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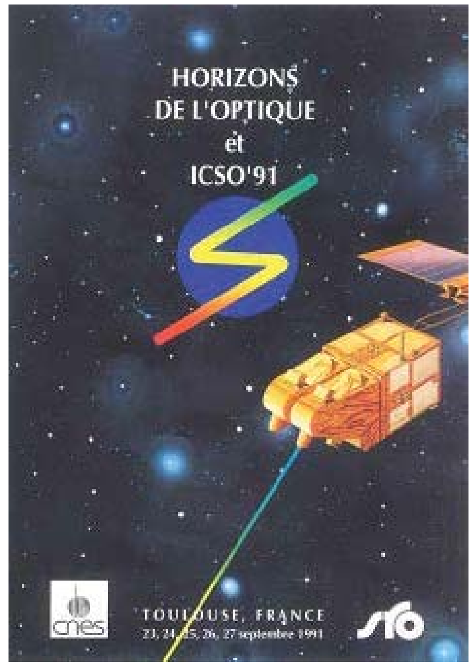

Session 5: Active Sounding

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LE LIDAR SPATIAL ALISSA
EMBARQUE SUR LA PLATEFORME SOVIETIQUE MIR

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Le lidar ALISSA (initialement : l'Atmosphere par LIdar Sur SAliout) est destiné à voler en 1992 dans le modèle NATURE (PRIRODA) qui sera placé sur la plateforme soviétique MIR. Il devrait être le ou l'un des deux premiers lidars embarqués.

L'objectif principal de la mission est la description fine de la partie supérieure de la couverture nuageuse. La connaissance précise de l'altitude de couches nuageuses est en effet essentielle pour décrire le rôle des nuages dans le bilan radiatif. Le but de cette mission exploratoire est d'estimer l'intérêt que présenteraient de tels lidars à bord des satellites opérationnels pour l'interprétation des mesures radiométriques. Celles-ci aujourd'hui représentent la base essentielle de notre connaissance actuelle des nuages et de leur répartition globale. L'étude couplée des mesures lidar et radiométriques effectuée simultanément sur des régions correspondant aux images Meteosat devrait aider à répondre à cette question.

Le lidar ALISSA est un lidar utilisant la rétrodiffusion d'un faisceau laser par les particules et gouttelettes. Dans cette première version simplifiée une seule longueur d'onde, le 2ème harmonique d'un Nd-Yag, est utilisée. Les caractéristiques du lidar sont les suivantes :

- Energie laser : 40 mJ à 50 Hz à 532 nm
- Diamètre du télescope de réception: Ø = 40 cm
- Champ de réception 10^{-3} radian (mesure de nuit seulement)
- Chaîne d'analyse par comptage donnant une résolution de 150 m
- Visualisation en temps réel.

Les lasers Nd-Yag très compacts sont fournis par les soviétiques. Les autres éléments sont de conception et de fabrication française. Une des principales originalités de ce lidar réside dans la conception du télescope utilisant des éléments d'optiques adhérés moléculairement sur une grande surface (Ø = 40 cm). Prismes de renvoi et miroir secondaire sont fixés sur la face avant du télescope éliminant ainsi les réglages mécaniques difficiles à réaliser en vol.

Le système sera décrit et les résultats des essais réalisés avec le modèle de vol seront présentés.

TOWARDS THE OPTIMISATION OF DUAL COLOUR SELECTION IN SUB-CENTIMETRIC LASER RANGING

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ABSTRACT

The state-of-the-art in laser ranging applied to the study of *long* baseline earth geo-dynamics is such that these measurements are derived from highly accurate, index-corrected determinations of the round-trip flight-time of a single-wavelength laser pulse. At present several such stations, situated around the globe, regularly achieve satellite and moon range determinations with centimeter to decimeter accuracies.

With the scientific drive for accurate studies of the earth's tectonics, crustal deformations, and ocean deviations from the nominal geoid, the need for global sub-centimetric accuracies arises. To this intent, NASA is presently planning the development of GLRS (Geoscience Laser Ranging System), a satellite-based dual-wavelength payload capable of ranging to a large number of passive retroreflector targets strategically sited around the globe.

Adequate correction for atmospherically induced ranging errors, traditionally based on the measurement of **T**, **P** and P_v, (temperature, total pressure & partial water vapour pressure) will require remote 'sensing' of this contribution, if the targets are to remain passive and optimal accuracies are to be achieved. The preferred solution for index correction, in this context, is the implementation of simultaneous, self-calibrating dual-colour ranging.

