# COMBINING HIGH RESOLUTION FORECASTS WITH DYNAMIC LINE RATING

PILOT SERVICE WITHIN DESTINATION EARTH (DESTINE) 374A

IRENE SCHICKER[1], ALEX DECKMYN[2], JORIS VAN DEN BERGH[2,6], WARRE VERLINDE[3], PIET TERMONIA[2,4], VICTOR LE MAIRE[5] AND TOMAS VAN OYEN[3]

[1]*GEOSPHERE AUSTRIA, VIENNA;* [2]*ROYAL METEOROLOGICAL INSTITUTE BELGIUM;* [3]*PROPHESEA;* [4]*GHENT UNIVERSITY;* [5]*ELIA TRANSMISSION BELGIUM; UNIVERSITY OF ANTWERP*[6]


Image Caption Udamendi geniet magnificius etv

# Motivation

## Why DLR Matters More Than Ever

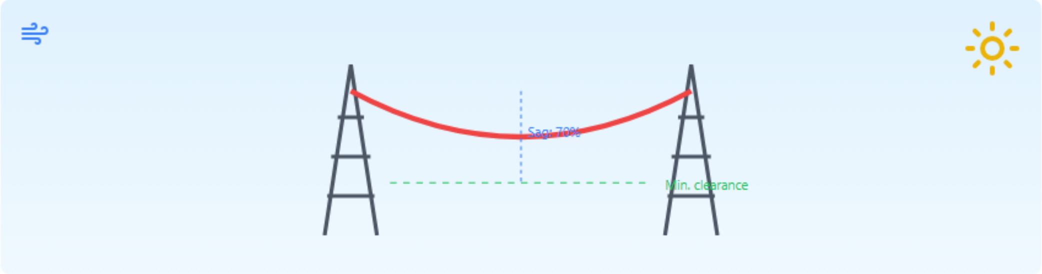
📍 **Hectometric Resolution** Modern meteorological forecast models at ~1 km and higher resolution and vertical high resolution enables nearly one grid point per transmission pylon — unlocking precise, location-specific DLR calculations.

🌡 **Impact of Climate Change** Rising temperatures and more frequent heat waves and possible changes in wind patterns, increase thermal stress on transmission lines already now, making weather-aware capacity management essential.

**Renewables distribution in Austria** High concentration of wind energy production in the east and storage capacities in the west require efficient grid capacity utilization to transport renewable electricity.

### Dynamic Line Rating (DLR)

Impact of temperature and wind on overhead transmission line capacity




Temperature: 32°C — 10°C … 45°C

Wind Speed: 0 m/s — 0 m/s … 12 m/s

| Static Rating | Dynamic Rating | Risk Assessment |
|---|---|---|
| 100% | 94% -6.3% | Elevated |

**Interpretation**

**Static Rating:** Based on conservative assumptions (high temperature, low wind). Protects the line but doesn't utilize full capacity.

**Dynamic Line Rating:** Uses real-time weather data for optimal line capacity utilization. Under favorable conditions (cool + windy), capacity can increase by 30-50%.

⚠ **Critical during heat waves:** High temperature + weak wind leads to: • Increased conductor resistance • Greater sag • Reduced transmission capacity (15-30% loss)

*Based on: IEEE Std 738-2023 & Karimi et al. (2018), Renewable and Sustainable Energy Reviews*

# Why Dynamic Line Rating?

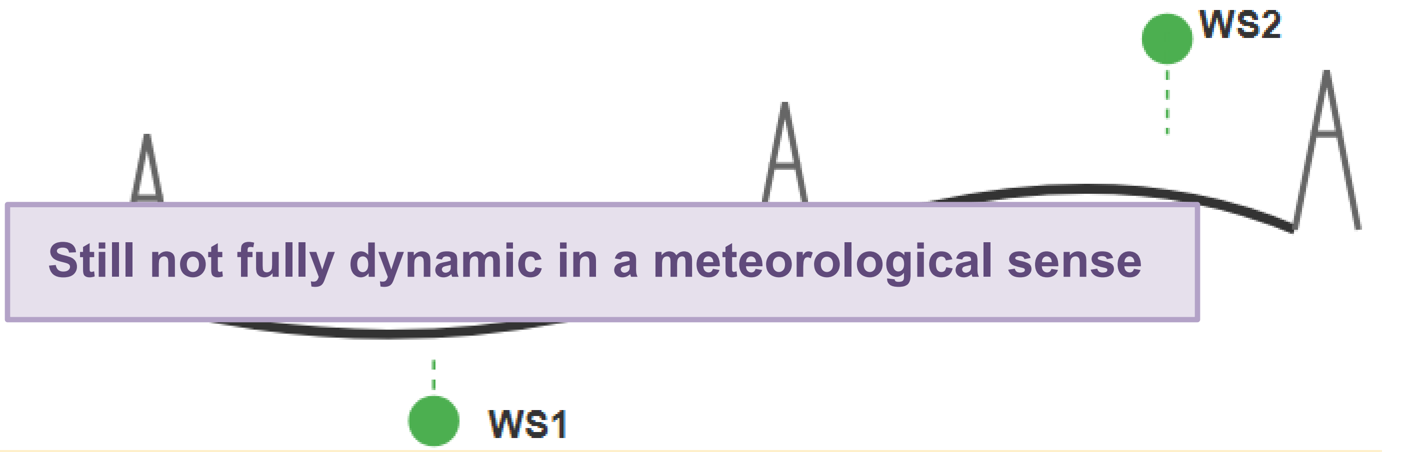
## Static Rating – T

**Conservative assum**

- Wind speed: 0.6 m/s
- High ambient tempe
- Clear sky radiation

**→ Underutilization o**

**→ Limits renewable**




**Still not fully dynamic in a meteorological sense**

**Fully dynamic 3: assigned weather station is representative for entire section/line**

, 15-min values wind speed and ambient temperature multiplied by reduction/increase factor

