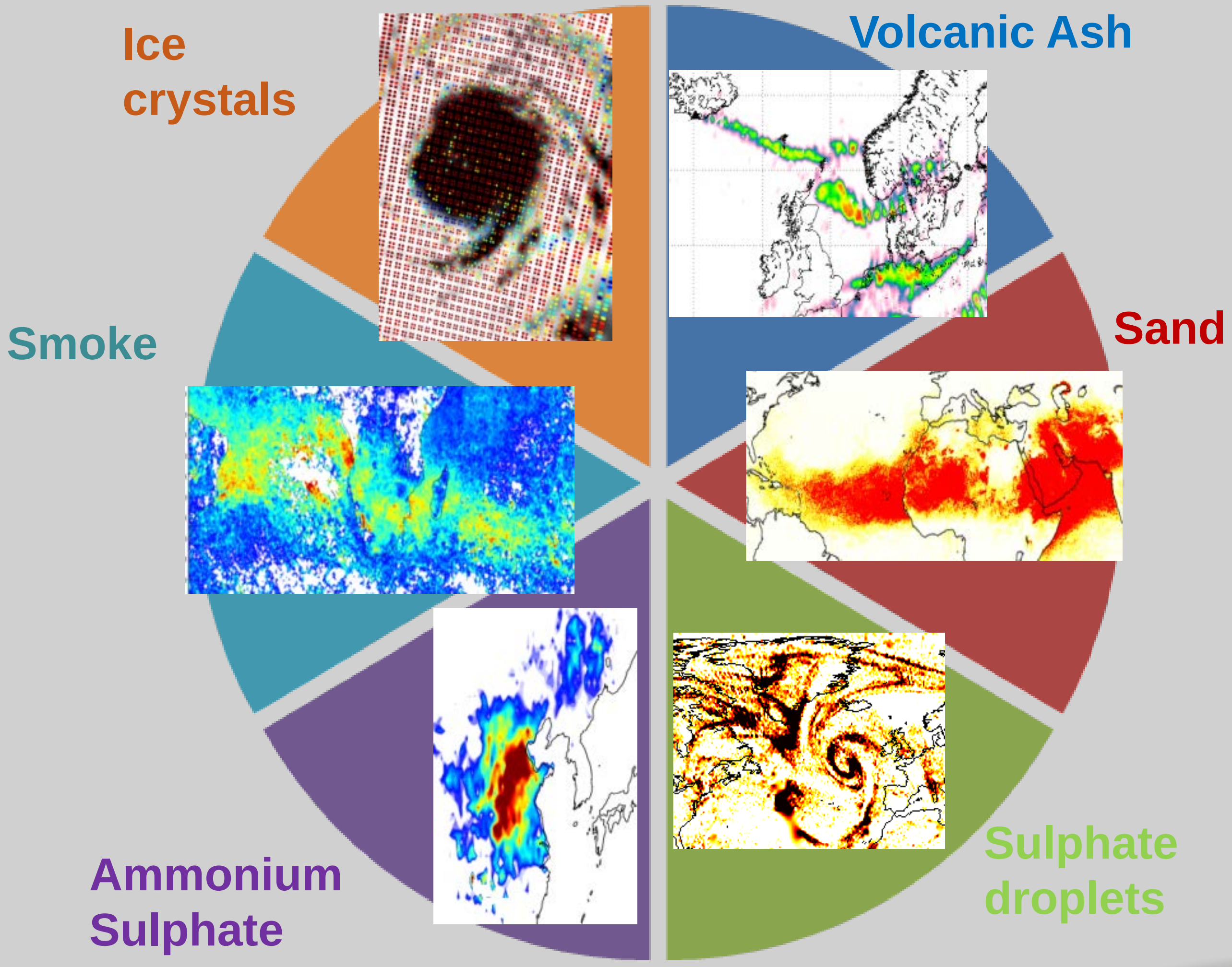
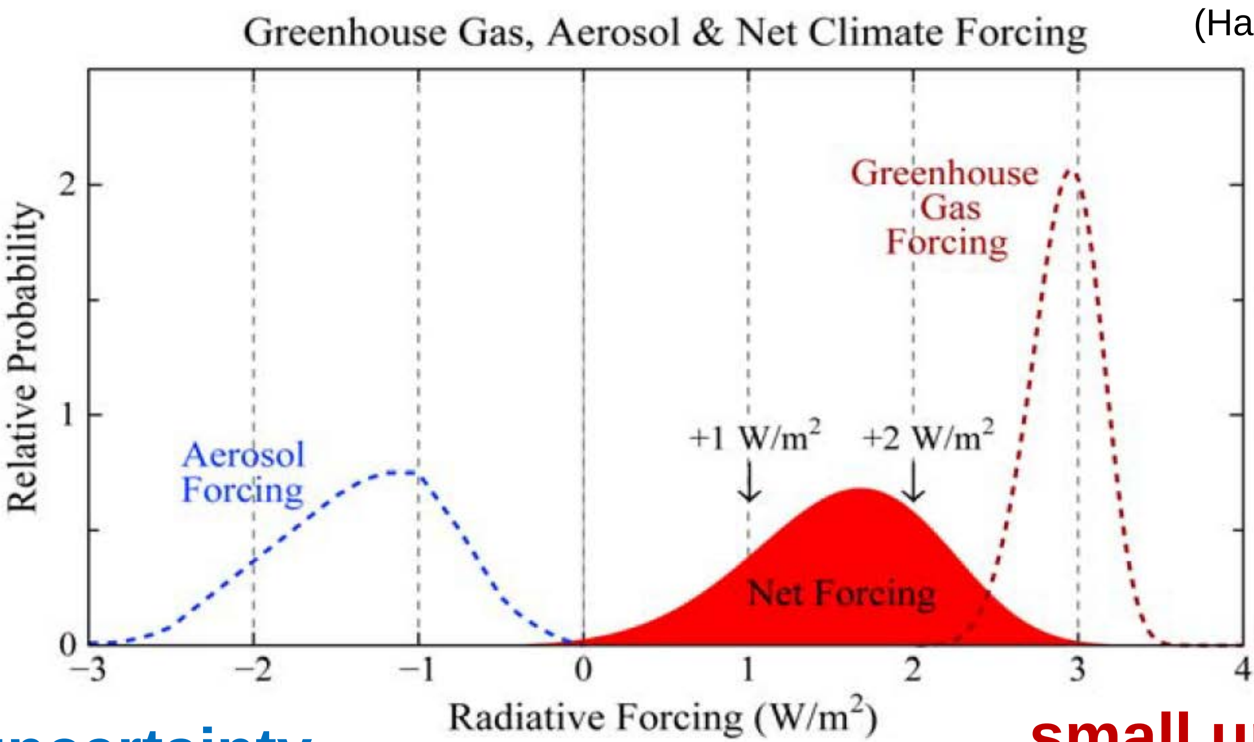
# A unified method for aerosol detection and type speciation

L. Clarisse, P.-F. Coheur, F. Prata, J. Hadji-Lazaro, D. Hurtmans, and C. Clerbaux



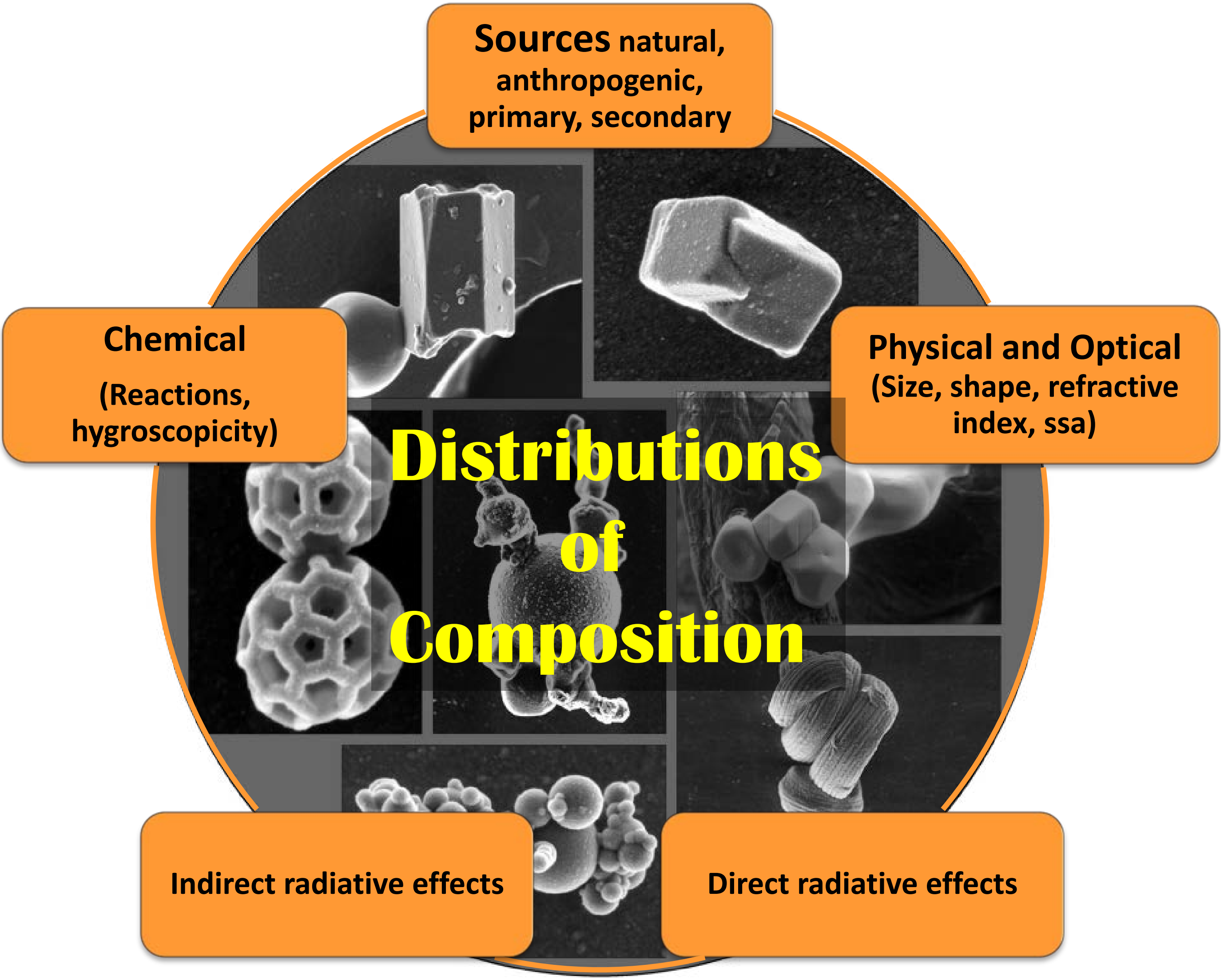
(Hansen et al, 2011)

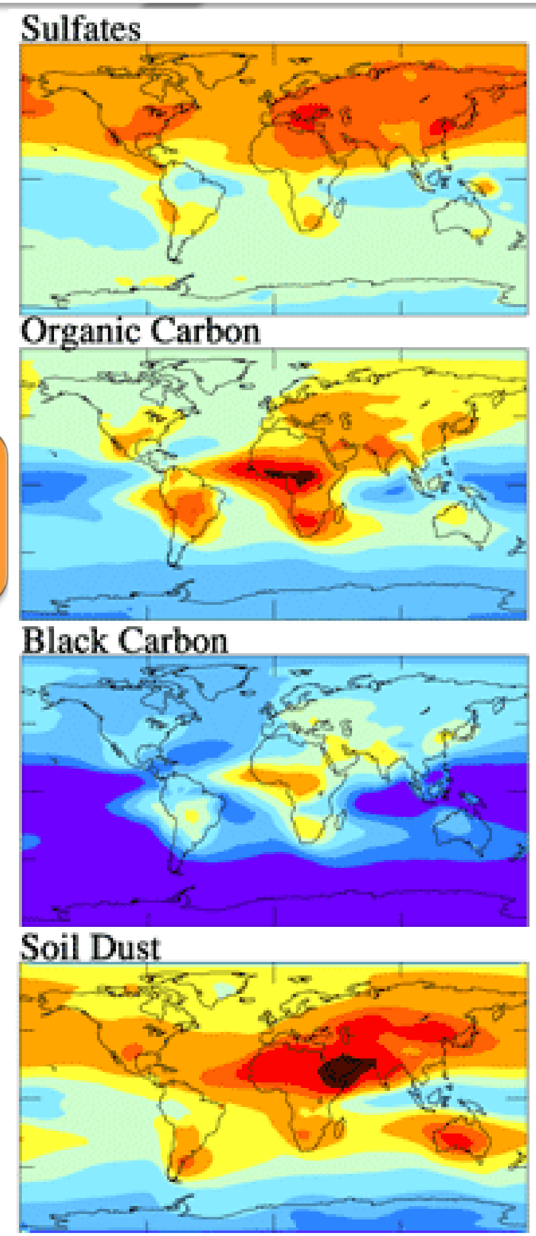



aerosol
LARGE uncertainty

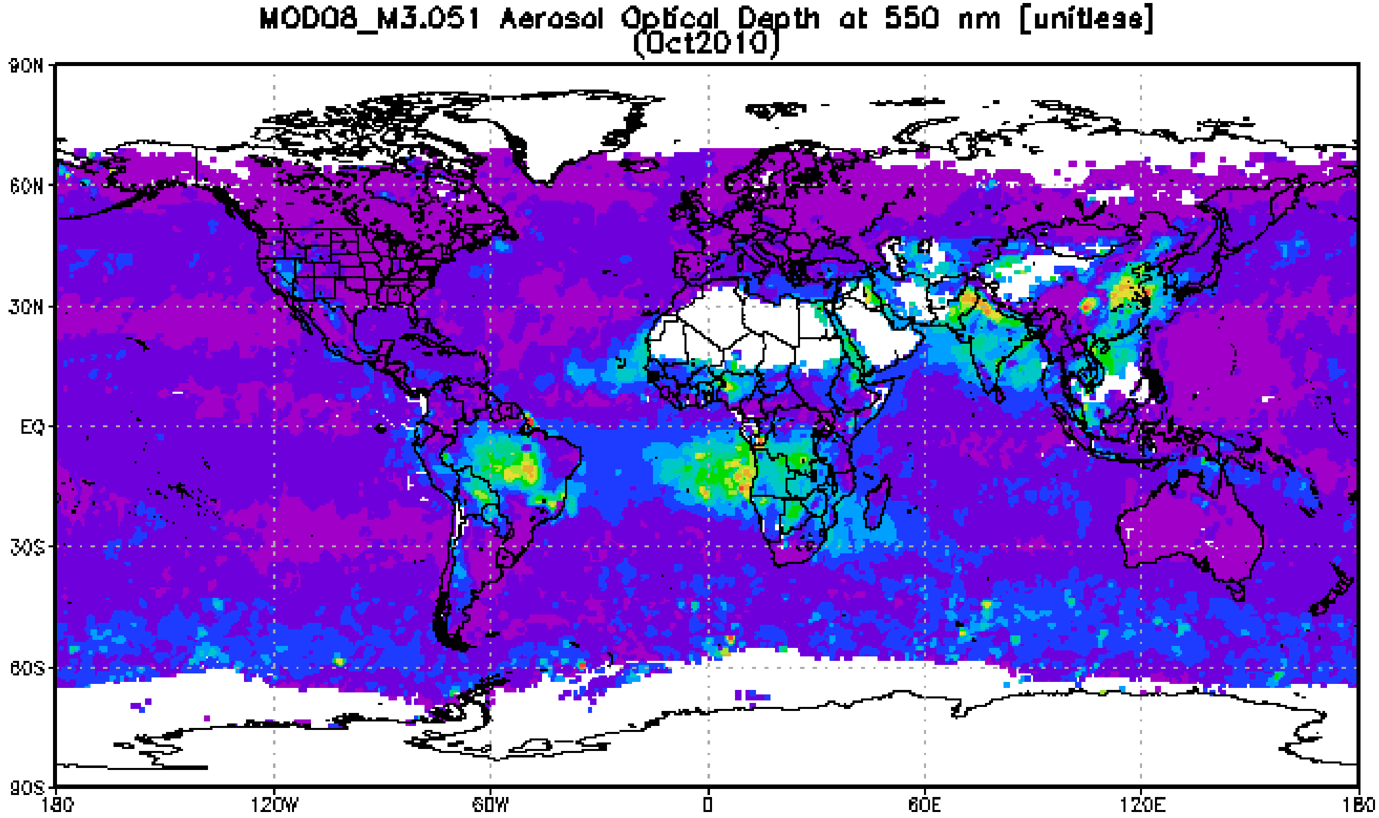
gases
small uncertainty

It is imperative to improve our knowledge on **aerosols** to make progress in resolving climate issues

