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EVIDENCE OF CLIMATE CHANGE ON HIGH ANDEAN MOUNTAIN WATERSHEDS: CHINCHINA RIVER BASIN, COLOMBIA

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Summary. The Analysis of hydro-climatic data records since the middle of the last century to the current period in an Andean Mountain Basin located in Colombia, show significant increases in temperature (0,18°C per decade), with significant warming increases with altitude of stations over 4000 m.a.s.l. (0,29°C per decade). The frequency of extreme rainfall increased (99 percentile) whereas mean precipitation and river flow records exhibit mixed positive and negative trends. Solar radiation decreased over time and is associated with the global dimming phenomenon. These trends build on a broader understanding of climate change in the tropics, and add new evidence of the accelerated rates of climate change associated with altitude.

1. INTRODUCTION

There is ample evidence of climate change signals in Latin America, which is confirmed by increasing temperatures, changes in rainfall and their extreme events during the 20th century in several areas[1,2]. Changes in precipitation have a strong effect on runoff and stream flow, which also are affected by melting process of tropical glaciers[3]. In addition, deforestation rates have increased, which also influences the hydrological cycle[2]. These variations and their signals depend on the geographical sub region[1,2]. As a consequence, eight tropical glaciers disappeared from the Colombian Andes during the 20th century, and the remaining six have experienced alarming retreat rates during the last decade[3-5]. Recent measurements indicate losses of 3-5% of coverage per year and a glacier retreat of 20-25m per year is reported[4].

In Colombia, several studies[3-5] have analyzed long time series (40–45 years) of monthly hydro-climatic records and they have detected signals of climatic change, which are confirmed by the presence of statistically significant positive trends in average monthly minimum and mean temperature, as well as in relative humidity and pan evaporation throughout the country. Monthly precipitation time series exhibit positive and negative trends , whereas most river flow records showed decreasing trends[5], which could be explained by the combined effects of deforestation, land use/land change, with global environmental change[5].

According to the second National Communication to the United Nations Framework

Convention on Climate Change (UNFCCC)[4] some evidences of climate change in Colombia are 1) Reduction of extreme rain events in the paramos and increase in high-intensity rainfall in most stations below 3000 m; 2) maximum temperature increase close to 1°C per decade in the high-paramo stations; 3) Sea Level rise along the Caribbean Sea and Pacific Coast of 3.5 mm per year and 2.2 mm per year, respectively; 4) positive trends in temperatures with a change rate of 0.11°C/decade for maximum temperatures, 0.10°C/decade for minimum temperatures and 0.13°C /decade for the mean temperature.

This research involves the historical behavior analysis since the middle of the last century to the current period of climatic variables: solar brightness, relative humidity, solar radiation, temperature and precipitation. The study also includes anomalies calculation and trends. Finally, climatic variable influences in the hydrological balance and water supply are evaluated.

2. METHODS

2.1. Climatic variables

Precipitation data were obtained from *Instituto de Hidrología, Meteorología y Estudios Ambientales de Colombi*a- IDEAM- (Institute of Hydrology, Meteorology and Environmental Studies of Colombia), *Centro Nacional de Investigaciones del Café*- CENICAFE- (National Center for Coffee Research), *Central Hidroeléctrica de Caldas*-CHEC-(Caldas Hydroelectric) and *Universidad Nacional de Colombia sede Manizales*. Daily data reported from rain gauges were used to estimate changes in precipitation. Time series of climatic variables which include minimum, maximum and mean Temperature; solar brightness and relative humidity data were obtained from IDEAM and CENICAFE. Records from the following stations Brisas, Agronomia, Cenicafe, Naranjal, Granja Luker and Santagueda were used for estimating climatic variables trends. Solar radiation was estimated by using mathematic models[6] as a function of solar brightness and relative humidity, which are available measurements.

