# Estimation of the Change in Convection Using WRF And Statistical Fitting Methods 11 August 1999 Solar Eclipse:

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**Abstract:**

Solar eclipse is an astronomical phenomenon happening at least two, up to five times a year; maximum, two of them being total solar eclipses. Previously, meteorological parameters such as temperature, wind speed direction and strength, humidity, and cloudiness are reported to change during solar eclipses. Convection is also reported to change during solar eclipses as it depends on meteorological variables like humidity and temperature difference which influence the rate of buoyancy. On August 11, 1999, Turkey was also one of the sites to witness a total solar eclipse with very favorable sky conditions. In this study, it is intended to quantify the convection change during eclipses, both using meteorological station data, and Weather Research Forecasting (WRF) model. Non-eclipse day temperatures are estimated in two ways: 1) Cubic spline 2) WRF model output, and the differences are compared. The results are interpreted from gliding point of view, in addition to taking physical mechanisms into account including the errors that may result from model assumptions.

**Keywords:** Solar eclipse, convection, micrometeorology, WRF, cubic spline

## 1 Introduction:

Solar eclipses are one of the most spectacular astronomical events that can be observed by even an ordinary person in the street with naked eye. From the early ages on, people's interest on solar eclipses grew, even becoming source of myths in some cultures (Crump, 1999). Scientific interest in solar eclipses began with the observations of Sun, and of the movement of planets. As solar eclipses give us a good chance to study the solar corona, they are also very important for solar physicists.

However, solar eclipses also modify the Earth's atmosphere by blocking the radiation reaching from the Sun to Earth's surface. As a consequence, latent and sensible heat fluxes, and atmospheric parameters such as temperature, cloudiness, relative humidity, and wind velocity change (Fernandez, 1993, Prakash , 2001, Kalafatoglu et al., 2006, references therein).

Previous studies revealed the reduced convection regime during 11 August 1999 solar eclipse in different parts of the world: temporal scales in the temperature data changed (Foken et al., 2001, Szalowski, 2002).Foken et al. found out that fluctuations having temporal scales less than 3 minutes disappeared while Szalowski hypothesizes the longer scale fluctuations of 22 minutes are due to the solar eclipse, and cloud cover affects shorter scale fluctuations of 5 minutes. The changes in temperature also affects the convection intensity. Szalowski points out the decreased intensity of convection leads to sharper plumes, and should be treated with the larger plume characteristics. Ratnam et al. also observed the decrease in thermal plume level and strong vertical downdrafts(subsidence) during the peak of 15 January 2010 eclipse. They even state that the effects of the eclipse on surface meteorological parameters lasted for two-days long (2010). In this study, we are mainly concerned about the convection change which is related with latent and sensible heat fluxes and temperature and relative humidity variables.Downdrafts and updrafts are especially important for gliders, and their path decision and they are affected by the changes in the environmental conditions(OSTIV, 2009). Hence, special emphasis will be given a solar eclipse's effects on gliding in this paper.

## 2 Data and Methodology:

August 11, 1999 was one of the recent total solar eclipses to be witnessed from Turkey. Total eclipse path started from the Black Sea at 09:56 UT and reached to eastern Turkey, quitting from Cizre at 12:59 UT. Total eclipse path and the duration of totality can be seen in Figure 1 below taken from Espanak's web site (http://eclipse.gsfc.nasa.gov/SEmono/TSE1999/TSE1999.html).

