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A weather-resolving index for assessing the impact of climate change on tourism related climate resources

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Abstract This study develops and tests a Modified Climate Index for Tourism (MCIT) utilizing more than 50 years of hourly temperature, wind and significant weather data from contrasting climatic regions, Florida and Alaska. The index measures climate as a tourism resource by combining several tourism-related climate elements. It improves previous methods by incorporating variables that are more relevant to tourism activities, by addressing the overriding nature of some conditions, and by incorporating hourly observations rather than simple daily averages. The MCIT was tested using hourly weather observations from King Salmon, Alaska and Orlando, Florida. The results show that average temperature alone is not sufficient to represent tourism climate resources. For example, at both the Florida and Alaskan sites, showers and thunderstorms are more limiting factors than temperature during much of the year. When applied to past climate data, the proposed MCIT generates meaningful results that capture tourism-related climate variations and trends, including (a) the increasingly favorable tourism conditions in Alaska due to a lengthening of the warm season and (b) a decrease of ideal climatic conditions in central Florida due to the increased summer temperatures. Thus, the index has the potential to become a useful quantitative tool to be used in conjunction with climate models to

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predict the nature and magnitude of the impact of anticipated climate changes on tourism.

1 Introduction

Climate change is one of the major environmental issues facing the world today. The ongoing global warming has had and will continue to have serious impact on natural environments (ACIA 2004; IPCC 2007). The impact of climate change on the natural environment is manifested in changes in geography, landscape and ecosystems (e.g., Bindoff and Willebrand 2007; Parmesan 2006; Hoegh-Guldberg et al. 2007). For example, the glaciers in the Blackfoot–Jackson Glacier Basin of Glacier National Park, Montana, decreased in area from 21.6 km^2 in 1850 to 7.4 km^2 in 1979 (Hall and Fagre 2003). The sea level has been rising since 1880 with an average rate of 1.6 mm/year (Bindoff and Willebrand 2007). Lakes are shrinking and forests are moving northwards (Smith 2005; ACIA 2004). Ecological changes in distribution of plants and animals are occurring in all well-studied marine, freshwater, and terrestrial groups (Parmesan 2006). Some of these impacts are directly relevant to the tourism industry. Tourism destinations, especially nature-based destinations, rely heavily on resources such as mountains, beaches, forests, and so forth. Some of these destinations are facing a serious reduction in attractiveness or even threats to their existence due to retreating mountain glaciers, the rise of sea level, and the redistribution of species (Tagliabue 2006; Phillips and Jones 2006; Hawkins and Porter 2003).

These potential consequences of global warming are expected to have a considerable impact on tourism. As tourist activities are very sensitive to climate change, the anticipated changes in climate patterns and consequently in the climate assets of tourism destinations are expected to influence tourist destination selection, tourism activity participation, tourism demand, and tourism seasonality (Scott et al. 2004, 2007; Lise and Tol 2002; Scott and Jonesa 2006; Hall and Higham 2005). Qualitative studies have indicated that climate is an important factor when choosing a destination (Lohmann and Kaim 1999), and these studies were supported by Hamilton and Lau's (2005) survey-based findings that climate is a main consideration of tourists in the choice of a destination. In particular, a changing climate pattern can create both new constraints and new opportunities for tourism-related outdoor recreation (Scott et al. 2005; UNWTO 2007; Becken and Hay 2007; Scott and McBoyle 2007). For example, it was suggested that low-altitude ski resorts face economic challenges due to less snowfall and shorter skiing seasons (Koenig and Abegg 1997; Scott et al. 2006; OECD 2006), while arctic regions will stand to gain as their summer season is likely to be lengthened (Pagnan 2003). However, empirical research on quantifying the impact of climate change on tourism demand remains limited, most likely due to the multifaceted nature of climate and the complex ways in which climate elements combine to shape the weather conditions that affect tourism (de Freitas et al. 2004). The purpose of this study is to devise and test a quantitative tool for measuring climate as a tourism resource. In this respect, the study is a step toward needed quantification of the very general statements in recent climate impact assessment reports that tourism is likely to be impacted by climate change (e.g., IPCC 2007; ACIA 2005, p. 1003). The tool presented here will utilize multivariate information at high temporal resolution, thereby bridging the weather that tourists experience in practice and the climate information that is generally represented by averages.

The paper is organized as follows. Section 2 reviews studies on the relationship between weather, climate, and tourism. Section 3 discusses the latest developments in the measurement of climate resources for tourism use, introduces an improved tourism climate index, and considers the ways it can be used for in-depth analysis. Section 4 illustrates the use of the index with data from two locations that are geographically very different. Conclusions, implications, limitations, and avenues of future research are discussed in Section 5.

2 Weather, climate, and tourism

Climate affects tourism critically along with other natural resources such as geography, landscape, and other attractions of the destination. Climate can directly affect tourism in many ways. First, atmospheric conditions impact tourist participation and experiences. Pleasant weather increases tourist satisfaction, whereas severe weather conditions such as rain, strong winds, fog and dust storms disrupt outdoor activities. In southern Alaska, for example, tour operators noted a marked difference between the sunny, dry summer of 2004 and wet summer of 2006. Revenues were down because visitors were less likely to go on marine tours or hikes in soggy conditions after departing cruise ships (Institute of Social and Economic Research 2007).

Smith (1993) and Matzarakis (2001) suggest that the weather parameters affecting tourists' comfort and safety include air temperature, humidity, radiation intensity, wind speed and direction, cloud cover, sunshine duration, and precipitation. de Freitas (2003) classifies climate according to its thermal, physical, and aesthetic aspects. The thermal aspect incorporates air temperature, humidity, wind, and solar radiation. The physical aspect includes rain and wind, while the aesthetic aspect relates to sunshine or cloud conditions. Hamilton and Lau (2005) found that while temperature is a dominant attribute, 91% of the respondents indicated that more than one tourism-related climate attribute is of significance. de Freitas et al. (2004) showed that within a broad range of "non extreme" thermal conditions, several different factors are important in determining the pleasantness rating of a given climate condition. For example, the non-thermal elements of rain, high wind, and low visibility have considerable impact on tourists' satisfaction. It is also widely recognized that extreme weather events like floods, excessive heat, and windstorms, affect human life and environments more than changes in the mean climate (Leckebusch et al. 2002). For example, strong winds, floods, hurricanes, and severe thunderstorms threaten the health and safety of tourists (Greenough et al. 2001).

Second, weather and climate play important roles in destination selection. Tourists are sensitive to climate and to climate change (Maddison 2001; Hamilton and Lau 2005; Bigano et al. 2006a). Climate is one important component which shapes a destination image (Lohmann and Kaim 1999) and climate is one of many factors that influence tourist decisions on where to go and when to go, although good weather may not be the primary reason for selecting destinations (Giles and Perry 1998). Hamilton and Lau (2005) confirmed that climate is at least the third most popular attribute in decision making and moreover, climate is the most popular for the tourists in their survey.

