

# Stratégie d'Observation atmosphérique par Lidar: *Surveillance et réseaux*



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# Plan de l'exposé: des exemples

- Contexte
- Le NDACC
- Discontinuités et tendances
- Production semi-opérationnelle
- Les nuages
- Les aérosols

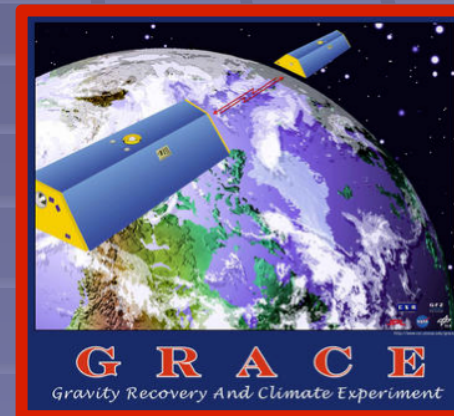
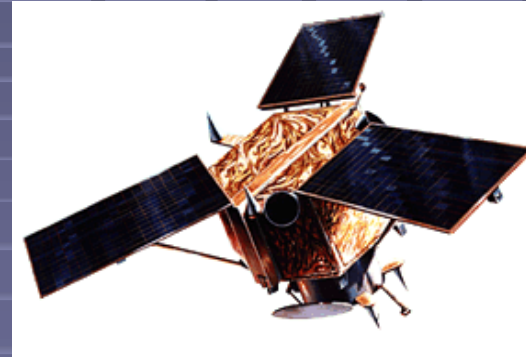
# Contexte

- Les mesures depuis l'espace étaient limitées en résolution et sont toujours limitées en durées de vie.
- Les instruments au sol peuvent servir de référence et accèdent à une échelle plus fine.
- En principe, les instruments sol sont organisés en réseaux pour échantillonner spatialement des scènes géophysiques et fournir une cohérence spatiale.
- En fait aujourd'hui ils permettent de faire des mesures systématiques sur plusieurs sites représentatifs.
- Les principaux challenges sont:
  - Discontinuités temporelles
  - Homogénéité spatiale
  - Production/automatisation du traitement et qualification

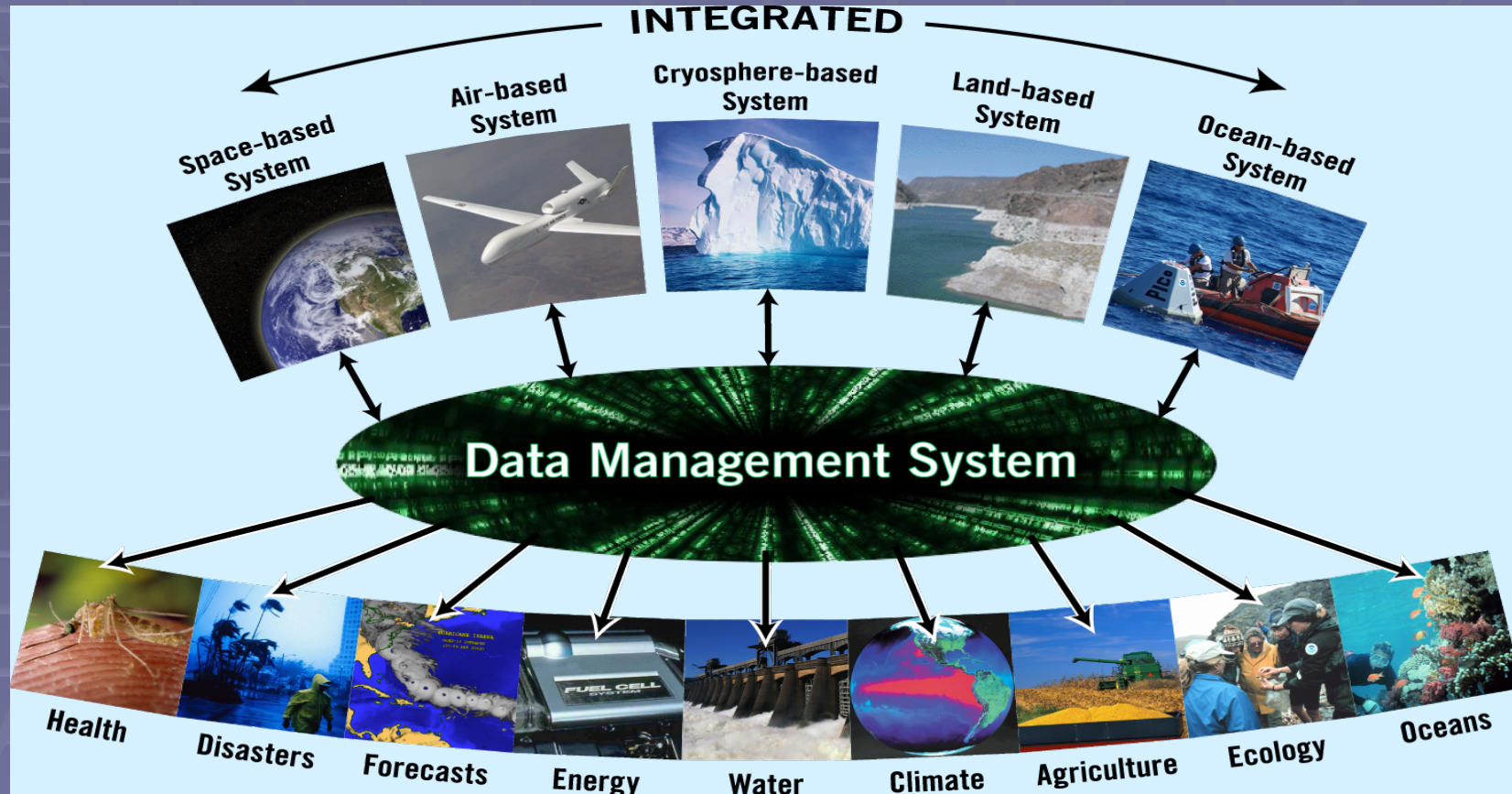
# GEO and GEOSS...

## Global Earth Observation System of System

- GEO is an Intergovernmental Organization
  - 65 Nations
  - European Commission
  - 43 Participating Organizations
- With a simple objective: To establish a global, coordinated, comprehensive and sustained system of Earth observing systems, **GEOSS**
- Contribution de l'expertise scientifique pour la communauté

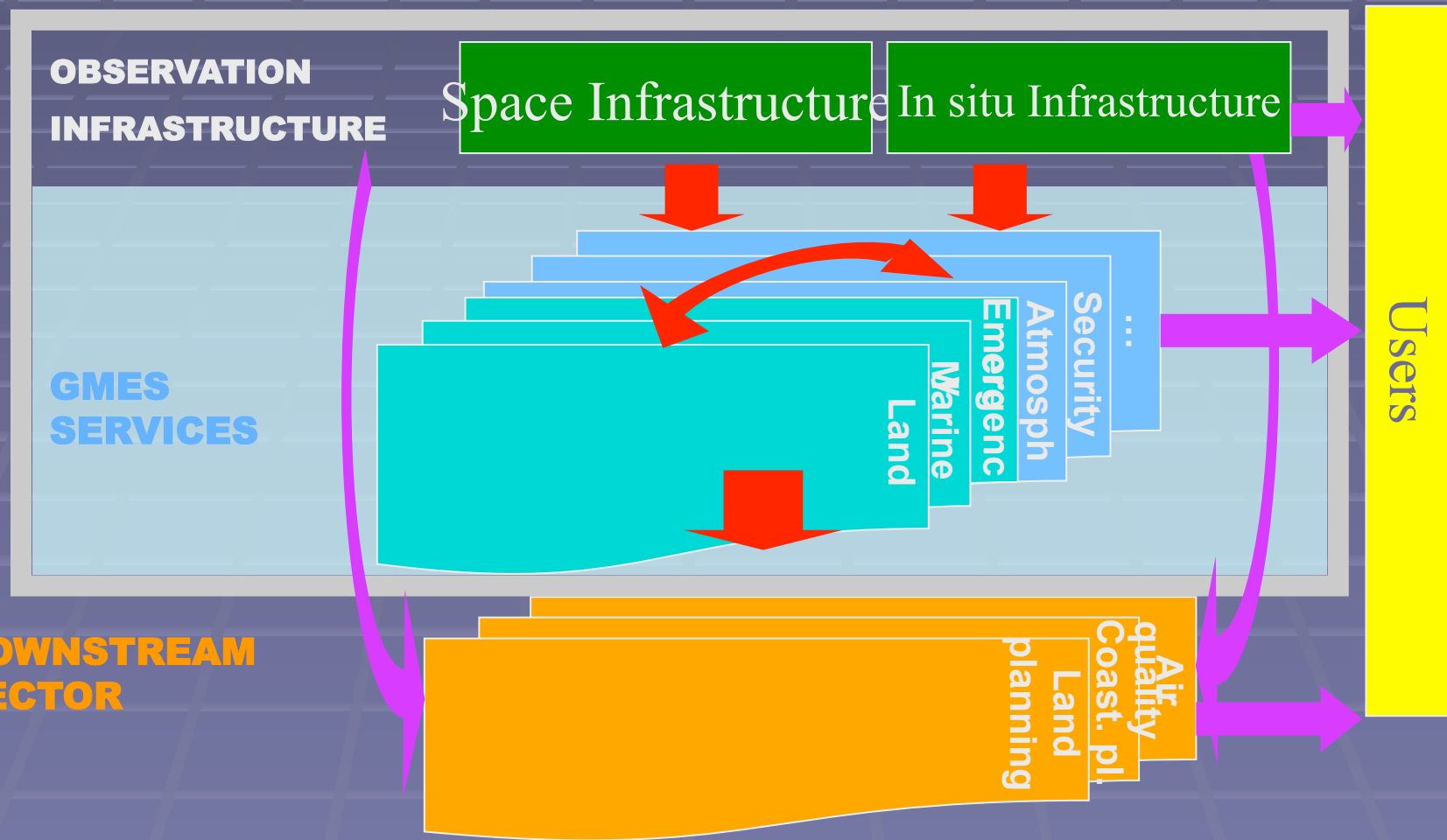


# GEOSS atmosphere

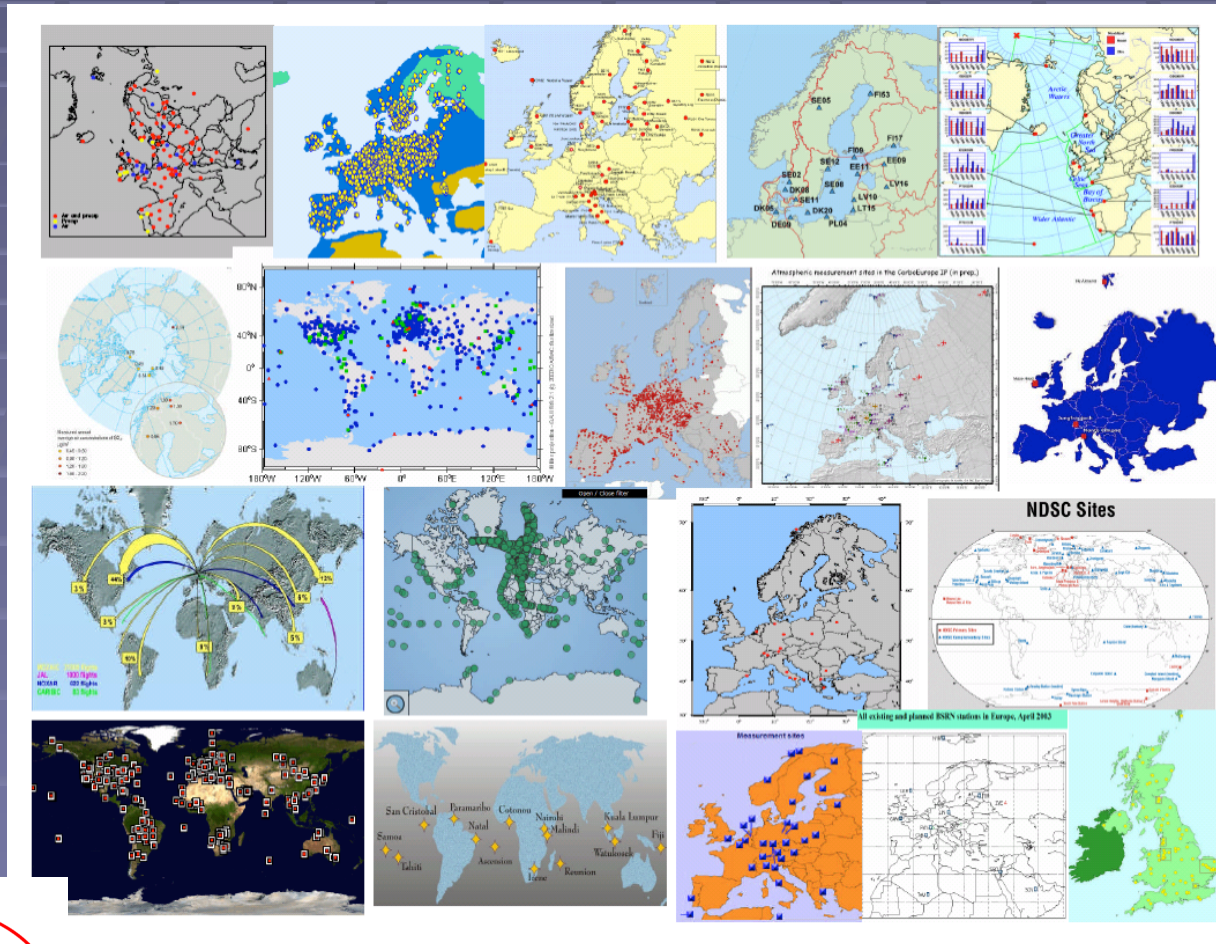


- Coordination des agences spatiales: CEOS, Sentinelles
- Europe:
  - ESFRI (European Strategy Forum on Research Infrastructures),
  - GMES (Global Monitoring for Environment and Security)
  - MACC (Monitoring Atmospheric Composition and Climate)

# Architecture d'ensemble GMES

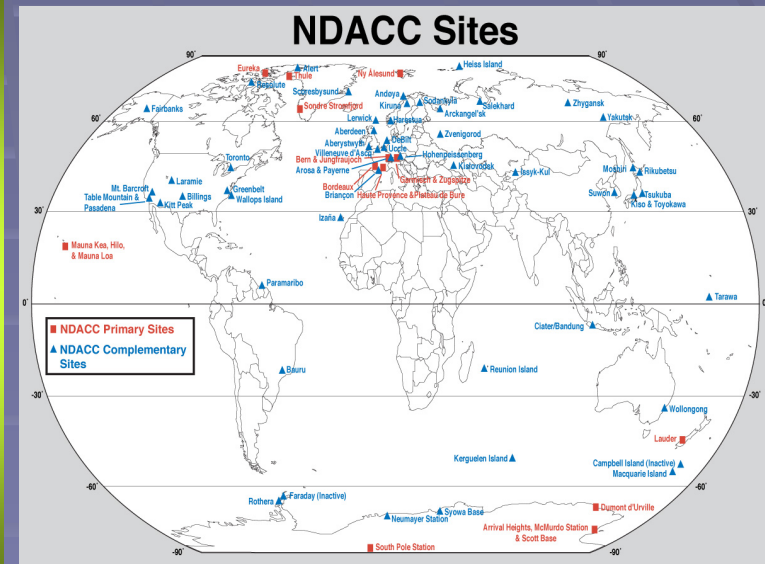


# Research network in Europe construit par des opportunités



# Liste des réseaux lidar recherche

- Stratosphere (Ozone, temperature, aerosols, water vapor) NDACC (Network for the Detection of Atmospheric Composition Changes) -> autres instruments
- Aerosols: EARLINET, ARM, NASA Micro-Pulse. Lidar Network (MPLNET), Asian Dust Network (AD-Net), SPALINET (Spanish and Portuguese Aerosol Lidar Network), The German Aerosol Lidar Network, Latin American, .... GALION, ENAN -> autres mesures





# Besoins opérationnels



### Le danger de la cendre volcanique pour les avions

La cendre volcanique est composée de fines particules abrasives de roches et de minéraux (de 0,001 à 3 mm de diamètre) rejetées dans l'atmosphère lors des éruptions volcaniques.

Les particules varient en taille et en composition d'un volcan à l'autre.

Les particules de 10 à 50 micromètres (0,01 à 0,05 mm) sont les plus dangereuses pour les avions, elles peuvent :

- être expulsées à plusieurs dizaines de kilomètres d'altitude
- être transportées par le vent sur de grandes distances
- fondre à une température assez basse (à partir de 670 °C)

**Température des ailettes des turbines**

Tu-154	650-700 °C
Boeing, McDonnell Douglas	1094 °C

La cendre érode les structures de l'avion, opacifie les fenêtres du cockpit

Petites explosions sur le revêtement de l'avion

Baisse de visibilité

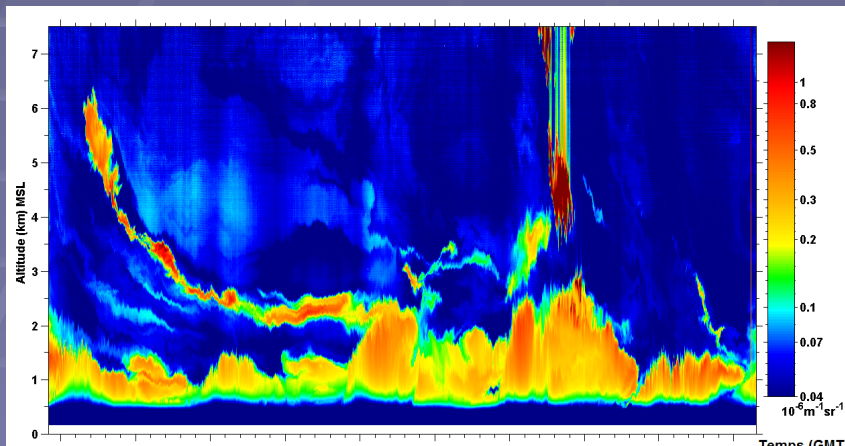
Des particules de cendre sont aspirées par les moteurs à réaction

La cendre fond sur les ailettes des turbines, dans la partie chaude du moteur

La cendre s'amalgame sur les parties en mouvement et fait caler le moteur

**LA PUISSANCE DU MOTEUR CHUTE EN QUELQUES SECONDES ET PEUT PROVOQUER SON ARRÊT**

Photo © A. M. Sama-Wojcicki, Service Géologique des États-Unis



## Difficultés:

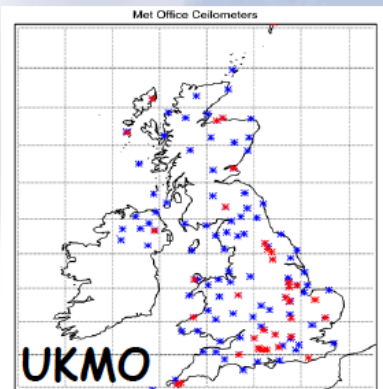
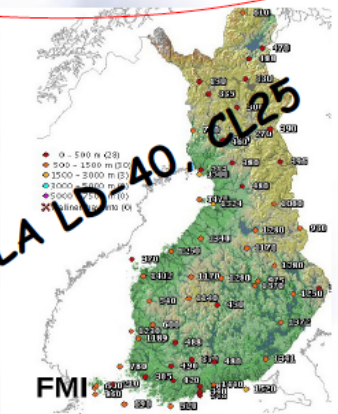
- Identifier/Détecter aérosols/nuages
- Advecter le panache
  - Extension verticale
  - Taille/sédimentation

# Réseaux opérationnels

Bikaner  
Bure-Andra  
Cabauw-KNMI  
Hovsoro-Riso  
Jodhpur  
Juelich  
Leipzig-UL  
Lerwick-UM  
Manchester-UM  
NewDelhi-NPL  
Orsay-Leosphere  
Palaiseau-Sira  
Toulouse-MF  
Zurich-ETHZ



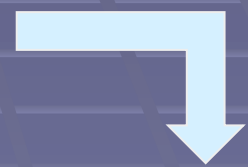
(GALION)  
EARLINET, Asian Dust Net, MPLNET  
CALIPSO, EARTH CARE,...