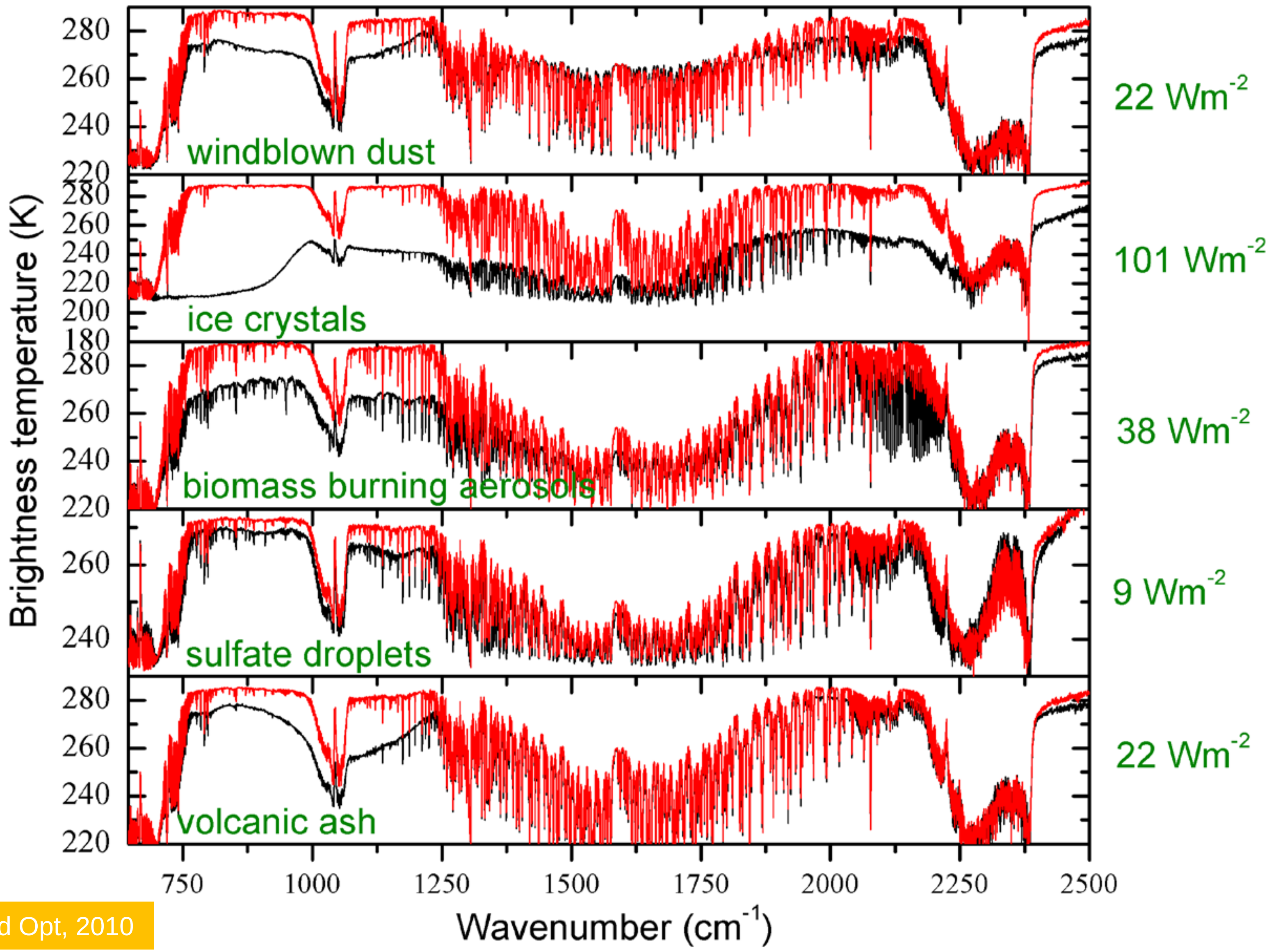

Sources natural, anthropogenic, primary, secondary
Chemical
(Reactions, hygroscopicity)
Physical and Optical
(Size, shape, refractive index, ssa)
Distributions of Composition
Indirect radiative effects
Direct radiative effects


Sulfates
Organic Carbon
Black Carbon
Soil Dust

Shortwave sounders still have a long way to go




Increasing measurement dimensions → ✓ Multi-angel ✓ Multi-spectral ✓ Polarization → ✓ Fine vs Coarse ✓ SSA ✓ Sphericity



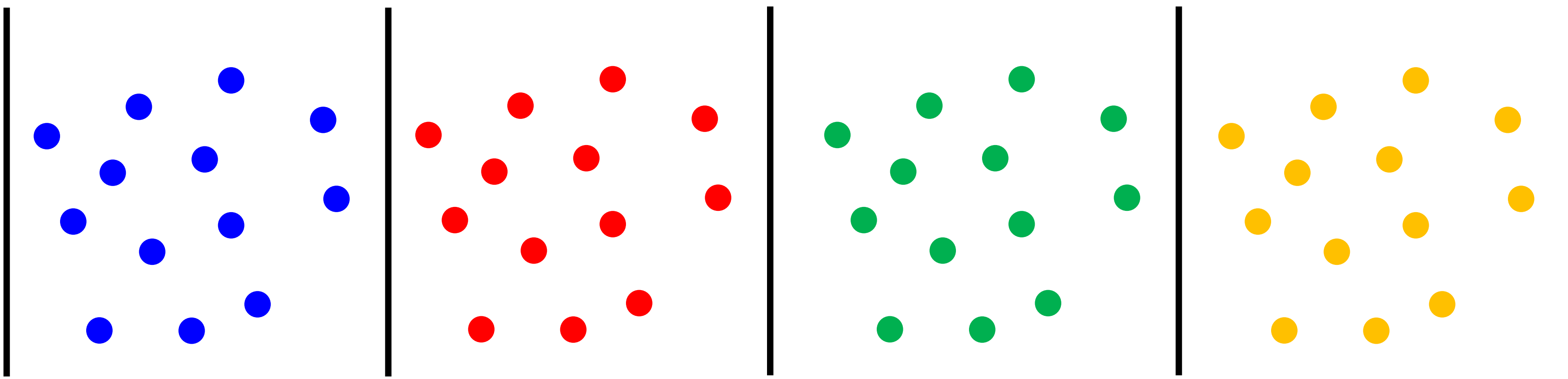

Clarisse et al., Applied Opt, 2010

# Uniform aerosol detection (Clarisse et al, 2012 ACPD)

1. **Relative distance** (is it more likely to be an aerosol than not)

2. **Absolute distance** (does it look like aerosol)

3. **Geophysical information** (space, time and other context)



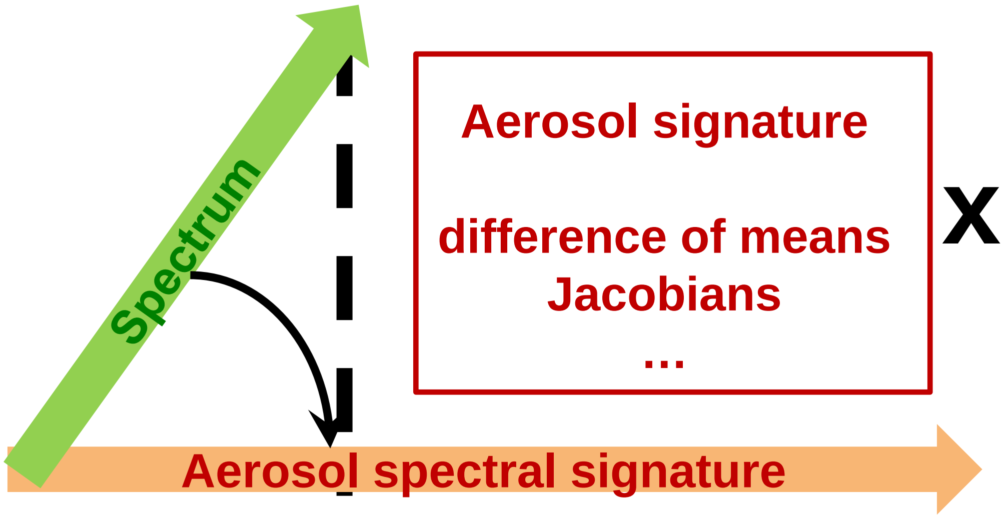
**Dust**
**Mean $\mu_1$**
**Covariance $S_\mu$**

**Volcanic Ash**
**Mean $\mu_2$**
**Covariance $S_\mu$**

**'Clean'**
**Mean $\mu_3$**
**Covariance $S_\mu$**

**Sulphate Aerosol**
**Mean $\mu_4$**
**Covariance $S_\mu$**

# I. Relative distance (weighted projection)




**Aerosol signature**

**difference of means**
**Jacobians**
**…**

**X**

**Projection weights**

**covariance $S^{-1}$ of unpolluted spectra**

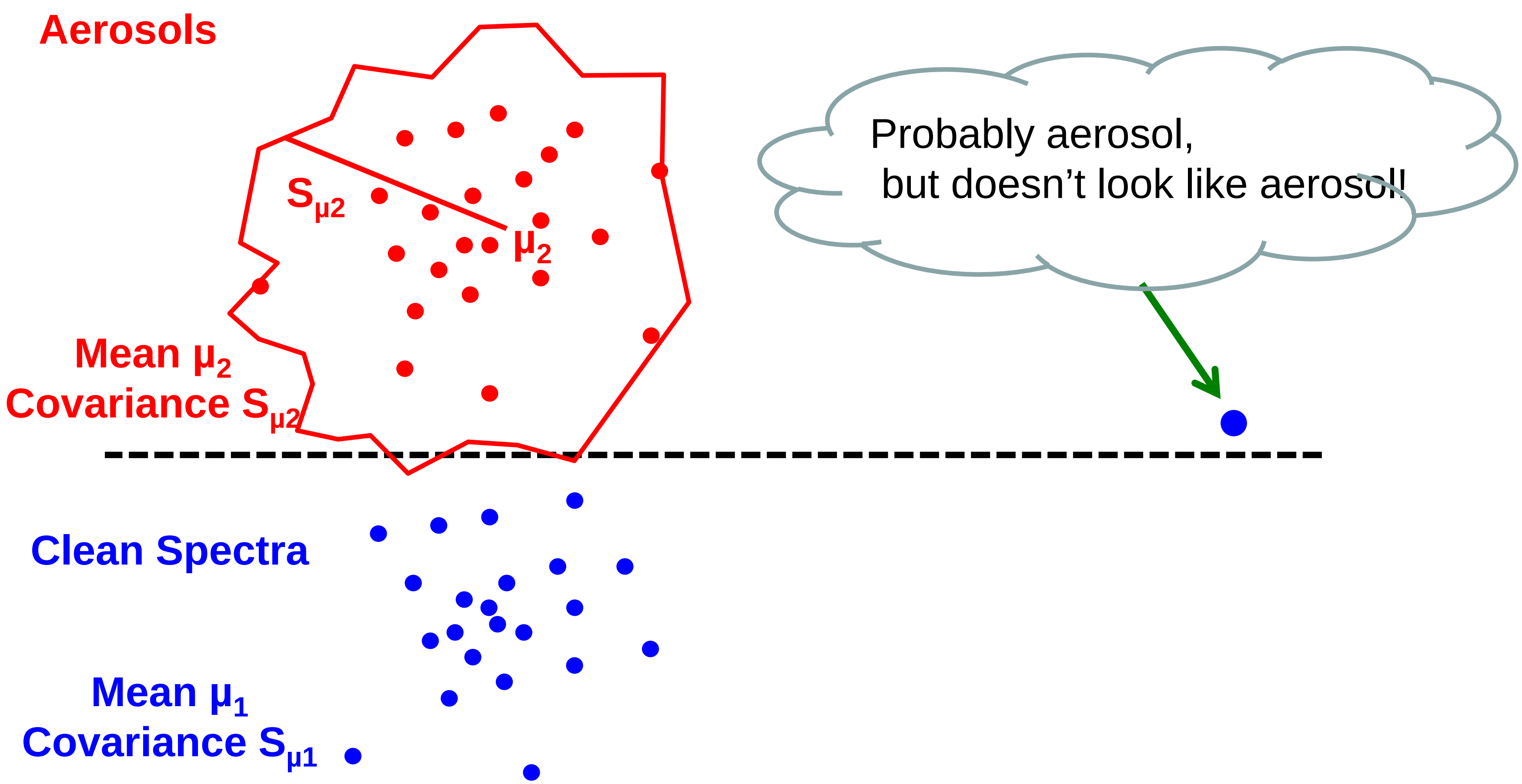
**X**

**Observed spectrum**

**This weighted projection unifies:**

1. Linear discrimination analysis (LDA): $R = (\mu_k - \mu_l)^T S^{-1}(y)$
2. Virtual optimal estimation: $(k)^T S^{-1}(y)$ (Walker et al, 2010)
3. PCA detection, uses different projection weights (Hurley et al., 2009)

# II. Absolute distance




Mahalonobis distance $A(y) = (y - \mu_k)^T S_k^{-1} (y - \mu_k)$

# Uniform aerosol detection

## Relative distance;

Fischer distance $R(y) = (\mu_k - \mu_l)^T S_k^{-1} (y - \mu_k)$

## Absolute distance;

Mahalonobis distance $A(y) = (y - \mu_k)^T S_k^{-1} (y - \mu_k)$

} Find suitable thresholds

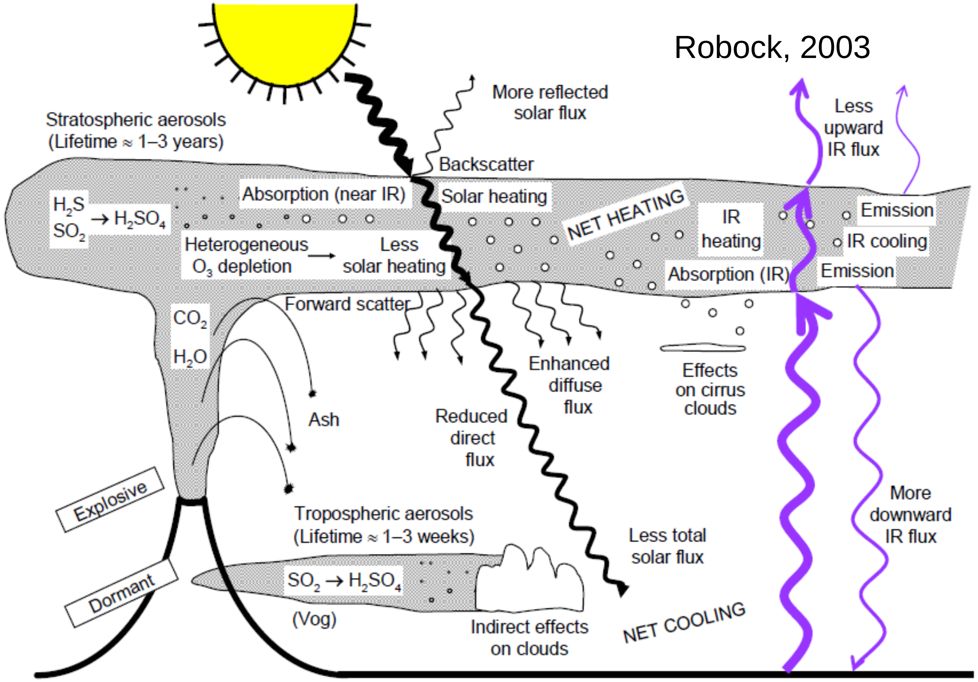
## Geophysical information -- context

Nearby detections (time and space) – short term context
Knowledge of scene (Sahara vs Pacific ocean) – long term context

