Satellite Retrievals (Ralph Kahn)

Knapp and Stowe – This AVHRR analysis team extended their algorithm capabilities to include a cloud-free, 1-channel land retrieval at 1° x 1° spatial resolution. Data are accumulated for 24-48 days, to sample surface BRDF over ±60° view zenith angle, and the darkest pixels are assumed to be affected by aerosol having optical depth 0.05. The MODIS Continental aerosol model is adopted, with single scattering albedo 0.96. Validation is performed using AERONET data. Sub-grid-cell surface variability was cited as a main source of measurement uncertainty.

Torres – The TOMS analysis group continued to enhance the sophistication of its 340 and 380 nm aerosol retrieval, examining the effect of choosing sulfate, carbonaceous, and dust aerosol models. They stressed their independence of assumptions about surface BRDF (it contributes less than 10%), claim insensitivity to particle phase function, relative to that in the visible, due to contributions from multiple scattering, and report an ability to retrieve non-absorbing as well as absorbing particles. However, for absorbing particles, the method demands knowledge of the aerosol vertical distribution. They have produced a global aerosol record over land and ocean covering 1979 to the present, with only one 1-month and one 3-year gap. Validation by comparison with co-located AERONET data indicates uncertainties in retrieved optical depth of 30% for absorbing particles, and 20% for non-absorbing particles.

Durkee – By combining a 2-channel AVHRR aerosol retrieval that constrains particle properties along with optical depth, Durkee has developed a 1-channel GOES aerosol retrieval providing 15 minute time resolution. The ubiquity of data from these sources is an enormous strength of this method. Validation was a main thrust of recent work, with emphasis on using geostationary satellite data at multiple times of day to help test the assumptions made about phase functions. Regional variability of δ and α for numerous field campaigns (TARFOX, ACE-1, ACE-2, INDOEX) was also presented using AVHRR retrievals.

Callan and Randall – The Solar Mesospheric Explorer (SME) team presented their global, vertically resolved aerosol extinction profiles at 1.27, 1.87, and 6.8 microns, for 1982-1986, with emphasis on the El Chichon eruption. Aerosol properties are assumed to be constant, spherical, having a log-normal size distribution with mode radius 0.27 micron, $\sigma = 1.65$, and indices of refraction 1.43 - 0.0i. Qualitative validation using SAM II and SAGE II data at about 1 micron has been completed, as a prelude to quantitative validation with similar data.

Winker and Menzies – The 11-day, September 1994 shuttle flight of the LIGHT experiment produced 53 hours of day and night 1064 and 532 nm lidar observations up to 57° latitude at a spatial resolution of 290 m and sample spacing of 740 m. The team reported on cloud-screened nighttime (low noise) retrievals. For an assumed particle extinction-to-backscatter ratio, they produce vertical distributions of aerosol backscatter and optical depth, even when capped by cirrus with optical depth up to 1 or 2. They introduced a "color ratio" of backscatter cross-section at 1064 vs. 532 nm. Its magnitude is large for large (e.g. desert) particles, and is low for smaller (eastern U.S., probably pollution) particles. They showed that the color ration distinguishes cloud from aerosol, except for layers having very low optical depth, < 0.01.

Liou – As a theoretician also having experience with data analysis, Liou cautioned us about the need to use phase functions for spherical from non-spherical particles, as appropriate, in radiative transfer modeling for satellite aerosol retrievals, a point also made by Mishchenko in several publications. He illustrated MODIS and AVHRR cases where cirrus, a non-spherical particle, makes important contributions to the column optical depth.

Kahn Comments:

I was impressed with the **variety**, and the continuing **innovation**, in satellite retrieval strategies, the focus on **validation**, and the increasing importance of AERONET, **Field Campaign**, and co-located satellite data in validation efforts.

There seems to be a promising possibility of eventually meeting the **goals of the climate modeling community, using satellites to provide the global, time-varying picture of aerosol optical depth and aerosol "type," combined with targeted, in situ measurements providing the detailed microphysical characteristics** of key aerosol types.

Cross-cutting issues remain for the satellite retrieval community regarding:

(1) approaches to **cloud clearing**

(2) accounting for **thin cirrus** in aerosol retrievals

(3) modeling and/or measuring **surface BRDF** for both land AND EVEN OCEAN

(4) the need for additional, coordinated **Intensive Field Campaigns** both for satellite algorithm validation and generally to strengthen the assumptions that must be made in satellite retrievals about aerosol microphysical and surface properties

(5) approaches to **combining data** from sources having different sampling characteristics

(6) **calibration**, particularly for the retrospective data sets such as AVHRR

Field Data (John Ogren)

What can field data component of GACP deliver by September 2001?

