NEURAL INFORMATION PROCESSING SYSTEMS

Australian National University

Short-term Solar Irradiance Forecasting from Sky Images

 

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Tackling Climate Change with Machine Learning

Background

- Global warming have become critical issue.

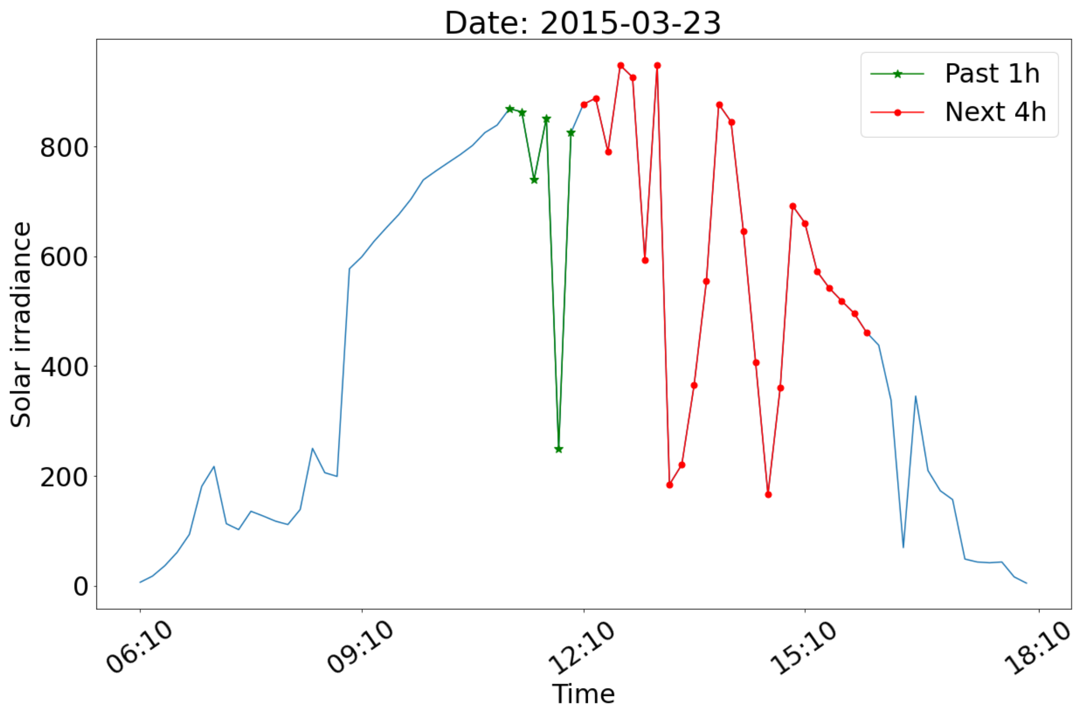
Copied from website https://www.gettyimages.com.au/detail/photo/polar-bear-repulse-bay-nunavut-canada-royalty-free-image/599854185?utm_medium=organic&utm_source=google&utm_campaign=iptcurl.

Producing solar power is not fully manageable due to the unstable environmental factors.

➔ Solar power forecasting helps the operation to be more stable.

Background

- Forecasting: forecast future solar irradiance using historical sky images and auxiliary data.
  - Deterministic intra-hourly predictions.
  - Future solar irradiance diverse over a relatively long-term (> 1 hour).



Example of forecasting: Use data in the past 1 hour to predict solar irradiance for the next 4 hours