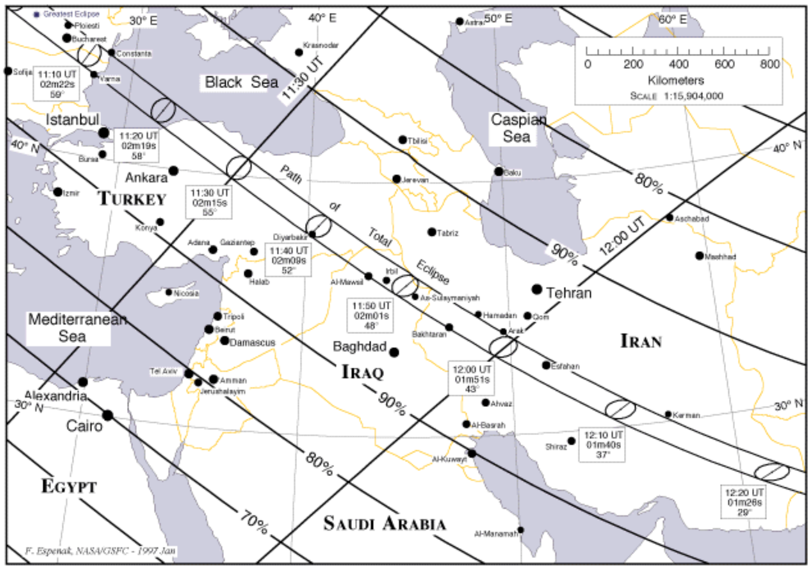


Figure 1. Total eclipse path and duration of totality

To investigate the changes, 4 stations in total eclipse path and 3 stations in partially eclipsed region were chosen. Among the totality stations, Divrigi and Merzifon were in cloudy conditions and Kastamonu and Cizre had cloudless sky. The other three stations are Antalya, Konya and Eskisehir which generally have favorable conditions for gliding. On August 11 they were in the 80% shaded partial eclipse region.

Locations and elevations of the eight stations are given in Table 1.

**Table 1.** Selected stations' properties

| station code | station name | latitude | longitude | elevation (m) |
|---|---|---|---|---|
| **17083** | Merzifon | 40.83 | 35.45 | 544 |
| **17734** | Divrigi | 39.37 | 38.12 | 1120 |
| **17074** | Kastamonu | 41.37 | 33.78 | 799.9 |
| **17950** | Cizre | 42.18 | 37.32 | 400 |
| **17300** | Antalya | 36.70 | 36.73 | 63.57 |
| **17244** | Konya | 37.98 | 32.55 | 1030.61 |
| **17123** | Eskisehir | 38.834 | 30.562 | 1130.2 |

Two methods were used to detect the changes in meteorological variables during the 11 August 1999 solar eclipse. First one was to estimate the expected variable value in the absence of a solar eclipse using cubic spline and second method was to estimate the variable by Weather Research Forecasting (WRF) model simulation.

In this work, main focus is given on the temperature, relative humidity, wind velocity, latent and sensible heat fluxes.

## 2.1 Cubic spline

Cubic spline is a spline fitting method by third order polynomials, especially fruitful in guessing the data gaps, and the tendency of smooth functions. Expected temperature values for stations on the totality path and partial eclipse stations outside the totality path in the absence of solar eclipse were found by cubic spline method. The previous and next day temperature values were also taken into account for data consistency. MATLAB curve fitting toolbox was used for the calculations. The data is taken from the Turkish Meteorological State Service with 1 hour resolution.

## 2.2 Experimental setup for WRF

WRF is a nonhydrostatic research and forecasting model which also has hydrostatic options both used for weather prediction and scientific research. It has been developed by several institutions: National Center for Atmospheric Research (NCAR), the National Oceanic and Atmospheric Administration (the National Centers for Environmental Prediction (NCEP) and the Forecast Systems Laboratory (FSL), the Air Force Weather Agency (AFWA), the Naval Research Laboratory, the University of Oklahoma, and the Federal Aviation Administration (FAA).

WRF contains several modules. The modules handle the associated physical processes which have been expressed with numerical methods. WRF uses Runge-Kutta 2$^{nd}$ and 3$^{rd}$ order time-integration schemes as well as 2$^{nd}$ to 6$^{th}$ order advection schemes for spatial derivatives. The gridding step is Arakawa C-grid.

WRF includes schemes for the land surface-atmosphere, soil-vegetation-atmosphere, water-atmosphere, planetary boundary layer and turbulence, convective, microphysics, radiation parameterizations. All parameterizations also have different choice of options which the user can readily select from.

We started our simulation run from August 10, 1999 00z and ended at August 12 06Z. This way we had the chance to predict the weather conditions on August 11, 1999 . We modified the namelist file so that we could derive time series of data, and observe the fluctuations of parameters chosen. The namelist file is a summary input file telling WRF which physics and parameterizations to use, which parameters to take with how many intervals, and also including the desired domain properties. Table 2 shows the selected schemes for our event. For all of the seven stations we demanded 1 min. resolution output. Our grid was 12 kmx12 km.

