Aerosol Monitoring and Modeling

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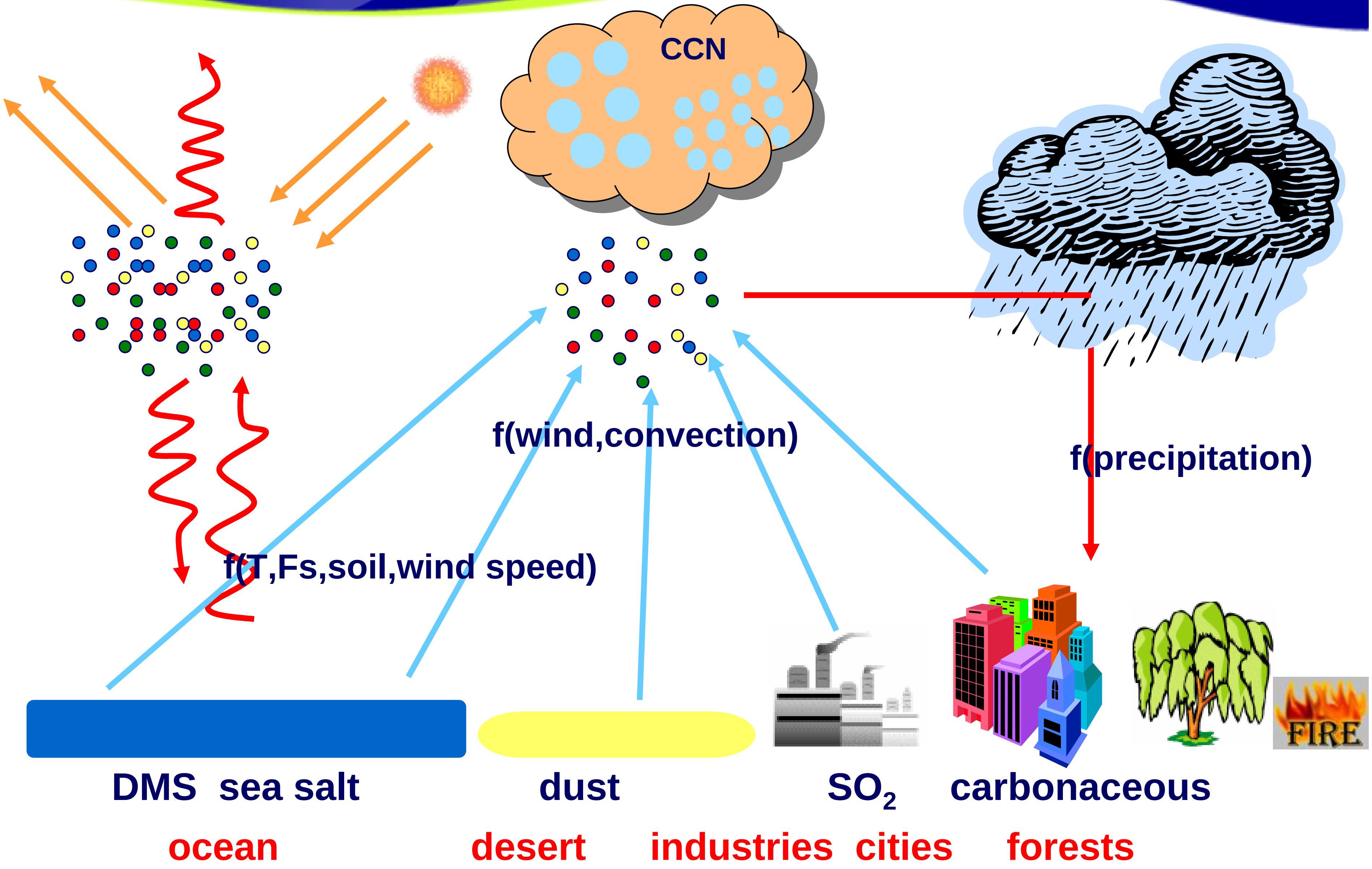
Presentation to ECMWF seminar on Global Earth-System Monitoring

5-9 September 2005

Aerosols are integral part of the Earth's system.



OUTLINE

1. Why do we need to monitor aerosols globally?

2. Design of an aerosol monitoring system

3. GEMS-aerosol

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Reasons for getting interested in aerosols

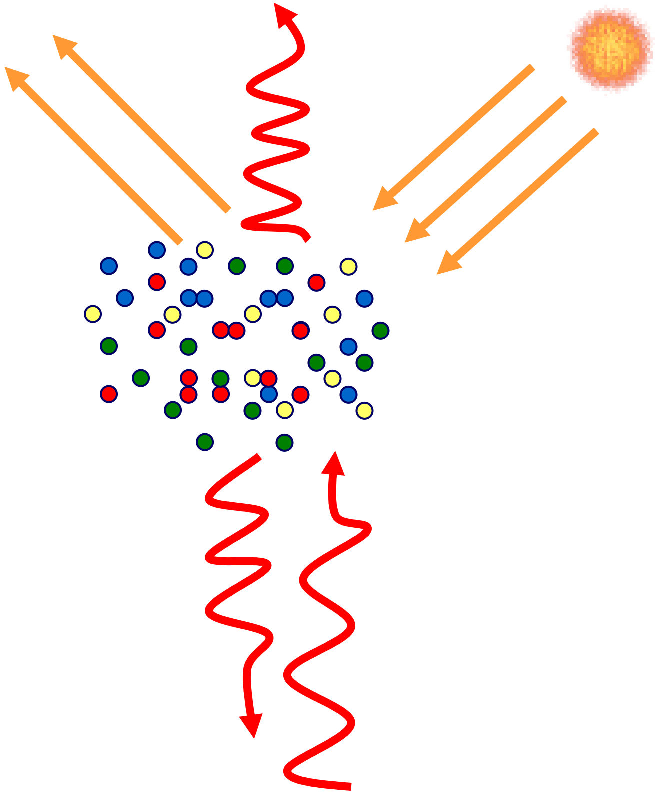
Met Office

- **climate effect (clear-sky, cloudy-sky)**
  - **- anthropogenic aerosols are responsible for a radiative forcing**
  - **- anthropogenic aerosols may modify the hydrological cycle**
  - **- natural aerosols may response to climate change**
- **visibility ==> tourism, aviation**
- **air quality issues ==> human health, ecosystems**
- **improvement in meteorological (re)analysis**
- **improvements in weather forecasts**
- **deposition and acid rain issues ==> ecosystems**
- **satellite atmospheric corrections**
  ==> retrieval of the properties of ocean, land, and atmosphere
- **role of aerosol deposition on ocean biology**
- **depletion of the stratospheric ozone layer**

Terminology: direct and indirect effects

- **Direct effect:** extinction of sunlight by aerosols in clear-sky (+extinction and emission of longwave radiation)
- **Semi-direct effect:** impact of aerosol absorption in clear- (and cloudy-) sky on the temperature and humidity profiles and hence on cloud formation
- **First indirect effect:** increase in cloud optical depth due to an increase in the number and a decrease in the size of cloud droplets (for a fixed liquid water content)
- **Second indirect effect:** increase in the cloud liquid water content, cloud height, or cloud lifetime due to a reduced precipitation efficiency

Aerosol direct effects



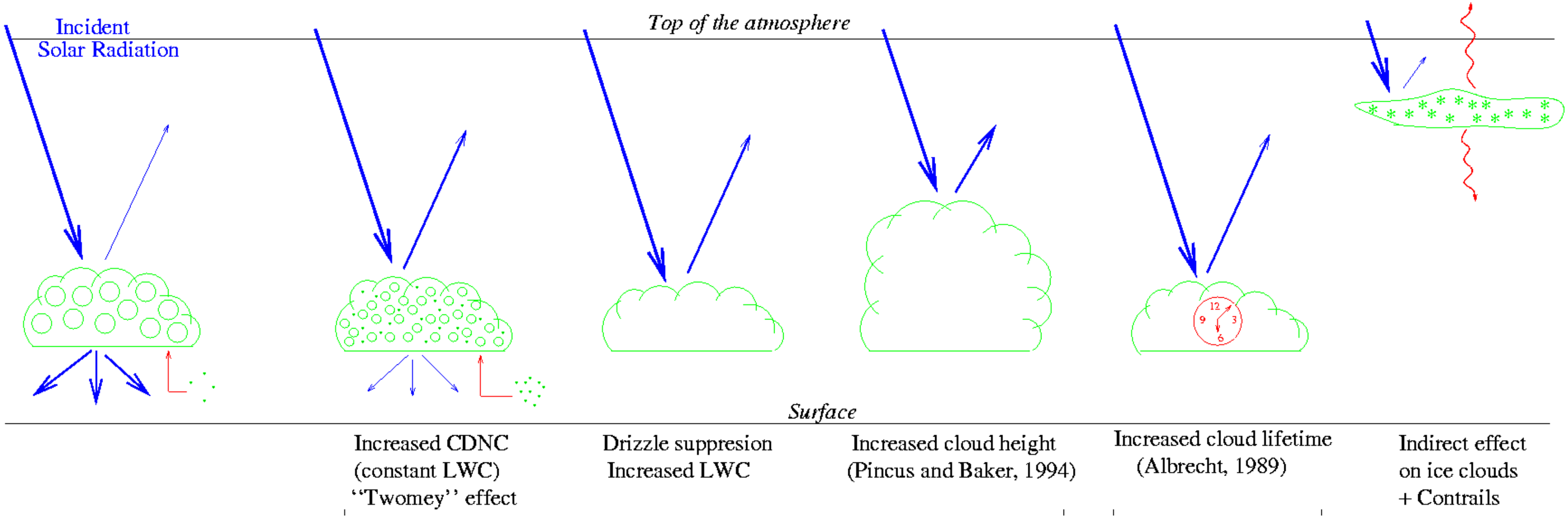
• Aerosols do scatter and absorb sunlight radiation.

• Anthropogenic aerosols suspected to be responsible for a negative radiative forcing of climate.

• Climate has not warmed as much as it would have in the absence of anthropogenic aerosols.

• The magnitude of the aerosol direct effect is now bound but remains uncertain.

