Building Damage Classification Post Natural Disasters for Optimized Relief

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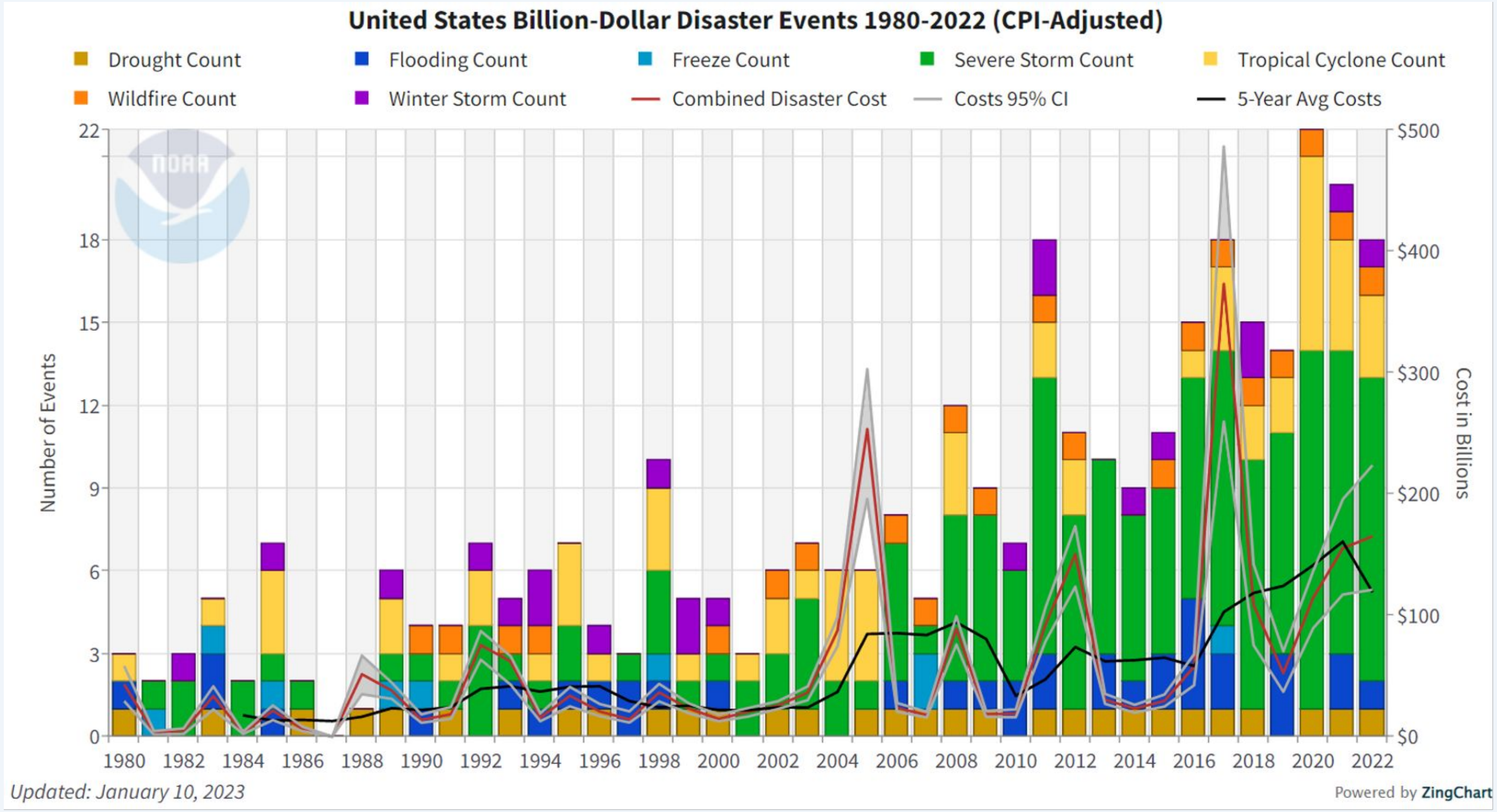
PROBLEM STATEMENT

Prioritization after post-disaster is key

Essential to determine which areas have suffered the most damage

Most urgent decisions need to be made within 48-72 hours; therefore manual assessment is not practical

MONEY SPENT ON DISASTER RELIEF (US)



IMPACT

- Research suggests that climate change will result in more natural disasters over time

- With rising temperatures, we can expect more intense natural disasters, therefore we need better tools to assist in disaster relief

TARGET USERS

- Crisis Responders
- Governments
- Non-Governmental Organizations
- Multilateral Organizations

WFP
World Food Programme

United Nations CERF
Central Emergency Response Fund

TARGET USER QUOTES

"We don't just care about the buildings. We care about the **people** in them."
- World Food Programme Staff

"During prioritization and targeting phases, the algorithm would be really useful alongside **population and vulnerability data**."
- World Food Programme Staff

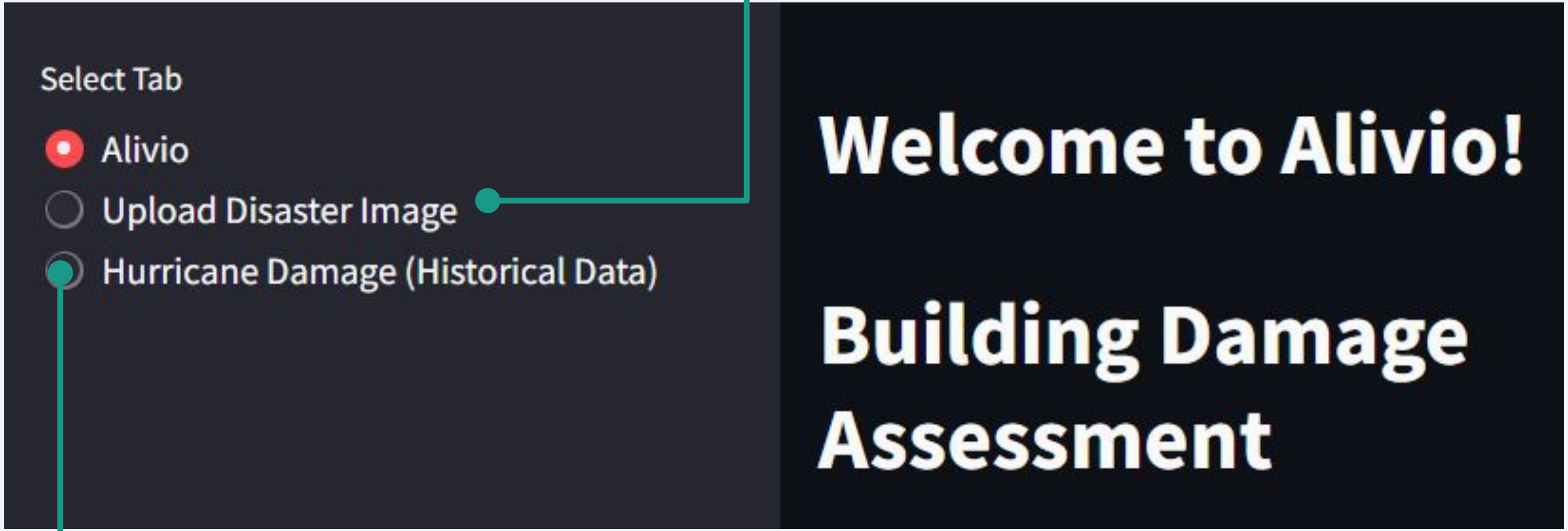
KEY USER QUESTIONS

Question 1: Which areas are **most severely damaged** post-disaster?

