Modeling interactions between the quasi-geostrophic vertical motion and convection in a single column

Ji Nie, Adam Sobel, and Daniel Shaevitz
Lamont-Doherty Earth Observatory,
Department of Applied Physics and Applied Mathematics,
Columbia University

Part I: a single-column modeling framework: interaction between LS and convection

Part II: applications on the 2010 Pakistan extreme precipitation events

Introduction:

the idea of modeling tropical precipitation in a single column

(Sobel and Bretherton 2000, Raymond and Zeng 2005, Kuang 2008, Romps 2012, …)

convective heating

$$\partial_t T = Adv_T + \boxed{\frac{\sigma p}{R} w} + \boxed{Q},$$

$$\partial_t q = Adv_q - s_q w + Q_q.$$

convective moistening

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<u>Q and w have to be solved simultaneously.</u>

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Applications: convection responses to ENSO (e.g. Chiang and Sobel 2002); Seasonality (Gentine et a. 2015); QBO (Nie and Sobel 2015), …

However, what about the extratropics?

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convective moistening

a closure (super-domain scale parameterization) that relate the large-scale vertical motion with the states of the local column :

tropics:	extratropics:
WTG	?

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tropics: extratropics:

WTG QG-omega

quasi-geostrophic omega equation:

- omega

convective heating

$$\partial_{pp} w + \frac{\sigma}{f_0^2}\nabla^2 w = -\frac{1}{f_0}\partial_p(Adv_\zeta) - \frac{R}{p f_0^2}\nabla^2 Adv_T - \frac{R}{p f_0^2}\nabla^2 Q,$$

differential vorticity advection

differential temperature advection

$$\omega_{total} = \omega_\varsigma + \omega_T + \omega_Q$$

$$\omega_{QG}$$

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<u>longwave limit: </u>middle-latitude dry dynamics (dry QG)

$$\omega_{total} = \omega_\varsigma + \omega_T + \cancel{\omega_Q}$$

<u>shortwave limit or f->0: </u>tropical dynamics (Strict WTG)

$$\omega_{total} = \cancel{\omega_\varsigma} + \cancel{\omega_T} + \omega_Q$$

$$\partial_{pp} w + \frac{\sigma}{f_0^2} \nabla^2 w = -\frac{1}{f_0} \partial_p (Adv_\zeta) - \frac{R}{p f_0^2} \nabla^2 Adv_T - \frac{R}{p f_0^2} \nabla^2 Q,$$

$$\omega_\varsigma + \omega_T \sim \omega_Q$$

<u>wavelength:</u> roughly between 700km and 2000km
<u>extratropics:</u> plenty of QG disturbances
<u>strong precip.:</u> the convective heating is significant

the modeling framework:
coupling the large-scale dynamics and convection with the QG-omega equation:

$$\partial_t T = Adv_T + \frac{\sigma p}{R} w + Q,$$
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a. assume there is a characteristic length scale:

$$\partial_{pp} w - \sigma (\frac{k}{f_0})^2 w = -\frac{1}{f_0} \partial_p (Adv_\zeta) + \frac{R}{p} (\frac{k}{f_0})^2 Adv_T + \frac{R}{p} (\frac{k}{f_0})^2 Q.$$

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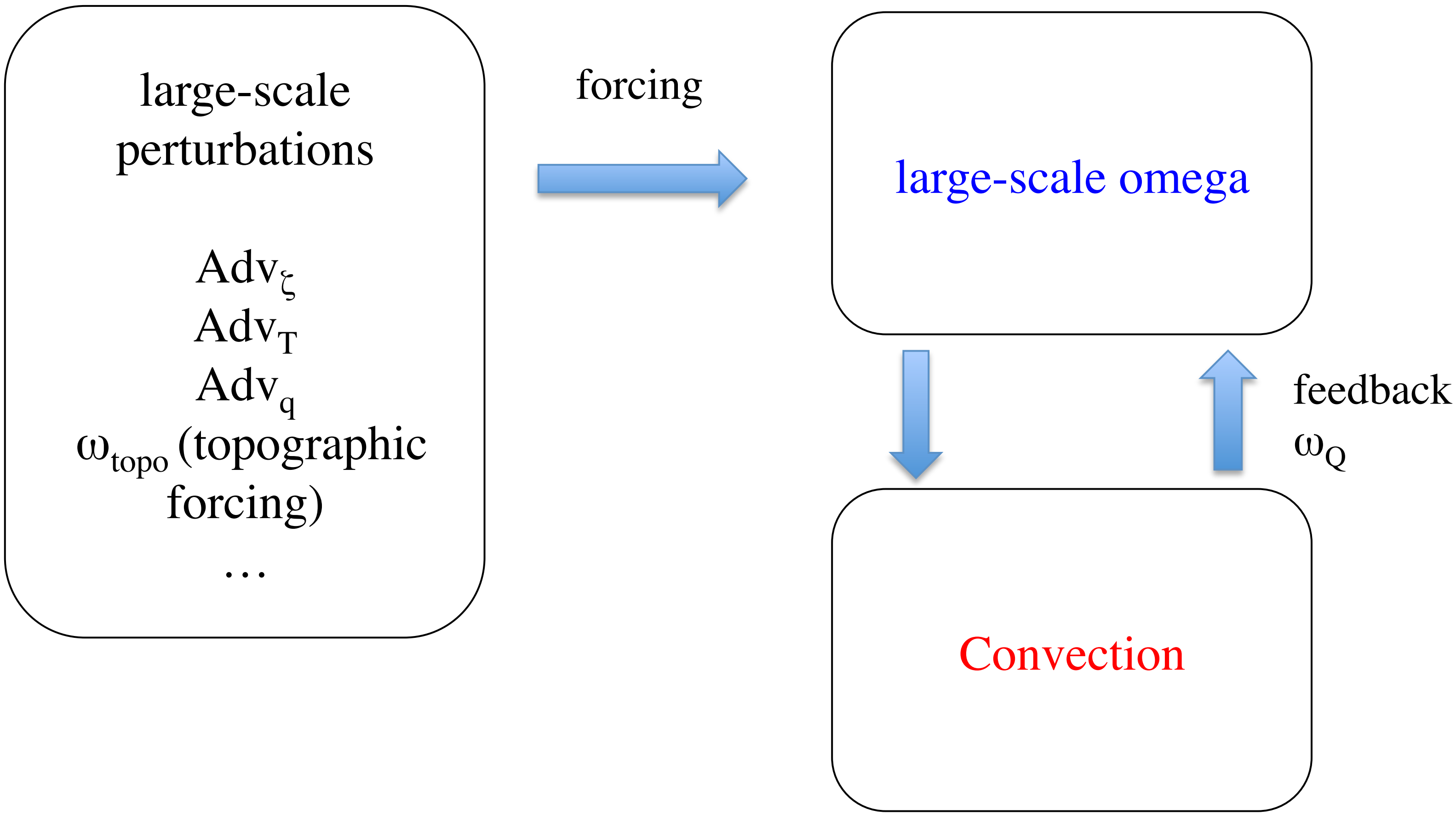
c. prescribe QG forcing (Adv_ζ, $Adv_{T,}$ $Adv_{q, \ldots}$)