Aerosol indirect effects



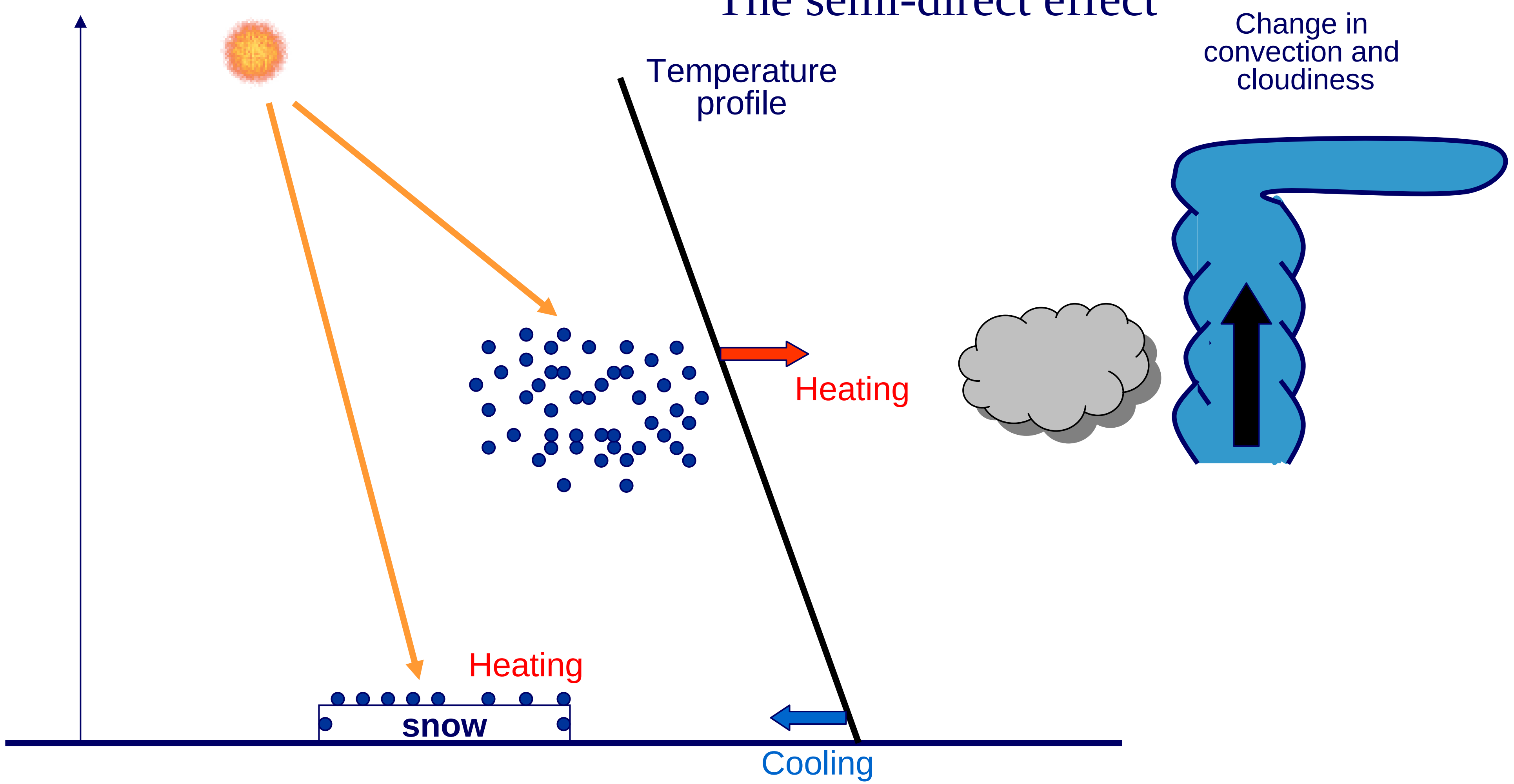
First indirect effect

Second indirect effect

Specific climate effects of black carbon aerosols

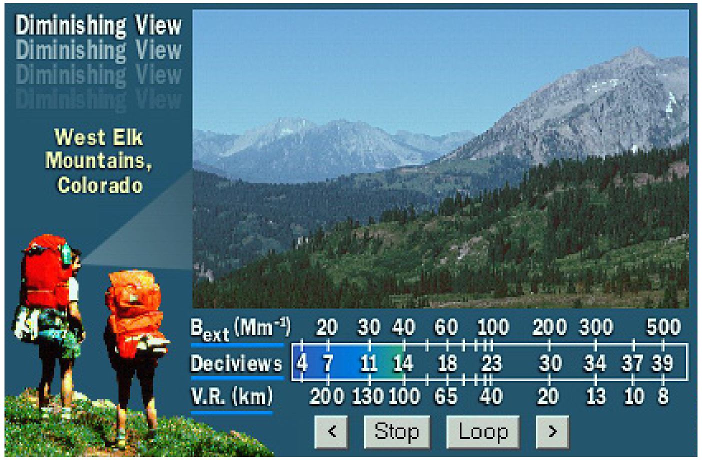
Altitude

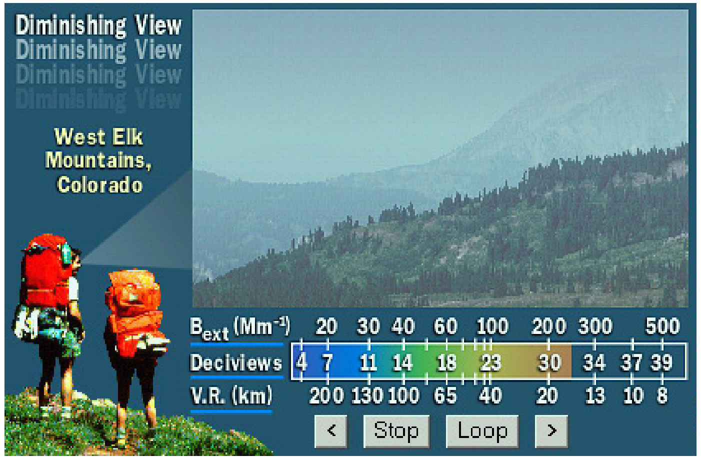
The semi-direct effect

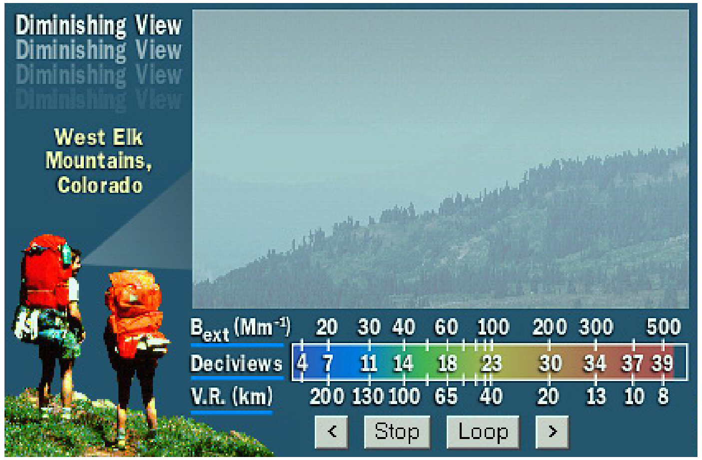


As aerosol concentrations increase and visibility decreases, there is

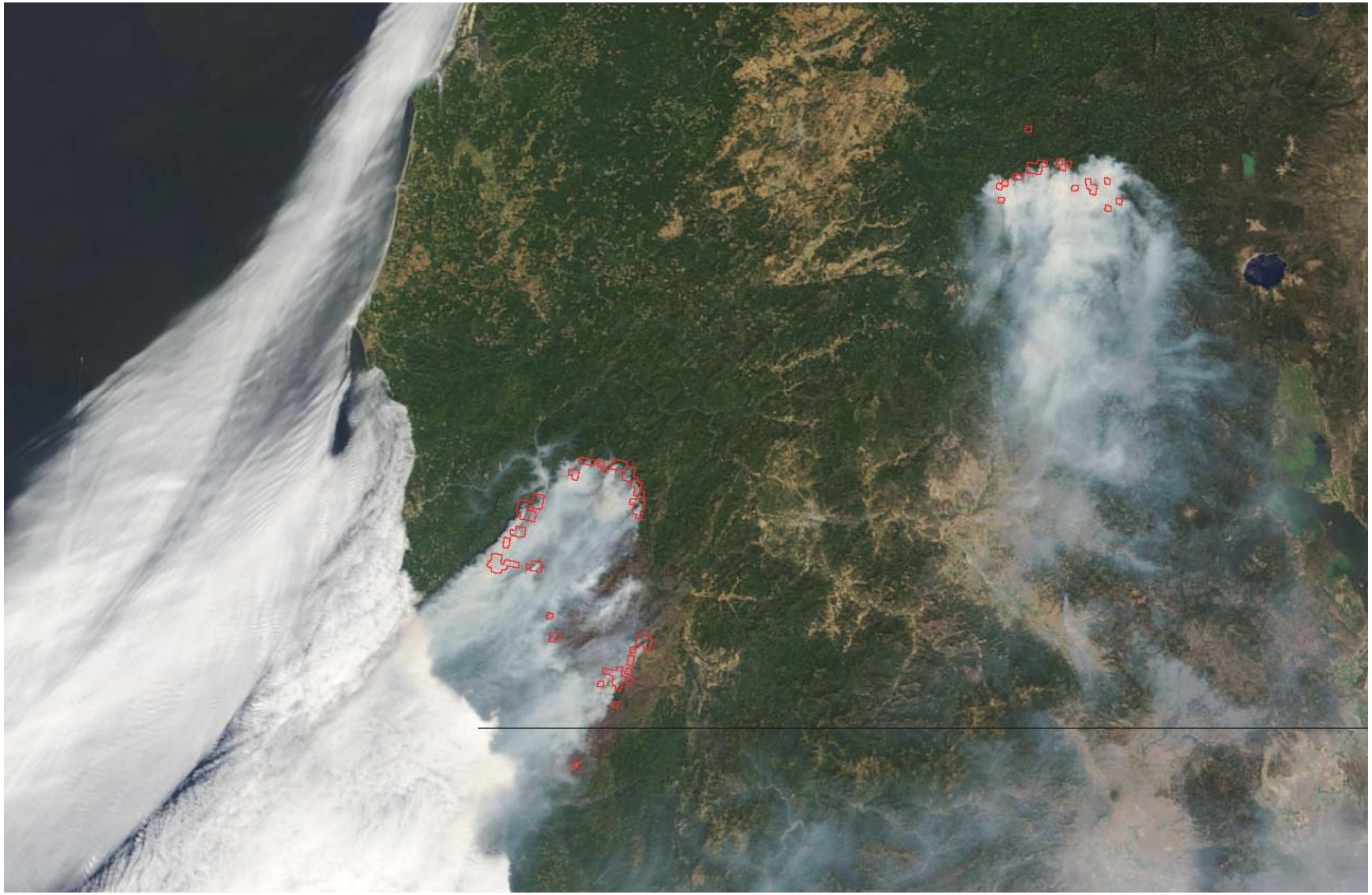
- a whitening of the landscape,
- loss of texture,
- loss of contrast.







Biscuit and Tiller Fires in California and Oregon (08/14/02)



Moscow – September 2002

Peat fires, Moscow, September 2002

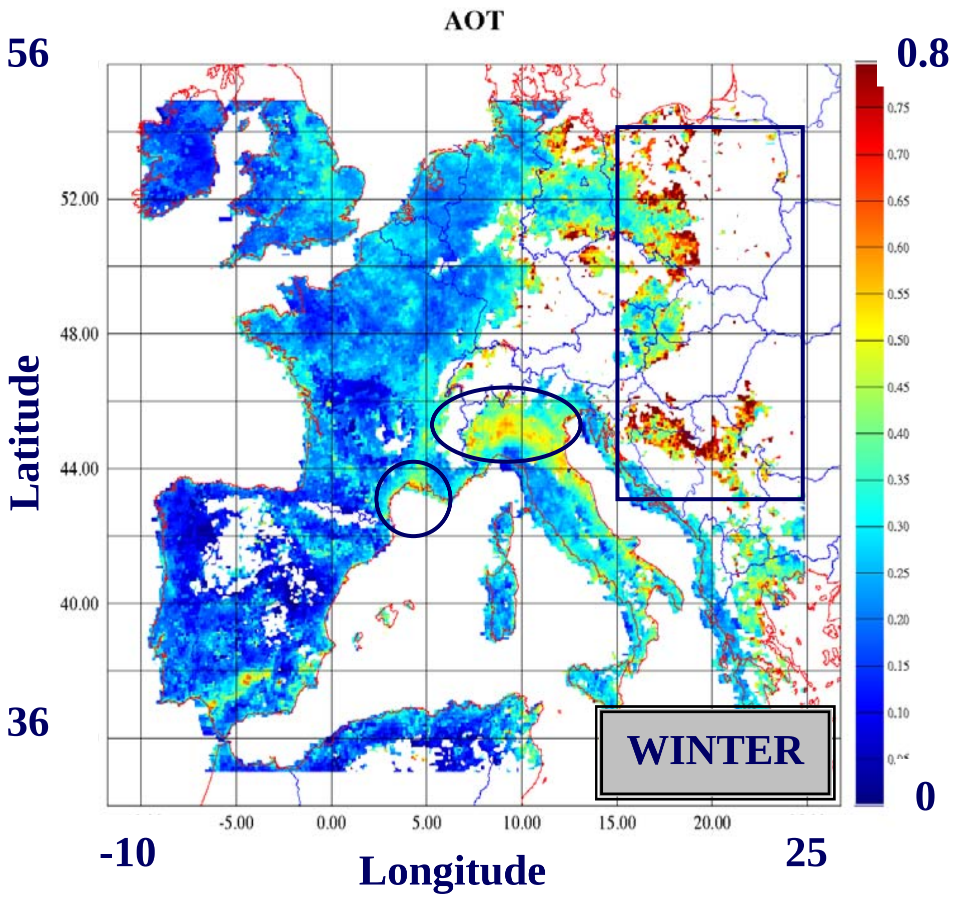
Irak – May 2005

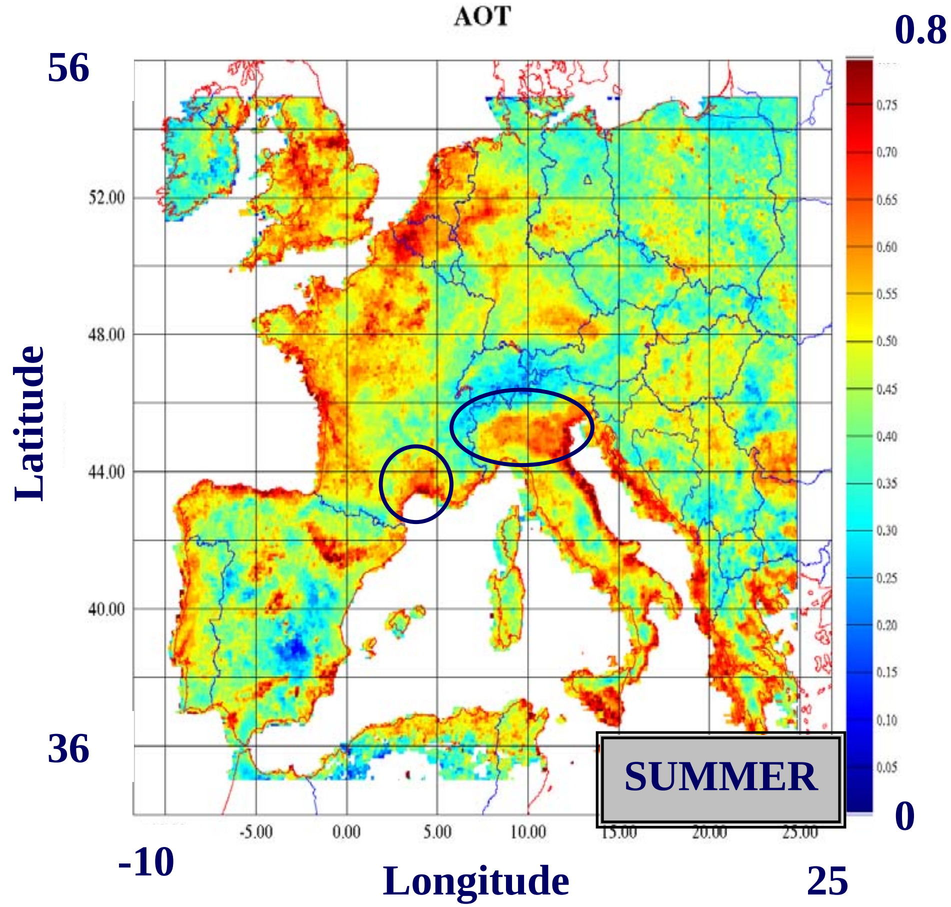
Malaysia – August 2005

11 August 2005

"Malaysia has declared a state of emergency as the air pollution index soars to extremely hazardous levels on the west coast, which is worst-hit by smoke from fires in Sumatra."

Global aerosol tools relevant to AQ!





Maps of aerosol optical depth from MODIS instrument

Global aerosol tools relevant to AQ!

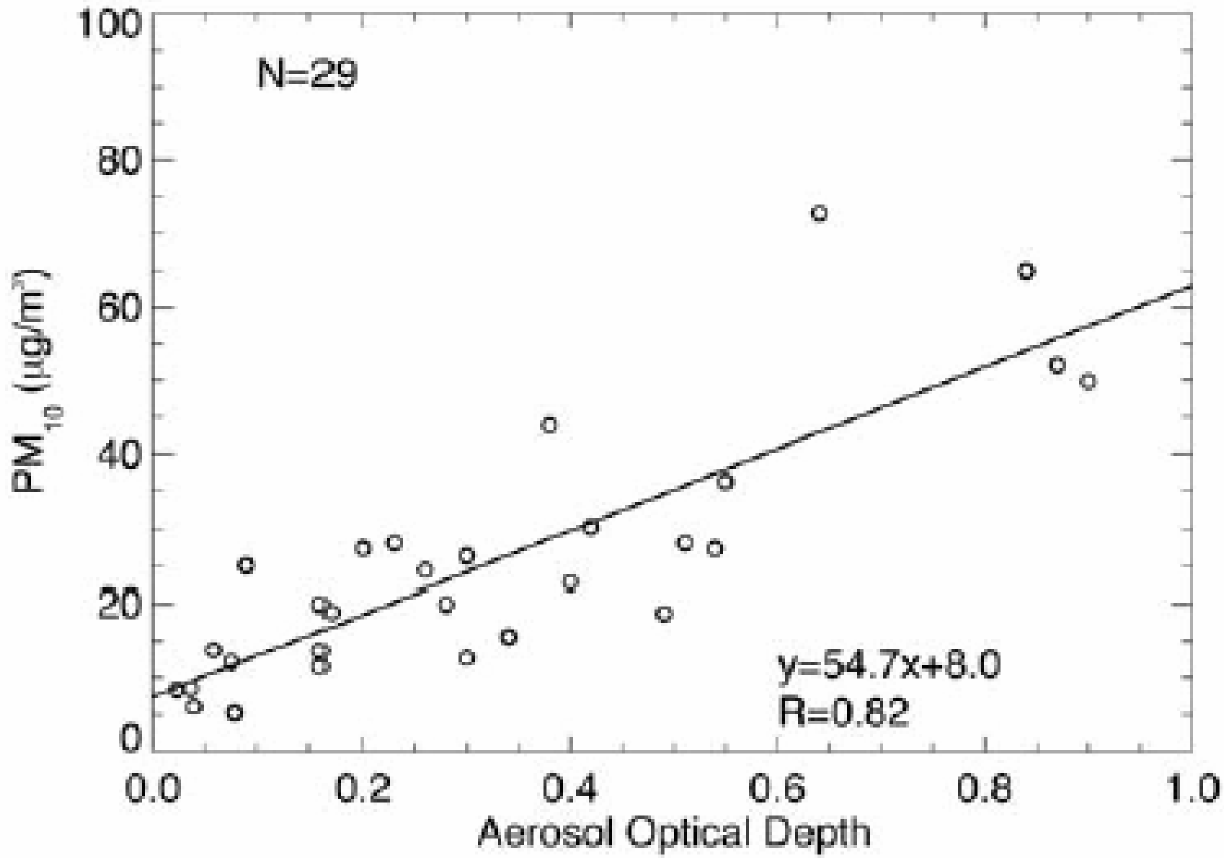


Figure 14. Relationship between 24-hour PM_{10} concentrations and daily averaged AERONET τ_a measurements from August to October 2000 in northern Italy.

Chu et al., JGR, 2003

Global aerosol tools relevant to AQ!

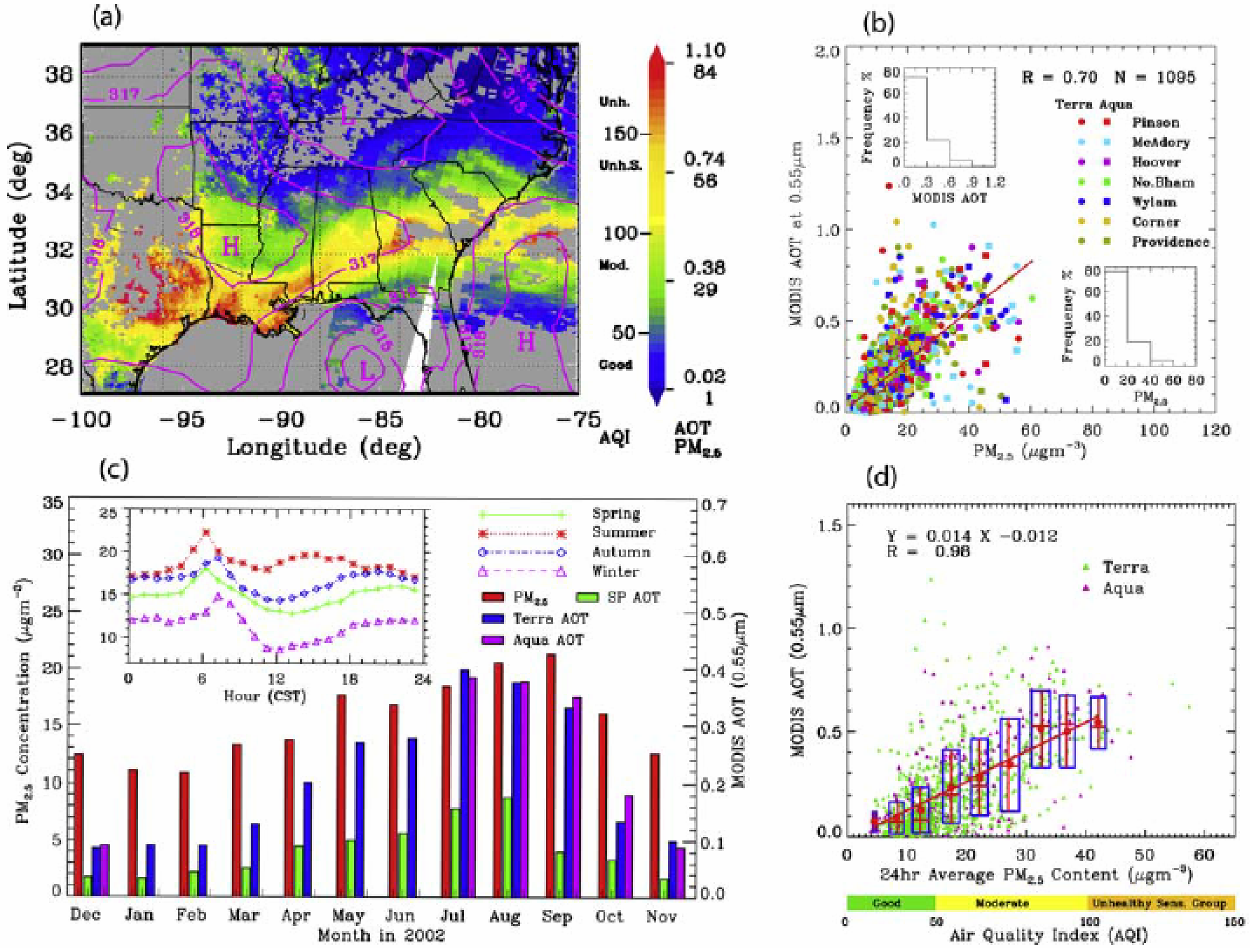
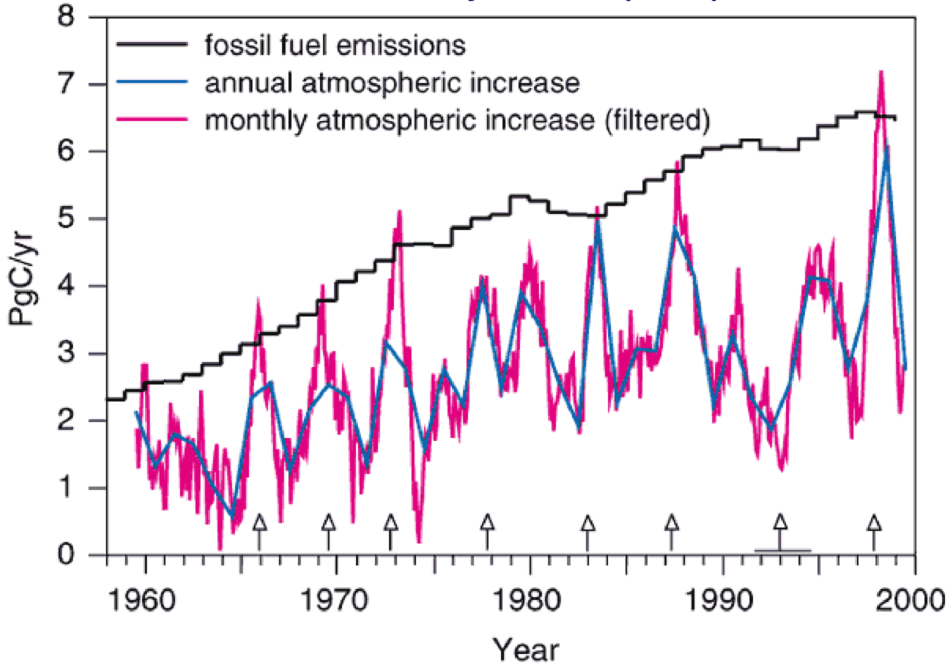


