CERES Science Team Meeting
Sept 20-22, 2000

EOS/CERES Program Status

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Outline

- Overall Climate Research Strategy Concerns
  - NASA 25-year vision workshops in spring, 2000
  - New NASA Science Implementation Plan: BAMS Draft

- NPOESS: Still planning radiation data in 1:30pm orbit starting in 2009: but still a gap from Aqua to NPOESS

- CERES and EOS Budgets

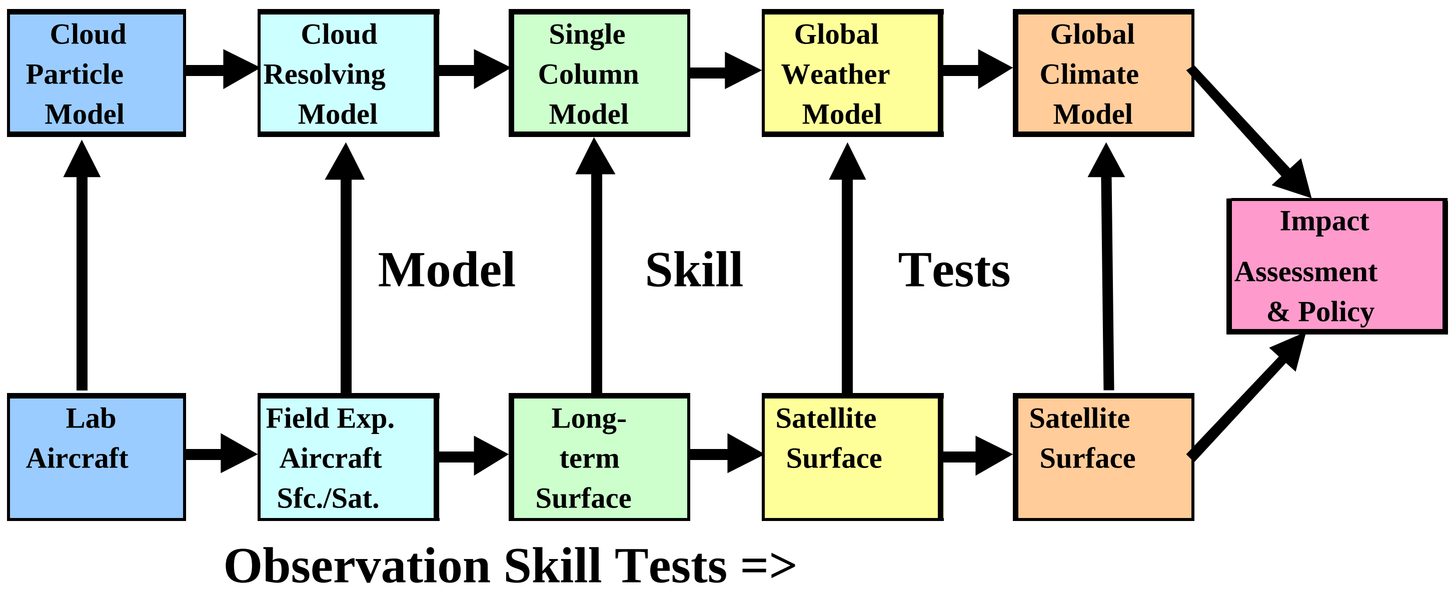
NASA Climate Research Strategy Concerns

- **25-year Vision Workshop concerns**
  - Climate prediction quantitative skill assessment requires systematic measurements: regional/global change,as well as for severe rare events
  - No climate agency: NOAA does weather, NASA does processes.
  - No where near the resources to do an "engineering approach"
    - Active lidar/radar for precip, clouds, aerosols: process and systematic
    - Calibration is much more of a challenge than space/time resolution
    - Need stability/overlap of systematic measurements
    - When the public suddenly believes in global warming and wants answers now: can buy computers fast, talent in 5 years, but systematic measurements in 20yrs. Will the data be there to test the models?
    - No climate modelers involved in the Vision workshops: the most important end users were not represented.

