polar stratospheric ozone

&

Southern Hemisphere climate change

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atmospheric circulation changes

for the last several decades observations indicate:

+ strengthening of the Southern Annual Mode (SAM)
  Thompson et al (2000), *Marshall* (2003)

+ poleward shift & intensification of storm tracks
  Archer & Caldeira (2008), O'Gorman (2010)

+ poleward shift of the edge of the Hadley cell
  Hu & Fu (2007), *Seidel & Randel* (2007)

+ poleward expansion of the subtropical dry zones
  Previdi & Liepert (2007)

interhemispheric differences...?

obvious question: what is the cause?

→ presumably greenhouse gas increases

most of our impression comes from models (CMIP3)

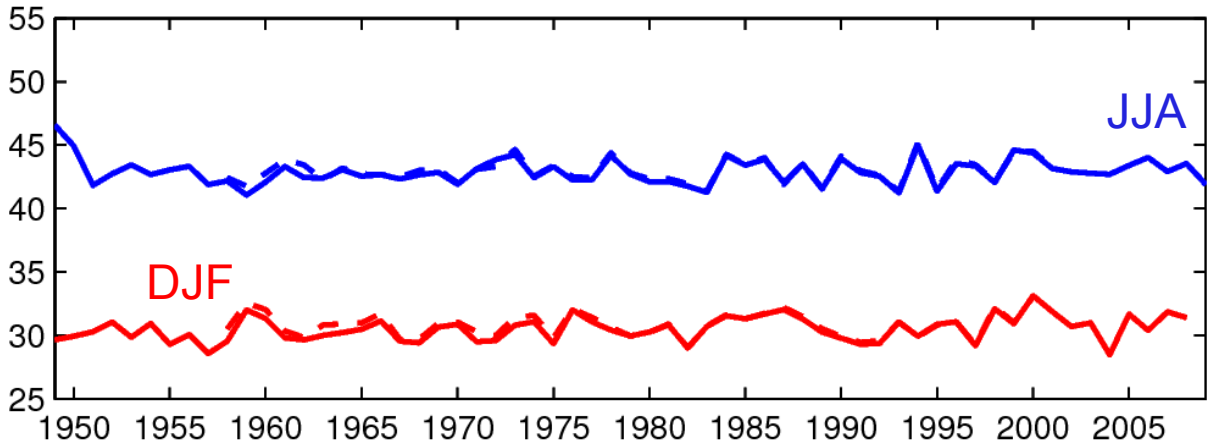
→ Yin (2005), Miller et al (2006), Lu et al (2007, 2008)

illuminating to look at NH vs SH differences in OBS

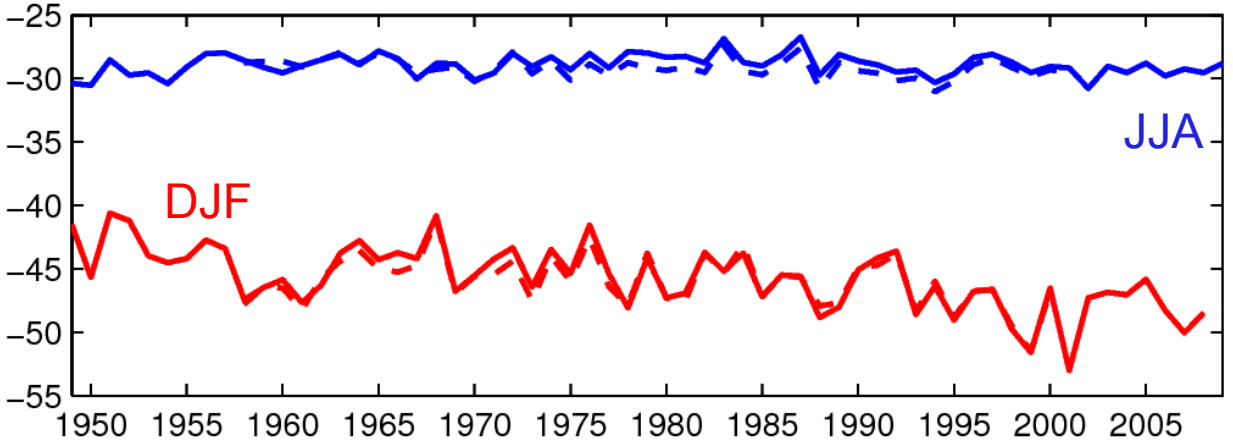
→ gives a clear indication of other possible causes

latitude of 850 hPa zonal wind max

NH



SH

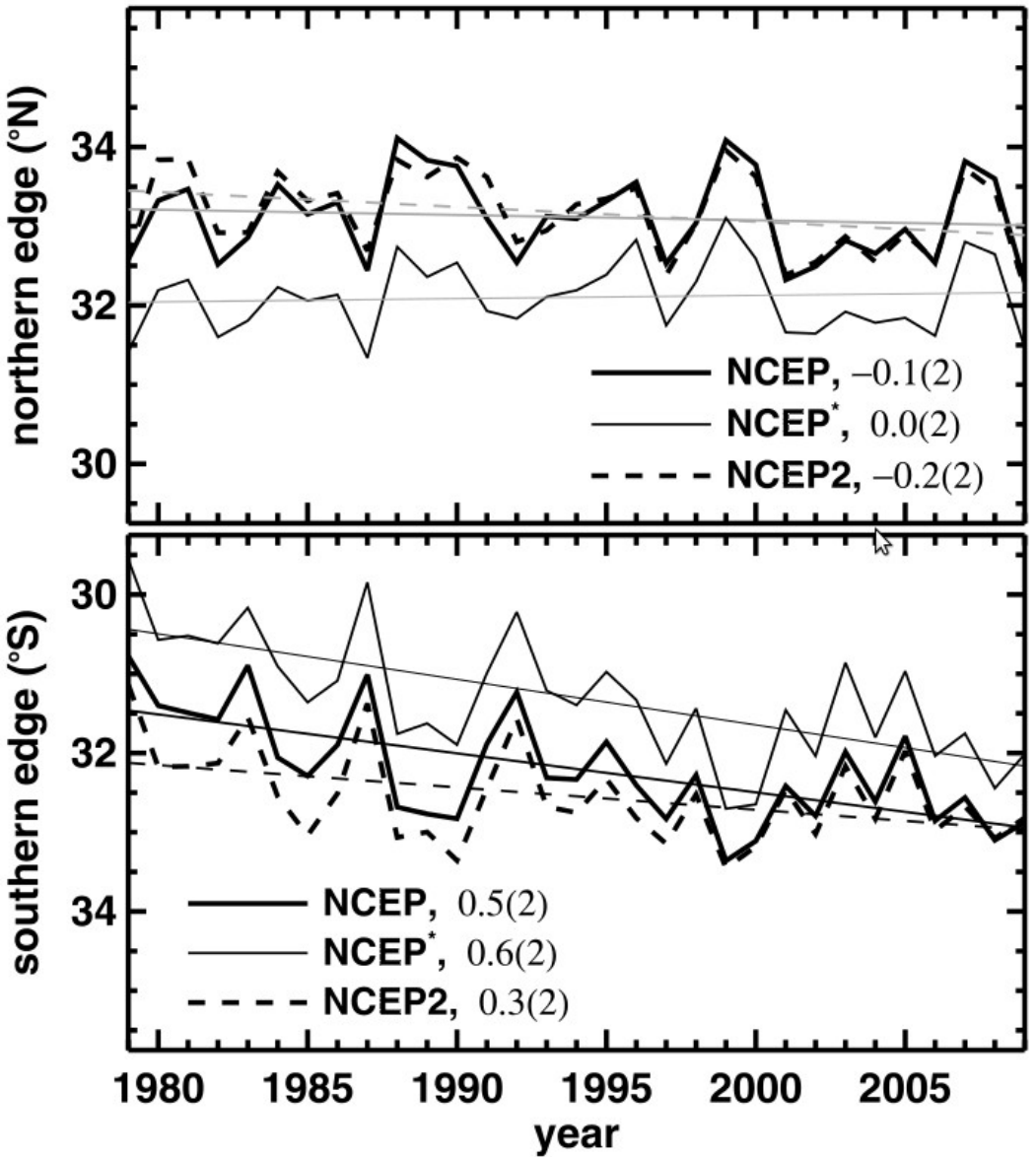


solid: NCEP, dashed: ERA (courtesy of Dr Sarah Kang)

poleward edge of the tropical belt

NH

SH



+ annual means

+ from *Birner (JGR, 2010)*

+ uses PDFs of trpps height

+ as in Seidel & Randel (2007)

+ plus some improvements

+ uses different reanals

+ this for ANNUAL mean...!

bottom line...

+ obs show circulation changes are largest in SH in DJF

+ GHG are well mixed: cannot account for the asymmetry

+ O3 depletion is much stronger in SH than in NH

hence: most of the observed circulation changes could be due to SH polar ozone depletion...

Q: can we demonstrate this with a model? YES.

