WeatherFlow

AI-Powered Weather Intelligence Platform

Complete Guide to Professional Weather Forecasting, Machine Learning, and Climate Analysis

From Zero to Expert in Minutes
⚡ Train Models • 🌦️ Forecast Weather • 📊 Analyze Climate

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📋 **Table of Contents**

1. Welcome to WeatherFlow 🌍

WeatherFlow is the world's most comprehensive AI-powered weather intelligence platform, combining cutting-edge machine learning, real-world weather data, and intuitive visualization into a single, powerful application.

> ## 🎯 What Can You Do with WeatherFlow?
>
> - **Train State-of-the-Art AI Models** - Use the same architectures as Google DeepMind (GraphCast), NVIDIA (FourCastNet), and other leading research labs
>
> - **Generate Professional Forecasts** - Create 7-day weather predictions with publication-quality visualizations
>
> - **Analyze Real Weather Data** - Work with ERA5 reanalysis data, the gold standard in weather observation
>
> - **Plan Renewable Energy** - Calculate wind and solar power generation with real atmospheric data
>
> - **Detect Extreme Events** - Identify heatwaves, atmospheric rivers, and extreme precipitation
>
> - **Benchmark Performance** - Compare your models against published results using WeatherBench2

Whether you're a researcher, student, renewable energy planner, or weather enthusiast, WeatherFlow provides everything you need to harness the power of AI for atmospheric science.

2. Why WeatherFlow? 🚀

Educational Excellence

Learn atmospheric dynamics, machine learning, and weather forecasting through interactive lessons and real-world applications.

Cost Transparency

See exact GPU costs before training. Know exactly what you'll pay on cloud platforms like GCP.

Research-Grade Quality

Generate publication-ready figures, use WeatherBench2-compliant metrics, and cite reproducible results.

Instant Results

Start with demo data and see results in minutes. No setup headaches, no configuration nightmares.

Real-World Data

Access ERA5 reanalysis, GEFS ensemble forecasts, and standardized datasets from WeatherBench2.

Beautiful Visualizations

Create stunning weather maps, animations, and charts with professional cartographic projections.

Flexible Architecture

Mix and match components, build custom models, or use proven architectures from research papers.

Scalable Training

Train on your laptop or scale to cloud GPUs. Support for distributed multi-GPU training.

🏆 Industry-Leading Features

WeatherFlow is the **only platform** that combines:

- 30+ state-of-the-art AI architectures in one place
- Physics-informed training with conservation constraints
- Renewable energy forecasting integrated with weather prediction
- Complete training-to-deployment pipeline
- Educational content for graduate atmospheric dynamics

3. Quick Start Guide (5 Minutes) ⚡

Get your first weather forecast in just 5 minutes! Follow these simple steps:

🎯 Your First Forecast - Step by Step

1 Launch WeatherFlow

Open your terminal and run:

```
 cd weatherflow
streamlit run streamlit_app/Home.py
```

Your browser will automatically open to `http://localhost:8501`

2 Load Demo Data

Navigate to 📁 **Data Manager** in the sidebar

Click the big blue button: "🎲 **Load Quick Demo Data**"

✅ You'll see "Demo data generated successfully!" in seconds

3 Train a Quick Model

Navigate to 🎯 **Training Workflow** in the sidebar

Select **"Quick Demo Training"** mode

Click "🚀 **Start Training**"

⏱️ Training completes in 2-5 minutes on CPU

4 Generate Your Forecast

Navigate to 🌦️ **Weather Prediction** in the sidebar

Select your trained model from the dropdown

Click **"Generate 7-Day Forecast"**

🎉 See professional weather maps instantly!

5 Explore the Dashboard

Navigate to 📊 **Live Dashboard**

See your model's predictions vs. ground truth

View performance metrics and error statistics

💡 **Pro Tip:** The demo mode uses synthetic data for instant results. When you're ready for real forecasts, switch to ERA5 data in the Data Manager!

🎊 Congratulations!

You've just completed your first end-to-end weather forecasting workflow using AI. You've done what takes professional meteorologists years to learn - all in 5 minutes!

Now let's dive deeper into each component...

