Forecast Service - Architecture Document

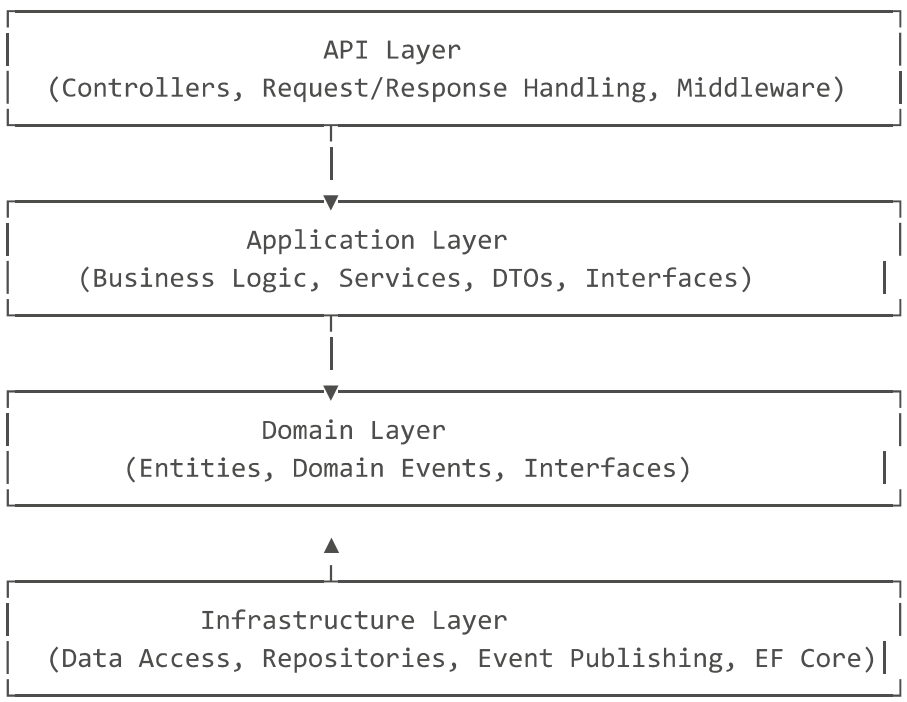
1. Overview

The Forecast Service is a microservice designed for managing power plant production forecasts in an energy trading platform. It provides RESTful APIs for creating, updating, and retrieving forecast data, as well as calculating company-wide position aggregations across multiple power plants.

