Weather Regimes: Part I

- What are weather regimes?
  - Interpretation of weather regimes
  - Implication for climate prediction
- How do we identify weather regimes?
- Application of weather regimes in S2S prediction

Impacts of Weather Regimes

- Weather regimes have strongly impacts on precipitation and near-surface temperature.
  - For example, fire risk is substantially increased in WR1 (west coast ridge) and reduced in WR3 (Pacific trough)

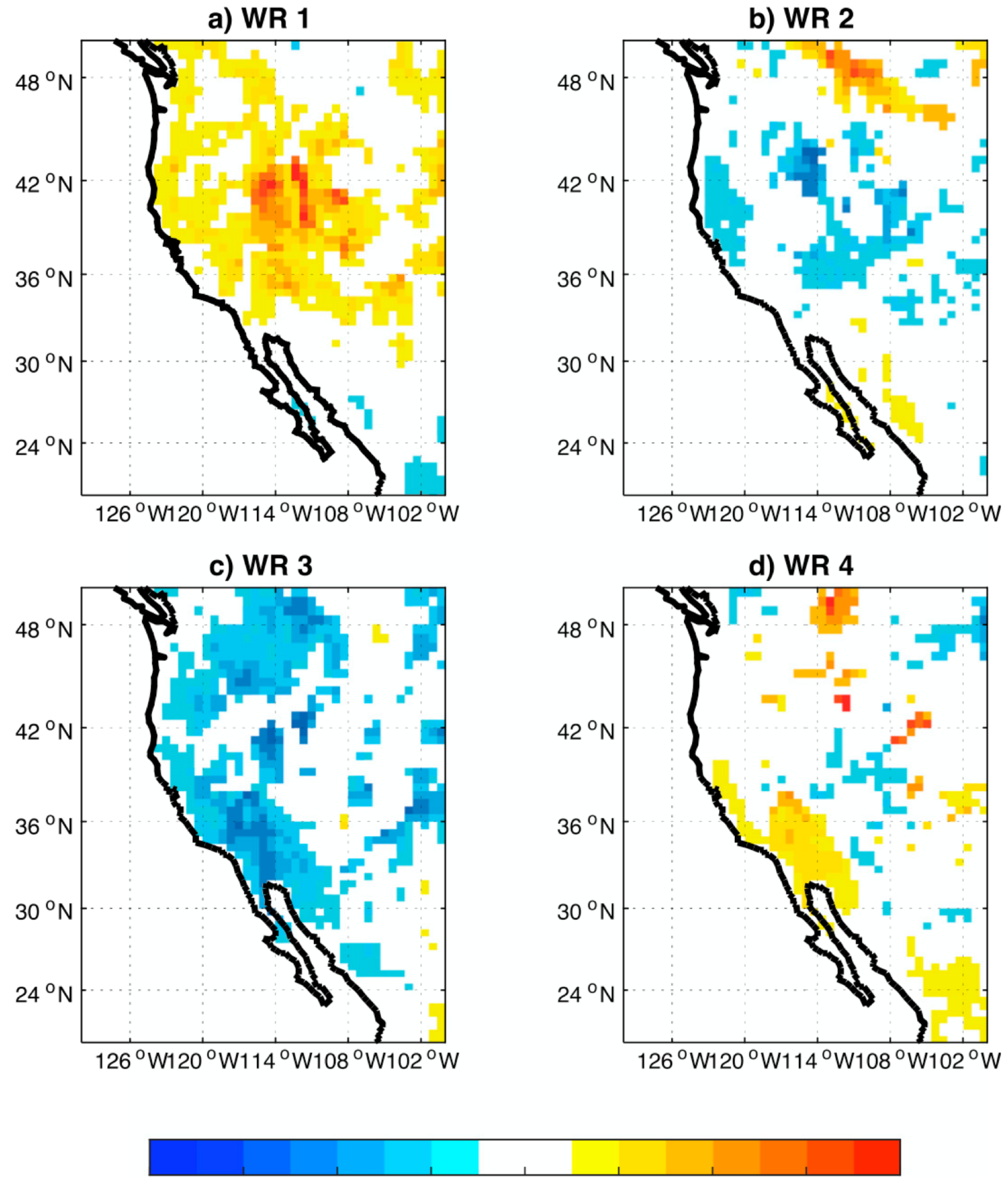


FIG. 2. Regime composites of fire weather index (dimensionless), expressed as deviations from the 1982–2014, October–March long-term average.

What are weather regimes?

- Weather regimes are quasi-stationary, recurrent atmospheric patterns, or the states of the atmosphere with high probability of occurrence (Michelangeli et al., 1995).

