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Rapid Intensification of Somali Jet Kinetic Energy prior to Monsoon Onset

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Background

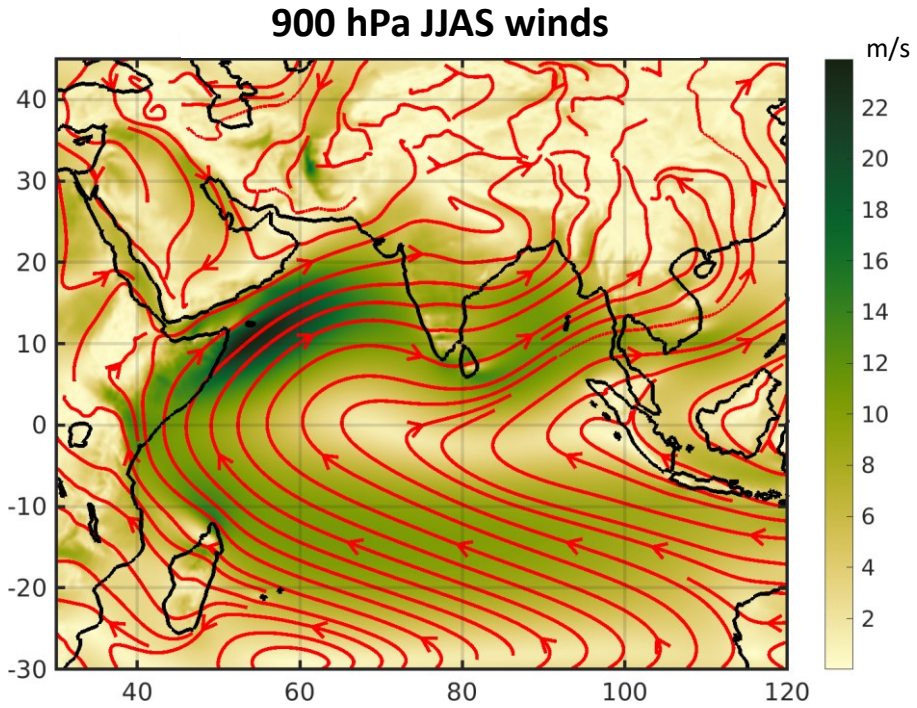
- A low level cross-equatorial flow that turns eastward and becomes zonal at around 10N is called as the Somali Jet. This jet is a key characteristic of the Indian monsoon.

- The jet transports energy and moisture from the southern hemisphere to the northern hemisphere and is essential for the ISMR.

- The jet intensifies rapidly within a few days and thus can not be explained as simply a linear response to the latitude of maximum temperature.

What causes this **sudden intensification of the Somali jet ?**

Kinetic Energy budget helps us answer that



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Kinetic Energy Equation

Horizontal momentum equation

$$\frac{D\boldsymbol{u_h}}{Dt} + f\hat{\boldsymbol{k}} \times \boldsymbol{u_h} + 2\Omega cos\theta w\hat{\boldsymbol{i}} = -\frac{1}{\rho}\boldsymbol{\nabla_h p} + \boldsymbol{F}$$

Scalar product with $\boldsymbol{u_h}$ and some further simplification

KE equation

$$\frac{\partial KE}{\partial t} + u\frac{\partial KE}{\partial x} + v\frac{\partial KE}{\partial y} + \omega\frac{\partial KE}{\partial p} + 2\Omega cos\theta wu = -\left(u_a\frac{\partial \phi}{\partial x} + v_a\frac{\partial \phi}{\partial y}\right) + Friction$$