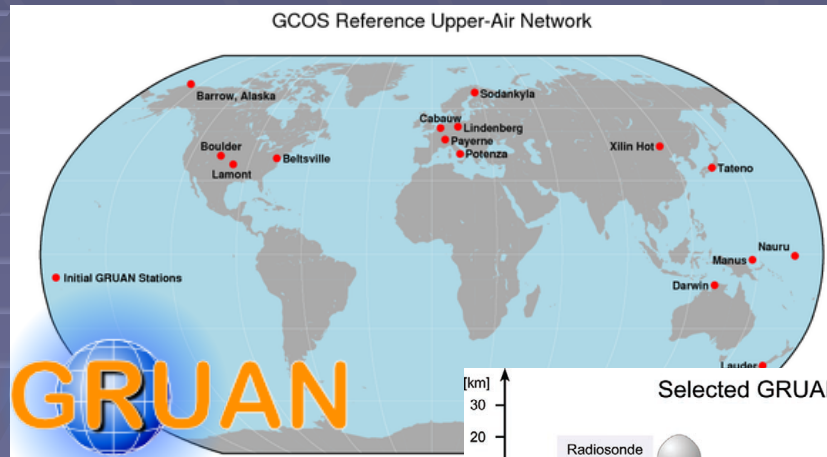
VAISALA LD40

Courtesy: Martial Haffelin,

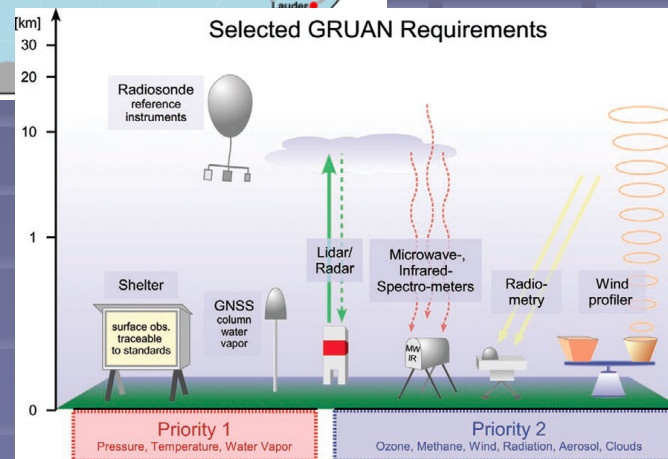
Courtesy: Owen Cox, UKMO



# Cadre climat



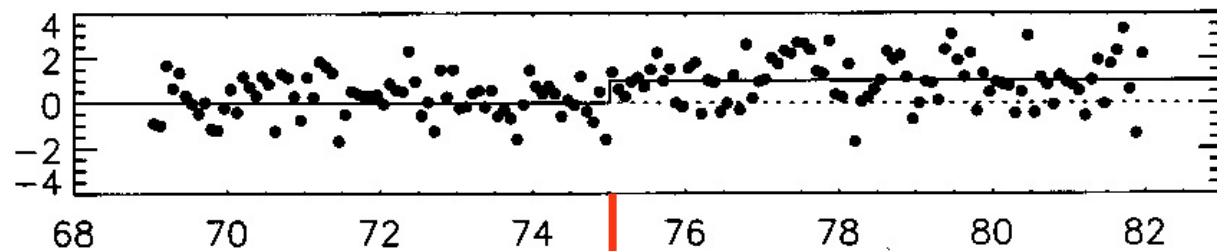
GRUAN



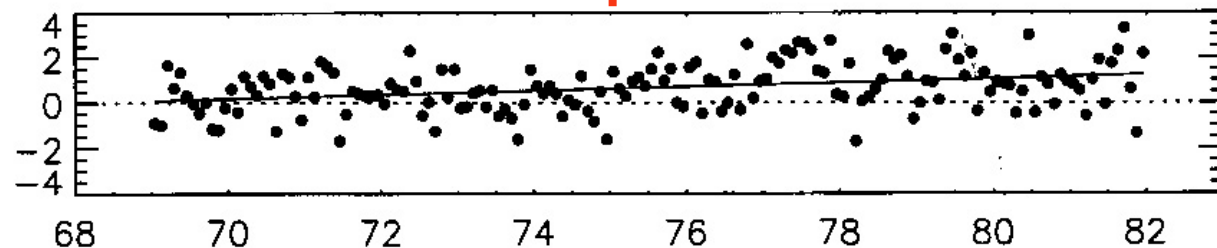
# Instrumental discontinuity

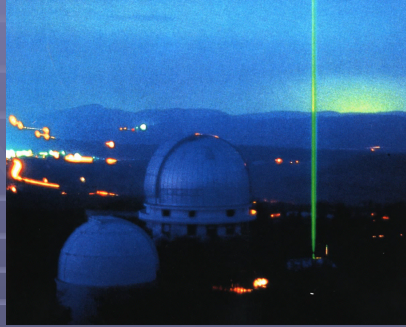
## Main factors de discontinuity :

- Improve accuracy, sensitivity, and sampling
- Reduce some instrumental bias
- Retrieval algorithm changes
- Protocol and operation changes
- Avoid changes
- Record time of changes (Metafile)
- Make redondent independent measurements



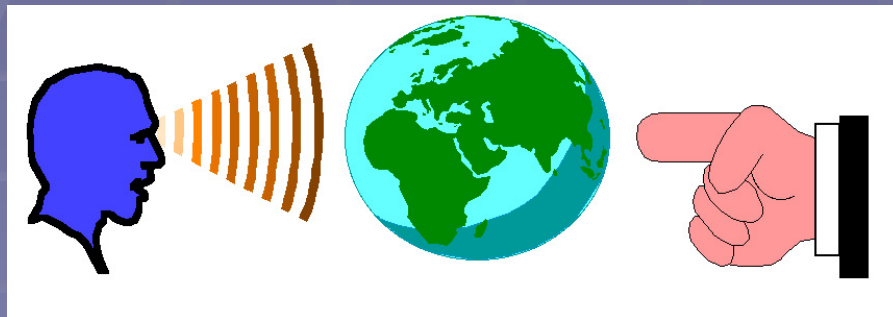
Random series shifted by  $1 \sigma$  in 1975





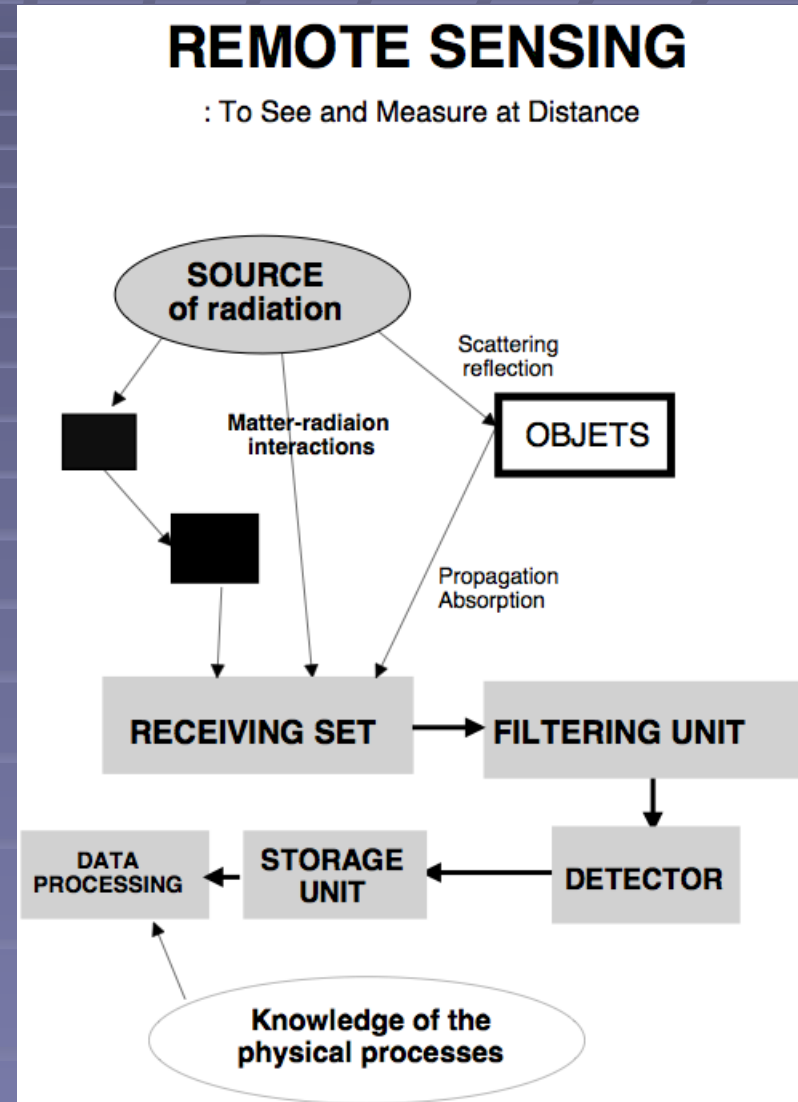
# Téledétection

- **Avantages des techniques de télédétection pour la surveillance atmosphérique :**
  - Réduit les interférences entre atmosphère et instruments
  - Requière qu'un seul instrument
  - Mesure indépendante des caractéristiques instrumentales



Remote sensing

Sensor



# Etat des réseaux: En construction

- Réseaux recherche ≠ Réseau opérationnel
- Opérationnel (mission/réglementation, coût):
  - Potentiel (couche limite, H2O, température, vent,....)
  - Demandes (aviation, météo, qualité de l'air,....)
  - Missions ≠ performances: en maturation
  - Pas encore de fortes cohérences internationales
- Recherche:
  - Exploitation des mesures opérationnelles
  - Structuration en cours: Europe
  - Objectifs: climat, pollution/processus-transport, validation satellite
  - Amélioration des techniques et méthodologie

# Le Network for the Detection of Stratospheric Changes: NDSC

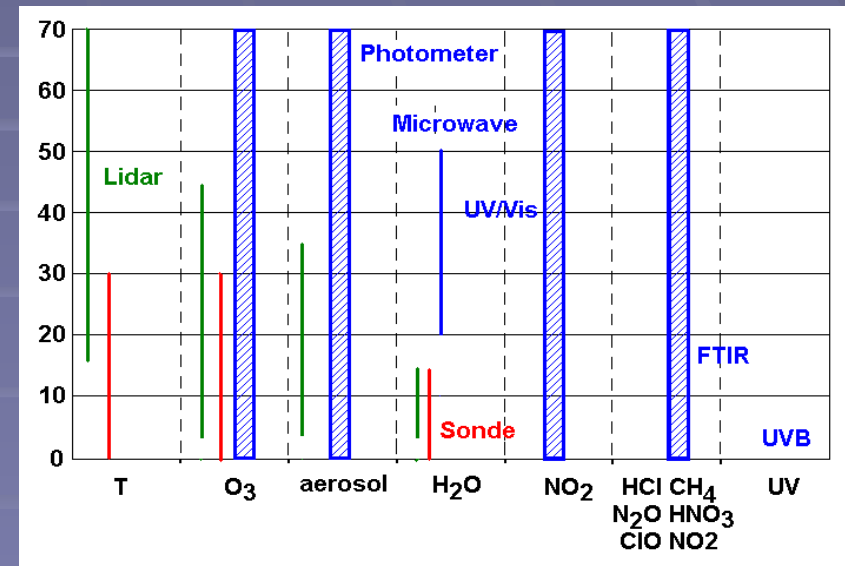
## ■ Objectifs

- Etudier la variabilité de la stratosphère et de l'ozone et détecter d'éventuelle perturbations anthropique
- Assurer la validation satellitaire: UARS (1991)

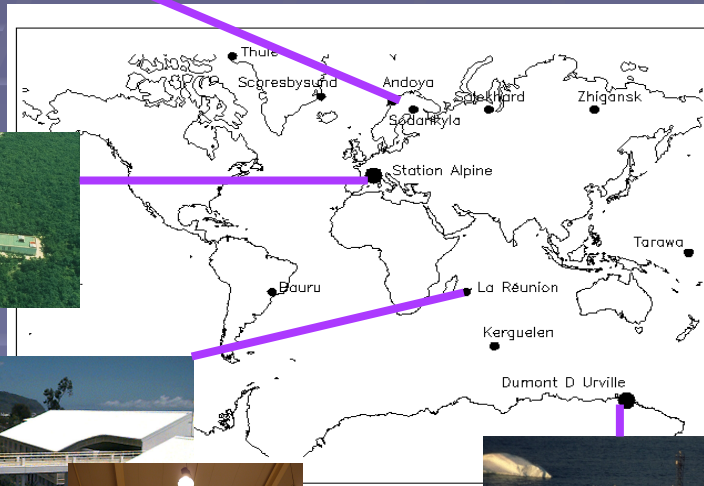
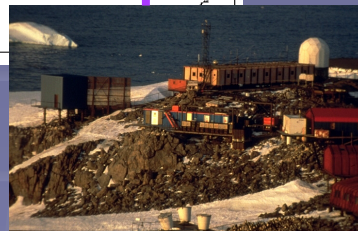
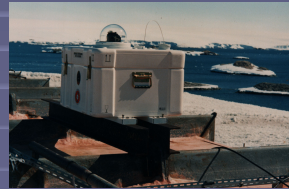
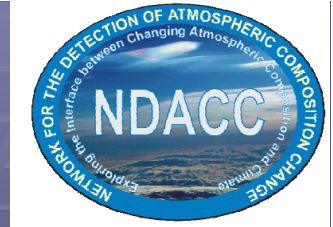


## ■ Paramètres

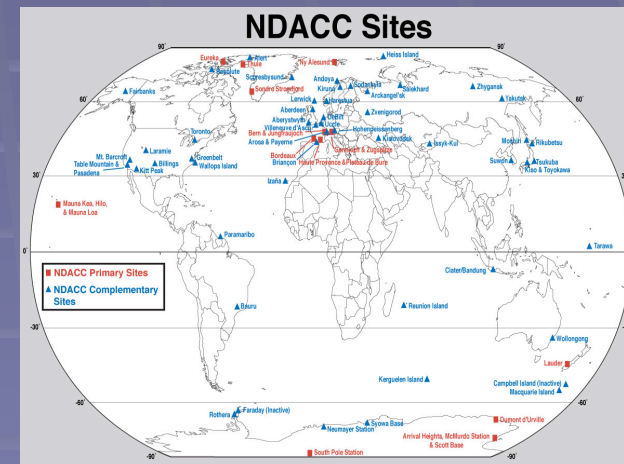
- Ozone et gaz impliqué dans la destruction de l'ozone
- Température
- Aérosols (volcaniques)
- Vapeur d'eau
- UV au sol



# Contribution NDACC Françaises



- Station Alpine (44°N)
  - OHP
  - Lannemezan (Bordeaux)
  - Villeneuve d'Ascq
- Dumont D'Urville (67°S)
- La Réunion (21°S)
- Réseau SAOZ
- ALOMAR (69°N)





# Extension des objectifs et domaines d'intérêt



Ozone stratosphérique / trou d'ozone / UV

**Network for the Detection of Stratospheric Changes**

Rôle de la stratosphère sur le climat

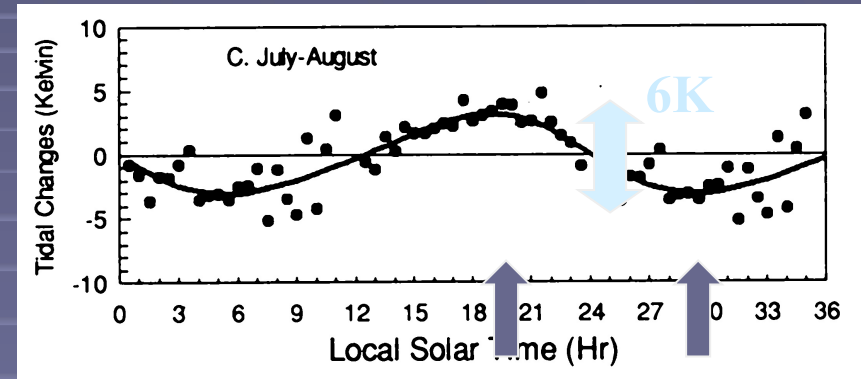


**Network for the Detection of Atmospheric Changes**

- Echanges tropo-strato
- Lidar vapeur d'eau et ozone troposphérique

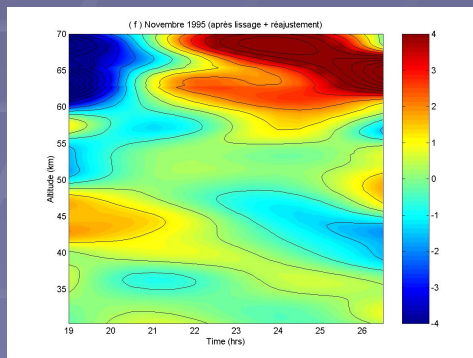
# Tide issue

- Tides are due to the absorption of solar radiation by O<sub>3</sub> and H<sub>2</sub>O.
- Atmospheric oscillations in phase with the diurnal cycle.
- Large amplitudes in the upper stratosphere and mesosphere.
- Observed with lidars and in satellite data

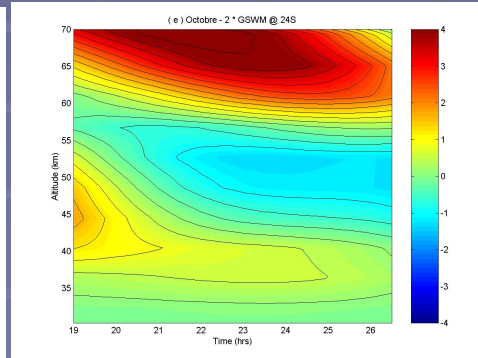


MLS/UARS 1 hPa

Lidar La Réunion



GSMW

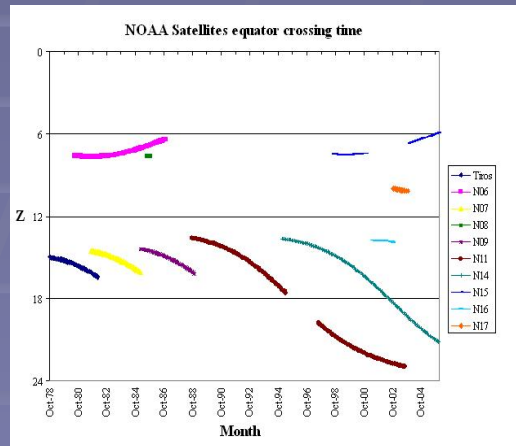
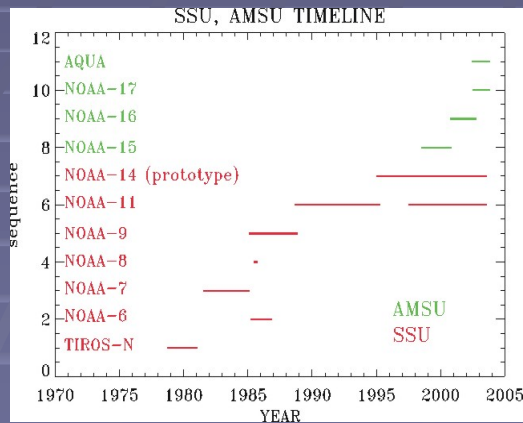


They induce large interferences in data comparisons, trends and satellite validations

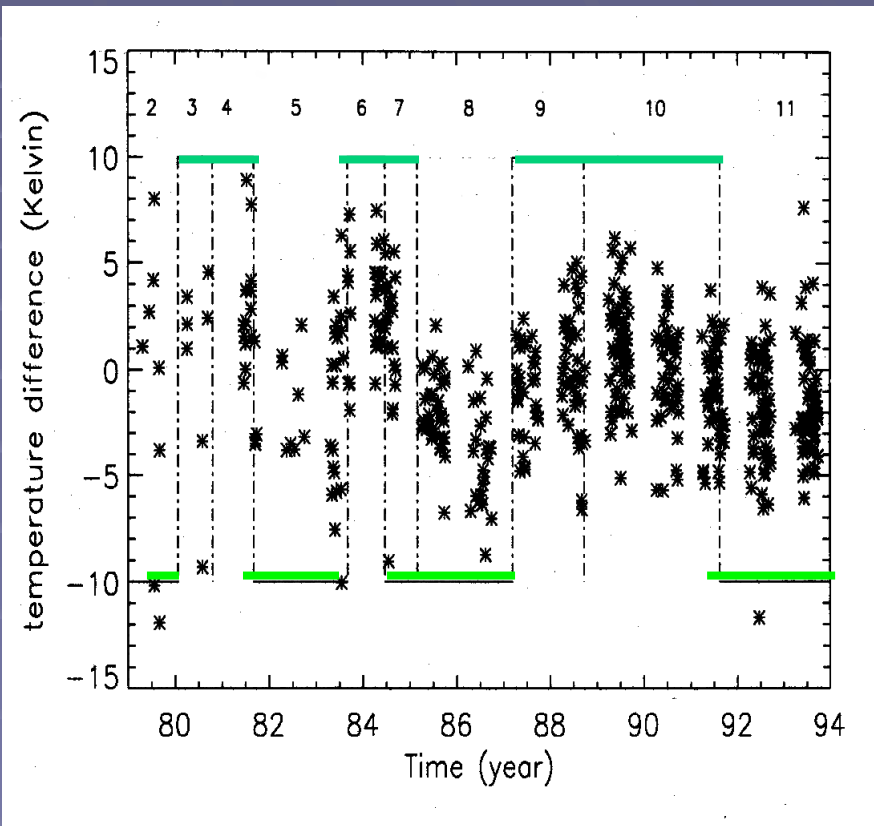
DEA B. Morel

Tides observed in the tropics

# Global trends



## NCEP analyses at 1 hPa ( $\approx 50$ km)



Keckhut et al., *J. Geophys. Res.*, p546, 2001

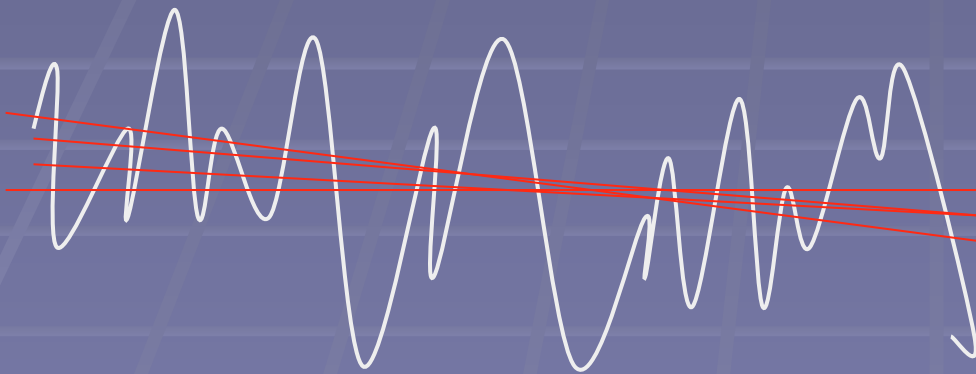
# Regression analysis: trend least mean square fit

$$\sigma_T^2 = \sigma_R^2 * F_c / \sum_v (t_i - t_m)^2$$

uncertainty on trend

variability

v nb of observation time



## Climate requirements

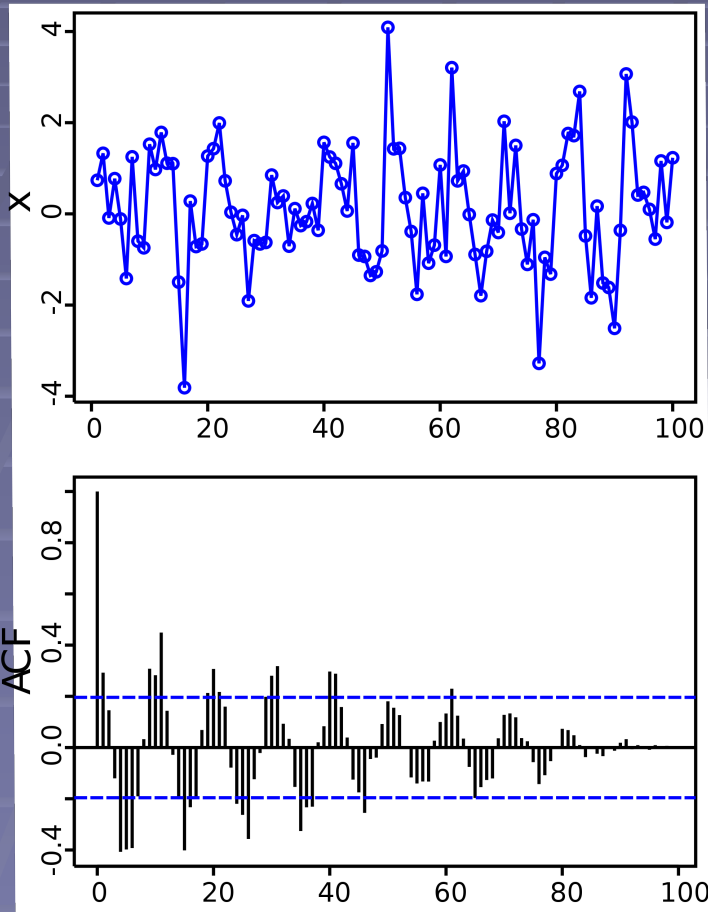
- Long time series
- $\sigma_R$  optimization when instrumental variance < natural variance
- Frequent measurements