4. Understanding the Interface 🖥️

4.1 Navigation Structure

WeatherFlow organizes features into logical sections in the sidebar:

🏠 Home

Your mission control center. Shows:

- **Current Status** - What data and models you have loaded
- **Guided Workflow** - Step-by-step path from data to forecasts
- **Feature Overview** - Tabs showcasing platform capabilities
- **Quick Actions** - One-click navigation to key tasks

4.2 Core Pages

Page	Purpose	When to Use
📁 **Data Manager**	Load and manage weather datasets	First step of any workflow
🎯 **Training Workflow**	Configure and train AI models	Building new forecast models
🌦️ **Weather Prediction**	Generate forecasts with trained models	Creating weather predictions
📊 **Live Dashboard**	Monitor model performance	Evaluating forecast accuracy
🎨 **Visualization Studio**	Create publication-quality graphics	Making charts for reports/papers

4.3 Specialized Sections

⚡ **Renewable Energy**

- **Wind Power Calculator** - Estimate wind farm generation
- **Solar Power Calculator** - Calculate PV system output

🌀 Extreme Events

- Detect heatwaves using temperature thresholds
- Identify atmospheric rivers
- Find extreme precipitation events

🔬 Advanced ML

- **Training Hub** - Multi-environment training orchestration
- **Model Library** - Browse 30+ AI architectures
- **Research Workbench** - Build custom model components
- **Flow Matching Models** - Next-generation generative models

📐 Physics & Science

- **GCM Simulation** - Run climate models from scratch
- **Physics Losses** - Visualize conservation constraints
- **Graduate Education** - Learn atmospheric dynamics

4.4 Interface Elements

Common UI Patterns

- **Status Indicators** - Green checkmarks ✅ show completed steps, orange warnings ⚠️ highlight issues

- **Expandable Sections** - Click triangles ▶️ to show/hide details

- **Interactive Forms** - Sliders, dropdowns, and inputs respond in real-time

- **Download Buttons** - Save results as PNG, PDF, CSV, or GIF

- **Progress Bars** - Track long-running operations like training

5. Core Workflows 🔄

WeatherFlow supports multiple end-to-end workflows. Choose the one that fits your goal:

Workflow A: Quick Demo (5 Minutes)

Goal: Understand the platform quickly with synthetic data

1. Data Manager → Load Quick Demo Data
2. Training Workflow → Quick Demo Training (2-5 min)
3. Weather Prediction → Generate 7-day forecast
4. Live Dashboard → View performance

Best for: First-time users, demos, understanding the interface

Workflow B: Real-World Forecasting (Hours - Days)

Goal: Train production-quality models on real weather data

1. Data Manager → Load ERA5 Sample or Download Custom Data
2. Model Library → Choose architecture (GraphCast, FourCastNet, etc.)
3. Training Workflow → Configure training parameters
4. Review cost estimate (GPU hours, memory, pricing)
5. Start training (local GPU or cloud)
6. Model Comparison → Evaluate against WeatherBench2
7. Weather Prediction → Generate operational forecasts
8. Visualization Studio → Create publication graphics

Best for: Researchers, serious forecasting, publications

Workflow C: Renewable Energy Planning

Goal: Forecast power generation for wind/solar facilities

1. Data Manager → Load ERA5 data for your region

2. Wind Power or Solar Power → Configure system specs

3. Select time period and location

4. Calculate power generation

5. Analyze seasonal patterns

6. Export results for planning

Best for: Energy planners, site assessment, ROI analysis

Workflow D: Research & Experimentation

Goal: Test new ideas, run ablation studies, compare architectures

1. Data Manager → Prepare datasets

2. Research Workbench → Build custom model

3. Configure hyperparameter sweep

4. Run mini-training experiments

5. Compare results side-by-side

6. Export best configuration

7. Publication Visualizations → Create figures

Best for: PhD students, ML researchers, method development

Workflow E: Extreme Event Analysis

Goal: Identify and study extreme weather events

1. Data Manager → Load ERA5 historical data
2. Extreme Events → Select event type (heatwave, AR, precip)
3. Configure detection parameters
4. Run detection algorithm
5. Visualize spatial/temporal extent
6. Export event catalog

Best for: Climate researchers, insurance, disaster planning

6. Working with Weather Data 📂

6.1 Data Sources Available

Source	Resolution	Coverage	Best For
Quick Demo	Synthetic	Global, any time	Learning, testing, demos
ERA5 Reanalysis	0.25° (~25km)	1940-present	Research, real forecasts
WeatherBench2 Samples	Various	Pre-packaged events	Benchmarking, standardized tests
GEFS Ensemble	0.25-1.0°	Real-time + archives	Uncertainty quantification
Custom Upload	User-defined	Any	Specialized applications

6.2 Understanding ERA5 Data

What is ERA5?

