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Supporting Information for

# A Robust Generative Adversarial Network Approach for Climate Downscaling and Weather Generation

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## Introduction

The attached supporting information includes additional figures for further detail, as referenced in the manuscript.

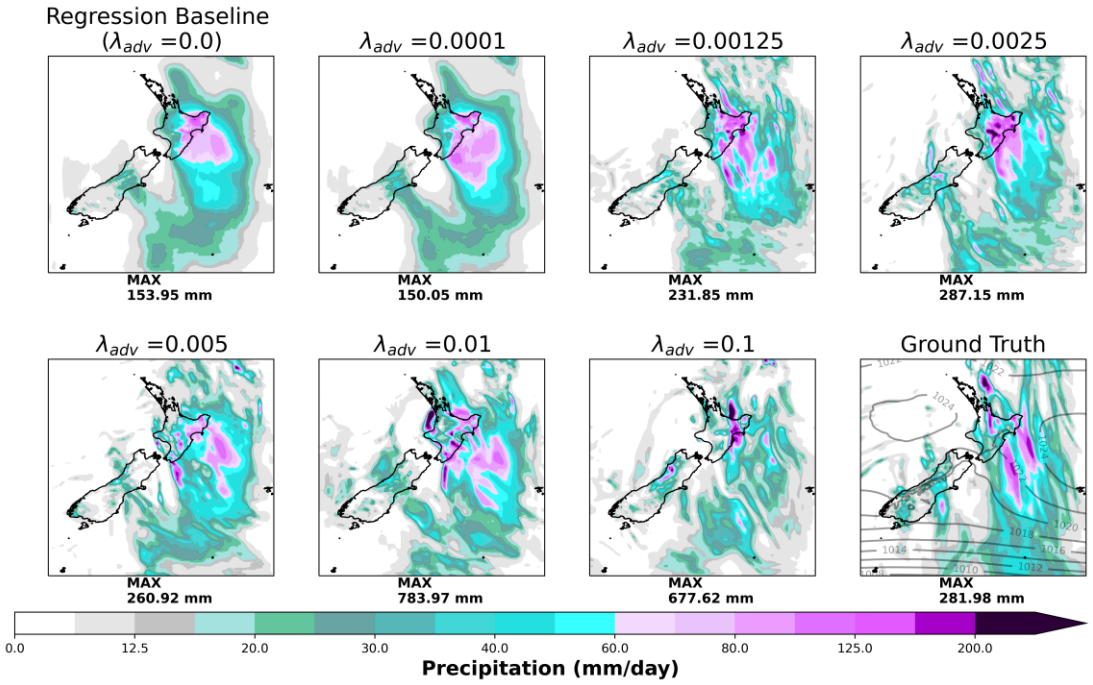


**Figure S1:** Example of daily precipitation predictions from GAN (without the intensity constraint) for a simulated extreme event from EC-Earth3 (2002-02-27), relative to the ground truth (CCAM downscaling EC-Earth3). The maximum precipitation intensity across the domain is shown in the text below the plot. The contours show CCAM's Mean Sea Level Pressure (MSLP) patterns for the same event. **Table S1.** Type or paste caption here.