NASA Climate Research Strategy Concerns

- **BAMS Article Concerns:**
  - Didn't see climate modelers involved in writing/review
  - No systematic measurements strategy for cloud properties, aerosols, radiation: the biggest feedback issues.
  - Process measurements are **critical** to unscramble cause/effect and to test process physics, but by themselves they are woefully inadequate:
    - When put together in a complex nonlinear system, we cannot guarantee they will work together correctly: they probably won't.
    - We always miss something when looking at pieces (e.g. ozone hole)
    - Systematic measurements needed for end-to-end tests of climate predictions. Would you fly a new airplane tested only at component level?
An airplane is a lot simpler than the climate system.
    - When processes have small but systematic errors (process tests look fine): these easily add to large feedback terms in large ensembles: climate.
    - Our process studies cannot constrain all input: e.g. vertical motions or levels of turbulence when modeling cloud fields.

Clouds and Radiation Research Strategy



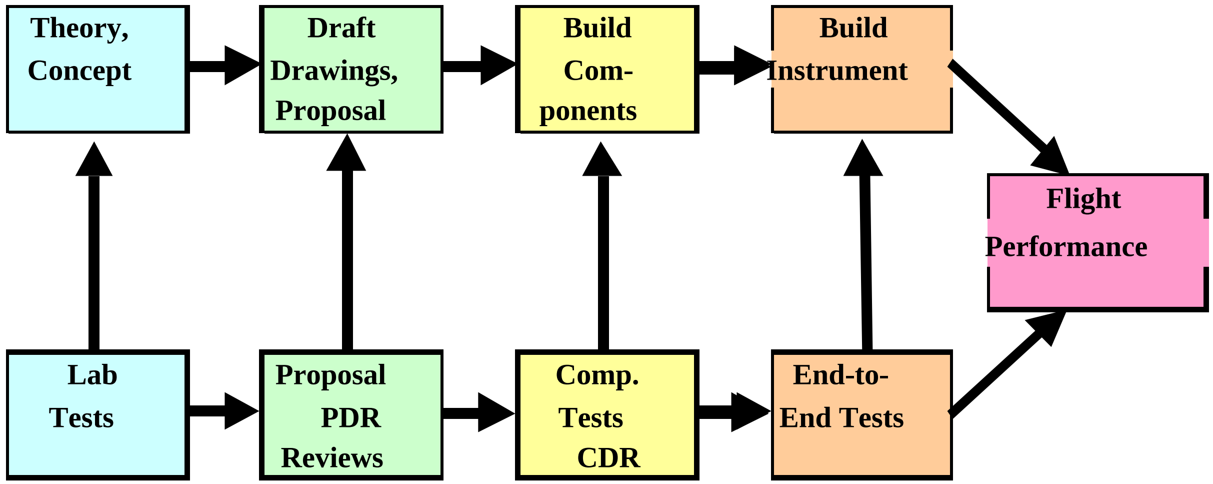
- *Cloud and weather model skill tests are tests of cimate system components*
- *Climate system model skill tests are tests of full end-to-end predictability.*

Climate System prediction skill tests require decadal systematic measurements:

1 day for a Numerical Weather Prediction Model is like a year for a Climate System Model

NWP diurnal cycle	=>	*CSM annual cycle*
NWP midlat cyclone	=>	*CSM biennial oscillation or ENSO event*
NWP blocking high	=>	*CSM arctic oscillation or pacific decadal oscillation*

Building a New Instrument or Aircraft



Concept validation/testing =>

Lessons learned with Mars Mission failures: experience and end-to-end testing critical
(especially in a resource limited environment: we are all rookies for climate prediction)
- Problem with lander leg retraction/shutoff passed all component tests,
but would have failed a second end-to-end test if attempted (skipped for lack of resources)
- For navigational units problem: not enough attention was paid to the systematic
trajectory measurements: the accumulation of small errors = large error.
Climate prediction is like a satellite: it has to work the first time
Testing full engineering models or test flights are costly: but they find surprises
Decadal systematic measurements of climate are the only end-to-end climate prediction test.

Other examples:
Space Telescope lack of an end-to-end optics test,
Early Pegasus rocket launch destruction: instability found by wind tunnel testing.