Although this technique has until recently been considered in terms of the potential of a limited number of wavelength pairs - the limit being imposed by laser type, pulse energy and width, and harmonic wavelength usefulness - the recent advent of large bandwidth crystal, picosecond domain lasers (such as that of Titanium/Saphire) has opened up new possibilities of system tuning. In effect the system ranging accuracy, although dependant on timing equipment performance, is also intricately related to the choice of wavelengths and the strength of the detected return signals.

In the following paper a brief review is given of the principal notions relevant to dual-wavelength laser ranging, followed by the presentation of results derived from numerical simulations of link budget, used to analyse the expected ranging accuracy performance.

THE ATMOSPHERIC LIDAR (ATLID)

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In the frame of the ESA First Polar Mission study, MATRA has conducted in 1989 the phase A of the Atmospheric Lidar in collaboration with ADLAS (Germany), DORNIER (Germany), LABEN (Italy) and QUANTEL (France). ATLID is an active instrument which will give informations on the lower atmosphere (0 to 15 Km range) by measuring the light of laser pulses backscattered by clouds and aerosols : the altitude and constitution of atmospheric objects will be derived from the precise sampling and datation of the detected signal.

The study has been carried out in two stages : first a trade-off phase dedicated to parametric analysis of the main subsystems : QUANTEL, DORNIER and ADLAS have analysed the performances, design, and feasibility of 3 pre-selected laser configurations. In parallel, MATRA has addressed the receiver design and the overall system performance. A baseline instrument has been issued for the detailed design phase : this paper briefly describes this baseline.

The instrument : transmitter, scan assembly and receiver

The transmitter is a Nd:Yag slab, side pumped by laser diodes, with a pulse repetition frequency of 100 Hz, and a mean pulse energy of 100 mJ at $\lambda = 1.06$ µm. The laser cavity operates in longitudinal and transverse multimodes in order to obtain the best wall-plug efficiency which is estimated between 4 and 6%, depending on the ageing of the diode stacks. Power supply and dispatching to the diodes is processed by the Laser Control Unit which monitors the output pulse energy. To optimize the efficiency, the temperature of the diodes shall be accurately controled around 0°C : given the high power consumption of the diodes (≈100W), the stacks are directly connected to the radiators by means of Variable Conductance Heat Pipes. An external beam expander is implemented to reach the 100 µrd divergence requirement.

TRANSMITTER TECHNICAL SPECIFICATION SUMMARY

Host material	Nd:Yag	Wavelength	1.064 µm	Pulse start monitoring	50 ns
Pulse energy	> 100 mJ	Beam divergence	100 µrd	Polarization	Linear
Energy monitoring	± 5 %	Beam diameter	< 60 mm	Lifetime	3 years
Pulse Repetition Freq.	100 Hz	Short term stability	± 10 µrd	Operations	Continuous
PRF stability	± 1 %	Long term stability	±200 µrd	Mass budget	30 Kg
Linewidth	1 A	Cavity mode	Multimode	Size	0.5x0.2x0.2
Frequency stability	± 0.1 A	Peak intensity	<100MW/cm^2	Power budget	220 W

The scan assembly provides the 1400 Km ground track scanning. This function is performed by an elliptical mirror at the instrument entrance : the scan period is 2.23 s, resulting in a grid pattern of 15 Km x 7.5 Km on ground sub satellite point. Due to the laser pulse roundtrip time, the pointing direction is different for the transmitter and the receiver : this offset is corrected by a two mirror Beam Steering Device (BSD) located at the transmitter output. The processor of the Instrument Control Unit (ICU) computes in real time the laser pointing direction.

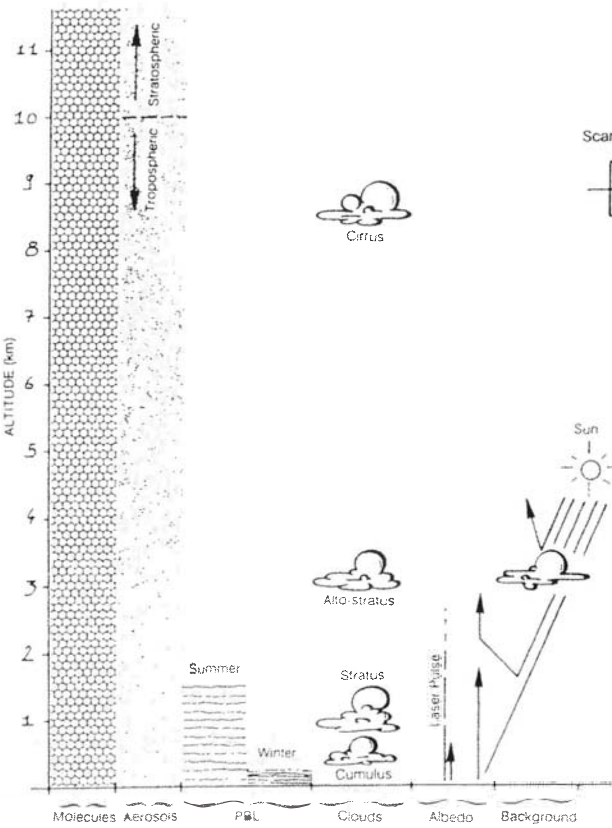
The backscattered light is collected by a 500 mm diameter Cassegrain telescope. The tight alignment with the transmitter is periodically calibrated by means of a corner-cube fixed on the scan mirror which retroreflects the laser light towards a 4-quadrants detector at the telescope focal plane. Within the receiver FPA, the beam is collimated, filtered and split in two polarization chains. During day-time, spectral filtering and instrument FOV are optimized to limit the background signal. The detectors are avalanche photodiodes which are well adapted to the large signal dynamic range.

