STRATOSPHERE RESEARCH OVERVIEW

Theme Lead: Dr. Karen Rosenlof

StoryMaps under this theme

- → *3.1 Stratosphere–Troposphere Coupling and Impacts on the Surface*
- → *3.2 Stratospheric Composition and Dynamics*
- → *3.3 Stratospheric Aerosols*

NOAA CHEMICAL SCIENCES LABORATORY

CIRES

STRATOSPHERE

CSL Review Themes

Climate

Stratosphere

Air Quality

The review is divided into separate themes, but much of what we do at CSL encompasses multiple themes.

CSL Review Themes

Climate

Stratosphere

Air Quality

CSL strives to understand what controls stratospheric composition as well as the impacts of stratospheric variability and trends on weather and climate.

Foci are:

- ❖ Understanding how climate change will impact the stratosphere
- ❖ Examining the chemistry, composition and transport features of the upper trop and strat
- ❖ Exploring the coupling between the stratosphere and troposphere
- ❖ Developing and deploying *in situ* instrumentation to measure key species including ozone, black carbon, water vapor, and sulfur dioxide in the lower stratosphere

Where do we fit within NOAA’s mission?

NOAA’s mission is to **understand and predict changes in climate, weather**, oceans, and coasts; to share that knowledge and information with others; and to conserve and manage coastal and marine ecosystems and resources

OAR objective: Detect changes in the ocean and **atmosphere**: Produce, analyze, and interpret observation records to understand the Earth system and inform the public.

Long-term Goal: Climate Adaptation and Mitigation: *An informed society anticipating and responding to climate and its impacts*

Objective: **Improved scientific understanding** of the changing climate system and its impacts

Objective: **Assessments** of current and future states of the climate system that identify potential impacts and inform science, service, and stewardship decisions

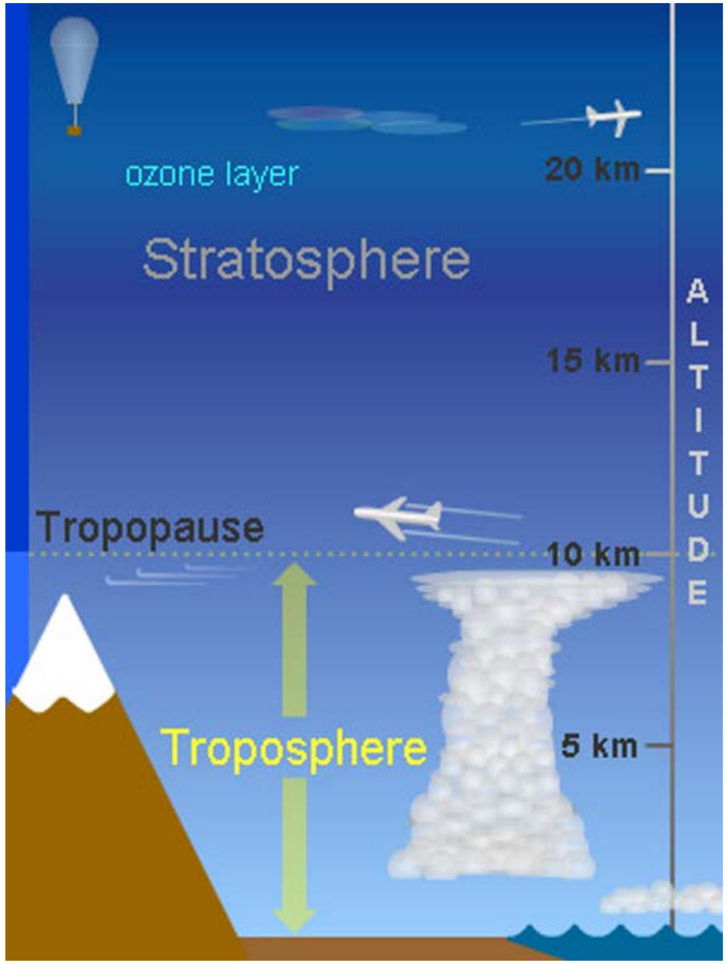
Research involving the stratosphere at CSL is addressing the question "*What is the state of the climate system and how is it evolving?*"

We approach the problem from multiple angles, including

1) Studying relevant chemical processes in the laboratory (4.2.4)
2) Developing and deploying instruments (also see 4.1)
3) Analyzing data from multiple sources (field missions, monitoring networks, satellites, model intercomparison projects)
4) Testing theories by running models spanning a range of complexities (also see 4.4)

Deliverables consist of dissemination of our findings in scientific journals, at conferences, via assessments, reports to stakeholders, and educational outreach.

CSL Stratosphere Research StoryMaps are grouped into 3 topics



1) Stratospheric Aerosols (3.3)

1) Stratospheric Composition and Dynamics (3.2)

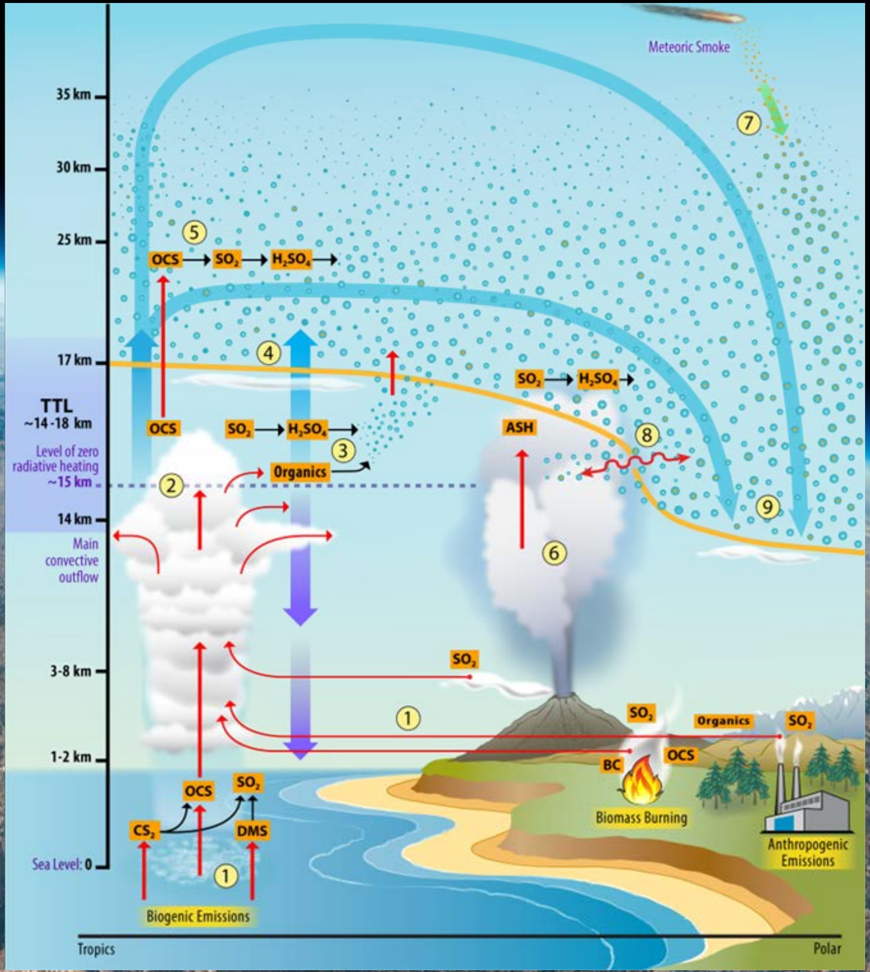
1) Stratosphere-Troposphere Coupling (3.1)

Stratospheric ozone plays a role in all of these topics. Recent work at CSL has expanded stratospheric related science to include aerosols (considering their radiative importance) and dynamical coupling between the stratosphere and the surface.

