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# Monsoon Forecast Under Climate Change

Delhi, IMD, 22<sup>th</sup> June, 2018

# Outline

1. Critical Transition & Critical phenomena
2. Spatially organized critical transitions.  
Tipping Elements approach for prediction of the Indian Summer Monsoon
3. Forecasting upcoming monsoon: observational evidences
4. Climate change effects

«The onset of monsoon.. Is not a transition from a regime of no rain to rain; it is a *critical* transition from a regime of sporadic rainfall to spatially organized and temporally sustained rainfall...»

R. Ananthakrishnan and M.K. Soman, 1990

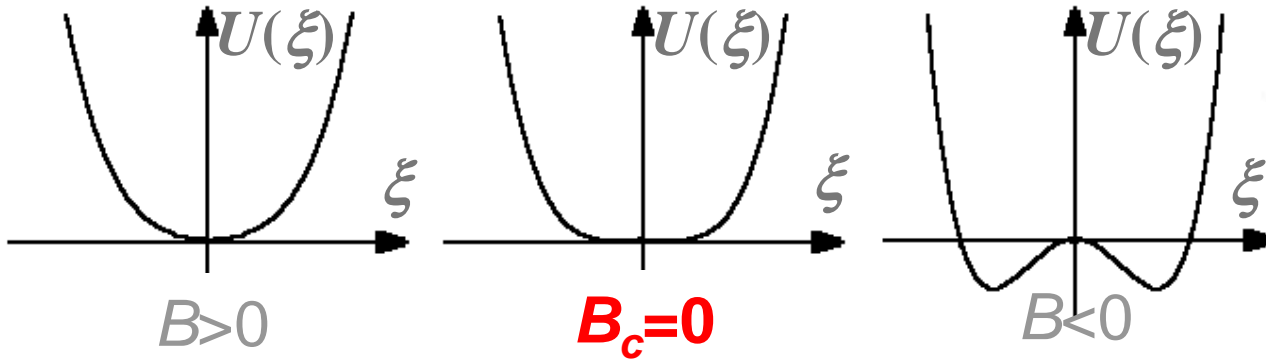
# The Treasure of San Gennaro (1966)

Operazione San Gennaro (original title)

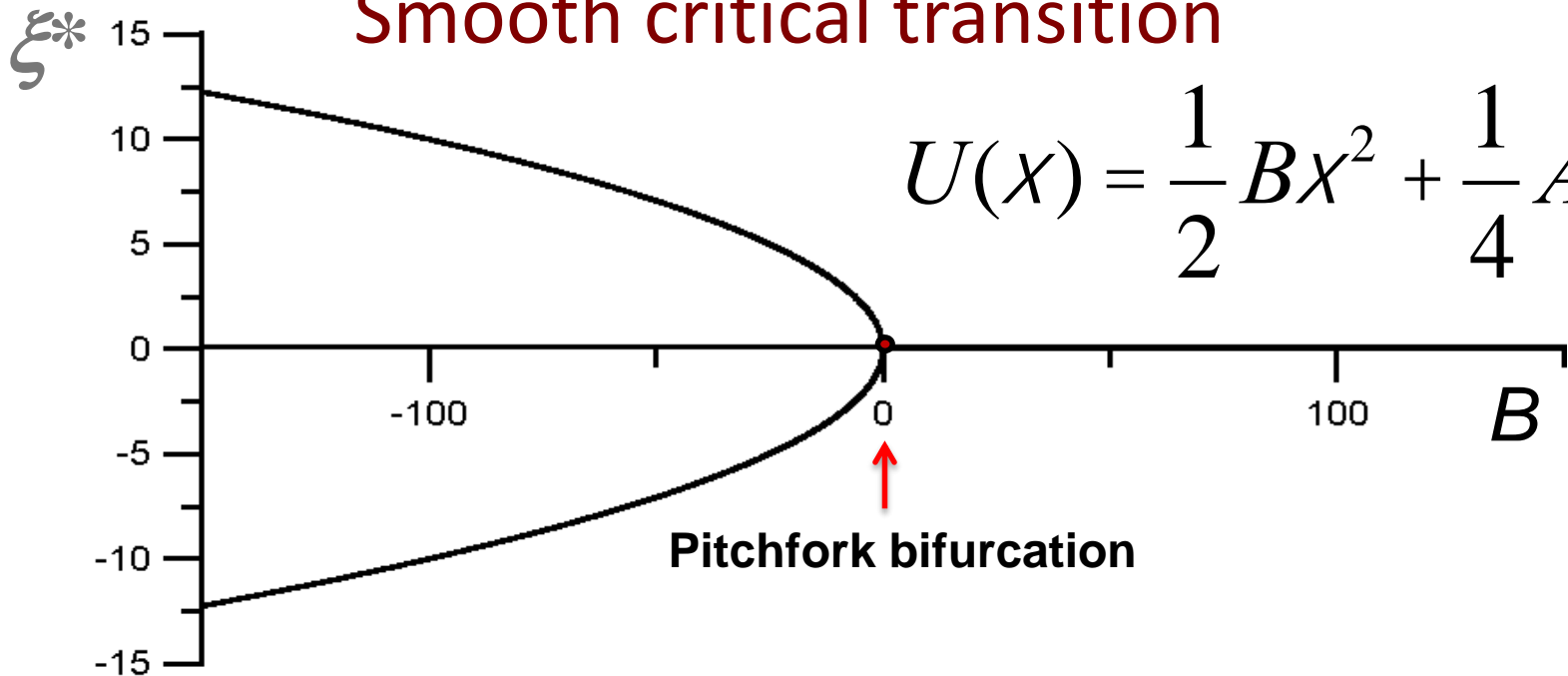


An American gangster in Italy enlists a local gang to help him steal the treasure of Naples' patron saint.

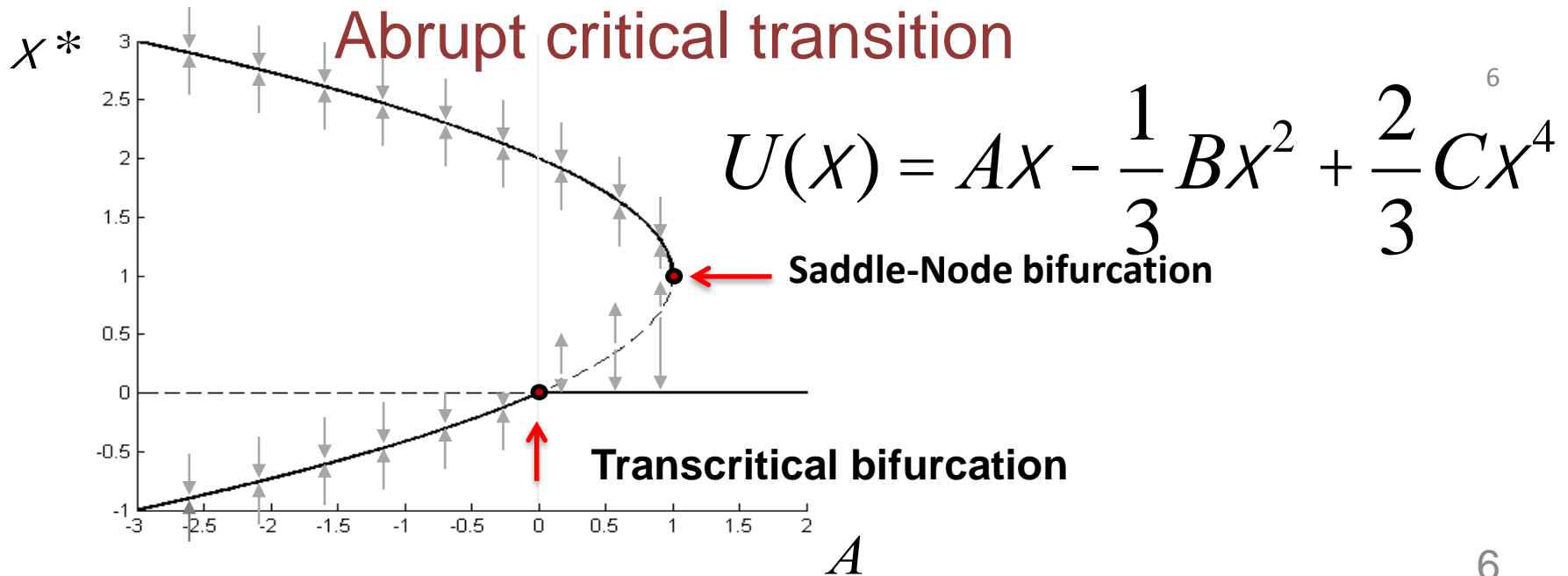
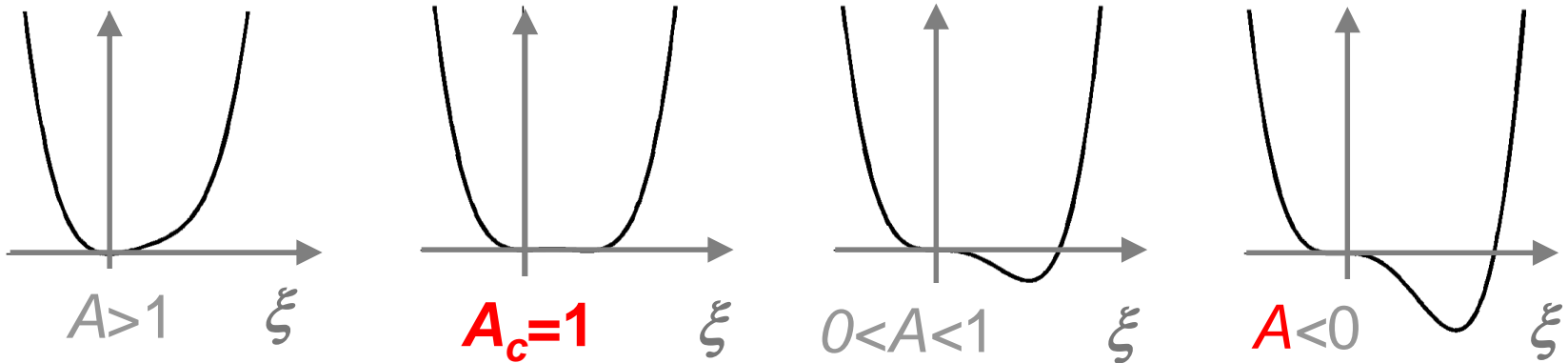
$$\ddot{\xi} + 2\gamma\dot{\xi} + \frac{dU}{d\xi} = 0$$



