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Letters to the Editor

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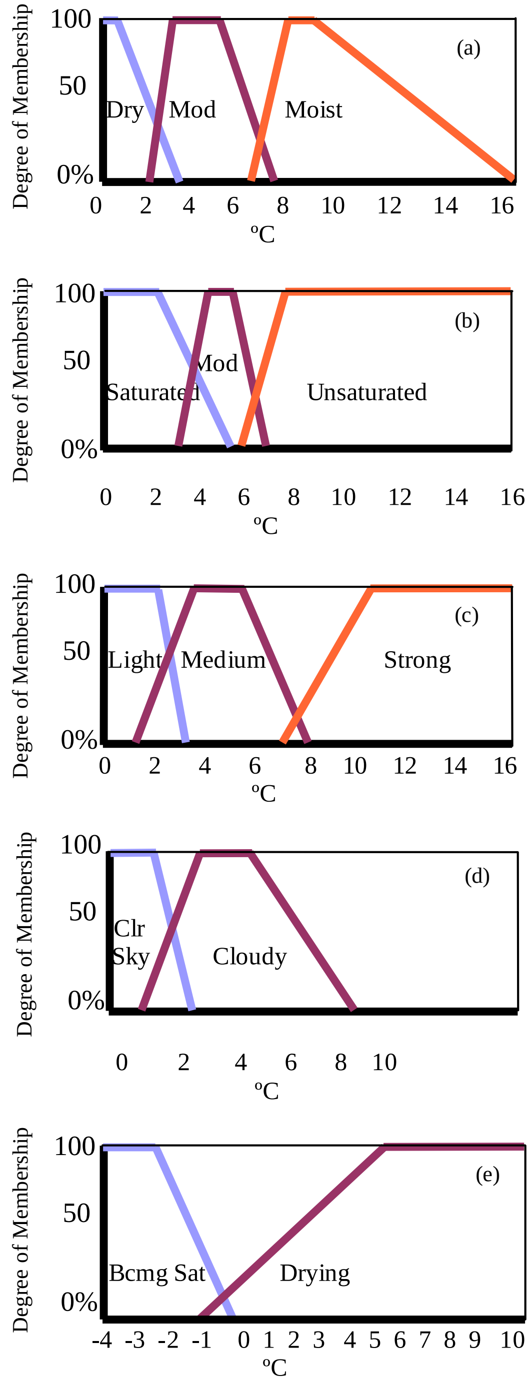
THE PROBABILITY OF THE FORMATION OF FOG OVER NEW DELHI : A FUZZY LOGIC APPROACH

1. During the winter season, fog formation is one of the most important weather events over northern parts of India, which affects the aviation badly. It is dangerous event for the aviation services, transport agencies due to poor visibility. Fog occurrence is basically mesoscale and synoptic scale phenomena. Extensive work has been carried out on such weather systems by Roy Bhowmik *et al*, (2004), Bhushan *et al.*, (2003), Mohapatra & Thulsidas (1998), Gupta (1987) and Basu (1952) on fog formation mostly over airports.

Fuzzy methods are most suited for finding optimal solutions to such problems with vague parameters. Fuzzy Logic is an extension of fuzzy set theory. Fuzzy logic allows something to be partially true and partially false. An attempt has been made by the authors in this paper to introduce the concept of Soft Computing (SC) as Fuzzy Logic (FL) and to explain how formulating the problem in a fuzzy framework can maximize optimal solution for prediction of probability of the formation of fog.

2. Current weather reports of Palam Airport, New Delhi have been used for a period of 5 years (1998-2002) from December to February and validated for the years 2003-2004 and 2004-2005. VHRR imageries in the Visible channel (0.55 µ -0.75 µ) from Indian National Satellites (INSAT) obtained from Satellite Meteorological Division, India Meteorological Department, New Delhi were used for validation purpose. In the present study, dew point (DP), dew point spread (DPS), wind speed (WS), sky condition (SKC), rate of change of the dew point spread (RCDPS) has been taken as the basic parameters.