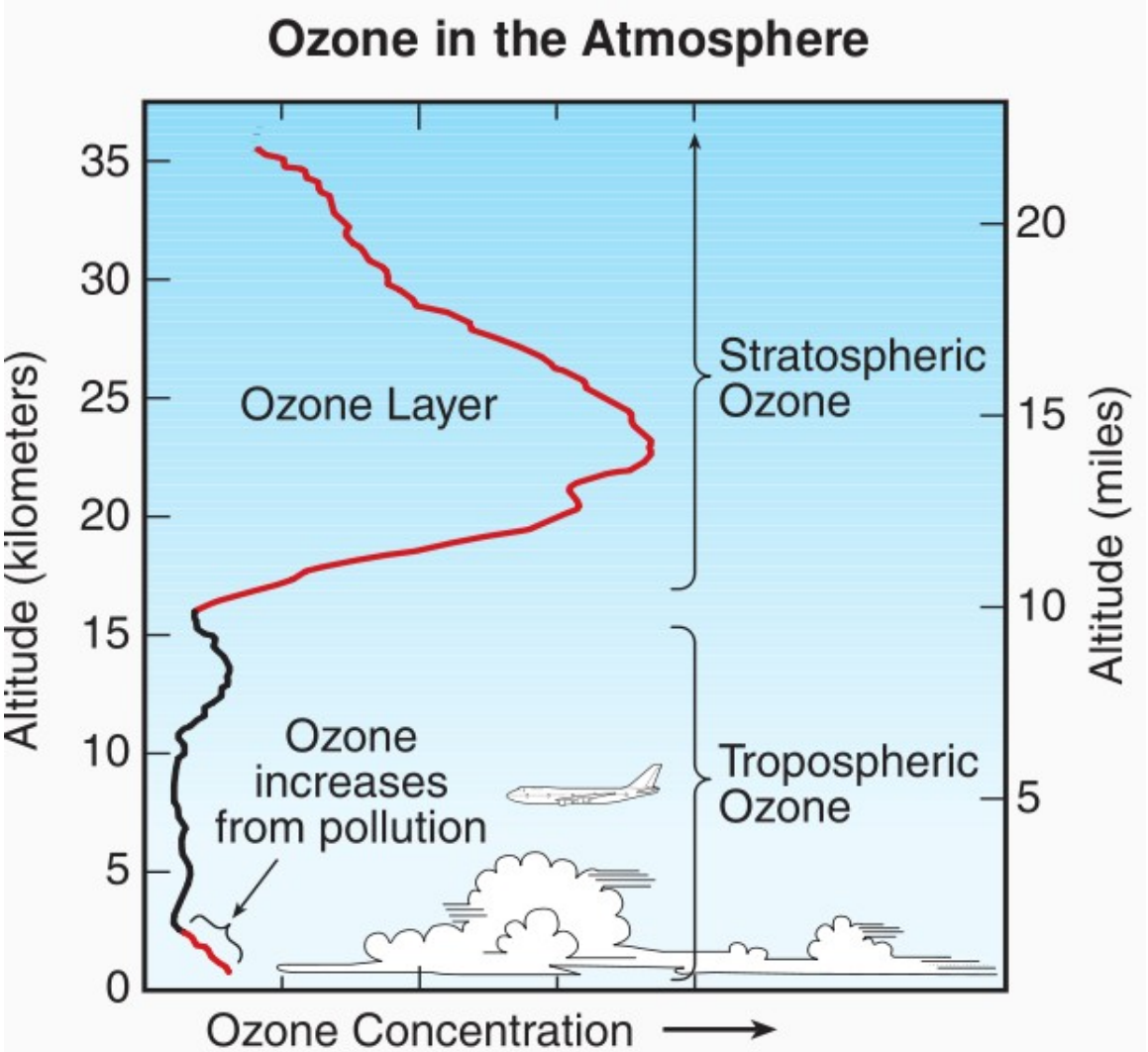
a new attribution study

our idea → a controlled set of model integrations
where we change stratospheric O3
and GHG levels independently

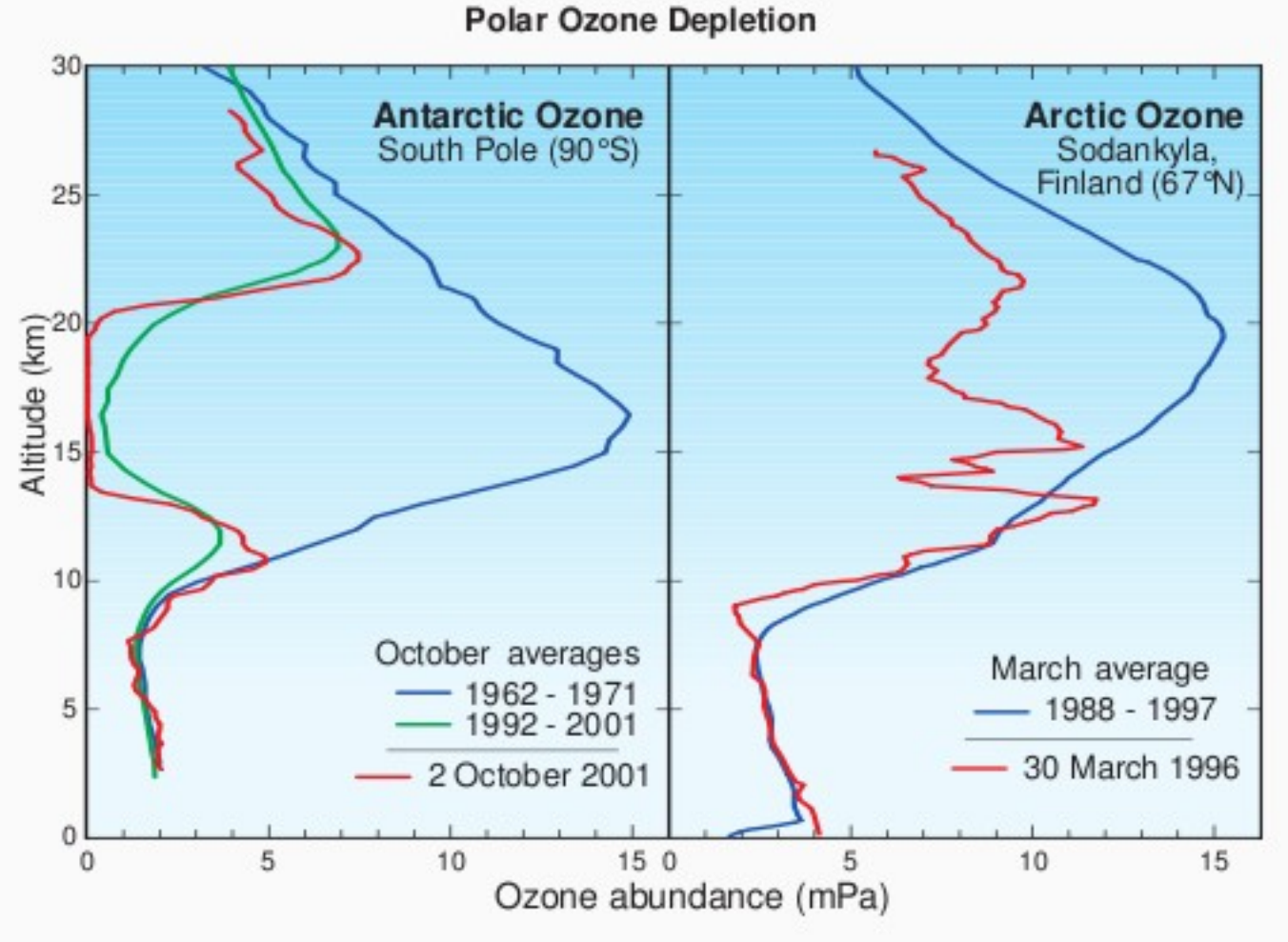
goal → QUANTIFY the relative importance
of O3 depletion and GHG/SST forcings

paper → LMP, D. Waugh, G. Correa and S.W. Son
J. Climate, in press (2011)

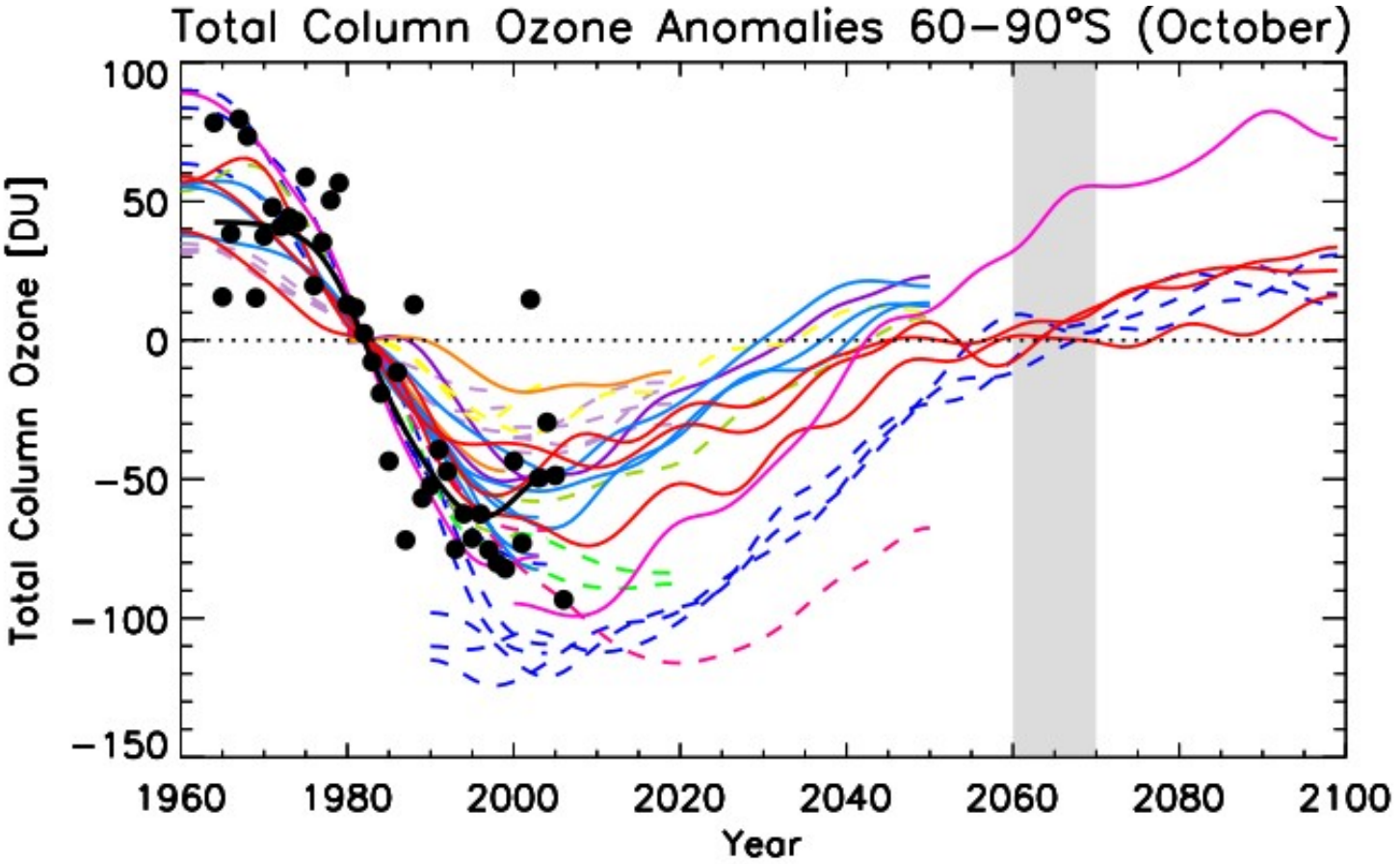
where is ozone found?