2.2.Long-Term Mean River Flows

Stream Flow time series from the following stations Chupaderos and El Retiro, reported by IDEAM and Sancancio and Montevideo from CHEC were used for estimating stream flow trends. The lumped version of the conceptual balance model called TETIS[7] was applied for hydrological simulations. Model consists of five vertical tanks, each one representing the different water storages in an ‘‘extended soil column’’. These tanks represent the static, surface, gravitational storages and aquifer. The vertical connections between tanks describe precipitation, evapotranspiration, infiltration and percolation processes. The horizontal connections describe the overland flow, interflow and base flow[7]. All the calibration and validation process were carried out satisfactorily. The Nash-Sutcliffe[8] efficiency index was used as a criterion for evaluating the reproductive potential of the hydrological model. Other statistical parameters as the mean absolute error, the root mean square error and the Percent bias-PBIAS- were employed during calibration and validation procedures[9].

2.3.Trends and anomalies

The historical series analysis was carried out in different time scales (daily, monthly and annual). The interdecadal variability and alteration the El Niño/Southern Oscillation (ENSO) were assessed. Climate change signals were detected analyzing tri-decadal periods. Variance analysis was use to determine significant differences between periods (α = 0,05). The ANOVA test was used in normally distributed series, after statistical verification of the Kolmogorov-Smirnov or Shapiro-Wilk (0,05% significance) tests and homoscedasticity assumption using Levene-test (0,05% significance). Otherwise, non-parametric tests were used for variance analysis. The software SSPS was used for statistics analysis of time series.

3. CASE STUDY

The Chinchina River Basin (1050 km^2) is located on the western slopes at the central range in the Andes between 4°48´and 5°12´N Latitude, at the south central region of Caldas, Colombia, as shown in the Figure 1.

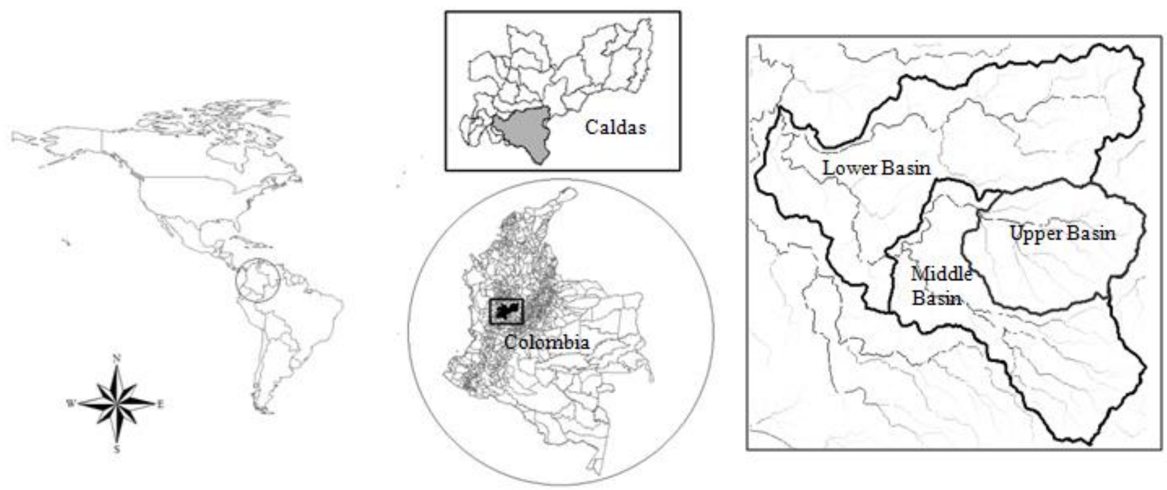

Figure 1: Chinchina River Basin Location

The climate of the Chinchina River Basin is influenced by the Intertropical Convergence Zone (ITCZ) combined with the orographic effects of the Andean ranges. Atmospheric circulation patterns from the Pacific and the Caribbean Sea, the moisture contribution from the Amazon and Orinoco River basins and the Ocean–atmosphere–land interactions create complex hydro-climatological features[10] on the Basin.

4. RESULTS

The main results which were found after the statistical analysis of time series for different assessed variables: temperature, precipitation, relative humidity, solar brightness and solar radiation as described as follows:

4.1.Temperatures

The climate change signals are evidenced by the increase in the mean temperature by 0,5°C; maximum temperatures by 0,25°C and minimum temperatures by 0,45°C for the period 1981-2010 in relation to the historic records dated 1951-1980, as reported by the IPCC[1]. The Figure 2 shows the mean temperature for the period 1981-2010 and the average annual time series of mean temperature; it reveals positive trends in the mean temperature; which were also observed for the minimum and maximum temperatures. Temperature anomalies calculated based on the immediately preceding tri-decade period, are presented in Table 1. The average warming is 0,18°C per decade, higher than national[4] (0,17°C per decade) and global warming rates[1] (0,13°C per decade). In the Paramo, based on inter-decadal records, warming rate is higher 0.29 ° C per decade.

