Aerosol and Cloud Remote Sensing from Space

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§ Remote Sensing from Space

§ Cloud properties observed by satellites

§ Aerosol properties observed by satellites

§ Surface measurements and validation

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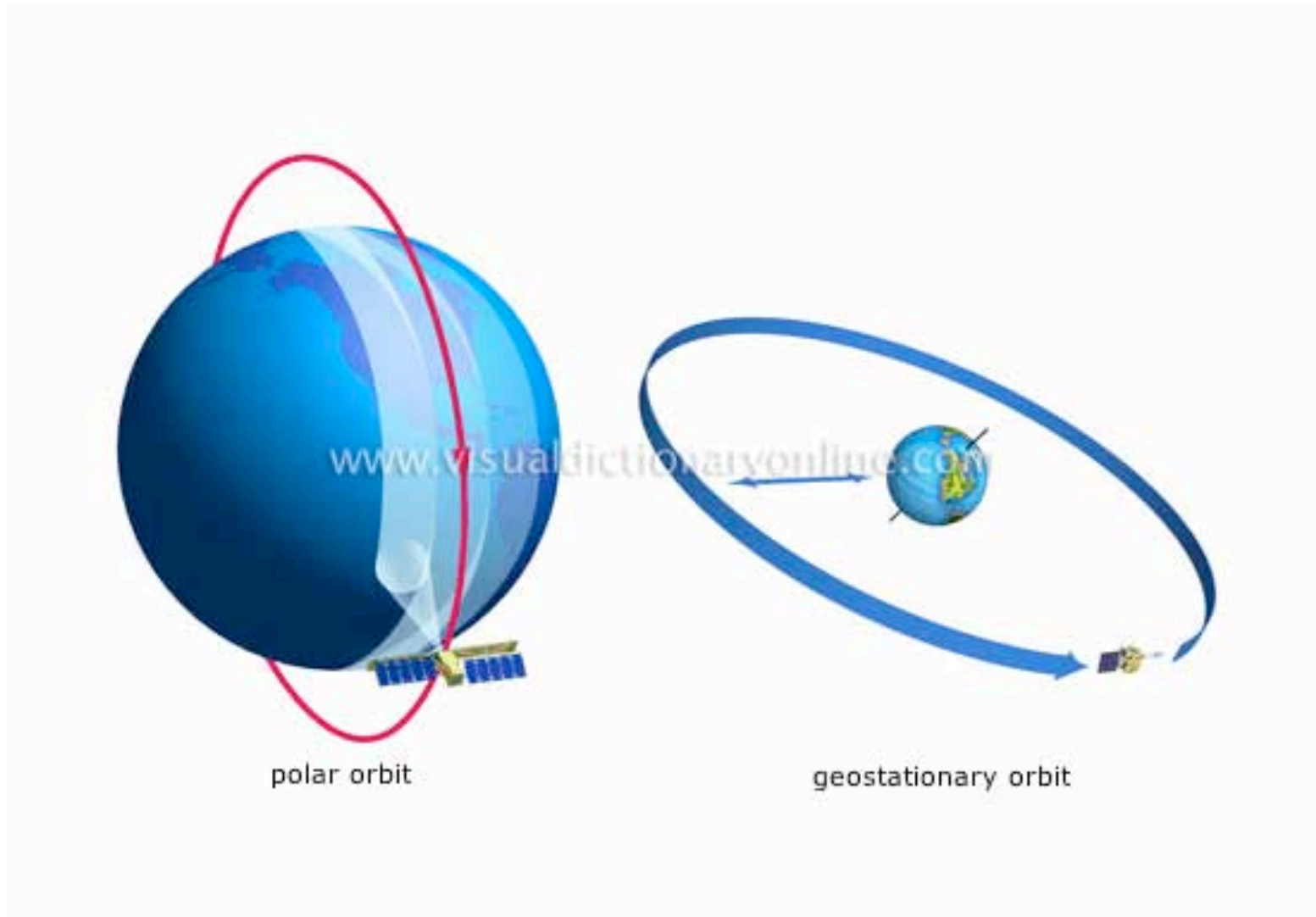
Why ?

- Imagery
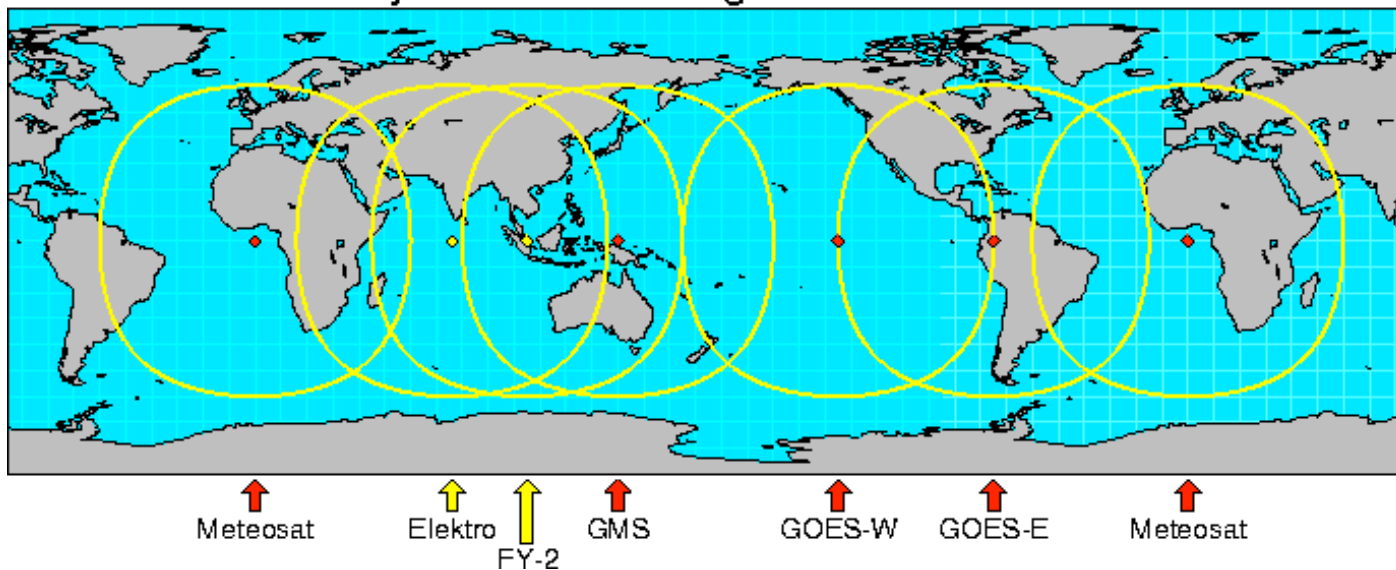- Spatial Coverage
- Measurement homogeneity

polar orbit

geostationary orbit

Global Geostationary Satellite Coverage
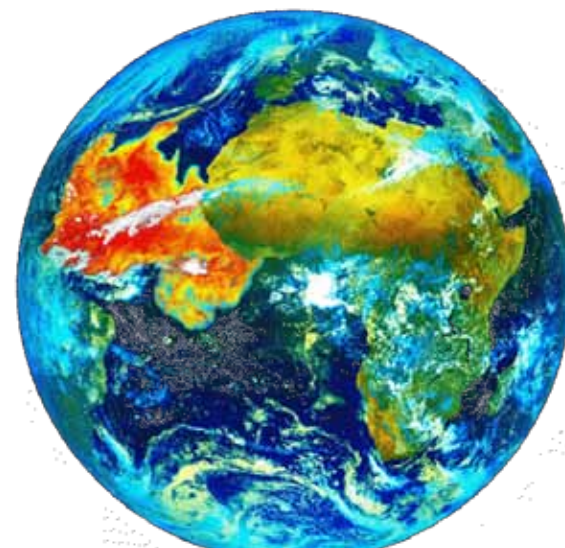
Meteosat   Elektro   GMS   GOES-W   GOES-E   Meteosat
FY-2

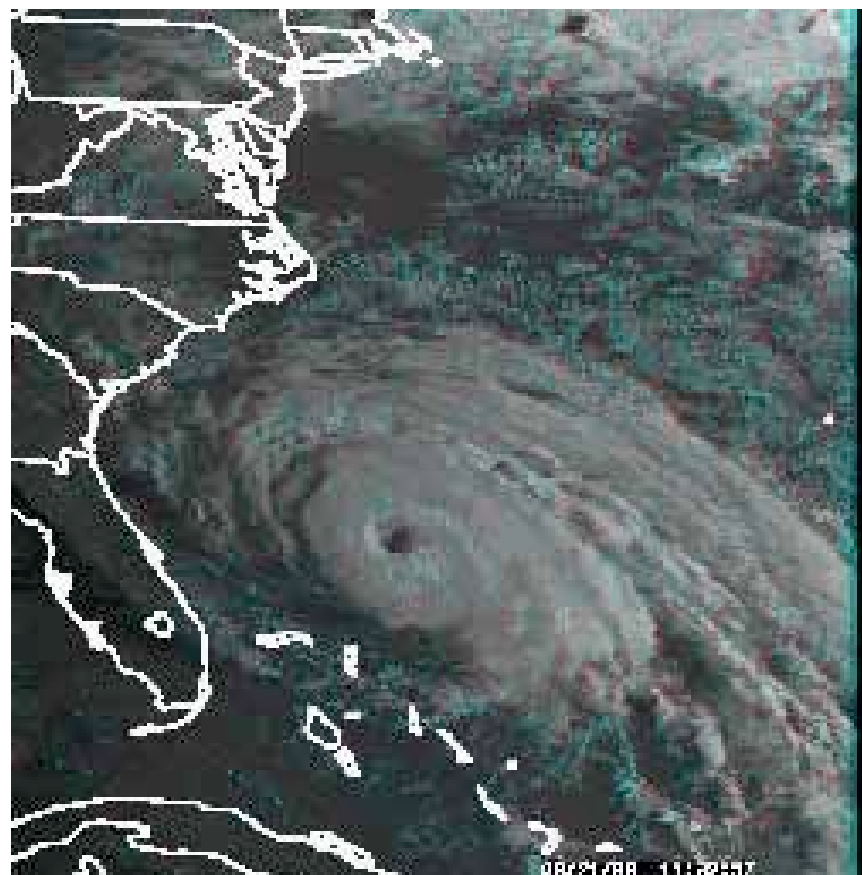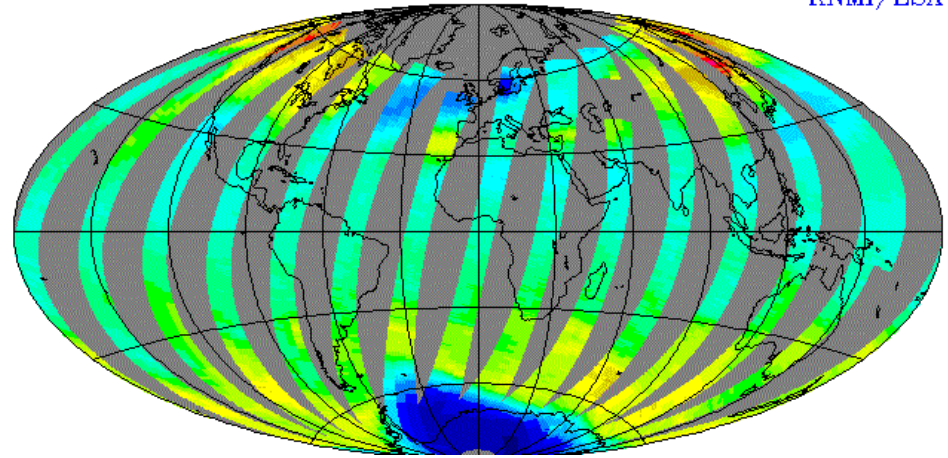**GOES WEST**   **GOES EAST**   Meteosat

