Development of Water Vapor DIAL

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ABSTRACT

For future spaceborne water vapor DIAL systems, we started a laser design study in 1994. New laser materials such as Cr:LiSAF are very attractive, but at present there are no high power diode lasers for direct pumping those materials. Therefore we determined to develop a high power diode-pumped Nd:YLF laser and Ti:sapphire laser for water vapor DIAL. The output energy of Nd:YLF laser is expected to be 550mJ at 1053nm and 400mJ at 527nm with a maximum repetition rate of 150Hz. A Ti:sapphire laser will be pumped by the SHG of the Nd:YLF laser. Tuning of the Ti:sapphire laser to a strong absorption line (ON1), a weak absorption line (ON2) of water vapor and an off line (OFF) is made by an injection seeder which consists of two single longitudinal mode laser diode modules. Two on-line laser diodes are locked to water vapor absorption lines using an absorption cell or a photo-acoustic cell. These three laser lines (ON1, OFF and ON2) are transmitted into the atmosphere with a triple pulse technique for measurements of water vapor profiles from the ground up to 10km. The laser spectral width of the on line is expected to be 0.5pm with a stability of 0.05pm. The output energy of each laser line is to be more than 100mJ. This laser system will be developed within three years, and then incorporated as an airborne water DIAL.

1. INTRODUCTION

Spaceborne Differential Absorption Lidar (DIAL) technique can measure the vertical profiles of atmospheric water vapor and improve understanding of the global hydrological cycle and the earth's radiation effect. Airborne DIAL measurements of water vapor have been reported [1)]. For spaceborne water vapor DIAL, we have to first develop an electrically efficient, compact, reliable and long lifetime laser system. At present, a Ti:sapphire laser pumped by a laser diode pumped solid state laser is very promising for a spaceborne water vapor DIAL. Preliminary DIAL measurements of water vapor were made using narrowband Ti:sapphire lasers by a frequency doubled Nd:YAG laser [2)]. However, the Nd:YAG laser was pumped by flashlamps and the electrical efficiency was very small. And the output energy of the Ti:sapphire was only 1mJ. According to numerical simulations [3)], the output energy of more than 100mJ is expected for spaceborne water vapor DIAL with a repetition frequency of about 50Hz. For simultaneous measurements of water vapor profiles from the ground to about an altitude of 10km, three laser lines of ON1, OFF and ON2 must be transmitted downward every about 1ms by a triple pulse technique. For these requirements, we determined to develop a Ti:sapphire laser with high power diode-pumped Nd:YLF laser and Ti:sapphire laser for water vapor DIAL.

2. LASER SYSTEM OUTLINE

2.1 Specifications

The specifications of the laser system planned for the water vapor DIAL system is shown in Table 1. To satisfy these specifications, there are two critical points. One is to generate a high output power of more than 15W (a single pulse energy of more than 100mJ and a triple pulse repetition rate of 50Hz) with high efficiency. Another is to control the absolute wavelengths of ON1 and ON2 lines within 0.05pm.

Table 1. Specifications of the water vapor DIAL laser system

Single pulse output energy	> 100 mJ (ON1, ON2, OFF)
Repetition rate	50 Hz (ON1, ON2, OFF)
Stability of the output energy	< ±10 %
Pulse width	~20 ns
Lasing wavelength	(ON1, ON2, OFF) = (818.3086 nm, 818.1814 nm, 818.15 nm) or (ON1, ON2, OFF) = (816.5329 nm, 816.8815 nm, 816.60 nm)
Spectral width	< 0.5 pm
Wavelength stability	< ±0.05 pm (ON1, ON2) < ±1.0p m (OFF)
Side mode suppression ratio	> 30 dB (ON1, ON2)

2.2 Block diagram

The blockdiagram of the DIAL laser system is shown in Figure 1. It consists of a frequency doubled Nd doped solid state pumping laser, a Ti:sapphire laser and an injection seeder. The pumping laser consists of a master oscillator power amplifier (MOPA) type diode-pumped Q-switched Nd:YLF laser[4] and a second harmonic generator (SHG)[5]. The Maximum repetition frequency of the laser is 150Hz.

An injection seeder consists of two single longitudinal mode (SLM) AlGaAs laser diode modules which contain 30dB optical isolators, an optical switch and a Fabry-Perot type optical filter. The wavelengths of two temperature stabilized AlGaAs laser diodes are locked to a strong water vapor absorption line (ON1) and a weak absorption line (ON2) each other by controlling the injection current using an error signal from an absorption cell or a photo-acoustic cell. An off line (OFF) frequency is generated by changing the injection current of the first laser diode. An optical switch selects the seeding wavelength of ON1 and OFF or ON2 synchronized with the fire timing of the pumping laser. A Fabry-Perot type optical filter is used for the side mode suppression of the laser diodes because the side mode suppression ratio (SMSR) of conventional Fabry-Perot type AlGaAs SLM laser diode is as low as 20dB and it is insufficient to obtain a 30dB SMSR of the Ti:sapphire laser output, which is necessary for DIAL measurements of water vapor.