**Static with monthly values & of forecast values:**

Conservative,vconstant wind speed (0.6 m/s), clear sky radiation, monthly/foreacsted max temperature and clear sky conditions

## tion

y



Source: APG – Current WAFB (Weather-dependent Overhead Line Operation) hierarchy

# Conductor Heat Balance and Weather – a sensible relationship

*Wind speed cooling capacity dominates – but compound effects matter most*

| Parameter | Unfavourable | Favourable | Impact |
|---|---|---|---|
| **Wind speed** | < 2 m/s | > 5 m/s | **DOMINANT – convective cooling** |
| **Temperature** | > 30°C | < 20°C | Temperature gradient |
| **Solar radiation** | > 600 W/m² | < 400 W/m² | Direct heating |
| **Precipitation** | — | > 0.1 mm/h | Evaporative cooling (+20-50%) |

*Thresholds based on CIGRE Technical Brochures 207 and 601*

Single parameters can be compensated if not too extreme.

The **combination** of unfavourable conditions = critical.

Example: 25°C is OK with 6 m/s wind, but critical with 1 m/s wind.

**Can we detect such conditions ahead in time?**

**Can we predict DLR along the power line?**

**Can we predict ampacity with meteorological forecasts at heights above ground suitable for DLR?**

# From Detection to Hectometric: The Workflow

*Smart triggering reduces computational cost while maintaining coverage*

### ⚡ Computational Efficiency

Hectometric data is expensive:
- 1489×1489 grid points
- 15-minute temporal resolution
- Multiple vertical levels

**Smart triggering = run only when & where needed**

### 🌍 Full European Coverage

Continental screening ensures:
- No critical event missed
- Early warning (2-5 days)
- Multi-TSO coordination

**"Always watching" without running everything everywhere**

### 🎯 Actionable Intelligence

TSOs need specifics:
- Which segment is critical?
- What is the ampacity?
- When does it change?

**Hectometric resolution answers these questions**

# Why This Matters

# Multi-Scale NWP Integration

*From continental early warning to local high-resolution analysis*

## Continental

ECMWF IFS ENS

**~9 km, 51 members**

Early warning and uncertainty (2-5 days)

## Global DT (Optional)

DestinE Global

**~4.4 km**

European screening

## Regional (Optional)

AROME/ALARO

**1 - 2.5 km**

Mesoscale features

## Hectometric

DestinE Extremes

**~500 m**

Bottleneck resolution

# Compound Event Detection Algorithm

*Categorical scoring system inspired by IPCC likelihood scales*

| Score | Category | Definition | Operational Action |
|---|---|---|---|
| ≤ -2 | Very Unfavorable | Multiple critical thresholds exceeded | **Capacity reduction required** |
| -1 | Unfavorable | Single critical threshold exceeded | Exercise caution |
| 0 | Neutral | All parameters within normal range | Static rating applies |
| +1 | Favorable | Single favorable threshold met | Moderate capacity increase |
| ≥ +2 | Very Favorable | Multiple favorable conditions | **Significant capacity increase** |

**Processing Modes:**

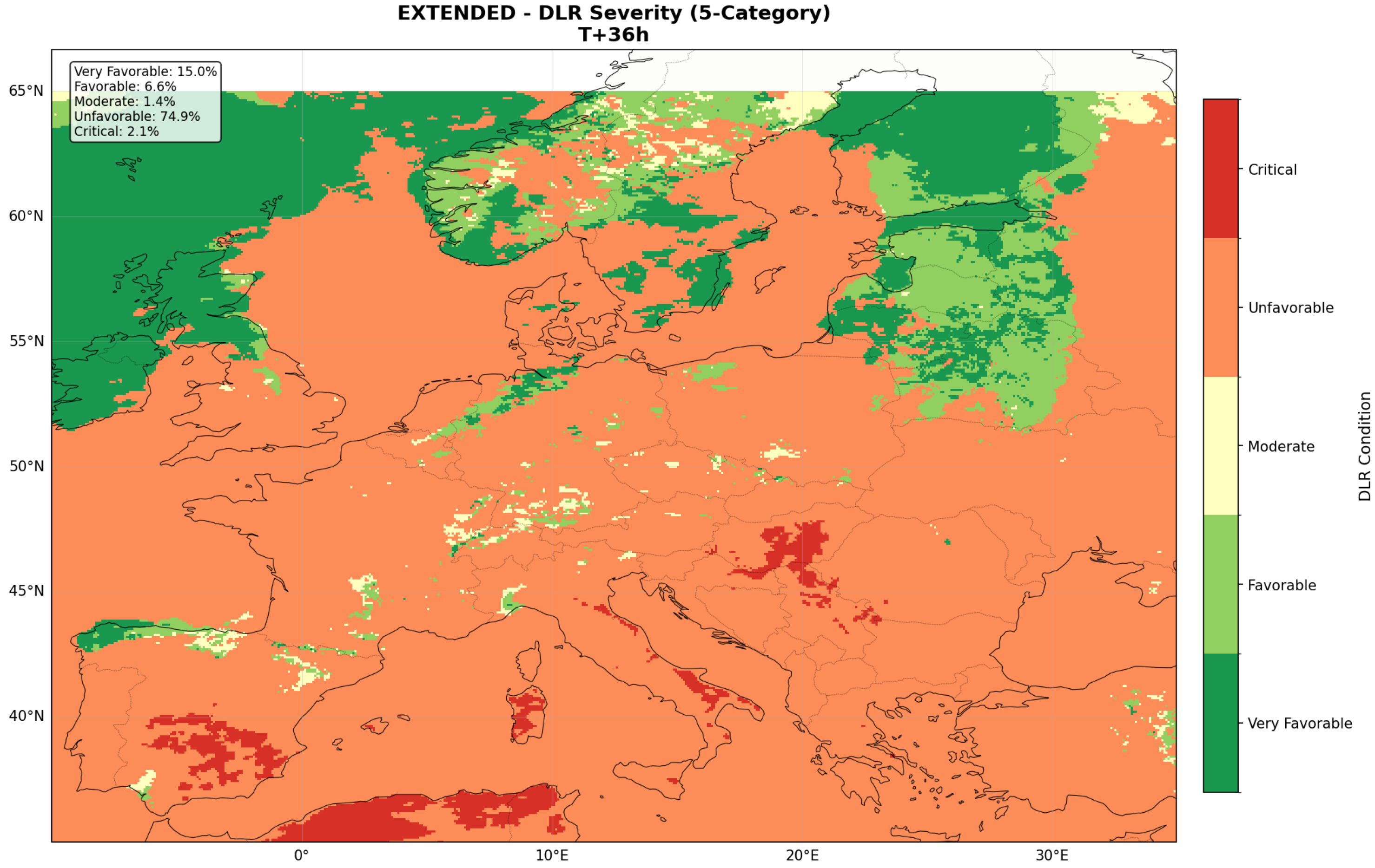
### Deterministic (AROME, ALARO)