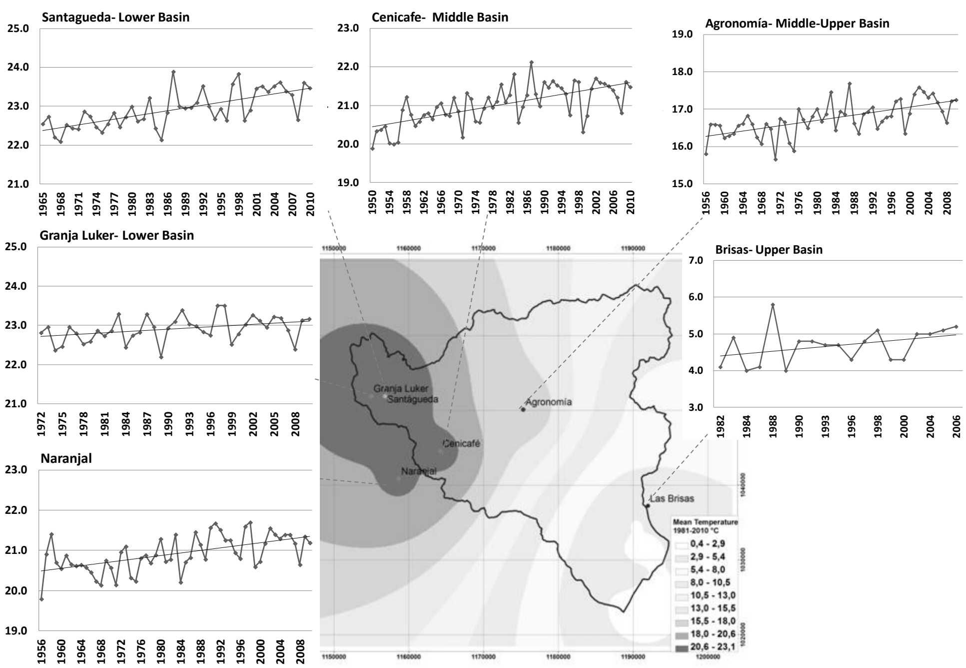

Figure 2: Annual Mean Temperature

Basin	Mean Temperature °C			Minimum Temperature °C			Maximum Temperature °C		
	1961-1990	1971-2000	1981-2010	1961-1990	1971-2000	1981-2010	1961-1990	1971-2000	1981-2010
Middle-High	0,16*	0,13	0,25*	0.06	0,10	0,27*	0.07	0.01	0.16
Middle	0,28*	0,14	0,16*	0,28*	0,14	0,05	-0.03	-0.07	0.31*
Low	NA	0,18	0,26*	NA	0,12	0,36*	NA	NA	0.12

* significant differences ($\alpha = 0,05$). NA: not available

Table 1: Temperature anomalies

4.2.Precipitation

The raised frequency of extreme rainfall over the percentile 95 and 99 was detected in stations located in the basin during the period 1981-2010 relative to 1971-2000 as shown in Figure 3. Regarding average annual precipitation, exhibits mixed positive or negative trends as shown in Figure 4. Precipitation anomalies fluctuate among -4.8% to 8.6% during the period 1981-2010 relative to 1971-2000. Stations located over 2200 m.a.s.l. exhibit decrease behavior whereas gauge stations located in the middle high Basin show increasing trends

