Application of RAMS 4.28 to transboudary air pollution studies in East Asia by Pentium Linux Cluster - Performance, Tips and Problems -

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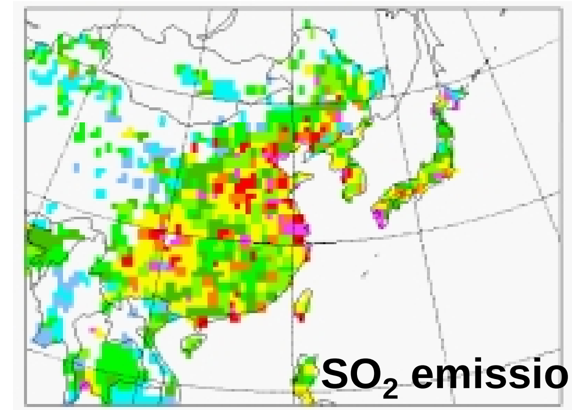
Objectives

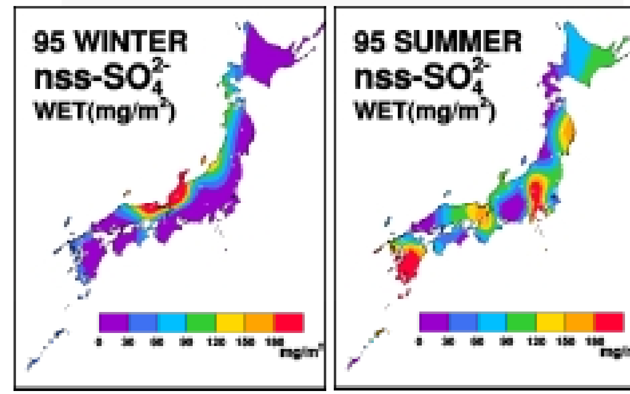
- **Regional Meteorological and Chemical Climate Simulation**
- **Role of Pacific and Continental Air Mass for air Quality over East Asia**
- **On-line regional scale chemical transport model fully coupled with RAMS was developed to study regional transboundary air pollution**
- **Role of meteorological and climatological conditions in the transboundary air pollution transport in East Asia was studied and indicates the importance of climatological changes for chemical composition concentration and deposition by season.**
- **12 month continuos model run to understand regional chemical climate**
- **Performance of Linux Cluster for RAMS 4.28 parallel run**

Background of this study

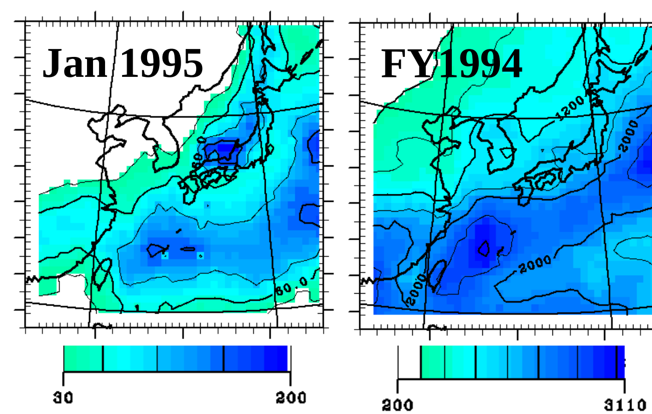
- Rapid increase in energy consumption shows a dramatic increase of the pollutants emission over Asia
- Oceans (East China Sea, Japan Sea, Pacific Ocean) cover a huge fraction of the East Asia surrounding Japan
- Strong seasonal variation in meteorological condition and depositions
- Very few observation station over the ocean
- Knowledge of both pollutant concentration and meteorological parameters over these oceans is critically necessary to understand the long-range transport and transformation processes



SO_2 emission



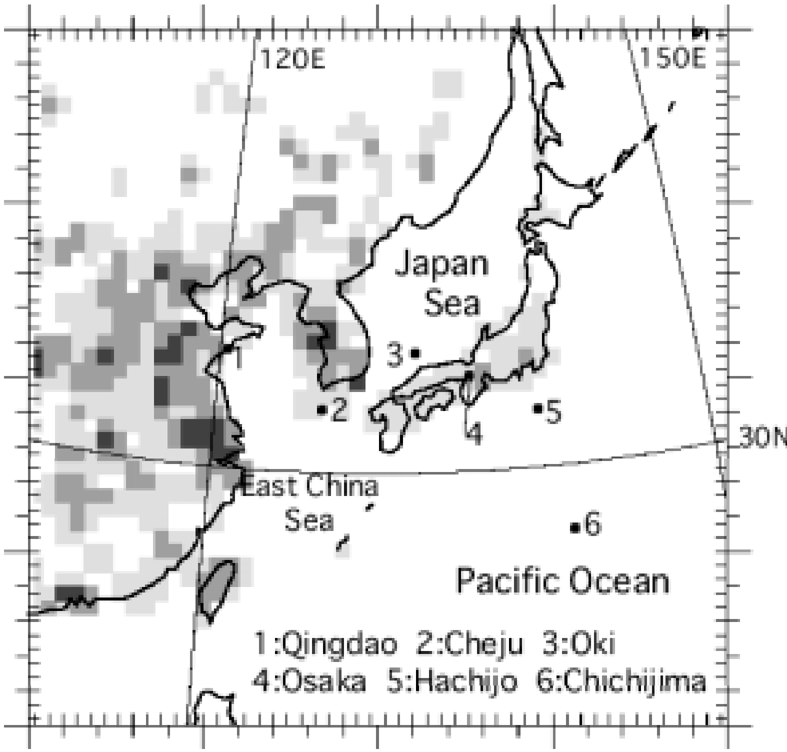
strong seasonal variation



CMAP Precipitation (mm)

Regional Met. Model

- RAMS (Regional Atmos. Modeling System, Pielke *et al*., 1992)
- RAMS 4.28 parallel version was used with Pentium Linux Cluster
- ECMWF Global Data Set for Assimilation & Monthly SST
- Microphysics option ON
- Additional Scalar Transport Channel for SO_2/SO_4 on-line transport
- Numerical simulation from April 1, 1994 to March 31, 1995 (FY1994)
- Grid system for) East Asia
  - $\Delta x=\Delta y=80$km, z-top=23km, PS-coordinate
  - NX=50, NY=50, NZ=23