Third, climate is one important factor that causes the seasonality of tourism, as does the school holiday schedule. Climate change is likely to change tourism seasonal pattern in the long run. The seasonal pattern in the Mediterranean region is expected to shift from the current summer peak to a two-shoulder pattern (Amelung et al. 2007). Studies also show that the projected impact of climate change on the ski season is serious (McBoyle and Wall 1992; OECD 2007). For example, results of a snow-cover simulation model show that a 2°C warming in the Alpine region of Austria will cause a 47–49% reduction of the old snow cover and a larger reduction of the number of skiing days (Breiling and Charamza 1999).

All these impact of weather and climate on tourism could ultimately impact tourism demand. The statistical model of Scott et al. (2007) projected that annual visitation in the Weston Lakes National Park would increase between 6% and 10% in the 2020s, between 10% and 36% in 2050s and between 11% and 60% over current baseline condition under different climate change scenarios (ranging from the scenario of least change to the warmest scenario). Results of the general equilibrium model of Bigano et al. (2006b) show that climate change would shift patterns of tourism towards high latitudes and altitudes. Domestic tourism may double in colder countries and fall by 20% in warmer countries relative to the baseline without climate change. International tourism may treble in some countries while it may be cut in half in others.

3 Research methods

One methodological challenge in assessing the impact of climate change on tourism demand is the measurement of tourism climate resources. A common approach to modeling the sensitivity of tourism demand to climate change is to use average temperature to represent climate resources (Bigano et al. 2005; Hamilton et al. 2005). For example, studies by Lise and Tol (2002) and Maddison (2001) correlated average temperature and precipitation with tourists' flow. Both studies found a nonlinear relationship between tourism demand and temperature, and the existence of an ideal temperature for tourism. Other researchers suggest that additional weather parameters should not be ignored (Gossling and Hall 2006). According to de Freitas (2003) climate data expressed as an average has no psychological meaning, as tourists respond to their immediate integrated weather environment rather than climatic averages. Moreover, as weather and climate are multifaceted, climate elements should be combined in an appropriate way to form a measure of tourism-related weather conditions (de Freitas et al. 2004). Accordingly, a climate index approach has been suggested to represent the multifaceted nature of climate resources by integrating several tourism related climate elements into a single index.

Researchers have developed several methods to integrate the various tourism related climate variables into a single index (Paul 1972; Yapp and McDonald 1978; Mieczkowski 1985; de Freitas et al. 2004). Using weights, Mieczkowski (1985) linearly combined various sub-indices to form a 'Tourism Climate Index' (TCI). These sub-indices included daytime comfort, daily comfort, precipitation, sunshine and wind, with a heavier weight (40%) placed on the daytime comfort. The sub-indices were based on seven climate variables, including *monthly means* of maximum daily temperature, mean daily temperature, minimum daily relative humidity, mean daily relative humidity, total precipitation, total hours of sunshine, and average wind speed. Utilizing this index, Amelung and Viner (2006) examined the potential change of seasonal tourism patterns under different climate change scenarios in the Mediterranean region.

Scott et al. (2004) modified Mieczkowski's (1985) TCI by replacing the 'effective temperature' with a 'heat index' as the measure of thermal comfort. While noted for its comprehensive nature and its applicability to general tourism activities, the TCI is not without limitations. The index combines its sub-indices linearly with unequal weights. It is based on the assumption that the effect of individual weather elements are additive while some are more important than other. Attempting to overcome this limitation, de Freitas et al. (2004) devised the 'Climate Index for Tourism' (CIT), integrating three conceptual attributes of climate for tourism and outdoor recreation, namely thermal, physical, and aesthetic. The nonlinear nature of the CIT addresses the overriding effect of the physical aspect of weather. de Freitas et al. (2004) report that a preliminary survey, which was conducted in a beach setting, shows that stated satisfaction ratings of the sample group approximated the theoretical satisfaction ratings.

Most application of CIT or TCI are at global or region scale (Scott et al. 2004; Amelung et al. 2007). Scott et al. (2004) explored the spatial and temporal patterns of the tourism climate resources in North America with their modified TCI. Amelung et al. (2007) examined the potential change of seasonal tourism patterns under different climate change scenarios in the Mediterranean region with Mieczkowski (1985)'s original TCI. They found that the locations of climatically ideal tourism conditions are likely to shift poleward under projected climate change and that the seasonal pattern in the Mediterranean region is expected to shift from the current summer peak to a two-shoulder pattern.

Previous TCI and the CIT are developed based on daily averages or extremes, which preclude the capture of the short-term variability that can profoundly affect tourist activities. For example, an average temperature of 70°F may be ideal for outdoor sightseeing, but a substantial fraction of the hours in a day may be sufficiently hot or cold that sightseeing is a much less enjoyable experience that it is at the average temperature of 70°F. Similarly, there is a tremendous range of possibilities for the nature of precipitation, especially its temporal distribution. If a daily total of several inches of precipitation occurs during a few brief but heavy showers or thunderstorms, then the vast majority of the day is free of precipitation, making sightseeing much more viable than if the same amount of precipitation fell at a slow steady rate throughout the day. To overcome this limitation and broaden the application of tourism climate index in climate impact assessment, we have developed an MCIT (modified CIT) with multivariate properties and high temporal resolution. This MCIT could provide in depth examination and assessment on the impact of climate change on specific tourism activity at a particular location.

3.1 The MCIT

The modified index introduced in this study includes three fundamental changes aimed at facilitating the assessment of climate resources as they pertain to specific tourism activities.

Different climate elements Two tourism-related climate elements, visibility and significant weather (e.g., rain, lightning, hail, and snow), that can impair the tourists' experiences were added to the index, while other elements, such as sunshine and clouds, have been removed. Our reasoning for the omission of clouds is that, while clouds and sunshine may impact tourists' satisfaction, they are less likely to determine whether the tourism activity will take place or not. By contrast, rain, lightning and poor visibility can preclude many tourist activities, including sightseeing.

Three levels The sub-indices and the final, aggregated index were scaled into three categories: unsuitable, marginal and ideal (0, 1, and 2 respectively) replacing the seven levels used in previous versions of the index. This reflects the importance of the occurrence of particular weather conditions for a specific tourism activity.

Hourly data The modified index uses hourly data instead of average data because hourly data contain the temporal specificity that allows assessments of suitability of a day's weather for tourist activities. For example, daily precipitation data do not suffice when evaluating the appropriateness of the conditions for outdoor tourism activity because the rain's intensity, timing and duration are not apparent in a daily total. A total precipitation measure of 1 inch could be the consequence of one hour of heavy rain or 10 hours of lighter rain. These two temporal distributions are likely to have considerably different impacts on outdoor tourism activities. For example, despite an hour of intense rain, many activities may still be feasible for tourists during the rest of the day. Also, rain prior to 6 A.M. or after 8 P.M. is less likely to influence outdoor tourism activities because most activities take place during daytime. In addition, hourly figures better reflect the influence of extreme temperature or wind on tourism activities. Finally, information on severe weather events such as thunderstorms and blowing dust is not reported in daily data but is available in hourly reports.

