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Deep Learning for Post-Processing Ensemble Weather Forecasts

ECMWF-ESA Workshop on Machine Learning for Earth System Observation and Prediction
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Presenting the work of many people

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DEEP LEARNING FOR POST-PROCESSING ENSEMBLE WEATHER FORECASTS

PREPRINT

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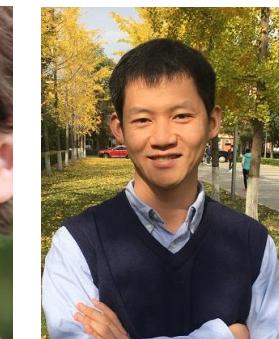
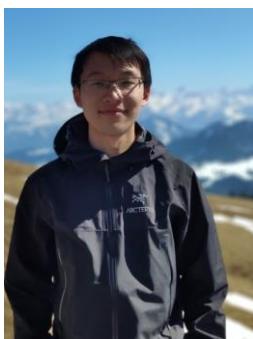
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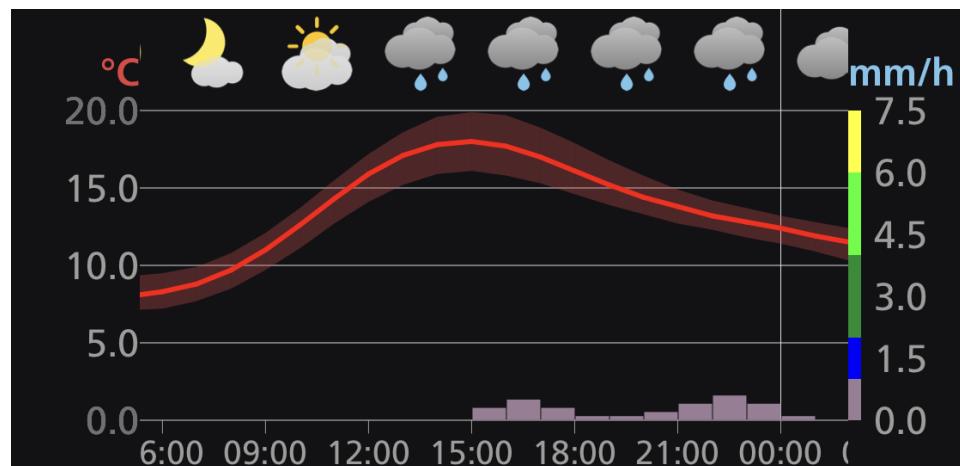
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<https://arxiv.org/abs/2005.08748> — <https://github.com/spcl/deep-weather>