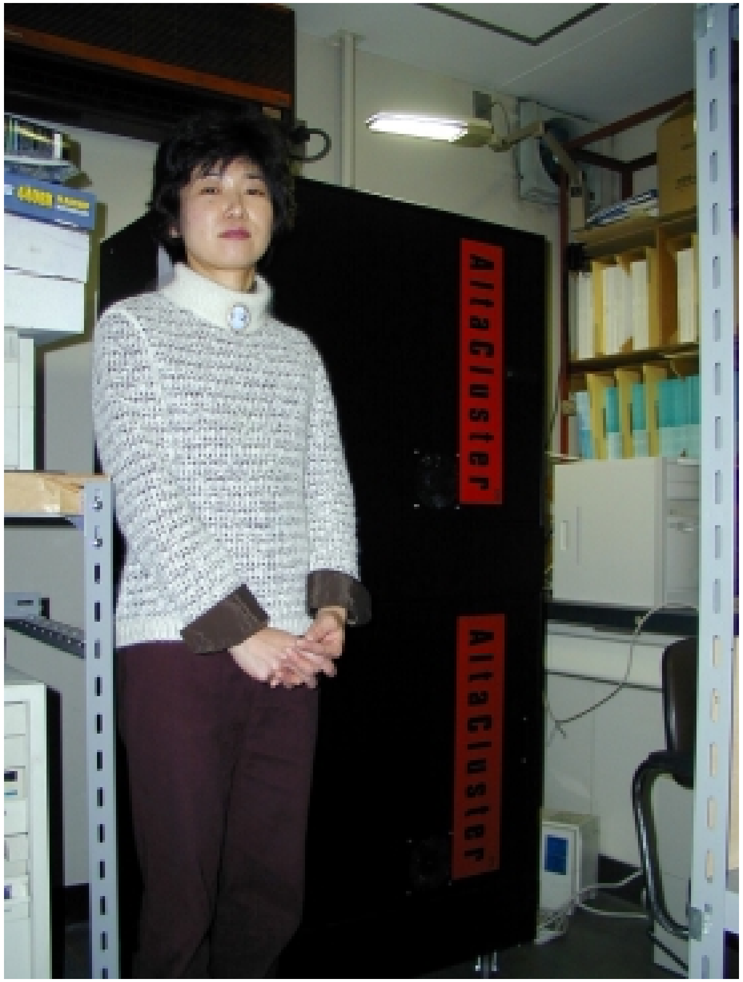


Calculation Domain and Emission Intensity for SO_2

On-Line SO_2/SO_4 Transport

- Sulfur transport and deposition is simulated using RAMS and an on-line long-range transport model.
- The tracer model is fully coupled with RAMS, and this is a unique approach because the regional meteorological conditions, which play significant role in the wet deposition and vertical diffusion of tracers, are continuously updated within the tracer model at the same time intervals.
- Transport and deposition processes can be directly handled by using real time meteorological parameters from the mesoscale model.
- At present stage the on-line transport model includes linear chemical reaction from SO_2 to SO_4^{2-} in the gas phase by $SO_2 + OH \rightarrow SO_4^{2-}$.
- In aqua phase, transport model includes two major reactions of $S(IV) + O_3(aq) \rightarrow SO_4^{2-}$ and $S(IV) + H_2O_2(aq) \rightarrow SO_4^{2-} + H_2O$. ($O_3$ and H_2O_2 concentration are given from Takemura *et al* (JGR), and pH=5.6 is fixed)

Pentium III Linux Cluster (RIAM stream cluster, Uno-Labo)

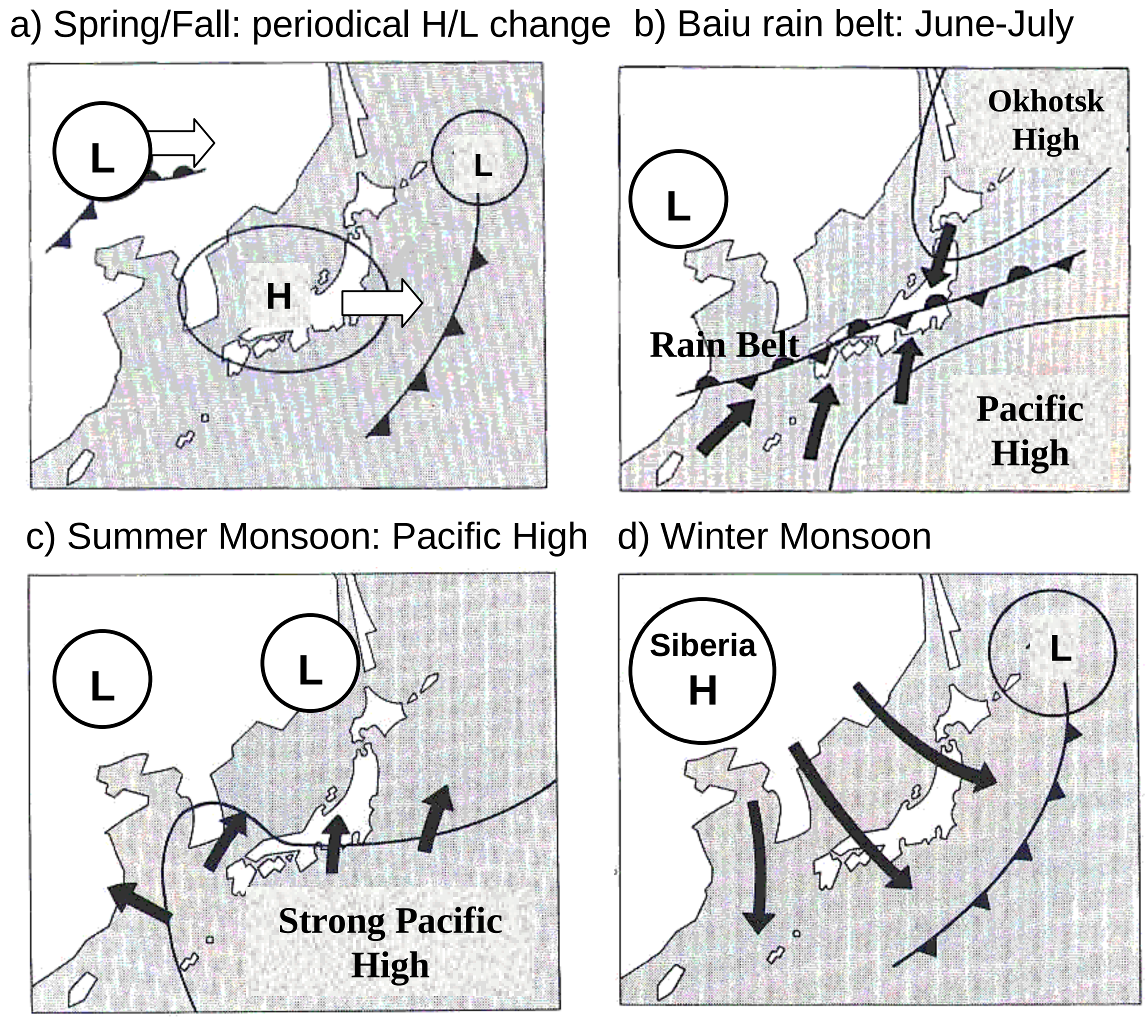


RAMS on-line sulfate transport 40 hours / 1 year run

NEC SX-4 (8cpu): PC Cluster (16cpu)=1 : 4

Important Weather Pattern over Japan

The important climate features of the region, schematically represented in this figure, show, for each season, a typical pattern depending on the relative strength of Pacific high and continental high pressure systems.



