Martian Weather Forecasting and Anomaly Detection

Leveraging NASA REMS Data for Predictive Insights

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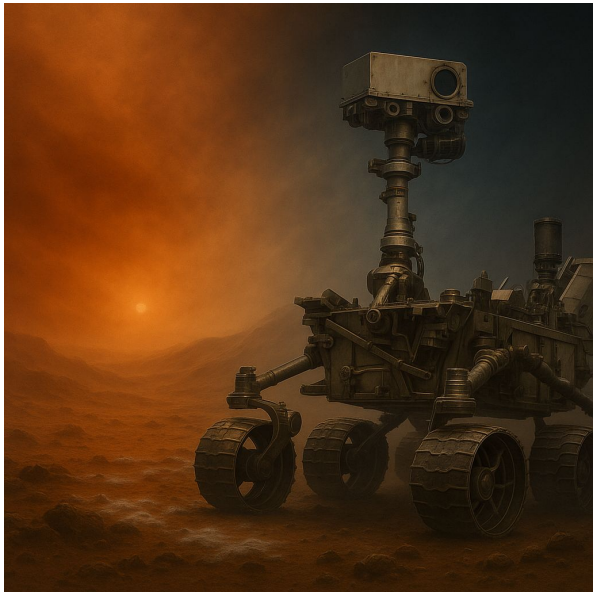
The Challenge: Mars's Unpredictable Environment

- Vital for Mission Success (Planning, Safety, Equipment Longevity)
- Need for Autonomous Real-Time Awareness
- Opportunity: Unique Long-Term REMS Dataset (**3,197** Sols)



Project Objectives: Delivering Actionable Insights

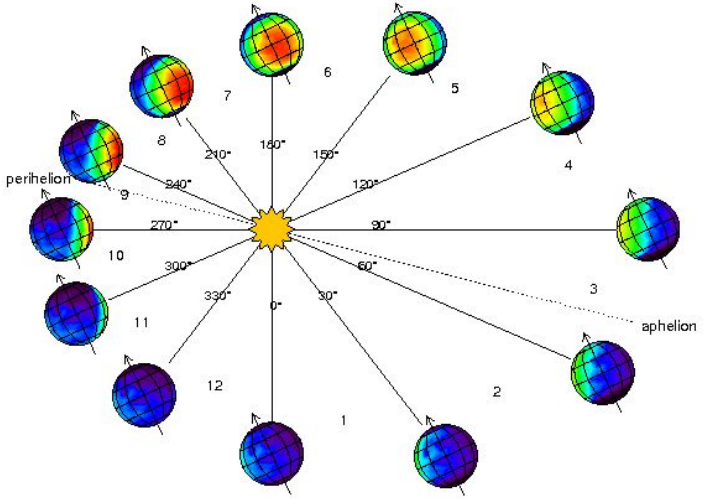
- **Forecast**:
  - Accurately predict Martian ground temperature
- **Detect**:
  - Identify atypical atmospheric behavior
- **Enable**:
  - Create robust data pipeline

The Data: Unveiling Mars from Gale Crater

- **Source**:
  - NASA Curiosity Rover (REMS Instrumentation)
- **Scope**:
  - **3,197** Martian Days (Sols) of Atmospheric Data
- **Key Variables**:
  - Temperature (Air and Ground)
  - Pressure (Atmospheric)
  - Solar Longitude (Mars Orbital Position)
  - UV Radiation (Categorical Index)
  - Day Length (Minutes of Sunlight)

Data Challenges: Unique Martian Complexities

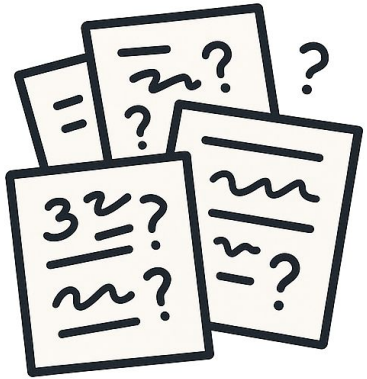
- Significant Missing Data
- Unique Martian Time Structure
- Complex Sequential Gaps