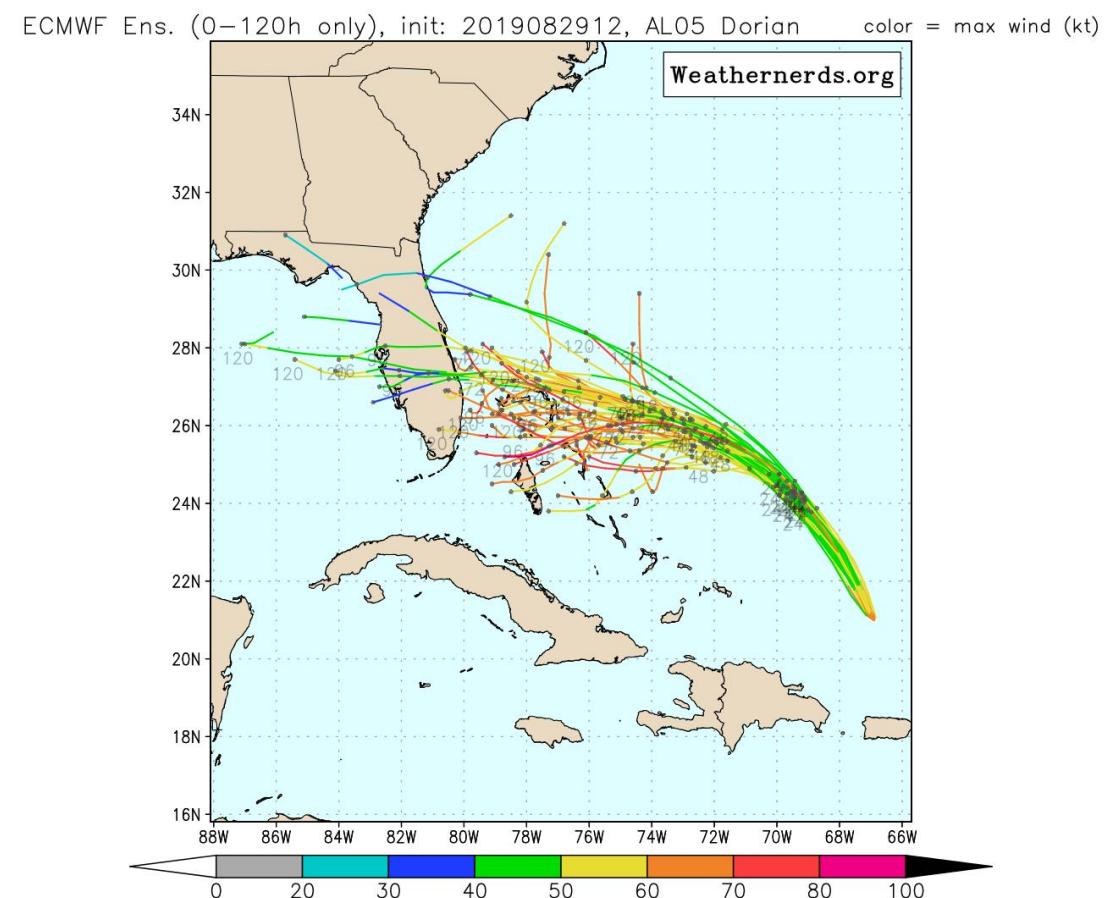


Weather Uncertainty

Weather is a chaotic process



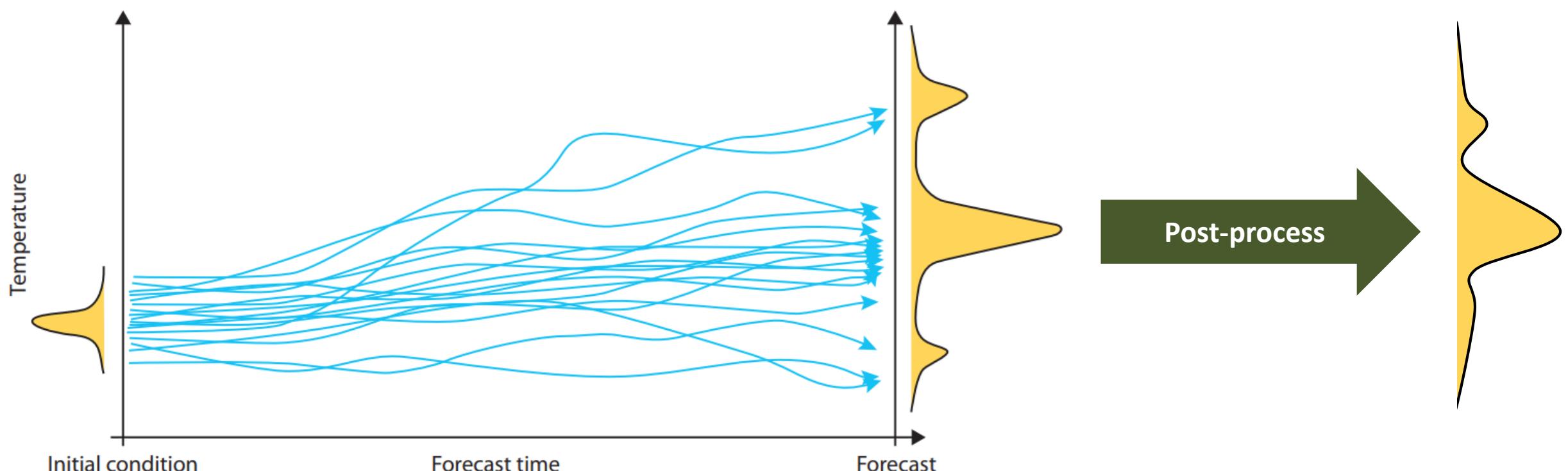
Source: MeteoSwiss app



Ensemble Prediction System

Cheap post-processing methods: EMOS & BMA

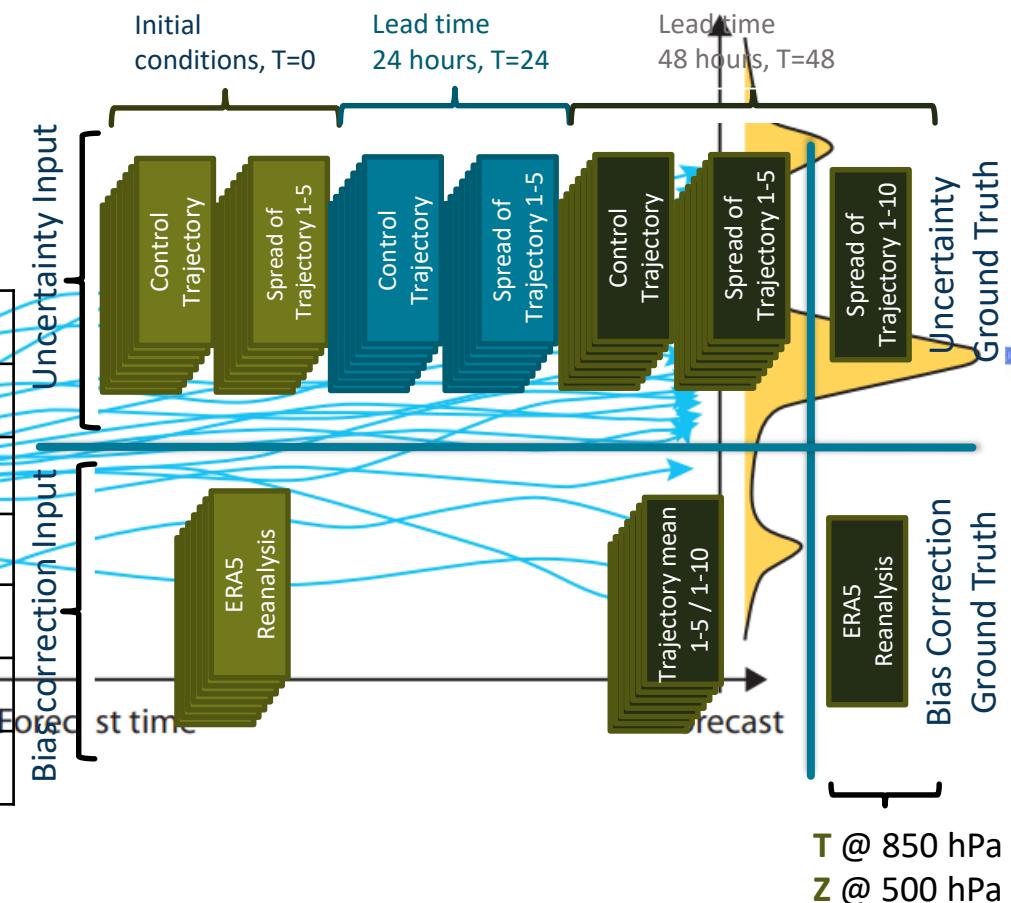
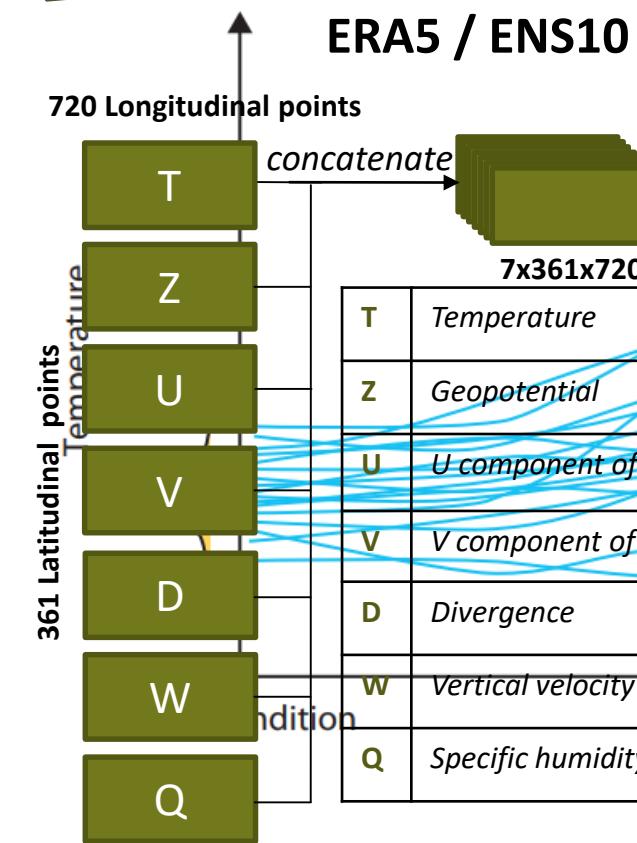
Simple neural networks [Rasp & Lerch 2018]



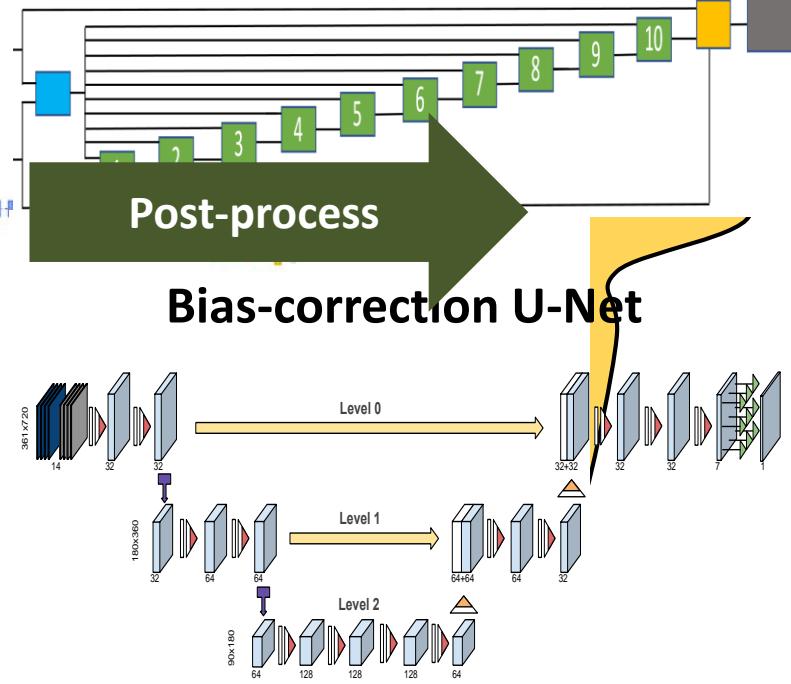
Source: ECMWF

Deep Learning for Post-Processing

Use complex neural networks!



