Model sensitivity to different boundary layer processes in predicting a severe weather event over Mecca, Saudi Arabia

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Out line of the presentation:

- Importance of study region (Mecca, Saudi Arabia)
- Vulnerability of the Extreme Weather Event (SWE)
- Observational Analysis (Synoptic and Remote sensing)
- Details of the Model - Sensitivity to different PBL processes
- Model predicted mesoscale features of the event

Importance of Mecca, Saudi Arabia:

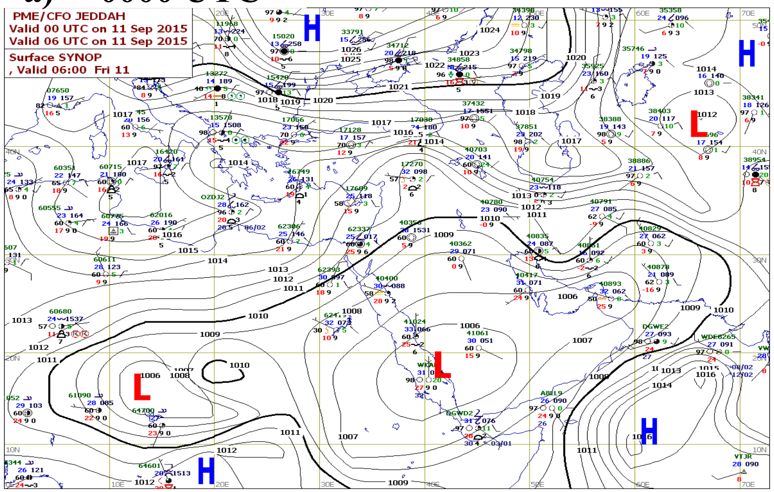
- The city of Mecca in the Kingdom of Saudi Arabia is the holiest city in the religion of Islam.
- More than 35 - 40 million Muslim pilgrims visits every year, including several millions during the 2 weeks of Hajj period in summer.
- This metropolitan city located in a narrow valley at a altitude of 277 m above sea level.
- The topography of the Mecca region is complex by nature, and height ranges between 82 m and 1200 m above mean sea level.

Vulnerability of EWE on 11 Sep, 2015:

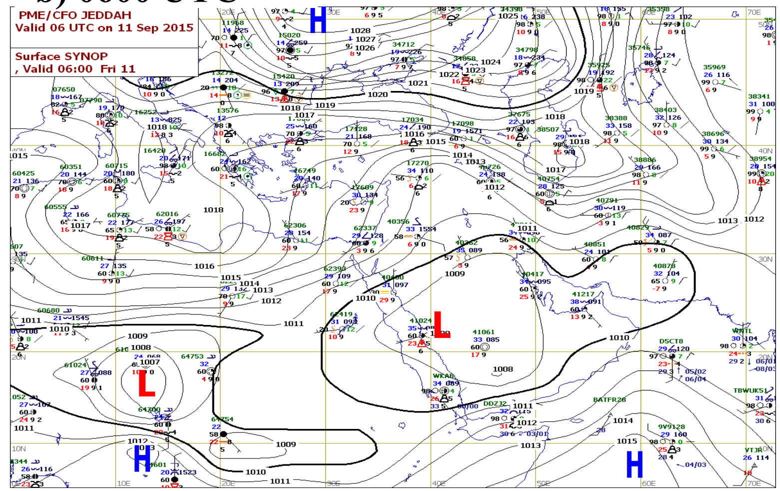
- **In the city of Macca, on 11 September 2015 from 1500 to 1630 UTC, a sudden increase in the wind speed over a short span of time (~1 hour) together with severe rainfall caused to the collapse of a high-elevated crane that caused nearly 111 deaths and 394 injuries. (https://en.wikipedia.org/wiki/Mecca_crane_collapse).**

