Leveraging Cloud Resolving Model Data and UNet for Subgrid Cold Pool Intensity Prediction

Yi-Chang Chen, Chien-Ming Wu

Department of Atmospheric Sciences, National Taiwan University (NTU), Taipei, Taiwan

國科會卓越領航計畫
山區雲氣候計畫
NSTC-112-2123-M-002-006

LCDM
Lab. for Cloud Dynamics and Modeling

Abstract

Previous research has demonstrated a significant relationship between the emergence of cold pools (CPs) and the development of secondary convection, particularly at the edges of CPs, where CP density currents can potentially trigger new convective activities. Interactions between a CP and its surrounding environment, or the collision of multiple CPs, can provoke additional convective activities. Studies also show that the intensity and three-dimensional structure of CPs may influence the strength of CP density currents. As CP is a high-density zone relative to the surroundings, the intensity of the CP may differ substantially under different degrees of convection. Past studies have identified phenomena such as CPs, which increase horizontal heterogeneity during the transition from shallow to deep convection. These heterogeneities serve as critical parameters for modeling the transition process.

With the recent development of deep learning tools, CPs can now be identified from two-dimensional fields using machine learning techniques. In this study, we adopt an Unet model and use data from a cloud-resolving model (CRM) during the shallow-to-deep transition to predict high-resolution CP intensity distribution from low-resolution two-dimensional fields. Our results demonstrate that Unet can effectively predict high-resolution CP intensity distribution using variables such as the horizontal wind and surface precipitation. Using the predicted high-resolution CP intensity distribution, we may identify areas where CPs could potentially trigger secondary convection. Such information may provide insight into areas where secondary convection is more likely to occur. This information also offers a new perspective for predicting convection using satellite data and performing sub-grid parameterization of CPs.

Keypoints

- The Cloud Resolving Model (CRM) allows us to accurately capture the evolution of CPs. A coarse-graining approach can be applied.

- A deep learning method is developed that is comparable to the high resolution field, to infer the distribution of CPs from low-resolution fields.

- Use a dataset that varies in convcection structures (shallow to deep transition) to construct a model that is insensitive to the different distribution of sizes of the cold pools.

- The predicted intensity of subgrid CPs helps us estimate the triggering of secondary convection.

Methodology

Model Settings:

- Vector Vorticity equation Model (known as VVM) [Jung & Arakawa, 2008; Wu et al., 2019]
- Domain size: 102.4 [km] x 102.4 [km] x 19 [km]
- 100[m] x 100 [m] in horizontal, 75 to 150 [m] stretching in vertical
- Integral time step = 10 [secs], Output per 10 [mins], Integral up to 100 [hrs] (STD transition)
- Initial Profile: Dynamics of the Madden-Julian Oscillation (DYNAMO) suppressed phase
- Large scale subsidence and constant sea surface temperature

