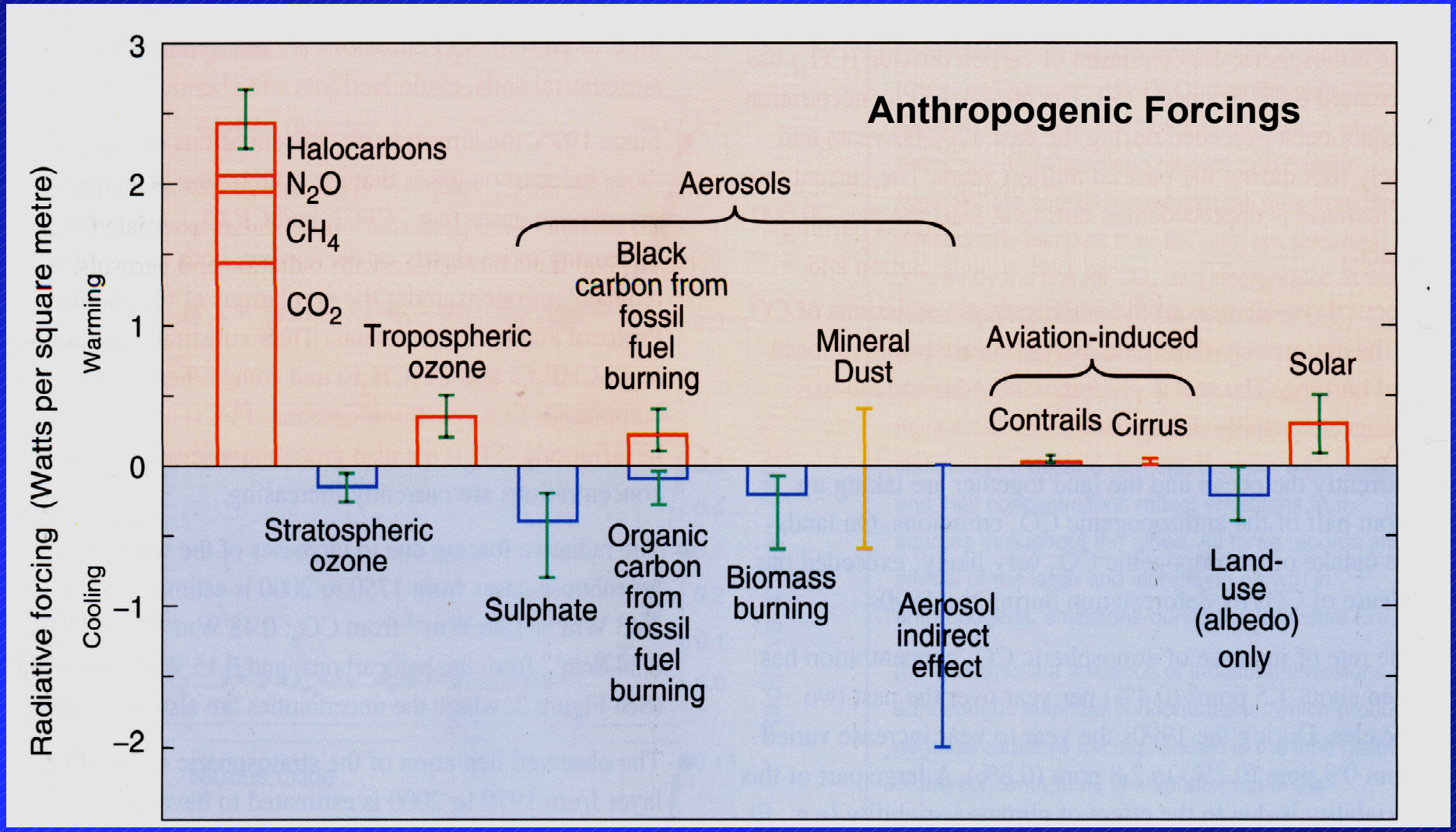
- Climate change background
- CERES introduction
- Advances of CERES over ERBE
- Data product examples
- Web site links
- Selected journal references
- Future directions

Human Influence on Climate



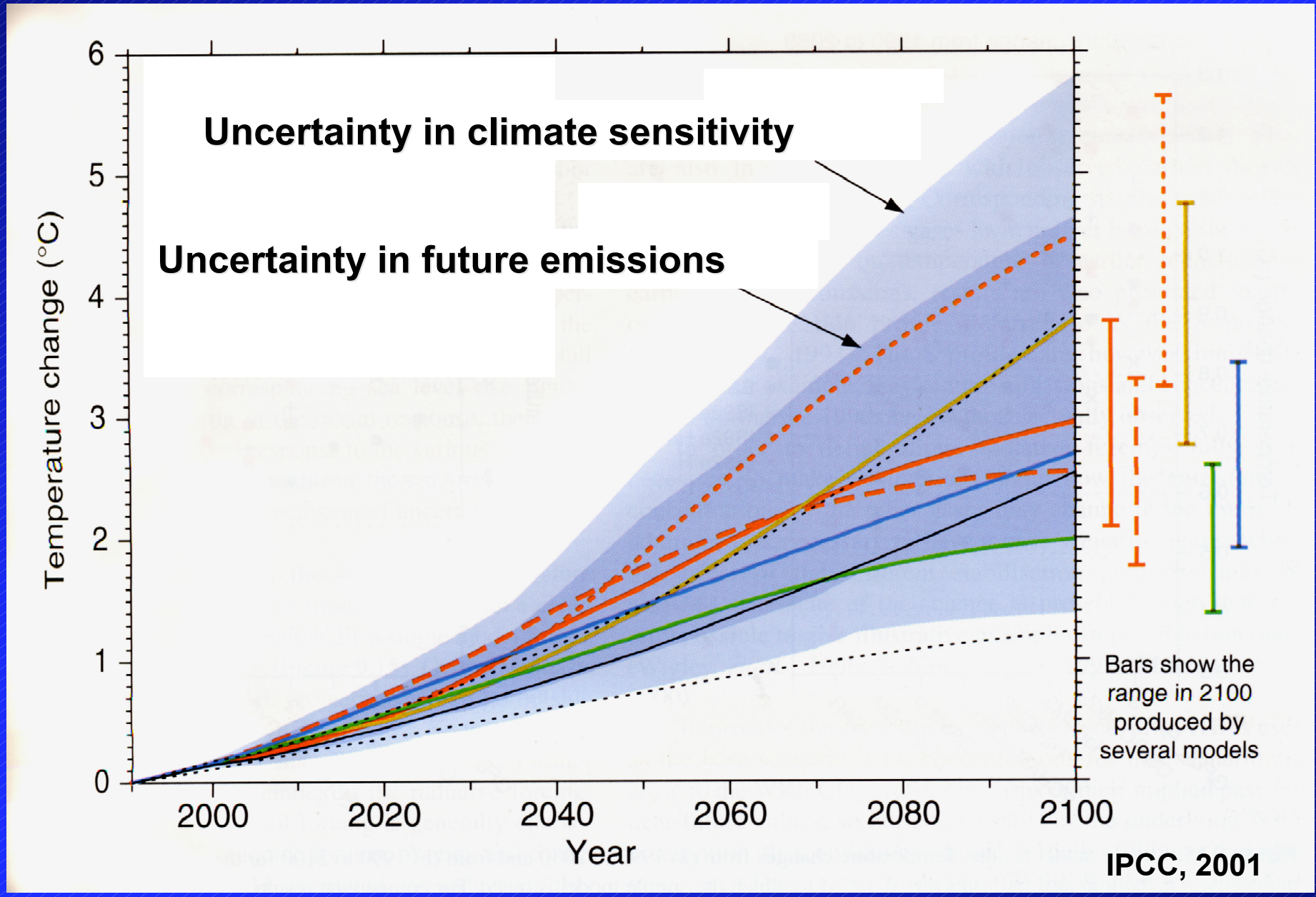
From M. Prather University of California at Irvine

Radiative Forcing from 1750 to 2000

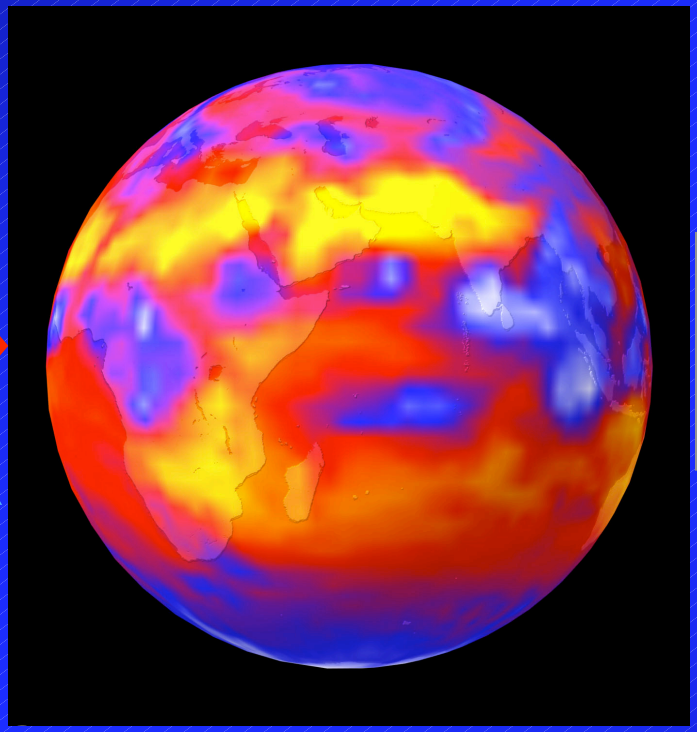


IPCC, 2001

Global Temperature Predictions



How does the Earth Respond?



