Modeling climate variability as anomalies of quasi-stationary PDF moments

F.-F. Jin
Department of Meteorology
University of Hawaii at Manoa

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Unavoidable uncertainties in climate predications:

→ Stochastic and dynamic modeling

→Fokker Planck equation for complete PDF prediction, which is an approach too difficult, if ever possible!

Ensemble Forecasting for Climate Variability

Stochastic-dynamic forecasting approach (not practical) Epstein (1969).

Monto-Carlo forecasting method (Leith,1974).

…

Existing ensemble forecasting method is adopted from NWP.

Question:

Alternatives?

Climate variability

Climate is normally defined by statistic measures such as long-term mean and standard deviations or is defined by the first a few (two) moments of associated with PDFs of physical variables.

Climate variability, such as anomalies in seasonal-mean fields and in standard deviations of daily weather variability, may be viewed as the anomalies of the first and second moments of the PDFs. This view is based on the assumption that the climate system can be considered as a quasi-stationary stochastic system.

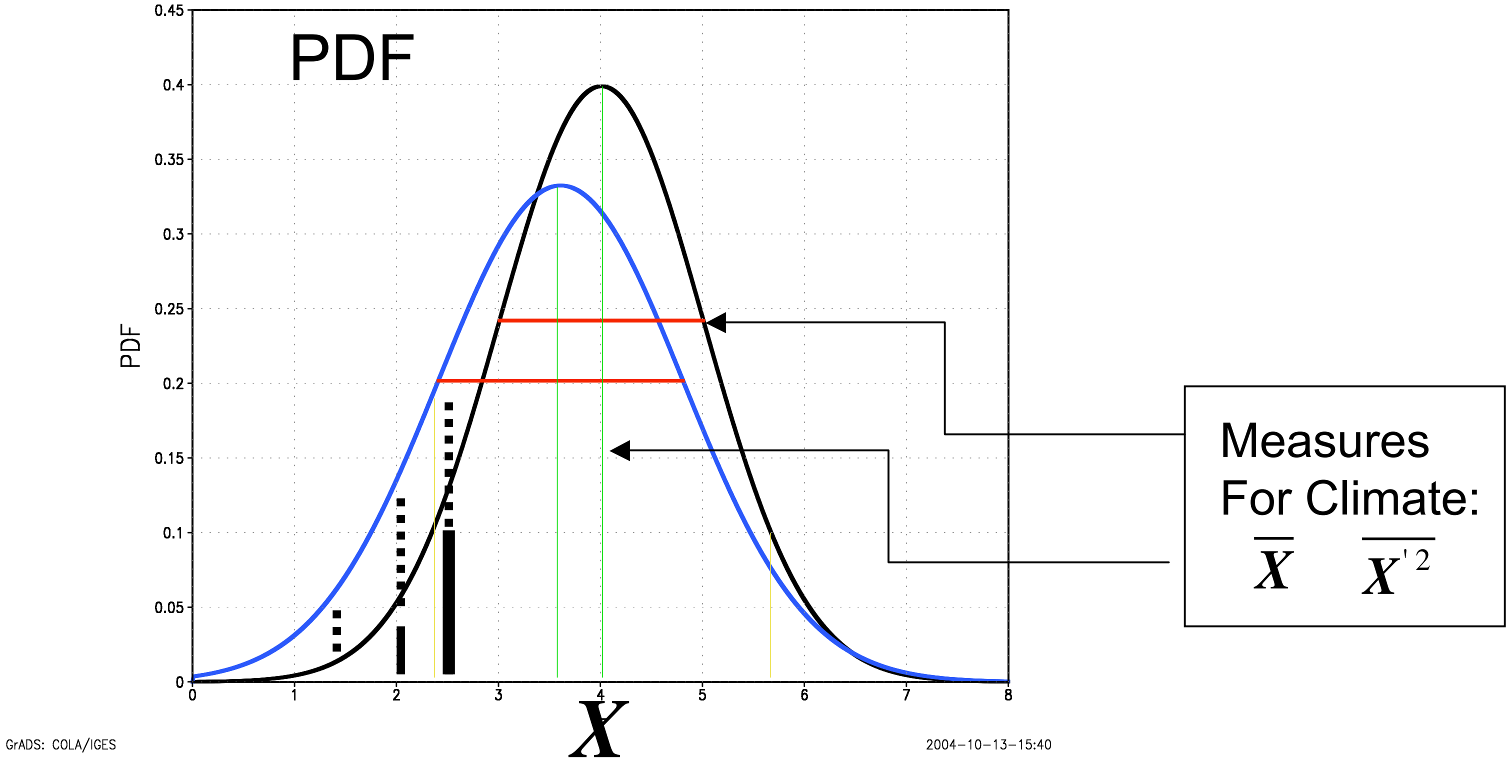
Quasi-ergodic assumption

$$\overline{X} \approx < X >$$

Namely: “long” time mean of a stochastic realization can be approximated by ensemble mean

