Impacts of Long-Duration Weather Balloon Observations on North American Forecasts

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WindBorne

Global sensing for better weather forecasts

Who we are:

WindBorne Systems was founded in 2019 following a project at Stanford University, during which our founders built the core platform that would become our first long-range weather balloon.

Since then, our platform has evolved through version after version, and through these iterations we've added and updated features again and again, but our mission has always remained the same.

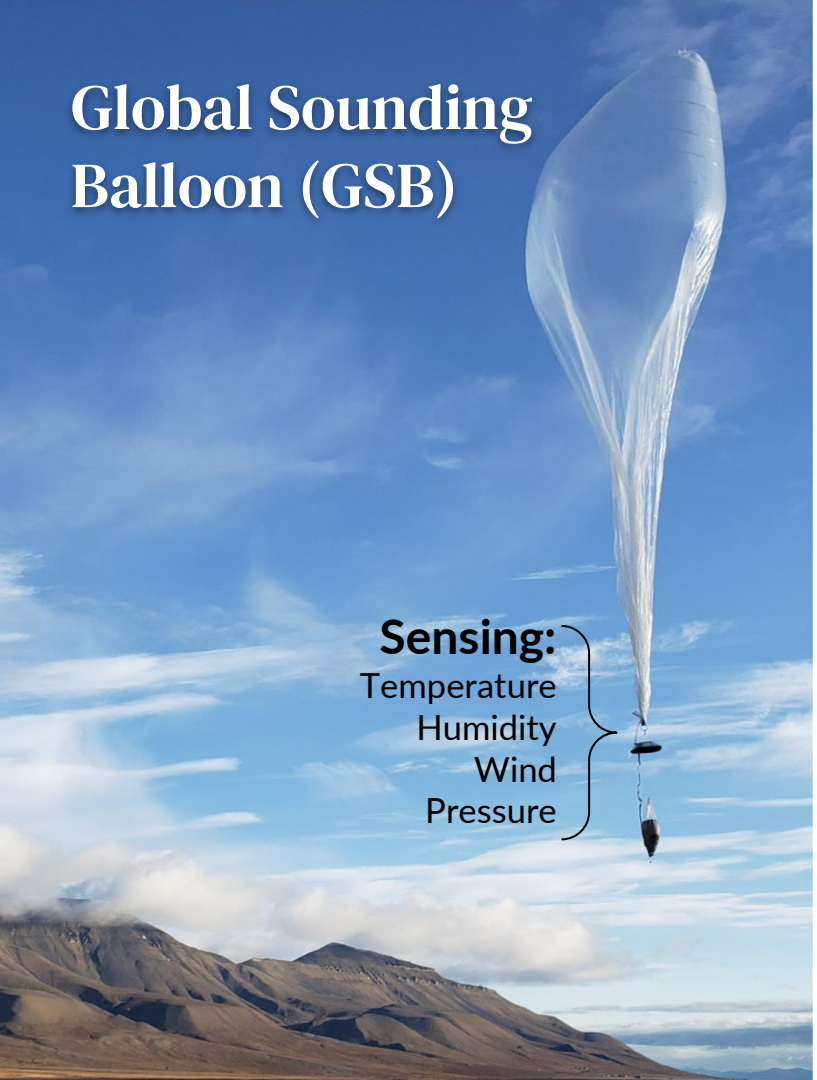
At WindBorne, we are on a mission to eliminate weather uncertainty, thereby enabling humanity to adapt to climate change and better understand our planet.

What we do:

Design, **build**, **launch**, and **operate** long-duration smart weather balloons

Map of flight groundtracks to date, with flights aloft on 6/26/2023 in white. >650 launches.

Global Sounding Balloon (GSB)



The GSB is a highly cost-effective platform that can reach data-sparse and -void regions, supplementing existing collection methods and **closing the existing in-situ data gap**.

- **In situ observations** from **surface to stratosphere**
- **Long duration:** 4-32 days
- **Long range:** able to circumnavigate the globe
- Real-time, **full-range altitude control**
- Can **target areas of interest** using wind
- Observations available within **10 minutes**
- **AI-powered** autonomous flight control
- **Small & lightweight**

