NEURAL INFORMATION PROCESSING SYSTEMS

NeurReps Workshop

Paper available at:

ECoNets: Rotation Equivariant Contrail Detection Neural Networks in Satellite Imagery

Edgar Loza[1*], Davide Di Giusto[1*], Vincent Meijer[2‡], Teodora Petrisor[1*]

[1]Thales, Research and Technology – CortAIx Labs France

*first.last@thalesgroup.com

[2]Delft University of Technology

‡V.R.Meijer@tudelft.nl

This work was partially supported by the HE BeCoM project (Grant Agreement No. 101056885).

Context

Contrails are artificial clouds formed from the mixing of warm and moist aircraft exhaust with cold and dry ambient air in particular weather conditions [1]. More than half of aviation climate impact comes from non-CO_2 emissions, persistent contrails being a major contributor [2]. Contrail avoidance can be achieved by rerouting flights depending on the weather forecast. *Robust contrail detection in satellite images helps in verifying contrail formation versus prediction as well as in improving forecast models.*

Contributions

1. **ECoNets - Equivariant Contrail segmentation Networks:** exploit symmetries in satellite data to increase detection robustness in a data frugal context.
2. **Benchmark ECoNets vs U-Nets** on two real world datasets with different training data budgets and versus data augmentation.
3. **In-house annotated Meteosat dataset (MSG):** for European contrail detection.

Contrail segmentation: Datasets & Challenges

Problem: *Contrail detection at scale*
Challenges.
I. High class-imbalance.
II. Different sensors:
- Spatial/temporal resolution.

III. Dataset size.

Approach: Geometric priors in models to ease regional transfer and increase detection quality.

Feature	Open Contrails [4]	MSG
Training Size	20,544	293
Test size	1,827	78
Region	America	Europe
Resolution	4km^2 / pixel	9km^2 / pixel
% contrail pixels train	1.2	0.3
% contrail pixels test	0.5	0.3

Methodology

Models: U-Net-like architectures [3]

- ECoNets: equivariance to discrete rotations (C_N) and dihedral (D_N) groups (escnn [5]).
  - Same architecture: reduction of trainable parameters for ECoNets.

Model	Trainable Parameters (M)	Data augmentation
U-Net	95.85	None, Rot(0, 360) and Flip+Rot(0, 360)
C_4 / C_8-ECoNets	10.54 / 5.27	
D_4 / D_8-ECoNets	5.27 / 2.63	None and Rot(0, 360)

Hyperparameters

- Training: early stopping and on-plateau scheduler.

	Initial learning rate		Batch size		Weight decay	
Dataset / Model	U-Nets	ECoNets	U-Nets	ECoNets	U-Nets	ECoNets
OpenContrails	10^{-4}	10^{-3}	16		10^{-3}	
MSG	10^{-4}, 10^{-3}		8			

What gains can be expected from these priors? What happens in a reduced training data context? Scalability between regions?

Results

ECoNets in OpenContrails

Higher metrics. ***Faster*** epoch convergence. ***Shorter*** wall-clock time at similar performance (article). ***More robust:*** than data augmentation and in low training budget.

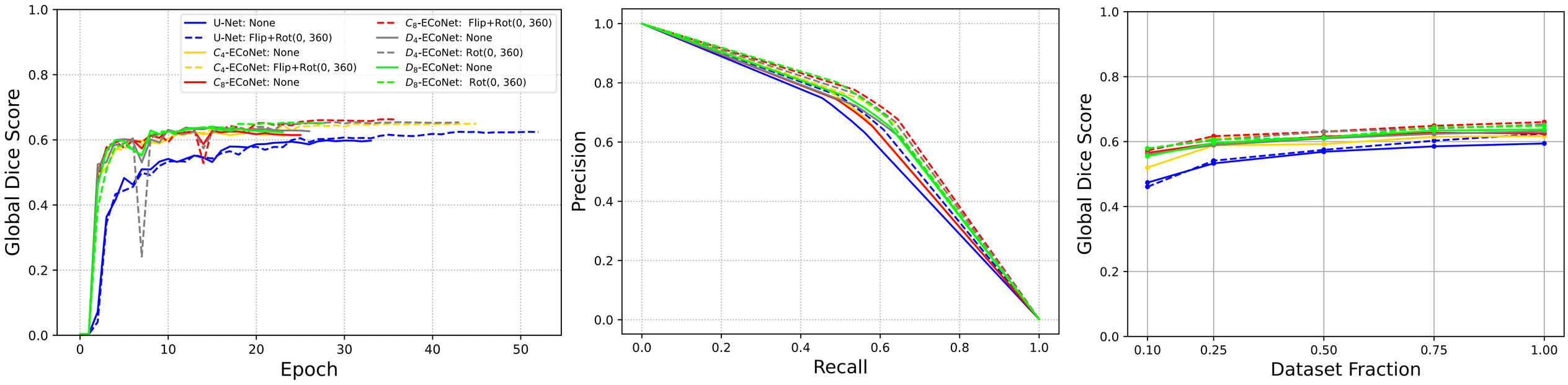

Figure 1. **Left and Center:** Score evolution and Precision-Recall curve of models trained on the entire OpenContrails dataset. **Right**: Score as a function of the training dataset fraction.

ECoNets in MSG

Fine-tuning pretrained on OpenContrails: EcoNets show a slight score increase.
Data frugality: From-scratch augmented ECoNets and fine-tuned U-Nets: similar.

