Hunga Tonga–Hunga Ha'apai Water Vapor and Composition of the Stratospheric Polar Vortices

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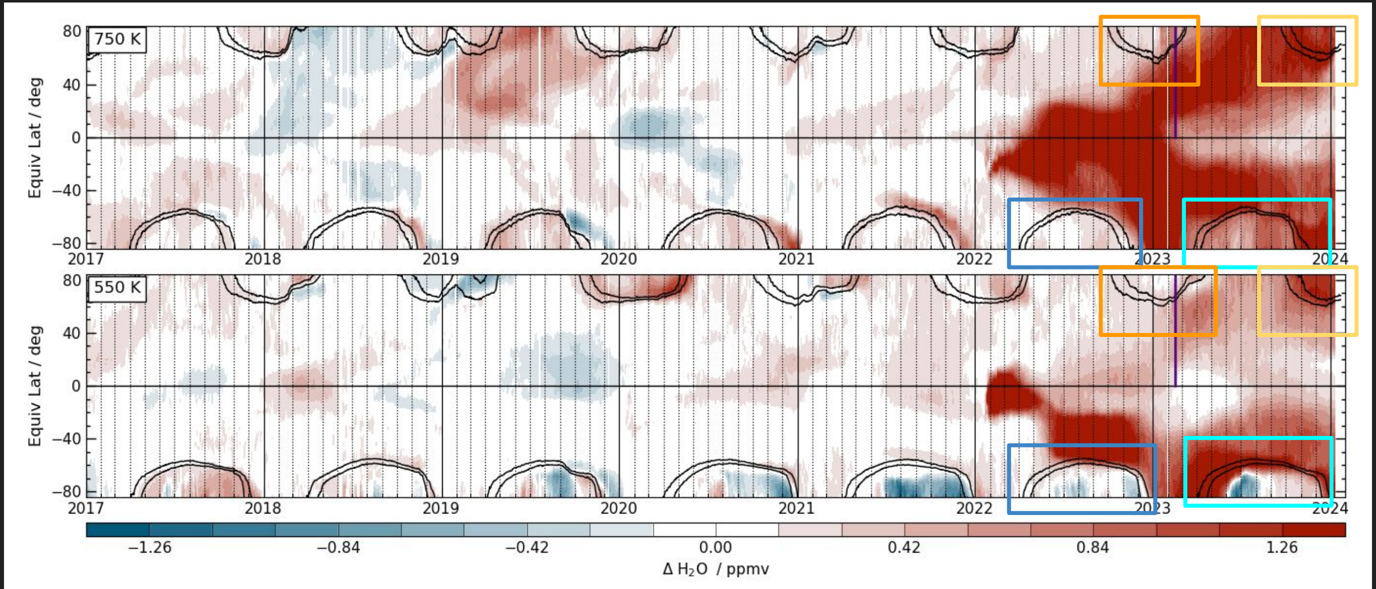
Overview

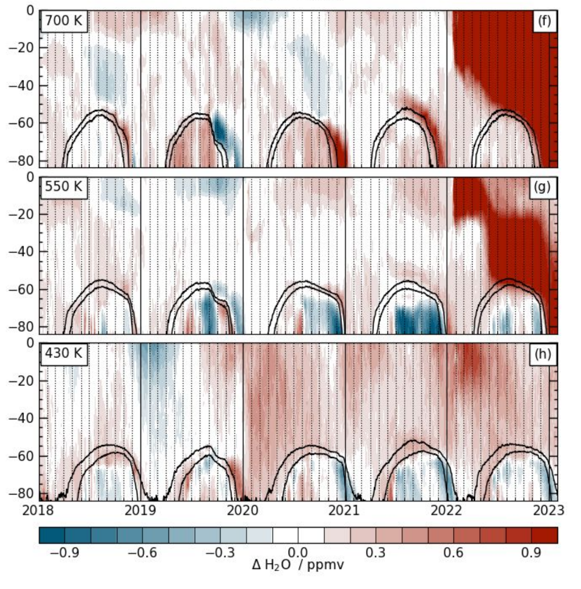
Aura MLS data (H_2O, N_2O, HNO_3, HCl, ClO, O_3), MERRA-2 reanalysis data (winds, temperatures, potential vorticity, etc), and CALIOP PSC data are used to investigate the impacts of the HT-HH stratospheric H_2O injection on the polar vortices in both hemispheres since the 15 January 2022 eruption