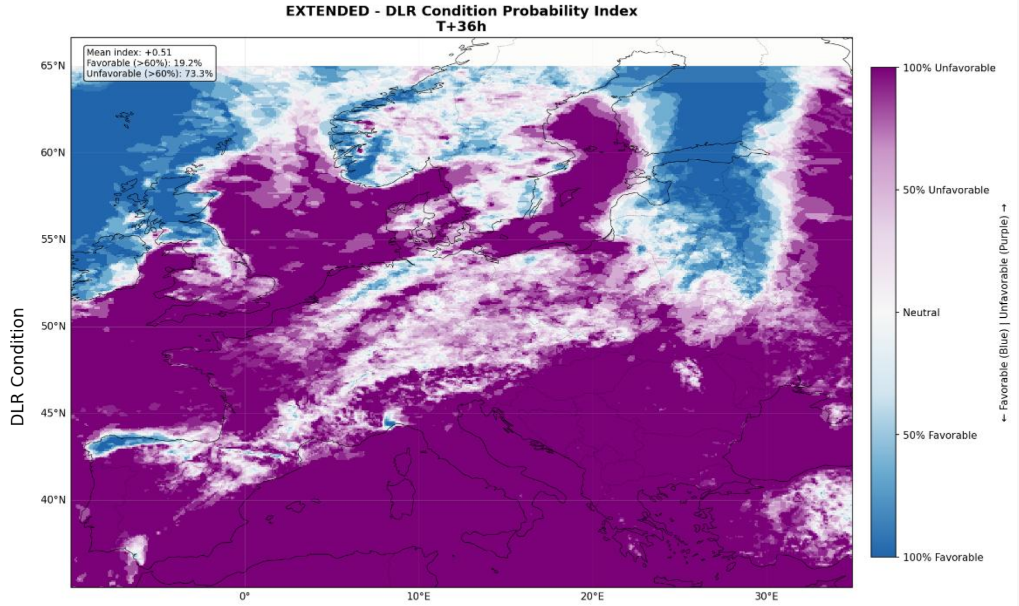
- Lateral sampling: ±1 grid points
- Creates "ensemble-like" spatial uncertainty
- Reduces sensitivity to single grid-point values

### Probabilistic (ECMWF ENS)

- K-means clustering (K=5-7 scenarios)
- Preserves forecast uncertainty
- Probability: P(ampacity > baseline) = $\Sigma_i w_i \times I(Imax,i > I_0)$