The final index is based on four sub-indices, derived from four key weather variables: perceived temperature, wind, visibility, and significant weather. Perceived temperature combines temperature, relative humidity, and wind elements. It is represented by the Wind Chill Index in the winter (temperature $< 50°$F) and by the Heat Index during the summer (Rauber et al. 2005). Low or high perceived temperature is uncomfortable and can be harmful to tourists. High wind and low visibility can considerably degrade tourist satisfaction and affect their safety when the tourism activity takes place outdoors. Significant weather categorizes present weather conditions coded from 0 to 99 as shown in Appendix. Its potential impact is based on the safety or satisfaction of tourists. Category 1 ($\mathrm{MCITsw} = 0$) includes rain, snow, thunderstorms, and severe dust and sand storms that are likely to hamper outdoor tourism activities. Category 3 ($\mathrm{MCITsw} = 2$) includes weather elements that are appropriate for outdoor tourism activities. The rest of the conditions (category 2) have a minor impact.

Each sub-index is scaled to three levels according to certain thresholds, which attempt to capture the favorability of the conditions for outdoor tourism activities (e.g., the visibility index is 0 if visibility is less than 1.0 km). In practice, these activity-specific thresholds could be determined by industry experts or from surveys of tourists. Table 1 contains a set of thresholds for an outdoor summer tourism

Table 1 Scaling criteria for the sub-indices

	Perceived temperature ($\mathrm{MCIT_{PT}}$) (°F)	Wind ($\mathrm{MCIT_W}$) (mph)	Visibility ($\mathrm{MCIT_V}$) (km)	Significant weather ($\mathrm{MCIT_{SW}}$)
0	< 20 or >95	> 20	< 1	9,17,19,25,26,27,28,29, 32,35,36,37,38,39,46, 47, >51 and <100
1	≥ 20 and <40, or >85 and ≤ 95	≥ 13 and ≤ 20	≥ 1 and ≤ 4	6,7,8,15,16,18,20,21,22,23, 24,30,31,33,34,40,41,42, 43,44,45,48,49,50,51
2	≥ 40 and ≤ 85	< 13	> 4	0, 1,2,3,4,5,6, 10,11,12,13,14

activity such as sightseeing. These criteria were adopted throughout this paper for illustration purpose only; since the categorization was not validated through a user survey or other formal procedure, it should not be used to assess the suitability of climate resources for an arbitrary choice of tourism activities. Rather, we stress that the thresholds and cutoffs can be modified to fit any activities for which a user can provide reasonable weather-related thresholds for tourist involvement.

To account for the overriding nature of these weather elements, MCIT is set to 0 when any of the four sub-indices is 0, and is set to 2 only when all sub-indices are 2. The MCIT ranges from 0 to 2, where 0 denotes unsuitable conditions for tourism, 1 denotes marginal conditions, and 2 ideal conditions. Formally, the structure of MCIT is

$$\mathrm{MCIT} = \begin{array}{lll} 0 & \text{if} & \prod_x \mathrm{MCIT}_x = 0 \\ 1 & \text{if} & 0 < \prod_x \mathrm{MCIT}_x < 16 \\ 2 & \text{if} & \prod_x \mathrm{MCIT}_x = 16 \end{array} \tag{1}$$

where x can represent PT, W, PW or V; MCIT denotes the combined hourly index; $\mathrm{MCIT_{PT}}$, $\mathrm{MCIT_W}$, $\mathrm{MCIT_{SW}}$, and $\mathrm{MCIT_V}$ are hourly sub-indices for perceived temperature, wind, significant weather, and visibility respectively (Fig. 1).

3.2 Applications of the MCIT

This hourly index can be used in a wide range of tourism-related climate applications. The annual, monthly, and hourly occurrence frequency of certain MCIT (and MCIT_x) values can be used to examine the overall quality of the destination's climate resource, to identify seasonal and daily patterns of variation, and to explore the impact of global warming on climate resources by examining the change of each weather or climate element over time. A daily-resolved tourism weather index is likely to outperform a climatological average measure when more weather constraints are to be considered (e.g., a minimum length of continuous ideal weather condition, or the precise length of a tourist "season"). Finally, the design of the MCIT as summarized above enables the determination of which weather element is a main obstacle or contributor to the overall suitability of a location's climate for tourism activities. The following subsections demonstrate how various integrated measures of tourism

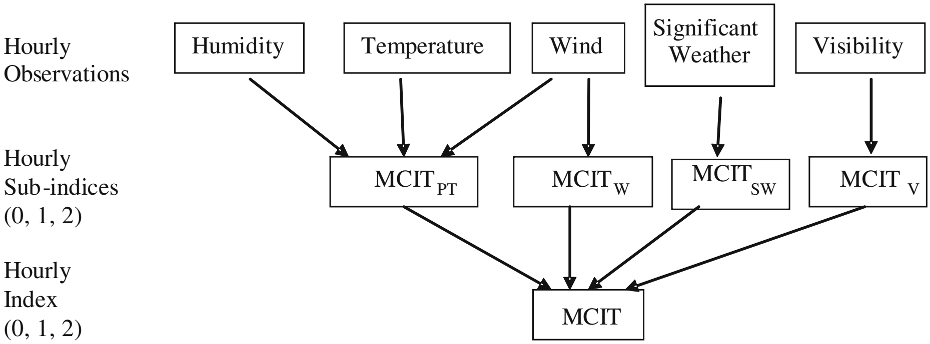

Fig. 1 From observed hourly weather elements to hourly MCIT

suitability are derived from the hourly MCIT index and sub-indices. Some examples of statistical analyses are also provided.

3.2.1 Frequency

A high frequency of ideal weather conditions (MCIT = 2) indicates that the destination possesses attractive climate resources, while a high frequency of unsuitable weather conditions (MCIT = 0) indicates limited climate resources for tourism. For an n-year period, the integrated frequency of level k, $F(k)$, is evaluated as follows:

$$F(k) = \sum_{y,m,d,h} \mathrm{MCIT}_{y,m,d,h}(k) * \frac{N}{(N-q)} \quad \mathrm{y} = 1,$$

$$n : m = 1.12;\ d = 1, d(m, y);\ h = 0, 23;\ k = 0, 1, 2 \tag{2}$$

$$\mathrm{MCIT}_{y,m,d,h}(k) = \begin{cases} 1 & \text{when } \mathrm{MCIT}_{y,m,d,h} = k \\ 0 & \text{otherwise} \end{cases}$$

where MCIT denotes the tourism climate index; y, m, d, and h denote year, month, day and hour respectively; n denotes the number of years, $d(m,y)$ denotes the number of days in month m and year y, N denotes the total number of hours, and q denotes the number of hours in which the data are missing.

