Detection and Characterization of Climate Extremes with Deep Learning

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1. Introduction: Climate Extremes

- The effects of global warming are worsening
- Mostly due to extreme events
  - ➢ Droughts, floods, heat waves…
- Severe impacts on people and human activities
  - ➢ Health, buildings, agriculture…
- To face them: adaptation and mitigation
- Detect and characterize the evolution of extremes
  - ➢ Frequency, intensity, geographical extent, duration
- First focus on heat waves, with daily maximum temperature

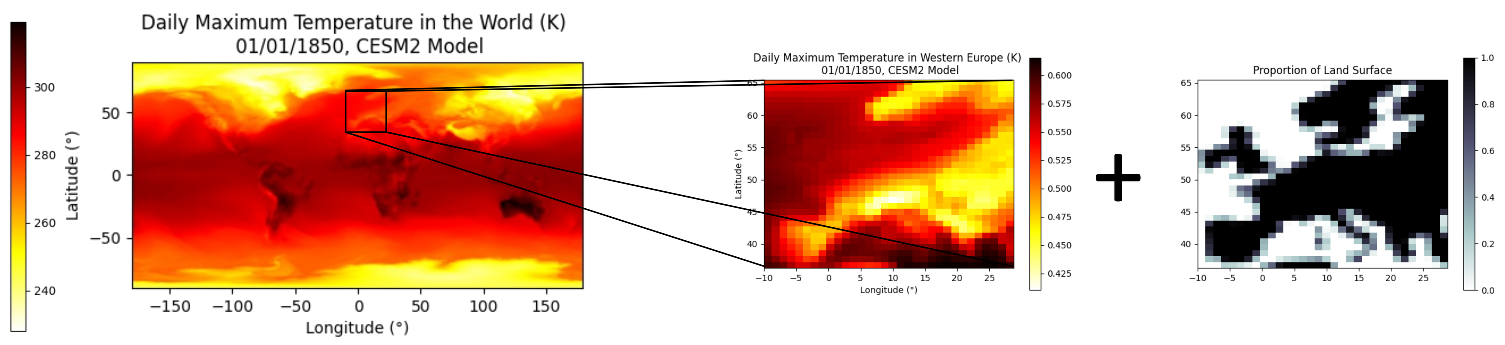
2. Future Climate Data

Raw Data

- Coupled Model Intercomparison Project, phase 6 (CMIP6)
- General Circulation Models (e.g. CMCC-ESM2)
- 1°×1° resolution (~125km spatial grid)
- Daily data from 1850 to 2100
- Climate variables: temperature, precipitations, wind…
- Various carbon emission scenarios (IPCC):
  - ➢ SSP1-2.6, SSP2-4.5, SSP3-7.0, SSP5-8.5

Preprocessing

- From NetCDF files to numpy tables
- 32×32 square over Western Europe
- Season split
- Min-max normalization

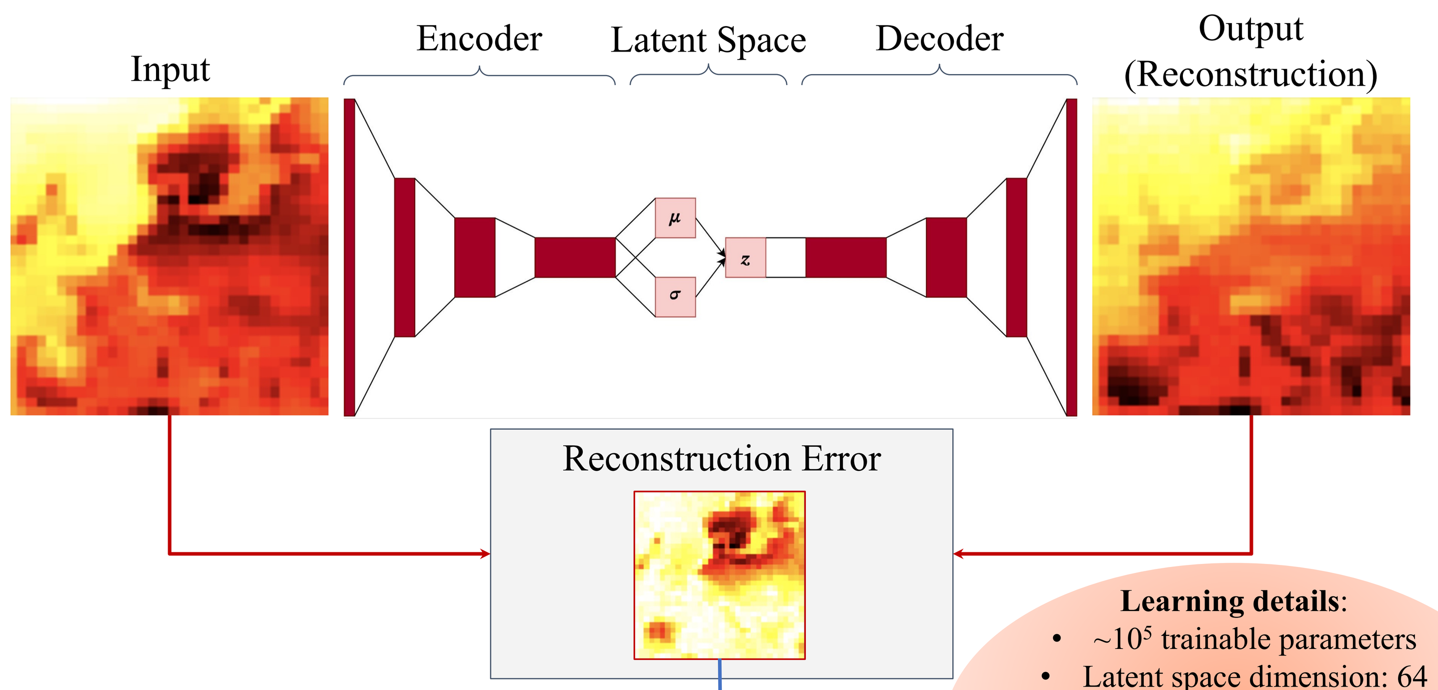


Preprocessing Steps: from World to Western Europe

Normalized and Enhanced with Land-Sea Proportion

3. Deep Learning Method

Convolutional Variational Auto-Encoder (CVAE)



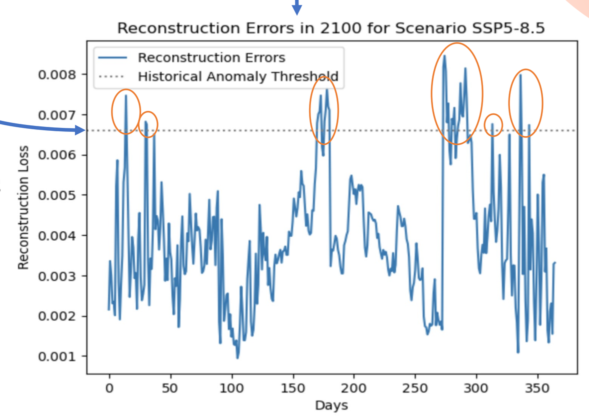
Learning details:
- ~10^5 trainable parameters
- Latent space dimension: 64
- 5-minute training for 1 member over 1950-2000, 100 epochs
- 1-minute inference, all SSPs, 2015-2100

Characterization

Anomaly threshold

defined over a reference period

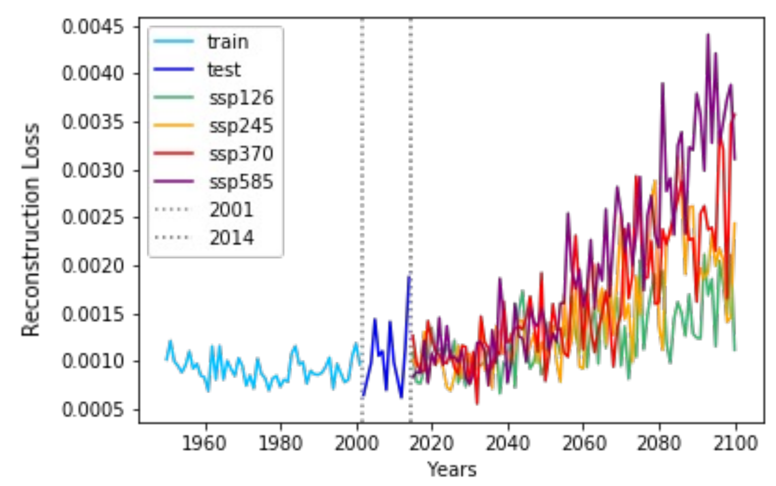
- ➢ Compute the reconstruction errors (time series) of this period,
- ➢ Keep the 1%-most-extreme events of the period,
- ➢ Compute the corresponding anomaly threshold,
- ➢ Compare the number of events with a greater reconstruction error on projection data.

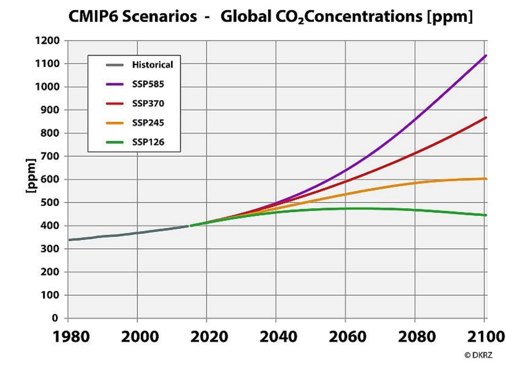


Extraction of event characteristics from time series:
- Frequency
- Duration
- Intensity

4. Results

Comparison between IPCC Scenarios





Anomaly Analysis in CMCC-ESM2 Model (Summers)

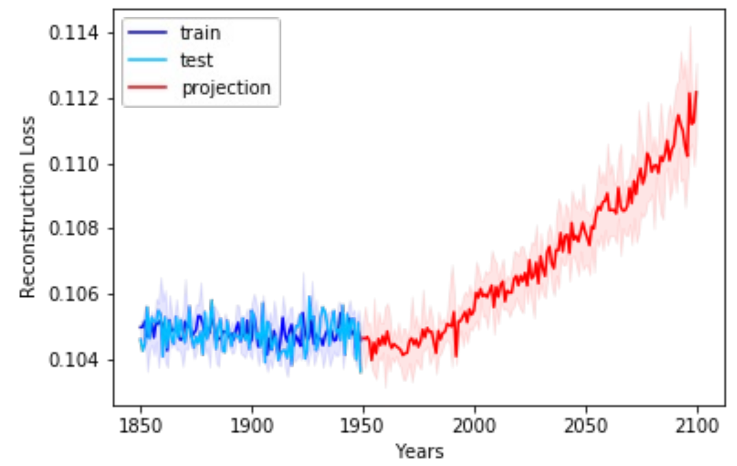
Detection when the reconstruction error exceeds a threshold

	2001-2014	2015-2100			
Scenario	Test data	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5
Proportion of unusual days	1,00%	3,78%	8,09%	11,07%	17,83%
Maximum spike	0,0051	0,0053	0,0089	0,0087	0,0095
Maximum duration (days)	5	22	27	53	55
Average duration (days)	2	3,44	5,66	6,17	7,51

Comparison between ensemble members

Reconstruction Errors in CESM2 Model

Summers, Members 1-5, Scenario SSP3-7.0



Anomaly Analysis in CESM2 Model

Member Comparison for Scenario SSP3-7.0

	1850-1950	1950-2100				
Member n°	Test Data - 5	SSP3-7.0 - 1	SSP3-7.0 - 2	SSP3-7.0 - 3	SSP3-7.0 - 4	SSP3-7.0 - 5
Unusual days	92	3530	3614	3931	3455	3798
Proportion of unusual days	1,00%	25,41%	26,02%	28,30%	24,87%	27,34%
Maximum spike	0,112	0,123	0,119	0,120	0,119	0,121
Average maximum	0,1094	0,1108	0,1108	0,1110	0,1109	0,1110
Maximum duration (days)	7	83	77	81	81	78
Average duration (days)	2,4	9,7	9,9	10,4	9,7	10,5
Proportion of spikes	39	91	91	94,25	88,75	90,25

5. Conclusion and Perspectives

Perspectives

- ➢ Exploitation of **geospatial information**
- ➢ Implementation of a **severity index**, to better compare events
- ➢ Exploitation of the **latent space** of the neural network
- ➢ Validation with climate indices (analytical method: icclim[1])
- ➢ **Integration** with the interTwin architecture and components
- ➢ Extension to **other climate variables** (e.g. precipitation)
- ➢ Paper preparation

Take-Home Messages

- ✓ The Convolutional **Variational Auto-Encoder** (CVAE) achieves **Unsupervised Anomaly Detection**
- ✓ The model handles **big data** sets of **high complexity**
- ✓ Events are **characterized** with various indicators
- ✓ Results are **consistent**
- ✓ This model unlocks the ability to better quantify **climate impact uncertainties** (ensemble approach)

1. icclim indices: https://github.com/cerfacs-globc/icclim

EU

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Github Repository
https://github.com/cerfacs-globc/xtclim

interTwin Project Website: https://www.intertwin.eu

CERFACS Website: www.cerfacs.fr