Application of Convolutional Neural Network to the forecasts of flare classification and occurrence using SOHO MDI data

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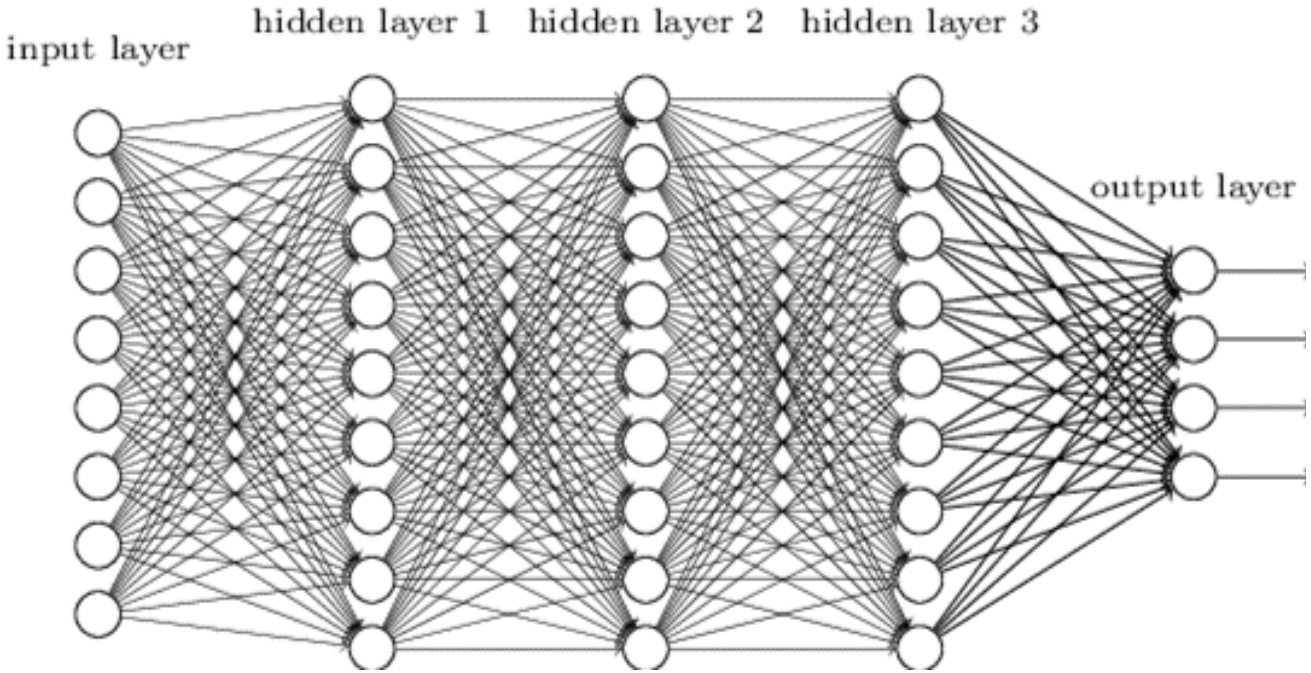
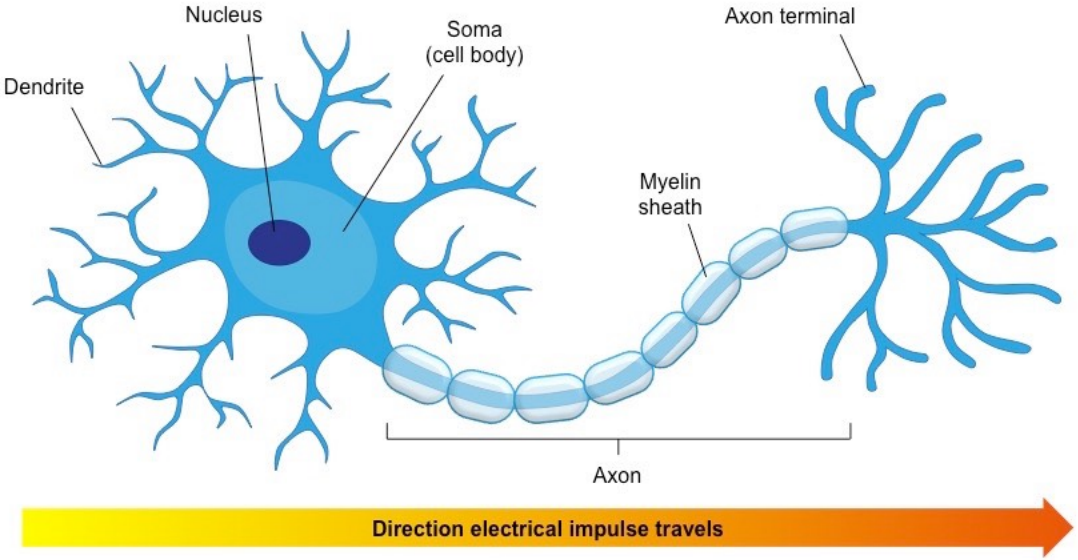
Introduction

Introduction – Deep Learning (Deep Neural Network, DNN)