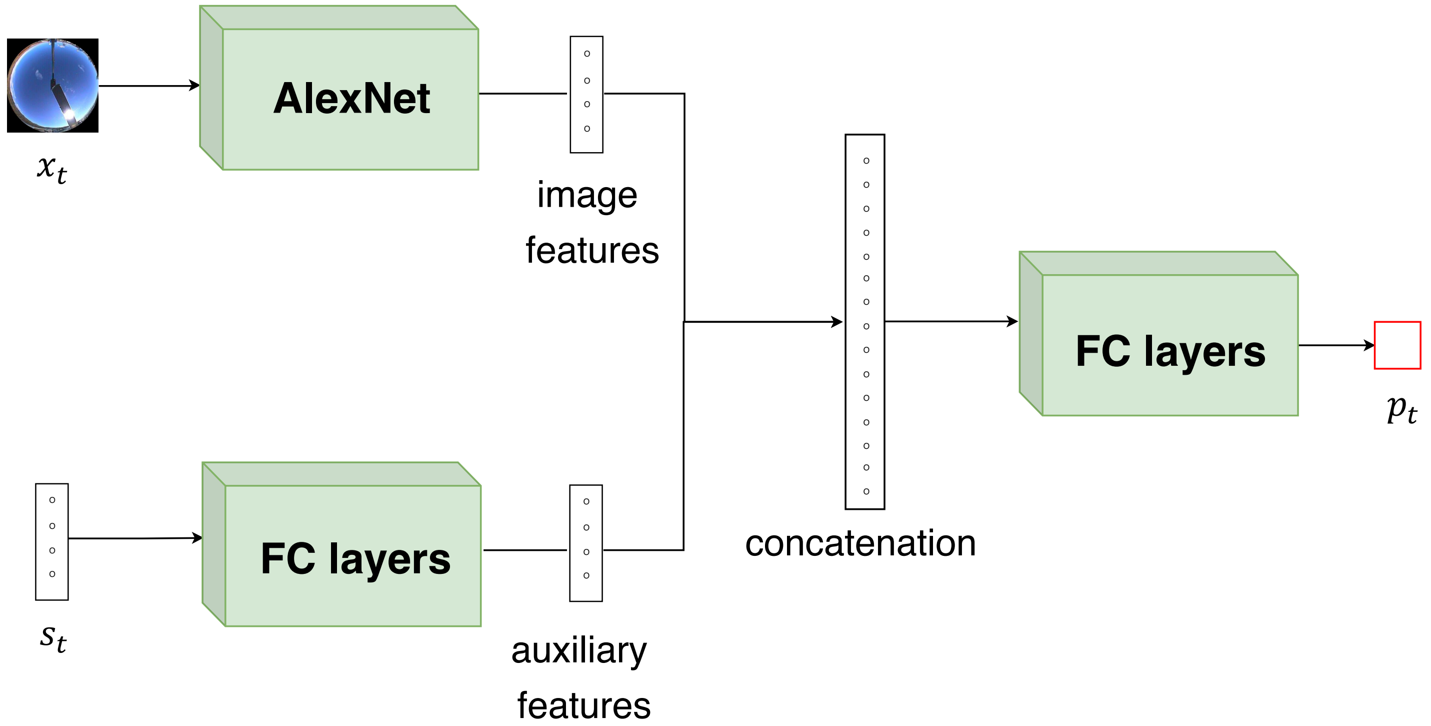
Methodology

- We propose two models for solar irradiance forecasting:
    1. Deterministic forecasting model.
    2. Stochastic forecasting model.

- Each model contains three components:
    1. A nowcasting model
    2. An auxiliary LSTM
    3. A model for predicting future sky images.

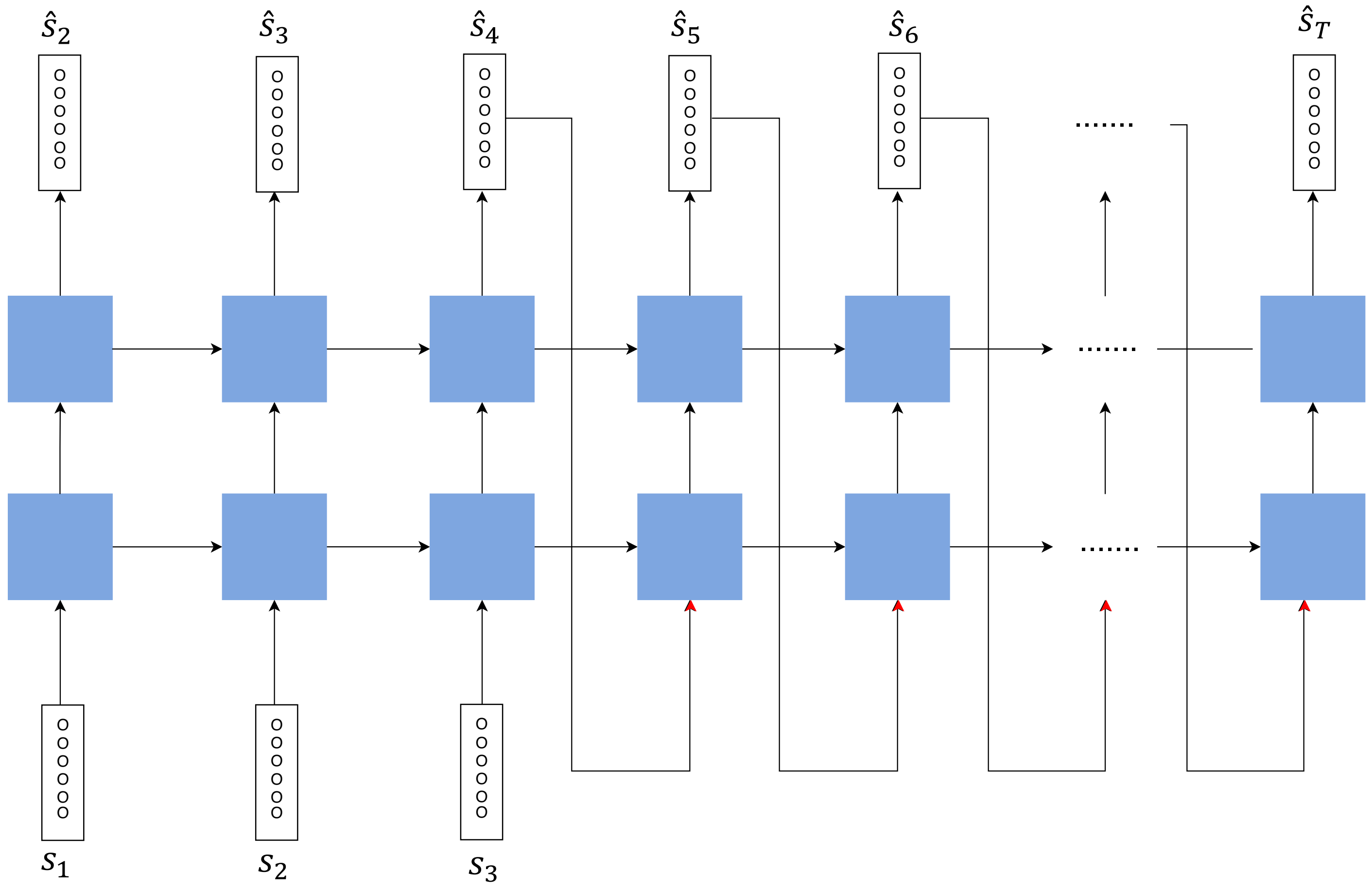
The nowcasting model

- Estimate solar irradiance at a specific timestep using:
  - Sky image
  - Auxiliary data.



