Ozone in the Free Troposphere: The Impact of Synoptic Meteorology on Ozone Transport to Southern California

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Research Questions

- **To what extent are high altitude air parcels of elevated ozone concentration impacted by meteorological phenomena?**
- **Can synoptic meteorology be utilized in a predictive capacity for the atmospheric transport of elevated ozone air parcels?**

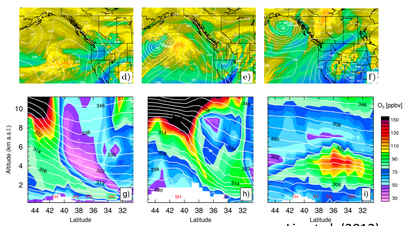
Background

Atmospheric ozone (O_3) is present at low (tropospheric) and at high (stratospheric) altitudes. Although stratospheric O_3 is important for protecting Earth's surface from the sun's harmful ultraviolet rays, tropospheric O_3 can cause respiratory illness and damage vegetation and crop production.

Local anthropogenic emissions account for much of the tropospheric ozone budget, but long range transport can also increase these levels. These transport phenomena include stratospheric intrusions, where regions of strong subsidence draw stratospheric air into the troposphere, and trans-continental transport whereby air masses travel long distances between continents.

Stratospheric Intrusion

Brings "good" O_3 from the stratosphere down into the troposphere

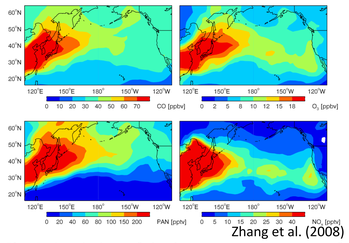


Lin et al. (2012)

Fig. 1: Water Vapor satellite imagery in conjunction with a cross section of O_3 concentration at the same time. High O_3 is brought to the lower levels.

Intercontinental Transport

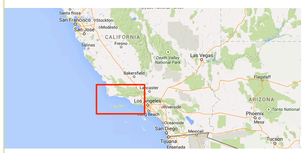
Transports O_3 produced by anthropogenic emissions across the Pacific Ocean.



Zhang et al. (2008)

Fig. 2: Depiction of the long range transport of anthropogenic emissions from Asia to the West Coast.

Methods

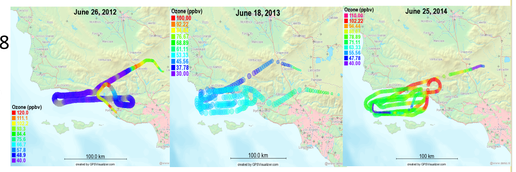


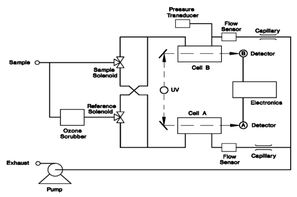
Sampling Location:

- Santa Barbara Channel located in Southern California
- Air aloft free of local emissions
- Good location to study the transport of O_3

Flight Information:

- Conducted onboard the NASA DC-8
- Three flights over three years
- A part of NASA's Student Airborne Research Program (SARP)
- Altitude between 10,000 ft and 26,000 ft.





Particle Trace Gas (PTG) Instrument:

- Sampled O_3, Carbon Monoxide (CO), and Relative Humidity (RH)
- Thermo Scientific (Franklin, MA, USA) Model 49C dual-channel U.V. photometric gas analyzer
- Corrected for ambient temperature and pressure using readings from internal thermistor and barometer

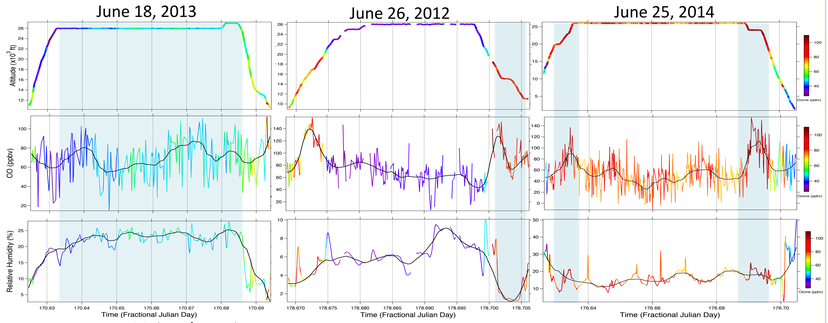
The WRF ARW Model:

To study the synoptic environment and identify possible stratospheric intrusions, the Advanced Weather Research and Forecasting (WRF ARW) was utilized. The WRF ARW is a community used model to forecast future weather and study past weather events. It creates a four-dimensional model of the atmosphere (3-dimensions of space; 1-dimension of time). The following conditions were used:

- Initialization and Boundary Conditions: **GFS**
- Grid Spacing: **12 km**
- Time Step: **30 sec**
- Vertical Levels: **32**

O_3, CO, and RH Measurements

Three different cases over three different dates were investigated



- **O_3**: Low
- **CO**: Low
- **RH**: High

Moist, clean air indicating origins over the Pacific Ocean

- **O_3**: High
- **CO**: Low
- **RH**: Low

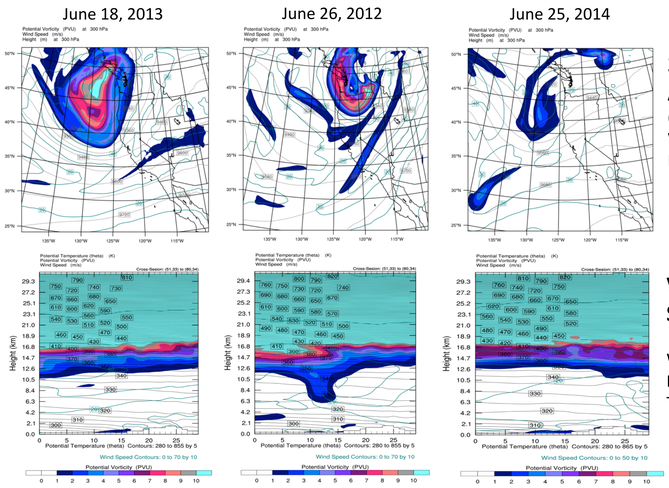
Dry air with high O_3 indicates Stratospheric air

