Zipline: Autonomous Delivery At Scale Even in Stormy Weather!

John Celenza, Weather Team Lead

22 Apr 2024

Zipline

We fly a lot

CI-1 Zipline Daloa at Nightfall.

Launch

Zipline

Delivery

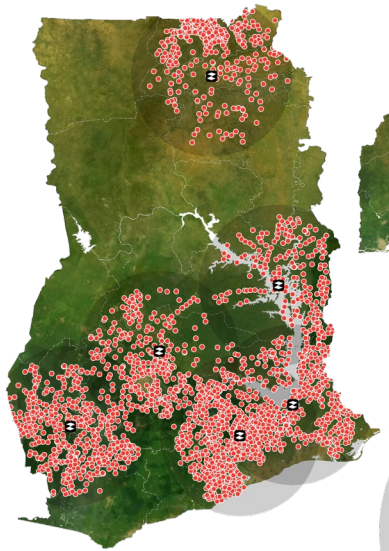
Zip launches from our hub.

Zipline

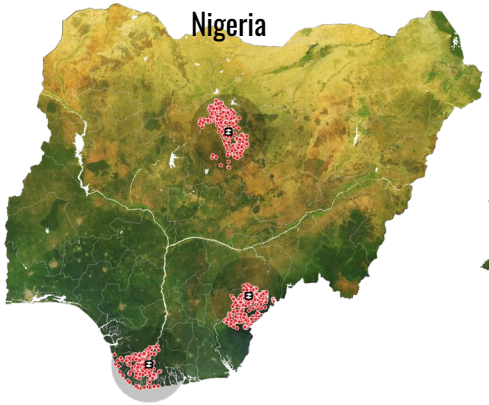
Recovery

Zipline

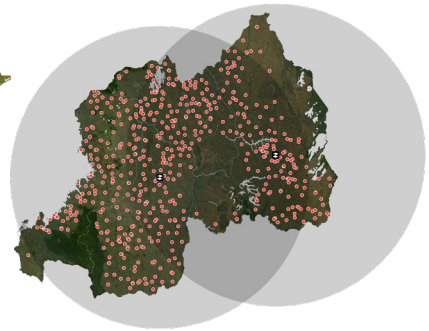
Where We Fly



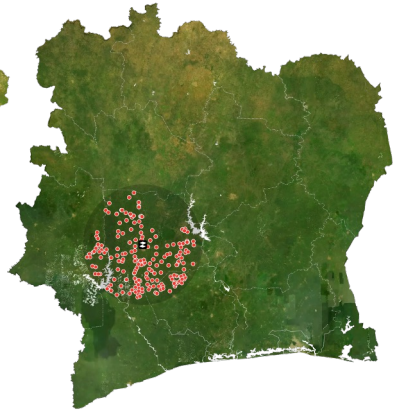
Ghana



Nigeria



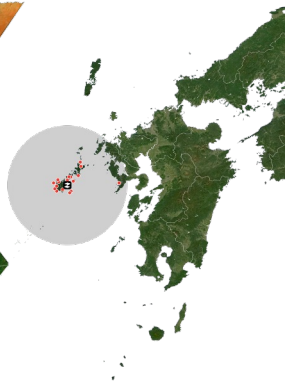
Rwanda



Côte d'Ivoire

North Carolina
Remote Ops Control Center

Kenya



Japan

Utah

Arkansas

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Delivery Truly at Scale

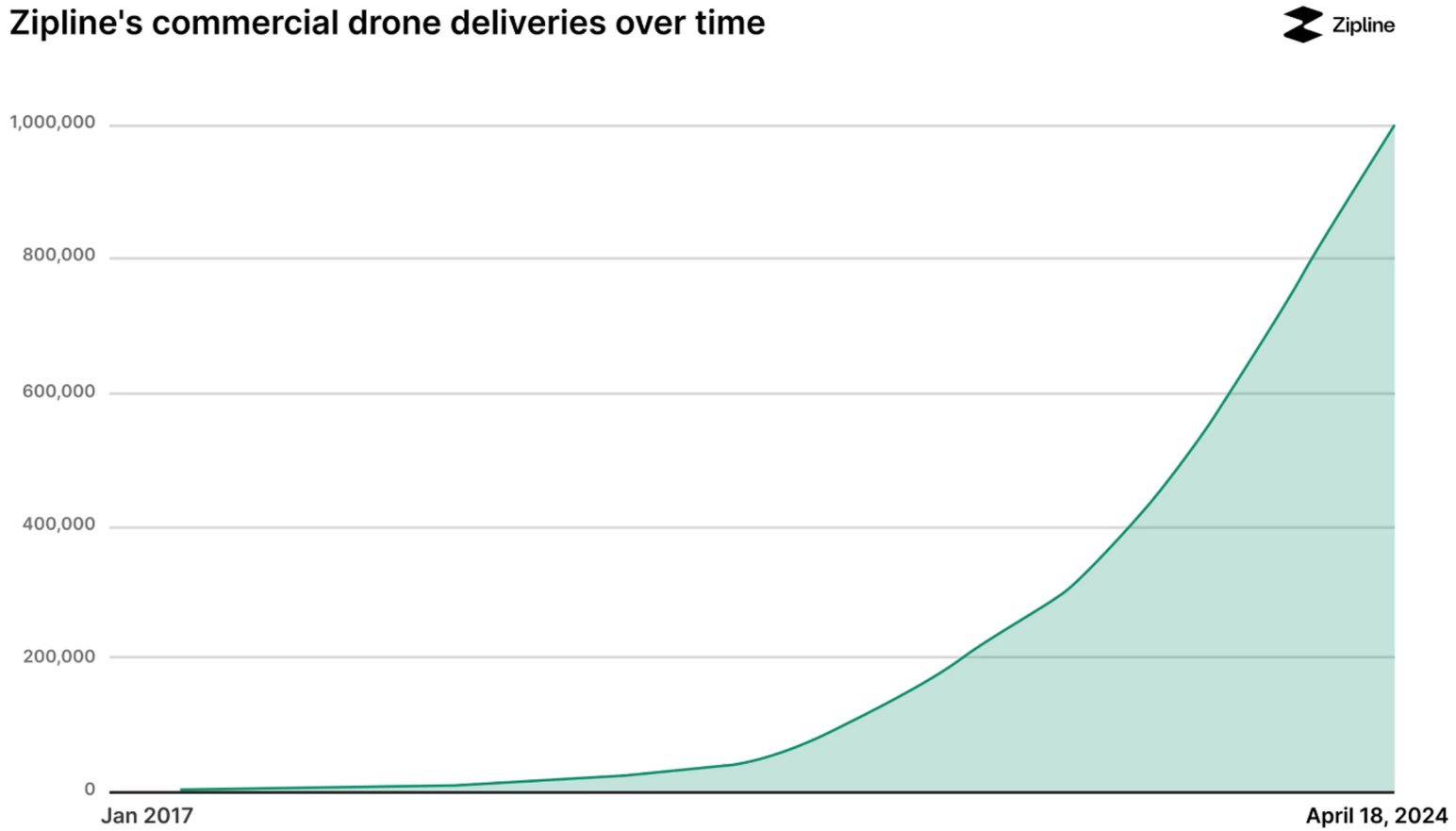
Many days we deliver over **1,500 deliveries**

Some nests deliver upwards of **450 packages** in one day

For a **single hour**, our record is **186 deliveries,** one every 19 seconds!

