Monsoons: Impact of Orography

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Outline

Monsoon Mission: Overview

- Main aim of Monsoon Mission is to improve forecast of monsoons at all scales
- Started in 2012. Phase completed in 2017
- Major Achievement has been estabilishment of dynical modelling framework at all scales.
- Before Monsoon Mission, India did not have a dynamical modelling frameworkat seasonal and extended ranges. Today India has a state-of-the-art systems at par with rest of the world.
- Encouraged by the success of the first phase - Second Phase was started with emphasis on model improvement and application to various sectors such as agriculture, water resources and energy sectors.

Objectives of Monsoon Mission

- To build a working partnership between the academic and R & D Organisations both national and international, and the MoES to improve the operational monsoon forecast skill over the country.
- To setup a state of the art dynamical modelling frame work for improving prediction skills of Seasonal and Extended Range predictions and Short and Medium range (up to two weeks) predictions'.
- At IITM, the principal focus of the mission is to develope Seasonal and Extended Range Prediction systems with the following objectives:
  - To develop a fully coupled ocean-atmosphere-land modelling system for dynamical prediction on Extended and Seasonal time scales and to improve the prediction skill.
  - Development of Data Assimilation system for Climate Forecast System (CFS)
  - To improve parameterization schemes in the coupled ocean-atmosphere-land models.
  - To study and understand the monsoon variability over different spatio-temporal scales.
  - To co-ordinate the working partnership amongst the ESSO-MoES organizationsand various national and international R & D and academic institutions.

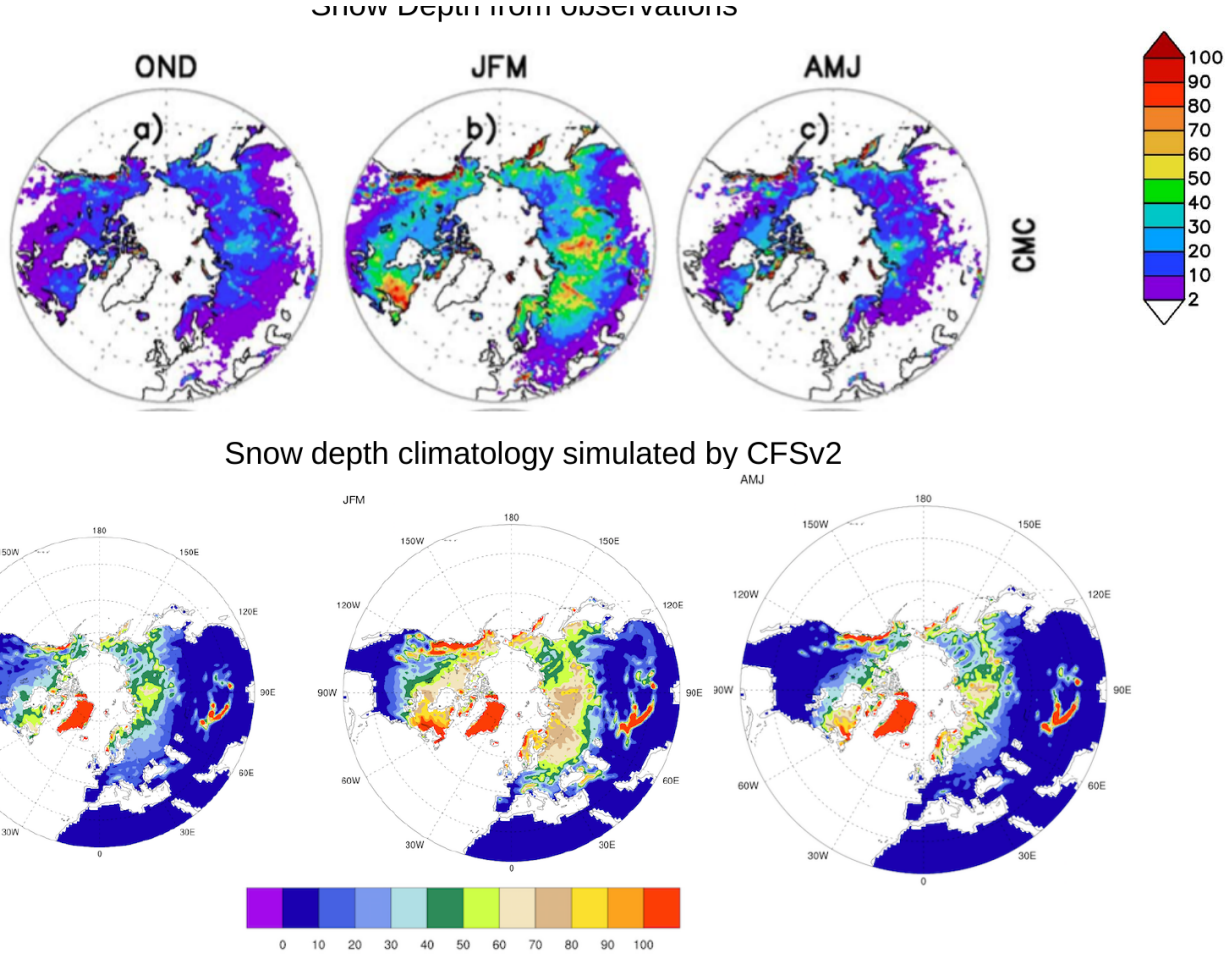
Achievements

- After the successful completion of Phase-I (2012-2017), the Ministry of Earth Sciences (MoES) launched the Monsoon Mission Phase II After the successful completion of Phase-I (2012-2017), the Ministry of Earth Sciences (MoES) launched the Monsoon Mission Phase II After the successful completion of Phase-I (2012-2017), the Ministry of Earth Sciences (MoES) launched the Monsoon Mission Phase II.
- Efforts are being made to link the IITM forecast products with the crop simulation models for major crops grown under variable agro-climatic zones of India
- IITM developed world's highest resolution Global Ensemble Forecast System (GEFS) for short range prediction at 12 km using 21 ensemble members. This system proves probablistic prediction for upto 10 days. This is being used by IMD from the monsoon season of 2018 This is being used by IMD from the monsoon season of 2018. This is also being used for agri-met forecasts.
- A coupled Ocean-Atmospheric data assimilation system using Local Ensemble Transform Kalman Filter (LETKF) has been developed and installed for CFSv2 at IITM. LETKF uses time-dependent covrariance from an ensemble of a forecast.
- Emphasis in Phase II is on predicting extremes and development of climatic applications based on monsoon forecasts,

Effect of Eurasian Snow Depth on Monsoon

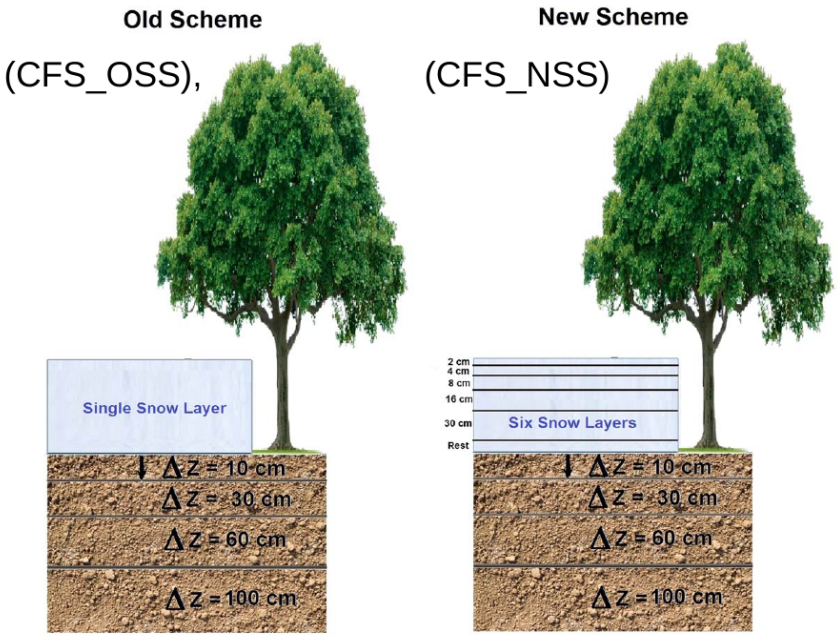
- Role of Eurasian Snow Depth was studied using CFSv2
- CFSv2 was run at T-126 resolution in a free-run mode for 15 years (control run)
- Last 15 years were used for analysis.
- The snow depth was compared between model and observations

Snow Depth in CFSv2 Free Runs



- Snow Depth was overestimated in all seasons.
- Hence decided to modify the snow and land surface schemes

Modification to Land Surface Scheme

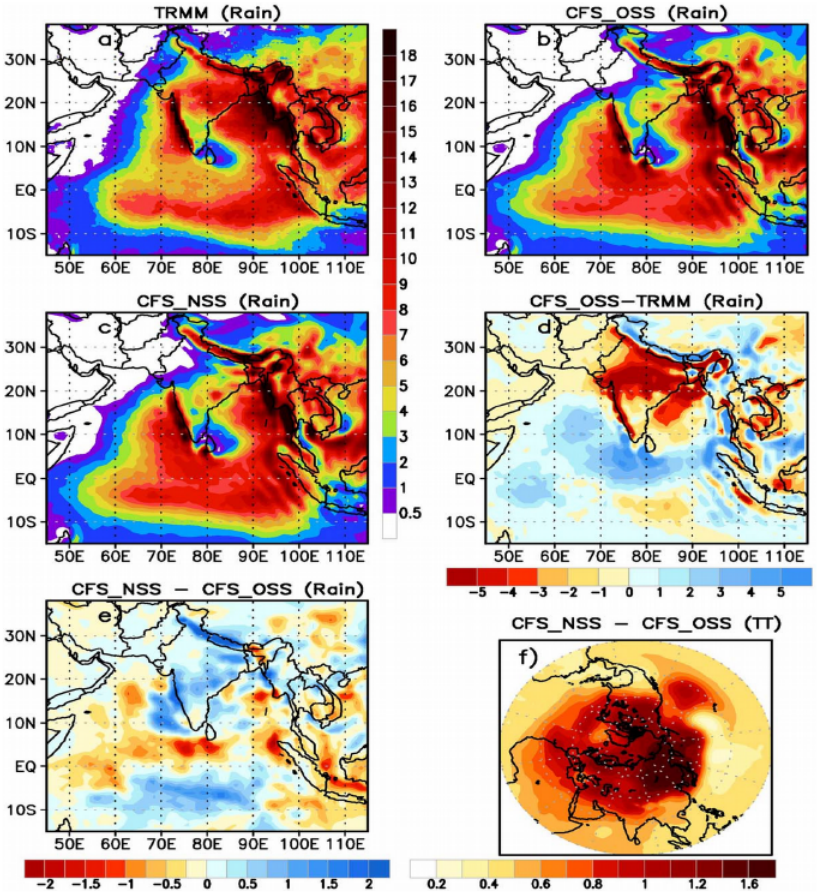


Schematic diagram of the snow and soil layers in the original and modified Noah.