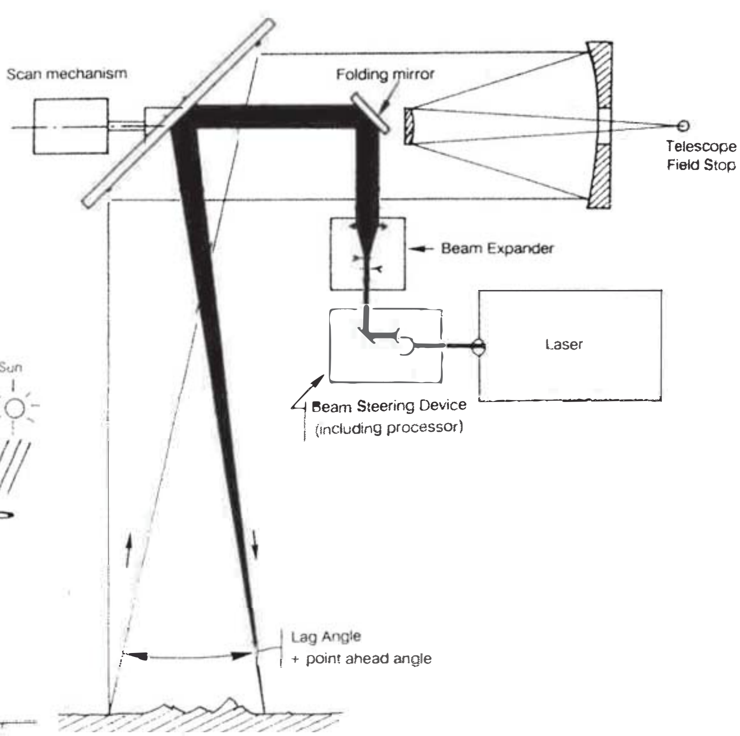
The electrical architecture, including detection and processing electronics, command and control electronics and power distribution has been designed to match the Polar Platform standard interface requirements.

Performance summary

ATLID will provide considerable useful informations on the atmosphere, of prime interest for meteorology and climatology. The radiometric performances have been computed on the basis of a dedicated Reference Atmospheric Model elaborated by ESA. Most of the measurements are performed with a comfortable signal to noise ratio with the 500 mm aperture telescope : marginal performances occurs for day-time observations of cumulus under cirrus and Planetary Boundary Layer (PBL), because of the high background due to the diffusion of sun light. The summer PBL requires an averaging over larger areas because of its very faint backscattered signal.

