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15th Coherent Laser Radar Conference

Proceedings

TOULOUSE - June 22-26, 2009

THALES

LEOSPHERE
Lidar Environmental Observations

LOCKHEED MARTIN

Cover page :

Hopital La Grave et son dôme- Toulouse – France
View extracted from a mosaic of 6 km X 3 km made with a high-resolution, multi-spectral airborne digital camera PELICAN. Dimension of the image at ground : 800 m x 800 m –
Forward motion compensation during the exposure time: up to 2,5 m
Resolution : 20 cm
Coloured composition made with 3 of 8 available spectral plans
Spectral Width of a band: 30 nm on the 435 - 900 nm domain
Date: 26/04/2005 - 13:00 (UTC) – Aircraft height: 2400 m (7875 ft)–Aircraft Speed: 330 km/h (178 knts)

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15th Coherent Laser Radar Conference

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15th Coherent Laser Radar Conference

Conference Agenda

Day 1 - Monday, June 22, 2009		
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9:30 to 9:45	**Welcome and Opening Remarks**	
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	M. J. Khan 11:30 to 11:50	Ultra-sensitive, room-temperature THz detector using nonlinear parametric upconversion
	C. Latrasse 11:50 to 12:10	Low noise semiconductor lasers for remote sensing applications
	K. Mizutani 12:10 to 12:30	Conductive-cooled 2micron laser development for CO2 and wind measurements
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	G. J. Koch 14:30 to 14:50	Wind Measurement Intercomparisons using New Compact, Pulsed, 2-Micron, Coherent-Detection Doppler Lidar Transceiver
	G. D. Emmitt 14:50 to 15:10	Airborne Doppler wind lidar: more than just wind profiles from P3DWL in TPARC
	A. Brewer 15:10 to 15:30	Preliminary Shipborne Doppler Lidar Results from the VAMOS Ocean-Cloud-Atmosphere-Land Study Regional Experiment (VOCALS-REx)
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	Y. Durand 16:40 to 17:00	A-SCOPE: objectives and concepts for an ESA mission to measure CO2 from space with a lidar
	S. Ishii 17:00 to 17:20	Development of Coherent 2-μm Differential Absorption and Wind lidar
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	S. Rahm 9:50 to 10:10	Airborne Doppler Lidar Wind Measurements from Polar to Tropical Regions
	S. Lolli 10:10 to 10:30	Long Range Wind Lidar for Atmospheric Dynamics Studies
	H. Iwai 10:30 to 10:50	Comparison of dual-Doppler lidar measurements of wind with helicopter measurements
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	A. Belmonte 11:30 to 11:50	Performance of coherent lidar receivers using atmospheric compensation techniques
	M. Boquet 11:50 to 12:10	Analysis and optimization of Pulsed Doppler Lidar Wind Profile measurement process in complex terrain
	V. Banakh 12:10 to 12:30	Visualization of 2-D transverse velocity fields in the atmosphere
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	Y. Durand 14:20 to 14:40	Lidar technology pre-development in support of A-SCOPE, the ESA mission to measure CO2 from space
	L. Joly 14:40 to 15:00	Laser diode absorption spectroscopy for accurate CO2 line parameters at 2 µm. Consequences for space-based DIAL measurements.
	D. Sakaizawa 15:00 to 15:20	Complementary measurement with multi-positioned in-situ sensors and the 1.57 µm laser absorption spectrometer
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	M. J. Kavaya 16:00 to 16:20	Computer Simulation of Global Profiles of Carbon Dioxide Using a Pulsed, 2-Micron, Coherent-Detection, Column-Content DIAL System
	S. Brousmiche 16:20 to 16:40	Parameters Estimation of Wake Vortices in Ground Effect
	R. Frehlich 16:40 to 17:00	Data Requirements for Doppler Lidar Measurements of Winds from Space
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18:00 to 20:00	**Poster Session**	
	M. Valla 18:00 to 20:00	Image quality study in spectral domain for Synthetic Aperture Ladar
	L. Michaille 18:00 to 20:00	System design and preliminary characterisation of a fibre-based pulsed MOPA system operating at a wavelength of 2.05 mm
	D. Jacob 18:00 to 20:00	Coherent detection post detection SNR for receivers employing incoherent and coherent integration
	N. S. Prasad 18:00 to 20:00	All-solid-state UV transmitter development for ozone sensing applications
	M. C. Welliver 18:00 to 20:00	On the Use of Optical Amplifiers in Coherent Receivers

Day 3 – Wednesday, June 24, 2009

8:00 to 8:40	Reception and Registration	
8:40 to 10:20	**Session 8: Turbulence and Vortex detection systems**	
	N. P. Schmitt 8:40 to 9:00	A340 flight test results of a direct detection onboard UV LIDAR in forward-looking turbulence measurement configuration
	C. Besson 9:00 to 9:20	Pulsed 1.5 µm LIDAR for axial aircraft wake vortex detection

	C. Hill 9:20 to 9:40	Airport trials with the Aviation ZephIR coherent lidar
	M.Valla 9:40 to 10:00	1.5μm lidar for helicopter blade tip vortex detection
	C. Fujiwara 10:00 to 10:20	Features of dust devils in the urban area detected by a 3-D scanning Doppler lidar
10:20 to 10:50	Coffee Break	
10:50 to 12:00	**Session 9: Hard target (I)**	
	D. Jameson 10:50 to 11:20	Vibrometry with atmospheric compensation
	M. P. Dierking 11:20 to 11:40	Genetically Optimized Periodic, Pseudo-Noise Waveforms for Multi-Function Coherent Ladar
	J. Totems 11:40 to 12:00	Signal Processing Methods and Poly-Pulse Waveforms for Laser Vibrometry in Pulsed Mode
12:00 to 14:00	Lunch	
14:00 to 18:00	Visit to Airbus A380 Assembly Line Old City Tour	
19:00 to 23:00	**Conference Banquet**	

Day 4 - Thursday, June 25, 2009

8:00 to 9:00	Reception and Registration	
9:00 to 10:20	**Session 10: Imaging lidar**	
	R. L. Kendrick 9:00 to 9:30	Anisoplanatic wavefront error estimation using coherent imaging
	D. Marker 9:30 to 10:00	Volume control manifold for membrane adaptive optics
	T. E. Wenski 10:00 to 10:20	Multiple screen image correction for digital holography
10:20 to 10:50	Coffee Break	
10:50 to 12:30	**Session 11: Synthetic and multi-aperture systems**	
	T. J. Karr 10:50 to 11:20	Power, Aperture and Wavelength Scaling of Synthetic Aperture Laser Radar
	P. McManamon 11:20 to 11:50	Conformal EO Sub- Aperture Array Based Laser Radar with non mechanical beam steering
	A. J. Stokes 11:50 to 12:10	Increasing image contrast using Golay-like sparse aperture arrays

	I. Anisimov 12:10 to 12:30	High Resolution Sparse Aperture Imaging Testbed
12:30 to 14:00	Lunch	
14:00 to 15:30	**Session 12: Novel Systems (I)**	
	I. Shpantzer 14:00 to 14:30	Digital Coherent Optical interferometric Sensing in Vibrometry and Explosive Detection
	R. V. Chimenti 14:30 to 14:50	A review of sparse frequency linearly frequency modulated (SF-LFM) laser radar signal modeling with preliminary experimental results
	A.T. Pedersen 14:50 to 15:10	Investigation of noise in Lightwave Synthesized Frequency Sweeper seeded LIDAR anemometers from leakage through the AO Modulators
	V. Jolivet 15:10 to 15:30	Coherent combining on a remote surface of fiber amplifier arrays after propagation through turbulent atmosphere
15:30 to 16:00	Coffee Break	
16:00 to 17:40	**Session 13: Wind energy**	
	P. Lindelöw 16:00 to 16:30	From Prototype to Standardization – Five Years of LIDAR Anemometry in the Wind Energy Industry
	Y. L. Pichugina 16:30 to 17:00	Lidar study of the nocturnal boundary layer at the heights of modern wind-turbines
	R. Frehlich 17:00 to 17:20	Coherent Doppler Lidar for Wind Energy Research
	R. Parmentier 17:20 to 17:40	WindCubeTM pulsed Lidar compact wind profiler: Overview on more than two years of comparison campaigns

Day 5 - Friday, June 26, 2009

8:30 to 9:30	Reception and Registration	
9:30 to 10:10	**Session 14: Hard target (II)**	
	Peter Lutzmann 9:30 to 09:50	Off Line-of-Sight Measurements of Target Vibrational Features Using Laser Vibrometry
	Véronique Jolivet 09:50 to 10:10	Coherent laser radar vibrometry for modal analysis in earthquake engineering
10:10 to 12:30	**Session 15: Novel systems (II)**	
	N. Newbury 10:10 to 10:40	Precision ranging LIDAR using femtosecond fiber lasers
10:40 to 11:10	Coffee Break	
	G. Pillet 11:10 to 11:30	Wideband Dual-Frequency Lidar-Radar: Waveform Generation and Field Experiment
	J. W. Stafford 11:30 to 11:50	Holographic aperture ladar laboratory demonstration

	S. Abdelazim 11:50 to 12:10	All-fiber Coherent Doppler LIDAR for Wind Sensing
12:10 **12:30**	**Conclusion and adjourn**	

Conference Banquet :

Wednesday , June 24 19:00 to 23:00 at “Hotel-Dieu”

The Hotel-Dieu is at walking distance from the city centre.
The main entrance is at the intersection of the Pont Neuf and Rue de la Viguerie.