The frequencies vary over several time intervals (i.e. year, month, day, and hour of the day). To examine these changing patterns, average annual, monthly, and hourly averages are computed by Eqs. 3, 4 and 5 as follows:

$$F_y(k) = \sum_{m,d,h} \mathrm{MCIT}_{y,m,d,h}(k) \times \frac{N_y}{(N_y - q_y)} \tag{3}$$

$$N_y = \sum_m d(m, y) \times 24$$

where $F_y(k)$ denotes the frequency of level k in year y, N_y denotes the number of hours in year y, and q_y denotes the number of hours in which the data is missing in year y.

$$F_m(k) = \sum_{y,d,h} \mathrm{MCIT}_{y,m,d,h}(k) \times \frac{N_m}{(N_m - q_m)} \tag{4}$$

$$N_m = \sum_y d(m, y) \times 24$$

where $F_m(k)$ denotes the frequency of level k in month m, N_m denotes the number of hours in year y, and q_m denotes the number of hours in which the data is missing in month m.

$$F_{h,m}(k) = \sum_{y,d} \mathrm{MCIT}_{y,m,d,h}(k) \times \frac{N_{m,h}}{\left(N_{m,h} - q_{h,m}\right)} \tag{5}$$

$$N_{m,h} = \sum_y d(m)$$

where $F_{h,m}(k)$ donates frequency of level k in month m, hour h, $N_{m,h}$ denotes the number of hours in month m at hour h, and $q_{h,m}$ denotes the number of hours in which the data are missing in month m at hour h. The frequencies of the sub-MCIT indices, are calculated for each level k in a similar manner.

3.2.2 Daily indices

An activity-specific daily index, which represents the weather condition during a certain time period, (i.e. 8 A.M.–7 P.M.) is derived from the hourly index as follows.

$$D_{\mathrm{MCIT}} = \begin{array}{lll} 1 & \text{if} & S \geq \mathrm{Sc} \\ 0 & \text{if} & S < \mathrm{Sc} \\ \Phi & \text{if} & Q > \mathrm{Qc} \end{array} \tag{6}$$

where D_{MCIT} denotes the daily index and S can assume different forms to better match the characteristics of the investigated tourism activity. For example, S can be an average MCIT score during a specific daytime period, the number of hours when the MCIT equals 2, or even more strictly, the largest number of consecutive hours in which the MCIT equals 2. Sc is a threshold, which is set according to the specific tourism activity. It could be set at a high level if the activity requires very good weather conditions. Q denotes the number of hours in which data is missing or incomplete. Qc is a threshold controlling for the availability of the weather data for that day. Φ can be any prescribed number serving as a flag to indicate the unavailability of sufficient data.

3.3 Statistical analysis

Linear regression models were fitted to assess the significance of observed trends and changes over time. The dependent variables were the frequencies of MCIT and the sub-index MCIT_x at each level, and the number of days with a daily index $\mathrm{D}_{\mathrm{MCIT}}$

equal to 1. Time (year) was the independent variable. The correlation between annual average temperatures and the frequency of a particular condition at an individual level provides a measure of the potential sensitivity of tourism-related climate attributes to changes in that weather condition (e.g., changes that might be driven by global warming).

4 Results

Weather observations from two destinations, King Salmon, Alaska (1943–2005) and Orlando, Florida (1953–2005, except for 1971 and 1972) were used to illustrate how the MCIT and sub-MCIT indices could be applied to measure climate as a resource for tourism. These hourly historical observation data were obtained from the National Climate Data Center (NCDC) of the National Oceanic and Atmospheric Administration (NOAA). The scaling criteria in Table 1 are used for calculating the MCIT and its sub-indices.

The frequency distribution of MCIT at three levels indicates that Orlando's tourism climate resource is more favorable than King Salmon's by the criteria in Table 1 (Fig. 2). Fifty percent of King Salmon's weather condition are unsuitable for outdoor tourism activities. Ideal weather for tourism activity is only present 18% of the time. In Orlando, the frequency of unsuitable weather conditions is less than 10%, tourists enjoy ideal weather conditions more than 60% of the time, and the frequency of marginal conditions is about 30 percent.

4.1 Weather elements affecting MCIT

The ratio of a sub-index MCIT_x (Section 3.2) to MCIT provides some indication as to the sub-index's role in affecting a certain weather condition. A higher ratio implies a larger contribution of that specific weather element to the overall index of tourism climate. As an example, we show in Table 2 the ratio of occurrences of a sub-index MCIT_x equal to 0 to the number of occurrences of MCIT equal to 0 in different months. In King Salmon, Alaska, the temperature is the main constraint on outdoor tourism activities in the winter, while rain and other "significant weather" (e.g., lightning, thunderstorms) are the main constraints during the summer season. In the case of Orlando, Florida, "significant weather" is the main constraint all year

Fig. 2 Frequency distribution of MCIT at each level

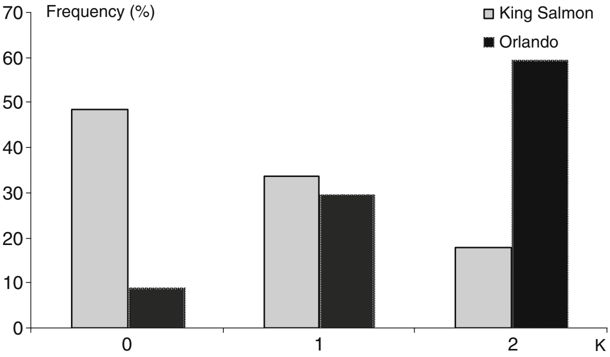

Table 2 Ratio of occurrences of sub-index $\mathrm{MCIT}_x = 0$ to occurrences of $\mathrm{MCIT} = 0$

	Month	1	2	3	4	5	6	7	8	9	10	11	12	Total
King Salmon, Alaska	$\mathrm{MCIT}_{\mathrm{PT}}$	82.4	81.6	78.5	56.1	8.8	0	0	0	3.7	53.1	76.5	83.5	43.7
	$\mathrm{MCIT}_{\mathrm{SW}}$	24	24.9	27.4	40.4	60.8	68.5	77.1	75.4	74	41.1	27	25.4	47.2
	$\mathrm{MCIT}_{\mathrm{W}}$	16.1	17.3	17.8	21.1	34	27.1	15.7	22.2	27.3	18.7	14.5	13.8	20.5
	$\mathrm{MCIT}_{\mathrm{V}}$	3.5	3.1	2.8	3.6	6.7	12	14.3	12.3	6.4	4.1	5	4.1	6.5
Orlando, Florida	$\mathrm{MCIT}_{\mathrm{PT}}$	3.6	0.4	0.3	0	2.5	12.5	26.0	26.2	11.7	0.9	0	1.8	7.1
	$\mathrm{MCIT}_{\mathrm{SW}}$	49.9	57.2	61	62.5	74.6	81.1	72.4	71	81.8	75.9	58.4	52.3	66.5
	$\mathrm{MCIT}_{\mathrm{W}}$	15.6	21.5	28.3	23.6	11	5.5	3.2	3.2	6.8	13.3	12.8	9	12.8
	$\mathrm{MCIT}_{\mathrm{V}}$	33.2	23.8	14.1	16.6	14.7	5.4	2.8	3.8	4.6	13.5	31.4	39.2	16.9

long. Other elements such as high winds and low visibility in the winter, and high temperature in the summer, also negatively affect the suitability of tourism weather conditions at Orlando, although to a lesser extent than precipitation and related events.