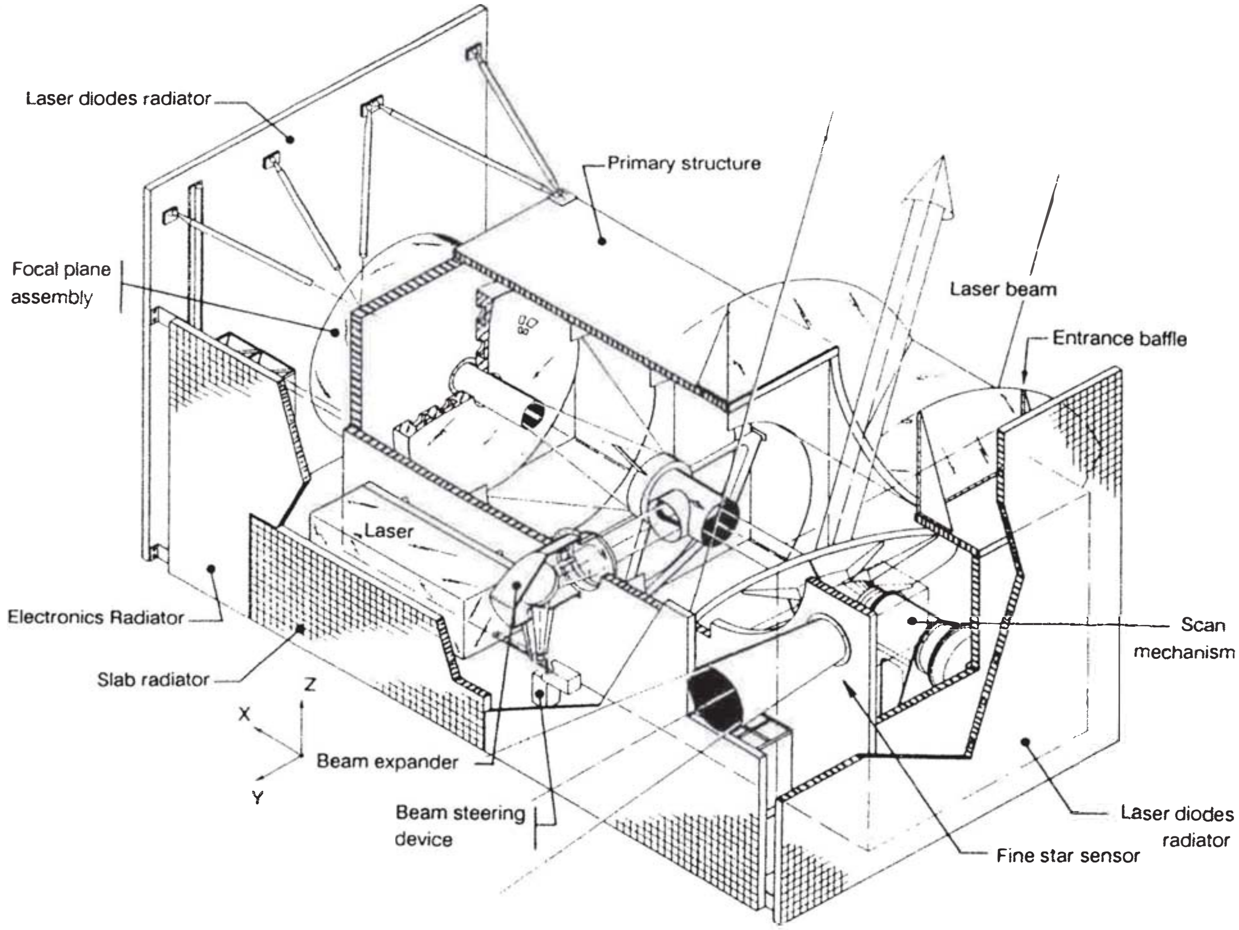
Each sample of the received signal is associated to a set of coordinates determined in a local earth reference frame : the altitude of the considered atmospheric layer is of major importance for the mission scientific return. The altitude restitution accuracy depends on the instrument optical alignment and stability, but also on the platform pointing accuracy ; a detailed analysis has demonstrated that a Fine Star Sensor shall be implemented in the instrument to enhance the Polar Platform pointing restitution.





ATLID PERFORMANCE SUMMARY				
TYPE OF MEASUREMENT	SNR SPEC.	MEASUREMENT / HORIZONTAL RESOL.	SPECIFICATION MET DURING :	COMMENTS
-Cloud top height	2-3	Single shot / 15 Km		
Altostratus			Day & Night	
Cirrus			Day & Night	
Cumulus under cirrus			Night	Day with 15x15 Km^2 averaging
-Cirrus extent	5	Averaged / 50 Km	Day & Night	
-Cirrus optical depth	20	Averaged / 100 Km	Night	SNR = 10 for day-time
-PBL top height	2-3	Averaged / 100 Km	Day & Night	
-PBL optical depth	6	Averaged / 100 Km	Day & Night	Winter only
[illegible]		Nadir	75 m	

Instrument layout and main characteristics



MAIN CHARACTERISTICS OF THE ATMOSPHERIC LIDAR

-Scientific objectives	Climatology, Meteorology	-Instrument principle	Emission of laser pulses Detection of backscattered signal
-Observations	Clouds: 0 -> 15 Km range Top height, Extent, Optical depth, Mapping Planetary Boundary Layer (PBL) 0 -> 2 Km range Top height, Optical depth	-Transmitter	Nd:Yag slab side pumped by laser diodes stacks 100 mJ pulses, 100 Hz frequency Wavelength : 1.06 µm Beam divergence : 100 µrd
-Orbit	Heliosynchroneous Descending node local time: 10:00 Altitude: 800 Km (Polar Platform)	-Receiver	500 mm aperture Cassegrain telescope Two polarization chains Fabry-Perrot narrow band filters Avalanche photodiodes detectors
-Earth coverage	Continuous operation 1400 Km swath width Sinusoidal scan 15 Km ground spot pattern 3 days earth coverage	-Budgets	Mass 250 Kg (incl. 20 % cont.) Power 400 W (end of life) Size 1.9m(X) x 1m(Y) x 1m(Z) Data rate 615 Kbits/s