Saha et al 2017

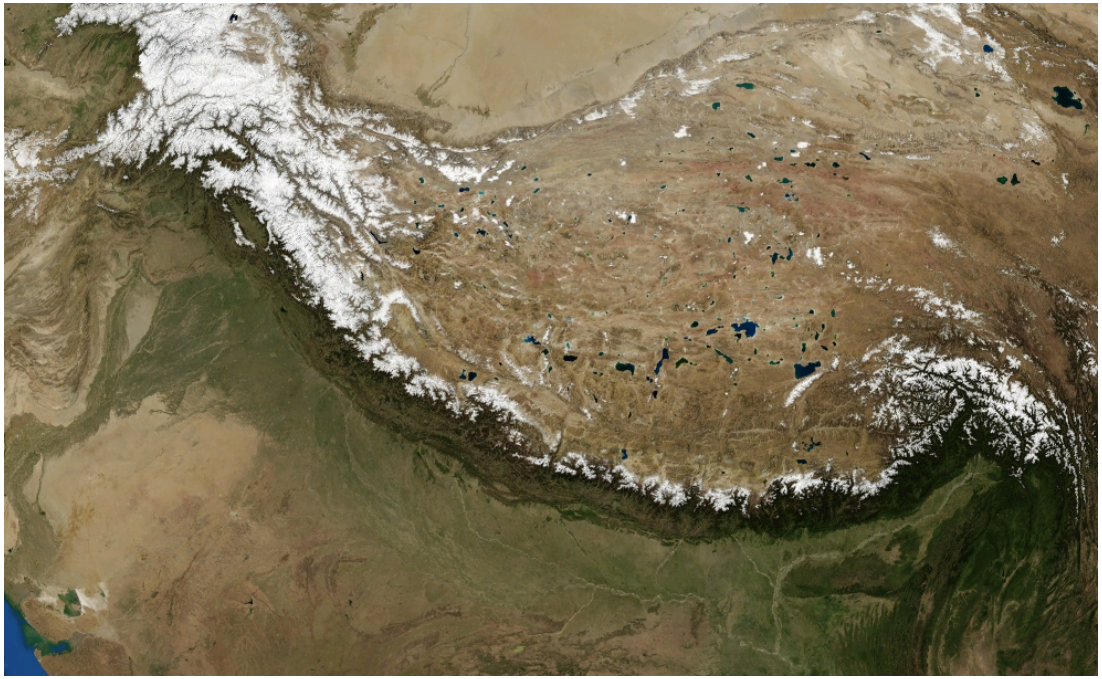
- The original scheme had a single layer for snow
- Modified to multi-layer scheme – allowing the upper layers to respond faster to changes in atmosphere above

How Did It Impact The Indian Monsoon?



- Signficant reduction in dry bias
- More realistic simulation of the mean monsoon (Saha et al 2017)
- Studies underway to study simulations/predictions over Himalayan Region in CFSv2.

Role of Himalayan Orography



- Studies have shown that Himalayas and Tibetan Plateau have a two-fold effect
  1. Act as a barrier for movement of air essentially between the tropical Indian landmass and the extra-tropical Eurasia
  2. Act as an elevated heat source

- If we look at the orography around India we notice that to the East Hamalayas/Tibetan Plateau to the north
- To the west is the thinner barrier of Western Himalayas with no substantial orography beyond
- Hence the role of Western Himalayas (west of 80^o) E could be different from that of Eastern Himalayas (east of 80^oE)
- A Series of season-long experiments were conducted with an AGCM
- The aim was to study the the role of orography on the intensity and length of the monsoon season

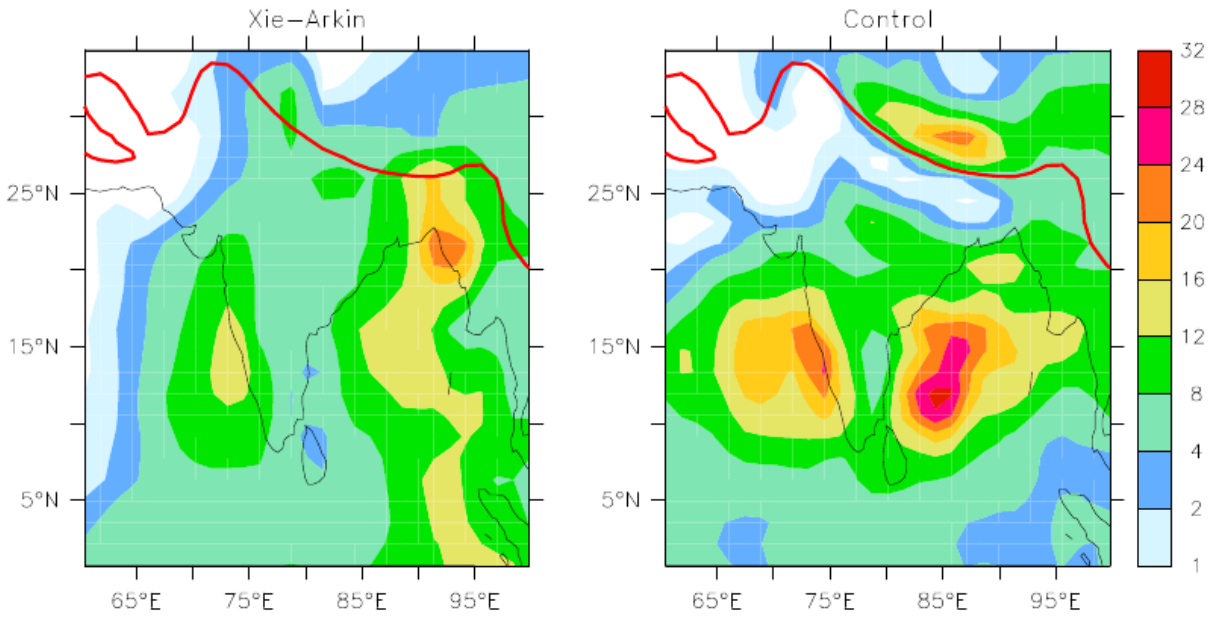
The Model & Experiments

- We have used the NCMWRF (National Centre for Medium Range Forecasting, New Delhi) model a derivative of the NCEP model
- Simulations have been done at T-80 ($\sim 1.4^o$ resolution) with 18 vertical Levels with Eulerian spectral dynamics
- We have used the Simplified Arakawa Schubert cumulus parameterization (Pan and Wu, 1994)
- SSTs presecribed to that of 1998; initial conditions from NCEP reanalysis

Details of Simulations

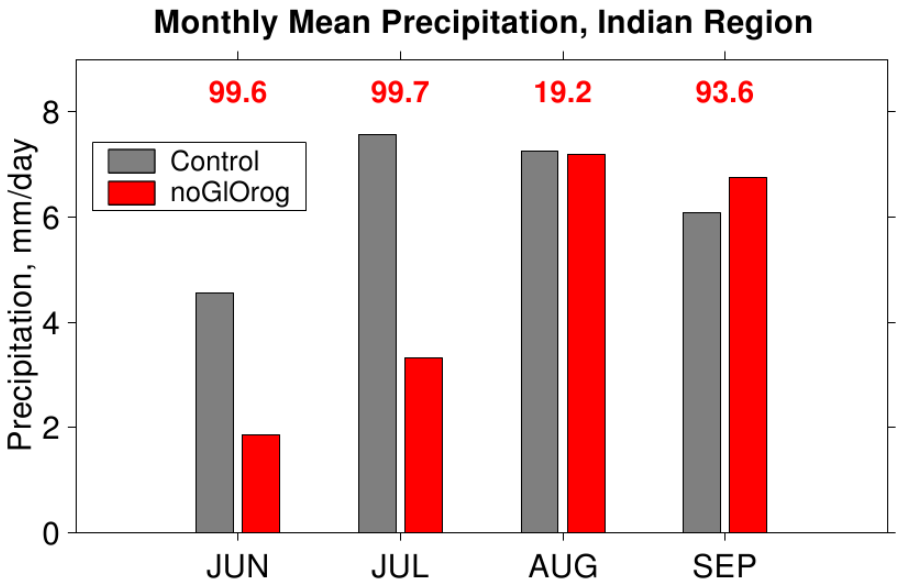
Name	Description	Number of the Integrations	
		Using SAS Conv.	Using Kuo Conv.
Control	Standard simulation with mean orography	25 (5-yr)	10 (5-yr)
noGlOrog	No orography all over the globe.	12 (5-yr)	5 (5-yr)
noTiOrog	No orography between 80°–120°E, 0–60°N.	5	5
noWhOrog	No orography between 60°–80°E, 25°–60°N.	5 (5-yr)	5
noAsOrog	No orography between 60°–120°E, 0–60°N.	5 (5-yr)	0
noWgOrog	No orography between 60°–80°E, 0–25°N.	5	0
noAfOrog	No orography over the African continent.	5	1
noEAfOrog	No orography over the east Africa (33°–50°E, 3°–18°N)	1	0
haAfOrog	Orographic height reduced to half over the African continent.	5	0
prAfOrog	Orography present only over the African continent.	5	0
noAmOrog	No orography over America (180°–330°E, 60°S–75°N).	5	0

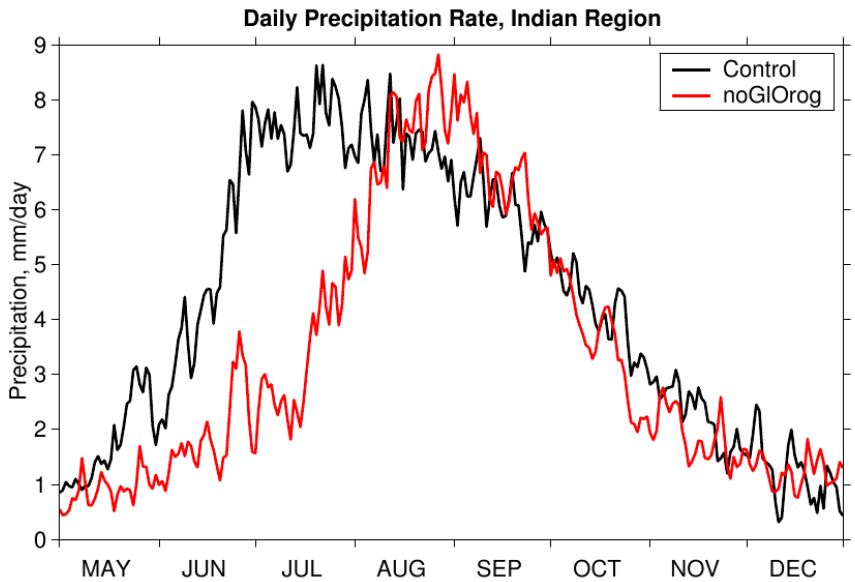
Seasonal Mean Pattern for the Model



- We compare the seasonal mean pattern (mean of the ensemble) for the ‘control with CMAP
- The spatial distribution is reasonable
- It captures the high precipitation over the Western Ghats
- Problems in capturing the high rainfall over Northern Bay of Bengal and parts of the trough
- Simulation as good as any other model

