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# Meteorological factors and the incidence of mumps in Fujian Province, China, 2005–2013: Non-linear effects

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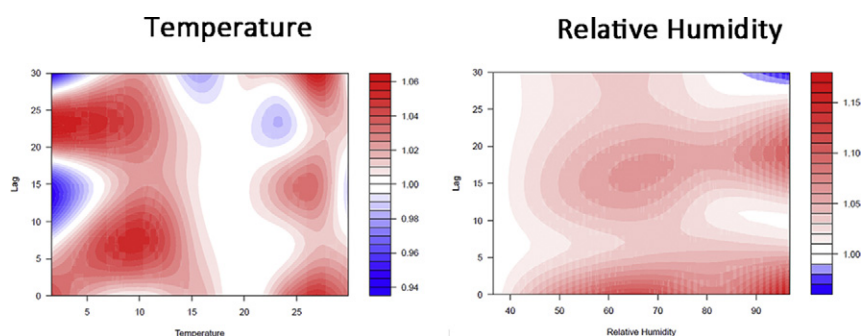
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## HIGHLIGHTS

- This study explored the associations between 7 meteorological factors and mumps.
- Low temperature and high relative humidity could increase the risk of mumps.
- Low wind velocity had larger cumulative effects within 30 lag days.
- Males, children aged 10–14 and students were vulnerable to low temperature.

## GRAPHICAL ABSTRACT



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## ABSTRACT

**Background:** Mumps is still an important public health issue in the world with several recent outbreaks. The seasonal distribution of the disease suggested that meteorological factors may influence the incidence of mumps. The aim of this study was to explore the possible association between meteorological factors and the incidence of mumps, and to provide scientific evidence to relevant health authorities for the disease control and prevention. **Methods:** We obtained the data of mumps cases and daily meteorological factors in Fujian Province in Eastern China over the period of 2005–2013. Using distributed lag non-linear model (DLNM) approach, we assessed the relationship between the meteorological factors and mumps incidence.

**Results:** The effects of meteorological factors on the mumps incidence were all non-linear. Compared with the lowest risk values, the upper level of precipitation, atmospheric pressure and relative humidity could increase the risk of mumps, whereas the low level of wind velocity, temperature, diurnal temperature range and sunshine duration may also increase the risk. Moderate atmospheric pressure and low wind velocity had larger cumulative effects within 30 lag days and the relative risks were 10.02 (95%CI: 2.47–40.71) and 12.45 (95%CI: 1.40–110.78). For temperature, the cumulative effect within 30 lag days of minimum temperature was higher than that from maximum temperature in most populations. The cumulative effects of minimum temperature for males, children aged 10–14 and students were higher than those in other populations.

**Conclusions:** Meteorological factors, especially temperature and wind velocity, should be taken into consideration in the prevention and warning of possible mumps epidemic. Special attention should be paid to the vulnerable populations, such as teenagers and young adults.

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## 1. Introduction

Characterized by the inflammatory parotid gland with precursory fever, mumps mainly targets on the children aged 5–9 (Hviid et al., 2008; Tyor and Harrison, 2014). It is caused by mumps virus, which belongs to paramyxovirus family and is transmitted by direct contact, droplet spread, or contaminated fomites. The incubation period of mumps is about 15 to 24 days, with 19 days as median (Richardson et al., 2001). Most mumps infections are mild and self-limiting, while some complications are meningitis and encephalitis, arising in 1–10% and 0.1% of mumps infections respectively. The mumps infection is also an important cause of sensorineural hearing loss (Tyor and Harrison, 2014).

Mumps is a vaccine-preventable disease. The incidences of mumps decreased in many countries at the beginning of 21st century, benefiting from the massive implementation of mumps immunization programs (Centers for Disease Control and Prevention, 2007; Peltola et al., 2000; Slater et al., 1999). However, there has been a global resurgence of mumps over the last decade, despite high vaccination coverage. Outbreaks have been noticed in many countries, including the United States (2006, 2016) (Barskey et al., 2009; Majumder et al., 2017), Ireland (2008) (Whyte et al., 2009) and the Republic of Korea (2013–2015) (Choe et al., 2017). The most vulnerable populations of recent outbreaks were teenagers and young adults, rather than children. The reasons for the recent outbreaks could be due to waning immunity after vaccination (Park et al., 2007; Rubin et al., 2012).

In China, the mumps vaccine has been integrated into National Immunization Program (NIP) since 2007. Nationwide, children aged 18–24 months receive one dose Measles, Mumps and Rubella Combined Attenuated Live Vaccine (MMR) for free. The immunization coverage rate differs in provinces and the seropositive rate is about 80%–90% in children (He et al., 2017; Wang et al., 2014). However, as WHO recommended, one dose of MMR may not fully control the epidemic of mumps and two doses of the vaccine are required for long-term protection (WHO, 2007). In China, vaccination rate of the second dose is much lower than that of the first and it may lead to the mumps epidemic during 2011–2012, with the incidence rates of 33.9/100,000 and 35.6/100,000 in total population (Su et al., 2016). The mumps is still a serious public health issue in China.

The reasonable distribution of mumps has been detected in various areas, with the highest incidence occurring in spring (Park, 2015; Sane et al., 2014; Shah et al., 2006). However, the seasonal distribution varies between northern and southern China, with the peaks in spring and summer respectively (Li et al., 2017b; Liu et al., 2015; Yang et al., 2014a). Such distributions indicate that meteorological factors may impact on the transmission of mumps. Although there have been some laboratory investigations exploring the effects of meteorological factors on viral diseases (Lowen et al., 2007; Walker and Ko, 2007), such as MERS-CoV (van Doremalen et al., 2013), the respiratory disease transmission in real world is more complex than laboratory environment. It is therefore necessary to explore the effects of meteorological factors in population.

At present, there are a number of ecological studies examining the relationships between meteorological factors and infectious diseases, such as hand, foot and mouth disease (HFMD) and dengue fever (Jiang et al., 2016; Li et al., 2017a; Nguyen et al., 2017), with only few focused on mumps and the results are inconsistent (Ho et al., 2015; Li et al., 2016; Onozuka and Hashizume, 2011; Yang et al., 2014a). This could be due to the different analytic methodologies and various geographic locations with different climatic characteristics.

Non-linear models have been widely used in assessing the relationships between meteorological factors and health outcomes (Peng et al., 2017; Wang et al., 2017). Meanwhile, most studies found the lagged effects of meteorological factors (Antunes et al., 2017; Seposo et al., 2017). Therefore, some researchers adopted distributed lag non-linear model

(DLNM) to assess the non-linear effects of meteorological factors and the lagged effects simultaneously (Gasparrini, 2014).

The aim of this study was to explore the effects of meteorological factors on the incidence of mumps in Fujian Province of China, and to provide scientific evidence for health authorities for mumps control and prevention.

## 2. Material and methods

### 2.1. Study area

Fujian is a coastal province in southeastern China, located in a low latitude region (23°33'N–28°20'N). This province has a 37.74 million population, covering a land area of 124 thousand square kilometers. Fujian has a typical subtropical monsoon climate. The annual mean temperature and precipitation of the province are 17–21 °C and 1400–2000 mm. The four seasons in Fujian are distinct, with comparatively longer summers and shorter winters. Fujian has implemented mumps virus vaccination in the expanded program on immunization since 2008.

We conducted the study in Fujian Province, as well as in four cities in the Province, including Fuzhou, Longyan, Ningde and Sanming. The locations of the province and four cities can be seen in Fig. 1.

### 2.2. Data sources

Data of reported mumps cases from 1 January 2005 to 31 December 2013 were obtained from China National Notifiable Disease Surveillance System (NDSS). Gender, age and occupation of cases were also collected from the system. For all mumps cases, both clinical diagnosis and laboratory confirmation were undertaken (Ministry of Health of China, 1997; National Health and Family Planning Commission of China, 2007). Medical institutions must report, required by law, all confirmed mumps cases to local health authorities within 24 h through NDSS.

