# Dynamics of Wind Erosion and Numerical Predictions of Dust Storm

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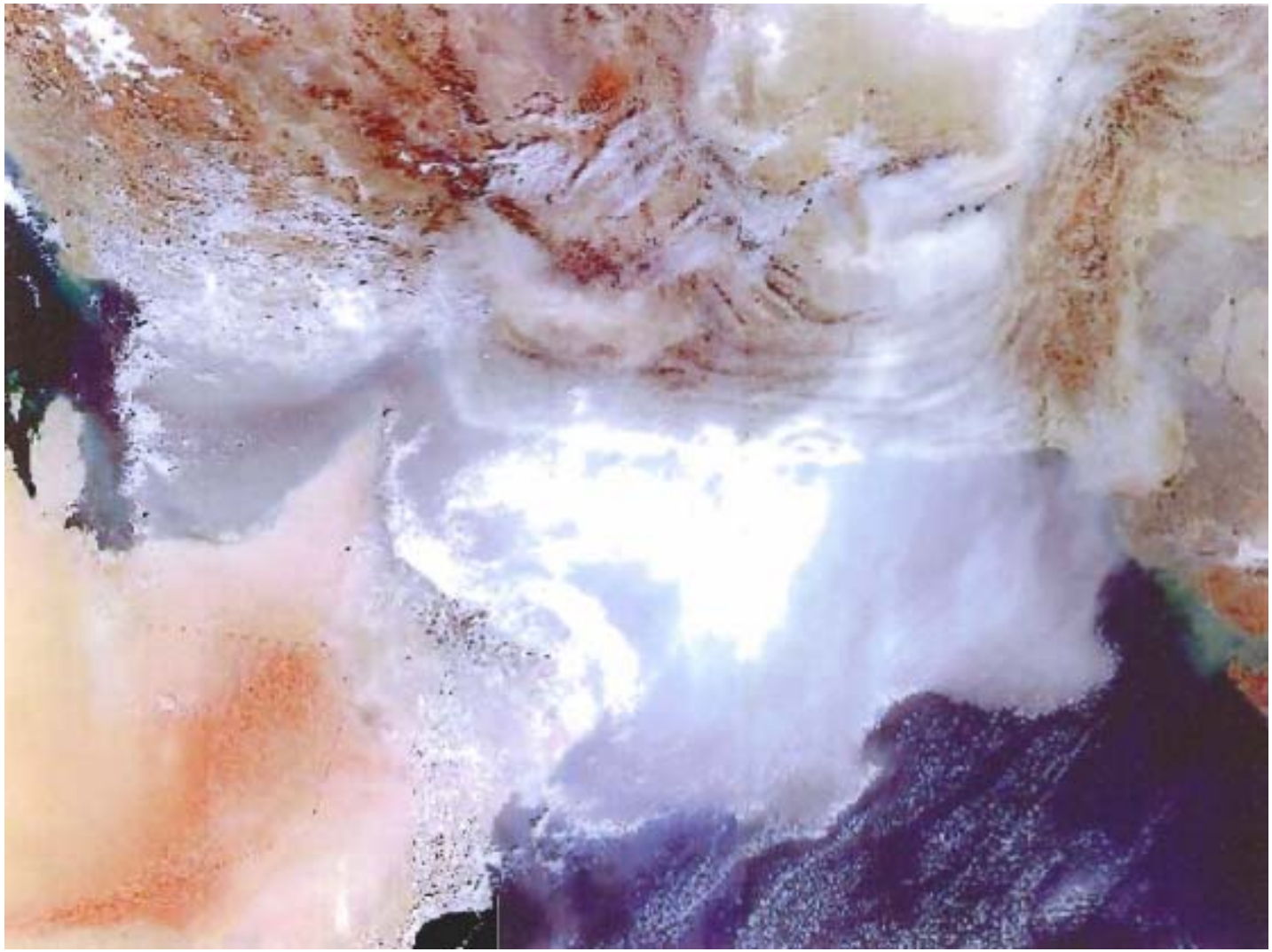
# Outline

1. General characteristic pictures of dust storm
2. The mechanism of soil erosion and dust emission
3. Impulsive emission of dust by the gust wind and Parameterization of gust effect.
4. Numerical prediction of dust storm
5. Climate-environmental conditions favorable (or suppressive) for the frequency and intensity of dust storms and their prediction by DCP/IAP

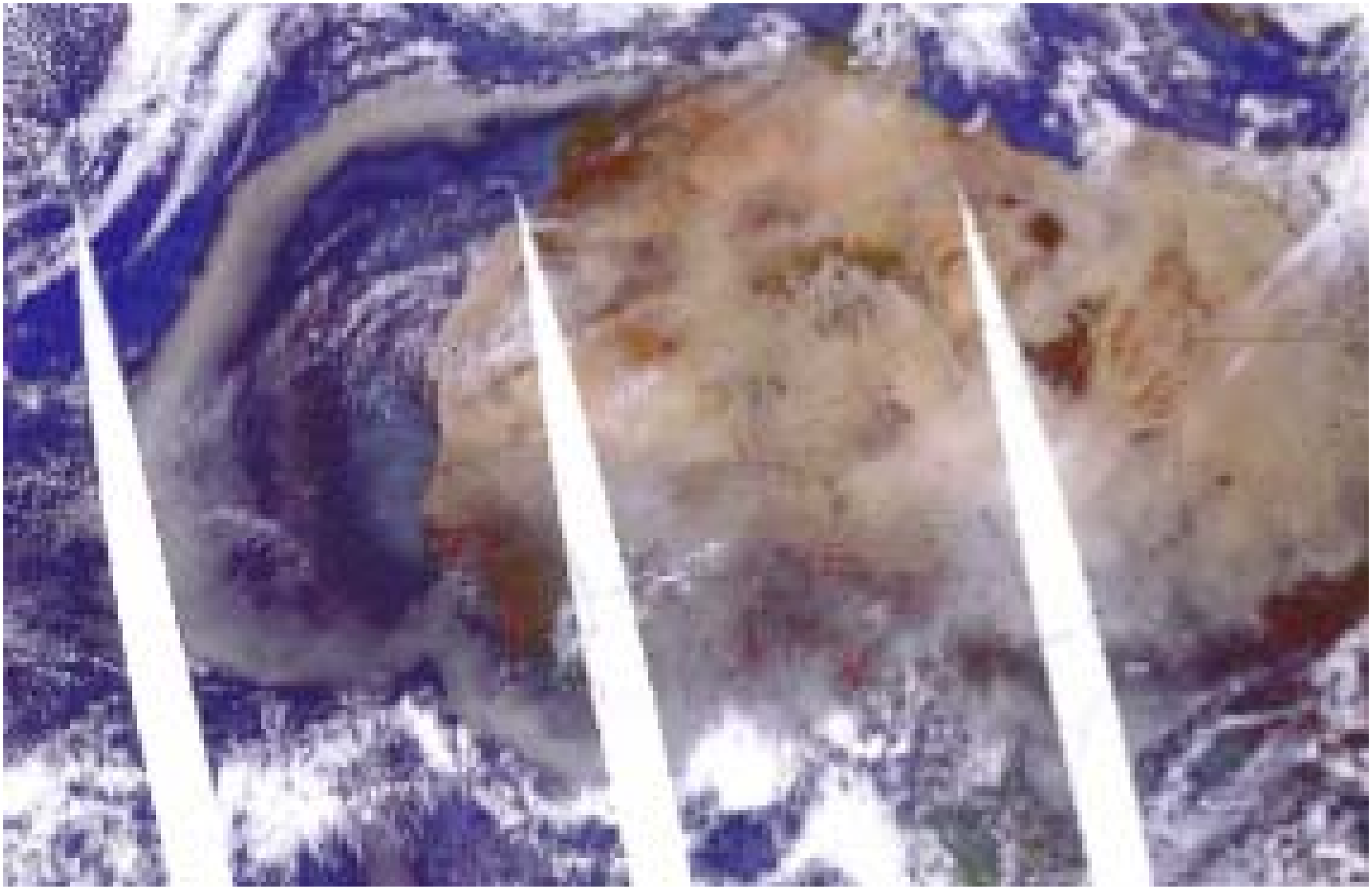
**Physically, dust storm is a natural phenomenon which is known to have already existed long before the appearance of human civilization.**

**There are vast regions of arid and semi -arid landforms around the Tropics on the Earth's surface, which are formed as a result of general circulation, topography and other factors. The typical landforms which emerge in these regions are large areas of desert, e.g. Sahara, Central and Southwest Asia, West Australia, and South-west part of North America.**

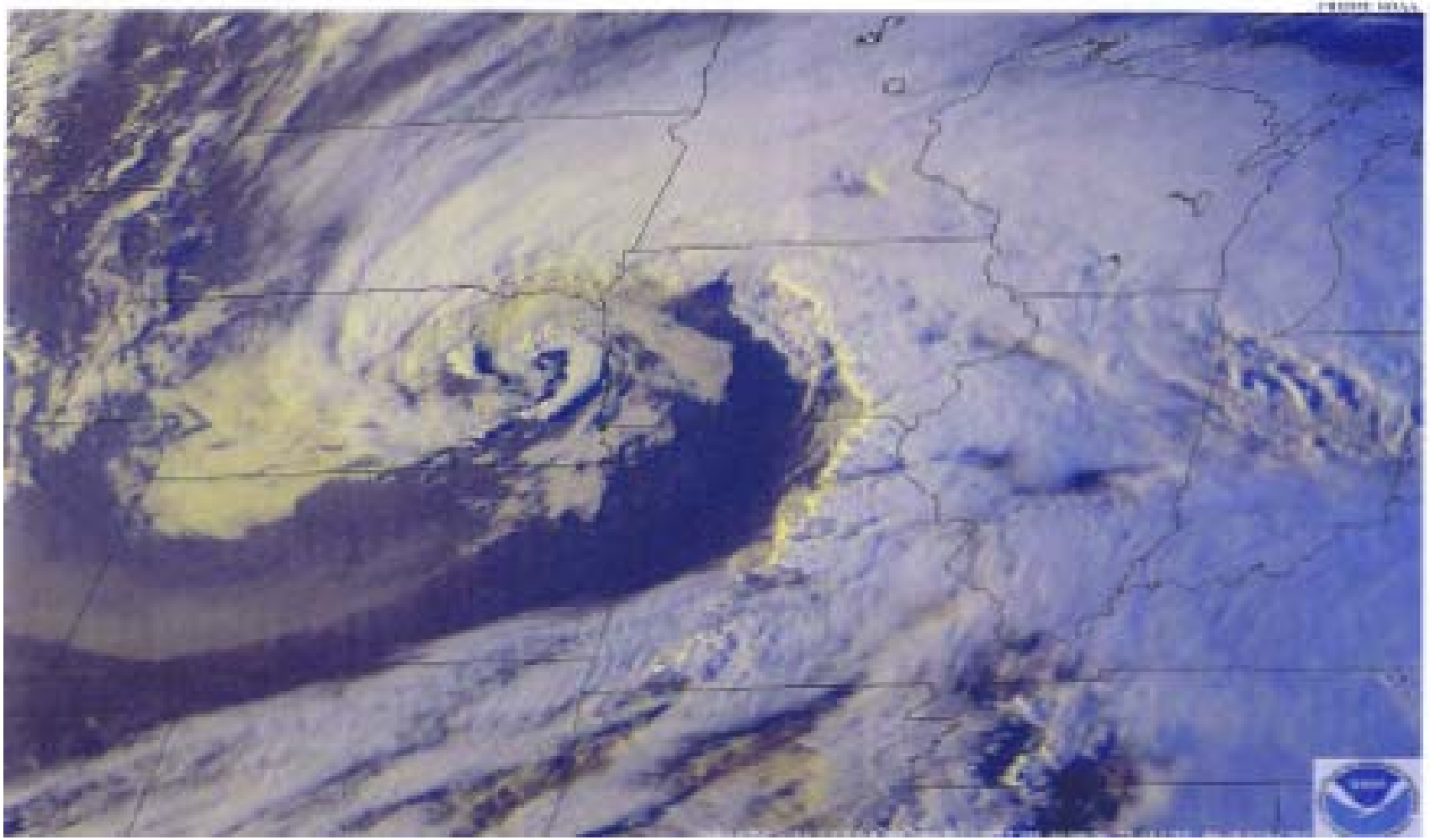
# Satellite Image of Dust Storm in Middle East and South Asia



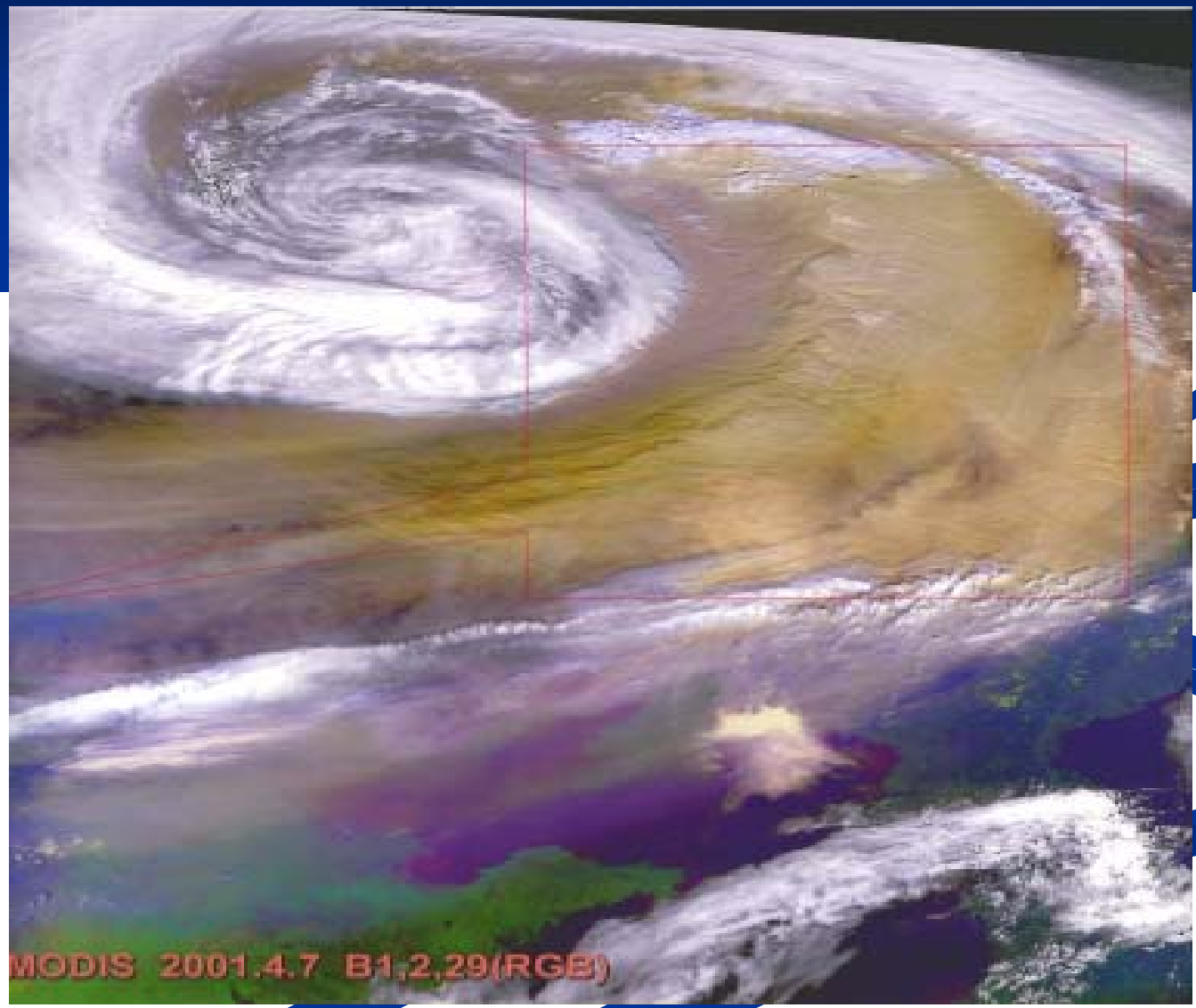
# Satellite Image of Dust Storm in Sahara Desert

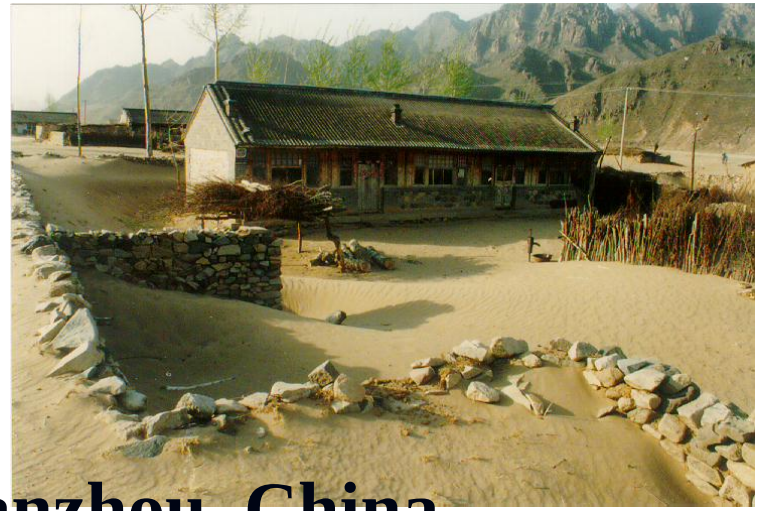


# Satellite Image of Dust Storm in United States



# Satellite Image of Dust Storm in East Asia





Lanzhou, China


Luoyang, China

# Beijing, China




**Seoul, Korea**

**Fukuoka, Japan**

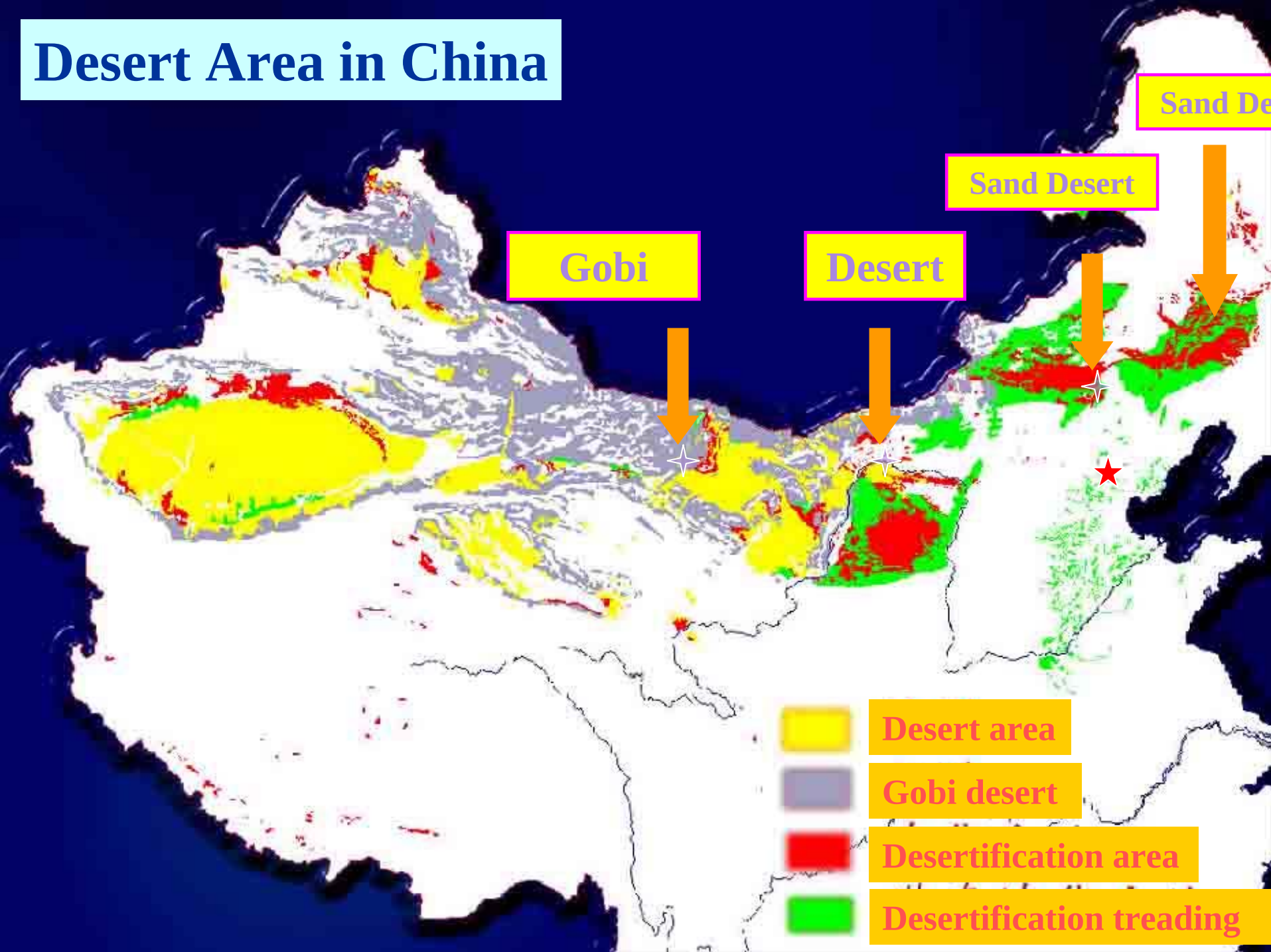
**Because dust storms cross international boundaries, they become a problem shared by many countries. For this reason, and owing to the wide expanses they cover, it is still hard to study and understand their causes and where they originate.**

**In recent years, much more attention has been paid on the impacts of human activities on Earth's environment, including the dust storm production. Indeed, with the rapid increase of world population and the rapid development of social-economy activity since the industrial era, human behaviours are showing an increasing ability to affect the global climate and environment.**

