MODELLING OF THE SHORT TERM PAVEMENT SURFACE TEMPERATURE BY METEOROLOGICAL DATA TRANSFER

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1. Abstract

The road surface conditions are important factors in the driving strategy of road users. During the winter, these conditions depend on the weather, the road characteristics, the measures taken to maintain the flow of traffic and of course on the traffic itself.

Road authorities have at their disposal forecast tools and decision making softwares. The forecast tools and methods of protective intervention could be improved. They need to be analysed such that their performances can be improved. For this purpose, a research program on the thermal behaviour of road surface during winter, called Winter Road Maintenance, has been undertaken by the Laboratoire central des Ponts et Chaussées – France in co-operation with Météo-France.

In this paper, we design a model to predict the short term road surface temperature (3 hours) taking into account the thermal and physical characteristics of the road as well as the weather conditions. This model, COGEL, combines the program GEL1D, a model for soil and road behaviour, and the program COBEL, a model for the atmosphere. The first program, GEL1D, allows the study of the evolution of the temperature field in a multi-layered, one-dimensional structure. The second program, COBEL, predicts fog formation and computes the distribution of atmospherical conditions : temperature, humidity, in the nocturnal boundary layer between the road surface and an altitude of approximately 1500 metres.

The combined method in COGEL has the advantage of entirely preserving the structures of the programs GEL1D and COBEL. The interactions between the programs result from energy exchanges.

In order to validate COGEL, in situ measurements have been recorded on two roads : RN 225 at Steenvorde (with traffic) and RN 455 at La Sentinelle (without traffic). Comparisons between the field measurements and the predictive model COGEL are discussed in the paper : they show a good agreement between simulations and actual evolutions.

2. Introduction

Road surface conditions constitute one of the important factors that are taken into account when driving. During the winter, these conditions depend on the weather, in particular on the temperature (Cames-Pintaux, Lerat, Dupas, 2000). In paragraph 3, we present the model COGEL of prediction of this short-term temperature: one calculates three hours in advance the temperature of surface of the road according to the thermal and physical characteristics of the road and the soil as well as according to the weather forecasts. This model results from the coupling of the model COBEL of Météo-France (Labbé, 1996) which predicts fog formation and computes atmospherical conditions : temperature, humidity and the model GEL1D of Laboratoire central des Ponts et Chaussées (Caniard, Dupas, Frémond, Lévy, 1975) which predicts the temperature of a road during winter. Two applications, presented in paragraph 4, at sites in the North of France, show the capacity of the model to predict thermal conditions of interest to users. These applications consisted in predicting the temperature of surface from 3 p.m. until 6 a.m. in the morning the next day.

Other studies on the formation of ice on road were conducted (Lassoued, 2000 ; Frémond, 2001).

3. The Model

It couples COBEL and GEL1D models which interact on the road surface. These two models are briefly described.

3.1. COBEL Model

It models the nocturnal boundary layer between the road surface and an altitude of approximately 1500 metres (Labbé, 1996). The initial state of the atmosphere is defined by the initial temperature, the humidity and the wind. External factors that are called the conditions of forcing, are given for the wind, humidity and temperature. Solar and cloudy flux are also given. With all this data, the program calculates the temperature. In practice, external factors are updated every three hours. It should be noted that COBEL possesses an elementary model of soil which is replaced in the coupling. The COBEL model manages the appearance and evolution of the fog formation (Bergot, Guedalia, 1994).

3.2. GEL1D Model

This model calculates the temperature $\theta(x,t)$ in a multi-layer unidimensional media. It takes into account the water - ice phase change (Caniard, Dupas, Frémond, Lévy, 1975 ; Frémond, 2001). Every layer is characterized by:

- its thickness ;
- its dry density (ρ_d);
- its water content (w) ;
- its calorific capacity;
- its unfrozen and frozen thermal conductivity (k_g and k_{ng}).

The initial temperature of the road structure is given. Boundary conditions in surface and in depth can be given by four different ways:

- imposed temperature (it is generally the condition chosen in depth) ;
- imposed heat flux : $\Phi = g_{imp}$;
- heat flux proportional to the difference between air temperature (θ_a is the temperature of the air) and the temperature of the surface of the soil : $\Phi = -\alpha(\theta - \theta_a)$;
- heat flux equal to the sum of an imposed flux and a flux proportional to the difference between air temperature and the temperature of the surface of the soil : $\Phi = g_{imp} - \alpha(\theta - \theta_a)$.

