

OBSERVATIONS LIDAR AEROPORTEES

pour l'étude de l'atmosphère (et des interfaces)

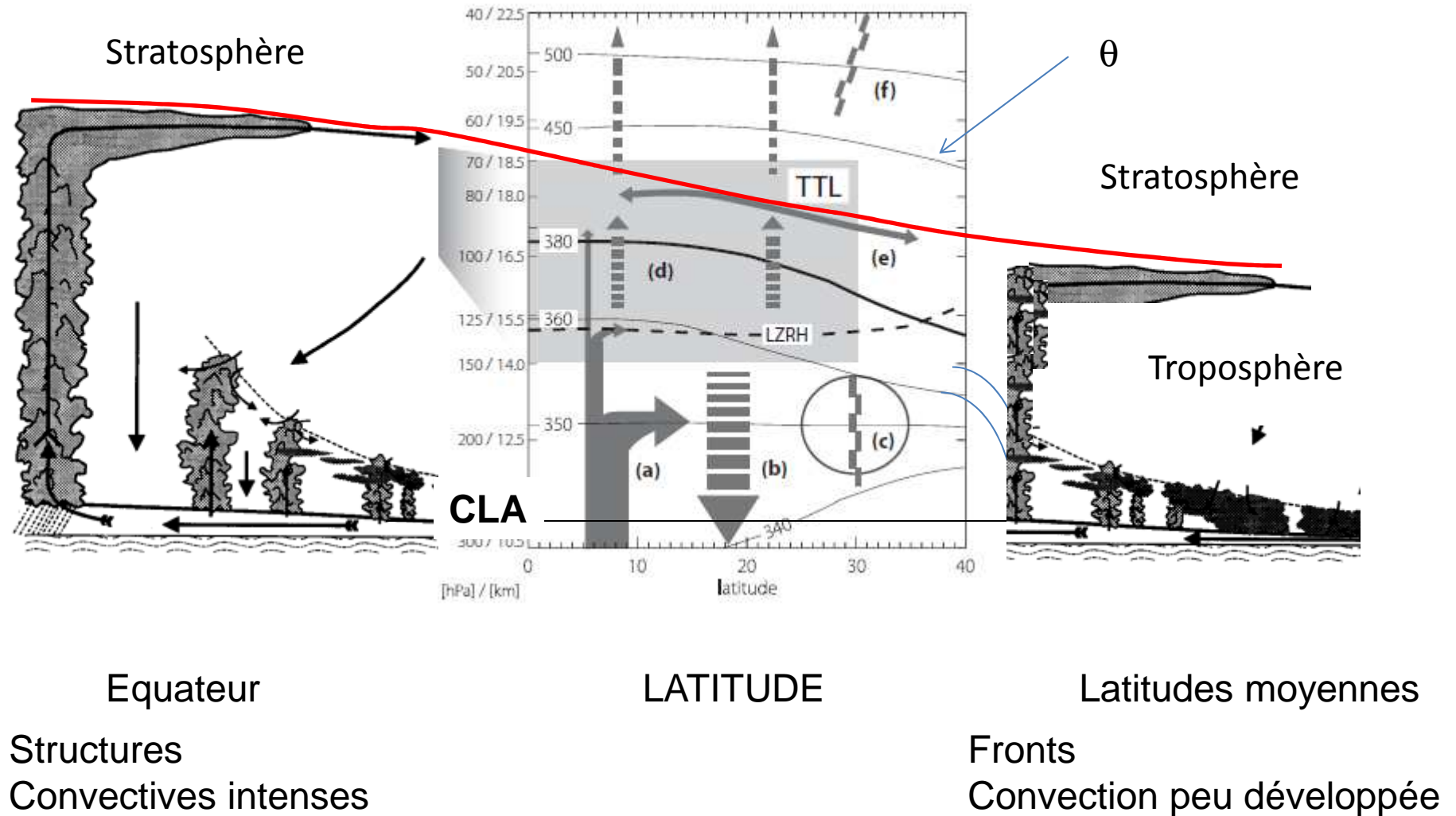
- Etude de processus à méso-échelle : dynamique, rayonnement, météo, physico-chimie et environnement;
- → plusieurs domaines d'altitude régis par des processus différents

- Tests de nouveaux équipements (aéroportés et démonstrateurs spatiaux)

- Tests de nouvelles méthodes d'analyse (restitution de paramètres par inversion des signaux mesurés) et confrontation aux mesures in situ

- Comparaison/Validation de mesures spatiales

Préambule



OBSERVATIONS LIDAR AEROPORTEES

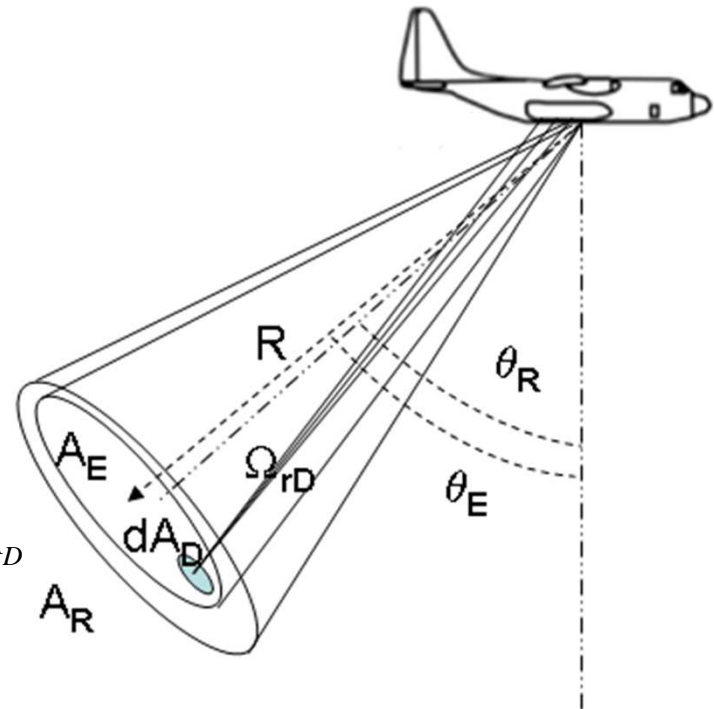
- Etude de la structure des couches d'aérosols et des nuages : dynamique (y compris la couche limite atmosphérique*)
- Etude des transports verticaux et flux aux interfaces (couche limite, tropopause) en mesure directe (H₂O, vent, turbulence) ou par l'utilisation de traceurs minoritaires;
- Etude des processus de formation nuageuse, caractérisation des propriétés microphysiques et impacts radiatifs,
- Quantification des sources/puits (H₂O, Aérosols, CO₂, CH₄, ...)
- Etude du transport à longue distance et des modifications induites (aérosols, composants minoritaires); pollution ; physicochimie de la troposphère/stratosphère
- Caractérisation de la surface (rugosité, flux, couvert, vent...) et subsurface (océan)

* En partie applicable à l'océan superficiel avec des longueurs d'onde pénétrant le milieu

Mesures par LIDAR aéroportées

C'est un peu plus compliqué qu'au sol (mouvements de l'avion, RSB plus limité par l'acquisition de données rapide) mais cette approche permet d'aller chercher les situations dans lesquelles les processus sont mis en œuvre, de les analyser à des échelles de 10m à 100 km, et d'en faire un suivi temporel (la durée de vol peut être de plus de 10h)

$$dP_R(R, \nu, \nu', t) = B(R, \nu, \nu') \frac{F_{0,\nu}(R, t)}{A_E} \Omega_{RD} \exp(-\tau_{ATM, D, \nu, \nu'}) dA_D$$



Applications

- Lidar rétrodiffusion (backscatter) simple (+ dépolarisation)
 - Dynamique (traceurs), Rayonnement (aérosols, nuages)
- Lidar rétrodiffusion à haute résolution spectrale (HRS)
 - Idem, mais plus précis
- Lidar rétrodiffusion à absorption différentielle (DIAL)
 - Thermodynamique (H₂O), physico-chimie (O₃), climat (GES)
- Lidar rétrodiffusion Doppler
 - Dynamique (transport, flux quantité mvt)
- Lidar rétrodiffusion DIAL + Doppler
 - Thermodynamique, flux

Le Tourbillon Potentiel (Potential Vorticity (PV))

$$PV = \frac{1}{\rho} [\vec{\nabla} \wedge \vec{V} + f\vec{k}] \cdot \vec{\nabla}\theta$$
$$\approx -g \frac{\partial\theta}{\partial p} [\vec{\nabla} \wedge \vec{V}_\theta + f\vec{k}]$$

PV est conservé dans une particule fluide en absence de chauffage diabatique et de forces de frottement et possède les propriétés suivantes :

- Fortes valeurs de PV dans la stratosphère car $PV \propto \frac{\partial\theta}{\partial p}$ et $PV > 3 \cdot 10^{-6} \text{ Kkg}^{-1}\text{m}^2\text{s}^{-1}$ (3 PVu)
- Bonne corrélation entre PV et le rapport de mélange d'ozone au voisinage de la tropopause
- Distribution horizontale de l'ozone sur des surfaces isentropes déduite des observations satellitales montrent des extremas identiques aux anomalies de PV

⇒ Une surface iso-PV peut donc être utilisée pour délimiter deux régions chimiquement différentes dans la haute troposphère/basse stratosphère

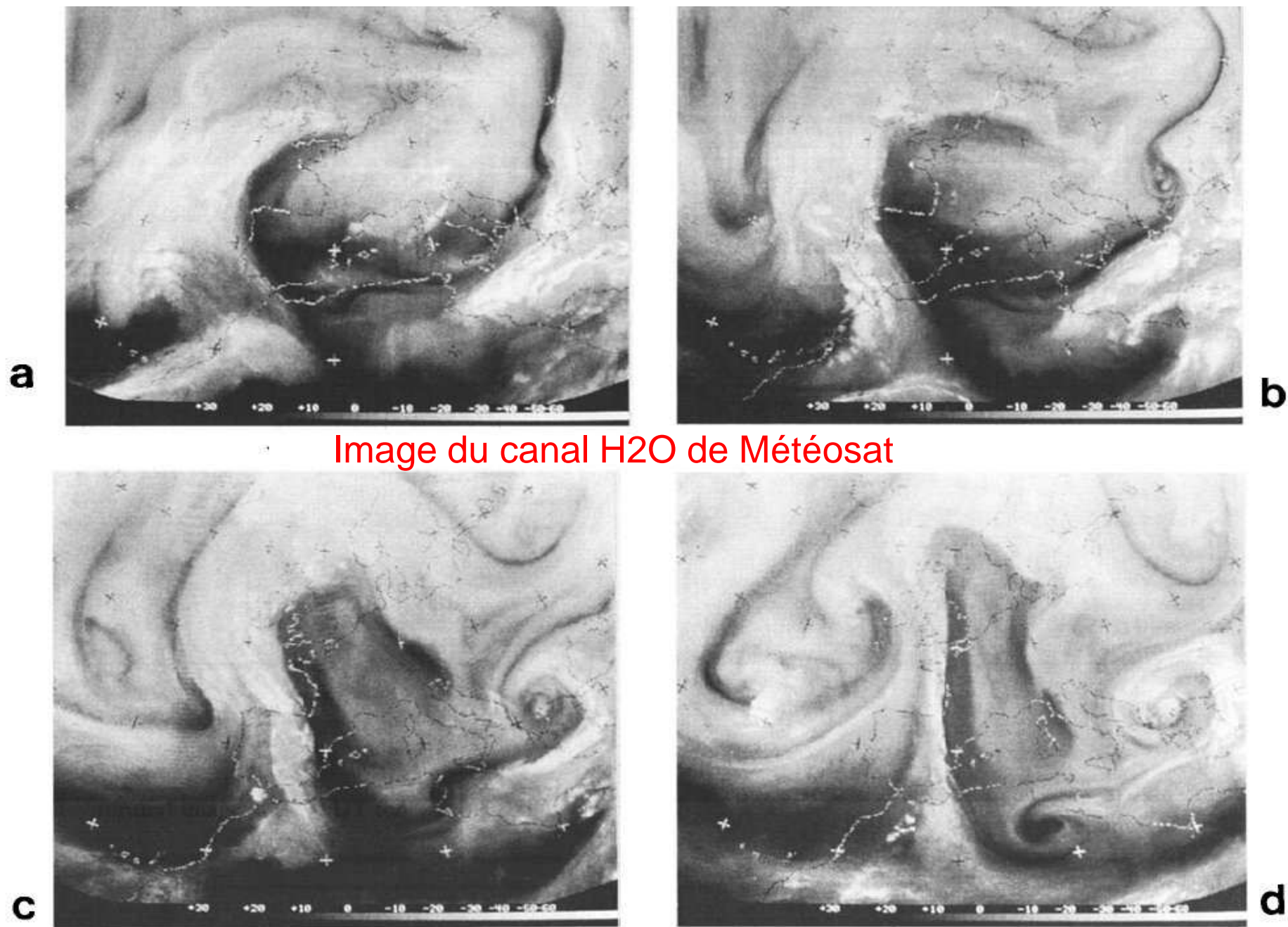


Image du canal H₂O de Météosat

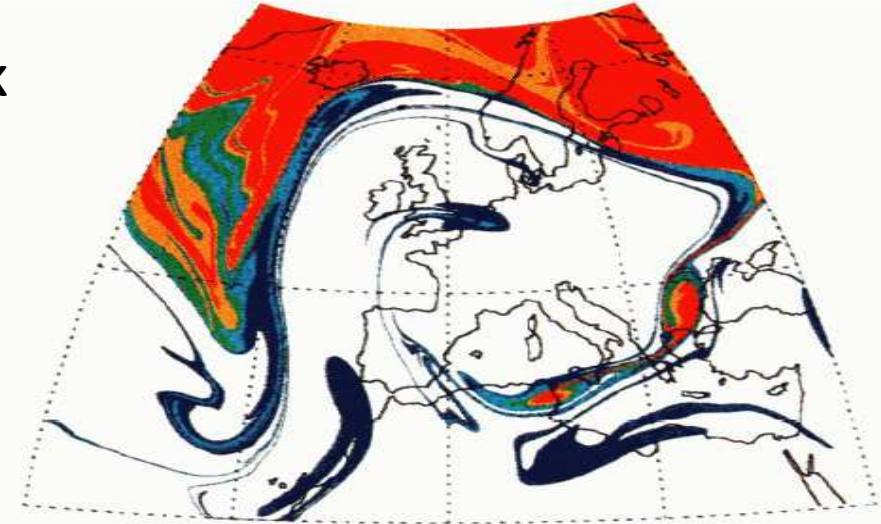
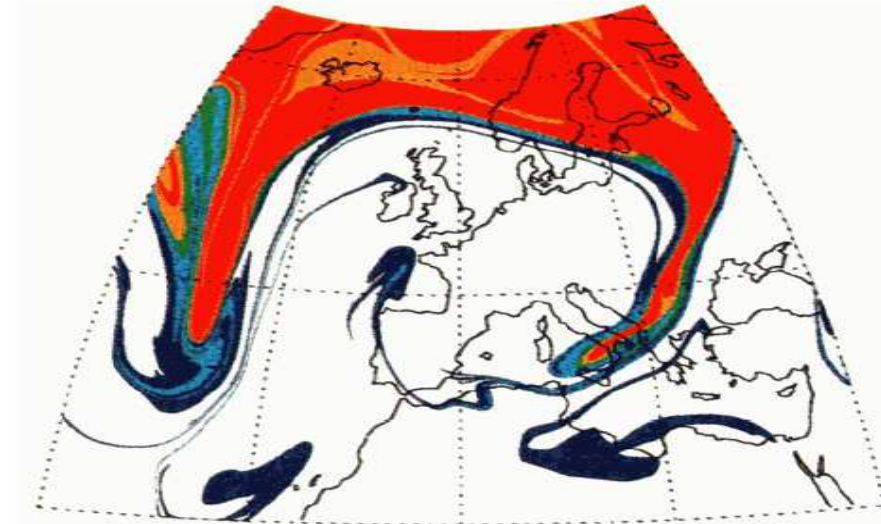
Figure 8. Satellite radiance images (compare Figure 3) at 12-hour intervals from 0000 UT, May 13, 1992 (compare panels for the same time periods as in Figure 7 and Plate 2).

Modèle d'advection des lignes iso-PV pour les images précédentes

DAY 92051300

DAY 92051312

320 K



DAY 92051400

DAY 92051412

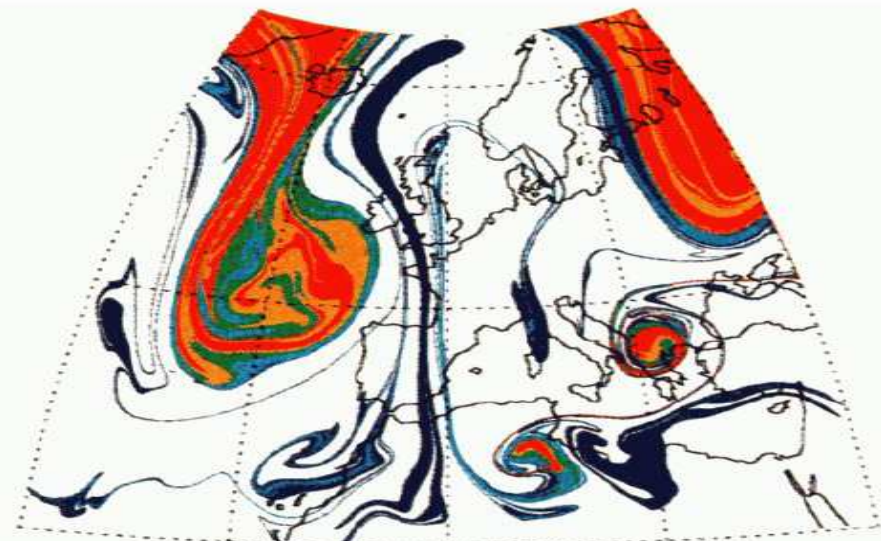
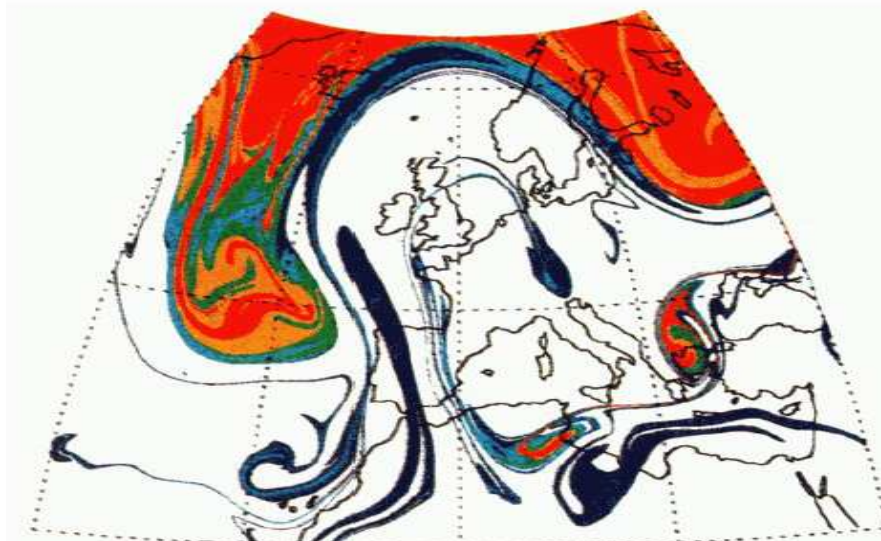


Plate 2. The pattern of select PV contours for the same four times and on the same isentropic surface as the panels in Figure 7, but derived using contour advection.

Limite de l'analogie PV/traceur (O3 ou autre)

1. PV s'annule à l'équateur et ne peut donc être utilisé pour définir la tropopause dans les tropiques. Il est alors remplacé par le gradient de température potentiel.
2. PV se modifie par chauffage diabatique ou frottement selon l'équation :

$$\rho \frac{dPV}{dt} = \overline{\nabla Q} \cdot \underbrace{[\overline{\nabla} \wedge \overline{V} + f\overline{k}]}_{\xi_a} + \overline{\nabla \theta} \cdot \overline{\nabla} \wedge \overline{F}$$

$$F = \text{Forces frottement} \propto \frac{dV}{dz}$$

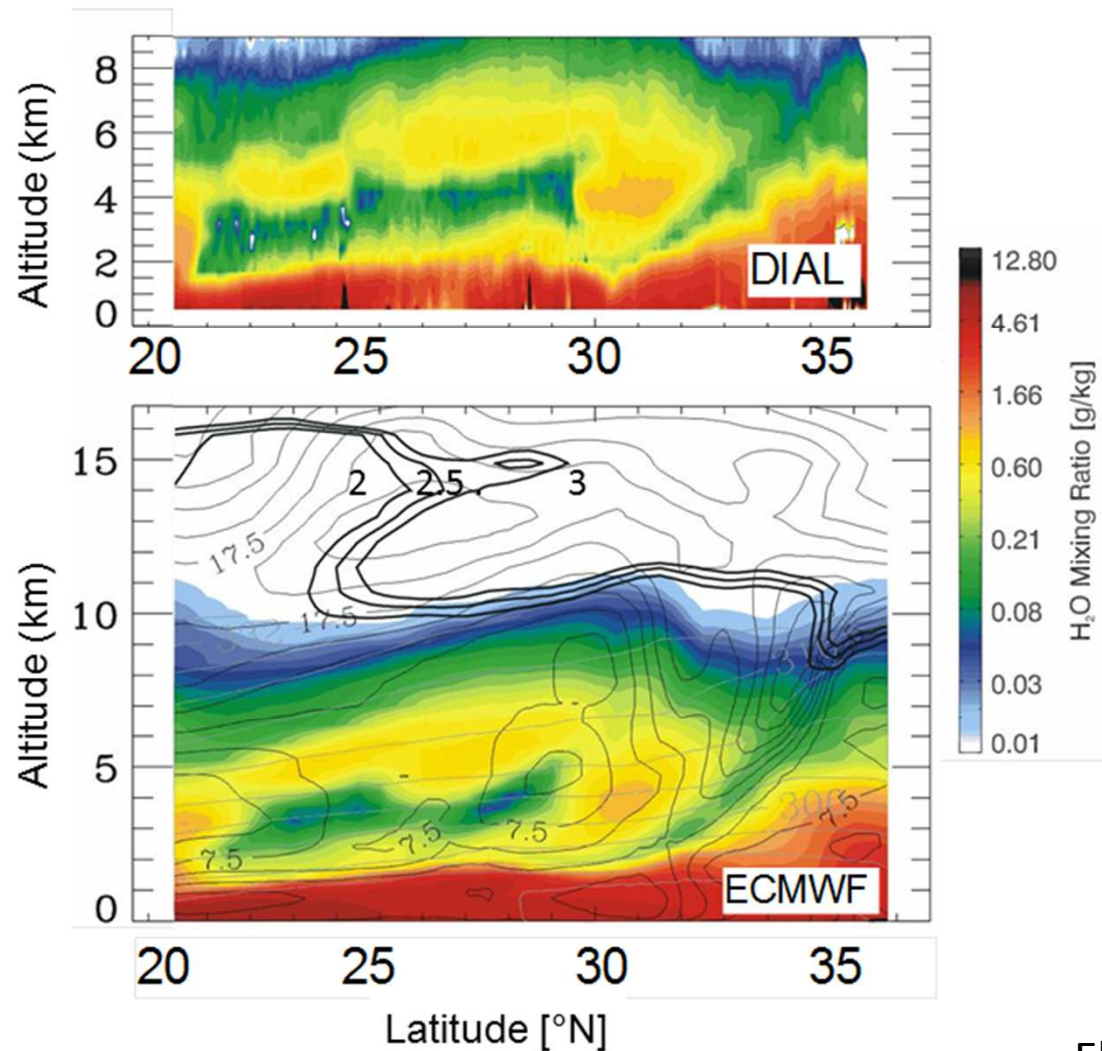
$$Q = \frac{d\theta}{dt} = \frac{J}{C_p T} \theta + Q_{\text{chaleur latente}}$$

J est le taux de chauffage radiatif par unité de masse et dépend du rayonnement solaire et IR absorbé par H₂O, O₃, CO₂, aerosol.

3. Le théorème d'imperméabilité du PV, noté \mathcal{P} : les surfaces isentropes sont perméables au transport de masse mais imperméables à celui de $\rho\mathcal{P}$ car le flux

→ Pas applicable à la troposphère, mais

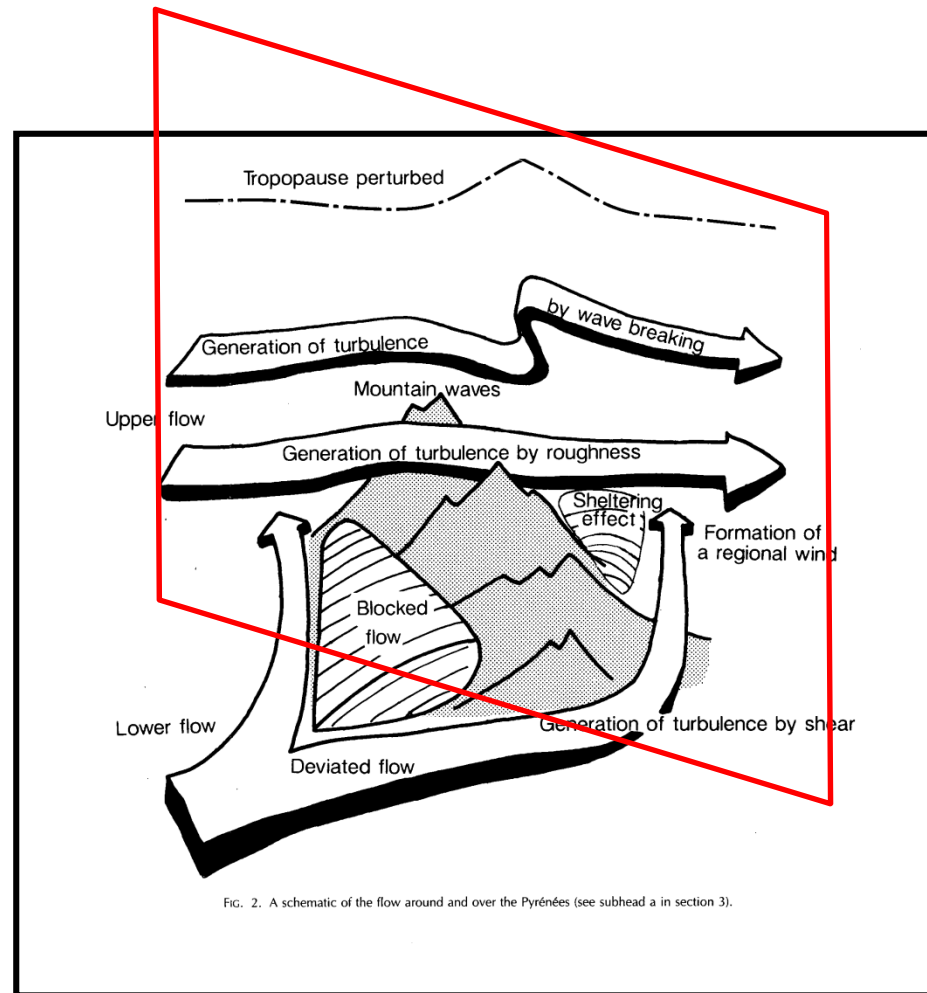
Dynamique associée aux foliations de tropopause (échanges troposphère-stratosphère)



Ehret et al., 1999

Etude des perturbations de l'écoulement atmosphérique

PYREX



(Bougeault et al, 1990)

Etude des perturbations de l'écoulement atmosphérique par les reliefs

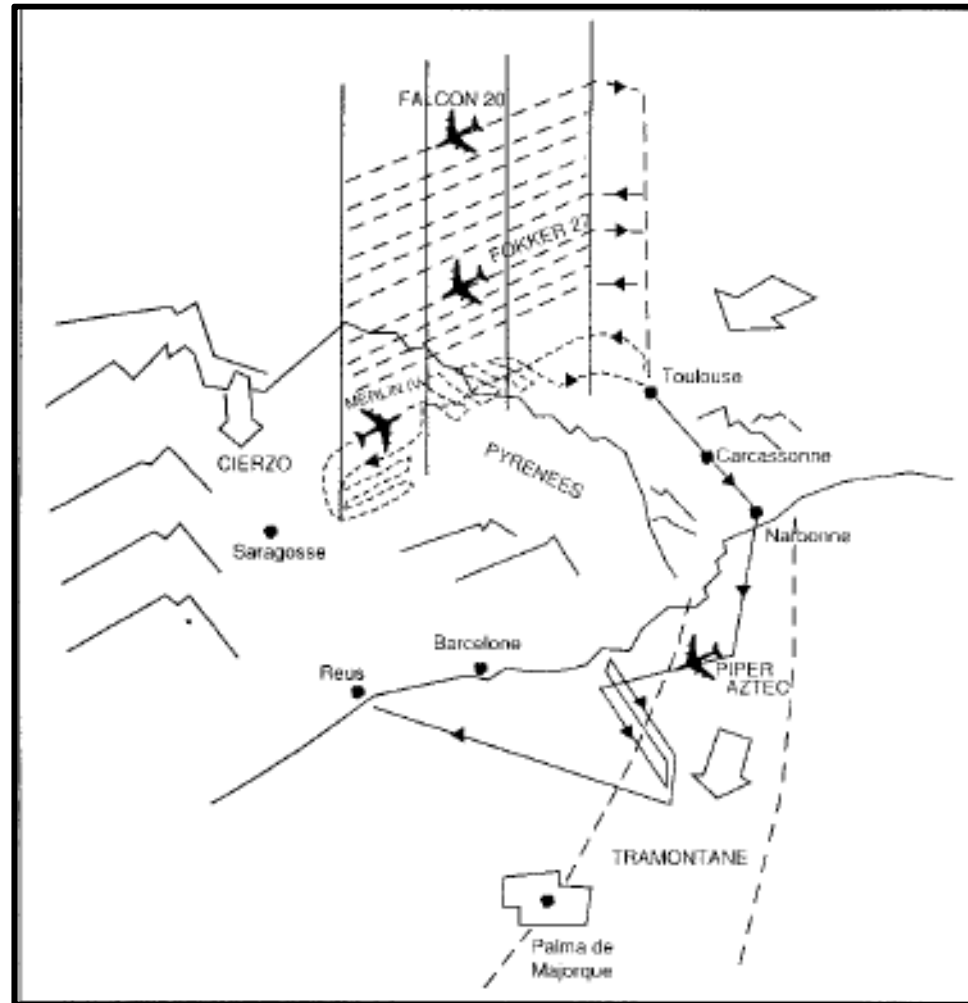


FIG. 2. An example of coordinated flights during a wave IOP with northerly synoptic flow.

