Observations, lecture 2

Research satellite observations of water vapour

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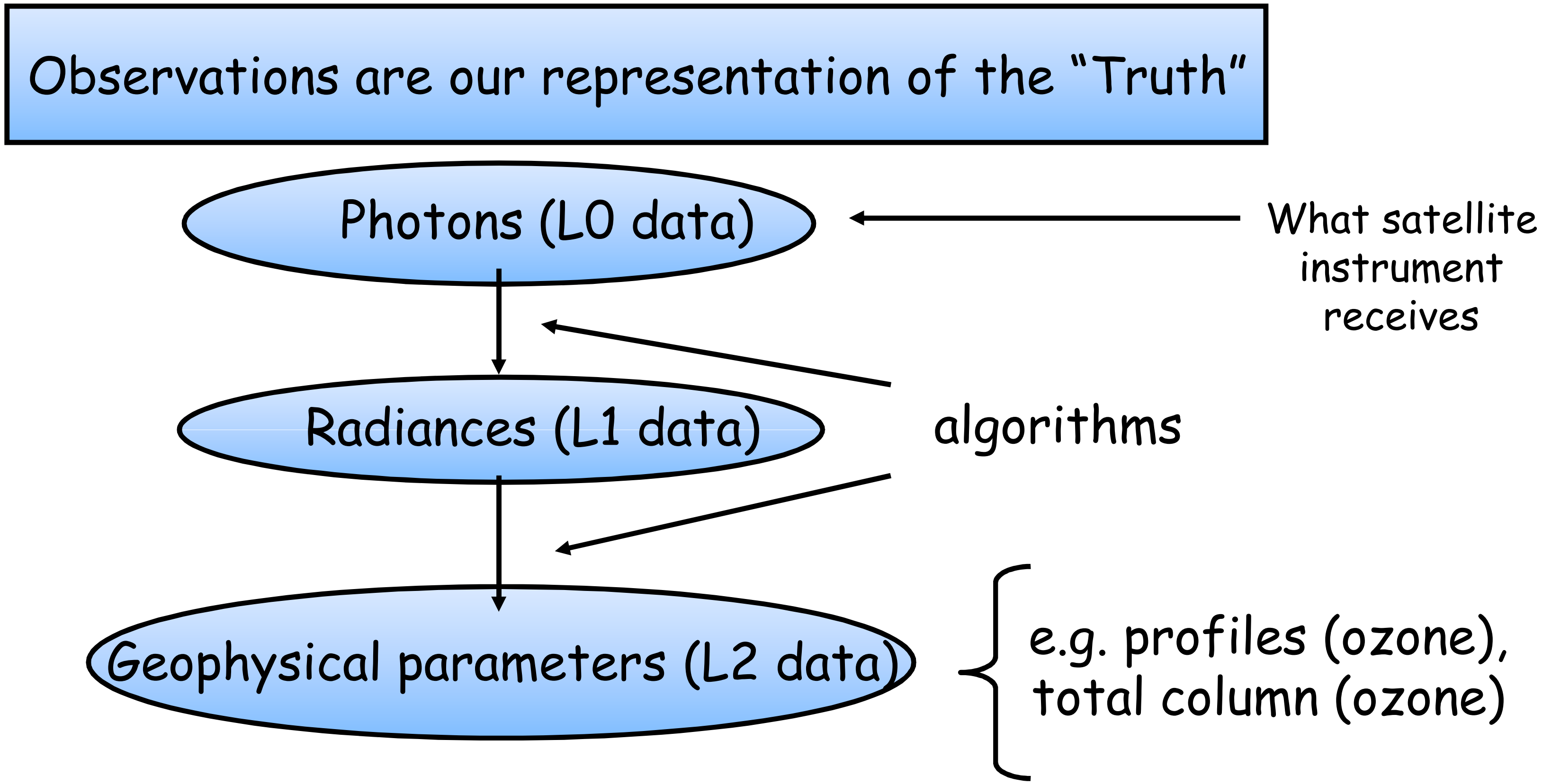
Outline

- Features of observations
- Research satellites and water vapour
- Features of atmospheric water vapour (stratosphere)
- Benefits of research satellites & the future

Features of observations

Representation of the "truth"

1. Resolution (temporal & spatial)
2. Frequency (temporal & spatial)
3. Frequency/wavelength of measurement (region of EM spectrum)
4. Radiometric noise (signal/noise ratio)
5. Coverage (global/local)
6. Geometry (nadir/limb)
7. Level of data (0: photons; 1: radiances; 2: geophysical parameters)
8. Errors (random, systematic – biases, "representativeness")
9. Platform (sondes, aircraft, satellites – this has a bearing on resolution)
10. Influences on time/space evolution (dynamics: temperature, winds, ozone; chemistry: ozone, ClO).



Scientists normally work with L2 data

Level of data L1/L2:

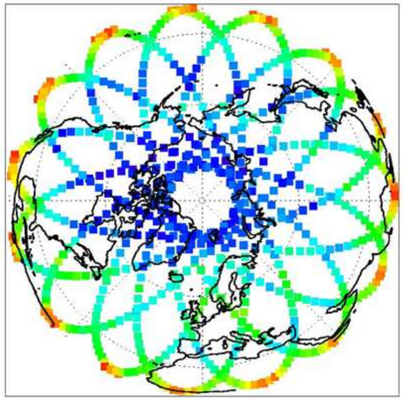
L2:

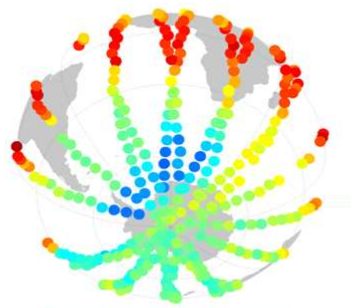
- Easier to assimilate than those of L1: historically L2 data has tended to be assimilated before L1
- Recent ideas from Rodgers ("information content") -> alleviate problems associated with L2 data (e.g. *a priori* information)

L1:

- less "contaminated" (e.g. by *a priori* information)
- Errors are less correlated than for L2 data
- Tendency to assimilate radiances: nadir radiances already assimilated by met agencies; limb radiances are much harder to assimilate
- Improvements in analyses & forecast skill at NWP centres

What does Level 2 (L2) data look like?





Ozone data at 10 hPa (approximately 30 km in height) for 1 February 1997 from the MLS (Microwave Limb Sounder) instrument onboard the UARS (Upper Atmosphere Research Satellite) satellite. Blue denotes relatively low ozone values; red denotes relatively high ozone values.

Ozone at 10 hPa (about 30 km in height) from the MIPAS (Michelson Interferometer for Passive Atmospheric Sounding) instrument onboard the Envisat satellite, at 1200 UTC on 23 September 2002.

Note the gaps between the satellite orbits

See data assimilation lecture (observation # 9 lecture)

Resolution of observations

Real resolution of observations could be coarser than that implied by the apparent resolution/frequency of the observations

-> correlations (horizontal/vertical) between observations

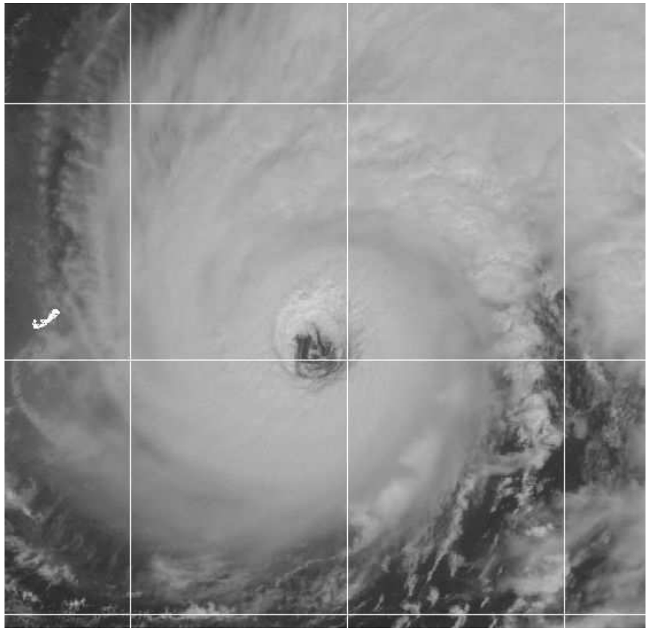
Correlations taken into account in the observation errors covariance (characterizes observation errors)

-> data assimilation (see later): non-diagonal errors; correlations between observations -> thin to give a reduced density of observations & represent observation field appropriately

In the stratosphere, horizontal correlations tend to be larger than in troposphere: flow dominated by smaller wavenumbers in the stratosphere

