Hydrometeorology in the Red Sea region: An analysis based on observations and climate downscaling simulations

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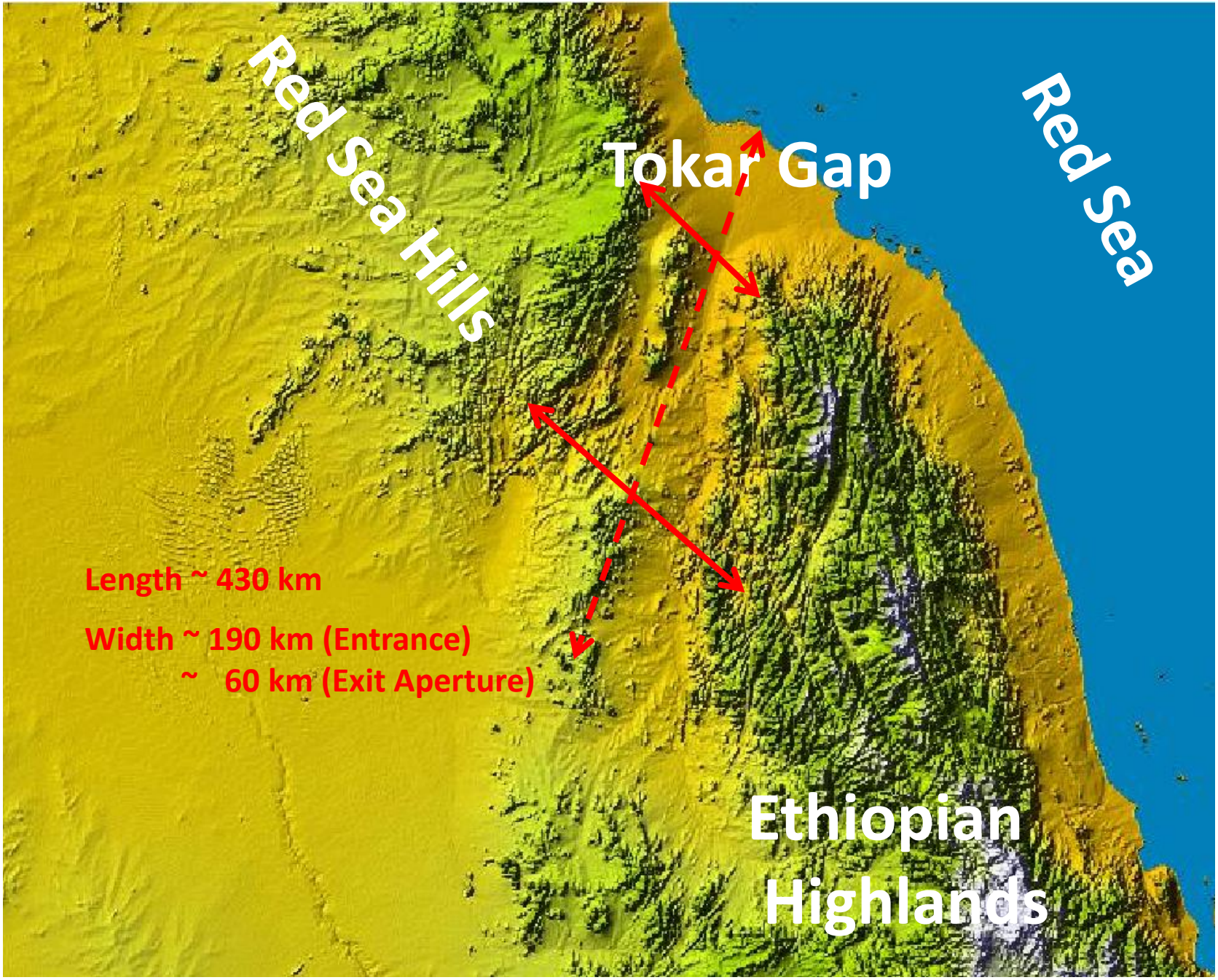
A Significant Crossroads

- Atmospheric dust source regions *(Prospero and Carlton, 1972, Hickey and Goudie, 2007)*

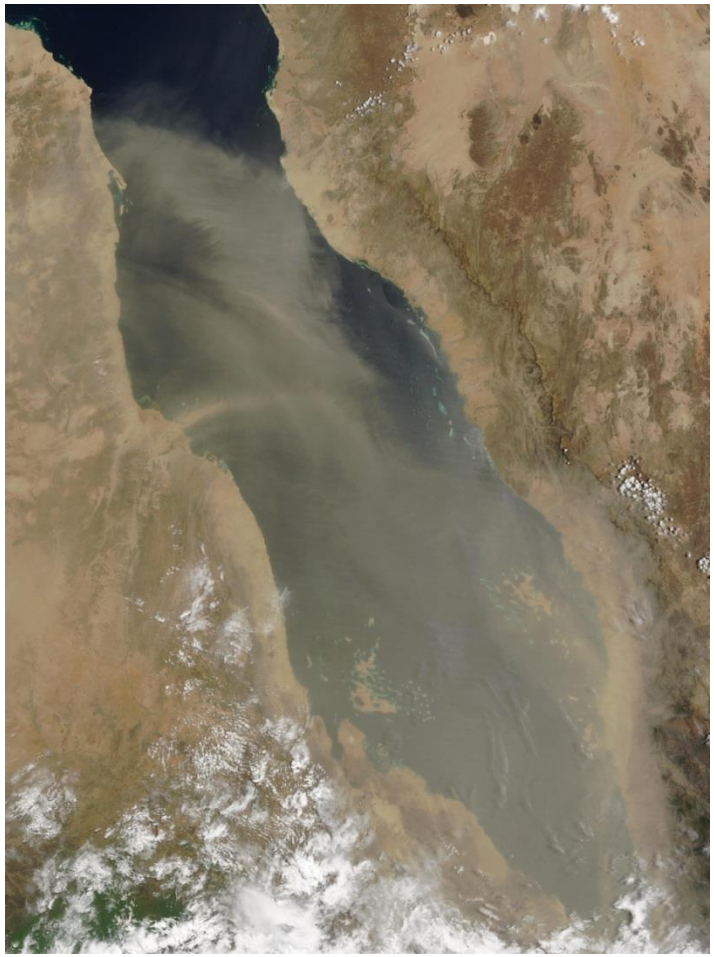
- Mesoscale rainfall (*Rodrigues et al. 2005, Viste and Sorteburg, 2013*)

- Tropical cyclogenesis (*Wu et al., 2003, Hill et al., 2003, Rodrigues et al. 2005, Viste and Sorteburg, 2013*)


Red Sea Hills
Tokar Gap
Red Sea
Length ~ 430 km
Width ~ 190 km (Entrance)
~ 60 km (Exit Aperture)
Ethiopian Highlands

Previous studies–general characteristics

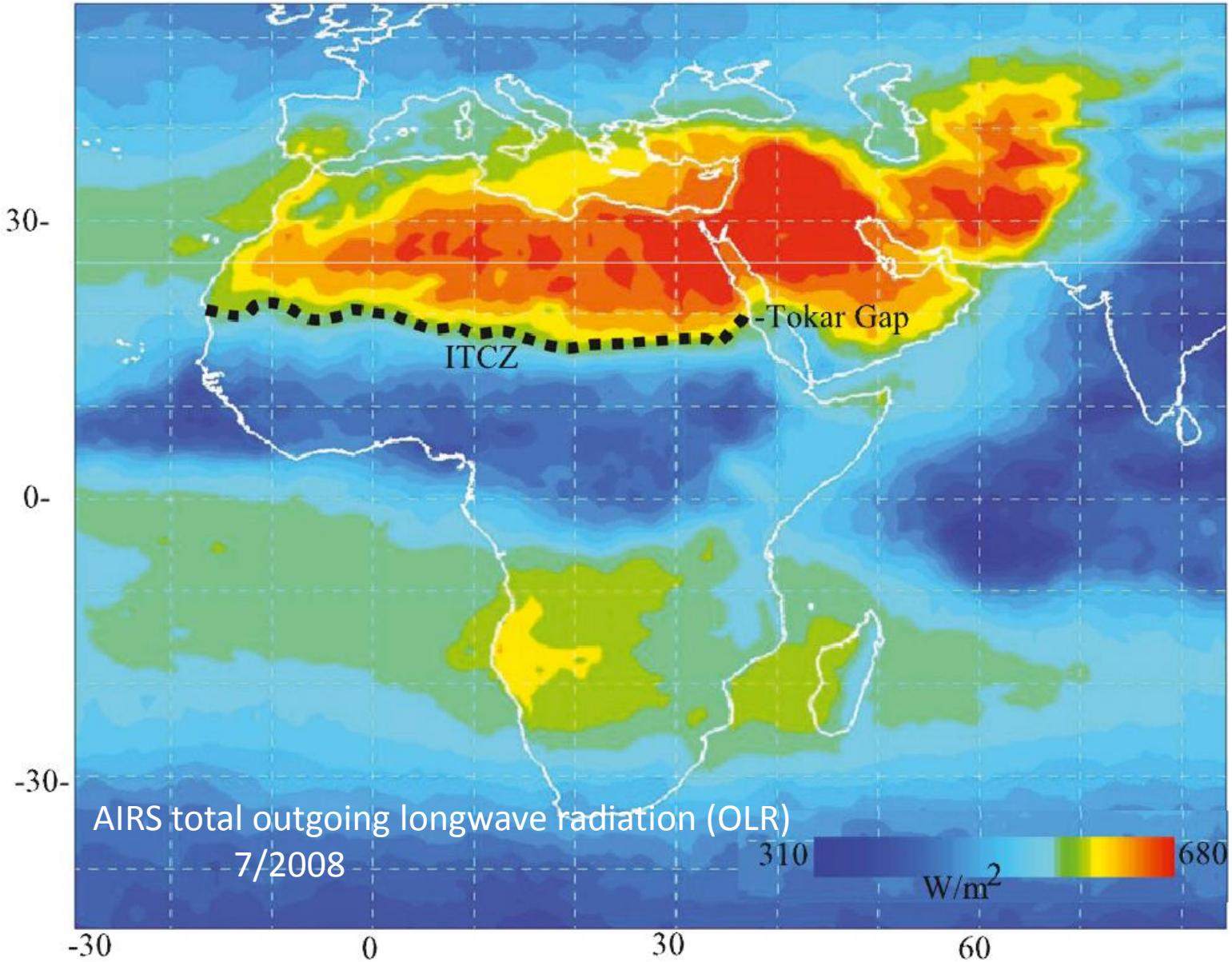
- Important to regional dust events
- Seasonal river valley of coastal Sudan, flows between the Red Sea Hills
- Frequency:- Quasi-diurnal
- Amplified land-sea breeze cycle (LSBC) or valley wind process (*hypothesized*)



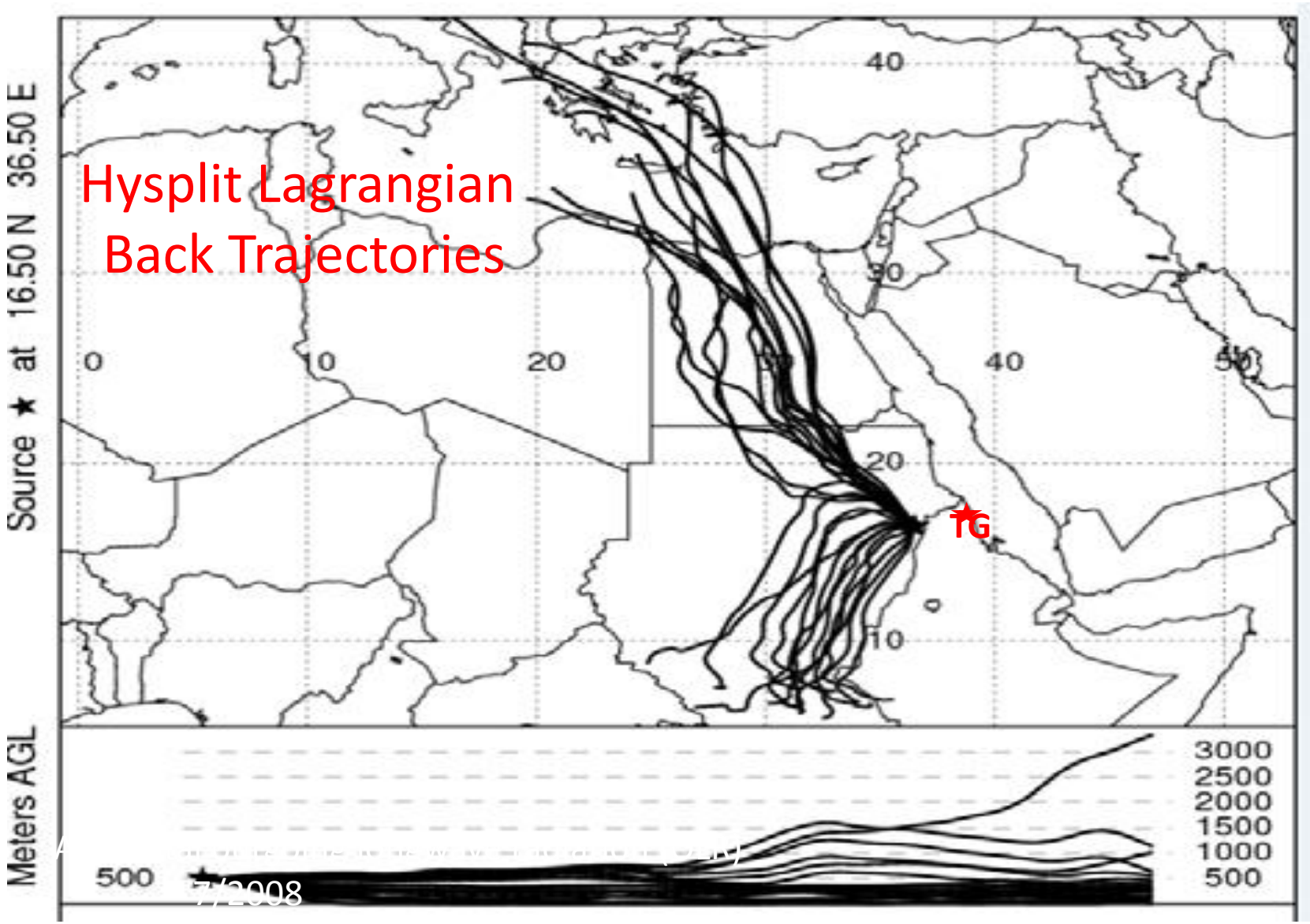
The TGJ: New Findings

- More than an enhanced valley wind or LSBC
- Tied to planetary scale atmospheric processes,
  - Seasonality controlled by the ITCZ position and the onset of the Indian Ocean monsoons
- Quasi-diurnal characteristics derived from the behavior of the surface ITCZ and channeled monsoon airmass
- “Moist” gap wind jet
- Significant mechanism of moisture transport/convergence to East Africa and Arabian Peninsula