Numbers in light blue are the story map index.

Stratospheric Aerosols (3.3)

Modeling (3.3.2)
Measurements (3.3.3 & 3.3.4)



CSL works to understand the processes that contribute to stratospheric formation, transport and removal and the radiative and chemical processes that stem from the presence of stratospheric aerosols.

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Troy Thornberry, Elizabeth Asher, Erik Larson, Chris Maloney and Joe Katich

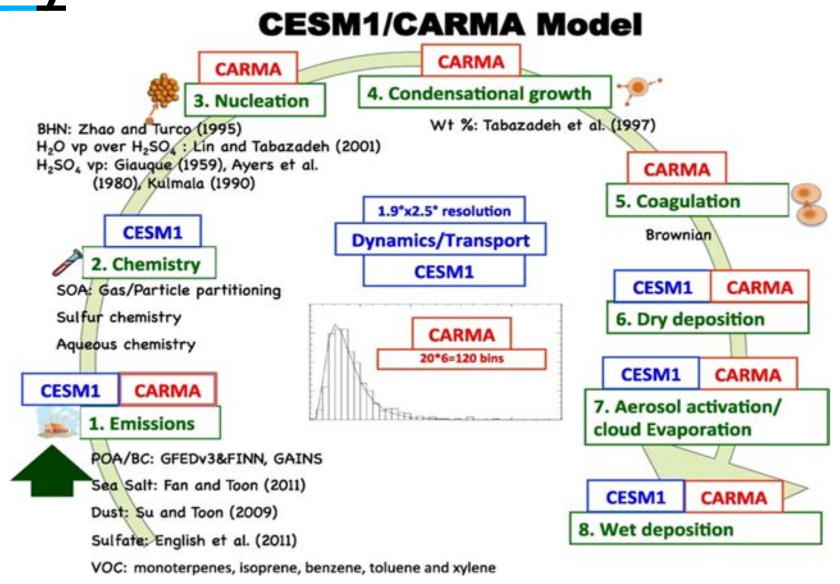
Modeling of Stratospheric Aerosols (3.3.2)

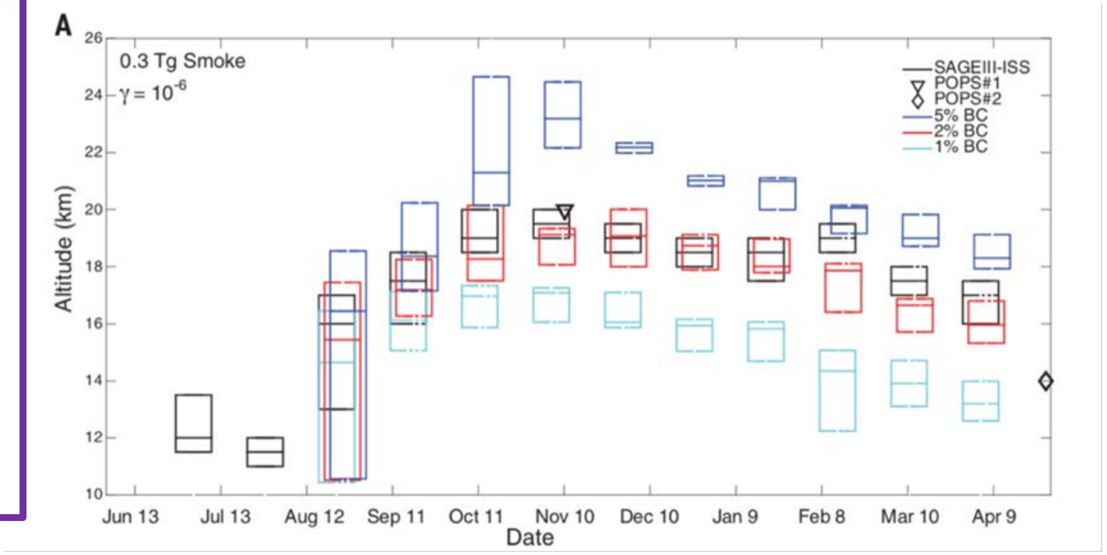
CSL uses global models with microphysical parameterizations of varying degrees of complexity that we constrain with observations to gain an understanding of what controls the background aerosol amounts as well as understand the impacts of episodic events.

Example: Pac NW PyroCb event: Aug 12, 2017

Pengfei Yu (now at Jinan University, Guangzhou, China)

1) Using observed plume rise rates to constrain the model, estimated that the **smoke plume was 2% BC**
2) Using observed time evolution of aerosol extinction to constrain the model, estimated an effective heterogeneous reaction probability between smoke and ozone. **Observed lifetime required an aerosol loss mechanism.**
3) Provided inspiration for a CSL led climate intervention paper currently under review