- **O_3**: High
- **CO**: High
- **RH**: High

Moist polluted air indicates an anthropogenic source

WRF ARW Potential Vorticity

High values of potential vorticity (PV) are found in the stratosphere. Because PV is quasi-conserved in our atmosphere, it is a good tracer for stratospheric air. PV greater than 1.6 can be considered stratospheric



300mb Height Analysis
(~9,500 m)
Wind speed: green
Height: gray

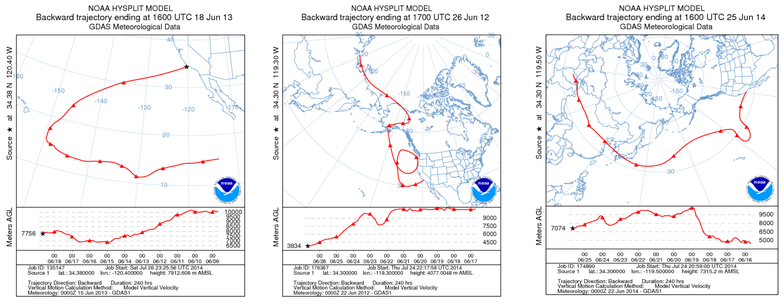
Vertical Cross Section
Wind speed: green
Potential Temperature: black

- For the 2012 case and the 2014 case, the atmosphere is typical (which is expected for the case of low O_3)
- The 2013 case depicts a dip of stratospheric air into the middle-atmosphere

Out of the two high O_3 cases, only one is the result of a stratospheric intrusion

HYSPLIT Back Trajectories

The Hybrid Single Particle Lagrangian Integrated Trajectory Model (HYSPLIT) is a model that uses initial conditions to find the origin of of a layer of air over a specific location



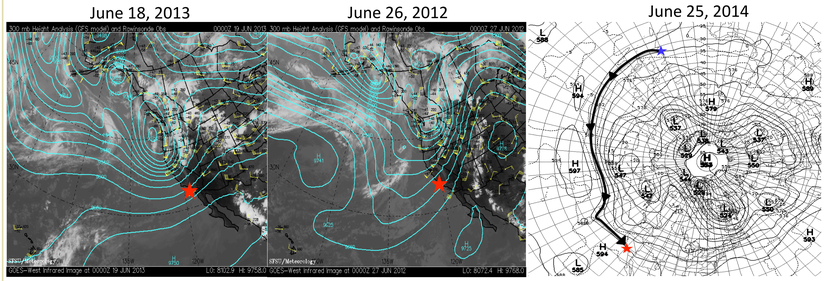
- Air originated from the Pacific
- Slow, clockwise moving air
- Indicaitive of High Pressure

- Originated from high altitude over the arctic
- Sank to Santa Barbara

- Originated from low altitude over Asia
- Fast moving over Pacific

Synoptic Setup

To identify the overall weather pattern dominating the region of interest, the synoptic setup in the upper levels of the atmosphere was investigated. Because synoptic-scale patterns can persist on a matter of days to weeks, long term transport of air can easily be visualized using these weather maps.

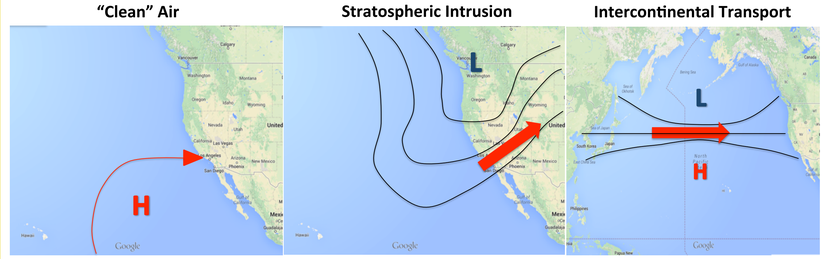


- High pressure system close to Santa Barbara
- Small height gradient
- Slow moving air

- Deep trough over the NW
- Fast wind speeds just north of Santa Barbara

- Low over High in the central Pacific
- Strong height gradient over Pacific
- Fast airflow from Asia to the U.S.

Conclusions



High Pressure in the Southwest:

- Moist air from the Pacific transported to Southern CA
- Free of anthropogenic emissions
- "Clean" air as a result

Deep Trough over West Coast:

- Jet streak over Southern CA
- Stratospheric intrusion along jet
- High O_3 from stratospheric air

Low over High in Central Pacific:

- Strong wind speeds over ocean
- Air spends less time between continents
- High O_3 from Asian pollution

Summary

O_3 in the troposphere is hazardous to human health and can have debilitating effects to the environment. Therefore, identifying the transport of tropospheric O_3 is important. Using three different case studies over Southern California – one consisting of low O_3 concentrations and two consisting of high O_3 concentrations – a technique for investigating air transport was presented. As a result, three different synoptic patterns were identified to affect tropospheric O_3 concentrations over Southern California. By adequately predicting synoptic-scale patterns, one can potentially predict the movement of O_3 through the atmosphere.

Acknowledgements and References

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