- Publish results to-date
    * New methods
    * Climatologies (with focus on testing models and satellites)
    * Initial integration efforts

- Continued integration of field date with satellites and models
    * Regional aerosol models
    * Uncertainty of AVHRR retrievals based on ϖ_o climatology
    * Global assimilation model
    * Comparisons with Terra retrievals

What has GACP accomplished with field data?

- Testing new experimental methods
    * 180°-backscatter nephelometer
    * Airborne polarimeter

- **Assembling climatologies**
    * *In situ* chemical composition
    * *In situ* radiative properties
    * *In situ* microphysical properties

* Optical depth and derived column properties

- Initial integration of field data with satellite data and model results

  * Marine aerosol chemical composition vs. models (chemical transport model, CTM)

  * Forcing over North Atlantic

  * Assimilation CTM, long-range transport (LRT) over Pacific

  * AVHRR and AERONET

Utilization of field data to enhance aerosol satellite retrievals / modeling studies

- **Need continued integration of field data with retrievals and models**

- Need multiple approaches for integration

- Need recommended priorities for field measurements

  * Vertical profiles of chemical composition
  * Utilize "test ban" filters?
  * Field campaigns
  * Long-term measurements
  * Process studies

Closure

John Ogren: Need new approaches for integrating field measurements, models, and satellite retrievals; e.g.:

- Systematic application of assimilation techniques

- Encourage teams proposals in next NRA?

- Funding for new measurements, optimized for this integration?

Modeling (Mian Chin)

Name	Model	Meteorology	Product
Chin	**Global**	**Assimilation** meteorology	**MASS, AOD, size,** direct effect
Chuang	Global	GCM	MASS, AOD, size, direct, indirect, semi-direct effect
Penner	Global	GCM	MASS, AOD, size, direct, indirect, semi-direct effects
Ackerman	Cloud evolution model		Semi-direct effects
Fuller	Aerosol optical model		Aerosol optical properties

Other models (not reported at this meeting):

Ghan	Global	GCM, nudged with ECMWF	MASS, AOD, size, forcing
Rasch	Global	NCEP	MASS, AOD, size, forcing
Koch	Global	GCM	MASS, AOD, size, forcing

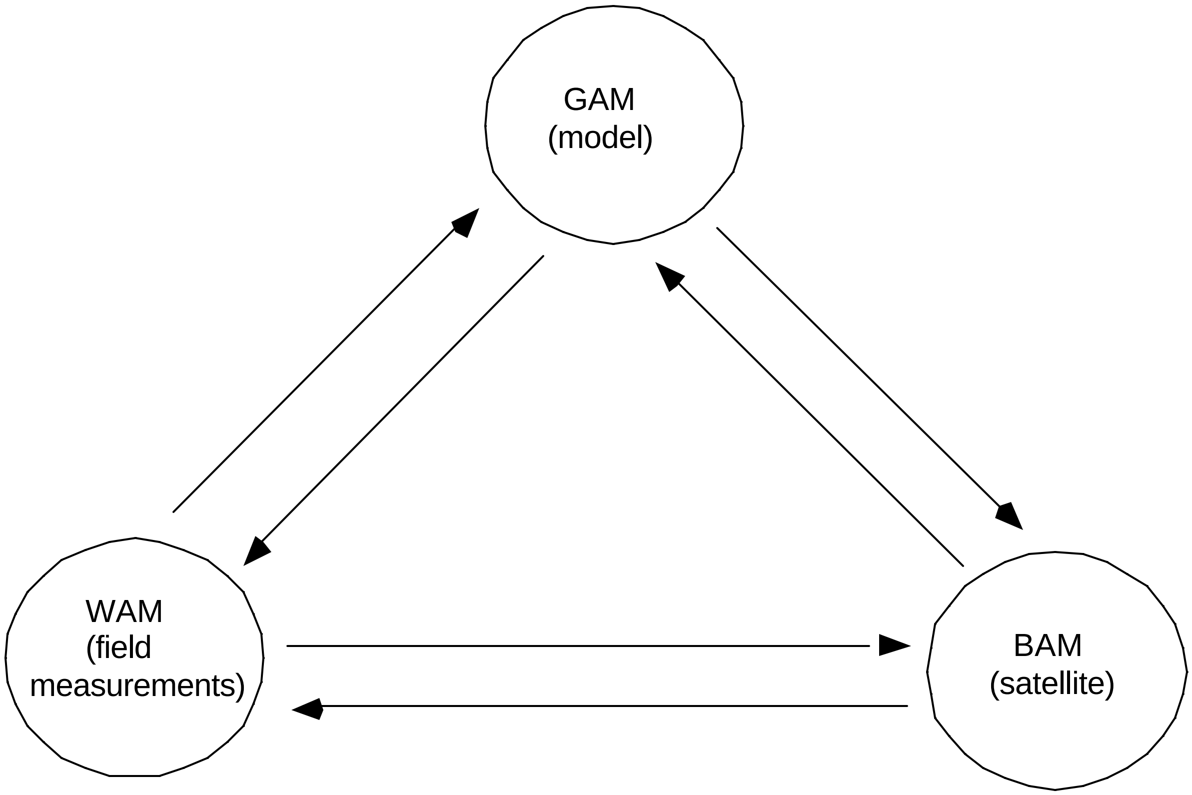
What have we accomplished?