ERA5 is the European Centre for Medium-Range Weather Forecasts (ECMWF) fifth-generation reanalysis dataset. It combines observations from weather stations, satellites, buoys, and aircraft with numerical models to create a comprehensive, consistent global weather history.

Key features:

- Hourly data from 1940 to near-present (5-day lag)
- 0.25° spatial resolution (about 25km at equator)
- 37 pressure levels from 1000 hPa to 1 hPa
- 100+ atmospheric and surface variables
- Widely used standard in weather AI research

6.3 Loading Data - Step by Step

Option 1: Quick Demo Data

1 Go to **Data Manager**

Click "🎲 **Load Quick Demo Data**"

Data generates in seconds - perfect for getting started!

Option 2: Pre-Bundled ERA5 Samples

1 Go to **Data Manager**

Browse sample datasets:

- **Hurricane Katrina (2005)** - Iconic tropical cyclone
- **European Heat Wave (2003)** - Extreme temperature event
- **Pacific Atmospheric River (2017)** - Moisture transport
- **Global Sample (2020)** - General training data

Click **"Load Sample"** for instant access

Option 3: Download Custom ERA5 Data

1 **Select Date Range**

Choose start and end dates for your study period

2 **Choose Variables**

Select atmospheric fields you need:

- **Pressure levels:** Temperature, geopotential, wind, humidity
- **Surface:** 2m temperature, 10m wind, pressure, precipitation

3 **Define Geographic Area**

Global or regional (specify lat/lon bounds)

4 **Download & Process**

Data downloads from cloud storage and preprocesses automatically

⏱️ Time depends on data size (minutes to hours)

6.4 Data Inspection
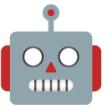
After loading data, WeatherFlow shows you:

- **Time range:** Start and end dates of your dataset

- **Spatial coverage:** Geographic extent and resolution

- **Variables available:** List of atmospheric fields

- **Data size:** Memory usage and file size

- **Sample statistics:** Min/max/mean values for quality checking

💡 **Pro Tip:** Start with sample data to understand the workflow, then move to custom downloads for your specific research needs.

7. Training AI Models 🤖

7.1 Choosing a Model Architecture

WeatherFlow provides 30+ state-of-the-art architectures. Here are the most popular:

Model	Organization	Strengths	Training Time
GraphCast	Google DeepMind	Highest accuracy, graph neural nets	Days (GPU)
FourCastNet	NVIDIA	Fast inference, transformer-based	Hours (GPU)
Pangu-Weather	Huawei	Strong tropical cyclones	Hours-Days
ClimaX	Microsoft	Transfer learning, flexible	Hours
UNet	Classical	Simple, fast, good baseline	Minutes-Hours
Flow Matching	Latest research	Generative, uncertainty estimates	Hours-Days

7.2 Training Configuration

🎯 Training Setup Process

1 Select Model Architecture

Choose from the dropdown menu

Click "ℹ️ Info" to see paper citation and architecture details

2 Configure Hyperparameters

- **Batch size:** Typically 4-32 (limited by GPU memory)

- **Learning rate:** Usually 1e-4 to 1e-3

- **Epochs:** 10-100 depending on data size

- **Optimizer:** Adam, AdamW, or SGD

3 Choose Training Environment

- **Local CPU:** Slow but free, good for small tests

- **Local GPU:** Fast if you have CUDA-enabled GPU

- **Cloud GPU:** GCP T4, A100, or H100 with cost estimates

4 Review Cost Estimate

Before training, see:

- GPU memory required

- Time per epoch estimate

- Total training time

- **Exact cost** in USD for cloud training

5 **Start Training**

Click "🚀 **Start Training**"

Monitor progress with live loss curves

Checkpoints save automatically every N epochs

7.3 Monitoring Training Progress

Real-Time Metrics

During training, you see:

- **Loss curve:** Training and validation loss over time

- **Learning rate schedule:** If using LR decay

- **GPU utilization:** Memory usage and compute %

- **Time remaining:** Estimated completion time

- **Current epoch:** Progress through training

7.4 Advanced Training Features

🔬 Physics-Informed Training

Add physics constraints to your loss function:

- **Divergence loss:** Enforce mass conservation
- **Energy spectrum:** Match realistic atmospheric scales
- **Geostrophic balance:** Physical wind-pressure relationships
- **Potential vorticity:** Conservation laws

Toggle these on in the "Physics Constraints" section

⚙️ Advanced Options

- **Mixed precision training:** Faster training with fp16
- **Gradient clipping:** Prevent exploding gradients
- **Learning rate scheduling:** Cosine annealing, step decay
- **Data augmentation:** Rotations, flips for robustness
- **Checkpoint frequency:** How often to save model

7.5 Cloud Training

Training on Google Cloud Platform

For large models or faster training:

1. Select "Cloud GPU" in training environment
2. Choose GPU type:

   - **T4:** Budget option (~$0.35/hr), good for small models
   - **A100:** Performance (~$2.50/hr), best balance
   - **H100:** Cutting-edge (~$4.50/hr), fastest training

3. Review estimated cost (shown in real-time)
4. Click "Launch Cloud Training"
5. Monitor from Cloud Training Dashboard
6. Checkpoints sync automatically to your local storage

⚠️ **Cost Warning:** Cloud training incurs real costs! Always check the estimate before launching. A typical research run on A100 might cost $50-200 depending on model size and epochs.

💡 **Pro Tip:** Start with 1-2 epochs on cloud to verify everything works, then launch the full training run. This prevents costly mistakes!

8. Making Weather Predictions 🌦️

8.1 Generating Forecasts

Creating a 7-Day Forecast

1 **Navigate to Weather Prediction**

Find "⛅ Weather Prediction" in the sidebar

2 **Select Your Model**

Choose from trained models in the dropdown

See model architecture, training date, and performance metrics

3 **Choose Initial Conditions**

Pick a start date/time from your dataset

Or use "Latest Available" for real-time forecasting

4 **Configure Forecast Parameters**

- **Forecast length:** 1-7 days (or longer if model supports)
- **Time step:** 6-hour, 12-hour, or 24-hour intervals
- **Variables to predict:** Temperature, wind, pressure, etc.

5 **Generate Forecast**

Click **"Generate Forecast"**

⏱️ Takes seconds to minutes depending on model complexity

8.2 Understanding Forecast Outputs

Forecast Visualization Types

- **Weather Maps:** Professional meteorological charts with pressure contours, wind barbs, temperature colors
- **Time Series:** Evolution of variables at specific locations
- **Animations:** GIF exports showing forecast evolution
- **Comparison Plots:** Side-by-side model vs. observations (if available)
- **Error Maps:** Spatial distribution of forecast errors

8.3 Forecast Skill Assessment

Evaluate your forecasts using standard metrics:

Metric	What It Measures	Good Value
RMSE	Root mean square error	Lower is better
MAE	Mean absolute error	Lower is better
ACC	Anomaly correlation coefficient	Higher is better (0-1)
Bias	Systematic over/under prediction	Close to 0
Spread-Skill	Ensemble spread vs. error	Ratio near 1.0

8.4 Exporting Forecasts

Export Options

- **PNG:** High-resolution images for reports

- **PDF:** Vector graphics for publications

- **GIF:** Animations for presentations

- **NetCDF:** Raw data for further analysis

- **CSV:** Time series data for spreadsheets

💡 **Pro Tip:** Use the "Batch Forecast" feature to generate forecasts for multiple dates automatically - great for building a forecast archive!

