FESD: The impact of the ozone hole on the climate of the Southern Hemisphere
Annual Meeting, June 1-2, 2015
Room 304 Olin Hall
Homewood Campus, Johns Hopkins University

Monday June 1

9:00-10:30 AM

- Susan Solomon (MIT) Understanding Antarctic temperature trends: radiation versus dynamics
- Doug Kinnison (NCAR) PSCs and ozone depletion in SD-WACCM
- Luke Oman (GSFC) The effect of GHG scenarios and VSLS on ozone recovery in GEOSCCM
- Gabriel Chiodo (Columbia) "The impact of ozone depletion on the Antarctic surface energy balance; results from WACCM and the Large Ensemble Project."

11:00-12:30

- Mark England (Columbia) Troposphere-stratosphere coupling: Links to the weather and climate of the Amundsen Sea sector, including their representation in CMIP5 models.
- Darryn Waugh (JHU) "Robustness of simulated tropospheric response to ozone depletion"
- Aditi Sheshadri (MIT) Responses of an idealized AGCM to ozone depletion-like polar stratospheric cooling
- Olga Tweedy (JHU) Impact of Ozone Asymmetries on Climate Trends

1:30-3:00 PM

- Jordan Thomas (JHU) Southern Hemisphere extratropical circulation: Recent trends and natural variability.
- Anirban Sinha (Columbia) Wind Driven Oscillations in the Southern Ocean and the Relationship between Forced and Internal Variability
- Ari Solomon (Columbia) The Effects of ODS on Budgets of Heat and Salinity in CESM1(WACCM)
- Feng Li (GSFC) The Impacts of Interactive Stratospheric Chemistry on Antarctic and Southern Ocean Climate Change
- Anand Gnanadesikan (JHU) Impact of isopycnal mixing on oceanic anthropogenic carbon uptake

3:30-5:00 PM

- David Ferreira (Reading) Can we use the ozone-hole response functions to make predictions?
- John Marshall / Yavor Kostov (MIT) How does the southern ocean respond to SAM forcing in nature and in models?
- Will Servoir (JHU) Ozone hole response functions in the JHU-GFDL model
- Dan Marsh (NCAR) How robust is a simulated two-timescale response to ozone loss
- Ute Hausmann (MIT) "Observational constraints on the response function of the Southern Ocean seasonal thermocline to 'ozone hole' forcing"

Tuesday June 2

Open Discussion:

- Future research and collaborations within each theme:
- Meeting plans
- Papers in preparation

NOTES – JUNE 1

Morning Session: Atmosphere (How does interactive chemistry modify the coupling between the stratospheric vortex and the rest of the climate system?)

1. **Susan Solomon (MIT): What controls polar stratospheric temperature: radiation versus dynamics.**
    a. Why does the Antarctic cool while the Arctic does not?
    b. WACCM gives a stronger cooling than observations show (differences in vertical and temporal profile).
    c. Use ozone datasets and MERRA Reanalysis and NCARs CAM4 radiative code to estimate dynamical temperature trends.
        i. Arctic:
            1. Dynamical warming in winter indicates increased wave activity.
            2. Summer trends are due to radiation.
        ii. Antarctic:
            1. Cooling trend in spring is mainly radiative (as opposed to dynamical trend in Arctic spring).
            2. Cooling in Antarctic summer is a combination of radiative and dynamical.
    d. Conclusions:
        i. Cooling and Antarctic is largely radiative due to ozone depletion
            1. Peak in radiative cooling with ozone lags by one month.
        ii. Cooling in Arctic is dynamical.
        iii. Dynamical 'warming above the cooling' is seen in both hemispheres.
            1. Acts to weaken the radiative cooling.
    e. Questions:
        i. The change in the temperature is what drives the vortex to get tighter. If you have (dynamical) warming it will weaken the vortex.
2. **Doug Kinnison (NCAR): Simulation of Polar Ozone Depletion: An update.**
    a. Why re-evaluate PSC and ozone depleting.
        i. Field and lab studies have provided new data.
        ii. Stratospheric modeling has progressed and is 'nudged' with reanalysis data.
        iii. Understanding impact of small volcanic eruptions since 2005.
    b. Look at assumptions about PSCs in WACCM
        i. In the SH, the REF case underestimates the observed TOZ by approx. ~25 DU.
        ii. Adding a -2K bias to the heterogeneous module overestimates observed TOZ (temperature matters).
    c. Results:
        i. Cold temperatures and PSC chem at $T<192K$ is essential to produce substantial ozone loss.
        ii. The magnitude of the calculated TOZ in both polar-regions is sensitive to small differences in temp and sulfate area density.
        iii. These results confirm earlier studies suggestion that liquid PDCs particles are sufficient to simulation nearly all of the O2L using current model chemistry.
        iv. The rate of change of HCl can be used as a key indicator od ozone depletion chemistry, primarily outside the vortex core.