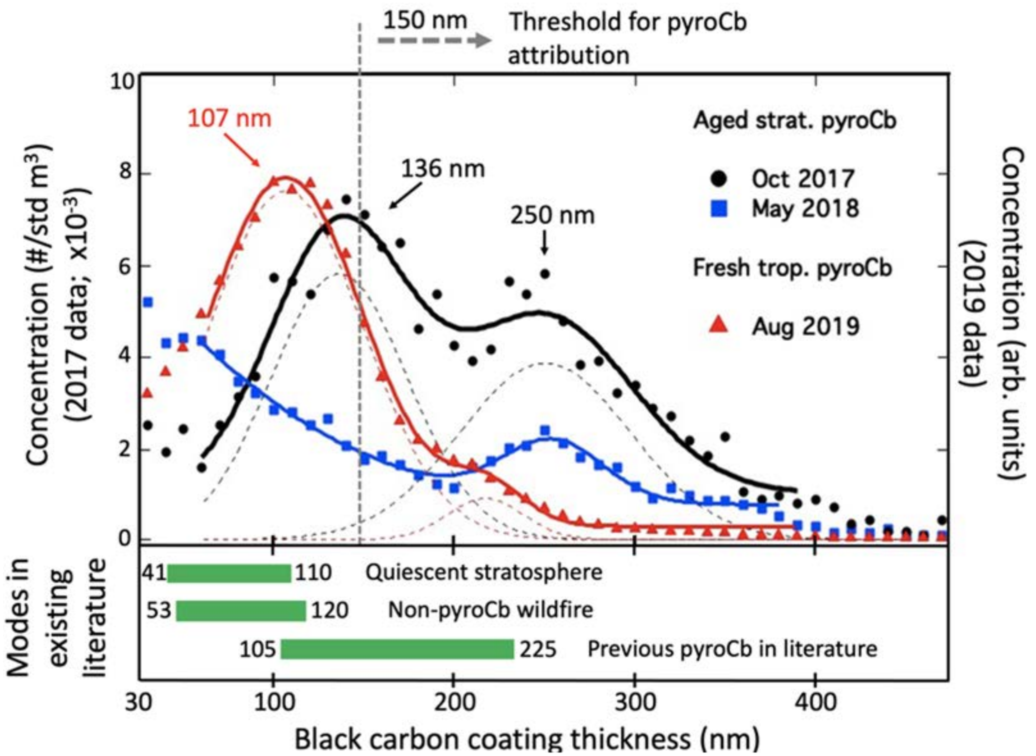


Measurements of Stratospheric Aerosols

SP2 (Single Particle Soot Photometer) (3.3.3)
PALMS (Particle Analysis by Laser Mass Spectrometry) (3.3.3)
POPS (Portable Optical Particle Spectrometer) (3.3.4)

ATom (4.3.2) DC8 flights occurred in multiple years, allowing stratospheric air heavily influenced by the 2017 PNE to be compared to other years.

CSL has demonstrated that black carbon coating thicknesses can be used to "fingerprint" the contribution of wildfire pyrogenic particles to stratospheric aerosol.



Joe Katich

Measurements of Stratospheric Aerosols

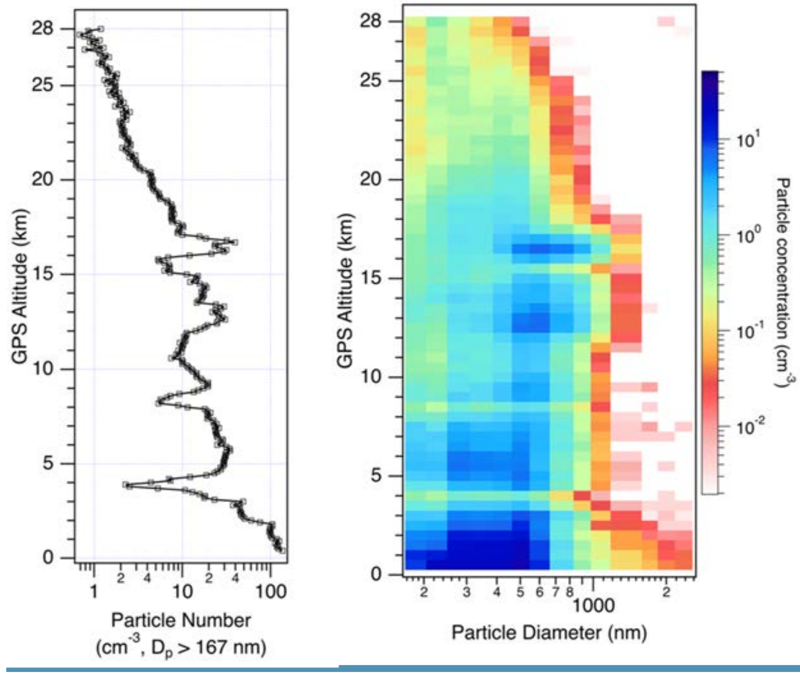
Balloon Baseline Stratospheric Aerosol Profiles (B2SAP) project (& SAGE IIII/ISS validation): regular launches in Boulder and Lauder, NZ

Lizzy Asher and Troy Thornberry

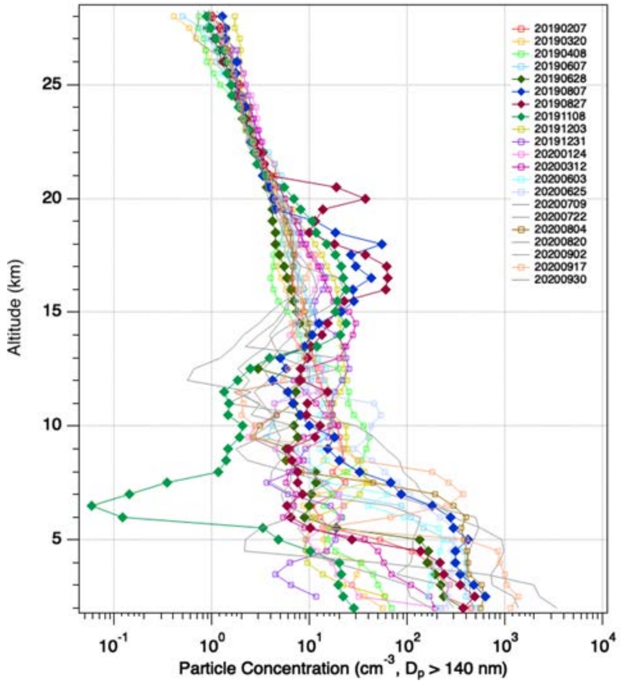
POPS (Portable Optical Particle Spectrometer) (3.3.4 & 4.1.2)

The CSL goal is to get an unprecedented set of measurements that describe seasonal variability as well as aerosol evolution after episodic events.