3. Fog generally confines to the horizontal area over the surface. Therefore surface temperatures have been considered in this study. The theory of FL or SC was introduced by Zadeh (1965) to model the uncertainty of the natural language. It is an innovative approach to construct computationally intelligent systems consisting of Artificial Neural Network (ANN) and fuzzy logic, approximate reasoning and derivative free optimization methods. In the present study, a general term associated with FL has been introduced. In general, a problem to be solved is referred to as a system. A system input that can store multiple values associated with an



Figs. 1(a-e). Membership functions associated with the (a) dew point,(b) dew point spread,(c) wind speed, (d) sky condition and (e) rate of change of dew point spread

object attribute in the form of fuzzy variables is being proposed in this study. This system inputs are to be known as a physical variable, which determines the solution of

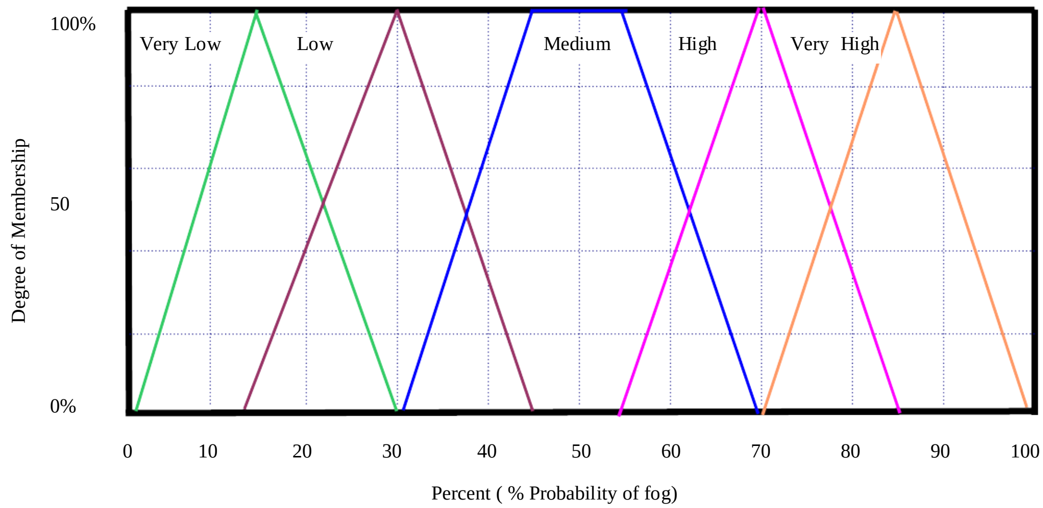


Fig. 2. Output membership functions associated with the probability of fog formation

TABLE 1

Fuzzy Sets

Category	Parameter				
	Dew-point (°C)	Dew-Point spread (°C)	Rate of change of dew point spread (°C /hour)	Wind speed (knots)	Sky condition (Octet)
1	dry	saturated	saturating	light	cloudy
2	moderate	moderate	drying	medium	clear
3	moist	unsaturated	-	strong	-

TABLE 2

Probability of fog formation after defuzzification

S. No.	Date (UTC)	Dew-Point (°C)	Dew-Point Spread (°C)	Wind Speed (knots)	Sky condition (Octet)	Rate of change of dew Point spread (°C /h)	Fog probability (%)
1.	02 Jan 2004 (0100)	4.7	0.3	0	0	0.3	60
2.	03 Jan 2004 (2100)	14.7	3.8	2	2	-0.4	55
3.	06 Dec 2003 (0200)	2.4	9.5	5	0	4.3	15
4.	28 Jan 2004 (0000)	6.2	7.4	0	0	1.3	30
5.	03 Jan 2005 (0200)	9.6	0.8	3	0	-0.1	58
6.	10 Jan 2005 (0200)	7.3	4.1	5	0	0.3	40

the problem, which is system output. Here system output is the probability of the formation of fog within the next 4-5 hours. Usually FL deals with complex dataset where the degree of vagueness is very high. Construction of fuzzy set is subjective in nature and reflects the context in which problem is viewed Pal and Mitra (1999). It is a rule-based dependent system. To incorporate fuzzy system into a rule-based dependent system, we have used a method which consists four parts.

3.1. Fuzzy sets are qualitative descriptions of the chosen domains of the inputs where each sets will be having specific effect on the output. The basic structure of the fuzzy sets, which has been used in this study shown in Table 1.

In the Table 1, fuzzy sets have been created from the qualitative study of fog and quantitatively defined by membership functions. These functions contain a specified domain of the value of the system input and have been shown in Figs. 1(a-e) in the form of trapezoids.