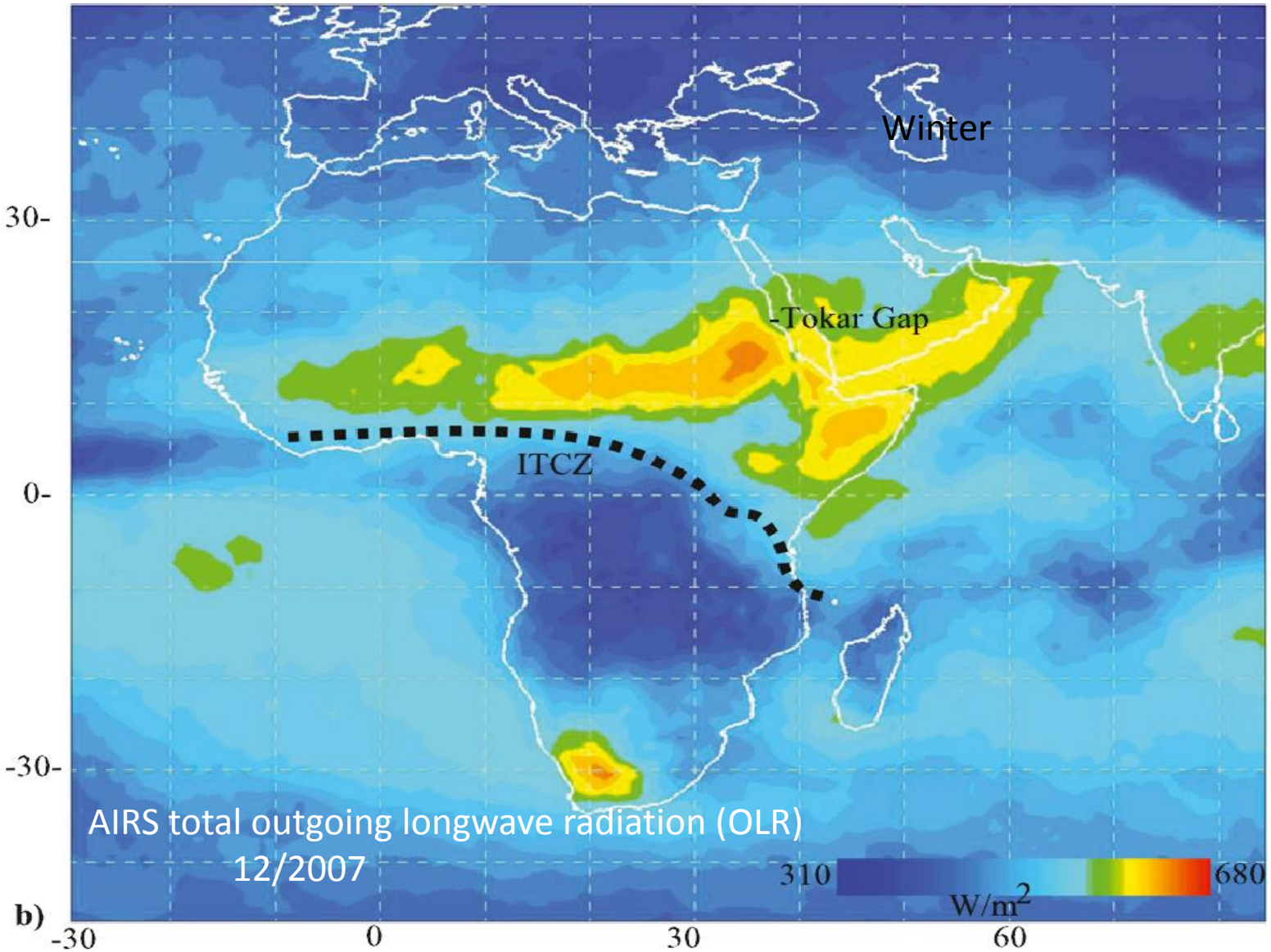
Seasonality: Role of the ITCZ



Seasonality: Role of the ITCZ



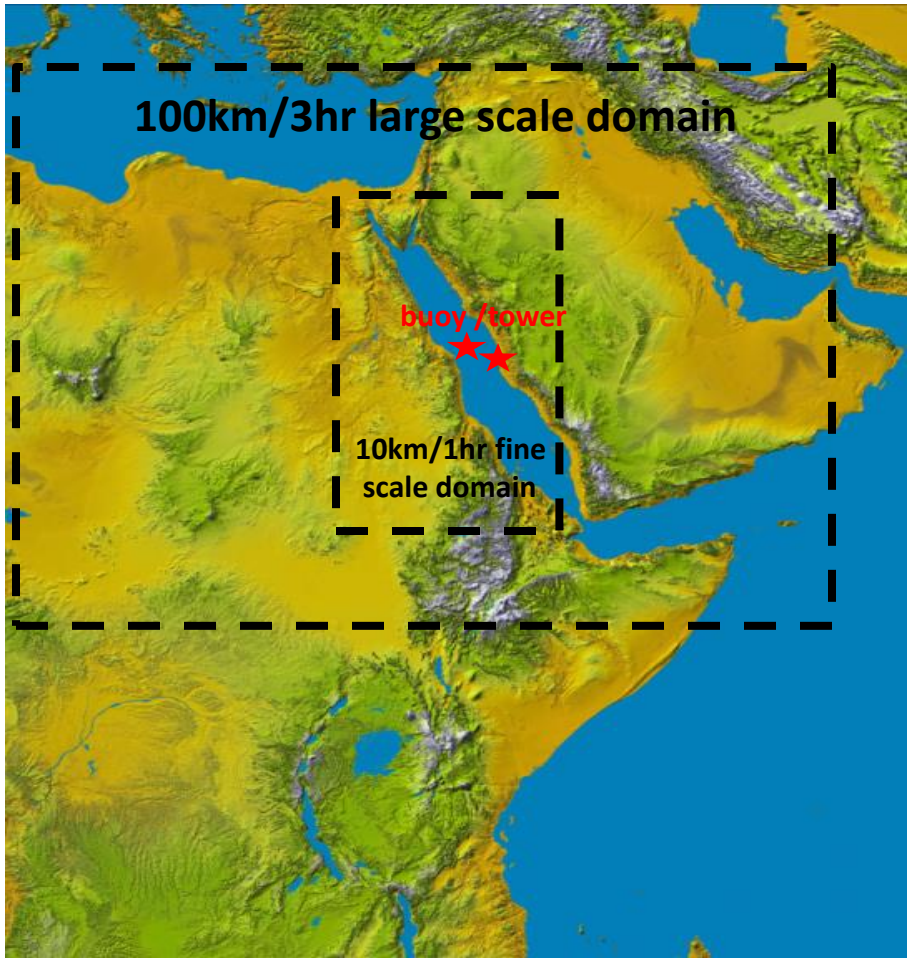
Seasonality: Role of the ITCZ

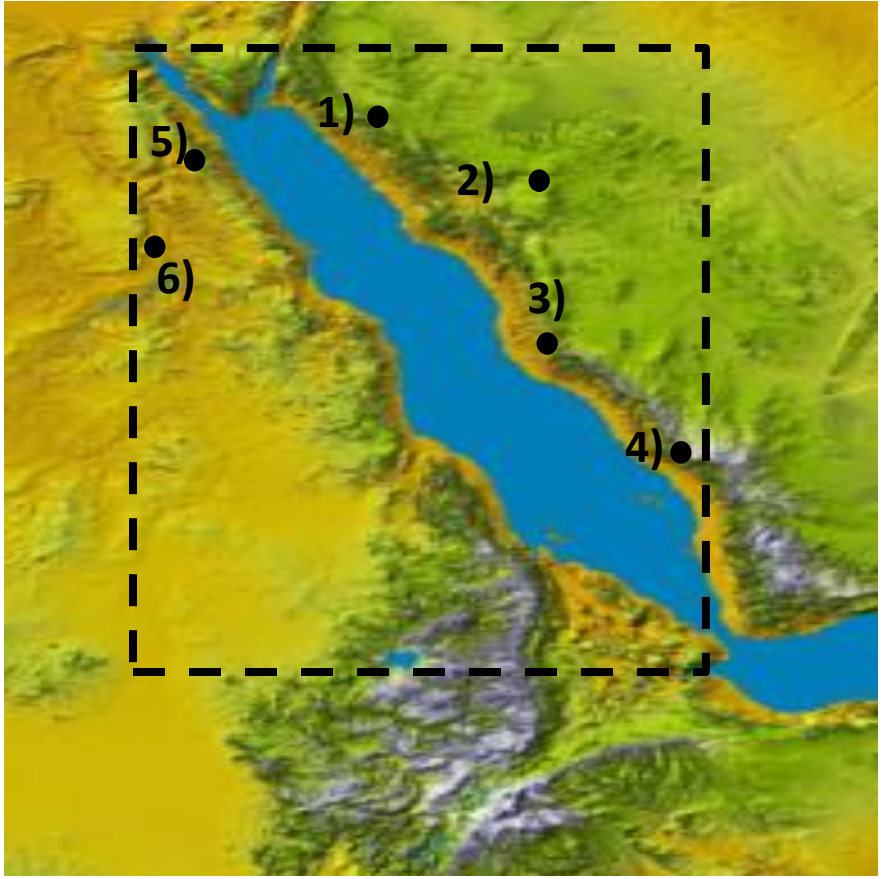


Model and Climate Downscaling Configuration

- Following Jiang et al. 2009
- WRF (Weather Research and Forecasting Model)
- Dynamic core 3.0.1.1 (2007/08)
- Horizontal resolution :
  - 100km (4-40N,12-68 W)
  - 10km within 8-30N, 46-32W
  - **Centered about air-sea buoy and meteorological tower locations**
- 35 sigma vertical levels
- Time steps:
  - 1 hour 10km grid
  - 3 hours 100km grid

- Forcing NCEP FNL (Final Global Analysis)
- Yonsei University (YSU) PBL scheme
- 3 hourly reinitializations (Lo et al., 2008)





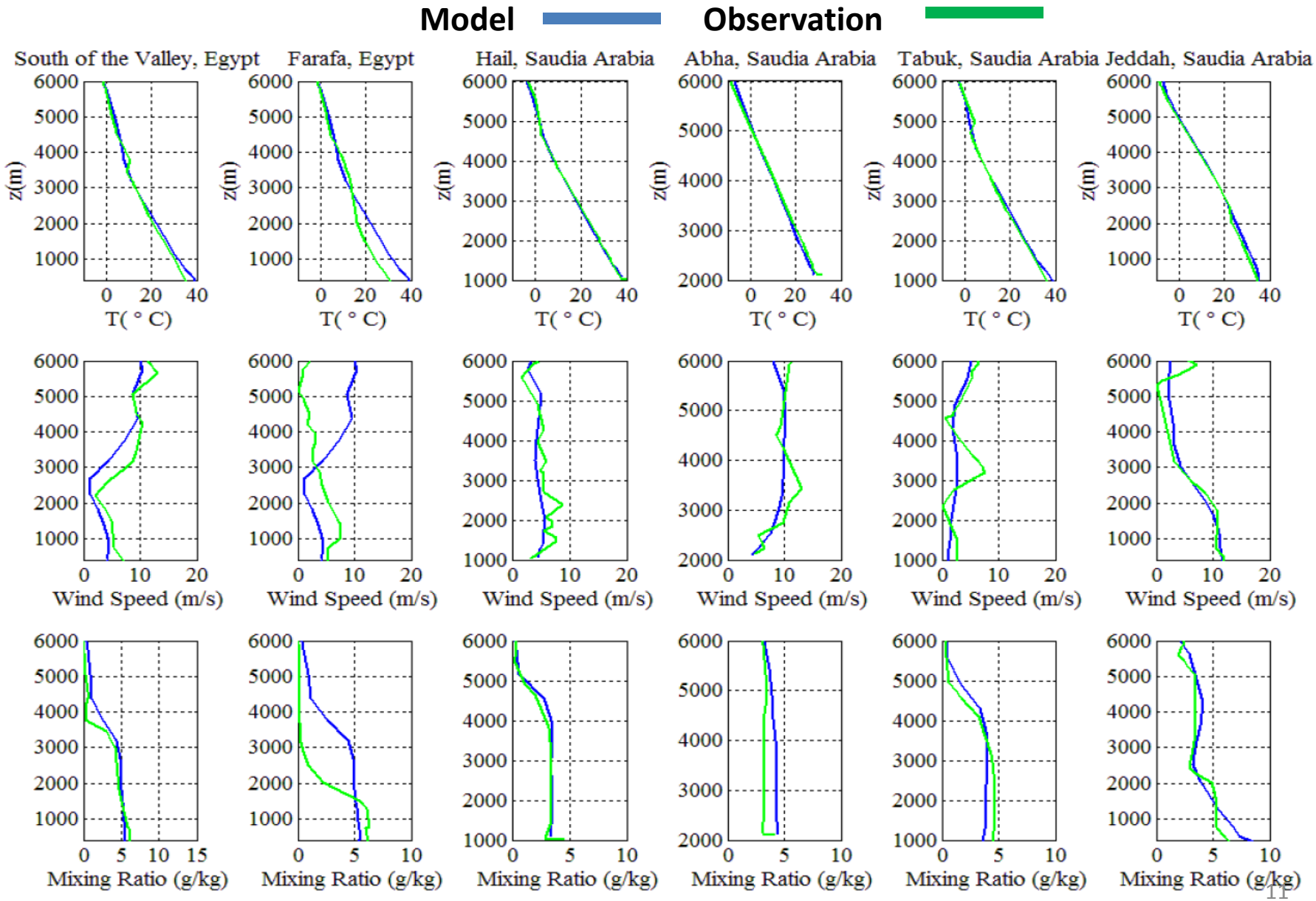
Model Observation Comparisons

Within lower 6km

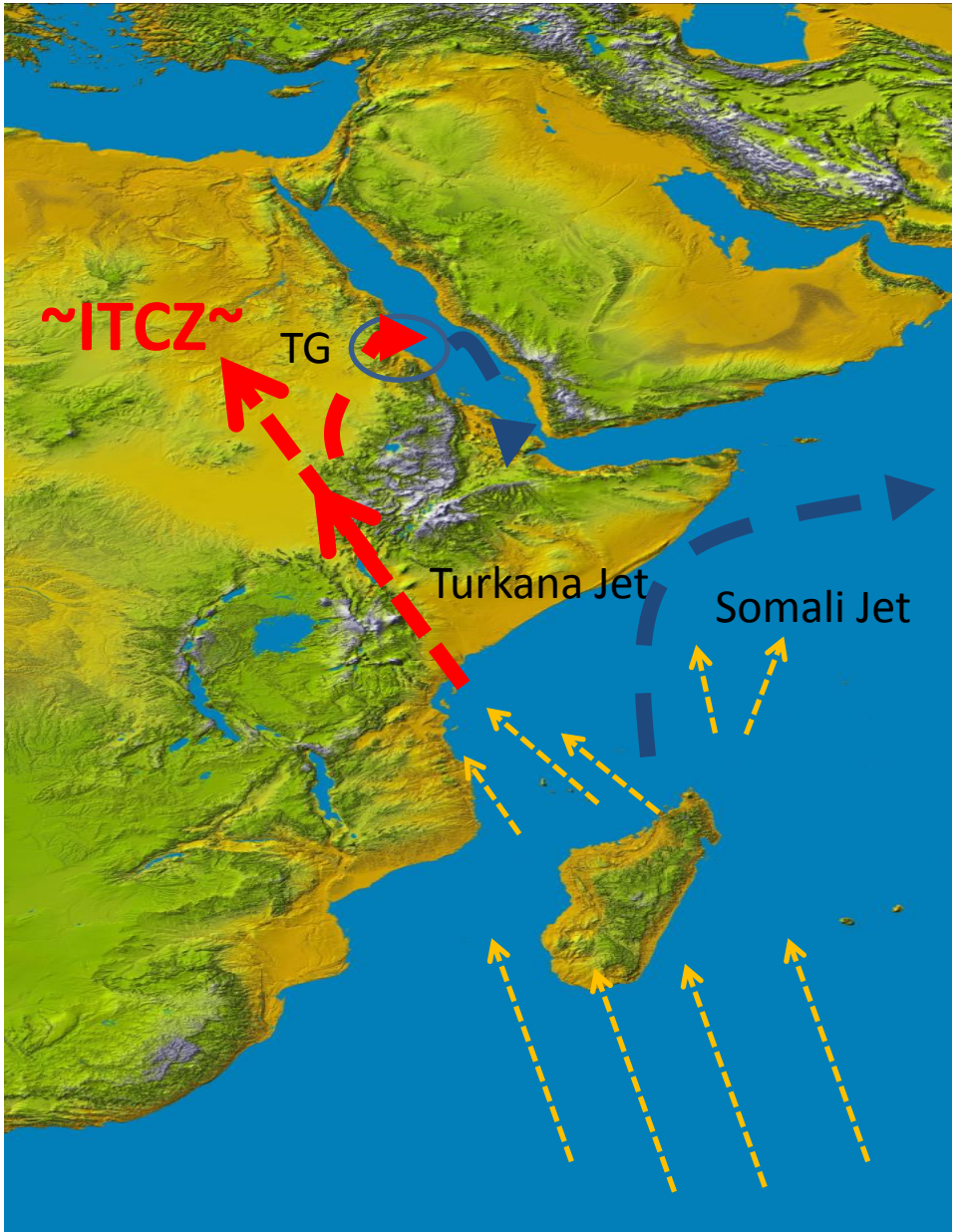
- 1.16m/s RMSE wind speed
- Corresponding 1.38 °C and 0.85g/kg RMSEs for temperature and water vapor mixing ratio
- no apparent bias

Location	1)Tabuk	2)Hail	3)Jeddah	4)Abha	5)South of the Valley	6)Farafra
Nation	Saudi	Saudi	Saudi	Saudi	Egyptian	Egyptian
Type	N. Coastal highlands	C. Inland Highlands	C. Coastal	S. Coastal Highlands	NW. Coastal	NW Inland
Elevation	768 m	1002 m	19 m	2093 m	78 m	96 m