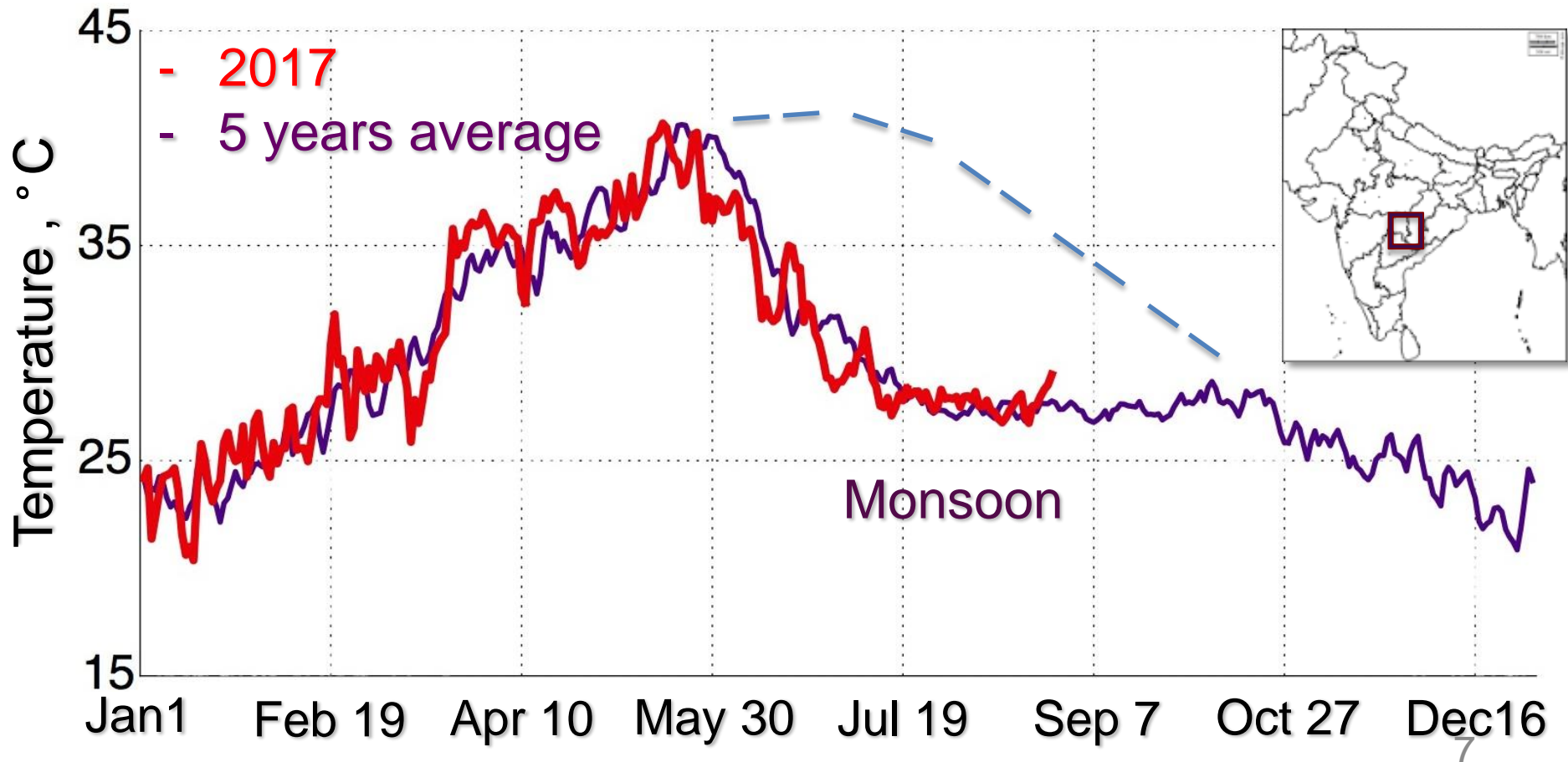
**Smooth critical transition**



$$\ddot{\xi} + 2\gamma\dot{\xi} + \frac{dU}{d\xi} = 0$$



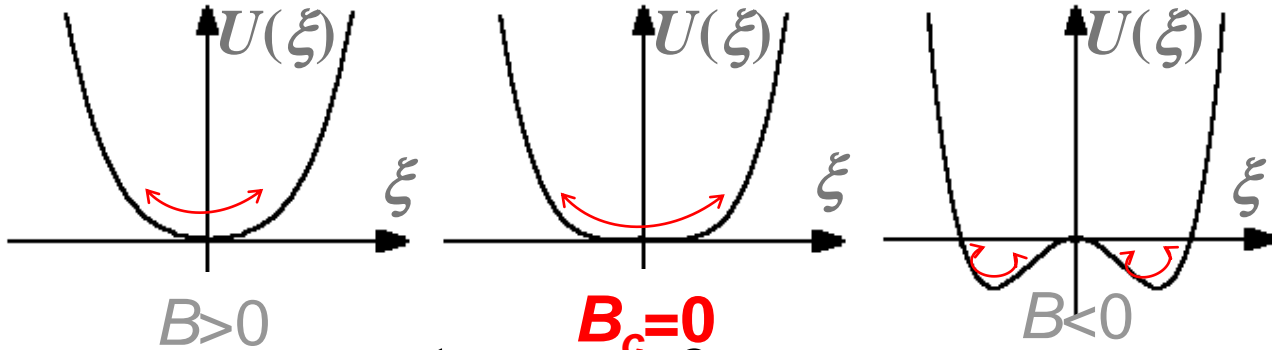
Is it a critical transition from a regime of sporadic rainfall to spatially organized and temporally sustained rainfall?



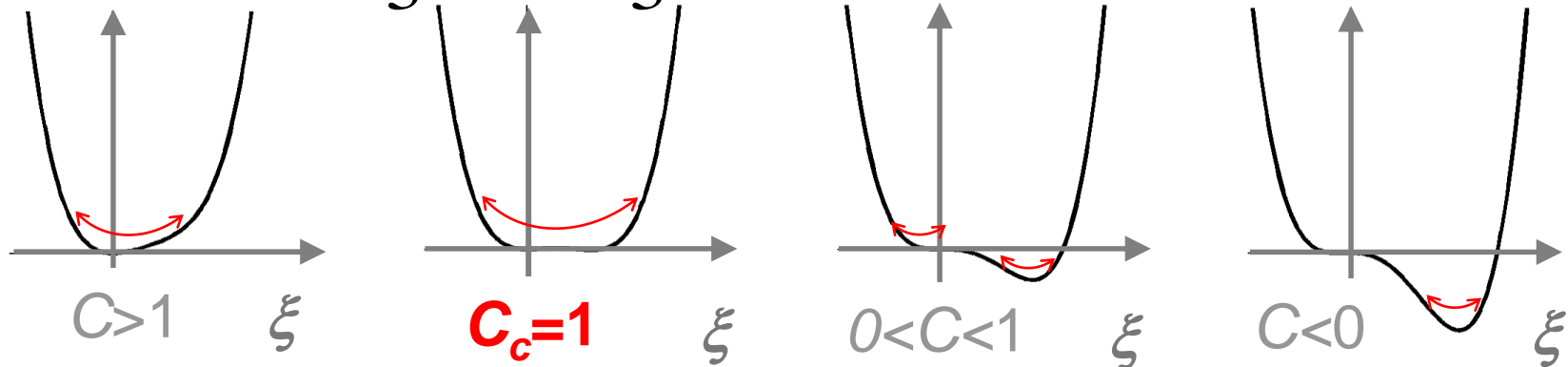
# Critical fluctuations

$$\xi + 2\gamma\xi + \frac{dU}{d\xi} = f(t) \text{ -noise}$$

$$U(x) = \frac{1}{2}Bx^2 + \frac{1}{4}Ax^4$$

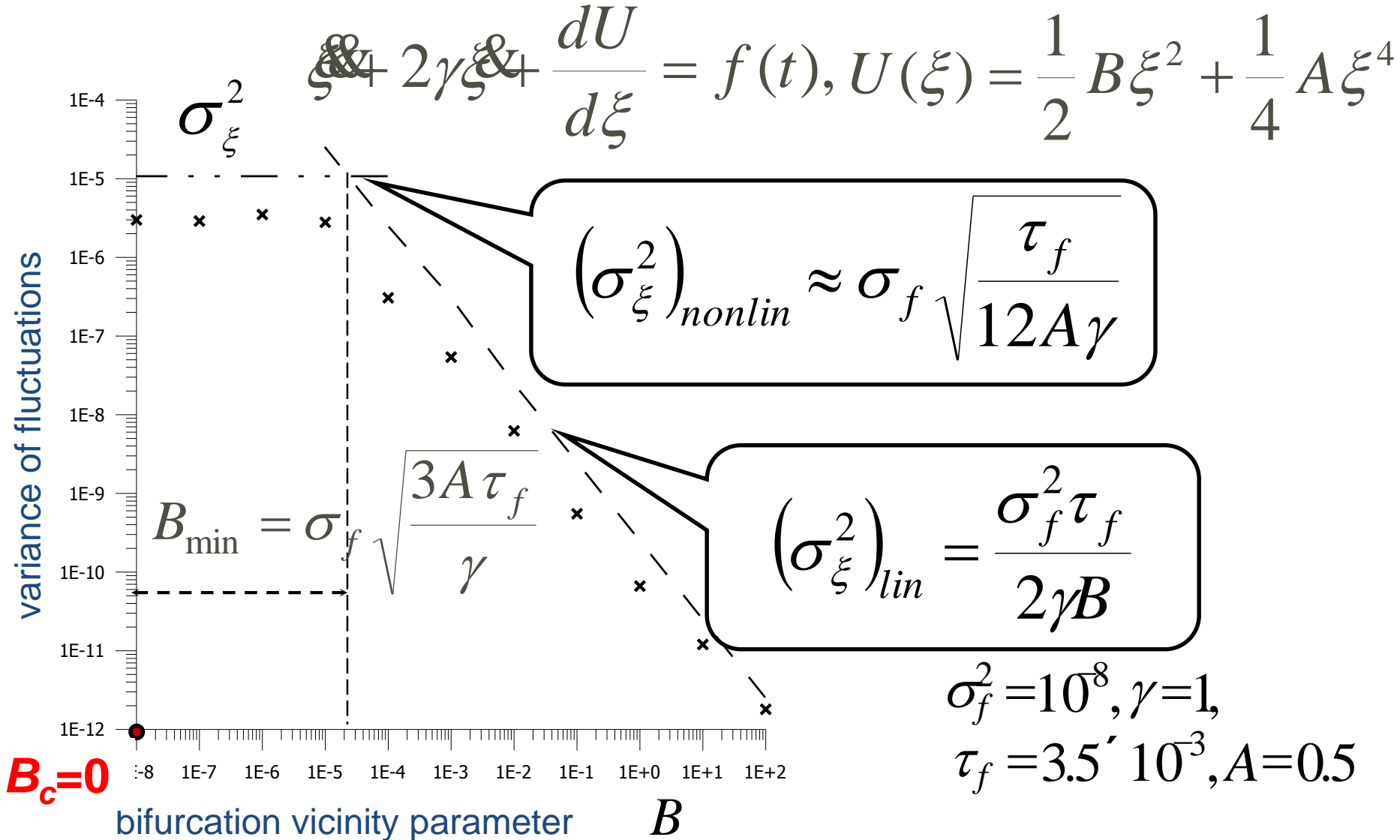


$$U(x) = Cx - \frac{1}{3}Bx^2 + \frac{2}{3}Ax^4$$





# Pre-bifurcation growth of fluctuations in the nonlinear oscillator



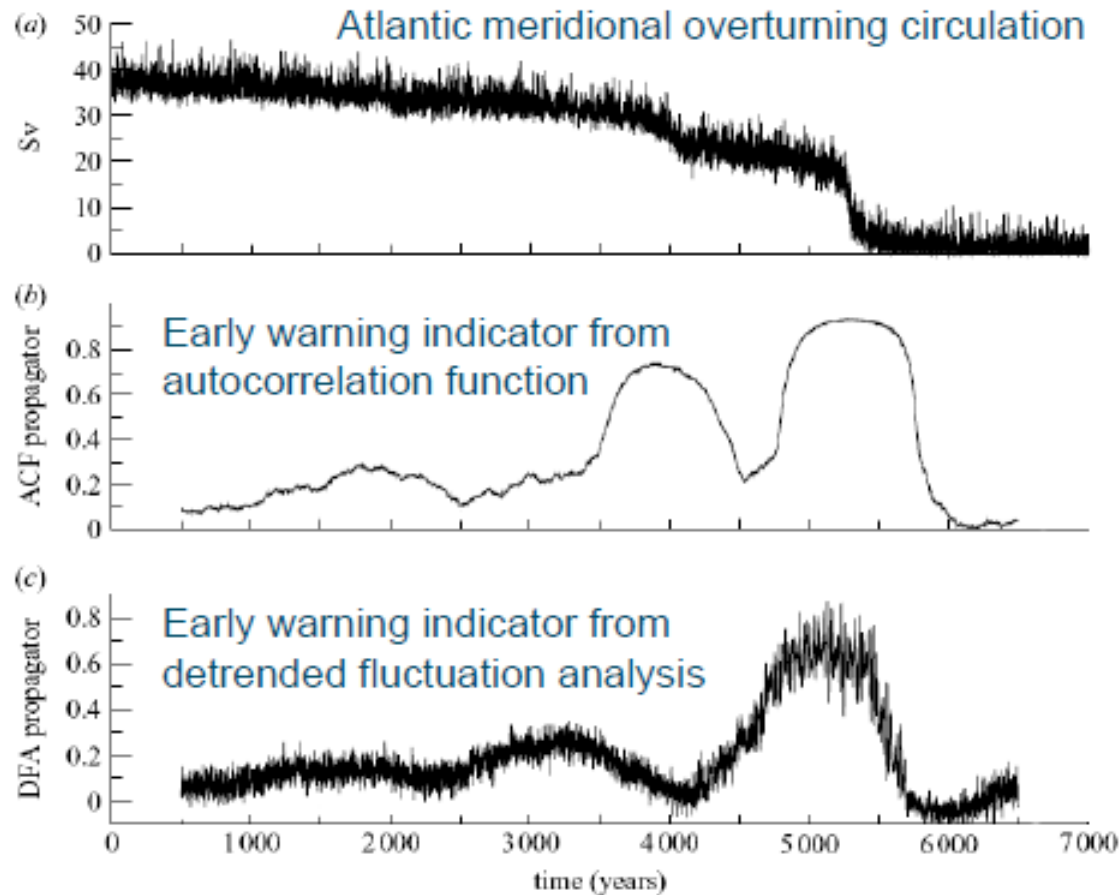
# Critical phenomena

- Pre-bifurcation growth and saturation of fluctuations  
Kravtsov Yu.A. , Surovyatkina E.D. , Phys. Lett. A 319 (3–4), (2003) 348.  
Surovyatkina E.D. , Kravtsov Yu. A. and Kurths Jü., Phys. Rev. E, 72, 046125 (2005)
- Pre-bifurcation rise and saturation of the correlation time of fluctuations  
Surovyatkina E.D. , Phys. Lett. A 329, (2004) 169.
- Rate–depended critical phenomena  
Majumdar Apala , Ockendon John , Howell Peter and Surovyatkina Elena.  
Transitions through Critical Temperatures in Nematic Liquid Crystals. Phys. Rev. E. 88, 022501 (2013)

