Test of the new LAS MkII Scintillometer for validation of statewide New Mexico evapotranspiration maps

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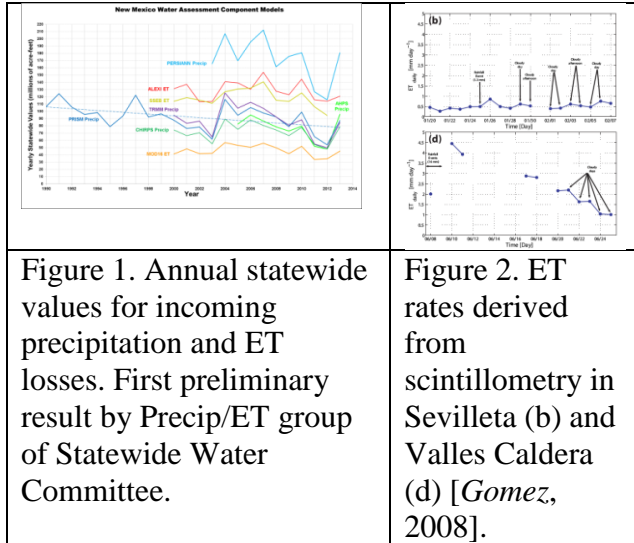

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Project title: Test of the new LAS MkII Scintillometer for validation of statewide New Mexico evapotranspiration maps

Problem Statement and Objectives:

Exact water quantity and availability measurements, as well as their temporal relationship, needed by water resource managers is lacking in New Mexico. To more accurately gauge water resource availability, the Statewide Water Assessment Steering Committee aims to quantify the components of the state's water balance: precipitation, evapotranspiration, stream flow, groundwater recharge, and changes in aquifer water storage. My faculty sponsor, Dr. Hendrickx, is a member of the work group that focuses on the comparison of operational precipitation and evapotranspiration (ET) products for statewide water assessment. Contrary to expectation the precipitation and ET products result in very different estimates of annual precipitation and ET in New Mexico (Fig. 1). In order to determine which products can be used in New Mexico it is necessary to validate them against ground measurements. The validation for precipitation is simply conducted by comparing the precipitation products against the many statewide rain gauge measurements. However, this approach cannot be used for ET since very few ET measurements have been made in New Mexico and these are at a limited number of sites.

The direct measurement of ET at the km-scale of the Statewide Water Assessment is difficult and costly. Therefore, we propose to use scintillometry for measurement of the daily sensible heat flux and radiation meters or remote sensing for net radiation [Hong, 2008]. Then, the latent heat flux or ET is found as the difference between net radiation and sensible heat flux since the daily soil heat flux is close to zero (Fig. 2). Dr. Hendrickx's research group has a great deal of experience operating a statewide scintillometer network [Gomez, 2008; Hendrickx et al., 2007; Kleissl et al., 2009]. Unfortunately, this network had to be abandoned when the measurements revealed severe biases (5 to 20%) in the sensible heat flux measurements of the first generation Kipp & Zonen scintillometers [Kleissl et al., 2008]. Pushed by the research results in New Mexico and elsewhere Kipp & Zonen has now developed a second generation LAS MkII Scintillometer with a greatly reduced bias (1-3%) for quantification of ET. The objective of my research is to evaluate this improved scintillometer for ET estimation under New Mexico conditions at the km-scale.

Figure 1. Annual statewide values for incoming precipitation and ET losses. First preliminary result by Precip/ET group of Statewide Water Committee.	Figure 2. ET rates derived from scintillometry in Sevilleta (b) and Valles Caldera (d) [*Gomez*, 2008].

Methodology:

A large aperture scintillometer (LAS) is an instrument that consists of a transmitter and a receiver. The receiver measures intensity fluctuations in the radiation emitted by the transmitter caused by refractive scattering by turbulent eddies in the LAS path. For LASs the observed intensity fluctuations are a measure of the structure parameter of the refractive index, C_n^2. At optical wavelengths the contribution of temperature fluctuations dominates, i.e., the structure parameter of temperature C_T^2 can be deduced from C_n^2. Using similarity theory in the atmospheric surface layer, surface fluxes of sensible heat can be determined from C_T^2 and supplemental meteorological measurements. Since similarity theory is used in the derivation of the sensible heat flux, surface homogeneity over the footprint area is required in principle, since no significant horizontal flux transport term or storage flux should exist. However, it has been demonstrated that a LAS sensible heat flux over a chessboard pattern of crop matched the weighted average of the individual crop sensible heat fluxes measured by Eddy Covariance (EC) [*Meijninger et al.*, 2002].