3. **Luke Oman (GFCS): The effect of GHG scenarios and VSLS on ozone recovery in GEOSCCM.**
    a. Four Scenarios:
        i. October Antarctic Ozone Recovery (60-90N) – Negligible GHG impact.
            1. GHG scenario does not strongly impact the recovery rate of stratospheric ozone.
        ii. Annual average total column ozone (60S-60S) – Sensitive to the degree of GHG radiative forcing.
            1. No net impact from RCP 6.0
        iii. Annual average total column ozone in Arctic (60-90N) – Sensitive to GHG changes and degree of radiative forcing.
            1. Up to a 40 DU difference between RCP 2.6 and RCP 8.5 in 2100.

2. Similar impact in mid-latitudes, but weaker.
iv. Annual average total column ozone in tropics (25S-25N) - Sensitive to the GHG changes, but not the degree of radiative forcing.
b. Impact of extra 5 ppt Br on October Antarctic ozone recovery:
i. Recovery is about a decade later with additional Br from VLSB.
ii. Later peak loss without extra Br in October.

4. **Gabriel Chiodo (Columbia): The impact of ozone depletion on the Antarctic surface energy budget.**
    a. Direct (radiative) impact of ozone depletion.
        i. What is the impact of a realistic O3 forcing in a comprehensive GCM including ice-feedbacks.
    b. Experiments with WACCM4 and Cam5-LE:
        i. WACCM: 6 members with ozone depletion (historical) vs 6 members with no ozone depletion.
        ii. CAM5: 8 members with ozone depletion (historical) vs members with no ozone depletion.
        iii. 2 W/m^2 SW-forcing, after clouds are taken into account (SON). Therefore, does ozone depletion warm Antarctica?
            1. Both models show warming around Antarctica (stronger in WACCM), but no significant warming directly over Antarctica.
            2. Slight increase in surface albedo in both models, compensating the 2 W/m^2 SW forcing, leading to a net zero change in surface SW.
        iv. Where does this increase in albedo come from:
            1. Increase in DJF snowfall (stronger in WACCM, less in CAM5)
        v. Can snowfall in DJF affect albedo in other seasons:
            1. Surface albedo in CISM is a function of snow age and depth. Since there is no melting in the Antarctic interior, a change in DJF snowfall can lead to an increase in albedo in SON.

5. **Mark England (Columbia): Troposphere-stratosphere coupling: Links to the weather and climate of the Amundsen Sea sector including their representation in CMIP5 models.**
    a. ERA-Interim analysis:
        i. NH (JFM) has larger extremes in high latitude **stratospheric heat flux** than the SH (SON).
            1. Extreme neg events <-33Kms^{-1} (10th percentile)
            2. Extreme pos events > 4 KMs^{-1} (90th percentile)
        ii. Strengthening of vortex during neg. events.
            1. Westward tilt with height
                a. Upwards propagation.
                b. Pole-ward shift (850mb).
        iii. Weakening of the vortex during pos. events
            1. Eastward tilt with height.
                a. Downward propagation.
                b. Equator-ward jet shift (850mb).
    b. CMIP5 Analysis:
        i. If a model is doing well… it should have approx. 10% extreme positive events and 10% extreme negative events.
            1. Most models under-represent extreme events.
                a. Low-top models are have high bias.
                b. High-top models are have low-bias.
                c. This relation is not exact.
        ii. CMIP5 models with large biases exhibit this tendency in both hemispheres.
            1. This does not hold for small-bias models.
        iii. Next Steps:
            1. Compare tropospheric conditions of large and small biases model ensembles.
            2. Find robust biases of models that do not capture heat flux extremes.
                a. Mean-state biases in CMIP5 models is proving to be a problem.