Then, predicting climate variability may become the question:

Can we directly predict the first and second (or even third) moments of the PDF of the quasi-stationary stochastic climate system?



Climate variability: $\Delta\overline{X} = \overline{X}_a, \ \Delta\overline{X'^2}, \ldots$

Can we directly formulate dynamic model for the first and second (or even third) moments of the PDF?

An new approach:
The climatological parts of the first and second moments of PDFs are prescribed by the observed history of the climate system, in other words, we prescribe the stationary part of the stochastic climate system.

A dynamic system for anomalies in the first and second is then formulated utilizing the GCM framework under closure approximations.

Expectations:

This dynamic anomaly framework for ensemble-mean modeling may become a useful new tool for predictions of climate variability.

Background Stochastic Stationary Ensemble

$$X_c = \bar{X}_c(\lambda, \varphi, z) + X_c^{'}(\lambda, \varphi, z, t)$$

$$X_c^{'} = \sum_{n=1}^{N_c} \sigma_n \xi_n(t) E_n(\lambda, \varphi, z, t) + cc$$

Anomaly Stochastic Ensemble: $X_a = X - X_c$

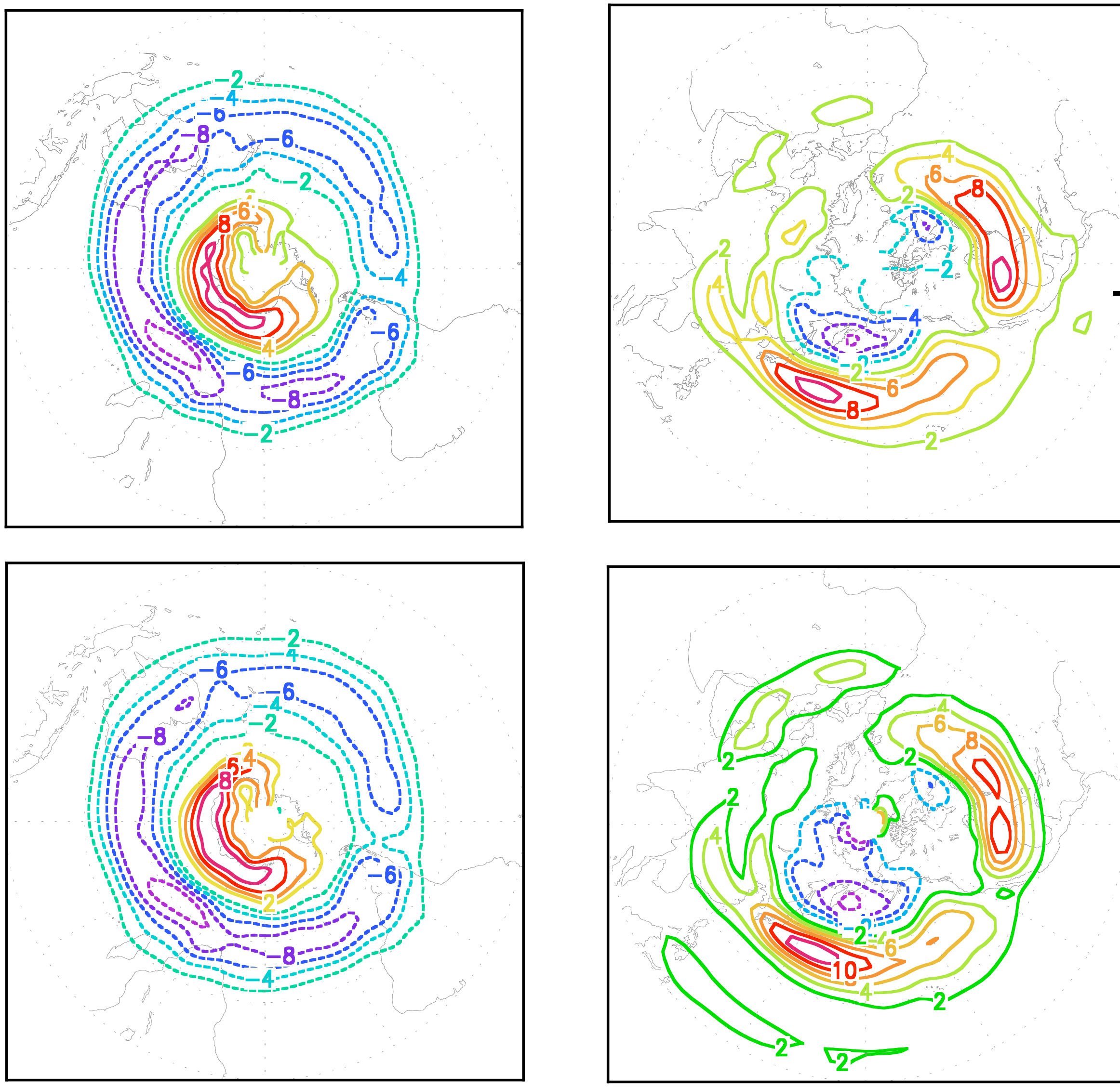
Linear EMD under the second order closure