zipline

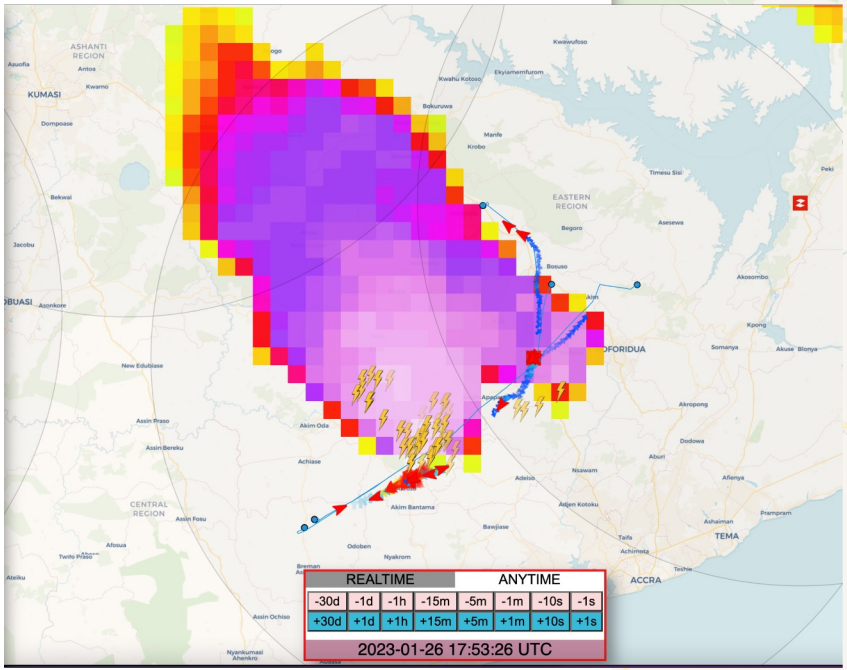
Zipline's commercial drone deliveries over time



We fly into very stormy weather!

Western Africa Severe Weather

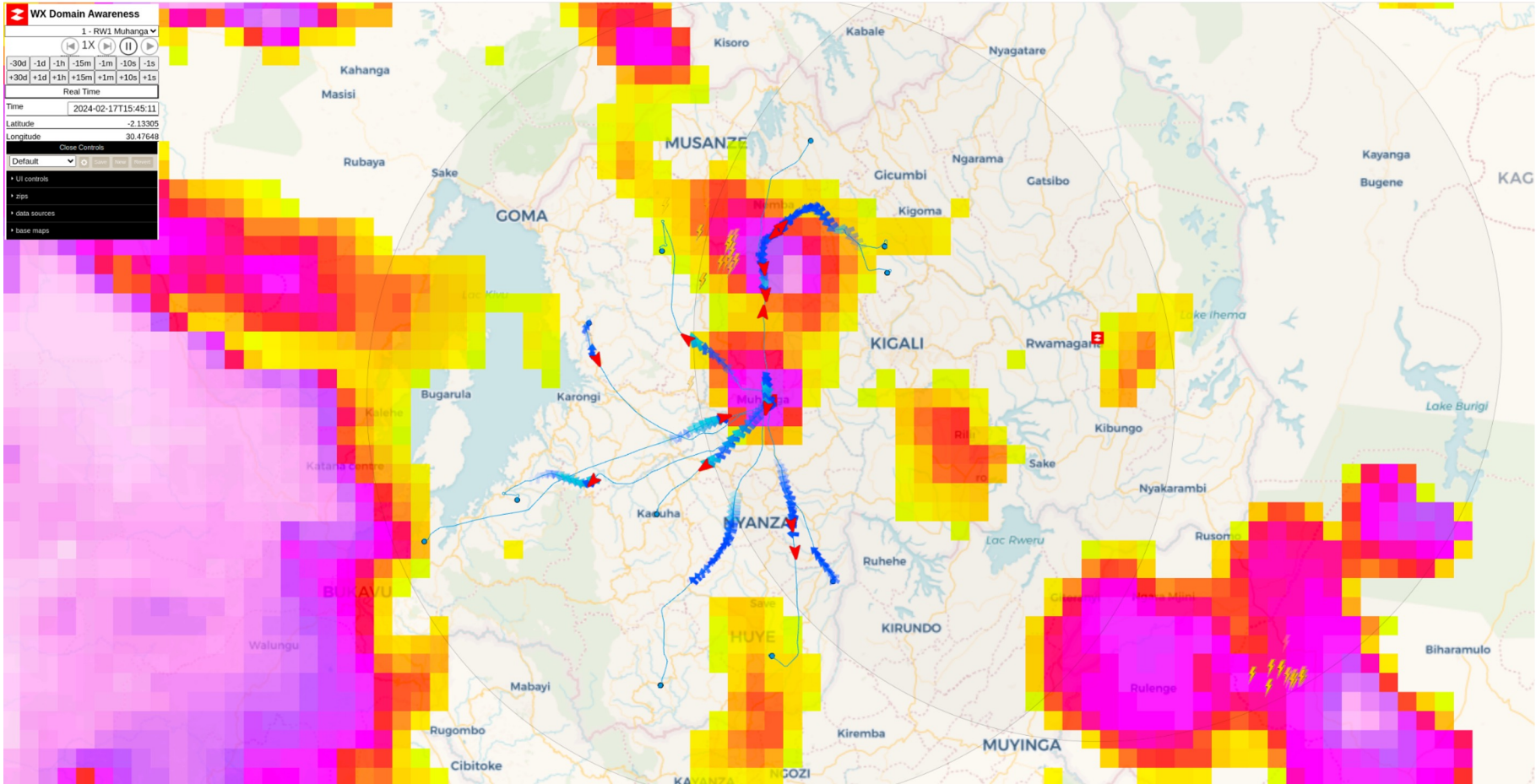
2023-01-26 Ghana



Wind Speed	16.91 m/s
Wind Direction	-159.20 deg
Timestamp	2023-01-26T17:16:11.21
Latitude	5.86960°
Longitude	-0.61816°
Position North	-23140.9m
Position East	-16731.2m
Altitude	269.6m
Pressure Altitude	289.4m
Nest	5
Flight	121882
Delivery Site	1915
Has Package	No
Battery	51.50%
Flight time	5176.0s
Mission State	MS_INBOUND
Failure Level	FL_NO_FAILURE
Failure Level Exception	undefined

