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BRED VECTOR APPLIED TO THE ATMOSPHERIC DYNAMICS

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Abstract: One remarkable conquer of science was the numerical weather prediction. However, some dynamics processes are not well represented in the simulation, generating a degradation of the forecasting. In addition, a chaotic atmospheric dynamics is also noted, with strong dependency of the initial condition. The initial condition is never known in a complete way. Indeed, the procedure to determine the initial condition in the operational prediction centers is called data assimilation, where the background fields (fore-casted atmospheric state) are combined with observations for producing the analysis – the new initial condition. The bred vector approach can be employed to investigate the sensitivity of a certain process in the atmospheric dynamics simulation, detecting the fastest-growing instabilities. The latter scheme is also applied to evaluate the goodness of the predicted dynamics, i.e., the breeding process is employed to evaluate the predictability. The bred vector is computed as the difference between reference and perturbed simulations for the dynamical system after a time period of integration. After the mentioned time integration period, the bred vector is scaled at the same size as the initial perturbation, and a new perturbed initial condition is added to restart the process. Several simulations using the SPEEDY model was done showing regions of instabilities for some prognostics variables.

keywords: Climate Dynamics, Numerical Simulation, Atmospheric dynamics, global circulation model, bred vector.

1. NUMERICAL WEATHER PREDICTION

The science of weather forecasting is a complex problem embracing different areas of study such us geophysics, thermodynamics, biological interactions, mathematics and others. The direct impact that mankind activities has on these interdependent phenomenons are increasing with the past of the years making changes in the climate equilibrium. The climate change can address most frequent and intense severe weather. The countries are studying several policies for adaptation and mitigation for these negative impacts. Under this scenario, the relevance of a good weather forecasting is increased.

The weather prediction process deals with a system of initial value problem of nonlinear differential equations. These mathematical modeling tries to capture the complex nature of the atmospheric dynamics. However, the model is not able to have a exact description of the dynamics. There are many challenges to be overcame: chaotic dynamics (strongly dependent from the initial condition), turbulence parameterization, formation and/or dynamics of clouds, surface representations, multi-scale phenomena, just to cite few of them.

Therefore, a previous evaluation of the goodness of the forecasting is searched. The forecasting evaluation can be quantified – predictability – by statistical methods, such as ensemble prediction, or Bred Vectors. The latter approach is suitable to quantify the quality of the forecasting, and it can be applied for further analysis such as the detection of instability regions and the influence of a certain meteorological variable in the dynamics.

2. BRED VECTORS

Breeding method has been used since 1992 to generate perturbation for ensemble forecasting at the NCEP, where the method simulates the development of growing errors in the analysis cycle [4]. This method, developed by Toth and Kalnay initially in the context of atmospheric data assimilation, make possible to find those perturbations that grows naturally in the system [5].

The Bred Vectors are computed as follows - see fig 1, there are reference $F(\vec{x};t)$ and perturbed $\delta F(\vec{x};t)$ models, where the initial state of the second model is slightly different. The vector $\vec{x}$ represent the vector state of the model, i.e., sea surface temperature (SST), surface pressure, wind fields, temperature, density, and moisture.

Both models are integrated forward in a time interval ΔT. The difference between these two nonlinear dynamics are called Bred Vectors. At the time step ΔT, known as "breeding interval", the bred vector are scaled down to the same size as the initial perturbation, and added to the control (reference) unperturbed model, generating a new perturbed mode. The time integration process is restarted and, after the same interval ΔT, a second bred vector is computed.

The process is repeated in cycles until the difference between the bred vectors. It is possible to verify some saturation, where the bred vector is approximately constant. At this point, the bred vectors created are approximations of the Leading Lyapunov Vectors (L.L.V.) and like them are independent of the size (norm) chosen initially to generate the perturbation [5].

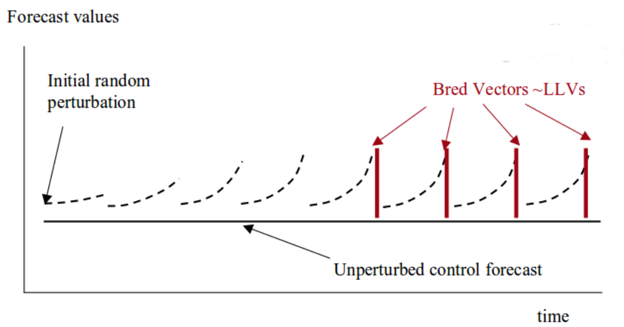

Figure 1 – Temporal Series of the Bred Vector in action. Source: [3]

The breeding method can insulate and to identify aspects of time-depend of nonlinear system flows. Such features are unstable to small perturbations. In addition, the bred vector are linked with high and low predictability – see [6].