(Jin et al 2006, Jin and Lin 2007)

$$\frac{\partial < X_a >}{\partial t} + L < X_a > = < Q_a > - < ND(X_c^{'}, X_a^{'}) >$$

$$= < Q_a > - L_f < X_a >$$

L_f: Synoptic eddy and low-frequency flow (SELF) feedback through nonlinear heat and moment advections

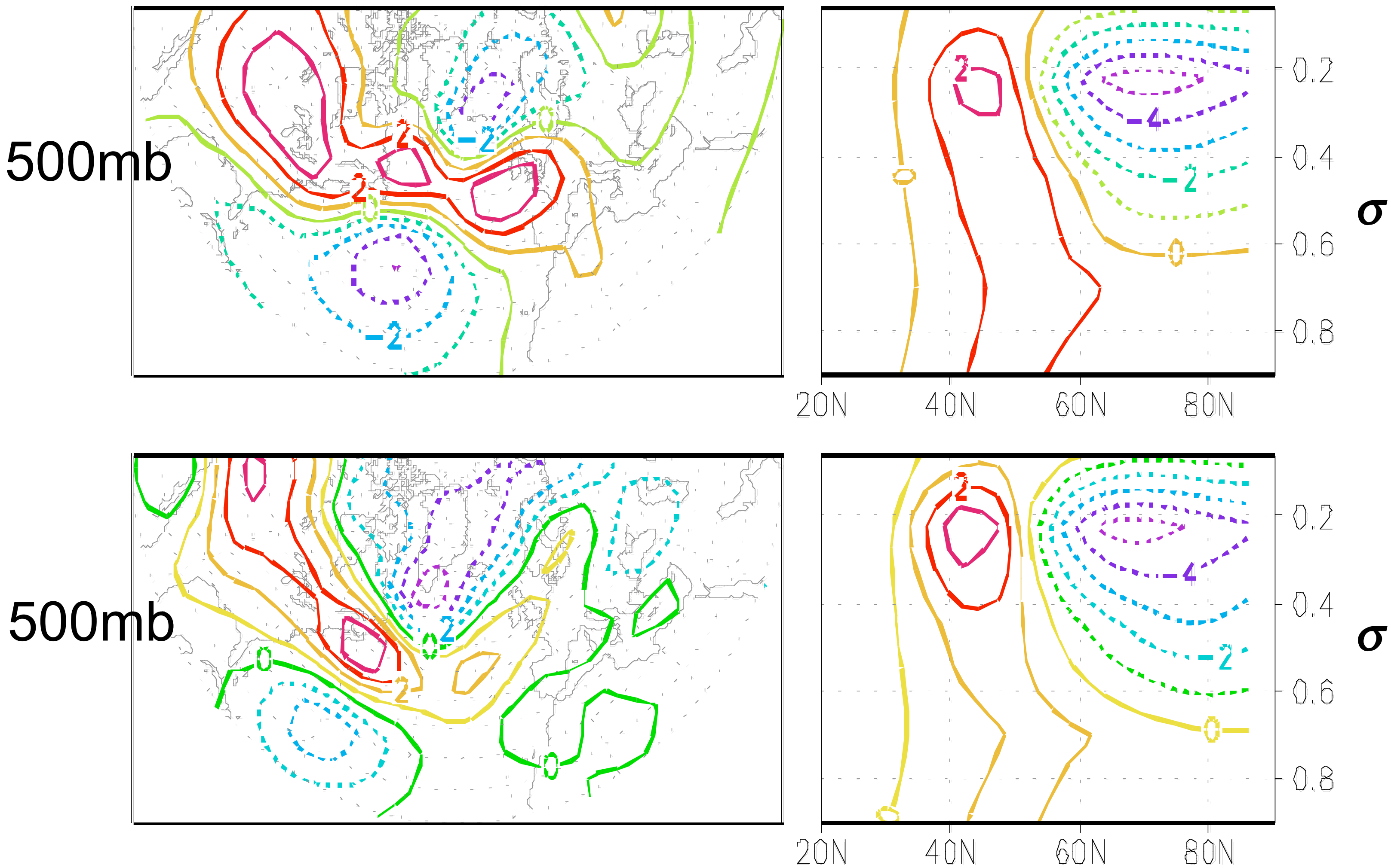


$$-\Delta^{-1}(\nabla\cdot(\overline{\vec{v}'\zeta'}^{c}))$$

Observed

Reconstructed

Observed eddy forcing related to NAO



Simulated eddy forcing related to NAO
by the new system based on a linear 5-layer-T21 PE model

Key undertaking is to formulate the SELF feedbacks in the physical processes of the climate models, for instance:

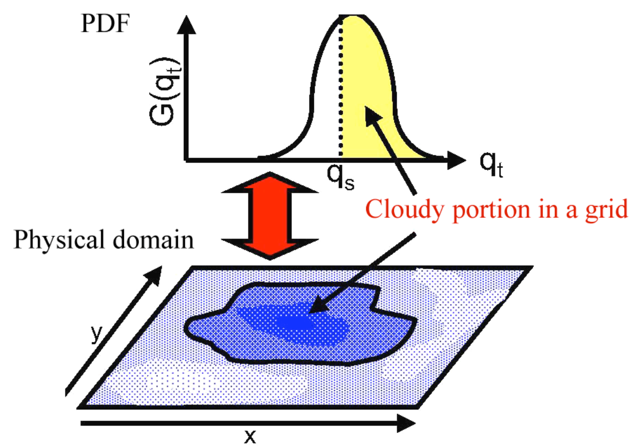
$$Q_a \approx G(X_c + X_c^{'})X_a + B(X_c + X_c^{'})F_a$$

$$< Q_a > \approx < G(X_c + X_c^{'}) > < X_a > + \frac{\partial G(X_c)}{\partial X} < X_c^{'} X_a^{'} > + \ldots$$

$$+ < B(X_c + X_c^{'}) > F_a$$

SELF feedback in physical processes

Large-scale condensation



'fast-condensation' adjustment

$$Q_h'^L = \frac{L}{\tau_l c_p} q_l' \quad , \quad Q_q'^L = -\frac{1}{\tau_l} q_l'$$