Inception-style UQ network



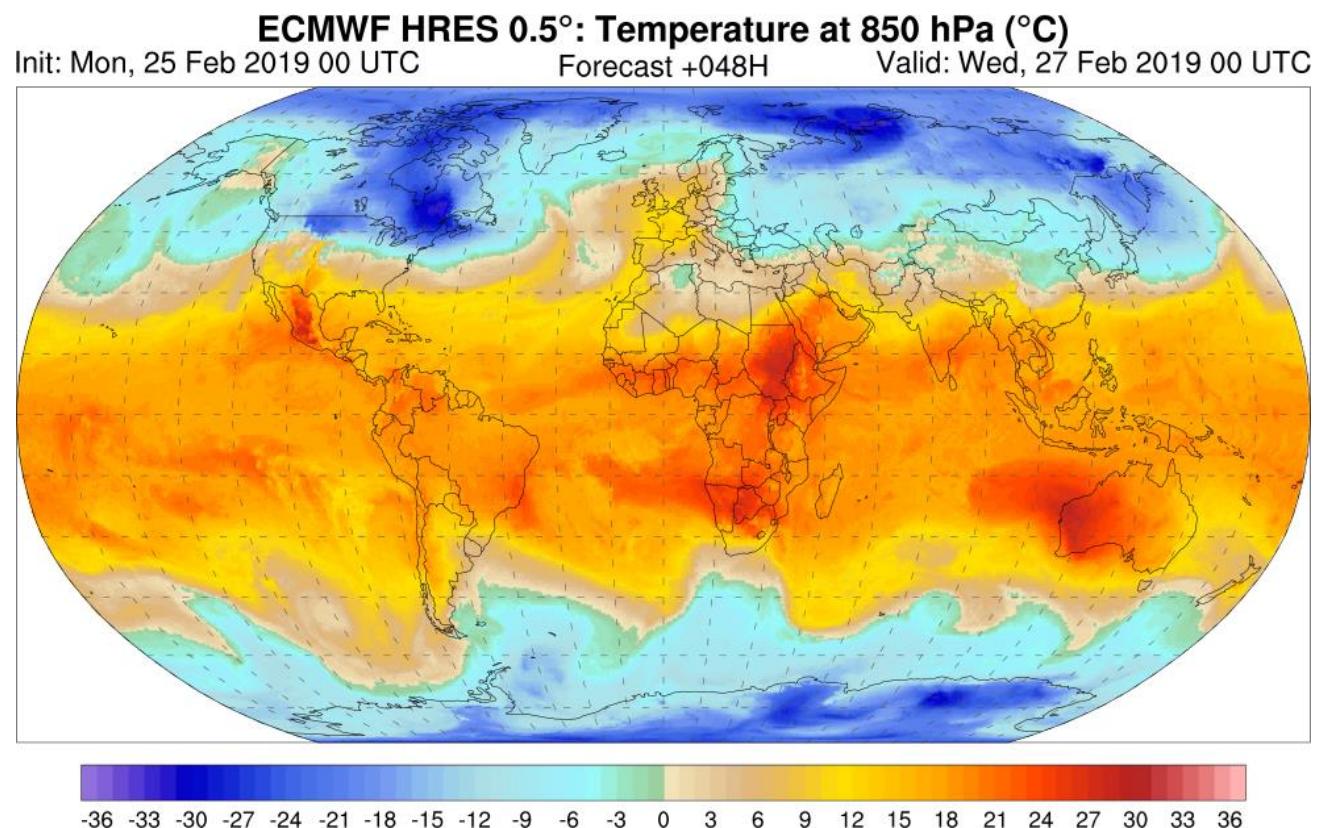
Datasets

ENS10

- Re-forecast (hindcast) dataset
- 10-member ensemble + control
- 0.5° latitude / longitude resolution
- 1999 – 2017
- 2/week, 0h, 24h, 48h lead time
- Training data

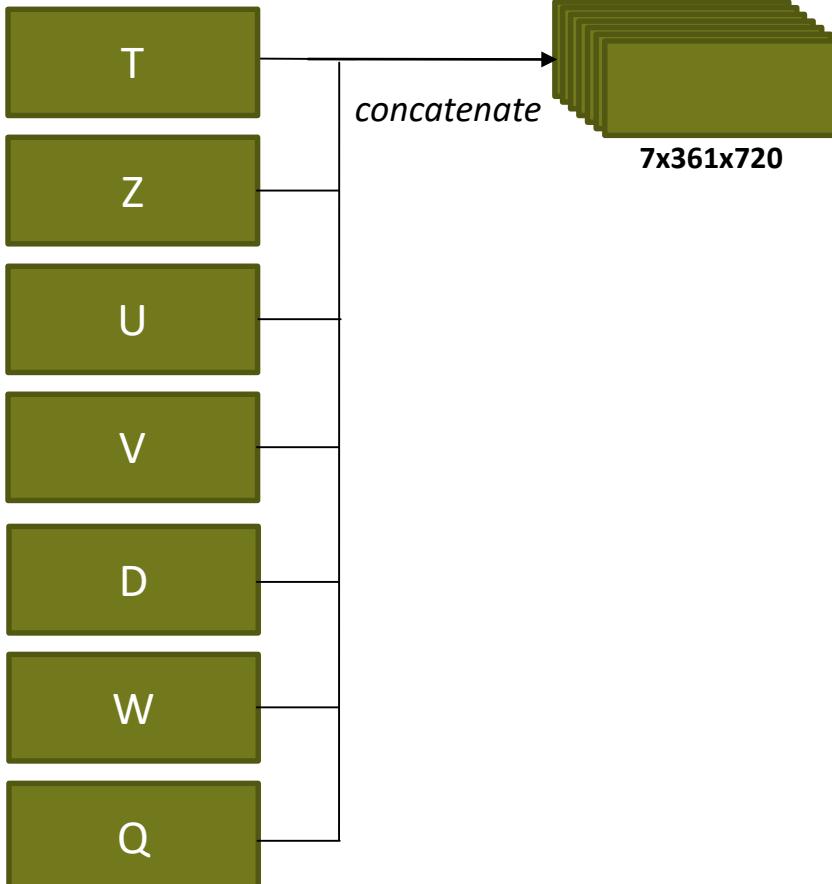
ERA5

- Re-analysis dataset
- 1 trajectory (mean)
- 0.5° latitude / longitude resolution
- 1979 – present
- Hourly
- Ground-truth data



Data selection

720 Longitudinal points



361 Latitudinal points

1 Pressure level: 500/850hPa

T @ 850 hPa
Z @ 500 hPa

Bias correction Input

Parameter Short name	Parameter Long name
SST	Sea surface temperature
T	Total Column Water
TQ	Total column water vapour
CP	Convective precipitation
MSL	Mean sea level pressure
TCC	Total cloud cover
10U	10m U wind component
10V	10m V wind component
2T	2m temperature
TP	Total precipitation
SKT	Skin temperature at the surface
U	U wind component
V	Wind component
Z	Geopotential
T	Temperature
Q	Specific humidity
W	Vertical velocity
D	Divergence