Repeated Vertical Profiles

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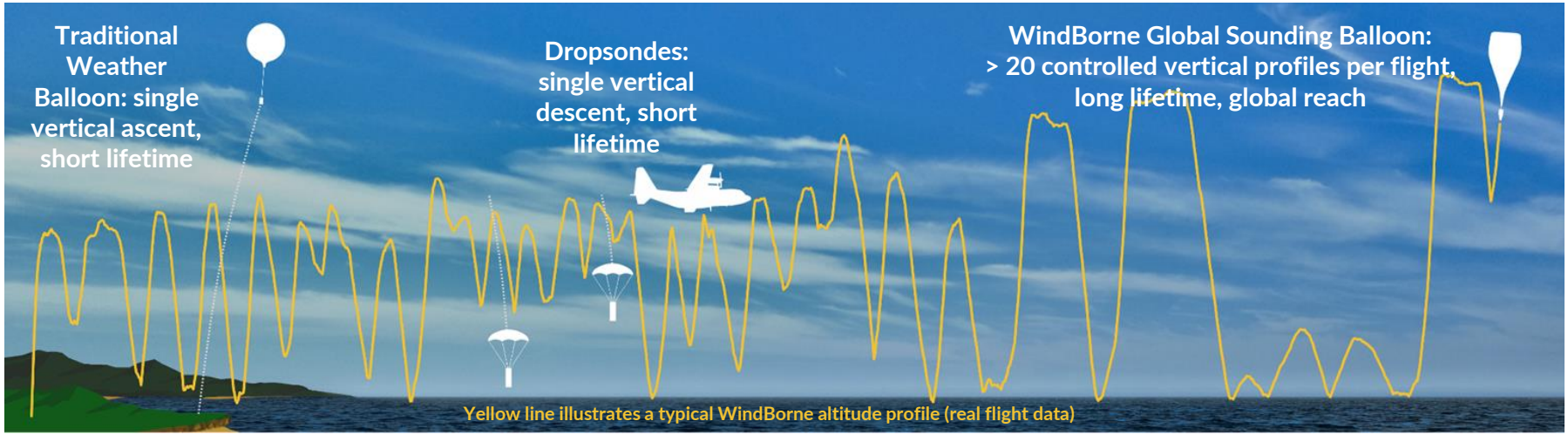

- Unlike any other in-situ data collection platform, the GSB can make **repeated vertical profiles from ground level to lower stratosphere,** creating repeated "soundings," or vertical ascents and descents that are 3 to 20 km in depth.
- GSBs shift altitude autonomously to change directions and maintain navigation settings while making **repeated planetary boundary layer (PBL) observations**. We can configure altitudinal boundaries for each GSB to pinpoint specific atmospheric layers for observation.

Streamlined Operations

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Launch

30 minutes to deploy with a single operator, nearly anywhere

Flight Control

Mostly autonomous, controllable from mission control suite

Regulatory

Compliant with FAA & ICAO regulations: access nearly anywhere

Winter 2021 and 2022 Campaigns

WindBorne

25 Feb - 15 Mar 2021
34 Flights; Eastern Pacific Coverage
Focused on Navigation and higher level obs

Avg Duration: 4.86 days Avg Vertical Distance/flight: 169 km

11 Feb - 21 Mar 2022
65 Flights; Full Pacific Coverage
Focused on Navigation and Deeper Profiles

Avg Duration: 4.34 days Avg Vertical Distance/flight: 237 km

Winter 2022 Flights

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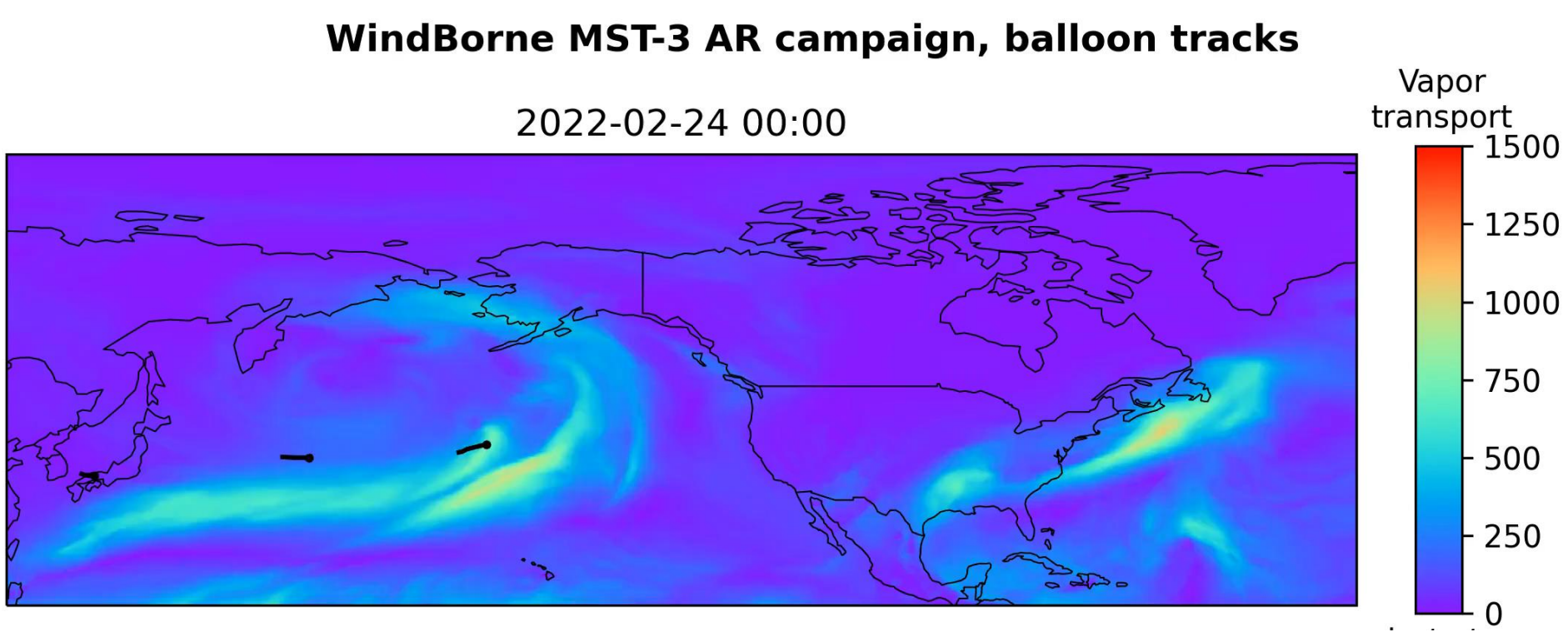