Cross-isobaric winds

KE Advection

Coriolis term ~ 0

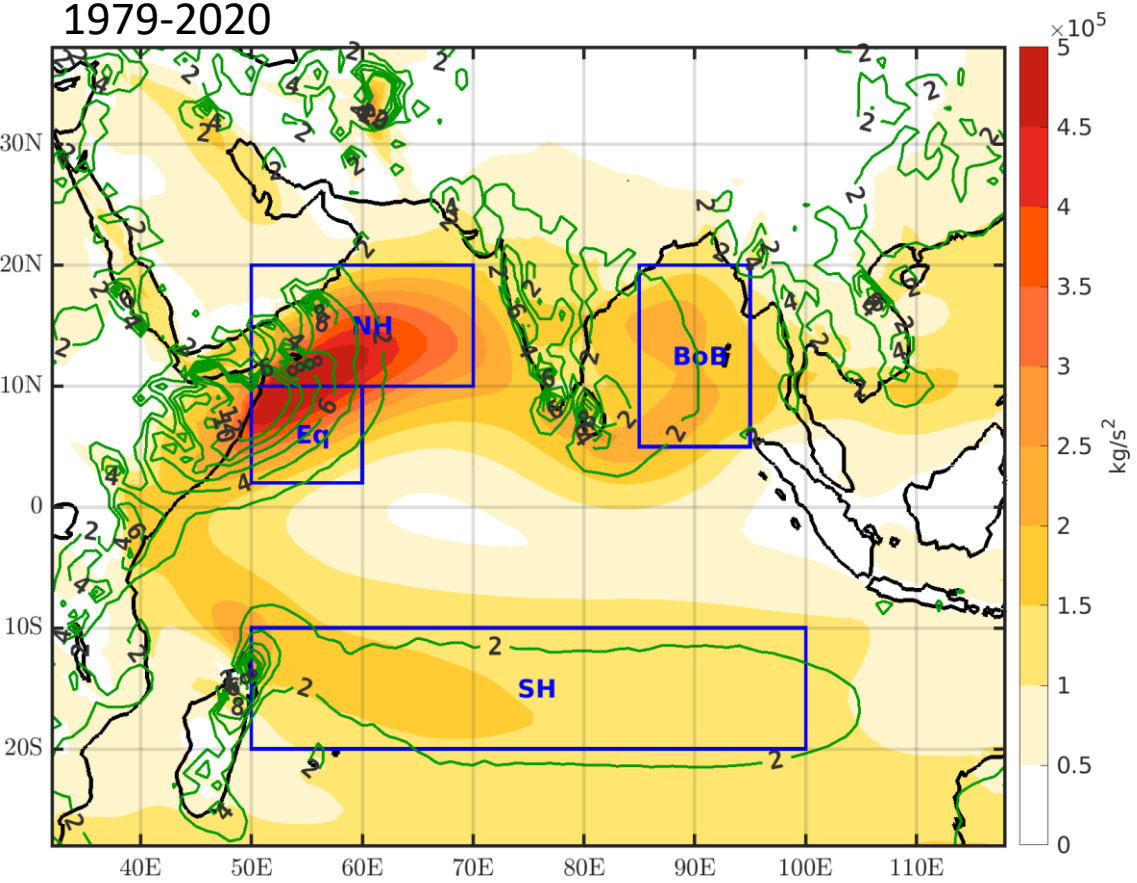
KE Generation (KE_{gen})

Dissipation

We will look at each term of the budget using the ERA5 reanalysis data (daily, $1^\circ \times 1^\circ$)

Regions of High Kinetic Energy

1979-2020



- Four high KE regions are identified.
- KE generation is high in regions with orography..
- High KE generation is also seen in the “Eq” region.

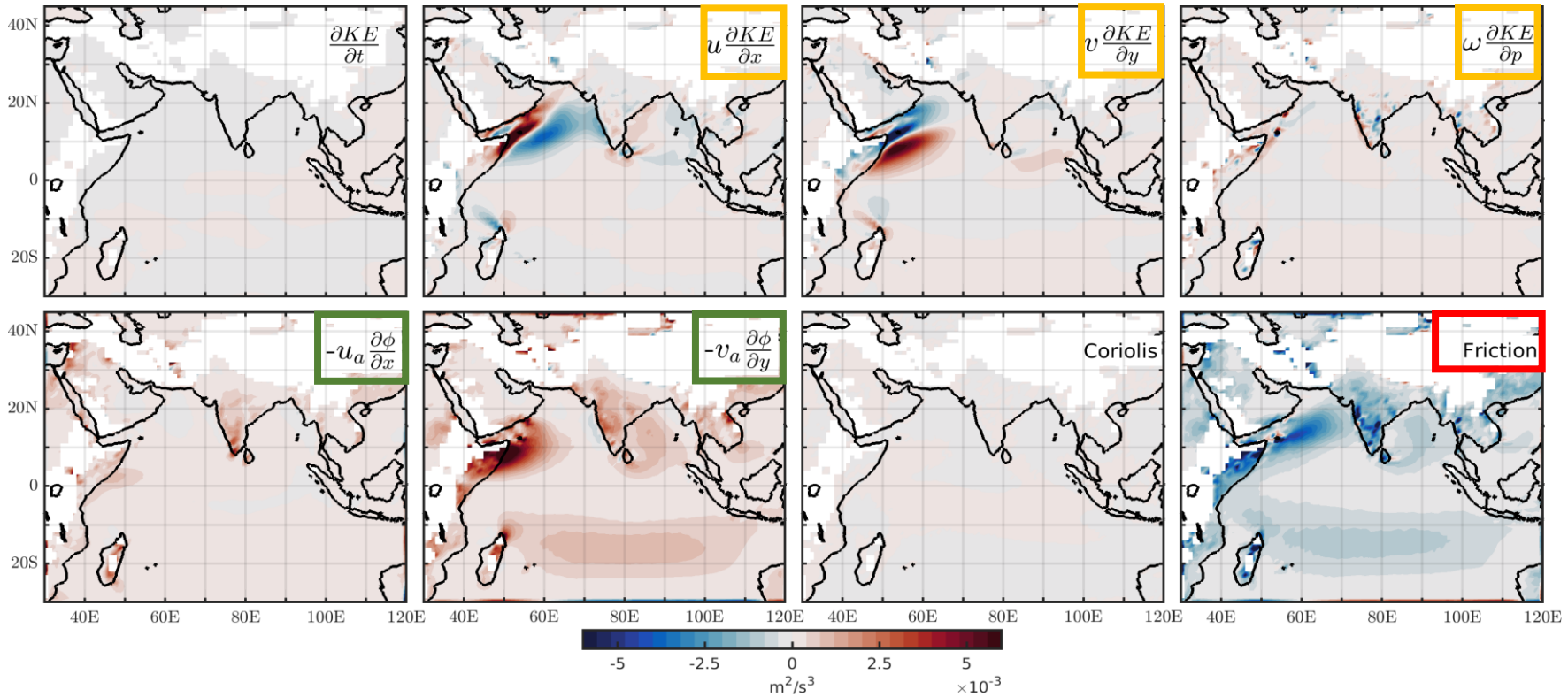
Shading: $-\frac{1}{g}\int_{1000}^{700} KE \cdot dp$; Where, $\boldsymbol{KE} = u^2 + v^2$