# Continental-Scale DLR Detection




*BASE index (Wind + Temperature) from ECMWF IFS at T+0h*

# Thermal Model Implementation

*CIGRE & IEEE 738 for quantitative ampacity calculation*

## CIGRE TB 207/601

European standard – typically more optimistic

## IEEE 738-2012

American standard – more conservative

**CIGRE Heat Balance: $I^2R(Tc)$ + qsolar = qconvective + qradiative**

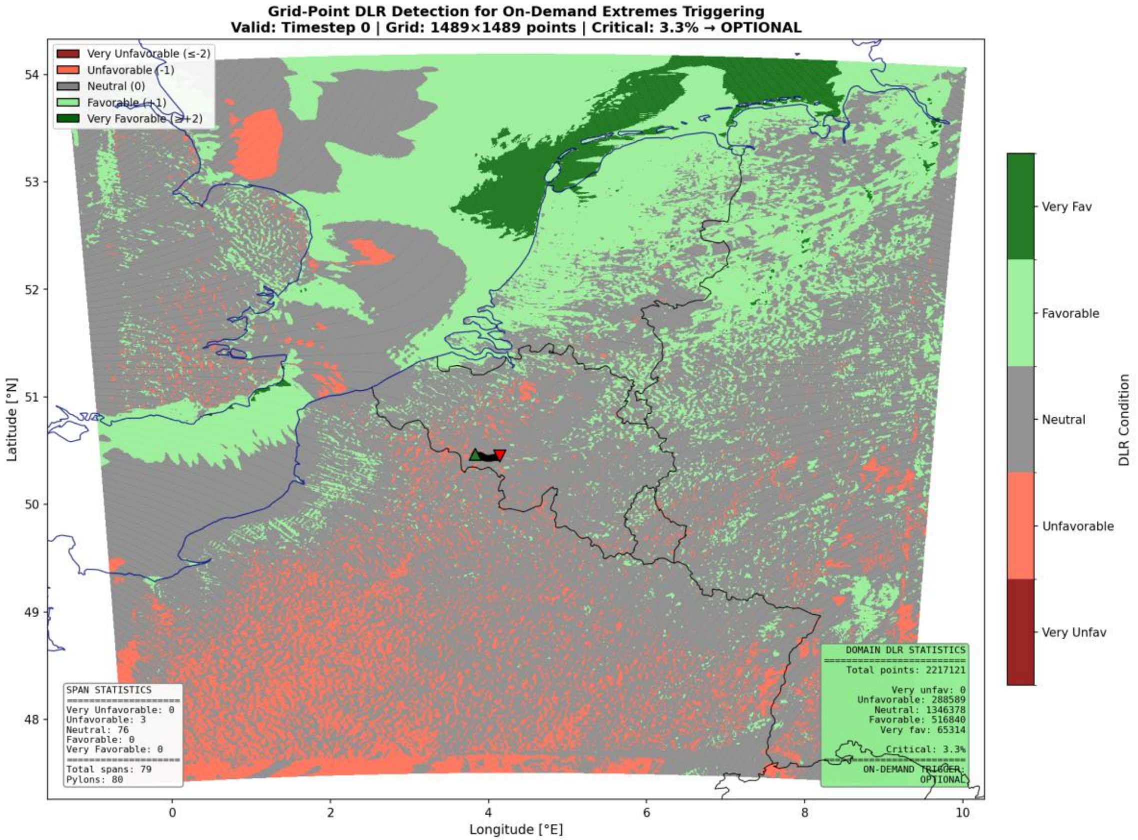
| Line | Conductor | Diameter | Baseline | Max Temp |
|---|---|---|---|---|
| APG 220 kV (Tyrol) | ACSR Drake | 28.1 mm | 1200 A | 80°C |
| E-Netze Steiermark 110 kV | ACSR 240/40 | 21.8 mm | 600 A | 80°C |
| Elia 150 kV (Belgium) | Generic ACSR | 25.0 mm | 800 A | 80°C |

**Implementation Features:**

- **Temperature-dependent resistance:** $R(T) = R_{20}[1 + \alpha(T-20)]$
- **Forced convection:** Nu = f(Re) with wind angle correction
- **Air density correction:** ~10% per 1000m elevation
- **Iterative solution:** Convergence tolerance 0.1°C

# Spatial Bottleneck Identification

*The weakest link determines corridor capacity*




*Grid-point DLR detection (1489×1489 points) with transmission line overlay*

## Hectometric Resolution Enables:

- 79 individual pylon-to-pylon spans
- Meteorological gradients resolved
- Temperature: 12°C gradient along 25 km!

**Line vs Domain comparison:**

- Line: 89% favorable spans
- Domain average: 40% favorable

## Operational Value:

→ Identify exactly where to install weather stations

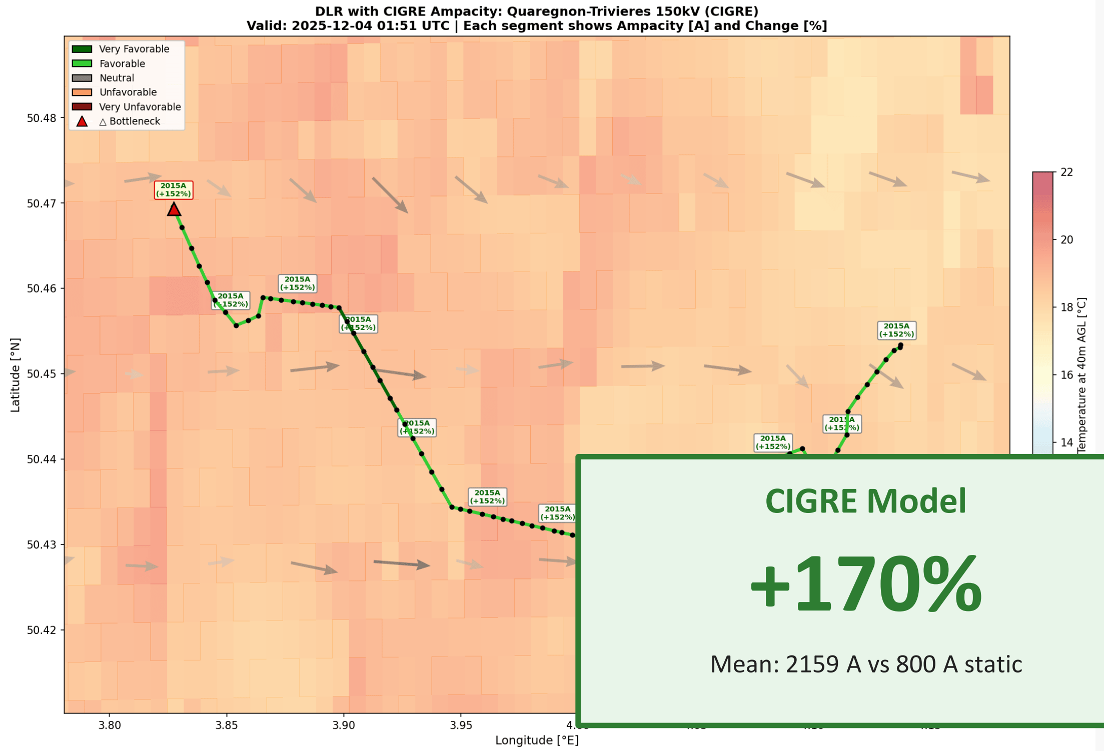
→ Target monitoring at critical segments only

