EXPLORING THE USE OF A MULTIVARIATE SNOW INDEX IN THE PYRENEES TO CHARACTERIZE SNOW SEASONS

The authors of this work would like to acknowledge and thank all the information provided over the years the ski resort of Andorra (Pal-Arinsal, Ordino-Arcalis, Soldeu - el Tarter and Pas de la Casa - Grau Roig), as well as the National Meteorological Service.

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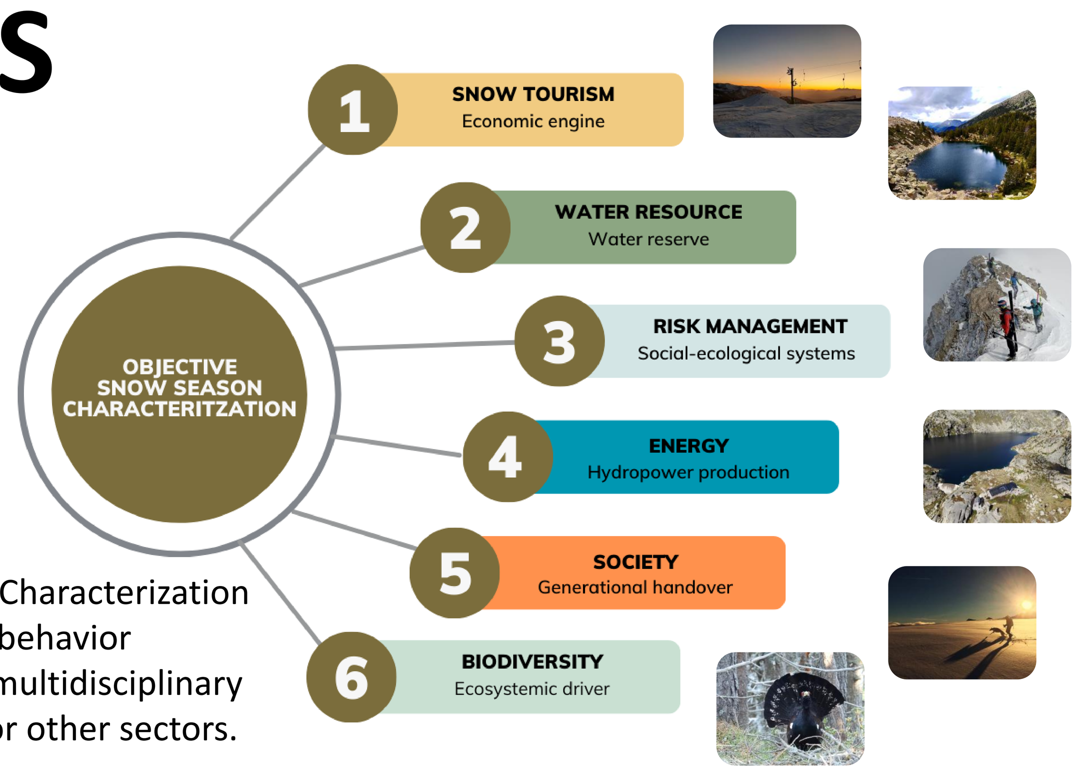

Figure 1: Characterization of winter behavior provides multidisciplinary insights for other sectors.

