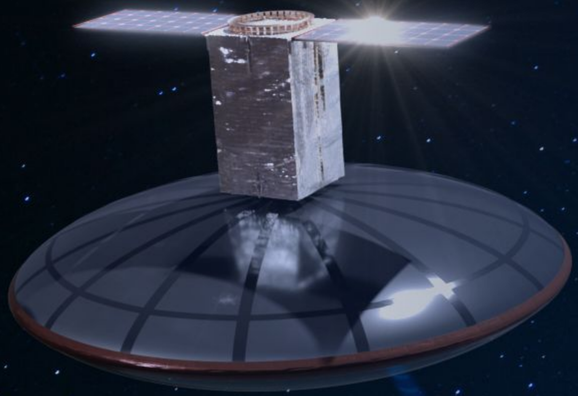

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Tomorrow.io Space Program Briefing

OCP Innovation Webinar

December 2021

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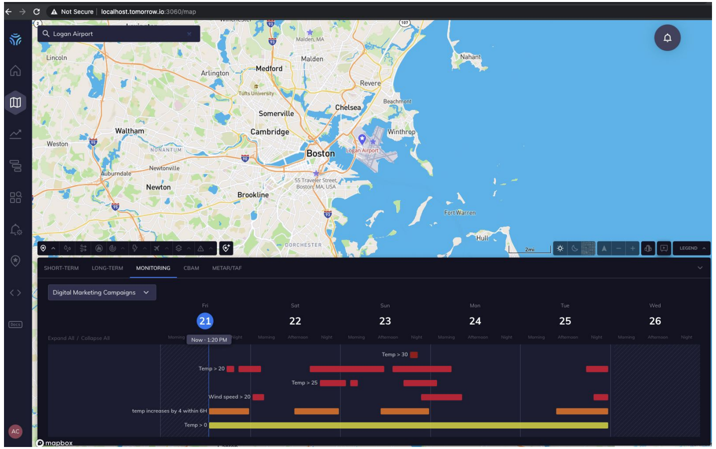
Tomorrow.io at a Glance

- Started in **2016** in Boston
- Locations in U.S., Israel, Singapore, Mumbai, Tokyo and Australia
- Raised over **$200M** in funding from more than a dozen top investors
- Partnering with the U.S. Air Force, NASA, JetBlue, Uber, Ford, and more
- Approximately **185** employees (**90** in R&D)

Scaling Weather Intelligence Globally



Weather Intelligence Alert

De-ice planes between 10 AM - 11 AM

Weather Intelligence Alert

Hail will start in 60 minutes. Move car to covered area and check road conditions

AeroMexico · Azul · DELTA · Drizly · evergy · facebook · Ford
FOX Sports · nationalgrid · IndiGrid · InMobi · [intact] · ITS ConGlobal · jetBlue
KAJIMA · Patriots · Porsche · Rappi · SB Energy · Denny's · Shipt
Swiggy · Uber · United · U.S. Air Force · USTA - US OPEN · Via · NASA · zomato

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What's the difference between weather forecasting and **Weather Intelligence™?**

Consider an operator receiving either of these communications...

VS

Weather forecast

"40% chance for rain on Tuesday across New Mexico."

Weather Intelligence™

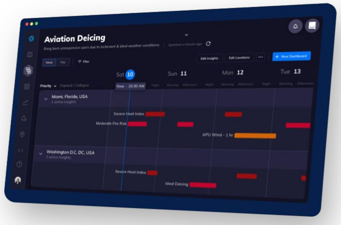
"Avoid flying within Flight Zone 27 on Tuesday between 1:45 PM - 3:15 PM *to avoid safety issues due to precipitation that is exceeding safety protocol."*

✓ Weather Intelligence™ isn't focused on the weather, it's focused on the predictive **impact of the weather, automated decisioning, and operational optimization.**

Tomorrow.io:

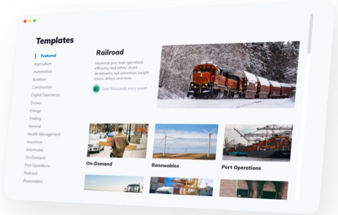
Bridging the gap from weather data to weather intelligence

Automating Decision Support



Easy-to-use SaaS

The world's first
Weather Intelligence Platform™



Multi Vertical Platform

One software that works horizontally across all industries and for specific tasks