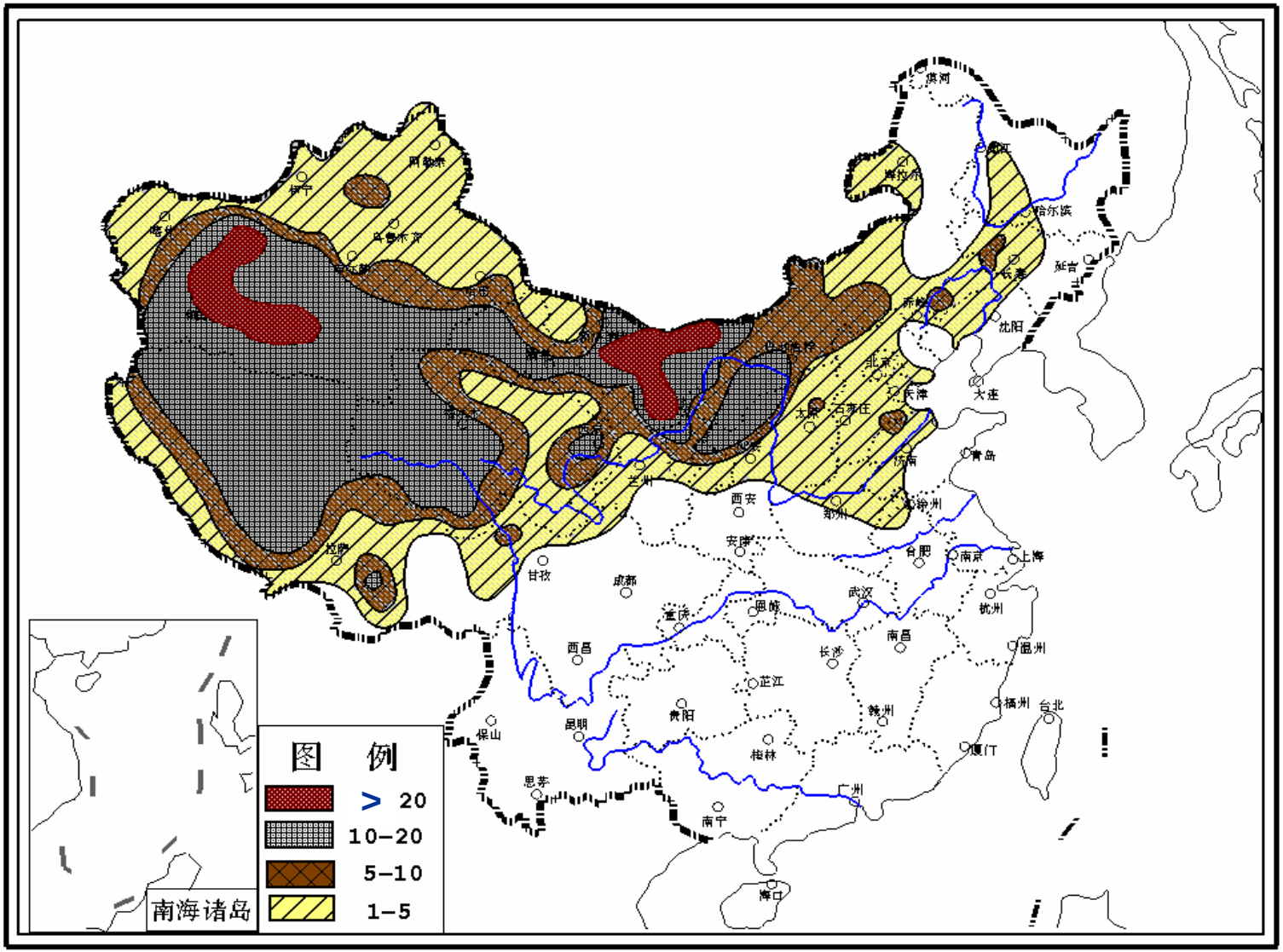
# Example of Grassland Desertification

## (Inn Mongolia China)

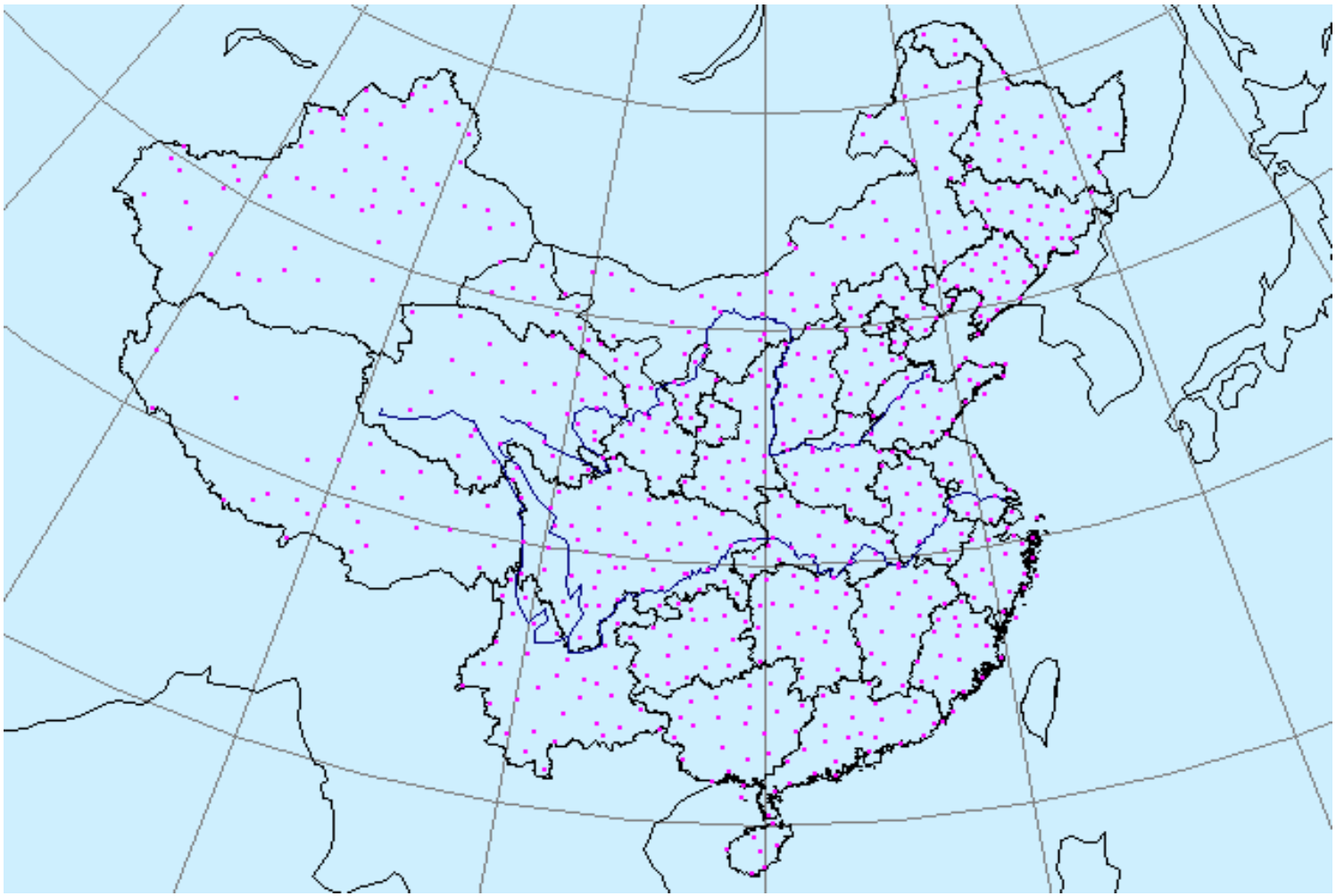
# Desert Area in China



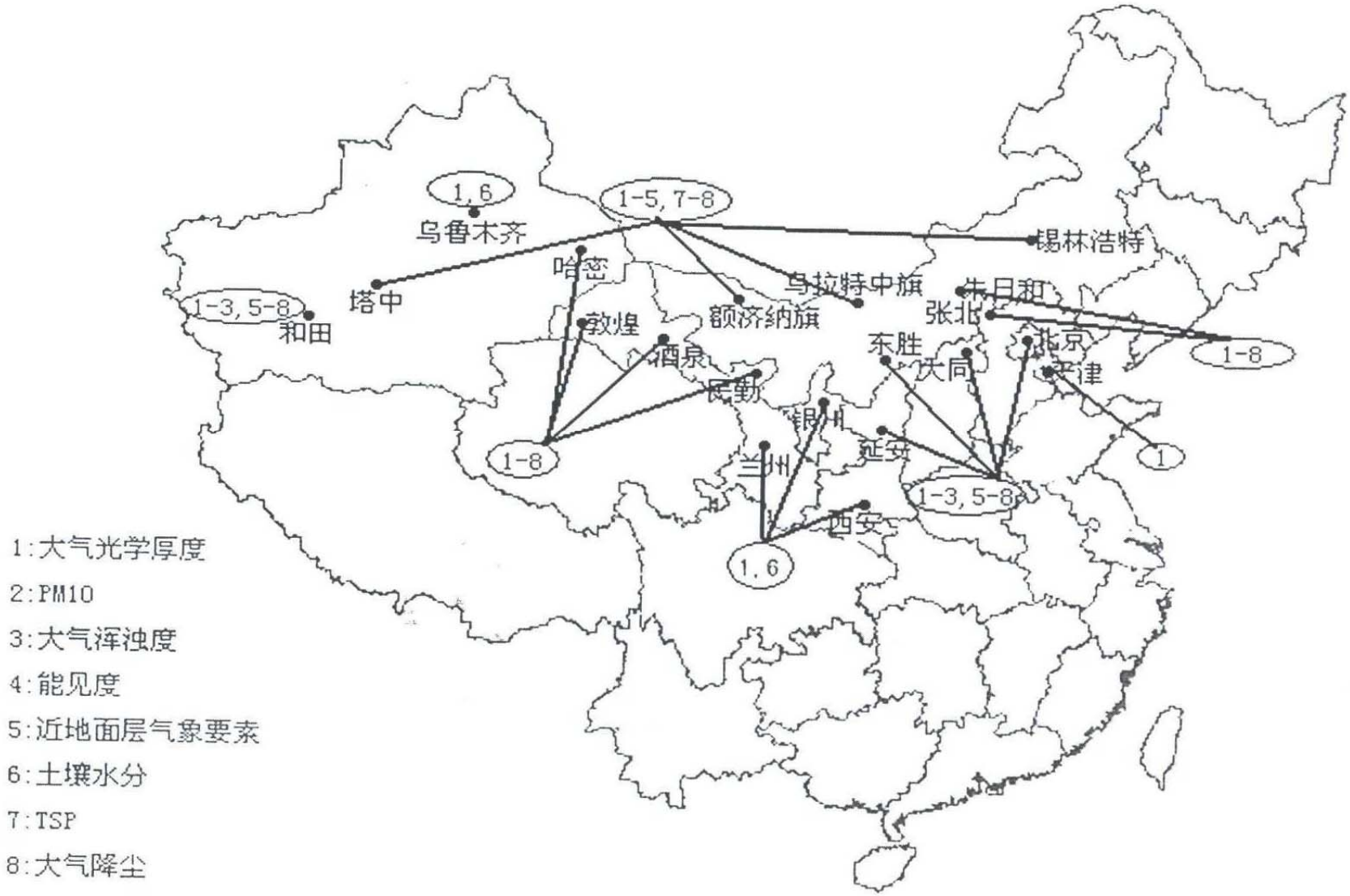
# Distribution of the total number of dust strom days over China averaged form 1956 to 2000



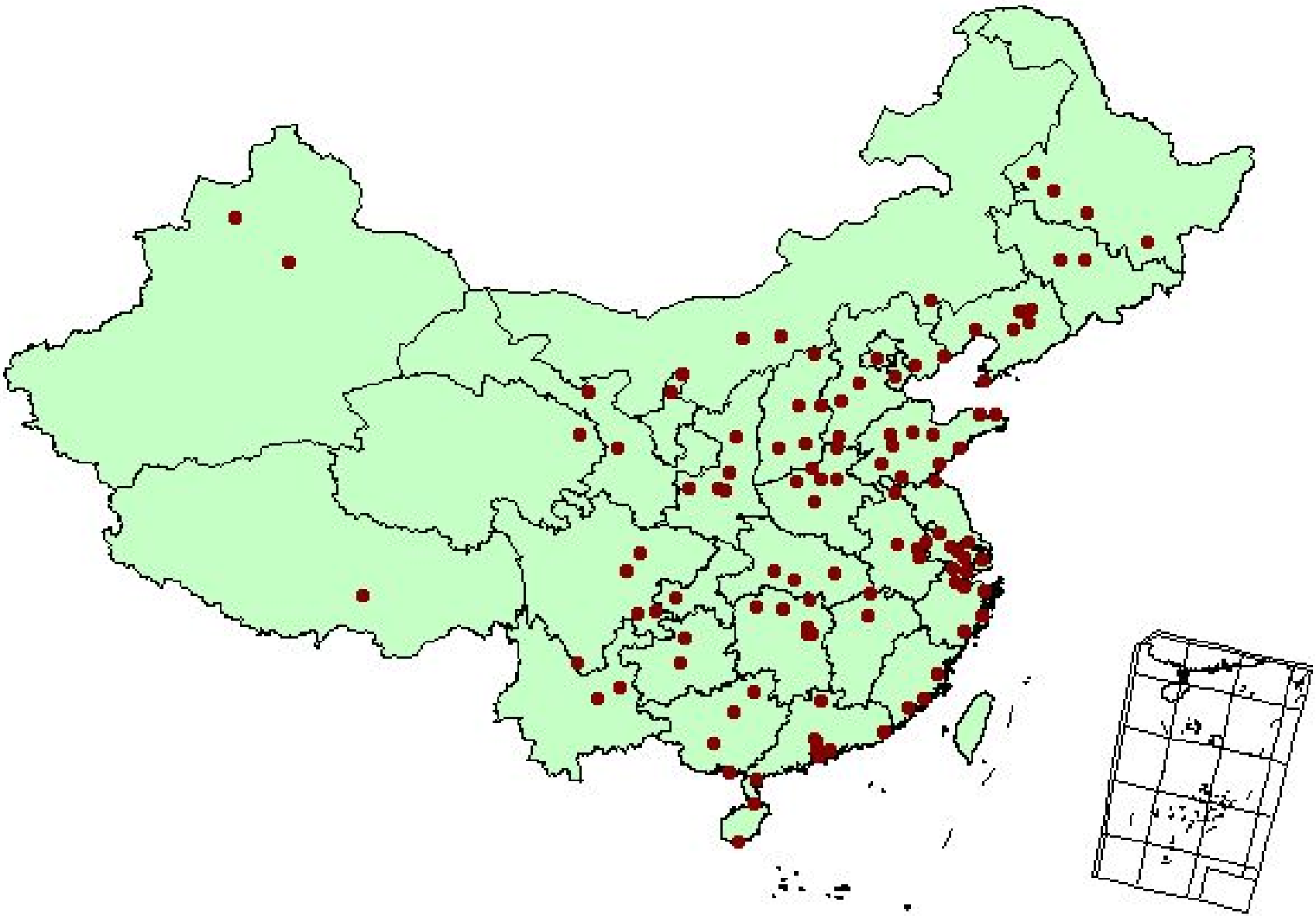
# 681 meteorological observation stations of China

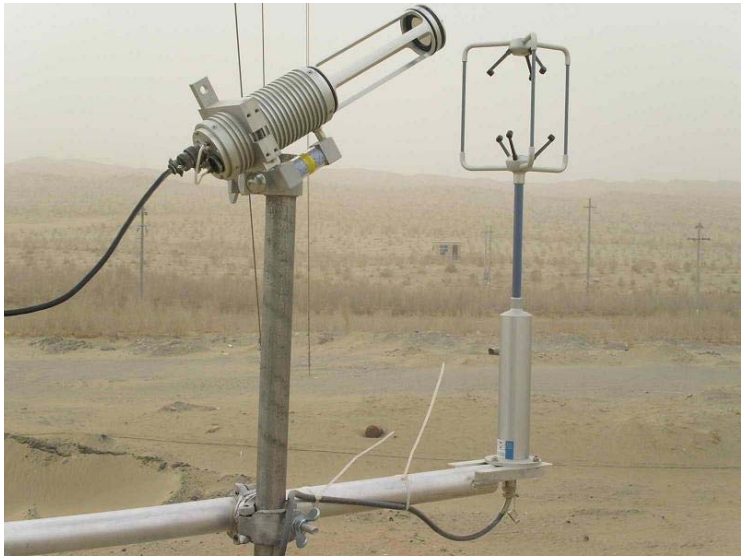


# Dust storm observation stations of China



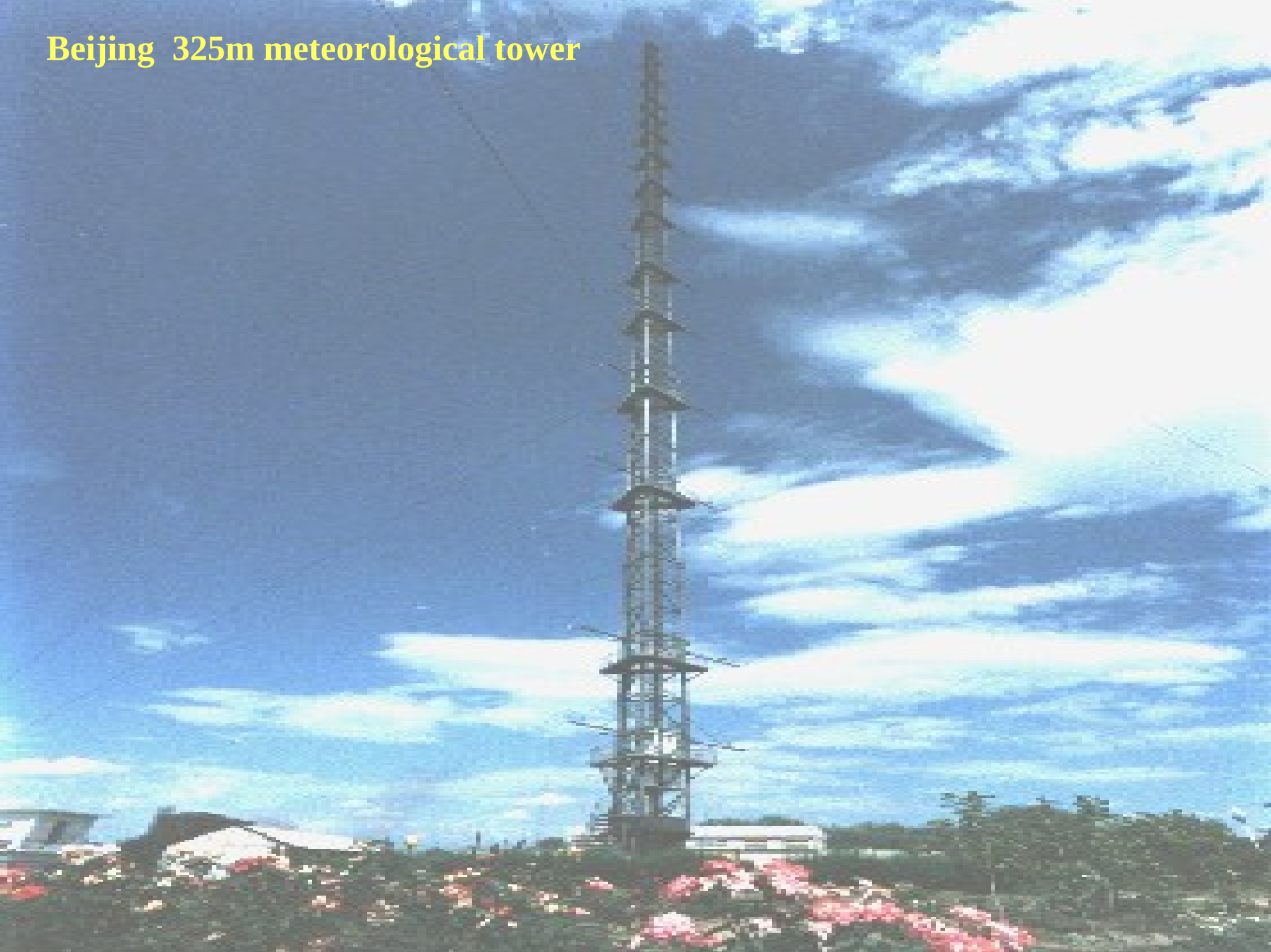
# More then 100 Air Quality Observation Stations (cities)





