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Astronomical Seeing

By: Jeff Beish

Association of Lunar and Planetary Observers (A.L.P.O.).

Introduction

From the first moments this observer gazed into the night sky with a telescope it was apparent our atmosphere was anything but crystal clear.

The Earth's sky is not completely transparent and as stable as we would like it to be. Experienced observers are well aware that turbulent air currents can cause telescopic images to blur or move around in the eyepiece field. We have coined the phrase, "astronomical seeing," to quantify, or put into perspective, the effect the atmosphere has on image quality.

Since the Earth's atmosphere acts like a fluid, we may think of it as a very thin body of water. Imagine yourself at the bottom of a clear lake looking up at the Moon!

None of this should be a surprise to anyone who has peered through a telescope, even at the Moon. At times the Moon appears like it swimming in water or above a smokestack! This atmosphere making them nearly impossible to study at times effects other Solar System objects even more.

Bad seeing can render a night's observing schedule useless, especially for us planet watchers. Even though seeing conditions may improve for brief moments during periods bad seeing, we should pay attention to weather reports. Just because a weather forecast calls for clear sky that does not mean the atmosphere will be good for observing.

First, a look at the composition of our atmosphere, the effects the upper atmosphere has on "seeing," and a study of micrometeorology will help readers understand these effects near to the ground.

A Turbulent Upper Atmosphere

Streams of warm and cold air mixing and flowing together cause atmospheric turbulence. Most of the disruptive atmospheric turbulence occurs very near the Earth's surface up to around 50,000 feet. Above this altitude the atmosphere begins to thin out and the airflows, or winds, tend to be in the same direction with each other-- therefore reducing the effects of turbulent cross winds or violent updrafts. In other words, the higher the altitude the steadier the airflow is.

The jet stream is a belt or band of rapidly moving air from 30,000 feet in altitude, or above, crossing the mid-latitudes of the U.S. Actually, there are two jet streams. One in the far northern U.S. and Canada and the other moves north or south across the center of our country. The jet stream tends to change in latitude seasonally and will meander across the country like a river of turbulent water.

The air at altitudes above or below the jet stream may be calm and flowing steadily in one direction, but the jet stream does not necessarily move in the same path as the surrounding airflow. Crosswinds or vertical wind in this circumstance causes a decrease in "seeing."

Also, the southern edge of the jet stream will often contain ice formations or cirrus clouds that tend to help seeing at times and hinder it at other times. Irregular, disturbed cirrus clouds are not good. Cirrus clouds, or "mare's tails" as they are often referred to, are usuall uniform streaks indicating smooth airflow. However, the clear region just north of this band of cirrus clouds may be very turbulent.

These air streams or "thermal currents" causes apparent starlight to change directions and intensity. Because the density of air varies with temperature and the refractive index of air depends on the density of air, starlight does not traverse through it without interference. Thermal currents in the air have the effect of thousands of lenses floating around in it.

Atmospheric thermal currents also vary the amount of starlight passing through it and we call this atmospheric "extinction." Random intensity fluctuations of starlight passing through the atmosphere are called "scintillation."

You can easily see the effects of scintillation by looking up at night right after a cold front and see the stars twinkle and change colors. Refraction within the thermal cells also causes the color of the object to rapidly change.

Atmosheric Particles Cause Turbulence

Air pollution also affects seeing. Seeing in large industrial areas will have several types of particles and dust materials circulating at lower altitudes. These particles store heat and will cause thermal air currents.

The largest polluters are not manmade though; volcanoes are known to wreck havoc on astronomical seeing. Starting with the irruption of Mt. St. Helens (northwestern U.S.A.) in the early 1980's, El Chichon (Mexico) sometime later, and the recent Penetubo (Philippines) irruption in 1991, we see how these natural phenomena can restrict our sky watching in the equatorial regions of Earth. That deep red sky at twilight may be beautiful; however, this indicates that the upper atmosphere is full of particles that disrupts the air flows and effects seeing. These dust particles fall to Earth in short order; however, several active chemical compounds remain in the upper atmosphere for months, even years, to reduce transparency and seeing.

Dust storms in the African deserts can also cause seeing problems in some parts of the southeastern United States. Dusty haze covers the entire sky for weeks at a time when this occurs and seeing goes right down the tube, so to speak.