**Table 2.** WRF setup for 11 August 1999 eclipse

| Physics | Scheme | Properties in Brief |
|---|---|---|
| **Microphysics** | WRF single moment 6 | Includes snow, graupel, rain, ice processes |
| **Longwave radiation** | RRTM6 | Random cloud overlap |
| **Shortwave radiation** | CAM | Aerosols+trace gases |
| **Surface layer** | MM5 | Monin-Obukhov with Carslon-Boland viscous sub-layer +standart similarity functions |
| **Surface physics** | 5-layer thermal diffusion | Soil temperature only scheme, using five layers |
| **Planetary boundary layer** | YSU scheme | K scheme with explicit entrainment and parabolic K profile in unstable mixed layer |
| **Cumulus** | Kain-Fritsch scheme | Deep and shallow convection with downdrafts |

## 3 Results:

Figure 2. indicates the temperatures over Turkey at the totality. Highest temperatures were recorded in South Eastern Anatolia with more than 37° C.

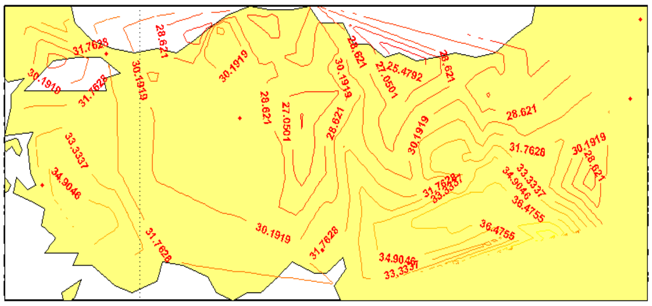

Figure 2. Temperature distribution over Turkey at 12 LT(local time) from Meteorological Station measurements.

We found the temperature deviations due to the solar eclipse using the method of splines. Table 3 gives the maximum temperature deviations, and cloudiness of the stations along with the distance of stations to the total eclipse path denoted with a. As seen, there is no apparent change with cloudiness, and a. This suggests that effects from topography, the distance to sea and synoptic scale systems play an additional complex role on the temperature change.

**Table 3.** Maximum temperature deviations and station conditions

| Station Code | Station Name | a (km) | Delta(T) | Cloudiness | Time of Max. deviation |
|---|---|---|---|---|---|
| **17083** | Merzifon | 22 | 3,44 | 6 | 14 |
| **17734** | Divrigi | 6 | 4,25 | 8 | 14 |
| **17074** | Kastamonu | 6 | 2,28 | 2 | 15 |
| **17950** | Cizre | 7 | 2,28 | 0 | 15 |
| **17300** | Antalya | 587 | 3,44 | 3 | 14 |
| **17244** | Konya | 424 | 3,55 | 0 | 14 |
| **17123** | Eskisehir | 550 | 2,2 | 0 | 14 |

Figure 3 depicts the WRF-ARW simulated temperature and wind velocity values in the absence of the solar eclipse. Similar to the observed temperature distribution in Figure 2, the highest temperature values are again seen in the south eastern Turkey. However, northern parts of the Anatolia have lower values.