**→ Construction covariance matrix and finding suitable thresholds is labour intensive**

# Formation of sulphuric acid aerosols

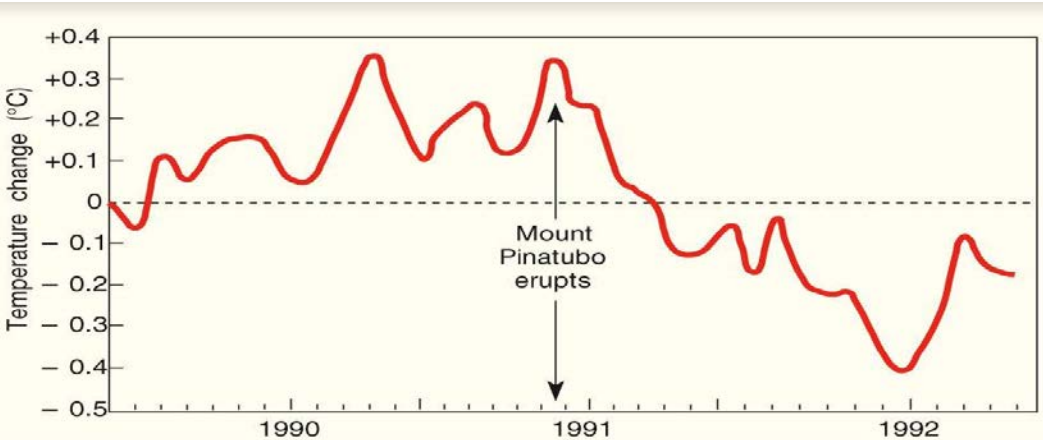
$$SO_2 + OH + M \rightarrow H_2SO_4 + HO_2$$



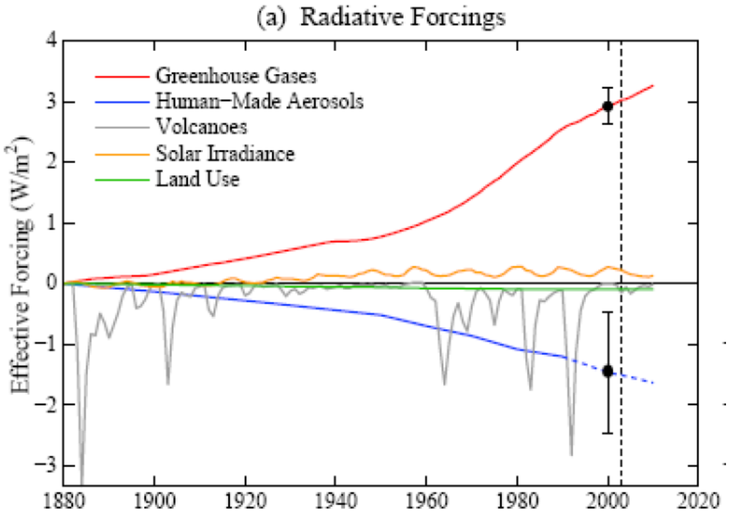

## Sulphuric acid aerosols

- efficiently scatter  solar light
- long lifetime (2-3 years)

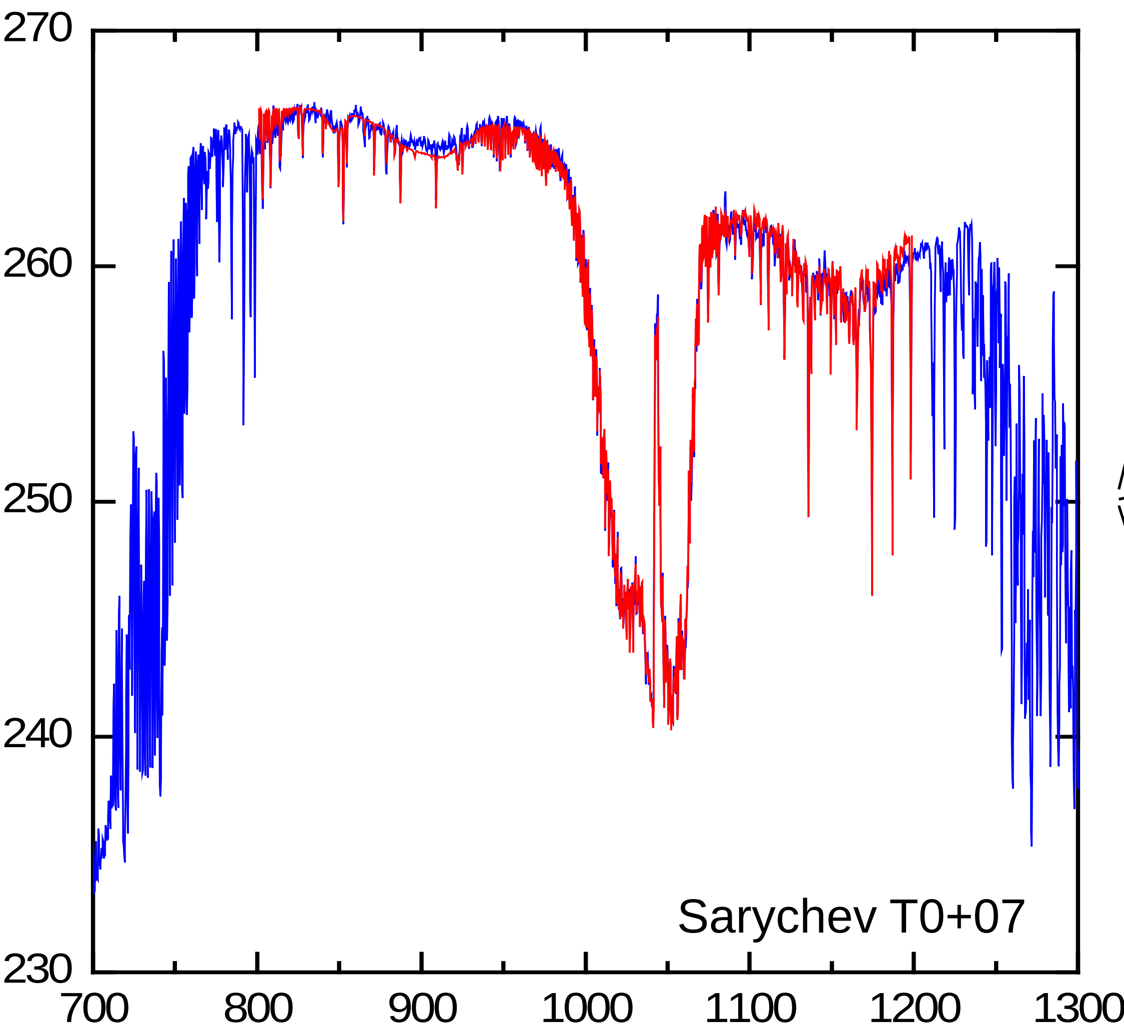
Large eruptions cause a short term Global climate impact
Eg. Mount Pinatubo 1990 ~ 1 K

