LEVERAGING GENERATIVE MODELS FOR ASI-BASED SOLAR NOWCASTING

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Agenda

- Motivation for Solar Nowcasting
- Generative Nowcasting Approach
- Qualitative Analysis of Generative Model
- Quantitative Evaluation
- Conclusion & Outlook

MOTIVATION FOR SOLAR NOWCASTING

Motivation

What is solar nowcasting?

- Forecast of solar irradiance (e.g. GHI) for the next minutes

What are ramp events and what are their effects?

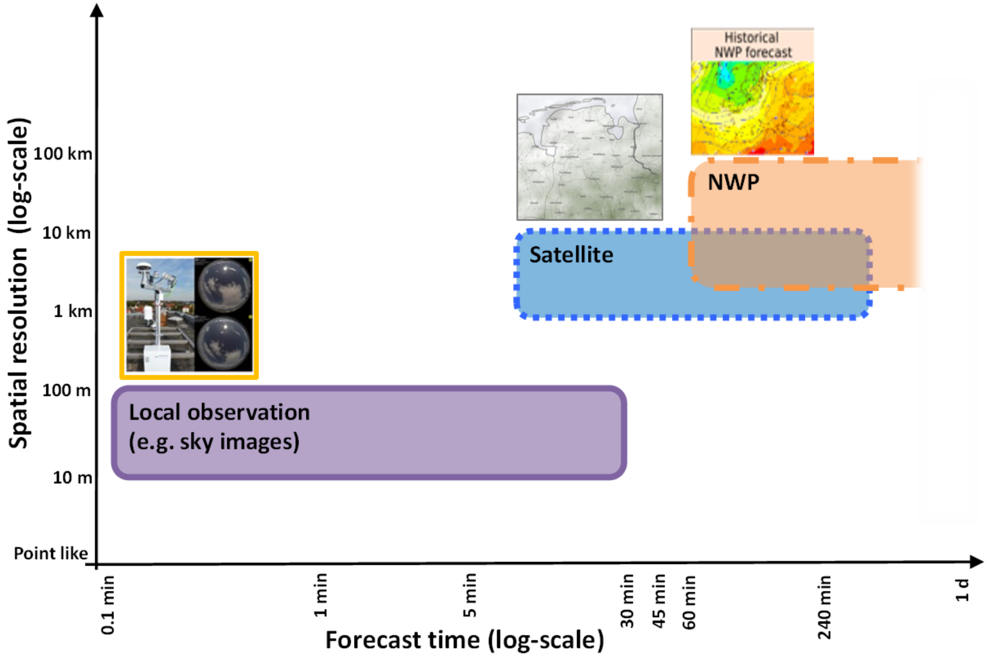
- Sudden local changes in irradiance due to cloud passings
  → Local fluctuations of generated power
  → Represents challenge for integration of solar energy

What are the benefits of nowcasting?

- Anticipate ramp events, leading to:
  - Increased awareness for plant/grid operator
  - Minimization of storage requirements

What are the requirements?

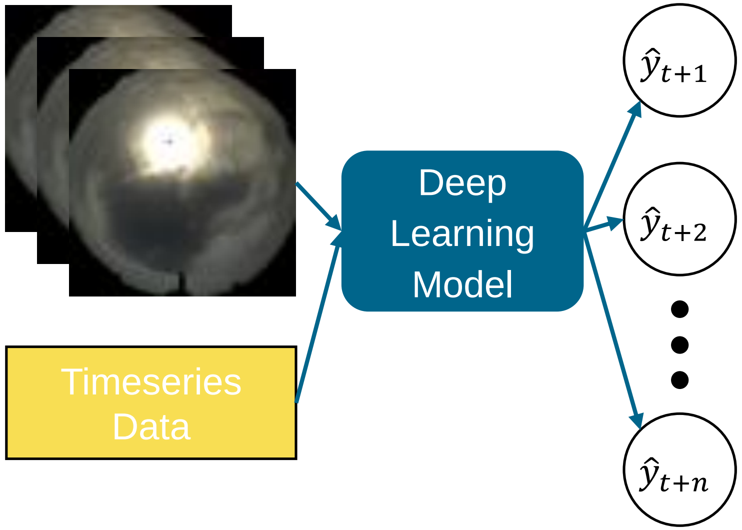
- Cloud information in spatially and temporally high resolutions
  → All-Sky-Imagers
- Model chaotic cloud dynamics → Data-driven models