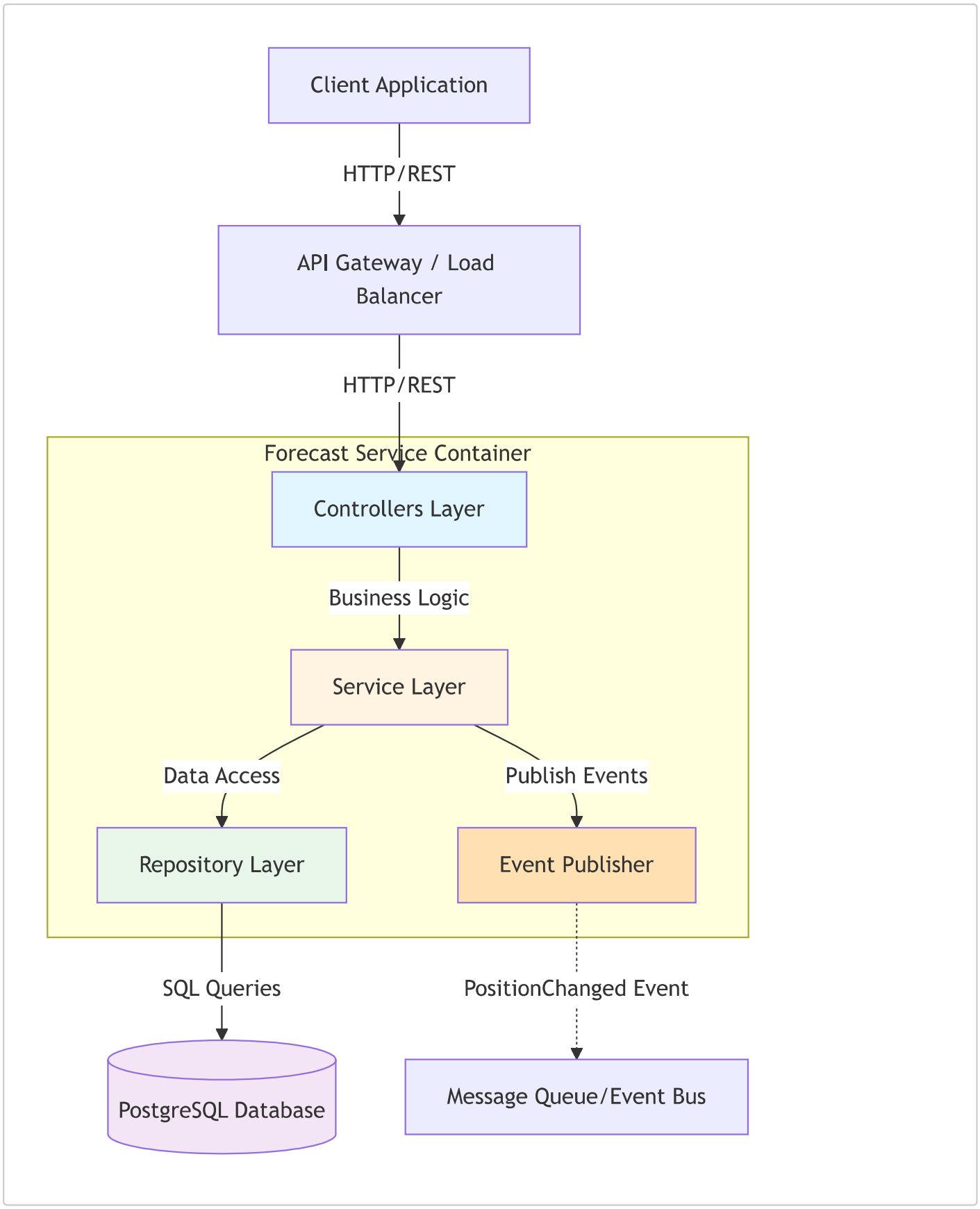
2. System Architecture

2.1 Architectural Pattern

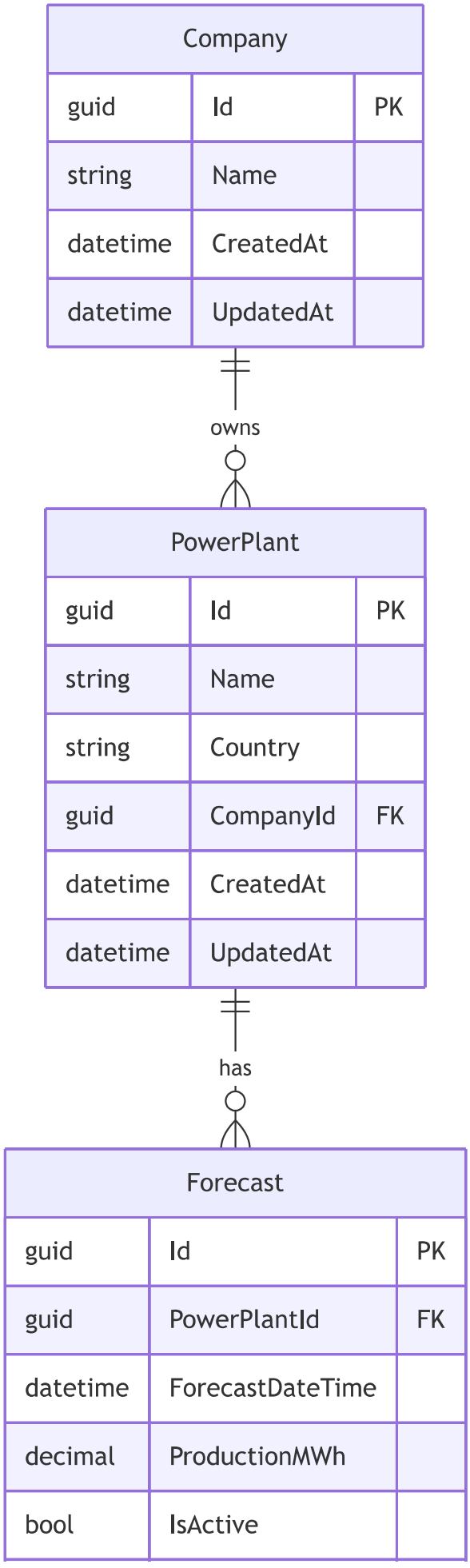
The service follows **Clean Architecture** principles with a clear separation of concerns across four layers:



2.2 System Flow Diagram



2.3 Domain Model


Company
guid
Id
PK
string
Name
datetime
CreatedAt
datetime
UpdatedAt
owns
PowerPlant
guid
Id
PK
string
Name
string
Country
guid
CompanyId
FK
datetime
CreatedAt
datetime
UpdatedAt
has
Forecast
guid
Id
PK
guid
PowerPlantId
FK
datetime
ForecastDateTime
decimal
ProductionMWh
bool
IsActive

datetime	CreatedAt	
datetime	UpdatedAt	

3. API Endpoints

3.1 Forecast Management

POST /api/forecasts

Create or update a forecast for a power plant.

Request Body:

```
{
  "powerPlantId": "guid",
  "forecastDateTime": "2026-01-16T12:00:00Z",
  "productionMWh": 150.5
}
```

Response (201 Created / 200 OK):

```
{
  "success": true,
  "data": {
    "id": "guid",
    "powerPlantId": "guid",
    "powerPlantName": "Turkey Power Plant",
    "country": "Turkey",
    "forecastDateTime": "2026-01-16T12:00:00Z",
    "productionMWh": 150.5,
    "createdAt": "2026-01-16T10:00:00Z",
    "updatedAt": "2026-01-16T10:00:00Z"
  },
  "error": null
}
```

Error Response (400 Bad Request / 404 Not Found):

```
{
  "success": false,
  "data": null,
```

```
  "error": {
    "title": "Not Found",
    "detail": "Power plant with ID ... not found",
    "status": 404,
    "instance": "/api/forecasts",
    "timestamp": "2026-01-18T10:30:00Z"
  }
}
```

GET /api/forecasts/{id}

Retrieve a specific forecast by ID.

GET /api/forecasts/power-plant/{powerPlantId}

Get all forecasts for a power plant within a date range.

Query Parameters:

- `startDate`: DateTime
- `endDate`: DateTime

3.2 Company Position

GET /api/companyposition/{companyId}

Calculate and retrieve the aggregated position for a company.

Query Parameters:

- `startDate`: DateTime
- `endDate`: DateTime

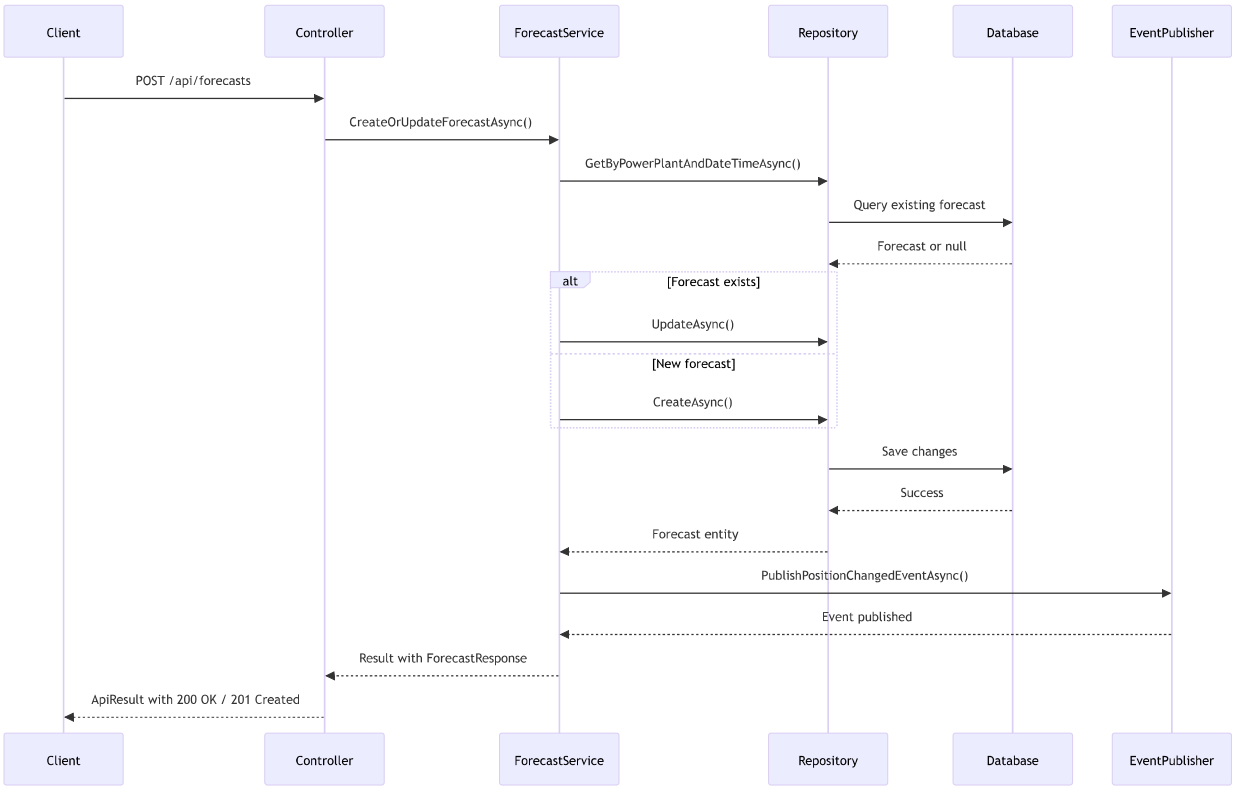
Response:

```
{
  "success": true,
  "data": {
    "companyId": "guid",
    "companyName": "Energy Trading Corp",
    "startDate": "2026-01-16T00:00:00Z",
    "endDate": "2026-01-17T00:00:00Z",
    "totalPositionMWh": 1250.75,
    "powerPlantPositions": [
      {
        "powerPlantId": "guid",
        "powerPlantName": "Turkey Power Plant",
        "country": "Turkey",
```