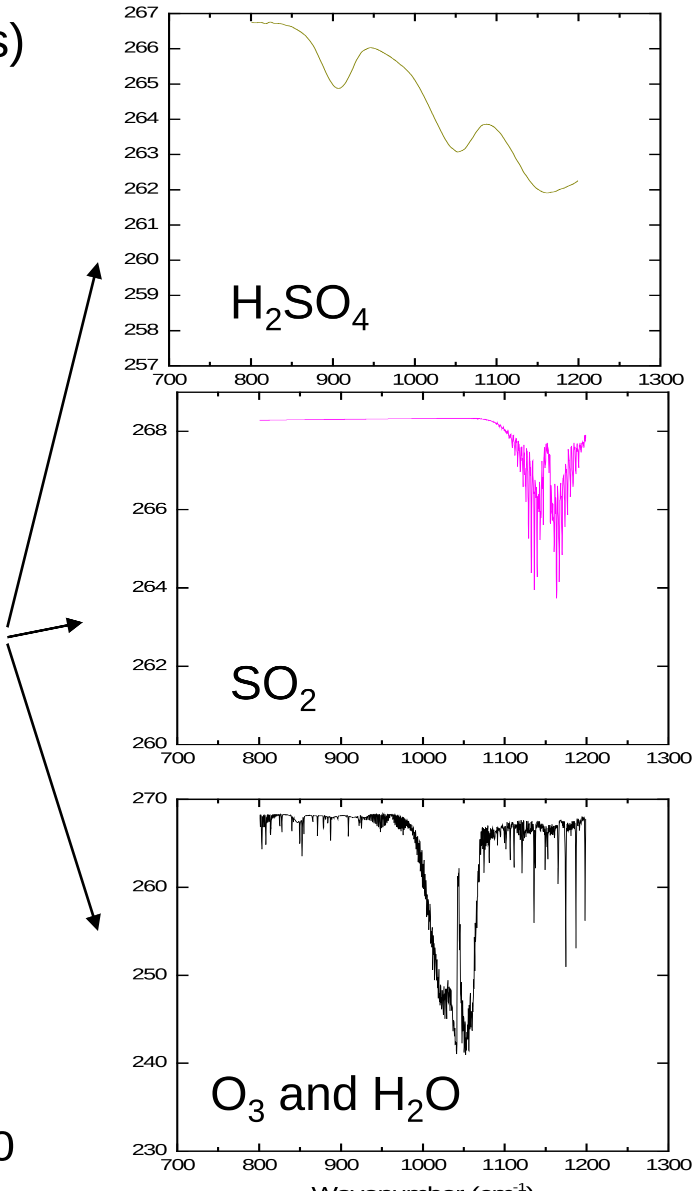


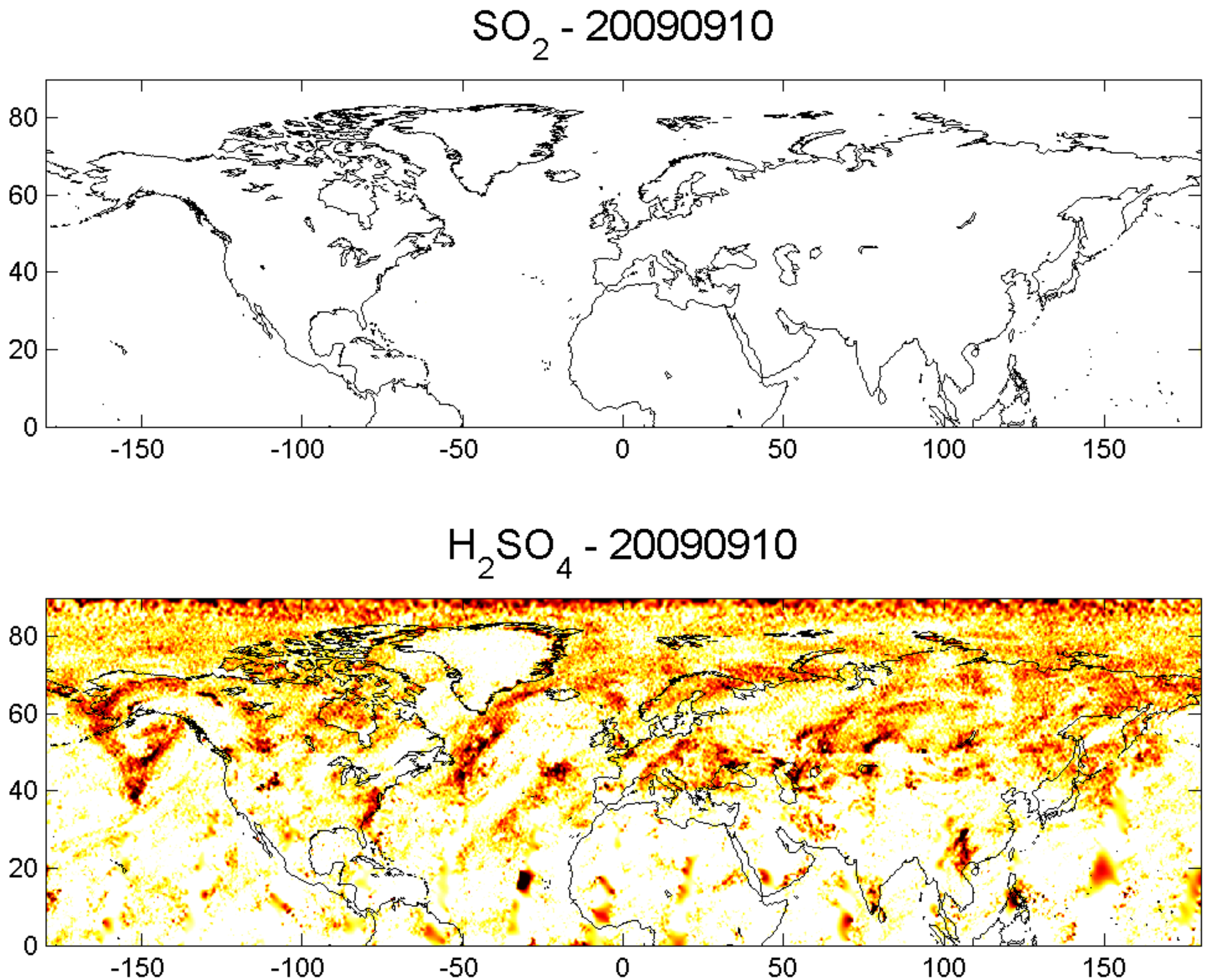

Hansen et al, ACP, 2011



# Sulfuric acid aerosols ($H_2SO_4 – H_2O$ droplets)

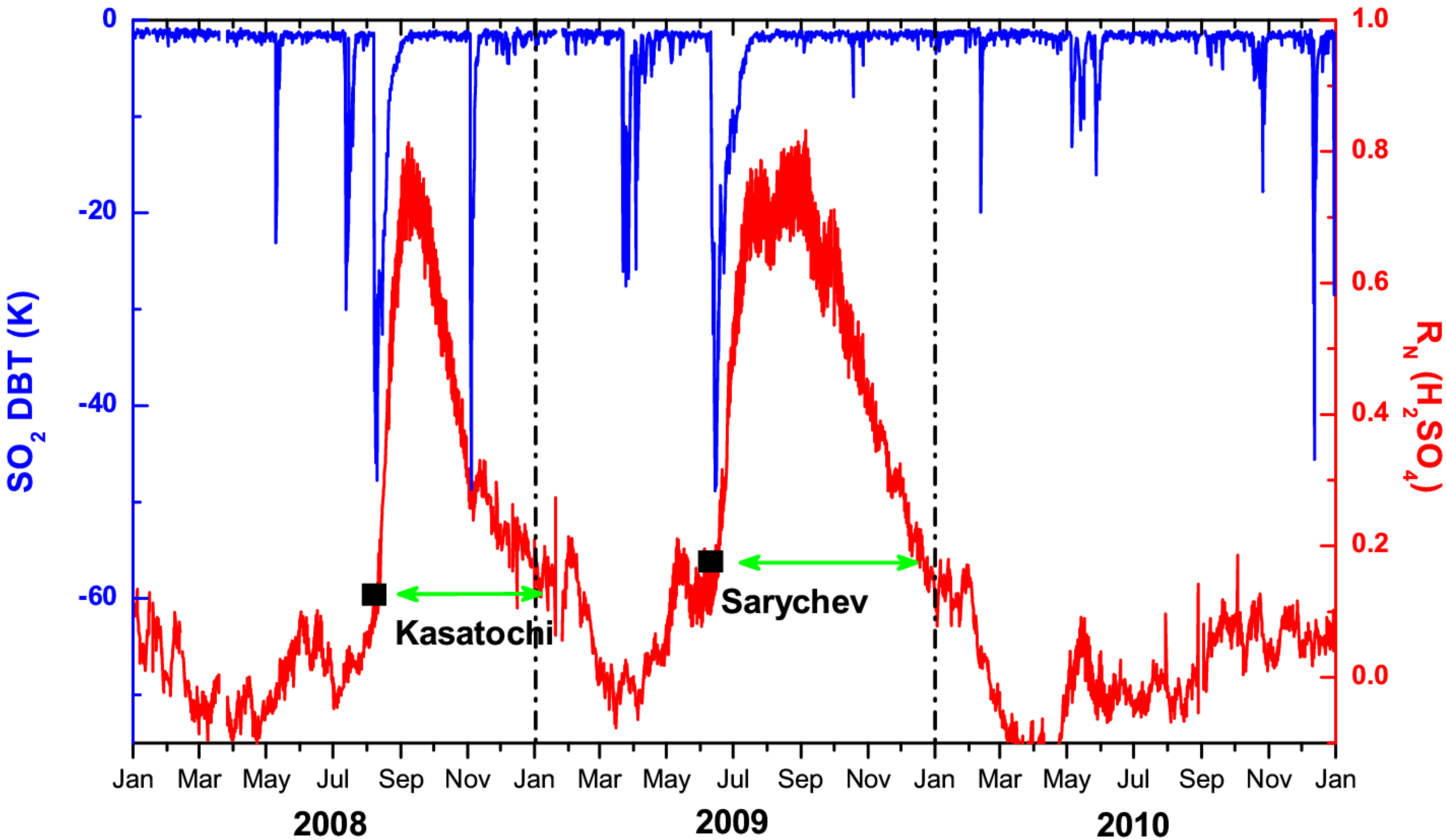



SO2 - 20090910
80
60
40
20
0
-150
-100
-50
0
50
100
150
H2SO4 - 20090910
80
60
40
20
0
-150
-100
-50
0
50
100
150

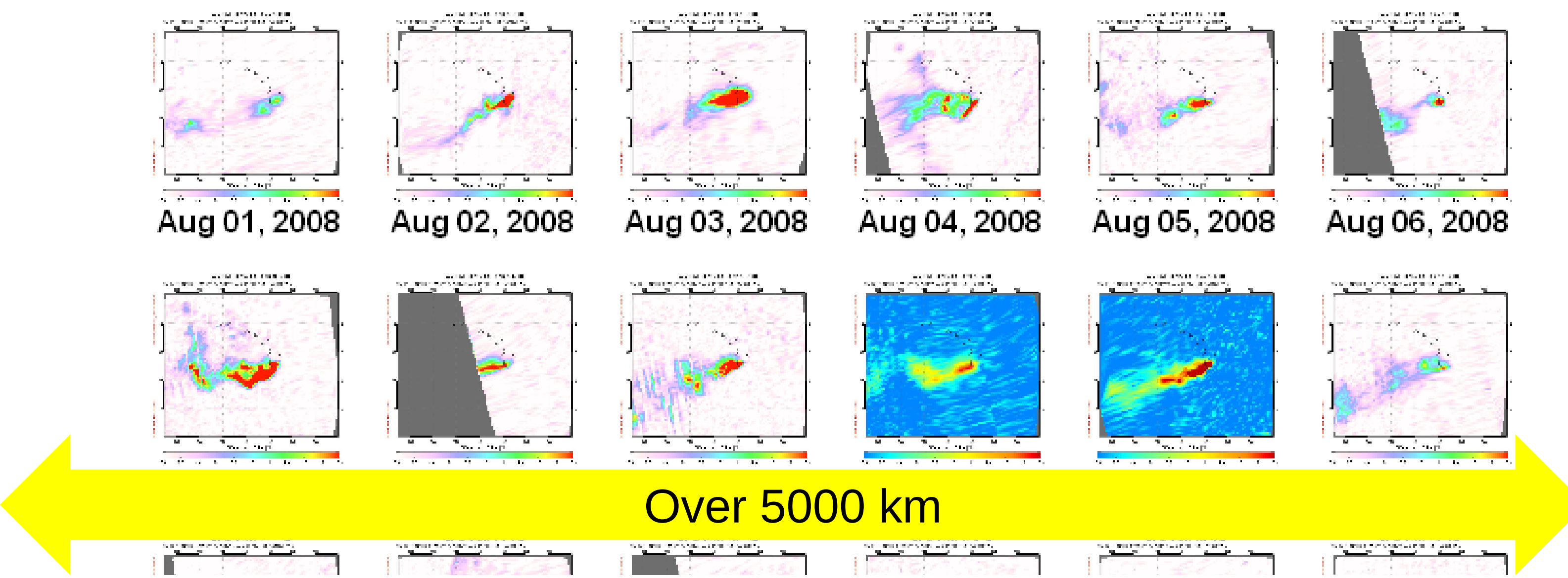
**Day 90**

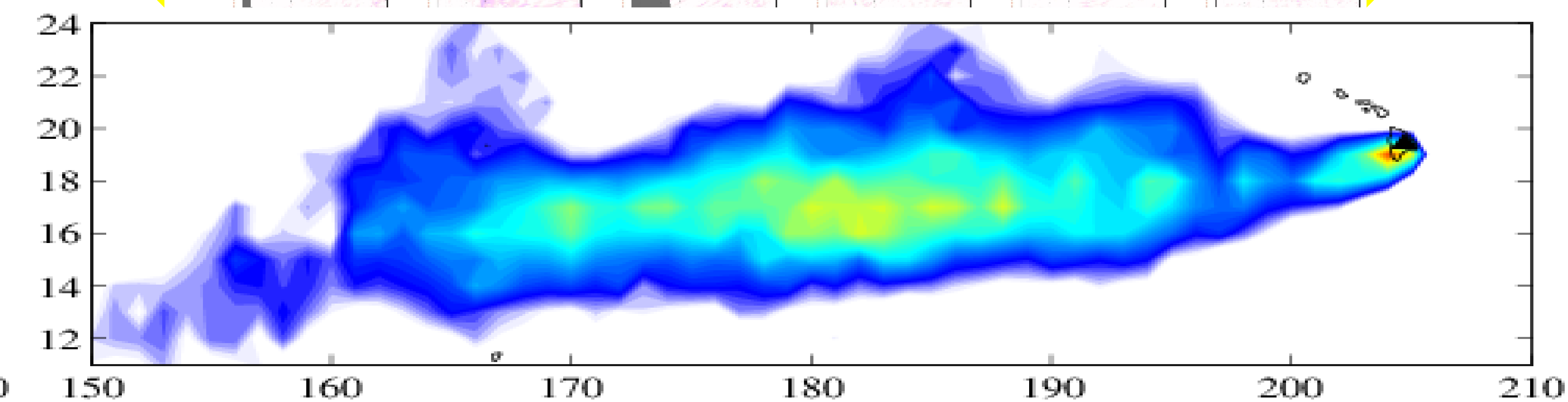
IASI 3 year time series of UTLS $SO_2$ – $H_2SO_4$



## Hawaii, USA

*** BEWARE: data that look like lines (NNW to SSE or NNE to SSW) are probably artifacts ***



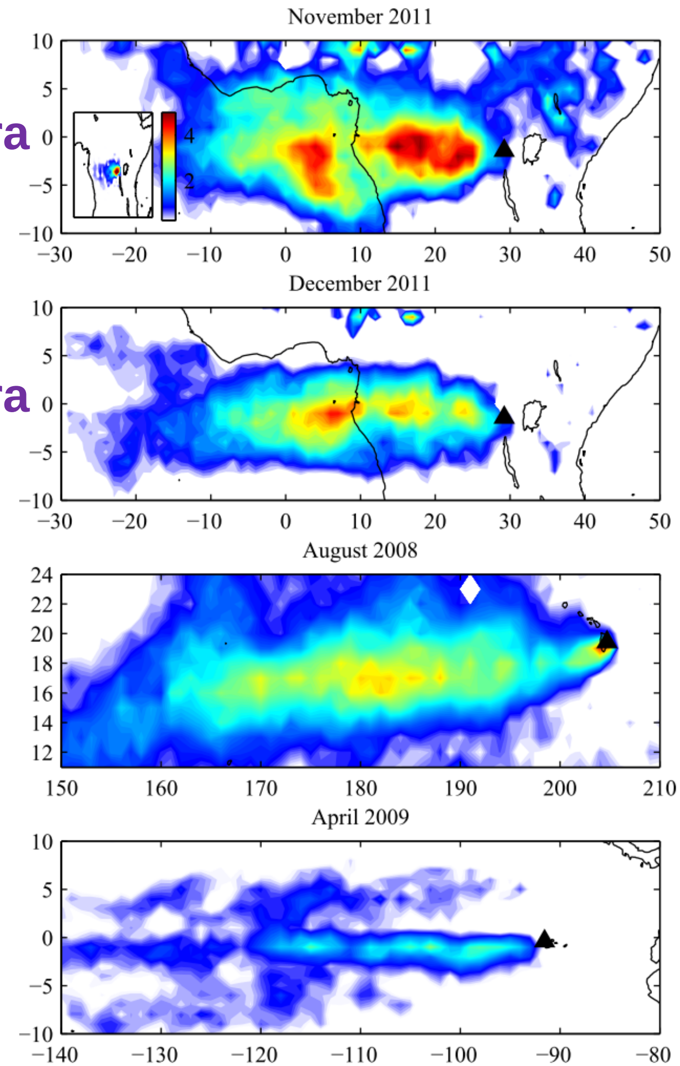



Nyamuragira

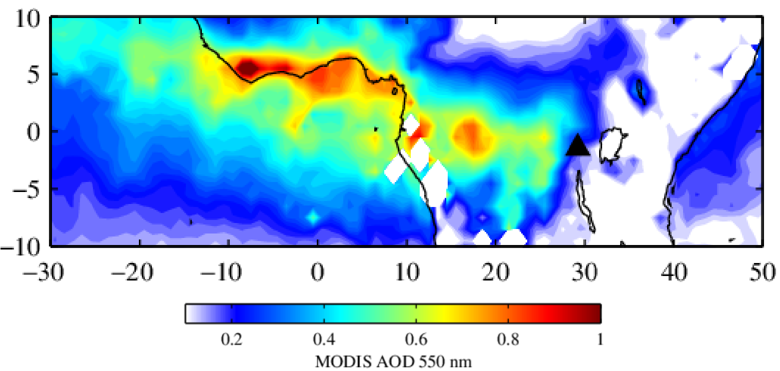
Nyamuragira

Kilauea

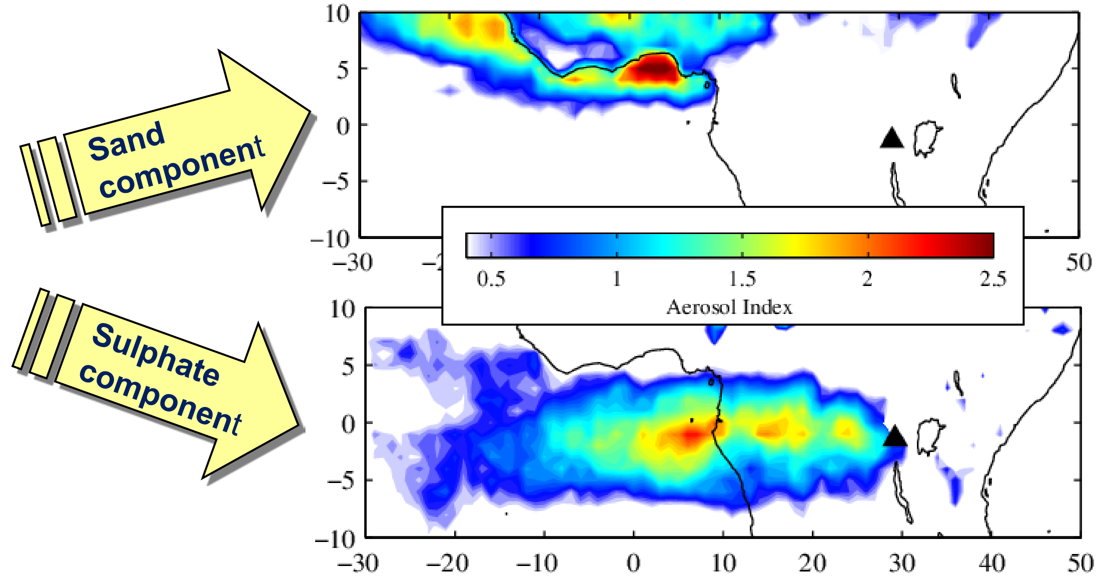
Fernandina




IASI



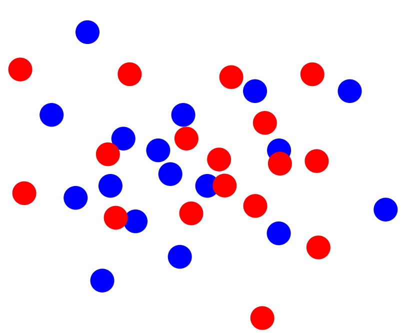

**Sand**

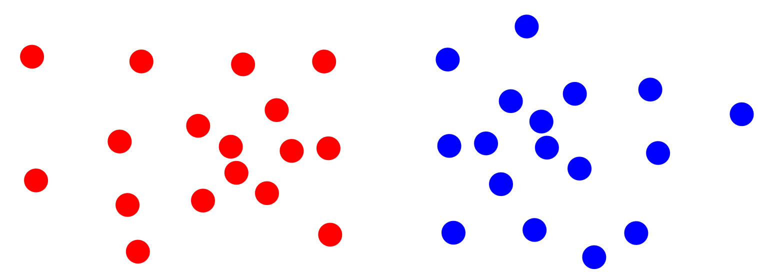



**Sulphate**

## MODIS Aerosol Soup

## IASI "deconvoluted" aerosols



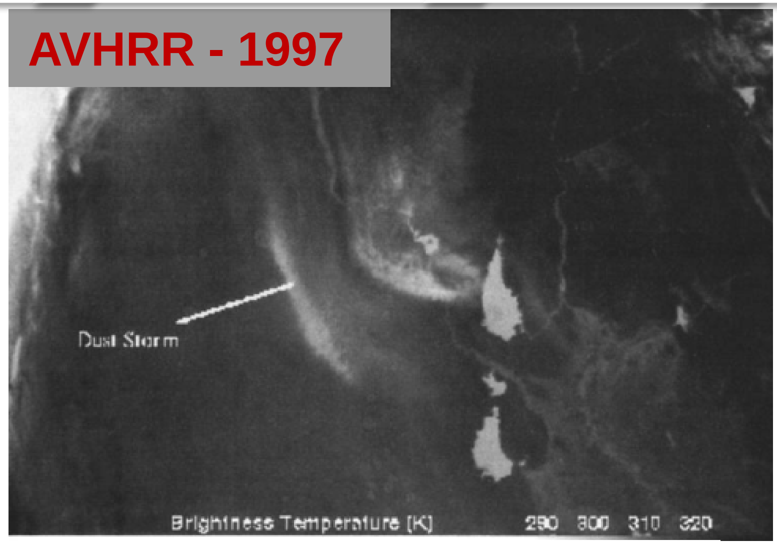


## NIMBUS - 1974

The Detection of Dust Storms Over Land and Water With Satellite Visible and Infrared Measurements