# Independent observations

Successive observations  
are not independent because of  
atmospheric processes



# Autocorrelation $\varphi$

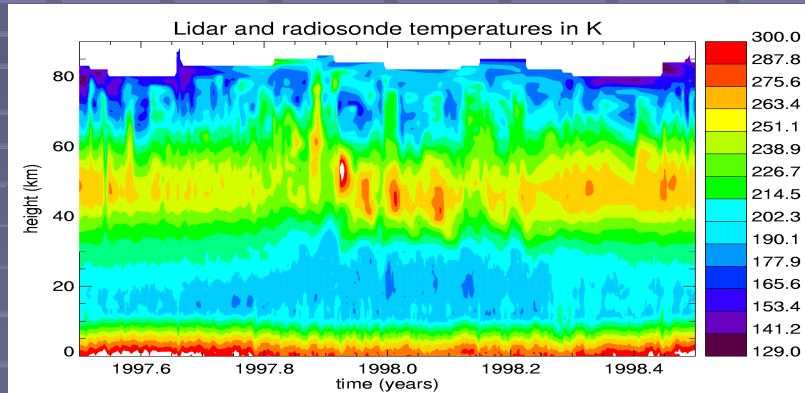


$$F_c = (1 + \varphi) / (1 - \varphi)$$

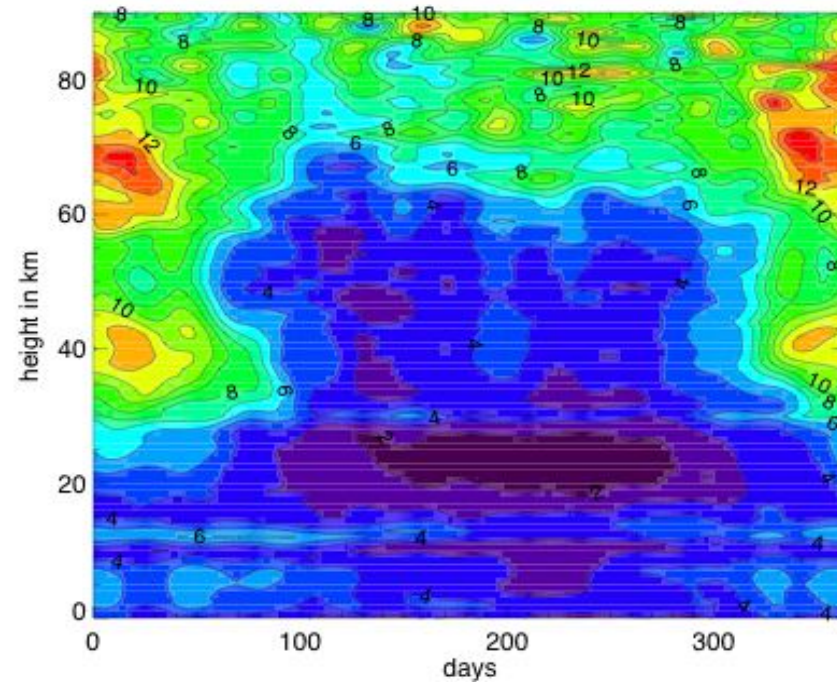
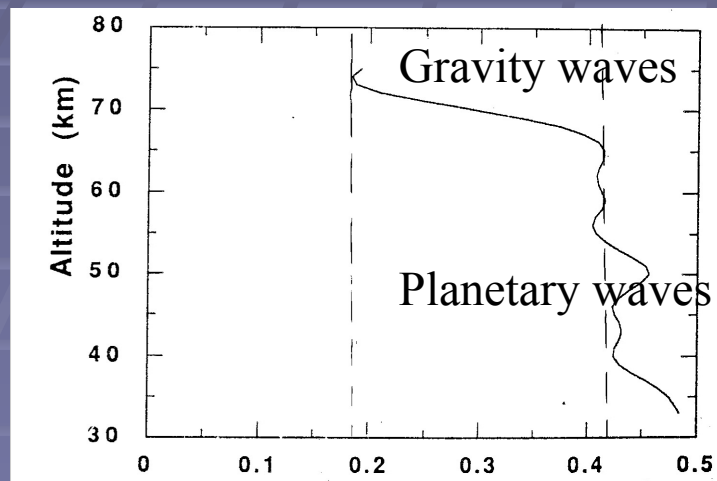
## Climate requirements

- Long time series
- $\sigma_R$  optimization when instrumental variance < natural variance
- Frequent measurements

# Auto-correlation and independent data



An example of lidar temperature series

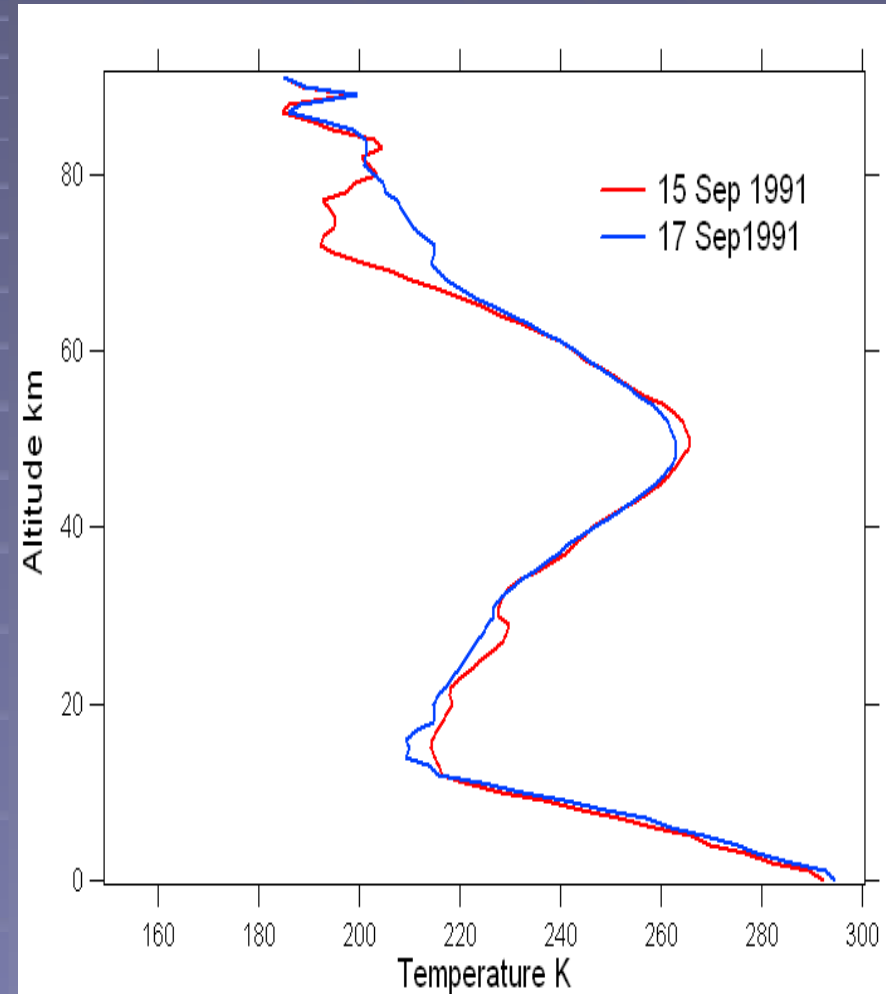
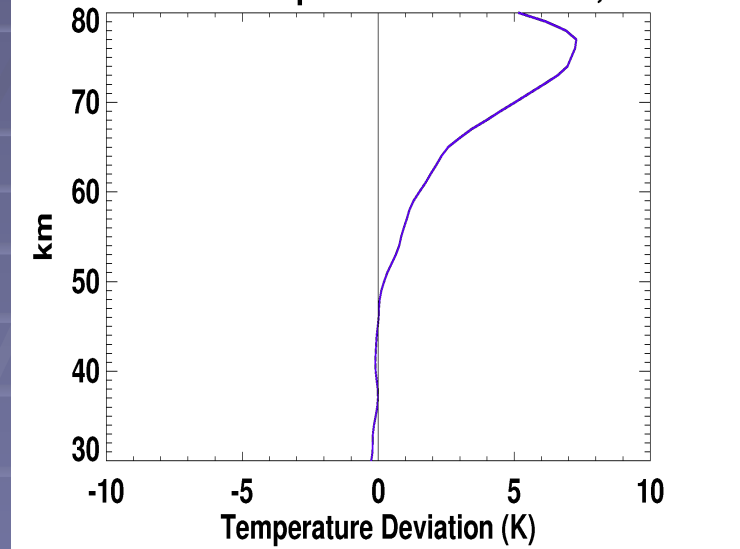


January

# Mesospheric mode

## Mesospheric inversion

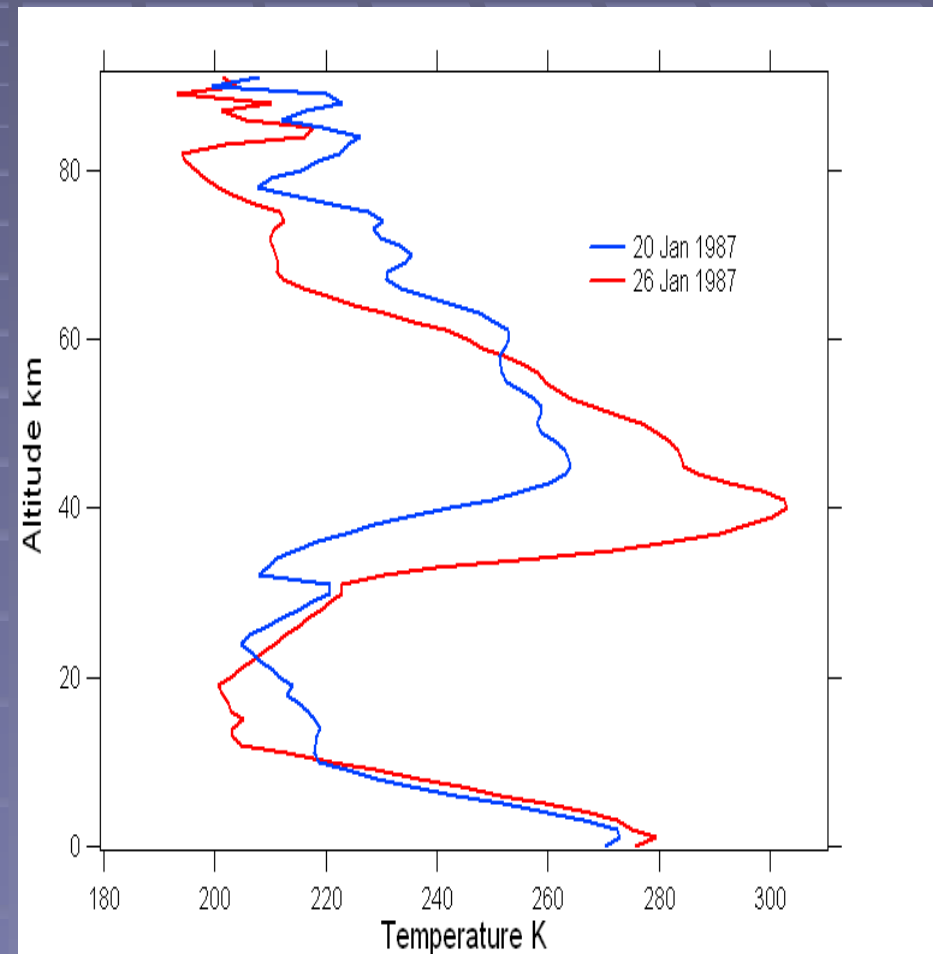
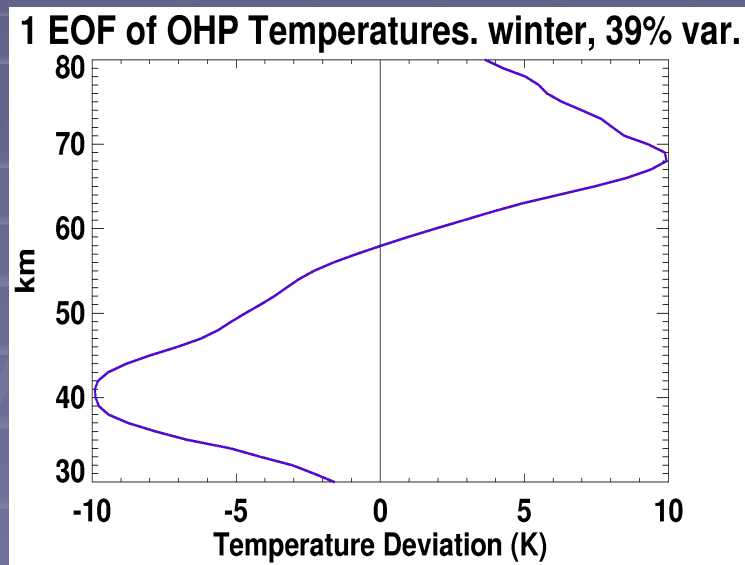
1 EOF of OHP Temperatures. all-winter, 40% var.





# Strato-mesospheric mode

## Stratospheric warming



# Echelle temporelle et signification statistique

Parametres	région	Variabilité résiduelle	Tendance attendue (/ décennie)	Temps nécessaire (années)
Température	Haute strato	3-8 K	1-2 K	<b>8-17</b>
	Mésosphère	8-10 K	1-3 K	<b>15-30</b>
Ozone	Basse strato	20 %	5-20%	<b>7-20</b>
	Haute strato	7%	5-10%	<b>5-10</b>
Vent		5-15 m/s	< 1m/s	<b>20-50</b>

Temps nécessaire pour une détection significative ( $2\sigma$ )

# Temperature measurements

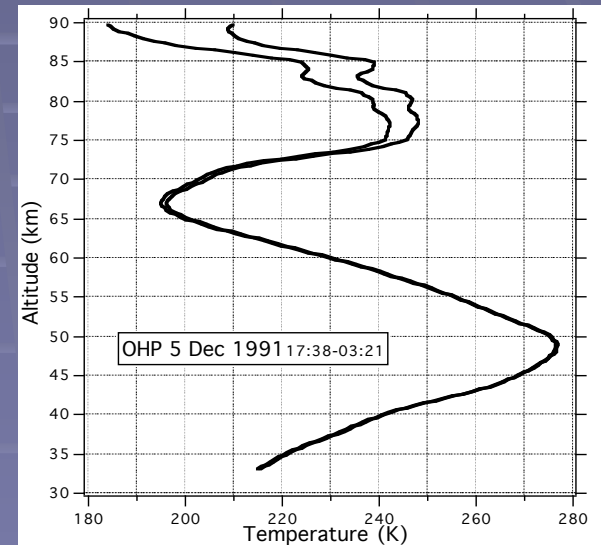
- Required pure molecular scattering
- Density and pressure are relative measurements
- Temperature is absolute

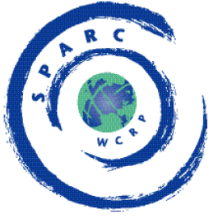
$$\varphi(z) = f(N(z))$$

$$dP(z) = -g\varphi(z)dz$$

$$T(z) = \frac{MP(z)}{R\varphi(z)}$$

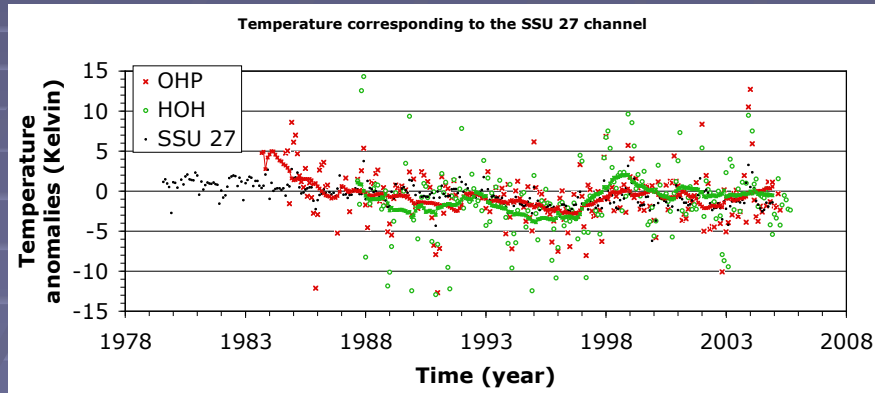
$$T(z) = \frac{M \int_0^z g\varphi(\kappa)\Delta z}{R \varphi(z)} = \frac{Mg \int_z^{top} N(\kappa)\Delta z}{R N(z)}$$



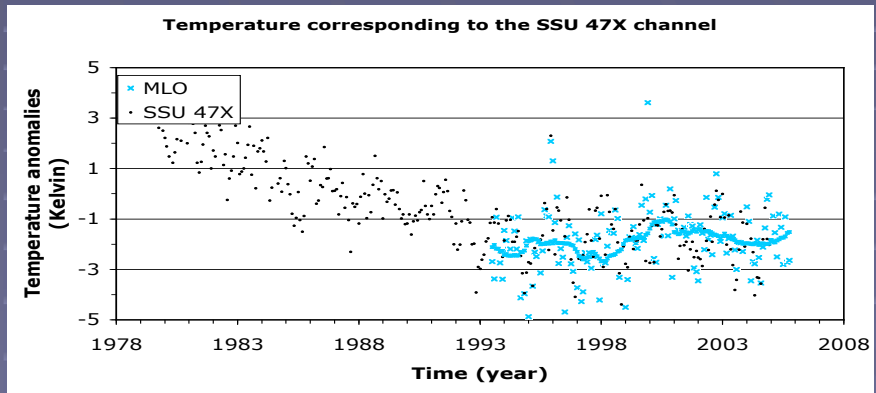


# SSU/Lidar comparisons

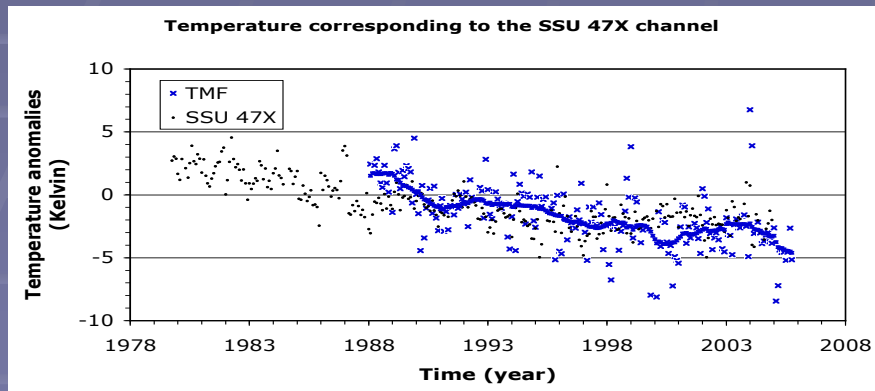
OHP & Hohenpeisenberg, Europe



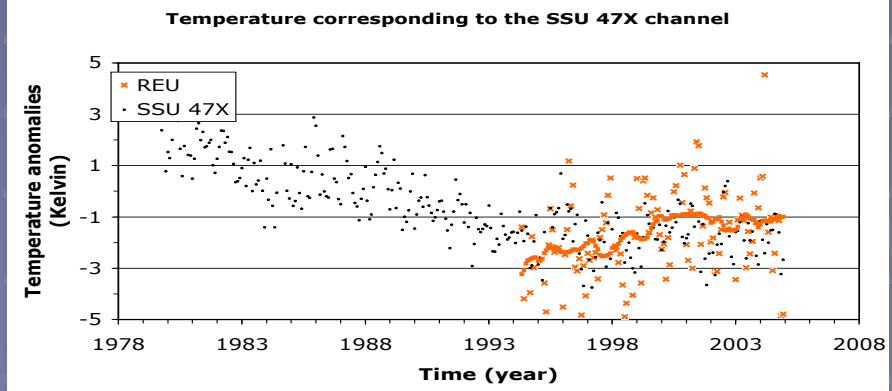
MLO, Hawaiï



TMF, California



La Réunion, Indian ocean



mid-latitudes

Tropics

# Temporal and spatial sampling effects

Tendencies of temperature with respect to time (in K/decade) based on simple linear regression for the period 2001-2007

			(b) W Europe		(c) Zonal Average (40-45°N)	
	(a) Lidar OHP		AMSU Lidar dates	AMSU all nights	AMSU Lidar dates	AMSU all nights
32 km	$-2.5 \pm 2.6$	ch 12	$-2.8 \pm 1.1$	$-1.6 \pm 0.7$	$-2.0 \pm 0.8$	$-1.4 \pm 0.5$
36 km	$-4.4 \pm 3.2$	ch 13	$-4.6 \pm 1.8$	$-2.5 \pm 1.2$	$-2.6 \pm 1.1$	$-1.8 \pm 0.8$
40 km	$-5.0 \pm 3.2$	ch 14	$-4.8 \pm 2.0$	$-2.5 \pm 1.4$	$-2.1 \pm 1.2$	$-1.5 \pm 1.0$

# Temporal and spatial sampling effects

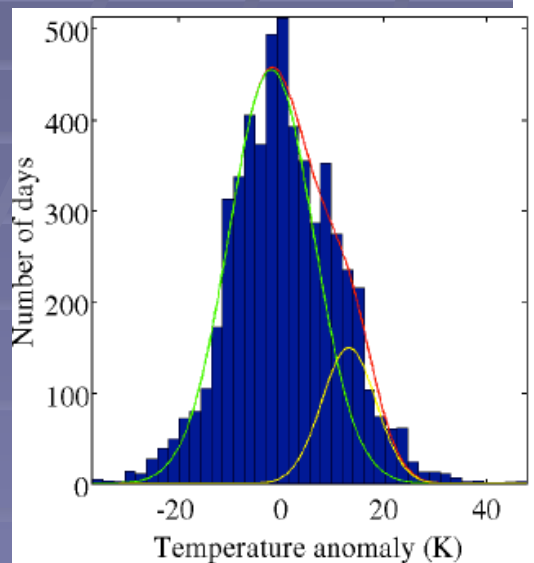
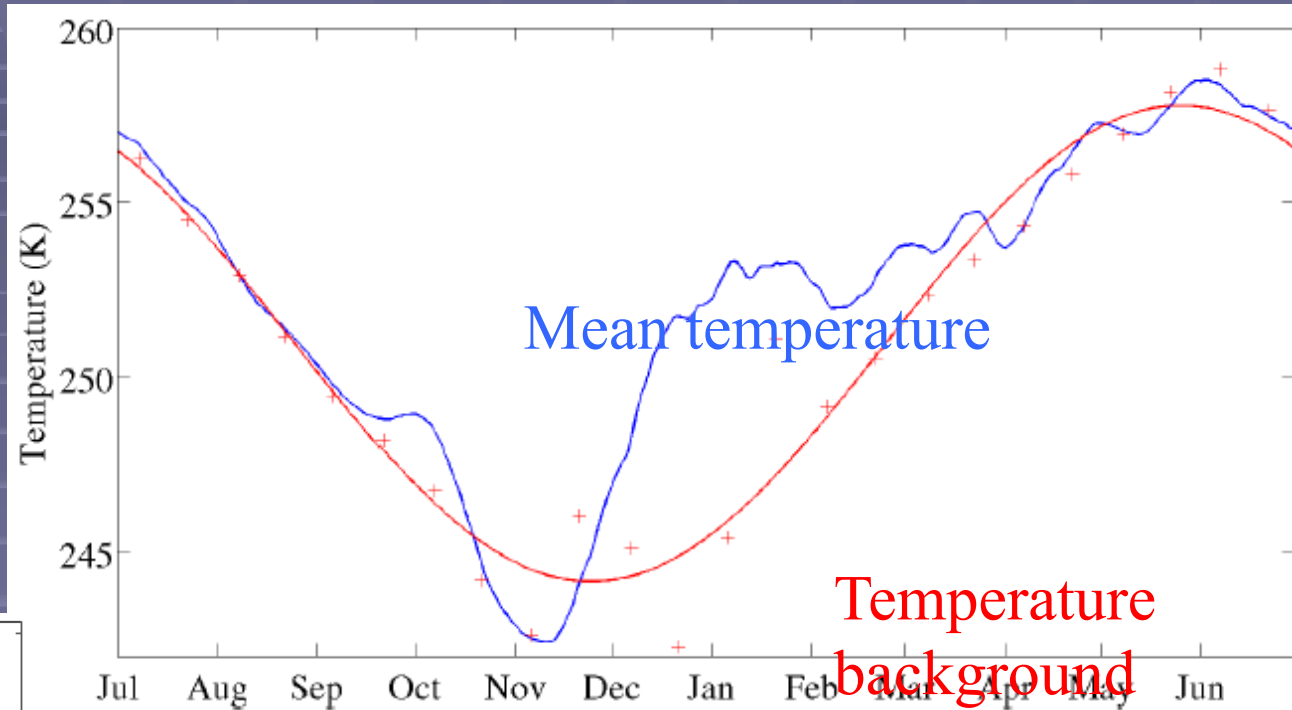
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40 km	-5.0 ± 3.2	ch 14	-4.8 ± 2.0	-2.5 ± 1.4	-2.1 ± 1.2	-1.5 ± 1.0

- AMSU based tendency is about 40% smaller when using all nights compared to lidar nights only
- When considering zonal averages, temporal sampling is less evident (i.e., AMSU all nights vs. AMSU lidar dates), but still present.

