

Improvement of Air Quality Modeling in Hong Kong by Using MM5 Coupled with LSM

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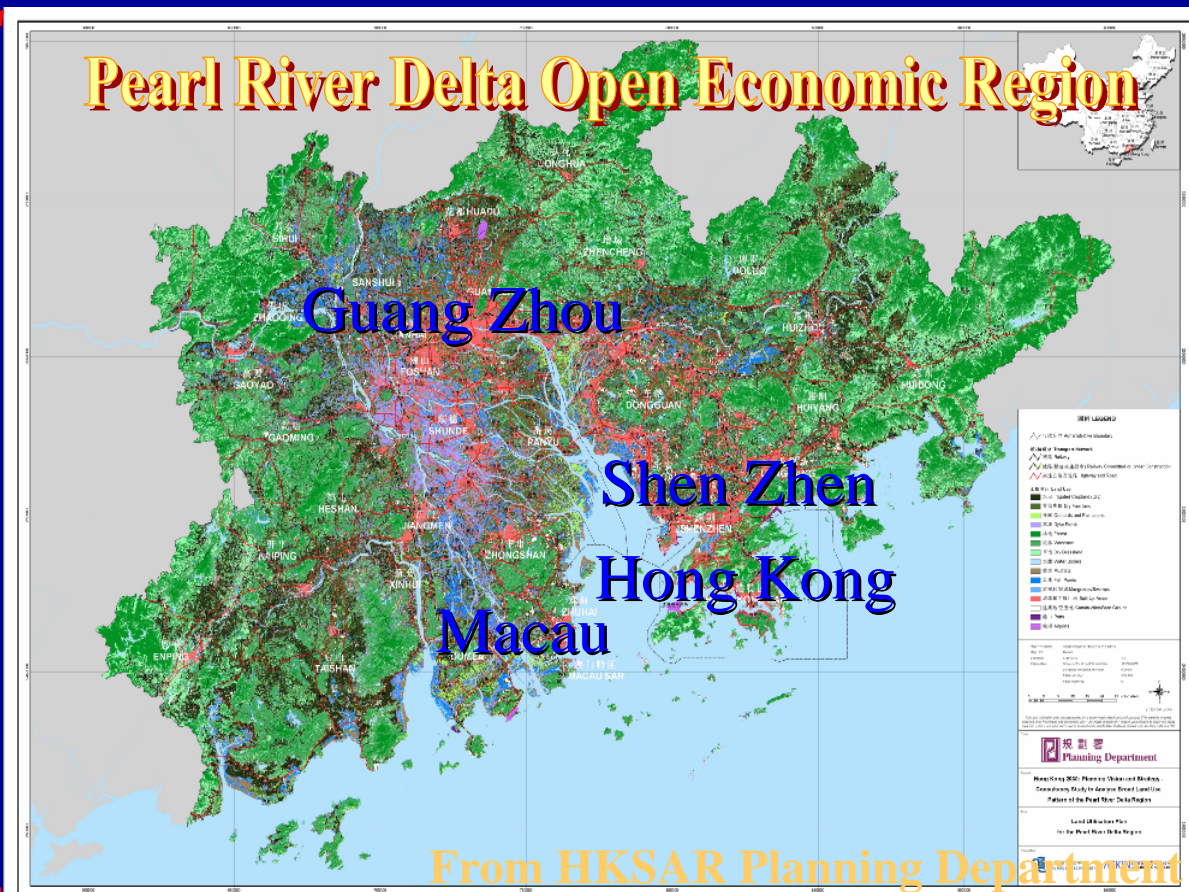
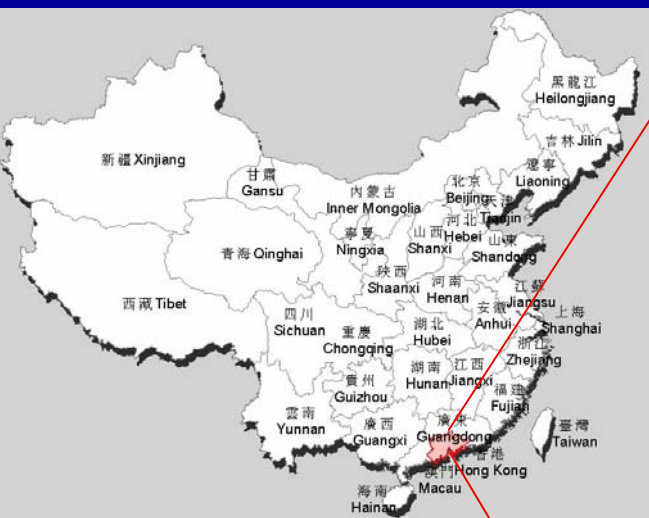
Hong Kong University of Science and Technology
North Carolina State University

Objective

- The objective of this research is to better understand and predict the atmospheric flow (in particular, within the Planetary Boundary Layer ~ 1 to 2 km) and air quality over HK and the Pearl River Delta.
- Different **dispersion models (SAQM and CMAQ)** has been used in this study.

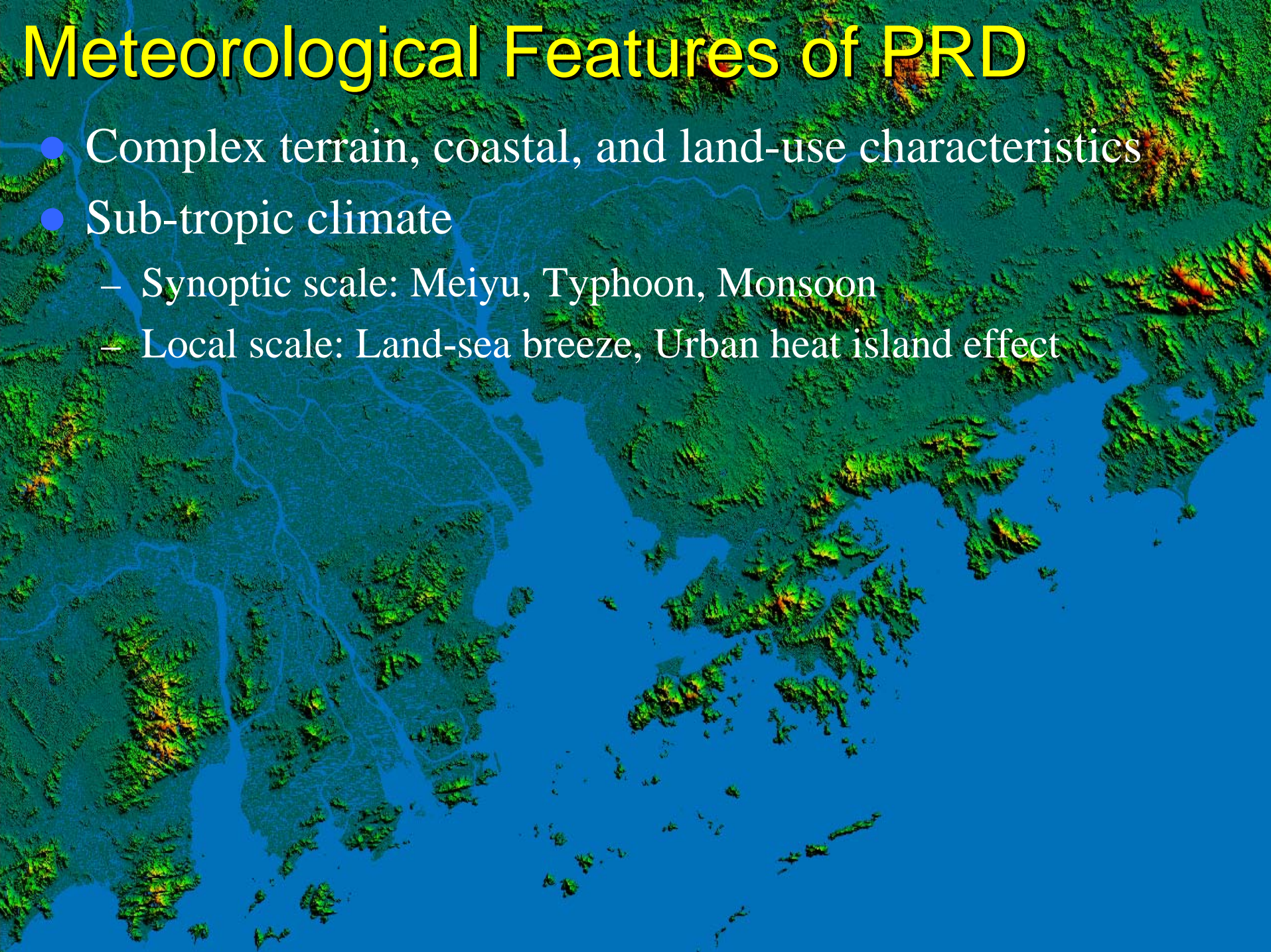
Features of Pearl River Delta (PRD)

- Located in Southern China
- 41,700 km² in size, **50 million in population**
- Major cities: Hong Kong, Shen Zhen, Guang Zhou and Macau, etc.
- Rapid economic and industrial growth; **high air pollution potential**

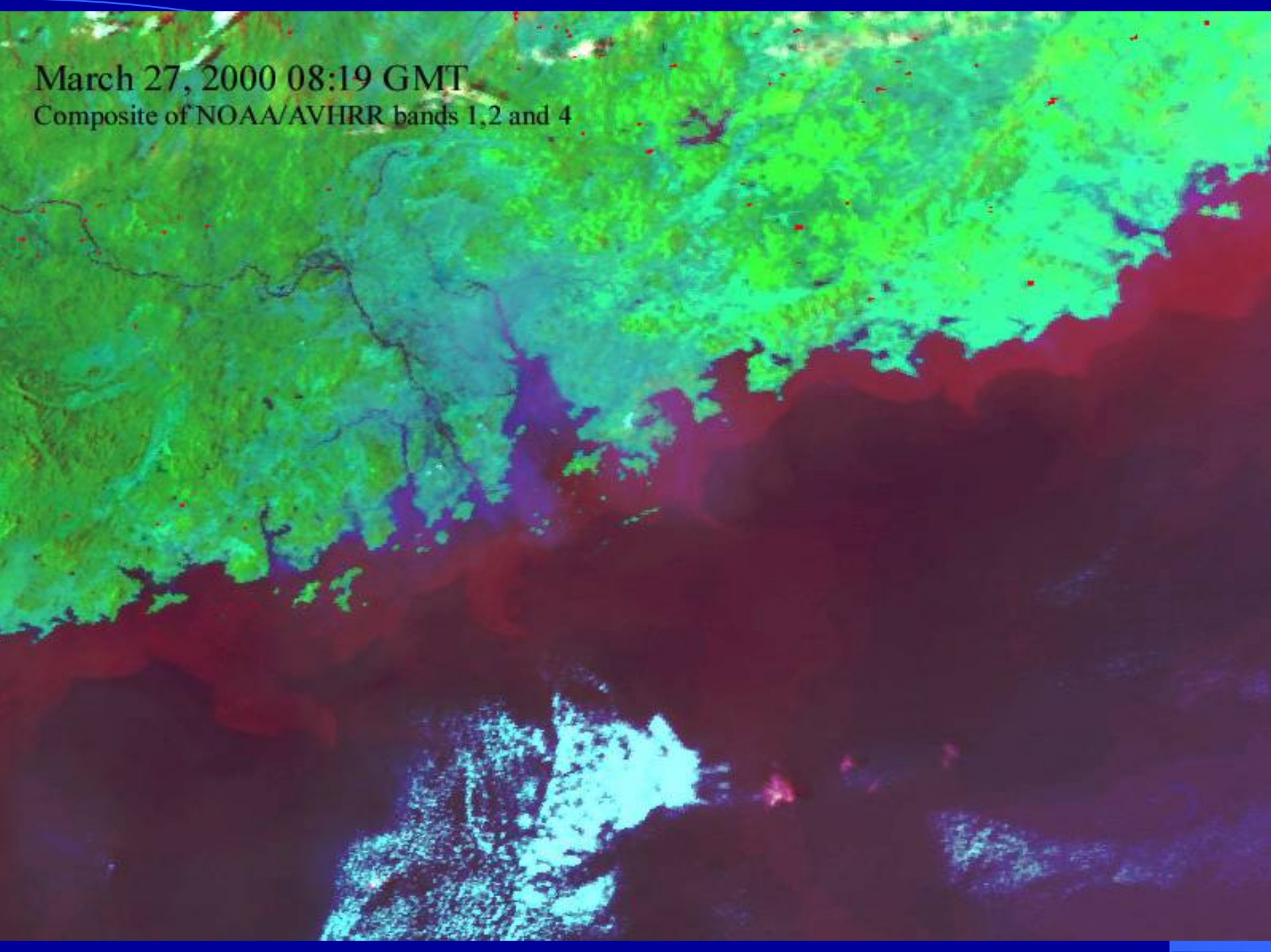


Meteorological Features of PRD

- Complex terrain, coastal, and land-use characteristics
- Sub-tropic climate
 - Synoptic scale: Meiyu, Typhoon, Monsoon
 - Local scale: Land-sea breeze, Urban heat island effect