# Early warning indicators

## Fully 3-D dynamical model test

Lenton *et al.* (2009) *Phil. Trans. A* 367: 871-884



August 24, 2010

GENIE-2 model

"We do not yet have an example where early warning signals were used to avert an upcoming shift (they have been used in models, experiments or retroactively)".

Early Warning Signals of Ecological Transitions: Methods for Spatial Patterns.  
[Kefi et al.(2014)]

In our study, we make a step forward in this direction. In contrast to traditional approaches to use precursors for a prediction of the time of the critical transition, we use precursors to find regions where conditions for a critical transition originate.

- Where (geographically) do critical conditions originate?
- How do the critical conditions propagate in space?

## 2. Spatially organized critical transitions: Tipping Elements approach for prediction of the Indian Summer Monsoon

# What does the term 'tipping' mean?

One of the definitions of tip

- *overbalance or*
- *cause to overbalance*

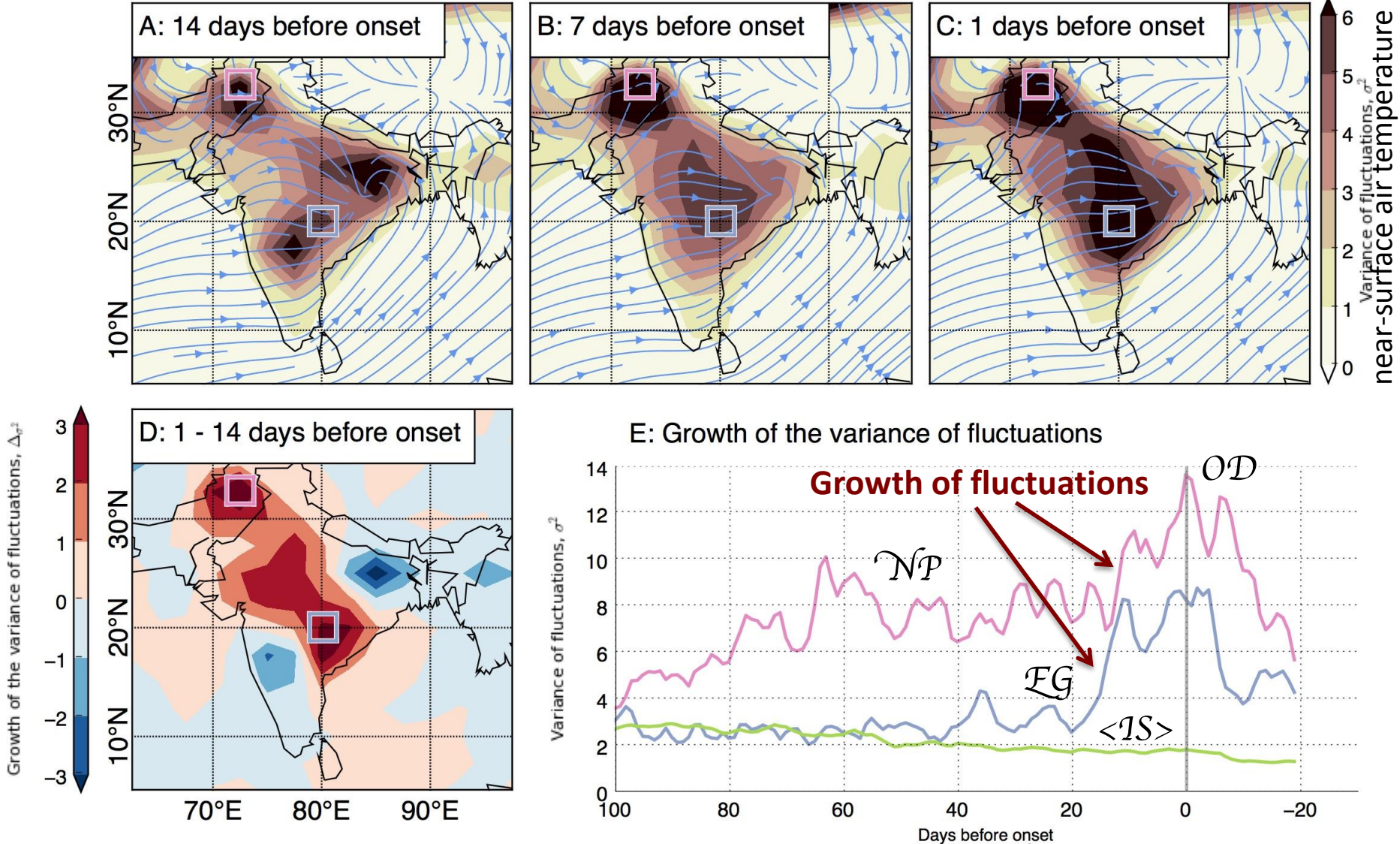
*“The hay caught fire when the candle tipped over.....”*



- ✓ The candle is an origin of the problem – *a tipping element of the system.*
- ✓ The time when the candle tipped over is *a tipping point.*
- ✓ An open window which gives the direction of flame propagation is *the second tipping element of the system.*

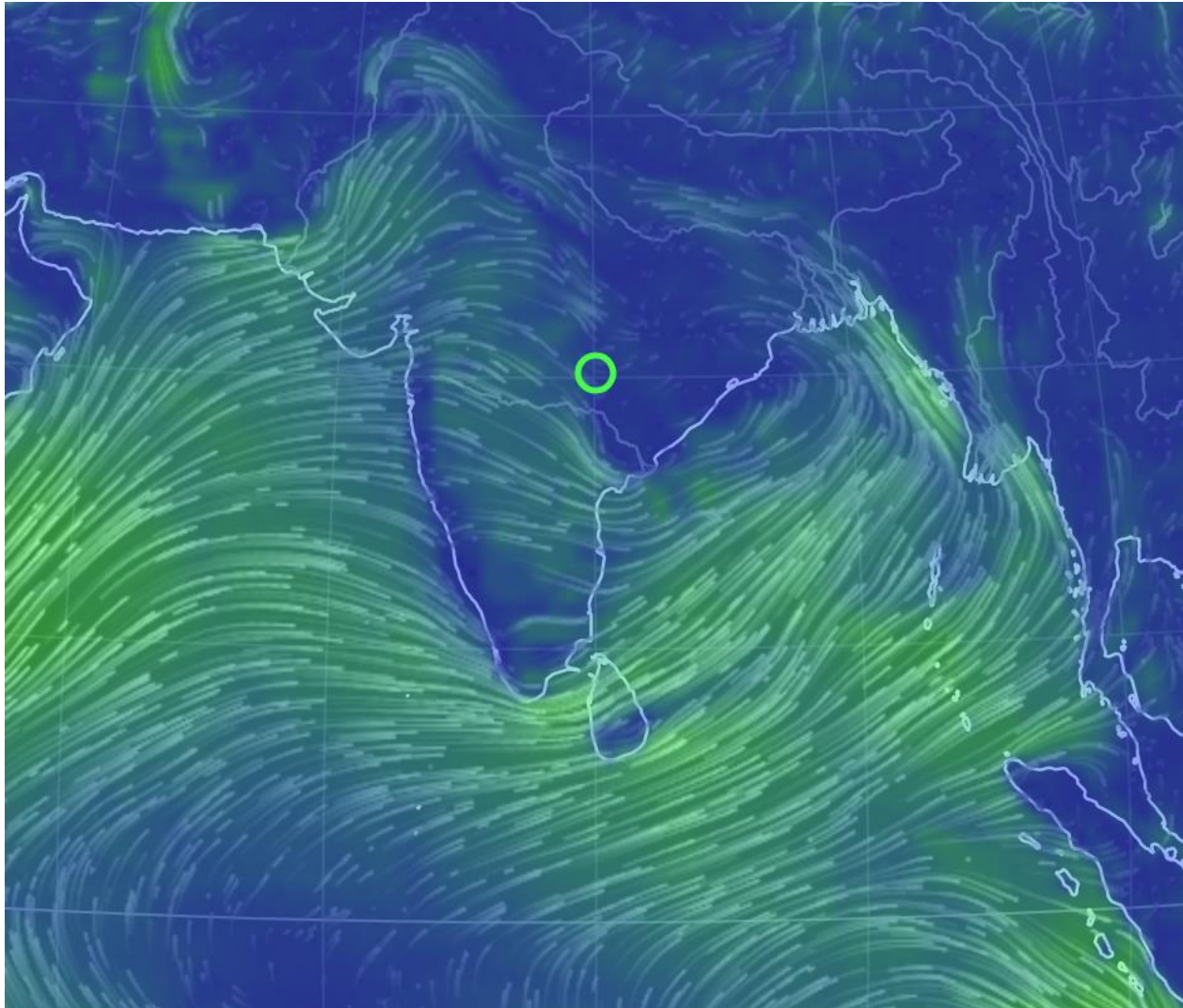
# Tipping elements and prediction of monsoon

DATA: ERA40: near-surface air temperature, 0.25°/0.25° resolution, (1958-2001)