GENERATIVE NOWCASTING APPROACH

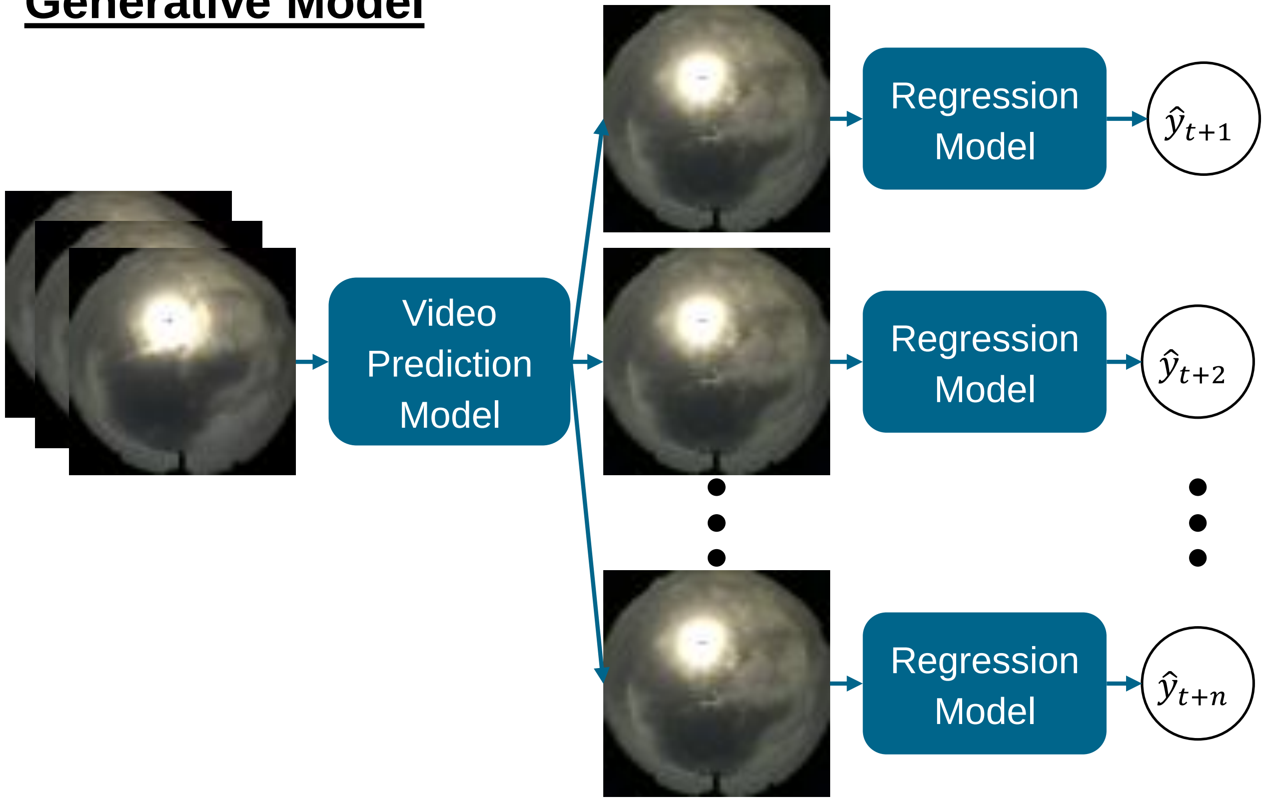
Data-driven Solar Nowcasting
State-of-the-art vs Generative Models

State-of-the-art



- DL model generates forecast directly from input (sky images and/or time series data)
- Optimized on RMSE of irradiance

Generative Model



- 2-step approach:
  - VP model predicts next frames
  - Regression model computes corresponding irradiance
- Independent optimization of VP and regression model

Data-driven Solar Nowcasting
State-of-the-art vs Generative Model

State-of-the-art

- High errors are reduced due to RMSE optimization
  → good approximations of expected energy yield
- **But**: Smoothening of forecast curve
  → short-term fluctuations are not well represented
- Black-box model
  → forecasts cannot be interpreted so easily

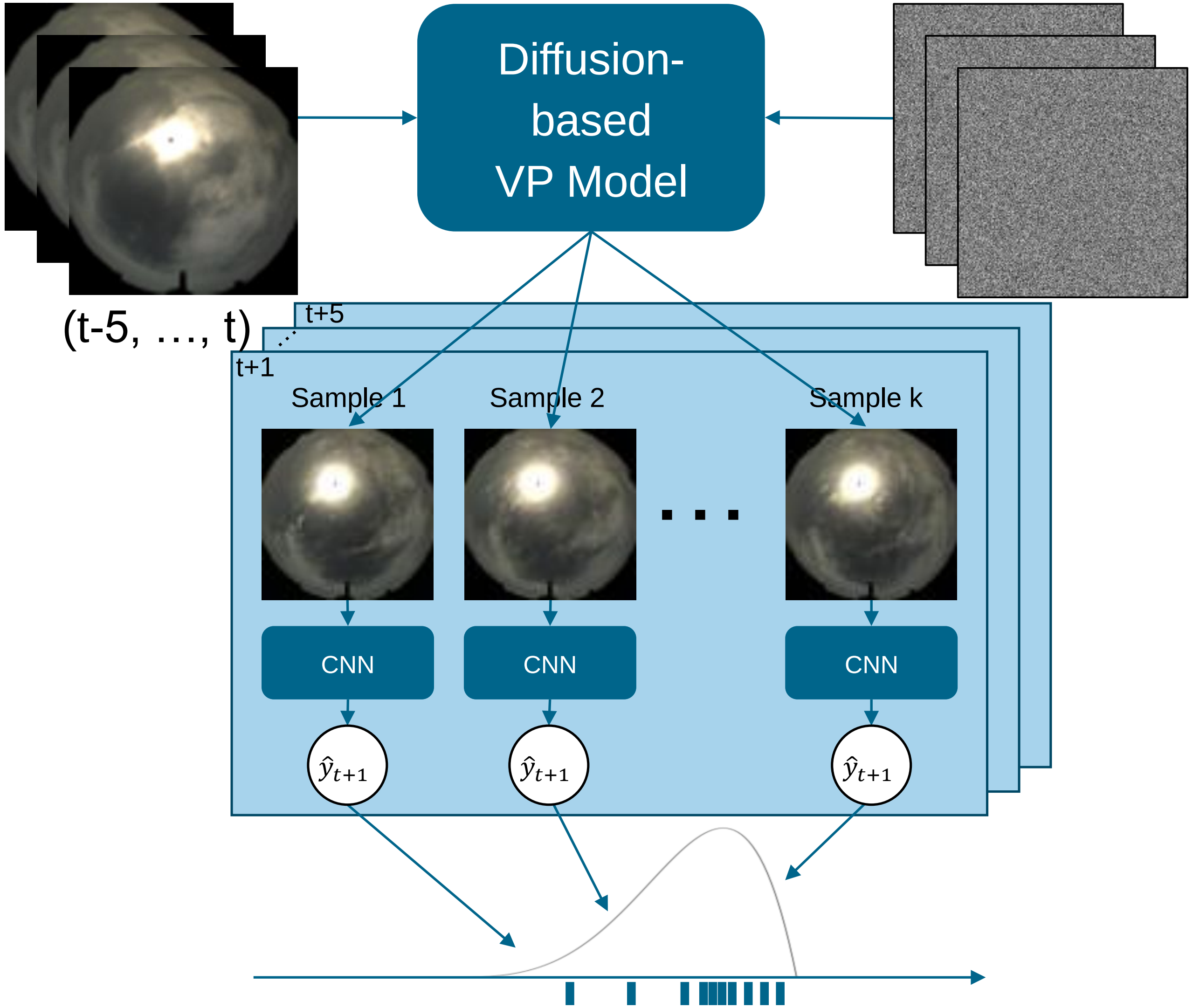
Generative Model

- Cloud motion is modelled implicitly by video prediction model
  → Increased interpretability due to addtional intermediate results
  → Fluctuations are better represented
- Video prediction models can create multiple „future scenarios“
  → Uncertainty estimation