Etude des perturbations de l'écoulement atmosphérique par les reliefs

$$\frac{\partial \widetilde{\rho u^2}}{\partial t} = - \frac{\partial \widetilde{\rho u^2}}{\partial x} - \frac{\partial \widetilde{\rho u v}}{\partial y} - \overline{\rho u w (Z_T)} + \overline{\rho u w (h)} - \frac{\partial \bar{p}}{\partial x} + \overline{\rho f \bar{v}} - \overline{\rho (h) \frac{\partial h}{\partial x}} \quad (2)$$

(a) (b) (c) (d) (e) (f)

Equation 2 offers an opportunity to discuss the different quantities that need to be determined, either directly (measurements) or indirectly (mesoscale models). Those are (a) the lateral advection of momentum at the boundaries; (b) the flux of momentum at the top (which classically is decomposed into a wave part and a turbulent part); (c) the flux at the lower boundary (which is, in principle, a turbulent flux); (d) the mean pressure gradient; (e) the Coriolis force; and (f) the pressure drag at the ground.

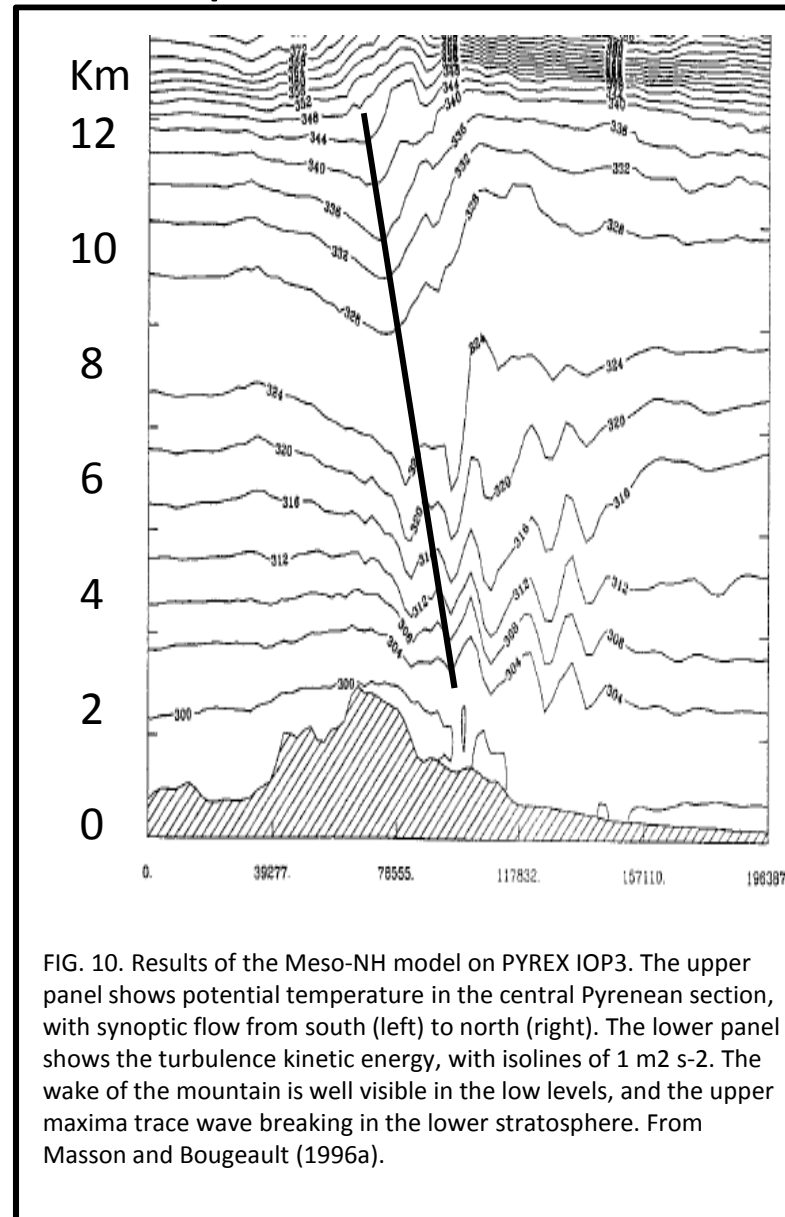
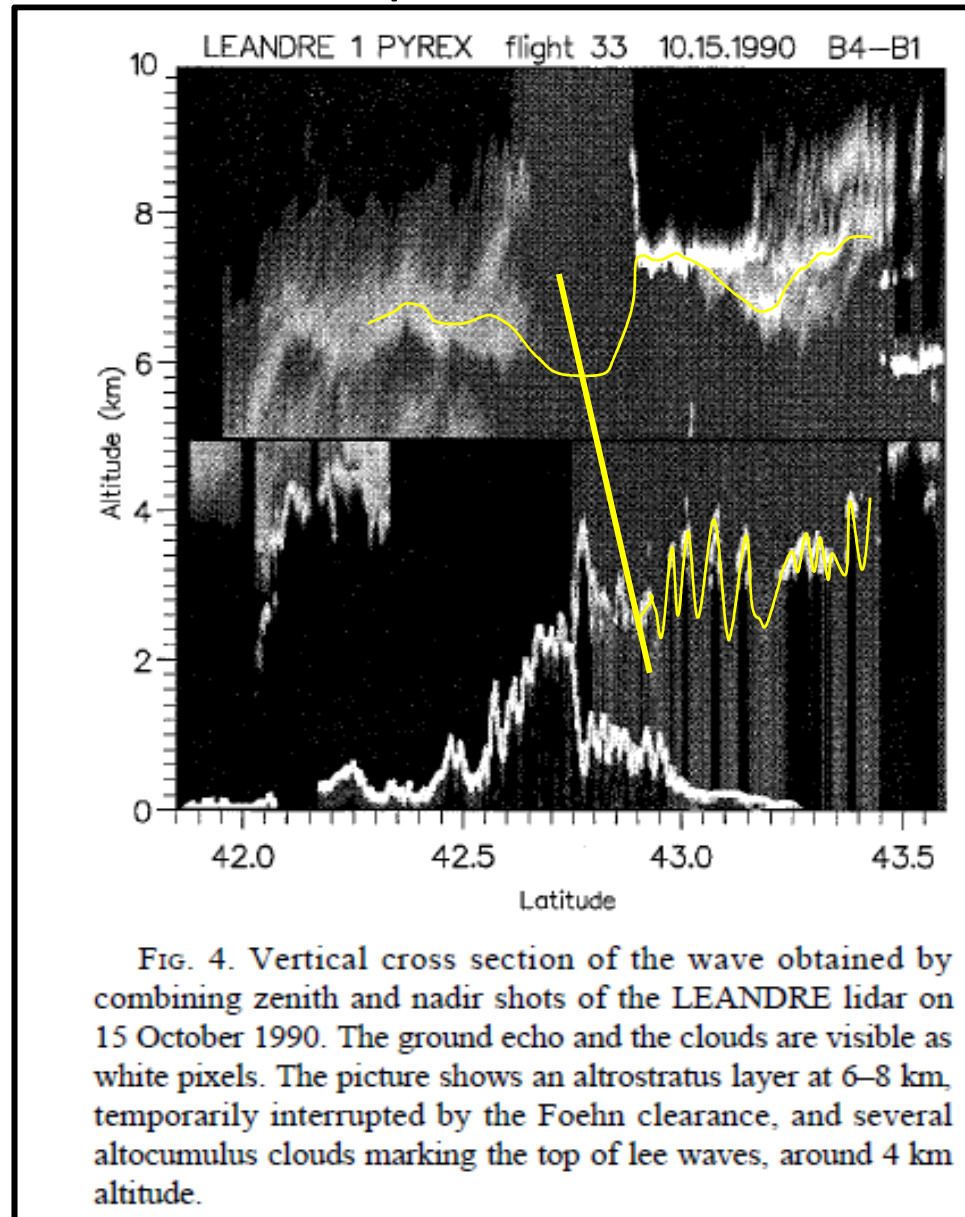


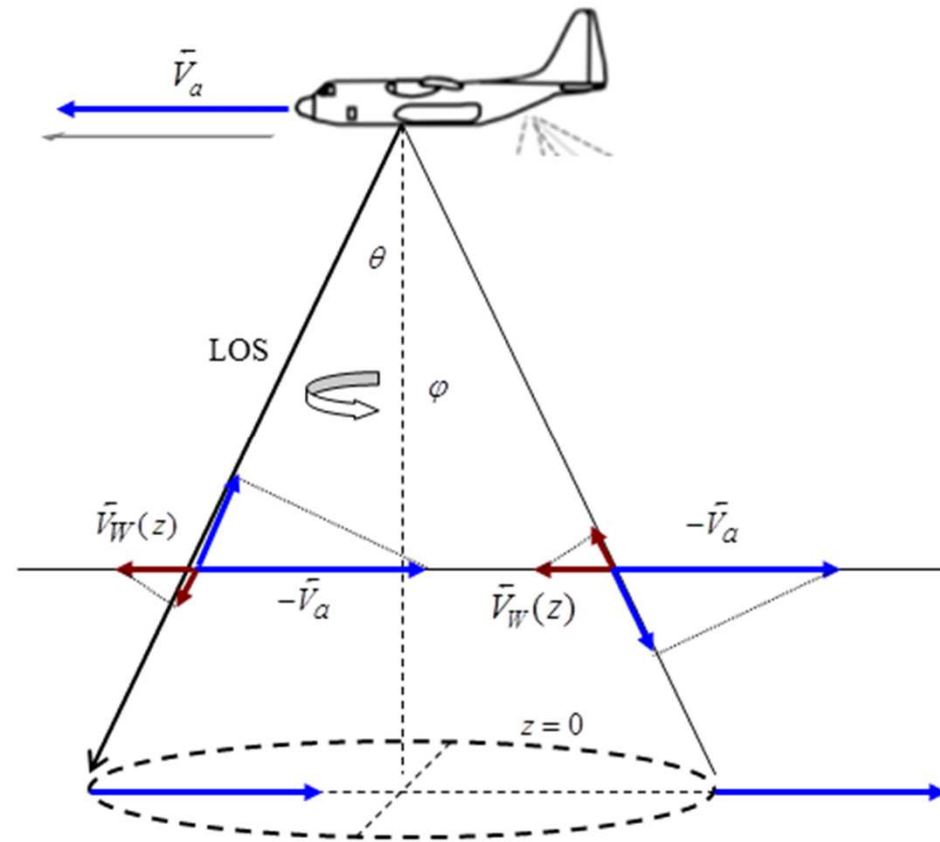
FIG. 10. Results of the Meso-NH model on PYREX IOP3. The upper panel shows potential temperature in the central Pyrenean section, with synoptic flow from south (left) to north (right). The lower panel shows the turbulence kinetic energy, with isolines of 1 m² s⁻². The wake of the mountain is well visible in the low levels, and the upper maxima trace wave breaking in the lower stratosphere. From Masson and Bougeault (1996a).

Etude des perturbations de l'écoulement atmosphérique par les reliefs

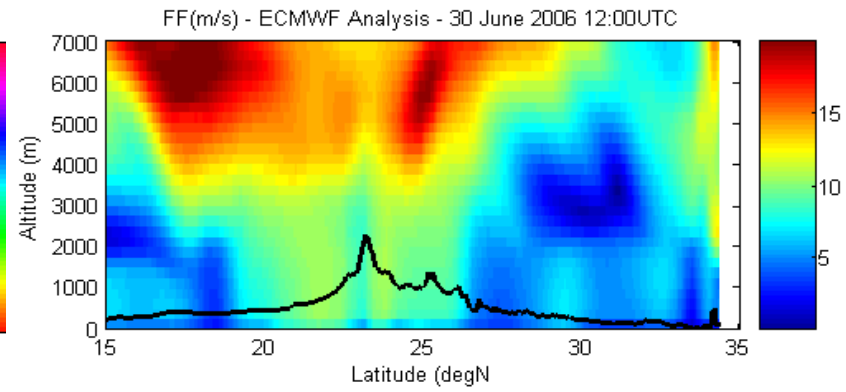
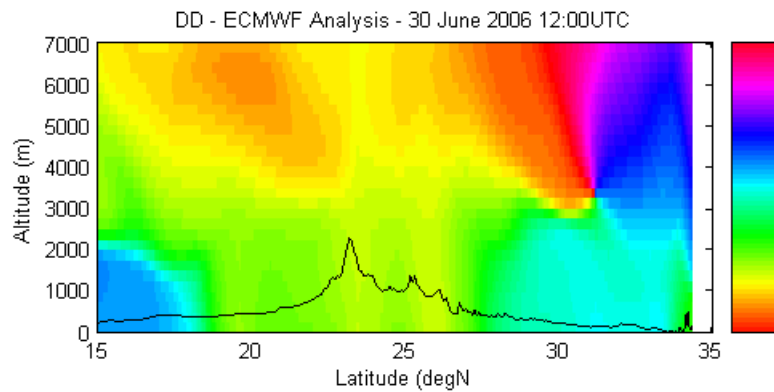
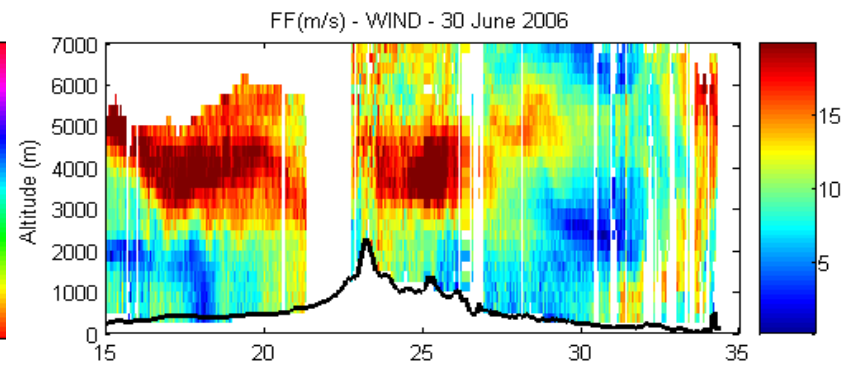
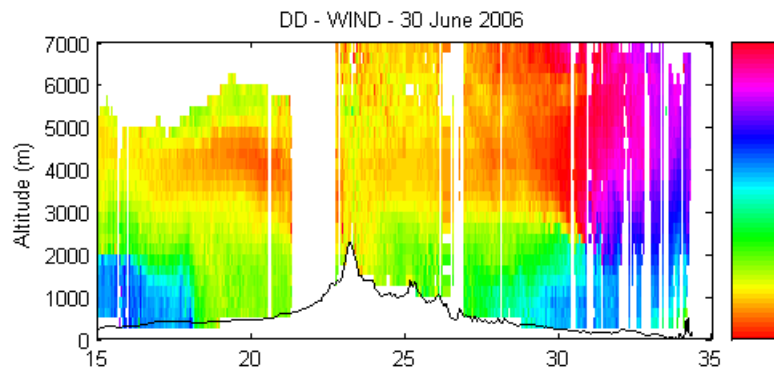


Bougeault et al, 1997

LA MESURE DE VENT et de TURBULENCE



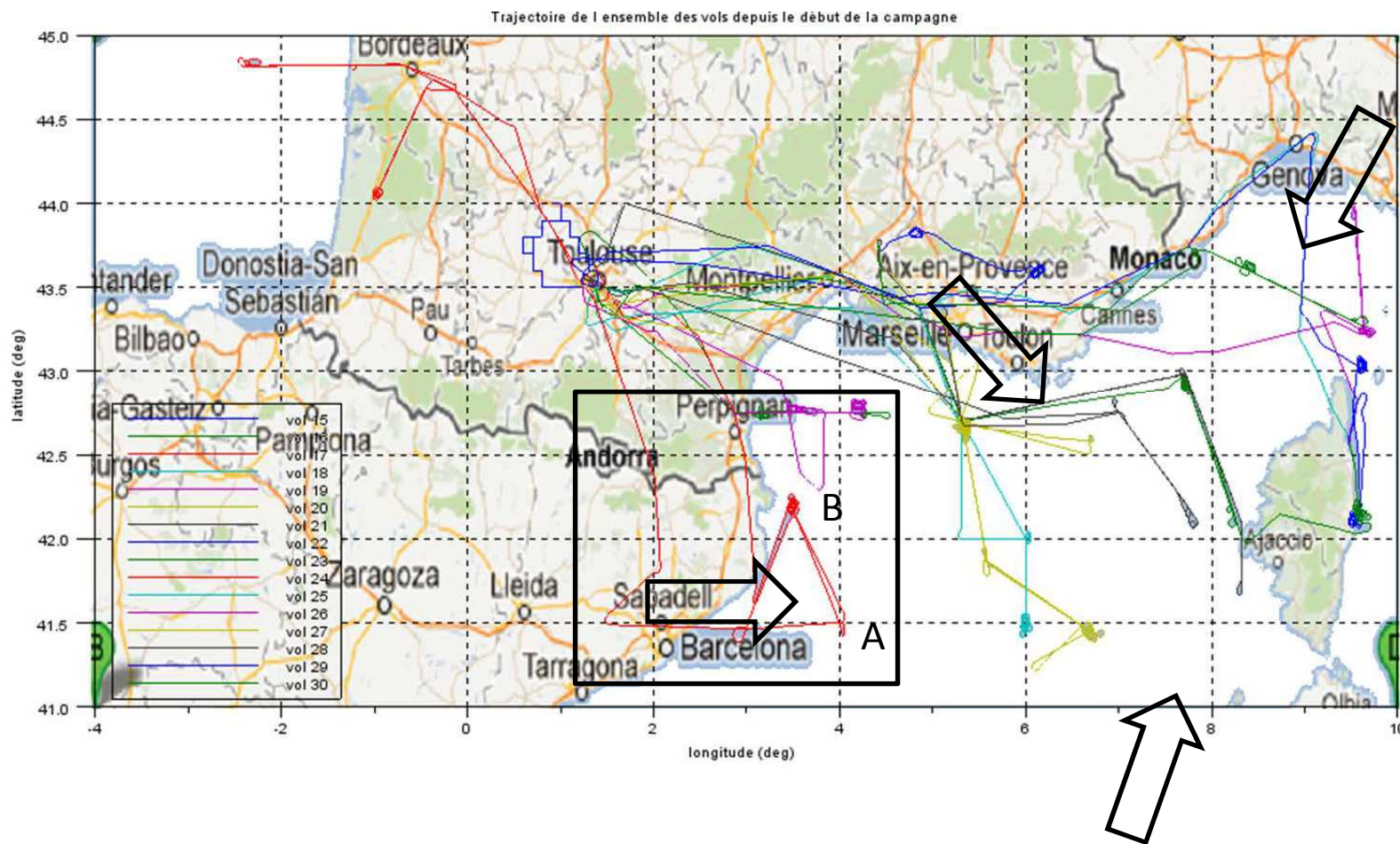
LE LIDAR AEROPORTE WIND (DLR-CNRS)



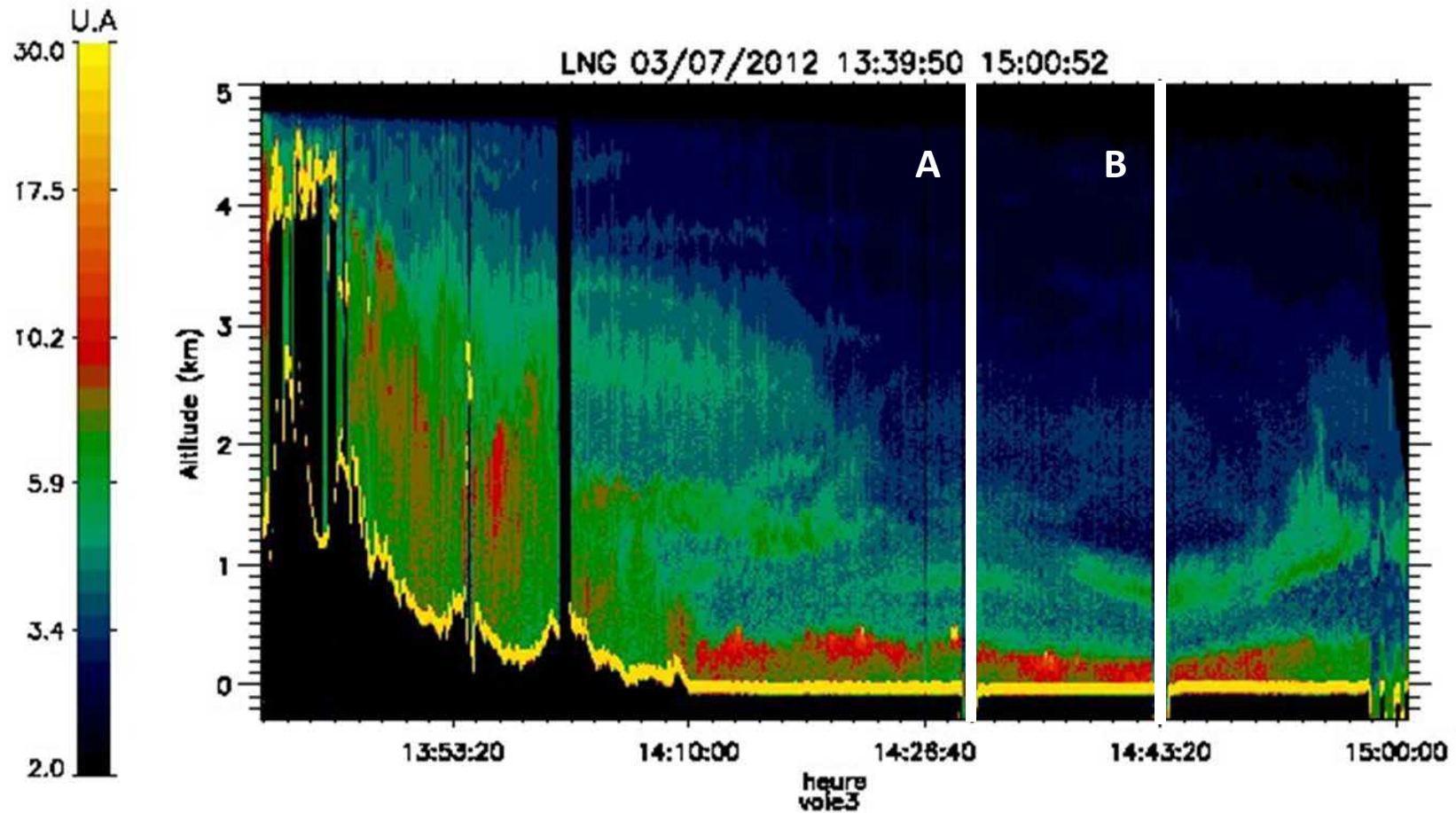
Campagne MAP

Reitebuch et al., 2003

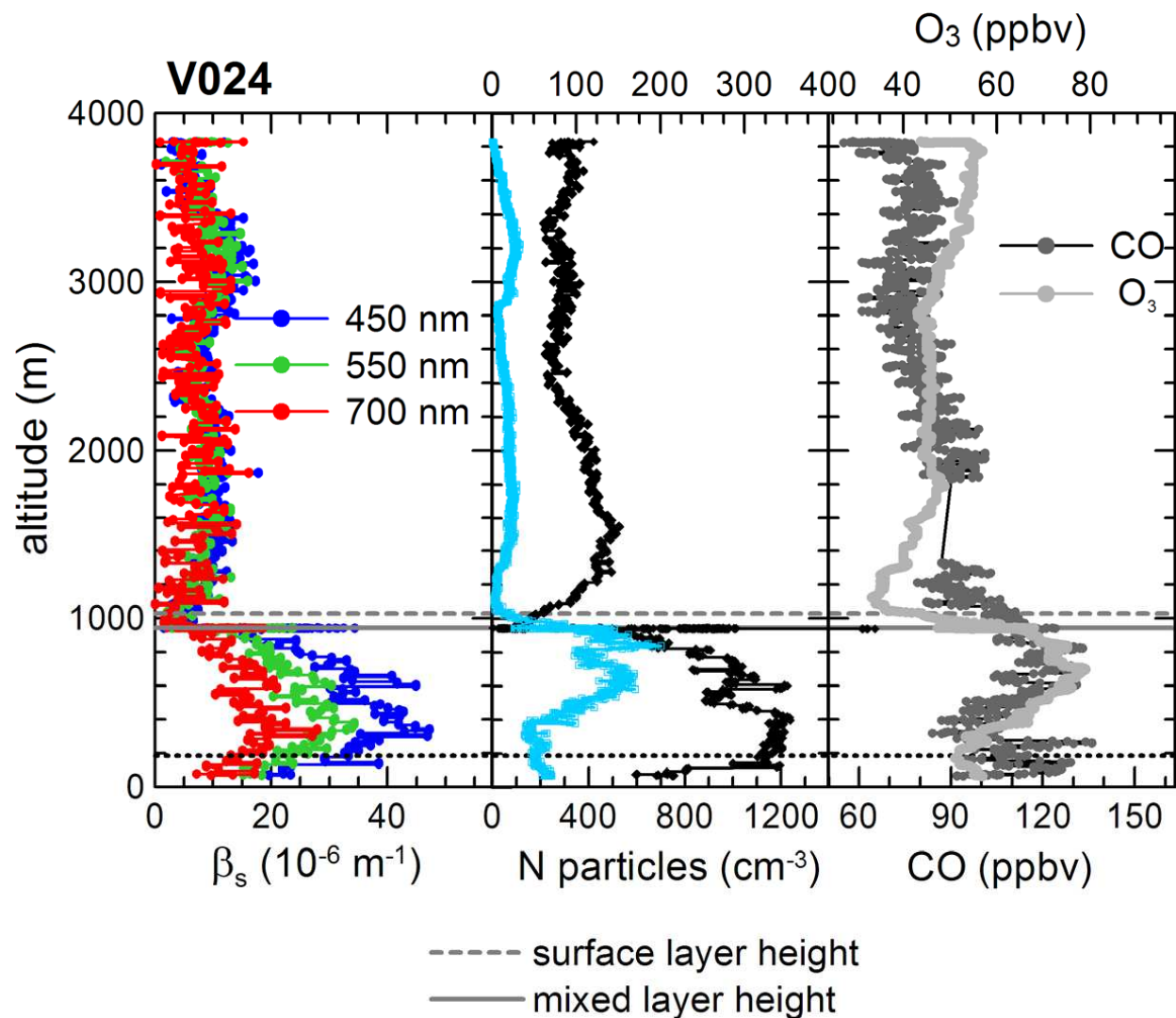
Etude des sources de pollution sur le bassin Méditerranéen : recirculations atmosphériques induites par les reliefs (TRAQA2012)