Figure 2. (a) Spatial distribution of MODIS AOT and linearly derived AQI from Terra on Sept 11, 2002. Also shown are the 700mb geopotential heights. Grey regions are areas where MODIS AOT is not available due to possible sun glint or cloud contamination. (b) Relationship between MODIS AOT and $PM_{2.5}$ mass, (c) Monthly variation of $PM_{2.5}$ and MODIS and Sunphotometer (SP) AOT, inset shows the diurnal variations (in Central Standard Time, CST) of $PM_{2.5}$ in different seasons. (d) AQI derived from MODIS data. The box shows the ±1 standard deviation of $PM_{2.5}$ and AOT centered in the mean value (red filled circles) in each bins. The red line in the box shows the median value in each bin.

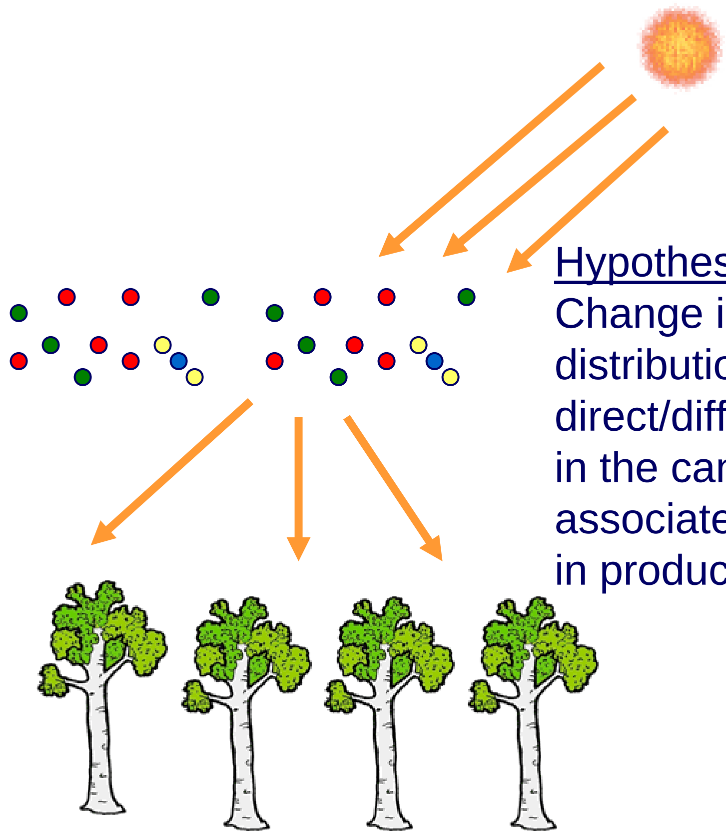
Wang and Christopher, GRL, 2003

An aerosol impact on carbon sinks?

Interannual variability in the (land) carbon sink



Hypothesis: some of it may be caused by large events of stratospheric aerosols



Hypothesis:
Change in the distribution of direct/diffuse light in the canopy with associated changes in productivity

If true, there must have been a (transient) effect of tropospheric aerosols on the land carbon sink during the XX century.

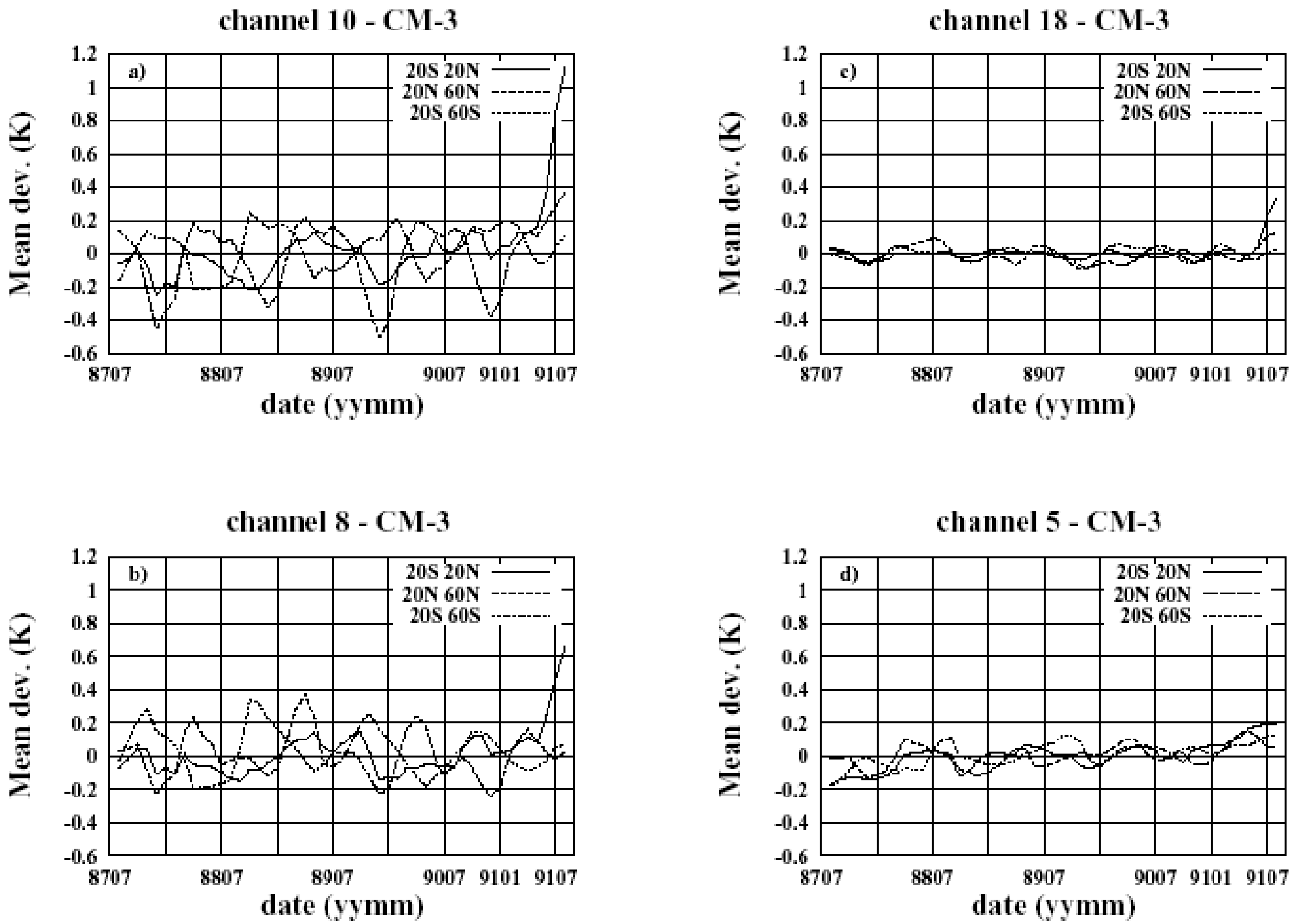
Aerosol impact on NWP forecasts

Aerosols can affect NWP forecasts, analysis and reanalysis through three different ways:

1. Aerosols may adversely impact satellite data or satellite retrievals which are assimilated in the NWP suite
2. Aerosols modify the clear-sky radiative fluxes with impact on the surface and atmospheric temperature profile (unaccounted term in the equation for energy conservation => imperfect model).
3. Aerosols modify cloud properties (unaccounted for in the model).

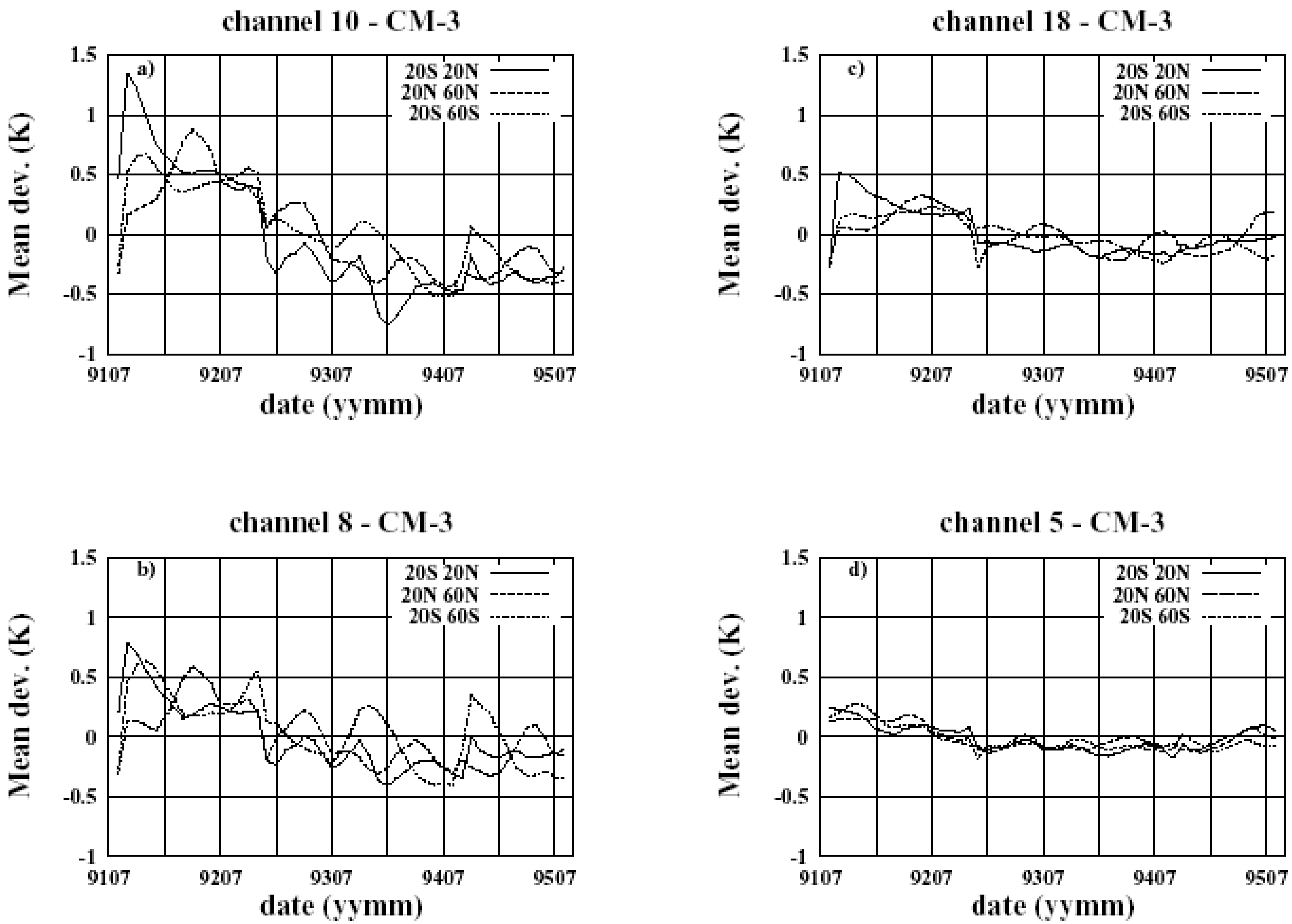
Aerosol impact on satellite retrievals (I)

CM3=3-month running mean difference in $BT_{calculated}$-$BT_{measured}$ for different HIRS channels



Pierangelo et al., JGR, 109, 2004.

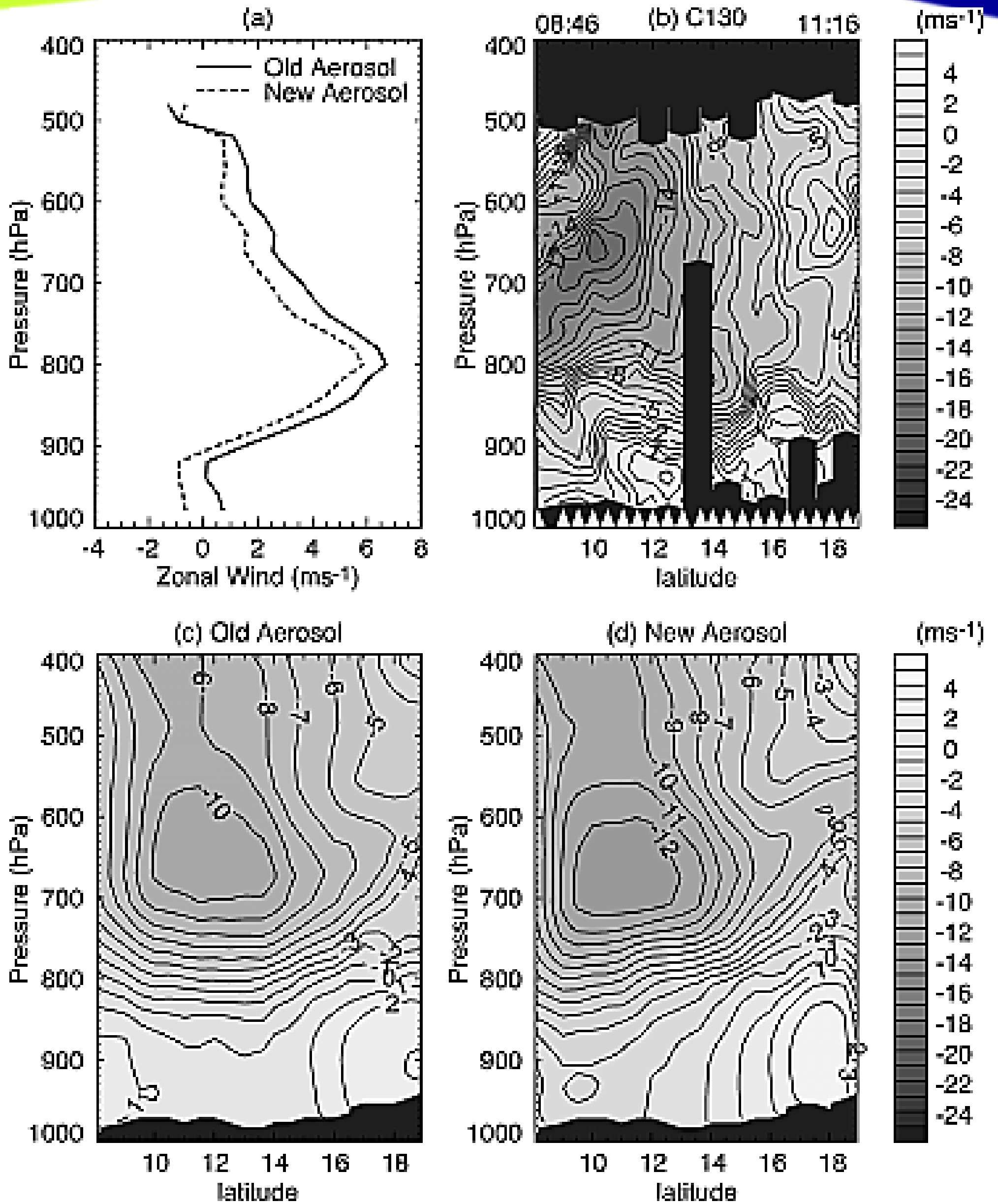
Aerosol impact on satellite retrievals (II)



Pierangelo et al., JGR, 109, 2004.

Aerosols may improve weather forecasts (I)

Tompkins et al., Influence of aerosol climatology on forecasts of the African Easterly Jet, GRL, 32, 2005.