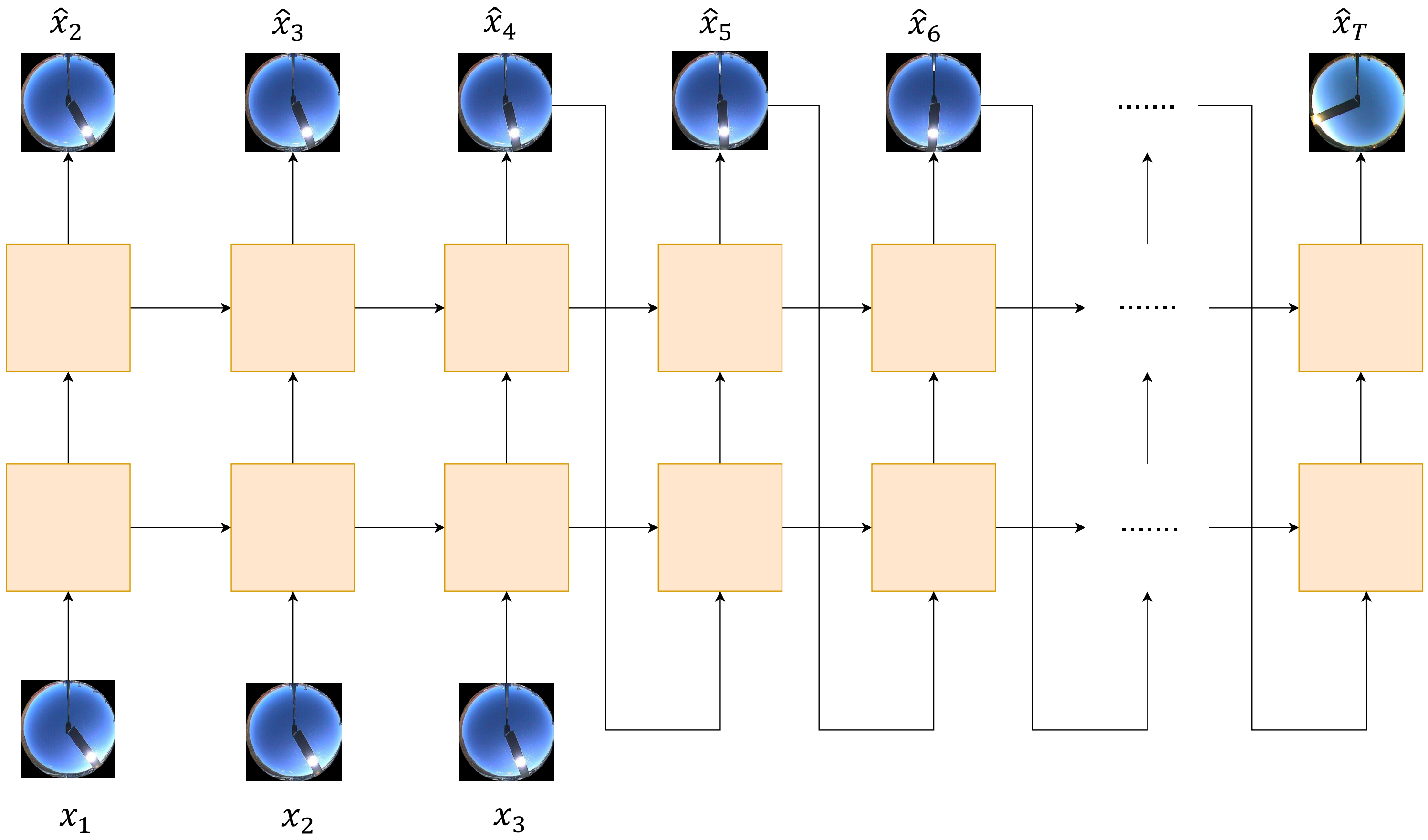
The auxiliary LSTM model

- Has a LSTM structure
- Aim to predict future auxiliary data autoregressively given the historical ones.



The PredRNN model [1]

