Semiconductor Lidar Design for Quantitative Atmospheric Profiling

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02.Emerging lidar techniques, methodologies, and discoveries

28-Jun, 12:15

P27

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Introduction

It is well known that semiconductor lasers offer the important advantages of lower costs, smaller footprint, simplicity, and wider spectral coverage compared to solid-state lasers. However, despite many advances, the output power achievable from semiconductor lasers is still far below solid-state lasers and generally has restricted their use in atmospheric profiling to lidar that does not allow quantitative backscatter information (e.g., ceilometers). Over the past decade, we have been developing lidar architectures using semiconductor sources that provide quantitative observations needed to advance atmospheric science and weather forecasting. This presentation highlights some of the limitations and benefits of this flexible laser technology. We introduce a semiconductor lidar architecture, based on a pulsed overdriven tapered amplifier and traveling wave amplifier, the latter being leveraged as a multifunction switch. This design has been implemented and is currently being tested for the measurement of water vapor, temperature, and calibrated aerosols via DIAL and HSRL techniques. We present initial results from a side-by-side comparison test of this design. Finally, preliminary data is shown from a field campaign in Taiwan currently underway (May-Aug 2022). This is the first international network deployment of three water vapor DIAL instruments. Semiconductor-based lidar technology can make a unique impact to atmospheric science.

Objectives:

1. Encourage the ILRC community to develop and apply semiconductor-based lidar designs
2. Discuss the limitations and benefits of this laser technology as applied to atmospheric lidar
3. Introduce a new master oscillator power amplifier transmitter architecture

Associated presentations

Presentation: Enhancing the Performance of the MicroPulse DIAL through Poisson Total Variation Signal Processing
Date/Time: 28-Jun 13:30 UTC
Session: 02-Emerging lidar techniques, methodologies, and discoveries

Presentation: Field Testing of a Diode-Laser-Based Micropulse Differential Absorption Lidar System to Measure Atmospheric Thermodynamic Variables
Date/Time: *30-Jun,* 16:00 UTC
Session: *09*- Atmospheric temperature, water vapor, wind, turbulence, and waves

Methods

- Semiconductor laser vs solid-state laser
  - electrical energy vs light energy used as the pump source
  - Advantages: lower costs, smaller footprint, simplicity, and wider spectral coverage.
  - Disadvantages: much lower output power

- Semiconductor-based lidar has been limited in atmospheric profiling applications to only relative backscatter instrumentation (e.g., ceilometers).

Tapered semiconductor optical amplifiers (see Fig 1) allow for suitable laser power for lidar applications while also providing good beam quality. Devices rated for 1 W in continuous wave (cw) mode can reliably be operated up to 8W in pulsed mode.

Traveling wave amplifiers (see Fig 2) are useful to boost the seed laser power prior to the tapered amplifier. Like the tapered amplifier, when operated in pulsed mode (i.e., low duty cycle) they can safely be driven to output peak powers above the cw rated levels.

Traveling wave amplifiers can be leveraged as a multifunction device (i.e., switch and amplifier), reducing cost and complexity while enhancing performance over traditional optoelectronic switching. When switched off, these devices have extinctions on the order of 40-50 dB.

Frequency agile lasers with spectrally narrow linewidth can be achieved by using tapered amplifiers in a master oscillator power amplifier (MOPA) configuration (see Fig 3). The tapered amplifier should be operated near its saturation point by injecting >10mW (cw equivalent) of a spectrally narrow seed laser into the input facet of the device.