- Global models:
  - Capable of simulating major aerosol types; some are more sophisticated than others
  - Used for assessment in IPCC report
  - Estimated direct, semi-direct, and indirect effects of aerosols
  - Field measurement and satellite data are widely used for model evaluation and comparisons
  - Initial attempt for aerosol assimilation (NCAR) has been made
- Small-scale models:
  - Process closely linked to field data
  - Better parameters of aerosol properties

What can we deliver by September 2001?

- Third-year progress report
- Multi-year global aerosol model products with composition, AOD, predicted effects
- Incorporated new data (MODIS, MISR, ACE-ASIA, etc.)
- Using data to improve the model
- Publications

Toward Global Aerosol Climatology (4-D):



- Field measurements: Detailed info on composition, properties, vertical profile; but limited time or spatial coverage

- Satellite: Large spatial and temporal coverage; but limited measurable quantities, validation

- Models: Machine to integrate our knowledge and observations to generate 4-D climatology; but …

Direct Effects (Tom Charlock)

This summarizes a rapporteur's presentation on the direct effects of aerosols to radiative forcing (DRF) at the 3rd GACP Science Team Meeting (October 11-13, 2000, Lanham-Seabrook, Maryland).

Rapporteurs for other components of GACP include descriptions of their respective formal discussion sessions. A formal discussion of DRF was pre-empted by the need to focus instead in the central goals of GACP. Those central goals are not addressed here. Instead, we summarize formal presentations on DRF and related informal discussions.

Charlock, Rose, Rutan, Su, Rutledge, and Haeffelin addressed surface broadband SW insolation in clear skies at the ARM SGP Central Facility for 1998-2000. They compared direct and diffuse components of observed flux, computed flux and aerosol forcing. For moderate AOT, the direct forcing generally exceeded the differences in the calculated and observed fluxes, giving some confidence in the time-mean forcing deduced from a model that uses observed spectral AOT and assumes a 10% fraction of soot. Some instrument deficiences could be partially corrected; others could not. Forcings deduced for shorter time intervals, or those due to smaller perturbations in AOT, were judged as unreliable.

Plans for the Cheasapeake Lighthouse and Aircraft Measurements for Satellites (CLAMS) field campaign (summer 2001) to validate retreivals of AOT, fluxes, and DRF were discussed. Some (Kahn) regarded CLAMS measurements of surface optics as a great opportunity to validate remote sensing with Terra (EOS) and AVHRR (GACP). Others (Mishchenko) were concerned that CLAMS measurements in coastal waters may not represent the broader ocean. One arguement was that, experiments in the 1990s (i.e., Shaw and Churnside, Appl. Opt., 1997) have shown that the distribution of sea slopes used in current ocean optics models are inadequate; and while coastal waters would not be a representative testbed of the blue ocean in the visible, they should suffice in the near IR.

Loeb showed maps of low-latitude, oceanic direct forcing of aerosols based on 1998 CERES TRMM data. Forcing was a difference of (1) observations broadband TOA flux from CERES and (2) theoretical fluxes for pristine skies from on a wind speed dependent Cox-Munk ocean with underlight.
A new angular distribution model (ADM) had been applied to the CERES data, and clear sky conditions were identified using the higher spatial resolution VIRS imager. Comparisons with more traditional methods for aerosol forcing (using respectively AVHRR and SeaWiFS to retrieve spectral AOT, from which flux was then computed) were favorable in some domains. Mishchenko and Anderson have advocated that GACP's AVHRR-based retrievals of spectral AOT should be validated with comparable AOTs from MODIS and MISR (i.e., GACP AOT vs EOS AOT). GACP DRF vs EOS RDF would appear to be another route. It was pointed out that even more advanced CERES products include AOT that has been tuned to match broadband TOA observations. Some team members suggested that not enough formal comparison of GACP to "something else" (i.e., GACP AOT vs VIRS AOT) has been presented to date. A strategy for using the new aerosol assimilations (i.e., Collins-Rasch) as a further supplement for testing GACP, evaluating aerosol forcing in partly cloudy regions, etc., has not yet emerged.