Surface Synoptic charts from PME, Jeddah on 11 September 2015

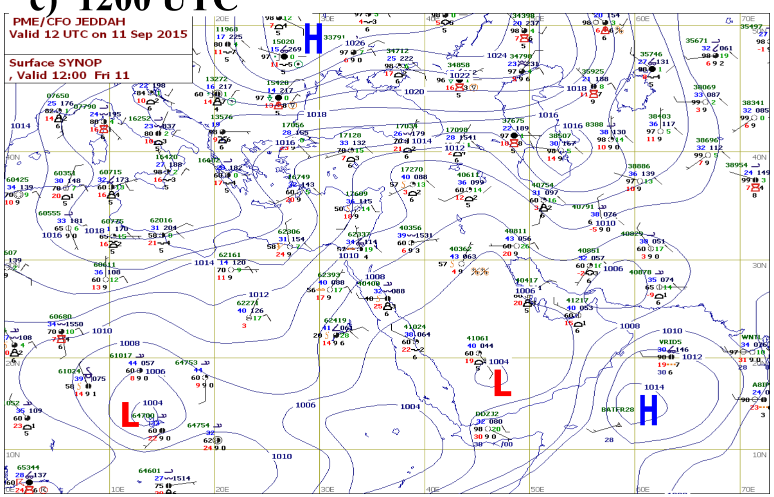
a) 0000 UTC



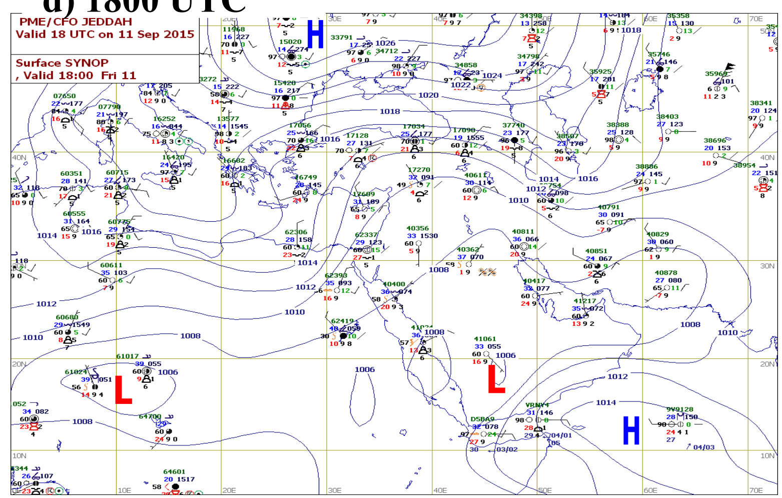
b) 0600 UTC



c) 1200 UTC

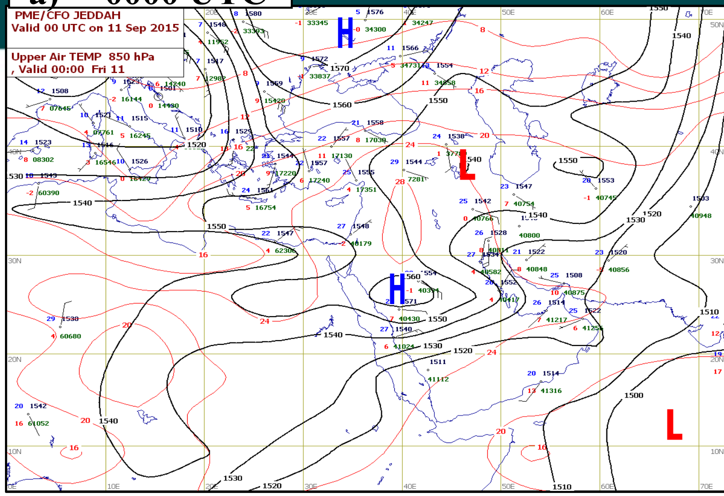


d) 1800 UTC

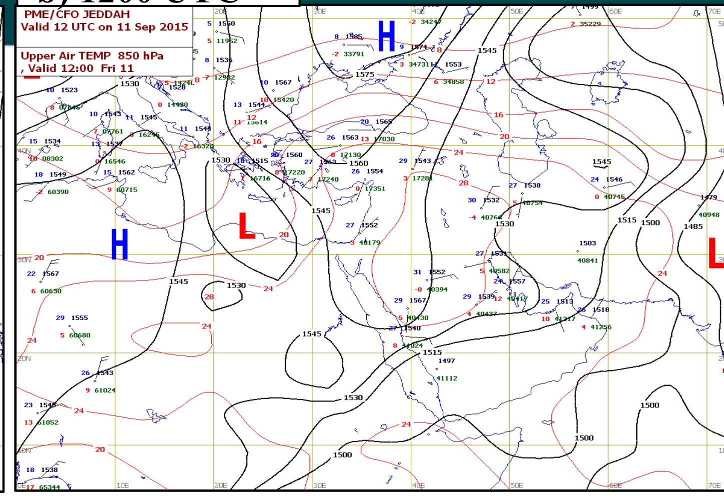


Geopotential height (gpm) at 850 hPa

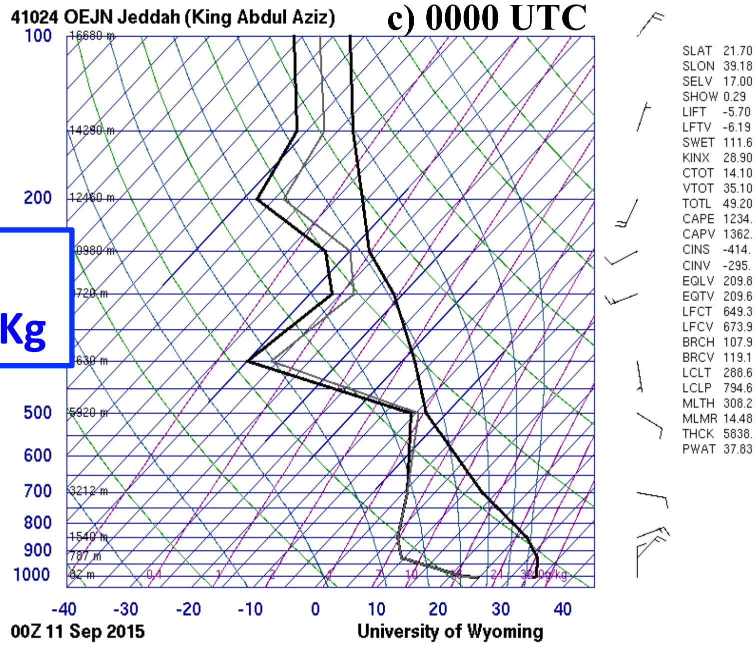
a) 0000 UTC



b) 1200 UTC

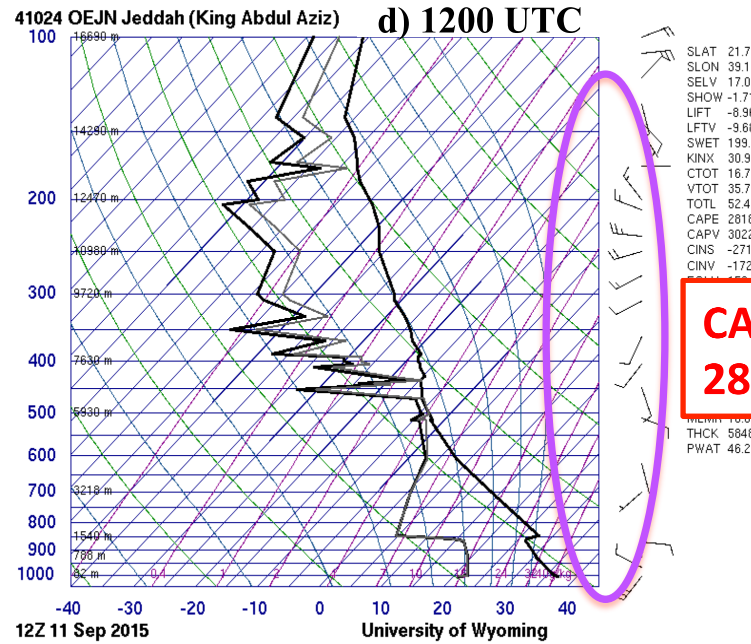


c) 0000 UTC



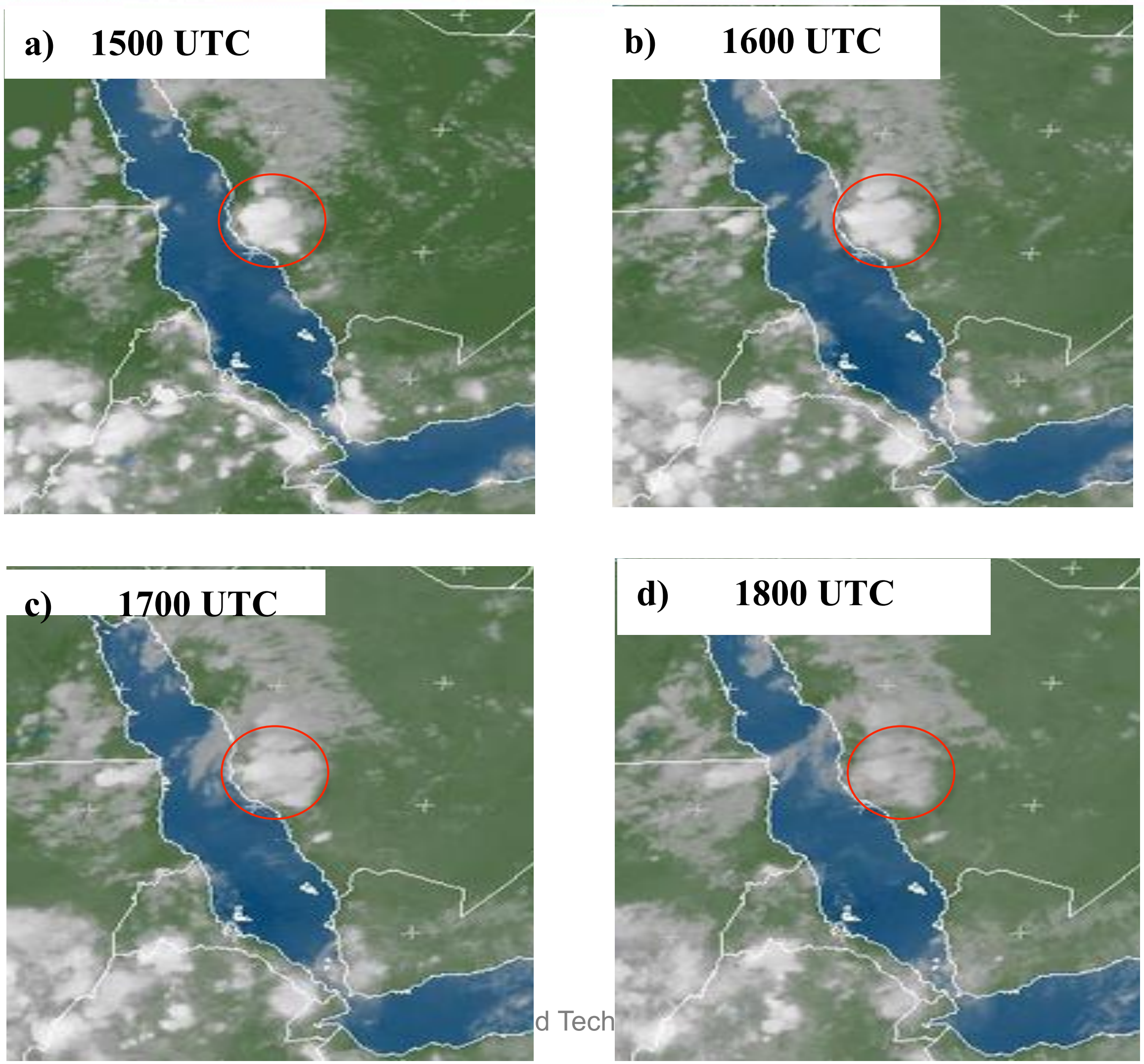
CAPE
1300 J/Kg

d) 1200 UTC

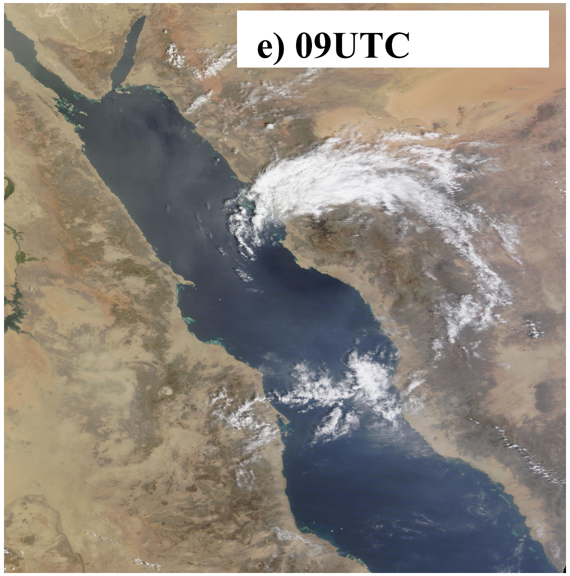


CAPE
2800 J/Kg

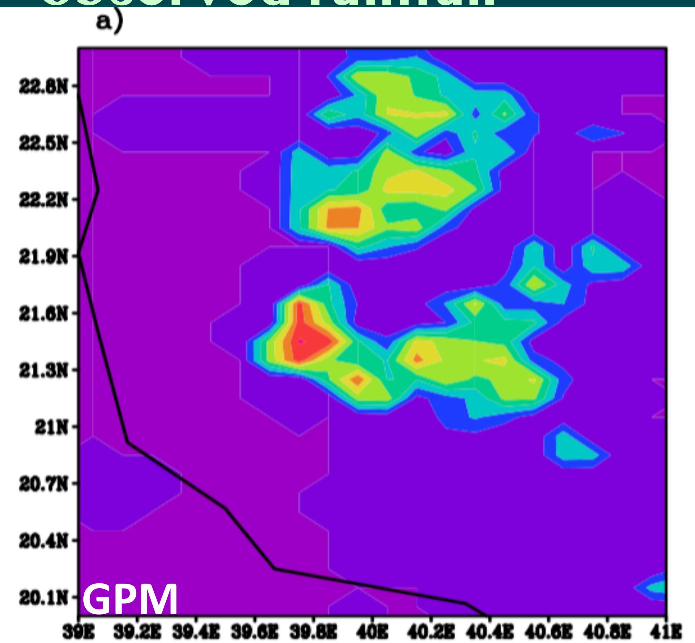
Meteosat-7 Infrared imageries on 11 September