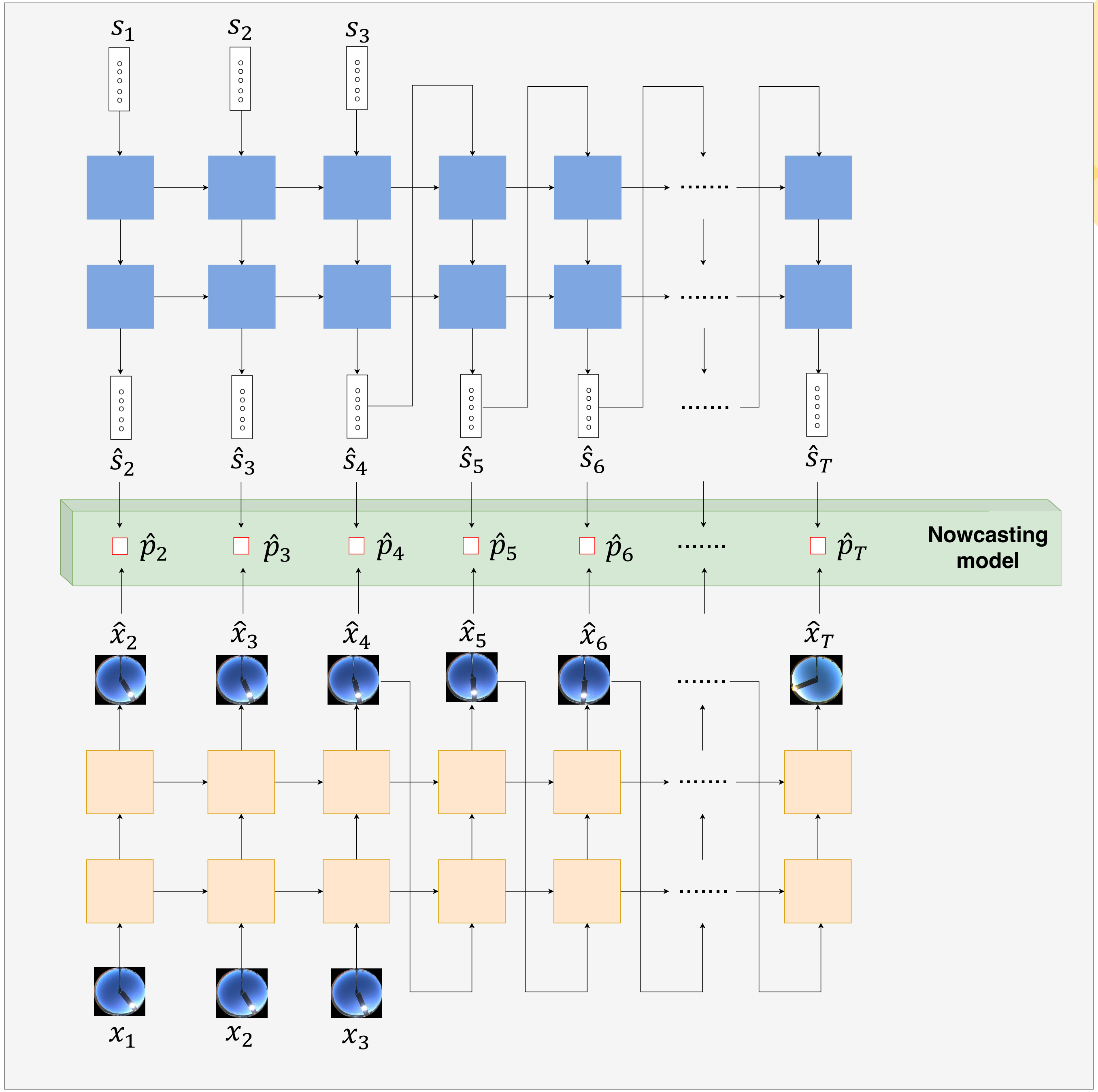
- Spatial-temporal model
- Aim to predict future sky images autoregressively given the historical ones.



[1] Wang, Y., Long, M., Wang, J., Gao, Z. and Yu, P.S., 2017, December. Predrnn: Recurrent neural networks for predictive learning using spatiotemporal lstms. In *Proceedings of the 31st International Conference on Neural Information Processing Systems* (pp. 879-888).

The deterministic forecasting model

- Contains three components:
  - The nowcasting model
  - The auxiliary LSTM
  - The PredRNN model
- Prediction process:
  - Step 1: PredRNN predicts future images
  - Step 2: Auxiliary LSTM predicts future auxiliary data
  - Step 3: The nowcasting model predicts future solar irradiance.



Loss function

$$\mathcal{L}_{det} = \frac{1}{M+T-1}\left(\sum_{i=1}^{M+T-1} \underbrace{\left\|p_{i+1} - \hat{p}_{i+1}\right\|_1}_{\textbf{Solar irradiance loss}} + \alpha \underbrace{\left\|x_{i+1} - \hat{x}_{i+1}\right\|_1}_{\textbf{Image loss}}\right)$$

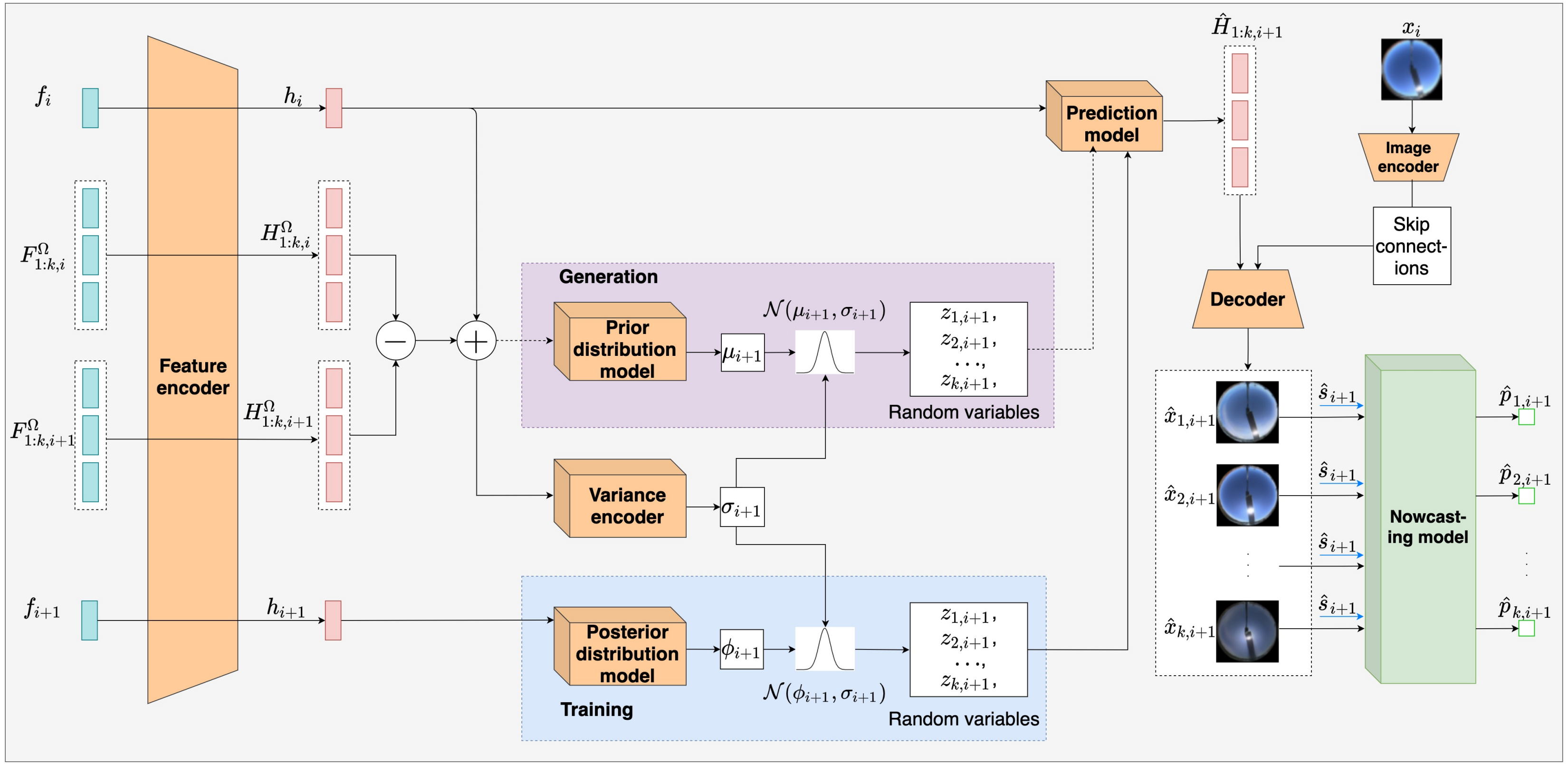
Where:

- p_{i+1} and $\hat{p}_{i+1}$ are ground-truth and predicted solar irradiance at timestep $i+1$
- x_{i+1} and $\hat{x}_{i+1}$ are ground-truth and predicted image at timestep $i+1$

The stochastic forecasting model

- Contains three components:
  - The nowcasting model
  - The auxiliary LSTM
  - The VPEG model

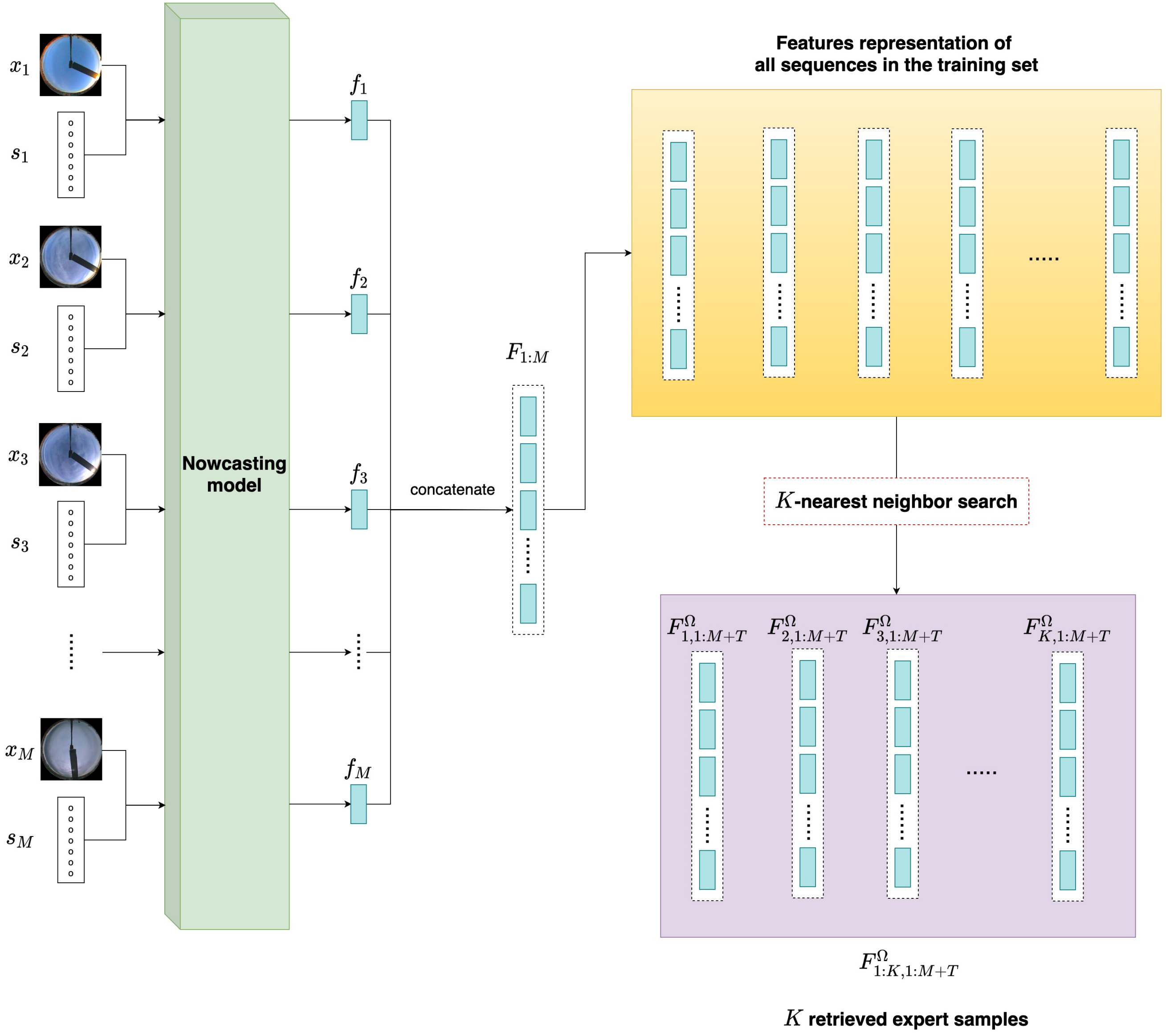
- VPEG model [2] aims predicts a distribution of future sky images.
- Contain three phases:
  - Expert samples retrieval
  - Training phase
  - Generation phase