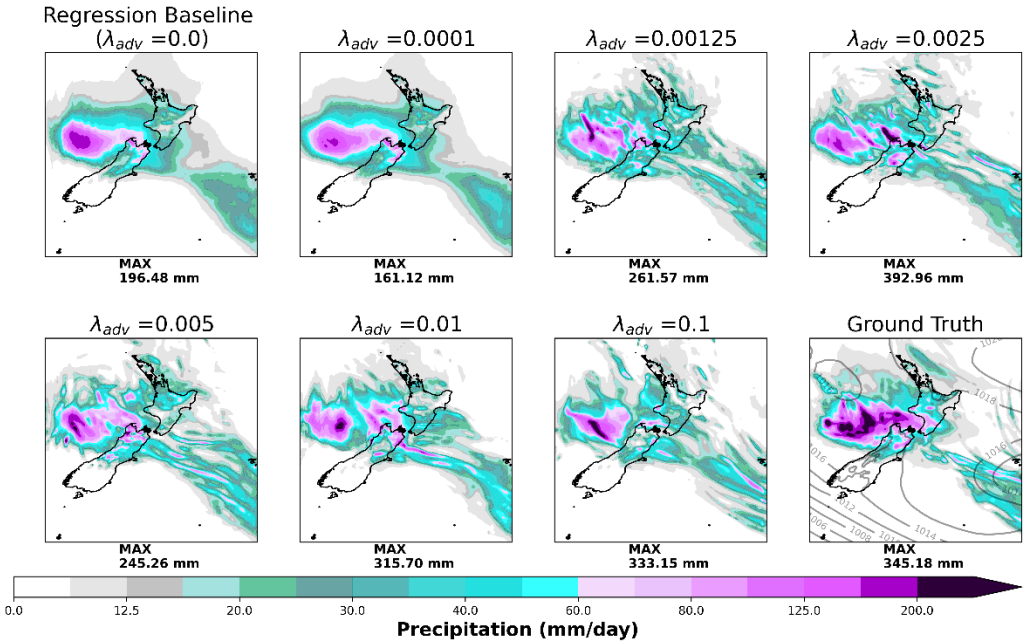


**Figure S2**: Example of daily precipitation predictions from GAN (without the intensity constraint) for a simulated extreme event from EC-Earth3 (2004-01-16), relative to the

ground truth (CCAM downscaling EC-Earth3). The maximum precipitation intensity across the domain is shown in the text below the plot. The contours show CCAM's Mean Sea Level Pressure (MSLP) patterns for the same event.

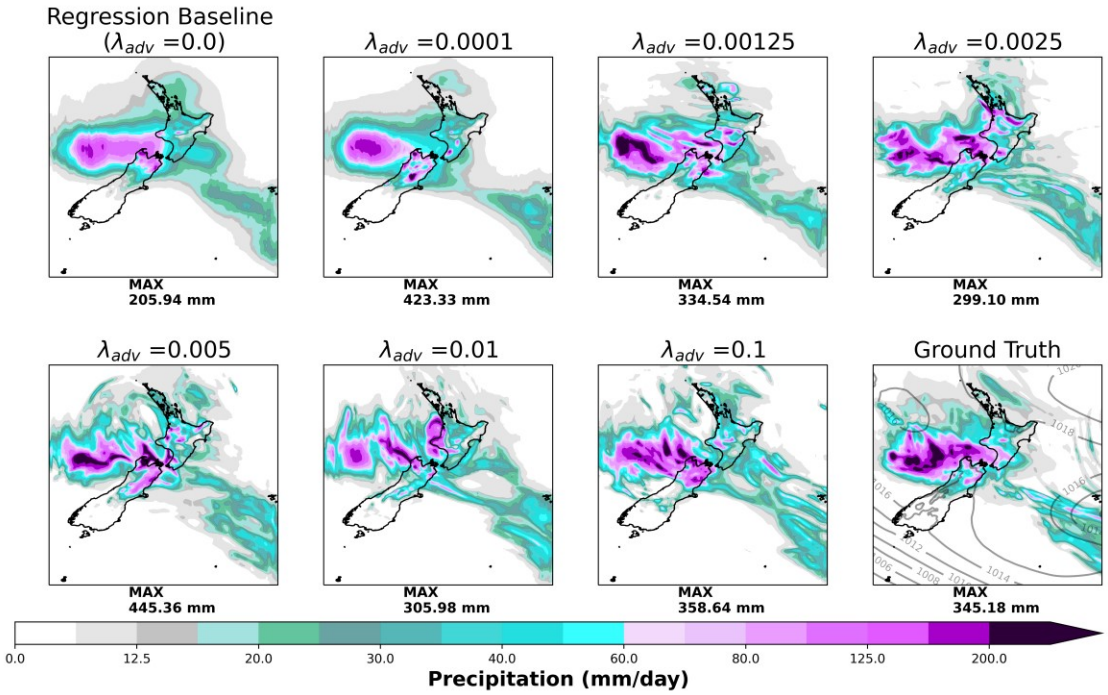


**Figure S3:** Example of daily precipitation predictions from GAN with the intensity constraint for a simulated extreme event from EC-Earth3 (2004-01-16), relative to the ground truth (CCAM downscaling EC-Earth3). The maximum precipitation intensity and average intensity across the domain are shown in the text. The contours show CCAM's Mean Sea Level Pressure (MSLP) patterns for the same event.