6. **Darryn Waugh (Johns Hopkins): Robustness of simulated tropospheric response to ozone depletion**
    a. Controlled ozone perturbation experiments with different models to test model sensitivity:
        i. Consistent response of jet to ozone depletion across a wide range of models.
            1. Polvani et al, 201 results hold for other models including the JHU-GFDL model.
        ii. Significant change in HC boundary in all-forcing runs. Insignificant trends in SST/GHG forcing runs in all but one study.
            1. Changes in SSTs are not the dominant driver.
        iii. Sensitivity to time period:
            1. Changes in SSTs have contributed to HC extent if you extend time period out to 2009.
                a. Due to transition in PDO.
    b. Comparison with observations
        i. Observed trends can be simulated if models use observed SSTs, realistic ozone depletion, and ensemble of runs.

7. **Aditi Sheshardi (MIT): Responses of an idealized AGCM to ozone depletion-like polar stratospheric cooling.**
    a. Is the surface response to imposed ozone depletion dependent on the timing of the prescribed ozone depletion (i.e. relative to the models final warming date).
        i. Surface response is very sensitive to timing
            1. Oct 20th start date is the closest to the observations.
        ii. The magnitude and persistence of the tropospheric circulation response increases with the annular mode timescale.
        iii. When imposed stratospheric cooling causes stratospheric westerlies at times when the flow was easterly in the control run resulting in an additional period of the lower stratospheric variability.
            1. Lengthens the 'active' period during which the stratospheric couples to the troposphere.

8. **Olga Tweedy (Johns Hopkins): Impact of ozone assymetries on climate trends.**
    a. Determine if differences in trends between full chemistry run (FC) and monthly zonal mean (MZM) are due to ozone assymetries.
        i. Full chemistry run has stronger ozone hole than monthly zonal mean.
            1. Due to interpolation between monthly values. This effect is largest during rapid ozone changes.
        ii. Differences in zonal mean temperature and zonal wind (DJF)
            1. FC has stronger cooling during austral summer than MZM or 3-day relaxation.
            2. Stronger mid-latitude westerlies using FC.
        iii. Prescribing daily zonal ozone (DZM) does not fix the problem. Daily zonal mean ~ monthly zonal mean (for the time period: 1975-1995)
            1. Prescribing the daily zonal mean does fix the problem for a longer period (1960-2010)
        iv. Zonal asymetires are important.
            1. FC and 3-day which do contain zonal asymmetries have a similar slope between 100 hPa temperature and 50 hPa ozone.
            2. MZM and DZM, which does not have zonal asymmetries, has a different slope from FC and 3-day.
    b. Conclusions:
        i. Simulations using daily ozone removes bias in ZM polar ozone.
        ii. Trend analysis and T-O3 scatter plots indicate that ozone asymmetries may still influence temperature trends during time of maximum ozone depletion.
            *** Are Daily Zonal Mean ozone enough? ***

Afternoon Session: Ocean (Changes in ocean circulation, ice cover, heat and carbon uptake, and biogeochemistry)

1. **Jordan Thomas (Johns Hopkins): SH extratropical circulation: Recent trends and natural variability.**

a. Recent trends and CMIP5 natural variability. Do models match the observations?
    i. Natural Variability:
        1. SAM has large variability
        2. Jet Location – no difference between 850mb and windstress.
        3. Correlation of jet metrics with SAM
    ii. Correlation is higher for jet location.
    iii. Always higher for wind-stress.

2. Anirban Sinha (Columbia): Wind Driven Oscillations in the Southern Ocean and the Relationship between Forced and Internal Variability.