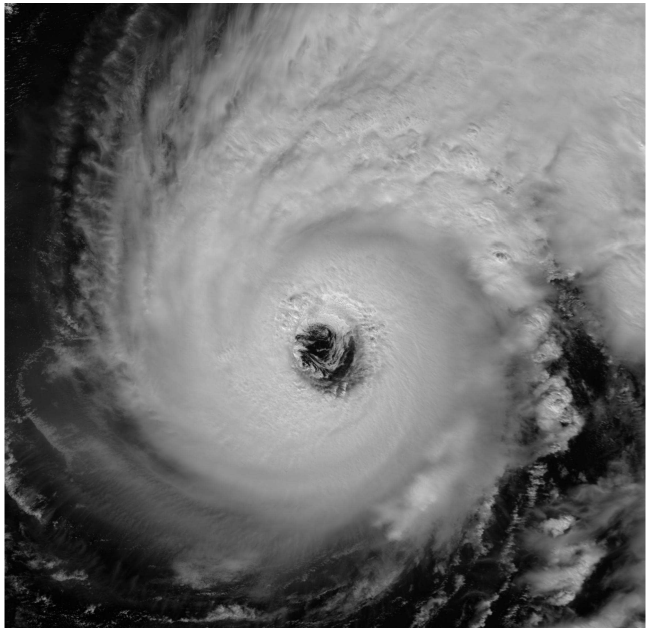
Example of spatial resolution

Hurricane Erin
09/09/01 ~1530 Z

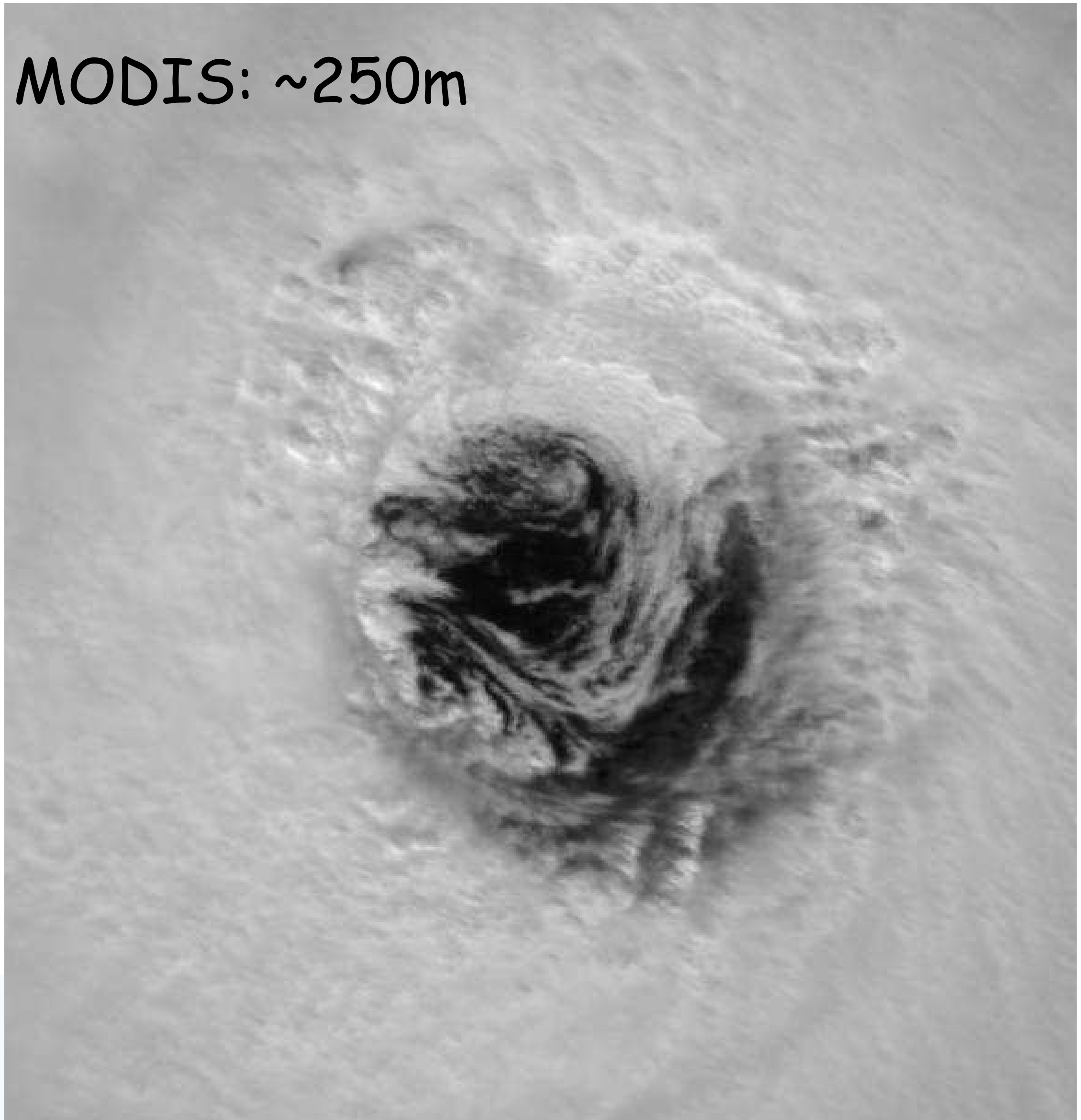


Courtesy James Purdom

Hurricane Erin
09/09/01 ~1530 Z



Courtesy James Purdom

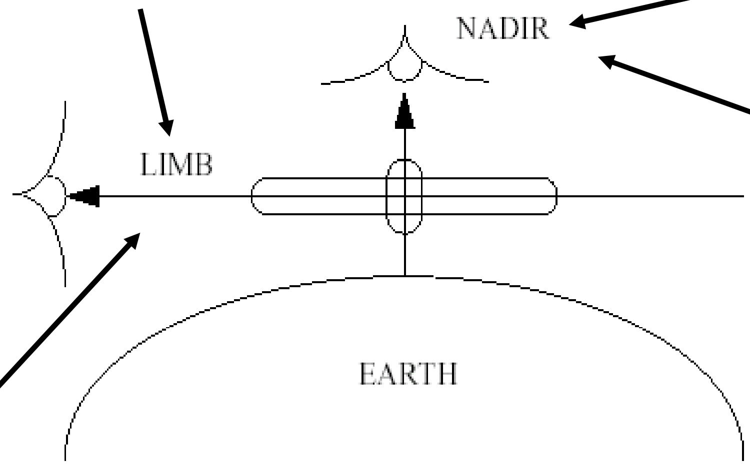


Relatively poor horizontal resolution

Relatively good vertical resolution

Relatively good horizontal resolution

Relatively poor vertical resolution



Met agencies use these data mainly

Research groups use these data mainly

Courtesy NATO ASI 2003

EM spectrum & observations

Types of satellite observations: frequencies

List of research satellites (non-exhaustive):

1. Infrared (IR): ISAMS (UARS), MIPAS (Envisat), HIRDLS (Eos-Aura)
2. Visible (Vis): GOME (ERS-2), SCIAMACHY (Envisat)
3. Ultraviolet (UV): GOME (ERS-2), GOMOS & SCIAMACHY (Envisat)
4. Microwave: MLS (UARS), Eos MLS (Eos Aura)

Variety-> opportunity to evaluate observations (e.g. UARS, Envisat)

EM spectrum properties: e.g. microwaves less affected by clouds

Observation types used by the Met Office

- Conventional: surface, sondes (local coverage; high spatial & temporal resolution) – temperature, humidity, winds

- Aircraft: local coverage; high spatial & temporal resolution – temperature, humidity, winds

- Satellites:
- Operational satellites: ATOVS, Satwinds, SSMI (nadir; global coverage; low spatial & temporal resolution) – temperature, humidity, winds

- Research satellites: (nadir & limb) Interest at NWP centres: e.g. SCIAMACHY ozone at ECMWF

  Now part of Global Observing System

See lectures by W. Bell

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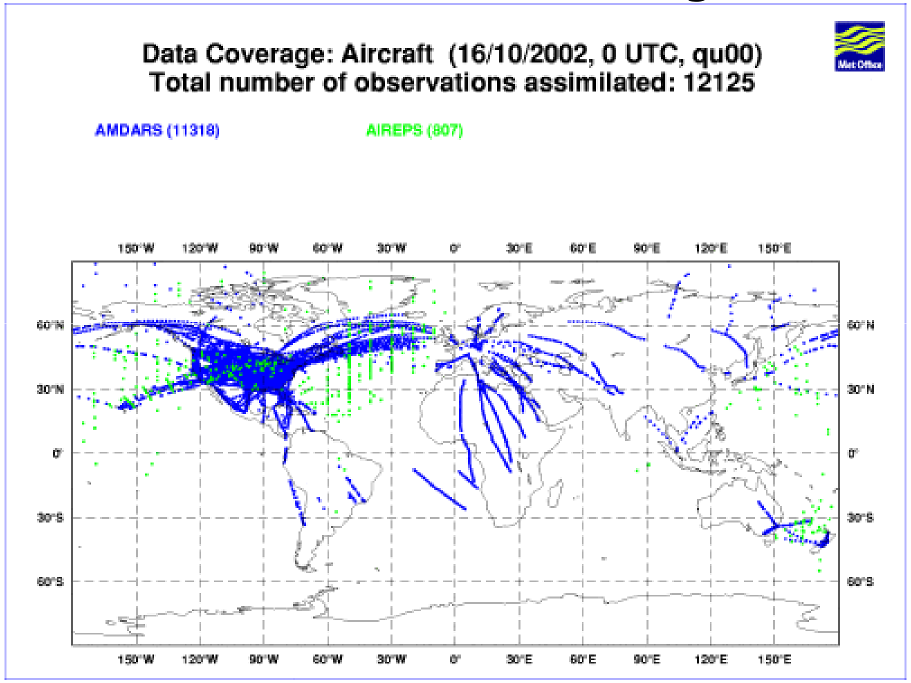
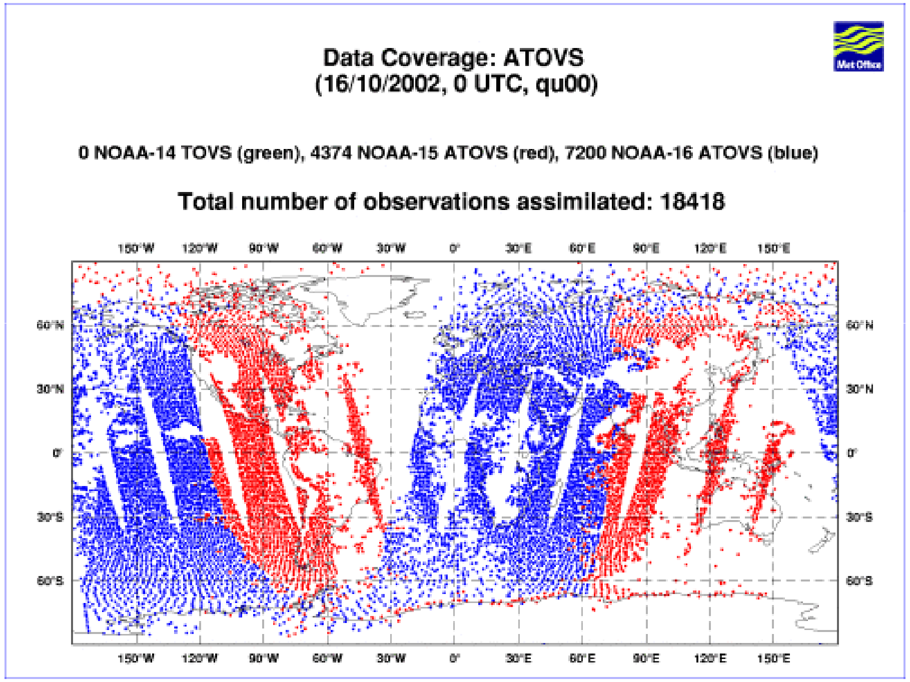
Aircraft Local coverage