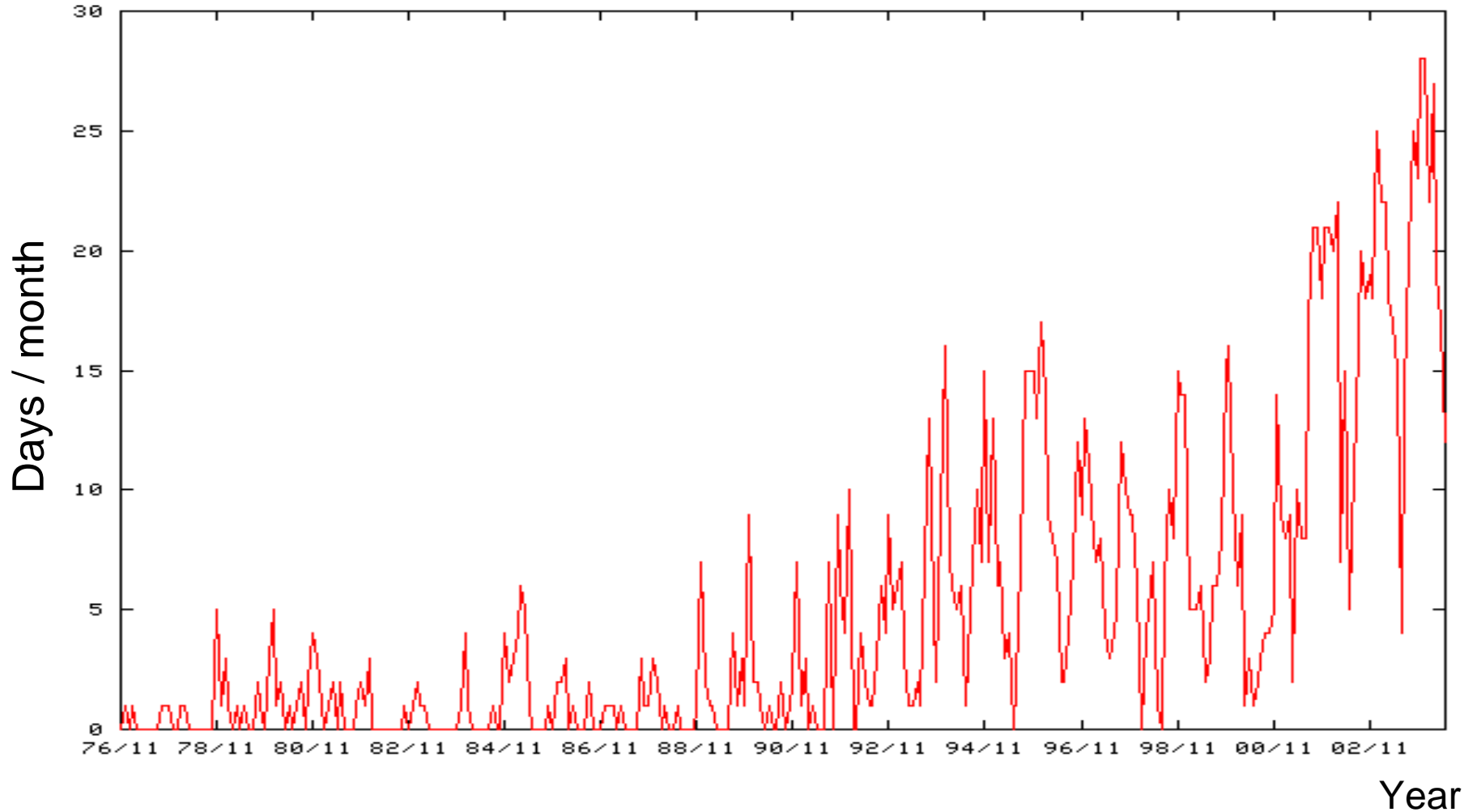


March 27, 2000 08:19 GMT
Composite of NOAA/AVHRR bands 1,2 and 4

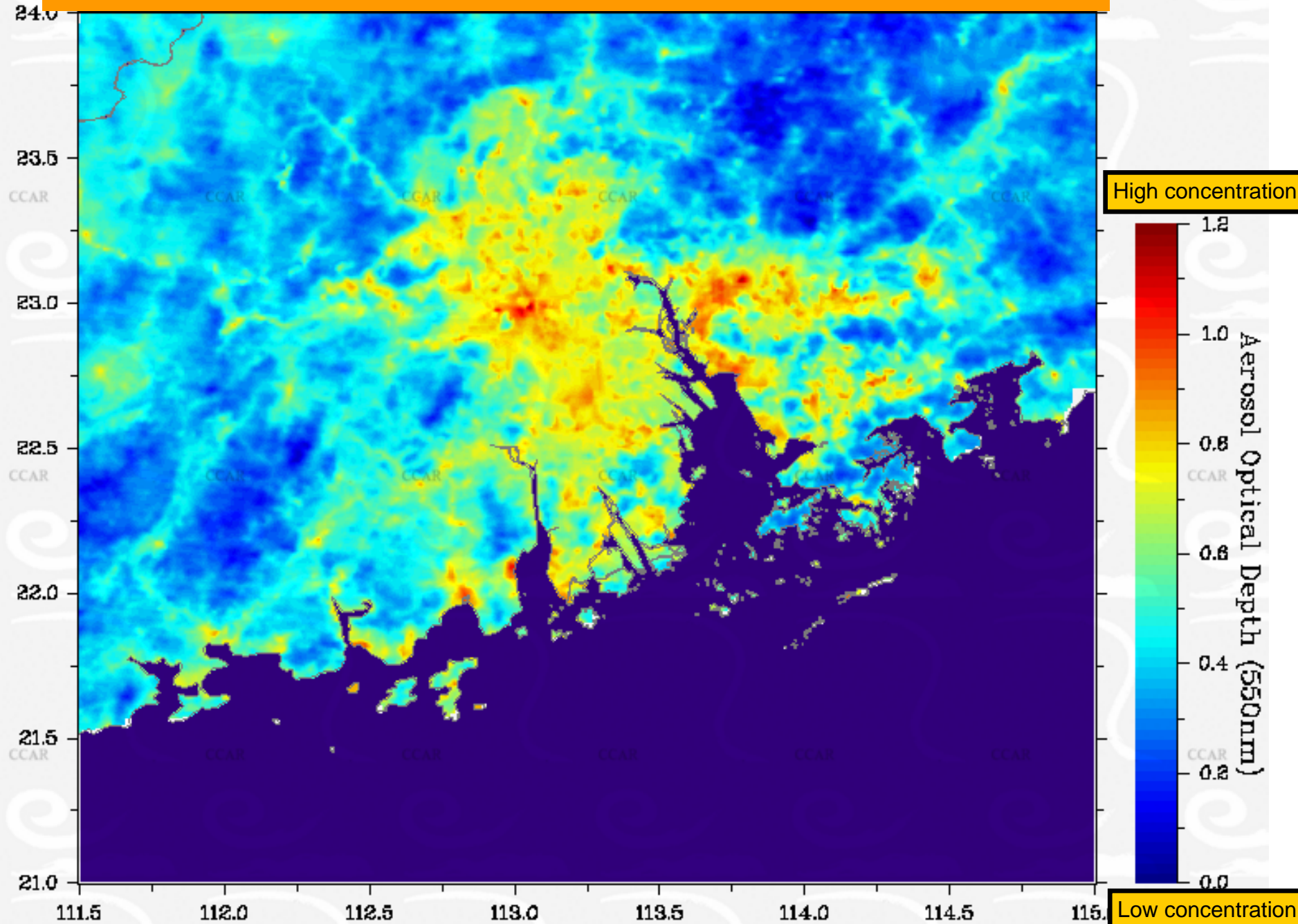


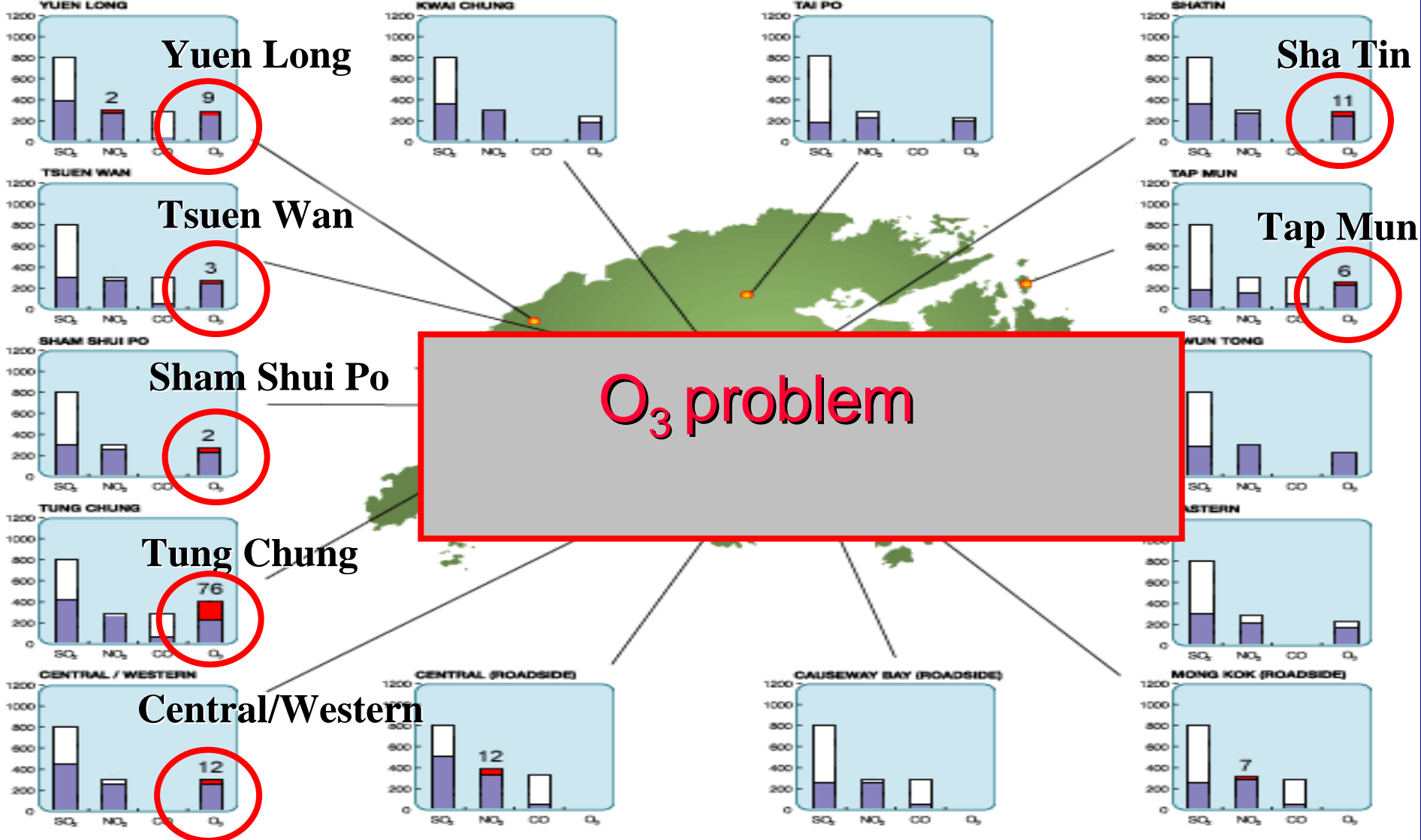
Visibility Report (11/1976 – 6/2004)

Monthly number of days with (Visibility reporting < 8km & RH < 80%)



Aerosol Optical Depth - Column sum of aerosol concentration



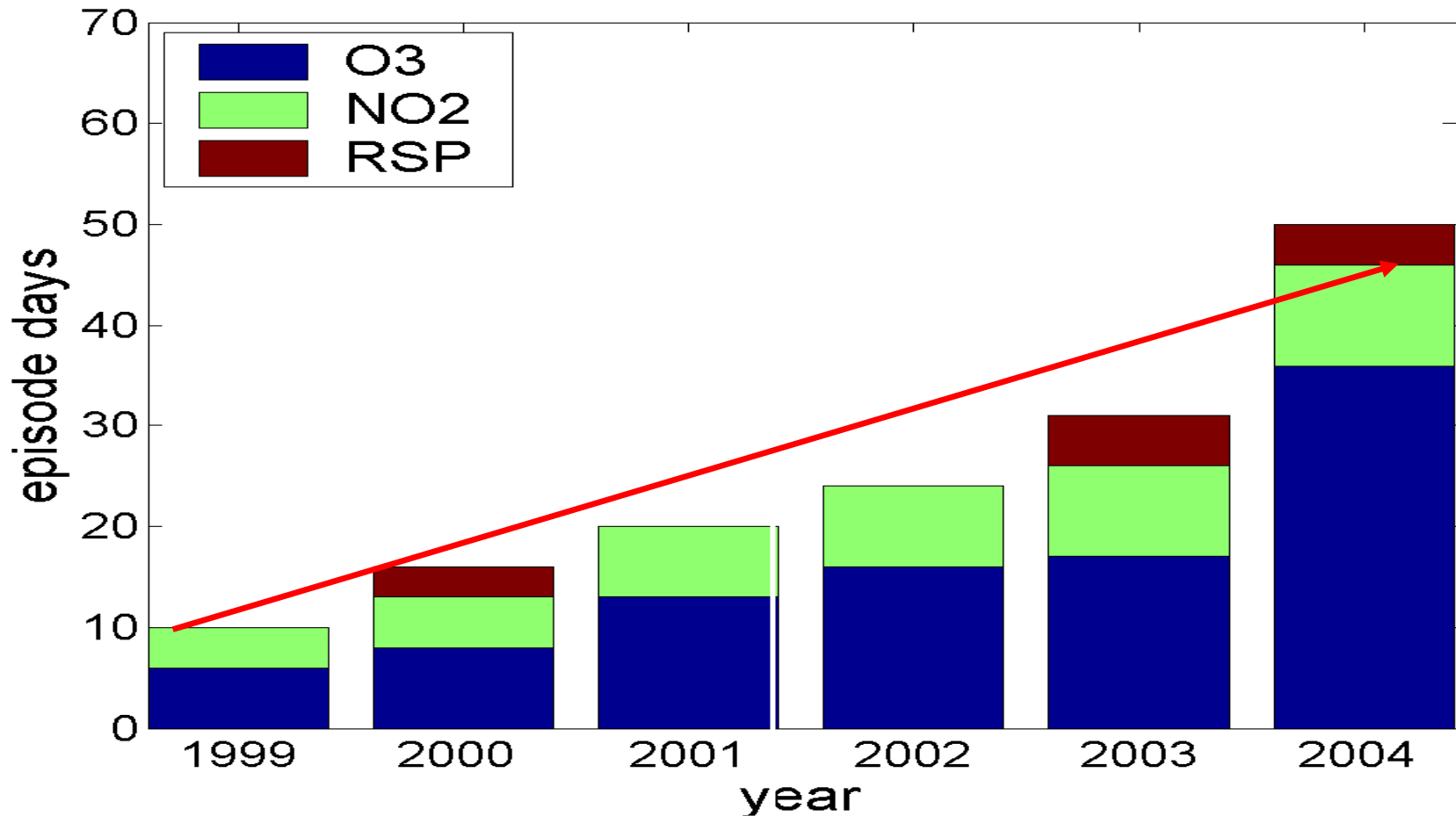


KEY:
AQO not complied
AQO complied

Air Quality Objective

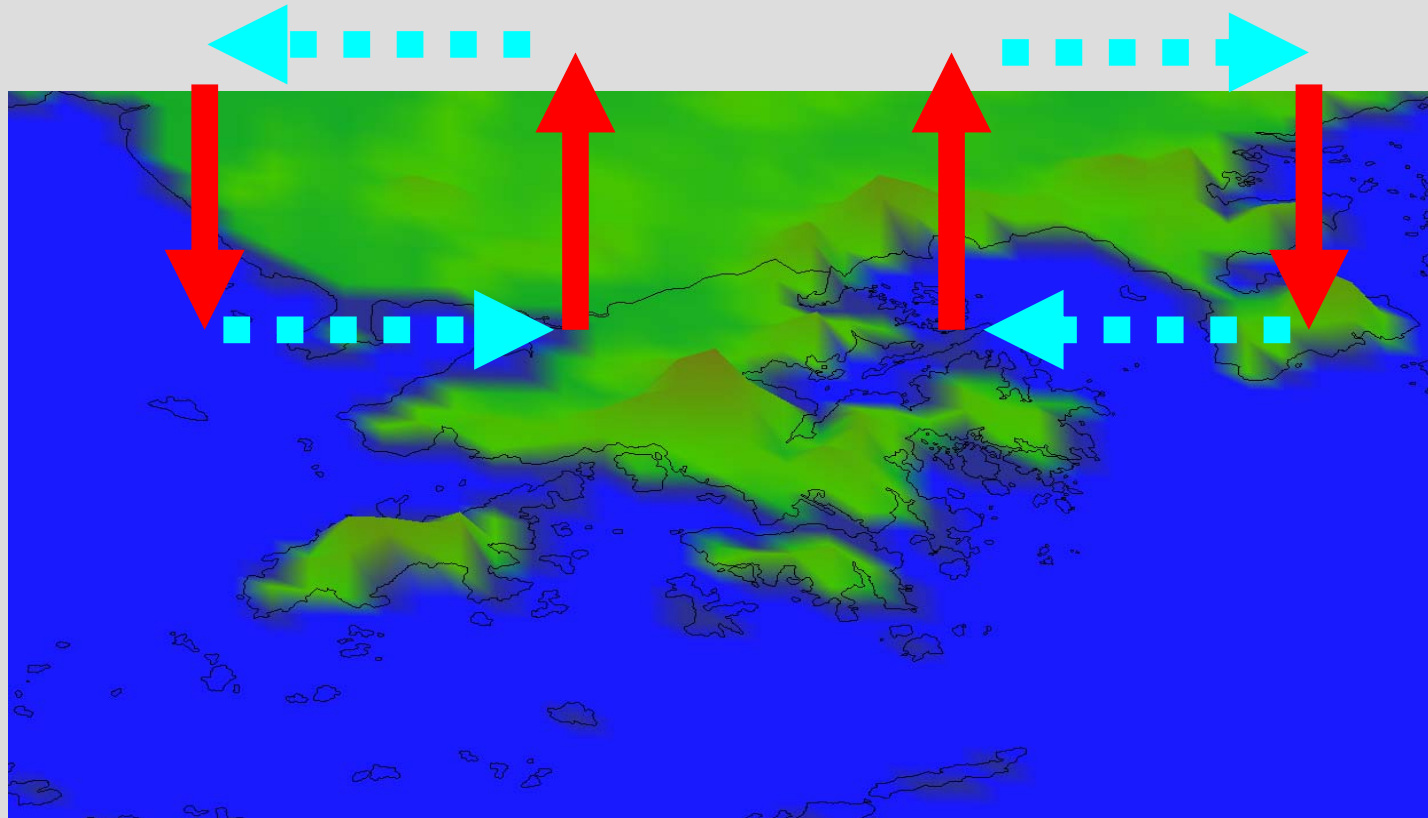
Number of non-compliance of hourly AQO (**red**) (from HKEPD, 2004)

O₃ problem in HK: episodes

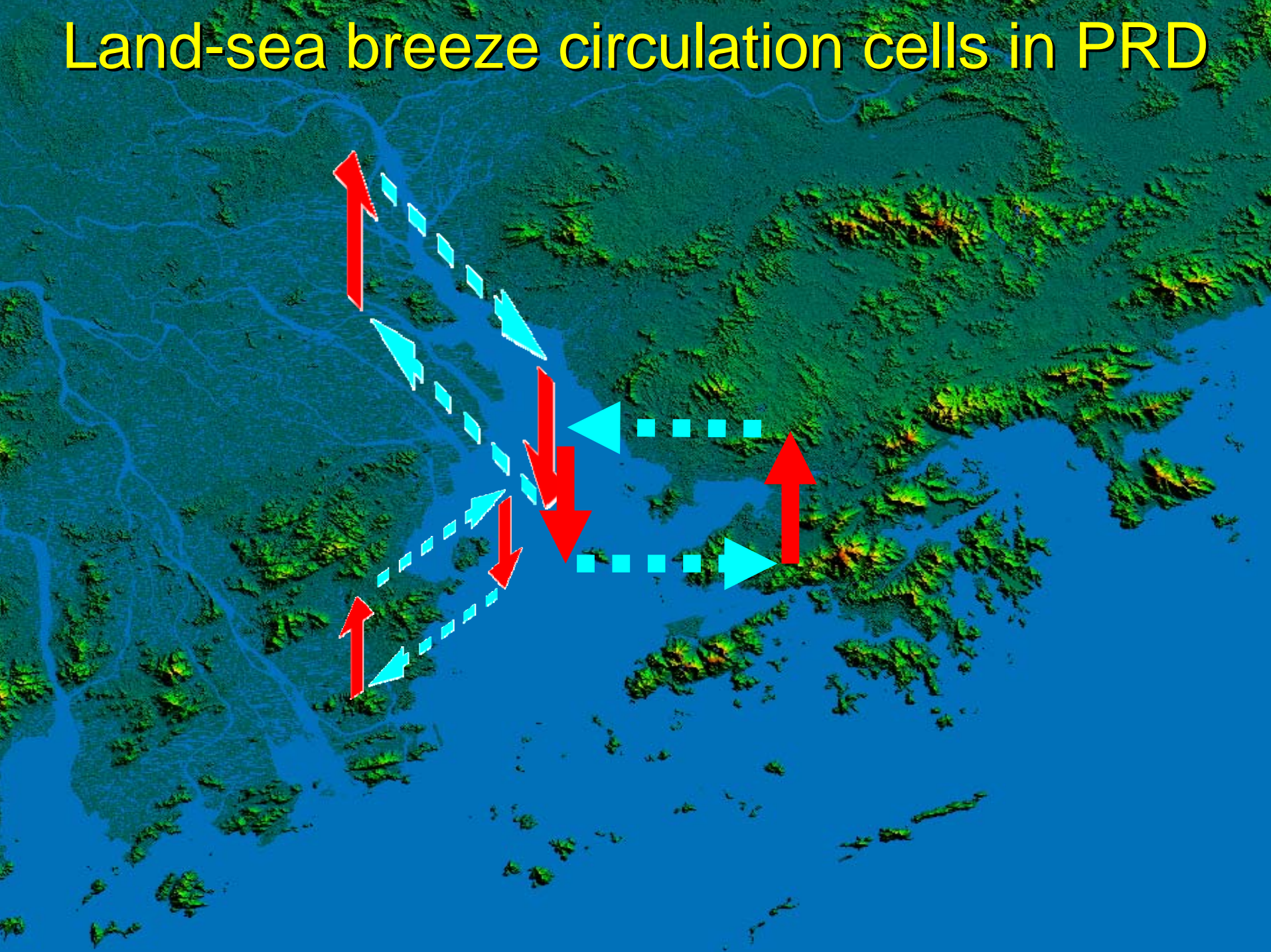


major contributors to air pollution episodes: O₃, NO₂ and RSP
O₃ : the biggest contributor

Sea breeze circulation



Land-sea breeze circulation cells in PRD



PATH Model System

Meteorological Model

PATH

Pollutants in the **A**tmosphere and their **T**ransport over
Hong Kong (HKEPD, 1997)

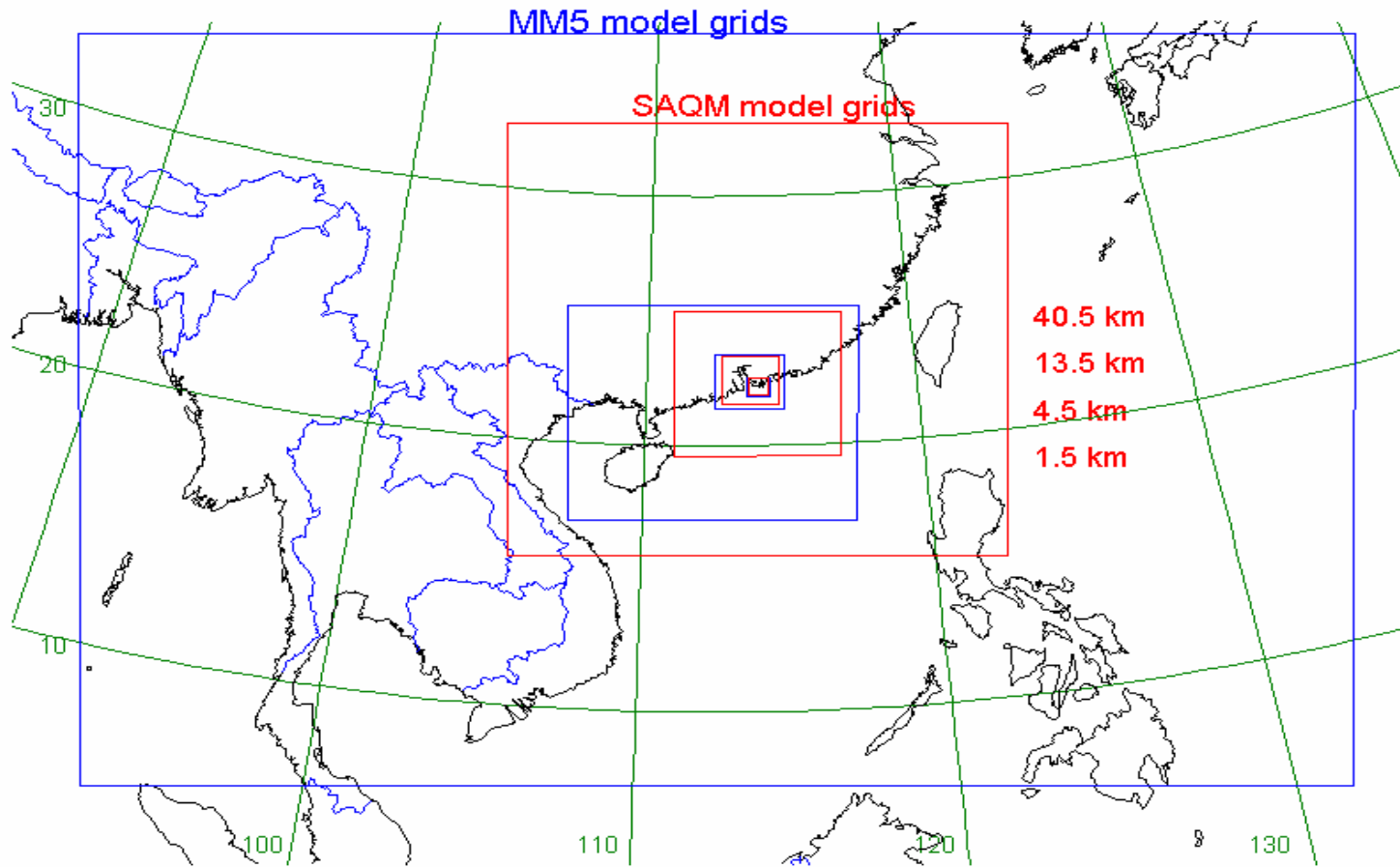
(MM5 v3.6)

Atmospheric Chemistry Model

Chemical reactions of various chemical species
and solve the advection-diffusion equations

(SAQM)

Domain configurations of MM5 & SAQM



26 sigma levels (mm5)

15 sigma levels (SAQM)