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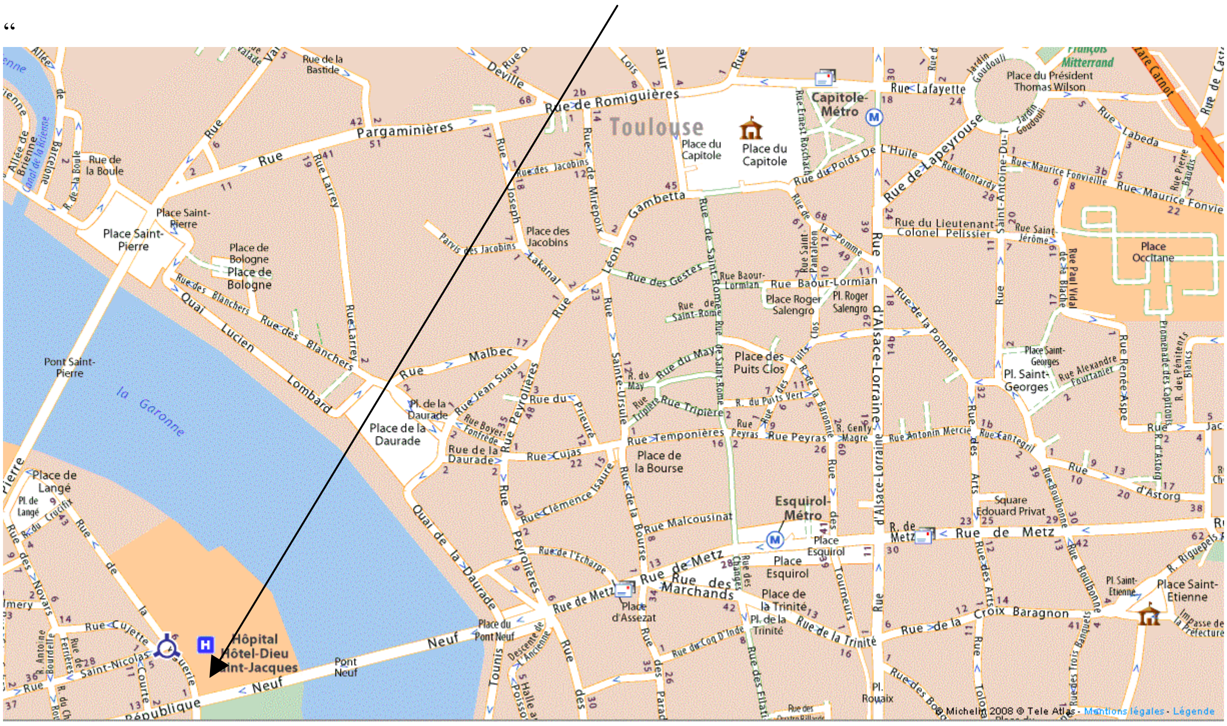

Short abstracts

Day 1 - Monday, June 22, 2009

Keynote Address 1
9:45 to 10:30

Reflections on interferometry

J. Michael Vaughan

Various historical, sometimes controversial, aspects of interferometry, spectroscopy and related topics which have interested the author over the years are discussed. These include coherence properties and cophasal surfaces, conditions for spectroscopic interference, Fabry –Perot operation and measurement of light scattering, comparison of coherent and direct detection, assessment of experimental accuracy and questions of scientific and engineering system choice set in a context of so-called paradigm shift. Many of these, it may be said, still have distinct relevance to present day tasks of laser remote sensing.

Session 1: Advanced component technologies

Chairman : H. Yoshihito.

11:00 to 11:30

High peak power Erbium-Ytterbium MOPFA for coherent Lidar Anemometry

G. Canat, L. Lombard, A. Dolfi-Bouteyre, S. Jetschke, S. Unger, C. Planchat, A. Durecu, J.Kirchhof

We report on an all-fiber high brightness pulsed 1.5µm laser source based on a MOPFA architecture with a large core fiber. The obtained beam quality is excellent (M2=1.3), achieved pulsed energy is 120µJ with a pulse repetition frequency of 12 kHz (or 220 µJ at 4 kHz) and a pulse duration of 800 ns. The MOPFA has been used in a coherent Lidar anemometer. We show that the interference between the few guided modes generate beam wandering which can be kept small enough to be compatible with Lidar use. An additional amplification stage has been added using a special multifilament core fiber. We then achieved pulsed energy of 800 µJ at 5 kHz pulse repetition frequency with M2=1.3.

11:30 to 11:50

Ultra-sensitive, room-temperature THz detector using nonlinear parametric upconversion

M. J. Khan, Jerry C. Chen, Zong-Long Liau, Sumanth Kaushik.

We demonstrate sensitive, room-temperature optical detection of terahertz by using nonlinear parametric upconversion. Terahertz radiation at 700 GHz is mixed with pump light at 1550 nm in GaAs crystals to generate an idler wave that is separated, coupled into optical fiber and detected using a triggered Geiger-mode avalanche photo-diode. We demonstrated a power sensitivity of 4.5 $pW/Hz^{1/2}$ using bulk GaAs. Recently, we fabricated quasi phase-matched (QPM) GaAs crystals, using a diffusion bonding process that has significantly enhanced the THz-to-optical conversion efficiency over bulk GaAs. In addition, we have designed 1550 nm AR coatings that have minimal losses at THz frequencies and have further improved the terahertz-to-optical conversion efficiency. The resulting room-temperature THz detector has a noise equivalent power of 800 $fW/Hz^{1/2}$ and a timing resolution of 1 ns.

11:50 to 12:10

Low noise semiconductor lasers for remote sensing applications

C. Latrasse, S. Ayotte, M. Aubé, A. Babin, F. Pelletier,F. Costin, I. Alexandre, J-F. Cliche, Y. Painchaud, M. Têtu.

Telecommunication-grade semiconductor lasers (SCL) are highly regarded for sensing applications: they are rugged, of small size, low weight and highly efficient. However their relatively high phase noise level is often a limitation for precise remote sensing applications. TeraXion has developed means to improve on natural

performances of SCL by locking their nominal frequency to the side of a frequency discriminator. For applications requiring a linewidth below 10 kHz, TeraXion has devised and packaged a narrow linewidth optical filter based on a phase-shifted Fiber Bragg Grating. Using this filter, the natural linewidth of a SCL is reduced from a few hundreds kHz to the kHz level, decreasing the laser frequency noise spectral density by four orders of magnitude. For applications requiring improved frequency stability, a molecular reference line can be chosen as locking reference. TeraXion has developed reliable and compact laser systems showing accuracy in the tens of MHz and frequency stability in the kHz range. A summary of the performances and applications of TeraXion's narrow linewidth semiconductor lasers and frequency controlled lasers is presented and performances discussed.

12:10 to 12:30

Conductive-cooled 2micron laser development for CO2 and wind measurements

Kohei Mizutani, Toshikazu Itabe, Shoken Ishii, Kazuhiro Asai, Atsushi Sato, Hirotake Fukuoka,Takayoshi Ishikawa

Moderate output lasers are needed for wind profile measurements and for CO2 DIAL measurements. We have developed a ground-based CO2 DIAL/Wind Doppler lidar system (Co2DiaWiL) with a conductive-cooled 2micron laser of 50-100mJ output at 20-30Hz and made test observations of LOS wind and CO2 concentrations. The system works well in these observations. We are also developing a compact mobile CO2 DIAL/Wind Doppler lidar system similar to Co2DiaWiL, but more compact and small. The laser oscillator will be operated in 50-100mJ output at 30-40Hz. It will be used for air-borne and ground-based observations. The lasers are conductive-cooled, laser diode pumped and eye-safe. Then, these are suitable for space-borne lidar to measure not only atmospheric CO2 and wind but also aerosol and cloud.

Session 2: Airborne and ground based wind measurement systems (I)

Chairman : G Ehret

14:00 to 14:30

Wind Resource Assessment Using Long Range Pulsed Doppler Lidar

Stephen M. Hannon

In the past two years, Lockheed Martin has adapted its pulsed Doppler lidar technology to support Wind Energy applications. Large area wind resource characterization has been a primary focus. Unlike sodar and short-range lidar devices, which measure wind profiles at a single location, the 3D scanning lidar can return accurate wind profiles over a large geographic area at high resolution. Initial evaluation of large-scale wind flow mapping using a single, scanning pulsed Doppler lidar has taken place and shows great promise. This paper presents results from wind resource assessment validation activities and efforts to improve spatial resolution of the resultant vector wind field. In addition to large area coverage for wind resource characterization, the long range Doppler lidar technology can provide improved energy management for operational wind farms, and progress along those lines is reported.