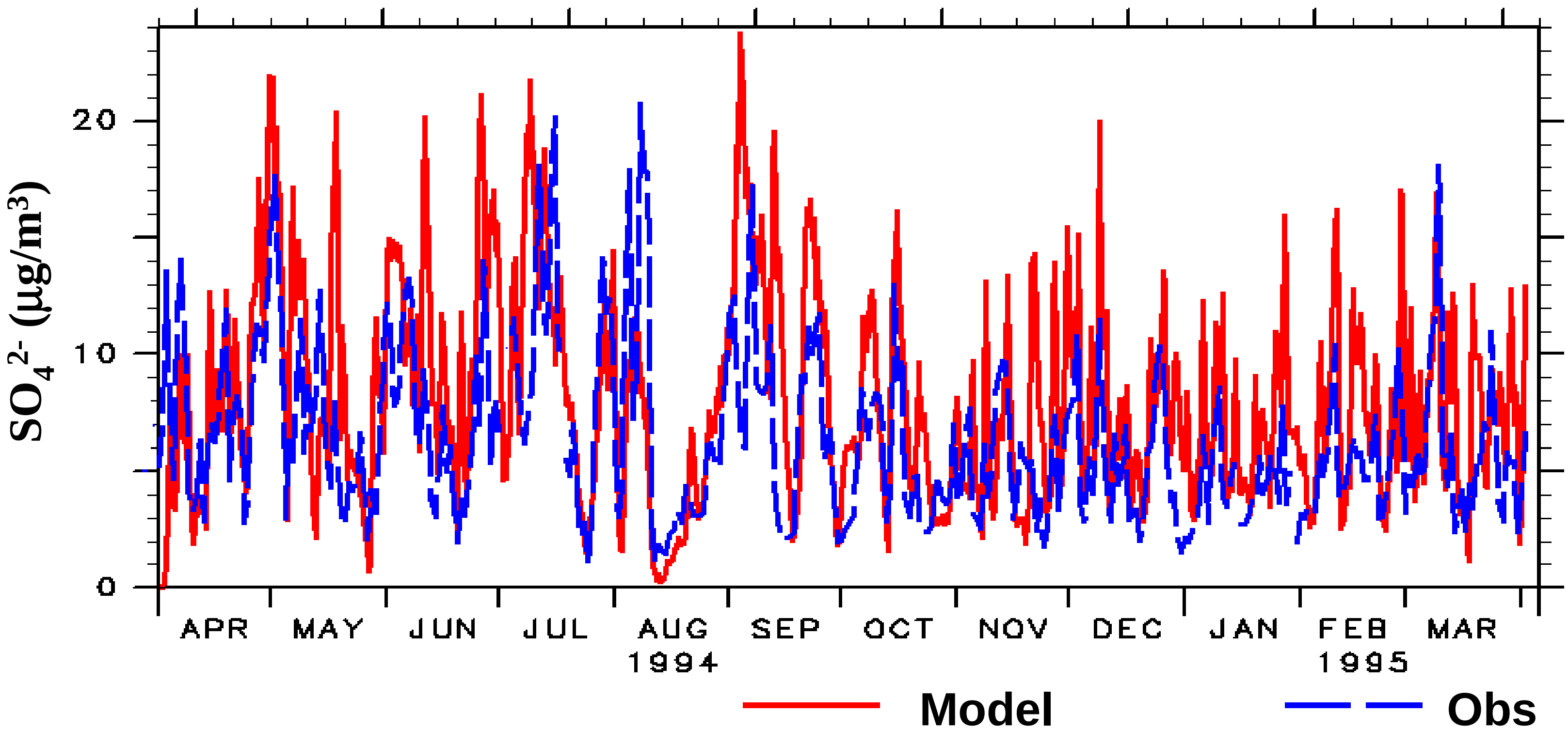
A large scale traveling high/low pressure system, moving slowly eastward is characteristic of the spring/fall weather (a). The Baiu rainy season, characterized by the presence of a rain belt with heavy precipitation, strongly affects the wet deposition in the region during late spring - early summer (b).

When Pacific high pressure system becomes stronger, then rain-belt disappears and Japanese area is covered by Pacific high, which characterizes the typical summer monsoon (c). In this condition, relative clean and hot/moist air dominates the East Asia domain.

Typical winter monsoon is shown in (d). From the middle of November to early March, strong pressure gradients between Siberia (Continental) High and Okhotsk Low exists in average.

Observation at Osaka and Model Results

Observed sulfate concentration at Osaka compared with model results show a good agreement, and the intermittency during the winter season and the periodicity typical of spring/fall rainy seasons, when the alternance of high/low pressure systems characterize the meteorology of the region, is nicely reproduced by the numerical model (RAMS on-line transport model).



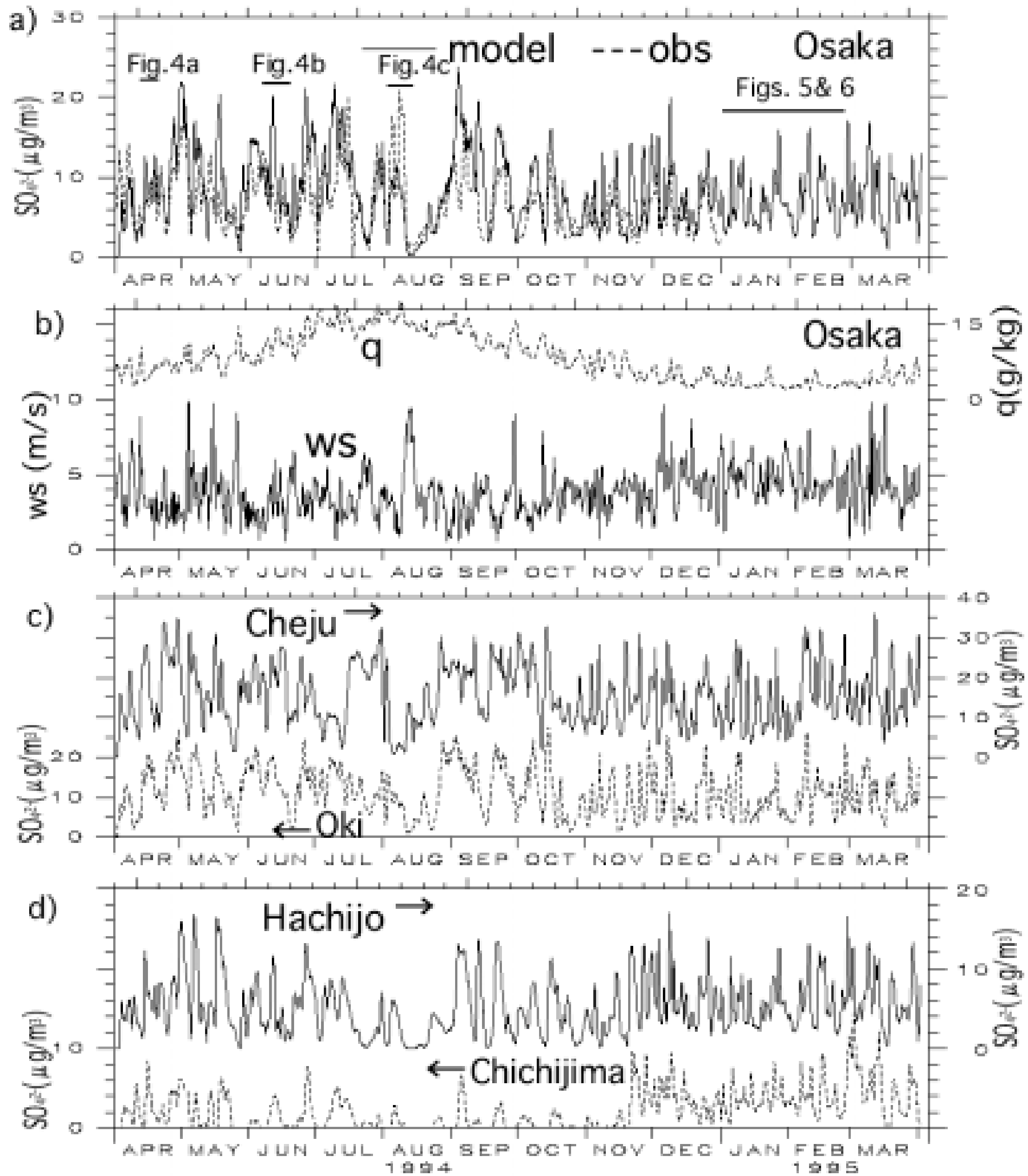
Modeled twelve hours averaged concentration (straight line) and daily averaged observation (dot line)

