Operational application of deep learning model for auto-detection of Atmospheric Gravity Waves (AGW) over the Asia-Pacific region

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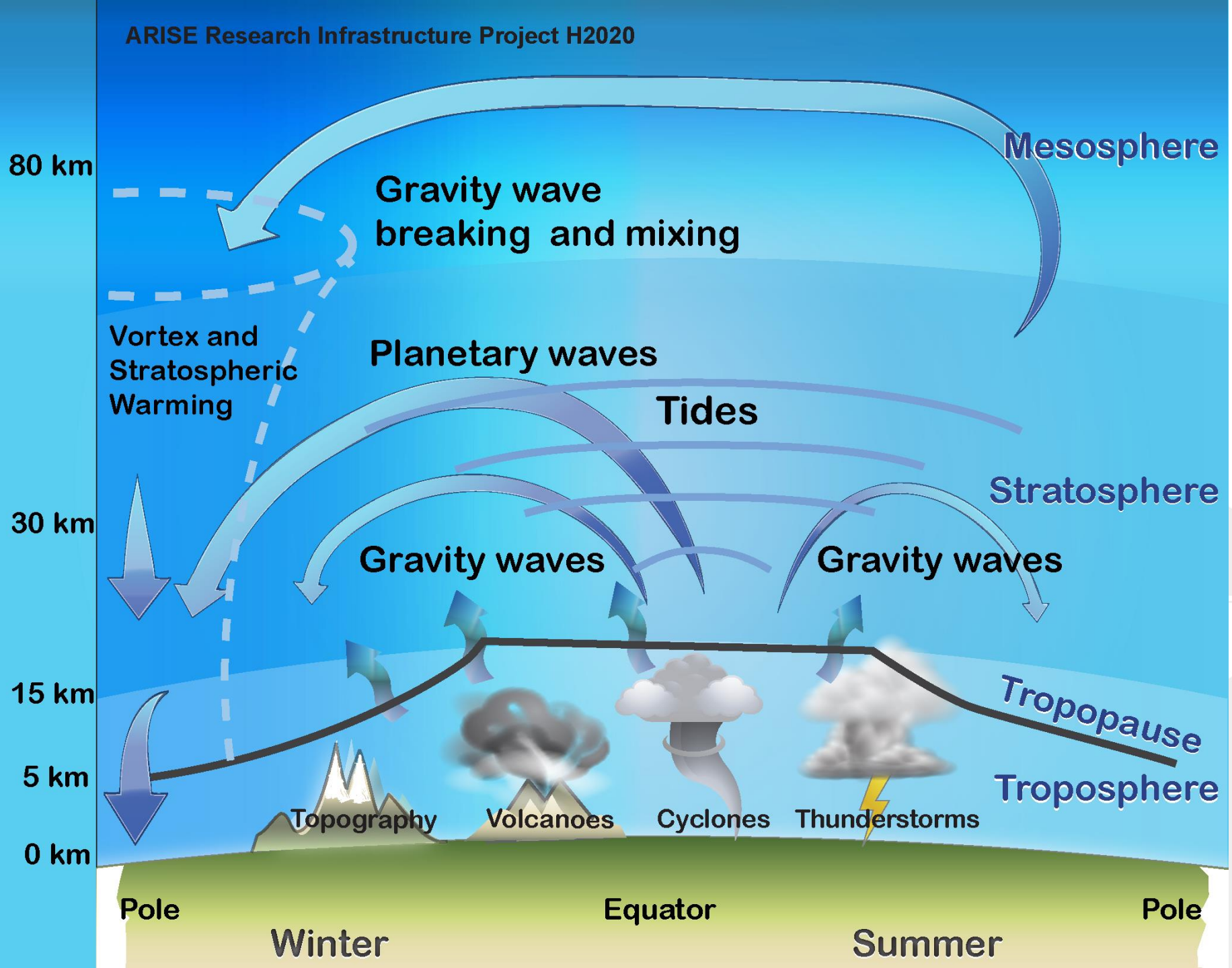


Reference website:
http://arise-project.eu/science.php

Weather features inducing AGW

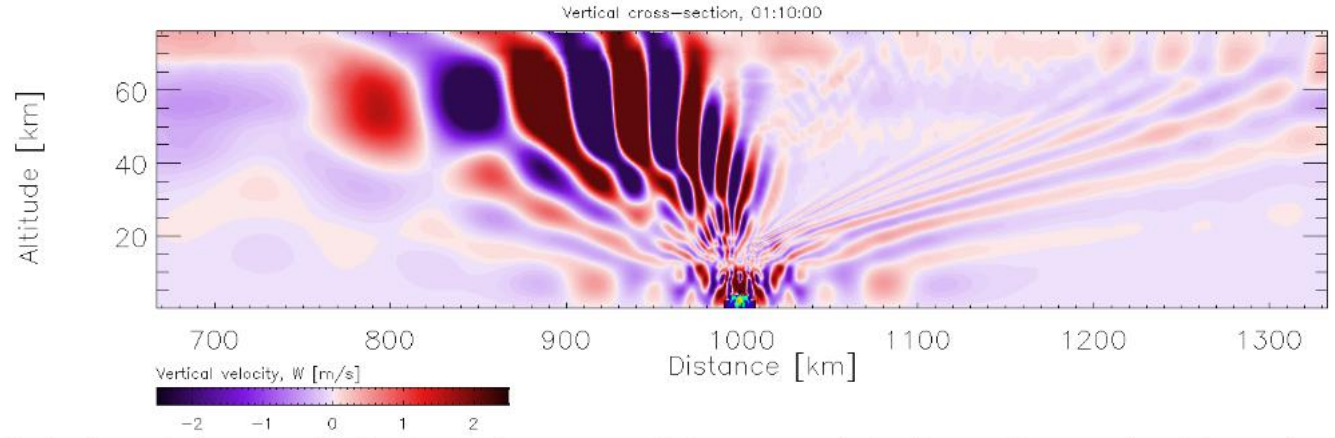
1. Jet stream
2. Orography
3. Convection

Note:

More pilot reports received from (1) and (2)

General properties of AGW

- Horizontal wavelength (several 10 to 1,000 km);
- Vertical wavelength (several km);
- At mid-latitudes, periods vary from several minutes to about 1 day;
- AGW can propagate vertically and transport momentum and kinetic energy upwards.



Small scale atmospheric waves, usually referred to as gravity waves, are an efficient transport mechanism of energy and momentum through the atmosphere. They propagate upward from their sources (flow over topography, thunderstorms, jet adjustment, etc.) to the middle and upper atmosphere. At a given altitude, gravity waves manifest as concentric rings. Depending on the horizontal wind shear, they can dissipate at different altitudes and force the atmospheric circulation of stratosphere and mesosphere.

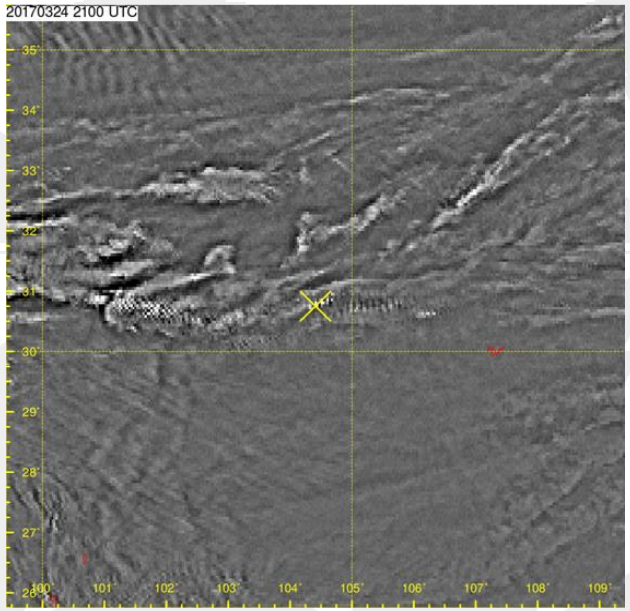
Reference website:
http://arise-project.eu/arise-results.php

Identifying AGW from Satellite Images

- Use Himawari-8 (H-8) 6.2μm water vapour channel images;
- Apply Gaussian high-pass filtering[Ref.] for highlighting AGW, and variations of -1K to +1 K of brightness temperature from the local average are displayed.

$$I_{\mathrm{hp}} = \mathrm{HP}(\sigma) * I\,,$$

$$\mathrm{HP}(\sigma) = 1 - \frac{c}{\sigma\sqrt{2\pi}} \sum_{x,y} e^{-(x^2+y^2)/2\sigma^2},$$