14:30 to 14:50

Wind Measurement Intercomparisons using New Compact, Pulsed, 2-Micron, Coherent-Detection Doppler Lidar Transceiver

G. J. Koch, Upendra N. Singh, Michael J. Kavaya, and Jeffrey Y. Beyon

Coherent Doppler wind lidar ground-based wind measurements and comparisons with other lidars and other sensors are presented. The pulsed coherent Doppler lidar system uses the state-of-the-art compact lidar transceiver recently developed at NASA Langley Research Center. The transmitter portion of the transceiver employs the high-pulse-energy, Ho:Tm:LuLiF, partially conductively cooled laser technology developed at NASA Langley. The transceiver is capable of 250 mJ pulses at 10 Hz. It is very similar to the technology envisioned for coherent Doppler lidar wind measurements from Earth and Mars orbit. The transceiver is coupled to the large optics and data acquisition system in the NASA Langley VALIDAR mobile trailer. The large optics consist of a 15-cm off-axis beam expanding telescope, and a full-hemispheric scanner. Vertical and horizontal vector winds are measured, as well as relative backscatter. The data acquisition system employs frequency domain velocity estimation and pulse accumulation. It permits real-time display of the processed winds and archival of all data.

14:50 to 15:10

Airborne Doppler wind lidar: more than just wind profiles from P3DWL in TPARC

G. D. Emmitt

A new generation 1.6 um coherent lidar was deployed for its first time on a Navy P3 aircraft to participate in TPARC and TCS08 in the western Pacific in the fall of 2008. Usually from a flight level of 3000 meters MSL, the side window mounted bi-axial scanner directed the lidar beam in various patterns including conical down, conical up, nadir stares and near flight path rasters. In the vicinity of tropical cyclones, including 4 typhoons, these pattern options were used to collect curtains of wind profiles (every 1.5 km), data for wave spectra, foam and sea spray signals, and indicators of the presence of organized large eddies and aerosol distributions throughout the cloud free troposphere.

14:00 to 15:30

Preliminary Shipborne Doppler Lidar Results from the VAMOS Ocean-Cloud-Atmosphere-Land Study Regional Experiment (VOCALS-REx)

Alan Brewer, Sara C. Tucker, Ann M. Weickmann, Scott P. Sandberg and R. Michael Hardesty

Motion stabilized, shipborne Doppler lidar measurements made during a Southeastern Pacific coupled climate system field experiment are being combined with scanning C-band precipitation radar, vertically staring W-band cloud radar, in-situ aerosol optical and chemical measurements and LES modeling to study the processes controlling the properties of stratocumulus clouds. Of particular interest is the life cycle of precipitation related structures called Pockets of Open Cells (POC) that open large areas within a stratus deck and expose the ocean surface. The stratocumulus clouds and embedded POC have an impact on planetary albedo and are not handled well in global scale climate models.

Session 3: CO2 and other DIAL measurements (I)

Chairman : F. Gibert

16:00 to 16:20

High Repetition Rate Pulsed 2-Micron Laser Transmitter for Coherent CO2 DIAL Measurement

Upendra N. Singh, Yingxin Bai, Jirong Yu, Mulugeta Petros, Paul Petzar, Bo Trieu, Hyung Lee

Upendra.N.Singh@nasa.gov A high repetition rate, highly efficient, Q-switched 2-micron laser system as the transmitter of a coherent differential absorption lidar for CO_2 measurement has been developed at NASA Langley Research Center. Such a laser transmitter is a master-slave laser system. The master laser operates in a single frequency, either on-line or off-line of a selected CO_2 absorption line. The slave laser is a Q-switched ring-cavity Ho:YLF laser which is pumped by a Tm:fiber laser. The repetition rate can be adjusted from a few hundred Hz to 10 kHz. The injection seeding success rate is from 99.4% to 99.95%. For 1 kHz operation, the output pulse energy is 5.5mJ with the pulse length of ~50 ns. The optical-to-optical efficiency is 39% when the pump power is 14.5W. The measured standard deviation of the laser frequency jitter is about 3 MHz.

16:20 to 16:40

The A-SCOPE Project and After

P. H. Flamant

In the framework of the ESA's 3rd explorer mission, A-SCOPE a space based DiAL for CO_2 total column content measurement with accuracy of 1 ppm has been considered for launch in 2016 with 5 other missions. Three of them were dedicated to atmospheric applications and 3 to surface applications. For each of the 6 potential missions a phase "0" study has been conducted by two industrial consortium and 6 Mission Assessment Groups have been selected by ESA for sciences and technical purposes. Beforehand, a preliminary study "FACTS" was conducted by IPSL and a parallel study for greenhouse gases was conducted by DLR. At present, a science study addressing globally the performance of various space based sensors, passive and active, to achieve the requested accuracy on CO_2 flux retrieval for sink and sources identification is conducted by IPSL and NOVELTIS with the support of several scientists in Europe. In parallel to the feasibility studies for the advent of an active CO_2 mission in space, several experimental groups develop ground-based and airborne CO_2 DiAL systems, and very promising results have been reported. Following GOSAT, a JAXA's passive mission launched in January 2009, and in the view of a CO_2 active mission in the next decade this talk is intended to

retrace the road that has been covered in less that a decade to better know where we are, to review briefly what has been accomplished with A-SCOPE and where we plan go in the next future.

16:40 to 17:00

A-SCOPE: objectives and concepts for an ESA mission to measure CO2 from space with a lidar

Yannig Durand, Jérôme Caron, Paolo Bensi, Paul Ingmann, Jean-Loup Bézy, Roland Meynart

A-SCOPE (Advanced Space Carbon and Climate Observation of Planet Earth) has been one of the six candidates for the third cycle of the Earth Explorer Core missions, selected by the European Space Agency (ESA) for assessment studies. Earth Explorer missions focus on the science and research aspects of ESA's Living Planet Programme. ASCOPE mission aims at observing atmospheric carbon dioxide (CO_2) for a better understanding of the carbon cycle. Knowledge about the spatial distribution of sources and sinks of CO_2 with unprecedented accuracy will provide urgently needed process information about the global carbon cycle. A-SCOPE mission encompasses a new approach to observe the Earth from space based on a Differential Absorption Lidar. Though building on the efforts deployed by ESA since the early eighties in the advancement of critical technology for lidar systems, the proposed measurement concept is innovative and is supported by different current technology developments. The objectives and the proposed implementation of the mission are presented in this paper as well the instrument concepts and their performance as derived from the assessment studies.

17:00 to 17:20

Development of Coherent 2-μm Differential Absorption and Wind lidar

S. Ishii, K. Mizutani, H. Fukuoka, T. Ishikawa, H. Iwai, P. Baron, T. Aoki, A. Sato, K. Asai, T. Itabe

The National Institute of Information and Communications Technology has developed a coherent 2-μm differential absorption and wind lidar (Co2DiaWiL). At the last conference, we presented the outline of the coherent differential absorption lidar. We improved performances of the laser and some issues shown at the last conference. The laser operates at a pulse repetition frequency of 30 Hz and emits an output energy of about 80 mJ with pulse width of 150 ns (FWHM). Preliminary experimental CO_2 measurements were made by the Co2DiaWiL on December 4-5, 2007 and we successfully obtained CO_2 concentration. Experimental CO_2 measurements were made to examine the performance of the coherent differential absorption lidar in April, May, and August 2008. Results of the CO_2 measurements were compared with those measured by a co-located *in situ* sensor. The results obtained by the Co2DiaWiL agreed with the co-located *in situ* sensor. Experimental wind measurements were also made to examine the performance of the Co2DiaWiL on wind profiling in August 2008. We found a potential that the coherent wind lidar obtained line-of-sight wind speed in a range of longer than 20 km in a short integration time.

Day 2 - Tuesday, June 23, 2009

Keynote Address 2

8:45 to 9:30

Lidar evolution over the last 30 years:
witness and actor, a confrontation of world wide and local points of view

P. H. Flamant

It is undisputed that lidar started well before laser, but lidar started for good with Ruby laser in the early 60's. Since the late 70's, this presentation will retrace the parallel evolution of lidar here and there, as it was and as it stands today.

Session 4: Airborne and ground based wind measurement systems (II)

Chairmain : O. Lerille

9:30 to 9:50

Development of a Compact, Pulsed, 2-Micron, Coherent-Detection, Doppler Wind Lidar Transceiver

Michael J. Kavaya, Upendra N. Singh, Grady J. Koch, Jirong Yu, Bo Trieu, Mulugeta Petros, Paul Petzar

We present results of a recently completed effort to design, fabricate, and demonstrate a compact lidar transceiver for coherent-detection lidar profiling of winds. The novel high-energy, 2-micron, Ho:Tm:LuLiF laser technology developed at NASA Langley was employed to permit study of the laser technology currently envisioned by NASA for global coherent Doppler lidar measurement of winds in the future. The 250 mJ, 10 Hz compact transceiver was also designed for future aircraft flight. Ground-based wind profiles made with this transceiver will be presented. NASA Langley is currently funded to build complete Doppler lidar systems using this transceiver for the DC-8 and WB-57 aircraft. The WB-57 flights will present a more severe environment and will require autonomous operation of the lidar system. The DC-8 lidar system is a likely component of future NASA hurricane research. It will include real-time data processing and display, as well as full data archiving. We will attempt to co-fly on both aircraft with a direct-detection Doppler wind lidar system being prepared by NASA Goddard Space Flight Center.