Because satellites are fixed with respect to the Earth, they can observe the same scene frequently (typically 30 minutes)
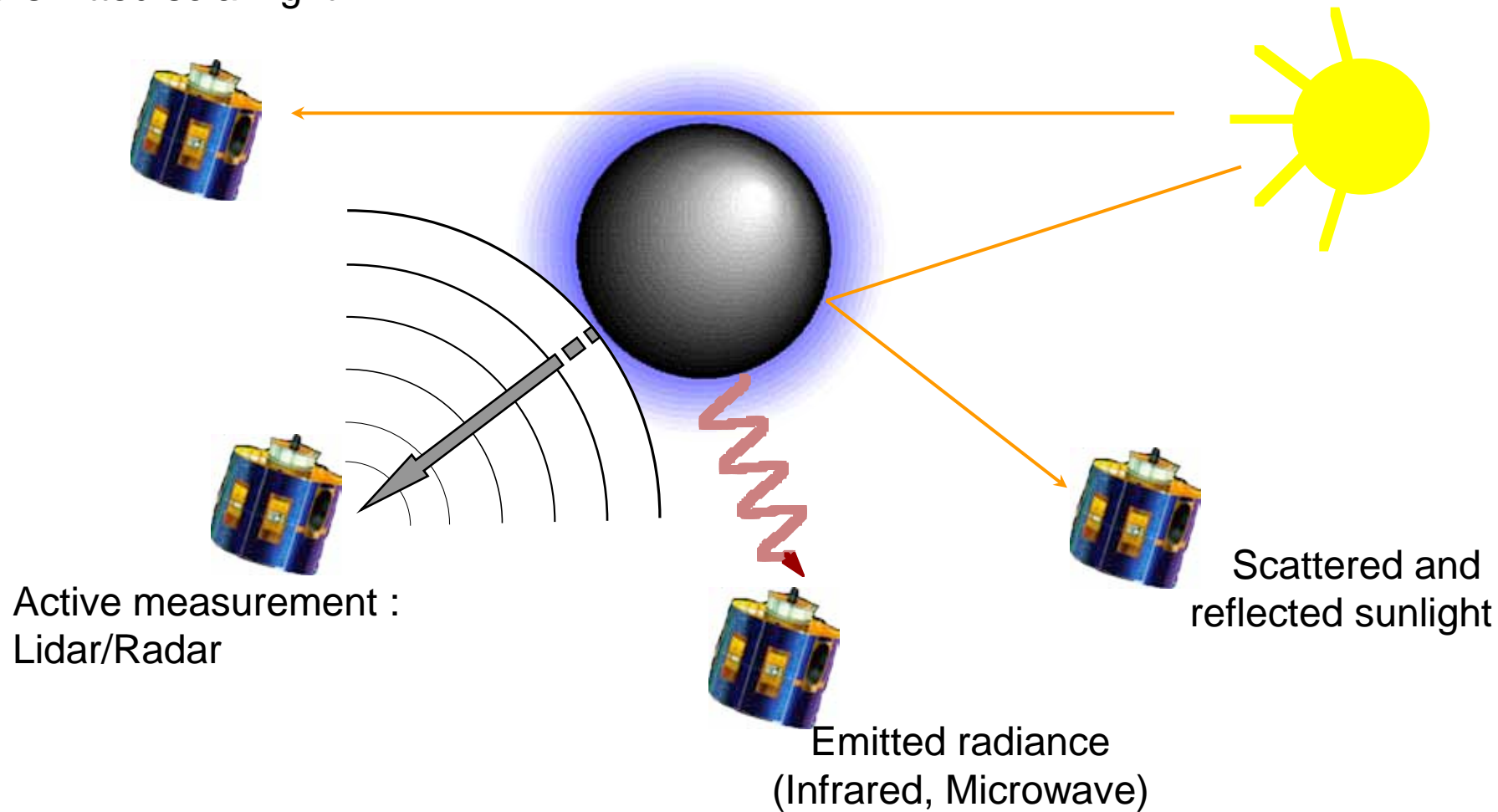
FD TOTAL OZONE VALUES — KNMI/ESA

The full Earth can be monitored with a single sat.

Two observations per day (night + day)

Orbit inclination is chosen so that the satellite precession is equal to that of the Earth around the sun => Constant time of observation.

Transmitted solar light

Active measurement :
Lidar/Radar

Emitted radiance
(Infrared, Microwave)

Scattered and
reflected sunlight

Cloud : Collection of water (ice or liquid) particles in suspension in the atmosphere.
Lifetime : hours/days

Aerosol : Liquid or solid particles in suspension in the atmosphere, to the exception of clouds.
Lifetime : Days / weeks

§ Remote Sensing from Space
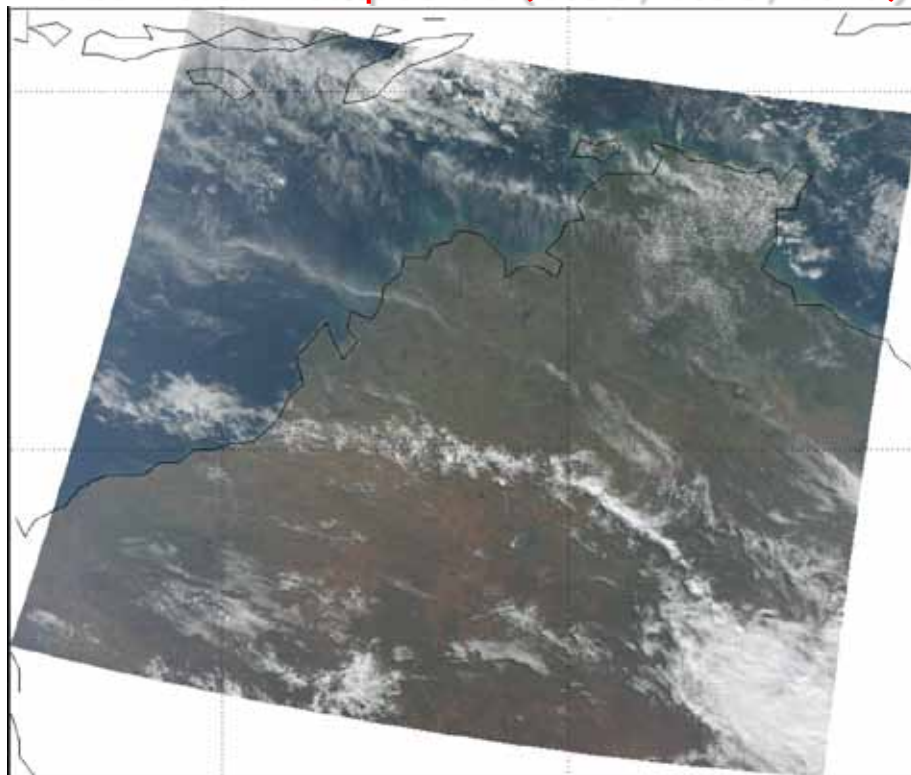§ Cloud properties observed by satellites
§ Aerosol properties observed by satellites
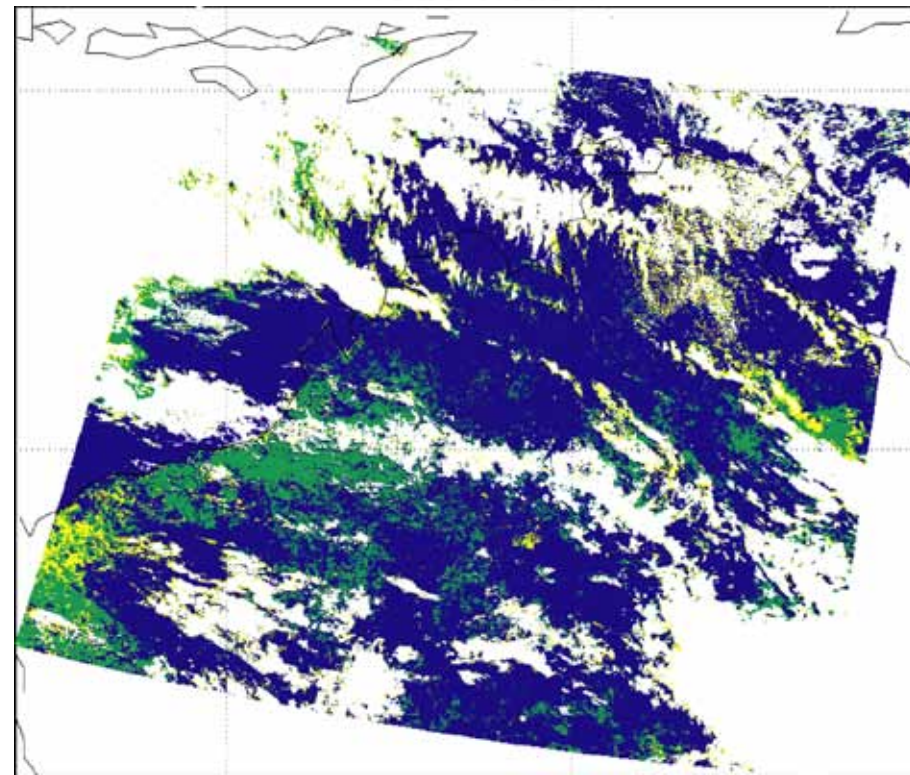§ Surface measurements and validation

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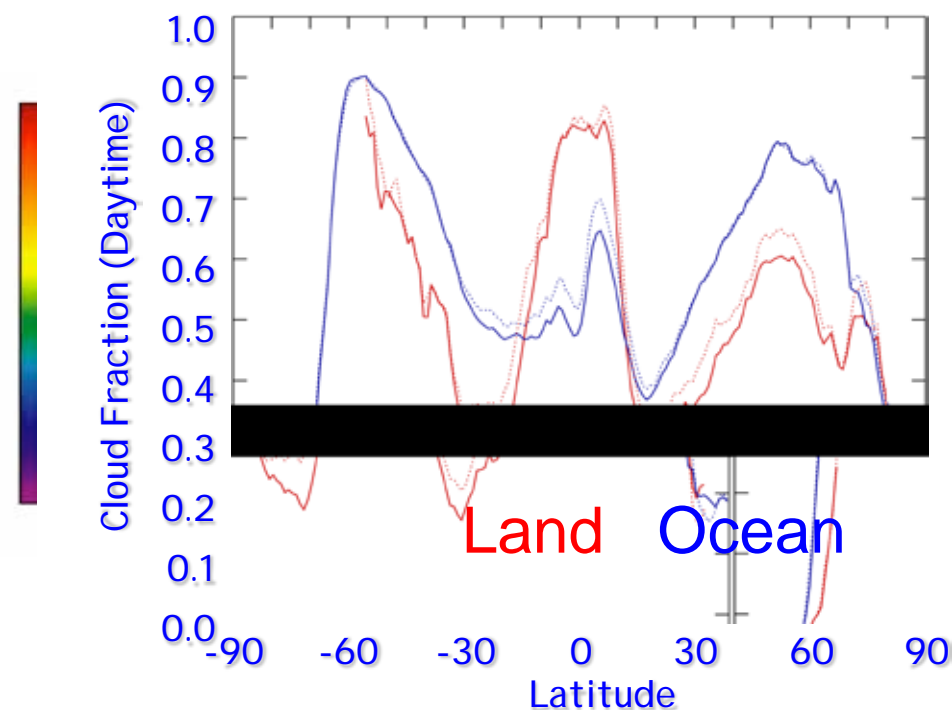True Color Composite (0.65, 0.56, 0.47)