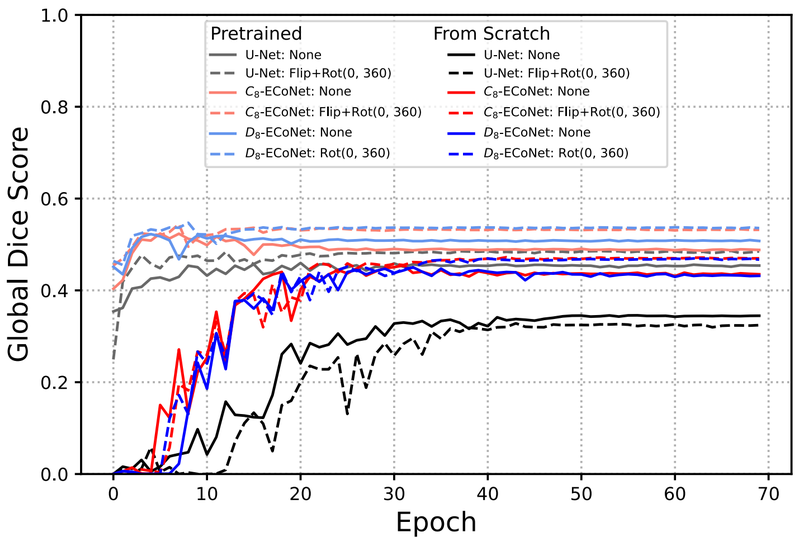

Figure 2. Score evolution for models trained from scratch and fine-tuned on MSG.

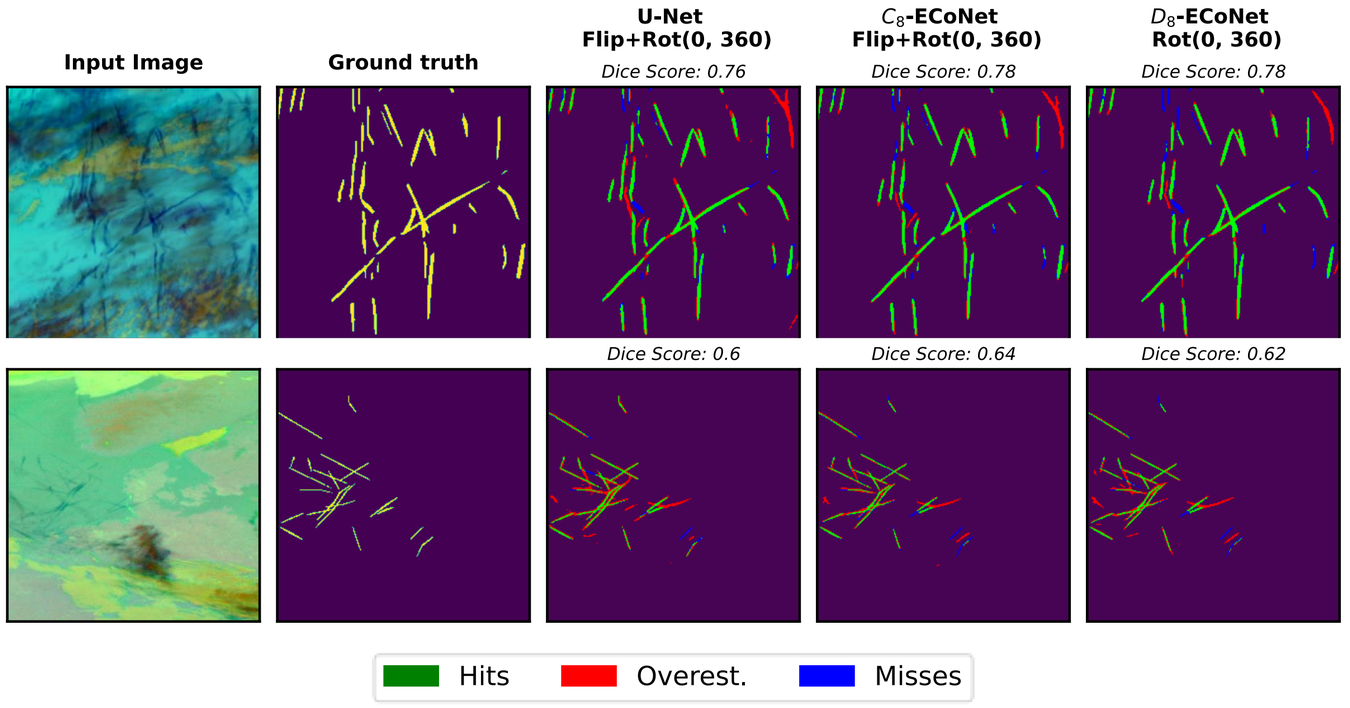

Figure 3. Images, ground truths and inferences for OpenContrails (top) and MSG fine-tuning (bottom).

Conclusions

ECoNets show increased performance and shorter wall-clock times at similar Dice Score for all the studied equivariance groups, data augmentation and training budget. ECoNets trained from scratch on MSG (**<1.5% of OpenContrails dataset size**) reach similar scores to pretrained & finetuned U-Nets: equivariance might substitute fine-tuning on small datasets when large datasets are missing. Extensions to continuous groups and invariance to colour changes are under study.

References:

[1] U. Schumann. On conditions for contrail formation from aircraft exhausts. Meteo. Zeit. 1996. **[2]** D.S. Lee et al, The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018. Atm. Env., 2021. **[3]** O. Ronneberger et al. U-net: Convolutional networks for biomedical image segmentation. MICCAI 2015 **[4]** Ng et al. Contrail detection on GOES-16/ABI with the OpenContrails dataset. IEEE Trans. Geosc. and Remote Sensing, 2024. **[5]** G. et al. A program to build E(N)-equivariant steerable CNNs. ICLR 2022.

THALES Building a future we can all trust

cortAIx Labs

TU Delft Delft University of Technology