Instrumentation

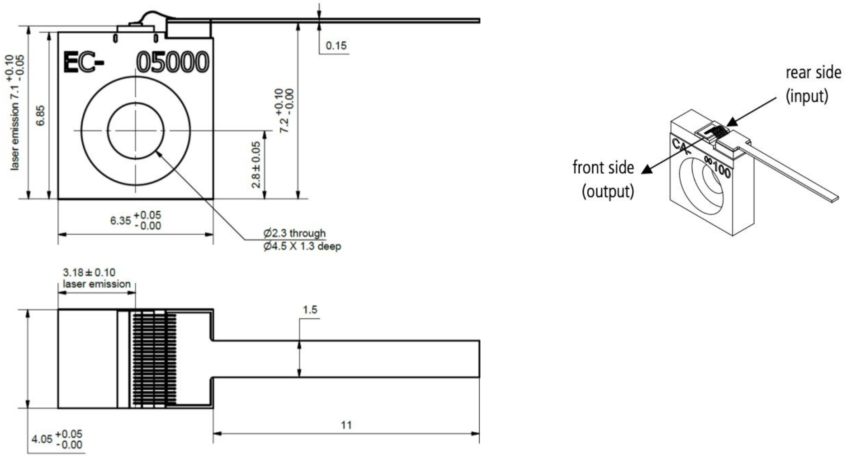


Fig 1. Manufacture package drawing (source Eagleyard) of a tapered semiconductor optical amplifier (TSOA). These free space power amplification devices have a ~4 µm square waveguide input section which tapers to an output facet width of ~200 µm along the horizontal dimension.

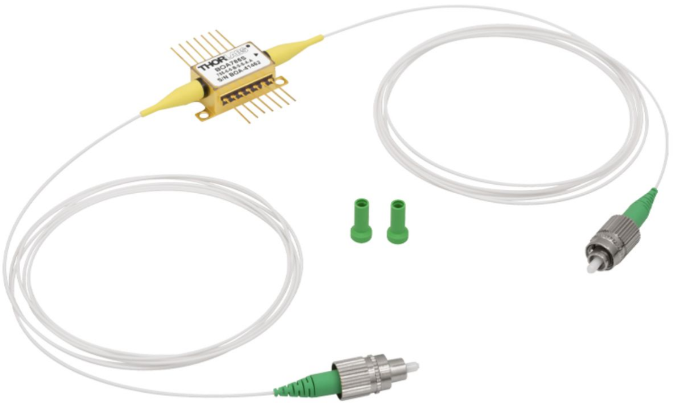


Fig 2. Manufacture photo (source Thorlabs) of a traveling wave amplifier (TWA), or booster optical amplifier. These semiconductor devices are generally housed in a standard 14-pin butterfly package with single mode fiber on both input and output sides.