Example Flight

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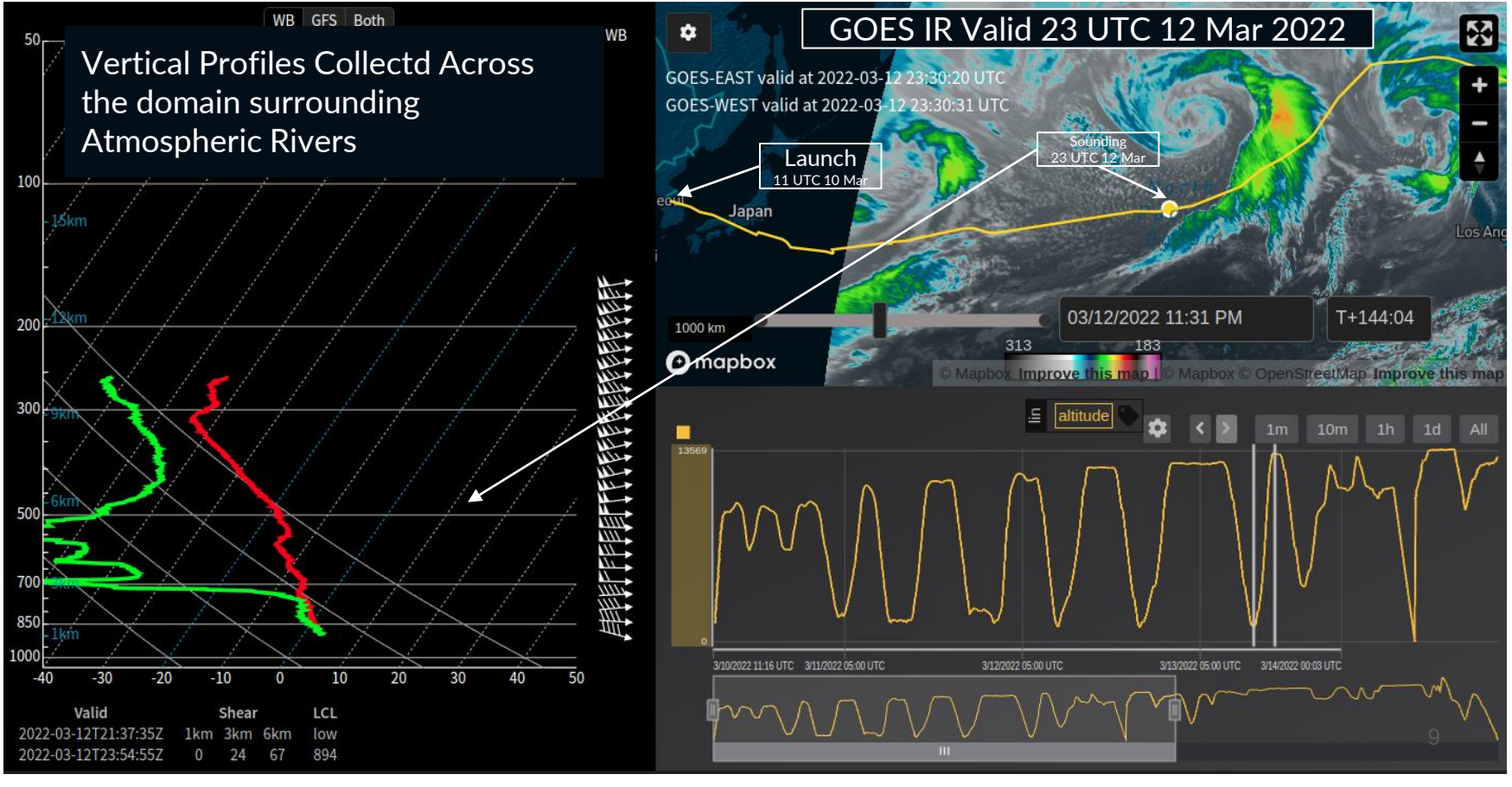