January 27, 2020, Lauder, NZ, POPS



Boulder, CO, 2019-2020

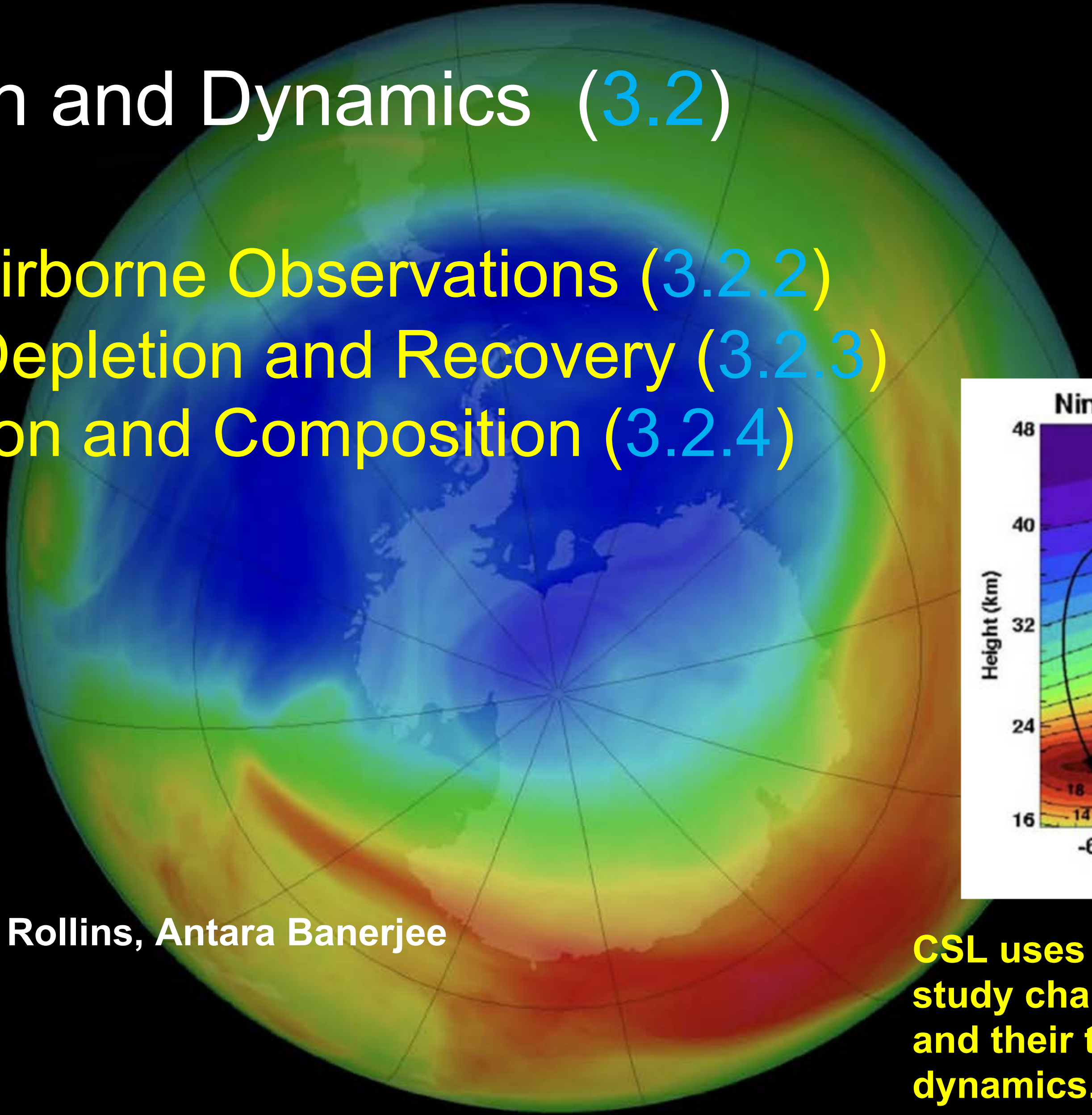


Next Steps for POPS.

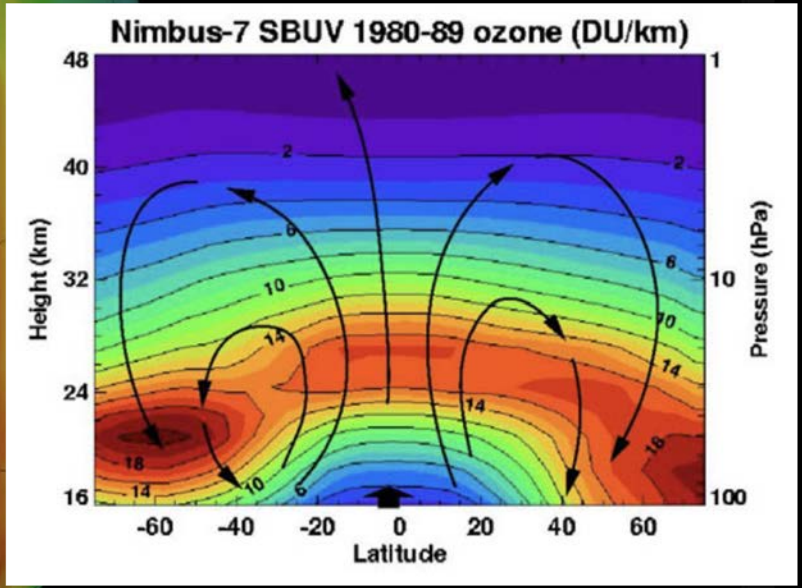
1) More balloon sites to get broader geographic coverage (Hilo next?)
2) Flying on World View's Stratollite long endurance balloon

CSL now has observations of pyroCB and volcanic aerosols; work continues on interpretation.

Composition and Dynamics (3.2)



UT/LS Airborne Observations (3.2.2)
Ozone Depletion and Recovery (3.2.3)
Circulation and Composition (3.2.4)



Sean Davis, Andrew Rollins, Antara Banerjee

CSL uses measurements and models to study changes in stratospheric trace gases and their two-way interactions with dynamics.

Composition and Dynamics: Airborne Observations (3.2.2)

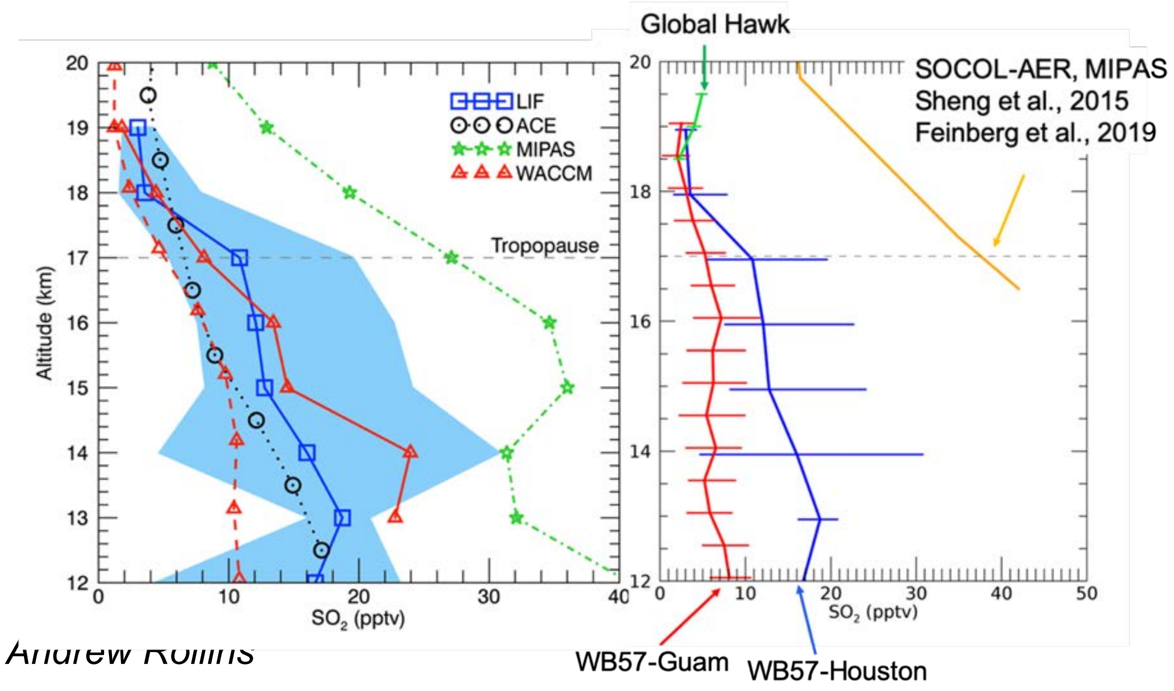
CSL makes observations of trace species from aircraft to guide the understanding of physical, chemical and dynamical processes affecting stratospheric composition.