Etude des sources de pollution sur le bassin Méditerranéen : recirculations atmosphériques induites par les reliefs (TRAQA)

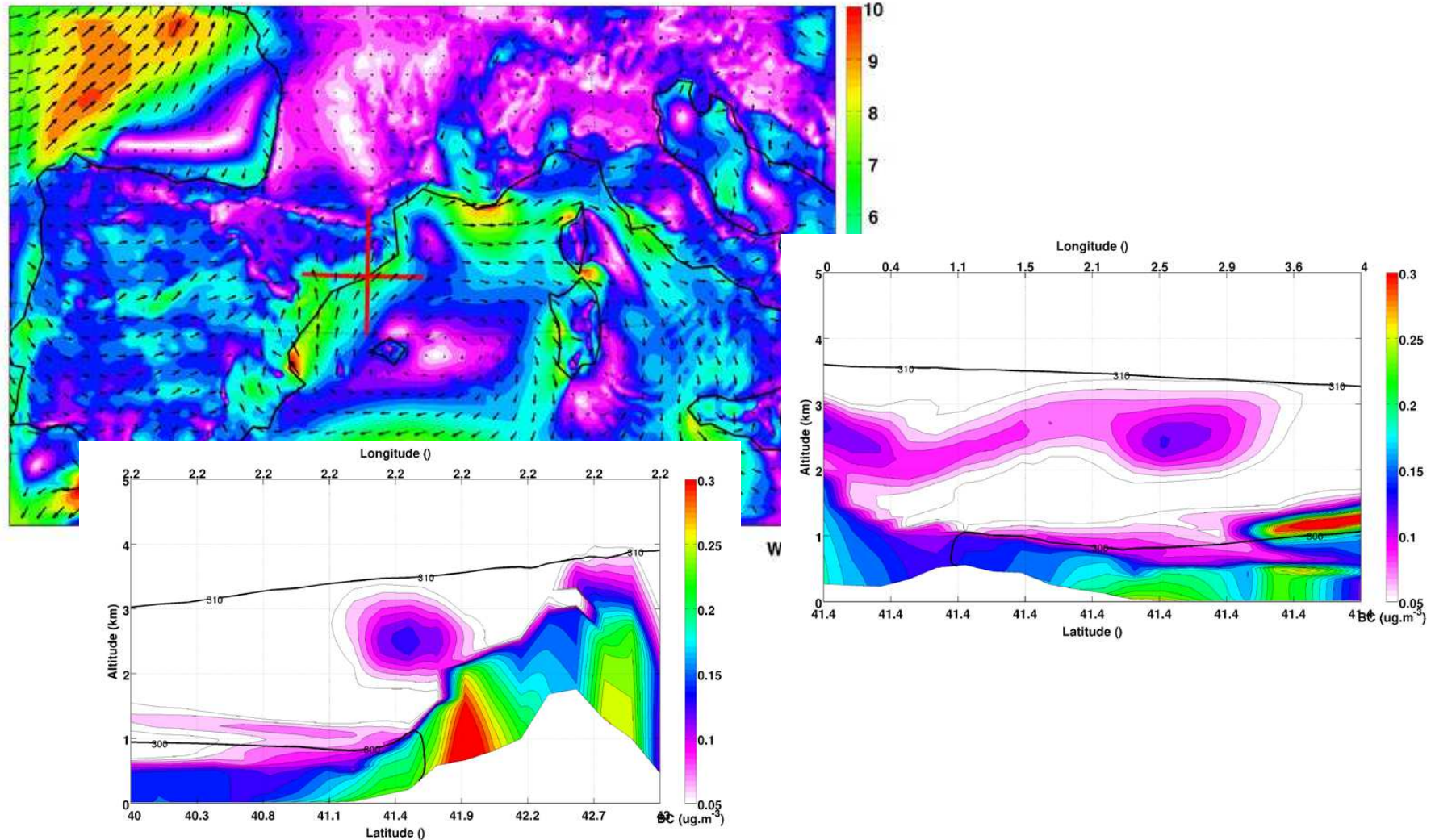


Etude des sources de pollution sur le bassin Méditerranéen : recirculations atmosphériques induites par les reliefs (TRAQA)

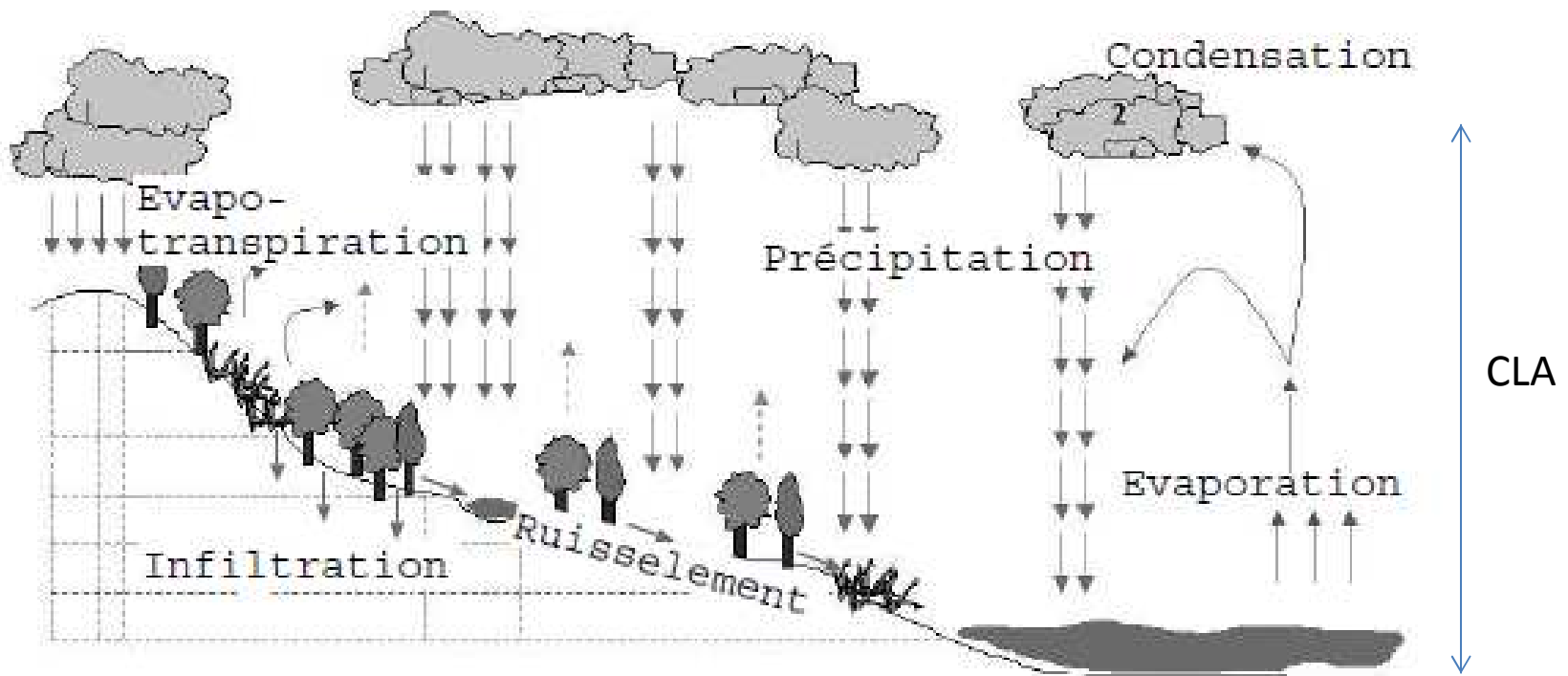


Etude des sources de pollution sur le bassin Méditerranéen : recirculations atmosphériques induites par les reliefs (TRAQA)

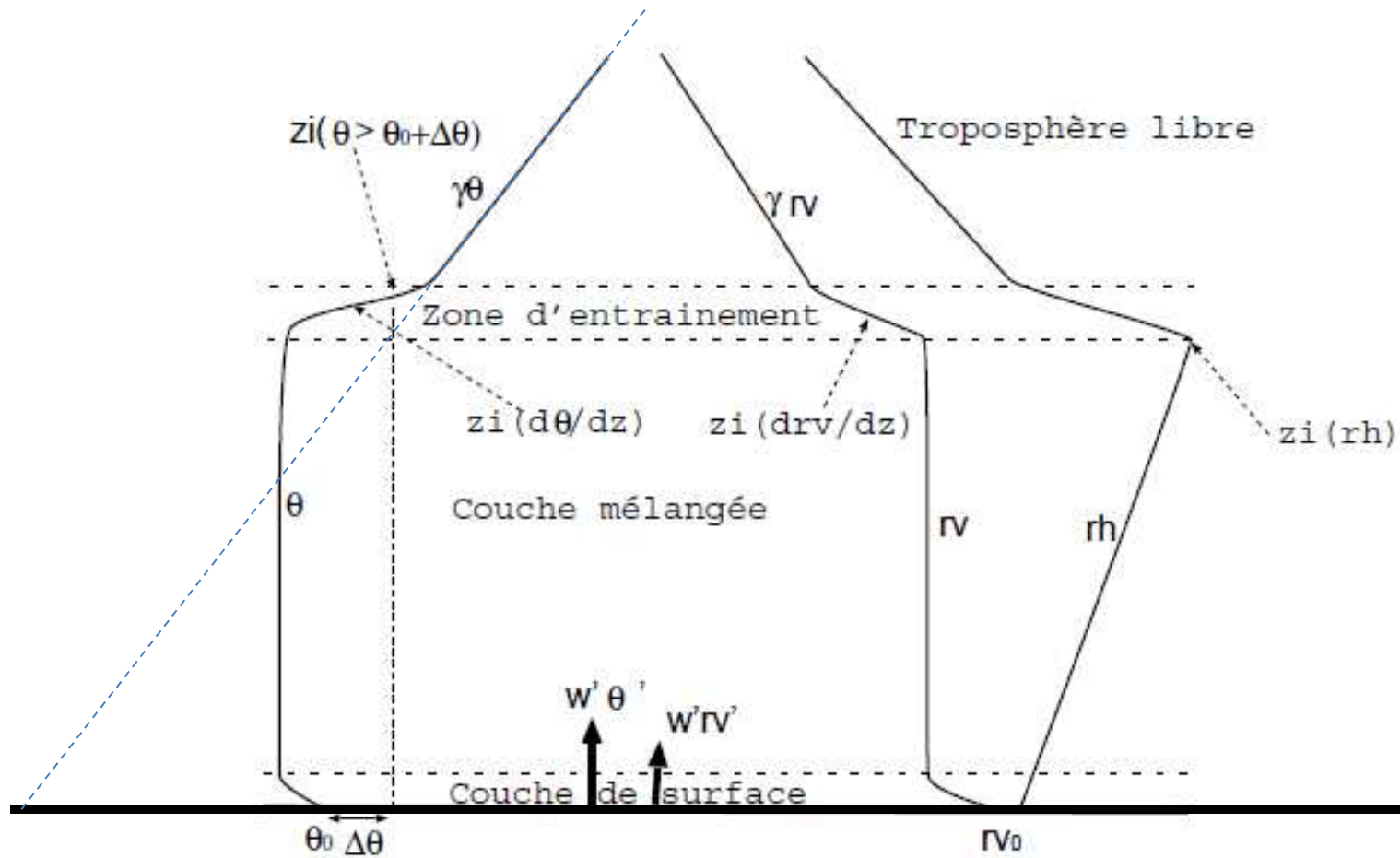
2012-07-03_14:00:00



Cycle de l'eau à plus petite échelle : la couche limite en interaction avec la surface

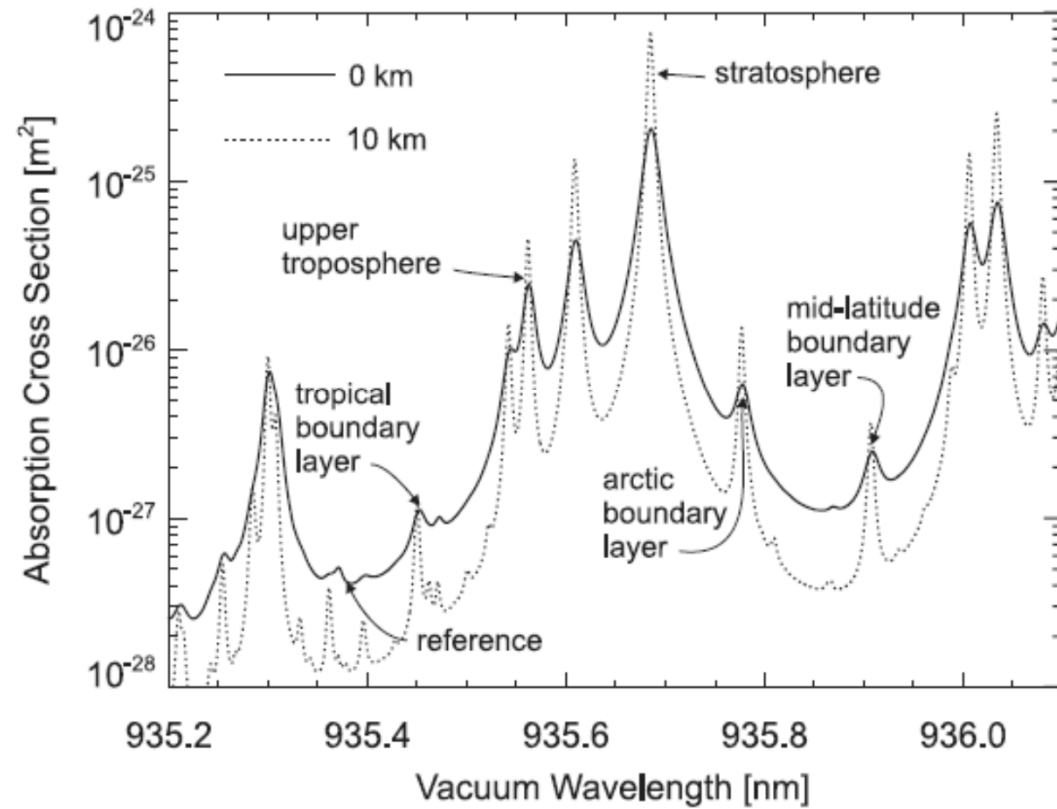


Modèle simplifié de couche limite convective

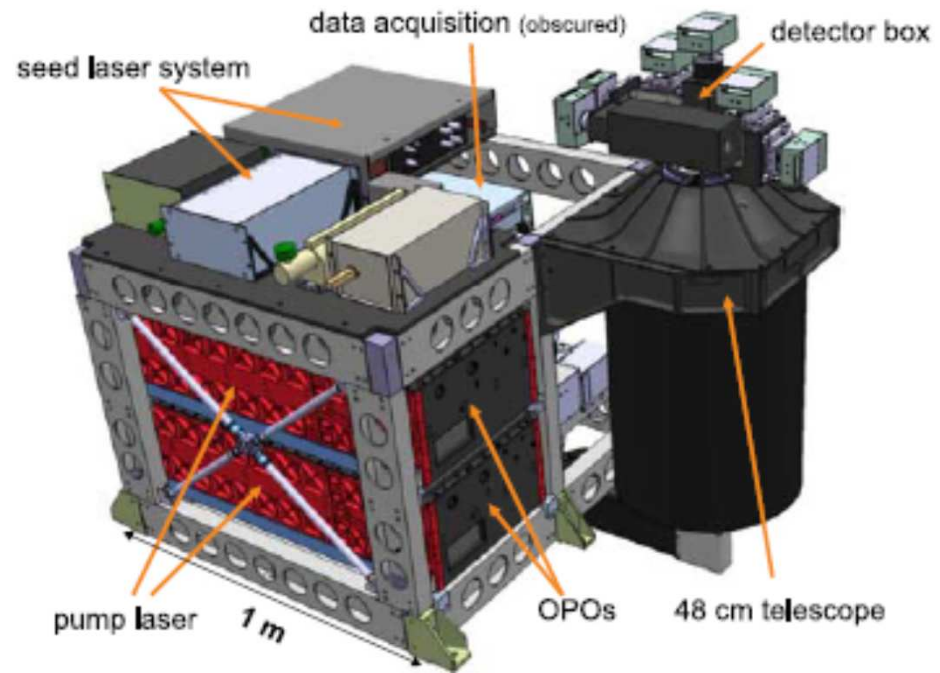
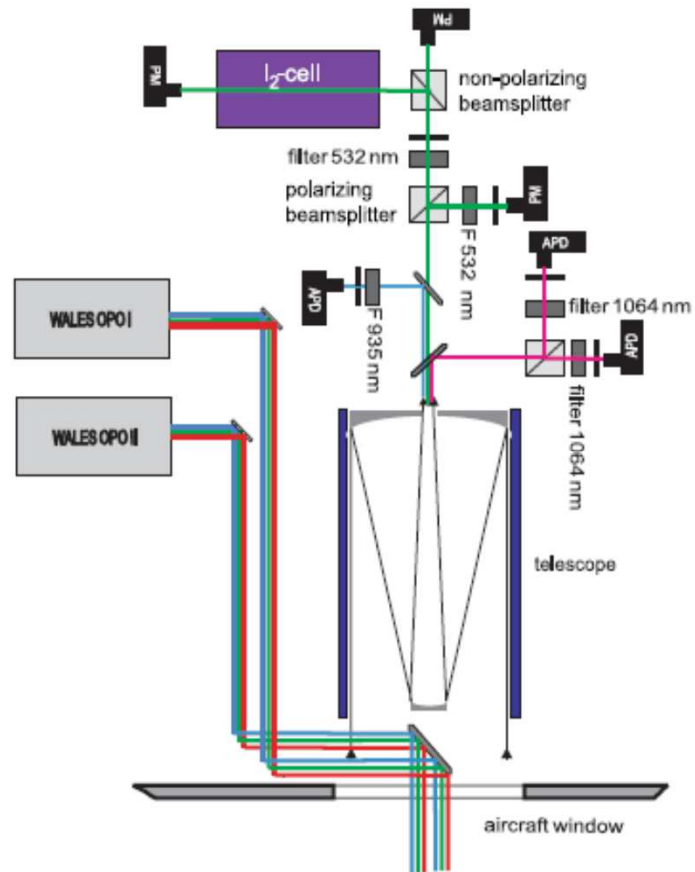


Mesure DIAL H2O

$$X_{\text{gas}} = \frac{\ln\left(\frac{P_{\text{off}}(p_{\text{surf}})/E_{\text{off}}}{P_{\text{on}}(p_{\text{surf}})/E_{\text{on}}}\right)}{2 \int_{P_{\text{aircraft}}}^{P_{\text{surf}}} \frac{\sigma(\lambda_{\text{on}}, p, T) - \sigma_{\text{off}}(\lambda_{\text{off}}, p, T)}{g \cdot M_{\text{air}}} dp}$$

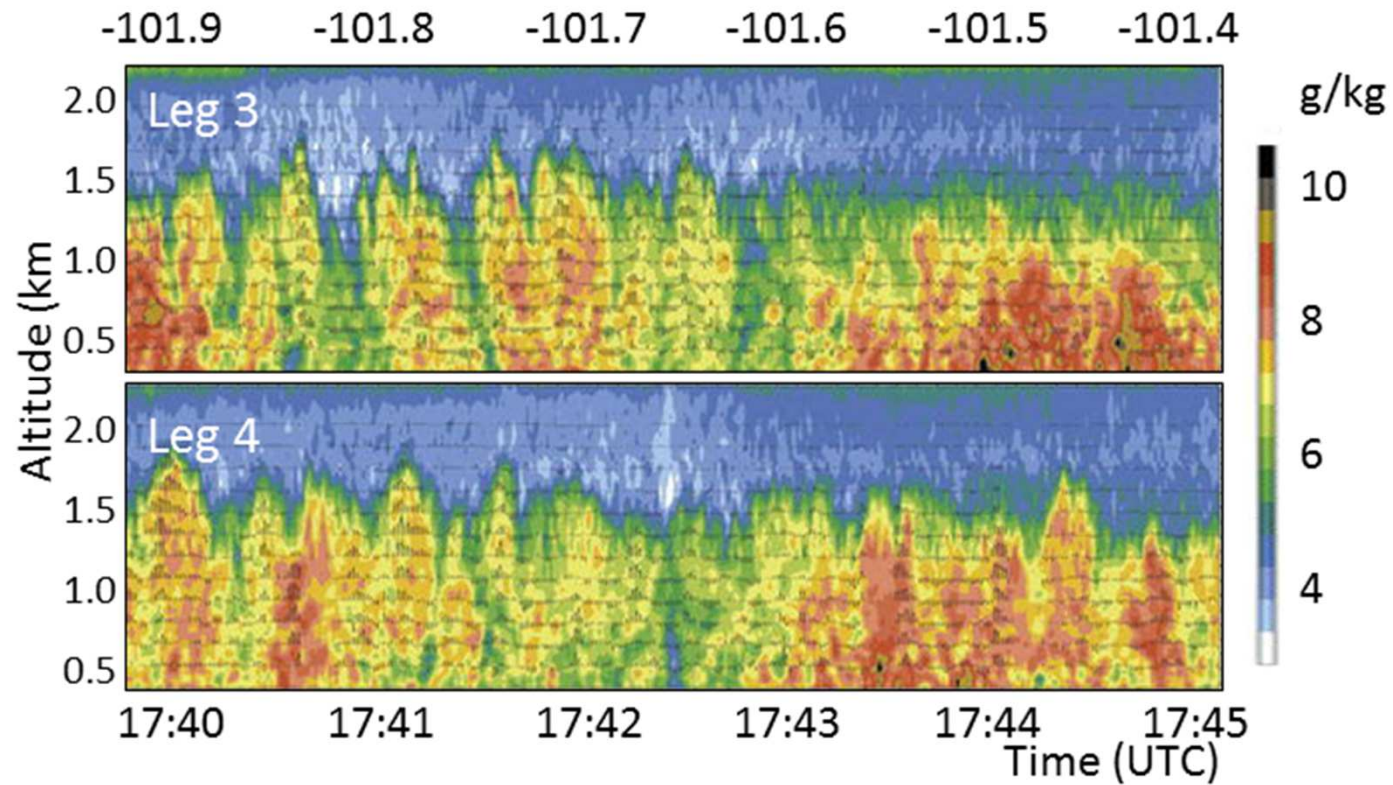


LA MESURE DIAL DE H2O (DLR)



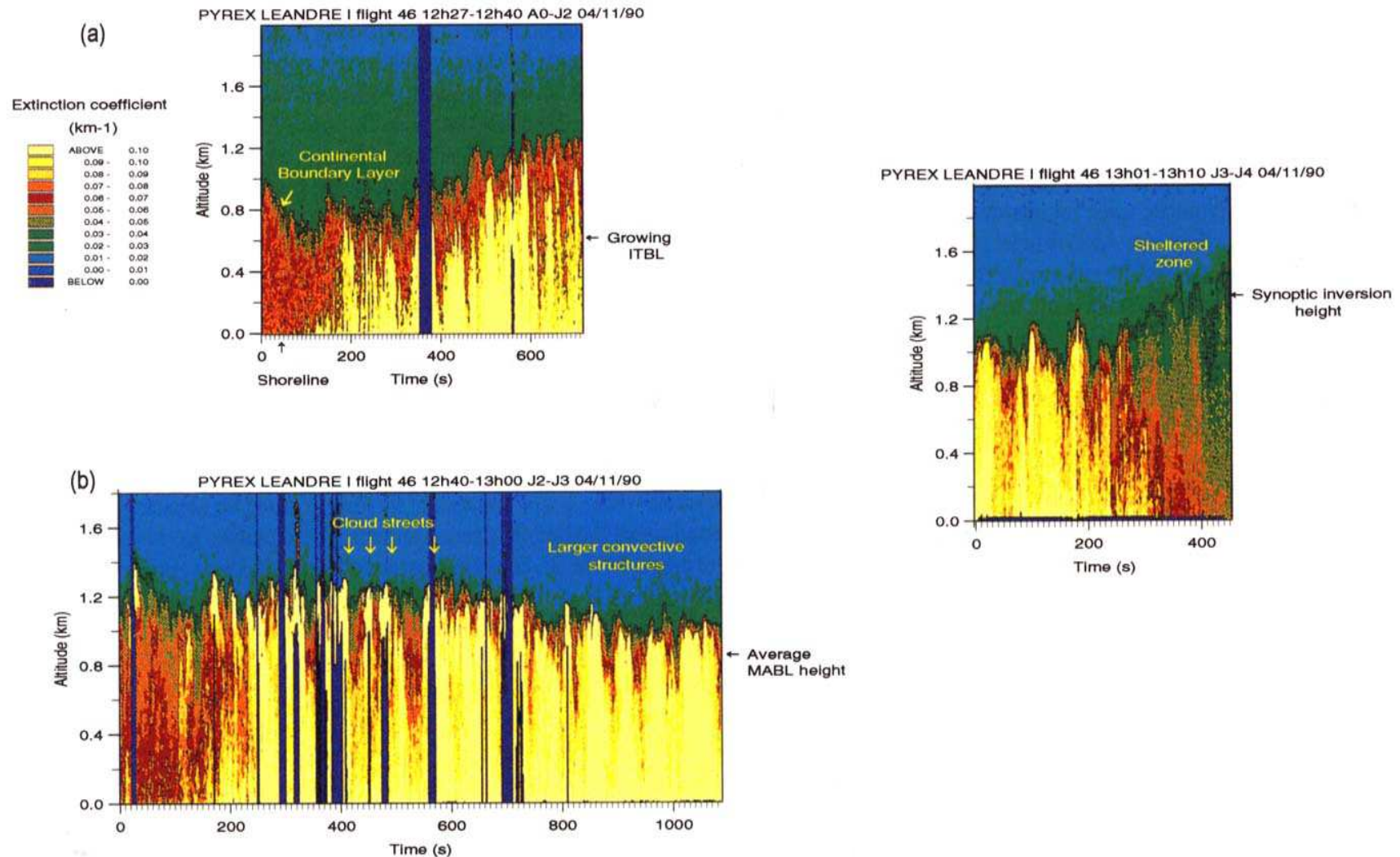
Etude de la couche limite

Structure et flux de surface



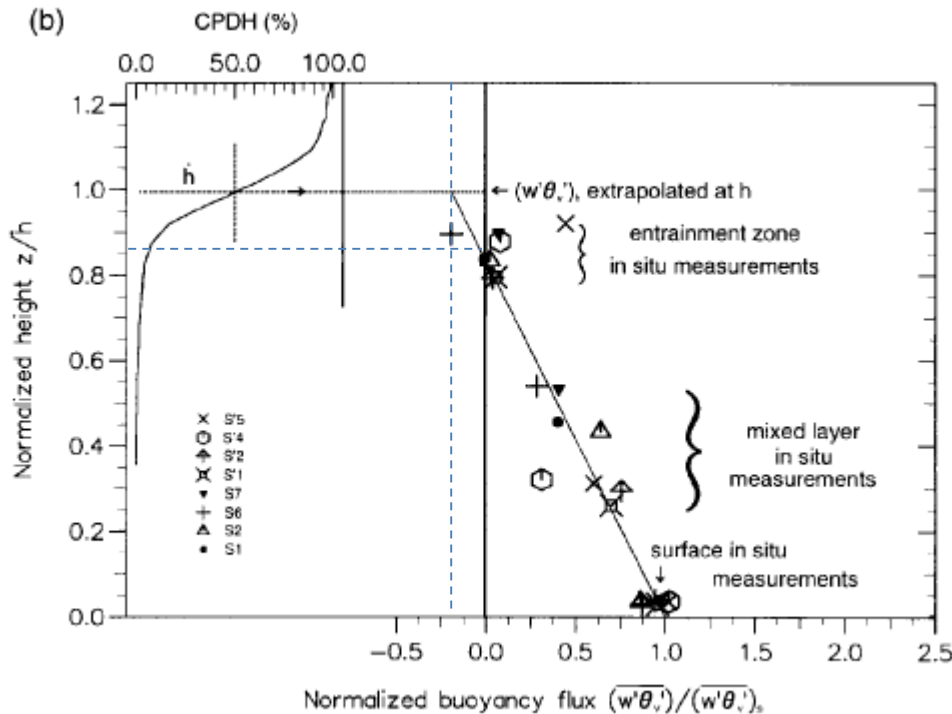
Etude des perturbations de l'écoulement atmosphérique

Structure et flux de surface : « cold air outbreaks » (PYREX)



Etude de l'écoulement la couche limite

Structure et dynamique moyenne échelle (PYREX)



Etude de l'écoulement la couche limite

Structure et dynamique moyenne échelle (PYREX)

Partie turbulente

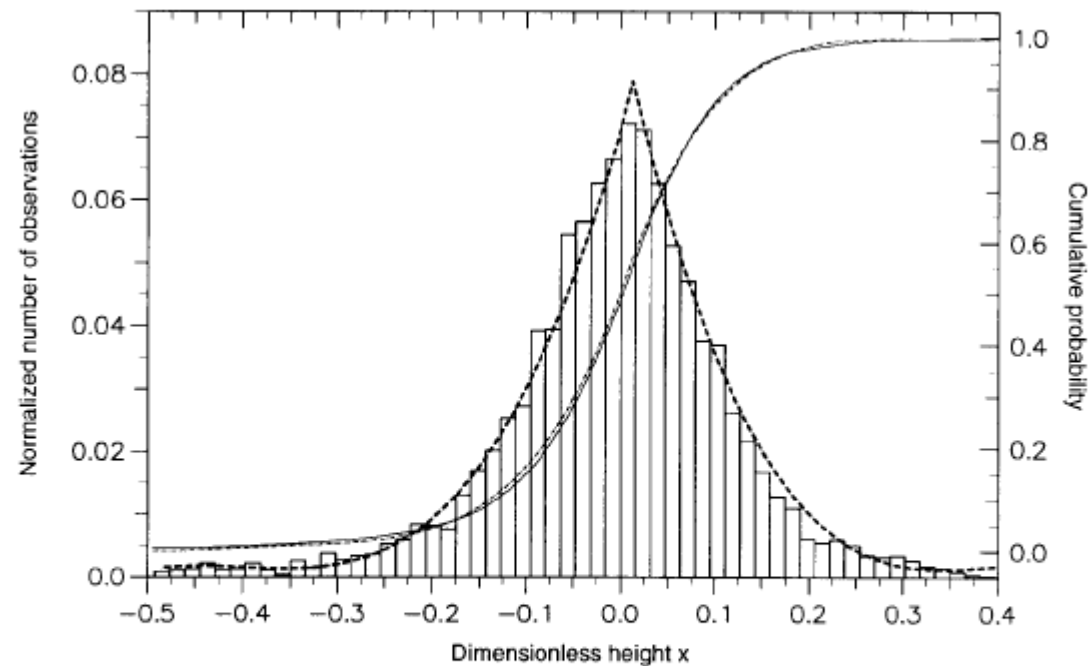


Figure 7. Frequency distribution of detrended IUBLHs, summed over the 11 segments, as a function of dimensionless height x . The solid curve represents CPDH associated with the observations. The two dashed curves correspond to the modelled CPDH (described by Equation (4)) and the modelled IUBLH distribution.