Daily meteorological data for the same period were obtained from China Meteorological Data Sharing Service System (<http://data.cma.cn/>), including daily precipitation, mean atmospheric pressure, mean wind velocity, mean temperature, maximum temperature, minimum temperature, mean vapor pressure, mean relative humidity, and sunshine duration. There are 28 national meteorological sites in Fujian Province (Fig. 1). These sites evenly distribute throughout the province, and distribute symmetrically in high incidence rate area and low incidence rate areas. The original data were observations from all 28 national meteorological sites in Fujian Province, and we calculated averages for each meteorological variable to represent the provincial level. The difference between daily maximum and minimum temperature was calculated as diurnal temperature range.

The population at the end of each year from 2005 to 2013 in Fujian Province was obtained from National Bureau of Statistics of the People's Republic of China (<http://data.stats.gov.cn/>).

### 2.3. Statistical analysis

We counted the annual total number of reported mumps cases and calculated the annual incidence rate, expressing by the line graph. Other descriptive analyses were also performed to characterize the mumps incidence and meteorological factors. The seasonal distribution of daily meteorological factors and mumps case counts were observed through time series plots. Then preliminary correlations among eight meteorological factors and mumps case counts were performed by Spearman's correlation analyses. The correlations are classified to 5 levels based on coefficients: negligible correlation (coefficient: 0.00–0.30), low correlation (coefficient: 0.30–0.50), moderate correlation (coefficient: 0.50–0.70), high correlation (coefficient: 0.70–0.90), and very high correlation (coefficient: 0.90–1.00) (Mukaka, 2012). When calculating vapor pressure, temperature is an important element of

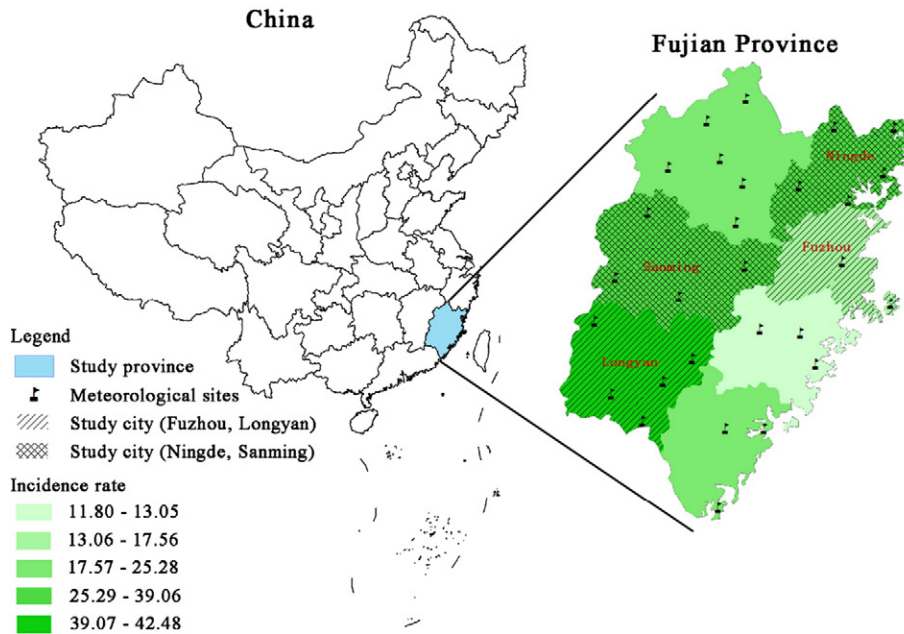


Fig. 1. Study area, locations of meteorological sites and incidence rates of mumps in Fujian Province.

the formula (Wexler, 1976). To reduce the possible multicollinearity, vapor pressure was removed from following analysis.

In order to identify more precise correlations among seven meteorological factors and mumps case counts, we applied DLNMs to explore the potentially non-linear and delayed effects of meteorological factors. DLNM is based on the definition of cross-basis, a bi-dimensional function expressed by the combination of two basis functions, which depicts the effects of predictor and lags simultaneously (Gasparrini et al., 2010). Given the possible multicollinearity between eight meteorological factors, the model would be unstable if it included all the meteorological factors. We therefore established a model for each meteorological factor separately and only included the factors, of which Spearman's correlation coefficients with main factor were less than 0.5, as confounders. We added quasi-Poisson generalized additive models to DLNMs to deal with the over-dispersion of daily number of mumps cases. The structure of DLNM is as follows:

$$\text{Log}[E(Y_t)] = a + cb(M, \text{lag}) + Scb(X_i, \text{lag}) + NS(\text{Time}) + dDow + gHoliday$$

where  $E(Y_t)$  denotes the expected number of mumps cases,  $cb(M, \text{lag})$  denotes the cross-basis function for the mainly studied meteorological factor,  $cb(X_i, \text{lag})$  denotes the cross-basis function for each confounding meteorological factor,  $NS(\text{Time})$  denotes natural cubic spline function to control long-time trend and seasonality,  $Dow$  denotes the categorical variable for the day of week,  $Holiday$  denotes the binomial variable for public holidays.

According to the incubation period of mumps, the lags of meteorological factors were defined as 30 days to cover all possible lag effects. Referring to previous literatures (Onozuka and Hagihara, 2015; Xiang et al., 2017), natural cubic spline functions were chosen to explore the effects of meteorological factors and their corresponding lags. We principally used Akaike's information criterion (AIC) to determine degrees of freedom (DF) of natural cubic spline functions. In the final model, long-time trend and seasonality were controlled by the natural cubic spline function with 7DF/year. Degrees of freedom for meteorological factors and their

corresponding lags are as follows: 3, 5 for precipitation; 5, 5 for atmospheric pressure; 3, 4 for wind velocity; 6, 5 for temperature; 4, 5 for diurnal temperature range; 3, 6 for relative humidity; 3, 2 for sunshine duration. The meteorological value with the lowest risk of mumps was selected as the reference to calculate relative risk and the value was identified according to the cumulative effect of meteorological factor by DLNM (Zhang et al., 2016; Li et al., 2015; Zhang et al., 2017).

Given the importance of temperature in the transmission of respiratory diseases, we performed subgroup analysis for temperature, taking gender, age and occupation as grouping principles. We also conducted sensitive analysis to test the robustness of our results by changing degrees of freedom and using alternative DLNM as follows:

$$\text{Log}[E(Y_t)] = a + cb(M, \text{lag}) + Scb(X_i, \text{lag}) + NS(\text{Time}) + dDow + gHoliday + \varepsilon\text{Vaccine} + \eta\text{Diagnosis}$$

where  $Vaccine$  denotes a binomial variable considering MMR being taken into immunization program in Fujian since 1st January 2008 and  $Diagnosis$  denotes a binomial variable considering the changes of diagnostic criteria of mumps since 15th October 2007 (National Health and Family Planning Commission of China, 2007).

The 0.05 level of statistical significance was selected for all statistical tests with two-sided tests. The "dlnm" package in R software (v.3.3.2, R Project for Statistical Computing) was used for data analysis (Gasparrini, 2011).

#### 2.4. Ethical approval

Disease surveillance data used in this study were obtained from the NDSS with the approval by the Chinese Center for Disease Control and Prevention. All identity information of patients was removed before data analysis. The study was approved by the Ethical Review Committee (ERC) of School of Public Health in Shandong University (20120501).

**3. Result**

*3.1. The distribution of mumps, demographic characteristics of the mumps patients and basic information of meteorological factors*

From 2005 to 2013, a total of 75,249 mumps cases were reported in Fujian Province, with the highest incidence rate in 2011 (Fig. 2). During the study period, the average amount of daily reported cases was 22.89, and the male/female ratio was 1.82:1 (48,551: 26,698). In terms of age and occupation, the highest proportions were found in children aged 5–9 (39.96%) and students (57.56%) (Table 1). In addition, seasonal pattern of the daily amount of mumps, as showed in Fig. 3, suggested the peak of mumps cases was found in May and June, followed by a smaller peak in December and January in next year. Seasonal patterns of meteorological factors in time series distribution also can be seen in Fig. 3, and there was obvious seasonality in plots of mean atmospheric pressure, mean temperature and mean vapor pressure. Details of meteorological factors of Fujian Province were summarized in Table 2. Details of meteorological factors of the four cities were summarized in Table A.1.