Model Validation



Moisture Pathways and Orographic Influences

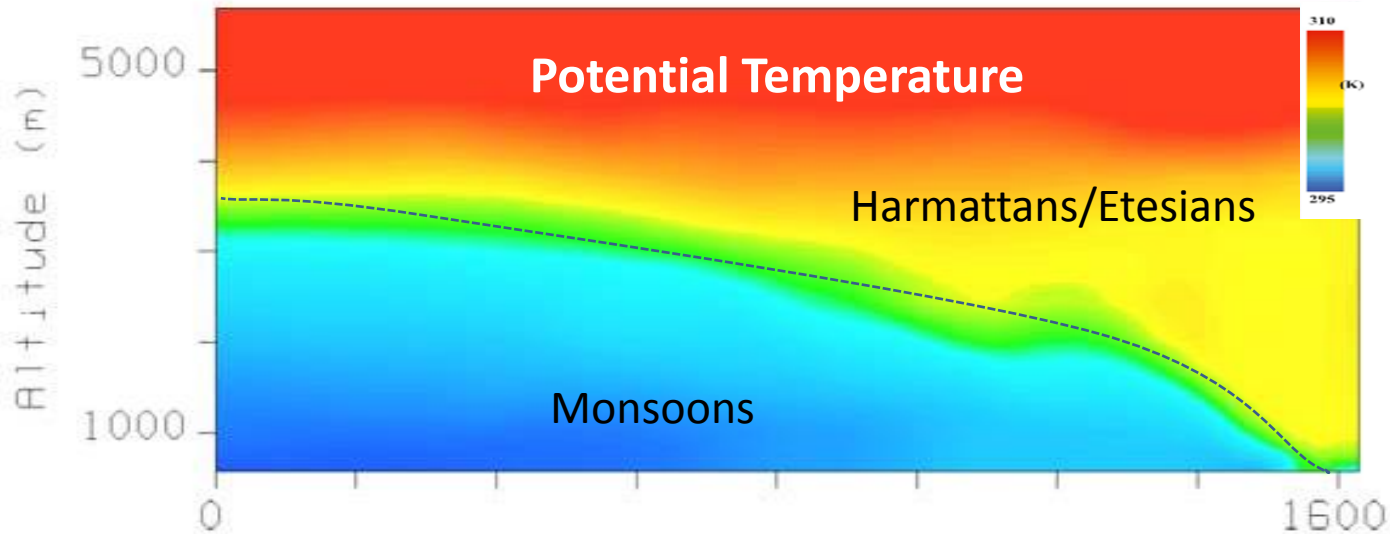


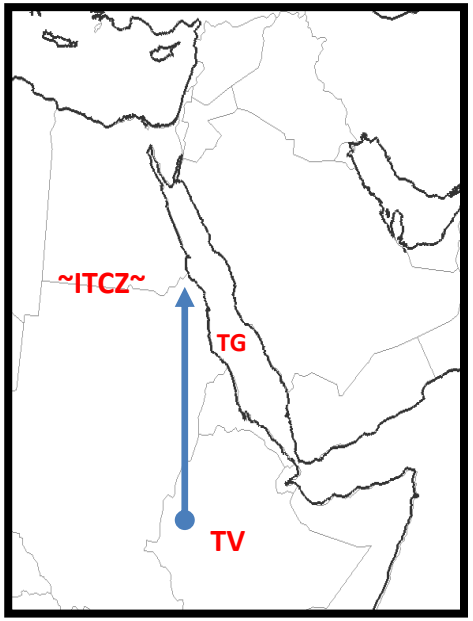
- **Somali/Findlater/East African Jet**
  - Findlater et al. (1969)
  - Krishnamurti et al. (1980)
- **Red Sea Moisture**
  - Viste et al. (2011)
- **Turkana Jet**
  - Kinuthia et al. (1982)
  - Indeje et al. (2011)

New Findings

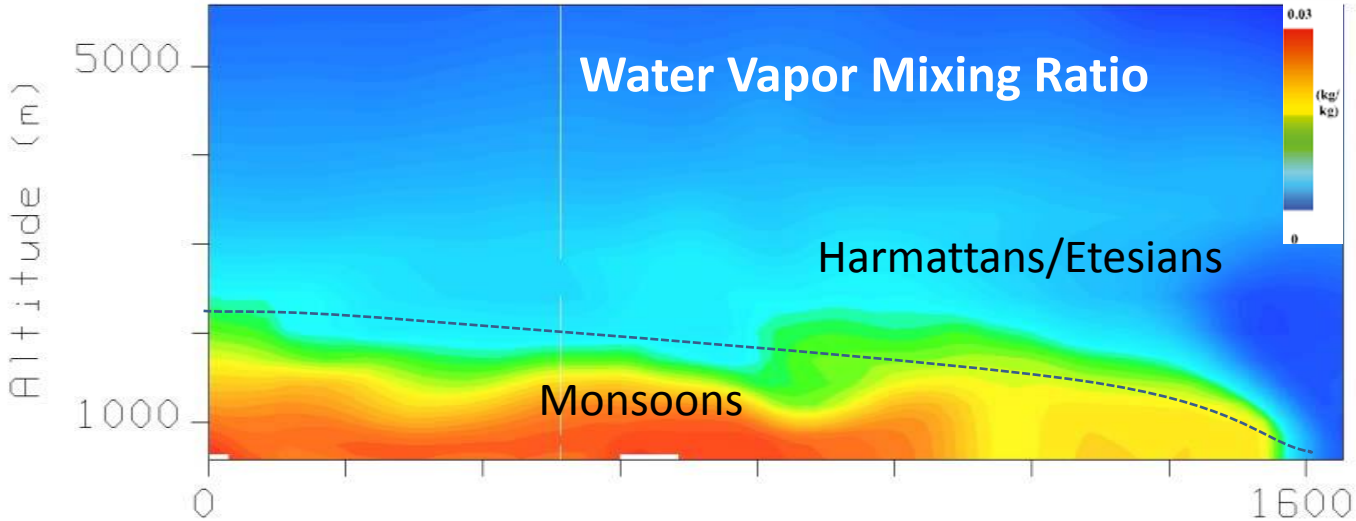
Previously Established

Monsoon Inflow: Cross Sections Along the Pathway





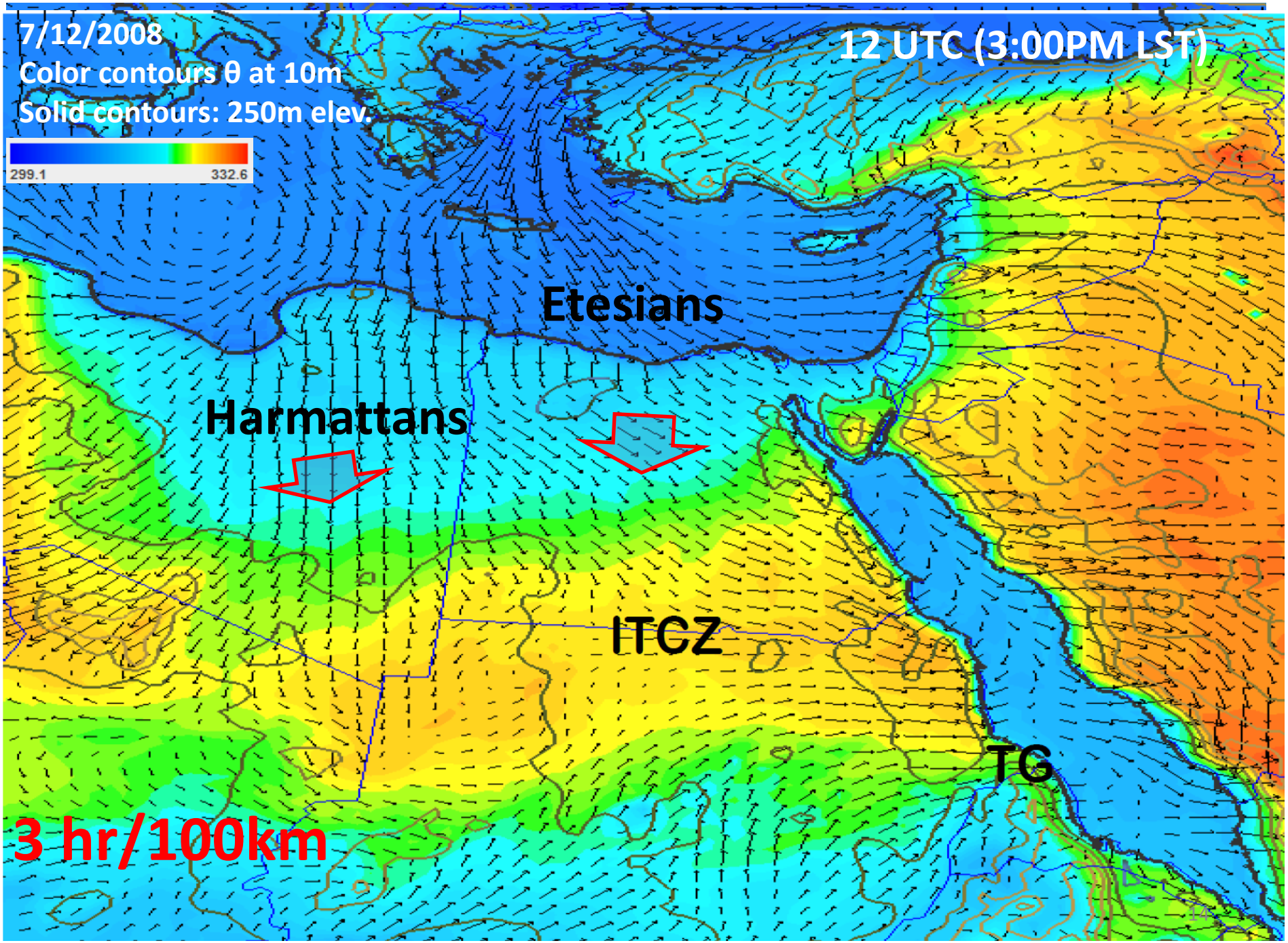
Turkana Valley (TV) **TG** **ITCZ**

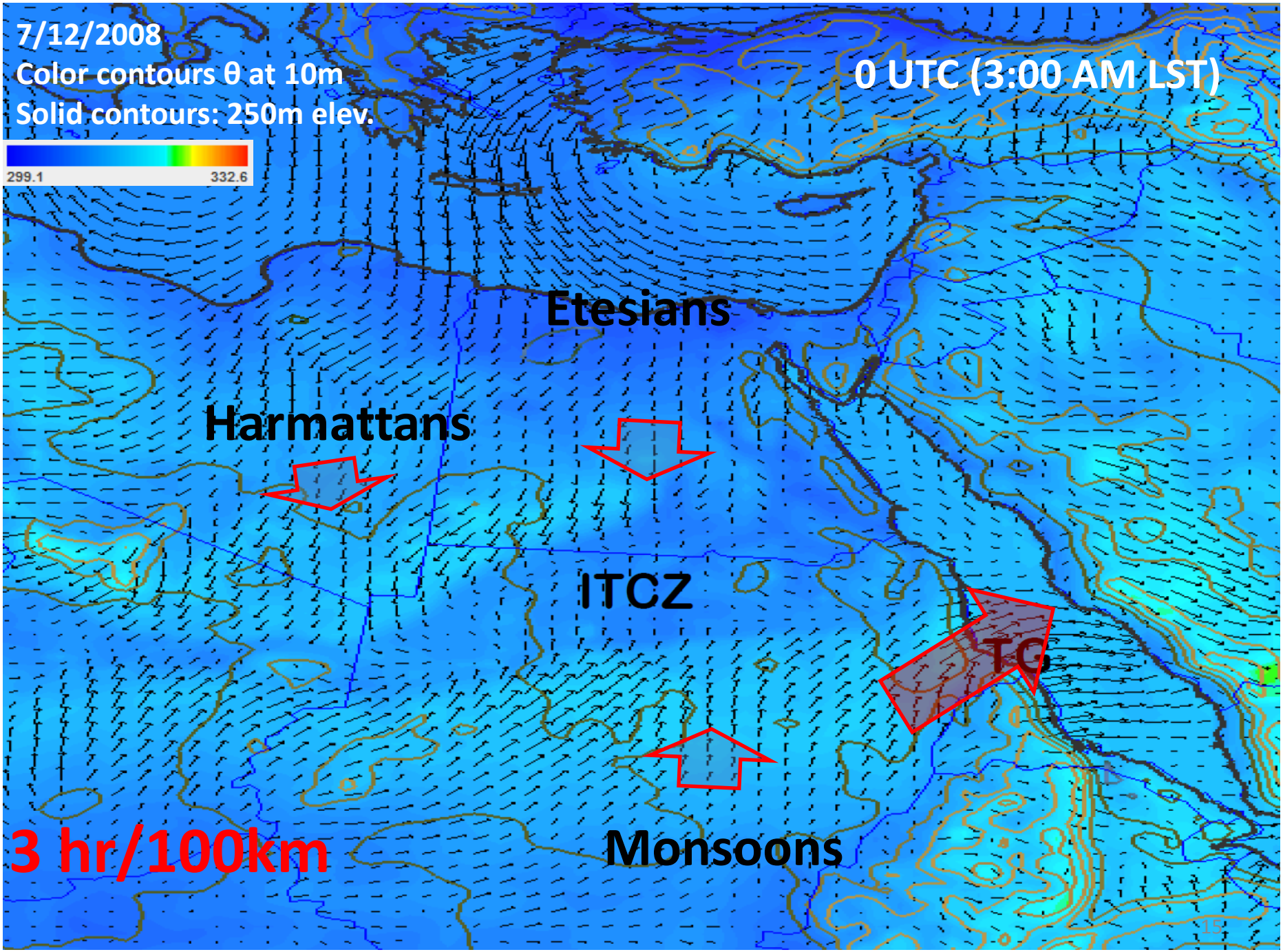


3 hr/100km

Gravity Current Characteristics

- movement at an approximate rate of 7 m/s
- compares with an estimated range of 11–16 m/s for a frictionless gravity current


7/12/2008
Color contours θ at 10m
Solid contours: 250m elev.
299.1
332.6
12 UTC (3:00PM LST)
Etesians
Harmattans
ITCZ
TG
3 hr/100km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299.1
332.6
0 UTC (3:00 AM LST)
Etesians
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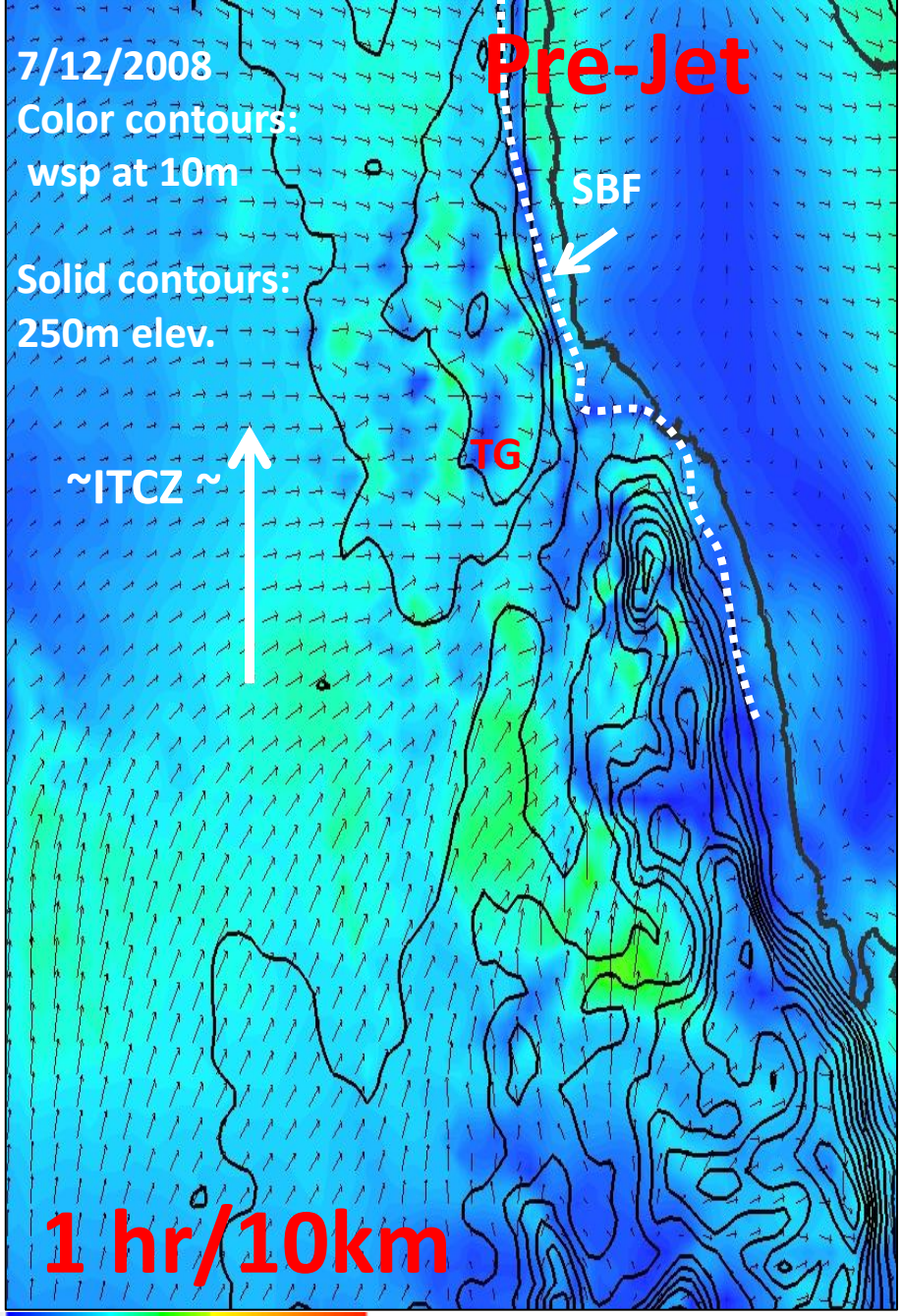
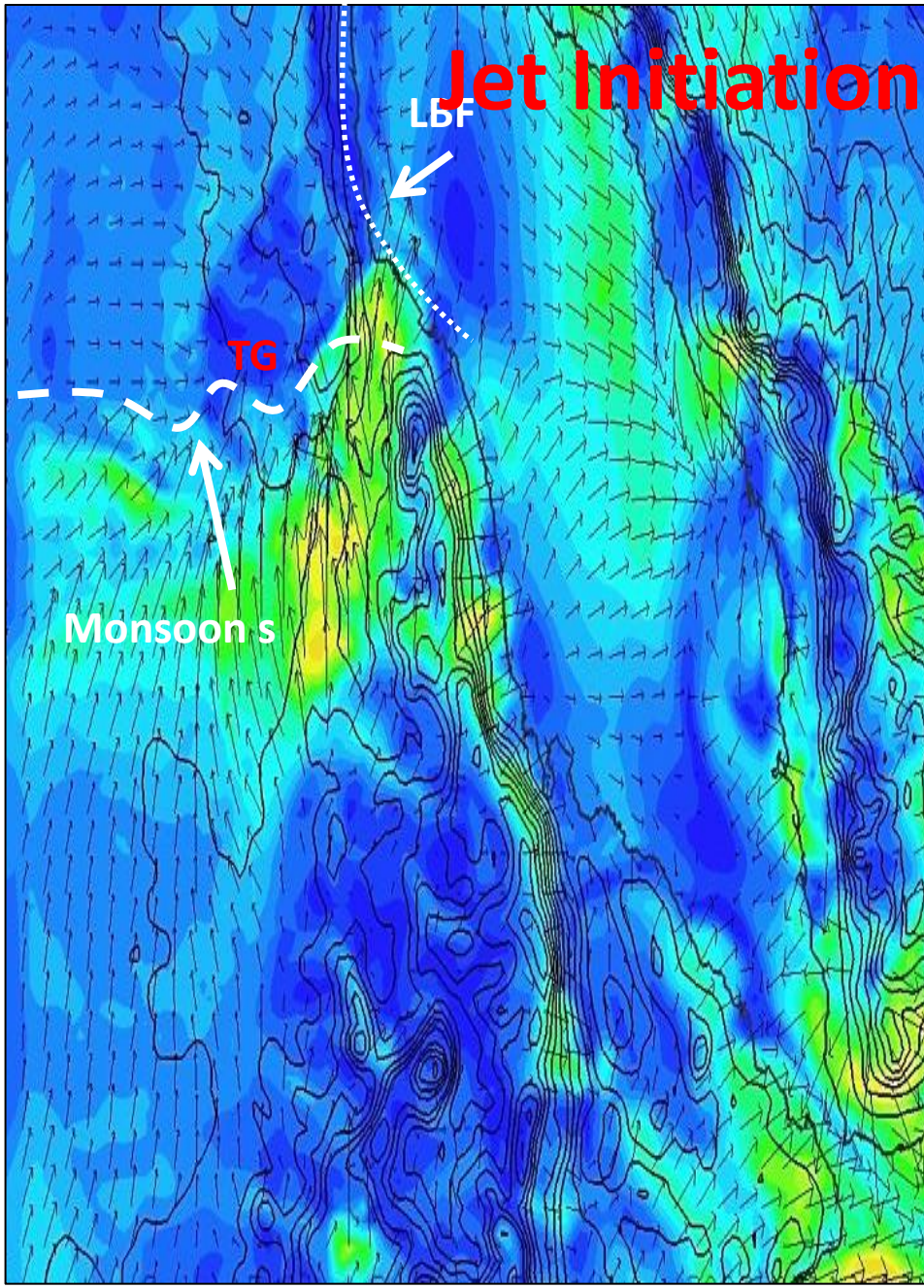
ITCZ
TC
Monsoons
3 hr/100km