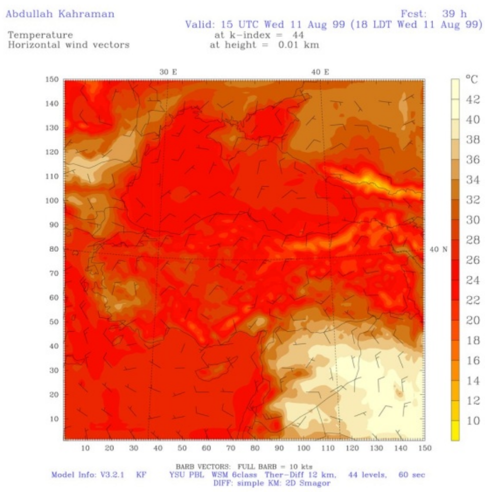


Figure 3. WRF-ARW simulated temperature and wind velocity values

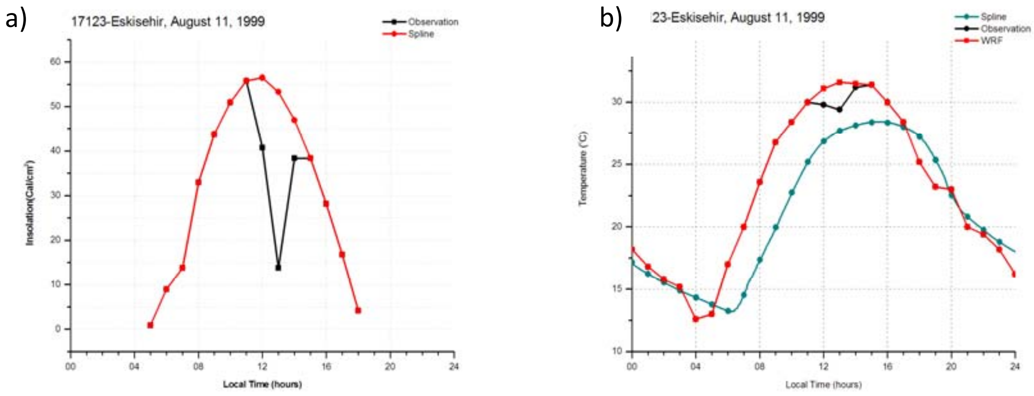


Figure 4. a) Insolation and b) temperature changes during the eclipse with respect to spline and WRF estimations

Figure 4 a and b show an example of spline method performation for Eskisehir. Eskisehir is a specially important city for gliding purposes.Aeronautical training center, situated in İnönü also gives glider training. Spline method is performed for solar insolation in part a. A maximum deviation of 40 cal/cm$^2$ from the expected value was found. In part b, both WRF simulation result and spline calculation can be seen. WRF estimated 1.5ºC lower temperatures from the lowest value of observations at 12 LT, while spline method expects 2.28 ºC higher temperature value for 12 LT.

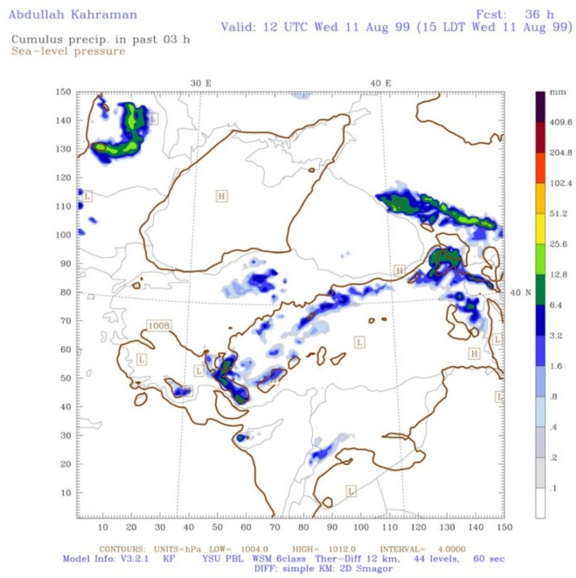


Figure 5. Convective precipitation at 15 LT.

Figure 5 presents WRF convective precipitation forecast for 15 LT. There are concentrated regions of convective precipitation in the plot. Antalya, Konya and Mersin are seen to be effected from the rainfall. However, the rain gauge measurements of Turkish State Meteorological Service do not contain information about any precipitation on 11 August. This suggests the supression of the convective activity which might lead to precipitation in the absence of the solar eclipse. However, this result should be validated with more simulations with different schemes, as parameterizations greatly influence the output of a model.

## 4 Summary and Conclusion:

Effects of a solar eclipse on the atmosphere range from the lowest levels of atmosphere to the ionosphere and even to the geomagnetic field (Chernogor, 2007). Those effects are largely controlled by the duration and intensity of the eclipse, besides the other factors which determine the ratio of the response. Additional factors which influence the rate of response are the topography, surface characteristics, meso or synoptic scale pressure systems, cloudiness, the distance to sea and likewise. A solar eclipse is a natural supressor of convective activity due to the blockage of solar radiation which is the main triggering mechanism for convection.