La couche limite en interaction avec la surface océanique

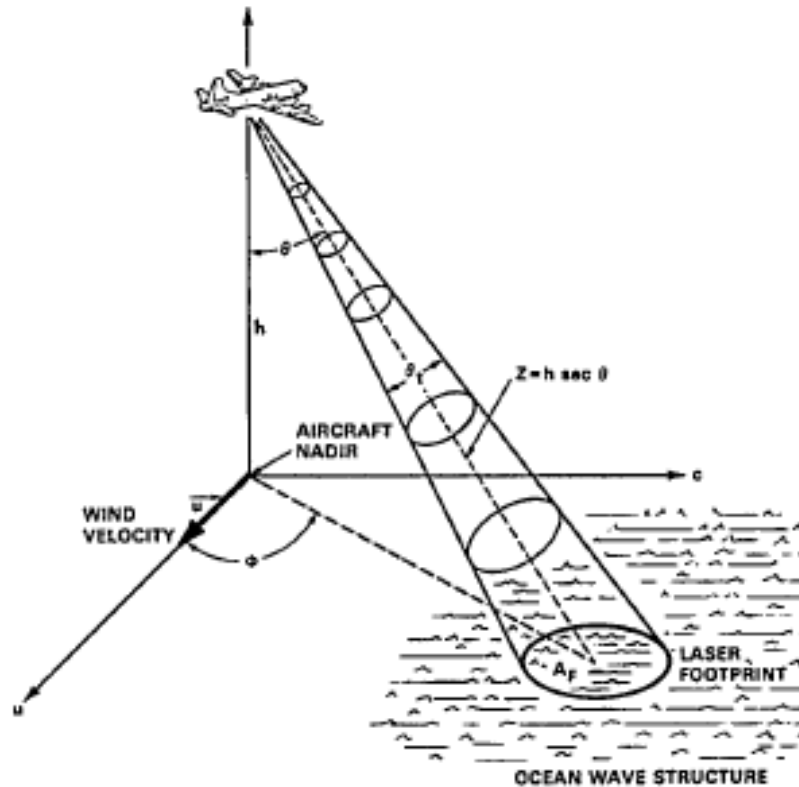
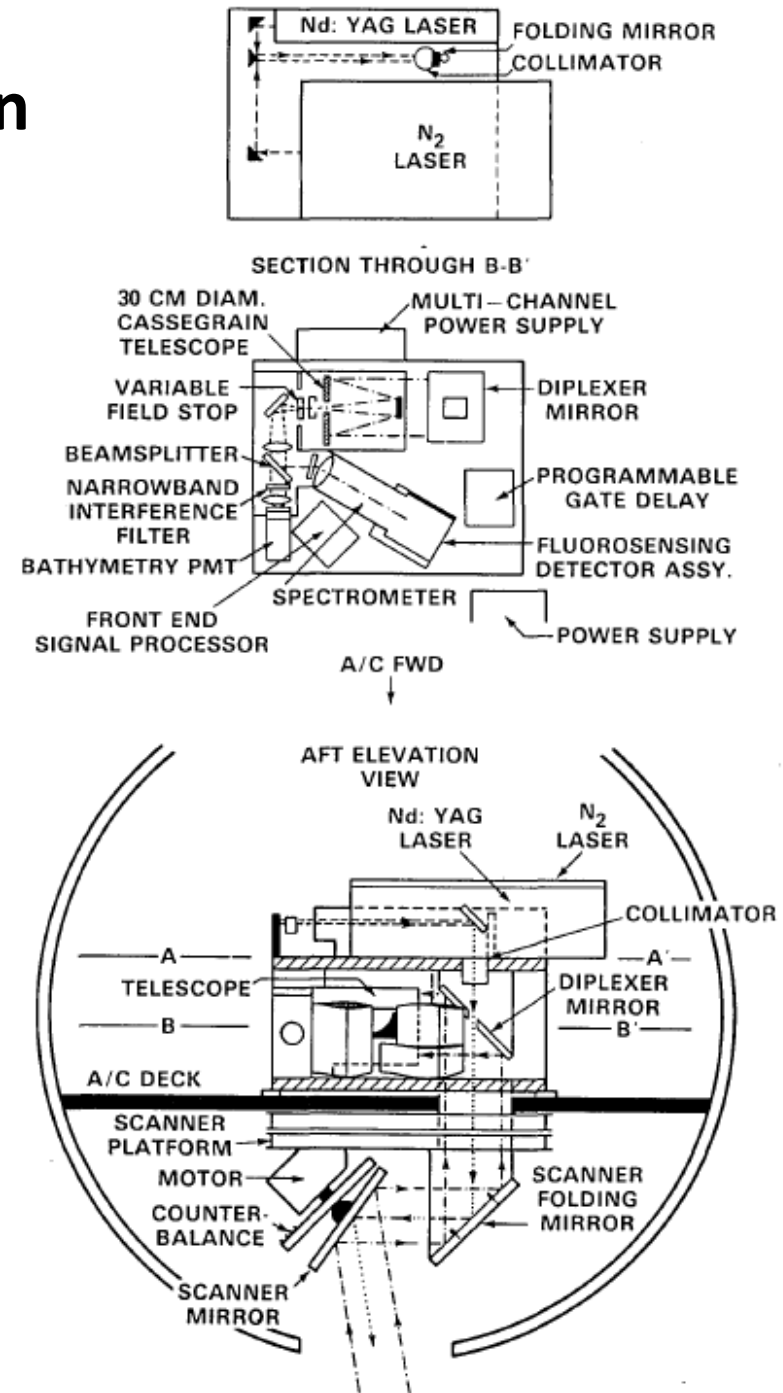


Fig. 1. Lidar backscatter measurement geometry.

Détermination du vent de surface
 Bufton, 1983



Surface océanique

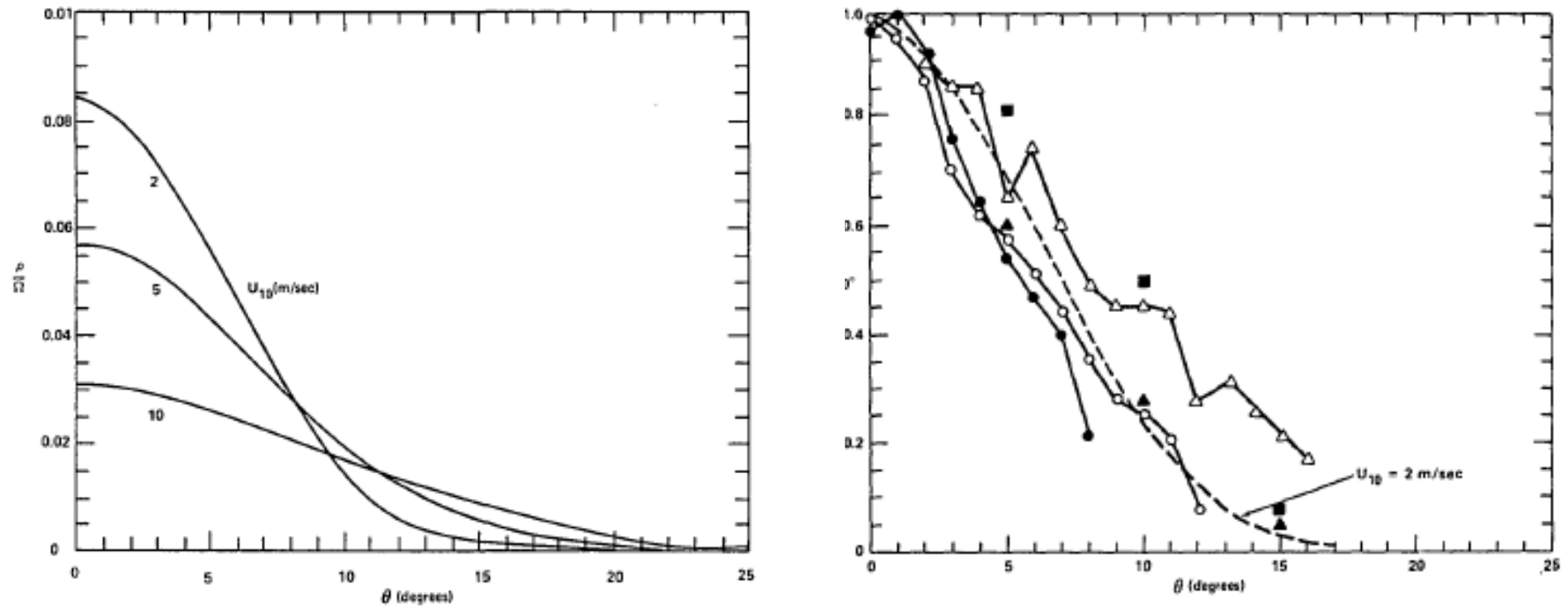
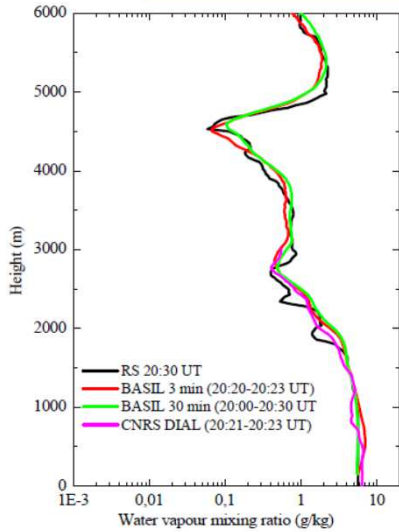


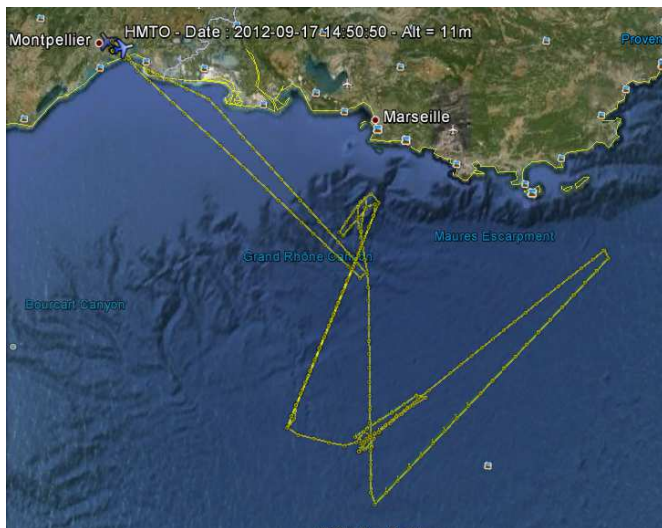
Fig. 2. Theoretical mean backscatter factor ρ/Ω of Eq. (12) vs off-nadir angle θ .

HyMeX

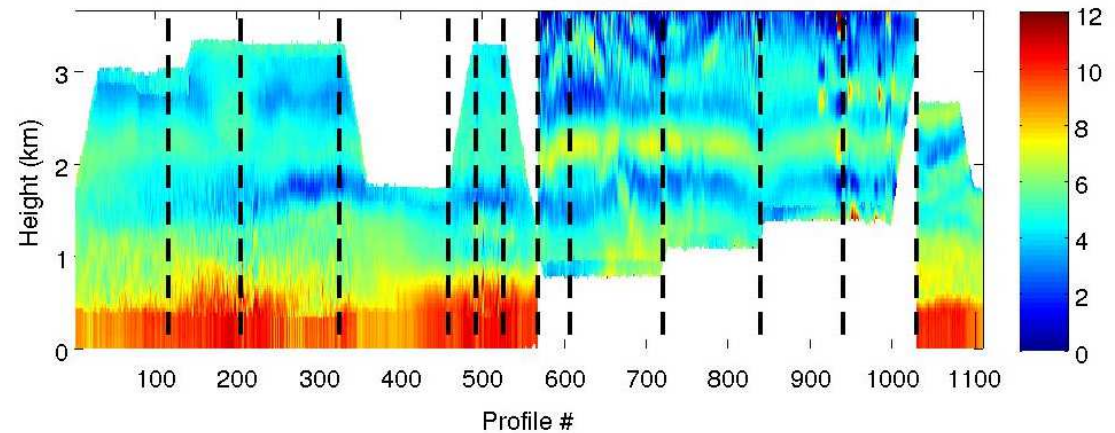


Exploitation des observations et des simulations effectuées à l'IPSL:

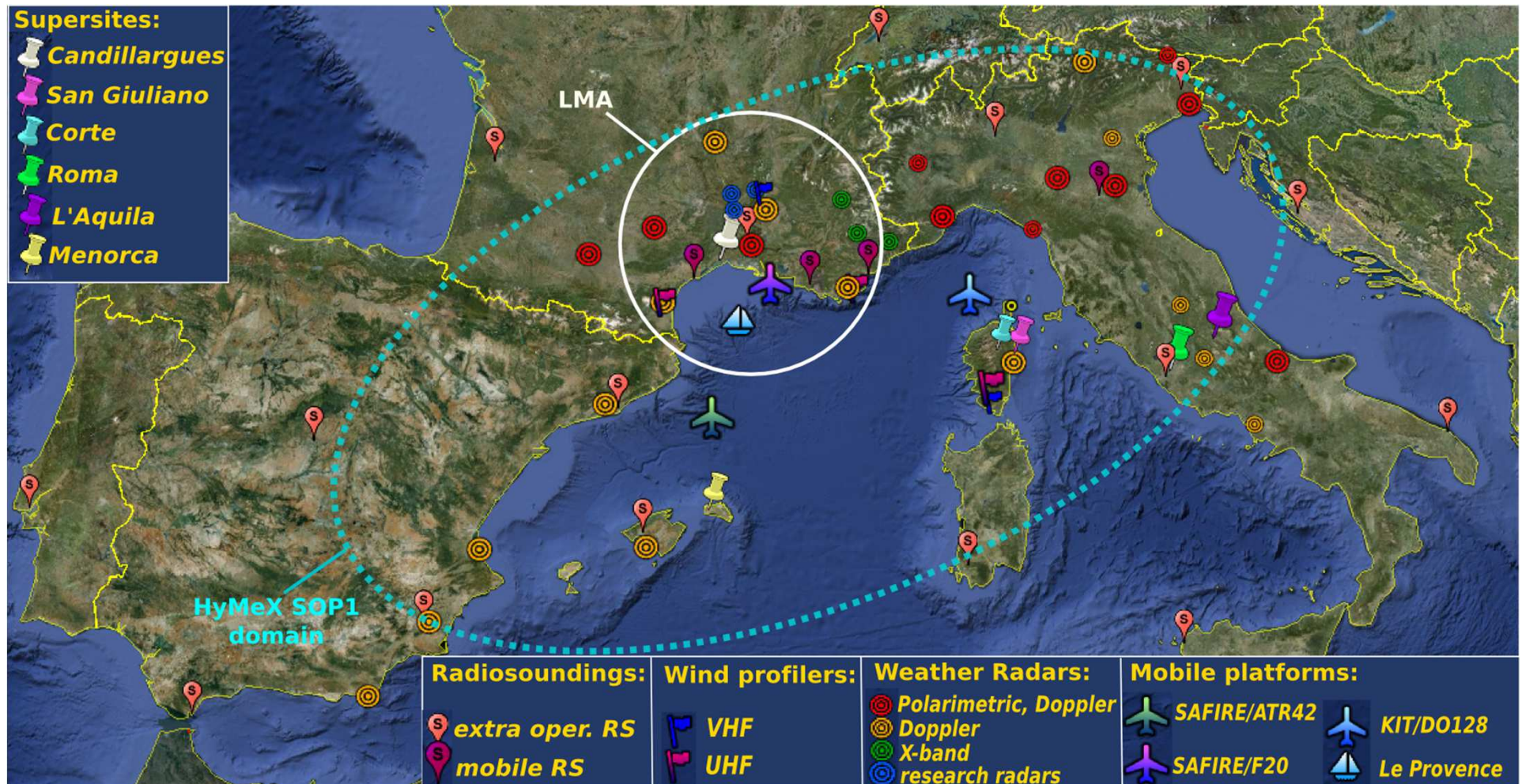
DIAL vapeur d'eau LEANDRE 2



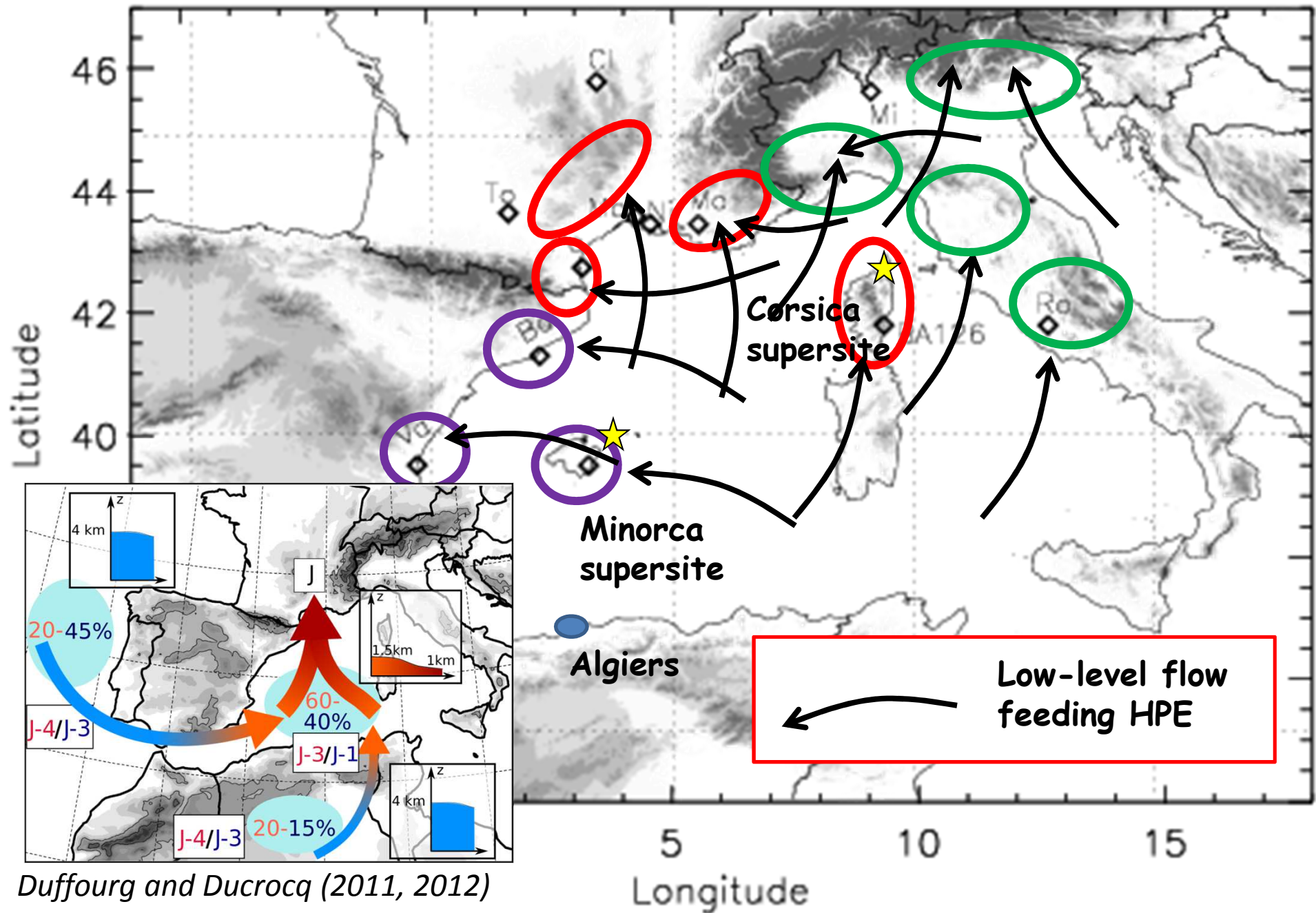
HyMeX - LEANDRE 2: H₂O mixing ratio (g/kg): VOL51



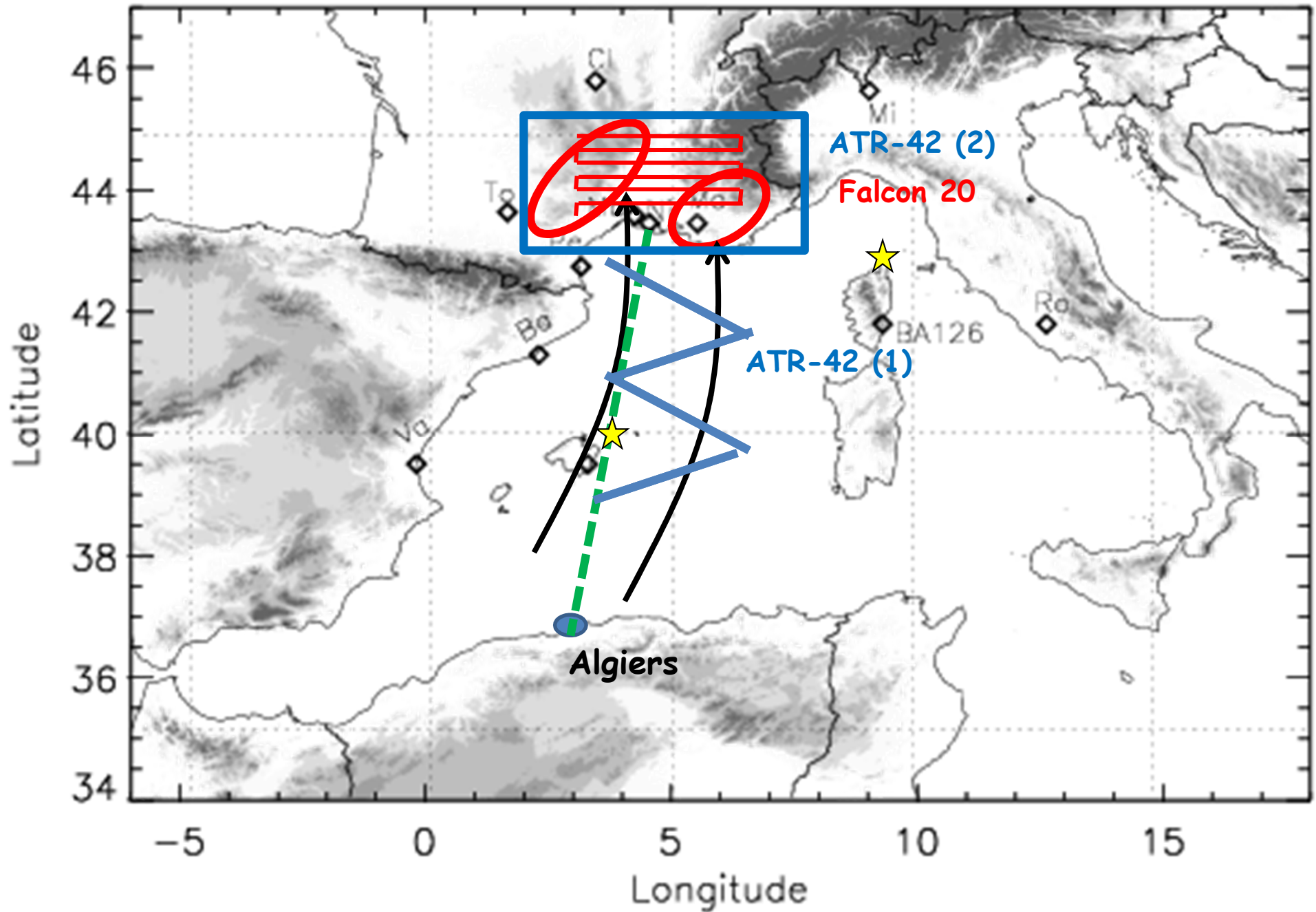
HYMEX SOP 1 (Sep-Nov 2012) detachment



HYMEX SOP 1 Target Areas / Hydrometeorological sites

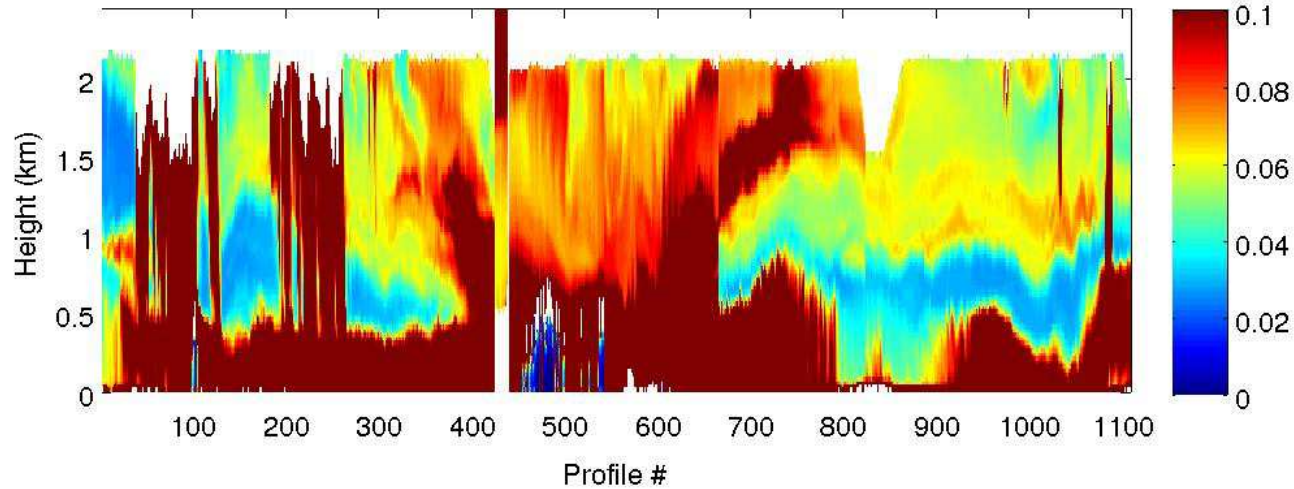


HYMEX SOP 1 Aircraft strategy

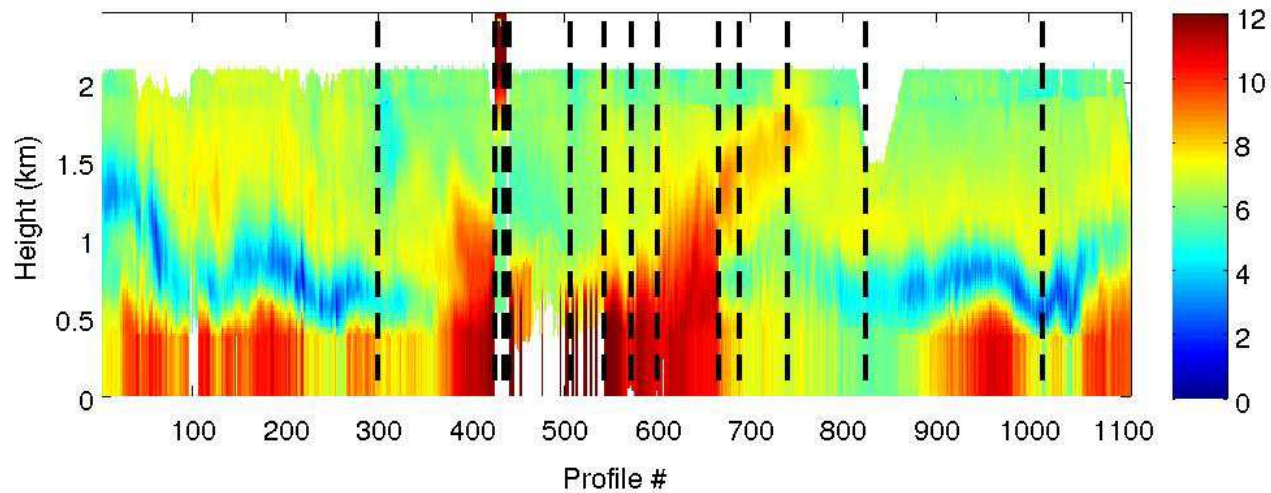


Flight AS41 28/09/2012 (1458-2016 UTC)