3. THE SPEEDY MODEL

The SPEEDY (**S**implified **P**arametrization, privitiv**E-E**quation **DY**namics) code [1], is an Atmospheric Global Circulation Model (AGCM) developed by the International Centre for Theoretical Physics (ICTP), Triesty (Italy), based on a spectral dynamical core, with a simplified set of physical parametrization schemes. The model is used for the dynamics study of the atmosphere at global scale close to numerical weather models employed in the prediction Centers [2].

The configuration of the model was T30L7, corresponding to a horizontal resolution with triangular spectral truncation at total wave-number 30 (T30), and standard Gaussian grid of 96 (longitude) by 48 (latitude) points, with seven vertical vertical pressure levels (100, 200, 300, 500, 700, 850, 925 HPa) [1, 2].

The prognostic variables of input and output model are the absolute temperature (*T*), surface pressure (*ps*), zonal wind (*u*), southern wind (*v*), and specific humidity (*q*) [2].

4. RESULTS AND DISCUSSION

The period of simulation was from 01/Jan/1982 00 UTC up to 07/Jan/1982 18 UTC, where the data assimilation has a cycle of 6 Hs. The forecasting fields are saved at every 6 Hs. The perturbed model was defined adding 10% in the initial of all variables from control state. The difference between the averages calculated in entire temperature domain of the two models was chosen as a norm, and it was observed a random variation of $O(10^{-3})$ on the full time integration interval.

Figure 2 and 3 show bred vectors at 06 UTC for the initial day (01/Jan/1982) and the last day (07/Jan/1982) of simulation. Large changes in the temperature field at the mid-latitudes regions can be observed, especially in the north of Canada and Europe.

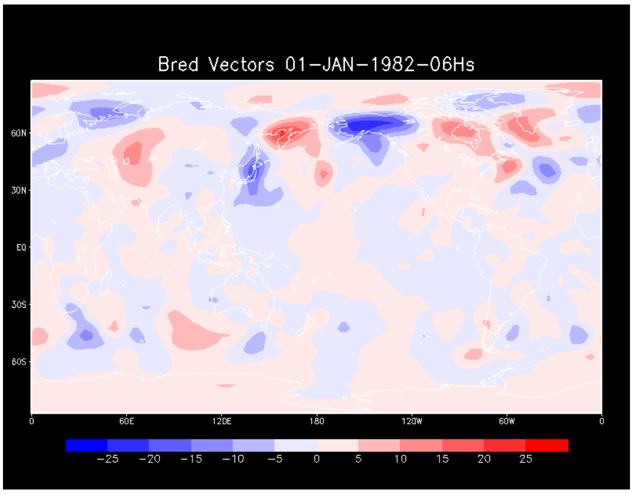

Figure 2 – Bred Vector: Temperature field at 01/Jan/1982, 06 UTC.

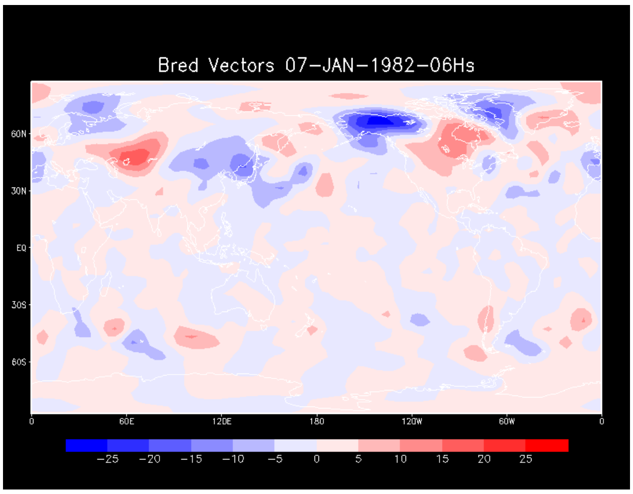

Figure 3 – Bred Vector: Temperature field 07/Jan/1982, 06 UTC.

Figures 4 and 5 show the bred vectors for the vorticity at 06 UTC for the day (01/Jan/1982) and the last day (07/Jan/1982). Similar patterns can be visualized, but with smaller intensity for the both Hemispheres.