2024-02-16 Ghana

Typical Snapshot



Avoiding Severe Wind: Let's build an AI (*Buzzwordy*) Model

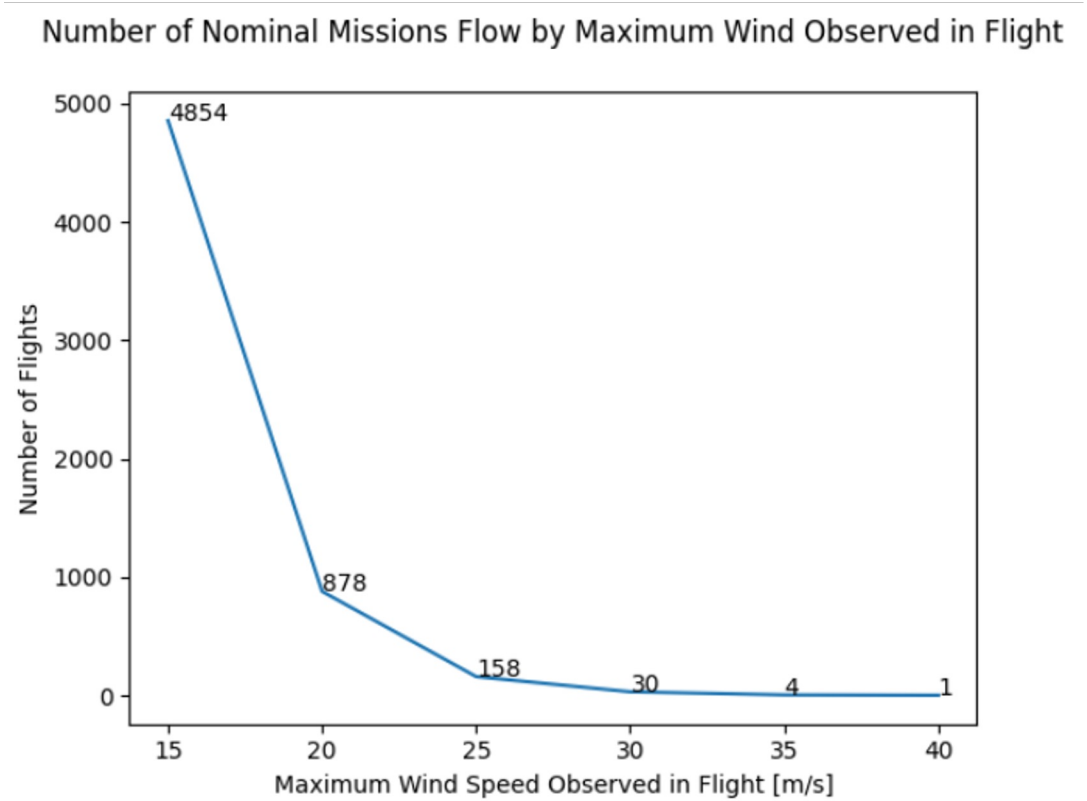
What Zips Measure

Observational Frequency - 50 Hz
Average Flight Duration - <1 Hour Globally
Variables

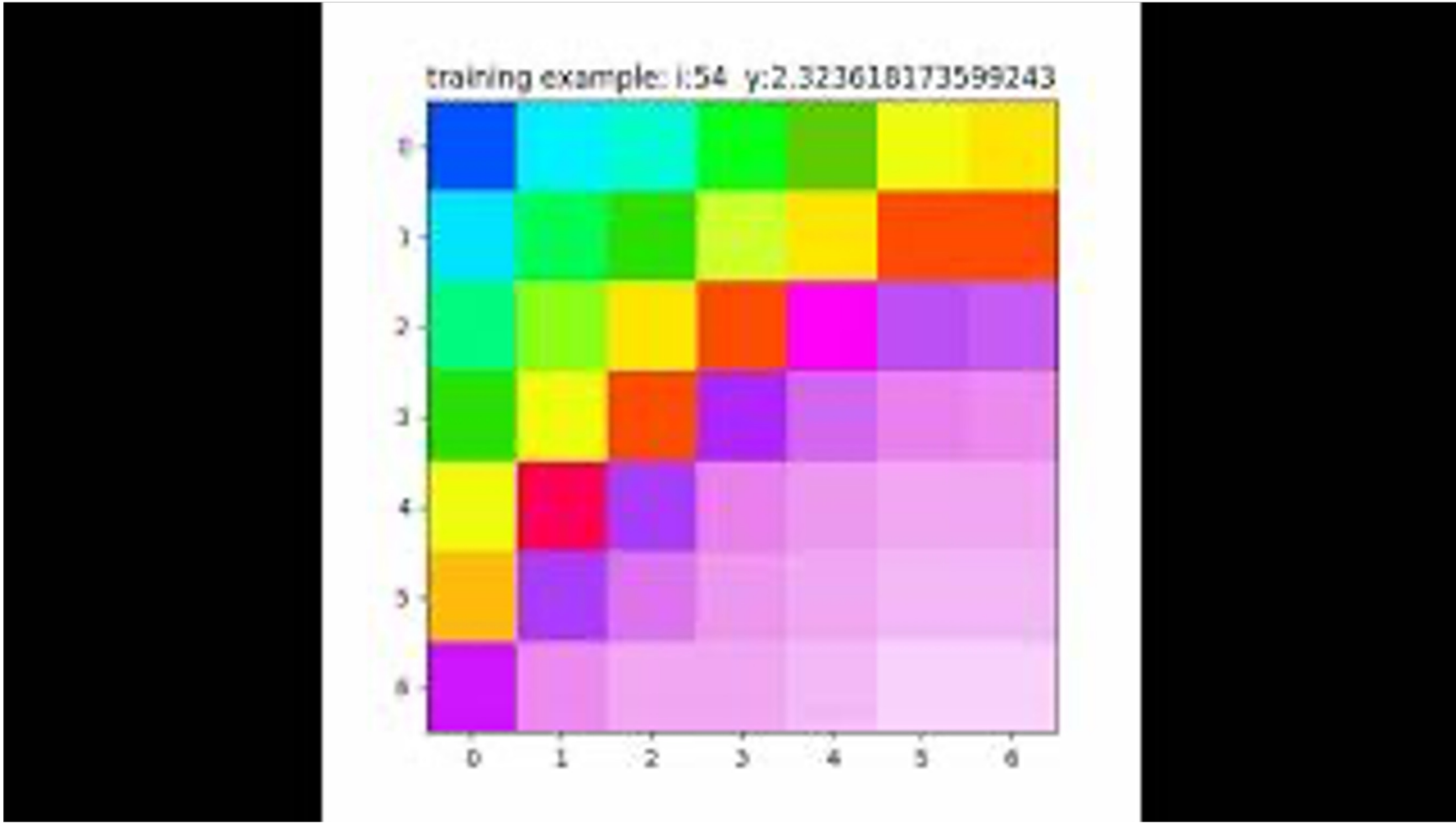
- **Wind Component (NED) -** ~ ±1.5 m/s
- **Temperature -** ~ ± 2.5 ℃
- **Relative Humidity**
- **Static Pressure -** High accuracy, used for pressure altitude

There are Plentiful Samples of High Wind Speed

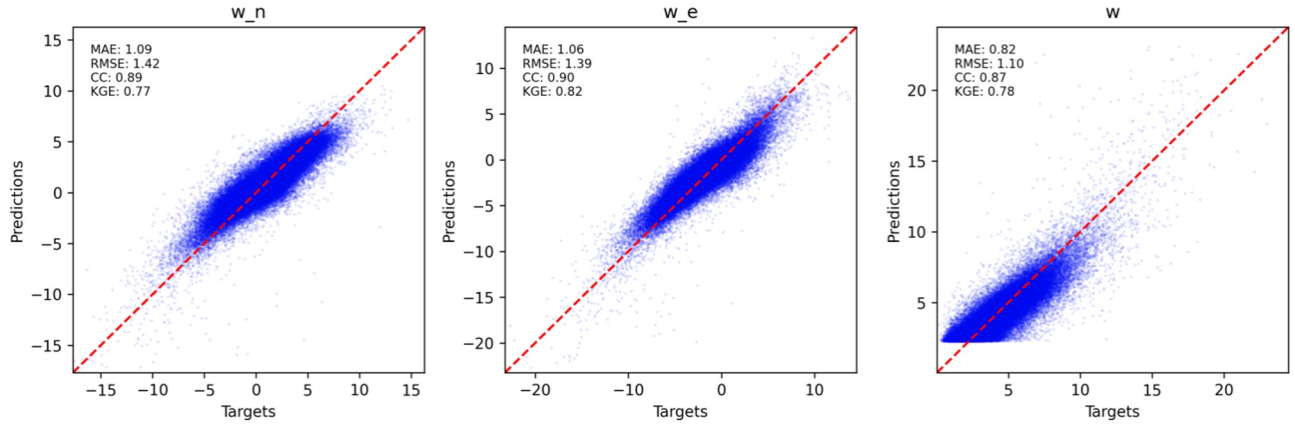
Each year, we experience hurricane force winds in flight!