ATLID - A SPACEBORNE BACKSCATTER LIDAR

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ATLID - A Spaceborne Backscatter Lidar

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Results of a study dealing with the conceptual design of a spaceborne Atmospheric Lidar instrument (ATLID) are presented. ATLID is intended as a pre-operational core-instrument for one of the Polar Platform Missions, a series of future European earth observation satellites for the years around 2000. Operating for three years in 800 km height ATLID shall provide data to determine the height of

- Cirrus, Altostratus, and Cumulus clouds with a height accuracy of 100 m and 10 km horizontal resolution and
- summer and winter planetary boundary layers (PBL) with a height accuracy of 100 m and 100 km horizontal resolution.

Besides the height of the scatterer, its strength and depolarisation properties can be measured. Global data coverage with an average laser footprint spacing of 10 km is provided in less than three days requiring a swath width of ± 700 km which requires a scanning lidar with a scan anlge of ± 40°. This large scan angle is a new demanding specification for such an instrument.

Special care was taken to reduce power consumption, mass, and volume. The reductions result from the novel design architecture selected for ATLID.

A number of trade-off studies were performed leading to the optimal layout of ATLID.
The novel ATLID architecture avoids the conventional scanning mirror which is reflecting the backscattered signal into the (stationary) telescope. Instead, the telescope (assembly) itself is scanning. The telescope assembly consists of a set of four rectangular telescopes mechanically coupled but separately adjustable. Fiber optics is used to guide the signal to the (stationary) detection packages. Such an architecture has already been successfully applied in a few ground-based lidar instruments.

This novel design has advantages if a large primary telescope mirror has to be used as it is necessary to achieve the performance goals of ATLID. Compared to a stationary telescope with a scanning mirror the scanning telescope then promises

- reduced instrument size and
- lower instrument mass,

because the large scanning mirror can be omitted. A further advantage is the

- improved measurement performance,

because due to the rectangular form the available space is better utilized than in the conventional systems and, consequently, the receiving area can be doubled. Alternatively, keeping the measurement performances as for the conventional design, laser transmitter power and thus prime power consumption can be reduced significantly. An

- easier rejection of stray light from the transmitted laser pulse and from background radiation

is also possible.

However, potential drawbacks of this concept have been recognized, in particular the

- larger mass to be scanned

requiring a more difficult momentum compensation. Furthermore, it has to be ensured that the

- non-standard structural design

provides the required rigidity to survive launch and to maintain the alignment of the instrument for a three years period of continous operation. Finally, the

- use of fiber optics in the receiver section

potentially leads to higher optical losses. These critical design features have been investigated in detail.

WIND an airborne coherent Doppler lidar for atmospheric applications

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An airborne Doppler coherent lidar for mesoscale wind field measurement is under developpement as a joint project between France (CNRS/CNES/DMN) and Germany (DLR). The instrument is designed around CO_2 lasers technology and heterodyne detection. The 9-11 µm emission domain coincides to an "atmospheric window" suitables for long range measurement. The measurement objectives are a 1 m s^{-1} accuracy for radial velocity (along the line-of-sight) and a 300 m vertical resolution. The wind field will be derived using an assimilation technique (optimal, and ultimately variational), combining various radial velocities. The instrument will be flown at first on the french Fokker F-27 and on DLR Falcon. These two platforms cover the range of meteorological applications. The sampling and resulting horizontal coverage depends on the flight altitude, aircraft speed, conical scan angle and duration, and laser transmitter pulse repetition frequency. A combination of all these parameters result in a several hundred meters size grid at the ground. The vertical resolution results in a combination of several factors which include the transmitter pulse length and shape, the signal processor characteristics and processing algorithm. The accuracy on radial velocity depends on the Signal to Noise Ratio (SNR) and signal processing algorithm. The SNR is determined by the transmitted energy, the receiver collecting area and other instrumental parameters as well as the atmospheric backscatter coefficient and transmission. It depends on the heterodyne efficiency which is a function of instrument parameters and atmospheric properties such as the index structure function (Cn^2). Also, it takes into account the speckles effect.