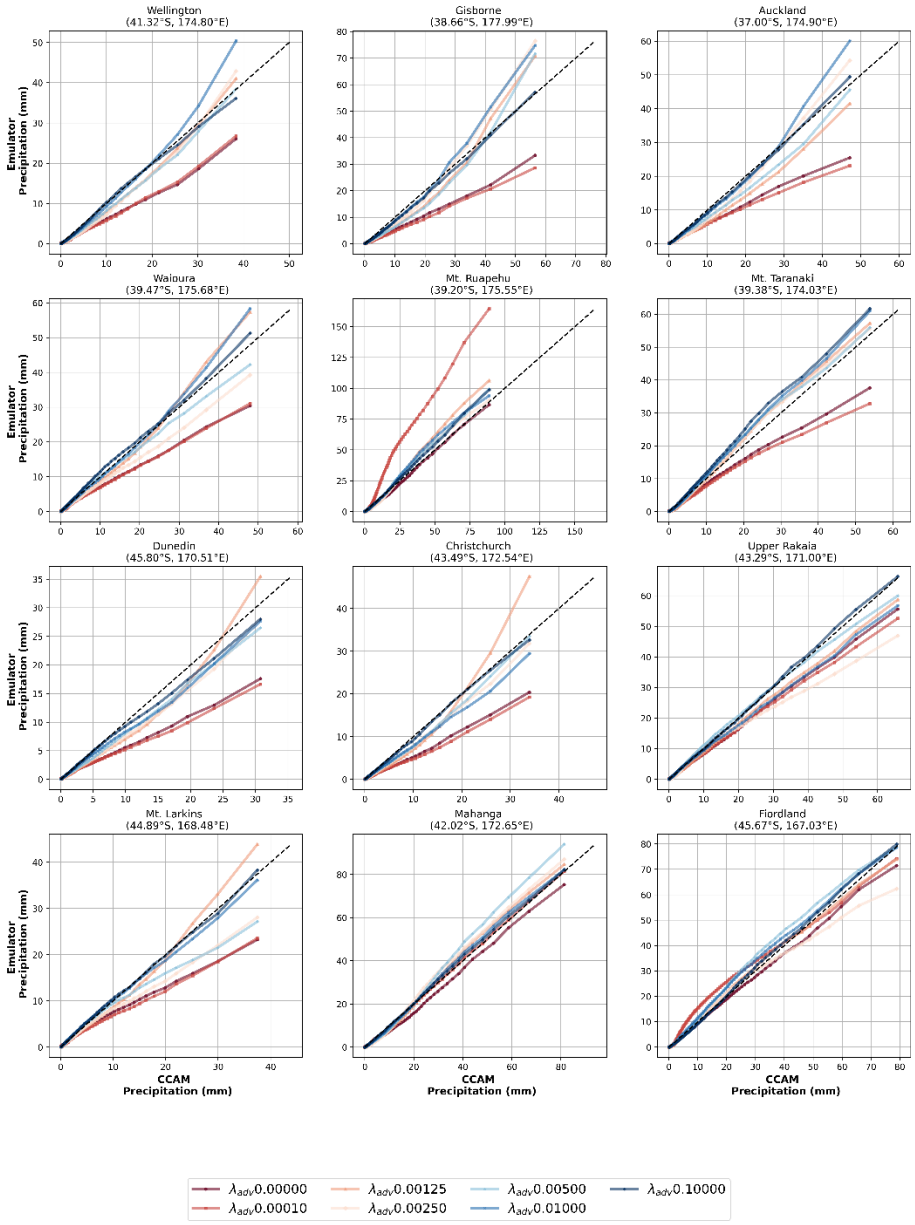


**Figure S4**: Quantile-Quantile (Q-Q) plots for the GAN with the intensity constraint as a function of $\lambda_{adv}$ for 12 selected locations over New Zealand for the EC-Earth3 (perfect framework simulation), which span both Islands and across diverse micro-climates. The quantiles shown here are from the 1st to the 99th quantile in increments of 1. The quantiles have been computed over 20 years from 1986-2005.