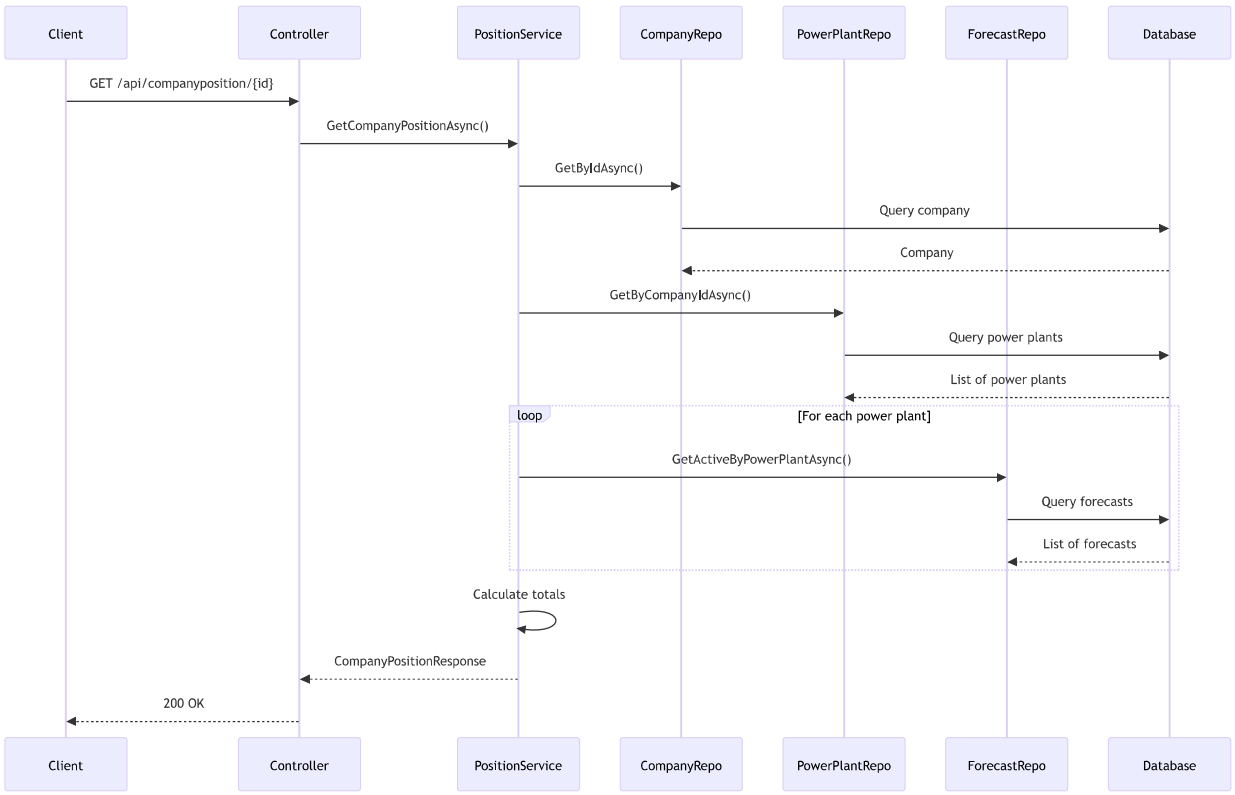
```
        "totalProductionMWh": 450.25,
        "forecastCount": 24
      }
    ]
  },
  "error": null
}
```

4. Data Flow

4.1 Create/Update Forecast Flow



4.2 Get Company Position Flow



5. Event-Driven Architecture

5.1 PositionChanged Event

When a forecast is created or updated, the service emits a `PositionChangedEvent`:

```
{
    "CompanyId": "guid",
    "StartDate": "2026-01-16T00:00:00Z",
    "EndDate": "2026-01-17T00:00:00Z",
    "TotalPositionMWh": 1250.75,
    "EventTimestamp": "2026-01-16T10:30:00Z",
    "Reason": "Forecast Created"
}
```

Current Implementation: RabbitMQ message broker running in Docker container

- **Exchange:** `forecast.events` (topic exchange)
- **Routing Key:** `position.changed`
- **Message Format:** JSON serialized events
- **Management UI:** http://localhost:15672 (admin/admin)
- **Connection:** Automatic reconnection with retry logic

Alternative Options: Azure Service Bus, Apache Kafka, or AWS EventBridge

6. Data Persistence

6.1 Database Strategy

- **Database:** PostgreSQL 16
- **ORM:** Entity Framework Core 10.0
- **Migration Strategy:** Code-First with automatic migrations on startup
- **Connection Pooling:** Managed by Npgsql provider
- **Indexing Strategy:**
  - Composite index on `(PowerPlantId, ForecastDateTime, IsActive)` for fast forecast queries
  - Composite index on `(CompanyId, Country)` for power plant queries

