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A Deep Learning Approach to Tropical Cyclone Intensity Estimation Using Satellite-based Infrared Images

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The standard method for estimating tropical cyclone (TC) intensity is by interpreting TC structure from geostationary satellite images, except when aircraft reconnaissance flights are routine. Since much of a TC life cycle occurs over an ocean, satellites are an excellent source of meteorological information for the task as it offers coverage much better than traditional observations. While satellite imagers do not directly measure variables related to TC strength such as winds and central pressure, TC intensity can be gleaned based on the extent and organization of its cloud patterns. One of the first comprehensive pattern recognition methods for estimating TC intensity using satellite-based images is known as the "Dvorak technique" introduced by Vernon Dvorak. The technique uses visible and infrared (IR) brightness temperature images to extract specific cloud patterns to detect rotation, deep thunderstorms, and eye; then relates them to the deepening or weakening of a TC.

Satellite-based TC intensity estimation is tackled as a feature extraction and pattern recognition task. In its basic principle, the detection of a well-formed eye is indicative of an organized TC structure. A well-formed eye is likely a sign of a strong TC. Likewise, visually disorganized cloud signatures are regarded as an attribute of weaker TCs. The original Dvorak technique is a rule-based algorithm that looks for central dense overcasts (CDO) and outer banding features of a TC to determine its intensity. Several objective methodologies developed, thereafter, also involved prior manual extraction of satellite image features that relate to TC intensity. These features included cloud organization properties, inner core characteristics, the radius of curvature and the rain rate. Recent approaches to image-based classification tasks though enabled implicit extraction of features from images. Particularly, artificial neural networks (ANN) designed for image classification such as the Convolutional Neural Network (CNN) learns about relevant low to high-level features through several layers of artificial neurons.

In this work, we posit that: since the features are directly engineered from TC satellite images, TC intensity estimation can be performed directly over the images without the need for explicit feature extraction. This idea transforms the task of satellite-based TC intensity estimation from a feature extraction and pattern recognition task into an image classification problem.

In this study, we investigate transfer learning of a pre-trained CNN architecture for estimating TC intensity based on grayscale IR images of TCs in the Western North Pacific basin; and identify relevant TC features relating to TC intensity. Transfer learning is the process of extending the knowledge of a pre-trained ANN to learn additional new knowledge. We particularly use the VGG19 network architecture for this task in this study. Furthermore, we qualify how much information IR image signatures offer in the estimation of TC maximum wind speeds. Different from previous works, the study explores a different approach without explicitly extracting TC features. To our knowledge, this is by far the first attempt use CNN transfer learning to estimate TC intensities solely based on grayscale IR images of TCs.

Specifically, we make the following contributions

- We construct a CNN model using transfer learning with VGG19 network architecture for the purpose of TC intensity estimation through satellite IR image classification.
- We show that our model performs well on 2015-2016 TC satellite images and is comparable to previous methods which require explicit feature extraction.
- We show that our model is also able to learn TC features which are previously found to be strong indicators of TC intensity, such as cloud formation and presence or absence of a well-formed eye.

Summary

The standard method for estimating tropical cyclone (TC) intensity is by interpreting TC structure from geostationary satellite images, except when aircraft reconnaissance flights are routine. Since much of a TC life cycle occurs over an ocean, satellites are an excellent source of meteorological information for the task as it

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