Question 2: Based on damage, population, and vulnerability data, **which area needs to be prioritized**?

DEMO

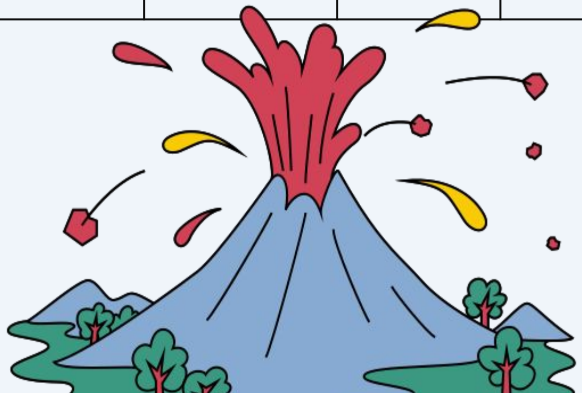
This tab is where you can upload a satellite image and building polygons to assess damage.

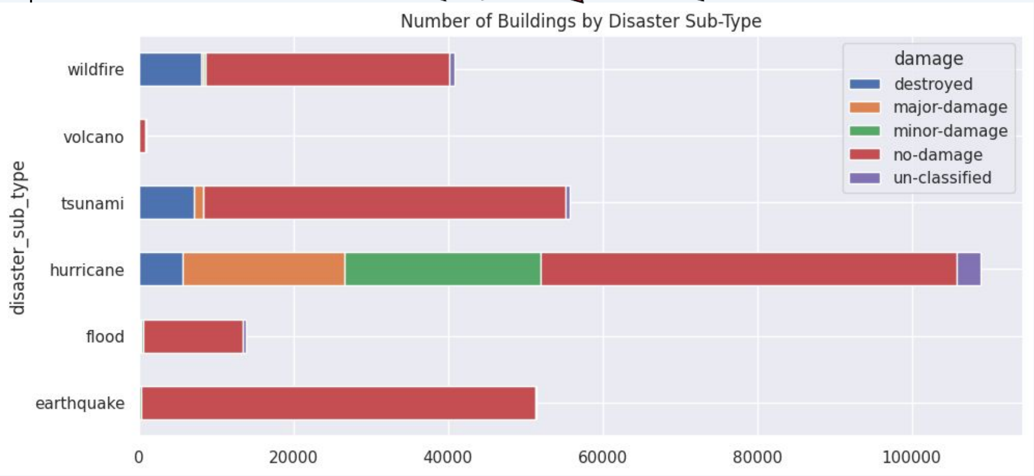


This tab shows historical data of hurricane damage, including building polygon layer and optional h3 layers.

DATASET - SUMMARY

Disaster Type	Building Count	Image Count	Buildings Per Image
Tsunami	55789	196	285
Earthquake	51473	193	267
Hurricane	108968	2023	54
Volcano	991	28	35
Flood	13896	445	31
Wildfire	40924	1780	23