6.2 Data Seeding

Initial data includes:

- 1 Company: "Energy Trading Corp"
- 3 Power Plants: Turkey, Bulgaria, Spain

7. Thread Safety & Concurrency

7.1 Thread Safety Considerations

1. **DbContext Scoping:** Each HTTP request gets its own scoped DbContext instance
2. **Repository Pattern:** Prevents shared state issues
3. **Async/Await:** All I/O operations are async for better scalability
4. **Optimistic Concurrency:** Can be added using row versioning if needed

7.2 Scalability

- **Stateless Design:** Service can be horizontally scaled
- **Database Connection Pooling:** Efficient resource utilization
- **Docker Support:** Easy container orchestration with Kubernetes or Docker Swarm

8. Security Considerations

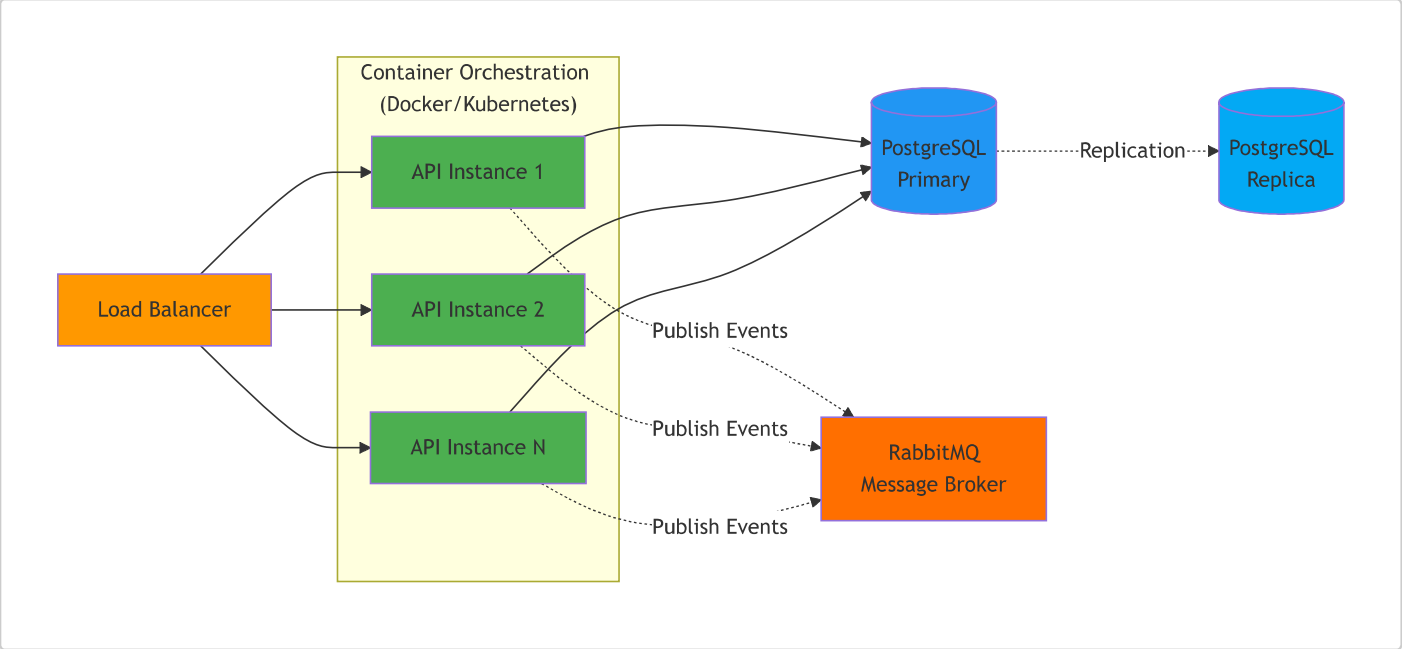
8.1 Current Implementation

- **Result Pattern:** Type-safe error handling without exceptions
- **Model State Validation:** Nullable properties with `[Required]` and `[Range]` attributes
- **Global Exception Handler:** Middleware for consistent error responses
- **Custom Validation Error Factory:** Returns unified error format for validation failures
- **Structured error responses:** Consistent error format with codes and messages
- **CORS configuration:** Configured for cross-origin requests
- **Docker isolation:** Services isolated in separate containers