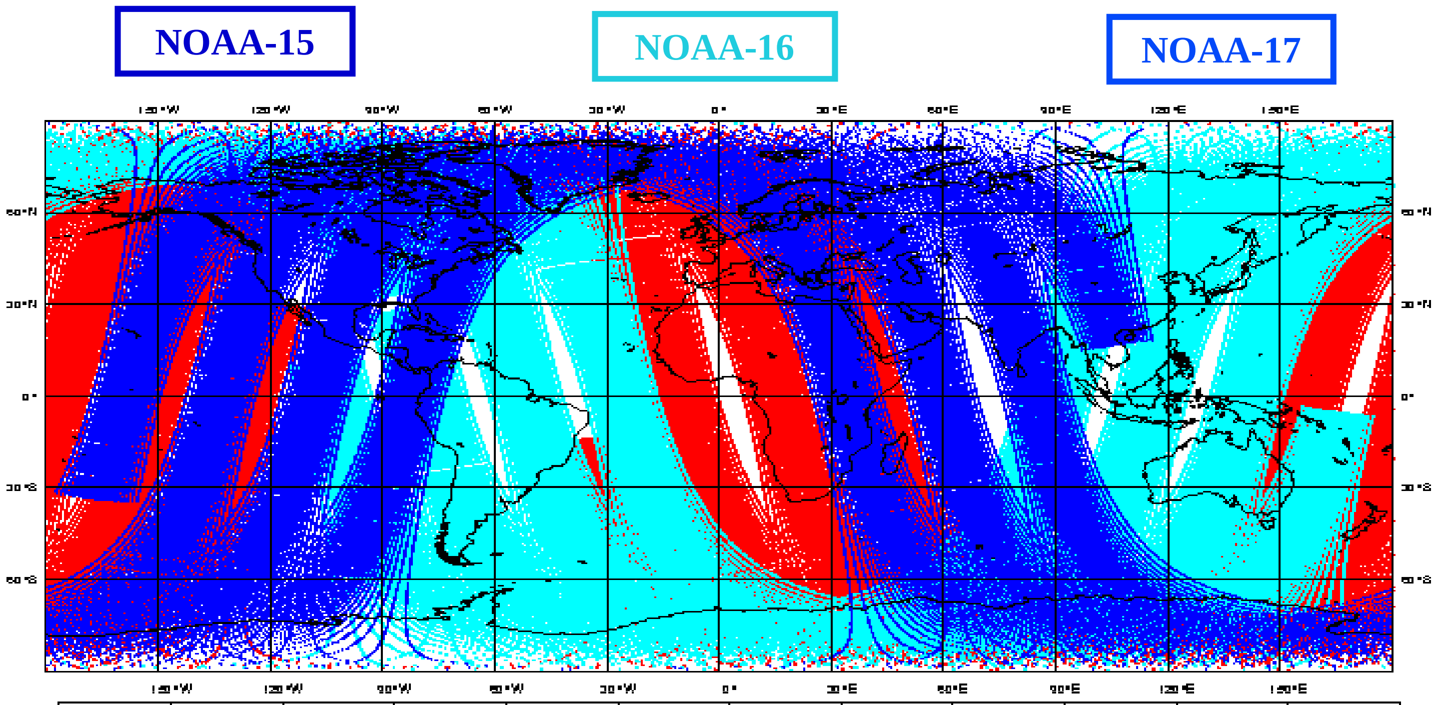


ATOVS Global coverage

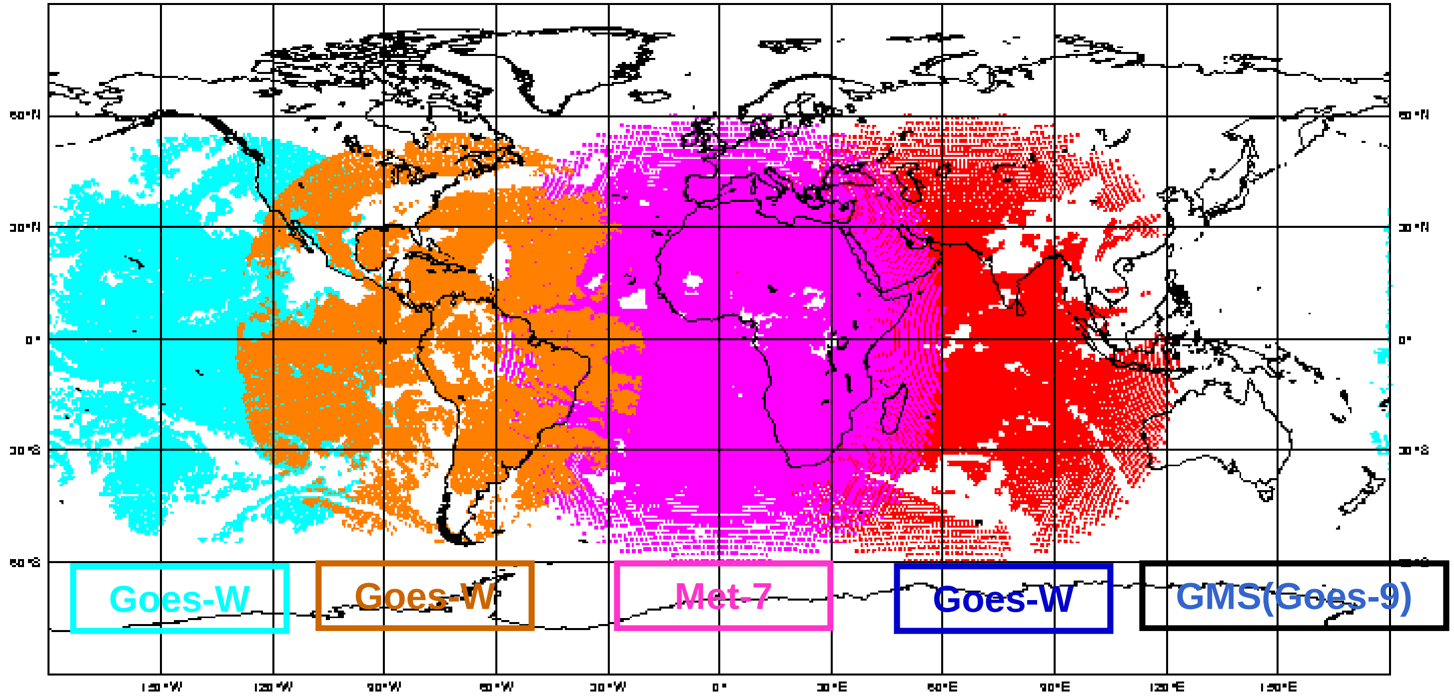


Observations used by Met Office

Courtesy ECMWF



Polar orbiters



Geostationary satellites

Sounding the atmosphere using satellites

Three ways:

Passive technologies: sense LW radiation emitted by atmosphere, SW reflected by atmosphere.

- imaging (optically thin -> information on Earth surface)
- sounding (optically thick -> information on atmosphere)

Active technologies: emit radiation & measure how much scattered/reflected back

GPS: measure phase delay of signal as it is refracted in atmosphere

Satellite orbits

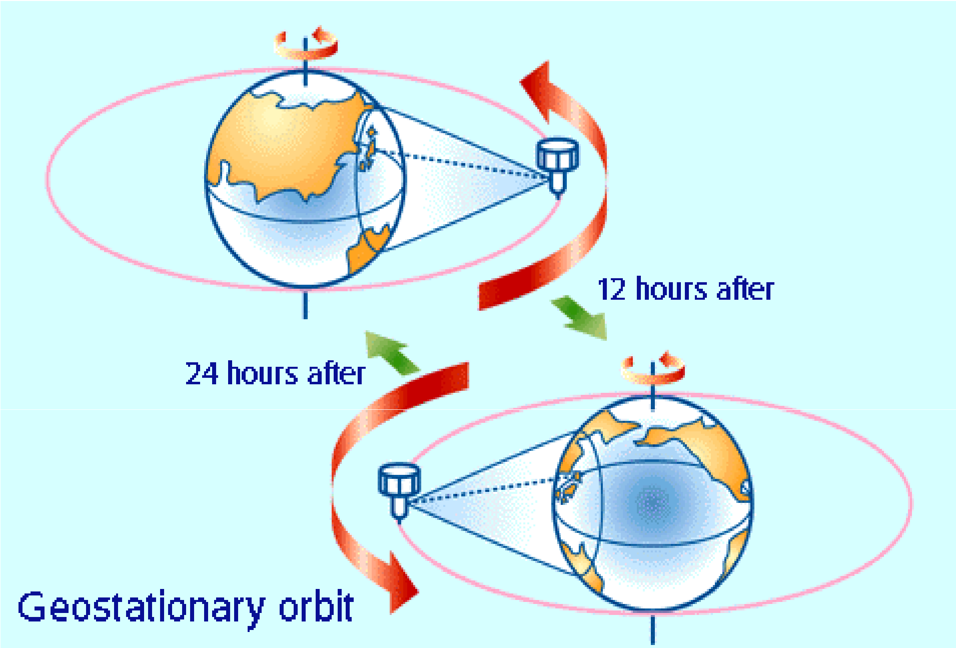
Types of satellite observations: orbits

1. Geostationary (fixed point over the equator): 60N-60S
   Only one orbit: 35,800 km; $\frac{1}{4}$ Earth's surface

2. Polar: quasi-global (e.g. 600 km Hubble, 225-250 km Shuttle)

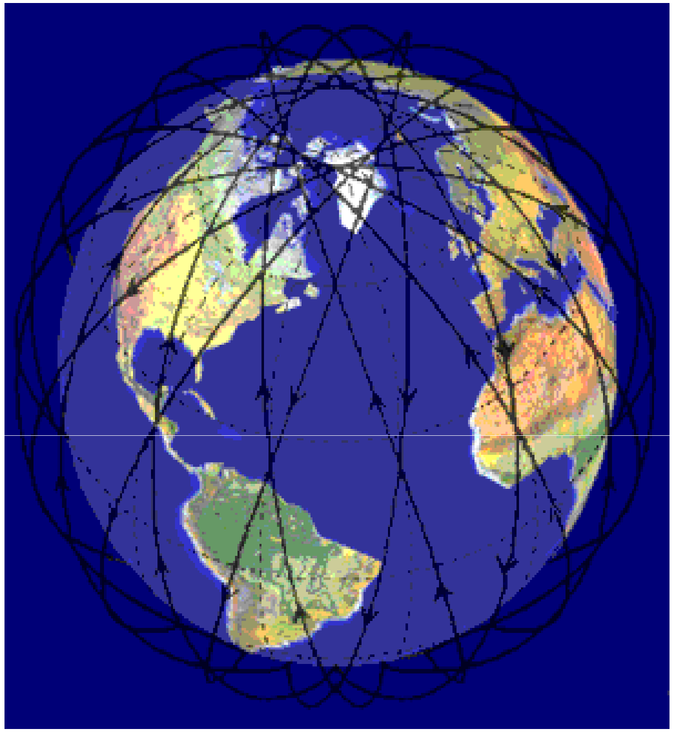
3. Sun-synchronous (fixed equator crossing time)

4. Non sunsynchronous (variable equator crossing time)



Geostationary satellite orbit

courtesy NASDA



Quasi-polar satellite orbits
courtesy www.planetearthsci.com

Diurnal cycle & orbit

1. Sun-synchronous satellites (e.g. ESA Envisat, NASA Eos Aura):
   - Instruments look away from the sun (no manoeuvre to prevent the sun damaging the instruments)
   - Cannot observe the diurnal cycle at a particular place (e.g. diurnal cycle of NO, NO_2)

2. Non sunsynchronous satellites (e.g. NASA UARS):
   - Can observe the diurnal cycle at a particular place
   - Have to do manoeuvres to prevent the sun damaging the instruments -> North look/South look for UARS MLS

Observation errors

Random: Assumed Gaussian; it is reduced by taking averages

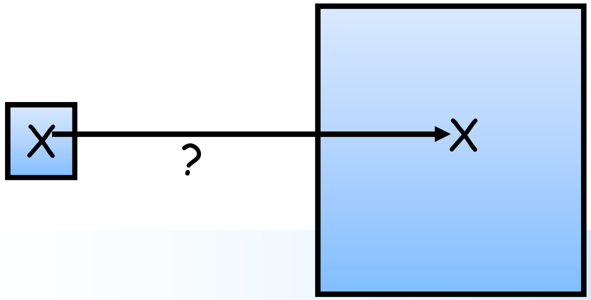
Is it Gaussian? How do we check? What could be non-Gaussian? -> bi-modal distributions, e.g., precipitation

Systematic (bias): Can vary temporally & spatially.

If fixed and known, it should be removed

Representativeness: Occurs when information is represented at a scale different from the source of the information (e.g. representation of sonde data in a GCM grid).

More important for small-scale observations.



Influence of chemistry/dynamics on observations

Depends on position & time of observations

Interesting case: ozone -> dynamics dominates in lower stratosphere

(except for ozone hole conditions), chemistry dominates in the upper stratosphere

Between these limits, both are important

-> can make it difficult to study the temporal/spatial distribution of ozone

-> need to take account of both dynamics and chemistry

How? -> design of parametrizations, coupled models

Water vapour observations from research satellites

For observations from operational satellites, see W. Bell lectures

Examples from NASA, ESA, CSA & JAXA

NASA:

UARS (mainly HALOE & MLS): Science: *JAS* 1994, Cal-val: *JGR* 1996

EOS Aura: (mainly Eos MLS): EOS Aura special issue in *IEEE*, 2006, Vol. **44**, special issue on EOS Aura validation in *JGR*, 2008, Vol. **113**

EOS Aura part of the EOS "A-Train" (http://www.spacetoday.org/Satellites/TerraAqua/ATrain.html)

ESA:

Envisat (mainly MIPAS and SCIAMACHY):

Use of data assimilation to evaluate Envisat: See obs 9 lecture

CSA:

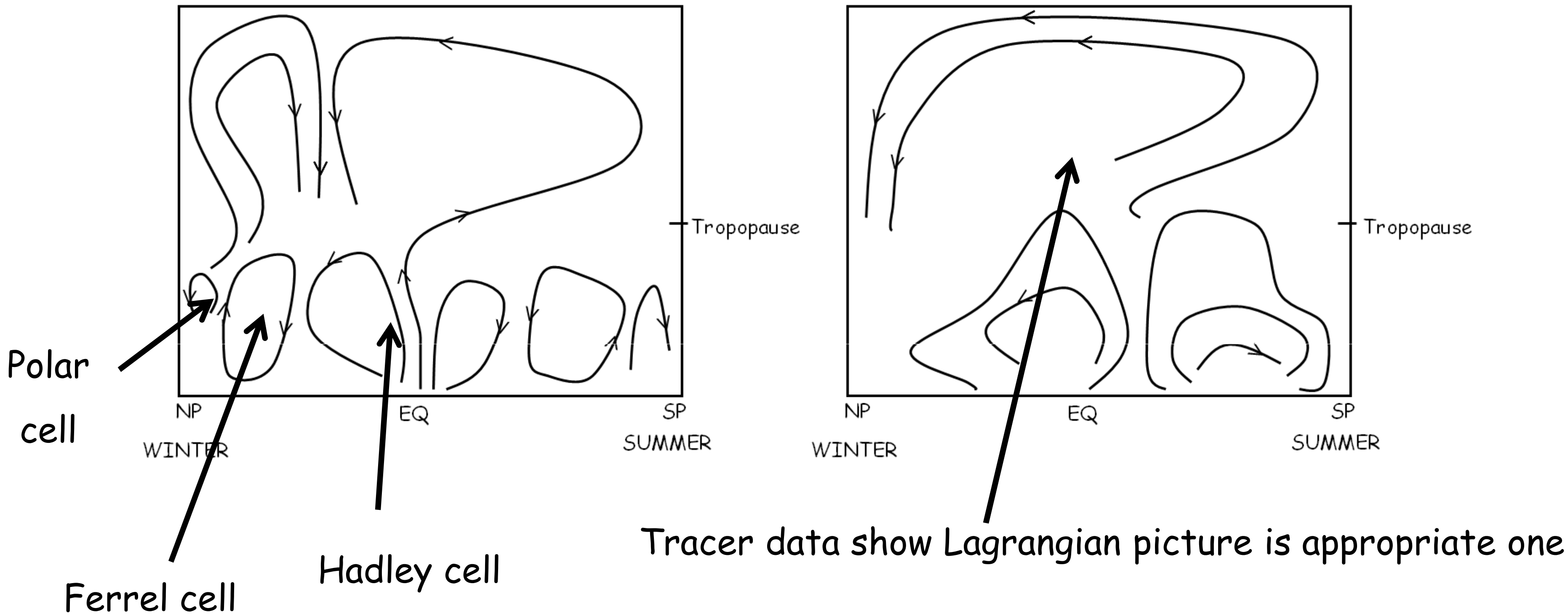
SCISAT-1/ACE: incl. ozone, water vapour, methane, N_2O and NO_2

NASDA-JAXA:

ADEOS: ADEOS-TOMS (ozone column), ILAS (temperature, ozone, water vapour & other constituents)

ADEOS-II: water column, precipitation & ocean and ice parameters (AMSR), temperature, ozone & other constituents (ILAS-II)

Picture of the flow



Left: Eulerian picture of the atmospheric circulation. Right: Lagrangian picture of the atmospheric circulation. NP and SP stand for North Pole and South Pole, respectively. Northern Winter conditions are assumed.