4.2 Trends over time

In the following sections, we present results both for "frequencies" of MCIT values (ideal, marginal, unsuitable) defined by Eqs. 1–5 and for the occurrences of "suitable days" defined by Eq. 6. The former are generally based on all hourly reports, while the latter are based on the consolidation of the hourly reports into the daily classifications.

The annual frequency of the ideal and unsuitable tourism weather conditions varies over time and across sites (Fig. 3). The year-to-year variation of ideal conditions at King Salmon is smaller than Orlando. There is an increase in the

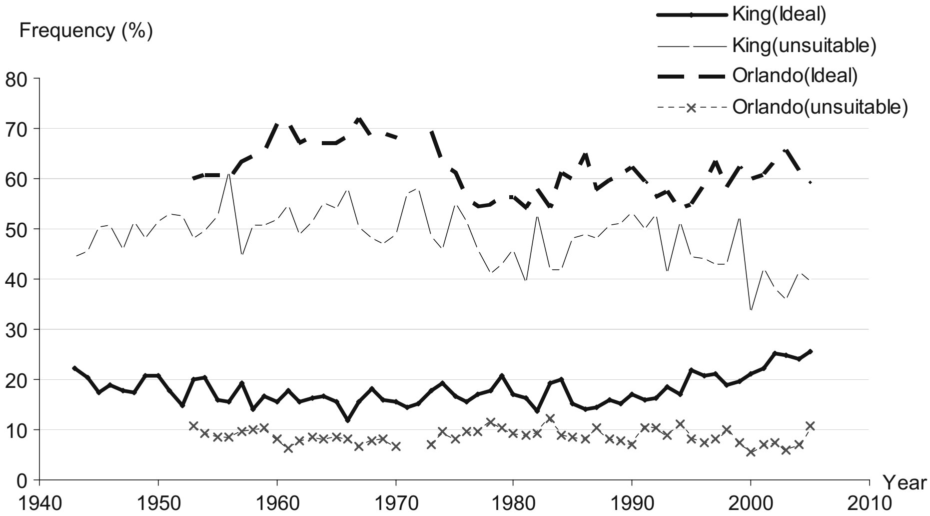

Fig. 3 Annual frequency of the ideal and unsuitable tourism weather conditions in King Salmon, Alaska and Orlando, Florida

frequency of the ideal conditions in Alaska (especially after 1990), and a decrease in the frequency of the unsuitable conditions. These changes arise mainly from the warming during spring, as shown in Sections 4.3 and 4.4. The frequency of ideal conditions in Florida decreases over time, with a peak during the 1960s (about 60%) and with lower values after 1970. As shown below, this decreasing trend is due mainly to more frequent occurrences of perceived summer temperatures (heat indices) above 95°F (cf. Table 1).

Figure 4 displays the variations of the number of days per year that satisfy a specific requirement (cf Eq. 6), i.e., the number of days in which MCIT = 2 for at least five consecutive hours (between 8 A.M. to 7 P.M.). This condition may be considered as an example of a prerequisite for a day to be considered appropriate for certain types of outdoor tourism activities. In Orlando there were around 180 such days a year during the 1960s and the 1970s. The number has decreased considerably in the last three decades to around 120 days a year. At King Salmon, Alaska, the number of such days was around 50 from the 1960s through the 1980s. This number increased in recent years, reaching 100 days a year. The trends revealed in Fig. 4 are similar to the patterns of Fig. 3, adding valuable information for tourism management.

As shown in Table 3, both the increasing trend of ideal tourism weather conditions and the decreasing trend of unsuitable tourism weather conditions in Alaska are statistically significant. The changes in the frequency of ideal and unsuitable conditions vary by calendar month and region. Some spring and summer months show significant increases in good tourism weather conditions, while some winter and spring months show significant decrease in unfavorable tourism weather conditions.

In Florida, the decrease in the annual frequency of ideal conditions is statistically significant. The frequency of ideal conditions for tourism has decreased over time in most months, especially during summer and autumn. However, the trend of unsuitable conditions is less significant than at King Salmon and inconsistent across months: the summer months (June through August) show significant increases, other months have experienced decreases. The trend of suitable days (D1 and D2) for tourism activities is similar to the change in the pattern of the frequency of the ideal

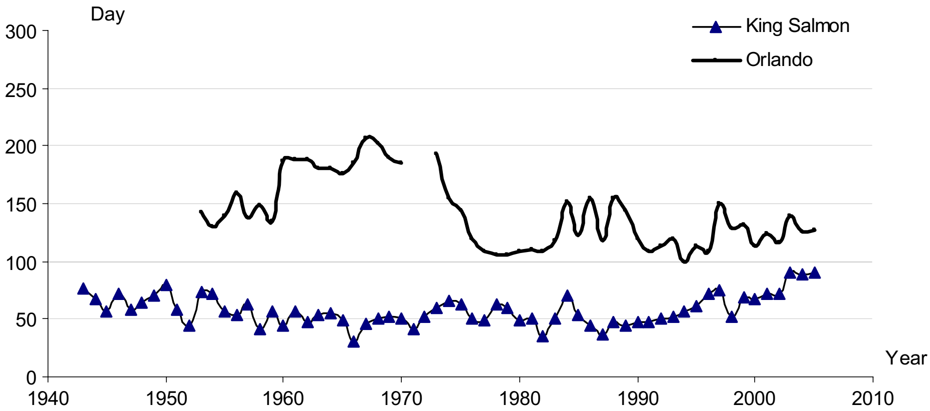

Fig. 4 Number of days (at least five consecutive hours between 8 A.M. and 7 P.M.) per year in King Salmon, Alaska and Orlando, Florida

Table 3 Regression coefficients for the time- (year-) dependence of the dependent variables

	Dep. variable	1	2	3	4	5	6	7	8	9	10	11	12	Annual
Alaska	Temp	0.25*	0.25	0.32**	034**	0.34**	0.24	0.34**	0.28*	0.12	−0.04	0.12	0.29*	0.50**
	MCIT(2)	–	–	0.19	0.29*	0.24	0.22	0.15	0.35*	0.06	0.19	–	–	0.30*
	MCIT(0)	−0.22	−0.38**	−0.40**	−0.26*	−0.29*	−0.19	−0.03	−0.23	−0.0	0.02	−0.10	−0.30*	−0.47*
	D1	–	–	–	0.24	0.14	0.13	0.05	0.17	–	–	–	–	0.22
	D2	–	–	–	0.23	0.08	0.03	0.0	0.13	–	–	–	–	0.12
Florida	Temp	0.11	0.20	0.21	0.09	0.19	0.26	0.37**	0.29*	0.32*	0.35*	0.28*	0.15	0.46**
	MCIT(2)	0.01	−0.04	−0.24	−0.27	−0.30*	−0.45**	−0.69**	−0.47**	−0.47**	−0.41**	−0.27	−0.01	−0.42**
	MCIT(0)	−0.33*	−0.26	−0.15	−0.17	−0.39**	0.29*	0.35*	0.32*	−0.13	−0.16	−0.05	−0.21	−0.13
	D1	−0.14	−0.13	−0.40**	−0.33*	−0.36*	−0.41**	−0.57**	−0.47**	−0.43**	−0.54**	−0.32*	−0.2	−0.56**
	D2	−0.03	−0.11	−0.44**	−0.39**	0.39**	−0.43**	−0.46**	−0.43**	−0.38**	−0.57**	−0.42**	−0.25	−0.54**

Number in () indicates index level

D1: cumulated hours (MCIT = 2) ≥ 5; D2: maximum consecutive hours (MCIT = 2) ≥ 5

$^{**}p < 0.01$, $^{*}p < 0.05$

conditions. However, there are noticeable differences. In King Salmon, Alaska, the increase is significant in April only while in Orlando Florida, the negative trend is significant for all months from March to November. Overall, the quality of weather conditions for tourism has been increasing in Alaska while it has been decreasing in Florida. Both locations have warmed in recent decades (IPCC 2007). Thus the opposite trends of favorable weather conditions for tourism show the importance of placing the impacts of climate variations into a geographical context. The results further imply that global warming will have widely varying impacts on different destinations, providing opportunities for some and challenges for others.

4.3 Seasonality

The ideal and unsuitable weather conditions exhibit strong seasonal patterns (Fig. 5). The frequency of ideal weather conditions in Alaska is maximum in the summer and low in winter. Conversely, ideal conditions in Florida are lowest in summer. Moreover, Florida's seasonality is not as strong as that of Alaska.

Table 4 shows the number of days suitable (by the D1 and D2 measures) for tourism by calendar month. Although the seasonal patterns are similar to the frequency of the ideal conditions, there are noticeable differences when these measures are used. The seasonal patterns of the number of suitable days are stronger, and the difference between King Salmon and Orlando in terms of suitable of days in the summer season is larger, when measured by D1 and D2. The explanation lies in the different time period used in the calculation of the frequency of suitable days. The measures of frequency (MCIT = 2 and MCIT = 0) are calculated for all hours (0–23) of the day, while the suitable day measures (D1 and D2) consider the weather

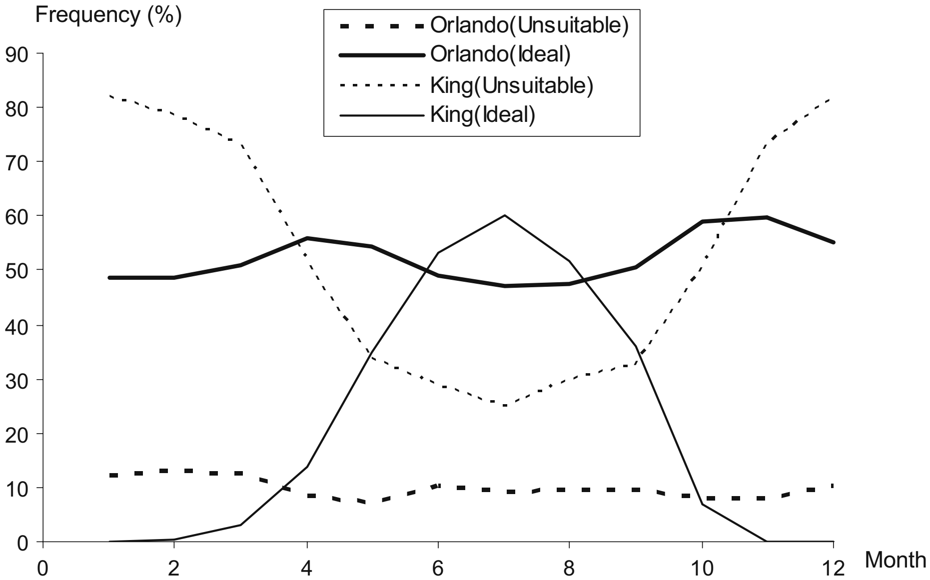

Fig. 5 Seasonal frequency patterns of MCIT (2) and MCIT (0) for Orlando, Florida and King Salmon, Alaska

Table 4 Number of days suitable for tourism in Orlando, Florida and King Salmon, Alaska

		1	2	3	4	5	6	7	8	9	10	11	12	Total
Alaska	D1	0	0.1	0.3	2.2	9.4	16.6	19.5	16.4	11.9	2.1	0.1	0	76.2
	D2	0	0.1	0.2	1.7	6.8	13	15.2	12.4	8.8	1.5	0.1	0	57.9
Florida	D1	22.7	19.7	20.9	20.4	15.3	6.7	4.2	4.2	7.3	20.6	24.5	24.7	191.1
	D2	19	15.2	14.6	12.9	7.8	3.3	2.6	2.7	4.8	15.3	21	22.2	141.6

D1: cumulative hours (MCIT $= 2$) ≥ 5; D2: the largest number of consecutive hours a day (MCIT $= 2$) ≥ 5

conditions during a specific time period (8 A.M. to 7 P.M. in our example). This latter period is generally the warmer part of the day, so D1 and D2 are more sensitive to the high temperatures. Given that typical tourism activities occur mostly during daytime, the D1 and D2 values provided in Table 4 may have more practical applications for the tourism industry.

4.4 Diurnal cycle

Figure 6 contrasts the daily cycles of ideal climate condition at Orlando, Florida during the four seasons. The patterns suggest that daily frequencies differ not only among locations, but also across seasons, that the daily variation in the summer is much larger than that of the other three seasons, and that the frequency of ideal tourism weather conditions between 10 A.M. and 7 P.M. is very low, especially during summer. This diurnal cycle is a manifestation of the afternoon peak of showers/thunderstorms ($\mathrm{MCIT_{SW}}$ in Table 1) and high afternoon temperatures (Heat Index values frequently exceeding 95°F) that characterize Orlando's climate and hence limit the attractiveness of outdoor sightseeing activities during the mid-day and afternoon hours. The corresponding graph for King Salmon, Alaska (not shown) has the opposite tendency, with the greatest frequency of ideal conditions

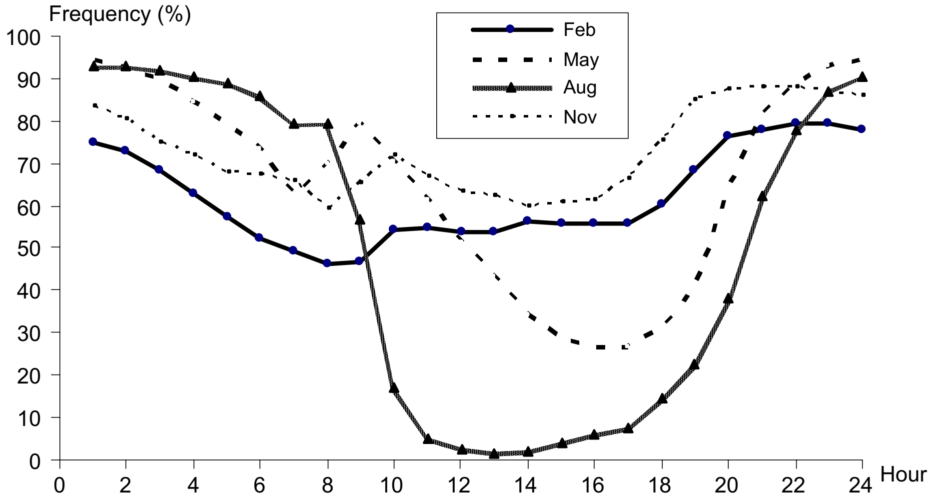

Fig. 6 Daily variation pattern of frequency of MCIT(2) in Orlando, Florida

Table 5 Correlation coefficients—annual frequencies of various climate conditions vs, average temperature (monthly, annual)

	Dep. variable	1	2	3	4	5	6	7	8	9	10	11	12	Annual
Alaska	MCIT(2)	0.33**	0.27*	0.44**	0.71**	0.78**	0.74**	0.50**	0.37**	0.43**	0.71**	0.32*	0.11	0.45**
	MCIT(0)	−0.90**	−0.91**	−0.87**	−0.90**	−0.53**	−0.46**	−0.40**	−0.20	0.15	−0.82**	−0.90**	−0.90**	−0.83**
	D1	–	0.15	0.32**	0.58**	0.66**	0.54**	0.47**	0.36**	0.18	0.63**	0.23	0.10	0.36**
	D2	–	0.01	0.28**	0.55**	0.60**	0.55**	0.41*	0.40	0.10	0.48**	0.22	0.09	0.23
Florida	MCIT(2)	0.54**	0.35**	0.09	−0.05	−0.62**	−0.74**	−0.75**	−0.86**	−0.72**	−0.26	−0.12	0.17	−0.33**
	MCIT(0)	0.11	−0.14	−0.32*	−0.04	−0.16	0.15	0.40*	0.56**	−0.02	−0.11	0.21	−0.08	0.10
	D1	0.46**	0.23	0.20	−0.04	−0.69**	−0.77**	−0.67**	−0.71**	−0.73**	−0.45**	−0.03	0.08	−0.48**
	D2	0.55**	0.10	−0.05	−0.20	−0.59**	−0.69**	−0.47**	−0.56**	−0.65**	−0.39**	−0.14	0.01	−0.49**

Number in () indicates index level

D1: cumulative hours (MCIT = 2) ≥ 5; D2: the largest number of consecutive hours a day (MCIT = 2) ≥ 5

$^{**}p < 0.01$, $^{*}p < 0.05$

(MCIT = 2) during the afternoon hours. This cold-limited tourism of King Salmon contrasts with the heat-limited tourism climate of Orlando.

4.5 Correlation between MCIT and average temperature

Correlation analysis between the frequency of the MCIT (at the 0 and 2 levels) and the corresponding average monthly and annual temperature confirms that the change in tourism climate conditions is highly correlated with climate warming, and that location is a mediating factor. Table 5 indicates that in Alaska, ideal weather conditions for tourism have significant positive correlation with the average monthly temperature during all months except for the winter, while unsuitable conditions have significant negative correlations with temperature during all months except August and September. The correlations are strongest from April to June for ideal conditions and during October–April for unsuitable condition. The correlation between average temperature and the number days suitable (by the D1 and D2 measures) for tourism activity is significant only from April to July, and in October. For Orlando, the sign of the correlation between the frequency of the ideal and unsuitable conditions and the average temperature varies from month to month. The frequency of the ideal condition is negatively correlated with the average temperature from May to September, and positively correlated in January and February. Conversely, the correlation between the frequency of unsuitable conditions and the average temperature is significantly positive from July to August, but significantly negative in March. The correlation between suitable days for tourism activity and average temperature is significantly negative from May to October, but positive in January.

These results imply that global warming will enhance tourism weather conditions in Alaska during the entire year, with the most improvement occurring in late spring and during summer months. For Orlando, while the influence of global warming on the quality of tourism climate conditions is negative overall (cf. the “annual” column in Table 5), there are substantial differences among seasons. Tourism conditions can be expected to deteriorate in summer, but to become more favorable in some winter months.

5 Discussions and conclusions

The proposed hourly-based index combines various weather elements in an attempt to better capture the dependence of outdoor tourism activities on climate and climate change. The empirical findings of this study support the use of a tourism-related climate index to assess the impact of climate change on tourism. Average temperature alone is not sufficient to represent the tourism climate condition. For example, severe weather and strong winds have a stronger impact than temperature in central Florida (Orlando). This supports the notion that an integrative weather/climate index is preferred to a measure based on a single element.

The proposed tourism index improves previous attempts to quantify tourism-related climate conditions. It includes weather elements more relevant to tourism activities, it addresses the overriding nature of some elements (e.g., visibility, precipitation), and it uses hourly weather data instead of the traditional aggregated daily figures. As was demonstrated here, this modified hourly index with its sub-indices and high temporal resolution is sufficiently flexible that it enables more comprehensive and robust analyses than would be possible with daily- or monthly-derived indices. Various statistics derived from the hourly index and sub-indices can be used to quantify trends of ideal and unsuitable tourism climate condition, seasonal and daily distributions, and the role of individual weather elements in shaping the combined tourism index.

While most applications of previous indices are on global or region scale (Scott et al. 2004; Amelung et al. 2007), the present MCIT could provide detailed and in depth examination and assessment about the impact of climate change on specific tourism activities in a particular location. Tourists as well as tourism managers need more accurate and easily interpretable information tailored to specific activities, rather than simple monthly average temperature and rainfall that typically appear in a destination's brochures and online information sites. Specific activity-oriented climate information for the destination would be more valuable for potential tourists with diverse leisure-activity interests. As illustrated in the previous sections, an integrated weather-based climate index can provide substantial information about the optimal time to visit, the time period most suitable for a particular tourism activity, the probabilities of ideal weather for a particular timeframe, and the expected weather attributes (i.e. rain, high wind) that may impair the travel experience.