*3.2. Preliminary correlations among daily meteorological factors and mumps case counts*

Table 3 showed the Spearman's correlations among meteorological factors and the number of mumps cases. We found that except sunshine duration, all other meteorological factors were correlated with the numbers of mumps cases significantly. Meteorological factors were correlated with each other significantly, except mean atmospheric pressure with diurnal temperature range and mean temperature with mean relative humidity. The pairs of meteorological factors of which Spearman's correlation coefficients were less than 0.5 were used in subsequent analyses.

*3.3. Non-linear and lagged effect of meteorological factors on the incidence of mumps*

In this DLNM analysis, separate effect represents the effect of meteorological factors on a specific lag day, while cumulative effect represents the comprehensive effect on the specific lag day and all days before it. Fig. 4 showed the cumulative effects of meteorological factors within 30 lag days, taking the median values as references. The meteorological factor values with the lowest risk were as follows: 6.2 mm for precipitation; 958.5 hPa for atmosphere pressure; 5.6 m/s for wind velocity; 18.7 °C for temperature; 18.2 °C for diurnal temperature range; 36.5% for relative humidity and 3.3 h for sunshine duration. These values were then used as references to estimate the effects of meteorological factors.

Fig. 5 showed the separate effects of meteorological factors in each lag day, taking the lowest effect value as reference. The effects of meteorological factors on the development of mumps were non-linear. For

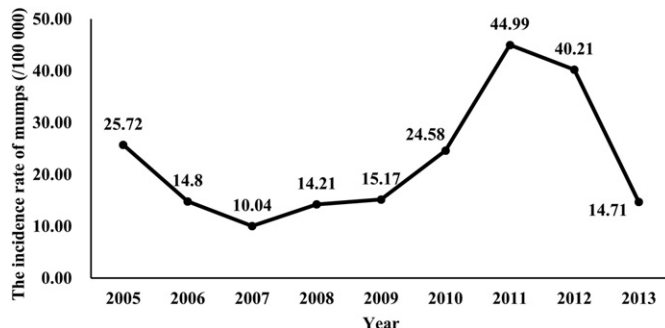


Fig. 2. The annual incidence rates of mumps in Fujian Province, China, 2005–2013.

**Table 1**

Demographic characteristics of patients with mumps in Fujian Province, China, 2005–2013.

Variables	Case counts	Percentage (%)
Total	75,249	100.00
Gender		
Male	48,551	64.52
Female	26,698	35.48
Age groups (years)		
0–4	12,156	16.15
5–9	30,071	39.96
10–14	20,183	26.82
15–29	8877	11.80
≥30	3962	5.26
Occupation		
Scattered children	9516	12.65
Nursery children	14,336	19.05
Students	43,316	57.56
Workers	8081	10.74

Fujian Province, the largest separate effect of each meteorological factor occurred at the maximum or minimum variable values. Precipitation and atmospheric pressure presented larger separate effects, with the RRs were 1.23 (95%CI: 1.11–1.37) and 1.33 (95%CI: 1.16–1.53), respectively (Table 4). The largest separate effect and corresponding variable values of four cities were summarized in Table A.2 and Table A.3. For precipitation and wind velocity, the largest separate effects occurred at the maximum level of precipitation and minimum level of wind velocity respectively, which was consistent to the results of Fujian Province. Fig. 6 showed the separate and cumulative effects of the specific meteorological variable values that the largest separate effects occurred, along lag days. Then we determined the largest cumulative effect and corresponding variable value for each meteorological factor. For atmospheric pressure, temperature and diurnal temperature range, the maximum separate and cumulative effects occurred at the different variable values. Precipitation, atmospheric pressure and wind velocity presented larger cumulative effects with the RRs were 7.40 (95%CI: 1.82–30.19), 10.02 (95%CI: 2.47–40.71) and 12.45 (95%CI: 1.40–110.78), respectively (Table 4).

*3.4. Effect of temperature in subpopulations*

We assessed the effect of temperature on the mumps incidence in several subpopulations, in terms of gender, age and occupations. We determined the largest separate effect and its corresponding variable value and lag day firstly, then calculated the cumulative effect of the 5th and 95th percentiles of temperature, because the effect of temperature showed an approximate “V” shape, indicating both high temperature and low temperature had impact on mumps. Although separate effects occurred at different variable value in subpopulations, they all occurred at comparatively low or high temperature, instead of the moderate one. As for cumulative effects, low temperature caused more adverse effect than that from high temperature. Male, children aged 10–14 and students were more susceptible to low temperature with the RRs were 2.52 (95%CI: 1.67–3.79), 6.58 (95%CI: 3.43–12.64) and 4.27 (95%CI: 2.65–6.87), respectively (Table 5).

*3.5. Robustness of distributed lag non-linear models*

Our results were robust to changed degrees of freedom of long-time trend and seasonality. The results were similar when we increased and decreased 1 unit of the degree of freedom of each meteorological factor and its corresponding lag day (Fig. A.2). Furthermore, our results were robust to the alternative model with two added items (Fig. A.3).

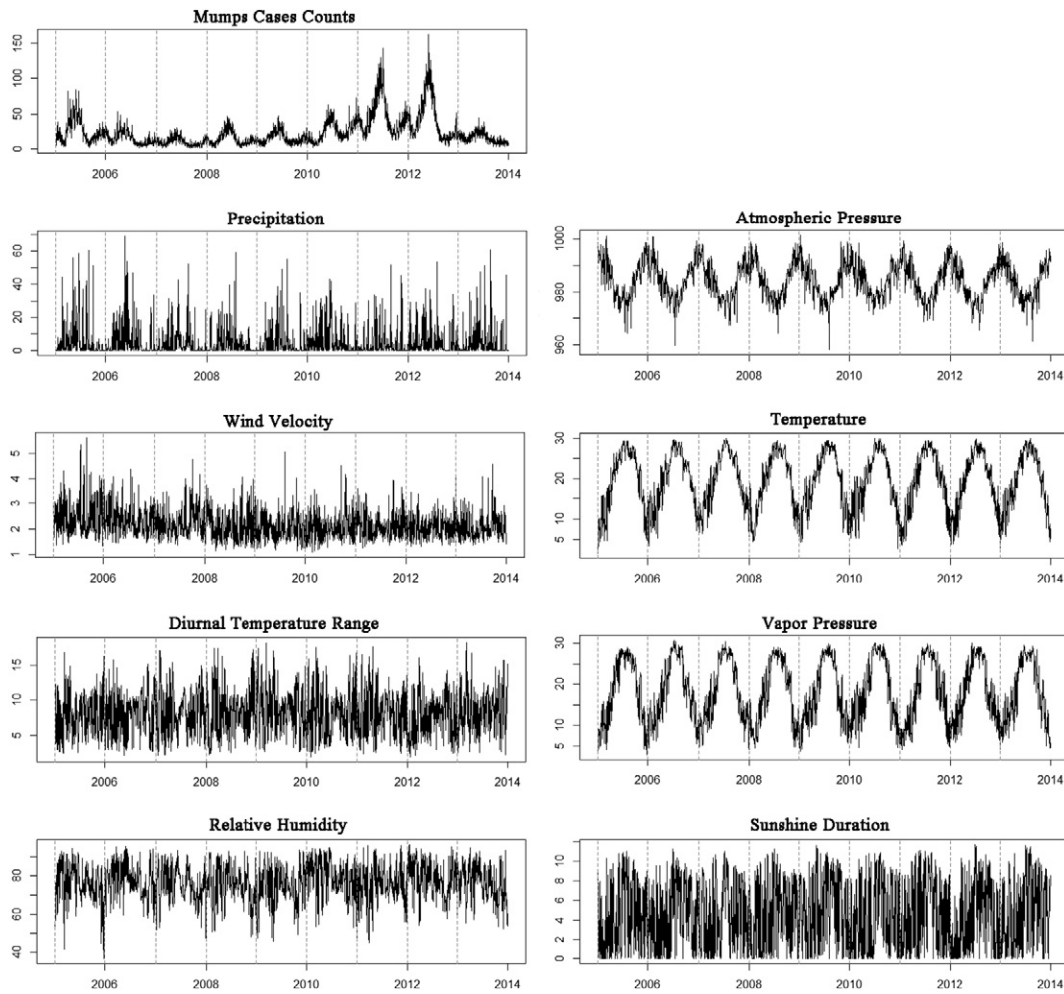


Fig. 3. The time series distributions of daily meteorological factors and mumps cases counts in Fujian Province, China, 2005–2013.