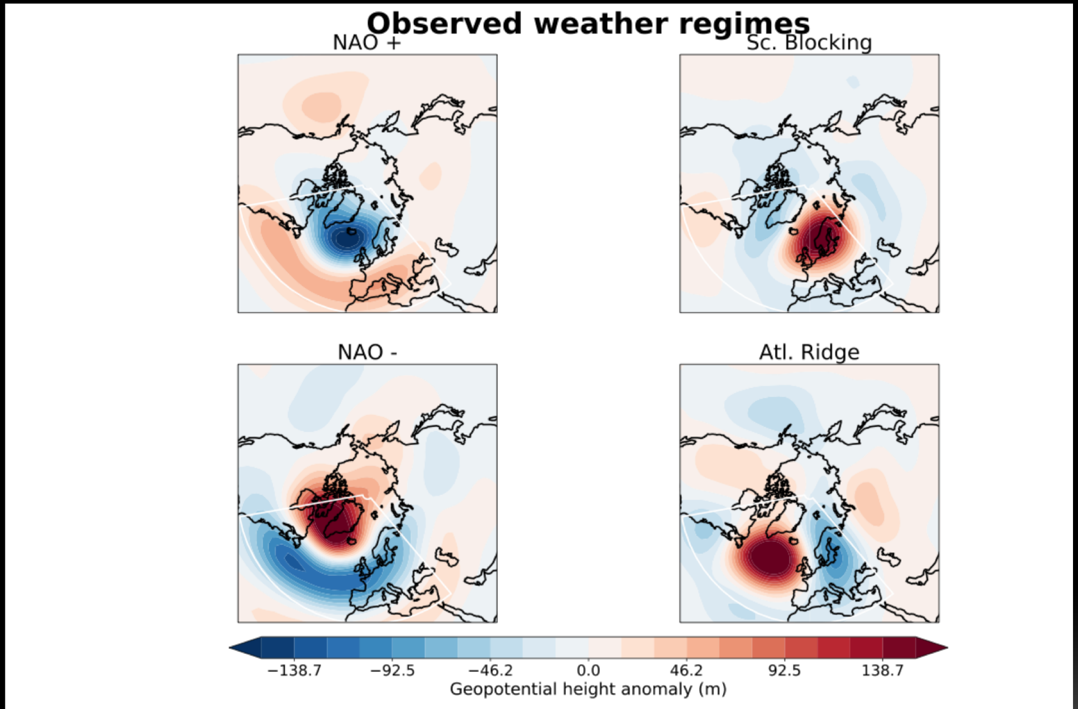


Figure 2. Spatial patterns of the four regimes defined by the cluster centroids for ERA-Interim (1979-2010), when using 10 EOFs in the phase space decomposition.

Strommen et al. 2019

Four weather regimes are often identified over the North Atlantic in boreal winter:

- the negative phase of the NAO (NAO-)
- the positive phase of the NAO (NAO+)
- Atlantic ridge
- Scandinavia blocking

Note that different from the EOF analysis

- the NAO+ and NAO- regimes have slightly different spatial patterns (not simply a mirror image of each other)
- The clusters are not orthogonal to each other.

What are weather regimes?

- The underlying assumption is that the large-scale atmospheric circulation can be approximately represented by a finite number of states, an assumption supported by theoretical work on the existence of multi-equilibria of the climate system (Charney & Devore, 1979).
- “Oscillations” and weather regimes represent two complementary views of atmospheric low-frequency variability.
  - (i) episodic, by means of multiple weather regimes or flow regimes, the duration and recurrence of a weather regime are fairly irregular
  - (ii) oscillatory, by means of broad-peak slowly modulated oscillations, have a more or less repetitive, quasi- periodic character (such as the ENSO, MJO and NAO)

Phase Space: Regimes vs. Oscillations

- In the phase space of the atmospheric state, oscillations are closed trajectories or limit cycles, while weather regimes are blotches of high probability density function (i.e., high concentrations of points, each point represents an atmospheric map),

