OSSEs for the Stratosphere

Richard Swinbank
with Mike Keil, David Jackson (Met Office)
William Lahoz and Roger Brugge (DARC, Univ.Reading)
Cecilia Girz (NOAA FSL) and many Met Office colleagues

OSSEs for the Stratosphere…

…or "Doing OSSEs on the cheap"

TALK OUTLINE

- Met Office Stratospheric Data Assimilation System (as used for the OSSE studies)
- ESA-funded study with DARC, to assess proposed SWIFT instrument
- Mike Keil's PhD study on stratospheric balloons – the POSSE
- After the OSSEs: current and future developments.

Introduction

Stratospheric Analysis – History

- "SSU Analysis" - 1978
  - Original stratospheric analysis, based on gridded retrievals of thickness; T and winds derived
- Analysis Correction Scheme - 1991
  - First Met Office stratospheric data assimilation system; asynoptic, repeated insertion
- Variational Assimilation – 2000
  - 3D-VAR assimilation; 6 hour cycle
  - Used for OSSE studies
- New Dynamics – 2003
  - Semi-Lagrangian Dynamics, on height grid
- 4D-VAR
  - Currently in global forecast model

3D-VAR for the stratosphere

- Direct assimilation of ATOVS & TOVS radiances
  - radiance bias correction
- Background error covariances using “NMC method”
  - use rotated vertical modes in stratosphere
- Prototype for future extended global forecast system, spanning stratosphere
  - 40-level model, based on the then-current global 30-L model
  - Horizontal resolution 2.5°x3.75°, but most testing done at higher resolution (0.83°x1.25°)
- Major benefit to forecast skill (not shown in this talk)

SWIFT study

(joint DARC/Met Office project;
Lahoz et al 2005, QJRMetS)

OSEs and OSSEs

- A technique often used to evaluate components of an existing observing system is the "Observing System Experiment" (OSE)
- An OSE studies the impact of one observation type by removing it from the system under study
- An Observing System Simulation Experiment (OSSE) applies the same idea to evaluate future observations. However, in that case the observations need to be simulated.
- This is more complicated, but still worthwhile for evaluating expensive future satellite missions

Structure of an OSSE

- Simulate atmosphere ("nature run"; N): using a model
- Simulate observations of instruments appropriate to the study, including errors: using N
- Assimilation system: using a model
- Control run C: all observations except those under study
- Experiment X: all observations, including those under study

OSSE goal: evaluate whether the difference X-N (measured objectively) is significantly smaller than the difference C-N

Proposed SWIFT instrument

- Based on Doppler effect of thermal emission (mid-IR) of ozone (1133 cm^{-1}). Similar technology to UARS WINDII.
- 2 wind components using 2 measurements at ~90°
- Global measurements of wind and ozone profiles (~20-40 km)
- SWIFT: http://swift.yorku.ca

Why SWIFT?

1. Current observing system:

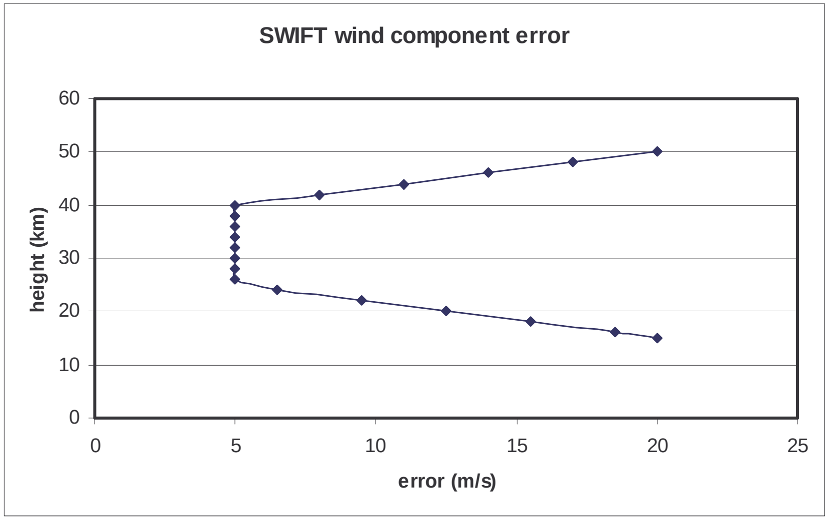
- No operational observations of winds for levels above those of radiosondes (~10 hPa)
- Note: indirect information on winds can be obtained from nadir soundings of temperature (thermal wind; but this breaks down in the tropics)

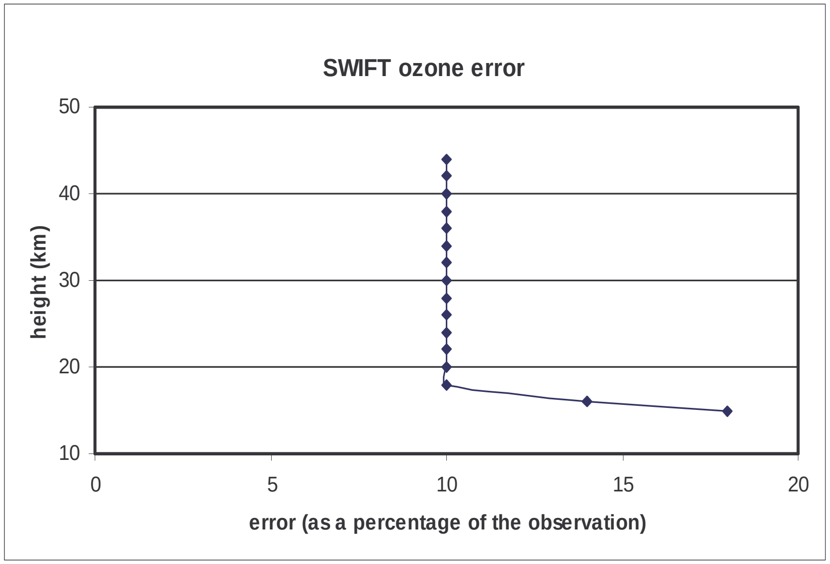
2. Science:

- Measurements of tropical winds
- Transport studies (e.g. ozone fluxes)
- Use assimilation to obtain 4-d quality-controlled datasets for scientific studies (e.g. climate change and its attribution)

SWIFT characteristics

- SWIFT: N - and S - observations (87°N-53°S, 53°N-87°S): non sun-synchronous orbit
  - winds 16-50km, every 2km approximately
  - ozone 16-44km, every 2km approximately
- Errors (conservative; random; representativeness error considered to be relatively unimportant):





Design of SWIFT OSSE

- Establish basis for assimilating SWIFT observations (u, v; ozone)
- Investigate scientific merits of SWIFT observations