9. Renewable Energy Applications ⚡

9.1 Wind Power Forecasting

🌬️ Calculating Wind Farm Output

1 **Load Weather Data**

Use ERA5 data for your wind farm location

2 **Navigate to Wind Power Calculator**

Find "🌬️ Wind Power" under Renewable Energy section

3 **Configure Turbine Specifications**

Choose from pre-loaded turbine types or enter custom specs:

- **Vestas V90-3MW:** Popular onshore turbine
- **GE Haliade-X 12MW:** Offshore giant
- **Siemens SWT-6.0:** Mid-range offshore
- **Custom:** Enter your own power curve

4 **Set Wind Farm Parameters**

- **Installed capacity:** Total MW
- **Hub height:** Height of turbine (affects wind speed)
- **Rotor diameter:** Swept area
- **Number of turbines:** Farm size

5   **Calculate Power Output**

View:

- Time series of power generation

- Capacity factor statistics

- Seasonal variations

- Wind resource assessment

9.2 Solar Power Forecasting

☀️ Modeling PV System Output

1 · Navigate to Solar Power Calculator

Find "☀️ Solar Power" under Renewable Energy

2 · Select Panel Type

- **Monocrystalline:** High efficiency (18-22%)
- **Polycrystalline:** Cost-effective (15-17%)
- **Thin-film:** Flexible applications (10-12%)
- **Custom:** Enter your own specifications

3 · Configure System Parameters

- **Installed capacity:** Total DC watts
- **Tilt angle:** Panel inclination (optimize for latitude)
- **Azimuth:** Panel orientation (180° = south in N. hemisphere)
- **Tracking:** Fixed, 1-axis, or 2-axis tracking
- **Temperature coefficient:** Efficiency loss per °C

4 **Calculate Solar Generation**

System uses ERA5 solar radiation data and calculates:

- Hourly power output
- Daily/monthly/annual energy yield
- Performance ratio
- Temperature deration effects

9.3 Energy Planning Insights

📊 Analytics Available

- **Seasonal patterns:** When does your resource peak?
- **Capacity factor:** Actual output vs. theoretical maximum
- **Variability analysis:** Understand intermittency
- **Complementarity:** Compare wind vs. solar for optimal mix
- **Financial metrics:** Estimate revenue based on power prices

💡 **Pro Tip:** Use historical ERA5 data (20+ years) to understand long-term resource variability and make more robust investment decisions!

10. Extreme Weather Detection 🌪️

10.1 Heatwave Detection

🔥 Identifying Heat Extremes

1 **Navigate to Extreme Events**

Find "🌀 Extreme Events" in the sidebar

Select "Heatwave Detection" tab

2 **Choose Detection Method**

- **Absolute threshold:** Temperature exceeds fixed value (e.g., 35°C)
- **Percentile-based:** Above 90th/95th/99th percentile
- **Duration-based:** Must persist for N consecutive days

3 **Set Parameters**

- Temperature threshold
- Minimum duration (days)
- Geographic region of interest

4 **Run Detection**

Algorithm scans ERA5 data and identifies events

View results as:

- Spatial maps showing affected areas
- Time series of event intensity
- Event catalog with start/end dates

10.2 Atmospheric River Detection

🌊 What are Atmospheric Rivers?

Atmospheric rivers (ARs) are narrow corridors of concentrated water vapor in the atmosphere. They transport vast amounts of moisture and can cause flooding when they make landfall.

Detection criteria:

- Integrated water vapor transport (IVT) > 250 kg/m/s

- Length > 2000 km

- Width < 1000 km (narrow corridor)

- Often associated with heavy precipitation

Detecting ARs in ERA5 Data

1. Select "Atmospheric River Detection" tab

2. Algorithm calculates IVT from wind and humidity fields

3. Applies geometric criteria (length, width)

4. Visualizes detected ARs on map

5. Export AR catalog for climate studies

10.3 Extreme Precipitation

💧 **Finding Heavy Rainfall Events**

1. Select "Extreme Precipitation" tab

2. Choose threshold (e.g., 99th percentile or fixed amount)

3. Set accumulation period (24h, 48h, etc.)

4. Run detection algorithm

5. View spatial distribution of extreme events

6. Analyze relationship to atmospheric patterns

10.4 Applications

🏢 **Insurance & Risk**

Quantify exposure to extreme events for actuarial models

🏛️ **Urban Planning**

Design infrastructure to withstand historical extremes

🌾 **Agriculture**

Understand drought, heatwave, and flood risks for crops

🔬 **Climate Research**

Study trends in extreme event frequency and intensity

11. Advanced Features 🔬

11.1 Research Workbench

🧪 Building Custom Models

The Research Workbench lets you mix and match model components like LEGO blocks:

- **Encoders:** CNN, Vision Transformer, Graph Neural Network

- **Processors:** Transformer, GNN message passing, Recurrent

- **Decoders:** MLP, Transposed CNN, Graph decoder

Build, test, and compare novel architectures in minutes!