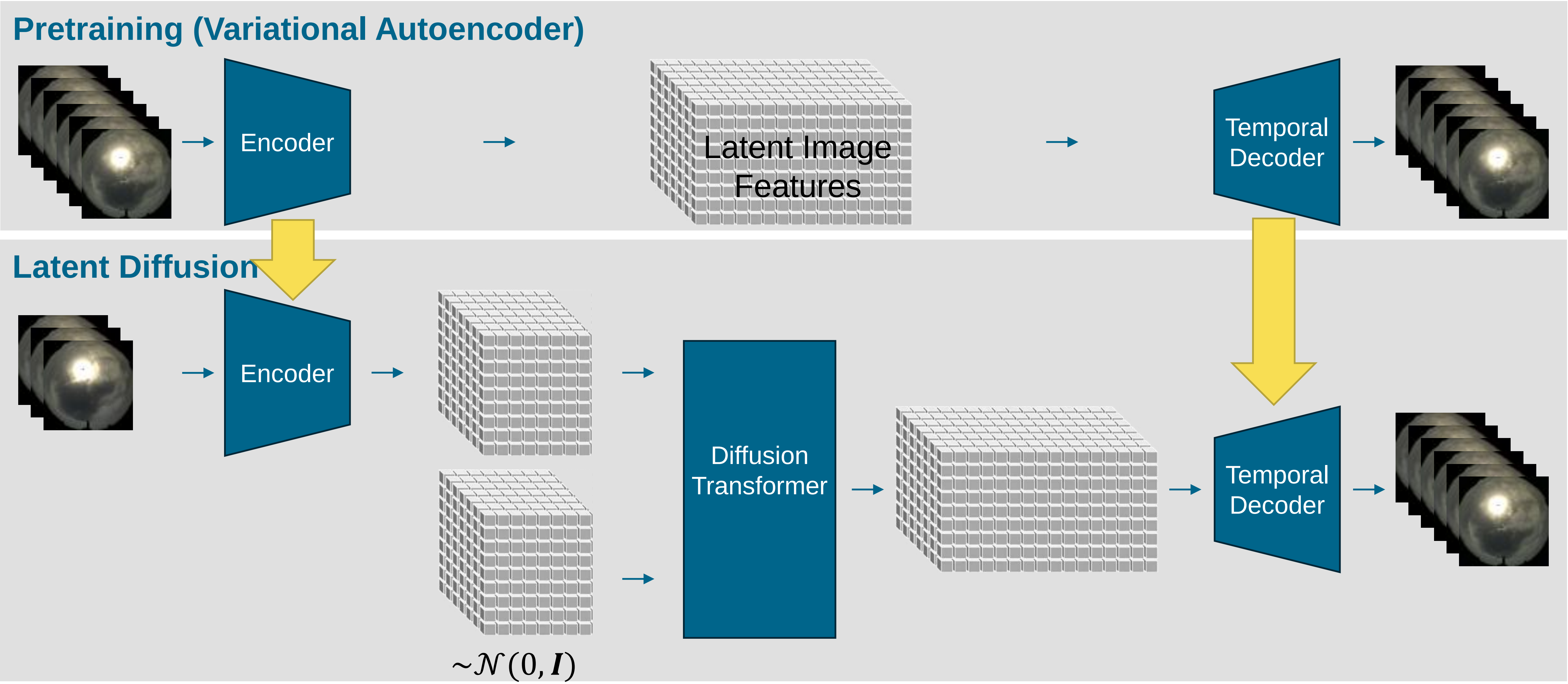
Generative Nowcasting
Model Architecture