William E. Shenk and Robert J. Curran

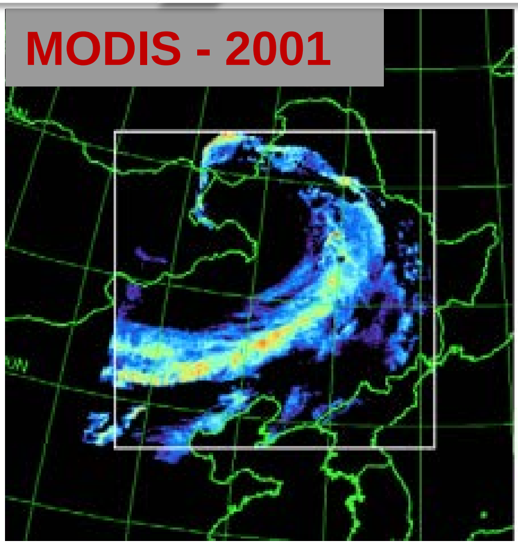
## AVHRR - 1997




**Remote sensing aerosols using satellite infrared observations**

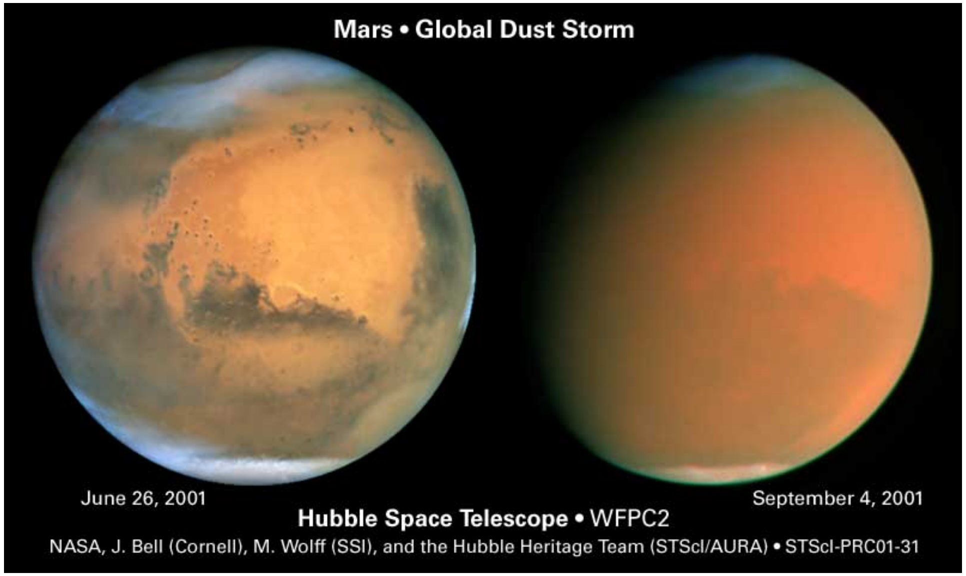
Steven A. Ackerman

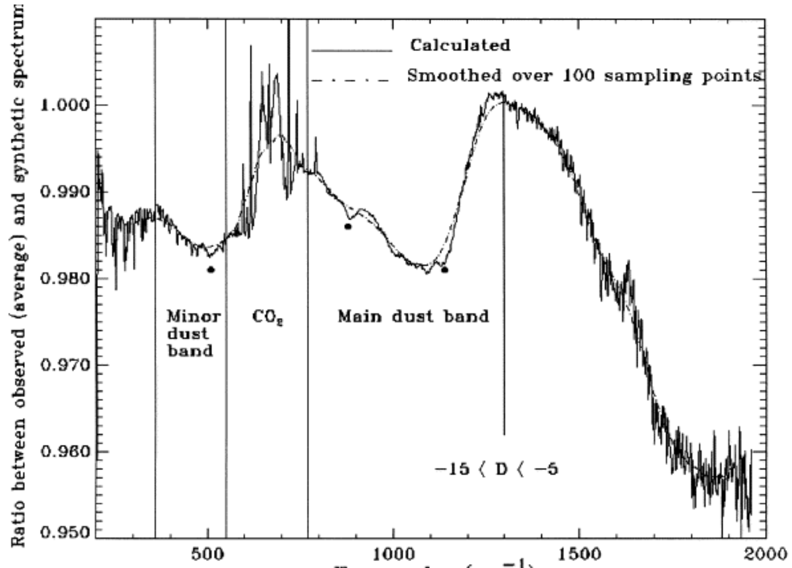
## MODIS - 2001



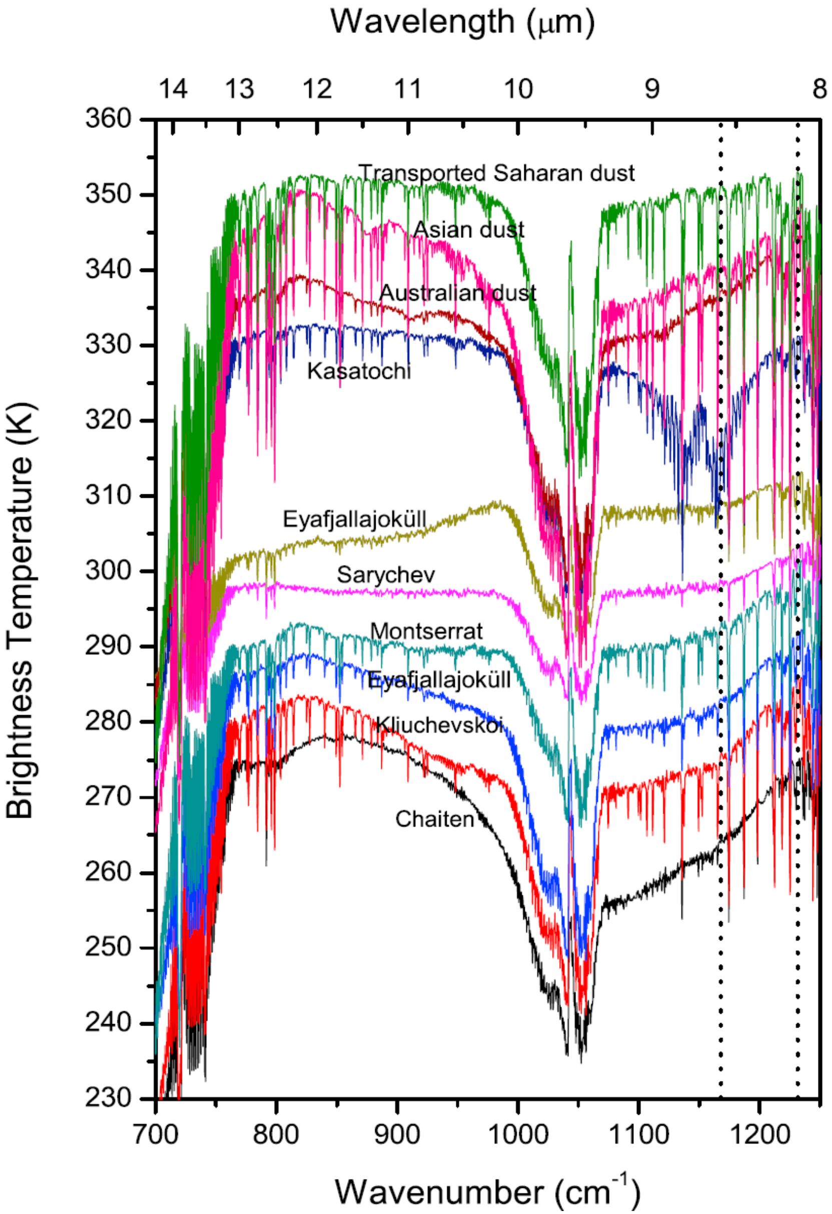
Retrieval of mass and sizes of particles in sandstorms using two MODIS IR bands: A case study of April 7, 2001 sandstorm in China