NRC Committee on Earth Studies
(Final Workshop Report on NASA/IPO Integration: 1/4/00)

- "A CERES-like instrument should be on NPP to provide a continuous set of broadband Earth radiation budget measurements across the gap between EOS-PM and planned broadband measurements on NPOESS. The broadband measurment set begins in 1978 with the Nimbus-7 ERB."
- "From the perspective of atmospheric measurements for weather prediction and climate, it would be better if the NPP were in a 13:30 local time orbit rather than a 10:30am orbit."
- "…. This would allow NPP to provide inter-instrument calibration for the IR sounders HIRS => AIRS => CrIS, microwave sounders MSU => AMSU => ATMS, imagers AVHRR => MODIS => VIIRS, and also tie together broadband radiation measurements that may be taken from EOS-PM, NPP, and NPOESS. The POES and EOS instruments will not be available in a morning orbit at the time NPP is planned to fly (2006-2011)."

CERES FM-5 Gap Filler Options (2005-2010)

- CERES FM-5 instrument built, calibrated, in storage.
- Optimal: CERES FM-5 on NPP, 1:30pm orbit, with VIIRS imager
  - Basically what is recommended by the NRC CES report.
  - Gives all surface/atmosphere/toa advanced fluxes + cloud properties
  - Optimal overlap opportunity and intercalibration: < 0.1%
  - Optimal diurnal sampling consistency for climate record
- Next-Best Option: CERES on Precip Mission, Inclined orbit with radar
  - Only ERBE-Like TOA fluxes (no cloud imager)
  - Provides simultaneous latent/radiative heating observations (TRMM: 8 mo.)
  - Use orbit crossings, CERES scanner plane rotation of one instrument to align scan planes: TRMM/Terra showed < 0.5% SW, and <0.1%LW 95% confidence bounds with 2 months of overlapping data.
  - Minimum Option: CERES alone in an inclined or sun-synch orbit.
  - ERBE-Like TOA fluxes only, Orbit crossing intercalibrations.

CERES FM-5 Gap Filler Options (2005-2010)

- How expensive is this gap filler option?
  - Instrument is complete. Might need $2 to $5M for interface changes depending on spacecraft bus power/data interface.
  - For launch and spacecraft costs similar to Terra/Aqua/TRMM, then predict about $30M for launch/spacecraft sharing (or could do a small spacecraft/pegasus launch for same cost). Instrument is small: 50kg, 50W and low data rate: 20kbits/sec.
  - Algorithm software mods/maintenance/Inst Ops/QC/validation ~ $3M per year 2005 - 2010, or $18M total. All major development done earlier by Terra and Aqua, so this is about 1/4 the peak CERES funding level.
  - DAAC processing/distribution/archive costs: $2M/yr = $12M total
  - Total for 6 years data +inst/launch/ops: ~ $65M
  - Out of $1400M/yr EOS program: ~0.8% spent each year for continuity of one of "24 measurement sets". If all were done this cheap: 19% of EOS yearly budget could maintain all systematic measurement sets.

CERES FM-5 Gap Filler Options (2005-2010)

- How does the $70M total cost for 6 years of systematic radiation measurements to transition Aqua => NPOESS compare to the cost for the first 7 years of CERES development and process data measurements for 1998 and 2000-2006?
- Additional 6 yrs is about 1/7 the original cost per year of CERES data.
- Original CERES data set was about 3.5% of EOS total costs from 1991 through 2006 (roughly 1/28th consistent with the 24 measurement sets)
- Systematic measurements in 2005-2010 are 1/7 the cost because:
  - Software development done (factor of 3-4 drop in software costs)
  - Processing hardware will be cheaper in 2005 and beyond (factor of 8 after 6 years using 2-yr performance doubling time)
  - Instrument already built
  - Only need 1 instrument instead of 5
    - No need for 2 instruments for platforms now that ADMs are finished.
    - Single orbit instead of 3: use geostationary to provide diurnal cycle correction: capability being developed by CERES TRMM and Terra level 3 data product development.

EOS Budgets: Phasing Development=>Science Use
Why is CERES Product Schedule Different?