With this data, the model GEL1D calculates the temperature at every point, at every instant. In case of the structure freezes, it supplies also the position of the frost front (the frost front is the point where the temperature is equal to zero and where water - ice phase change occurs).

3.3. The Coupling of the Two Models

It is made at the surface of the road by an iterative method which preserves the architecture of two models globally (Lassoued, 2000). The energy balance at the road surface is reminded on the figure 1.

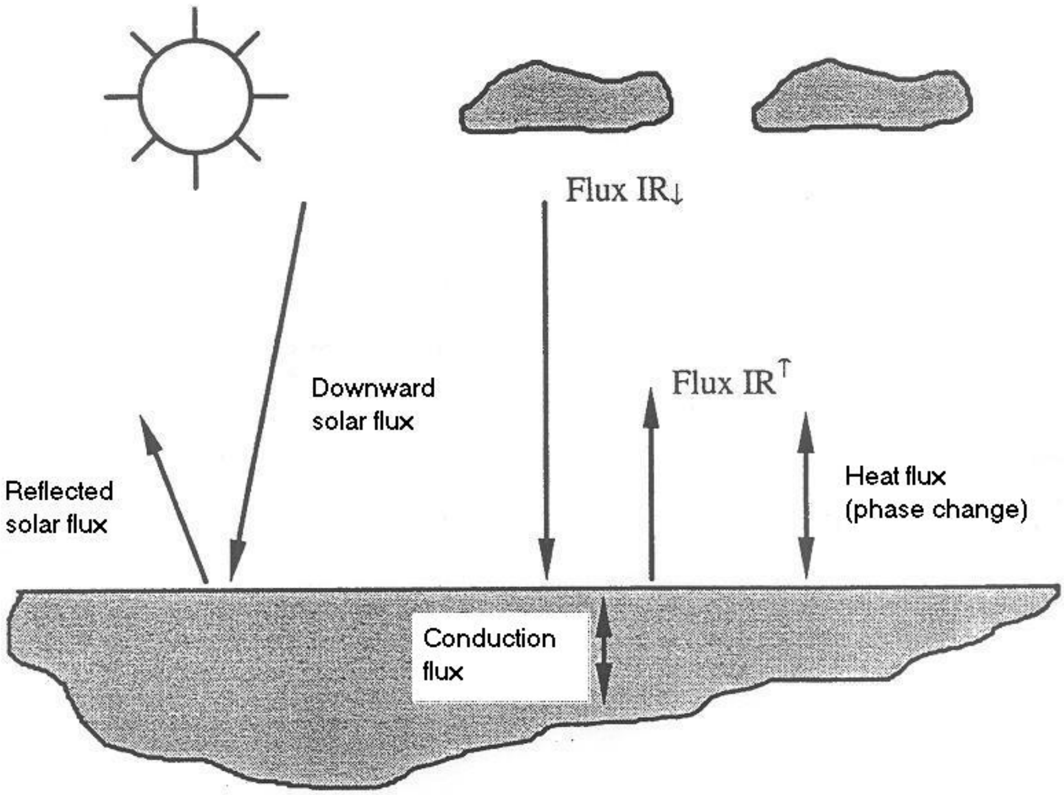

Figure 1. Energy Balance of Surface

Coupling comprises two stages (figure 2):

- first stage : the atmospheric part of the model supplies the flux of conduction Φ in the soil at the time t. With this condition in the limit (it is fourth boundary condition presented first), the soil part of the model is resolute and supplies the temperature of surface θ_{surf} at the time t ;
- second stage : with the temperature of surface at the time t, the atmospheric part of the program is resolute and supplies the flux of conduction Φ=(∑ flux, θ_a , α) (t+Δt) at the time t+Δt where Δt is the increment in time of the method of calculation. We get back to the first stage.

