MODELING OF AEROSOL OPTICAL DEPTH VARIABILITY DURING THE 1998 CANADIAN FOREST FIRE SMOKE EVENT

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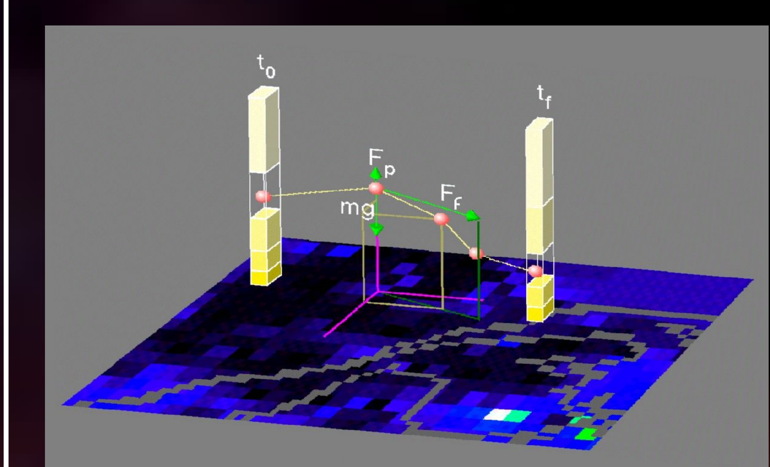
ABSTRACT

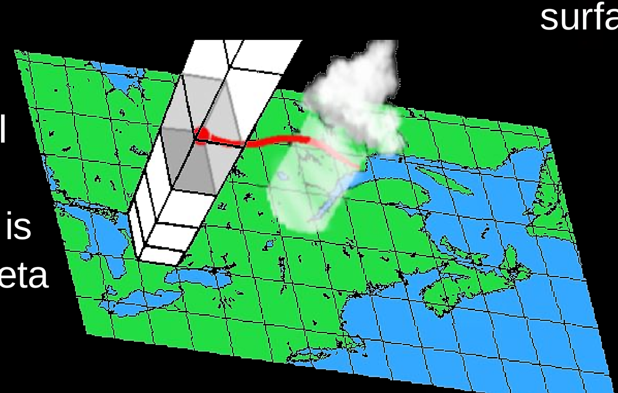
Monitoring of aerosol optical depth (AOD) is of particular importance due to the significant role of aerosols in the atmospheric radiative budget. Up to now the two standard techniques used for retrieving AOD are; (i) sun photometry which provides measurements of high temporal frequency and sparse spatial frequency, and (ii) satellite based approaches such as DDV (Dense Dark Vegetation) based inversion algorithms which extract AOD over dark targets in remotely sensed imagery. Although the latter techniques allow AOD retrieval over appreciable spatial domains, the irregular spatial pattern of dark targets and the typically low repeat frequencies of imaging satellites exclude the acquisition of AOD databases on a continuous spatio-temporal basis. We attempt to fill gaps in spatio-temporal AOD measurements with a new methodology that links AOD measurements and particulate matter Transport Model using a data assimilation approach. This modeling package (AODSEM for Aerosol Optical Depth Spatio-temporal Evolution Model) uses a size and aerosol type segregated semi-Lagrangian-Eulerian trajectory algorithm driven by analyzed meteorological data. Its novelty resides in the fact that the model evolution is tied to both ground based and satellite level AOD measurement and all physical processes have been optimized to track this important but crude parameter. We applied this methodology to a significant smoke event that occurred over Canada in august 1998. The results show the potential of this approach inasmuch as residuals between AODSEM assimilated analysis and measurements are smaller than typical errors associated with remotely sensed AOD (satellite or ground based). The AODSEM assimilation approach also gives better results than classical interpolation techniques. This improvement is especially evident when the available number of AOD measurements is small.

