Measurements of Stratospheric Volcanic Aerosol Optical Depth from NOAA/TOVS Observations

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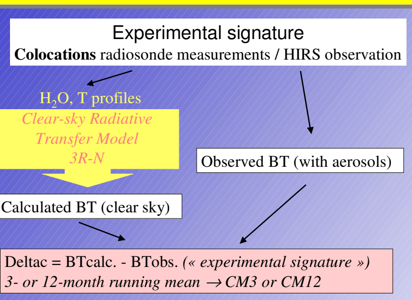
Introduction :

In June 1991, the eruption of Mount Pinatubo (Philippines) injected about 20 Mt of sulfur dioxide into the stratosphere. The rapid conversion of sulfur dioxide into sulfuric acid (H_2SO_4) droplets caused a significant extinction, both in the visible and infrared. Here, we present a method to retrieve the Pinatubo aerosol optical depth at three infrared wavelengths (4.0 µm, 8.3 µm and 11.1 µm) from HIRS-2 measurements onboard NOAA-10 and NOAA-12 and collocated radiosonde measurements. No assumption on aerosol size distribution or refractive index is used, which is a major advantage of our method.

1. Signature of Pinatubo aerosol on CM-3 and CM-12 time series



Experimental signature
Colocations radiosonde measurements / HIRS observation

H_2O, T profiles

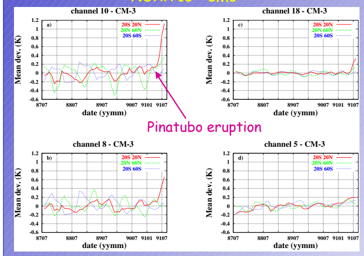
Clear-sky Radiative Transfer Model 3R-N

Observed BT (with aerosols)

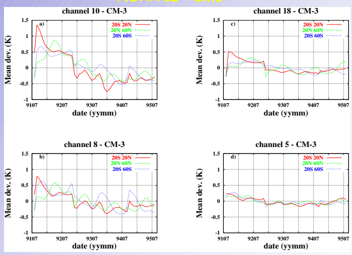
Calculated BT (clear sky)

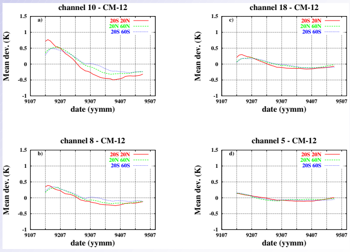
Deltac = BTcalc. - BTobs. (*« experimental signature »*)
3- or 12-month running mean → CM3 or CM12

NOAA 10 – CM3



NOAA 12 – CM3





NOAA 12 – CM12

top pannels : CM3 : 3-month centered running mean deviation (calculated – observed) for three latitude bands (20N-60N, 20S-20N, 20S-60S), for NOAA10 (left pannel) and NOAA12 (right pannel).

bottom pannel : CM12 : 12-month centered running mean deviation for NOAA12.

(a): channel 10 (8.3 µm), (b): channel 8 (11.1 µm), (c): channel 18 (4.0 µm), (d): channel 5 (14.0 µm)

Potential sources of error :

- seasonal water vapour cycle
- NOAA12 drift since early 1994
- greater diurnal cycle of temperature and humidity over land: →only sea collocations
- solar contamination of channel 18 : →only sea-night collocations for channel 18

2. Simulation of the impact of volcanic aerosol on observations

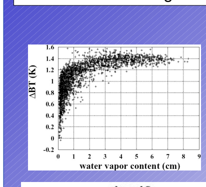
Radiative transfer simulations with absorbing aerosols

$$\Delta I_\nu(\text{sat}) = \varepsilon_\nu(\text{surf})\tau_\nu^m(\text{surf})(1-\tau_\nu^a(surf))B_\nu(T\text{surf}) + \sum_{k=0}^{\text{sat}} B_\nu[T(k)]\left(\tau_\nu^m(k+1)(1-\tau_\nu^a(k+1)) - \tau_\nu^m(k)(1-\tau_\nu^a(k))\right)$$

Theoretical signature (1)

ΔI : difference between the radiance emerging at the satellite level for an aerosol free and an aerosol loaded atmosphere
ε : surface emissivity
$\tau^m(k)$: molecular transmittance between level k and satellite
$\tau^a(k)$: aerosol transmittance between level k and satellite

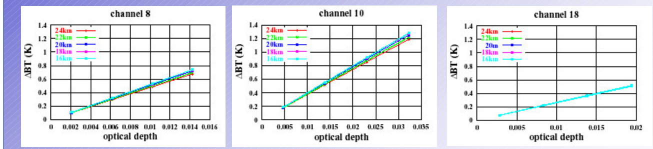
Sensitivity study



Variability of the simulated brightness temperature difference, ΔBT, between an aerosol-free and an aerosol-loaded atmosphere at 8.3 µm (channel 10), with total water vapor content, for the 2311 atmospheric situations of the TIGR data base.