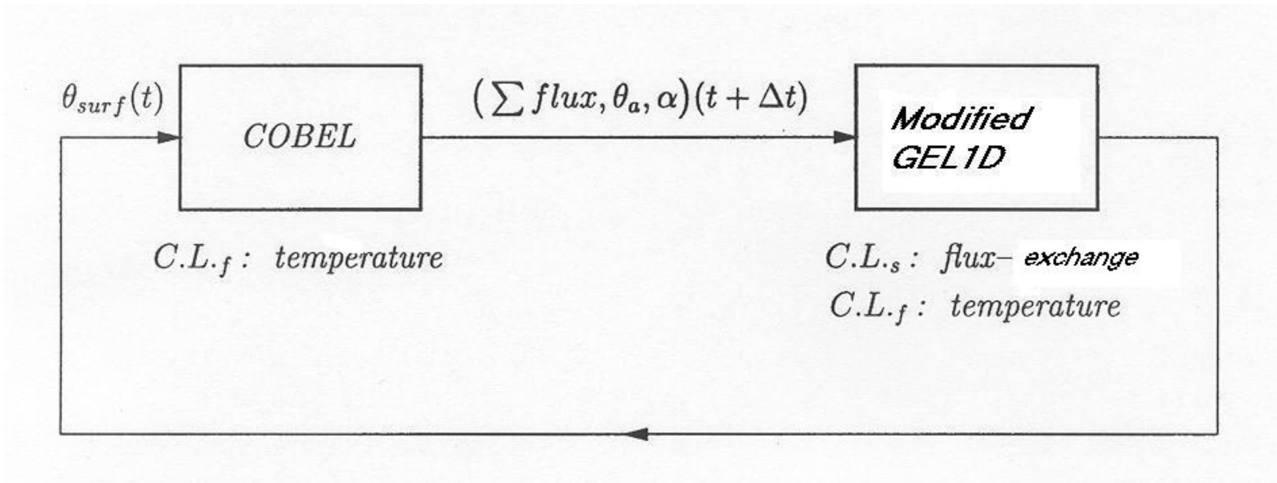

Figure 2. Principle of Functioning of the Model COGEL

4. Two Applications

Two experimental sites of the department of the North have been equipped : the site of la Sentinelle (RN455, who is not circulated) and that of Steenvoorde (RN225, who is circulated). Several types of sensors have been installed (Livet, Morlot, 1997) :

- meteorological sensors: pressure, temperature of the air sheltered at 1.5 meters of the soil, temperature of dew, precipitation, visibility, downward infrared flux, downward solar flux, force and direction of the wind, temperature in the natural soil;
- road sensors: temperature of road surface, state of surface, temperature in the body of the road.

4.1. The Main Road 455 at La Sentinelle

The description of the structure is given in the table 1.

thickness cm	structure	sensor position (cm) *(θ - 21/03/97, 3 p.m.)*	ρ_d kg m^{-3}	k_{ng} Wm^{-1}K^{-1}	k_g Wm^{-1}K^{-1}	w %
3	porous asphalt	0 *(19.3°C)*	1960	1.1	1.1	0
8	bituminous concrete of connection	-3.5 *(16.7°C)*	2350	2	2.1	1
22	granular material	-14 *(12.1°C)*	2250	1.9	2.1	5
25	treated fly ash	-36 *(9.6°C)*	1350	0.6	0.93	14
100	red and black schist	-61 *(9.8°C)*	1800	1.4	1.52	12
842	natural ground	*(8°C)*	1610	1.4	1.8	20

Table 1. Geometrical and Physical Characteristics of the Structure of the RN455 at La Sentinelle.

Measures were made during the winter of 1996-1997. As example, the surface temperature from 21/03/97, 3 p m until 22/03/97, 6 a m, have been measured. The values of the various flux are given in the table 2. Besides, calculations have been made by updating meteorological data, every three hours.

term (h)	incident solar flux W m^{-2}	cloudy infrared flux W m^{-2}
3 p.m.	588	74.6
6 p.m.	57	87
9 p.m.	0	24.9
0 a.m.	0	0
3 a.m.	0	0
6 a.m.	0	20

Table 2. Values of the Incident Solar Flux and Cloudy Infrared Flux of 21/03/97 at 3 p.m. to 22/03/97 at 6 a.m.

