Combination of spaceborne sensor(s) and 3-D aerosol models to assess global daily near-surface air quality

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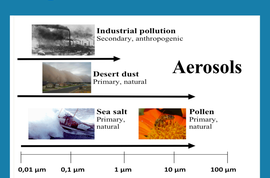
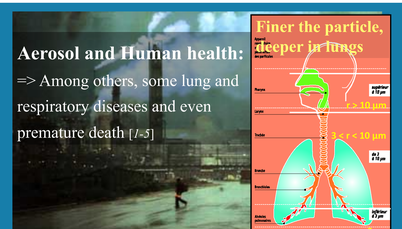
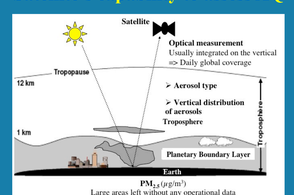
Background





Satellite's capability to assess AQ



Space-borne sensors

POLDER satellite:

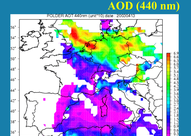
•Polarized radiances in different viewing directions (14-16) and 3 wavelengths (443, 670 and 865 nm),

• Retrieval algorithm over land [6] provides AOD, angstrom exponent and refractive index on a ~20 x 20 km averaged area at the ground,

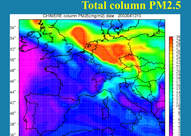
• POLDER sensitive to fine polarizing particles ($r \leq 0.3$ µm) [7]

3-D aerosol transport forecast models

POLDER, Apr. 13 03 — AOD (440 nm)



CHIMERE, Apr.13 03 — Total column PM2.5



=> provides vertical distribution and aerosol type simulation

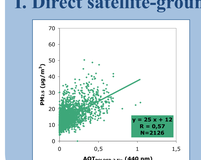
CHIMERE model:

European
MM5, GOCART, EMEP
PM mass in 6 bin size from 0.01 µm to 40 µm
$PM_{2.5}$(z) profiles composed of primary mass(industrial dust, biomass burning), sulfate, nitrate, ammonium, SOA.
0.5x0.5° and 8 layers (50m to ~ 6 km)

• Wide spread aerosol plume (North Sea, Netherlands, Germany)
• Pixel to pixel direct comparison over Western Europe, R =0.9

Results From Previous studies

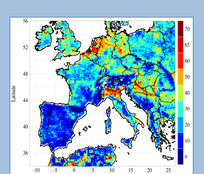
I. Direct satellite-ground mass comparison



$$AOD(\lambda) = \int_0^{z_{max}} s_{ext}^{mass}(\rho,\eta,n(r),\lambda,z) \times PM(z)dz$$

s_{ext}^{mass} : mass extinction cross section ($m^2/\mu g$)

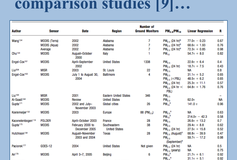
We know AOD_{POL}, we can infer: $PM_{2.5}^{POL} \approx 25 \times AOD_{POL} + 12$



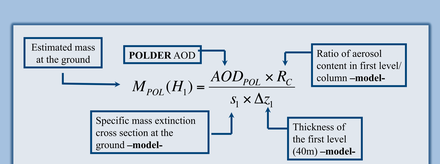
Days (%) above « Moderate » POLDER AOD threshold [8]
(/ total number of observations)

Overall Data set…
helps define a POLDER satellite AOD threshold to characterize « moderate » pollution event
(= 0.17 at 440 nm from April to October)

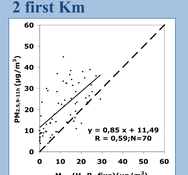
Many Direct satellite AOD-PM comparison studies [9]…



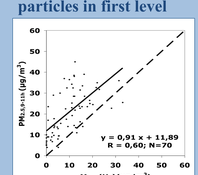
II. Combine satellite and model to infer ground-mass



Without model
All particles in the 2 first Km



With model
Simulated content of particles in first level



Very weak improvement when using the model (slope closer to 1)
mostly due to lack of mass in the model (underestimation of SOA formation in summer, lack of dust,…)