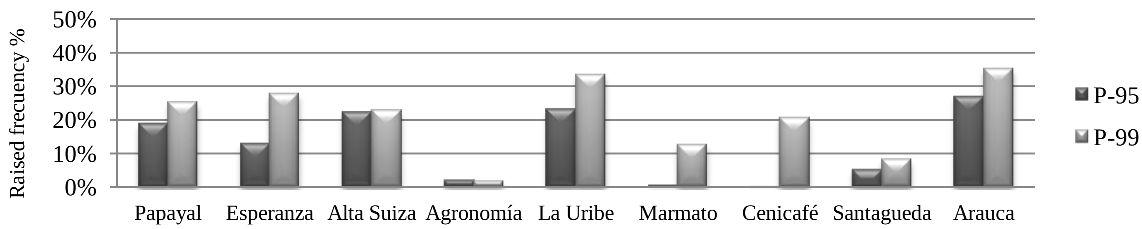

Figura 3.- Raised frecuency of extreme rainfall 1981-2010 relative to 1971-2000

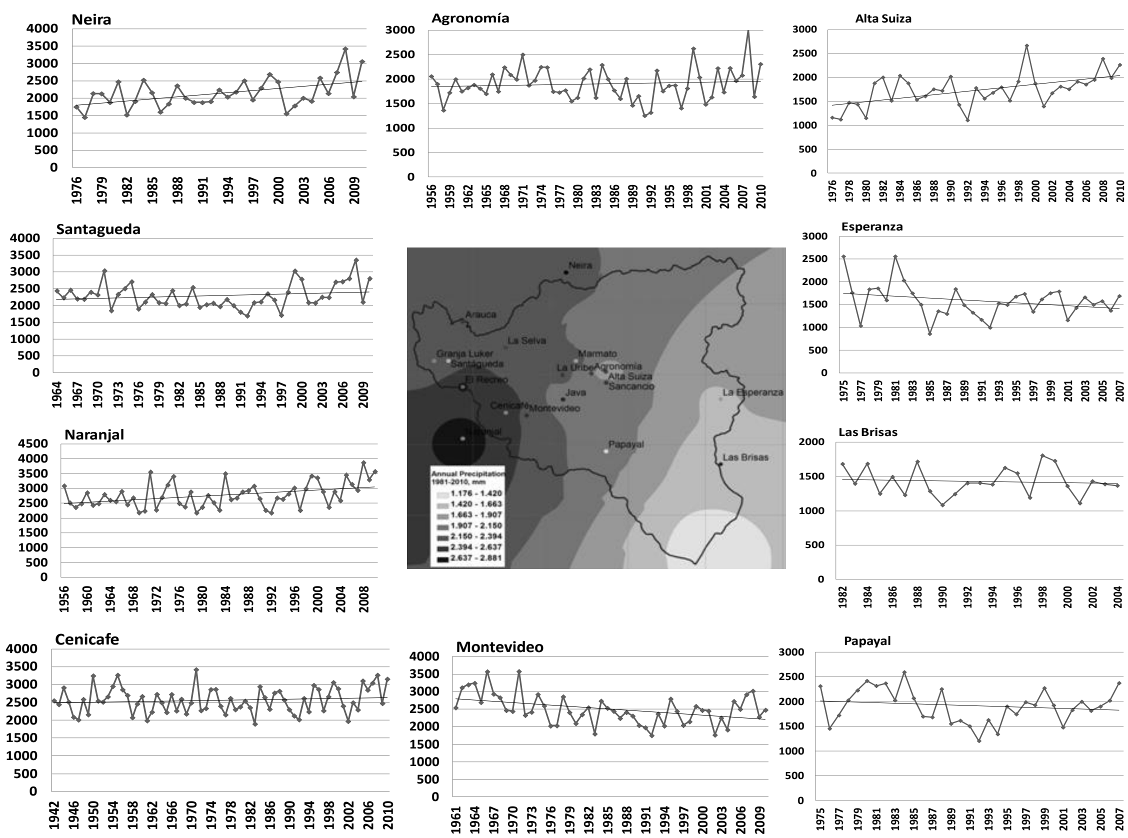

Figure 4: Annual Mean precipitation

4.3.Relative humidity

Average anomaly in the relative humidity was calculated in 1,5% at the medium Basin, higher than national[4] reported as 1%. However, no significant changes were found in the upper and lower Basin, which it is consistent with IPCC projections[1].

4.4.Solar brightness and solar radiation

Statistically significant reductions in the sunshine (Figure 5), since the 50's until the last decade, were detected in time series, which it is an evidence of the global dimming phenomenon. However, in the last decade, a trend change has been detected.

Solar radiation anomalies were calculated as the local difference between current period and the immediately preceding tri-decade period (Table 2). This reduction is around 1,9% lower than global estimate in 2,7% per decade[11].