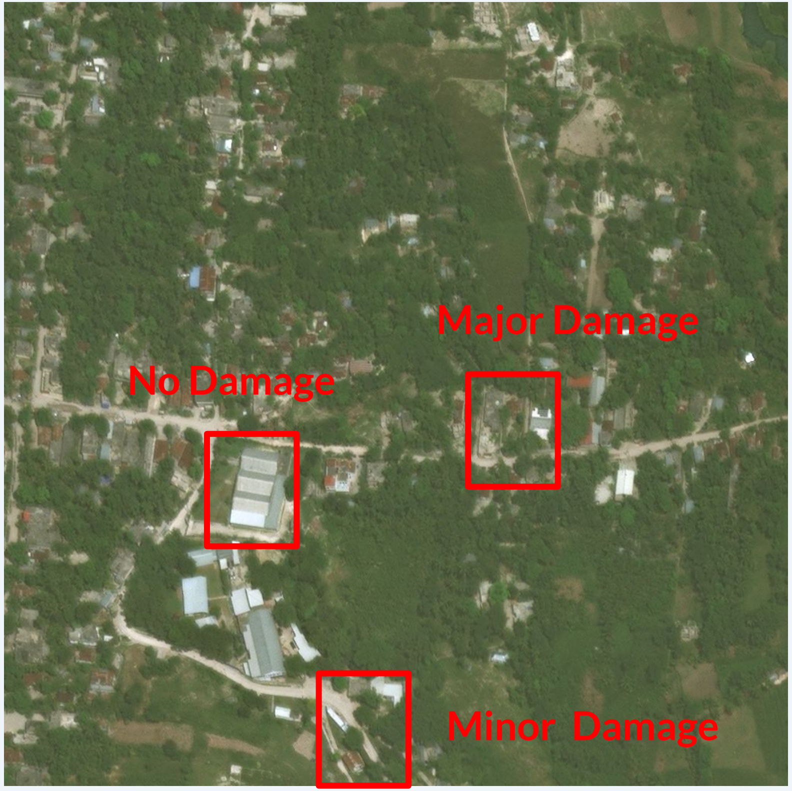




CLASS IMAGE SAMPLES

PRE- DISASTER

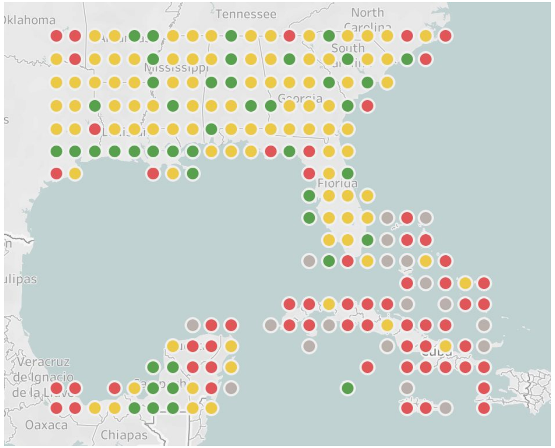
POST-DISASTER



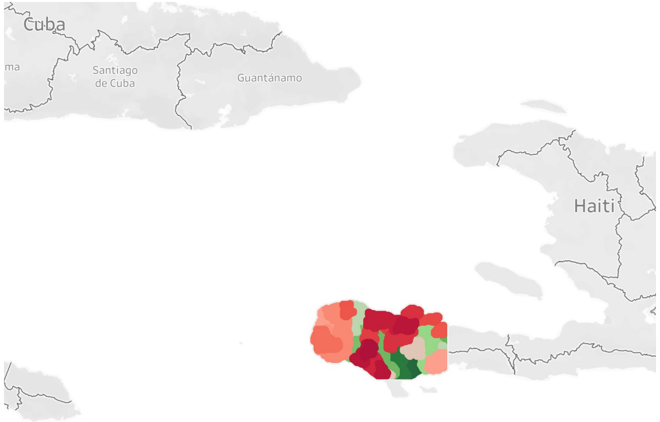
SECONDARY DATA - RASTER DATA FOR VULNERABILITY

RAW POPULATION DATA + RAW GDP & FOOD DATA
(FILTERED FOR HURRICANE AREA)

GDP PER CAPITA



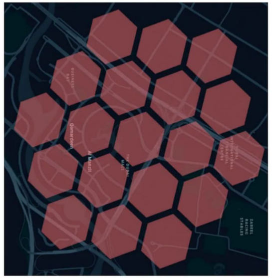
FOOD INSECURITY



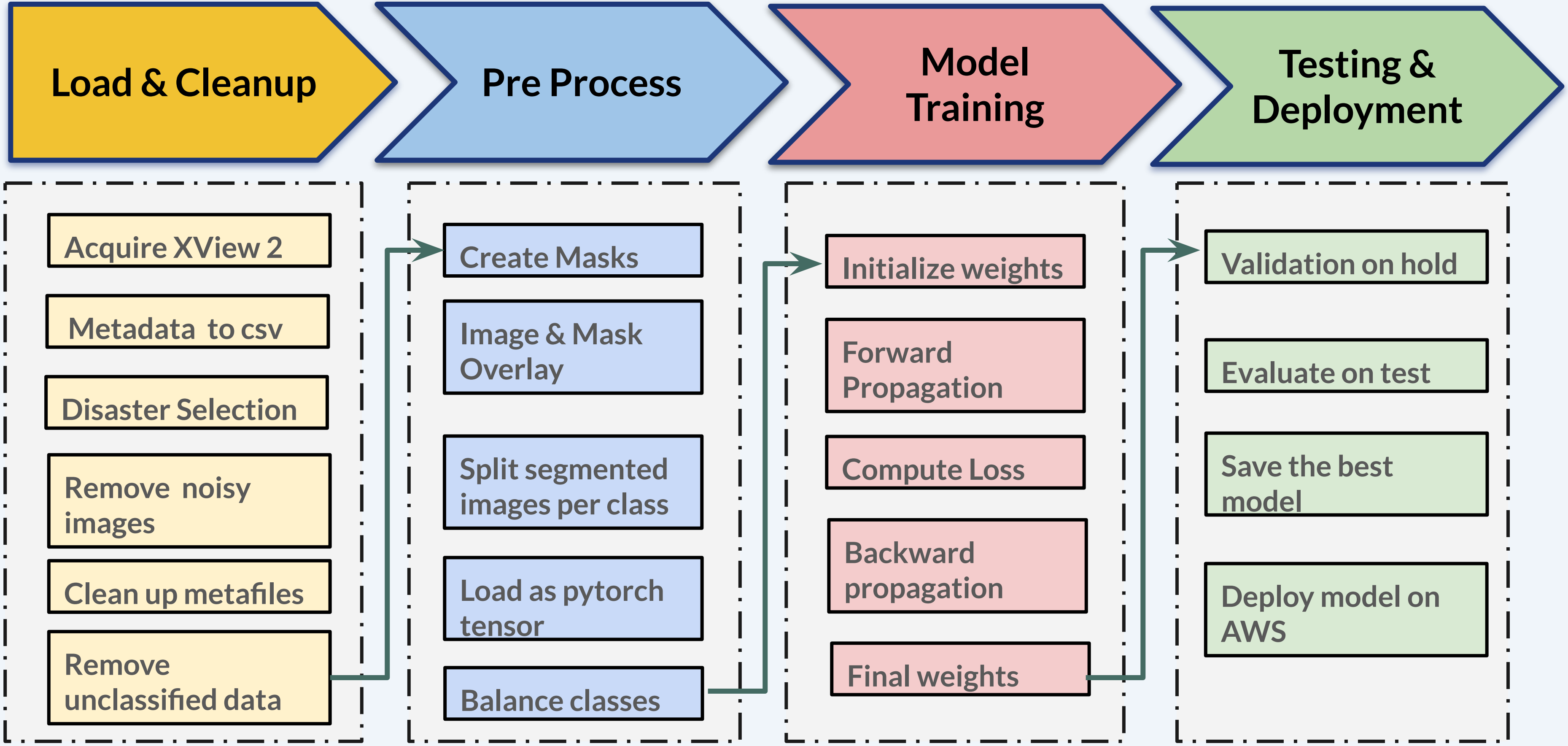
SECONDARY DATA - H3 HEXAGONS

H3 is a geospatial analysis tool that provides a hexagonal, hierarchical spatial index to gain insights from large geospatial datasets. **The building blocks of H3 are different sized regular hexagonal polygons.**

H3 Resolution	Average Hexagon Area (km^2)	Average Hexagon Edge Length (km)	Number of unique indexes
0	4,250,546.8477000	1,107.712591000	122
1	607,220.9782429	418.676005500	842
2	86,745.8540347	158.244655800	5,882
3	12,392.2648621	59.810857940	41,162
4	1,770.3235517	22.606379400	288,122
5	252.9033645	8.544408276	2,016,842
6	36.1290521	3.229482772	14,117,882
7	5.1612932	1.220629759	98,825,162
8	0.7373276	0.461354684	691,776,122