q_l' is a perturbation cloud water as determined by linearizing the subgrid-scale PDF of LeTreut and Li (1991).

$$q_l' = \begin{cases} q' - \dfrac{c_p}{L}\gamma T' & \text{for} \quad (1-b)\overline{q} > q_s(\overline{T}) \\ \mathcal{A}' & \text{for} \quad (1-b)\overline{q} \le q_s(\overline{T}) < (1+b)\overline{q} \\ 0 & \text{otherwise} \end{cases}$$

$$\mathcal{A}' = \frac{d\mathcal{A}}{d\overline{q}} q' = \frac{\Delta\overline{q}}{2b\overline{q}}\left[(1+b)q' - \frac{c_p}{L}\gamma T'\right] - \frac{\Delta\overline{q}^2}{4b\overline{q}^2} q'$$

$$\Delta\overline{q} = (1+b)\overline{q} - q_s(\overline{T})$$

$$\mathcal{A} = \frac{1}{2bq_w}\int_{q_s}^{(1+b)q_w} (\hat{q}_w - q_s)\, d\hat{q}_w = \frac{1}{4bq_w}\left[(1+b)q_w - q_s\right]^2$$

b is only the parameter which determines the PDF width (ordinary b=0.1-0.2).

Summary:

A new framework is proposed for modeling (predicting) climate variability as anomalies in the first(and second) moments of PDF.

Its usefulness is yet to be demonstrated by conducting hindcast and forecast experiments.