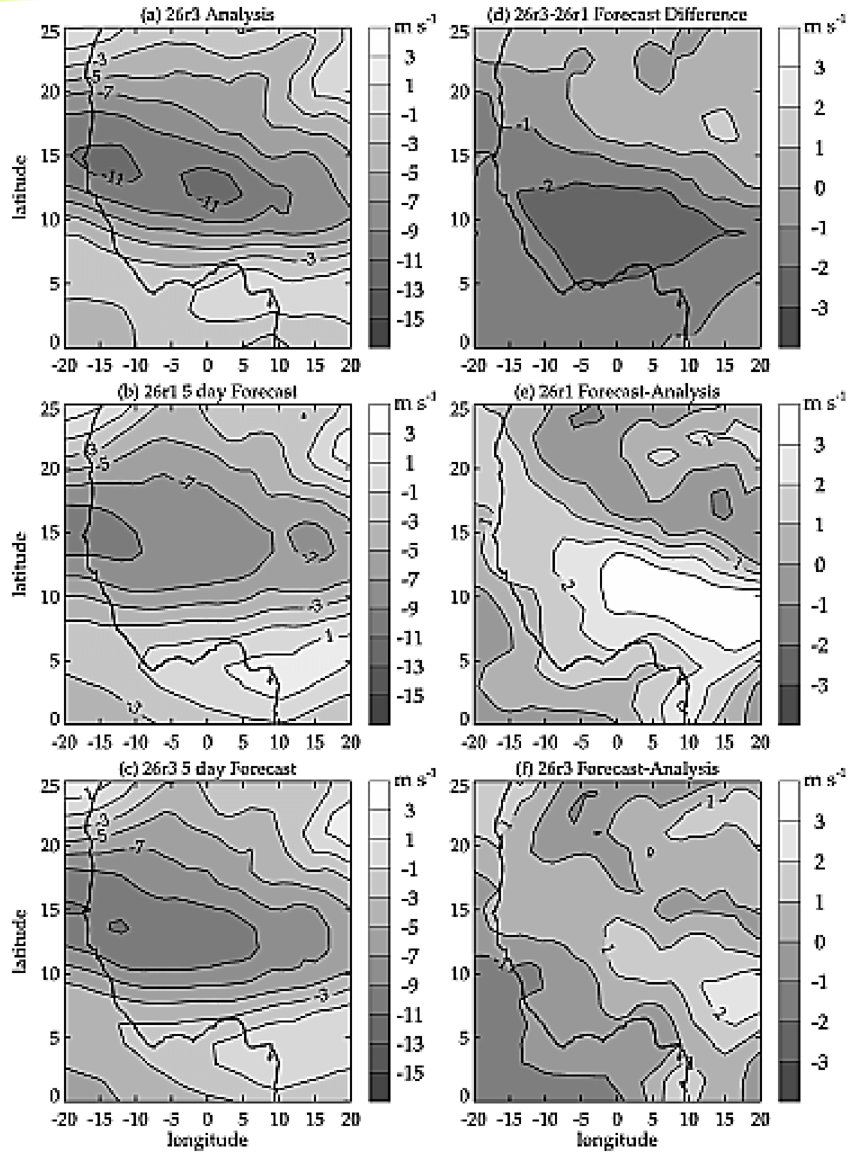


Aerosols may improve weather forecasts (II)

Tompkins et al., Influence of aerosol climatology on forecasts of the African Easterly Jet, GRL, 32, 2005.

OLD

NEW



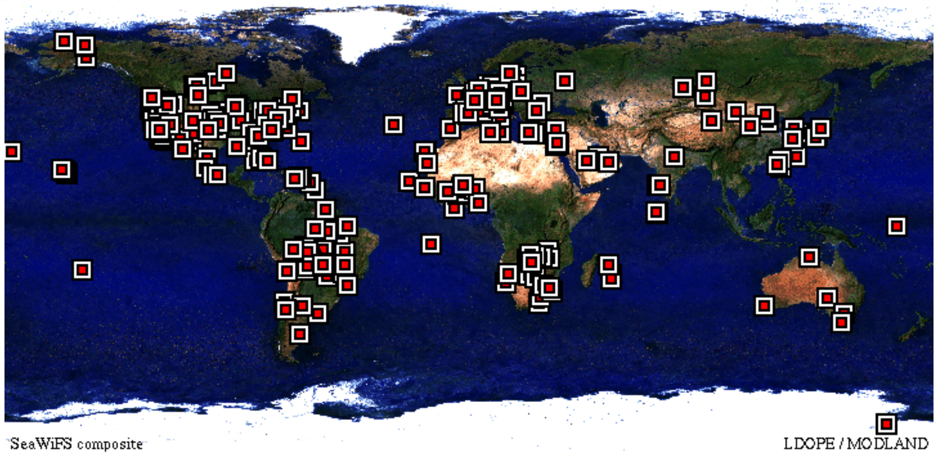
OUTLINE

1. **Why do we need to monitor aerosols globally?**

2. **Design of an aerosol monitoring system**

3. **GEMS-aerosol**

Ground-based networks (examples)

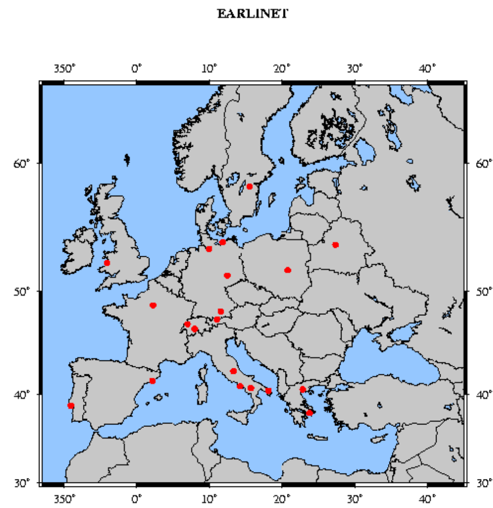


AERONET (PHOTONS)

aeronet.gsfc.nasa.gov

www-loa.univ-lille1.fr/photons

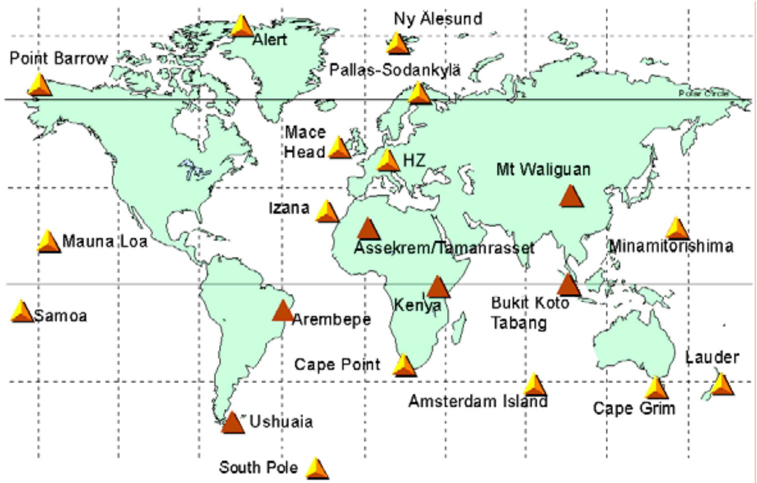
EARLINET



lidarb.dkrz.de/earlinet/

World Data Centre for Aerosols

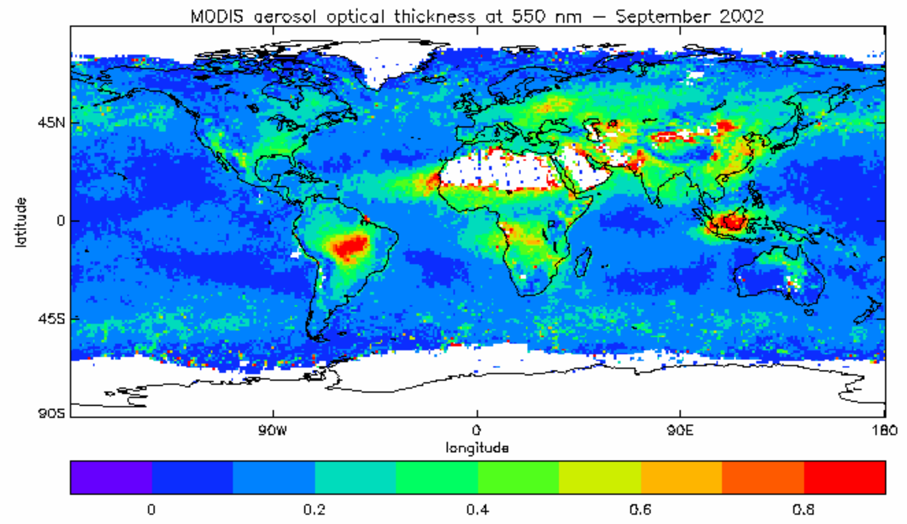
(GAW / WMO) www.ei.jrc.it/wdca/

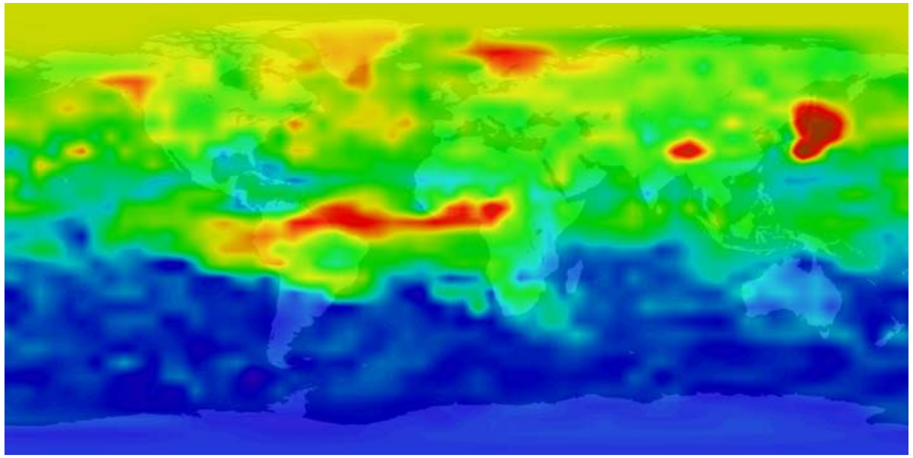


+ EMEP / IMPROVE

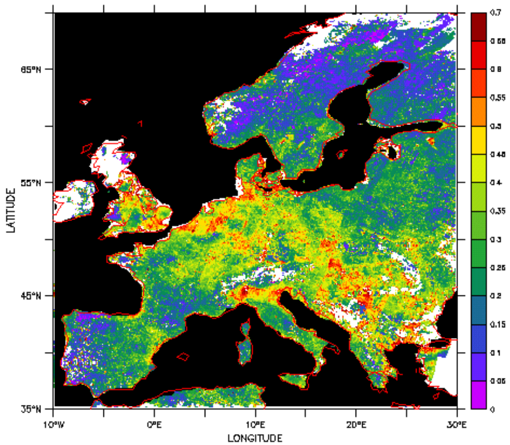
Aerosol-relevant satellite data (examples)

MODIS aerosol optical depth



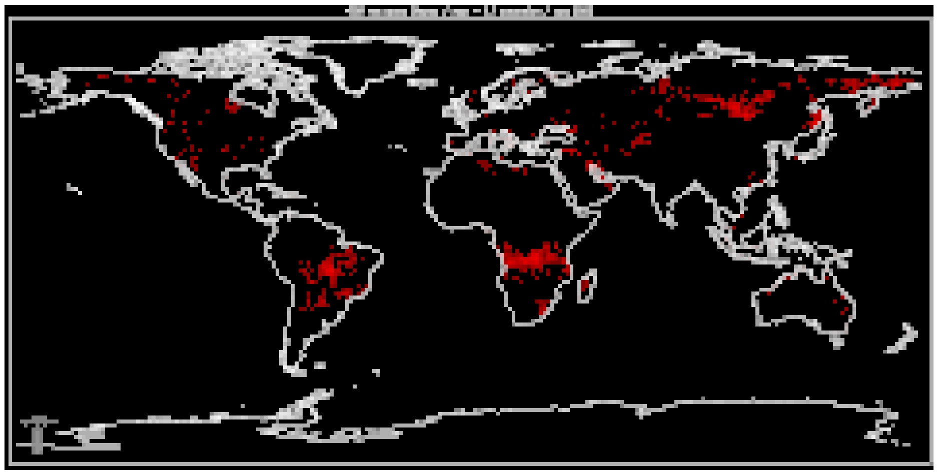


MOPITT CO concentrations



ATSR (G. de Leeuw, TNO)

ATSR fire counts

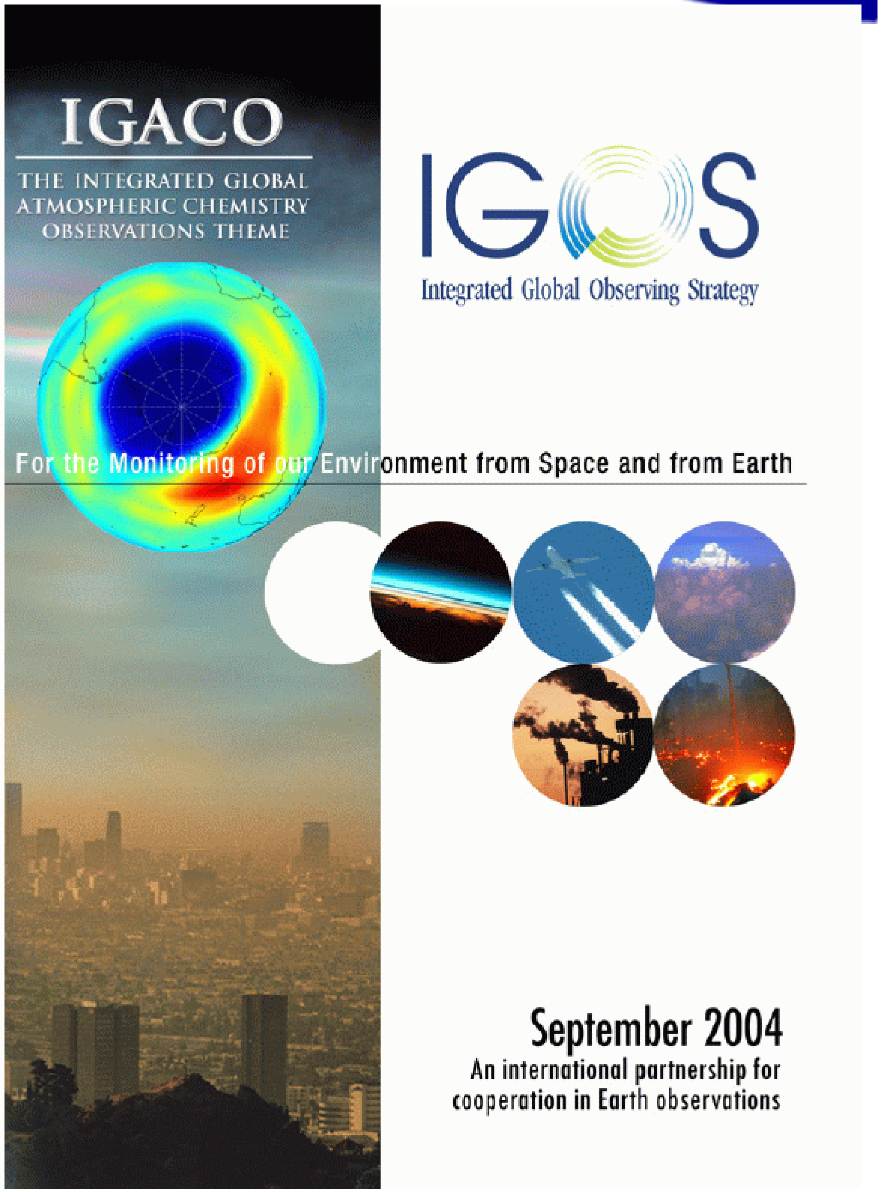


IGACO

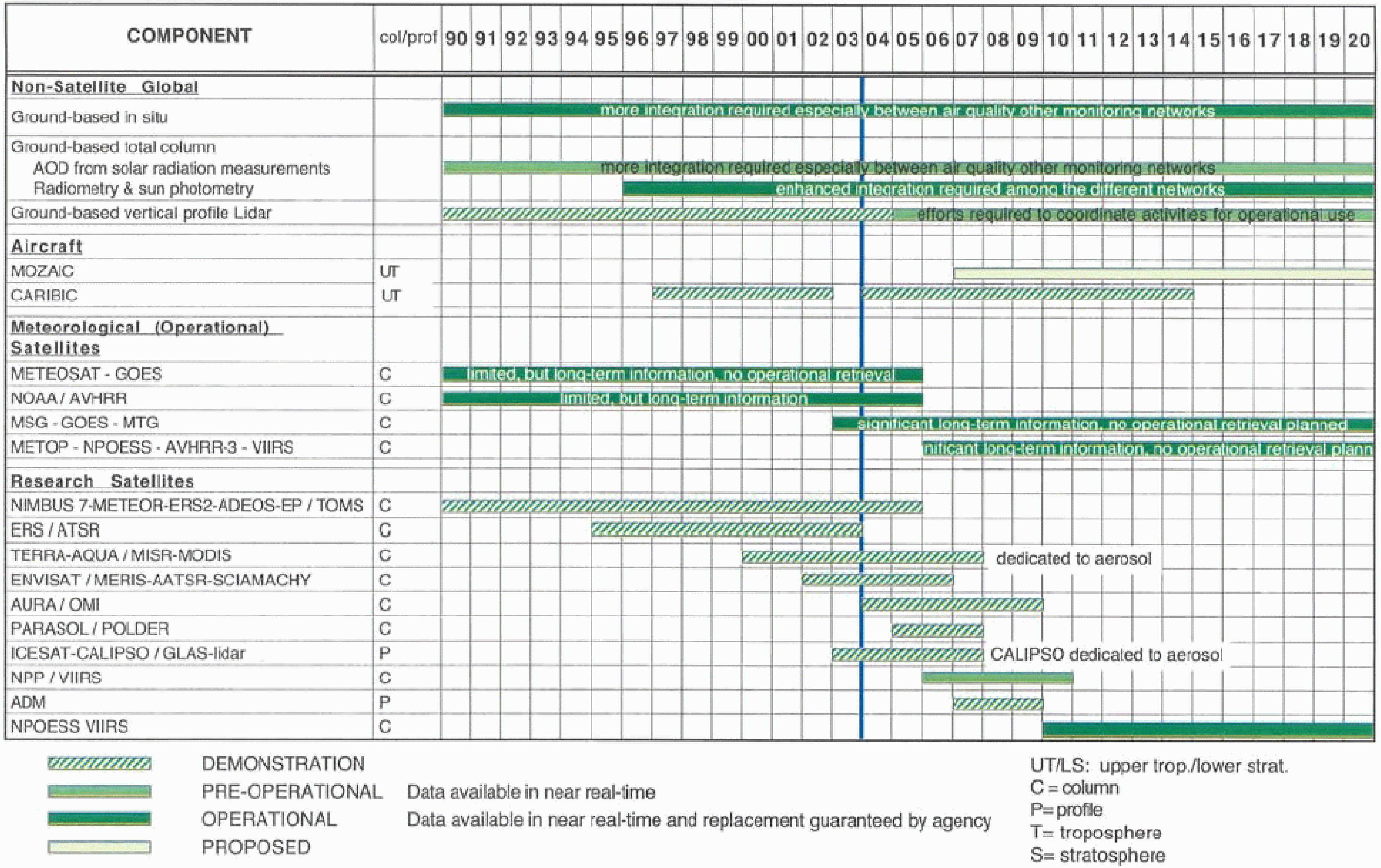
The report summarizes
- ground in-situ
- aircraft in-situ
- spaceborne remote-sensing
- ground remote-sensing