Tokar Gap Jet
Case Study (10 km/1 hr)
for
7/12/2008



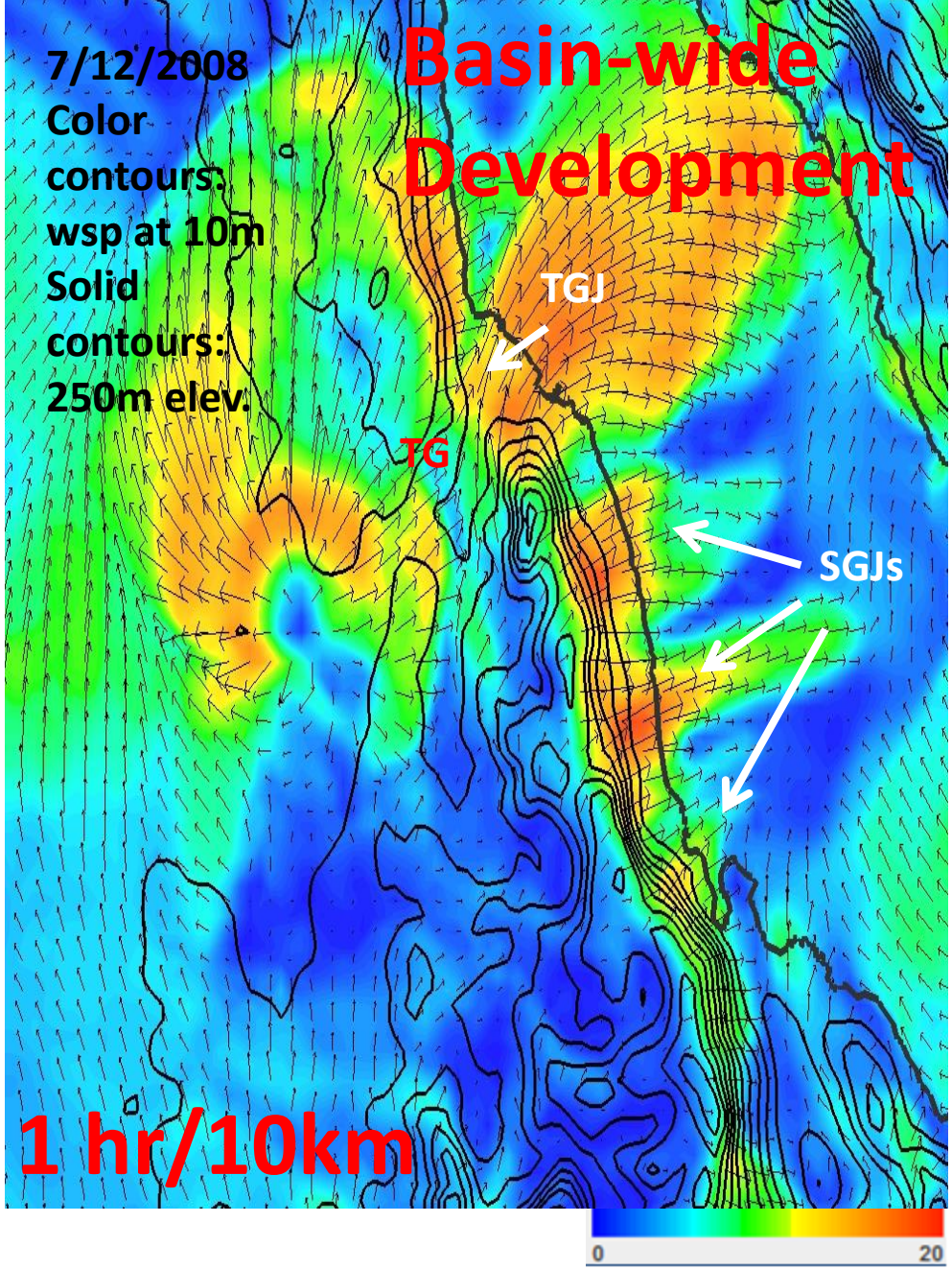
17 UTC (8:00 PM LST)

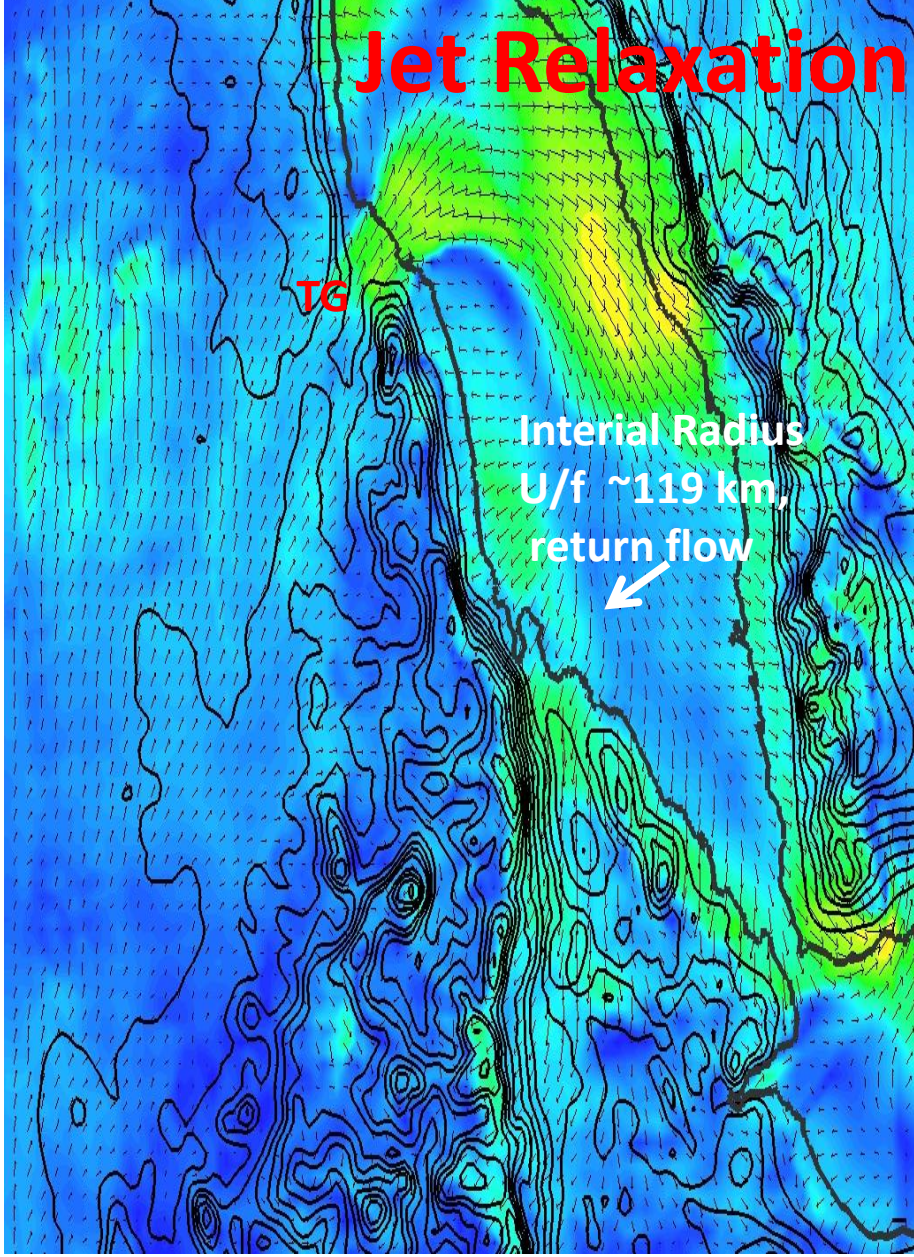
Pre Jet Onset, Sea breeze



+ 2 hrs

TG Jet Onset and secondary gap jets

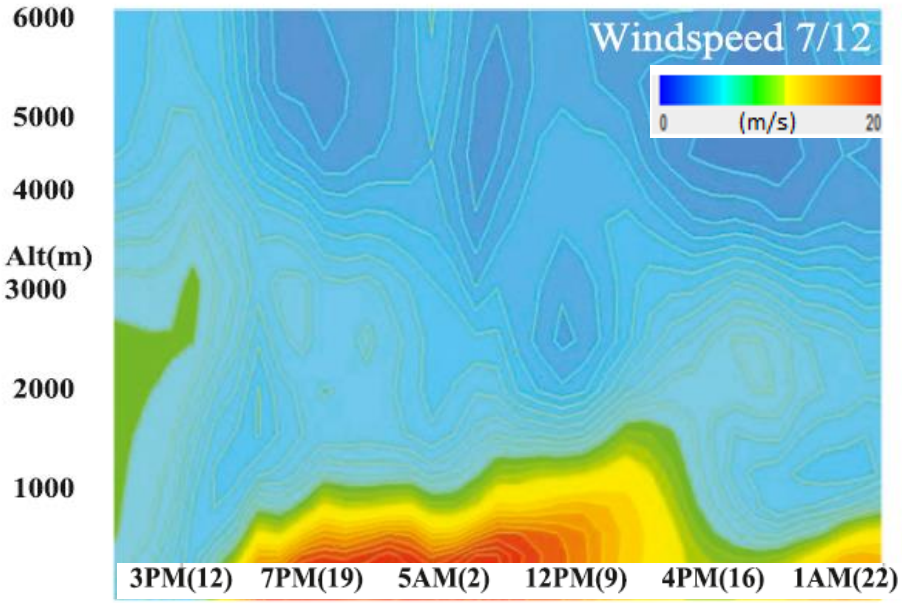


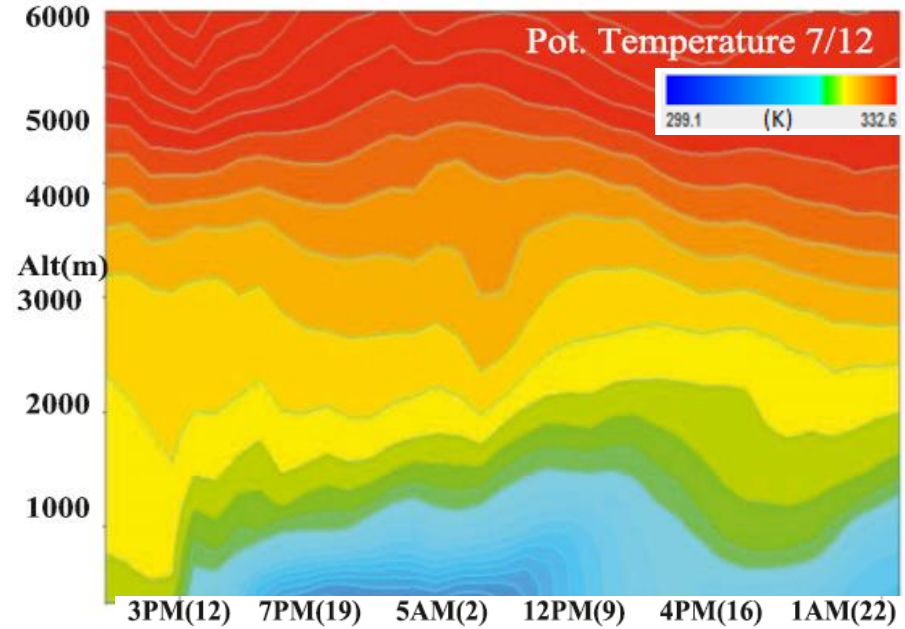


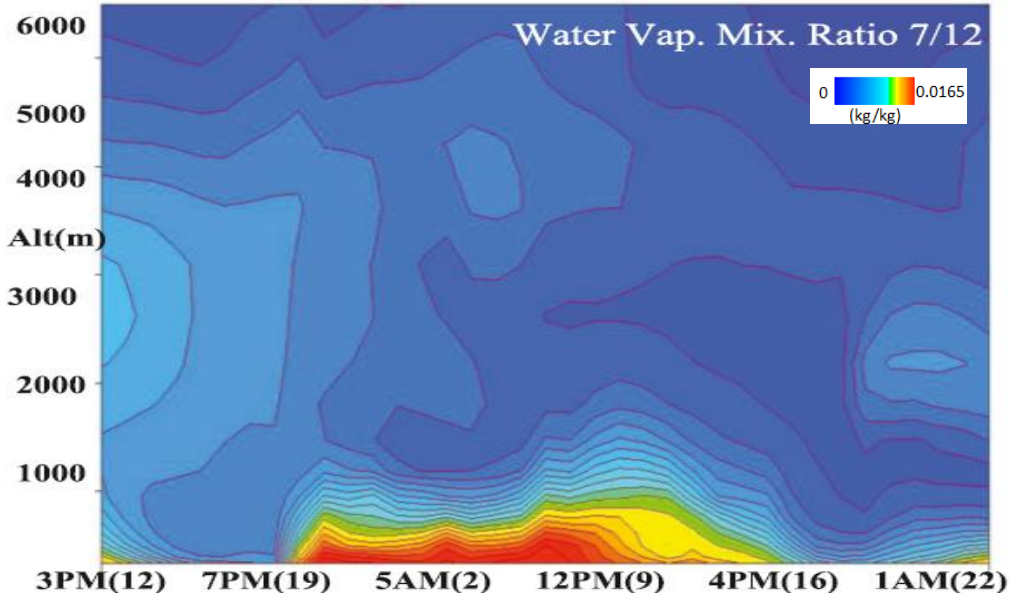
22 UTC (1:00 AM LST next day)