We compared the refractive index measured with a first generation scintillometer that is retrofitted into a second generation LAS MkII Scintillometer by Kipp & Zonen over a homogeneous desert transect of about 600 m in the Sevilleta National Wildlife Refuge with those measured with a first generation LAS as well as a new second generation MKII LAS. The scintillometers are set up next to each other, 4.0 m apart, such that the transmitter of adjacent scintillometers are on opposite ends of the transect and cannot contaminate the neighboring receivers.

Figure 3: Generalized transect layout at Sevilleta National Wildlife Refuge. Note that this image is not to scale. Used for descriptive purposes only. Red zone represents area of highest sensitivity for a LAS.

The GPS survey was conducted using a Topcon IS 303 Total Station. To get transect length and relative elevation, a reference point was back sighted to. That point was set to 5000 m N by 5000 m E at 500 m. All other points were measured relative to the back sight. The total station was set up at point A'. The transects were walked from A' to A, B to B' and finishing with C' to C. Measurements were recorded approximately every 50 m. A linear interpolation was performed to calculate the elevation of the crossing transects C-A' and A-C'. The western transect (C-C') was used as the reference transect for the entire comparison study and the eastern (A-A') and middle (B-B') transects were used for different scintillometer models.
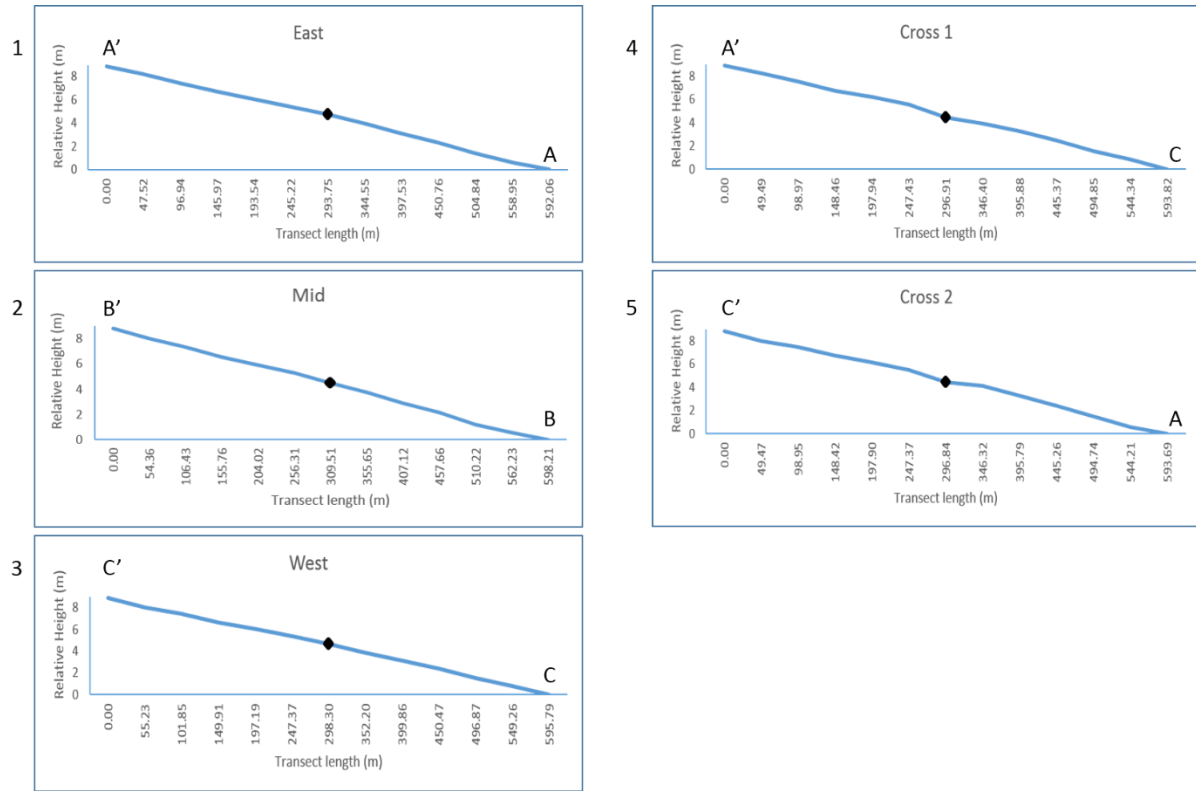
Results:

Figure 4: Panels 1-5 show the relative elevation change along each transect from South to North. The black diamond indicates the midpoint of each transect.
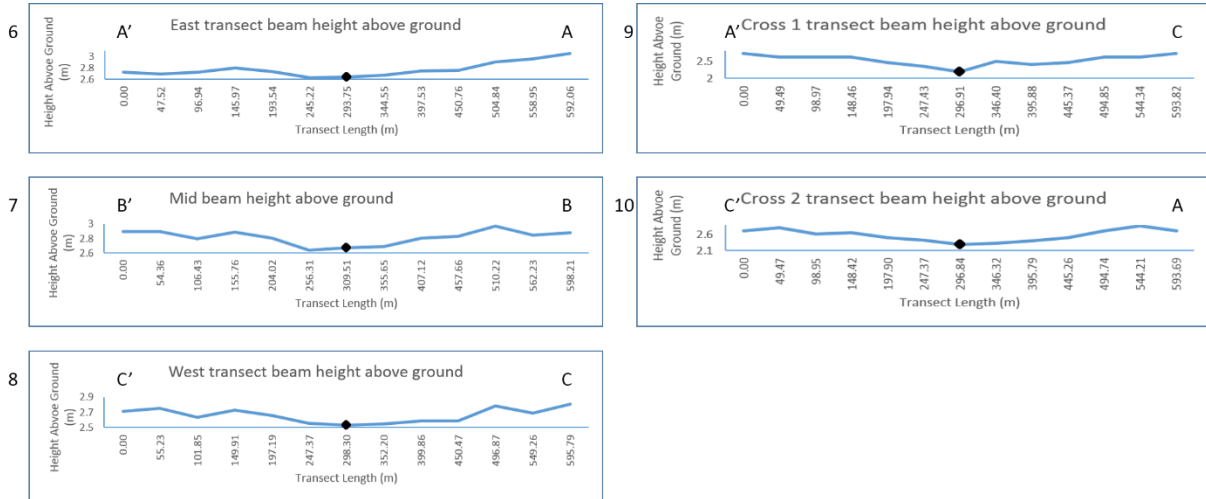

Figure 5: Panels 6-10 show the height of the beam above the land surface along each transect from South to North. The black diamond indicates the midpoint of each transect.

Figure 4 shows the five different transects in the GPS survey. Each transect is dipping to the north with 8.8-8.9 m of elevation loss over transect lengths of 592-598 m. Figure 5 depicts the change in beam height above the land surface along each transect. Changes in beam height over the transects range from 0.25 m to 0.58 m. The maximum beam height typically occurs at either end of the transect but not always as seen in panel 7 at 510.0 m. However the minimum beam height occurs at the midpoint for each transect.
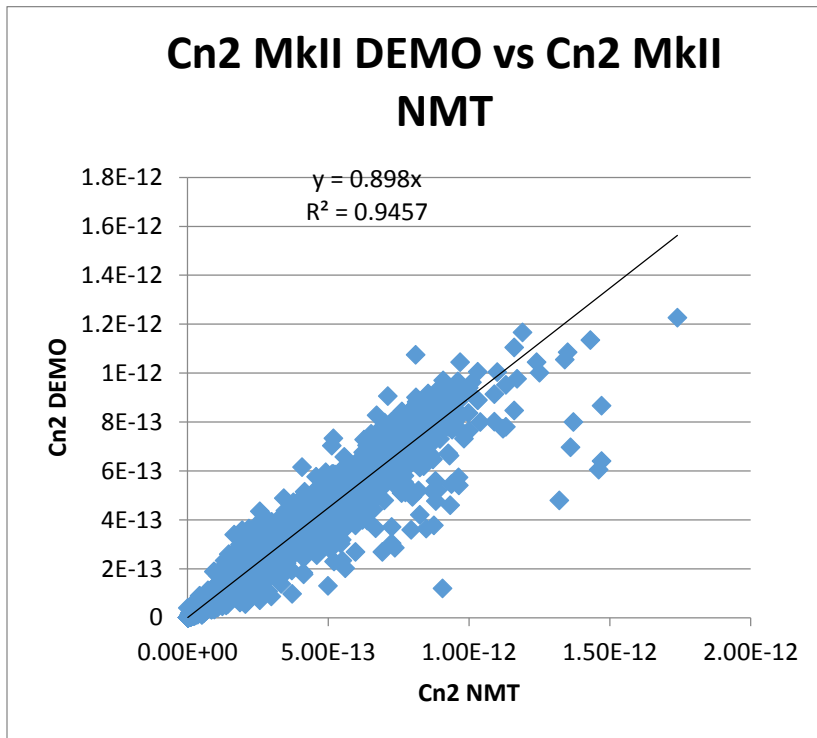