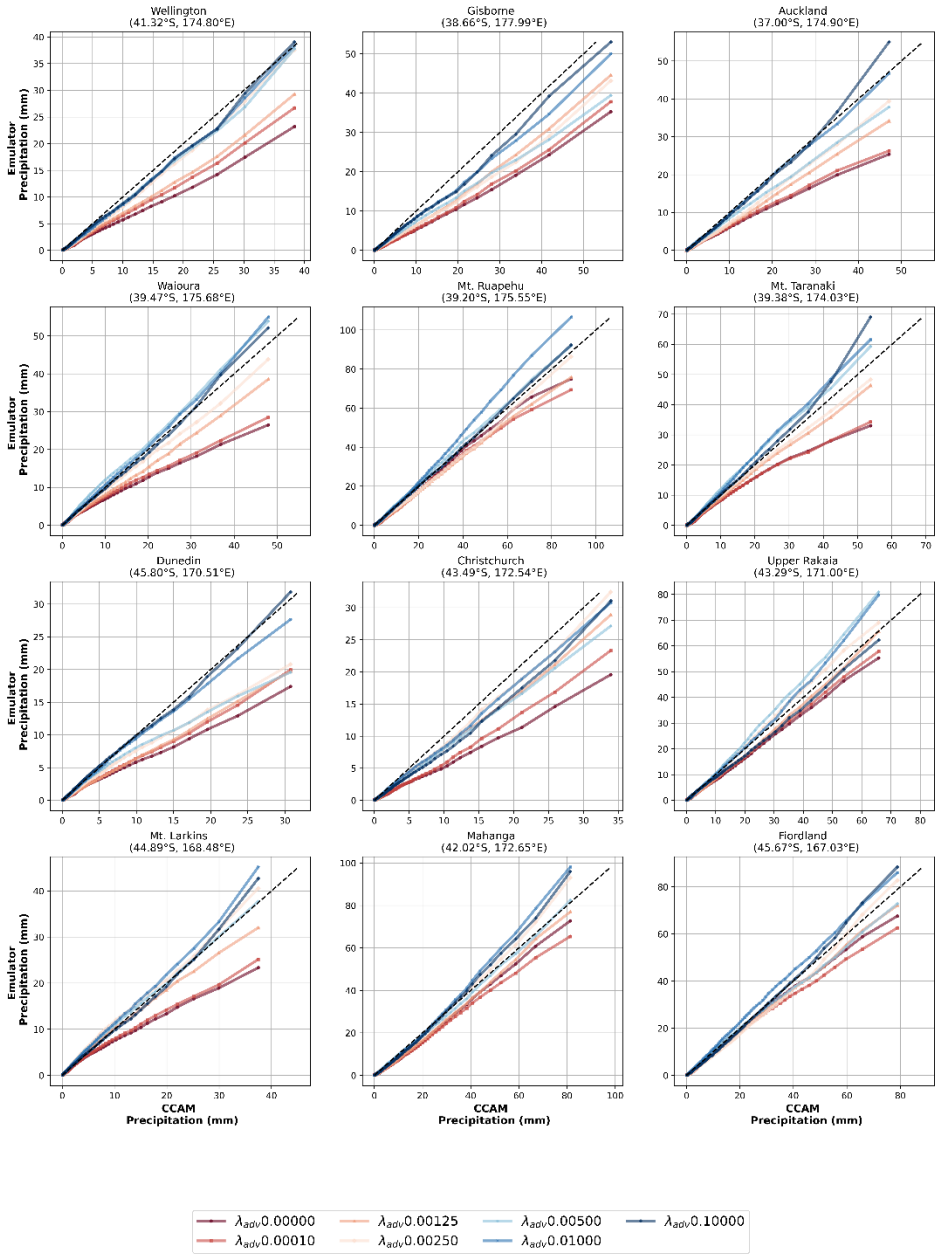


**Figure S5**: Quantile-Quantile (Q-Q) plots for the GAN (without the intensity constraint) as a function of $\lambda_{adv}$ for 12 selected locations over New Zealand for the EC-Earth3 (perfect framework simulation), which span both Islands and across diverse micro-climates. The quantiles shown here are from the 1st to the 99th quantile in increments of 1. The quantiles have been computed over 20 years from 1986-2005.