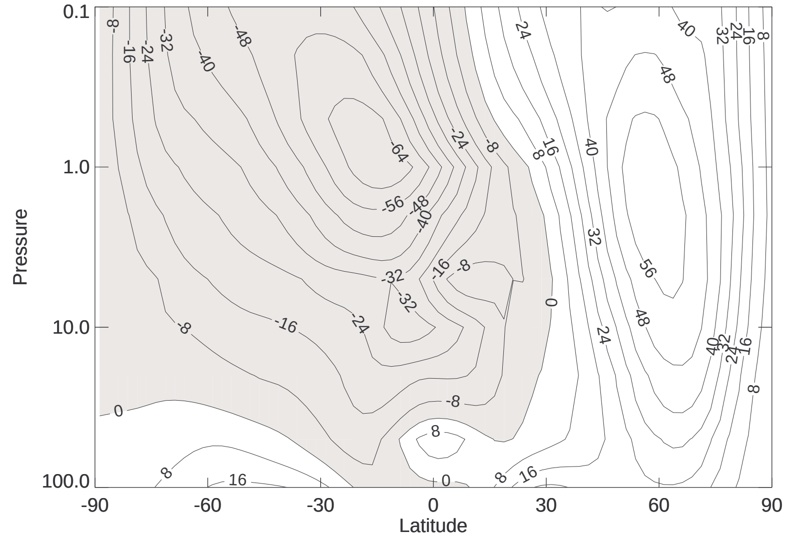
- Models used:
- "Nature" (ECMWF analyses; ozone from a CTM)
- Assimilation system (Met Office, stratospheric, low resolution)

- Simulated observations:
  - NoSwift: C {MetOp, MSG, sondes, balloons, aircraft, surface}
    - Temperature, winds, humidity, ozone
  - Swift; Operational+SWIFT = X
    - Ozone, winds (stratosphere, conservative errors)

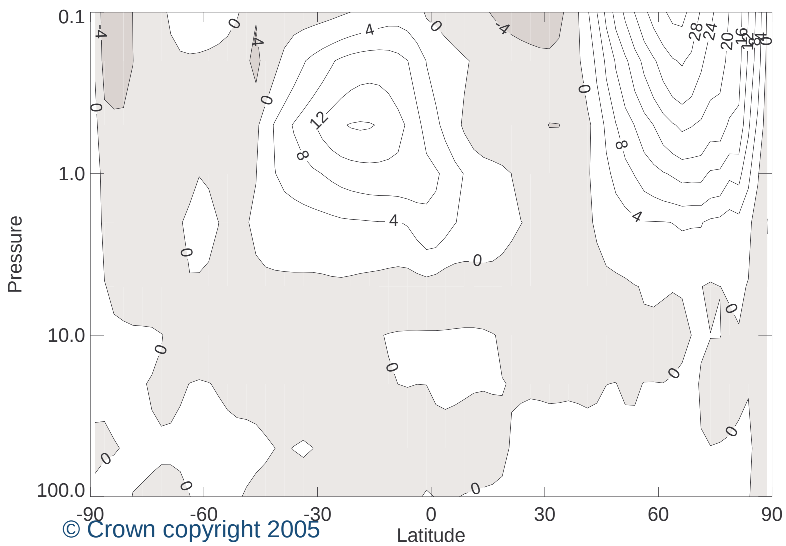
- NB. To reduce costs, we assimilate "retrieved" profiles of Temp. (etc.) not radiances. We call this approach a Reduced OSSE.

Zonal mean westerly winds

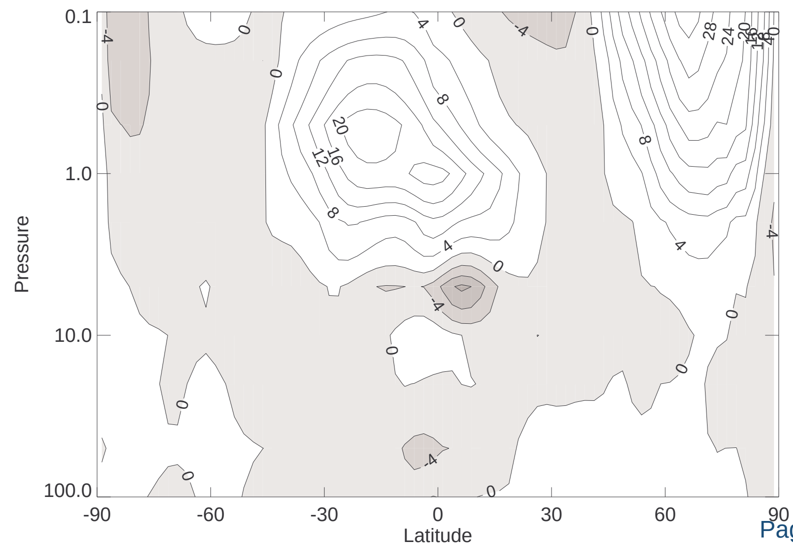
“Nature” – mean westerly winds (m/s) for January 2000



“Swift” minus “Nature”



NoSwift” minus “Nature”



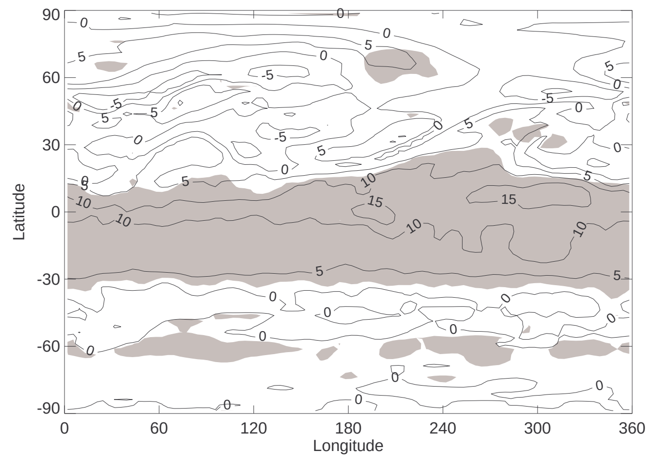
Westerly wind differences

Monthly mean differences:

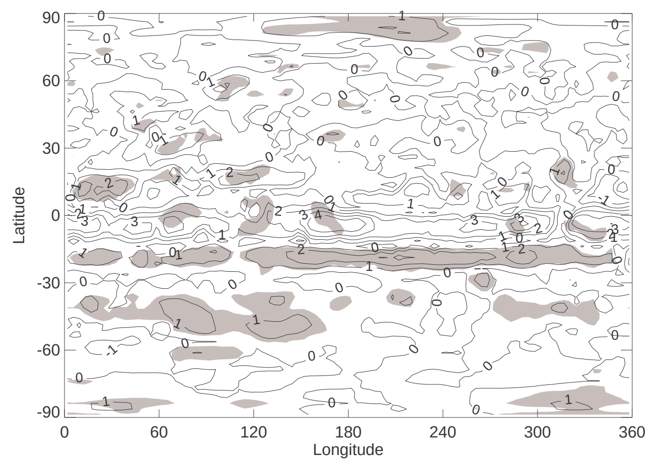
Abs(NoSwift-Nature) - Abs(Swift-Nature) (m/s)

Shading shows areas significantly different at 95% level (and positive values)

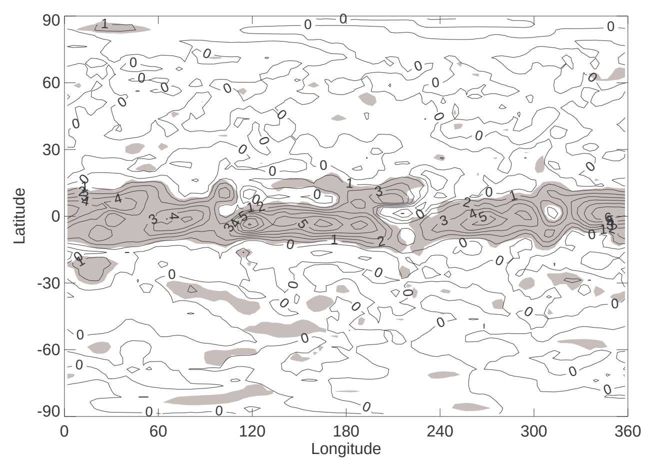
(Results for April 2000 are similar)