Transmitter Schematic for HSRL and DIAL

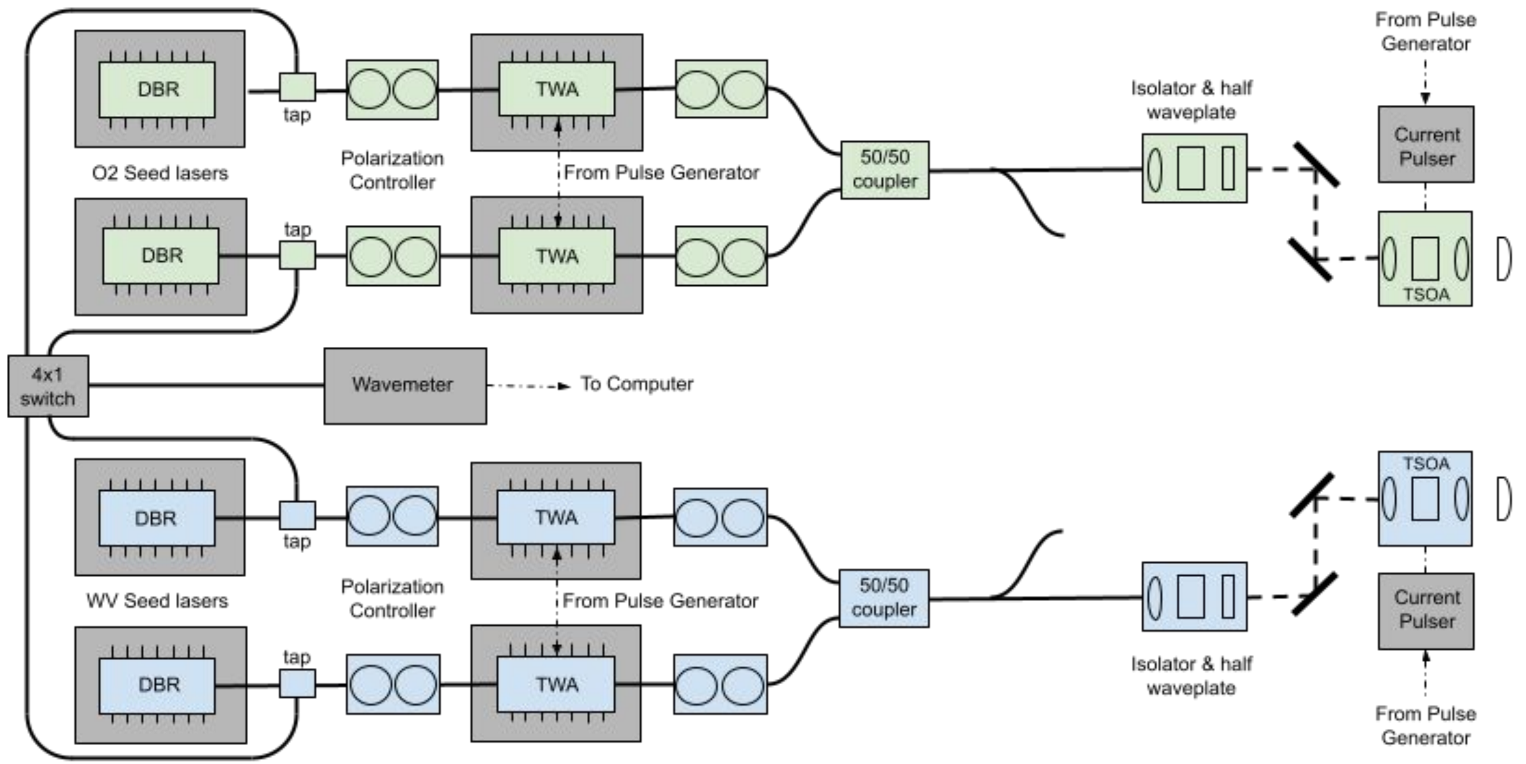
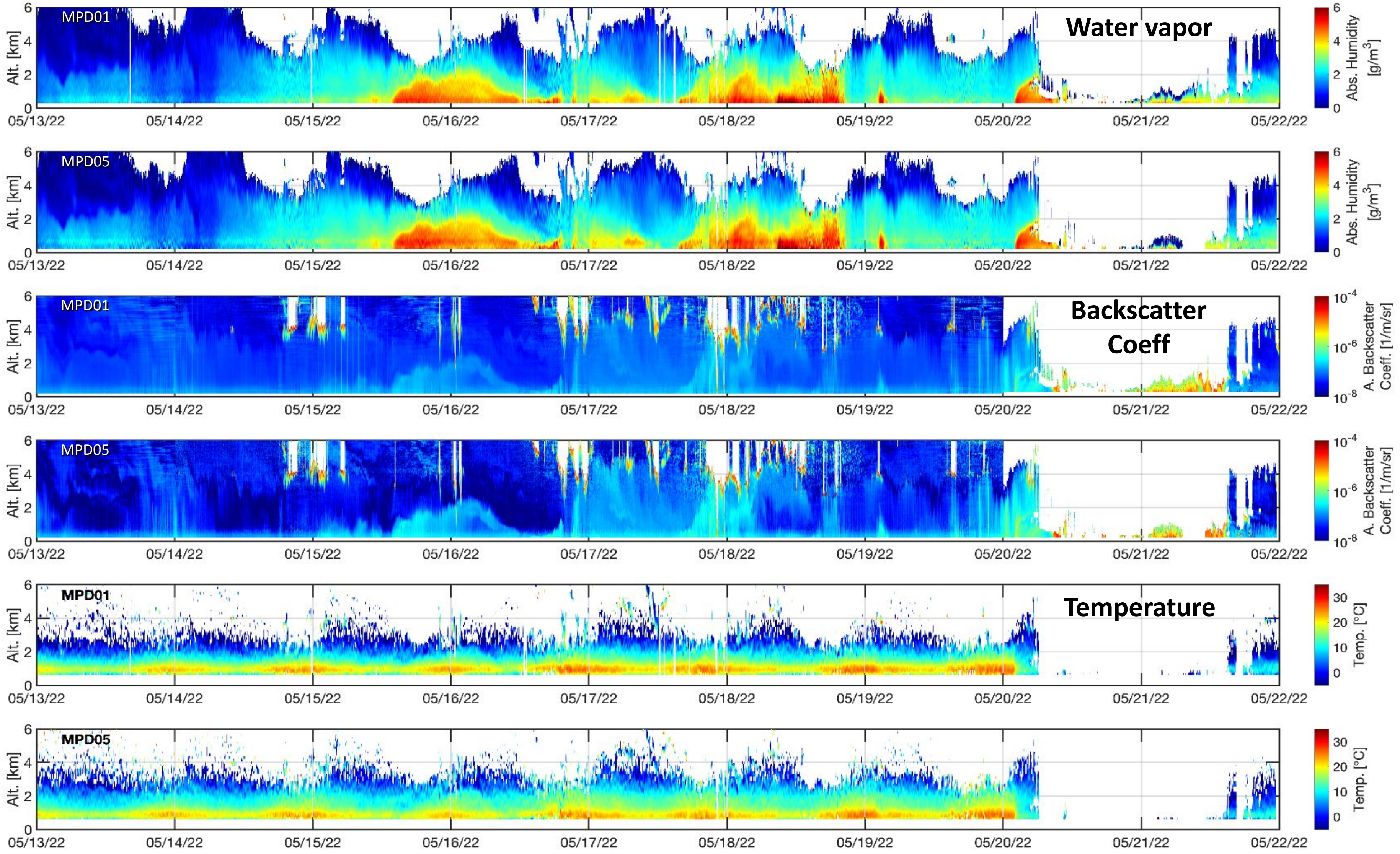