Water vapour
tape recorder
Mote et al., JGR, 1996

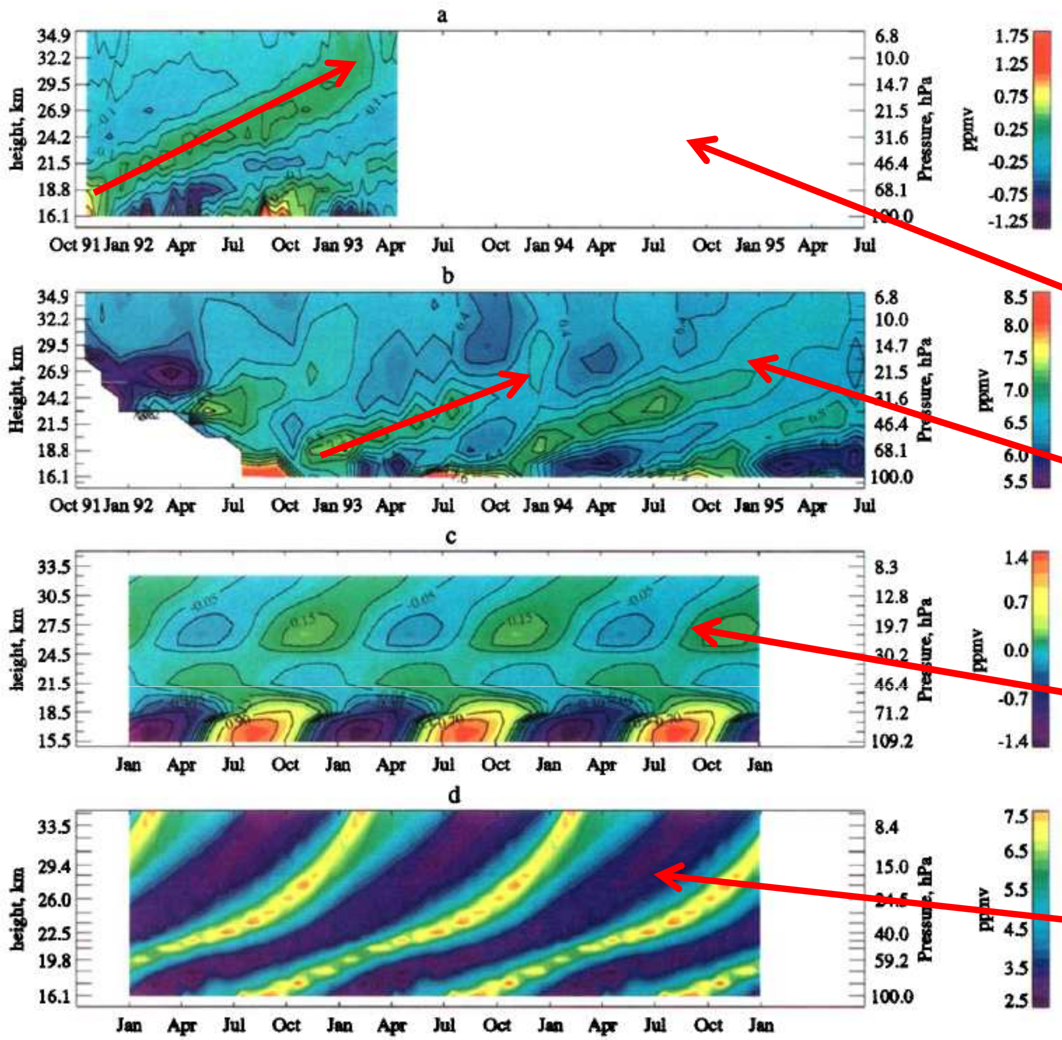


Plate 1. Time-height sections of (a) MLS water vapor mixing ratio q shown as the deviation from the time-mean profile, between 12°S and 12°N; (b) HALOE $\hat{H} = 2(CH_4)+(H_2O)$, the variable part of total hydrogen, between 12°S and 12°N; (c) SAGE II water vapor mixing ratio q, annual and semiannual Fourier harmonics for January 1986 to May 1991, between 15°S and 15°N (retrieval affected by aerosol layer, 20–25 km); and (d) TEM 2-D back-trajectory calculation of q (see text). For each panel, tick marks on the ordinate indicate the vertical grid points used, and the color scheme is as indicated in the color bar to the right. This figure is available on the Internet at web site http://www.damtp.cam.ac.uk/atmos-dynamics, or by anonymous ftp from ftp.damtp.cam.ac.uk, cd pub/papers/mem, get tape1.ps.

Interhemispheric comparisons

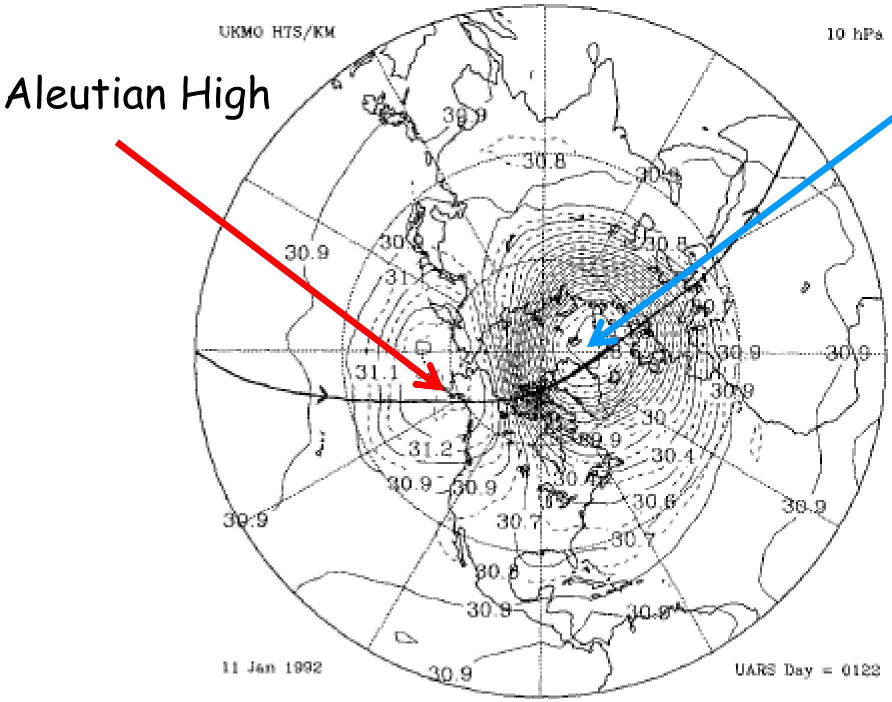
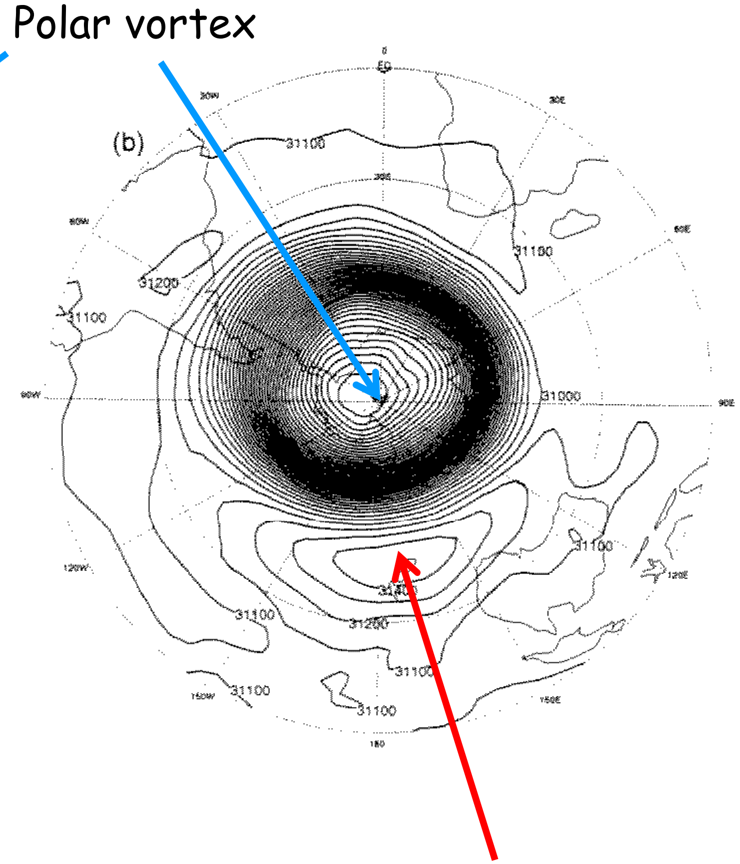


FIG. 6. As Fig. 2 but for the geopotential height field (km) at 10 hPa from UKMO analyses for 11 January 1992 (*UARS* day 122). Superimposed on the field is the viewing track of the MLS instrument, which refers to Figs. 7–11. The arrow shows the direction of motion along the track.



Met Office analyses of geopotential height. Left: NH winter, 10 hPa, 11 January 1992 (*Lahoz et al. 1994, JAS*). Right: SH winter, 10 hPa, 9 September 1992 (*Lahoz et al. 1996, QJRMS*).