# Revisiting mean temperatures

Seasonal change exhibits warming in winter

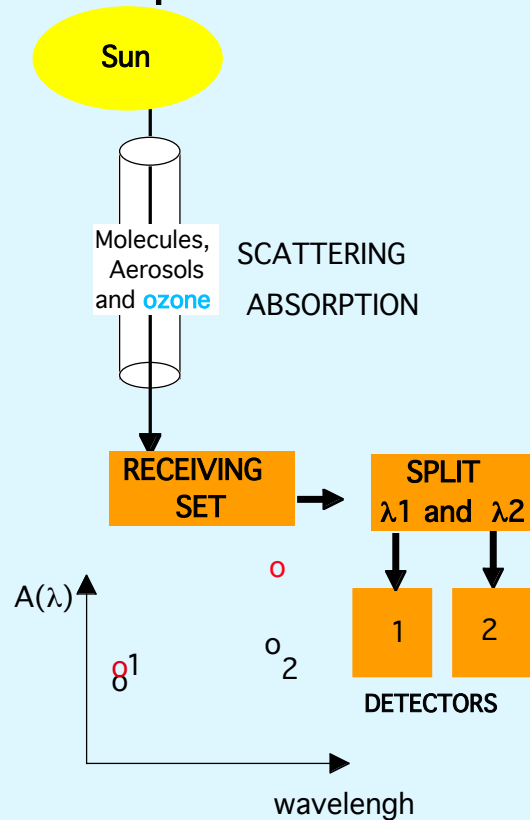


Temperature anomalies in winter shows multimodal distributions:

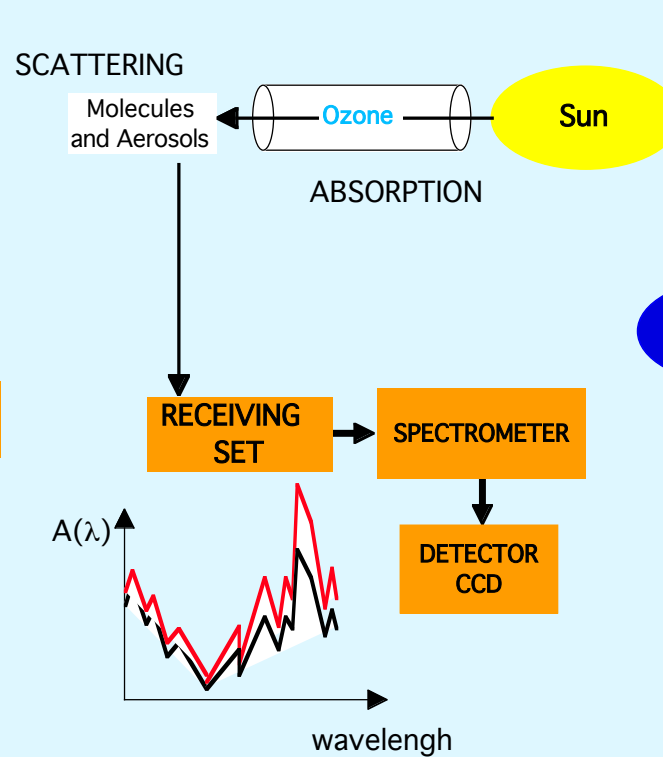
- Temperature background (radiative + mean dynamic effects)
- Temperature anomalies associated with SSW

# DIAL Differential Absorption Lidar

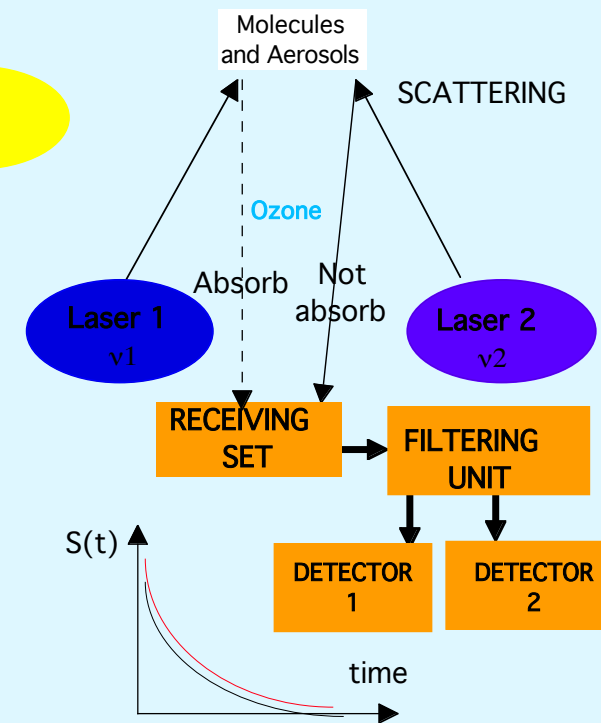
## Dobson Spectrometer



## UV/Visible Spectrometer

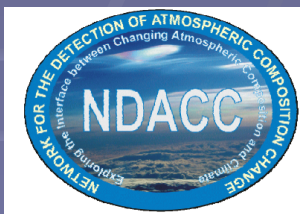
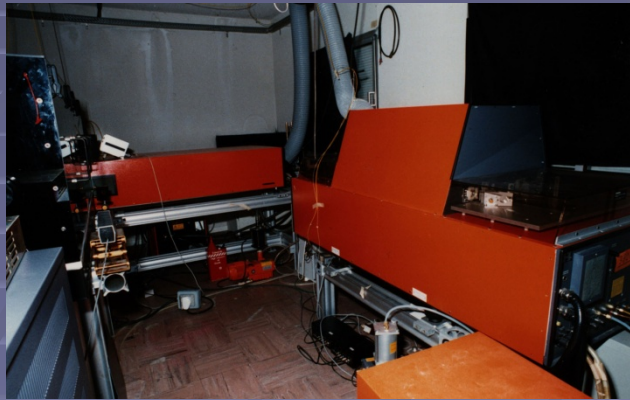


## DIAL Lidar

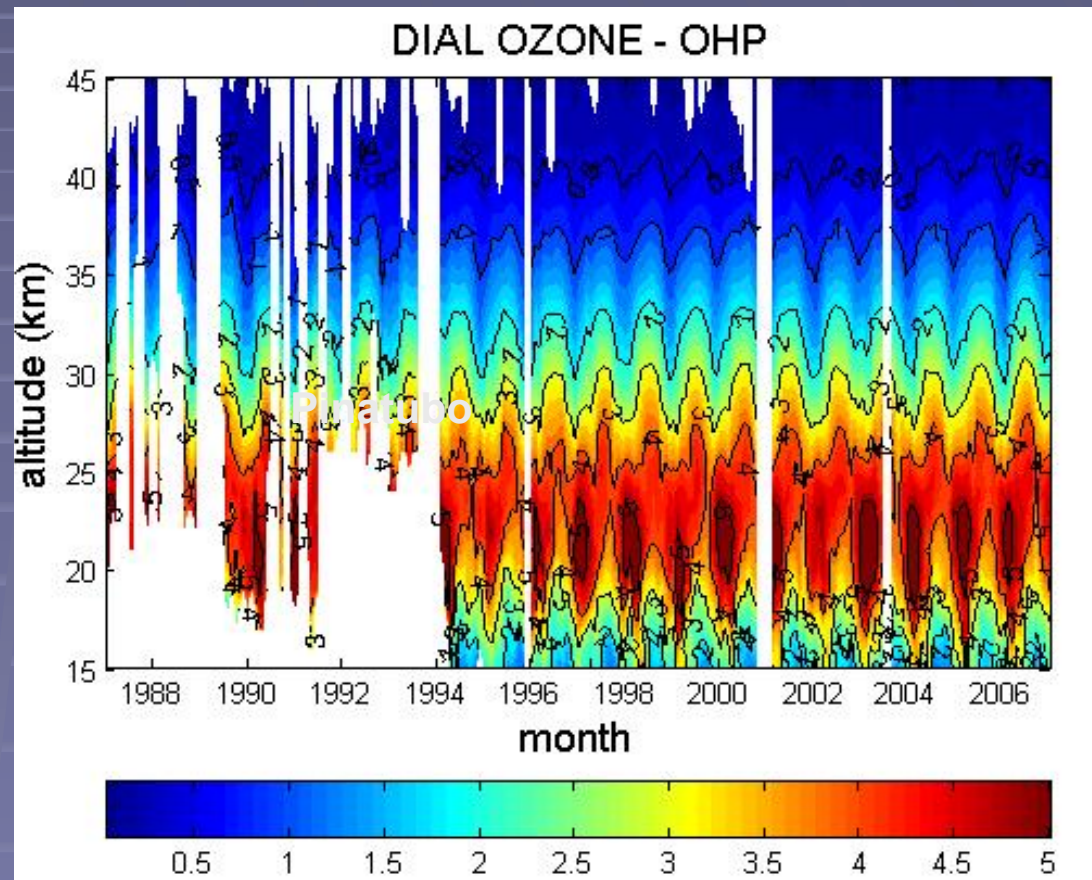




# Series lidar d' ozone

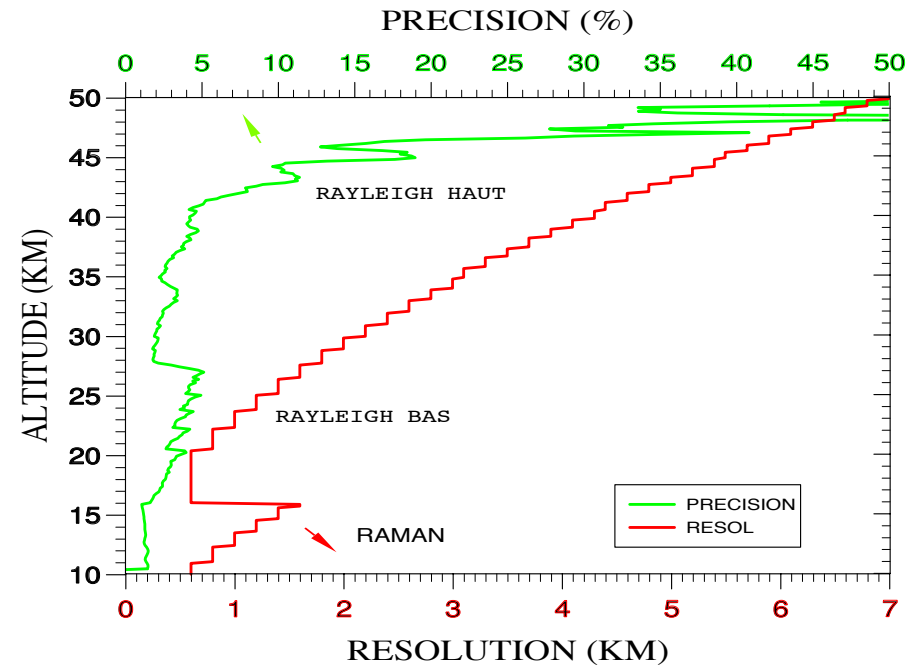
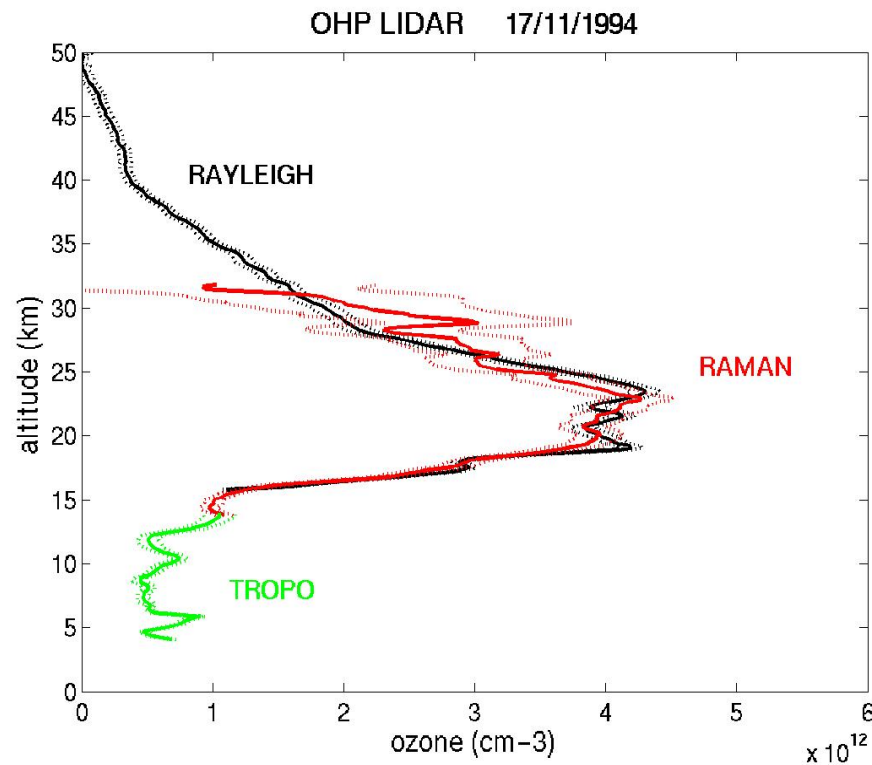


S. Godin-Beekmann



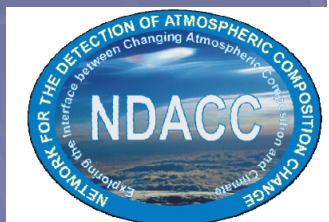
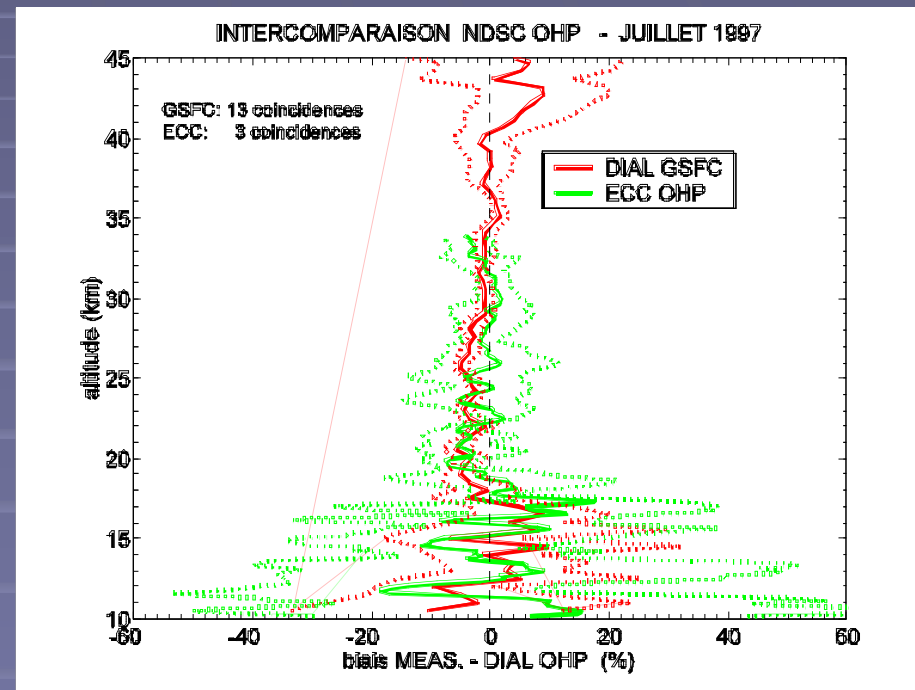
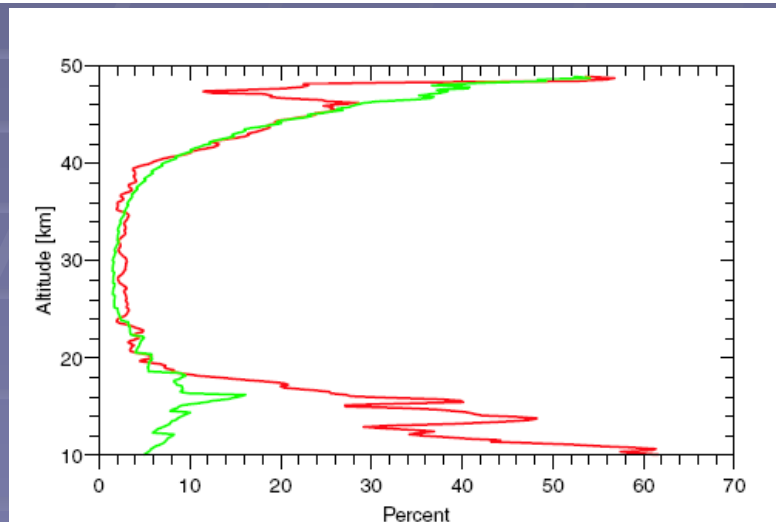
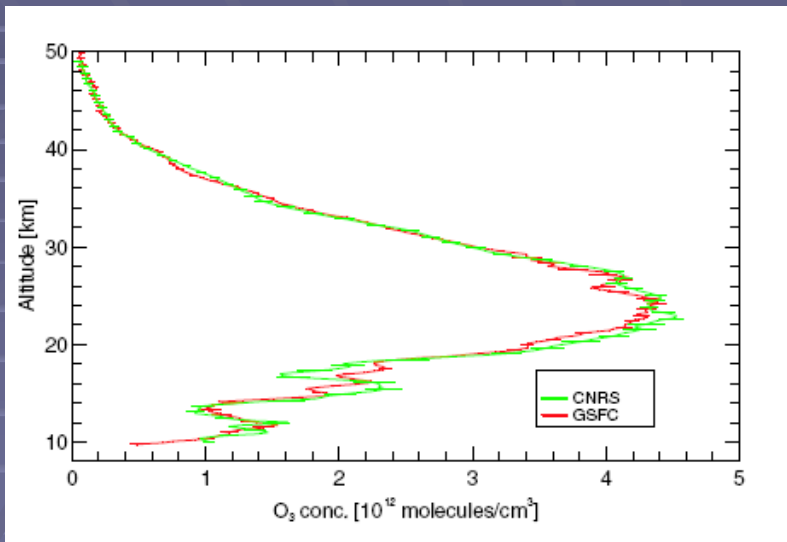
# Ozone profile

S. Godin-Beekmann



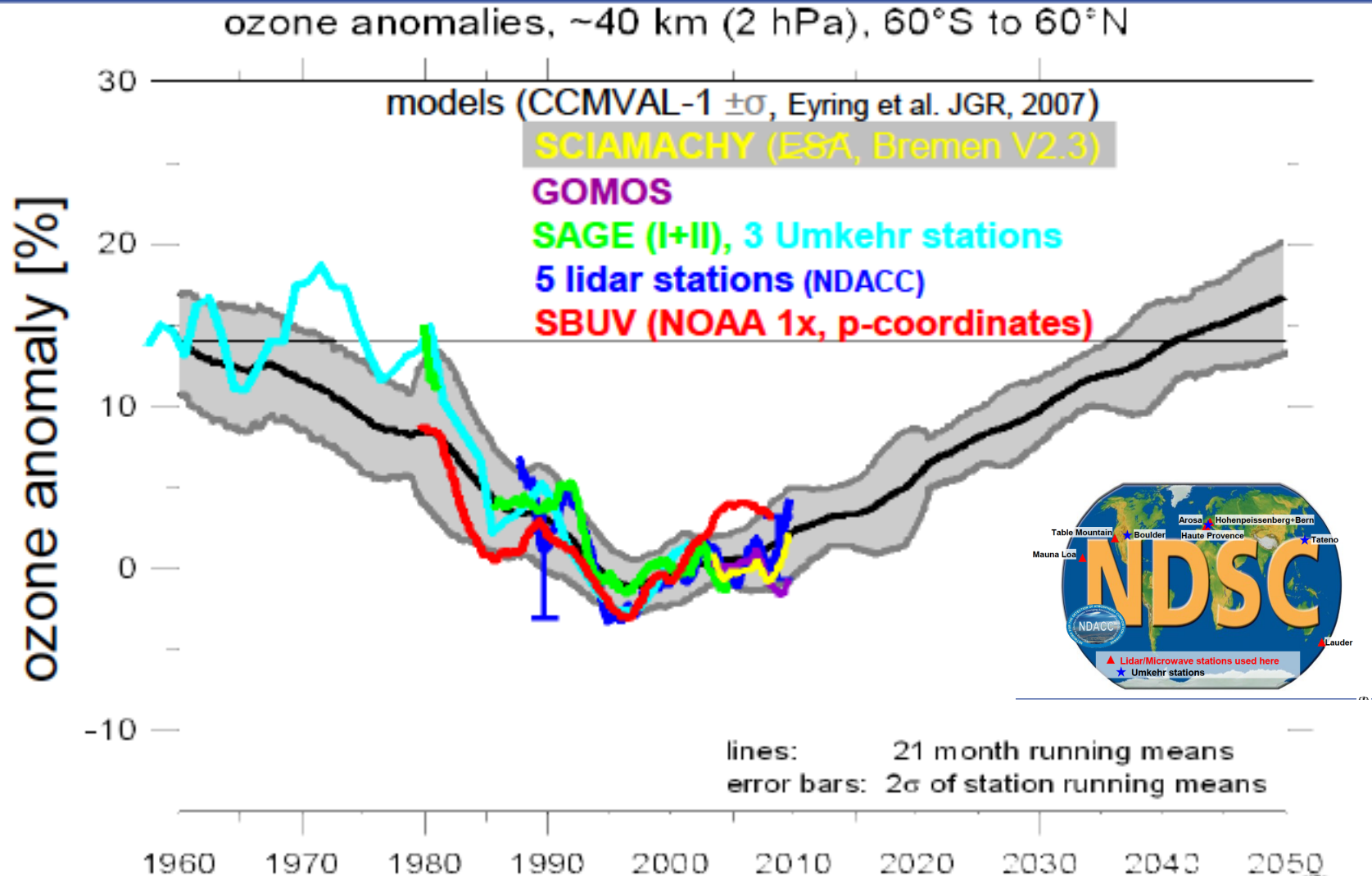
- Ozone measurements performed during the night
- Temporal resolution 3 - 4 hours
- Require clear skies