1 hPa



10 hPa



50 hPa

Breakdown of SWIFT impact

RMS(Swift-Nature)/RMS(NoSwift-Nature); lower values indicate higher impact

	Globe	90S-60S	60S-30S	30S-30N	30S-60N	60N-90N
All Jan						
100 hPa	0.95	0.91	0.92	0.95	0.94	0.96
50 hPa	**0.61**	0.95	0.96	**0.55**	0.92	0.90
10 hPa	**0.66**	0.90	**0.76**	**0.52**	0.86	0.82
1 hPa	**0.66**	0.83	0.91	**0.49**	0.99	0.86
NH look						
100 hPa	0.94	1.03	0.95	0.92	0.97	1.04
50 hPa	**0.67**	0.95	0.99	**0.62**	0.91	1.00
10 hPa	**0.55**	1.00	0.87	**0.39**	**0.78**	**0.78**
1 hPa	**0.64**	0.90	0.91	**0.58**	0.86	0.87
SH look						
100 hPa	0.94	0.81	0.93	0.96	0.92	1.00
50 hPa	**0.63**	0.98	1.00	**0.53**	0.93	1.02
10 hPa	**0.76**	**0.76**	**0.69**	**0.57**	0.94	0.98
1 hPa	**0.71**	0.95	0.92	**0.47**	0.89	0.82

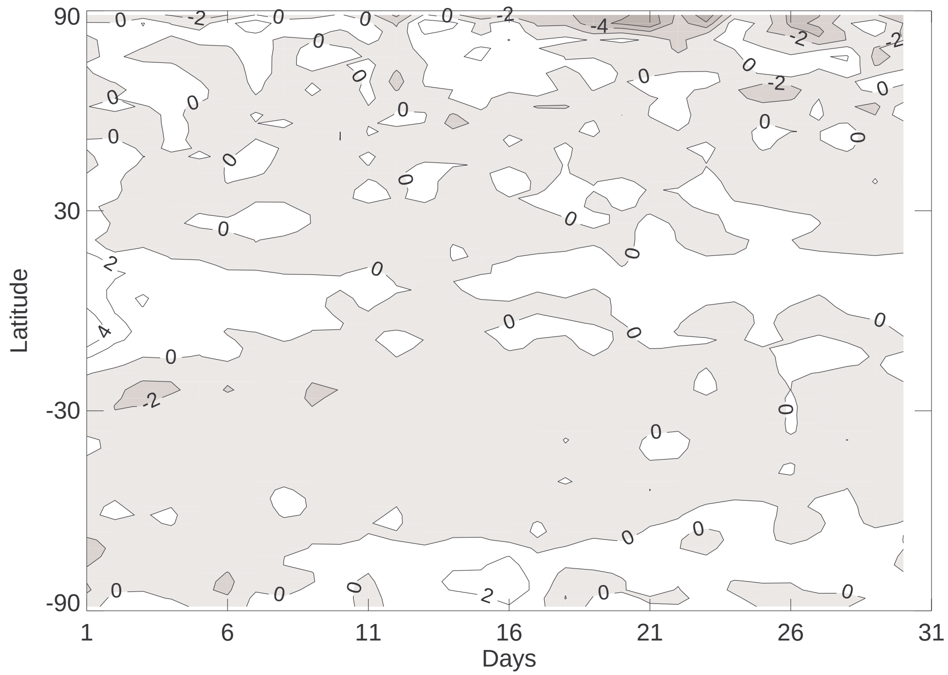
Spin-up

Time series of 10 hPa westerly wind, January 2000

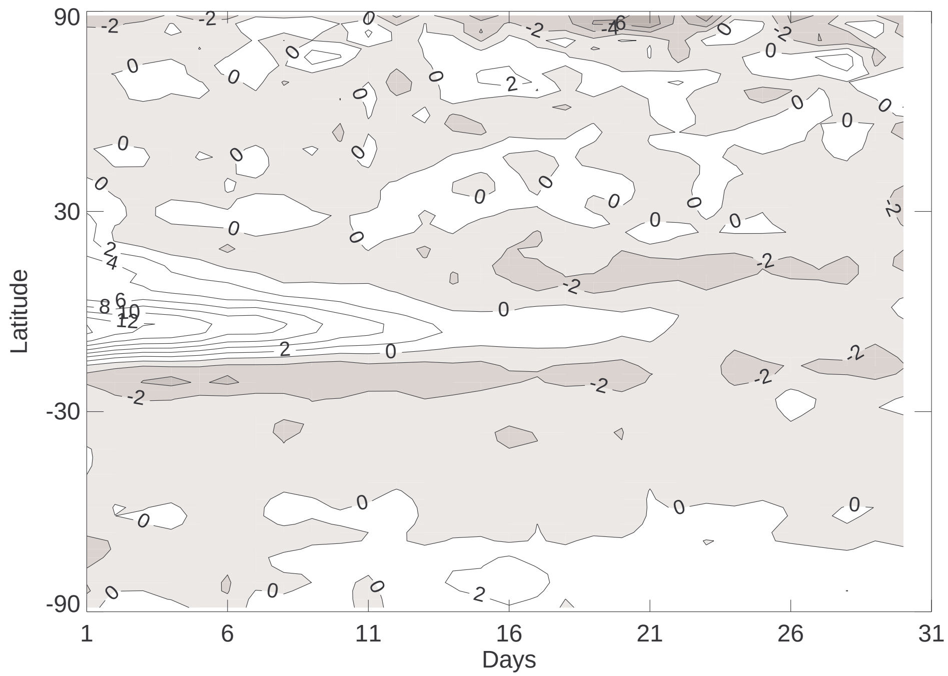
Negative values shaded

(Similar results for April 2000)

Swift minus Nature



NoSwift minus Nature



Conclusions of SWIFT OSSE

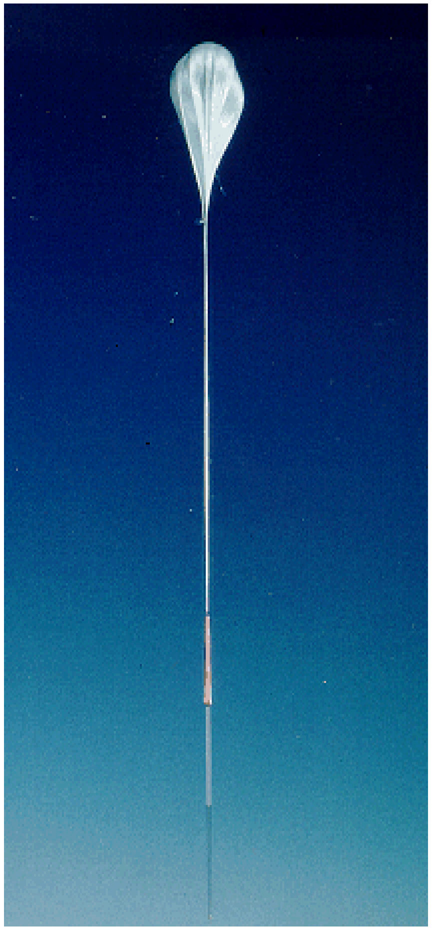
- SWIFT winds:
  - Significant impact in tropical stratosphere (except lowermost levels)
  - Can have significant impact in extra-tropics when flow regime is variable (relatively fast changing)
  - Improve information on tropical winds and wintertime variability
- SWIFT ozone (not shown):
  - Significant impact at 100 hPa & 10 hPa
  - and regions of relatively high vertical gradient