Model Results

(b) shows the specific humidity and surface wind speed at Osaka.

(c) and (d) show SO_4^{2-} concentration variation at Cheju, Oki, Hachijo and Chichijima

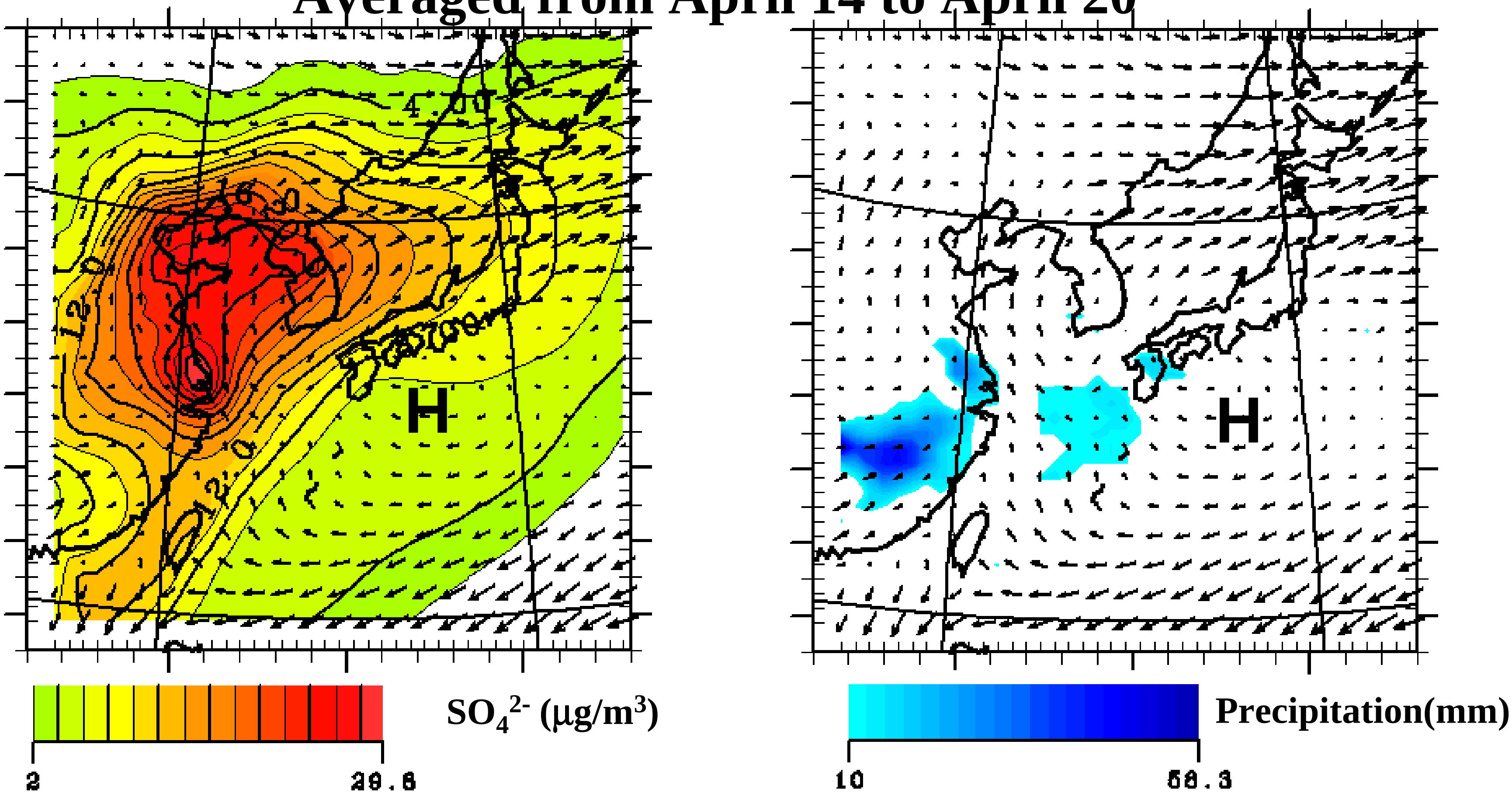
One of the surprising facts is the time variation among these 5 stations in winter shows very similar spiky pattern



Spring/Fall (Periodical H/L change)

Averaged flow field, SO_4^{2-} concentration and precipitation from April 14 to April 20, which represents typical spring time travelling high pressure pattern. Almost no precipitation observed and the clockwise outflow at the northern edge of high pressure system transports the pollutants toward the northern part of Japan.