The WIND instrument sub-systems are : a TE-CO_2 laser transmitter, a transceiver optics made of a telescope and a scanning system, a heterodyne detection package including an HgCdTe photomixer and a cw CO_2 laser acting as a local oscillator, a signal processor with an RF electronics section and transient digitizers, a servicing electronics and a computer. The on-board signal processing involves several steps. After the photomixer the intermediate frequency signal is corrected from the aircraft motion and scanning position prior the generation of the In-phase (I) and quadrature (Q) components. Then a wired processor will calculate in real time the radial velocity and wind field at selected altitudes. At the present, several algoritms are studied which all have advantages depending on the experimental conditions : Covariance (poly-pulse-pair), Fast Fourier Transform, and recursive filter (Adaptative Notch Filter). For each flight, the raw lidar signals (0 level data) will be stored with the corresponding aircraft and instrument information useful to process the data on the ground.

The french team will provide the following sub-systems : the transmitter, the heterodyne detection package and a real time Doppler processor. The principle of an airborne coherent Doppler lidar will be reviewed during the presentation and the sub-systems described. The WIND project organization and the various developpment phases will be presented until the instrument integration in the aircraft.

BEST PROJECT FIRST ASSESSMENT OF DOPPLER WIND LIDAR FEASIBILITY

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1 - INTRODUCTION

The BEST mission is part of the GEWEX program, which is envisaged under a world-wide cooperation around the year 2000, in order to study the overall energetic budget of the earth atmosphere. The Wind Lidar is one of the instruments expected to be embarked on this platform ; its mission is to measure the vertical profile of the wind within the atmosphere from 0 to 20 Km altitude. The design goal is to achieve an overall measurement accuracy of 1 to 3 m/s, with an altitude resolution lower than 1 Km from an orbit which altitude is 430 to 520 Km with an inclination of 28.5 degrees. System studies are performed by CNES while MATRA, associated to GEC-FERRANTI (UK) and BERTIN (F), is responsible of the study of the main critical points of the instrument, including the overall architecture, in the frame of a CNES contract.

2 - INSTRUMENT CONCEPT

The general concept is based on CO_2 laser transmitter (9.1 to 9.3 micron) due to stringent output power performances. The main principle is to perform a measurement over the same area in two different directions from the instrument and thus, assuming negligible vertical component of wind speed, assess the module and orientation of horizontal component.
This dual measurement is achieved through a cycling among 2 to 4 fixed telescopes (4 for improving the coverage periodicity) at approximately 45° apart from the NADIR direction, as illustrated in figure 2/1.
The received signal (transmitted signal backscattered by the earth atmosphere) is mixed with a local oscillator in order to perform heterodyne detection. After a coarse on board compensation of satellite and earth doppler shifts (respectively $\pm$ 800 MHz and up to $\pm$ 70 MHz) the wind doppler shift (up to $\pm$ 10 MHz) is extracted on ground with the required accuracy.
The main challenges of this instrument are related to the laser transmitter itself (high energy, high frequency stability, 3 years lifetime) and to the doppler shift extraction which requires to know very accurately (around $\pm$ 100 urd) at any time, possibly after some ground processing, the actual pointing direction. A preliminary laser transmitter specification is provided in figure 2/2.

3 - PRELIMINARY INSTRUMENT ARCHITECTURE AND BUDGETS

A typical instrument configuration is illustrated in figure 3/1, on which the main building blocks are shown. On one side of the optical bench, the four 0.8 m telescopes assembly can be identified. They are protected from the space environment by an almost closed structure in order to reach an accurate thermal control of the whole and thus good thermo-elastic stability (pointing direction knowledge). New materials could also be envisaged for it. On the other side of this optical bench appear the focal plane with mainly the laser transmitter and the detection block with its associated active cryocooling assembly. An instrument attitude reference (pointing direction knowledge) shall also be implemented, not too far from this focal plane ; it is proposed to materialize it by a block of 3 to 4 star sensors (including redundancy). Apart from these important elements, 4 to 5 m^2 of radiators are necessary on the sides of the instrument, for thermal control purposes.
The overall expected volume is around 2x2x2 m^3 while in terms of mass/ power, it should be in the range 600 to 1000 Kg/ 800 to 1000W.

4 - CONCLUSIONS

This instrument is representative of a new class of active instruments among the "LIDAR" type. The requirement for accurate pointing direction knowledge and good short term pointing stability (reception mixing efficiency constraint) calls for highly stable big structures and micro-vibrations characterization.
The expected Mass/ Power/ Volume figures are also quite impressive and require a new class of platform (e.g. Polar platform).

