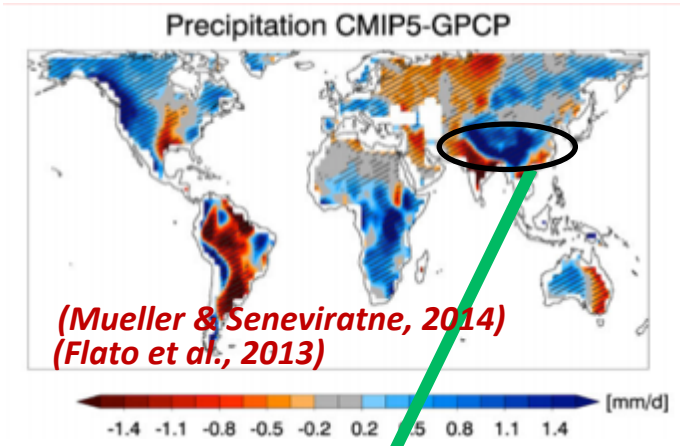
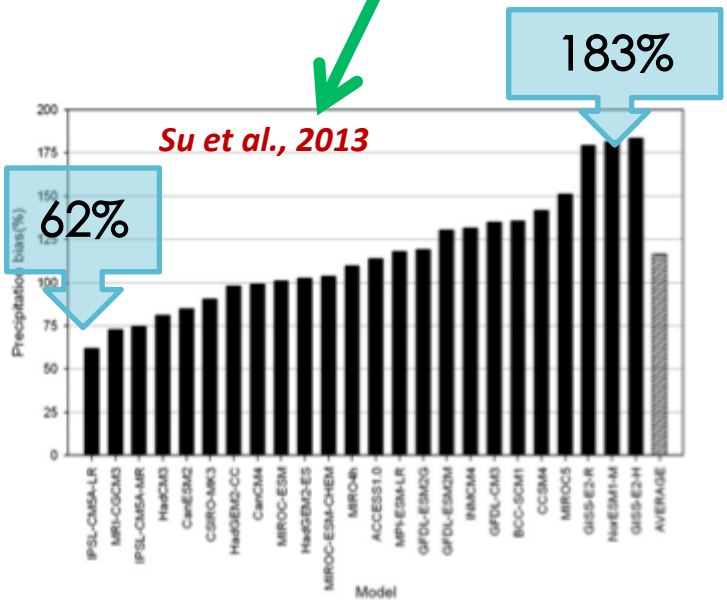
Observation and modeling of water vapor crossing over the Central Himalaya

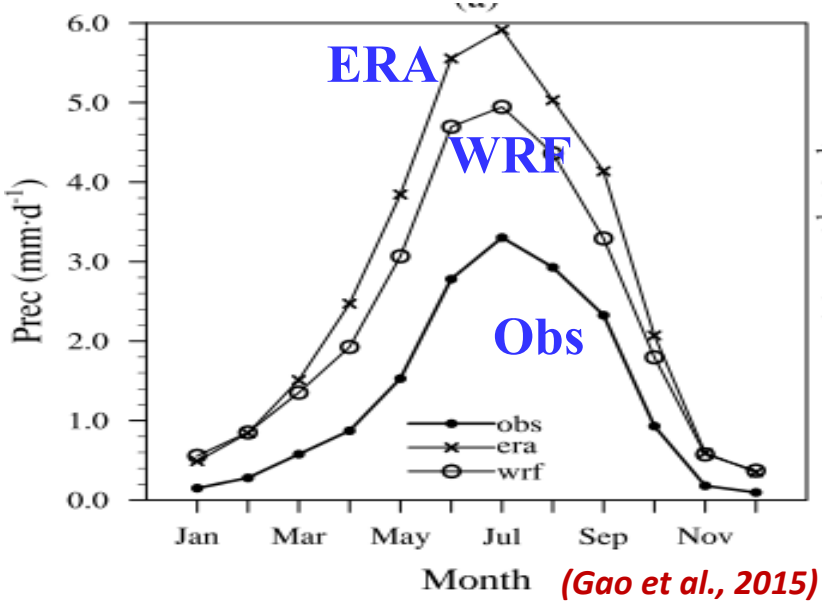
Kun Yang
Xu Zhou Yan Wang Changgui Lin Deliang Chen

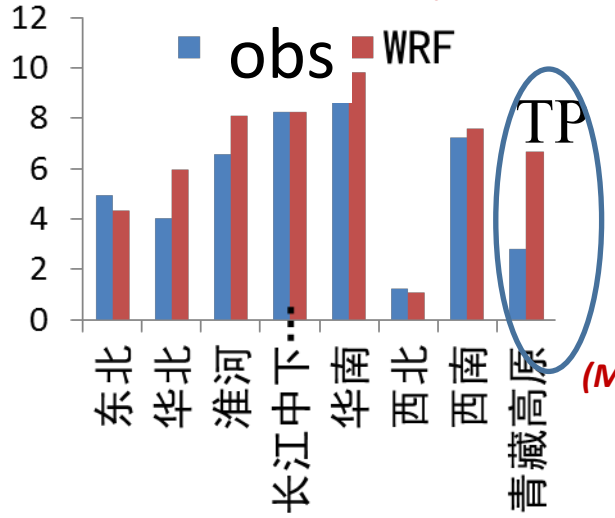
ITP, CAS
University of Gothenburg
Tsinghua University
Regional Climate Group

Motivation: Distinct precipitation biases for the Tibetan Plateau (TP) in current GCMs and RCMs



