Radio Telescope & Antenna Tracker Project

Project Vision

Incremental build of an antenna-tracked radio telescope system, starting with automated weather satellite reception and a weather prediction AI for Warsaw, then expanding into radio astronomy and citizen science contributions.

PHASE 1: Automated Weather Satellite Station + Weather AI

1A: Meteor-M LRPT Reception (No Tracker Needed) — ~$60-100

The easiest and fastest entry point. Meteor-M N2-3/N2-4 are Russian polar-orbiting weather satellites transmitting at 137 MHz. Multiple passes over Warsaw daily. No tracking needed (omnidirectional antenna). Will be available into the 2040s.

Important context: All NOAA POES satellites (15, 18, 19) were decommissioned in mid-2025. Meteor-M is now the primary 137 MHz weather satellite. From Warsaw, GOES satellites are NOT visible (geostationary over Americas).

Hardware

Item	Cost	Notes
RTL-SDR Blog V4	~$35	Main receiver
QFH antenna (DIY)	~$10-15	Copper pipe + PVC, circularly polarized
SAW filter + LNA (137 MHz)	~$15-25	Optional but recommended for Warsaw RFI
Raspberry Pi 4/5	~$50-80	Or use existing PC
SMA cables, adapters	~$10	

Software Stack

- **SatDump** (satdump.org) — all-in-one: satellite tracking, SDR control, decoding, image generation. Has built-in automation (auto-track, auto-record, auto-decode). Replaces the old chain of 6+ programs
- Runs on Raspberry Pi 5 or any Linux box
- Outputs: visible light images, infrared images, false-color composites, map overlays

What you get

- 1 km/px resolution images of Europe (JPEG compressed but good)
- 3 spectral channels (visible, near-IR, thermal IR)
- Multiple passes/day, automated capture 24/7
- Cloud patterns, storm systems, snow cover over Warsaw region

1B: HRPT Reception with Antenna Tracker — ~$300-500 additional

The big upgrade: high-resolution, uncompressed multi-channel imagery. This requires building the antenna tracker (your main engineering project).

Receivable satellites from Warsaw with HRPT (1.7 GHz, L-band)

Satellite	Operator	Status	Data
Meteor-M N2-3	Roscosmos	Active	6 channels, 1 km, uncompressed
Meteor-M N2-4	Roscosmos	Active	6 channels, 1 km, uncompressed
Metop-B	EUMETSAT	Until ~2027	6 channels AVHRR, 1 km
Metop-C	EUMETSAT	Until ~2030	6 channels AVHRR, 1 km
AWS (Arctic Weather Sat)	ESA	Active	Microwave radiometer

Hardware — Antenna Tracker (custom build)

Item	Cost	Notes
2x NEMA23 stepper motors	$30-60	Torque for dish + wind
2x TMC2209 stepper drivers	$10-20	Silent, reliable
ESP32 dev board	$8-12	Rotator controller
GT2 timing belt + pulleys (80T+20T)	$15-20	4:1 first stage reduction
Worm gear set (or 3D printed)	$15-30	Second stage, 10:1-15:1
6200/6201 bearings (4-6x)	$10-20	AZ and EL axes
2040 aluminum extrusion	$20-40	Frame structure
3D printed parts (PETG)	$20-25	Gear housings, mounts, adapters
Slip ring (12-wire)	$10-15	Cable management through AZ axis
Steel plate/tube (base)	workshop	Welded base for rooftop mount
Weatherproof enclosure	$15-25	For electronics
AS5600 magnetic encoders (2x)	$5-10	Position feedback

Hardware — RF Chain

Item	Cost	Notes
80-100cm offset satellite dish	$0-50	Used, from classifieds (OLX.pl)
L-band helicone feed (3D printed)	$5-10	Popular open-source design
Nooelec SAWbird+ GOES LNA	~$35	0.5 dB NF, filtered for 1.7 GHz
Airspy Mini (upgrade from RTL-SDR)	~$100	12-bit, 6 MHz BW, much better for HRPT

Tracker Software (your code)

```
Rotator Controller (ESP32, C/C++):
├── Stepper motor control (AccelStepper library)
├── AS5600 encoder feedback (I2C)
├── EasyComm2 protocol over serial/WiFi
├── Web interface for manual control
├── Homing routine (limit switches or encoder)
└── Wind stow mode (auto-park in high wind)

Host Software (Python, Raspberry Pi):
├── SatDump integration (autotrack + decode)
├── Satellite pass prediction (pyorbital/skyfield)
├── Rotator command interface (rotctld/Hamlib)
├── Image post-processing pipeline
├── Database for captured images + metadata
└── API for weather AI module
```

What you get

- 1 km/px UNCOMPRESSED images, 6 spectral channels
- Thermal IR for cloud-top temperatures
- Near-IR for vegetation, water vapor
- Multiple satellites per day = more frequent coverage of Warsaw
- Raw data for serious weather analysis

1C: Geostationary Satellite Reception (Fixed Dish) — ~$50-150 additional

Add continuous weather monitoring from Elektro-L (Russian geostationary satellite being repositioned to cover Europe in late 2025/2026).