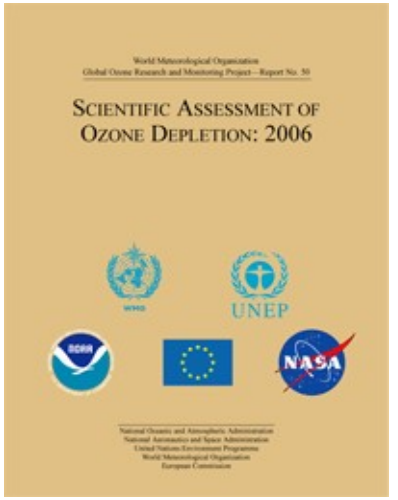


ozone depletion



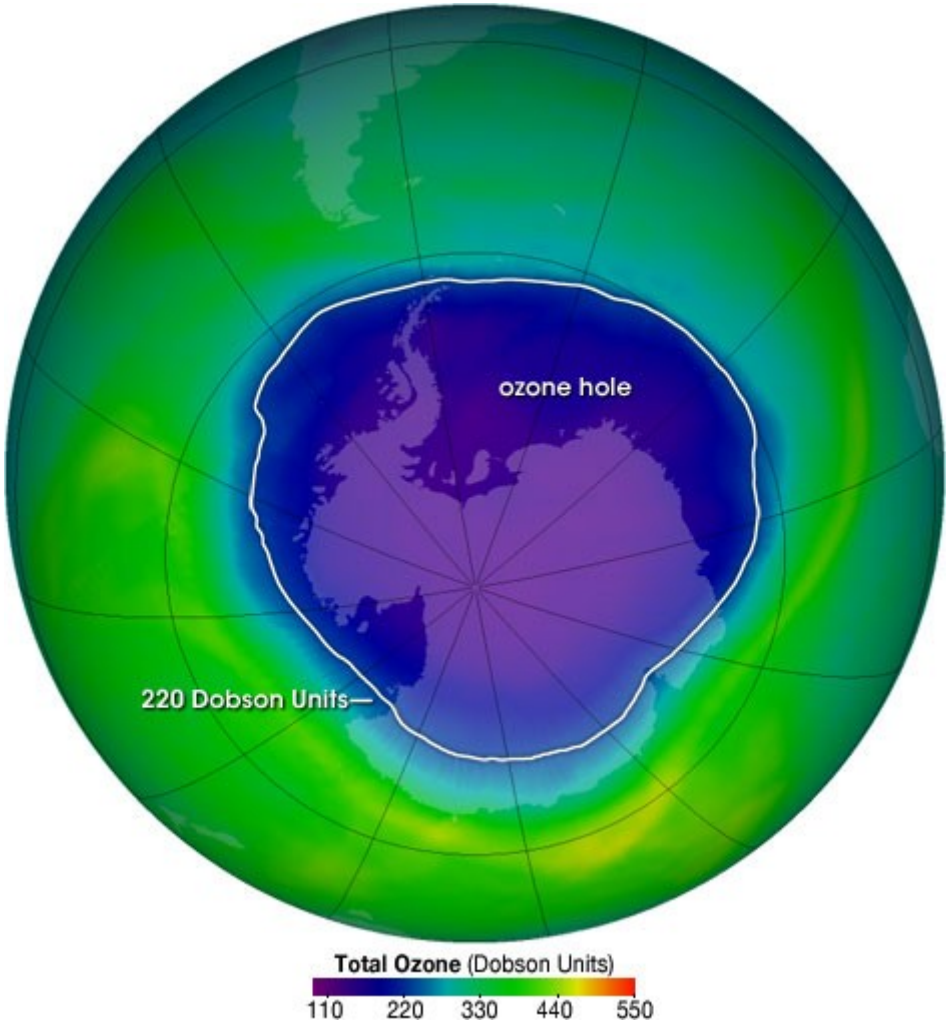
ozone depletion & ozone recovery





from *Eyring et al JGR* (2007)
colored lines: Chemistry Climate Models (CCMs)
black dots: observations