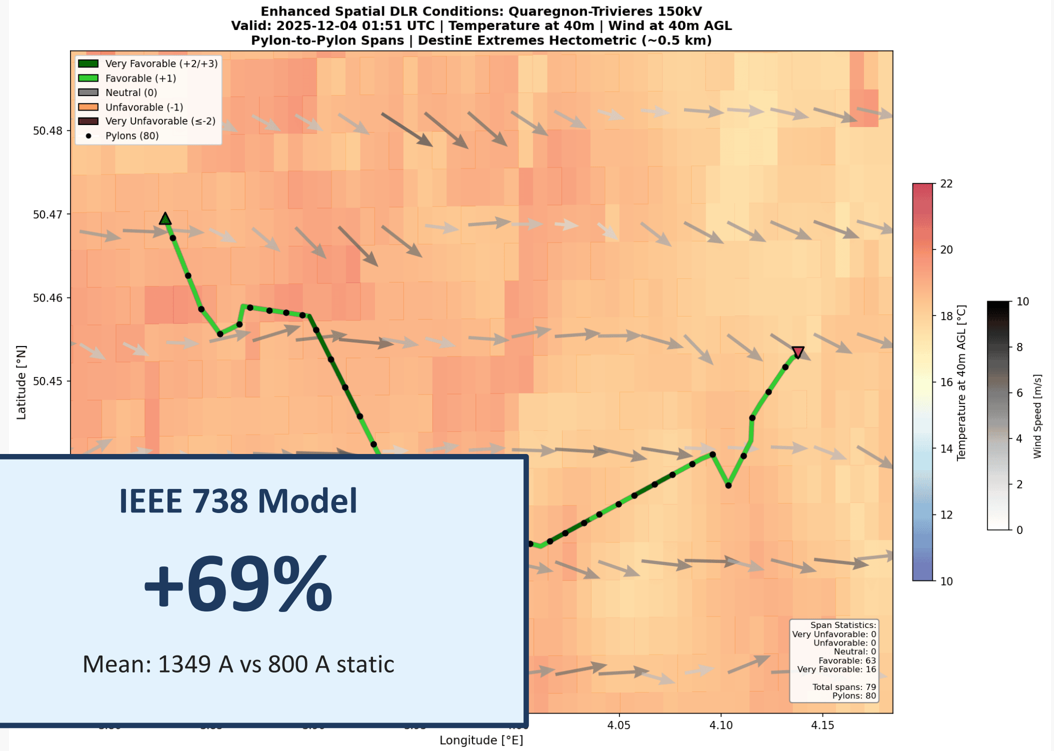
→ Inform infrastructure investment decisions with spatial precision

# Belgian Case Study: Elia Quaregnon-Trivieres 150 kV

**Conditions:** T: 10-22°C | Wind: 4-6 m/s | DLR Score: +2 to +3

**DestinE Extremes:** ~500 m resolution | 25 km corridor | 79 spans | 48h forecast




**CIGRE Model**

**+170%**

Mean: 2159 A vs 800 A static

**IEEE 738 Model**

**+69%**

Mean: 1349 A vs 800 A static

*Left: CIGRE ampacity per segment [A] | Right: Spatial DLR conditions with wind vectors*

# HIRENEXT VS STANDARD MODEL

*AMPACITY KPIS: OPTIMIZED FOR HIRENEXT*

**01** Comparison of ampacity

Same algorithm with the same derating factors for Hirenext & standard model.

**02** Derating factors optimized for Hirenext

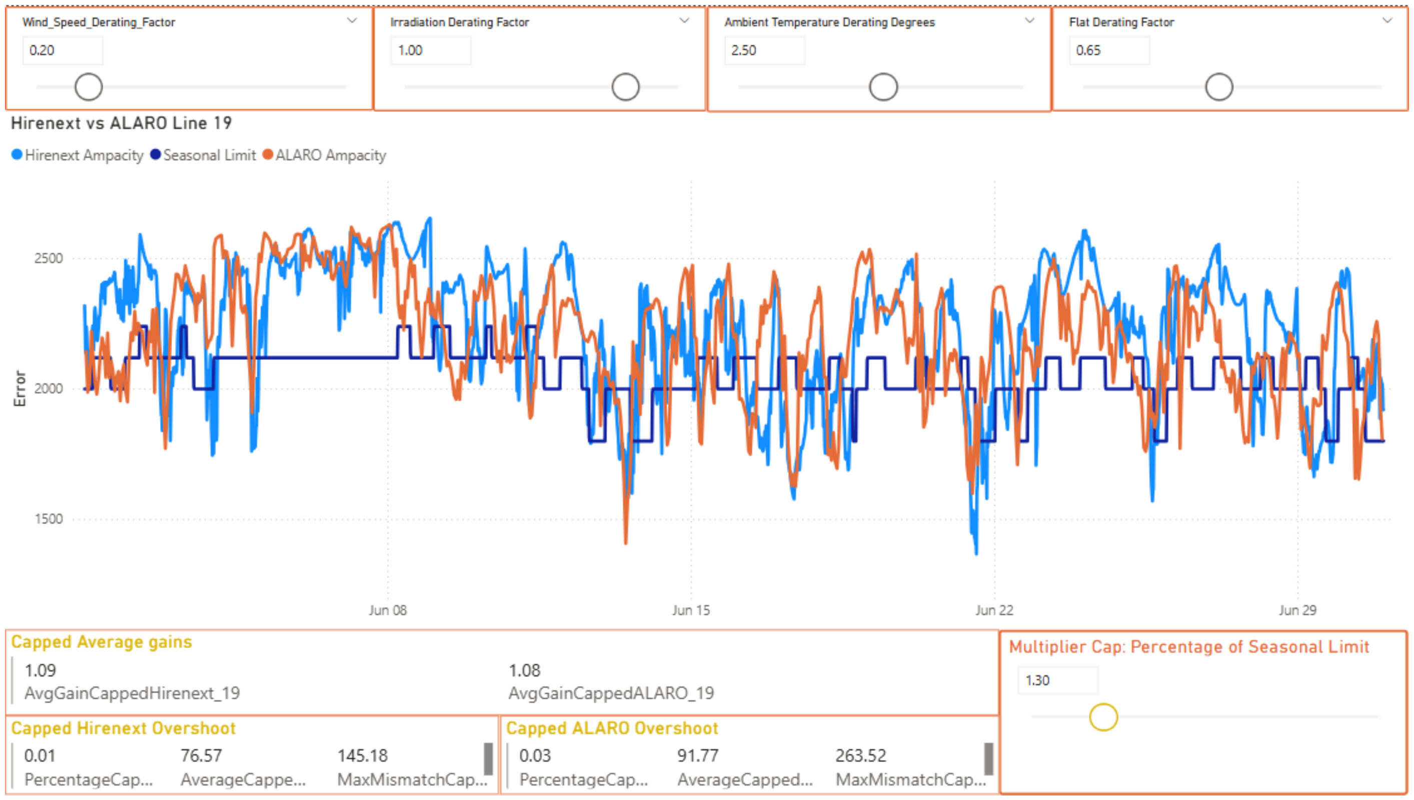
Ensure Hirenext to be P99 safe while maximizing gain.