Forecast Impact Study Overview

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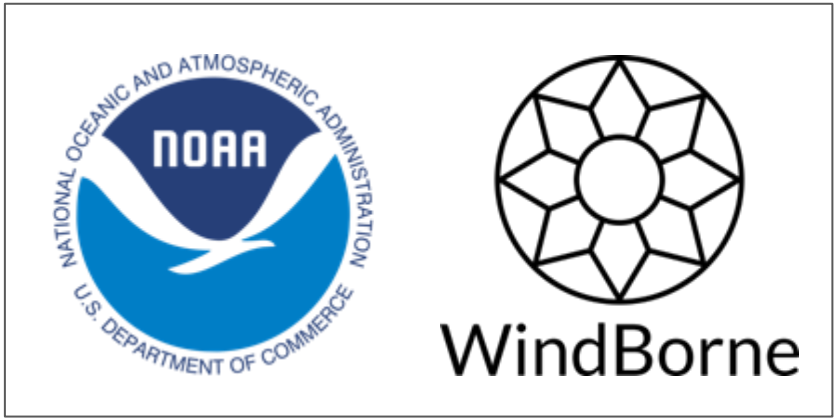
- WindBorne is collaborating with NOAA agencies to assess impact of observations on Forecasts
  - In 2022, NOAA/QOSAP ran GFS (½ resolution) retrospective study
  - In 2023, NOAA/EMC is running GFS (full resolution) retrospective study
- WindBorne is also running MPAS coupled with JEDI internally to assess impact



Our partnership with NOAA enables the validation of GSB observation impacts on weather prediction and forecasting.

Forecast Impact Study Details

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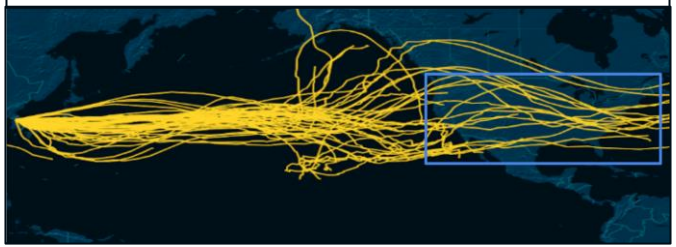
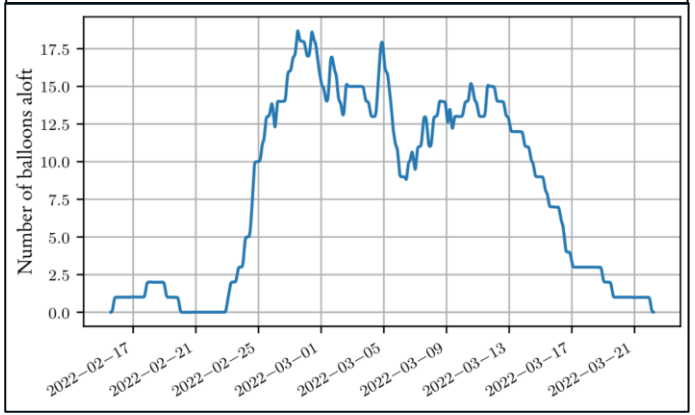
	Forecast				Data Assimilation		
	Model	Resol	Period	Init (UTC)	cycles	Res.	Spinup
NOAA/QOSAP	GFS 16.1	~25 km	23 Feb-18 Mar	00, 12	6-hrly	~50 km	5 days
NOAA/EMC	GFS 16.3.6	~13 km	17 Feb - 19 Mar	00	6-hrly	~25 km	5 days