Ref.: Wimmers A., S. Griffin, J. Gerth, S. Bachmeier and S. Lindstrom, 2018 "Observations of Gravity Waves with high-pass filtering in the new generation of Geostationary Images and their relation to aircraft turbulence", *Wea. Forecasting*, **33**, Issue 1, 139-144. https://doi.org/10.1175/WAF-D-17-0080.1

Building Deep Learning Model

1. Data collection
2. Data annotation
3. Data augmentation
4. Generation of TensorFlow Records

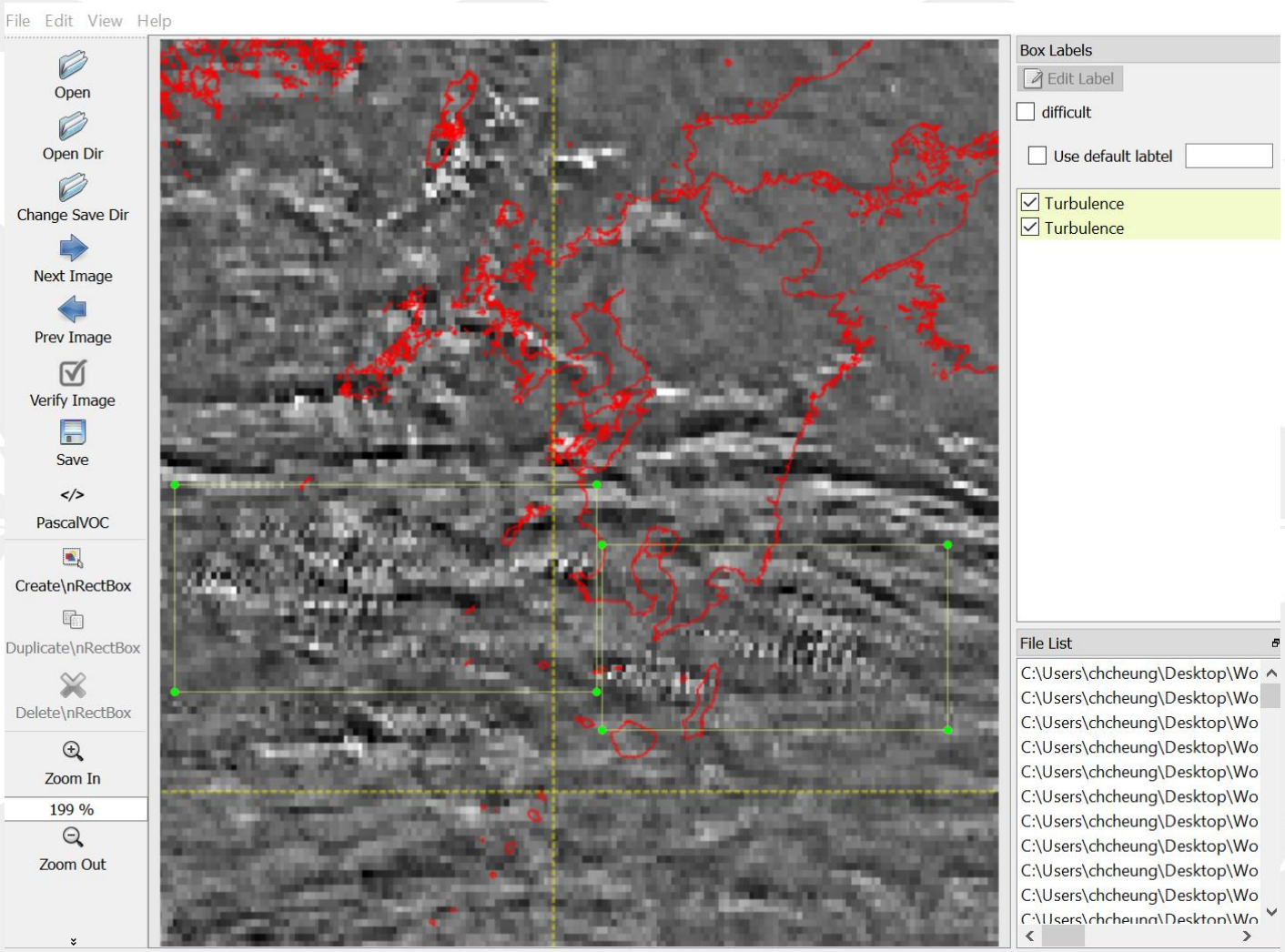
1. Architecture selection
2. Model configuration

1. Model streamlining
2. TensorRT optimization

Data Preparation

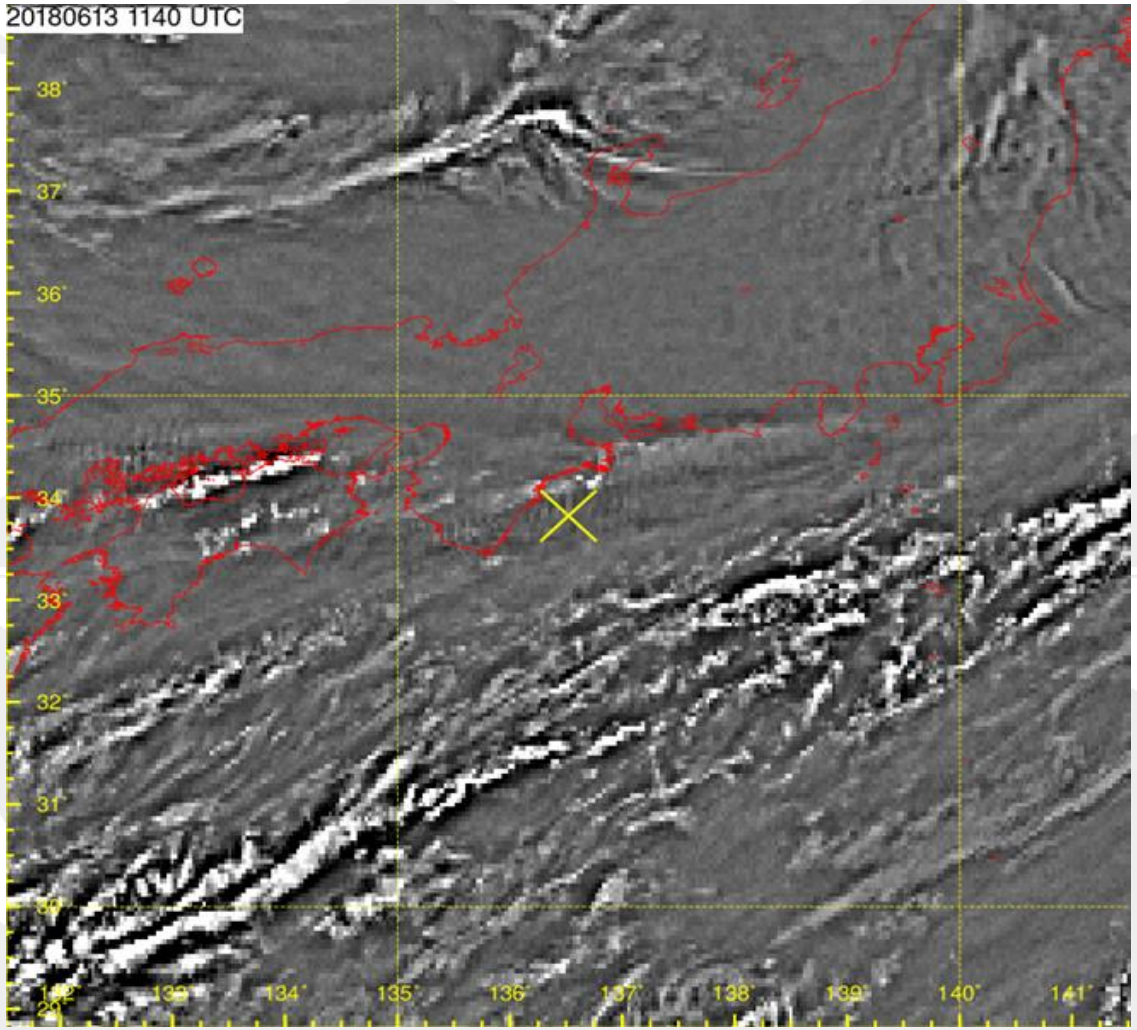
- Collect over 750 pilot reports from Jan. 2018 to Jun. 2021;
- Generate high-pass filtered images based on T ± 30 min. from the observation time (T) of the pilot reports;
- Identify AGW rectangular boxes (Human Truthing);
- Classify AGW intensity.