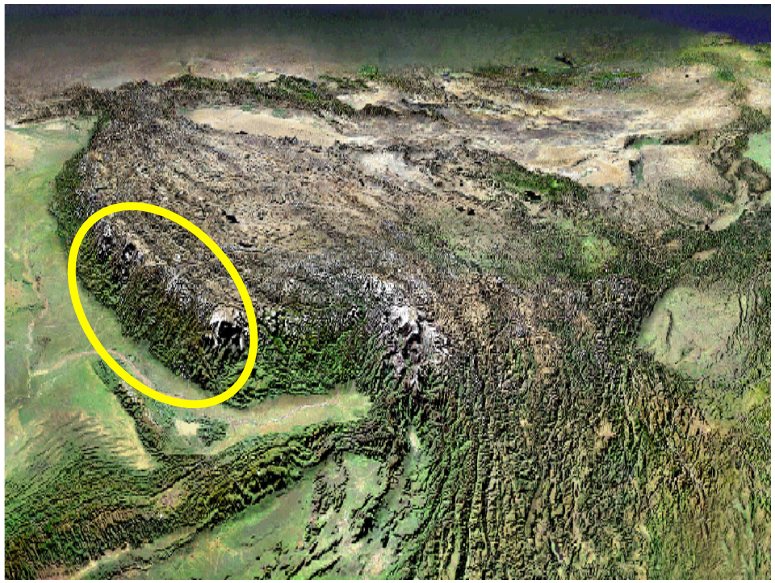




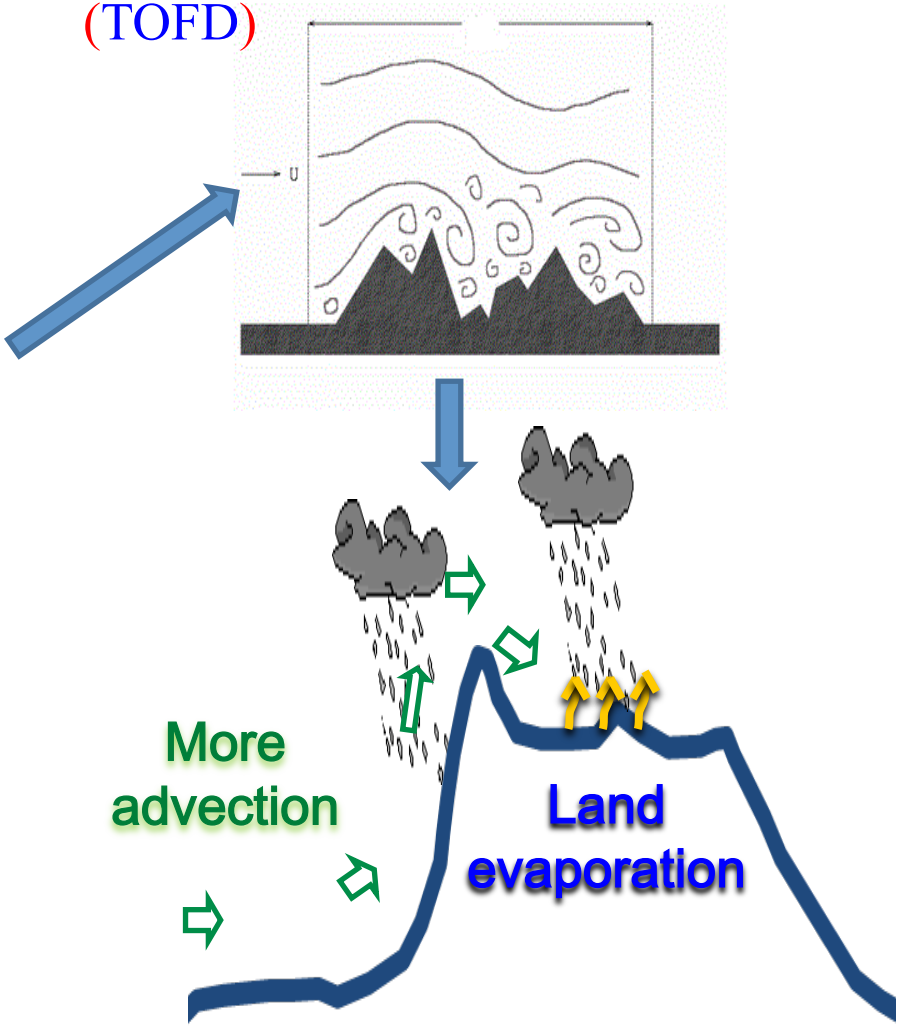


Hypothesis: Because of unresolved steep slope and complex terrain in the Himalayan range, excessive water vapor is transported from South Asia into TP, causing excessive precipitation in models

Steep and complex terrain in Himalaya



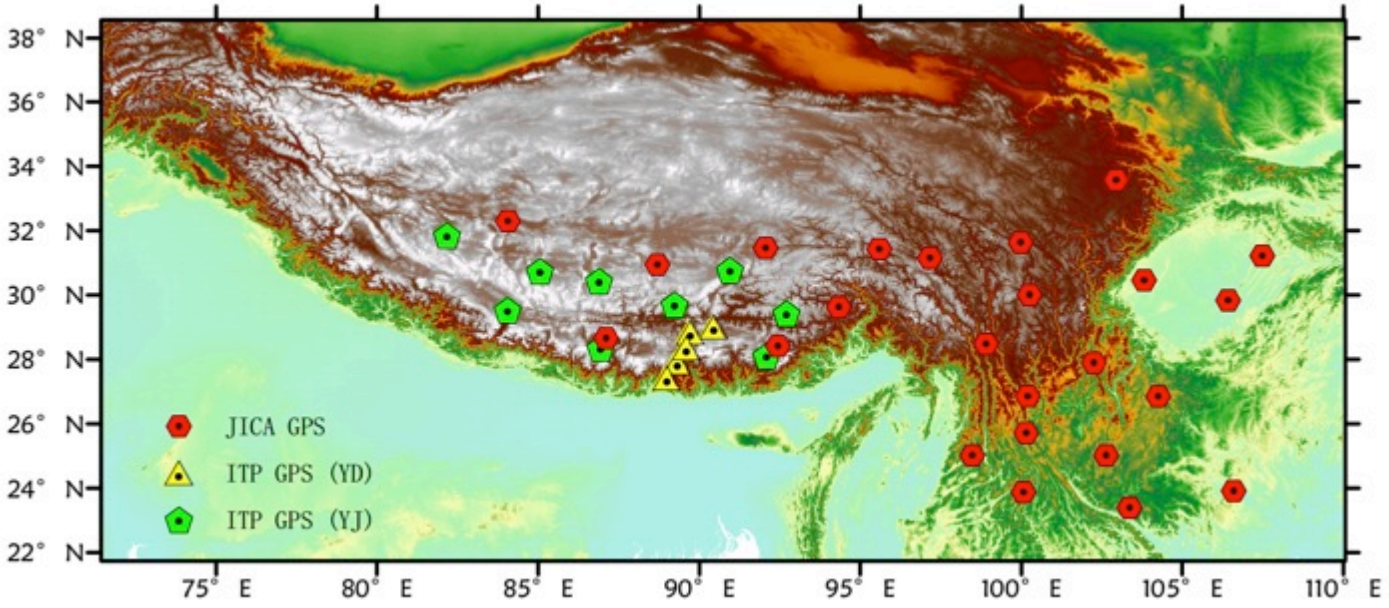
Turbulent scale orographic form drag (TOFD)

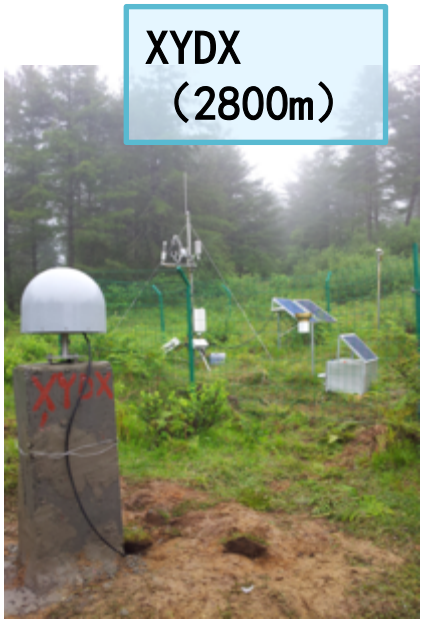


Outline

GPS observations + Reanalysis data	⇨	Positive water vapor bias in South TP
WRF simulation at dx=30, 10, 2km	⇨	Water vapor transport highly depends on model resolution
WRF + TOFD scheme	⇨	Implement Beljaars et al. (2004) TOFD in WRF
Winter simulation Summer simulation	⇨	TOFD retards wind speed, reduces water vapor transport and precipitation