Flight Paths



Observation Count



Forecast Impact

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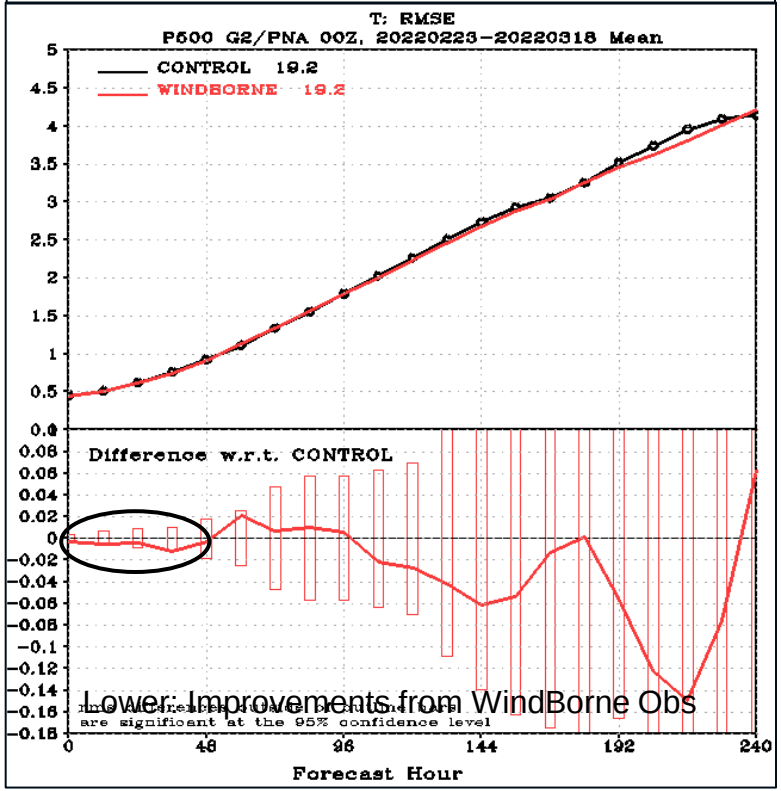
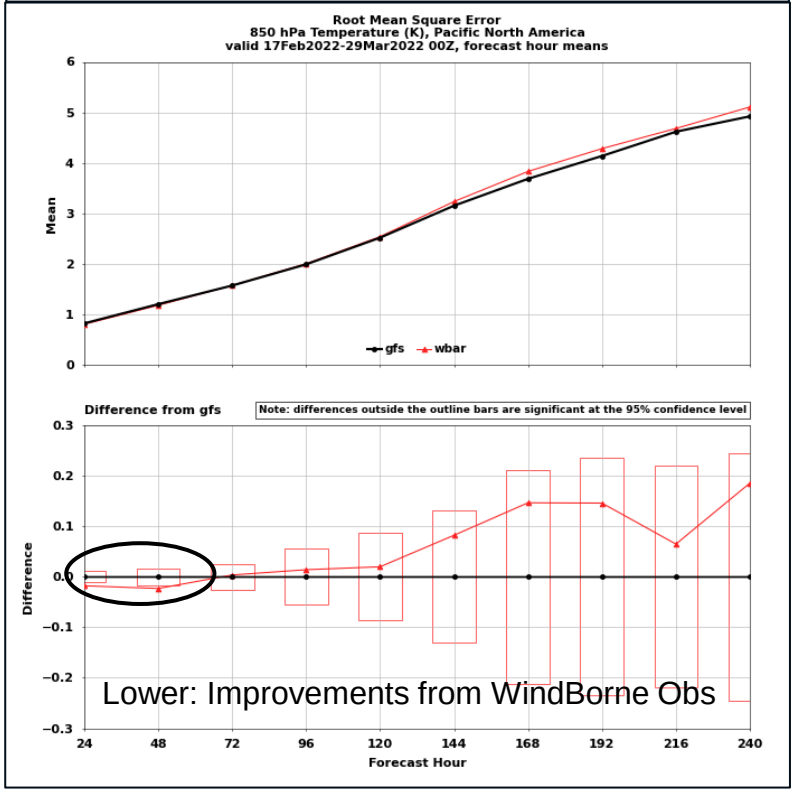
Coarse Resolution (25km)



Lower: Improvements from WindBorne Obs

Full Resolution (13 km)



Lower: Improvements from WindBorne Obs

Forecast Impact: Early Forecast Hours

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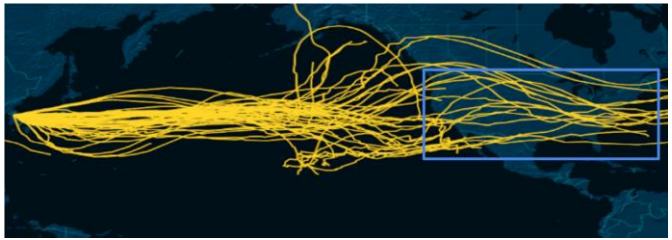
- Statistically significant positive impacts early in forecasts (12-60 h)
- Very little significance beyond 60 h indicating observations are not harming forecast