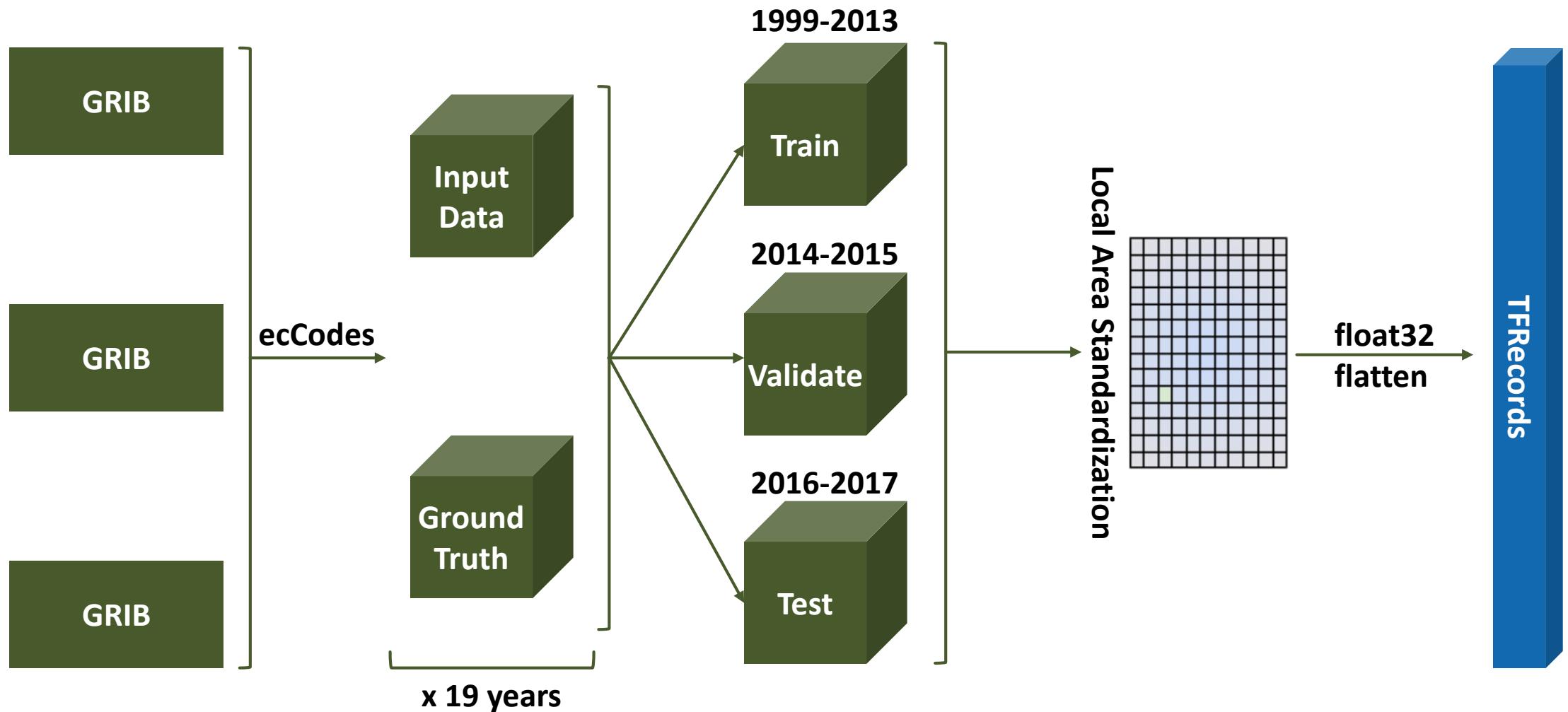
Uncertainty Input

Parameter Short name	Parameter Long name	Initial conditions, T=0	Lead time 24 hours, T=24	Lead time 48 hours, T=48
T	Temperature	Control Trajectory	Control Trajectory	Control Trajectory
Q	Specific humidity	Spread of Trajectory 1-5	Spread of Trajectory 1-5	Spread of Trajectory 1-5
W	Vertical velocity	Control Trajectory	Control Trajectory	Control Trajectory
D	Divergence	Spread of Trajectory 1-5	Spread of Trajectory 1-5	Spread of Trajectory 1-5

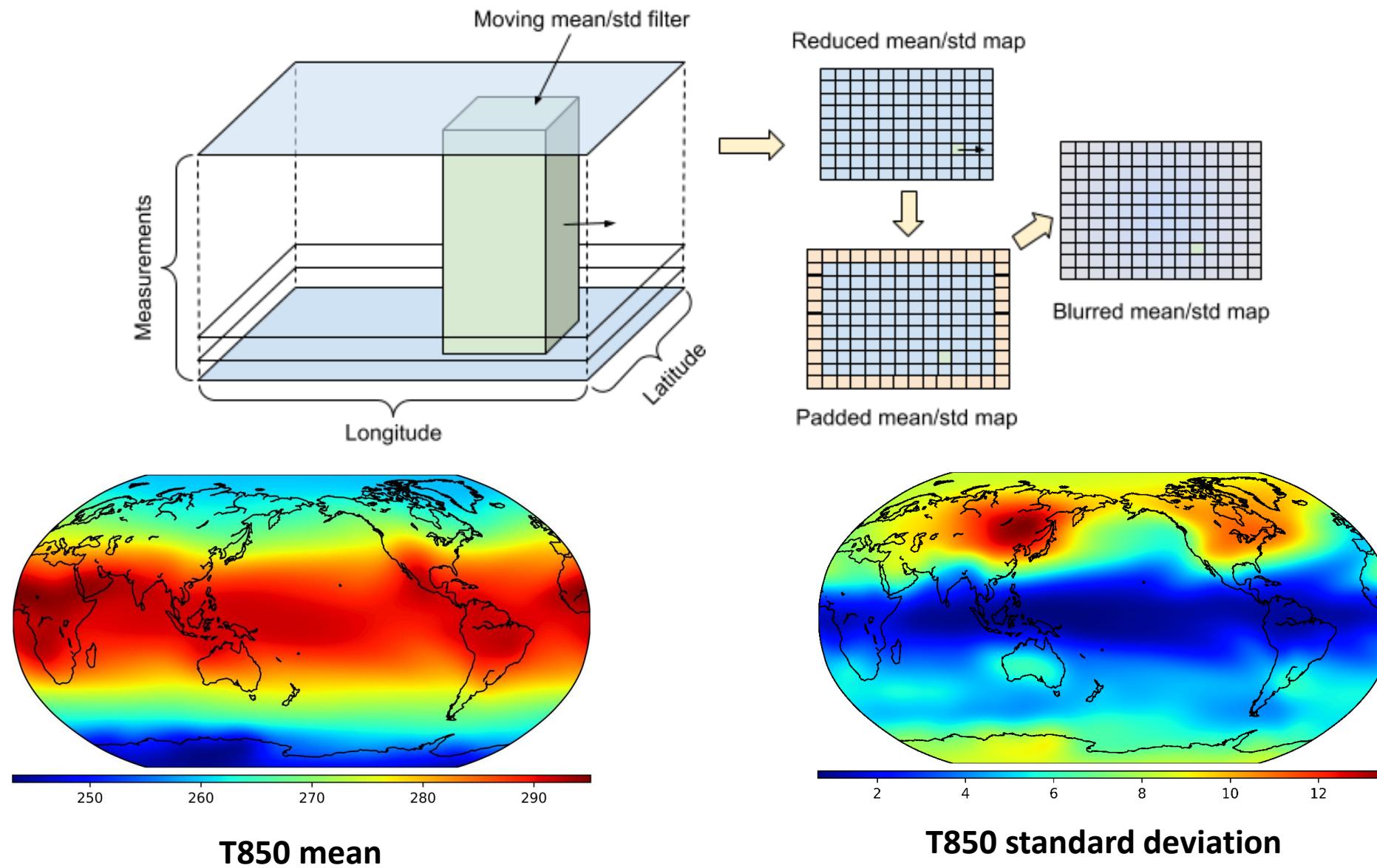
Bias Correction
Ground Truth

Uncertainty
Ground Truth

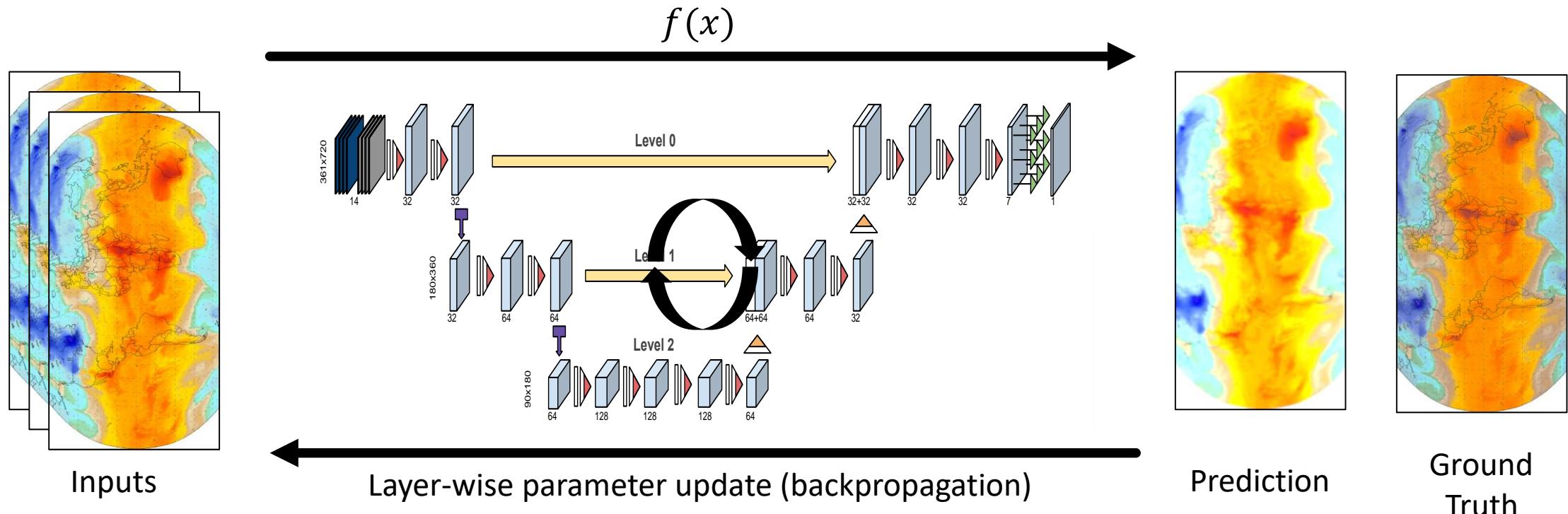
Data Preprocessing



Local Area Standardization



Training Neural Networks



$$f(x): X \rightarrow Y$$

network structure
(fixed) weights w
(learned)