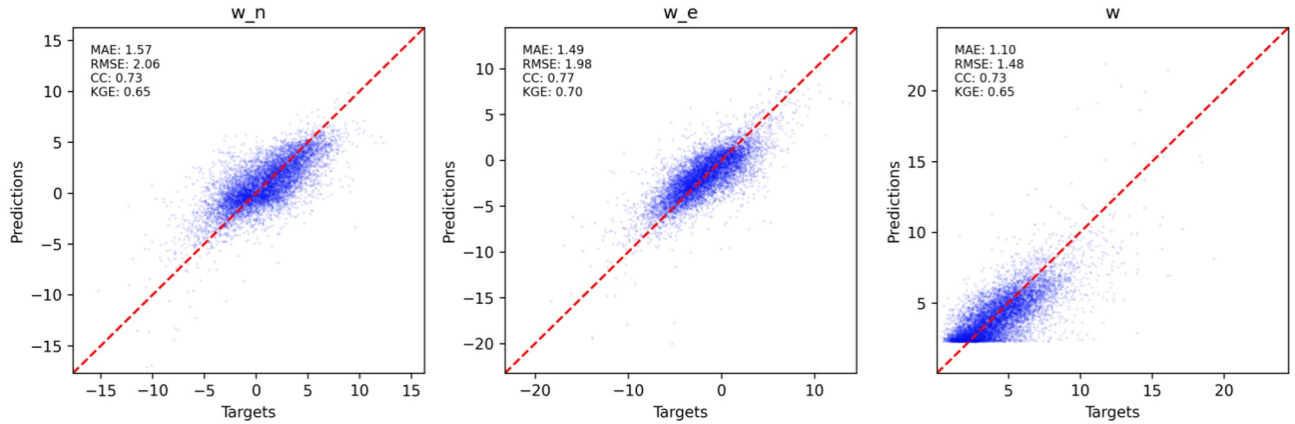
Let’s train a model!



How well does it work?