11.2 Physics Loss Functions

🎢 Incorporating Physical Constraints

Pure data-driven models can violate physics. Add constraints:

Divergence Loss

Enforces mass conservation: $\nabla \cdot v \approx 0$

```
loss_divergence = || ∂u/∂x + ∂v/∂y + ∂w/∂z ||²
```

Energy Spectrum Loss

Matches realistic atmospheric scales (Kolmogorov -5/3 law)

Geostrophic Balance

Physical relationship between wind and pressure gradients

```
f × v ≈ -∇Φ  (Coriolis force balances pressure gradient)
```

Potential Vorticity Conservation

Fundamental conservation law in atmospheric dynamics

11.3 GCM Simulation

🌍 General Circulation Model

Run a complete physics-based climate model from scratch! Unlike AI models that learn from data, the GCM solves the fundamental equations of atmospheric motion.

Features:

- Configurable resolution (32×16 to 128×64 horizontal grid)

- Vertical levels (10-26 layers)

- Time integration schemes (Euler, RK3, Leapfrog, Adams-Bashforth)

- Radiative forcing (CO_2 effects)

- Climate diagnostics (Hadley circulation, jet streams)

Educational Value:

See how weather emerges from basic physics equations. Compare AI forecasts to traditional numerical weather prediction.

11.4 Model Library

📚 30+ Pre-Configured Architectures

Browse and learn from cutting-edge research:

- GraphCast (Google DeepMind 2023)

- FourCastNet (NVIDIA 2022)

- Pangu-Weather (Huawei 2023)

- ClimaX (Microsoft 2023)

- GenCast (DeepMind 2024)

- NeuralGCM (Google 2024)

- And 24 more...

Each entry includes:

- Paper citation and link

- Architecture description

- Parameter count

- Pretrained model availability

- Performance benchmarks

11.5 Visualization Studio

🎨 Publication-Quality Graphics

Map Projections:

- **Plate Carrée:** Simple lat/lon grid

- **Orthographic:** Globe view

- **Mollweide:** Equal-area world map

- **Lambert Conformal:** Regional analysis

- **Polar Stereographic:** Arctic/Antarctic

Plot Types:

- Contour maps with customizable levels

- Filled contours (colormaps)

- Vector fields (wind barbs, arrows)

- Overlay multiple variables

- Add geographic features (coastlines, borders)

Export Options:

- PNG (300-600 DPI for publications)

- PDF (vector graphics)

- GIF animations

- MP4 videos (with ffmpeg)

11.6 Graduate Education Module

🎓 Learn Atmospheric Dynamics

Interactive Calculators:

- **Geostrophic Wind:** Calculate wind from pressure gradients
- **Rossby Waves:** Understand planetary-scale oscillations
- **Potential Vorticity:** Key concept in dynamics
- **Thermal Wind:** Vertical wind shear relationships

Study Resources:

- Practice problems with solutions
- Physical constants reference
- Derivations of key equations
- Links to textbooks and papers

12. Model Evaluation & Benchmarking 📊

12.1 WeatherBench2 Integration

> ### 🏆 What is WeatherBench2?
>
> WeatherBench2 is the standardized benchmark for weather AI models, developed by Google Research, ECMWF, and collaborators. It ensures fair comparison across models.
>
> **Key Features:**
>
> - **Standardized metrics:** All models evaluated identically
> - **Published baselines:** Compare to GraphCast, FourCastNet, etc.
> - **Multiple variables:** Z500, T850, T2M, WS10, MSLP, Q700, TP24h
> - **Regional breakdown:** Global, tropics, extra-tropics
> - **Lead time analysis:** How skill degrades over forecast horizon

12.2 Evaluation Metrics

Metric	Description	Interpretation
RMSE	Root mean squared error	Overall magnitude of errors (lower better)
ACC	Anomaly correlation coefficient	Pattern similarity (higher better, 0-1)
MAE	Mean absolute error	Average error magnitude (lower better)
BIAS	Mean forecast - observation	Systematic over/under prediction (near 0 best)
SEEPS	Stable equitable error in probability space	Specialized for precipitation (0-1, lower better)