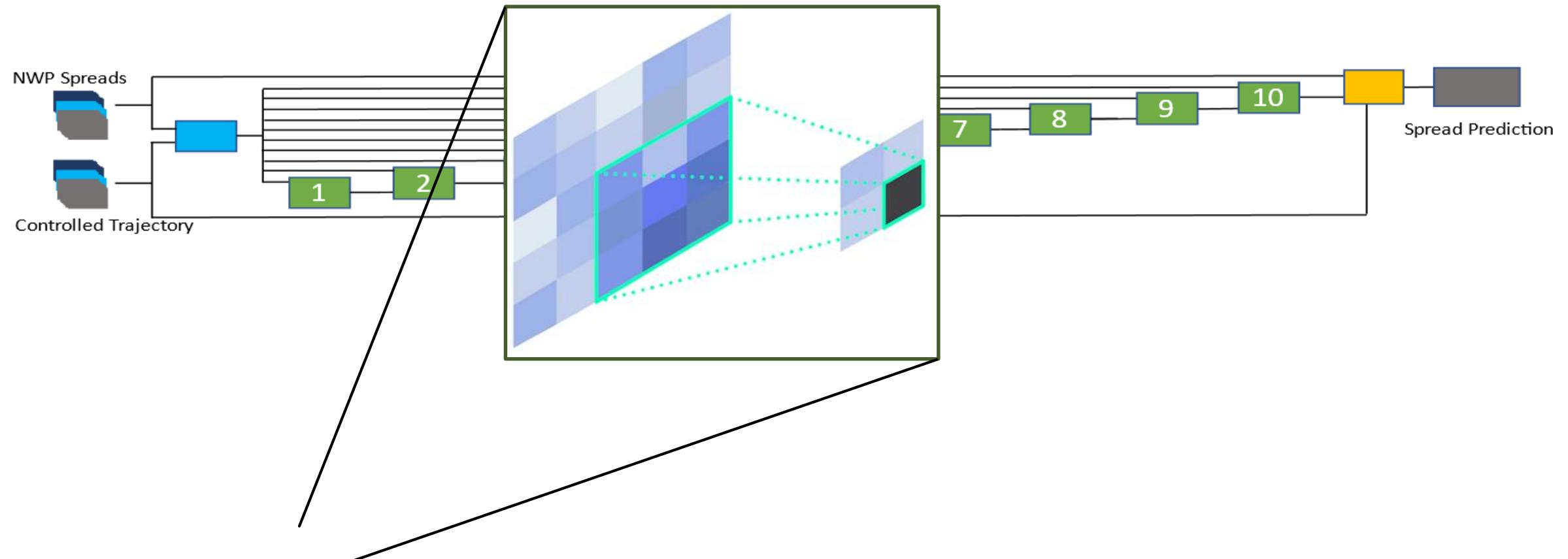
$$w^* = \operatorname{argmin}_{w \in \mathbb{R}^d} \mathbb{E}_{x \sim \mathcal{D}} [\ell(w, x)]$$

Stochastic gradient descent

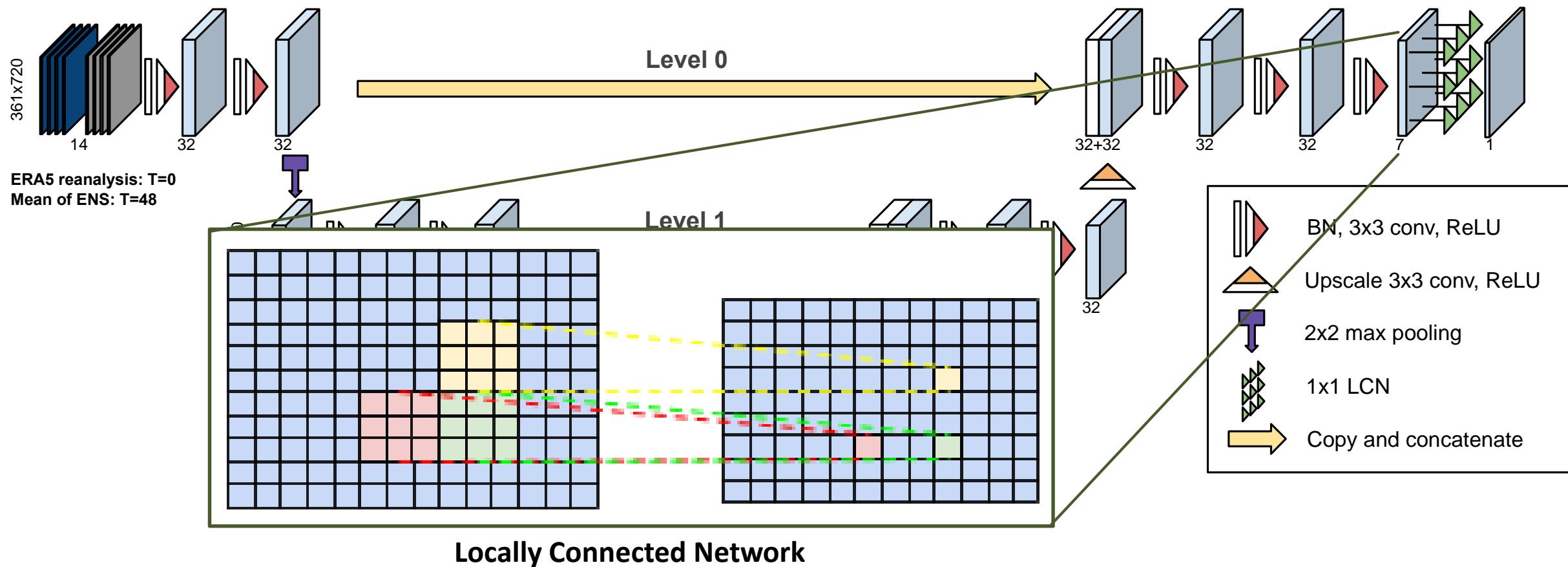
- Momentum
- AdaGrad
- Adam
- ...