Fig. 3. Block diagram of a semiconductor lidar transmitter in a MOPA configuration. Distributed Bragg Reflector (DBR) seed lasers are followed with pulsed overdriven traveling wave amplifiers (TWA) used as a multifunction device (switch and amplifier). Final amplification occurs in a free-space pulsed overdriven tapered semiconductor optical amplifiers (TSOA). Green shaded components are for temperature profiling and blue shaded components are for water vapor DIAL (see Spuler et al., [1] for details of the receiver which are not shown in this figure).

Side-by-side Thermodynamic Testing

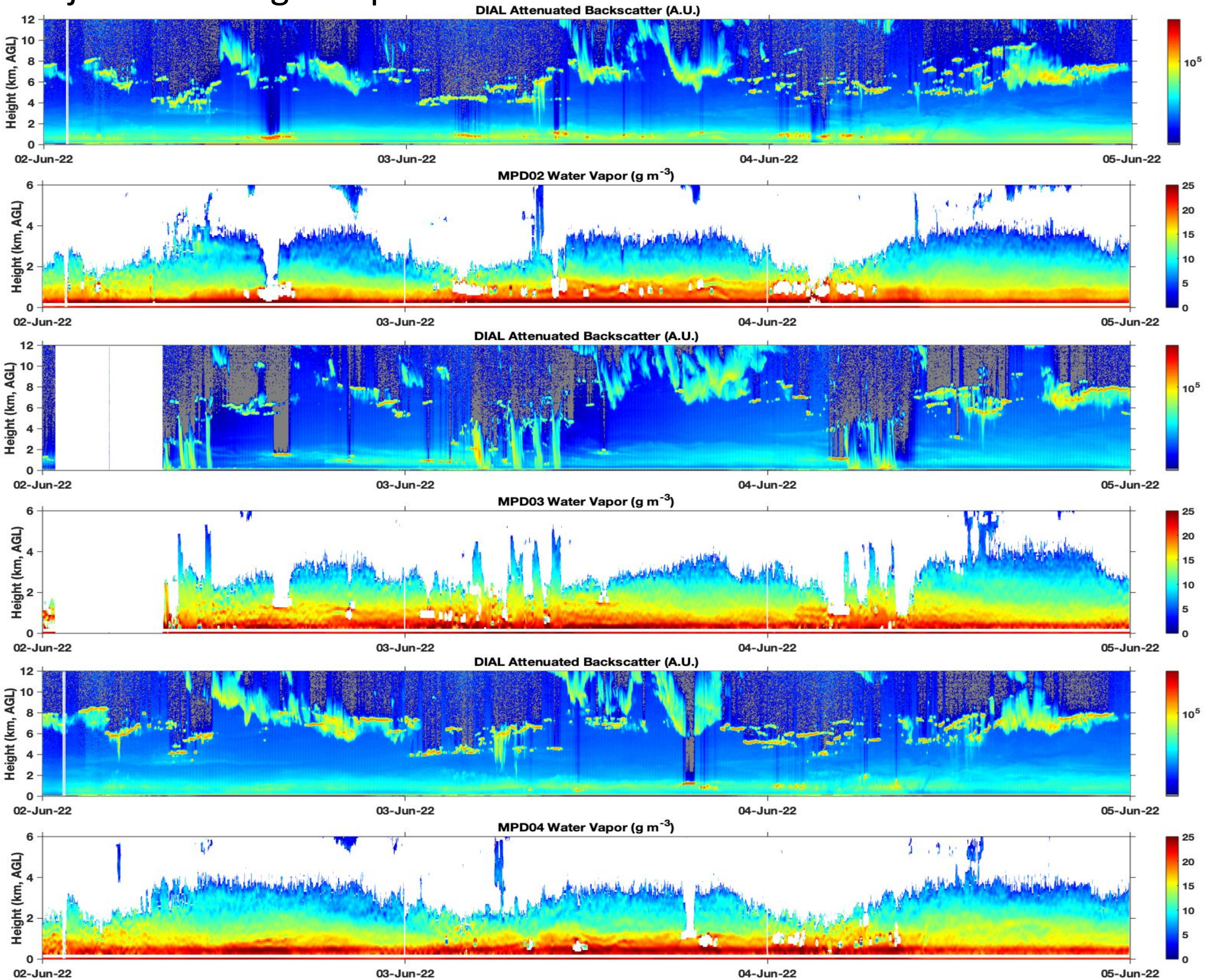
Side-by-side testing between two thermodynamic profiling MicroPulse DIAL (MPD) units began in Dec 2021 from the NCAR Foothills Laboratory campus in Boulder CO USA.