Gliders mostly get use of the thermal activity within a day. Thermal activity is largely dependent on the heating of the surface and moisture in the atmosphere. During a day, thermal activity is the most at 1:30 pm-2:30 pm. Climb rates of gliders are closely related to the maximum depth of Convective Boundary Layer (OSTIV, 2009).

On August 11, 1999, solar eclipse over Turkey reached to its maximum obscuration between 14:20 and 14:40 LT, and the partial shading already began at 12:56 LT in Bartin.

1) WRF-ARW predicted lower temperatures than the observed values for some cities like Konya and Eskisehir, while predicting closer values for Cizre and others.
2) Solar insolation was seen to decrease notably during the eclipse. For Eskisehir, the value was approximately 40 cal/cm$^2$. This will have strong effects on convection, especially on thermal generation since convection is mainly triggered by the surface heating.
3) Spline method guesses the temperature decrease as maximum 5ºC and minimum 1.17ºC for the eclipse day. Eskisehir temperatures showed a 2.28ºC decline.
4) WRF-ARW predicted large amount of convective precipitation for August 11, 1999. However, daily total precipitation data set which was taken from Turkish State Meteorological Service doesn't show any rainfall for the same day. This may be due to the cease of convection because of the solar eclipse. That point will be further investigated in our future studies.
5) More simulation runs with WRF-ARW should be done with different parameterizations for validation.
6) Effects of height, synoptic scale systems and distance to the sea should be investigated in more detail.
7) Variations in temperature can be investigated by higher resolution data set which will provide more information about the oscillations, and the delay times.

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**References:**

Crump, Thomas, 1999. **Solar eclipse ,**London : Constable, 1999

Fernández, W., Castro, V., & Hidalgo, H. , 1993. Air Temperature and Wind Changes in Costa Rica During the Total Solar Eclipse of July 11, 1991, *Earth, Moon, and Planets*, vol. 63, no. 2, Proceedings of the second United Nations/European Space Agency Workshop, San Jose, Costa Rica, 2-7 November, 1992, p. 133.

Prakash M. Ramchandran, Radhika Ramchandran, K. Sen Gupta, S. M. Patil and P. N. Jadhav, 2002. Atmospheric Surface-Layer Processes During the Total Solar Eclipse Of 11 August 1999, *Boundary-Layer Meteorology*, Volume 104, Number 3, 445-461, DOI: 10.1023/A:1016577306546

Kalafatoglu, E.C., Kaymaz, Z. and Tan, E., 2007. August 11, 1999 Solar Eclipse and Associated Effects on Clear Days over Turkey*, IEEE Proceedings, Special Issue*.

T. Foken, W. Bodo, K. Otto, G. Jörg, W. Martin and Weidinger Tama, 2001 . Micrometeorological measurements during the total solar eclipse of August 11, 1999, *Meteorol. Z.* **10** (3), pp. 171–178
K. Szalowski, 2002. The effect of the solar eclipse on the air temperature near the ground, *J. Atmos. Solar-Terr. Phys.* **64**, pp. 1589–1600.

M. Venkat Ratnam, M. Shravan Kumar, Ghouse Basha, V.K. Anandan, A. Jayaraman, 2010. Effect of the annular solar eclipse of 15 January 2010 on the lower atmospheric boundary layer over a tropical rural station, Journal of Atmospheric and Solar-Terrestrial Physics, Volume 72, Issue 18, Pages 1393-1400, ISSN 1364-6826, DOI: 10.1016/j.jastp.2010.10.009.

ORGANISATION SCIENTIFIQUE ET TECHNIQUE INTERNATIONALE DU VOL À VOILE, & WORLD METEOROLOGICAL ORGANIZATION. 2009. Weather forecasting for soaring flight. Geneva, Switzerland, World Meteorological Organization.

*D. Bala Subrahamanyam*, *T. J. Anurose*, *Mannil Mohan*, M. Santosh, **...** *Impact* of *Annular Solar Eclipse* of *15 January 2010* on the *Atmospheric Boundary Layer Characteristics over Thumba*: A *Case Study*, Pure and Applied Geophysics (In Press)

L. F. Chernogor, 2007. *Izvestiya Atmospheric and Oceanic Physics*, Volume 44, Number 4, 432-447, DOI: 10.1134/S000143380804004X