and suggests priorities

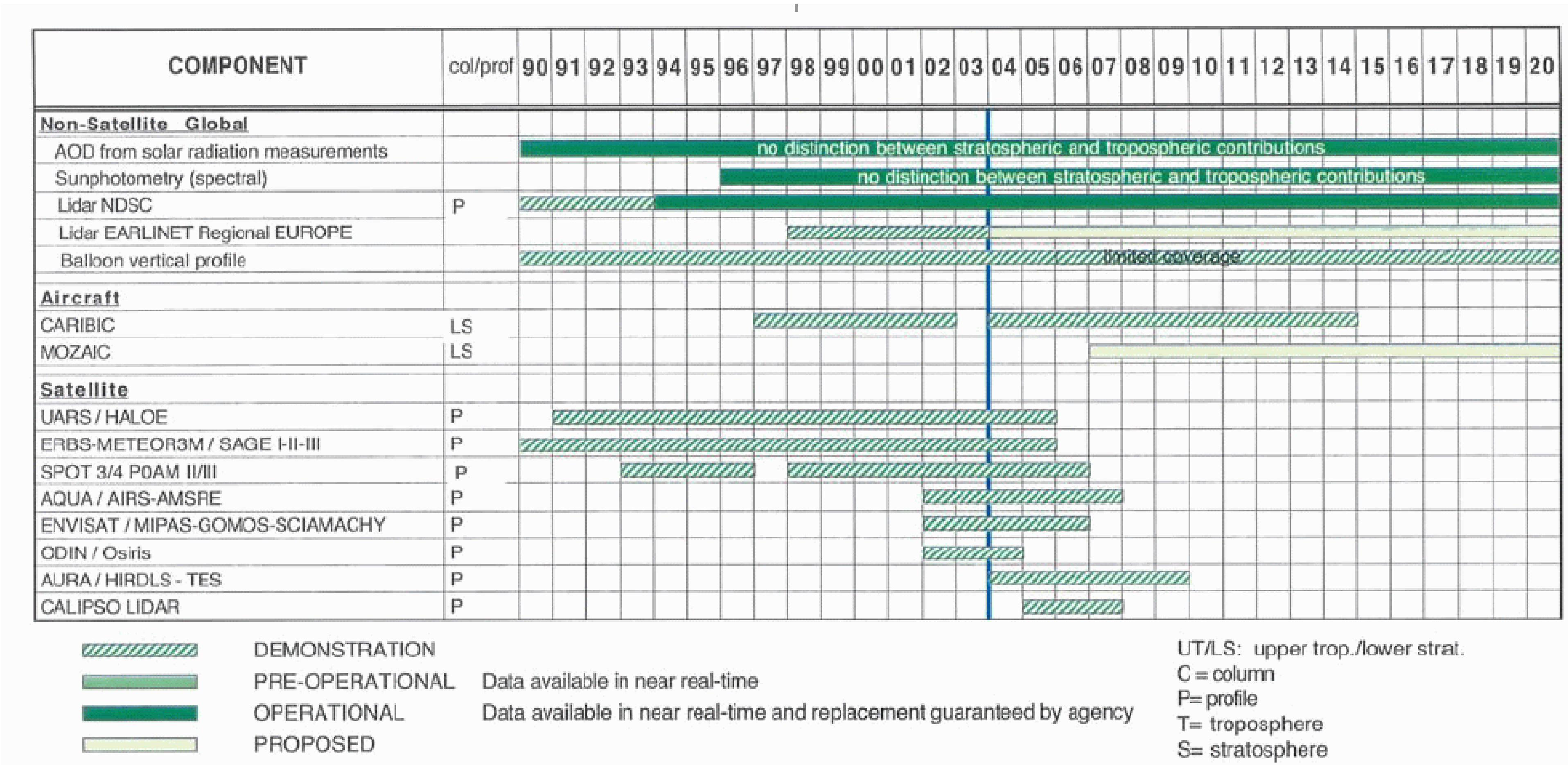
Implementation plan ongoing



IGACO – Tropospheric aerosols

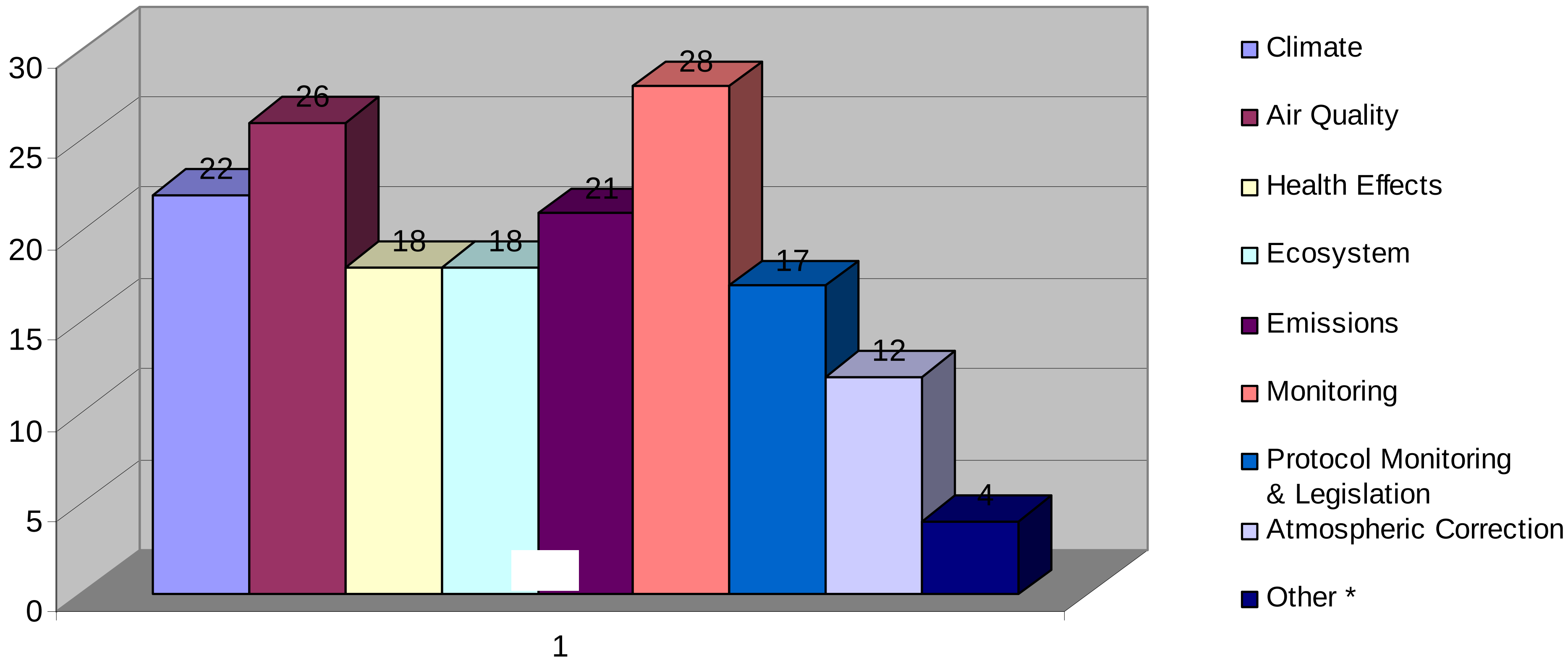


IGACO – Stratospheric aerosols



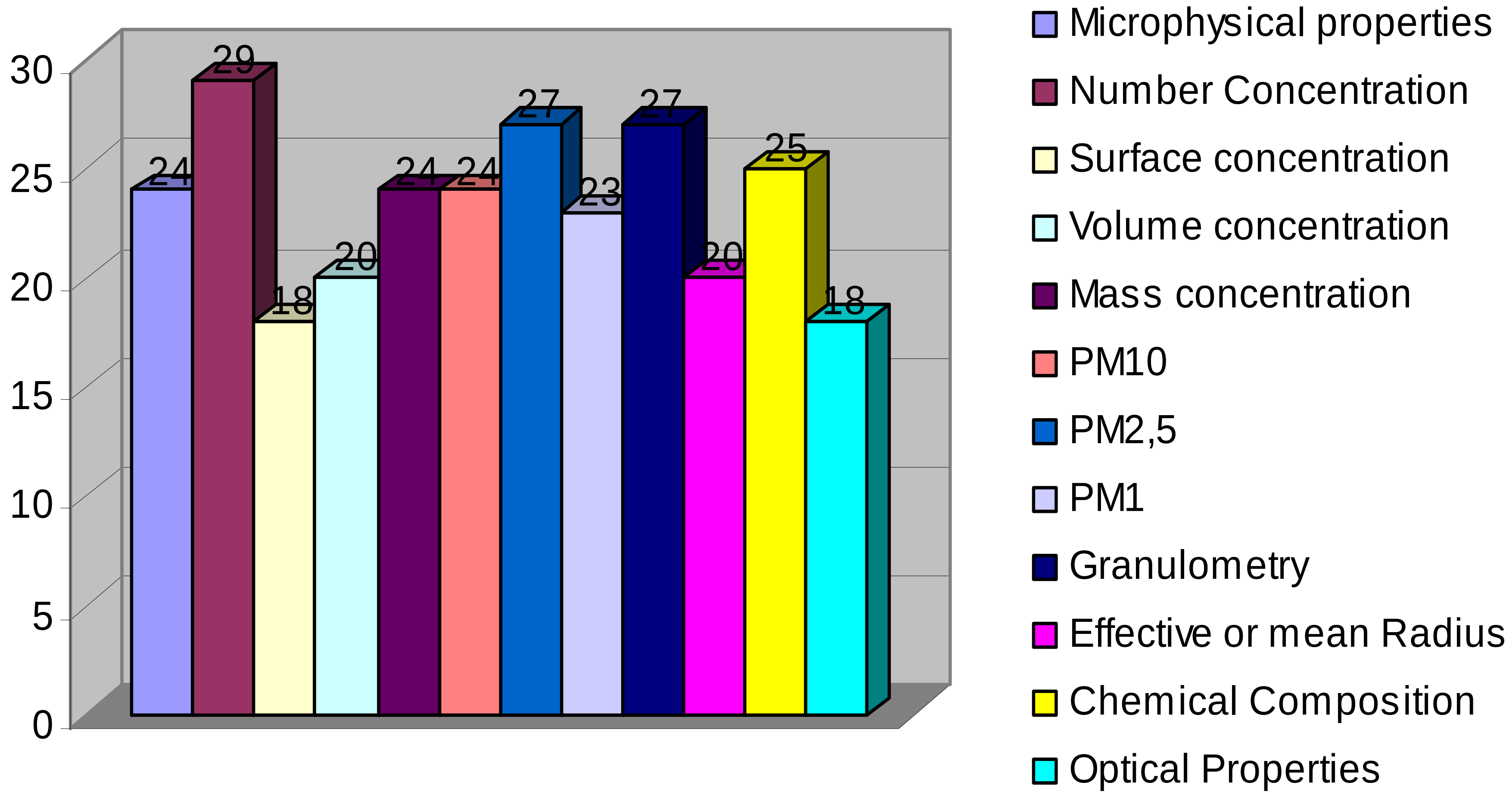
Areas of interest

Climate	Air Quality	Health Effects	Ecosystem	Emissions	Monitoring	Protocol Monitoring & Legislation	Atmospheric Correction	Other *
22	26	18	18	21	28	17	12	4

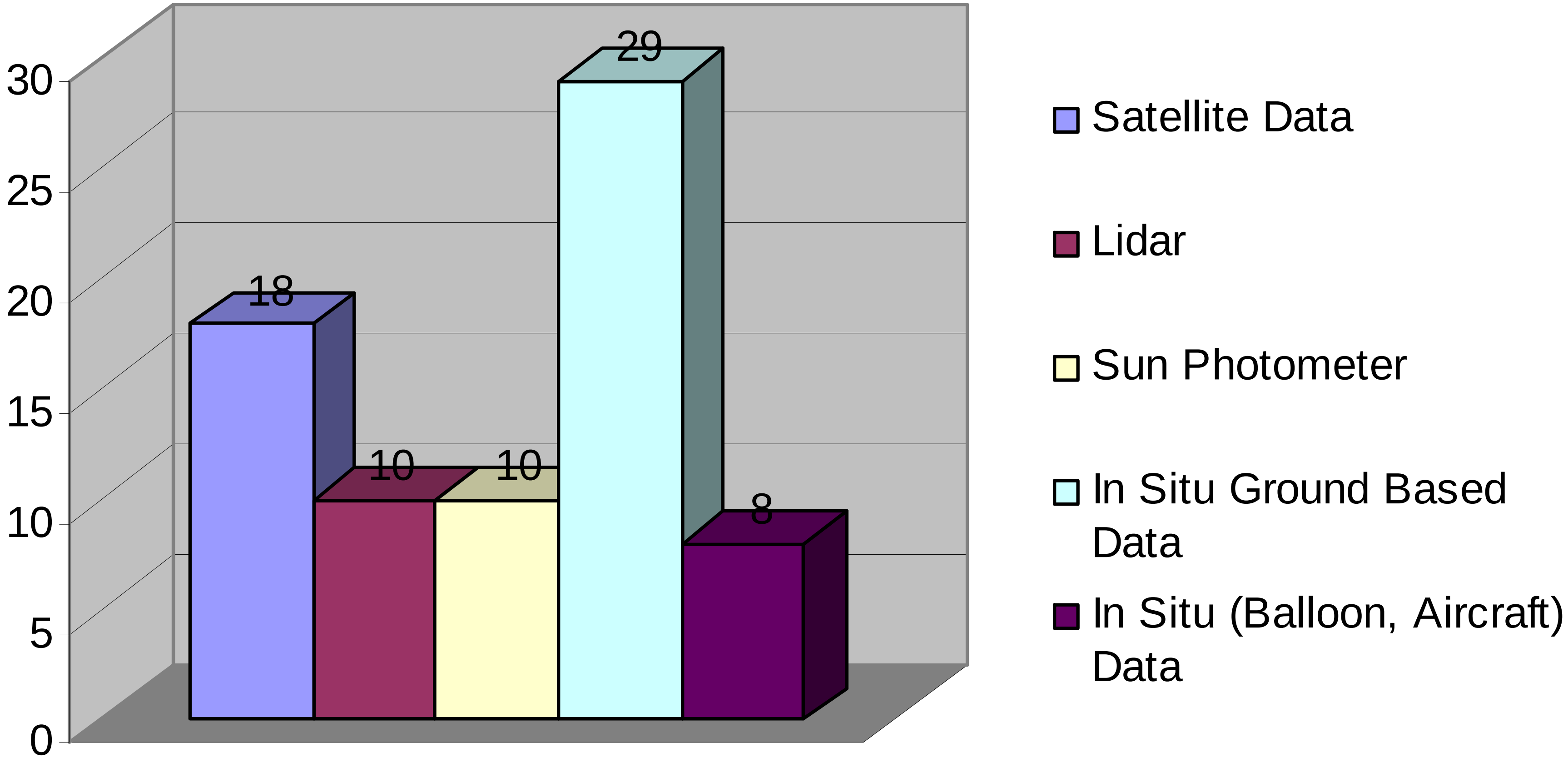


Aerosol properties of interest

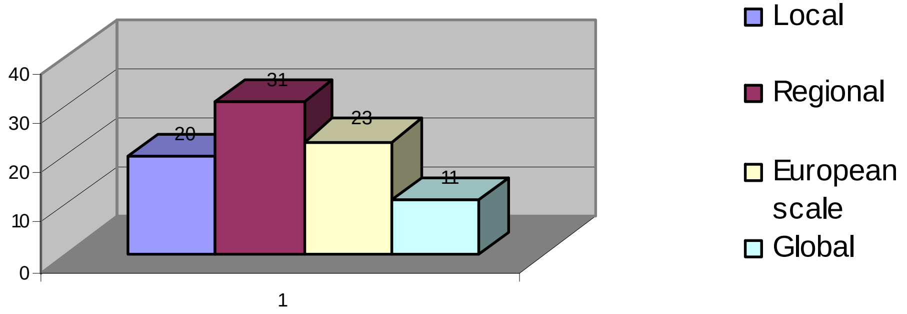
97% of users interested in aerosols (3% in gas species)
91% of users interested in tropospheric aerosols
38% of users interested in stratospheric aerosols