Stratospheric Balloon experiment: the POSSE

(Keil 2004, QJRMetS)

Introduction

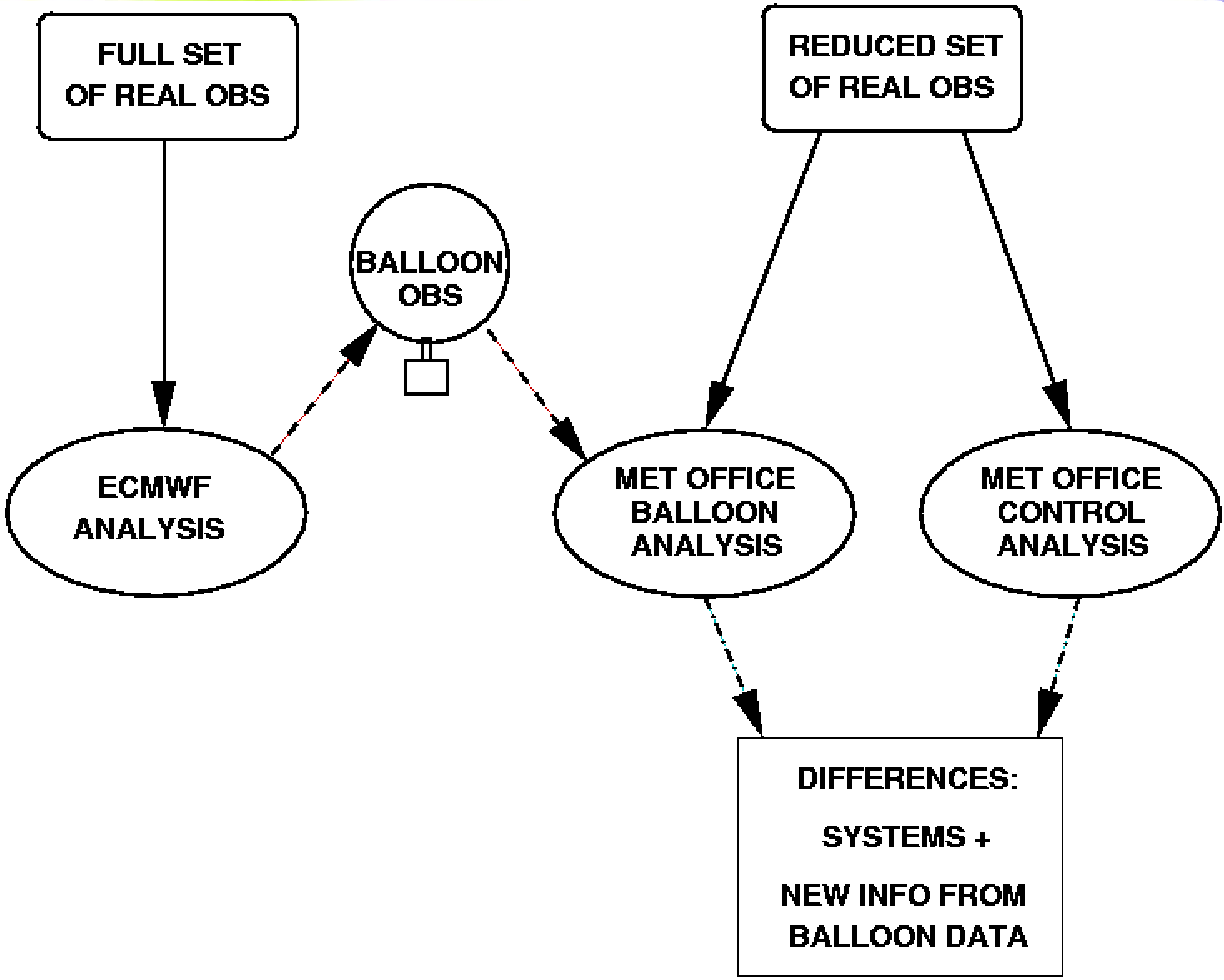
- Investigation of the impact on analyses and forecasts from assimilating various constellations of long-duration stratospheric balloon data.
- These balloons are a potential new component of the global observing system
  - GAINS: Global Air-ocean IN-situ System
  - THORPEX: The Hemispheric Observing System Research and Predictability Experiment
- The balloons would carry dropsondes
- As with SWIFT, this experiment is motivated by the lack of stratospheric wind data



POSSE

- Partial (or Poor-man's) Observation System Simulation Experiment
- Hybrid between an OSE and an OSSE
- Simulate balloon data as in an OSSE
- All other observations are real as in an OSE
- ECMWF analysis as the Nature Run
- Similar to OSRE (Observation System Replacement Experiment, Wergen 2000)