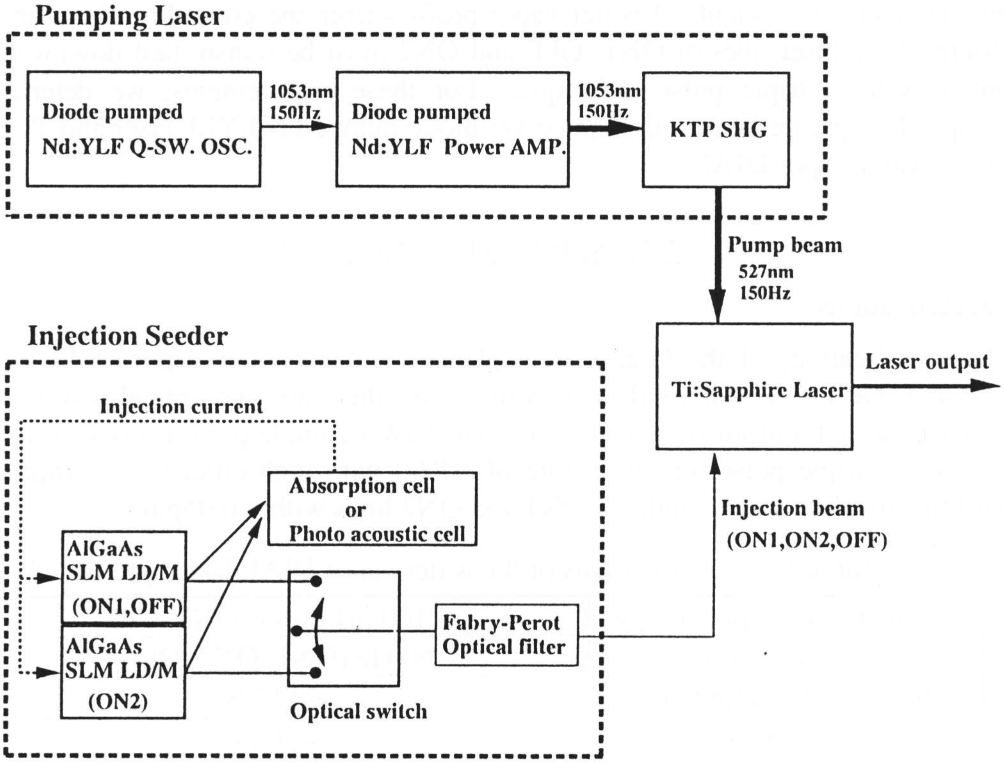

Figure 1 Blockdiagram of a water vapor DIAL laser system.

3. CONCLUSION

For future spaceborne water vapor DIAL systems, a high power diode-pumped Nd:YLF laser and Ti:sapphire laser for water vapor DIAL were simulated. The energy flow of the simulated DIAL system is shown in Fig 2. The output energy of Nd:YLF laser is expected to be 400mJ at 527nm with a maximum repetition rate of 150Hz and the output energy of 167mJ is an enough energy level for planning water vapor DIAL system even if the designed margin of 3dB is assumed. Considering an electrical efficiency of 50% for pumping laser diodes, the electrical to optical efficiency of this system is expected to be as high as 4%. A Ti:sapphire laser pumped by the Nd:YLF laser will be tuned to a strong absorption line (ON1), a weak absorption line (ON2) of water vapor and an off line (OFF) by an injection seeder which consists of two single longitudinal mode laser diode module. Two on-line