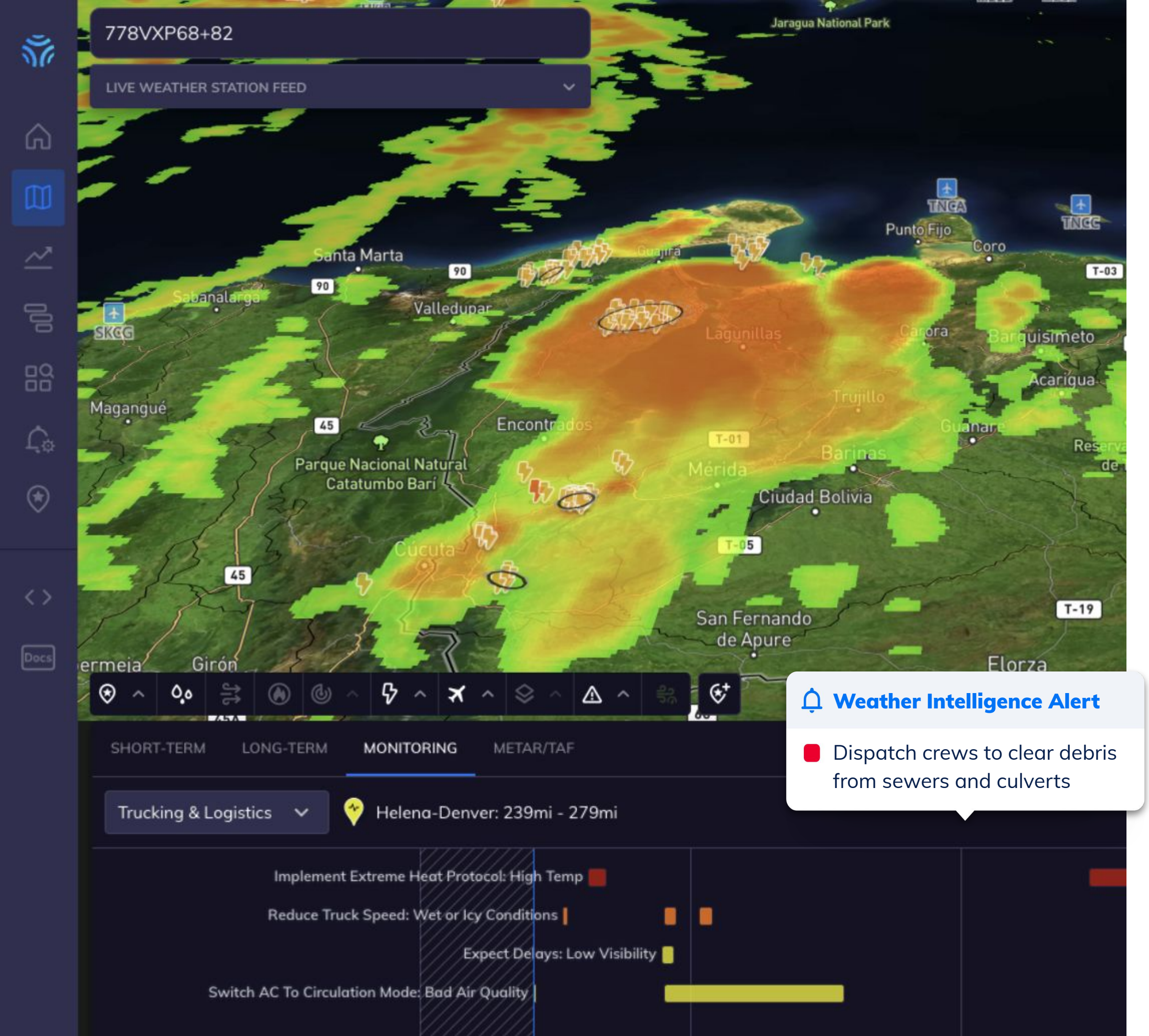
Filling Critical Data Gaps

Deep Tech

Leveraging hyperlocal proprietary modeling, the cloud, and artificial intelligence

Global Coverage

Equally distributed across land and ocean, available in the developed and developing world



Automate customized action plans with Tomorrow.io's Weather and Climate Security Platform

- **Interactive map displays over 30+ weather and air quality parameters**, enabling users to visualize and track weather, in addition to their short-term and longer-term timelines

- **Predictive insights dashboard shows how weather will impact your operations** or business across the next 6 days so you can optimize operational plans in advance

- **Autonomously monitor many locations** at once and automatically send alerts to your team about specific locations and weather conditions

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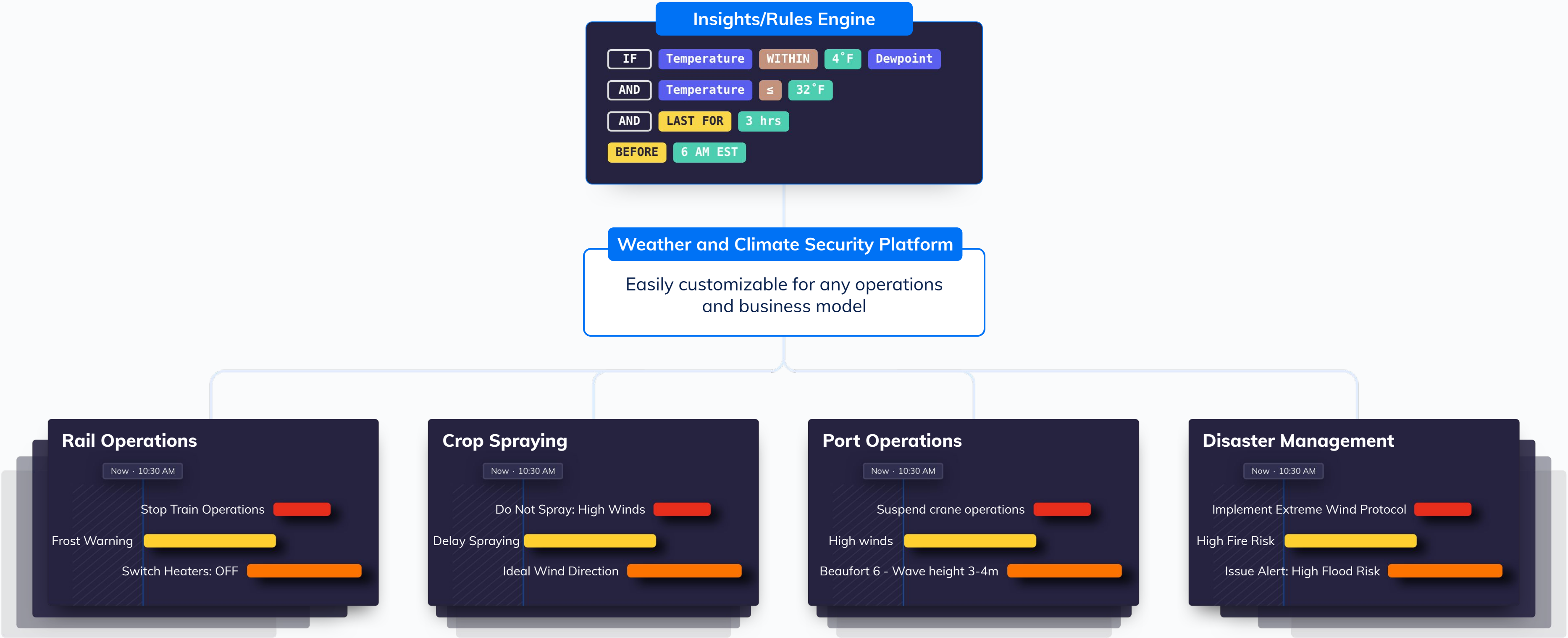
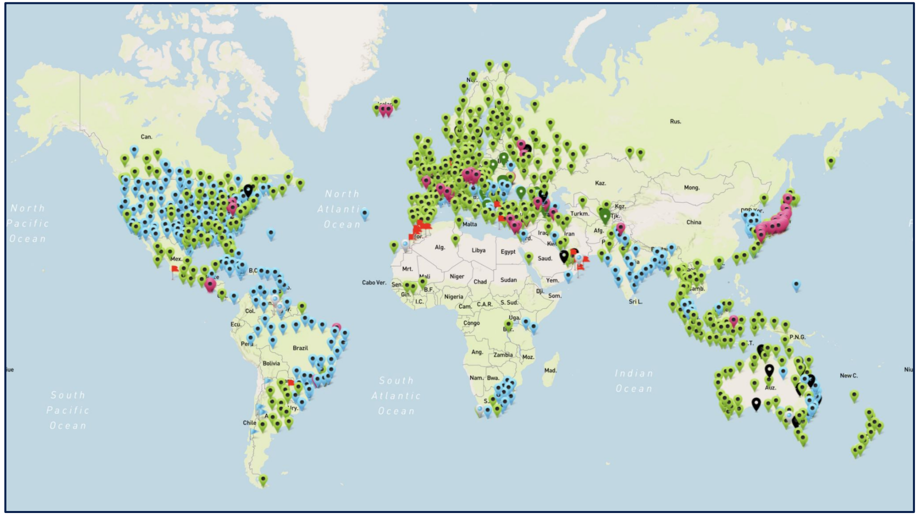
Scaling Hyperlocal Weather Intelligence Globally



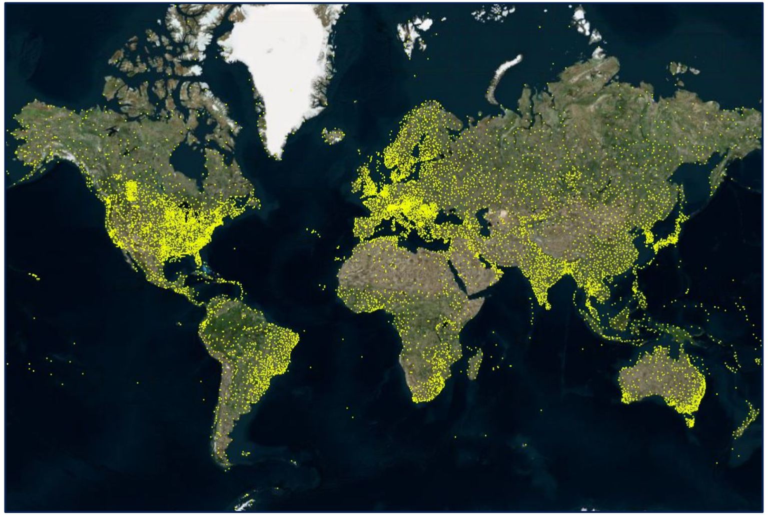
The Weather Gap

Global distribution of ground-based sensors show inequality in weather-sensing infrastructure

