15.3 Observations and Conclusions from the Surface Layer Stability Transition Experiments

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ABSTRACT

The behavior of the atmospheric boundary layer during the transition from a stable nocturnal boundary layer to an unstable daytime boundary layer is not well understood, yet, is of interest to several fields, including chemical and pollutant modeling. Vaucher and Endlich observed a seasonal pattern associated with the Stability Transition timing and local sunrise in 1994 and 1995. In 2001, the Army Research Laboratory pursued a validation of the Stability Transition seasonal pattern, as well as a further transition period characterization, by conducting three specifically timed field experiments. The first and third experiments were executed when a statistically minimum delay between the sunrise and transition (neutral) atmospheric conditions was expected. The second experiment was conducted when a statistically maximum time period between sunrise and transition was forecasted. The results of these experiments validated an evolving Neutral Event Forecasting Model and provided a Eulerian and quasi-Lagrangian perspective on the Nocturnal Stable, Neutral and Day-time Unstable sub-cases. This paper presents the key Experiment observations and conclusions.

1. Background

The surface layer stability transition research began as an Electro-Optical [EO] propagation research project. The greatest EO propagation hurdle is the atmosphere, or more specifically, random density variations within the atmospheric. To quantitatively assess the atmosphere's impact on EO propagation, atmospheric turbulence measurements were taken. Unlike the classical meteorological turbulence studies, atmospheric optical turbulence [AOT] is primarily dependent on the buoyancy terms and relatively independent of wind shear [Kunkel and Walters, 1983]. A key parameter in this study was the index of refractive structure function, C_n^2. By definition,

$$C_n^2 = [79\ P/T^2 \times 10^{-6}]^2\ C_\theta^2,$$

where P is pressure, T is temperature and C_θ^2 is the structure function for potential temperature variations [Strohbehn, 1978]. As you can see, there is no reference to wind shear in this parameter. Therefore, in theory, if one had an isopycnic atmospheric layer and could induce strong wind shear, there would be no impact on the EO propagation through the sheared – isopycnic atmosphere layer.

The surface layer provides at least two naturally occurring periods, within a 24-hour cycle, in which the atmosphere has a minimal impact on EO propagation. These events have been called, "Neutral Events [NE]" or, "Stability Transitions". Consider the surface layer nighttime temperature profile under clear skies. Coldest temperatures are near the surface, with warmer air just above. As a low level EO beam attempts to propagate parallel to the surface through this nighttime stable environment, the beam path would be slowed by the colder, denser air mass, bending the beam toward the colder environment. [Hecht and Zajac, 1979]. Now consider the unstable daytime vertical temperature structure under clear skies. Warm temperatures, a less dense atmosphere is near the surface, with cooler, denser air above. The beam path bends towards the cooler environment. At the point in time where the stable nighttime profile transitions to the unstable daytime profile, is the optimal period for EO propagation. At this time, the atmosphere has a 'neutral' impact on the propagation ('Neutral Event') and is in a stability transition state. Thus, the two references used in this study are defined in EO-Propagation forecasting terminology. For simplicity, a Night to Day transition will be referenced as a Sunrise NE; a Day to Night transition will be called a Sunset NE.

Under ideal conditions (clear skies, low humidity, low winds), this surface layer transition can last for less than two minutes. Under non-ideal conditions, the duration of this transition has been observed for more than 25 minutes. Ironically, the best forecasting results have been for ideal condition scenarios. Forecasts made in the initial study's desert environment could be calculated months in advance. Provided ideal conditions occurred during the actual Test day, the Forecast results (with seasonal correction – see next section) were accurate to the minute. Under non-ideal conditions, only an on-site meteorologist trained in EO propagation forecasting could salvage the results. Based on the frequency of non-ideal conditions, even in the desert, the research continued. What follows is a brief review of a seasonal stability transition pattern discovered while fine-tuning the NE forecasts under ideal conditions, and a Results Summary from the three subsequent 2001 field tests conducted at an alternate desert site from the initial study.

2. Stability Transition Seasonal Pattern

The initial effort to develop a NE Forecast Model began in the early 1990s. Sixteen months of NE times were ultimately assimilated into one dataset, along with C_n^2, Delta-Temperatures [T_{16m}-T_{2m}], Solar Radiation, Wind Speed and Direction values. Much to the researchers' amazement, two relatively well-behaved sinusoidal curves emerged from the NE data. (See Figure __) Running a Fourier Waveform Analysis on the data yielded coefficients that permitted the researchers to formulate a correction curve to the original, grossly inadequate, 'Rule of Thumb' NE Forecast Model. The resulting model was successfully used operationally at the High Energy Laser Systems Test Facility at White Sands Missile Range [WSMR], NM.