MODEL OVERVIEW -Aerosol Optical Depth Spatio-temporal Model (AODSEM 1.0)

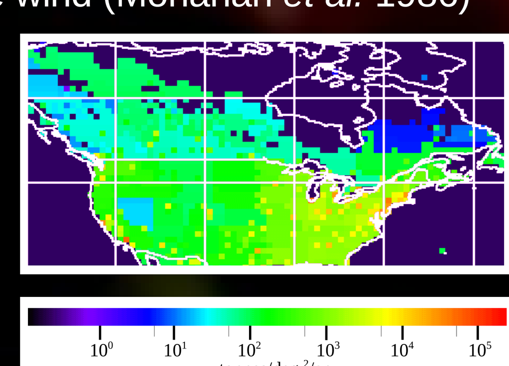
AEROSOL TRANSPORT MODEL (TM)



- Under-cloud scavenging (size dependent, Garcia Nieto *et al.* 1994)
- In-cloud scavenging (Walton *et al.* 1988)
- Gravitational settling
- Coagulation is available in beta version



- Gravitation, buoyant force, drag force
- Dynamical computations using Global Environmental Multiscale (GEM, Côté *et al.* 1997) global meteorological analysis.
- Hygroscopic growth (dynamical and optical)
- Aerosol types: Black Carbon, Organic Carbon, Sulfate, Sea Salt and Soil Dust.
- 12 size bins 0.005-20.24 µm
- Domain boundary nested by GADS aerosol climatology (Koepke *et al.* 1997)
- Sulfate emissions (2 levels, Voldner, Li *et al.*), carbon aerosol (1 level, Cooke and Wilson 1996, soon Lavoué *et al.*) mainly GEIA inventory
- Sea salt emissions determined by near surface wind (Monahan *et al.* 1986)



Black carbon emission inventory (forest fires & fossil fuel)

DATA ASSIMILATION SYSTEM

The assimilation system is a combination of the Cressman objective analysis approach and the incremental analysis update (IAU). In the Cressman method, the analysis increments are computed every 24 hours to match typical satellite images acquisition frequencies. We used IAU to distribute this analysis increment over intermediate time steps (typically every 3 hours). IAU offers the advantage of not modifying the background (model forecast) while retaining the high spatial frequency pattern produced by the physics. In fact only the analysis increments are modified by IAU.

Cressman data assimilation scheme

$$\rho_a(\vec{r}_i)=\rho_b(\vec{r}_i)+H_P^{-1}\left[\frac{\sum_{j=1}^{n} w(i,j)\{AOD_o(j)-H_P[\rho_b(j)]\}}{\sum_{j=1}^{n} w(i,j)}\right]$$

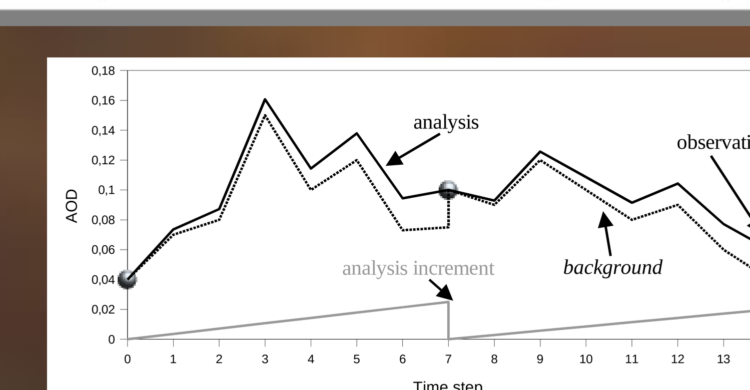
$$w(\vec{r}_i-\vec{r}_j)=\frac{1}{C_{xy}\|\vec{r}_i-\vec{r}_j\|^2}$$