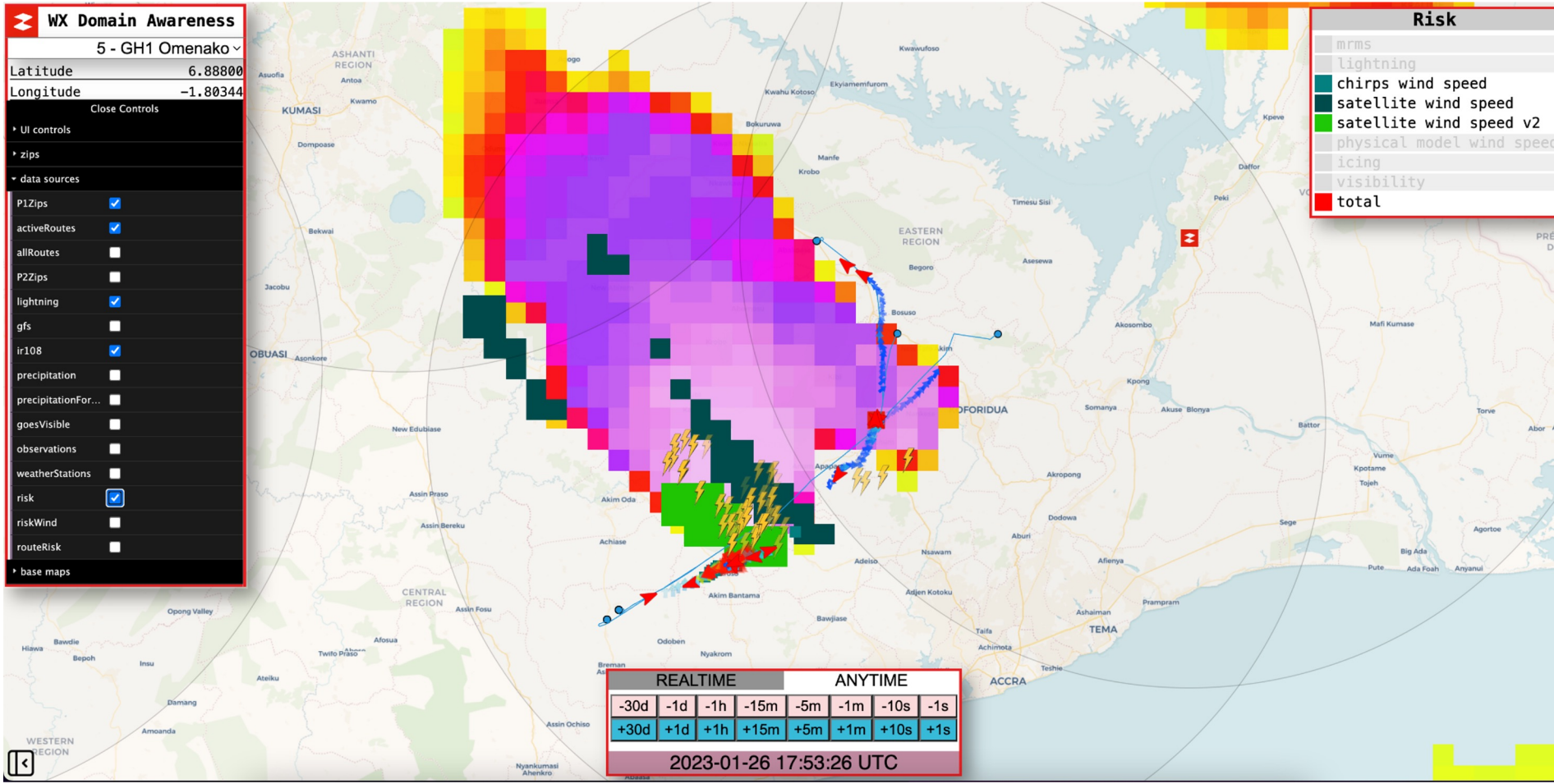


Train

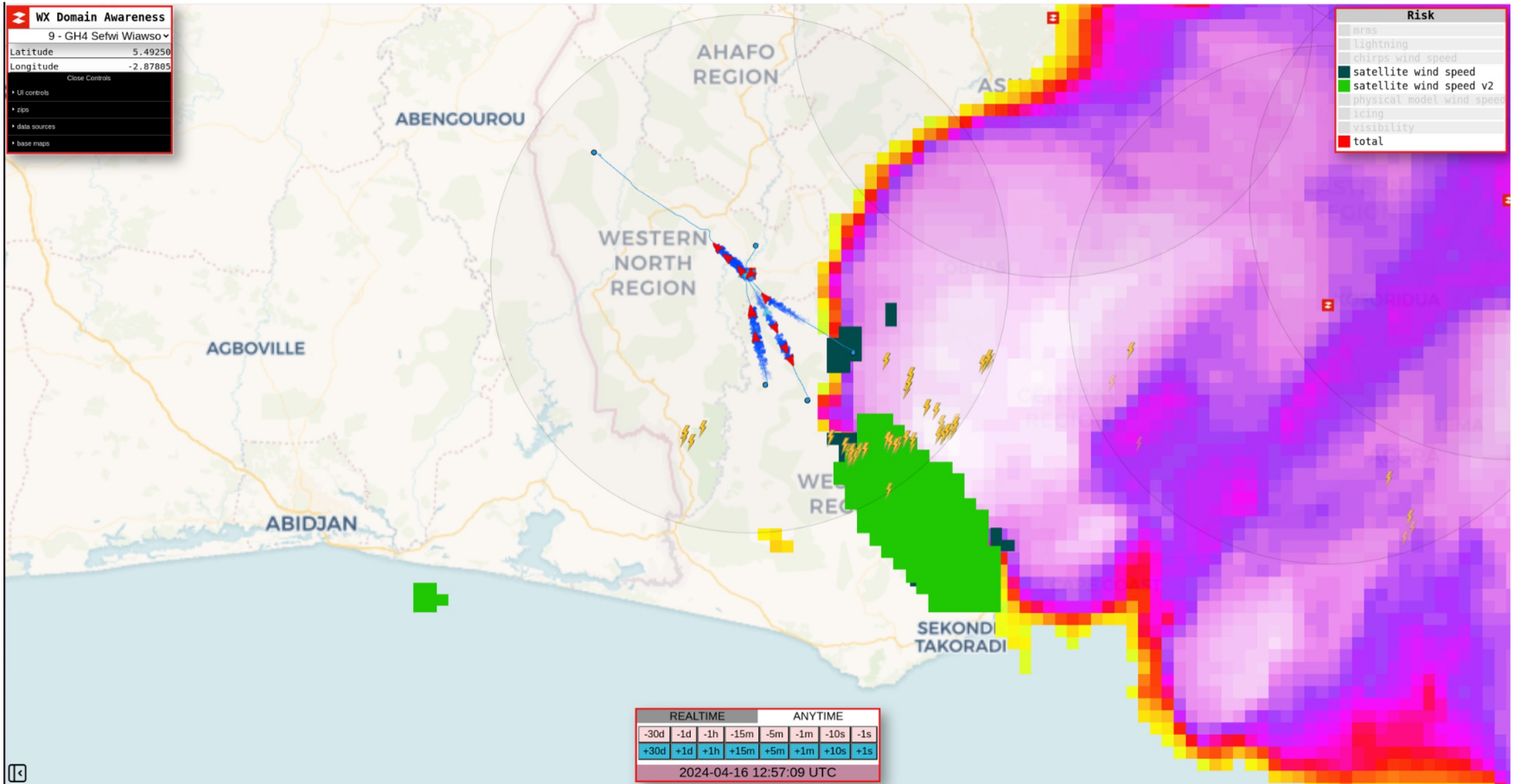


Test

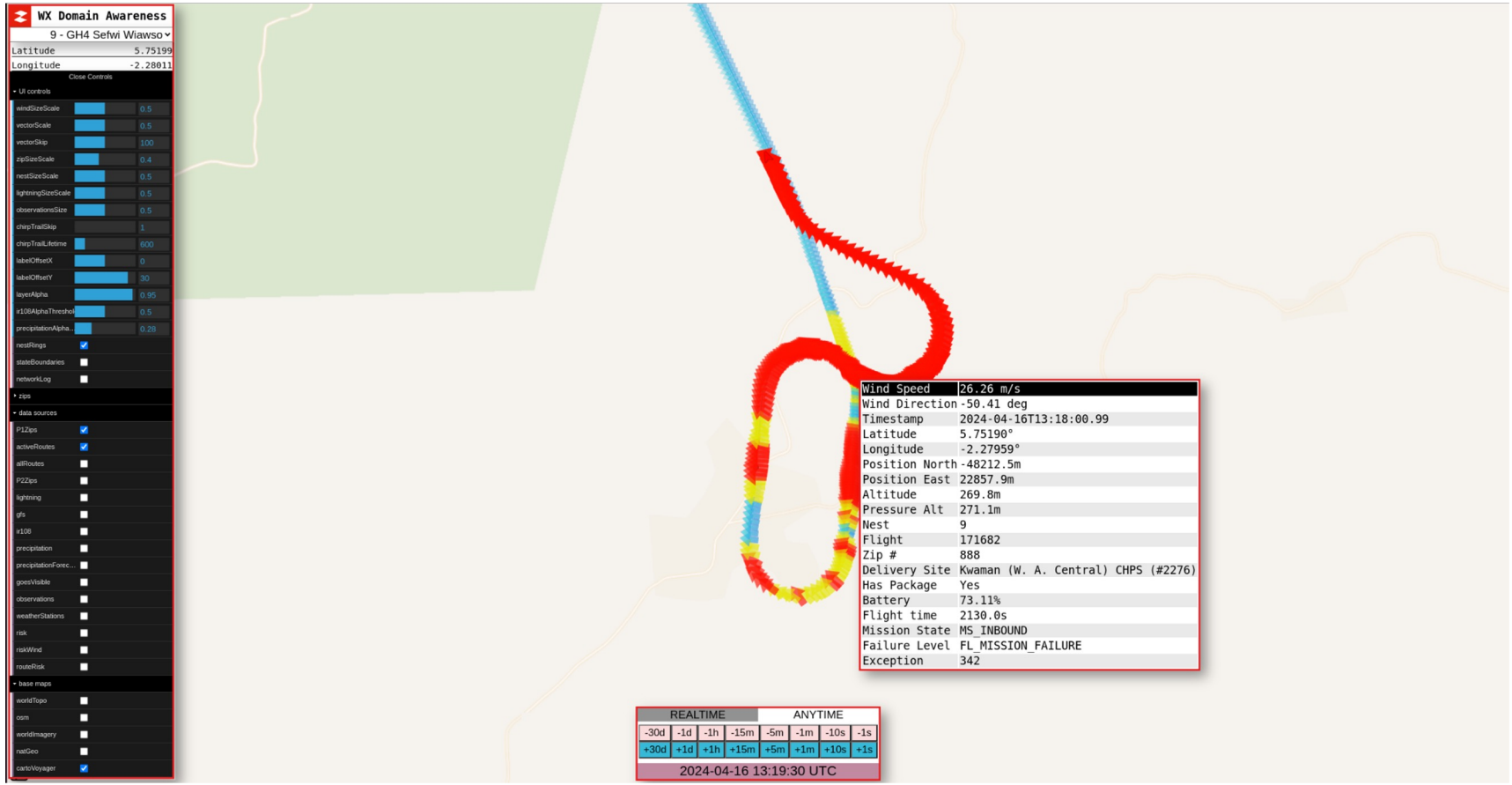
2023-01-26 Ghana



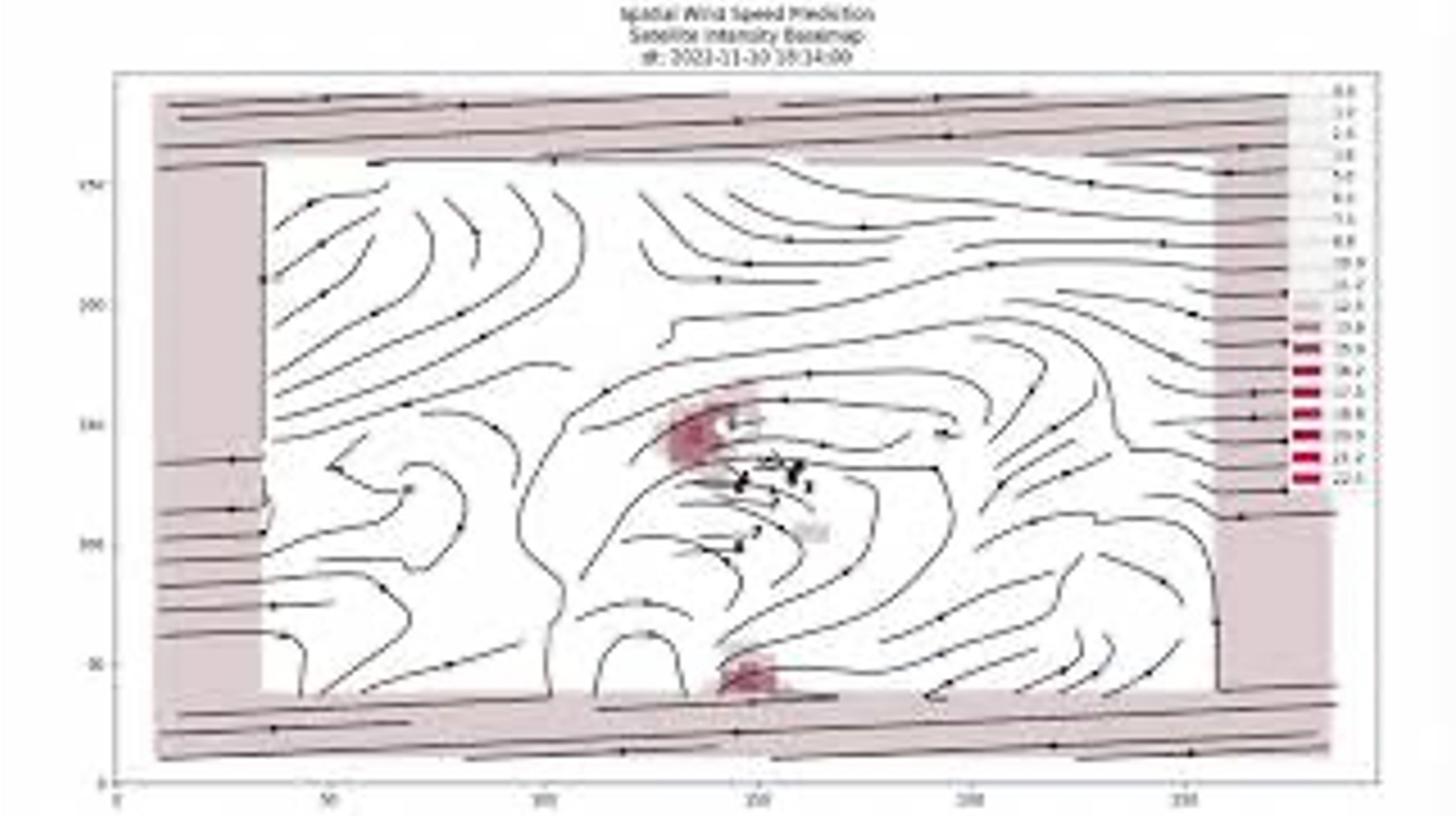
2024-04-16 Ghana



2024-04-16 Ghana



We can even predict wind direction



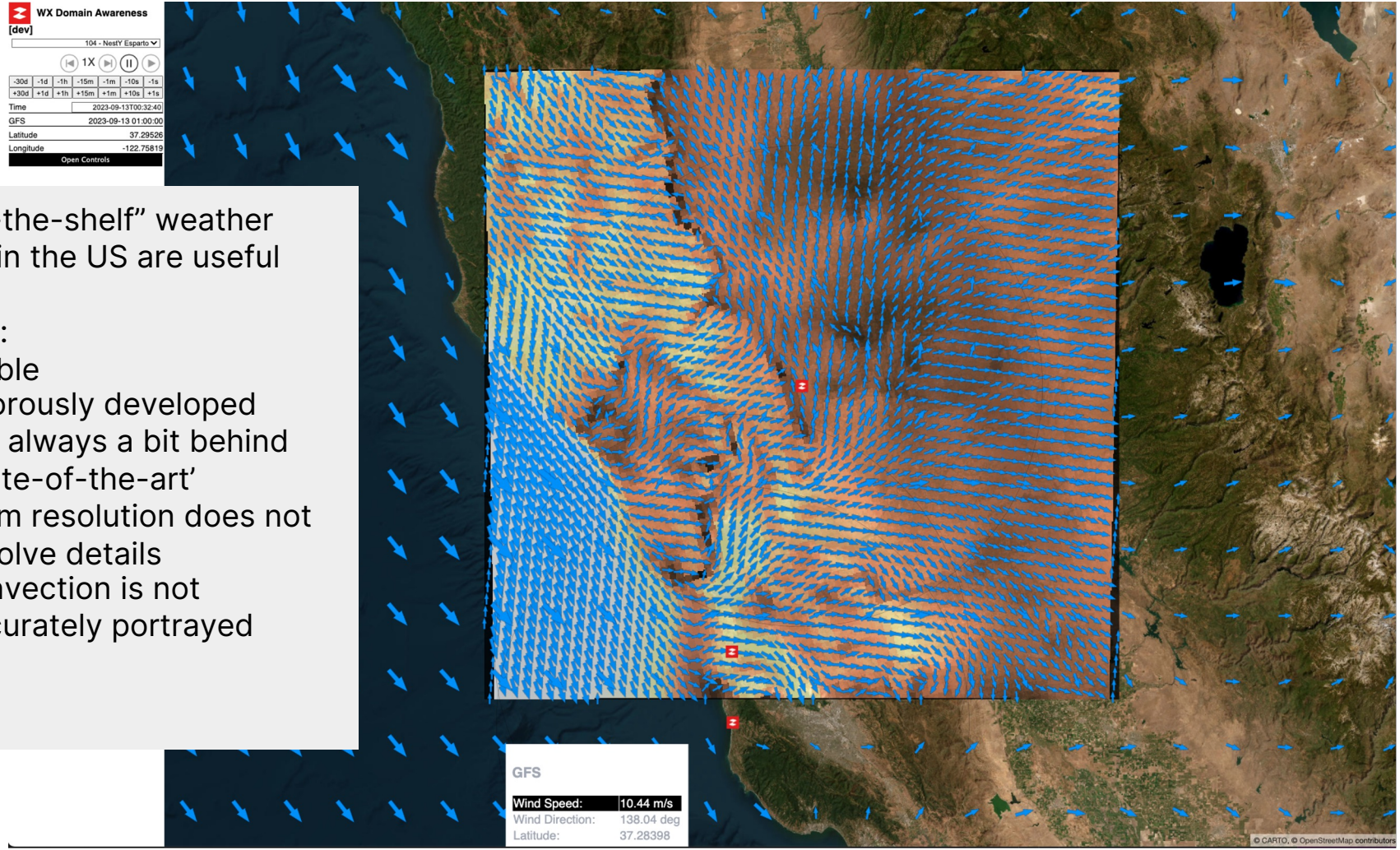
The US is Next...

The US is a different place:

- Regulatory environment is distinct
- More diversity in weather challenge - icing, ceiling, visibility, snow

Questions / How do we deal with:

- We can’t fly into thunderstorms in the US as easily to train a model!
- Can we transfer the learning from METEOSAT?
- How to handle RADAR’s lack of “pre-signal”
- Models don’t yet catch thunderstorm initiation **accurately**



The “off-the-shelf” weather sources in the US are useful

They are:

- stable
- rigorously developed
- but always a bit behind ‘state-of-the-art’
- 3 km resolution does not resolve details
- convection is not accurately portrayed