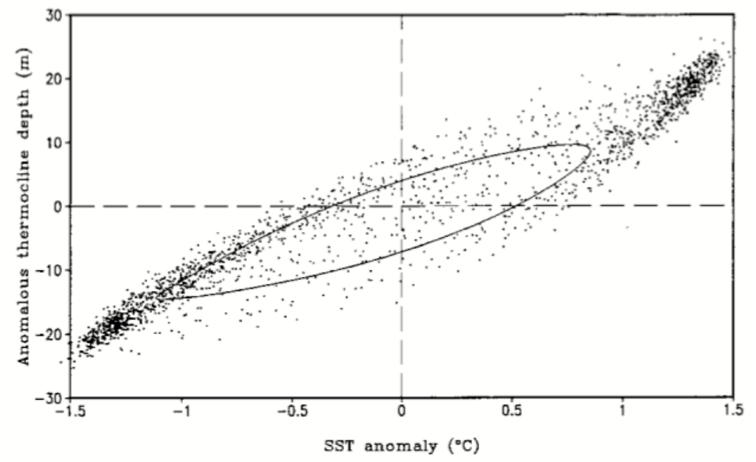


FIG. 6. The phase orbit of the limit cycle without stochastic forcing (solid curve) and the phase-scattering diagram showing the stochastic response of the ENSO system in the same limit cycle regime (point B in Fig. 2).

Wang et al. 1999

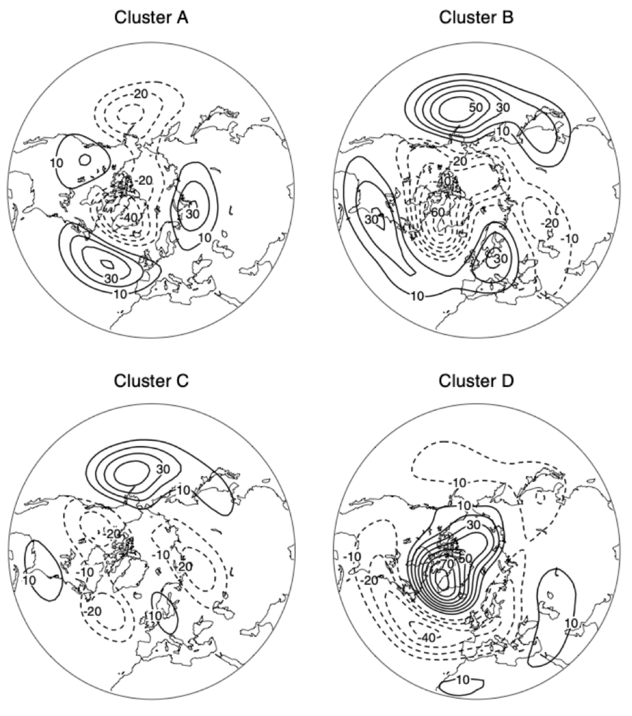
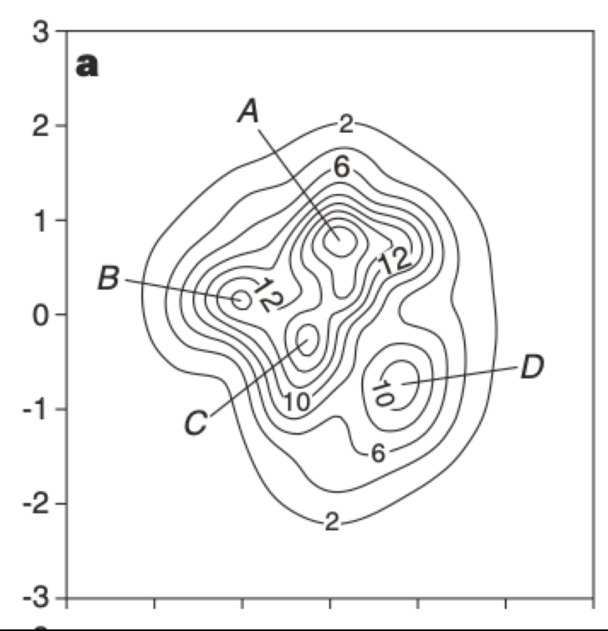


Figure 3 Geographical patterns of the four atmospheric regimes. Shown is the geographical distribution of 500-hPa geopotential height anomaly associated with clusters A (The "cold ocean warm land" regime) B, C and D (the "Arctic Oscillation" regime). Contour interval, 10 m.



The atmospheric state vector PDF based on monthly-mean 500-hPa geopotential height in the space spanned by the two dominant atmospheric EOFs computed from detrended monthly mean timeseries. From Corti and Palmer 1999

Complementarity of Regimes and Oscillations

- A regime may be the slow phase of a limit cycle (Ghil and Robertson 2002).
- Regime and oscillations may co-exist in the atmosphere.