Yingxin Gu, William I. Rose, and Gregg J. S. Bluth

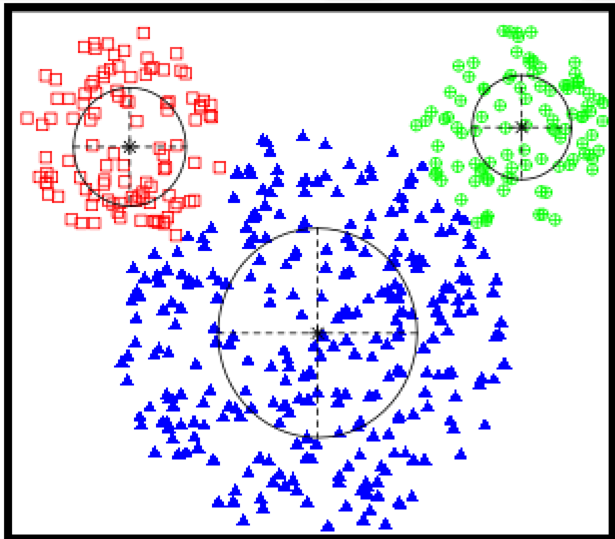


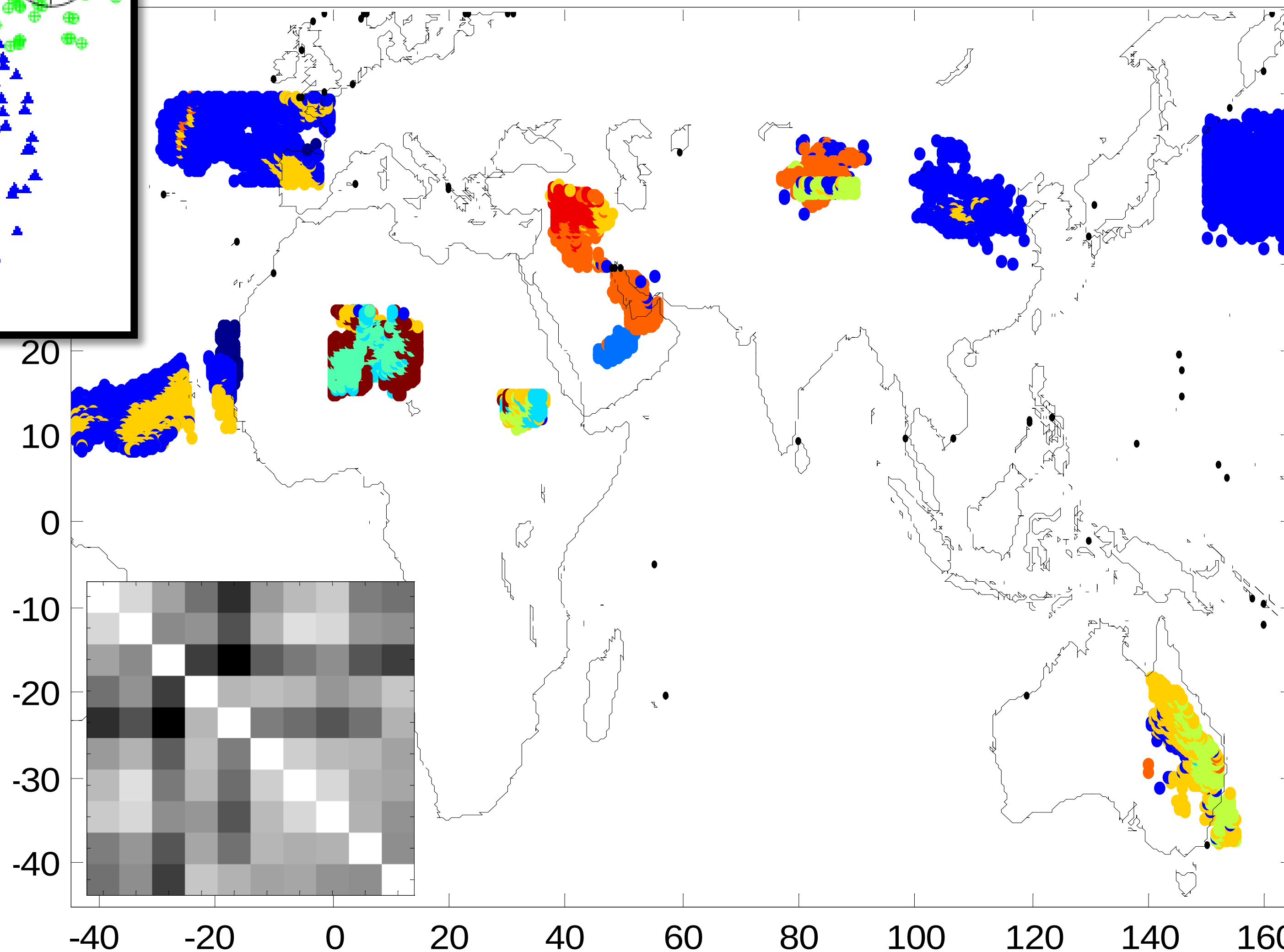



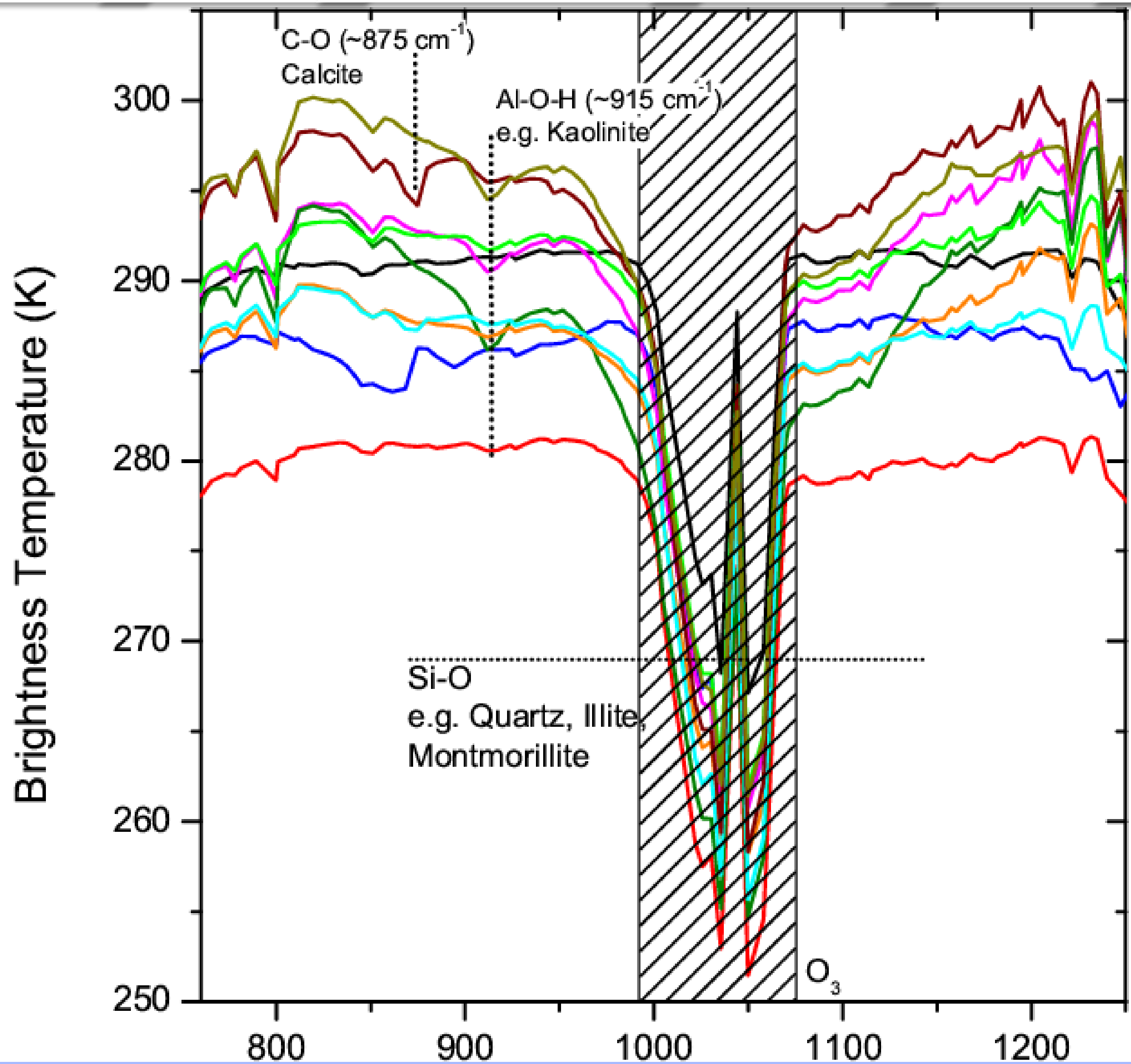

IRIS Mariner 9, D. Grassi and V. Formisano , PSS, 2000

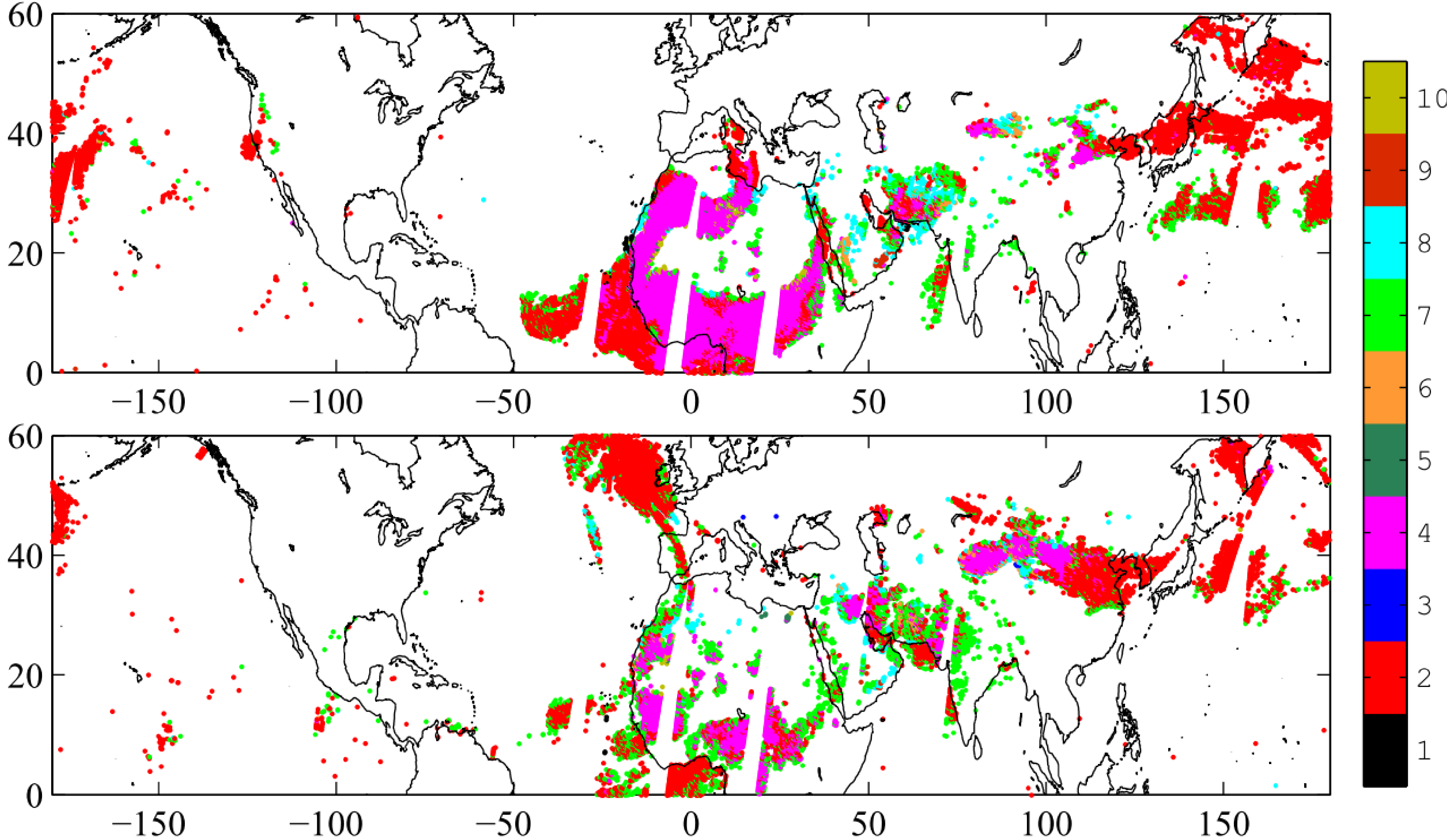

Wavelength (μm)
14 13 12 11 10 9 8
Brightness Temperature (K)
360 350 340 330 320 310 300 290 280 270 260 250 240 230
Transported Saharan dust
Asian dust
Australian dust
Kasatochi
Eyafjallajokull
Sarychev
Montserrat
Eyafjallajokull
Kliuchevskoi
Chaiten
700 800 900 1000 1100 1200
Wavenumber (cm$^{-1}$)

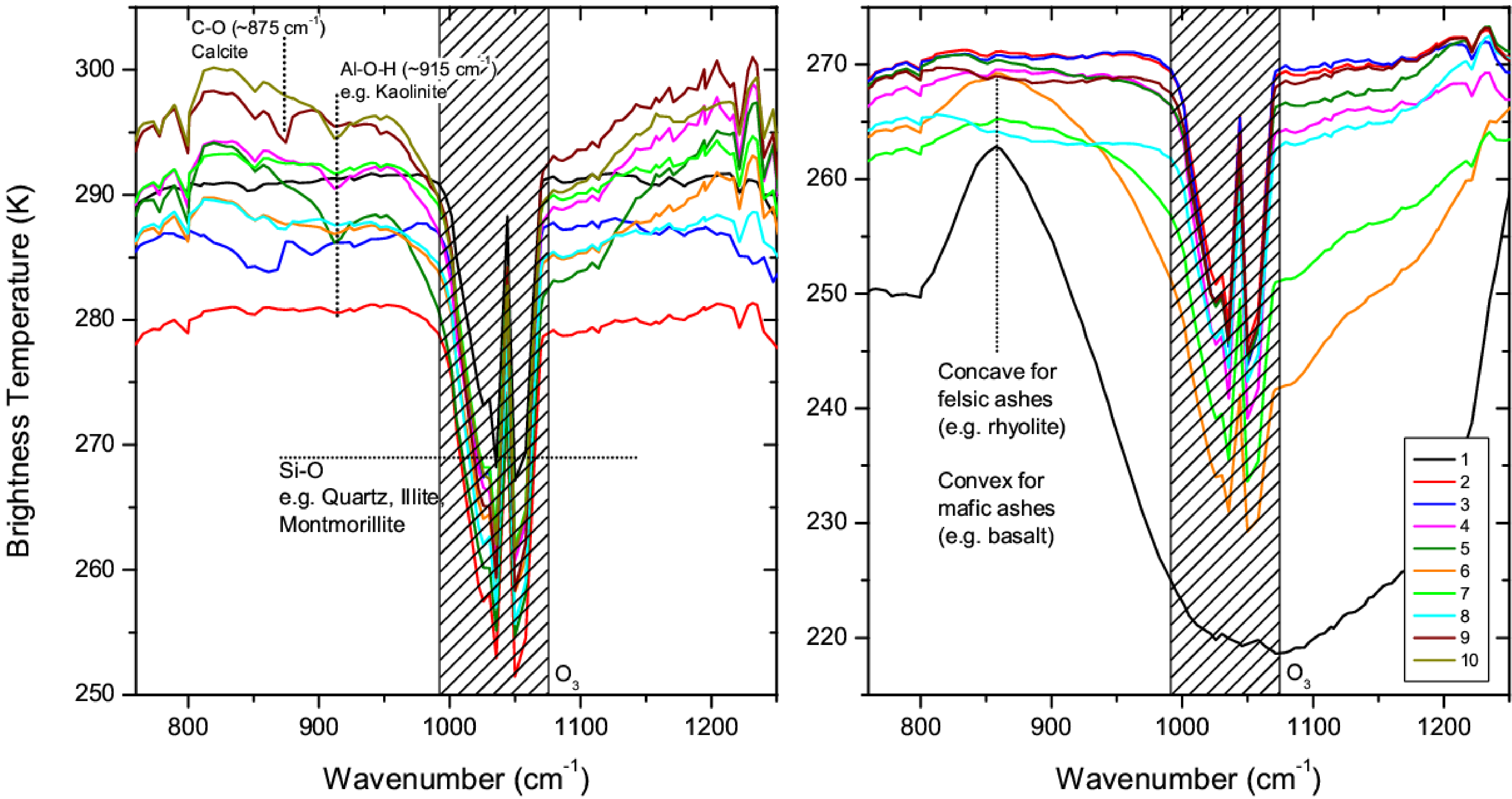
# K- means clustering



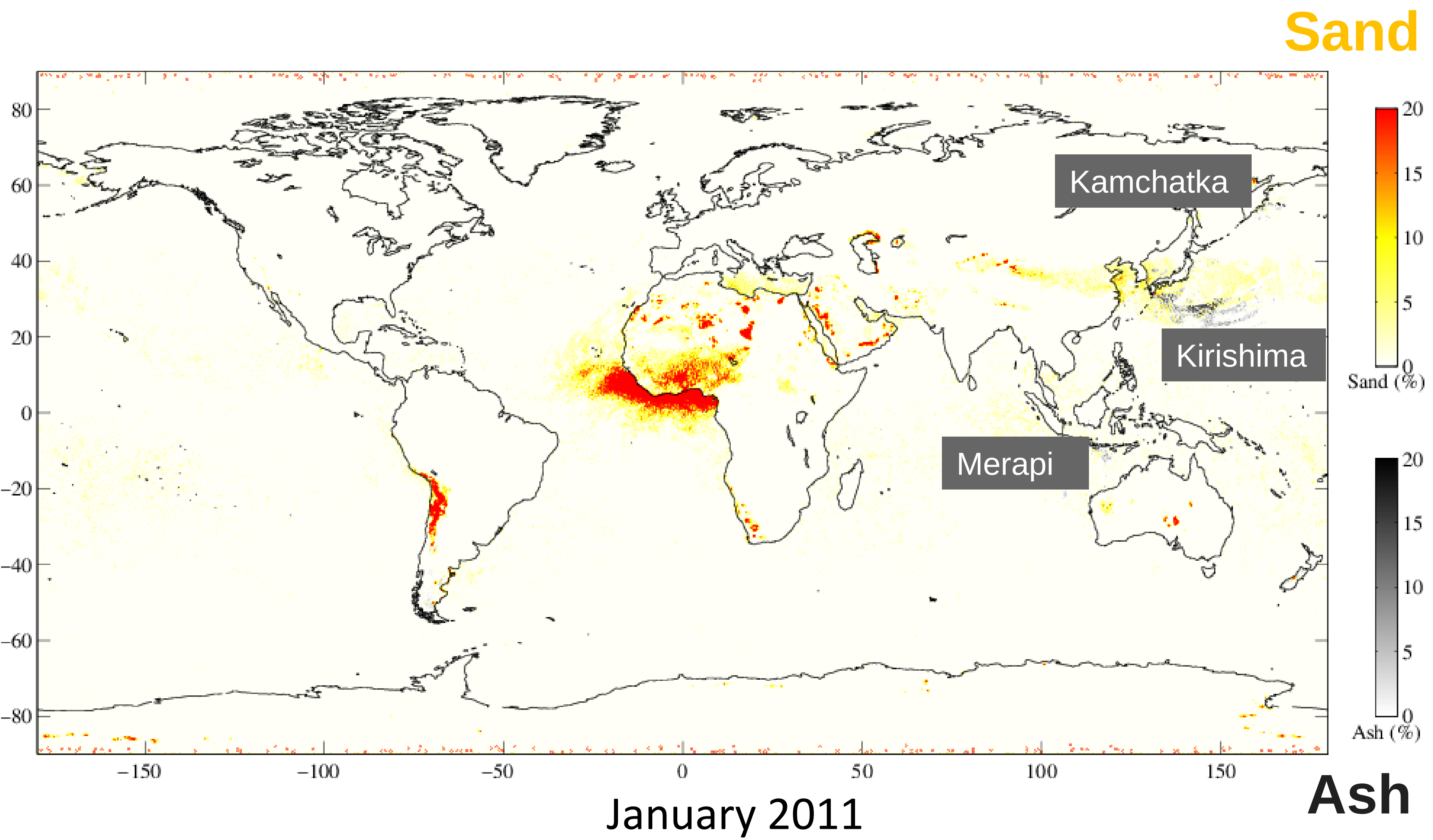



C-O (~875 cm-1)
Calcite
Al-O-H (~915 cm-1)
e.g. Kaolinite
Si-O
e.g. Quartz, Illite,
Montmorillite
O3
Brightness Temperature (K)
300
290
280
270
260
250
800
900
1000
1100
1200