Existing and well exercised CSL instruments include: water vapor & ozone; SO_2 (LIF) was developed recently and flew during VIRGAS and POSIDON, providing the first survey of SO_2 in the tropics up to the lower stratosphere.

Also see 4.1 Innovative Instrumentation and 4.3 Field Campaigns

Composition and Dynamics: Airborne Observations (3.2.2)

These measurements were significantly lower than MIPAS satellite measurements that had been used to compare with models; the CSL measurements agreed well with ACE-FTS and NCAR and NASA climate model output, demonstrating it is not a significant source of stratospheric aerosol mass.



New development is underway for high altitude aircraft instruments to measure reactive nitrogen, chlorine and bromine. This will allow for detailed and precise in-situ diagnosis of radical ozone-destroying chemistry.

LIF NOx/NOy and I^-HToF-CIMS (4.1.2)

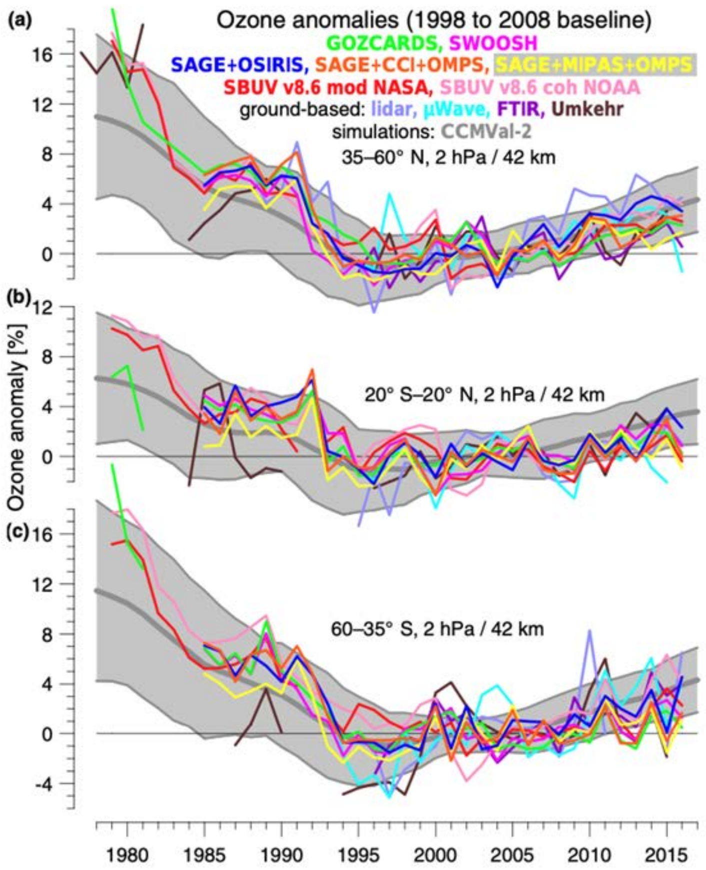
Composition and Dynamics: Ozone (3.2.3)

CSL scientists study the past evolution and predicted future changes to the ozone layer using model simulations and long-term data sets.

For over a decade we have been developing a merged satellite data set (SWOOSH: The Stratospheric Water and OzOne Satellite Homogenized data set). This has been used for trends and variability studies, comparisons with CCMs, and dynamical studies. It is regularly updated, and new satellites are being added to continue the record.

Sean Davis

SWOOSH is freely available for download in multiple grids and in multiple data formats. It has been used in over 60 publications to date including playing a role in stratospheric ozone assessments.



Steinbrecht et al, 2017

Composition and Dynamics: Circulation (3.2.4)

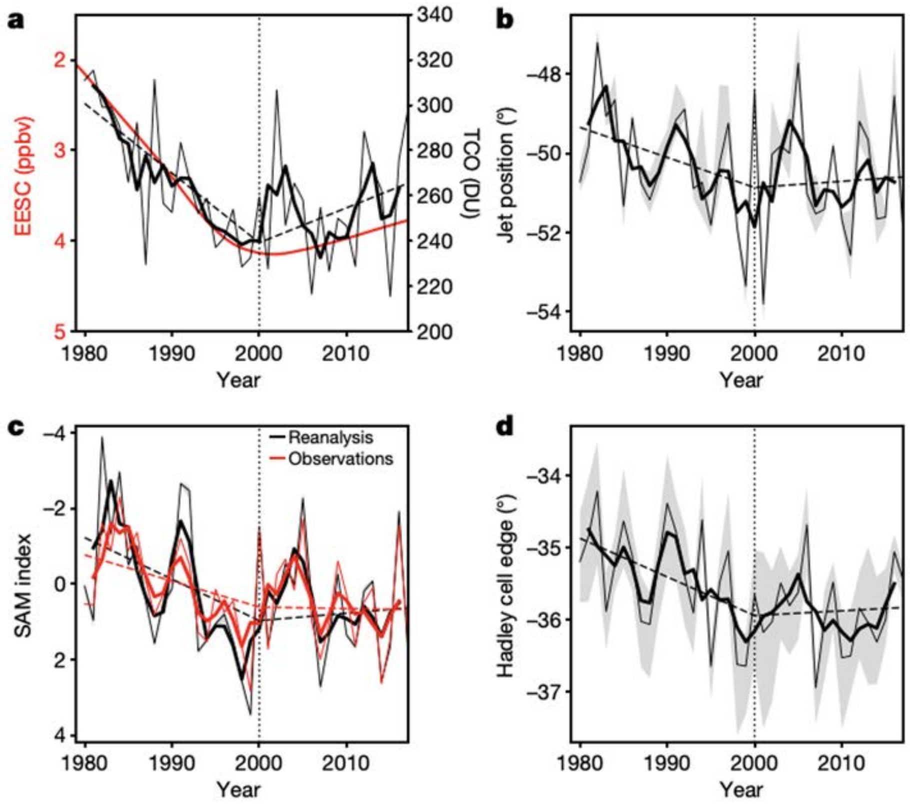
CSL scientists study the past evolution and predicted future changes to the ozone layer using model simulations in conjunction with long-term data sets.