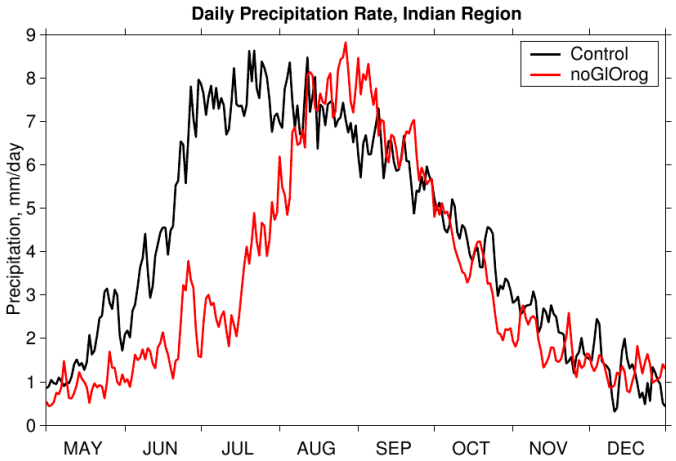
Impact on Monsoon Rainfall

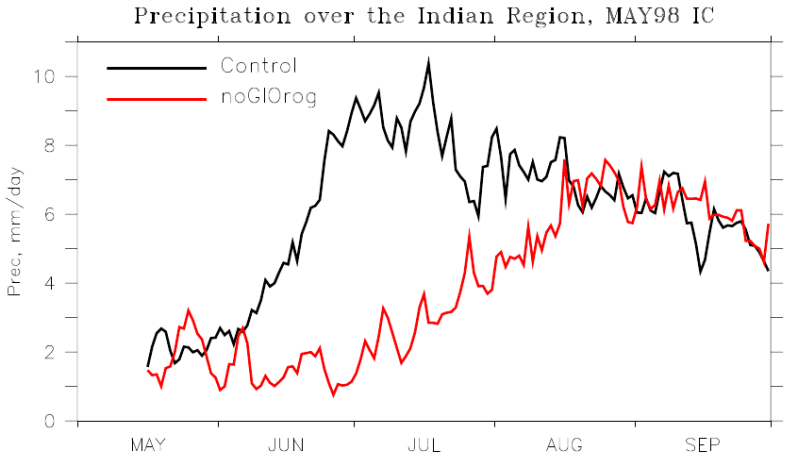




- Here we compare the control simulation with that where mountains have been removed all over the globe
- We notice that rainfall in June and July is markedly lower in noGlOrog vis-a-vis control
- During August and September the rainfall are comparable, actually noGlOrog has slightly higher rainfall in September
- So it appears that orography plays an important role during the earlier phase of the monsoons than in the later phase
- How sensitive are the simulations to initial conditions?
- What is the impact of orography from different regions of the world?

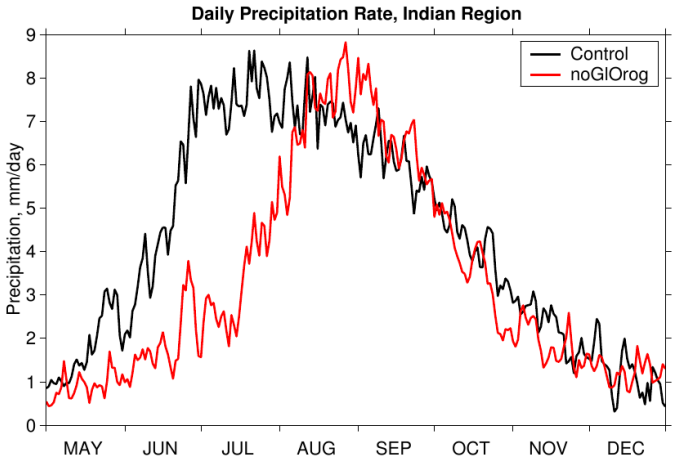
Sensitivity to Initial Conditions

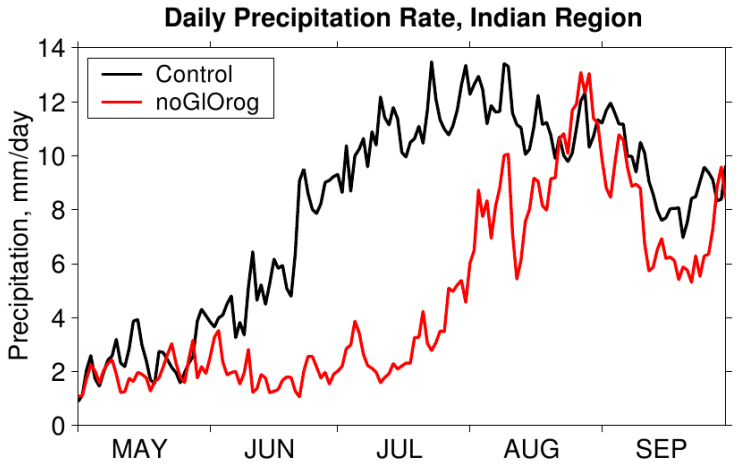




- We compare simulations with March initial conditions (ensemble mean) with those using May 1-5 initial conditions
- Largely insensitive to Initial Conditions.
- In both only the early part of the monsoons are affected

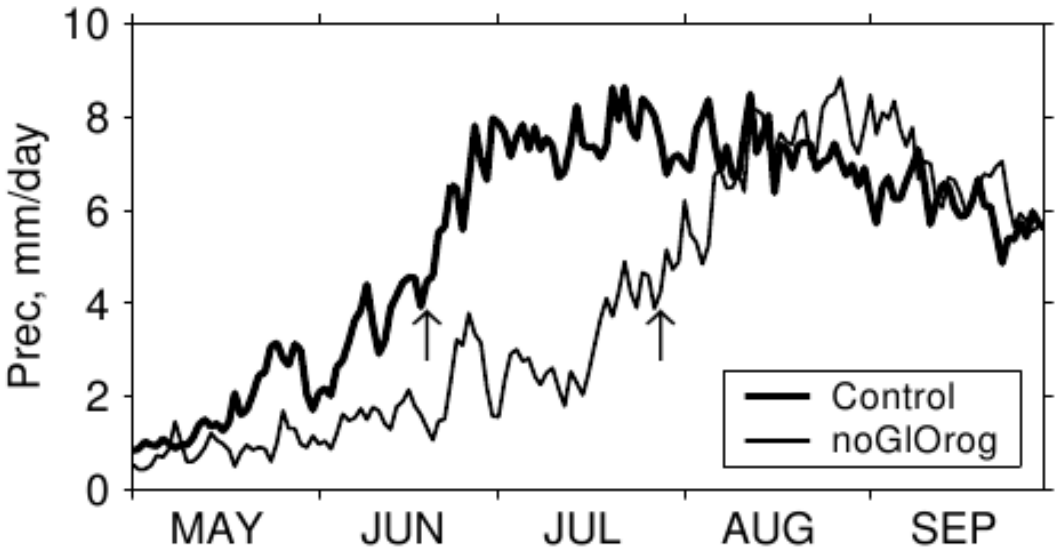
Are the results sensitive to Model Physics?





- We compare simulations with and without orography with two different cumulus schemes (SAS and Kuo)
- We find that qualitatively the impact of removing orography is the same
- Hence we did further simulations only with SAS

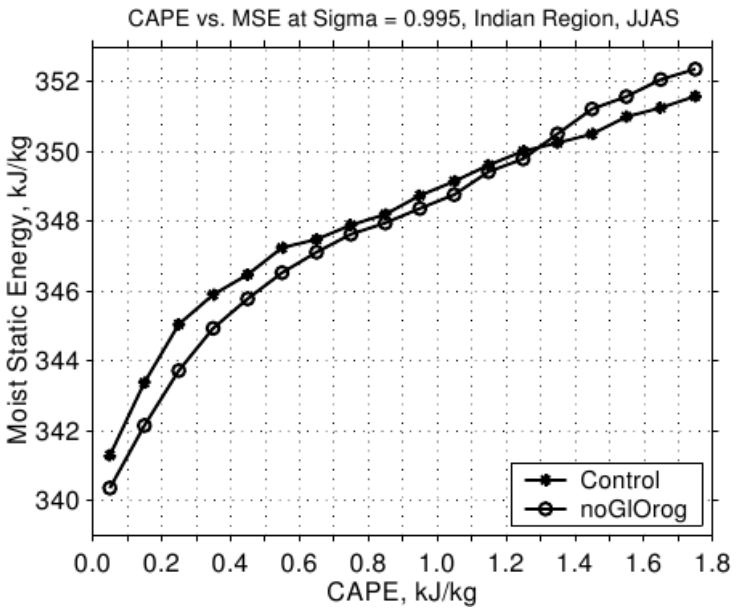
How does Orography impact June/July Rainfall



- We find that rainfall in May is not very different
- Only during June does the rainfall become much higher in presence of orography
- So it appears that orography has a major role to play in the onset phase

- For our purpose we define 'onset' as *the first day of monsoon when precipitation exceeds 4 mm/day over the entire Indian region and remains so for atleast five consecutive days*
- By this yardstick in the 'control' the onset is 19 June
- It is 28 July in noGlOrog – delay of about 40 days
- What causes this delay?
- Could it be delay in destabilization of the atmosphere?