Radars



Weather Stations



Most of the world lacks observation coverage and thus reliable forecasts

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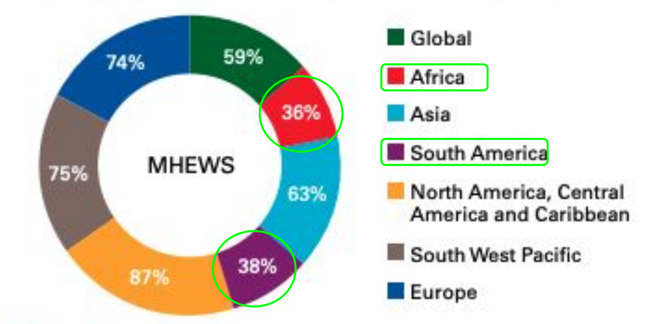
Majority of Developing World Lacks Early Warning Systems

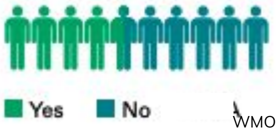
Africa, South America, and Least Developed Countries Have Lowest Percentage of Early Warning Systems



Percentage of WMO Members with a multi-hazard early warning system (MHEWS) in place, by region

WMO

Least Developed Countries: Only 46 percent of people are covered by early warnings



WMO

Severe Weather Causes Many More Deaths in Developing Countries Compared to Rest of the World

Washington DC July 2019

Severe floods:
0 casualties

Mozambique March 2019

Severe floods:
1,000 deaths
3 million impacted

More than 91% of deaths due to weather, water and climate hazards occurred **in developing countries** (WMO)

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A Breakthrough Solution: The World's First Weather Radar Constellation

- A radar satellite design that is 50X smaller and lighter than current state-of-the-art
- Enabling the deployment of multiple satellites at a fraction of the cost of existing single satellite
- Revisit frequency increased by 50X - from every 3 days, to approximately every hour
- Patented and protected technology

> "*A new [active radar] instrument architecture that is compatible with low-cost satellite platforms...will enable constellation missions and **revolutionize climate science and weather forecasting.***"

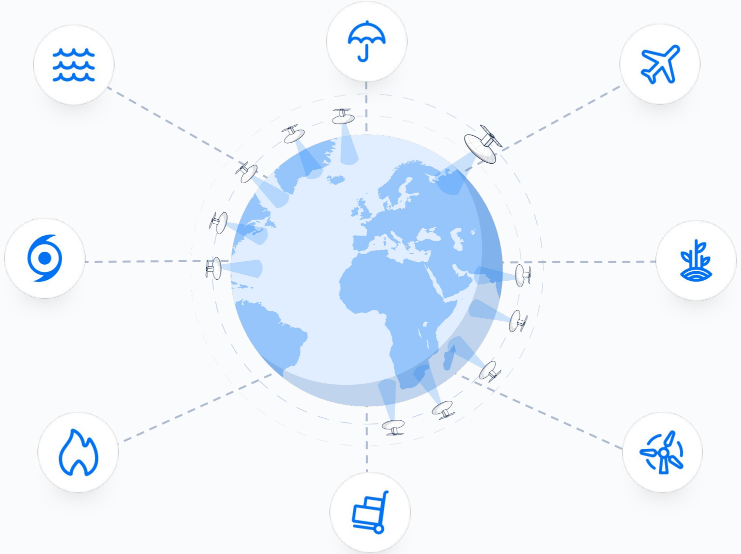
NASA JPL

Our Constellation Will Address Numerous Applications

Numerical Weather Prediction
Drive significant improvement in forecast skills for global and regional NWP models

Flood & Landslide Risk
Accurate early warnings of flooding and landslide risk for developed and developing world

Aviation
Global en-route storm detection tracking. Weather radar and nowcast for every airport on earth.



Hurricanes & Typhoons
Improve intensity and trajectory forecast for every hurricane, typhoon and cyclone on earth

Agriculture
Power farming decisions for every farm on earth using the world's most accurate and comprehensive rainfall data.

Wildfire & Drought Risk
Worldwide precipitation data to inform fire danger indices and drought forecasts

Renewables
Storm prediction for assets outside of terrestrial radar coverage; accurate and timely streamflow forecasts.

Shipping & Supply Chain
Global en-route storm detection. Ocean wave height and surface winds mapping

No Other Solution on the Horizon to Meet Operational Needs

Several space radar missions have flown to date, but **none have accomplished global coverage with high revisit rates** suitable for operational meteorology needs, leaving us to rely on passive sensing with significant limitations

Nothing is planned to meet these requirements through 2030

All planned space radar missions are limited coverage and low revisit rate

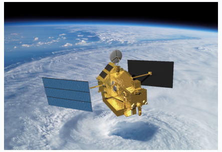
Executed

Single Large Satellites - Low Revisit Rate, ~1B/unit

Concepts/Planned

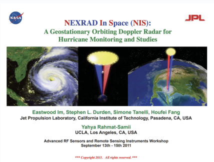
Major technical challenges/costs

Precipitation Mapping Missions (wide swath)

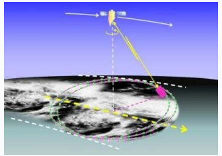


NASA/JAXA TRMM
1997-2015

NASA/JAXA GPM
2014- ~2030



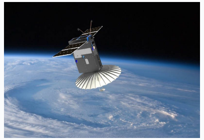
NASA JPL NIS
Not pursued
Expected costs over $2B to cover only the U.S.



ESA WIVERN
Pre-feasibility studies ongoing

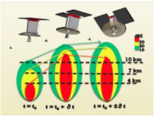
Science/Process Missions (narrow swath)

NASA CloudSat 2006-present

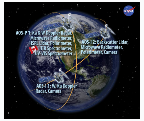


NASA JPL RainCube
2018-2021
Small Satellite
<$5M/unit

ESA EarthCARE
Launch in 2023



NASA INCUS
Launch in 2027



NASA AOS
First launch in 2028

Instrument	NRT?	Relevance	Satellite	Orbit	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
PR (!)		3 - high	TRMM	35 °												
Rainradar		1 - primary	FY-3G	50 °					X	X	X	X	X	X		
Rainradar		1 - primary	FY-3J	50 °							X	X	X	X	X	X
RainCube		4 - fair	ISS RainCube	51.6 °	X	X										
DPR	No	1 - primary	GPM Core Observ:	65 °	X	X	X	X	X	X	X	X				
CPR (CloudSat) (!)		5 - marginal	CloudSat	13:30 asc	X	X										
CPR (Earth-CARE)		5 - marginal	EarthCARE	14:00 desc					X	X	X	X				

