Atmospheric effects on electro-optical sensor performance in coastal areas

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Measurements taken through the year in False Bay, South Africa, are helping to validate models of sensor performance for a range of practical applications.

Many countries use electro-optical sensors in coastal areas for harbor surveillance, search and rescue, drug enforcement, and detecting piracy. The benefit of these devices compared with radar sensors is that they can provide sufficiently detailed information about a target to identify it. For users, a well-validated sensor-performance model is essential for predicting the range at which a target can be identified in special operational areas (e.g., at sea). Such a model also enables optimization of sensor parameters, such as the choice of spectral band or spatial resolution. Atmospheric propagation—which causes decreasing contrast with increasing range, and hence a lower probability of detection—plays a major role in these models.

At our institute, TNO, we developed Electro-Optical Signal Transmission and Ranging (EOSTAR),[1] a tool for predicting range performance for given atmospheric conditions, and wanted to validate it in a representative location. We chose False Bay, near the Institute of Maritime Technology (IMT) in Simonstown, South Africa, where we measured propagation effects for a path length of 15.7km in a year-round campaign called FATMOSE (FalseBay Atmospheric Experiment). We measured absolute refraction and atmospheric scintillation and blurring effects (to validate the boundary layer model) simultaneously with multiband transmission (to test a new aerosol-retrieval method).

For our propagation setup, we installed light sources on the roof of the National Sea Rescue Institute (NSRI) near Strandfontein and receivers in a room at IMT. A weather station was mounted on Roman Rock Lighthouse, 1.8km away, that included a Vaisala visibility meter, a Scintec scintillometer, and a

Figure 1. The Roman Rock Lighthouse in False Bay, South Africa, where the mid-path weather station and other sensors, provided by the Institute of Maritime Technology (IMT), are mounted.

Heitronics radiometer for probing the temperature of the sea surface (see Figure 1). The instrumentation installed consisted of a five-band (from 0.45 to 2.25μm) transmissometer, a Topcon theodolite with a Sony CCD camera for measuring absolute refraction, and a high-resolution Celestron telescope with a Marlin CCD camera for measuring atmospheric blur and scintillation. All data were preprocessed and downloaded automatically. Figure 2 shows a view of the four sources at NSRI as observed using the Celestron camera on a clear and low-turbulence day. More information on the setup is available elsewhere.[2]

Figures 3–5 show samples of the sorts of data collected that are useful in validating the model. We assume that the particle size distribution (PSD) for atmospheric aerosols follows a Junge distribution, which shows a decrease in the number

Figure 2. *Image of the National Sea Rescue Institute (NSRI) building, showing the four FATMOSE (FalseBay Atmospheric Experiment) sources, taken with the 2m Celestron telescope at IMT. The modulated source at left is used by the transmissometer. The two sources in the middle are used to measure turbulence, scintillation, and distortion. The source at right, together with a theodolite, is used to measure the absolute angle of arrival (AoA, the angle below the horizon).*
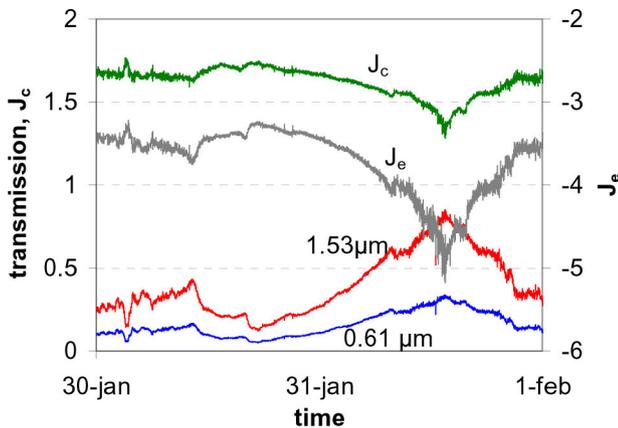

Figure 3. *Example of retrieved particle size distribution data from a multiband transmissometer. J_c, J_e: Junge coefficient and exponent, respectively*

of particles with increasing size, according to the formula $\log(dN/dD)=J_c+J_e*\log(D)$. Here, dN/dD is the number of particles per cubic centimeter per micron, and J_c and J_e represent the Junge coefficient and exponent, respectively. Based on comparison of the transmission values in the different spectral bands, we developed a calculation tool that allows direct retrieval of J_c and J_e.[3] Figure 3 shows the result of such an effort for a day with a dip in the relative humidity, during which the larger particles tend to vanish first. The lower the number of larger particles, the better the atmospheric transmission for longer wavelengths.
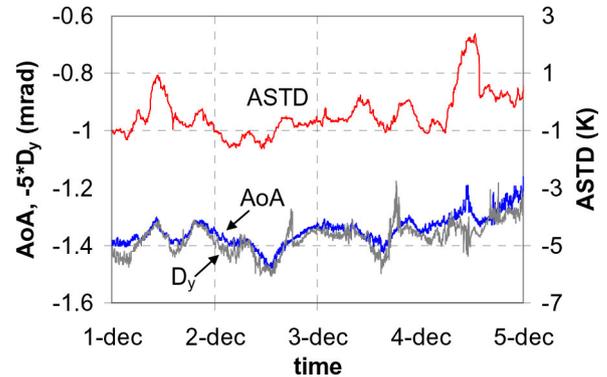

Figure 4. *Example of simultaneously collected air-sea temperature difference (ASTD) and refraction data (AoA and D_y). D_y: Angular separation.*
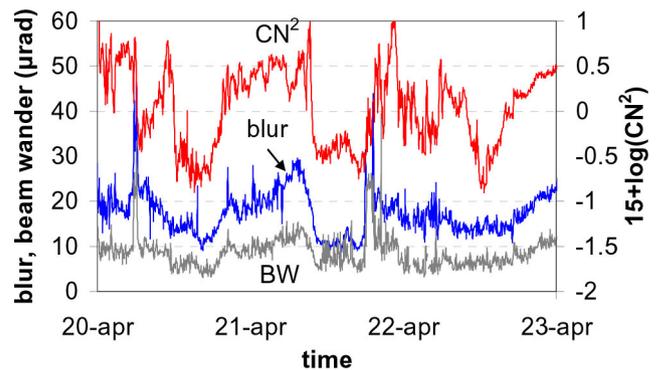

Figure 5. *Example of blur and beam wander (BW) data from the Celestron camera together with turbulence data (CN^2, the structure function for refractive index) from the scintillometer.*

Figure 4 shows the correlation of the angle of arrival (AoA, the angle below the horizon) with the air-sea temperature difference and the angular separation, D_y. Note that the value of the AoA provides direct information regarding the vertical temperature profile in the boundary layer. Figure 5 presents the variation in atmospheric blur as well as the rapid temporal variation in the AoA (beam wander). Data from the local scintillometer appears to correlate quite well with the blur and beam wander data.

The FATMOSE trial has delivered a substantial amount of propagation data over a long measurement period. The information is being used to further validate aerosol models and the boundary-layer model for the prediction of temperature profiles and turbulence. Future work will involve additional analysis of refraction and blur data.

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Arie de Jong is a senior scientist. He initiated an IR search and track short course for SPIE in 2004. He has conducted many transmission experiments over coastal waters for validating propagation models on refraction, aerosols, and turbulence.

References

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