Figure 6: First comparison in New Mexico of the C_n^2 of two second generation scintillometers during May 23-25, 2015.
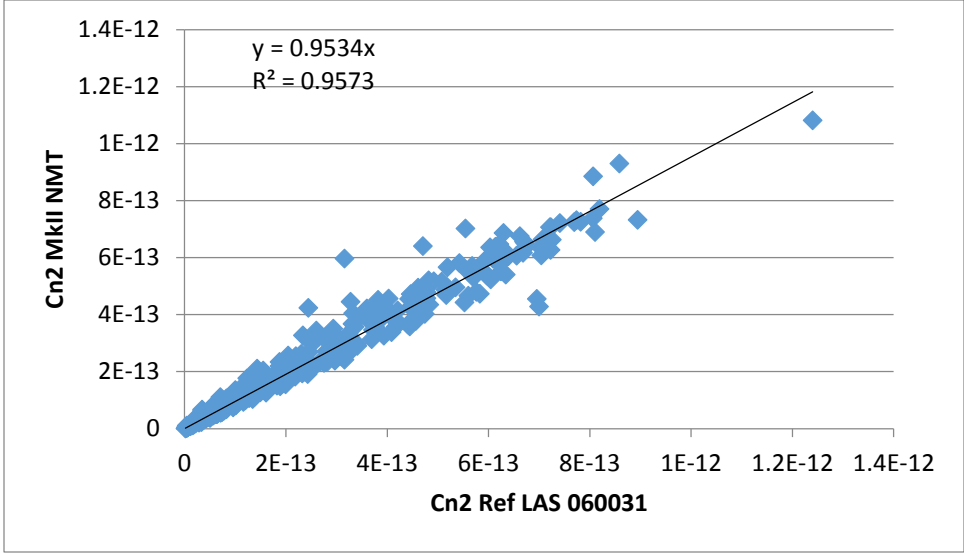
Figure 7: The comparison of the second generation MkII NMT scintillometer versus the selected first generation reference scintillometer 060031.
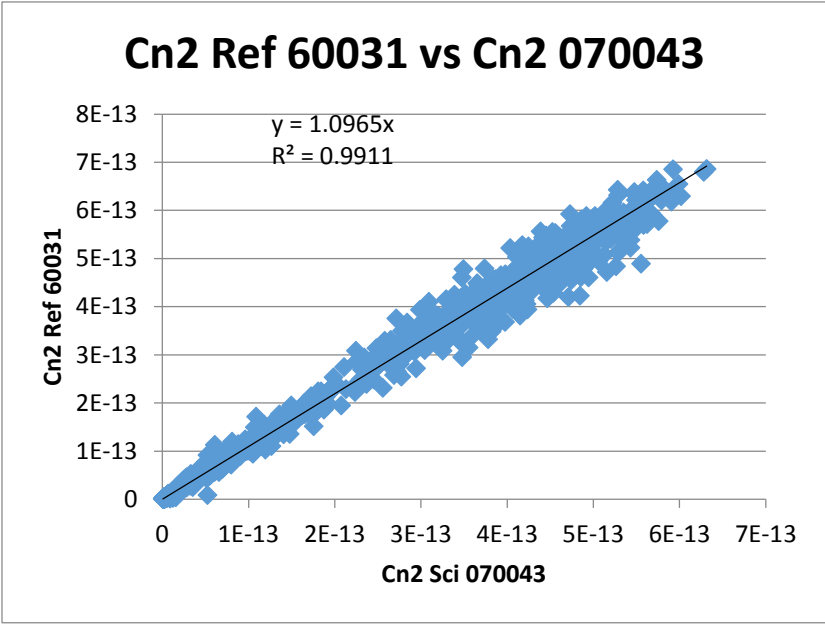