MM5 Model Configurations

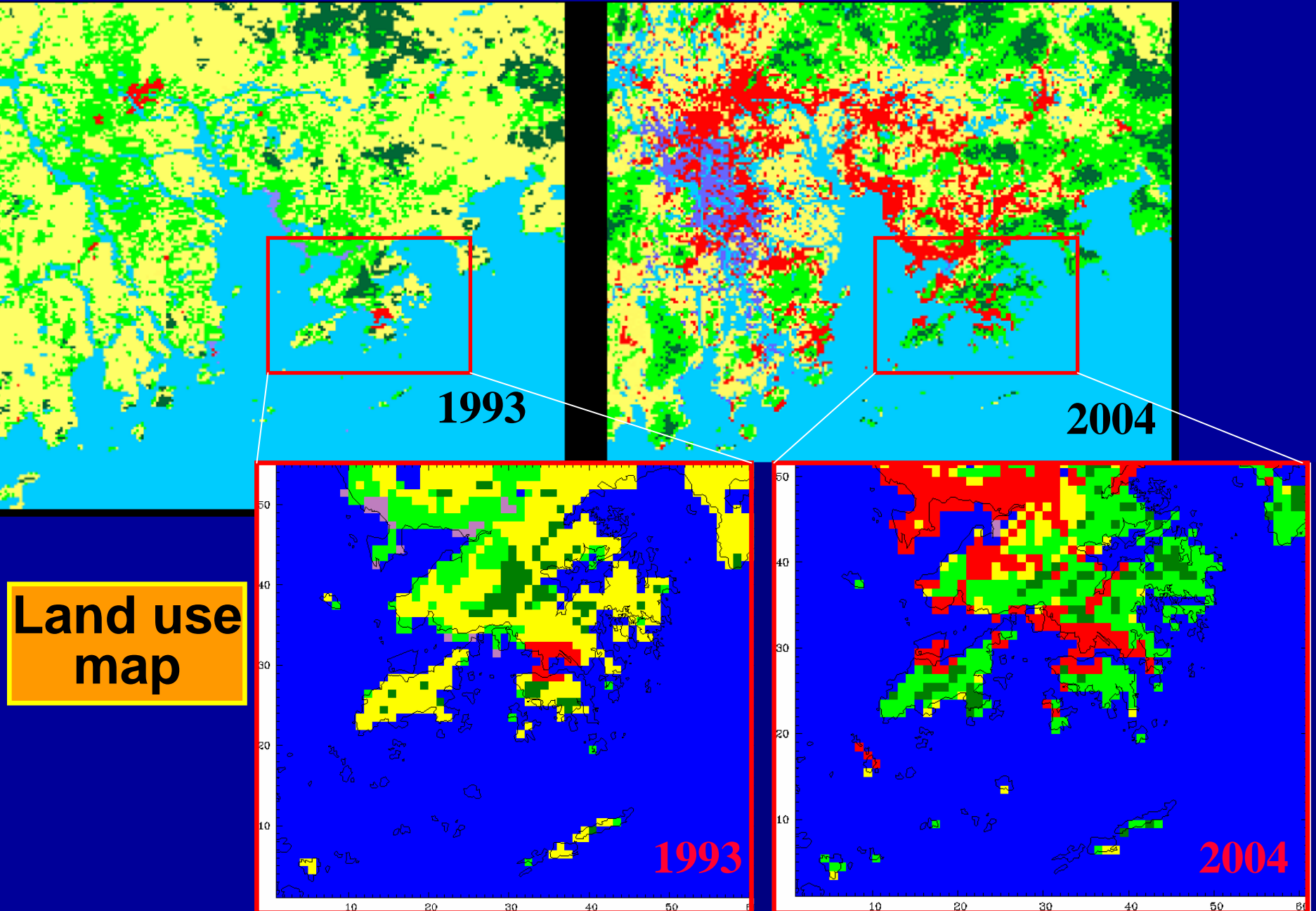
- **MM5 v3.6**
- **4 nested Domains:**
 - **40.5 km (115x75), 13.5km (85x73) , 4.5km (85x73) and 1.5km (61x55)**
 - **2-ways nesting**
 - **26 full sigma levels (~10 levels below 1km)**
- **Physical parameterization schemes**
(for the unresolved scales)

	40.5km, 13.5km	4.5km, 1.5km
Cumulus	Grell	None
PBL	MRF	MRF
Moisture	Simple ice	Simple ice
Radiation	RRTM	RRTM

MM5 Model Configurations (continued)

- **Up-to-date fine resolution land use**
(as fine as 30 m) is applied to Hong Kong and PRD (i.e. both D3 and D4)
- **Initial and Boundary Conditions**
NCEP Global Final Analyses ($1^\circ \times 1^\circ$)
(<http://dss.ucar.edu/datasets/ds083.2>)

Rapid development over PRD during the past ten years



1993

2004

1993

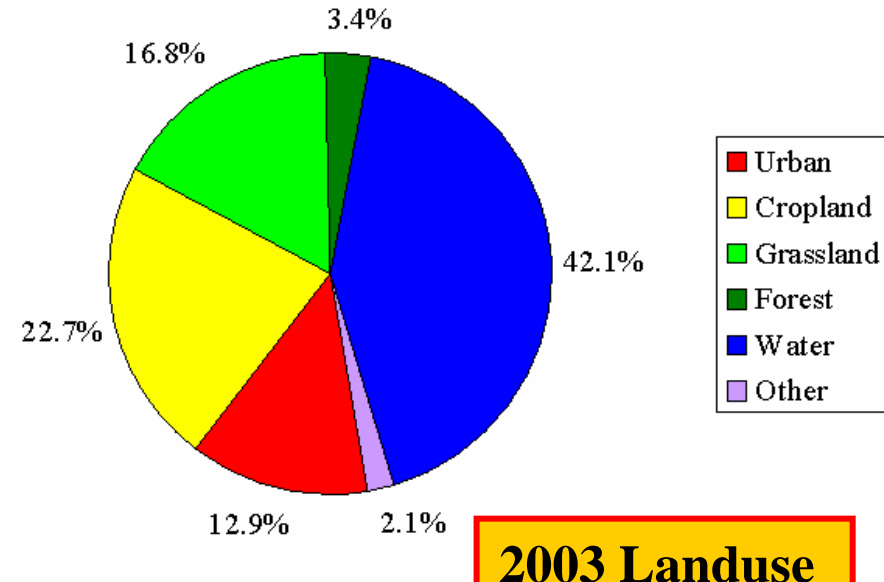
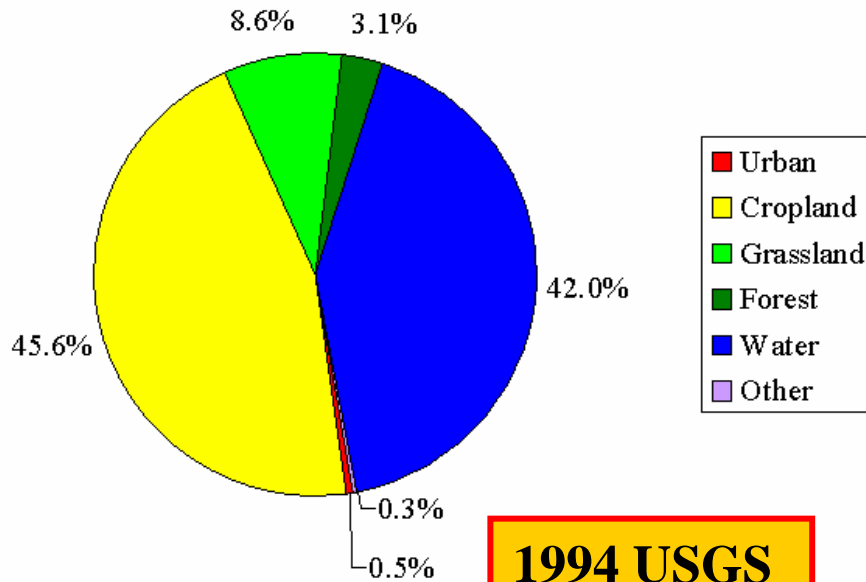
2004

Land use map

Percentage of each land-use classification in the innermost domain:

Urban area: increase from 0.5% to 12.9%

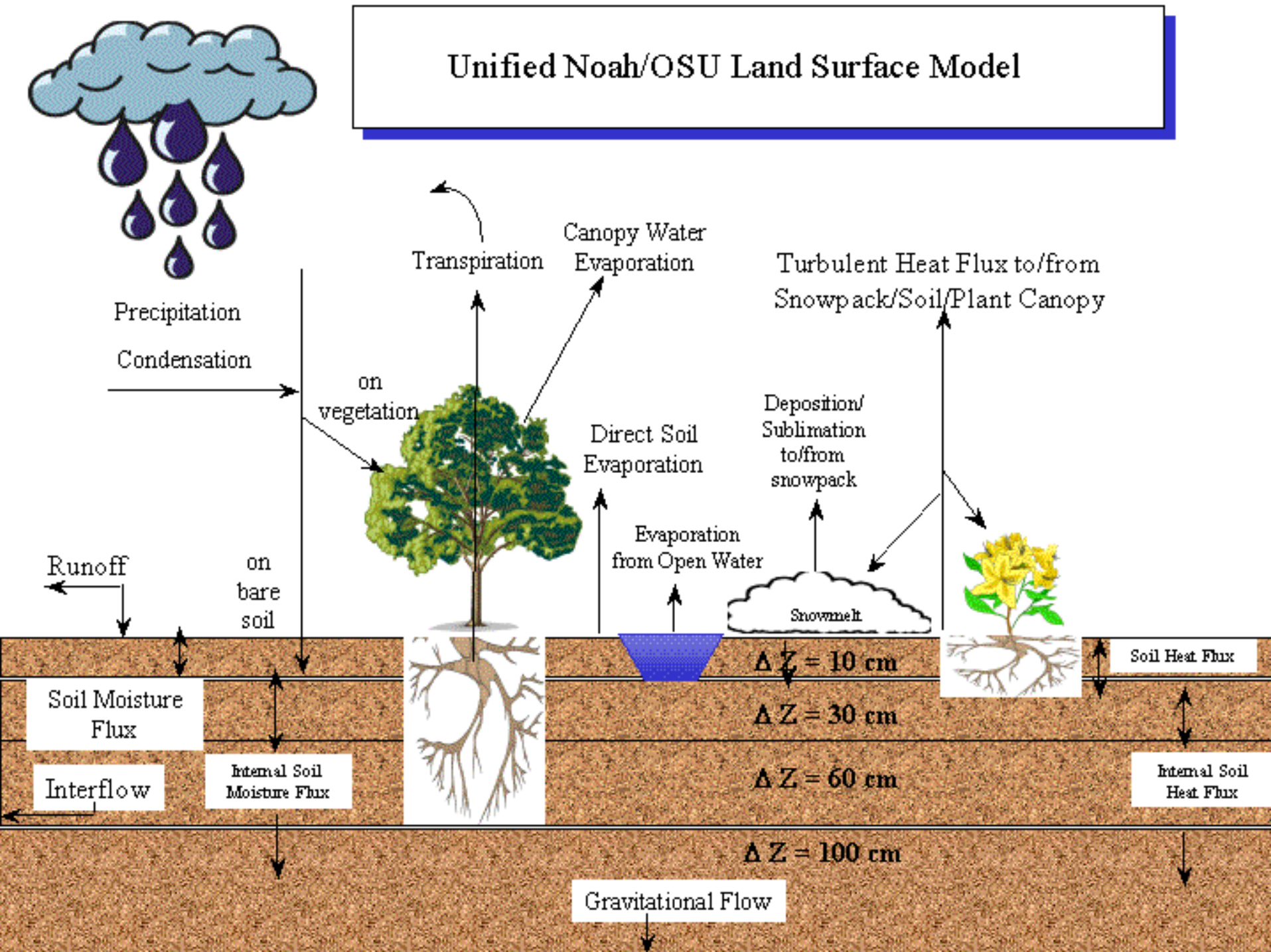
Cropland: decrease from 45.6% to 22.7%



Land Surface Model (LSM)

- ❖ **NOAH community land-surface soil hydrology module, which was jointly developed by the**
 - **National Centers for Environmental Prediction (NCEP)**
 - **Oregon State University**
 - **the U.S. Air Force**
 - **the Office of Hydrology**
- ❖ **Coupled mode; the scheme is fully interactive with MM5**
- ❖ **MM5 simulations of surface radiation, precipitation, and near-surface winds, humidity, and temperature provide the external forcing for the land surface**
- ❖ **The Noah-LSM provides surface sensible heat flux, latent heat flux and skin temperature as lower boundary condition to MM5**
- ❖ **Heat and moisture fluxes are then process by PBL scheme and transported to the atmosphere.**

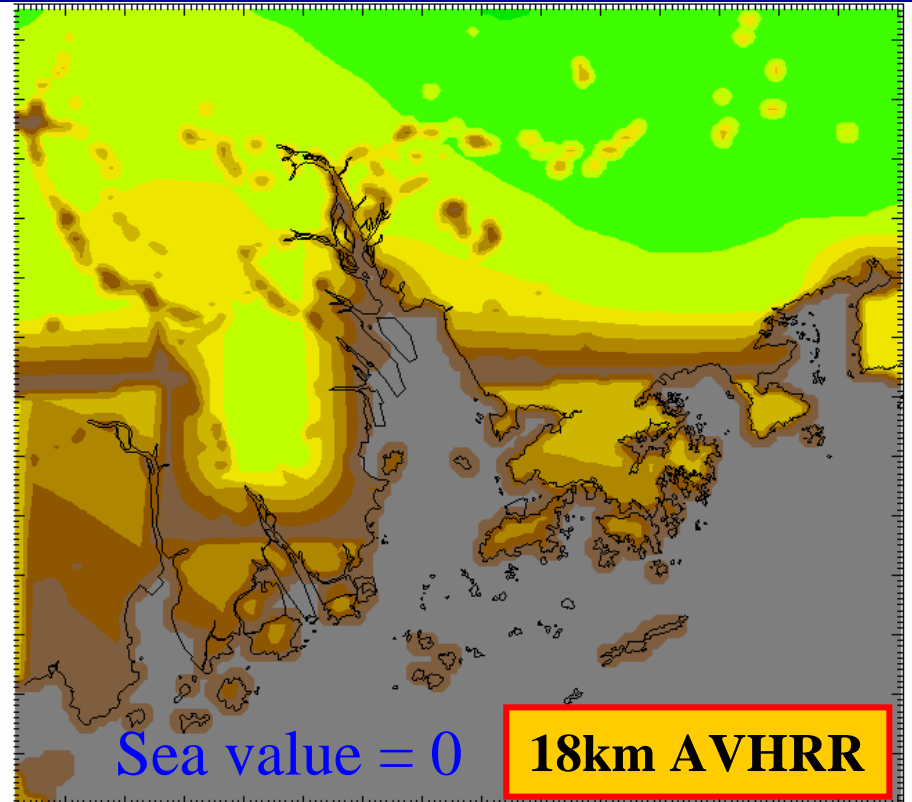
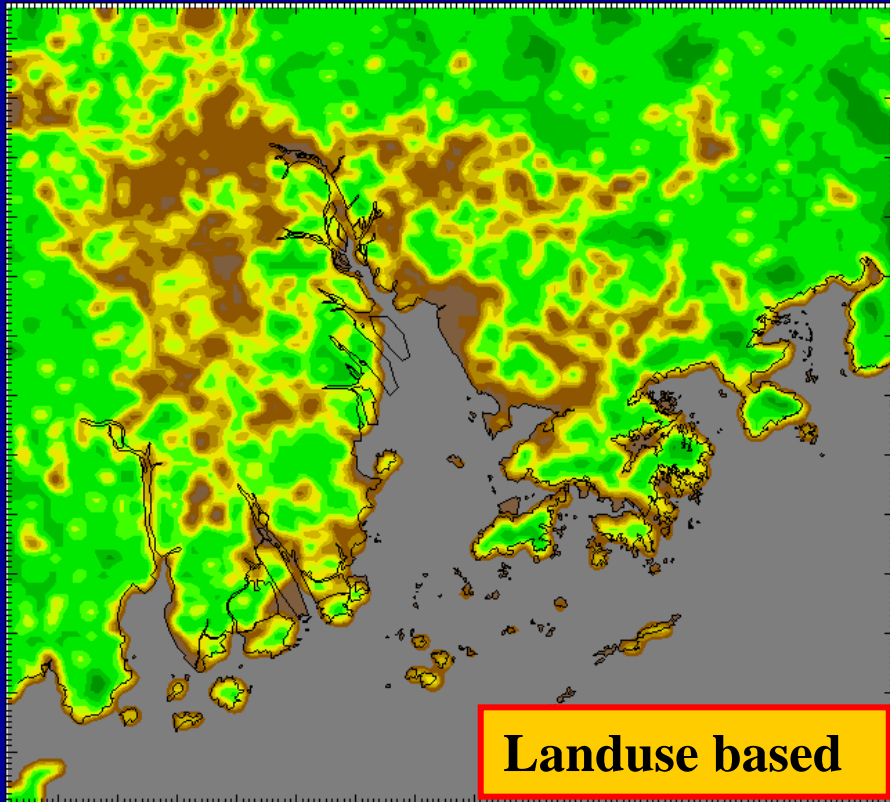
Unified Noah/OSU Land Surface Model