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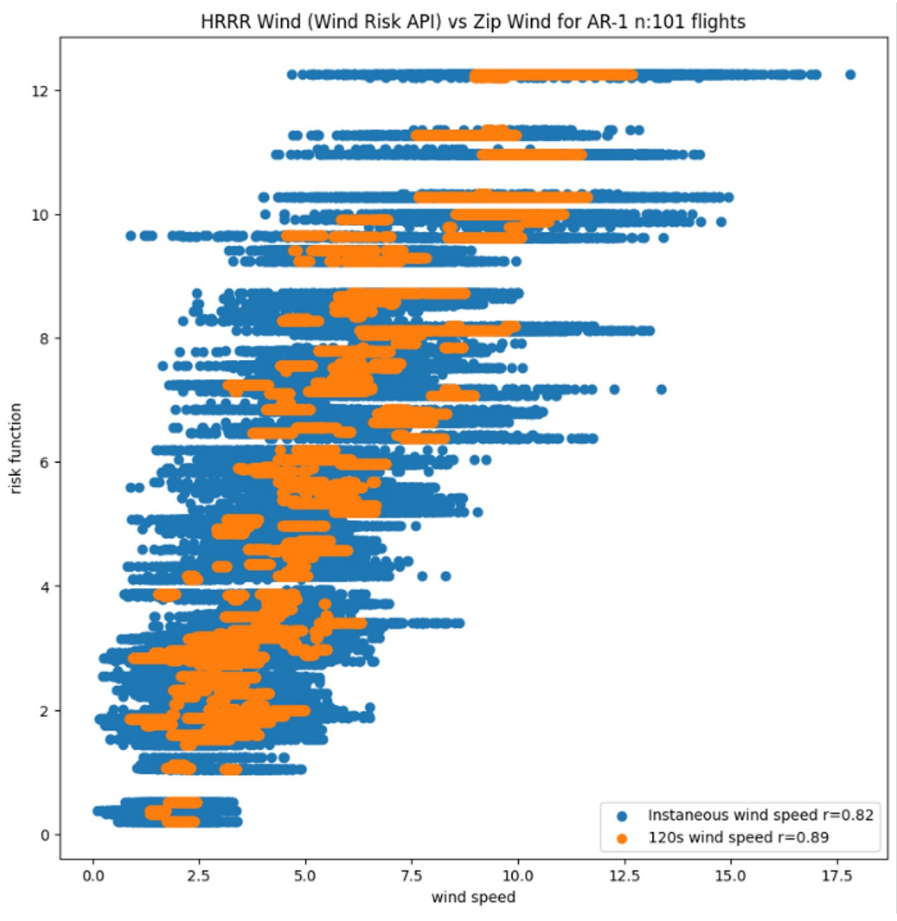
HRRR Wind Speed Verification from Flights

- Verification of 101 flights at Pea Ridge, AR
- Over non-complex terrain
- Correlation between HRRR 80 meter 0-hr Wind Speed and Zip flight level instantaneous wind speed
- But, what about complex terrain?



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With Terrain: HRRR Doesn’t Cut It

- HRRR can’t “see” San Bruno Mountain’s Eddy
- It’s a pretty big feature
- Even 300 meter models miss this eddy!
- I live this eddy on my bike daily!

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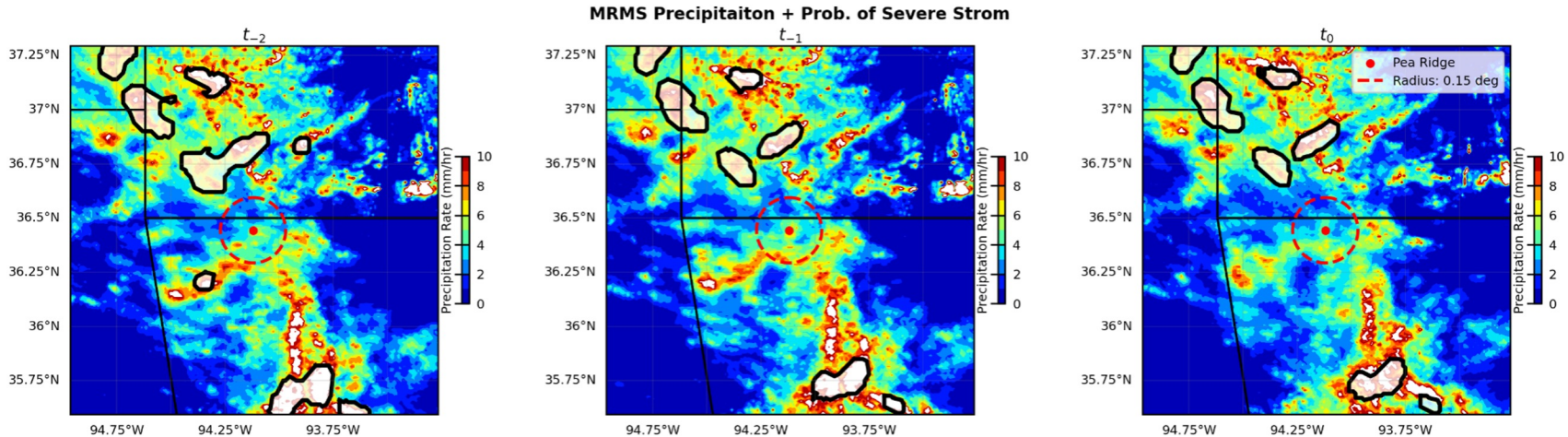
Then there’s convection…

MRMS - Multi - Radar / Multi - Sensor - Progress

- We won’t fly into MRMS polygons
- Can we accomplish this?
- **Experimental Assumptions:**
  - 15 minute flights
  - 7.5 minutes out/ 7.5 minutes back
  - 30 m/s ground speed
  - make fly decision at launch time