3.2. The rule base contains a set of fuzzy decision rules of the If-Then form for query matching. If part, is known technically as the antecedent. Then part is called the consequent or associated system output fuzzy set. The antecedents of rules correspond directly to degrees of membership calculated during the fuzzification that consists of tests to be made on existing data. Fuzzy rules can be designed manually or automatically, it means that it can generate rules for all combinations of selected variables and can be fills consequent fuzzy terms.

3.3. Let a, b, c, d and e be sets of antecedents where a, b, c, d, and e is different fuzzy sets whereas X be sets of consequences. The rules are applied in this manner :

$$\text{If } (a_i \;\&\; b_i \;\&\; c_i \;\&\; d_i \;\&\; e_i) \text{ Then } (Xj) \qquad (1)$$

Where in Eqn. (1), 'i' is the variable, which belongs to that fuzzy set, and 'j' is the maximum possible consequences in terms of very low, low, medium, high and very high.

The total number of rules is the product of the number of fuzzy sets in the system. Here there are three sets associated with the DP, three with the DPS, two with the RCDPS, three with the WS and two with the SKC. The total number of rules that completely define the set then is $3\times3\times2\times3\times2 = 108$. The strength of a rule is the value of its least true antecedent, or If portion, which is simply the degree of membership of each system input in the corresponding fuzzy set(s). More than one rule can lead to the same consequence. In this case, the rule with the highest strength is used.

3.4. To achieve a meaningful system output, a method is required to combine the rule outputs, which is defined by the membership functions similar to the inputs shown in Fig. 2. The methodology employed is referred to as the center-of-gravity method. The final system output is then calculated as the weighted average of the centroid of each membership function, with the area of the enclosed set used as the weighting factor.

System output is calculated as :

$$\text{S (centroid) } i \times \text{(area) } i / \text{S (area) } i = \text{P} \qquad (2)$$

Where P is probability of fog formation.

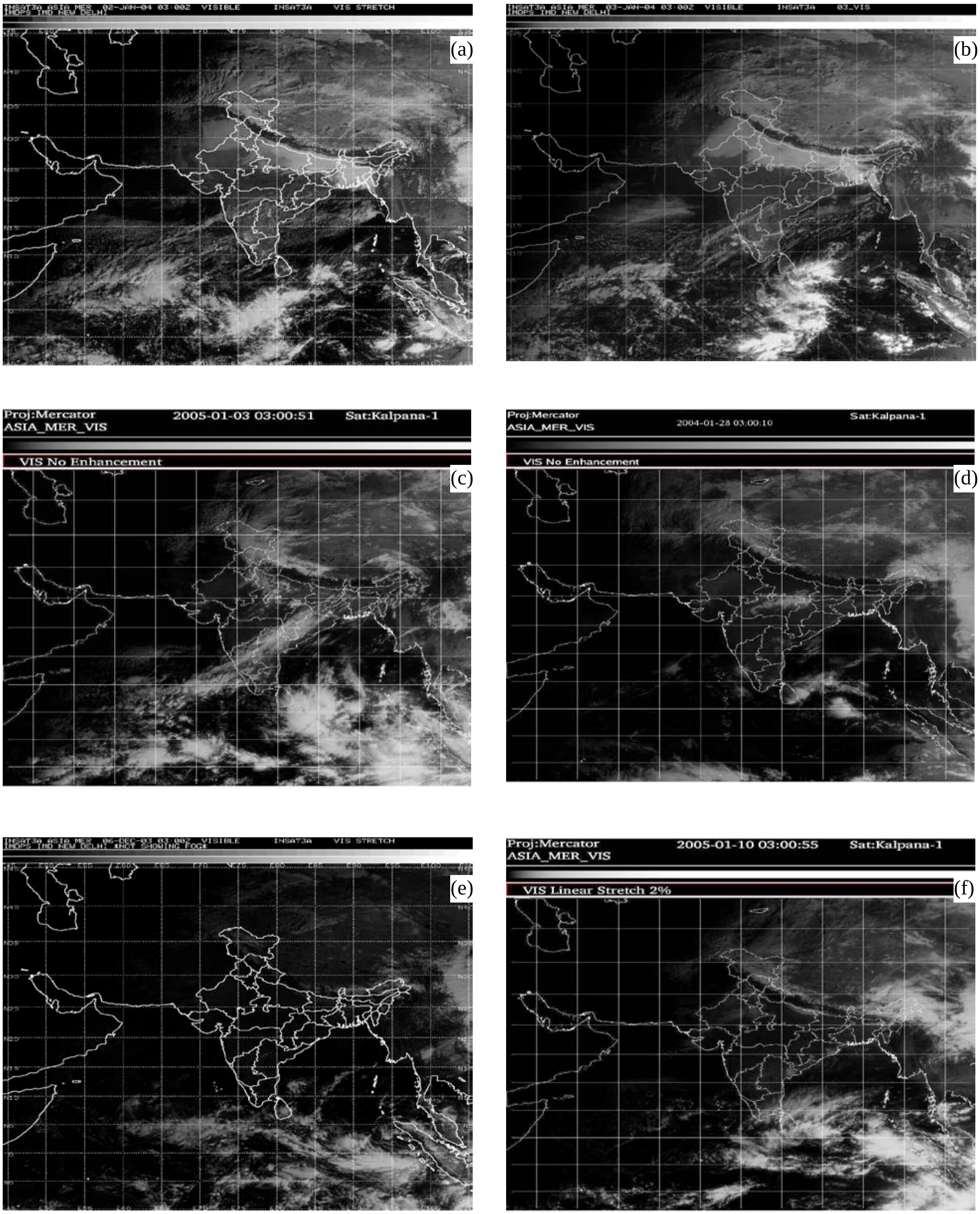
During the rule evaluation, extended input domain with membership of 100% has a larger weighting. It has been reflected in the final output. Narrow output membership functions, map the solution into a more restricted domain but the associated weighting by area is less, and shown in Fig. 2.