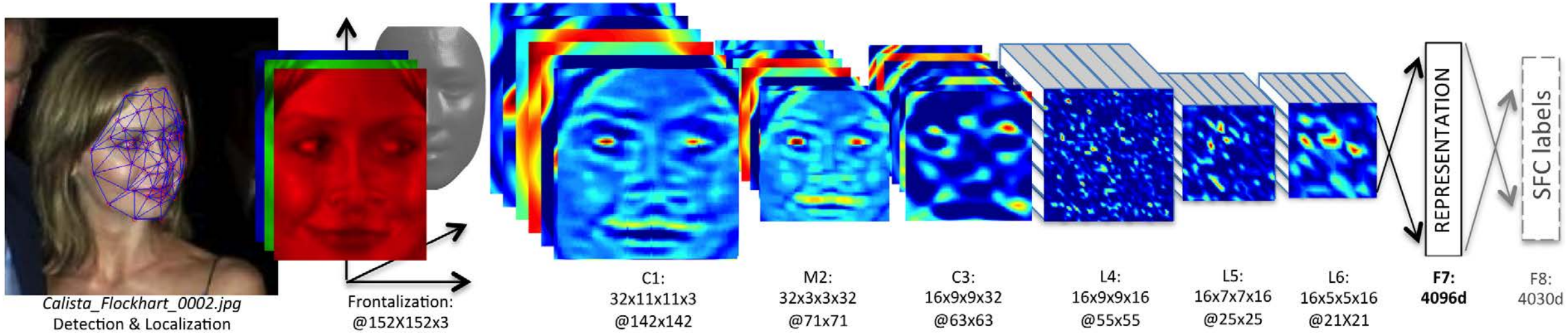
Deep neural network





A deep neural network is a kind of an artificial neural network, which is developed to learn the way human think and recognize an object, using deep layer structure.

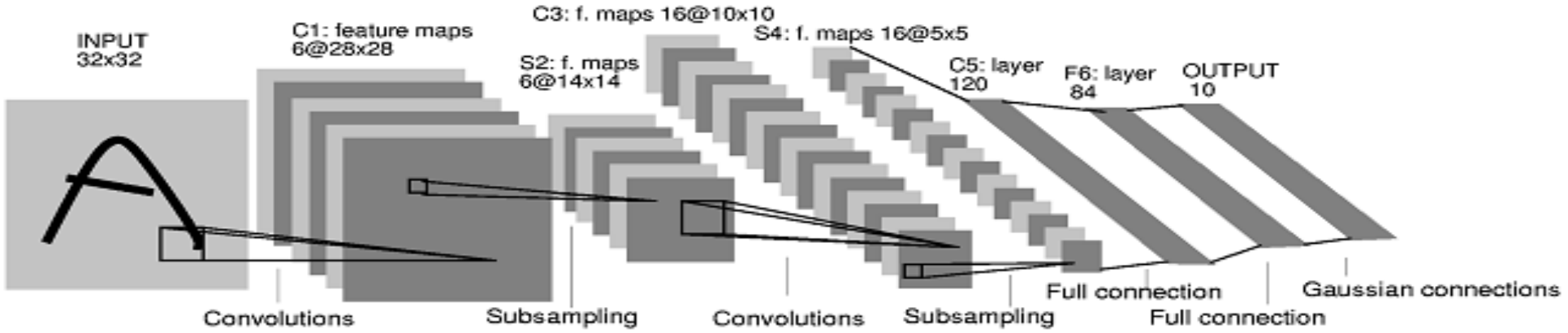
Introduction – Convolutional Neural Network, CNN



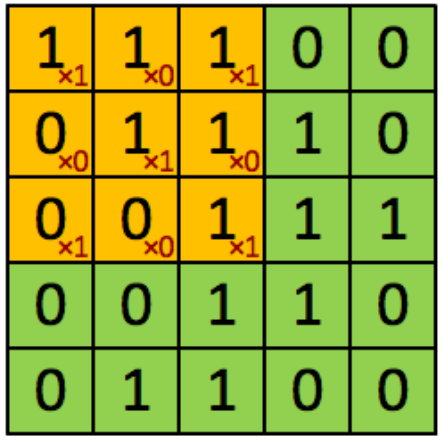
Taigman et al., 2014

A convolutional neural network is one of the well-known deep learning methods in the area of image processing and computer vision and widely used in various fields such as face recognition, object detection, autonomous driving car, and playing Go.

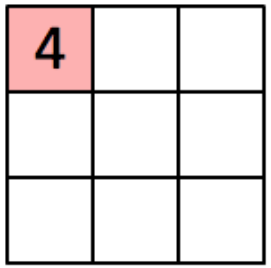
Introduction – Convolutional Neural Network, CNN



LeCun et al. 1998



Image



Convolved Feature

The convolutional neural network consists of several convolutional layers(convolutional filters) and this network trains these filters.

Generally, this network needs only image data, it means that this network uses little image pre-processing compared to other image classification algorithms.