Cloud Mask

| Confident Clear | Probably Clear | Probably Cloudy | Cloudy |

Identification of Clouds in remote sensing images is complex
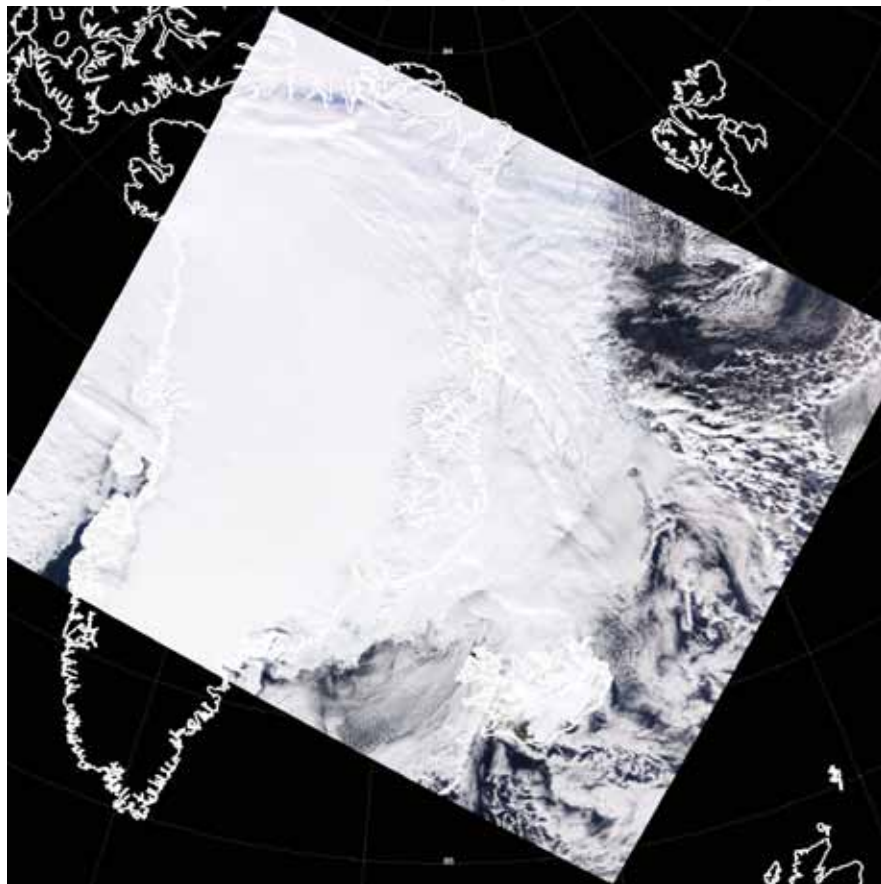Uses tests on reflectance, spatial variability, spectral
signatures...
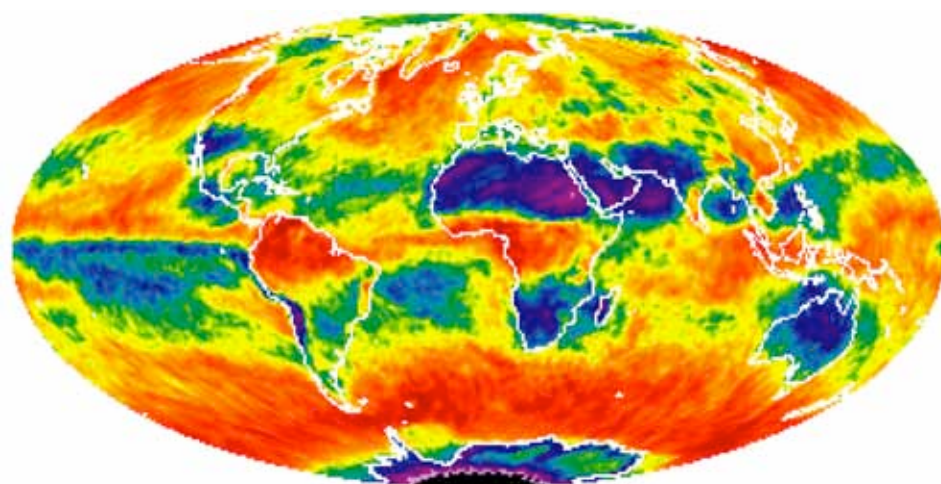
Simple statistics on cloud identification leads to the *cloud fraction*, one of the main cloud parameter
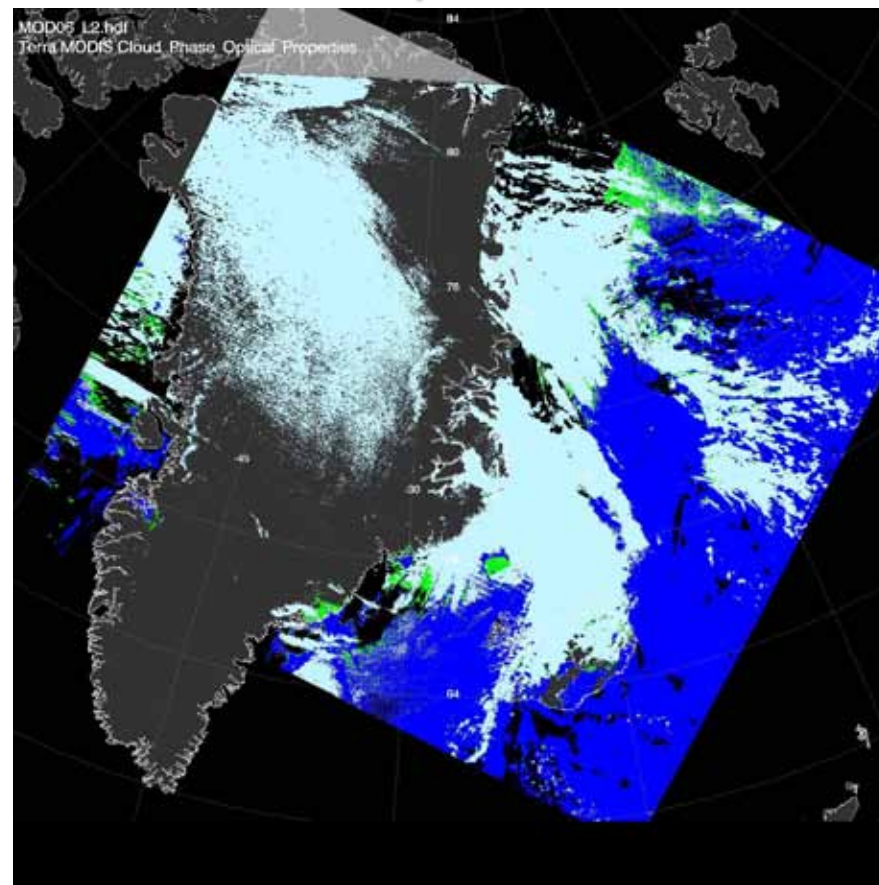
True Color Composite (0.65, 0.56, 0.47) Thermodynamic Phase

MODIS Terra, March 22, 2001

Clear Sky Liquid water Ice Uncertain

Because their spectral properties differ, liquid and ice clouds can be distinguished

§ Liquid water clouds

– Larger droplets in SH than NH

– Larger droplets over ocean than land (less condensation nuclei)

§ Ice clouds

– Larger in tropics than high latitudes

– Small ice crystals at top of deep convection

Cloud Effective Radius (Liquid Water)   Terra

Cloud Effective Radius (μm): 25, 20, 15, 10, 5

Cloud Effective Radius (Ice)

Cloud Effective Radius (μm): 32, 30, 28, 26, 24, 22, 20
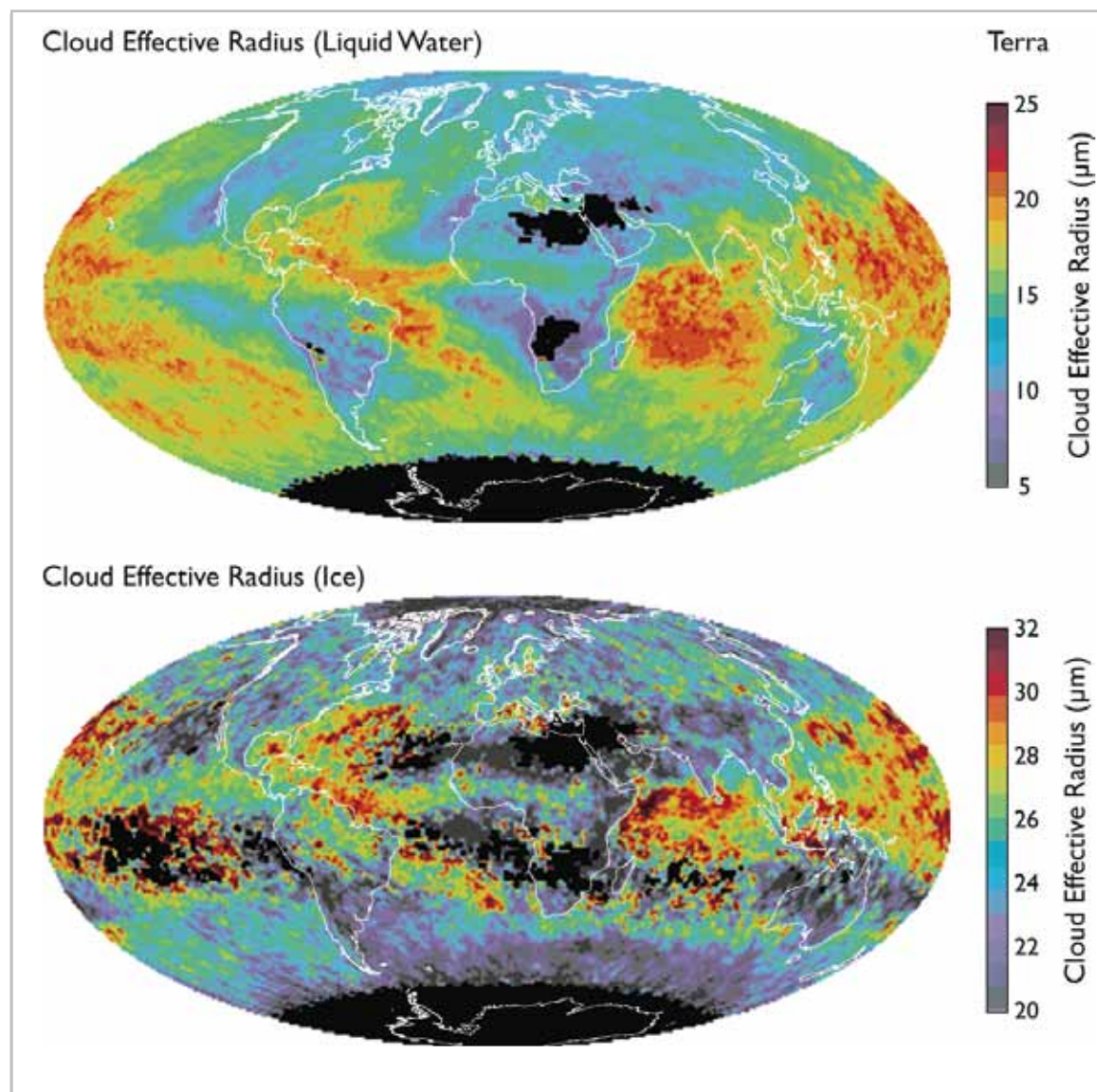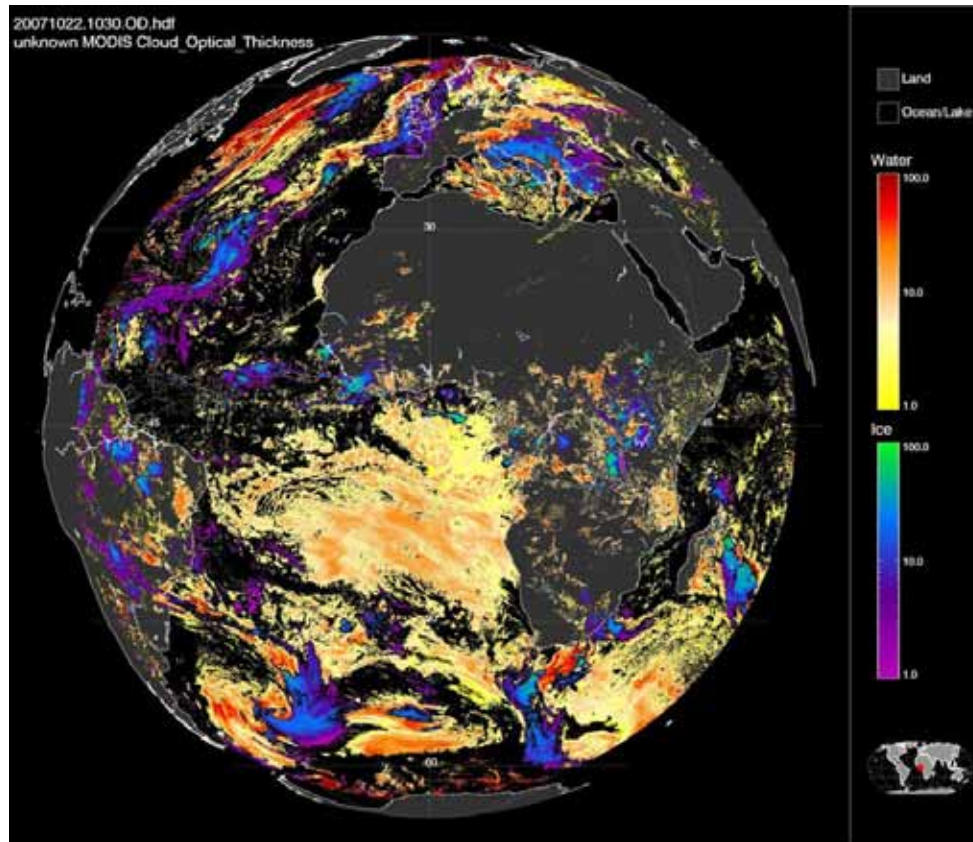
Cloud optical thickness is derived from the measured cloud reflectance but with some dependency on cloud phase and cloud droplet radius.