$$\ell_{sq}(w, x) = (f(x) - l(x))^2$$

Uncertainty Quantification (UQ) Network



Bias Correction (BC) Network



Metrics

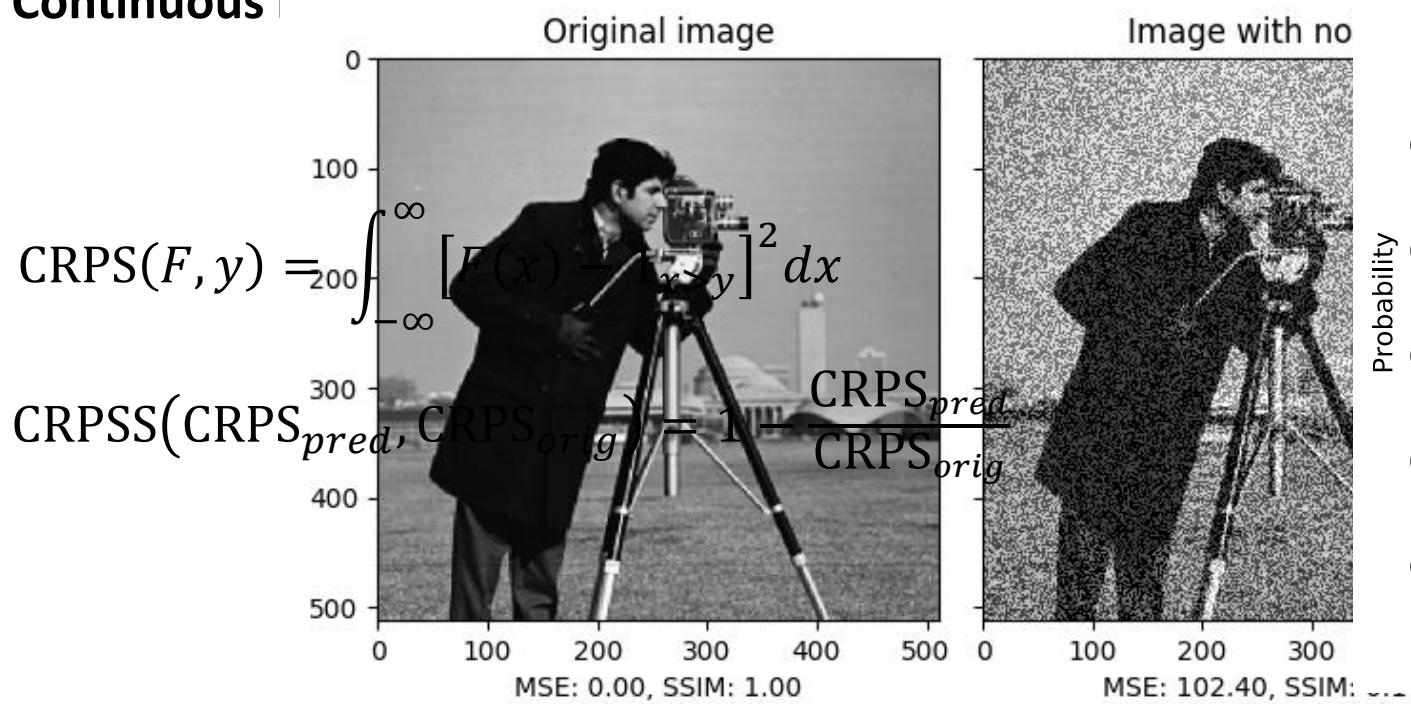
Mean Squared Error (MSE)

Root Mean Squared Error (RMSE)

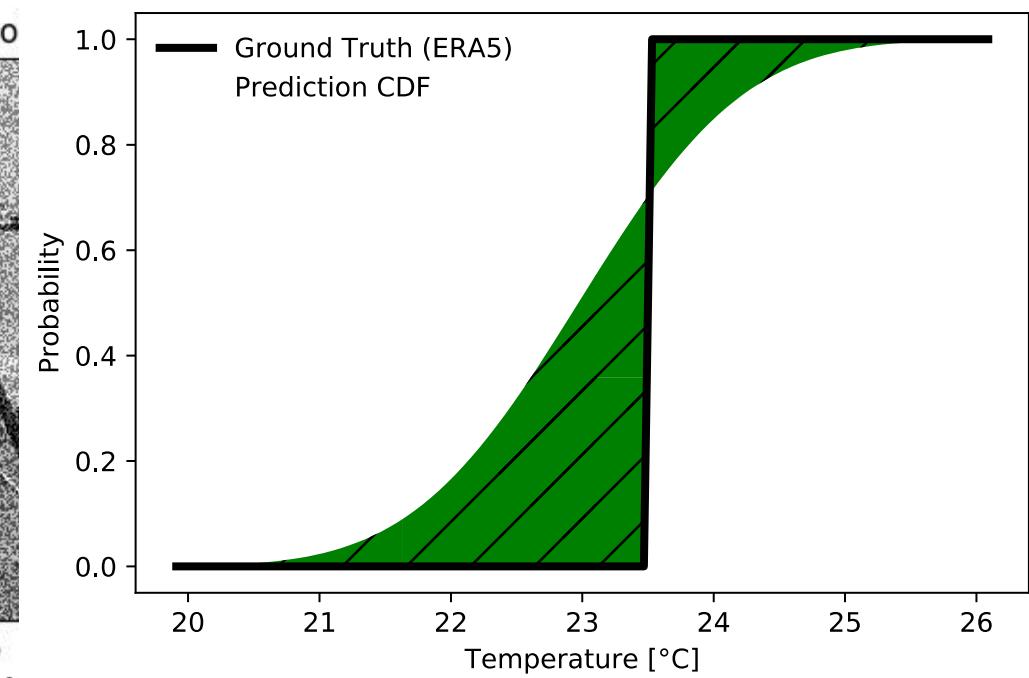
Structural Similarity Index Measure (SSIM)

Continuous Ranked Probability Score (CRPS)