Error Reduction CONUS-Winter 2022

rms		conus					
		12 h	24 h	36 h	48 h	60 h	72 h
Height	All levels	0.09 (1.5%)	0.04 (0.7%)	-0.09 (-0.5%)	-0.19 (-1.0%)	-0.03 (-0.0%)	0.35 (2.1%)
	300 mbar	0.03 (0.9%)	-0.13 (-1.1%)	-0.23 (-0.7%)	-0.42 (-1.9%)	-0.39 (-1.7%)	0.20 (1.7%)
	500 mbar	0.13 (2.7%)	0.10 (2.1%)	-0.05 (0.8%)	-0.22 (-0.6%)	-0.01 (0.6%)	0.47 (3.6%)
	700 mbar	0.12 (2.4%)	0.14 (2.2%)	0.04 (0.6%)	-0.00 (1.1%)	0.32 (2.6%)	0.73 (5.3%)
	850 mbar	0.06 (1.4%)	0.04 (0.7%)	-0.06 (-0.8%)	-0.11 (-0.4%)	0.33 (2.6%)	0.72 (4.9%)
	1000 mbar	0.01 (0.2%)	-0.02 (-0.1%)	-0.22 (-1.7%)	-0.31 (-1.6%)	0.10 (0.8%)	0.46 (2.5%)
Temperature	All levels	-0.00 (-0.1%)	-0.01 (-0.4%)	**-0.01 (-1.0%)**	**-0.02 (-1.5%)**	-0.02 (-1.4%)	-0.01 (-0.4%)
	300 mbar	-0.01 (-1.1%)	**-0.02 (-3.2%)**	-0.02 (-1.9%)	-0.01 (-1.2%)	-0.00 (-0.1%)	-0.01 (-0.3%)
	500 mbar	-0.00 (-0.7%)	-0.01 (-1.2%)	-0.02 (-1.7%)	-0.02 (-1.7%)	-0.01 (-0.3%)	0.02 (2.1%)
	700 mbar	0.00 (0.4%)	0.00 (0.2%)	-0.01 (-1.0%)	**-0.04 (-2.8%)**	-0.02 (-1.1%)	-0.00 (0.1%)
	850 mbar	0.00 (0.2%)	-0.00 (-0.2%)	-0.02 (-0.9%)	**-0.03 (-1.6%)**	-0.03 (-1.4%)	-0.01 (-0.3%)
	1000 mbar	-0.01 (-0.2%)	-0.01 (-0.2%)	-0.02 (-0.6%)	-0.03 (-1.0%)	**-0.04 (-1.4%)**	-0.02 (-0.6%)
U wind	All levels	**-0.02 (-1.0%)**	**-0.03 (-1.4%)**	**-0.04 (-1.3%)**	-0.05 (-1.4%)	-0.03 (-1.0%)	0.04 (0.6%)
	300 mbar	-0.05 (-1.9%)	-0.06 (-1.8%)	0.05 (1.4%)	-0.02 (-0.3%)	-0.05 (-1.3%)	0.09 (1.2%)
	500 mbar	-0.03 (-1.4%)	**-0.06 (-2.1%)**	**-0.07 (-2.0%)**	-0.08 (-2.0%)	-0.02 (-0.1%)	0.06 (1.3%)
	700 mbar	-0.02 (-1.0%)	-0.02 (-0.9%)	-0.03 (-0.9%)	**-0.06 (-2.0%)**	-0.04 (-1.0%)	-0.01 (-0.5%)
	850 mbar	-0.01 (-0.5%)	0.01 (0.5%)	-0.02 (-0.6%)	**-0.05 (-2.0%)**	-0.03 (-0.9%)	0.02 (0.9%)
	1000 mbar	-0.01 (-0.5%)	-0.01 (-0.5%)	-0.01 (-0.9%)	**-0.02 (-1.5%)**	-0.01 (-0.8%)	0.02 (1.1%)
V wind	All levels	-0.01 (-0.5%)	**-0.04 (-1.7%)**	**-0.07 (-2.2%)**	-0.07 (-1.8%)	-0.04 (-1.0%)	-0.00 (0.1%)
	300 mbar	-0.05 (-1.7%)	-0.08 (-2.3%)	**-0.12 (-2.7%)**	-0.12 (-2.4%)	-0.07 (-1.1%)	0.03 (1.2%)
	500 mbar	-0.03 (-1.3%)	-0.05 (-1.8%)	**-0.08 (-2.2%)**	-0.10 (-2.5%)	-0.05 (-0.8%)	-0.03 (-0.4%)
	700 mbar	-0.00 (-0.1%)	-0.00 (-0.1%)	-0.05 (-1.5%)	-0.07 (-1.8%)	-0.02 (-0.3%)	-0.03 (-0.7%)
	850 mbar	-0.02 (-1.1%)	-0.03 (-1.2%)	-0.02 (-0.8%)	-0.04 (-1.2%)	-0.02 (-0.5%)	0.04 (1.0%)
	1000 mbar	-0.01 (-0.4%)	-0.00 (-0.1%)	-0.01 (-1.0%)	-0.01 (-0.7%)	-0.02 (-0.7%)	-0.01 (-0.4%)
Relative humidity	All levels	**-0.08 (-0.6%)**	**-0.13 (-1.0%)**	**-0.16 (-1.0%)**	-0.19 (-1.0%)	-0.18 (-0.9%)	-0.05 (-0.2%)
	300 mbar	-0.10 (-0.4%)	-0.20 (-1.1%)	0.05 (0.4%)	-0.19 (-0.8%)	-0.12 (-0.3%)	0.11 (0.6%)
	500 mbar	-0.20 (-1.6%)	-0.28 (-1.8%)	-0.25 (-1.2%)	-0.26 (-1.0%)	-0.13 (-0.4%)	-0.16 (-0.6%)
	700 mbar	0.02 (0.1%)	-0.02 (-0.2%)	-0.06 (-0.2%)	**-0.35 (-1.8%)**	**-0.41 (-1.7%)**	-0.16 (-0.4%)
	850 mbar	0.05 (0.4%)	0.00 (0.0%)	0.02 (0.2%)	-0.09 (-0.5%)	-0.05 (-0.1%)	0.13 (0.8%)
	1000 mbar	0.02 (0.2%)	-0.02 (-0.1%)	-0.04 (-0.3%)	-0.08 (-0.6%)	-0.02 (-0.2%)	0.01 (0.1%)
Sea level pressure	Surface	-0.02 (0.1%)	-0.45 (-0.2%)	-2.85 (-1.6%)	-3.93 (-1.6%)	0.74 (0.6%)	5.03 (2.2%)
100 metre U wind	Surface	-0.01 (-0.5%)	-0.01 (-0.5%)	-0.03 (-1.2%)	**-0.05 (-2.3%)**	-0.02 (-0.8%)	0.03 (1.2%)
100 metre V wind	Surface	-0.01 (-0.5%)	-0.00 (-0.2%)	-0.02 (-1.2%)	-0.03 (-1.3%)	-0.03 (-0.8%)	-0.00 (-0.0%)
10 metre U wind	Surface	-0.00 (-0.3%)	-0.00 (-0.3%)	-0.02 (-1.2%)	**-0.03 (-2.1%)**	-0.01 (-0.7%)	0.02 (1.4%)
10 metre V wind	Surface	-0.00 (-0.2%)	-0.00 (-0.3%)	-0.01 (-1.1%)	-0.01 (-0.9%)	-0.02 (-0.8%)	-0.00 (-0.1%)
2 metre dewpoint	Surface	-0.00 (-0.1%)	-0.00 (-0.0%)	-0.00 (-0.1%)	-0.01 (-0.3%)	-0.00 (-0.0%)	0.01 (0.4%)
2 metre temperature	Surface	-0.01 (-0.3%)	-0.01 (-0.2%)	-0.01 (-0.4%)	-0.01 (-0.3%)	-0.02 (-0.6%)	0.00 (0.1%)