the ozone hole over the South Pole

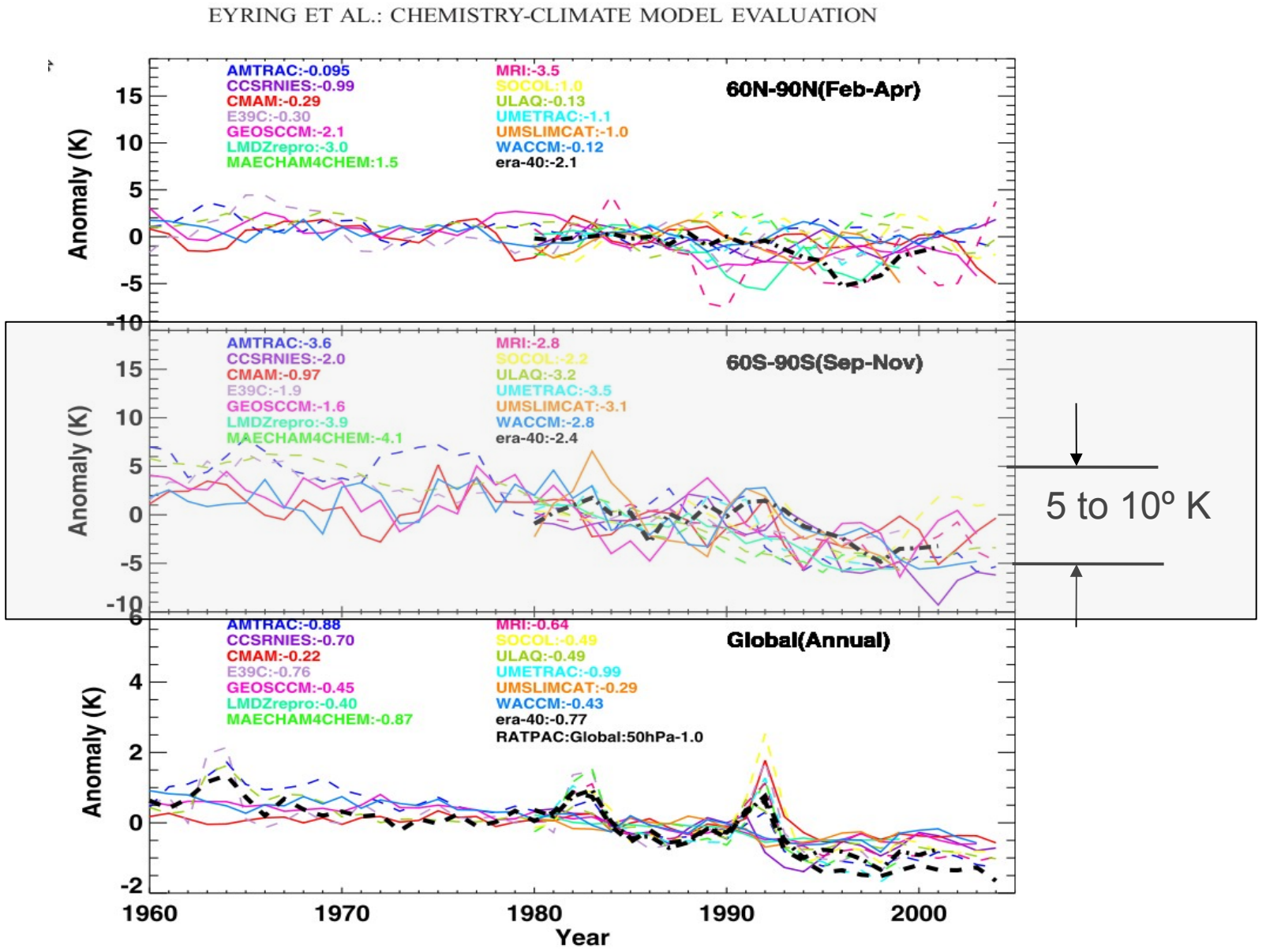


column ozone over
the South Pole
on October 4, 2004

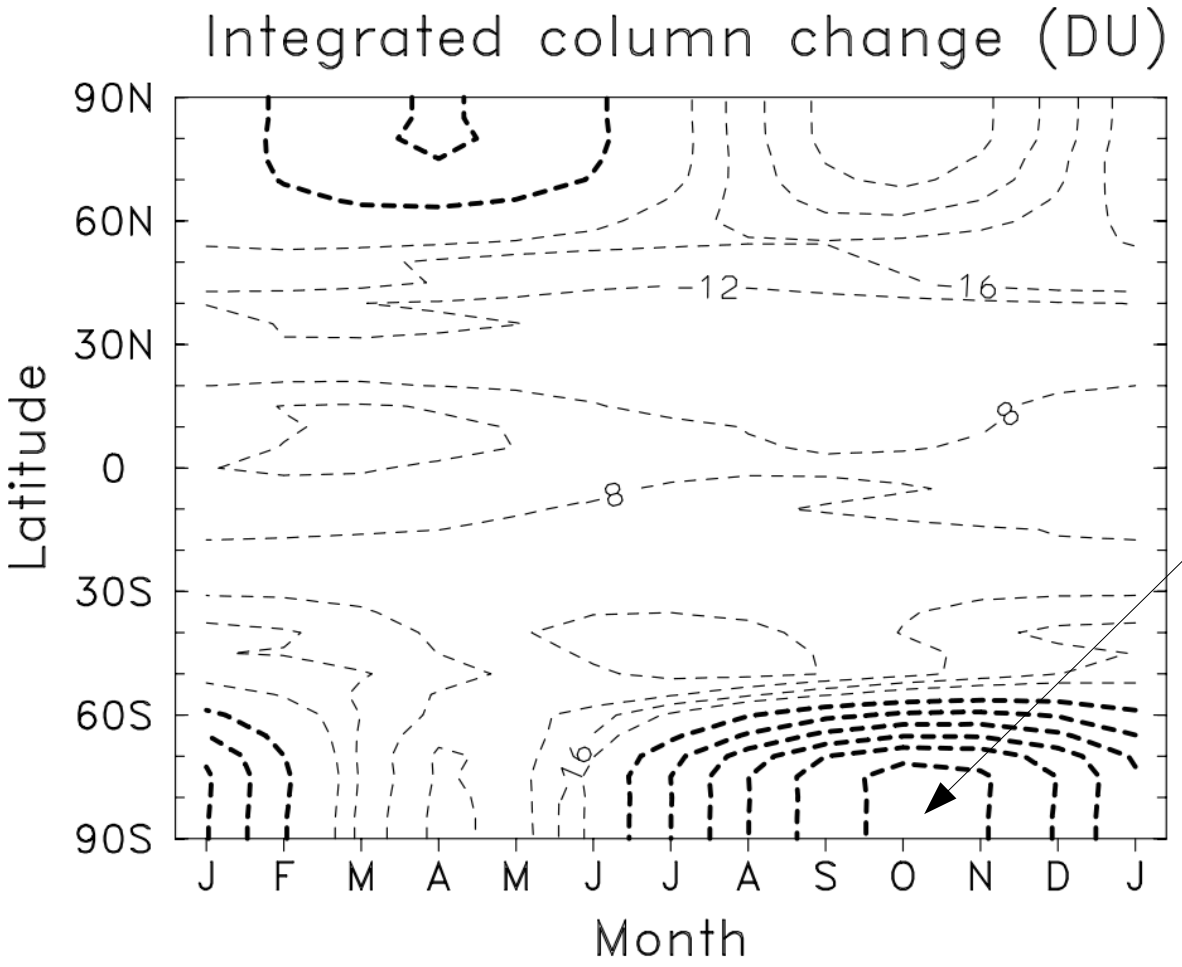
as measured from
a NASA instrument
on the AURA satellite

hole covers the whole
polar cap [60N to 90N]

ozone induced temperature anomalies



seasonal character of ozone depletion



ozone hole in SON

1979–2005 trends in column ozone
[dashed lines → negative values = depletion]
from *Randel & Wu JGR* (2007) – integrated SAGE/sonde data

our new integrations

+ use NCAR's CAM3 (atmospheric GCM)
+ IPCC class model, run in AMIP mode
+ standard resolution T42 with 26 hybrid levels

+ key forcings (all other are left unchanged)
    1. SST and sea ice (use Hadley Center)
    2. GHG concentrations (from SRES/A1B scenario)
    3. ozone field (new dataset from AC&C/SPARC)

+ focus on 1960-2000 (greatest O3 depletion)
+ all forcings are known from observations

compare FOUR integrations

+ we run a set of FOUR integrations
+ each is 50-years long in time-slice mode

  i.e. only a seasonal cycle on the forcings (NO trends)

name	ozone	GHGs	SSTs
REF1960	1960	1960	1952-1968
OZONE2000	2000	1960	1952-1968
GHG2000	1960	2000	1992-2008
BOTH2000	2000	2000	1992-2008

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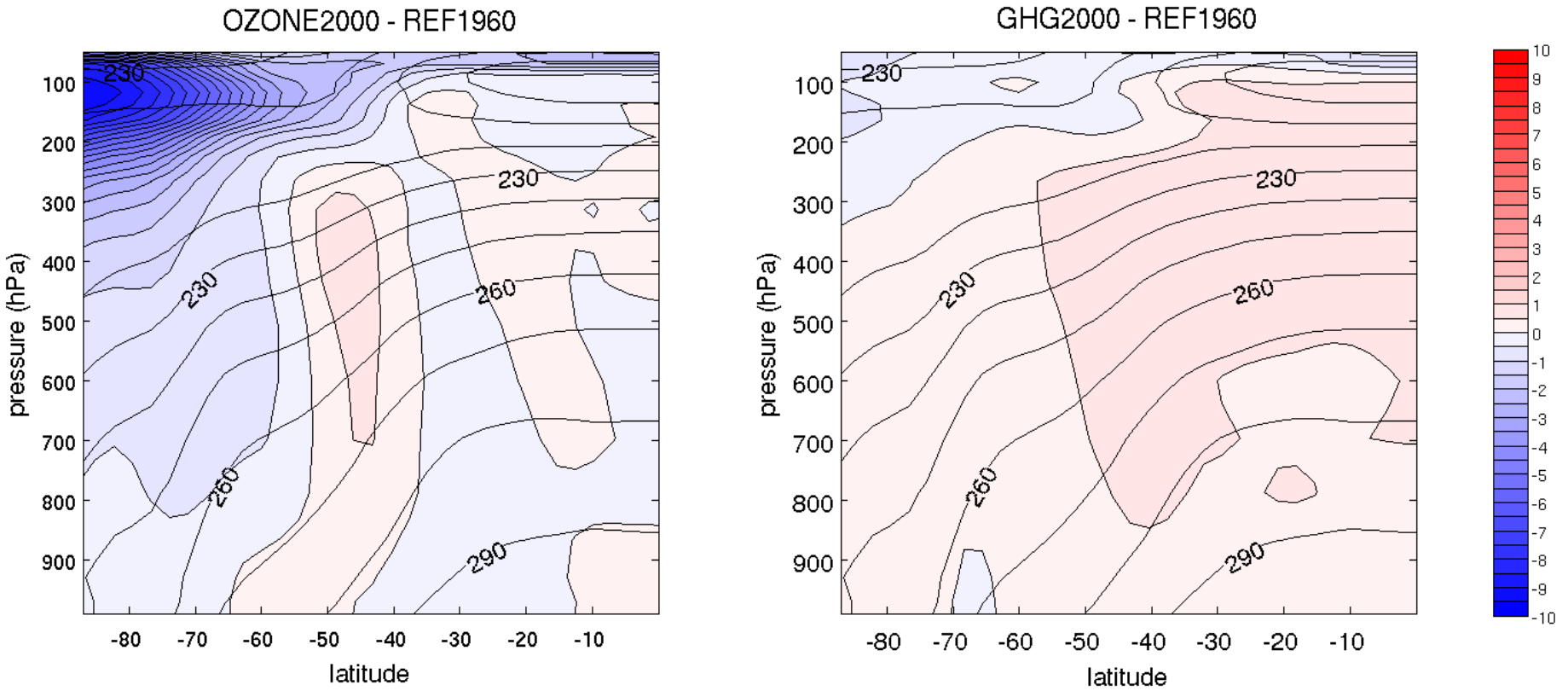
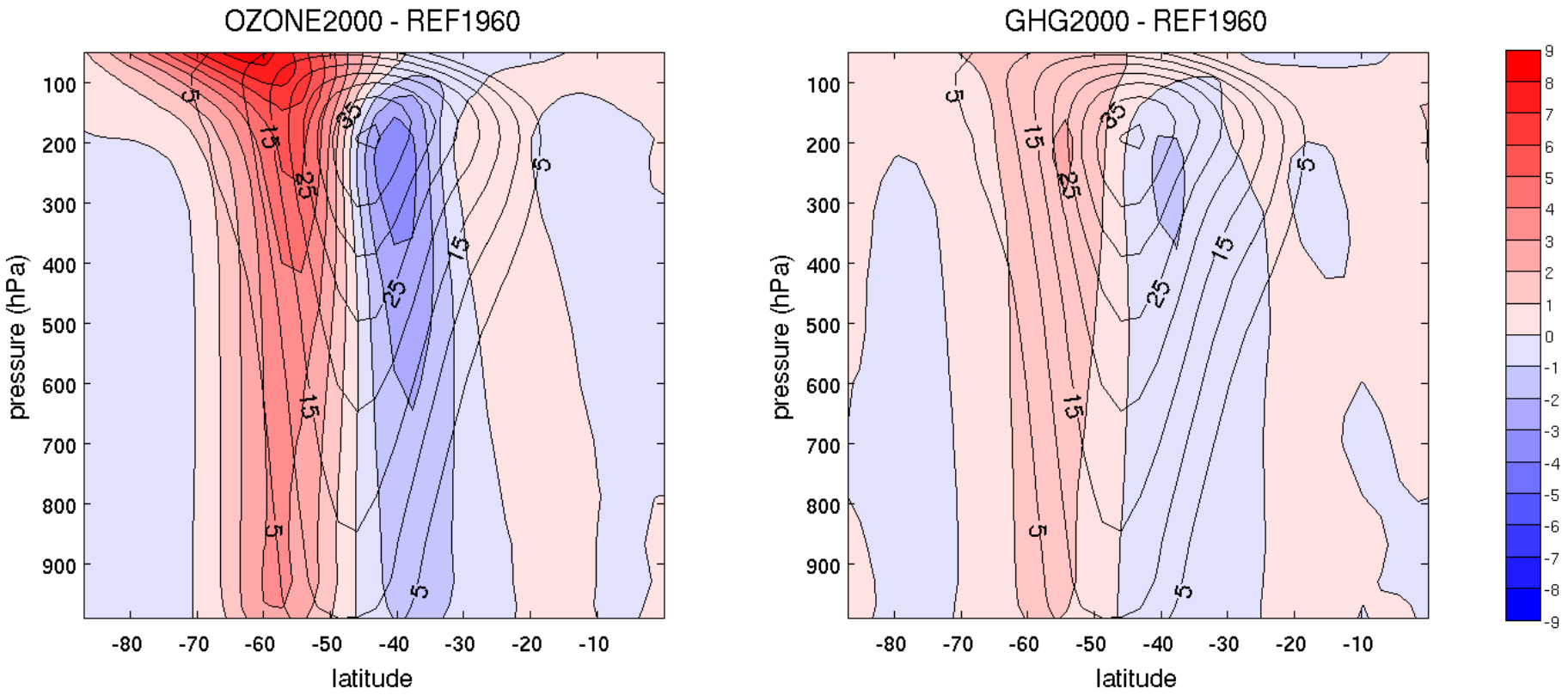
temperature response (DJF)



black: REF1960 time mean [c.i. 10º K] – colors: model response [c.i. 0.5º K]

from LMP, Waugh, Correa & Son (2011, in press)