#### 4. Discussion

Over the last decade, there have been frequent and widespread mumps outbreaks all over the world, threatening children's health. In China, the epidemic occurs every 2–5 years (Zhan et al., 2013; Huang et al., 2014). The incidence rates peaked around 2011 in many provinces (Fig. A.4) including Fujian, with the high incidences appeared in 2011 and 2012. Mumps is still an important public health issue for China and Fujian Province.

The results from Fujian Province showed that the relationships between meteorological factors and the incidence of mumps were all non-linear. We found that the maximum level of precipitation, atmospheric pressure and relative humidity could increase the risk of

mumps, whereas the minimum level of wind velocity, temperature, diurnal temperature range, and sunshine duration may also increase the risk for mumps development. Precipitation and atmospheric pressure had larger separate effects. Atmospheric pressure and wind velocity had larger cumulative effects within 30 days lagged effect. For temperature, the adverse effect of low temperature was worse than that from high temperature. Male, children aged 10–14 and students were more vulnerable to low temperature than other population groups.

Compared with the result from the provincial level, the effects of precipitation, atmospheric pressure, wind velocity and temperature from the four cities in Fujian are consistent with that from the province. While there were variations for the effects of diurnal temperature range, relative humidity and sunshine duration, which may be related to

Table 2

Description of daily meteorological factors in Fujian Province, China, 2005–2013.

	MIN	P <sub>5</sub>	P <sub>50</sub>	P <sub>95</sub>	MAX	Mean(SD)
Precipitation (mm)	0.00	0.00	0.82	22.02	69.26	4.54(8.36)
Mean atmospheric pressure (hPa)	958.03	974.01	984.15	995.15	1001.55	984.27(6.76)
Mean wind velocity (m/s)	1.08	1.47	2.06	3.21	5.64	2.16(0.54)
Mean temperature (°C)	1.56	7.04	20.36	28.65	29.99	19.27(7.01)
Diurnal temperature range (°C)	1.87	3.43	8.19	13.53	18.30	8.20(3.07)
Mean vapor pressure (hPa)	2.90	6.93	17.68	28.61	30.82	18.21(7.50)
Mean relative humidity (%)	36.50	60.58	76.65	90.82	96.82	76.48(9.22)
Sunshine duration (h)	0.00	0.00	4.41	9.94	11.76	4.62(3.39)

MIN: minimum level of variable, P<sub>5</sub>: the 5th percentile of variable, P<sub>50</sub>: the 50th percentile of variable, P<sub>95</sub>: the 95th percentile of variable, MAX: the maximum level of variable, SD: standard deviation.

**Table 3**  
Spearman’s correlation coefficients between daily meteorological factors and mumps case counts.

	P	MAP	MWV	MT	DTR	MVP	MRH	SD
MAP	−0.425*							
MWV	0.036*	0.139*						
MT	0.202*	−0.866*	−0.128*					
DTR	−0.675*	0.012	−0.241*	0.152*				
MVP	0.415*	−0.894*	−0.152*	0.953*	−0.051*			
MRH	0.798*	−0.248*	−0.138*	0.018	−0.694*	0.287*		
SD	−0.613*	−0.170*	−0.132*	0.410*	0.856*	0.192*	−0.704*	
Mumps case counts	0.139*	−0.221*	−0.052*	0.114*	−0.069*	0.154*	0.139*	−0.033

P: precipitation, MAP: mean atmospheric pressure, MWV: mean wind velocity, MT: mean temperature, DTR: diurnal temperature range, MVP: mean vapor pressure, MRH: mean relative humidity, SD: sunshine duration.

\*  $P < 0.05$ .

differences of the meteorological and social factors between the four cities and the province as a whole.

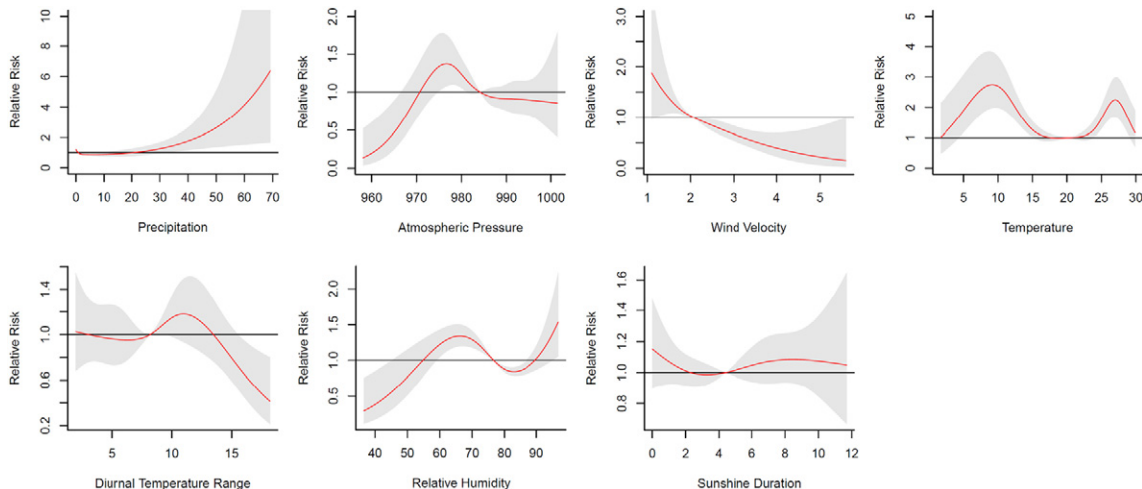
Our results about the effects of temperature and relative humidity on mumps incidence are consistent with the results of a study in Guangzhou, China (Yang et al., 2014a), that the minimum level of temperature and maximum level of relative humidity could increase the risk of mumps. However, our result on temperature is different from the results of studies conducted in Taiwan and Jining, China (Ho et al., 2015; Li et al., 2016). They showed that the risk increased with temperature increasing. The discrepancy may result from the methodologies. We used a non-linear function to simulate the effect of temperature, whereas the studies in Taiwan and Jining used linear function and linear function with thresholds separately. The effect of temperature on infectious diseases transmitted by respiratory or alimentary tract has been discovered to be non-linear (Huang et al., 2016; Yang et al., 2014b), so the result of this research may be much closer to the true effect of temperature.

The non-linear effect of temperature is biologically plausible. A laboratory investigation using the guinea pig as model host shows that cold and dry conditions help the spread of influenza virus aerosol (Lowen et al., 2007). Considering that influenza virus and mumps virus are all lipid enveloped, the conclusion of this laboratory investigation may explain our finding in some degree. It supports our result that low temperature has more adverse effect than high temperature. In terms of relative humidity, the lab results were different from ours. This could be due to they only assessed the influence of relative humidity at a constant temperature of 20 °C, while the temperature in our study ranging from 1.56 °C to 29.99 °C. Furthermore the mumps virus transmission among population was much more complicated than that in laboratory, which could be one of the reasons for the result from the laboratory were different from these population-based research.

Even though the results on temperature and relative humidity of this study are similar to those of the study in Guangzhou, the results about atmospheric pressure and wind velocity were different (Yang et al., 2014a). Given only few researchers exploring the effects of atmospheric pressure and wind velocity on the incidence of mumps, we compared our result with studies about other infectious diseases. A study explored the relationship between meteorological factors and the incidence of HFMD (Wang et al., 2016), and found that in the area including Fujian Province, the association between atmospheric pressure and the disease is positive and that of wind velocity is negative, which was consistent with our results. Whereas another research showed no effect of atmospheric pressure on HFMD (Zhao et al., 2017). Considering that the occurrence of mumps is clustered and half of the mumps patients are students, the high atmospheric pressure and low wind velocity may increase the virus concentration in a certain classroom by hindering the airflow, particularly in winter, and then increase the incidence of mumps (Morawska, 2006; Wei and Li, 2016).