PWV measurement: GPS network in South TP

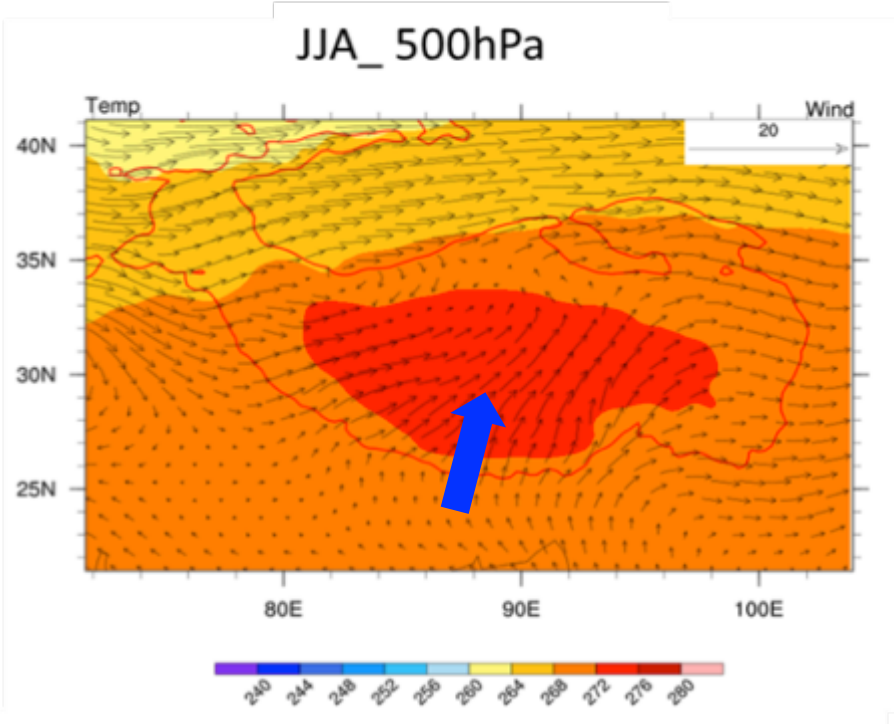


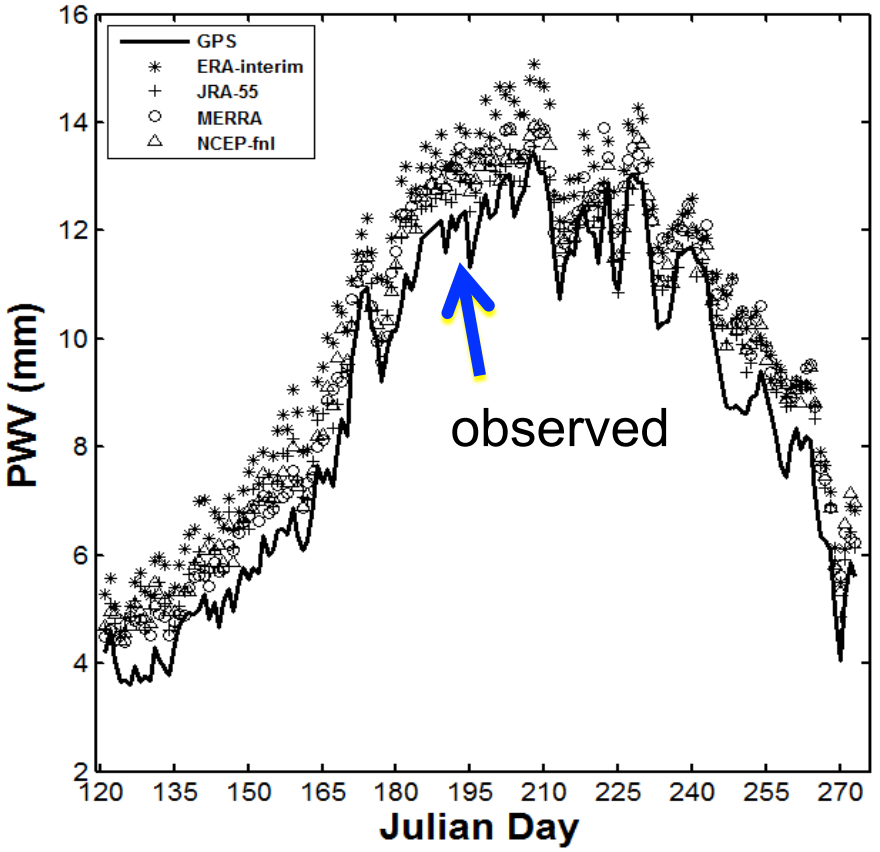


9 stations (2007.05--) in Yarlung Zangbo valley
5 stations (2015.6.26--) along Yadong-Lhasa transect

All reanalysis models over-estimated PWV. Why?