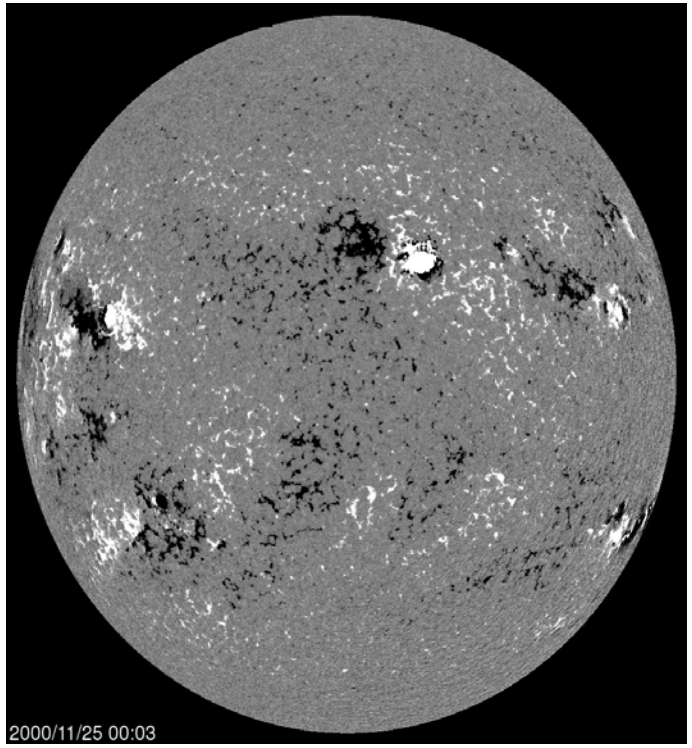
Introduction

	Method	Data
Bloomfield et al. (2012)	Statistics	✓ Average flare rates for each McIntosh class
Lee et al. (2012)	Statistics	✓ Flare occurrence rate for each sunspot class
Shin et al. (2016)	Multi-layer Perceptron	✓ WMFR value for the McIntosh classification ✓ Maximum flare flux of the previous day ✓ Active region area ✓ Weighted total flare flux of the previous day ✓ WMFR value for the Mount Wilson classification (WMFR : Weighted Mean Flare Rate)
This study	**Convolutional Neural Network**	**✓ SOHO MDI images without any pre-processing.** Simple

Method

Method – Input Data

Input
: SOHO/MDI images

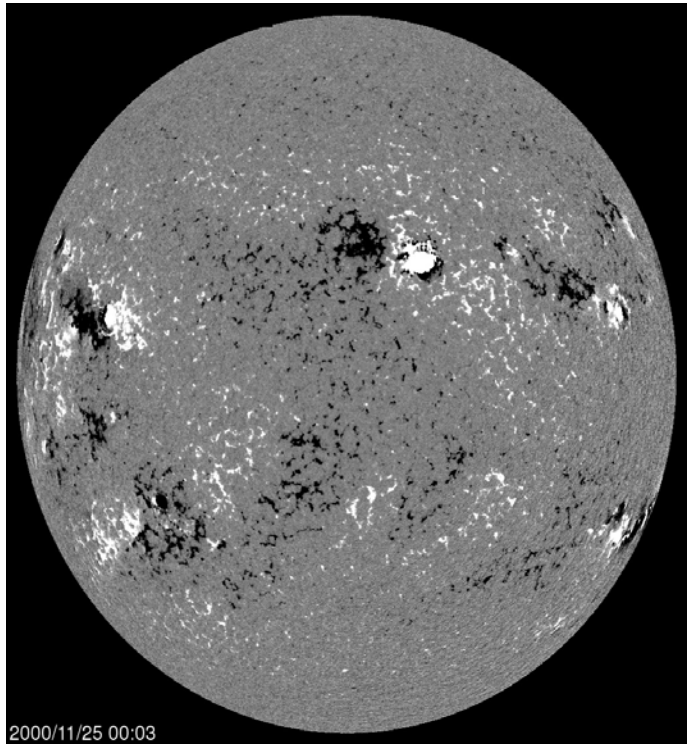


Class	Non	C	M	X
Occurrence	No		Yes	
Training : 90% (random selection)	360	360	360	360
Test : 10% (random selection)	40	40	40	40
Total	400	400	400	400
Total 1,600 images				

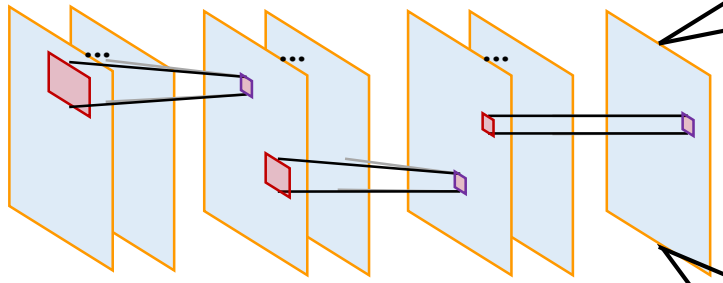
Input : The same number of SOHO/MDI images at 00:00 UT from Jan 1996 to Dec 2010

Method – Output Data

Input
: SOHO/MDI images



CNN



Output
: Solar Flare Class

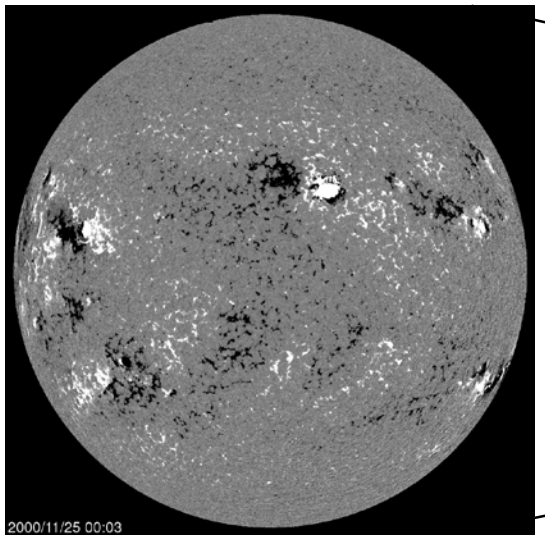
work 1 Classification	work 2 Occurrence
Non flare	Non flare (≤ C)
C class	Flare (M and X)
M class	
X class	