Forces Acting On the Earth System

Earth System Response

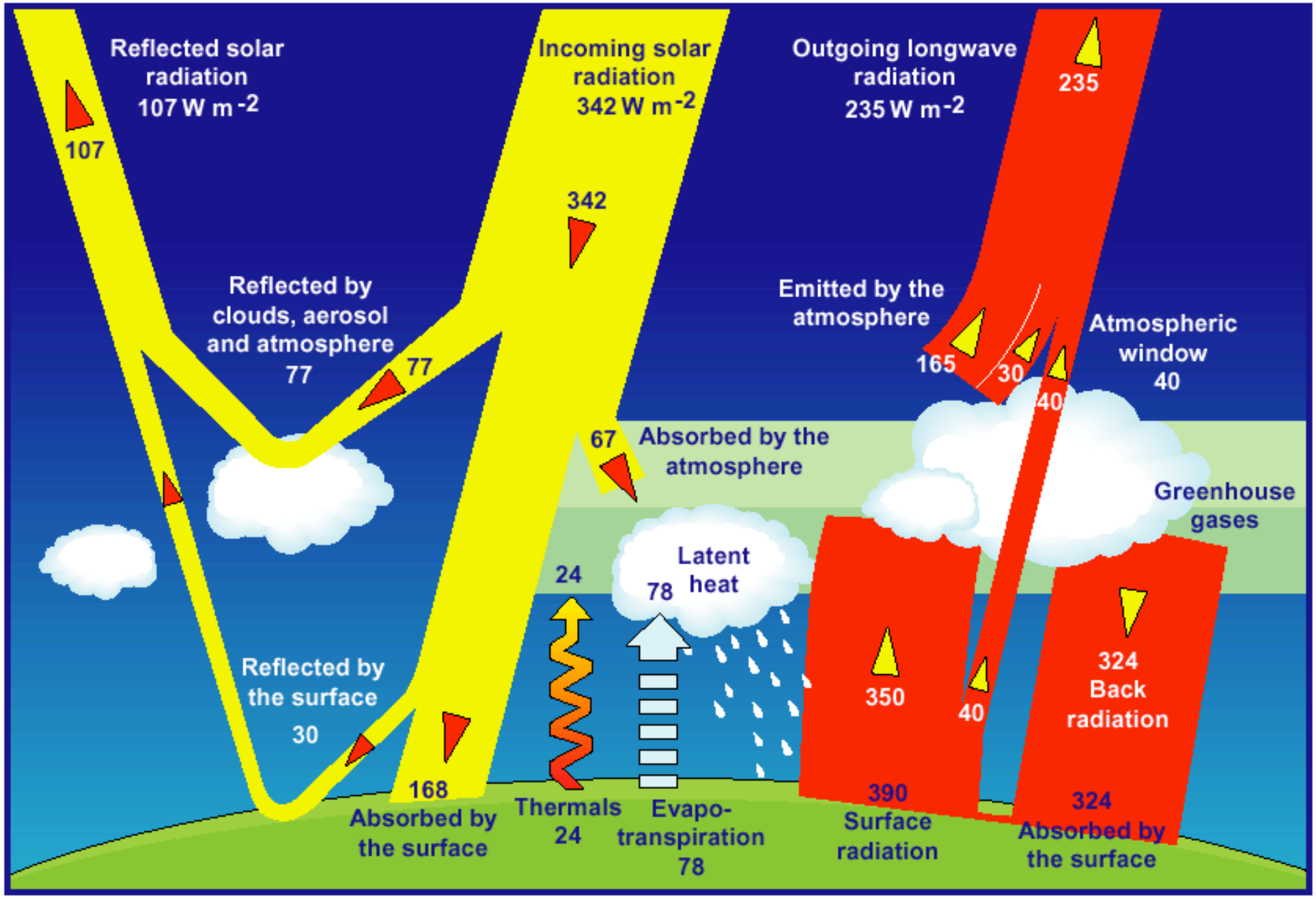
IMPACTS

Feedback

Feedbacks examples:

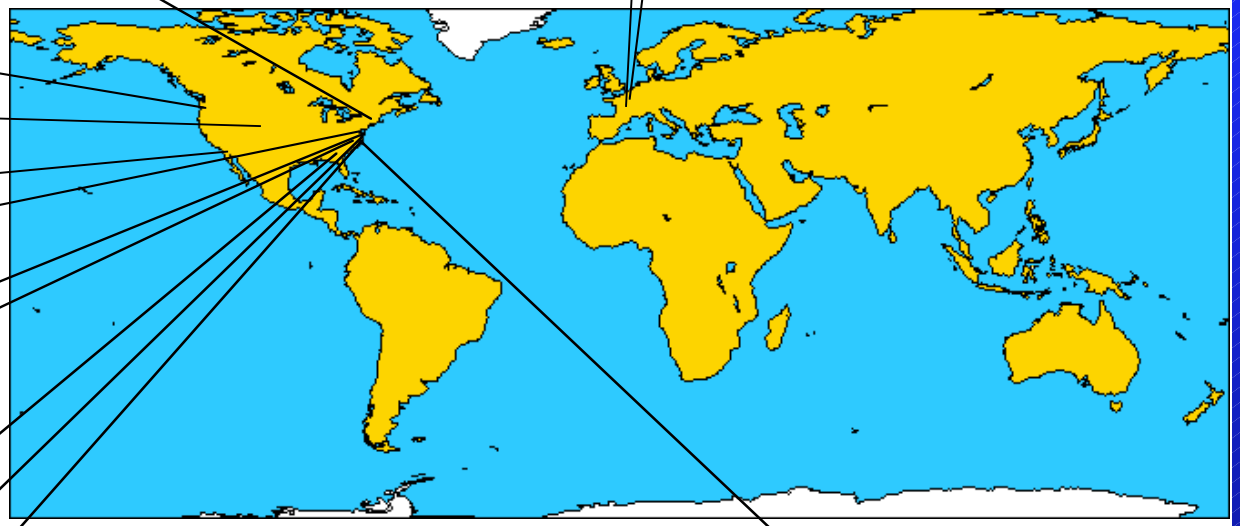
Water vapor (positive), clouds (unknown), snow/ice albedo (positive)

Climate System Energy Balance



CERES Science Team

Bruce A. Wielicki, Principal Investigator



R. D. Cess - SUNY/SB
J. A. Coakley - OSU
D. A. Randall - CSU
V. Ramanathan - Scripps
M. D. King - GSFC
A. J. Miller - NOAA/NWS
G. L. Smith - VPI&SU
R. M. Welch - UA/Huntsville
L. J. Donner - NOAA/GFDL
N. G. Loeb - HU

M. Viollier - CNRS
S. Dewitte - RMIB

LaRC

B. A. Baum
L. H. Chambers
T. P. Charlock
R. N. Green
D. P. Kratz
R. B. Lee III
P. Minnis
K. J. Priestley
T. Wong
D. F. Young

CERES Instrument

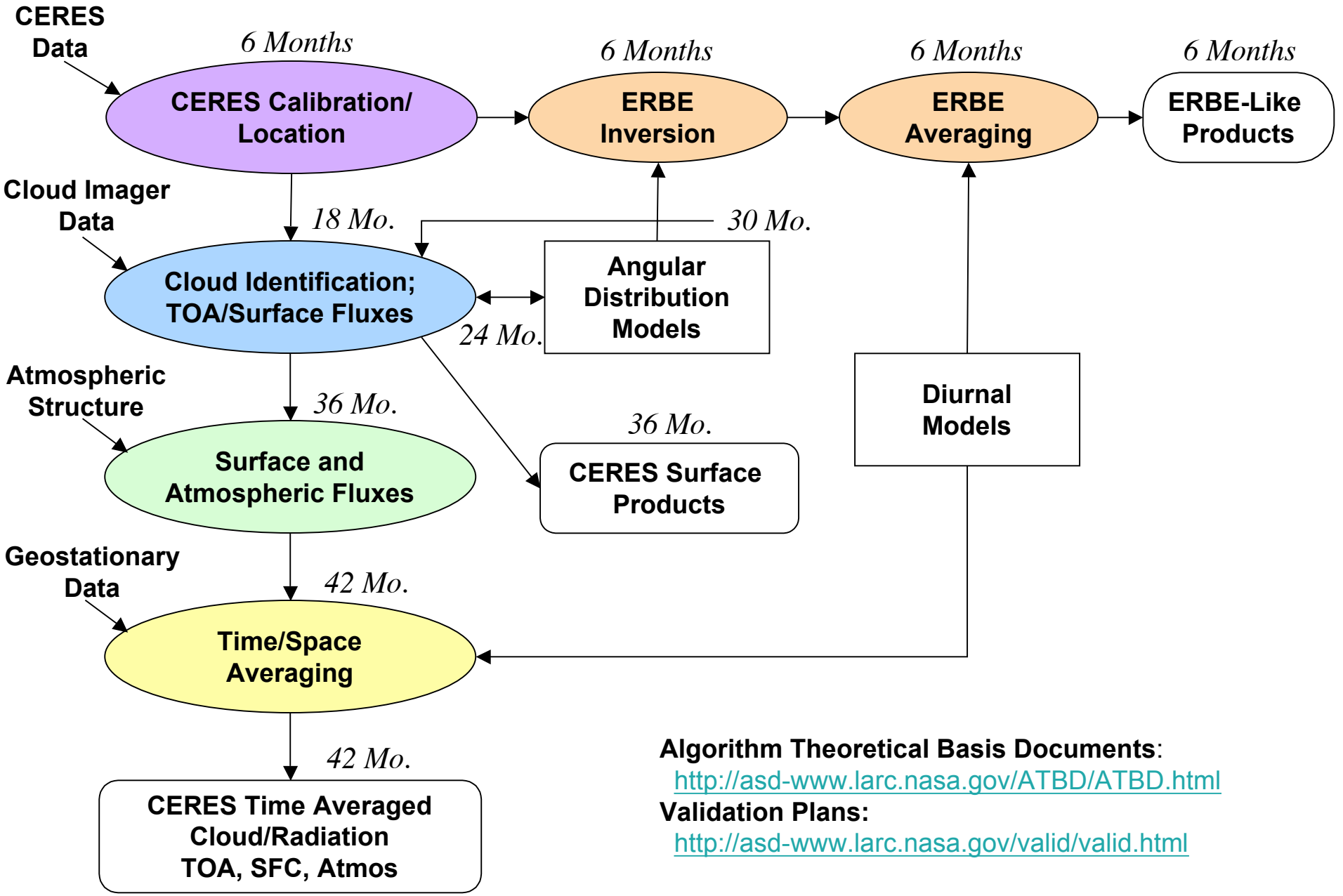
TRMM:
Jan-Aug 98
and Mar-Apr 2000
overlap with Terra