the modeling framework:



Part I: a single-column modeling framework: interaction between LS and convection

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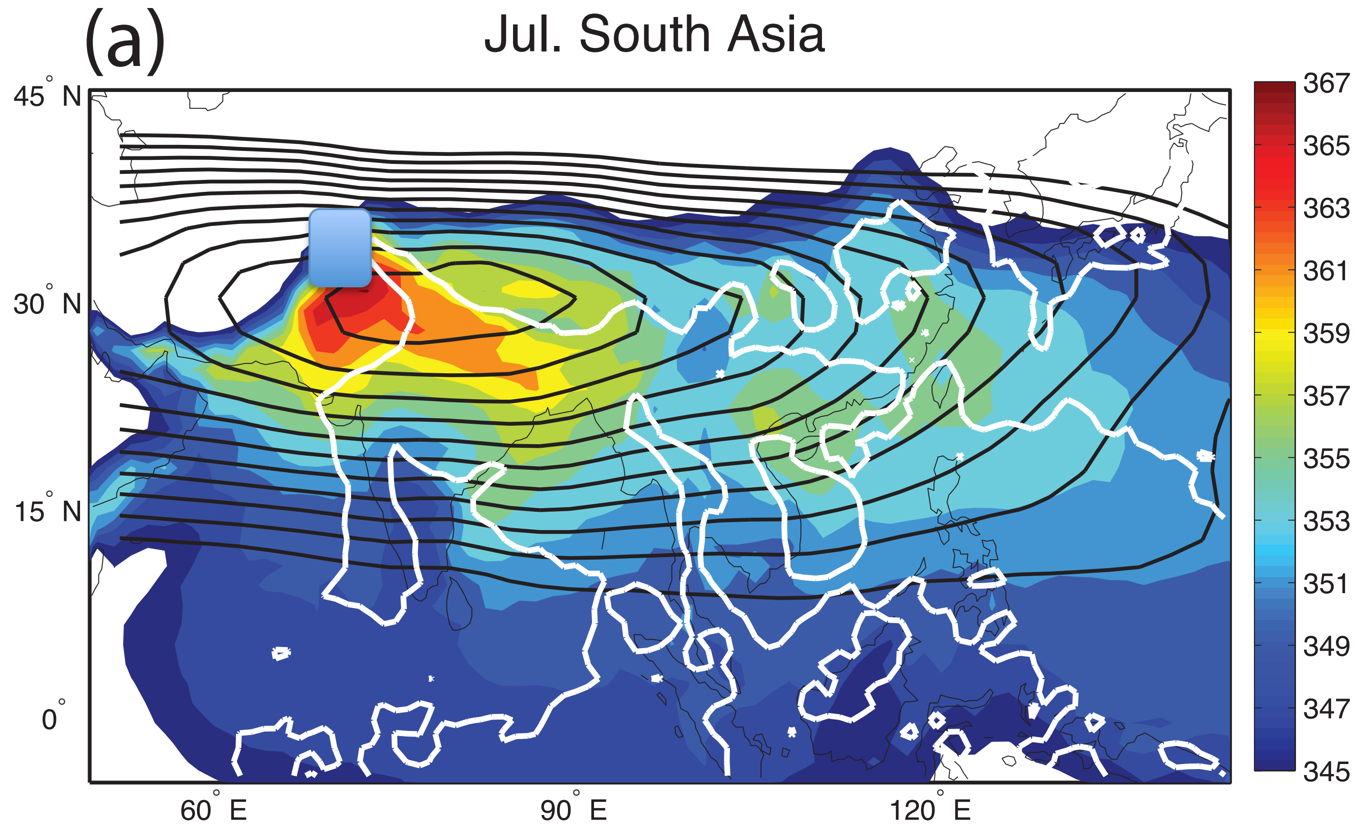
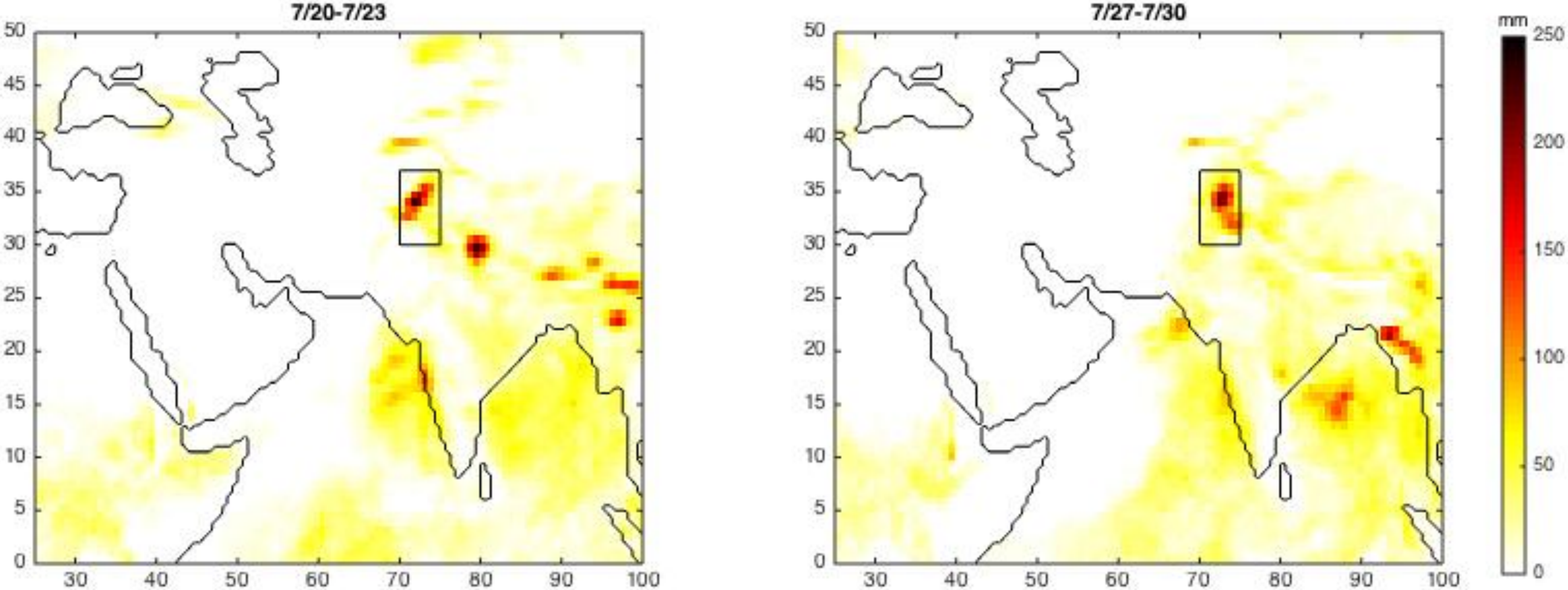
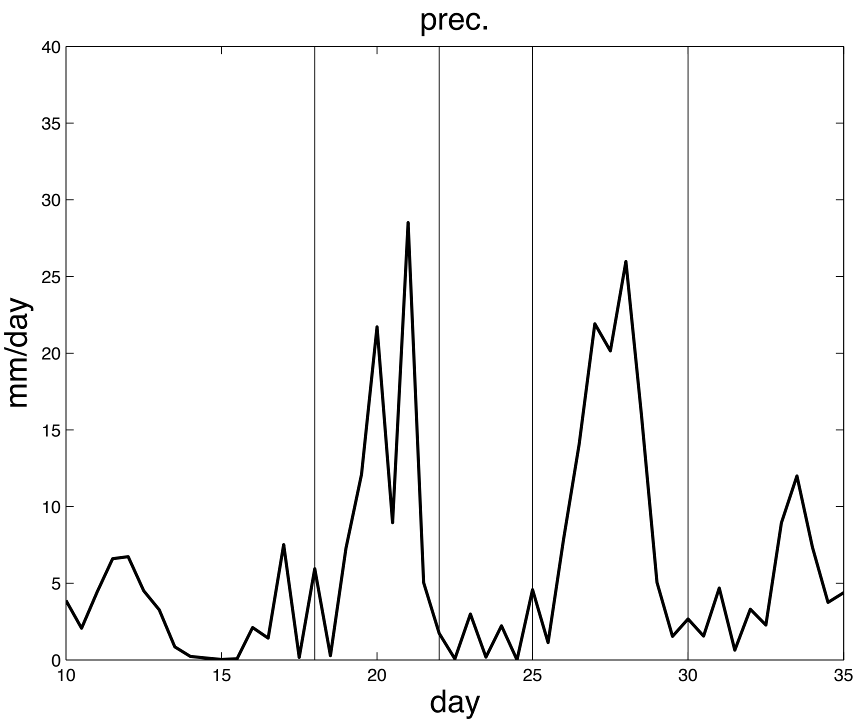
Northrn Pakistan floods
during monsoon seasons:

…
2003
2007
2010
2011
2012
2013
2014



Nie et al. 2010



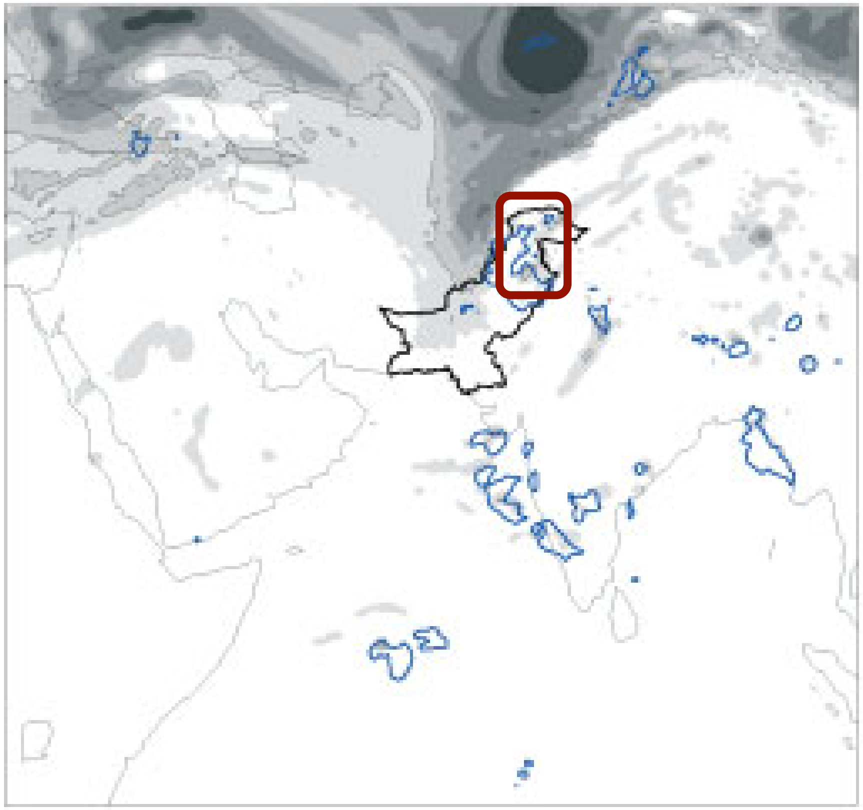


2010 Pakistan flood events:
ERA-interim Precip.

favorable conditions:

upper-level PV intrusion
monsoon depression
moisture transport
topographic wind
CAPE
surface-moisture
…