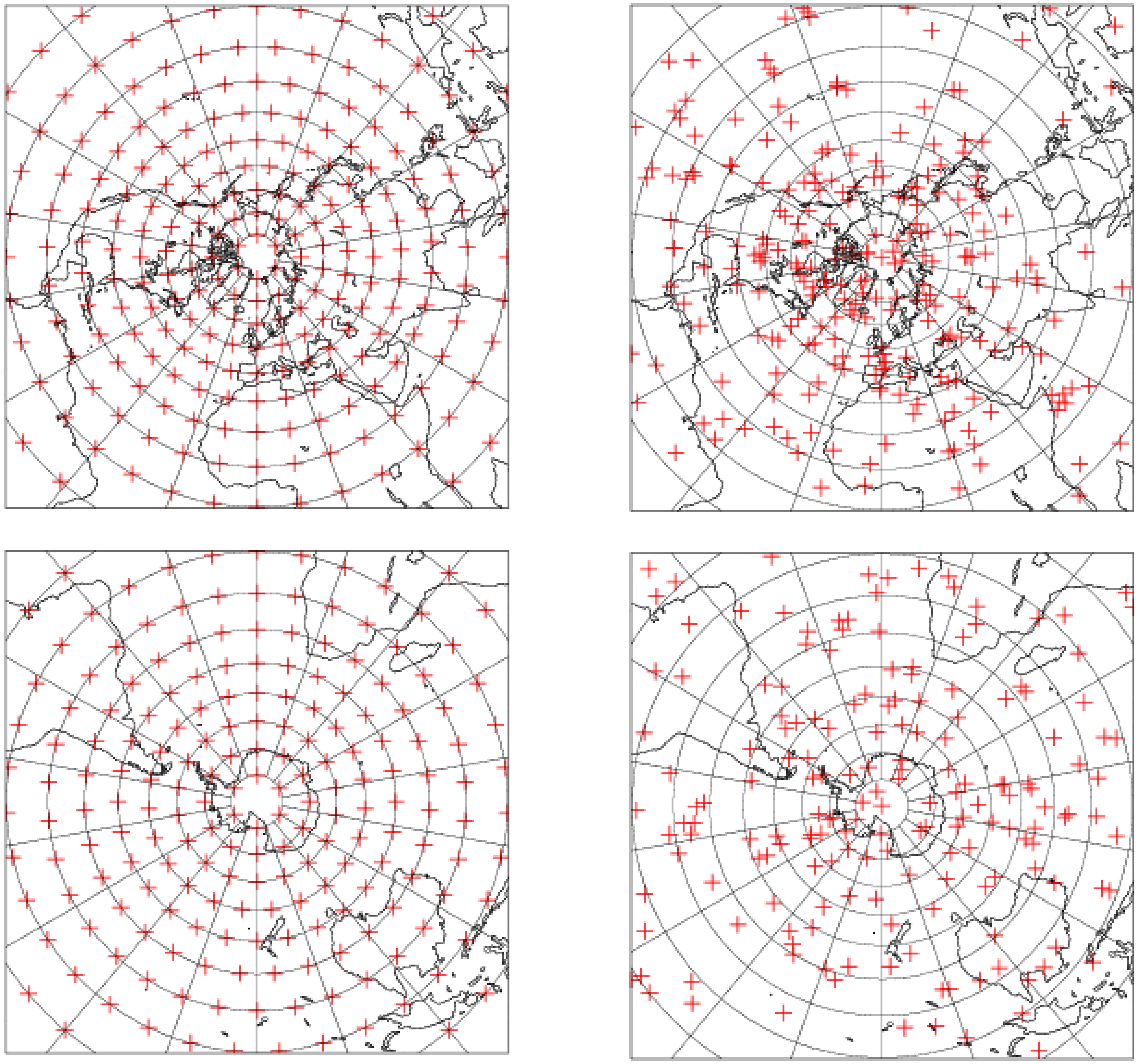
Schematic of the POSSE



Experiment Configurations

- Evolution over a month of a 410 balloon constellation at 30hPa provided by GAINS team (using NCEP reanalysis winds)
- Extracted U & V from ECMWF analysis ("Nature run")
- Subsampled the full constellation of 410 drifting balloons:
  - 205 drifting balloons
  - 103 drifting balloons
  - 52 drifting balloons
- In addition 410 static balloons

Simulated balloon distributions

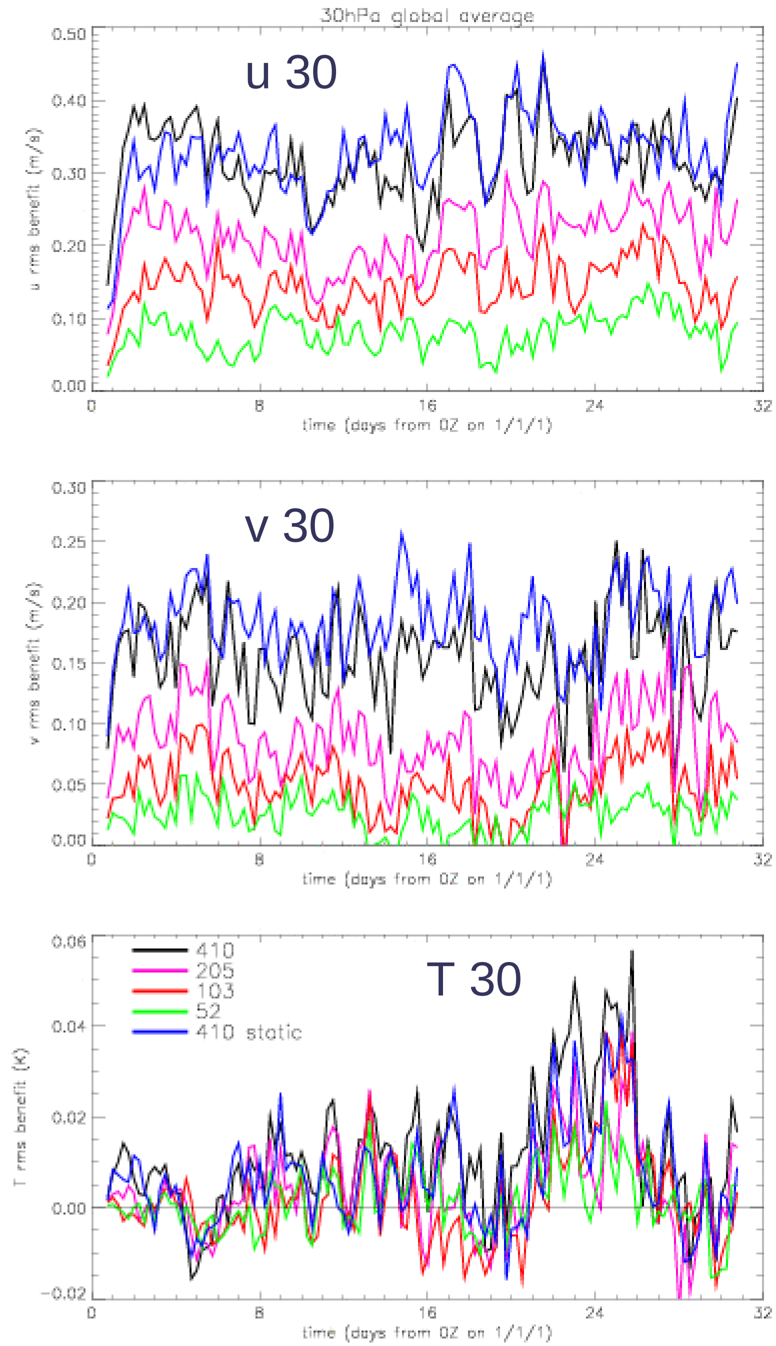


The experiments

- Run using the Unified Model with 3D-Var assimilation
- Five trials, plus a control (no balloon obs)
- Trial period January 2001
- Analyses every 6 hours
- 10 day forecasts initialised daily from 12Z run
  - output at days 1,2,3,4,5 and 10
- Verified using ECMWF analyses

Results

- §RMS Benefit:
  - RMS(control - nature)
  - minus
  - RMS(balloon - nature)
- §Positive values indicate the balloon run is “better”