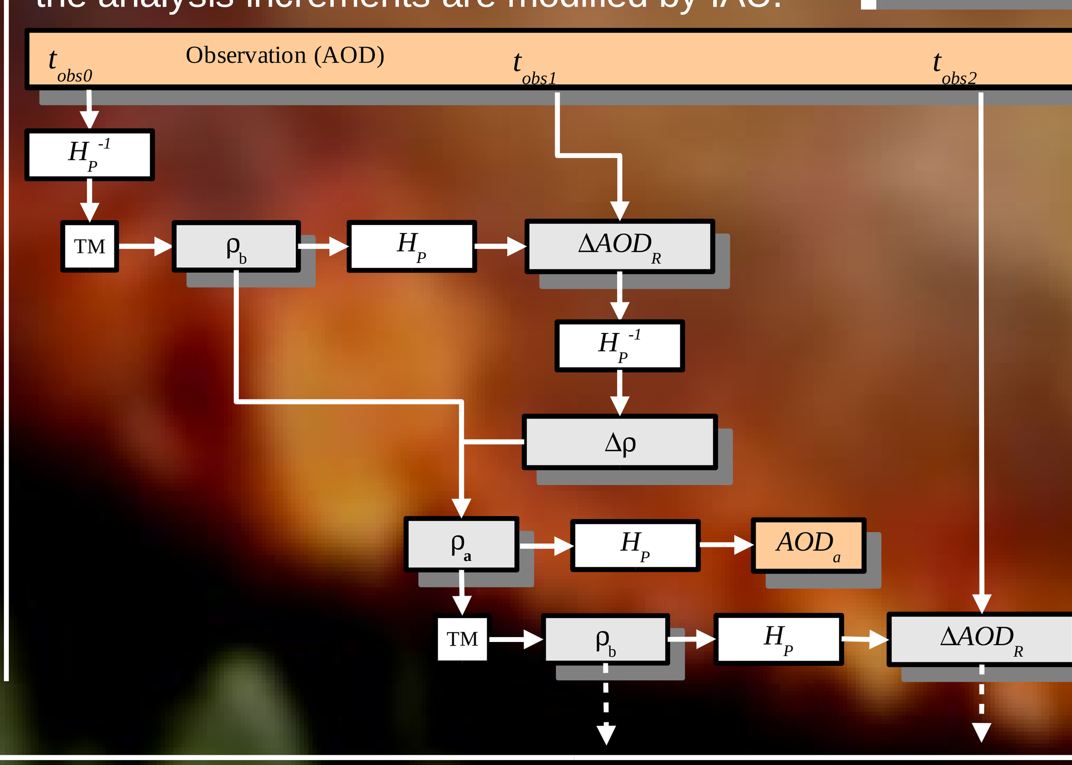
ρ_a = analysed number density, ρ_b = background number density, $\vec{r}_i$ = position of a grid point, $\vec{r}_j$ = position of the observation AOD_o, H_P and H_P^{-1} = observation operators, $w(i,j)$ = Cressman weight

Incremental analysis update (IAU)

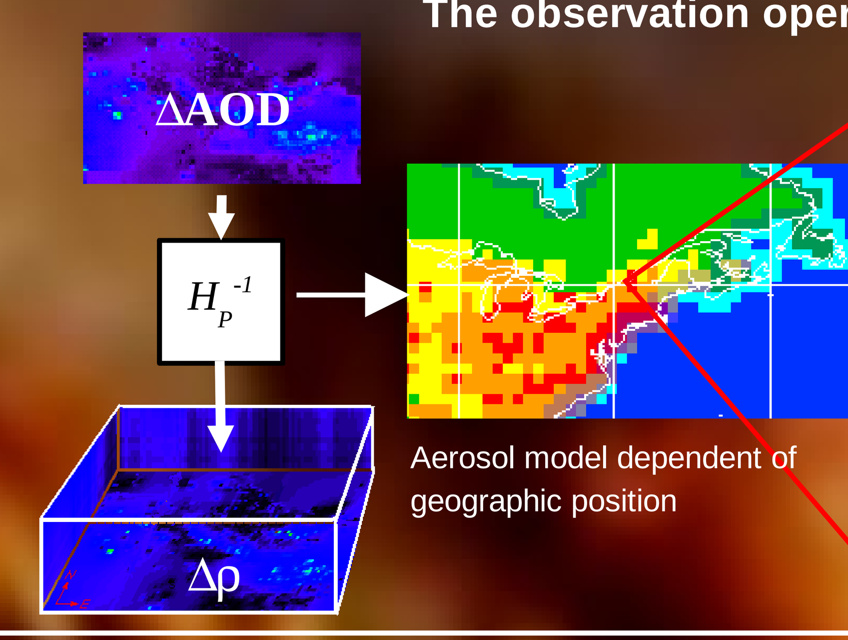
$$\rho_a(t_{obs0}+n\,\Delta t)=\rho_b(t_{obs0}+n\,\Delta t)+\Delta\rho(t_{obs1})\frac{n\,\Delta t}{(t_{obs1}-t_{obs0})}$$