Source - World Meteorological Organization Satellite Mission Database
Not shown: ACCP mission (2027 or later) will be low revisit rate; IMERG product is based on weaker sensors with lower spatial and temporal resolution

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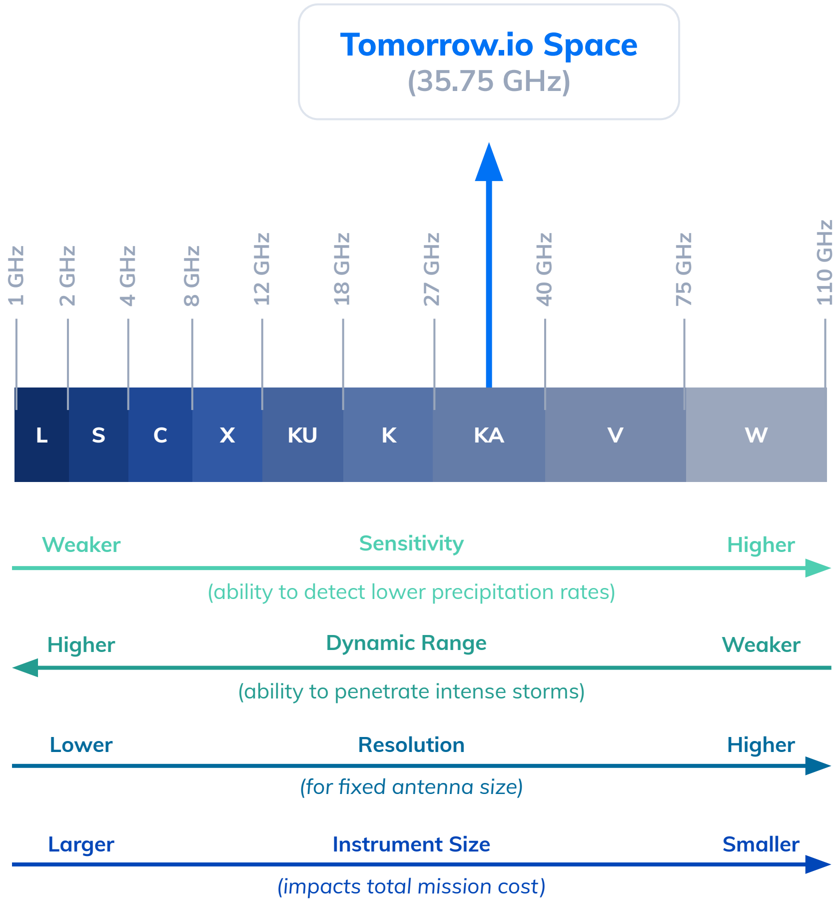
Why Ka-Band?

Tomorrow.io's radar sensors will operate in the Ka-band at a frequency of **35.75 GHz** (8.4 mm wavelength), the same as NASA/JAXA GPM's KaPR instrument and the radar on NASA's RainCube satellite

Advantages of Ka-band over other frequencies:

- Sensitive to low- and high-intensity precipitation, and other high-value geophysical parameters, from orbital distances
- More sensitive to vertically integrated liquid water than Ku, yet still able to estimate a wide range of surface precipitation intensities
- **Enables smaller antenna and components, and thus lower SWAP and cost**, for a desired sensitivity and resolution



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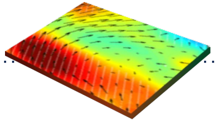
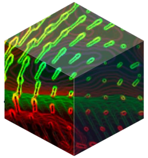
Weather Radar From Space:
A New Paradigm in Weather and Climate Prediction



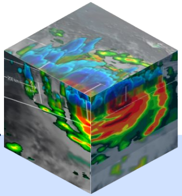
Ocean Surface Winds

- Detect tropical cyclone formation and measure radius of tropical storm winds
- Resolve hurricane inner-core wind structure and detect hurricane winds over ocean
- Improve marine wind/wave warnings, ship routing, and wind energy forecasts



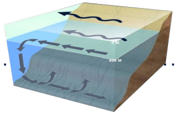
3D Wind Profiles
(inside clouds and rain)

- One of the highest ranked observation priorities to improve weather models
- Better forecasts of daily weather, hurricane track and intensity, and extreme winds
- Improve prediction of El Niño/La Niña and transport of pollutants and trace gases



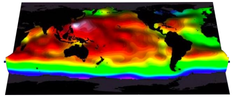
3D Precipitation

- Ranked the highest priority out of 152 parameters by Group on Earth Observations
- New level of understanding and prediction of hurricanes
- Improve flood, landslide, wildfire and drought monitoring and prediction
- Enable equal access to radar and reliable weather forecasts worldwide



Ocean Surface Currents

- Inform planning for military anti-submarine and amphibious operations
- Reduce ship fuel consumption and enable safe and efficient marine navigation
- Improve search and rescue, hazmat cleanup, and marine ecosystem management



Sea Surface and Wave Height

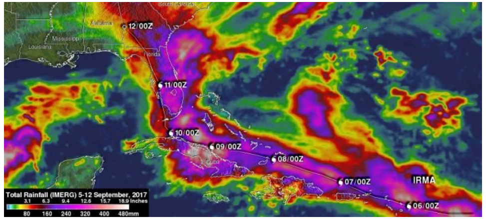
- Enhanced monitoring and prediction of tides, sea level rise and coastal erosion
- Track ocean heat storage and improve seasonal and individual hurricane forecasts
- Improve ship routing, fisheries management, and coupled ocean-atmosphere models

All data available globally, at high horizontal and vertical resolution, with hourly (avg) revisit

What Will the Precipitation Products Look Like?

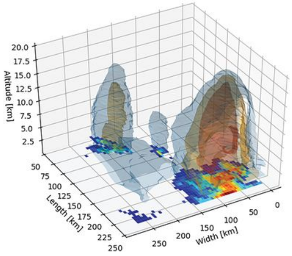
Visualization data and products will look similar to those from previous and current precipitation radar missions such as RainCube, TRMM and GPM

2D Precipitation Maps



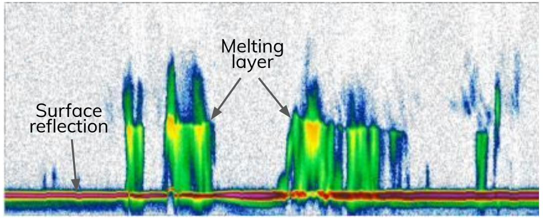
Example: Estimated rainfall from Hurricane Irma as shown by GPM IMERG