Station	Anomalies %,		
	1961-1990	1971-2000	1981-2010
Agronomía	-2.1%	-2.8%	-0.7%
Cenicafe	-1.3%	-2.4%	-1.8%
Granja Luker	ND	ND	-1.9%
Santagueda	ND	-0.4%	0.0%

Table 2: Solar radiation anomalies

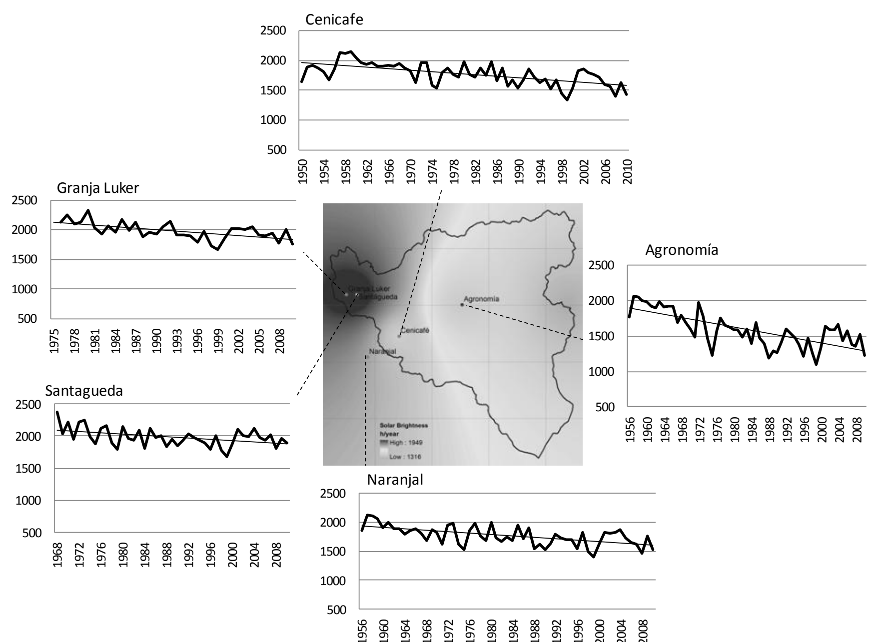

Figure 5: Annual Mean solar brightness

4.5.Water Balance

Time series of river flows (annual averages) showed positive and negative trends as shown in the Figure 6. The hydrological regime in Chinchina River Basin is also affected by natural climate variability. The cold ENSO events cause an increased flow of 28% average, with extreme events up to 83%. On the other hand, the warm ENSO events produce a decreased flow of 24% average, with extreme reductions up to 80%; these flow changes are due to rainfall pattern alterations, typical of tropical High Mountain Andes region.

Anomalies from the period 1981-2010 in relation to 1971-2000 are -6% in Montevideo (Middle Basin) and +6% in El Retiro station (Lower Basin). Regarding water balance, hydrological simulation of rainfall-runoff phenomenon has projected reduction in water supply (-1,9%). Differences between observed and simulated flows could be explained by effects of model errors, land use/land change and glacier retreat, among other factors. The contribution of melting snow and glacier-retreat from National Natural Park Los Nevados should be considered. The average annual retreat rates were estimated[3] in 360000 m^2 $year^{-1}$ from the Nevado del Ruiz volcano and 214000 m^2 $year^{-1}$ from the Nevado de Santa Isabel volcano.