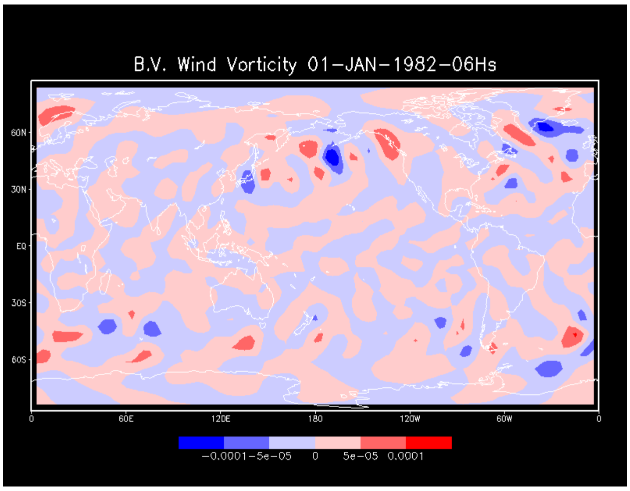

Figure 4 – Bred Vector: Vorticity field at 01/Jan/1982, 06 UTC.

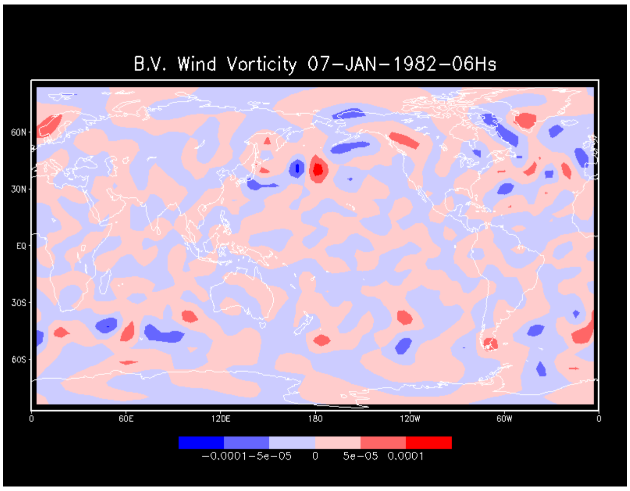

Figure 5 – Bred Vector: Vorticity field at 07/Jan/1982, 06 UTC.

Bred vectors computed by the surface pressure field is shown in Figures 7 and 6. The variation is more intense and the its significance is spread for entire globe. The differences become explicit the instabilities.

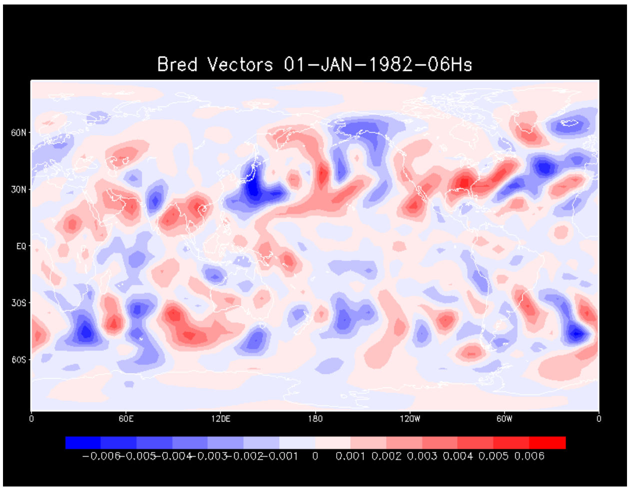

Figure 6 – Bred Vector: Pressure field at 01/Jan/1982, 06 UTC.

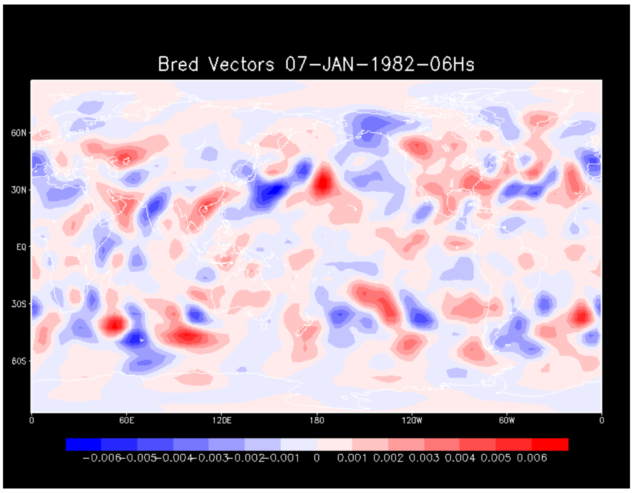

Figure 7 – Bred Vector: Pressure field at 07/Jan/1982, 06 UTC.

5. CONCLUSION

The breeding technique was applied to the SPEEDY model. The model simulates the atmospheric dynamics for the Earth. The bred vector method indicates the regions with high and low predictability, regions with small and large bred vector magnitude – respectively. Temperature and vorticity presented similar results. The analysis for the pressure field showed significant magnitudes for all planet.

6. ACKNOWLEDGMENTS

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