large-scale conditions of the 2010 event
PV on 340K

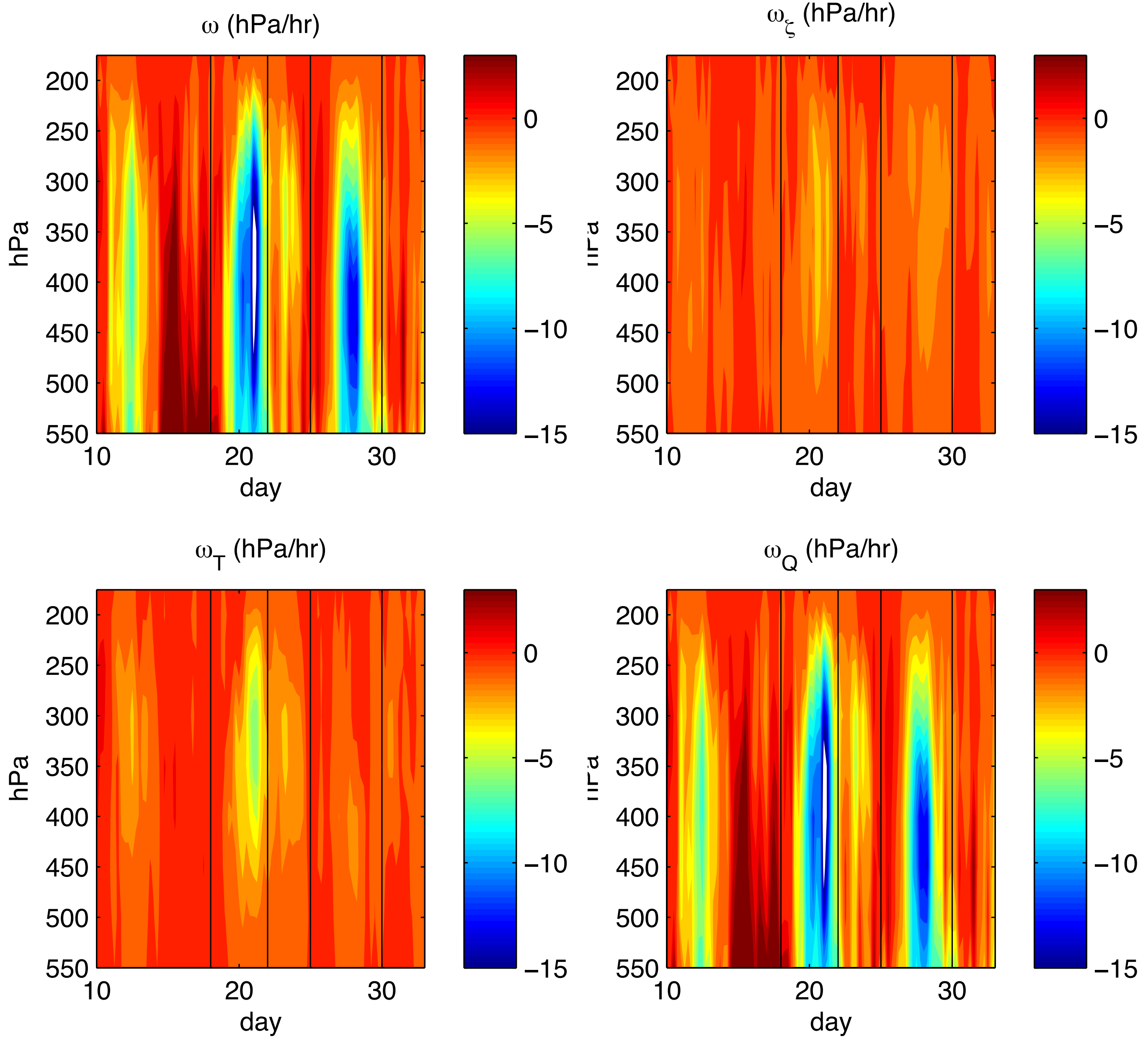


Martius et al. 2013

Q: What causes the extreme precipitation?

Obs. $\omega_Q > \omega_\varsigma + \omega_T$

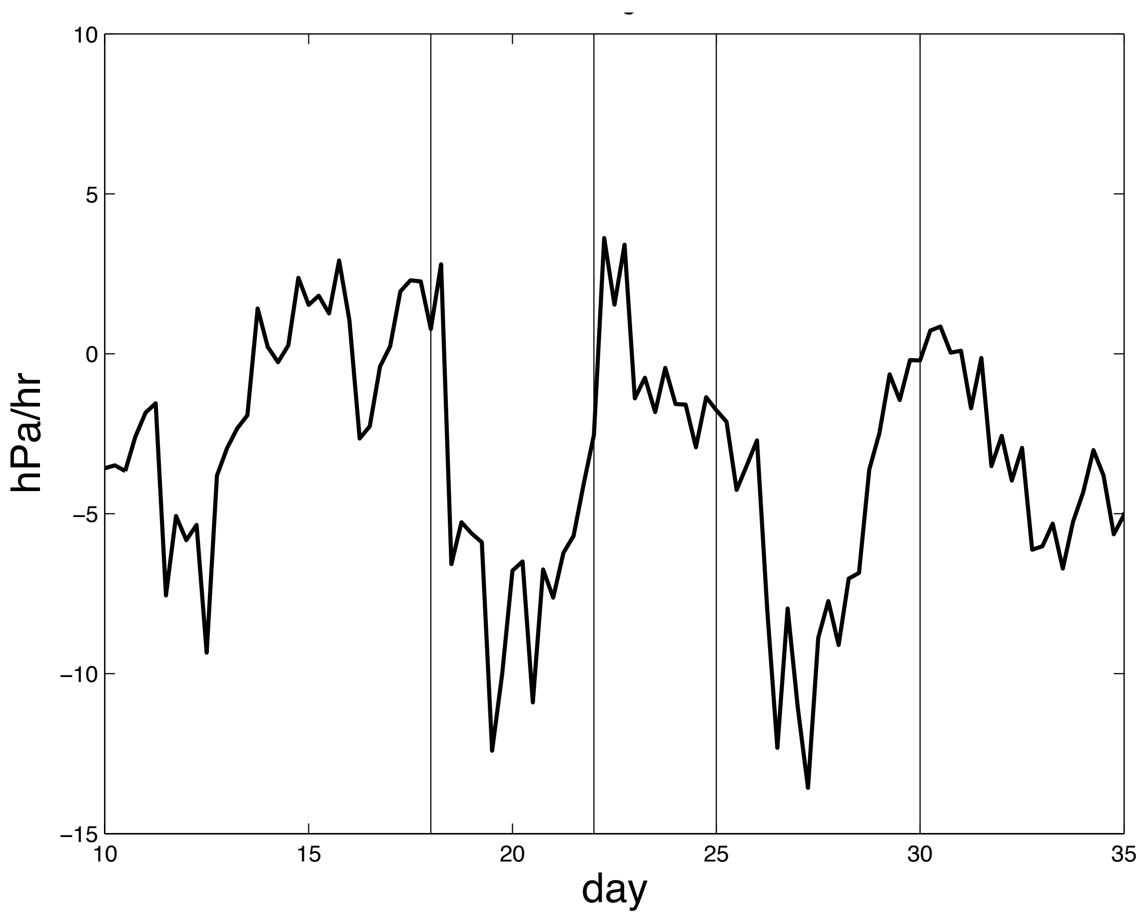
3D QG-omega inversion:



Obs.

topographic wind (lower b.c.):

$$\omega_{PBL} \approx V_{g,PBL} \bullet \nabla h_0 = \omega_{\text{topo}}$$



Obs.