Introduction

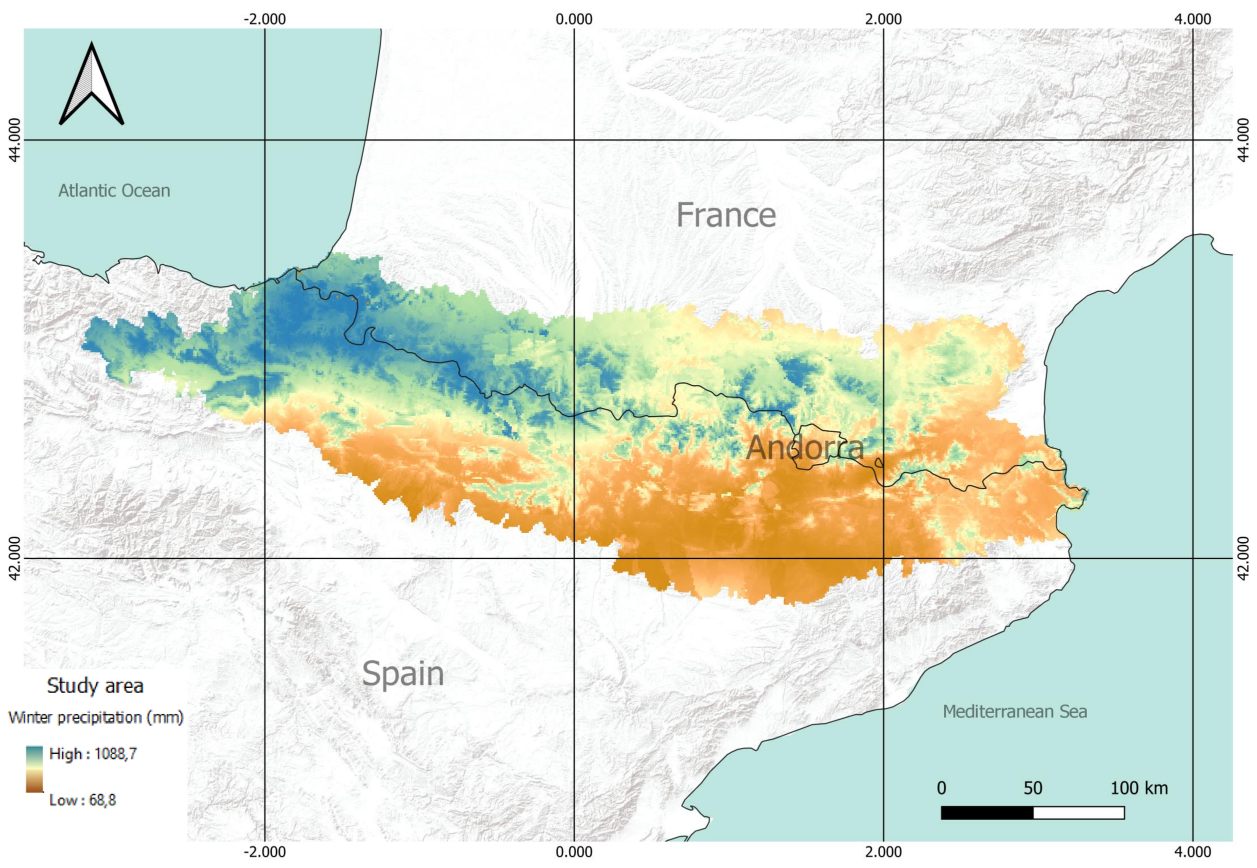

Figure 2: Study area located in the north-east of the Iberian Peninsula, winter precipitation map (in mm) in the Pyrenees Mountains for the period 1981-2015. Source: CLIM-PY PROJECT.

In recent decades, snow depth in European mountain regions like the Pyrenees has tended to decrease due to the increase in both temperature and precipitation variability. The impacts of climate change on high mountain areas are more pronounced, and there are records of daily and monthly temperature exceeding the alert thresholds established in international agreements. Several sectors, such as snow tourism and hydroelectric power generation, are affected by these changing snow trends.

In order to monitor winter snow seasons, **a multivariate snow index (MSI)** has been proposed to characterize the climatic variability of the snow depth in time and space. This new index is based on high/low quantiles of daily maximum snow depth (HS) distributions and can be applied to any cold or mountain region, at different spatial scales and for both the present and future climate.

The trend analysis on the parameters derived from the MSI (e.g., duration and intensity of snow depth anomalies) can provide a useful tool to identify the vulnerable areas during the snow season.

Datasets and method

Snow datasets has been used, the available variable for the calculations of the snow indicators is the daily snow depth observed by automatic weather stations with a laser sensor and manual observations (Ignacio López Moreno et al., 2020). To perform the indicators, we need to have a sufficiently long period for trend analysis and a minimum days with snow on the ground.

We propose **Multivariate Snow Index (MSI +Surplus or –Scarcity)**. Consists in the objective characterization of the climatic snow depth anomaly. Its calculation is inferred from the daily maximum of snow depth (SH).