→ the aerosol effect highly depends on the atmospheric situation :

→ careful selection of TIGR atmospheric situations for the retrieval scheme



Variability of ΔBT with the optical depth and the altitude of the aerosol layer for channels 8, 10 and 18

→Linearity between ΔBT and the aerosol optical depth

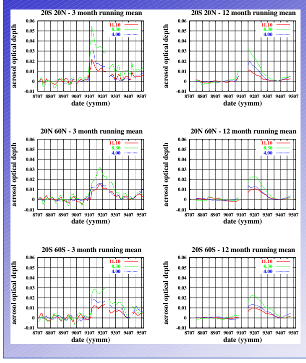
Eq.(1) becomes : $\Delta I = \sum a_k \delta_k$ (2)

→ no effect of the altitude

Eq.(2) becomes : $\Delta I = a\delta$ (3)

a depends on the atmospheric and surface situation, on the wavelength, but not on the aerosol properties

3. Retrieval of aerosol optical depth



Inversion is based on Eq.(3).

For each collocation, and each channel :

- Deltac (BTcalc-BTobs cf 1.)
- *ΔBT* calculated from the closest TIGR situation for a reference optical depth (0.01), cf 2.

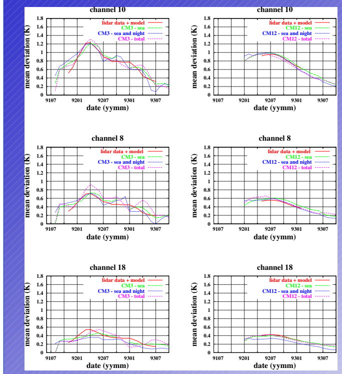
→ Computation of the corresponding coefficient a, for each wavelength (a = *ΔBT / 0.01*)

$$\delta = \frac{Deltac}{a}$$

No assumption on the aerosol size distribution or refractive index

Retrieved optical depth at three infrared wavelengths and for three latitude zones. Left hand-side pannels: 3-month running mean, right hand-side pannels : 12-month running mean.
From top to bottom : 20N-20S, 20N-60N, 20S-60S. Missing data correspond to month when the number of collocations is lower than 50.

4. Validation of the results



Computation of the maximum particle number :

- as expected, does not depend on the channel
- for August-July 1991 in the northern midlatitudes, we retrieve 10 to 20 particles/cm^3, in agreement with in-situ measurements of *Deshler et al.,[1992, 1993]*

Spatial and time behaviour of the aerosol loading :

- transport faster to southern latitudes (peak in November 1991 for 20S-60S, in April/May 1992 for 20N-60N) [*Lambert et al., 1993]*
- aerosol removal faster in the tropics than in midlatitude zones

Comparison between the experimental CM-3 (left hand-side) or CM-12 (right hand-side) time series from NOAA12, and their simulated ΔBT (in red), using TIGR climatological atmospheric profiles and lidar aerosol profiles at Observatoire de Haute Provence (France) (3 month and 12 month running means) [Chazette et al., 1995].

Comparison between ISAMS aerosol optical depth at 12.1 µm and HIRS-2 aerosol optical depth at 12.1 µm retrieved from channels 8, 10, and 18.

Conclusions :

Covering the time period July 1987- September 1995, this analysis of differences between HIRS-2 measurements and collocated temperature and water vapor radiosonde profiles clearly reveals the signature of Mount Pinatubo aerosols. Simulations of their effect on brightness temperature using the climatological data base TIGR shows that, for a given channel, it depends on the atospheric situation and linearly on the aerosol optical depth, and not on their microphysical properties. 3- or 12- month running mean aerosol optical depth at 4 µm, 8.3 µm and 11.1 µm are retrieved from channels 18, 10 and 8 measurements, for three latitude zone. Validation with lidar measurements and comparison with ISAMS measurements show good agreements.