Averaged from April 14 to April 20

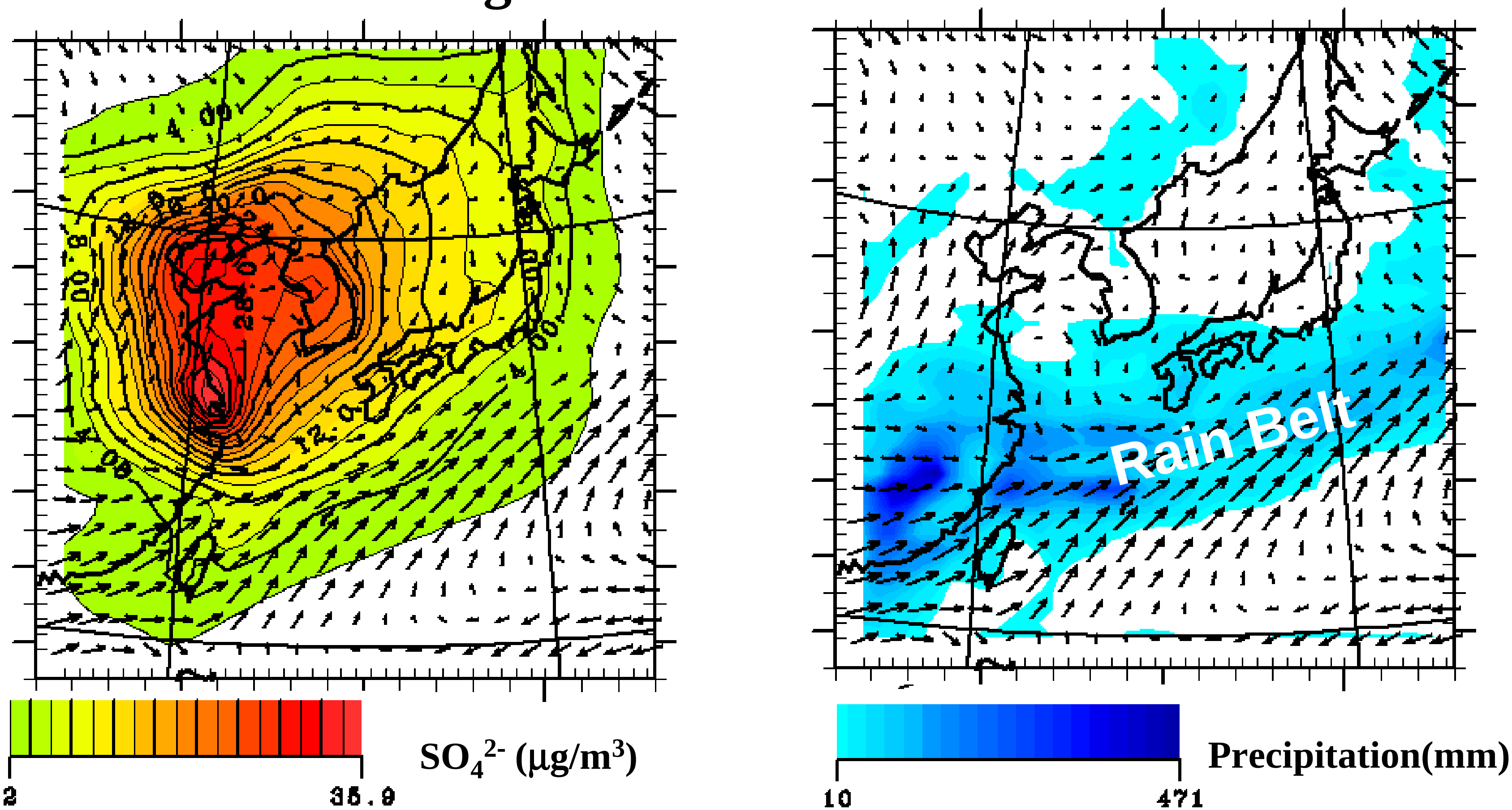


Rainy Season : June-July

Rain-Belt (Baiu, Meiyu) over Japan

Averaged field from June 6 to June 18, which represents the rainy season. It shows clearly that the high concentration is trapped north of the rain belt.