Northward water vapor transport





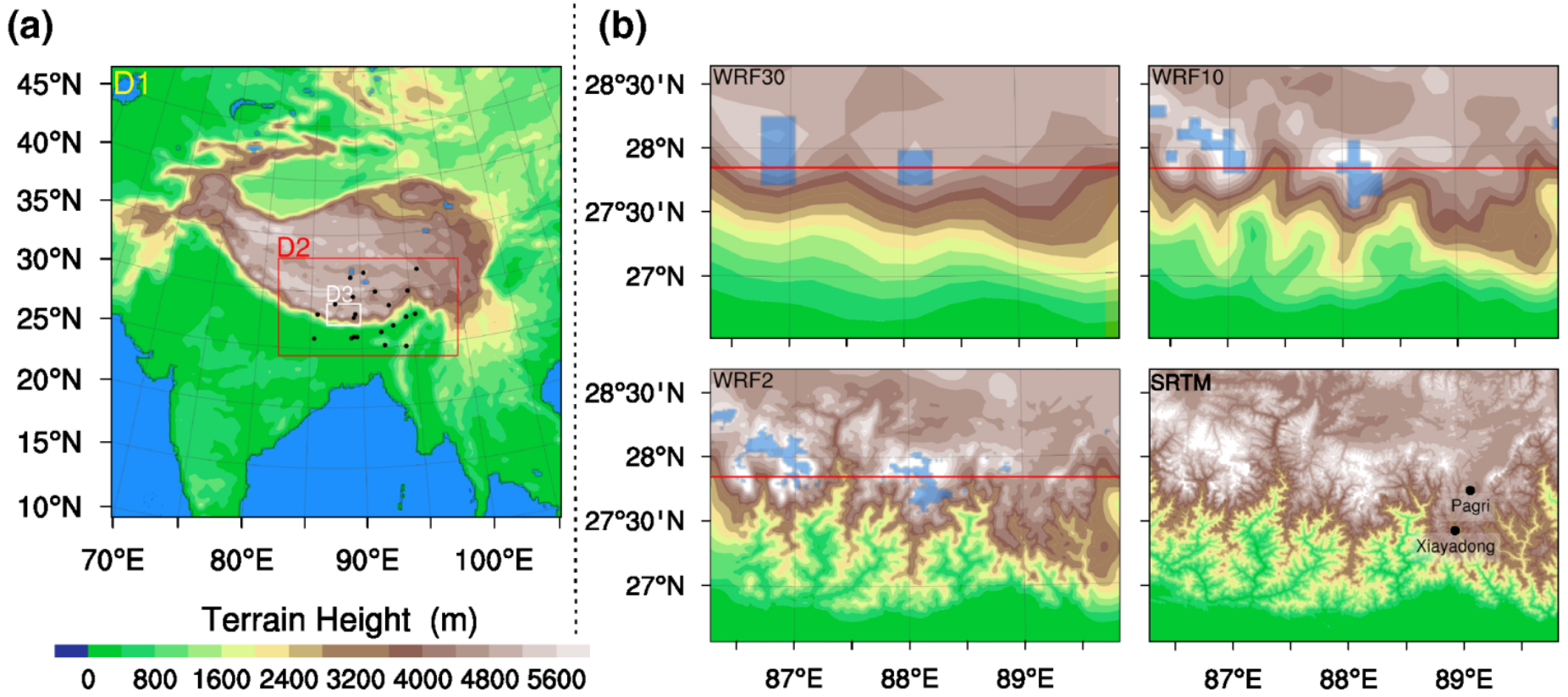
Seasonal march between observation and reanalyses, after elevation correction and average at 9 GPS stations during 2007~2013

(Wang, Yang et al., 2017, JC)

Outline

GPS observations + Reanalysis data	⇨	Positive water vapor bias in South TP
WRF simulation at dx=30, 10, 2km	⇨	Water vapor transport highly depends on model resolution
WRF + TOFD scheme	⇨	Implement Beljaars et al. (2004) TOFD in WRF
Winter simulation Summer simulation	⇨	TOFD retards wind speed, reduces water vapor transport and precipitation

Domain and spatial resolution of three WRF-simulations



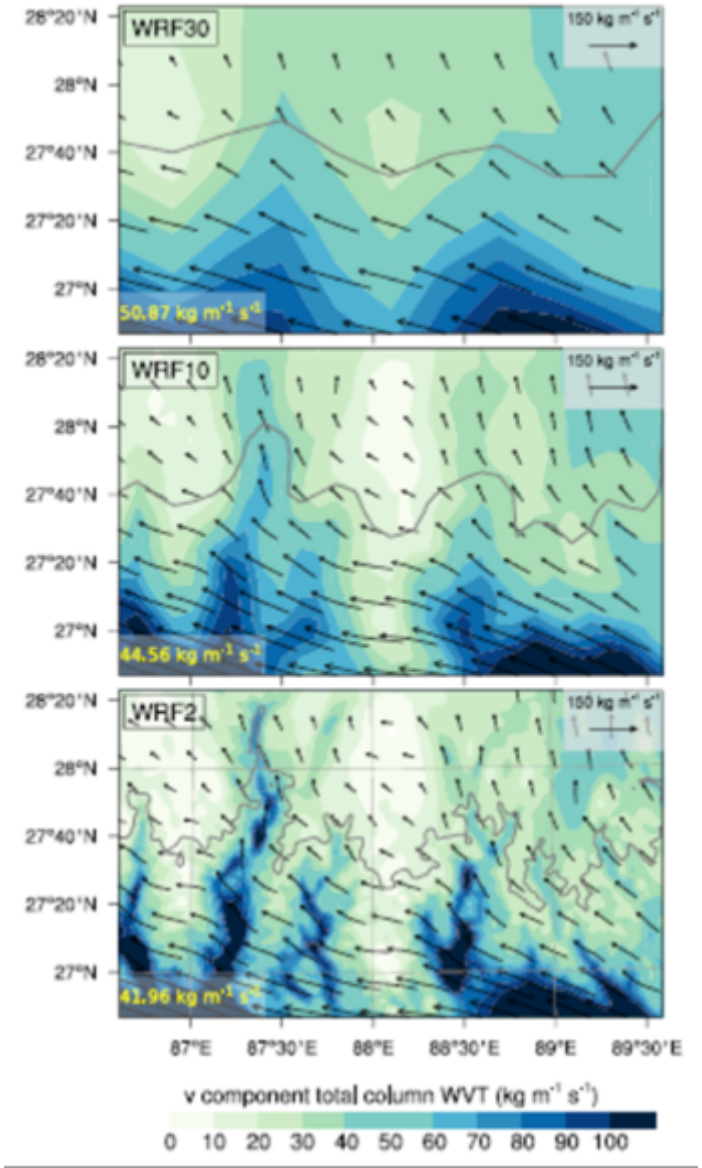
dx=30km cannot reproduce both complex terrain and envelope topography
dx=10km can reproduce envelope topography but not complex terrain
dx=2km can resolve both envelope topography and complex terrain

(Lin et al., 2018, CD)

WRF-simulated water vapor flux from South Asia to Tibet highly depends on model resolution

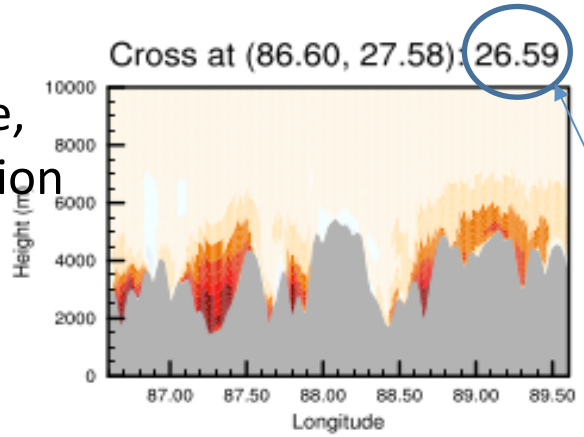
- Coarse resolution produces stronger wind and brings more water vapor into TP
- Strong vapor flux is only seen at narrow valleys, indicating complex terrain plays an important role.
- We do need TOFD parameterization for this region when simulated with a coarse resolution.

