Rapid Transpacific Transport in Autumn Observed by the A-train Satellites

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NASA Sounder Science Team Meeting
November 14, 2012

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Background: Transpacific Transport

• Long-range transport of air pollutants across the Pacific has been:
  ✓ Long recognized (observational evidence goes back to at least the 1980s [Kritz et al., 1990])
  ✓ Extensively studied (from PEM-West A/B, TRACE-P, ACE-ASIA, to INTEX-B and ARCTAS)

• Important potential influence on air quality and climate over North America
  ✓ “Aerosols from Overseas Rival Domestic Emissions over North America” [Yu et al., 2012]
Background: Some Findings from Previous Studies

- Closely associated with mid-latitude cyclones and highly episodic
- Strongest in spring (focus of most studies)
- **Warm Conveyor Belt** (WCB) is the main mechanism exporting Asian pollution in spring
- Short-lived species can be lofted into FT in WCB, but the export efficiency is low (~10-20% for NO$_y$ and SO$_x$)
- Once in FT, downwind transport controlled by meteo. pattern over E Pacific

[liang et al., 2004]
Background: Satellite Observation of Long-range Transport

- Tracking Asian super dust storm using TOMS Aerosol Index [Husar et al., 2001]
- CO retrievals combined with aircraft and modeling [e.g., Zhang et al., 2008]
- Flux of aerosol transport estimated using MODIS and CALIPSO [Yu et al., 2012], but for cloud-free conditions only
- Studies on short-lived gaseous species: large uncertainty (S/N)

[Li et al., 2010]
Motivation

Transpacific transport is expected to take place in autumn, but has been rarely studied or reported.

- IASI detected an SO$_2$ transport event in November 2010 [Clarisse et al., 2011]
- Presumably anthropogenic SO$_2$ plume crossed the Pacific in just few days (November 7-11, 2010)
- OMI captured the same event

Short transit time means a larger fraction of short-lived species can reach North America

Scientific Questions:
- How do these events occur – Spring vs. Autumn?
- How important are they? (Magnitude? Flux? Frequency?)
Data and Methodology

• A-train satellite observation of: SO$_2$ (Aura/OMI), CO (Aqua/AIRS), and plume height (CALIPSO)
• NOAA ARL HYSPLIT trajectory model
  ✓ Forward trajectories tagged with SO$_2$ retrievals (projecting the movement of the plume)
  ✓ Backward trajectories (locating plume source region)
• NASA GMAO MERRA meteorological data
• Why SO$_2$ and CO?
  ✓ Short-lived SO$_2$ indicator of rapid transport
  ✓ Noise/bias in operational SO$_2$ product
  ✓ Differentiate industrial plumes from volcanic and BB ones
Case One: October 2006

OMI SO₂ (DU)

Trajectory SO₂ plume
Height (3 km)

AIRS CO (10^{18} mole/cm³)
Aerosol Plume Height over NE China on October 8, 2006

CALIPSO Vertical Feature Mask Product over NE China
Aerosol Plume Height over NE China on October 8, 2006

CALIPSO Vertical Feature Mask Product over NE China
Trace back to the Source Region

Sea Level Pressure at 18Z 10/06

SO\textsubscript{2} and CO, 05Z 10/07

850 mb geo. height and wind, 06Z

18Z 10/06  05Z 10/07  (sat. overpass)  05Z 10/08  (sat. overpass)

Figure 4.

Retrospective-Analysis for Research and Applications (MERRA) 850 hPa geopotential height (blue lines) and 850 hPa wind vector (arrows) at approximately the same moment. Pollutants accumulated over northern China as a midlatitude wave cyclone approached the region. The former study used radon as a tracer while the latter observed a host of pollutants including CO, PAN, and with deep convection [e.g., Yienger et al., 2004; Eckhardt et al., 2004] and [Barletta et al., 2009]. Similar transit time in spring [e.g., Barletta et al., 2003; Kritz et al., 1990; Yienger et al., 2007] The similarity in transit time between spring and...
Downstream Transport: More Cases

Oct. 2006

Oct. 2008

Nov. 2011
Downstream Transport: More Cases

Oct. 2006

Oct. 2008

Nov. 2011

5-7 days from E Asia to N America
Streamlined Transport Pathway:
A strong **Aleutian Low** or a north-south alignment of the **subtropical high** and **Aleutian low**
Consistent with some previous studies on transport in spring [e.g., Liang et al., 2005]
A few Observations on the Cases

• **Similar mechanism** (frontal systems, and WCB) and transpacific **transit time** (~6 days) between autumn and spring

• Asian $\text{SO}_2$ and sulfate previously observed over the remote Pacific in spring (**typically less than 1 ppb**), but the magnitude of transport observed by satellites is **much larger** (several ppb)

• WCB is an important rain producer, but some of the $\text{SO}_2$ **can survive the washout** during the ascent and will form fine sulfate particles during transport across the Pacific (mechanism first proposed by *Brock et al.*, [2004])
How often do they happen? 62 outflow events, 14 inflow events in 4 years

Asian Outflow Region:

N America Inflow Region

Frequency of high SO2 (> 0.2 DU) and CO (> 2.5x10^{18} mole./cm²) in SON 2005-2008
How about Spring? Stronger Transport

Asian Outflow Region:

N America Inflow Region

Preliminary results sensitive to selection of threshold, particularly AIRS CO.
Why Transpacific Transport more Active in Spring?

- Number of frontal passages and pollution lifting events in East Asia: similar between Spring and Autumn [Liang et al., 2004]
- But spring can be drier – less washout

The difference in mean precipitation (mm/day) between autumn and spring during 2005-2008. The precipitation data are from the GPCP daily one-degree resolution data set.
Issues

• Estimated frequency of transport events sensitive to threshold (AIRS CO, OMI SO$_2$, and number of grid cells)
  – A more objective, sophisticated method for pattern recognition and tracking is needed

• How to quantify the amount of SO$_2$ (or other pollutants) exported from E Asia and imported into N America using satellite data?
  – An approach utilizing aircraft measurements and tracer modeling has been demonstrated, but only works on a case-to-case basis

• Improvement in retrievals may reduce the noise/bias, making satellite data more useful in long-range transport studies
  – A spectral fit algorithm for OMI SO$_2$ retrievals is being developed, which has the potential in significantly reducing the noise in SO$_2$ product
Summary

• A number of transpacific transport events observed by Aura/OMI and Aqua/AIRS sensors in autumn (~4 events/year)
• WCB’s are the main mechanism for exporting Asian pollution, meteorology over E Pacific is important for the rapid transport events
• Satellite observations suggest the magnitude of such rapid transport events can be much stronger than previously observed in field experiments
• Combined use of AIRS CO and OMI SO₂ helps improve confidence in detection of such events, and also differentiate different types of plumes
• Paper # 2011JD016626 in JGR, 2012