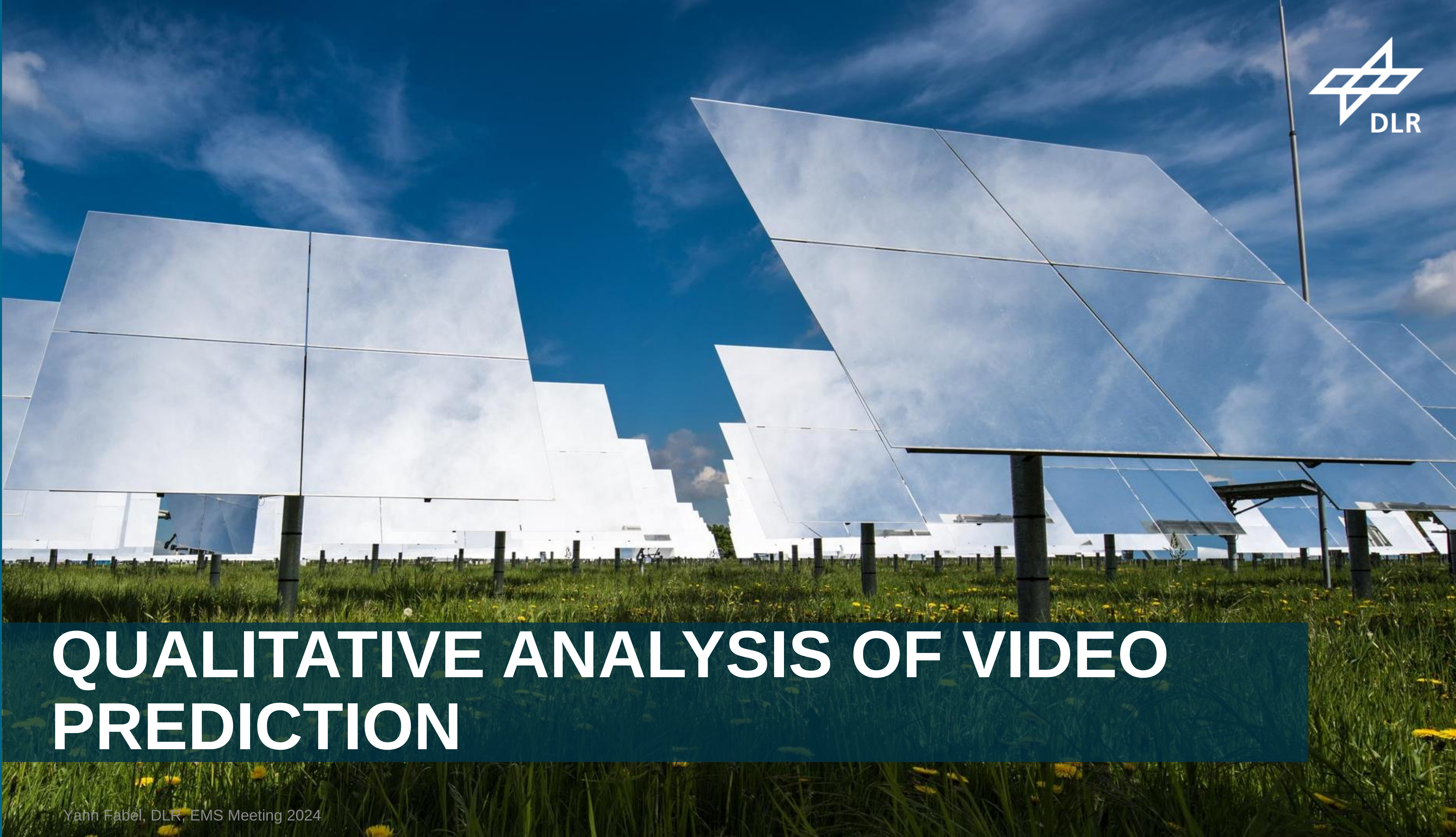
- **VP-Model**:
  - Architecture: Diffusion-transformer [1,2]
  - Input: sky images of past 5min
  - Output: next 5min sky images
  - Image Size: 128x128

- **Regression Model:**
  - CNN (ResNet34 architecture [3])
  - Input: Single sky image
  - Output: GHI (clear-sky-index)
  - Trained on real sky images



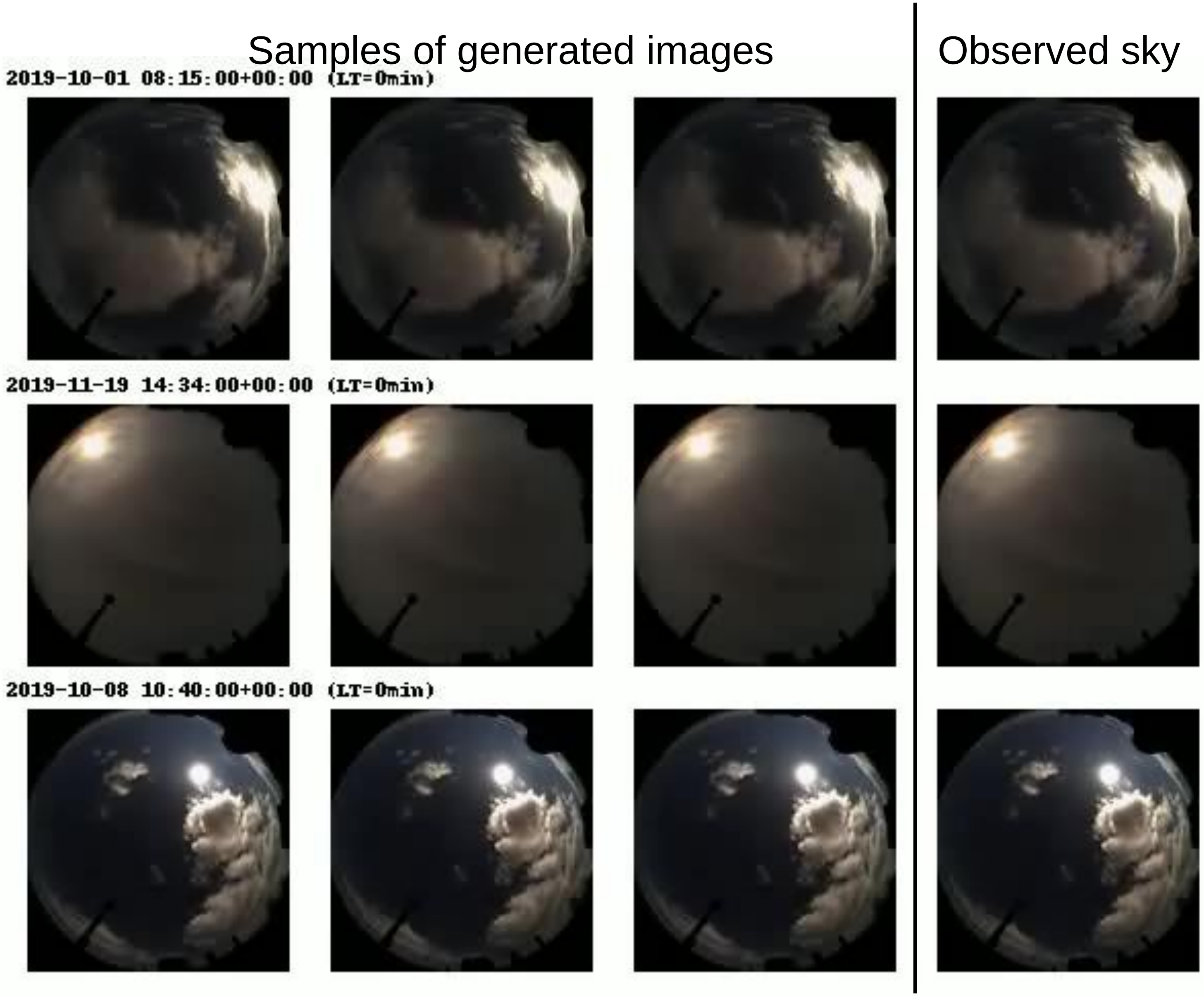
Generative Nowcasting
Diffusion-based Video Prediction