Source: https://www-mars.lmd.jussieu.fr/mars/time/solar_longitude.html

Approach: Building a Solid Data Foundation

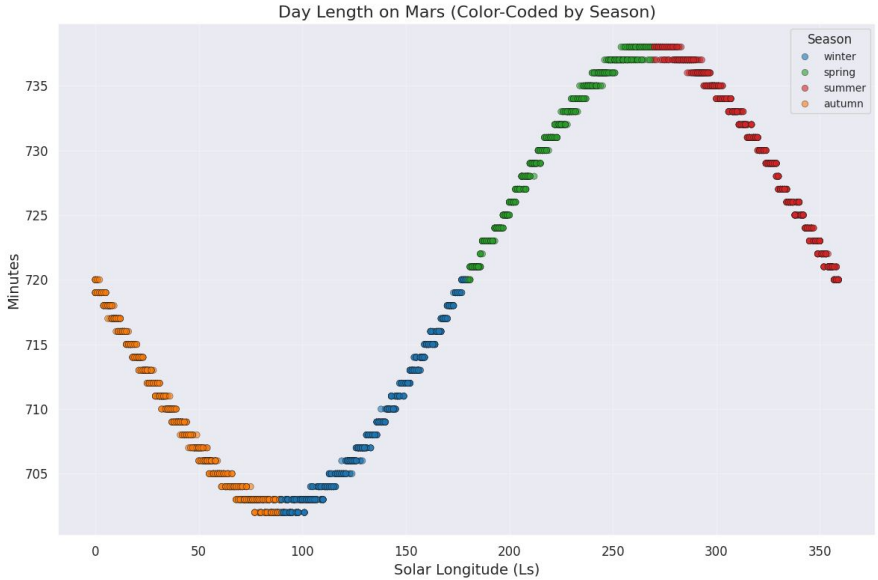
- **Rigorous Cleaning**:
  - Dropped unusable features
  - Standardized values
- **Targeted Imputation**:
  - Numerical: Linear
  - Categorical: Rolling Mode
- **Outcome**:
  - Chronologically sound
  - No missing data
  - Ready for analysis



Date	Temp	Pressure
Sol 1	12	750
Sol 2	2	
Sol 4	6	745

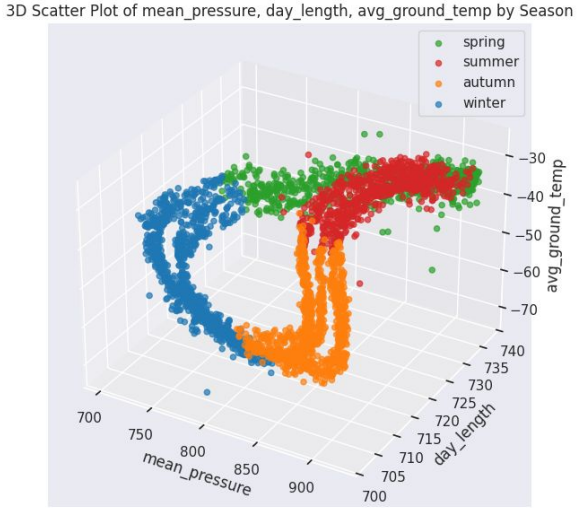
Approach: Unlocking Temporal Insights

- **Cyclical Encoding**:
  - Capture seasonal patterns from Solar Longitude
- **Derived Features**:
  - Day Length, Martian Month, Year, and Seasons
- **Result**:
  - Enhanced data for time-series modeling



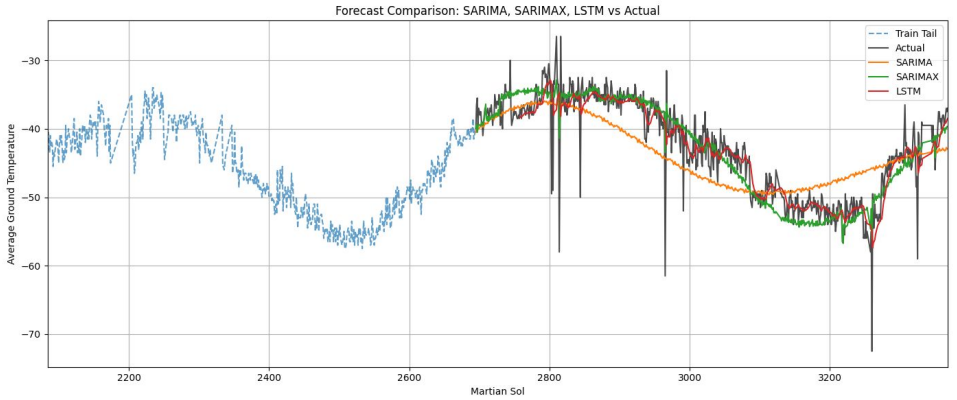
Key Insights: Understanding Martian Dynamics