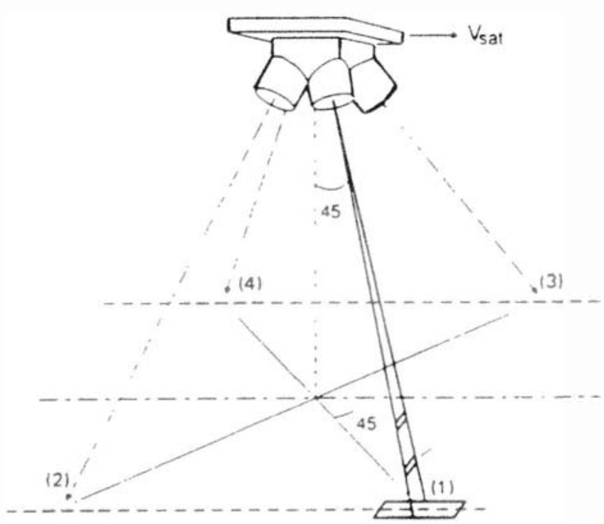

Figure 2/1 : Measurement principle

- Pulse energy	:	3 à 6 J
- Repetition Frequency	:	2 Hz
- Pulse duration (90% of energy)	:	5 us
- Wavelength	:	9.1 to 9.3 um
- Frequency stability		
. spectrum width including CHIRP (FWHM)	:	200 KHz
. central frequency variation between 2 pulses		
===> short term	:	+/- 100 KHz
===> long term	:	+/- 10 MHz
- Lifetime	:	2.10^8 shots over 3 years
- Overall efficiency	:	2.5 %
- Polarization	:	circular
- Beam divergence (long term)	:	1 mrd
- Beam direction fluctuations	:	+/- 200 urd
- Emission area	:	< 5 x 5 cm^2
- Overall volume	:	100x100x50 cm^3
- Total mass	:	200 Kg

Figure 2/2 : Preliminary transmitter specification

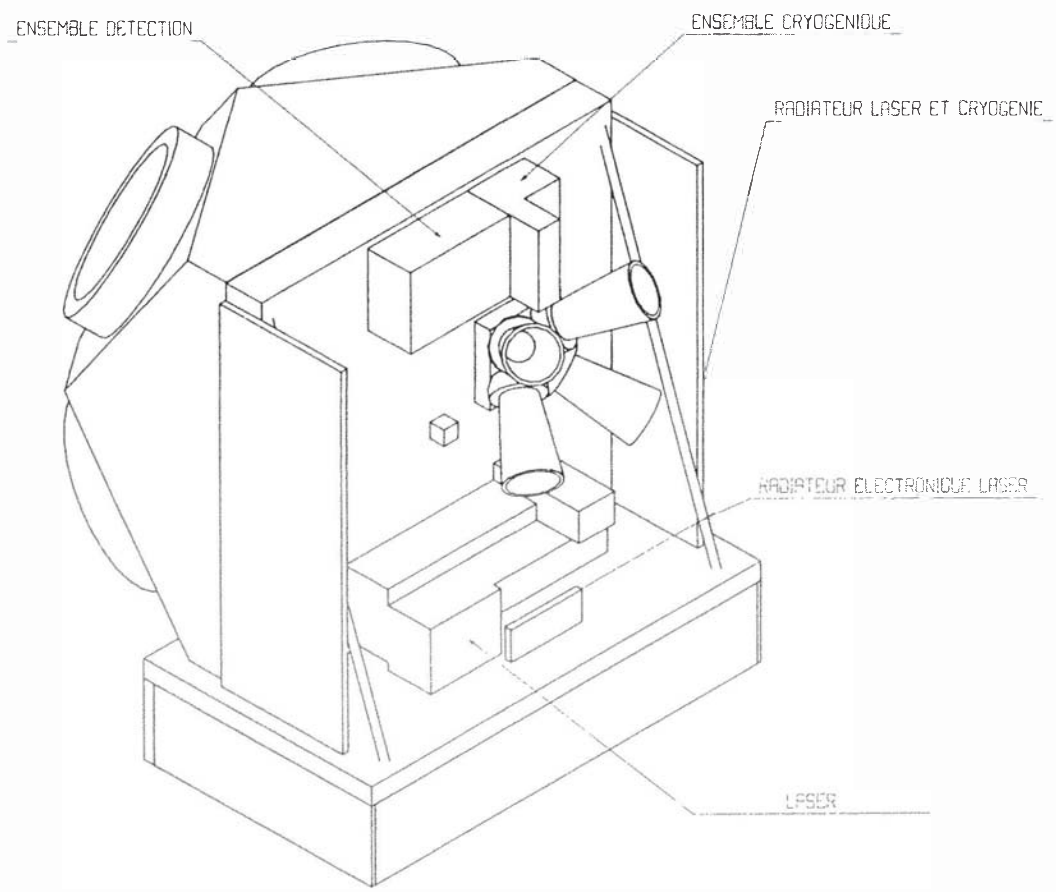

Figure 3/1 : Typical instrument configuration

THE FRENCH AIRBORNE LIDAR PROGRAMME LEANDRE

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Introduction

A new research programme LEANDRE for lidar application to meteorological studies is being developed in France by CNRS (Institut des Sciences de l'Univers (INSU), Service d'Aéronomie and Laboratoire de Météorologie Dynamique) and CNES. The scientific objectives of the LEANDRE programme are related to the study of the lower atmosphere, with specific emphasis on mesoscale boundary layer and free troposphere meteorology.