3D Precipitation Structure



Example: 3D structure of the "champion storm" from TRMM mission

Vertical Cross-Section of Reflectivity



Example: Cross-section of Typhoon Trami from Raincube Mission

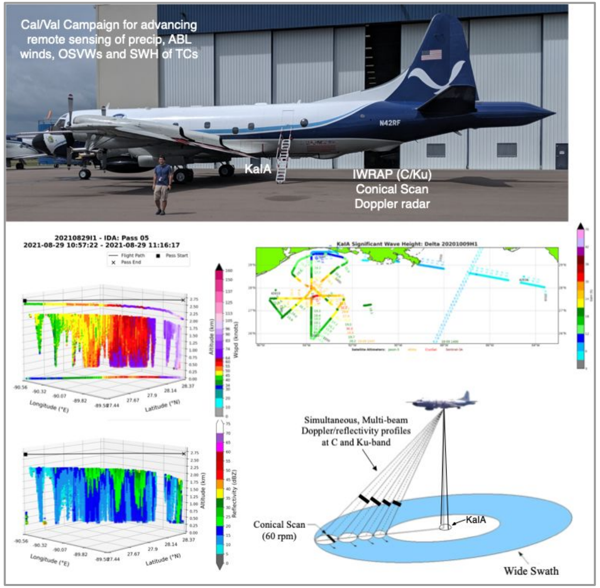
Tomorrow.io global coverage and hourly revisit rate **will dramatically improve** these real-time precipitation products and accumulated rainfall estimates, which are currently based on 3-4 day revisit times

Calibration and Validation

Vertical profiles of precipitation will be retrieved across the instrument’s 400 km swath width at a minimum rain rate sensitivity of 0.2 mm/hr (similar to GPM dual-frequency radar)

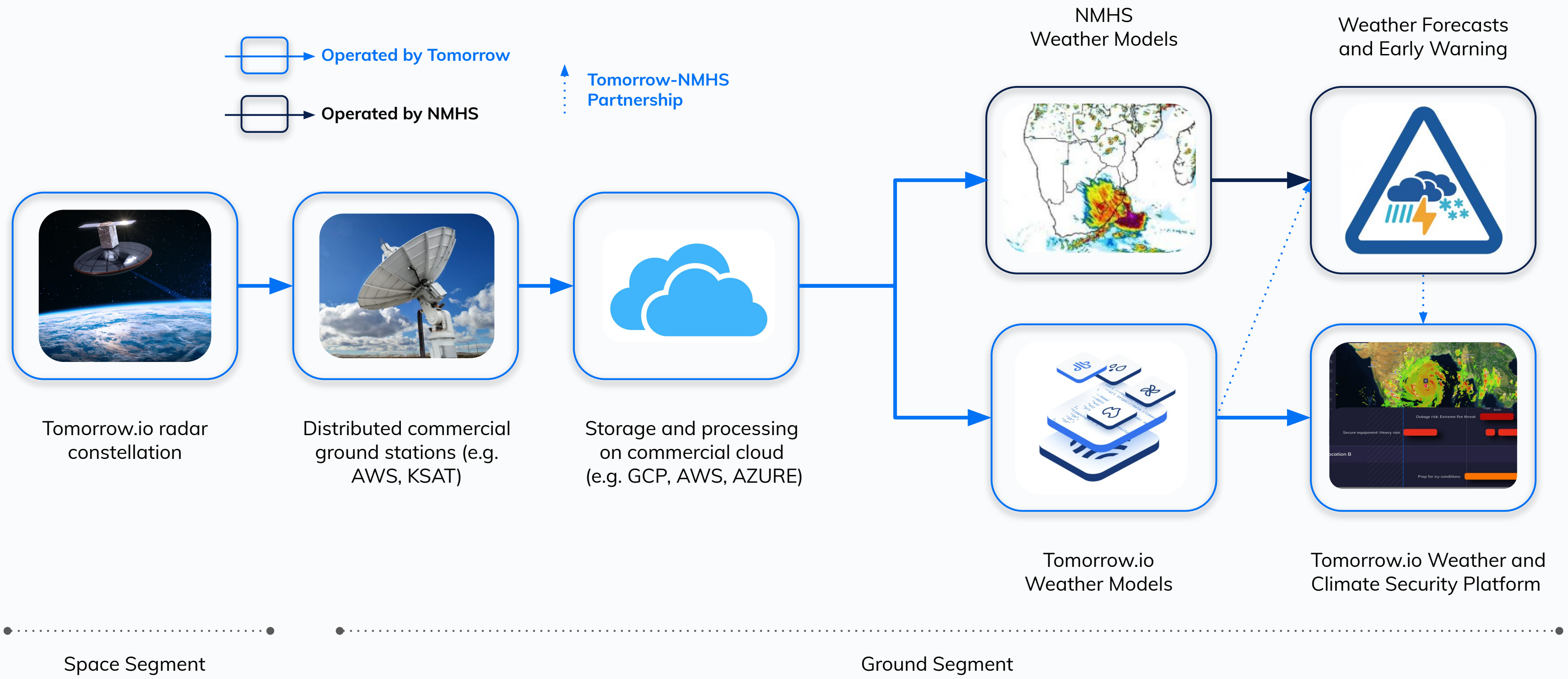
As part of the mission development roadmap, Tomorrow.io will perform extensive calibration and validation measurement campaigns—in collaboration with government, academic and industry partners—to verify the accuracy of the precipitation retrievals:

- Comparison against both ground-based and airborne sensors
- Validation of retrievals across a variety of geographies and precipitation regimes
- Internal simulation studies (using simulated L1 radar data) to develop algorithms prior to launch
- Airborne testing led by Tomorrow.io’s radar team, which has extensive experience in both radar and airborne test campaigns



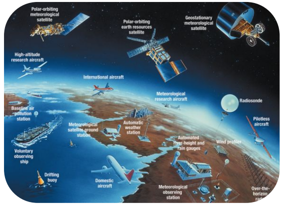
Calibration/Validation campaign executed by Tomorrow.io’s ARENA team with NOAA. Radar reflectivity data is from Hurricane Ida (Aug. 2021) as observed by airborne conical scan Doppler radar. (Image credit: NOAA/NESDIS/STAR)

High-Level Data Flow From Space to Mission Support



Enabling Early Warning and Early Action Worldwide

Tomorrow Space



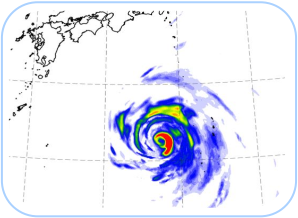
Global Observing System

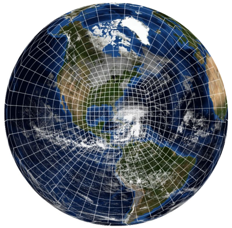
Private Sector Augmentation

+

Public Weather Infrastructure

Tomorrow Global and Regional NWP

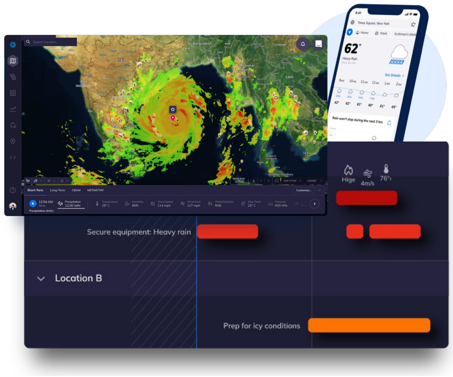




World-Class NWP Models

=

Scalable Implementation of Early Warning Systems Across the Globe



And the Weather Intelligence Needed to **Translate Early Warnings into Early Action**

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Tomorrow.io supports global scientific advancement and collaboration