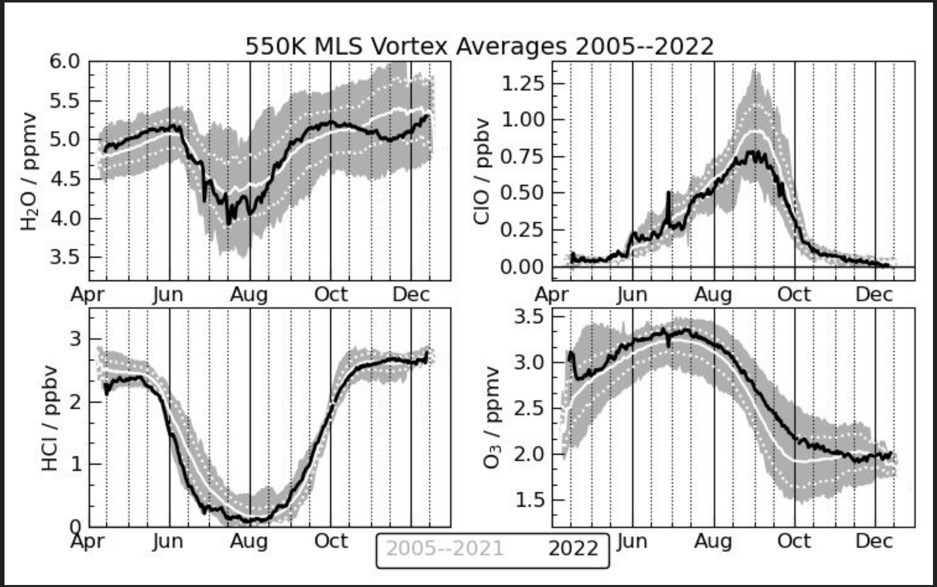


1. 2022 Antarctic polar vortex (formed before HT-HH H_2O reached high latitudes)
2. 2022/2023 Arctic polar vortex (sudden stratospheric warming, SSW, in mid-February)
3. 2023 Antarctic polar vortex (unprecedentedly high H_2O anomalies entrained into developing vortex)
4. 2023/2024 Arctic vortex (TBD after brief SSWs in January)

Equivalent latitude (above) and vortex-averaged views from MLS “Level 3” products provide a vortex-centered view and, unlike zonal means, allow us to distinguish vortex from extra-vortex air

HT-HH H_2O Plume Excluded from 2022 Antarctic Vortex





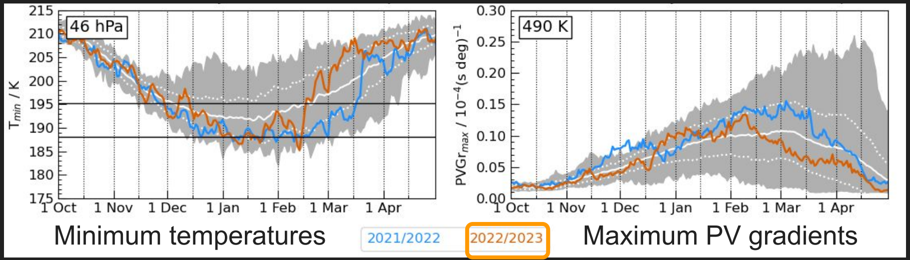
- HT-HH H_2O plume reached the vortex edge by June/July 2022, but was stopped there; extremely strong H_2O gradients then developed across that transport barrier (e.g., 700 K, 550 K)

Vortex-averaged MLS data show that:

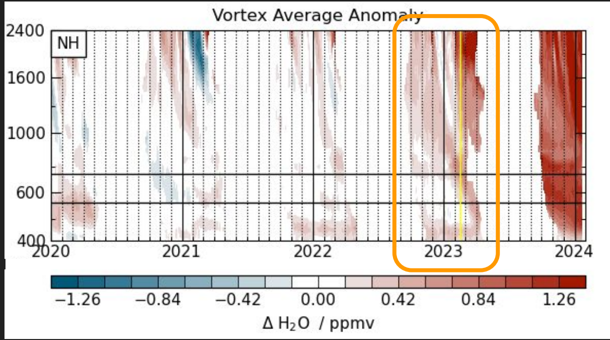
- Moist air from HT-HH did not penetrate the 2022 Antarctic vortex to any significant extent
- Polar chemical processing and ozone loss were unexceptional – no evidence of a substantial impact from the eruption on the 2022 Antarctic ozone hole