- Climate focused as opposed to process focused:
  - Sub-1% accuracy/stability goals: validation increases
  - Focus not on level 1 or 2, but on level 3 data products

- Angular models for radiance => flux conversion
  - New CERES rotating azimuth plane scanners require 2 years of observations to get sufficient sampling for advance from 12 models for ERBE to ~ 100-200 for CERES.
  - Factor of 3 to 4 improvement in TOA flux accuracy needed to constrain instantaneous surface/atmosphere fluxes (35 => 10W/m^2)
  - Provide fluxes not just for grid box monthly mean but accurate as a function of surface type, cloud phase, cloud optical depth, cloud height, cloud amount: examination of cloud => radiation partial derivatives.
  - 2 years to get > 30 samples per scene type and per solar zenith, view zenith, view azimuth bin.
  - After 2 years sampling, develop angular models and then reprocess level 2 data.

Why is CERES Product Schedule Different?

- Multiple instruments needed: imager surface/cloud properties to classify CERES fovs for angular models and for improved surface/atmosphere fluxes.
  - VIRS on TRMM
  - MODIS on Terra and Aqua
- Multiple satellite orbits used for rigorous tests of diurnal sampling. Level 3 products must merge multiple spacecraft data
- When a single CERES instrument is available (TRMM, early Terra) then require additional 3-hourly global geostationary data to provide diurnal cycle correction of fluxes. Allows 3-hourly synoptic fluxes and more accurate diurnal average/monthly average. Critical to allow 1 orbit for NPOESS broadband radiation data at 1:30pm only.

What's Wrong with the 30/50/70 Strategy?

- Not based on any experience or data for past data product development, or validation: Mike was pressed for time, pressed for resources, and tried to come up with something that seemed reasonable, but had no data to base it on.
- Assumes schedule for all instruments/data products is the same: a CERES level 3 surface flux (42 months) very different than a level 1b CERES radiance or ASTER/Landsat level 1b (one of primary products for land community: not for radiation community)
- Assumes mature continuation data products like CERES ERBE-Like TOA fluxes, or MODIS SST/NDVI take the same time after launch as data products never produced before like CERES ADMs, MODIS cloud mask/optics, etc. Mature products take much less time: CERES ERBE-Like ready in 6 months after instrument covers opened: on schedule.
- ERBE experience: we assumed it would take 6 months. Tom Vonder Haar laughed and said 3 years. Took 3.5 years. But the same products now developed and understood when applied to CERES took 6 months.

What's Wrong with the 30/50/70 Strategy?

- Level 1 products take the least time, Level 3 the most.
- Climate accuracy products take longer than process products: data must be verified to be stable over years: instrument, auxiliary data, algorithms.
- Software industry has metrics for expectations of cost to develop code, time to develop it, and cost to maintain it. CERES development costs, schedule, and maintenance goals are consistent with or better than these software industry metrics.
- For instrument/spacecraft hardware we have metrics based on experience to estimate cost/time as a function of mass, power, data rate, volume. No similar data-base and metrics for science data products and validation as a function of product maturity, data volume, number of parameters, climate vs process, lines of code, level 1-3.
- Prediction: most new EOS data products will take 2 to 3 years after launch to develop,test,fix,validate,finalize. "Old" products will be quicker (e.g. SST)

What's Wrong with the 30/50/70 Strategy?

- CERES has been more realistic than other teams because of our ERBE experience producing a global, all-the-time, satellite data product. Few in HQ and EOS project have this experience. Many more will have it in 3 more yrs.
- Evidence to date: of Terra expected beta products supposed to be routinely available 90 days after launch: only CERES ERBE-Like beta products were in fact ready. The entire globe for March, April, and May of 2000 has been processed through level 3 ERBE-Like in "beta" quality and released. But even CERES has none of its "new" products available yet in beta format. All instruments in the same boat.
- Following the 30/50/70 strategy will cripple the new EOS data products. They will either be put out early full of errors, or they will be delayed. Note: this is where most of the funding is: producing the heritage data products as for CERES ERBE-Like is cheap: development and most of validation done or we know how to do it quickly because we have done it before.
- Remember the Mars missions: too little experience, too few resources, too little time.

What's Wrong with the 30/50/70 Strategy?