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Volcano (Japan)

Forest Fire Smoke (Amazone

Desert Dust
(Sahara)

Satellite observation is well suited to monitor atmospheric aerosol sources and transport
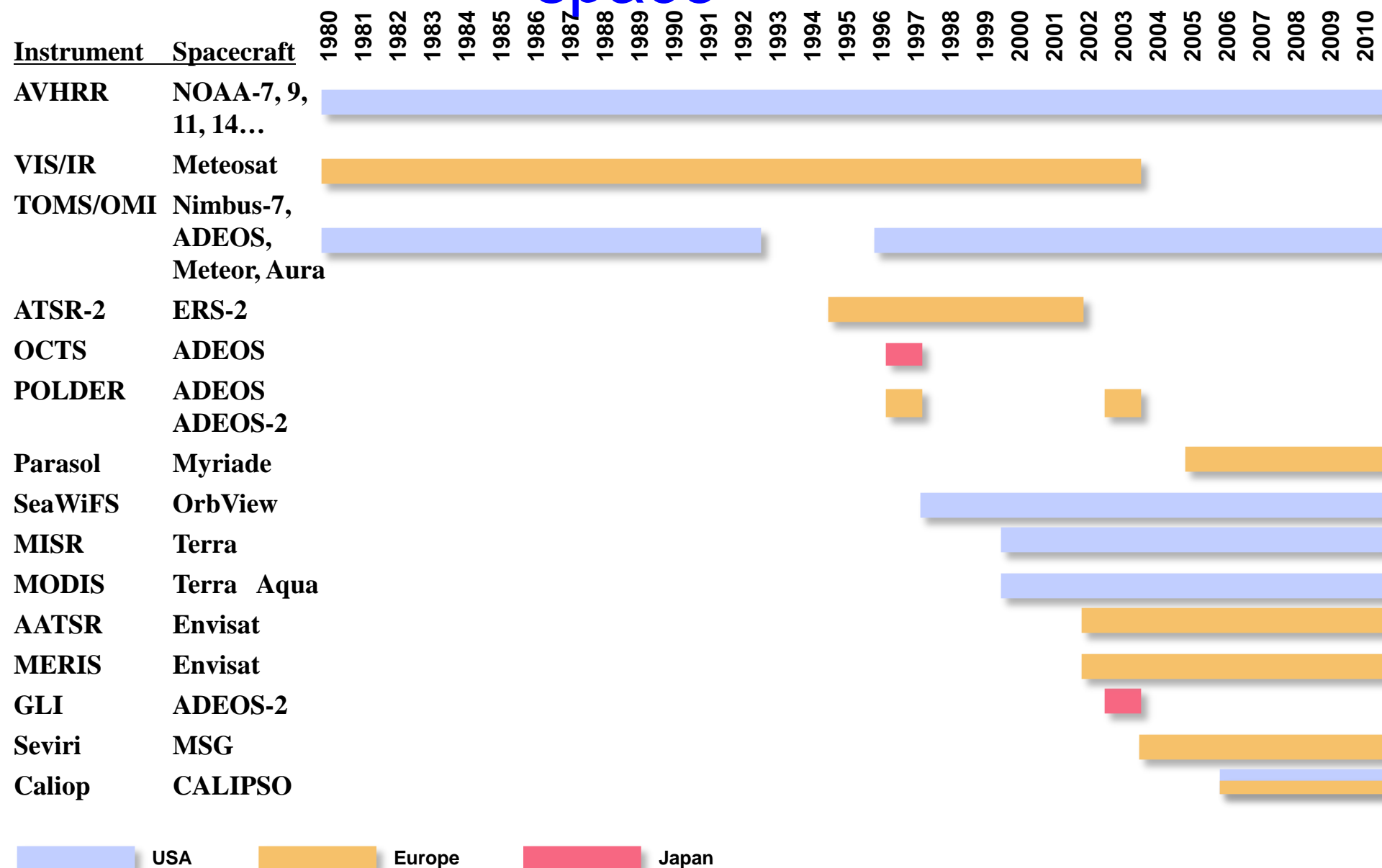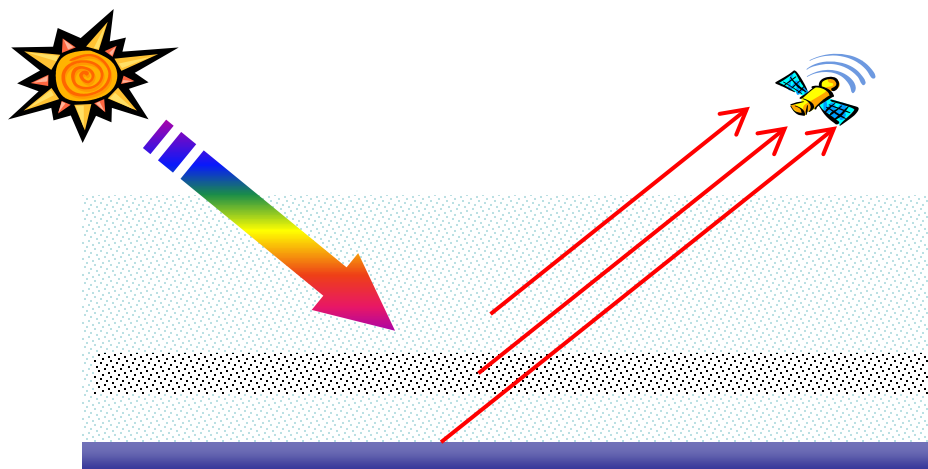
Instrument	Spacecraft																														
		1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
AVHRR	NOAA-7, 9, 11, 14…																															
VIS/IR	Meteosat																															
TOMS/OMI	Nimbus-7, ADEOS, Meteor, Aura																															
ATSR-2	ERS-2																															
OCTS	ADEOS																															
POLDER	ADEOS ADEOS-2																															
Parasol	Myriade																															
SeaWiFS	OrbView																															
MISR	Terra																															
MODIS	Terra Aqua																															
AATSR	Envisat																															
MERIS	Envisat																															
GLI	ADEOS-2																															
Seviri	MSG																															
Caliop	CALIPSO																															

USA   Europe   Japan

$$R_{sat} = \frac{\varpi\ \tau_{aer}P_{aer}(\gamma)}{4\ \mu_s\ \mu_v}$$ Aerosol contribution

$$+\frac{\tau_{mol}P_{mol}(\gamma)}{4\ \mu_s\ \mu_v}$$ Molecule contribution; Well known

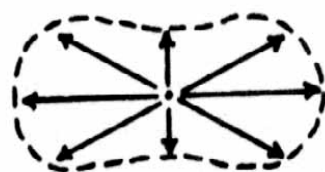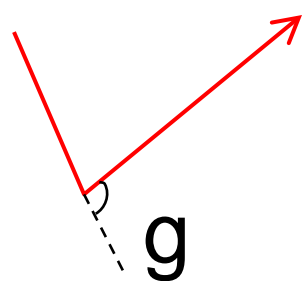$$+R_{surf}\ T_{atm}^{\Downarrow\Uparrow}$$ Surface contribution; Small

$$R_{aer} = \frac{\varpi \, \tau_{aer} P_{aer}(\gamma)}{4 \, \mu_s \, \mu_v}$$

g

d = 0,01 µm

d = 0,1 µm

d = 1 µm

λ=550nm

PHASE FUNCTION

SCATTERING ANGLE (°)

DUST-LIKE
OCEANIC
SOOT
WATER SOLUBLE
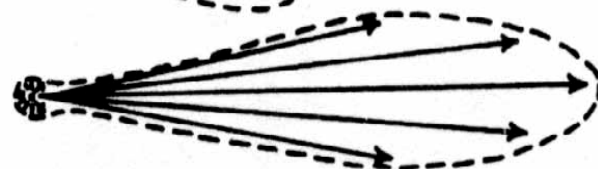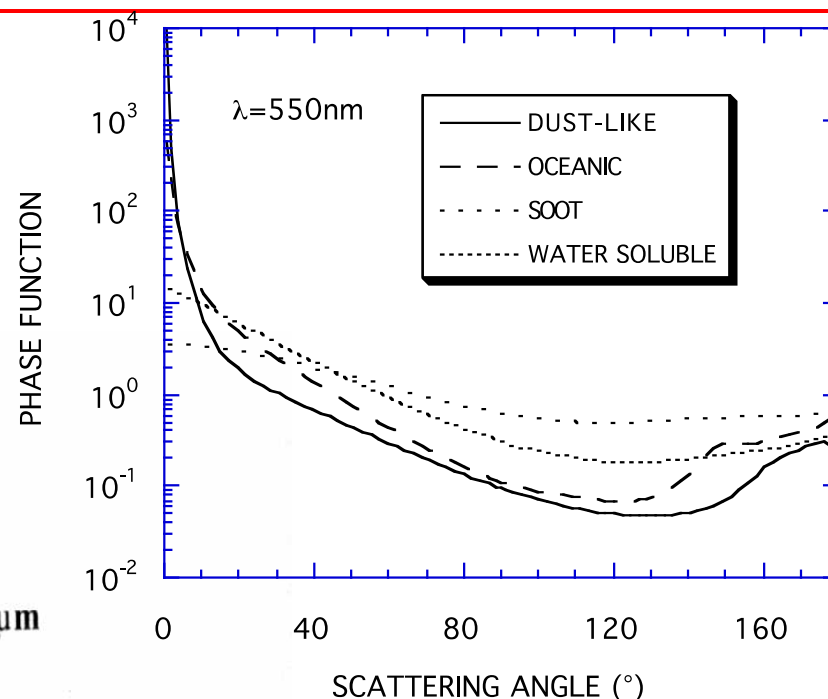
The good news : P_{aer} varies with the aerosol type **ỳ** Potential to retrieve aerosol model