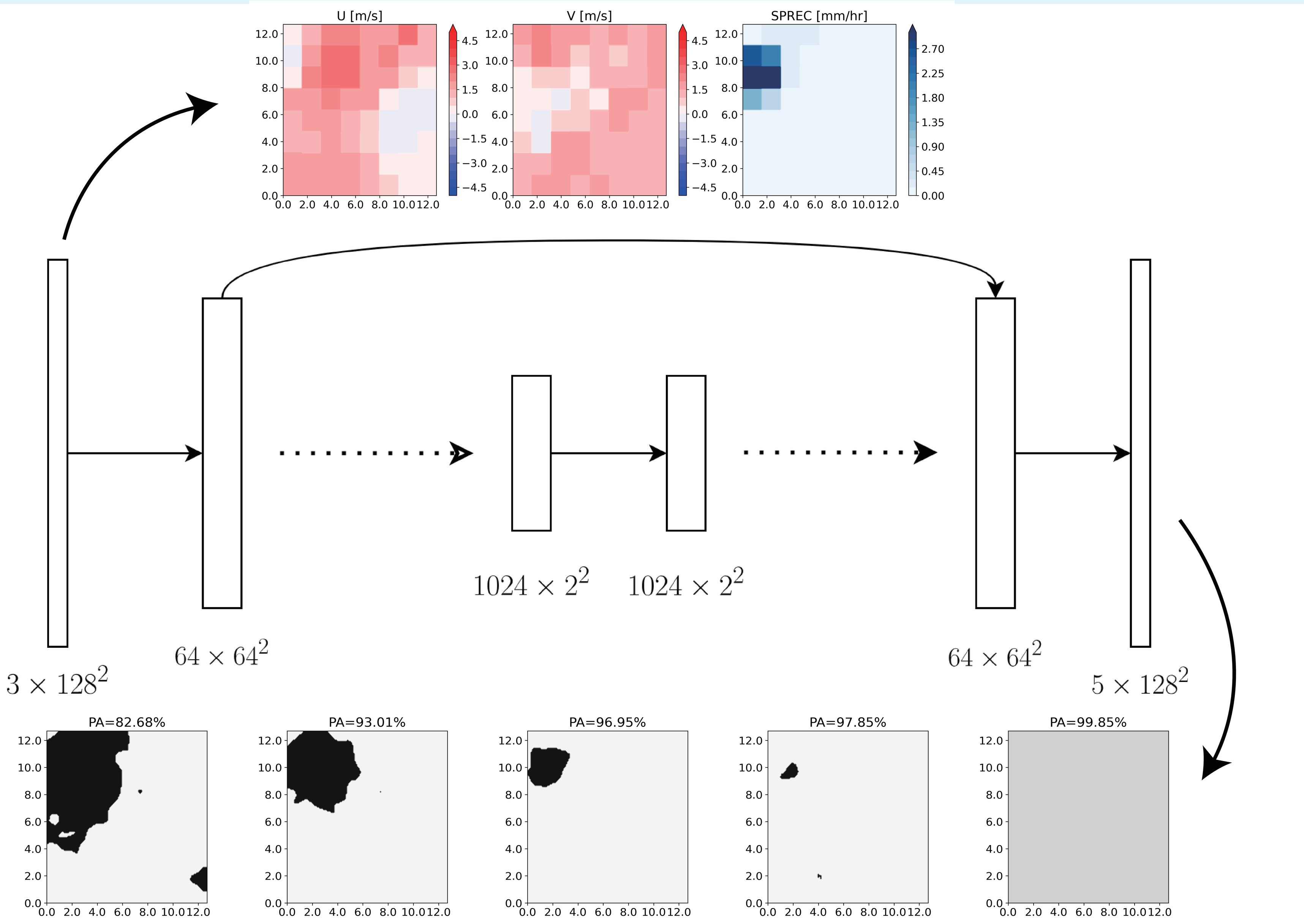

Figure 1. Unet structure with an example of low-resolution horizontal wind and surface precipitation. Output of the Unet shows the inferenced subgrid cold pools' intensity in binary representation.