Contour: $-\frac{1}{g}\int_{1000}^{700} KE_{gen} \cdot dp$; Where, $\boldsymbol{KE_{gen}} = -\left(u_a \frac{\partial \phi}{\partial x} + v_a \frac{\partial \phi}{\partial y}\right)$

Seasonal Mean KE Budget

900 hPa

1979-2020



- KE generation majorly comes from the meridional component.
- High values of horizontal advection is present in the Arabian sea.
- Localized vertical advection is seen in regions where orography is present

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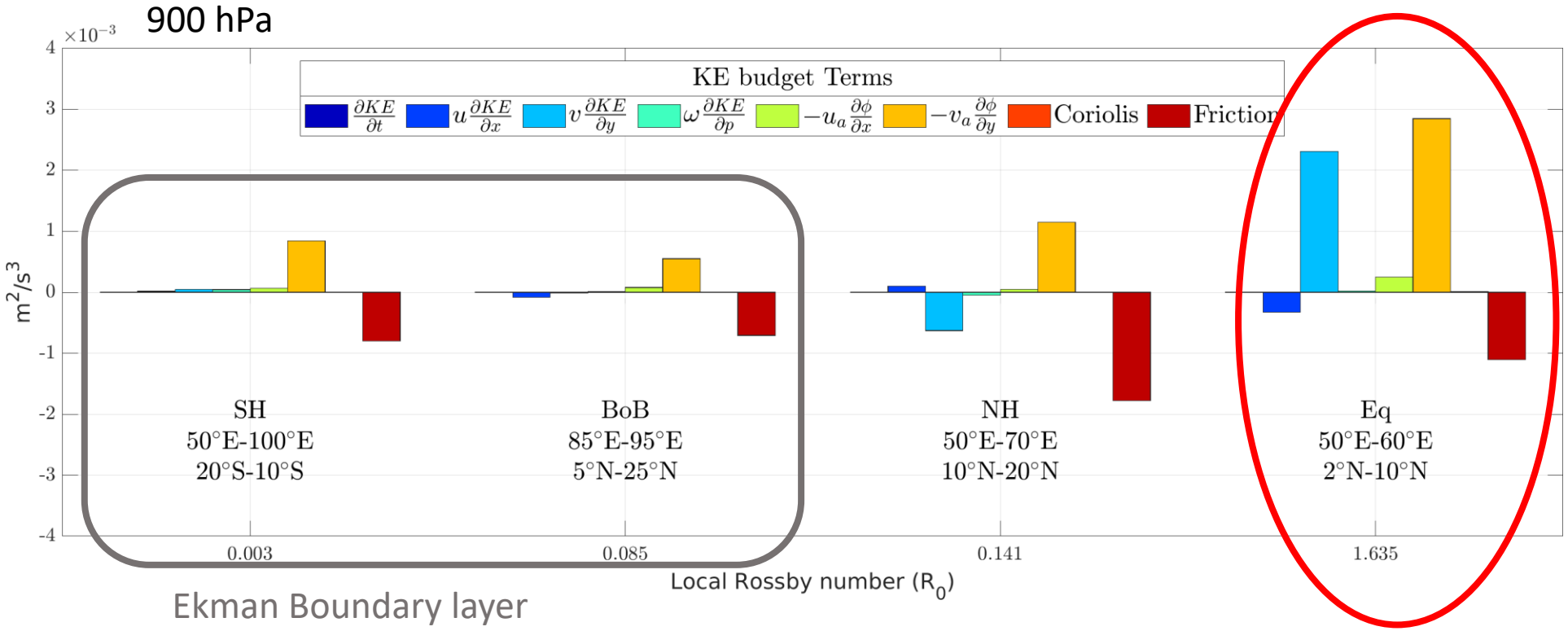
Dominant Balances during Monsoon