The bad news: P_{aer} varies with the aerosol type **ỳ** Large variations on the relationship between measurement (R_{aer}) and optical depth (t_{aer})

$$R_{aer} = \frac{\varpi \, \tau_{aer} P_{aer}(\gamma)}{4 \, \mu_s \, \mu_v}$$

Select a proper value for $w\,P_{aer}$

(i)   Assume an aerosol model
(ii) Choose among several models based on spectral signature
(iii) Choose among several models based on directional signature
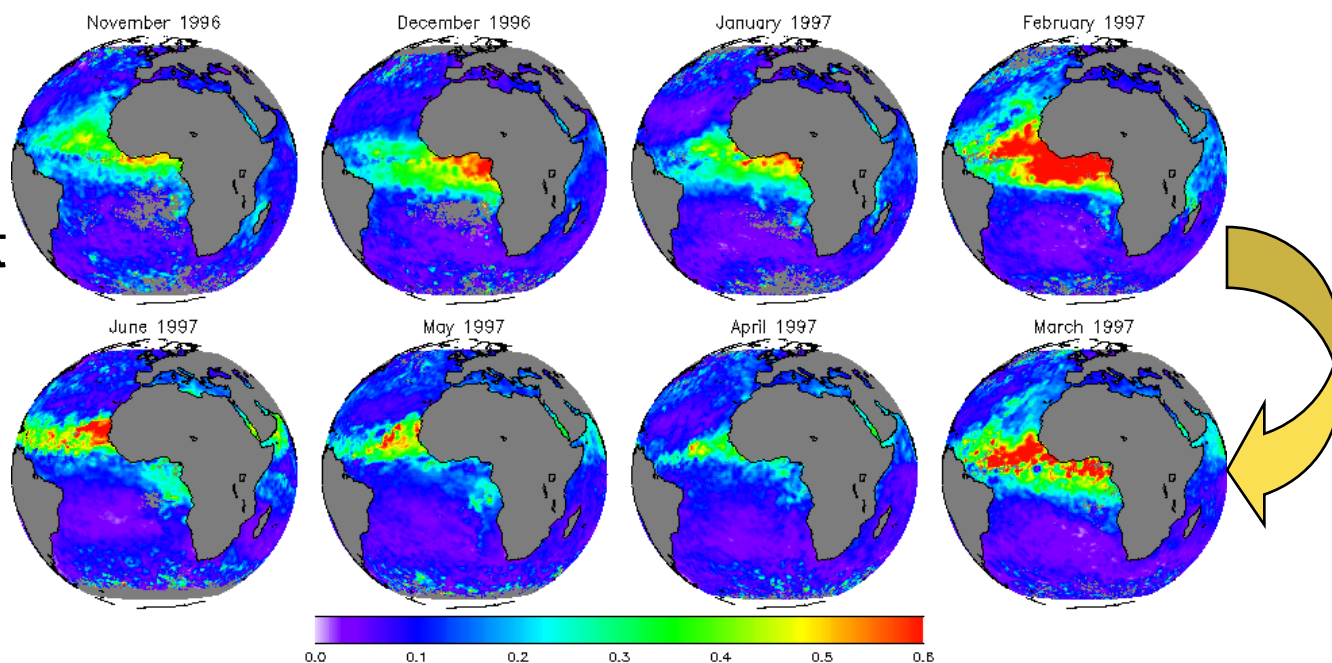(iv) Choose among several models with some information on polarized
        signature

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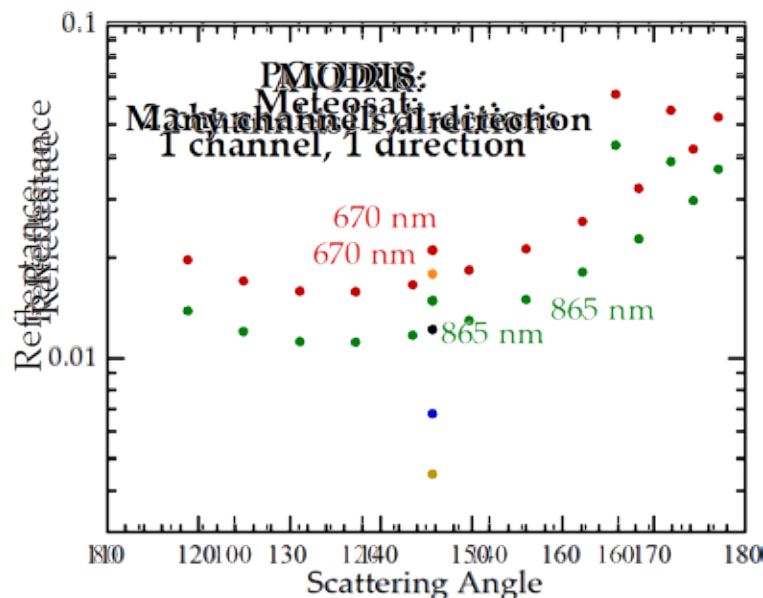
FOV well suited to observe major sources of aerosols and their transport

Large optical thickness of Saharan Dust

Long time series
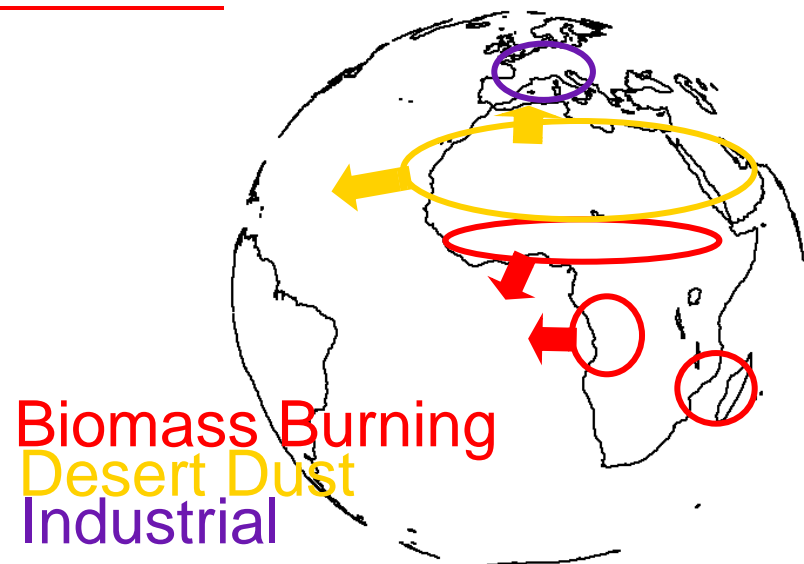
Biomass Burning
Desert Dust
Industrial

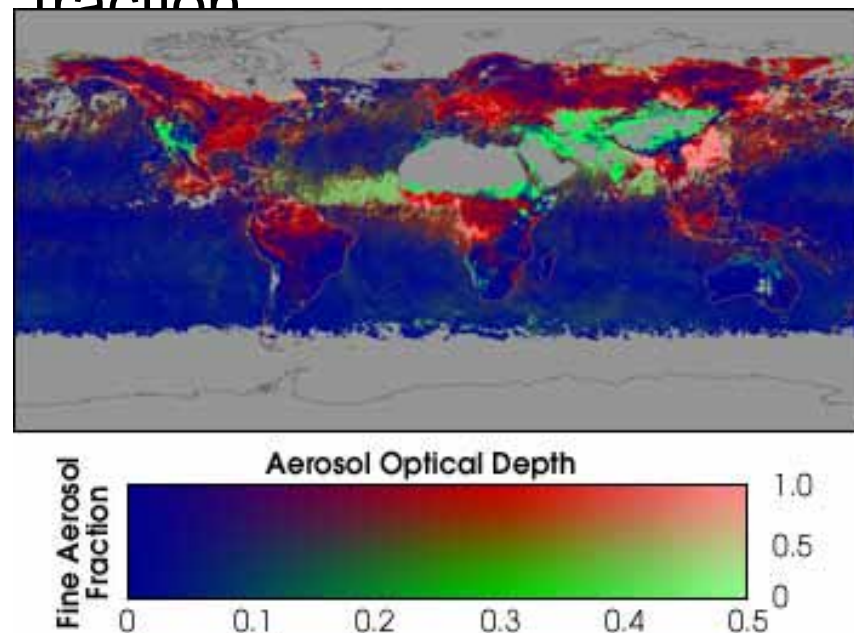Mix of Saharan dust and biomass burning in January-March

November 1996 December 1996 January 1997 February 1997

June 1997 May 1997 April 1997 March 1997

0.0   0.1   0.2   0.3   0.4   0.5   0.6
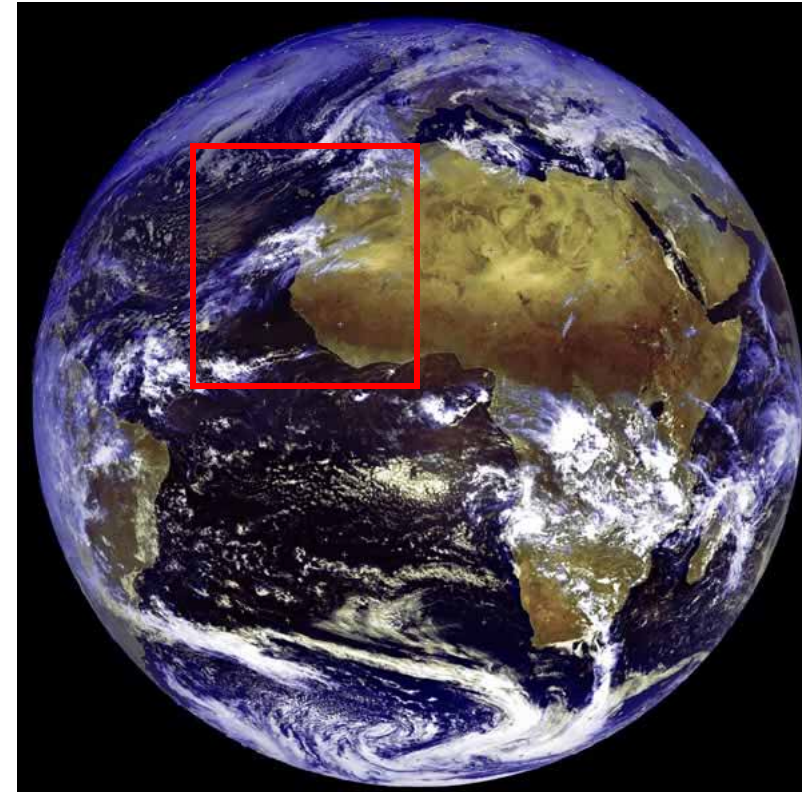
30 mn time step

- An indication of aerosol size is needed

- $t = t_0 (l / l_0)^{-a}$

- Angström exponent (a) provides an indication of the aerosol size

- Large aerosol (dust) have a in[0;0.5] range while small aerosols (pollution, biomass burning) have values around [1.5;2]

POLDER "Fine Mode" AOD, accumulation mode fraction
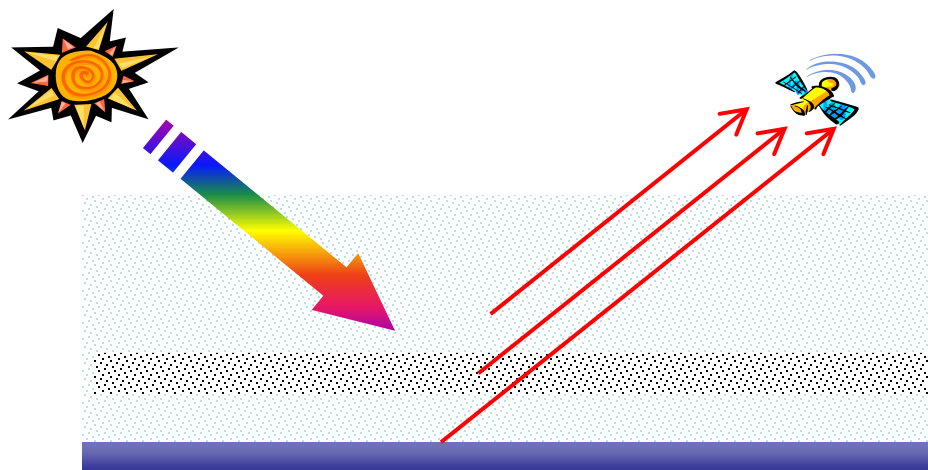
MODIS Combination of optical depth and particle size

Aerosol Optical Depth

Fine Aerosol Fraction

1.0

0.5

0

0   0.1   0.2   0.3   0.4   0.5

$$R_{sat} = \frac{\varpi \; \tau_{aer} P_{aer}(\gamma)}{4 \; \mu_s \; \mu_v}$$ Aerosol contribution

$$+ \frac{\tau_{mol} P_{mol}(\gamma)}{4 \; \mu_s \; \mu_v}$$ Molecule contribution; Well known

$$+ R_{surf} \; T_{atm}^{\Downarrow \Uparrow}$$ Surface contribution; Large, variable

The difficulty is therefore to separate the contribution of aerosols and the surface

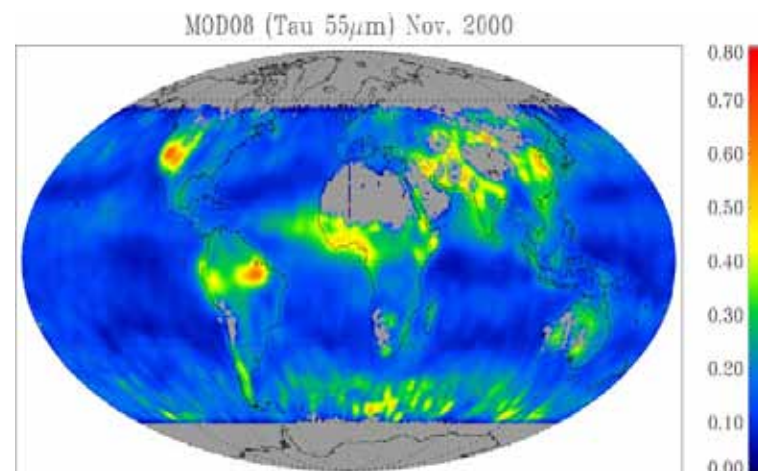**PEKING UNIVERSITY**

Spectral signature of reflectance

Using the spectral information to sense aerosol over the land

ER-2, AVIRIS spectral image from SCAR-B of smoke over Cuiaba on Aug. 25, 1995

(From Kaufman et al., 1997)

parent in the mid-IR, surface features are visible.