Figure 8: C_n^2 of first generation reference scintillometer 060031 compared to another first generation scintillometer 070043 being calibrated for field use in Panama. The high R^2 of 0.99 reflects a solid setup with stable towers and good time synchronization.
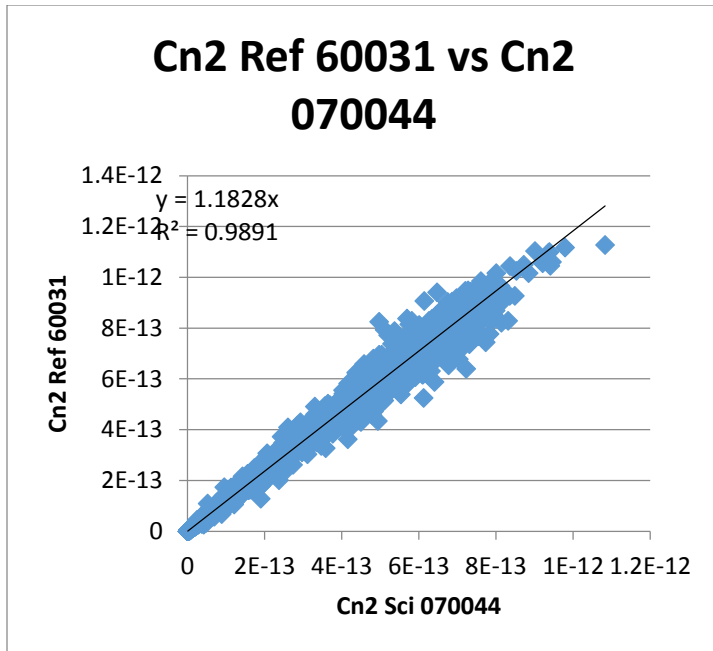
Figure 9: C_n^2 of first generation reference scintillometer 060031 compared to another first generation scintillometer 070044 being calibrated for field use in Panama. The high R^2 of 0.99 reflects a solid setup with stable towers and good time synchronization.

Assuming that the MkII NMT second generation scintillometer is the principal standard after its calibration in The Netherlands, the following corrections are obtained for the three first generation scintillometers tested in this study:

Cn2_true = $0.9534 \times$ Cn2_Ref_060031

Cn2_true = $0.9534 \times 1.0965 \times$ Cn2_070043 = $1.0454 \times$ Cn2_070043

Cn2_true = $0.9534 \times 1.1828 \times$ Cn2_070044 = $1.1277 \times$ Cn2_070044

Discussion:

GPS Survey

When calculating sensible heat flux (H), an error in effective beam height calculation can result in at least half that error in the resulting H (Kleissl 2009). Since the calculation of H is sensitive to effective beam height we decided to conduct a GPS survey of the transects using a total station provided by Dr. Daniel Cadol at NMT.

We found that all the transects dip from south to north with elevation loss of an average tower height of 8.85 m over and average transect length of 595 m. Since the LASs are fixed to towers of equal height on either end of the transect the beam of the LAS experiences the same 8.85 m dip from south to north. What is really important in the calculation of effective beam height are the undulations of the ground surface over the transect. Figure 5 shows that the beam

is closest to the ground surface at the midpoint for all transects. This result shows that despite local variation there is a gentle rise from each end towards the center.

Knowing how the surface varies locally as well as along the entire transect is critical since the LAS is most sensitive in the middle third of the transect (Kipp & Zonen 2012), see red zone in Figure 3. Previously we had to assume that the ground surface was perfectly parallel to the LAS beam. After the survey we can more accurately calculate the effective beam height to further reduce error in our sensible heat flux calculations.