# Intercomparaisons NDACC avec lidar mobile NASA 1992, 1997

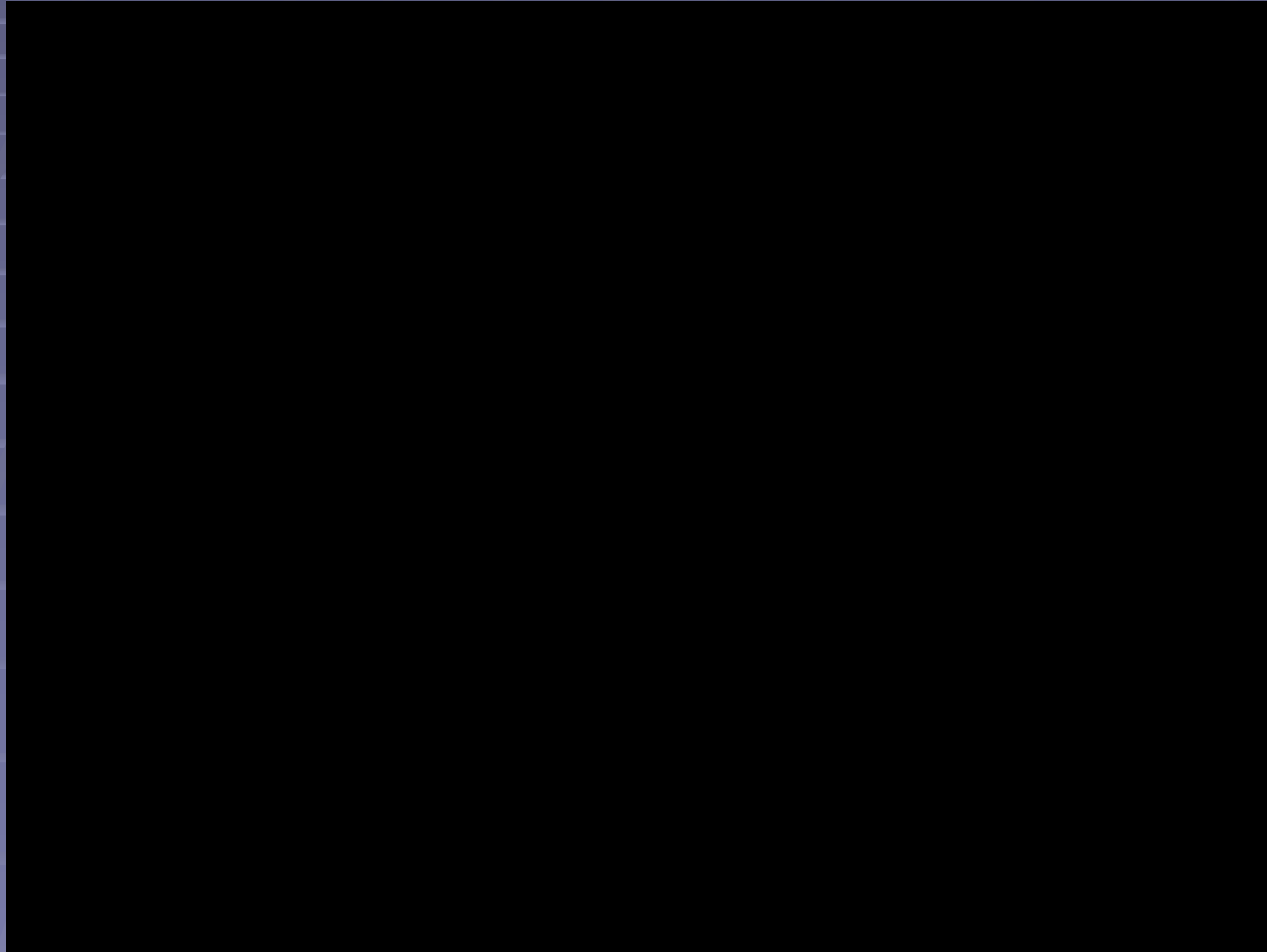


# O<sub>3</sub> evolution @ 40 km

Deutscher Wetterdienst  
Wetter und Klima aus einer Hand



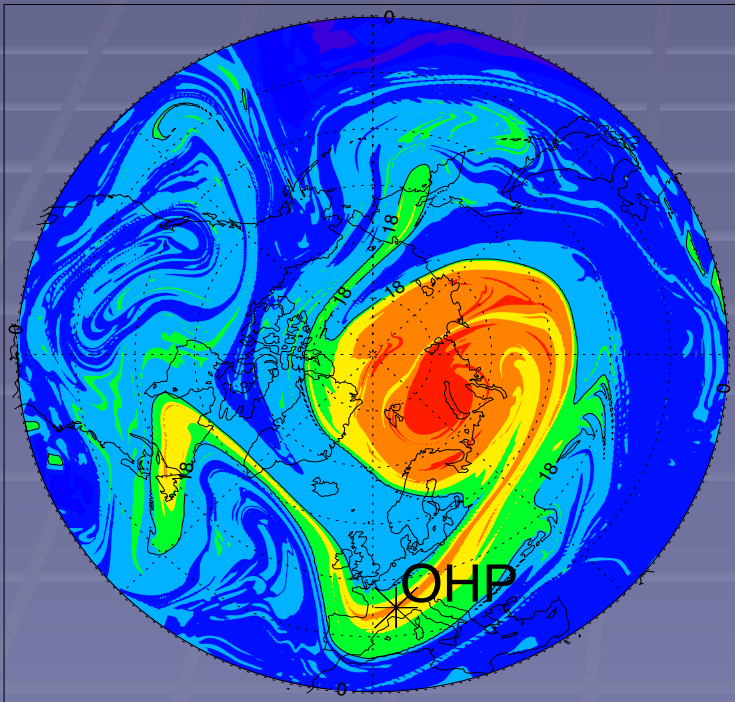
# Vortex evolution in December 1997



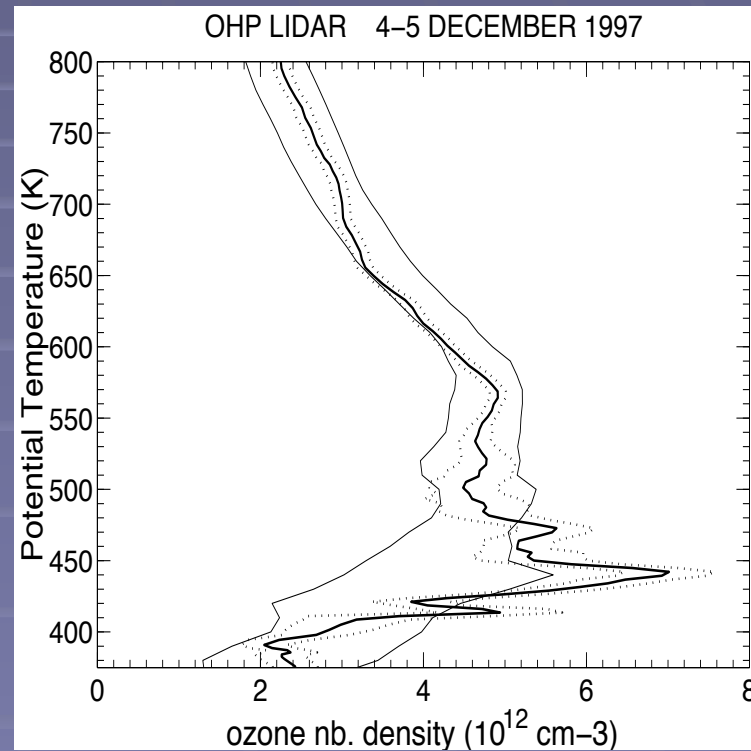
# Study of polar filaments

Example of polar filament simulated by the high-resolution transport model MIMOSA (Hauchecorne *et al.*, 2002, Godin *et al.*, 2002)

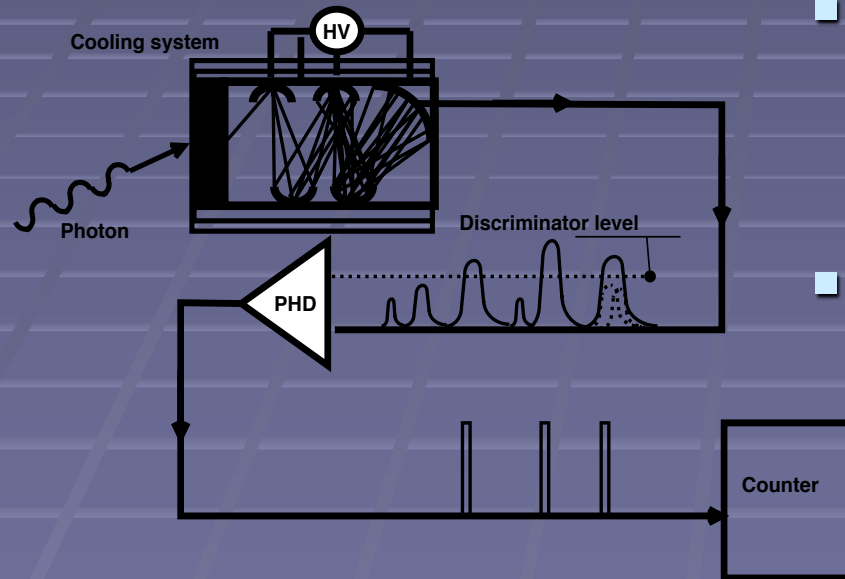
DECEMBER 5 1997 0h 440 K



OHP LIDAR 4-5 DECEMBER 1997



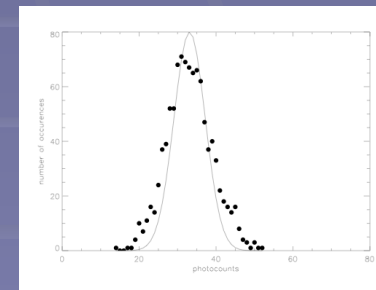
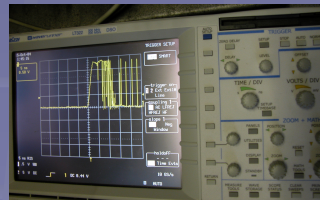
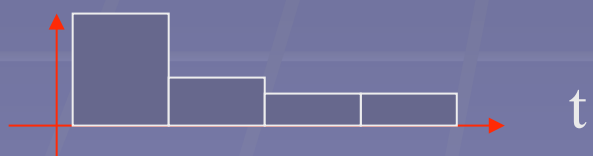
# Comptage de photons



- Measurement = Histogram

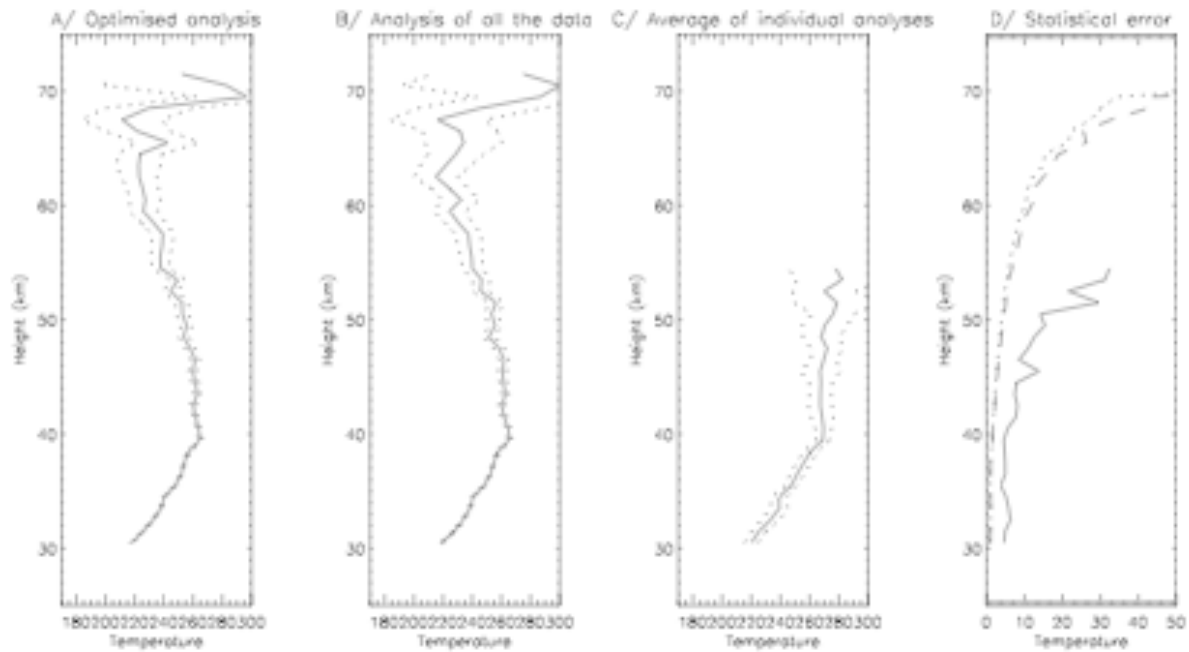
$$\Delta = \frac{1}{\sqrt{NbPhotons}}$$

- Improvements = increase the number of collected photons
  - Size of the telescope
  - Laser power
  - Vertical resolution
  - Temporal resolution



# Sommation

$$X(z) = \sum_{i=1}^n S_i(z,t) - b_i(t) \neq \sum_{i=1}^n S_i(z,t) - \sum_{i=1}^n b_i(z,t)$$

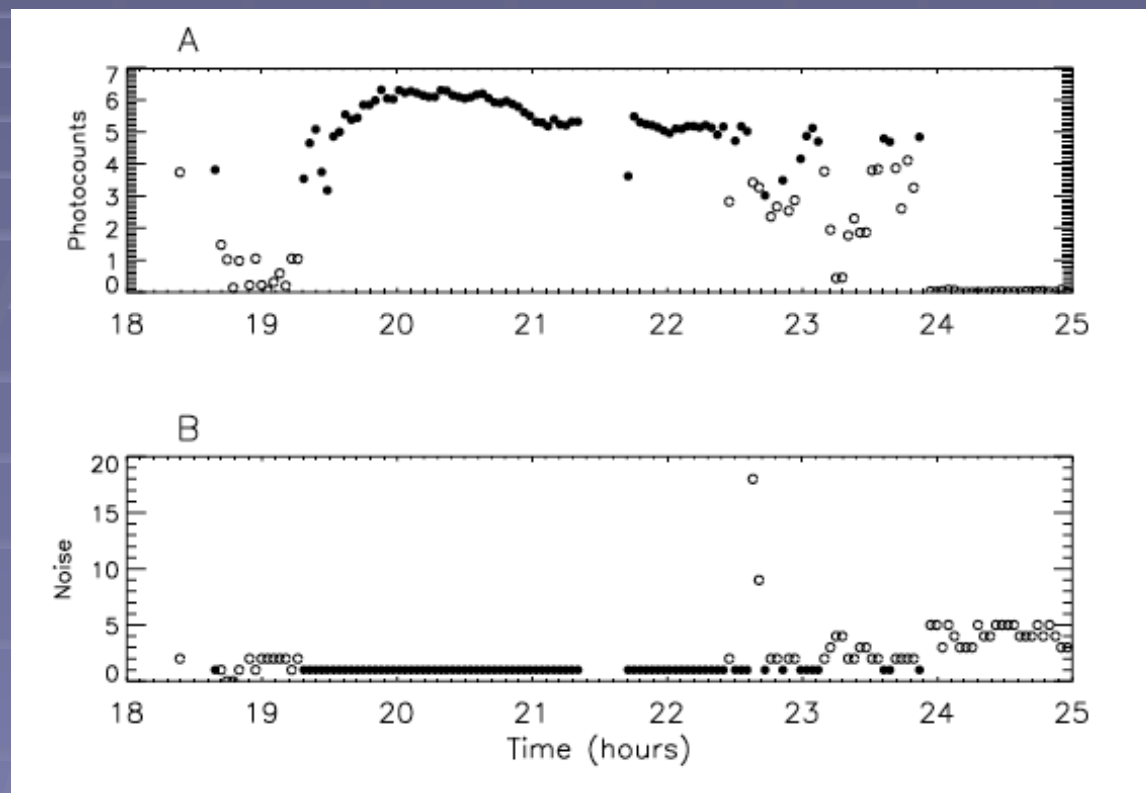




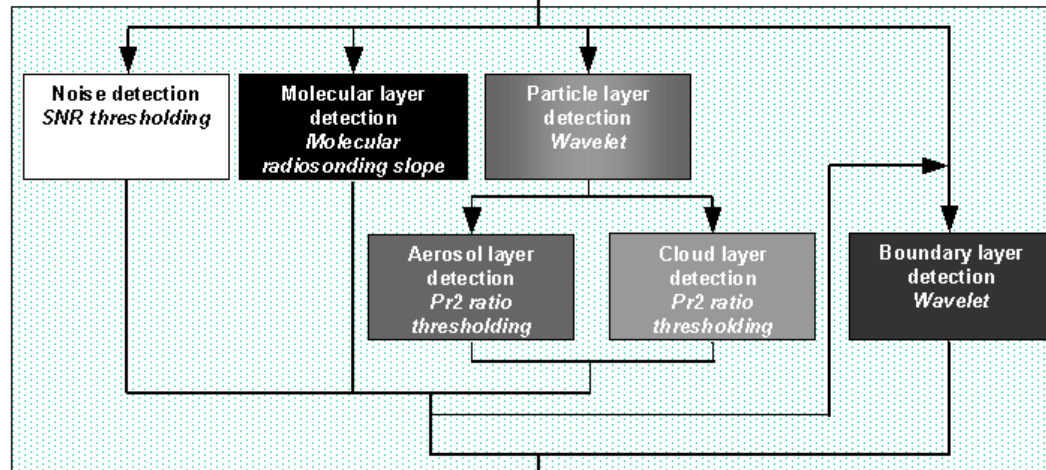
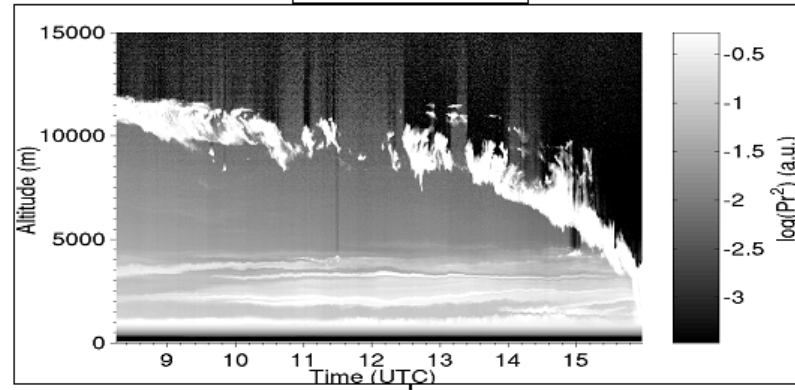
# AROLS Automatic Range Optimisation of Lidar Signals

$$\frac{\Delta S(z)}{S(z)} = \frac{\sqrt{N(z) + B(z)}}{N(z)}$$

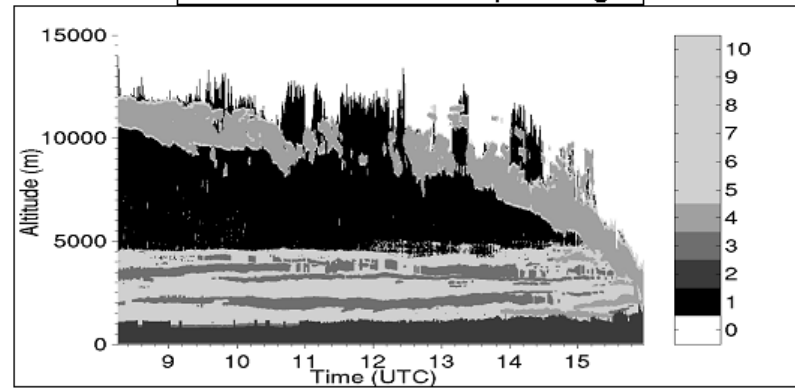
$$\frac{\sqrt{N(z) + B(z)}}{N(z)} < \frac{\sqrt{[N(z) - n_i(z)] + [B(z) - b(z)]}}{N(z) - n_i(z)}$$