4. Based upon the observations collected from the Regional Meteorological Center, New Delhi, the basic parameters associated with the various fuzzy subsets are displayed in Figs. 1(a-e). It is seen from the Figures that the membership function associated with each fuzzy set provides a quantitative value of the degree of membership of the input into each fuzzy set. The validation has been done for the year 2003-2004 and 2004-2005 from December to February. From the each season we have taken some of the observations that are presented along with associated probability of fog formation after defuzzification in a Table 2.

From the Table 2, higher probability formation and lower probability formation has been discussed.

4.1. Generally Clear skies combined with sufficient moisture and a saturating trend with light winds indicates a higher probability of fog formation. Using rule-based fuzzy theory only one rule would be applicable for [S.No.(1)] condition, which is "moist & saturated & medium & clear sky & saturating". After defuzzification, we have found that probability of fog formation is 60%, which corresponds to high probability of fog as defined by the current set of the output membership function (Fig. 2). The observation at 0300 UTC of 02 January 2004 and satellite imagery of Fig. 3(a) indicated the foggy condition. Applying the same method, as above 16, 1, 2, 2, 4 rules would be applicable for the S.No.(2), S.No.(3), S.No.(4), S.No.(5), and S.No.(6) respectively. After defuzzification, it has been found that probability of fog formation is 55%, 15%, 30%, 58%, and 40% respectively. This has been verified by observation and satellite imageries. Shown in Figs. 3(b-f).

4.2. However, the success of this technique mainly depends on tuning and calibration of fuzzy sets. Careful



Figs. 3(a-f). INSAT VIS image on (a) 02 Jan 2004, 0300 UTC, (b) 03 Jan 2004, 0300 UTC, (c) 03 Jan 2005, 0300 UTC showing fog and (d) 28 Jan 2004, 0300 UTC, (e) 06 Dec 2003, 0300 UTC, (f) 10 Jan 2005, 0300 UTC without fog construction of the membership functions as well as the rule base is necessary. The extremely useful feature of this system is that it can provide a credible advice to the user in an uncertain environment. To ensure fog formation prediction accuracy, the number of fuzzy membership functions and new fuzzy rule base has been worked out. The iterative process of designing the rule base, choosing a defuzzification algorithm, and testing the system performance was repeated several times with a subsequent observational hours and different shapes of fuzzy memberships.

5. The present study indicates that optimal solution for the probability of the formation of fog can be obtained by formulating the problem in a fuzzy framework. The dew point spread and the rate of change of dew point spread has been the most important parameters for the formation of fog.

Fuzzy analysis at Palam Airport, New Delhi reveals that fog occurance is dominant when dew point and dew point spread is between 6-10° C and 1-3° C respectively. A negative saturating trend and light winds approximately 0-4 knots also plays the major role for the formation of fog. Clear skies combined with sufficient moisture and a saturating trend and light winds eventually result in fog formation.

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