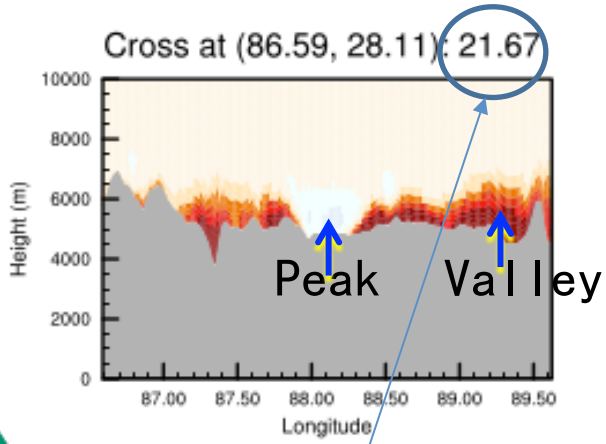
(Lin et al., 2018, CD)



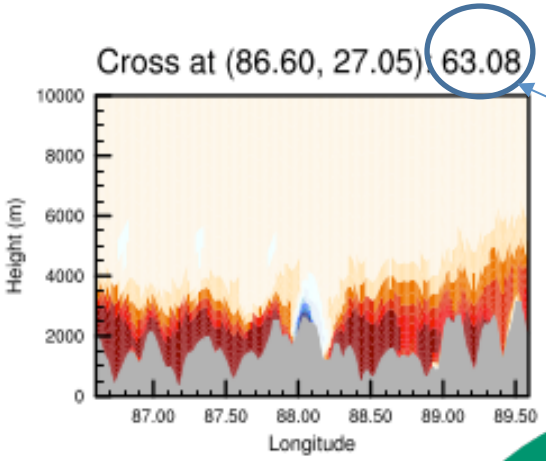
Water vapor depletes greatly when crossing from South Asia to TP

South slope,
high elevation





North slope

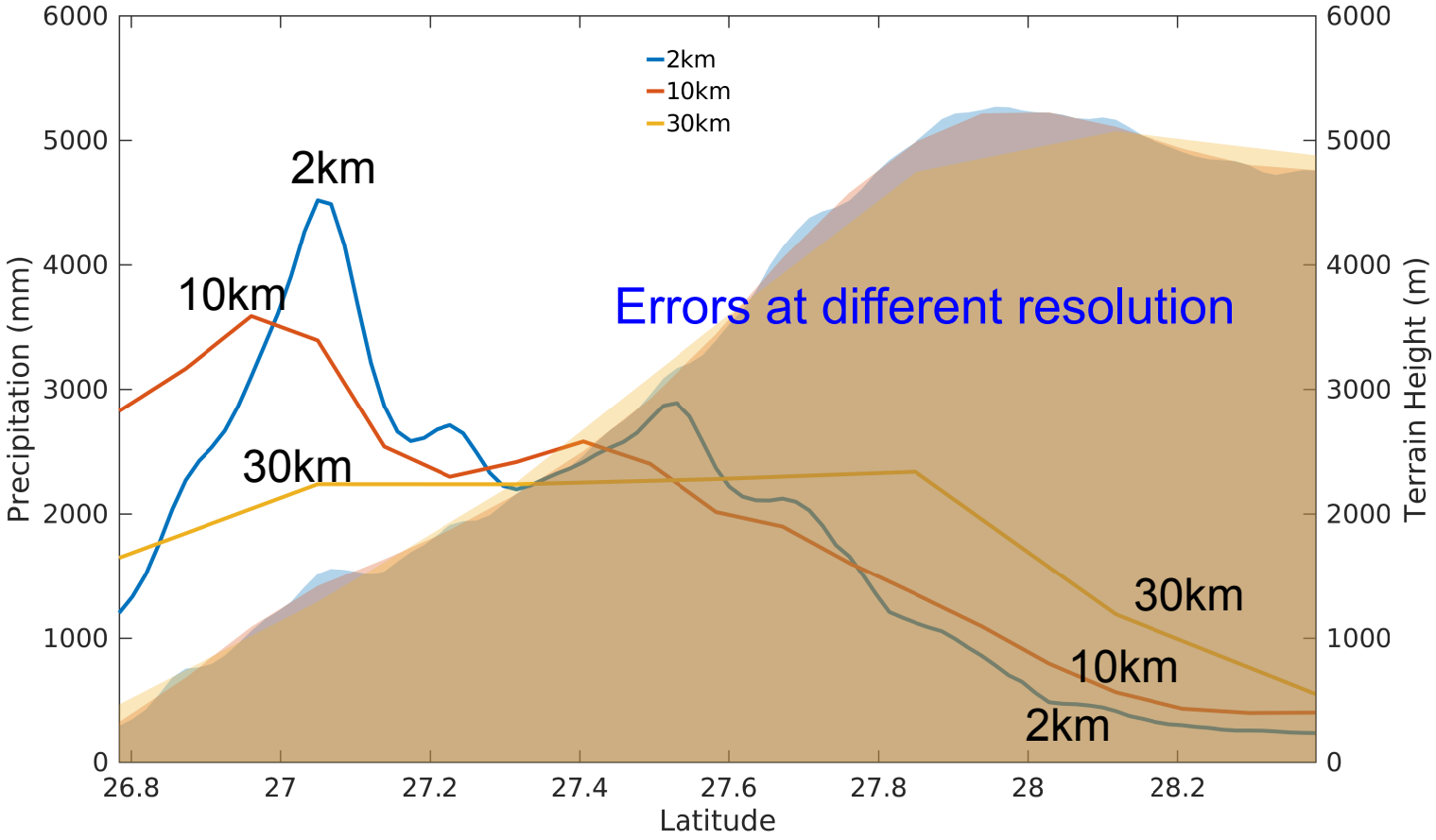


South slope,
low elevation

Mean meridional transport
(from 2km-res.
simulation)

(Lin et al., 2018, CD)

Positive biases in vapor flux results in much more precipitation in the Plateau and less in south slope