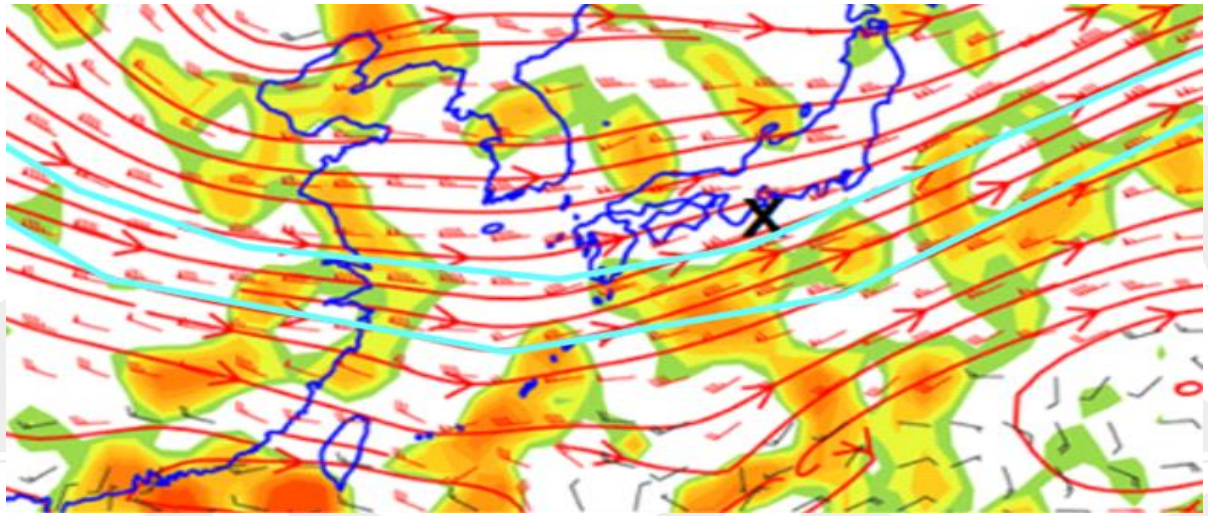
Data Annotation



Classification

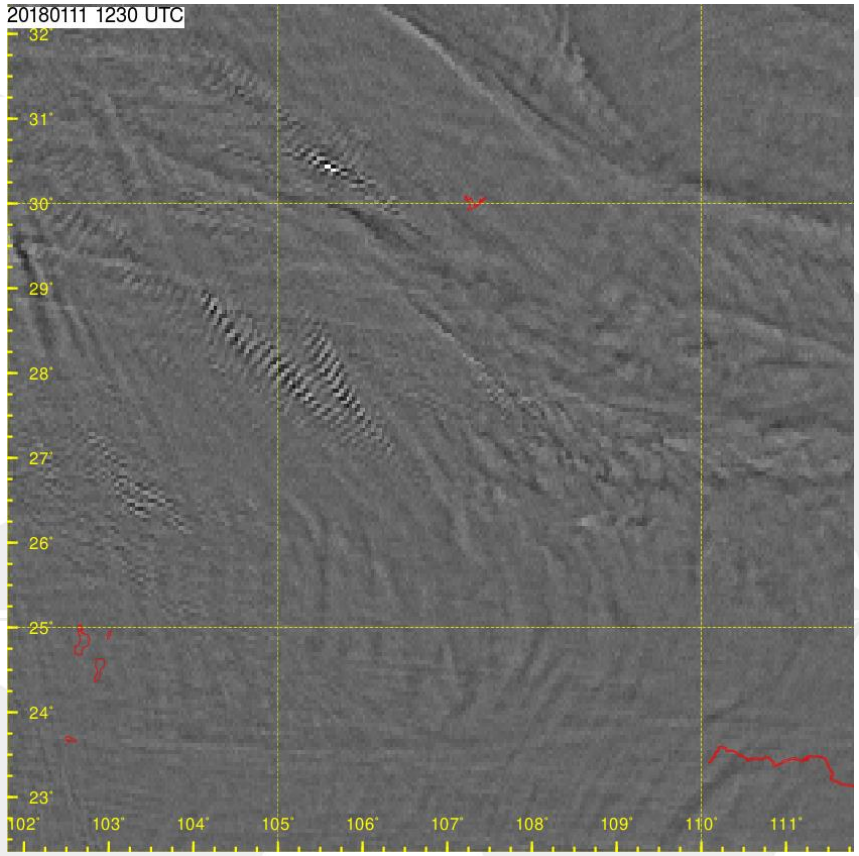
Severe Turbulence



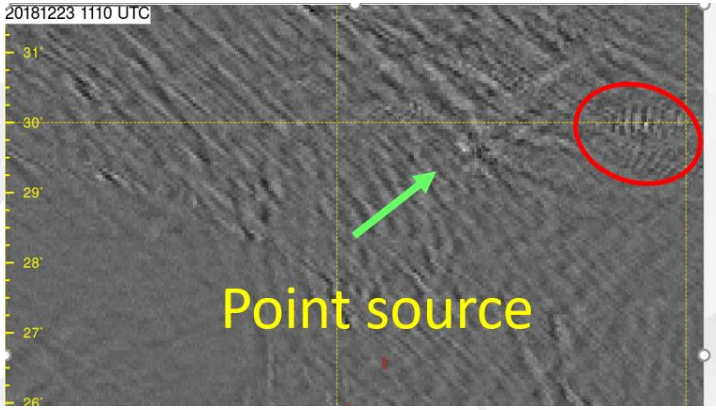


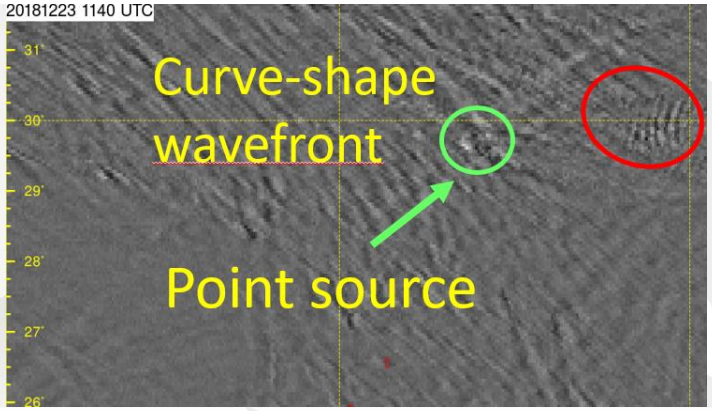
Classification

Significant Severe Turbulence



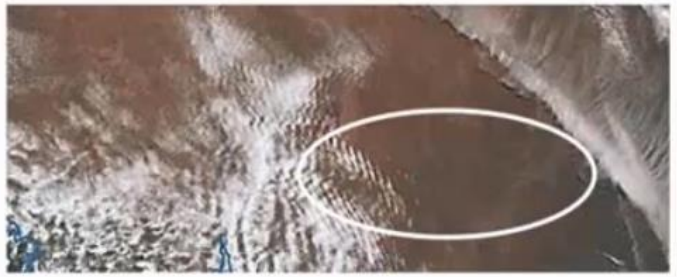
Larger contrast in brightness temperature
in regions with overlapping wavetrains





Merging of gravity waves or
waves displaying Herringbone patterns

AGW events showing Herringbone pattern



Two characteristics coincident with mountain wave turbulence.

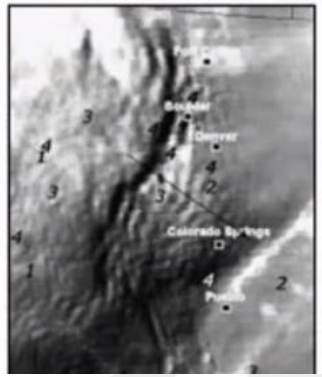
- Mountain waves with higher amplitudes (>5K)
- **Mountain waves that displayed Herringbone patterns**

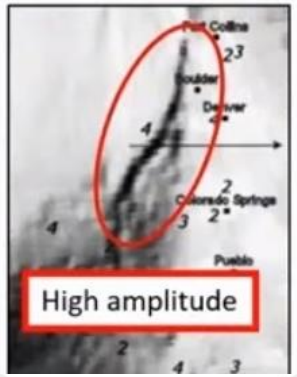
Case observed in Australia

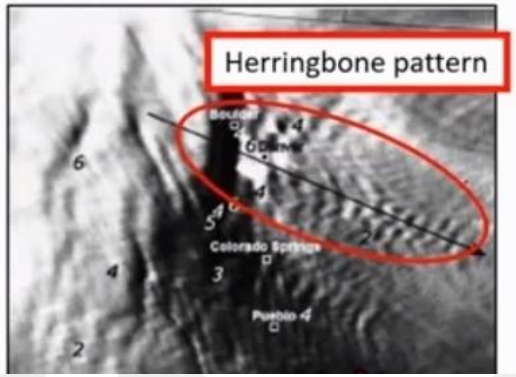
Case observed in Colorado U.S.A.