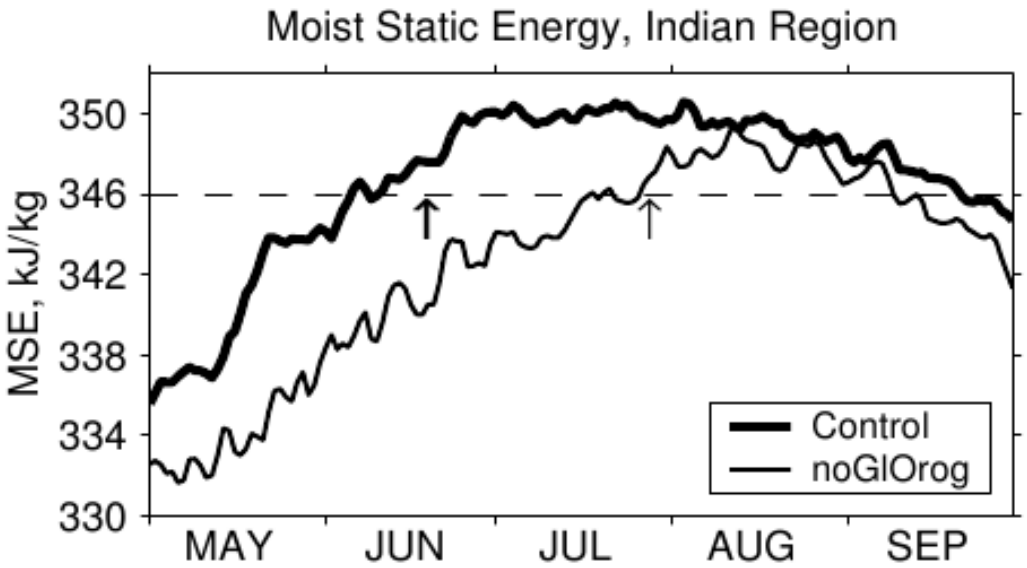
CAPE and SMSE



- We examine two parameters which are indicators of vertical static instability in the atmosphere viz. CAPE (Convectively Available Potential Energy) and MSE (surface Moist Static Energy)
- We define MSE as $MSE = C_p T + gz + Lq$
- Here T, temperature, z, geopotential, and q correspond to lowest model level

- We find that MSE and CAPE are closely associated
- Also change in MSE is less rapid with CAPE beyond 346 kJ/kg
- We examine the variation of MSE in simulations with and without orography

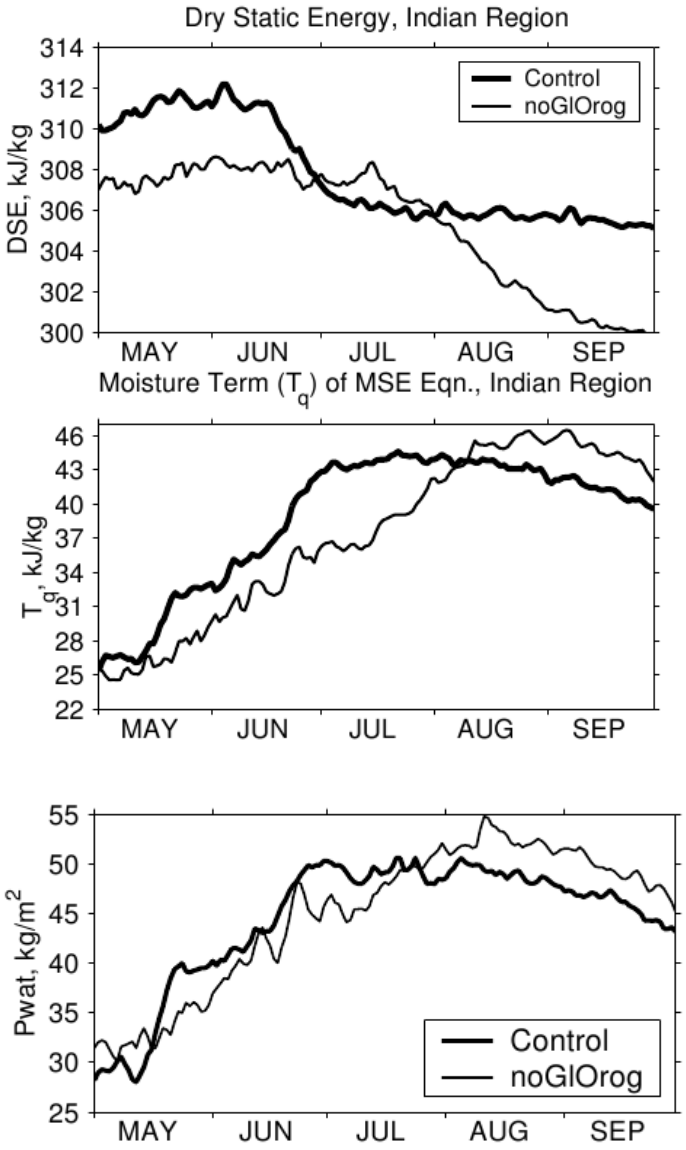
Evolution of MSE



- We find that MSE is lower in noGlOrog simulation as compared to the control
- We also notice that onset in both cases occurs just after MSE reaches 346 kj/kg (same as where there is a change in gradient)

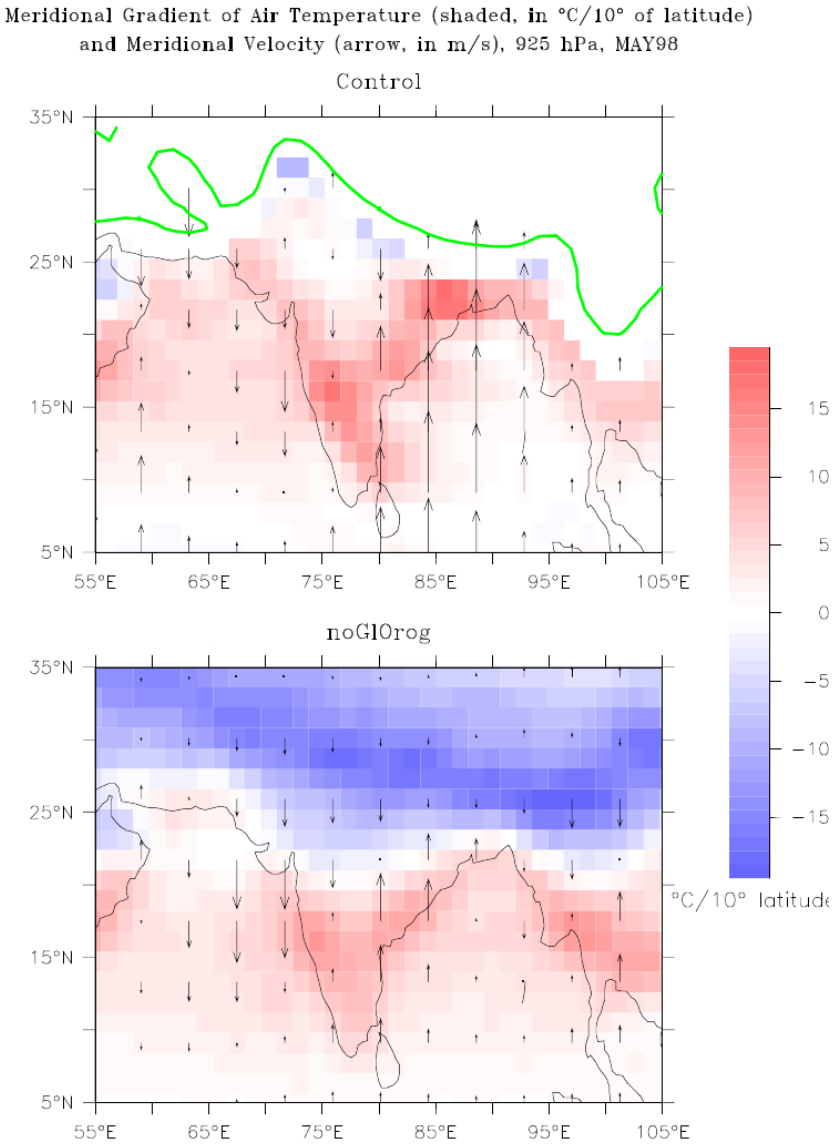
- So what causes the delay in reaching the threshold?
- We next examine the dry component $DSE = C_p T + gz$ and moisture component $T_q = Lq$

Is it Dry Air or Cold Air that delays the onset?



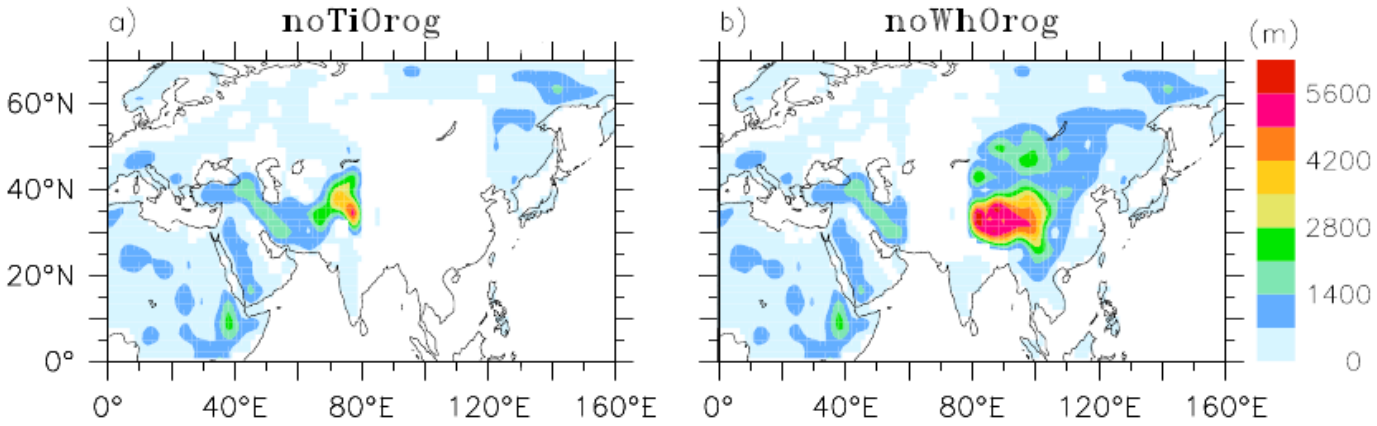
- We notice that DSE in ctl is much higher in May/June and decreases post-onset (due to cooling of surface)
- T_q are comparable in both during May, increases raplidly in ctl post-onset in June
- We also examine integrated water vapour: we find that the values of integrated water vapour are comparable
- It is the colder air being advected that causes delay in onset