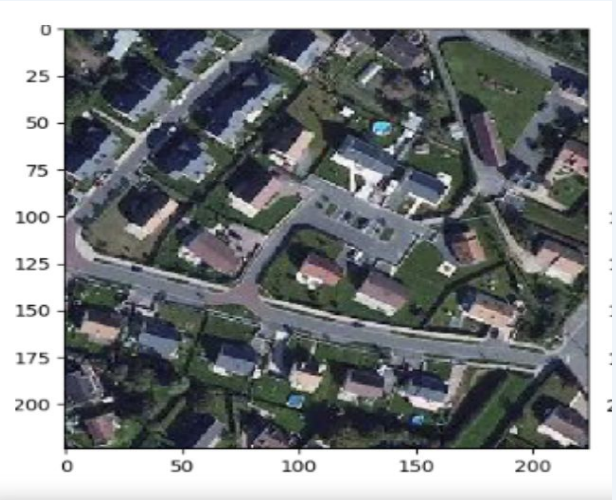


ML PIPELINE


Load & Cleanup
Pre Process
Model Training
Testing & Deployment
Acquire XView 2
Metadata to csv
Disaster Selection
Remove noisy images
Clean up metafiles
Remove unclassified data
Create Masks
Image & Mask Overlay
Split segmented images per class
Load as pytorch tensor
Balance classes
Initialize weights
Forward Propagation
Compute Loss
Backward propagation
Final weights
Validation on hold
Evaluate on test
Save the best model
Deploy model on AWS

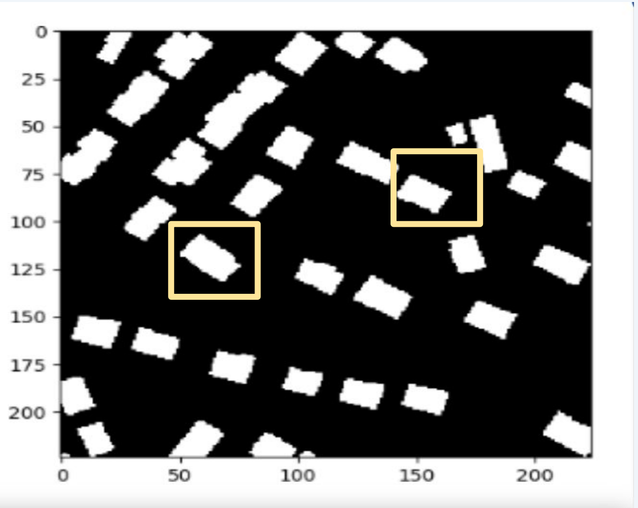
SEGMENTATION

The process of identifying a region on the image that represents same target class



MASKING

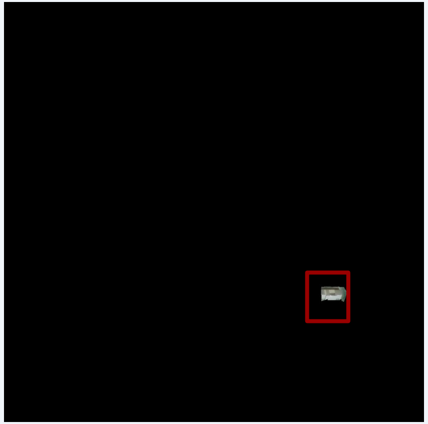
The process of separating the segmented region from its background and can be achieved by darkening the the background