images from Uhlenbrock et al. 2007

Turbulence conditions for mountain waves



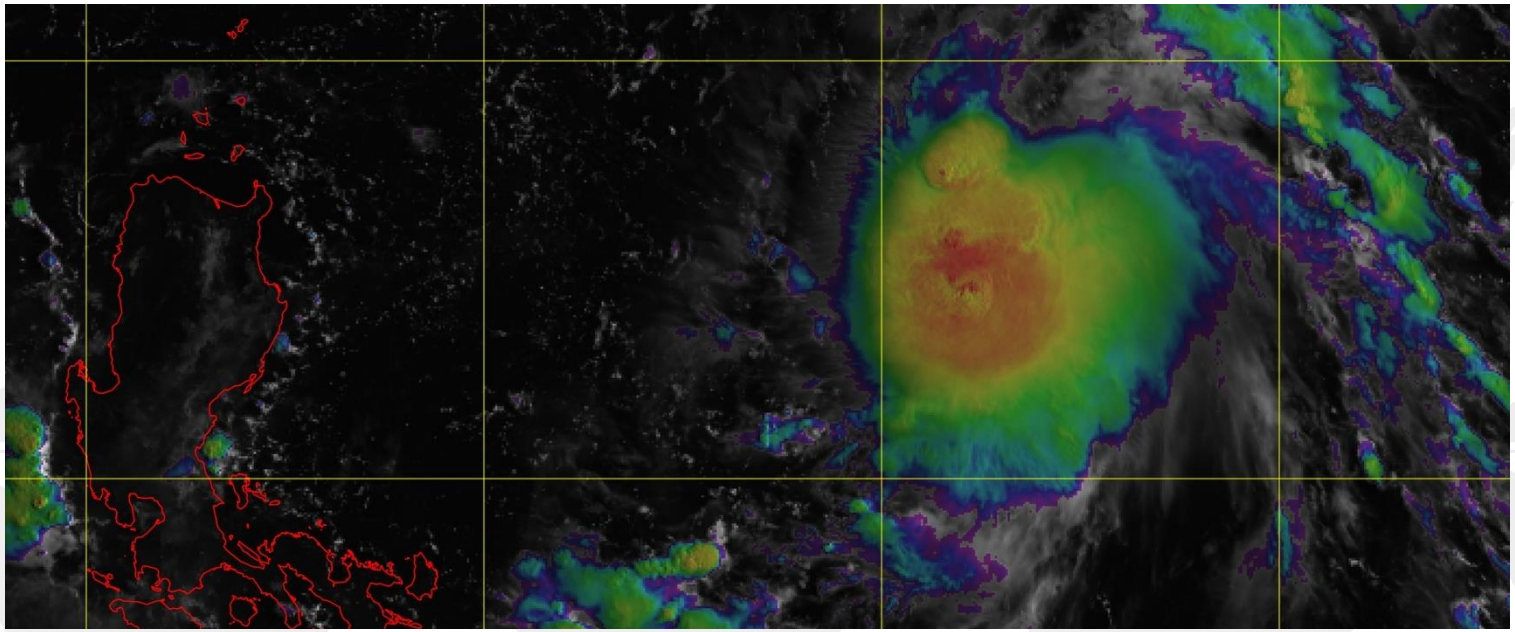




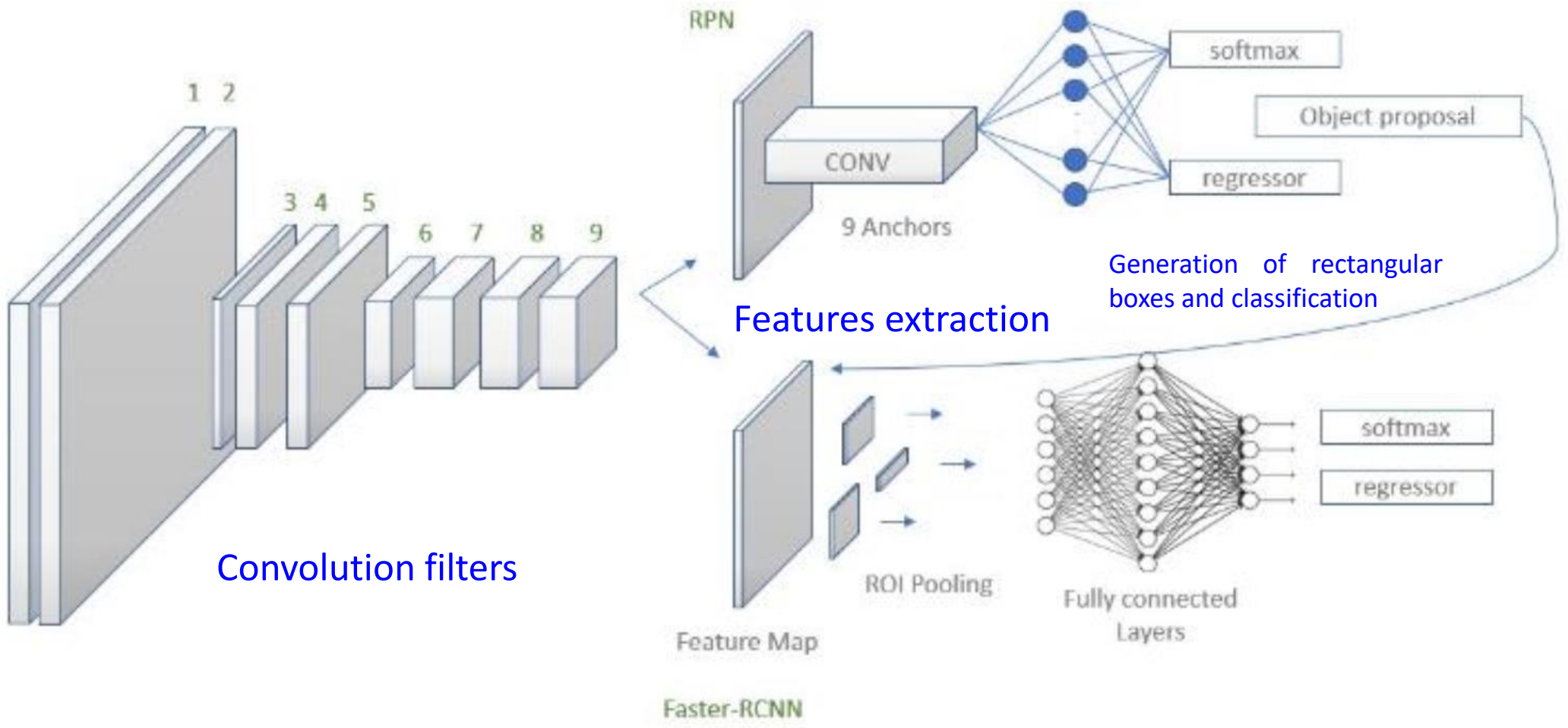
Ref.: Uhlenbrock N.L., K.M. Bedka, W.F. Feltz and S.A. Ackerman, 2007 “Mountain wave signatures in MODIS 6.7µm Imagery and their relation to pilot reports of turbulence”, *Wea. Forecasting*, **22**, Issue 3, 662-670. https://doi.org/10.1175/WAF1007.1

Classification

Convection-induced Turbulence

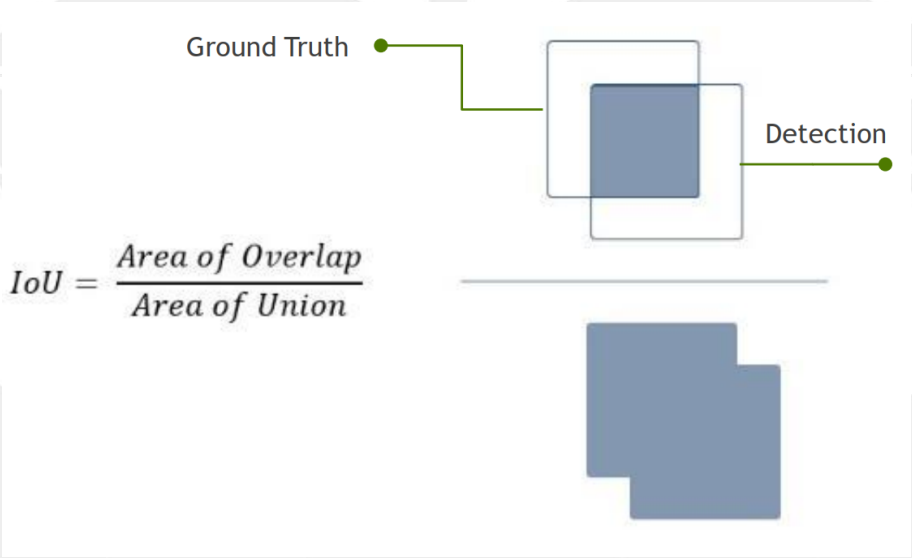


Model Architecture: Faster Region-based Convolutional Neural Network (Faster RCNN)



Model Training and Testing

- 80% of dataset collected for training and 20% for testing (randomly selected);
- Calculate model precision (IoU: Intersection over Union);
- After model training, $IoU_{0.5}$ = 0.7182;



Verification

- Pilot reports in Jul. – Dec. 2021 were extracted for verification.
- Reports seem to follow a flight route are removed.
- Reports with severe turbulence at low level say 500 ft are removed
- 38 reports with flight levels at least 15,000 ft are used for verification
- High-pass WV images ± 10 minutes from the reported time was counted.