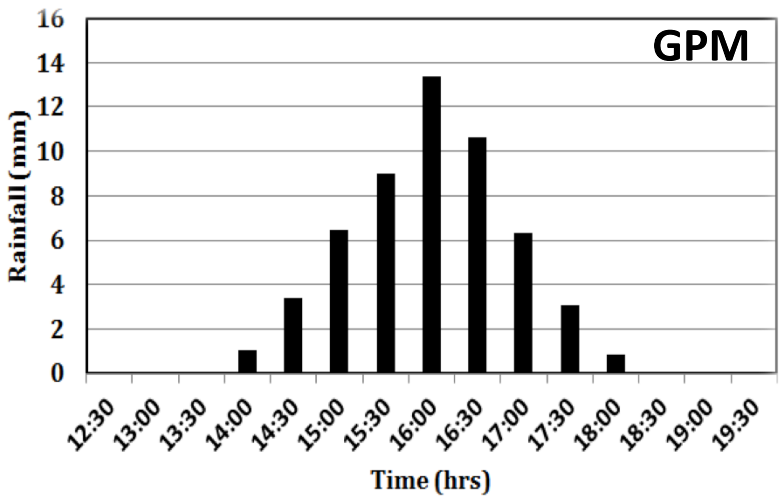


Cloud image snapshot from MODIS

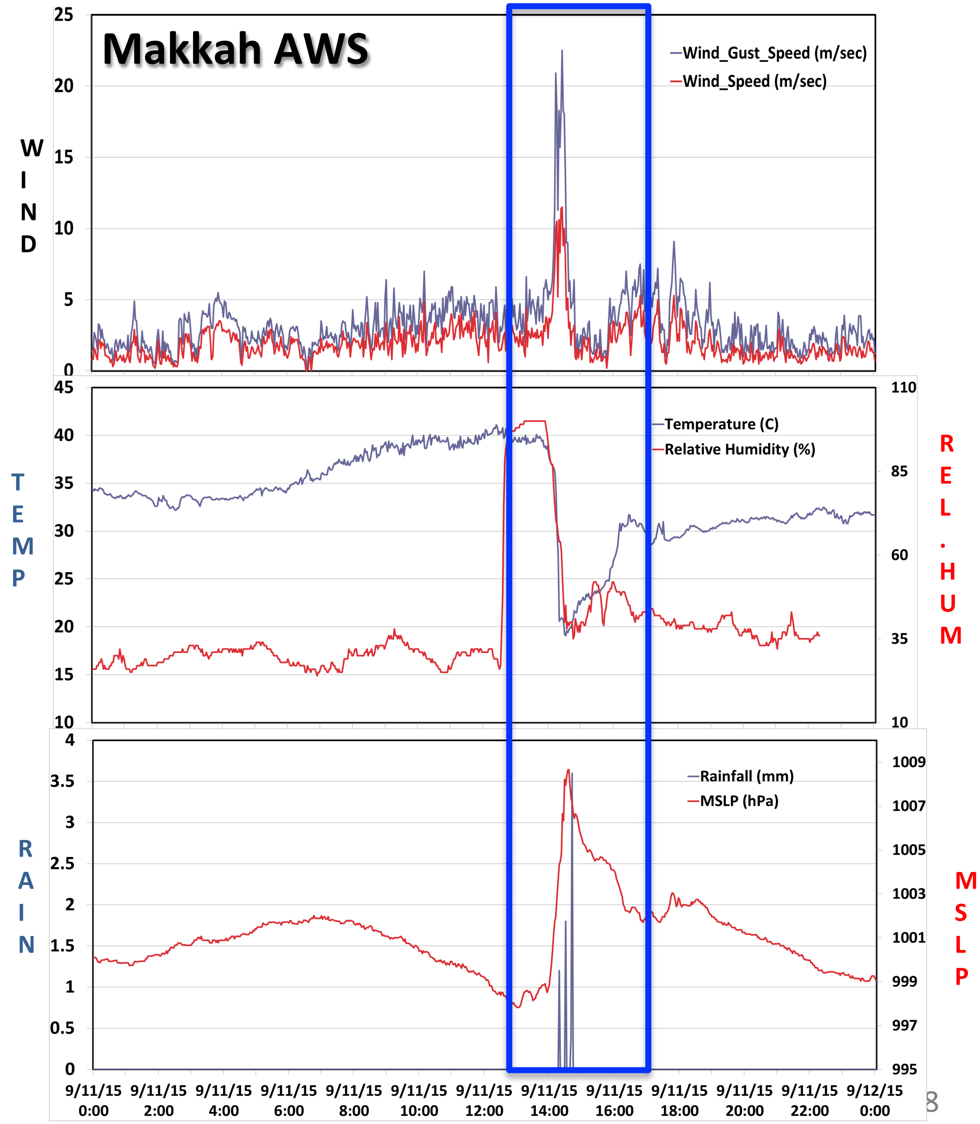


Spatial distribution of observed rainfall



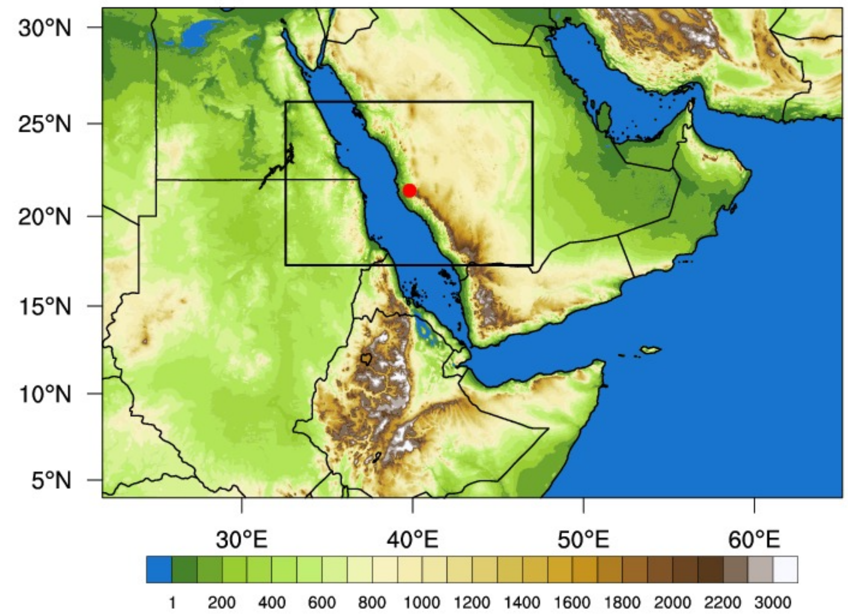


Time variation of surface weather parameters



Model Configuration:

- ✧ Weather Research and Forecasting model used for this study
- ✧ Initial and boundary conditions are taken from NCEP GFS forecasting fields (0.25 degree resolution, 3hr time interval)
- ✧ Two-way interactive nested domains with 3 and 1km horizontal resolution are used



- ✧ WSM6 for microphysical processes and different PBL schemes are used for sensitivity study
- ✧ Model integration starts from 00UTC of 10 Sep 2015 and boundary forcing are updated at every 3 hour interval

Conducted Experiments for testing model sensitivity to different PBL scheme to simulate the Makkah evet

1.5-order closure turbulent kinetic energy (TKE) PBL schemes

MYJ	local	1.5-order closure	
QNSE	local	1.5-order closure	Intended to account for wave phenomena within stable boundary layer
BouLac	local	1.5-order closure	**Design is relevant for terrain-enhanced turbulence**
UWMT	local	1.5-order closure	Number of layers determined by vertically varying stability of the thermodynamic profile