ODSs peaked ~2000, and there are many studies looking at the ozone response. Banerjee et al., 2020 analyzed model output and data to attribute circulation changes to the cessation of ozone depletion. **This paper was highlighted as one of the 10 remarkable discoveries from 2020 by Nature.**

Using a pattern-based detection and attribution analysis of atmospheric zonal wind, the pause in the poleward migration of the eddy driven jet stream and the Hadley cell edge was attributed to changes in stratospheric ozone.

Antara Banerjee

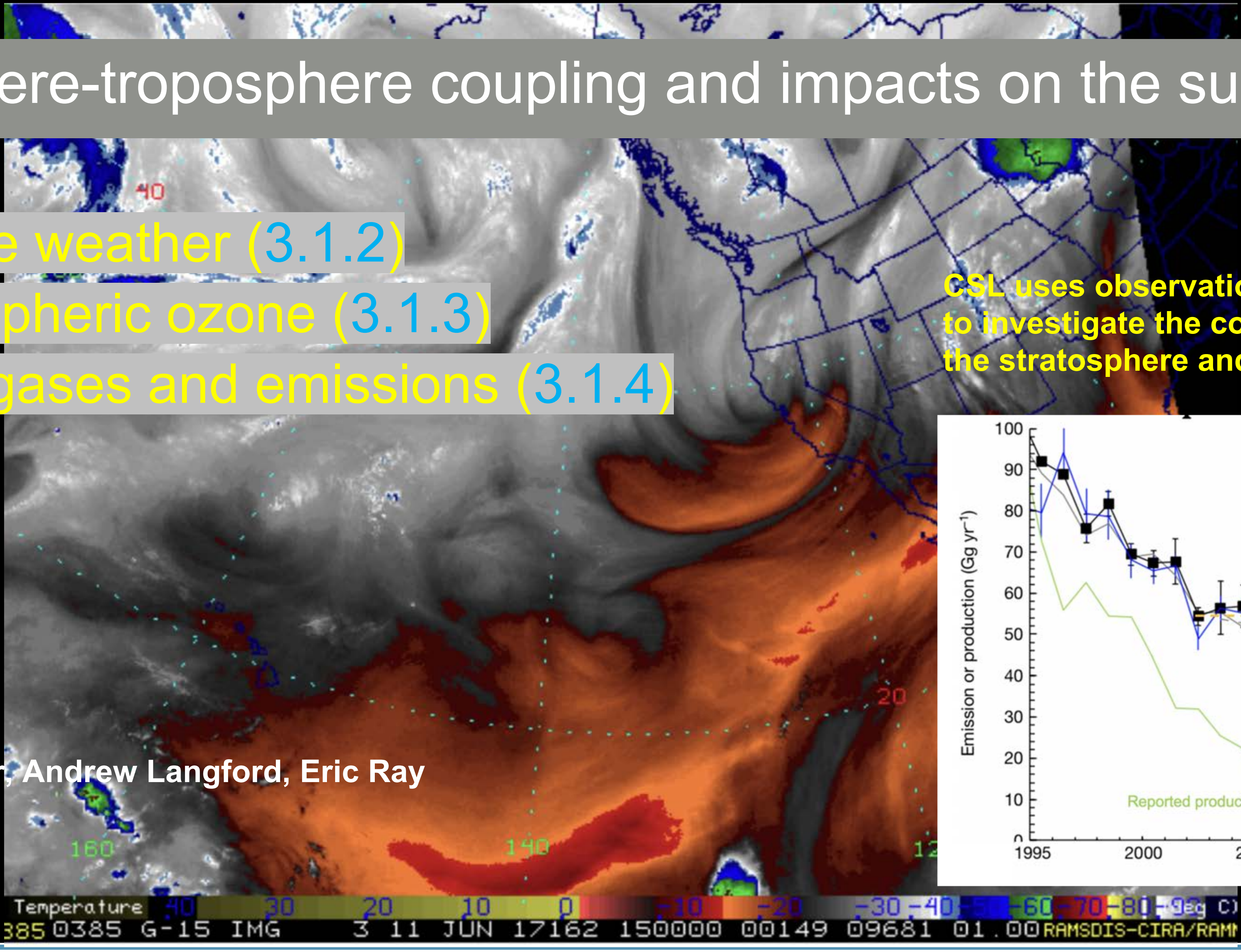
Jet latitude



SAM index

Hadley cell edge

Stratosphere-troposphere coupling and impacts on the surface (3.1)

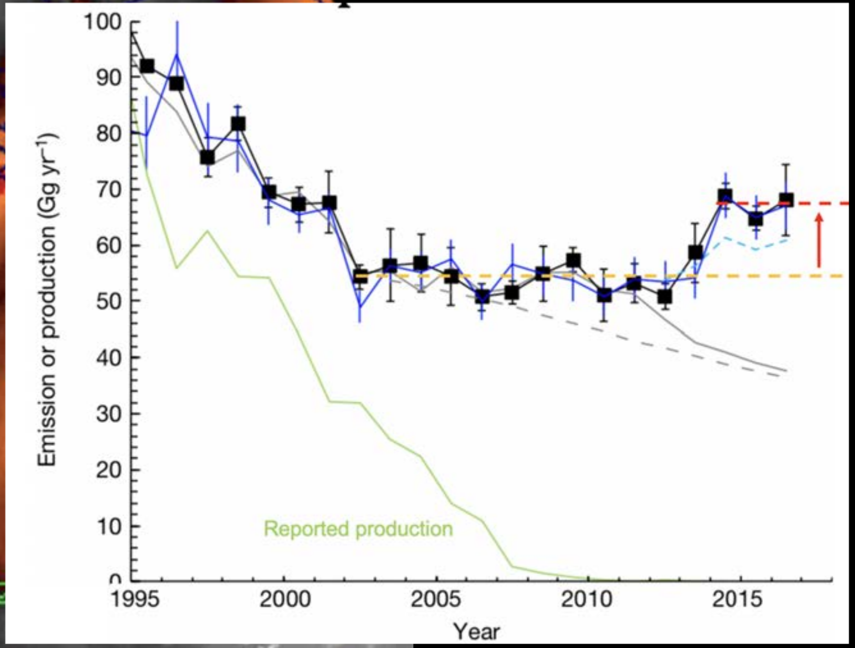


Surface weather (3.1.2)

Tropospheric ozone (3.1.3)

Trace gases and emissions (3.1.4)

CSL uses observations and models to investigate the coupling between the stratosphere and troposphere