12.3 Running Benchmarks

📈 Benchmark Your Model

1 **Navigate to WeatherBench2 Metrics**

Find "📊 WeatherBench2 Metrics" in sidebar

2 **Select Model to Evaluate**

Choose your trained model from dropdown

3 **Configure Evaluation**

- Select test period (typically 2020 for WB2)
- Choose variables to evaluate
- Set forecast lead times (6h, 12h, 1d, 3d, 5d, 7d, 10d)

4 **Run Evaluation**

Click "Run Benchmark"

⏱️ Can take minutes to hours depending on data size

5 **View Results**

- **Scorecard:** Heatmap comparing to baselines
- **Lead time plots:** Skill vs. forecast horizon
- **Variable breakdown:** Performance per atmospheric field
- **Leaderboard position:** How you rank vs. published models

12.4 Model Comparison

🔄 Compare Multiple Models

Navigate to "Model Comparison" page to:

- Load 2+ models for side-by-side comparison
- Generate difference maps showing where models disagree
- Plot skill scores on same axes
- Identify strengths/weaknesses of each architecture
- Export comparison tables for papers

12.5 Publishing Your Results

📝 Prepare for Publication

1. **Run WeatherBench2 evaluation** for standardized metrics
2. **Use Visualization Studio** to create figures
3. **Export high-DPI PNGs or vector PDFs**
4. **Document training details** (architecture, hyperparameters, data)
5. **Include comparisons** to published baselines
6. **Share checkpoints** for reproducibility

💡 **Pro Tip:** Use the "Publication Visualizations" page for journal-specific formatting (AMS, AGU, Nature style guides)

13. Pro Tips & Best Practices 💡

13.1 Getting Started

✅ Do's

- **Start with demo data** - Get comfortable with interface before using real data

- **Use pre-bundled samples** - Hurricane Katrina, heatwaves, etc. are ready to go

- **Check cost estimates** - Always review cloud training costs before launching

- **Save checkpoints frequently** - Don't lose hours of training to a crash

- **Validate on held-out data** - Use proper train/val/test splits

❌ Don'ts

- **Don't train on CPU for large models** - It will take forever. Use demo mode or GPU

- **Don't skip data inspection** - Always check your data quality first

- **Don't ignore physics losses** - They often improve generalization

- **Don't over-fit** - Monitor validation loss, use early stopping

> • **Don't forget to normalize** - Most models expect standardized inputs

13.2 Training Optimization

🚀 Speed Up Training

- **Mixed precision (fp16):** 2-3x speedup on modern GPUs
- **Larger batch sizes:** More GPU utilization, but watch memory
- **Data caching:** Pre-load data to RAM if possible
- **Multi-GPU:** Distributed training for very large models
- **Gradient accumulation:** Simulate large batches on small GPUs

📈 Improve Accuracy

- **More data:** Use longer time periods from ERA5
- **Data augmentation:** Rotations, shifts for robustness
- **Ensemble models:** Average multiple trained models
- **Physics constraints:** Add divergence, energy losses
- **Curriculum learning:** Start with easy tasks, increase difficulty
- **Transfer learning:** Start from pre-trained checkpoints

13.3 Data Management

> 💾 **Storage Tips:**
>
> - ERA5 data is large! A year of global data at 0.25° can be 100+ GB
> - Use zarr format for efficient chunked access

- Download only variables you need

- Consider temporal/spatial subsampling for initial experiments

- Cache preprocessed data to avoid recomputing

13.4 Visualization Tips

🎨 Creating Impactful Visuals

- **Choose appropriate colormaps:** Perceptually uniform (viridis, plasma) for continuous data
- **Use diverging colormaps** for anomalies (RdBu, RdYlBu)
- **Add geographic context:** Coastlines, borders, cities
- **Include colorbars with units**
- **Annotate key features** (storms, fronts, etc.)
- **Export at 300+ DPI** for publications

13.5 Workflow Efficiency

⚡ Work Smarter

- **Use keyboard shortcuts:** Navigate faster through pages
- **Bookmark common workflows:** Save favorite configurations
- **Batch operations:** Train multiple models overnight
- **Export configurations:** Save training setups as JSON
- **Version control your work:** Track model changes with git