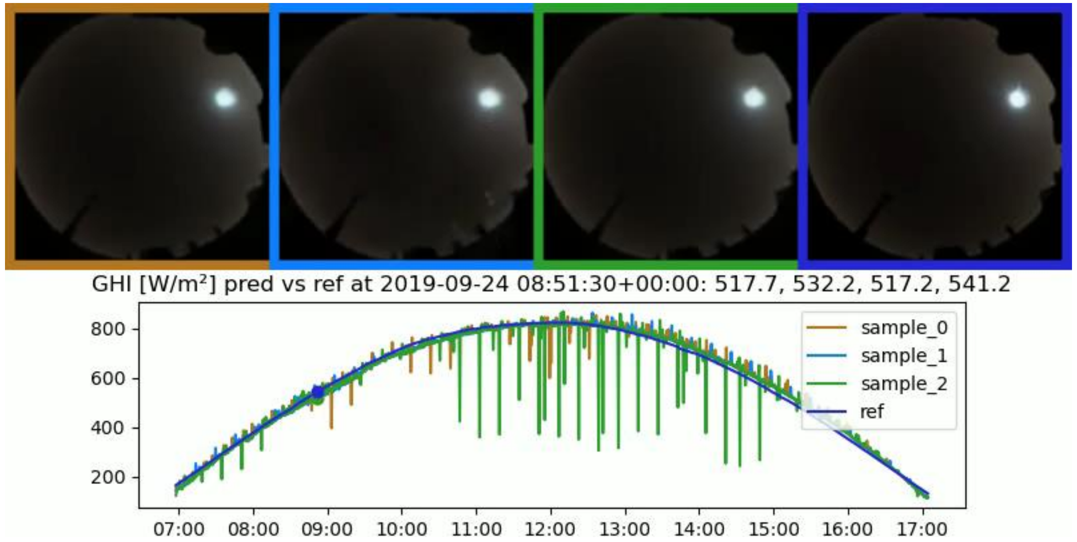
QUALITATIVE ANALYSIS OF VIDEO PREDICTION

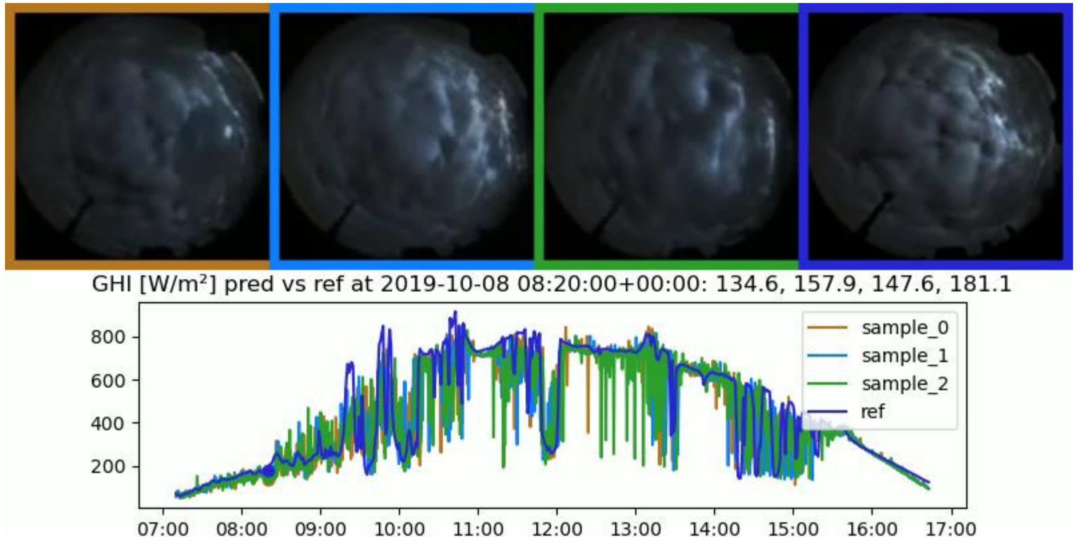
Qualitative Analysis of Video Prediction



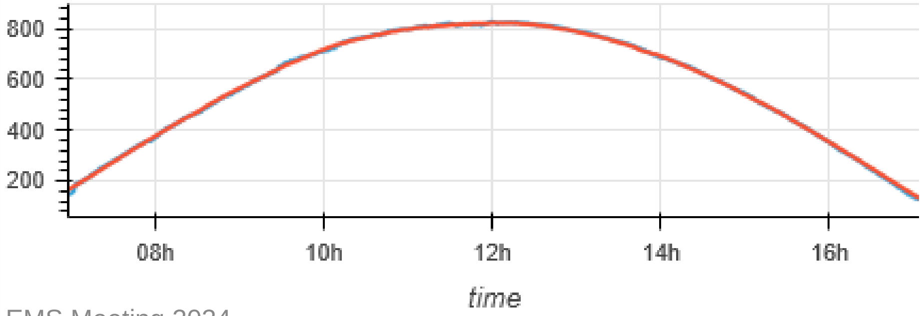
Qualitative Analysis of Video Prediction
Nowcasts