We would like to use cross-sections that cut across polar vortex & anticyclone

MIPAS, *Lahoz et al. 2006, QJRMS*

Quasi-stationary anticyclone SH winter;

31 August 2003

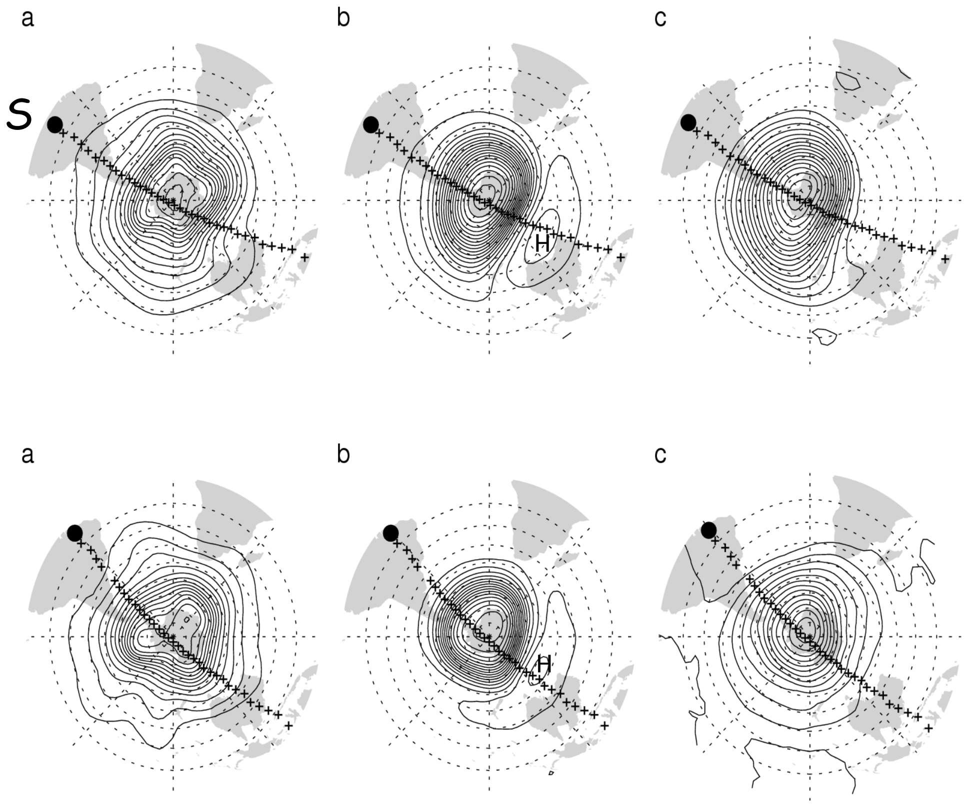
- see later: MIPAS cross-sections

Quasi-stationary anticyclone SH winter;

24 September 2003

Met Office geopotential height

100 hPa 10 hPa 1 hPa



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Vertical structure of cross-sections:

SH winter 2003 (*Lahoz et al. 2006, QJRMS*)

Events depicted with Met Office geopotential height: 31/08/03

Low amounts of O_3 in polar vortex: Transport & chemistry

Ozone

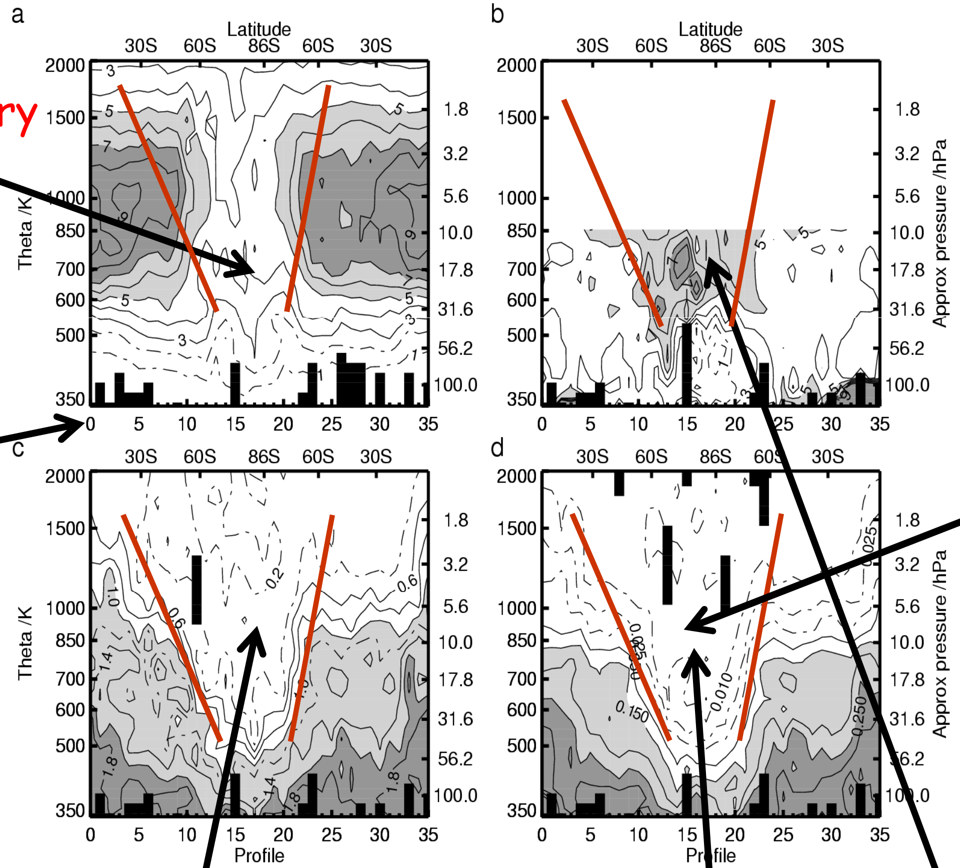
H_2O

Start of orbit, S

Descent in polar vortex

CH_4

N_2O



Note: low amounts of CH_4, N_2O; high amounts of H_2O in vortex:

Sources/sinks in stratosphere & tracers

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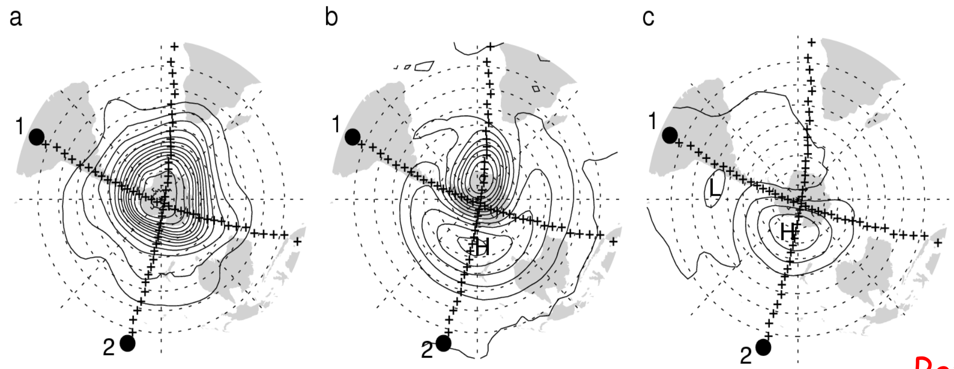
3-D filamentation event: Met Office geopotential height 17/10/03

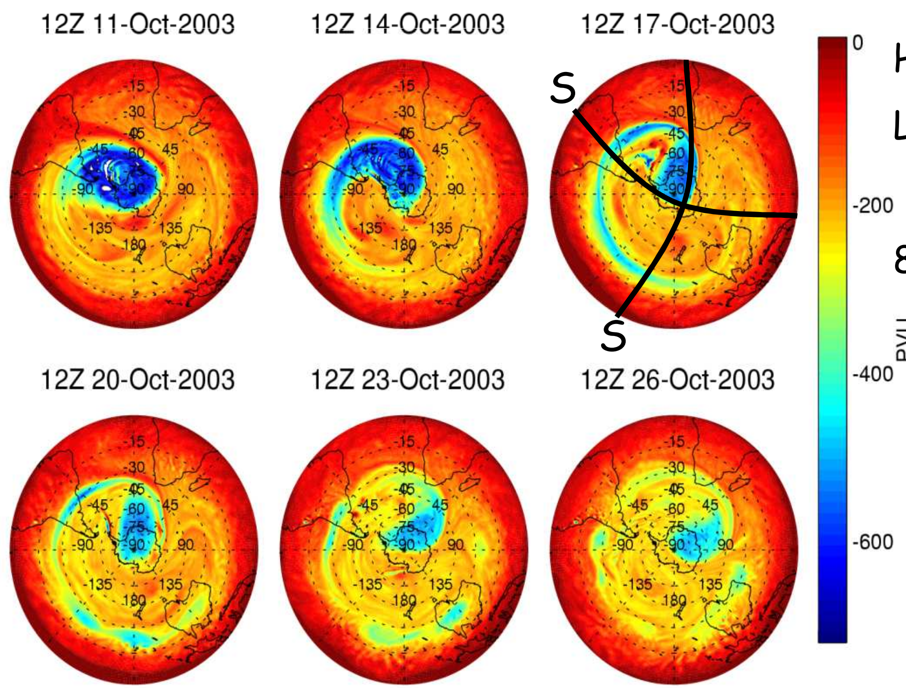
100 hPa 10 hPa 1 hPa



Potential vorticity, PV: tracer

ECMWF PV maps 850 K

11/10/03 – 26/10/03



High magnitude: high lat air

Low magnitude: low lat air

850 K approx 10 hPa

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Cross-section "1"

17/10/03

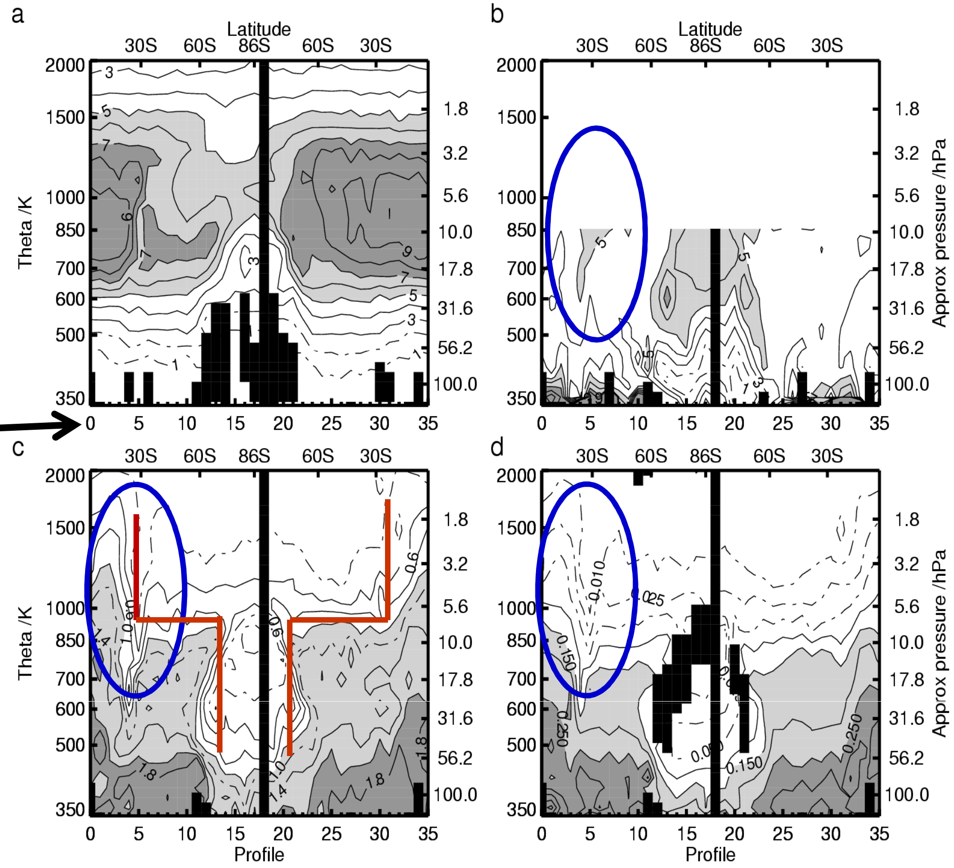
Ozone

H_2O

CH_4

N_2O

S



Cross-section "2"

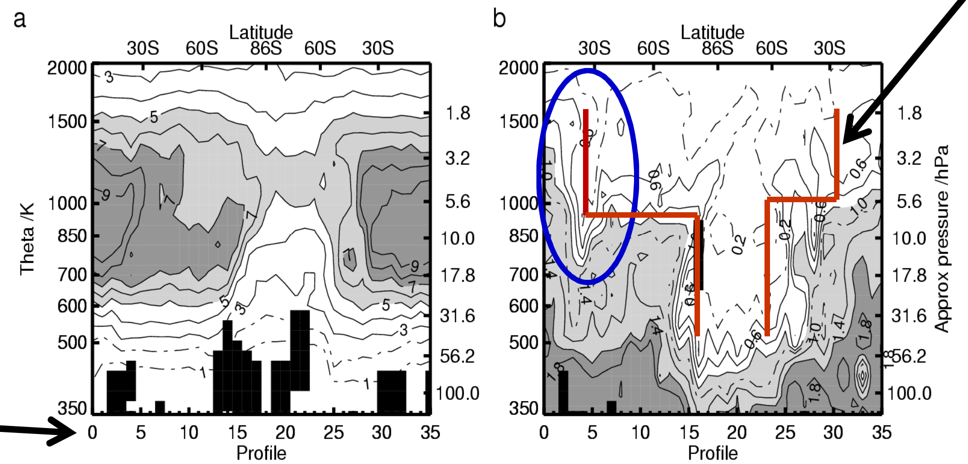
17/10/03

Ozone

CH_4

Note "champagne glass"