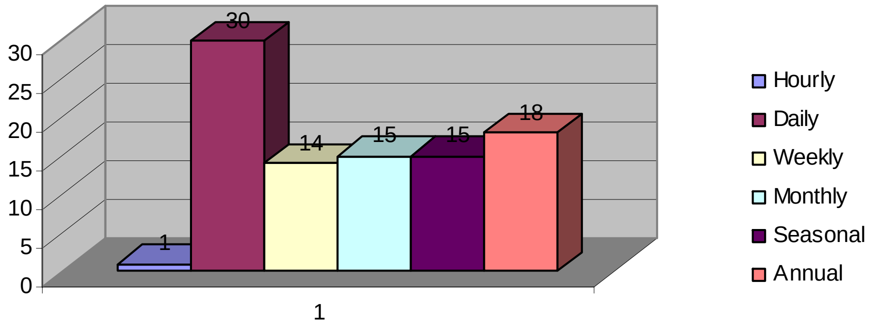
Present use of aerosol data



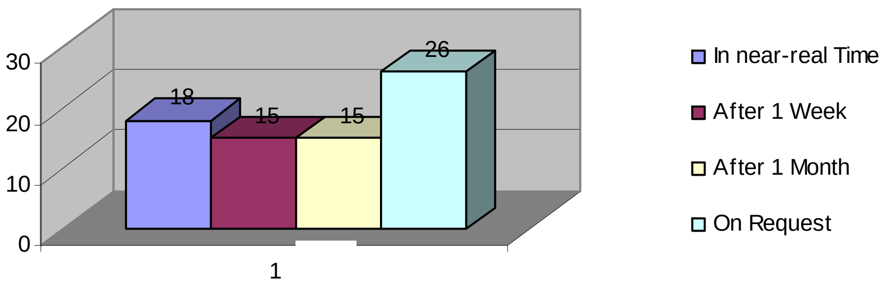
Requirements for satellite data



Spatial resolution



Time resolution (average)



Timeliness

OUTLINE

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Satellite coverage

Chu et al., JGR, 2003

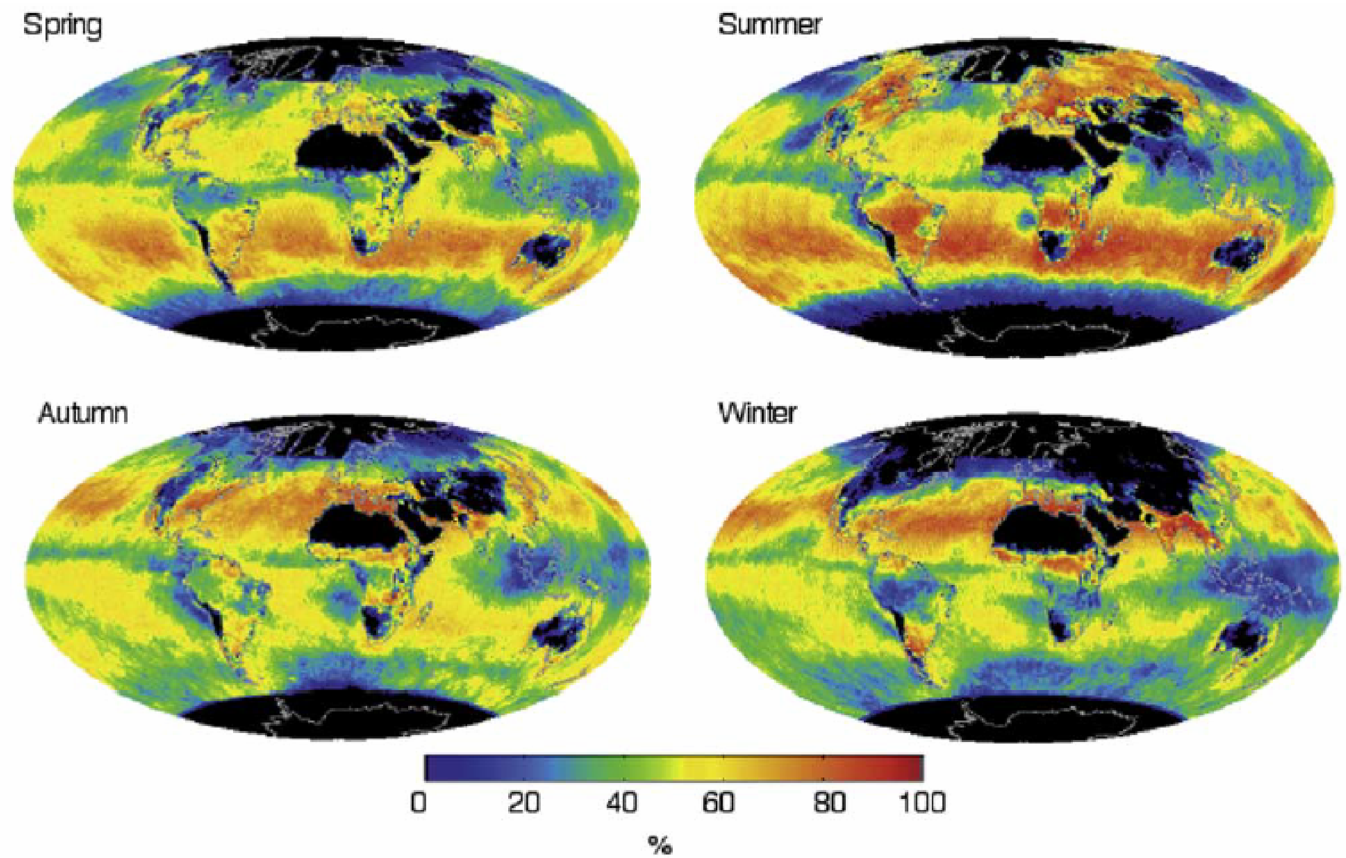
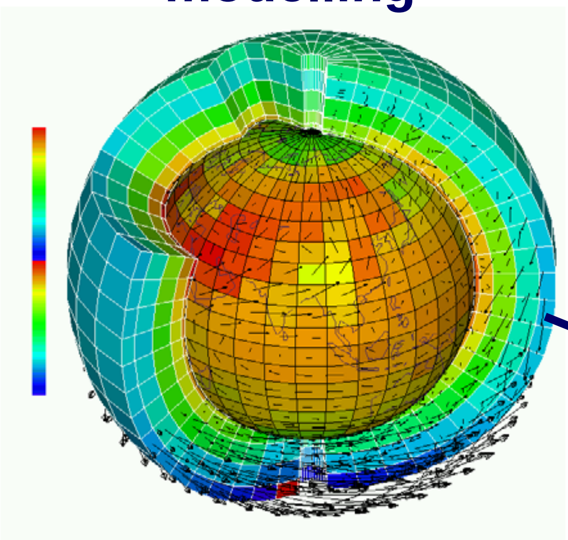


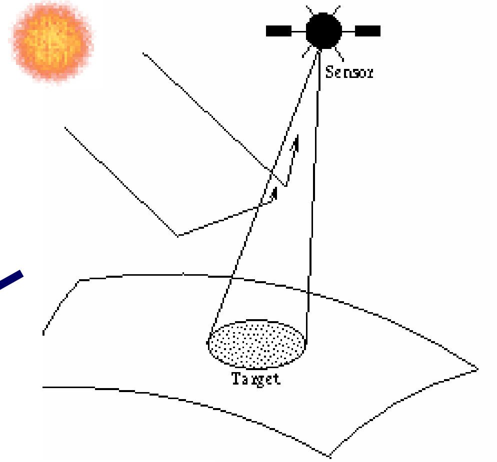
Figure 6a. Frequency maps of MODIS aerosol retrievals for spring (March–May 2001), summer (June–August 2001), autumn (September–November 2001), and winter (December 2000–January 2001). Frequency (%) is calculated using MODIS L3 daily products as the number of days with successful retrievals in 1° × 1° grids divided by the total number of calendar days in the season. Filled value (e.g., −9999) is filled in grids with unsuccessful retrieval. Note that a single retrieval from a 10 × 10 km^2 area of L2 is allowed to represent a 1° × 1° area of L3.

Aerosol monitoring in GEMS

modelling



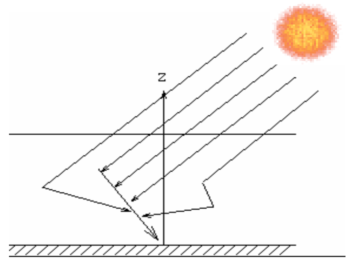
Spaceborne remote sensing



data assimilation

Operational Weather Centre

in-situ
(ground, aircraft)



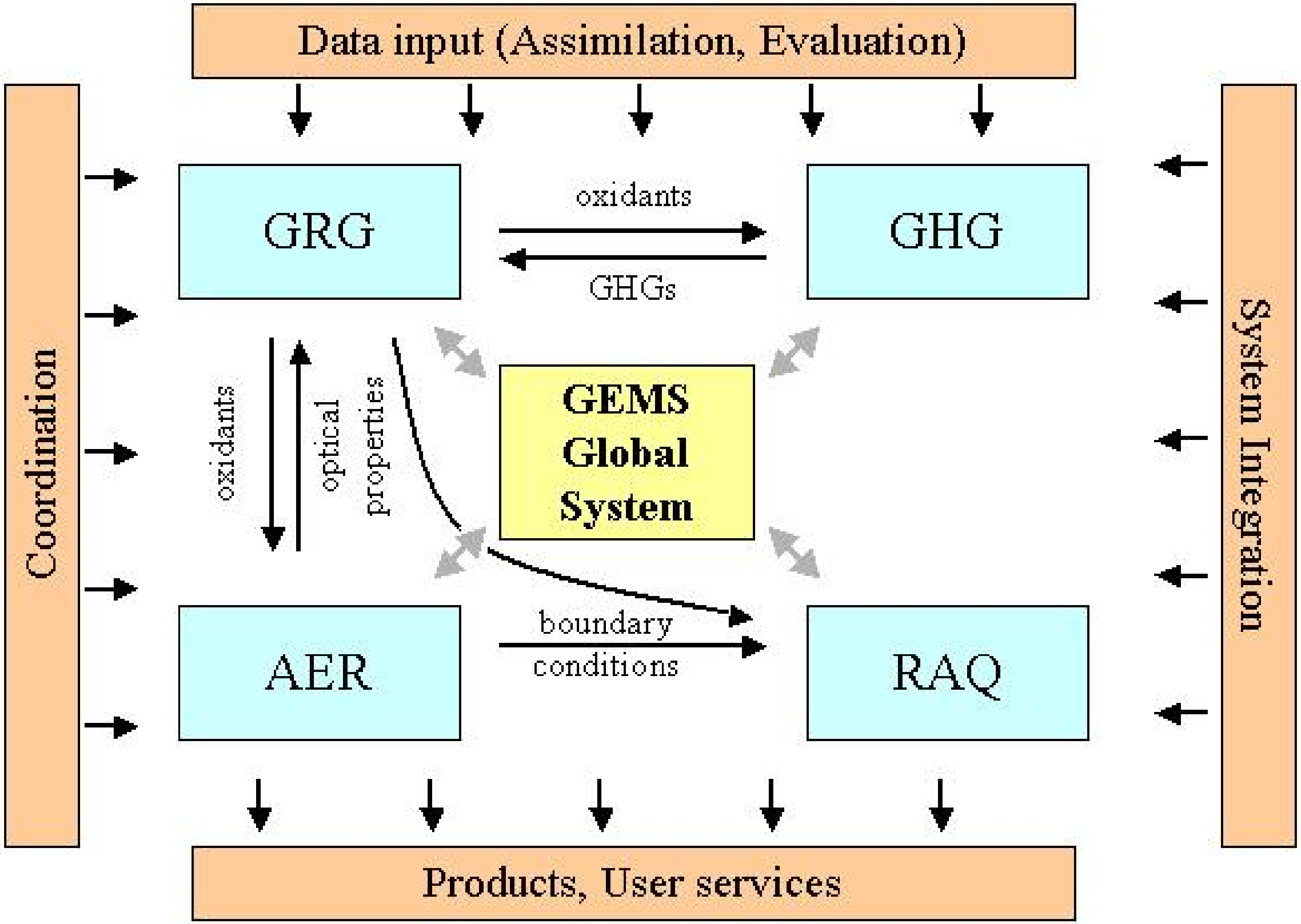
Ground-based remote-sensing

validation

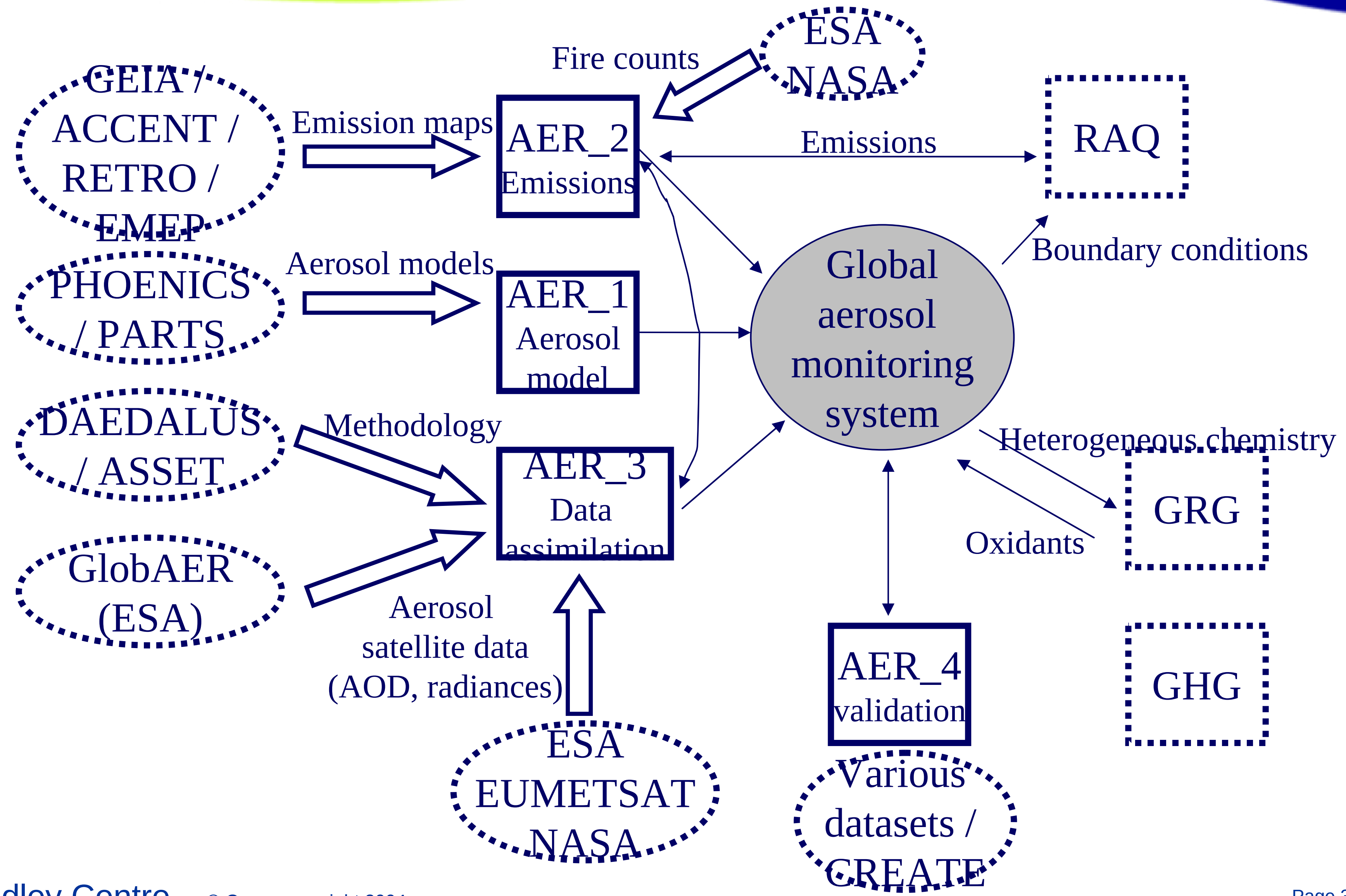
Analyses

Users community:
meteorology/climate/
pollution/ecosystems/
atmospheric
corrections