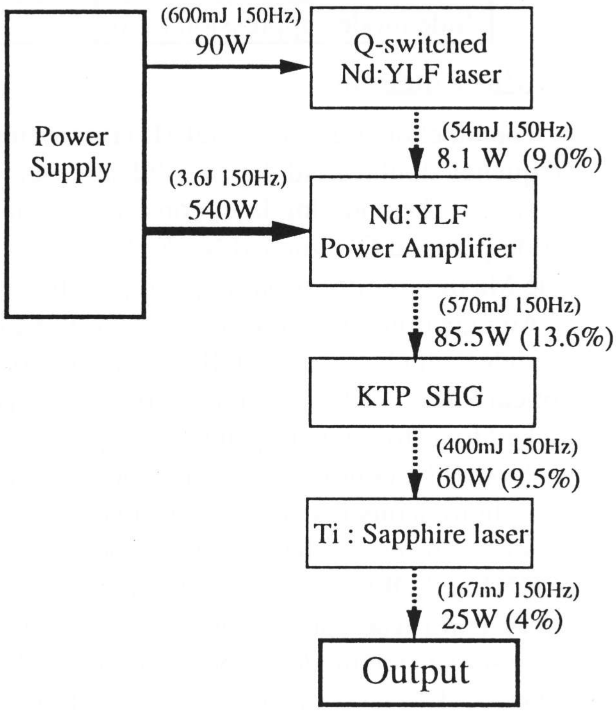

Figure 2 Energy flow simulated for a water vapor DIAL laser system.

laser diodes are locked to water vapor absorption lines using an absorption cell or a photo-acoustic cell. These three laser lines (ON1, OFF and ON2) are transmitted into the atmosphere with a triple pulse technique for measurements of water vapor profiles from the ground up to 10km. The laser spectral width of the on line is expected to be 0.5pm with a stability of 0.05pm. The output energy of each laser line is to be more than 100mJ. This laser system will be developed within three years, and then incorporated as an airborne water DIAL.

5. REFERENCE

1. N. S. Higdon, E. V. Browell, P. Ponsardin, B. E. Grossmann, C. F. Butler, T. H. Chyba, M. N. Mayo, R. J. Allen, A. W. Heuser, W. B. Grant, S. Ismail, S. D. Mayor and A. F. Carter, "Airborne differential absorption lidar system for measurements of atmospheric water vapor and aerosols", Appl. Opt., 33, pp6422-6438, 1994.
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4. O. Uchino, T. Nagai, T. Fujimoto, C. Nagasawa, M. Abo, T. Moriyama, T. Nakajima, N. Murate, K. Tatsumi, and Y. Hirano "Diode-pumped solid state laser for spaceborne water vapor DIAL", Euro. Sympo. on Satellite Remote Sensing II, EOS/SPIE Proceedings, in this volume, 1995.

Scientific objectives of space-borne water vapor DIAL

Improve understanding of the global hydrological cycle, the Earth' s radiation budget, atmospheric energy cycle and climate through the observations of atmospheric water vapor.

Measure the vertical profiles of water vapor from the ground to about 10 km with a vertical resolution of 1 km and with accuracy of better than 10 percent.

For Spaceborne water Vapor DIAL

Laser
- electrically efficient
- compact
- reliable
- long lifetime

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Laser diode pumped Solid State laser

○ A High Power Diode-pumped Nd:YLF Laser and Ti:sapphire laser

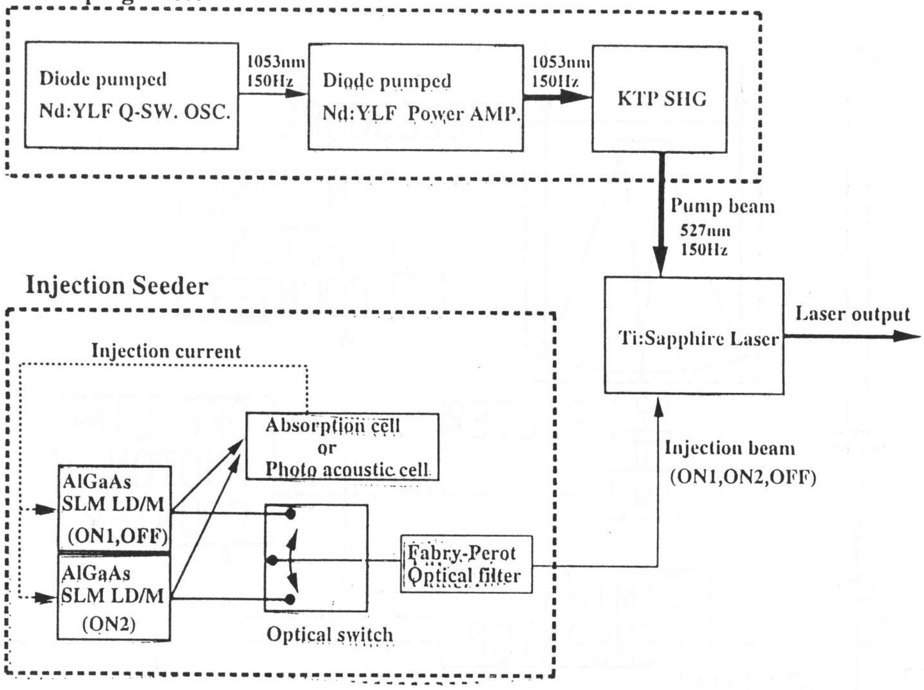

Figure 1. Block-diagram of a water vapor DIAL laser system.