S



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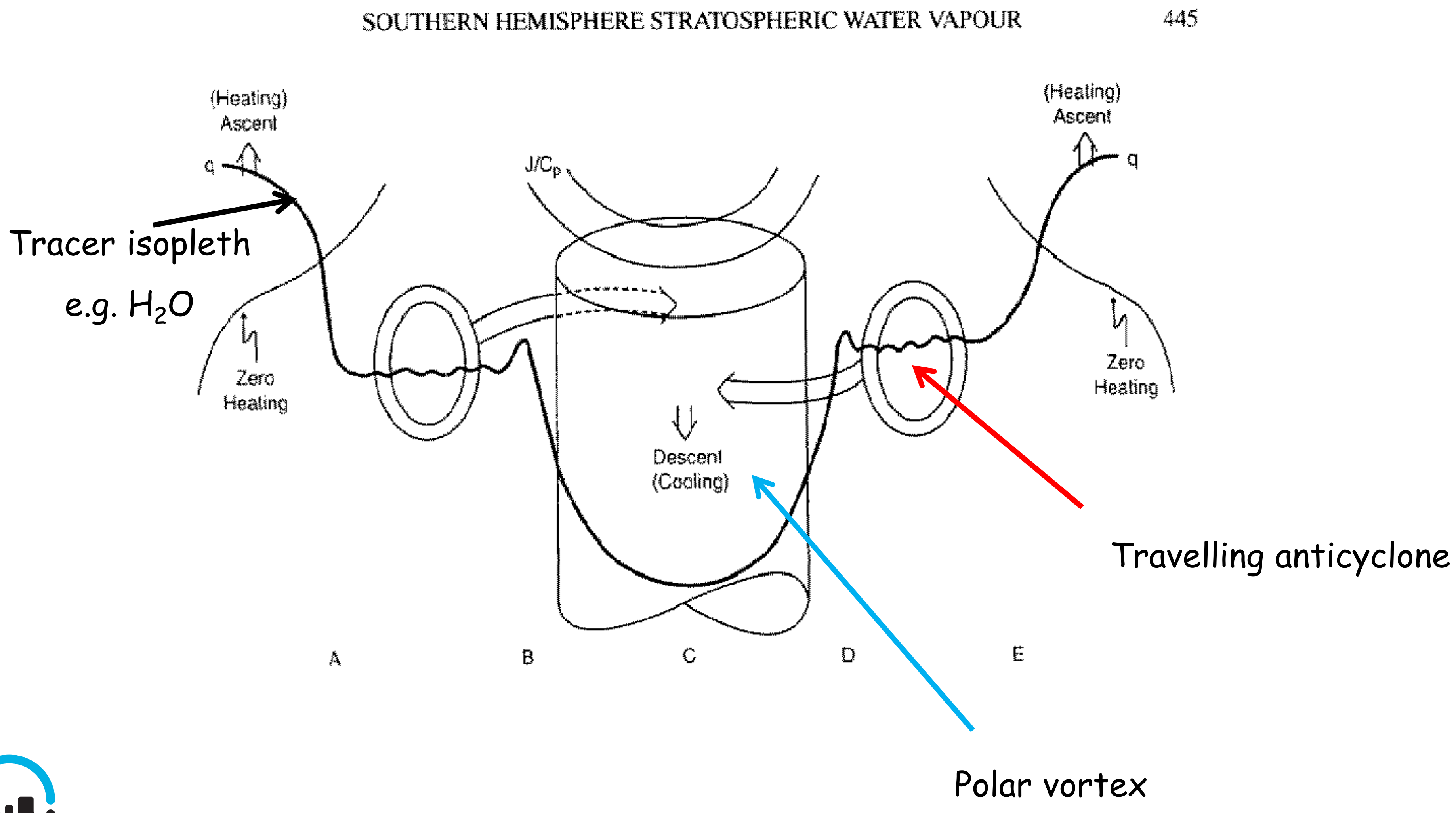
Schematic for SH stratospheric mid winter:



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Atmosphere:

Understanding spatial/temporal variability of the atmosphere requires considering:

•Meteorology, transport, chemistry & their interaction

Advantageous to use satellite observational geometry (along orbit track)

By considering satellite observational geometry & synergies between measurements:

•Meteorology (geopotential height,...)

•Tracer species (CH_4, N_2O, H_2O,...)

•Chemical species (O_3,...)

•Derived products (PV,...)

We can build up a consistent picture (spatial/temporal variability) of the atmosphere

& improve understanding (this helps in looking at, e.g., temporal evolution)

Benefits from research satellites

- Test Earth Observation concepts
- Today's research satellite is tomorrow's operational (NWP) satellite (mainly ozone, but could help with water vapour)
- Information to help make chemical forecasts

Interest in research satellites by the met agencies make them more attractive to the EO community

Exploitation of satellite data

- Satellite data have been v. successfully exploited by new data assimilation, DA, schemes (4d-var, ECMWF). DA schemes -> introducing additional satellite data that is well characterized improves system
- Combined availability of new & accurate satellite observations & improvements in models -> improved extraction of information content from these new observations using DA techniques
- Proliferation of new satellite instruments -> data management/data use
- Massive investment in data handling (metadata, data management, efficient data dissemination) & monitoring (data evaluation) needed
- Important that a dialogue is maintained between the data suppliers (space agencies & NWP agencies) & end-users

See lectures on data assimilation (W. Bell, W.A. Lahoz)

The future

- Operational use of research satellite data by significant numbers of operational centres: ozone (already assimilated operationally at ECMWF), stratospheric water vapour, CO_2 and aerosols

- Assimilation of limb radiances by research & operational groups. Work on developing fast & accurate forward models & interface between forward model and assimilation. Progress more advanced for IR radiances than for UV/Vis radiances (scattering effects for latter two)

- Chemical forecasting & air quality studies, including tropospheric pollution forecasting & estimation of sources and sinks of pollutants & greenhouse gases

- Earth System approach to environmental & associated socio-economic issues. Incorporate biosphere & carbon cycle & coupling of all components of Earth System. GEMS project (Hollingsworth *et al.* 2008) & MACC

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Schoeberl, M.R., et al., 2006. The carbon monoxide tape recorder. Geophys. Res. Lett., 33, L12811, doi:10.1029/2006GL026178.

Web-sites:

http://www.ecmwf.int/newsevents/training/lecture_notes/LN_DA.html

(Lecture notes on ECMWF course, including satellite data)

http://darc.nerc.ac.uk/asset

(ASSimilation of Envisat daTa, web-site. ASSET a EU FP5 project)

http://www.esa.int/esaEO/index.html

(ESA web-site with Envisat and other images)

http://www.nasa.gov

(NASA web-site with many satellite images)

http://www.temis.nl

(KNMI Website for ozone data, analyses & forecasts)

Extra slides

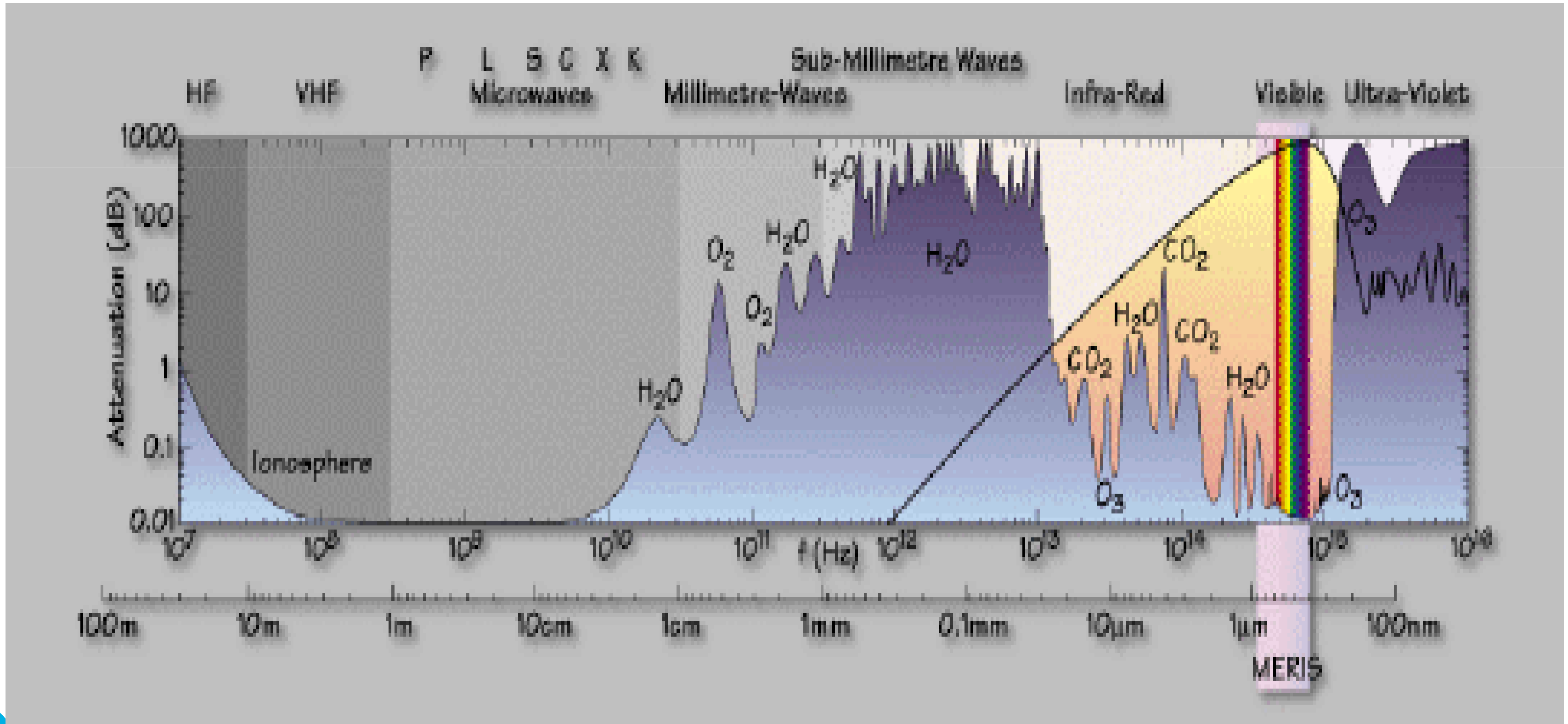
Sampling EM spectrum using satellites

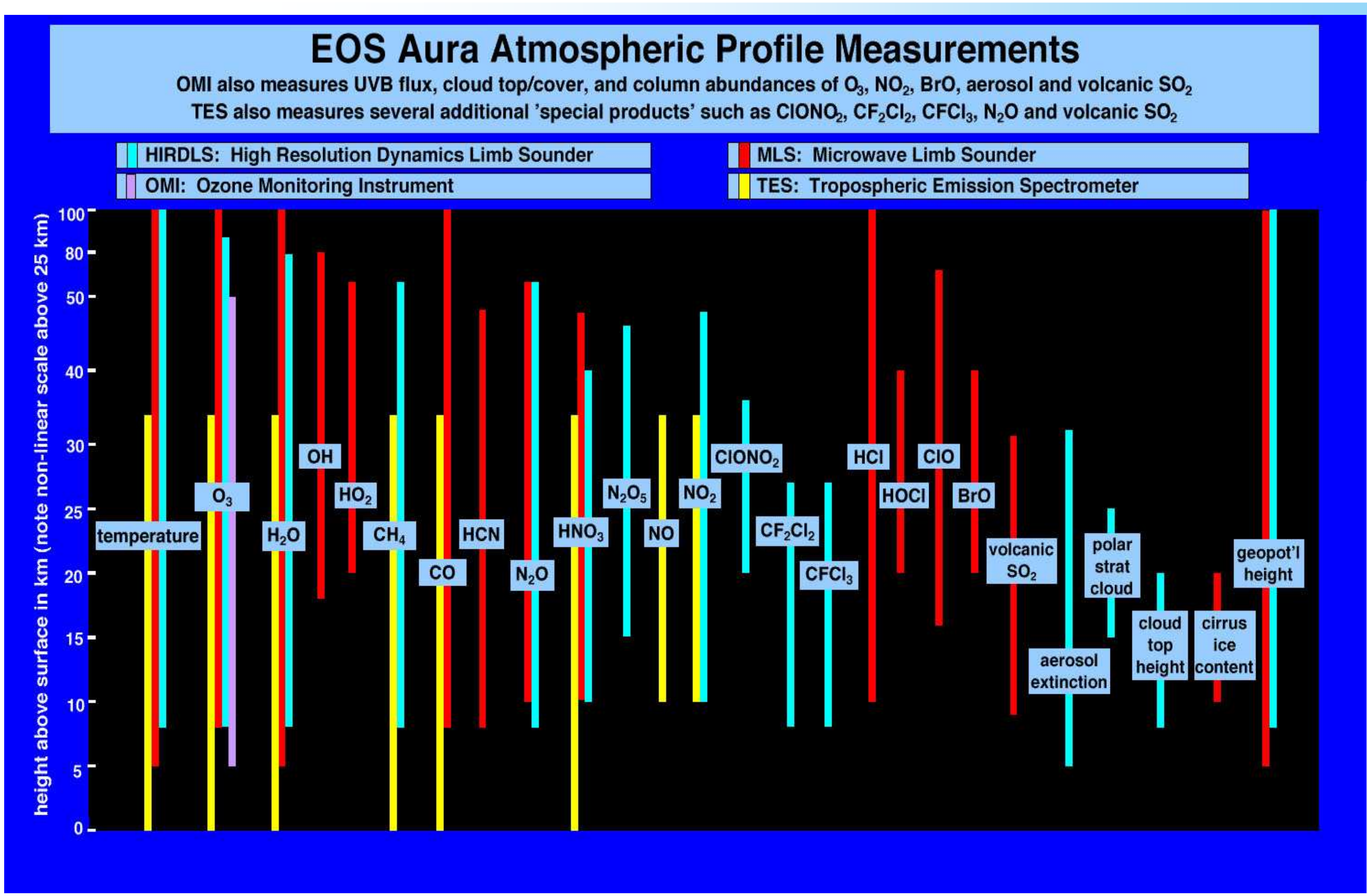
- Depending on wavelength, radiation at top of
- Atmosphere is sensitive to different atmospheric constituents (Courtesy ECMWF)