The methodology to compute **MSI+**, first defines two parameters to quantify the surplus season from the treatment of SH:

a) Duration $[SD_d]$: The total number of days in during the winter season from November to April when the SH is greater than or equal to P_{50}.

$$SD_d = \sum_{i=1}^{n} \mathbb{1}(SH_i \geq P_{50})$$

b) Intensity $[SD_i]$: The sum of the positive differences between the daily SH and P_{50}, starting from the third consecutive day when SH exceeds. The intensity is divided by the number of the days of the season.

$$SD_i = \frac{\sum_{i=k}^{n}(SH_i - P_{50}) \cdot \mathbb{1}(SH_i \geq P_{50})}{n} \quad for\ i \geq k$$

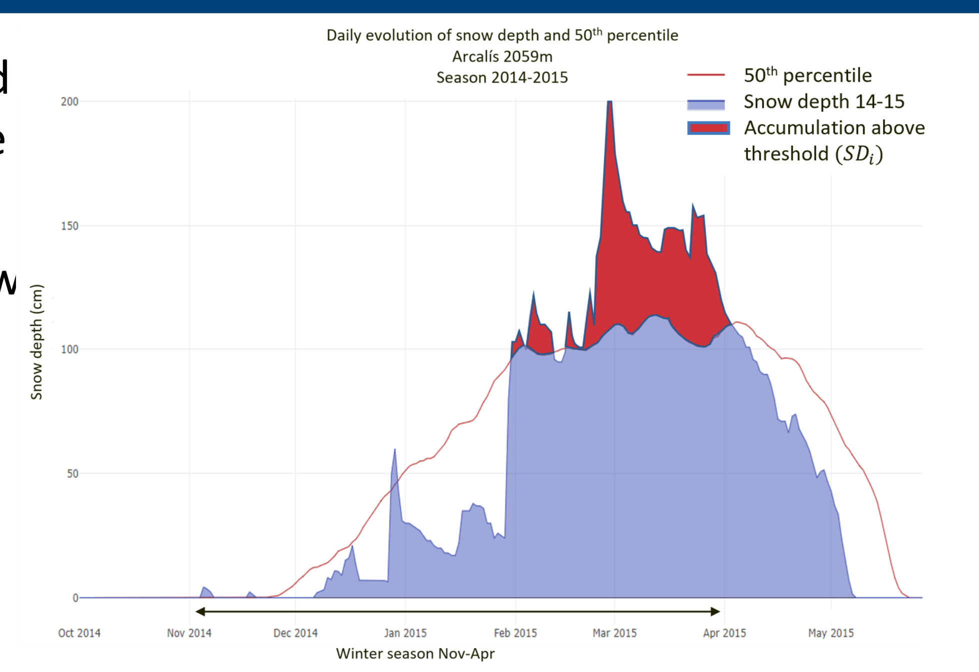

Figure 3: Temporal evolution of snow depth (blue area) during the season 2014-2015 at Arcalis station. The red line indicates de P_{50} for a refence period 1980-2016. The red area represents SD_i.

Results and conclusions

- The distribution of the snowpack in the high mountains regions is very unevenly both in space and time. This distribution can be determined by few or several snowfalls through the indicator Concentration Index (CI) (Lemus-Canovas et al., 2023).
- Prior to 2000 it is noteworthy that the duration never exceeded 140 days. The intensity values SD_i for the same period do not surpass 50cm/day per season, with a higher regularity between seasons. (Fig. 4)
- After three consecutive scarcity season (1999-2002), the difference between seasons is more marked, showing a very high interannual variability.
- The points located in the easternmost Pyrenees and on the Mediterranean slope exhibit a statistically significant decreasing trend in SD_d (Fig.5a). As for the trend of intensity (Fig. 5b), the spatial variation it is not as pronounced as the one presented in duration, but the decrease persists at the same stations in the easternmost Pyrenees.
- In terms of trends, there is no homogeneous behavior throughout the mountain range either. However, it has been possible to identify the areas where the decrease in duration and intensity is most relevant and statistically significant.