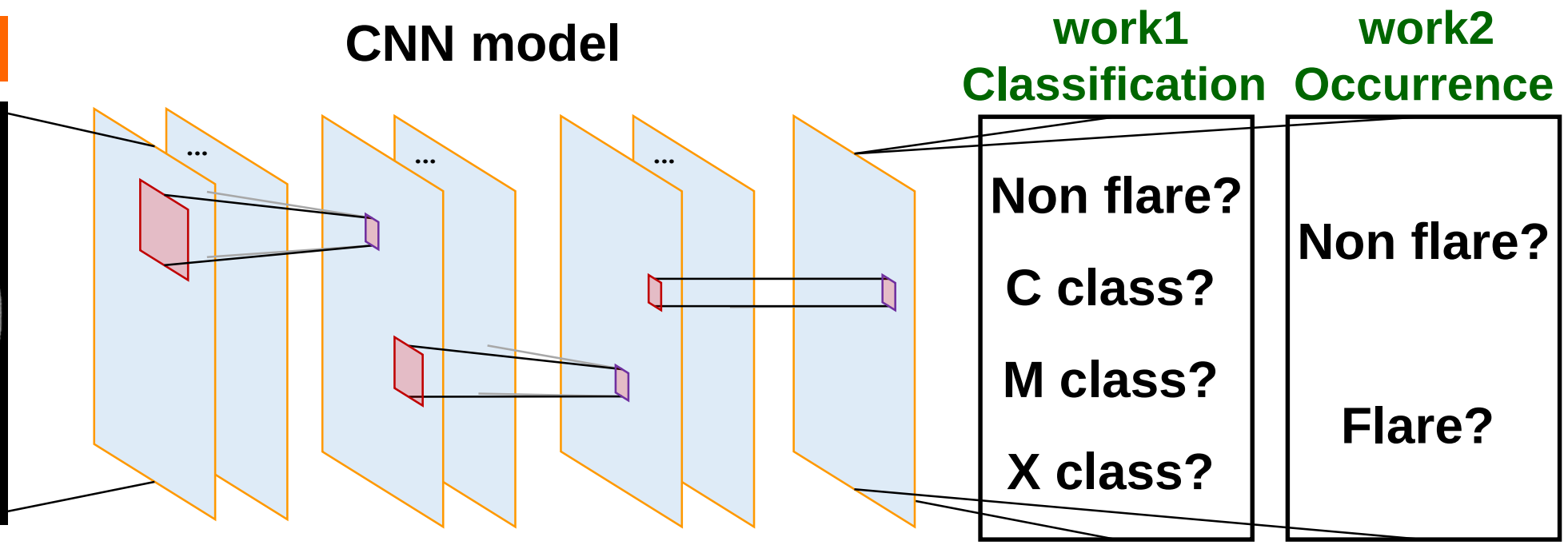
Input : The same number of SOHO/MDI images at 00:00 UT from Jan 1996 to Dec 2010

Output : the results of daily flare forecasting for flare classification and occurrence.

Method – Process

- Training -



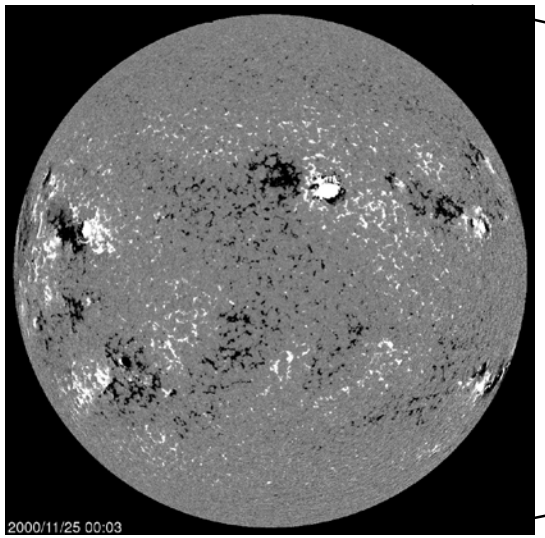


Training Input : SOHO/MDI image at 00:00 UT from Jan 1996 to Dec 2010
Daily Peak Flux Class or Flare Occurrence from 00:00 UT to 24:00 UT