Average root mean square error (RMSE) differences between GFS experimental and control runs during February/March 2022 for CONUS for lead times as columns every 12 hours through 72 hour lead times. Parameters and vertical levels evaluated for rows in the table are indicated on the left. RMSE (m) is shown with percentage error reductions in parentheses. Shading indicates direction of error reduction, with blue (red) indicating positive (negative) forecast impact as a result of WindBorne observations. Statistical significance (student-t test) is indicated with solid bars indicating significance at the 95% level and bold text values indicating significance at the 99% level.

WindBorne 2023 Target Operations

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WindBorne will be launching from 5 sites by end of 2023, and expect to be collecting nearly 200 vertical profiles per day

Simulated Flight Paths for January and February

WindBorne

WindBorne will be launching from 5 sites by end of 2023. NMP-funded balloons will be launched from Palo Alto and Schenectady. NMP will have access to data from all launch sites during 2023.

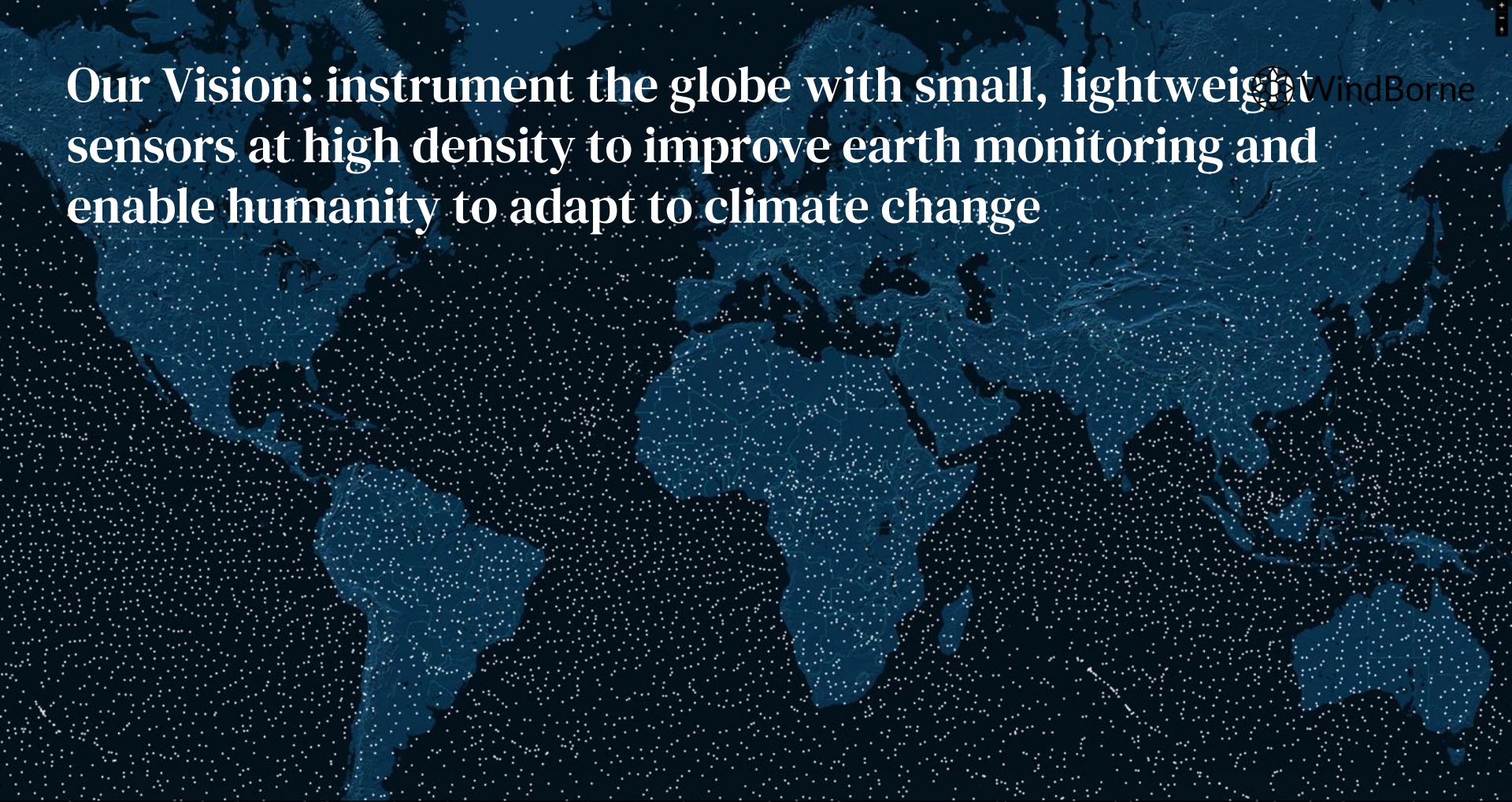
Daily launches from 5 sites
(Fairbanks, S. Korea, Palo Alto, Cabo Verde, New York State)