All of the above conditions cause starlight to oscillate about the sky, or "twinkle," and blur, thereby causing them to appear larger than they really are. In smaller telescopes these fluctuations appears to shift star images around or make the entire planetary images to oscillate. In larger instruments the image tends to blur or smear.

In the case of the small instruments the apparent size of these "seeing cells," or "thermal currents," are closer to the same size as the apparent angle of the object we see at the telescopes focal plane. However, in larger instruments the angular image size is larger so these "seeing cells" can disrupt different areas within the image. This is, of course, speculation and observers should heed this warning. So the planet image may expand and contract or blur.

There is some dispute in the scientific community as to what constitutes a major contributor to air pollution. Some declare the Earth is in eminent peril due to Man's machinery and others say this not so. Those who discount what volcanic eruptions or African dust storms can do to our atmosphere should go out and look up sometimes after a newsbreak of such an event. Maybe look up with a telescope!

Micrometeorology

Micrometeorology is the study of the atmosphere from the surface up to a few yards. Since we cannot do much about the atmosphere, we do have some control over where we locate our observing site.

The Earth's atmosphere is composed of gases, mostly nitrogen, oxygen-- and water vapor -- and it is not invisible. Gaseous vapors have mass and at times may feel like a fluid, especially in South Florida were the humidity reaches nearly 100% at times.

Humidity is a measure of how much moisture is in the air and also indicates at what point the air will become foggy or hazy. Meteorologists call this point or condition the "dew point."

Nearer to the Earth's surface there are obstructions, such as mountains, hills, lakes, trees, buildings, etc., that disrupts the air flow and is a major cause of bad seeing. Yes, even trees can effect seeing and some more than others. We will discuss this later.

When planning an observing site it is important to select high ground if possible. Airflow is less turbulent over hills than in valleys. Also, observing from the lee side of a lake can be interesting (the lee side is where wind blows over the water to you). You will see improved seeing when you move to the opposite side of the lake where the wind is from the dry land. This depends on how large the lake is however.

Air circulation over the ocean and shorelines in coastal areas is very complex and defies a simple or brief explanation here. However, well known to those living near coastal areas is that astronomical seeing can be excellent, at times providing the best conditions for telescopic viewing. Conditions near the coast changes dramatically with the seasons too. This is another very complex subject and will be omitted as well.

The same thing occurs near buildings that happen to be near lakes or mountains. The wind may not blow your telescope around as much behind the house, but seeing will suffer. The peaked roof from the house causes turbulent down drafts that spoils airflow over your telescope. Also, and heat rising from the roof causes turbulence. Move your telescope to the other side, away from the "lee" side and seeing improves.

Trees will radiate heat and emit vapors at nightfall, therefore spoiling the air immediately above them. Pine trees are among the worst offenders and this writer avoids setting up a telescope in a densely populated pine forest.

The problem in forests is not quite as simple as previously stated. The main force that disrupts the air above the forest comes from vertical air circulation within the trees. Also, in pine forests a thick layer of the heat storing biomoss (dead pine needles) releases heat plumes after the Sun sets. Combined with the up and down airflow this heat causes much turbulence over the trees.

All is not lost for tree dwellers though. A forest may be beneficial to day-time telescopic observing. It is well know among glider pilots that air above a forest is calmer during day time than at night, giving rise to the suggestion that seeing may be good during the daylight hours over these trees.

The Seeing Scales

Over the years visual observers have derived many schemes to describe "astronomical seeing" in a quantitative manner. First, the scales used by many in the Association of Lunar and Planetary Observers (A.L.P.O.).

An A.L.P.O. Scale: The **first step** is to determine the observer's "personal constant" by using several double stars on a "night of exceptional seeing", and with the aperture stopped down to 1 inch. This "personal constant, **r**, is the separation in seconds of arc of the closest pair which can barely be separated.

Step two: This requires that, on a night of actual observing, the observer find the closest double star, which can be resolved, using the full aperture and then multiply that separation by the aperture in inches, yielding a value **r'**. This is used along with **r** (as found above) to calculate the telescope efficiency, **e**, as:

$$e = r / r'$$

and the effective aperture, **D'**, can be determined from:

$$D' = (rD) / r'$$

where **D** is the telescope aperture in inches.