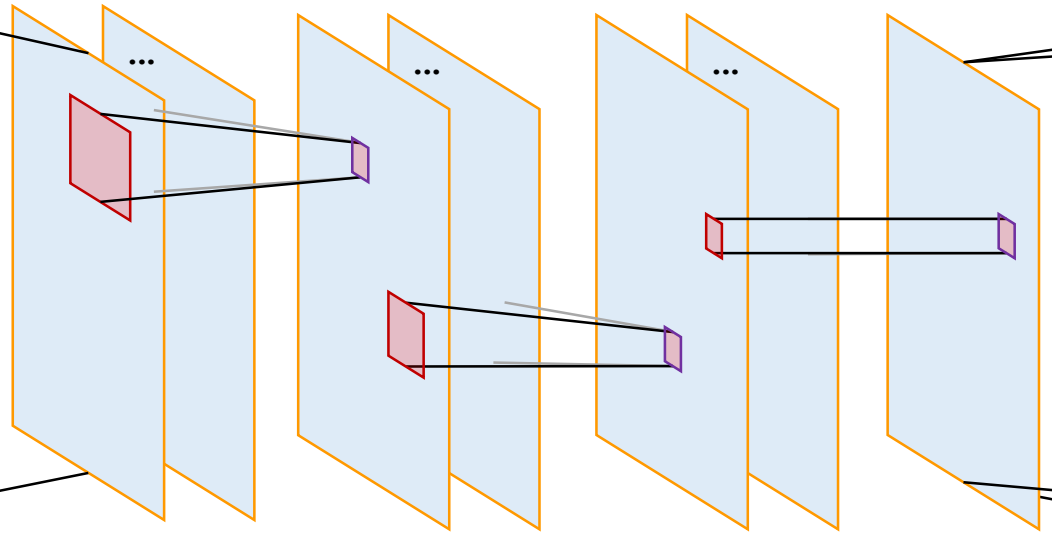
In the training, we put training data(images and labels) into the model, and the model calculate the answer using input data. Then the model modify itself to increase the correct answer rate by comparing its own answer and the correct answer of input data.

Method – Process

- Test -



CNN model



work1 Classification

Non flare?

C class?

M class?

X class?

work2 Occurrence

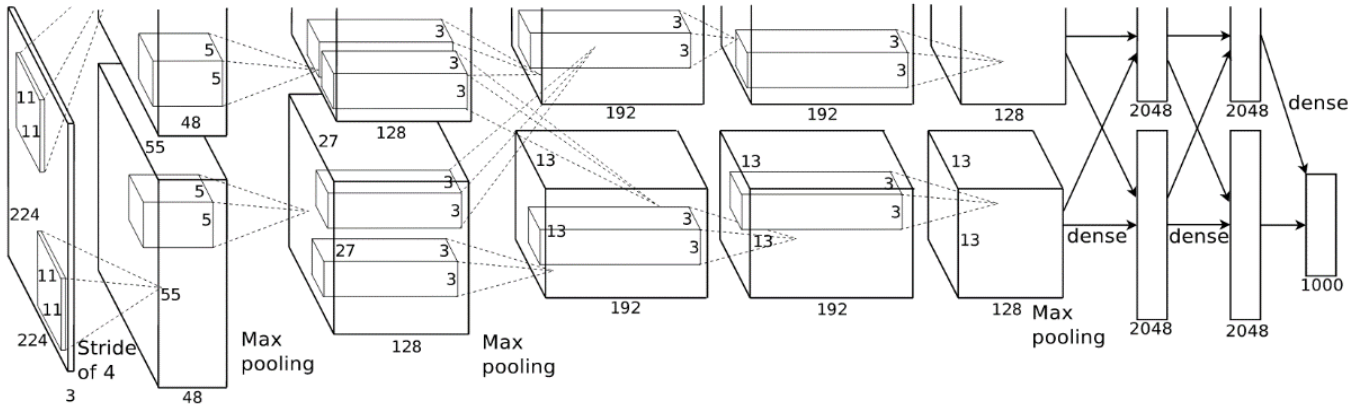
Non flare?

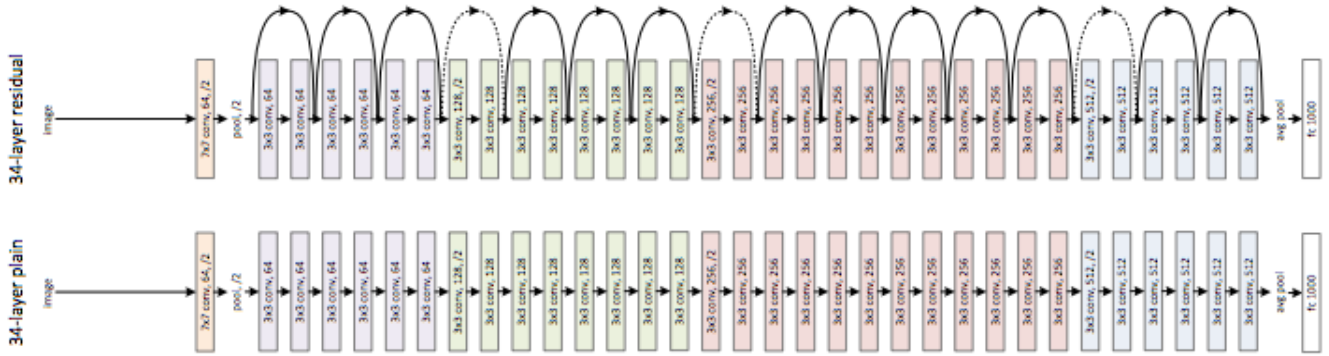
Flare?

Test Input : SOHO/MDI image at 00:00 UT from Jan 1996 to Dec 2010

In the test, we put test data(images) into the model, and the model calculate the answer using input data. Then we compare the answer of the model with actual daily peak flux class or flare occurrence to calculate the accuracy of the model.