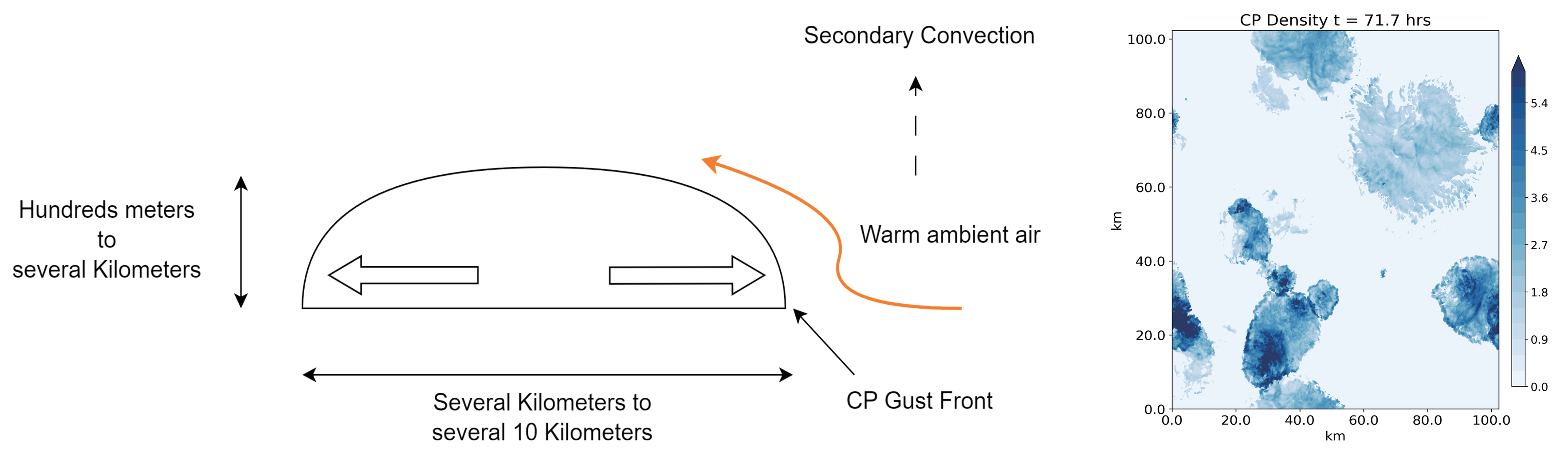

Figure 2. A schematic diagram of cold pool and a snapshot of cold pool intensity [m/s] from VVM output.

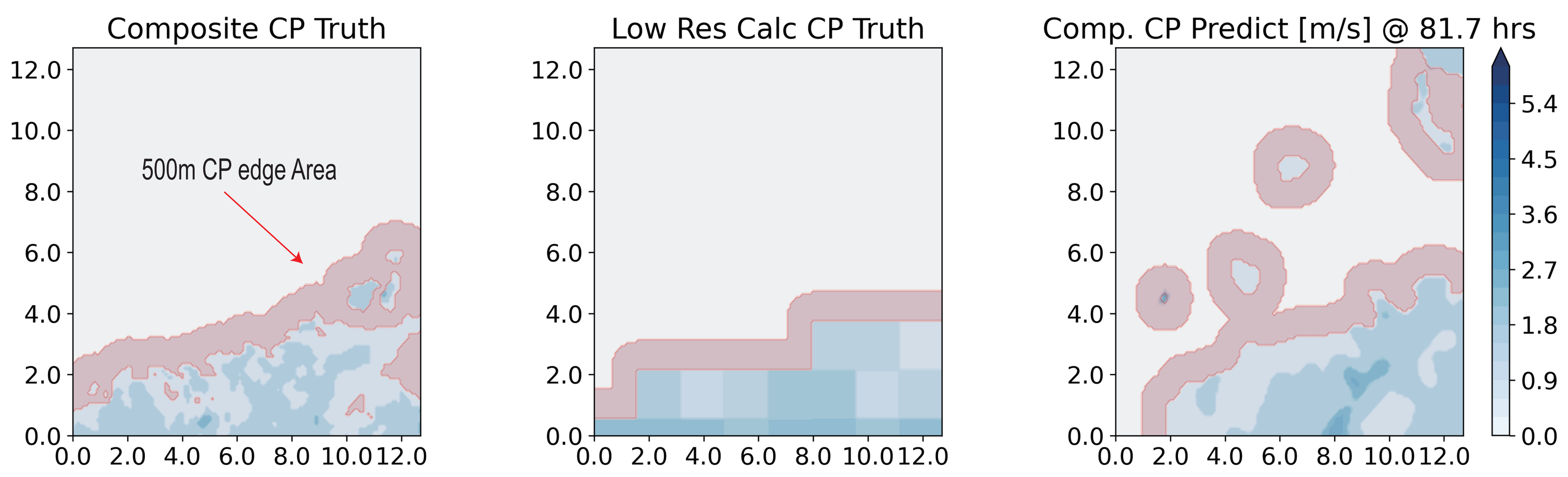

Figure 3. Cold pools' intensity and 500[m] cold pool edges of CRM simulated (left), CRM simulated in low resolution (Middle), and Unet inferenced (right).