Outline

GPS observations
+
Reanalysis data

⇒ Positive water vapor bias in South TP

WRF simulation at
dx=30, 10, 2km

⇒ Water vapor transport highly depends on model resolution

WRF
+
TOFD scheme

⇒ Implement Beljaars et al. (2004) TOFD in WRF

Winter simulation
Summer simulation

⇒ TOFD retards wind speed, reduces water vapor transport and precipitation

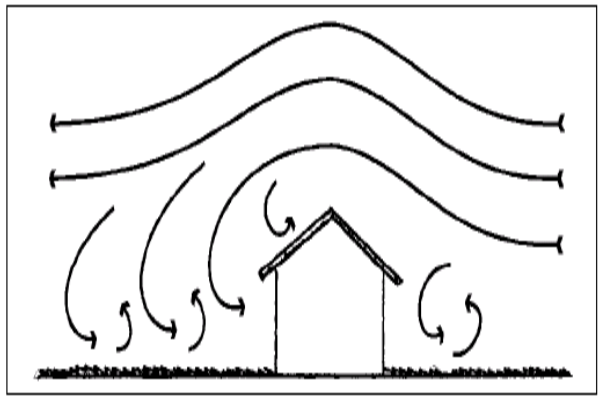
Sub-Grid orographic drags in WRF

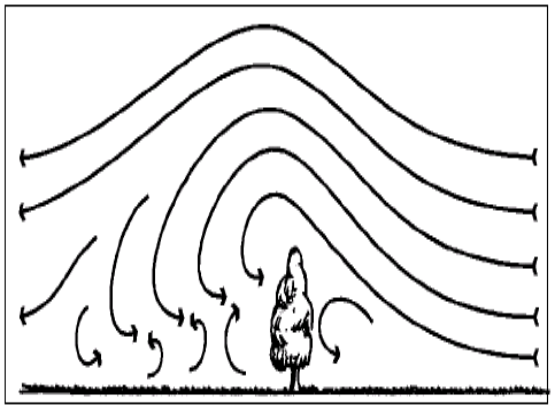
Turbulence scale drag, ca. <5km

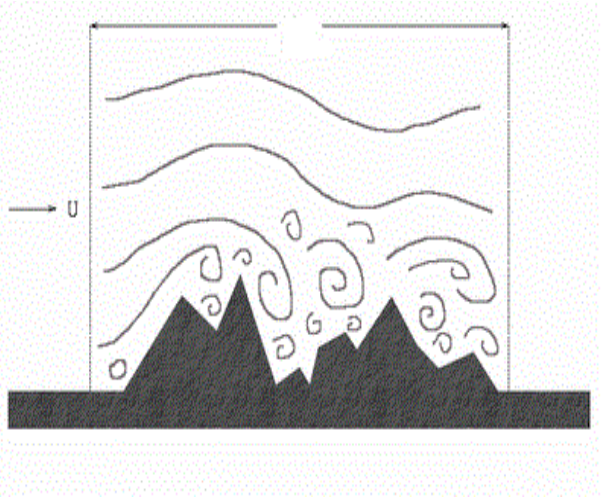
Wind stress from surface roughness units e.g. vegetation, buildings)

Turbulent scale orographic form drag (TOFD)

- Original in WRF(Jimenez and Dudhia, 2012)(JD12)
  - The TOFD exerts on the surface layer
- New scheme in WRF (Beljaars et al., 2004)(BBW)
  - The TOFD directly exerts on all layers







Outline

GPS observations
+
Reanalysis data

⇒ Positive water vapor bias in South TP

WRF simulation at dx=30, 10, 2km

⇒ Water vapor transport highly depends on model resolution

WRF
+
TOFD scheme

⇒ Implement Beljaars et al. (2004) TOFD in WRF

Winter simulation
Summer simulation

⇒ TOFD retards wind speed, reduces water vapor transport and precipitation

Winter simulation design

Model setup

Simulation period :

Spin up: 2007.11.20-2007.11.30

Result: 2007.12.01-2007.12.31

Time step: 120 seconds

Model resolution: 0.1˚

Atmosphere forcing: ERA-Interim

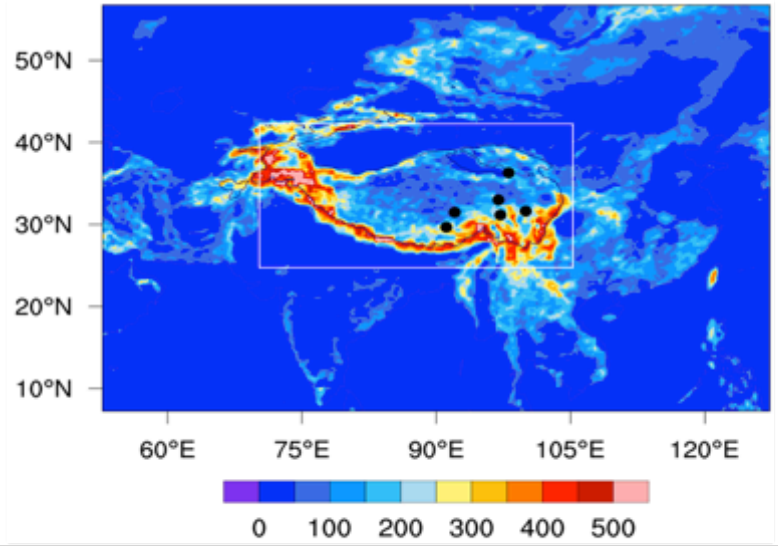
Land surface scheme: Noah-LSM

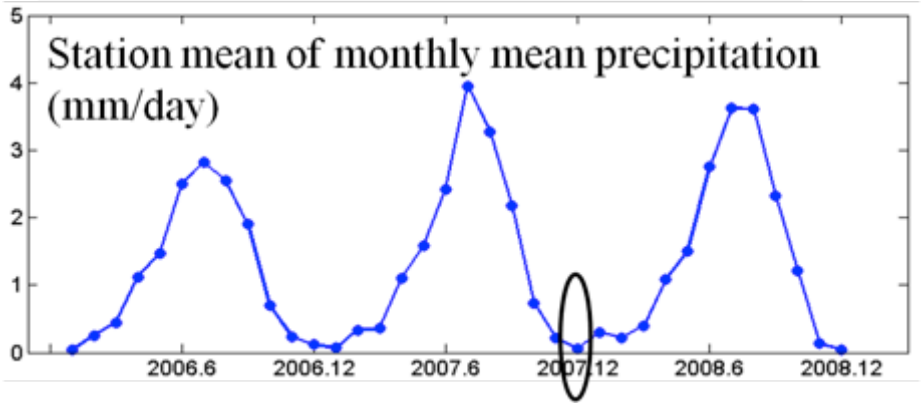
Simulations:

CTRL: Old TOFD (JD12)

TOFD: New TOFD (BBW)