9:50 to 10:10

Airborne Doppler Lidar Wind Measurements from Polar to Tropical Regions

S. Rahm, A. Fix, C. Lemmerz, O. Reitebuch, R. Simmet, M. Wirth, B. Witschas

In the past two years DLR has participated in several meteorological campaigns as COPS (Germany and France), THORPEX (Norway) and TPARC (Japan). Consequently the obtained data covers the region from polar weather over mid-latitude to tropical cyclones. At all campaigns the DLR two micron Doppler wind lidar was installed in the Falcon aircraft together with the DLR 4-wavelength water vapor DIAL and a dropsonde system. With this instrumentation it was possible to obtain a wide rage of atmospheric profiles, e.g. wind, water vapor, pressure and temperature. This paper gives an overview of the three campaigns with the varying atmospheric conditions with focus on the coherent Doppler wind lidar data.

10:10 to 10:30

Long Range Wind Lidar for Atmospheric Dynamics Studies

S. Lolli, M. Boquet, J.P. Cariou, R. Parmentier, L. Sauvage

To fully understand atmospheric dynamics, climate studies, energy transfer and weather prediction, the wind field is one of the most important atmospheric state variables. Studies indicate that a global determination of the tropospheric wind field to an accuracy of 0.5 m/s is critical for improved numerical weather forecasting. Leosphere recently developed a new generation long range compact, eye safe and transportable wind Lidar capable to fully determine locally the wind field in real time in the planetary boundary layer (PBL). The WindCube WLS70 is a new generation wind Lidar developed for meteorological applications. The Lidar is derived from the commercial Windcube ™ widely used by the wind industry and has been modified increasing the range up to 4 km. In this paper are presented some first results of the intercomparison measurement

campaign (LUAMI) which took place in Lindenberg, Germany in December 2008. Measurements put in evidence both vertical wind speed and atmosphere structure (PBL height , clouds top and base) derived from Lidar data with good time resolution (10s/profile), good range resolution (50m from 100m to 4000m), and good velocity resolution (0.2m/s).

10:30 to 10:50

Comparison of dual-Doppler lidar measurements of wind with helicopter measurements

Hironori Iwai, Shoken Ishii, Nobumitsu Tsunematsu, Kohei Mizutani, Yasuhiro Murayama, Toshikazu Itabe, Izumi Yamada, Naoki Matayoshi, Dai Matsushima, Weiming Sha, Takeshi Yamazaki, Toshiki Iwasaki

Dual-Doppler lidar and heliborne sensor were used to investigate the three-dimensional structure of the wind field over Sendai Airport in June 2007. We applied a variational method developed for multiple Doppler radar measurements to dual-Doppler lidar analysis. The comparison of wind fields retrieved from dual-Doppler analysis to wind fields measured by the JAXA heliborne sensor reveals differences of horizontal wind speed and wind direction of 0.11 m s^{-1} and 10.1°, on average, with standard deviations not exceeding 0.75 m s^{-1} and 16°, respectively

Session 5: Modeling and simulation (I)

Chairman : Stephen Hannon
11:10 to 11:30

Matched Filter CNR, Diversity and Signal Detectivity for Deterministic and Random Coherent Ladar Signals

Philip Gatt , Don Jacob

In this paper we consider the wideband and matched-filter heterodyne signal Carrier-to-Noise Ratio (CNR), with specific emphasis on continuous ladar signals with arbitrary coherence times. We show that if the coherence time is long compared to the integration time then the conventional CNR expression is valid, and the signal has unit diversity. However when the coherence time is short compared to the integration time, the CNR is reduced by the ratio of these times and the diversity is increased by this same factor. We provide a spectral model for arbitrary coherence times and compare that model to Monte Carlo simulations. We also show how signal detectivity is related to CNR and diversity.

11:30 to 11:50

Performance of coherent lidar receivers using atmospheric compensation techniques

A. Belmonte,

There is an emphasis on elucidating those implications of the atmospheric propagation problem that bear on the design and reliability of optical coherent systems. We present recent studies on the impact of phase and amplitude fluctuations on Doppler lidars using coherent detection and consider, in a unified framework, the effects of wavefront distortion, amplitude scintillation, and diffuse target speckle on the performance of coherent receivers utilizing atmospheric compensation techniques. As the effects ascribed to turbulence and speckle are random and subsequently must be described in a statistical sense, we define a mathematical model for the probability density function of the received coherent signal after propagation through the atmosphere. In our model, the parameters describing the signal statistics depend on the turbulence conditions and the degree of modal compensation applied in the receiver. We provide analytical expressions and use them to study the effect of various parameters on performance, including turbulence level, signal strength, receive aperture size, speckle effective area, and the extent of compensation.

11:50 to 12:10

Analysis and optimization of Pulsed Doppler Lidar Wind Profile measurement process in complex terrain

Matthieu Boquet, Bruno Ribstein, Rémy Parmentier, Laurent Sauvage, Jean-Pierre Cariou

Accuracy of Lidar remote sensors for wind energy has been previously reported. Coherent Doppler lidars have shown very high correlation with calibrated cup anemometers in flat terrain, both onshore and offshore. However, in more complex terrain, not only more turbulent air flow but also loss of flow homogeneity happen, and remote sensors measurement process need to be closely examined. We compare and simulate cup's point and lidar's volume measurements to understand and explain for the two sensor's response. We put in evidence the main error term in the horizontal and vertical wind speed retrieval. Geometrical optimizations of the WindcubeTM measurement process are

also investigated to get more reliable wind speed estimate. We show our conclusions and the results of the CFD simulation performed on a Spanish complex terrain case.

12:10 to 12:30

Visualization of 2-D transverse velocity fields in the atmosphere

Viktor Banakh, Andrey Falits

Possibility for visualization of 2D velocity fields in the atmosphere based on laser radiation scattered by the particles moving in a turbulent air flow is discussed. By numerical modeling it is demonstrated that visualization of the flow velocity field is possible based on displacements of large-scale intensity inhomogeneities in the speckle structure arising in the optical image of scattering layer of moving particles.

Session 6: CO2 and other DIAL measurements (II)

Chairman : A. Brewer

14:00 to 14:20

Turbulent CO2 flux measurements by lidar: length scales, results and comparison with in-situ sensors

Fabien Gibert, Grady J. Koch, Jeffrey Y. Beyon, Timothy W. Hilton, Kenneth J. Davis, Arlyn

The vertical CO_2 flux in the atmospheric boundary layer (ABL) is investigated with a Doppler DIAL. The instrument was operated next to the WLEF instrumented tall tower in Park Falls, Wisconsin during three days and nights in June 2007. Profiles of turbulent CO_2 mixing ratio and vertical velocity fluctuations are measured by *in-situ* sensors and Doppler DIAL. Time and space scales of turbulence are precisely defined in the ABL. The eddy-covariance method is applied to calculate turbulent CO_2 flux both by lidar and in-situ sensors. We show preliminary mean lidar CO_2 flux measurements in the ABL with a time and space resolution of 6 h and 1500 m respectively. The flux instrumental errors decrease linearly with the standard deviation of the CO_2 data, as expected. Although turbulent fluctuations of CO_2 are negligible with respect to the mean (0.1 %), we show that the eddy-covariance method can provide 2-h, 150-m range resolved CO_2 flux estimates as long as the CO_2 mixing ratio instrumental error is no greater than 10 ppm and the vertical velocity error is lower than the natural fluctuations over a time resolution of 10 s.

14:20 to 14:40

Lidar technology pre-development in support of A-SCOPE, the ESA mission to measure CO2 from space

Yannig Durand, Jérôme Caron, Jean-Loup Bézy, Roland Meynart.

Advanced Space Carbon and Climate Observation of Planet Earth (A-SCOPE) has been one of the six candidates for the third cycle of the Earth Explorer Core missions, selected by the European Space Agency (ESA) for assessment studies[1]. Earth Explorer missions focus on the science and research aspects of ESA's Living Planet Programme[2]. ASCOPE mission aims at observing atmospheric carbon dioxide (CO_2) for a better understanding of the carbon cycle. Knowledge about the spatial distribution of sources and sinks of CO_2 with unprecedented accuracy will provide urgently needed process information about the global carbon cycle. In order to achieve both accuracy and high coverage, the A-SCOPE mission encompasses a new measurement technique based on a lidar. Though building on the efforts deployed by ESA since the early eighties in the advancement of critical technology for lidar systems, the proposed measurement concept based on an Integrated Path Differential Absorption (IPDA) lidar is highly innovative. Following a brief description of the proposed instrument implementation this paper reports on the status of the predevelopment activities initiated in support of the instrument critical technologies for both the detector and the transmitter.

14:40 to 15:00

Laser diode absorption spectroscopy for accurate CO2 line parameters at 2 µm. Consequences for space-based DIAL measurements.

Lilian Joly, Fabien Marnas, Fabien Gibert, Bruno Grouiez, Pierre H. Flamant, Didier Bruneau, Georges Durry, Bertrand Parvitte, Virginie Zéninari [1]

Space-based active sensing of CO_2 is a very promising technology for a global monitoring of CO_2 concentrations and surface fluxes. Nevertheless spectroscopic parameters of the targeted line must be known with a great

accuracy. After a selection of the most appropriate CO_2 absorption line (R30 of the $(20^01)_{III} \leftarrow (000)$ band), new spectroscopic measurements of these parameters are presented for this particular line and 4 others. The line strength, air-broadening halfwidth and its temperature dependence coefficient have been investigated. The measurements are conducted by laser diode absorption spectroscopy. These results exhibit significant improvement as they reach uncertainty levels never obtained before.