8.2 Production Recommendations

- Add JWT authentication
- Implement rate limiting
- Add API versioning
- Enable HTTPS only
- Add request logging and monitoring
- Implement API key authentication

9. Deployment Architecture



10. Monitoring & Observability

10.1 Recommended Metrics

- Request latency (p50, p95, p99)
- Error rates by endpoint
- Database query performance
- Event publishing success rate
- Active connections

10.2 Logging

- **Structured logging using Serilog:** Already implemented
- **Console Sink:** Real-time log output during development
- **File Sink:** Daily rolling logs stored in `logs/` directory with 30-day retention
- **Log levels:** Debug, Information, Warning, Error, Critical
- **Log format:** JSON structured format with timestamps, log levels, and context
- **Future Enhancement:** Correlation IDs for distributed request tracing

10.2 Modern C# Features

C# 14 field Keyword (Limited Usage):

- **BaseEntity only:** Used for UTC timestamp normalization in CreatedAt and UpdatedAt properties
- **Benefit:** Cleaner code by eliminating explicit backing fields for date normalization logic
- **Example:** `set => field = value.Kind == DateTimeKind.Unspecified ? DateTime.SpecifyKind(value, DateTimeKind.Utc) : value.ToUniversalTime();`

Validation Strategy - Data Annotations (ASP.NET Core Standard):

- **Approach:** Nullable properties with `[Required]` and `[Range]` data annotations
- **Rationale:**
  - Data annotations are the ASP.NET Core idiomatic way for input validation
  - Automatic validation before controller action execution
  - Consistent error responses through custom `InvalidModelStateResponseFactory`
  - Separates validation concerns from business logic
  - No exceptions during model binding - validation handled declaratively

Rationale for Pragmatic Approach:

- This is an **I/O-bound microservice** where network/database latency dominates performance
- Event publishing happens **occasionally** (on forecast changes), not in tight loops
- Advanced C# 14 features like `Span<T>` would add complexity without measurable benefits
- **Principle:** Favor readability, maintainability, and ASP.NET Core conventions over micro-optimizations

C# 14 Features Evaluated but Not Used:

- ❌ **Extension Members:** Only replaced `Sum()` which is already concise (overengineering)
- ❌ **Span optimizations:** No performance bottlenecks in string operations or byte encoding
- ❌ **field keyword for validation:** Data Annotations provide better separation of concerns

11. Technology Stack Summary

Layer	Technology
Framework	.NET 10 / ASP.NET Core
Language	C# 14
Database	PostgreSQL 16
ORM	Entity Framework Core 10.0
Message Broker	RabbitMQ 3.13 with Management Plugin
Containerization	Docker & Docker Compose
API Documentation	Scalar.AspNetCore (OpenAPI)
Logging	Serilog with Console and File Sinks
Design Patterns	Clean Architecture, Repository Pattern, Result Pattern

12. Future Enhancements

1. **Caching Layer:** Redis for frequently accessed data
2. **Dead Letter Queue:** Error handling for failed RabbitMQ messages
3. **GraphQL Support:** Alternative to REST API
4. **Real-time Updates:** SignalR for live position updates
5. **Time Series Optimization:** TimescaleDB for historical data
6. **Authentication:** Identity Server or Azure AD B2C
7. **Monitoring:** Application Insights, Prometheus + Grafana
8. **Event Consumers:** Separate microservices subscribing to RabbitMQ events