EGU21 Session ITS4.4/AS4.1
Machine learning for Earth system modeling

Inferring precipitation from atmospheric general circulation model variables with deep learning

Philipp Hess and Niklas Boers

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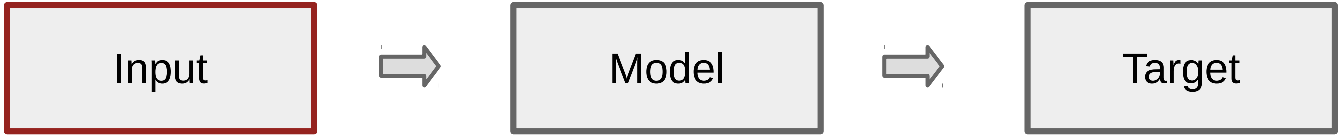
Motivation

- Predicting precipitation is important:
  - Large impact on society, e.g. agriculture, disaster mitigation, ...
  - Extremes are projected to become more frequent and severe.

- Challenges for numerical weather prediction (NWP) models:
  - Large range of scales
  - Subgrid parameterizations for computational efficiency
  - Strong intermittency

- Our aim:
  - Improve the prediction of precipitation extremes of a NWP model ensemble.
  - Learning extremes with a neural network to post-processes of the ensemble output.

Method

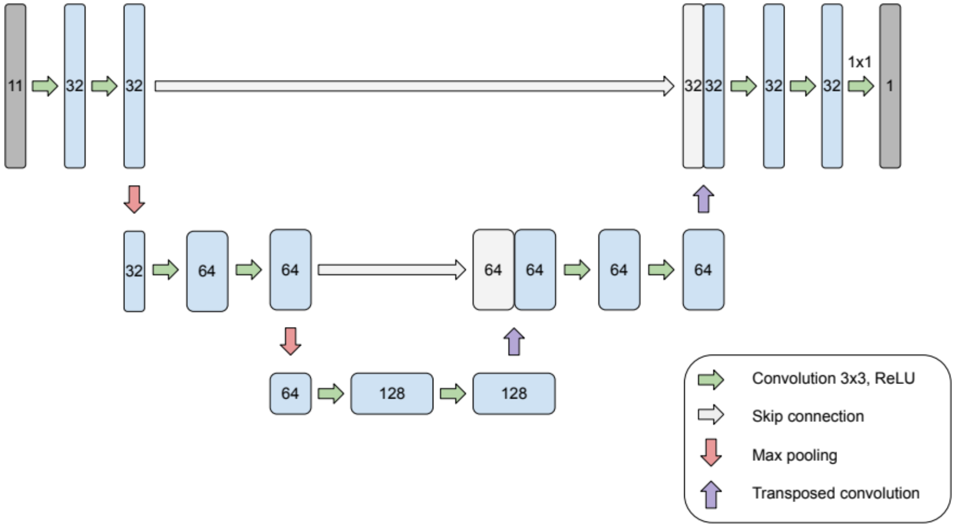

Input → Model → Target

- **Features**:
  - Vertical velocity
  - Precipitation
- **Integrated Forecast System (IFS)**
  - From the ECMWF[1]
  - 10-member GCM ensemble mean
  - 12h forecasts, twice daily
- **Resolution:**
  - Time: 3-hourly, JJA season, 1998-2014
  - Space: 1.25° horizontal, 11 vertical levels
  - Region: 50°S – 50°N, 180°W – 180°E

Method

Input ⇒ **Model** ⇒ Target

- U-Net[2]:



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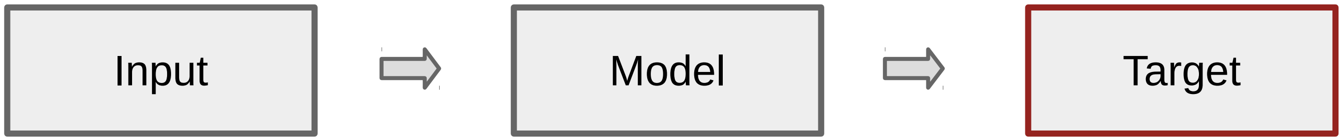
Method



Input

Model

Target

- Tropical Rainfall Measurement Mission (TRMM), TMPA[3]
- Satellite-based observations
- High accuracy in the tropics and for heavy precipitation
- Same resolution as the input

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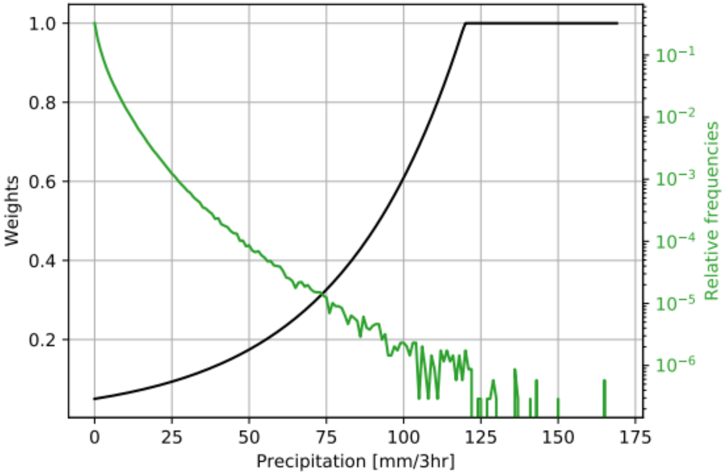
Learning the distribution tail