15:00 to 15:20

Complementary measurement with multi-positioned in-situ sensors and the 1.57 μm laser absorption spectrometer

D. Sakaizawa Daisuke Sakaizawa, Shuji Kawakami, Masakatsu Nakajima, Kazu Asai

The Green-house gas Observation SATellite (GOSAT) was launched to determine the continental CO2 inventories. Its sensor is based on a passive remote sensing technique that was developed to achieve less than 1% accuracy for CO2. The CO2 total column is estimated from the 1.6μm absorption bands during daytime and its profile above a height of 800-hPa is estimated from the CO2 thermal bands during the day and at night. This study investigates whether the newly developed laser absorption spectrometer is accurate enough to conduct a validation of the GOSAT during days and nights. Preliminary study examined the linearity of the instrument using a gas cell and a field test with an in-situ sensor. The instrumental response indicated a correlation coefficient of 0.99 compared with the known CO2 density. A field test showed an accuracy of 0.64% for, and in good agreement (within 0.79% standard deviation) of the CO2 mixing ratio obtained with an in-situ sensor. The measurement using multi-positioned in-situ devices will present.

Session 7: Modeling and simulation (II)

Chairman : A. Belmonte

15:40 to 16:00

Simulation of Doppler Random Error in Wind Profiles in Atmospheric Boundary Layer

A.P. Shelekhov, E.A. Shelekhova, A.V. Starchenko, D.A. Belikov

The wind profiles and its random error from the Doppler lidar measurements in the atmospheric boundary layer (ABL) are simulated numerically. The wind velocity retrievals are performed by minimizing the least-squares fit cost function, which is the difference between the modeled and observed radial wind velocity. Numerical simulation is based on “e-l” model of atmospheric turbulence and one-dimensional model of the homogeneous ABL, which take into account diurnal variations of meteorological parameters and the turbulent structure of the ABL. In the paper the results of the numerical simulation of profiles of the wind components, its random errors, as well as potential temperature, TKE, TKE-rare are presented for the case when the atmospheric stratification varies significantly during daytime.

16:00 to 16:20

Computer Simulation of Global Profiles of Carbon Dioxide Using a Pulsed, 2-Micron, Coherent-Detection, Column-Content DIAL System

Michael J. Kavaya, Upendra N. Singh, Grady J. Koch, Jirong Yu, Rod G. Frehlich

We present preliminary results of computer simulations of the error in measuring carbon dioxide mixing ratio profiles from earth orbit. The simulated sensor is a pulsed, 2-micron, coherent-detection lidar alternately operating on at least two wavelengths. The simulated geometry is a nadir viewing lidar measuring the column content signal. Atmospheric absorption is modeled using FASCODE3P software with the HITRAN 2004 absorption line data base. Lidar shot accumulation is employed up to the horizontal resolution limit. Horizontal resolutions of 50, 100, and 200 km are shown. Assuming a 400 km spacecraft orbit, the horizontal resolutions correspond to measurement times of about 7, 14, and 28 s. We simulate laser pulse-pair repetition frequencies from 1 Hz to 100 kHz. The range of shot accumulation is 7 to 2.8 million pulse-pairs. The resultant error is shown as a function of horizontal resolution, laser pulse-pair repetition frequency, and laser pulse energy. The effect of different on and off pulse energies is explored. The results are compared to simulation results of others and to demonstrated 2-micron operating points at NASA Langley.

16:20 to 16:40

Parameters Estimation of Wake Vortices in Ground Effect

S. Brousmiche, L. Bricteux, P. Sobieski, G. Winckelmans, B. Macq, C. Craeye

In this paper, we propose a method for evaluating the parameters, i.e. core positions and circulation, of wake vortices with a ground-based coherent Doppler Lidar assuming a scanning plane perpendicular to the runway. Its principle is to fit a modified Hallock-Burnham model on the velocity estimates given by the output of a LIDAR simulation module working directly on the velocity space. This simulation uses the results of a computational fluid dynamics simulation of wake vortices in presence of ground effect. The robustness of this method can therefore be assessed when secondary vortices are present in the sensing volume. This model allows us to evaluate how the pulse duration as well as the spatial resolution affects the estimates. The obtained vortex circulations are compared to the exact circulation, as well as to the $\Gamma 5-15$ quantity evaluated on the fluid simulation field. It is shown that the estimation error can vary substantially depending on the position of the vortices and the pulseduration.

16:40 to 17:00

Data Requirements for Doppler Lidar Measurements of Winds from Space

Rod Frehlich, Robert Sharman

An important input to the design of space-based measurement systems is the data requirements which are typically defined in terms of the bias and random error of the measurement for various spatial and temporal sampling conditions. The dominant driver for space-based wind measurements is Numerical Weather Prediction (NWP) models. Since many types of data are used in operational NWP, the data requirements for all measurements must be defined in a consistent manner to correctly determine the value of each measurement technology in terms of total measurement error and the improvement in the initial state of the atmosphere (data assimilation). The total measurement error consists of the instrument error and the observation sampling error (related to the error of representativeness) which defines the mismatch between the observation sampling pattern and the spatial sampling of the desired measurement or "truth". To produce a consistent definition of observation error and forecast error, the spatial average for "truth" is defined as the effective resolution of the NWP model. The resulting implications for Doppler lidar data requirements is presented.

Poster Session

18:00 to 20:00

Image quality study in spectral domain for Synthetic Aperture Ladar

M. Valla

The Synthetic Aperture Ladar, known as SAL, is a coherent imaging technique which is defined as the optical equivalent of Synthetic Aperture Radar. Recent works initiated by the DARPA (SALTI program) have shown that SAL is quickly increasing its technological readiness level: from the laboratory experiments in two dimensions of the early 2000s to the airborne prototypes of Northrop Grumman and Raytheon first demonstrating airborne SAL in 2006.

The goal of this short paper is to undertake an imaging quality study in the image spectral domain considering the case of SAL. Numerical simulations of SAL imaging of a Johnson square bar array show good agreement with analytical modeling derived from earlier works in coherent imaging.

System design and preliminary characterisation of a fibre-based pulsed MOPA system operating at a wavelength of 2.05 mm

L. Michaille, C.R. Bennett, T.J. Shepherd.

In this poster, a pulsed MOPA system using fibre amplifiers for single frequency emission at a wavelength of 2.05 μm will be presented. The results from modelling including thermal management aspects, non-linear optical limitation and gain optimisation will be discussed. Preliminary experimental results from the amplification of a single frequency DFB diode using Thulium-doped silica-fibre amplifiers will be presented, including discussion of the gain, the amplified spontaneous emission and the stimulated Brillouin scattering generated in the fibre amplifier

Coherent detection post detection SNR for receivers employing incoherent and coherent integration

Don Jacob and Philip Gatt

Optical signals are generally detected electrically and receiver performance is characterized in terms of electrical quantities. The important performance metric is the post-detection SNR (PDSNR) since measurement estimates of range, velocity, etc. are based on the post-detection signal. In this paper we first discuss the PDSNR for a coherent ladar employing coherent or incoherent integration. Without integration the PDSNR saturates at 0 dB due to speckle. In this regime coherent or incoherent integration increases the PDSNR to the number of independent signals integrated. Finally, we discuss how incoherent spatial integration can improve performance for ladars operating in refractive turbulence

All-solid-state UV transmitter development for ozone sensing applications

Narasimha S. Prasad and Upendra N. Singh

We designed and tested two different configurations for nanosecond non-harmonic, single longitudinal mode UV generation using a flash lamp pumped Nd:YAG pump laser for ozone sensing applications based on differential absorption lidar (DIAL) technique. They are extra-cavity configuration, where the SFG crystal is outside the OPO cavity, and intra-cavity configuration, where the SFG crystal is inside the OPO cavity. For the extra-cavity configuration we generated greater than 190 mJ at 320 nm with 1064 nm to 320 nm optical conversion efficiency of 21%. For the intra-cavity configuration we generated approximately 140 mJ at 320 nm with 1064 nm to 320 nm optical conversion efficiency of 24%. The two configurations used a **R**otated **I**mage **S**ingly-**R**esonant **T**wisted **R**ect**A**ngle (RISTRA) OPO pumped by the 532 nm second harmonic of Nd:YAG at 532 nm to generate an 803 nm signal. The signal was subsequently summed with additional 532 nm light to generate UV at 320 nm. The pump laser beam and the pulsed seed beam had high quality flat-topped spatial profiles to further enhance the overall conversion efficiency. The technique is general and can access other UV wavelengths including 308 nm by selecting a different signal wavelength for the OPO. Although intra-cavity SFG is more susceptible to heating effects in the SFG crystal because the OPO signal passes through the heated crystal many times, we've selected this configuration as the most promising for deployable systems due to its inherent simplicity. In this paper, the results of integration of UV converter with an all-solid-state Nd:YAG laser with output energy > 1J/pulse are discussed along with current efforts to improve conversion efficiency.