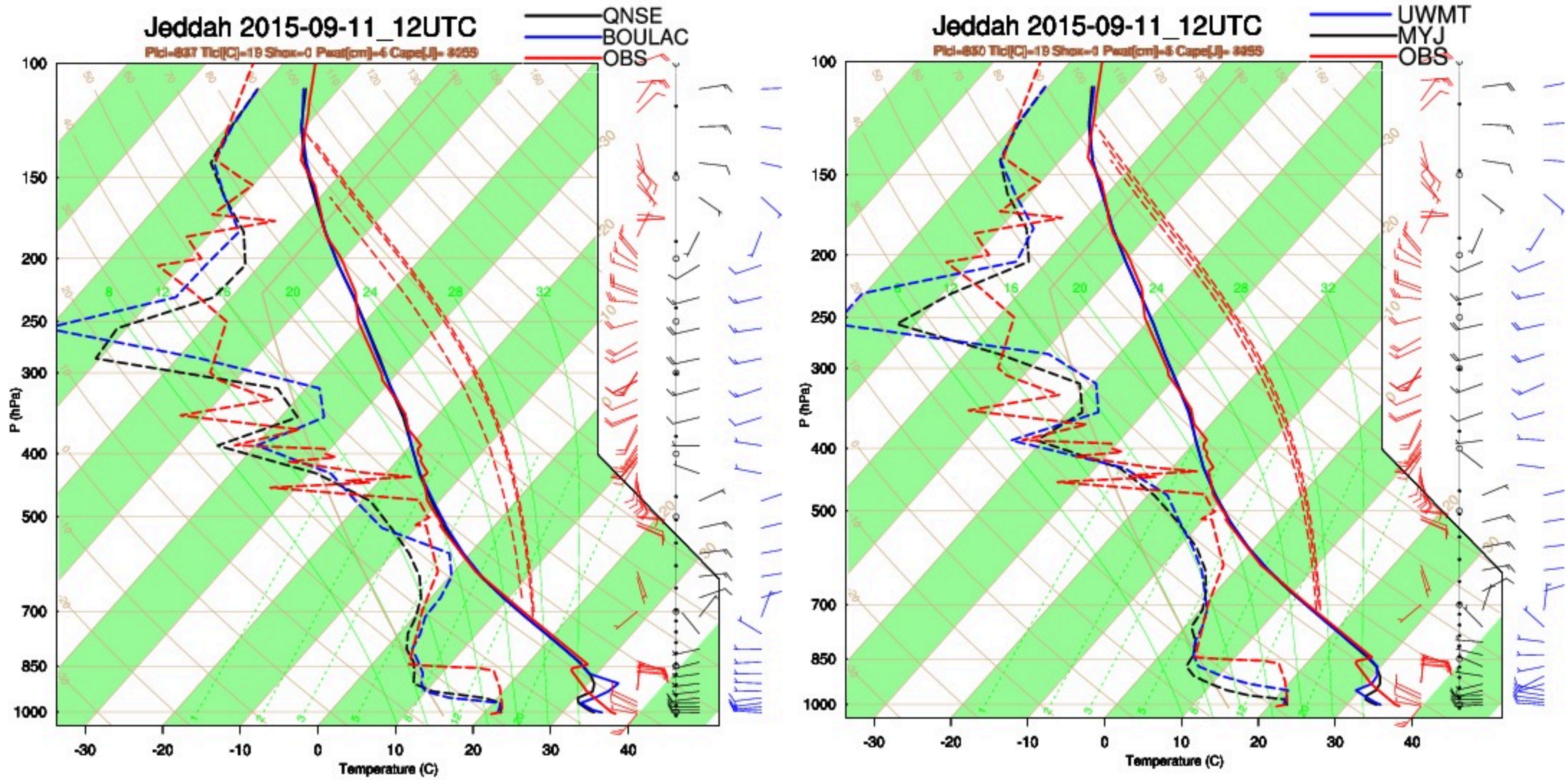
non-local, first order closure

MRF	Non-local	First order closure	Incorporate downgradient diffusion expressed by local mixing
YSU	Non-local	First order closure	Similar to MRF but entrainment represents at the top of the PBL

hybrid, local-nonlocal closure

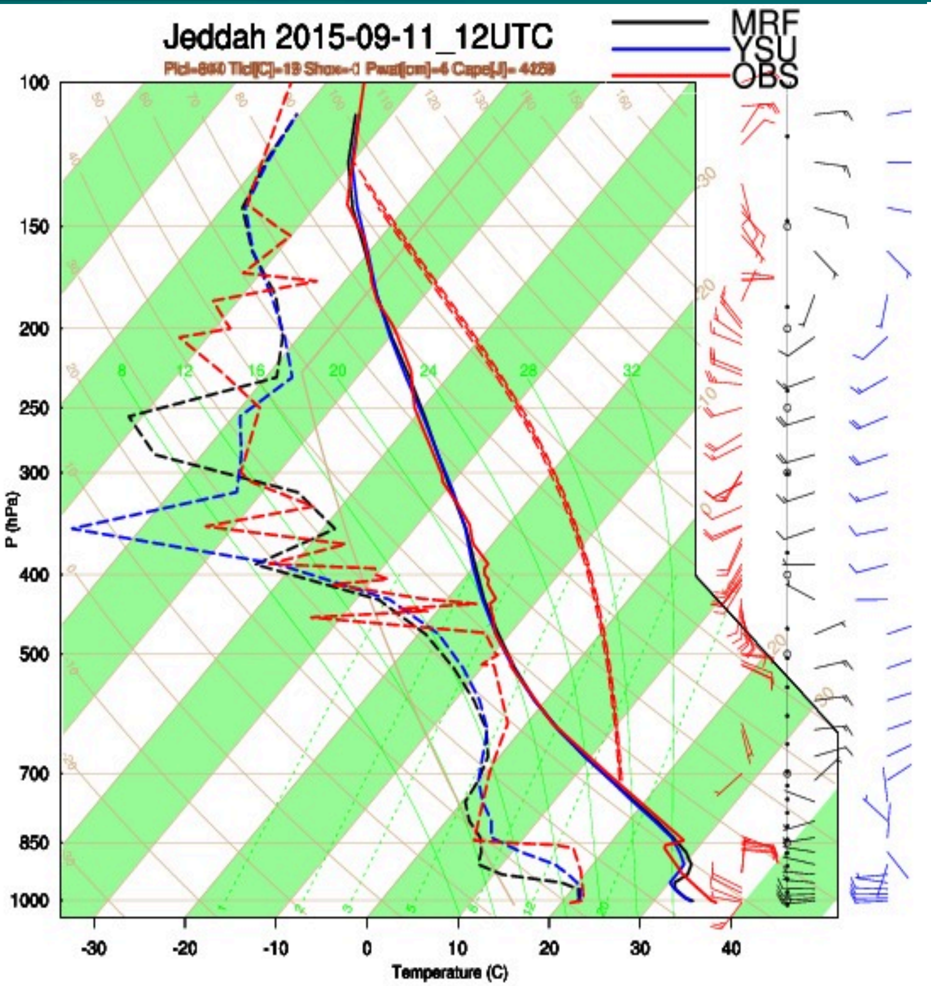
ACM2	Local, non-local	First order closure	Represents upward fluxes within the PBL as interaction between surface and each layer above
TEMP	Local, non-local	1.5 order closure	Represents by updrafts owing to upward heat fluxes from the surface through the PBL

1.5-order closure turbulent kinetic energy (TKE) PBL schemes

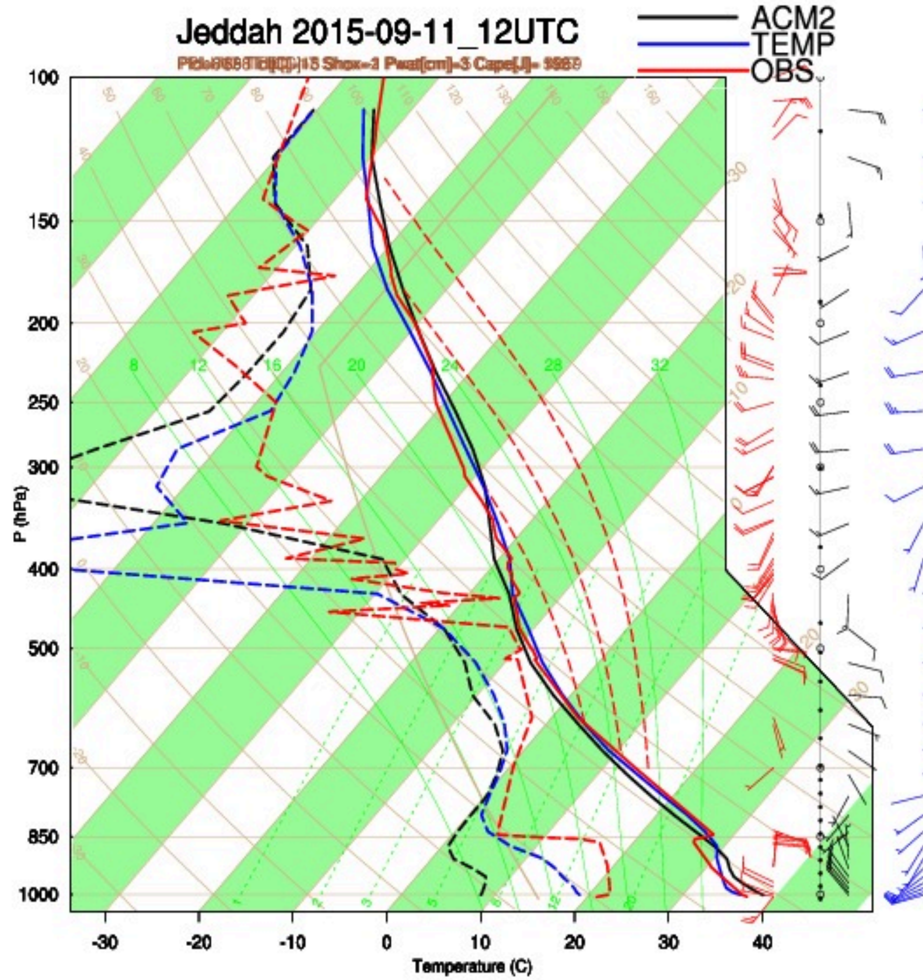


Skew T plots from University of Wyoming (Red: Radiosonde) on the representative day 11 September 2015 at 1200 UTC over Jeddah station along with different PBL schemes