Results

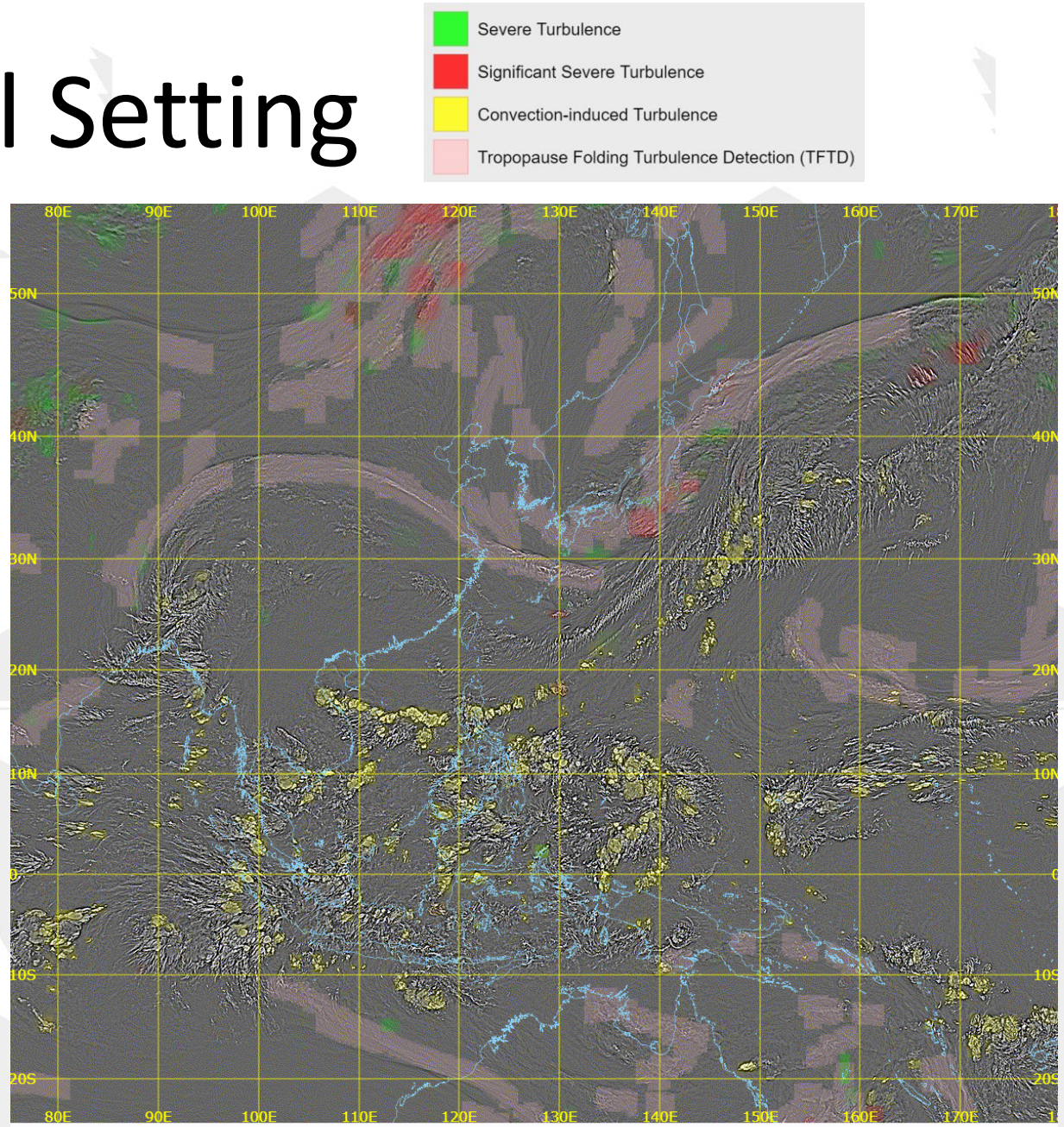
	Location of severe turbulence within ± 1° of boxes	Location of severe turbulence within ± 2° of boxes
No. of reports = 38	21	33
Percentage (%)	55	87

Post-processing

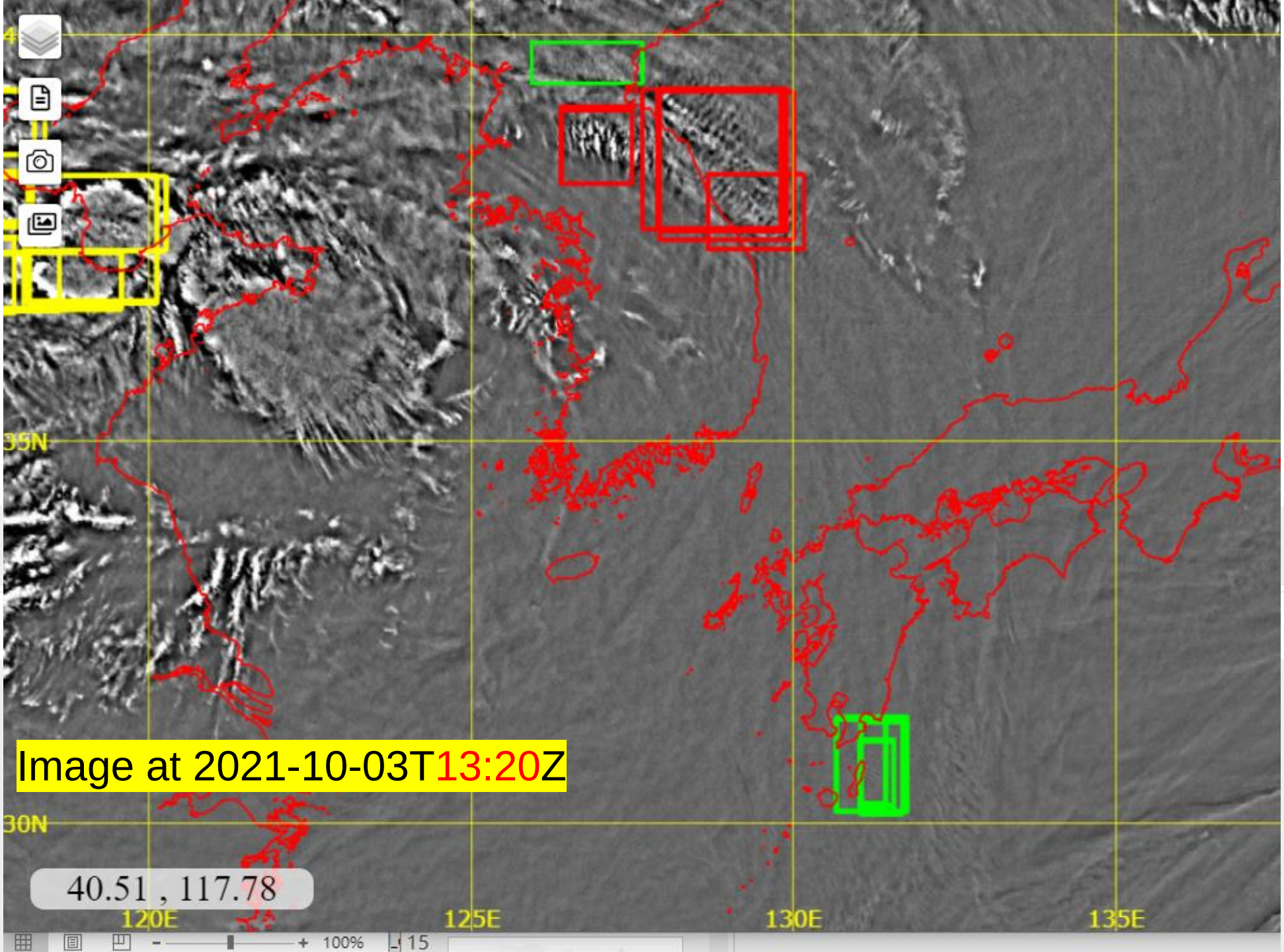
- Rectangular boxes in the last 30 minutes were also shown to enhance continuity;
- Boxes were filled in colours but transparency was added to enable visualization of high-pass filtered satellite images on the back.