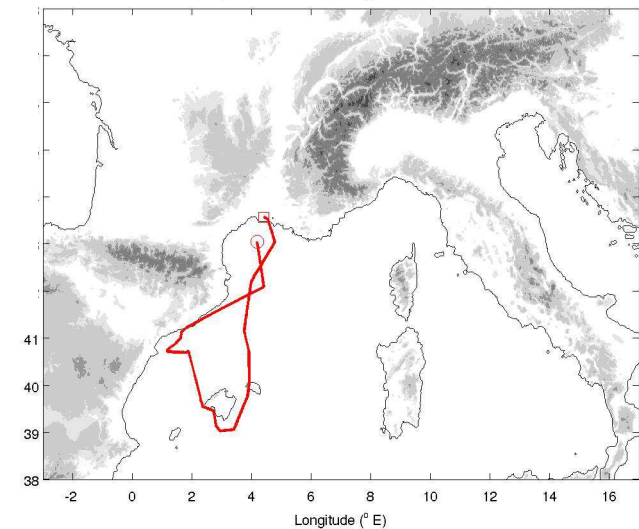
HyMeX - LEANDRE 2: Backscatter profile: VOL41



HyMeX - LEANDRE 2: H₂O mixing ratio (g/kg): VOL41

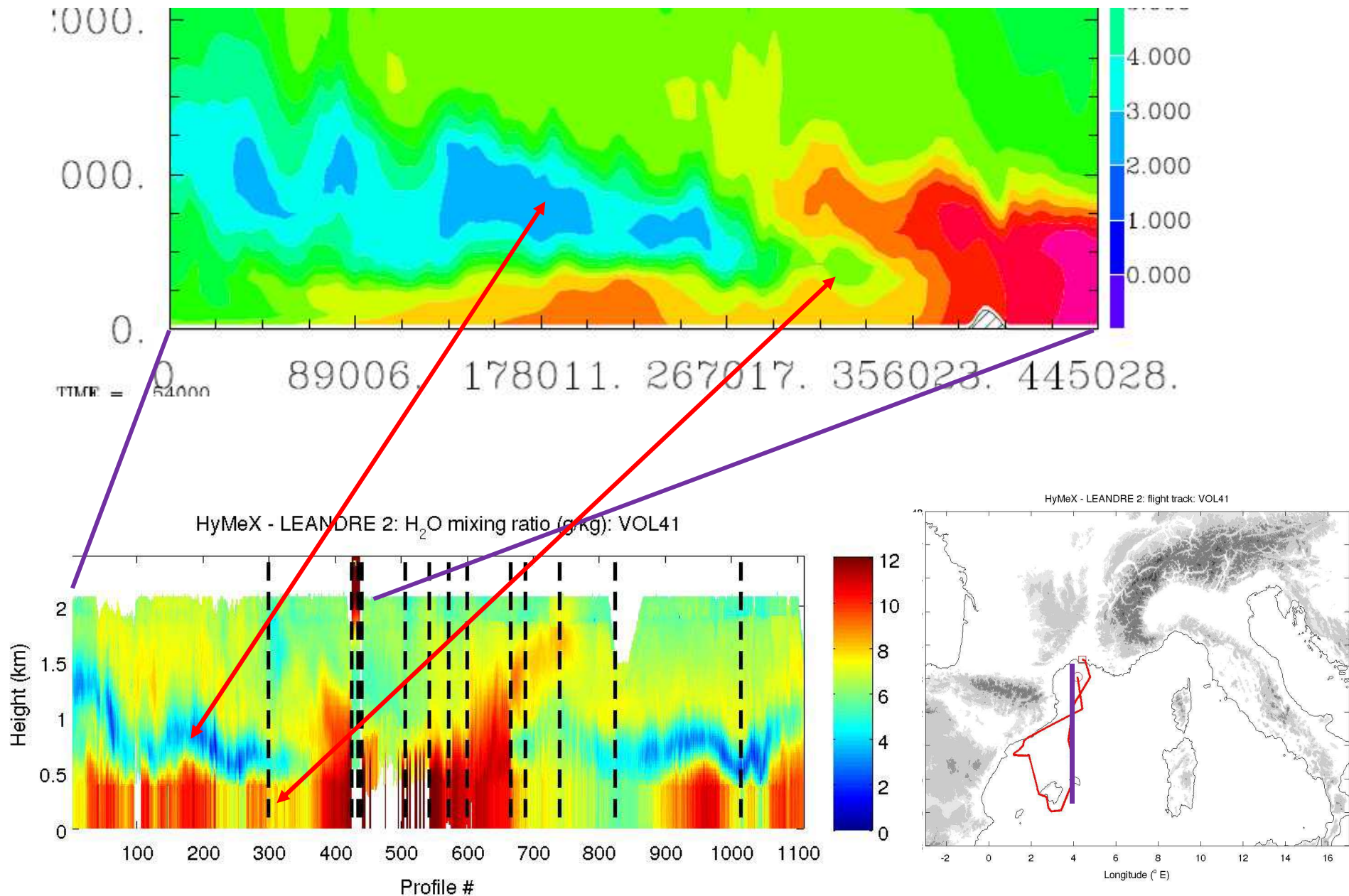


HyMeX - LEANDRE 2: flight track: VOL41



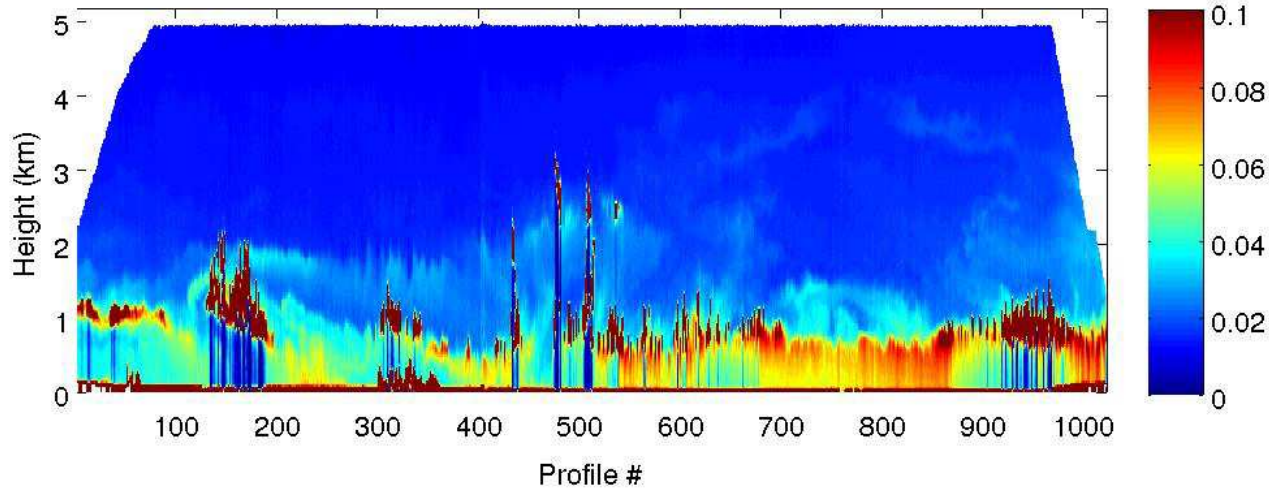
Flight AS41 28/09/2012 (1458-2016 UTC)

Meso-NH transect at 4°E, 15 UTC (time of Leg1)

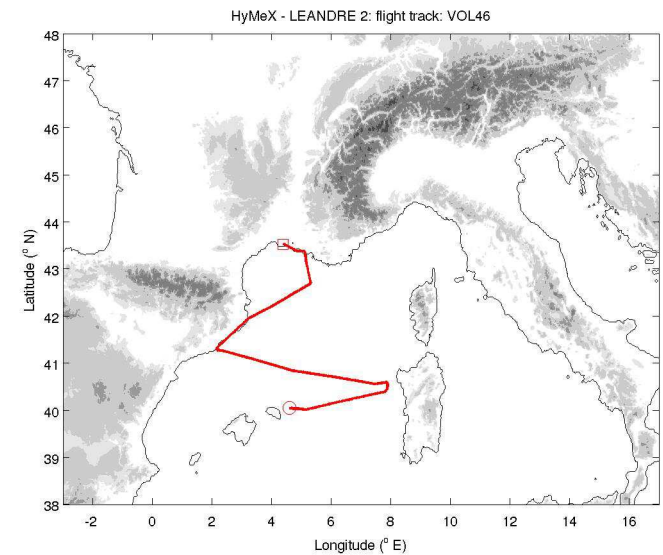
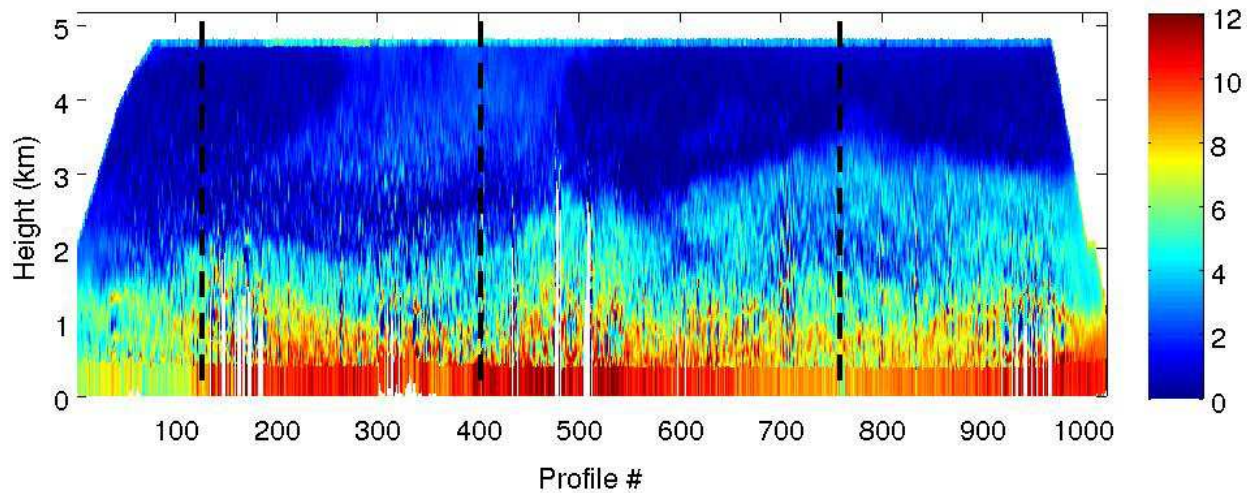


Flight AS46 14/10/2012 (0819-1134 UTC)

HyMeX - LEANDRE 2: Backscatter profile: VOL46



HyMeX - LEANDRE 2: H₂O mixing ratio (g/kg): VOL46



Propriétés microphysiques des nuages

Nuages de couche limite : stratocumulus

Importants par leur effet de refroidissement induit à la surface par occultation solaire (effet d'albedo).

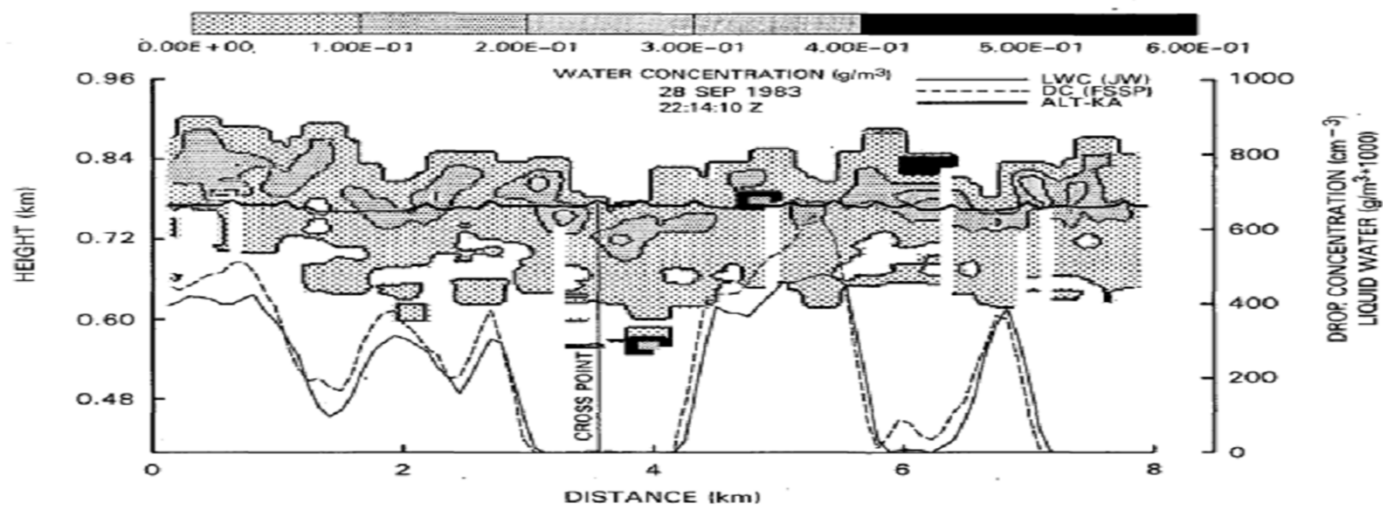
Leur formation est liée aux forçages thermodynamique dans la couche limite le couplage CL-nuage, l'entraînement sommital, le refroidissement radiatif, et le flux solaire qui font intervenir processus de petite échelle (turbulence) et de moyenne échelle (organisation en cellules, rouleaux,)

Propriétés microphysiques des nuages

Nuages de couche limite : stratocumulus

Formation contrainte par la turbulence dans la couche limite le couplage CL-nuage, l'entraînement sommital, le refroidissement radiatif, et le flux solaire qui font intervenir processus de petite échelle (turbulence) et de moyenne échelle (organisation en cellules, rouleaux, ...)

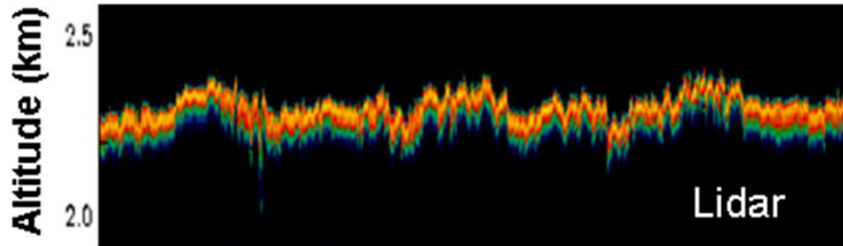
→ Dynamique « figée » pour des observations aéroportées



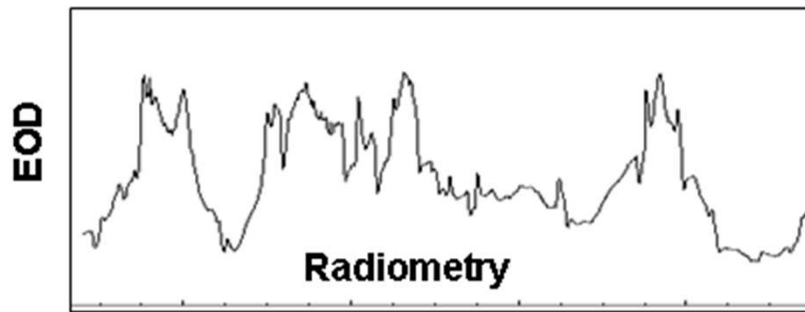
Spinhirne et al, 1988

Propriétés microphysiques des nuages

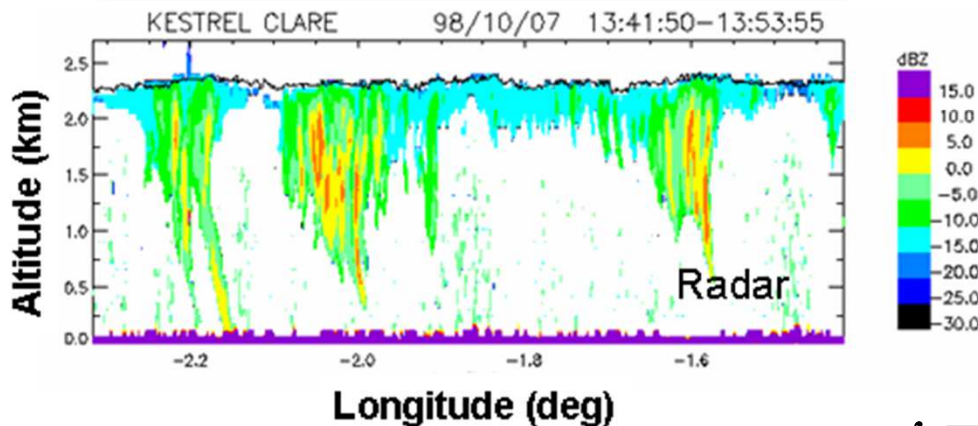
Stratocumulus



← Altimétrie : Sommet
Intensité/dépolarisation :
Densité



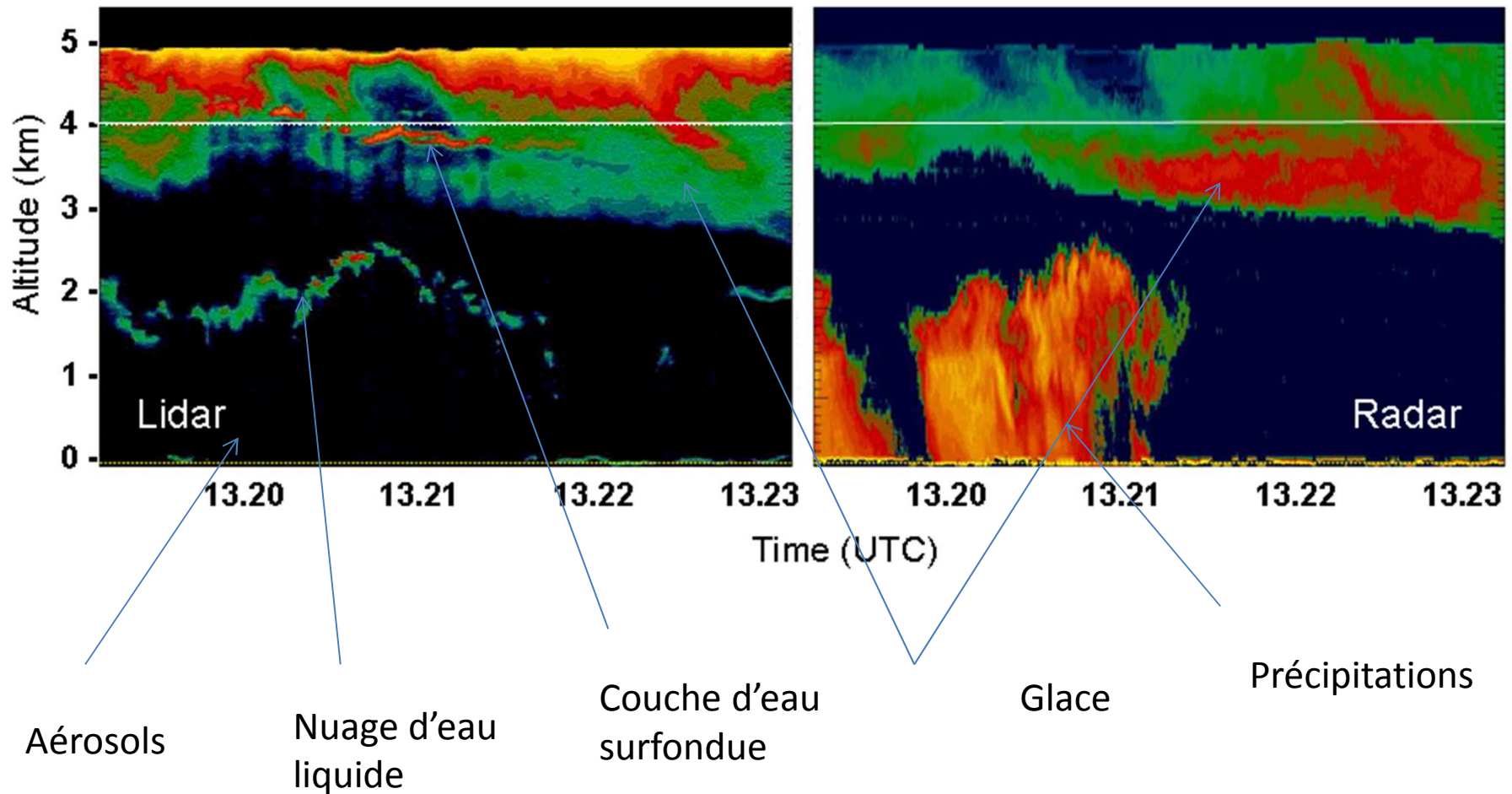
← Radiométrie : diffusion
Intégrée, AOD



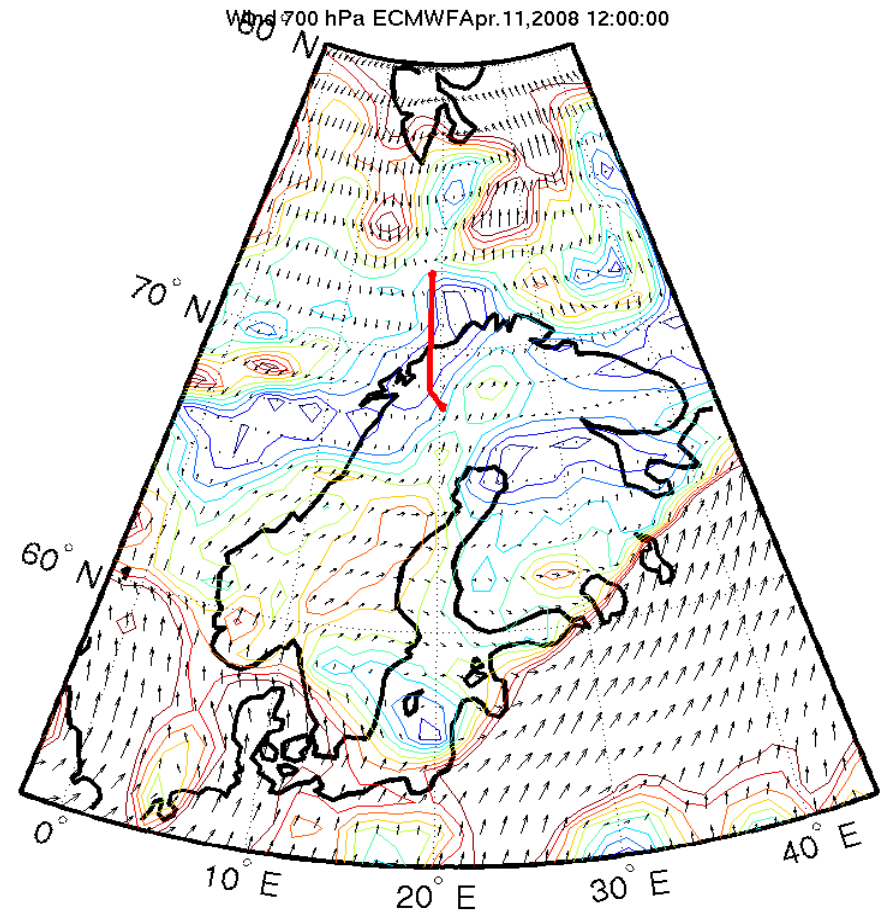
Réfectivité : Précipitations

$$\beta, \alpha(D, \lambda) = \int_D \sum_i \sigma_{i,e} N_i(D) dD = \pi \int_D D^2 \sum_i N_i(D) Q_{i,e}(D, \lambda) dD$$

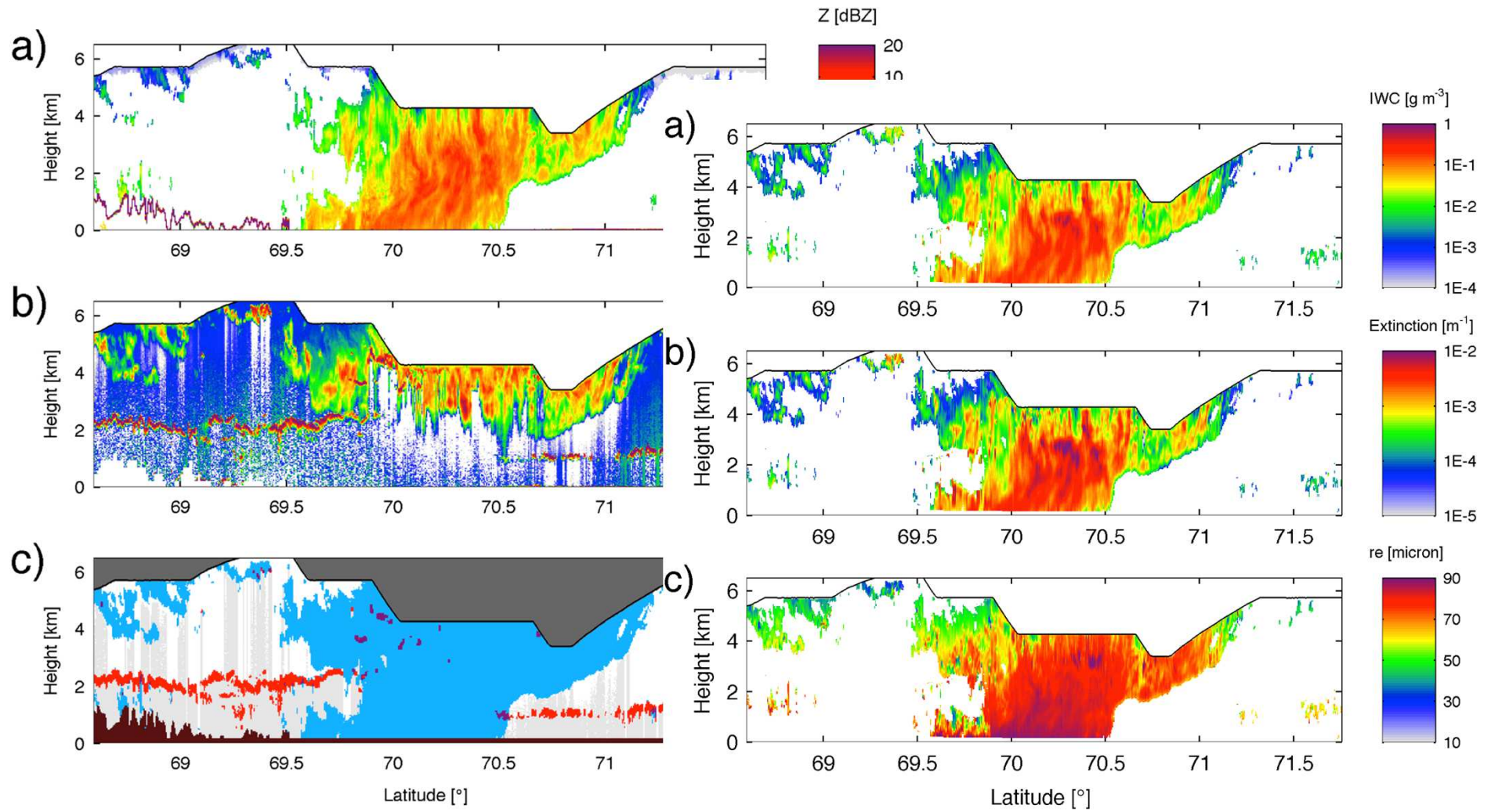
Complémentarité spectrale pour la caractérisation des nuages