**Observation Tower in the desert**

# Observation tower in Beijing city

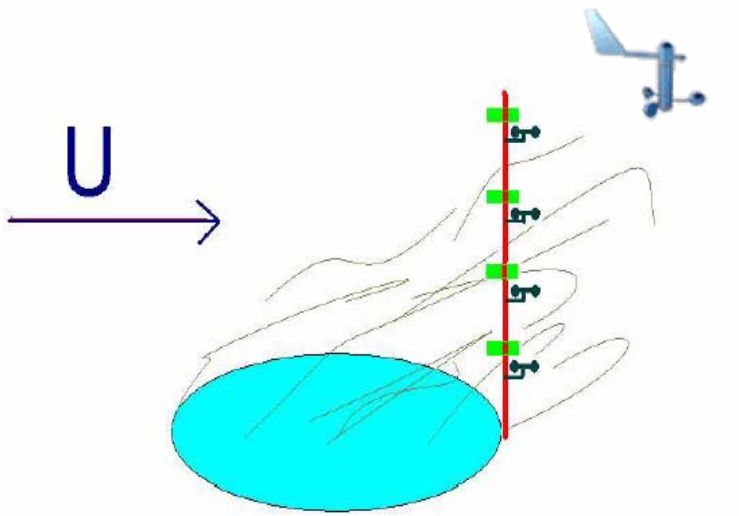

Beijing 325m meteorological tower

# Eddy-correlation method

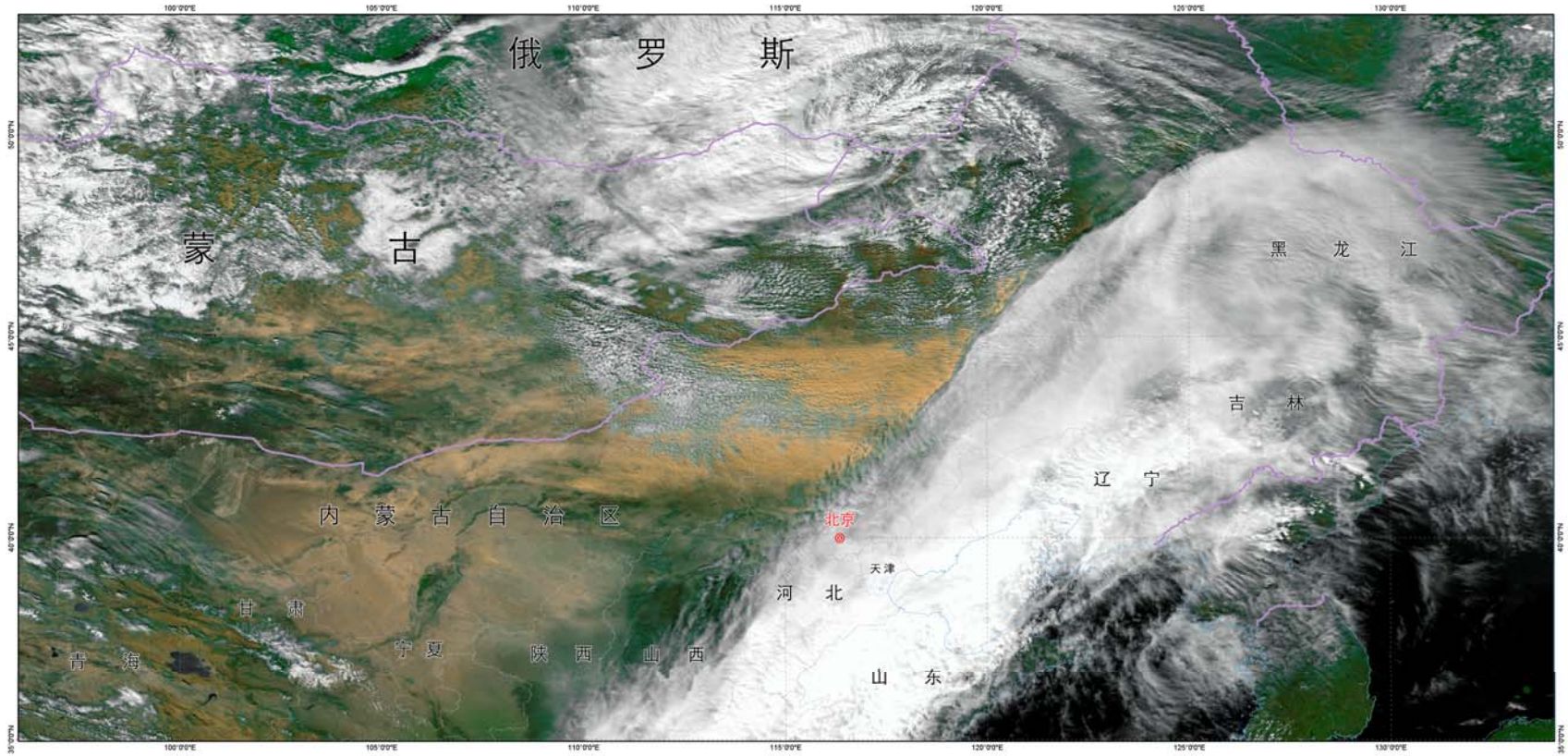
$$\tau = \rho u_*^2$$

$$H = \rho C_p \overline{w'\theta'}$$

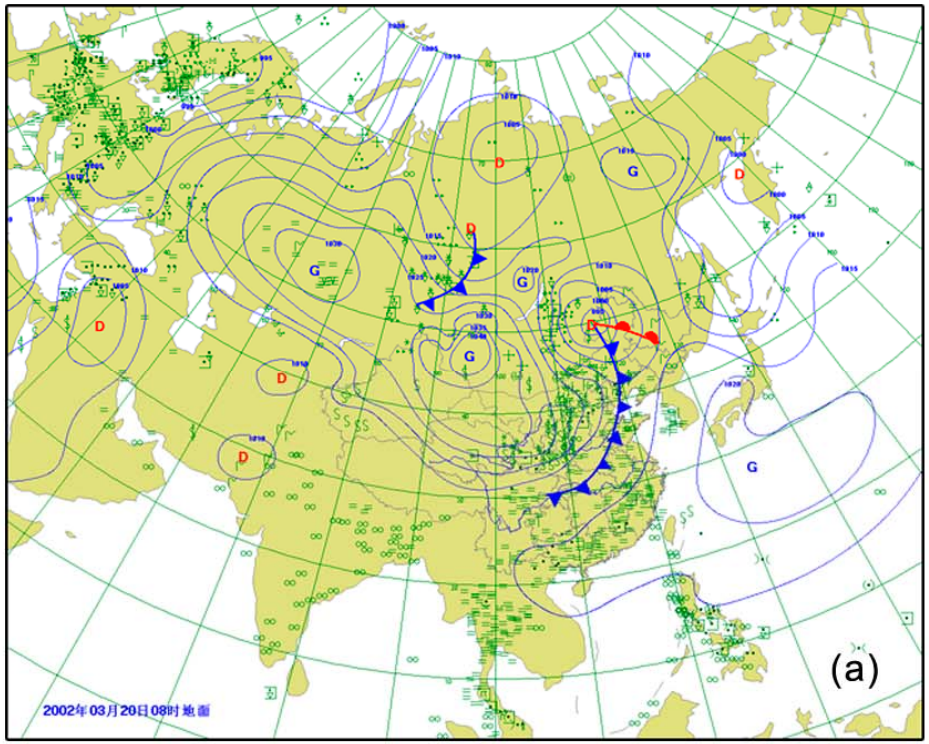
$$E = \rho \overline{w'q'}$$

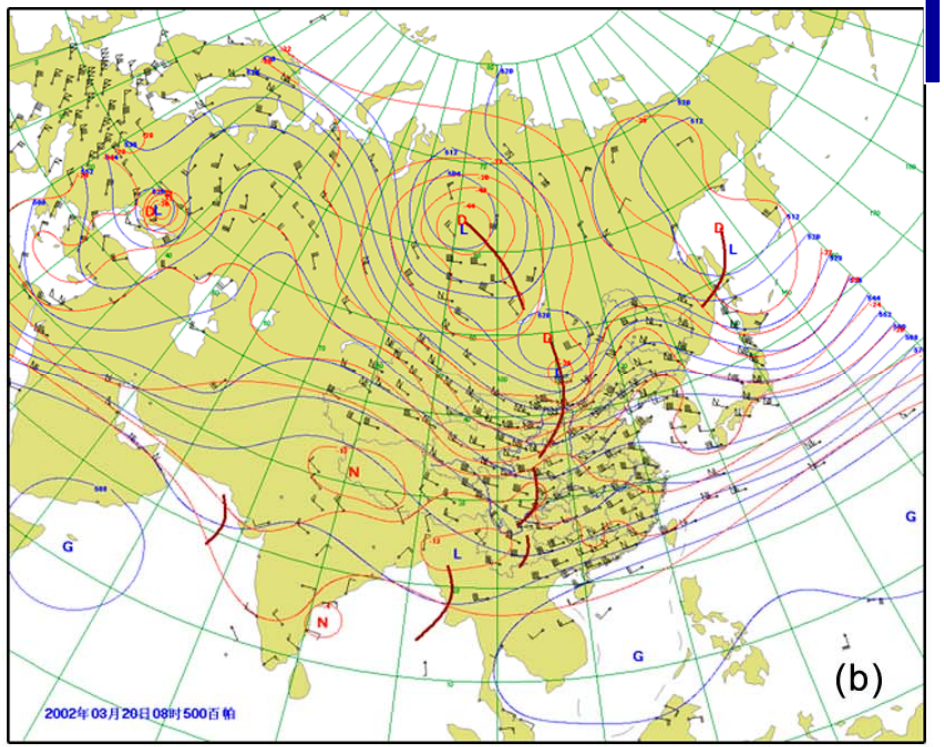


# Example Case: March 20, 2002



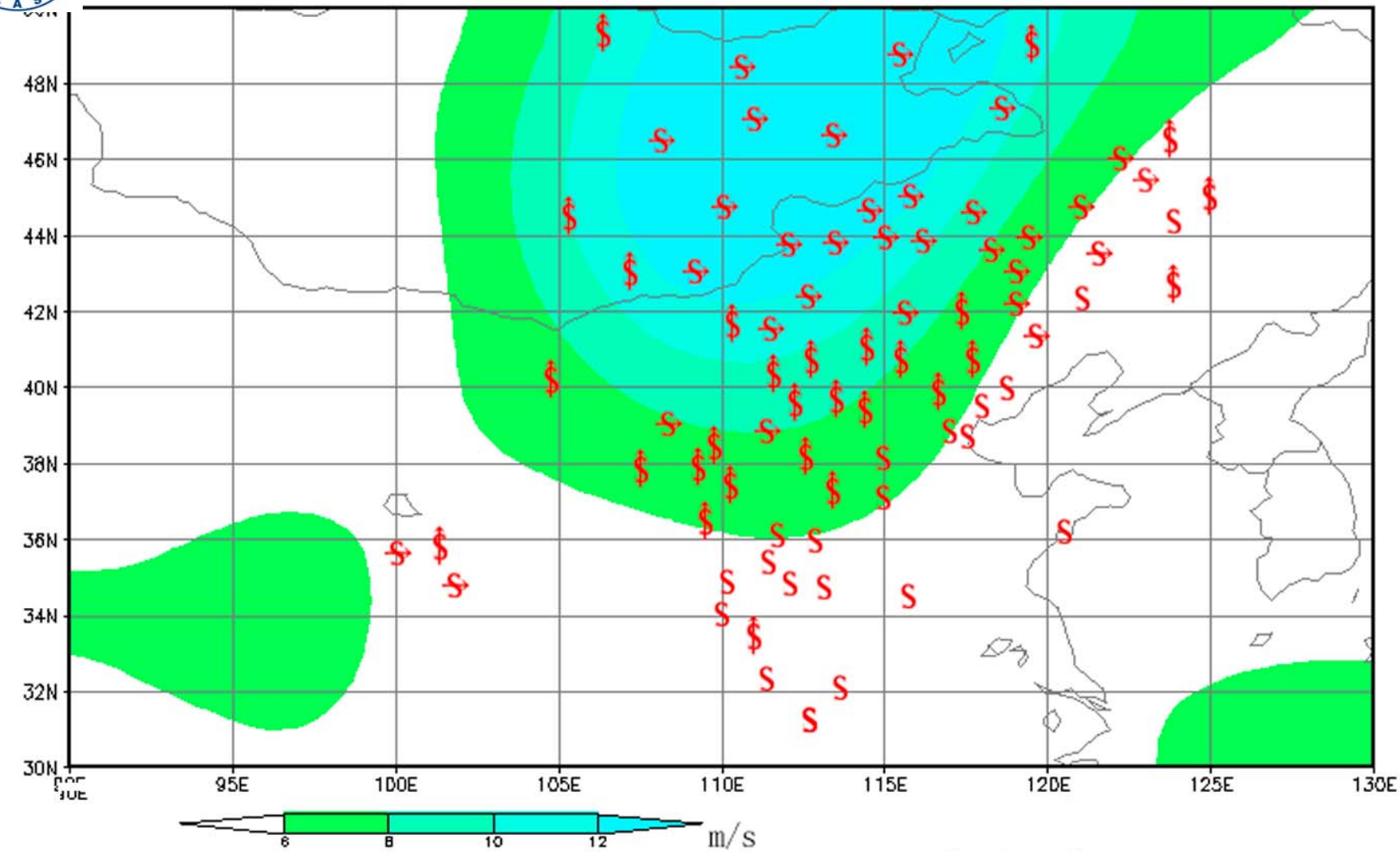
# March 20, 2002

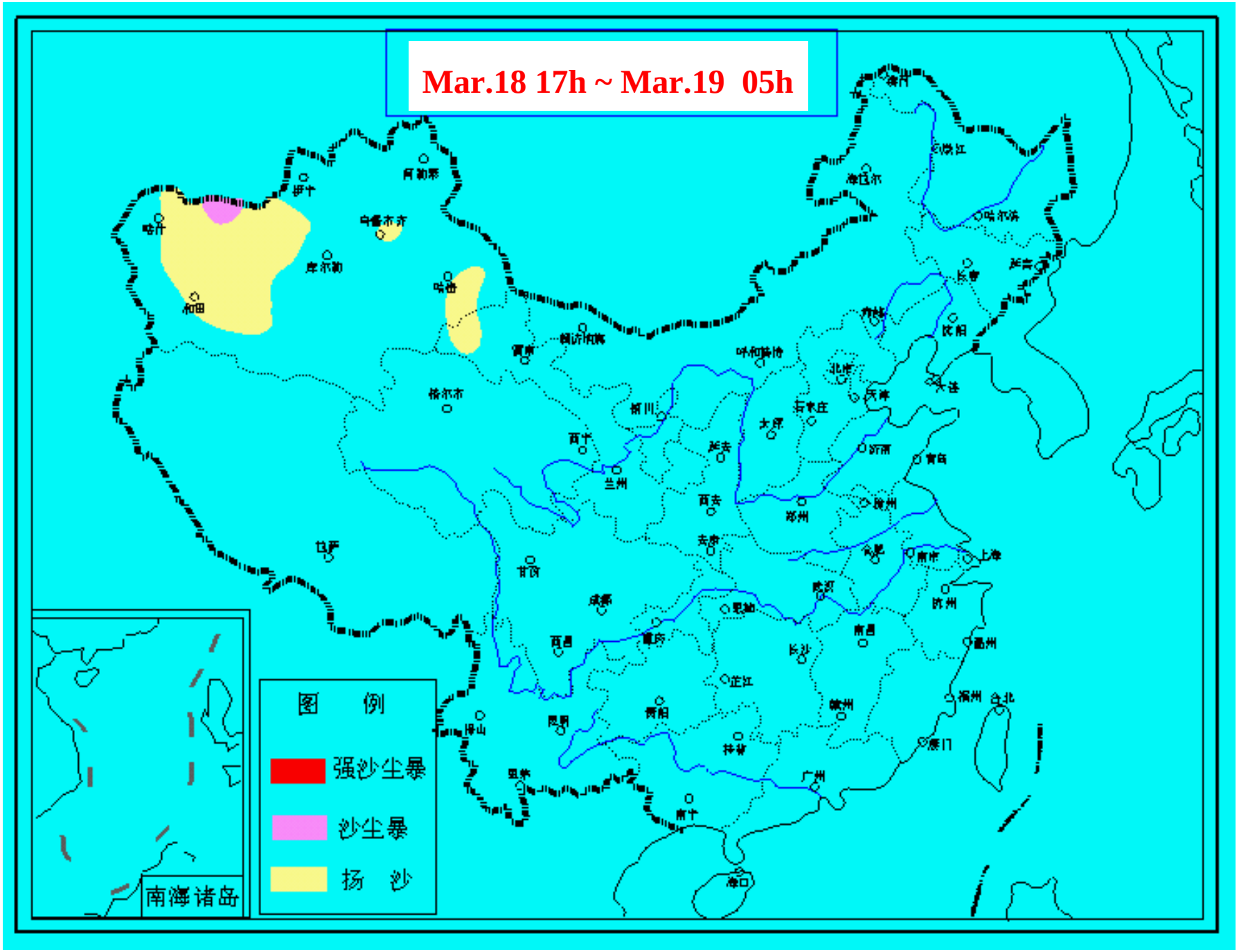


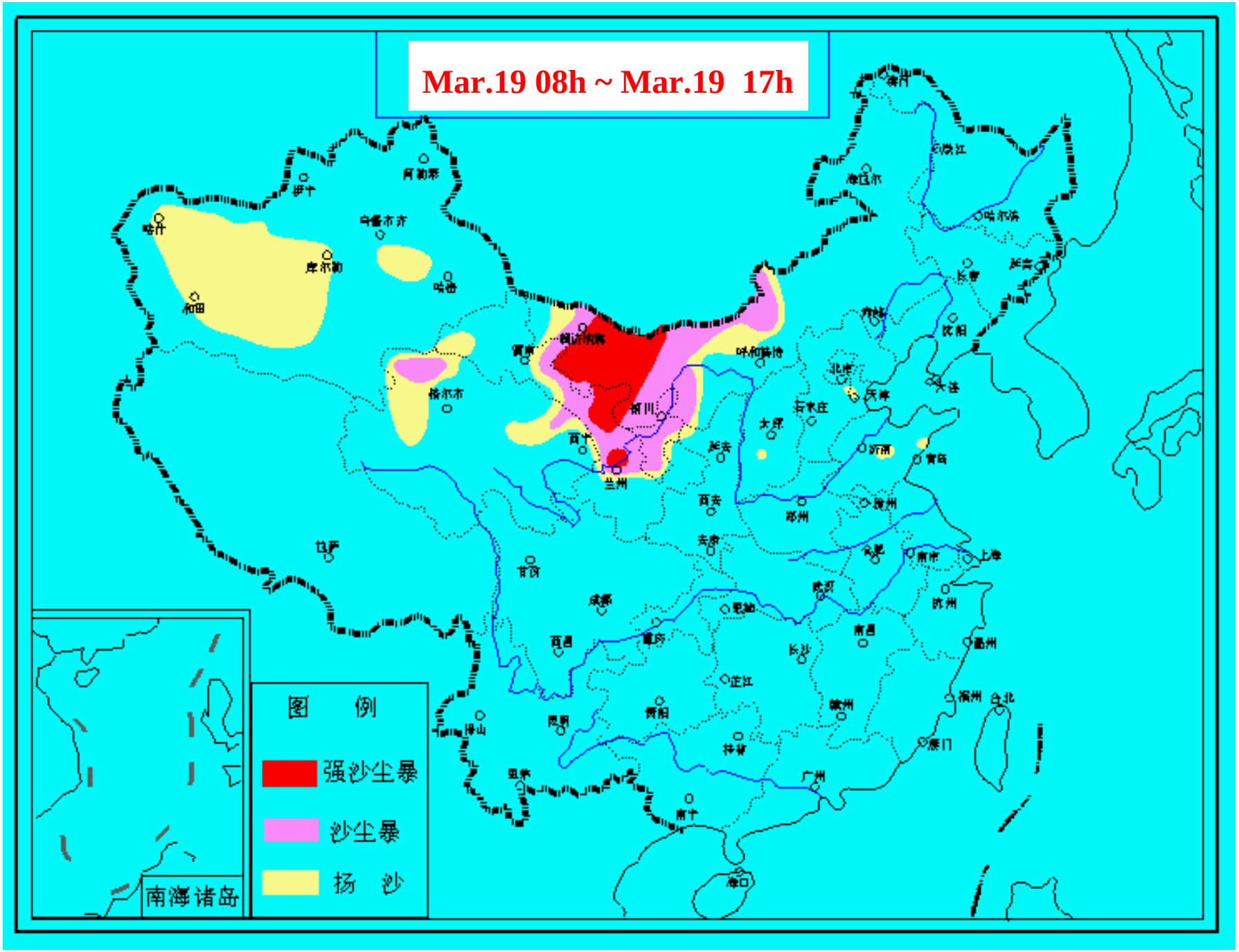



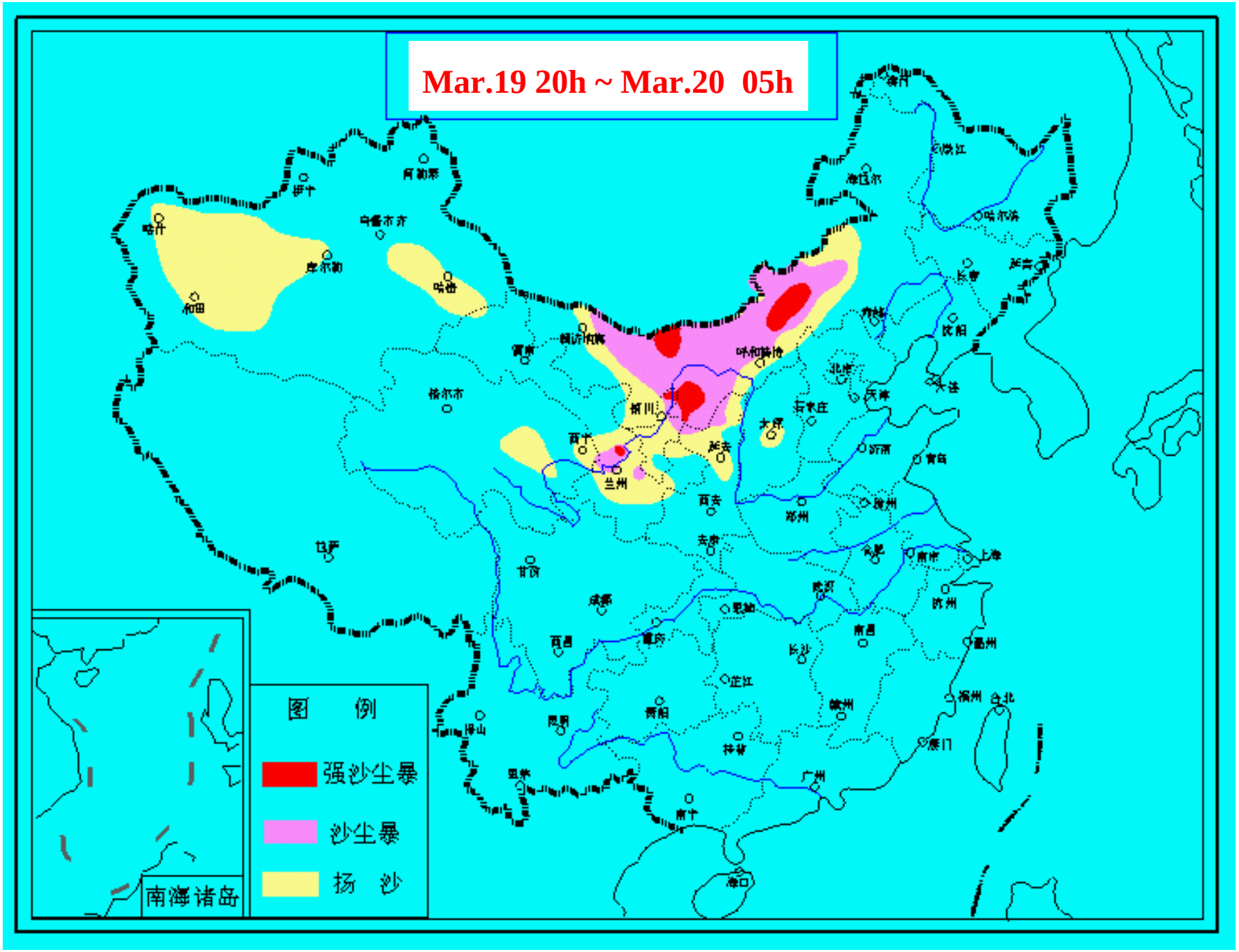

Cold Front,  High Pressure, Strong wind

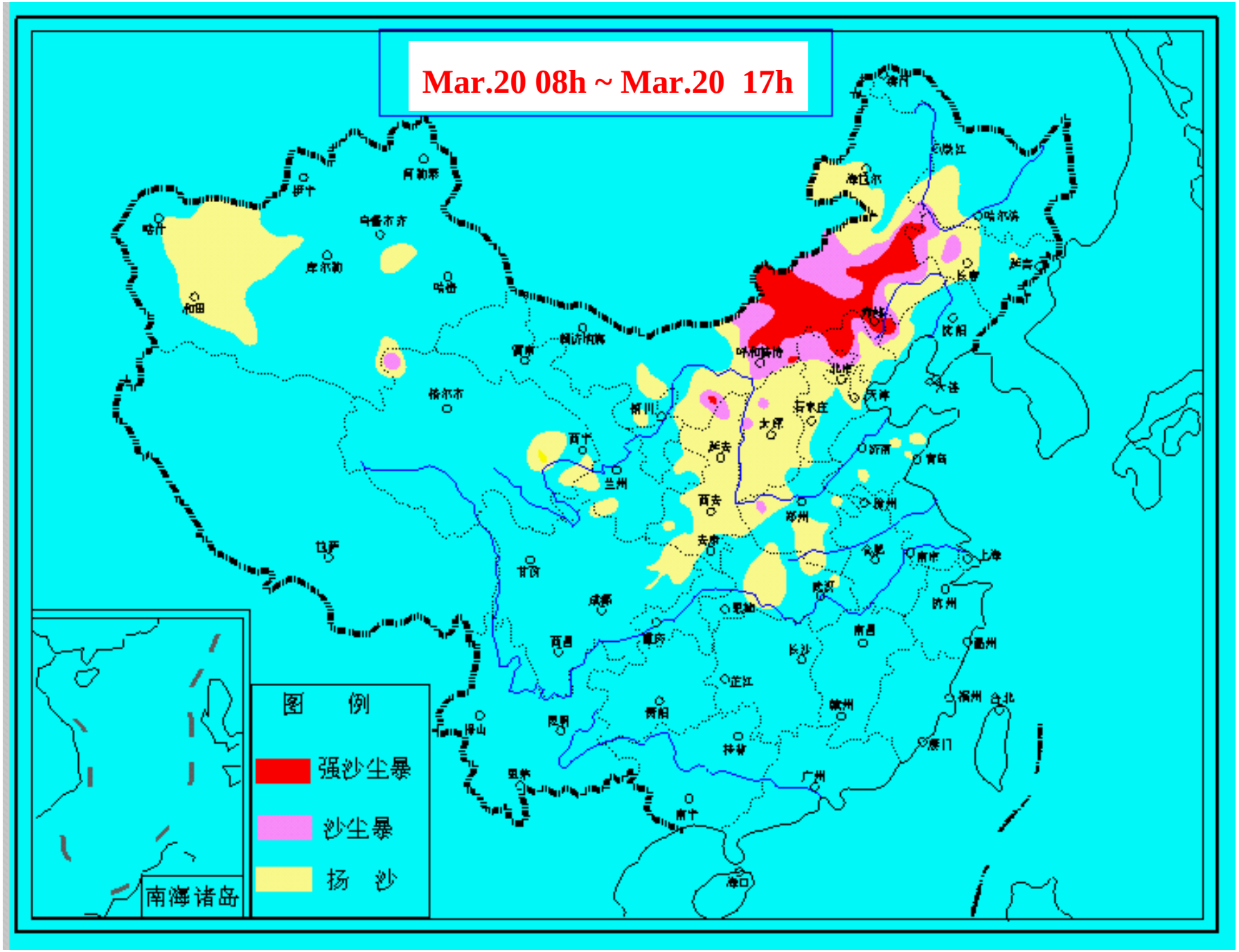
# March 20, 2002

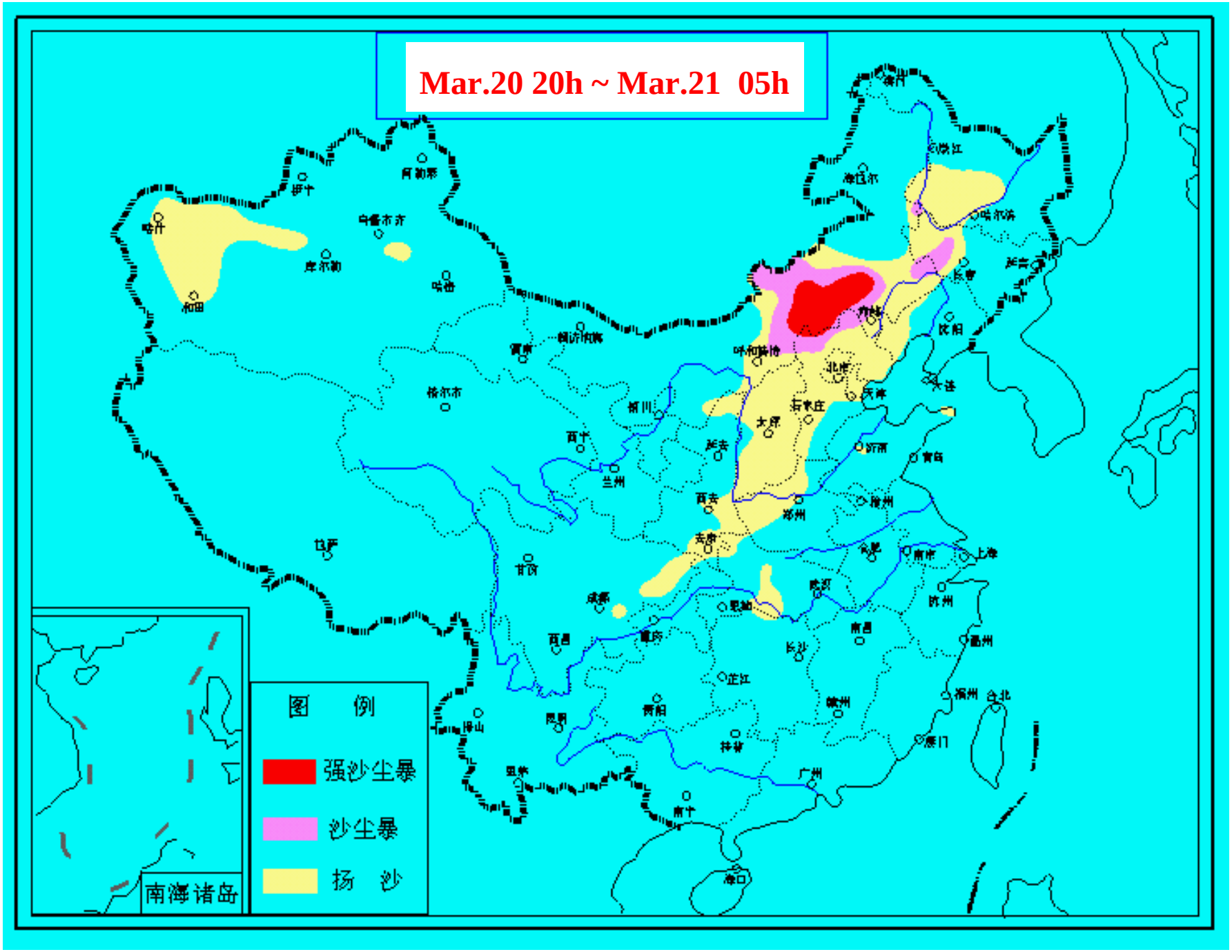


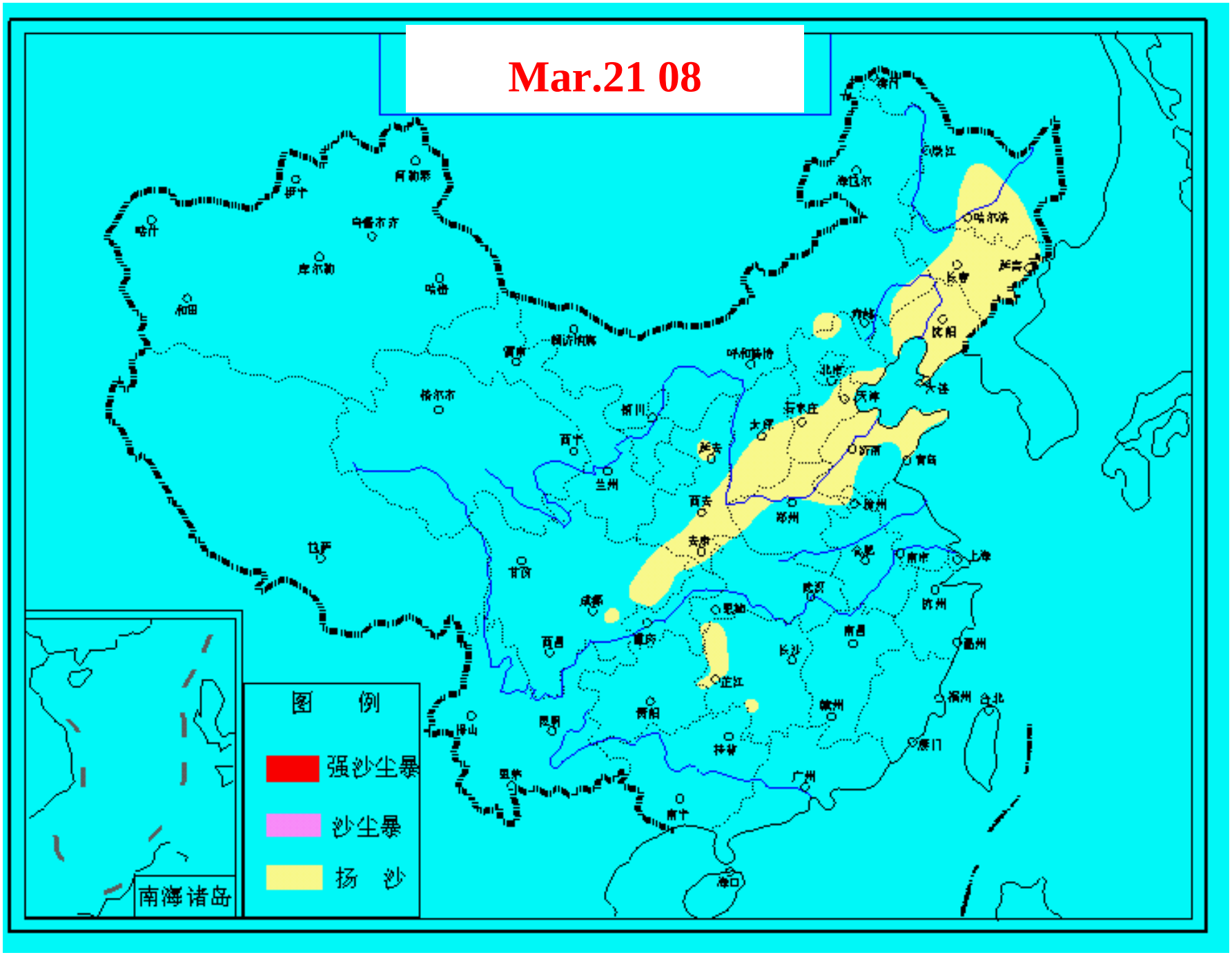

Mar.18 17h ~ Mar.19 05h
图 例
强沙尘暴
沙尘暴
扬 沙
南海诸岛


Mar.19 08h ~ Mar.19 17h
图 例
强沙尘暴
沙尘暴
扬 沙
南海诸岛

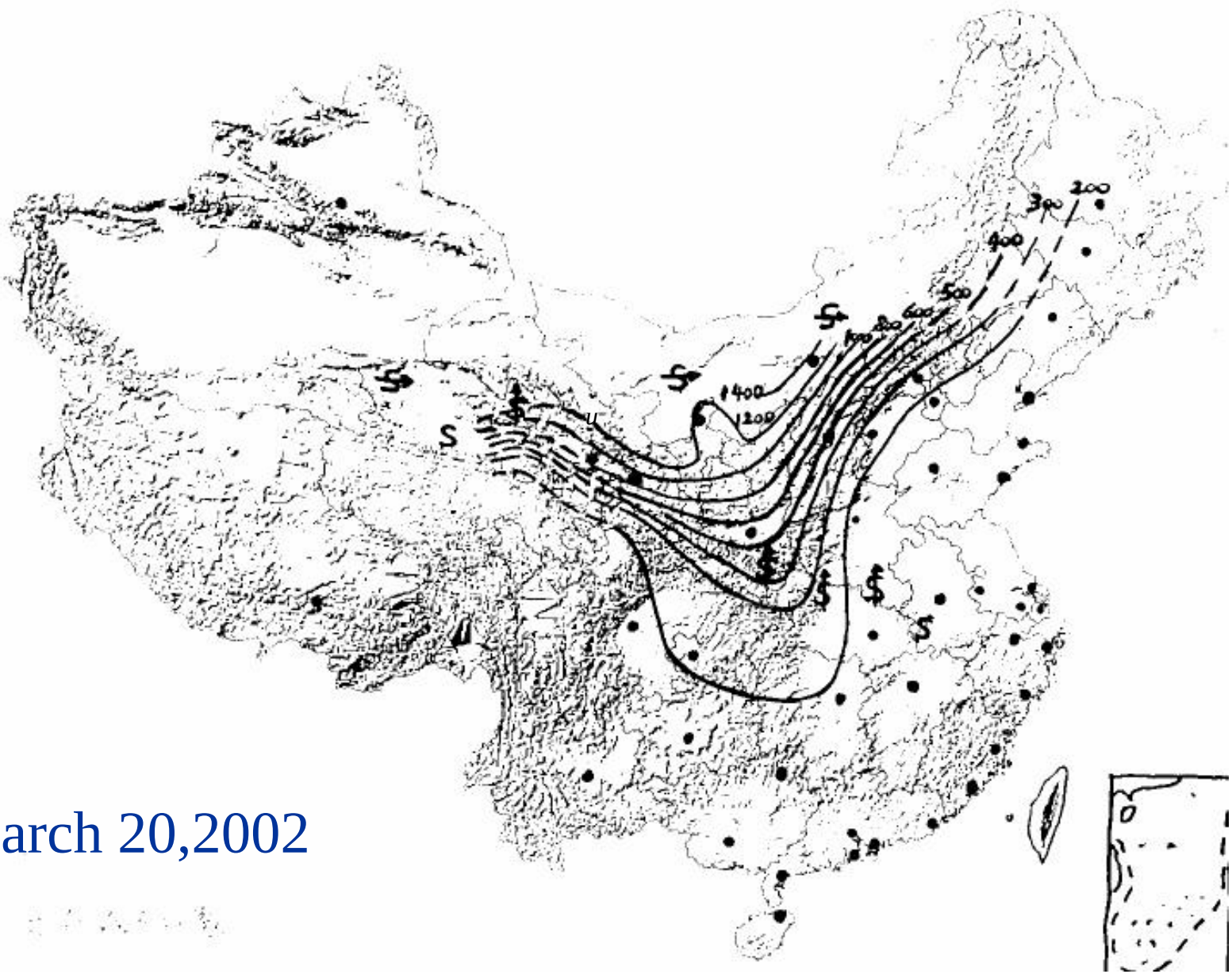

Mar.19 20h ~ Mar.20 05h
图 例
强沙尘暴
沙尘暴
扬 沙
南海诸岛


Mar.20 08h ~ Mar.20 17h
图 例
强沙尘暴
沙尘暴
扬 沙
南海诸岛


Mar.20 20h ~ Mar.21 05h
图 例
强沙尘暴
沙尘暴
扬 沙
南海诸岛