Aerosol monitoring in GEMS



Aerosol monitoring in GEMS



Aerosol monitoring in GEMS

Products	Usage
4D distribution of aerosol concentrations at 50-100 km resolution (troposphere and stratosphere)	climate research; monitoring of the atmospheric chemical composition; monitoring of the stratosphere (air traffic); monitoring of volcanic eruptions for local populations; initial and boundary conditions for regional air quality models
4D distribution of aerosol optical properties at 50-100 km resolution (troposphere and stratosphere)	atmospheric corrections for remote sensing of land surfaces and ocean; prediction of surface UV radiation
Surface distribution of particulate matter PM	regional air quality
Improved visibility range	air traffic, tourism
Improved photosynthetically active radiation (PAR) at the surface	study of the carbon cycle; monitoring of the Kyoto protocol
Aerosol deposition flux (dry and wet)	study of the ocean biology; impact on ecosystems (acid rain monitoring)
Improved photolysis rates	regional air quality; global monitoring of the atmospheric chemical composition
Improved surface, atmospheric, and top-of-atmosphere radiative budget	climate research

Aerosol modelling

Important criteria for model implementation:

- aerosol parametrisations need to be consistent with the ECMWF physics
- aerosol parametrisations need to be computationally affordable
- choice of aerosol parametrisations guided by skill scores
- to become interactive aerosols should at least not deteriorate the weather scores

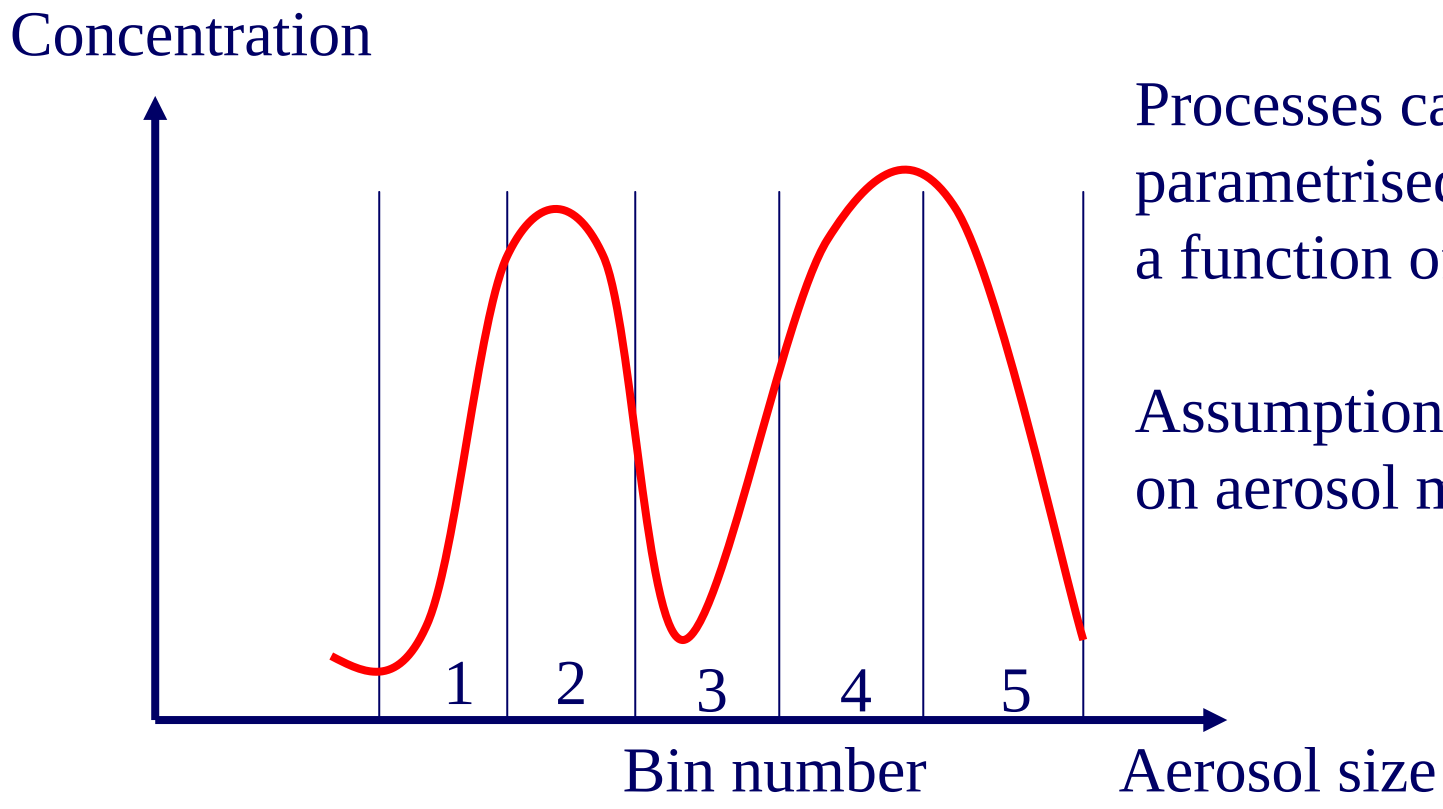
Open questions:

- how sophisticated the aerosol scheme should be?
  - If plenty of good-quality data to assimilate
    - monitoring purposes: simple aerosol scheme is enough
    - forecasting purposes: more complex scheme
  - If limited availability of good-quality data to assimilate
    - a more sophisticated aerosol scheme is desirable

  ==> Balance between data availability, model quality and CPU
  number of model variables > or >> number of satellite variables

- what is the best approach: sectional or modal representation?

Aerosol modelling: sectional approach

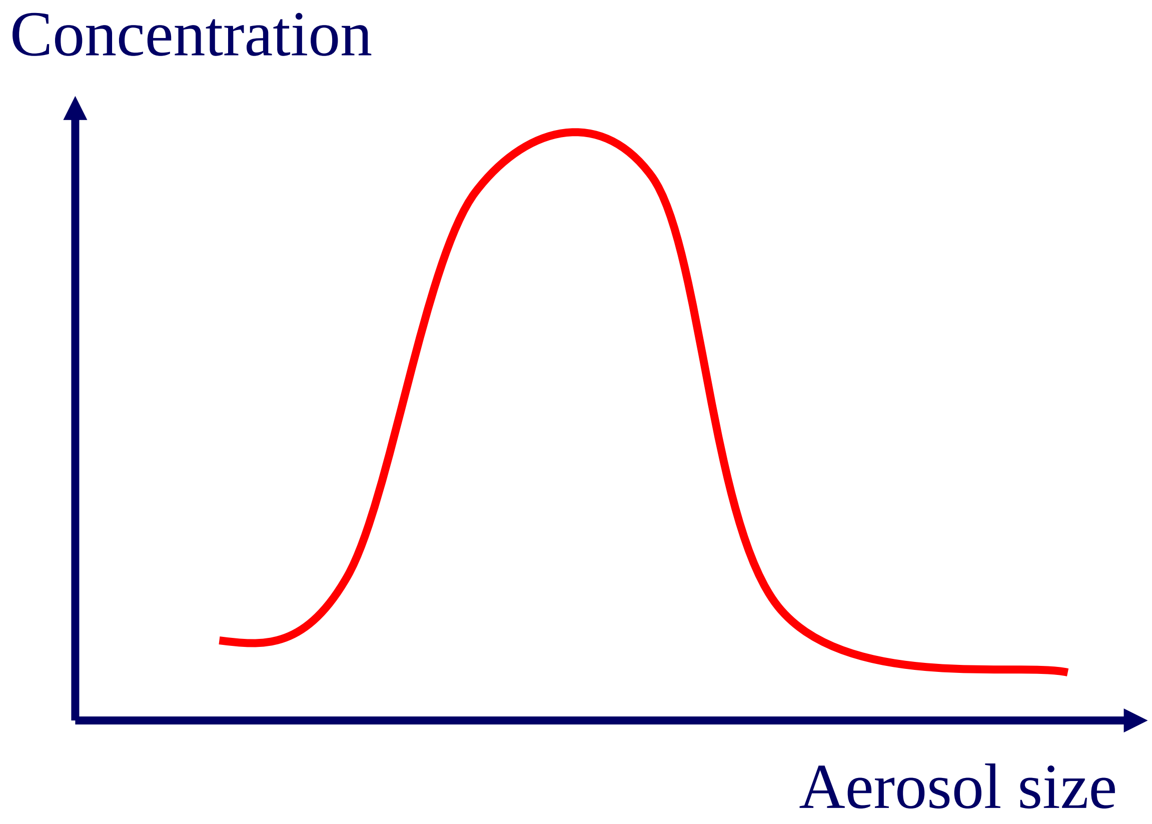


Variables: number or mass in each bin.

Processes can be parametrised in each bin as a function of aerosol size.

Assumption may be needed on aerosol mixtures

Aerosol modelling: modal approach



Assumed shape for the mode size distribution (usually a log-normal)

Variables: number and mass for each mode (average radius can be computed)

Processes can be parametrised as an integral over each mode.

Assumption may be needed on aerosol mixtures

Aerosol modelling: modal approach

HAM-M7

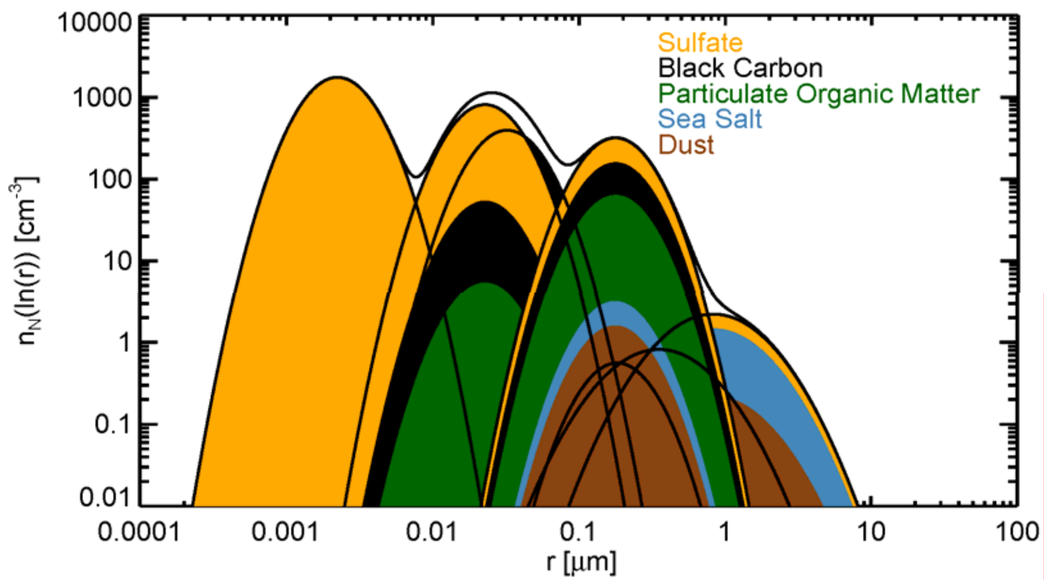
Considered Compounds:

Sulfate | Black Carbon | Organic Carbon | Sea Salt | Mineral Dust

Resolve aerosol size-distribution by 7 log-normal modes

Three modes are composed of solely one aerosol component

Four modes are internal mixtures of several components



Aerosol modelling: modal approach
HAM-M7

Considered Compounds:

Sulfate | Black Carbon | Organic Carbon | Sea Salt | Mineral Dust

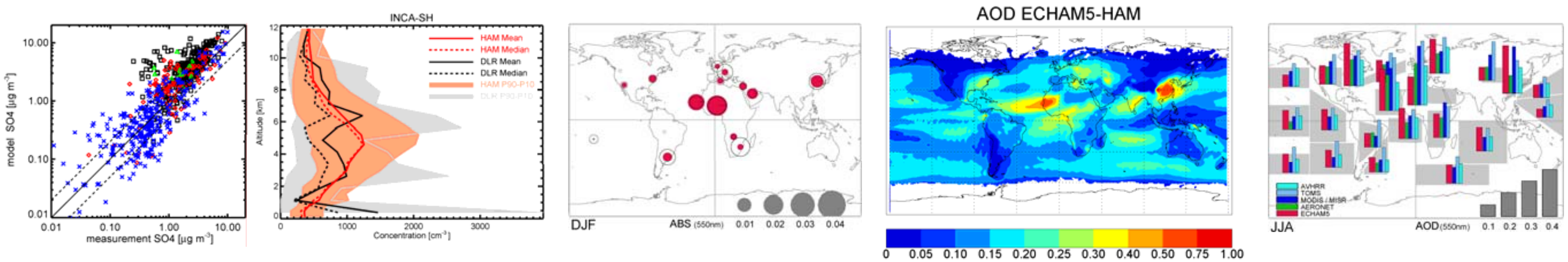
Resolve aerosol size-distribution by 7 log-normal modes

Three modes are composed of solely one aerosol component

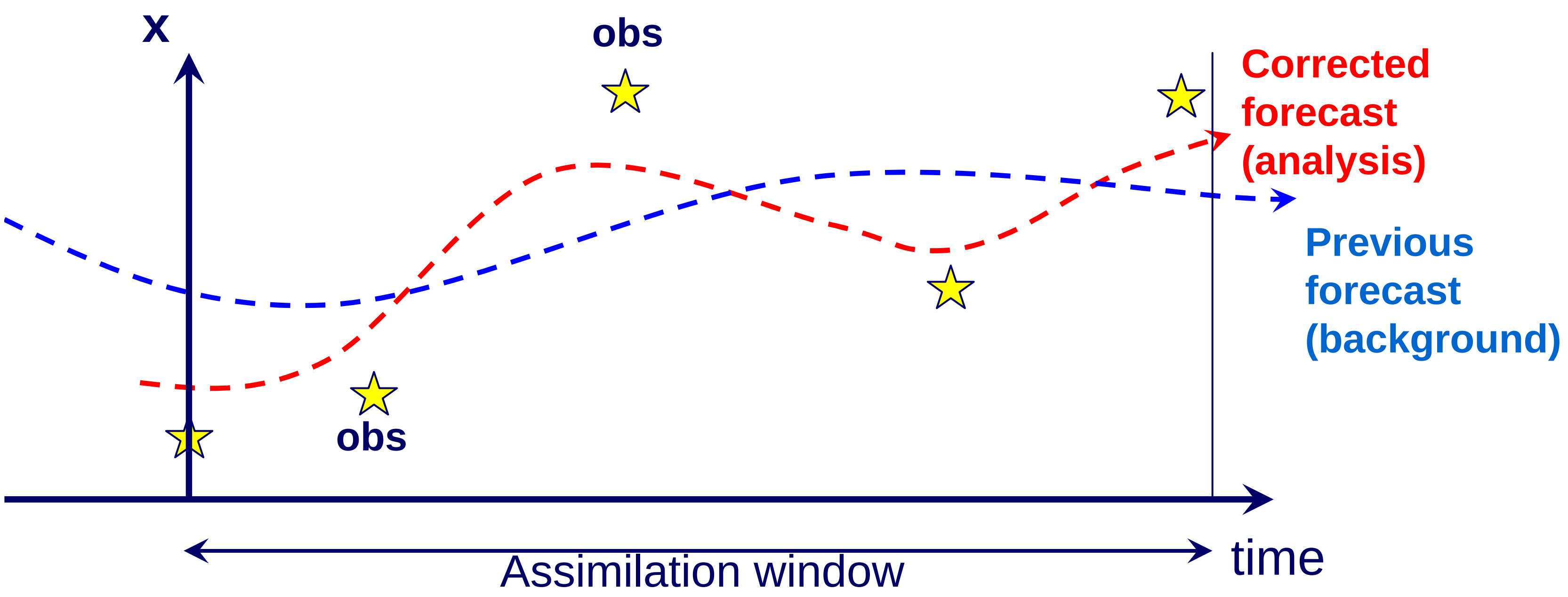
Four modes are internal mixtures of several components

Mode size, mixing state, and composition predicted by microphysical and thermodynamical processes

Detailed description and evaluation in Stier et al., ACP, (2005)



Variational assimilation



$$J=(x-x_b)^T \boldsymbol{B}^{-1}(x-x_b)+(y-\mathbf{H}[x])^T \boldsymbol{R}^{-1}(y-\mathbf{H}[x])$$