=> The use of the model to constrain PM-satellite AOD is not satisfying…

Let's push the study further…

Proposed Research, methodology and procedure

A. Selection of NASA airborne field campaigns

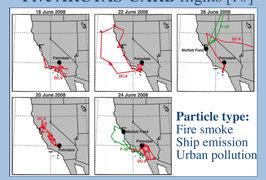
ARCTAS-CARB (June 18-26 08)

•Aerosol **chemical speciation/microphysical** (*) and **vertically resolved measurements** (**) help improve model emission inventories and chemical processes

•Aerosol **optical measurements** (***) help evaluate satellite AOD retrieval (MODIS and OMI validation study already underway during ARCTAS-CARB)

(*) HR-ToF-AMS, particle counter, … on DC-8; (**) DIAL LIDAR on DC-8;
(***) ATTS-14, Tracking sun photometer on P3-B

Five ARCTAS-CARB flights [10]



B. Relative strengths and weaknesses of different 3-D aerosol transport model (First, evaluation of MM5-CMAQ-4km (CARB) vertical distribution of PM and chemical composition)

C. Selection of most suitable space-borne sensor(s) for AQ application (and possible combination)

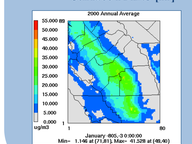
D. Emission sources assessment (using satellite sensors)

E. Improving mass estimation algorithm using 3-D aerosol model and satellite (simple to sophisticated…)

F. Are satellites capable of quantifying PM attributes responsible for health effects? (collaboration with Population Studies Section at the Air Resources Board)

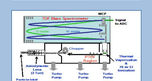
Preliminary results

MM5-CMAQ (California)
Surface PM2.5 [11]



MM5-CMAQ-4km model:

CMAQ v4.64, MM5, SAPRC99, AE4, 4km x 4km x 30 vert. lev. up to 100 mb, PM composed of Sulfate, Nitrate, Ammonium, Anthropogenic secondary Organics, Primary Organics, Secondary biogenic organics, elemental carbon, unspecified anthropogenic, marine and soil-derived; **No fire emission yet**
Water content simulated for every specie according to water activity

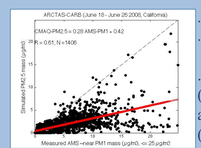


Particle beam generation, aerodynamic sizing and particles composition detection

HR-ToF-AMS instrument:

Mass of all non-refractory species (i.e. volatile at 540 deg. C)
PM of Sulfate, Nitrate, Ammonium, Chloride and Organics *with "Organics ": Organic Carbon and elemental compounds like H, O and N*
Humidity is low (cabin temperature and aerodynamic lens)20
"Near PM1" instead of PM2.5

=> Model and meas. are not expected to match in values but in feature and trends (outside fire)

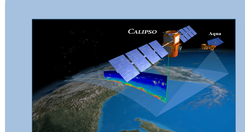


. Max.(AMS)~97 µg/m^3
. Max.(CMAQ)~22µg/m^3

. Best correlation (R=0.6) when AMS PM above 25 µg/m^3 deleted (fires?).

=> CMAQ underestimates AMS PM by ~72 %
Next step is CMAQ PM profile and chemical composition evaluation with DC-8 LIDAR, AMS, …

Why not use CALIPSO for aerosol vertical distribution?



MODIS-AQUA passive satellite:
High spectral (AOD in 7 bands, 466-2119 nm, [12]) and spatial resolution (10 x 10 km)

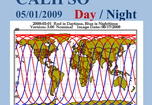
CALIOP on CALIPSO "Cloud-Aerosol Lidar with Orthogonal Polarization"
Active –Downward pointing elastic laser-
90 m foot print every 333 m x Vertical –"curtain scene" Same track (+-10 km) every 16 days
Attenuated backscatter coefficient profiles at 532 (Total and cross polarized) and 1064 nm and **Aerosol extinction coefficient** profiles at 532 nm
Vertical distribution, shape and size of aerosols