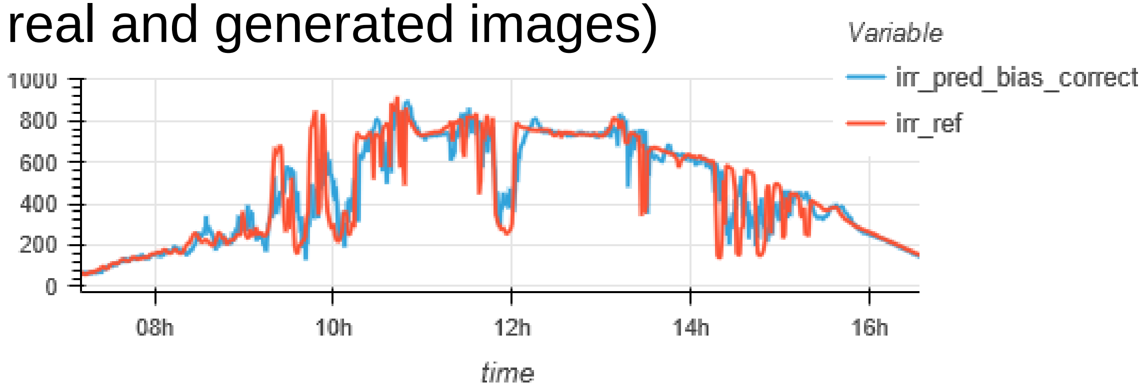
Forecasts for Clear Sky and Cloudy Examples for **LT 5min**





- Artifacts in generated images lead to outliers in irradiance predictions
  → Deterministic forecast by median of all samples
- Additional bias correction (reality gap between real and generated images)





QUANTITATIVE EVALUATION

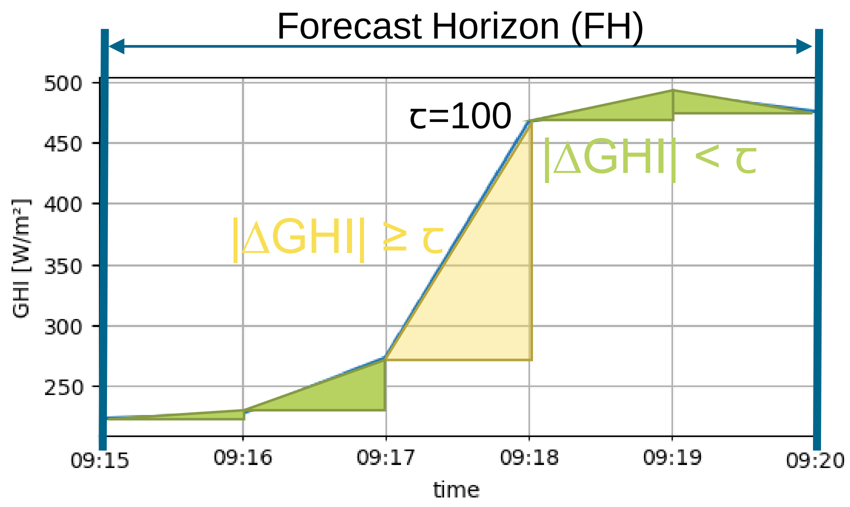
Quantitative Evaluation

Evaluation of Deterministic Forecasts

- **Dataset:**
  - 28 manually selected days of previous benchmark study of 2019 [4]
- **Comparison to state-of-the-art:**
  - DL model based on vision and timeseries transformer [5]
- **Forecasting Metrics**:
  - RMSE, MAE, MBE
- **Ramp Event Validation**:
  - Ramp Event Definition:

$$\frac{|\Delta GHI|}{\Delta t} > \tau \Longrightarrow Ramp$$

$$t\colon\ if\ \exists\ Ramp\ in\ FH \Longrightarrow Ramp\ Event$$

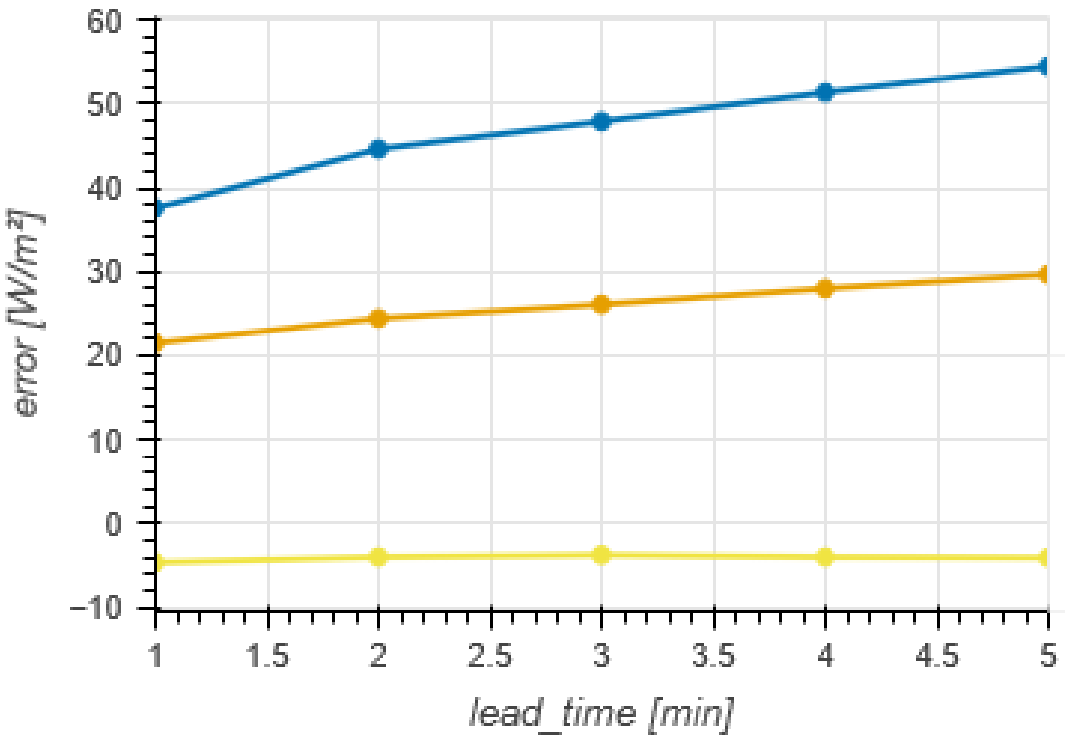


  - Evaluation by confusion matrices and f1-score:

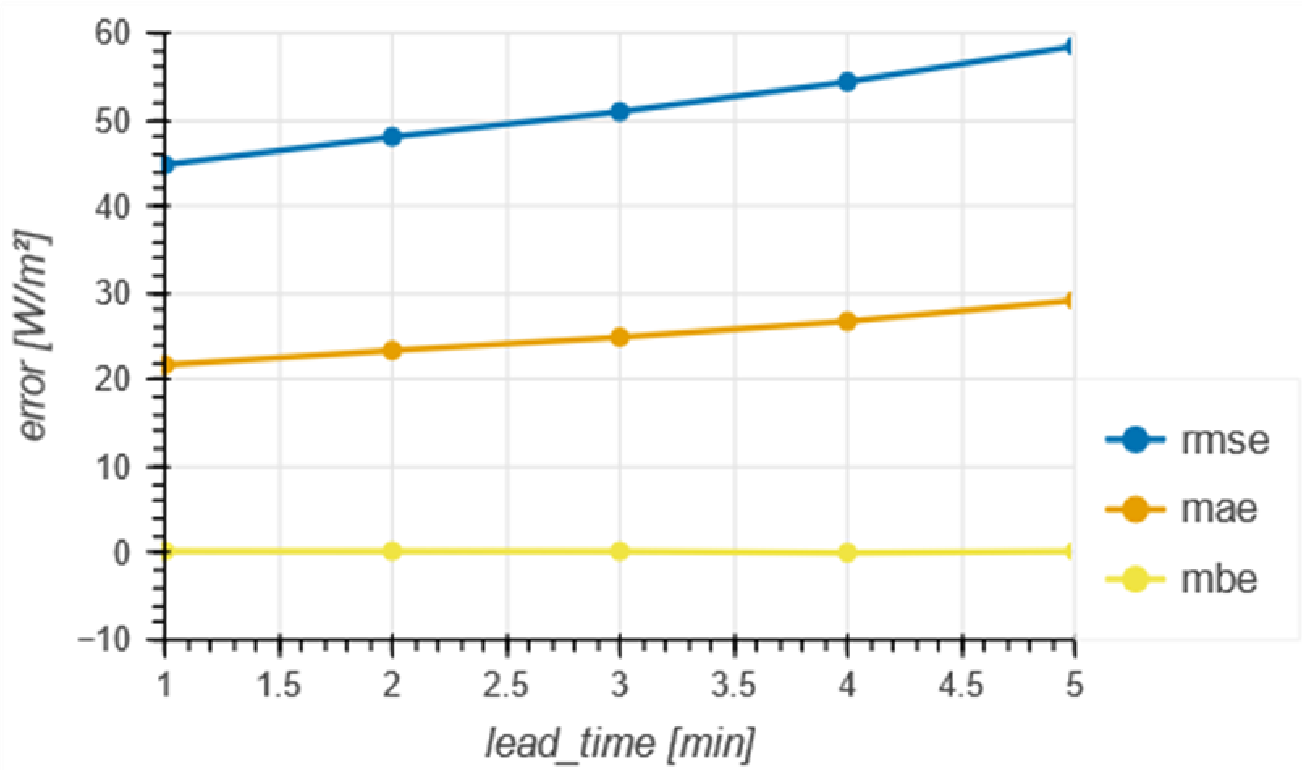
$$F1 = 2 \times \frac{precision\ \times recall}{precision + recall} \qquad precision = \frac{TP}{TP + FP} \qquad recall = \frac{TP}{TP + FN}$$