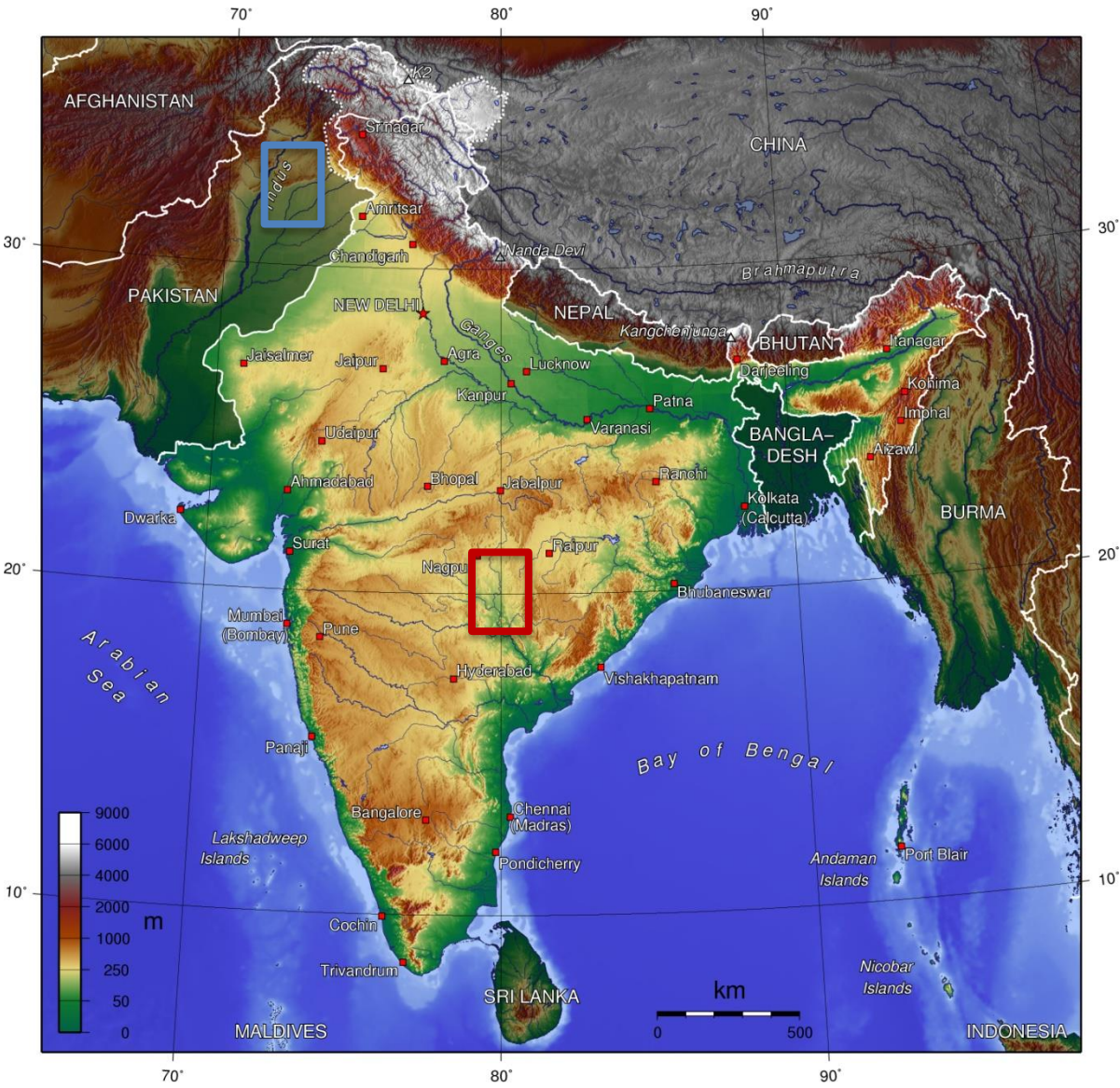
• Stolbova V., Surovyatkina E., Bookhagen B., Kurths J., Tipping elements of the Indian monsoon: prediction of onset and withdrawal. Geophysical Research Letters 43, 1–9, 2016, 2016

• Surovyatkina E.D., Kravtsov Yu. A. and Kurths J., Phys. Rev. E, 72, 046125 (2005)



<https://earth.nullschool.net/#2016/06/17/0300Z/wind/isobaric/1000hPa/orthographic/c=78.74,8.05,626/loc=80,20>





North Pakistan (32.5N,72.5E) is the tipping element of ISM where the ISM ceases to exist.

The Eastern Ghats (20N, 80E) is the tipping element of the ISM where we deliver our forecast of monsoon onset on **May 6**.

Stolbova V., Surovyatkina E., Bookhagen B., Kurths J., Tipping elements of the Indian monsoon: prediction of onset and withdrawal. *GRL*, 43, 1–9, April 20, 2016

# Networks analysis

Stolbova V. et al., NPG, 2014.

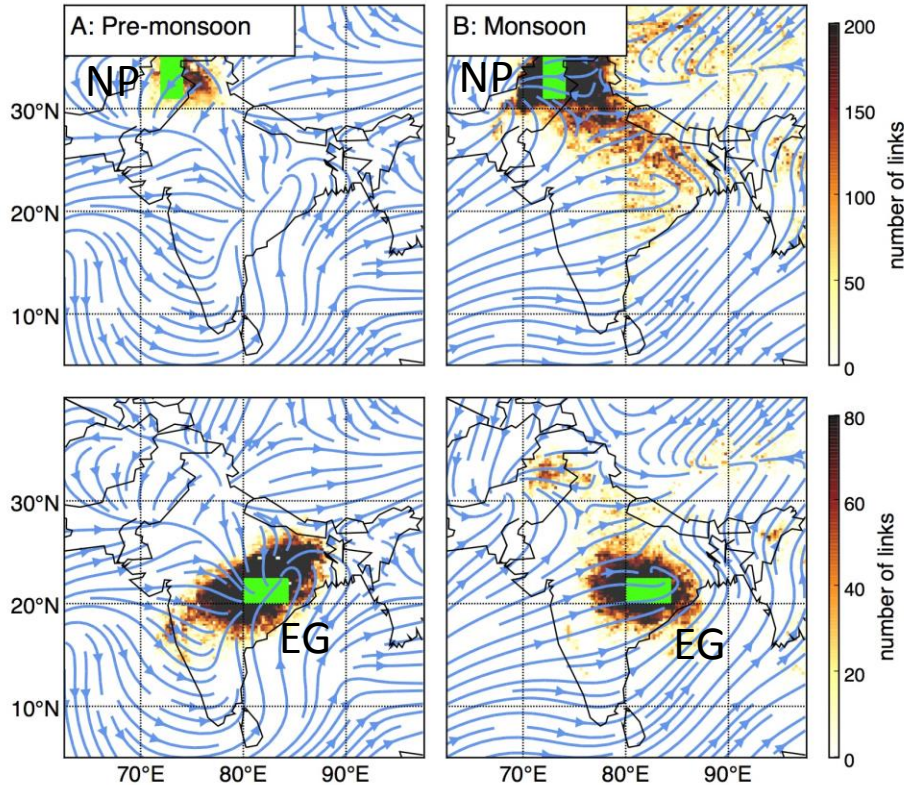


Figure 3. Links between a set of 153 reference grid points to other grid points and surface wind vector mean 1998-2012.

# Temperature & wind fields

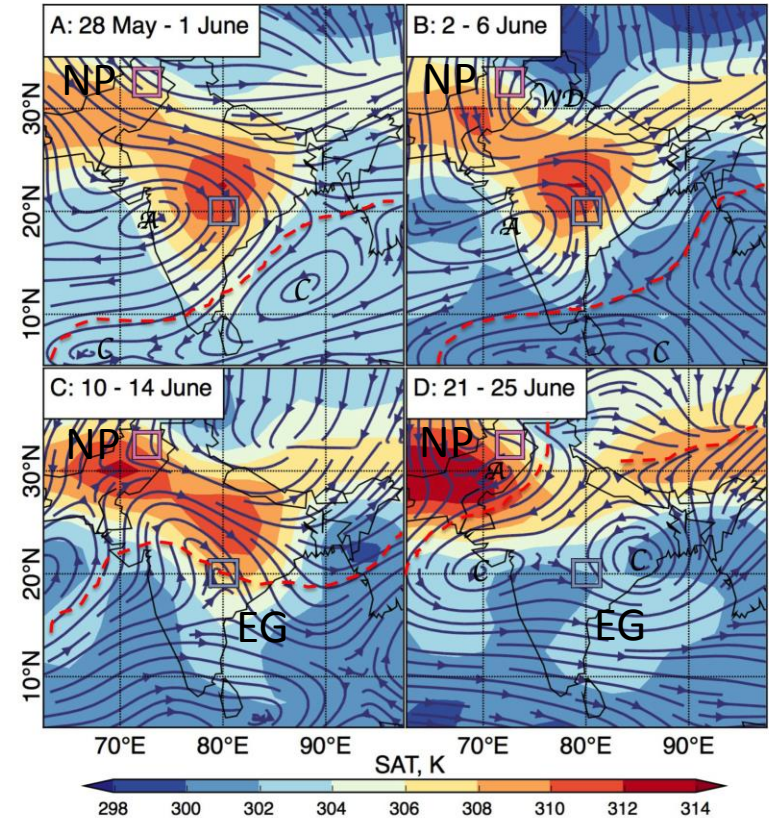


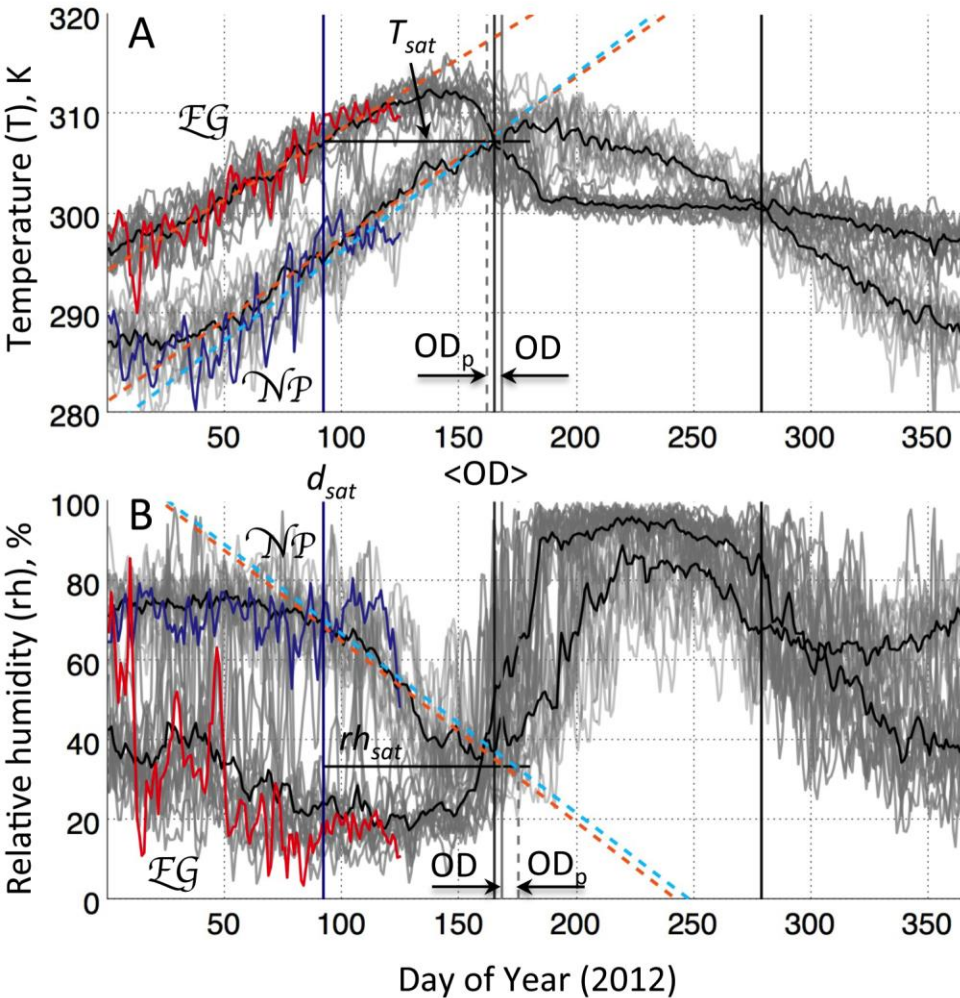
Figure 4. Wind fields and near-surface temperature: before, during and after the onset of monsoon