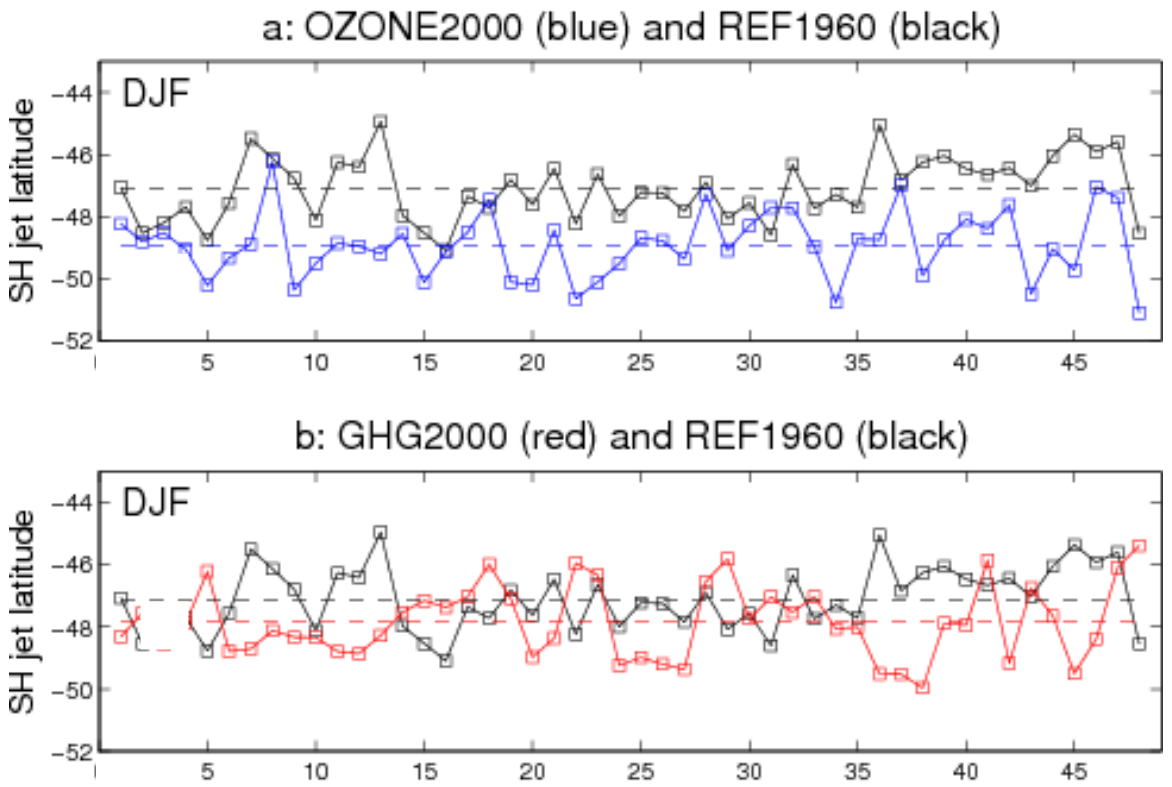
zonal wind response (DJF)



black: REF1960 time mean [c.i. 5 m/s] – colors: model response [c.i. 1 m/s]

from LMP, Waugh, Correa & Son (2011, in press)

DJF latitude of max zonal wind at 850 hPa

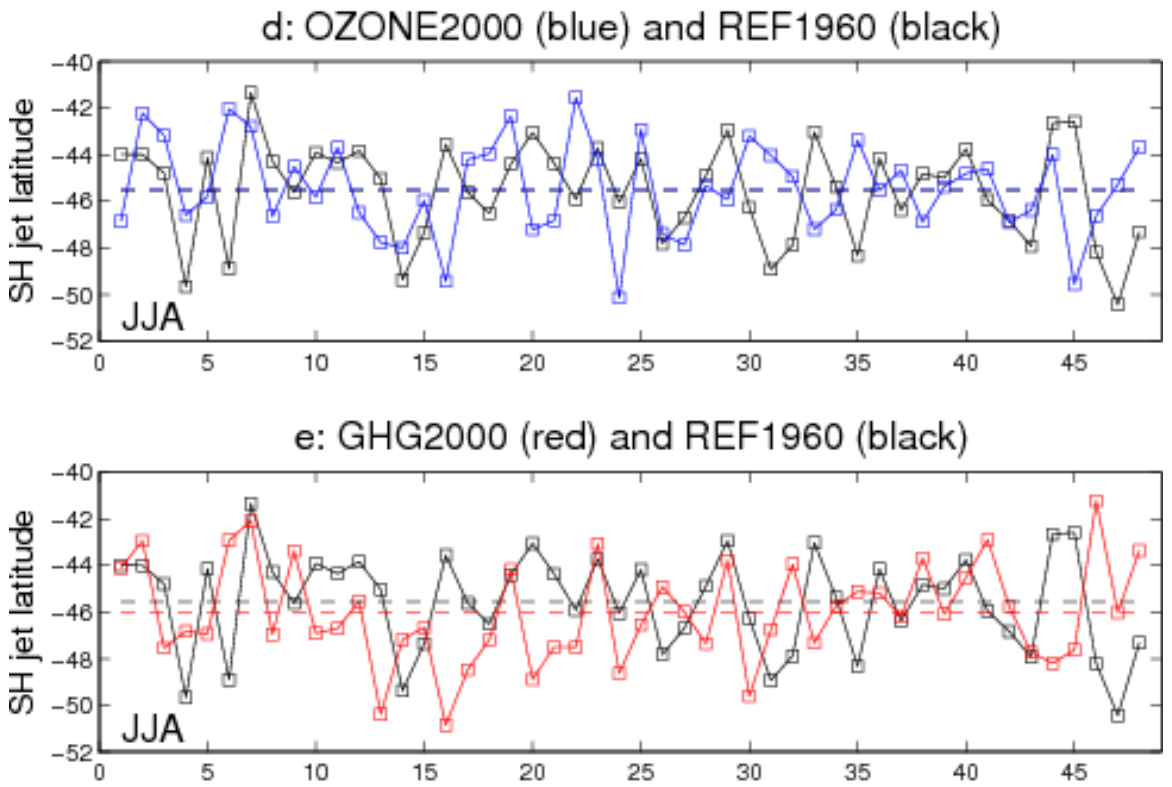


← ozone vs REF

← GHGs vs REF

from LMP, Waugh, Correa & Son (2010, in press)

JJA latitude of max zonal wind at 850 hPa

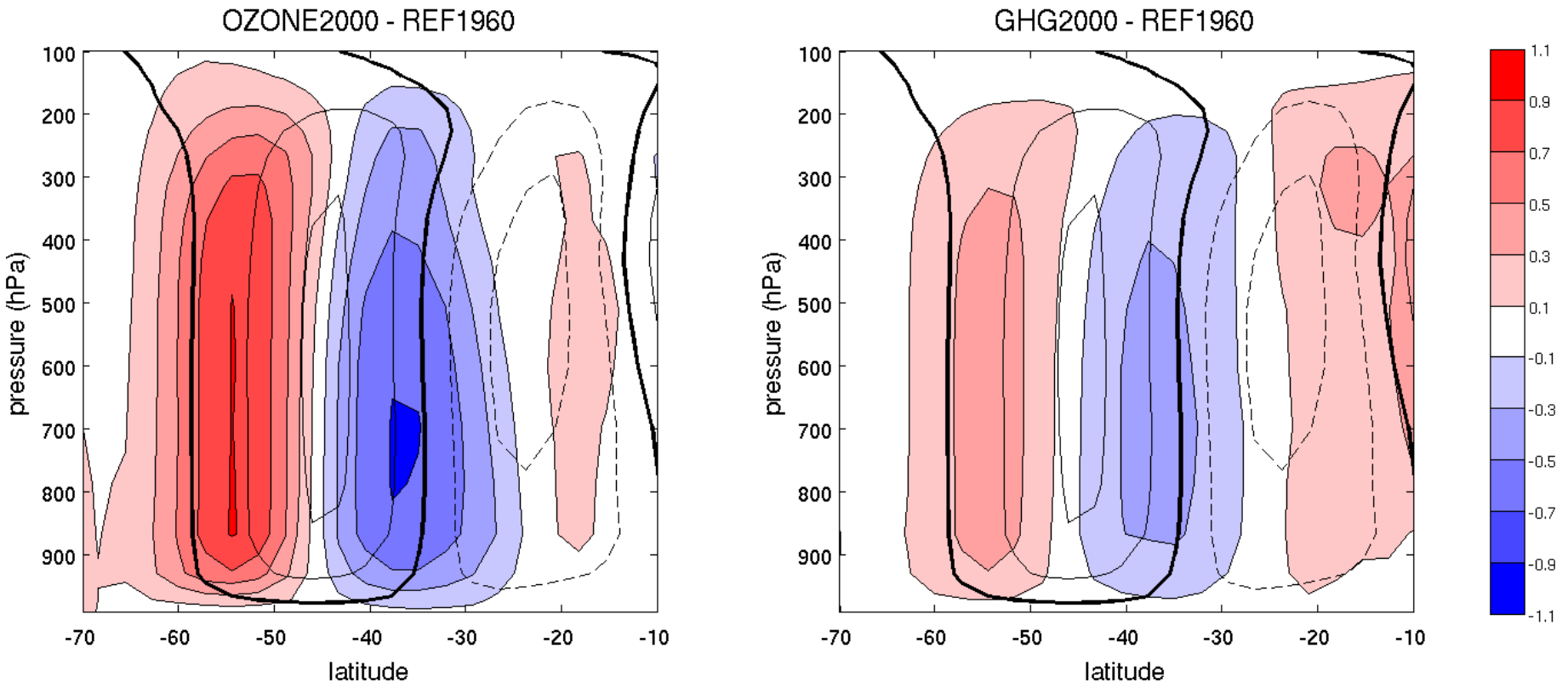


← ozone vs REF

← GHGs vs REF

from LMP, Waugh, Correa & Son (2010, in press)