Modification of *Step One* above: the observer would perhaps be better served by using the methodology described by *Couteau* in Chapter 4 of **Observing Visual Double Stars** where he explains in detail how to use artificial lighting and small ball bearings to create artificial double stars located some distance away from the observer. In his own words (p. 89):

"You will have a stable stellar image, unaffected by seeing, that can easily be examined comfortably, without twisting your neck. Reflections from two lamps, side by side, will give a beautiful double star. The separation can be varied at will, up to the limit of resolution, and even differences in brightness can be created by moving one lamp with respect to the other."

By using the formula *Couteau* provides all variables are used to define the separation of the artificial pair in arcseconds. In his example, he uses a 4mm ball bearing; lamps separated by 10cm and located 1m from the bearing, and an observer 100m away, to yield a 0.2 arcsecond separation (ball bearing radius, distance between the lamps, distance from lamps to ball bearing, and distance from telescope objective to ball bearing).

A suitable "test stand" could be built to allow the "personal constant" to be determined without regard to whether or not it was a "night of exceptional seeing." Such a test stand could also be used to compare telescopes of the same aperture to determine which had the better absolute resolution.

In *Texeraux's* **How to make a Telescope**, Willmann-Bell, 2nd Ed, p309-310) and *Jean Dragesco's* **High Resolution Astrophotography**, CUP, p3-4) and noted the following quantitative scale to estimate seeing based on the work of *Danjon* and *Couder* (1935). It also gets a mention in *Sidgwick's* **Amateur Astronomer's Handbook**, 2nd Ed, p454-455). Thi scale provides an absolute notion of seeing expressed in arcseconds and is not tied to any specific aperture, unlike some of the other scales in common use e.g. *Antoniadi.* We may assume the ***Rayleigh limit*** (140/Dmm) as the baseline measure. In use one simply compares the degree of turbulence in the ***Airy*** pattern with the description, and then reads off the value.

$$a \text{ (in arcsecs)} = 140/D(\text{mm})$$

Table 1. Scale of "Astronomical Seeing"

Scale	t-value	Description
I	$t > 1.5a$	Image tending towards a planetary appearance
II	$t = a$	Strong turbulence; rings weak or absent
III	$t = 0.5a$	Medium turbulence, diffraction rings broken,

		central spot having undulating edges
IV	t = 0.25a	Complete rings crossed by moving ripples
V	t =< 0.25a	Perfect images without visible distortion and little agitated

Yet another scale: Harvard Observatory's *William H. Pickering* (1858-1938). Pickering used a 5-inch refractor. His comments about diffraction disks and rings will have to be modified for larger or smaller instruments. A good starting point:

1. Star image is usually about twice the diameter of the third diffraction ring if the ring could be seen; star image 13" in diameter.

2. Image occasionally twice the diameter of the third ring (13").

3. Image about the same diameter as the third ring (6.7"), and brighter at the center.

4. The central Airy diffraction disk often visible; arcs of diffraction rings sometimes seen on brighter stars.

5. Airy disk always visible; arcs frequently seen on brighter stars.

6. Airy disk always visible; short arcs constantly seen.

7. Disk sometimes sharply defined; diffraction rings seen as long arcs or complete circles.

8. Disk always sharply defined; rings seen as long arcs or complete circles, but always in motion.

9. The inner diffraction ring is stationary. Outer rings momentarily stationary.

10. The complete diffraction pattern is stationary.

On this scale 1 to 3 is considered very bad, 4 to 5 poor, 6 to 7 good, and 8 to 10 excellent.

Transparency

While this paper covered several aspects of "astronomical seeing," the transparency scale that is often asked for in A.L.P.O. or B.A.A. observational forms is seldom mentioned in detail.

Most often transparency is simply described as the measure of how clear the sky is. By looking for the faintest star in the sky and fitting this to some arbitrary scale we satisfy this criteria.

Some A.L.P.O. sections use a transparency of 1 to 6, or the faintest star detectable from; 1st magnitude through 6th., where the latter is near the lower threshold of the human sight.

Transparency is a measure of the clarity of the air. Haze, smoke, dust particles will reduce the clarity of out atmospheres and can be readily seen in and around brightly lit cities and a general background glow.

A 6th magnitude star out in the darker countryside may not be visible in the city. One may not even detect 4th or 5th magnitude stars in the city because of the background glow of "light pollution."

Light pollution can light up particles suspended in the atmosphere up to thousands of feet. Clouds can bee seen to glow even above 6,000 feet altitude.

Regions with high humidity can also effect transparency, especially in the red end of the spectrum.