Aerosol "transparent" at 1.6-2 μm
Surface reflectance highly correlated at 0.66 and 2 μm
Use both reflectance measurements to derive aerosol
   contribution

Aerosol tend to cool the daytime apparent temperature

- Direct effect on IR radiance
- Surface cooling by reduction of solar incoming radiation

Monthly reference of apparent temperature T_{clear}

Dust Index based on T_{clear}-T_{obs}

Sensitive to other atmospheric variables (humidity)

Well adapted to desert dust ==>
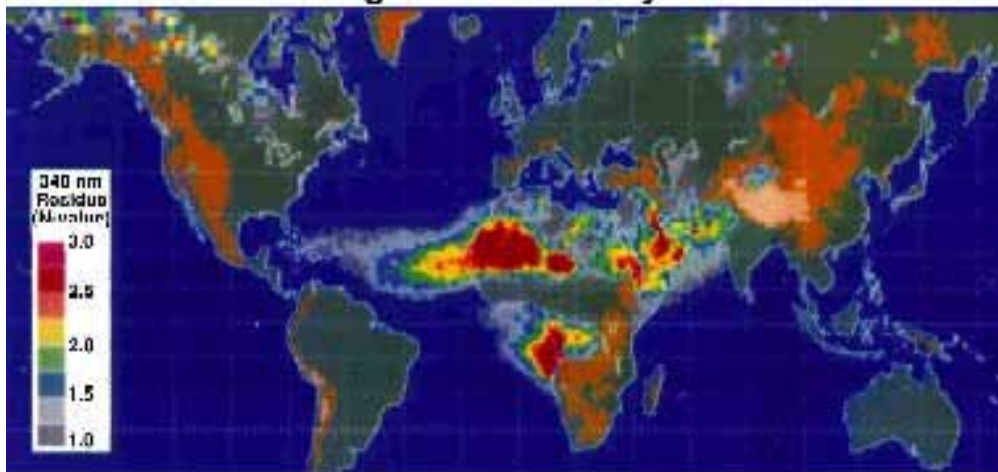
Complementary to other techniques

Legrand et al., 1989
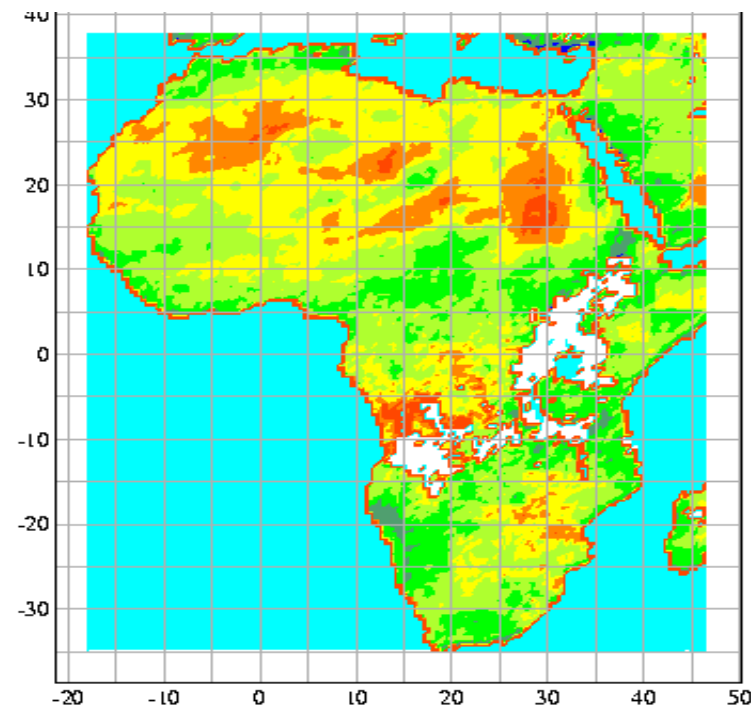
March climatology

Making good use of an Ozone monitoring instrument…

$$AerIndex = Ln\left[\frac{R_{340}}{R_{380}}\right]_{mes} - Ln\left[\frac{R_{340}}{R_{380}}\right]_{mol}$$

TOMS Absorbing Aerosols - July 1989 and 1990

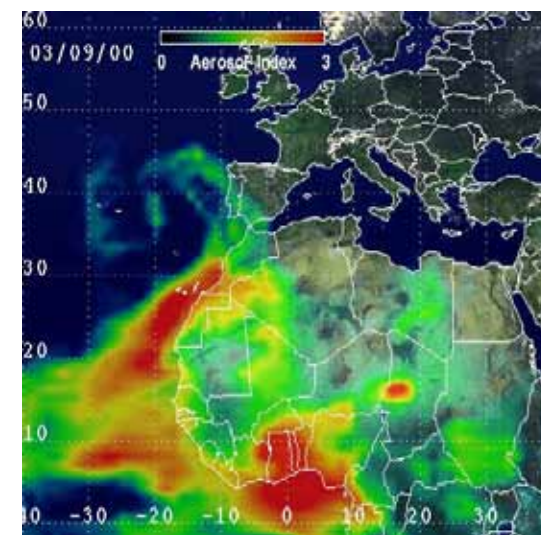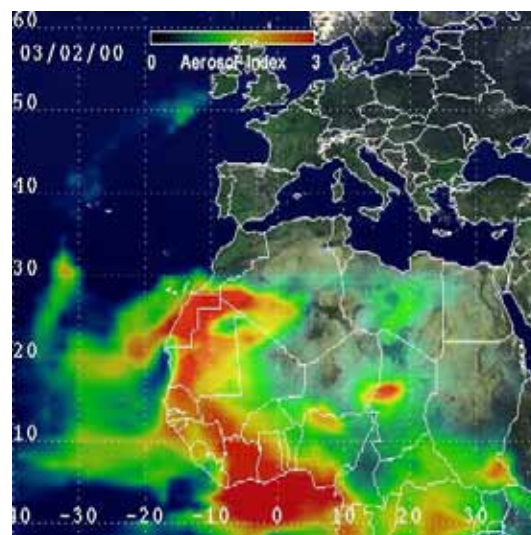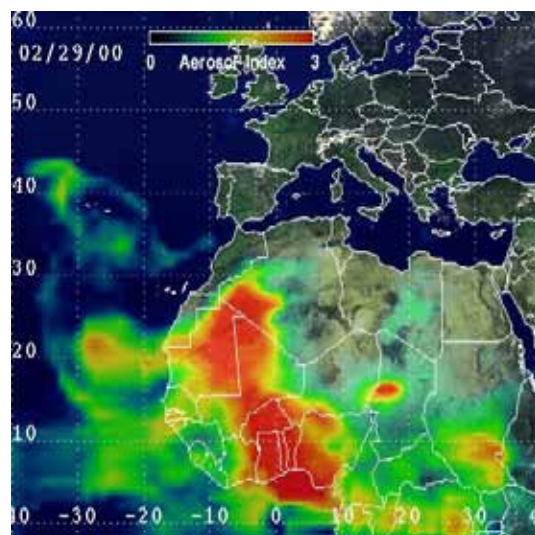340 nm
Residue
(N-value)
3.0
2.5
2.0
1.5
1.0

- Spectral signature of reflected radiance in the near-UV (340-380 nm)
- Sensitive to absorbing aerosols (dust, biomass burning)
- Both over ocean and land
- Little constrain on cloud cover => near daily global coverage
- Sensitive to aerosol height and absorption
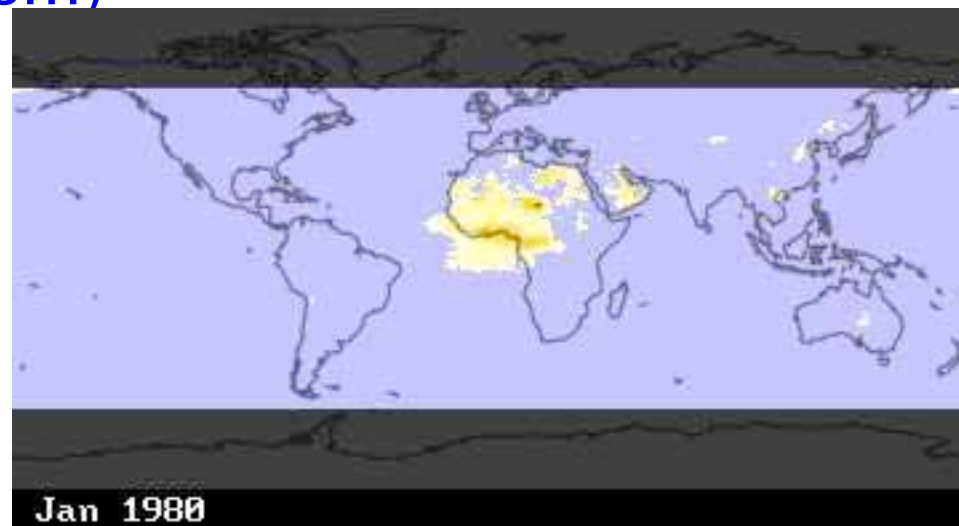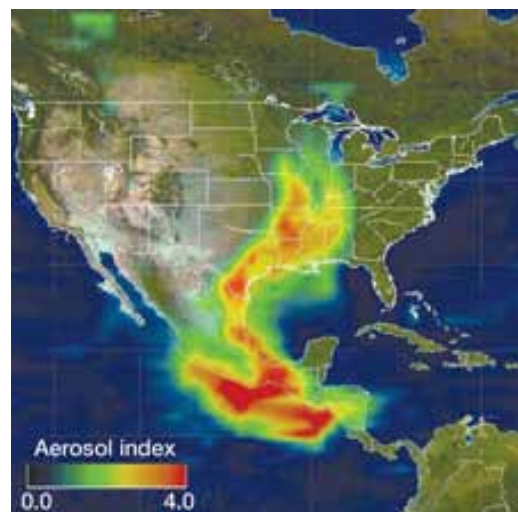
Long time series
Very consistent record

| Technique	Works well for...	Drawback
UV	High aerosol	Insensitive to low aerosol Sens. to aerosol absorption
Spectral signature	Vegetated surfaces	Not over bright surf.
Polarization	Small particles	Large particles
Thermal IR	Dust over desert	Surface variability Atmospheric variability
Multi-Views	All aerosols	Surface BRDF