Current Operational Setting

- Model output to WebGIS display;
- GK2A Tropopause Folding Turbulence Detection (TFTD) products were also displayed.



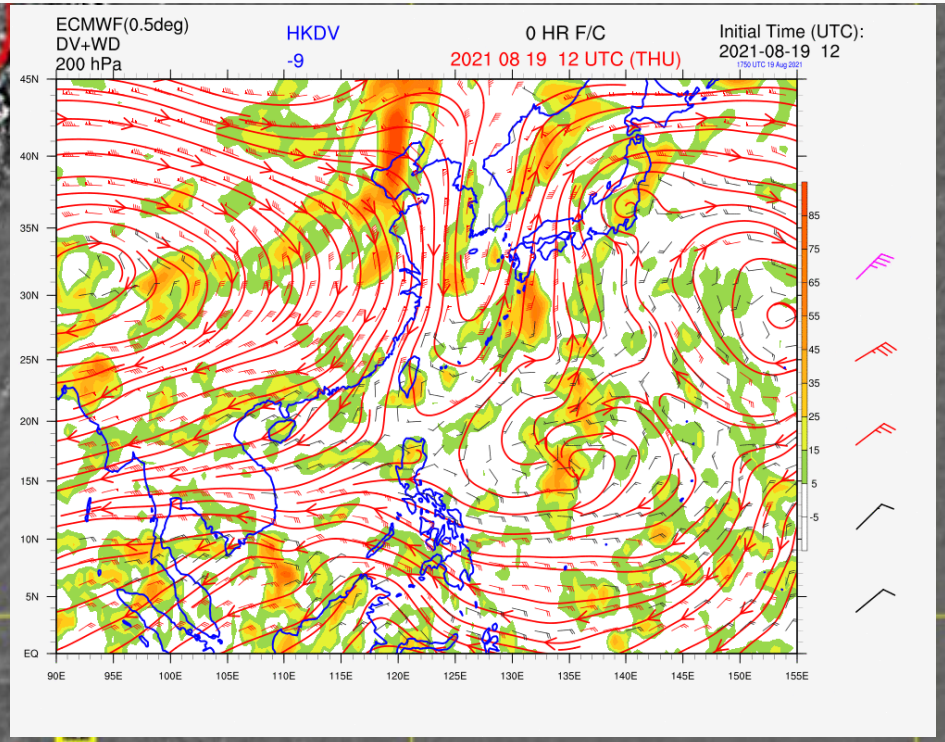
Beautiful Catch


35N
30N
Image at 2021-10-03T13:20Z
40.51 , 117.78
120E
125E
130E
135E
100%
15

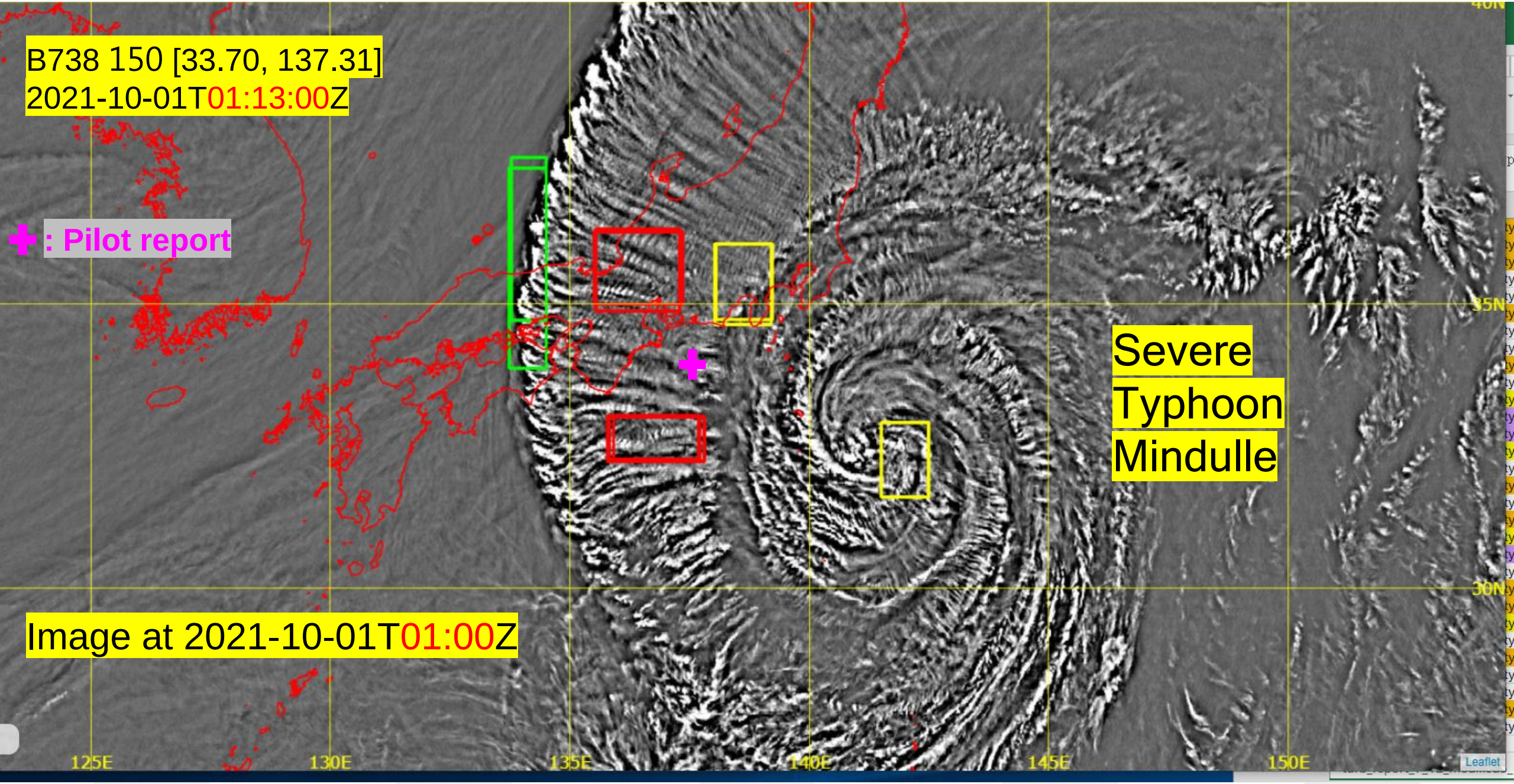
A359 410 [30.37, 130.72,]
2021-08-19T12:13:00Z