Scat, Altimeter
AMSU, SSM/I

HIRS GOES
METEOSAT
AIRS

SBUV





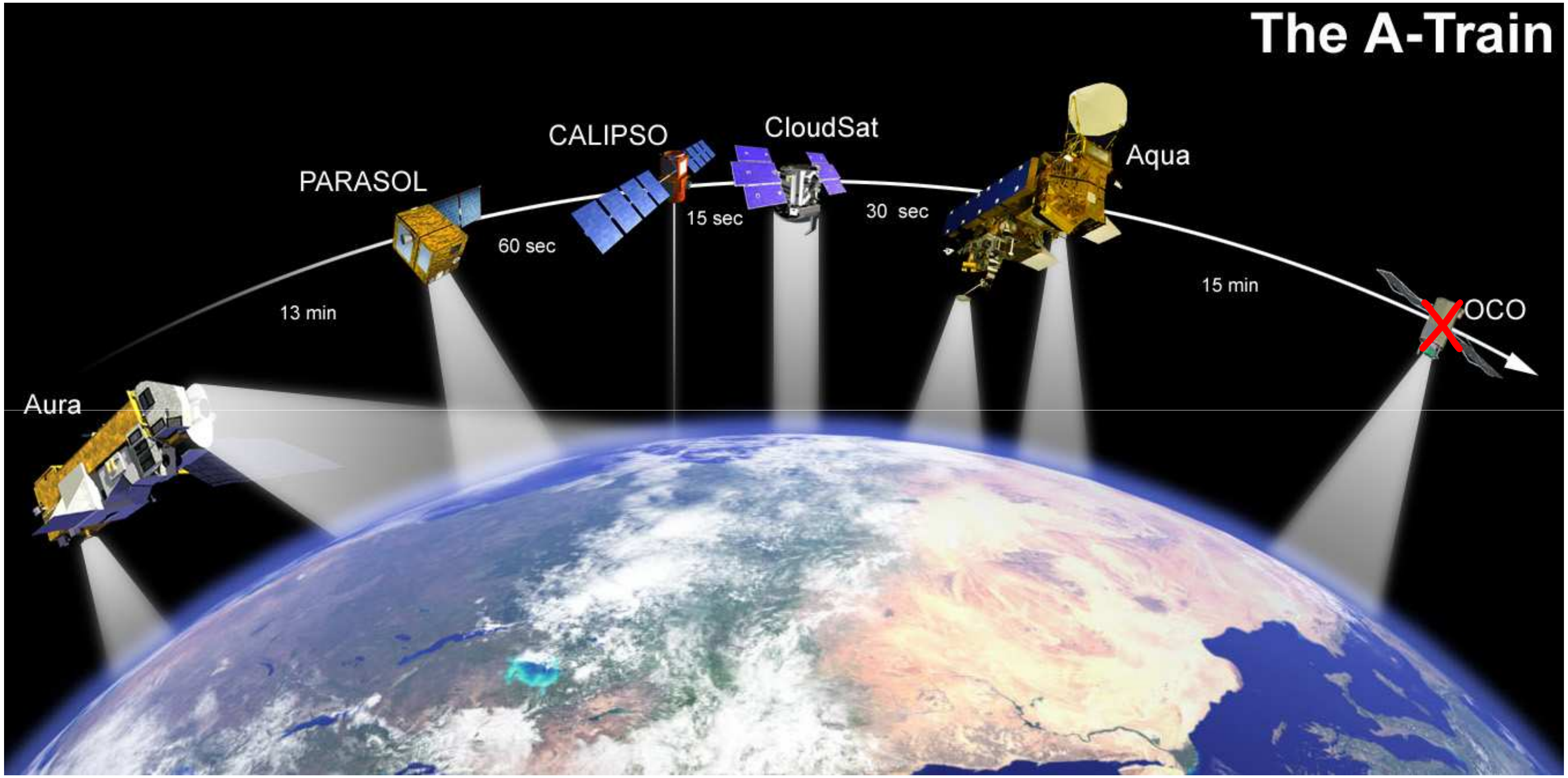
Is the Earth's ozone layer recovering?

Is air quality getting worse?

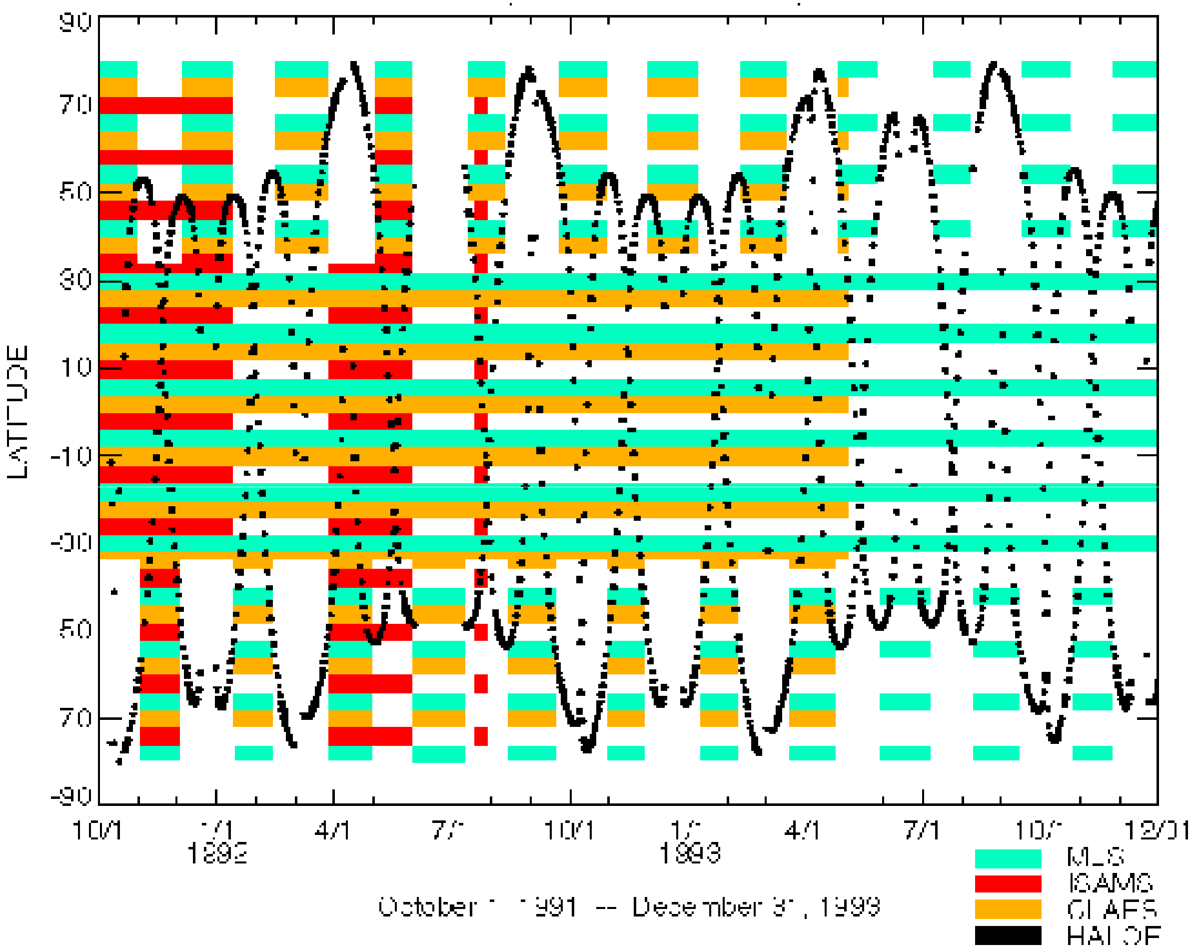
How is Earth's climate changing?

⟵ Questions that Eos Aura & Envisat could help answer

Envisat: http://envisat.esa.int


The A-Train
Aura
13 min
PARASOL
60 sec
CALIPSO
15 sec
CloudSat
30 sec
Aqua
15 min
OCO

UARS orbits: Oct 1991 – Dec 1993. From UARS web-site



CO tape recorder, *Schoeberl et al. 2006, GRL*

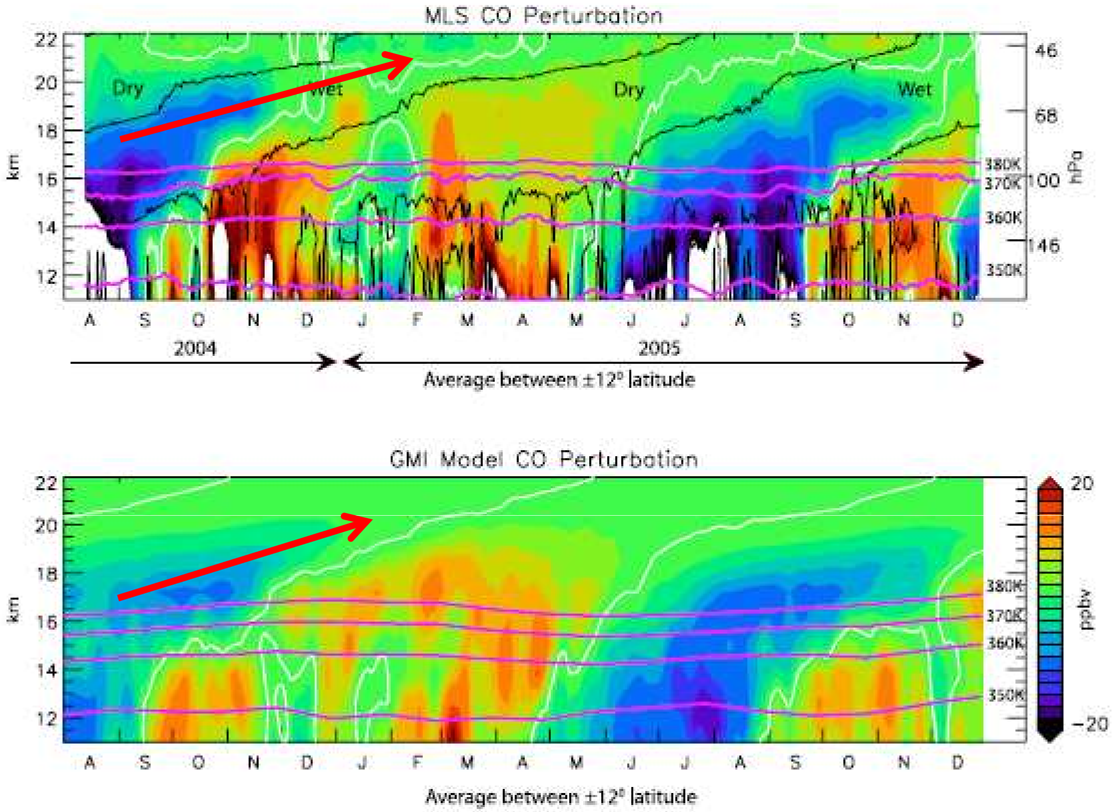


Figure 1. (a) Zonal mean MLS CO data with the annual average removed verses time (months). Altitude scale is 7 km log(1000/p) where p is pressure. Black lines show the zero contour for MLS water vapor tape recorder with 'wet' and 'dry' labels indicating the sign of the perturbation. White contours are zero lines for CO data. Right hand scale shows pressure levels for MLS level 2 data. Pink lines show the zonal mean potential temperature surfaces (350–380 K). (b) GMI chemical transport model CO simulation using climatological sources. The GMI chemical model is driven by the GEOS-4 GCM meteorology with 1994–5 observed sea surface temperature forcing and has fixed water vapor amounts.

