3.16 An Empirically Developed Forecast Model for the Surface Layer Stability Transition Period

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ABSTRACT

Fifteen years of observations and field experimentation have yielded a surface layer model capable of forecasting the time of transition between the stable, nighttime atmosphere to the unstable daytime atmosphere over a desert and under clear skies. For years, astronomers have sought to eliminate the atmosphere's corrupting impact on their 'Seeing' capabilities. Unfortunately, the naturally occurring atmospheric density variations make this quest most difficult. There are, however, periods within a 24 hr day cycle in which the atmospheric density variations drop to a minimum. These are called "Neutral Events" and are grossly characterized as occurring when the nighttime stable condition transitions to a daytime unstable condition (and visa versa). In the process of forecasting these events, two categories of conditions were defined: Ideal and non-ideal. This paper will focus on the ideal conditions and the empirically-derived major contributors to the forecast model.

1. An operational Stability Transition Forecast

"Meteorologist, I need to schedule a 90 second, $1M Test for next fiscal year, that requires a minimal amount of atmospheric optical turbulence [AOT]. Forecast the weather for XX Months from now and tell me which day and what time I should use as 'T-zero'. And, I need the answer by tomorrow morning." Thus, started the development of an operational Stability Transition Forecasting Model.

Already known was that at least twice a day, the stability of the atmospheric surface layer shifts between stable and unstable conditions. Figure 1 demonstrates the second critical understanding. Namely, that atmospheric optical turbulence, or the cumulative atmospheric density variations along a path, drops to a minimum during these transition events. According to the local 'rule of thumb', the morning stability transition over a mid-latitude desert occurred about 1 hr after the sun rises, when the stable nighttime atmosphere closest to the earth surface is sufficiently warmed to a near-unstable condition. The evening transition traditionally occurred about 40 minutes before sundown, under the waning rays of the sun, which allowed the unstable, surface daytime atmosphere to cool and form a near-stable environment.

Unfortunately, the 'rule of thumb' doesn't always work. In fact, statistically, it rarely worked. In the mid-1990s, a two-month study sponsored by the Army Research Laboratory [ARL], occurred in a mid-latitude desert environment. The purpose was to investigate the exact timing of the Stability Transition, also known as the 'Neutral Event'. The results showed: First, the two-month average NE timings were 70 minutes after sunrise and 60 minutes before sunset. The respective ranges were: 40-133 minutes after sunrise and 12-98 minutes before sunset. The second finding was that there were two distinct forecasting scenarios: Ideal and Non-ideal. Under Ideal conditions, there were clear skies, low winds and no significant ground moisture. The Non-ideal conditions included all other conditions, with a pre-dominance of local forcing and sun occultation by thin cirrus. The third and perhaps most haunting observation was an implied systematic increase in the monthly average sunrise–to-transition time interval. (Vaucher, 1994) This latter point prompted a subsequent 16-month study, which will be discussed in the next section.

2. Seasonal Effects on Ideal Surface Layer Stability Transition Periods.

The 16-month, 1994 Feb to 1995 June Study was conducted along a 1 km desert path in the Tularosa Basin in New Mexico. The meteorological parameters sampled were collected on two 32-m towers, instrumented at 2, 4, 8, 16 and 32 m levels. The level for observing the transition time was at 8 m AGL and was defined as the period when C_n^2 reached a minimum. [C_n^2 is a the Index of Refraction Structure Function, a parameter that quantifies the AOT along a 1-km path.] Sunrise/sunset references were taken from US Naval Astronomical Tables for the Test Site's latitude. The study/results published explained four key findings (Vaucher, 1995):

1. The AOT minimum (a.k.a. stability transition, neutral event, thermal crossover) was found to occur, not under isothermal conditions, but rather in a very slightly unstable environment.

2. A seasonal oscillation was observed in the monthly average stability transition timing (See Figure 2). The maximum monthly average time from sunrise to transition occurred in the months of June and December. The minimum monthly average time from sunrise to transition was observed to be in September and March.

3. An unproven theory was offered that the stability transition timing was primarily a function of solar angle and the strength of the surface temperature inversion.

4. Using the seasonal oscillation curves, the forecasting equation for the morning and evening transition periods were updated to: sunrise/set + ‘rule of thumb’ + seasonal correction.