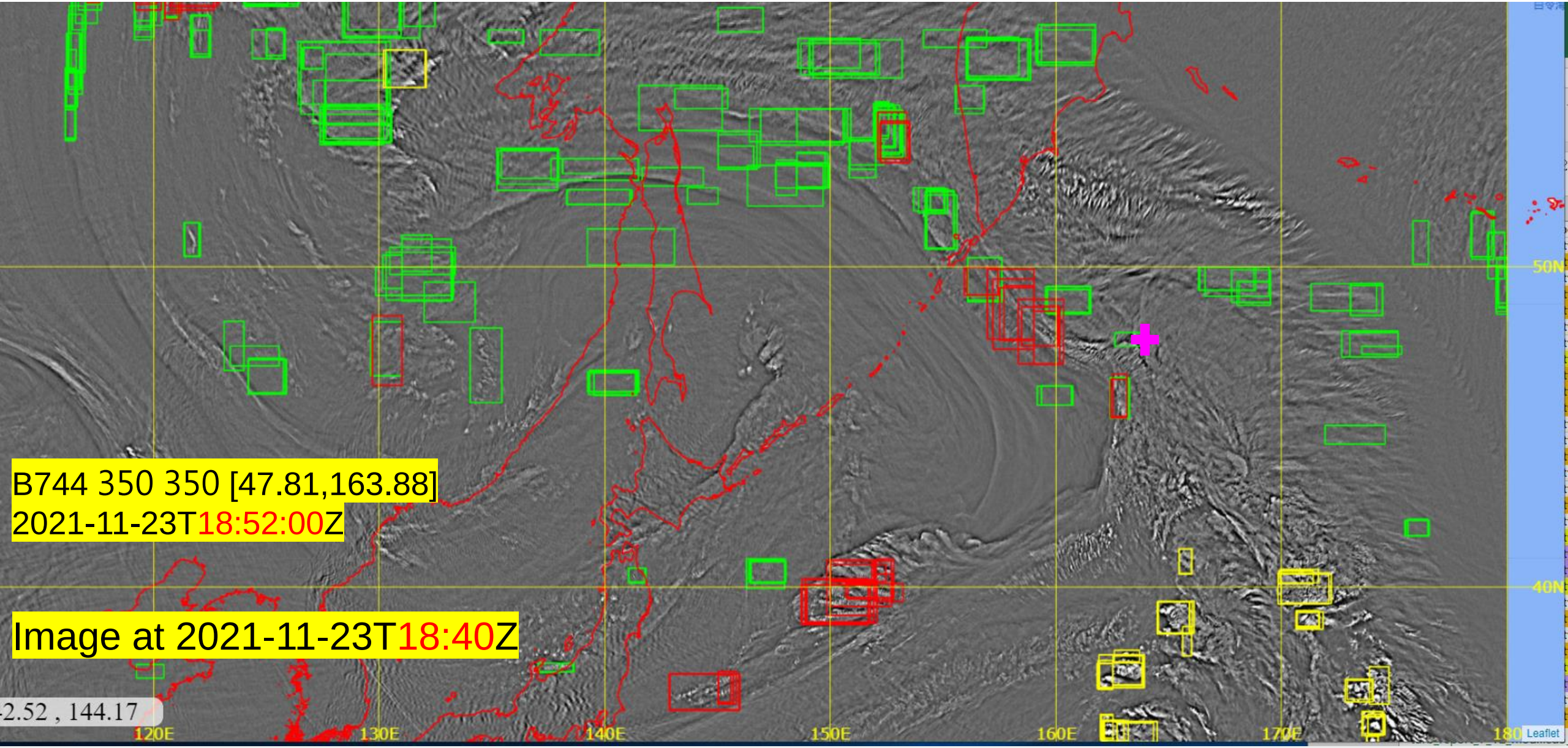
Image at 2021-08-19T12:10Z

✚: Pilot report

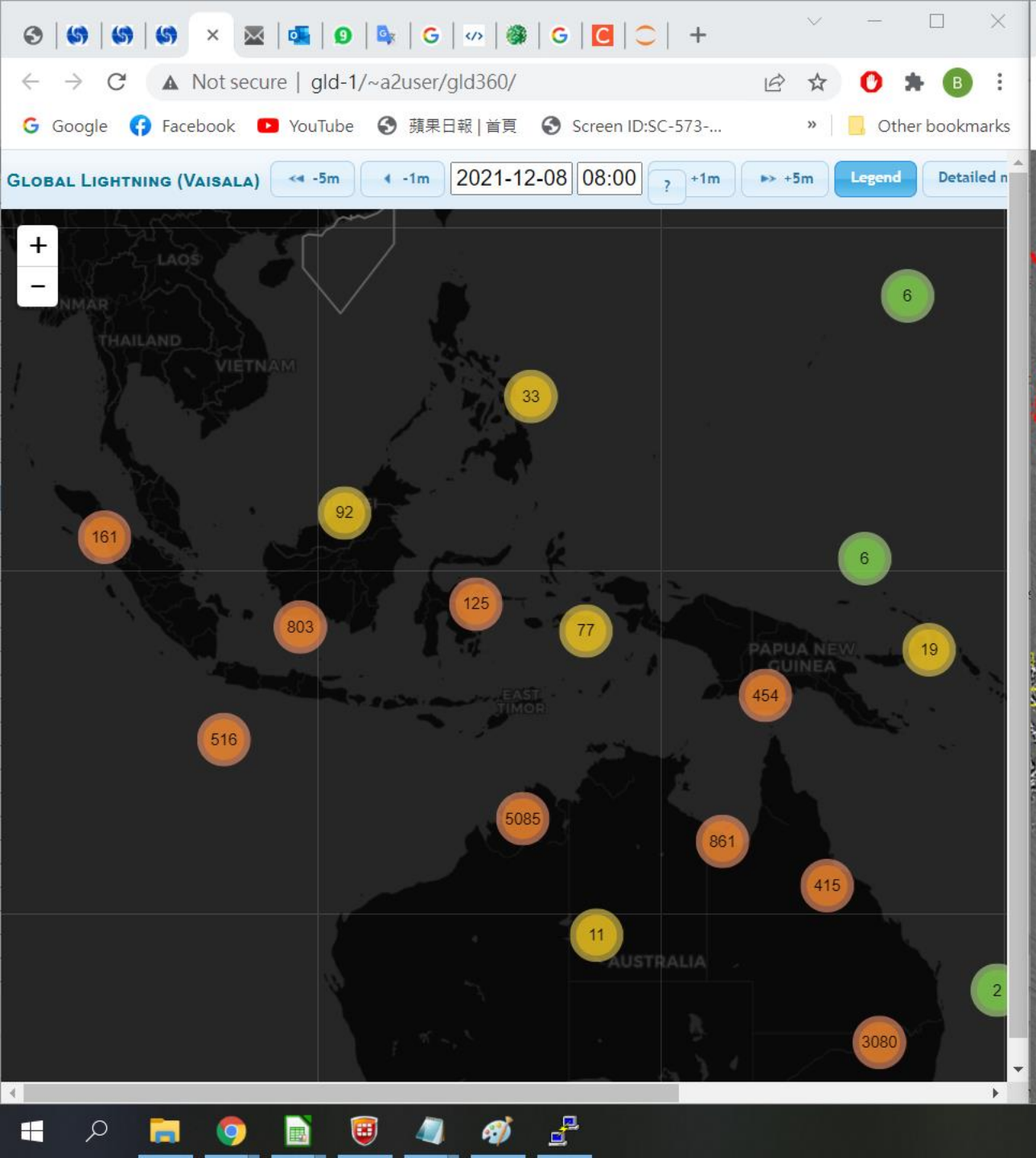


30N
20N
120E
130E
140E
150E
160E
Leaflet


B738 150 [33.70, 137.31]
2021-10-01T01:13:00Z
: Pilot report
Severe
Typhoon
Mindulle
Image at 2021-10-01T01:00Z
125E
130E
135E
140E
145E
150E
35N
30N
Leaflet


B744 350 350 [47.81,163.88]
2021-11-23T18:52:00Z
Image at 2021-11-23T18:40Z
-2.52 , 144.17
120E
130E
140E
150E
160E
170E
180
50N
40N
Leaflet