Intercomparison MIPAS retrieval/ozonesondes

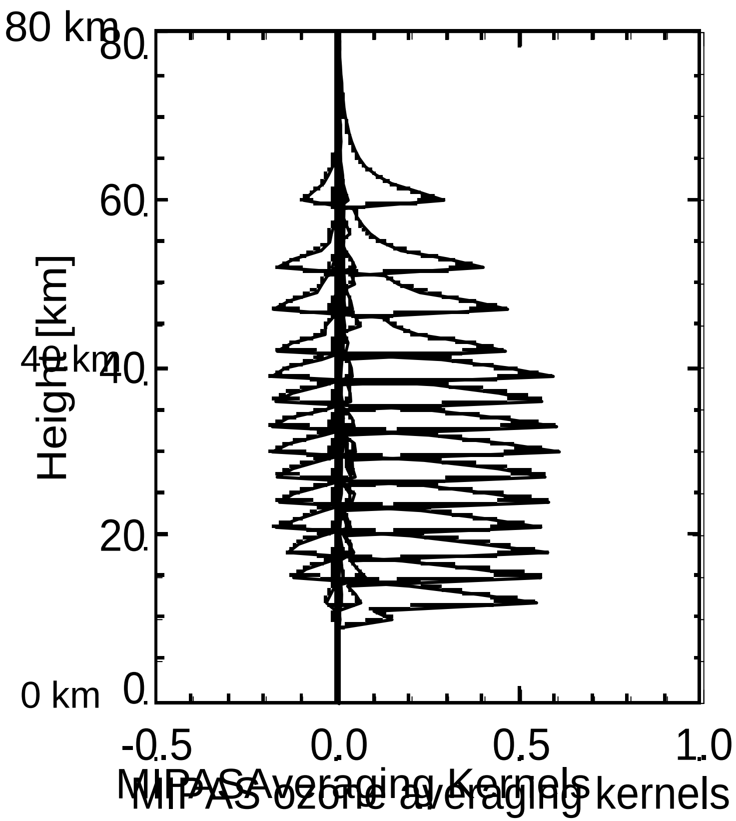
1. Sondes have good vertical resolution, but limited height range

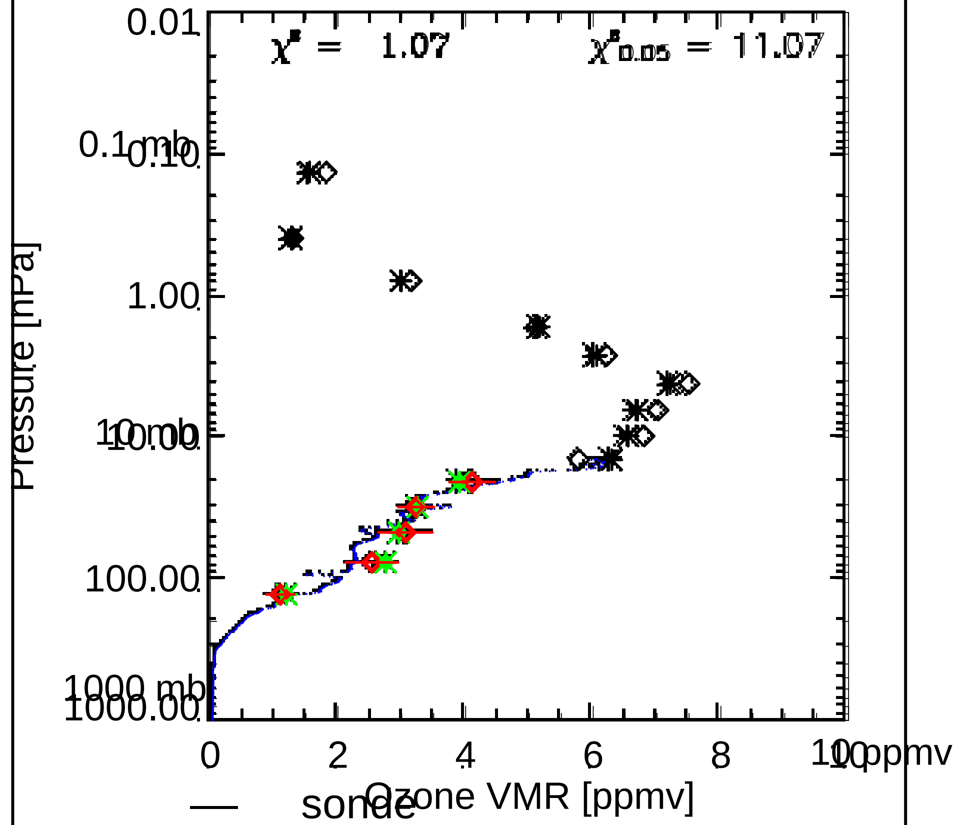
2. Retrievals have a poorer resolution, greater height range and better coverage.

   -> We cannot compare them directly

To compare a simulated retrieval based on the sonde profile with MIPAS retrieval: convolve sonde profile with MIPAS averaging kernel

Ozone Intercomparison





— sonde

* retrieval

◊ simulation

Courtesy Clive Rodgers

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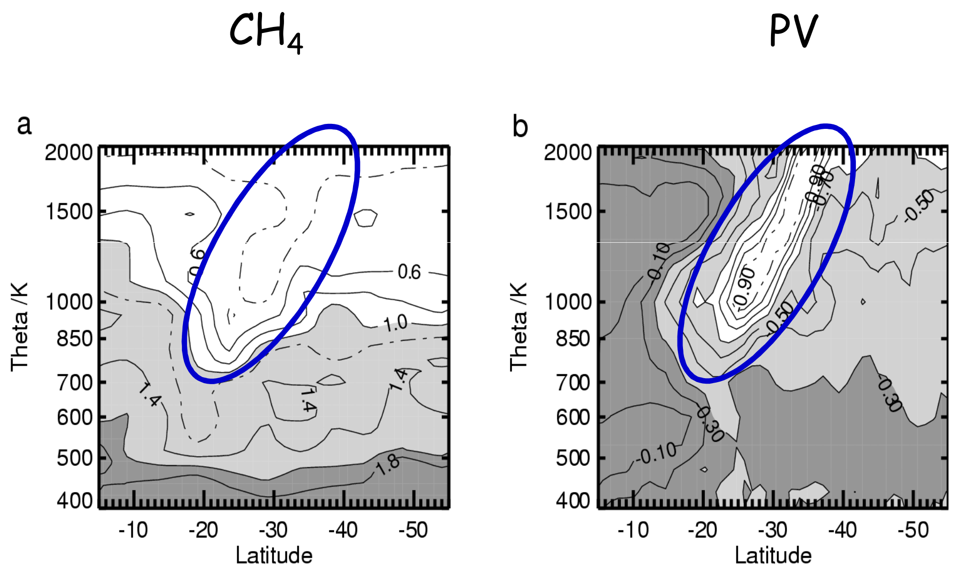
Norwegian Institute for Air Research

3-d filamentation: spatial structure

CH_4 cross-section "1" & PV (potential vorticity)



Schematic for NH stratospheric winter (note artwork!):

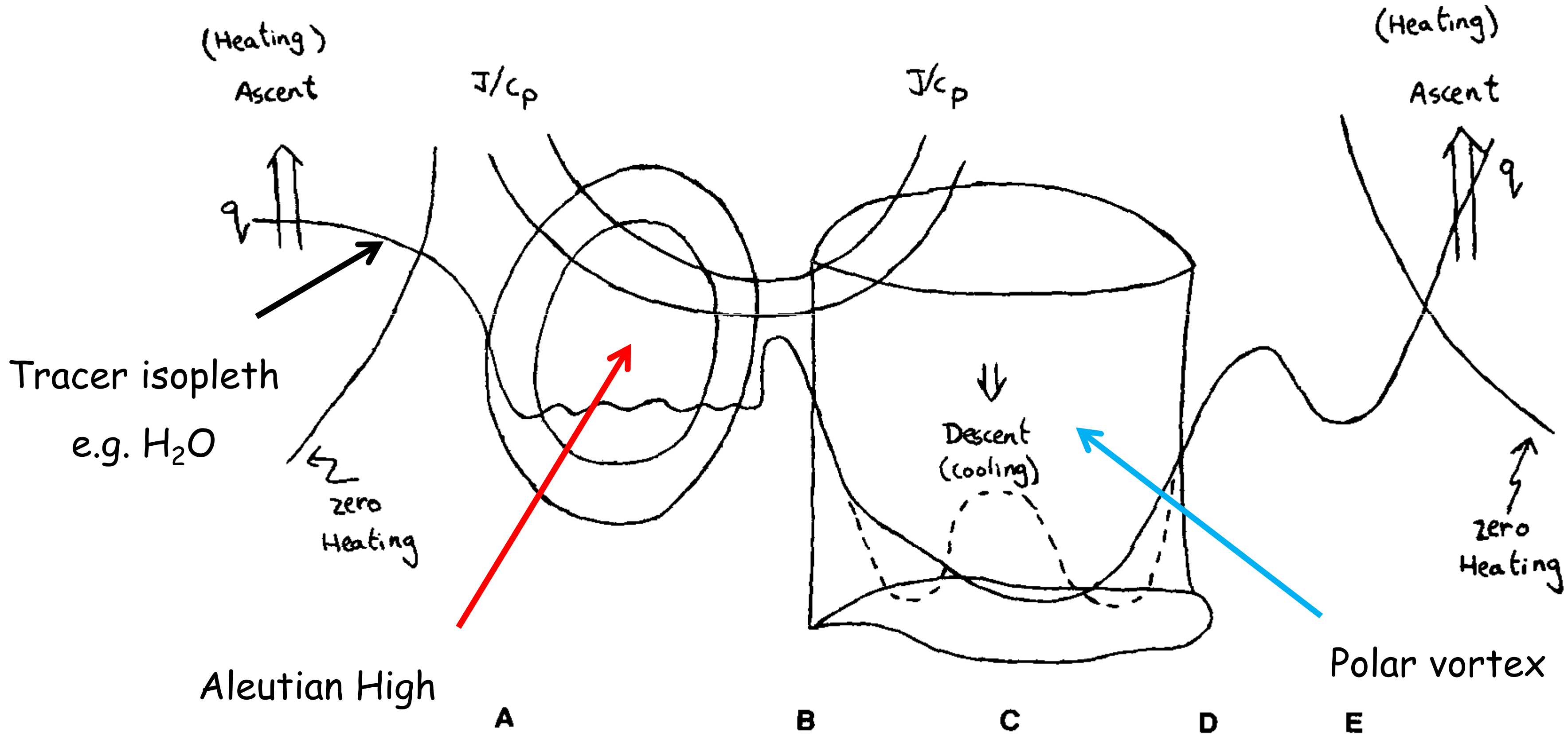


FIG. 20. Typical representation of the northern winter stratosphere vertical cross section. The Aleutian high is marked *AB*; the polar vortex is marked *BCD*, with *C* being the center of the vortex. The region marked *DE* indicates a "ridge" of relatively dry air. The diabatic heating field (marked J/c_p) and a typical isopleth of water vapor (marked q) are superimposed.

Schematic for SH stratospheric late winter/spring: