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Annex VI: Climatic Impact-Driver and Extreme Indices

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1 AVI.1 Introduction

2
3 This Annex provides background information on indices used within Chapter 11, Chapter 12, and the Atlas,
4 including technical details of calculation and related references.
5

6 In the climate science literature, a number of indices are used to characterize and quantify one or several
7 aspects of climate phenomena occurring due to natural variability or due to long-term changes in the system.
8 There is an extremely large number of examples. One can cite mean global climate indices, such as global
9 mean sea level rise or global surface temperature, which characterize the state of the climate system and act
10 as a shifting baseline for regional changes. One can also examine mean regional trends, for example in mean
11 springtime precipitation, which reflect large-scale patterns and alter the background conditions within which
12 episodic hazards may occur. One can also calculate indices of extremes characterizing episodic events within
13 the tail of the distributions of specific variables within their variability range, for instance the annual
14 maximal temperature at a given location or the 100-year return value of river discharge characterizing
15 extreme floods. Such extreme indices have been the subject of a number of studies and have been used to
16 characterize how climate change modifies extreme values of climate variables and subsequent impacts in the
17 IPCC Special Report on “Managing the risks of Extreme Events and Disasters to Advance Climate Change
18 Adaptation” (IPCC, 2012), as well other recent IPCC reports.
19

20 Indices can also characterize aspects of climatic impact-drivers (CIDs) (see Chapter 1 for the definition) that
21 are key to impacts and risks to society and ecosystems. Chapter 12 proposes a definition of “climatic impact-
22 driver indices” as “numerically computable indices using one or a combination of climate variables designed
23 to measure the intensity of the climatic impact-driver, or the probability of exceedance of a threshold. For
24 instance, an index of heat inducing human health stress is the Heat Index (HI) that combines temperature and
25 relative humidity (e.g., (Burkart et al., 2011; Lin et al., 2012; Kent et al., 2014)) and is used among others by
26 the US National Oceanic and Atmospheric Administration (NOAA) for issuing heat warnings”.
27

28 Climatic impact-drivers may not be related only to extremes, and therefore require a much broader set of
29 indices. For instance, the rate of coastline recession, due to sea level rise, assessed in Chapter 12, is involved
30 in the risk of damage and losses in coastal settlements and infrastructures. Mean trends and changes
31 themselves are considered throughout the report as CIDs. For instance, beyond the warming trend which has
32 a large number of consequences, changes in other indices such ‘snow season length’ is often used to study
33 economic impacts on winter tourism (Damm et al., 2017). Furthermore, (Mora et al., 2018) used a set of 11
34 very different key CID indices among which about half are related to extremes to characterize broader
35 threats to society. Section 12.3 in Chapter 12 reviews the CIDs described in the literature to characterize
36 impacts and risks, and reveal the wide variety of indices used to characterize them.
37

38 Indices are, in principle, computable from observations, reanalyses or model simulations, although it is
39 important to consider scale in comparing across datasets. For example, an extreme precipitation event has a
40 lower magnitude across a large grid cell than it would at a single station within that grid cell. In many cases,
41 CIDs are simply characterized by the exceedance of a threshold for an Essential Climate Variable (ECV).
42 For instance, the probability of crop failure dramatically increases as temperature rises above certain
43 thresholds, which may differ from one species to another (Hatfield and Prueger, 2015; Grotjahn, 2021). To
44 assess the effect of climate change on threshold-based indices (e.g., the change in the number of days with
45 maximum temperature above 35°C), a bias adjustment of model outputs should be considered where sensible
46 as model simulations can have biases compared to observations and reanalyses (Section 10.3.1.3, Cross
47 Chapter Box 10.2, 12.2).
48

49 Indices are used in many chapters of this Report: in Chapter 4 for assessing changes in the global climate, in
50 Chapter 8 for water cycle changes assessment, in Chapter 9 for oceans and the cryosphere, in Chapter 11 for
51 assessing changes in extreme conditions, and in Chapter 12 for assessing CIDs and their changing
52 characteristics due to climate change. The Atlas assesses changes in mean variables/indices (temperature,
53 precipitation and snow). The Interactive Atlas includes indices of mean changes (for temperatures,
54 precipitation, snowfall and wind) and a number of extreme indices and CIDs, allowing for flexible spatial
55 and temporal analysis of the results.

AVI.2 Extreme indices selection

In Chapter 11, extreme weather and climate events (collectively referred to as extremes) are assessed and the main focus is on extreme events over land. Since the analysis of extremes often involves the examination of the tails of the statistical distributions, a parametric or non-parametric approach can be used to define extremes. The non-parametric approach is largely adopted in most of the literature to characterize moderate temperature and precipitation extremes with shorter return periods. The Expert Team on Climate Change Detection and Indices (ETCCDI -<https://www.wcrp-climate.org/etccdi>) defined 27 indices to characterize different aspects of moderate temperature and precipitation extremes, which are described by (Frich et al., 2002; Alexander et al., 2006; Zhang et al., 2011; Donat et al., 2013; Sillmann et al., 2013), and were also extensively used in previous IPCC reports. In Chapter 11, a subset of these indices is assessed in detail (Section 11.3 and Section 11.4). For events with longer return periods (e.g., events that occur once in 20 years or even rarer), the parametric approach based on Extreme Value Theory (EVT) (Coles, 2001) is used and adopted in the literature (e.g., (Kharin and Zwiers 2000; Brown et al. 2008; Kharin et al. 2013)). These events are also assessed throughout the chapter. Aside from temperature and precipitation, the chapter also assesses indices used to characterize droughts. Table AVI.1 list the indices used.

[START TABLE AVI.1 HERE]

Table AVI.1: Table listing extreme indices used in Chapter 11

Extreme	Label	Index name	Units	Variable
Temperature	TXx	Monthly maximum value of daily maximum temperature	°C	Maximum temperature
	TXn	Monthly minimum value of daily maximum temperature	°C	Maximum temperature
	TNn	Monthly minimum value of daily minimum temperature	°C	Minimum temperature
	TNx	Monthly maximum value of daily minimum temperature	°C	Minimum temperature
	TX90p	Percentage of days when daily maximum temperature is greater than the 90th percentile	%	Maximum temperature
	TX10p	Percentage of days when daily maximum temperature is less than the 10th percentile	%	Maximum temperature
	TN90p	Percentage of days when daily minimum temperature is greater than the 90th percentile	%	Minimum temperature
	TN10p	Percentage of days when daily minimum temperature is less than the 10th percentile	%	Minimum temperature
	ID	Number of icing days: Annual count of days when TX (daily maximum temperature) < 0°C	days	Maximum temperature
	FD	Number of frost days: Annual count of days when TN (daily minimum temperature) < 0°C	days	Minimum temperature
	WSDI	Warm spell duration index: Annual count of days with at least 6 consecutive days when TX >90 th percentile	days	Maximum temperature
	CSDI	Cold spell duration index: Annual count of days with at least 6 consecutive days when TN <10 th percentile	days	Minimum temperature
	SU	Number of summer days: Annual count of days when TX (daily maximum temperature) > 25°C	days	Maximum temperature
	TR	Number of tropical nights: Annual count of days when TN (daily minimum temperature) > 20°C	days	Minimum temperature

	DTR	Daily temperature range: Monthly mean difference between TX and TN	°C	Maximum and minimum temperature
	GSL	Growing season length: Annual (1st Jan to 31st Dec in Northern Hemisphere (NH), 1st July to 30th June in Southern Hemisphere (SH)) count between first span of at least 6 days with daily mean temperature $TG > 5^{\circ}\text{C}$ and first span after July 1st (Jan 1st in SH) of 6 days with $TG < 5^{\circ}\text{C}$	days	Mean temperature
	20TXx	One-in-20 year return value of monthly maximum value of daily maximum temperature	°C	Maximum temperature
	20TXn	One-in-20 year return value of monthly minimum value of daily maximum temperature	°C	Maximum temperature
	20TNn	One-in-20 year return value of monthly minimum value of daily minimum temperature	°C	Minimum temperature
	20TNx	One-in-20 year return value of monthly maximum value of daily minimum temperature	°C	Minimum temperature
Precipitation	Rx1day	Maximum 1-day precipitation	mm	Precipitation
	Rx5day	Maximum 5-day precipitation	mm	Precipitation
	R5mm	Annual count of days when precipitation is greater than or equal to 5mm	days	Precipitation
	R10mm	Annual count of days when precipitation is greater than or equal to 10mm	days	Precipitation
	R20mm	Annual count of days when precipitation is greater than or equal to 20mm	days	Precipitation
	R50mm	Annual count of days when precipitation is greater than or equal to 50mm	days	Precipitation
	CDD	Maximum number of consecutive days with less than 1 mm of precipitation per day	days	Precipitation
	CWD	Maximum number of consecutive days with more than or equal to 1 mm of precipitation per day	days	Precipitation
	R95p	Annual total precipitation when the daily precipitation exceeds the 95th percentile of the wet-day (>1mm) precipitation	mm	Precipitation
	R99p	annual precipitation amount when the daily precipitation exceeds the 99 th percentile of the wet-day precipitation	mm	Precipitation
	SDII	Simple precipitation intensity index	mm day ⁻¹	Precipitation
	20Rx1day	One-in-20 year return value of maximum 1-day precipitation	mm day ⁻¹	Precipitation
	20Rx5day	One-in-20 year return value of maximum 5-day precipitation	mm day ⁻¹	Precipitation
Drought	SPI	Standardized Precipitation Index	months	Precipitation
	EDDI	Potential evaporation, Evaporative Demand Drought Index	months	Evaporation
	SMA	Soil moisture anomalies	months	Soil moisture
	SSMI	Standardized Soil Moisture Index	months	Soil moisture
	SRI	Standardized Runoff Index	months	Stream flow
	SSI	Standardized Streamflow Index	months	Stream flow
	PDSI	Palmer drought severity index	months	Precipitation, Evaporation
	SPEI	Standardized precipitation evapotranspiration index	months	Precipitation, Evaporation,

				Temperature
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[END TABLE AVI.1 HERE]

Some of these indices are included in the Interactive Atlas allowing further analysis (seasons, regions, baselines and future periods – using both time-slices/scenarios and global warming levels): TXx, TNn, Rx1day, Rx5day, FD, CDD, and SPI.

AVI.3 Climatic Impact-Drivers indices selection

In Chapter 12, 33 CID types are identified on the basis of relevance for risks and impacts and available literature. They are classified into 7 categories: heat and cold, wet and dry, wind, snow and ice, coastal, oceanic, and other (see Tables 12.1 and 12.2). It would be impossible to cover all indices that have been developed in the literature. However, in order to illustrate how indices can inform on future regional climate, Chapter 12 and the Atlas use a limited number of indices to illustrate the main CIDs and their evolution with climate change.

The selection of indices, as displayed in Chapter 12 and the Atlas, is based on expert judgement using the following guiding principles. The set of indices should:

- (i) describe the evolution of a manageable and illustrative number of indices,
- (ii) cover these categories, while giving more weight to those with a higher number of potential impacts as described in the literature,
- (iii) be used broadly in the literature,
- (iv) allow easy computation from publicly available model outputs and observations, or be accessible from published material through contact with the authors,
- (v) be well-evaluated in model simulations, or based on ECVs that are well-evaluated in model simulations, and
- (vi) represent CIDs of interest to regional impacts and risk assessments.

The selection results in 16 regional indices that are reported in Table AVI.2. The description of the formulae used for processing is described below.

AVI.3.1 Regional CID indices used in Chapter 12 and the Atlas

Climatic impact-drivers indices

Length of frost-free period (LFFP): Many ecosystems and crops are sensitive to frost conditions, and can only develop over a frost-free period (e.g., Wolfe et al., 2018); the length of frost-free period is calculated in the Atlas as in McCabe et al., (2015) by counting the number of days between the last spring frost and first fall frost using 0°C as a threshold for the daily minimum temperature and adjusting for season between hemispheres (from January to December in the Northern Hemisphere and from July to June in the Southern Hemisphere).

Growing degree-days (GDD): Ecosystems and crop growth is often linked to a widely used index of thermal conditions, the cumulative number of degrees above a threshold (often between 0 and 10 °C, depending on species and farming system) during a given growing period. In Chapter 12 and the Atlas we use 5°C as an indicative threshold, which was also used in Ruosteenoja et al., (2016), and the calculation is taken from this reference. GDD calculations sometimes include a high temperature threshold above which plant development does not occur (e.g., Mu et al., 2017), but no cap was employed for our calculations. The GDD index used here is therefore the accumulated sum of the difference between daily mean temperature and the threshold (when higher than the threshold) over the April-September months that forms the primary growing season for mid-latitude agricultural areas in the northern Hemisphere; and October-March for the

1 Southern hemisphere.

2

3 **Cooling Degree-days (CD)**: Energy consumption in hot environments typically depends on the excess of
4 temperature above a given threshold, where cooling is required. In Chapter 12 and the Atlas we used the
5 formulation of Spinoni et al., (2015), which uses the mean (T_M), max (T_X) and min daily (T_N) temperature
6 with the formula taken from this reference:

$$7 \quad CDD_i = \begin{cases} 0 \\ \frac{T_X - T_b}{4} \\ \frac{T_X - T_b}{2} - \frac{T_b - T_N}{4} \\ T_M - T_b \end{cases} \quad \text{if} \quad \begin{cases} T_X \leq T_b \\ T_M \leq T_b < T_X \\ T_N \leq T_b < T_M \\ T_N \geq T_b \end{cases}$$

8

9 With $T_b=22^\circ\text{C}$, then

10

$$11 \quad CDD = \sum_{i=1}^{365} CDD_i$$

12

13 The difference between Chapter 12, Atlas, and the previous reference is that in this report the sum is
14 cumulated over the entire year instead of 6 months, so it applies to all hemispheres.

15

16 **Number of days with maximum daily temperature above threshold (TXnn)**: The number of days with
17 maximum temperature above a threshold can be critical for human health, infrastructure, ecosystems, and
18 agriculture. Different thresholds are used for different crops, generally varying between 30 degrees and 40
19 degrees (Hatfield and Prueger, 2015; Grotjahn, 2021).. Chapter 12 uses the 35°C threshold globally (Figure
20 12.4), which was identified as a critical temperature for maize pollination and production (Wolfe et al., 2008;
21 Schlenker and Roberts, 2009; Hatfield et al., 2011, 2014; Lobell and Gourdji, 2012; Gourdji et al., 2013;
22 Lobell et al., 2013; Deryng et al., 2014; Hatfield and Prueger, 2015; Tripathi et al., 2016; Schauburger et al.,
23 2017; Tesfaye et al., 2017) as well as a notable threshold for human health hazards (Kingsley, Eliot, Gold,
24 Vanderslice, & Wellenius, 2016; Petitti et al., 2016). The Interactive Atlas includes both TX35 and TX40
25 (both raw and bias adjusted; see Atlas 1.4.5).

26 **NOAA Heat Index (HI)**: HI is used by the US National Oceanic and Atmospheric Administration (NOAA)
27 for issuing heat warnings and was applied in several studies that investigated adverse health impacts due to
28 heat stress (e.g., Burkart et al., 2011; Lin et al., 2012; Kent et al., 2014). HI is calculated as multiple linear
29 regression with temperature (T_F in $^\circ\text{F}$) and relative humidity (RH) as input variables (Steadman, 1979;
30 Rothfus, 1990):

$$31 \quad HI = \begin{cases} HI_1 + HI_{A1}, & \text{if } RH < 13\% \text{ and } 80^\circ\text{F} < T_F < 112^\circ\text{F} \\ HI_1 + HI_{A2}, & \text{if } RH > 85\% \text{ and } 80^\circ\text{F} < T_F < 87^\circ\text{F} \\ HI_1, & \text{otherwise} \end{cases}$$

32 with:

$$33 \quad HI_1 = c_0 + c_1 \cdot T_F + c_2 \cdot RH + c_3 \cdot T_F \cdot RH + c_4 \cdot T_F^2 + c_5 \cdot RH^2 + c_6 \cdot T_F^2 \cdot RH + c_7 \cdot T_F \cdot RH^2$$

$$34 \quad + c_8 \cdot T_F^2 \cdot RH^2$$

$$35 \quad HI_{A1} = (13 - RH)/4 \cdot \sqrt{(17 - |T_F - 95^\circ\text{F}|)/17}$$

$$36 \quad HI_{A2} = (RH - 85)/10 \cdot (87^\circ\text{F} - T_F)/5$$

$$37 \quad c_0 = -42.379^\circ\text{F}, c_1 = 2.04901523, c_2 = 10.14333127^\circ\text{F}, c_3 = -0.22475541,$$

$$38 \quad c_4 = -0.00683783^\circ\text{F}^{-1}, c_5 = -0.05481717^\circ\text{F}, c_6 = 0.00122874^\circ\text{F}^{-1}, c_7 = 0.00085282$$

1 $c_8 = -0.00000199 \text{ } ^\circ\text{F}^{-1}$

2 If $HI < 80 \text{ } ^\circ\text{F}$, the following equation is used:

3 $HI = 0.5 \cdot (T_F + 61 \text{ } ^\circ\text{F} + 1.2 \cdot (T_F - 68 \text{ } ^\circ\text{F}) + 0.094 \text{ } ^\circ\text{F} \cdot RH)$

4 The calculated HI is converted into $^\circ\text{C}$.

5 HI is calculated for CMIP5, CMIP6 and CORDEX using daily mean near-surface specific humidity, daily
6 mean surface pressure, and daily maximum near-surface air temperature. For CMIP5 and CMIP6, daily
7 mean surface pressure is calculated from daily mean sea level pressure by applying a height adjustment (see
8 Schwingshackl et al., (2021) for details) Additionally, HI is calculated for WFDE5, which is a bias adjusted
9 version of the ERA5 reanalysis (Cucchi et al., 2020). Daily maximum temperature is calculated as
10 maximum, daily mean pressure and humidity as average of the hourly WFDE5 variables near-surface air
11 temperature, near-surface specific humidity, and surface air pressure.

12 To quantify heat stress, yearly sums of daily HI threshold exceedances are calculated using a threshold of
13 41°C , which corresponds to conditions that the US National Weather Service classifies into the category of
14 “Danger” (Blazejczyk et al., 2012). Bias adjusted model simulations are used for calculating threshold
15 exceedances of HI, employing the quantile delta mapping (QDM) approach as described by (Cannon et al.,
16 2015). The QDM approach adjusts the model data in the application period to fit the reference data in the
17 reference period (using quantile mapping). Subsequently, the climate change signal is added for each
18 quantile by considering the change between the model’s reference and application periods. QDM is directly
19 applied to the HI data using WFDE5 as reference dataset and 1981-2010 as reference period. WFDE5 HI
20 data are conservatively remapped to each model’s grid before bias adjustment is performed. QDM is applied
21 on each grid point individually and for each month separately. The application periods are the IPCC periods
22 1995-2014, 2041-2060, and 2081-2100 and 20-year periods for specific warming levels (1.5°C , 2°C , 3°C ,
23 and 4°C).

24 **Heating Degree-days (HD):** symmetrical to the Cooling Degree Day index, the HD index is used for
25 illustrating energy demand for heating. It has been used in several studies of impacts of climate change on
26 the energy sector. The Atlas follow the formulation proposed by (Spinoni et al., 2015). The calculation
27 follows:

28

$$HDD_i = \begin{cases} \frac{T_b - T_M}{2} - \frac{T_X - T_b}{4} & \text{if } \begin{cases} T_X \leq T_b \\ T_M \leq T_b < T_X \\ T_N \leq T_b < T_M \\ T_N \geq T_b \end{cases} \\ \frac{T_b - T_N}{4} & \\ 0 & \end{cases}$$

29

30 With $T_b=15.5^\circ\text{C}$, then

31

$$HDD = \sum_{i=1}^{365} HDD_i$$

32

33 Where T_M , T_X and T_N correspond to daily mean, maximum and minimum temperature respectively.

34 To account for various geographic zones, however, the HD index is cumulated over the entire year, instead
35 of 6 months, as in the previous reference. This index is included in the Interactive Atlas.

36
37 **Number of frost days (FD):** Frost affects crops (Barlow et al., 2015; Crimp et al., 2016; Craddock-Henry,
38 2017; Mäkinen et al., 2018), and there has been a number of studies investigating changes in the number of
39

1 frost days, with various thresholds, mostly between -10°C and 2°C. In Chapter 12 and the Atlas, we use the
 2 simple threshold of 0°C for the daily minimum temperature to define frost days as in Table AVI.1. This
 3 index is included in the Interactive Atlas.