non-local, first order closure

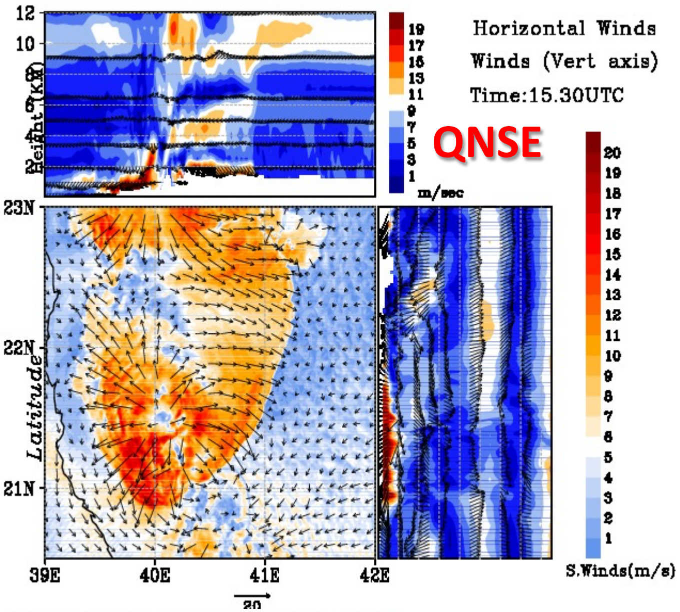


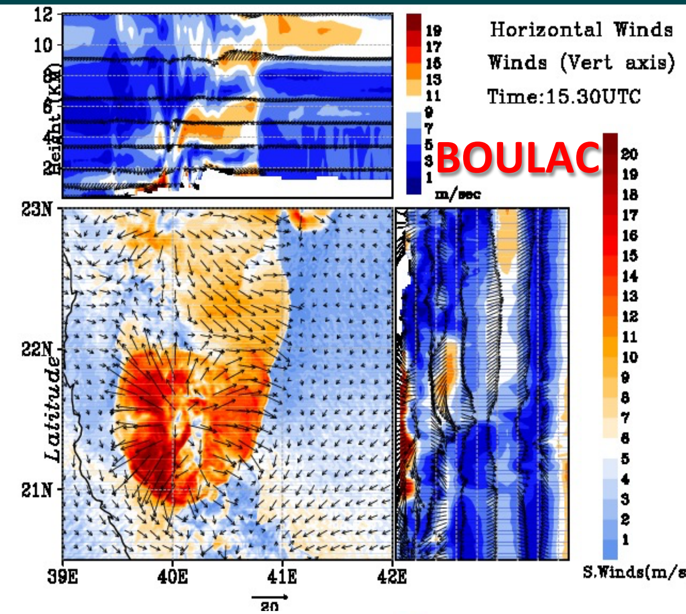
hybrid, local-nonlocal closure

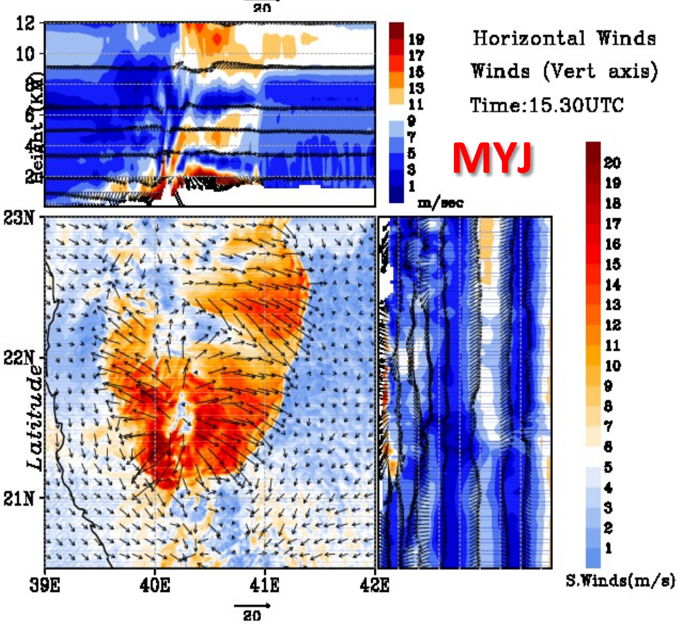


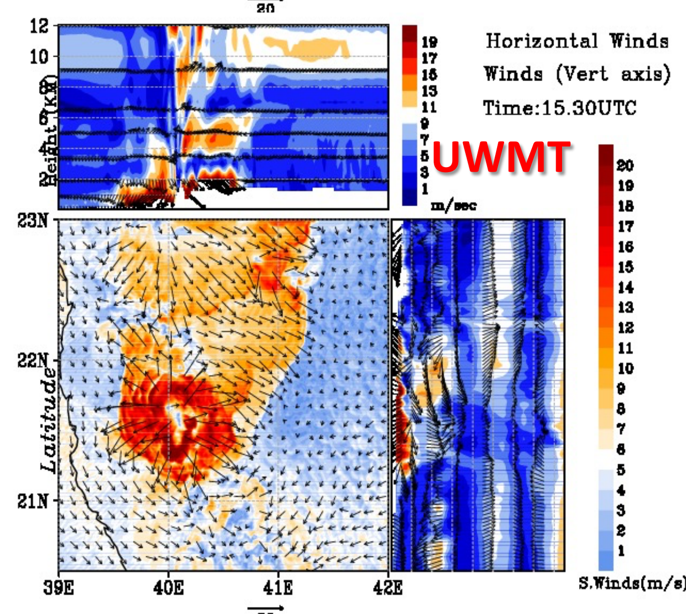
Skew T plots from University of Wyoming (Red: Radiosonde) on the representative day 11 September 2015 at 1200 UTC over Jeddah station along with different PBL schemes

Surface and height-section of Winds (m/s) for TKE PBL schemes.

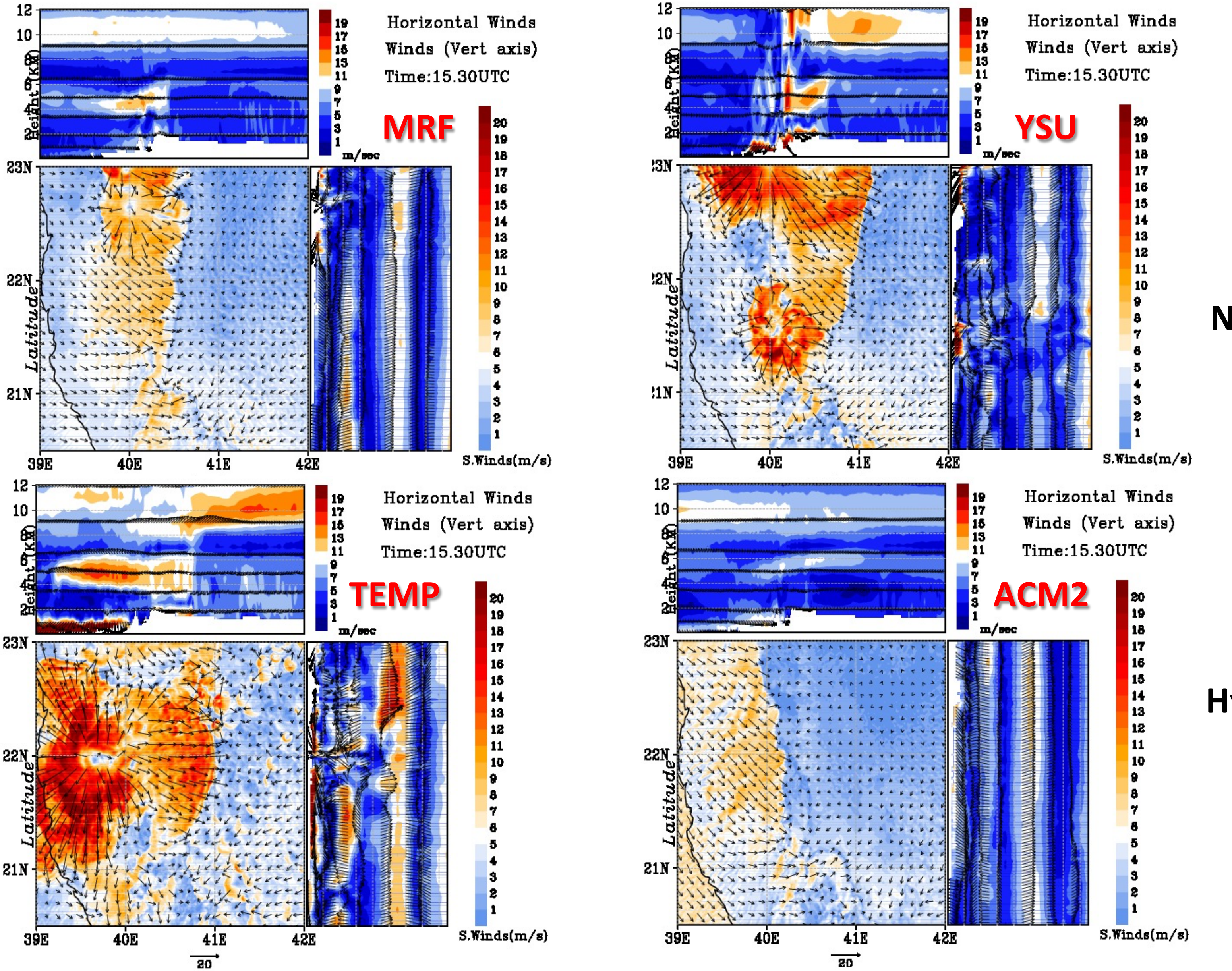








Surface and height-section of Winds (m/sec) for different PBL schemes.