Refinements in Noah-LSM experiments

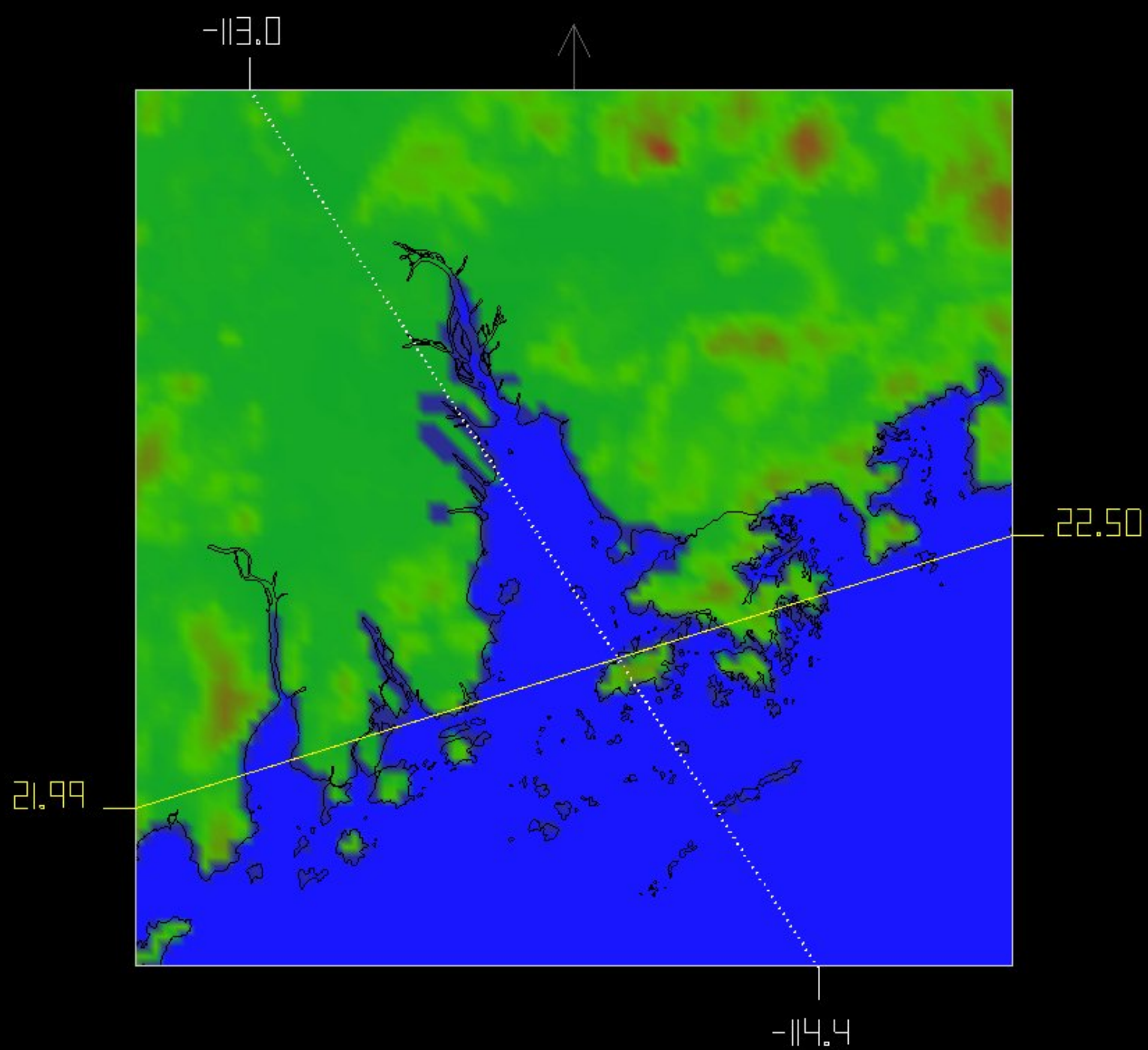
Green vegetation fraction definition

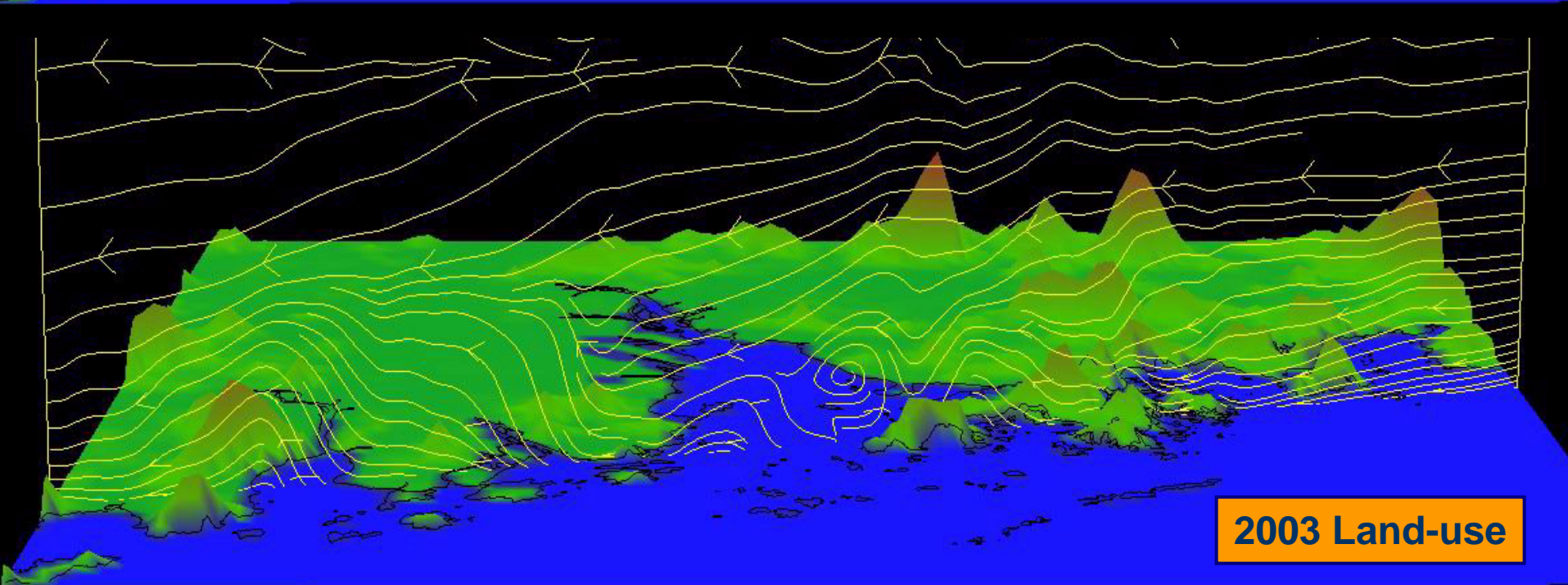
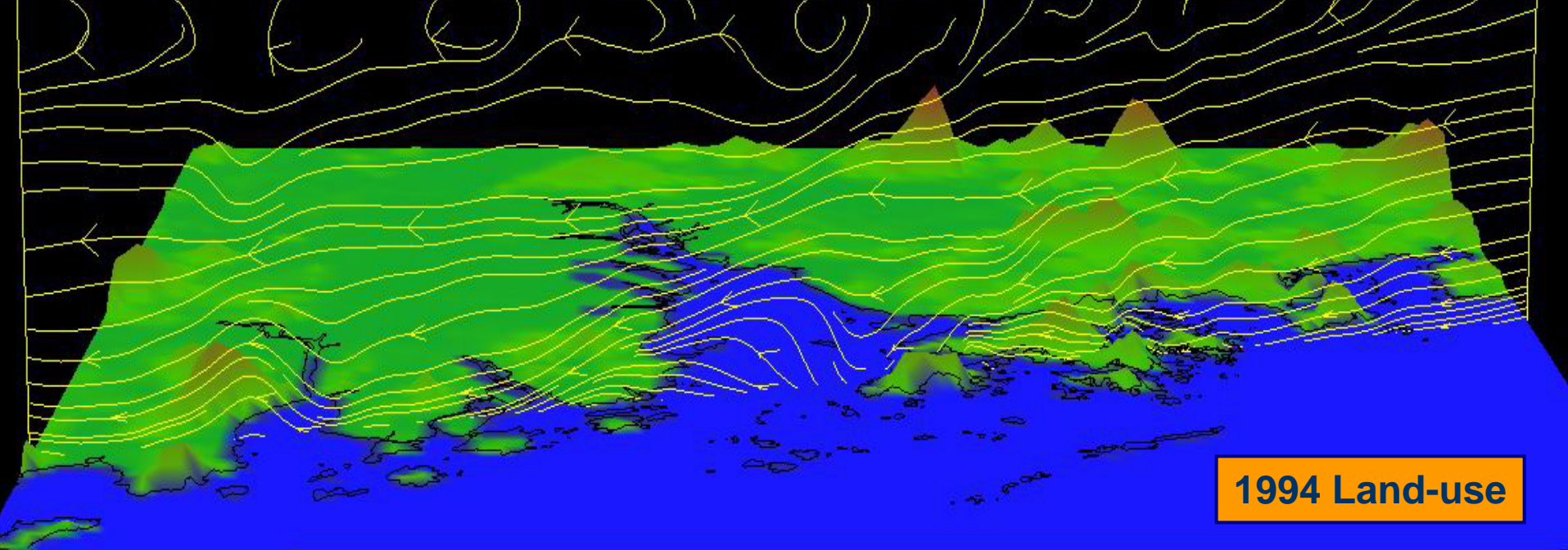
- Problems caused by interpolating the 18km AVHRR data into our inner domains (4.5km, 1.5km)
- Landuse based green vegetation is used in the inner domains
 - PRD located in subtropics, seasonal variation is very small

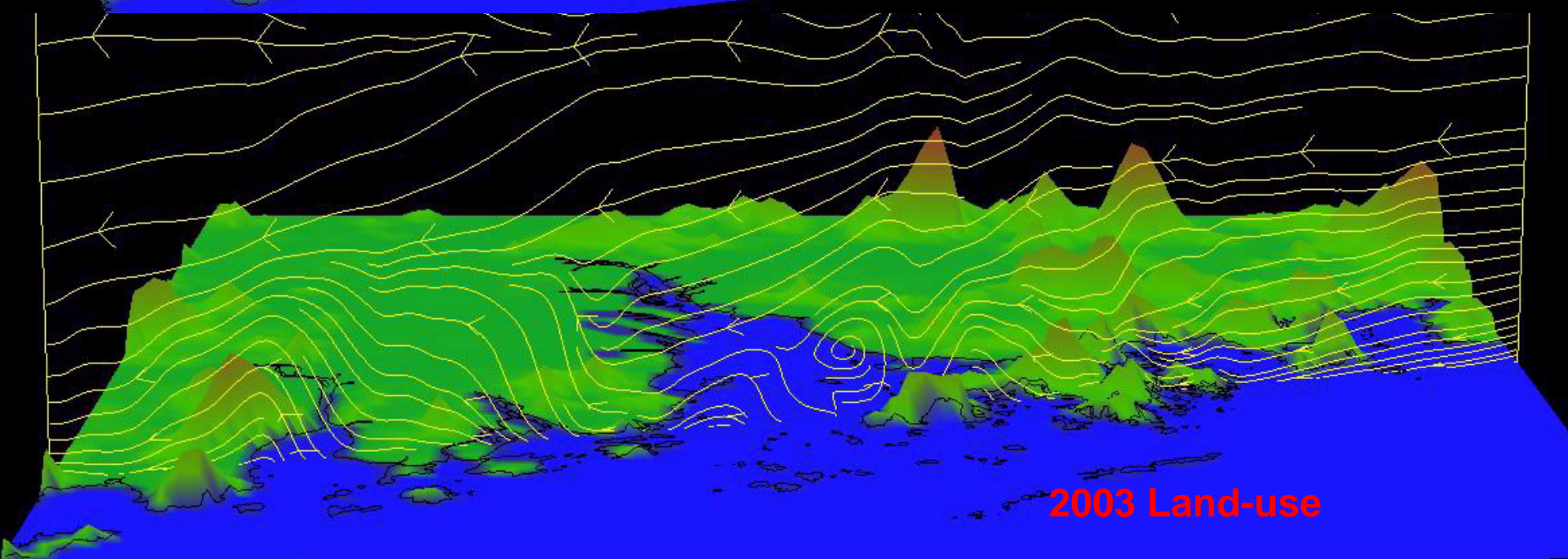
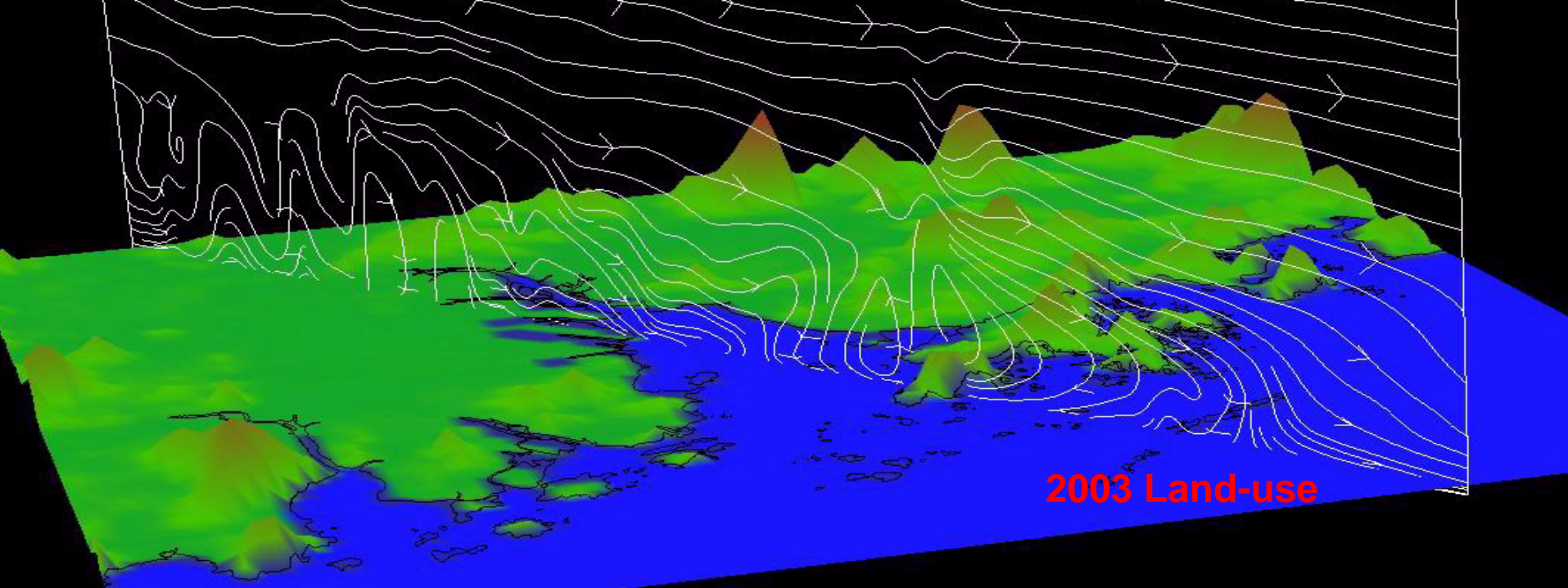


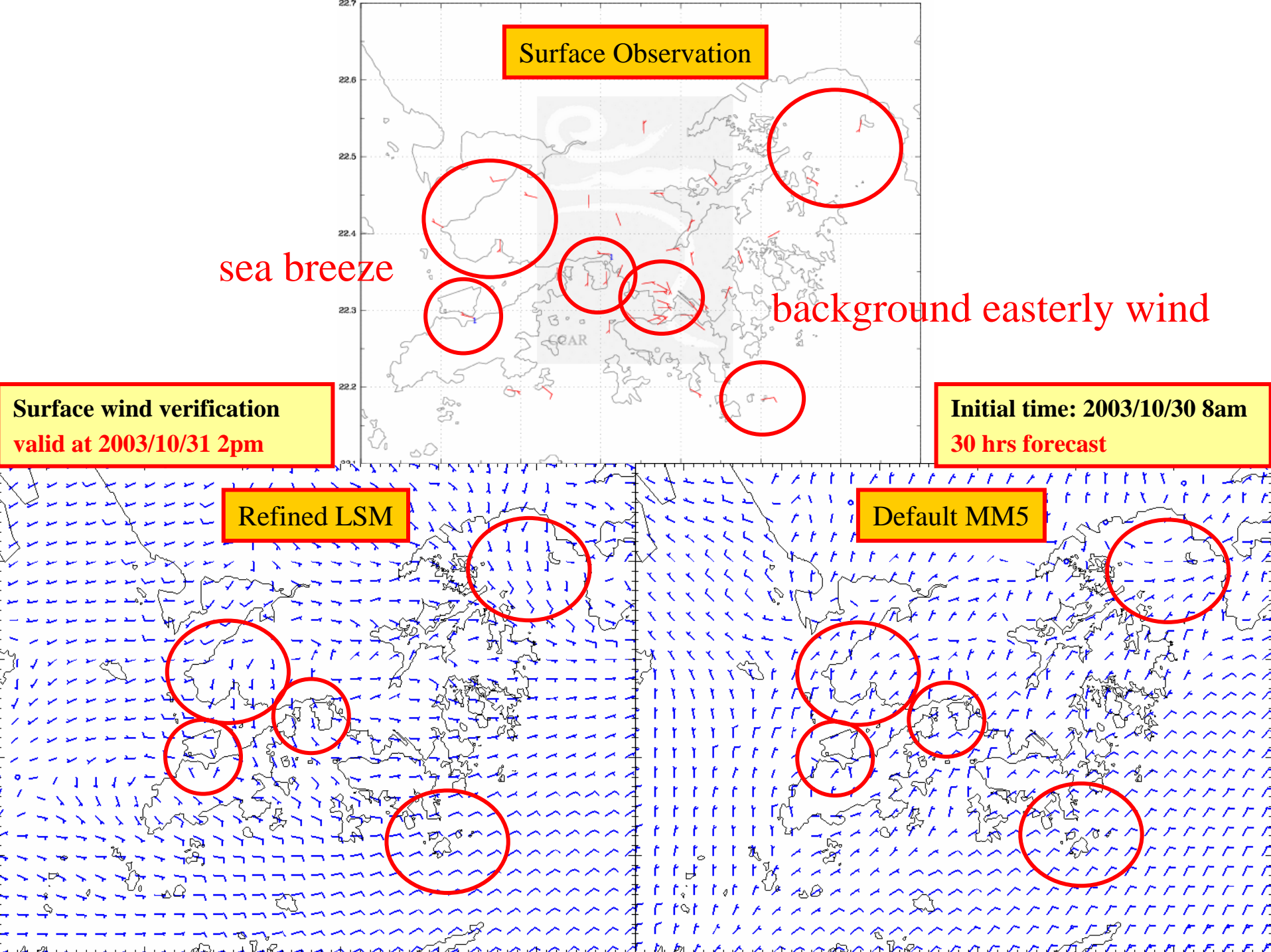
Refinements in Noah-LSM experiments

- 1. Up-to-date landuse map for PRD**
- 2. Better green vegetation fraction in inner domains**
- 3. Enhancements of urban landuse treatment in Noah-LSM**
 - Simply modifying the values of physical parameters for urban landuse – albedo, roughness length, soil thermal properties and evaporation
- 4. Modification of MRF PBL scheme**
 - Better methods for computation of free convection turbulence, PBL height and surface heat flux
(Liu Y., F. Chen, T. Warner, S. Swerdlin, J. Bowers, and S. Halvorson, 2004)



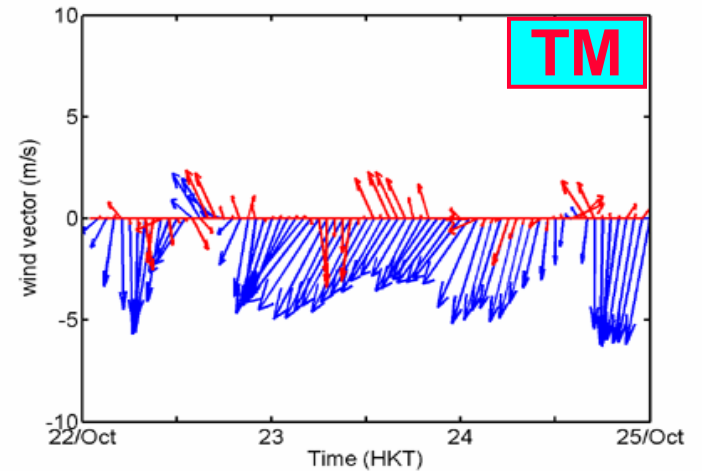
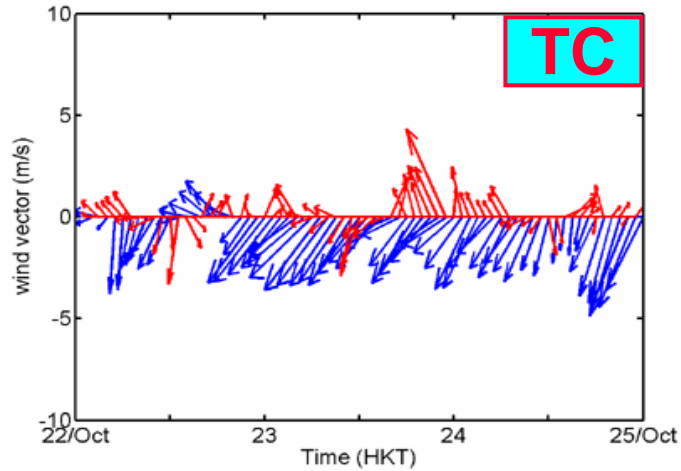




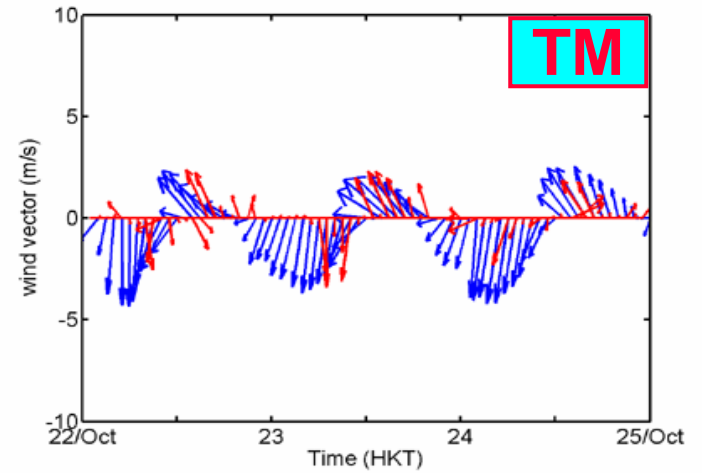
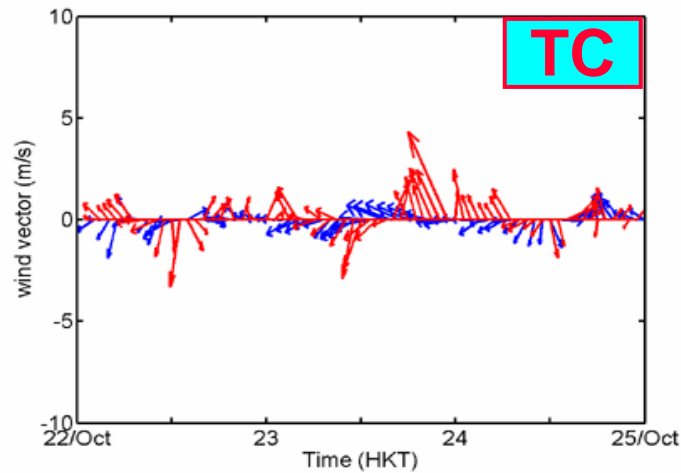