Continuous

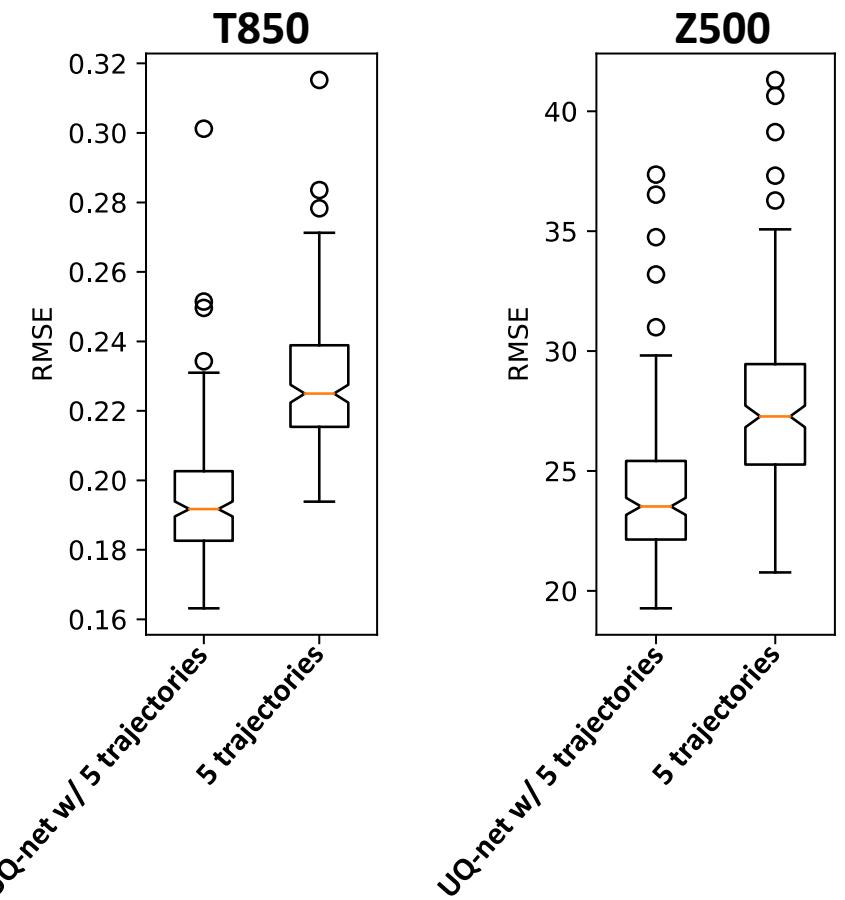


Source: scikit-image.org

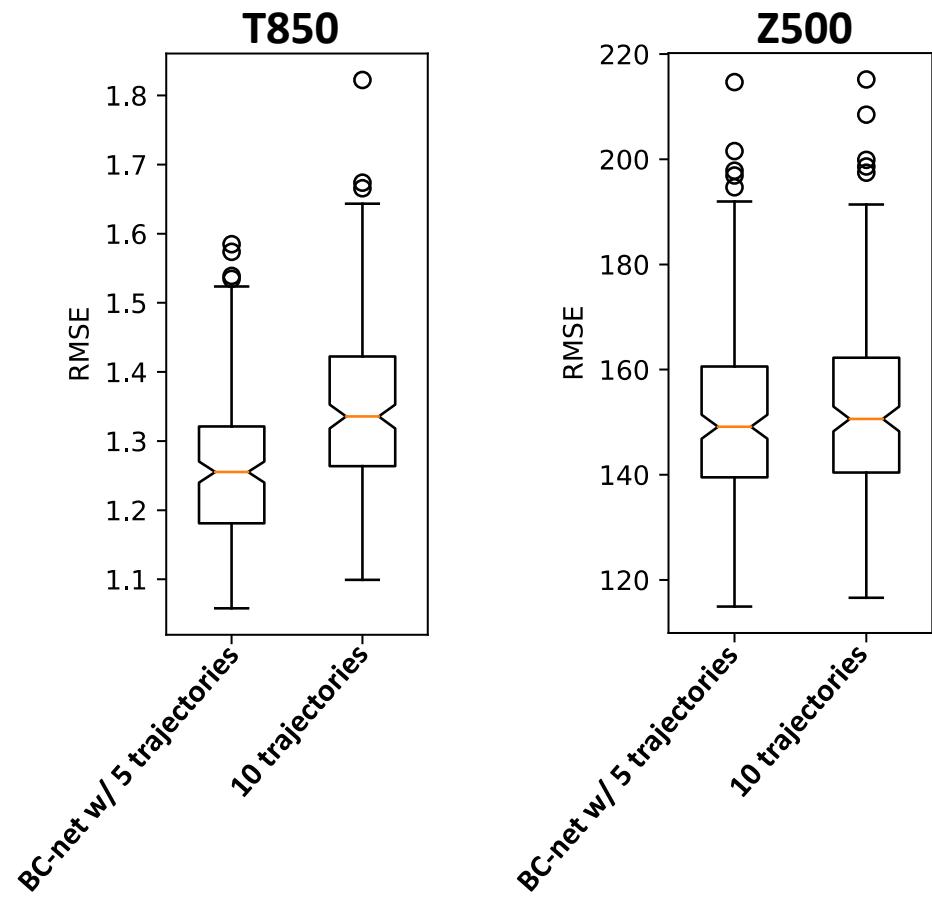


Evaluation – Global RMSE

Spread



Bias



Evaluation – Ablations

Spread – Number of trajectories for T850

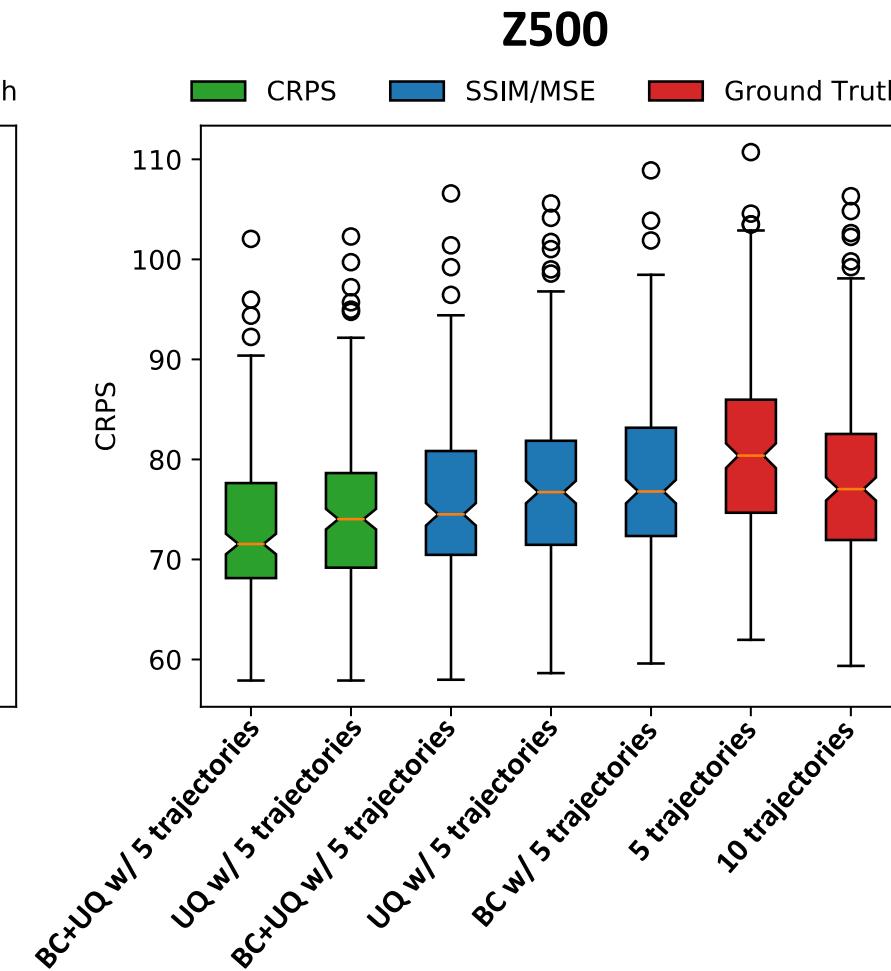
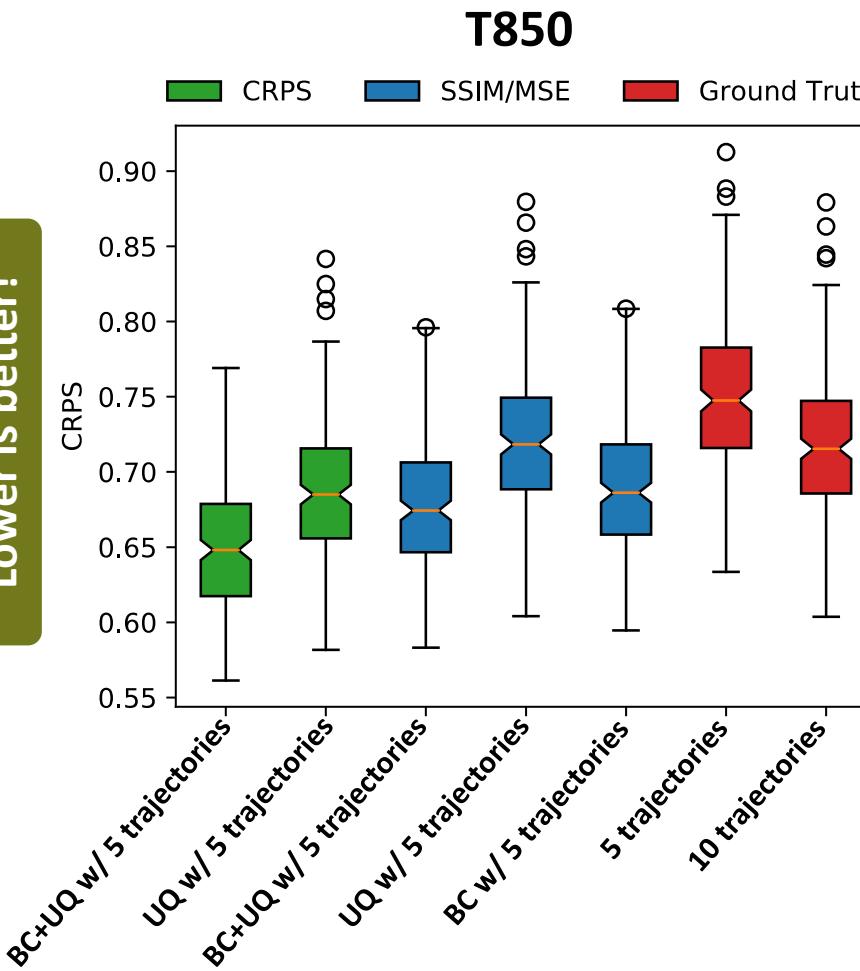
	Trajectories										
	3	4	5	6	7	8	9	Lin w/ 5	UQ w/ 3	UQ w/ 4	UQ w/ 5
Abs.	0.35	0.28	0.23	0.19	0.15	0.11	0.07	0.21	0.26	0.23	0.19
Rel.								8.9%	26.6%	18.7%	16.4%

Bias correction – Relative improvement for U-Net variants

	Lin w/ 10	Level 0	Level 0-1	Level 0-2	Level 0 + LCN	Level 0-1 + LCN	Level 0-2 + LCN	Level 0-1 + LCN + ℓ_1
T850	4.8%	6.3%	7.1%	6.7%	7.6%	7.7%	7.6%	7.9%
Z500	2.1%	1.2%	1.6%	1.0%	2.6%	2.5%	2.4%	2.3%

Evaluation – PDF Calibration

Lower is better!