Non Local

Hybrid

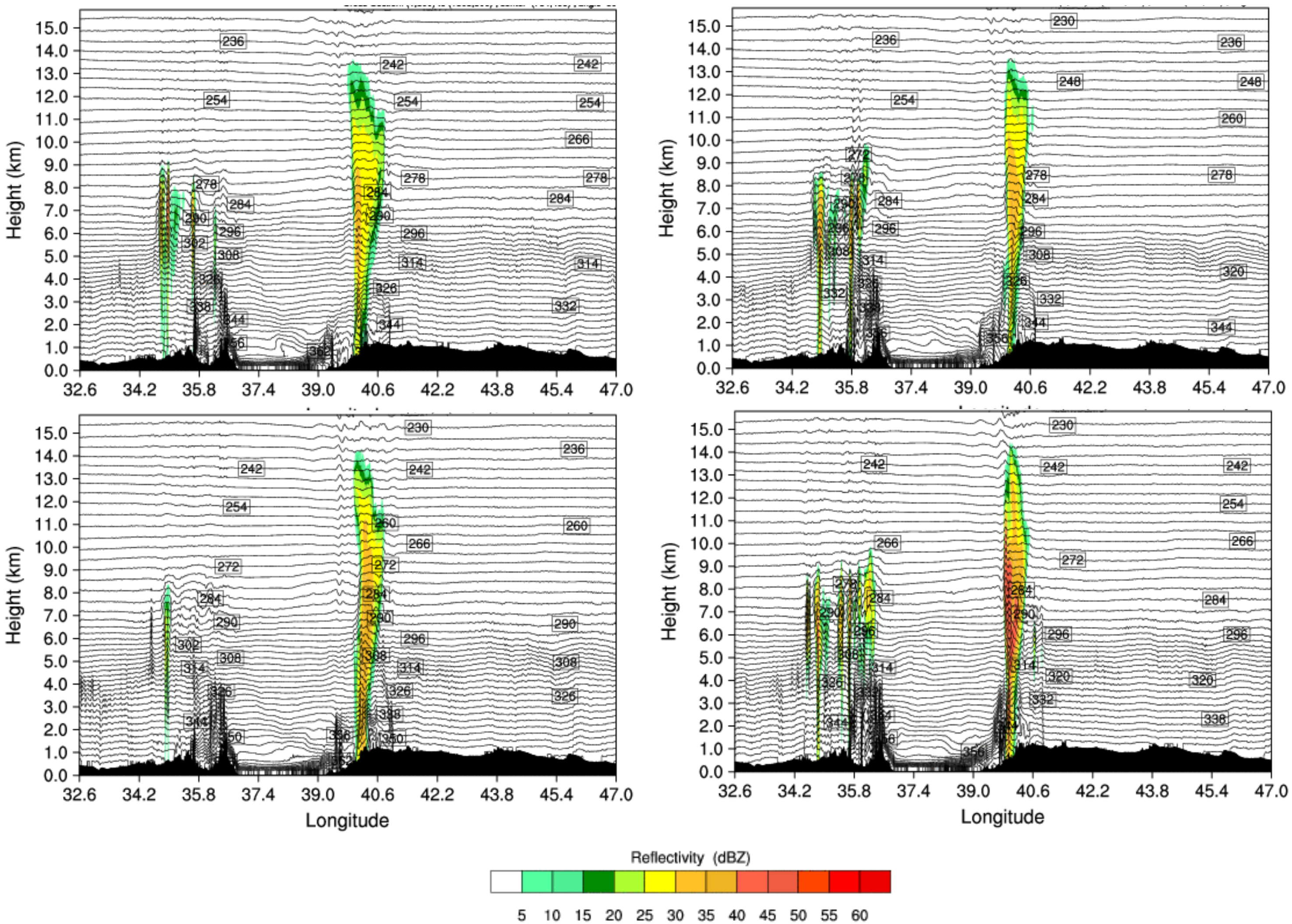
Simulated reflectivity (shaded. dBZ) along with Equivalent Potential Temperature

QNSE

BouLac

MYJ

UWMT



Radar Reflectivity (shaded. dBZ) along with Equivalent Potential Temperature

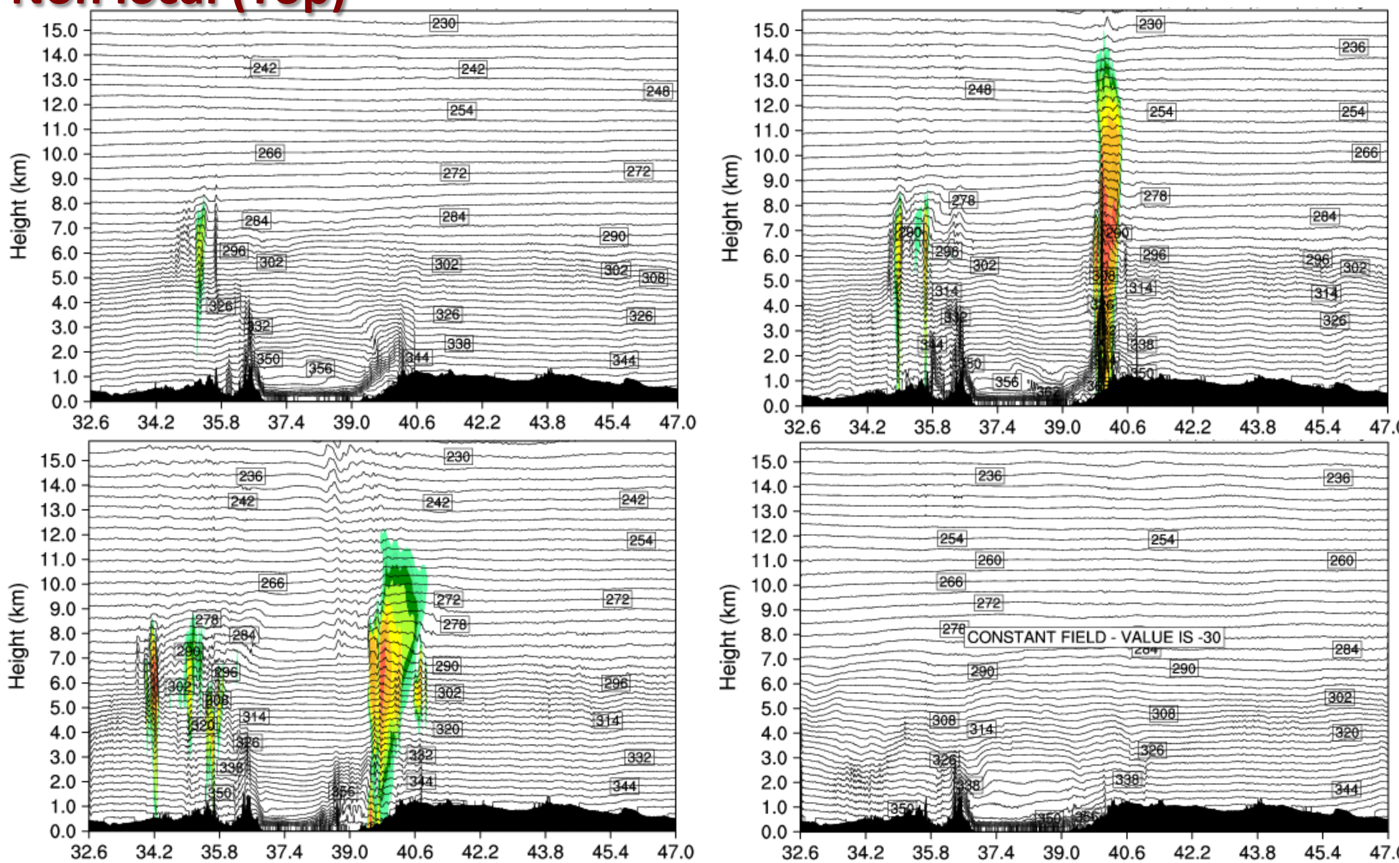
Non local (Top)