Polarcat : pollution en arctique



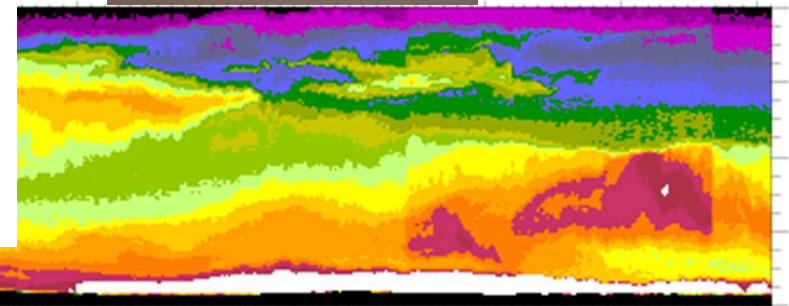
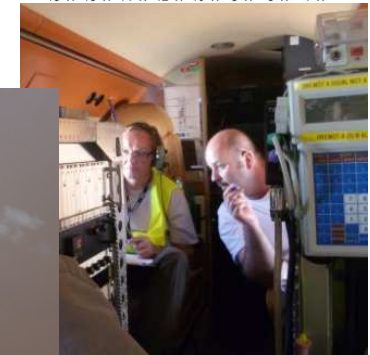
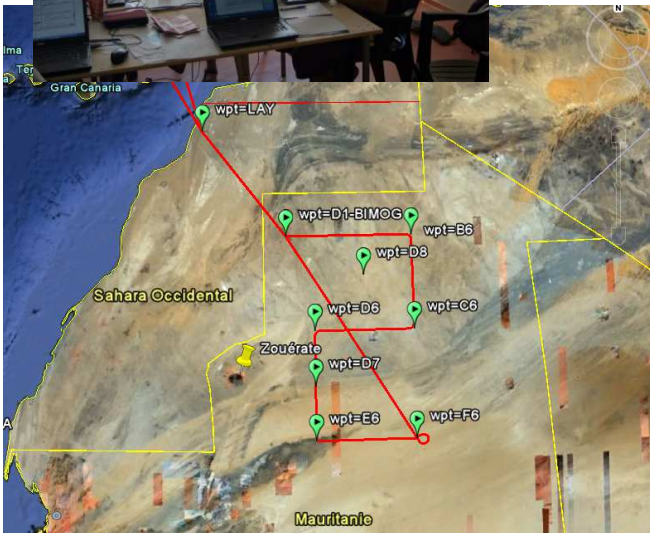
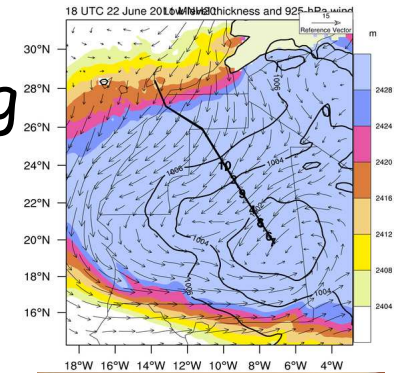
POLARCAT: lidar (LNG) + Radar (RASTA)





DUST LOAD & Dust Outbreaks during AMMA, FENNEC

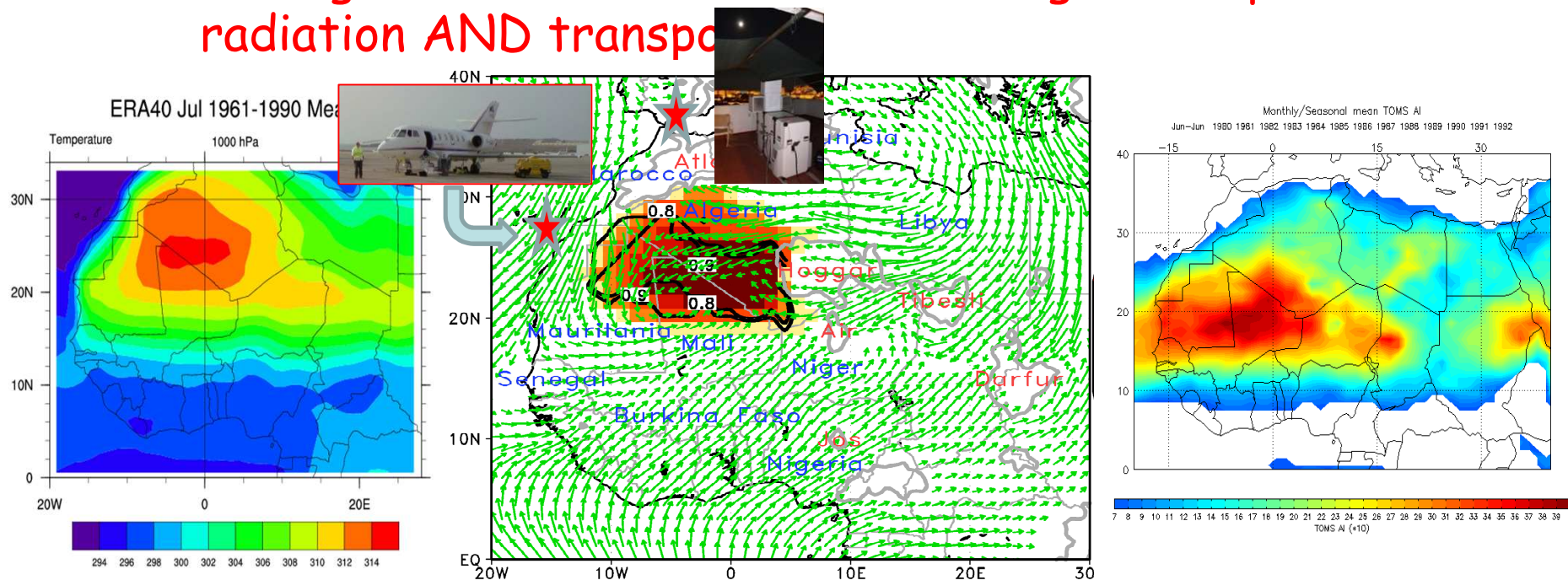
*C. Flamant and colleagues
& SAFIRE
& DT/INSU*



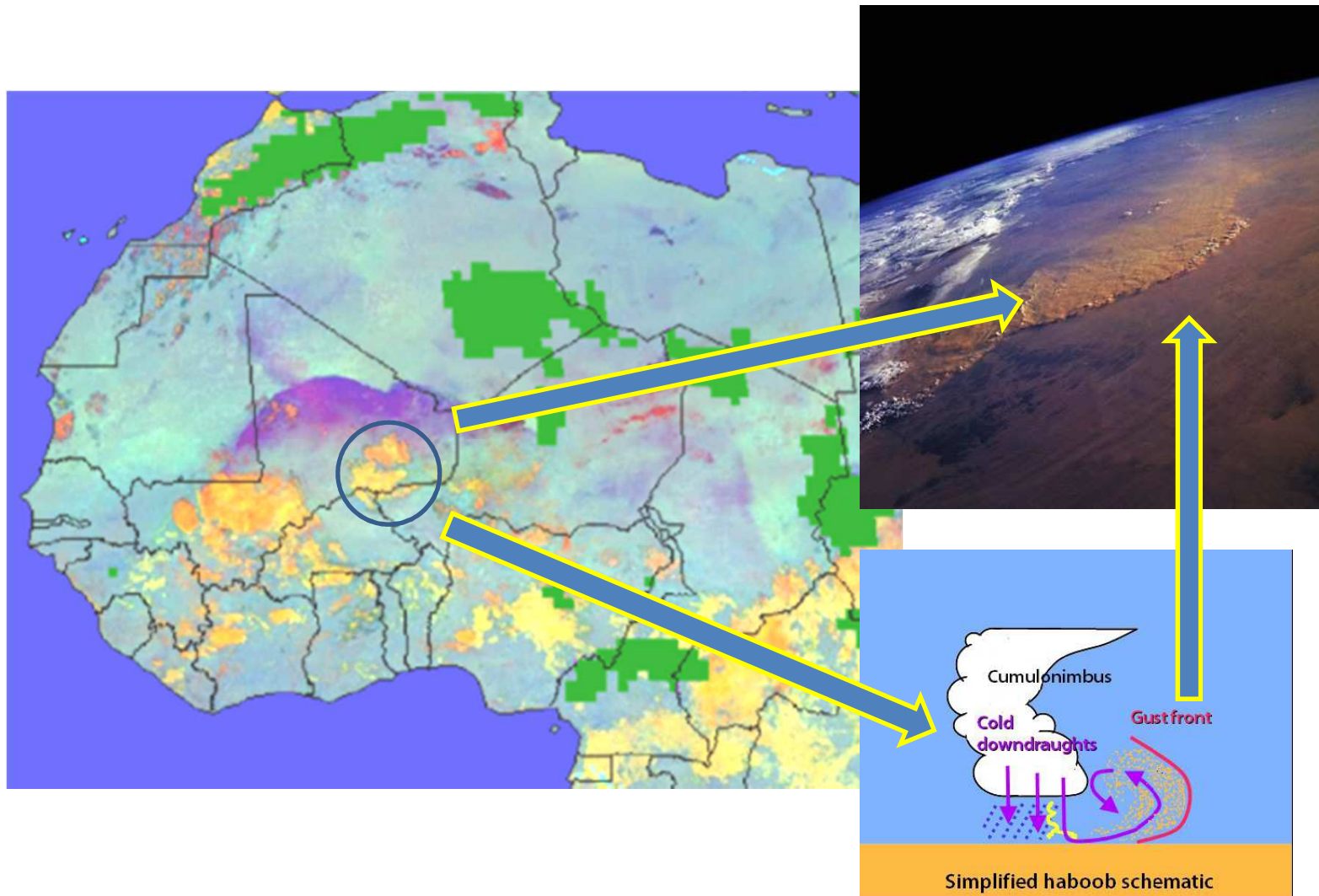
FENNEC Rationale

The Saharan climate system is the locus of numerous extremes within the general circulation during the Boreal summer:

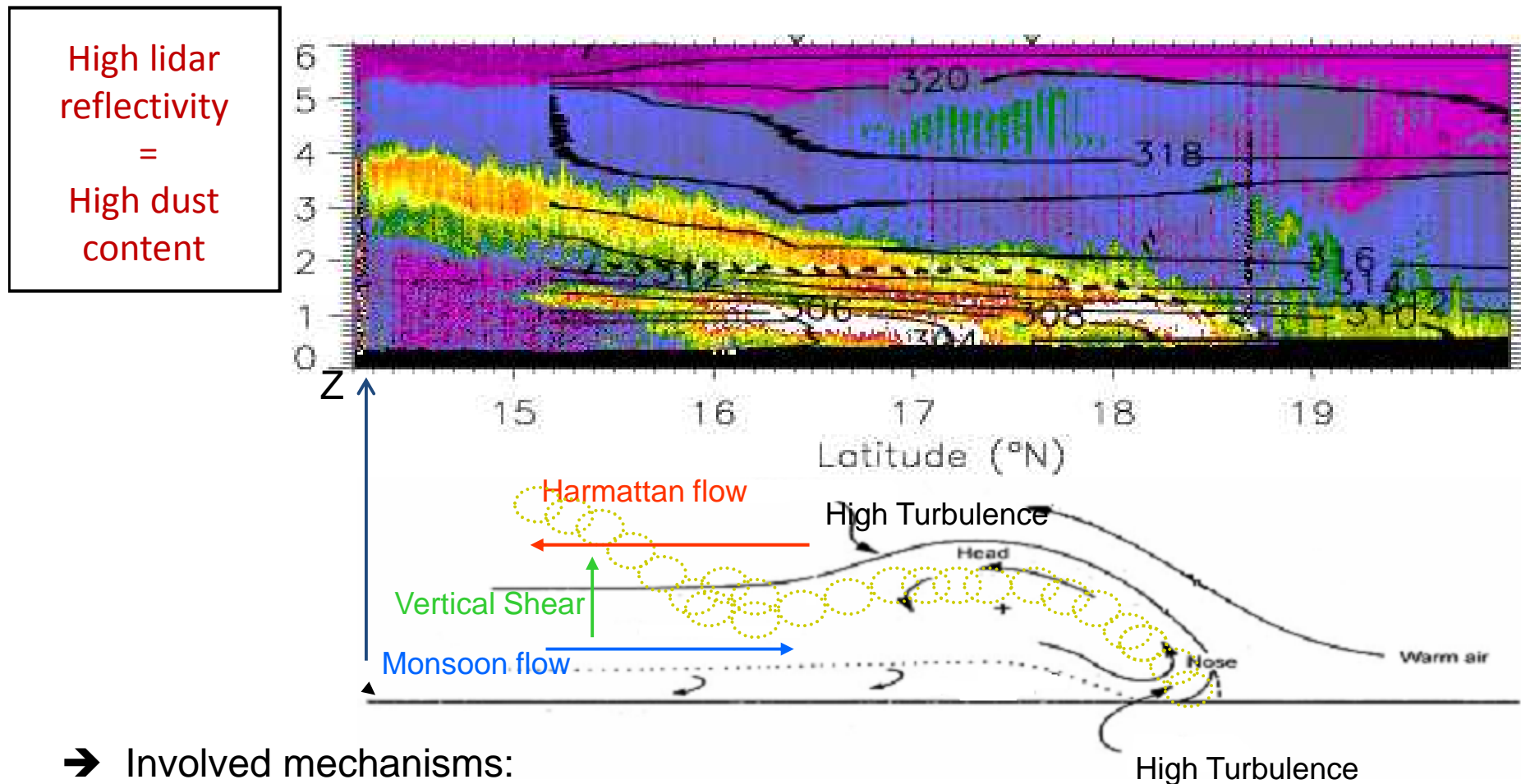
- Intense surface heating produces the deepest boundary layers on Earth,
- Development of the Saharan Heat Low (SHL) which plays a key role in the West African Monsoon system,
- **Largest loads of dust aerosols : regional impact on radiation AND transport**



Courants de densité liés à la convection (haboobs)



LEANDRE2 Lidar observations of Haboobs during AMMA



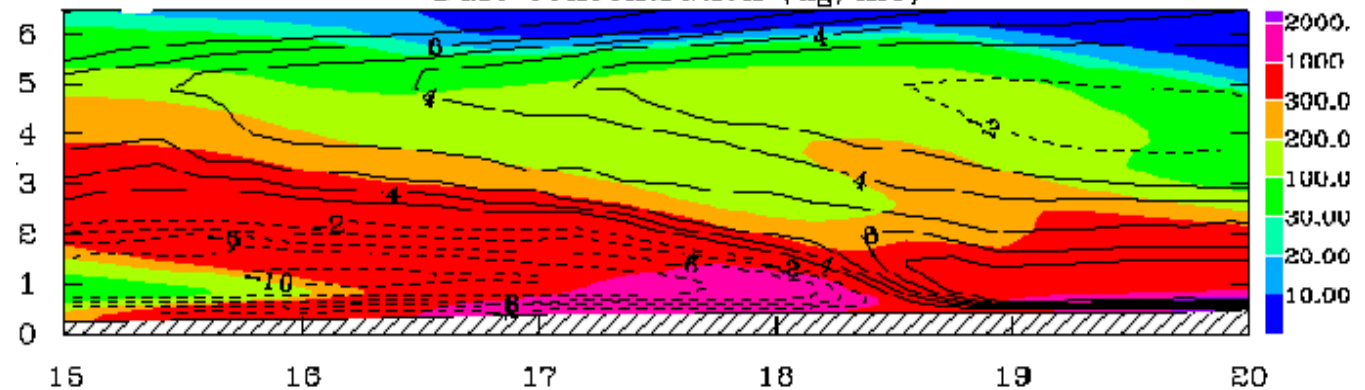
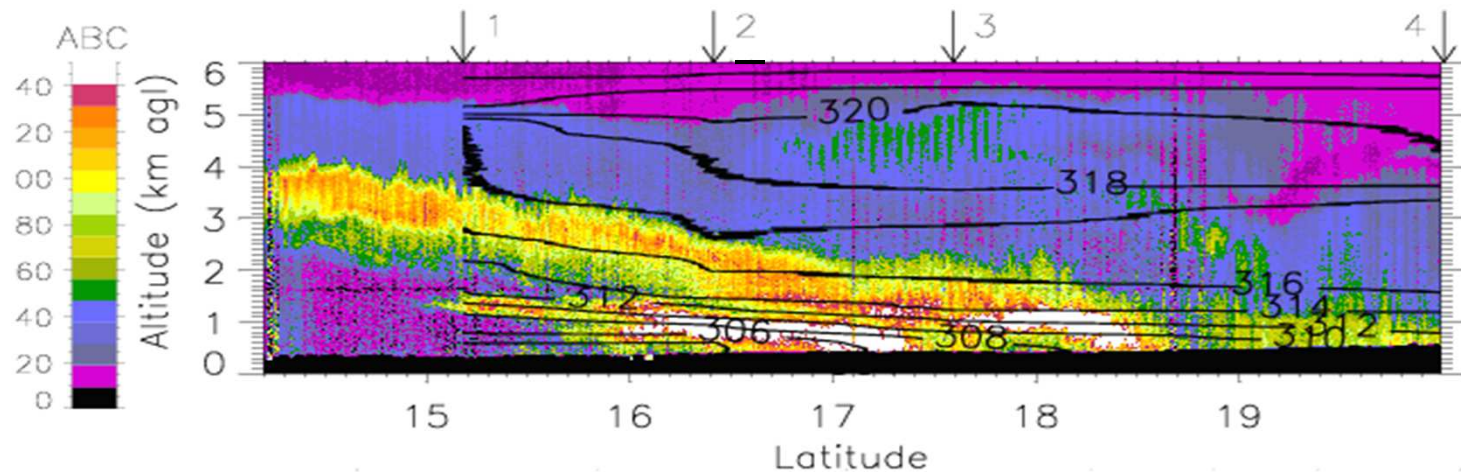
→ Involved mechanisms:

- High turbulent winds at the nose of the monsoon,
- Transport within the monsoon layer by the closed circulation at the head of the monsoon
- Cross-isentropic transport in the wake of the density current enhanced by the turbulence generated by the vertical shear.

Simulation of the highlighted mechanism

!! Near source regions, Lidar reflectivity can be used as a proxy for dust concentration

LEANDRE2 Lidar observations



Simulated dust concentration using MESO-NH model ($\mu\text{g}/\text{m}^3$)

Bou karam et al., 2009

Haute résolution spectrale (DLR)

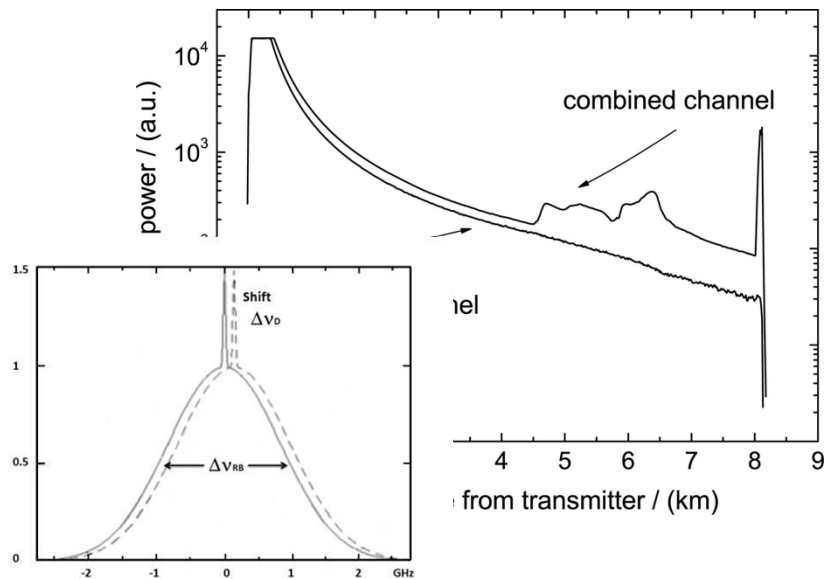
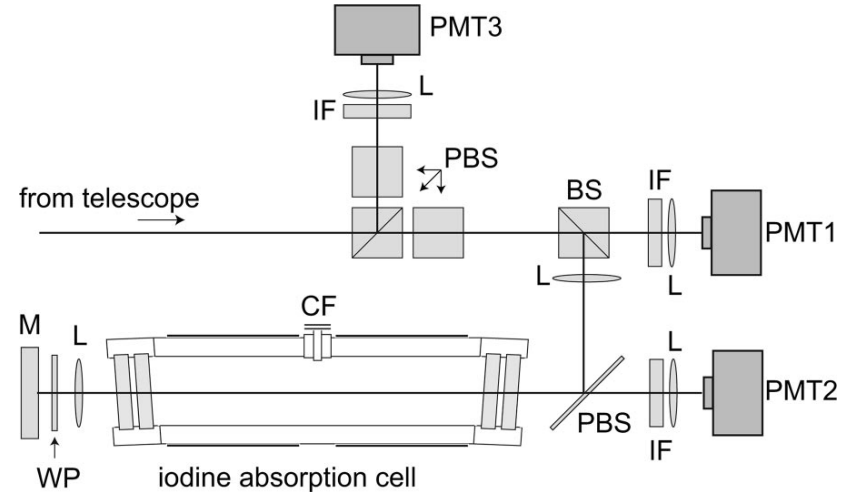
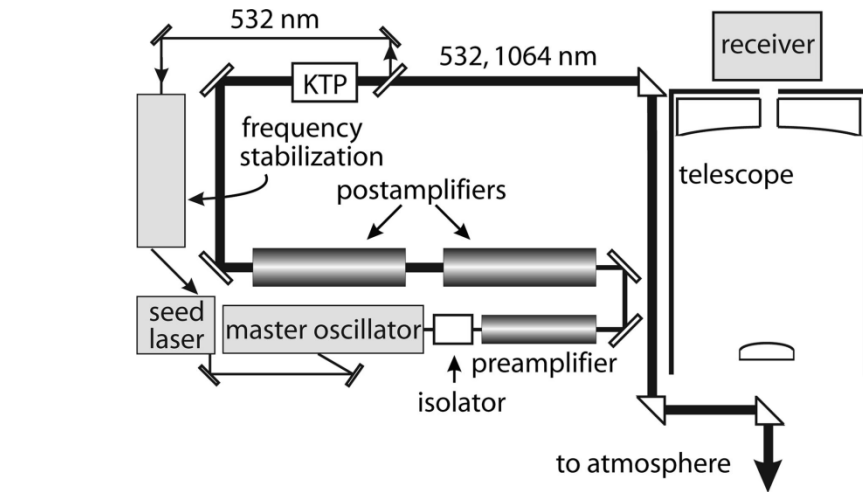
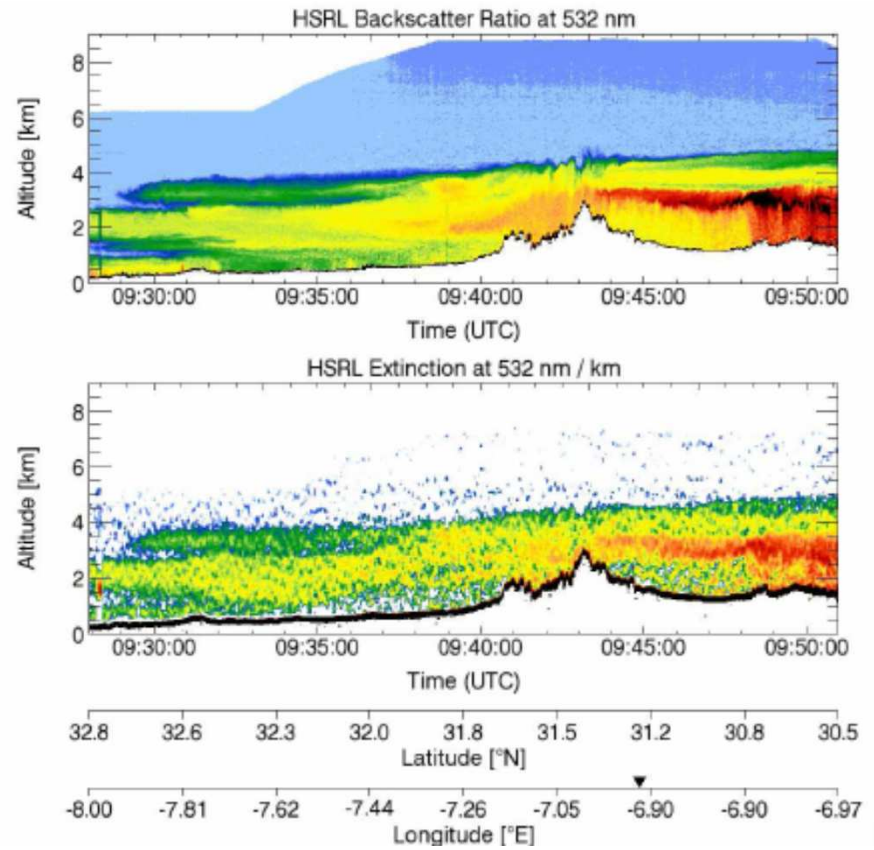
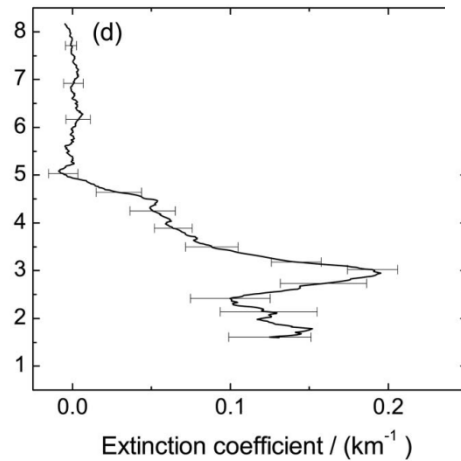
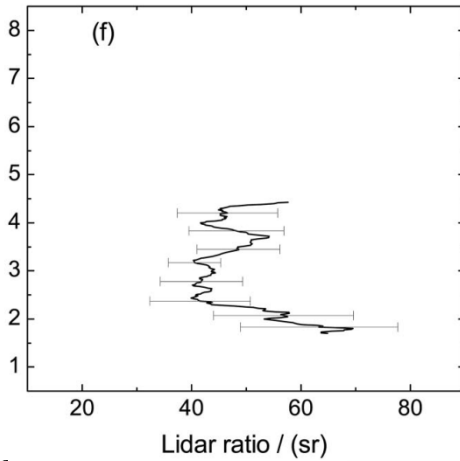
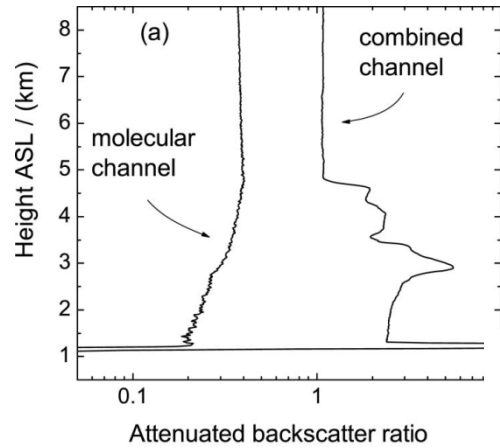