+ 12 hrs

Case Study Cross Sections on 7/12/2008







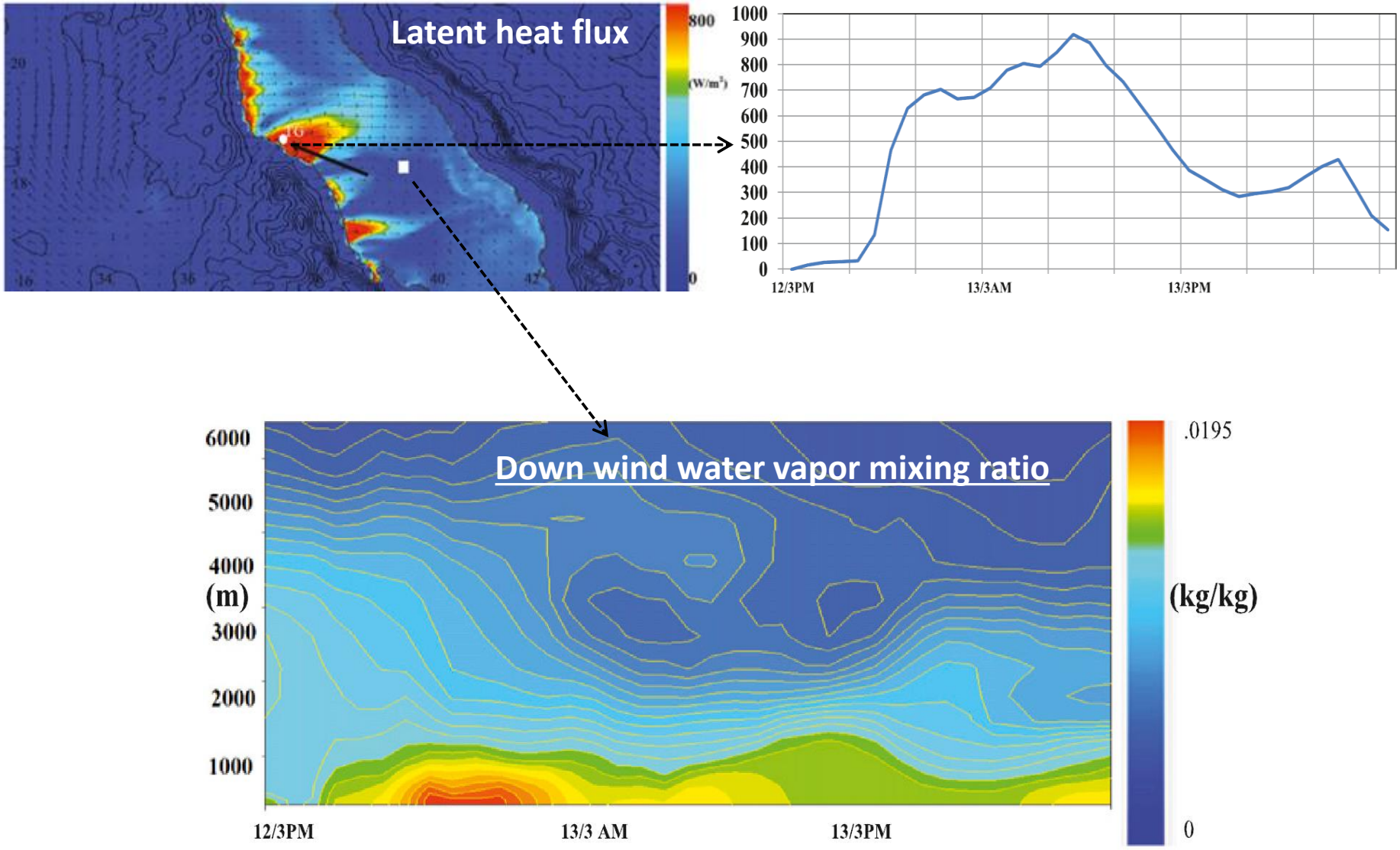
Influence on Moisture Fluxes

- Enhancement of near surface winds, increasing the frictional velocity u* in particular, thus enhancing the latent heat fluxes from the Red Sea surface

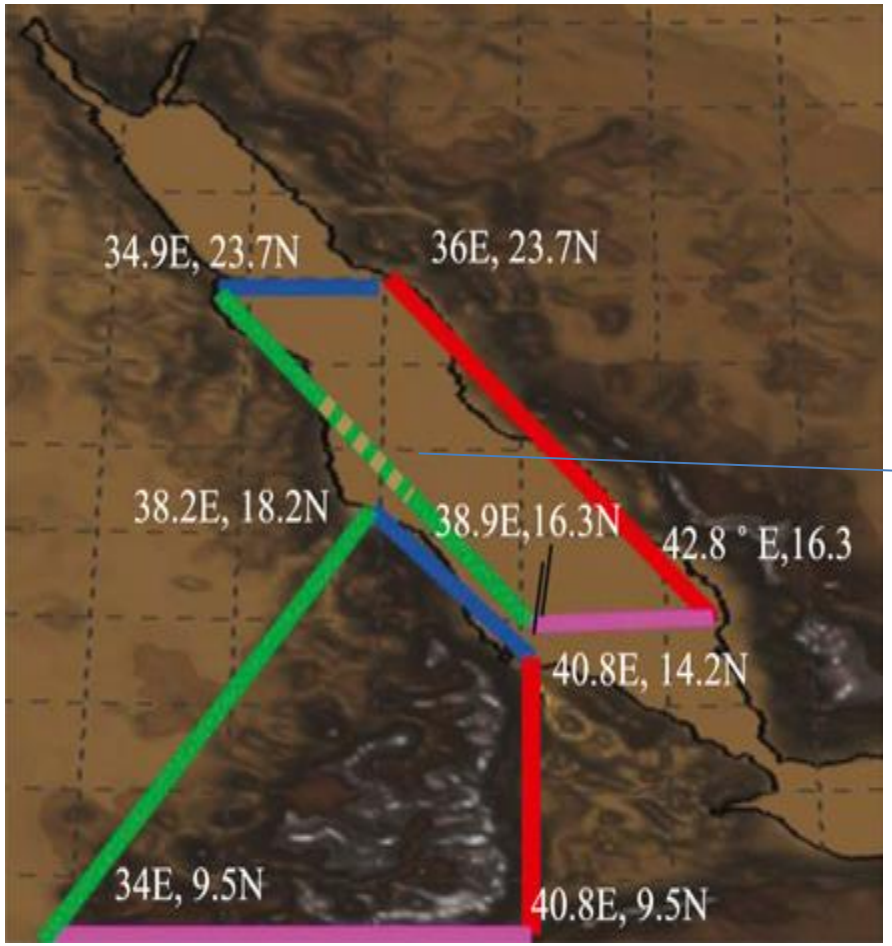
- Monsoon enhanced lateral moisture flux

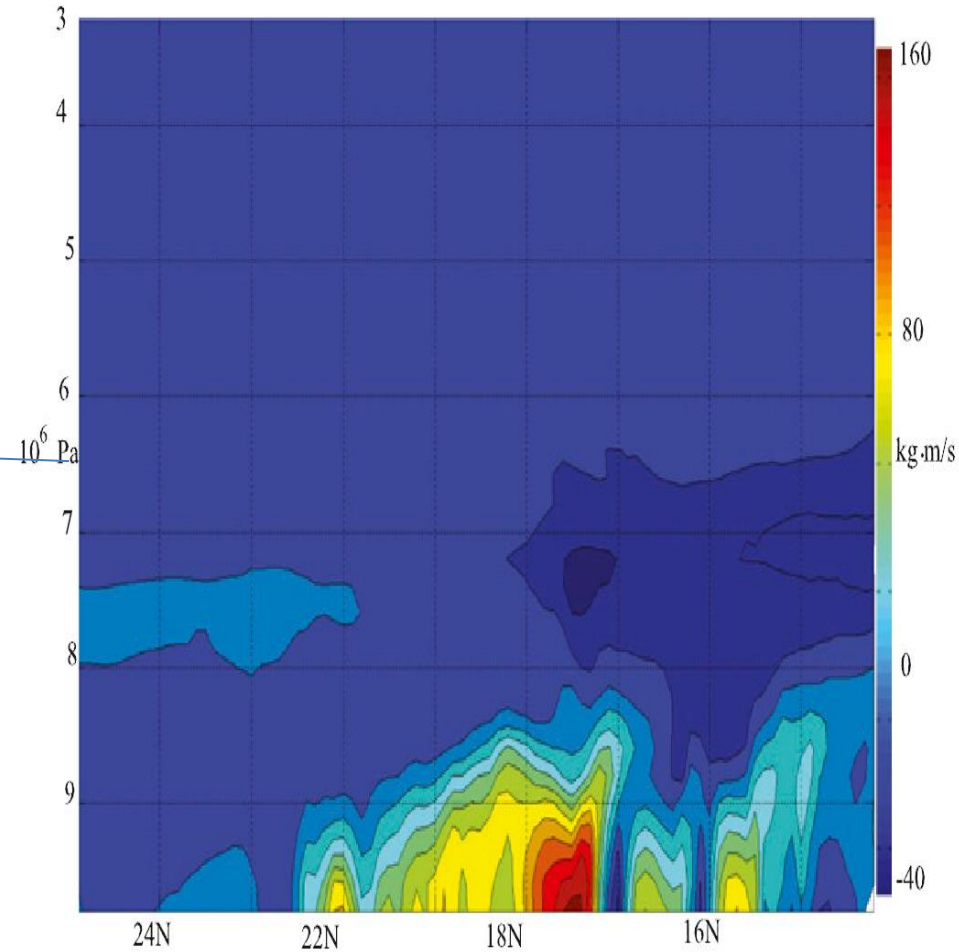
$$\text{flux} = \frac{1}{g} \int_{\text{sfc}}^{8000\text{Pa}} v_n q \, dp \, ,$$

Latent heat Flux and Down Wind Moisture Evolution



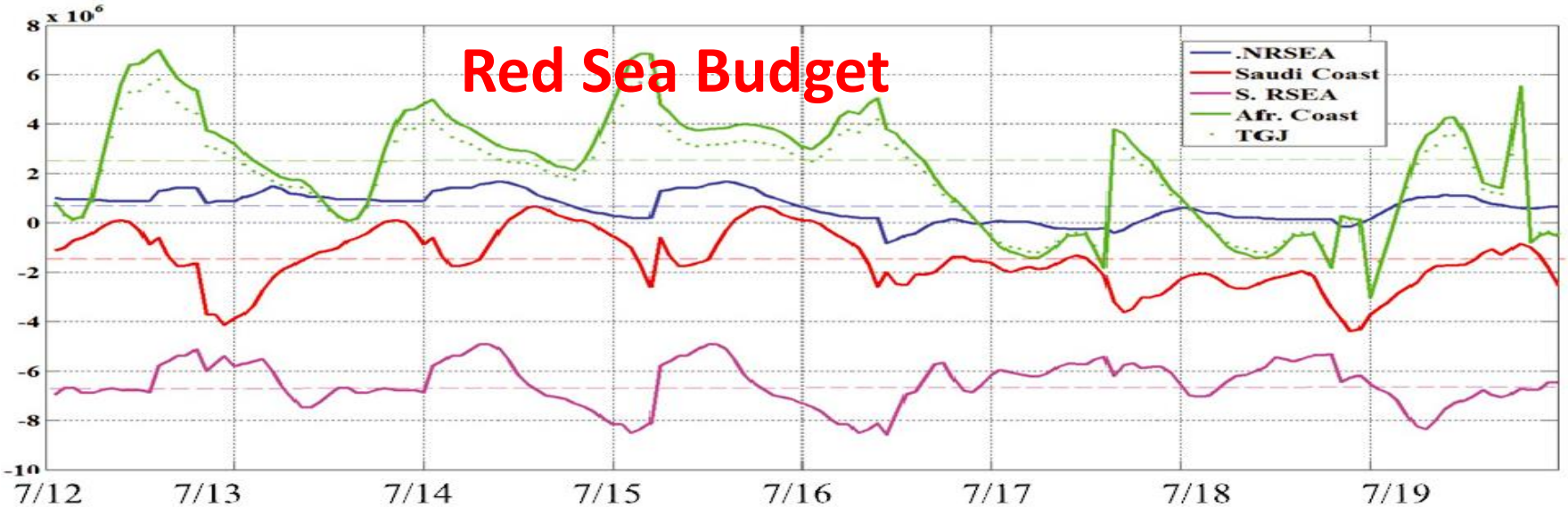
Integrated Lateral Moisture fluxes

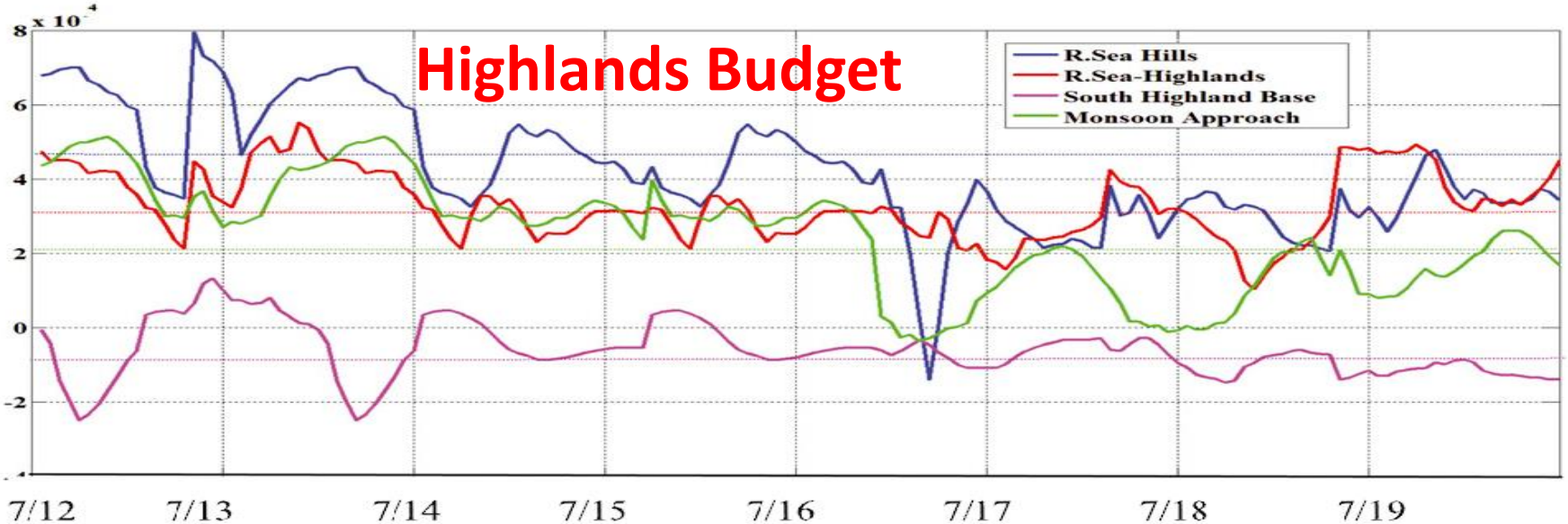




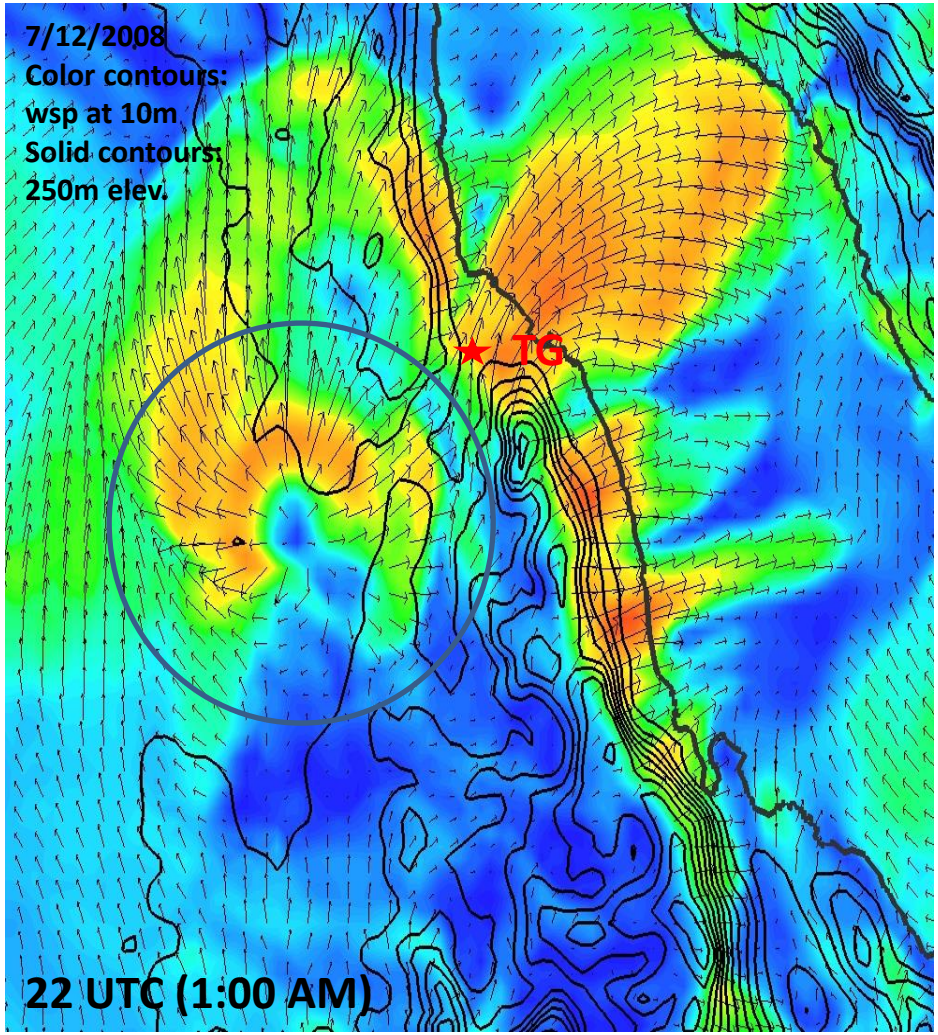
A representative vertical cross section of the moisture flux (q*yn)