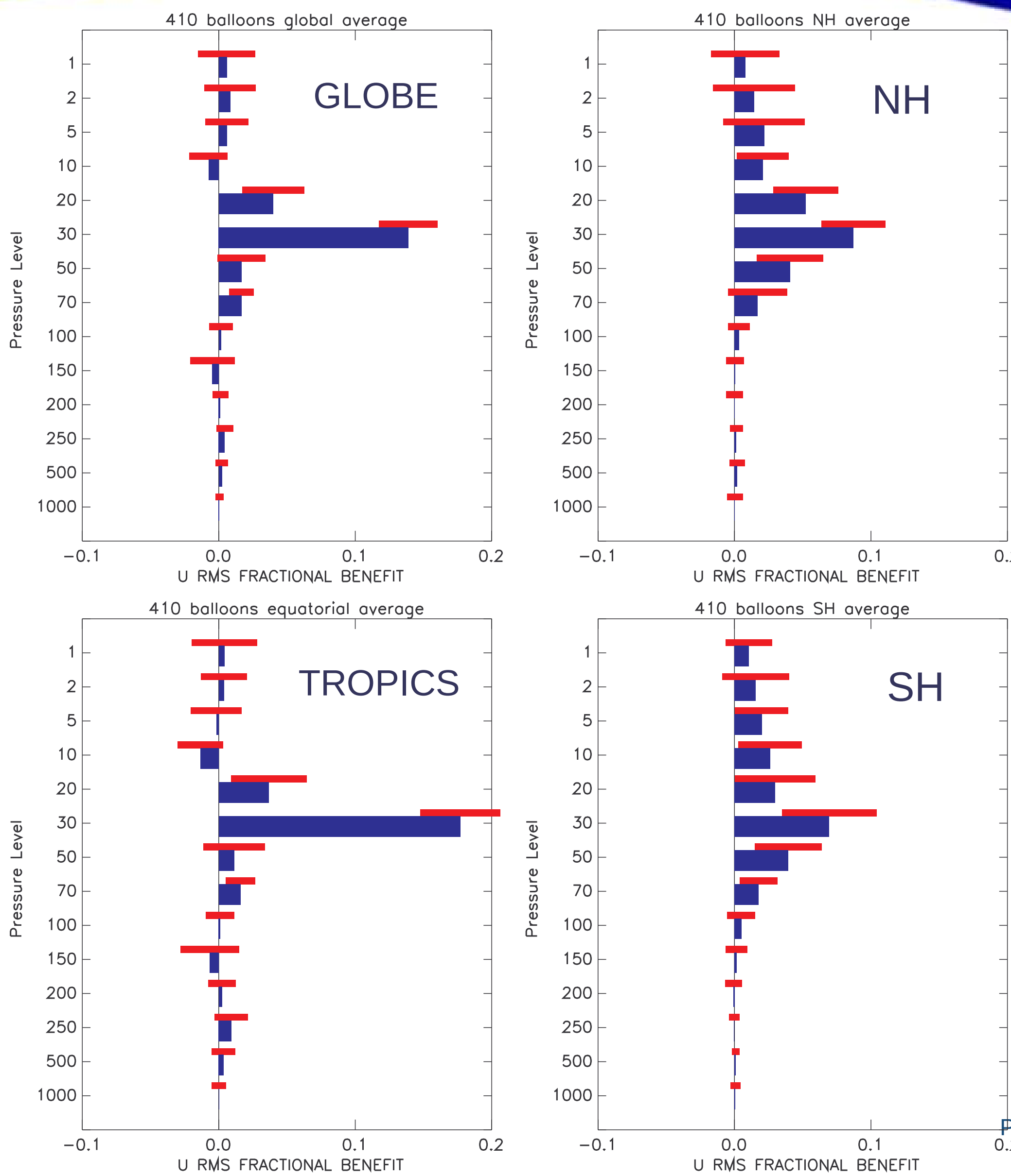
Fractional benefit for westerly wind

410 Balloons

Average fractional RMS Benefit over all (120) analyses

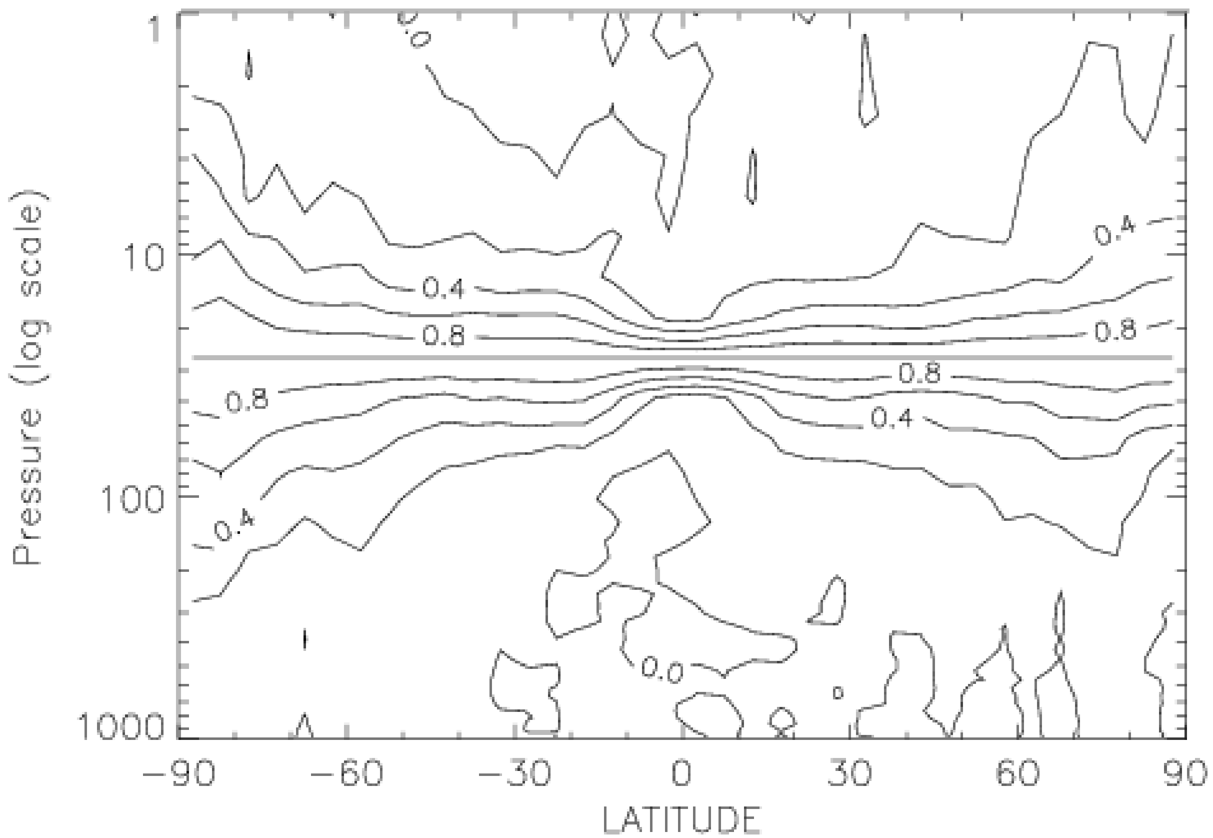
Fractional rms benefit: RMS benefit divided by RMS(control - nature)