**03** Hirenext consistently outperforming

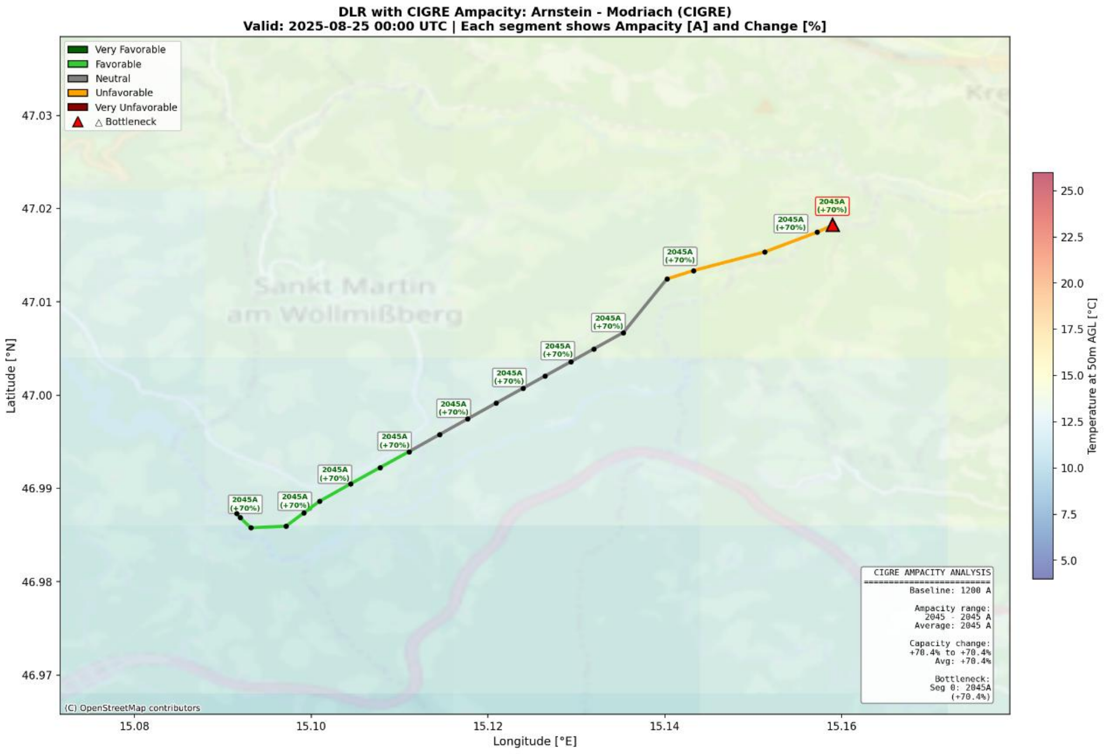
Gain on average 2/3% higher than standard model while staying P99.