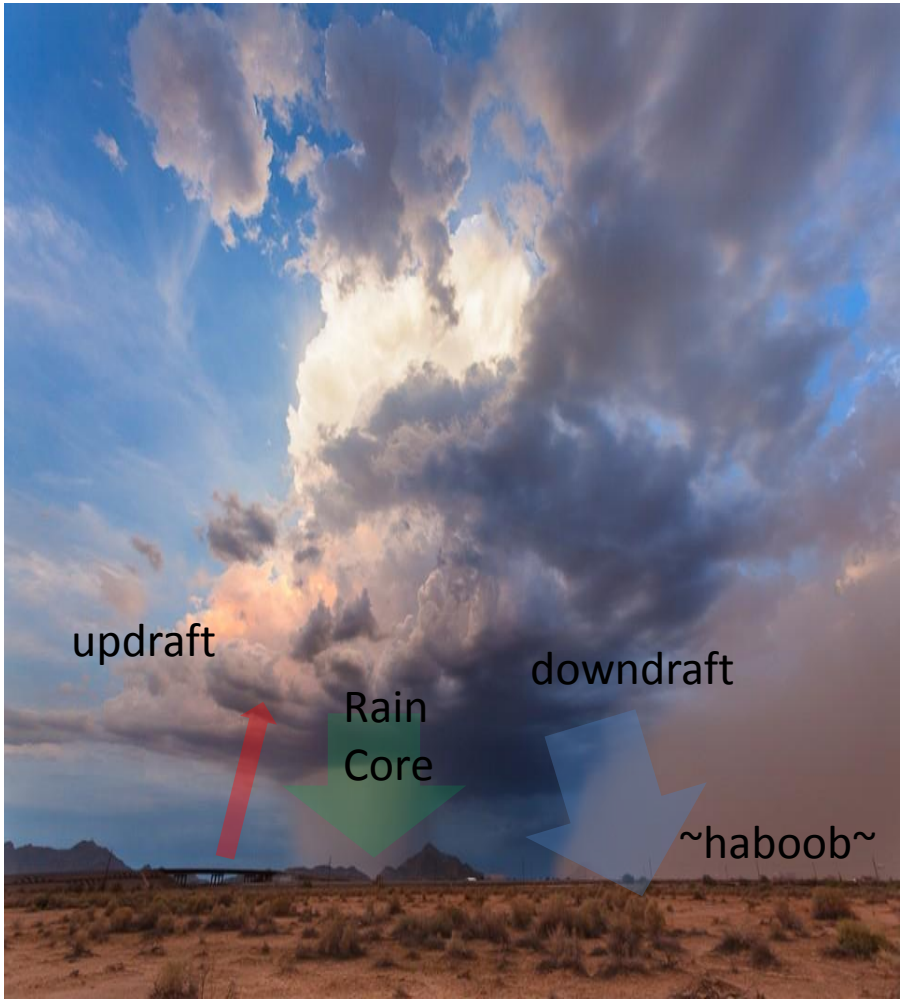
Role in the Regional Moisture Budget



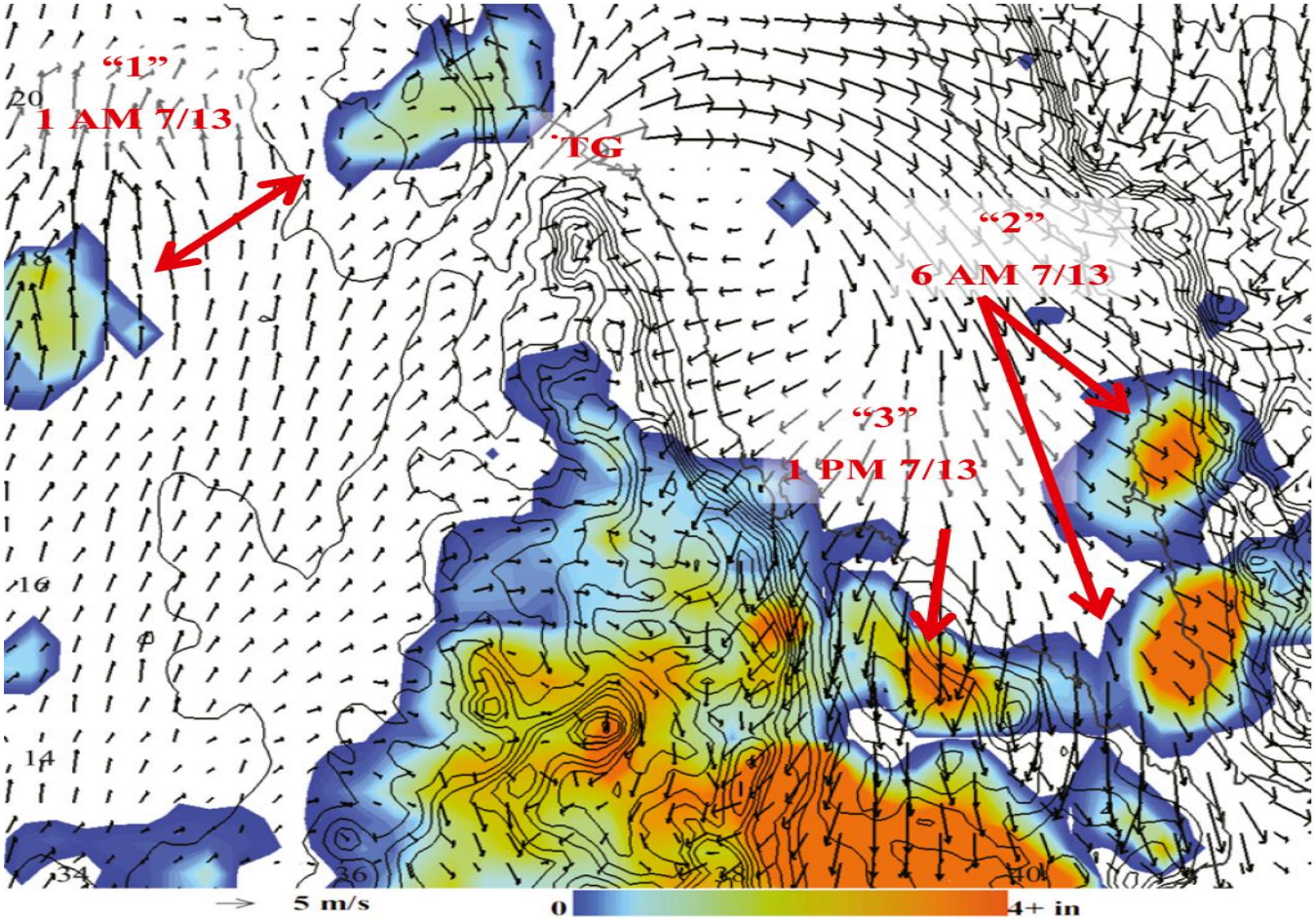


Mesoscale Convective Complexes

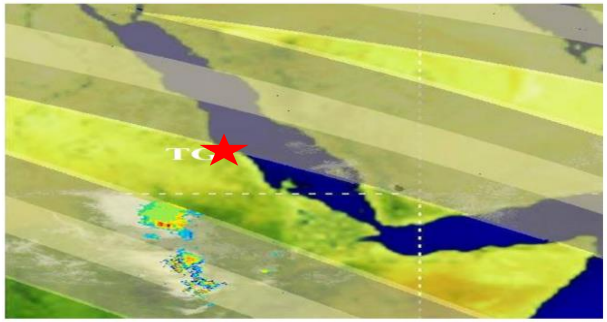




MCC's throughout TGJ event



WRF winds overlaying TRMM precipitation observations



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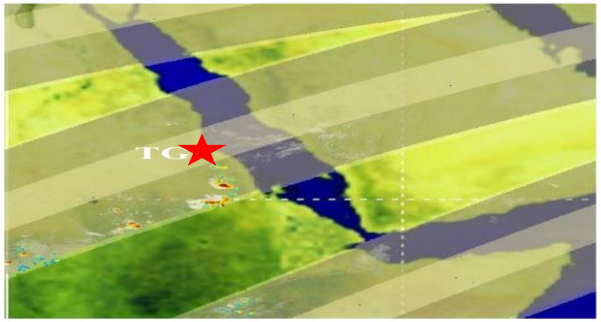

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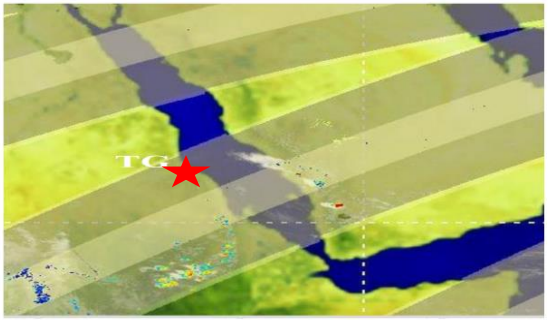

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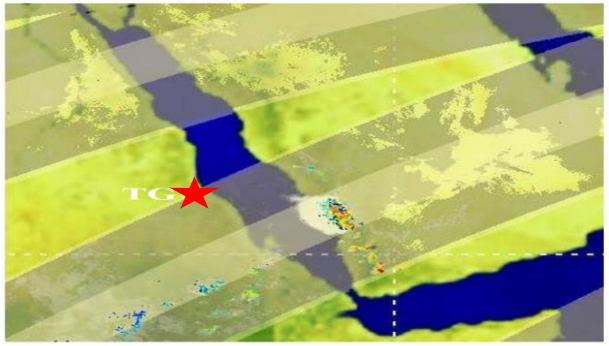
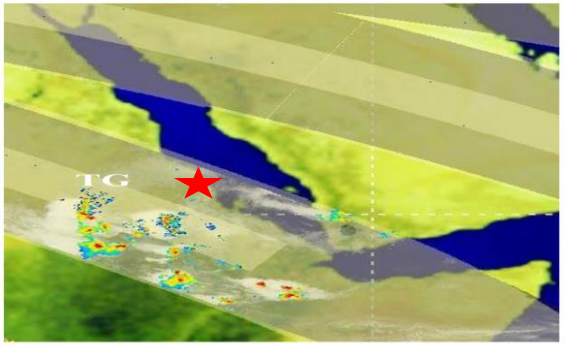


7/08



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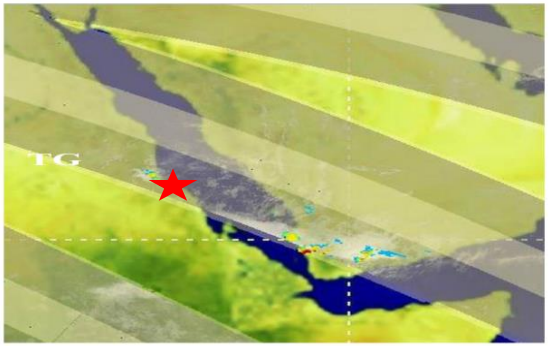

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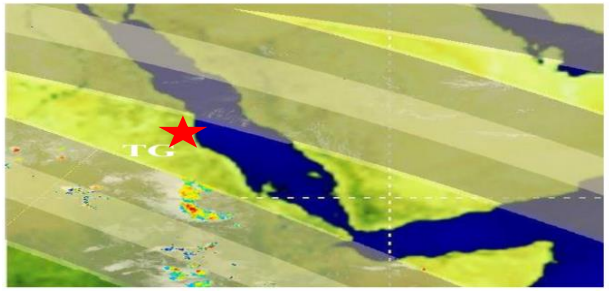
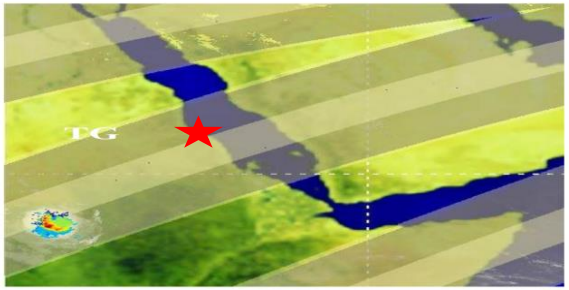


7/13



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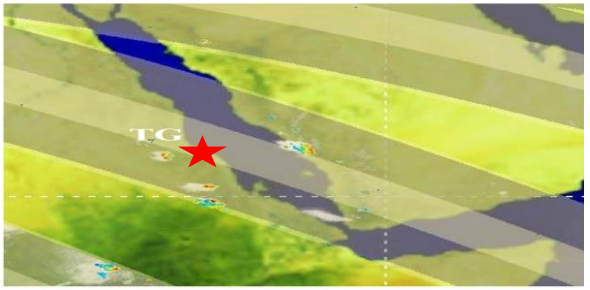
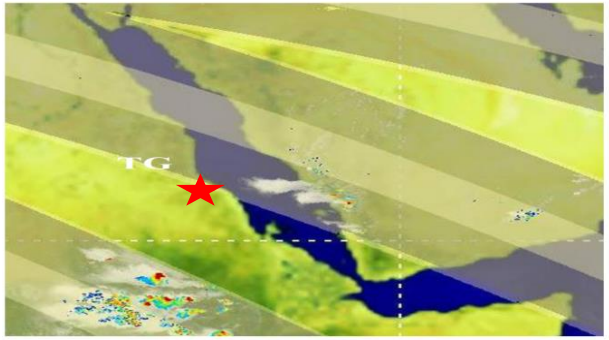


7/15d



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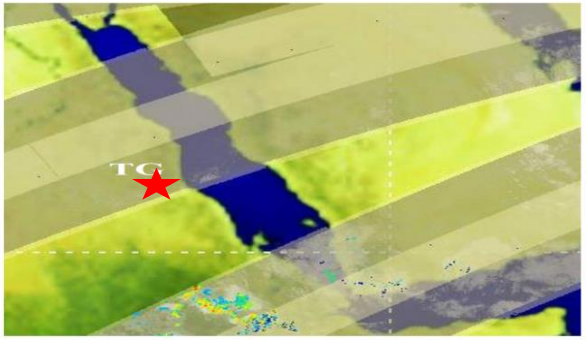

