How Emissions Will Impact Wildfire Risk

Website

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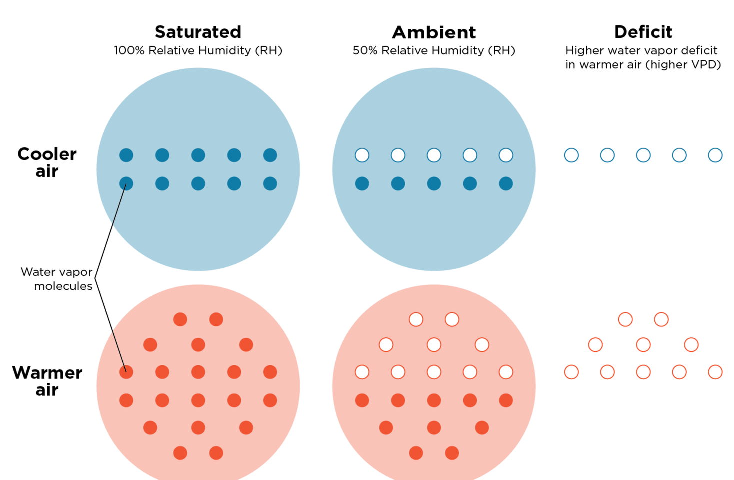
Why Wildfires Are Important

Wildfires are occurrences of uncontrolled fires that spread rapidly across vegetation. These fires have many effects on the ecosystem, including:

- Climate Change Wildfires emit carbon dioxide into the atmosphere, which leads to an increase in temperatures globally.
- Destruction of Vegetation Many plants and soil are destroyed in the process.
- Health effects Smoke from wildfires can cause respiratory issues in humans and animals.

Vapor Pressure Deficit (VPD) represents the difference between the water vapor present in the atmosphere and the maximum amount of water vapor the atmosphere can hold. This can be used to represent how dry plants are within a surface area, which is an indicator of high wildfire chance. We plan to use 3 different machine learning models to analyze how emissions can affect VPD.



Data Background

- Coupled Model Intercomparison Project Phase 6 (CMIP6): A collection of many of the most advanced climate models.
- Community Earth System Model 2 (CESM2): A part of CMIP6 and the specific climate simulation model used in this project.

To calculate VPD, we utilized CESM2's data regarding near-surface relative humidity and near-surface average temperature. To confirm that the data was sufficiently complete, we compared the two variables between two time periods.

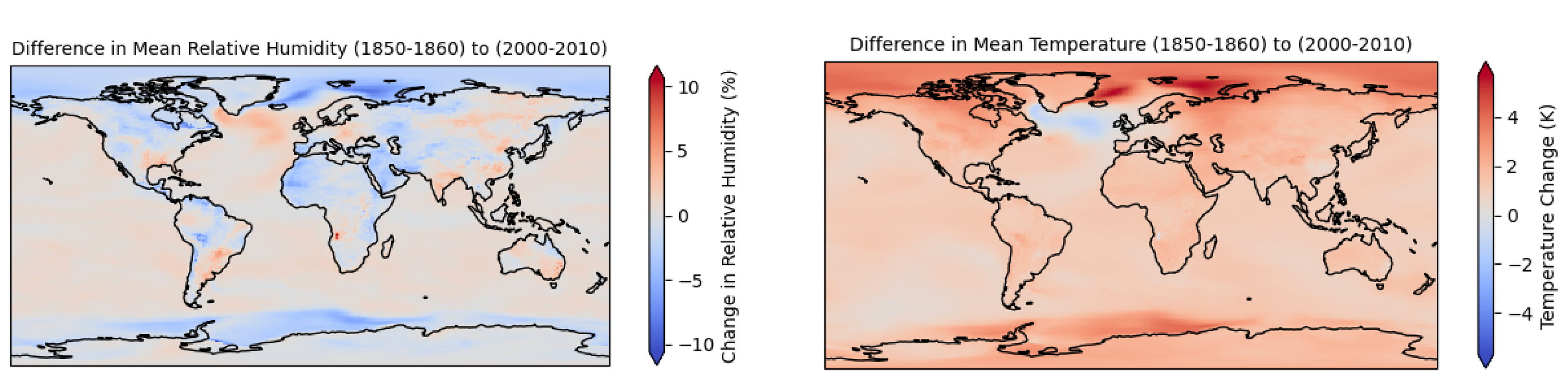


Figure 1. Humidity and Temperature Differences

There are two steps to calculate the VPD using relative humidity and average temperature:

1. Calculate the saturation vapor pressure (SVP) using the Clausius-Clapeyron Equation.

$$SVP = 0.6112 \exp\left(\frac{17.76 \times T}{T + 243.5}\right)$$

2. Calculate the VPD as the difference between relative humidity (RH) and SVP.

$$VPD = \left(1 - \frac{RH}{100}\right) \times SVP$$

The Models We Used

Our models used the emissions of CO_2, CH_4, SO_2 and BC (black carbon) from several different climate scenarios to make predictions of global VPD up to the year 2100. We followed the approach of the ClimateBench paper [4] to test our predictions on the climate change scenario ssp245 (moderate climate change). Like [4], we used the following models:

- Linear Model: We fit a linear model to predict VPD from the global mean temperature. This is our baseline model to compare the performance of our machine learning models.
- Gaussian Process: We performed dimensionality reduction on the aerosol emissions, then fit a GP model with a Matern-1.5 kernel onto the data.
- Random Forest: We used the same dimensionality reduced data as the Gaussian Process to fit a random forest.
- Convolutional Neural Network: We fit a CNN-LSTM trained in 10 year chunks using ReLU activation functions.

Our Models' Predictions

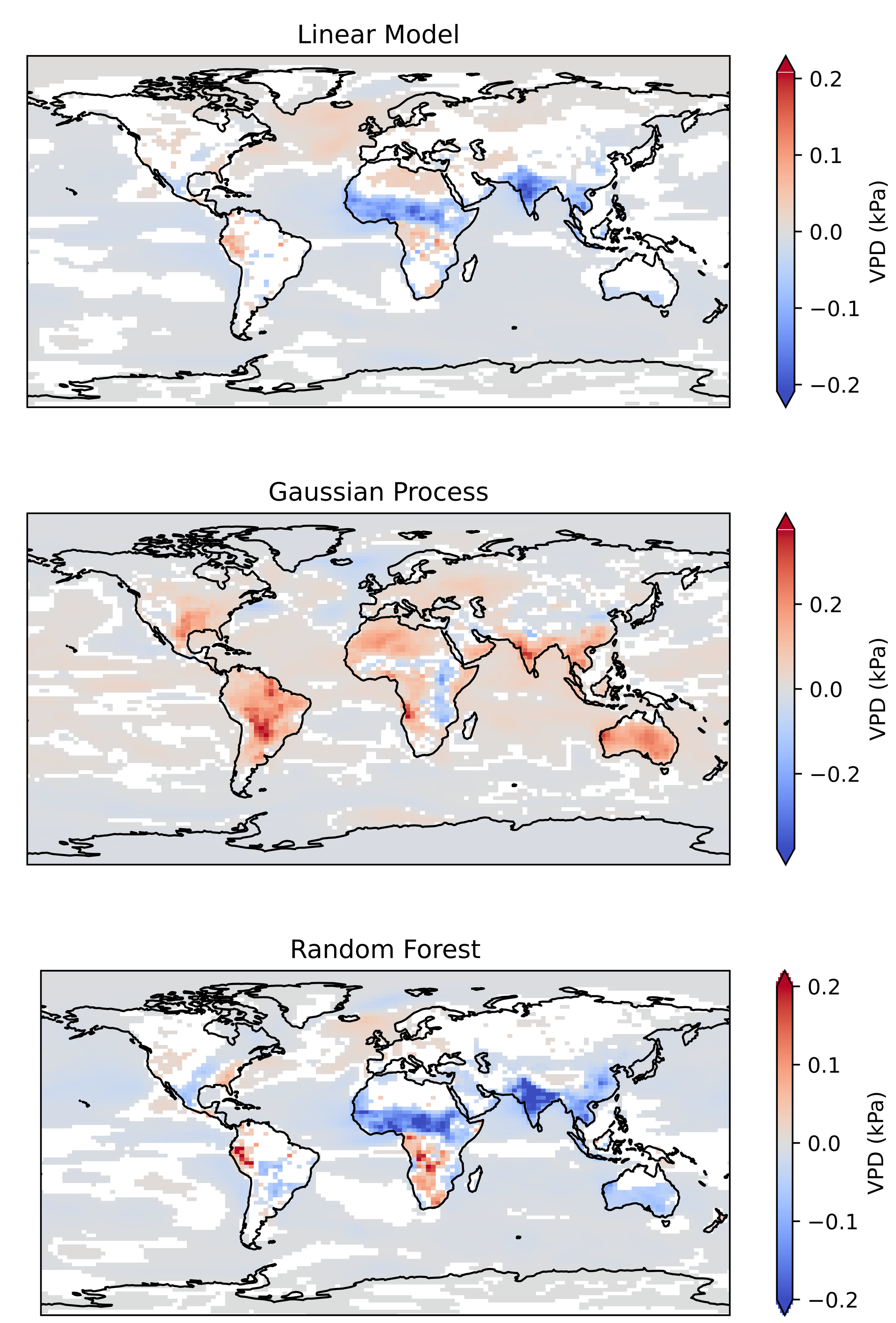


Figure 2. Model Error Comparisons

Results and Discussion

To compare our emulator predictions, we calculate the root-mean square error (RMSE), normalize it spatially (NRMSE_s) and globally (NRMSE_g), then compare using a weighted sum (NRMSE). These are defined in [4] as follows:

$$\text{NRMSE}_s = \sqrt{\langle(|x_{i,j,t}|_t - |y_{i,j,t,n}|_{n,t})^2\rangle} / |\langle y_{i,j}\rangle|_{t,n}$$

$$\text{NRMSE}_g = \sqrt{|(\langle x_{i,j,t}\rangle - \langle|y_{i,j,t,n}|_n\rangle)^2|_t} / |\langle y_{i,j}\rangle|_{t,n}$$

$$\text{NRMSE} = \text{NRMSE}_s + \alpha \cdot \text{NRMSE}_g,$$

where $\langle x_{i,j}\rangle = \frac{1}{N_{lat}N_{lon}}\sum_i^{N_{lat}}\sum_j^{N_{lon}}\cos(\text{lat}(i))x_{i,j}$ is the global mean, and $\alpha = 5$. In the following table, we compare the NRMSE results of each of our models. Global NRMSE represents the global averages across the Earth, while spatial is concerned with differences in individual regions.