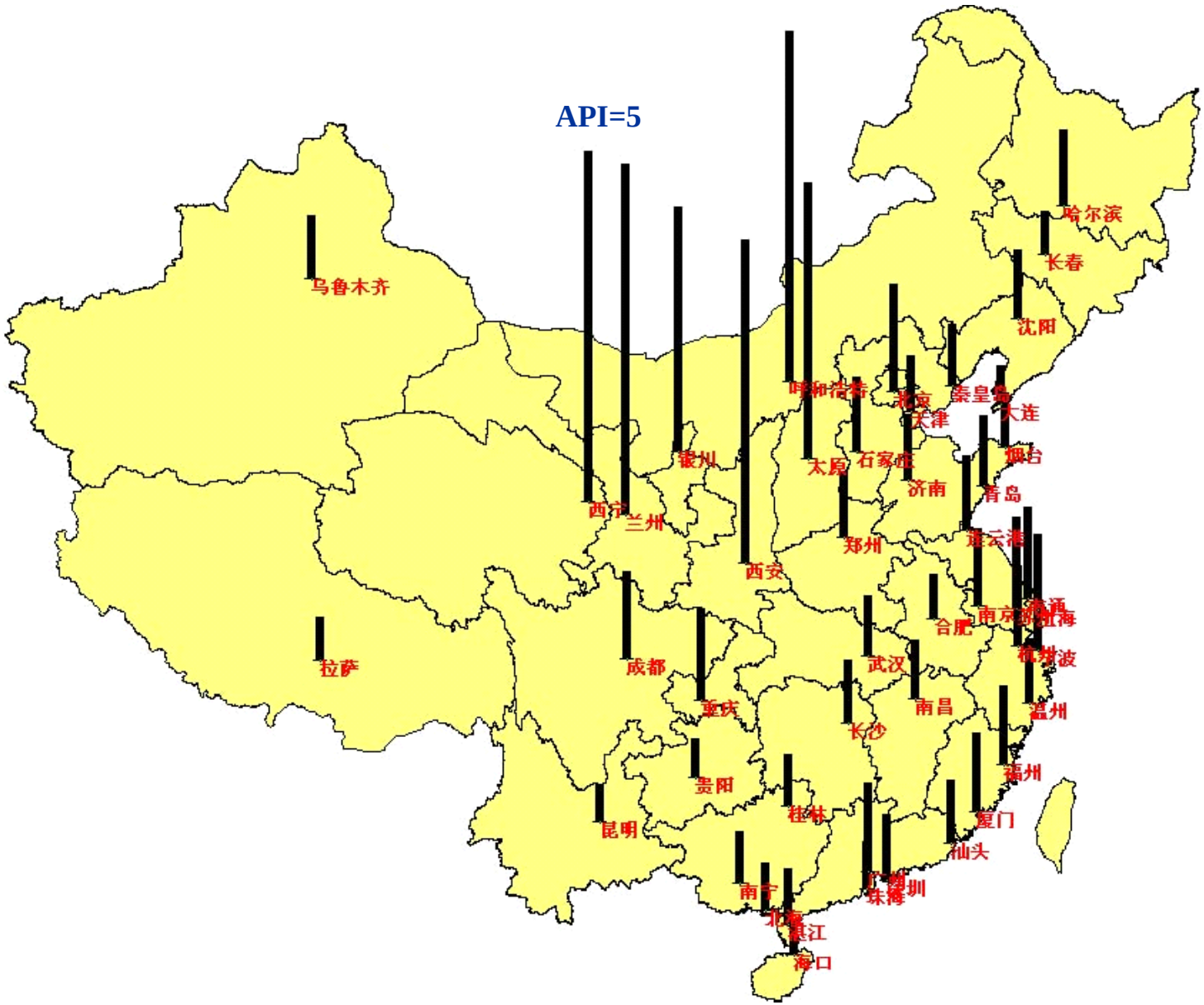

Mar.21 08
图 例
强沙尘暴
沙尘暴
扬 沙
南海诸岛

# 24h averaged PM10 concentrition distribution (μg/m$^3$)

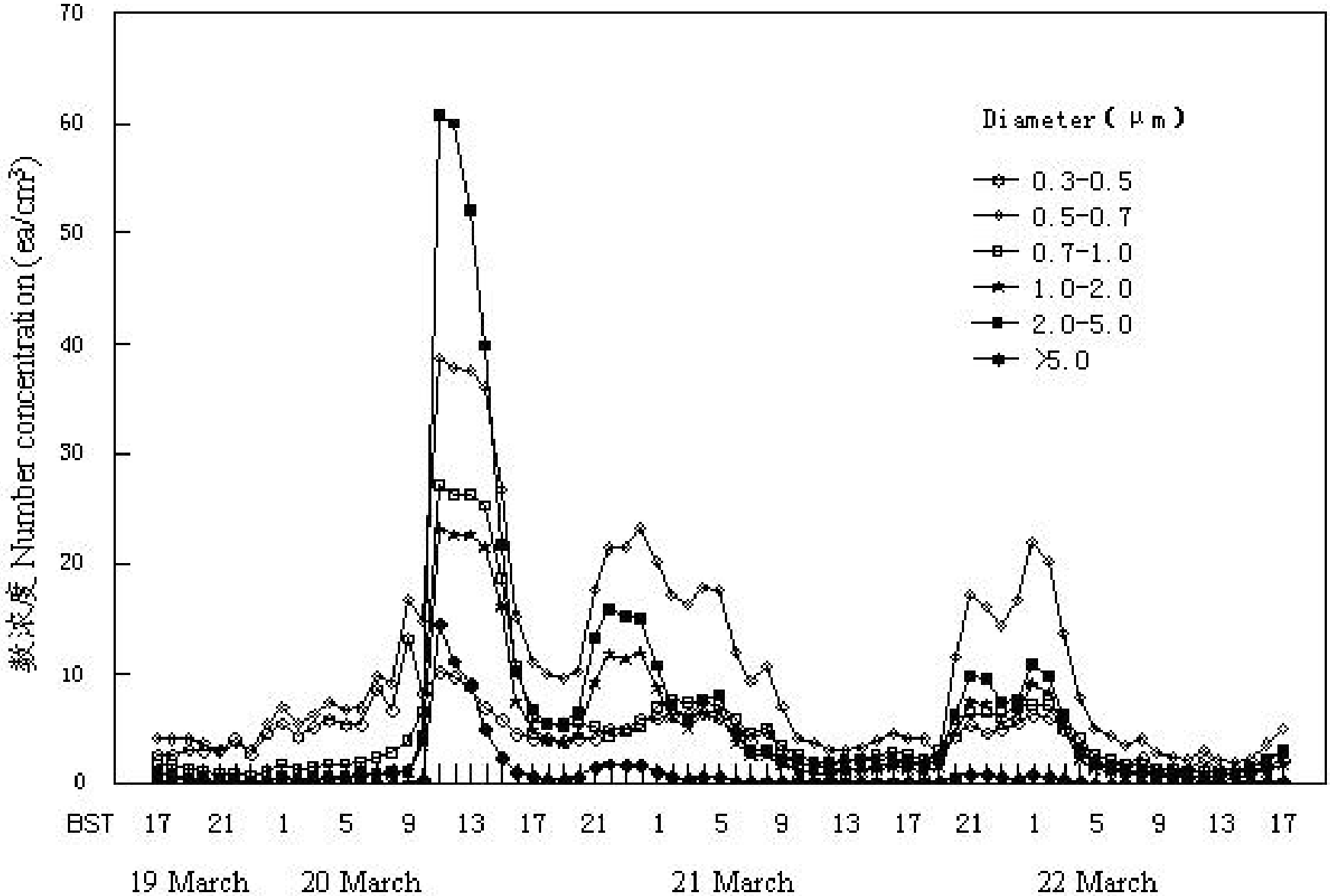



March 20,2002

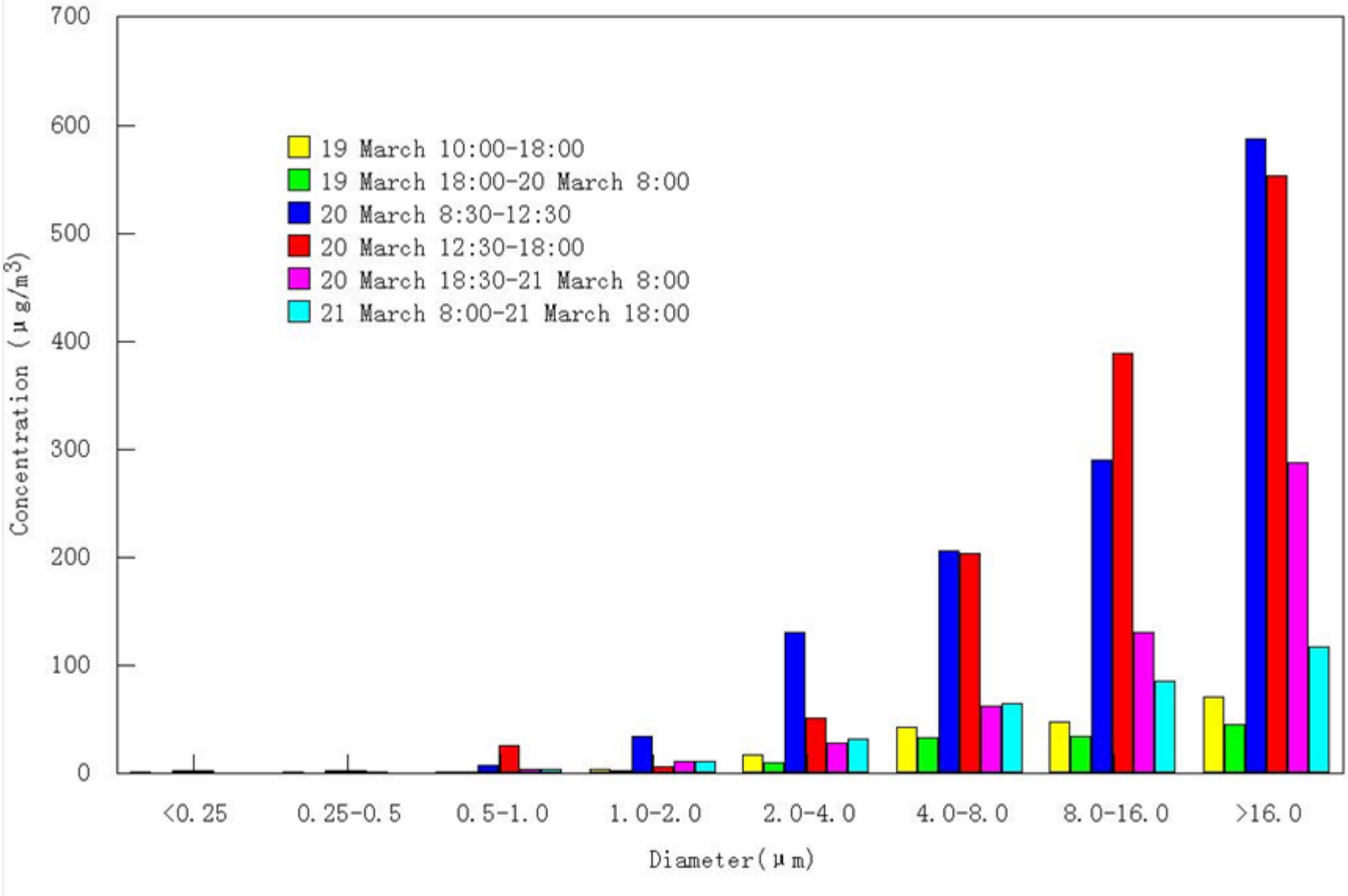
# Air Quality Index API distribution over China (March 20, 2002)



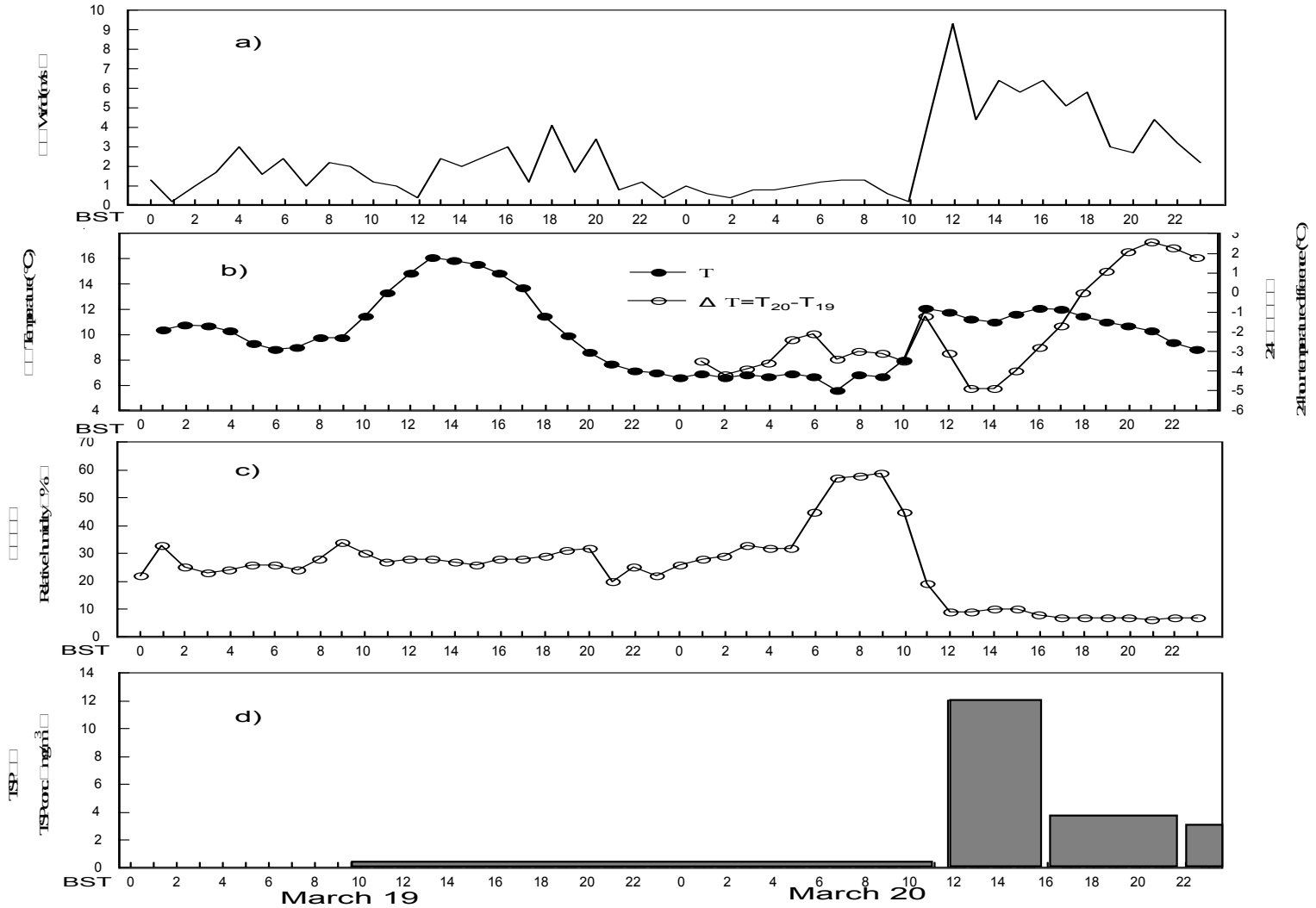
# Number concentration distribution near surface during the dust storm period Mar. 19 ~ Mar. 22 ,2002



# Dust particle concentration distribution near surface during the dust storm period Mar. 19 ~ Mar. 21 ,2002

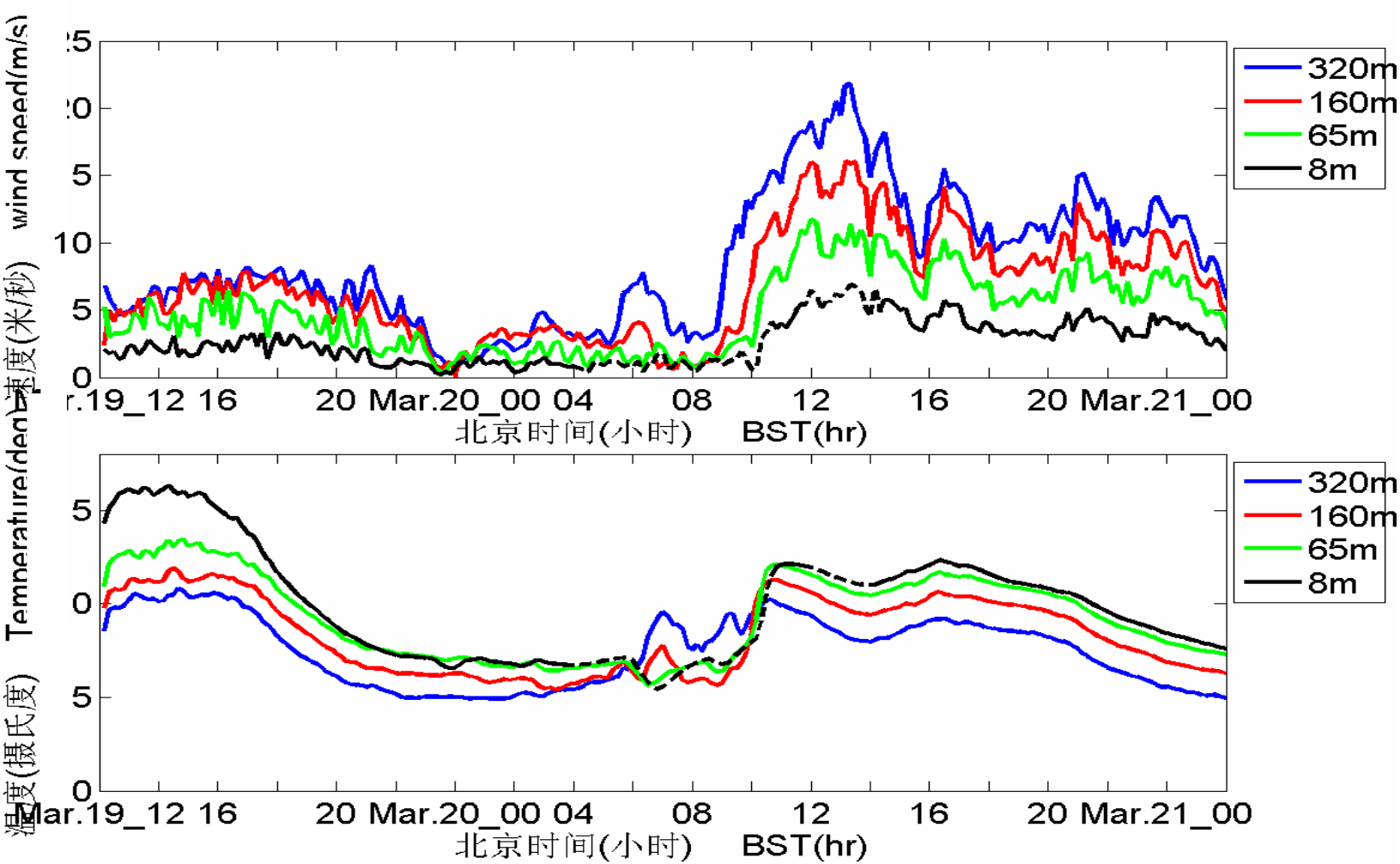


# The Dust Storm Passing Beijing (March 20, 2002)

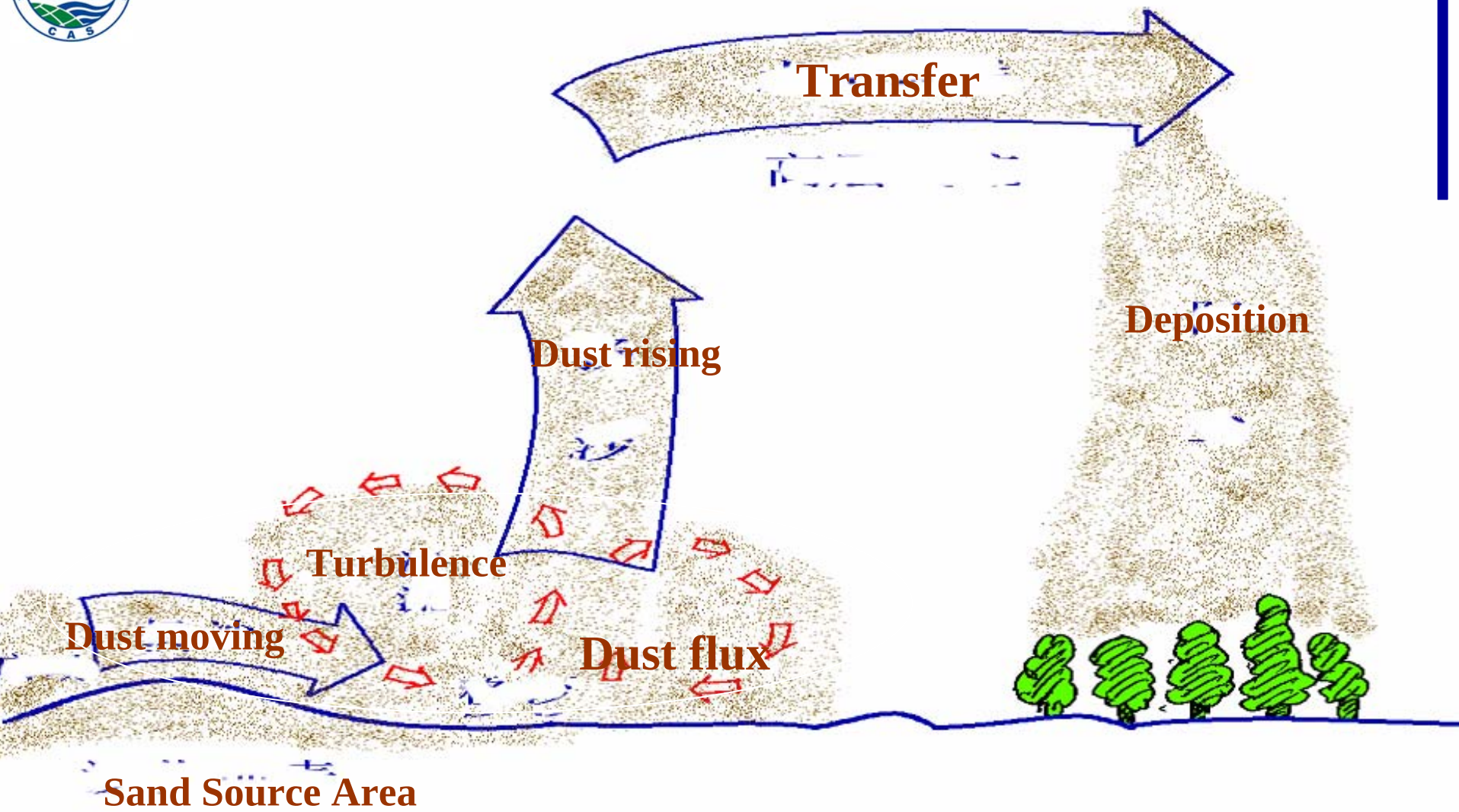



**(a)Wind, (b)T, (c)RH, (d)Concentration of Dust (TSP)**

# The Passage of Dust Storm

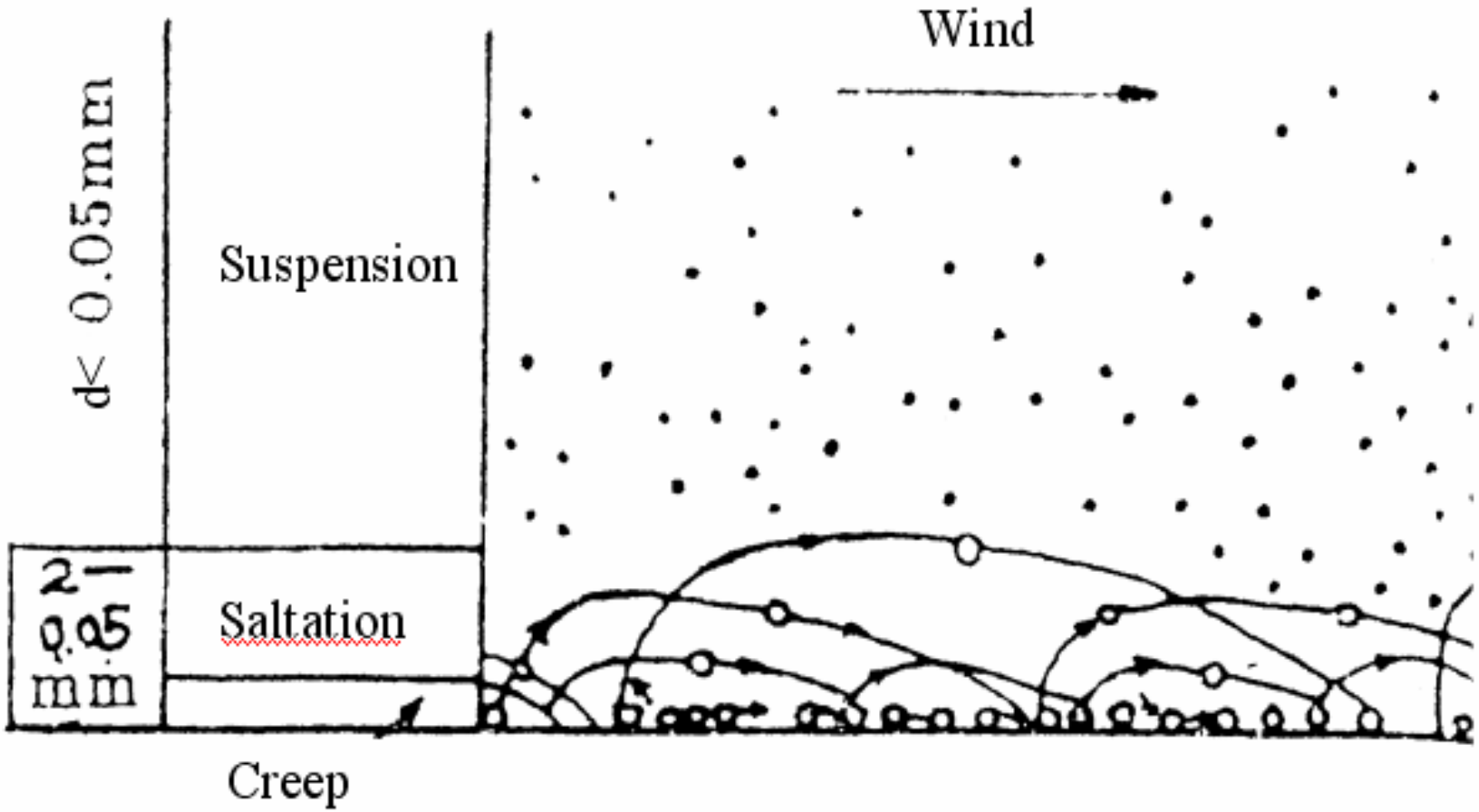



**The wind speed and temperature (by wind wane and anemometer and thermometer on Beijing 325m Meteorological Tower).**




The sketch map of dust storm

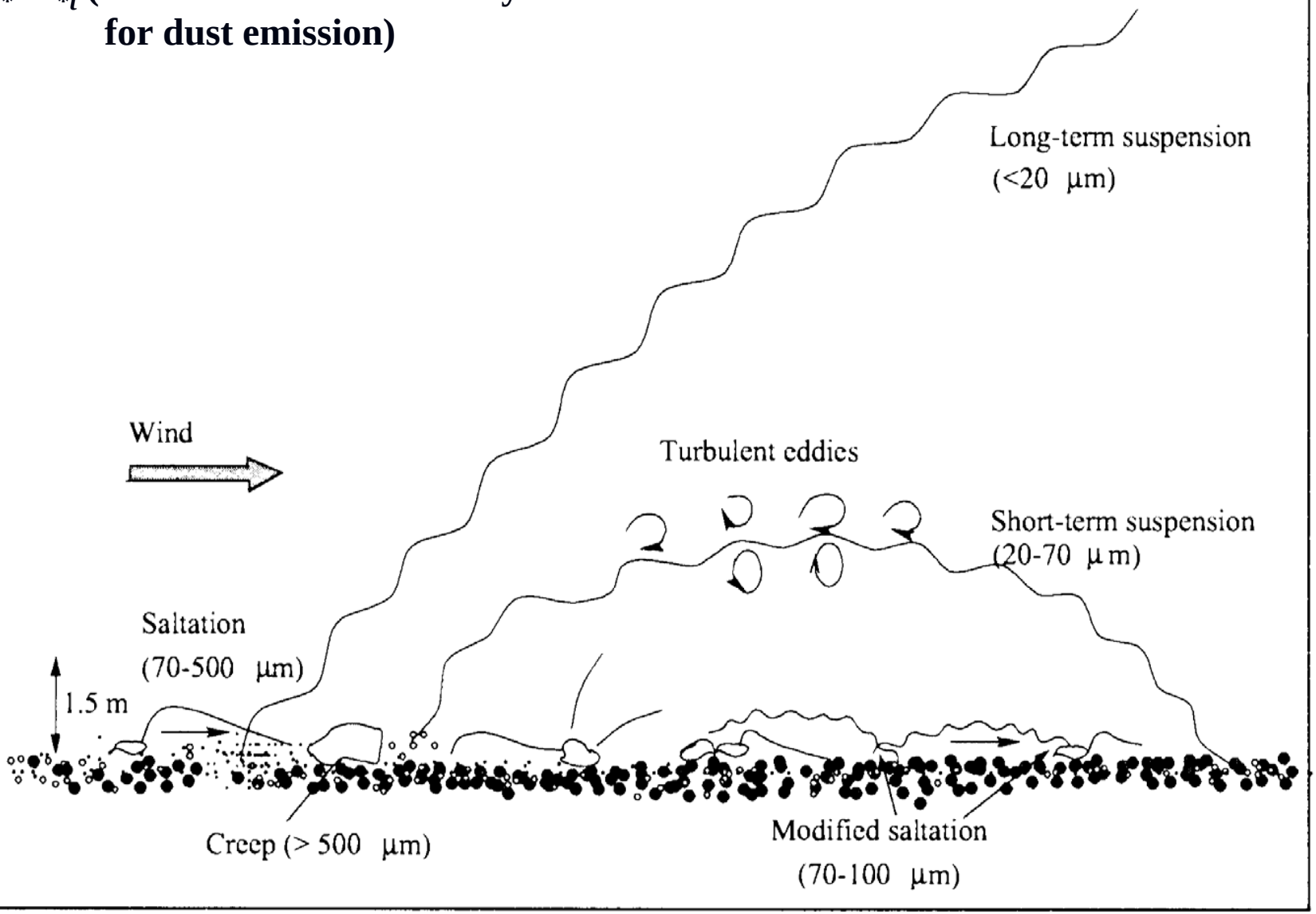
# The Mechanism of Dust Emission (Laboratory Modeling)