Data Sales and R&D Collaboration Approach

	Scientific Research	Operational Forecasting
Government (Defense)	Yes	Yes
Government (Civil)	Yes	Partial
Academia	Yes	N/A
Private	Case-by-case	No

Licensed with some restrictions on data:

- **Geography** (e.g. localized region)
- **Parameter** (e.g. OSVW)
- **Latency** (e.g. delayed/historical archive)
- **Revisit** (e.g. reduced temporal resolution)
- **Forecast application** (case-by-case)

Global Radar Observations Working Symposium (GROWS):

An open-source, international collaboration to develop radar data assimilation tools to address global precipitation challenges

POC: Thomas Cavett
thomas.cavett@tomorrow.io

Global Scientific Community

Government Agencies

Academia

Non-profits

Tropical Cyclones

Hydrology and water resource management

Climate resilience and more

When

- **Phase 1:** Gather global community Q1 2022
- **Phase 2:** Synthetic Data Q2 2022
- **Phase 3:** Pathfinder Data Q4 2022
- **Phase 4:** Operational Data 2023 and beyond

Who

Global atmospheric science, meteorology and remote-sensing community who are passionate about bringing new tools to the forefront

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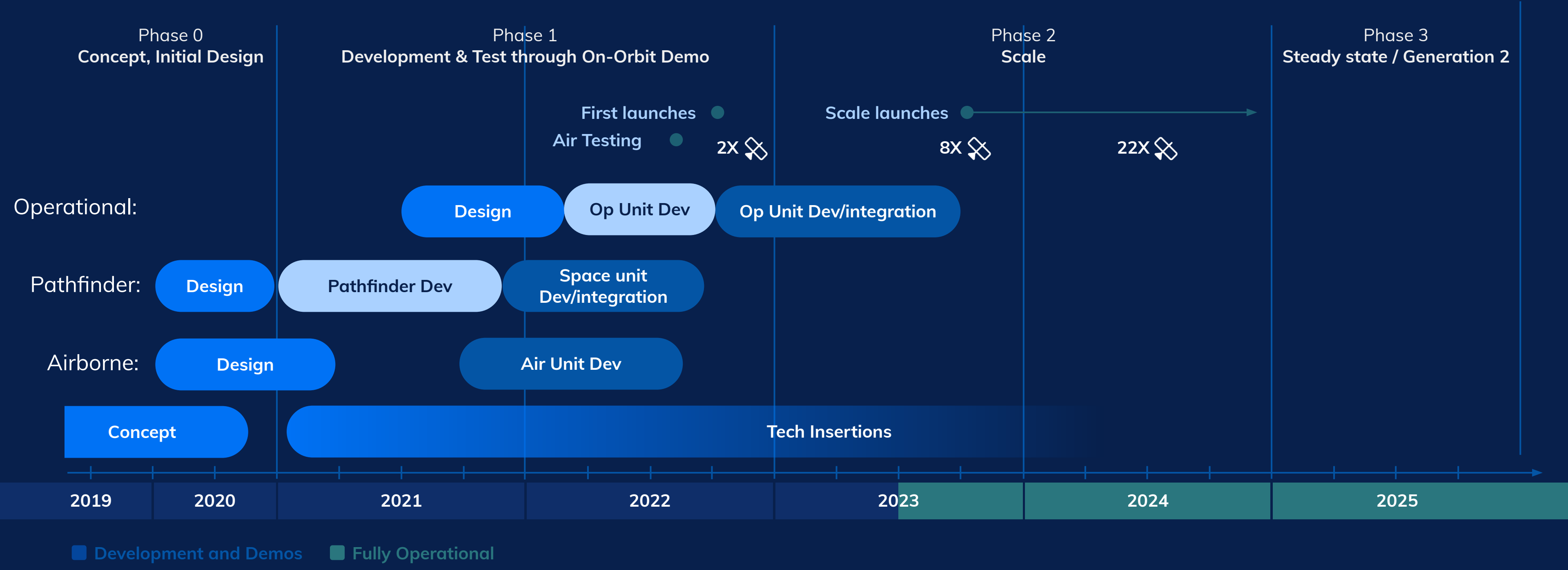
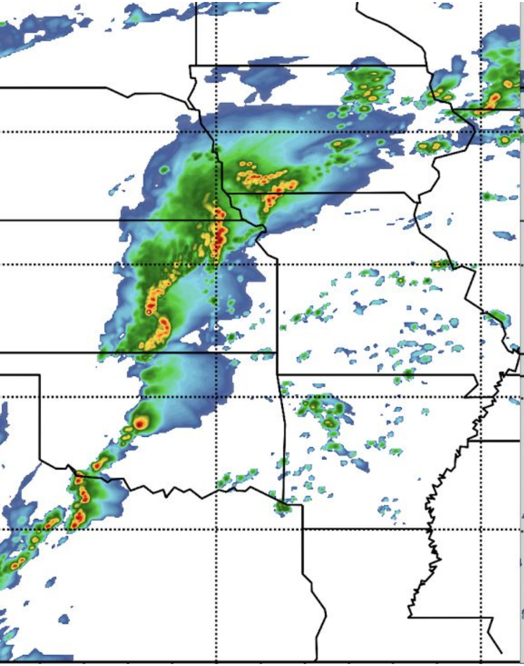
Development and Launch Timeline

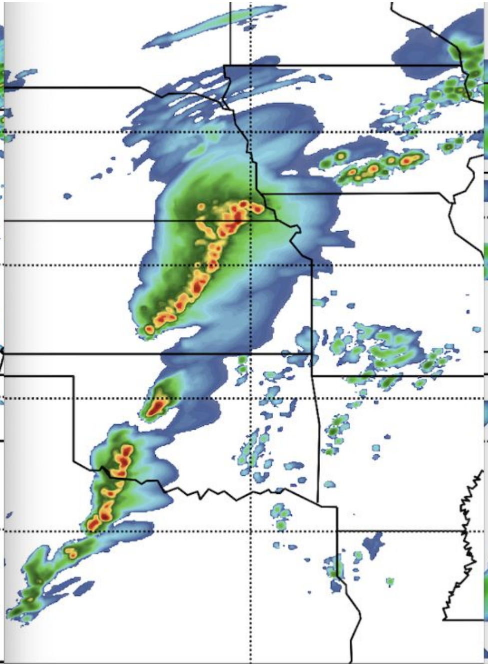


Global/Regional Model Versus Observations

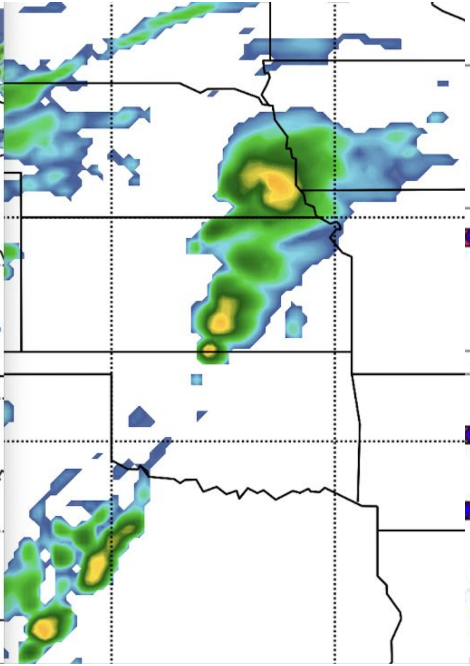
Kansas Squall-Line case: 2018/05/03 00 UTC