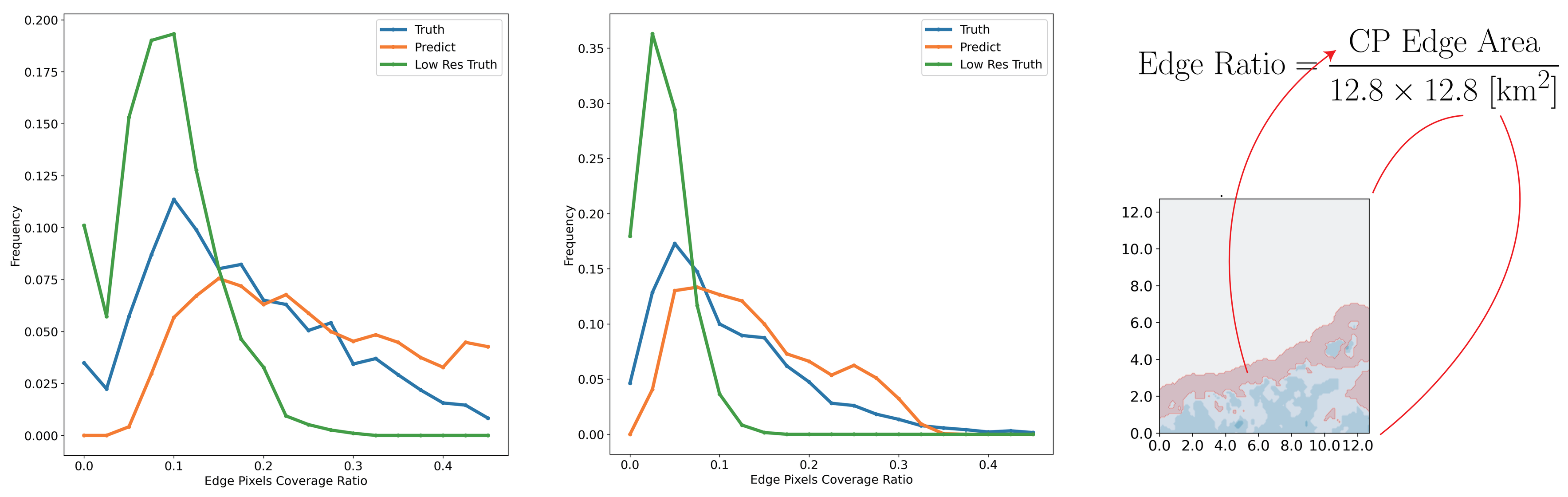

Figure 4. Comparision of the edge area ratio over all test data (not used in training Unet) between truth, low res. truth, and the Unet CP. (left) The edge ratio frequency of 500m cold pool edge area in truth, predicted by Unet, and low resolution truth. (middle) same as left, but take 1000m edge. (right) The schematic of the calculations of edge ratio in a single snapshot.

Results

The results indicate that the Unet is capable of inferring the subgrid CP intensity, particularly in terms of enhancing the details of the CP. As observed in Figure 3, although there is a misjudgment in the Unet's prediction, it offers a more detailed representation of the cold pool's edge than the low-resolution truth. Figure 4 demonstrates that, throughout the entire dataset, when it comes to capturing the edge of the cold pool, the subgrid cold pool inferred by the Unet aligns more closely with the original data than the low-resolution cold pool does. Figure 5 further illustrates the cold pool edge index (CPI) calculated from the truth, the low-resolution truth cold pool, and the Unet-predicted subgrid cold pool. Although the vertical velocity estimates, based on the Unet-predicted CPI, for 10 minutes later are generally lower than the truth, its P(w|CPI) is more in line with the original data compared to the estimates from the low-resolution cold pool truth.