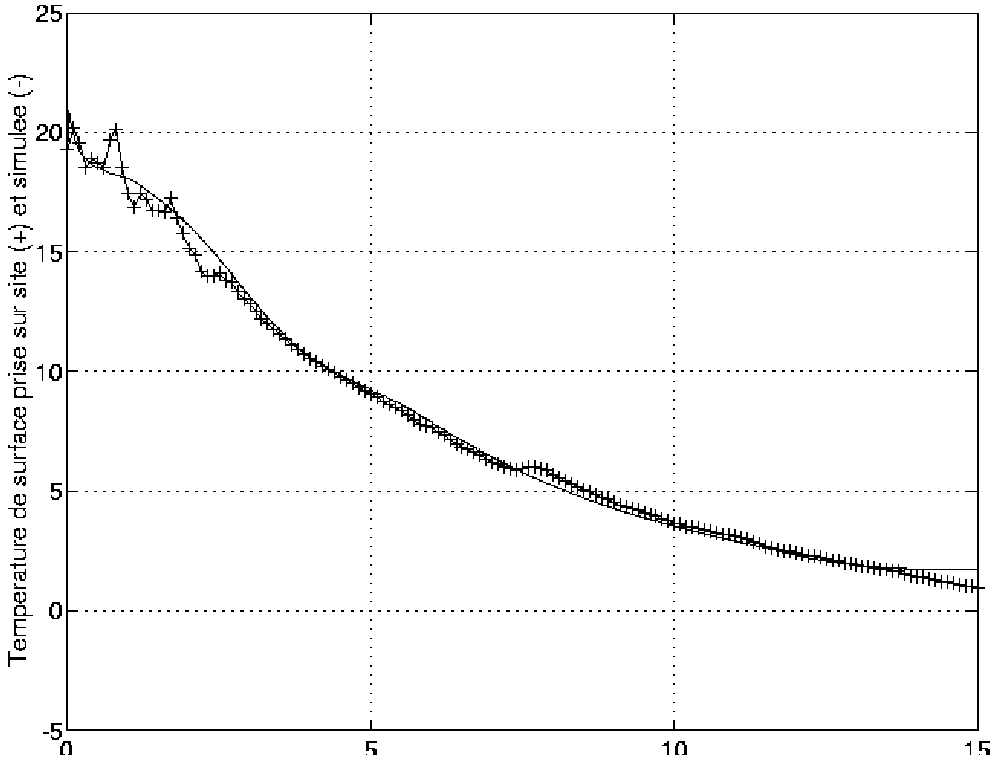

Figure 3. Measured (+) and Calculated (-) Temperatures at the Surface of the Road at La Sentinelle

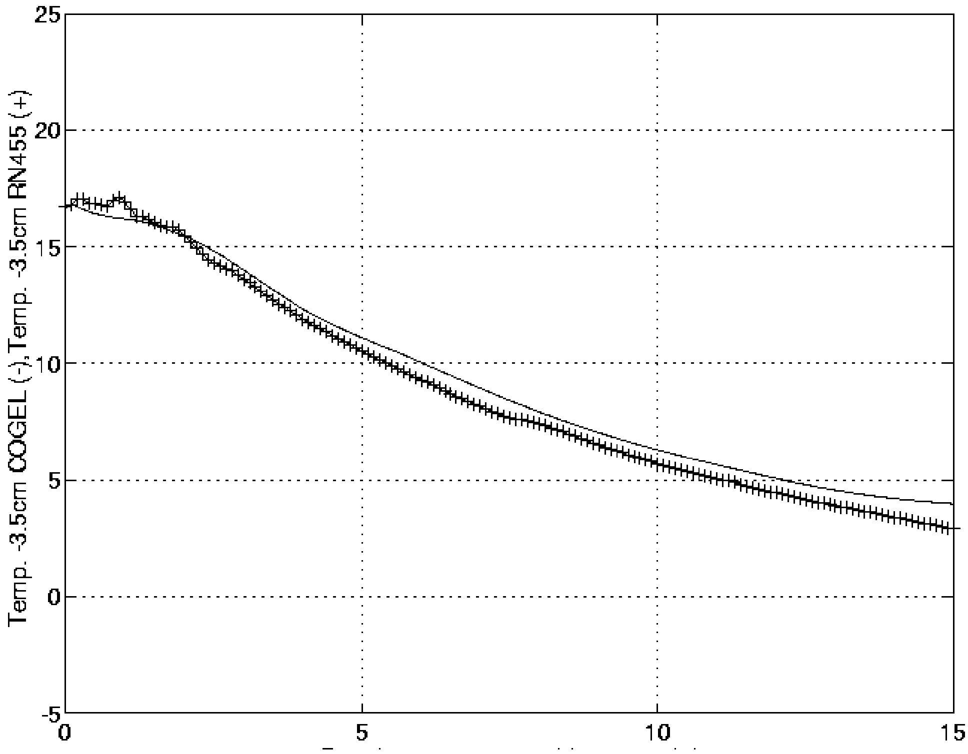

Figure 4. Measured (+) and Calculated (-) Temperatures at 3.5 cm depth at La Sentinelle