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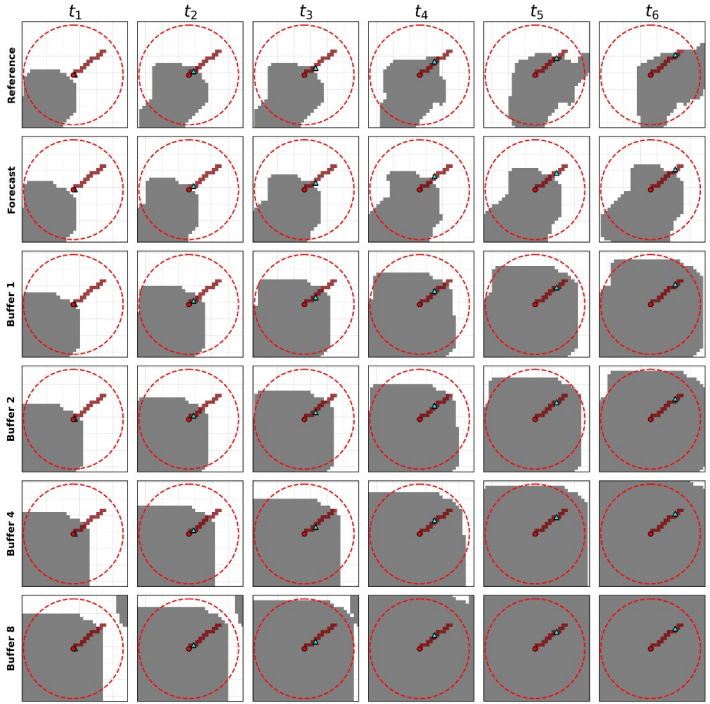
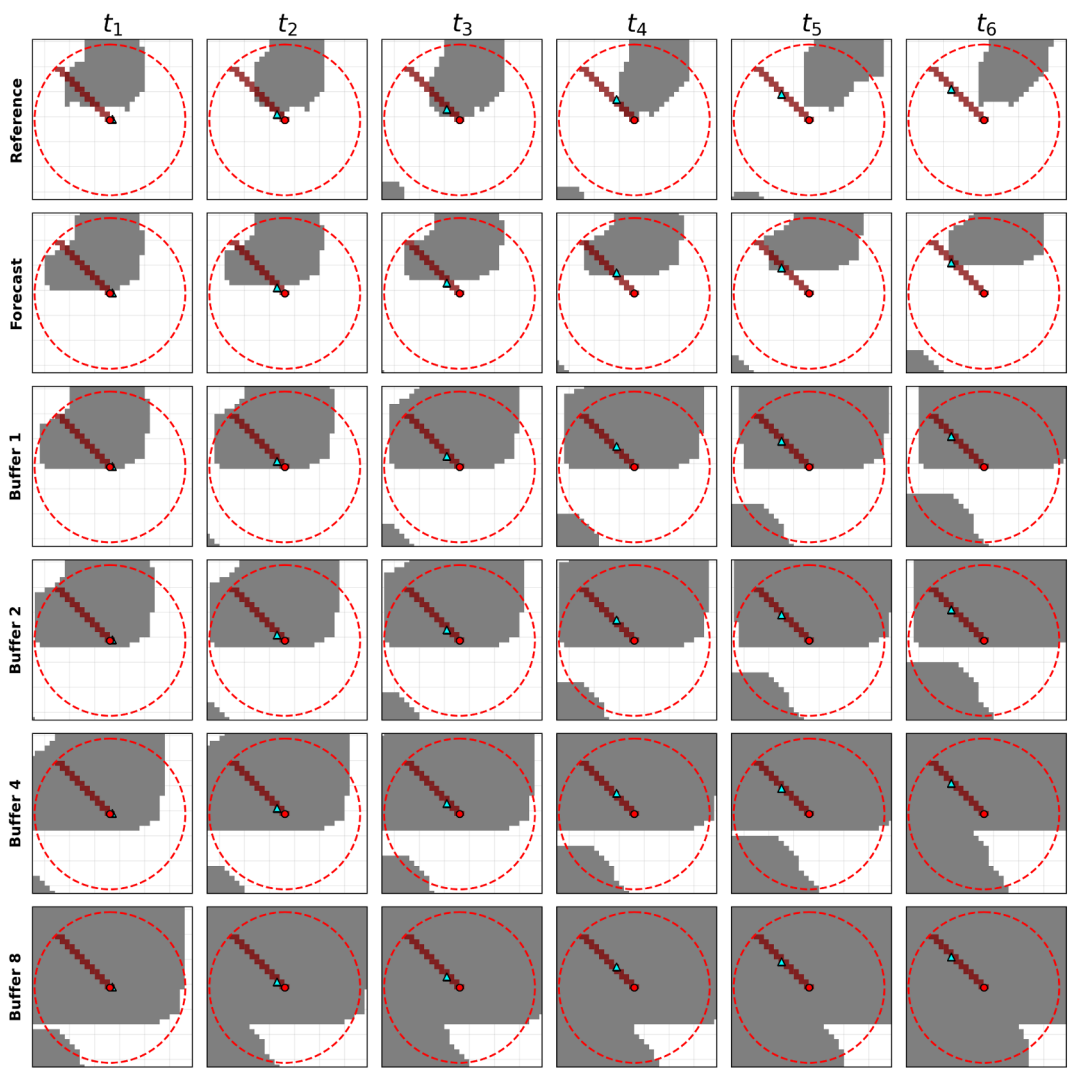
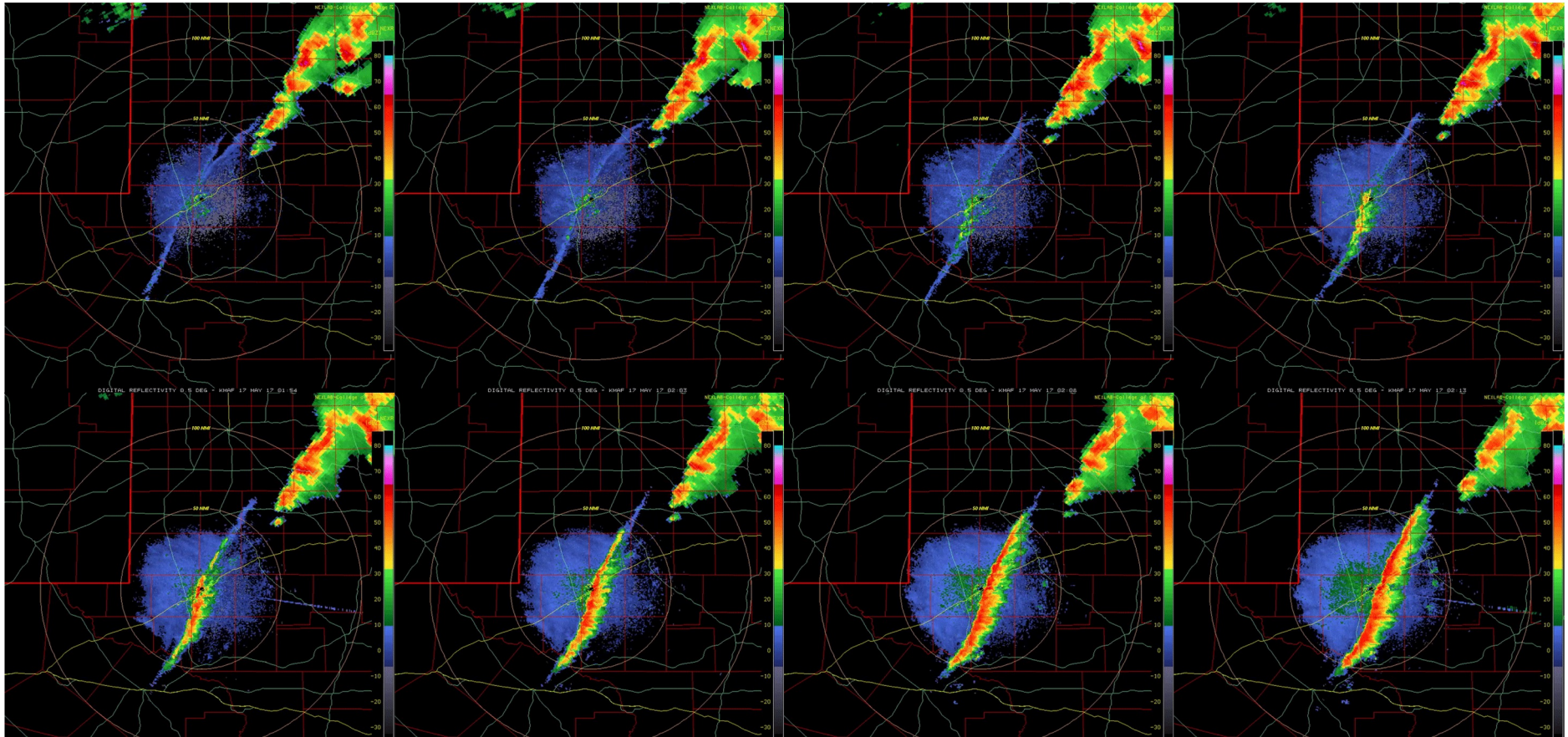
MRMS - Case Study

- **Most conservative** - Assume MRMS echoes expand in all directions





But, storms form out of (almost) nothing!



How do we measure risk in this situation?

Flight Failure Math

Assumptions
P(detection) = 0.96, P(false negative) = 0.04
P(storm interaction | any Pea Ridge flight) = 0.02
P(flight failure | storm interaction) = 0.015 (from P1 P(ff | >= 15 m/s wind)

Formula
P(flight failure) = P(storm interaction | any Pea Ridge flight) * P(false negative) * P(flight failure | storm interaction)
P(flight_failure) = 0.02 * 0.04 * 0.015 = 0.000012

Flight Failure Rate = 1:83,000, Delay rate = 0.03
If P(false negative) = 0.01, then FFR = 1:333,333

Thank you!

- **There is so much more than wind!**
- **Questions?**
- **Contact: john.celenza@flyzipline.com**