Comparison of velocity

MM5-STD



MM5-LSM

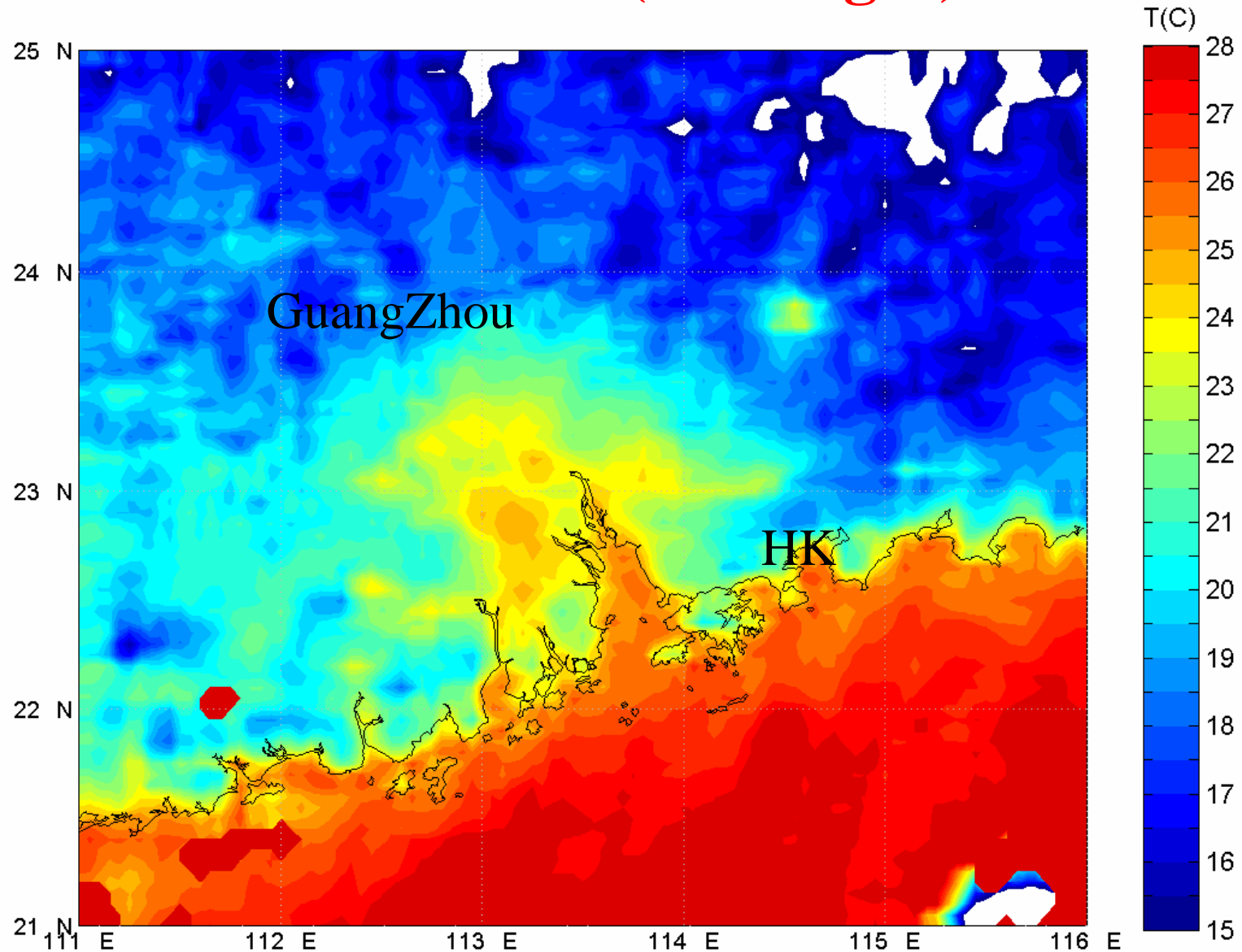


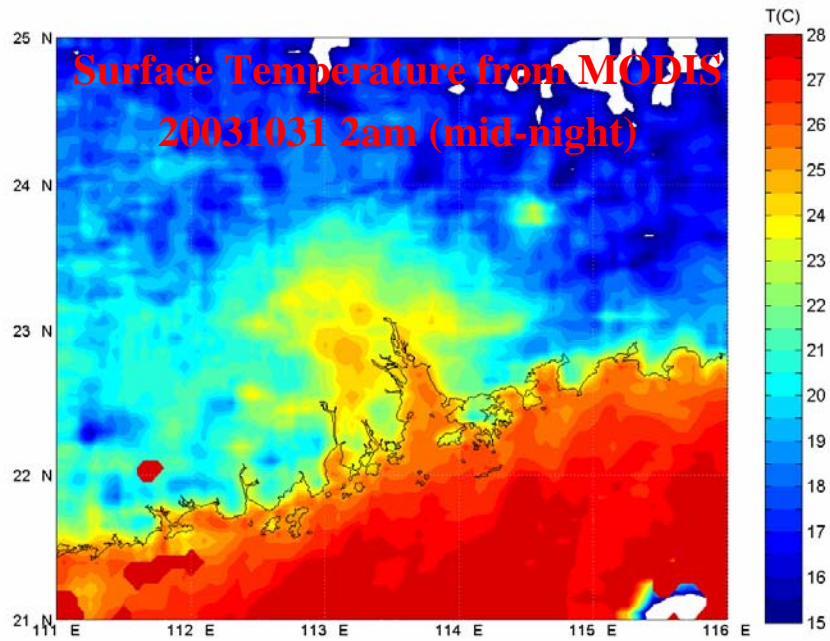
Results

Urban heat island

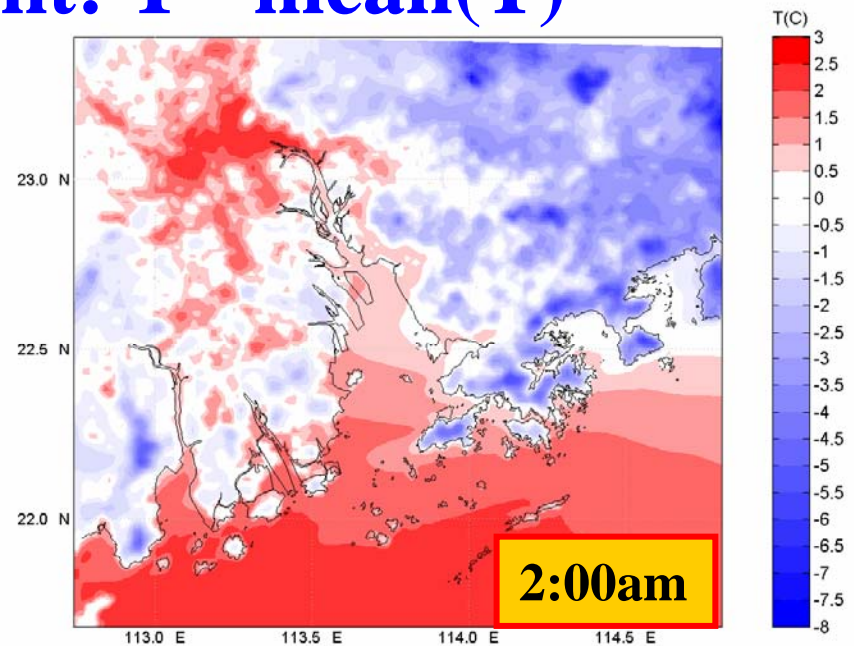
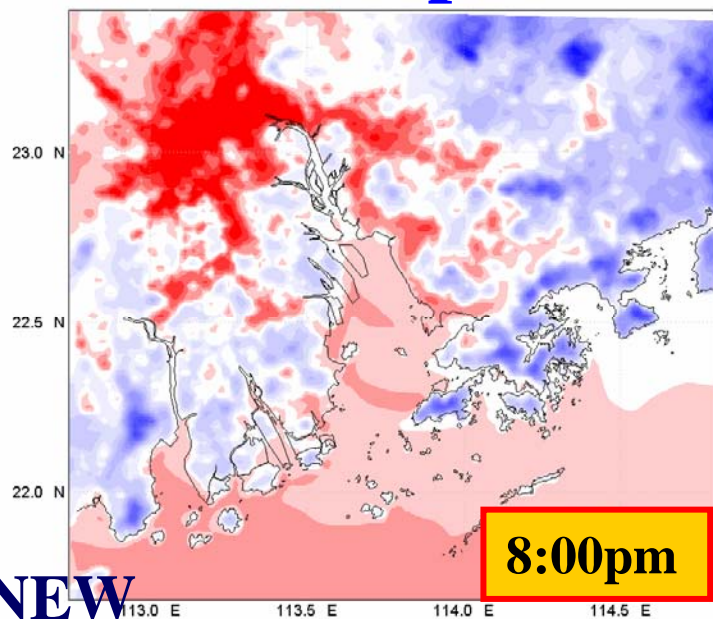
Surface Temperature from MODIS

20031031 2am (mid-night)

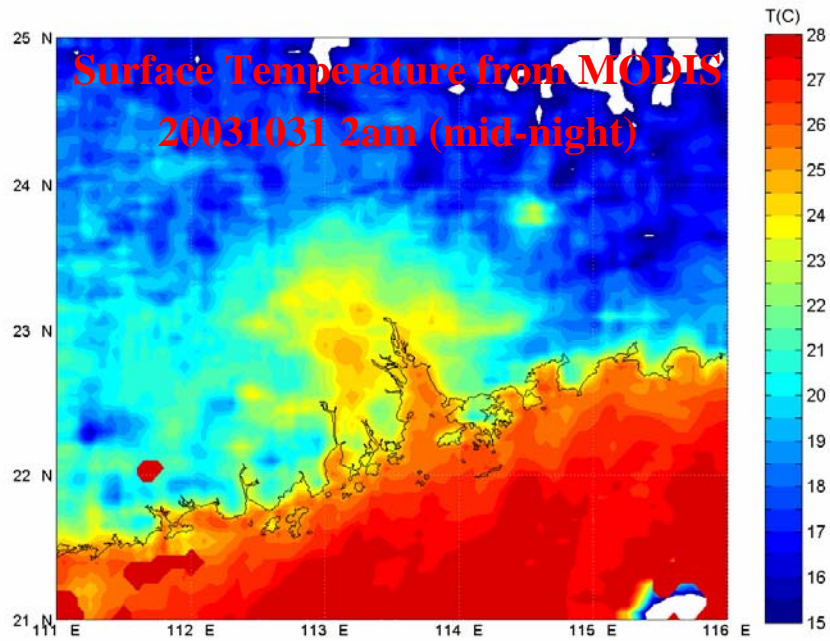




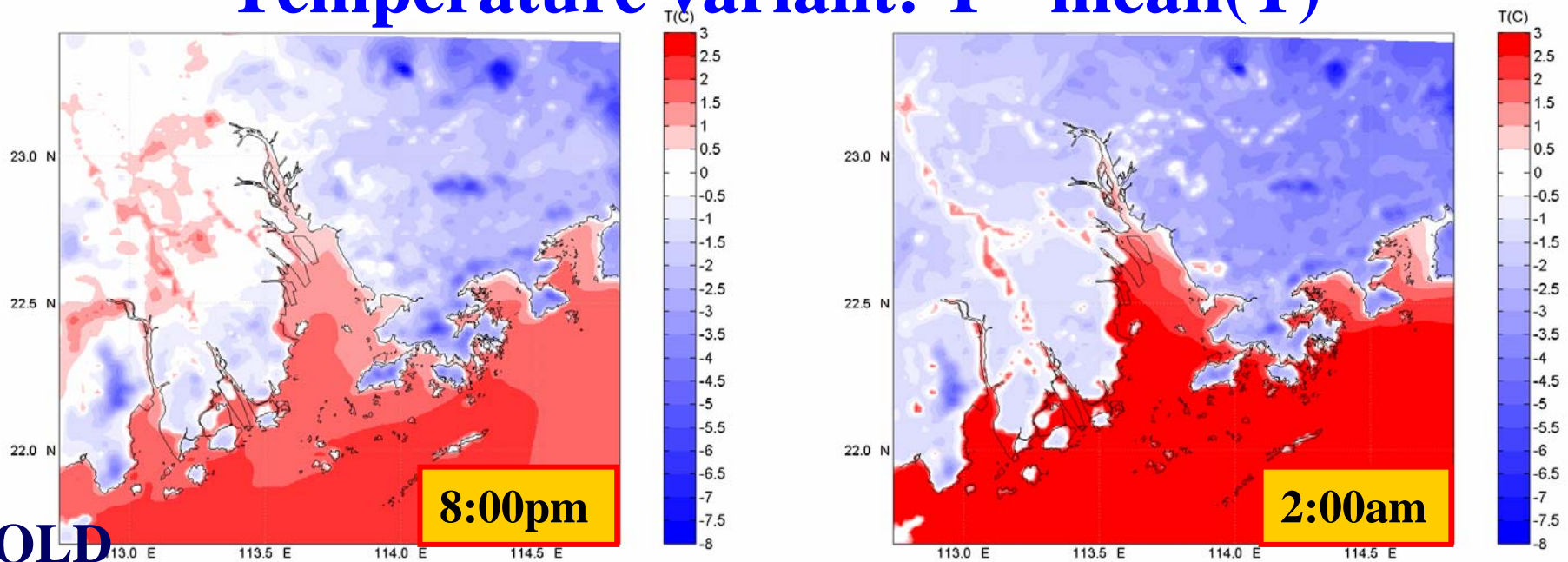
Temperature variant: $T - \text{mean}(T)$