LIDAR DATA Pr<sup>2</sup>

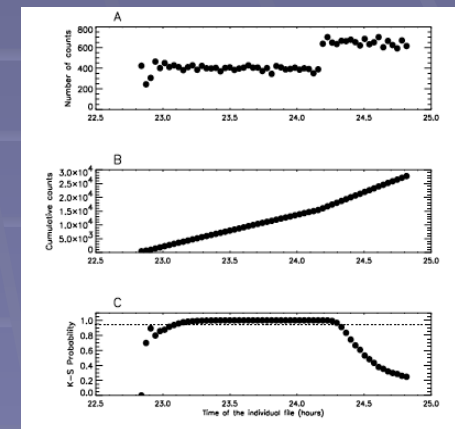


STRucture of the ATmosphere flag



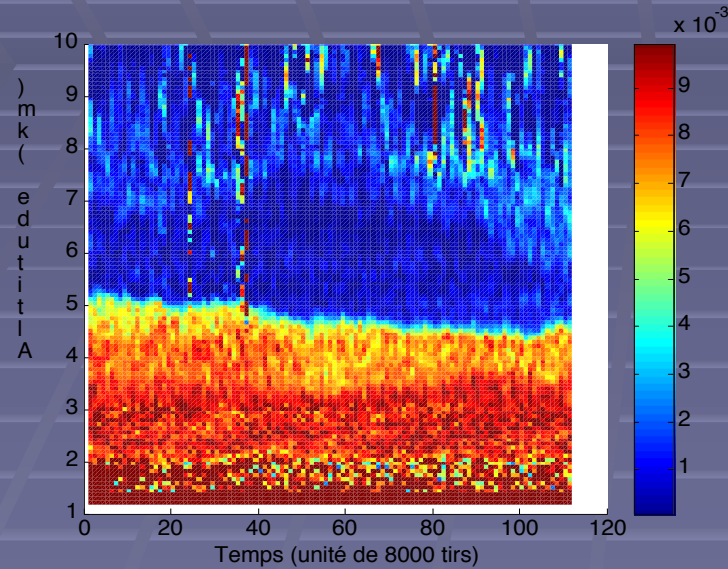
# Paramètres avec une forte variabilité: H2O

$$X(z) = \sum_{i=1}^n \frac{SH_2O_i(z,t) - bH_2O_i(t)}{SN_{2i}(z,t) - bN_{2i}(t)} \neq \frac{\sum_{i=1}^n SH_2O_i(z,t) - \sum_{i=1}^n bH_2O_i(z,t)}{\sum_{i=1}^n SN_{2i}(z,t) - \sum_{i=1}^n bN_{2i}(z,t)}$$

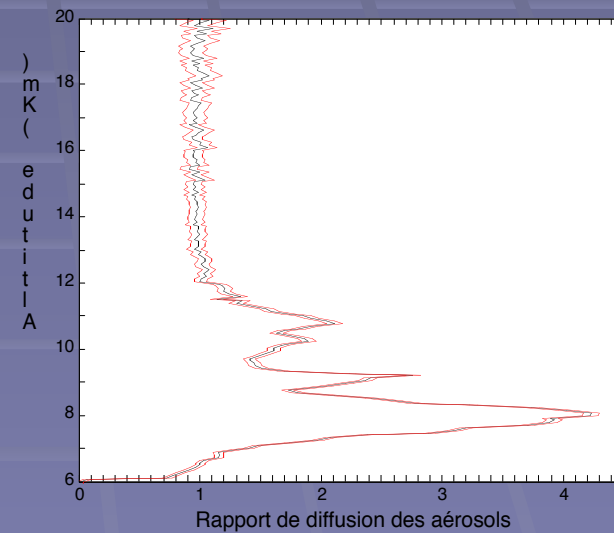
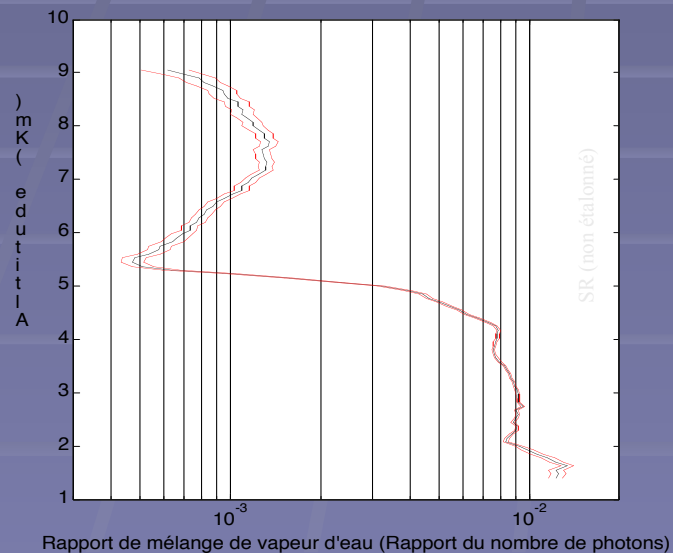
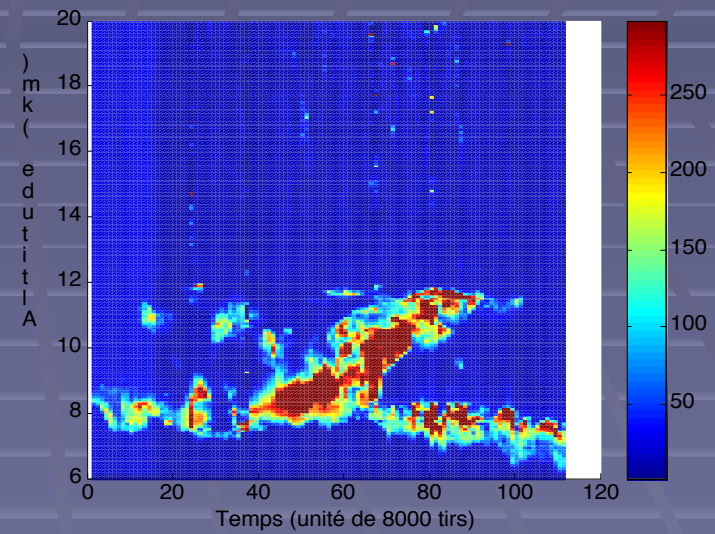


# Variabilité vapeur d'eau/cirrus

Rapport de mélange de vapeur d'eau

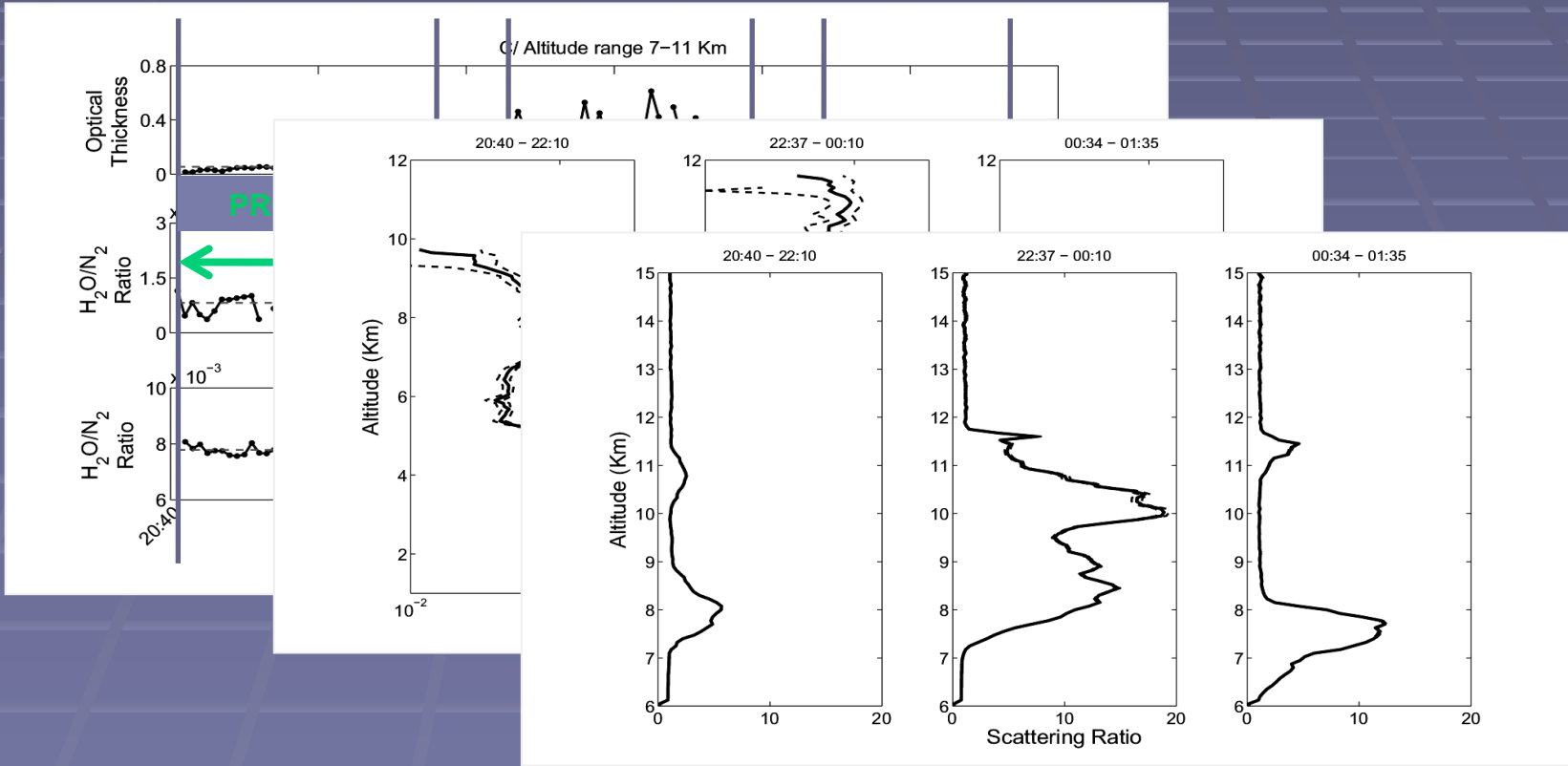


Rapport de diffusion



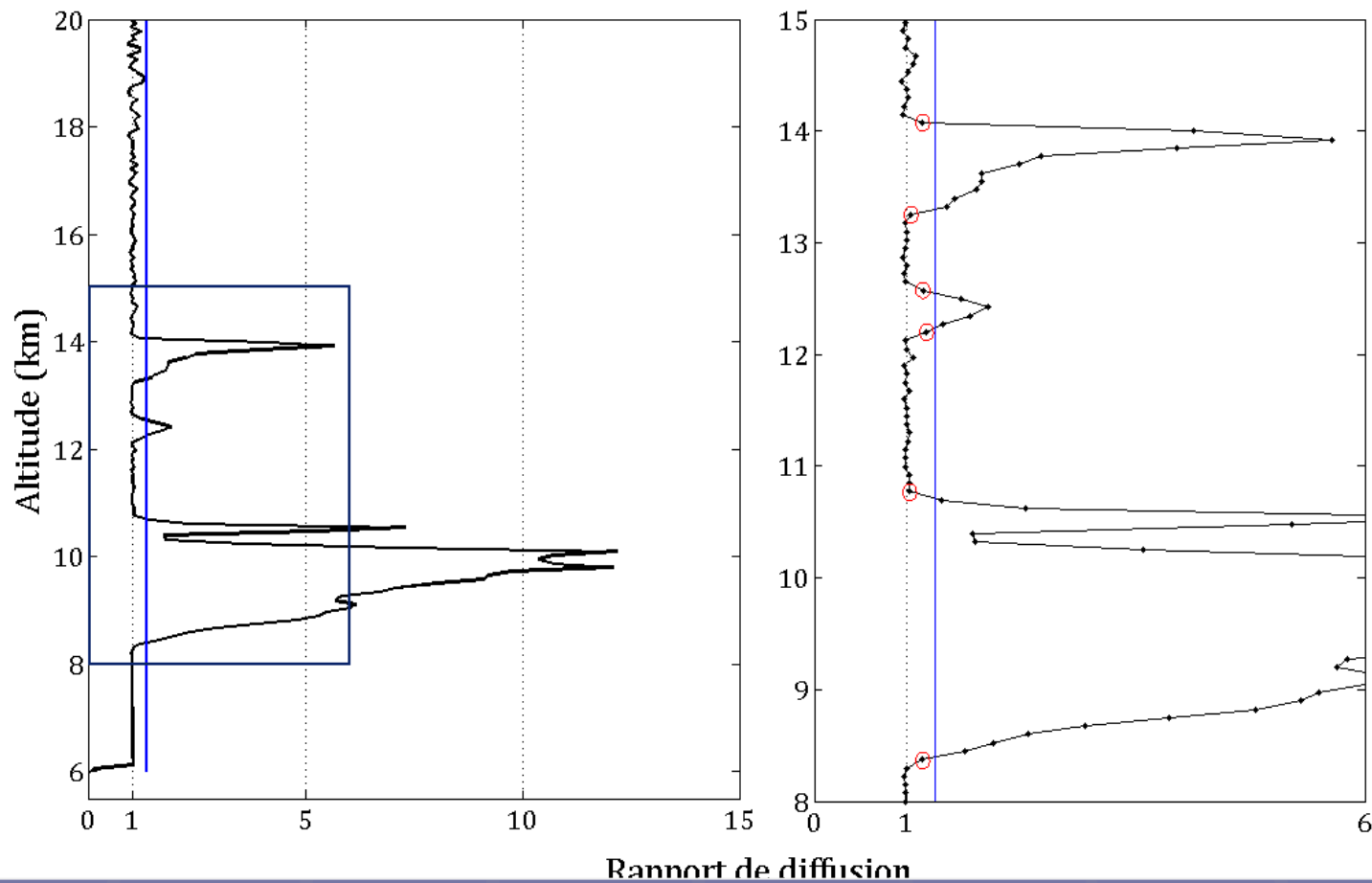
# Data sampling

- The method consists of adjusting the integration time with the discontinuities of the flow sounded

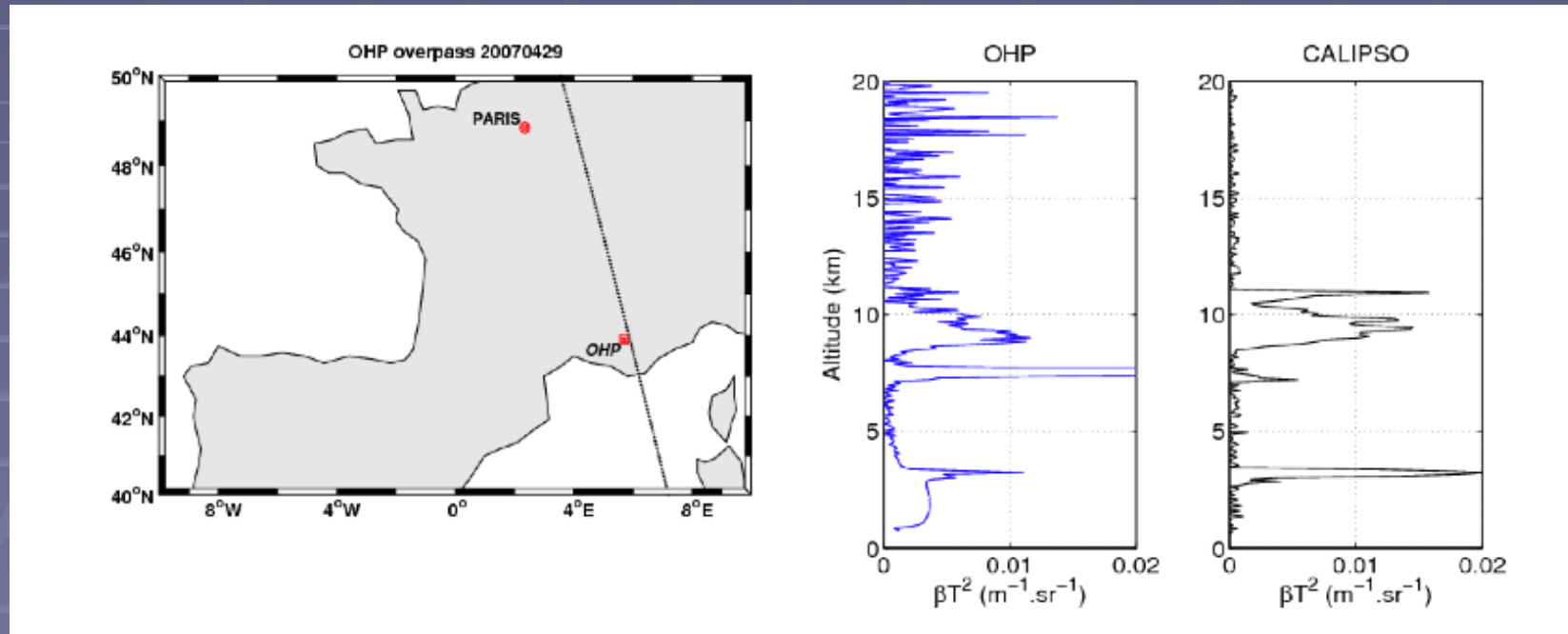


Reasonable compromise between accuracy and atmospheric variability

# Retrieval of cloud altitude parameters

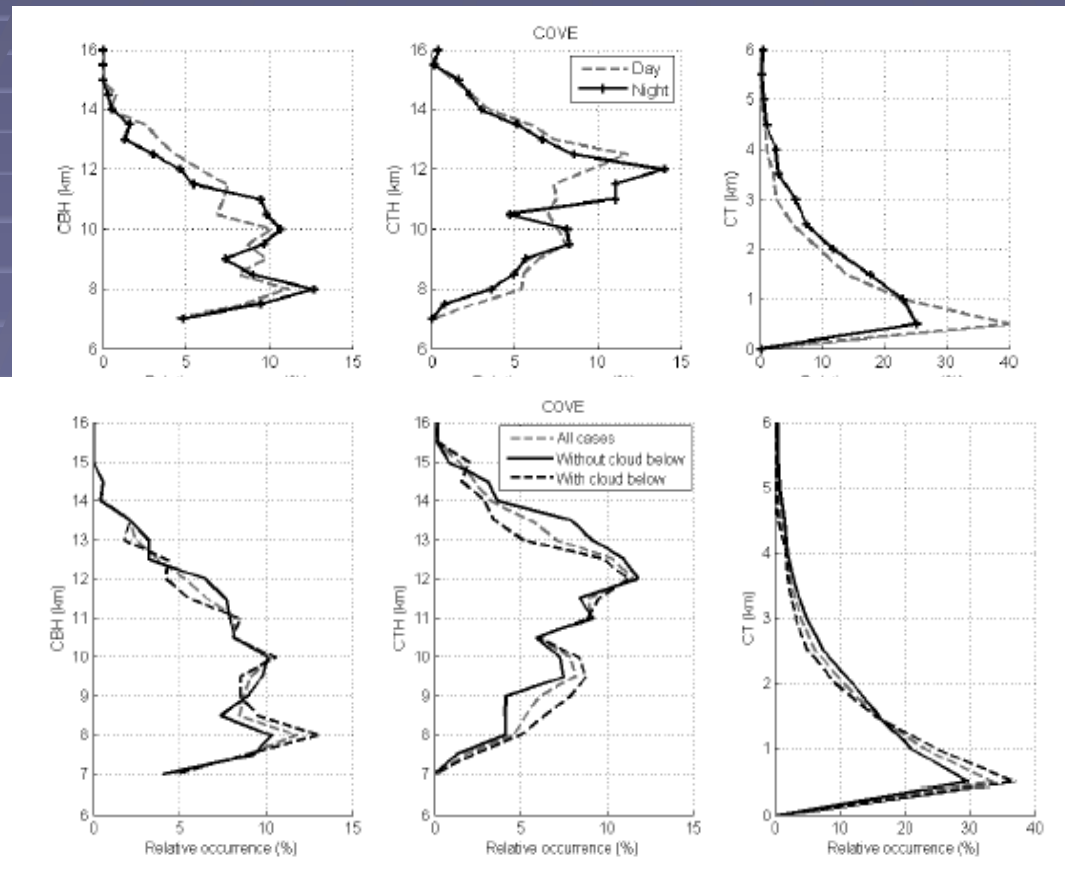


# Observation des Cirrus



Haeffelin, Morille, 2008

# Tests des biais de la statistique de cirrus



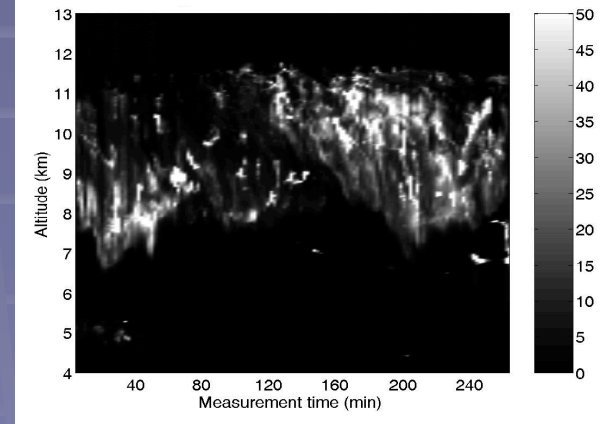
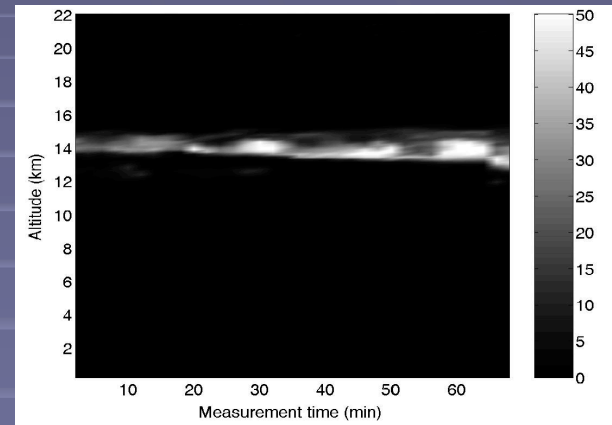
Nuit/Jour