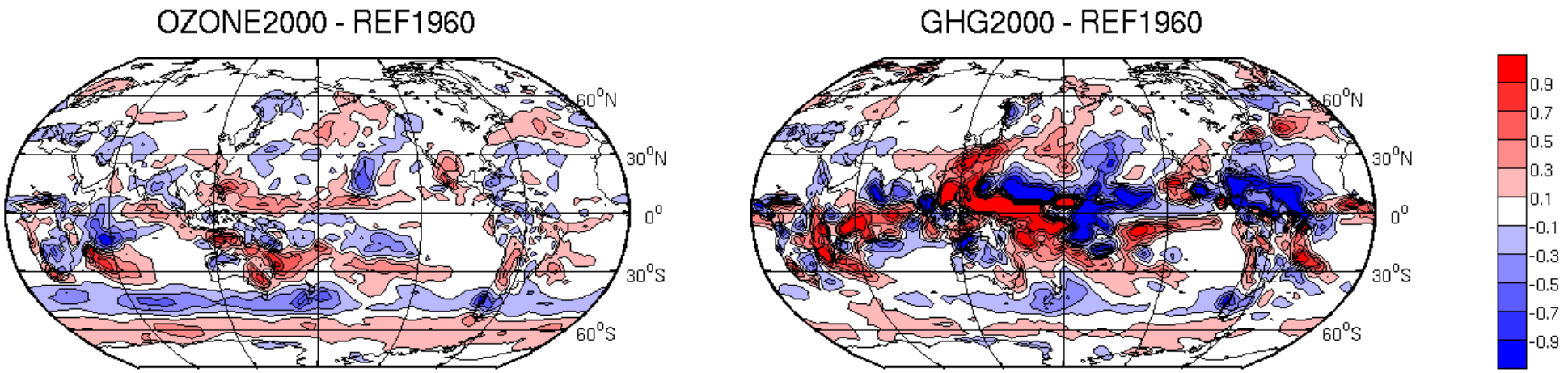
mean meridional streamfunction ψ (DJF)



black: REF1960 time mean [c.i. 2e10 kg/s] – colors: model response [c.i. 0.2e10 kg/s]

from LMP, Waugh, Correa & Son (2010, in press)

precipitation response (DJF)



colors: model P response [mm/day]

from LMP, Waugh, Correa & Son (2010, in press)

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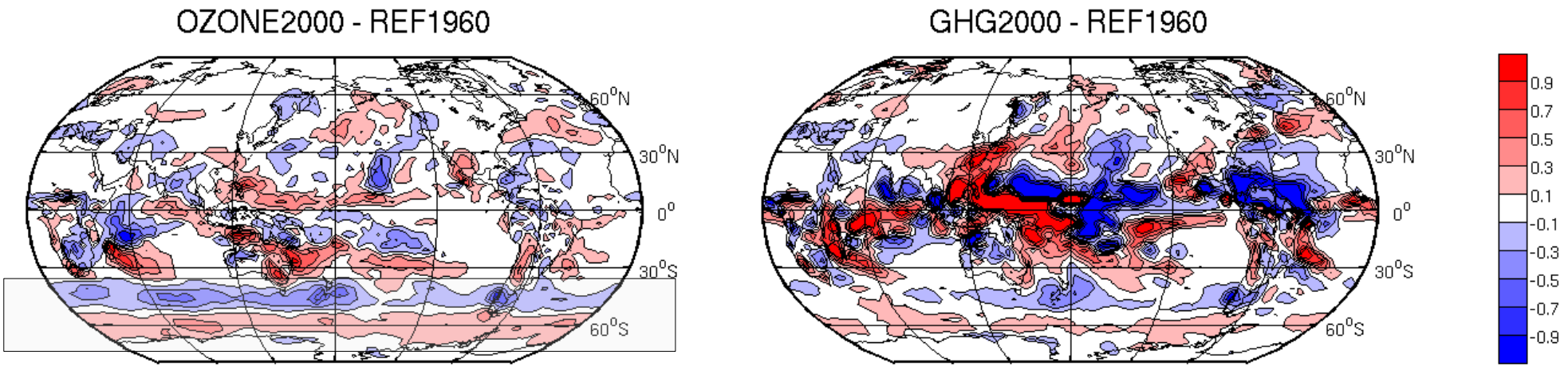

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from LMP, Waugh, Correa & Son (2010, in press)

comparison with other modeling studies

model integration	polar cap cooling (K)	tropopause raising (hPa)	midlatitude jet shift (° lat)	Hadley cell edge shift (° lat)
OZONE2000	−8.3	−17.4	−1.9	−1.0
GHG2000	−0.35	−2.3	−0.74	−0.50
BOTH2000	−7.5	−17.3	−2.1	−1.2
CCMVal2	−7.9	−16.4	−2.0	−0.87
CMIP3	−7.2	−15.5	−1.7	−0.58

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good quantitative agreement with both CCMVal2 and CMIP3 (for period 1960-2000)

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but now we know ozone depletion is the greater contributor

take home message – Part 1

+ stratospheric ozone is the DOMINANT driver of the observed SH circulation changes

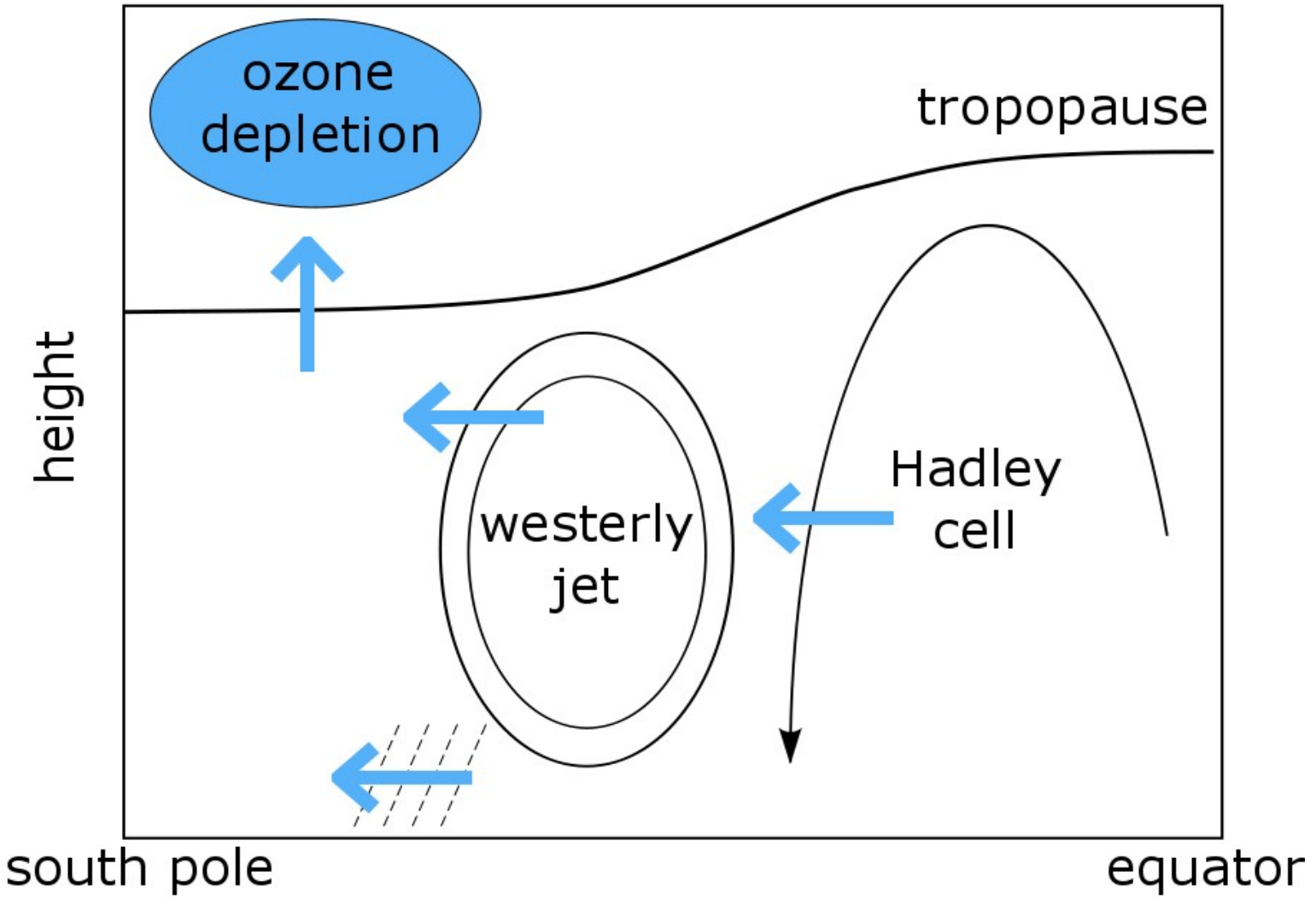
+ O3 effect is several times larger than GHG (in DJF)