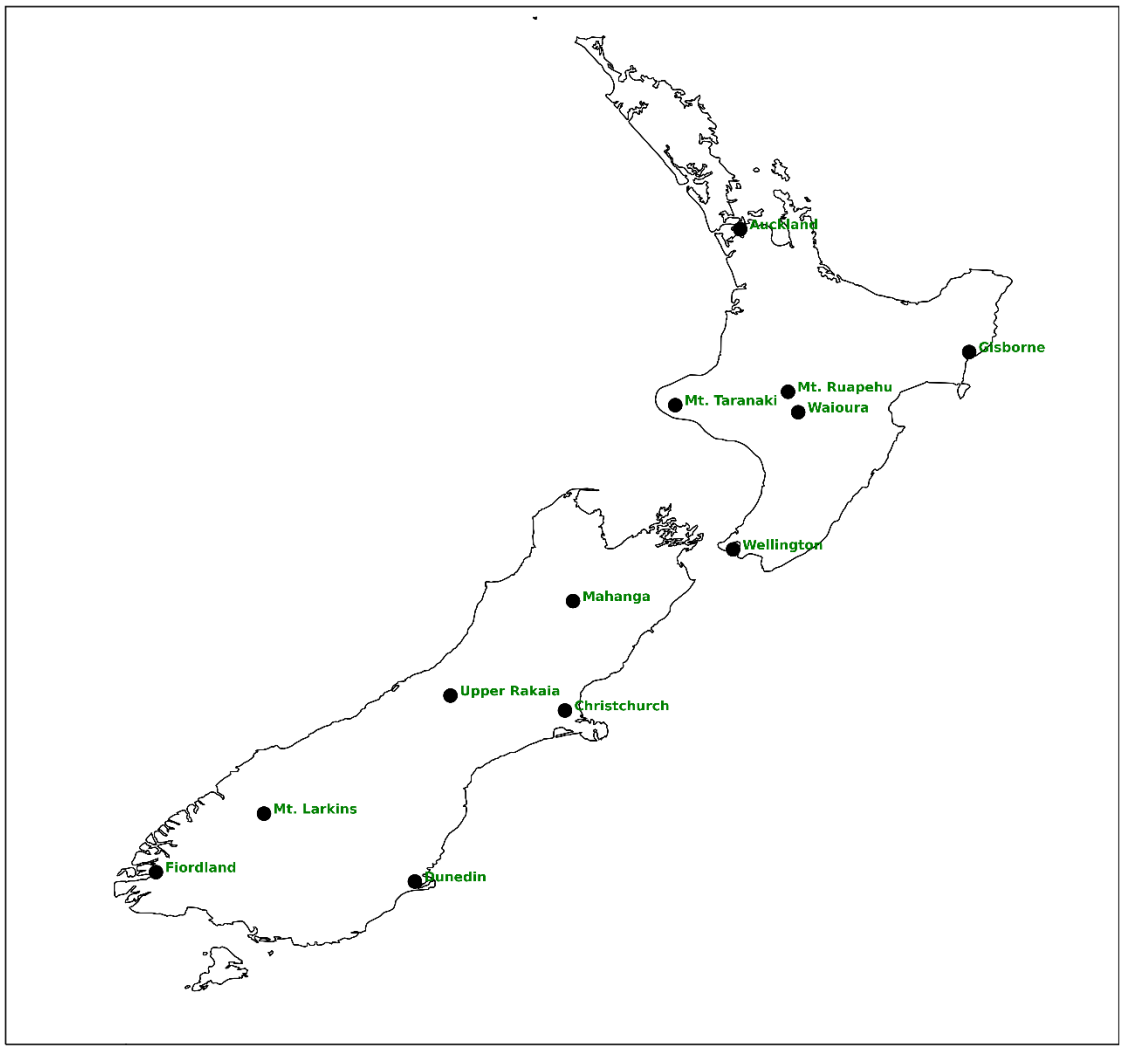


**Figure S6**: The locations of the 12 selected sites for the Quantile-Quantile (Q-Q) in Figure S5 and Figure S6.

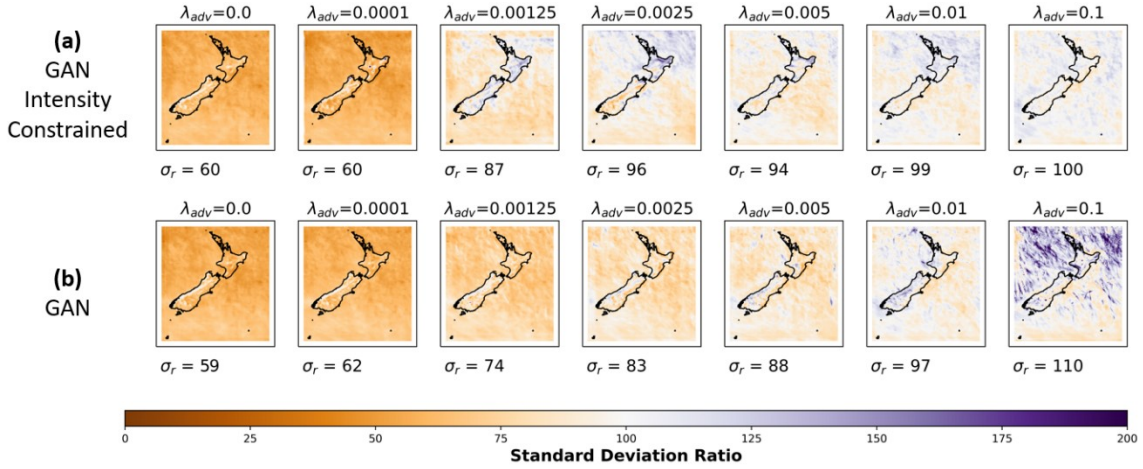


**Figure S7**: The percentage ratio of RCM emulated to ground truth temporal standard deviation in CCAM for the EC-Earth3 simulation. (a) shows the percentage ratio for the LeakyReLU activation with an intensity constraint applied and (b) without the constraint across varying $\lambda_{adv}$. The variance ratio is calculated per grid pixel relative to the CCAM ground truth. The text below each Figure shows the average ratio ($\sigma_r$) across the entire domain.