The most interesting features of the seasonal curve were (1) that the months where the greatest time lapsed between local sunrise and NE were the two Solstice months and (2), the shortest time lapse between local sunrise and NE were in the two Equinox months. Vaucher and Endlich have proposed a theory that during the Solstice months, the skewed night/day heating resulted in a stronger and/or deeper temperature inversion that had to be overcome before a NE could occur. During the Equinox months, the equal heating/cooling cycle yielded a relatively weaker and/or shallower temperature inversion that had to be overcome before the NE occured. [1995, Vaucher and Endlich]

Based on the seasonal curve, a series of three Sunrise NE Model validation field tests were designed for an alternate desert site at WSMR, NM. The NE Model forecasts were calculated for 'ideal' atmospheric conditions. The research defined 'ideal conditions' as clear skies, low moisture, and low winds. Non-ideal conditions included everything else. This alternate Test site was south and west of the initial study.

The three 2001 Atmospheric Surface Layer Tests were executed at the 100 ft Thompson Tower Site on WSMR, NM; with a scintillometer path extending about 1 km west-southwest to Ammo Site. Meteorological sensors at the Ammo site included a 4-m TacMet II Unit and a 10-m 3-level tower of 3-D Sonic Anemometers. At the Thompson Tower, a Campbell Data Logger linked two levels (2m and 38m) of Temperature, Relative Humidity, Wind Speed and Direction sensors. Vaisala GPS rawinsondes were launched from a High Mobility Multi-Wheeled Vehicle [HMMWV] situated west of the Thompson Tower. The HMMWV also served as the 924 MHz Wind Profiling Radar housing. The Radar Antenna was placed west of Thompson Tower and slightly southwest of the HMMWV. A 25Kw Quiet Generator powered the HMMWV. A High Speed Trailer was placed north and slightly west of the Tower, and used hard power.

The 1213 m desert terrain was generally flat with random mesquite bushes. North-south mountain ranges framed the desert basin, rising about a mile off the desert floor. The steep mountain rises were often associated with a nighttime drainage flow.

3. 2001 March and September Minimum Time Lapse Cases

During the 2001 March Case, only 1 of the 3 days had Ideal conditions. On this day, the forecasted and observed times for this Ideal Case were coincident. The Non-ideal conditions of the other two days were primarily due to the clouds obscuring sunrise. The Non-ideal scenario caused a delay in the NE timing and a slight extension of the NE itself.

The September Case proved to be a good example of how moisture influences NE timing [Kunkel and Walters, 1983]. While all 3 days reported a NE within the forecasted time, the character of each NE was unique. On Day #1(19 Sept), the clear skies were accompanied by ground moisture (dew). The result was a single transition that extended 4 minutes.

On September Test Day #2 (20 Sept), clouds obscured sunrise and created multiple stability transitions. Despite the non-ideal conditions, the first of these transitions occurred at the forecasted time. The second transition extended for about 18 minutes. The final transition occurred shortly after, and consumed the least amount of time. Dew was present during this test day.

Test Day #3 (21 Sept) presented both ideal and non-ideal conditions. Clear skies were observed before and after sunrise. During sunrise, however, there were clouds reported along the eastern horizon and ground moisture noted (non-ideal). A brief cloud obscuration was observed just prior to the stability transition. It is interesting to note that a single NE occurred, prior to the forecasted time, but within the Forecasted standard deviation for September.

4. 2001 June Maximum Time Lapse Cases

The June Cases were the most unusual, and the most instructive. Normally, in June, the desert southwest is very hot, dry and dominated by clear skies. All three Test days began with partly cloudy skies that evolved into isolated thunderstorms by evening. This early, pseudo-Monsoon pattern delayed the local sunrise. An UN-obstructed sunrise for this latitude and these dates would have been 0559 (Day #1) and 0600 (Day #2 and #3) MDT.

On Day #1(20 June), cirrus clouds delayed sunrise 6 minutes. Between sunrise and NE, there were 2 periods in which the sun was fully obscured by cirrus. The consequences of the irregular surface heating manifested in a 27-minute delay from the Ideal Conditions-NE forecast. The morning transition for this day was a single event that lasted 6 minutes.

On Day #2 (21 June), sunrise was delayed 9 minutes due to mid-layer clouds along the eastern horizon (residue of early morning cumulonimbus). Intermittent occulting of the rising sun was coupled with the effects of a significant increase in local soil-moisture from the overnight thunderstorms. The resulting delay in the Ideal Conditions-NE forecasted was about 49 minutes. The morning transition was a single, 3-minute event for Day #2.

Day #3 (22 June) presented the most fascinating data of the Test (Fig 2). This data set began in a nighttime NE! In Post-Test analysis, the NE definition was subdivided into two empirically derived Delta-T threshold gradients: +/-0.25 and +/-0.09. Using the grosser threshold, the length of the in-progress NE was at least 26 minutes. The finer thresholds sampled a 4-minute NE. One proposed explanation for the nighttime-NE was that the cool outflow of a locally, active thunderstorm generated the extended, pre-dawn NE conditions.

Day #3 sunrise was delayed 31 minutes by the decaying anvil (cumulonimbus) occulting the solar disc. The abundance of cloud cover prohibited the normal steady increase in surface heating, resulting in three daylight-NE/stability transitions. Using gross thresholds, these lasted 4, 10 and 3 minutes. The final transition occurred once the sun disc had cleared the thickest of the altocumulus cloud cover.