The Motion of Sand – Dust Particles

# The Natural Picture of Dust Emission (Imagination)

$u_* > u_{*t}$ (threshold friction velocity for dust emission)



## What is it in the reality?

**There is large scale/mesoscale systematic descending motion in the free atmosphere and even in the atmospheric boundary layer(ABL) behind the cold front.**

**Descending motion suppresses the dust particles to penetrate into the troposphere, and those particles can only be accumulated in the very low levels in the ABL.**

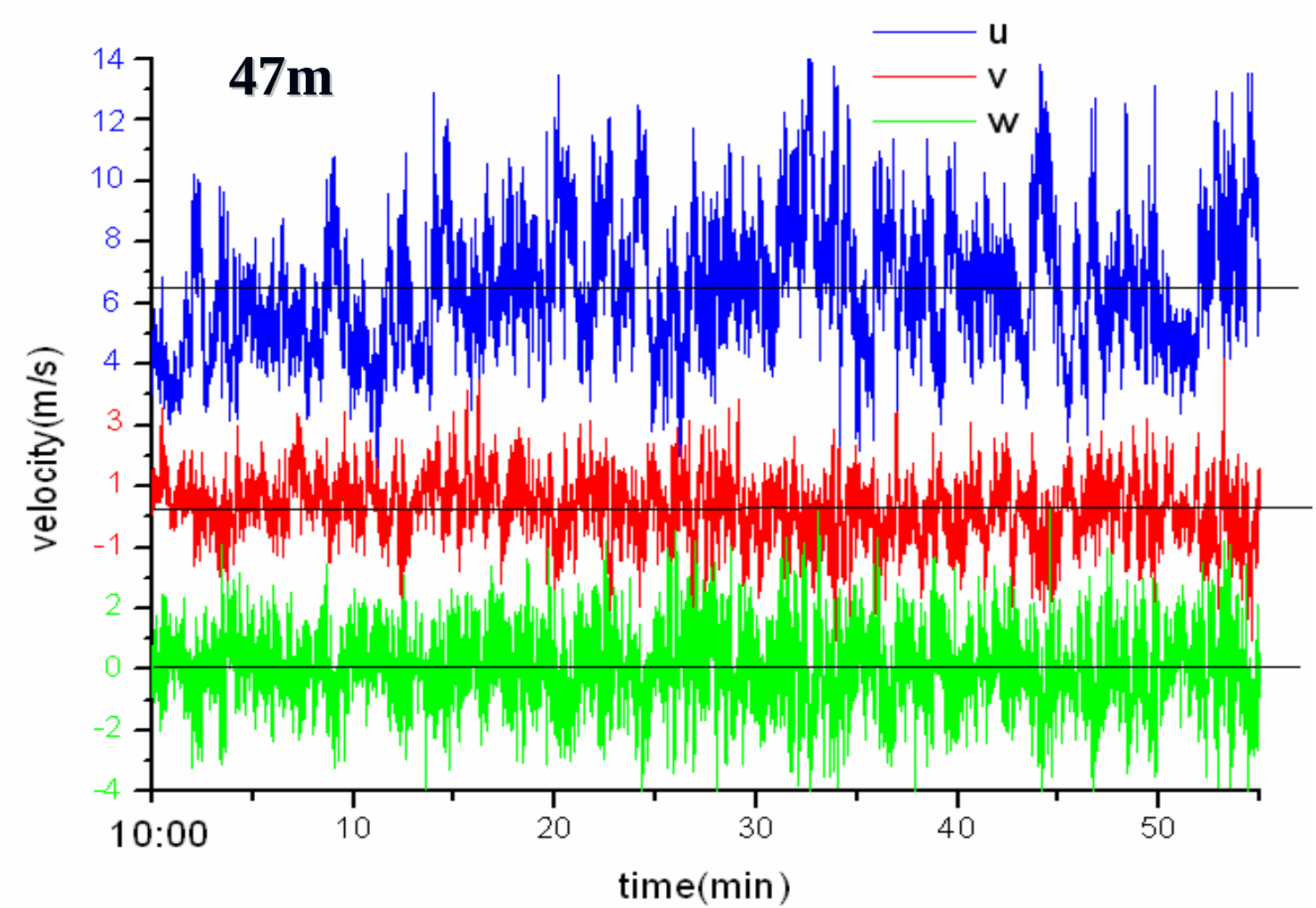
**There must be another effective mechanism for the penetration of dust particles into the atmosphere.**

**Wind (as well as $u_*$) is non-steady. The sand-dust particles creeping on the land surface have more chances to collide with each other, so the probability of saltation is enlarged. Therefore, we have to modify the (laboratorial determined) $u_{*t}$, or apply an apparent fraction velocity.**

# Gust Wind and the 3-D Coherent Structure of Wave Train

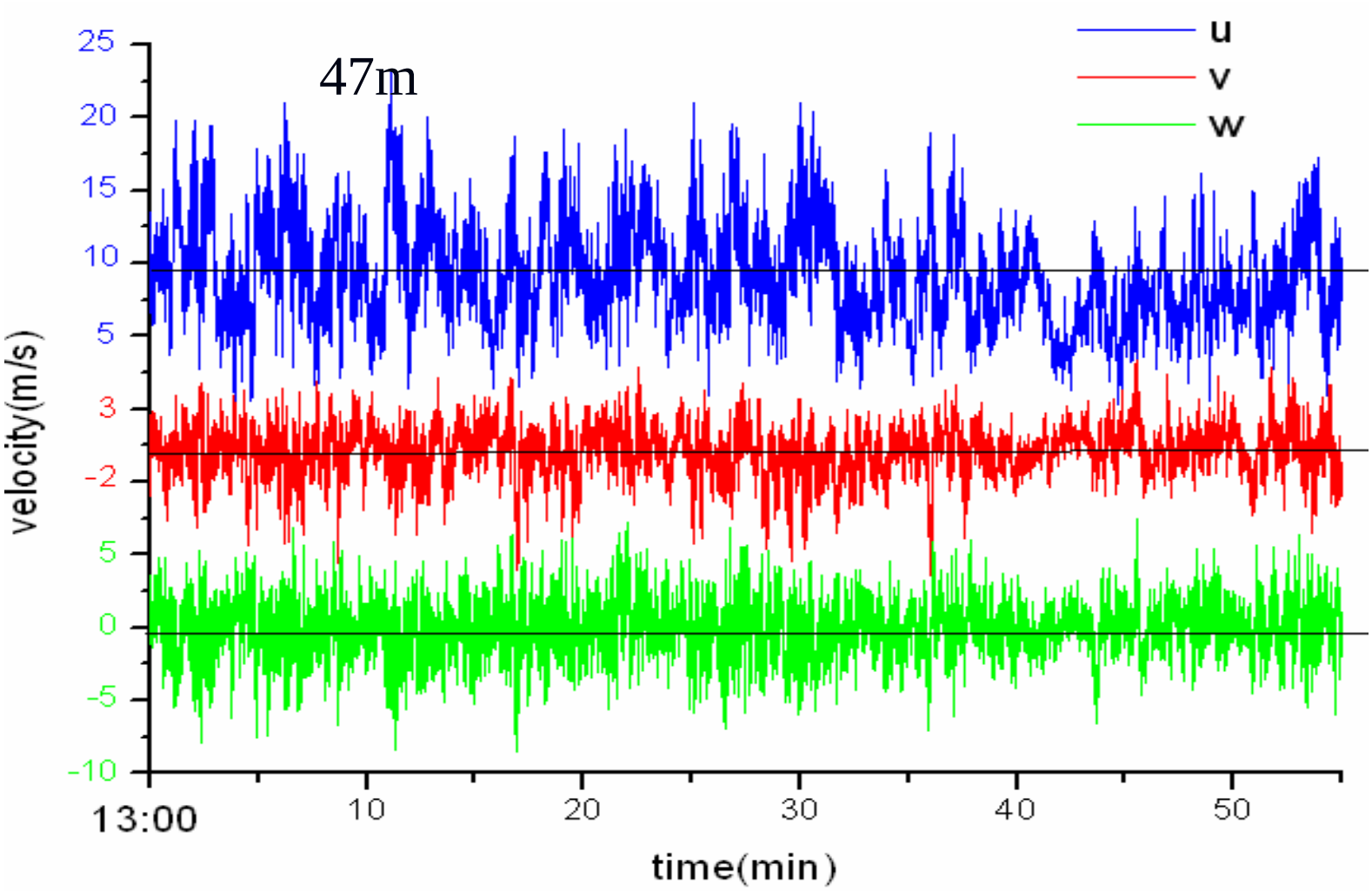
- Detection of the wave train
- The coherent structure and the vertical propagation of wave train
- The efficiency of coherent disturbances in the vertical flux of momentum.
- Friction (turbulent) Velocity.

# Wind speed observation from Beijing 325m tower




**Observed by ultrasonic anemometer**

# Wind speed observation from Beijing 325m tower

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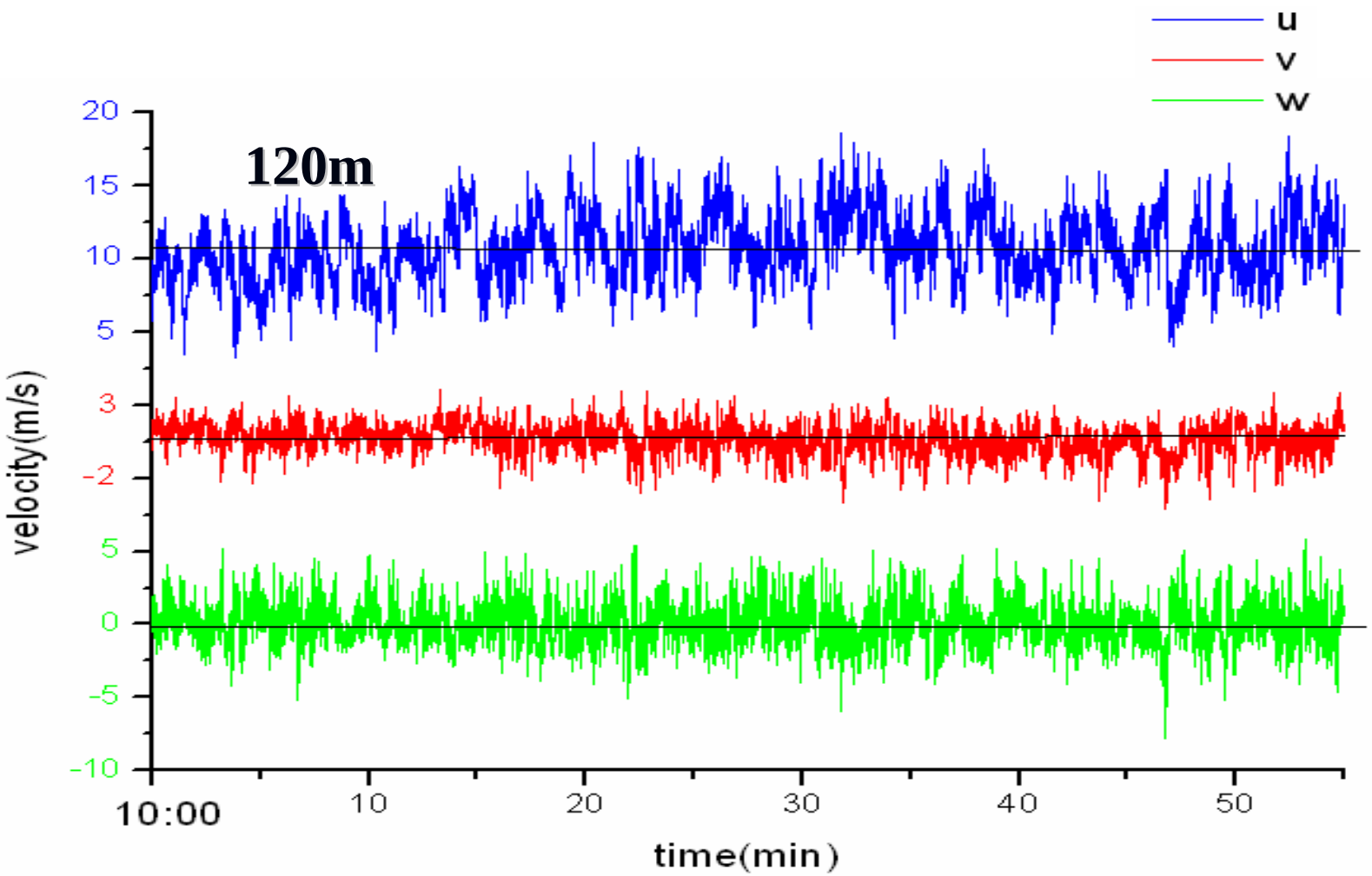


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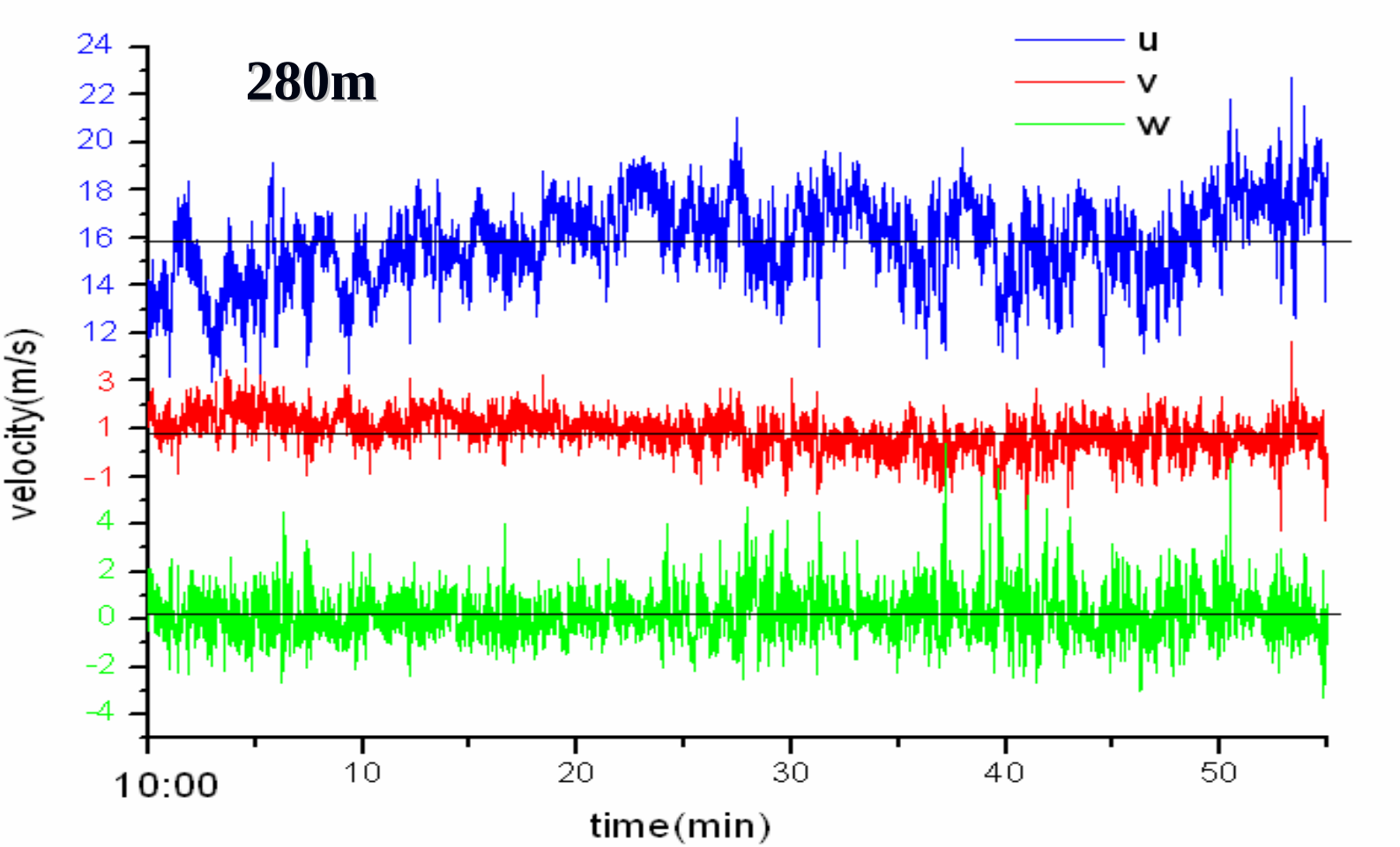
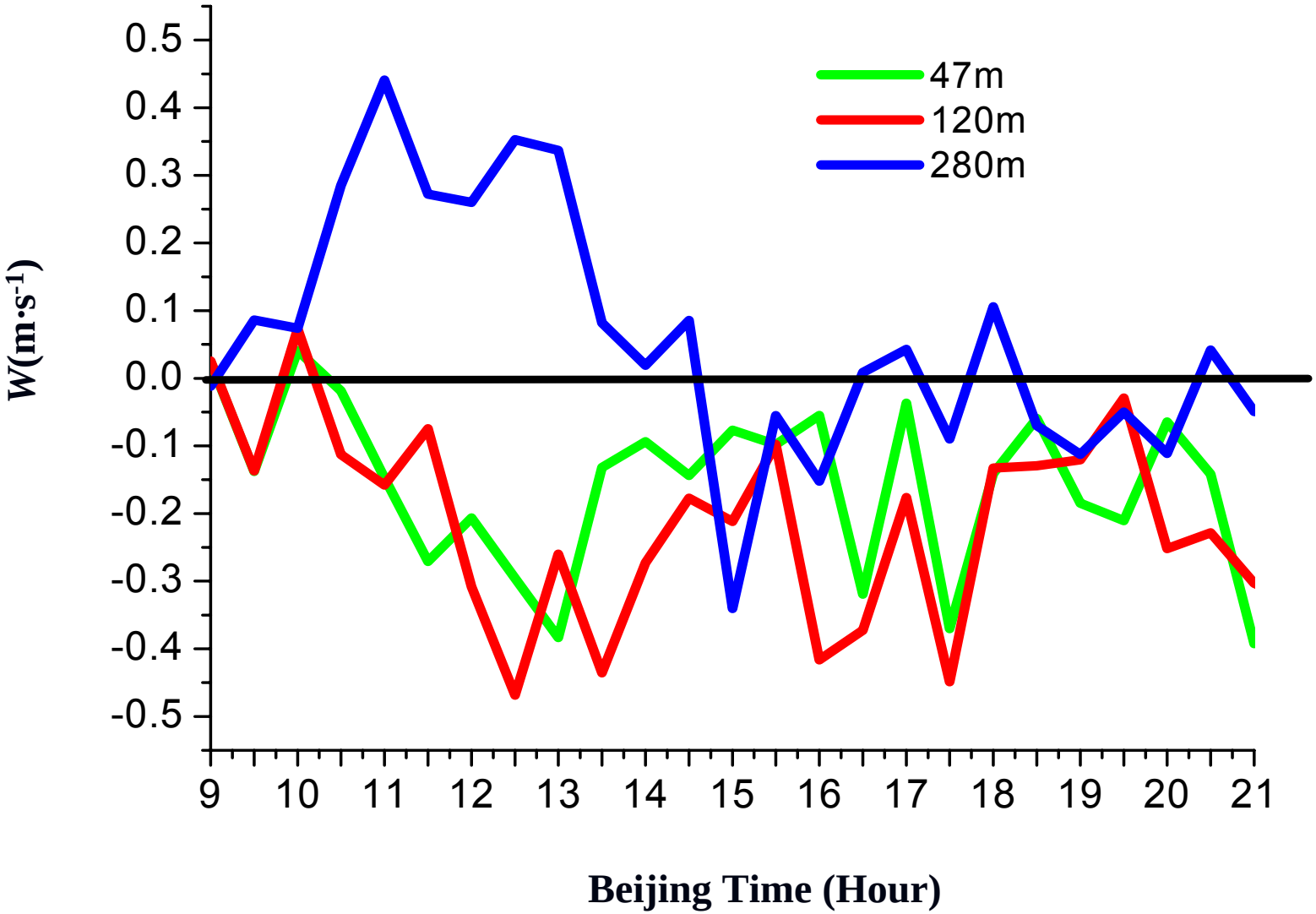
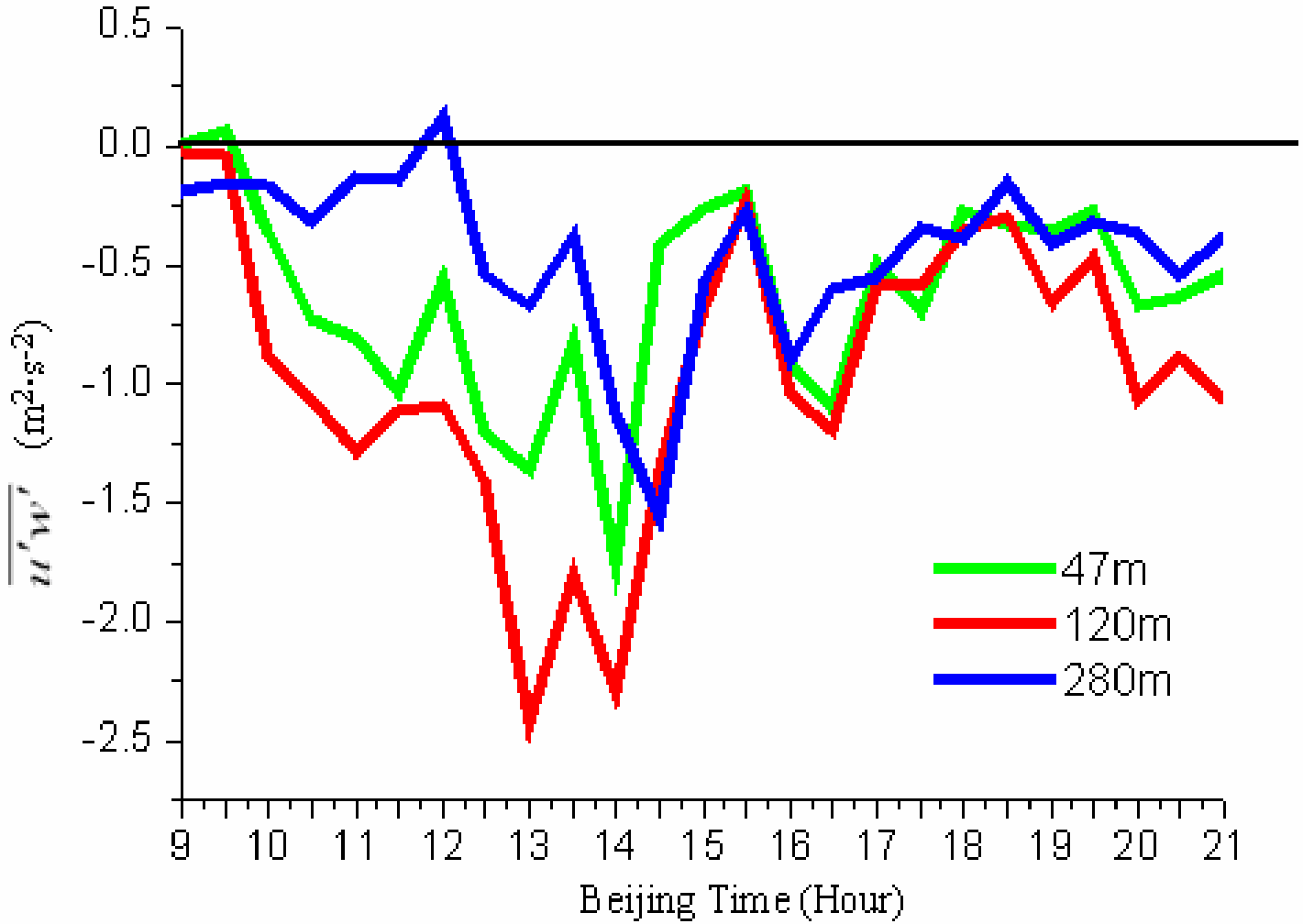