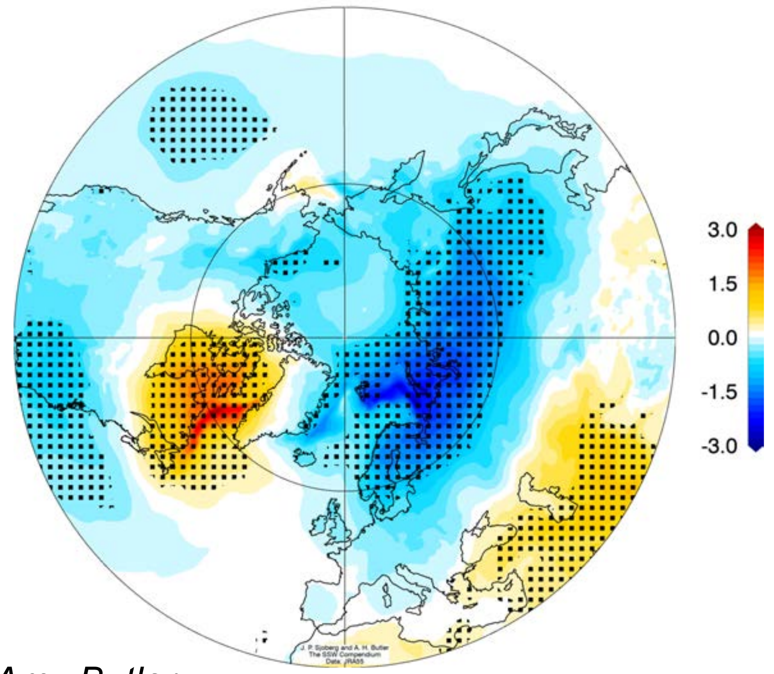
Amy Butler, Andrew Langford, Eric Ray

Stratosphere-Troposphere Coupling: Surface Wx (3.1.2)

CSL scientists are investigating how the stratosphere influences weather and climate patterns.

One example of this connection involves stratospheric warmings, which are often followed by surface weather extremes.

Surface temperature anomaly [C], 0-60 days after SSWs



	stratospheric precursor	tropospheric extreme event	impact	affected region
Northern Hemisphere	sudden stratospheric warming	(marine) cold air outbreak	infrastructure damage, health impacts	Arctic, northern Europe, North Atlantic
		increased storminess	flooding, wind damage	southern Europe
		regional sea ice changes	shipping impacts, resource extraction	Arctic
	strong vortex event	storm series	flooding, wind damage	northern Europe, North Atlantic
		drought	agricultural damage	southern Europe
	wave reflection	cold air outbreak	health impacts	North America
tropics	Quasi-Biennial Oscillation	changes in the Madden-Julian Oscillation	precipitation extremes	tropics, subtropics
		atmospheric rivers	flooding	western North America
		changes in the monsoon	drought / flooding, agricultural impacts	India, Southeast Asia
Southern Hemisphere	early vortex weakening	heat, drought	wildfires, agricultural losses	Australia, Antarctica
		cold spell	health impacts	southeastern Africa, South America
	ozone anomalies	poleward shift of storm track	sea ice changes	Southern Ocean
		increased UV radiation	health impacts	Australia
		hot spells	health impacts	southern Africa, Australia, South America

From Domiesen and Butler, 2020

Understanding how the system works -> understanding the biases in the current operational forecast models -> basis for S2S forecast improvements

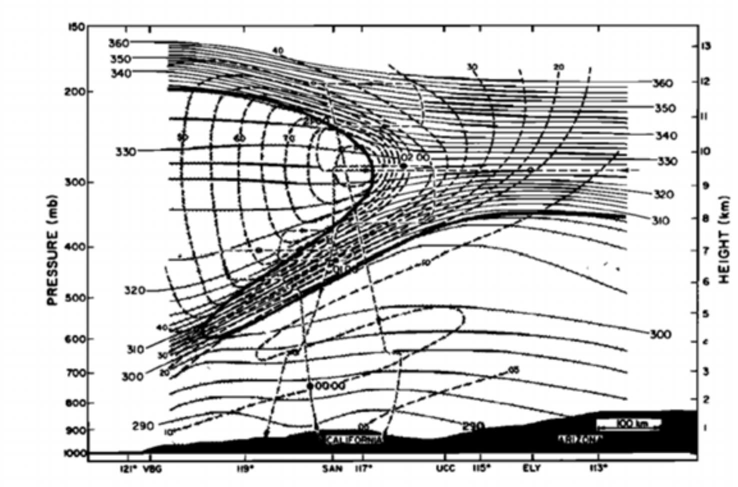
Amy Butler Figure constructed from data in the CSL SSW Compendium

Stratosphere-Troposphere Coupling: Tropospheric O_3 (3.1.2)

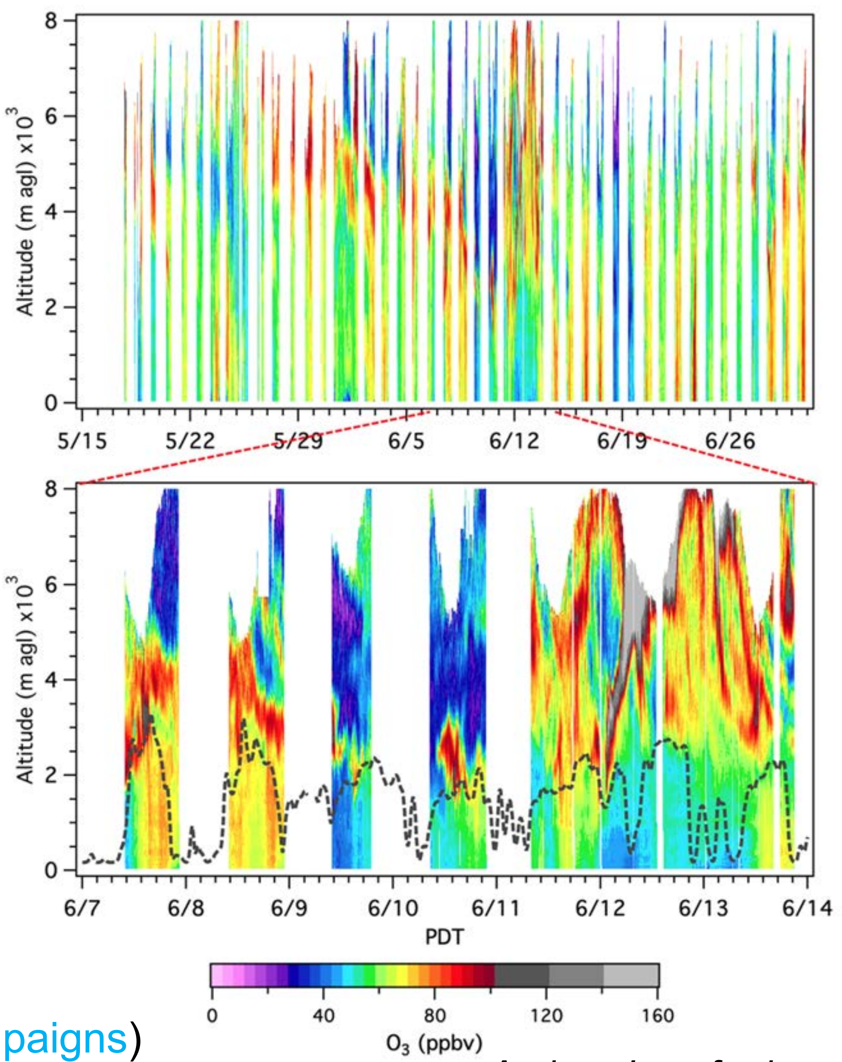
CSL research is quantifying the impacts of STT on surface ozone in the southwest US.