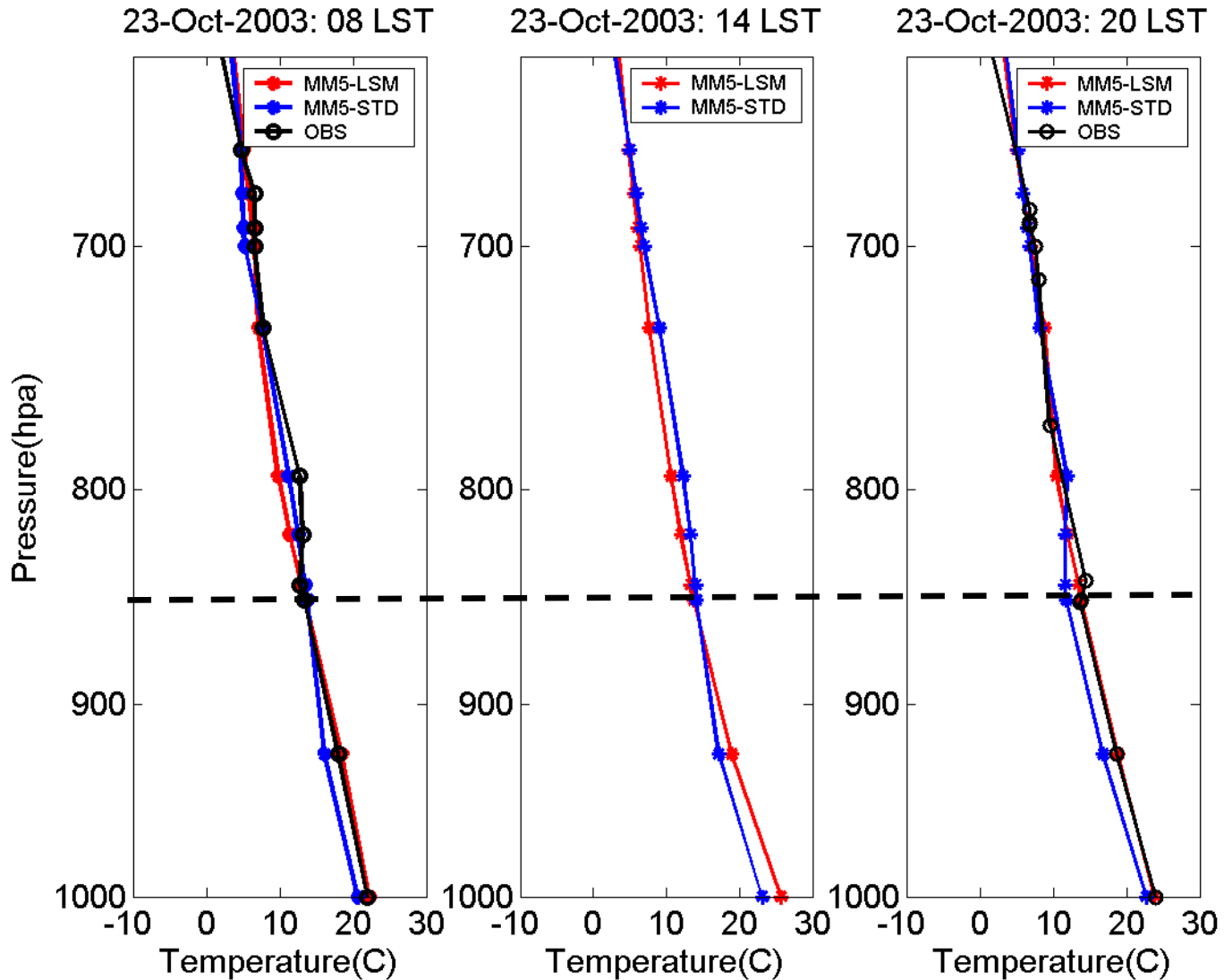
NEW



Temperature variant: $T - \text{mean}(T)$

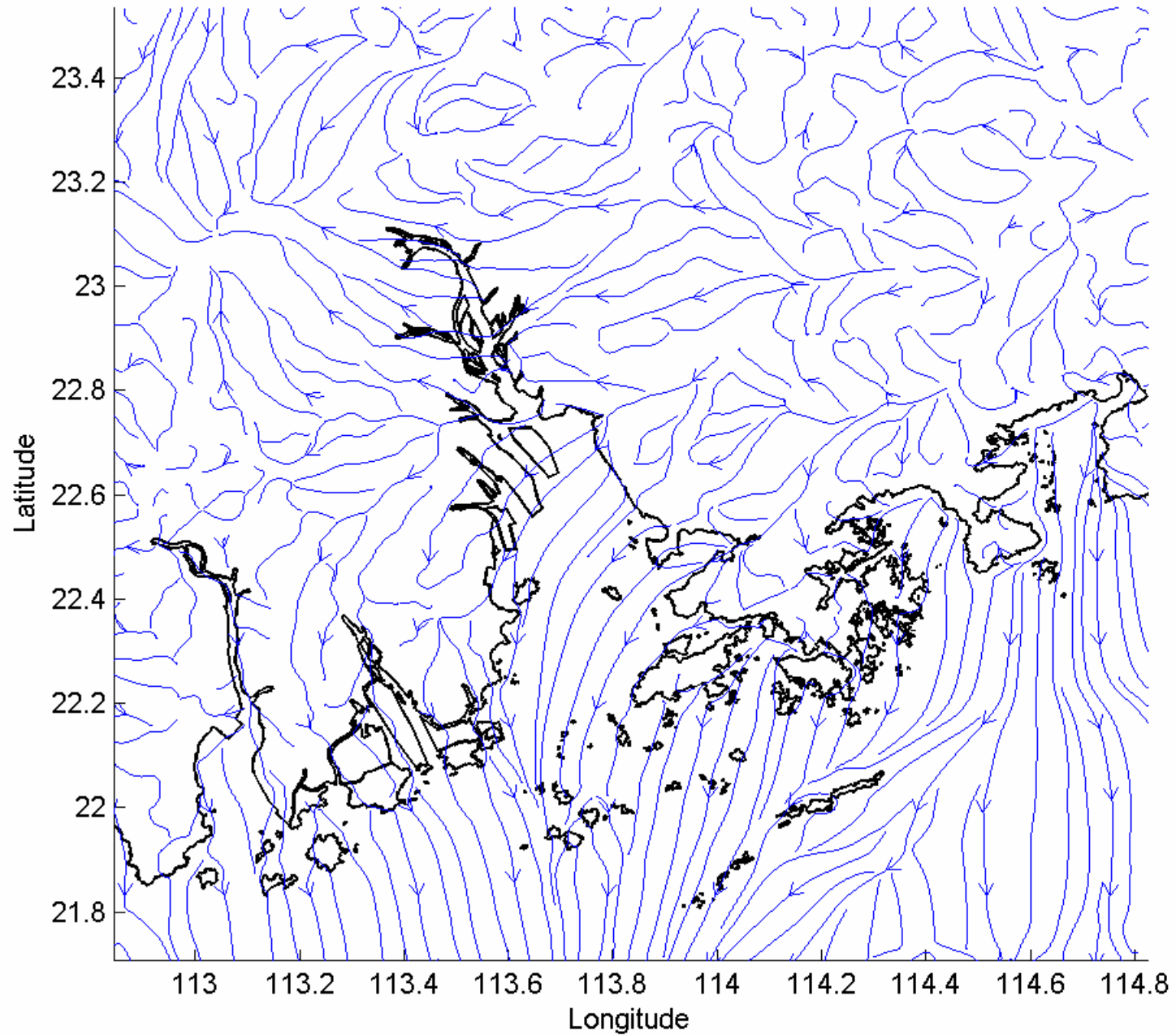


Temperature Profiles Comparison



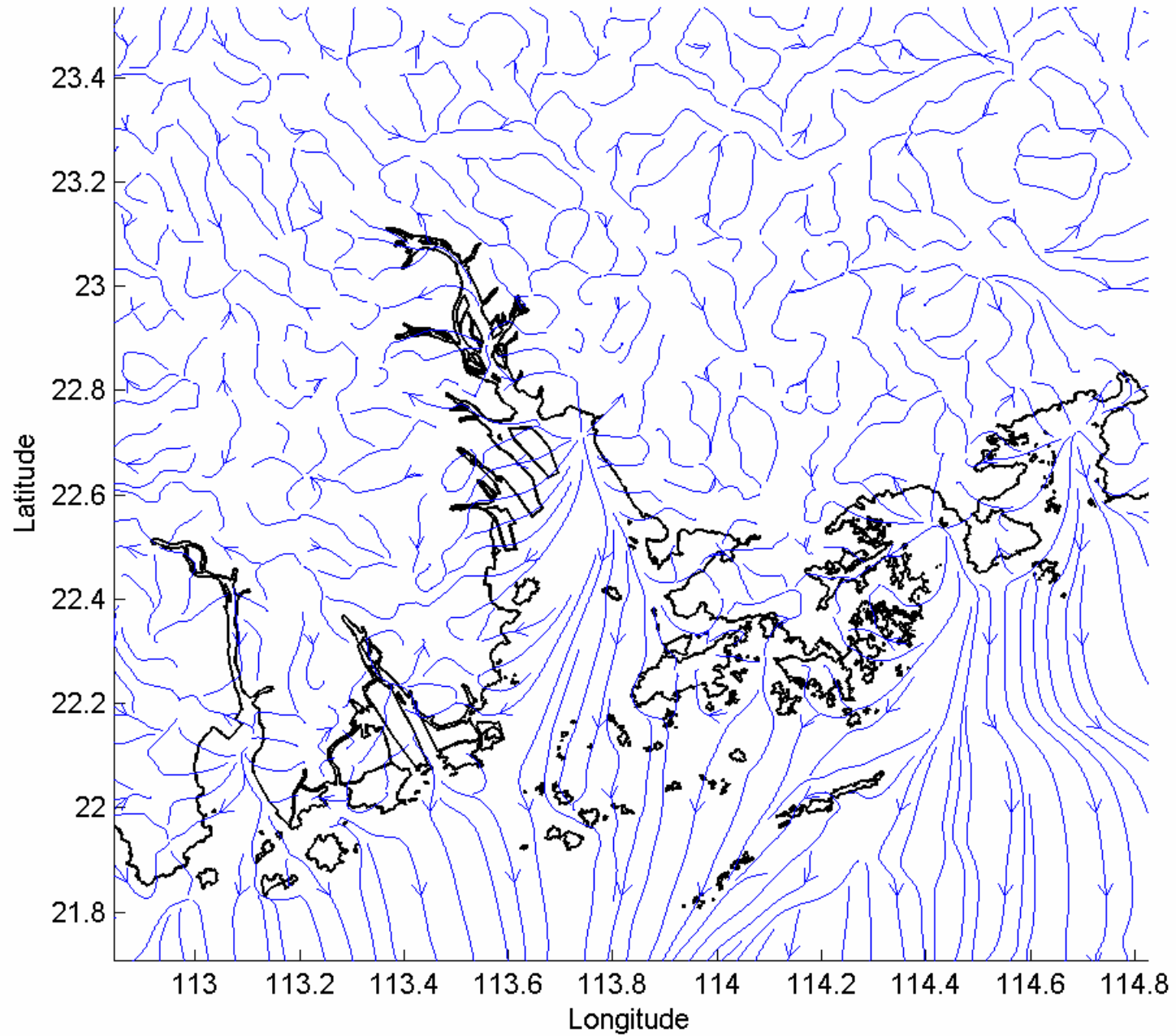
10:00 AM

Surface streamline pattern



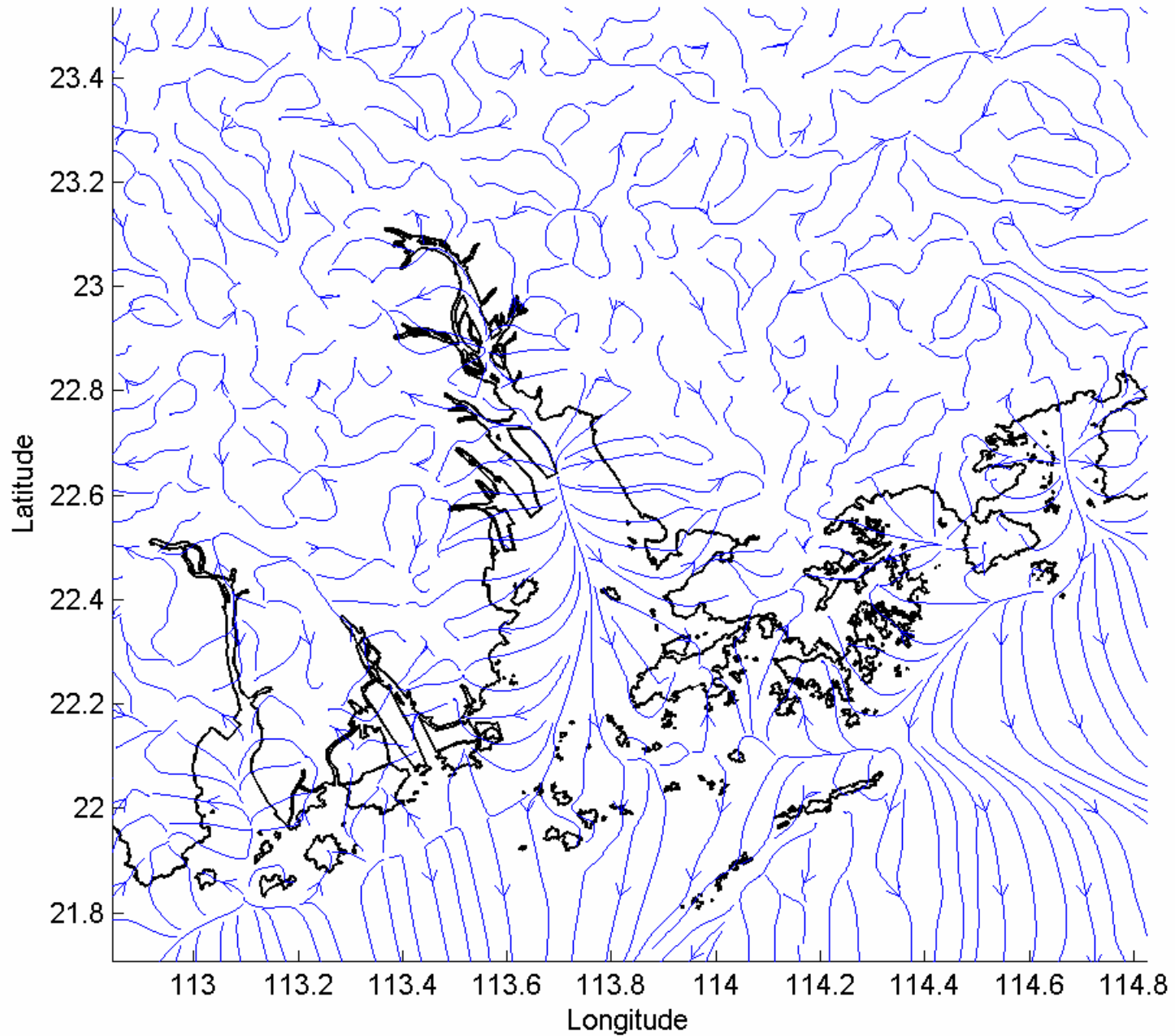
11:00 AM

Surface streamline pattern



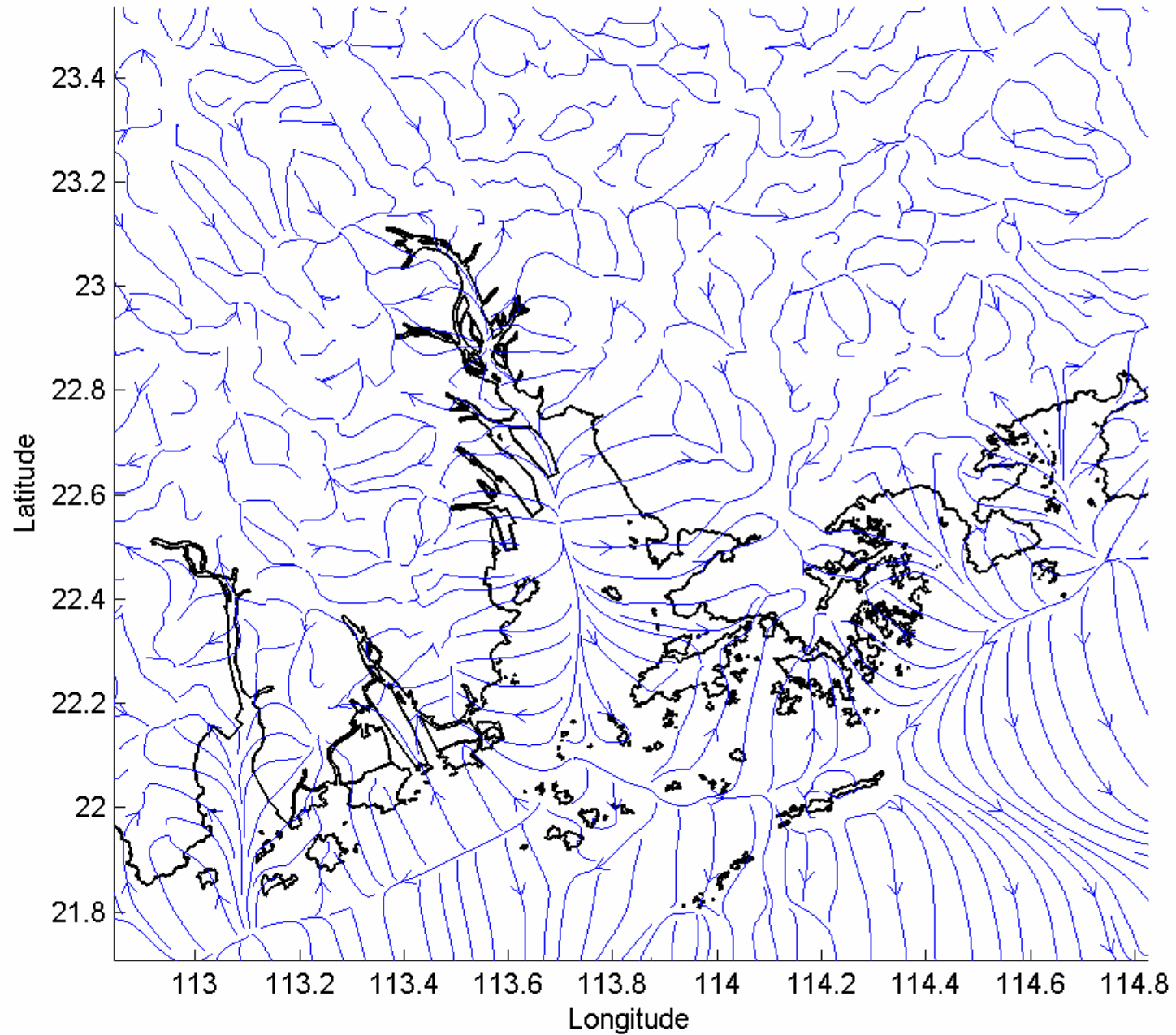
12:00 PM

Surface streamline pattern



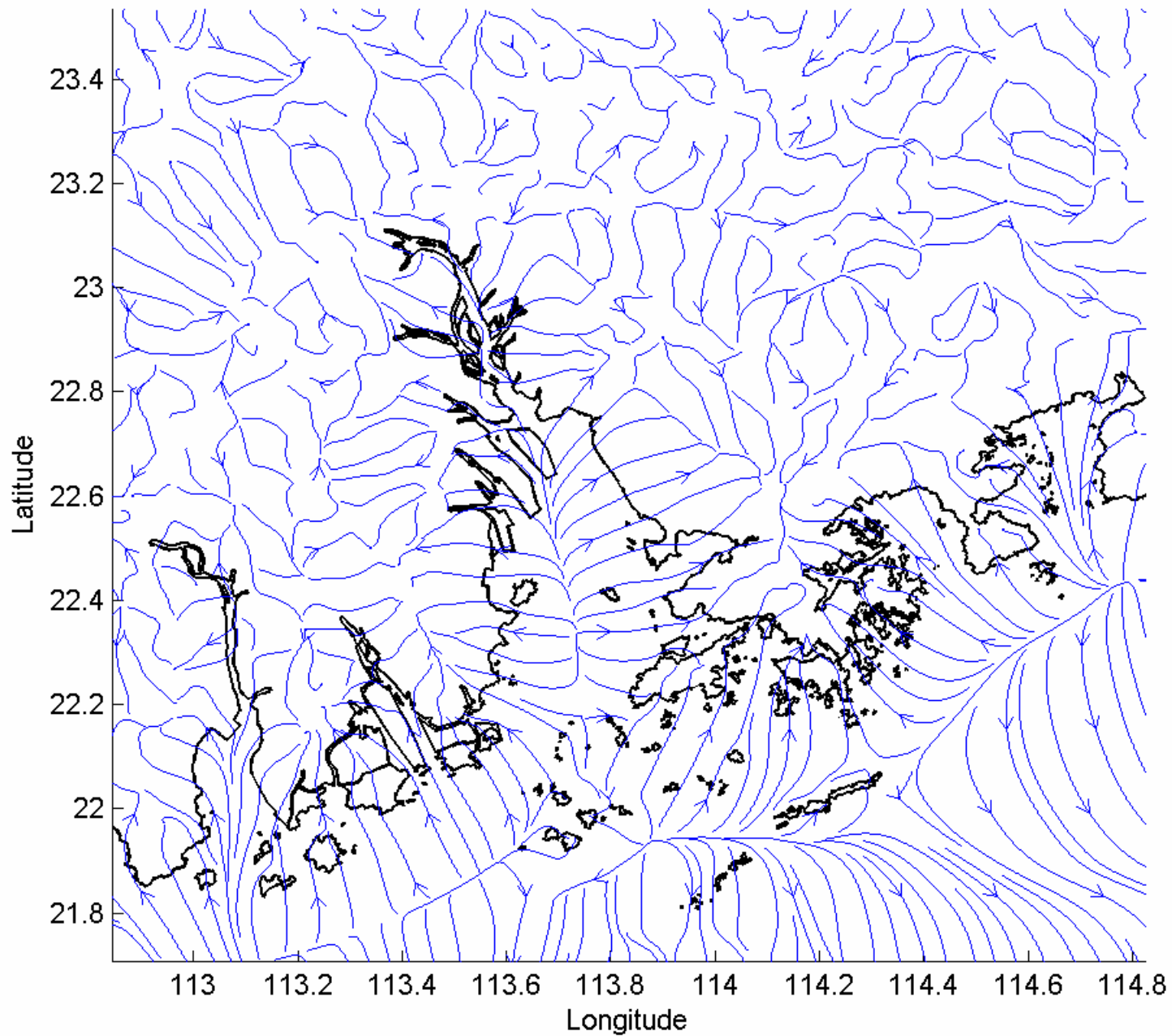
1:00 PM

Surface streamline pattern



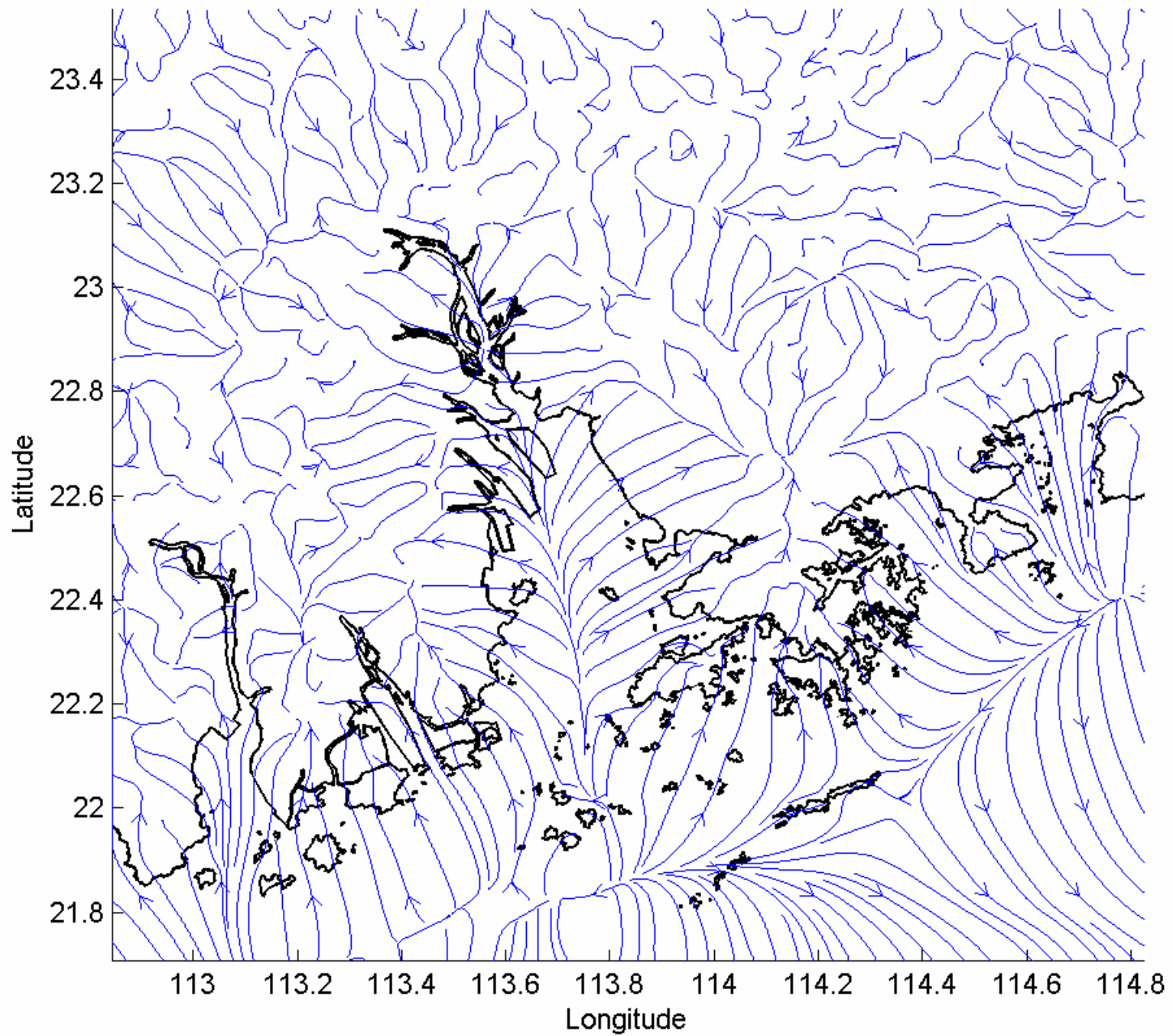
2:00 PM

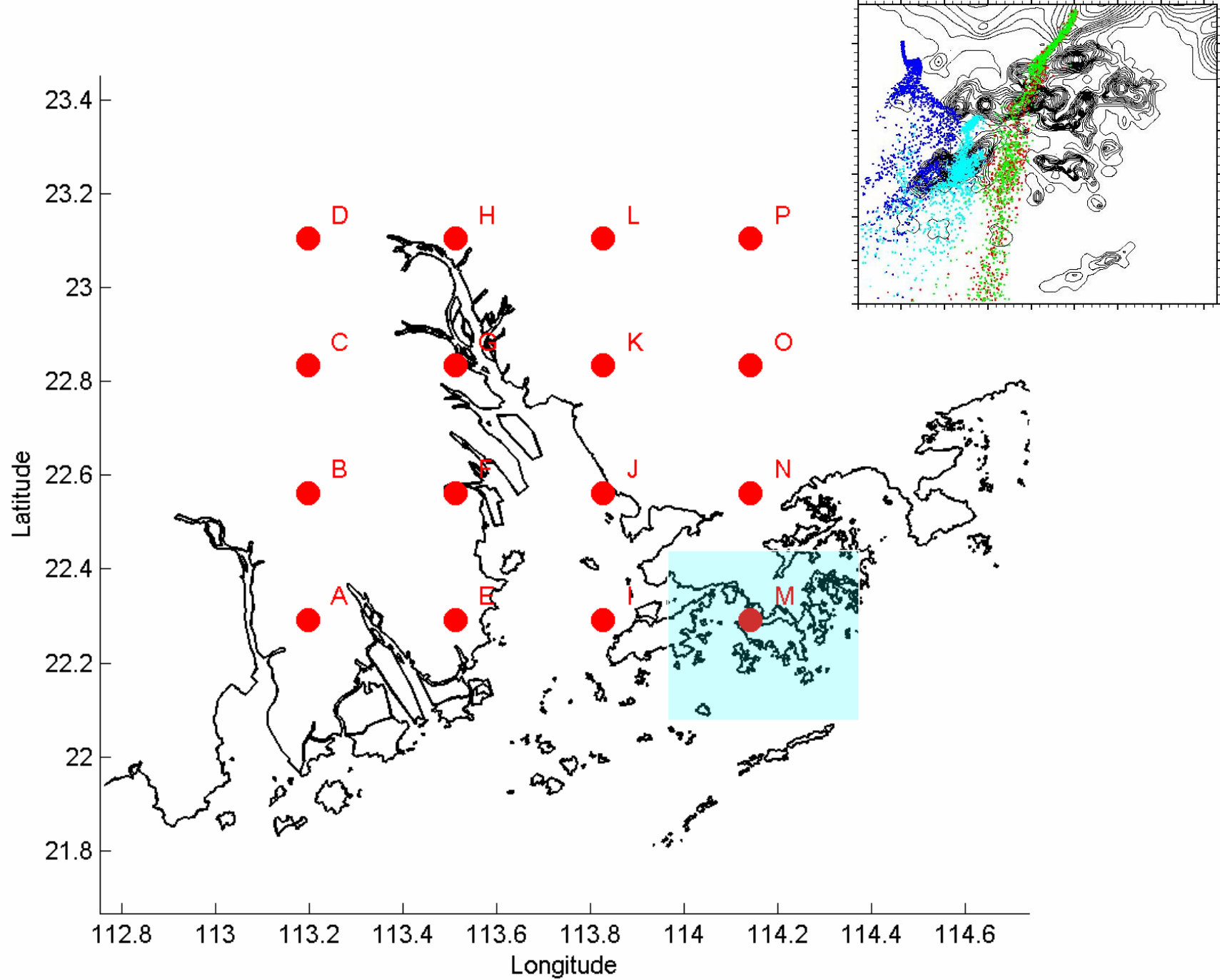
Surface streamline pattern



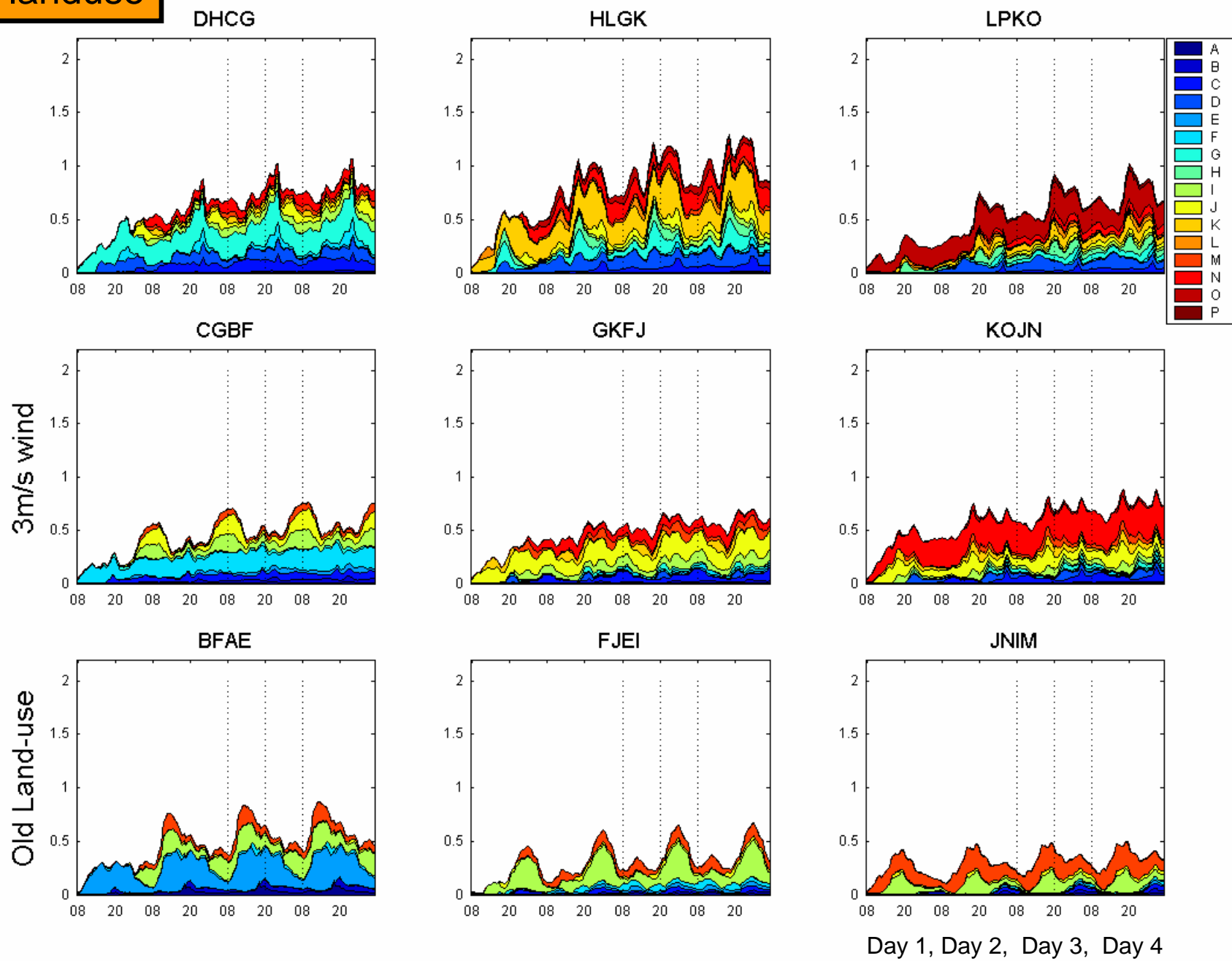
3:00 PM

Surface streamline pattern



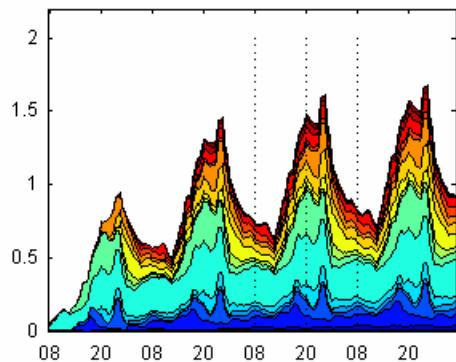


1993 landuse

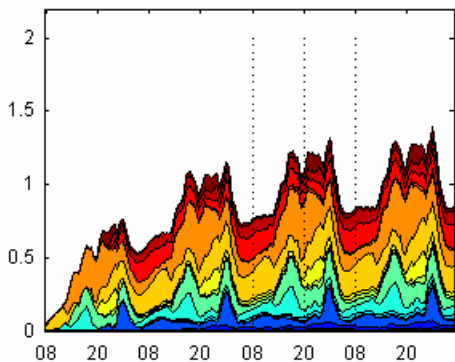


2004 landuse

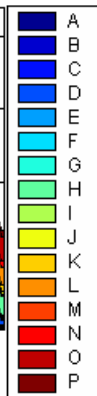
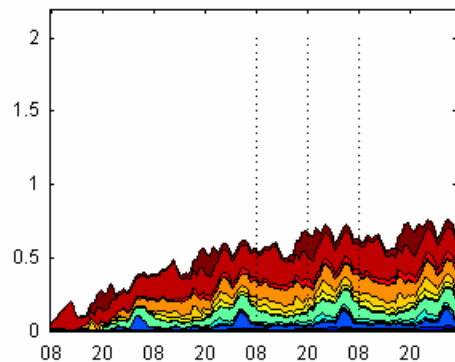
DHCG



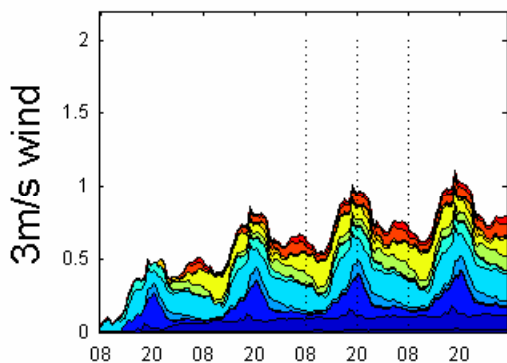
HLGK



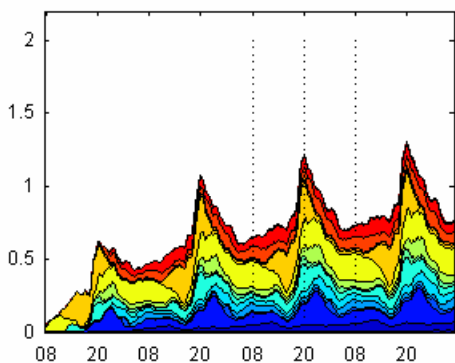
LPKO



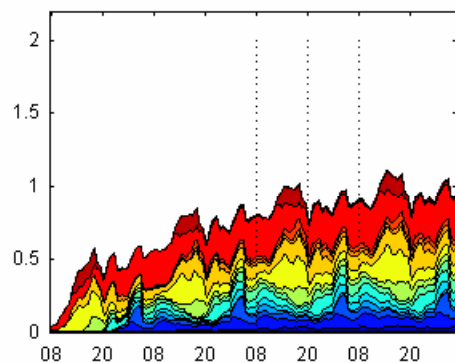
CGBF



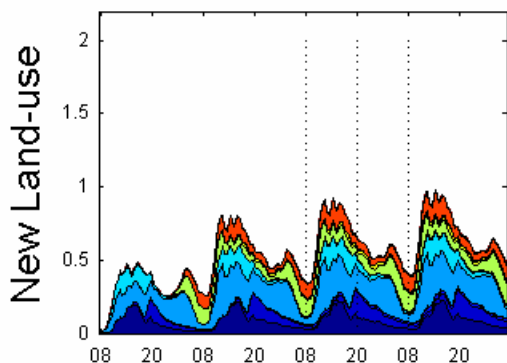
GKFJ



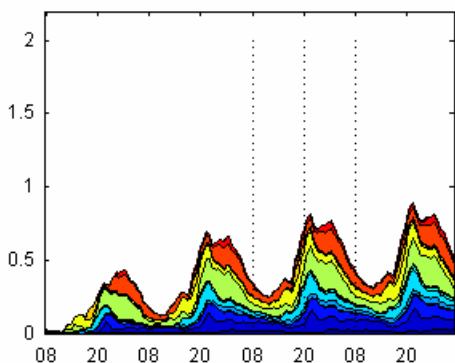
KOJN



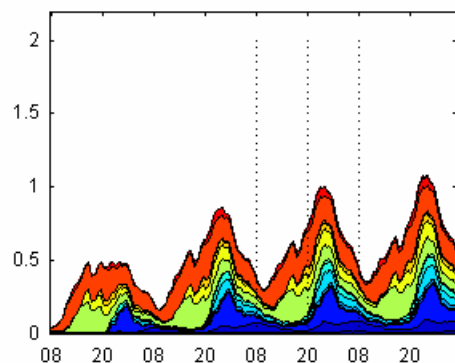
BFAE



FJEI



JNIM



Day 1, Day 2, Day 3, Day 4

PATH Model System

Meteorological Model

Create Physical Atmosphere