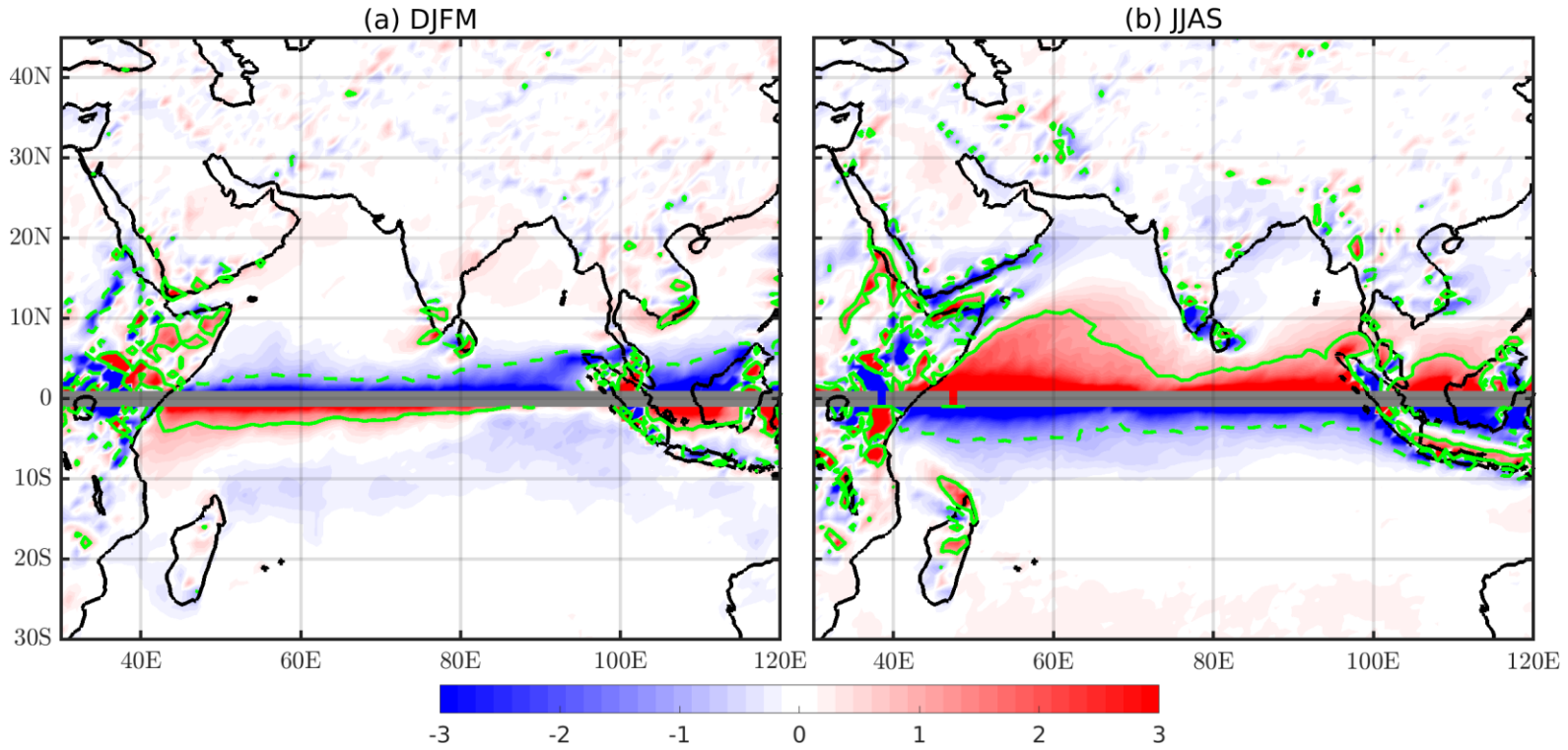


1979-2020

Local Rossby Number (R_o) = Ratio of advective acceleration to Coriolis acceleration

$$R_o = -\frac{\zeta}{f}$$

Local Rossby Number (R_o)