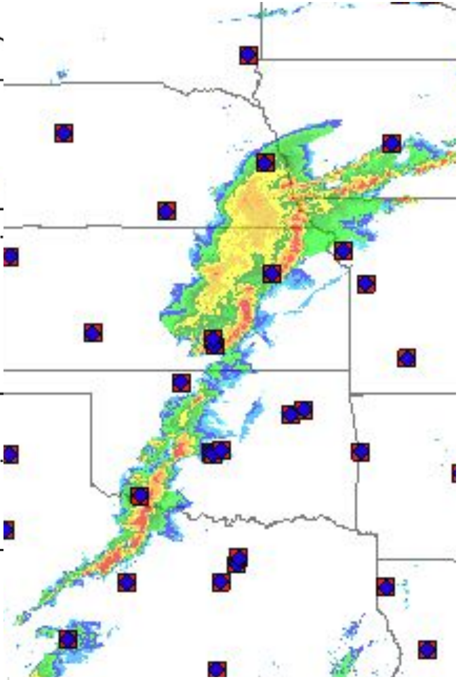
Regional model 1 (3 km)



Regional model 2 (3 km)

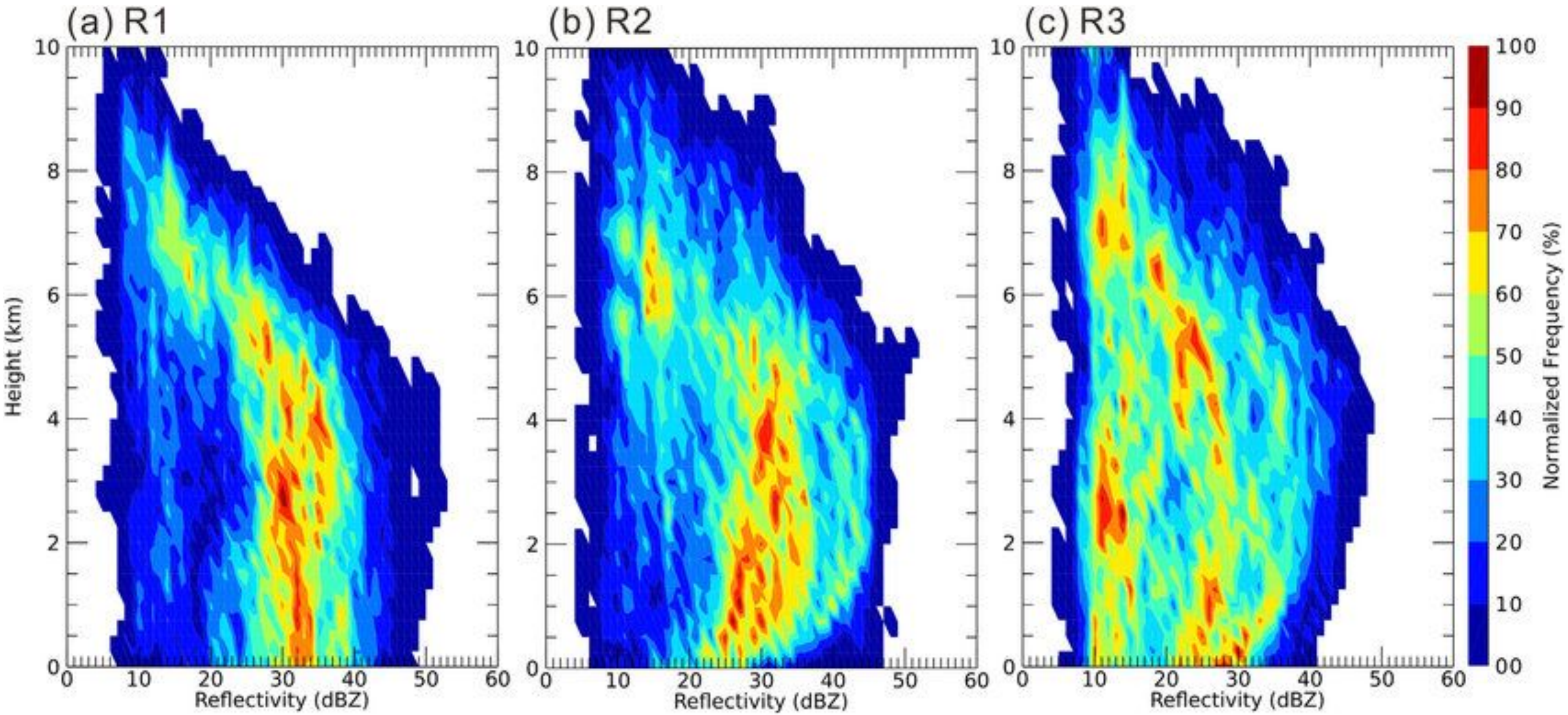


Global model (12 km)



NEXRAD composite observations

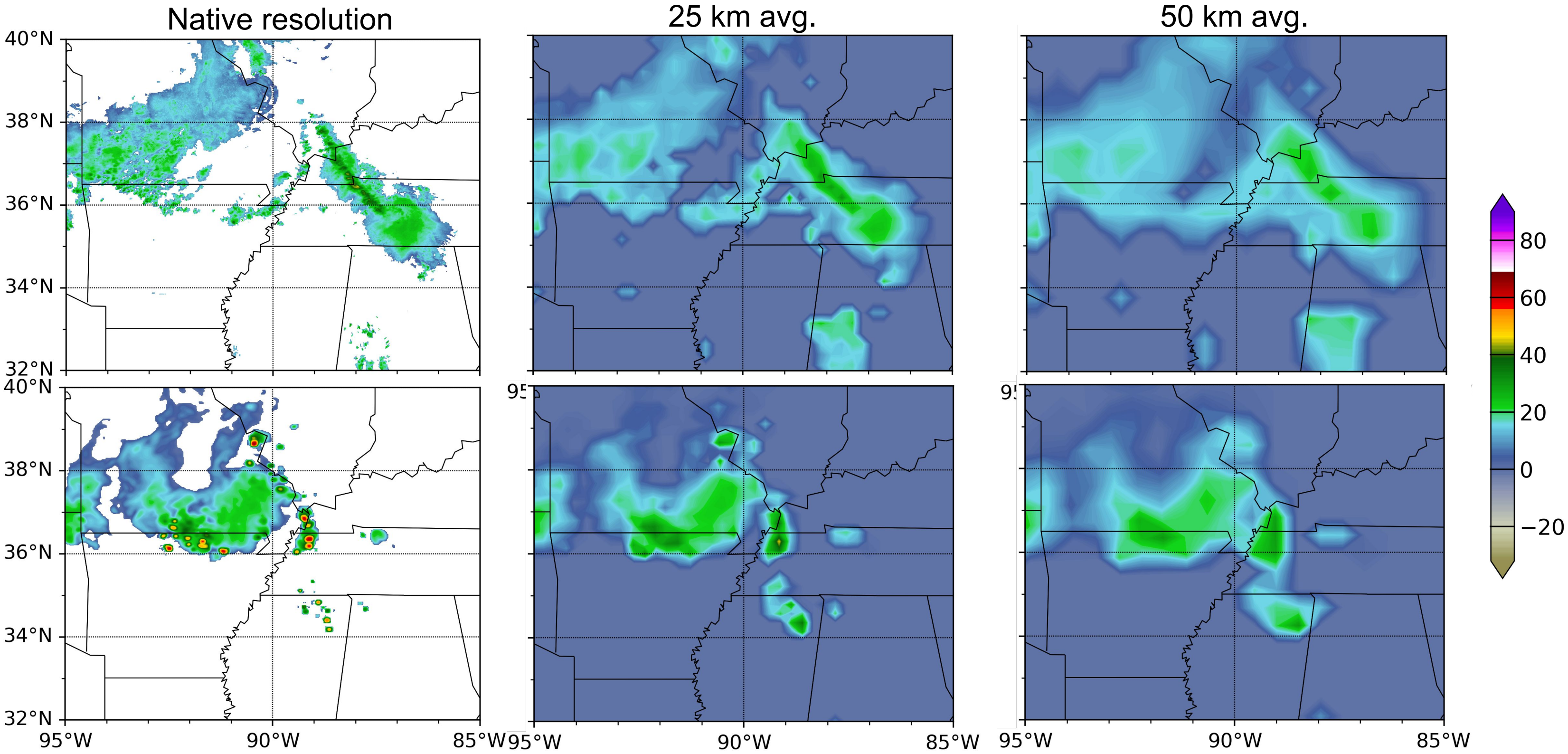
Contoured Frequency by Altitude (CFAD) Diagram Example