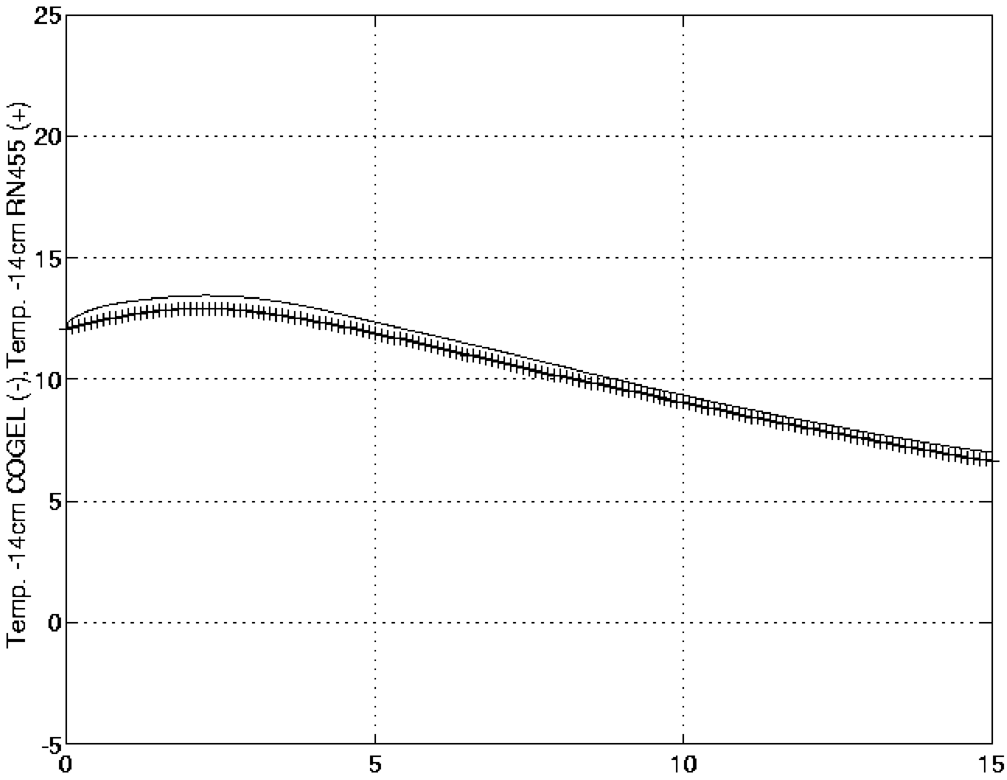

Figure 5. Measured (+) and Calculated (-) Temperatures at 14 cm depth at La Sentinelle

Results are presented on figures 3, 4 and 5. A good agreement with some localized differences, especially for the surface temperature, is noted. These differences are explained by local meteorological variations: passing clouds, variation of the wind, … and maybe by the sensitivity of the sensors.

4.2. The Main Road 225 at Steenvoorde

The description of the road structure is given in the table 3.

thickness cm	structure	sensor positions (cm) *(θ - 21/03/97, 3 p.m.)*	ρ_d kg m^{-3}	k_{ng} Wm^{-1}K^{-1}	k_g Wm^{-1}K^{-1}	w %
18	bituminous concrete	0 *(3.7°C)* -10 *(2°C)*	2350	2	2.1	1
45	slag-bound graded aggregate	-20 *(1°C)* -30 *(0.9°C)*	2050	1.1	1.3	4
18	treated sand		1900	1.1	1.3	7
919	natural ground	*(8°C)*	1610	1.4	1.8	20

Table 3. Geometrical and Physical Characteristics of the Structure of the RN225 at Steenvoorde.

term (h)	incident solar flux W m^{-2}	cloudy infrared flux W m^{-2}
3 p.m.	268.9	79.3
6 p.m.	43.2	56.6
9 p.m.	0	11.3
0 a.m.	0	0
3 a.m.	0	34
6 a.m.	32.1	56.6

Table 4. Values of the Incident Solar Flux and Cloudy Infrared Flux of 02/02/98 at 3 p.m. to 03/02/98 at 6 a.m.