$R_o = 1$ contour shifts poleward during the northern hemisphere summer while in winters it is confined to equator

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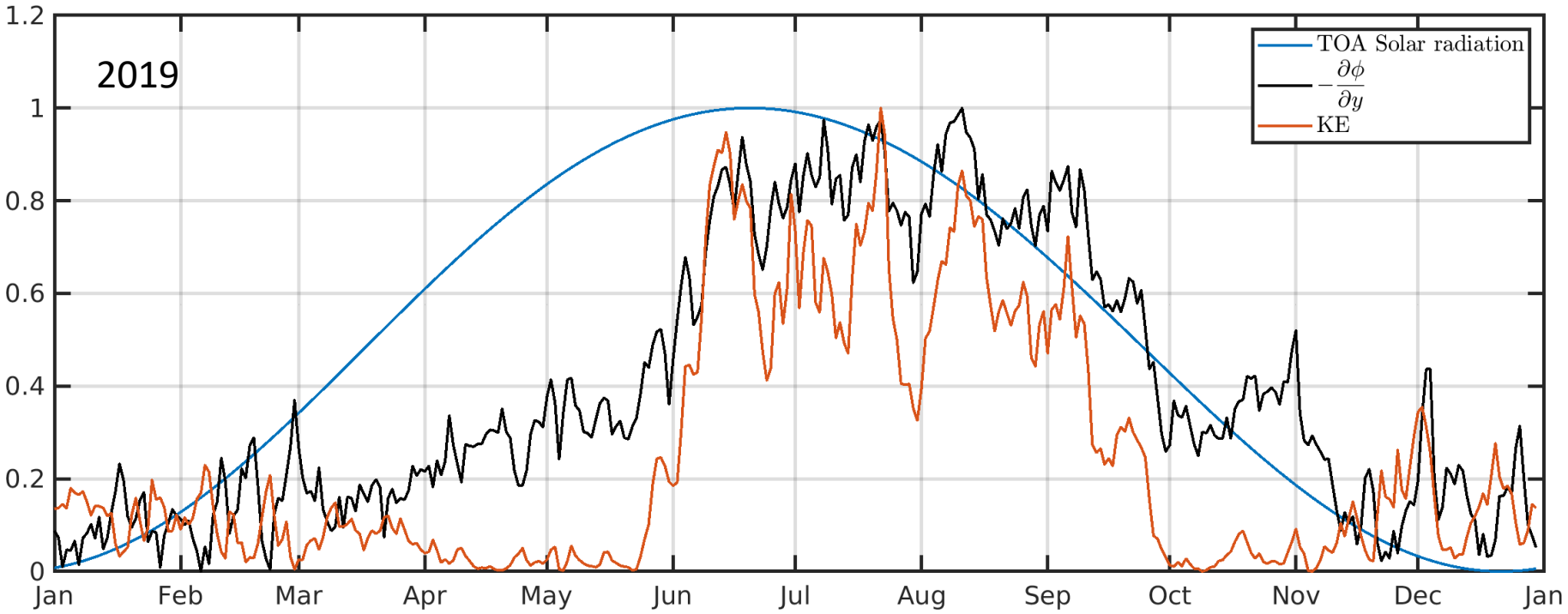
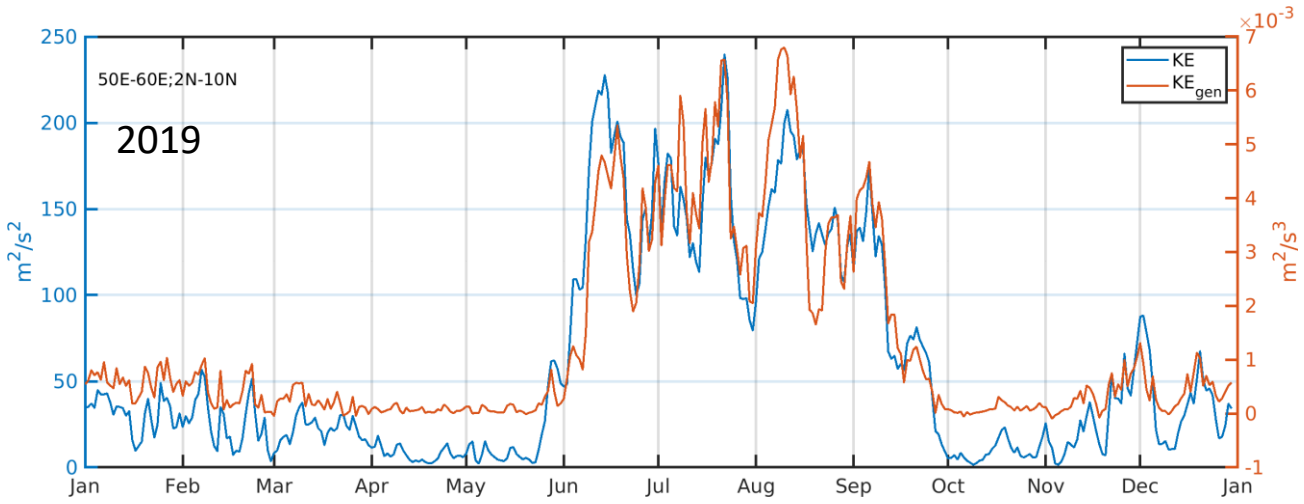
Rapid Increase of KE