NoTOFD

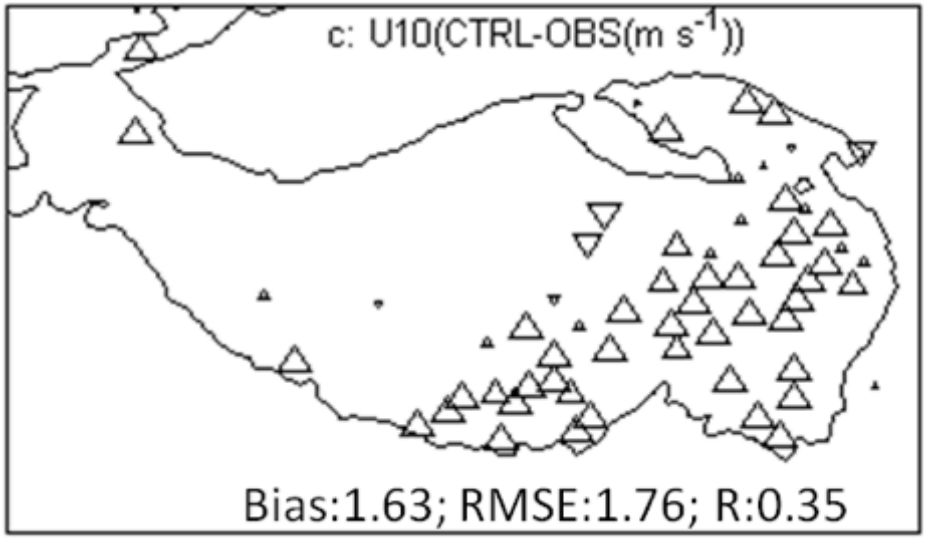




Winter simulation

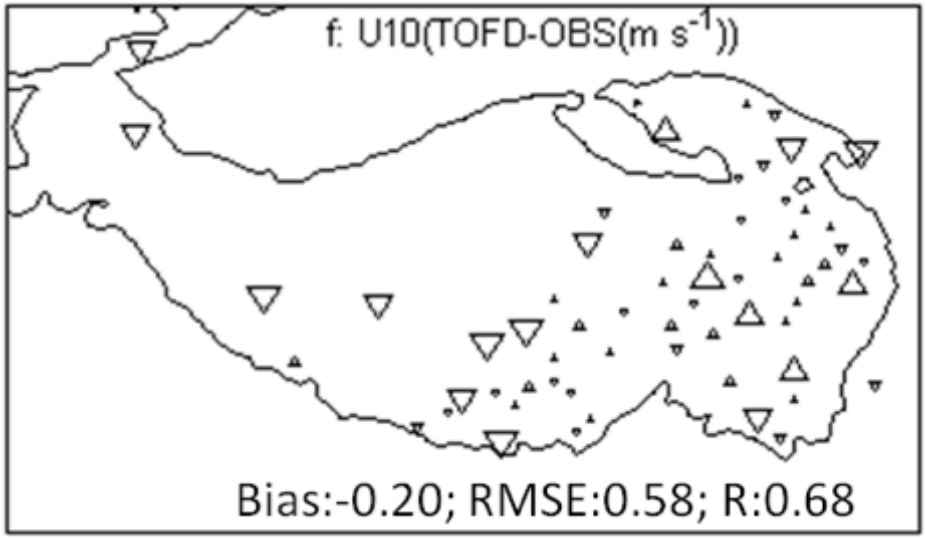
Evaluate wind bias against with CMA station observations

With Old TOFD



With New TOFD

Much reduce errors



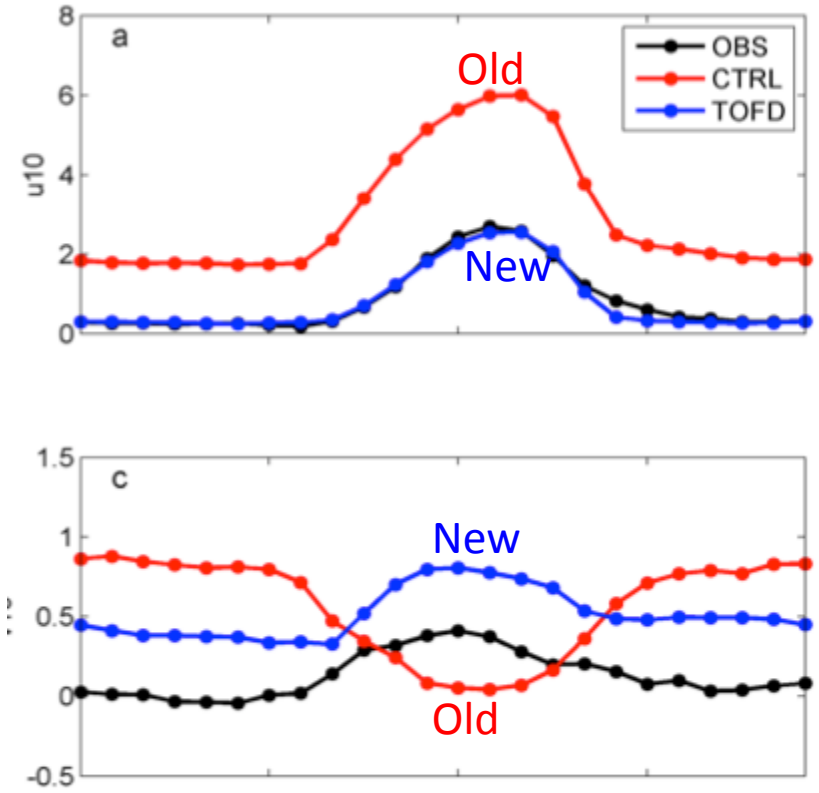
(Zhou et al., 2017, JGR)

Winter simulation

Evaluate wind bias against with CMA station observations:

Simulated diurnal cycle of 10-m wind speed is much closer to station-observed one;

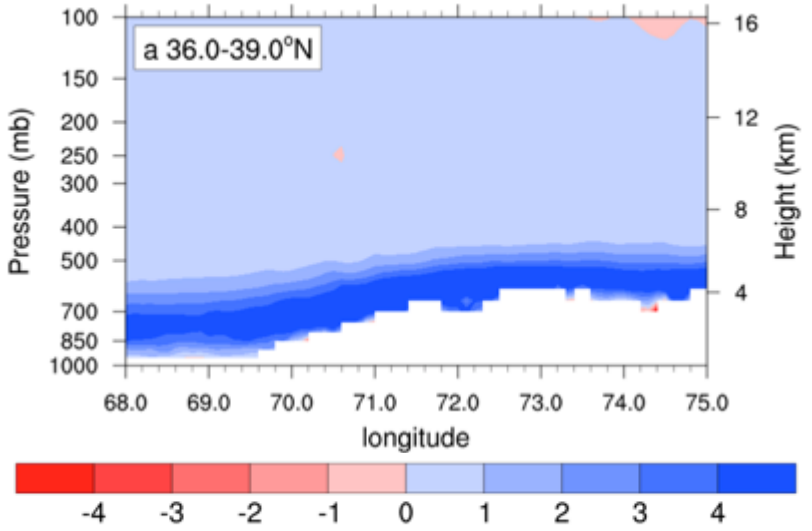
Simulated wind profile is also improved (not shown)



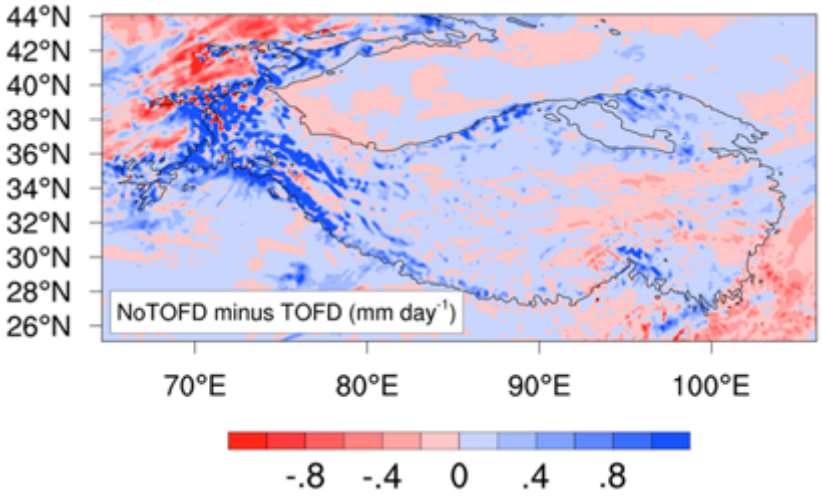
Winter simulation

In winter, more westerly water vapor flux and more snowfall are simulated in western Tibet, if TOFD is not considered