n = time step number between $obs0$ and $obs1$, Δt = time step





The observation operator (H_P^{-1})

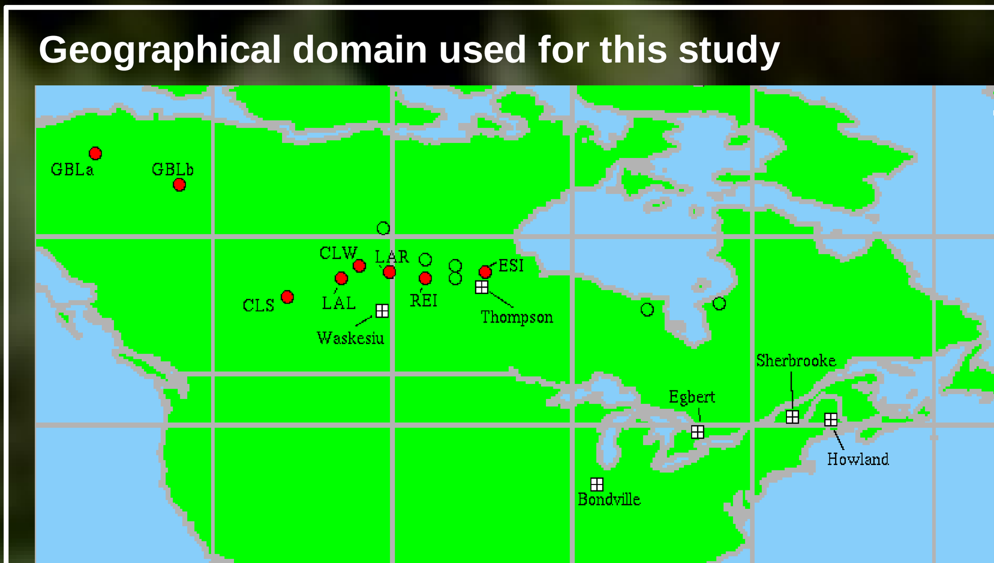


Aerosol model dependent of geographic position

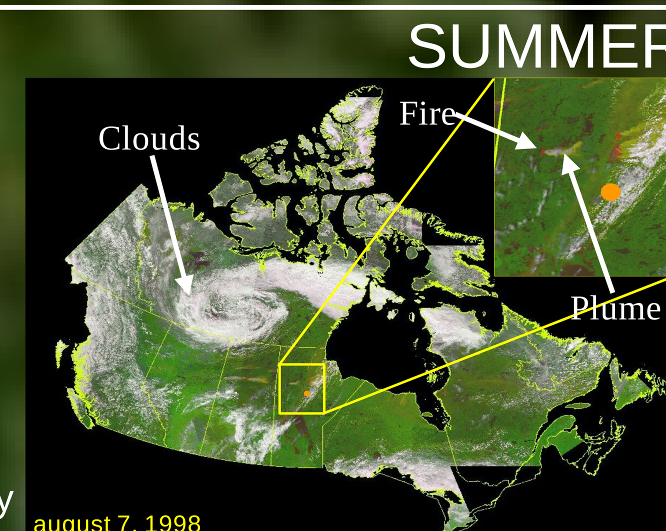
- Urban mask (FFBC, Cooke and Wilson 1997)
- Land-sea mask
- Typical size distribution for maritime, rural and urban environment (Shettle and Fenn 1979)
- Vertical profiles for standard atmosphere (McClatchey *et al.* 1982)
- Extinction optical cross sections (Aubé 1998)
- Optical sensitivity to relative humidity (RH from GEM, Côté *et al.* 1997)