On the Use of Optical Amplifiers in Coherent Receivers

Marc Welliver, Paul Suni, Stewart Tuvey

The present work summarizes theoretical and experimental investigations of the excess noise realized through use of an Erbium doped fiber amplifier (EDFA) to produce a heterodyne receiver local oscillator. Phase insensitive optical amplifiers necessarily produce optical fields with amplitude noise in excess of the fundamental shot-noise floor. Such excess noise in an LO represents a direct reduction in mean coherent receiver CNR. We measured the noise characteristics of an LO created by a shot-noise limited seed laser undergoing amplification followed by attenuation. The noise power spectrum was measured for a variety of EDFA operating conditions in order to compare with the theoretical analysis. When gain and attenuation are equal the excess noise factor is >6 dB, but when the EDFA is seeded with significantly more power than is required for single-pixel shot-noise limited performance of the coherent receiver, the excess noise factor approaches unity. Hence, ideal coherent receiver performance can be achieved with an EDFA-based LO. This approach enables LO power scaling for large coherent receiver arrays.

Day 3 – Wednesday, June 24, 2009

Session 8: Turbulence and Vortex detection systems

Chairman : S. Rahm

8:40 to 9:00

A340 flight test results of a direct detection onboard UV LIDAR in forward-looking turbulence measurement configuration

N. P. Schmitt, W. Rehm, Th. Pistner, H. Diehl, P. Navé, G. Jenaro Rabadan

A direct detection short pulse UV Doppler LIDAR onboard aircraft sensor for forward looking air speed / turbulence measurement was developed and flight tested. This detection schemes allows measurements even in aerosol-depleted air at distances of 50m, which is necessary for reliable and high-frequency measurements of clear air turbulence at cruise altitude. A fringe-imaging technique was used applying an intensified CCD camera, allowing fast gating for longitudinal measurement volume reduction (as necessary for real-time control purposes) and in-flight re-calibration by image processing. Algorithms have been developed and applied to determine the wind speed around 1 m/s accuracy.

It was shown that the direct detection Rayleigh/Mie LIDAR is capable of detecting the wind speed under flight test conditions up to cruise altitudes, in clear air and in clouds. Standard deviations of the line-of-sight LIDAR signal as low as about 1.0-1.5m/s at an altitude of 39,000ft and measurement range of 54m have been achieved. The update rate was 60Hz for each LOS measurement (15Hz for full vector) and the measurement volume depth was +/- 15m.

9:00 to 9:20

Pulsed 1.5 µm LIDAR for axial aircraft wake vortex detection

C Besson, M Valla, G Canat, B Augère, D Fleury, D Goular, JP Cariou, A. Dolfi-Bouteyre, S Brousmiche, S Lugan, L.Bricteux, B Macq[2].

We present the development of an axial aircraft wake vortex Lidar sensor working in Mie scattering regime and based on a pulsed 1.5µm fiber laser. An end to end Doppler heterodyne Lidar simulator is used for the Lidar design. The simulation includes the observation geometry, the wake vortex velocity image, the scanning pattern, the Lidar instrument, the wind turbulence outside the vortex, and the signal processing. A Doppler heterodyne Lidar is developed with an innovative high brightness pulsed 1.5µm laser source, based on a MOPFA architecture with a special large core fiber amplifier. The Lidar includes a real time display of the wind field. Wind dispersion is post-processed. Field tests carried out at Orly airport in April 2008 are reported. Axial aircraft wake vortex signatures have been successfully observed and acquired at a range of 1.2km with an axial resolution of 75m for the first time with a fiber laser source.

9:20 to 9:40

Airport trials with the Aviation ZephIR coherent lidar

Chris Hill, John Bennett, Dave Smith

QinetiQ's ZephIR™ is a conical-scan coherent Doppler lidar operating eyesafe near 1.5 microns, typically providing five-height wind speed profiles up to 150 m, updated once or twice per minute. More than 50 units are installed worldwide for applications including meteorology, wind farm assessment, and wind turbine studies. It already offers an attractive solution for real-time, low-altitude, wind profiling and gust warning at airports. In a joint venture with Advantage West Midlands, we have recently fielded a modified version "Aviation ZephIR". This can use results within a single one-second scan, not only to estimate the wind speed, but also to detect the presence of wake vortices. Over a few consecutive scans, the vortices can be tracked as they descend and are blown by the local wind. Aviation ZephIR senses a small, possibly critical, volume of air – for example the critical airport regions near takeoff and landing. We have deployed the sensor at Birmingham International Airport (where most aircraft are light or medium) and at London Heathrow Airport (used by many large Airbus and Boeing aircraft, and by the Airbus A380). We present wind profiles, vortex detections, and vortex tracks.

9:40 to 10:00

1.5µm lidar for helicopter blade tip vortex detection

Matthieu Valla, Béatrice Augere, , Agnes Dolfi-Bouteyre, Didier Goular, Didier fleury

The objective of Onera study in the AIM project 'Advanced In-flight Measurement Techniques' is to assess the capability of on board lidar technique to investigate in-flight tip vortices behaviour. This paper presents the design of the 1.5µm lidar sensor dedicated to tip vortex detection and tests on ground during a trials campaign on DLR helicopter in hover flight. The relevant information resulting from these trials is tip vortex velocity field but also vortex evolution according to time. The technical challenge here is to characterize a very small phenomenon at short range: vortex core radius with respect to age varies from typically 10 to 30 mm. Study result shows that lidar technique is promising for onboard measurement in real flight conditions. The velocity measurement is direct and absolute (not calibration needed) and its accuracy can be up to 0.25 m/s and commonly 1m/s. However, seeding is necessary to realize compact and reliable lidar system with components 'off the shelf': flight measurements within clouds could be a very good solution for efficient and powerful vortex lidar.

10:00 to 10:20

Features of dust devils in the urban area detected by a 3-D scanning Doppler lidar

Chusei Fujiwara, Kazuya Yamashita, Mikio Nakanishi, Yasushi Fujiyoshi

Using a three-dimensional scanning coherent Doppler lidar (3D-CDL), we conducted atmospheric boundary layer (ABL) observation in an urban area, Sapporo, Japan, from April of 2005 to June of 2007. During this period, we succeeded in detecting more than one hundred "invisible dust devils" in 7 days, which is the first detection of such a dust devil in urban areas. They appeared only in the daytime under relatively weak wind conditions with superadiabatic lapse rate near the ground surface, when the "fish net" pattern of wind fields in ABL scale was also detected by the 3D-CDL. Characteristics of relatively strong dust devils having vertical vorticity of more than 0.1s-1 are summarized as follows: the diameter ranged from 30m to 120m, the maximum vorticity was 0.26s-1, and the number ratio of cyclonic to anti-cyclonic rotation was 2:1 on the average. Vertical vortices were also detected along sea-breeze fronts. This fact suggests that horizontal shear associated with the sea-breeze front would play an important role in their formation.

Session 9: Hard target (I)

Chairman : D. Letalick

10:50 to 11:20

Vibrometry with atmospheric compensation

D. Jameson

Ladar vibrometry provides a technique for target identification at long range. Vibrometry has particular utility when used to identify targets at very long distances beyond the diffraction limited resolving ability of an imaging aperture. A one-dimensional target vibration signature can be extracted from a single pixel measurement across the target's body. This signature can aid in identification of the target's plant. However, atmospheric turbulence along this propagation path leads to fluctuations in the effective index of refraction. These index fluctuations appear as a piston phase modulation and thus as vibration noise especially over long path lengths. This paper describes a ladar vibrometer which utilizes multiple wavelengths to measure surface velocity while minimizing the effect of atmospheric turbulence. Wavelengths can be found by describing the vibrometry process and applying relevant models for the index of refraction of air. Measurements made with multiple wavelengths have the capability to minimize or eliminate the effects of turbulent atmosphere.

11:20 to 11:40

Genetically Optimized Periodic, Pseudo-Noise Waveforms for Multi-Function Coherent Ladar

Matthew P. Dierking, Bradley D. Duncan

We report the use of periodic, pseudo-noise waveforms in multi-function coherent ladar. We exploit the Doppler sensitivity of these waveforms, mode specific processing, to enable diverse ladar functions including high range resolution imaging, macro-Doppler imaging, synthetic aperture ladar and range resolved micro-Doppler imaging. A genetic algorithm was used to optimize the ideal point response of the waveforms for both single and multiple code implementations. We present analytic expressions and simulations demonstrating the utility of the pseudo-

noise waveforms for each of the ladar modes. Finally, we demonstrate phase recovery from the pseudo-noise waveforms in micro-Doppler imaging through laboratory experiments.

11:40 to 12:00

Signal Processing Methods and Poly-Pulse Waveforms for Laser Vibrometry in Pulsed Mode

J. Totems, V. Jolivet, J.-P. Ovarlez, N. Martin

We present our work to jointly optimize modulation waveforms and signal processing for long range vibration sensing using a heterodyne coherent laser radar in pulsed mode. The performance of various existing Instantaneous Frequency (IF) estimators is compared through simulation, taking into account Continuous Wave (CW) and pulse-pair waveforms, and for the first time poly-pulse waveforms. A new estimator, based on a pseudo time-frequency representation of the IF's likelihood function, was developed in response to the specific noise conditions encountered in laser radar. In agreement with theoretical calculations, our simulations show that, for pulsed mode, poly-pulse waveforms and our IF Likelihood (IFL) processing outperform the classical pulse-pair waveform in case of dominant speckle noise. With the same available laser power for the various operating modes, CW mode often demonstrates the best signal-to-noise ratio, given the strong speckle noise conditions and the vibration bandwidth considered here. Yet, pulsed mode with IFL processing proves to be more robust when the analysis bandwidth is increased and allows better demodulation, at low carrier-to-noise ratio.