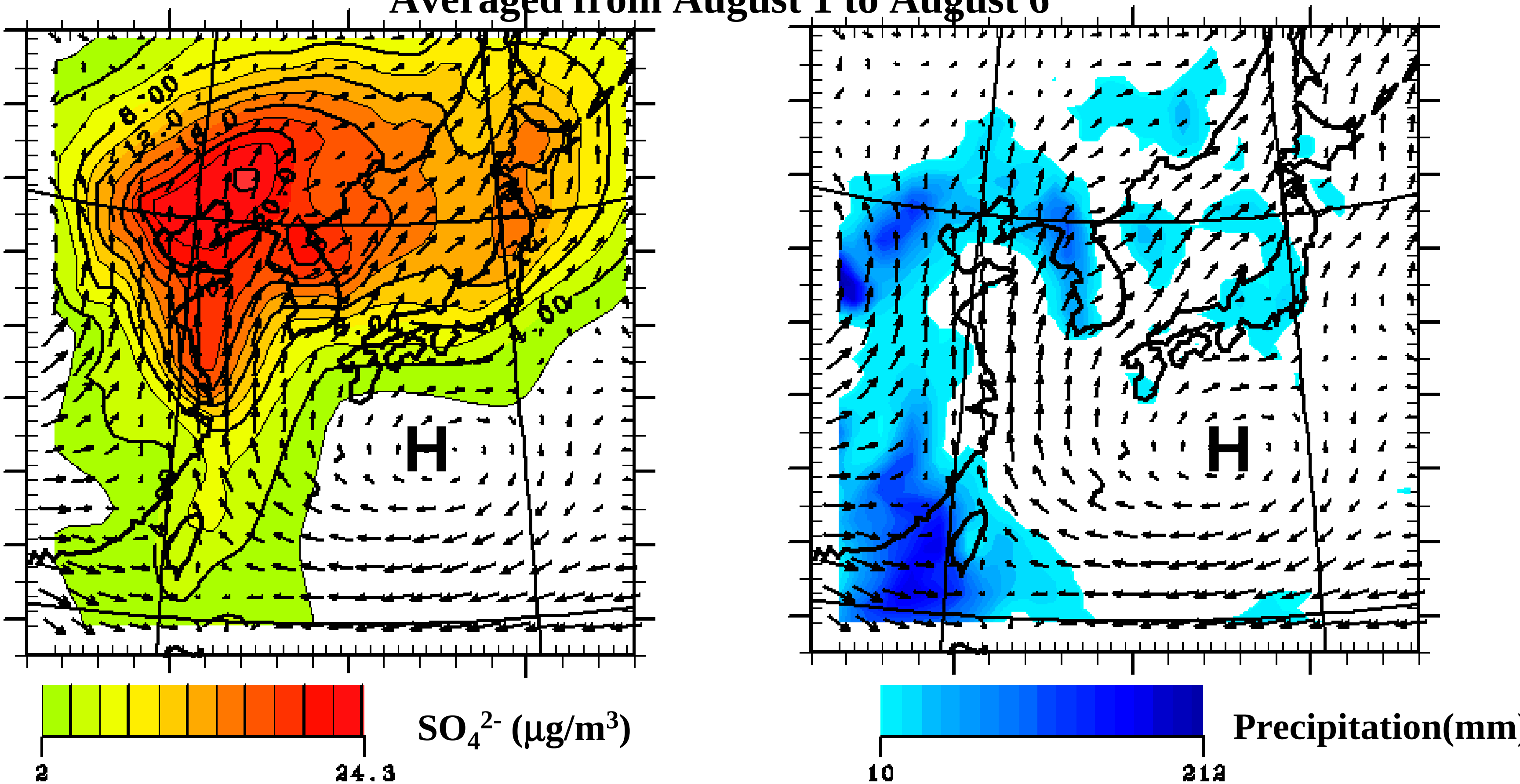
Averaged from June 7 to June 18



Summer Monsoon

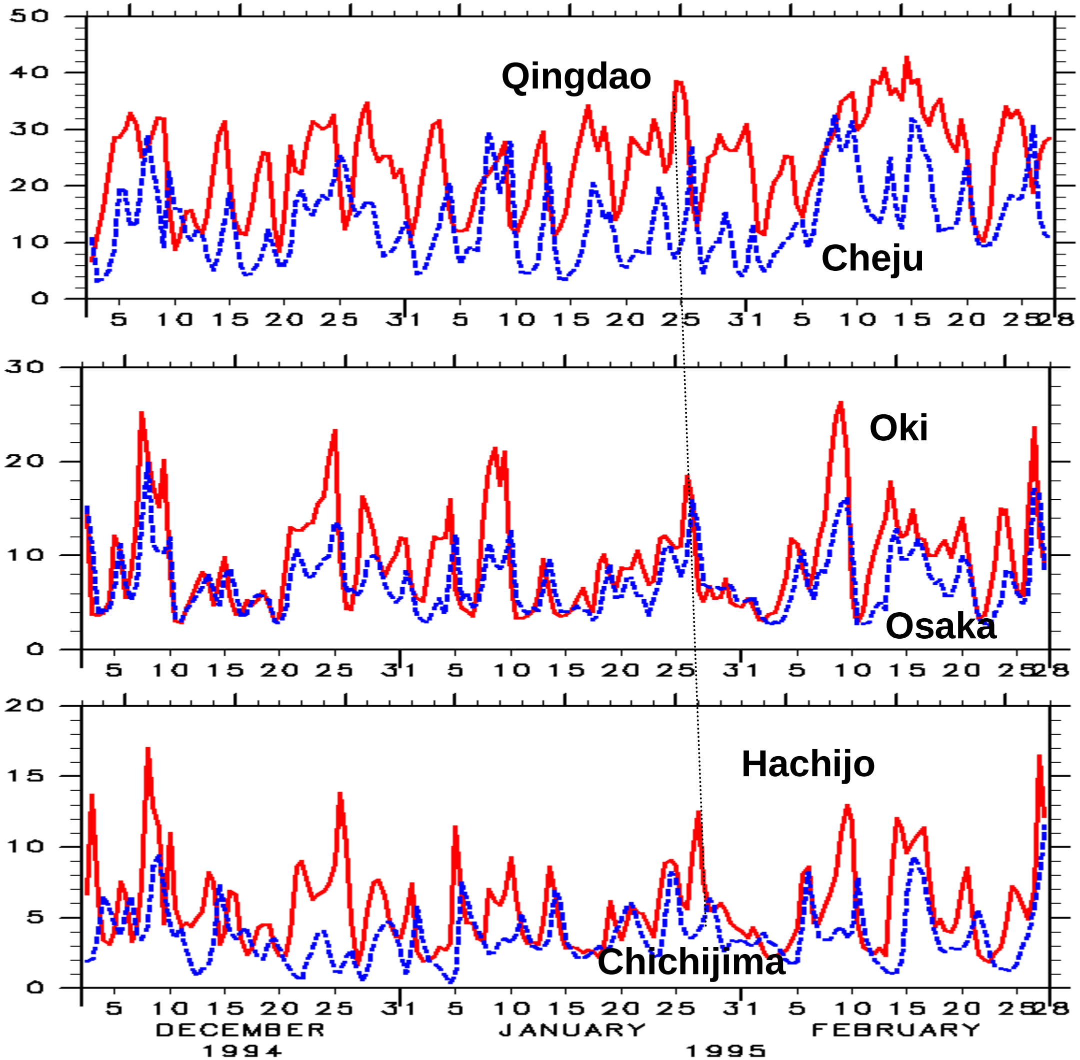
Strong outflow from Pacific high and precipitation occur in the northern part of China and Korea, and pollutants are transported to these precipitation zones.

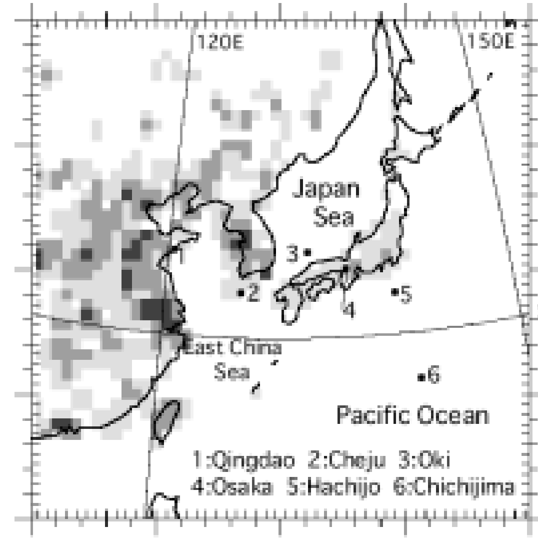
Averaged from August 1 to August 6



Winter Monsoon /DJF

SO_4^{2-} ($\mu g/m^3$)





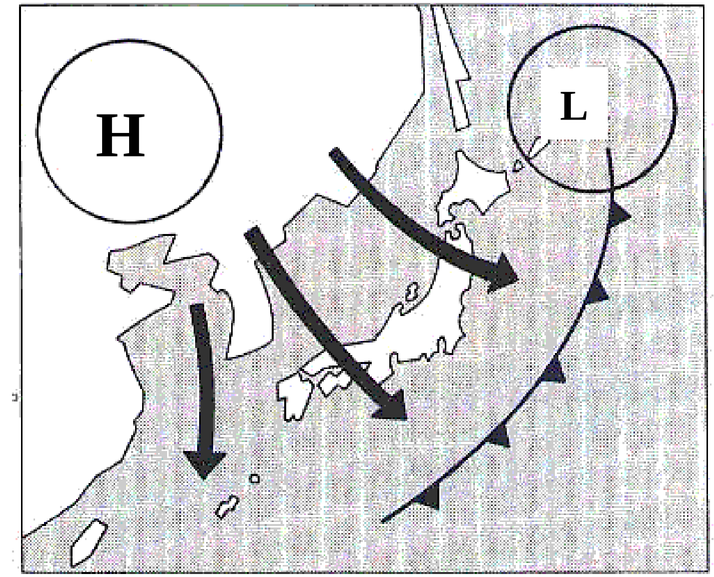
It shows the time variation of SO_4^{2-} concentration during winter monsoon in December 1994 – February 1995 at 6 locations