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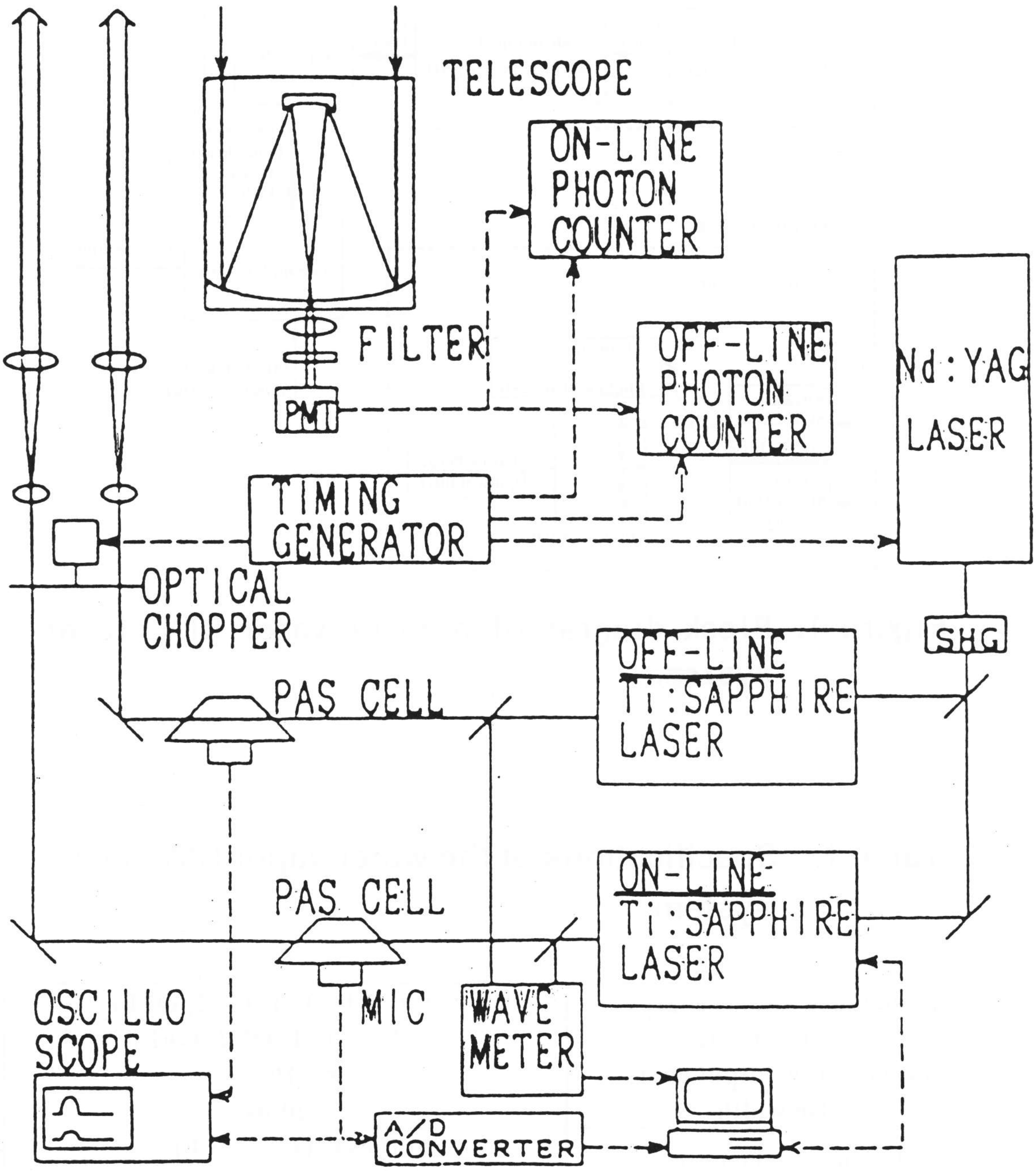
Spectral width	< 0.5 pm
Wavelength stability	< ±0.05 pm (ON1, ON2) < ±1.0p m (OFF)
Side mode suppression ratio	> 30 dB (ON1, ON2)



Block diaglam of the quasi-simultaneous dual wavelength water vapor differential absorption lidar system.