Day 4 - Thursday, June 25, 2009

Session 10: Imaging lidar

Chairman : T. Karr

9:00 to 9:30

Anisoplanatic wavefront error estimation using coherent imaging

R. L. Kendrick, J. C. Marron, R. Benson

We have developed a technique for extracting atmospheric turbulence induced wavefront error by means of digital holography. The technique enables wavefront error determination as a function of field angle. Closed form expressions for the anisoplanatic wavefront error caused by atmospheric turbulence have been developed for comparison. We show very good agreement between experimental data and the closed form solution. The comparison is made over C_n^2 values from approximately 10^{-12} to 10^{-15} $m^{-2/3}$.

9:30 to 10:00

Volume control manifold for membrane adaptive optics

D. K. Marker 1, J. Rotge 2, S. Hanes 2

An innovative adaptive optic concept is discussed that provides a dramatically improved dynamic bandwidth over existing approaches. This innovation is associated with membrane adaptive optics such as silicon nitride and polymer based films. This concept utilizes a volume control manifold that is co-located with the electrostatic actuators to dramatically improve total actuator force which in turn improves dynamic bandwidth and stroke. Presented is the result of a laboratory experiment showing time lapse images of a polymer film that is actuated by a single volume control actuator. An important constraint of the concept involves the depth of the air gap between the activated membrane and the backplate which includes both the electrostatic and volume control actuators. This depth is nominally less than 100μm. At these depths, the viscosity of air becomes an important physical phenomenon.

10:00 to 10:20

Multiple screen image correction for digital holography

T. E. Wenski, James E. Mason

Imaging through the volume atmosphere often leads to anisoplanatic (space-variant) imaging conditions. A feature of digital holographic coherent imaging is that the phase and amplitude of the signal beam is acquired at the pupil plane Using wave-propagation methods, the pupil field can be propagated back through a virtual atmosphere toward the object. A nonlinear optimization process using an image quality metric can determine the description of the atmospheric phase needed to correct the image. Work presented here demonstrates multiple screen anisoplanatic image correction in both simulated and experimental data through a horizontal atmospheric path.

Session 11: Synthetic and multi-aperture systems

Chairman: M Halmos

10:50 to 11:20

Power, Aperture and Wavelength Scaling of Synthetic Aperture Laser Radar

T. J. Karr

Synthetic aperture laser radar (SAL) in principle can achieve resolution independent of range-to-target, and may produce high resolution optical/infrared images of hard targets from long range using smaller optics than a passive imager with the same resolution. However, a necessary condition for this feat is that the energy delivered by the SAL to the target exceeds a range- and resolution-dependant minimum. The synthetic aperture radar (SAR) energy-aperture product limit is a fundamental bound on the tradeoff between energy, antenna size, resolution and range. Starting from this fundamental limit, the minimum power required to form a synthetic aperture image is derived for any active "antenna"—laser or microwave. Any technological implementation

would need greater laser power than this minimum. Changing the transmitting/receiving aperture size in the scanned and cross-scanned directions, and changing the SAL wavelength changes the laser power $\propto D^{-4}$, and $\propto \lambda^{0}$, λ^{-1} or λ^{2} depending on the target and how the phase history data is collected. Some simple remote sensing examples illustrate the magnitude of power and aperture required for a SAL and a passive sensor with the same resolution.

11:20 to 11:50

Conformal EO Sub- Aperture Array Based Laser Radar with non mechanical beam steering

P. McManamon,

Future Laser Radar systems can benefit substantially by coherent combining of multiple sub-apertures and by non mechanical steering of the transmit and receive functions. This can provide conformal apertures – providing a much smoother aero-optical layer, can allow larger receive array diameters for higher real beam resolution, and can improve adaptive optics capability. The benefits of this approach compared to conventional laser radar will be reviewed. Non mechanical methods of steering laser beams have recently been improved significantly. This technology will be reviewed. In addition coherent methods of combining multiple sub-apertures will be reviewed.

11:50 to 12:10

Increasing image contrast using Golay-like sparse aperture arrays

A. J. Stokes, B. D. Duncan, M. P. Dierking, N. J. Miller

An unfortunate consequence of using a sparse aperture optical imaging system is the reduction of mid-spatial frequency contrast. Non-redundant (autocorrelation) sparse aperture systems are capable of achieving high resolution with a small light collection area compared to that of a conventional monolithic aperture with the same resolution. However, boosting the mid-frequency response of these systems is necessary for quality image formation. Our numerical and theoretical results will demonstrate that the judicious introduction of redundancy in both the Golay-9 and Golay-12 arrays can yield considerable increases in mid-band optical power, or image contrast.

12:10 to 12:30

High Resolution Sparse Aperture Imaging Testbed

Igor Anisimov

High resolution imaging of distant targets is a very complex problem that involves understanding of diffractive properties of the optical imaging system, statistical properties of the atmospheric refractive index variations, coherence properties of the light source etc. In coherent laser radar imaging system, the target is illuminated with the laser beam, and the returned from the target light wave is referenced to the light wave from the same source. Such system is referred to as spacial heterodyne imaging system. In this work we present a heterodyne imaging interferometer as a simple experimental platform that can be used for developing high resolution sparse aperture imaging algorithms. This algorithms will be used in a high resolution sparse aperture imaging testbed that the Ladar and Optical Communications institute (LOCI) is currently building in collaboration with industry partners, academic institutions, and the government.

Session 12: Novel Systems (I)

Chairman: M. Rubin

14:00 to 14:30

Digital Coherent Optical interferometric Sensing in Vibrometry and Explosive Detection

I. Shpantzer

Fast turbulence in turbid channel give rise to fast (~sub-ms to μs) power fades. Conventional adaptive optics does not have sufficient speed to track fast fading. An integrated optical beam combiner with adaptive control is proposed to mitigate fast fading of turbid channels in a space-diversity reception architecture. Simulation results of a lossless beam combiner showed that unity power combining efficiency can always be achieved regardless of the input optical power and phase distribution. The proposed device is applicable in a variety of digital coherent optical sensing applications such as in coherent laser radar, standoff explosives detection, and laser vibrometry that will be covered in the talk..

14:30 to 14:50

A review of sparse frequency linearly frequency modulated (SF-LFM) laser radar signal modeling with preliminary experimental results

Robert V. Chimenti, Eric S. Bailey, Peter E. Powers, Joseph W. Haus, Matthew P. Dierking

Sparse frequency linearly frequency modulated (SF-LFM) laser radar (ladar) signals have been shown through analytical and numerical modeling to increase the effective bandwidth of a ladar signal without the need for large bandwidth modulation sources. SF-LFM waveforms increase the effective bandwidth, and hence the range resolution, of ladar signals by superimposing multiple frequency offset laser lines into the same waveguide and then coupling the superimposed lines into a single linear frequency modulator (or a quadratic phase modulator). While SF-LFM ladar signals have the distinct advantage of producing lager bandwidth signals without sacrificing linearity, the segmented bandwidth nature of the SF-LFM ladar signals can introduce additional ghosting in the matched filter output. This manuscript will review the previously developed models for SF-LFM ladar signals, and discus some preliminary experimental data which verifies some of the results of the previous models.

14:50 to 15:10

Investigation of noise in Lightwave Synthesized Frequency Sweeper seeded LIDAR anemometers from leakage through the AO Modulators

A. T. Pedersen, P. Lindelöw-Marsden

Lightwave Synthesized Frequency Sweepers (LSFS) have potential use as lightsources in lidar anemometers. In this paper noise due to leakage in the acousto optic modulators in an LSFS is investigated. Theoretical expressions describing the build-up of noise in the LSFS due to leakage are derived. Two types of leakage are measured. First the non-shifted leakage through a closed AOM is measured and good agreement with the expected value is found and secondly the non-shifted and multiple-shifted leakage through an open AOS is measured in heterodyne setup. In LSFS driven Frequency Stepped Pulse Train (FSPT) modulated lidars the leakage will give rise to rapidly growing noise in the bins which corresponds to the signal from low radial wind velocities. It is likely that noise canceling techniques similar to those used for RIN removal has to be deployed for measurements of low wind velocities.

15:10 to 15:30

Coherent combining on a remote surface of fiber amplifier arrays after propagation through turbulent atmosphere

Véronique Jolivet, Pierre Bourdon, Baya Bennai, Laurent Lombard, Didier Goular, Guillaume Canat, Olivier Vasseur

Coherent combining with active phase control is a powerful way to overcome the physical limitations of power scaling of fiber amplifiers. It allows not only increasing the available power in the central lobe, thanks to the interference process, but also beam shaping and beam steering. For example, phase errors induced by atmospheric turbulence can be compensated for in real time. However, succeeding in coherently combining fiber amplifiers on a remote surface requires compensating only the onward, and not the backward, atmospheric turbulence effects. We present the experimental demonstration of coherent combining of three fiber amplifiers on a remote scattering surface, after propagation through turbulent atmosphere, without the use of any other subsystem for turbulence phase error measurement. This result is achieved using the backscattered signal and a specific spatial filtering to lower sensitivity to backward turbulence phase errors. The resulting residual phase error is $\lambda/15$ rms, for a turbulence strength equivalent to propagation in the kilometric range in real atmosphere.