Method – Models





AlexNet (Original, Customized)

Krizhevsky et al. 2012

A winner of ILSVRC for 2012

Residual Net (18, 34, 50 layers)

He et al. 2016

A winner of ILSVRC for 2015

+ customizing with several options

* ILSVRC : ImageNet Large Scale Visual Recognition Challenge

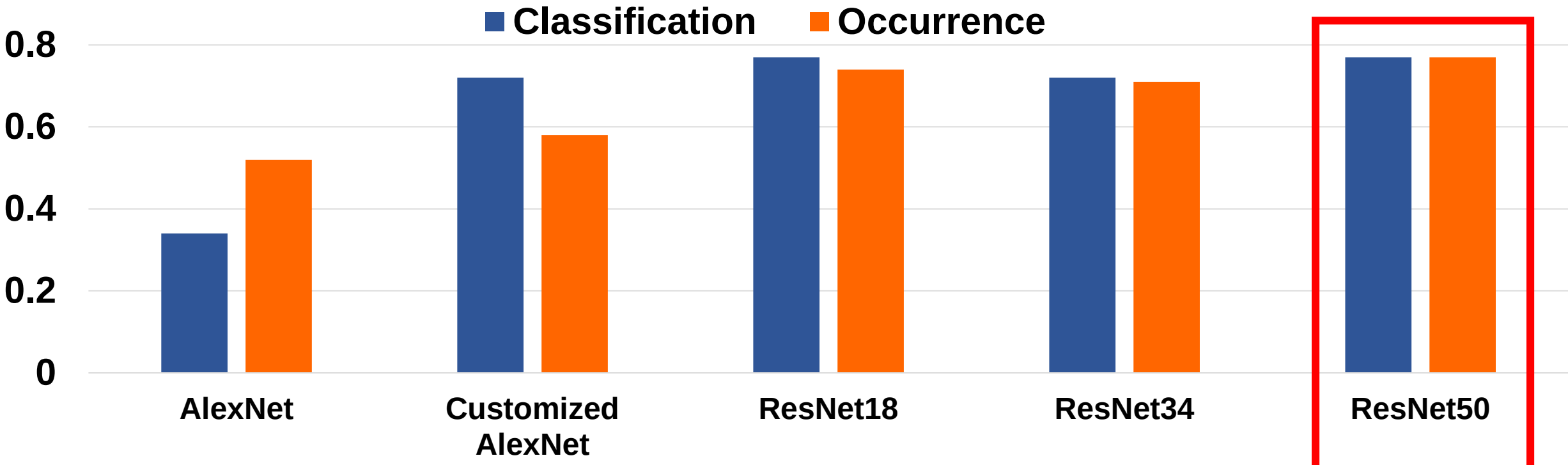
Method – Software Library

We build, train, and test the models on TensorFlow, which is one of the most popular deep learning software libraries developed by Google brain team, installed on our single GPU machine.

GPU is well known to be much more efficient for parallel computing and deep learning.

Results

Results - Classification and Occurrence Accuracy



Accuracy	AlexNet	Customized AlexNet	ResNet18	ResNet34	ResNet50
4 Classes (N, C, M and X)	0.34	0.72	0.77	0.72	0.77
Occurrence (M and X)	0.52	0.58	0.74	0.71	0.77

Results – AlexNet

AlexNet

Class		Prediction				Accu.
		N	C	M	X	
IN PUT	N	19	12	0	9	0.48
	C	1	16	0	23	0.40
	M	3	13	8	16	0.20
	X	18	10	0	12	0.30
Class Accuracy : 0.34						

Our customized AlexNet

Class		Prediction				Accu.
		N	C	M	X	
IN PUT	N	39	0	0	1	0.98
	C	0	17	23	0	0.43
	M	0	4	36	0	0.80
	X	14	0	2	24	0.60
Class Accuracy : 0.72						

There is the comparison between basic AlexNet and our customized version.

We change the number of layers, optimization method, and dropout ratio.

There are much improvements of classification accuracy in the customized model.

Results – Customized AlexNet

work 1 : Classification

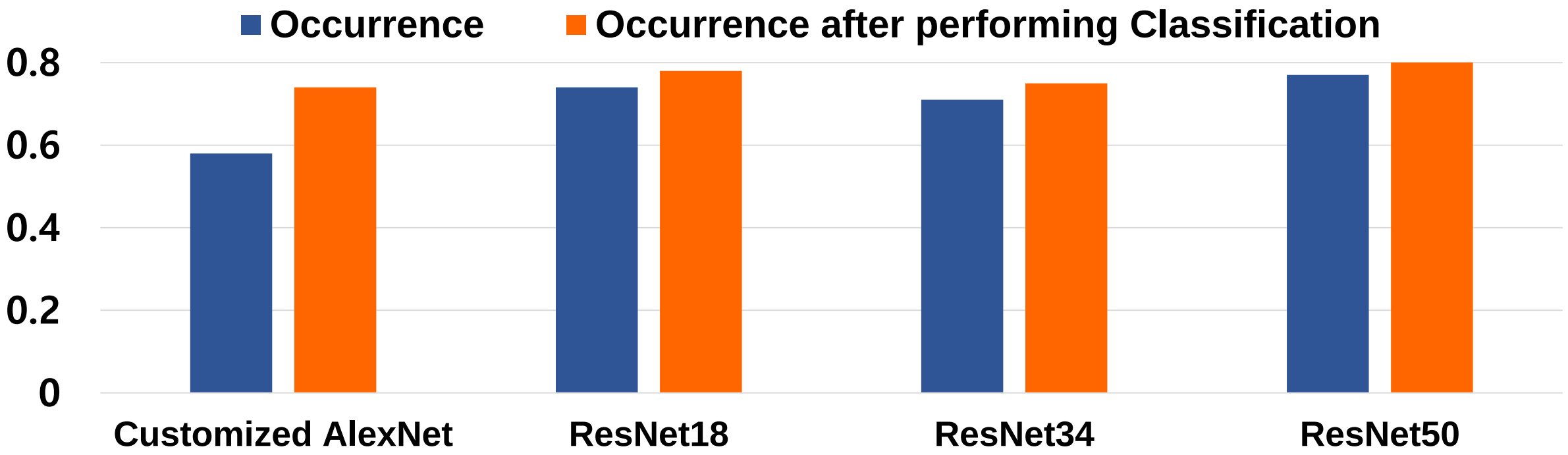
Class		Prediction				Accu.
		N	C	M	X	
IN PUT	N	56		24		0.70
	C					
	M	18		62		0.78
	X					
Occurrence Accuracy(M and X) : 0.74						