Manney et al., GRL, 2023, https://doi.org/10.1029/2023GL103855

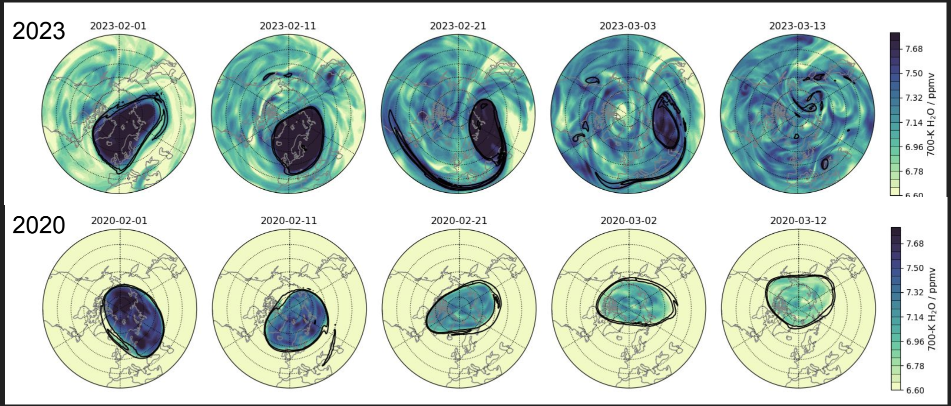
Arctic Vortex 2022/2023: H_2O Largely Excluded Until Sudden Stratospheric Warming (SSW)



- Arctic vortex minimum temperatures were lower than usual from late December 2022 until an SSW in mid-February 2023 abruptly warmed the lower stratosphere, halted chemical processing, and eroded the vortex
- Exceptionally high H_2O values mixed throughout the Arctic stratosphere within a few weeks after the mid-February SSW



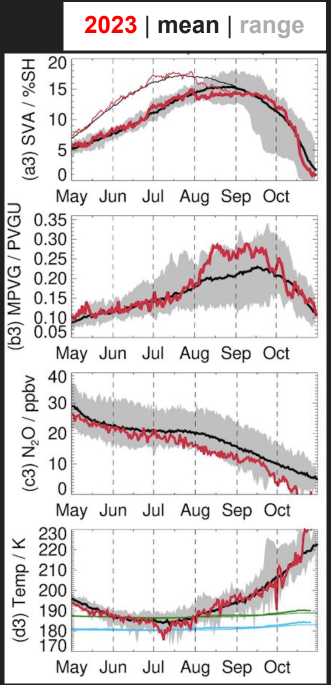
Vortex Averaged H_2O Anomalies



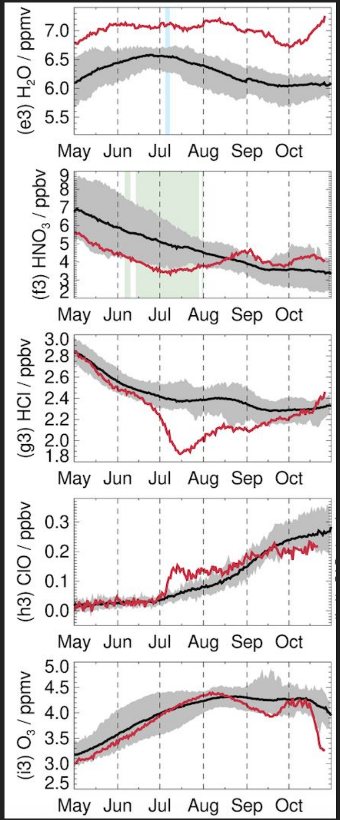
700 K H_2O maps compare values in 2023 (top; SSW in mid-February) with those in 2020 (bottom; strong, long-lived vortex) using the M2-SCREAM composition reanalysis of MLS data

Although it was unusually cold in January, the mid-February 2023 SSW led to an early vortex breakup, early cessation of polar processing, and higher-than-average springtime polar O_3

The 2023 Antarctic Vortex: Middle Stratosphere (750 K, ~28 km)

