# 140509\_50.md — Climate Change Impact Modeling & Mitigation Platform

**Theme:** Classical AI/ML/DL for Prediction, Deep-Tech Research  
**Mission:** Integrate climate, socio-economic, and Earth observation data to project impacts under multiple scenarios, quantify risks and costs, and recommend actionable mitigation/adaptation strategies for policy and operations.

## README (Problem Statement)

**Summary:** Create an AI platform that models climate change impacts, predicts environmental changes, and recommends mitigation strategies for organizations and governments.  
**Problem Statement:** Climate decisions need robust projections, risk quantification, and costed action plans. Build a system that fuses climate model outputs, EO/sensor data, and economic models to run scenario analyses (RCP/SSP), assess multi-hazard risks (flood/heat/drought/wildfire/SLR), perform cost–benefit analyses, and recommend mitigation/adaptation portfolios with stakeholder views.

**Steps:**  
- Climate modeling integration & fusion  
- Scenario analysis (RCP/SSP, policy levers)  
- Economic impact & cost–benefit assessment  
- Sectoral risk frameworks (agri, infra, health, energy)  
- Strategy recommender (mitigation/adaptation)  
- Policy simulation & stakeholder impact assessment

**Suggested Data:** CMIP6/ERA5 reanalyses; hydrology models; EO (Landsat, Sentinel, VIIRS); DEM; census/economic data; asset registries; mitigation case studies.

## 1) Vision, Scope, KPIs

**Vision:** A decision-intelligence platform that turns climate uncertainty into quantified, actionable plans.  
**Scope:**  
- v1: data lake + downscaled baselines, multi-hazard risk maps, dashboards.  
- v2: dynamic scenario engine (RCP/SSP + policy levers), economic cost–benefit, portfolio optimizer.  
- v3: policy lab with stakeholder modeling, real-time EO assimilation, twin-of-twins for cities & supply chains.

**KPIs:**  
- Downscaling RMSE/CRPS beats baselines by ≥15%  
- Risk map resolution ≤ 1 km² (urban ≤ 100 m)  
- Scenario turnaround < 10 minutes for national scale  
- Portfolio NPV ↑ and expected loss ↓ ≥ 20% vs status quo

## 2) Personas & User Stories

* **Policy Maker:** prioritizes investments with quantified benefits and equity impacts.
* **City Planner:** needs parcel/ward-level flood & heat risks and adaptation options.
* **Utility Operator:** wants grid stress forecasts & resilience investments.
* **Enterprise Risk Manager:** assesses supply-chain & asset risks.

**Stories:**  
- US‑01: Rank district‑level adaptation portfolios within a fixed budget.  
- US‑06: Simulate heat mitigation (albedo, urban tree canopy) and health co‑benefits.  
- US‑10: Project substation flood risk under RCP4.5 vs 8.5 to inform capex.

## 3) PRD (Capabilities)

1. **Data Fusion Layer:** harmonize climate model outputs, EO/sensors, hydrology, socioeconomics.
2. **Downscaling & Bias Correction:** statistical + DL super‑resolution on variables (temp, precip, wind, SLR).
3. **Multi-Hazard Risk Engine:** flood (river/coastal/pluvial), drought, heat, wildfire, landslide; return-period curves.
4. **Impact & Loss Modeling:** sector‑specific damage functions; mortality/morbidity models; supply-chain disruptions.
5. **Scenario Studio:** RCP/SSP combinations + policy levers (carbon price, standards, land‑use).
6. **Economic Engine:** cost–benefit, NPV, ROI, distributional impacts; IAM coupling.
7. **Recommender:** portfolio optimizer with constraints (budget, equity, feasibility).
8. **Policy Lab & Dashboards:** what‑if UI; maps; uncertainty bands; audit trails.

## 4) FRD (Functional Requirements)

* **Ingestion:** CMIP6 ensembles, ERA5, DEM, land cover, river networks, tide gauges; census/IO tables; asset inventories.
* **Processing:** regridding, temporal harmonization, bias correction; hazard-specific models (HEC‑RAS surrogates, VIC hydrology, fire risk indices).
* **Downscaling:** CNN/UNet super‑res; quantile mapping for bias; uncertainty via ensembles.
* **Risk Computation:** exceedance probability, AAL (Average Annual Loss), VaR/TVaR; criticality mapping for network assets.
* **Impact Models:** crop yield (ML + process hybrids), heat-health (WBGT, exposure), infra fragility curves.
* **Scenario Engine:** parameterized controls; Monte Carlo draws across climate & socioeconomics.
* **Economics:** discounting, shadow pricing of carbon, co‑benefits (air quality, jobs).
* **Optimizer:** multi‑objective (min loss, min variance, max equity index, max ROI).
* **Explainability:** drivers (feature attribution), intervention sensitivity, counterfactuals.
* **APIs/Exports:** GeoTIFF/COGs, vector layers, CSV, policy briefs (PDF), JSON.