source

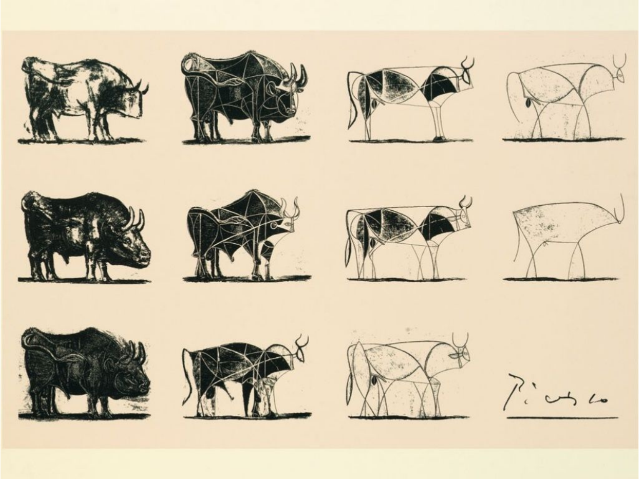
MRMS 3D Mosaic and Model Simulated Radar Signals

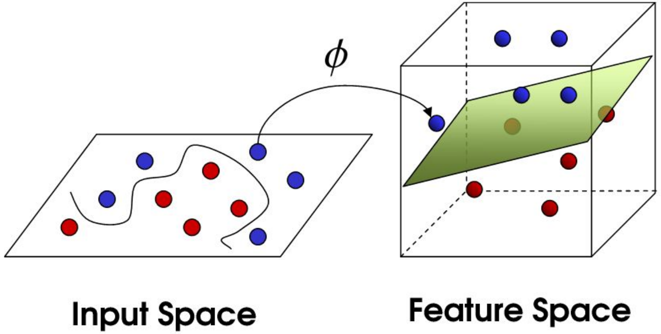
Tennessee flooding - 2021/08/21 12z



Observation Operator

- Ka-band physically realistic modelling (the full bull)
  - Likely too slow for DA applications
  - Need to capture uncertainty in microphysics
- Direct statistical operator regression: regress from x to y
  - Find regression coefficients based on training DB
  - Similar to RTTOV
- Kernel regression: regress from x’ = K(x) to y’ = L(y)
  - One kernel *K* for geophysical vars, another *L* for obs
    - Superobbing, thinning, averaging
    - Maximize variance explained: PCA
    - Maximize covariance explained: CCA
    - Neural networks
    - Classification (can only use observations)
    - Make use of the kernel trick





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Space Team

Science and Engineering Leadership

John Springmann, PhD
BlackSky
Rocket Lab
University of Michigan

James Carswell, PhD
Remote Sensing
Solutions
UMass Amherst

Richard Roy, PhD
NASA JPL
University of Washington

Joe Munchak, PhD
NASA Goddard
Colorado State
University

Jeff Steward, PhD
NCAR, NASA JPL
UCLA

Scott Williams, PhD
SRI International
Stanford University

Advisory

Whitney Q. Lohmeyer, PhD
MIT, OneWeb

Christopher Williams, PhD
NASA GPM

Jonny Dyer
SkyBox, Google
Lyft

Decades of accumulated experience in dozens of commercial and government space missions, radar instruments, satellite data assimilation

Stanford University
NCAR NATIONAL CENTER FOR ATMOSPHERIC RESEARCH
lyft
MIT
UNIVERSITY OF MICHIGAN
UCLA
UMASS
NASA
Google
JPL Jet Propulsion Laboratory California Institute of Technology
BLACKSKY
SRI International
ROCKET LAB
OneWeb
Remote Sensing Solutions
L3 Technologies
Colorado State University
UNIVERSITY of WASHINGTON

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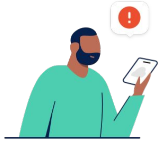
TomorrowNow.Org

We are invested in a future where everyone has access to the innovations needed to act and adapt to a changing climate.

We work with NGOs, Governments and multinational organizations to build capacity and **solve the hardest challenges of Climate Adaptation.**



Billions still without access to early warnings

Delivering Hope with Innovation and Partnerships

"Although desert locusts have been here since biblical times, recent intense outbreaks can be linked to anthropogenic climate change and the increased frequency of extreme weather events"

Nature Magazine

Partnering with

WMO · THE WORLD BANK IBRD • IDA · NCAR UCAR · Republic of Kenya Ministry of Agriculture, Livestock and Fisheries · CGIAR Platform for Big Data in Agriculture · BILL & MELINDA GATES foundation · MERCY CORPS · Kenya Red Cross · Digital Green · WFP · Inspire Challenge

tomorrow.io

Our Advisory Team

All-star advisory team with deep understanding of weather and space across government, defense and academia

Kathryn Sullivan, PhD

Former NOAA Administrator
and NASA Astronaut

First US woman to walk in space
and reach deepest point in ocean

Kerri Cahoy, PhD

Director, MIT STAR Lab

Co-Director, MIT Small Satellite Center

NASA and Stanford University

Steve Smith

Former NASA Astronaut and
Lead Spacewalker

Director, International Space
Station US National Laboratory

Rear Admiral Tim Gallaudet, PhD
US Navy (Ret)

Former NOAA Deputy Administrator

Former Commander, US Navy
Meteorology & Oceanography Command

Marshall Shepherd, PhD

Director, University of Georgia
Atmospheric Sciences Program

Elected to National Academy of
Engineering; Former AMS President

Keith Masback
US Army (Ret)

Former CEO, US Geospatial
Intelligence Foundation

Former Senior Executive at NGA

Thank you