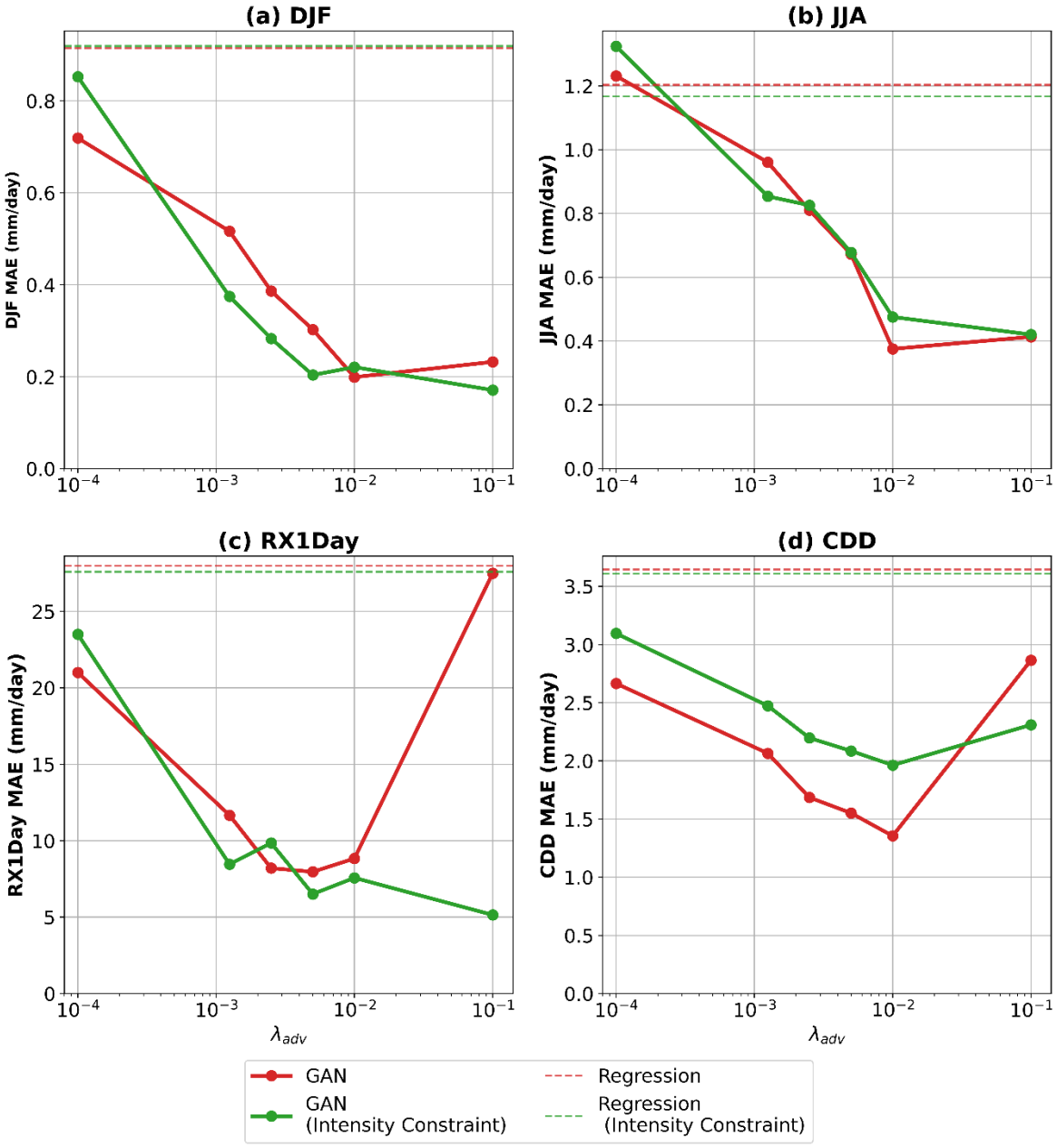


**Figure S8**: The MAE as a function of $\lambda_{adv}$ for the GAN trained with and without the intensity constraint across four key climatological evaluation metrics — DJF precipitation (a), JJA precipitation (b), RX1Day (b), and CDD (c) — relative to ground truth CCAM RCM simulation from NorESM2-MM.


**Figure S9**: In-sample performance of the two GAN loss function configurations as a function of $\lambda_{adv}$; with (i) and without the intensity constraint (ii) in generating DJF and JJA climatological precipitation relative to ground truth CCAM RCM simulations (ACCESS-CM2) for a single ensemble member. The