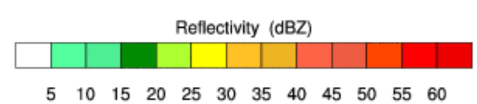
MRF

YSU

TEMP

ACM2

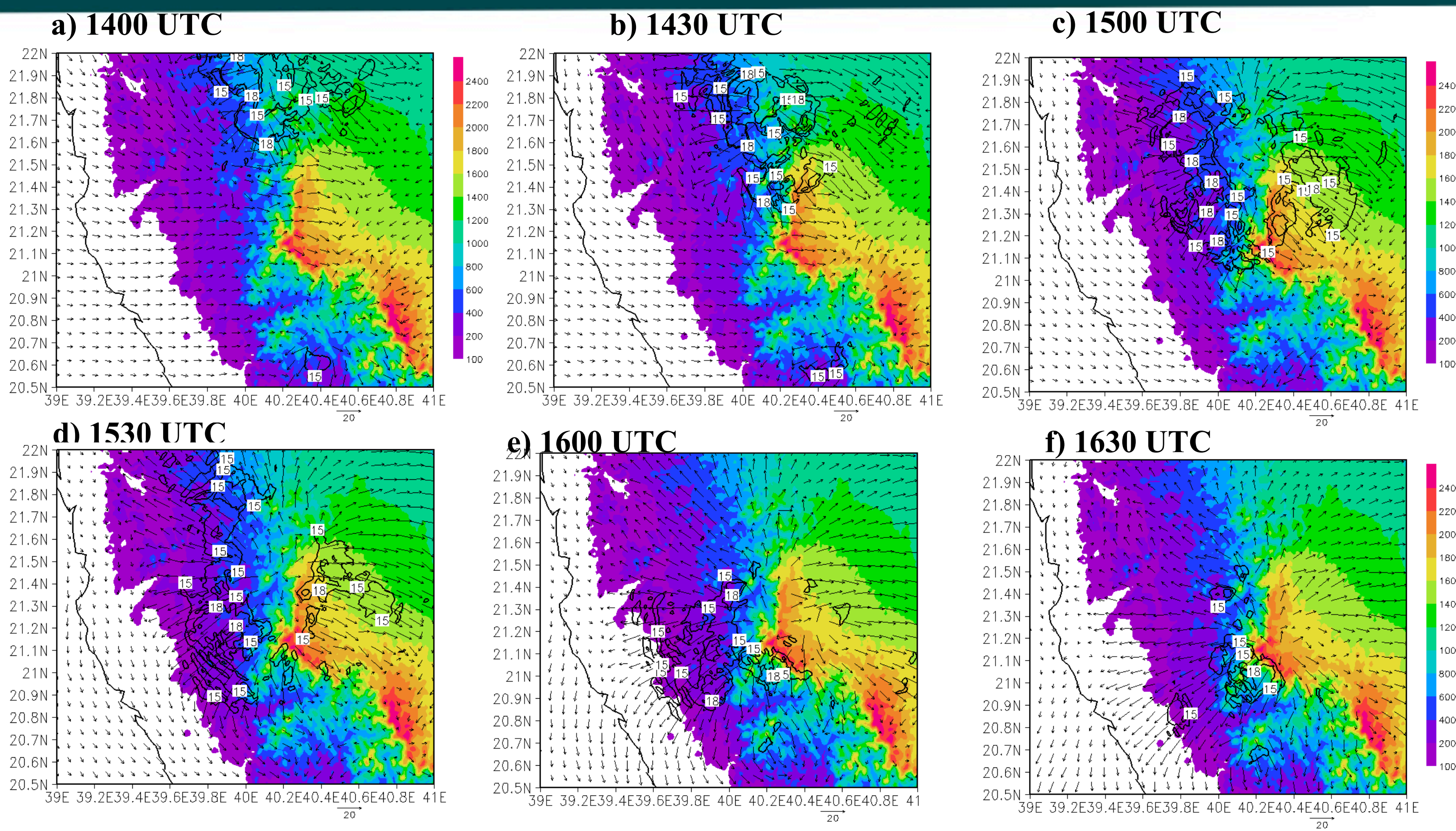




Hybrid PBL Schemes

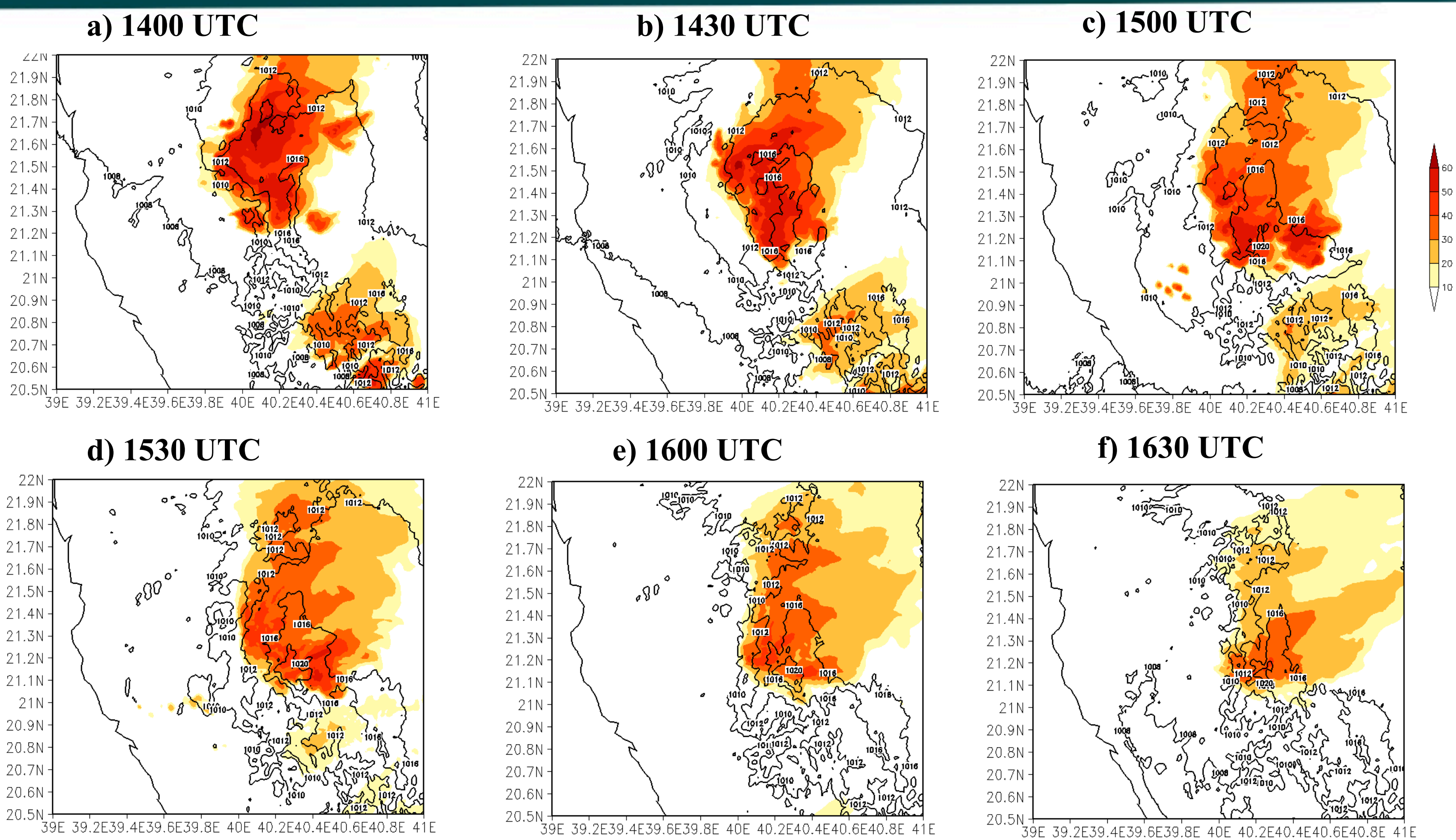
Characteristics of extreme event:

Spatial distribution of model produced winds (m/s) at 10m height on 11 September 2015. Shaded is the model topography. Contours are wind magnitudes.