Operationally, the subsequent updated stability transition algorithms worked quite well under ideal conditions in the desert environment. However, the theory tying the max and min timing to the solstice and equinox months remained unproven and the Non-ideal conditions remained un-addressed.

In the Equinox month of March 2001, the Army Research Laboratory conducted the first of three field tests aimed at empirically validating the minimum time-from-sunrise Forecast for a stability transition to occur. The desert test site contained a single tower and relied on Temperature differences (Lapse Rate) to determine the stability transition. The 3-day Test had one Ideal Day (Equinox day), which recorded the transition to be within 30 seconds of the forecasted time. The Non-Ideal days were dominated by cloud cover occulting the sunrise over the horizon. The consequences manifested in a 19- and 12-minute delay in the anticipated stability transition.

3. Non-Ideal Conditions Yield Multi-transitions.

In June 2001(Solstice month), the Army Research Laboratory conducted the second of three field tests empirically studying the systematic seasonal influences on the Stability Transition. Three sub-cases, aimed at characterizing the full transition period, were defined: Nighttime stable (0500-0700 MDT), Transition (0700-0900 MDT), Daytime unstable (0900-1100 MDT). While June weather over the Tularosa Basin, New Mexico, would typically fall under Ideal conditions, this three-day test in the desert provided Monsoon-type conditions. On 20 June, the cirrus deck obscuring the sun’s rise and trek through the first 25^o elevation delayed the transition by 27 minutes. On the actual Solstice day, the effects of ground moisture added to the occulted sun influence and delayed the transition by 49 minutes. Finally, on 22 June, the pre-dawn data acquisition case began with a stability transition in-progress. This nighttime transition persisted for approximately 26 minutes (See Figure 3). The abundance of local cloud cover prohibited the steady increase in surface heating, resulting in three daylight stable-to-unstable transition cycles which lasted 4, 10, and 3 minutes. The final transition occurred once the sun disc had cleared the thickest of the altocumulus cloud cover. We suspect, the extended pre-dawn transition was prompted by local forcing (outflow of a thunderstorm to our northeast).
At the time of this writing, a Sept-Equinox Test was in-progress. Results are pending test completion.

4. Stability Transition Forecasting Application.

The stability transition has application in both the civilian and military communities. The initial forecasting requirement cited in this article presented just one application. Meso-and Micro-scale Modeling have productively examined many of the facets of the boundary layer. However, the transition cycle research has had limited open literature references.(Angevine, 2001) In Angevine’s paper, he explains the usefulness of knowing this transition timing for initiating the Convective Boundary Layer Models. He also cites the practical use as it relates to air pollution concerns. Angevine’s study concluded that “A parameterization or diagnostic relationship based on surface flux alone, or on an entrainment flux… is clearly inappropriate.” He suggests using a blend of both influences.

Both military and civilian worlds deal with daily forecasts and the dispersion and distribution of chemical constituents. As we gain more exacting forecasts of when these transitions will occur, the added precision will assist in improving the output of other time-dependent modeling.

Recently, NOAA/CIRES published a study of the transition in two different agricultural environments. Sample cases were taken from June and August. While only one of the two June transition times reported were within the Desert’s Forecasted +/- Standard deviation value, both of the August sample cases fell within the +/-Standard Deviation footprint of the Desert Forecasted time.

5. Summary

An operational requirement to precisely forecast the time of minimal AOT prompted the development of a Stability Transition/AOT Neutral Event Forecast Model. When the initial ‘rule of thumb’ forecasting technique failed, two long-term studies were conducted and unveiled the existence of a seasonal solar cycle dependency under Ideal atmospheric conditions. These ideal conditions were defined as clear skies, low winds, and low moisture. Implied by the solar cycle was an alternate dependency on the strength of the local surface temperature inversion. In 2001, ARL conducted Field Tests that successfully demonstrated the Model application for an alternate desert site. Also, reported was verification that under Non-ideal atmospheric conditions, the stability transitions can occur multiple times at any hour of the 24-hour cycle.

The civilian and military applications range from Atmospheric Model enhancement (for Air Pollution, Convective Boundary Layer Models, etc) to optimizing military sensors and weapons.

Stability Transitions are being studied in non-desert environments. NOAA/CIRES has recently been investigating stability transitions over an agricultural terrain. ARL will be expanding their mid-latitude, desert-based stability transition study in FY02, to include an Alaskan High Latitude forested region.