- We have budget problems: new missions coming up and can't finish the ones we have on our plate. This is a build it and they will come strategy: like Nimbus 7 and SeaSat: great hardware: in 5 or 10 years we will give you some well understood data products from it.
- CERES has not over-run any of its original algorithm/science/scf budgets.
- The GSFC April, 2000 Budget Guidelines convert large parts of the budget to data analysis/science before the products are developed/validated, and cuts the overall budgets planned as well: result will be greatly delayed data products :
- Fiscal Year

Fiscal Year	FY01	FY02	FY03	FY04
– Budget Cut (vs LaRC plan)	10%	11%	18%	9%
– Convert to Data Analysis	21%	27%	30%	32%
– % Loss to data products effort	31%	38%	48%	41%

- The most recent budget guidelines (late Aug. 2000) for FY01 are draconian.
  - Budget Cut: 10%, Convert to Data Analysis: 58%, Total loss to data products: 68%
  - At this rate it will take 10 years to produce the first new Level 3 Terra data products: not 42 months. We are assuming the budget names are meaningless in FY01.

What do we do?

- Re-evaluate the rate at which we can send up new missions by ramping down the development costs of data products. Apparently unrealistic and inexperienced assumptions are being made about cutting budgets, and data product delivery schedules.
- Get ready for surprises as new data products don't come on line as fast as inexperienced developers expected.
- Extensions of traditional data products should be ok.
- Don't cut EOS team budgets without more justification than "we just ran short".
- For CERES: 75% of funds planned for 1991 through 2006 are already spent (instrument, spacecraft, launch, most of software development). We are now looking to severely cut the last 25% that funds CERES and the DAAC to finish algorithm development, validation, Q/C, produce the products, archive, and distribute the products.

What do we do?

- These final CERES cuts and transitions to science analysis will fund science without any data products to use.
- The planned budget profiles should not be cut. Cuts will delay data product delivery and also delay transition to science analysis.
- The transition of funding to science/analysis should follow the production of the new products, not a generic 30/50/70 independent of data product schedule and availability.
- For CERES, if a 30/50/70 strategy is followed by data product, satellite, and by the fraction of resources required for each data product, then the transition to science funding follows a profile (% of CERES funding in science/analysis) that starts as a baseline of 12% which is the level in FY00:
- FY01 FY02 FY03 FY04 FY05 FY06
  - 15% 20% 29% 41% 51% 58%
- According to software industry guidelines, by FY06, we need about $4.5M/yr to maintain software/Q-C, but only have $3.0M to do the job. And the GSFC POP-00 guideline for FY06 is down to $2.0M: more than a factor of 2 low.

What do we do?

- If forced to use GSFC April POP-00 guidelines through 2006, we delay all advanced CERES data products by a factor of 1.5 for TRMM, and a factor of 2 for Terra and Aqua (up to 3.5 year delay: first Terra climate level-3 data products won't be delivered until 7 years after launch. All products will be of lower quality.
- We in effect waste a substantial fraction of a total $480M investment in the total CERES program to save $20M over the last 6 years of the program: a total savings of 4%. As a result, estimate product quality degradation 50%, and schedule slip a factor of 2, with most important final level 3 climate data products delayed by 3.5 years.
- With such a drastic last minute cut and delay in all advanced products, it is not clear that the talent needed for success will remain with the team.
- The justification for these cuts is not technically well founded, and we strongly urge HQ and the EOS project to reconsider the 30/50/70 transition based on realistic product development schedules, algorithm software maintenance experience/cost, and product readiness for science use.
- EOS is building the next generation of mission scientists: don't lose them.

Bottom Line

- What can we do?
  - NASA and USGCRP Science Strategy: be involved
  - Workshop on climate model skill (hypothesis test) requirements?
    - Process through systematic measurements
    - Can we define a relative balance in resources?
    - Involve both measurement and modeling scientists?
    - International perspective?
    - Or do we punt?
- Near future depends on whether Dan Goldin stays in
- Farther future depends on climate change itself
- In an engineering sense, global change prediction is an order of magnitude larger job than current resources: if serious, then -
- Computer power, brain power, can be bought relatively quickly (years)
  - Long-term climate data sets to test the models take decades to develop.
  - Need balanced strategy. We seem to be on a semi-random walk.