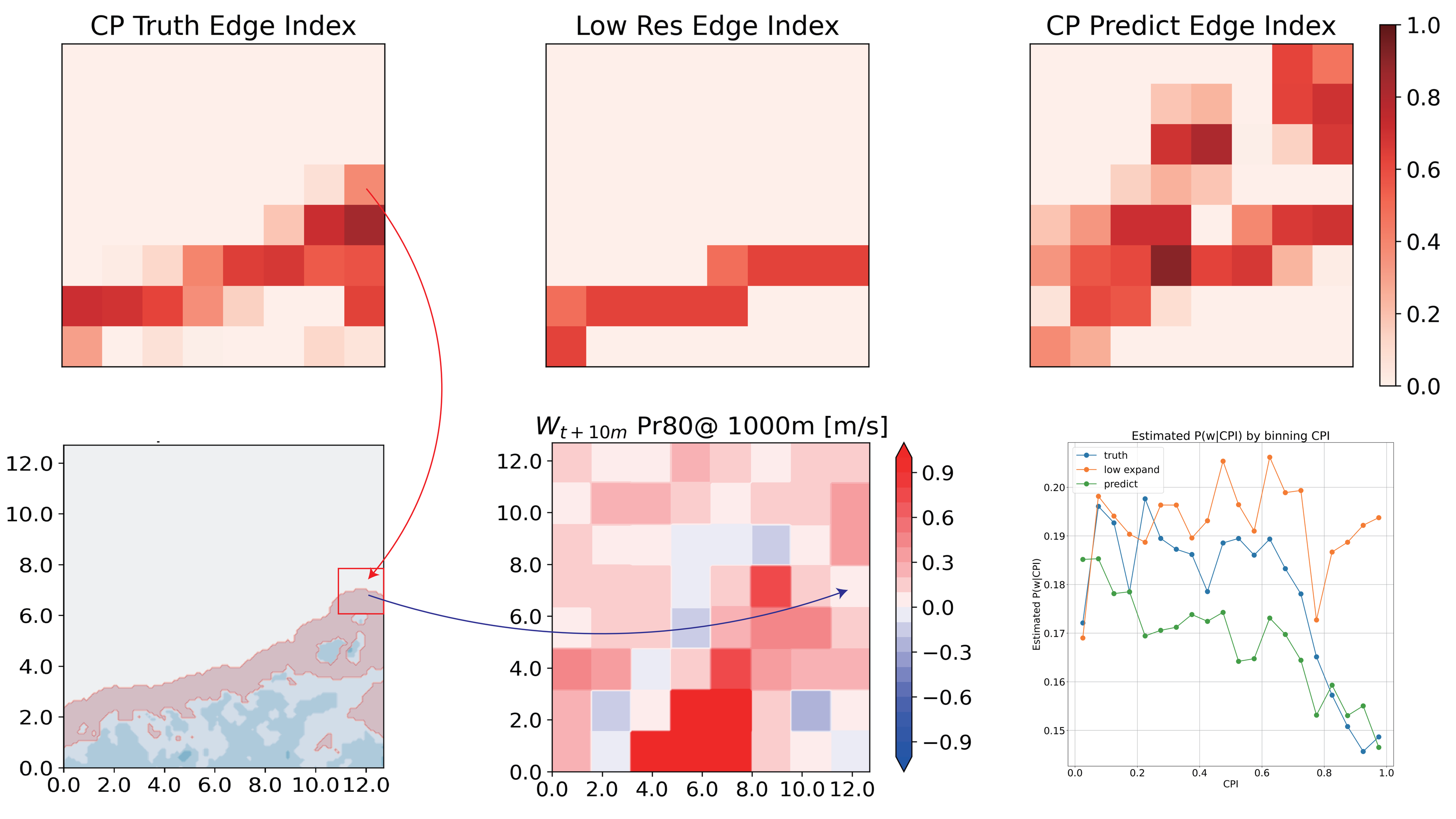

Figure 5. The upper panel displays the cold pool edge index (CPI), which is calculated using the cold pool edge area ratio within each 1.6 x 1.6 [km^2] grid. The lower panel (on the left) references the CP edge index corresponding to the upper panel, while the other references are illustrated in Figure 3. The lower middle panel depicts the 80th-percentile of vertical velocity for each 1.6 x 1.6 [km^2] grid. The right panel provides a comparison of the estimated P(w|CPI), shows that the P(w|CPI) from Unet is more in line with the original data compared to the estimates from the low-resolution cold pool truth.

Remark

- Unet is capable of predicting the intensity of subgrid cold pools using surface wind fields and surface precipitation.
- A comparison of the edge area ratio distribution reveals that Unet can provide more detailed information on the cold pool's edge than low-resolution data can.
- When comparing secondary convection triggered by the cold pool edge, the Unet's subgrid cold pool offers a closer estimation of vertical velocity, though its strength is less than the actual value.
- Further research is required to understand the relationship between the tendency of secondary convection and the edge of subgrid cold pools.

Reference