5. Conclusions

The Surface Layer Stability Transition or Neutral Event study began as an EO Propagation research task. Random atmospheric density variations are the primary concern when forecasting for EO propagation. The turbulence parameter, index of refraction structure function C_n^2, quantifies EO propagation atmospheric conditions. Unlike classical meteorological turbulence, this parameter has little to no wind shear dependence, but is strongly tied to buoyancy and moisture.

When building the operational Surface Layer Stability Transition Model, Vaucher and Endlich divided the atmospheric conditions into Ideal (clear skies, low moisture, low winds) and Non-ideal (all else) scenarios. They also discovered a seasonal dependency that significantly advanced the inadequate 'Rule of Thumb' NE Forecast Model. The maximum and minimum points on the sinusoidal seasonal curve (Fig 1) prompted three subsequent field tests to validate the Surface Layer Stability Transition Model in an alternate desert location.

Results of these three field tests validated the Ideal scenario conditions observed in the minimum sunrise –to-NE time interval cases (March and Sept Tests). The June 2001 maximum sunrise-to-NE time interval study yielded only Non-ideal scenarios. Despite the lack of Ideal conditions, the June 2001 study provided excellent examples of multiple and extended stability transitions. The longest recorded NE state exceeded 25 minutes and occurred at night. Combining the June results with the March and September Non-ideal scenarios, researchers have empirically linked the multiple and extended morning transitions with clouds occulting the rising sun and ground moisture. The quantifying and weighting of these identified factors is a future goal in the development of the complex, Non-ideal Operational NE forecast algorithms.

REFERENCES

Hecht, Eugene and Alfred Zajac, *Optics*, Addison-Wesley Publishing Co, MA, 1979, pp 60-71.

Kunkel, K.E., D.L. Walters, "Modeling the Diurnal Dependence of the Optical Refractive Index Structure Parameter", *Journal of Geophysical Research*, VOL. 88, NO. C15, pp. 10999-11004, Dec 20, 1983.

Strohbehn, J.W., *Topics in Applied Physics, Laser Beam Propagation in the Atmosphere*, Springer-Verlag, 1978, pp. 12-14.

Vaucher, G.T. and R.W. Endlich, "Forecasting Atmospheric Optical Neutral Events – Part II", *1995 Battlefield Atmospherics Conference Proceedings*, White Sands Missile Range, NM, 5–7 Dec, 1995.

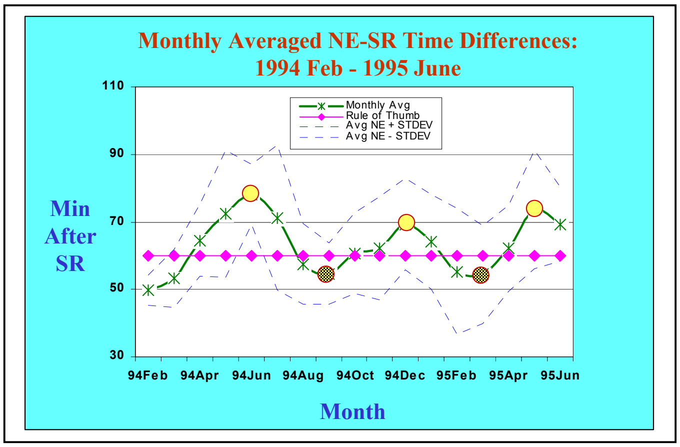

Fig 1. 16 Monthly-Averaged Neutral Event-to-Sunrise time differences. Open circles = MAX (Solstice); checkered circles=MIN (Equinox).

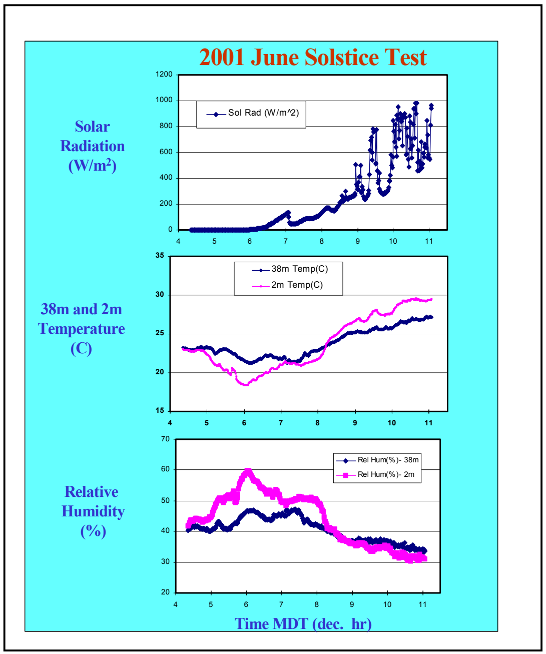

Fig 2. Multiple and extended surface layer stability transitions were observed during the 2001 June Solstice Test Non-Ideal conditions. Time series include Solar Radiation, Temperature (38 and 2 m AGL), and Relative Humidity.

ACKNOWLEDGEMENT: The author would like to thank all the ARL, Meteorological-sensors Integration Team members for their efforts in executing the 2001 field tests supporting this study.

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