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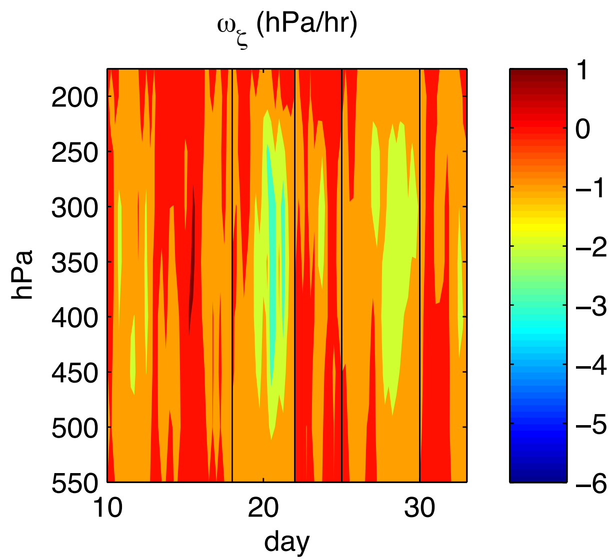
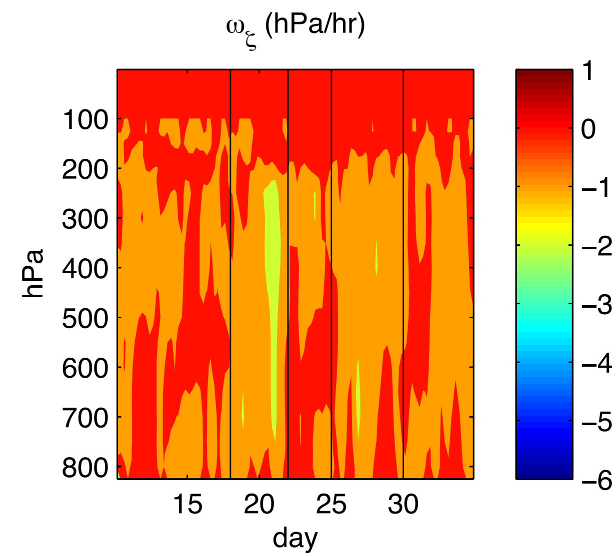
3D inversion