Advection of Colder Air



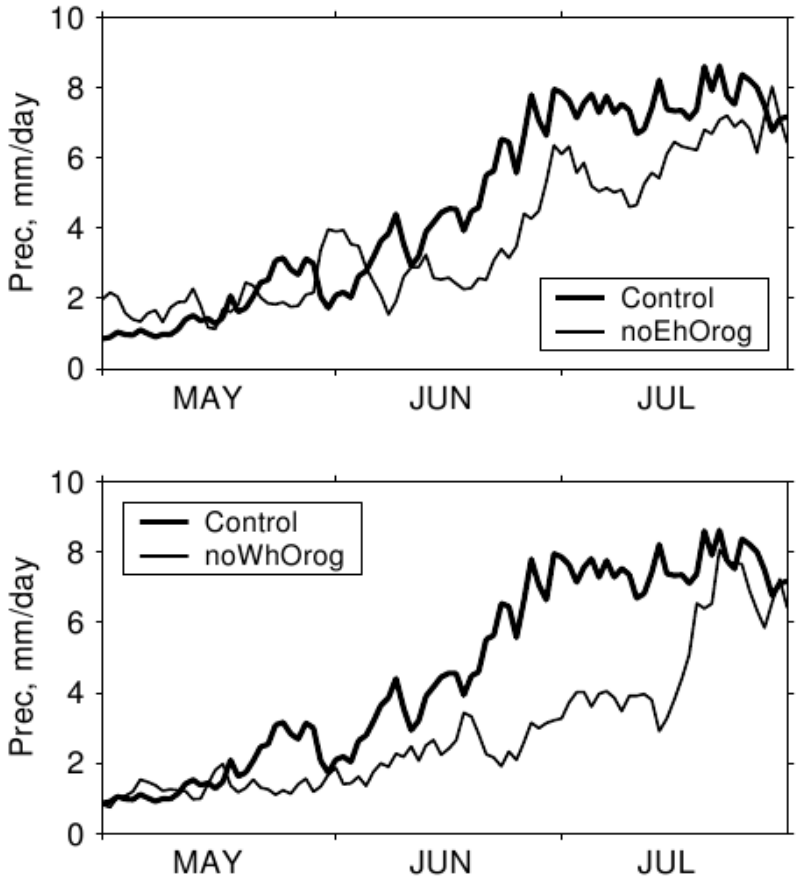
- We examine $\frac{\partial T}{\partial y}$ and Meridional wind at 925 hPa
- We find that gradients of temperature are more negative in the noGlOrog simulation north 22^oN and wind is northerly
- This results in cold air advection which stabilises the air over Indian region and delays the onset
- The cold air advection is more prominent to the West of 80^oE
- Which affects rainfall more Eastern Himalayas vs Western Himalayas?

Impact on Indian Monsoon: Tibet or W Himalaya?



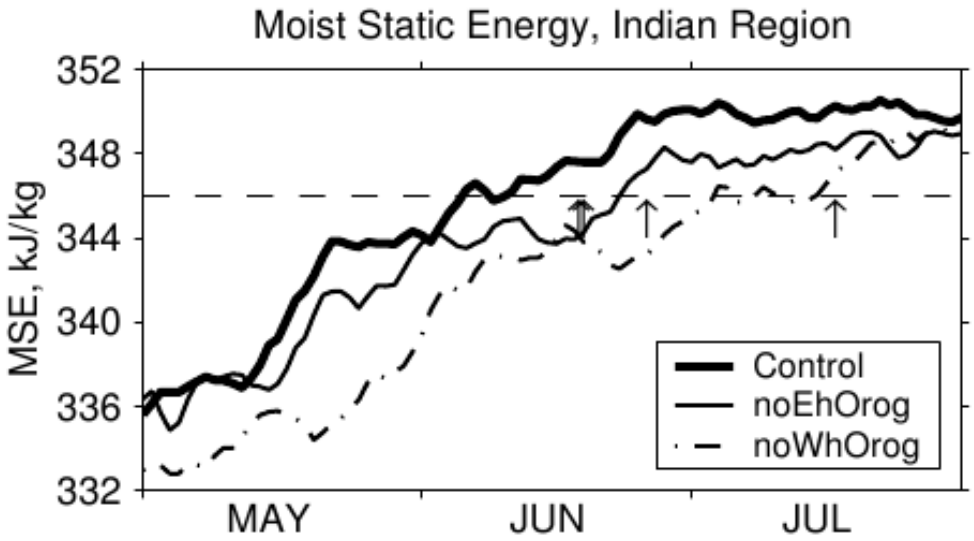
- We conducted two simulations, one in which Tibetan orography (east of 80^oE) was removed (noEhOrog or noTiOrog)
- Another in which West Himalayan orography (west of 80^o E) was removed

W Himalayas vs E Himalayas



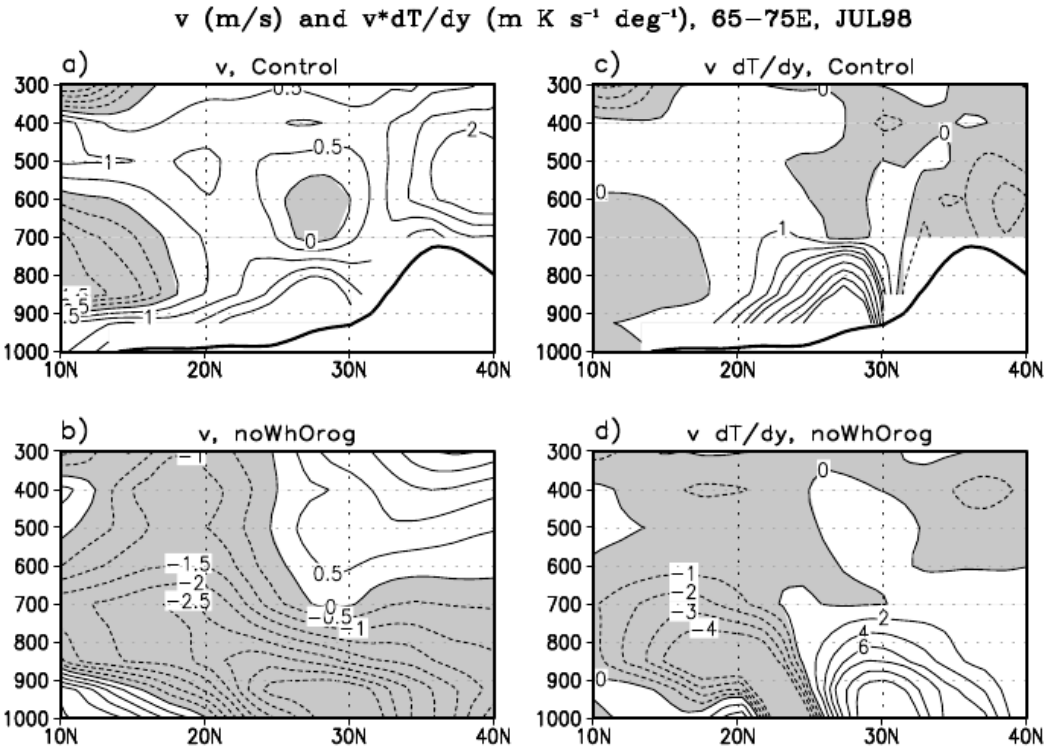
- Onset when Tibet is removed occurs in June
- Onset when W Himalayas are removed is in July
- Does MSE threshold explain this?

MSE Changes without Tibet/ W Himalayas



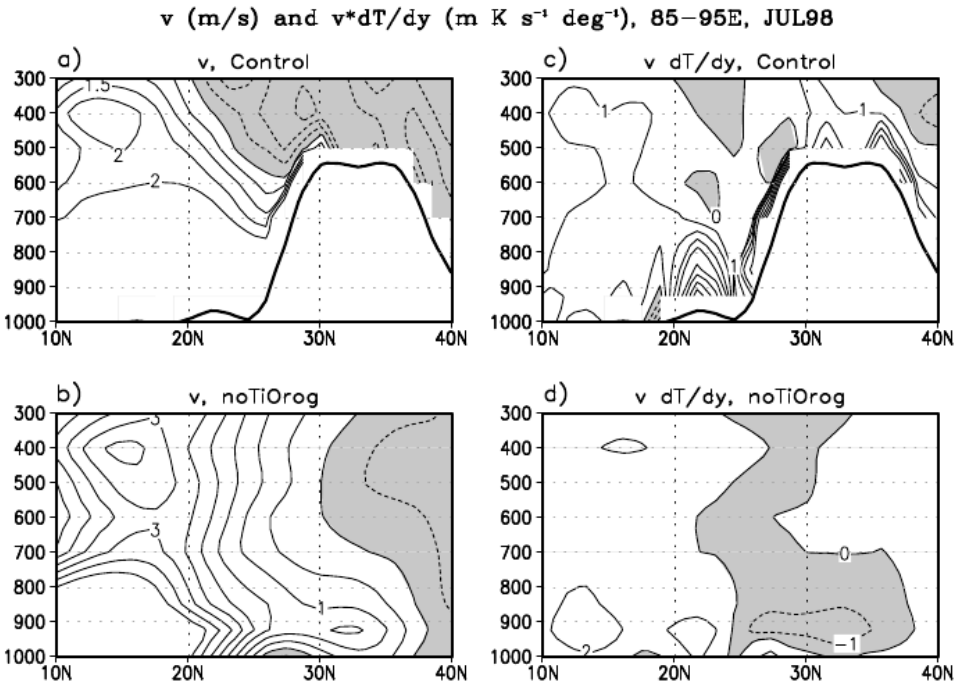
- We find that in absence of Tibet the MSE threshold is reached in June (not very different from control)
- In absence of W Himalayas, the threshold is reached much later in July than in the absence of Tibet

Advection In the ‘West Himalayan Gap’



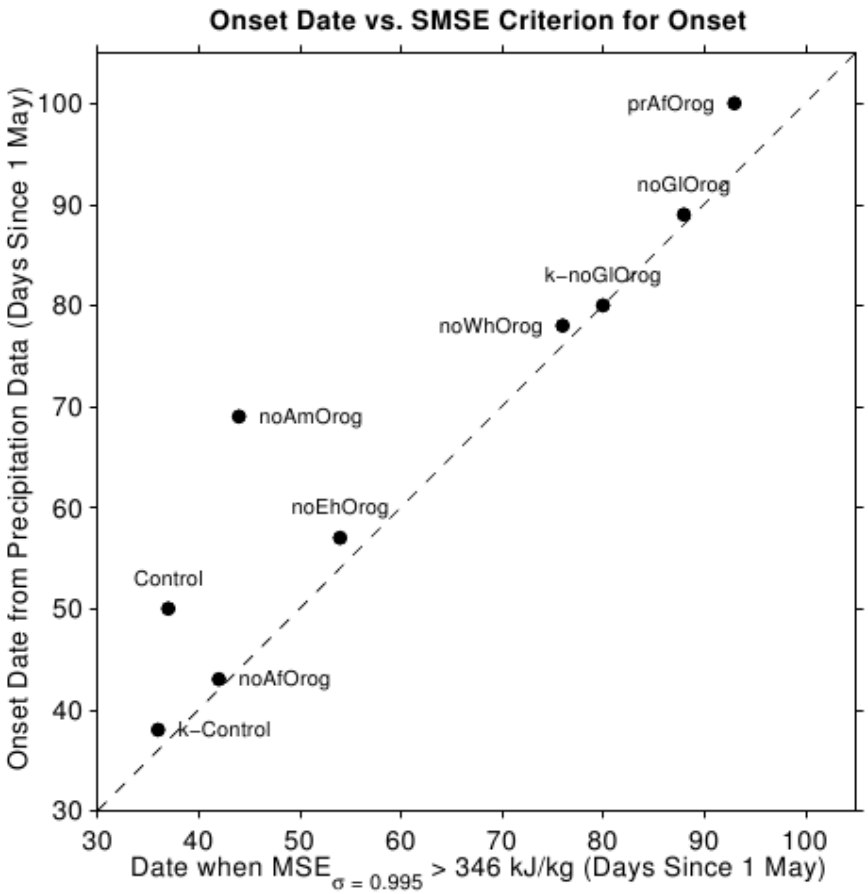
- Increased advection of cold air through the West Himalayan region

Advection In the 'Tibet Gap'



- Less noticeable effect of cold air advection when Tibet is removed
- Hence it is the advection of cold air from mid-latitudes that delays onset and reduces the strength of the Indian monsoon
- In observations during some years, effect of mid-latitude incursions are known to reduce the strength of the Indian monsoons (2009/1979?)
- These incursions (in observations) are more prominent towards W Himalayas.
- Is MSE threshold sufficient to define onset?