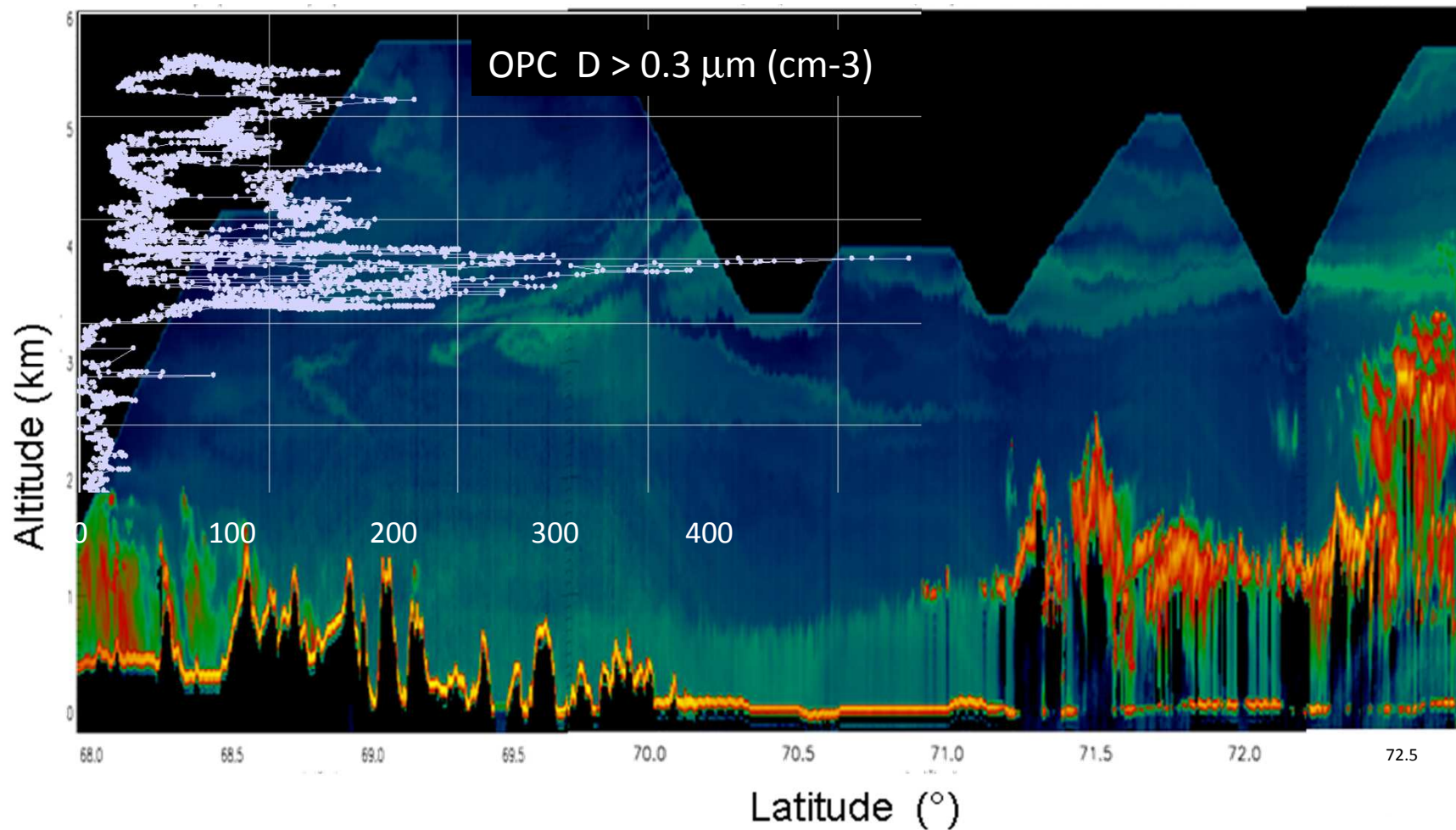
Fig. 4. Schematic of the receiver module used for detection at 532 nm. BS, beam splitter; CF, cool finger; IF, interference filter; L, lens; M, mirror; PBS, polarization beam splitter; PMT, photomultiplier; WP, quarter-wave plate.

Esselborn et al., 2008

Caractérisation des poussières désertiques



POLARCAT (11 April 2008): aerosol in situ + lidar (LNG)



Profils LNG. D'après J. PELON et col.

Etude de la couche limite : Pollution continentale européenne

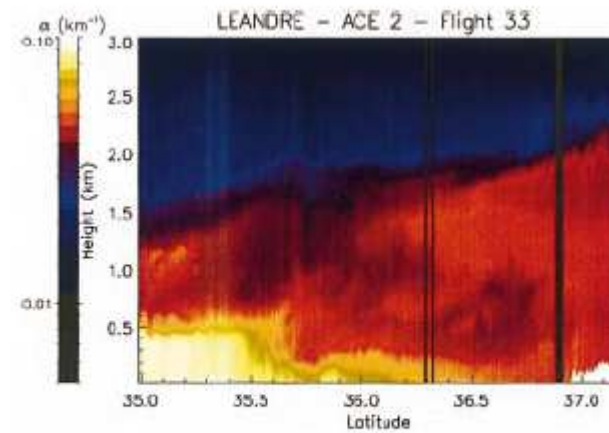


Fig. 4. Lidar-derived particulate extinction coefficient for flight mission F33 on 6 July 1997 between 0900 and 1000 UTC.

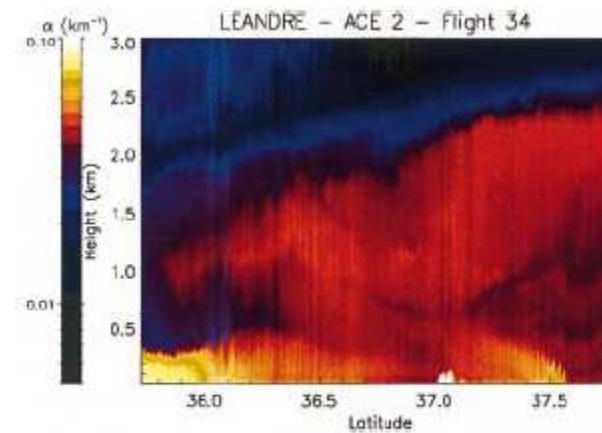


Fig. 5. Lidar-derived particulate extinction coefficient for flight mission F34 on 6 July 1997 between 1930 and 2100 UTC.

Etude de la couche limite : Pollution continentale européenne

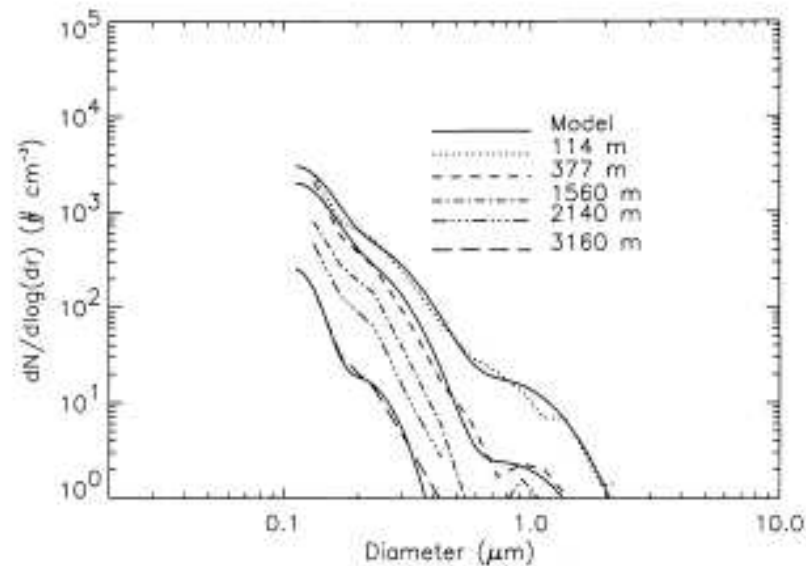


Fig. 6. Aerosol size distribution in the lower troposphere on 6 July as measured by the particle measuring system (PMS), active scattering aerosol spectrometer probe (ASASP) mounted on the avion de recherche et Télédétection (ARAT) during the ascent of F33. The solid lines correspond to the best fit obtained with the modeled size distribution.

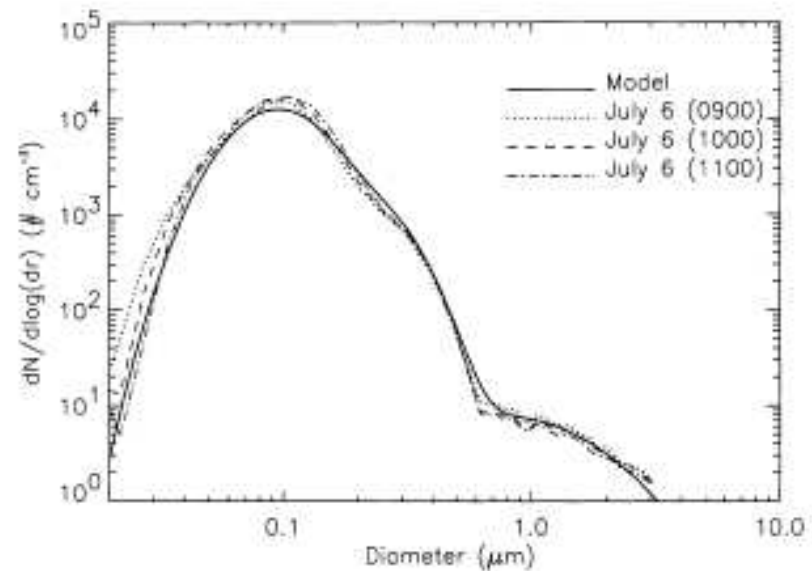


Fig. 7. Aerosol size distribution in the marine atmospheric boundary layer (MABL) on 6 July at 0900, 1000 and 1100 UTC (dotted, dashed and dot-dashed lines, respectively) as measured on-board the RVV. The solid line corresponds to the best fit obtained with the modeled size distribution which characteristics are given in Table 1.

Etude de la couche limite : Pollution continentale européenne

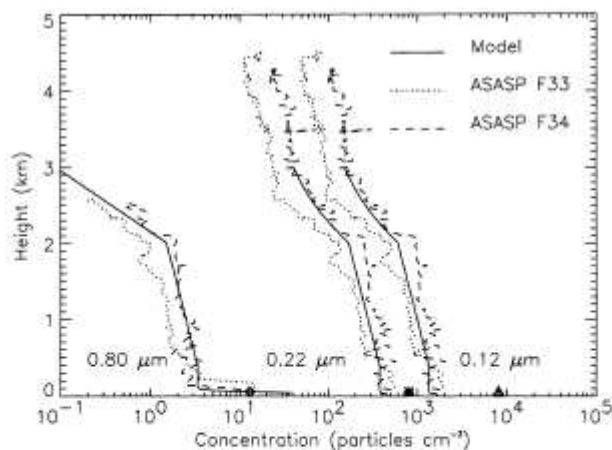


Fig. 8. Number concentration profiles of particles in the 0.11, 0.22 and 0.8 μm modes as derived from ASASP measurements made during the ascent of F33 and F34. The surface number concentration values n 10 m on the RVV are reported as a triangle, and a lozenge for the 0.11, 0.22 and 0.8 μm respectively.

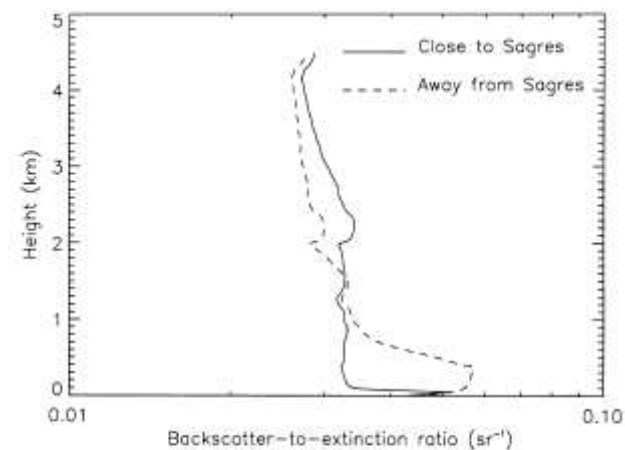


Fig. 9. Backscatter-to-extinction profile at 0.73 μm near Sagres (solid line) and 250 km away from Sagres, near the end of the flight track F33 (dashed line), derived by parameterized aerosol vertical distributions 2). RH soundings performed at noon on 6 July July are used for the "near Sagres" and "away agres", respectively.

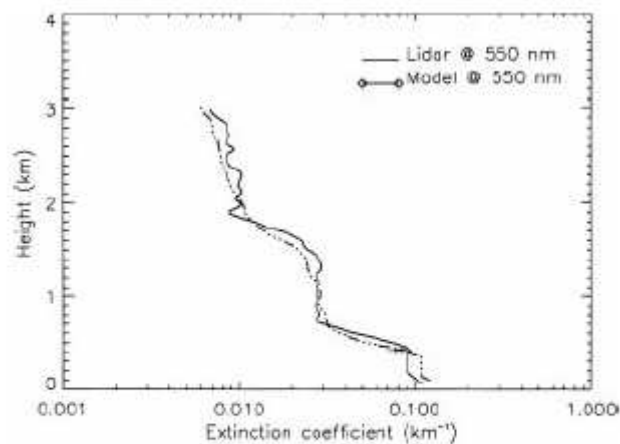


Fig. 13. Same as Fig. 12 but near 35°N and for the LPEC and MPEC profiles only (solid and open symbols, respectively).

Epaisseurs optiques faibles
Typ. 0.2-0.3

Flamant et al., 2000

Etude de la couche limite : Pollution continentale indienne (INDOEX)

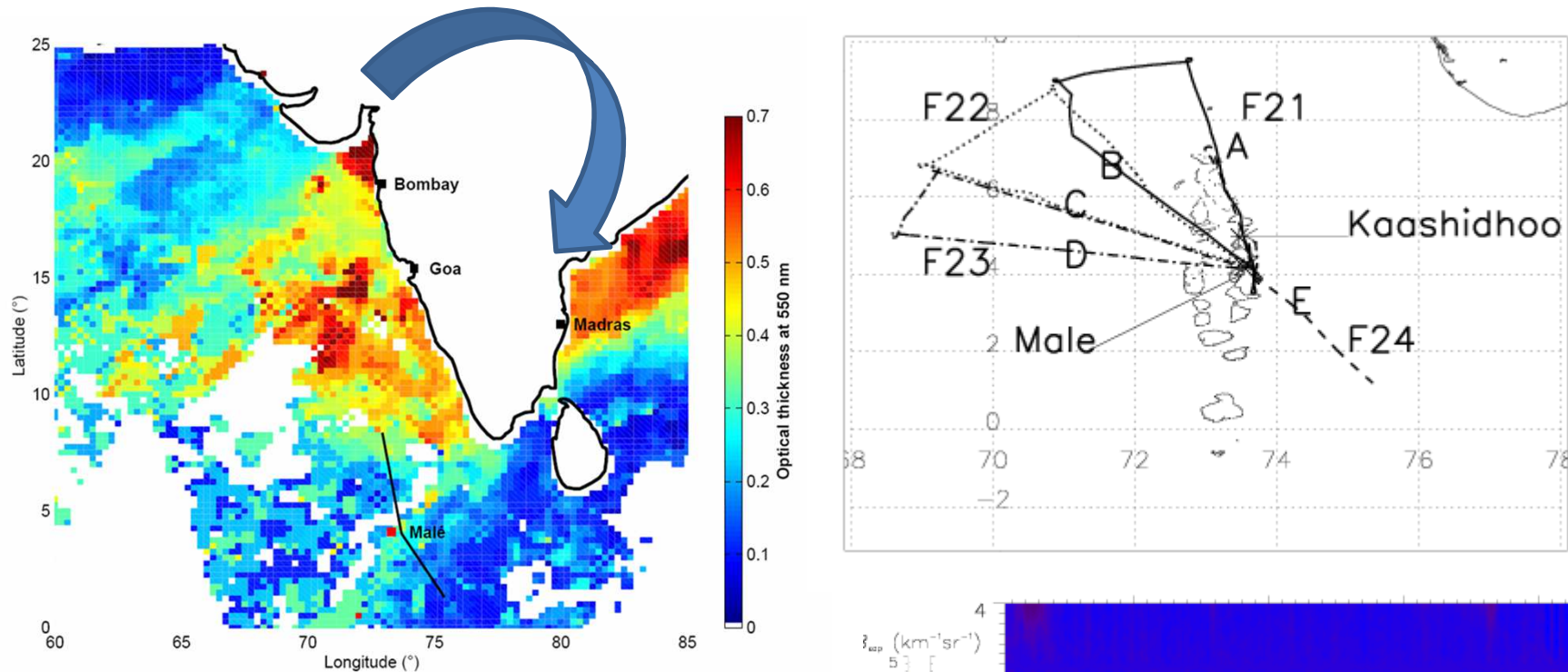
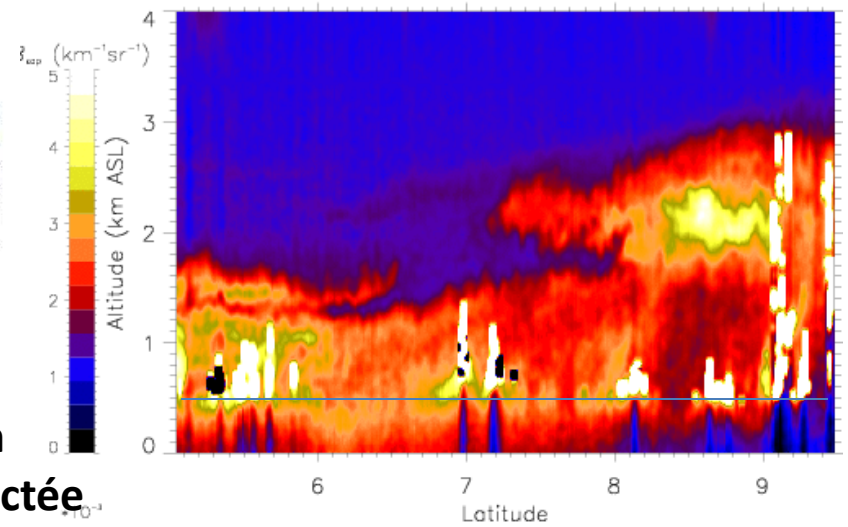


Figure 4. Average AOD derived from Meteosat-5 for the three days considered. The AOD field is a composite of the daily averaged AOD field for 7, 8 and 9 March 1999. White pixels correspond to clouds. Only clouds that are persistent enough to have been observed at the same location during the 3 days are presented as such. In the other cases, the AOD is taken as the average of the non cloudy pixels. The thick solid line represents track A and track E (north and south of Male, respectively) flown by the M20 on 7 March 1999 and 9 March 1999, along which Meteosat-5 AODs shown in Figure 10 have been extracted.

Pelon et al., 2002

Epaisseurs optiques élevées typ. 0.3-1
zones polluées !! les nuages se développent au som
Met de la CLAM danbs la couche de pollution advectée



Etude de la couche limite : Pollution continentale indienne (INDOEX)

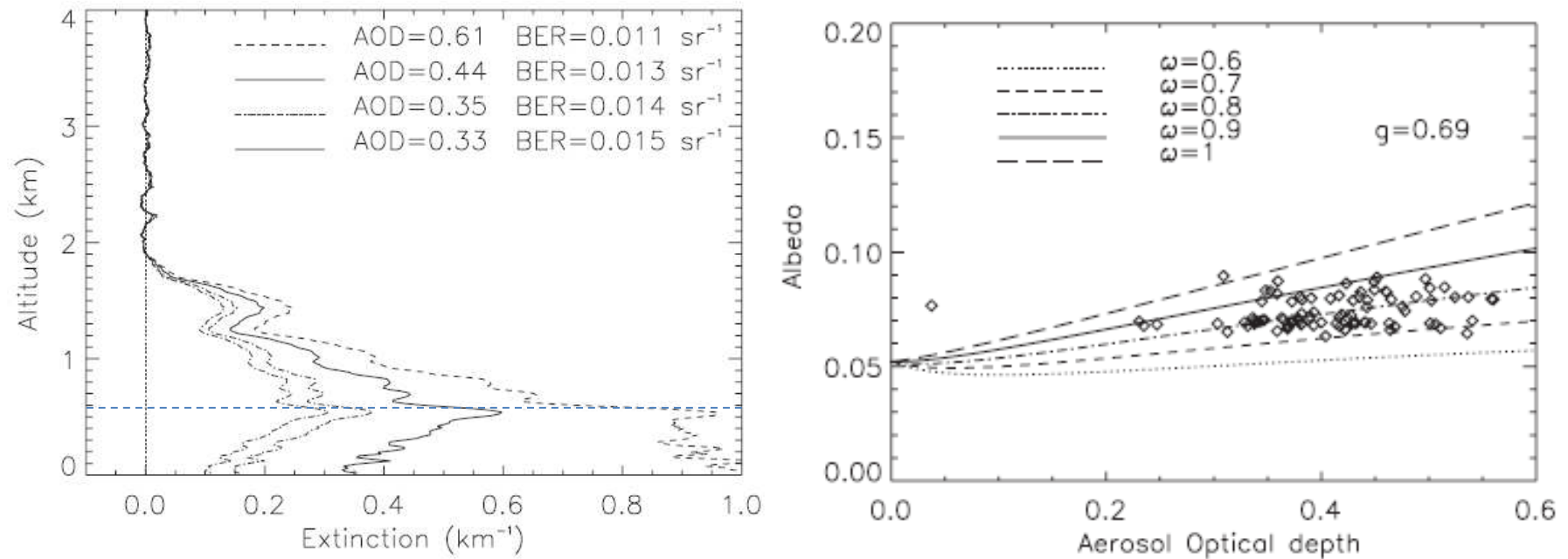


Figure 9. Lidar-derived extinction coefficient profiles obtained for different values of the backscatter-to-extinction ratio (BER) assumed constant with height. The total aerosol optical thickness corresponding to the vertical profile is reported for the different BER used.

The lines represent the relationships between albedo and AOD modeled (for different values of ω_0) using the two-stream approximation for a value of $g = 0.69$. The short-dashed, dot-dashed, 3-dot-dashed and long-dashed lines correspond to single scattering albedos of 0.7, 0.8, 0.9 and 1, respectively.

Etude de la couche limite : Pollution continentale indienne (INDOEX)

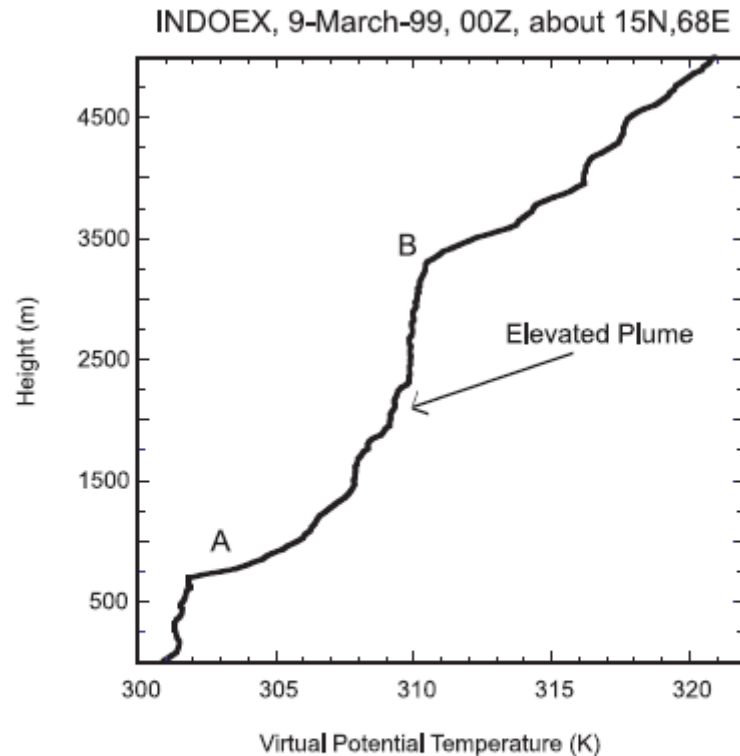


Figure 2. Typical thermodynamic profile over the INDOEX study region about 500-km downwind of landmass. Region between 'A' and 'B' indicates the depth of the aerosol rich land plume over the ocean.

Raman et al., 2001

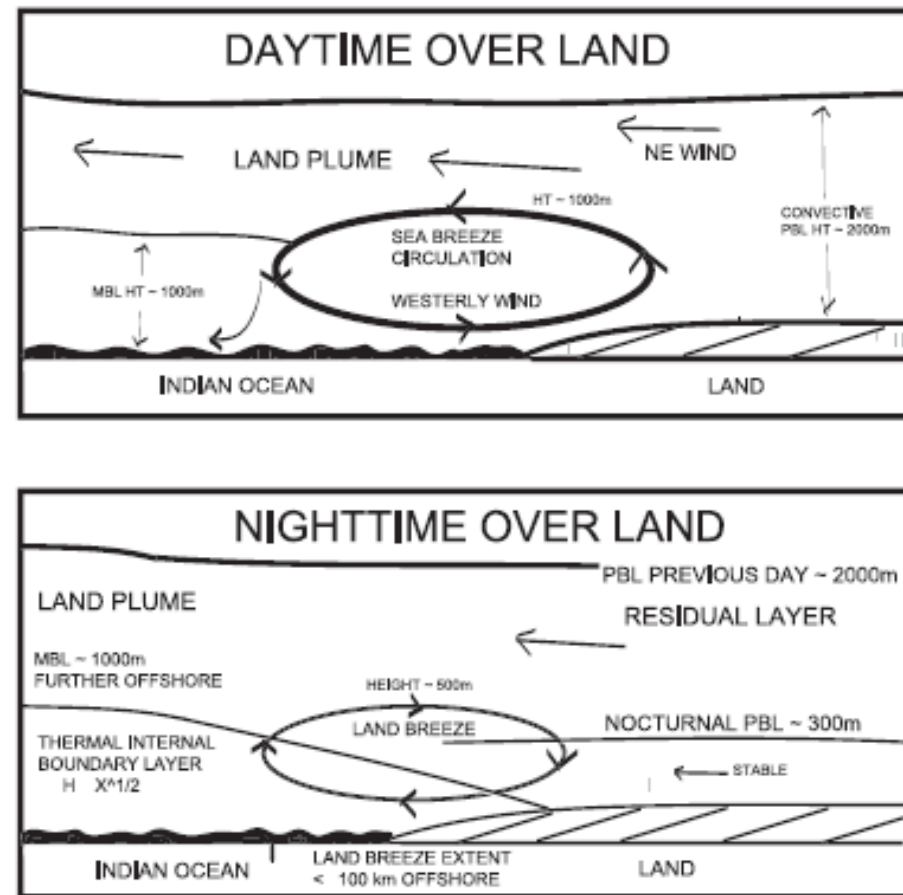


Figure 5. Conceptual depiction of the interaction between the coastal circulations and the land plume over the Indian ocean for day and night.