**DATA: NCEP/NCAR** reanalysis, 2.5 °, near –surface air temperature, (1951-2015)

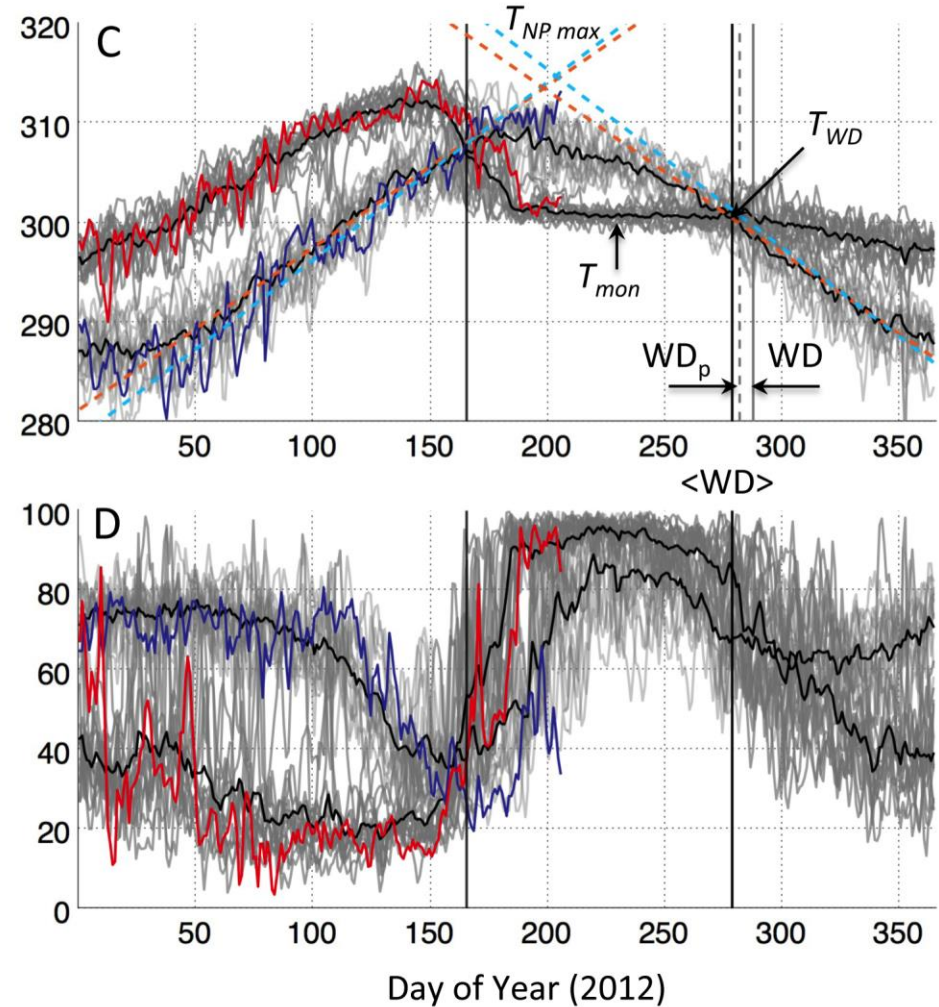
How can we use obtained result for the predictability of the onset of monsoon?

# Prediction scheme for monsoon onset and withdrawal over the Eastern Ghats (20N,80E)

## Prediction of onset date (OD)

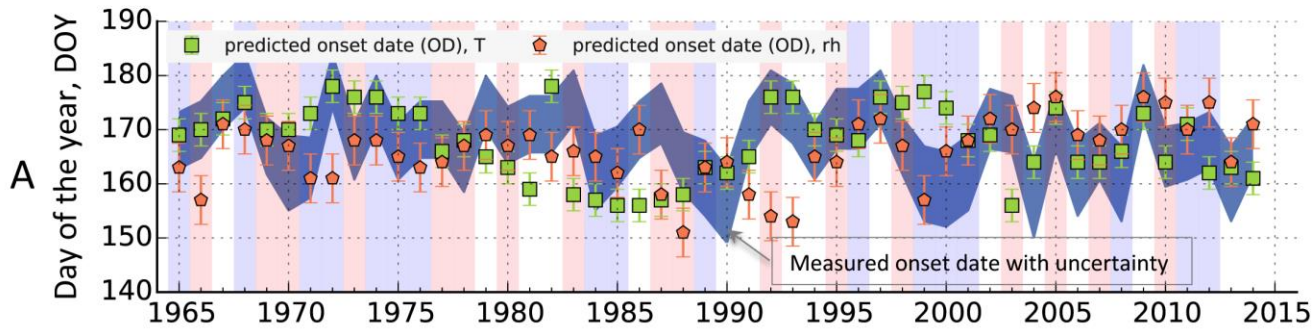


## Prediction of withdrawal date (WD)



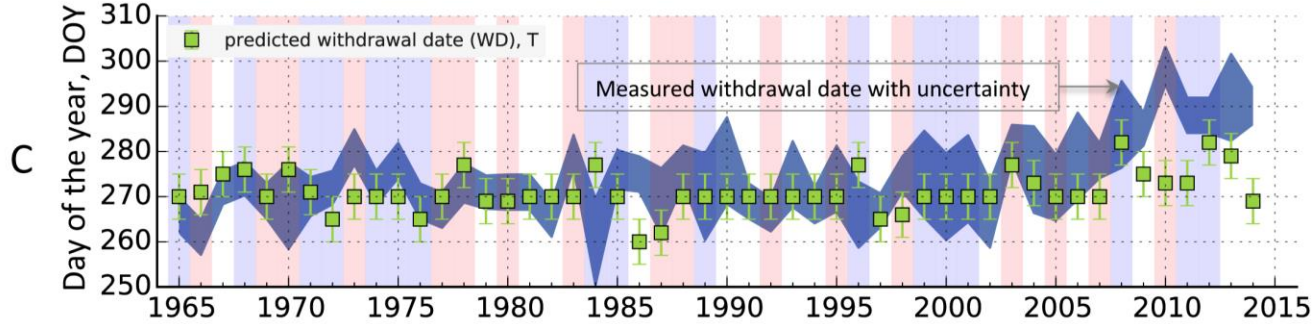
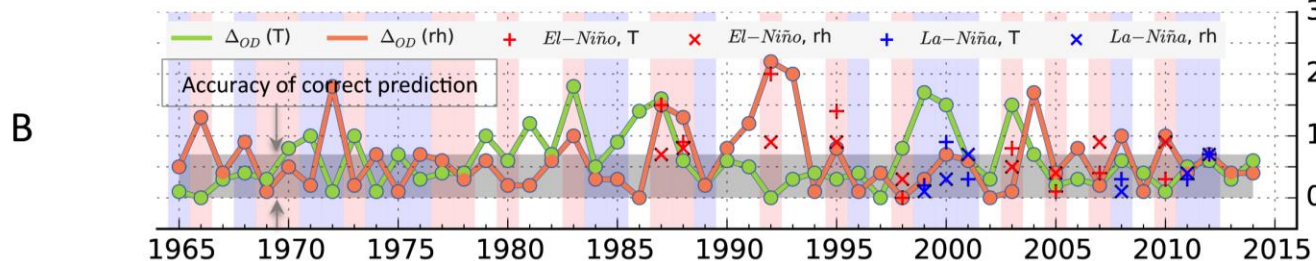
# Performance of prediction scheme

O  
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T

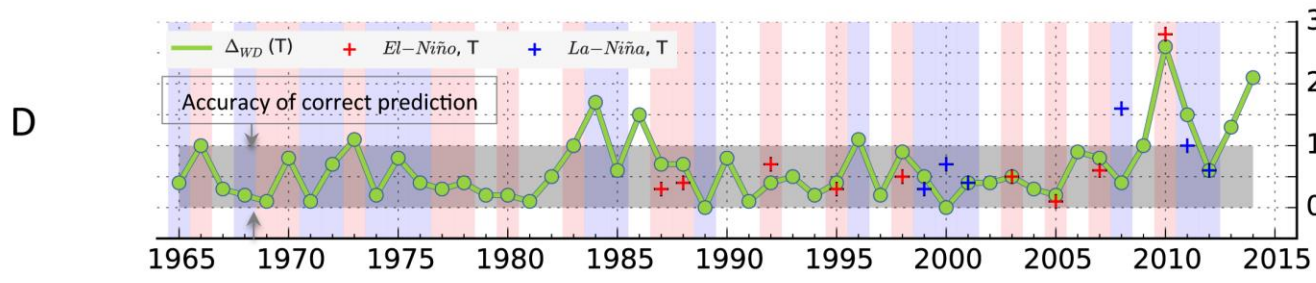


74% of success rate

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H  
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A  
L



84% of success rate



Years

# 3. Forecasting upcoming monsoon: observational evidences

https://www.pik-potsdam.de/services/infodesk/forecasting-indian-



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## SERVICES

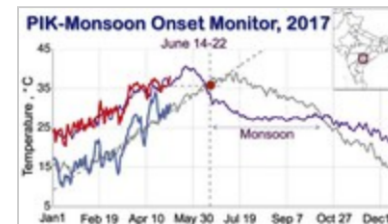
- ▶ IT-Services
- ▶ Climate & Weather Potsdam
- ▶ ClimateImpactsOnline
- ▼ Info Desk
  - ▶ Telegraphenberg
  - ▶ Museum "weather factory"
  - ▶ PIKee/PIKeeBB-Environmental education
  - ▼ [Forecasting of Indian Monsoon](#)
    - ▶ News about Monsoons

## Welcome to the PIK monsoon page!

This web page provides a long-term forecast of the onset and withdrawal of the Indian Summer Monsoon (the Southwest Monsoon) for the central part of India. The long-term forecast means 40 days in advance for the onset date, and 70 days in advance for the withdrawal date. Our approach is based on a teleconnection between the Eastern Ghats (EG) and North Pakistan (NP) - Tipping Elements of Indian Summer Monsoon. The forecasts are performed by Elena Surovyatkina.

### LATEST NEWS

**October 16, 2017**  
**Successful earliest forecast of the Withdrawal Date of Indian Summer Monsoon from the Central part of India.**



Daily mean near-surface air temperature till May 5, 2017 for EG (red) and NP (blue). Violet and

## NEWS

- ▶ Successful earliest forecast of onset and withdrawal of the Indian Summer Monsoon
- ▶ New forecast method predicts 2017 Indian Summer Monsoon onset
- ▶ Successful forecast of onset and withdrawal of the Indian Summer Monsoon
- ▶ Prediction of Monsoon withdrawal

# Indian Summer Monsoon - 2017

*The PIK- monsoon onset monitor news*

*May 08, 2017*

## **Forecast of the Onset date of the Indian Summer Monsoon - 2017 over the central part of India**

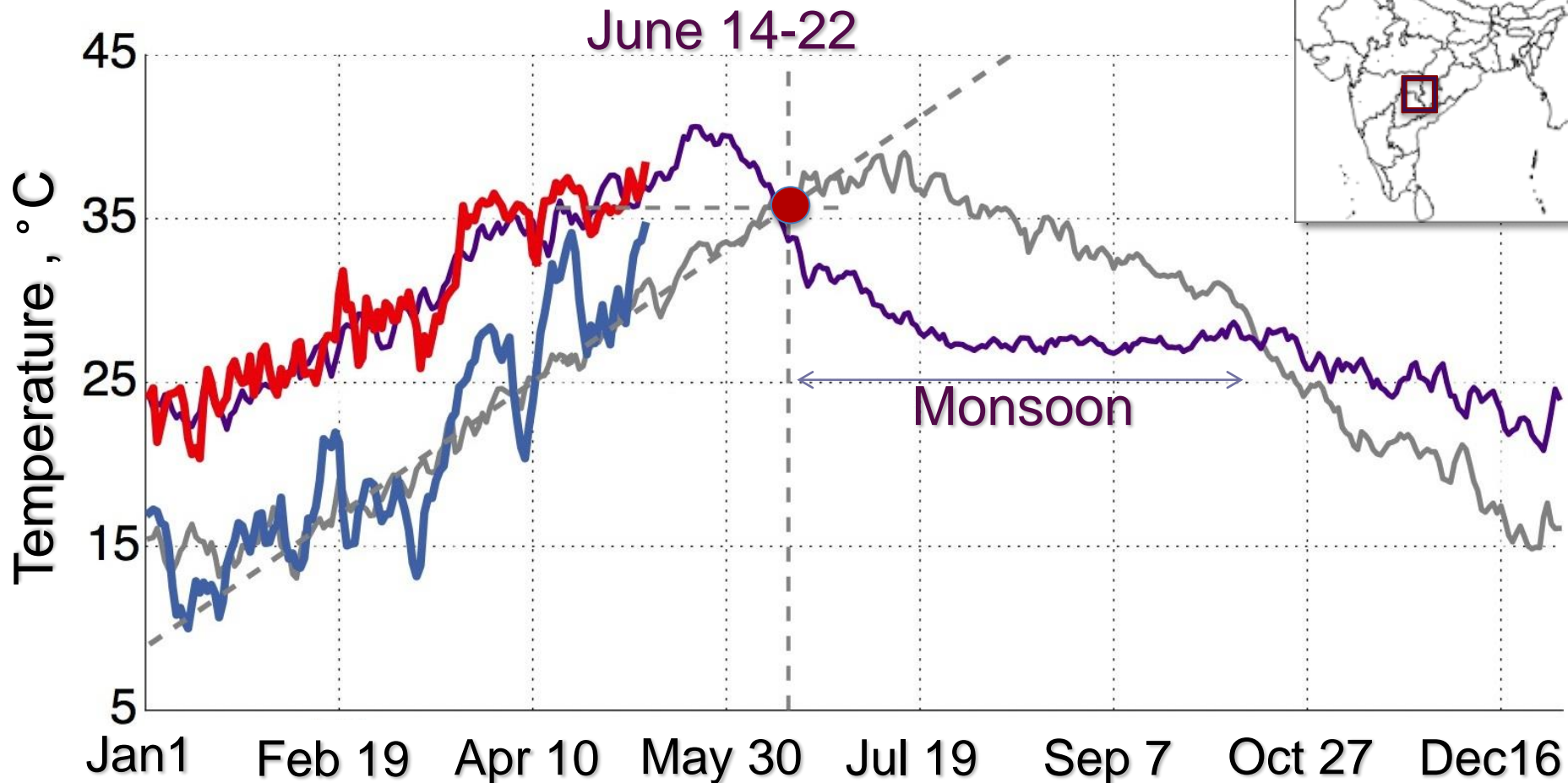
The Indian Summer Monsoon (the Southwest Monsoon) is likely (with a 73% probability) to set over the central part of India, the Eastern Ghats region (20°N,80°E) on or **around 18th June (+/- 4 days)**.