Regimes as the slow phase of a limit cycle

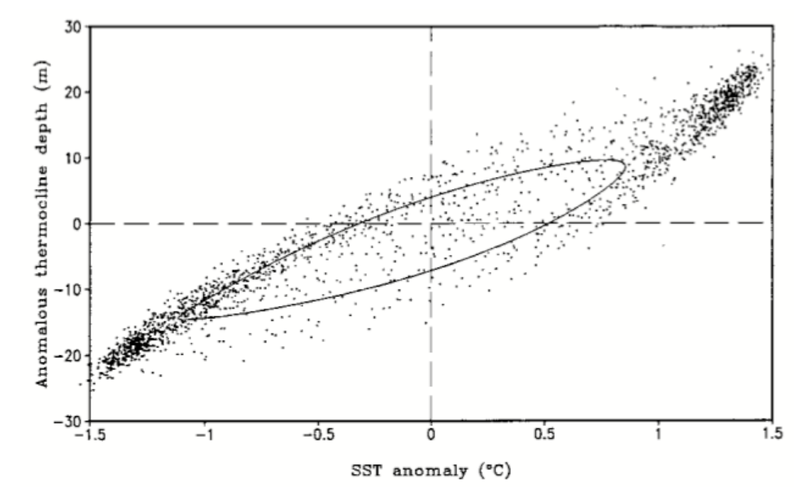


FIG. 6. The phase orbit of the limit cycle without stochastic forcing (solid curve) and the phase-scattering diagram showing the stochastic response of the ENSO system in the same limit cycle regime (point B in Fig. 2).

Wang et al. 1999

Coexistence of a fixed point (regime) and a periodic orbit (oscillation)

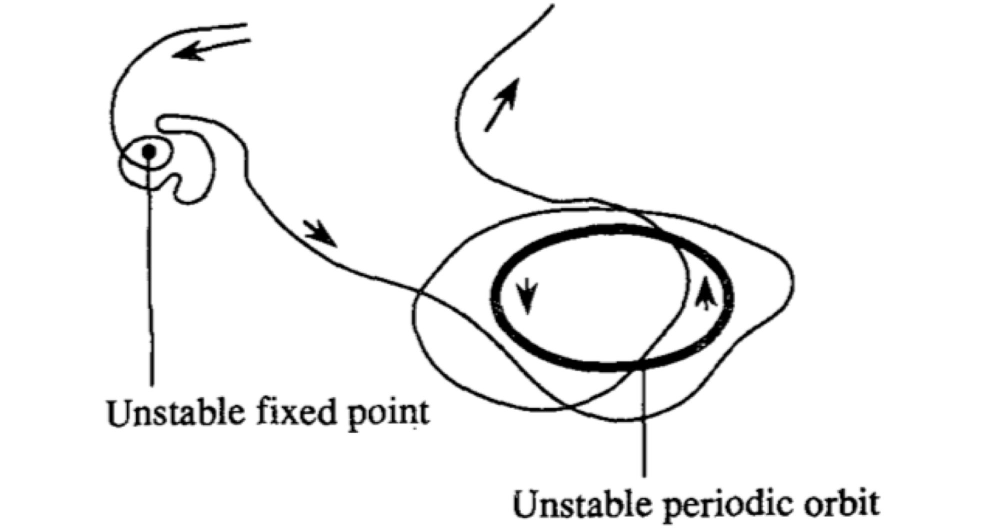


FIG. 1. Schematic diagram representing the evolution of the trajectory of a dynamical system in which there is an unstable fixed point and an unstable periodic orbit.

Plaut and Vautard 1994

Implications for Climate Variability

- It is generally believed that the spatial patterns of weather regimes are determined by the internal dynamics of the atmosphere, while low-frequency climate modes, boundary forcing (e.g., SST), and external forcing (e.g., anthropogenic forcing) may modulate the frequency of occurrence of WRs (Michelangeli et al., 1995; Molteni & Palmer, 1993).
- Climate variability/change can be regarded as the changes in the frequency/probability of weather regimes