Nuages bas

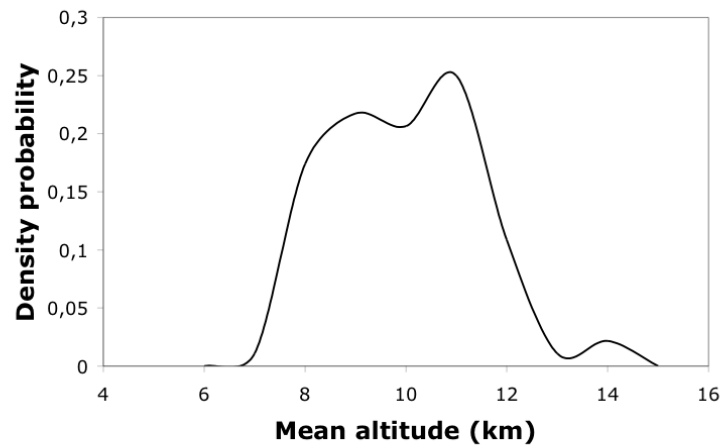
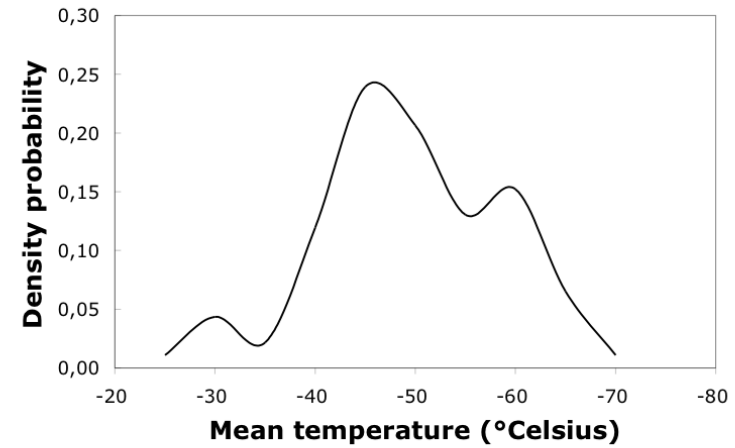
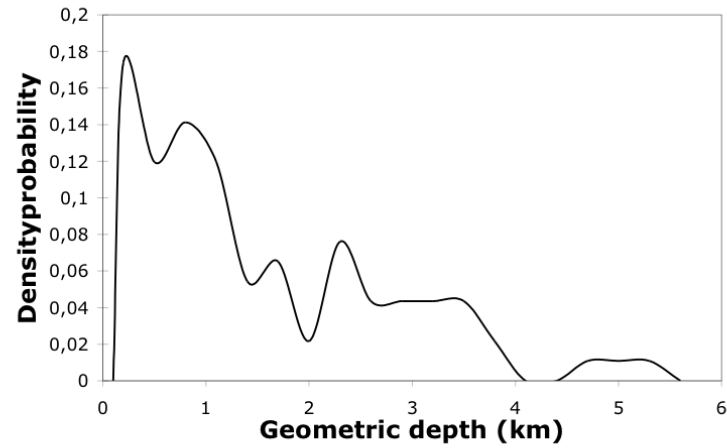
Dupont et al, 2009



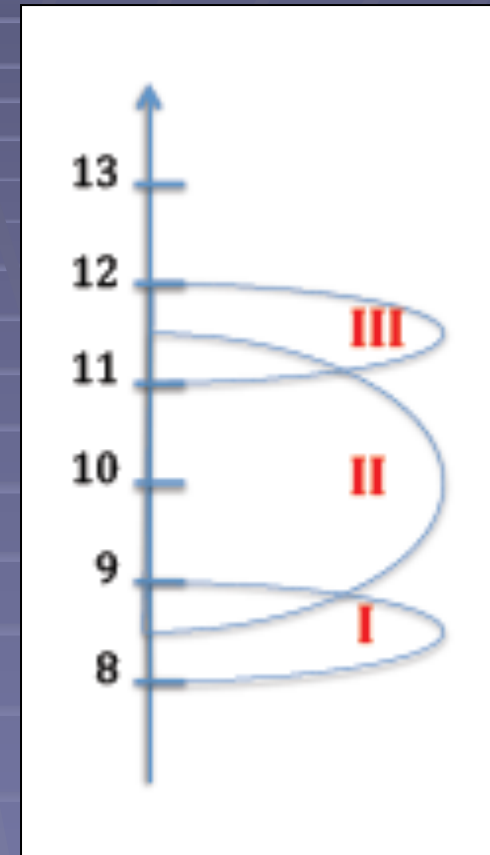
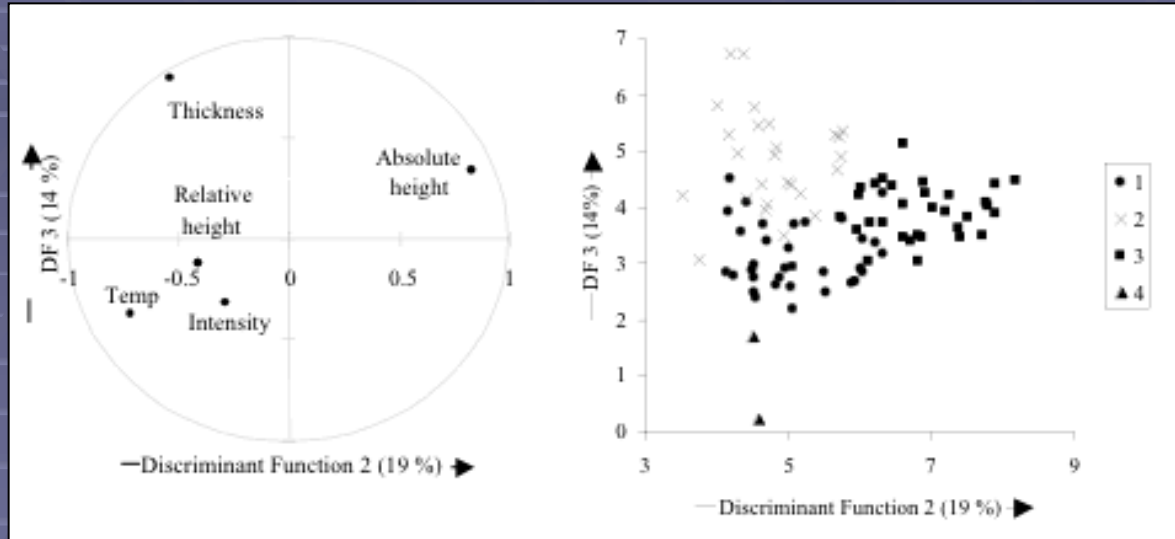
# Cirrus types



# Distribution des anomalies



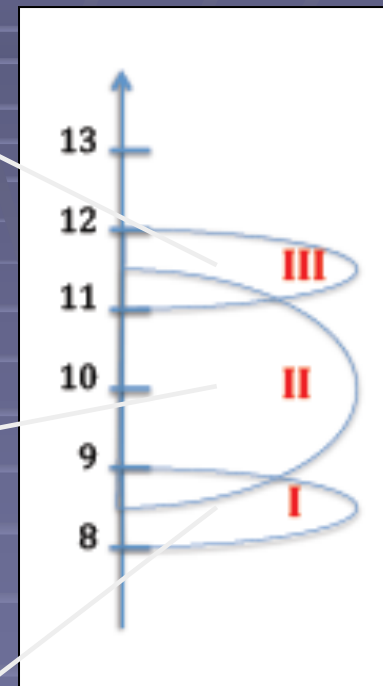
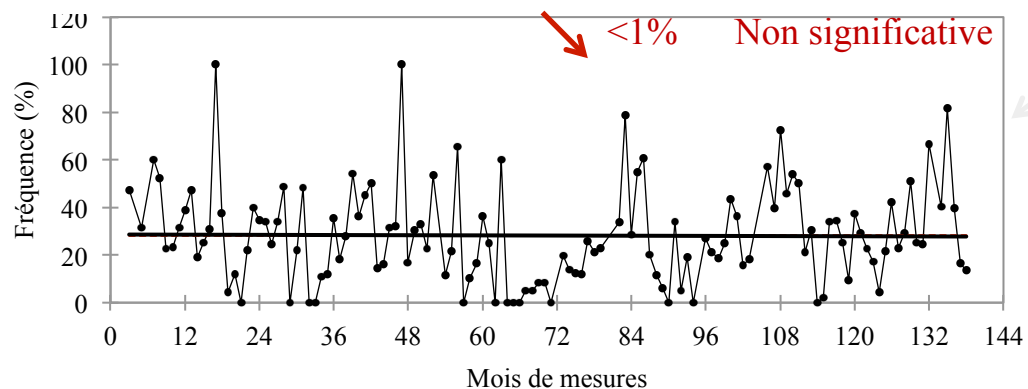
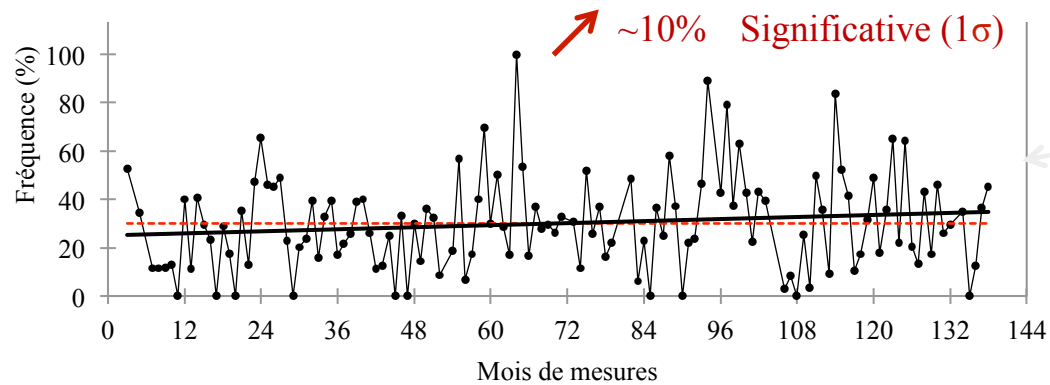
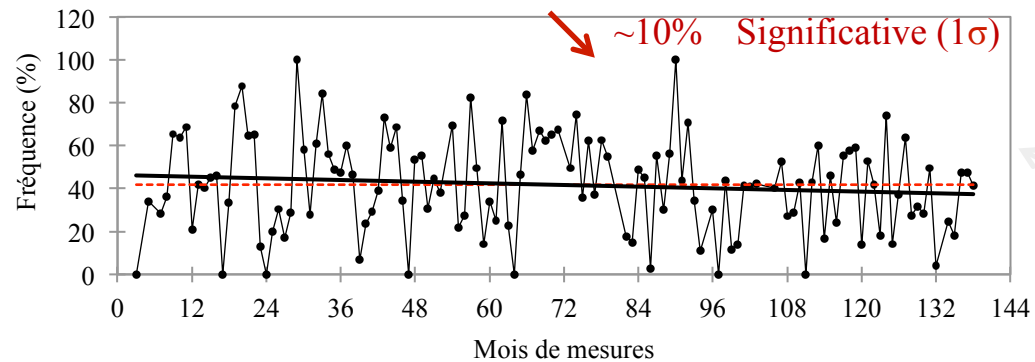
# Cirrus clusters



Class	I	II	III
Occurrence (%)	36	27	35
Height (km)	8.6 ± 0.9	9.8 ± 0.7	11.5 ± 0.9
Altitude relative to tropopause	-7 ± 8	-0.5 ± 13	+7 ± 16
Thickness (km)	0.9 ± 0.6	3.2 ± 0.9	0.9 ± 0.6
Temperature (°C)	-41 ± 6	-50 ± 6	-58 ± 6

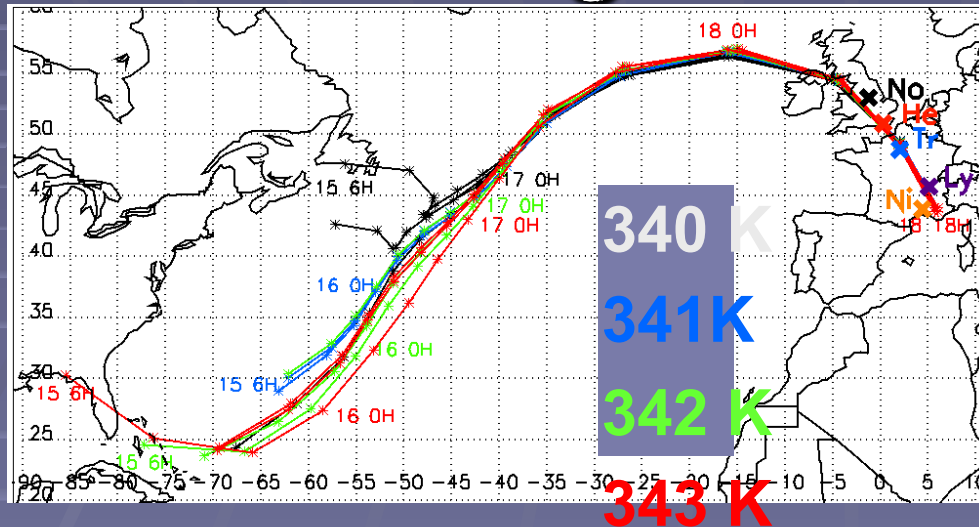
Keckhut et al.,  
*J. Appl. Meteo.*, 2005 (in press)

# Long term trends according to clusters



→ Different classes = different time evolution

# Classe III: Cirrus clouds at the vicinity of the tropopause



Keckhut et al., *Atmos. Chem. Phys.*, 2005

Montoux et al., *J. Geophys. Res.*, 2009

MIMOSA trajectories:

$\theta \leq 340\text{K}$ : midlatitudes

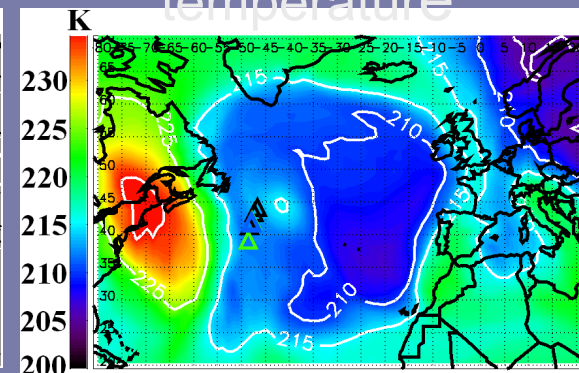
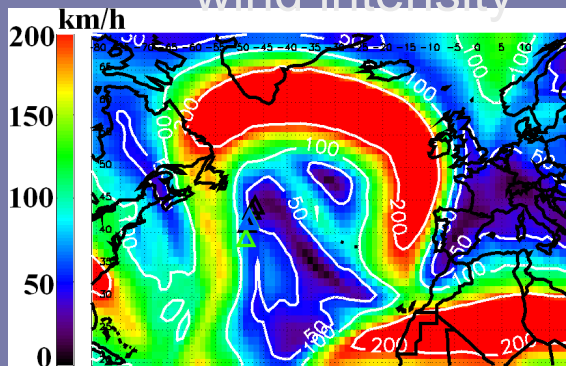
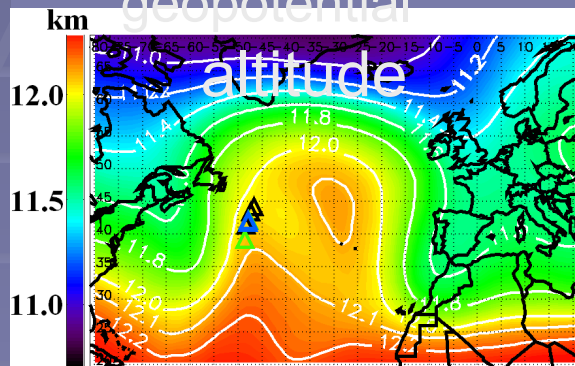
$\theta \geq 342\text{K}$ : subtropics ( $24\text{-}30^\circ\text{N}$ )

16 January 2006 12:00 UTC - 200 hPa - ECMWF analysis:

geopotential

wind intensity

temperature



# Simulation of the cirrus cloud

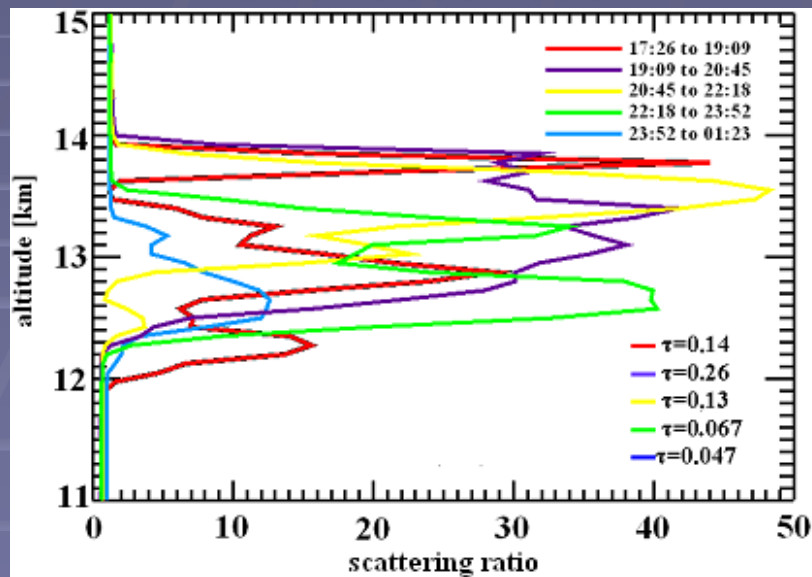
4-day simulation

supersaturation threshold = 130%

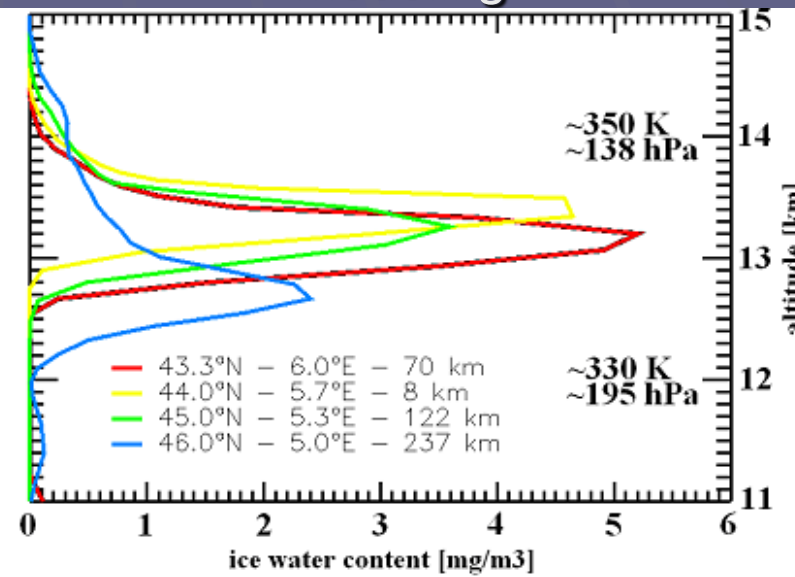
Fall speed = 4 mm/s (very small ice particles  $\sim 5 \mu\text{m}$ )

Fromoux et al., J. Geophys. Res., 2009

Lidar observation



Modeling



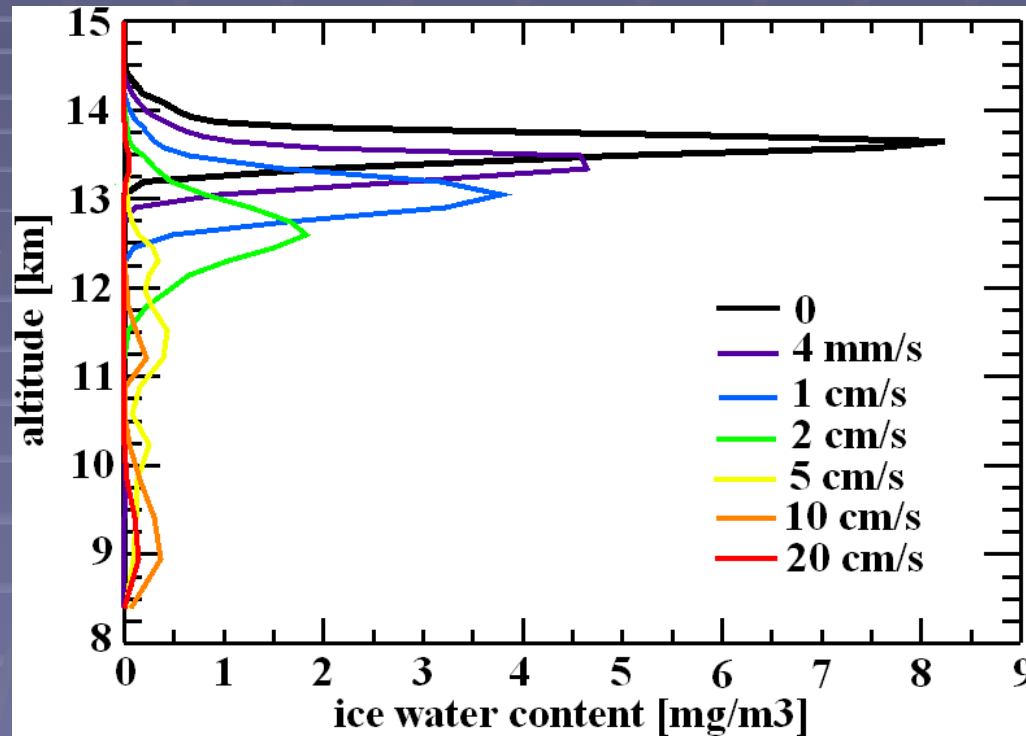
## Altitude of the cirrus cloud well-reproduced

Great spatial and temporal variability similar to that seen by lidar

Maximum ice water content  $\sim 5.3 \text{ mg/m}^3$

⇒ small, hardly detectable from space

# Influence of the fall speed

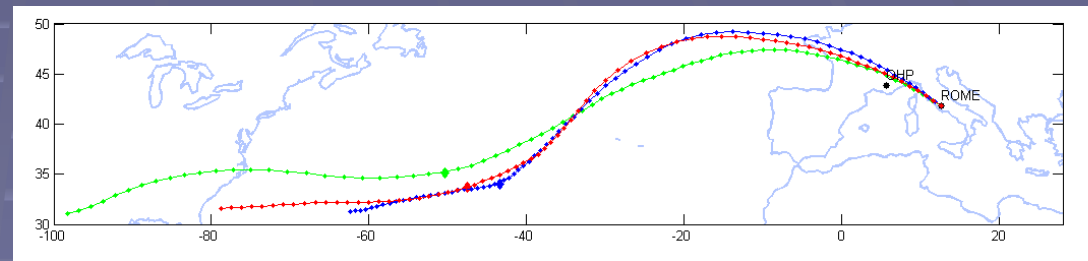
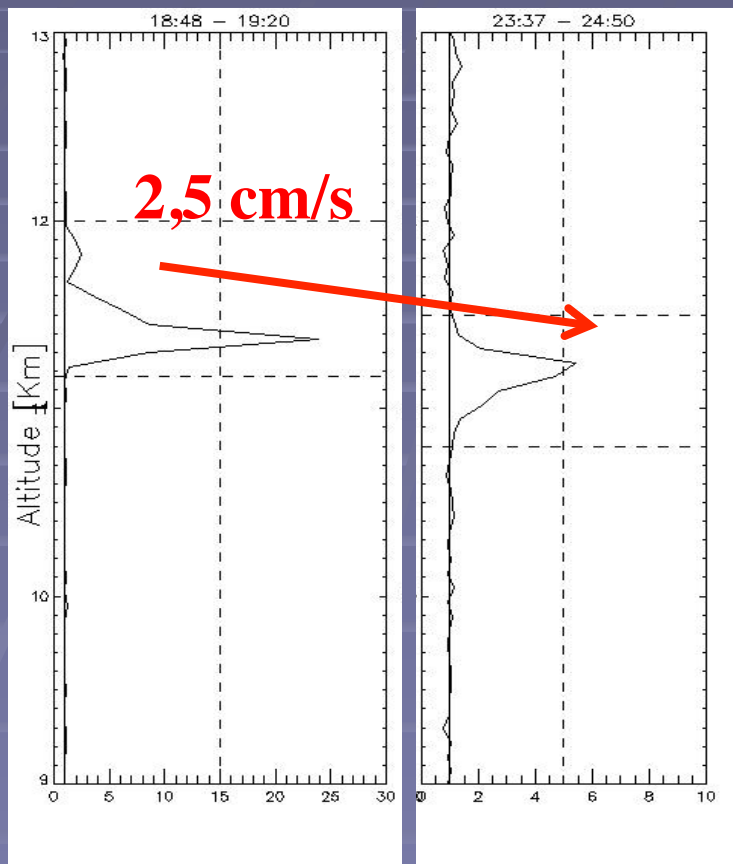