13.6 Troubleshooting

🔧 Common Issues

Out of Memory (OOM) Errors

- Reduce batch size
- Lower model resolution
- Use gradient checkpointing
- Enable mixed precision

Training Not Converging

- Lower learning rate
- Check data normalization
- Increase batch size for stability
- Use gradient clipping

Slow Training

- Enable GPU if available
- Use data loaders with workers
- Pre-fetch data to RAM
- Profile to find bottlenecks

Poor Forecast Quality

- Train longer (more epochs)
- Use more training data
- Add physics constraints
- Check for data leakage
- Validate preprocessing

14. Troubleshooting 🔍

14.1 Installation Issues

Problem: Streamlit won't start

Solution:

```
 # Check installation
pip show streamlit

# Reinstall if needed
pip install --upgrade streamlit

# Run from correct directory
cd weatherflow
streamlit run streamlit_app/Home.py
```

Problem: Missing dependencies

Solution:

```
 # Install all requirements
pip install -r requirements.txt


# Or install individually
pip install torch xarray zarr plotly cartopy
```

14.2 Data Issues

Problem: ERA5 download fails

Possible causes:

- No CDS API key configured
- Network connectivity issues
- ECMWF server maintenance

Solution:

- Set up CDS API key (see Data Manager help)
- Try pre-bundled samples instead
- Check ECMWF status page

14.3 Training Issues

Problem: CUDA out of memory

Solution:

```
 # Reduce batch size
batch_size = 2  # or 1

# Enable gradient checkpointing
use_checkpointing = True

# Use mixed precision
use_amp = True
```

Problem: Loss is NaN

Possible causes:

- Learning rate too high
- Data not normalized
- Numerical instability

Solution:

- Lower learning rate (try 1e-5)
- Enable gradient clipping
- Check data for inf/nan values
- Use mixed precision carefully

14.4 Performance Issues

Problem: App is slow/laggy

Solution:

- Close unused browser tabs

- Reduce visualization resolution

- Clear cached data periodically

- Use demo data for UI exploration

14.5 Visualization Issues

Problem: Maps not rendering

Possible causes:

- Cartopy installation issues

- Missing geographic data

Solution:

```
 # Reinstall cartopy
pip install --upgrade cartopy


# Download geographic data
python -c "import cartopy; cartopy.io.shapereader.natural_earth()"
```

14.6 Getting Help

📞 Support Resources

- **Documentation:** Check inline help (ℹ️ icons throughout app)

- **GitHub Issues:** Report bugs or request features

- **Community Forum:** Ask questions, share experiences

- **Email Support:** For enterprise/research partnerships

💡 Before reporting issues:

- Check this troubleshooting guide

- Try with demo data to isolate the problem

- Note your OS, Python version, and error messages

- Include minimal reproducible example

🎉 Conclusion

Congratulations! You now have a comprehensive understanding of the WeatherFlow platform.

What You've Learned

- ✅ How to load and work with real weather data (ERA5)
- ✅ Training AI models for weather forecasting
- ✅ Generating and visualizing professional forecasts
- ✅ Applying weather AI to renewable energy
- ✅ Detecting extreme weather events
- ✅ Benchmarking models with WeatherBench2
- ✅ Advanced features for research and education

Next Steps

🚀 Continue Your Journey

1. **Experiment:** Try different model architectures and compare results
2. **Customize:** Build your own models in the Research Workbench
3. **Publish:** Share your findings with the community
4. **Collaborate:** Join the WeatherFlow community forum
5. **Contribute:** Help improve the platform on GitHub

🌟 Join the Weather AI Revolution

WeatherFlow puts cutting-edge weather AI in your hands. Whether you're forecasting tomorrow's weather, planning a wind farm, or publishing breakthrough research, you have the tools to succeed.

The future of weather forecasting is here. Let's build it together.

Quick Reference

Task	Page	Time Required
Quick demo forecast	Data Manager → Training → Prediction	5 minutes
Train on real ERA5 data	Data Manager → Training Workflow	Hours-Days
Wind power estimation	Wind Power Calculator	Minutes
Detect heatwaves	Extreme Events	Minutes
Benchmark model	WeatherBench2 Metrics	Minutes-Hours
Create publication figure	Visualization Studio	Minutes

WeatherFlow - AI-Powered Weather Intelligence Platform