Transmitter	
Pulse energy	100mJ (ON & OFF)
Repetition rate	50Hz
Wavelength	810～820nm
Spectral width	<0.5pm
Wavelength stability	<±0.05pm
Spectral purity	0.999
Altitude	460km
Ground velocity	7km/s
Receiver	
Aperture	1m
Field of view	0.1mrad (day) 1mrad (night)
Filter bandwidth (FWHM)	0.05nm (day) 1.0nm (night)
Optical transmittance	30%(day),50%(night)
Detector quantum efficiency	50% (APD)
Dark count	50 count/s
Δz	100m～1000m
Δx	100km (≒700shot)

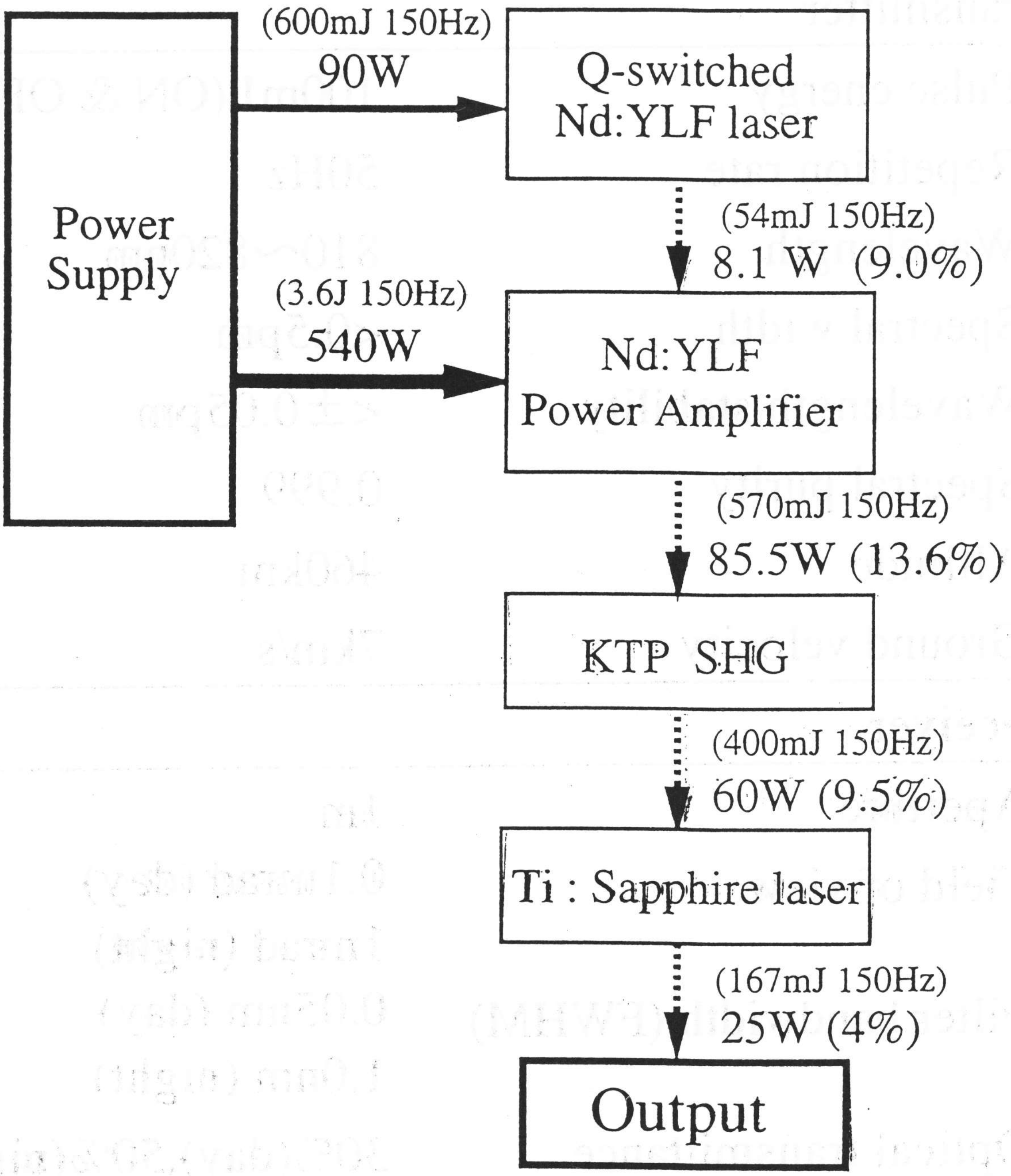
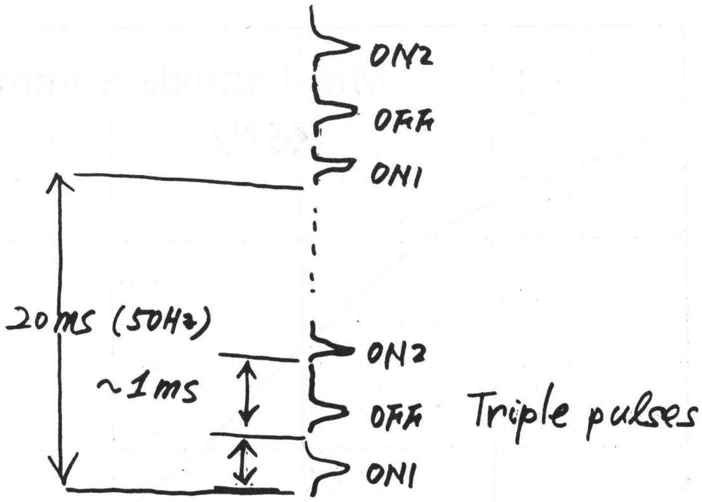
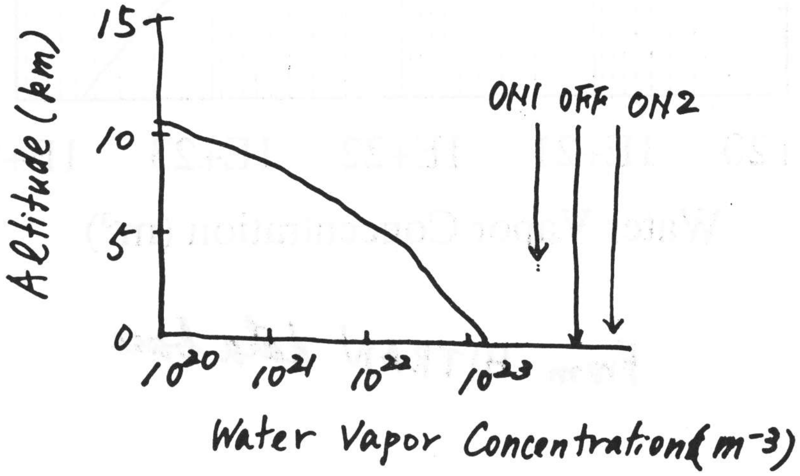
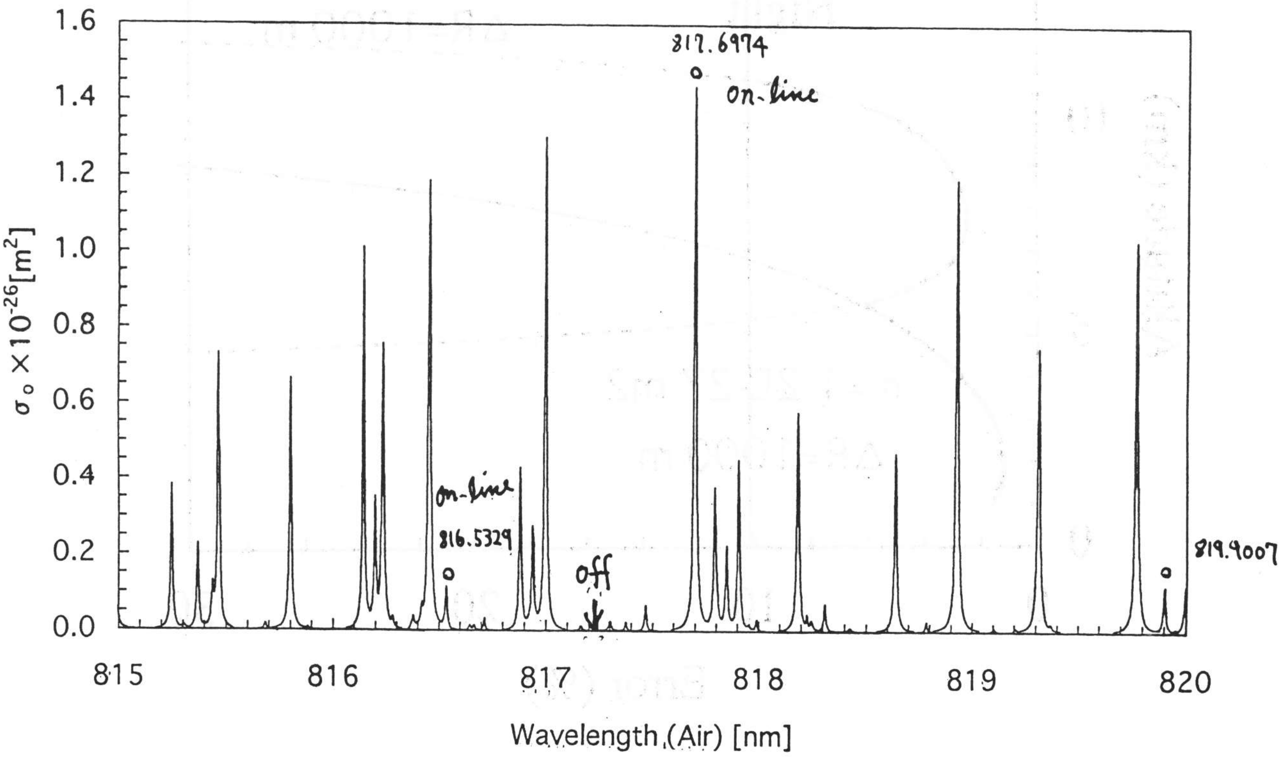