The region of our forecast locates in the central part of India in the area of the Eastern Ghats (EG).



<https://www.pik-potsdam.de/services/infodesk/forecasting-indian-monsoon>

# PIK-Monsoon Onset Monitor, 2017

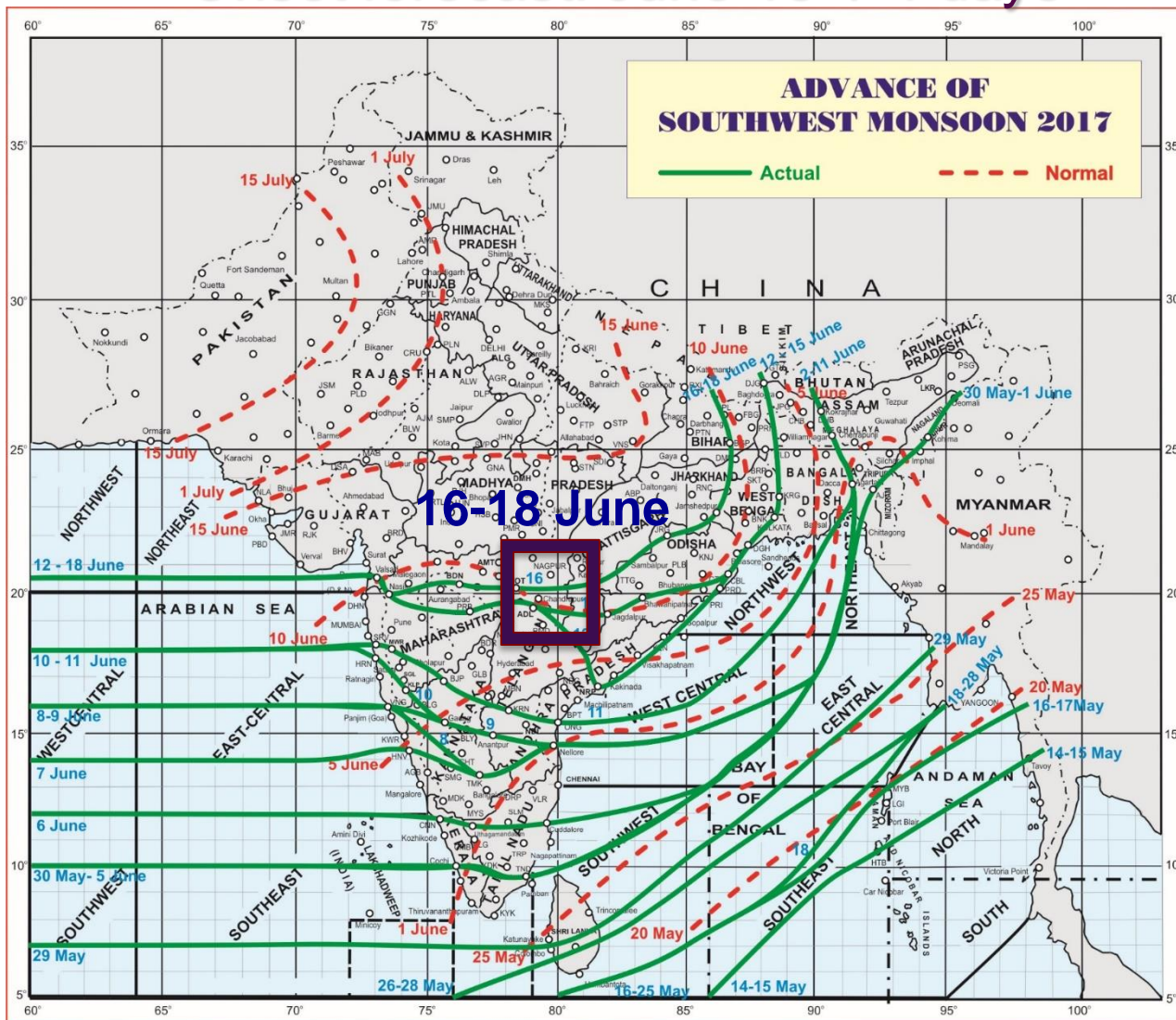


Daily mean near-surface air temperature till **May 8, 2017**, for the Eastern Ghats (red) and North Pakistan (blue). Violet and gray lines- past 5-years average for same regions. The tipping point (red) indicates the critical temperature and the forecasted onset date. The forecasted withdrawal dates are from 7th to 17th October.



# The Evidence for successful PIK-Monsoon onset forecast - 2017

## Onset forecast: June 18+/-4 days



The Map of Advance of Southwest Monsoon by the Indian Meteorological Department (<http://www.imd.gov.in/pages/allindiawxfcbulletin.php>)

# Indian Summer Monsoon - 2017

*The PIK- monsoon onset monitor news*



*July 30, 2017*

Earliest Forecast of the Withdrawal Date of Indian Summer Monsoon - 2017 from the Central part of India.

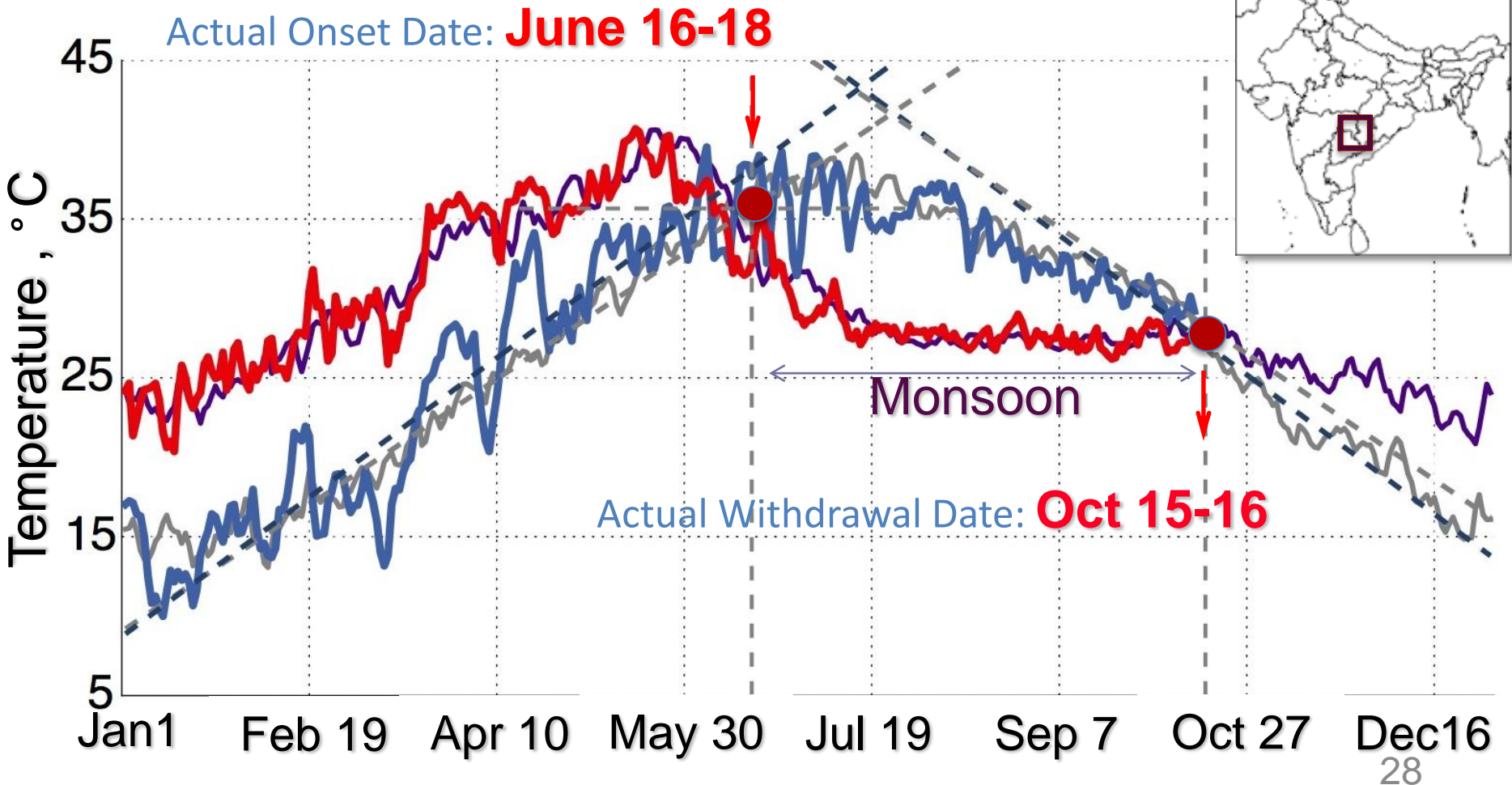
The Indian Summer Monsoon (Southwest Monsoon) is likely (with an 84% probability) to withdraw from the Central part of India (20N, 80E) around 12th October (+/- 5 days), namely between **7th and 17th October 2017**.

<https://www.pik-potsdam.de/services/infodesk/forecasting-indian-monsoon>



# Indian Monsoon Monitor, 2017

Onset Date Forecast: **June 18 +/-4 days**    Withdrawal Date Forecast: **Oct 12 +/-5 days**  
Forecast issued:     *40 days in advance*                      *70 days in advance*



# Indian Summer Monsoon - 2018

*The PIK- monsoon onset monitor news*

*May 07, 2017*

## **Forecast of the Onset date of the Indian Summer Monsoon - 2017 over the central part of India**

The Indian Summer Monsoon (the Southwest Monsoon) is likely to set over the central part of India, the Eastern Ghats region (20°N,80°E) around **15th June** (+/- 4 days) namely **between 11th to 19th June 2018**.