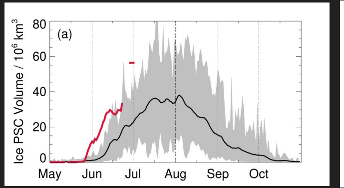


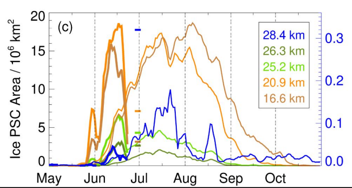
- The 2023 vortex area and area exposed to sunlight near average
- Maximum PV gradients show near-average vortex strength, except during enhanced wave activity in August / September
- Values of long-lived tracer N_2O, indicative of diabatic descent, mostly within previous range
- Vortex minimum temperatures near average except for short colder period in early July



- H_2O: remained ~1 ppmv above mean; mostly followed typical evolution; little effect from early ice PSCs
- HNO_3: clear signs of uptake into PSCs; values outside envelope by July
- HCl and ClO: Unprecedented chlorine activation; HCl (ClO) far below (above) ranges
- O_3: mostly near average
- ClO enhancement redefined envelope, but was nearly order of magnitude weaker than at lower altitudes >> little effect on O_3

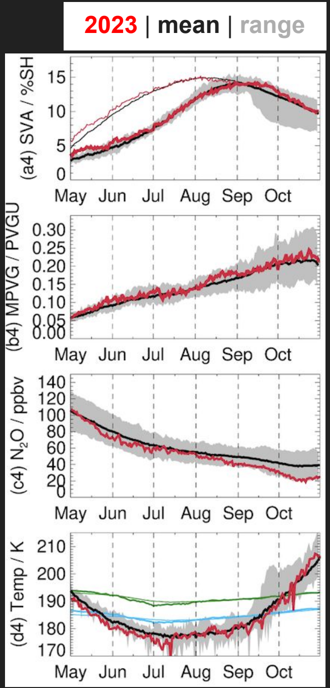
CALIOP: exceptionally early ice PSC formation





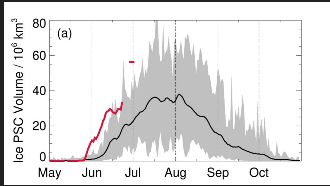
Santee et al., submitted to JGR-Atmospheres, 2024
DOI: 10.22541/essoar.170542085.55151307/v1

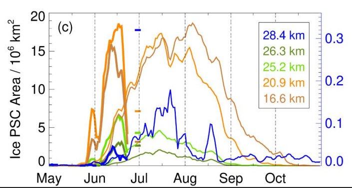
The 2023 Antarctic Vortex: Lower Stratosphere (550 K, ~23 km)

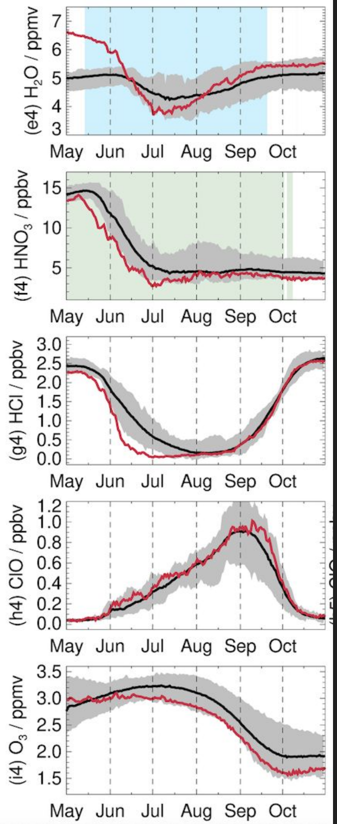


- The 2023 vortex area and area exposed to sunlight fairly typical
- Maximum PV gradients show near or slightly above average vortex strength through winter
- N_2O near average except for a suggestion of slightly enhanced descent in October
- Vortex minimum temperatures near / below average, especially during an early-July cold period