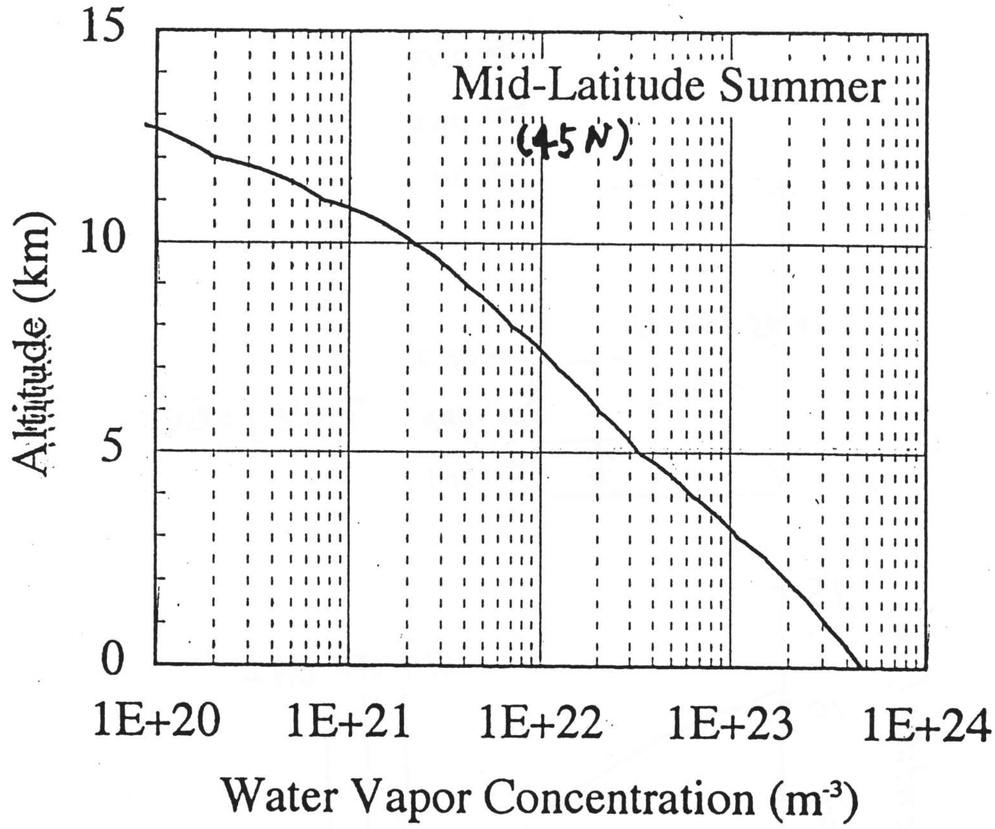
Figure 6. Energy flow simulated for a water vapor DIAL laser system.