A presentation by Remer and Feingold focused on INDIRECT effects, i.e., cloud reflectance vs aerosol, cloud droplet radii bs smoke optical depth. Results for Dln(radius)/Dln(tau) versus latitude were shown. Remer reported a field campaign wherein the effects of smoke on cloud microphysics from two distinct scales (~1km and ~50m,) appeared to be consistent. Feingold showed results from sophisticated, high resolution cloud models. The models include microphysics of complexity sufficient for detailed comparison with some of these remote sensing results. It may however be a challenge to judge whether the dynamical and other inputs for the cloud models (this would be mesoscale, or tighter, to drive an even higher resolution) are credible for the respective cases.

Pilewskie and Bergstrom described moderate resolution spectral observations and modeling that is relevant to DRF. Pilewskie recalled attention to reported discrepancies between computed and observed broadband fluxes at the surface for clear skies. One possible source for the discrepancies is the solar constant; results from some field campaigns suggest an uncertainty of a few per cent in parts of the spectrum. Bergstrom's moderate resolution radiative transfer model has 140 bands (300-1700 nm).

Stackhouse and Cox explored the utility of the Global Energy Balance Archive (GEBA) historical record of surface insolation (some is available through the GEWEX SRB Project) for the validation of GACP DRF. A separate AVHRR-LAC study of Canadian smoke showed a massive forcing of 223 Wm-2 at noon (and the NWP models predicting for the fire fighters are not including this component of heating).

Tsay described the Surface Measurements for Atmospheric Radiative Transfer (SMART) package. This is a portable system which can be deployed in field campaigns. The broadband and spectral quantities measured by SMART are indeed those needed to validate components of aerosol forcing. One highlight of SMART is the measurement of AOT at 2.1 micron; ground-based measurement of AOT that far into the near IR are rare (and much sought). Other SMART instrumentation includes the MicroPulse Lidar (MPL) and a Microwave Radiometer. Only a handful of observatories have, at their home bases, the instrumentation that SMART can deploy for in field campaigns.

Echoing other presentations, Tsay noted the defiencies of current ground-based radiometers, especially for the measurement of diffuse insolation (shaded pyranometer). Goddard has begun a program to characterize the thermal offset in the pyranometer and reduce the uncertainty in the measurement (Haeffelin at Langley has a comparable program). Measurements with the standard Eppley Precision Spectral Pyranometer (PSP) are often plagued with errors of 20-30 Wm-2. The discrepancy has caused enormous confusion: Americans using the PSP have reported discrepancies between theory and observation that Europeans (who generally use the Kipp and Zonen pyranometer - with a far smaller error than the Eppley PSP) find to be much smaller. Some ARM, SURFRAD, and CMDL sites are planning to replace the PSP. Over 4,000 PSPs are in use. Some GEBA sites use PSP, and others use Kipp and Zonen. The Langley "CAVE" on-line record of surface radiometer data partly corrects for the
PSP thermal offset at ARM sites. Tsay and others are seeking to improve on the correction. Rigorous validation of aerosol forcing to the surface depends on improvements in this area.

Chou displayed maps of AOT at 865 nm and broadband aerosol DRF based on SeaWiFS data. TOA DRF was 4-6 Wm-2 for clear skies (~2.5 Wm-2 when clouds are included); the magnitude is comparable to those reported from GACP and CERES (Loeb). The Indonesian fires (1997) caused DRF of ~10 Wm-2 at TOA and ~20 Wm-2 at the surface. Information from SeaWiFS retrievals of ocean parameters (i.e., chlorophyl concentration) were not used in this study.

Indirect Effect (Tony Del Genio)

Pre-GACP:	Now:
Sulfate only	**Sulfate, OC, BC, SS, dust**
Offline distributions	Interactive
Empirical N_d	Aerosol growth/nucleation
1^{st} IE	1^{st} and 2^{nd} IE
Validation : r_e	Validation : r_e, N_c, dA/dN_c, df/dN_c

- **But range of IE estimates has broadened**
- Analogous to history of cloud feedback
- Large natural variability in τ (LWC, ΔZ, DSD) hides small indirect effect in observations
- Vertical distribution details of aerosol <u>and</u> low cloud matter
- Uncertainty in PI background affects IE estimates, but not what we're after
- Role of BC murky
- Remer, Feingold, Chuang, Ackerman, Coakley, Penner, Harshvardhan, Han, Brenguier, Del Genio

Where do we go from here?