**Observed by ultrasonic anemometer**

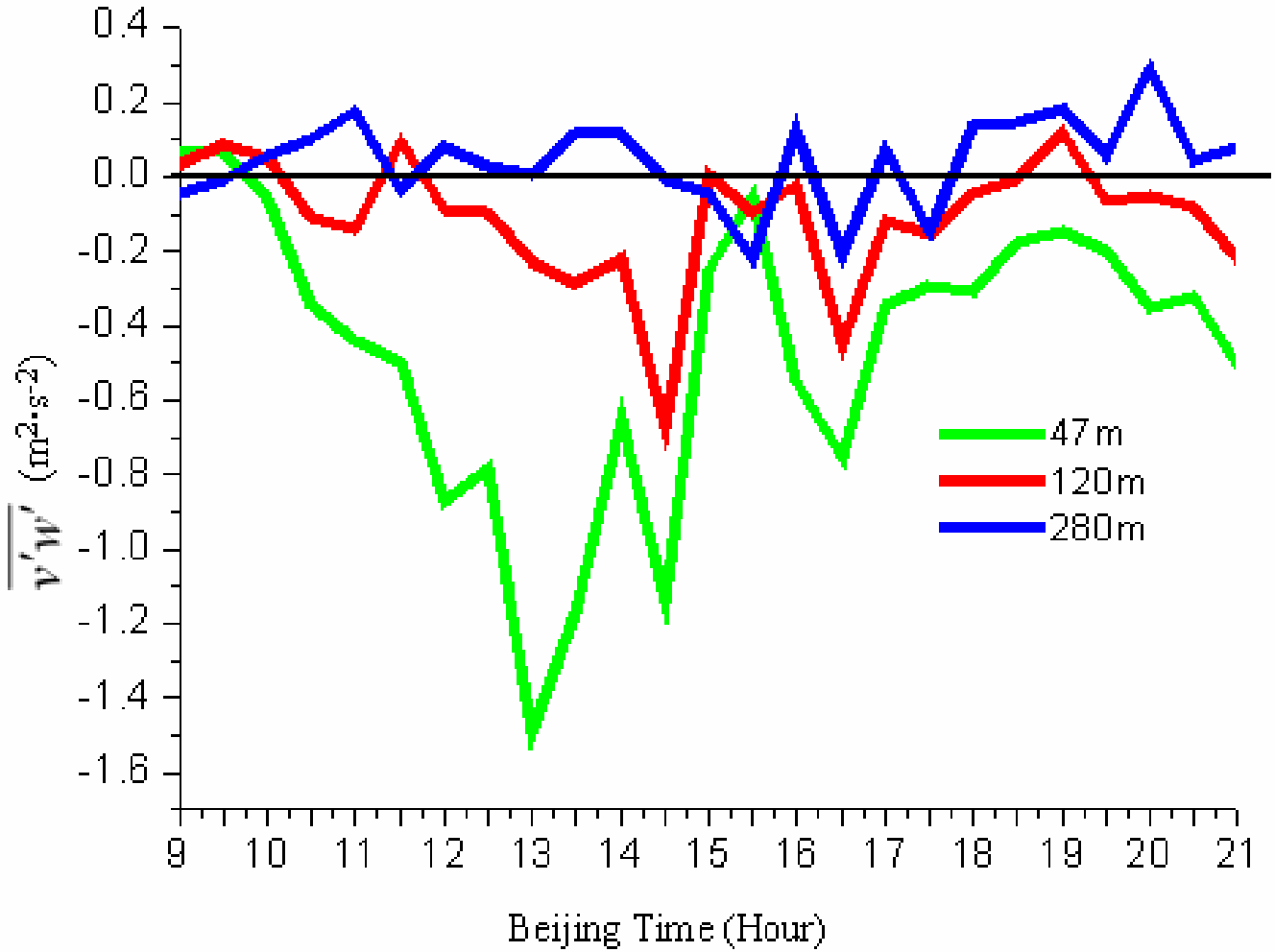
# 20min-average vertical wind speed



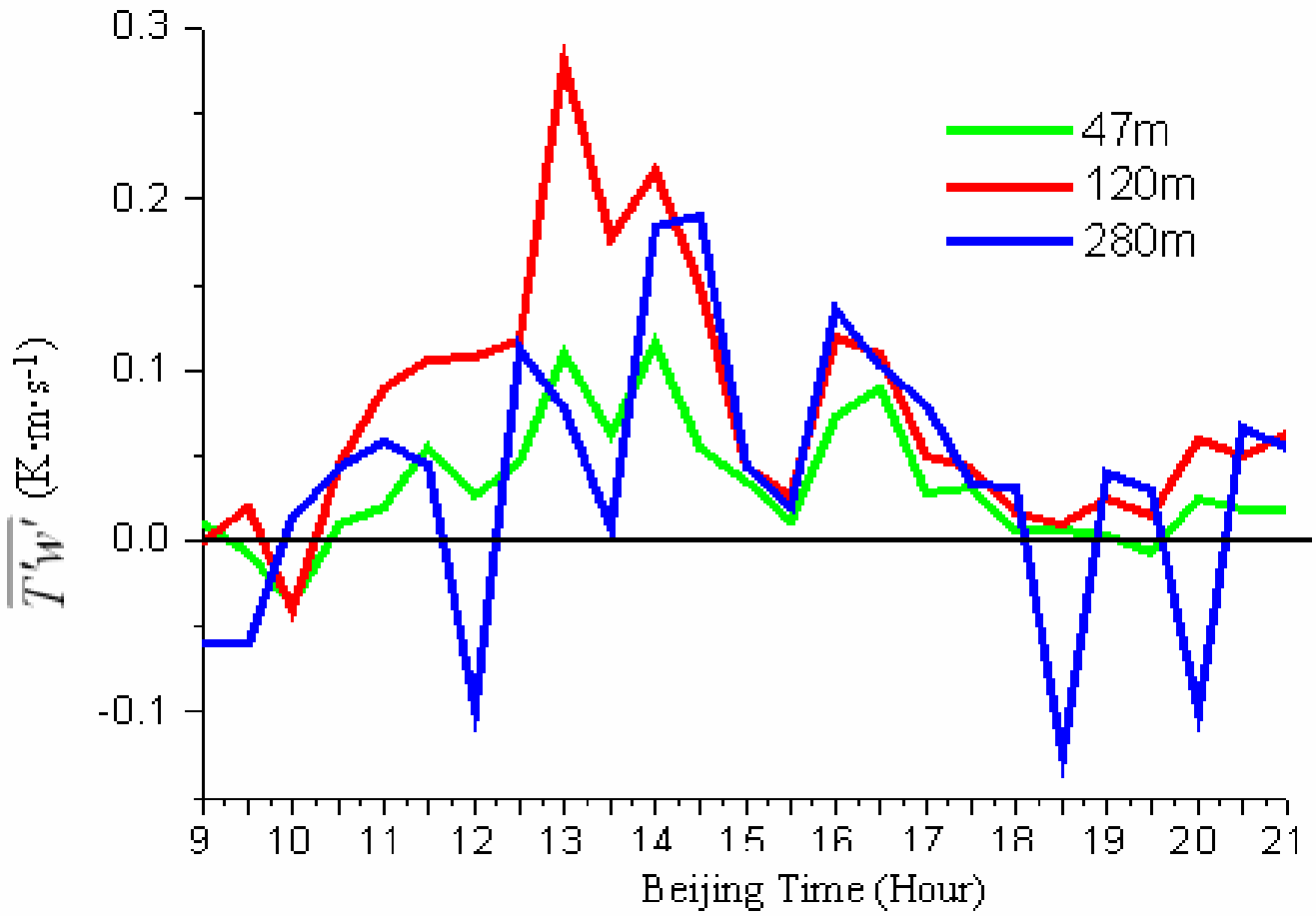
# Vertical Flux of U Momentum



# Vertical Flux of V Momentum

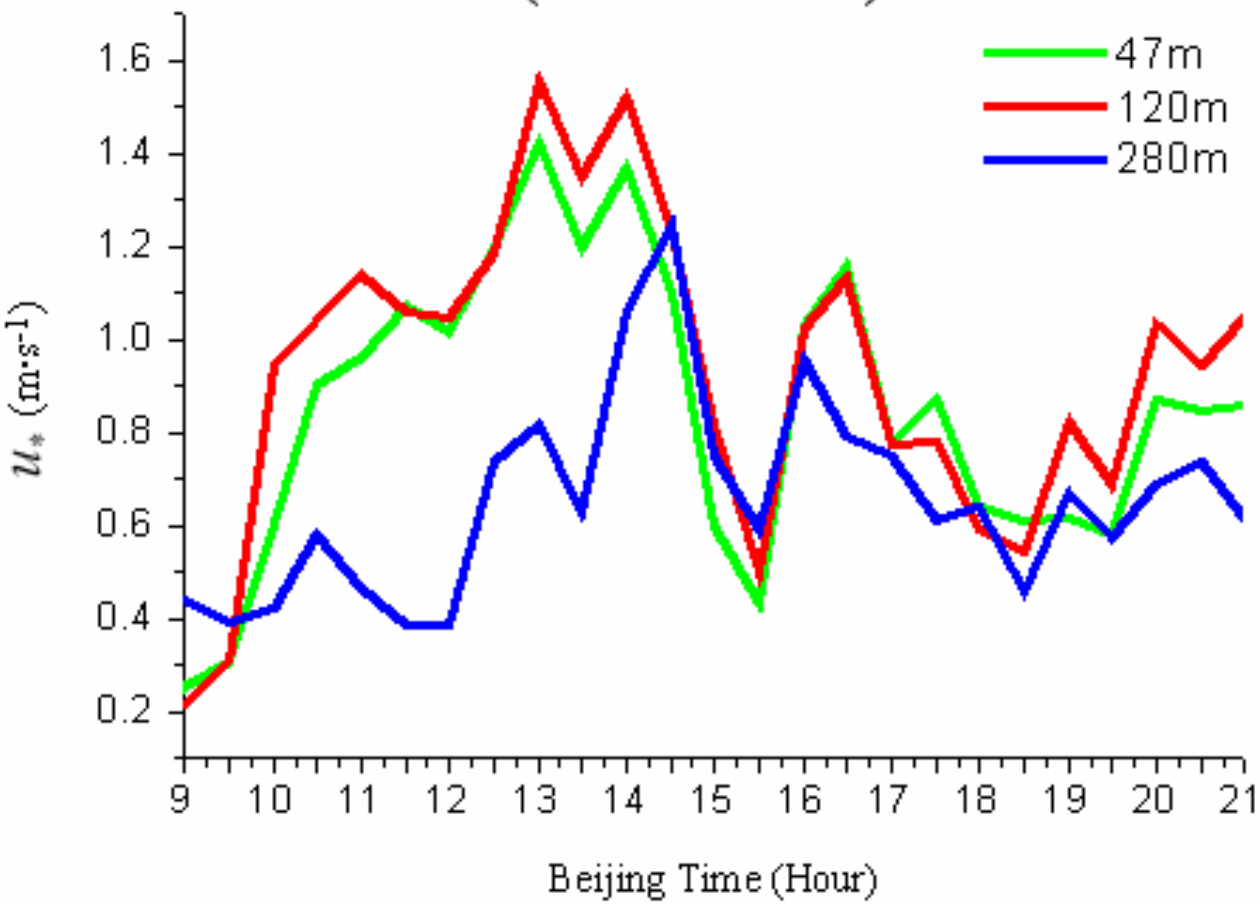


# Vertical Flux of Sensible Heat

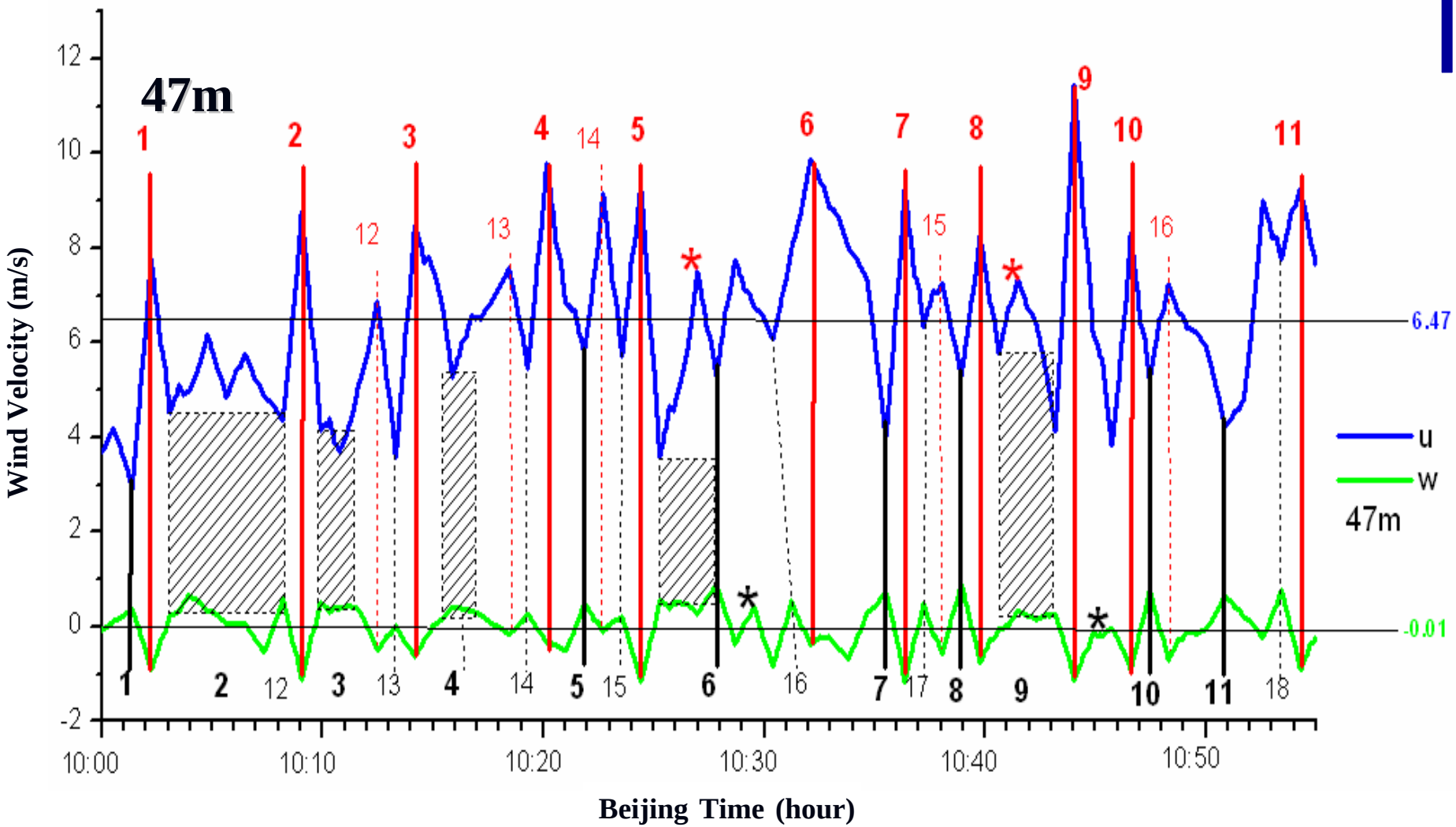


# Friction Velocity $u_*$

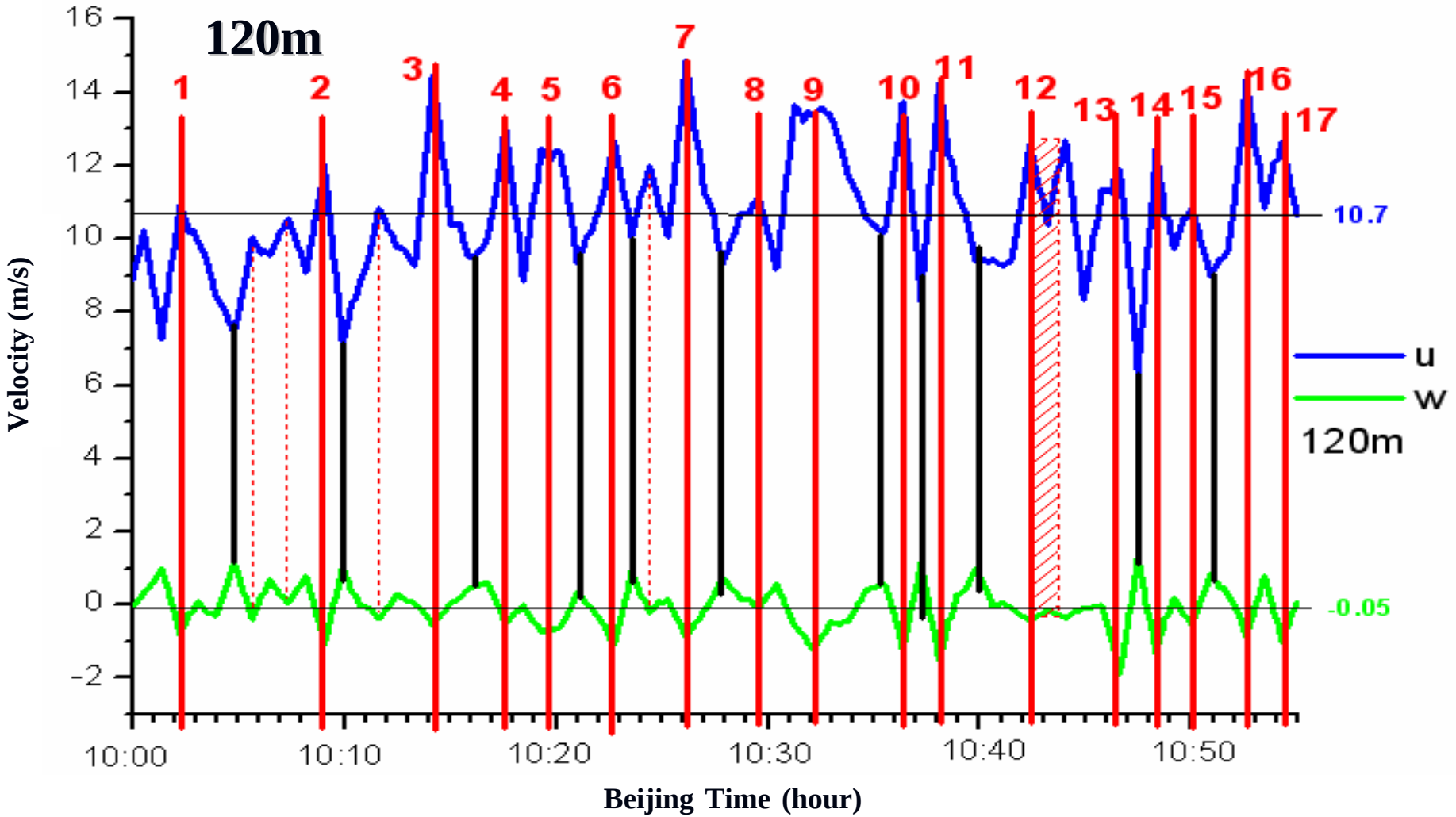
$$u_* = (\overline{u'w'}^2 + \overline{v'w'}^2)^{1/4}$$



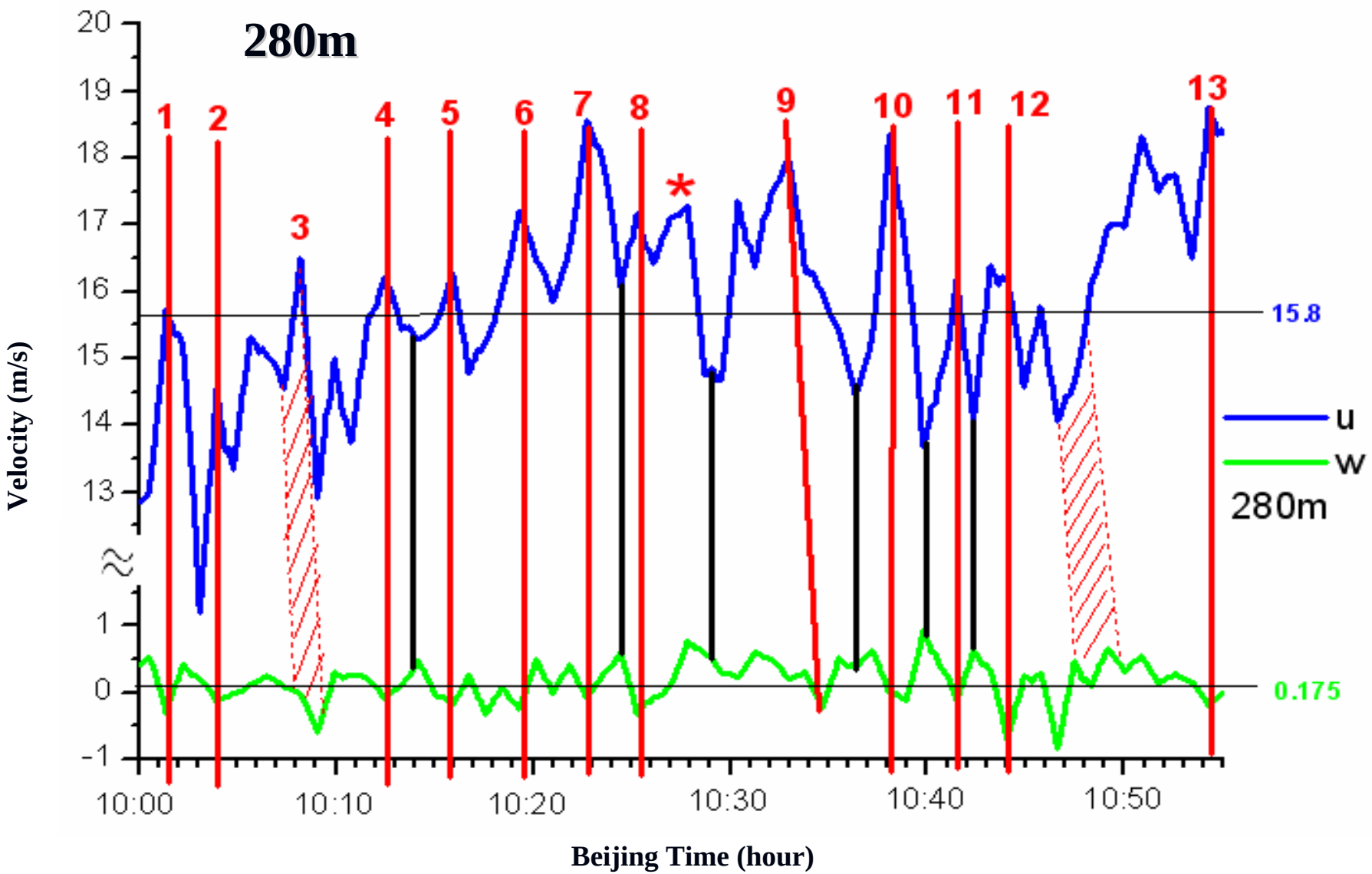
# Averaged for every 1min (coherent structure)