- Introducing weights in the MSE loss:
  - ⇨ Larger penalty on rare (extreme) events
- In combination with a structural similarity measure[4] (SSIM)

$$L(y, \hat{y}) = \frac{1}{N}\sum_{i=1}^{N} w(y_i)(y_i - \hat{y}_i)^2 + \lambda \mathrm{SSIM}(y, \hat{y})$$

$$w(y_i) = \min(\alpha \exp(\beta y_i), 1)$$



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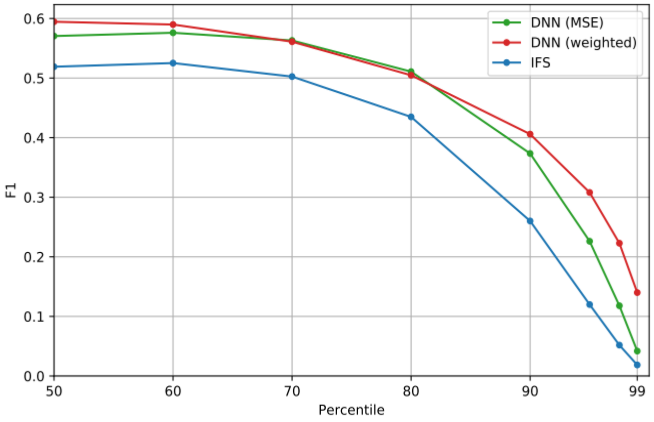
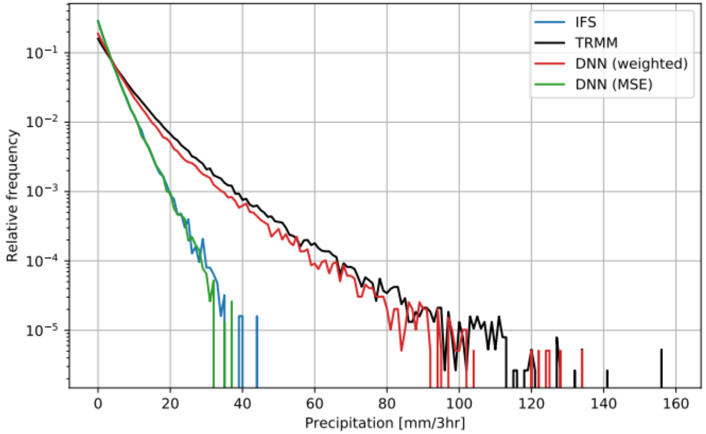
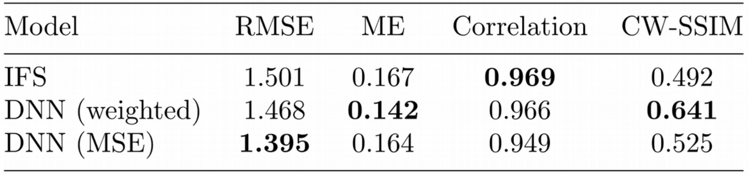
Results



F1 classification score of precipitation events above different percentile thresholds.



Relative frequencies of precipitation rates over the entire test set period 2012-2014 and global region.



Model	RMSE	ME	Correlation	CW-SSIM
IFS	1.501	0.167	**0.969**	0.492
DNN (weighted)	1.468	**0.142**	0.966	**0.641**
DNN (MSE)	**1.395**	0.164	0.949	0.525

Globally averaged cell-wise metrics. The CW-SSIM denotes the complex wavelet-based structural similarity index[5] and is averaged over all test examples.

hess@pik-potsdam.de

Summary & Outlook

- We applied a UNet to post-process the precipitation output of a NWP ensemble to improve:
  - The statistical representation of precipitation rates
  - The prediction of categorical extreme events (F1 score)
  - Reduced mean error (bias) and higher structural similarity

Future work:

- Using the full ensemble
- Longer forecast leads times

References

1. European Centre for Medium-Range Weather Forecasts, “The ECMWF ensemble prediction system” https://www.ecmwf.int/sites/default/files/the_ECMWF_Ensemble_prediction_system.pdf
2. O. Ronneberger et al., U-net: Convolutional networks for biomedical image segmentation. In International Conference on Medical image computing and computer-assisted intervention (pp. 234-241). Springer, Cham. 2015.
3. G. J. Huffman et al., The TRMM Multisatellite Precipitation Analysis (TMPA): Quasi-global, multiyear, combined-sensor precipitation estimates at fine scales. Journal of hydrometeorology, 8(1), 38-55 2007.
4. Z. Wang, et al., Image quality assessment: from error visibility to structural similarity. IEEE transactions on image processing, 13(4), 600-612 2004.
5. A. Rehman et al., Image classification based on complex wavelet structural similarity. Signal Processing: Image Communication, 28(8), 984-992 2013.

Acknowledgments

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