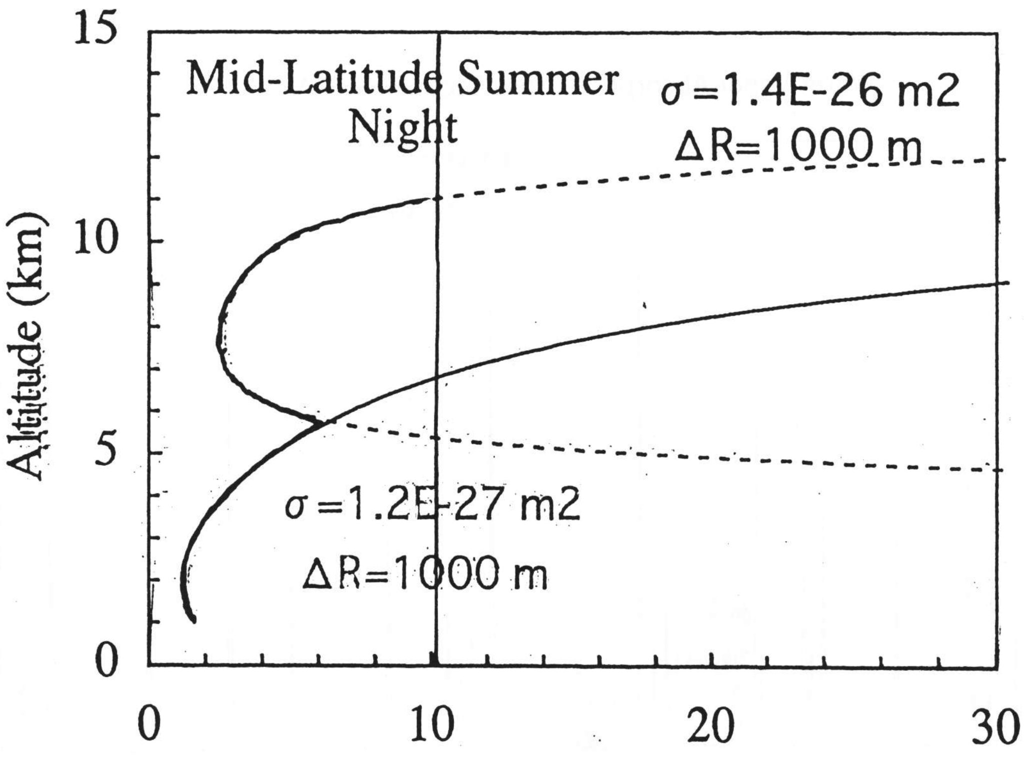


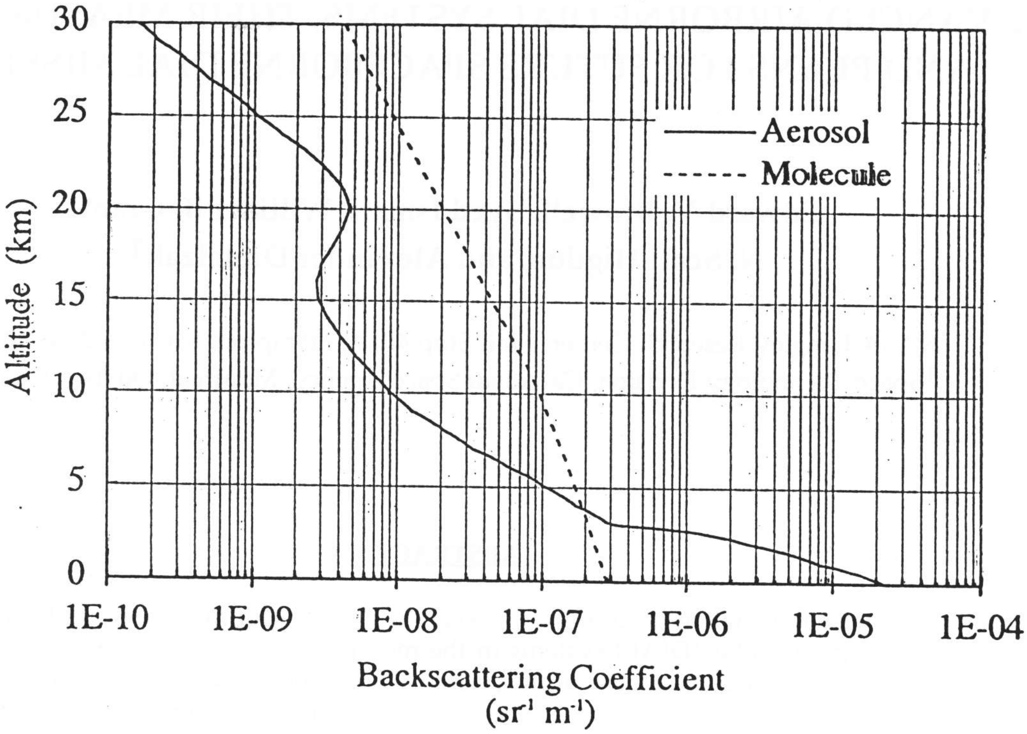
Water Vapor Absorption Cross Section (HITRAN)





From HITRAN data base





Schedule for water vapor DIAL

1994	**Laser design study and DIAL simulation**
1995	**Development of a Nd:YLF laser**
1996	**Development of a Ti:Sapphire laser and injection seeding technique**
1997	**Development of an airborne water vapor DIAL**
1998	**Airborne DIAL measurements of water vapor profiles**
	Development of a space-borne water vapor DIAL