Terra:
Mar 00 - present
planned life: 2006

Aqua:
July 02 start
Now in checkout
Planned life to 2008

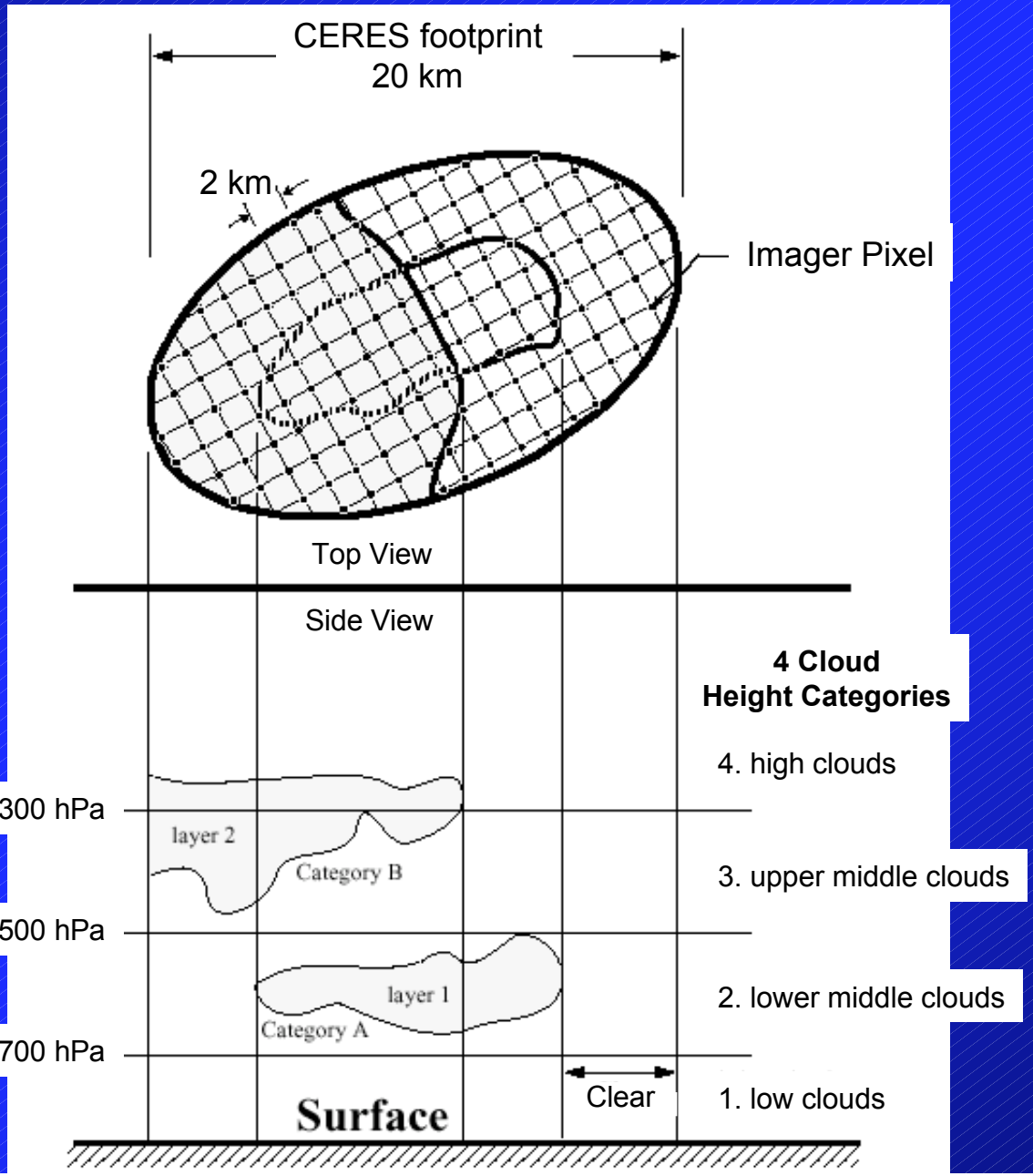
NPOESS:
TBD: gap or overlap?
2008 to 2011 launch

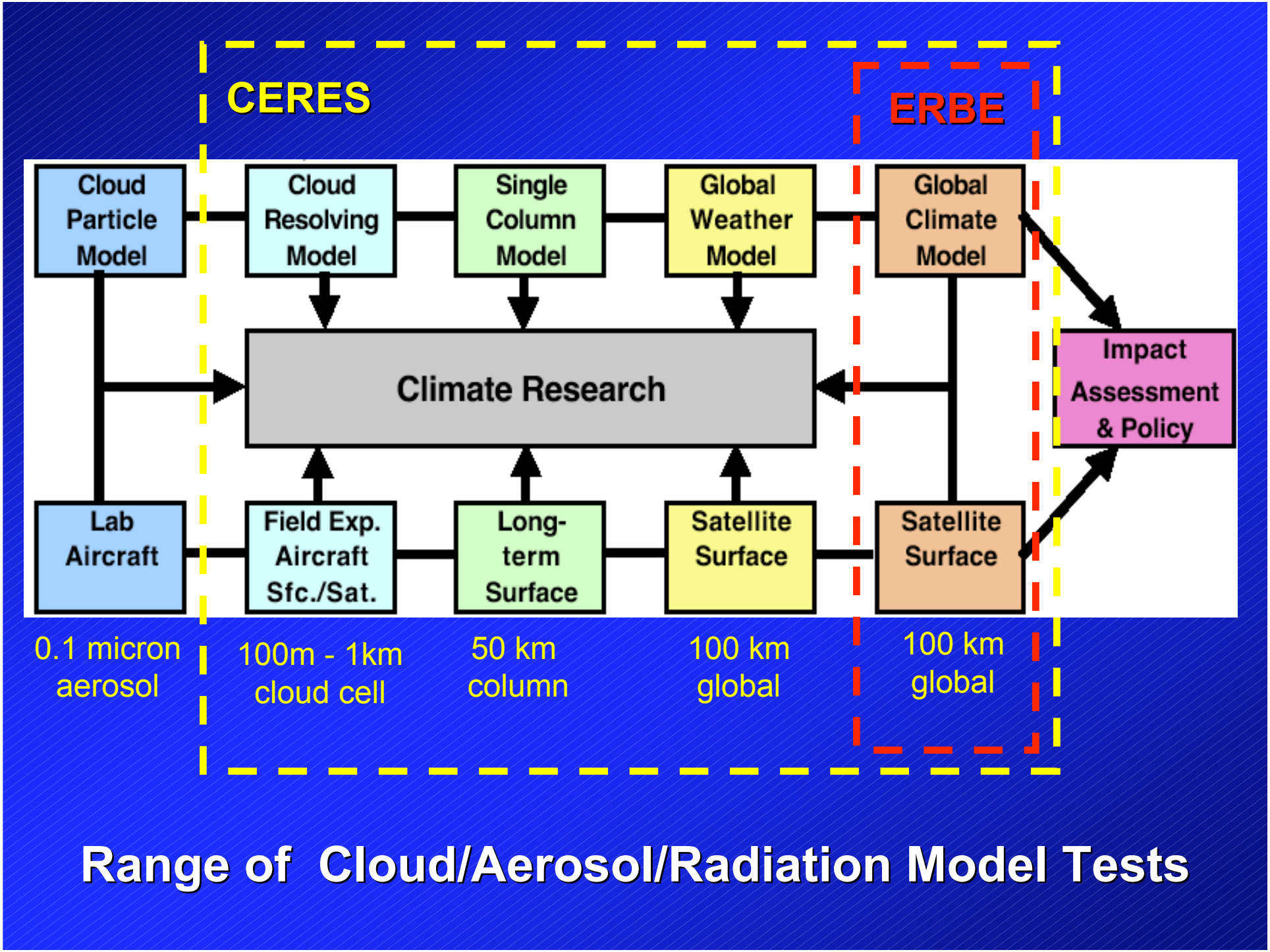
CERES Data Processing Flow



Algorithm Theoretical Basis Documents:
http://asd-www.larc.nasa.gov/ATBD/ATBD.html
Validation Plans:
http://asd-www.larc.nasa.gov/valid/valid.html

Matching CERES Fovs with Imager Cloud Properties





Range of Cloud/Aerosol/Radiation Model Tests

ERBE Error Analysis: CERES goals

- **Instantaneous TOA Flux error dominated by:**
  - Angle Sampling Error: (new adms: factor 2-3 reduction)
- **Monthly mean regional TOA flux errors dominated by: (CERES improvement)**
  - Absolute calibration (factor of 2 improvement)
  - Angle Sampling Error (new adms: factor 2-5 reduction)
  - Time Sampling Error (add geo: factor of 2-3 reduction)
- **Interannual/Decadal errors dominated by:**
  - Calibration stability (< 1 Wm^{-2}, goal 0.25 Wm^{-2})

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 2004 with vertical aerosol/cloud

Move toward unscrambling climate system energy components

What makes CERES unique?

- **Calibrate. Calibrate. Calibrate.**
  - *most accurate and stable of EOS radiometers.*
  - *climate is a 1% game: calibration before resolution.*

- **Sample. Sample. Sample.**
  - *Radiation is an 8-dimensional sampling problem:*
    $x, y, z, t, \theta, \theta_0, \phi, \phi$
  - *2 CERES scanners: one for **x,y**. One for θ, θ_0.*
  - *Imager for **z**, θ, ϕ (select ADMs. z later using lidar/radar).*
  - *TRMM precessing orbit: all ϕ_0.*
  - *Geostationary and Terra/Aqua orbits for t*
  - *Data products integrate up to 11 instruments on 7 spacecraft.*
  - *500,000 lines of production code, another 500K offline.*

- **Validate. Validate. Validate.**
  - *Large ensembles of cases: ARM, BSRN, etc to reach 1%*
  - *Satellite checks using GERB (diurnal), Calipso/Cloudsat (z)*
  - *Few field experiment cases not enough: A/C > Sfc > Sat*
  - *Created data quality summaries for quick assessment*
  - *Beta to Validated (Edition) to involve community early*

CERES is Complex: Why does it work?