Quantitative Evaluation
Deterministic Forecasting Metrics

State-of-the-art Model



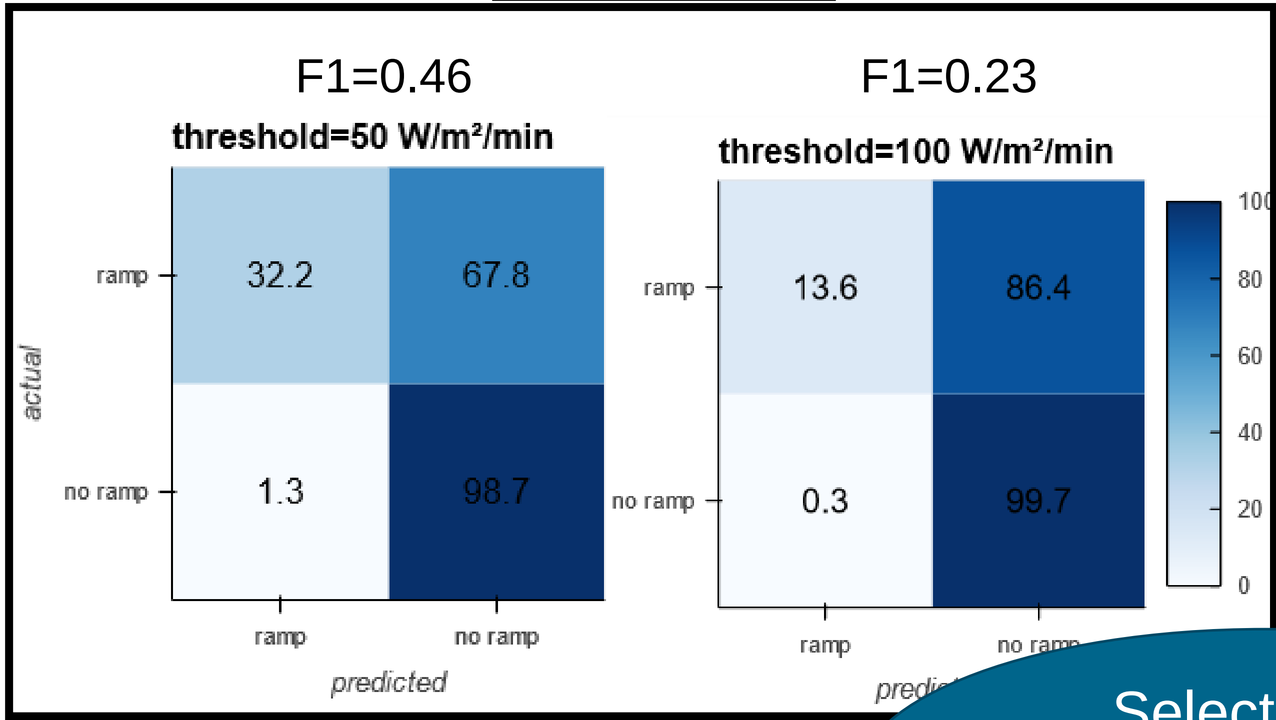
Generative Model



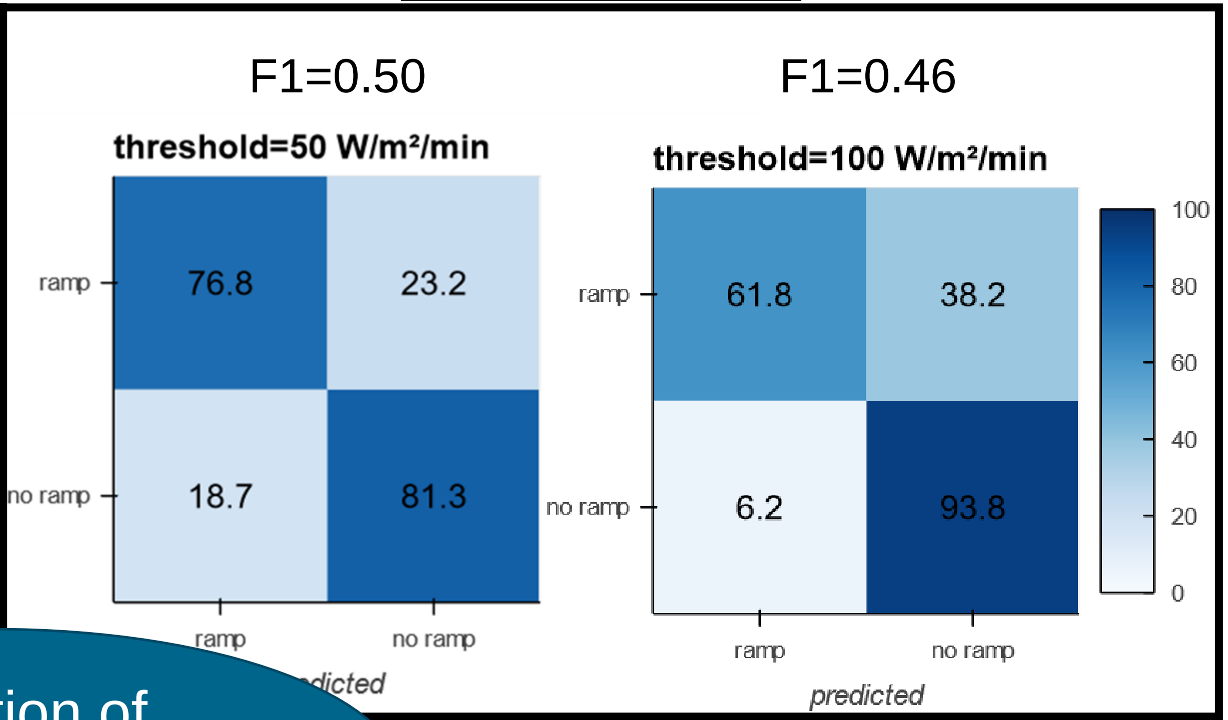
- SOTA still slightly better in RMSE
- MAE almost identical
- No bias for generative model

Quantitative Evaluation
Ramp Event Detection

State-of-the-art



Generative Model



Selection of threshold depends on application [6]

- The SOTA DL models detect le… observed ramps
- Strong decrease in F1-Score for higher thresholds

- …ive model predicts majority of … events while maintaining high …%) of no-ramp events
- Only slight decrease in F1-Score for higher thresholds

CONCLUSION & OUTLOOK

Conclusion

- **Summary:**
  - **Quality of solar nowcasting models depends on use case**
    - State-of-the-art models often achieve good error scores but may not be well-suited for ramp event detection (optimization on RMSE)
  - **Presentation of diffusion-based generative model for solar nowcasting**
    - Diffusion transformer for predicting future synthetic sky images
    - CNN regression model for predicting irradiance (GHI)
  - **Validation of nowcasts based on standard metrics and ramp events**
    - SOTA and generative model achieve similar results on standard metrics
    - Generative model superior in ramp event detection
- **Outlook**:
  - Improve video prediction model by training on larger, more versatile dataset
  - Combined optimization of both models (video prediction & irradiance model)

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6. Bijan Nouri, Yann Fabel, Niklas Blum, Luis F. Zarzalejo, Andreas, Kazantzidis, Stefan Wilbert (EUPVSEC 2024)
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THANK YOU FOR YOUR ATTENTION!
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