Active Sensing provide the expected information on aerosol vertical distribution
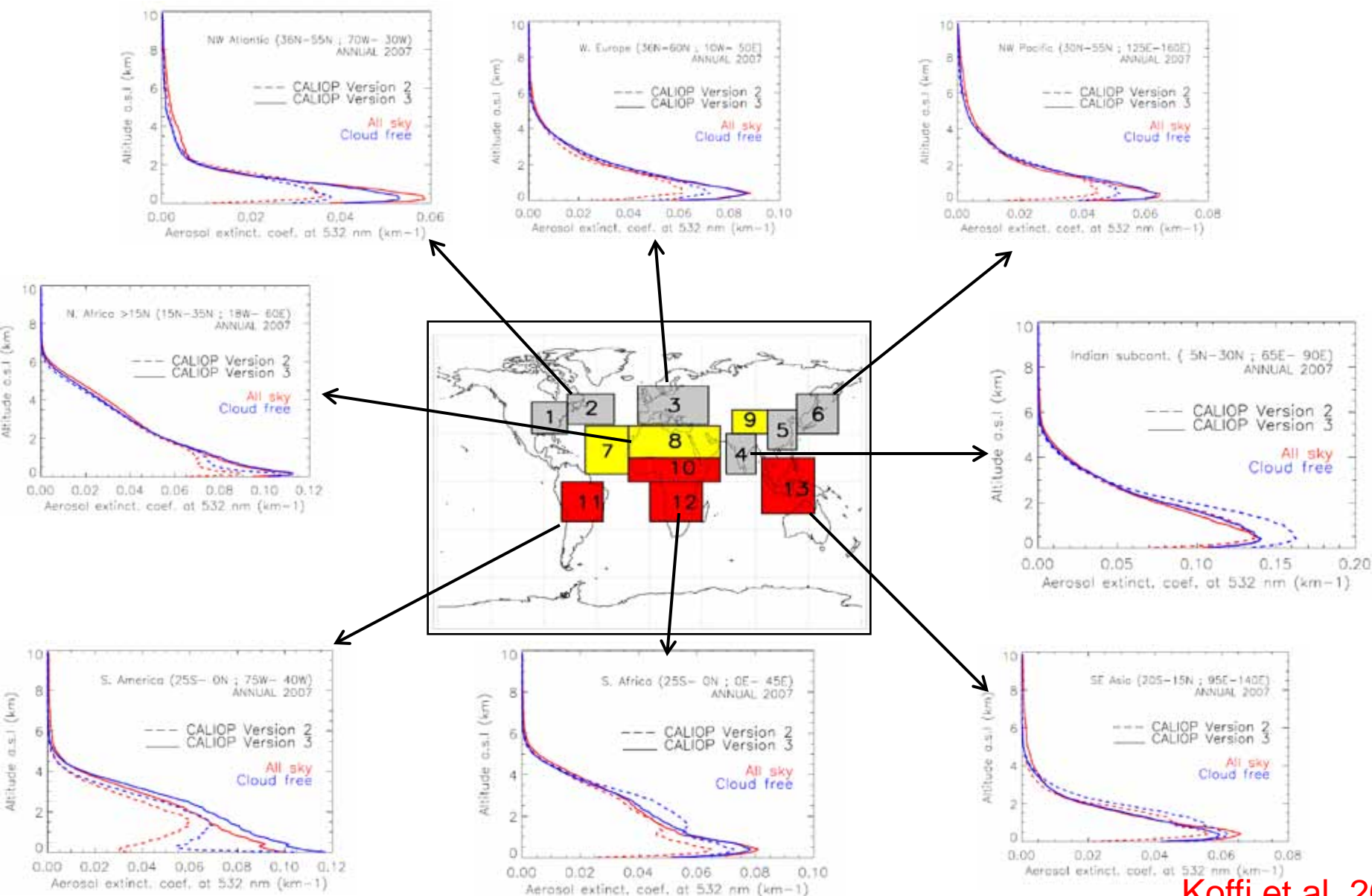Calipso (NASA/CNES) was launched in 2006
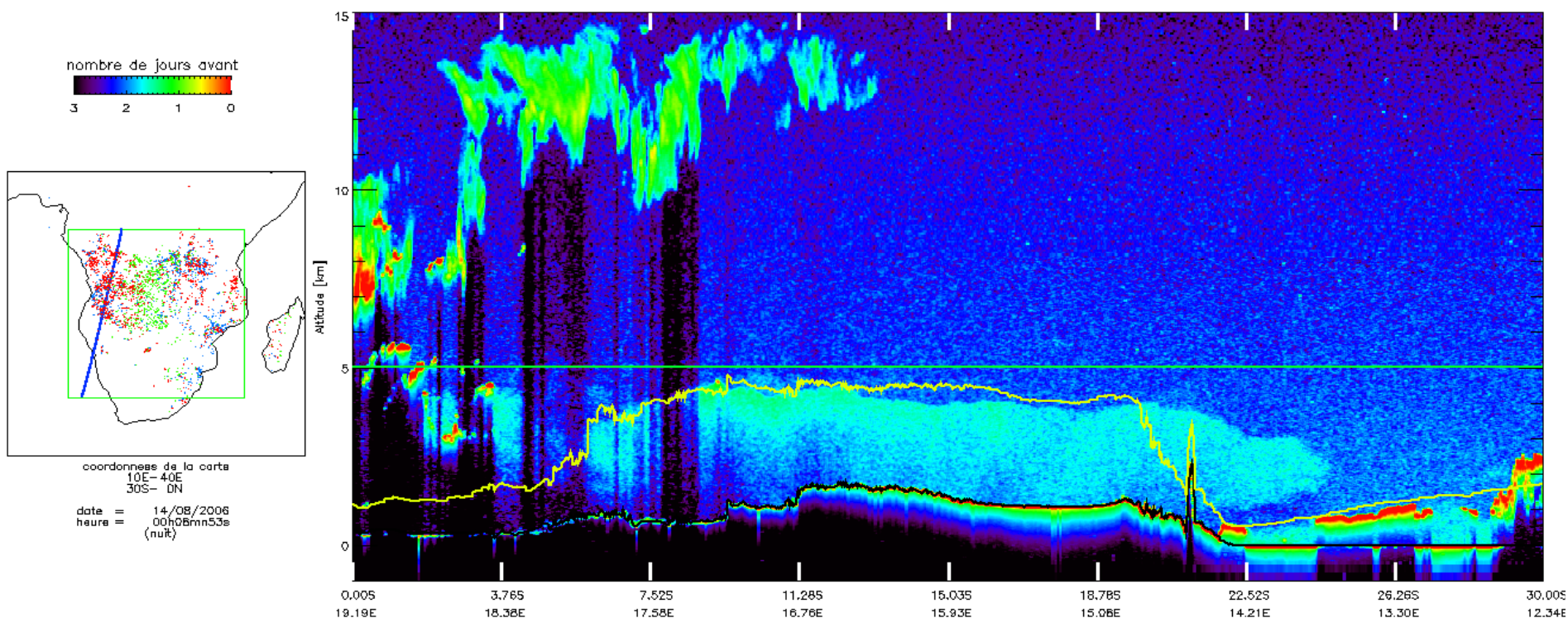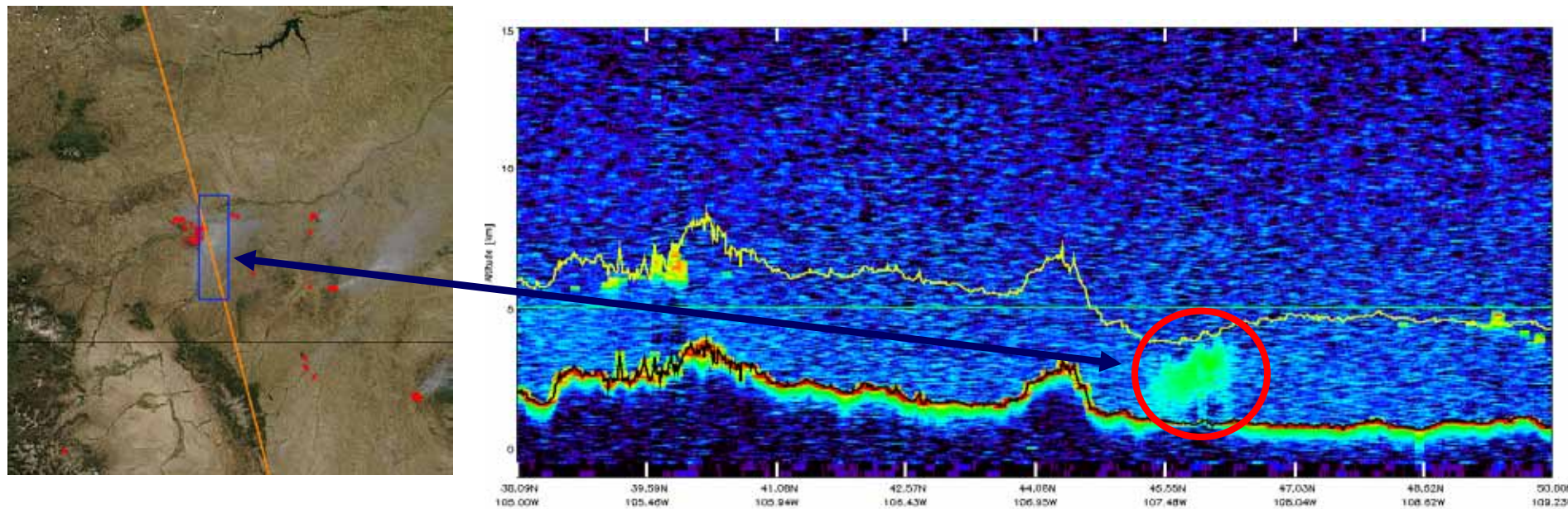
Calipso is a great tool to observe dense aerosol plumes
Useful in particular for injection height analysis

Koffi et al. 2012

Pros

- Only instrument that provides reliable vertical profiles

- Can observe aerosol layers, even in the presence of thick clouds below, and/or thin clouds above

- Provide measurements both day and night

Cons

- Limited information on aerosol model => Uncertainty on extinction to backscatter ratio => Large uncertainty on extinction/optical depth

- Noisy measurements, in particular during daytime

- Some confusion between aerosol and cloud layers

- Limited spatial coverage

§ Remote Sensing from Space
§ Cloud properties observed by satellites
§ Aerosol properties observed by satellites
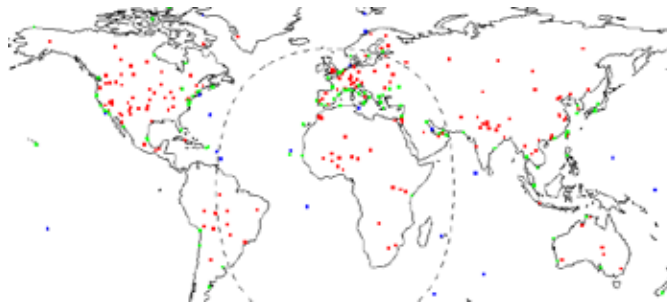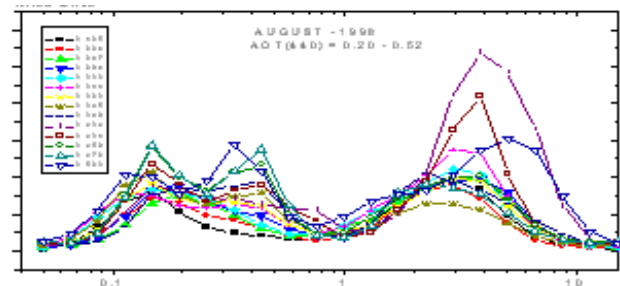§ Surface measurements and validation