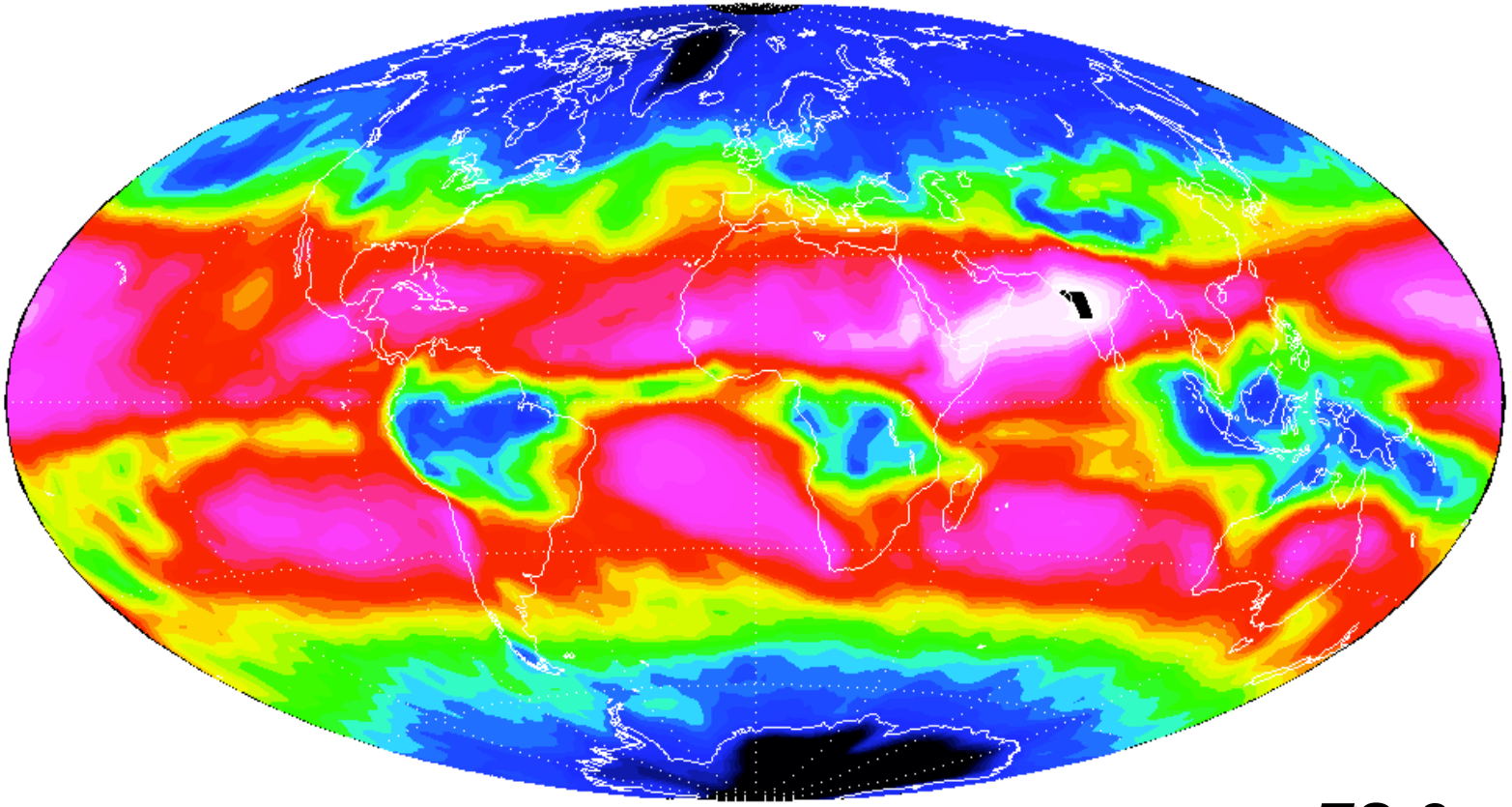
Failed IRS, FAA, Denver baggage code similar size

- Difficulty of software is a power law: not linear in lines of code.
- CERES is ~ 500K lines of production code, and 500K lines of offline qc/validation. Failed FAA system was similar, but over $1B spent before failed.
- ERBE earlier experience with 1/4 the difficulty was key.
- Most of the team has been together for 10 to 20 years: turnover for software "contracts" can be 30%/yr
- Team dedicated to a mission, not a profession: a science advantage.
- Team focused first on interface definitions (data products) between major components and then let individual working group chairs control their part. Analogous to the way the web works.
- Science team, Algorithm team, Data Management team, Data Center team work together well: most at LaRC so that science and data are closely tied.
- Cost to develop CERES only 70% of computer industry cost for similar size developments.

Examples of Results

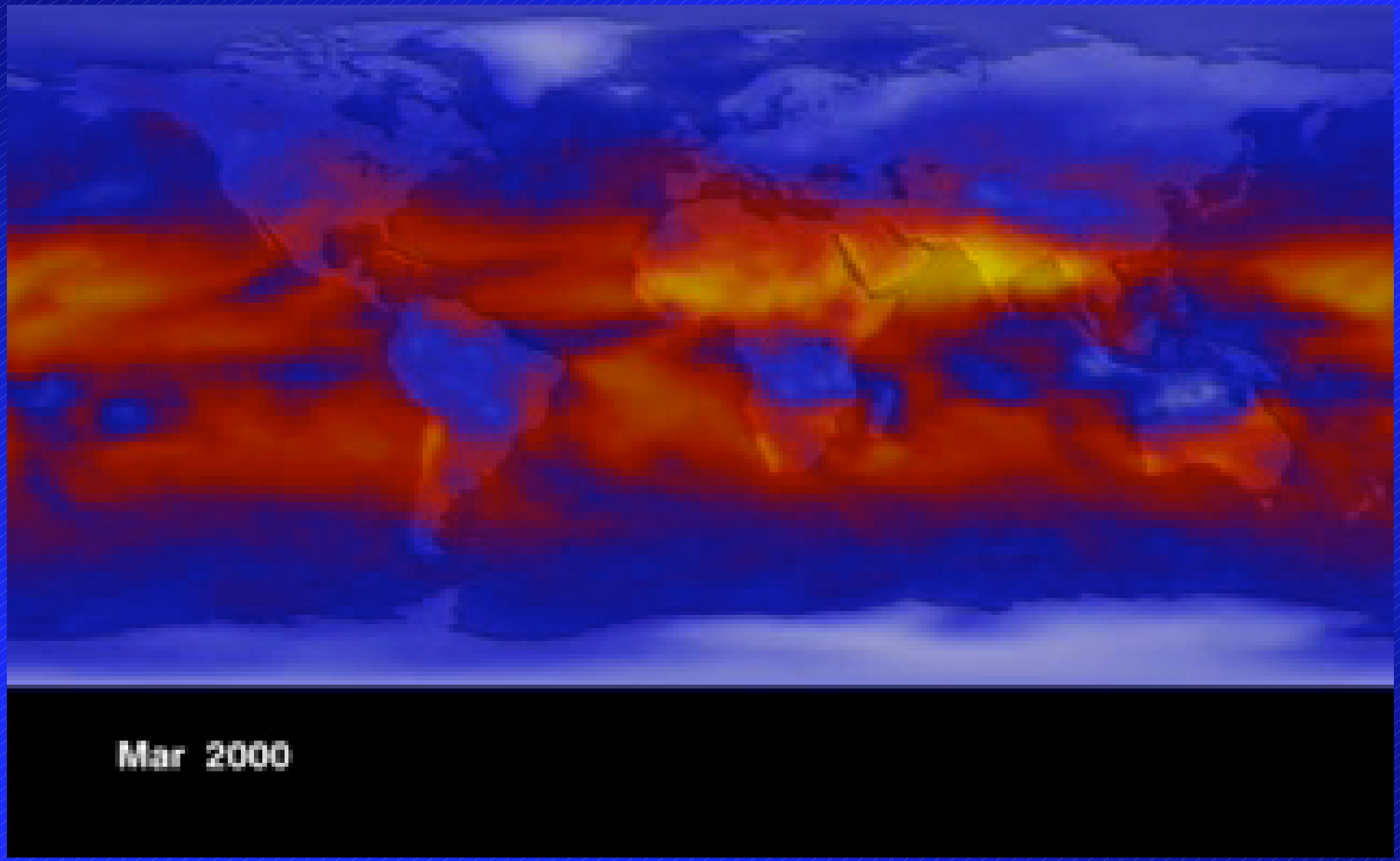
Unprecedented Accuracy of new EOS Radiation Data