General Improvement (CRPSS)

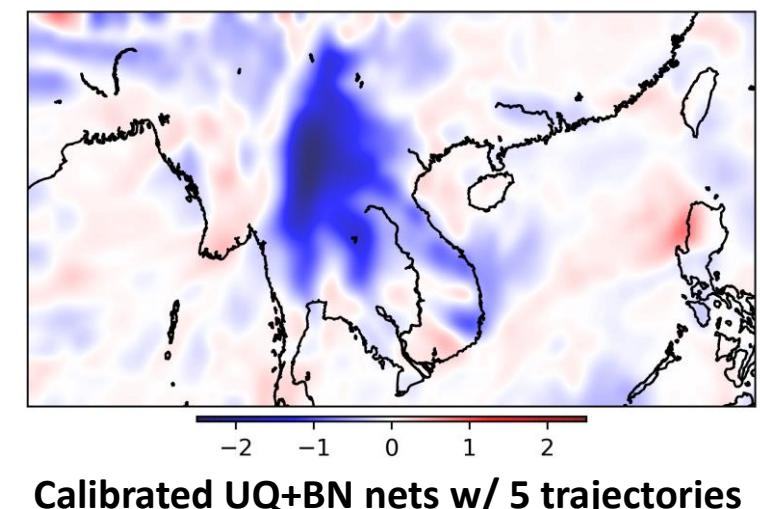
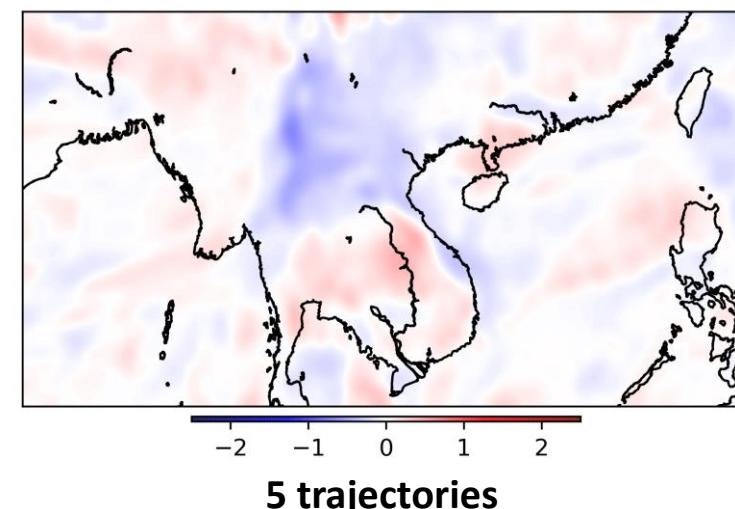
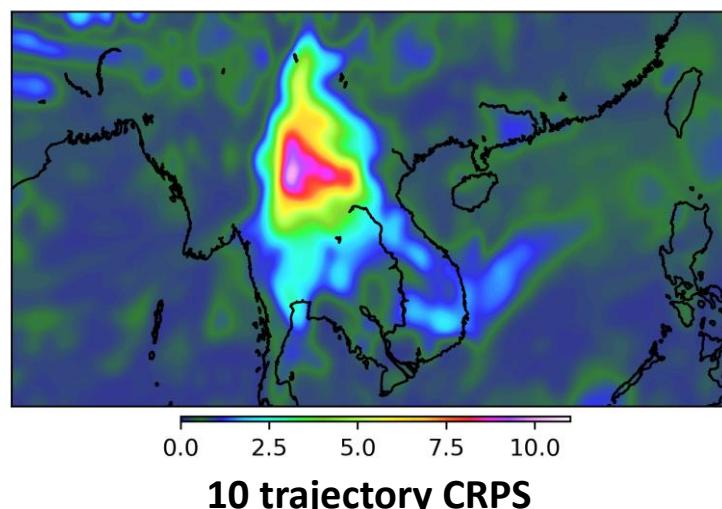
Higher is better!

	T850	Z500
10 traj.	0.1098	0.0756
5 traj.	0.1458	0.1074

EMOS5 for T850: 0.055

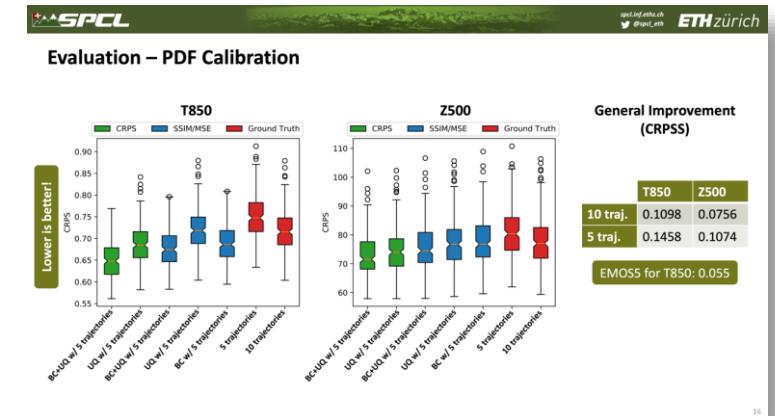
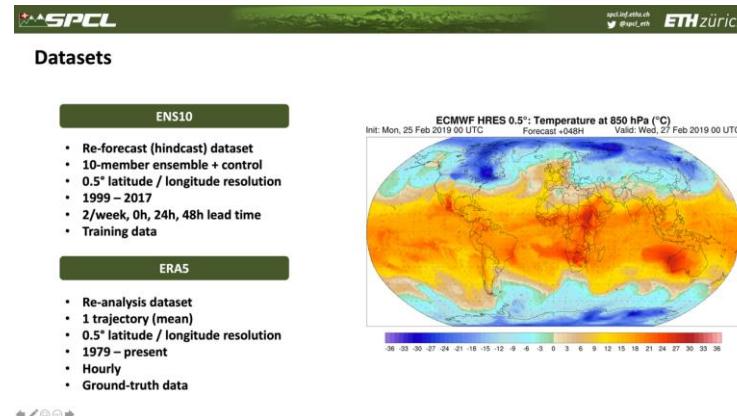
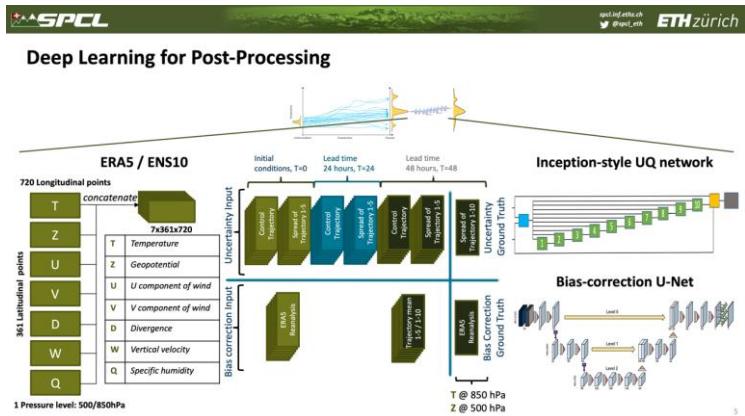
Evaluation – Extreme Weather

Cold front over E & SE Asia (24 Jan 2016)



Overall CRPSS Improvement: 0.195

Conclusions



More results in our paper!

<https://arxiv.org/abs/2005.08748> — <https://github.com/spcl/deep-weather>