4
 5 **River flood index using runoff (FI):** As a flood indicator, the 100-year return value of discharge value (Q)
 6 has been used. The computation of the index follows Alfieri et al., (2015):

- 7
- 8 1. Annual maximum river discharges are selected and an Extreme Value Type I (Gumbel) distribution
- 9 is fitted on time slices of 30 years and an analytical function is obtained.
- 10 2. The analytical function is used to estimate extreme discharge peaks with chosen return period
- 11 Q(RP), by inverting the formulation of the Gumbel distribution:

$$Q(\text{RP}) = \xi - \alpha \ln \left(-\ln \left(1 - \frac{1}{\text{RP}} \right) \right)$$

12 where α and ξ are the scale and location parameters of the analytical Gumbel distribution.

- 13
- 14
- 15 3. The peak discharge corresponding to the 100-year return period, Q(RP=100), is then calculated.

16
 17 For CORDEX regional models the total runoff of each of the models has been used as an input of the
 18 hydrological model CHyM (Coppola et al., 2007, 2018) to produce the river discharge for all the European
 19 network. The Q(RP=100) value has been computed for each of the river segment and for each of the 29
 20 CHyM simulations. The results are shown in the regional Figures of 12.4.

21
 22 **Standardized Precipitation Index (SPI):** The SPI is a statistical index that compares cumulated
 23 precipitation for n months ($n=6$ or $n=12$) with the long-term precipitation distribution for the same location
 24 and cumulation period. The SPI months have been selected so SPI represent medium-term cumulated value
 25 and can be used to measure the medium term impact on river flow and reservoir storage (McKee et al., 1993).

26
 27 The index is computed in this way:

- 28 1. A monthly precipitation time series is selected (at least 30 years).
- 29 2. The running average for the n -months window is computed.
- 30 3. The Gamma distribution is used to fit the data. The fitting can be achieved through the maximum
- 31 likelihood estimation of the Gamma distribution parameters.
- 32 4. The values from this probability distribution are then transformed into a normal distribution, so that
- 33 the mean SPI for the location and desired period is zero and the standard deviation is 1 (Edwards and
- 34 McKee, 1997).

35
 36 Once SPI has been computed, the calculation of the Drought Frequency (DF) follows the method in (Spinoni
 37 et al., 2014): a drought event starts in the month when SPI falls below -1 and it ends when SPI returns to
 38 positive values, for at least two consecutive months.

39
 40 It has to be noted that the SPI index has been recognized to be difficult to interpret in high latitudes and in
 41 arid areas due to statistical issues linked to inaccuracies in the estimation of the Gamma function (Spinoni et
 42 al., 2014). The duration of 6 months is considered in Figure 12.4.

43
 44 This index is included in the Interactive Atlas, both SPI-6 and SPI-12 versions.

45
 46 **Soil moisture (SM):**

47
 48 The soil moisture index is used in Chapter 12 figures. It is simply using the total soil moisture content
 49 integrated over the soil depth, normalized by the recent past climatological values at each grid point.

50
 51 **Snow season length (SWE100):** Several studies use the Snow Water Equivalent (SWE) variable (variable
 52 *snw* in model outputs) in order to define a “snow season length” as the number of days with enough snow on
 53 the ground. This index is particularly important for the winter tourism sector (Damm et al., 2017; Jacob et
 54 al., 2018). Several thresholds are used to define a day with “enough snow on the ground”, with (Wobus et

al., 2017) marking 100mm as a key threshold for skiing. However, this index is important not only for winter tourism but also in other sectors such as water management. In several figures of Chapter 12 and the Atlas, the snow season length is calculated then as the number of days with SWE > 100mm, following the definition of (Damm et al., 2017; Wobus et al., 2017). Seasonal limits are given (November through March) for studies in the Northern hemisphere, and the index for the Southern Hemisphere is taken over the opposite season (May through September). SWE was assessed in several studies and its simulation depends on the representation of surface processes dealing with snow. Despite limitations, SWE was found to be useful in giving insight on the sign of changes (McCrary et al., 2017). When interpreting the figures shown in Chapter 12 and the Atlas, one should also keep in mind that ‘altitudes’ are model altitudes and may not correspond to real ones due to the coarse resolution, and the changes can be quite sensitive to such effects.