Emitted Thermal Flux Measured By CERES
Terra March 2000



ES-8
ERBE-Like

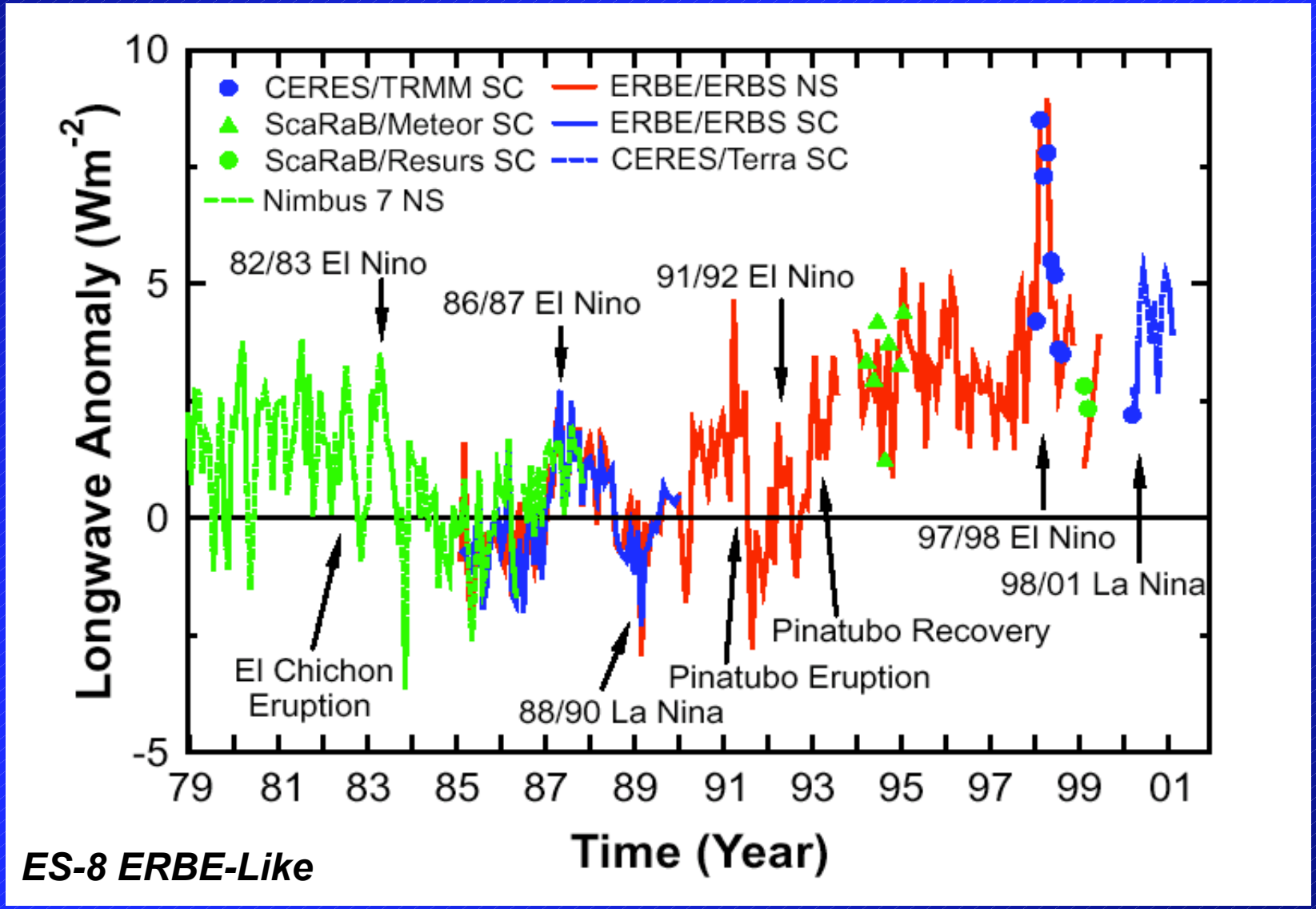
CERES Terra 14 day Running Average for TOA LW Flux
March 2000 to May 2001



ES-8 ERBE-Like

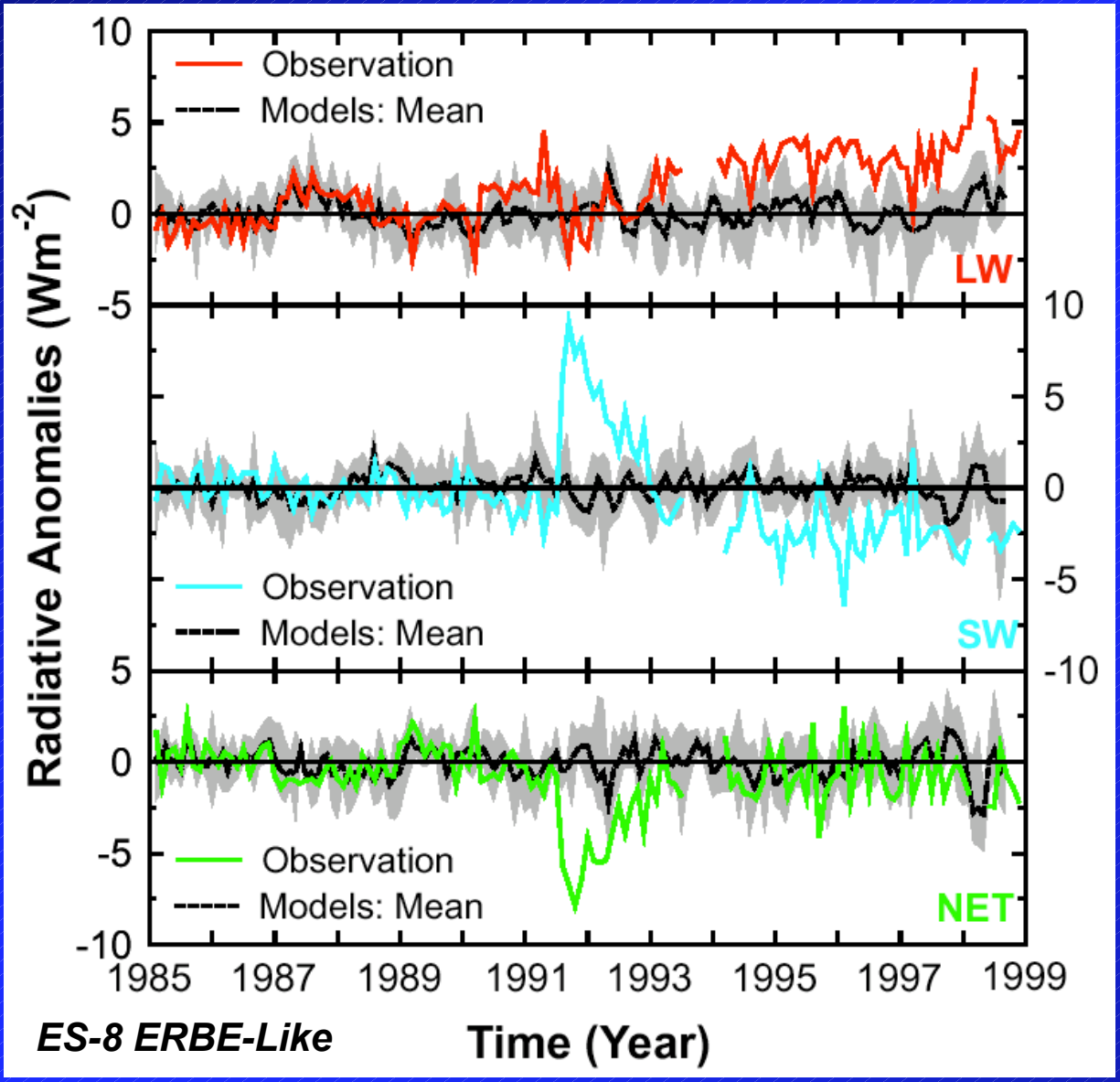
T. Wong, NASA LaRC and Data Visualization Group, NASA GSFC

An overlapping Earth radiation climate record: 22 years from Nimbus 7 to Terra.



ES-8 ERBE-Like

Comparison of Observed Decadal Tropical Radiation Variation with Current Climate Models



LW:
Emitted Thermal Fluxes

SW:
Reflected Solar Fluxes

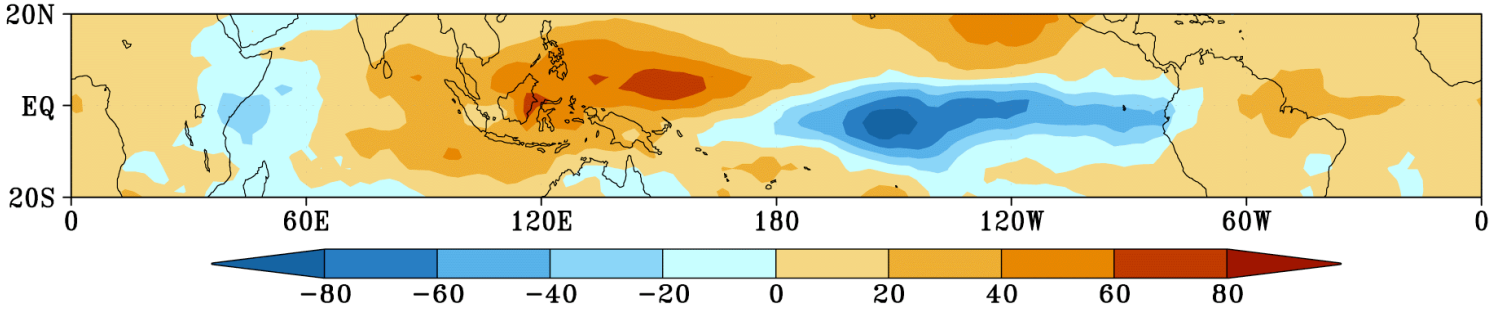
Net:
Net Radiative Fluxes

Models less variable than the observations:
- missing feedbacks?
- missing forcings?
- clouds physics?