Session 13: Wind energy

Chairman: C. Hill

16:00 to 16:30

From Prototype to Standardization Five Years of LIDAR Anemometry in the Wind Energy Industry

Petter Lindelöw

Accurate wind sensing at turbine hub height is a crucial measurement disciplines in the wind energy industry. As wind turbines get higher, so too does the attraction of ground based profilers, capable of measuring horizontal

wind speeds remotely at heights up to or beyond that of the upper blade tip. In many environments, for example offshore or in complex terrain, the cost of high meteorological towers is considerable.

Lidars are beginning to be commercially used in the wind energy industry, mainly for resource assessment. It is estimated that 100 systems are deployed worldwide and the lidar market was approximately 10 M€ in 2008. In this talk I will take the opportunity to describe the possible market niches for lidar anemometry in the wind energy business, the state of lidar profiler development and indicate where I see the need for further initiatives.

16:30 to 17:00

Lidar study of the nocturnal boundary layer at the heights of modern wind-turbines

Yelena L. Pichugina, R. M. Banta, N. D. Kelley, W. A. Brewer, S. P. Sandberg, Mike Hardesty, B. J. Jonkman

Scan data from NOAA's High Resolution Doppler lidar (HRDL) during two field programs conducted in the Great Plains region have been analyzed at turbine rotor heights to provide information on wind flow characteristics important to wind energy applications. Quantities of interest obtained from HRDL measurements include wind and turbulence profiles, low-level jet properties and nighttime evolution, and wind and directional shear across the rotor heights. Detailed analysis of wind flow statistics at both sites, along with some examples of atmospheric events that can impose critical loads on wind turbines, will be given.

17:00 to 17:20

Coherent Doppler Lidar for Wind Energy Research

Rod Frehlich, Neil Kelley

Wind energy has become an important new and rapidly growing source of renewable energy. However, many issues for efficient energy production and use of wind energy are unresolved. Wind resource assessment requires accurate profiles of both the wind speed and turbulence statistics to identify the most promising locations for efficient wind production with minimal damage to the turbines from high shear and turbulence. Optimal control of the turbine blades requires high quality wind information upstream of a wind farm or at each individual turbine. Accurate short term forecasts of power production require accurate wind profiles at various distances upstream of the wind farm. Scanning coherent Doppler lidar is the most attractive instrument for high quality measurements of the wind fields for the conditions of interest for wind energy research. New results are presented from a field campaign at the National Wind Technology Center to evaluate coherent Doppler lidar for wind energy research. Lidar derived wind and turbulence estimates are compared with results from a nearby instrumented tower for various conditions.

17:20 to 17:40

WindCubeTM pulsed Lidar compact wind profiler: Overview on more than two years of comparison campaigns.

R. Parmentier, M. Boquet, J.P. Cariou, L. Sauvage

LEOSPHERE introduced in 2006 its compact eye-safe 1.5µm coherent Pulsed Doppler Lidar system for wind profiling in the first 200 meters of the PBL. This instrument is mainly dedicated to wind energy industry which requires extremely accurate wind measurement tools (less than 1% accuracy). More than 50 WindCube^{TM} are currently running on the field and lots of them have been compared to calibrated sensors. We focus this paper on more than two year of lidar vs. met masts comparison campaigns at many locations around the world representing a comprehensive set of climate and terrain conditions. Operational aspects such as deployment, power, and remote access are briefly described. Agreement between reference and calibrated sensors is described and analysed with emphasize on WindCube^{TM} accuracy in flat and complex terrains. Impact of weather, surface roughness, topography and trees are rapidly described.

Day 5 - Friday, June 26, 2009

Session 14: Hard target (II)

Chairman: J.P. Cariou

9:30 to 09:50

Off Line-of-Sight Measurements of Target Vibrational Features Using Laser Vibrometry

Peter Lutzmann, Gregor Anstett, Benjamin Göhler

Laser vibrometry based on coherent detection techniques allows the remote measuring of vibrational target characteristics with high resolution. So far previous work concentrated on measurements where a direct line-of-sight between target and sensor was given. In this paper we investigate situations where the target is hidden and out-of-sight, but target-induced vibrations can be captured from the environment. This approach opens up new areas of application in the field of defence and security. The presented measurements were performed with an in-house-developed all fiber-based 1.5 µm laser radar named SAVIS (**S**hort Wave **A**ctive **VI**bration **S**ensor).

09:50 to 10:10

Coherent laser radar vibrometry for modal analysis in earthquake engineering

Véronique Jolivet, Philippe Gueguen, Clotaire Michel, Anne-Sophie Schveitzer

A major issue in earthquake engineering is to determine the dynamic parameters of buildings, and more particularly their fundamental frequency, which can be helpful for building integrity monitoring and damage assessment. One method of survey consists in installing velocimeters in the target building and in recording ambient vibrations (AV). Even though AV dynamic parameters cannot be fully associated to the seismic response of buildings, AV surveys have gained an increasing interest because of their low cost and fast operability. However, they require entering the building. Being able to get the resonance frequency using a remote system would be faster and safer in case of post-earthquake assessment of the building integrity, when aftershocks are able to collapse the damaged buildings. We demonstrate the ability of coherent lidar to measure such low velocity and frequency vibration (few µm/s and few Hz) and to remotely get building resonance frequency. After a brief description of the target building, the two experimental approaches based on velocimeter and lidar techniques are compared. Finally, a cross validation of the two methods is performed.

Session 15: Novel systems (II)

Chairman : R. Heinrichs

10:10 to 10:40

Precision ranging LIDAR using femtosecond fiber lasers

N. R. Newbury, I. Coddington, W. C. Swann

We discuss a coherent laser radar that uses two coherent femtosecond fiber lasers to perform absolute ranging at long distance. One coherent femtosecond fiber lasers acts as a source and the other as a local oscillator for heterodyne detection of the return signal from a cooperative target. The system simultaneously returns a time-of-flight range measurement for coarse ranging and an interferometric range measurement for fine ranging. Furthermore, it is insensitive to spurious reflections that can cause systematic errors. The range is measured with 3 µm precision in 200 µs and 5 nm precision in 60 ms over a 1.5 m ambiguity range. This ambiguity range can be extended to 30 km by simply reversing the roles of the signal and LO sources. We will also discuss the possibilities of using such a system for precision vibrometry and for even more rapid absolute ranging.

11:10 to 11:30

Wideband Dual-Frequency Lidar-Radar: Waveform Generation and Field Experiment

G. Pillet, L. Morvan, D. Dolfi, J.-P. Huignard

We report on a wideband direct-detection lidar-radar dedicated to high range and velocity resolution measurements, which benefits from a novel waveform generation architecture. A laser beam intensity modulated at high frequency is generated, thanks to the use of a dual-frequency laser (DFL). To ensure a modulation frequency stability compatible

with the range of the lidar, the laser is included in an optical frequency locked loop (OFLL) which reduces the linewidth of the modulation.

The novelty of this architecture is the realization of a tunable OFLL to generate the pursued wideband frequency chirp. The tunable OFLL is mainly composed of a fiber-optics delay-line frequency discriminator that can be quickly tuned with an optical phase shifter. While maintaining a frequency stability below 1 kHz, we are able to generate with this setup a 1 GHzbandwidth chirped waveform around a central frequency between 1 to 20 GHz, in few milliseconds. A pulsed version of this laser source (600 ns pulse duration) has been used in a lidar-radar field experiment to measure distances and velocities with 30 cm and 0.75 m/s resolutions, and 5 km and 350 m/s ambiguities.

11:30 to 11:50

Holographic aperture ladar laboratory demonstration

J. W. Stafford, B. D. Duncan, M. P. Dierking

Holographic Aperture Ladar (HAL), a variant of Synthetic Aperture Ladar (SAL), makes use of a two-dimensional translating sensor array to increase cross-range scene resolution by synthesizing a large effective aperture through the motion of a smaller receiver. The HAL transformation involves the application of a simple phase correction to pupil plane field segments, which are then mosaicked together to create a coherently phased collection of sub-images. However, the assumption of a nominally planar target implicit in the transformation does not hold when extended targets are examined on a small bench-top in the laboratory. In this paper we will address the phase corrections necessary when using optical quality ball bearings as targets at much shorter ranges than are normally associated with field LADAR applications. In particular, we will demonstrate that the ball targets effectively simulate a δ function that is offset in both range and cross-range from the target center. We will also show that the angular width of the target reflection limits the transmitter (TX) and receiver (RX) separation in the bistatic case. Lastly, we will present the results of our first ever HAL imaging experiment.

11:50 to 12:10

All-fiber Coherent Doppler LIDAR for Wind Sensing

S Abdelazim, D Santoro, M Arend, F Moshary, S Ahmed

Coherent Doppler LIDAR is being utilized to develop a mobile wind speed measuring station. We are building an all fiber based eye safe laser system to measure wind speed in urban areas. A 1.5μ.m polarization maintained fiber optics master oscillator power amplifier system is used which leverages components from the telecommunication industry. We chose a heterodyne balanced detection to suppress the RIN noise. We have calculated the optimum local oscillator power for maximum optical detector's efficiency. A/D conversion will be performed at 400 MHZ by using a data acquisition card with FPGA on board, which can be programmed to perform autocorrelation and/or FFT onboard for faster performance. This system can be used along with other units on top of high buildings in New York City as a way of detecting wind speed profile for Homeland security.