STT has been shown to be a significant contributor to background ozone in the SWUS during spring.

A combination of higher stratospheric ozone and descending entrained Asian pollution can increase tropospheric ozone



TOPAZ lidar measurements in California and Nevada are helping to explain how these intrusions can contribute to NAAQS exceedances.



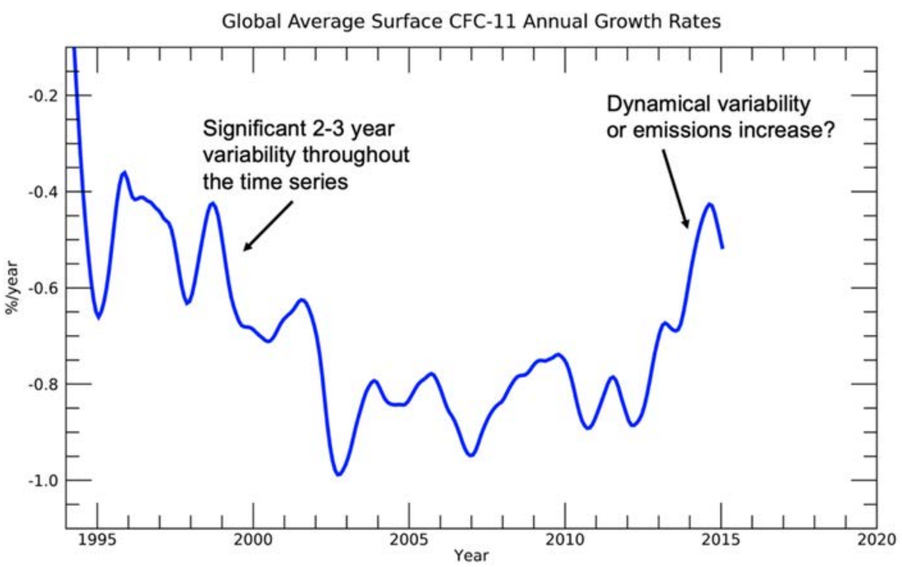
California Baseline Ozone Transport Study (CABOTS) 2016 (also see 4.3 Field Campaigns)

Fires, Asian, and Stratospheric Transport - Las Vegas Ozone Study (*FAST*-LVOS) 2017

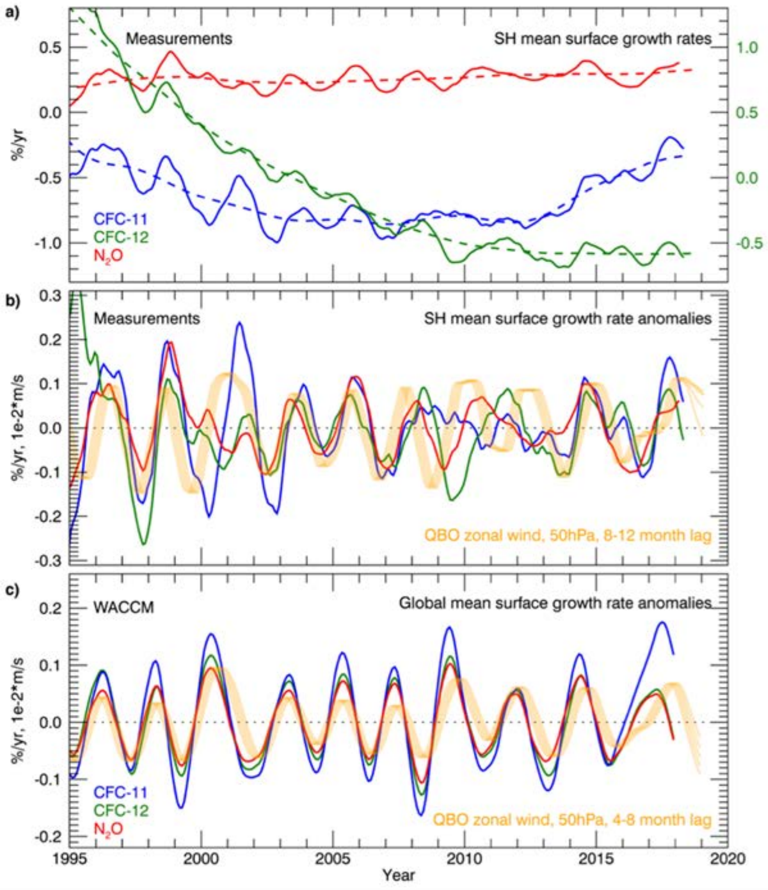
Andrew Langford

Stratosphere-Troposphere Coupling: Trace Gases (3.1.3)

CSL research is determining how interannual variability in the stratosphere impacts surface concentrations of long-lived trace species.



In 2013, a steady decline of F11 began to slow down. In 2015, S. Montzka (GML) asked CSL scientists for help in understanding how stratospheric transport variability could alter surface growth rates of long-lived trace species.



QBO signal apparent in surface data

Interannual variability in stratospheric processes can add uncertainties to emissions estimates.

By quantifying those uncertainties, it was possible to unambiguously attribute the increase in F11 at the surface to increases in emissions.

Eric Ray

Final Remarks

The stratosphere is the home of the ozone layer, which plays an import role in the climate system by shielding the surface from the damaging effects of solar radiation. **CSL research will continue to explore how the ozone layer is changing, and work toward attributing those changes to natural variability and anthropogenically forced climate change.**

However, study of the ozone layer is not CSL's only focus regarding the stratosphere. The stratosphere couples to the troposphere, and **CSL researchers will continue to study how dynamical and radiative processes in this remote region of the atmosphere impact surface conditions and use that knowledge to contribute to improvements in sub-seasonal to seasonal prediction.**

To do this will **require continued laboratory work, instrument development, measurement campaigns, data analysis and modeling studies**. Using the ERB funding recently allocated by Congress, over the next 5 years we anticipate a larger emphasis on aerosol studies, reflecting a recent interest to understand the background stratospheric aerosol layer to give a basis to predict how the earth/atmosphere system would respond to deliberate stratospheric aerosol modification.