In this programme a backscatter lidar and a DIfferential Absorption Lidar (DIAL) are developed within two phases. Both lidars use solid state laser technology and similar optical and electronic systems. They will be implemented on board the IGN/CNRS/CNES/DMN research aircraft. This aircraft, a Fokker F27, is also instrumented with radiometry and numerous in situ sensors. The backscatter lidar has been completed in 1990, and the DIAL is under development. In phase 1 (L1) measurements are related to aerosol and cloud layer structure, and in phase 2 (L2) the capability of water vapour profiling will be added.

The LEANDRE programme is thus an important step for meteorological studies towards the future implementation of lidar systems on space platforms (ATLID, BEST...).

General description of the LEANDRE lidar systems

The LEANDRE lidar system is composed of a laser source (Nd-Yag for L1 and alexandrite for L2), a 30 cm receiving telescope, a mobile mirror designed for coaxial emission, zenith and nadir pointing and nadir cross-track scanning, four detection channels, and central computer (HP 1000/A900) for the experiment control and real time data processing. Subsystems are designed as compact, modular and automatized devices. Compactness is connected to a low weight allowed by the use of composite material structure.

Telescope field of view can be selected, its typical value being 4 mrd. Emission and reception axes alignment and lidar calibration are controlled prior to each flight. No in flight adjustment is required.

Due to the high photon density backscattered by the atmosphere, analogical signal detection is performed. High dynamics, fast recovery preamplifiers are mounted in the socket of detectors. Signals issued from up to three channels are fed into three 12 bits 10 Mhz transient digitizers. An additional 80 Mhz 10 bits digitizer can be used in parallel to one channel to zoom a selectable region of the atmosphere. Ground surface and cloud return signals are measured with a specific channel.

The central computer collects the information from all subsystem microprocessors, controls the signal averaging, data storage on a 2 Go video tape recorder and real time data analysis and display. Selected data from in-situ sensors and inertial navigation system are recorded simultaneously with lidar data.

LEANDRE I description

The L1 emitter is a Nd-Yag laser designed by Quantel for aircraft operation. It emits 130 mJ in the infrared at 1.06 μm and 70 mJ at 0.53 μm in 10 ns pulses at a 10 Hz repetition frequency. Divergence is controlled with a 7X beam expander for eye safety. Alignement of the cavity mirrors is controlled by an internal microprocessor.

The detection optical system is designed to separate the two wavelengths, and at 0.53 μm the two polarizations. Narrow bandwidth temperature controlled filters (0.5 nm) are used to limit the background noise for day operation. Detection in the visible is performed by photomultipliers. In the infrared a photomultiplier or an avalanche photodiode can be used. The surface and dense cloud top return measurement is performed in the infrared with an avalanche photodiode. High voltages are selected as other parameters using the central computer keyboard.

LEANDRE II description

In the second phase, the emitter is a double pulse alexandrite laser source emitting twice 50 mJ at 730 nm in 150 ns pulses with a 10 Hz repetition frequency. Spectral linewidth is 1 pm, and time separation between the ON absorption and OFF absorption pulses is 50 μs (1). Wavelength control and positionning is performed by a three stage Fizeau wavemeter developed by CNRS (2).

The two wavelength detection is sequential : one filter and one detector is used to analyze ON and OFF signals. Three detection channels are used : two for polarized and depolarized signals, and one channel for ground surface and cloud top/base return signal.

LEANDRE campaigns

The L1 system has been installed on board the Fokker in November 1989 for a first technological campaign. The first scientific campaign PYREX has been held last autumn to study the perturbation induced on the atmospheric flow by the Pyrenean barrier. Following campaigns will be devoted to marine cloud topped boundary layer studies.

Acknowledgments

This programme is developed under financial support of CNRS and CNES, and could not have been realized without the LEANDRE team composed of A. Abchiche, B. Brient, D. Bruneau, G. Cornet, F. Fassina, C. Leroy, C. Loth, J.P. Marcovici, M. Maillard, R. Poiet, B. Romand, G. Velghe, we want to thank particularly.

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