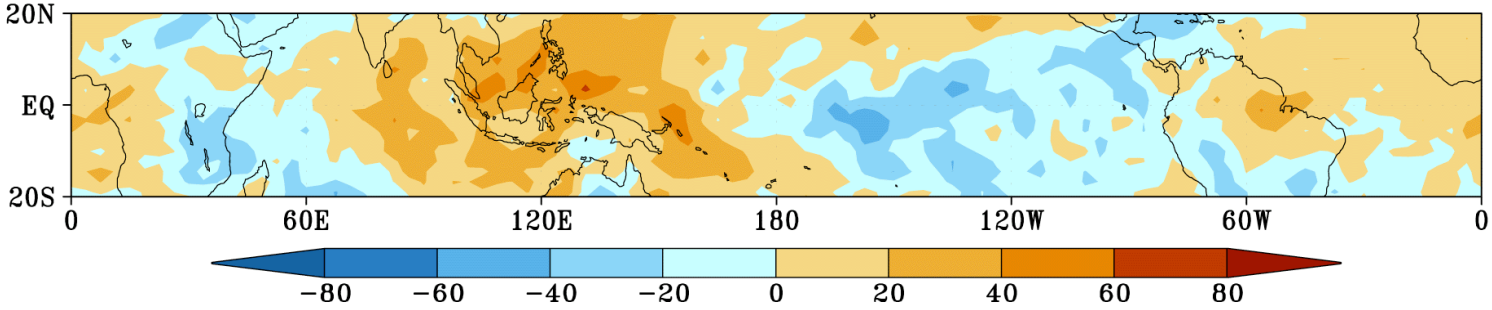
Wielicki et al., Science 02

Jan/Feb 98 El Nino Thermal Flux Anomalies

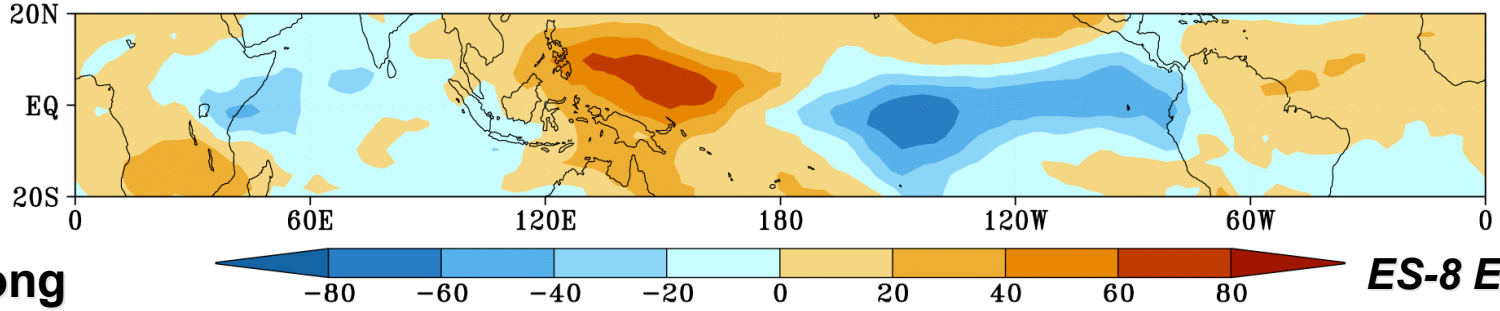
NASA CERES Radiation Observations



NOAA GFDL Standard Climate Model



NOAA GFDL Experimental Prediction Model

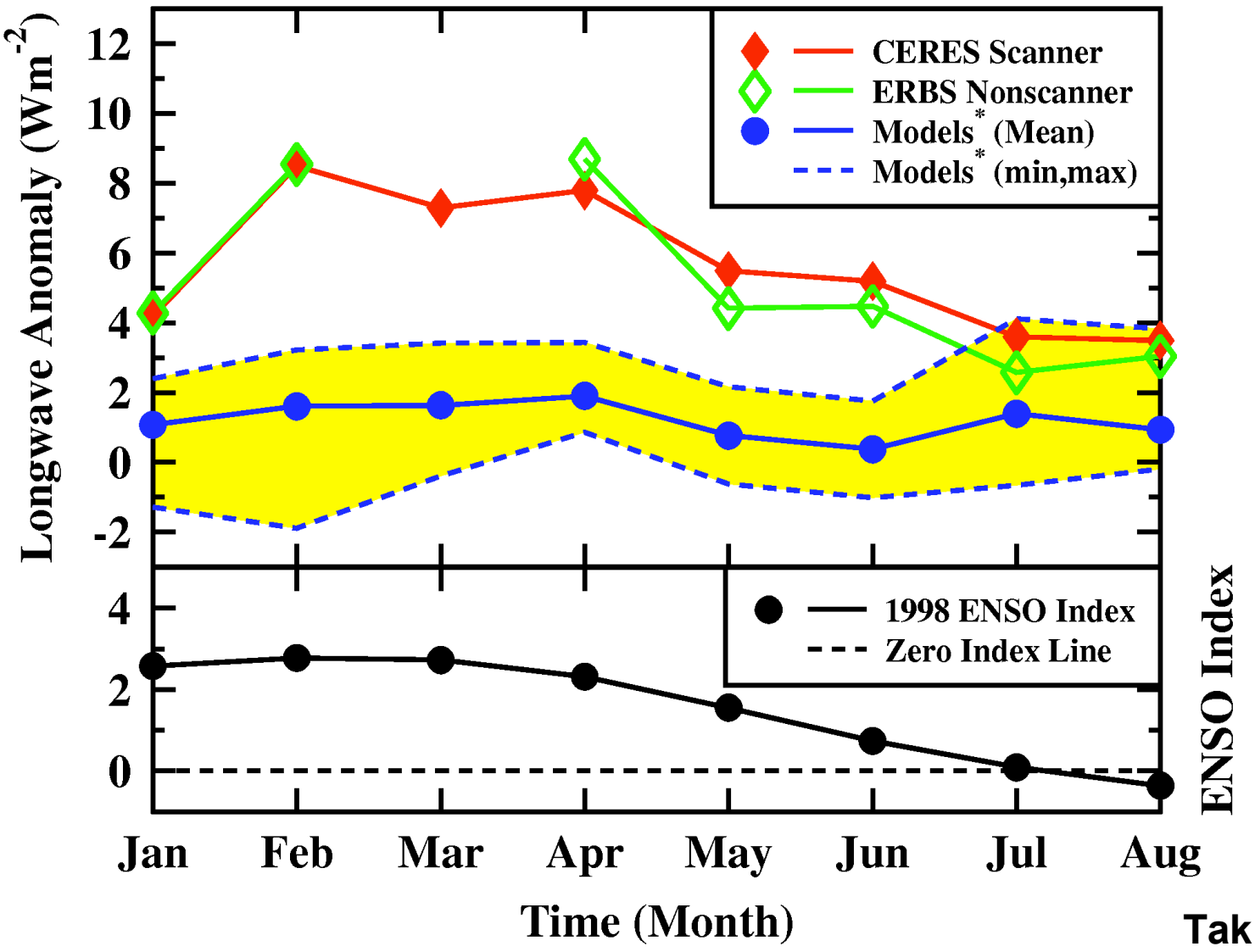


Tak Wong

ES-8 ERBE-Like

1998 El Nino Tropical Mean (20S - 20N) Longwave Flux Anomalies

(Anomalies Referenced to 1985 through 1989 Baseline)



Tak Wong

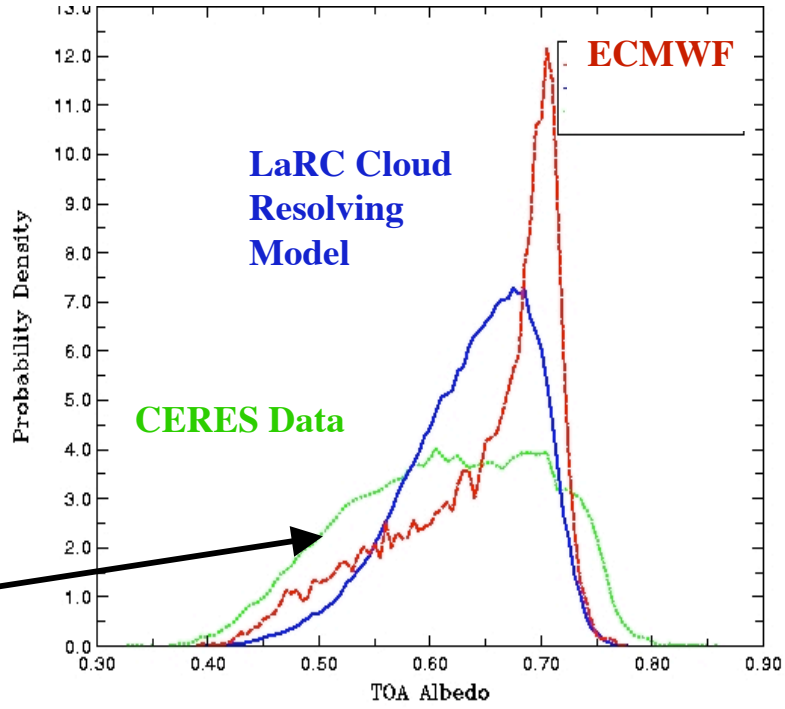
*5 Climate Models and NCEP Re-analysis; All used observed SSTs; Climate Models: NCAR-CSM (Kiehl) UKMO (Allan, Slingo), GFDL and GFDL-EP (Soden, Gordon), CSU (Randall)

A New EOS Cloud Object Approach to Testing Climate and Cloud Resolving Models

Example: Tropical Deep Convective Cloud Systems Test

- ***NWP atmospheric state drives cloud models***
  - ***Drive the ECMWF cloud model: 50 km global 3-D***
  - ***Drive a Cloud Resolving Model: 1 km 2-D grid over 500 km domain.***
- ***EOS cloud and radiation data for over 50 cloud systems verifies model performance:***
  still a long way to go....

TOA Albedo PDF

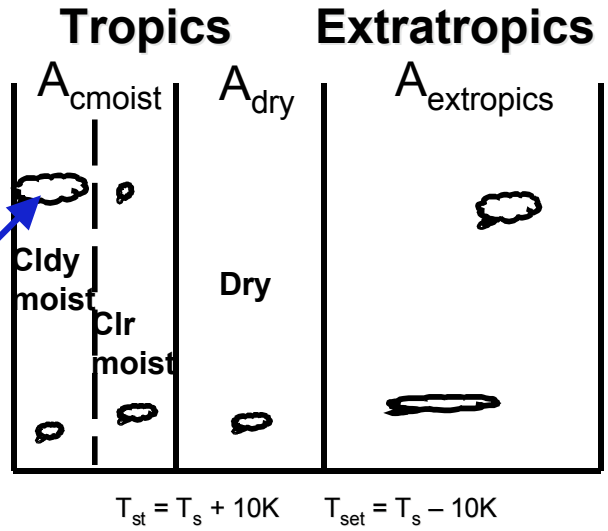


SSF TRMM Data

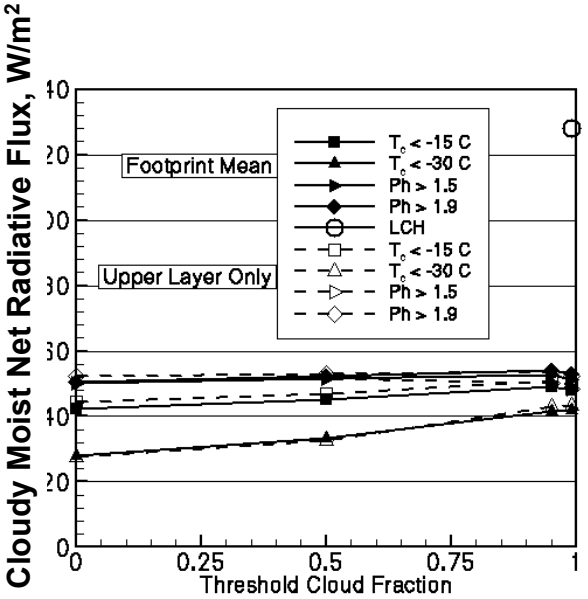
Kuanman Xu and Tak Wong

NASA EOS Data Directly Tests Policy Relevant Climate Sensitivity Hypotheses: The Iris

New EOS CERES fluxes accurate by cloud type allow direct testing of the Iris hypothesis: a simple climate model of strong negative cloud feedback:



Are the Iris assumed convective cloud radiative properties right?