Solve full set of atmospheric equations for evolution of wind, temperature, pressure and moisture content, etc.

(MM5 v3.6)

Emissions Model

Anthropogenic, Natural

(EMS95)

Atmospheric Chemistry Model

Chemical reactions of various chemical species
and solve the advection-diffusion equations

(SAQM)



Introduction of PATH: EMS-95

EMS-95: The US Emission Modeling System (1995, version)

➤ **Point sources**

(power plants and industrial sources)

➤ **Mobile sources**

(road vehicles, railways and aircrafts)

➤ **Area sources**

(domestic and commercial fuel combustion)

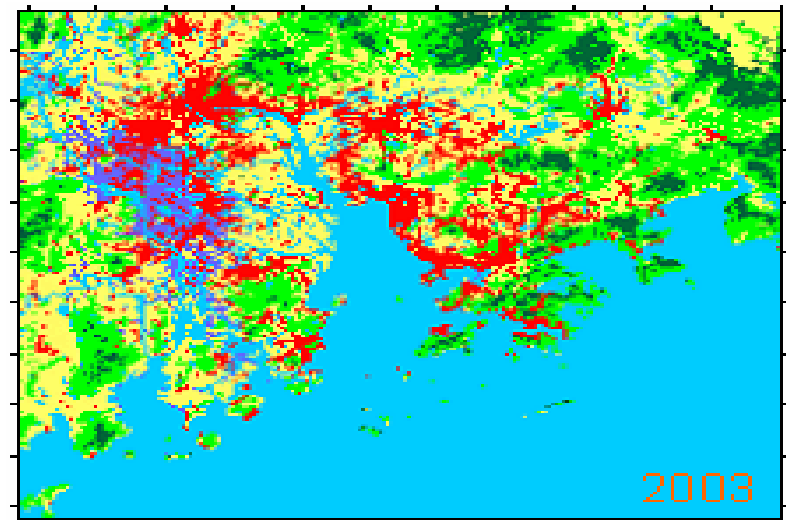
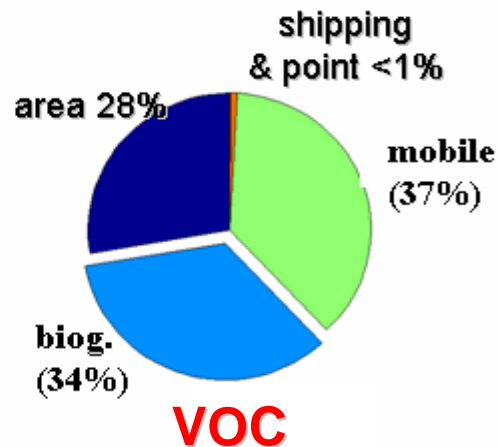
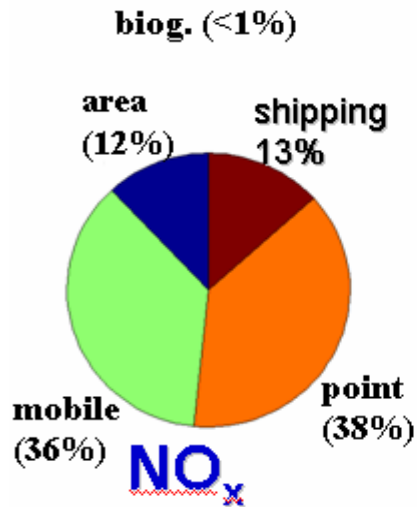
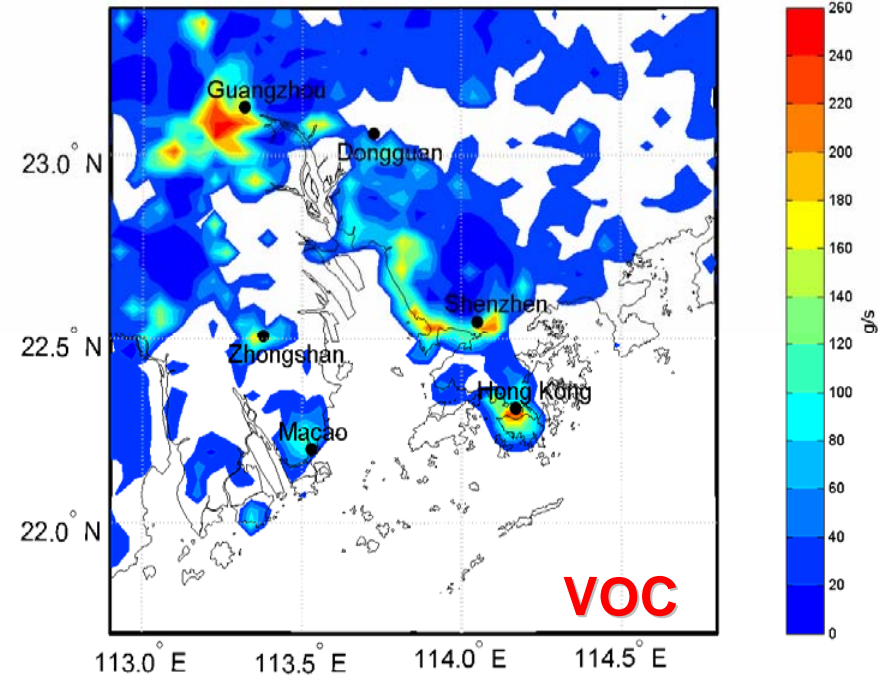
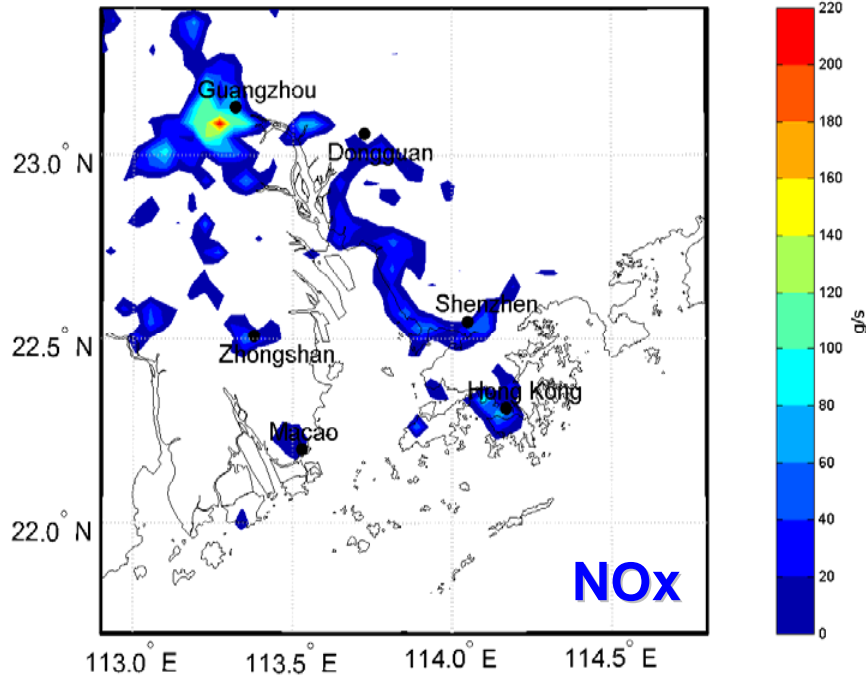
➤ **Shipping sources**

(marine traffics)

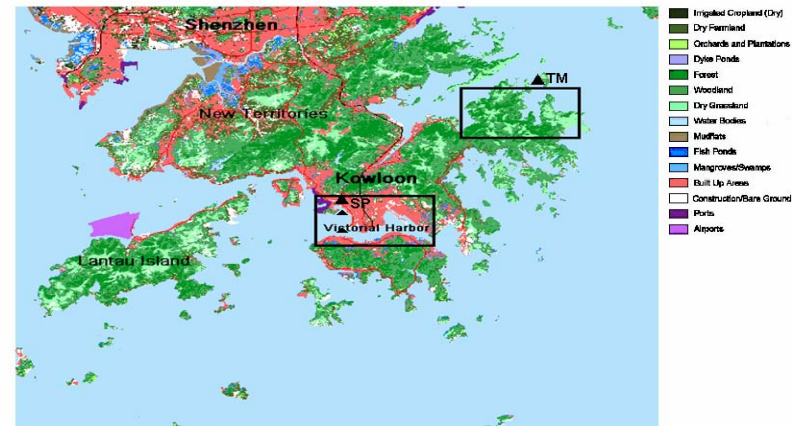
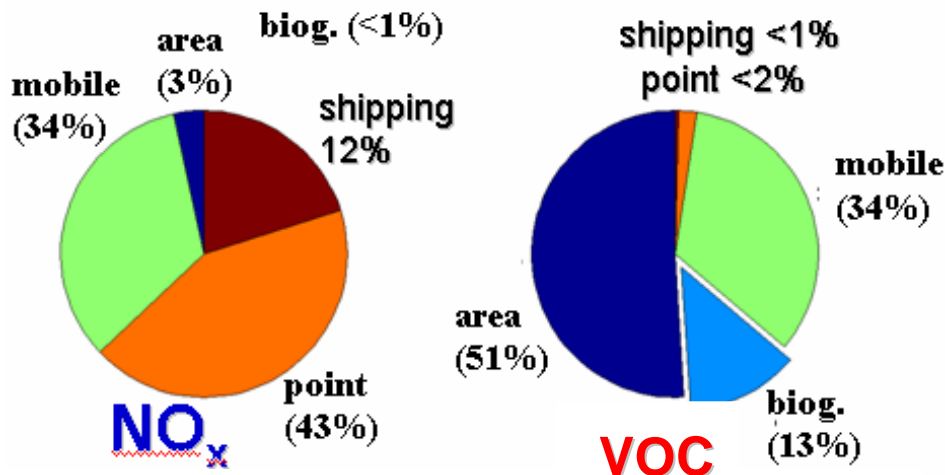
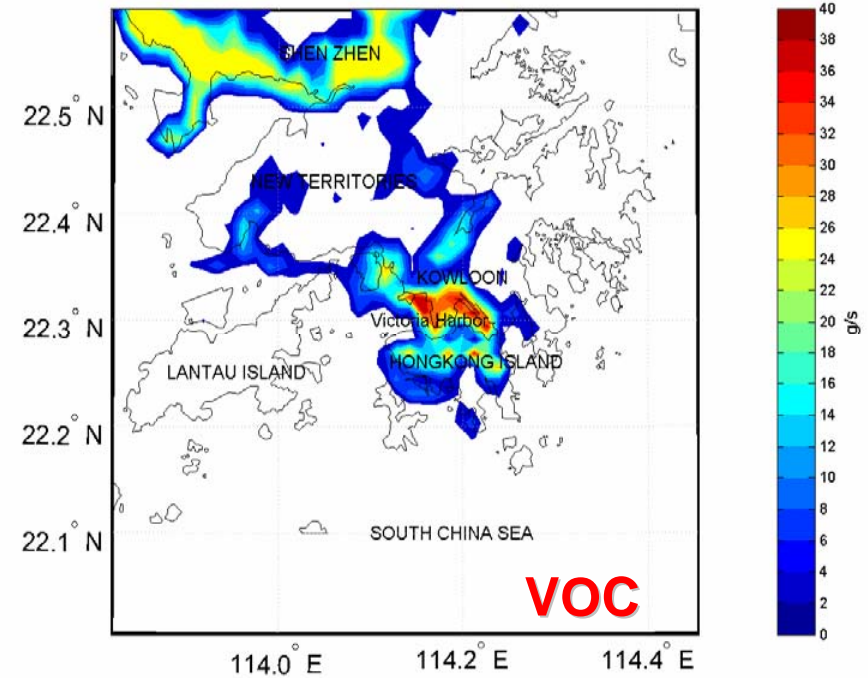
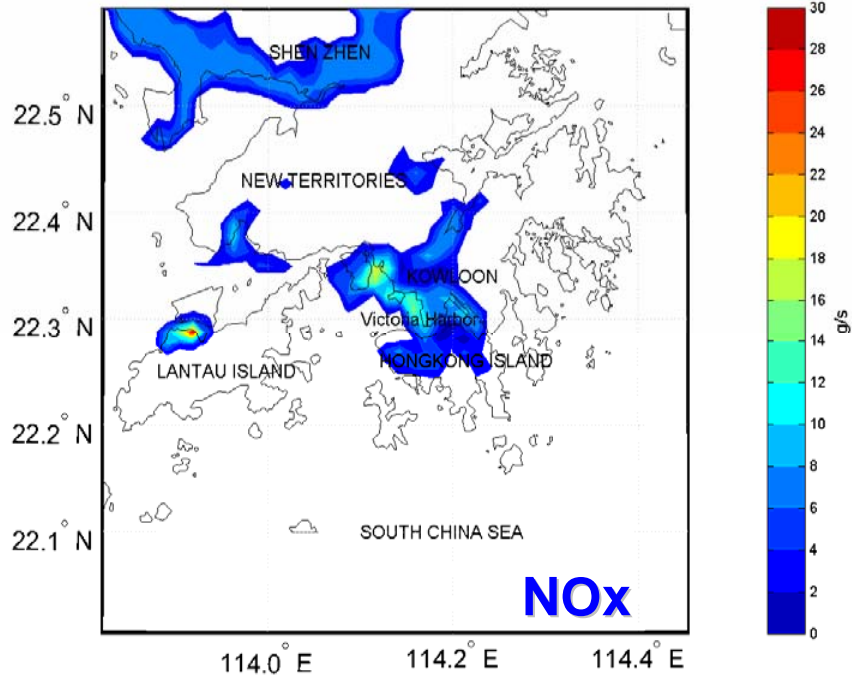
➤ **Biogenic sources**

(vegetation)

Typical ground level emission rates in PRD



Typical ground level emission rates in HK



PATH Model System

Meteorological Model

Create Physical Atmosphere
Solve full set of atmospheric equations for evolution of wind, temperature, pressure and moisture content, etc.