early and extensive PSC activity



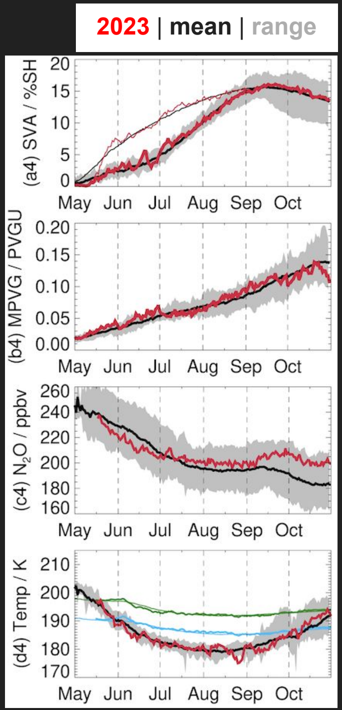




- H_2O: initially ~1.5 ppmv above average; reaches bottom of its range in early July; rebounds to above the mean in August despite continuing $T<T_{ICE}$, but never fully recovers, implying the occurrence of dehydration
- HNO_3: nearly the entire vortex severely denitrified by early July
- HCl and ClO: chlorine activation underway much earlier than usual, but values about average by late July; deactivation starts later than in most years
- O_3: relatively low (but still within the previous range) values at the end of winter may be related to the delayed deactivation

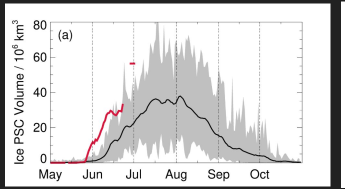
Santee et al., submitted to JGR-Atmospheres, 2024
DOI: 10.22541/essoar.170542085.55151307/v1

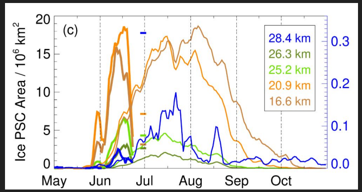
The 2023 Antarctic Vortex: Lower Stratosphere (410 K, ~17 km)

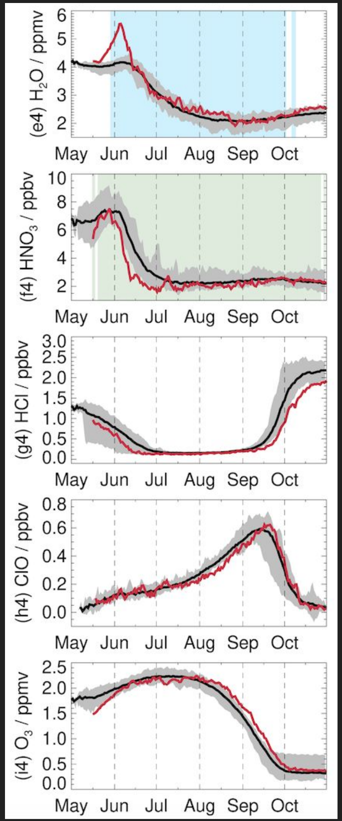


- The 2023 vortex area and area exposed to sunlight fairly typical
- Maximum PV gradients show near-average vortex strength
- N_2O near average until late winter, when descent appears to weaken
- Vortex minimum temperatures mostly near average

early and extensive PSC activity



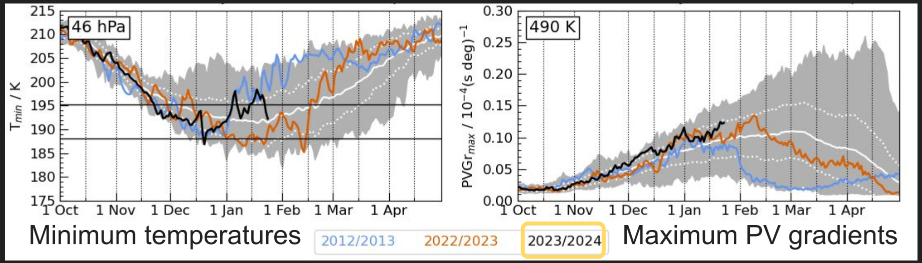


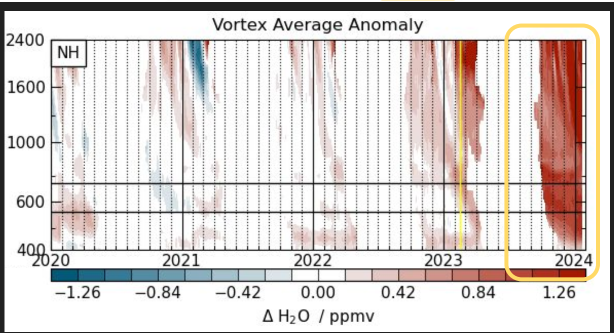


- H_2O: transient maximum in early June likely due mainly to evaporation at this level of ice particles falling from above (i.e., rehydration), but the evolution is typical by midwinter
- HNO_3: initial steep rise due to renitrification, then uptake into widespread PSCs; again, typical behavior after mid-July
- HCl and ClO: early chlorine activation, delayed deactivation; ClO slightly low in between
- O_3: slightly high in August / September (when ClO low); otherwise near-average values