For sunshine duration, we found that the minimum level of sunshine duration could increase the risk of mumps. Among all the literatures we searched, only the research conducted in Jining, China referred to the effect of sunshine duration on the incidence of mumps (Li et al., 2016), and the result is discordant to ours. While an experimental study shows that air disinfection using 254 nm UV-C can inactivate viral aerosols (Walker and Ko, 2007) and 254 nm UV-C is contained in sunlight. As a result, high level of sunshine duration may do more harm to the virus and decrease the incidence of mumps, which is consistent with our result.

Due to the lack of relative research and biological evidence, the effect of precipitation and diurnal temperature range may be explained by the correlation with other meteorological factors. There is a strong and



**Fig. 4.** Cumulative effects of meteorological factors on mumps within 30 lag days. The median values of meteorological factors was selected as references.

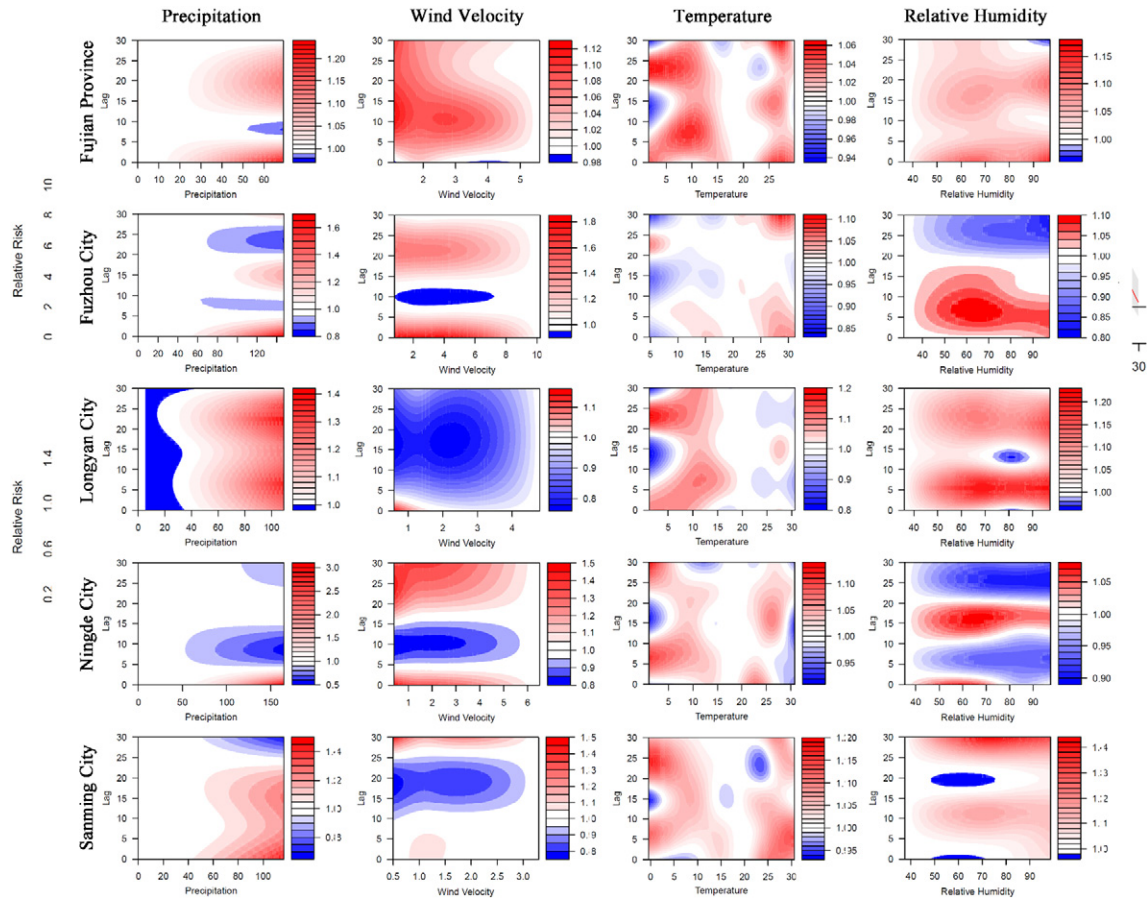


Fig. 5. Contour plots of relative risks of meteorological factors on mumps within 30 lag days. Meteorological factors include precipitation, wind velocity, temperature and relative humidity.

positive correlation between precipitation and relative humidity in this study, so high level of precipitation and relative humidity may occur simultaneously and increase the incidence of mumps, the same as diurnal temperature range and sunshine duration.

In this study, the largest separate effect of each meteorological factor occurred at the maximum or minimum variable values. The maximum or minimum values of variables generally represent the extreme weather conditions that help the virus development and transmission. For example, low wind velocity and high atmospheric pressure can increase the virus concentration in a certain room by hindering the airflow (Morawska, 2006; Wei and Li, 2016) and low sunshine duration will do less harm to the virus (Walker and Ko, 2007), as mentioned before. Furthermore, immune status and behavior pattern of individual may change in extreme weather conditions. A study shows that the drop in

core body temperature can impair immune function and further increase the chance of infection (Polderman, 2004), which may explain, at some degrees, why the risk of mumps peaks in extreme low temperature condition.

The effects of meteorological factors may last several days as indicated in the DLNM analyses of this study. This may be related to the incubation of the disease, which is about 15 to 24 days (Richardson et al., 2001). When the individual exposures to an unfavorable weather condition, the risk of being attacked by mumps virus increase, but the individual may develop into disease after a few day because of the incubation of the disease. It is noteworthy that sunshine duration can affect the incidence of mumps on the specific lag day, but there are not statistically significant cumulative effects within 30 lag days. Meanwhile, although other meteorological factors have statistically significant cumulative effects within 30 lag days, their separate effects along lag days are fluctuating, even turn into protective factors from risk factors in some days. These phenomena can be observed in many studies, especially those used the DLNMs (Limper et al., 2016; van Gaalen et al., 2017). They can be explained by “short-term displacement” or “harvesting effect”, which means that a raised risk ratio at short lags is followed by an apparently protective effect at longer lags (Bhaskaran et al., 2013). Vulnerable population has an earlier onset of mumps than usual time when adverse weather condition occurs, and vulnerable population decreases in the following days so that the incidence decreases.

The result of this study may explain, in some degree, the seasonal pattern of mumps. For precipitation, the highest level of variable value has the maximum separate effect and cumulative effect on mumps. During study period, the average daily precipitation in May and July was 9.28 mm and comparatively higher than other months (3.59 mm). These also applied to atmospheric pressure and relative

**Table 4**  
The largest separate and cumulative effects of meteorological factors and corresponding variable values in Fujian Province, China. (Taking the lowest effect values as references).

Variable	Separate effect			Cumulative effect	
	Maximum RR(95%CI)	Variable value	Lag	Maximum RR(95%CI)	Variable value
P	1.23 (1.11–1.37)	69.2 mm	0	7.40 (1.82–30.19)	69.2 mm
MAP	1.33 (1.16–1.53)	1001.5 hPa	0	10.02 (2.47–40.71)	976.7 hPa
MWV	1.12 (1.02–1.24)	1.1 m/s	12	12.45 (1.40–110.78)	1.1 m/s
MT	1.06 (1.02–1.07)	1.6 °C	23	2.78 (2.06–3.76)	9.2 °C
DTR	1.11 (1.04–1.19)	1.9 °C	0	2.86 (1.30–6.26)	11.0 °C
MRH	1.18 (1.07–1.30)	96.8%	0	5.24 (1.78–15.38)	96.8%
SD	1.02 (1.01–1.04)	0 h	0	1.17 (0.89–1.52)	0 h

P: precipitation, MAP: mean atmospheric pressure, MWV: mean wind velocity, MT: mean temperature, DTR: diurnal temperature range, MRH: mean relative humidity, SD: sunshine duration.