SUMMER 1998 DATA SET

Geographical domain used for this study



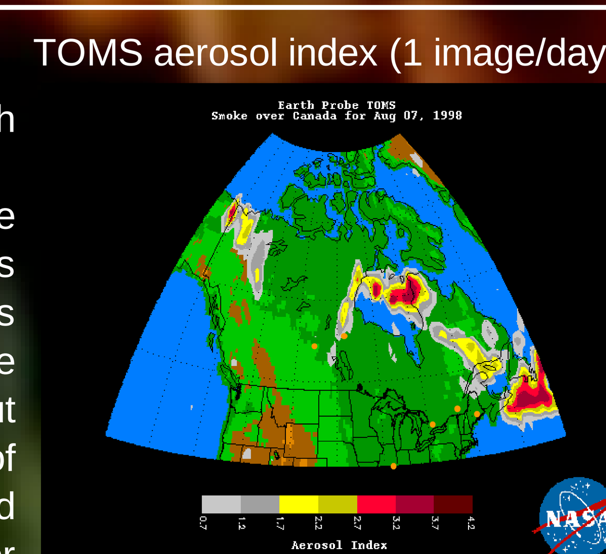
- Resolution = 0.5 x 0.5 deg.
- Time step = 3 hours
- Period = august 1-12, 1998
- Red circles= important fires considered in emission inventory
- White squares = sunphotometers



AVHRR color composite (1 image/day)

AVHRR images were used in combination with TOMS images to create the emission inventory. Fire position information was extracted from the AVHRR imagery while fire emission intensities were estimated from corresponding plume sizes on TOMS images. We assumed that each fire detected was active during at least 24 hours about the AVHRR acquisition time. A small subset of TOMS data was used to perform assimilation and interpolation. TOMS data were also used for spatial validation of AODSEM results.

TOMS aerosol index (1 image/day)



AERONET-MFRSR sunphotometers

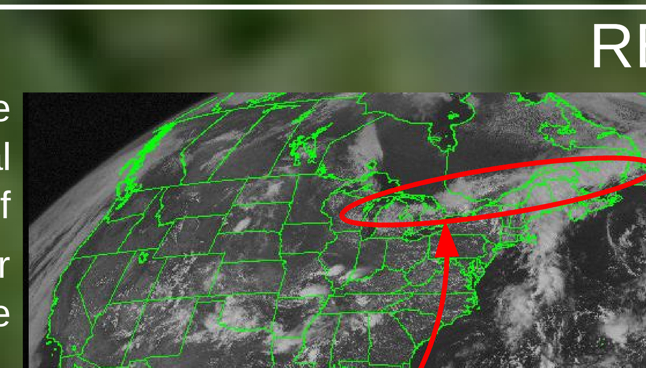
Sunphotometer data were used for temporal validation of AODSEM.