PRE PROCESS PIPELINE

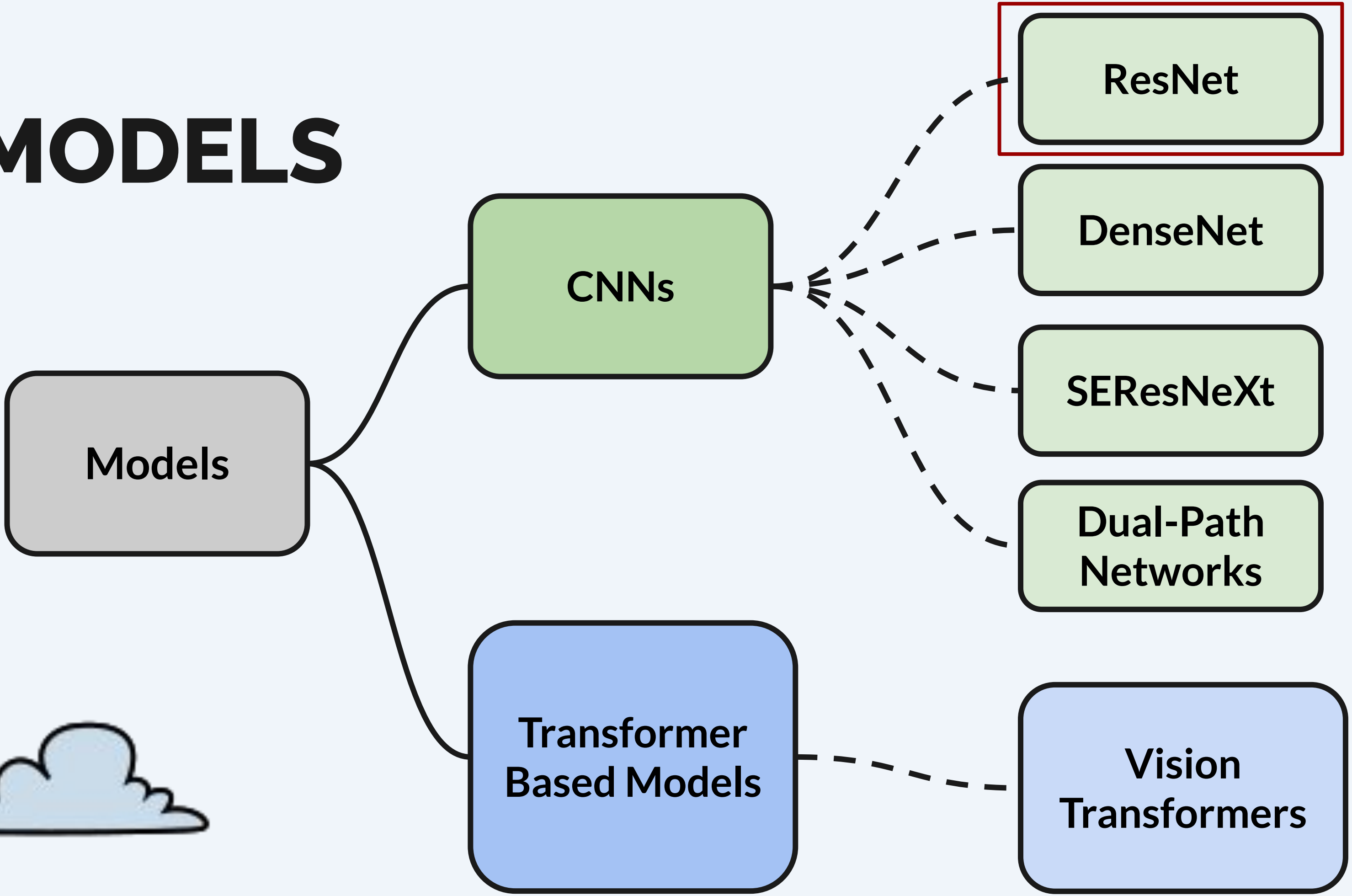
Original Image

Masked & Segmented Image

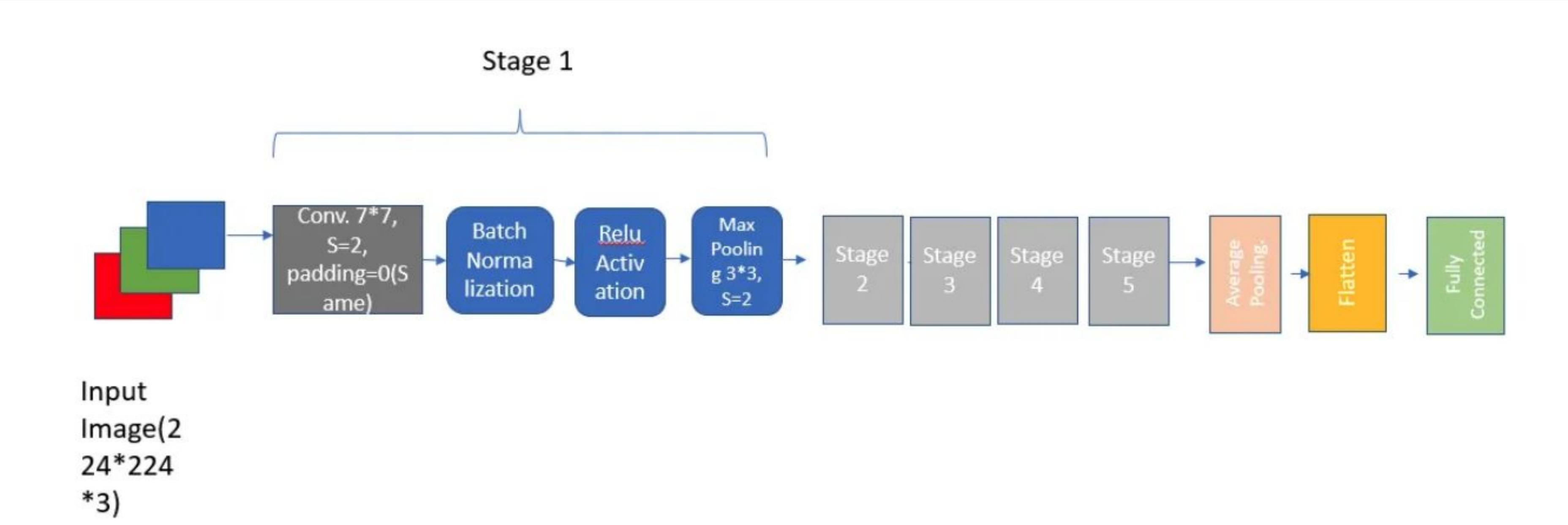


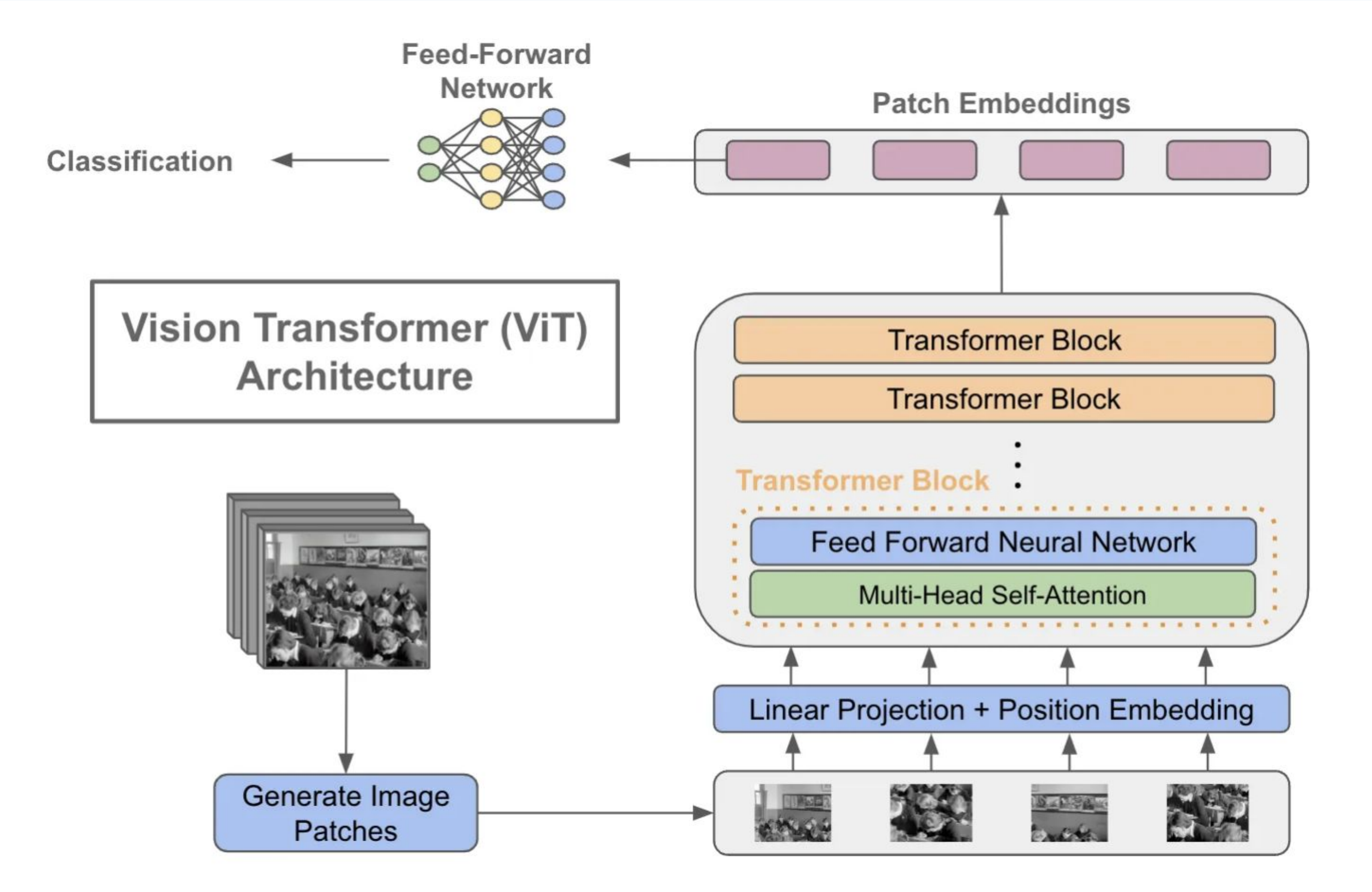
Cropped version - Input to VIT

MODELS

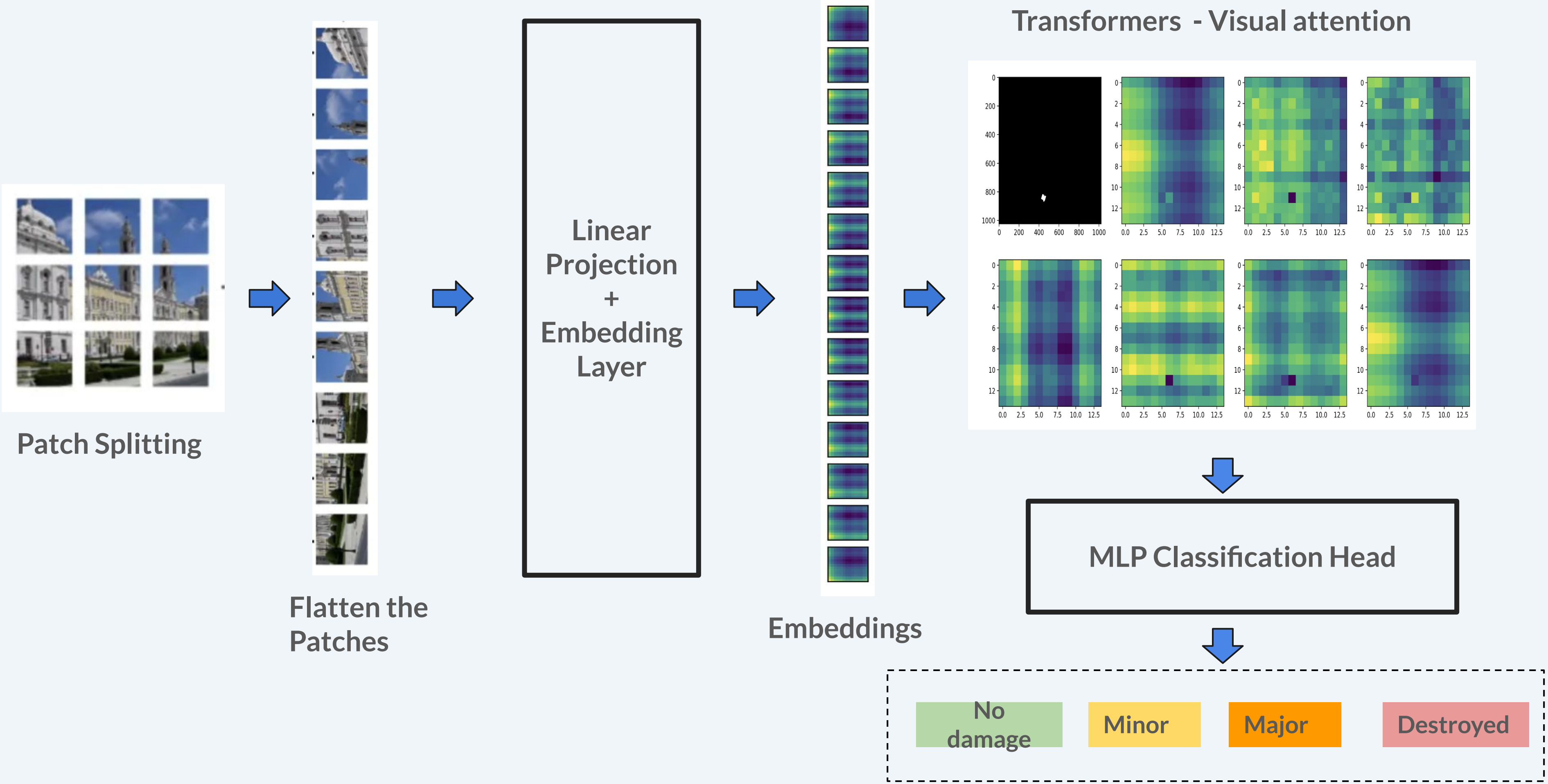

Models
CNNs
Transformer Based Models
ResNet
DenseNet
SEResNeXt
Dual-Path Networks
Vision Transformers

CNN - RESNET ARCHITECTURE

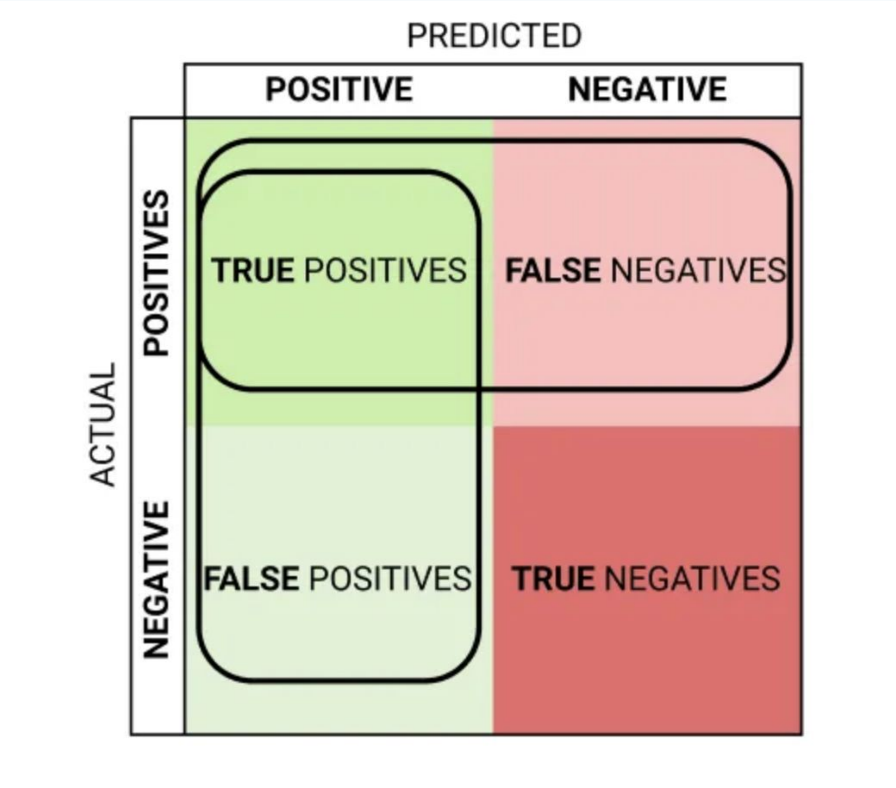



Feed-Forward Network
Patch Embeddings
Classification
Vision Transformer (ViT) Architecture
Transformer Block
Transformer Block
Transformer Block
Feed Forward Neural Network
Multi-Head Self-Attention
Linear Projection + Position Embedding
Generate Image Patches

UNDER THE HOOD - VISION TRANSFORMERS



METRICS



Precision

$$\frac{\textbf{TRUE POSITIVES}}{\textbf{TRUE POSITIVES} + \textbf{FALSE POSITIVES}}$$