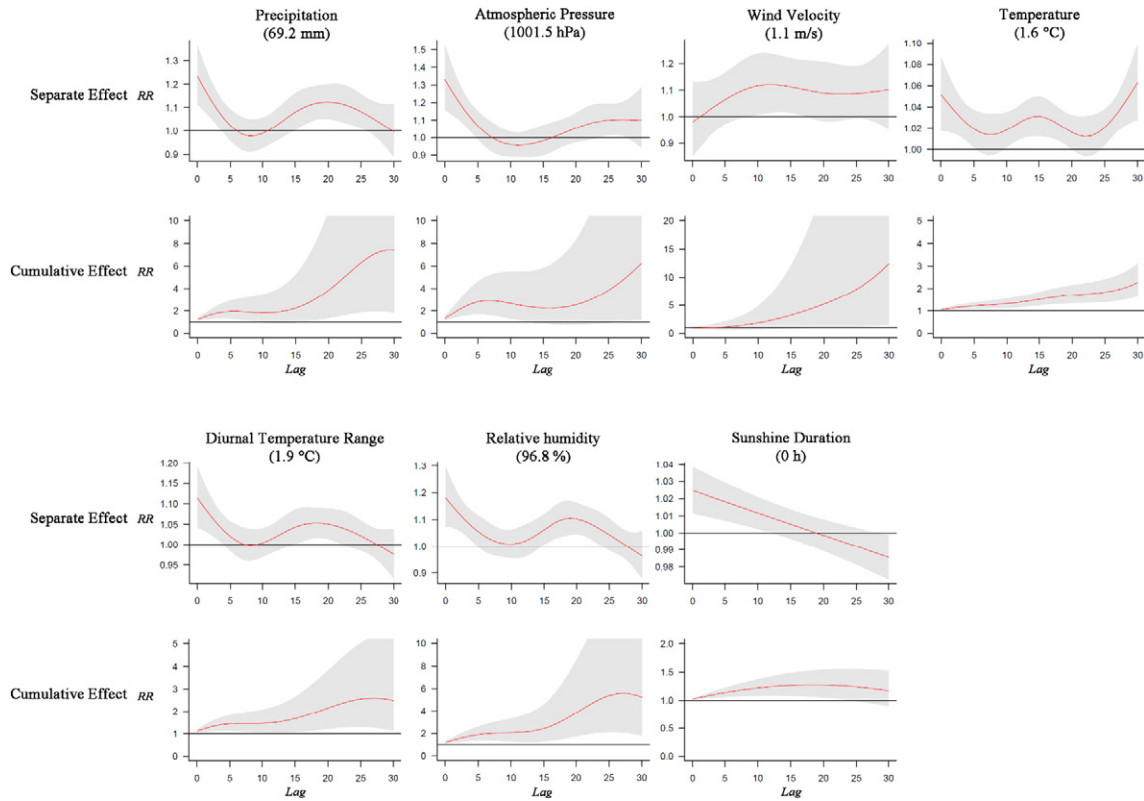


Fig. 6. Separate and cumulative effects within 30 lag days of the specific variable values of meteorological factors corresponding to the maximum separate effects.

humidity. Low level of atmospheric and high level of relative humidity can increase the risk of mumps. These two factors are much lower or higher in high epidemic months than other months (978.46 hPa vs 985.46 hPa, 80.82% vs 75.65%), indicating the seasonable distribution of the disease could be due to the weather pattern.

In subgroup analysis, we found that low and high temperatures could increase the incidence of mumps in most subpopulations. It further indicated the non-linear effect of temperature. We also found that cold effect (5th percentile of temperature) was much more severe than hot effect (95th percentile of temperature) when we take the median as reference. The research in Guangzhou (Yang et al., 2014a) used another strategy to define cold effect as the effect of the 1st percentile of

temperature compared with the 10th percentile and found that extremely cold temperature was a protective factor in some populations.

This is the first study in Fujian Province, China, using DLNM approach to assess the impact of meteorological variables on the mumps incidence, and has several strengths. Firstly, we explored the effect of seven meteorological factors on the incidence of mumps, including diurnal temperature range, and minimize the impact from the multicollinearity. Secondly, both separated and cumulated effects were examined, with considering the lagged effect. Thirdly, the non-linear effects were identified, with both low and high end values for each meteorological variable were examined. Fourthly, the most vulnerable sub-populations were identified. All

Table 5  
The largest separate effect and cumulative effect of temperature in subpopulations.

Variables	Separate effect			Cumulative effect	
	Maximum RR(95%CI)	Temperature	Lag	RR(95%CI) (P5)	RR(95%CI) (P95)
Total	1.06 (1.02–1.07)	1.6	23	2.49 (1.75–3.55)	1.78 (1.22–2.61)
Gender					
Male	1.06 (1.04–1.09)	9.1	7	2.52 (1.67–3.79)	1.84 (1.19–2.86)
Female	1.10 (1.03–1.17)	1.6	22	2.47 (1.44–4.23)	1.68 (0.94–3.01)
Age (years)					
0–4	1.06 (0.97–1.16)	29.9	0	1.21 (0.60–2.46)	2.42 (1.19–4.94)
5–9	1.08 (1.05–1.11)	9.4	7	2.61 (1.53–4.47)	1.41 (0.79–2.51)
10–14	1.15 (1.02–1.30)	1.6	0	6.58 (3.43–12.64)	2.18 (1.04–4.55)
15–29	1.21 (1.07–1.36)	29.9	0	1.54 (0.63–3.78)	2.06 (0.78–5.46)
≥30	1.07 (0.85–1.33)	1.6	30	0.22 (0.06–0.79)	0.55(0.15–2.05)
Occupation					
Scattered children	1.10 (0.99–1.22)	29.9	0	1.42 (0.59–3.41)	4.13 (1.79–9.54)
Nursery children	1.10 (1.04–1.16)	26.1	0	2.09 (1.04–4.18)	1.40(0.69–2.85)
Students	1.08 (1.04–1.13)	26.9	30	4.27 (2.65–6.87)	1.69 (0.98–2.91)
Workers	1.03 (0.98–1.08)	26.2	15	0.32 (0.13–0.79)	0.83 (0.33–2.10)

P<sub>5</sub>: the 5th percentile of temperature, P<sub>95</sub>: the 95th percentile of temperature.

these findings will provide solid scientific evidence for health authorities for their designing and implementing public health intervention strategies.

The limitations of this study should be acknowledged. Firstly, even though the National Notifiable Disease Surveillance System is a mature system, there are under reporting including mumps cases. Secondly, similar to most ecological studies, we used the meteorological information to analyze instead of individual exposure condition, and it will bring bias to our result. Thirdly, the information of meteorology for analysis is the arithmetic average level of Fujian Province, instead of spatial average of meteorological variables. Arithmetic average is less specific than spatial average. To improve this limitation, we have conducted DLNM analysis in four cities of the province to strengthen our conclusions.

## 5. Conclusions

All meteorological factors in this study are associated with the incidence of mumps and the relationships are non-linear. Therefore,

relevant public health intervention strategies should be developed to different seasons, and immunization program should be promoted, especially the most vulnerable groups such as teenagers and young adults.

## Conflict of interest

The authors declares that they have no conflict of interest.

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## Appendix A. Appendices

**Table A.1**

Description of daily meteorological factors and mumps cases count in four cities of Fujian Province.

	Fuzhou City		Longyan City		Ningde City		Sanming City	
	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
Precipitation (mm)	0.00	147.35	0.00	109.10	0.00	165.03	0.00	116.70
Mean atmospheric pressure (hPa)	974.20	1026.50	960.50	1003.90	945.10	997.30	958.5	1002.6
Mean wind velocity (m/s)	0.75	10.20	0.58	4.80	0.33	6.50	0.50	3.30
Mean temperature (°C)	4.80	31.25	1.17	30.64	0.97	30.83	-0.45	30.60
Diurnal temperature range (°C)	1.10	14.95	1.50	22.50	1.08	18.32	1.25	23.20
Mean vapor pressure (hPa)	3.25	33.55	2.83	30.77	2.80	30.73	3.12	31.05
Mean relative humidity (%)	31.50	97.50	36.00	97.33	35.40	97.40	37.50	98.75
Sunshine duration (h)	0.00	12.40	0.00	12.10	0.00	12.47	0.00	12.05
Mumps cases counts	0.00	27.00	0.00	44.00	0.00	32.00	0.00	34.00

**Table A.2**

The largest separate effects of meteorological factors and corresponding variable values in Fuzhou and Longyan.