Etude de la couche limite : Pollution continentale indienne (INDOEX)

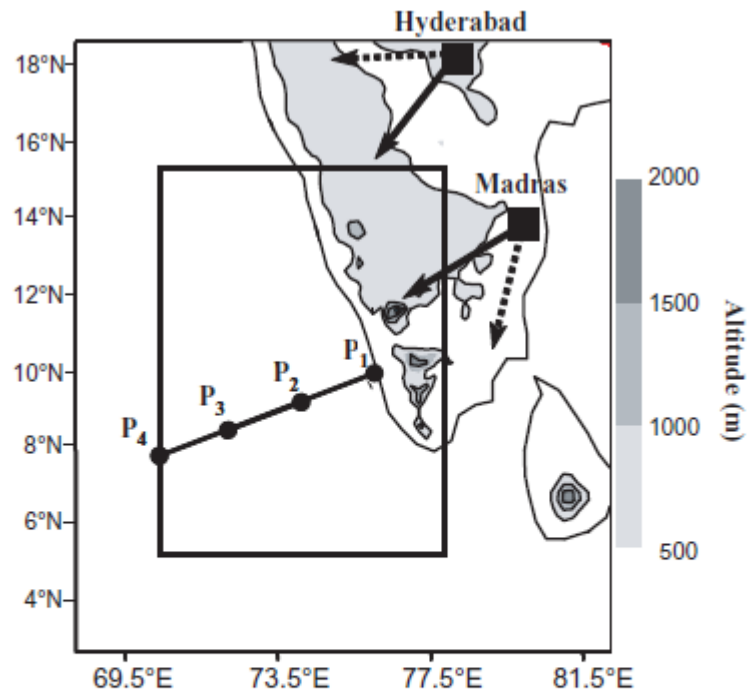


Fig. 11. Map of south India (with terrain elevation) and position of the 4 locations used to inspect the spatial and temporal structure of pollutants plume over the ocean: P1 (76.5°E; 10°N), P2 (74.3°E; 9.3°N), P3 (72.7°E; 8.6°N), P4 (69.9°E; 7.6°N). Dotted (solid) arrows represent the main wind direction before (after) 6 March 1999.

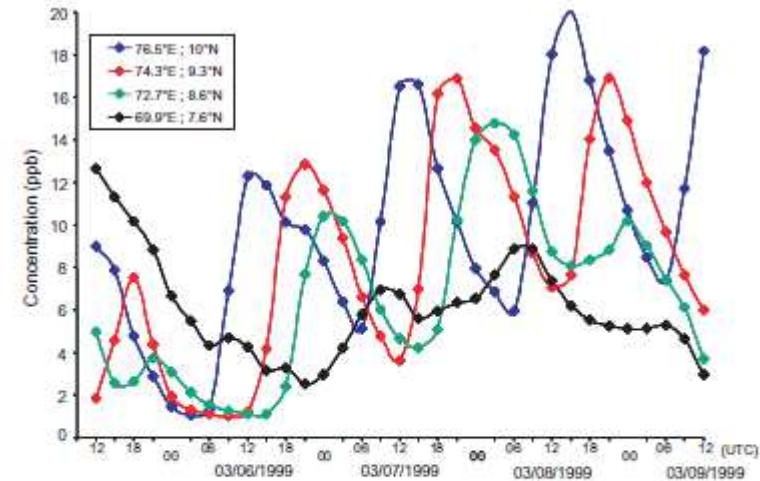
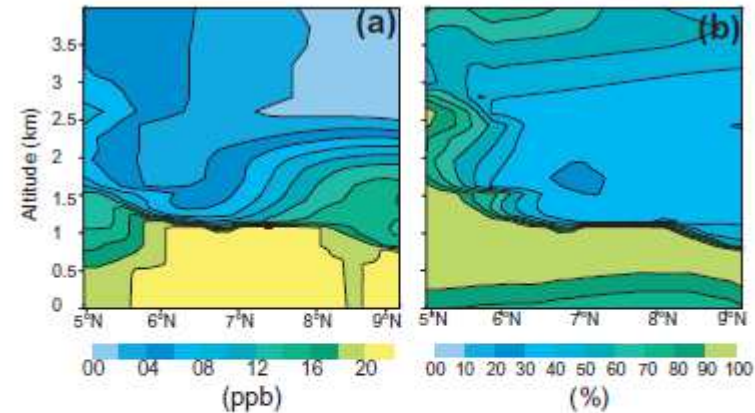


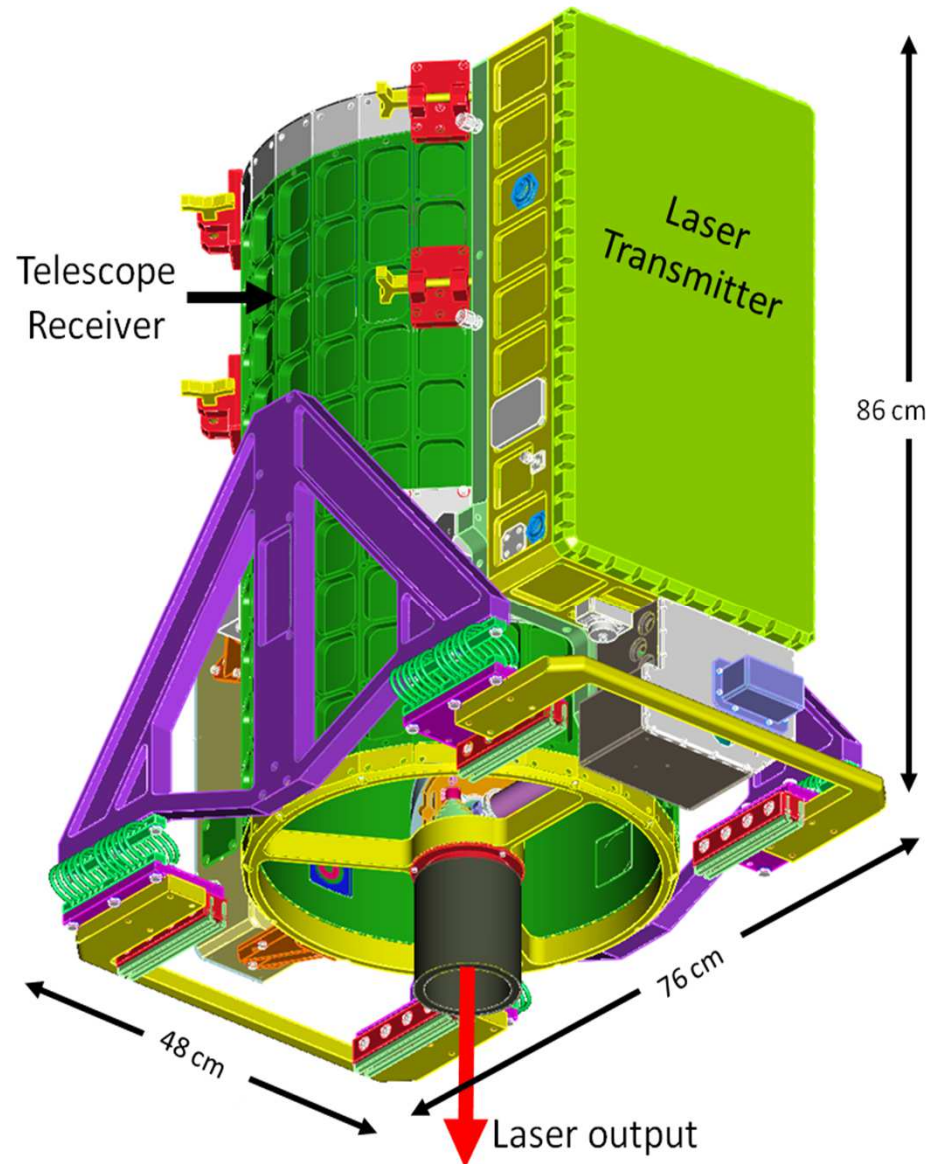
Fig. 12. Diurnal evolution of the top of the tracer plume (ppb, at 2000 m msl) between 5 March (12:00 UTC) and 9 March (12:00 UTC), along the mean winds line for (P1, blue), (P2, red), (P3, green) and (P4, black) from the high resolution simulation (run C) on grid 2.

LaRC Airborne High Spectral Resolution Lidar (HSRL)



- Airborne HSRL has logged **>630 flight hours** and **>160 science flights** on NASA Langley King Air B200
- **Highly robust:** have never missed a flight due to instrument problems

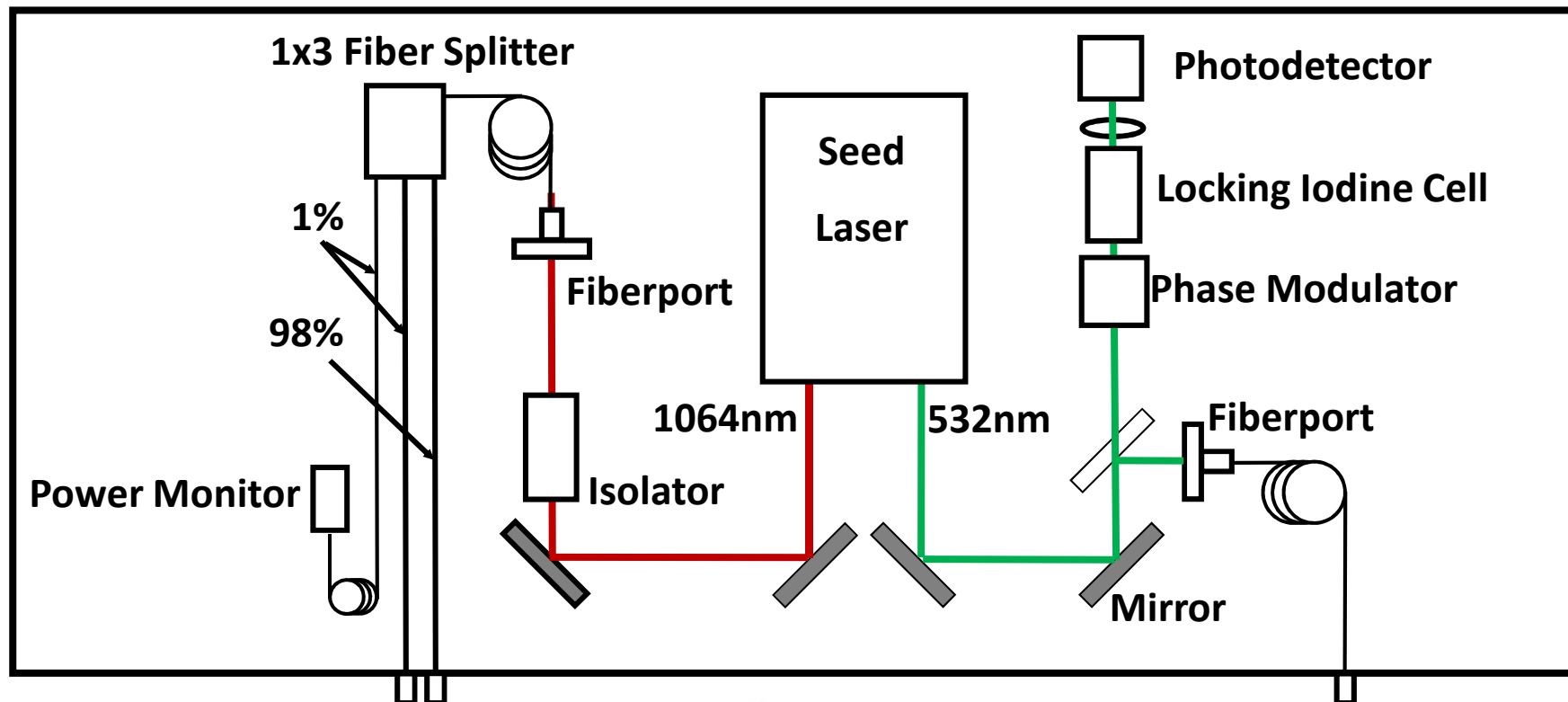
LARC Airborne High Spectral Resolution Lidar (HSRL)



- Capabilities: **1- α , 2- β , 2- δ (2011)**
 - HSRL at 532 nm (iodine technique)
 - Backscatter lidar at 1064 nm
 - Depolarization at both 532, 1064 nm
- History
 - 2000-2004: instrument development
 - Dec 2004: first test flight on Lear 25-C
 - Dec 2005: first test flight NASA King Air
 - 2006: 3 field campaigns
 - 2007: 3 field campaigns
 - 2008: 3 field campaigns

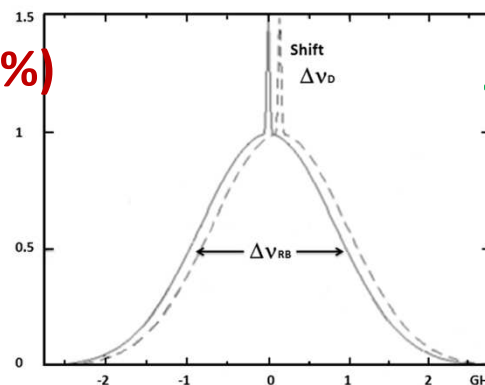
Courtesy C. Hostetler

LaRC High Spectral Resolution Lidar



**1064 nm Seed Laser Output (98%)
& Diagnostics Output (1%)**

**532 nm Iodine Filter
Scan Output**



LaRC High Spectral Resolution Lidar

- Seed Laser
 - Innolight, GmbH, Prometheus
 - CW output at both 1064 and 532 nm
 - Tuning range >90 GHz at 532 nm
- Pulsed Laser
 - Fibertek, Inc.
 - SLM using ramp-and-fire frequency control technique
 - 200 Hz
 - Energy (after transmit optics)
 - 2.5 mJ @ 532 nm
 - 1.1 mJ @ 1064 nm
 - Spectral purity > 5000:1
 - Spectral purity monitored for every laser shot

LaRC High Spectral Resolution Lidar

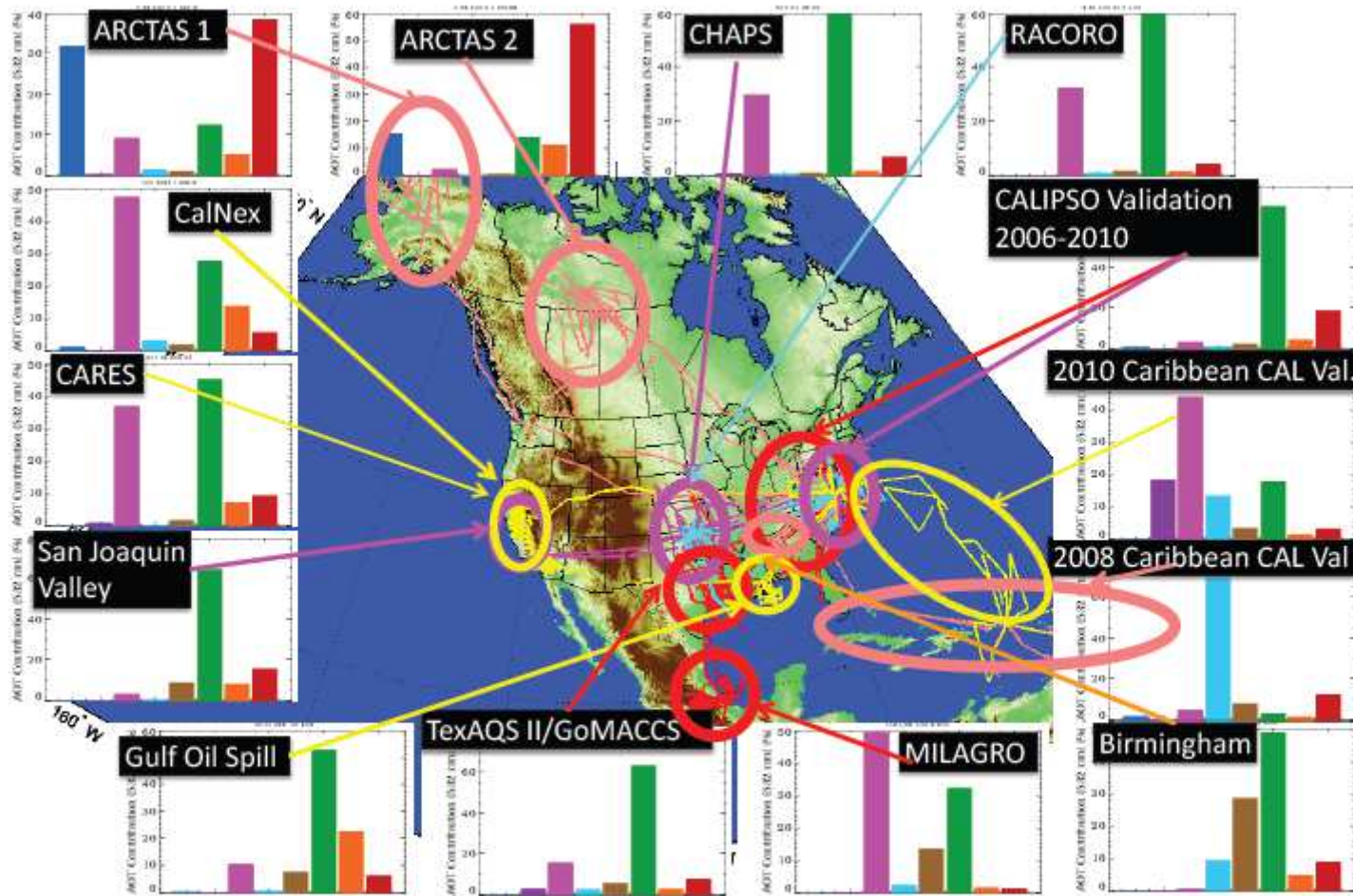


Fig. 18. All HSRL missions through 2010 are shown, along with the partitioning of total optical depth among the eight aerosol types for each of these missions. Several CALIPSO validation campaigns in the Eastern US and off the east coast have been grouped together in the single category "CALIPSO Validation" in this figure.

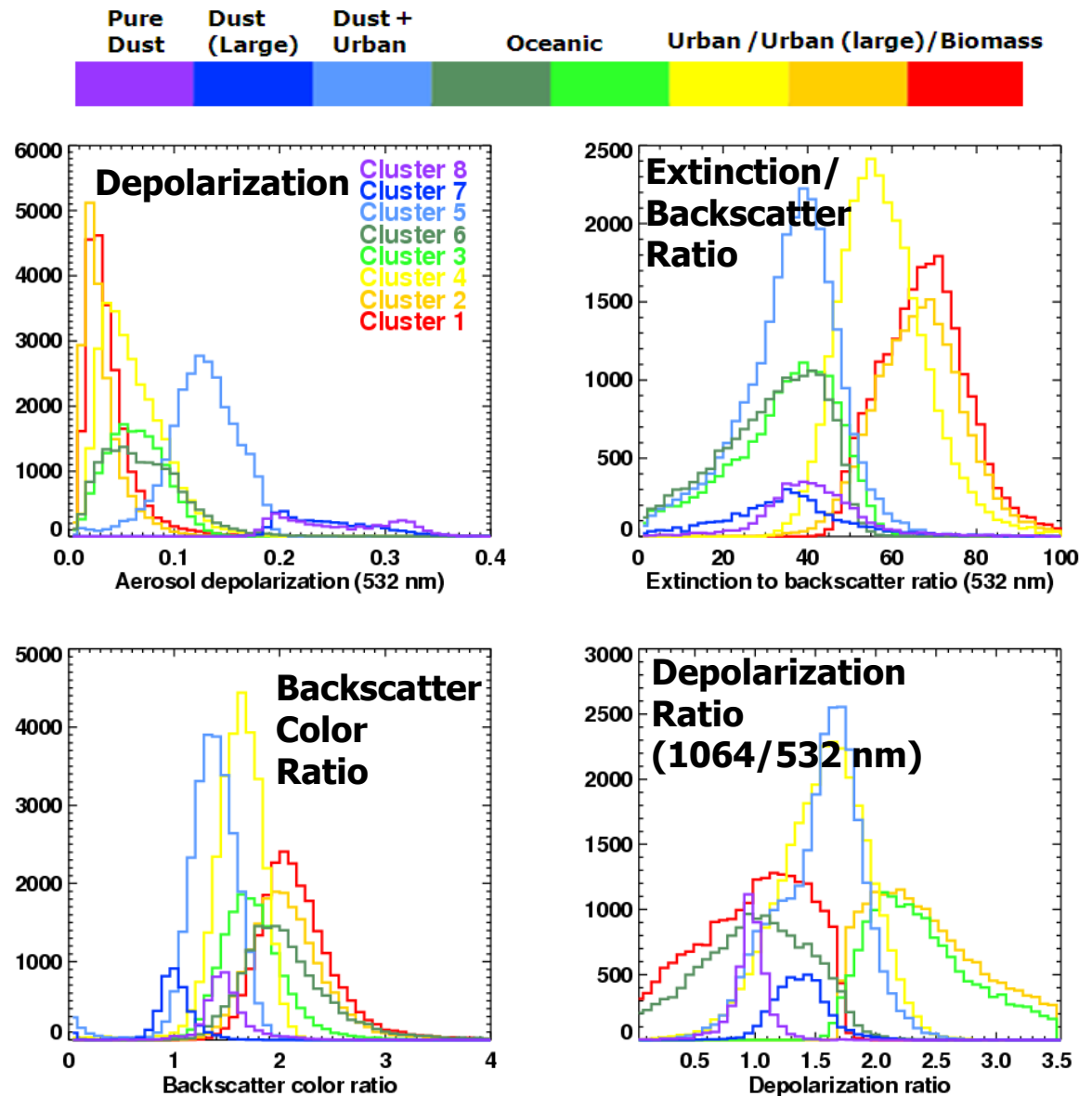


Aerosol Classification using HSRL measurements

Aerosol classification is based on HSRL measurements of aerosol intensive parameters

- Extinction/Backscatter Ratio (~absorption)
- Depolarization (~spherical vs. nonspherical – dust/ice)
- Backscatter Color Ratio (~size)
- Depolarization Ratio (1064/532 nm) (~nonspherical/spherical size)

The HSRL measurements of aerosol intensive parameters were used in an objective cluster analysis scheme to discriminate aerosol type. These aerosol types were subjectively related to the aerosol types inferred from AERONET data by Cattrall et al. (2005).



LaRC High Spectral Resolution Lidar

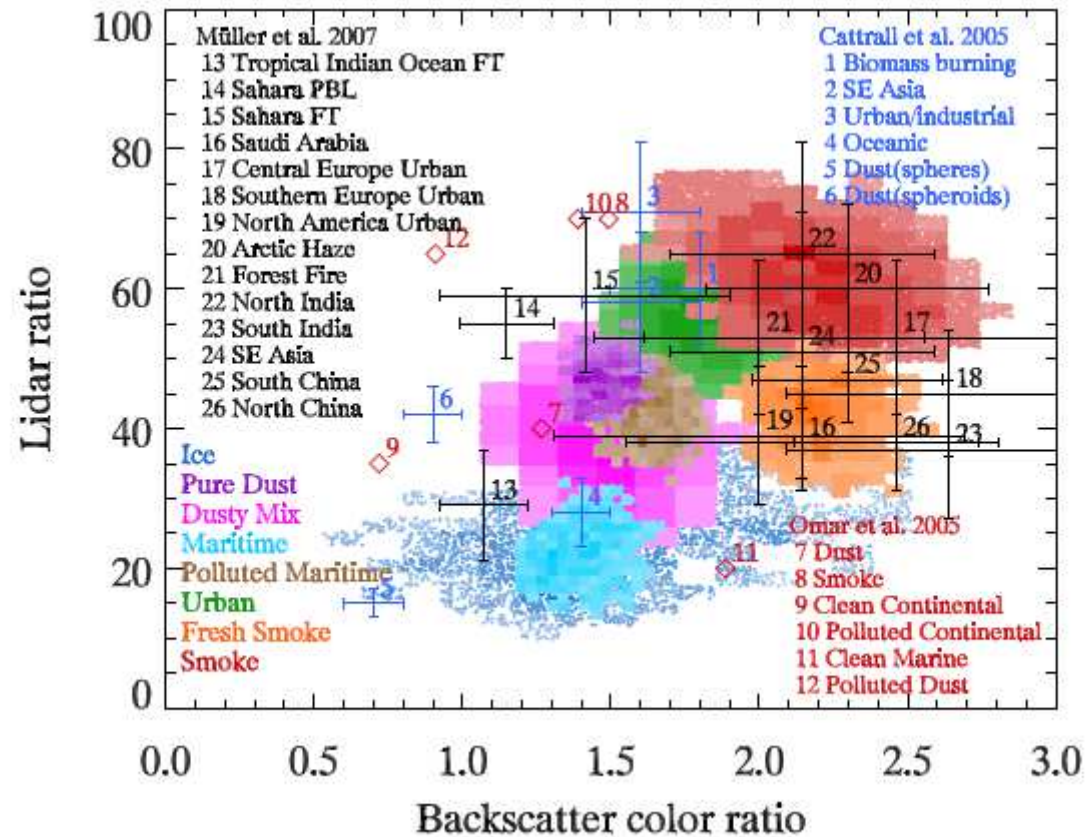


Fig. 11. The results of the classification of HSRL measurements are shown here, projected onto a two-dimensional subset of the four dimensional space. HSRL measurements are color coded by inferred aerosol type, with the saturation in each hue indicating relative population density. Points are shown for the most populous bins such that about half of the population of each cluster is represented. Also indicated in this figure are the aerosol types identified by Cattrall et al. (2005), Omar et al. (2005), and Müller et al. (2007a). (Some of these variables have been inverted to conform to the axes chosen here).

LaRC High Spectral Resolution Lidar

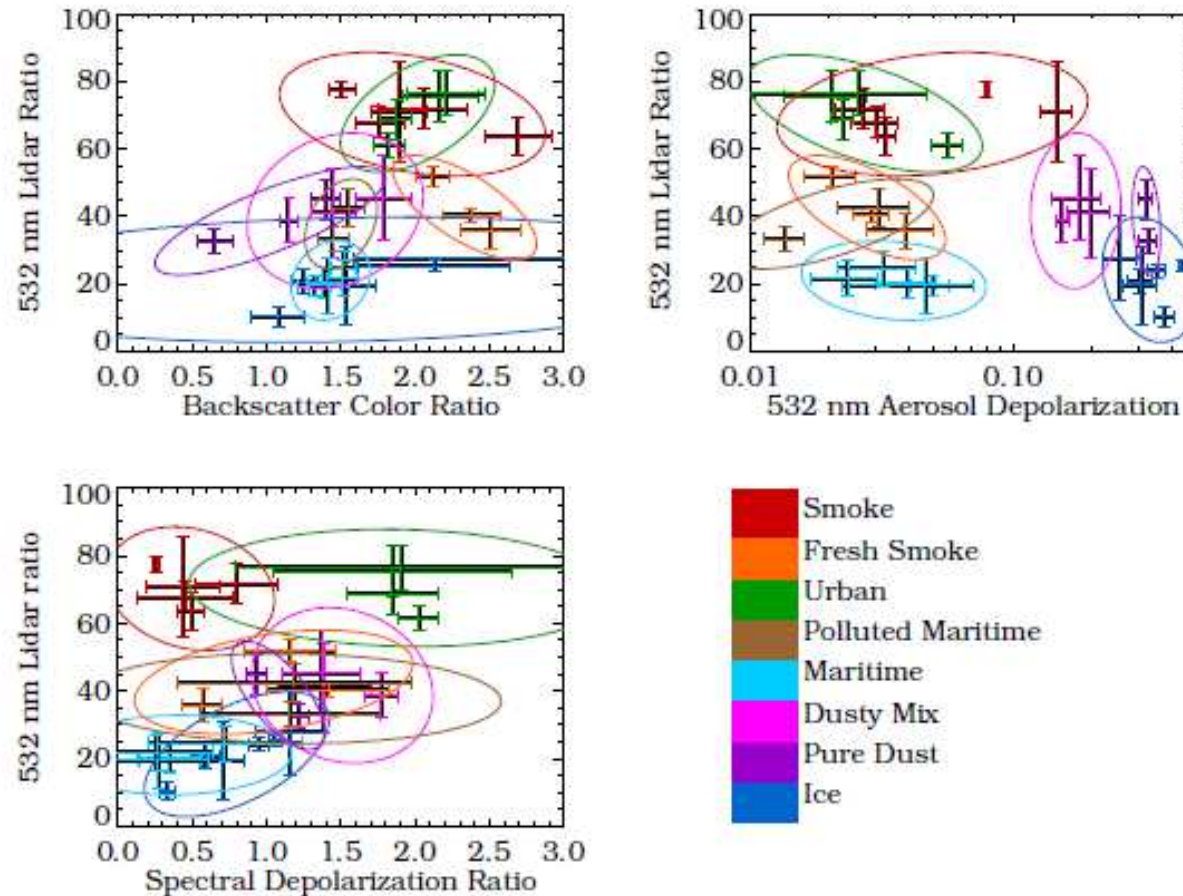


Fig. 4. Illustrates the models used in the aerosol classification algorithm in three projections of a space defined by the four aerosol intensive variables measured by HSRL. Crosshairs indicate data samples of known type as mean and standard deviation of the four variables. The aerosol type models that are based on these samples are indicated by two-sigma ellipses, calculated using the eigenvectors and eigenvalues of the model covariance matrices.

MERCI DE
VOTRE ATTENTION