On this site, the temperature of the road surface have been measured from 02/02/98, 15 p.m., until the next day, 6 a.m.. The solar and infrared flux are given in the table 4. The cold has been sufficient for the temperature of road surface becomes sharply negative (from 8:30 p.m.). Measured and calculated surface temperatures are represented in figure 6.

A considerable difference appears at 11:30 p.m. It seems to be due to a cloud system which was not taken into account by COGEL because information about the cloudy cover is supplied every three hours from extrapolated observations. Furthermore, these observations are made on a Steenvoorde's nearby site, in this particular case on a remote site of Dunkerque, 32 kilometers away. It seems that the effects of the cloudy flux have a considerable importance. Furthermore, these effects are localized in time and space. The forecast of the surface temperature requires a good spatial information about the cloudy cover.

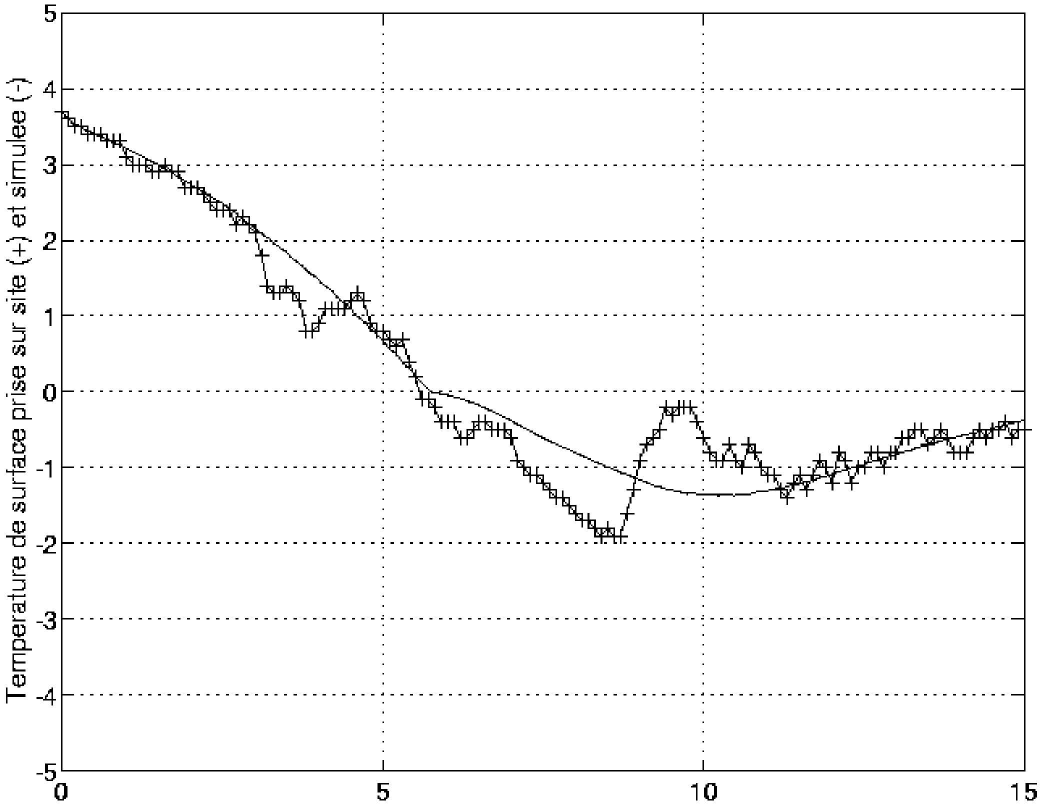

Figure 6. Measured (+) and Calculated (-) Surface Temperatures at Steenvoorde

5. Conclusion

COGEL model, developed by the Laboratoire central des Ponts et Chaussées and Météo-France, gives a satisfactory forecast of the temperature of the road surface. Presented applications show all the interest of the frequent updating of local weather conditions in particular those that describe the cloudy cover.

6. References

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