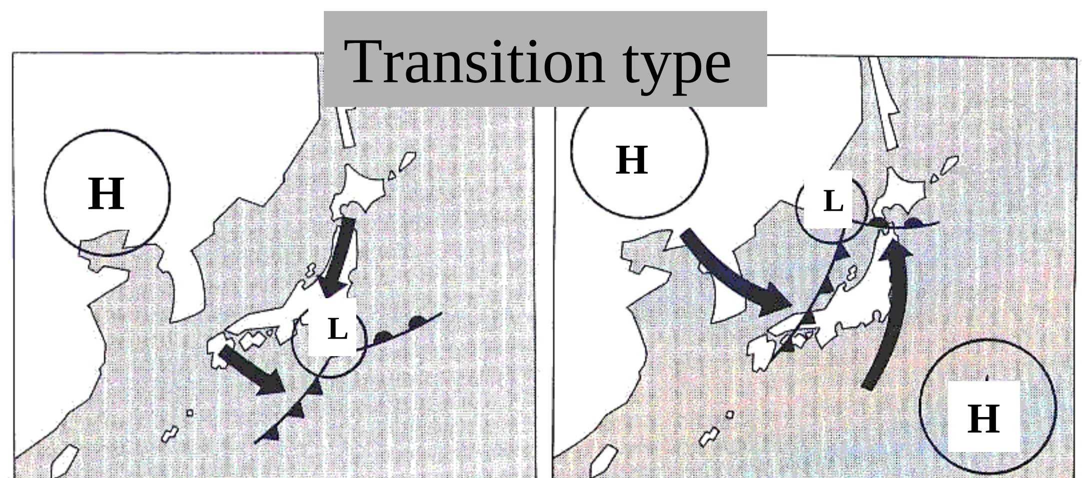
Winter season is characterized by the intermittent outbreak of cold/dry air masses, carrying air pollution from mainland Asia towards the Pacific Ocean and over Japan. Such an intermittence is clearly shown in the time series of SO_4^{2-} concentration.

Concentration peak time within 6 sites clearly shows time lag (it takes about 2-3 days from Qingdao to Chichijima).

Understanding by Intermittent Outflow in winter

This typical winter monsoon usually lasts a few days, and after this, low pressure system develops and moves from China continent to eastside of Japan as a transition of weather change. Such a transition pattern is usually observed 1 – 2 times per week.





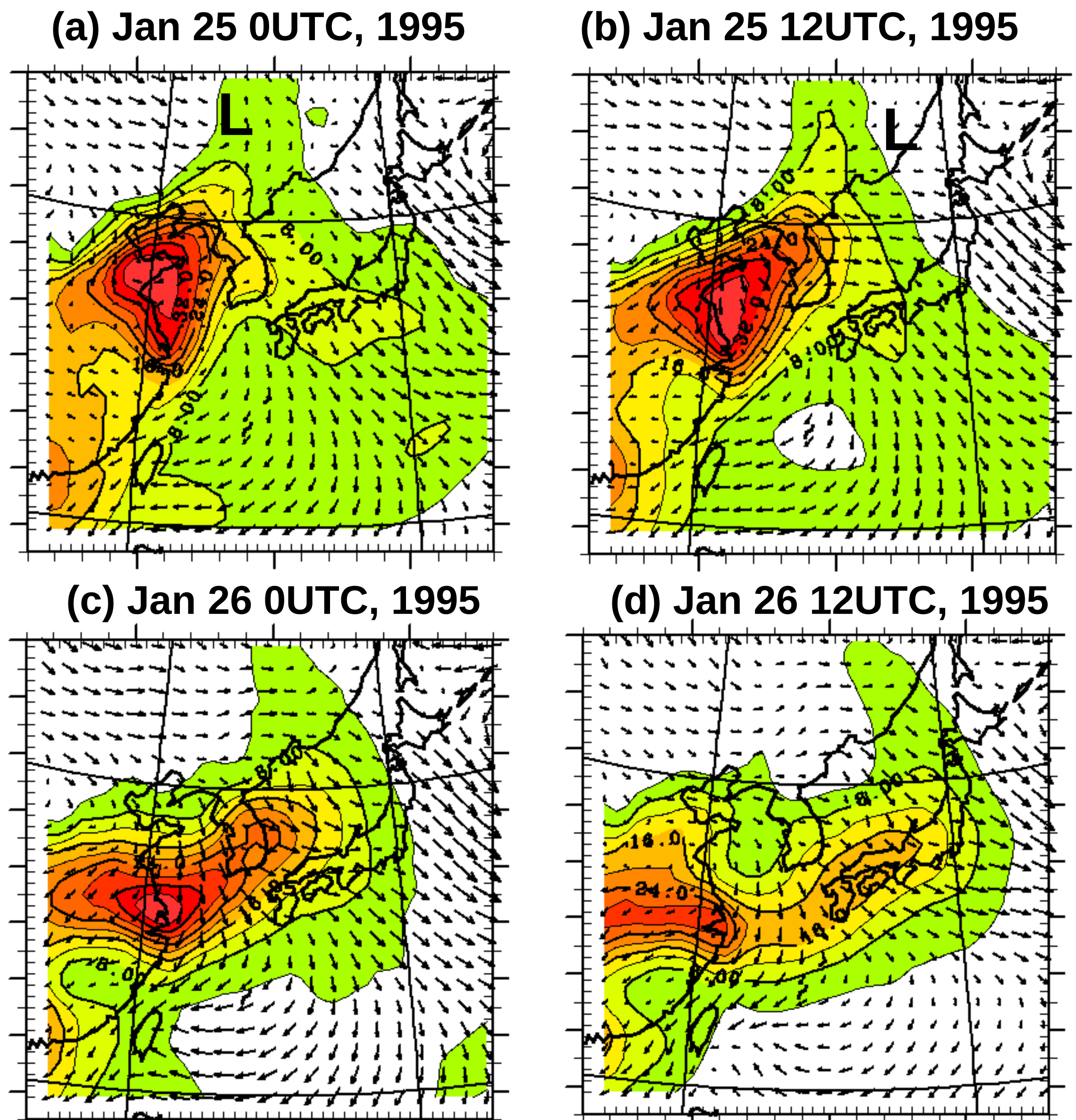
South Coast Low type   Japan Sea Low type

Winter Monsoon

outbreak pattern

Winter season is characterized by the intermittent outbreak of cold/dry air masses, carrying air pollution from mainland Asia towards the Pacific Ocean and over Japan. Such an intermittence is clearly shown in the time series of SO_4^{2-} concentration. Low pressure systems, moving southeasterly from China mainland to eastside of Japan, bring pollution as far as Chichijima, and a clear footprint of the motion of such cyclonic systems is given by the SO_4^{2-} concentration time series in several sites in the domain.