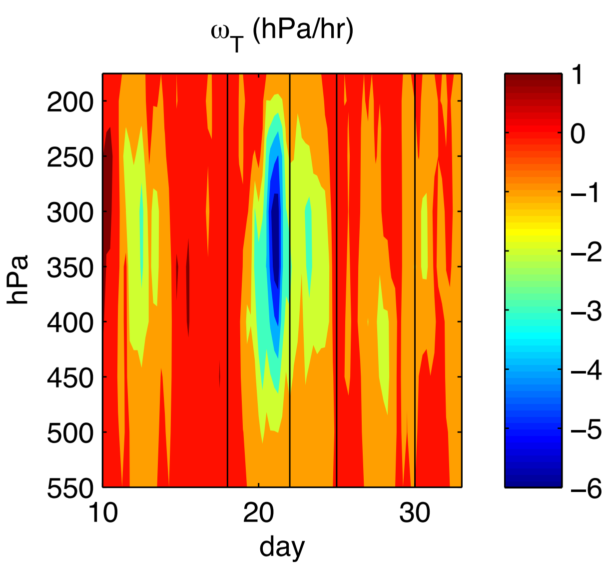
1D inversion

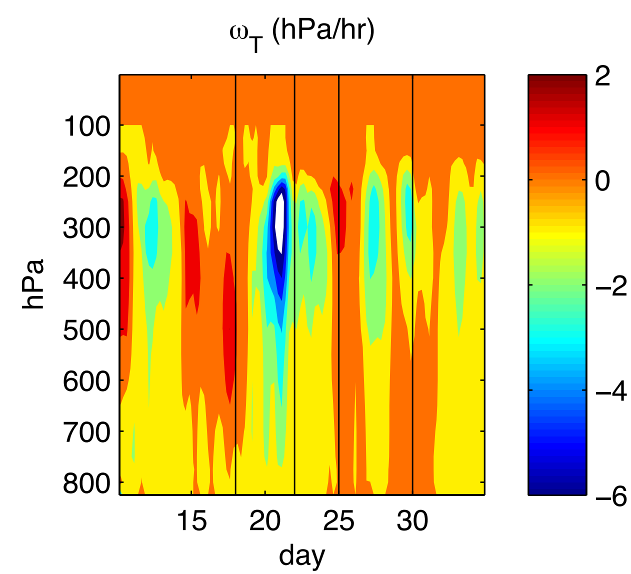


$\nabla^2 \sim -k^2$

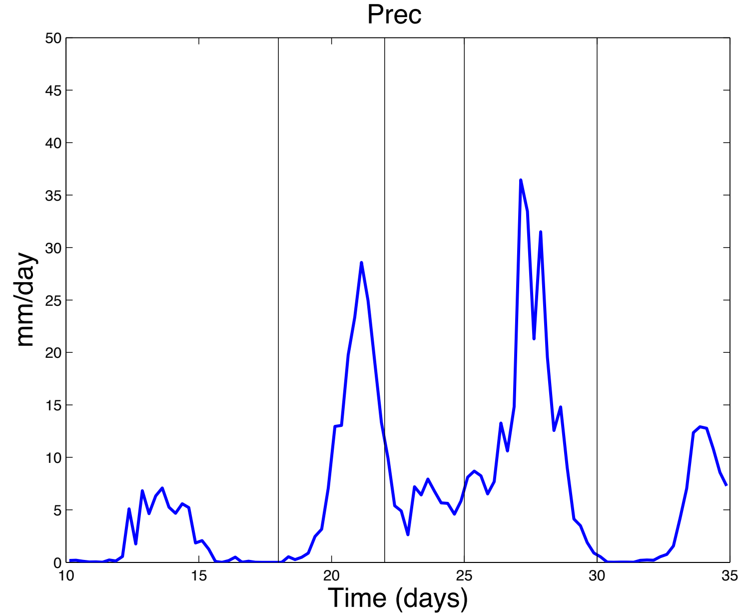
$k \approx 2\pi/1000$km

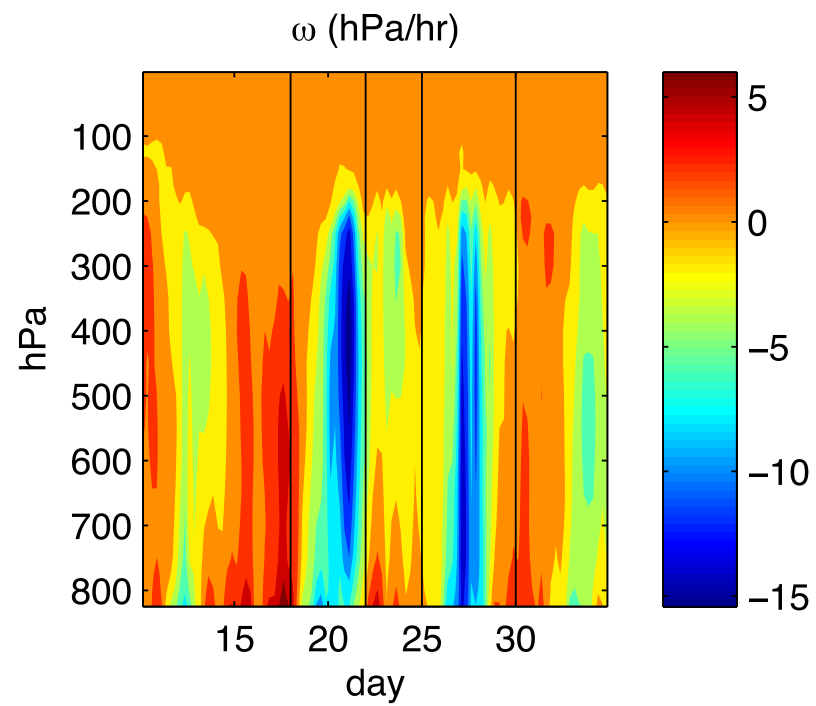


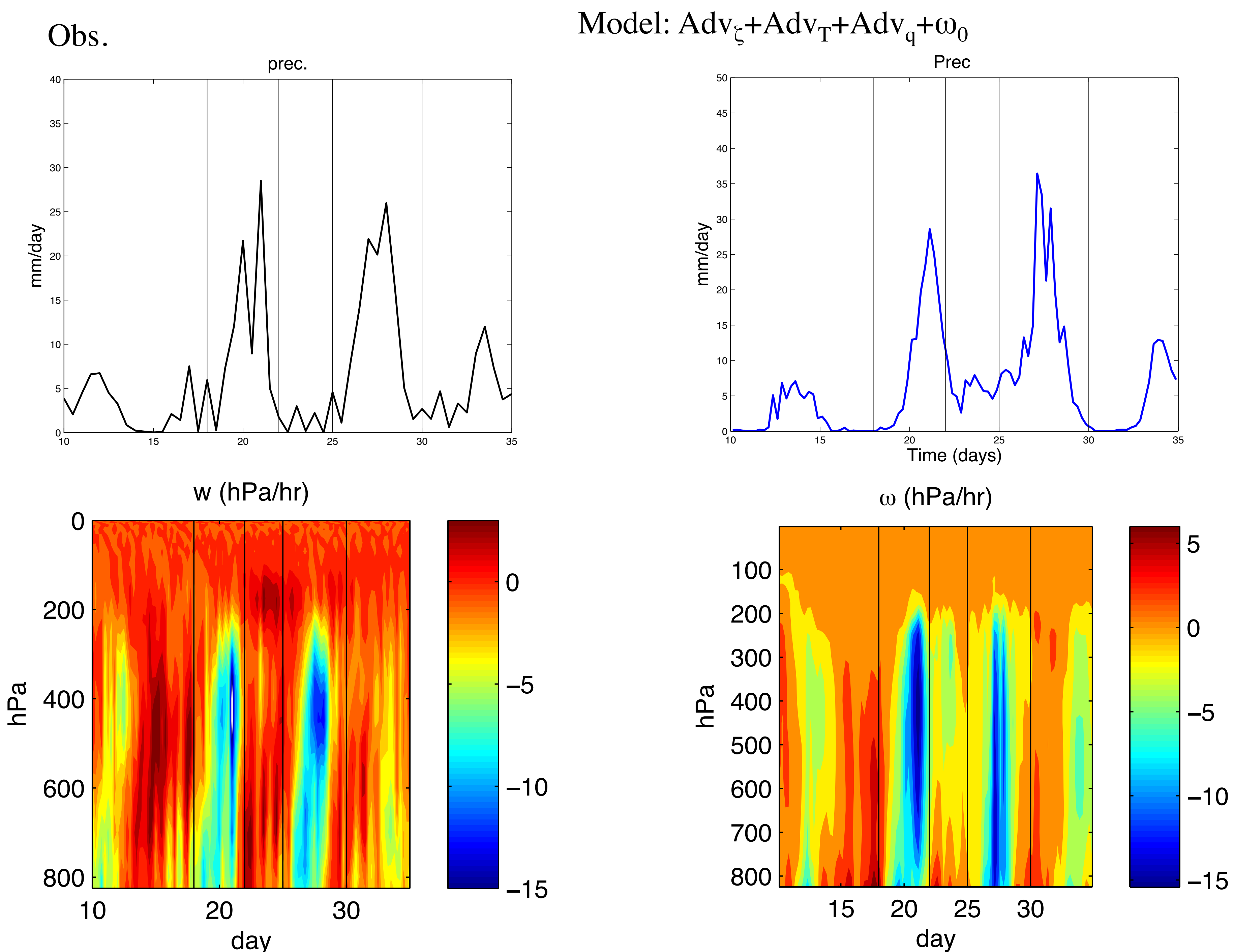




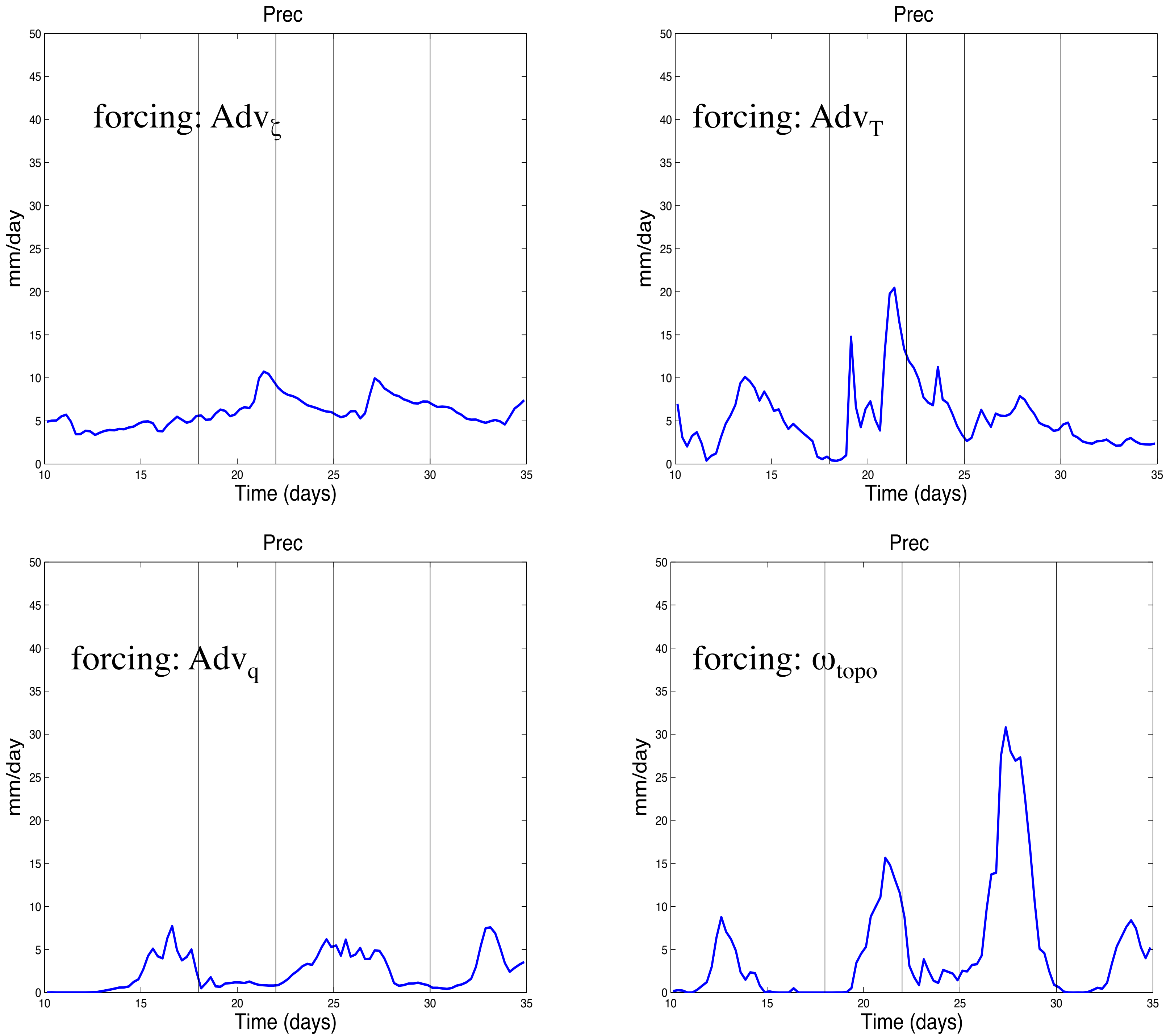
Model: $Adv_\zeta + Adv_T + Adv_q + \omega_0$







Obs.
Model: Adv$_\zeta$+Adv$_T$+Adv$_q$+ω_0
prec.
mm/day
Prec
mm/day
Time (days)
w (hPa/hr)
hPa
day
ω (hPa/hr)
hPa
day



Prec
forcing: Adv$_\zeta$
Prec
forcing: Adv$_T$
Prec
forcing: Adv$_q$
Prec
forcing: ω_{topo}
mm/day
Time (days)

Summery:

- convection + QG-omega in single column modeling

- Using this modeling framework, we reproduces the 2010 Pakistan flood events quite well.

  * the coupling between convection and large-scale dynamics is important.

  * the topographic wind accounts for the triggering the extreme events in these event.

Thank you.