BLUE = value
RED = std dev



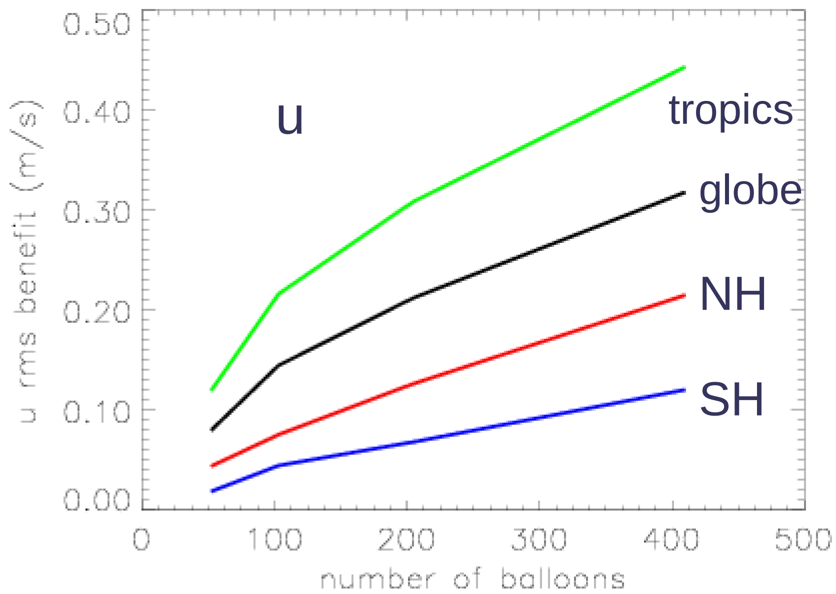
Vertical spreading of increments

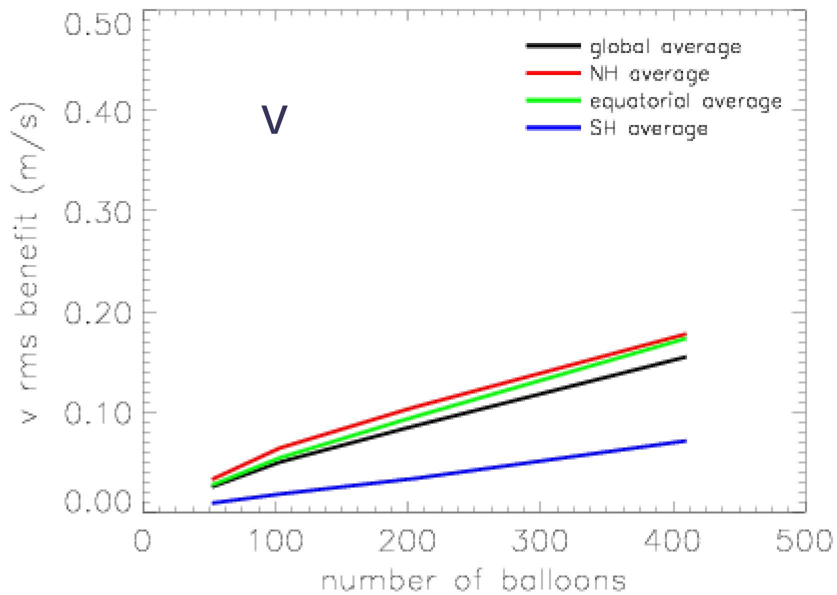
- Vertical U correlation with model level 29
- plotted from covariance statistics used in these runs



Impact of constellation size

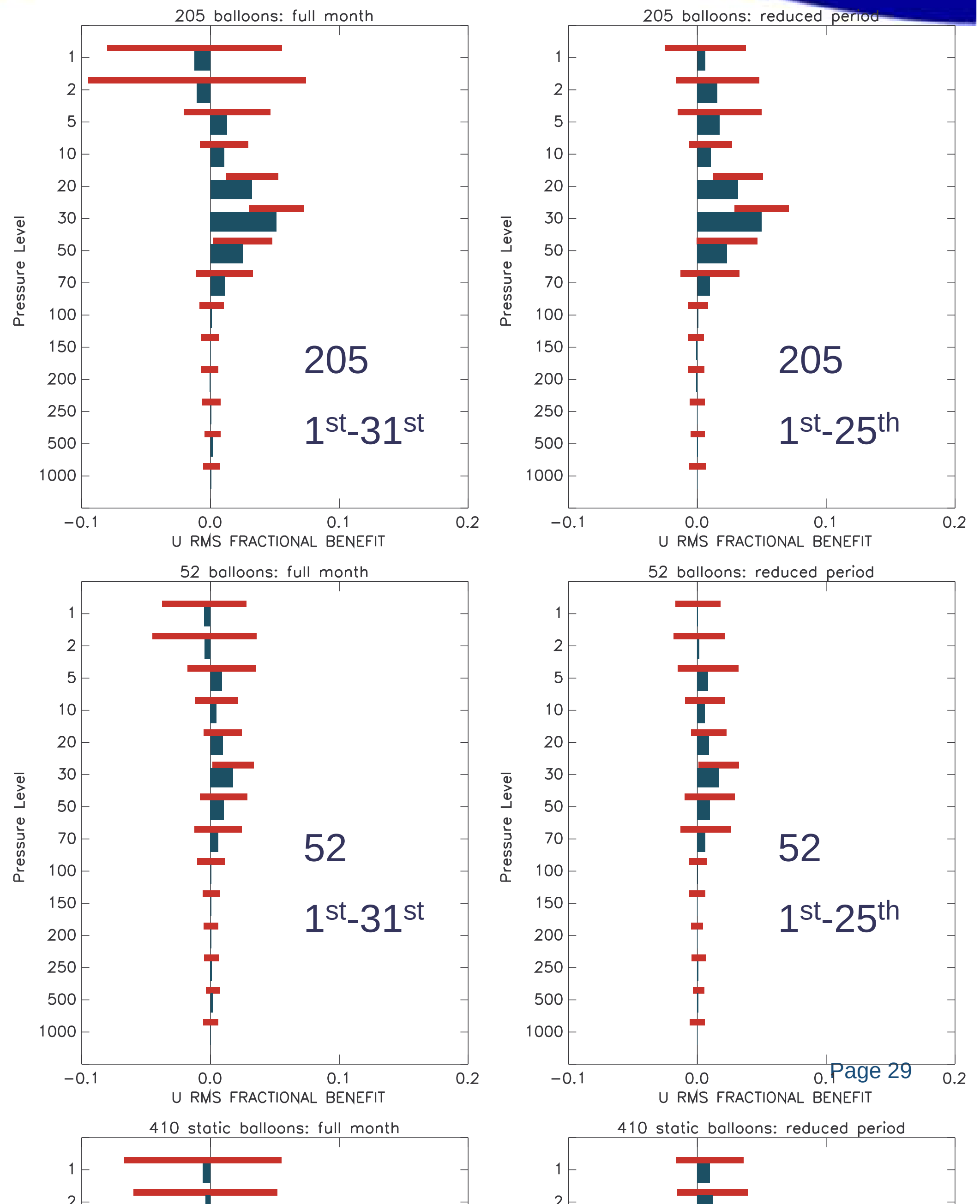
RMS benefit averaged over all analyses at 30 hPa