work 2 : Occurrence

Occurrence		Prediction		Accu.
		X	O	
IN PUT	X	79	1	0.99
	O	53	27	0.34
Occurrence Accuracy(M and X) : 0.58				

Accuracies of the models for occurrence are greatly improved when we performed the classification in advance.

Results - Flare Occurrence (M and X) Accuracy



Accuracy	Customized AlexNet	ResNet18	ResNet34	ResNet50
Occurrence	0.58	0.74	0.71	0.77
Occurrence after performing Classification	0.74	0.78	0.75	0.83

Results

Occurrence (M+X) Scores

	Convolutional Neural Networks Occurrence After Performing Classification		Multi-layer Perceptron Shin et al. (2016)		Statistics Bloomfield et al. (2012)	
	AlexNet	ResNet50	ANN1	ANN2	Optimum TSS	Optimum HSS
POD	**0.78**	0.66	0.51	0.40	0.70	0.30
TSS	0.48	**0.66**	0.32	0.31	0.54	0.27
CSI	0.60	**0.66**	0.24	0.21	-	-
FAR	0.28	**0.00**	0.39	0.67	0.85	0.68
HSS	0.46	**0.57**	0.32	0.29	0.19	0.28

Our results show a great possibility that convolutional neural network can be applied to flare forecasts, as well as similar types of problems.

Summary

Summary

We have applied CNN to two kinds of flare forecasting models

: flare classification and occurrence.

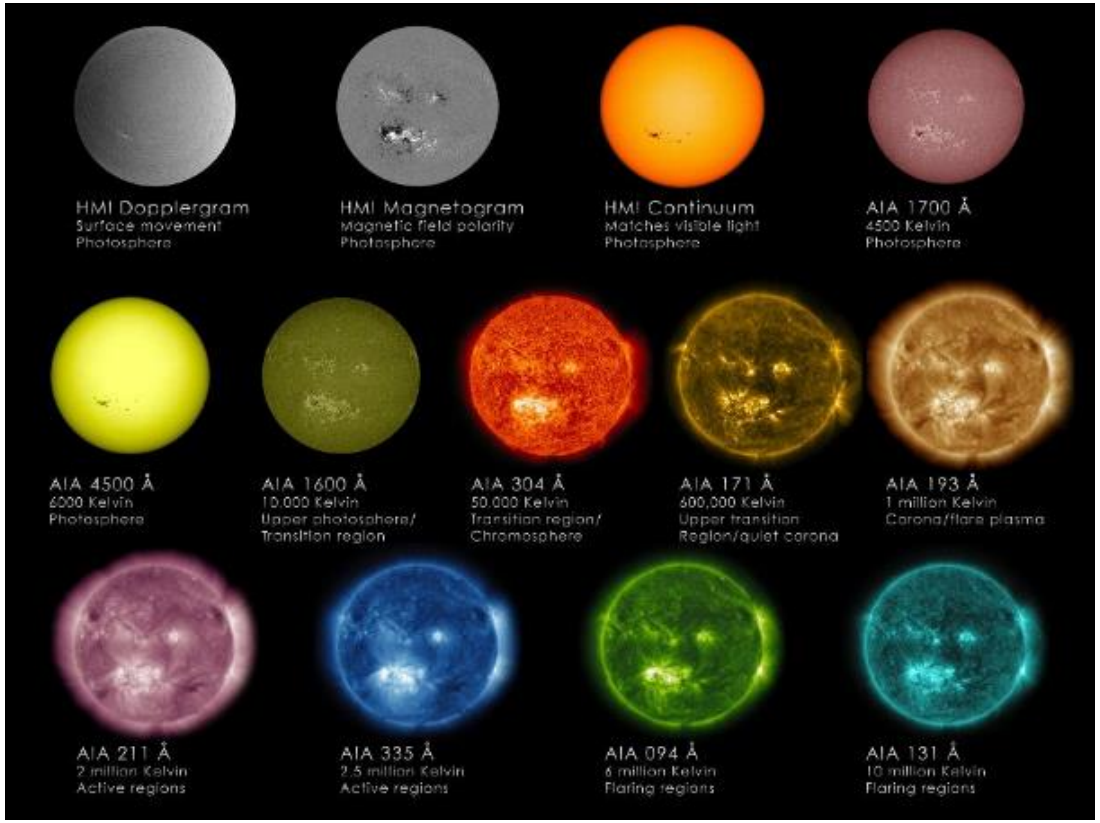
Our results are as follows,

1. **Most of the models have accuracies more than 70%.**
2. **ResNet developed by Microsoft has the best accuracies.**
3. **Accuracies of the models for occurrence are greatly improved when we performed the classification in advance.**
4. **Our results show a great possibility that CNN can be applied to flare forecasting as well as similar types of problems.**