Setup

- Small fixed dish (60-80cm) pointed at Elektro-L N°3 (14.5°W from Warsaw = ~30° elevation, ~245° azimuth)
- Same L-band LNA + SDR as HRPT setup (can share or add second RTL-SDR)
- SatDump decodes LRIT/HRIT
- Full-disk images every 30 minutes, continuously

Alternative: **EUMETCast via DVB-S2** — standard satellite TV setup pointed at Hotbird 13°E, provides Meteosat data. Requires EUMETSAT registration (free for non-commercial/educational use).

1D: Weather Prediction AI — Software Project

This is the software centerpiece: an AI system that learns weather patterns from your satellite imagery and predicts weather for Warsaw.

Architecture


Weather AI System
DATA COLLECTION
Satellite images (your captures)
Meteor-M LRPT (137 MHz, automated)
Meteor-M/Metop HRPT (1.7 GHz, tracked)
Elektro-L HRIT (geostationary, continuous)
Ground truth weather data
IMGW API (Polish Met Institute)
OpenWeatherMap API (current + historical)
Your own weather station (optional, future)
Timestamp + geolocation metadata
DATA PIPELINE
Image preprocessing
Georeferencing (map projection)
Crop to Warsaw region (~200km radius)
Normalize channels
Cloud classification (IR thresholding)
RFI artifact removal
Feature extraction
Cloud coverage %
Cloud motion vectors (consecutive images)
Cloud-top temperature distribution
Visible albedo patterns
Temporal sequences (last N images)
Storage (PostgreSQL + image files)
AI MODELS
Nowcasting (0-6 hours)
ConvLSTM / U-Net for cloud motion prediction
Input: sequence of satellite images
Output: predicted cloud/rain patterns
Short-term forecast (6-24 hours)
Transformer-based sequence model
Input: satellite images + weather features
Output: temperature, precipitation, cloud cover
Evaluation
Compare vs actual weather (IMGW data)
Compare vs official forecast (IMGW/ECMWF)
Track accuracy metrics over time
Skill score relative to persistence forecast
DASHBOARD (Web)
Live satellite image viewer
AI prediction display with confidence
Comparison: AI vs actual vs official forecast
Historical accuracy charts
Alerts for severe weather detection

Tech Stack

- **Python** — main language (PyTorch/TensorFlow, SatDump integration, data pipeline)
- **PostgreSQL** + **TimescaleDB** — time-series weather data + image metadata
- **FastAPI** — backend API
- **React or Svelte** — dashboard frontend
- **PyTorch** — model training (ConvLSTM, U-Net, or transformer)
- **Docker** — containerized deployment on Raspberry Pi 5 or mini PC

Open-Source Models to Build On

- **NPM** (github.com/seominseok0429/Data-driven-Precipitation-Nowcasting-Using-Satellite-Imagery) — directly uses satellite imagery, 2 km resolution
- **OpenClimatefix skillful_nowcasting** — DeepMind DGMR reimplementation
- **ConvLSTM** implementations for sequence prediction
- **Awesome-LWMs** (github.com/jaychempan/Awesome-LWMs) — curated list of weather AI models

Training Data Strategy

1. **Bootstrap**: Start collecting satellite images + corresponding IMGW weather data from day 1
2. **Pre-train**: Use publicly available satellite datasets (SEVIR, EarthNet2021) for initial model training
3. **Fine-tune**: Once you have weeks/months of Warsaw-specific data, fine-tune on your own captures
4. **Iterate**: Continuously retrain as more data accumulates

Warsaw-Specific Weather Data Sources

- **IMGW (Instytut Meteorologii i Gospodarki Wodnej)** — Polish meteorological data API
- **OpenWeatherMap** — free tier: current weather, 5-day forecast, historical data
- **Open-Meteo** — free, open-source weather API, historical + forecast data
- **ECMWF** — European Centre for Medium-Range Weather Forecasts (open data)

PHASE 2: Radio Astronomy (Future, ~$100-300 additional)

After the weather station is operational, add radio astronomy capability to the same tracked dish:

- Swap/add a 1420 MHz feed horn + SAWbird+ H1 LNA
- Hydrogen line detection and Milky Way mapping
- Join SARA, contribute data
- Same tracker, same SDR infrastructure