- **Strong Seasonal Swings**:
  - Temperature and pressure driven by solar longitude
- **Temp-Pressure Correlation**:
  - Clear positive relationship observed
- **UV Radiation**:
  - Follows seasonal trends
  - Often a lagging indicator



Forecasting Martian Temperature: Diverse Modeling Approaches

- **SARIMA**:
  - Univariate Time Series
  - Focus on Core Seasonal Trends
- **SARIMAX**:
  - Multivariate Time Series
  - Improved Accuracy via Atmospheric Context
- **LSTM**:
  - Neutral Network for Sequence Learning
  - Complex Patterns and Fine Scale Variations



Forecasting Performance: Selecting the Right Tool

Model	MAE	RMSE	sMAPE	Directional Accuracy
SARIMA	3.570	4.525	8.326%	43.98%
SARIMAX	2.097	**2.914**	4.913%	**50.24%**
LSTM	**1.768**	2.939	**4.162%**	49.66%

Key Findings:

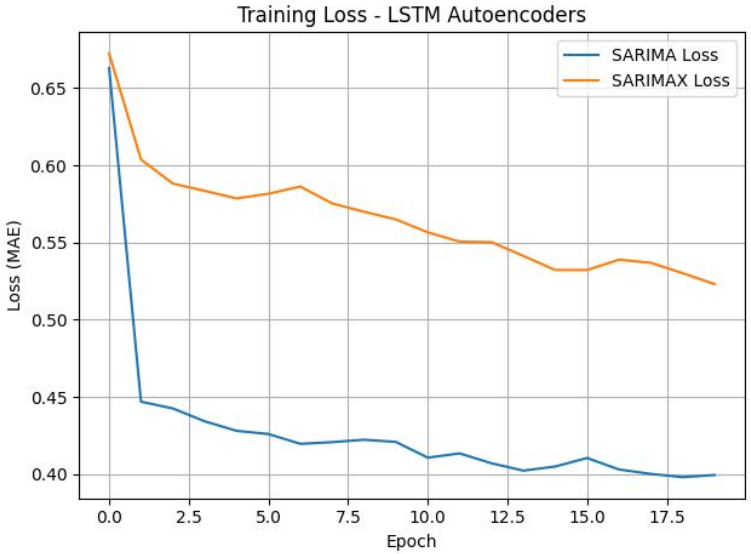
- **SARIMAX** offers best balance
- **LSTM** excels at MAE performance

Select SARIMAX for robust, contextual forecasts

LSTM for nuanced, high-accuracy predictions

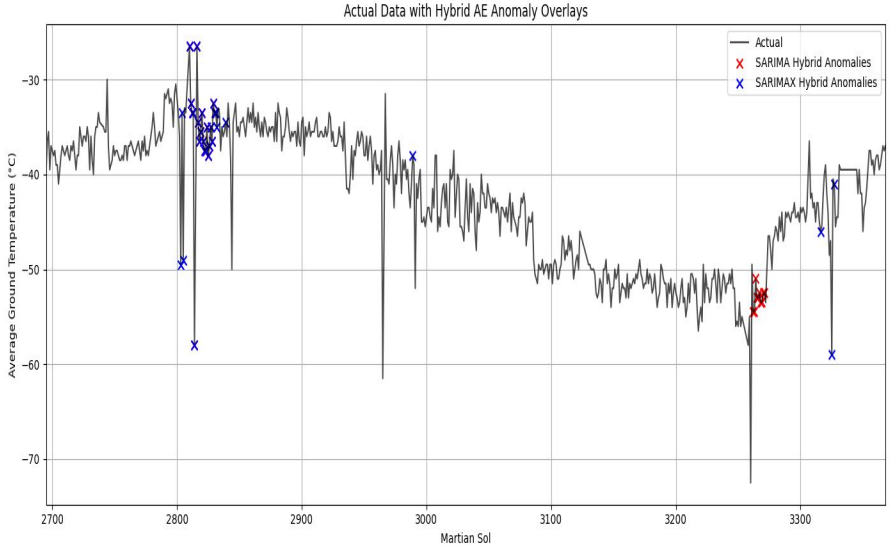
Anomaly Detection: Spotting the Unexpected