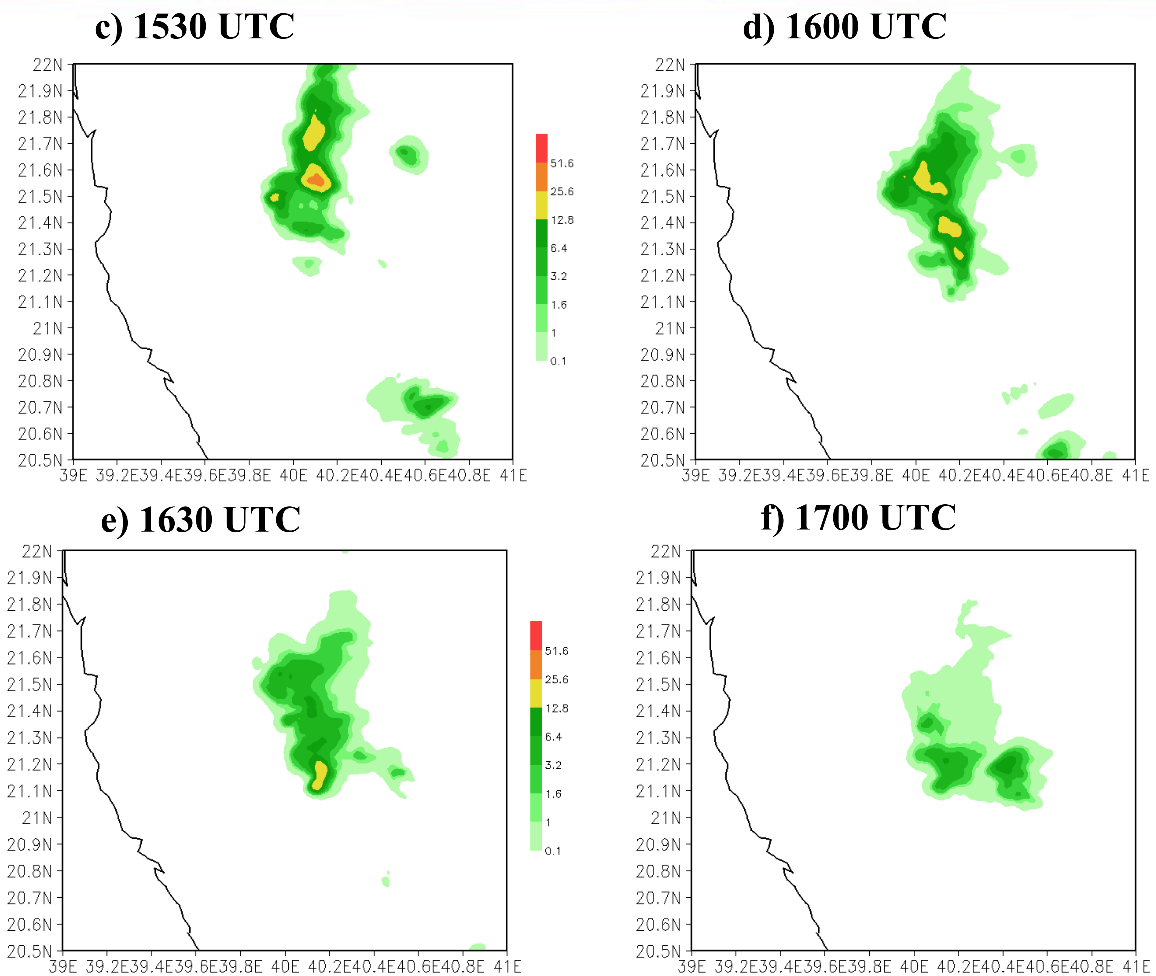


BouLac PBL scheme is used for further analysis

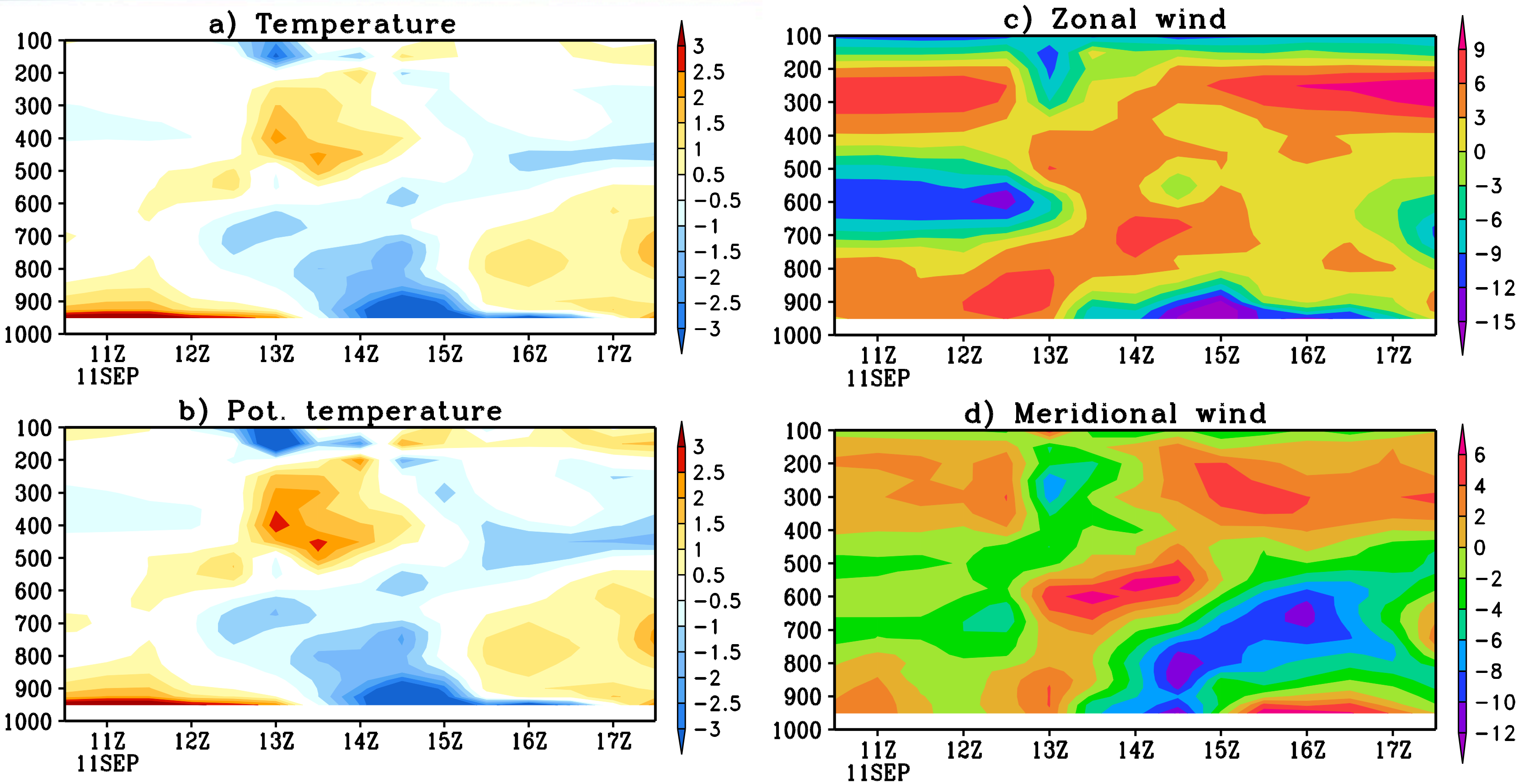
Spatial distribution of simulated maximum radar reflectivity (dBz) at different times on 11 September 2015



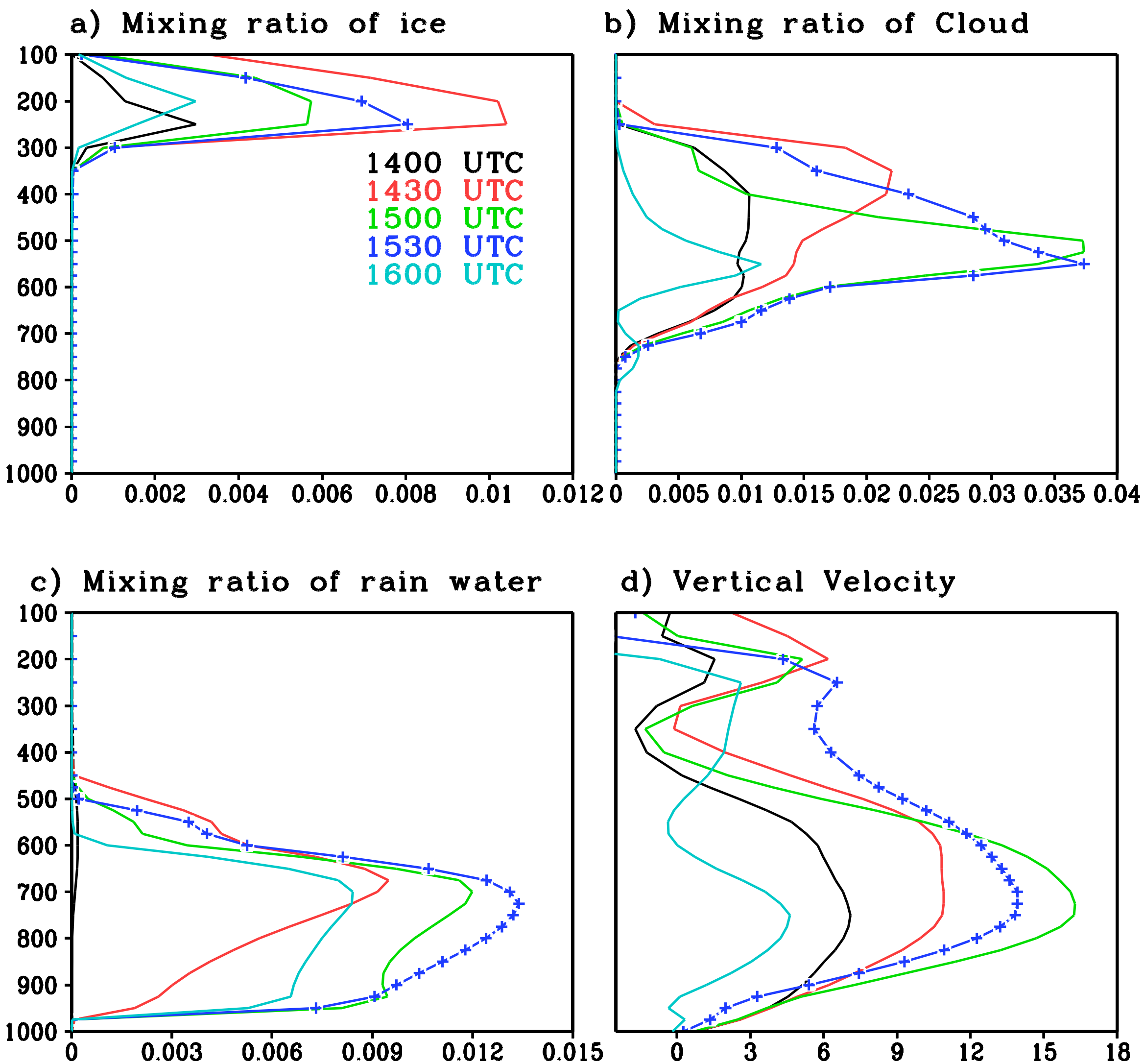
Spatial distribution of model simulated accumulated rainfall (mm) from 1530 UTC, 1600UTC, 1630 UTC and 1700UTC on 11 September 2015



Time height cross section of anomalies for (a) Temperature (K), (b) Potential Temperature (K), (c) zonal wind (ms^{-1}) and (d) meridional winds (ms^{-1}) over Mecca region on 11 September 2015



Simulated vertical profiles of mixing ratio of (a) cloud ice, (b) cloud water, (c) rain water and d) vertical velocities at a grid point containing Mecca region on 1530 UTC 11 September 2015.



Summary:

- ✧ Extreme weather event is initially associated with the synoptic conditions and then intensifies by interaction with the local orography, leads to severe rainfall along with sudden gusty winds.
- ✧ Moisture from the Red sea through a channeling flow feeds the convective storm and intensifies the convection in the early evening.
- ✧ The model sensitivity analysis from different PBL schemes revealed that the local, 1.5 order TKE closure schemes are more suitable in predicting the characteristics of rainfall and gale winds.
- ✧ Other non-local first order closure and hybrid schemes are not able to generate gale winds as well as rainfall.

Summary:

- ✧ Few hours prior to the storm, between the surface and 700 hPa level, the temperature warms up by 3 ˚C and a sudden fall of 5 ˚C is then recorded at the peak time of the event. These changes in temperature modulated the wind flow and then the interaction of the local topography with winds leads to an extreme event.
- ✧ It is observed that the strong vertical velocities are responsible for the development of microphysics (frozen hydrometers and liquid hydrometers) and associated precipitation.
- ✧ Simulation results suggests that the WRF model at high resolution is more suitable in predicting these type of events.

Acknowledgments:

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Thank you very much for your attention