Wind driven Oscillations in the Southern ocean

-westerly winds -> Ekman transport
-SAM index
-different timescales
-Two limits hypothesis : - low frequency and high frequency
-we don't know transient behavior of eddies
-High limit: no eddy effect Isopycnal gold model:
Movie: spin up of the model- eddies try to flatten isopycnals
Steady sinusoidal wind jet + oscillations with different periods
Key diagnostics: EKE, PE/APE/wind energy input
Spectral analysis

- same power , different frequency;
- response – different amplitude

Composite analysis

- ½ year forcing cycle

-Regime shift
- actual wind is a superposition of different frequencies
composite analysis tells us about characteristic lag exists

? what controls the transitions from one phase to another

3. Ari Solomon (Columbia): The Effects of ODCs on Budgets of Heat and Salinity in CESM1 (WACCM)

1) changes in T
    - 30 % changes are from ODS
2) changes in heat flux
    - DJF heat flux has increased at all lat.
    - Heat flux change comes from changes in the clouds
    - Global ocean heat content: 19% of global heat is due to increased heat uptake by ODS

Salinity changes: decreased at the surface, increased bellow
1) 31% due to ODS
2) big dipoles – somewhat related to the sea ice
3) the global ocean becomes more fresh and the ozone hole accounts for 37% of that change in salinity
3) increase in the precipitation and run off sea ice and precipitation are anti-correlated
4) changes in MOC are seasonal, with a shift in DJF.

Poleward shift in MOC; SST anomalies indicate that ODS cause a slight DJF cooling; ODS result in additional melting of sea ice

Summary: the ozone hole accelerated the melting of sea ice

4. Feng Li (GSFC): The Impacts of Interactive Stratospheric Chemistry on Antarctic and Southern Ocean Climate Change

Intro: Interactive vs prescribed ozone fields

Prescribed ozone underestimates ozone hole and locks ozone asymmetry
Motivation: how FC stratospheric chemistry affects ocean circulation
Model – GEOS5, coupled ocean
Exp design : two simulations : 4 members
Prescribed ozone underestimates ozone depletion and locks ozone asymmetries
Prescribed and interactive simulations have different climatologies
Dynamic heating in the lower stratosphere
Prescribed simulations underestimate NDJ Antarctic climate trends
Surface winds: FC >MZM during NDJ
Surface winds: 20% difference in the stratosphere;
Surface ZM wind stress: FC > prescribed; FC = symmetric tau
Interactive runs simulate larger trends in ocean currents: x2 stronger
MOC: the spin up and poleward shift in the MOC cell in stronger in FC simulations
Changes in MOC affect Southern warming
Antarctic sea ice extent trends 1979-2010

Conclusions: Interactive chemistry impacts rad and dynamical processes in the stratosphere

Q: what is the origin of the change?

5. **Anand Gnanadeskan (Johns Hopkins): Impact of isopycnal mixing on oceanic anthropogenic carbon uptake.**
    Greens function experiments with CO2
    Basic exp: controls with different lateral mixing coef
      xCO2 at 1860; quadrupling run (800);
    Carbon uptake: range of about 20 % from lowest to highest after 100 yrs
    Results collapse
    Pattern of uptake in x2
    Green function approach works
    Conclusions: Greens function is unlikely to work if convection is important

6. **David Ferreria (Reading): Can we use the ozone-hole response functions to make predictions?**
    a. Coupled Ocean-Atmosphere-Sea Ice MITgcm response to a step function.
        i. Green's function works well to describe the change in sea-level pressure.
        ii. GF doesn't work as well to describe the SST response (2-timescale problem).
            1. Works better with SST anomaly.
        iii. The response to a trend is not always a trend.