Model	Spatial	Global	Total
Linear	**0.036**	**0.012**	**0.096**
CNN	0.074	0.075	0.456
GP	0.079	0.027	0.212
RF	0.051	0.019	0.144

Table 1. NRMSE results of different climate models used.

The linear model performed best when calculating the spatial, global, and total NRMSEs. This indicates a very linear relationship between global emissions and vapor pressure deficit.

Future Direction

Additional data to analyze

To further improve our results we can utilize other variables within the dataset to increase accuracy. For example, we could look at evapotranspiration, wind direction, and other variables that might not have as large an impact as VPD but could still contribute to greater accuracy.

Another approach we can take to improve the real-world implication of our model could be to find where trees and other possible flammable plants are prevalent on Earth. Combining our VPD data with this data will allow us to predict where wildfires will occur with greater accuracy.

Improvements to Model

To increase the accuracy of our models in how they apply to predicting wildfires, we can focus on predicting VPD only over land. This would make our models' predictions more focused on the locations where wildfires can actually occur.

References

[1] Clausius-clapeyron equation. *American Meteorological Society: Glossary of Meteorology*, Jan 2024.

[2] J. T. Randerson F. Sedano. Multi-scale influence of vapor pressure deficit on fire ignition and spread in boreal forest ecosystems. *Biogeosciences*, 2014.

[3] Carly Phillips. What is vapor pressure deficit (vpd) and what is its connection to wildfires? *Union of Concerned Scientists*, Apr 2023.

[4] Rao Y. Olivié D. Seland Ø. Nowack P. Camps-Valls G. et al. Watson-Parris, D. Climatebench v1.0: A benchmark for data-driven climate projections. *Journal of Advances in Modeling Earth Systems*, 14, 2022.