Future Works

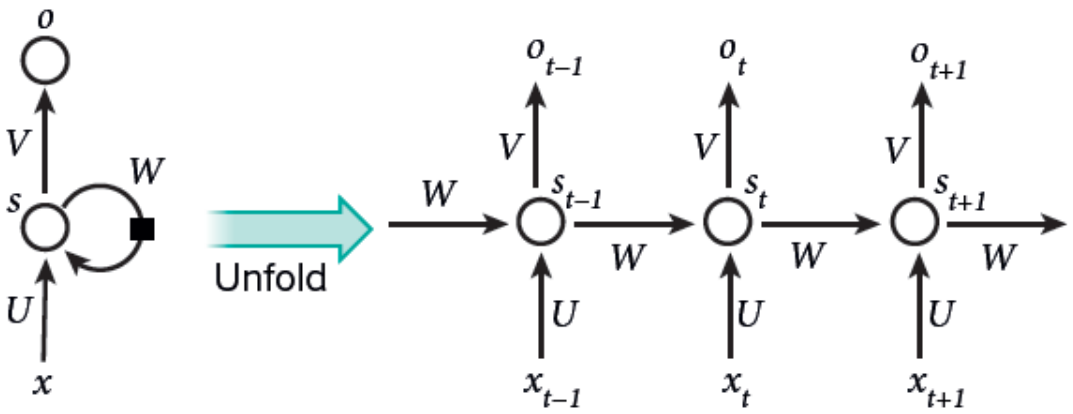
Future Works

Class, 96min		Prediction				Accuracy
		N	C	M	X	
INPUT	N	343	106	28	3	0.72
	C	52	354	69	5	0.74
	M	11	77	382	10	0.80
	X	10	20	42	402	0.84
Class Accuracy : 0.77						
Occurrence Accuracy(M and X) : 0.88						

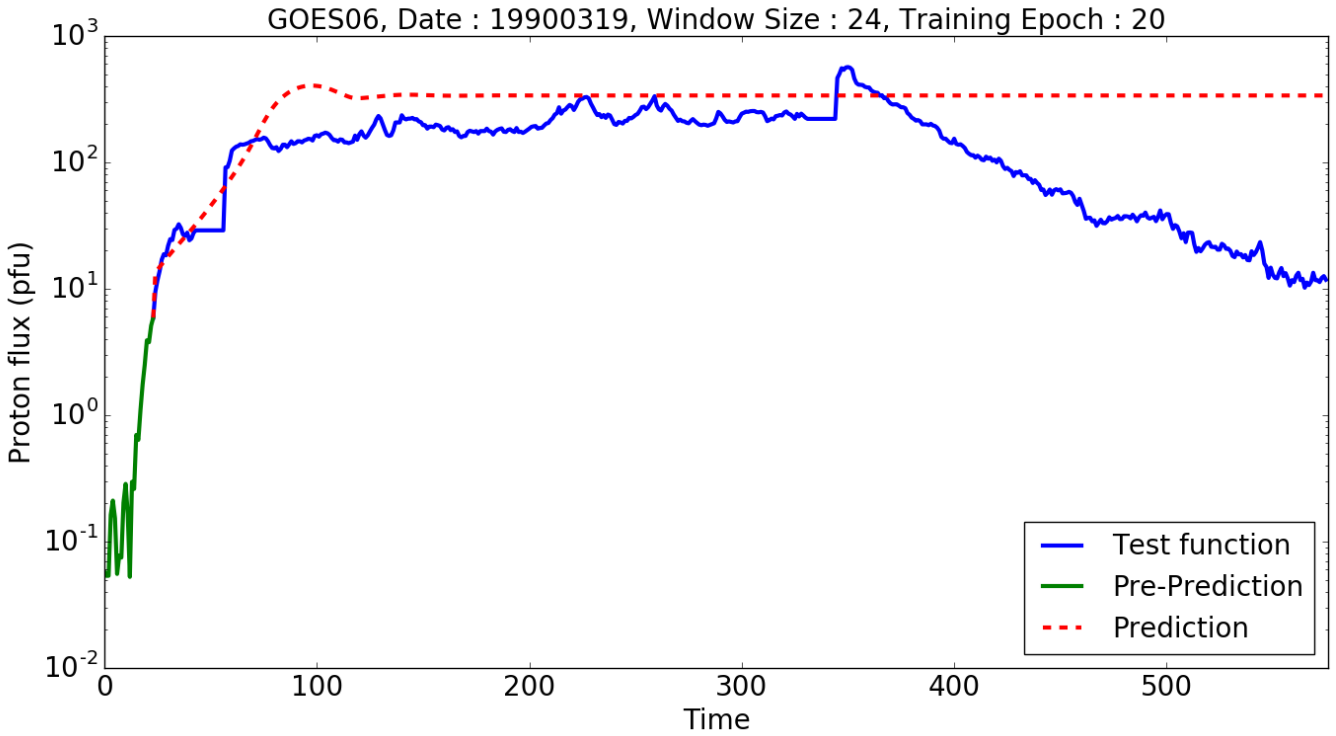


We have been trying to increase the number of images by using MDI data with 8 hour or 96 min cadence or using various types of images from other instruments.

Future Works



LeCun et al., 2015



We plan to improve our space weather forecast models by employing several modern deep learning methods and applying them to several types of input data.

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Thank you!