Water vapor flux
(NoTOFD - TOFD)



More snowfall
(NoTOFD - TOFD)



Summer simulation design

Model setup

Simulation period:

2010.05.01-2010.10.31

Time step: 120 seconds

Model resolution: **0.25°**

Atmosphere forcing: NCEP-FNL reanalyzed data

Land surface scheme: Noah-LSM

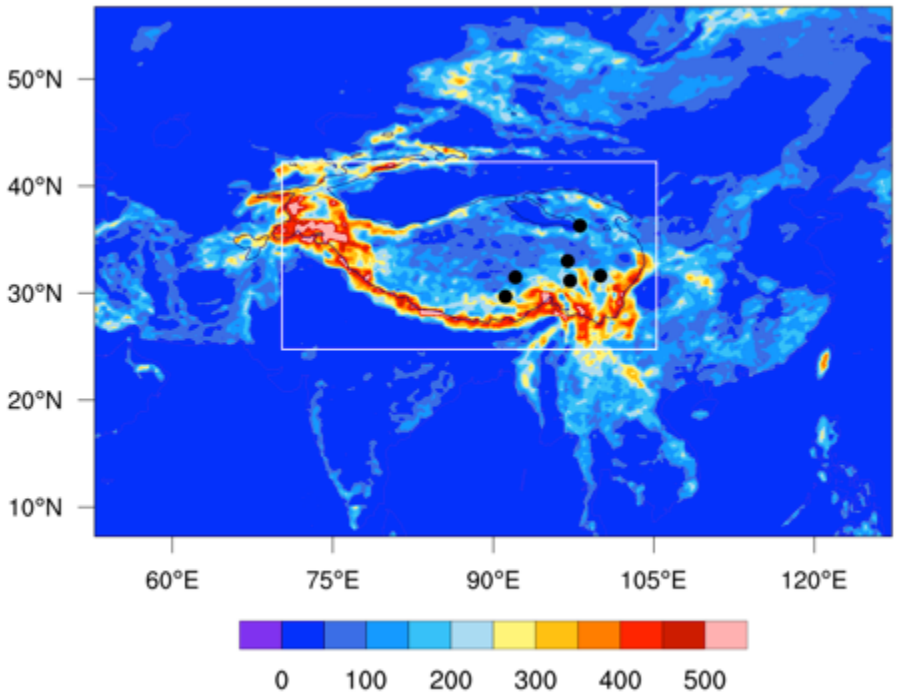
Cumulus convection:
Kain-Fritsch scheme

Simulations:

CTRL: Old TOFD (JD12)

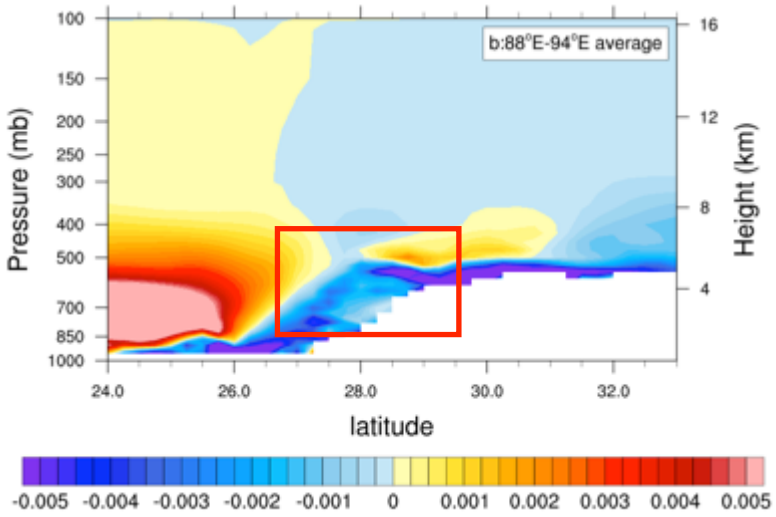
TOFD: New TOFD (BBW)

Color: standard deviation of the orography in m (< 5km scale)
Black points: radio soundings

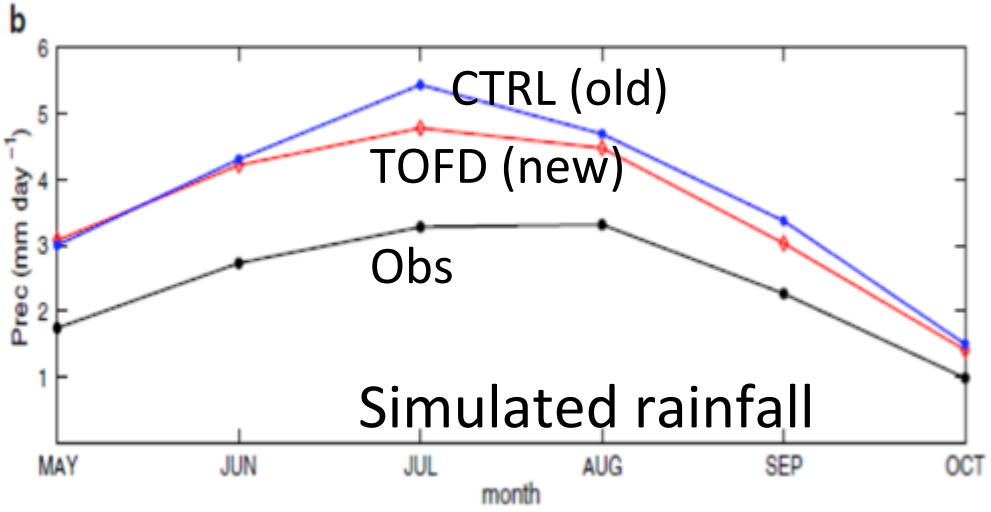


Summer simulation: water vapor flux from South Asia reduced

Less meridional vapor flux (New-Old)



Less precipitation (New-Old)



(Zhou, Yang et al., 2017, CD)

Summary

- GPS observation shows systematical wet bias in water vapor in reanalysis data for the south TP.
- WRF simulation with low res. produces much more vapor flux crossing the Himalayan Mountains.
- Parameterizing turbulent orographic form drag (TOFD) improves the simulation of wind, vapor flux and precipitation, indicating TOFD is a key process in this complex-terrain region.
- Validation basis should be extended from TP to adjacent regions, and other processes in WRF needs improvements