Recall

$$\frac{\textbf{TRUE POSITIVES}}{\textbf{TRUE POSITIVES} + \textbf{FALSE NEGATIVES}}$$

$$\text{Accuracy} = \frac{(TP + TN)}{(TP + FP + TN + FN)}$$

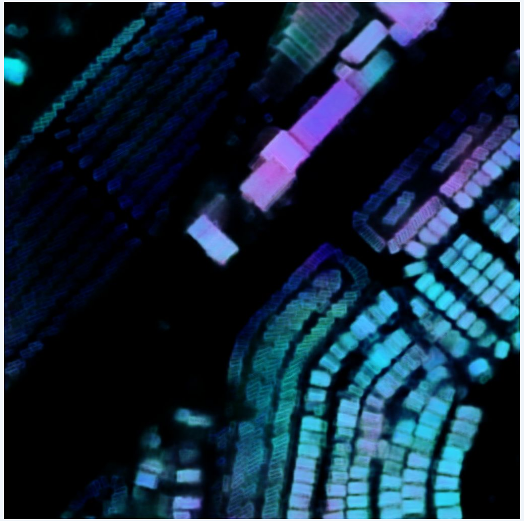
$$F1 = 2 \times \frac{Precision * Recall}{Precision + Recall}$$

$$\text{Dice} = \frac{2 * |X \cap Y|}{|X| + |Y|}$$

EVALUATION RESULTS

Model	Epochs	Weight Decay	Learning rate	F1-score				
				No Damage	Minor Damage	Major Damage	Destroyed	Combined
VIT	30	0.075	0.0001	64.47	52.78	38.65	42.81	55.79
ResNet 34	20	0.000001	0.00015	87.33	60.29	80.19	48.85	65.60
SeResNext 50	20	0.000001	0.00015	87.44	53.71	76.91	45.31	61.42
SeNet 154	16	0.000001	0.00015	84.44	45.68	59.48	29.00	48.58
DPN 92	10	0.000001	0.00015	84.49	35.98	59.30	34.48	48.33
ResNet34 BL	10	0.000001	0.00015	75.88	33.48	46.27	35.95	43.25

EVALUATION CONCLUSIONS



- F1 scores best on “No Damage” class
- Challenges distinguishing between damaged classes
- Both VIT and CNNs perform well on hurricanes —inconclusive which model will perform on all natural disasters

BEST PERFORMING VIT MODEL

```
AdamW (
Parameter Group 0
    amsgrad: True
    betas: (0.9, 0.999)
    capturable: False
    differentiable: False
    eps: 1e-08
    foreach: None
    fused: None
    lr: 0.00097
    maximize: False
    weight_decay: 0.0075
)
```

BEST PERFORMING VIT EVALUATION RESULTS

Overall

F1-Scores: 54.87%

Test accuracy: 53.42%

Precision: 59.29%

Recall: 53.42%

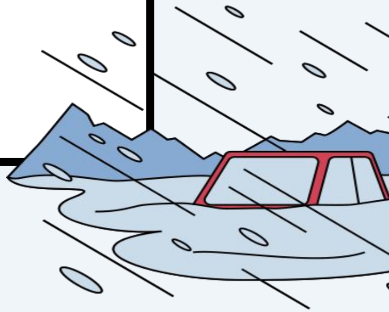
Class-Wise Metrics

Destroyed : 72%

Major-Damage: 40%

Minor-Damage: 56%

No-Damage: 54%



TECHNICAL CHALLENGES

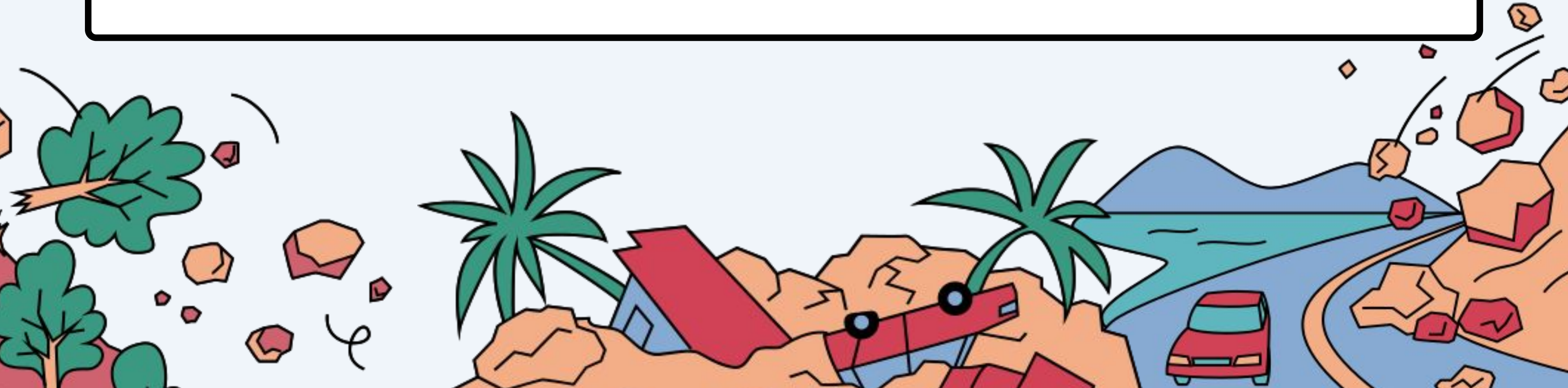
- Low resolution satellite images
- Segmentation and masking
- Pre-processing data

FUTURE PLANS

- Use staged approach to use *both* CNNs and VIT
- Process new satellite images without polygons provided–polygonize output for localization models
- Expand model to other natural disasters such as floods, fires, and earthquakes

CONCLUSION

We have used machine learning and satellite imagery to identify areas that have been hardest hit by hurricanes and combined it with demographic data to make clear where vulnerable populations in those areas live.



QUESTIONS?