RESULTS

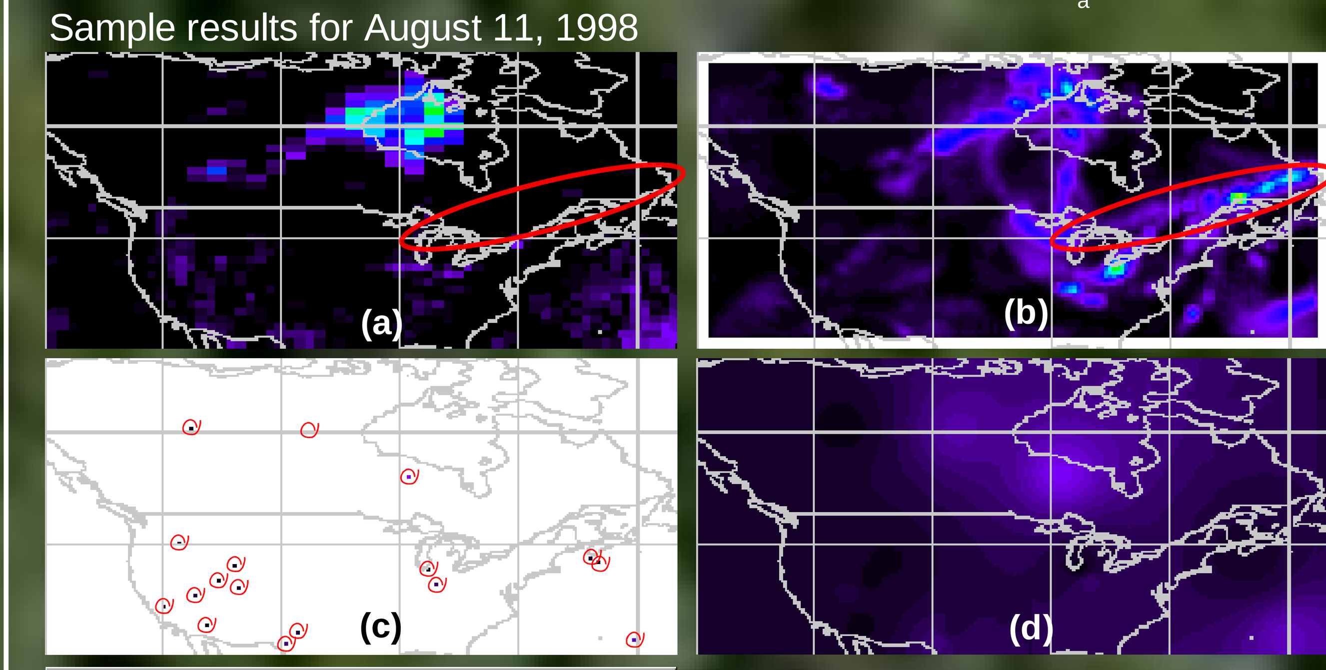
Spatial validation

We only used 1% of TOMS data to constrains the evolution of AODSEM. The other 99% of TOMS data were used for validation. We found that typical residuals between TOMS and AODSEM were about $<\Delta\tau_a>=0.015$ which is of the order of the typical errors associated with AOD sunphotometer measurements and significantly lower than the average residuals between the classical ($1/r^2$) interpolation scheme and AERONET data ($<\Delta\tau_a>=0.04$).