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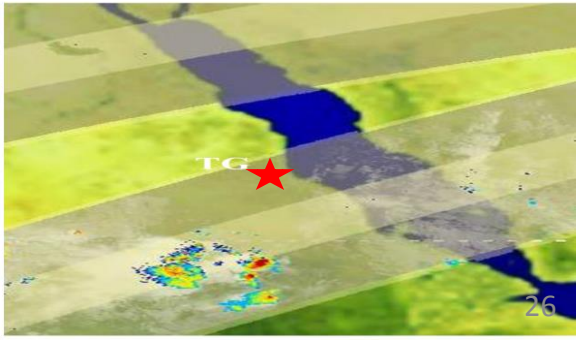
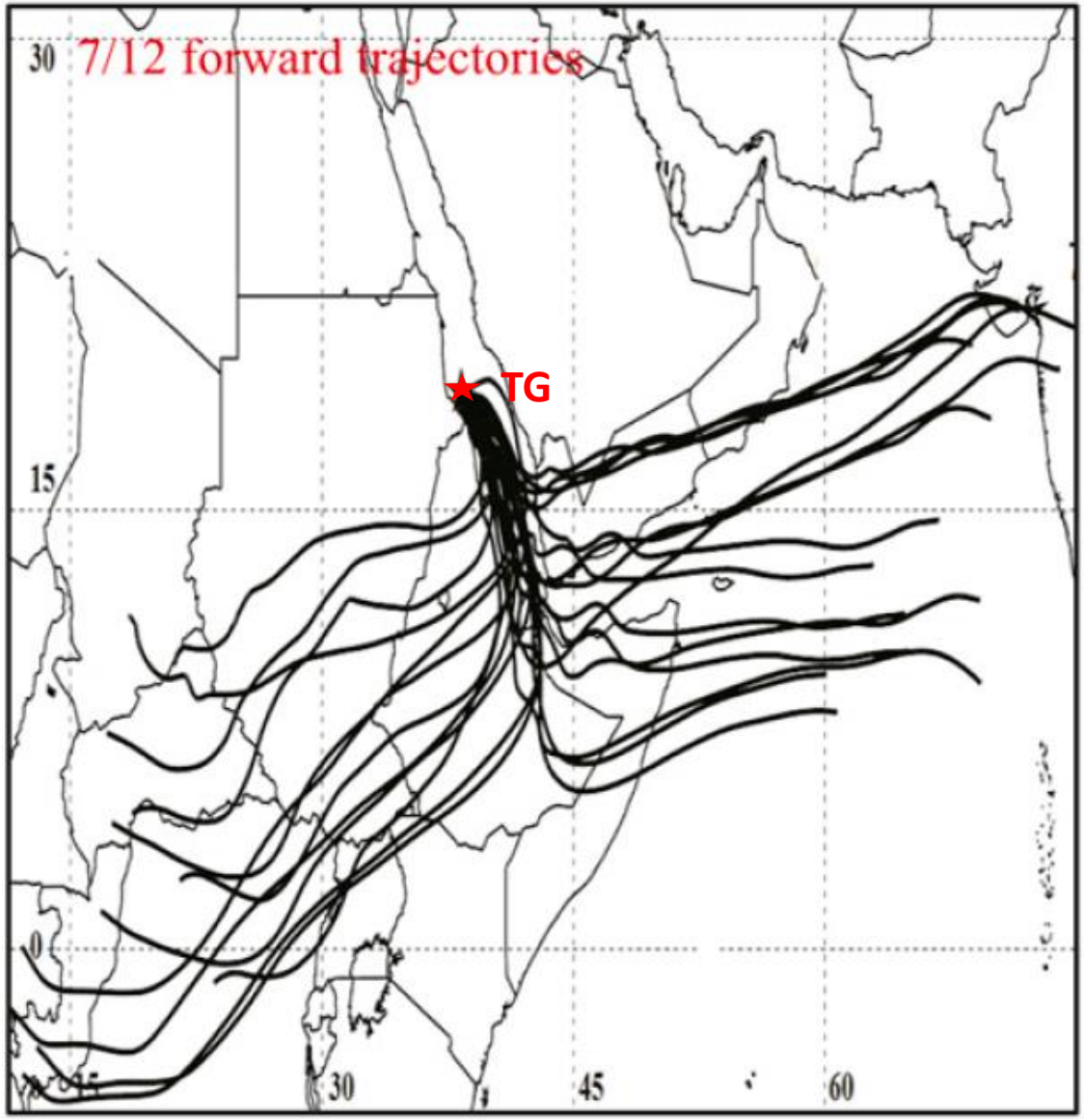
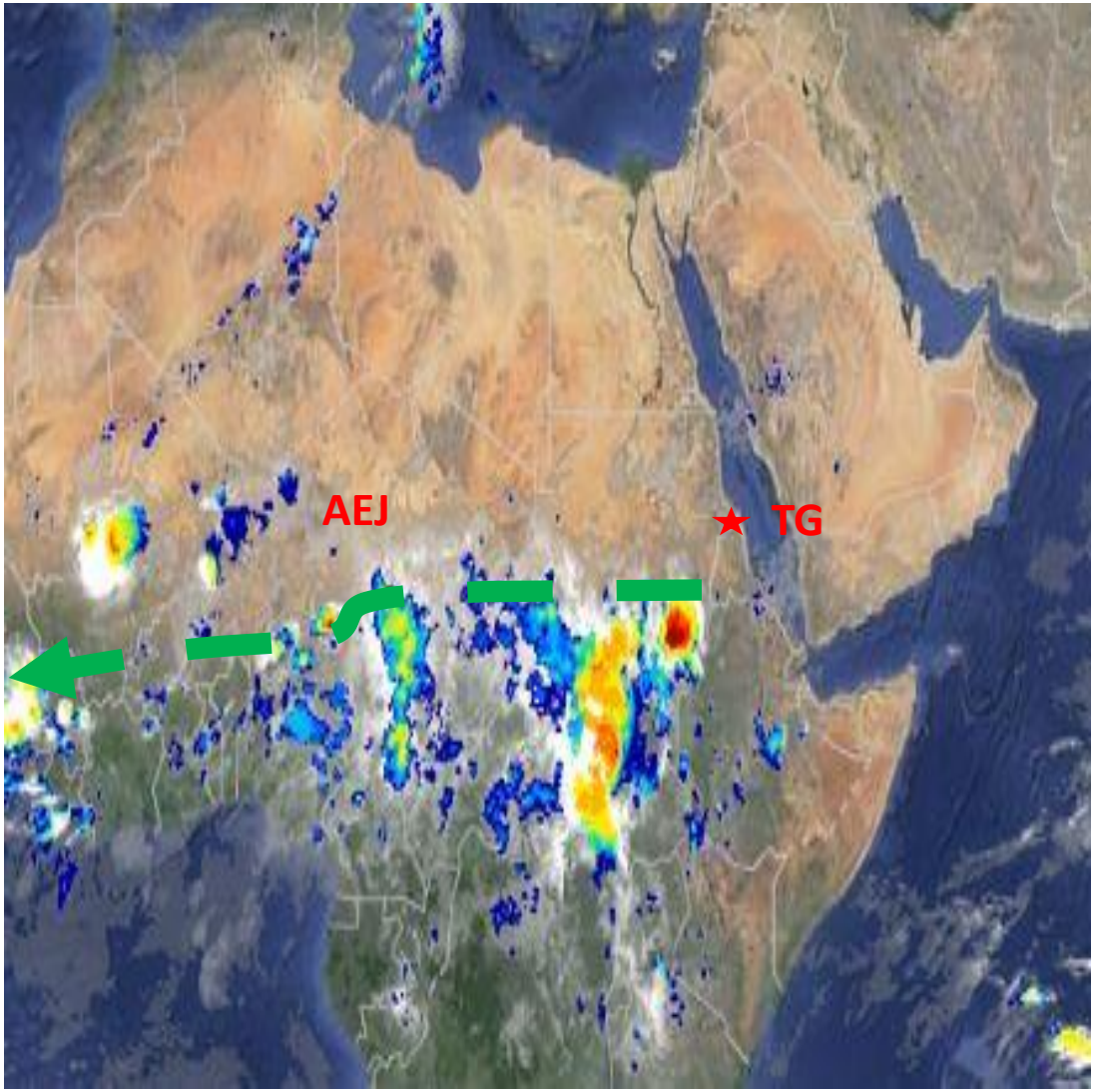


8/02

Impacts of the TGJ



Ties To Atlantic Tropical Activity



- Sahelian Rainfall and Hurricanes (Grey et al. 1990, Landsea et al. 1991)
- Hurricane Alberto (Hill et al. 2003)
- Hurricane Isabel (Rodrigues et al. 2005)
- Sandy (NASA, 2013)

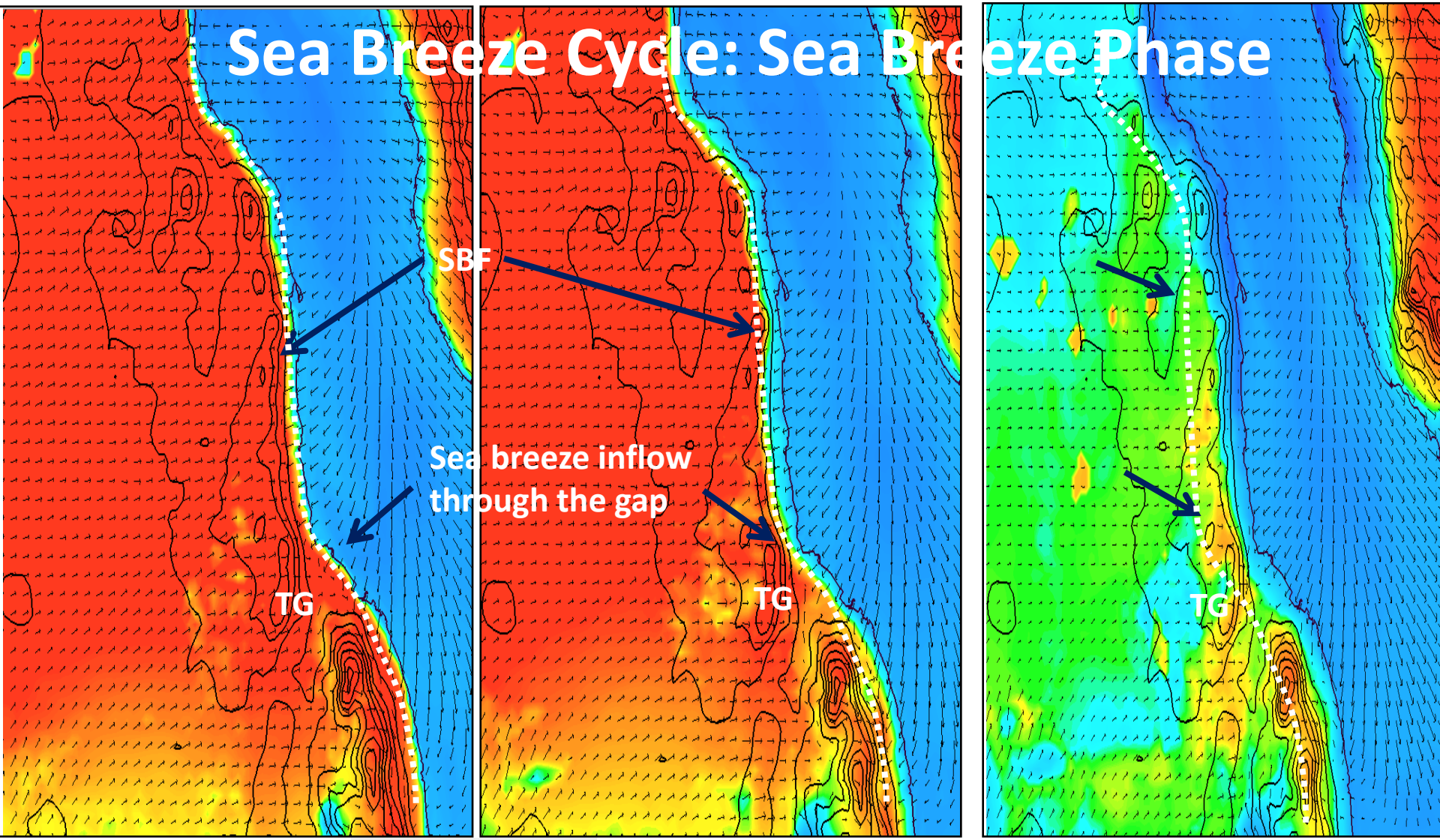
The Tokar Gap Jet (TGJ): Key Points

- **Seasonal feature directly tied to the migration of the ITCZ and Indian Ocean Monsoons**
- **Not just a coastal gap wind jet tied to local wind regimes but a feature tied to the surface dynamics of the ITCZ in East Africa**
- **Moist gap wind jet**
- **Part of a network of orographic flows conveying moist monsoon airmasses to East Africa and the Red Sea**
- **Based on an analysis of the vertically integrated horizontal moisture fluxes, it was seen that the TGJ played a prominent role in the atmospheric moisture transport into the central and southern Red Sea**
- **Mechanism of orgraphic uplift and convergence in the lateral moisture fluxes behind mesoscale convective storm development**

Davis, Shannon R., L. Pratt and H. Jiang: 2015: The Tokar Gap Jet: Regional Circulation, Diurnal Variability, and Moisture Transport Based on Numerical Simulations. J. Climate, 28, 5885–5907, doi: 10.1175/JCLI-D-14-00635.1.

the local (coastal) atmosphere

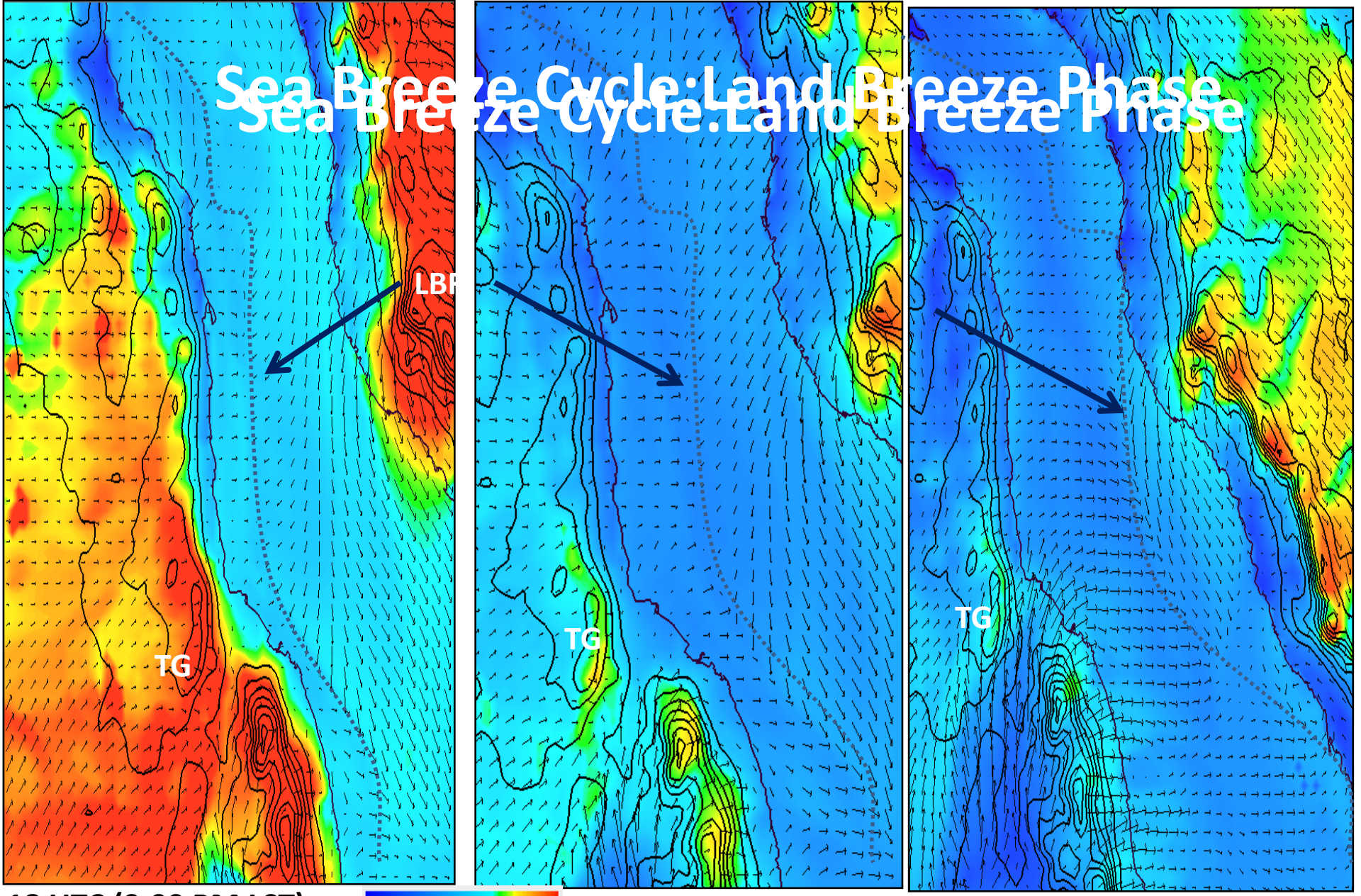
Sea Breeze Cycle: Sea Breeze Phase



14 UTC (5:00 PM LST) 299.1 332.6 +1 hr +2 hrs UTC

7/11/2008; Color contours θ at 10m;Solid contours: 250m elev.