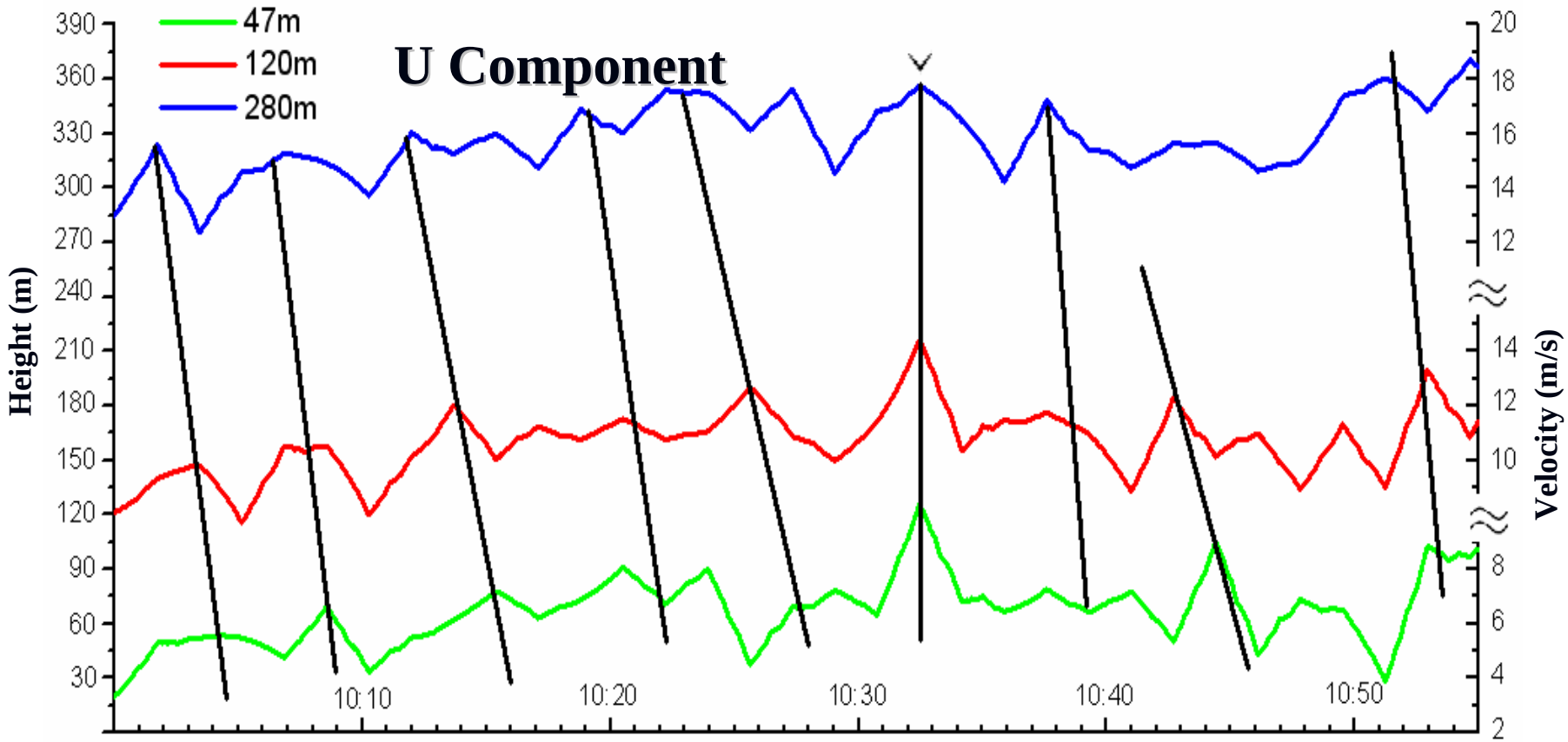
# Averaged for every 1min



# Averaged for every 1min

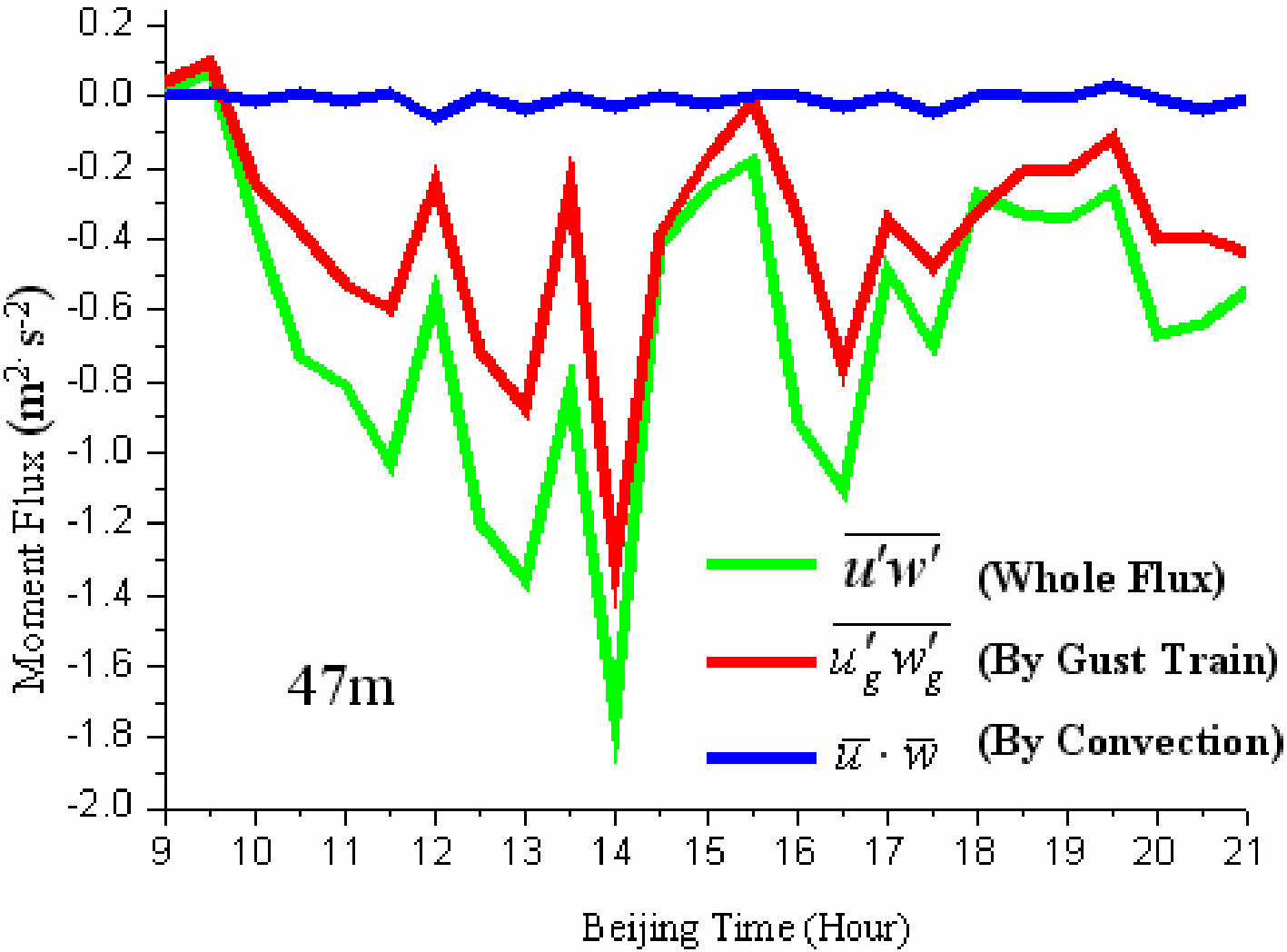


# Averaged for every 2min

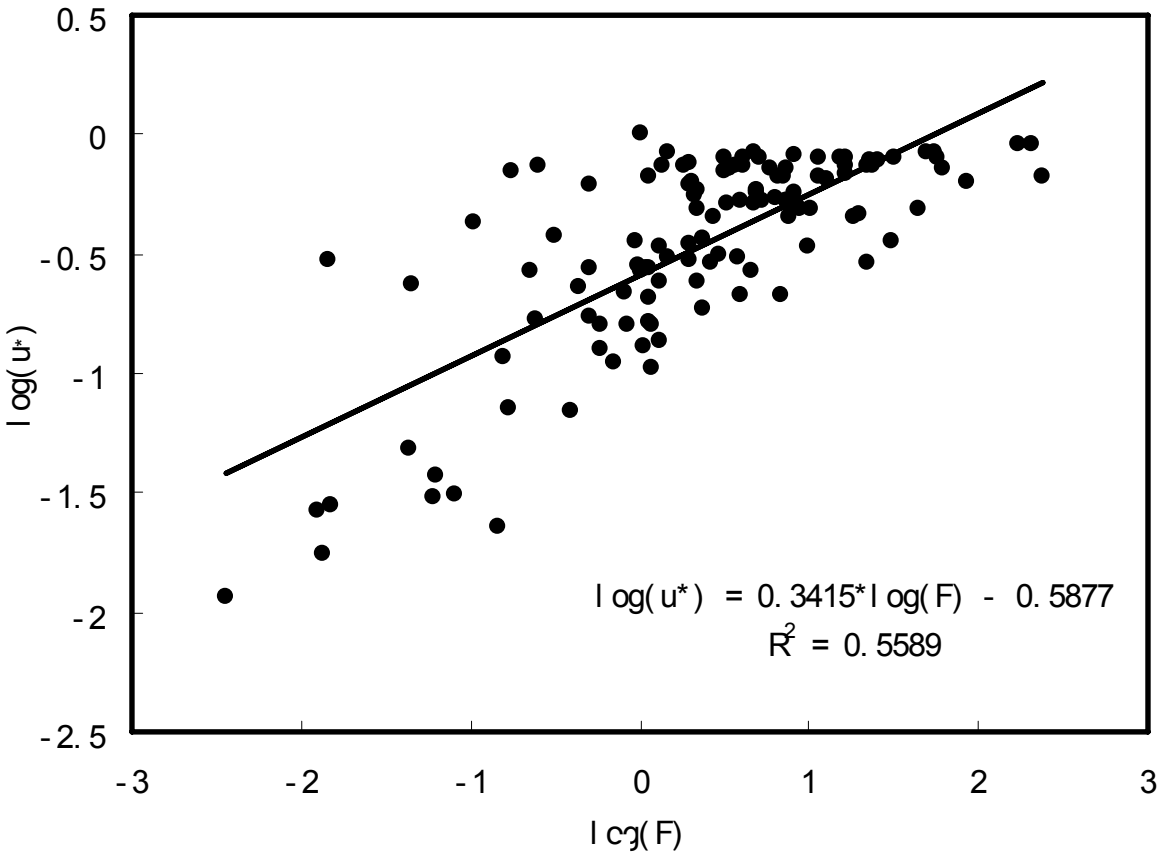



**Vertical propagation of gust wave train**

# Vertical Flux of U Momentum



# Relationship between dust flux and friction velocity




$$F = 10^{1.72} \cdot u_*^{2.93}$$

$$F \propto C \cdot u_*^3$$

**Correlative coefficient:**

$$R = 0.748$$

**For dust emission, $u_*$ should be corrected as $u_*^*$**

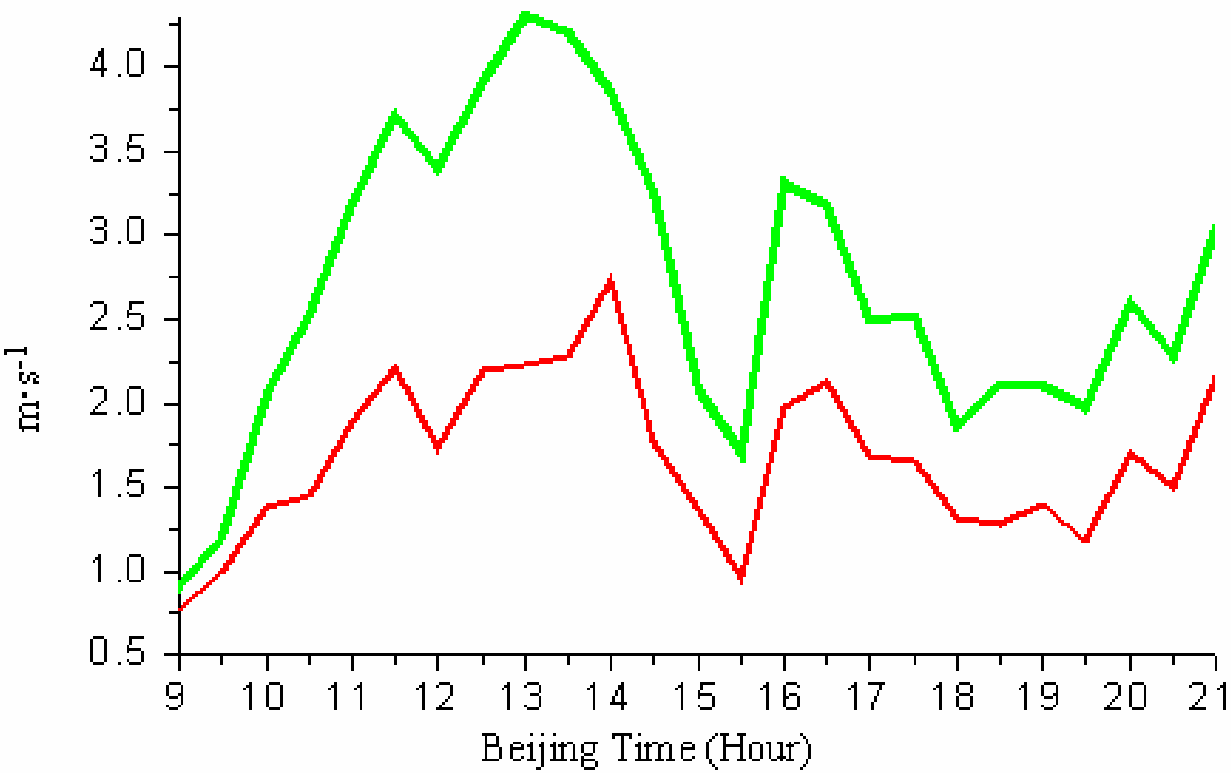
**by taking the effect of gust wave train into account.**

$$(u_*^*)^4 \approx u_*^4 + A(e_g')^2$$

# Intensity of 3D Velocity Fluctuation

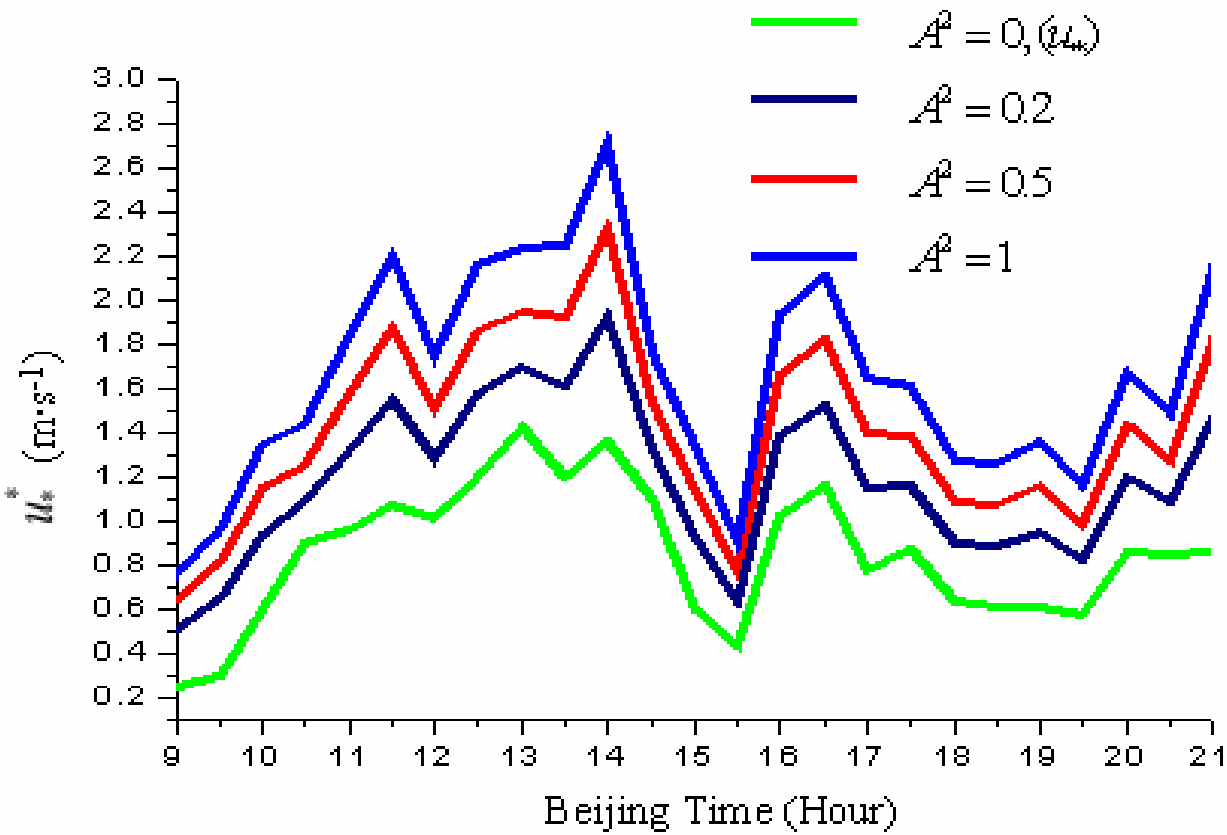
$[e]^{1/2}$ (All Fluctuation)

$[e_g]^{1/2}$ (Gust Wave Train Alone)

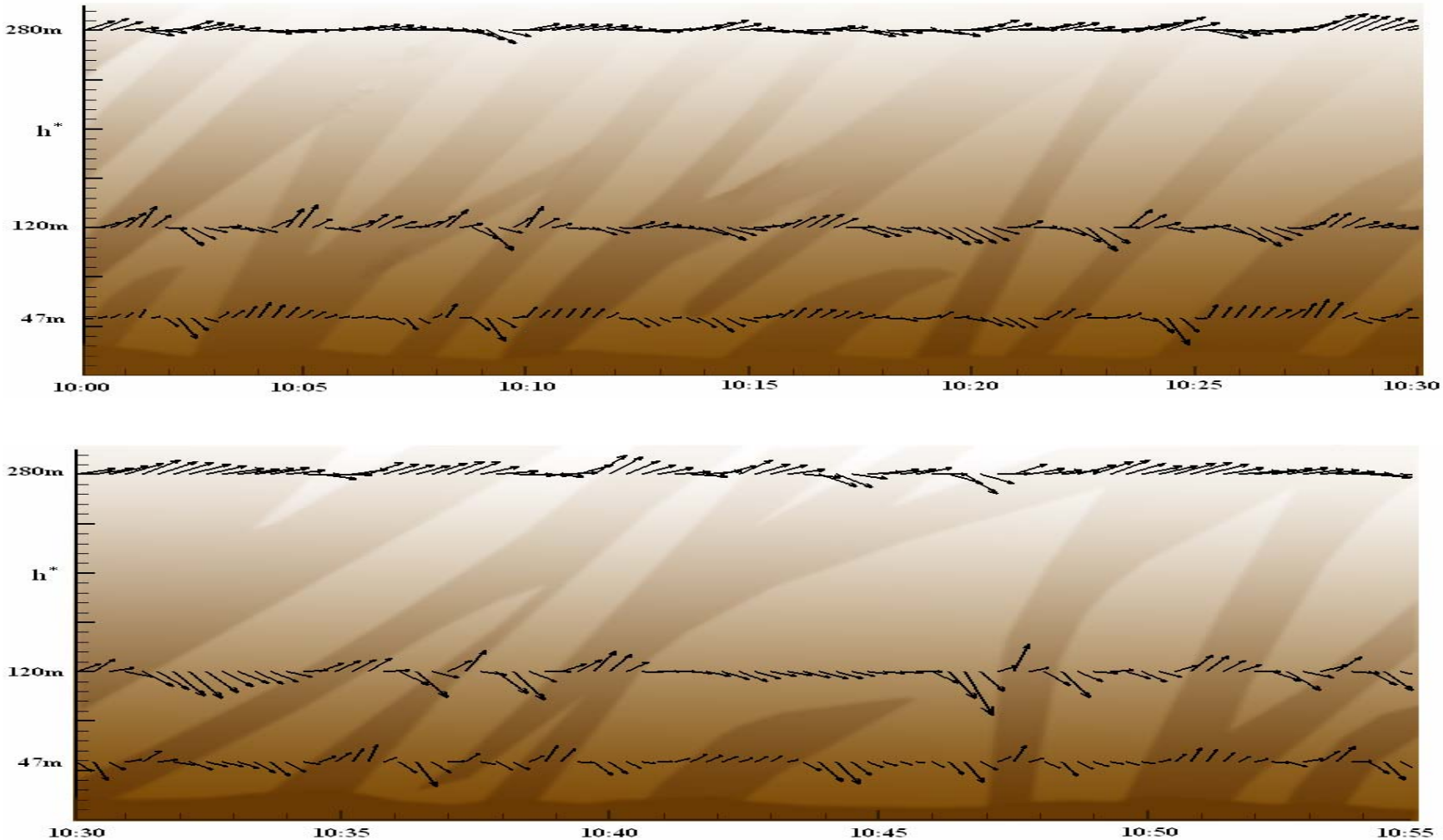


# $u_*$ and $u_*^*$

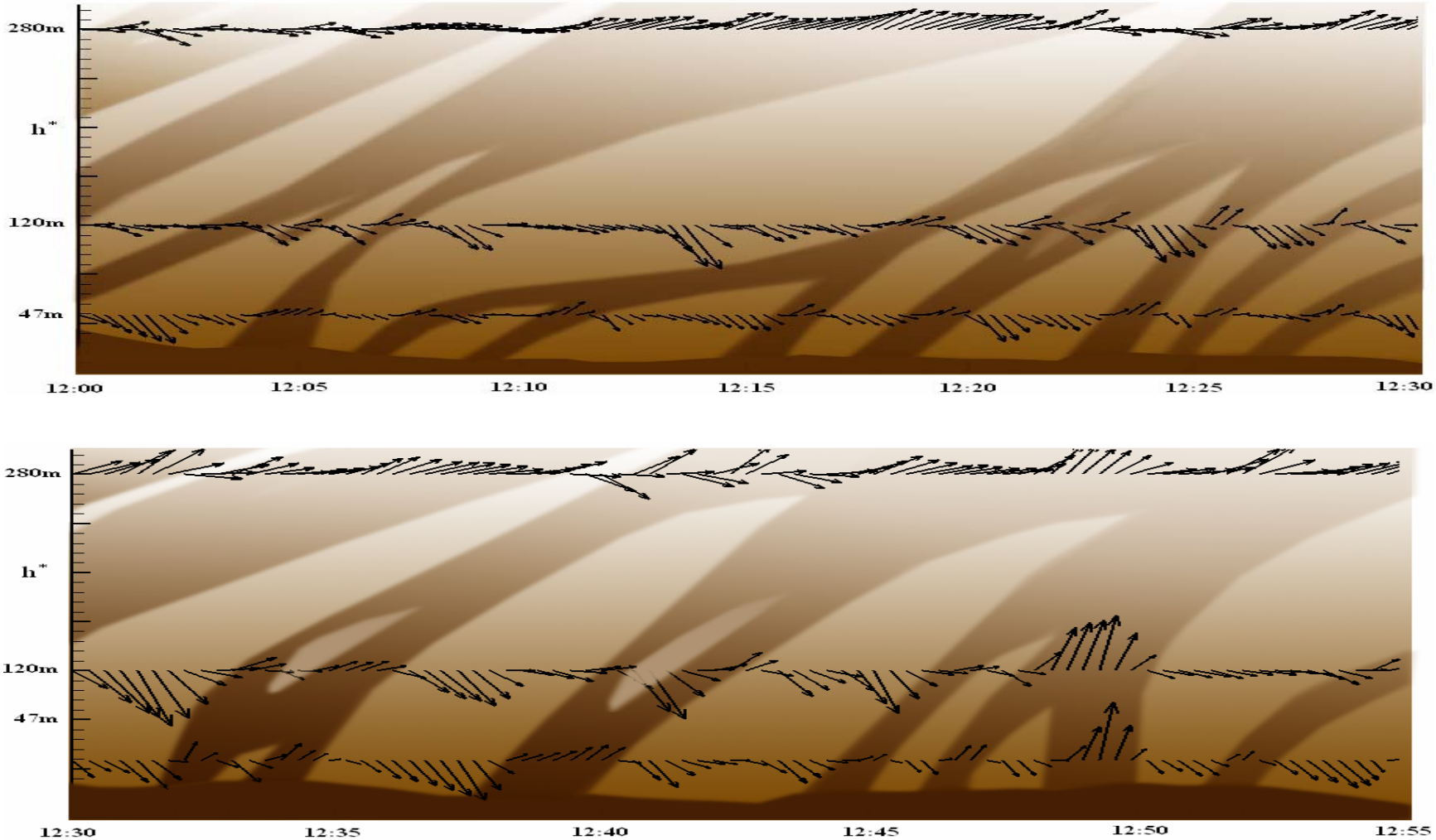
$$[(u_*^*)^4 \approx (u_*)^4 + A^2(e'_g)^2]$$



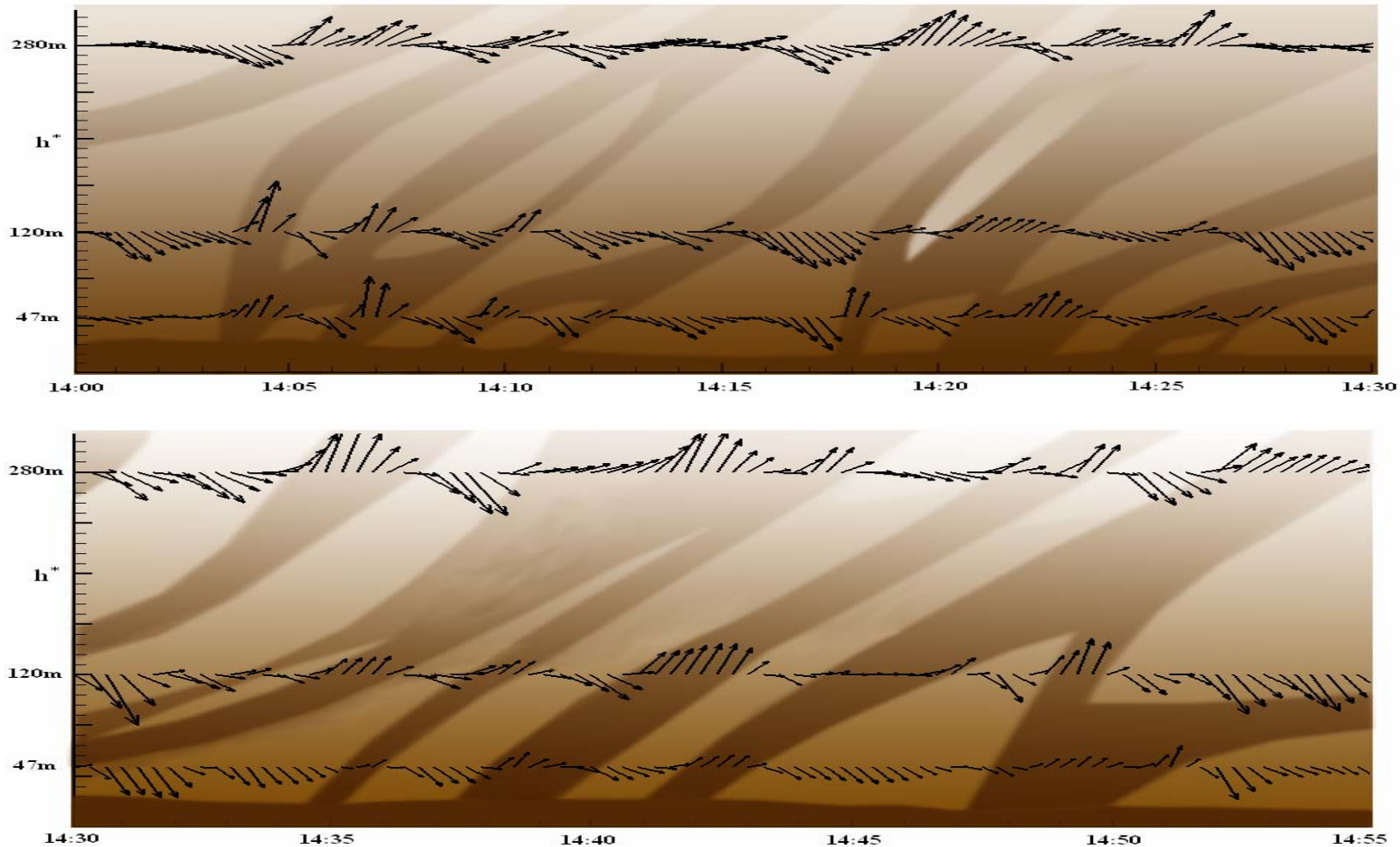
# 3D Coherent Disturbances and Impulsive Penetration of Dust



# 3D Coherent Disturbances and Impulsive Penetration of Dust

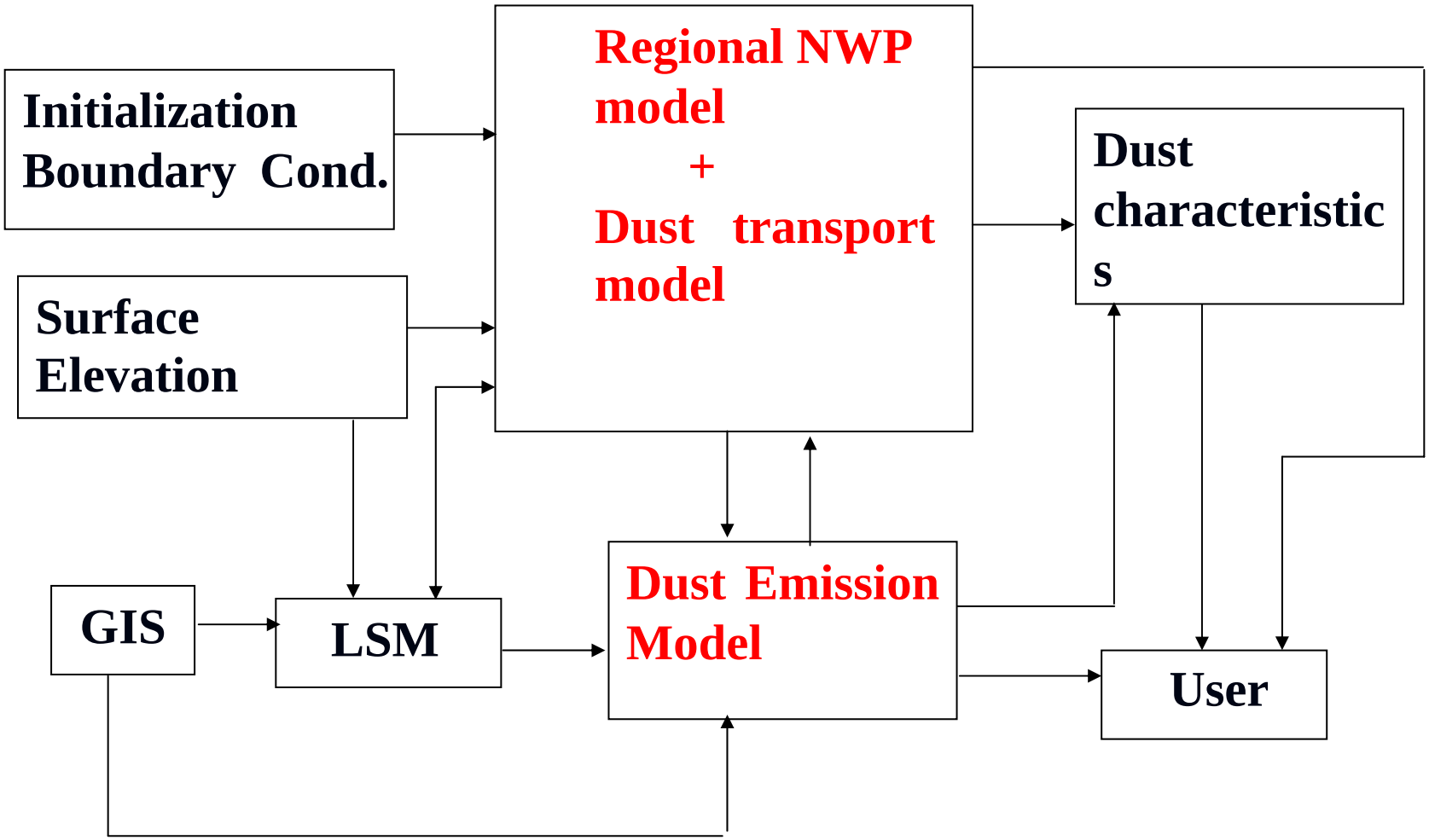


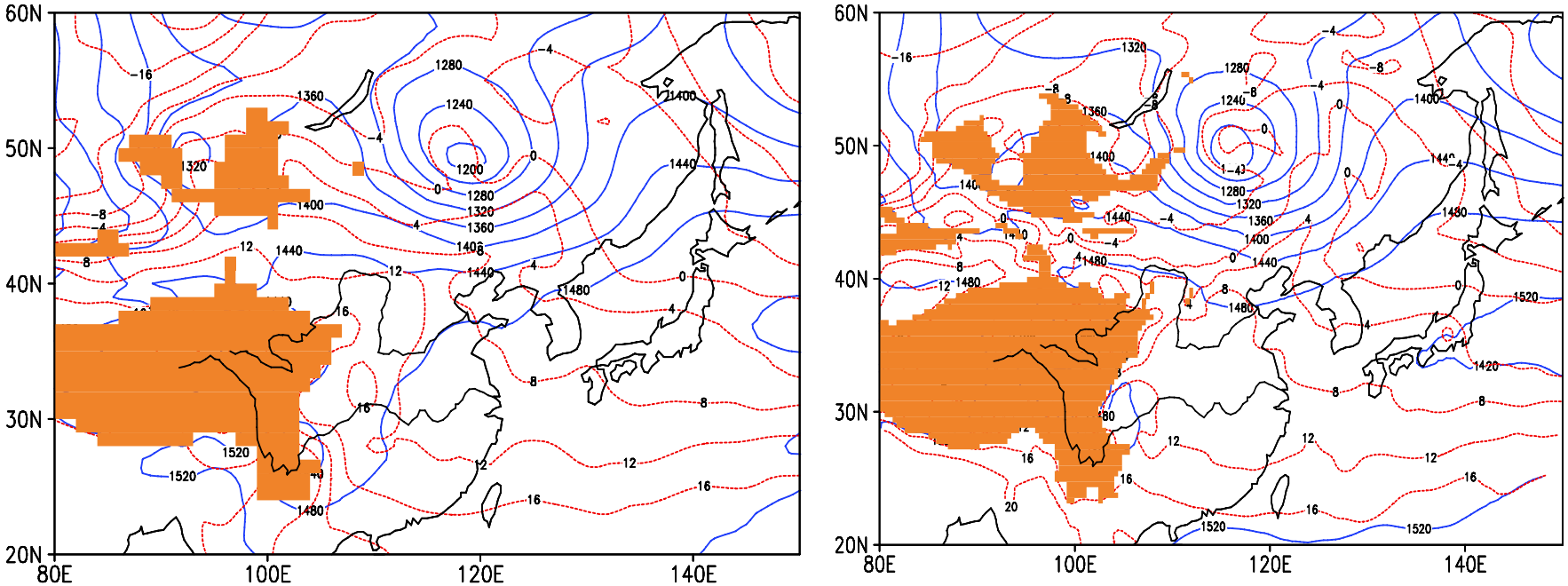
# 3D Coherent Disturbances and Impulsive Penetration of Dust



**During dust storm event, there is always very strong wind, and the prevailing type of motion in the ABL is gust wind.** It processes 3-D propagating wave train. The gust impulse ( $u_g' > 0$) is accompanied by strong descending motion ($w_g' < 0$), downward transport of momentum ( $\overline{u'w'} < 0$, $\overline{u_g'v_g'} < 0$ ), and dust emission *(F, Q > 0*) from soil surface layer; while the gust break is accompanied by strong impulse of ascending motion ($w_g' > 0$ ), which makes the dust particles accumulated in the surface and lowest levels of ABL due to the suppression of systematical meso-scale descending motion) penetrating into the upper levels of ABL and further into the free atmosphere. **This is a very effective mechanism of downward transport of momentum and dust emission and entrainment.**