## 5) NFRD (Non-Functional)

* **Scale:** 10–100 TB input; cluster compute; tiling & streaming.
* **Performance:** national scenario < 10 min; city sub‑km maps < 2 min/tile.
* **Reliability:** 99.9% availability.
* **Security:** data classification, row/geom-level ACLs; encryption; lineage.
* **Compliance:** FAIR data; provenance (W3C PROV); open model cards.
* **Sustainability:** carbon-aware scheduling; spot/preemptible nodes; green regions.

## 6) Architecture (Logical)

[CMIP6/ERA5/EO/Sensors] -> [ETL & Harmonization] -> [Data Lake + Catalog]  
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 v v  
 [Downscaling/BiasCorr] [Feature Store]  
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 v v  
 [Multi-Hazard Risk Engine] [Impact Models]  
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 [Scenario Studio] [Economic Engine]  
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 [Portfolio Optimizer]  
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 [Dashboards & APIs]

## 7) HLD (Key Components)

* **Data Lake & Catalog:** Delta Lake/Parquet; STAC catalog for EO.
* **Compute:** Spark/Flink for ETL; Dask/Ray for modeling; GPU DL for downscaling.
* **Downscaling:** UNet/EDSR; physics‑guided losses; CRPS minimization.
* **Hazard Models:** flood depth via surrogates calibrated to HEC‑RAS; wildfire risk from fuel+weather; drought via SPEI/soil moisture forecasts.
* **Impact:** fragility curves; crop yield hybrid (process + ML).
* **Economics:** IAM link (DICE/RICE/GCAM) + micro‑level costs; co‑benefits.
* **Optimization:** NSGA‑II/ParEGO; constraints & equity (Gini/GEI) scoring.
* **Visualization:** deck.gl/kepler.gl maps; uncertainty ribbons; explainer panels.
* **MLOps:** model registry; data versioning; scenario reproducibility IDs.

## 8) LLD (Selected)

**Downscaling Loss:**  
L = α\*MSE + β\*CRPS + γ\*physics\_penalty (mass/energy consistency).

**Flood Risk AAL:**  
AAL = ∑\_r P\_r \* Loss(depth\_r) over return periods r.

**Portfolio Objective:**  
maximize U = w1\*(-ExpectedLoss) + w2\*(-Variance) + w3\*Equity + w4\*ROI, s.t. Budget ≤ B, Feasibility ≥ θ.

**Equity Constraint Example:**  
At least 30% of benefits accrue to lowest‑income quintile tracts.

## 9) Pseudocode (Scenario → Portfolio)

climate = ingest(CMIP6, ERA5, EO)  
X = downscale\_bias\_correct(climate)  
risks = compute\_hazards(X, DEM, landcover)  
impacts = sector\_impacts(risks, assets, populations)  
scenarios = run\_scenarios(SSP, RCP, policies)  
econ = economic\_eval(impacts, scenarios)  
portfolio = optimize(measures, econ, constraints)  
return maps(risks), tables(impacts), plan(portfolio)

## 10) Data & Evaluation

* **Data:** CMIP6 ensemble members; ERA5; Landsat/Sentinel; SRTM/ALOS DEM; census; sector assets; case studies.
* **Validation:** backtesting vs observed extremes; cross‑climate holdouts; hindcast skill; Brier/CRPS; expert elicitation.
* **Benchmarks:** compare against process models; scenario plausibility checks; sensitivity analyses.

## 11) Security, Governance, Ethics

* Data licensing compliance; indigenous data sovereignty (CARE principles).
* Transparent model cards; uncertainty communication; do‑no‑harm guidelines.
* Stakeholder consent for socio‑economic layers; de‑biasing and fairness in resource allocation.

## 12) Observability & FinOps

* **Metrics:** ETL lag, downscaling error, scenario runtime, optimizer convergence, portfolio NPV, equity index.
* **Tracing:** pipeline IDs; lineage graphs; reproducibility packs.
* **Cost:** tiered storage; spot GPUs; cache tiles; lazy COG rendering.

## 13) Roadmap

* **M1 (4w):** Data lake + baseline downscaling + initial risk maps.
* **M2 (8w):** Scenario studio + economic engine.
* **M3 (12w):** Portfolio optimizer + policy lab UI.
* **M4 (16w):** Real‑time assimilation + twin‑of‑city pilots.

## 14) Risks & Mitigations

* **Model uncertainty:** ensembles; prediction intervals; communicate limits.
* **Data gaps/quality:** imputation; QA flags; crowd/partner data.
* **Policy misuse:** governance board; audit logs; open assumptions.
* **Performance costs:** tiling, streaming, mixed precision, schedule green clouds.