This index could also provide valuable information for destination-specific long-term planning by the tourism industry. The results show that the impact of recent global warming on climate resources for tourism varies from site to site. Warming temperatures have positive impacts on climate resources for tourism in high-latitude regions such as Alaska, but negative impacts on some regions such as Florida. Moreover, this impact varies from season to season. The improvement of weather conditions for tourism in Alaska has occurred mostly in the spring and summer seasons, especially in April and August. Weather conditions in Florida have deteriorated in the summer but improved in the winter. It is also expected that the impact of global warming on different outdoor tourism activities (e.g., sightseeing and skiing) will be very different. For example, increased frequency of ideal condition in April in Alaska implies that season appropriate for outdoor recreation may be starting earlier, while snow-related activities such as skiing and snow machining may end earlier in the spring.

The results presented here point to the feasibility of an assessment of the sensitivity tourism-related climate resource on a regional or national scale. The sample results for the two locations discussed in previous sections show that changes of climate tourism resources are already detectable and that they vary with location. Broader assessments can show which tourism regions are most susceptible to global warming and which regions are likely to gain or lose from the global warming. Such assessments can draw upon scenarios of future change from global climate models to provide information on the likely rates of future change, thereby facilitating planning and adaptation by the tourism industry.

Another direction for further exploration is the relationship between changed tourism climate conditions and tourism demand in specific tourism destinations. Future research will utilize available tourist arrival data in King Salmon Alaska and Orlando Florida to determine if the changing climate conditions have resulted in changes in tourism demand.

A major limitation of this study is that it lacks a quantitative measure of the climate-tourism associations and their economic impacts. Secondly, as noted above, the improved MCIT was tested using only two destinations. Future research will further test the proposed MCIT with data from additional locations to further the comparison with destinations that have a wider range of climate characteristics.

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Appendix

Table 6 Present weather code table

Code	Observed weather	Code	Observed weather
00	Clear sky	19	Funnel cloud(s) (Tornado cloud or waterspout)
01	Clouds generally dissolving	20	Drizzle (not freezing) or snow grains
02	State of sky on the whole unchanged	21	Rain (not freezing) not falling as shower (s)
03	Clouds generally forming	22	Snow not falling as shower(s)
04	Visibility reduced by smoke	23	Rain and snow or ice pellets not falling as shower(s)
05	Haze	24	Freezing drizzle or freezing rain not falling as shower(s)
06	Widespread dust in suspension in the air	25	Shower of rain
07	Dust or sand is under developed near the station	26	Shower of snow or rain
08	Well developed dust or sand whirl(s)	27	Shower of hail
09	Dust storm or sandstorm within sight	28	Fog or ice fog
10	Mist	29	Thunderstorm
11	Patches of shallow fog or ice fog	30	Slight or moderate dust storm (decreasing)
12	More or less continuous shallow fog or ice fog	31	Slight or moderate dust storm (no change)
13	Lightning visible, no thunder heard	32	Slight or moderate dust storm (increasing)
14	Precipitation within sight, not reaching the ground	33	Severe dust storm or sandstorm (decreasing)
15	Precipitation within sight, reaching the ground	34	Severe dust storm or sandstorm (no change)
16	Precipitation within sight, but not at the station	35	Severe dust storm or sandstorm (increasing)
17	Thunderstorm, but no precipitation	36	Slight or moderate drifting snow (low than eye level)
18	Squalls	37	Heavy drifting snow (low than eye level)

Table 6 (continued)

Code	Observed weather	Code	Observed weather
38	Slight or moderate blowing snow (high above eye level)	65	Rain, not freezing, continuous heavy
39	Heavy blowing snow generally (high above eye level)	66	Rain, freezing, slight
40	Fog or ice fog	67	Rain, freezing, moderate or heavy
41	Fog or ice fog in patches	68	Rain or drizzle and snow, slight
42	Fog or ice fog, sky visible (thinner)	69	Rain or drizzle and snow, moderate or heavy
43	Fog or ice fog, sky invisible (thinner)	70	Intermittent fall of snowflakes, slight
44	Fog or ice fog, sky visible (no change)	71	Continuous fall of snowflakes, slight
45	Fog or ice fog, sky invisible (no change)	72	Intermittent fall of snowflakes, moderate
46	Fog or ice fog, sky invisible (thicker)	73	Continuous fall of snowflakes, moderate
47	Fog or ice fog, sky invisible (thicker)	74	Intermittent fall of snowflakes, heavy
48	Fog, depositing rime, sky visible	75	Continuous fall of snowflakes, heavy
49	Fog, depositing rime, sky invisible	76	Diamond dust (with or without fog)
50	Drizzle, not freezing, intermittent, slight	77	Snow grains (with or without fog)
51	Drizzle, not freezing, continuous, slight	78	Isolated star-like snow crystals
52	Drizzle, not freezing, intermittent, moderate	79	Ice pellets
53	Drizzle, not freezing, continuous, moderate	80	Rain shower(s), slight
54	Drizzle, not freezing, intermittent, heavy	81	Rain shower(s), moderate or heavy
55	Drizzle, not freezing, continuous, heavy	82	Rain shower(s), violent
56	Drizzle, freezing, slight	83	Shower(s) of rain and snow mixed, slight
57	Drizzle, freezing, moderate or heavy	84	Shower(s) of rain and snow mixed, moderate or heavy
58	Drizzle and rain, slight	85	Show shower(s), slight
59	Drizzle and rain, moderate or heavy	86	Snow shower(s), moderate or heavy
60	Rain, not freezing, intermittent, slight	87	Shower(s) of snow pellets or small hail, slight
61	Rain, not freezing, continuous slight	88	Shower(s) of snow pellets or small hail, moderate or heavy
62	Rain, not freezing, intermittent, moderate	89	Shower(s) of hail, slight
63	Rain, not freezing, continuous, moderate	90	Shower(s) of hail, snow pellets, moderate or heavy
64	Rain, not freezing, intermittent, heavy	91	Slight rain, thunderstorm during the preceding hour

Table 6 (continued)

Code	Observed weather	Code	Observed weather
92	Moderate or heavy rain, thunderstorm during the preceding hour	96	Thunderstorm, slight or moderate, with hail
93	Slight snow, or rain and snow mixed or hail, thunderstorm during the preceding hour	97	Thunderstorm, heavy, without hail, but with rain and thunderstorm
94	Moderate or heavy snow, or rain and snow mixed or hail thunderstorm during the preceding hour	98	Thunderstorm combined with dust storm or sandstorm
95	Thunderstorm, slight or moderate, without hail but with rain. Thunderstorm.	99	Thunderstorm, heavy, with hail

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