[2] Xu, J., Xu, H., Ni, B., Yang, X. and Darrell, T., 2020, November. Video prediction via example guidance. In *International Conference on Machine Learning* (pp. 10628-10637). PMLR.

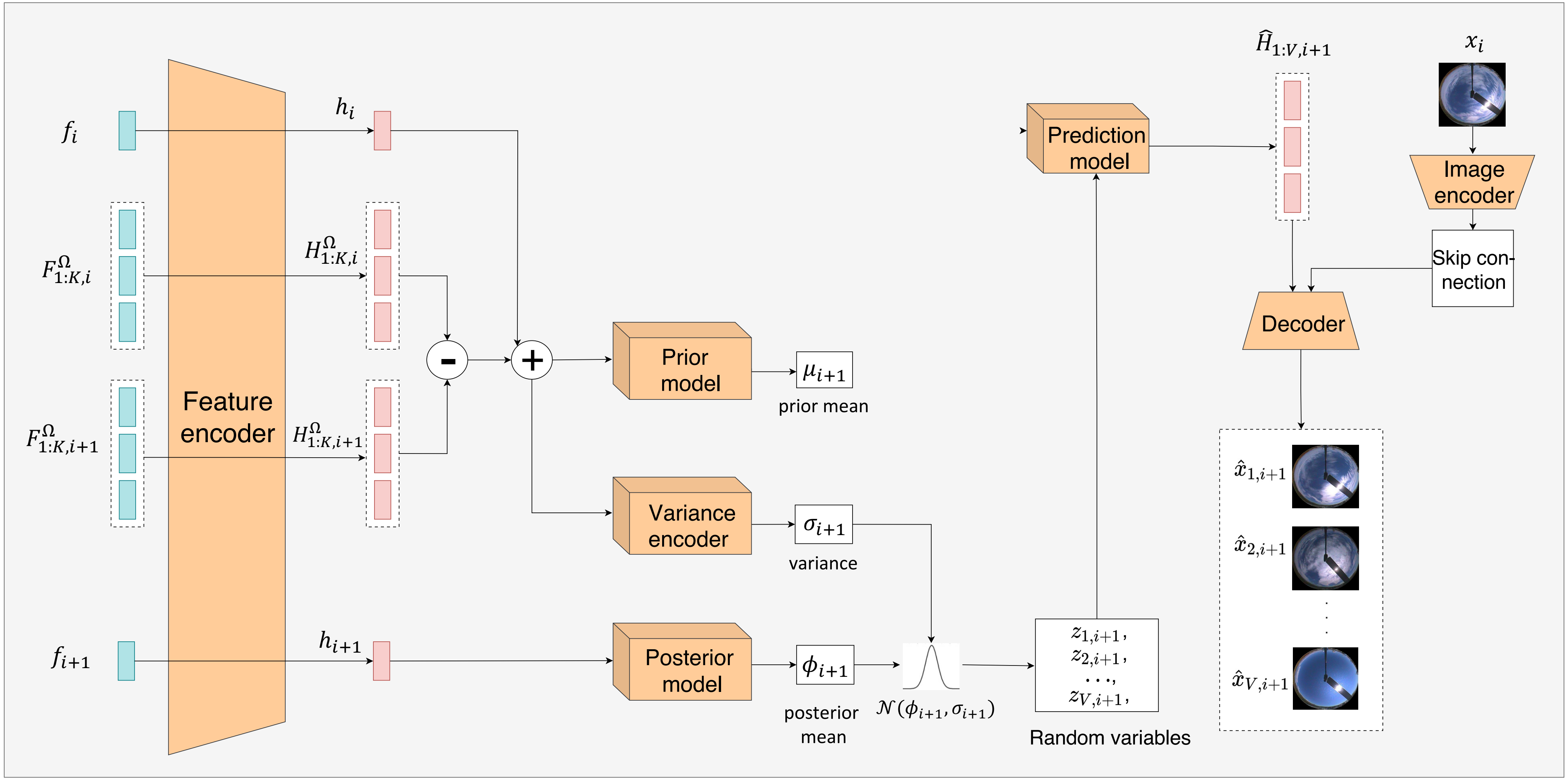
Retrieval phase

- Use the output of the last hidden layer of the nowcasting model.
- Each sequence is represented as a sequence of features f.
- Perform K-nearest neighbor search to retrieve K expert examples.