$V_{sed} \nearrow$ , cloud top altitude  $\searrow$ , geometrical thickness  $\nearrow$

$V_{sed} > 30 \text{ cm/s} \Rightarrow$  cloud disappearance

**Cirrus cloud quite well reproduced for  $V_{sed} \sim 1 \text{ cm/s}$**

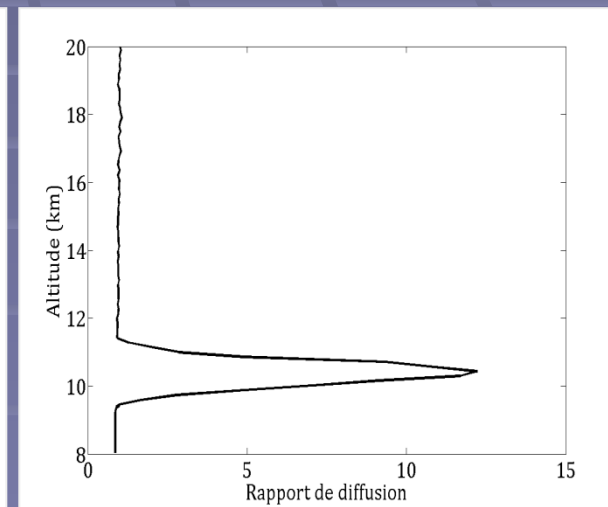
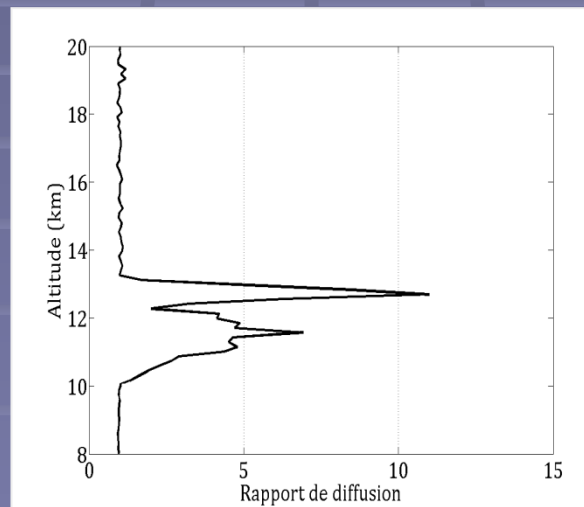
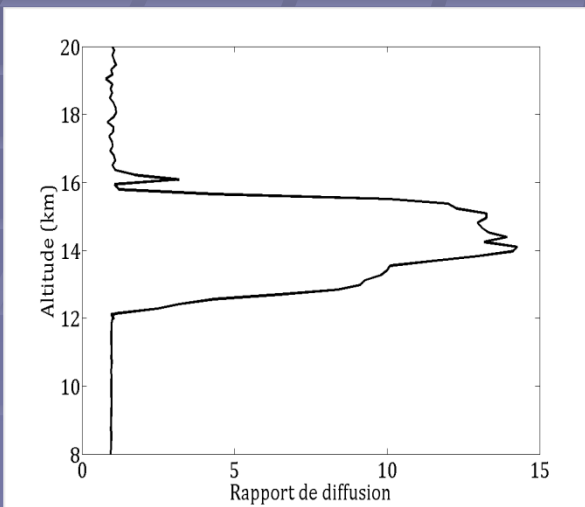
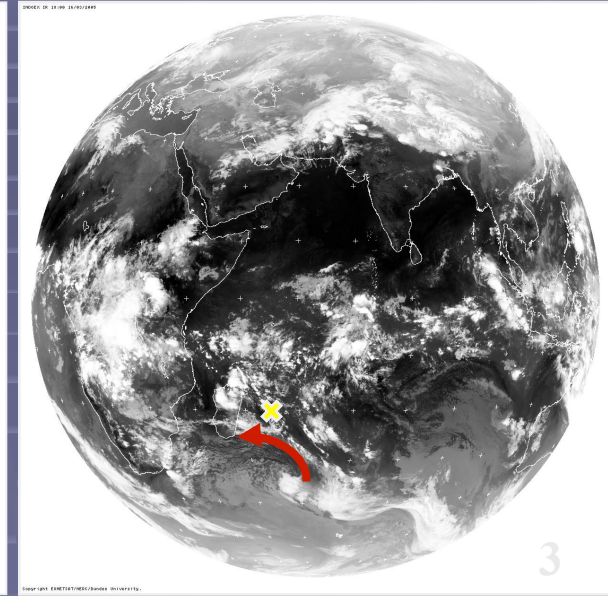
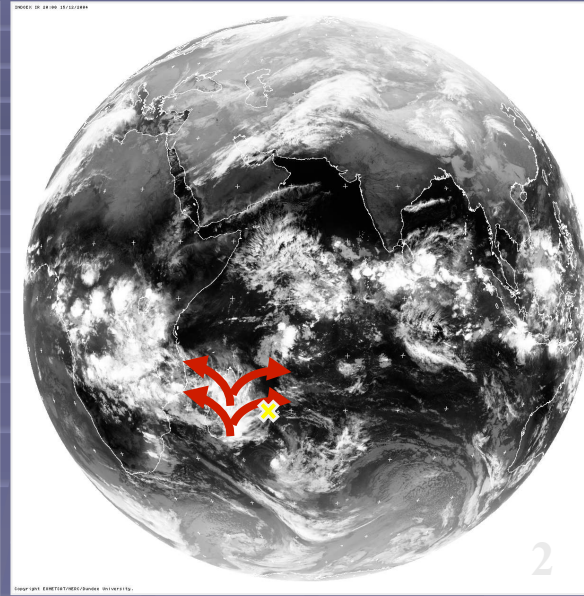
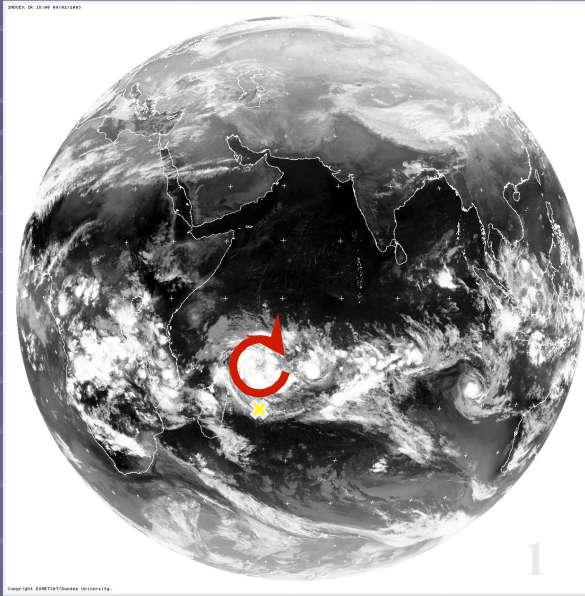
# Particle fall velocity estimates with lidar MATCH approaches



Dionisi et al., to be submitted



# Cirrus cluster attribution through case studies

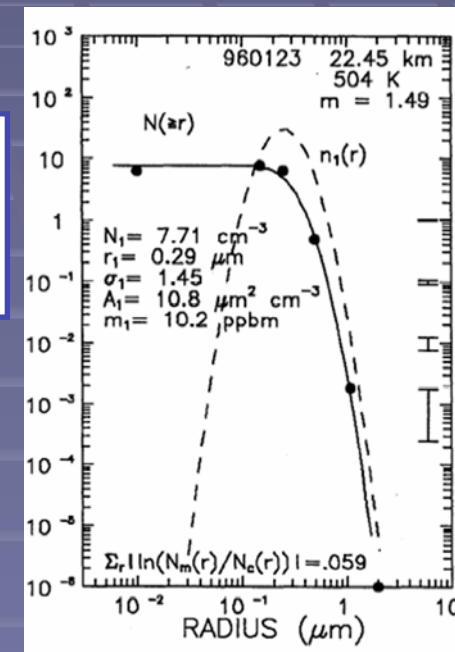
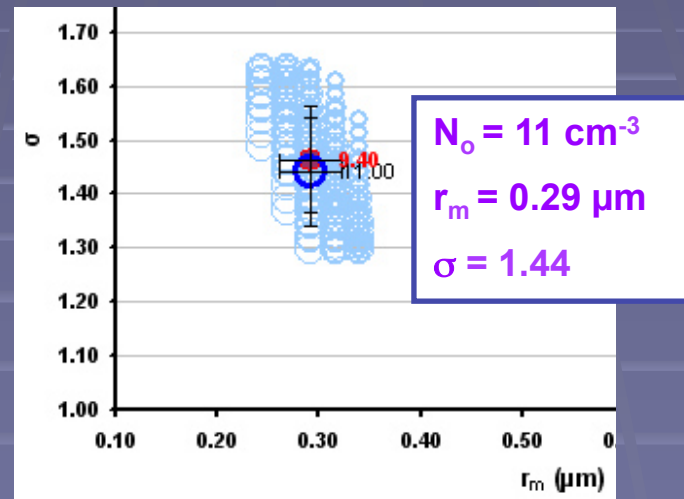
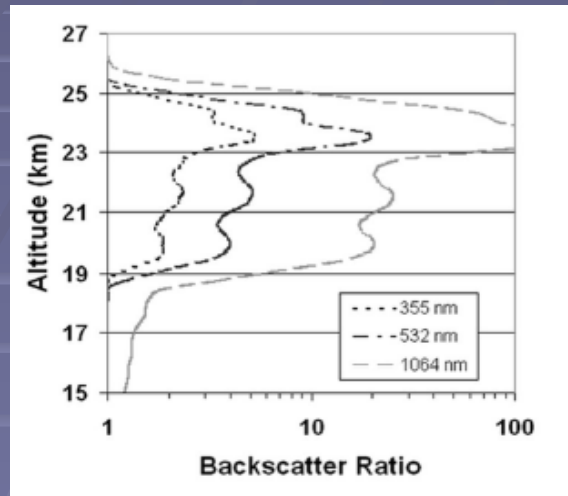


# Distribution en taille à partir du lidar



Distribution log-normale caractérisée par

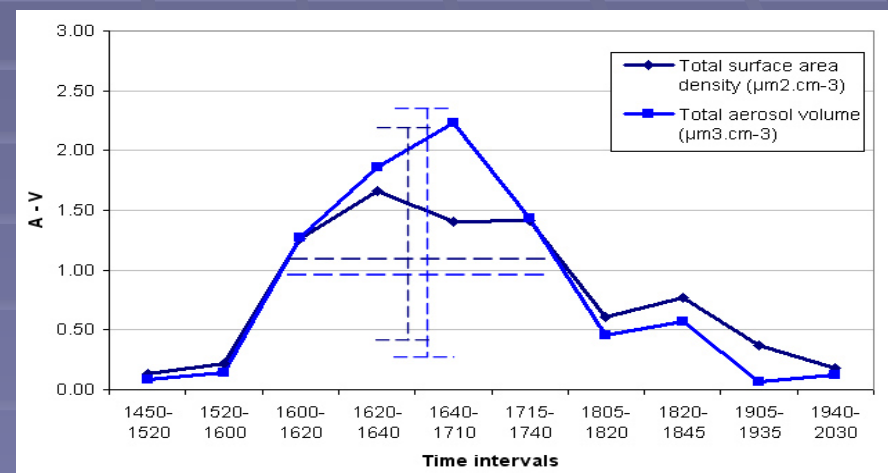
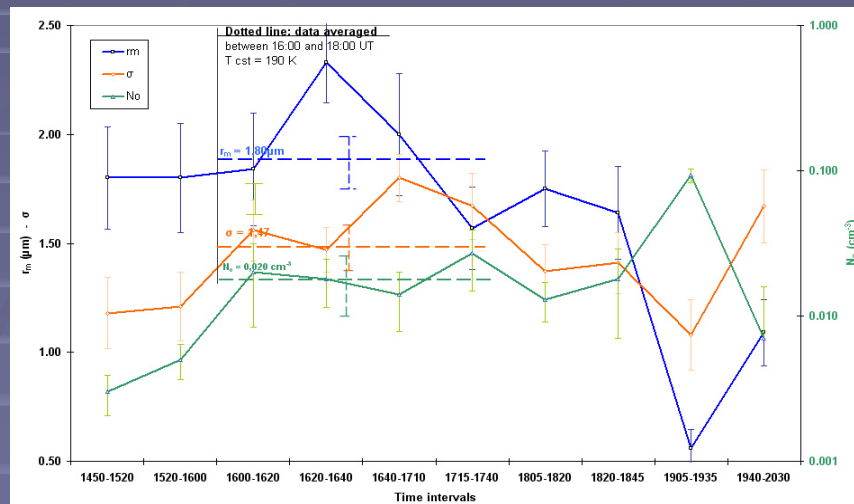
- Concentration des particules
- Le rayon médian
- Dispersion du rayon



$$\frac{dN}{dr}(r) = \frac{N_o}{\sqrt{2\pi} r \cdot \ln(\sigma)} \exp\left(-\frac{\ln(r/r_m)}{2\ln(\sigma)}\right)$$

Jumelet et al., 2008

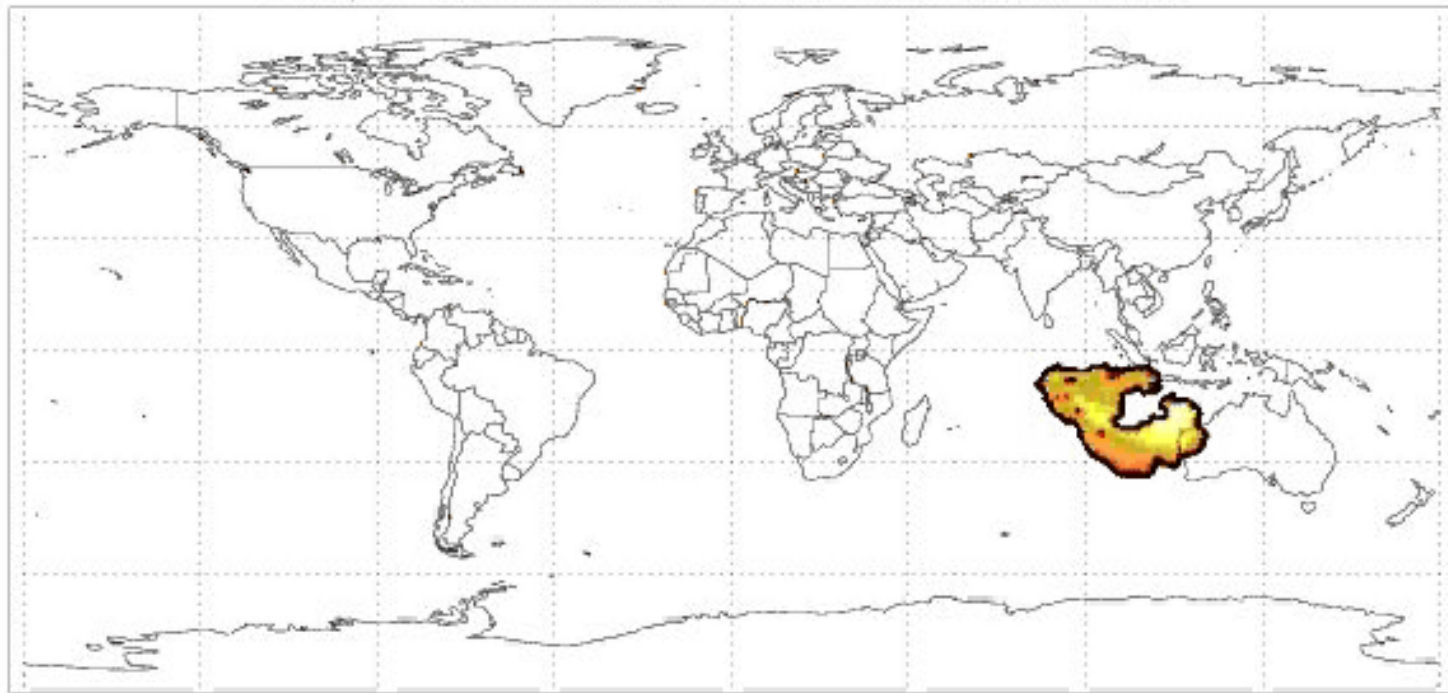
# Size distribution -> Aerosol surface and volume



Transport B532nm 380K 10110718 GMT Global ECMWF

B.R.532nm

2.0  
1.8  
1.6  
1.4  
1.2



# Assimilation Caliop du volcan Merapi avec Mimosa

*Mt MERAPI Eruption 3 Nov 2010*

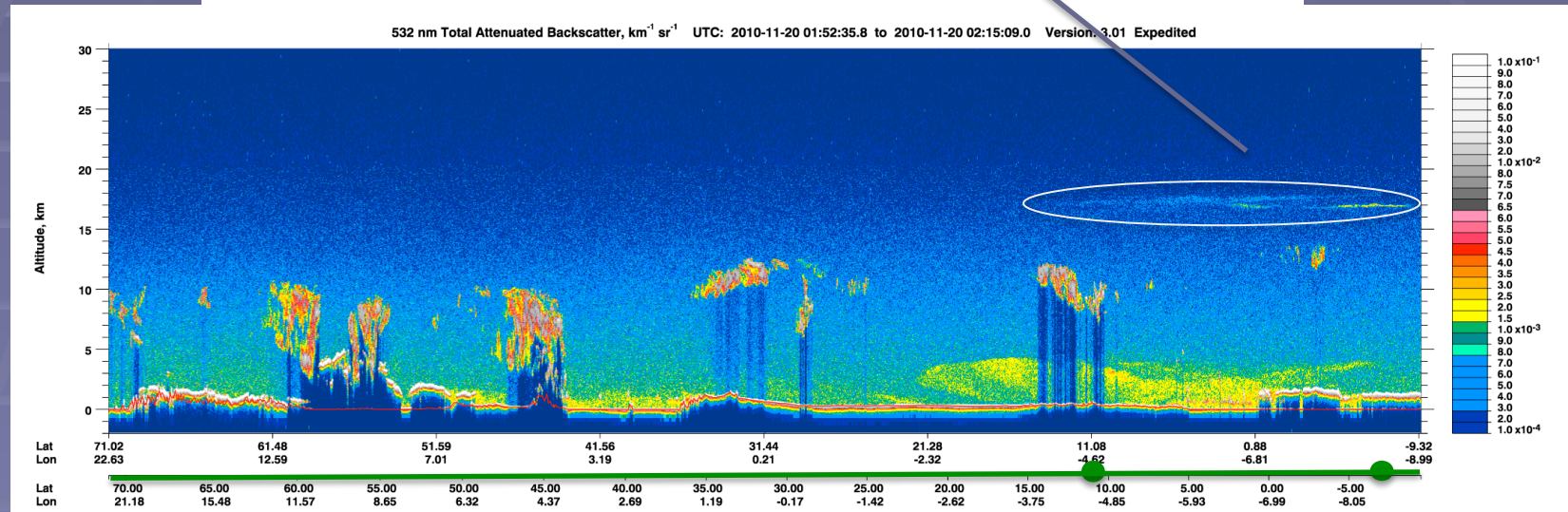
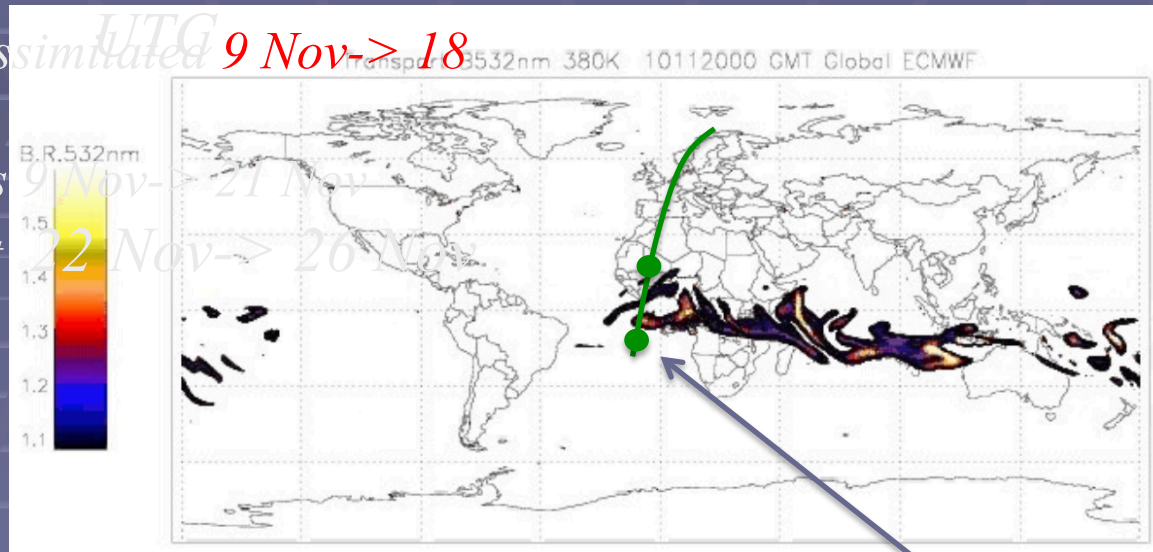
*Case on 20 Nov at 00 J. Jumelet*

*CALIPSO data assimilated 9 Nov -> 18*

*Nov*

*ECMWF analysis 9 Nov -> 21 Nov*

*ECMWF forecast 22 Nov -> 26 Nov*



# Conclusions

- Les lidar sont des instruments idéaux pour la surveillance atmosphériques et complémentaires des mesures depuis l'espace.
- Assurer cette surveillance nécessite d'éviter ou de documenter les discontinuités et d'étudier leurs effets à long terme.
- L'analyse des tendances est d'autant plus performante que l'on sépare les différents processus.
- Les réseaux permettent de sonder plusieurs sites différents et offrir un dispositif efficace pour la validation satellitale et l'estimation de tendances globale à long-terme.
- Les réseaux actuels restent avec une géométrie dictée par les opportunités plus que par des questions scientifiques et il existe peu de recouvrement. Ils n'exploitent donc pas toujours les synergies instrumentales. Ces réseaux sont en construction.