9. **John Marshall/Yavor Kostov (MIT): How does the Southern Ocean respond to SAM forcing in nature and models?**
    a. Use least-squares regression of the lagged SST and wind time-series to estimate an impulse response function.
    b. Fast-Response: equator-ward transport of colder water → cooling.
    c. Slow response: upwelling of warmer water → warming (stratification dependent).
    d. Inter-model difference in the ocean's response to wind may be related to different background stratification.
    e. Differences in stratification can explain differences in the cross-over between the fast response (cooling) and slow response (warming)

10. **Will Seviour (Johns Hopkins): Ozone hole response functions in the JHU-GFDL model.**
    a. Use JHU-GFDL coarse resolution model control simulation with '1860' ozone from the SPARC dataset is used to branch Green's Functions.
        i. Cold-start: 3 Green's Functions spaced 5 years apart.
            1. Gets warmer with time
        ii. Warm-start: 3 Green's functions spaced 5 years apart.

        1. Gets colder with time and warms
    iii. Internal variability is large relative to the ozone-induced response in SST.

11. Dan Marsh (NCAR): How robust is a simulated two-timescale response to ozone loss.

a. CMIP5 Models have an initial increase in sea-ice extent, with a decrease as time increases.
    i. Models with strong positive correlation have high time lag.
b. Two-timescale response of pre-industrial sea ice to DJF SAM anomalies within some CMIP5 models.
    i. The strength and timescale of the slow response differs considerable across models.

12. Ute Hausmann (MIT): Observational constraints on the response function of the Southern Ocean seasonal thermoclime to 'ozone hole' forcing.

- ACC air/sea damping feedback parameter is about 4x smaller than in N Atl. Subtropical gyre. (about 10W/m^2/K).
- Seasonal thermocline feedbacks also important. The re-emergence mechanis operates, but it's not very important for summer anomalies.
- 2-layer model. Solve at equilibrium.
- Looks at upwelling/downwelling impact on temperature via w dT/dz. Alpha/beta ocean distinction is important.
- John says that world is more robust to sea ice loss, and actually sea ice growth seems favoured, compared to the models, which seem to lose their sea ice too easily.

NOTES – JUNE 2

Future research and collaborations:

- **Radiative and dynamical heating – Gabirel Chiodo***
  - How well do the models historical runs agree with observations of radiative heating and dynamical heating)
    - GISS, JHU-GFDL, NCAR
      - Who… need someone to take this on
  - Gabriel Chiodo to work with Susan Solomon on detailing what needs to be done here.
- **Antarctic surface budget – Gabirel Chiodo***
  - Reconvene in the fall and extend (Chiodo & Polvani) analysis (Paper to be written this summer) to other models.
- **Jet-ozone response and variability – Will Seviour***
  - Jet-ozone response:
    - Problems with modeling groups using different ozone inputs.
      - Progress has been made on zonal jet response to ozone forcing (Waugh and Seviour paper to be written this summer).
        - Need to look at SAM?
      - Using WACCM specified dynamics ozone averaged over a particular period.
        - Looked at GFDL, Goddard, CAM3, Canadian Model
        - Need to look at WACCM?
        - Need to look at full seasonality?
      - Look at CMIP5 models that use the 'correct' ozone forcing.
    - Look at the non-zonal aspect because these differences could project very differently on the ocean
      - Will Seviour to look at this.
- **Variability (wind, SST, Sea-ice) – Ute Hausmann***
  - MIT: SST lag correlation with SAM-like index.
  - JHU: variability in jet metrics and SAM.
    - Connect to SST variance, fit an AR1 process to it.
  - NCAR: Marikia looking at similar SST variability.
    - She needs to look at the step response (as opposed to the pulse response) to be consistent with MIT analysis.
  - Need to look into the convective variability across models (deLavergne recently published a paper along these lines).
    - CCSM models are strongly stratified, do not have this long-term variability.
    - Other models have consistent polynyas which add long-term variability.
      - Turn off convection in JHU-GFDL model?
  - How much of the variability in the SAM is coming from SST variability (as opposed to ozone)?
  - Coordination:
    - Ute Hausmann to take the lead.
    - Jordan to do natural variability analysis with SSTs.
      - Two groups of models: 1 group that convects that does reproduce the observations, 1 group that does not convect that do not reproduce the observations.
- **Ozone response runs – John Marshall***
  - MITgcm, NCAR, JHU-GFDL, GISS.
  - Look at the climatologies of these four different models.
  - 10 ensemble members to capture signal
- **Single-forcing runs (single forcing elimination runs) – Lorenzo Polvani***
  - Single-forcing runs have been done in the NCAR models.
    - Fixed ODS and GHGs
    - CMIP5 historical run 1955-2005 as the baseline.
    - Should up the number of runs to 10.