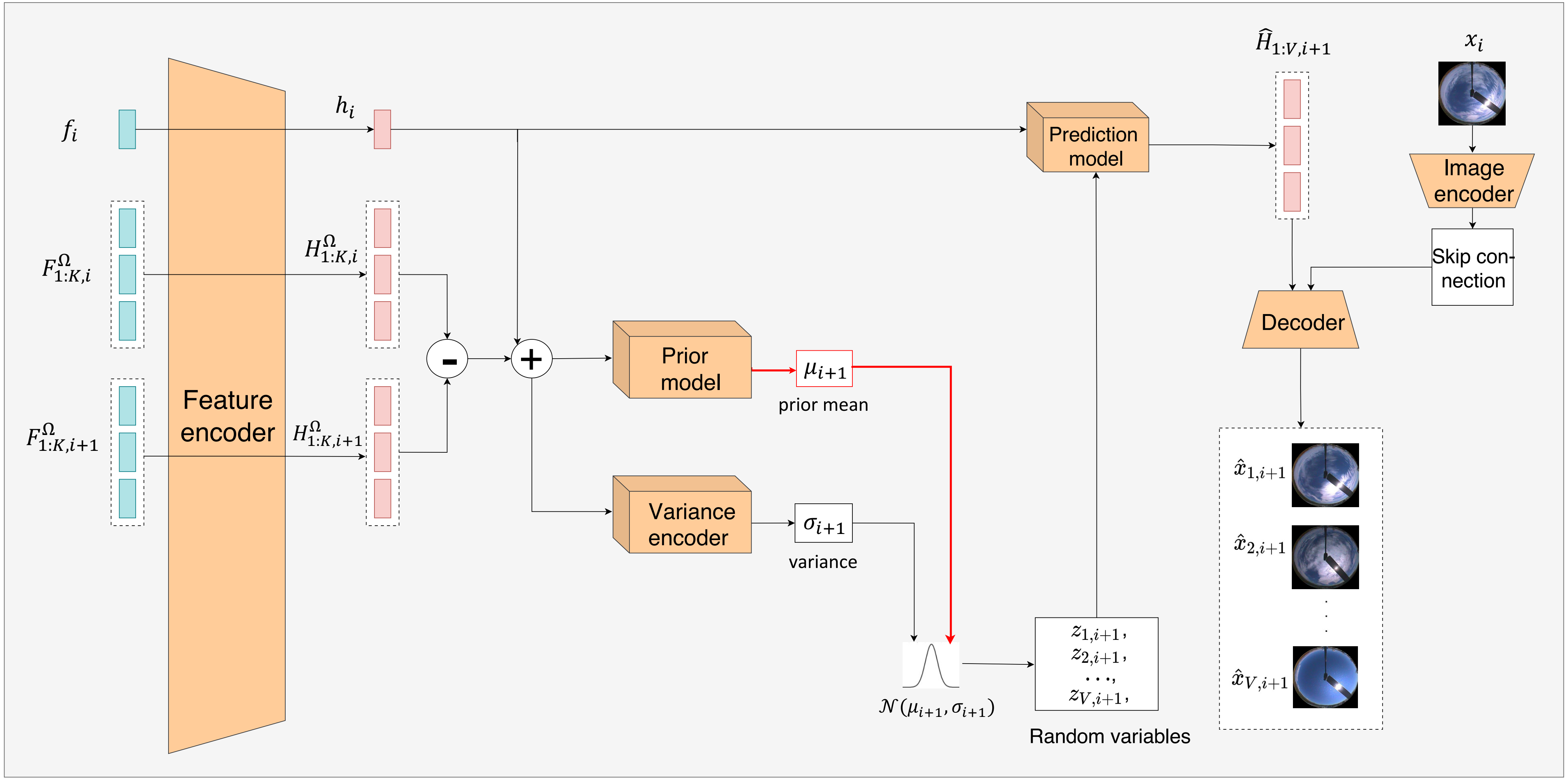
Training phase

The prior mean is also predicted



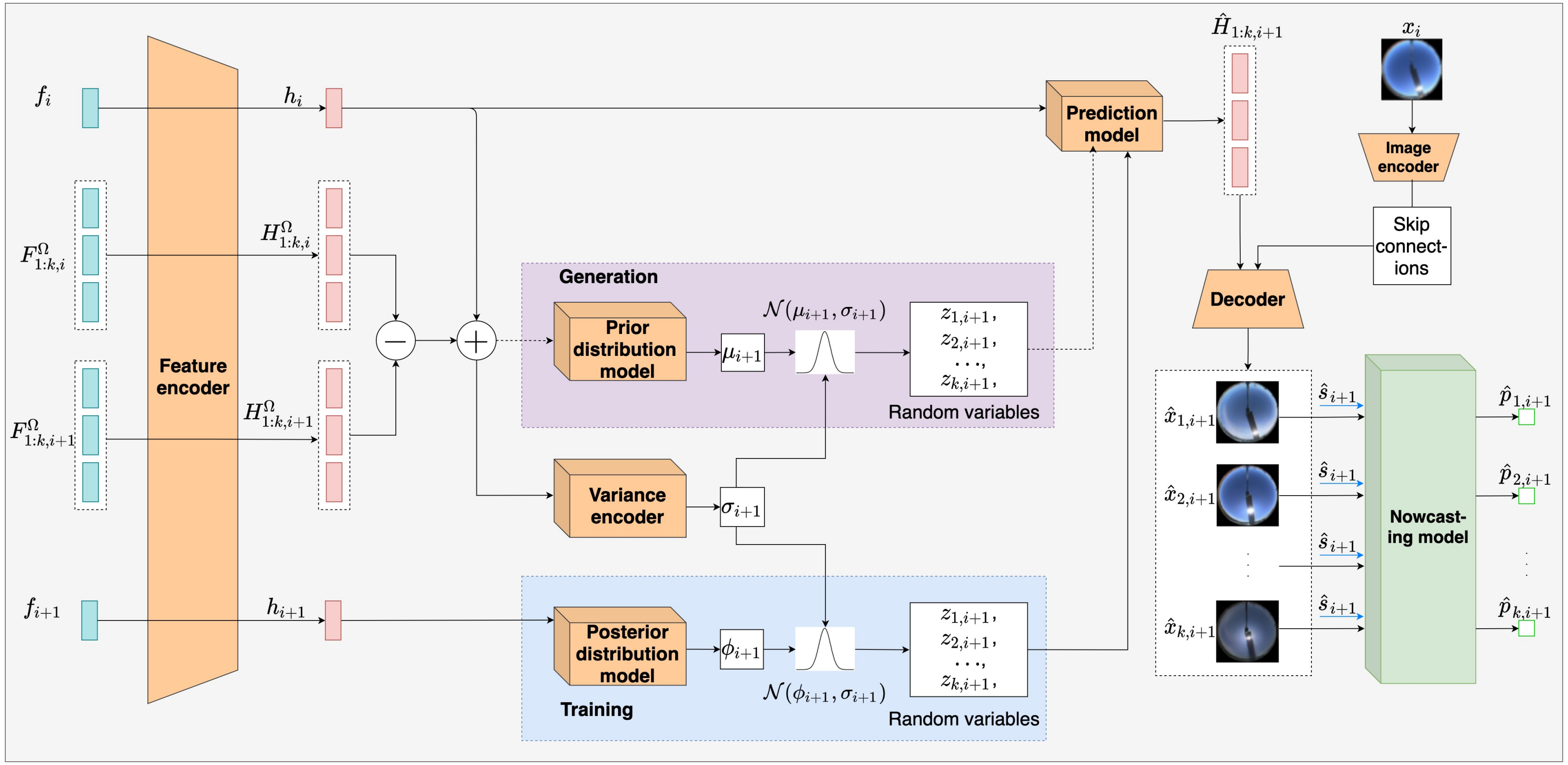
Generation phase

Use the prior distribution (instead of the posterior distribution)



The stochastic forecasting model

- Prediction process:
  - Step 1: VPEG generates multiple future images.
  - Step 2: Auxiliary LSTM predicts future auxiliary data.
  - Step 3: The nowcasting model predicts multiple future solar irradiance.



Loss function

$$\boldsymbol{Loss} = \lambda_1 \textbf{image loss} + \lambda_2 \textbf{expectation loss} + \lambda_3 \textbf{variance loss} + \lambda_4 \textbf{solar loss}$$

$$\text{image loss} = ||\text{best predicted image} - \text{ground truth image}||_2^2$$

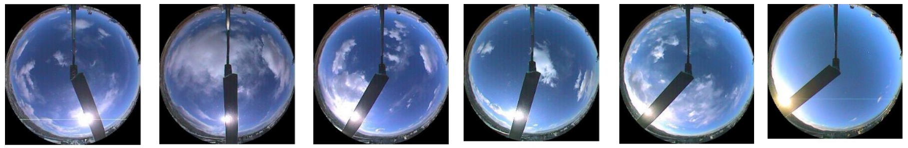
$$\text{expectation loss} = ||\text{prior mean} - \text{posterior mean}||_2^2$$

$$\text{variance loss} = ||\text{variance of predictions} - \text{variance of expert samples}||_2^2$$

$$\text{solar loss} = ||\text{best predicted solar irradiance} - \text{ground truth solar irradiance}||_1$$

Experiment setups

- Golden, Colorado Dataset:
  - Contains sky images and auxiliary data recorded from 2004 to 2016.
  - Auxiliary data contains date, time, clear-sky irradiance, azimuth angle and zenith angle
  - Data in 2015 and 2016 is used as test sets.



11:00 12:00 14:00 13:00 15:00 16:00

- Evaluation metrics:
  - Normalized mean absolute percentage error (nMAP):