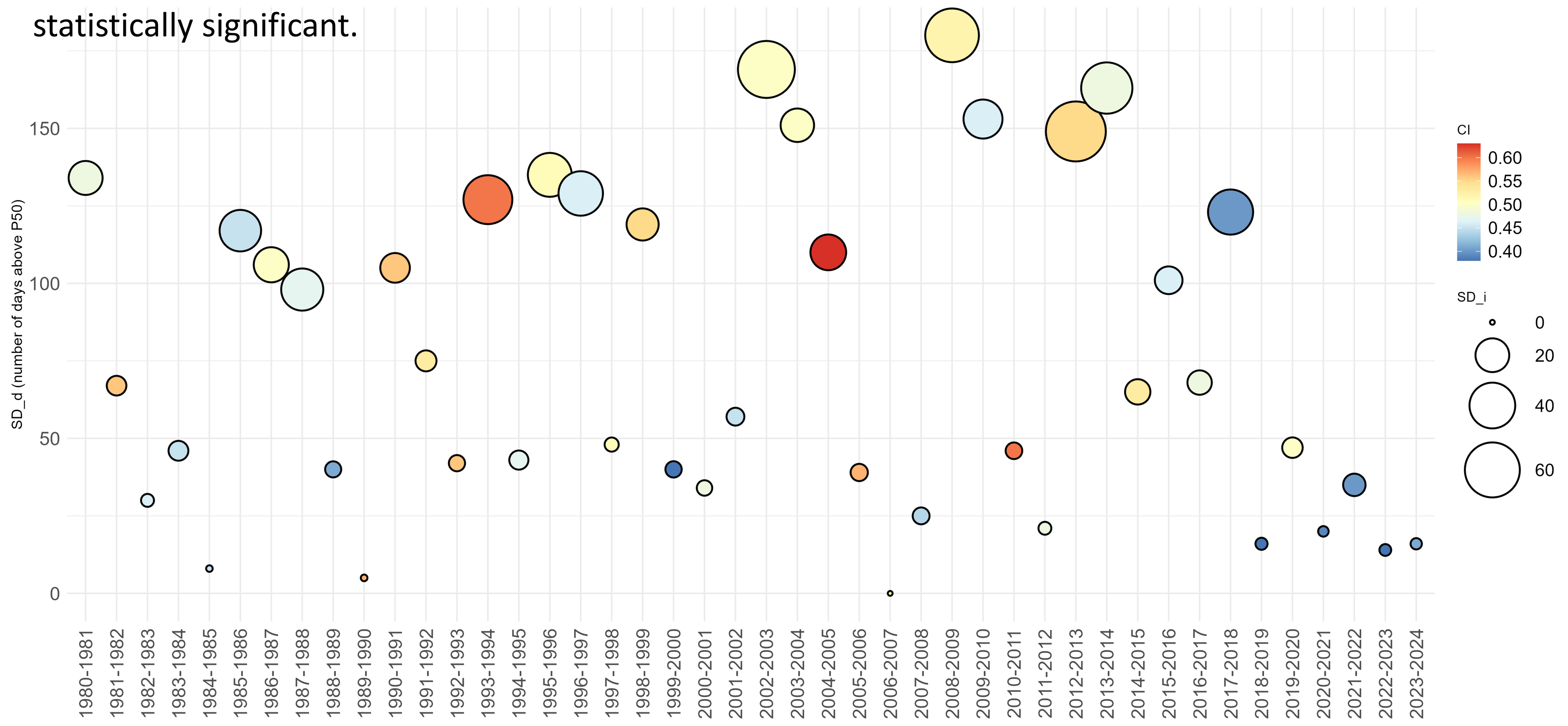

Figure 4: Evolution **of MSI+** and CI at Arcalis station 2059m.a.s.l. from 1980 to 2024. The x axes shows the season and y axes shows the SD_d. The size of the bubbles is SD_i and the color de CI (high values indicates a a few snowfalls).

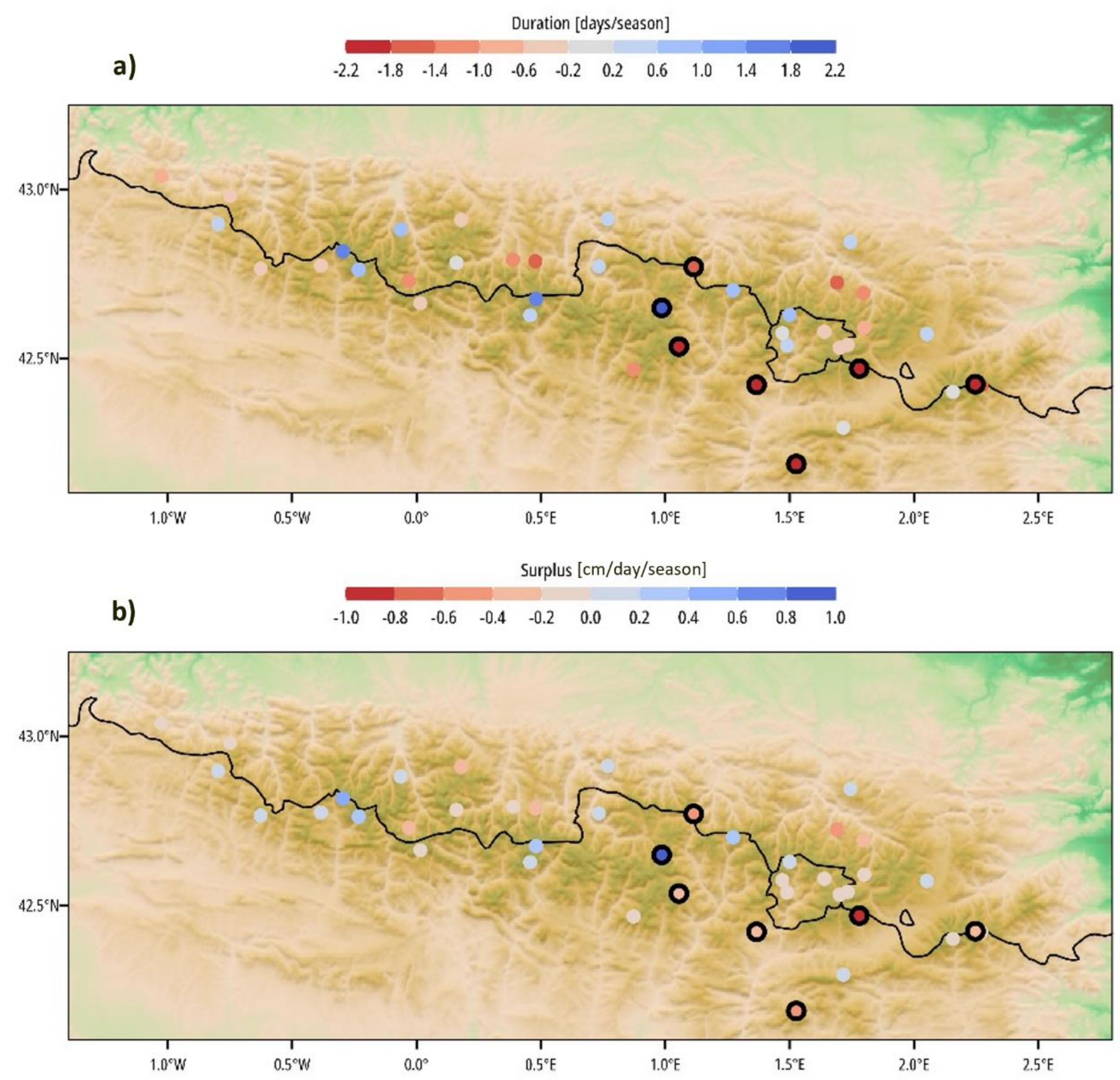

Figure 5: Temporal and spatial trends of the behavior of MSI+ in the Pyrenees region for the 1980-2016. The a) map displays the duration trend SD_d and b) the SD_i trend. The black outline of the dots indicates the statistical significant trend.

The knowledge of the snow variable is a key in addressing and improving the adaptation to climate change in high mountain regions. In this sense, we will be open to work with other datasets to test our functions and the indicator that has been developed in this work.

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