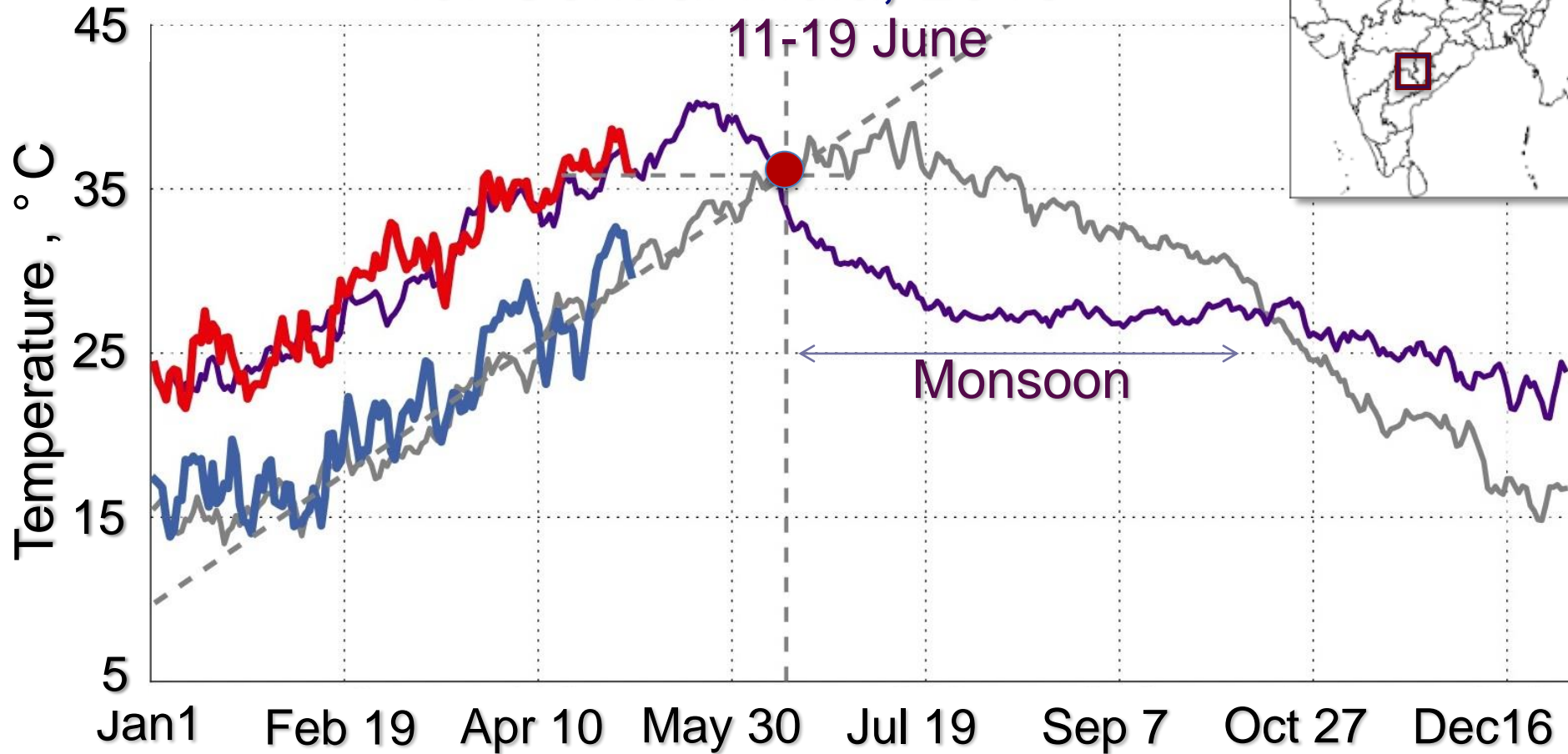
The region of our forecast locates in the central part of India in the area of the Eastern Ghats (EG).



<https://www.pik-potsdam.de/services/infodesk/forecasting-indian-monsoon>

7 May 2018

# PIK - Monsoon Onset Forecast for Central India, 2018

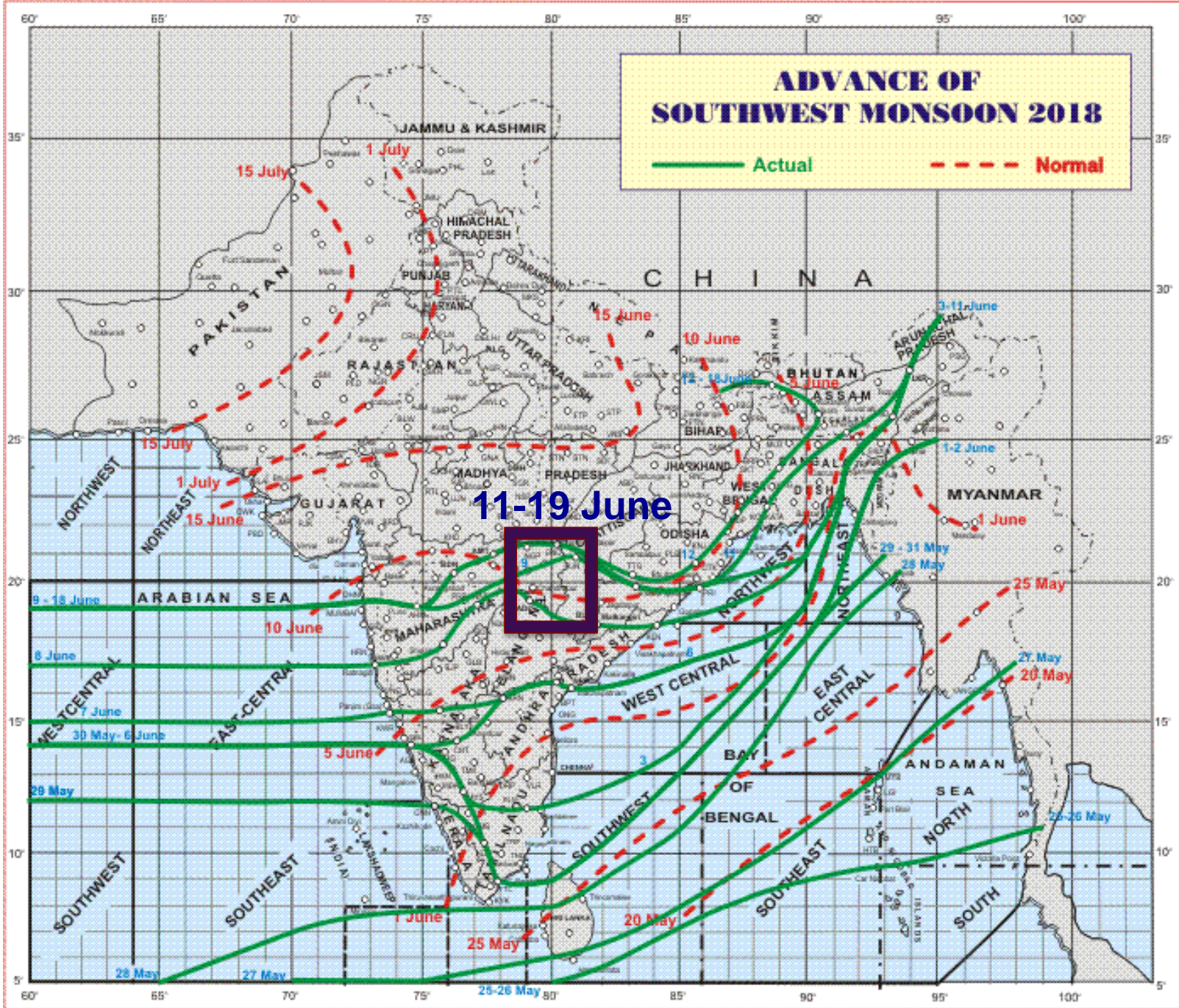


Daily mean near-surface air temperature till **May 7, 2018**, for the Eastern Ghats (red) and North Pakistan (blue). Violet and gray lines - past 5-years average for same regions. The tipping point (red) indicates the critical temperature and the forecasted onset date.