The Iris assumed cloud radiative fluxes

CERES observed cloud radiative fluxes: differ by 80-100 W/m² from the Iris, and rejects the Iris Hypothesis.

B. Lin and L. Chambers

CERES Linkages

- Validation:
  - ARM (DOE), BSRN (International), Surfrad (NOAA), Aeronet (NASA)
  - Aircraft => ARM => Satellite as an overall strategy
- Climate Modeling Community:
  - Randall (CSU), Donner (GFDL), Miller (NCEP)
  - Kiehl (NCAR), Slingo/Allan (UKMO)
  - GCSS (Randall, Xu)
- Global Satellite Observations:
  - VIRS/MODIS imagers for cloud properties
  - ISCCP geostationary radiance data (3hrly time sampling)
  - GERB geostationary broadband validation
  - A-train Cloudsat/Calipso vertical aerosol cloud data
  - TRMM Precipitation for latent/radiative heat budget

K-12 Education Outreach: S'COOL Student Cloud Observations Online

- Over 1300 schools
- Schools in 61 countries
- K – post-graduate, focus on grades 3-6
- Schools observe at satellite overpass time
- Over 17,000 ground observations for CERES validation

Annual Teacher Workshops

http://scool.larc.nasa.gov

L. Chambers

NASA's Surface meteorology and Solar Energy (SSE) Project and Beyond

Purpose: Provide NASA ESE data for the feasibility analysis and preliminary design of renewable energy power systems from small to large (Solar, Wind, Buildings, etc.).

Data Delivery Method: Easily accessible data tables and maps generated real-time for user at

http://eosweb.larc.nasa.gov/sse/

Users: Web site has 35,000 Hits/month, with 3,500 data downloads; the most accessed site at ASDC. Users include small to large companies, universities, government agencies, and banks.

Future: Teaming with NOAA, DOE/NREL, and Electric Power Research Institute to expand into forecasted data sets

P. Stackhouse

CERES by the Numbers

Publications (CERES team):	Journal	Conference
2002 (scaled SI index)	*40*	*40 at Rad Conf*
2001	*36*	*22*
2000	*39*	*40*
1999	*13*	*40*

Data Products Delivered:

8,000 Gbytes of data to date **4,000 Gbytes/yr currently**

50 unique users per quarter **1/3 international (15 countries)**

ES-8/4/9 ERBE-Like most popular early, then SSF dominates (TRMM).

Shipped 3.3 times the volume of all L2 and L3 validated products

Data Products Processed at Full Production:

Input Data: **up to 11 instruments on 7 spacecraft:**
1,000 Gbytes/month, in 20,000 files

Output Data Products: **600 Gbytes/month, in 3,000 files**
75% in SSF and CRS Level 2 pixel products

Products range from 262GB/month(CRS L2) to 30MB/month (ES4 L3)

CERES Reference List

- **CERES General Background**
  - CERES Brochure (on the CERES home page)
  - Role of Clouds and Radiation in Climate, Wielicki et al., BAMS,76, 853-868, 1995.
  - CERES Experiment Overview: Wielicki et al., BAMS, 96, 853-868, 1996.
  - CERES Instrument Calibration: Priestley et al., J. Appl. Met, 39, 2249-2258, 2000.
- **CERES Data Products and Algorithms**
  - CERES Algorithm Theoretical Basis Documents (ATBDs) NASA Reference Publication 1376, Volumes 1 through 4, Dec. 1995. ATBD overview published in Wielicki et al., IEEE Trans Geoscience Rem Sens, 36, 1127-1141, 1998.
  - CERES Data Products Catalog: summary of data products
  - CERES Data Collection Guides: one per data product; defines formats/variables.
  - CERES Data Quality Summaries: one per data product; summarizes current estimates of the accuracy of variables in each validated archived CERES product.
  - The above can be found at: http://asd-www.larc.nasa.gov/ceres/docs.html
- **Tropical decadal variability**
  - Wielicki et al., Science, Vol 295, Feb 1, 2002, p841-844. (decadal radiation changes)
  - Chen et al., Science, Vol 295, Feb 1, 2002 p838-841. (hadley/walker hypothesis)
  - Trenberth, Science 295 (5576): U1-U2 Jun 21 2002 (letter to science)
  - Wielicki et al., Science 295 (5576): U2-U3 Jun 21 2002 (response)
  - Allan et al., J. Climate 15 (14): 1979-1986 Jul 2002 (UKMO runs)
  - Wang et al., GRL, 29, No. 10, 2002. (SAGE II cirrus height changes)

CERES Reference List, con't

- **1998 El Nino Radiative Anomalies**
  - Cloud Forcing Ratio Anomaly: Cess et al., J. Climate, 14, 2129-2137, 2001.
  - Cloud Forcing Ratio Anomaly/SAGE II cloud height anomalies: Cess et al., GRL, 28, 4547-4550, Dec 15, 2001

- **Iris tropical cloud negative feedback hypothesis**
  - The Iris Hypothesis: Lindzen et al., BAMS, 82, 417-432, 2001.
  - Cloud amount/SST relation: Hartmann and Michelson, BAMS, 83, 249-254, 2002.
  - Cloud radiative properties: Lin et al., J Climate, 15, 3-7, 2002.
  - Cloud radiative properties: Fu et al., Atm Chem Phys, 2, 31-37, 2002.
  - Improved cloud radiative properties using new CERES merged cloud/radiation data products (TRMM SSF): Chambers et al., J Climate, in press (for a pdf copy, contact l.h.chambers@larc.nasa.gov)

Where do I go for CERES data and documentation?