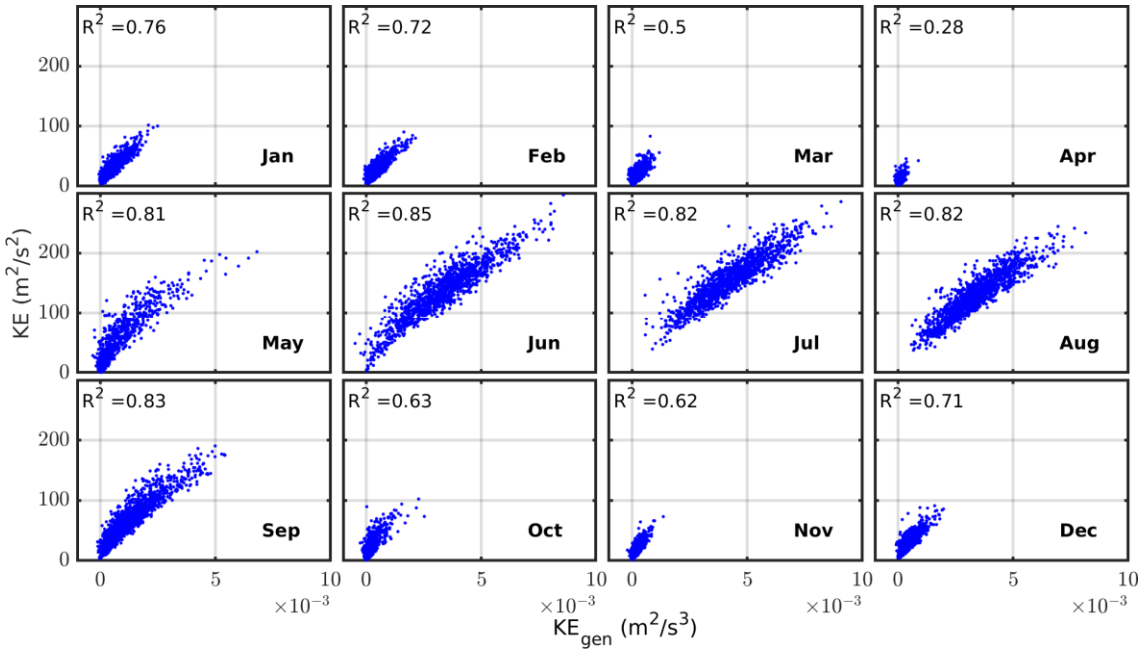


- Northern hemisphere solar insolation increases on a seasonal time scale.
- The increase in geopotential gradient is faster.
- Intensification of KE of the jet is much more rapid.

