Analog Ensemble Probabilistic Forecasting Using Deep Generative Models (Case study: Wind Speed)

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Predictions uncertainty has to be addressed!

**NWP**

**Forecast**

- Initial & Boundary conditions
  - (scientific & data uncertainty)
- Physics (science)
- Dynamics (science)

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1- NWP: Numerical Weather Prediction
2- Figure from: Wilks D., (2011): Statistical Methods in the Atmospheric Sciences
3- Figure from: Delle Monache L. at al., (2013): Probabilistic Weather Prediction with an Analog Ensemble
But we can use the conditional probability distribution instead of the huge memory-consuming dataset.
But we can use the conditional probability distribution instead of the huge memory-consuming dataset.

Meme from: https://www.reddit.com/r/funny/comments/gipss/the_awkward_moment_when_you_spell_a_common_word/
Conditional Variational AutoEncoder (CVAE) is a Generative not a Discriminative machine learning (ML) model.
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Discriminative model

Generative model

Is it a cat?

Give me a cat image

2- Generative figures from: https://affinelayer.com/pixsrv/
The performance of a ML model significantly depends on the Architecture and Hyperparameters.

Conditional Variational AutoEncoder

1- North American Mesoscale (NAM) Forecasting system (model) and NAM Analysis (observation)
Conditional PDF is stored in the Latent Representation layer.

Latent Representation (z)

Condition Layer (C)

Generated Input Noise (r)

CVAE-Decoder Block

Output Layer (x')

Tested for 7 days (21 ensemble members)

T_obs_Gen

P_obs_Gen

Wd_obs_Gen

Ws_obs_Gen
How to evaluate performance of probabilistic forecasts?

**Consistency:**
- Continuous Ranked Probability Score (CRPS)

\[
CRPS = \frac{1}{N} \sum_{i=1}^{N} \int_{-\infty}^{\infty} (F_i(x) - F_i^a(x))^2 \, dx
\]

**Reliability:**
- Rank Histogram (RH)

An observed value will be ranked based on its corresponding ensemble members and the results after giving ranks to all the observed values will be presented.

- Dispersion

\[
E[(x - \hat{x})^2] = \frac{m + 1}{1m} E[s^2]
\]

CRPS for CVAE is comparable to AnEn.
CVAE probabilistic forecasts are as reliable as AnEn but with higher Bias.
CVAE probabilistic forecasts are as reliable as AnEn but with higher Bias.
CVAE is highly memory- and time-efficient comparing to AnEn.

- **CVAE needs a constant model to be loaded.**
- **AnEn has to keep a new dataset in memory.**

**CVAE uses a constant model.**
**AnEn has to search the physical dataset.**

- **Memory Usage (MB)**
  - Size of historical dataset (years)
  - CVAE
  - AnEn

- **Prediction Time (Sec)**
  - Size of historical dataset (years)
  - CVAE
  - AnEn
Summary

- CVAE is a probabilistic machine learning model that can be used for probabilistic forecasts.
- Probabilistic forecasts evaluation for CVAE shows consistent and reliable performance of the model.
- CVAE significantly saves computational resources.

Future work

- Training the model with more features.
- Tuning the model to be applicable to bigger datasets.
- Testing the model with different datasets.
Thanks for your time.
Extra Slides
Analog Ensemble (AnEn) method is memory consuming!

Figure courtesy of GEOlab group at PSU: http://geoinf.psu.edu/people.shtml
Kullback-Leibler (KL) loss function

\[-D_{KL}(Q_\phi(z|x)\|P_\theta(z)) = 0.5 \sum_{j=1}^{J} (1 + \log(\sigma_j)^2 - (\mu_j)^2 - (\sigma_j)^2)\]