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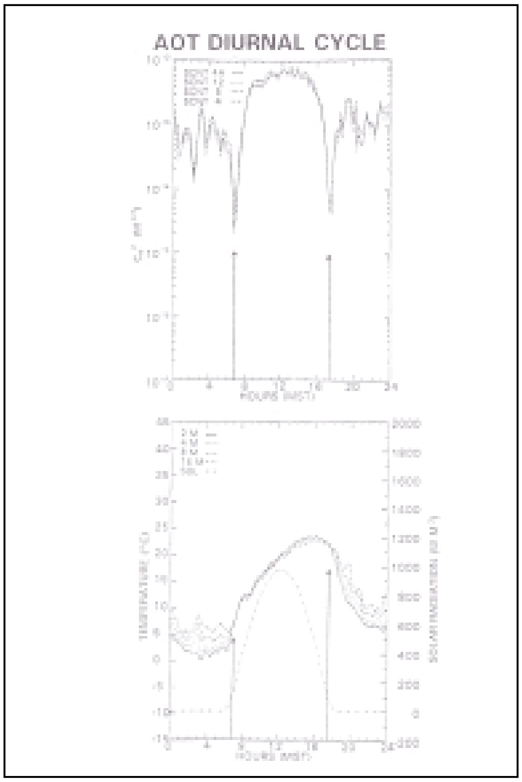

Fig 1. C_n^2, Insolation and Temperature (2,4, 8,16 m AGL) time series during an Equinox Day in a desert, under Ideal conditions. Arrows show stability transitions/minimal optical turbulence.

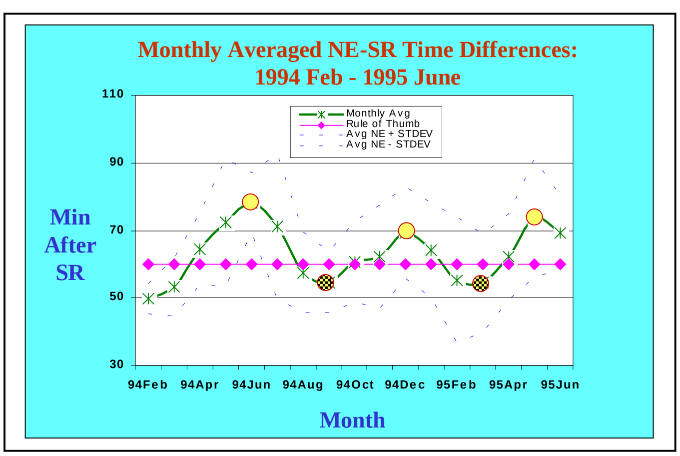

Fig 2. Monthly Averaged[avg] Neutral Event to Sunrise time difference for a 16-month period. Open circles = MAX (Solstice) avg; checkered circles = MIN (Equinox) avg.

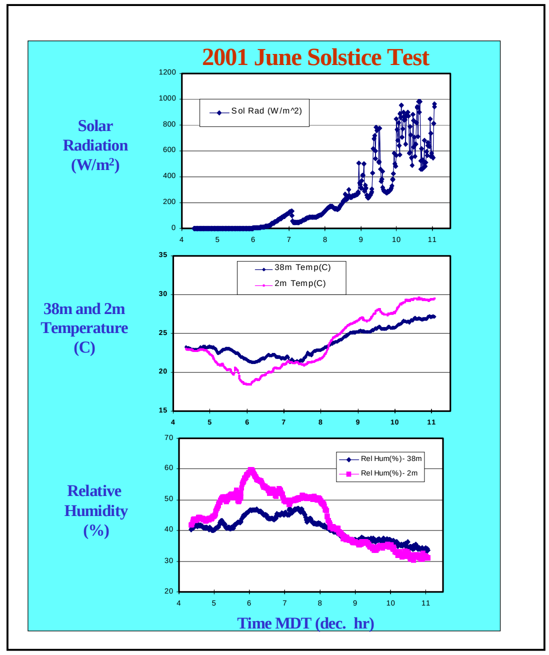

Fig 3. The 2001 June Solstice Test time series for Solar Radiation, Temperature (38 and 2 m AGL), and Relative Humidity show multiple stability transitions during Non-Ideal conditions.

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