# ADVANCE OF SOUTHWEST MONSOON 2018

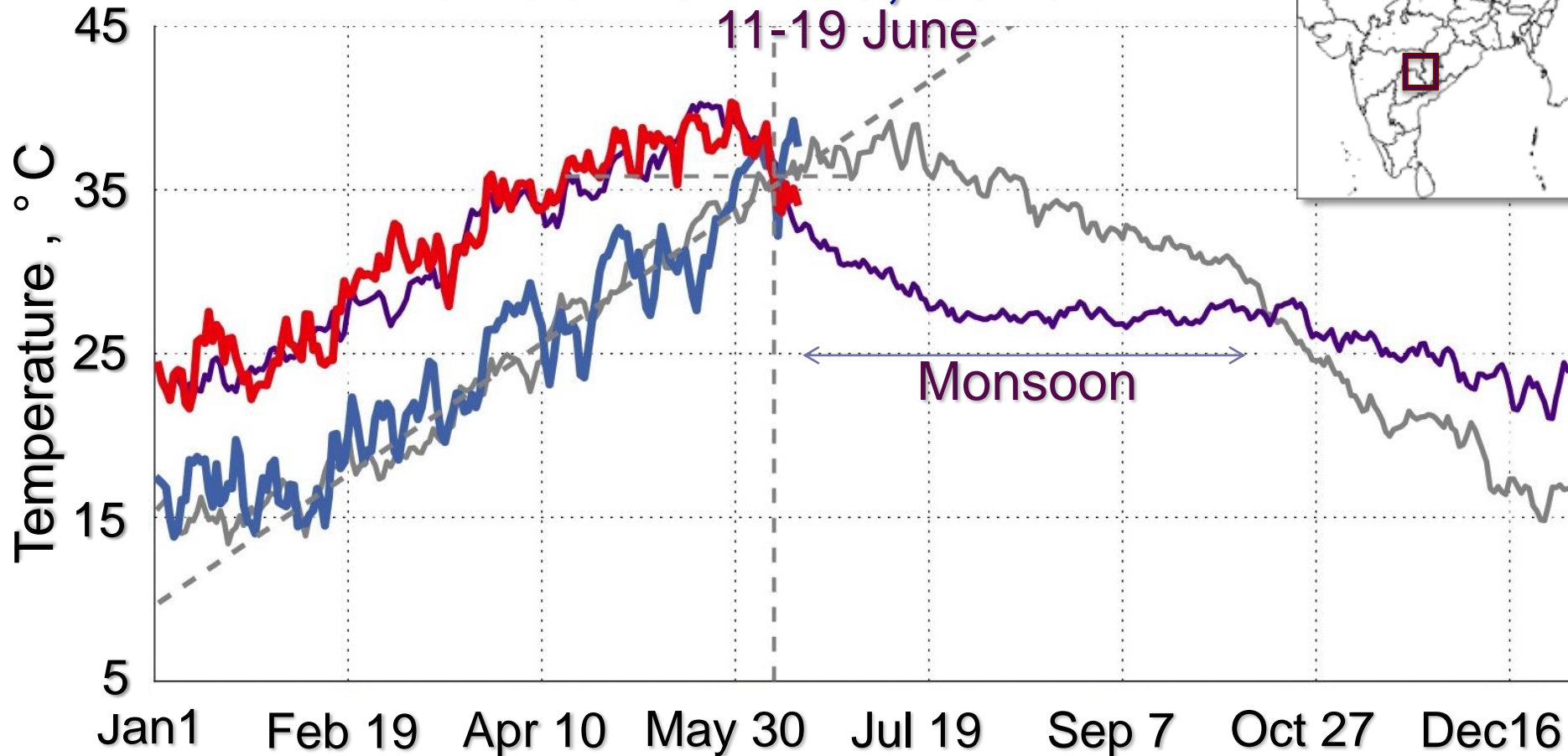
— Actual      - - - - Normal

11-19 June



15 June 2018

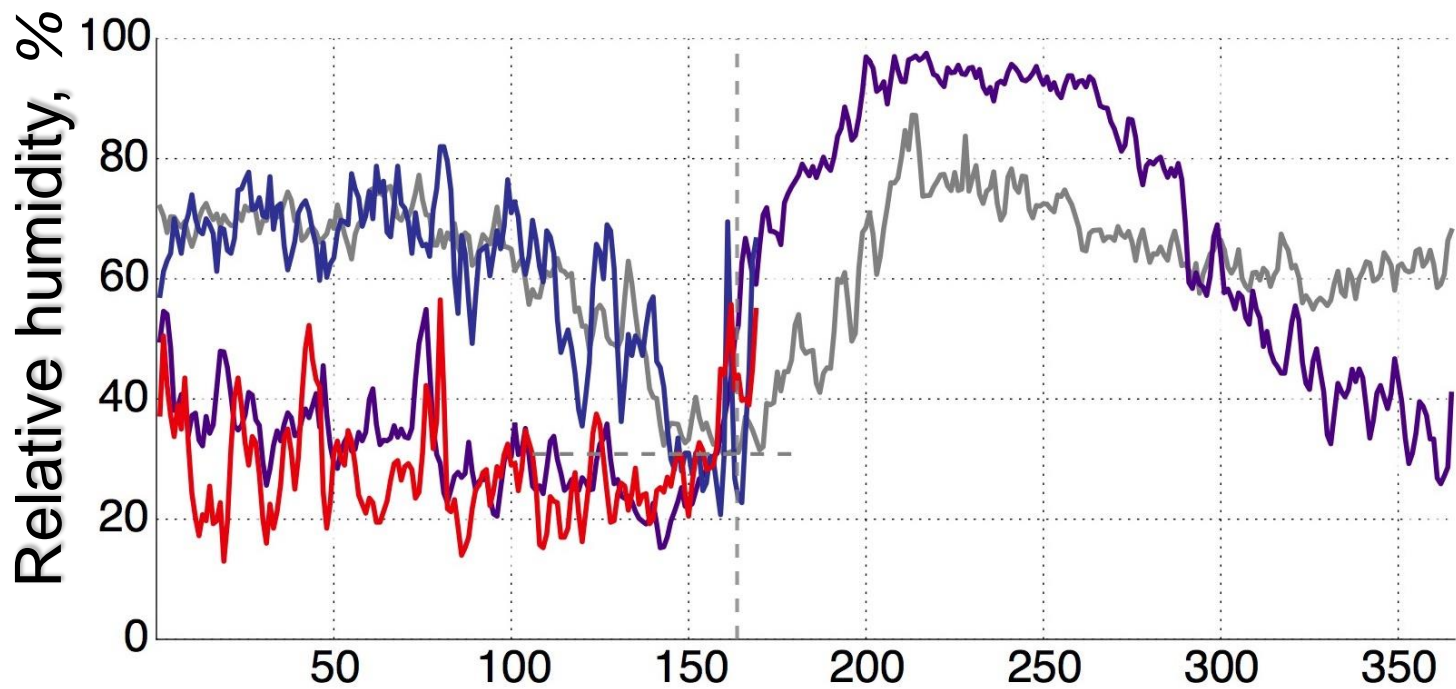
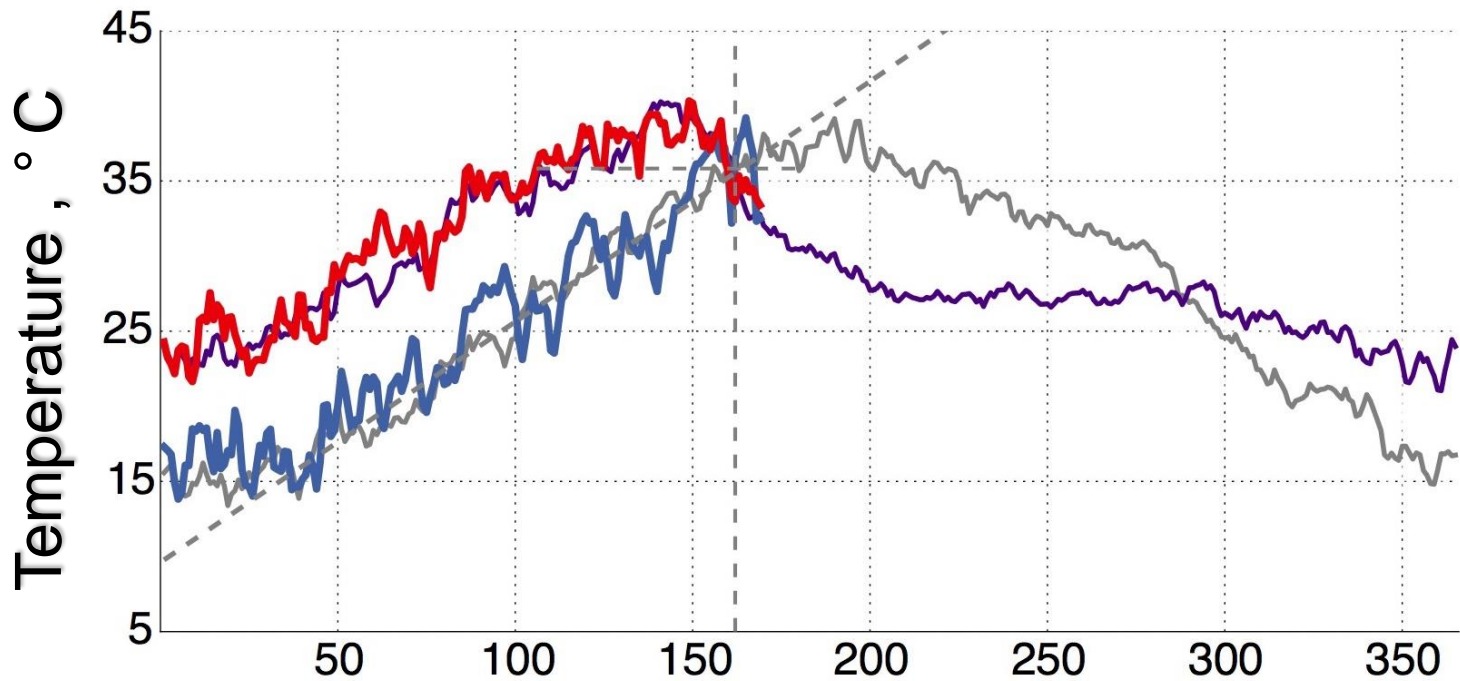
# PIK - Monsoon Onset Forecast for Central India, 2018



Daily mean near-surface air temperature till **June 15 , 2018**, for the Eastern Ghats (red) and North Pakistan (blue).Violet and gray lines - past 5-years average for same regions. The tipping point (red) indicates the critical temperature and the forecasted onset date.



18 June 2018



# 4. Climate change effect

Climate change affects the Indian Summer Monsoon in several aspects:

1. In the last decade, the intensity of monsoon rainfalls in the central part of India has increased.
2. Local Overheating - Premature Release – Bogus.
3. The delay of withdrawal of the monsoon.
4. In Central India, the variability of Monsoon is quite high due to local changes such as rapid urbanization, industrialization.

The forecasting of monsoon is a challenge mostly because of there is no recent historical precedent for such changing in the climate system.

# Conclusion

- Our approach is based on a teleconnection between two geographical areas - the Eastern Ghats (EG) and North Pakistan (NP), which we defined as Tipping Elements of Indian Summer Monsoon.
- We have found the Tipping Elements approach allows us predicting the timing of the upcoming monsoon onset and withdrawal for 40 and 70 days in advance respectively.
- Our results show that our method allows predicting the monsoon not only retrospectively (over the period 1951-2015) but also in the future. In 2016 and 2017, we proved that such early prediction of the monsoon timing is possible.
- The proposed approach is applicable to different kind of season, which exhibits properties of critical transition. Our prediction is based on observational data only when the model cannot accurately anticipate the transition or does not exist yet.

# References

- Stolbova V., Surovyatkina E., Bookhagen B., Kurths J., Tipping elements of the Indian monsoon: prediction of onset and withdrawal. GRL43, 1–9, 2016, 2016
- Kravtsov Yu.A. , Surovyatkina E.D. , Phys. Lett. A 319 (3–4), (2003) 348.
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- J. Tony, S Subarna, K. S. Syamkumar, G. Sudha, S. Akshay, E. A. Gopalakrishnan, E. Surovyatkina & R. I. Sujith. Experimental investigation on preconditioned rate induced tipping in a thermoacoustic system . Scientific Reports, 2017, 7(1), 5414.



Mathematical Institute





IMD, Pune



IIT Madras



IITM, Climate Change Center, Pune



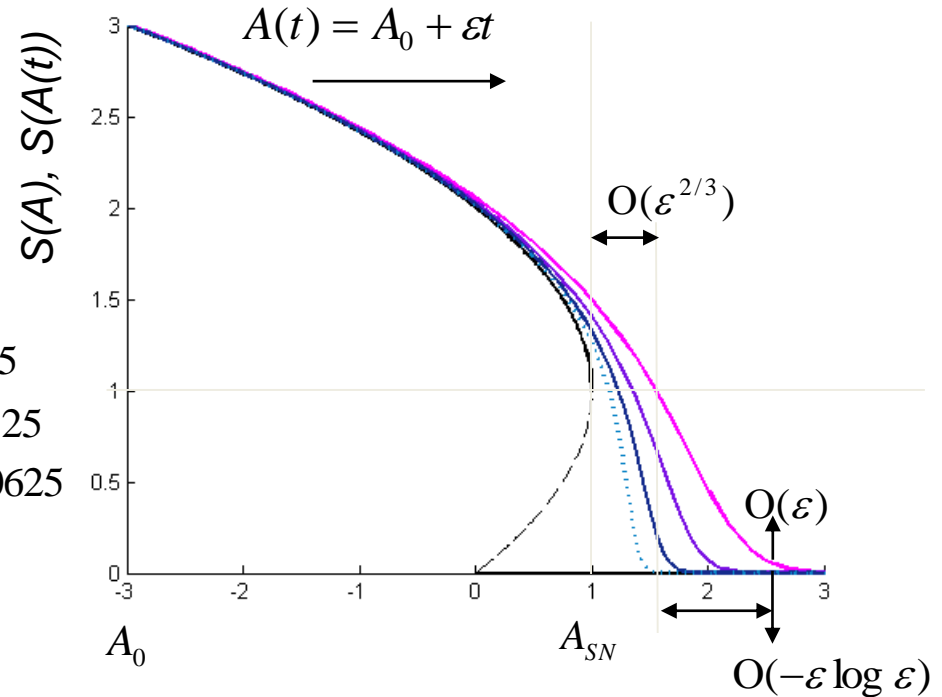
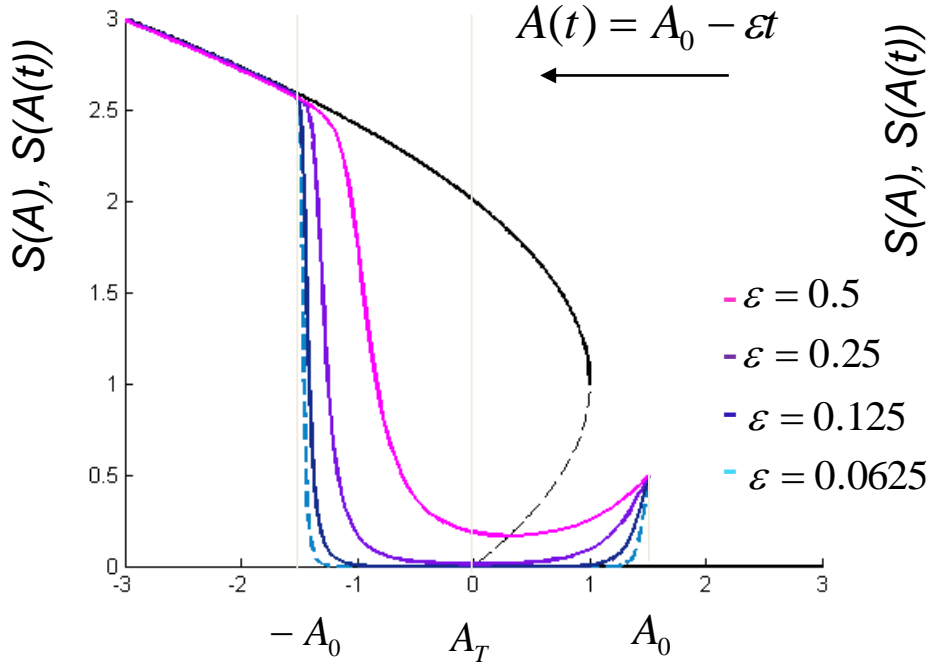
Amirta University, Coimbatore

# Dynamic case: the effect of the rate of change of the bifurcation parameter

$$\frac{dS}{dt} = S(S^2 - 2S + A(t))$$

**Transcritical bifurcation:**  
backward transition through  $A_T = 0$

**Saddle-node bifurcation:**  
forward transition through  $A_{SN} = 1$



The delay in stability exchange is **independent** of  $\epsilon$  and proportional to the initial value of  $A$  [1]. The dynamic transition overshoots the static value  $A = 1$  and this overshoot is **dependent** on  $\epsilon$