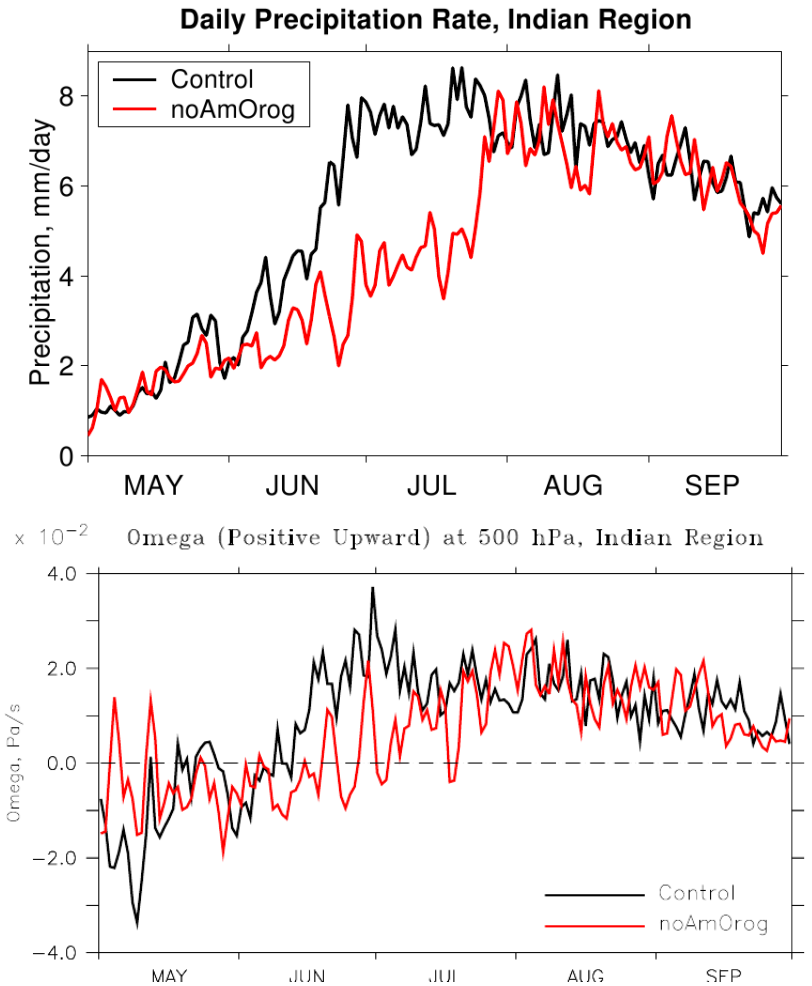
IS MSE sufficient to Define Onset?



- We notice that for most simulations this is a sufficient criteria.
- There is one major outlier : simulations with No Orography over the American Region
- It appears to have an impact on the Indian Monsoon

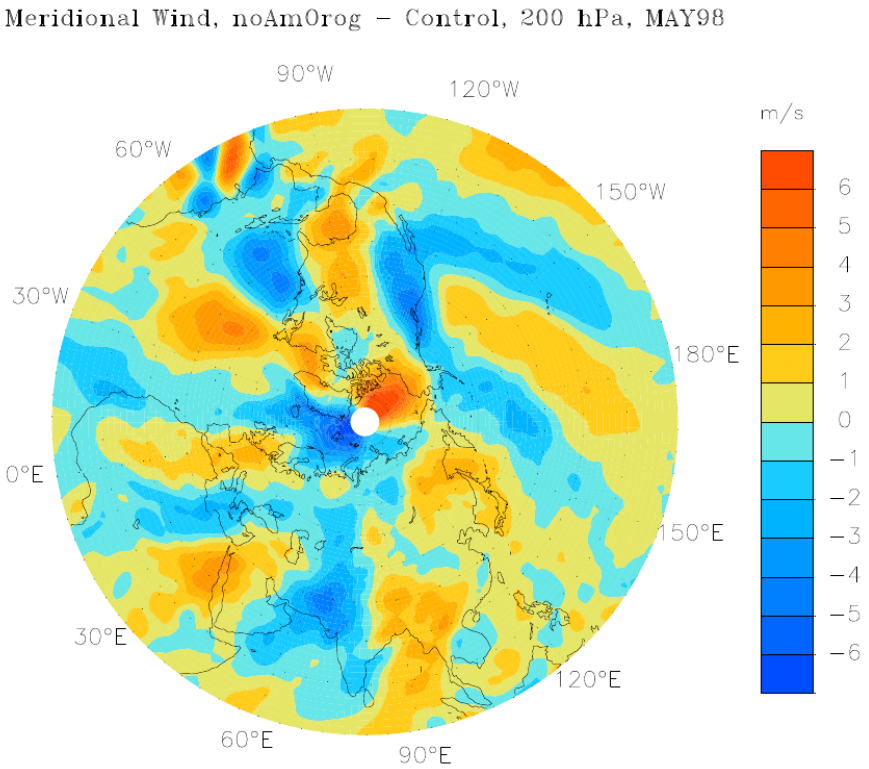
- In this case MSE crossed the threshold around 15 June
- Onset (as defined through rainfall) occurred around 10 July
- We found that vertical velocity was not upward enough to sustain large-scale convection in this case.
- How does American orography effect the monsoons?

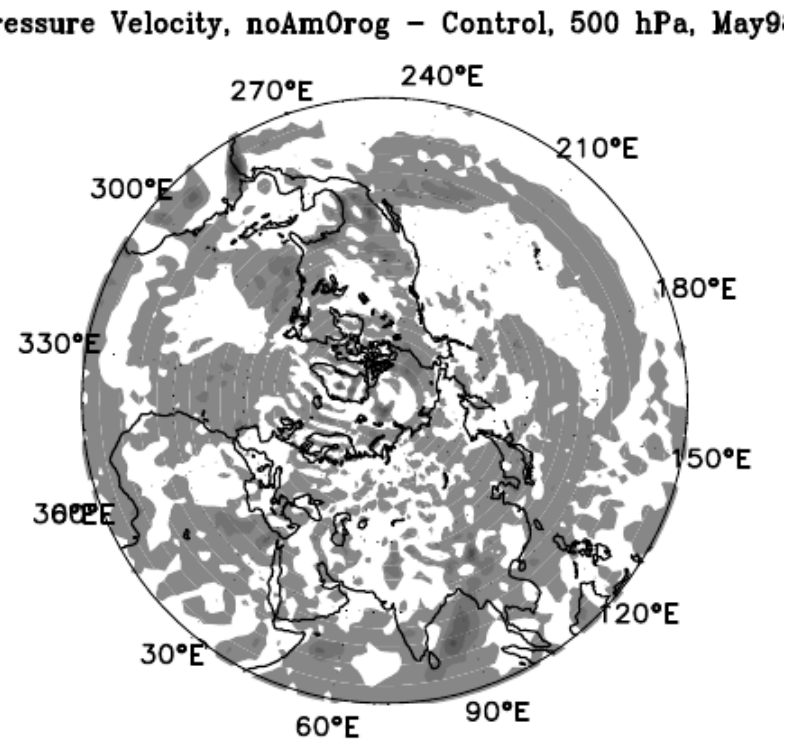
American Orography and the Monsoon



- We find that onset is delayed by about 20days without American orography
- This is related to more downward motion when American Orography is removed
- Though atmosphere is unstable, more downward motion delays onset
- Removal of American Orography changes the upper air circulation