+ mechanism... basically 3 links

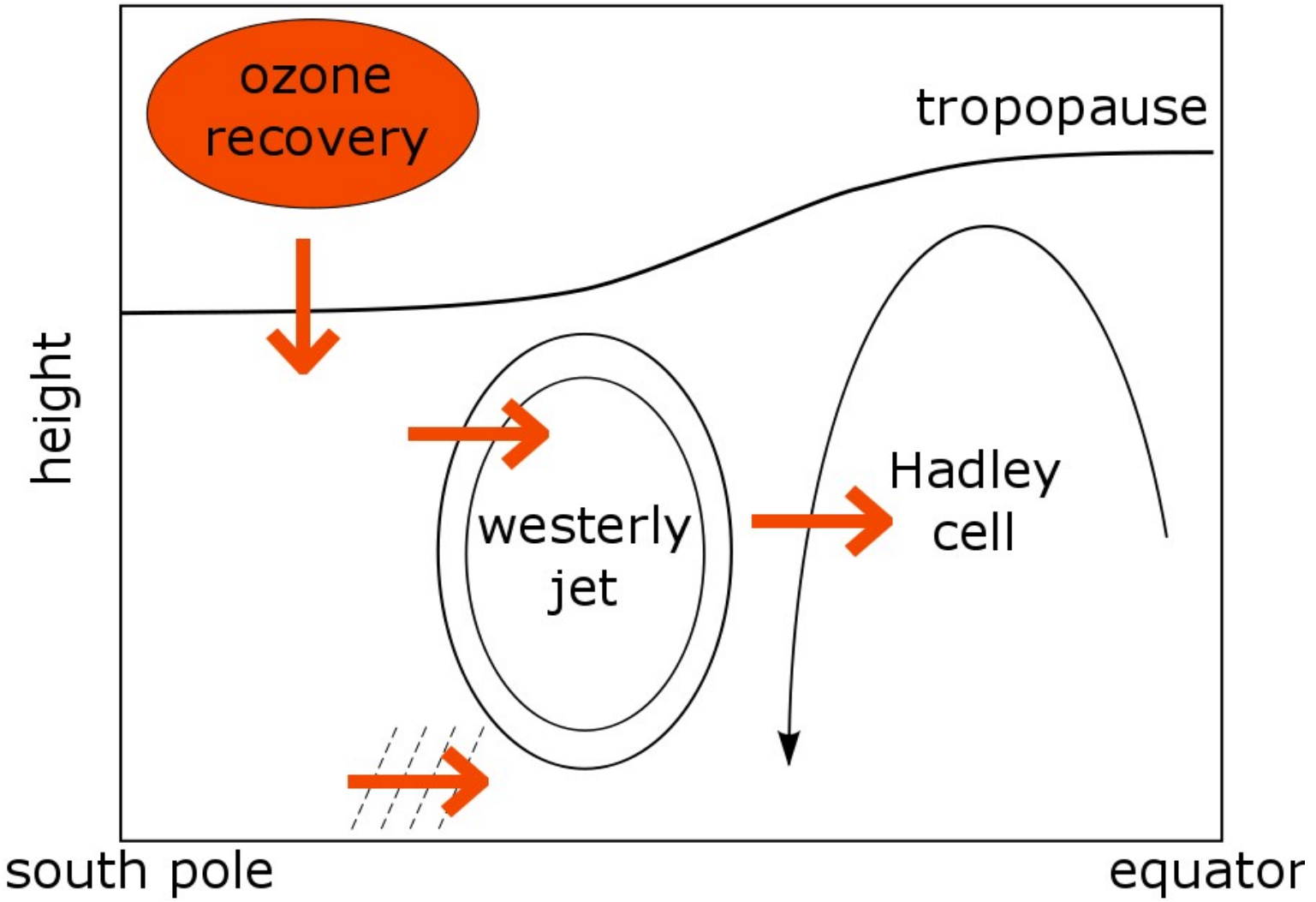
  1. ozone depletion → raises the polar tropopause
  2. higher/colder tropopause → poleward jet shift
  3. poleward jet shift → Hadley cell expansion

+ what happens next 50 years (ozone recovery)?

statospheric ozone and SH climate



statospheric ozone and SH climate



large ensemble experiment (Deser 2010)

+ large ensemble (40) of A1B runs with CCSM3

+ for 2000-2060 many CAM3 runs with individual forcings

+ we focus on 2 sets of 10 integrations with CAM3
  - one set has all forcings (GHG, SSTs, O3, etc)
  - other is forced with only OZONE recovery

+ contrast the two sets to understand what ozone does

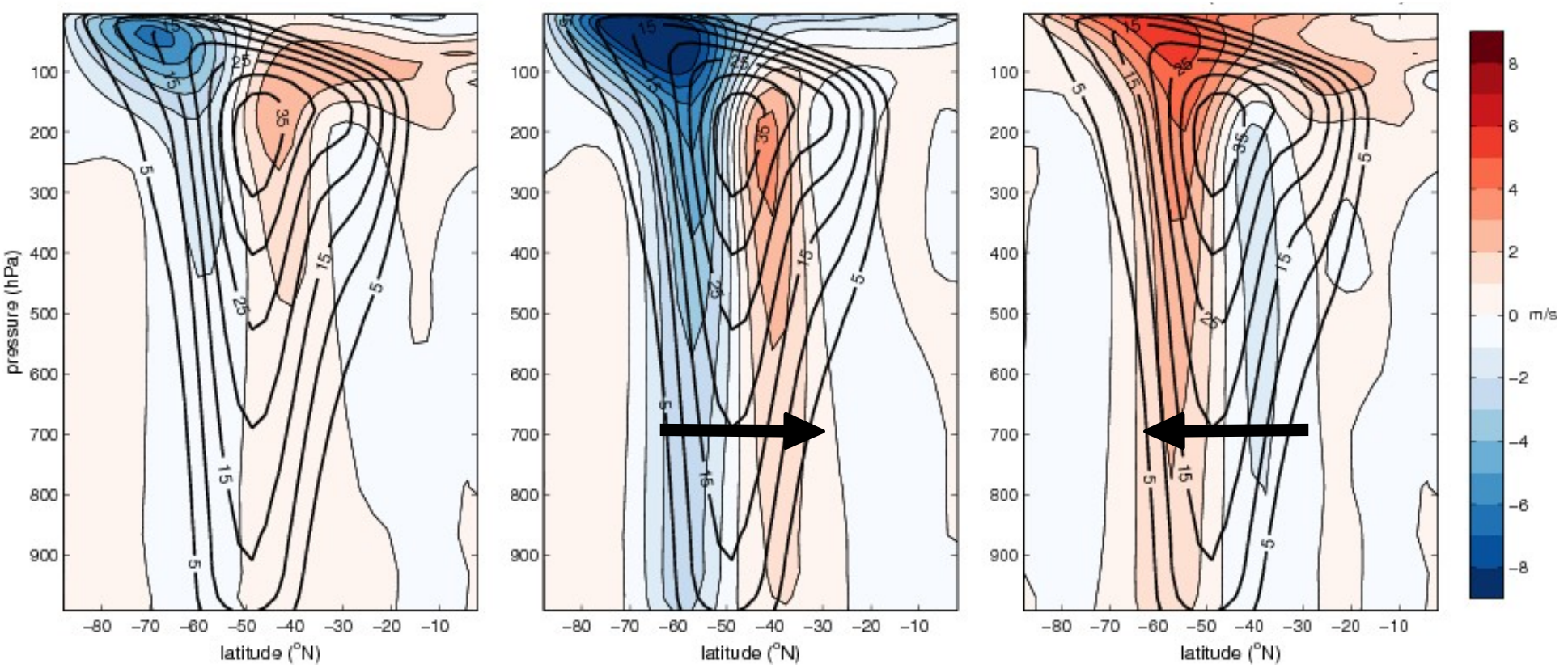
→ ozone recovery leads to a near cancellation of trends

zonal wind trends 2000-2060

all

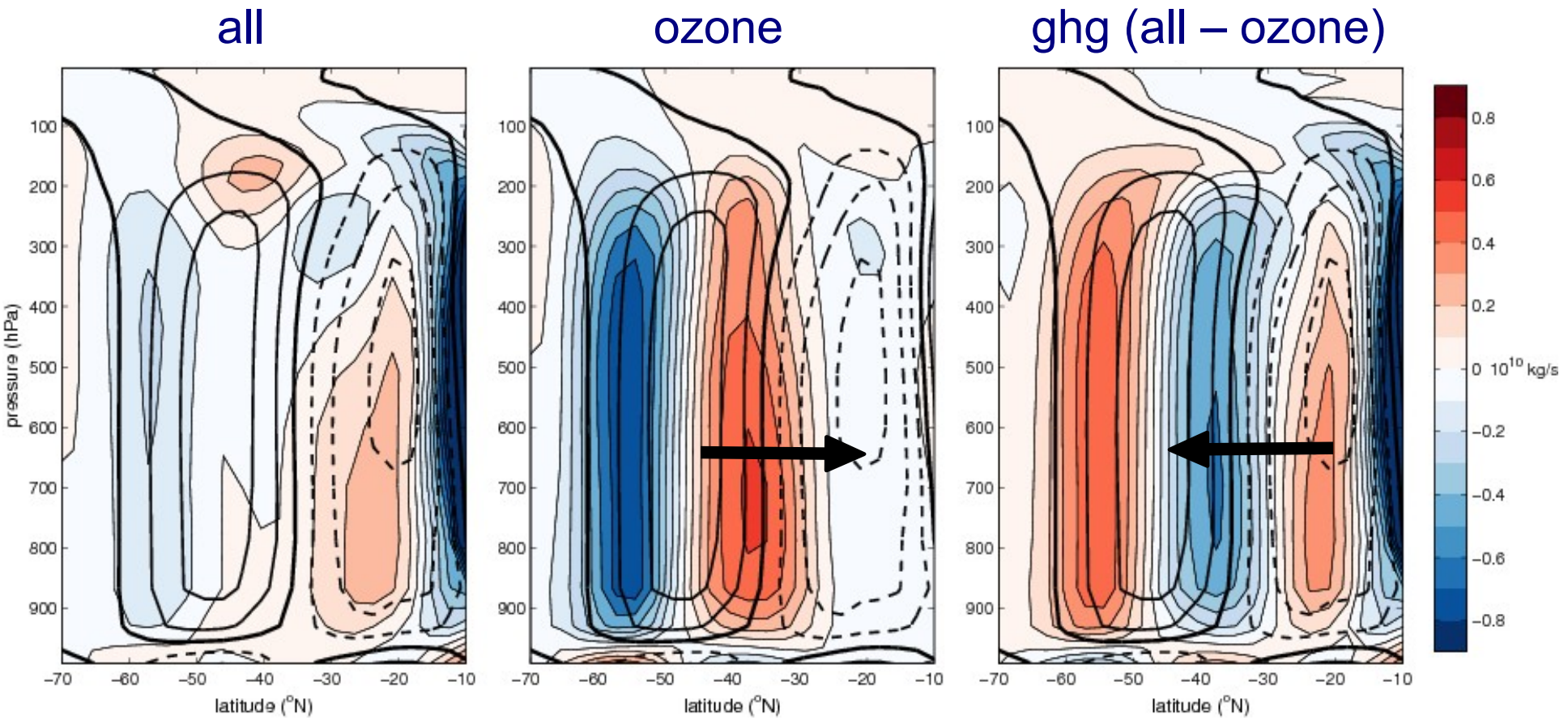
ozone

ghg (all – ozone)



from LMP, Previdi and Deser (GRL 2011, in press)