(MM5 v3.6)

Emissions Model

Anthropogenic, Natural
(EMS95)

Atmospheric Chemistry Model

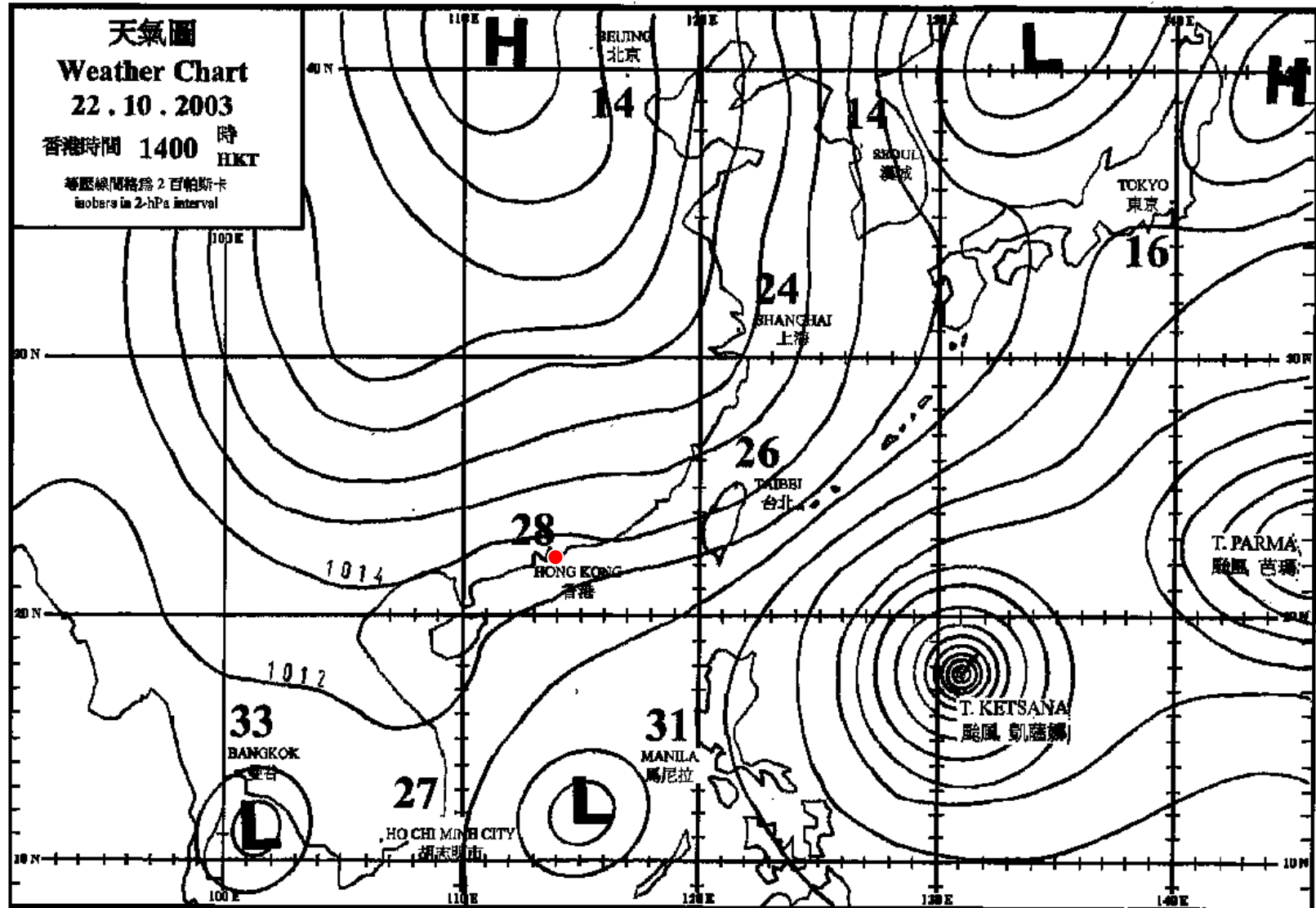
Chemical reactions of various chemical species
and solve the advection-diffusion equations

(SAQM)

SAQM Model Configurations

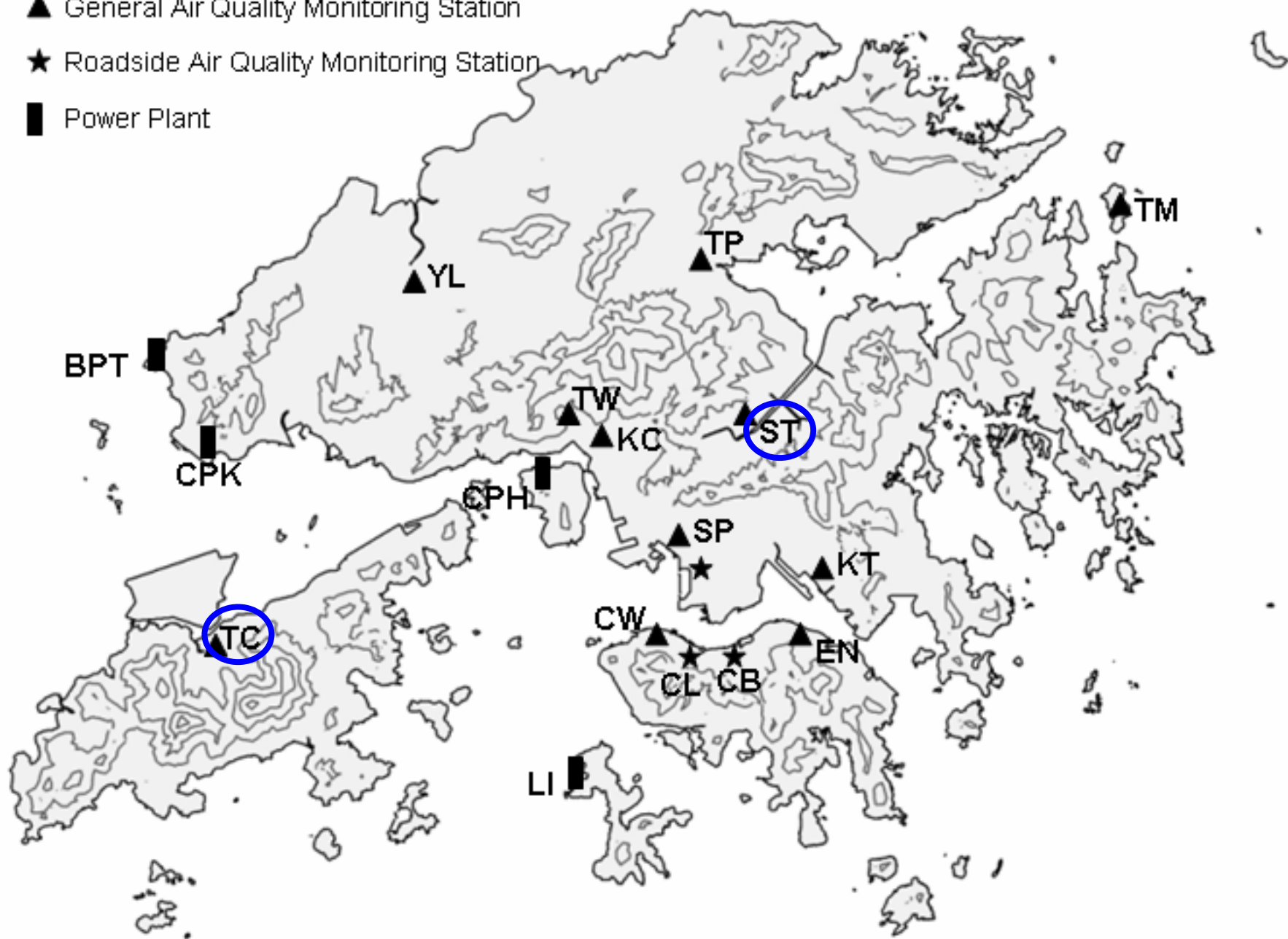
- **SAQM:** the **S**ARMAP **A**ir **Q**uality **M**odel (Chang, 1997), modified for its application to PATH in HK;
- **4-nested domains:** 40.5, 13.5, 4.5, 1.5 km with 49x49 grid cells for each domain;
- **CB-IV chemical mechanism** is used;
 - diffusion:** horizontal-briggs; vertical-eddies;
 - horizontal advection:** 4th order Botts scheme;
- **78** thermal-kinetic reactions, **11** photolytic reactions, **56** reactive species, **31** output species (15 for gas and 16 for particle matters).

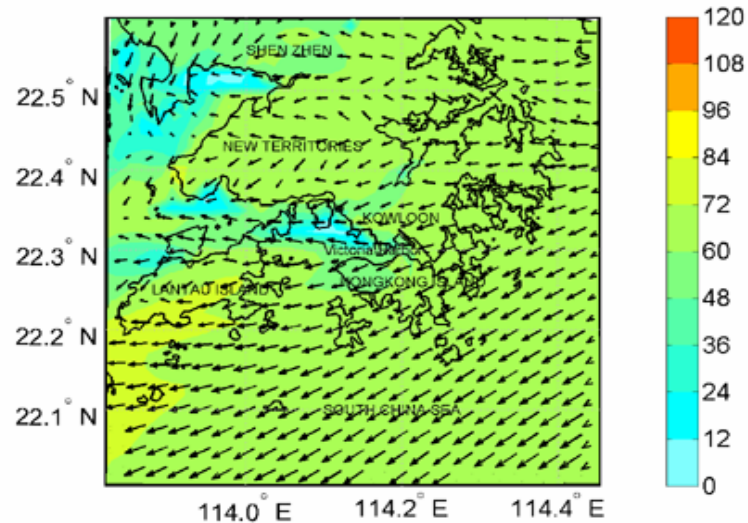
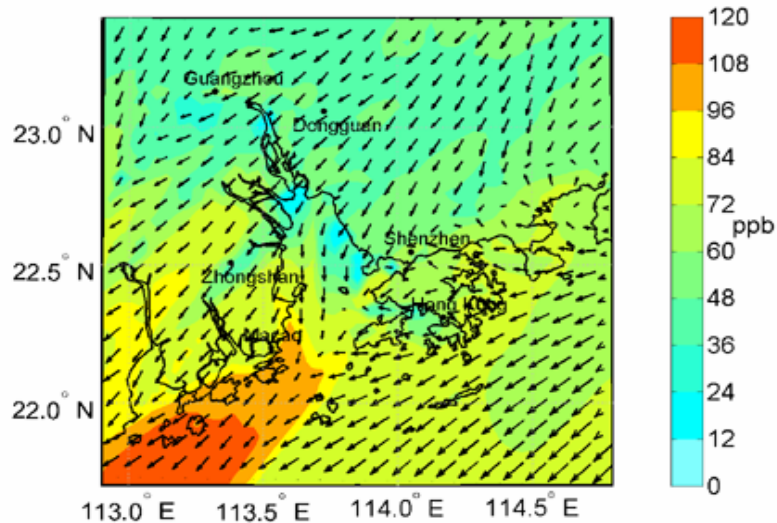
An O₃ episode: (22-24 October 2003)



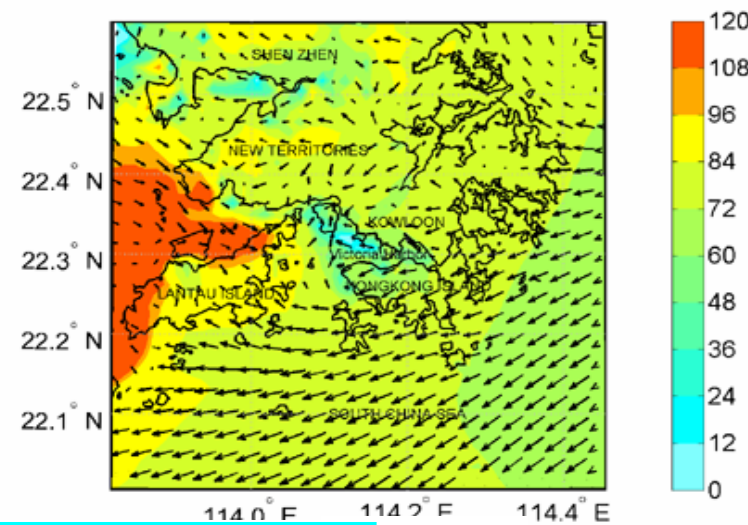
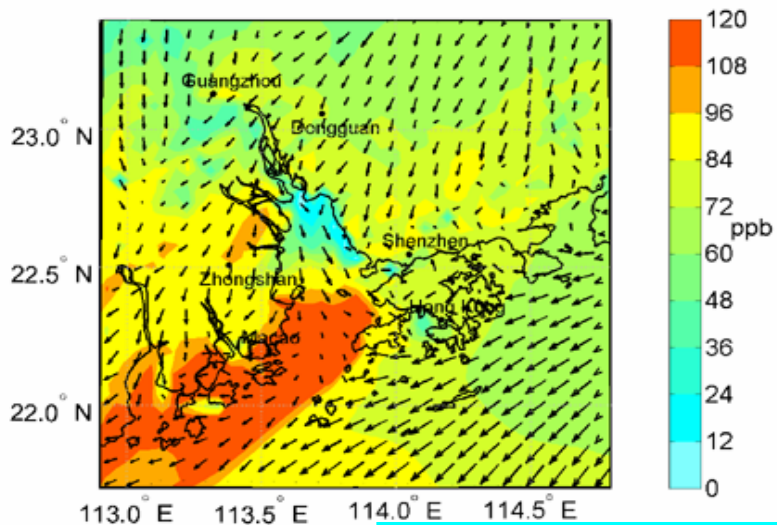
Model results

- ▲ General Air Quality Monitoring Station
- ★ Roadside Air Quality Monitoring Station
- Power Plant

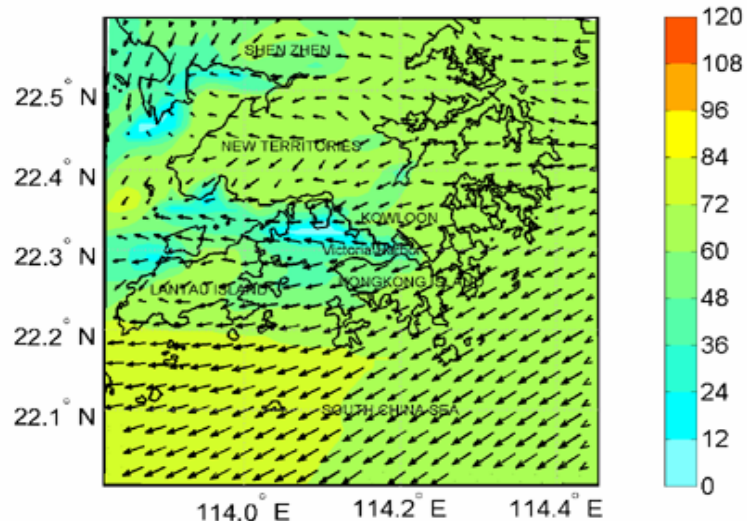
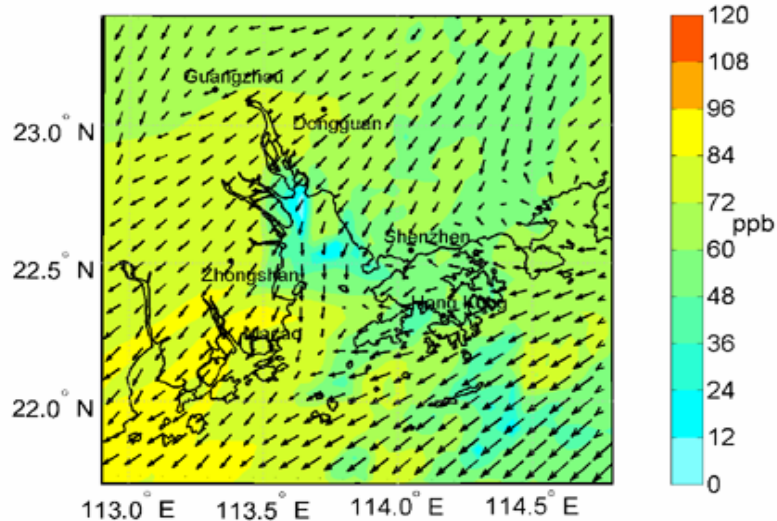




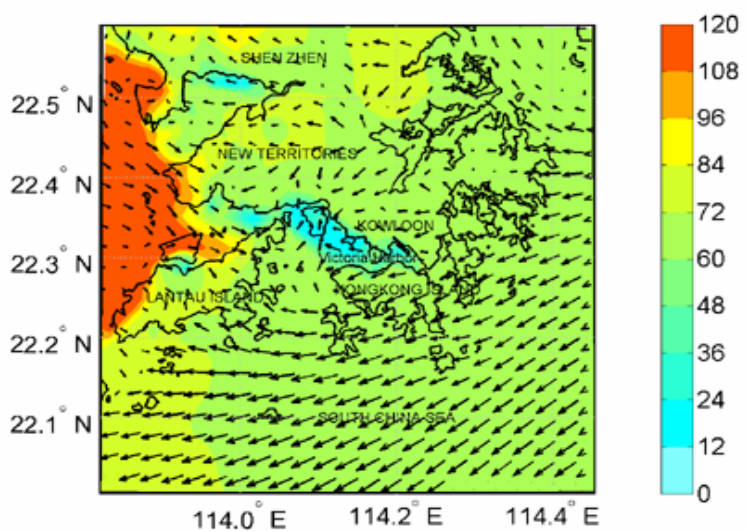
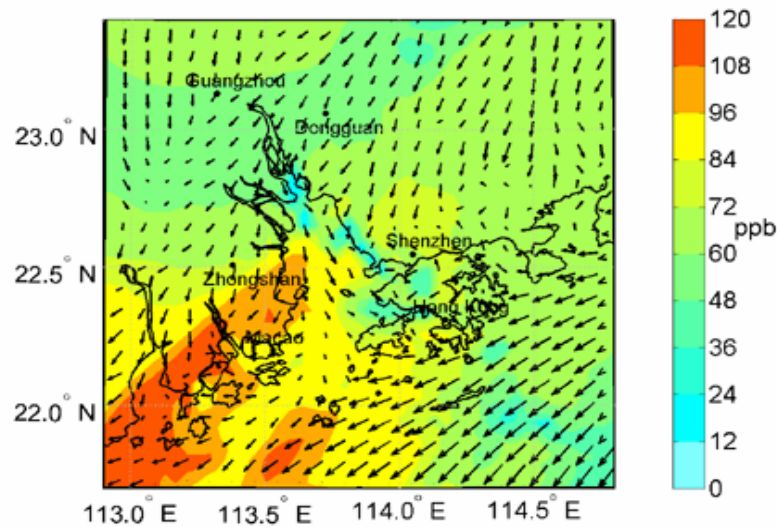
SAQM simulation: standard MM5



SAQM simulation: MM5-LSM



CMAQ simulation: standard MM5



CMAQ simulation: MM5-LSM

Summary and Conclusion

- ❖ **The simulations of MM5 with NOAH LSM show a better agreement with meteorological observations such as surface winds and temperature profiles below 850 hpa, etc., than those of MM5-STD, in comparison with observations;**
- ❖ **The surface ozone simulations have been improved in terms of the peak ozone and spatial patterns when MM5/NOAH LSM is used to generate meteorological fields for air quality models;**
- ❖ **However, the impact of MM5/NOAH LSM on PM modeling is still under investigation.**

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