Additional Values


Not secure | gld-1/~a2user/gld360/
Google
Facebook
YouTube
蘋果日報 | 首頁
Screen ID:SC-573-...
Other bookmarks
Global Lightning (Vaisala)
-5m
-1m
2021-12-08
08:00
+1m
+5m
Legend
Detailed n
LAOS
THAILAND
VIETNAM
PAPUA NEW GUINEA
EAST TIMOR
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5085
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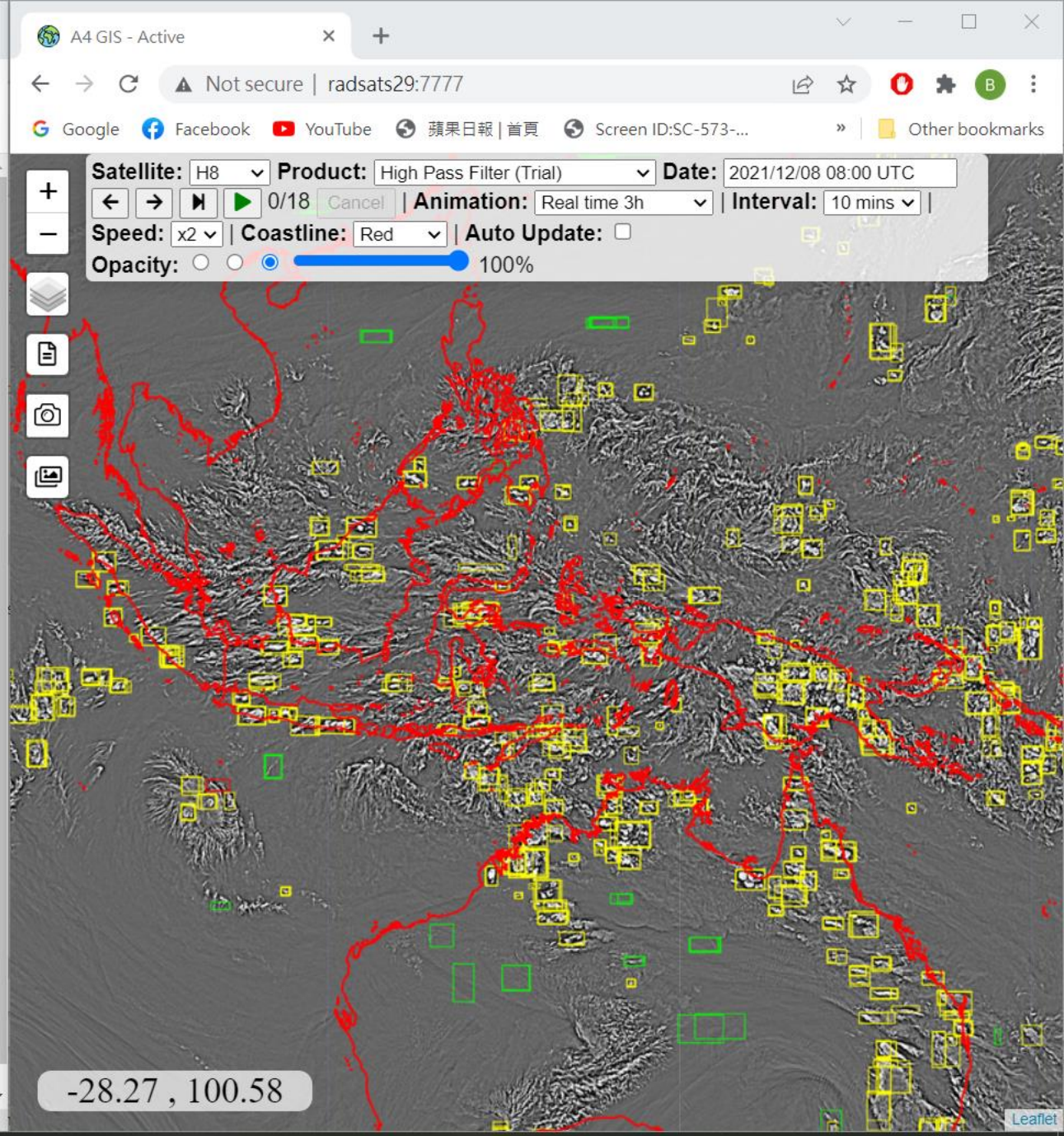
A4 GIS - Active
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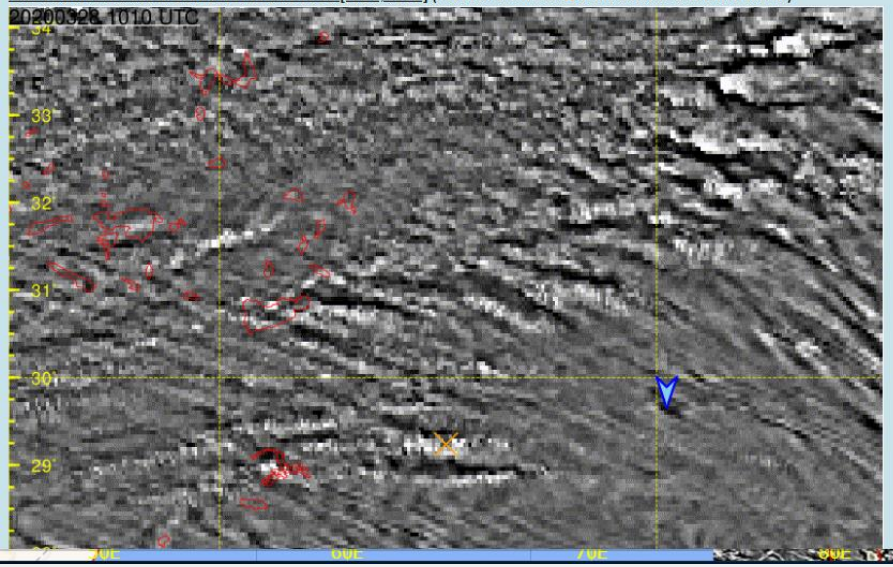
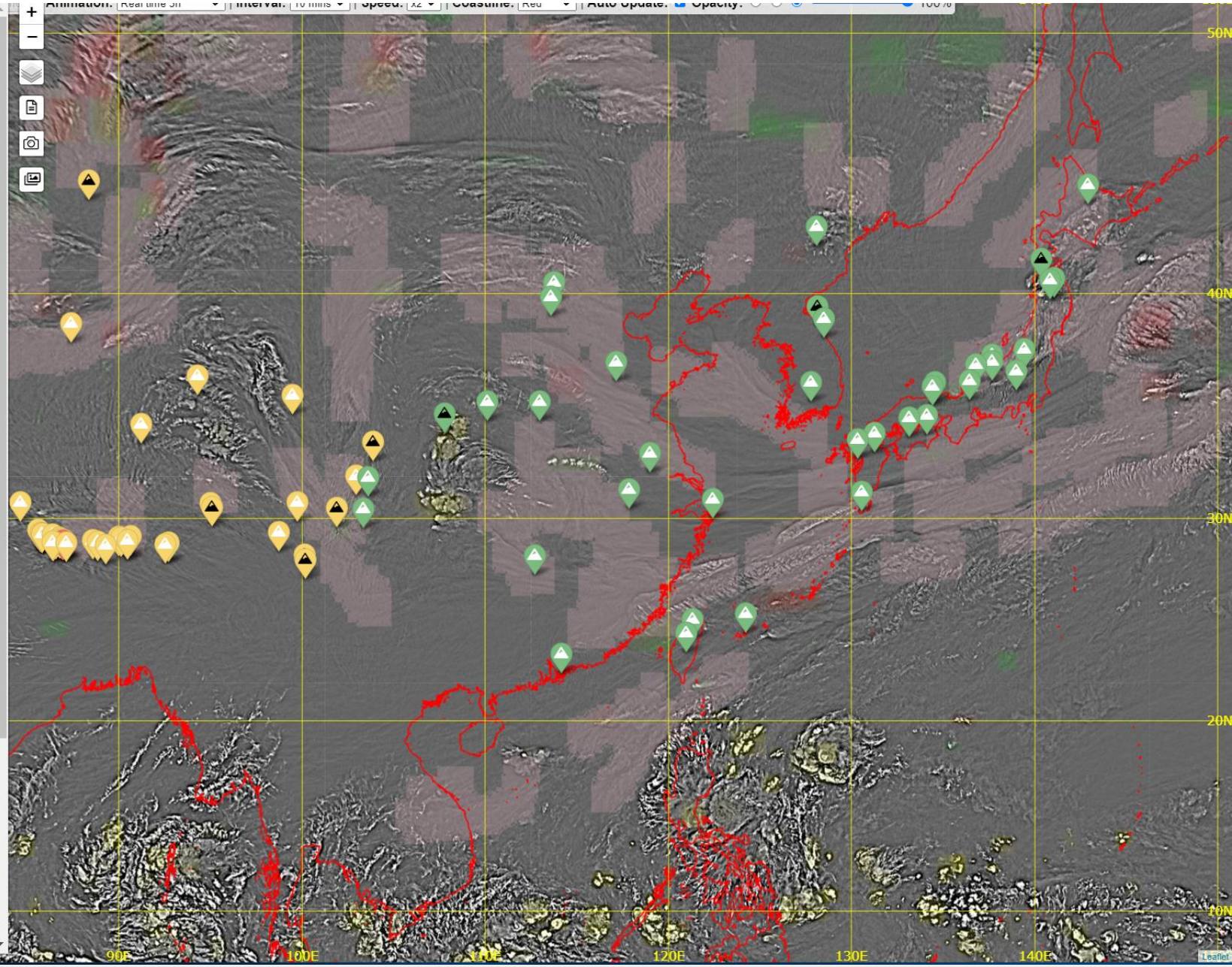
Google
Facebook
YouTube
蘋果日報 | 首頁
Screen ID:SC-573-...
Other bookmarks
Satellite: H8
Product: High Pass Filter (Trial)
Date: 2021/12/08 08:00 UTC
0/18
Cancel
Animation: Real time 3h
Interval: 10 mins
Speed: x2
Coastline: Red
Auto Update:
Opacity:
100%
-28.27 , 100.58
Leaflet

英
16:29
14/3/2022

Mountain Info:
Name: Namcha Barwa
Height: 7,782 m
Lat/Long: 29.62, 95.05 (Please see V in the satellite animation below)

Past Turbulence Case in 2020/03/28 10:00 UTC at [29.23, 92.59] (Position shown as X in the satellite animation below)





Conclusion and Future Work

- Verification shows reasonably good model skills
- Those yellow boxes possibly reflect lightning locations
- AGW casebook as educational materials
- Identify flight levels affected by AGW events

Thank You !