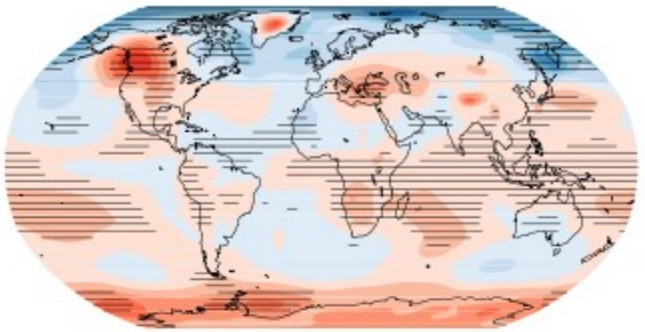
mean meridional circulation trends 2000-2060

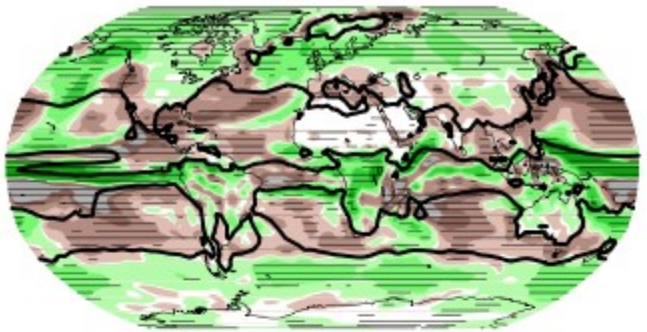


from LMP, Previdi and Deser (GRL 2011, in press)

SLP and P-E trends 2060-2000

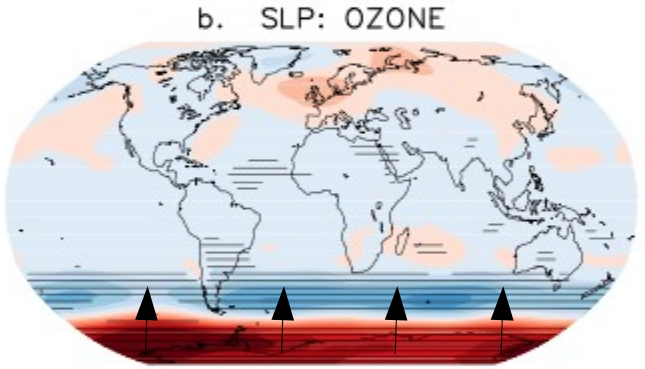
NO trends

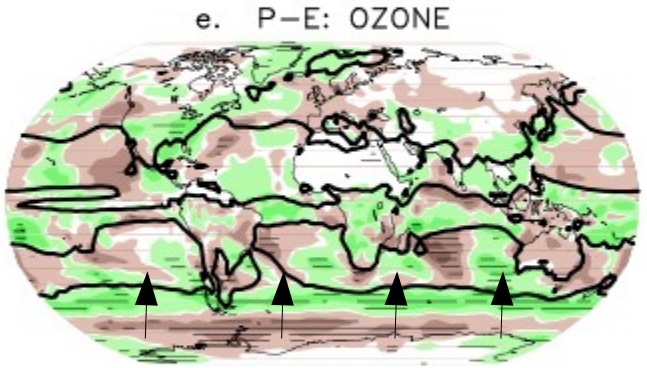




NO trends

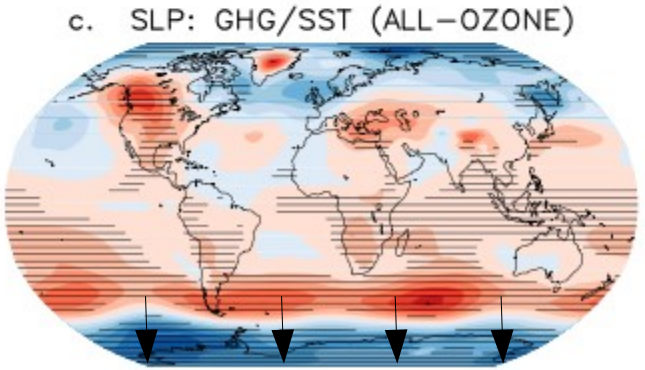
-ve SAM

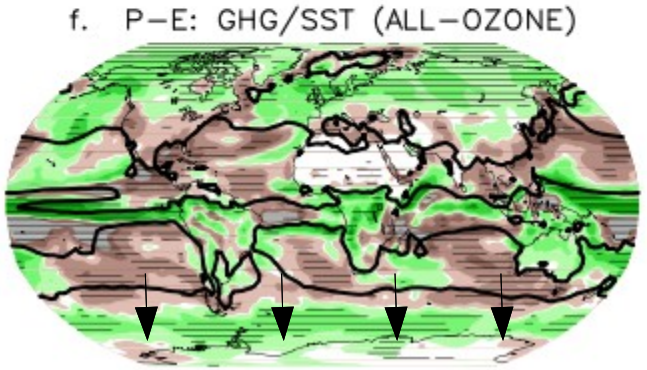




contraction

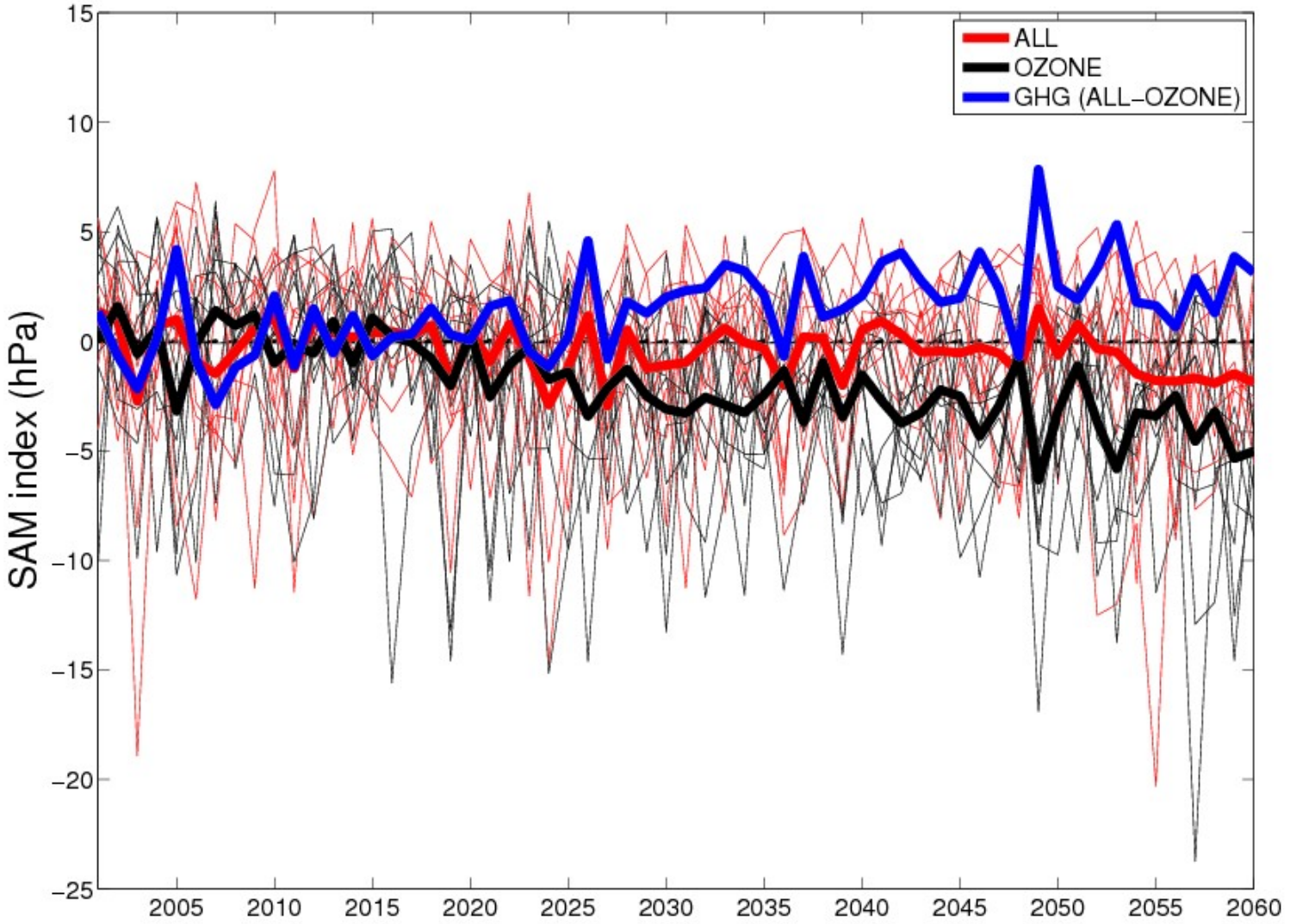
+ve SAM





expansion

Southern Annular Mode trends 2000-2060



from LMP, Previdi and Deser (GRL 2011, in press)

take home message – Part 2

+ ozone recovery projected to occur about 2065 ± 10

+ ozone recovery will push the jet equatorwards

+ ozone recovery will oppose effect of increasing GHGs

+ expect cancellation in the SH circulation

  → weaker/no trends in jet position and HC expansion

+ also a CLEAR indication in CMIP3/CCMVal2 models...

summary

1960 – 2000: ozone depletion was the dominant forcing of observed SH atmos circulation changes

2000 – 2060: ozone recovery will be a major player, and cause large trend cancellations in SH