All the variables are scaled to have values from 0 to 1

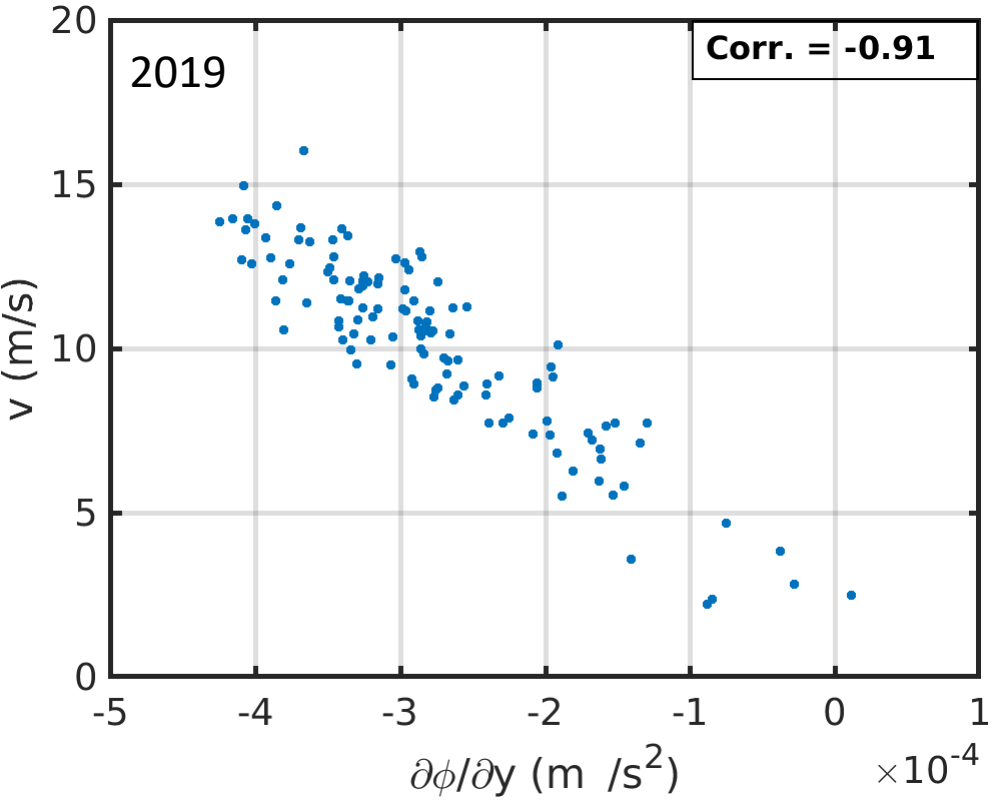
Intensification of KE generation





- KE generation also shows a rapid increase during monsoon onset
- Kinetic energy and its generation has a strong linear relationship especially during monsoons.
- Further $KE_{gen} \sim -v\frac{\partial \phi}{\partial y}$
- Thus we look at the relationship between v and $\frac{\partial \phi}{\partial y}$

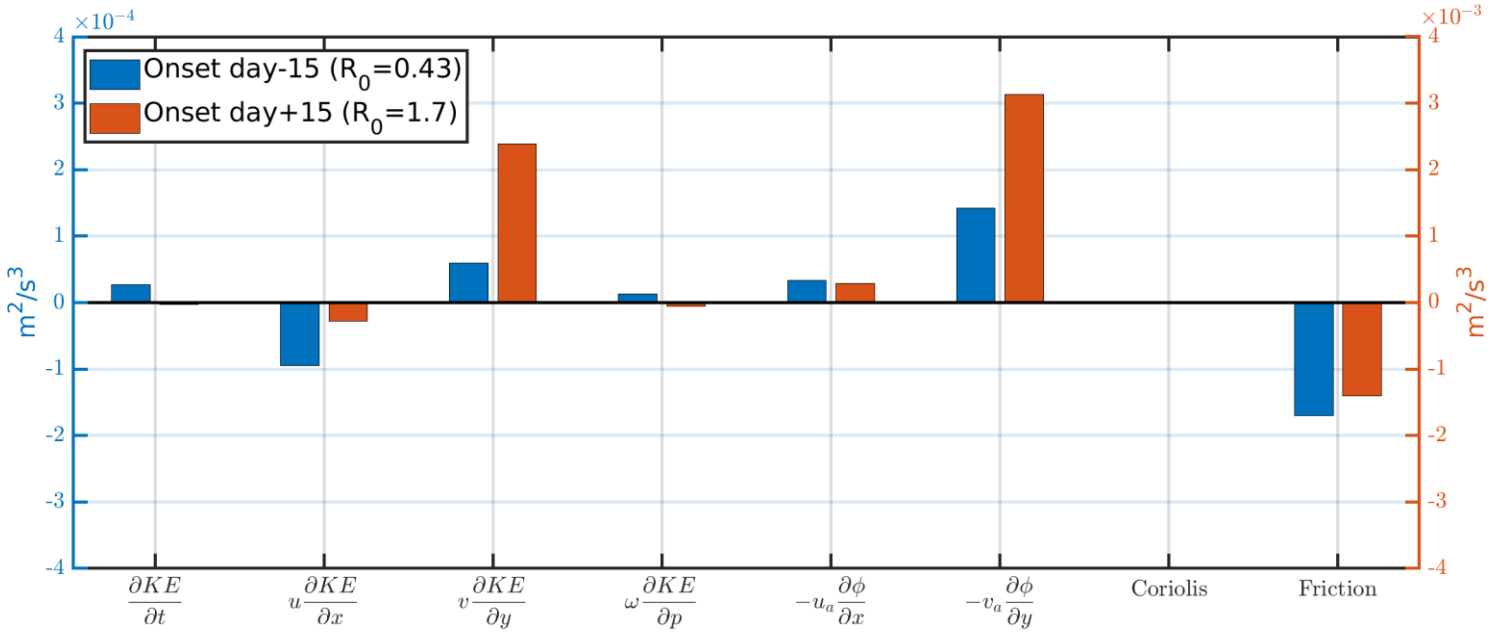
Meridional wind vs meridional geopotential gradient