$$nMAP = \frac{1}{N}\sum_{n=1}^{N}\frac{|p_n - \hat{p}_n|}{\frac{1}{N}\sum_{n=1}^{N} p_n} \times 100$$

  - Diversity: Average L1 difference of each pair of predictions.

Result

	nMAP							
	Test 2015				**Test 2016**			
	+1h	**+2h**	**+3h**	**+4h**	**+1h**	**+2h**	**+3h**	**+4h**
Siddiqui [3]	**17.9**	25.2	31.6	39.1	**16.9**	25.0	31.9	39.5
Our deterministic model	21.6	25.7	30.1	35.6	19.2	23.3	27.2	32.7
Our stochastic model (best prediction)	19.7	**21.2**	**22.5**	**27.8**	17.4	**19.1**	**21.2**	**25.5**

➔ Our deterministic model outperform the state-of-the-art model for predictions in the far future.

➔ The best prediction of the stochastic model better than the that of the deterministic models.

[3] Siddiqui, T.A., Bharadwaj, S. and Kalyanaraman, S., 2019, January. A deep learning approach to solar-irradiance forecasting in sky-videos. In *2019 IEEE Winter Conference on Applications of Computer Vision (WACV)* (pp. 2166-2174). IEEE.

Diversity in the predictions of the stochastic model

	Diversity							
	Test 2015				**Test 2016**			
	+1h	**+2h**	**+3h**	**+4h**	**+1h**	**+2h**	**+3h**	**+4h**
Our stochastic model	77.4	91.5	97.5	100.2	70.1	82.2	88.0	90.0

→ The diversity increases as we predict further into the future.

→ Our stochastic model is able to capture uncertainties in the future.

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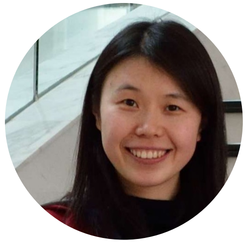

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