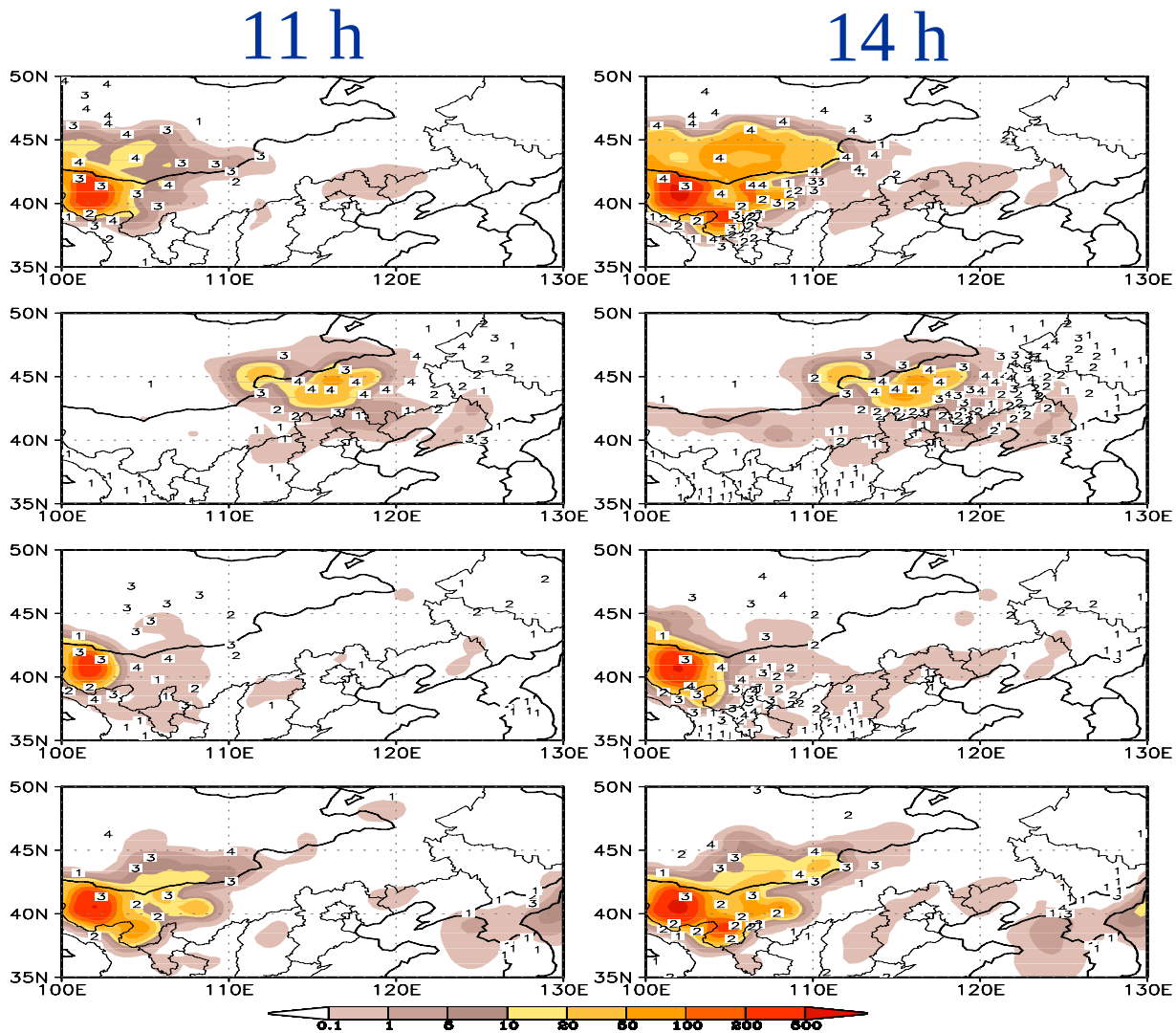
# Numerical Prediction of Dust Storm Weather





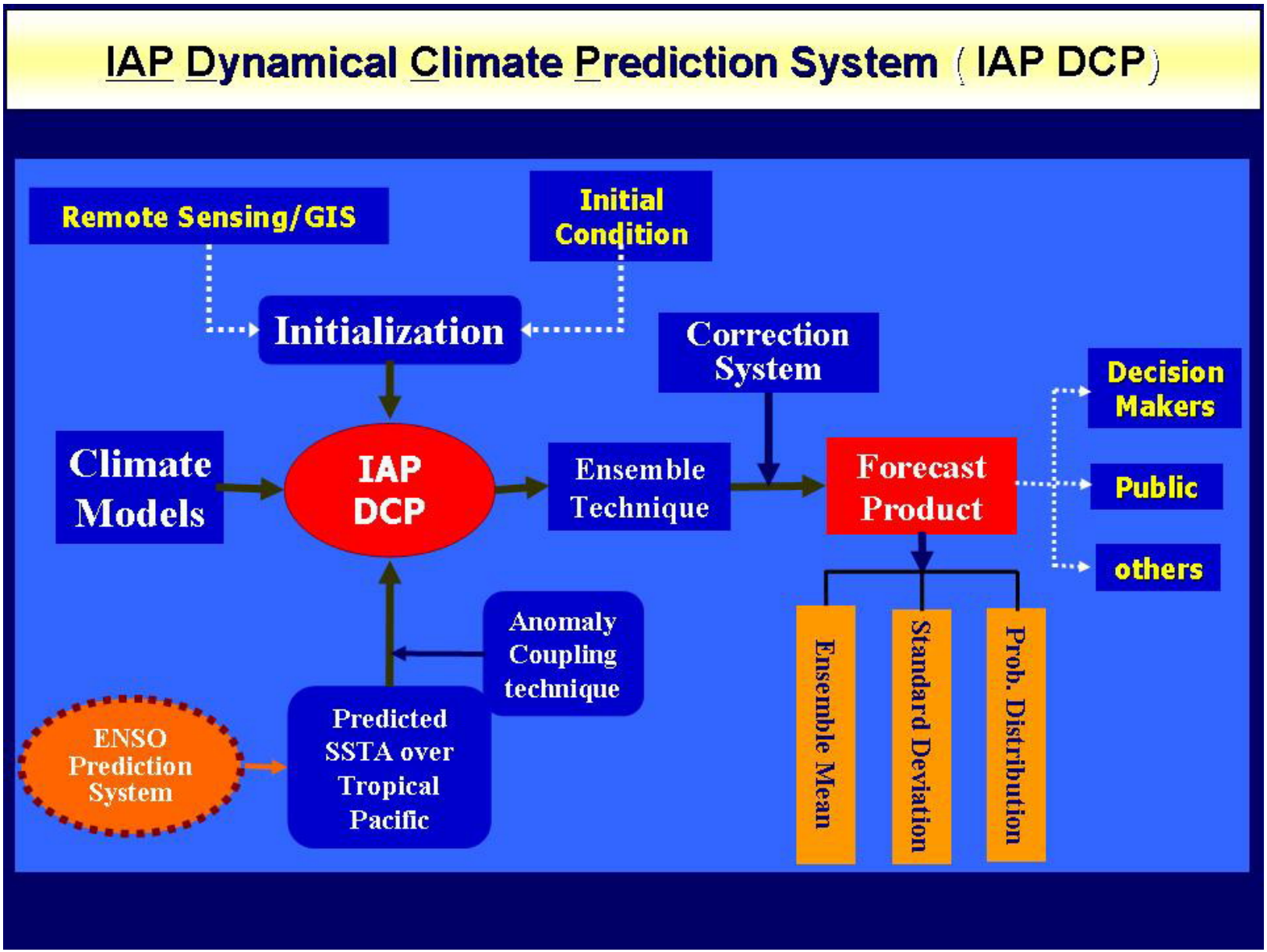

**850hPa (08:00, April 7, 2001)** **— Height, ···· Temperature**

**Left Observation Right 24 hour prediction**



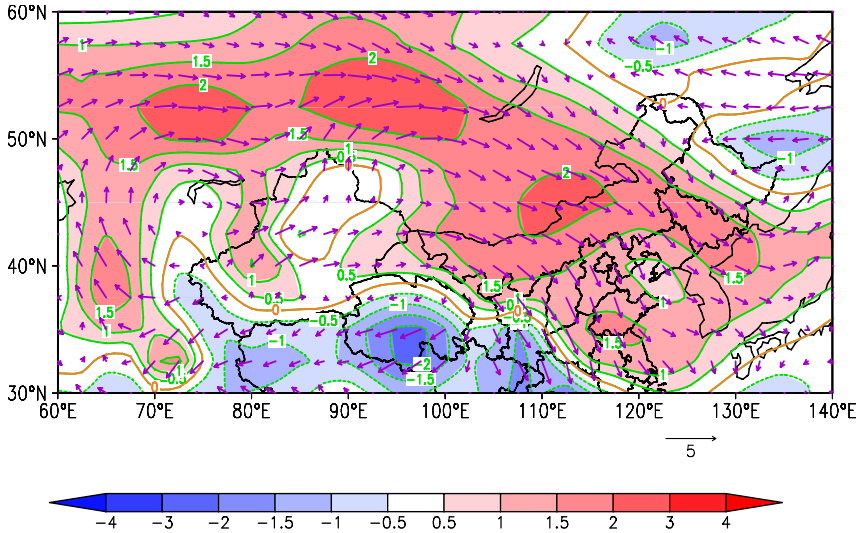

**Predicted dust concentration and the observed weather phenomena**

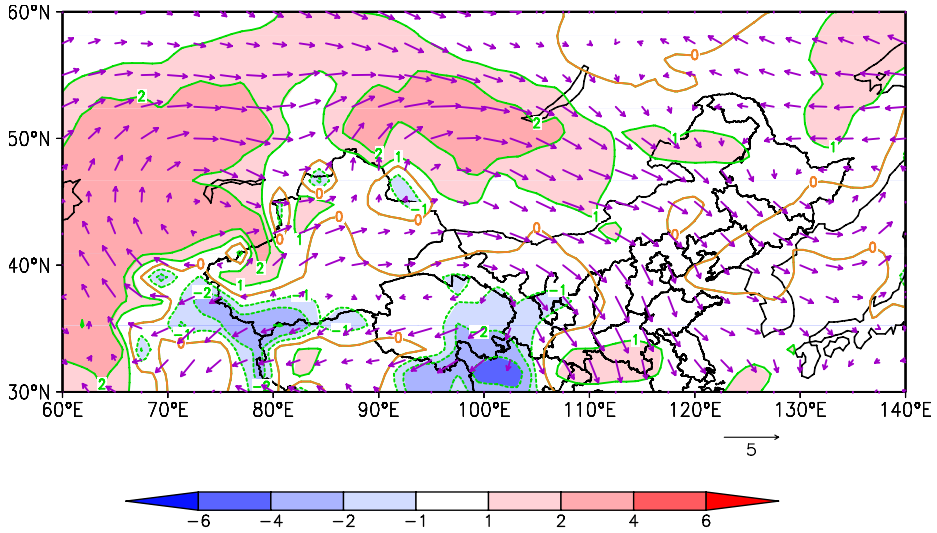
# IAP Dynamical Climate Prediction System (IAP DCP)

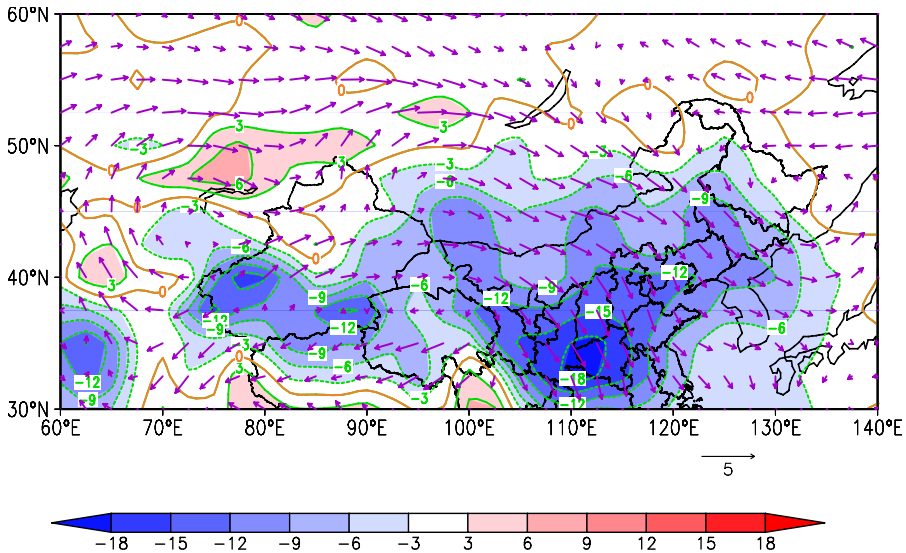


# Climate Anomalies and Environmental Conditions

## Favorable (/Suppressive) for the Frequency and Intensity of Dust Storms and Their Predictions (Extraseasonal, by IAP/DCP)



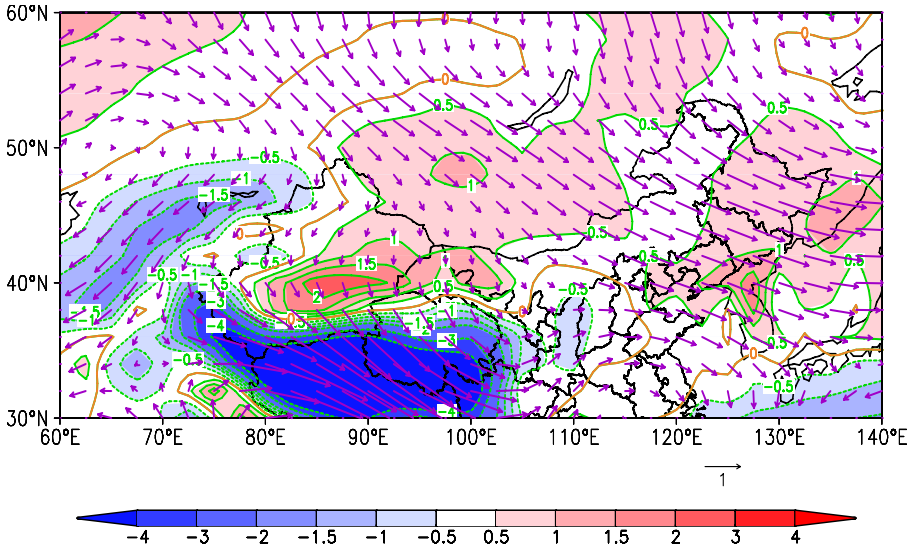

**Mar.- Apr. mean anomalies, 2001.**

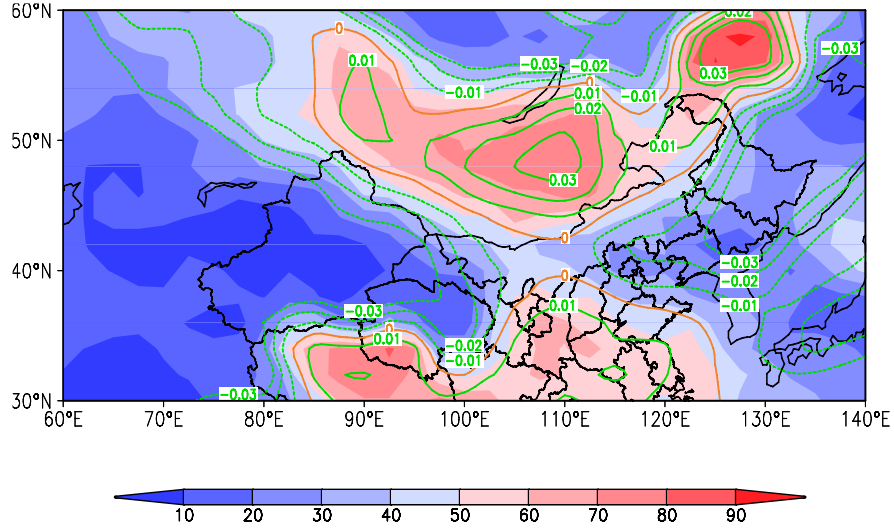
**Frequent and strong dust storm events**

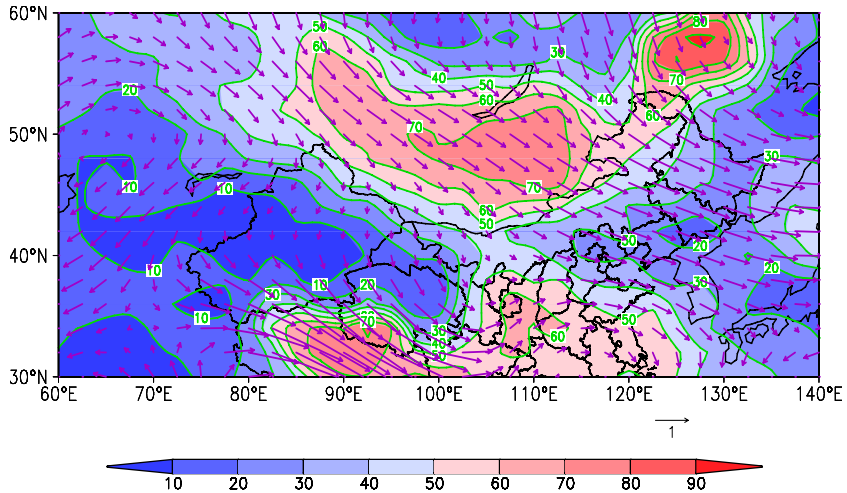
**Upper left: 850hpa wind vector and wind speed.**
**Upper right: 850hpa wind vector and surface temperature.**
**Bottom: 850hpa wind vector and surface RH.**

**Red: positive anomaly,**
**Blue: negative anomaly.**

# Observation



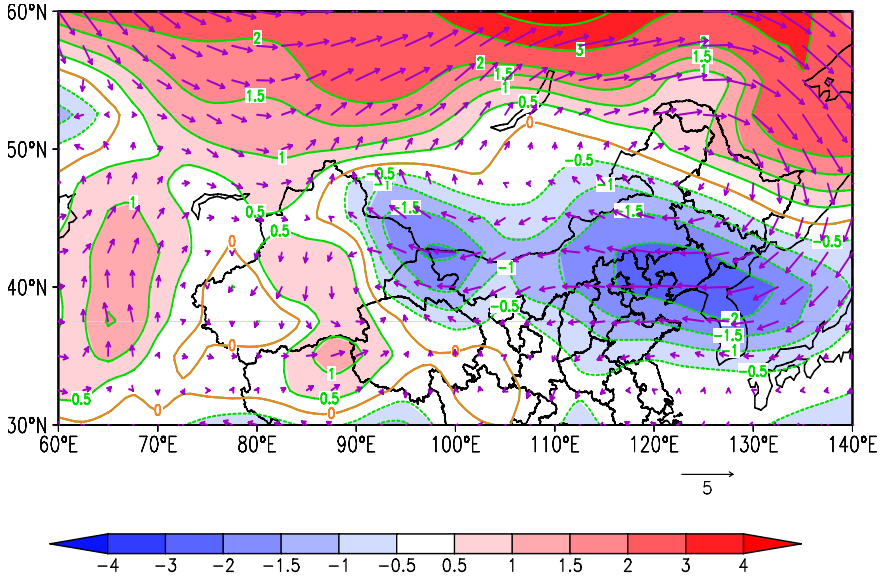



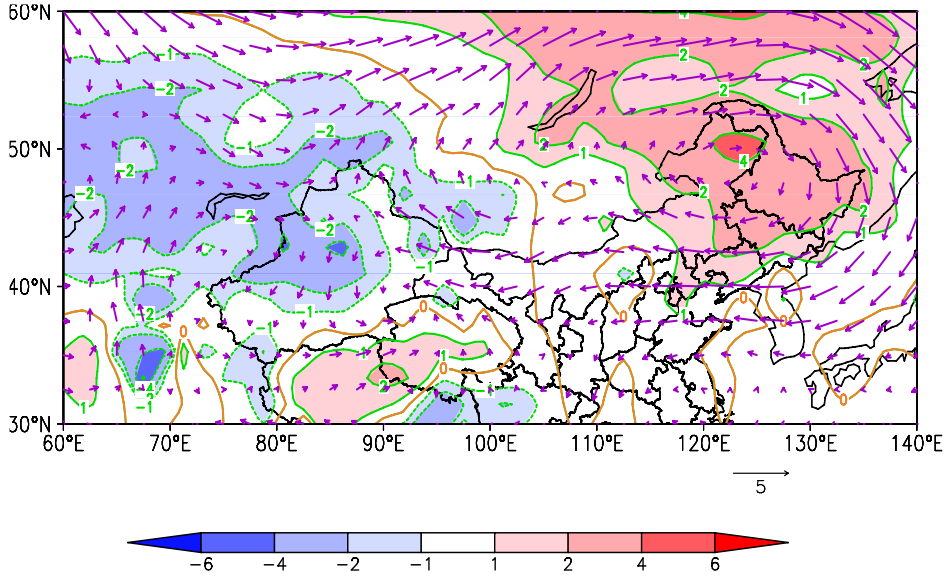



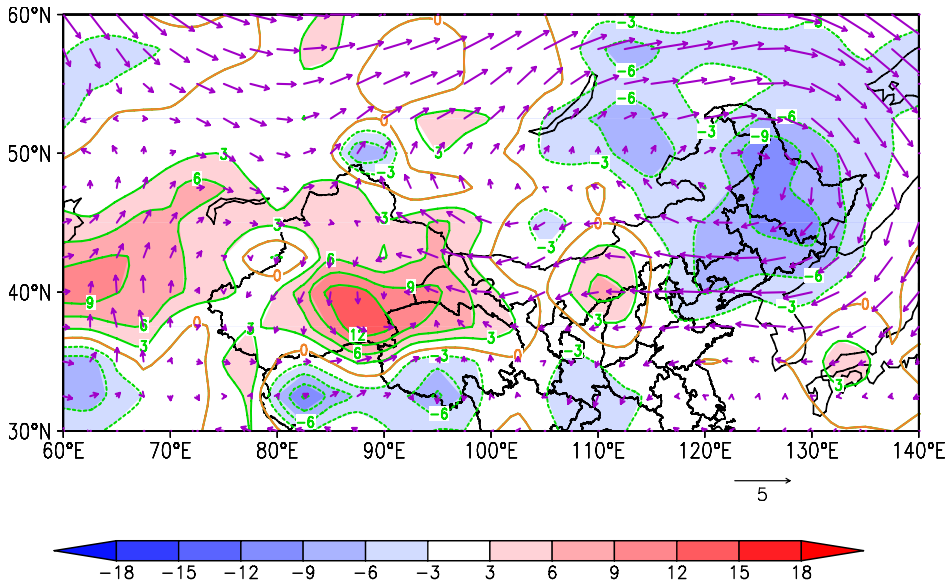

# Prediction

**Mar.- Apr. mean anomalies, 2001. (Predicted by DCM/IAP, initiated from Oct. 2000)**

**Upper left: 850hpa wind vector and wind speed (red: positive anomaly, blue: negative anomaly).**
**Upper right: Soil wetness and probability of its positive anomaly (red: >50%, blue:<50%)**
**Bottom: 850hpa wind vector and probability of positive anomaly of soil wetness. (red:>50%, blue:<50%)**



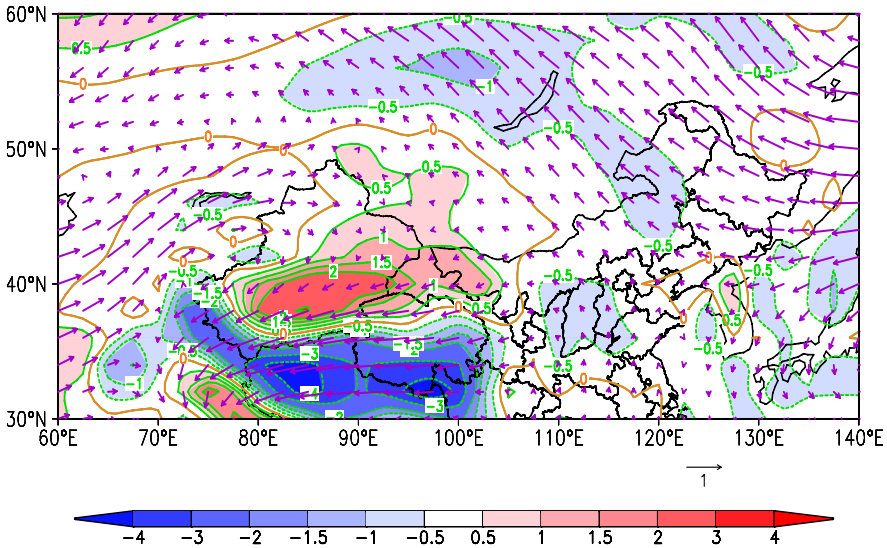



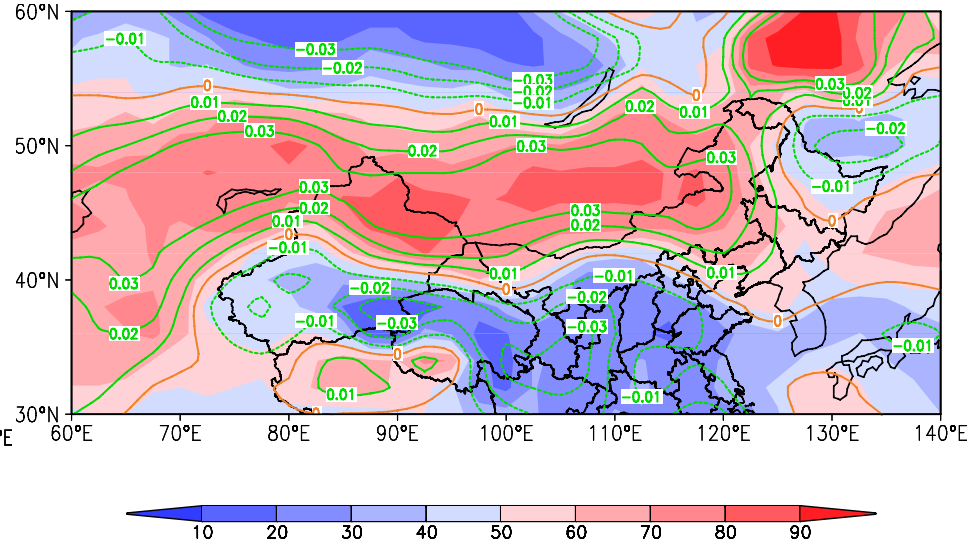

# Observation

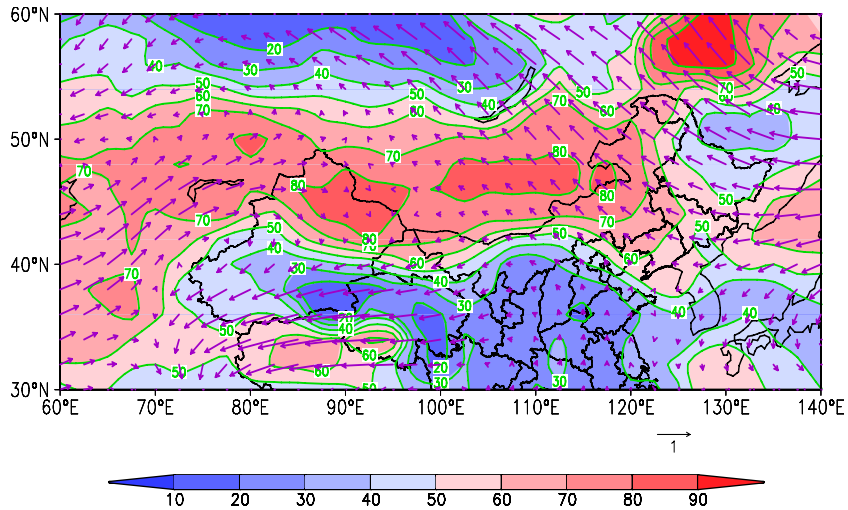
**Mar.- Apr. mean anomalies, 2003.**
**(Seldom and weak dust storm events)**

**Upper left: 850hpa wind vector and wind speed.**
**Upper right: 850hpa wind vector and surface temperature.**
**Bottom: 850hpa wind vector and surface RH.**

**Red: positive anomaly,**
**Blue: negative anomaly.**




# Prediction

**Mar.- Apr. mean anomalies, 2003. (Predicted by DCM/IAP, initiated from Oct. 2002)**

**<u>Upper left</u>: 850hpa wind vector and wind speed (red: positive anomaly, blue: negative anomaly).**
**<u>Upper right</u>: Soil wetness and probability of its positive anomaly (red: >50%, blue:<50%)**
**<u>Bottom</u> : 850hpa wind vector and probability of positive anomaly of soil wetness. (red:>50%, blue:<50%)**

# Conclusions

- **Dust storm is a very severe disastrous weather system consisting of strong wind, soil erosion, air pollution by dust particles, and very low visibility.**
- **Wind gust and its relevant coherent disturbances in the ABL play a crucial role in the dust emission and its penetration into the atmosphere.**
- **Dust storm weather can be well predicted.**
- **Dynamical prediction of climate condition favorable (or suppressive) for the frequent occurrence of dust storms is encouraging.**


Thank You

# Satellite Image of Dust Storm in East Asia