Sample results for August 11, 1998



GOES-8 (visible) showing cloud cover



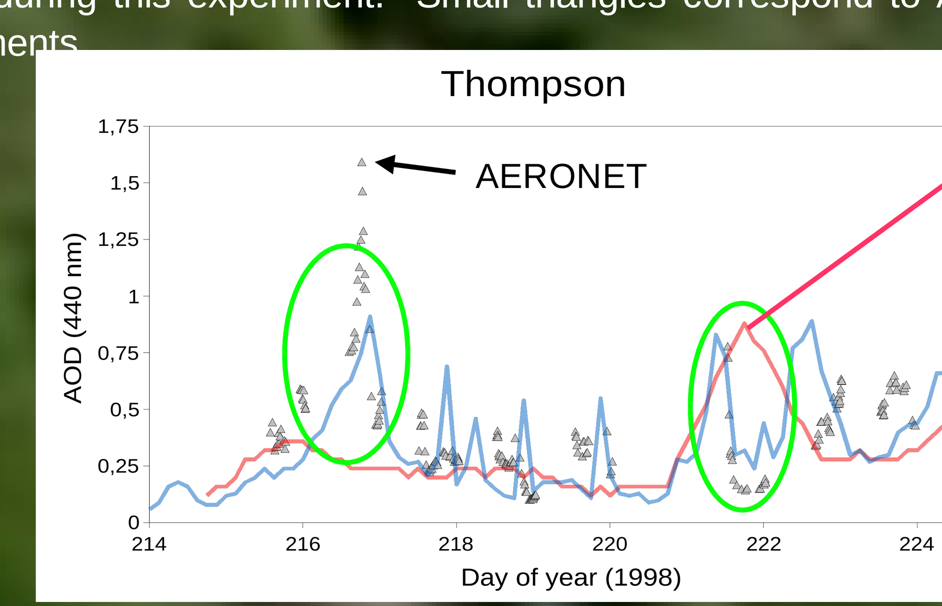
AOD and TOMS Aerosol Index

(a) TOMS satellite imagery
(b) Assimilation of a subset of TOMS data (shown in c)
(c) Subset of TOMS data set used for data assimilation and by the interpolation scheme (1% of the available TOMS data)
(d) Simple interpolation scheme (SIS) ($1/r^2$)

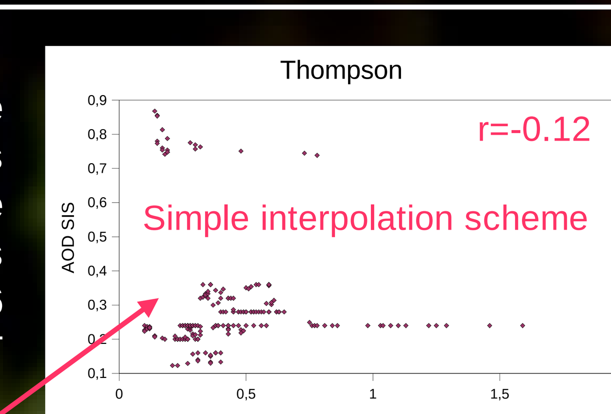
This result clearly shows the superiority of the assimilation technique compared to a classical ($1/r^2$) interpolation scheme. The physics included in the model gererates key information which premits the filling of large gaps in the TOMS spatial distribution of the small subset of TOMS data (see c on left figure). The red ellipse highlights an important discrepancy observed between AODSEM and TOMS. This difference can be explained by the presence of clouds in that zone as revealed by the GOES image presented above. In fact, TOMS cannot detect aerosol situated inside or below clouds.

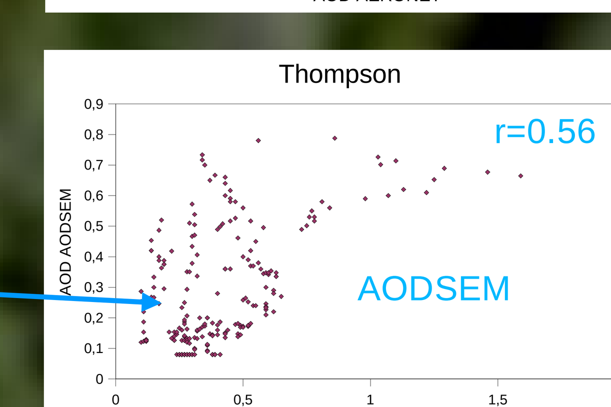
Temporal validation

The figure below represents a time series produced by extracting the AOD value nearest to a sunphotometer site (here Thompson) from AODSEM AOD images (blue) and based on a simple spatio-temporal interpolation scheme applied to the remotely sensed AOD images (red). The Thompson site was chosen for this example because it was characterized by the best temporal coverage of all 6 available sites during this experiment. Small triangles correspond to AERONET AOD measurements.



Green ellipses in the figure highlight periods for which AODSEM (blue curve) performed particularly well compared to classical ($1/r^2$) interpolation (red curve). A significant part of the residuals between the AODSEM and AERONET AODs is due to the difficulty relating TOMS aerosol index to AOD. This problem can also explain the relatively low temporal correlation of r=0.56 observed. In fact, we found in a previous validation experiment that assimilation based on AERONET AOD (more precise data) could result in temporal correlations as high as r=0.9.





Correlation between AERONET data and AODSEM model is clearly better than correlation with the simple ($1/r^2$) interpolation scheme.

Funding for this research was provided by the Canadian Institute for Climate Studies (CICS), the National Sciences and Engineering Research Council of Canada (NSERC), the ministère des Finances, Économie et Recherche du Québec, the Collège de Sherbrooke and the Fondation du Collège de Sherbrooke