- **Approach**:
  - Hybrid statistical forecasting with Deep Learning
  - LSTM autoencoder
- **How it Works**:
  - Models “normal” forecast errors
  - Flags large deviations
- **Threshold**:
  - Deviations greater than 95th percentile of reconstruction error

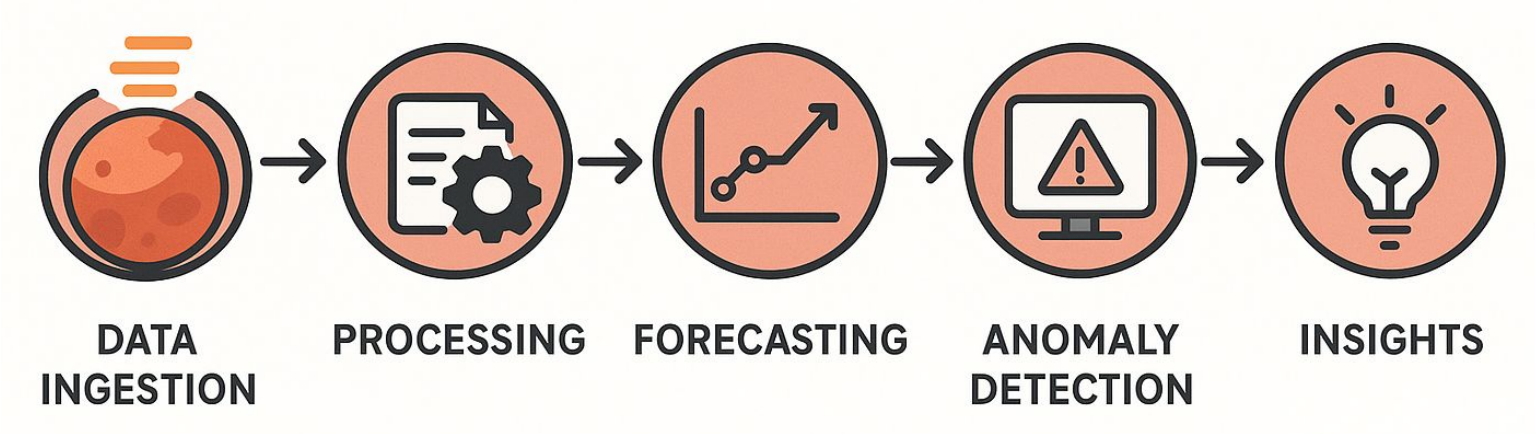


Detection Results: Identifying Significant Deviations

- **Success**:
  - System flagged atypical atmospheric sequences
- **Key Insight**:
  - Flagged anomalies suggest areas of high volatility
- **Impact**:
  - Highlights subtle patterns missed by direct observation



Integrated Pipeline: Data to Insights



Key Achievements & Impact

- **Developed**:
  - End-to-end Martian weather analysis pipeline.
- **Demonstrated**:
  - Effective forecasting
    - SARIMAX MAE: 2.10°C
    - LSTM MAE: 1.77°C
- **Enabled**:
  - Hybrid anomaly detection identifying key environmental shifts
- **Foundation**:
  - For enhanced scientific analysis and autonomous mission ops.

Recommendations: Putting Insights to Work

- **Monitor**:
  - Integrate anomaly detection for early warnings.
- **Plan**:
  - Use forecasts for tactical rover operations.
- **Simulate**:
  - Employ pipeline in mission rehearsals and system testing.

Thank You!

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Open to Questions and Feedback!

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