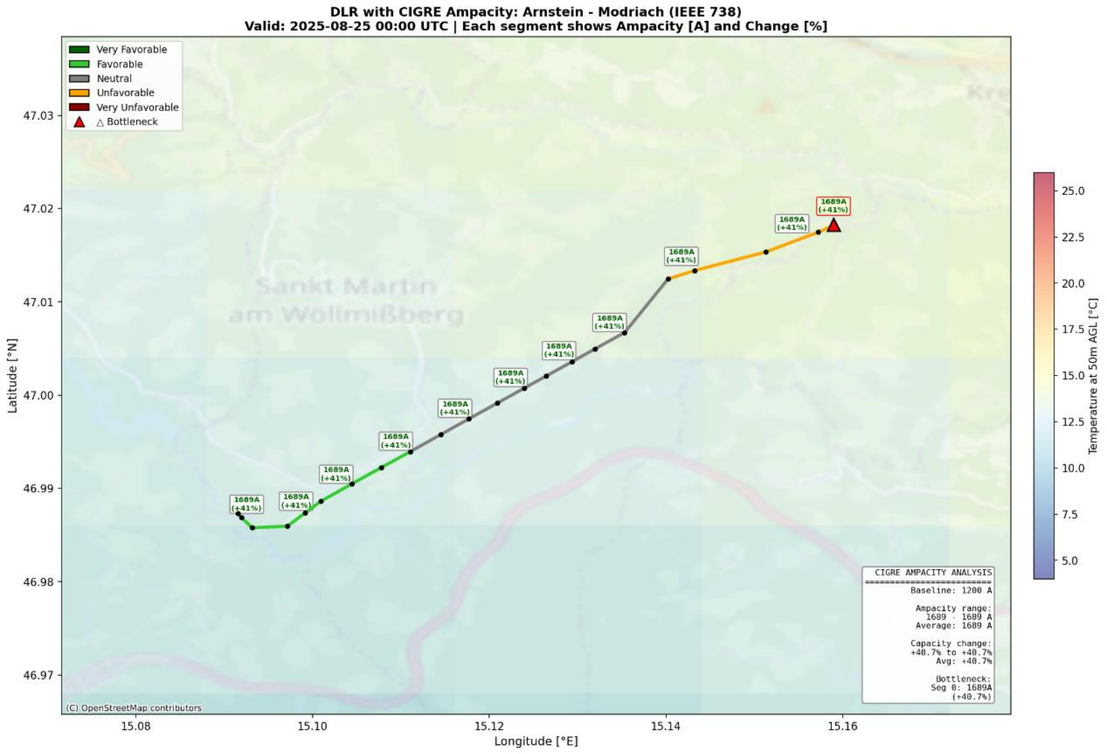
**04** Average gain of 10%

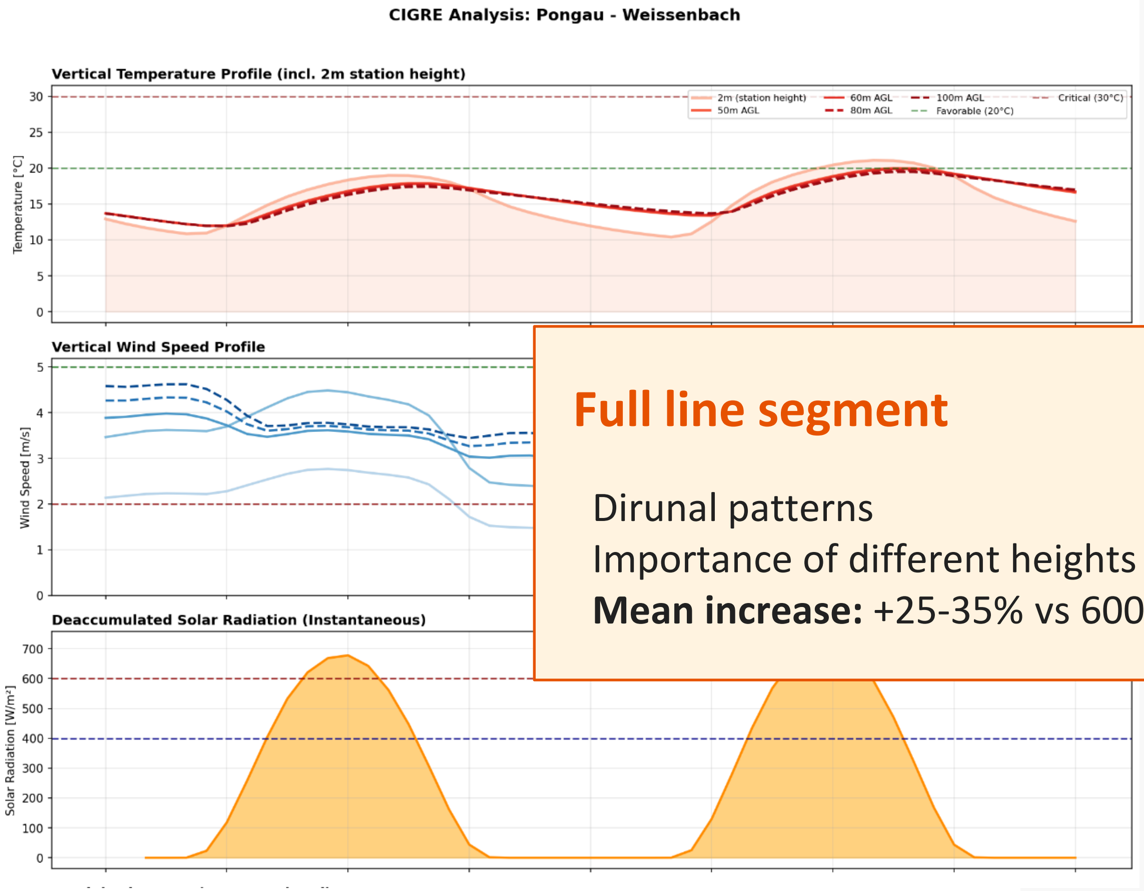
Compared to current operational (seasonal) limits, a gain of 10% would be achieved.