For an advanced course in "astronomical seeing" and transparency, Sidgwick's **Amateur Astronomer's Handbook**, chapter 26, "The Atmosphere and Seeing," starting on page 445, describes these factors in great detail. Another more advanced dissertation can be found in a chapter, "The Theory of Visual Lunar and Planetary Observation," in the A.L.P.O. book **Observing the Moon, Planets, and Comets** by: Clark Chapman and Dale Cruikshank

However, for most observers a more general statement and definition can be found in Phil Harrington's, **Star Ware**, Chapter 9, beginning on page 241 and Michael **Porcellino' Through the Telescope**, Chapter 7, page 101, "Transparency."

The "Astronomical Seeing" In South Florida

The "astronomical seeing" in South Florida, maybe the entire State, is excellent most of the time during all seasons. The atmosphere is very stable near the East Coast because of the upward movement of the warm, humid air from the Gulf Stream. Air pollution does not seem to be a big problem here; however, it is on the increase and may very well decrease our seeing conditions in the future. Although we do see numerous clouds, they are usually the "fair weather" cumulus type and have little effect on seeing.

Prevailing winds in this region tend to be from the east or from the coast during most seasons. However, in winter, winds may be from the north and north west over the land. Sea breezes are common and tend to cause inversion layers over the coastal area up to a few miles inland. These inversions stabilize the air from a few yards above the surface to around 1,500 to 2,000 feet altitude. Above this altitude the air may be variable and winds are usually from either directly from the east or south east from the sea.

In 1990, this writer measured hundreds of star trails from glass plates to determine the steadiness of the South Florida air over a period from the early 1960's throughout 1970's. A precision measuring engine was used and plates taken by the U.S. Naval Observatory's 8-inch f/22 Photographic Zenith Tube (PZT). I concluded that the typical seeing for all seasons at this observing site was less than one second of arc (< 1"). A detailed report will be published in the future.

It appears that our seeing conditions in this area may be controlled to some extent by a phenomenon called El Niño. El Niño is a condition named by meteorologists that occurs in the central Pacific Ocean. This condition retards the westerly trade winds from South America to near Southeast Asia. Recently this phenomena has been shown to effect the weather over the United States and my studies seem to indicate it also affects the weather to a considerable extent in Florida. We have seen periods of dry, clear conditions for years -- interrupted by a few years of wet and cloudy weather corresponding with El Niño cycles.

During the mid- to late-1970's some planetary observers in South Florida noted that our seeing was mediocre. Excellent seeing periods were fewer and the atmosphere in general was not as stable as "usual." Following the peak period of El Niño in 1979 throughout 1983, our seeing became very good -- ranging from excellent to perfect for long periods of time. Then it appeared to return to mediocre again throughout the late 1980's, and early 1990's.

A weak El Niño appeared in late 1989 and seemed to strengthen during 1990 causing an apparent shift of our weather patterns back to that of the 1970's.

However, something always comes up to cloak our understanding of nature. The water flow through the Everglades increased in the early 1990's and seemed to modify the weather pattern. We had experienced a drier climate during the late 1960's through the late 1980' with fewer afternoon thunderstorms or showers. This compounded the complexity of the climate in this region, especially for us amateur weather watchers.

By 1992 the sky was just not as steady as usual, and with several of the volcanoes irrupting around the world the sky also became brighter than usual. The sky in the day time was not that usual deep blue, but was hazy and bright -- less blue. The night sky-glow had increased noticeably and seeing seemed to diminish accordingly.

During the first months of 1994 the sky appeared to be clearing. Then in June a big storm blew up in Africa and dust went aloft in the upper atmosphere spreading over South Florida. This happens occasionally, so we just wait until the dust settles, so to speak. Well, the seeing was about as bad as it could be that month, but, by the second week of July the sky cleared and seeing returned to excellent again.

During July of 1994, several local astronomers and noted ALPO members assembled at my observatory to use the 16-inch f/7 Newtonian to record the comet Shoemaker-Levy 9/Jupiter event. A typical magnification used during the two or three weeks of observing ranged from 390x to 600x. Occasionally, I would treat them to observing at 1,125x. A few observers were stunned by the amount of surface details seen on Ganymede! It was the usual ho hum stuff to the local inhabitants....

Now living in Virginia I have grown to appreciate how good seeing can be at times. Maybe be it was selection of the observing site, but it seems to me the air is good most every I observe.

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