- Meridional winds are controlled by the meridional geopotential gradient.
- KE generation, which is a product of v and $\frac{\partial \phi}{\partial y}$, thus has a nonlinear response to geopotential gradient and increases rapidly.
- As seen in previous slide, KE generation has a high correlation with KE. Thus the rapidity in KE generation will be translated to KE.
- This leads to rapid intensification of the jet kinetic energy.

$$KE \propto KE_{gen} \propto v\frac{\partial \phi}{\partial y} \propto \left(\frac{\partial \phi}{\partial y}\right)^2$$

Regime change in KE budget at the start of monsoon



- 15 days before onset, R_o is less than 1 and the KE generation is balanced by friction.
- 15 days after onset, R_o exceeds 1 and the generation term is balanced by meridional advection making the boundary layer advective

❖ Notice different scales for pre and post onset KE Budget.

❖ Onset day is selected using the criteria by *Wang et al. (2009)*

Summary

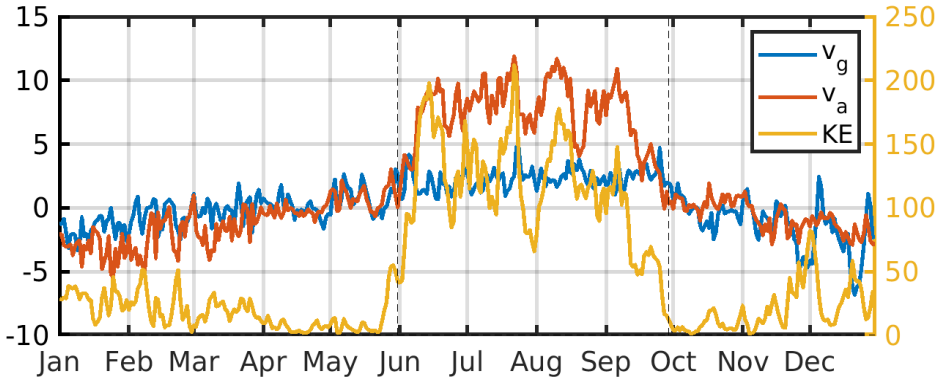
- Boundary layer till 10N is advective during monsoon with local Rossby number exceeding 1.

- Immediately after the onset of monsoon, the balance in KE budget of Somali jet shifts from one being dominated by friction to a one where nonlinear advection balances KE generation.

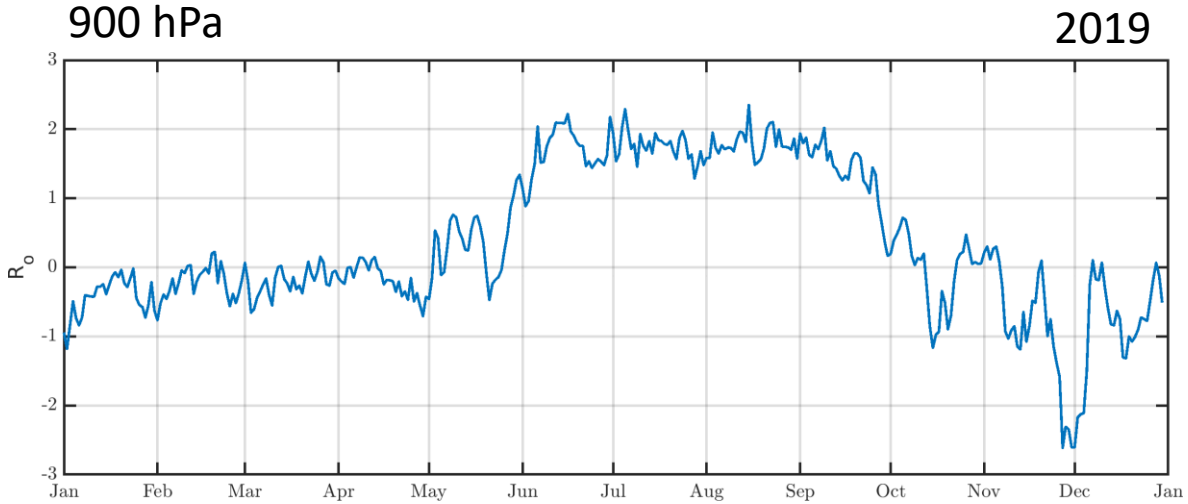
- Rapid intensification is seen in KE generation term, which is caused by the nonlinear response to meridional geopotential gradient.

QUESTIONS?

Appendix



Cross-isobaric meridional wind (v_a) intensify at the start of monsoon



Local Rossby number exceeds 1 at the start of monsoon. Leading to a nonlinear advective boundary layer.