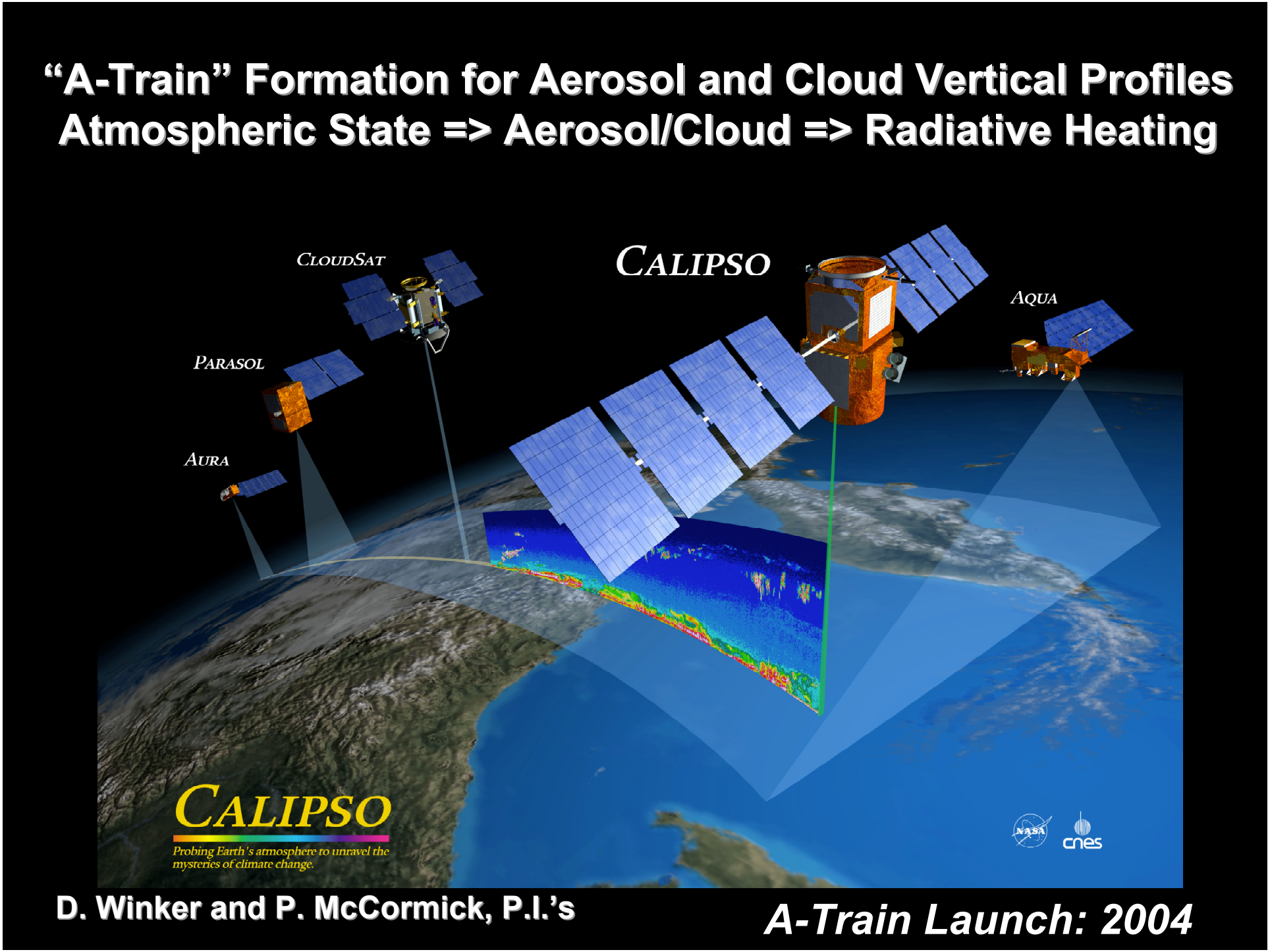
- **CERES Documentation/Home Page at**

http://asd-www.larc.nasa.gov/ceres/docs.html

- **CERES Data Orders at**

http://eosweb.larc.nasa.gov/project/ceres/table_ceres.html

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

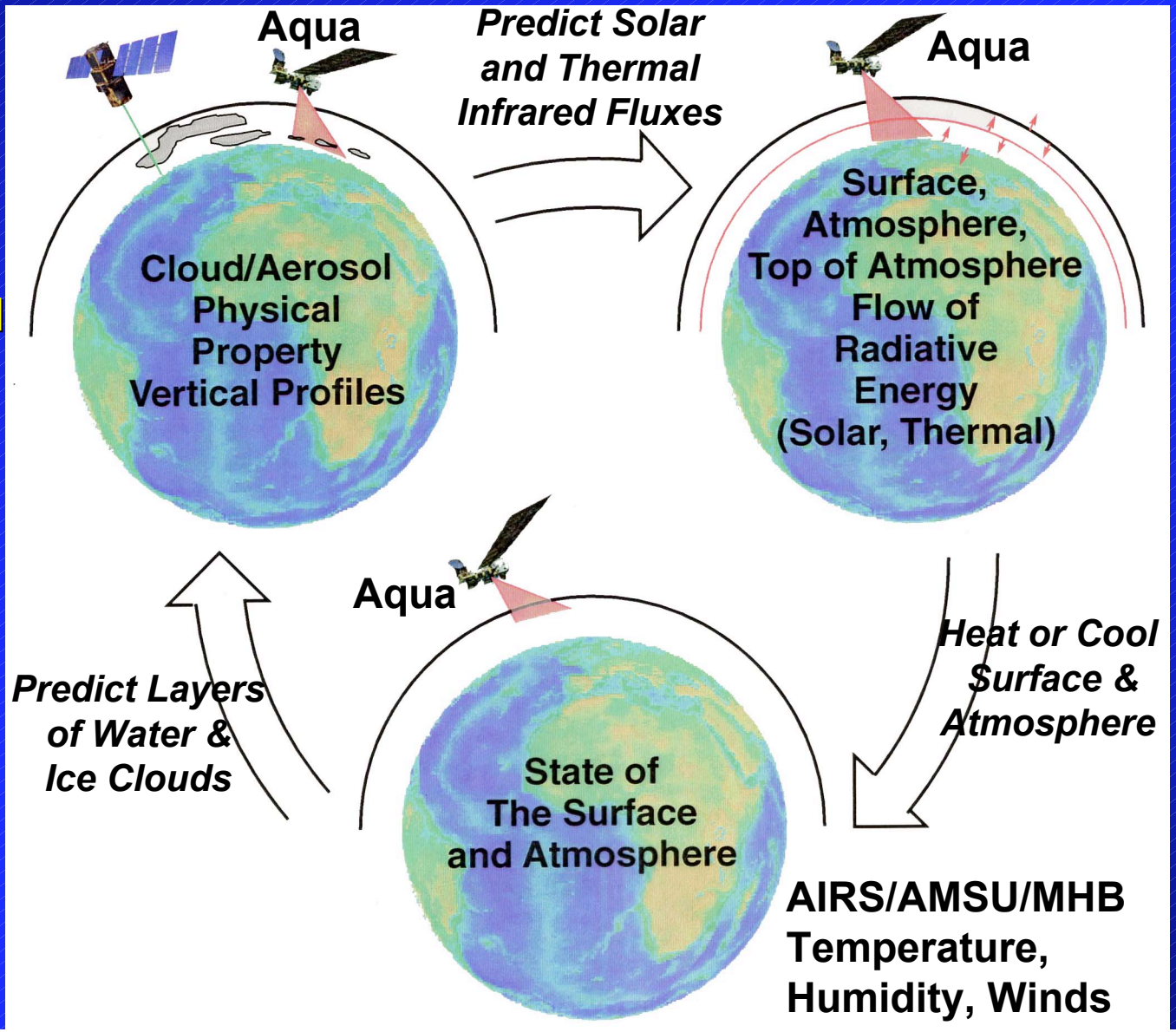


D. Winker and P. McCormick, P.I.'s

A-Train Launch: 2004

Calipso, Cloudsat and Aqua in Formation: Testing Global Cloud Models

CALIPSO Lidar and Cloudsat Radar: aerosol and cloud vertical profiles



CERES energy fluxes, MODIS cloud optics

CERES continues as ERB on NPOESS in 2011

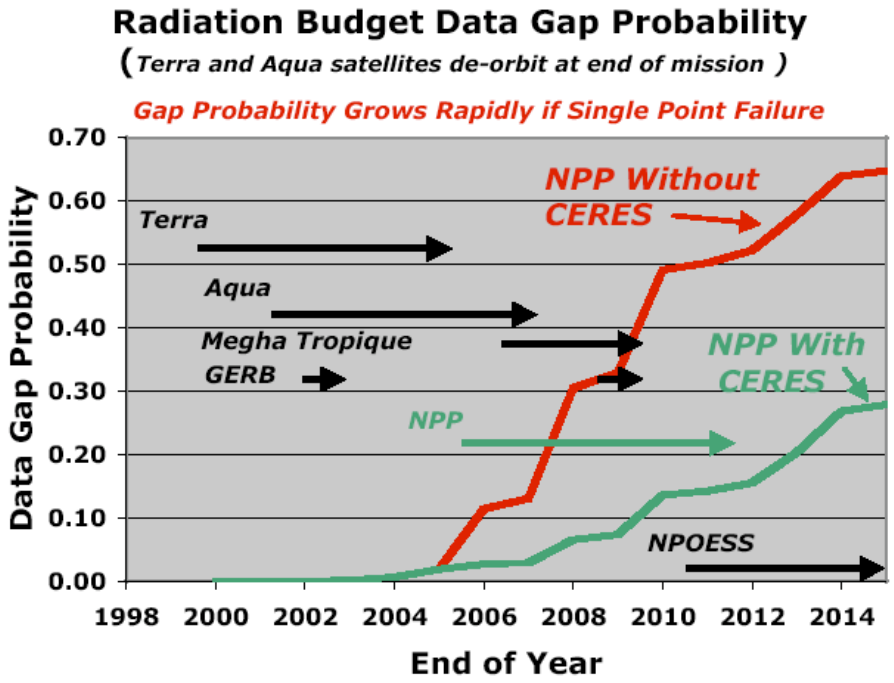
what about end of Aqua in 2008 to 2011? NPP?

Currently EOS to NPOESS transition has a 50% risk of a critical radiation data gap.

NASA is trying to resolve this with NPP mission plannd for launch in 2006 if funding allows.

NPOESS only plans to replace *after* failures....

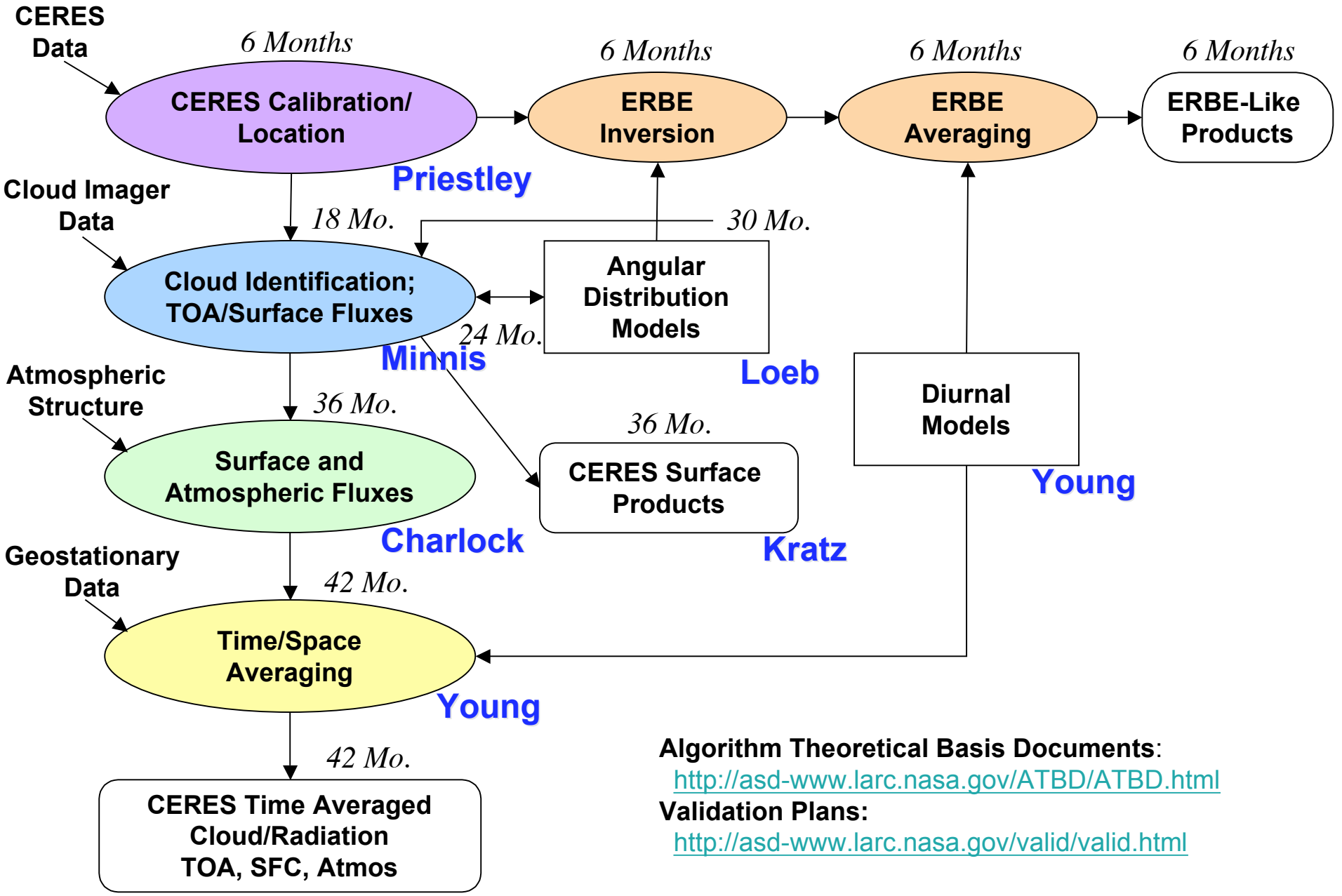
Symptomatic of a climate observing system spread across agencies with different missions & priorities: climate is not #1 at any of them.



What is an acceptable gap risk? 5%/decade? 10%/decade?

A climate observing system should have hot spares designed to assure overlap: not there yet.

CERES Data Processing Flow



Algorithm Theoretical Basis Documents:
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Validation Plans:
http://asd-www.larc.nasa.gov/valid/valid.html