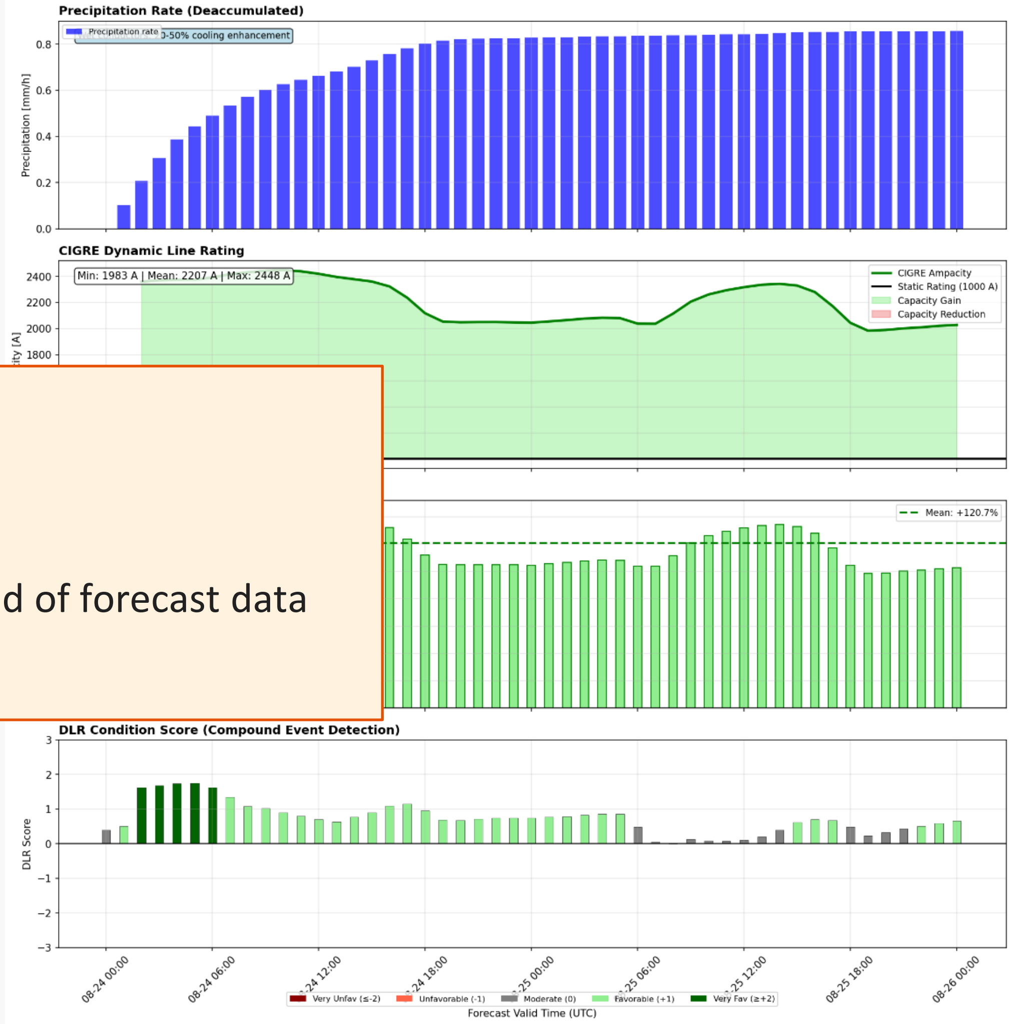


# Austrian Case Study: 110 kV line





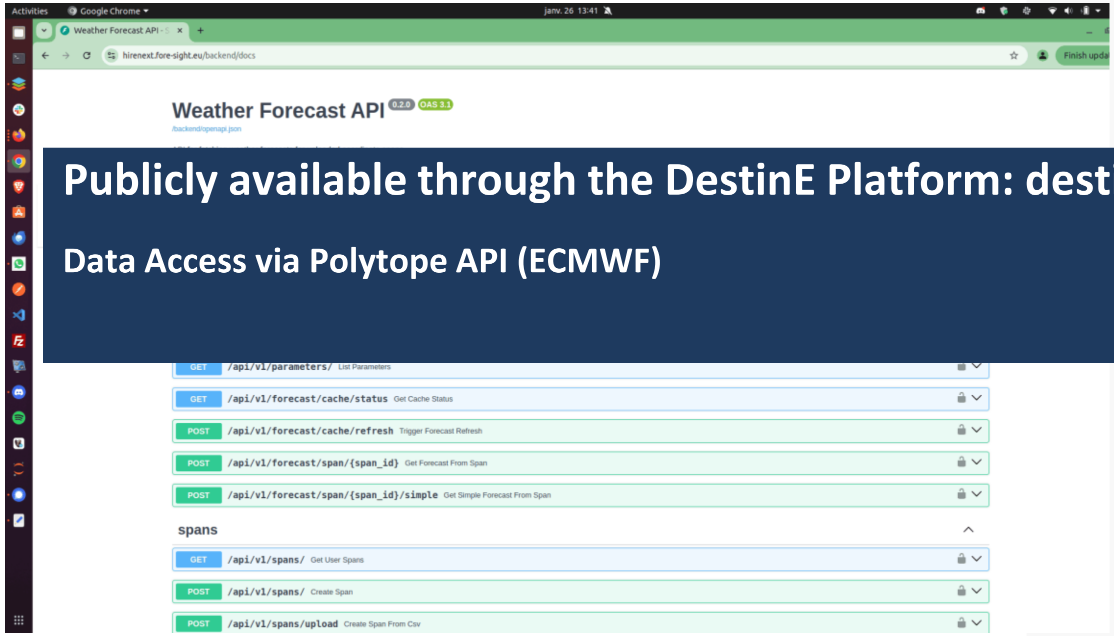




## Full line segment

Dirunal patterns
Importance of different heights above ground of forecast data
**Mean increase:** +25-35% vs 600 A static

# Web API & Service Access

*Accessible through the DestinE Platform*




**Publicly available through the DestinE Platform: destination-earth.eu**

**Data Access via Polytope API (ECMWF)**

- **Spatial subsetting:** Extract along transmission line geometry
- **Vertical profiles:** Multi-level extraction (2m, 10m, 50m, 60m, 80m, 100m AGL)
- **Temporal windowing:** 0-48h for day-ahead TSO planning

3. Spatial analysis – Per-segment conditions
4. Quantitative output – Ampacity in Amperes

# Conclusions & Outlook

## Key Achievements

✓ Multi-scale NWP integration

(9 km → 500 m)

✓ Compound event detection

✓ 48-hour forecasts

for day-ahead planning

## Future Development

→ Probabilistic forecasting with ensemble NWP models

→ ML enhancement of detection algorithms

→ Extension to additional European TSOs and DSOs

### Take-Home Message

Combining DestinE high-resolution forecasts with thermal models enables spatially-resolved DLR forecasting – identifying exactly where and when transmission capacity can be safely increased.

**Thank you! – Questions?**