- GCMs:
  * Higher vertical resolution in lower troposphere
    - **Cu semi-indirect effect ® DZ ~ 200 m**
    - $\frac{d\ell nh}{d\ell nr_e} \sim +0.5 \rightarrow \Delta Z \sim 100\,\text{m}$ for Δr_e ~2 µm
    - **Explicit or parameterized?**
  * Need prognostic Cu

    * Turbulence-cloud linkages, inversion simulations

- Observations/climatologies:

    * Need to stratify satellite observations by P_{top}

    * Need to combine satellite with analysis products to separate natural variability from aerosol indirect effects

    * Now: Cloud radars/Raman lidars where available to get at vertical structure

    * After 2003: satellite estimates of same

    * **Existing satellite retrievals of r_e, N_c, t need to be extended to other time periods:**

        - Times/locations of previous field experiments

        - Major trend regions, episodic events as indicated by 20-yr. climatology of aerosols

        - Times/locations of surface remote sensing datasets

Global Climatology (Paul Stackhouse)

Dr. James Hansen of GISS began the discussion by noting the purpose of the Global Aerosol Climatology Project to provide information to reduce uncertainties in tropospheric aerosols leading to the improvement of long-term climate change simulations. The uncertainties of tropospheric aerosol forcing remain factors of 2-3 larger than the current estimate of the forcing. As an example, the uncertainties associated with the estimate of forcing from black carbon were noted. The direct, semi-direct, cloud absorption and even possible surface albedo effects due to deposition on snow covered surfaces are all uncertain, but together may provide a substantial forcing. So, the basic requirements for an aerosol climatology are:

1. a time history
2. ability to use past history to study implications for future
3. the climatology has to be derived via a model which provides composition specific information in time; model can be an assimilation type or free running
4. satellite data to improve/validate simulations

DISCUSSION SUMMARY

Assessment of a Satellite Parameter Time History (i.e, what parameters can be retrieved over past 20 years and how good are they?):

- Currently retrieved parameters (and available data sets):
    - AVHRR: optical depth (0.65 μm) and Angstrom coefficient over oceans (at least 2 algorithms available)
    - TOMS: global aerosol index
    - SAGE: global aerosol optical depth above 6 km
- Near future retrievals from old data sets:
    - TOMS: aerosol optical depth (0.38 μm)
    - AVHRR: optical depth over land
- Uncertainty assessments (how useful are retrievals currently?):
    - AVHRR calibration uncertainty: drift in time (are retrievals useless?)
- PROPOSAL: produce and distribute current satellite retrieval data set for research

A First Time History From Assimilation?

- NCAR (Rasch/Collins) aerosol assimilation for 2-5 years to be completed w/ AVHRR optical depth and NCEP/ECMWF reanalysis

Additional Model Requirements For Validation (what are the priorities?):

- aerosol types (composition; n, k, ω_o, g)
- vertical distribution (models vary by factor of 10 in upper troposphere)
- temporal variability (??)

New Parameters From Old Measurements (additional parameters to provide model constraints):

- air mass retrievals
- upper tropospheric information (SAGE, TOMS)

Role Of In Situ Observations:

- Closure studies for validation of satellite retrievals and model results
  - CHALLENGE: assessment of AVHRR, TOMS variability and especially trends (or lack thereof) compared to surface measurements at Barbados and Midway islands
  - vertical profile from existing lidar measurements; redistribute column optical depth measurements
- New in situ measurement opportunities:
  - enhanced AERONET w/ collocated CIMEL and Lidar
  - Nuclear Test Ban Treaty enforcement network

New Satellite Measurement Uses:

- much improved column retrievals from MISR, MODIS
- vertical distribution from PICASSO-CENA
- opportunities for new collaborations in closure studies (CLAMS)
- further assessment/improvement of old measurement algorithms

EDITORIAL REMARKS

Key Questions For Now and The Future:

- How useful are current satellite products for modeling validation?
- What improvements would be required to advance knowledge of aerosol forcing through observations and modeling?
- Can these improvements be made to past data sets?
- Is assimilation of fundamental radiance information the best use of data or are derived parameters more useful? Or both?
- Is the best use of in situ data for closure or can in situ data be used to tie down uncertainty in calibrations? (i.e., blended in situ/satellite data sets?)
- What further advancements in instrumentation/measurements are required for far future improvements (i.e., scanning polarimeter?)