APPENDIX

SECONDARY DATA -
RASTER LEVEL DATA TO MEASURE INVULNERABILITY

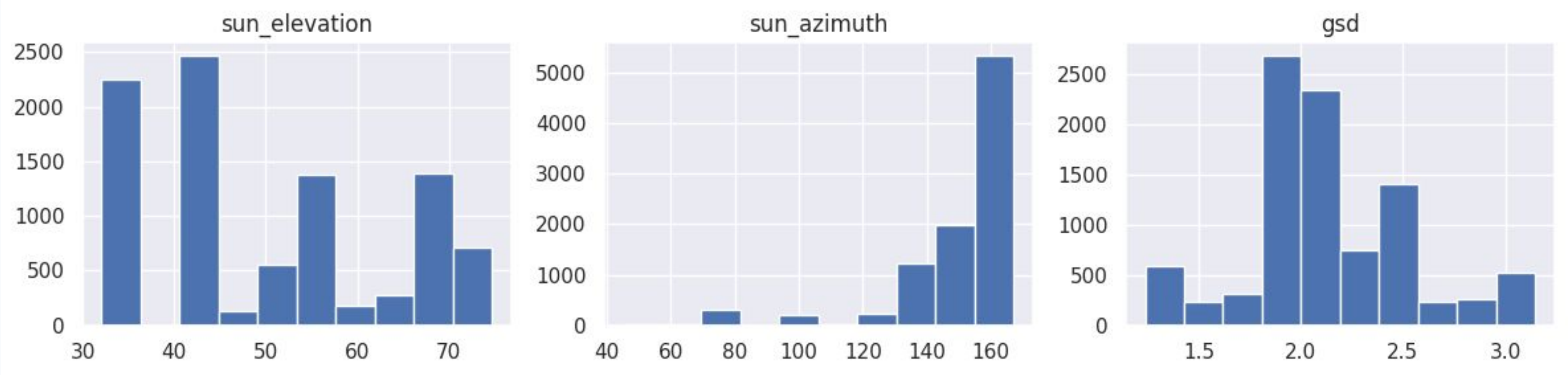
Raster Data - a spatial resolution of 30 arc-seconds (~1 km at equator)

- **Population Data*** -Population input data are collected from the results of the 2010 round of Population and Housing Censuses. We are using 2020 projected data. To create the raster population data sets, the population estimates were distributed to raster level using an areal-weighting method.

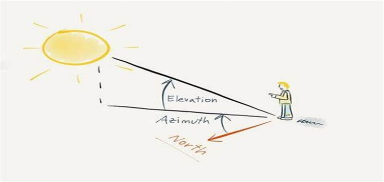
- **GDP Data**** - Use LitPop (nighttime light images and the LandScan Global Population database) maps to disaggregate national GDP in 2005 and to downscaled to raster level, and we are using 2020 projected data.

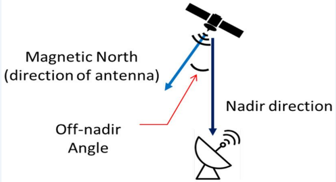
- **Food Insecurity Hotspot Data***** - The Famine Early Warning Systems Network (FEWS NET) periodically collaborate with partners on household surveys as well as joint assessments in in hotspot areas that have experienced consecutive food insecurity events. The food insecurity level ranging from 1 to 5, with 1: Minimal, 2: Stressed, 3: Crisis, 4: Emergency, and 5: Famine. What we are using are the average of the quarterly reported data over the 10 year period.

SATELLITE IMAGERY TERMS



- **GSD:** the distance between two consecutive pixel centers measured on the ground. The bigger the value of the image GSD, the lower the spatial resolution of the image and the less visible details.
- **Azimuth and Elevation:** are two angles that describe the position of a point in the sky. **Azimuth** is the measure of direction in the horizontal plane, starting from the north and going clockwise. **Elevation** is the measure of height in the vertical plane, starting from the horizon and going up.



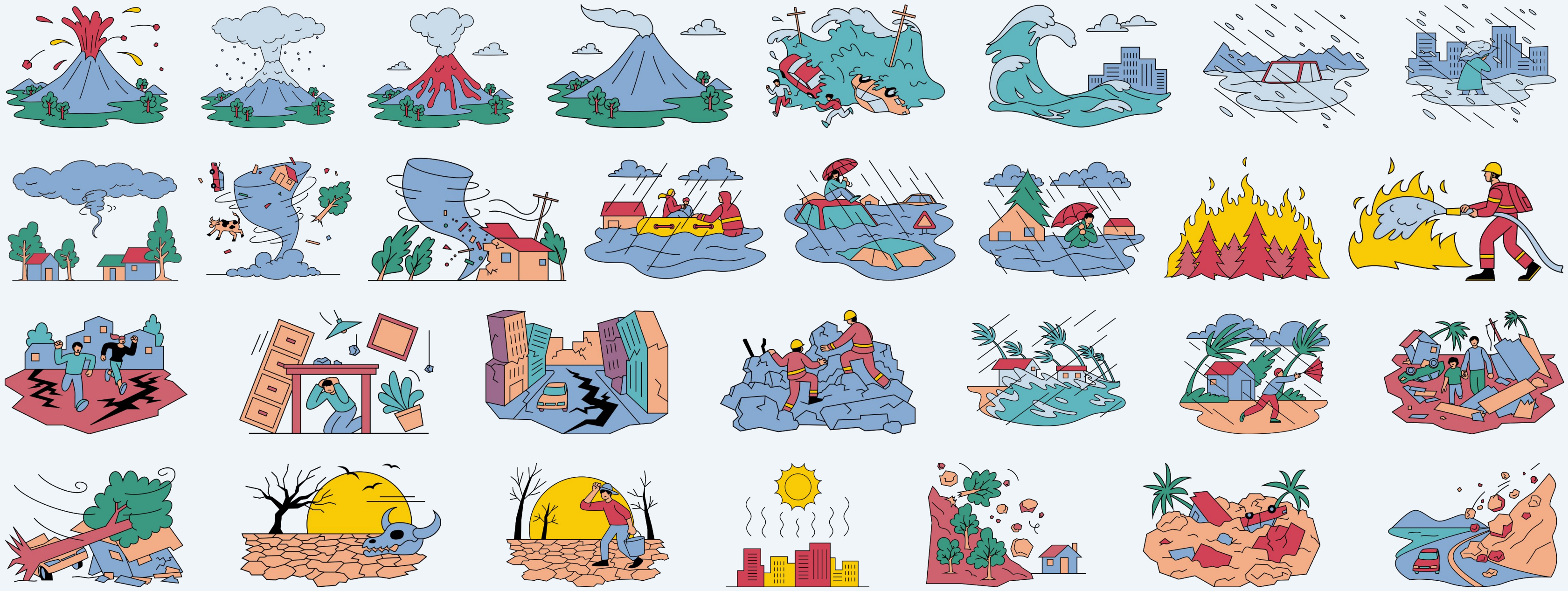


NATURAL DISASTERS

Natural disasters refer to extreme and catastrophic events caused by natural processes or forces, resulting in significant damage, destruction, and loss of life.

These events occur without human intervention and can have severe impacts on the environment, infrastructure, and communities.

RESOURCE PAGE



WHAT TO DO?

Be prepared for aftershocks and continue to follow the "Drop, Cover, and Hold On" technique.

If you are indoors, stay there. Avoid running outside during the shaking, as falling debris or broken glass may pose a risk.

Stay informed about the latest updates and information from local authorities regarding the earthquake and potential aftershocks.

Keep away from potential hazards, such as tall furniture, bookshelves, or cabinets that could topple over.