    - Also currently being done in MITgcm
        - Fixed ODS and GHGs
    - Should we be doing this in other models as well?
        - JHU-GFDL join the party
- **Ozone Asymmetries – Dan Marsh***
    - 2nd order problem
- **Ozone-loss processes – Dan Marsh***
- **Biogeochemistry – Anand Gnanadesikan***
    - Analysis of carbon, radiocarbon, helium in the ozone response runs and comparing with the CO2 response runs (JHU-GFDL).
    - Similar analysis planned this summer with the NCAR model.
    - Two time scale issue apply to carbon uptake?
        - Diagnose the implications of carbon uptake response to step-function forcing.
        - JHU-GFDL, NCAR(?), and GISS have biogeochemistry
        - MITgcm has a (really) simple biogeochemistry scheme
- **Observables – Darryn Waugh (atmosphere) and Ute Hausmann* (ocean)**
    - Biogeochemical floats in the Southern Ocean and ARGO program.
        - Relate this to SAM, westerly jet, and sea-ice.
        - Look in upwelling regions in order to attribute to ozone or GHGs
            - Need to determine where, what level, and what to measure.
    - What do we need to monitor in the next decade?
        - Why are the SAM, jet latitude, and jet magnitude not the same? What does this pattern look like? What does the non-SAM pattern on wind-stress look like?
            - Are there things to observe to give a more sensitive connection?
    - **Write a paper (or at least outline) detailing what we know and what we still need → working document.**
        - Use models in order to understand the convection variability and use this info to select regions to monitor in the Southern Ocean.

- Other topics: Over-ride experiments (wind-stress), RCP Scenarios, World-Avoided

*** Listed person will email Darryn with a paragraph to a page detailing the plan and individuals/groups involved by June 15th.**

Meeting:

1. Monthly tele-meeting
    a. Each meeting has a 'theme'
    b. ~2 people present
    c. Start this summer
    d. Google Hangout

2. Open Meeting (Summer 2016)
   Options discussed
    a. Joint with SOCOM (May-ish) or OCM (July in Woods Hole).
    b. FESD Meeting with 15ish hand picked people from other communities (ocean, SOCOM, sea-ice, clouds, reanalysis)
    c. Special session at a big conference.

   Option b preferred - **Location: MIT, Time: Late May- early June 2016; 2-day meeting.**
   Also consider special session option c for late 2016 or 2017.

Planned Papers:

1. MIT
   a. Kostov et al. – CMIP5 historical runs, SST-SAM connections.
   b. Kostov et al. – Response of Southern Ocean to wind trends.
   c. Hausmann et al. – Observational constraints on ocean response to SAM forcing.
   d. Ferreira et al. – How linear is the Southern Ocean climate system to ozone perturbations in the MITgcm?
   e. Sheshadri et al. – The responses of an idealized GCM to the timing of polar-stratospheric cooling
   f. Solomon (S) et al. – PSC chemistry

2. Johns Hopkins:
   a. Seviour et al. – Robustness of tropospheric response to ozone
   b. Seviour et al. – Ozone response functions
   c. Thomas et al., 2015 (GRL) – Southern Hemisphere extratropical circulation: Recent trends and natural variability
   d. Gnanadesikan and Romanou, in prep – Biogeochemistry
   e. Garfinkel – tropical expansion response to ozone and SSTs
   f. Gnanadesikan – anthropogenic carbon uptake

3. Columbia
   a. Solomon (A) et al., 2015 (GRL) – Temperature and salinity trends in Southern Ocean (WACCM).
   b. England et al. – Extreme stratospheric events and teleconnections over Antarctica.
   c. Chiodo et al. – Surface energy balance over Antarctica.

4. NCAR
   a. Holland et al – SAM and sea-ice
   b. Marsh et al – zonal asymmetries in ozone

More cross-fertilization of papers may be desirable in future.