Santee et al., submitted to JGR-Atmospheres, 2024
DOI: 10.22541/essoar.170542085.55151307/v1

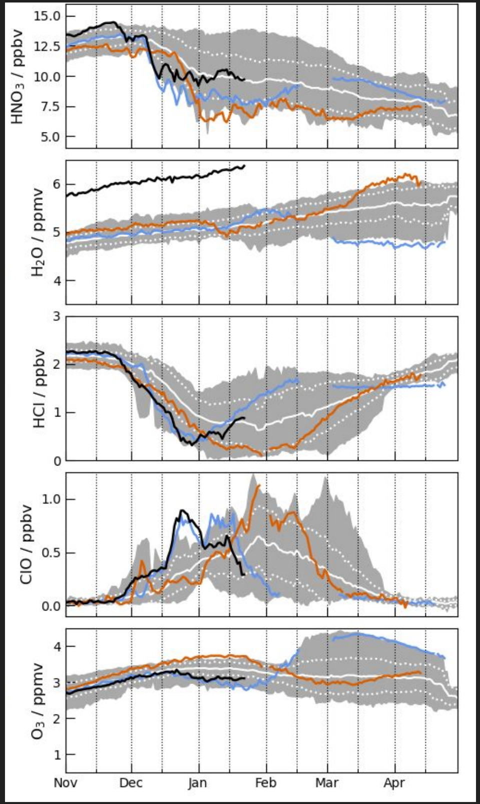
Arctic Vortex 2023/2024: Cold Early Vortex, Brief SSW, Season Impacts TBD



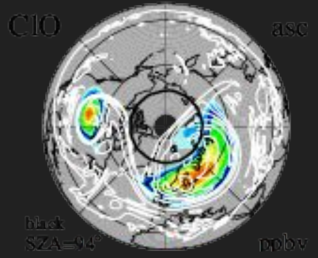


Vortex Averaged H_2O Anomalies

- Minor SSW in early January, brief major SSW in mid-January
- Unusually cold before SSWs; quickly dropped below PSC thresholds again after
- Unprecedentedly high H_2O throughout vortex since its formation



- Polar processing so far resembles that in 2013* (blue lines)
- Vortex split moved offspring with activated chlorine into sunlight
- Unlike 2013, temperatures have dropped again, so continued chlorine activation is expected



MLS 490K ClO 15 Jan 2024

*For 2013 polar processing in split vortex, see Manney et al, 2015, ACP, https://doi.org/10.5194/acp-15-5381-2015

Summary

1. 2022 Antarctic polar vortex:
   - HT-HH water vapor excluded from 2022 Antarctic vortex
   - No clear evidence of HT-HH impacts on vortex or polar processing
2. 2022/2023 Arctic polar vortex:
   - HT-HH H_2O largely excluded from 2022/2023 Arctic vortex until a sudden stratospheric warming (SSW) in mid-February
   - HT-HH H_2O rapidly mixed throughout the polar regions during / after the SSW
3. 2023 Antarctic polar vortex:
   - Began season with unprecedentedly high water vapor anomalies in the vortex
   - Earliest ice PSC formation and chlorine activation on record, also extending to higher altitudes
   - Associated larger removal of H_2O via dehydration
   - Little impact on ozone loss because chemical processing saturated at most levels
   - No obvious impacts on polar vortex strength / longevity
4. 2023/2024 Arctic vortex?
   - HT-HH enhanced H_2O entrained into early winter vortex
   - Vortex unusually cold until minor and then major SSWs in early / mid-January 2024.
   - Temperatures rose briefly above PSC thresholds but have again dropped below
   - Vortex split moved offspring vortices with activated chlorine into sunlight, with evidence of greater than usual early ozone loss.