Extreme Total Water Level (ETWL): Factors contributing to extreme sea levels (ETWL) are sea level rise, storm surge (e.g. associated with tropical cyclones and extra-tropical cyclones), tide, and extreme waves (resulting in high wave setup at the shoreline). The ETWL used here is the summation of the aforementioned factors (Vitousek et al., 2017; Vousedoukas et al., 2018) and the commonly used 1:100yr ETWL (the 100-year ETWL return value) is adopted here as the index relevant to episodic coastal flooding. Here, the median ETWL, together with the associated 5% -95 % confidence interval, resulting from a fully probabilistic model that incorporates storm surge and waves derived from models forced by an ensemble of 6 GCMs, is used as the index relevant for long-term coastal erosion.

Coastal Erosion (CE): Coastal erosion is generally accompanied by shoreline retreat, which can occur as a gradual process (e.g., due to sea level rise) or as an episodic event due to storm surge and/or extreme waves, especially when combined with high tide (Ranasinghe, 2016). The most commonly used shoreline retreat index is the magnitude of shoreline retreat by a pre-determined planning horizon such as 50 or 100 years into the future. Here, the median shoreline retreat, together with the associated 5% -95 % confidence interval, resulting from a fully probabilistic model that incorporates storm surge and waves derived from models forced by an ensemble of 6 GCMs, is used as the index relevant for long-term coastal erosion.

Some of these indices are included in the Interactive Atlas allowing flexible analysis (seasons, regions, baselines and future periods – using both time-slices/scenarios and global warming levels): TX35 and TX40 (both raw and bias adjusted; see Atlas 1.4.5), FD, CD, HD, SPI-6 and SPI-12.

[START TABLE AVI.2 HERE]

Table AVI.2: Regional CID indices table and relevant references.

CID category	Climatic impact-driver (from Table 12.1) and potential affected sectors	Index	Required ECVs	Way to calculate	Bias adjustment	References
Heat	Warming indicator for crops, ecosystems and hydrosystems	Length of Frost-Free period (LFFP)	Tasmin	from projections	yes	(Kunkel, 2004; McCabe et al., 2015; Wolfe et al., 2018)
Heat	Warming indicator for agriculture and ecosystems	yearly cumulated GDD over 5°C	Tas	from projections	yes	(Bonhomme, 2000; Cayton et al., 2015; Ruosteenoja et al., 2016)
Heat	Change in cooling demand for energy demand and building consumption	CD above 22°C	tas, tasmin, tasmax	from projections	yes	(Spinoni et al., 2015, 2018)
Heat	Heat, with thresholds important for agriculture	#days Tmax>35°C or 40°C (TX35, TX40)	Tasmax	from projections	yes	(Hatfield and Prueger, 2015; Hatfield et al., 2015; Grotjahn, 2021)
Heat	Heat stress index combining	NOAH Heat Index (HI) : Number of	tasmax huss ps	from projections	yes	(Burkart et al., 2011; Lin et al., 2012; Kent et al., 2014)

	humidity used in occupational and industrial health	days above 41°C threshold				
Cold	Heating Degree Day for Energy consumption	HD below 15.5°C	tas, tasmin, tasmax	from projections	yes	(Spinoni et al., 2015, 2018)
Cold	Frost	#Frost days below 0°C (FD)	Tasmin	from projections	yes	(Barlow et al., 2015; Rawlins et al., 2016)
Wet	River flooding	Flood index (FI)	srroff/ mrro	from projections and simplified routing model	no	(Forzieri et al., 2016; Alfieri et al., 2017)
Drought	Aridity	Soil Moisture (SM)	mrso	from projections	no	(Cook et al., 2020)
Drought	droughts	SPI accumulated over 6 months and 12 months (SPI-6 and SPI-12)	Pr	from projections	no	(Naumann et al., 2018)
Wind & storm	Mean wind speed	Annual mean wind speed	sfcWind	from projections	no	(Karnauskas et al., 2018; Li et al., 2018)
Snow/ice	Snow season length	Number of days with Snow Water Equivalent > 100 mm. (SWE100) over the snow season (NOV-MAR for NH)	Snw	from projections	no	(Damm et al., 2017; Wobus et al., 2017)
Coastal	Extreme Sea level (ETWL) inducing storm surges	100-year return period level (ETWL)		data from authors	no	(Vousdoukas et al., 2018)
Coastal	Coastal Erosion	Shoreline retreat by mid, end century		data from authors	no	(Vousdoukas et al., 2020)

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[END TABLE AVI.2 HERE]

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