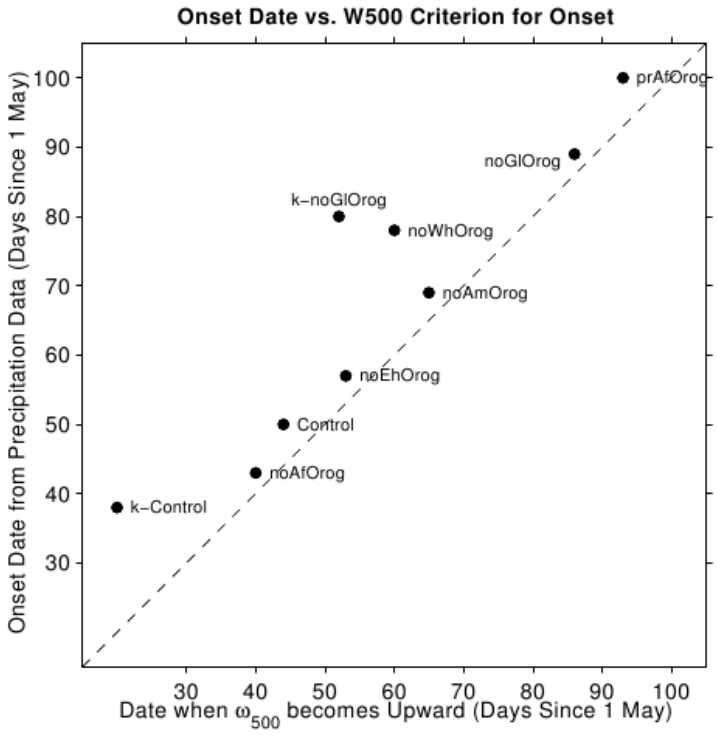
Changes in Upper Air Circulation

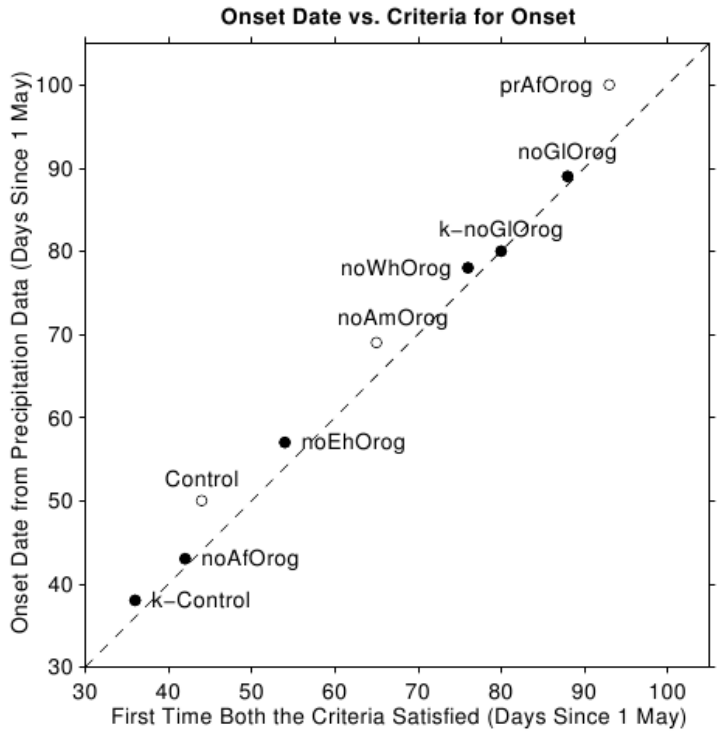




- Upper Air circulation could change the meridional velocity pattern
- This leads to reduced ascent over parts of India and Bay of Bengal
- Reduced convection over Bay could lead to reduced Westerly Jet and hence lower moisture transport and reduced rainfall over Indian landmass

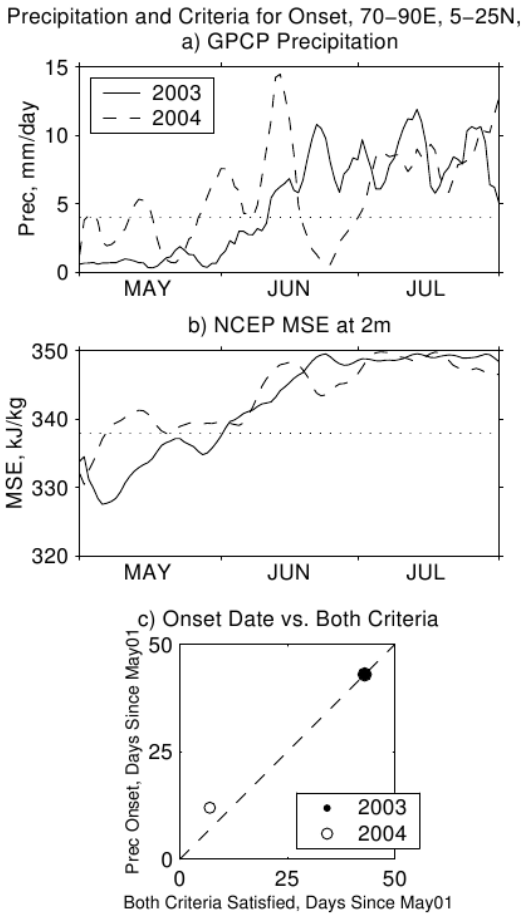
Theory of Onset





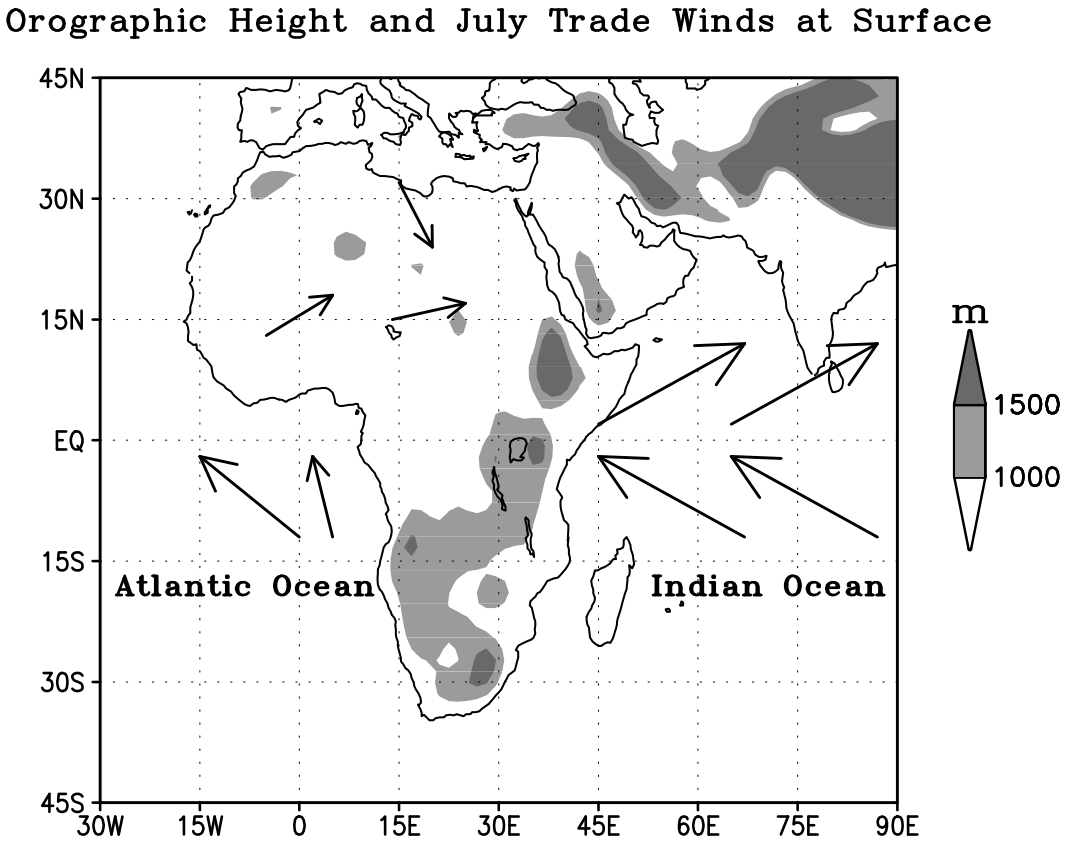
- We find that both MSE alone and W500 alone cannot explain dates of onset
- When both criteria are satisfied, onset occurs
- Thus atmospheric moist static instability (essentially related to thermodynamics) and large vertical motion (related to atmospheric dynamics) need to be favourable for onset to occur
- Does this theory (based on AGCM) hold for observations?

Observations



- In observations the dates of onset do not change dramatically
- However we have looked at two years 2003 & 2004
- We find that the onset in 2003 was much later than in 2004
- This is qualitatively similar to the dates of Monsoon onset over Kerala according to IMD, though our methods gives a substantially early onset in 2004

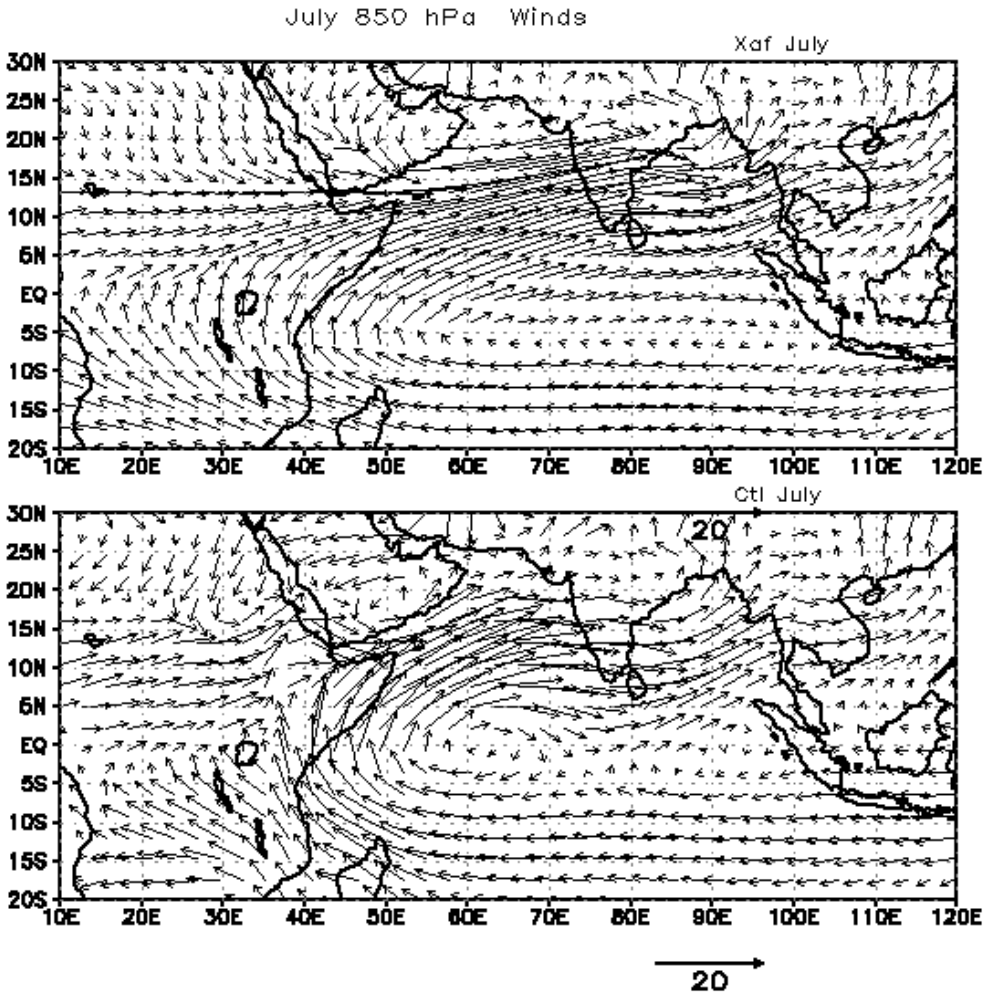
African Orography & Indian Monsoon



- Most previous studies about African orography & monsoons are with linear models
- Most of them suggest that African orography is essential for the Westerly Jet, — as a boundary current
- However, the Westerly Jet occurs only during the Monsoon season