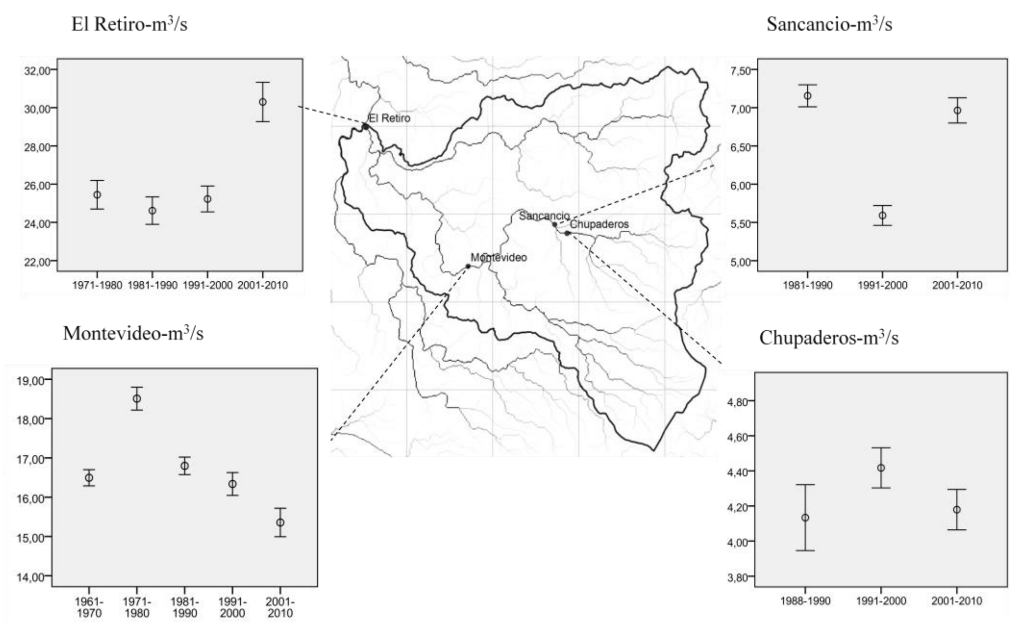

Figure 6: Observed stream Flow

5. CONCLUSIONS

Clear-cut evidences of Climate Change in Chinchina River Basin were discussed for diverse hydro-climatic records. Climate change signals are evident from observations of increases in mean, minimum and maximum temperatures as well as in relative humidity and in the frequency of extreme rainfall. Precipitation and river flow records exhibited mixed positive and negative trends.

On the other hand, there are signals of the Global Dimming phenomenon in the Basin which also affected the water balance. Although positive trends in evapotranspiration were expected by climate change, their behavior was slightly decreasing. Then, it is advisable to monitor these negative trends in the solar radiation that diminish the global warming effects.

These climatic trends enable a better understanding of the hydro-climatic features on a high Andean mountain Watershed and their analyses would be considered in the vulnerability assessment to climate change in order to establish effective adaptation measures.

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REFERENCES

[1] IPPC. *Climate Change 2007: impacts, adaptation and vulnerability*. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press. (2007)

[2] Magrin, et. al. Latina America, Climate Change 2007: Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. (2007)

[3] Poveda and Pineda. Reassessment of Colombia's tropical glaciers retreat rates: are they bound to disappear during the 2010–2020 decade?. Adv. in Geosciences.7, 1–10, (2009)

[4] IDEAM et.al. 2a Comunicación Nacional ante la Convención Marco de las Naciones Unidas sobre el Cambio Climático. Bogotá: Instituto de Hidrología, Meteorología y Estudios Ambientales. Ministerio de Medio Ambiente, Vivienda y Desarrollo territorial. (2010)

[5] Ochoa, and Poveda: Distribución espacial de señales de cambio climático en Colombia, Proc. XXIII Latin American Hydraulics Meeting, IAHS, Cartagena, Colombia, (2008).

[6] Swartman, R. K.; Ogulande, O. An investigation on packed bed collectors. Solar energy, 10 (3), pp. 106-110. (1966)

[7] Francés F, Vélez J.I y Vélez J.J. "Split parameter structure for the automatic calibration of distributed hydrological models". Journal of Hydrology, 332, p 226-240. (2007).

[8] Nash, & Sutcliffe. River flow forecasting through conceptual models part I. A discussion of principles. Journal of Hydrology 10 (3) , 282-290. (1970).

[9] Moriasi. Model Evaluation Guidelines for Systematic Quantification of Accuracy in Watershed Simulation. Transactions of the ASABE 50: (3) , 885-900. (2007).

[10] Poveda Mixed memory, (non) Hurst effect, and maximum entropy of rainfall in the tropical Andes. Advances in Water Resources, 34 (2), 243-256 (2011).

[11] Stanhill, & Cohen. Global dimming: A review of the evidence for a widespread and significant reduction in global radiation with discussions of its probable causes and possible agricultural consequences. Agriculture and forest meteorology 107 , 255-278. (2001).