Variable	Fuzhou City			Longyan City		
	Maximum effect (RR(95%CI))	Variable value	Lag	Maximum effect (RR(95%CI))	Variable value	Lag
P	1.69 (1.18–2.43)	147.3 mm	0	1.41 (1.07–1.85)	109.1 mm	22
MAP	1.11 (0.77–1.62)	994.0 hPa	30	1.92 (1.33–2.78)	1003.9 hPa	30
MWV	1.84 (1.07–3.17)	0.8 m/s	0	1.15 (0.78–1.68)	0.6 m/s	0
MT	1.10 (1.01–1.20)	28.7 °C	30	1.19 (1.06–1.34)	1.2 °C	23
DTR	1.16 (1.04–1.29)	3.3 °C	23	1.13(0.97–1.32)	10.0 °C	30
MRH	1.10 (0.95–1.27)	64.6%	7	1.22 (1.07–1.40)	97.3%	5
SD	1.03 (1.00–1.06)	0 h	30	1.05 (1.00–1.11)	12.1 h	0

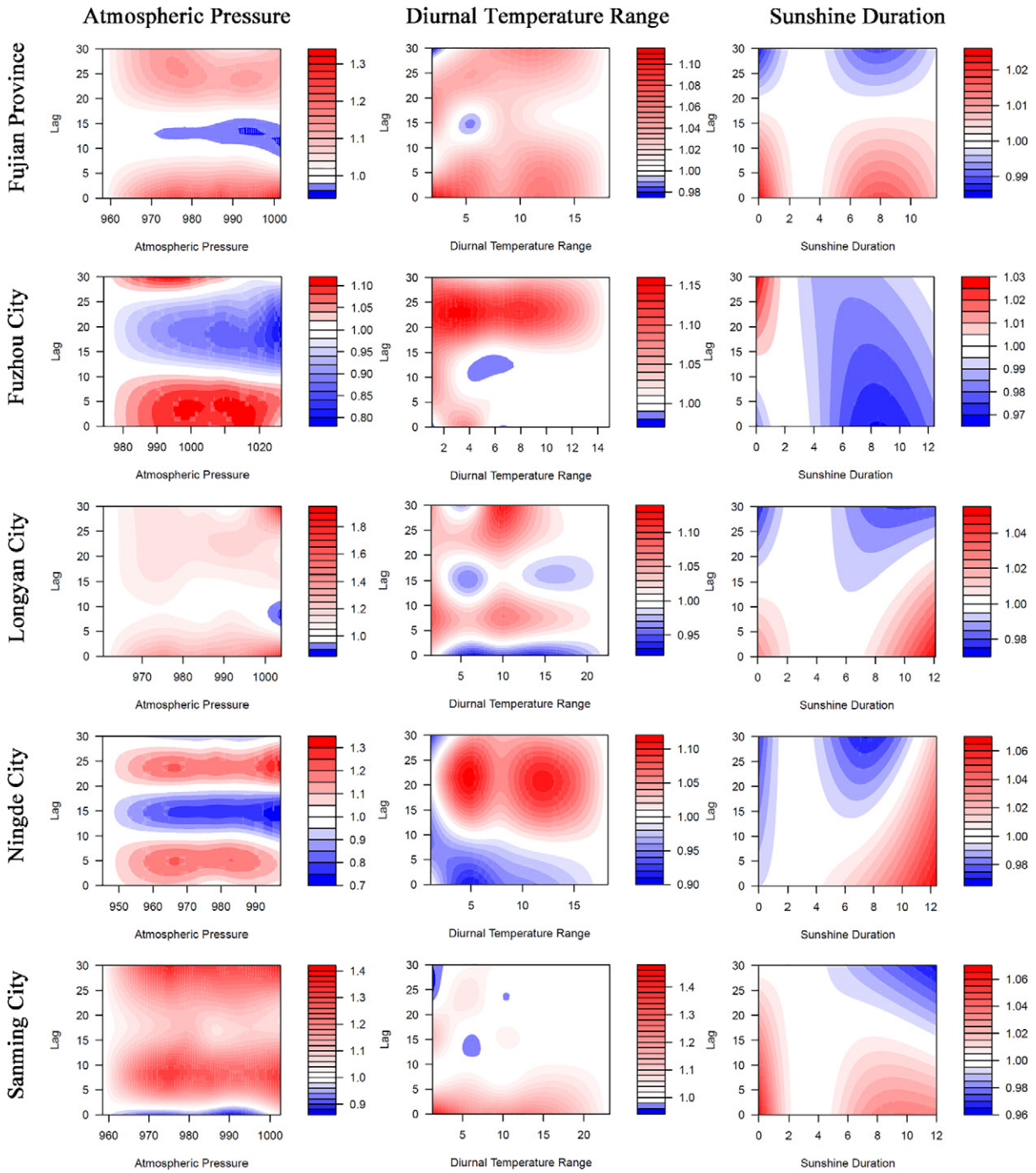
P: precipitation, MAP: mean atmospheric pressure, MWV: mean wind velocity, MT: mean temperature, DTR: diurnal temperature range, MRH: mean relative humidity, SD: sunshine duration.

**Table A.3**

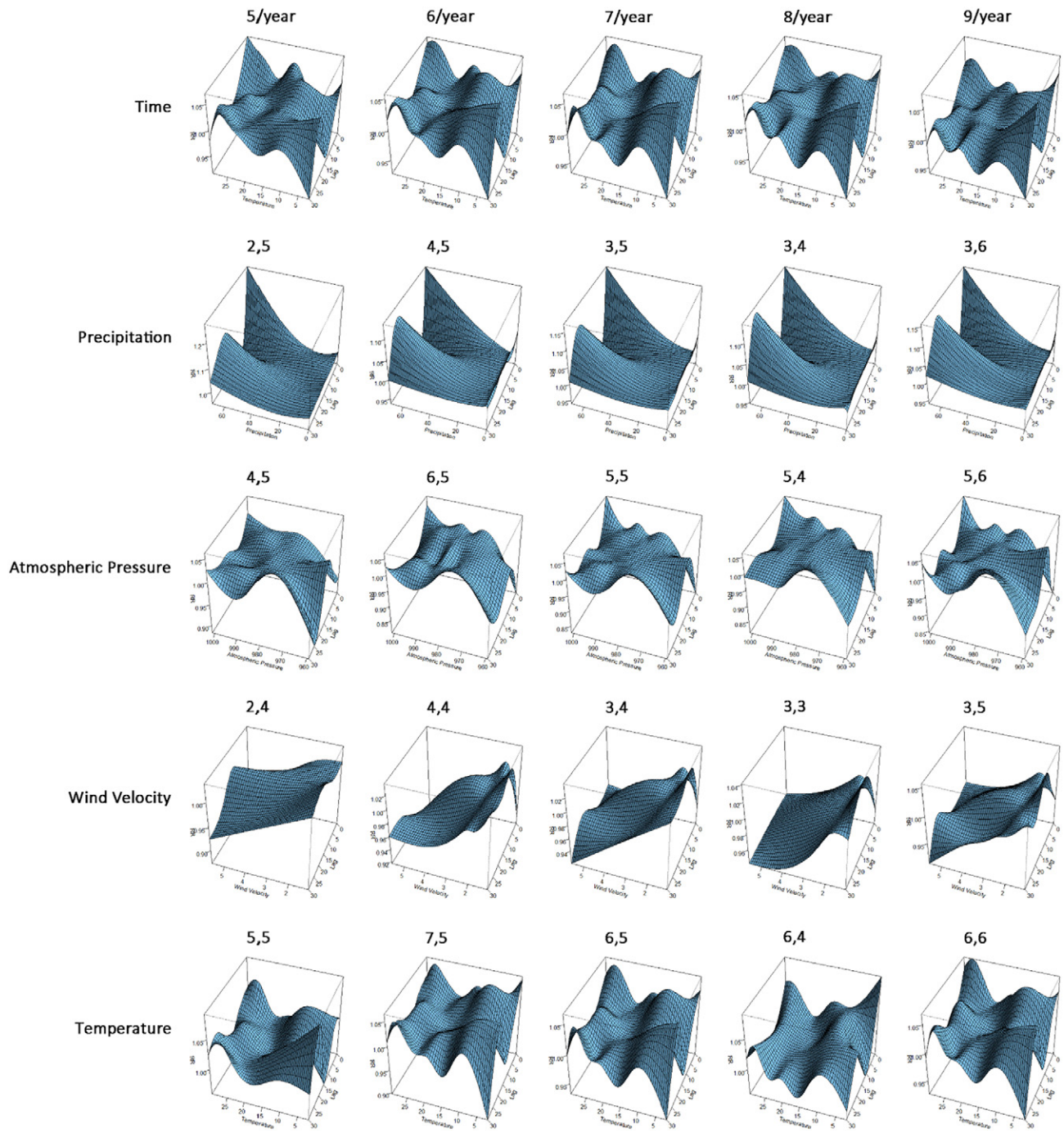
The largest separate effects of meteorological factors and corresponding variable values in Ningde and Sanming.