Simulated flight paths
(used 2022 wind data)

Winter 2023/2024
~25-30 balloons in air at any time
~200 profiles/day

Our Vision: instrument the globe with small, lightweight sensors at high density to improve earth monitoring and enable humanity to adapt to climate change

WindBorne



This is a simulated map of our future global constellation. Each dot represents an aloft GSB.

Data Availability

WindBorne web site access and data is available upon request:

todd@windbornesystems.com

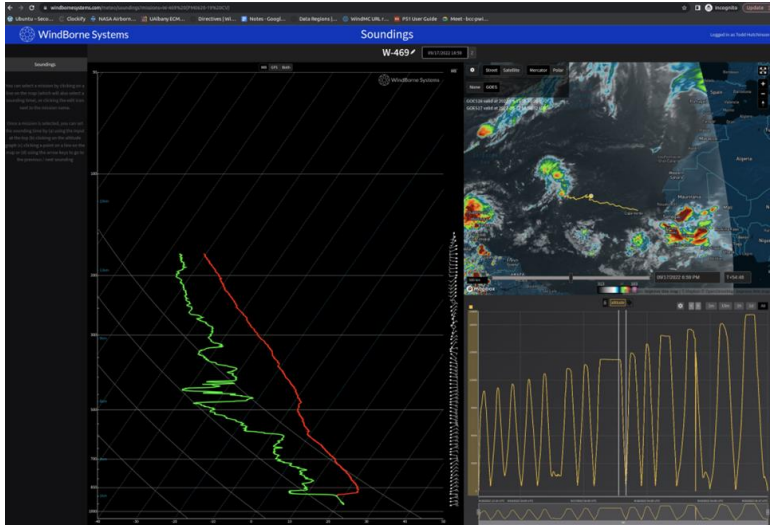
bufr, netcdf, textual, skew-T images available

Thank you

Accessing WindBorne Data

WindBorne will complete approximately 7,500 vertical soundings in support of the NMP through April of 2024.

- The location of all in-flight GSBs, as well as legacy data from past flights, is available through the WindBorne meteorological viewer, which can integrate directly through our configurable API.
- WindBorne data will also be available in NCEP Central Operations' (NCO) data tanks for integration into numerical weather prediction models, as well as displays on AWIPS.
- For more information, submit a request at https://windbornesystems.com/access_requests/new.



The WindBorne meteorological viewer with the vertical profile data from balloons displayed on a skew-T, balloon trajectories overlaid on infrared satellite, and the vertical profile panel.

Minimizing Environmental Impact

With our commitment to continued development, WindBorne is continually reducing waste while progressively collecting more data and decreasing costs.

	12+ mo. ago	Now	6 mo.	12 mo.	Long-term
Envelope (grams)	700	700	150	150	Recovery & reuse
Payload (grams)	480	200	150	100	~30 grams
Soundings per flight	18	30-50	40	80	hundreds

- We currently purchase plastic offsets representing 2x the waste we produce, and we collect 4x more data per dollar than other similar in-situ observation methods.
- By early 2024, WindBorne balloon mass will be reduced by half, from 2.8 kg to 1.4 kg.
- As GSB flight durations continue to lengthen, we will develop a targeted landing and collection method, aiming to collect 80% of our balloons.

Summer of 2022 - Launch Sites