Sunphotometer provide a near-direct measurement of the AOD $t(l)$
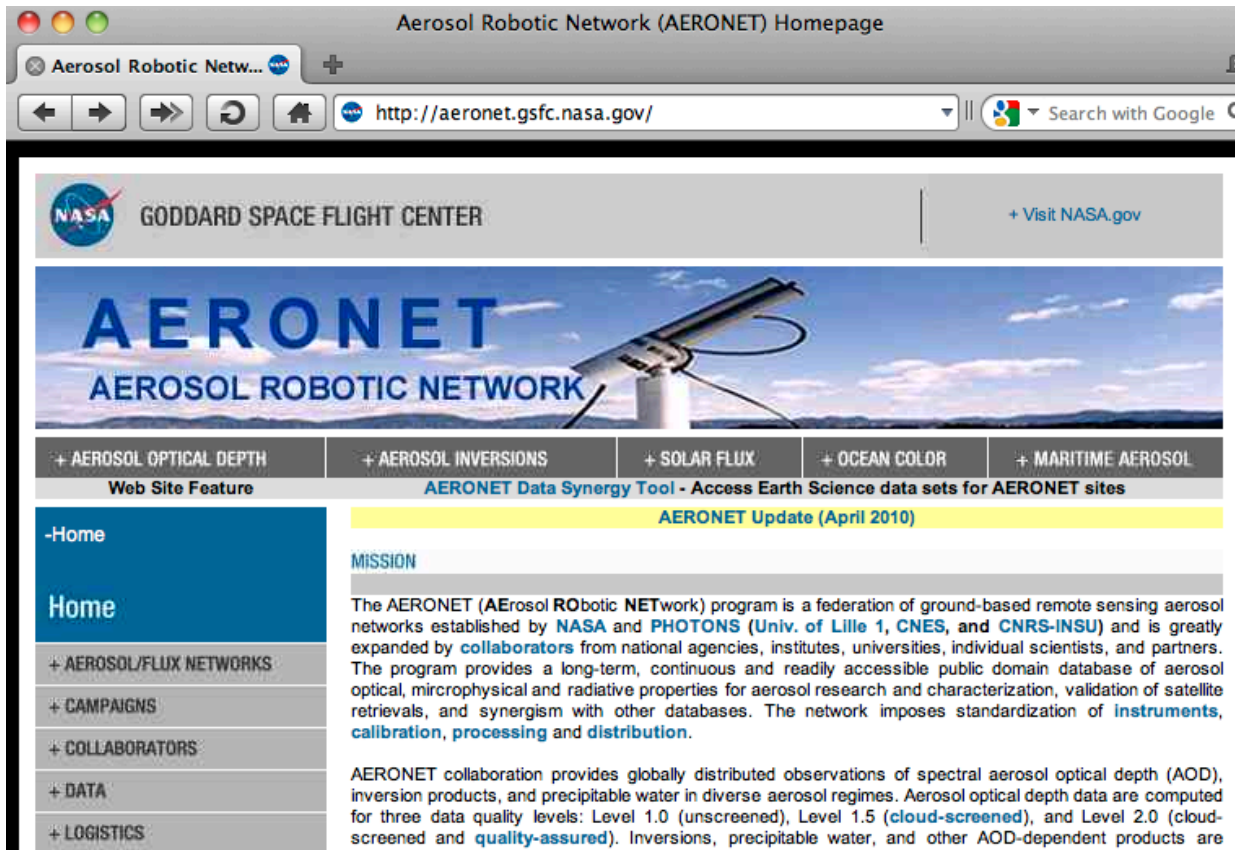
The spectral variation of $t(l)$ can be used to derive a Fine Mode and a total AOD with little uncertainty

Sky radiance measurements are needed to estimate the size distribution.

Although these size distributions are widely accepted, they are difficult to validate.

No doubt that the sunphotometer measurements are much more accurate than their satellite-derived counterparts. They can therefore be used for validation
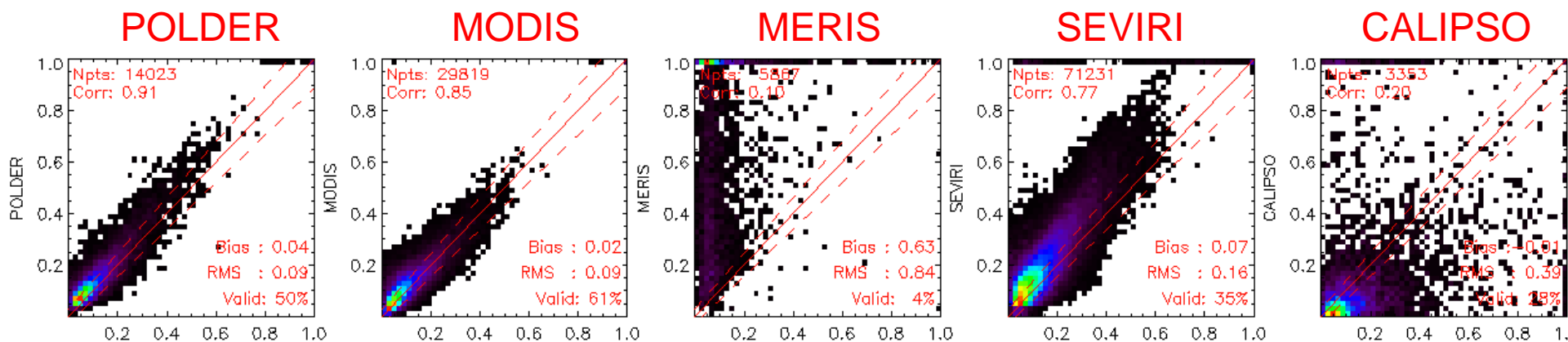
Sunphotomer measurements are standardized and freely accessible through AERONET.

200+ sites

It is an impressive achievement of international collaboration among researchers with the help of funding agencies

POLDER   MODIS   MERIS   SEVIRI   CALIPSO
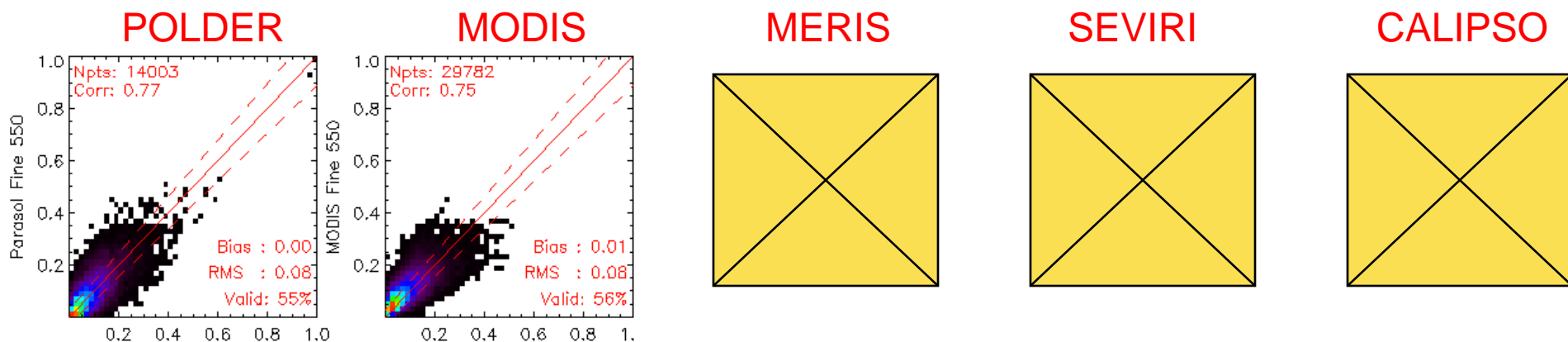
POLDER and MODIS provide the best AOD estimates
SEVIRI rather good, with the advantage of much higher temporal
      resolution
MERIS and CALIPSO AOD of doubtfull value

Correlation ≈ 0.9; RMS ≈ 0.09
≈60% of retrievals within 0.03+0.08 t
Small (high) bias for POLDER retrievals

Ocean; Fine Mode AOD

POLDER	MODIS	MERIS	SEVIRI	CALIPSO

Only POLDER and MODIS provide this estimate

No bias
Correlation ≈ 0.75; RMS ≈ 0.08
≈55% of retrievals within 0.03+0.08 t
There is clearly some information on the distinction between Fine and total AOD

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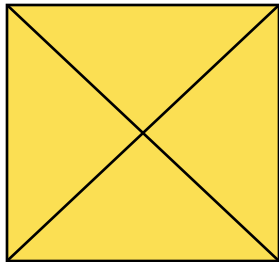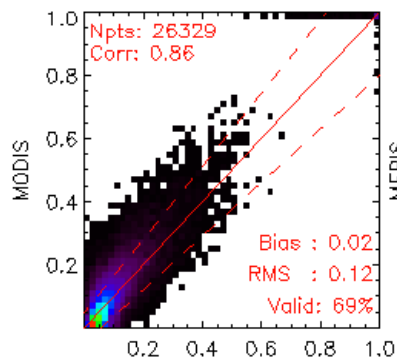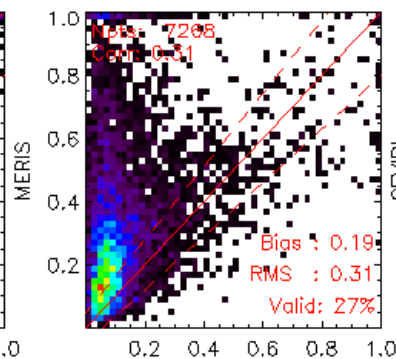
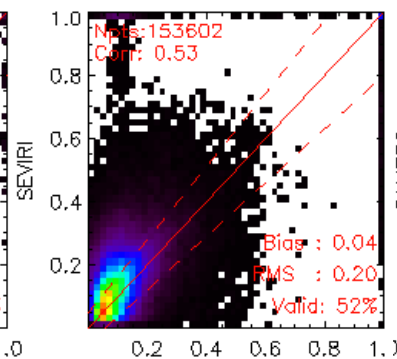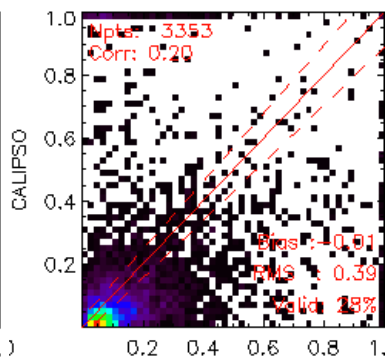POLDER   MODIS   MERIS   SEVIRI   CALIPSO

POLDER does not attempt a total AOD estimate
MODIS estimates are clearly better than the others
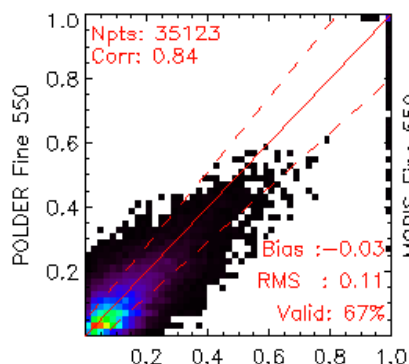
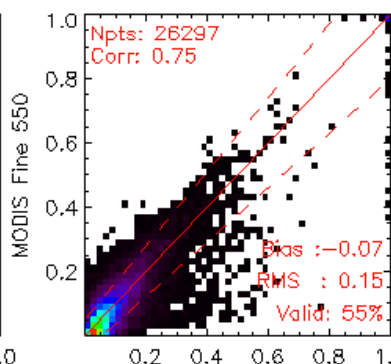Correlation ≈ 0.85; RMS ≈ 0.12
≈69% of retrievals within 0.05+0.15 t

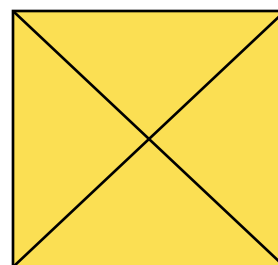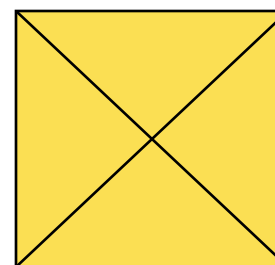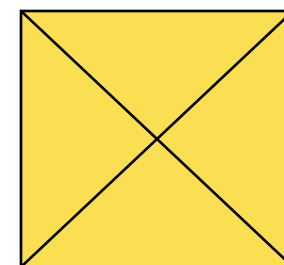**POLDER**   **MODIS**   **MERIS**   **SEVIRI**   **CALIPSO**

Only POLDER and MODIS provide this estimate

POLDER estimate of the Fine Mode AOD better than that of MODIS
Recent studies have shown that MODIS size discrimination has little value

Correlation ≈ 0.84; RMS ≈ 0.11
≈67% of retrievals within 0.05+0.15 t

Results suggest to use total AOD from MODIS and Fine Mode AOD from
    POLDER/Parasol

More than 20 years of experience for the remote sensing of aerosols and clouds from space

The two MODIS instruments, onboard Terra and Aqua, provide the most comprehensive datasets to study aerosols, clouds, and their interactions

Surface measurements and field campaigns are needed to validate the satellite-derived products, and to measure parameters that are not observable from space

Calipso and Cloudsat are two active sensors that measure the vertical profiles of aerosols and clouds. They provide a very detailed survey of the vertical profile, but on a limited swath

There are still large uncertainties on the aerosol-cloud interactions and satellites are one of the tools needed to improve our understanding