I. Not enough global coverage to infer surface mass on a daily basis

MODIS-AQUA
05/01/2009

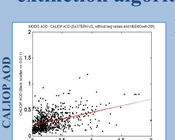
Near global coverage

CALIPSO
05/01/2009 Day / Night



No global coverage

II. Weaknesses in current CALIPSO extinction algorithm (V2)



II.1. CALIPSO versus MODIS

• The standard **CALIPSO extinction** product seems to **underestimate MODIS AOD (by 75%)**

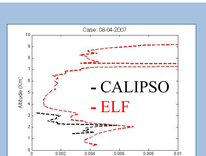
• MODIS AOD could be biased by wrong surface reflectance, cirrus cloud contamination…

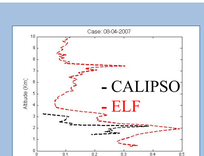
CALIPSO extinction evaluation -August 4 2007 case-

Measurements:
. MODIS and CALIPSO AOD
. Airborne HSRL LIDAR profiles
. Several sunphotometers (CATZ campaign)
. Ground-based UMBC- **E**lastic **LI**DAR **F**acility (ELF)

II.2. CALIPSO and ELF extinction profile

CALIPSO and ELF:
Similar instrument, 73 km apart (not same air mass but ~ same source), with down (up) ward pointing and ≠ extinction and backscatter retrieval algorithm





• Similar trend for CALIPSO and ELF-hour mean
• Comparing point by point… Satisfying correlation CALIPSO-ELF ext. coeff. (R~0.8, N=14)

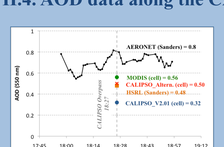
CALIPSO underestimates ELF by ~20 % on this day
. Comparing AOD… CALIPSO AOD (56<Sa<70) ~ 0.3 and ELF AOD (Sa=77) ~ 1.7

Study limited by spatial-temporal correlation between CALIPSO (7km.sec^{-1}) and ground instrument (min. 40 km away from CALIPSO track)…

II.3. Possible sources of CALIPSO extinction underestimation

1. **Wrong Sa** value (see right for retrieval using HSRL Sa)
2. Very **little detection** of tenuous **aerosol layers aloft** by day (study underway: Quantify AOD of layers above highest aerosol layer identified by CALIPSO using HSRL data)
3. Signal "dies out" at the surface, **lowest aerosol layer does not extend to the ground** (study underway with Mark Vaughan)

II.4. AOD data along the CALIPSO track



. "CALIPSO_V2.01" still under-estimates MODIS
. Both CALIPSO and MODIS underestimate AERONET
. When using HSRL Sa [13] and retrieving our own CALIPSO AOD ("CALIPSO_Altern.", iterative method): Δ_{AOD} = 0.20, closer to MODIS/ HSRL AOD and still underestimates AERONET AOD

References

1. Samet, et al., *N. Engl. J. Med 343, 1742-1749 (2000)*
2. Pope, C. A., *Aerosol Sci. Technol. 32, 4-14 (2000)*
3. Pope, C.A., *N. Engl. J. Med 360: 376-386 (2009).*
4. Wallace, L., *Aerosol Sci. Technol. 32, 15-25 (2000)*
5. Krewski D. et al., *Health effects Institute, Research report, Number 140 (2009)*
6. Deuzé J.-L. et al., J. Geophys. Res., 106, 4913-4926 (*2001*)
7. Vermeulen A. et al., Appl. Opt., 39(33), 6207-6220 (*2000*)
8. Kacenelenbogen M. et al., Atmos. Chem. Phys., 6, 4851-4866 , (*2006*)
9. Hoff R. M. et al., J. Air & Waste Management, (*2009*)
10. Jacob D. J., Atmos. Chem. Phys. Discuss., 9, 17073–17123, (*2009*)
11. CMAQ Model Performance Evaluation for 2000 in Central California, California Environmental Protection Agency, March 12, (*2008*)
12. Kaufman Y. J. et al., Product ID : MOD04, 85 pages, (*1998*)
13. McPherson et al., ILRC, (*2008*)

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