Variable	Ningde City			Sanming City		
	Maximum effect (RR(95%CI))	Variable value	Lag	Maximum effect (RR(95%CI))	Variable value	Lag
P	3.05 (1.81–5.13)	165.0 mm	0	1.46 (1.08–1.98)	116.7 mm	0
MAP	1.33 (1.01–1.76)	997.3 hPa	24	1.40 (0.92–2.14)	1002.6 hPa	30
MWV	1.47 (0.88–2.44)	0.4 m/s	0	1.46 (1.13–1.89)	0.5 m/s	30
MT	1.14 (0.98–1.32)	1.0 °C	30	1.19 (1.08–1.32)	-0.4 °C	24
DTR	1.12(1.01–1.24)	4.8 °C	22	1.47(1.22–1.77)	1.3 °C	0
MRH	1.08 (0.98–1.19)	65.9%	16	1.44 (1.09–1.89)	73.3%	30
SD	1.07 (1.02–1.12)	12.4 h	0	1.07 (1.03–1.11)	0 h	0

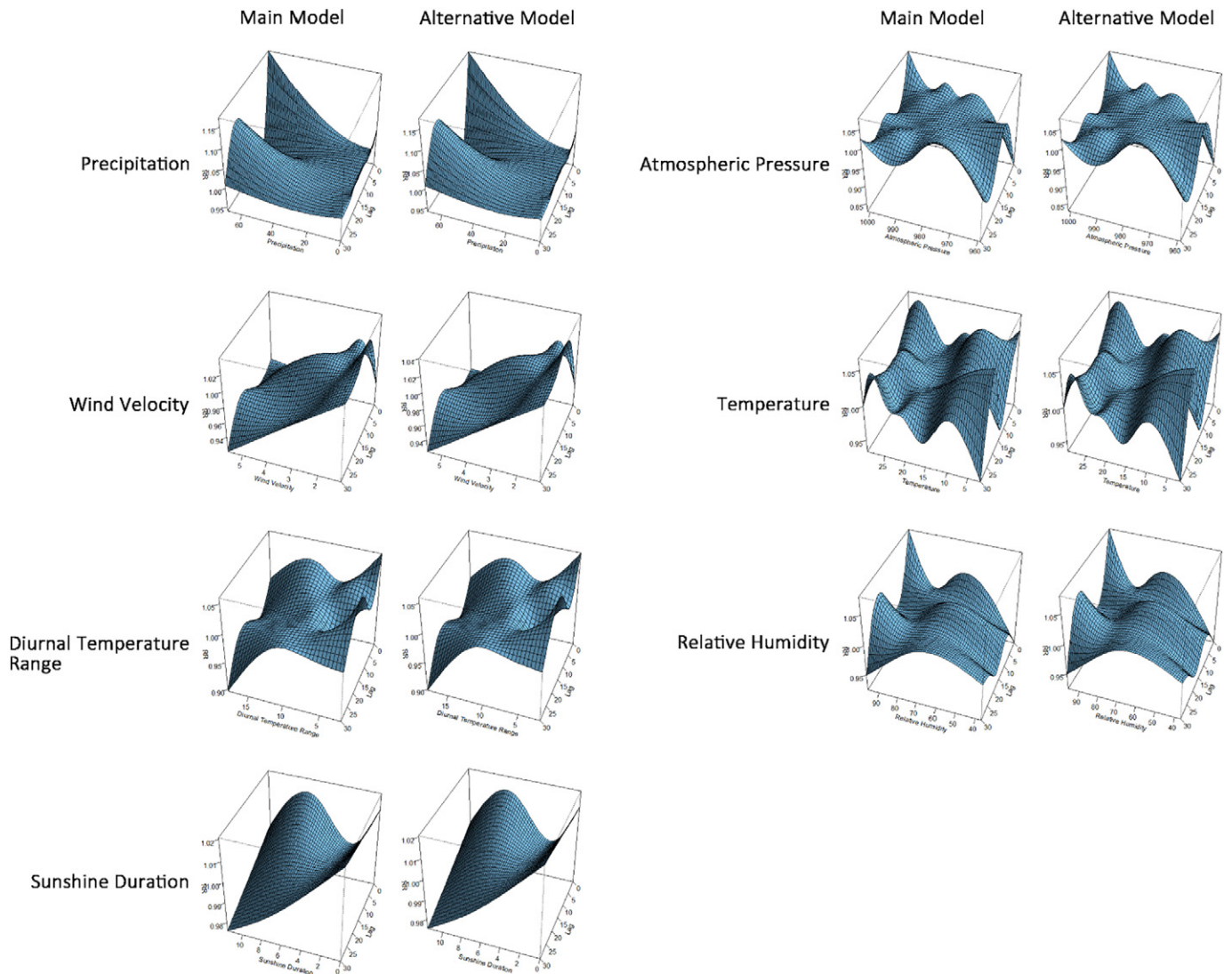
P: precipitation, MAP: mean atmospheric pressure, MWV: mean wind velocity, MT: mean temperature, DTR: diurnal temperature range, MRH: mean relative humidity, SD: sunshine duration.



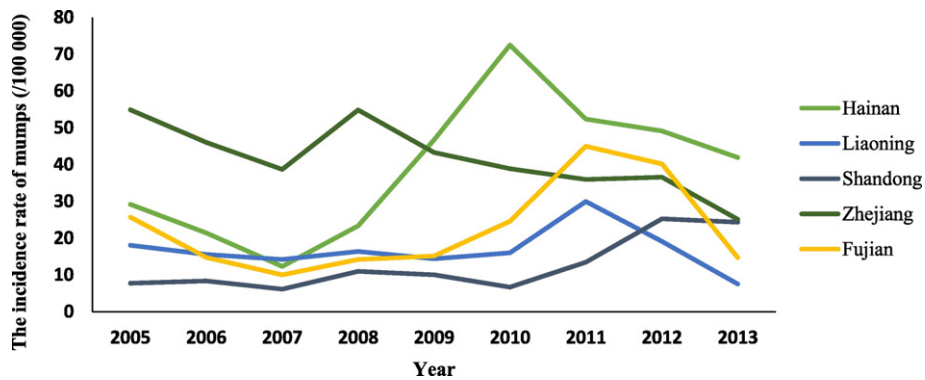
**Fig. A.1.** Contour plots of relative risks of meteorological factors on mumps within 30 lag days. Meteorological factors include atmospheric pressure, diurnal temperature range and sunshine duration.



**Fig. A.2.** Results of sensitive analysis by changing the degree of freedom of long-term trend and seasonality and changing the degrees of freedom of meteorological factors and corresponding lags. The parameters above each 3D plot mean the degrees of freedom used in DLNM. The 3D plot in the middle of each line represents the result of main model and the rest represent the result of alternative model. There is a vacancy for sunshine duration because the model is invalid when the degree of freedom is 1.



**Fig. A.3.** Results of sensitive analysis by using the alternative model. The alternative model contains two added items: Vaccine and Diagnosis, denotes the MMR being taken into immunization program in Fujian since 1st January 2008 and the changes of diagnostic criteria of mumps since 15th October 2007.



**Fig. A.4.** The annual incidence rates of mumps in 5 provinces in China, 2005–2013.

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