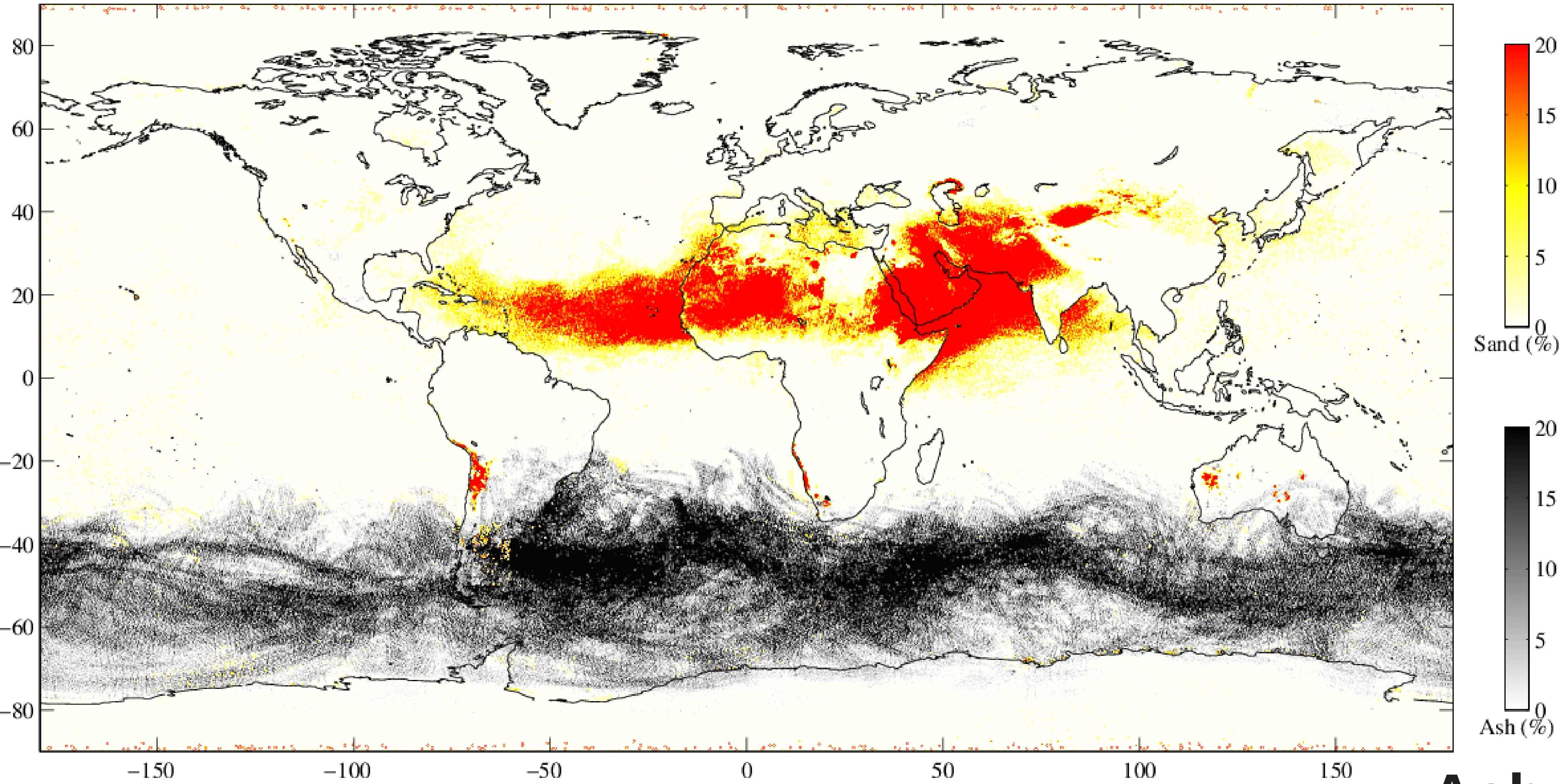

60
40
20
0
−150
−100
−50
0
50
100
150
60
40
20
0
−150
−100
−50
0
50
100
150
10
9
8
7
6
5
4
3
2
1



C-O (~875 cm-1)
Calcite
Al-O-H (~915 cm-1)
e.g. Kaolinite
Si-O
e.g. Quartz, Illite,
Montmorillite
O3
Brightness Temperature (K)
Wavenumber (cm-1)
Concave for
felsic ashes
(e.g. rhyolite)
Convex for
mafic ashes
(e.g. basalt)
1
2
3
4
5
6
7
8
9
10

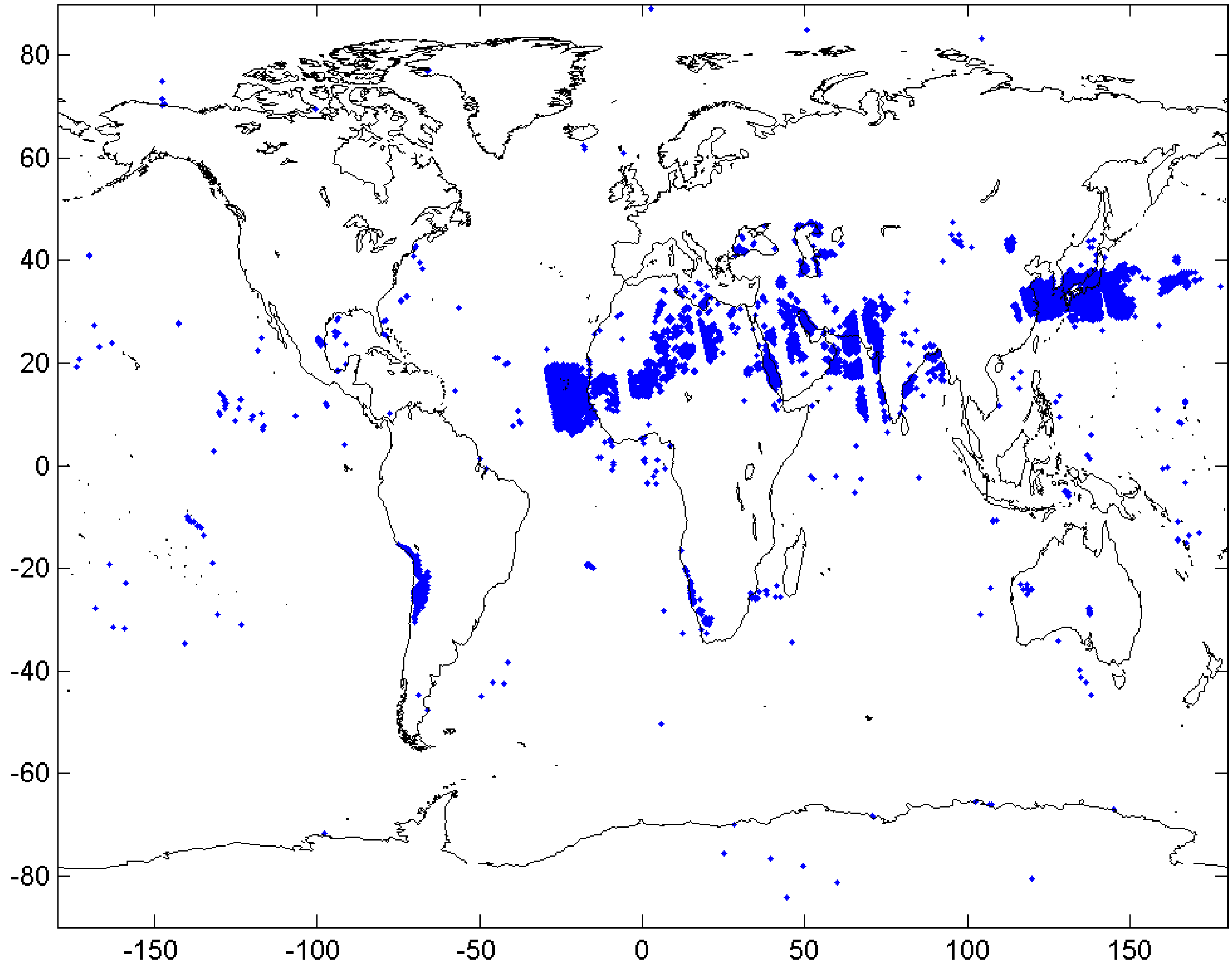

Sand
Kamchatka
Kirishima
Merapi
Sand (%)
Ash (%)
Ash
January 2011

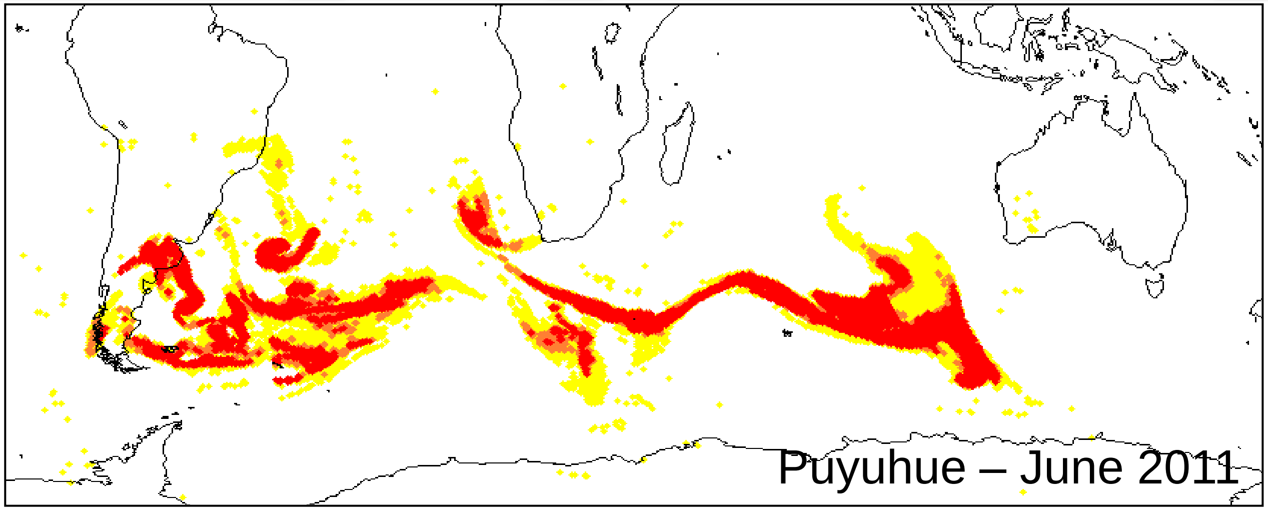
# Sand

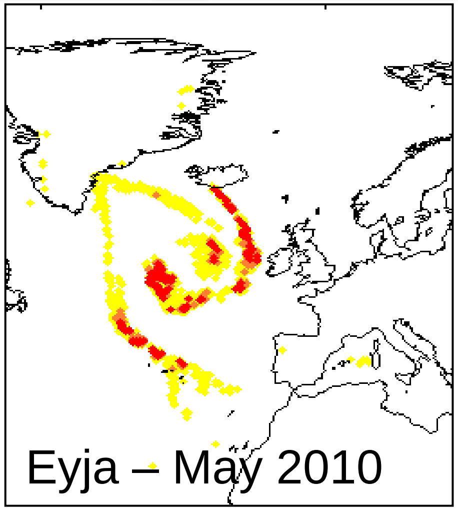


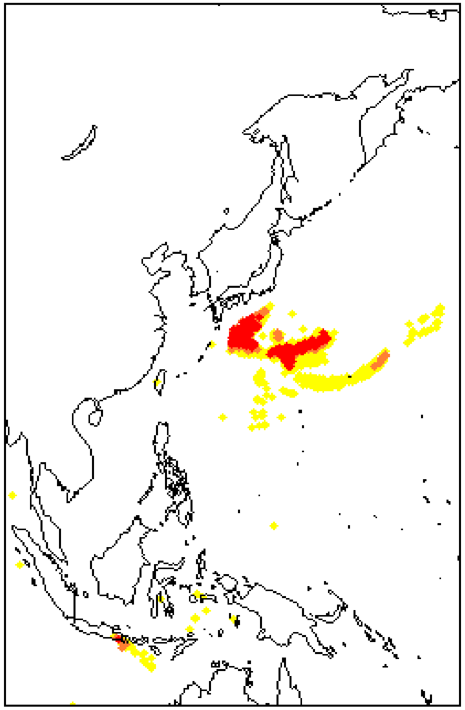

June 2011

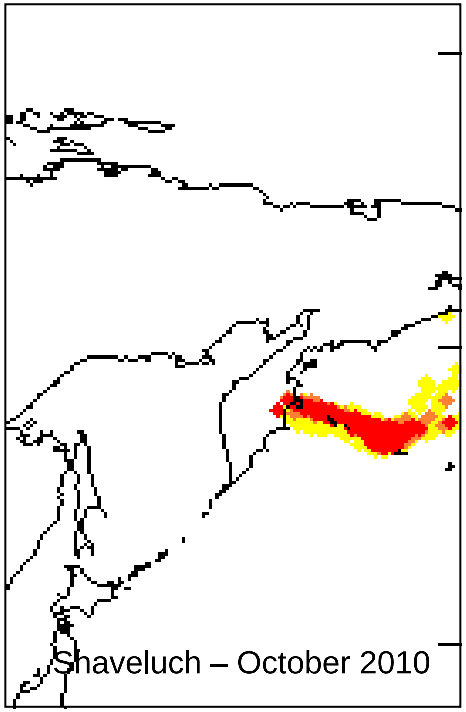
# Ash


80
60
40
20
0
-20
-40
-60
-80
-150
-100
-50
0
50
100
150



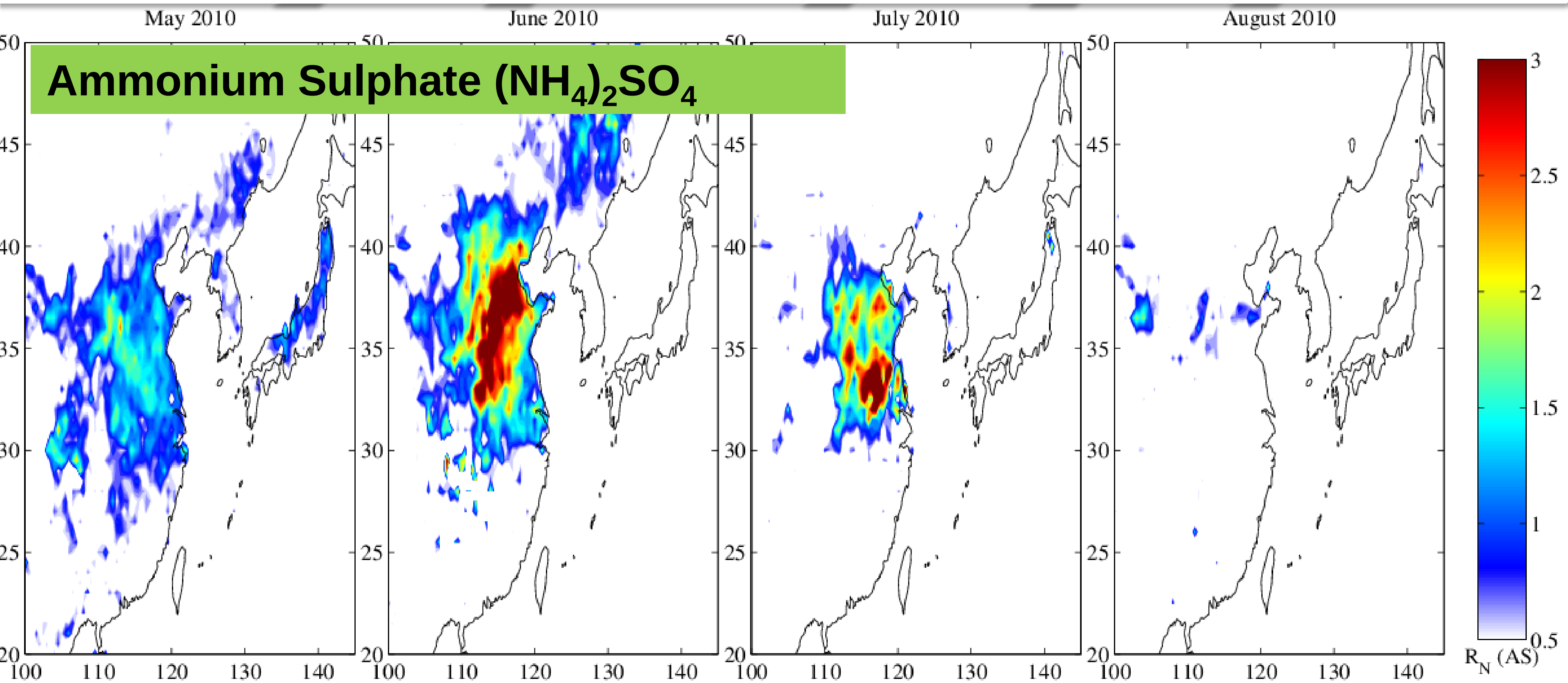





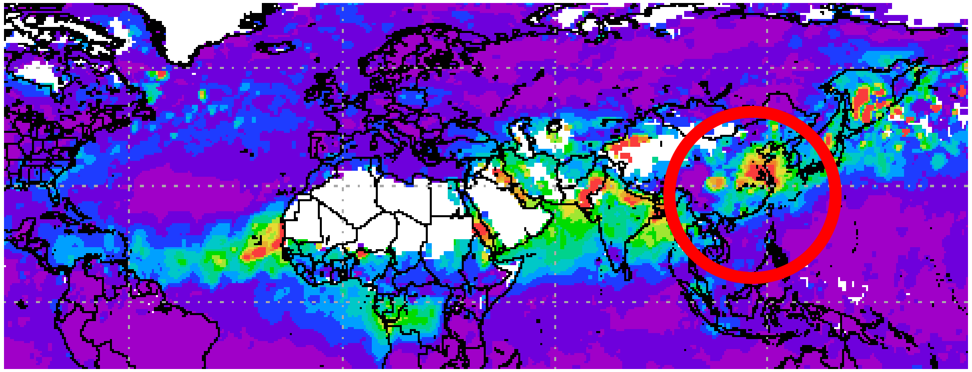

- **SACS** service (SO$_2$ and ash)
- Soon in NRT
- IASI and AIRS
- Archive data (2007-2012)