regression baseline is indicated by $\lambda_{adv}$= 0.0. The text for each subplot shows the MAE and the mean bias (MBIAS) relative to ground truth.

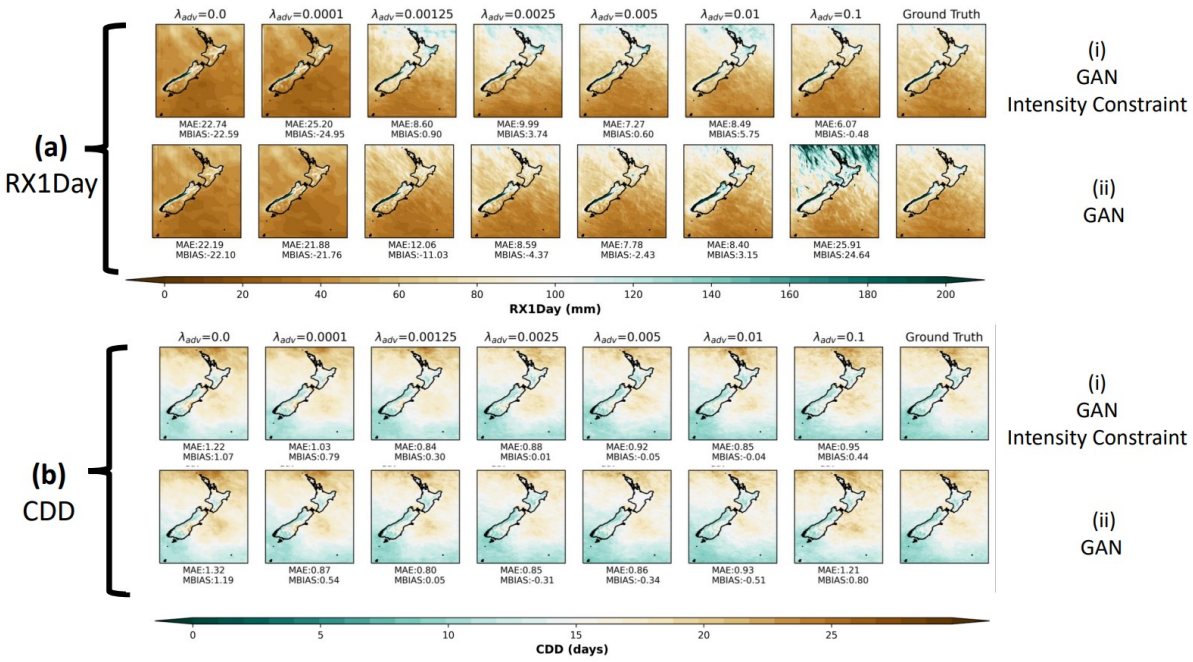


**Figure S10**: In-sample performance of the two GAN loss function configurations as a function of $\boldsymbol{\lambda_{adv}}$; with (i) and without the intensity constraint (ii) in generating climatological RX1Day and CDD relative to ground truth CCAM RCM simulations (ACCESS-CM2) for a single ensemble member. The regression baseline is indicated by $\boldsymbol{\lambda_{adv}}$ = 0.0. The text for each subplot shows the MAE and the mean bias (MBIAS) relative to ground truth.