MPD01 is in the Gen 5 configuration as discussed in Spuler et al. 2021 [1], and MPD05 is configured with the new pulsed seed architecture shown in Fig 3. In general, the two units provide nearly identical measurements, but some slight differences still need to be examined more carefully.

Field Projects

Three MicroPulse DIAL (MPD) instruments are currently deployed in Taiwan May-Aug 2022 for the Prediction of Rainfall Campaign in the Pacific (PRECIP) project. This is the first deployment of the network of water vapor DIAL instruments for a science project. Water vapor and relative aerosol profiles just following setup of these instruments are shown below.



Conclusions

Lidar systems built with semiconductor lasers can capitalize on their lower cost, smaller footprint, simplicity, and wider spectral coverage compared to solid-state lasers. Atmospheric profiling lidar transmitters using these components in a MOPA configuration – utilizing current-overdriven tapered amplifiers – have suitable output power and properties for advanced quantitative forms such as DIAL and HSRL. Semiconductor lidar architectures have the potential to advance atmospheric science and weather forecasting in ways that ceilometers and high-power solid-state lidar designs are not capable of providing. Small networks of these instruments are actively being deployed in atmospheric science field studies.

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References

1. Spuler, S.M., Hayman, M., Stillwell, R.A., Carnes, J., Bernatsky, T., Repasky, K.S.: MicroPulse DIAL (MPD) – a diode-laser-based lidar architecture for quantitative atmospheric profiling. Atmos. Meas. Tech. 14, 4593–4616 (2021).

Associated Poster presentations

Presentation: Performance Modeling of a Diode-Laser-Based Direct Detection Doppler Lidar
Date/Time: 28-June, 12:00
Poster Session: P08, 09.Atmospheric temperature, water vapor, wind, turbulence, & waves

Presentation: When can Poisson random variables be approximated as Gaussian?
Date/Time: 29-June 12:00 UTC
Poster Session: P27**,** 02- Emerging lidar techniques, methodologies, and discoveries

Presentation: Planetary Boundary Layer Height Measurements Using MicroPulse DIAL
Date/Time: 28-June, 12:00 UTC
Poster Session: P14, 08. Atmospheric boundary layer processes

Presentation: MicroPulse Differential Absorption Lidar for Temperature Retrieval in the Lower Troposphere
Date/Time: 28-June, 12:00 UTC,
Poster Session: P11, *09*- Atmospheric temperature, water vapor, wind, turbulence, and waves