http://sacs.aeronomie.be

## Ammonium Sulphate $(NH_4)_2SO_4$



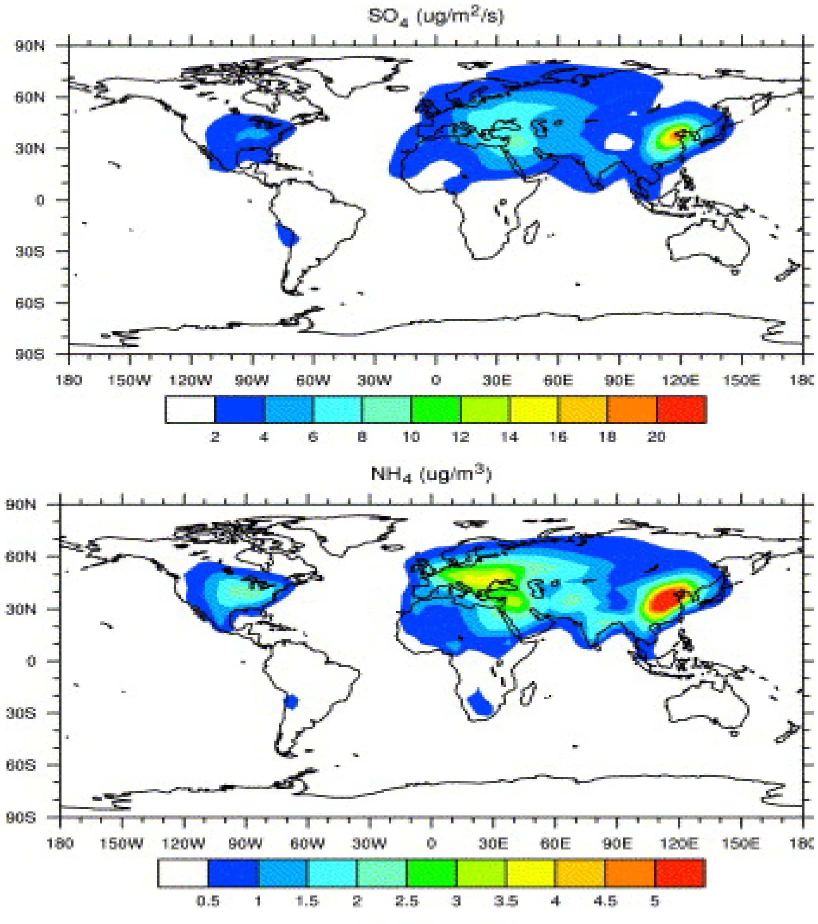

MODIS AOD



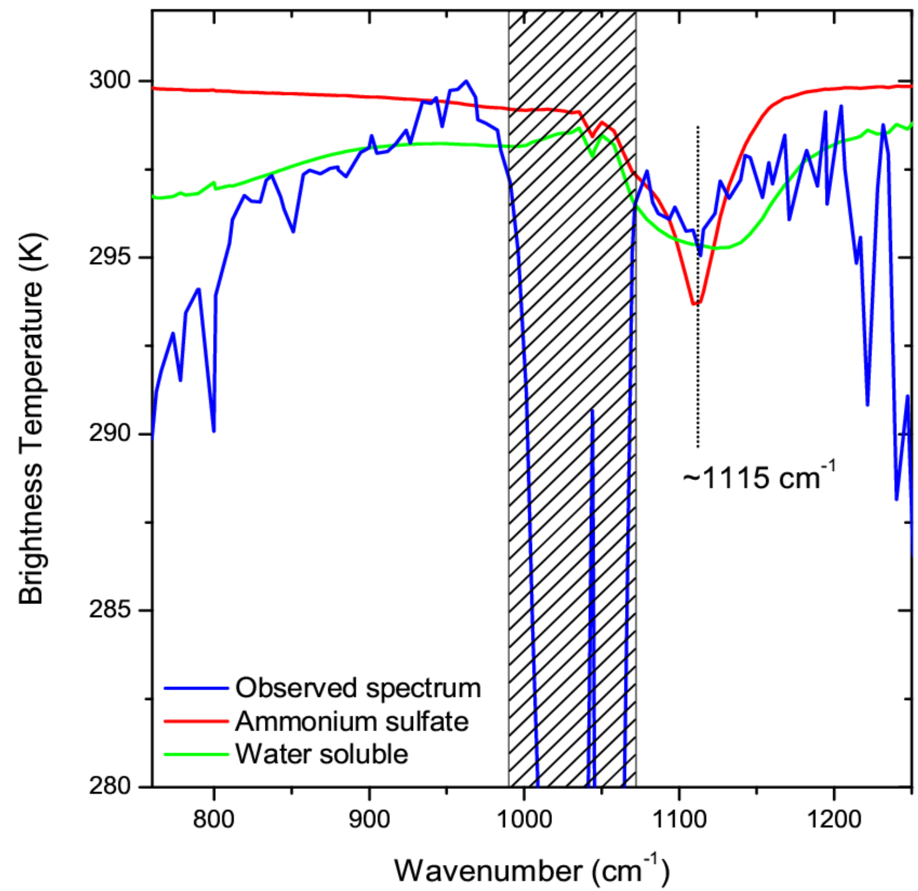
# Ammonium Sulphate $(NH_4)_2SO_4$

Crystalline: Volz, 1973; Toon et al., 1976; Earle et al., 2006; Segal-Rosenheimer et al., 2009
Aqueous: Remsberg, 1973; Downing et al., 1977; Boer et al., 2007.

Mayor component of **anthropogenic boundary layer aerosol!**

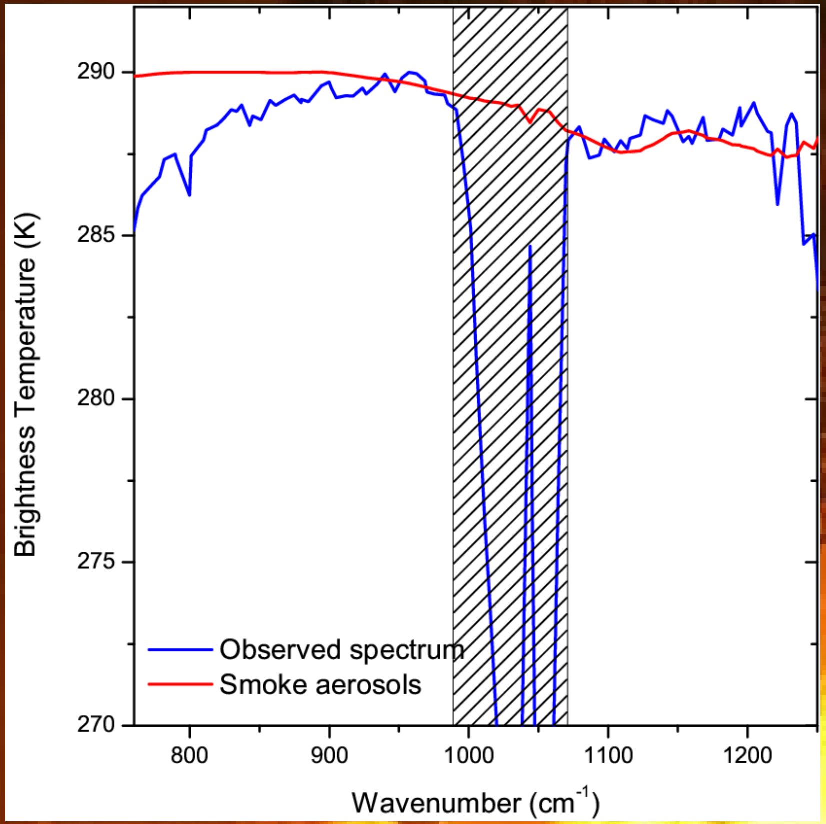


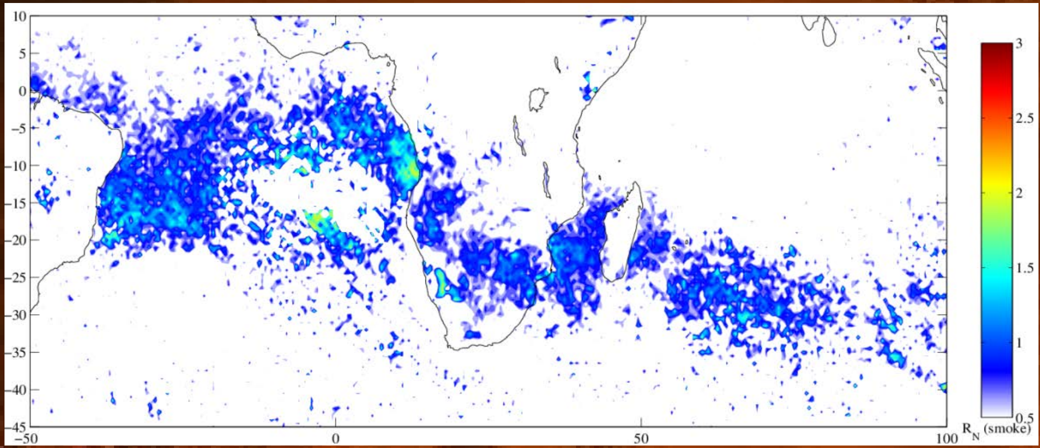

Luo et al. (Atmos. Env., 2007)

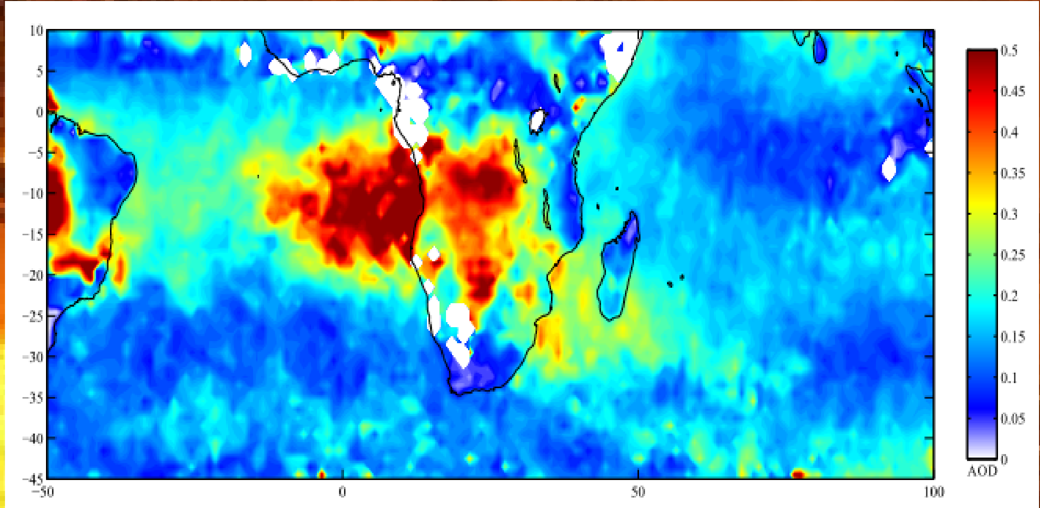


# Biomass burning aerosols
# Smoke

October 2010




Small particles < 1 µm

Hard to detect in thermal infrared 10 µm

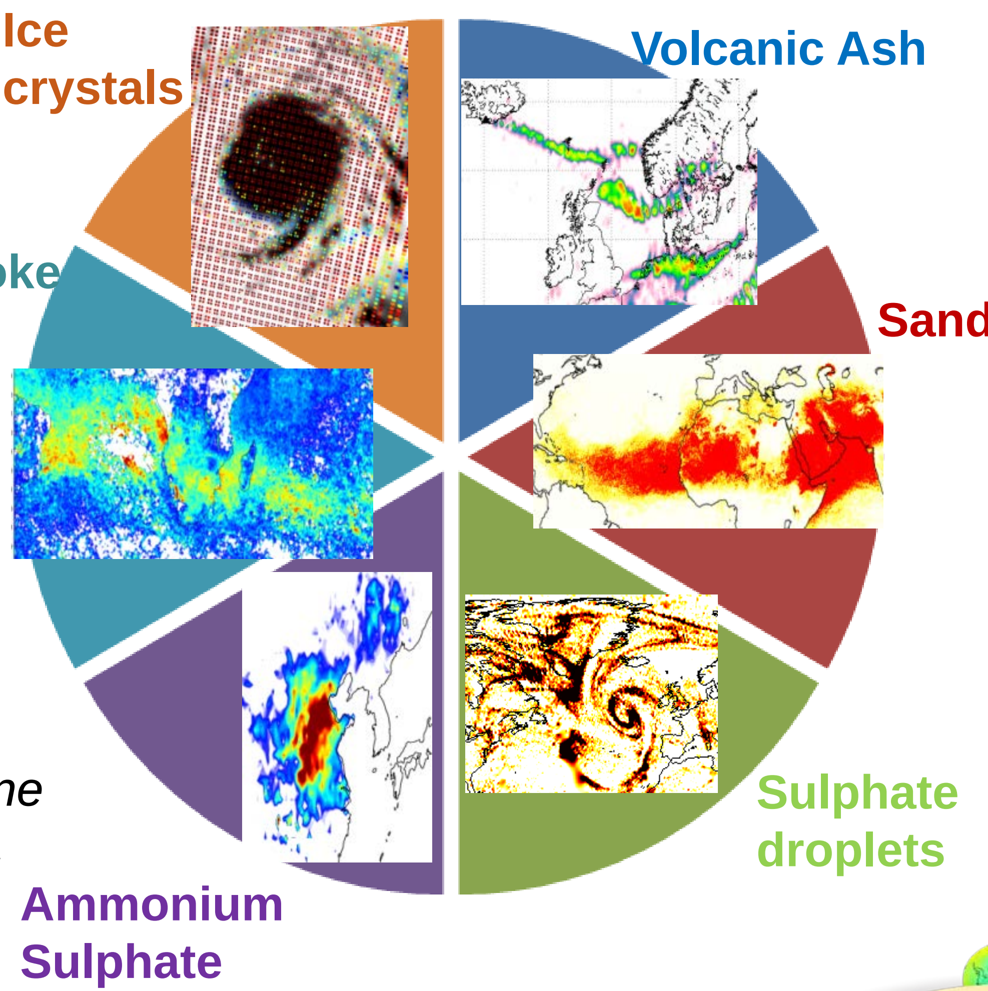
*Differentiation of 6 types*

*Sensitivity to sulphates (sulphuric acid / ammonium sulphate surprising)*

*Mostly coarse mode aerosols*

*This uses only ~100 channels in the 750 – 1250 cm$^{-1}$ wavenumber range!*

*Imagine what can be done if we add to this a SWIR, NIR or UV band!*




Sea salt aerosols ?