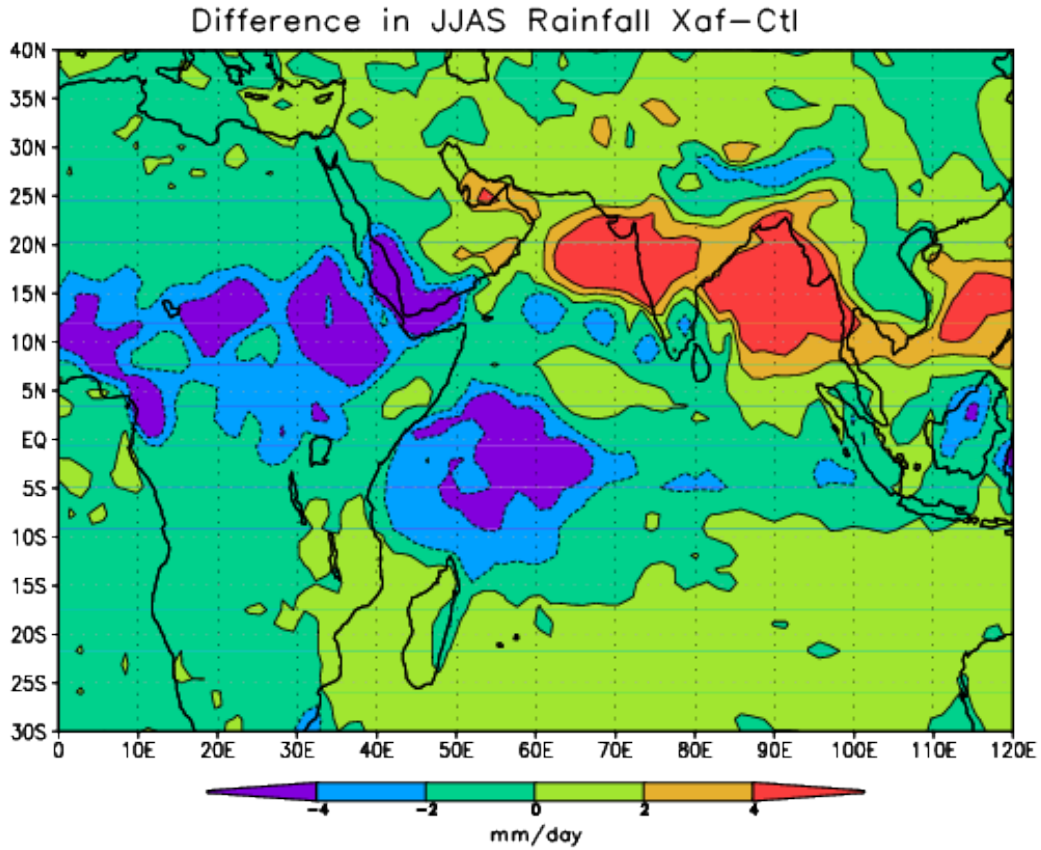
- Hence it should be a response to monsoonal heating
- We studied the impact of African orography on the Westerly Jet and Indian monsoon rainfall with an AGCM
- We compared simulations with and without African orography

Does the Westerly Jet Collapse in Absence of African Orography?



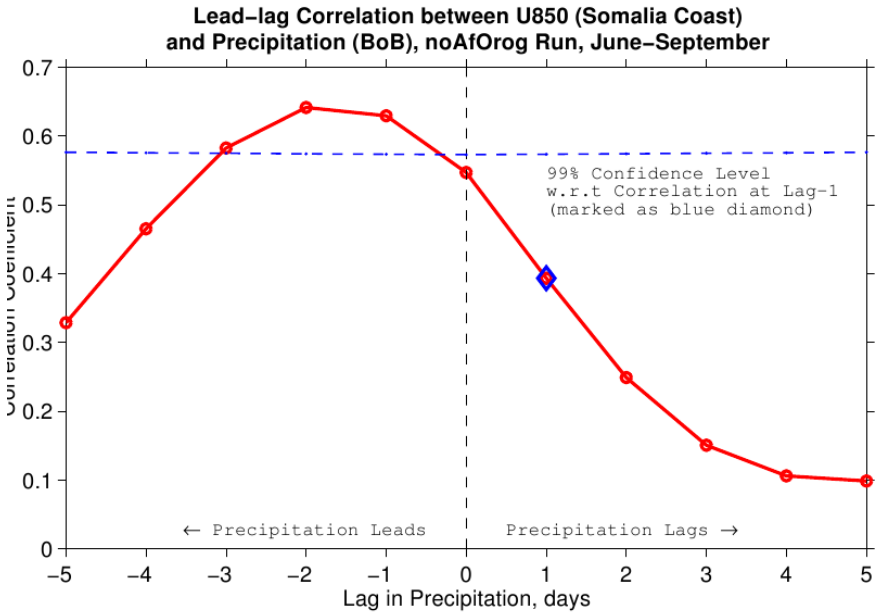
- We find that the Jet is actually stronger in the absence of orography
- What happens to rainfall?

Rainfall Without African Orography



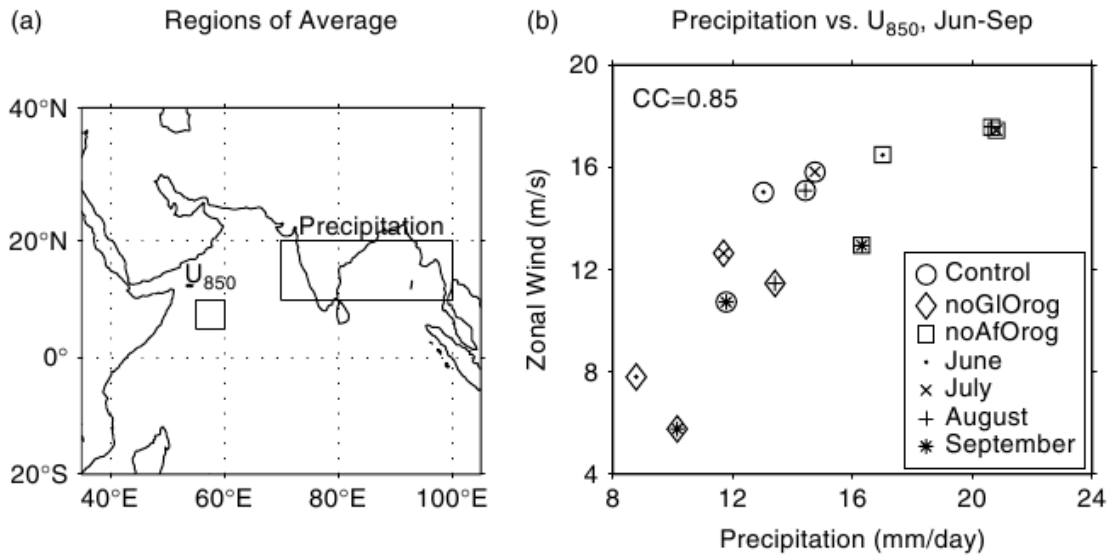
- Over Indian region we find that rainfall increases
- There is a decrease in African rainfall
- Is the strength of the jet related to monsoonal rainfall?

Rainfall and Wind on the Intraseasonal Scale



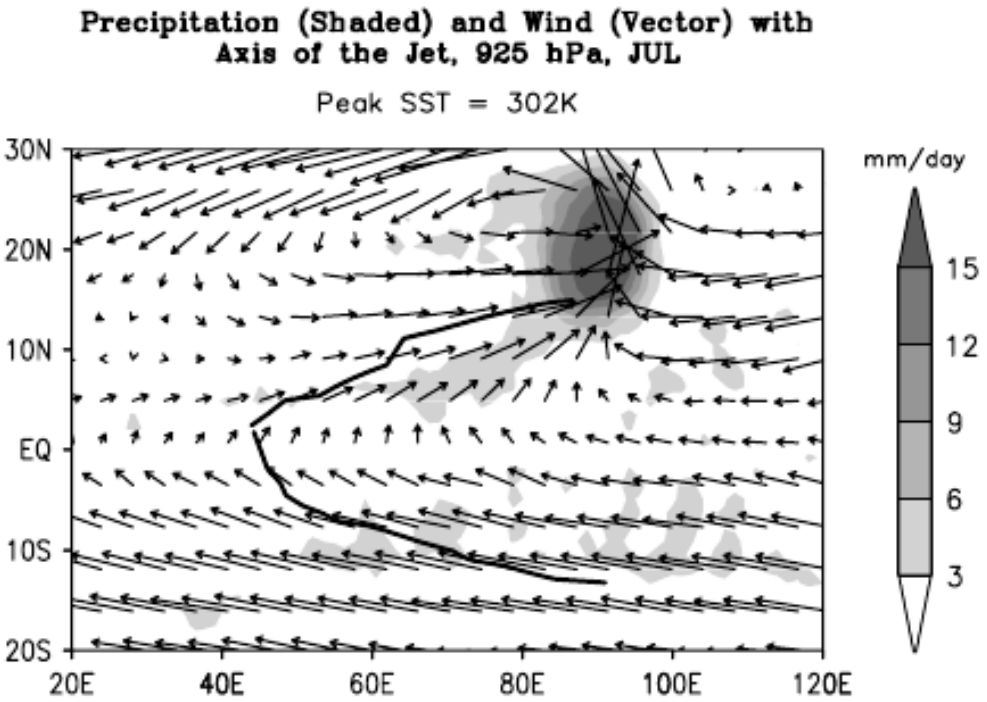
- We find that winds in the Arabian Sea are correlated with Rainfall over Bay of Bengal
- Winds lag rainfall by about 3 days i.e. they respond to rainfall
- Does this hold on the seasonal scale?

Relationship Between Westerly Jet and Rainfall



- The relationship hold across different simulations
- Higher the rainfall, stronger the jet
- Can we have a jet even in the absence of land-contrast?
- We examine an aqua-planet simulation with off-equatorial SST maxima

Jet in an Aqua-Planet



- The aqua-planet simulation has an off-equatorial (20^{o}N) SST maxima of 29^{o}C
- This mimics the conditions over Bay of Bengal
- Rainfall is concentrated around the SST maxima
- The wind clearly shows a cross-equatorial jet structure

- The turning of wind occurs about 30-40^o west of rainfall maxima
- For the Indian reigon this corresponds to heating over Bay of Bengal and the wind turning near Africa — The Low Level Jet
- Thus the Low-Level Jet is a response to monsoonal heating rather than a boundary current

Summary

- We find that orography both remote and proximate can have an impact on the Indian monsoon
- West Himalayan orography has a larger impact than East Himalayan orography—date of onset is delayed much more
- Once onset occurs, the strength of the monsoon is no longer related to the presence or absence of orography
- The Low level Westerly Jet is a response to monsoonal heating and not a boundary current (as usually shown by linear studies)

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