Quick change→

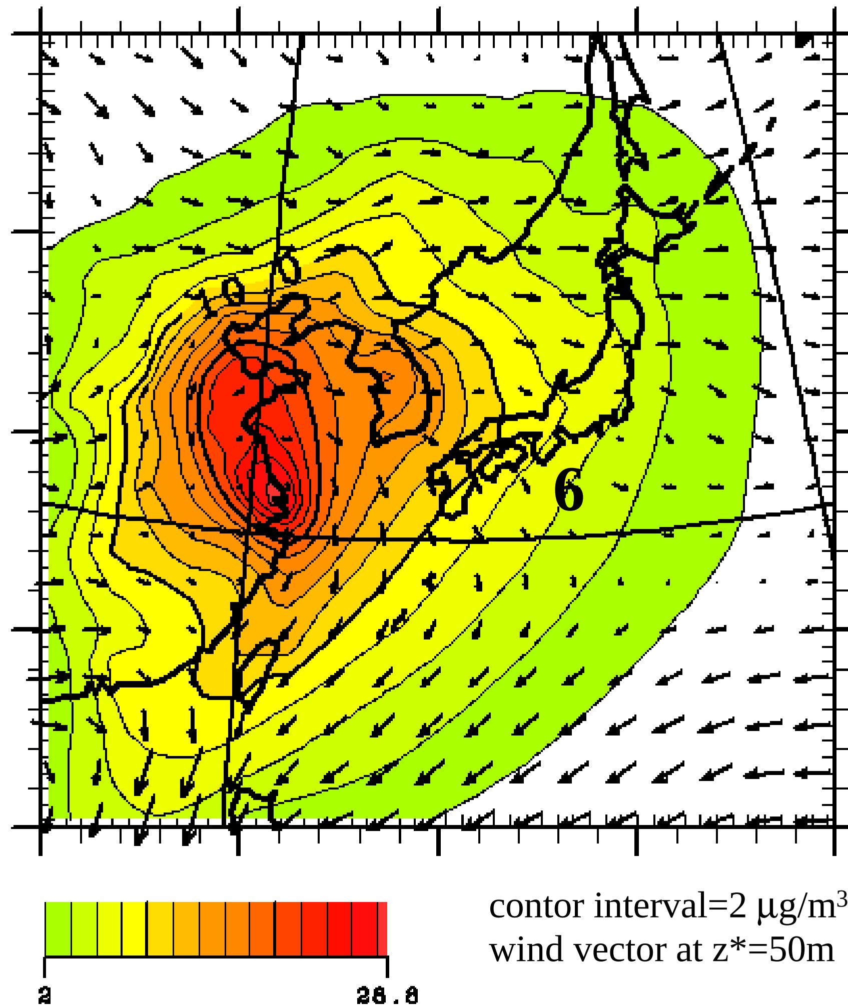


Annual averaged SO_4 concentration pattern (SO_4 Chemical Climate)

Annual averaged sulfate concentration fields over the China mainland is strongly affected by the horizontal distribution of SO_2 emission intensity. Contour lines of the annual averaged sulfate field show a distribution parallel to the ideal line connecting Taiwan and Japan Islands in the SW-NE direction, with a gradient more gentle than over the mainland.

Sulfate concentration differences on the Japan mainland is within a factor of 2･3.

Surface level SO_4^{2-} concentration



contor interval=2 μg/m³
wind vector at z*=50m

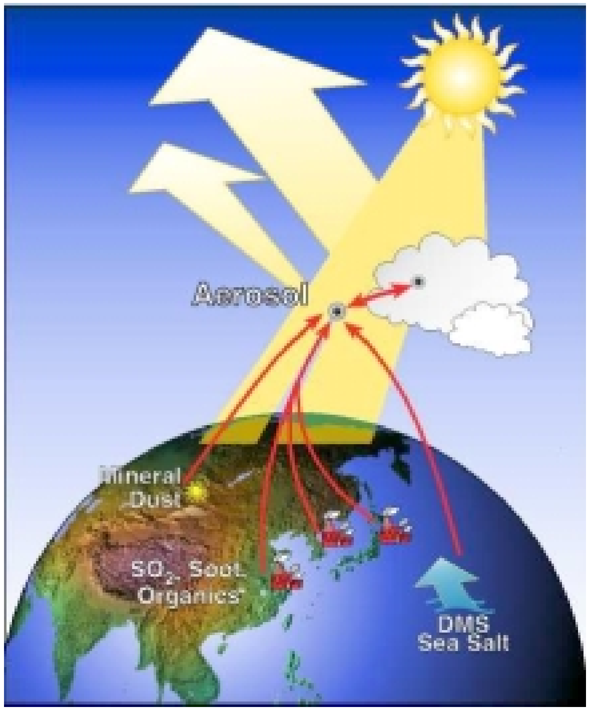
Conclusions

- Surface concentration, and dry/wet deposition amount of sulfate, modeled using a chemical model fully coupled with the RAMS show patterns consistent with the climatology of the region both at annual and seasonal scale, explain the important meteorological condition for transboundary air pollutants transport in East Asia
- It shows the dramatic changes of chemical composition concentration by season. In addition the coupled model is able to correctly simulate specific episodes.
- The numerical experiments using the Pentium III - Linux 16 CPU cluster system successfully simulated the regional climate over a 12-months time period.
- However, absolute values of sulfate concentration and accumulated deposition, although comparable with observations, are not completely satisfactory and the chemical model requires more improvements.
- In particular, the wet scavenging and SO_2 oxidation reaction processes, not fully implemented in the present stage on-line tracer model, due to the complexity of those processes, must be parameterized more accurately.

Future Work Direction
Chemical Weather Forecast for ACE-Asia Intensive Study

- Extension of transport model :
- Anthropogenic pollutants transport (coupling natural and anthropogenic aerosol species)
- More tracer (more mineral elements, dust, SO_x, NO_x, O_3, Black Carbon)
- Chemical reaction (CBM-IV)
- On-line coupling to met. model radiation fields (radiation forcing)
- On-line cloud nuclei formation ?

- 2-3 days weather and chemical forecast for supporting intensive 3-D observation (Spring 2001)



Asian-Pacific Regional Aerosol Characterization Experiment

Parallel Tips (RAMS workshop)

- System Configuration
  - ALTA Cluster (Pentium -III 600MHz, 256 MB memory ×17nodes)
  - 200 GB hard disk
  - 100 Base network
  - Firewall
- Be careful for internal time differences between each nodes
- Attention to ghost process before you submit parallel run (when you cancel jobs, there remain some zombie !) Parallel run(mpirun) uses rsh !
- File sync problems when you edit file in one node
- SUN terminal emulator buffer over flow
- Run both single and parallel mode to check the results
- 4.28 does not stop if some node’s calculation blow up (in this case all node will have NaN)
- MPICH communication error: Sometime just reboot the system solves it
- Calculation speed
  - 8CPU Pentium cluster (Pen-II 450 MHz) is faster than IBM SP-2 (8cpu; 133MHz). Cluster : SP-2 = 4 : 7

Reasonably cheap and fast enough

Typical MPICH error during RAMS 4.28

- **PC Linux parallel job control utility is poor**
- **Previous ghost process must be killed in each nodes**
- **Even if some node dies by numerical instability, it runs !**
- **MPI communication error p4 error**

```
---> p15_723:  p4_error: interrupt SIGSEGV: 11
---> rm_l_15_724:  p4_error: interrupt SIGINT: 2
---> rm_l_11_733:  p4_error: net_recv read:  probable EOF on socket: 1
---> Broken pipe
```

  - **cpu blow up ?**
  - **Somebody using some nodes (cpu or network busy) ?**
- **Scalar transport upper limit (more than 30 scalars ?)**