PHASE 3: Large Dish + Advanced Targets (Future, ~$500-1500)

- Upgrade to 2-3m dish (used TVRO)
- Upgrade SDR to SDRplay RSPdx (14-bit)
- Pulsar detection attempts
- Join SatNOGS network, Wow@Home
- Multi-band capability

Project Repository Structure

```
space-station/
├── firmware/                   # ESP32 rotator controller
│   ├── src/
│   │   ├── main.cpp
│   │   ├── stepper_control.cpp
│   │   ├── easycomm.cpp        # EasyComm2 protocol
│   │   ├── encoder.cpp         # AS5600 position feedback
│   │   └── web_server.cpp      # Status + manual control
│   └── platformio.ini
├── tracker/                    # Host-side tracking software
│   ├── scheduler.py            # Satellite pass scheduler
│   ├── rotator.py              # Rotator communication
│   ├── satdump_integration.py  # SatDump automation hooks
│   └── config.yaml
├── weather-ai/                 # Weather prediction AI
│   ├── data/
│   │   ├── collectors/         # IMGW, OpenWeatherMap scrapers
│   │   ├── pipeline.py         # Image preprocessing
│   │   └── dataset.py          # PyTorch dataset class
│   ├── models/
│   │   ├── nowcast.py          # ConvLSTM nowcasting model
│   │   ├── forecast.py         # Transformer forecast model
│   │   └── evaluate.py         # Accuracy metrics
│   ├── api/
│   │   └── main.py             # FastAPI backend
│   └── train.py
├── dashboard/                  # Web frontend
│   ├── src/
│   └── package.json
├── hardware/                   # CAD files, wiring diagrams
│   ├── rotator/                # 3D print STL files
│   ├── antenna/                # QFH, feed horn designs
│   └── enclosure/
├── docs/
│   ├── build-guide.md
│   └── calibration.md
├── docker-compose.yml
└── README.md
```

Implementation Order

Sprint 1: Get Images Flowing

1. Order RTL-SDR V4, build QFH antenna
2. Install SatDump on Raspberry Pi / PC
3. Receive first Meteor-M LRPT image
4. Set up automated capture (SatDump autotrack)
5. Build image storage database
6. Start collecting IMGW/Open-Meteo weather data for Warsaw

Sprint 2: Build the Tracker

1. Design rotator in CAD (Fusion 360 / FreeCAD)
2. 3D print gear housings and structural parts
3. Weld steel base frame
4. Assemble mechanical system
5. Write ESP32 firmware (stepper control + EasyComm2)
6. Integrate with SatDump for automated HRPT tracking

Sprint 3: HRPT Reception

1. Acquire/build dish (80-100cm) + L-band feed
2. Install LNA + cabling
3. First tracked HRPT capture
4. Set up multi-satellite automated schedule

Sprint 4: Weather AI v1

1. Build data pipeline (satellite images → preprocessed dataset)
2. Implement baseline model (ConvLSTM for cloud motion)
3. Train on accumulated data + public datasets
4. Build dashboard with live images + predictions
5. Start tracking prediction accuracy vs actual weather

Sprint 5: Iterate & Expand

1. Improve AI model based on accuracy data
2. Add Elektro-L geostationary reception
3. Add radio astronomy capability (1420 MHz feed)
4. Join SARA / SatNOGS communities

Verification

Phase 1A (LRPT)

- First Meteor-M image captured within first evening
- SatDump autotrack captures 4+ passes per day unattended
- Images show recognizable cloud patterns over Europe

Phase 1B (HRPT + Tracker)

- Rotator responds correctly to EasyComm2 commands
- Gpredict satellite tracking test: rotator follows predicted pass
- HRPT image quality visibly superior to LRPT (sharper, more channels)
- Tracker survives wind test (weights attached to simulate dish wind load)

Phase 1D (Weather AI)

- Dashboard shows latest satellite images + weather data
- Nowcast model produces cloud predictions for next 1-3 hours
- Track "skill score" vs persistence baseline (just predicting "same as now")
- After 1+ month of data: compare AI accuracy vs IMGW official forecast

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Sources

- SatDump — all-in-one satellite decoding software
- Beyond POES: Amateur Satellite Reception — post-NOAA landscape

- Meteor-M Reception Guide — Jacopo's comprehensive guide
- HRPT Beginners Guide
- SatDump Automation
- Tysonpower DIY Rotator
- SatNOGS Rotator v3
- NPM Precipitation Nowcasting
- DGMR Reimplementation
- Awesome Large Weather Models
- SARA — Society of Amateur Radio Astronomers
- SatNOGS — satellite ground station network
- Radio JOVE