While during this scintillometer comparison we did not use the crossing transects, their establishment will further advance the calibration efforts of New Mexico Tech's scintillometer program. The idea is that since the beams cross at the midpoint of both transects we remove local variation of parallel transects and measure the same patch of ground where the LASs are the most sensitive. This calibration method should further reduce the differences in recorded sensible heat flux measurements between instruments and improve the reliability of our results state wide.

LAS Intercomparison

To compare the measured results between scintillometers we opted to use the refractive index (C_n^2). This removed any chance of minor mistakes and rounding from impacting the results of the comparison. In addition the goal of this project was to determine how the measured results from old and new LAS models compared not to derive H for our transect. We felt this was the best method since the measured values are treated the same when calculating H. The only difference in the calculations is the input of the C_n^2 value that comes from each individual device.

In figure 6 the slope of the regression line indicates a rather large difference of about 10% and its R^2 is well below the value of 0.98 that indicates high quality comparison measurements. The causes for these deviations are: 1. The EVATION software used didn't allow setting the start of each 60 second measurement period at the beginning of each minute, i.e. zero seconds. Therefore, the one minute time intervals didn't overlap well and as a result the value of R^2 dropped; 2. The brick towers of the scintillometers were moving in the strong winds during this comparison which also lead to deterioration of the measurements. Both scintillometers have been sent back to The Netherlands for software updates to the latest version of the EVATION software and a maintenance check.

Results in Figure 7 show a rather good agreement on the order of 5%. Yet the relatively low R^2 of 0.957 indicates that some problems exist with time synchronization and/or wobbling towers. The MkII NMT scintillometer has been sent to The Netherlands for a calibration check and the towers have been improved by tying them down to a ground anchor. After the return of the MkII NMT scintillometer this calibration will be repeated.

Figures 8 and 9 show the comparison between the NMT reference scintillometer (60031) and two scintillometers that needed to be calibrated for field use (70043 and 70044). We found that there was a discrepancy of approximately 10% between the reference scintillometer and the

calibrated LAS 70043. LAS 70043 under reported the reference scintillometer. This is a marked improvement compared to the 20% to 30% discrepancies reported in 2009 by Kleissl et al. 70044 under reported the reference as well however there was an 18% discrepancy. This is still lower than previously reported but the result is not as significant. The high R^2 values for both comparisons indicate good timing as well as tower stability and proper alignment.

Using the slopes of the curves, we were able to calculate correction factors for each of the scintillometers. All the scintillometers were corrected to the MKII NMT LAS which will become the reference scintillometer once it has returned with a software upgrade.

Conclusion

In conclusion we were able to conduct a detailed GPS survey to better understand the topography below the beams to improve future calculations of sensible heat flux at the scintillometer calibration site. This will improve the reliability of the deployed scintillometers around the state for use in computer models, quality assurance of remote sensing data and improved energy budget closure.

The LAS models all showed improvement and reduced bias compared to the Kleissl et al study of 2009. Analysis of results from the first generation LAS that was upgraded to a second generation LAS reported less discrepancy than the first generation LAS 70043 when both were compared to the reference LAS 60031. This makes a strong case for Dr. Hendricks to seek additional funding to retrofit all current first generation LAS scintillometers.

The comparison between the two MKII scintillometers was better than results from previous studies of first generation LAS. However the discrepancy was not as low as was hoped. The increased discrepancy was due to software issues that prevented proper synchronization of the devices.

Future work includes using the reference scintillometer on the crossing transects to see if the discrepancy between devices can be further reduced by measuring the same patch of ground in the most sensitive part of the LAS transect. Secondly, a repeat of comparisons with the retrofitted second generation LAS once it is returned to New Mexico Tech with upgraded software.

Who Benefits

The positive results in the SNWR will give Dr. Hendrickx the data needed to seek additional funding for retrofitting and converting his ten first generation into second generation scintillometers. After this upgrade we can deploy his ten scintillometer transect sensor sets at strategic locations in New Mexico for validation of the operational ET products needed for the Statewide Water Assessment.

Presentations:

Poster presentation at the 59th Annual New Mexico Water Conference:

Title - Test of the new LAS MkII Scintillometer for validation of statewide New Mexico evapotranspiration maps

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