+ minimisation algorithm

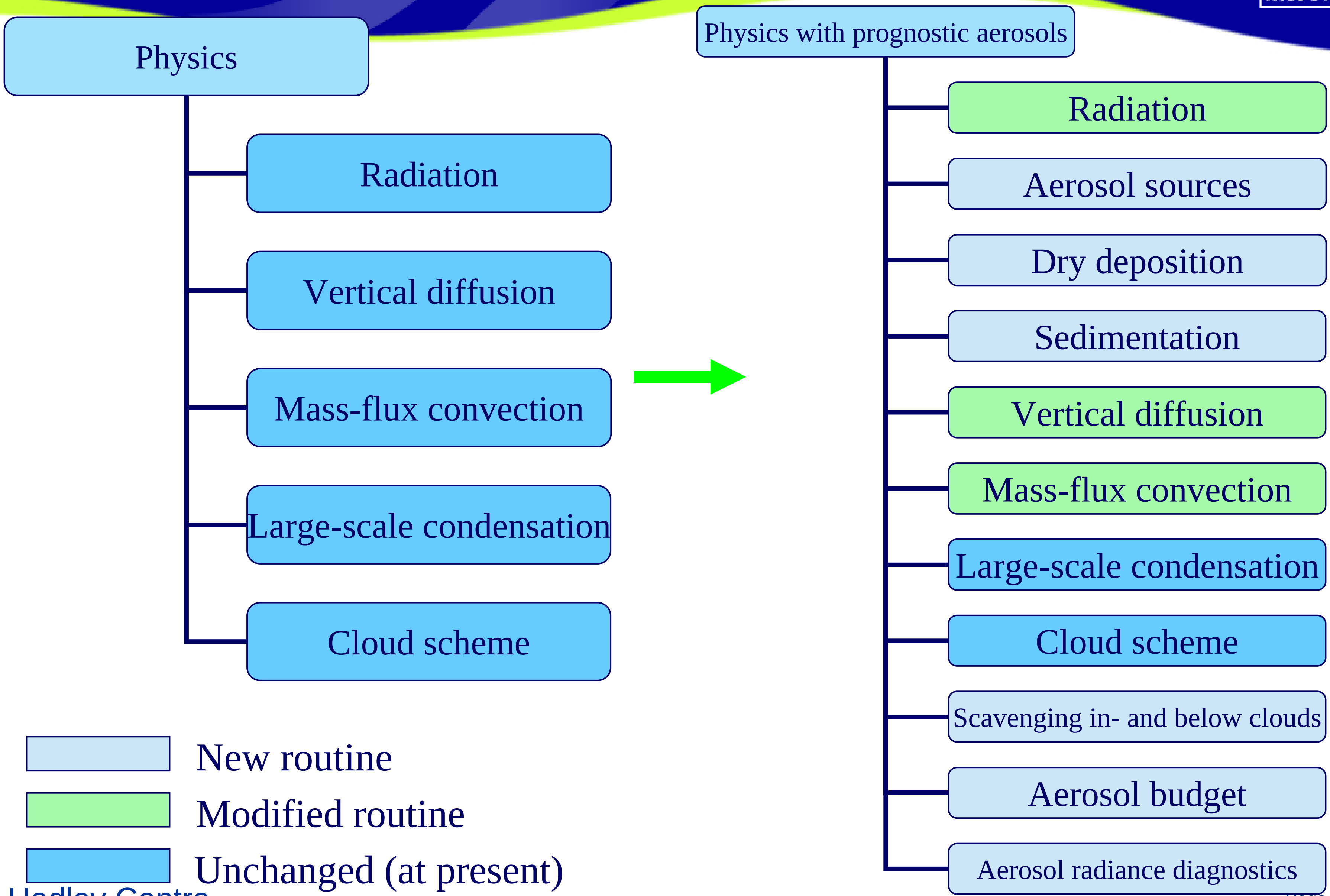
B,R: Covariance error matrices

y: observation

x_b: background

H: obs operator

Development of a prognostic aerosol package in the ECMWF model



Skill scores

- Correlation coefficients (observed vs simulated aerosol properties)
  - current models perform well on monthly means
  - challenge will be to get good correlation on daily means

- Linear fits: slope, offset

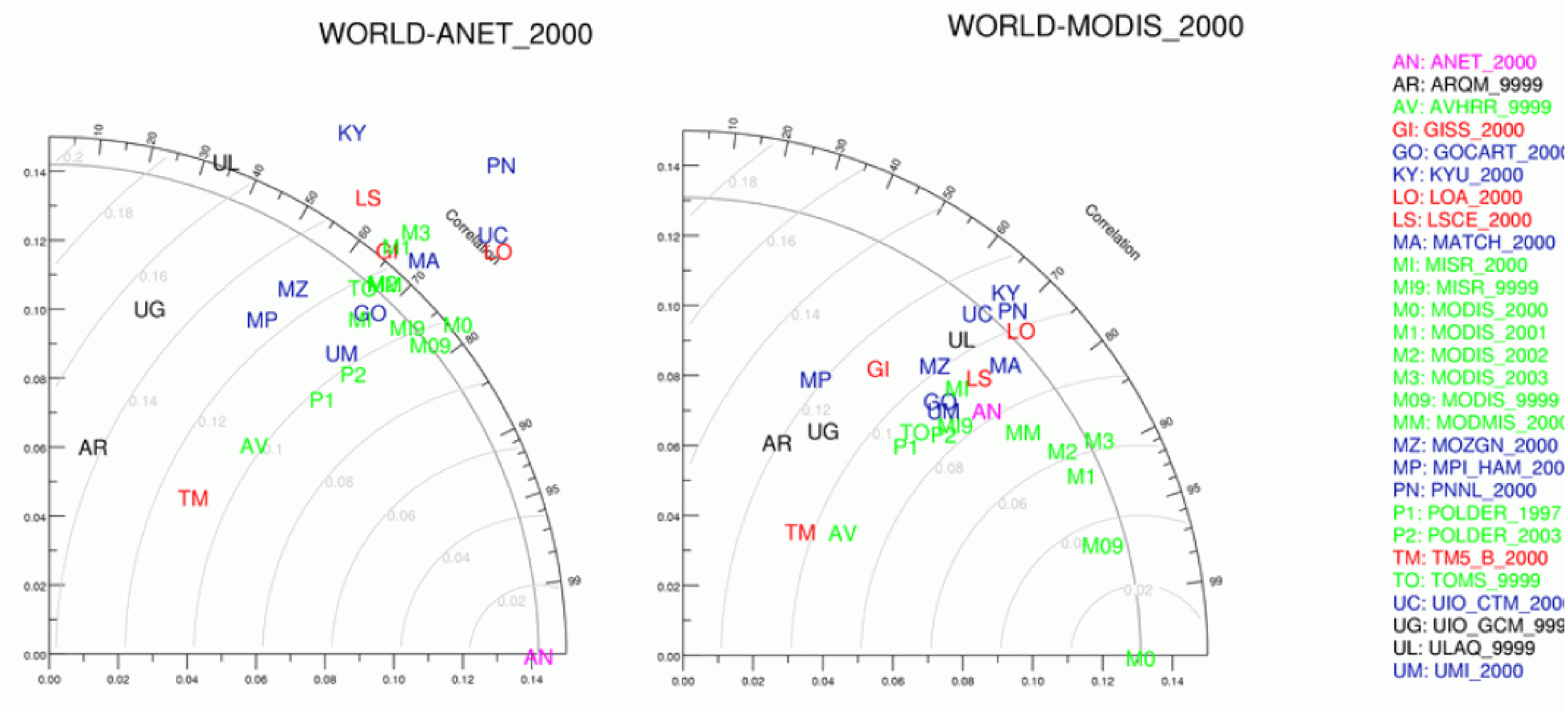
- Root-mean square errors
  - largely used in RAQ

- Taylor diagrams
  - summarizes model performance in terms of correlation coefficient, standard deviation, and RMS.

- Figures of merit
  - useful to test the transport for particular events
  - has been used for ETEX

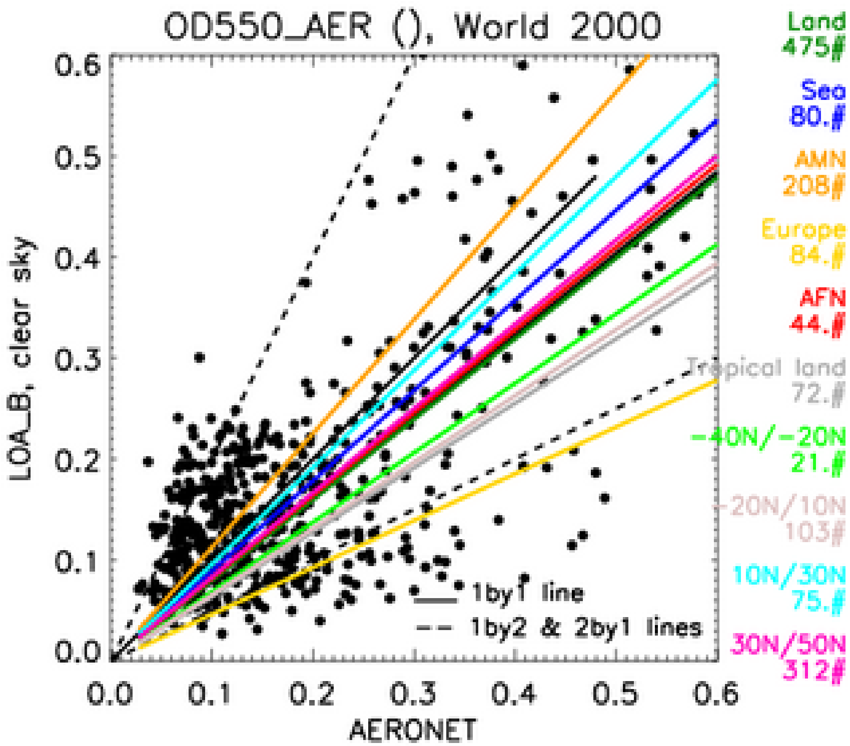
Skill scores

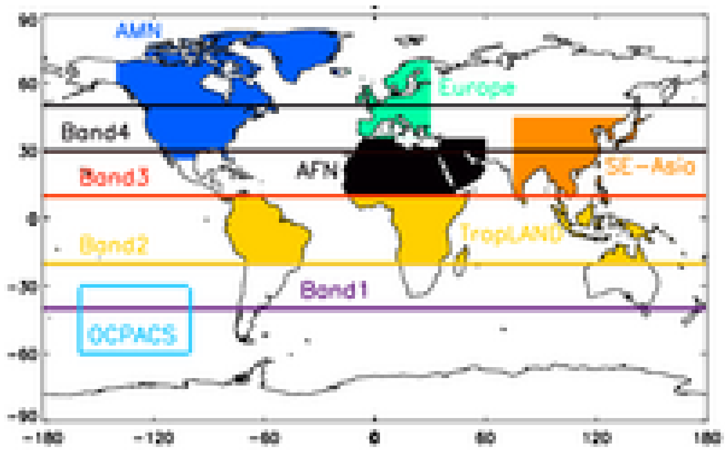
- Taylor diagrams

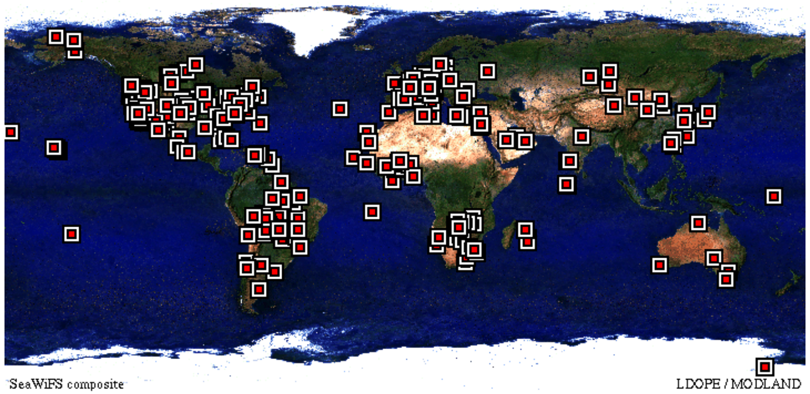


Skill scores

- Correlation plots

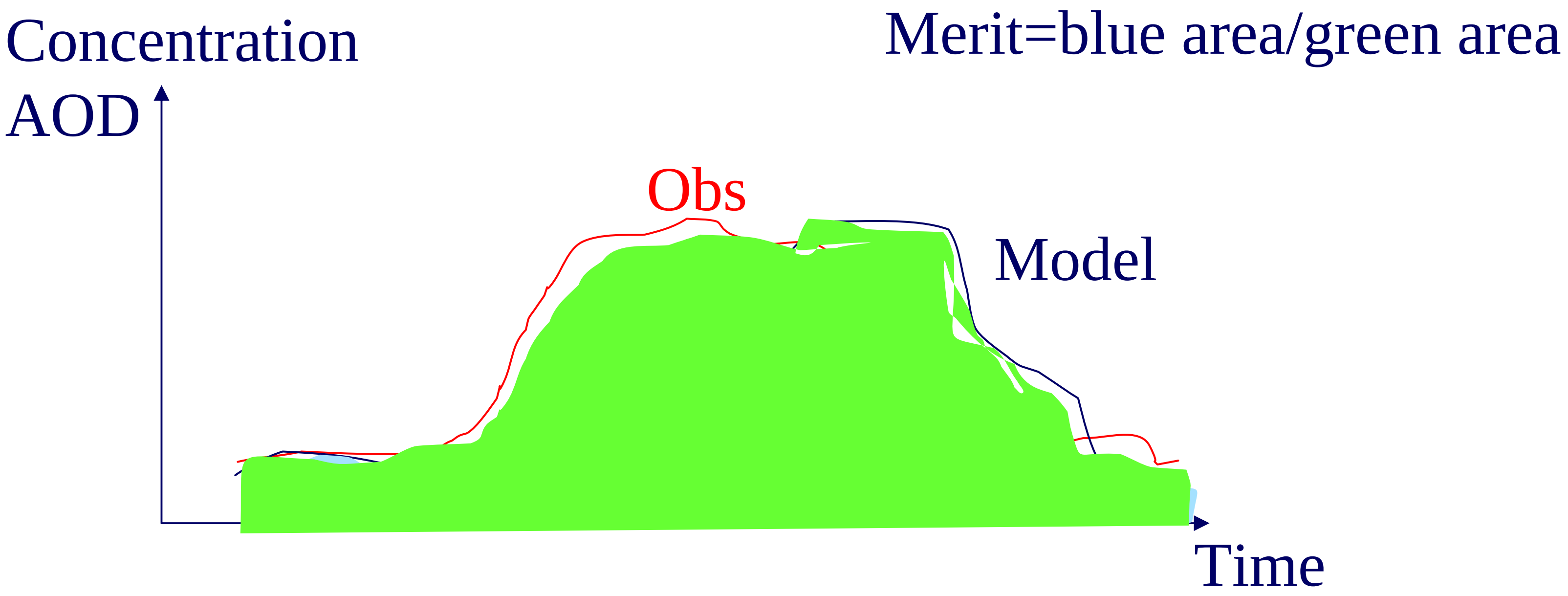






Skill scores

- Figures of merit
    - useful to test the transport for particular events
    - has been used for ETEX

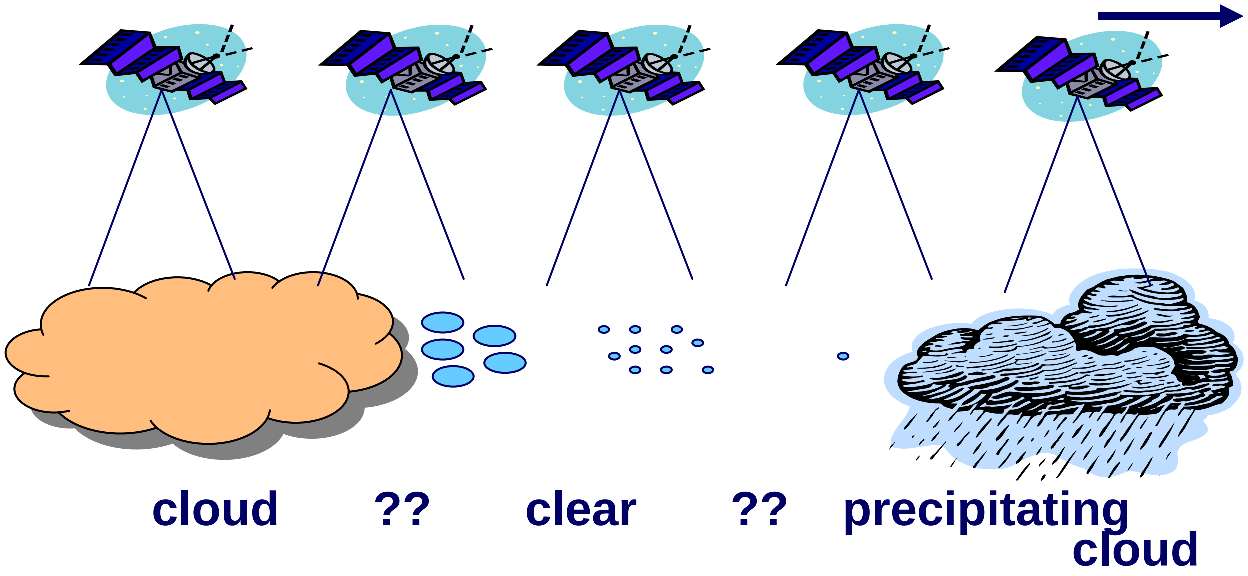


Conclusions

- GEMS will be a major step forward in global aerosol monitoring.
- Continuous work needed to make the best use possible of satellite data (METOP + NPOESS + spaceborne lidar)
- Monitoring of aerosol absorption is also needed.
- Are aerosol indirect effects important for numerical weather prediction?

Standing problems with aerosol radiative effects

1./ Aerosol near clouds ?



2./ Aerosol absorption ? land + ocean
==> Aerosol and cloud vertical profiles