Sea Breeze Cycle:Land Breeze Phase



18 UTC (9:00 PM LST)

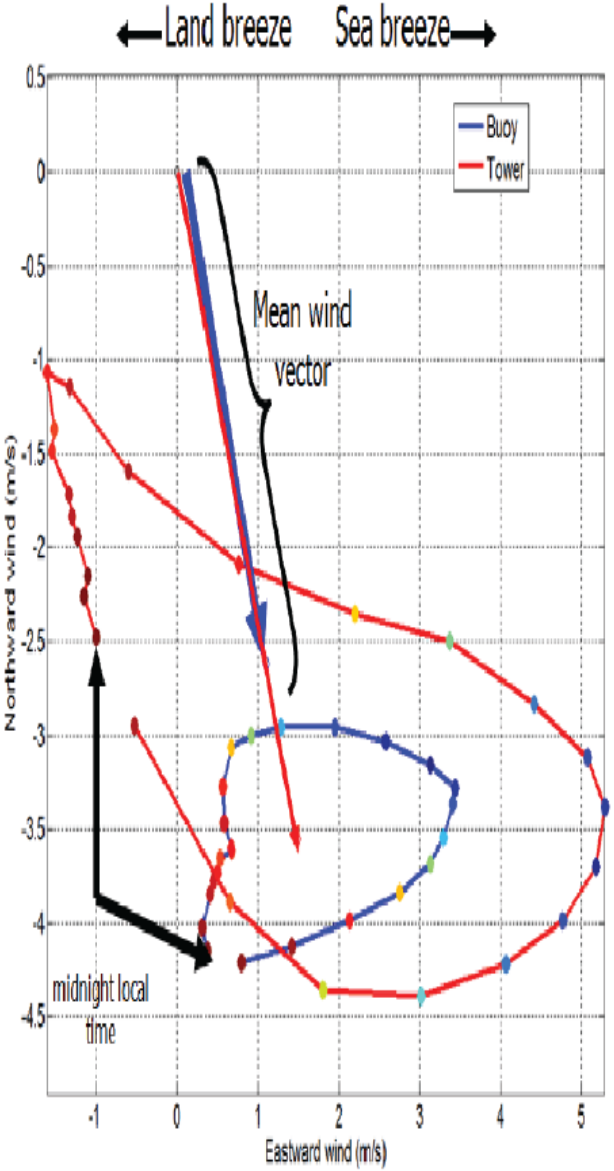
299.1 332.6

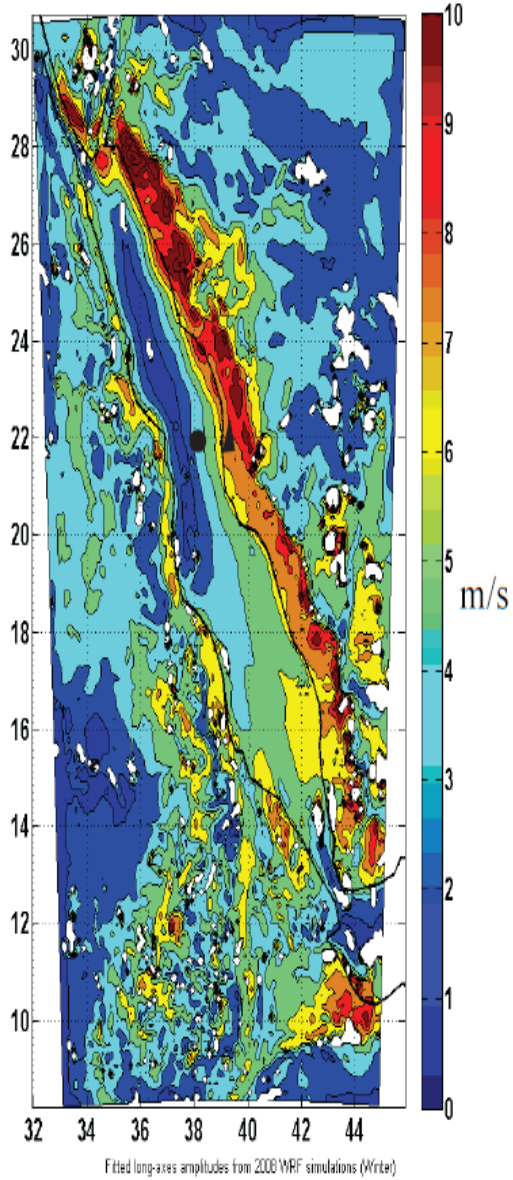
+ 1hr

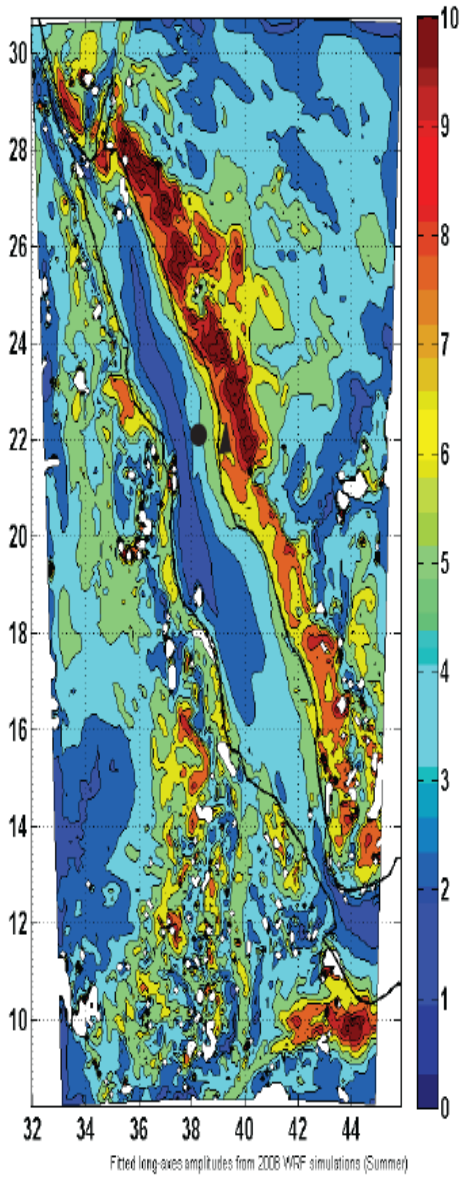
+5 hrs

7/11/2008; Color contours θ at 10m;Solid contours: 250m elev.

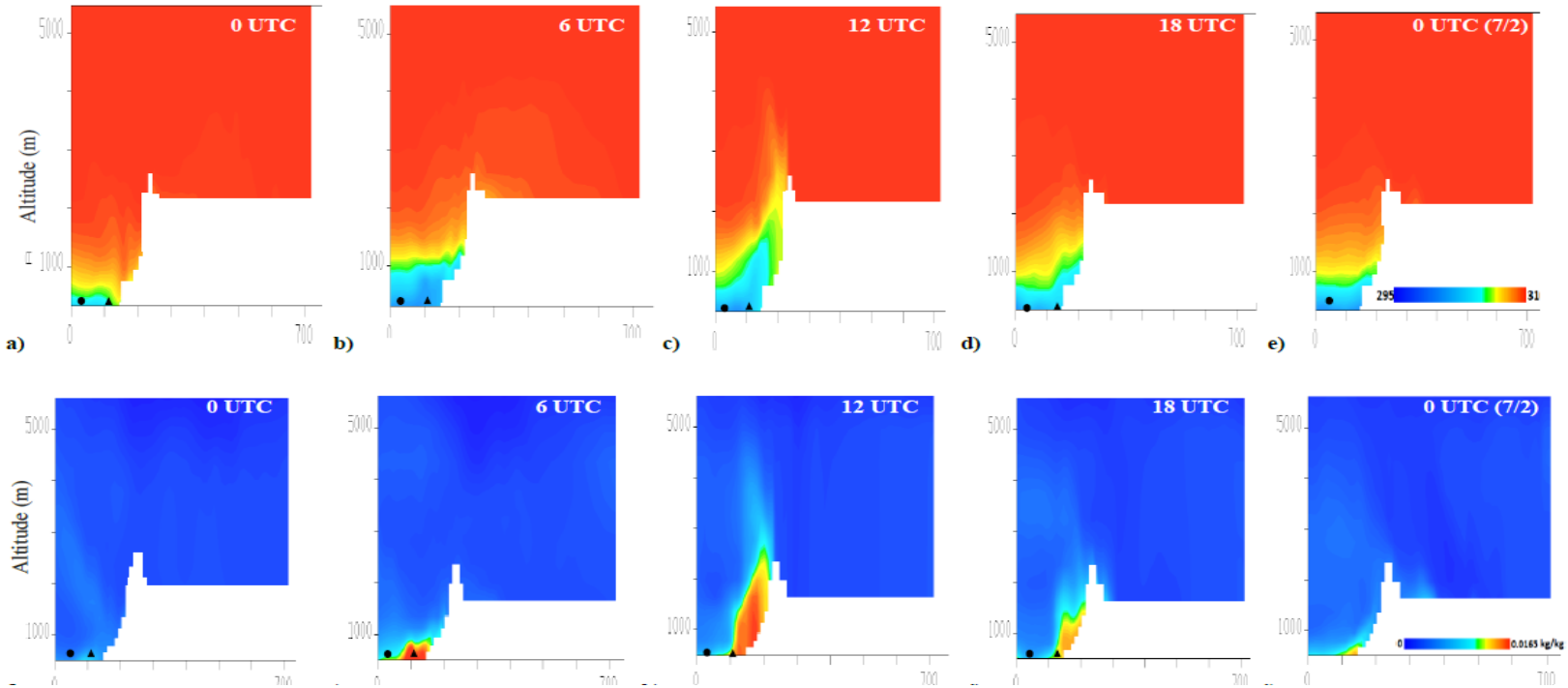
The LSBC Amplitudes: Observed and Simulateds

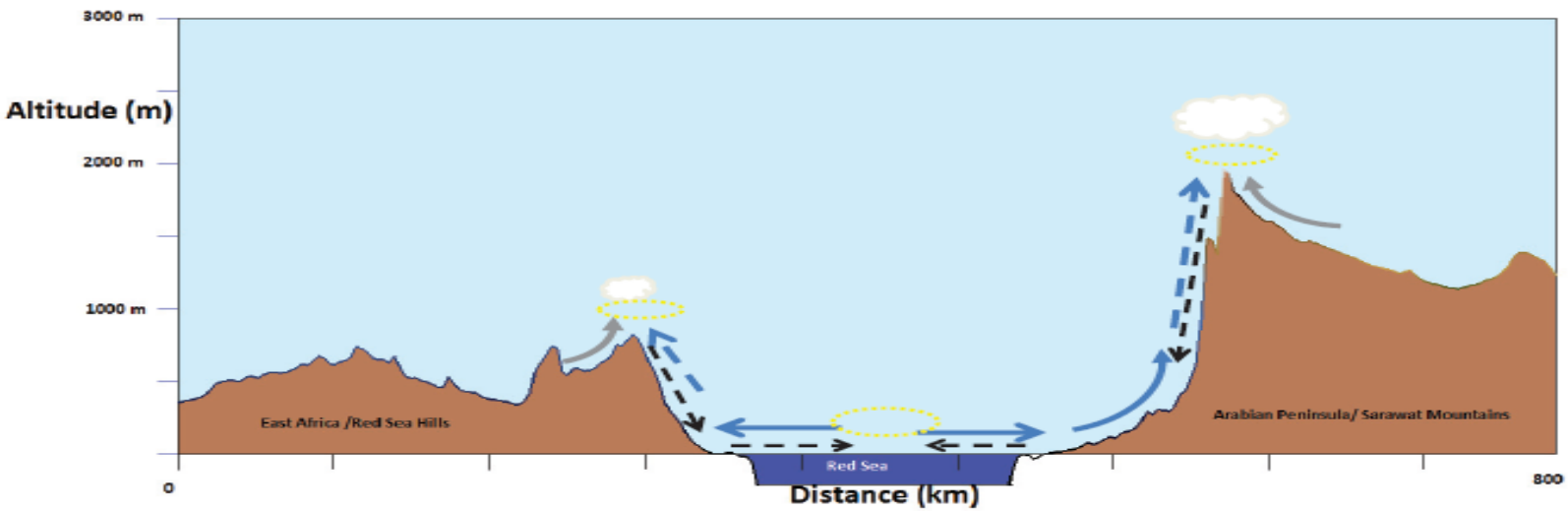




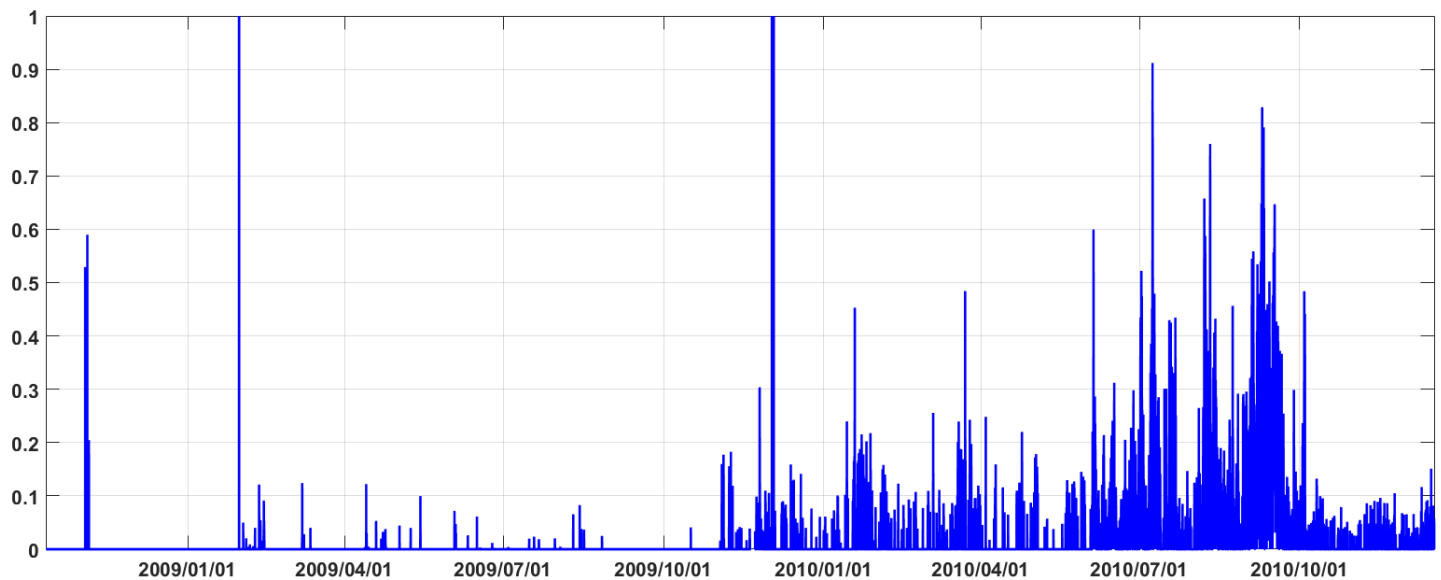


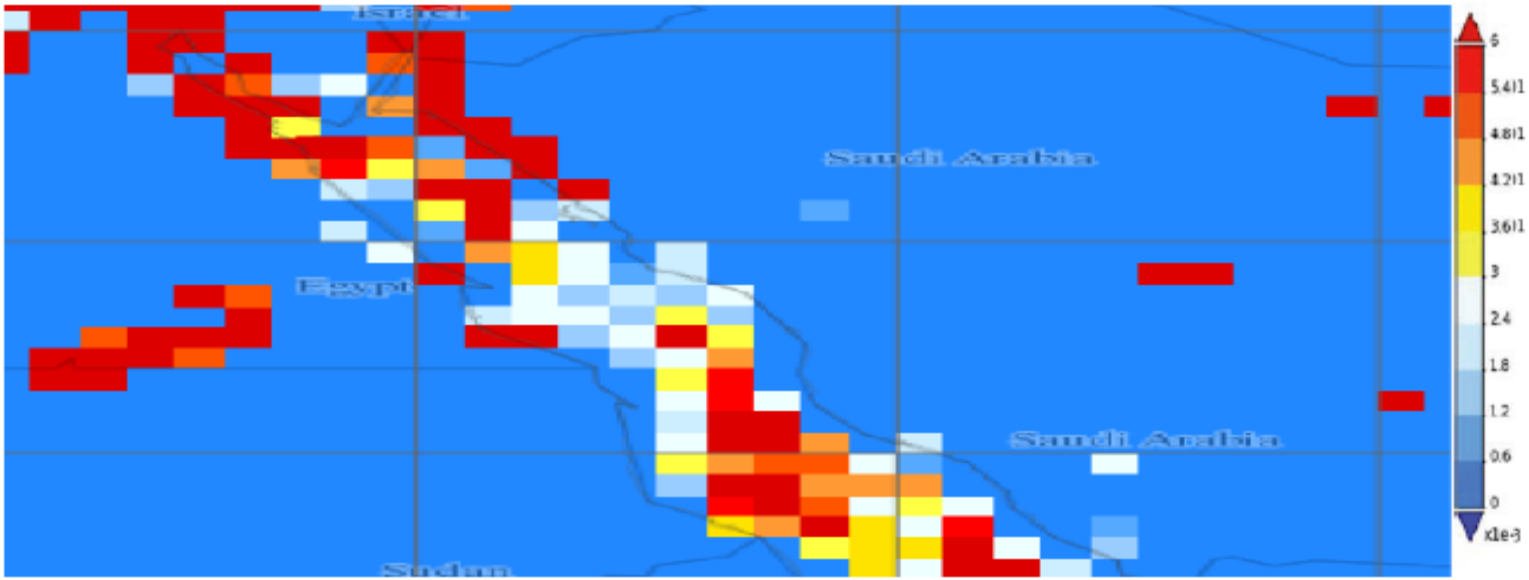
Topography and Comvergence in the LSBC





Buoy/Red Sea Precipitation Rates





Summary

- While the ITCZ plays a role in the seasonality (i.e. monsoon forcing) of the TGJ, it is also a very dynamic feature in the surface/lower atmospheric flow with strong diurnal characteristics
- The convergence of distinct wind regimes is seen in conjunction with the TGJ onset
- The monsoon forcing of the TGJ is unique relative to other gap jets, its a “moist gap wind”
- This characteristic is central to its role in regional moisture transport, and regional precipitation
- The LSBC is prolific year round
- Amplitude of the LSBC is significantly enhanced in the presence of steep topography
- The LSBC can be a mechanism of cloud formation and precipitation around the basin in response to the LSBC convergence.

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