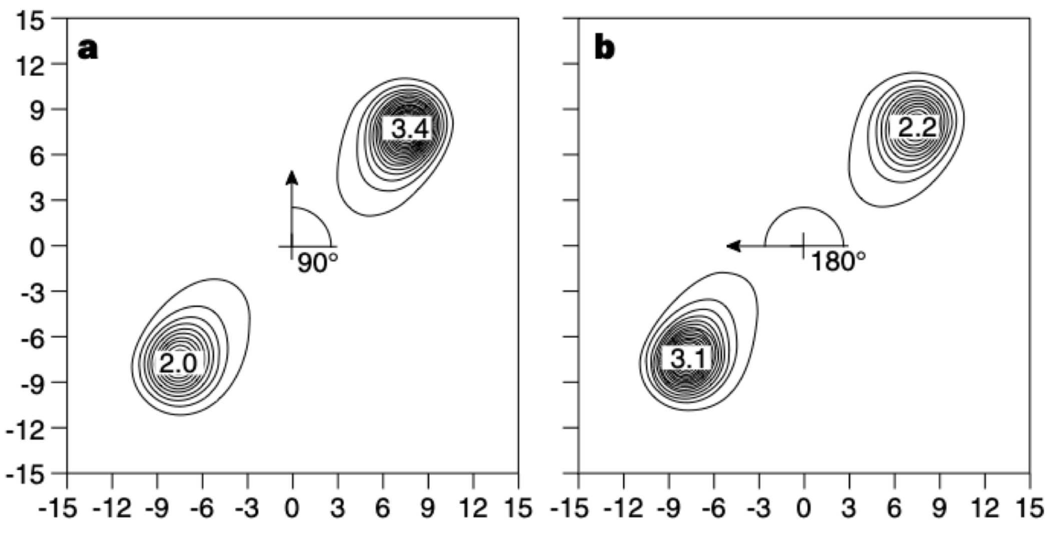
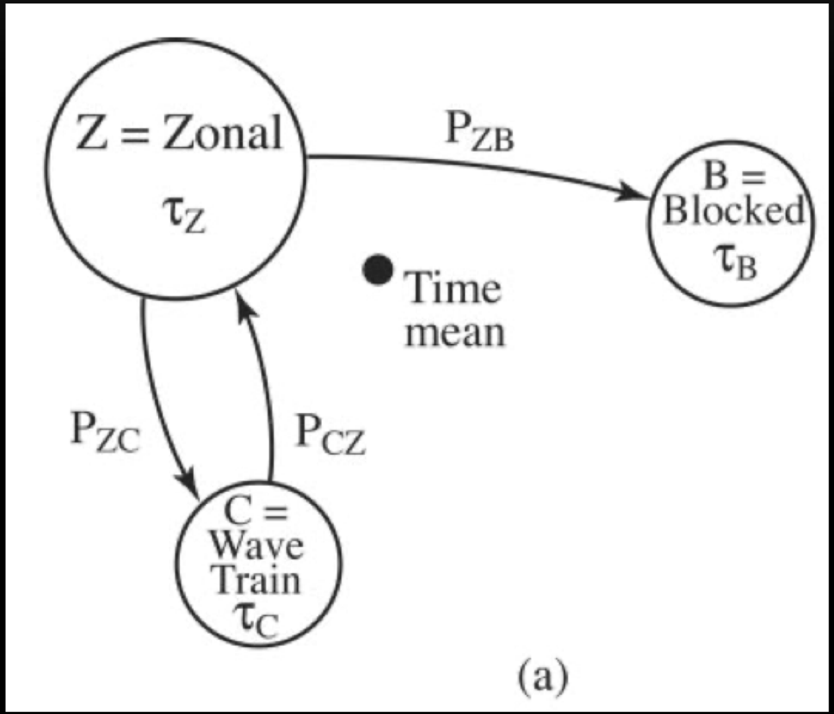


Figure 1 Response of a nonlinear chaotic model to imposed forcing. Illustrated is the state vector PDF (invariant measure) of a forced Lorenz[3] attractor, with governing equations $\dot{X} = -10X + 10Y + 2.5\cos\theta$, $\dot{Y} = -XZ + 28X - Y + 2.5\sin\theta$, $\dot{Z} = XY - (8/3)Z$, in X, Y phase space. The arrow shown is the forcing vector $(2.5\cos\theta,\ 2.5\sin\theta)$ in this two-dimensional phase space. A short running time-average has been applied to the state vector to emphasise the regime character of the Lorenz attractor. **a**, $\theta = 90°$; **b**, $\theta = 180°$. The numbers shown correspond to maxima of the PDF at the regime centroids. The quantities plotted on the horizontal and vertical axes are values of X and Y respectively. See ref. 3 for details.

From Corti and Palmer 1999

Implications for Climate Prediction

- Weather regimes are characterized by a large spatial scale and often persist beyond the lifetime of weather systems. A persistent weather regime may induce extreme or severe weather (Miller et al. 2020).
- The Markov-chain view of low-frequency variability: the existence of multiple regimes, the expected residence time in each regime, and the probabilities of transition from one regime to another provide the basis for long-range forecasting (Ghil and Robertson 2002).
- Studies have also suggested that certain pathways of transition between weather regimes are more probable than others (Namias 1968; Kalnay and Livezey 1985), which implies potential predictability of the weather regimes.
- It was consistently found that transitions between regimes tend to avoid, rather than favor, passages through the climatological mean.



Schematic Markov chain with three regimes, B, C, and Z. (*a*) Some preferential paths between pairs of regimes are shown, along with the corresponding transition probabilities, for instance *p*ZB. (Ghil and Robertson 2002)

References

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