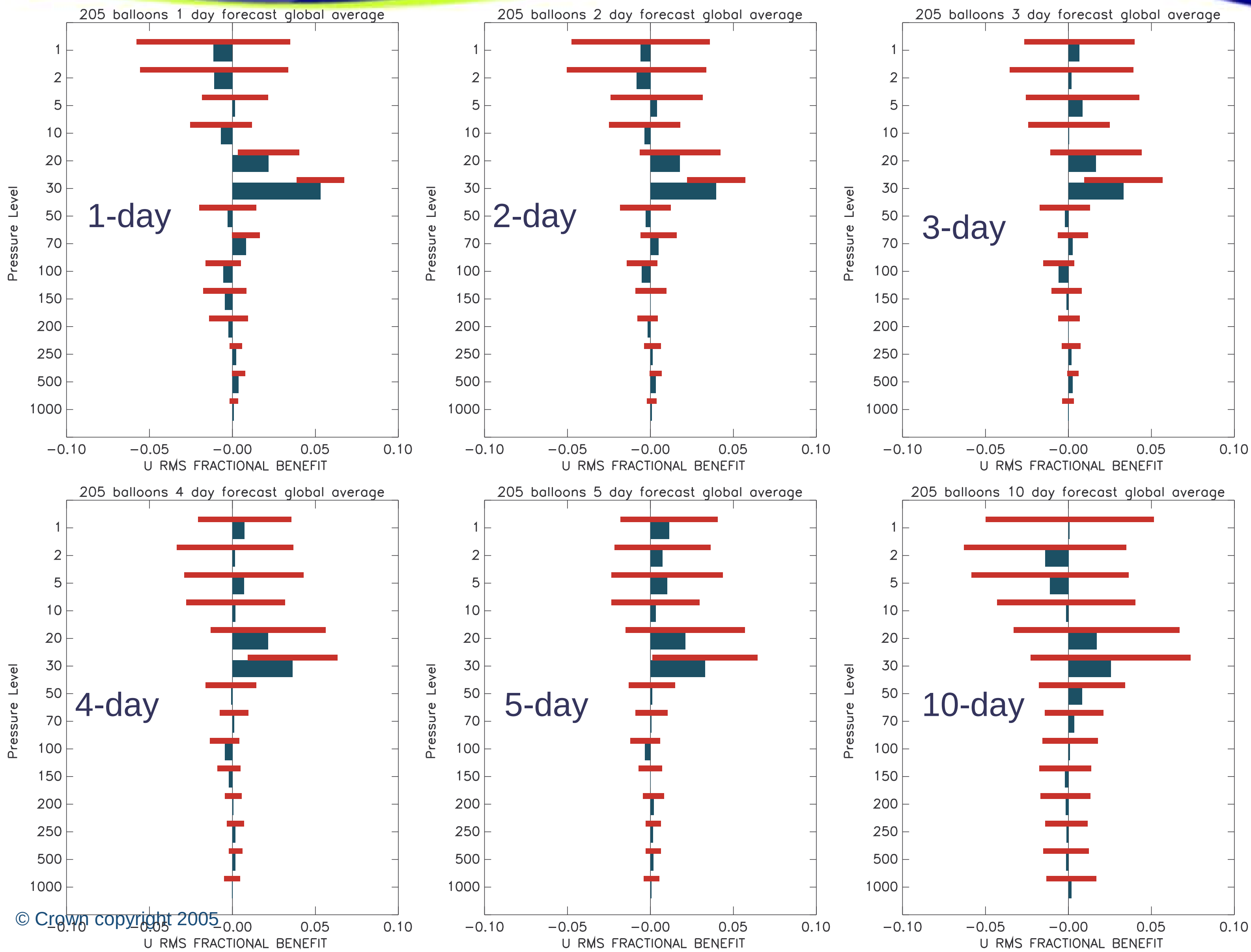


Effect of stratospheric warming

- A sudden stratospheric warming occurred in late January 2001
- The statistics for the full month (left panels) were degraded because of the atypical upper stratospheric flow
- The results for 1-25th (right panels), before the warming, are more consistent with expectations.

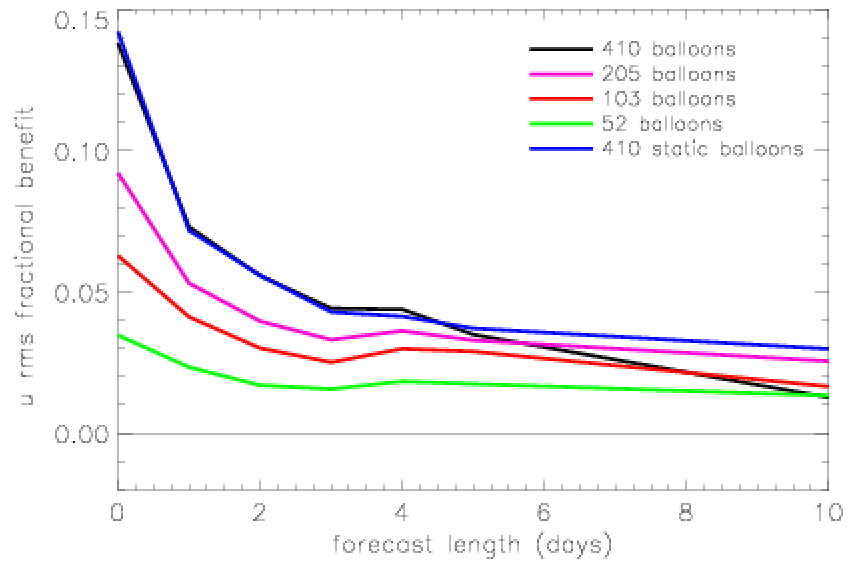


Impact on forecasts (205 balloons)

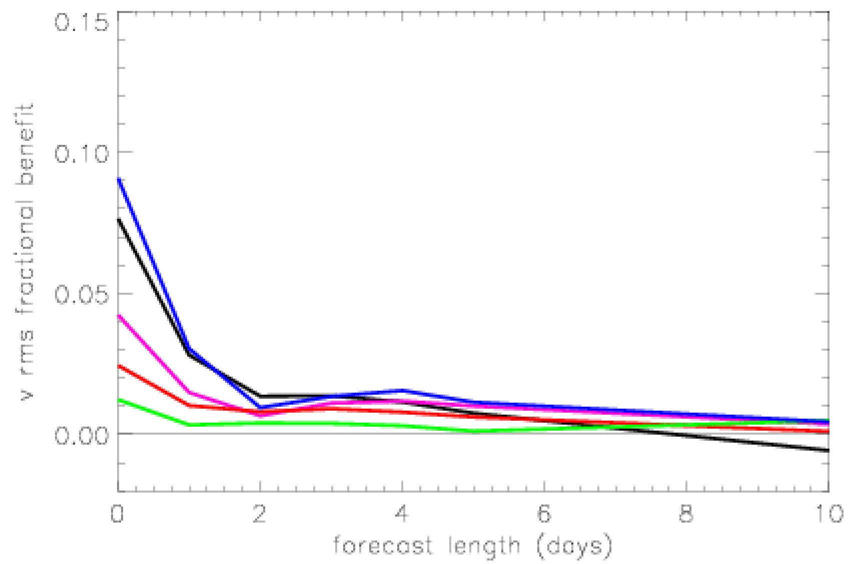


Benefit through the forecast

- U RMS fractional benefit versus forecast length



- V RMS fractional benefit versus forecast length



Conclusions - POSSE

§POSSE balloon analyses have increased skill

- §largest RMS improvement in the tropics
- §greater vertical region affected in the extra-tropics

§POSSE balloon forecasts have increased skill

- §impact decreases with forecast time
- §still measurable at T+10days

§Increasing constellation density increases both analysis skill and forecast skill

OSSEs – general comments

- OSSEs are expensive
  - To do the job properly would require simulating all the (current and anticipated) observations, as well as the observation systems being assessed.
- Due to limited resources, we have made some drastic simplifications.
- Nevertheless, we consider that the conclusions are justifiable if we are considering observations (e.g. stratospheric winds) that fill a major gap in the observing network.
- To examine more marginal improvements to the observing network (e.g. improved tropospheric winds or a new satellite temperature sounder), the signal being sought will be smaller and far more care would need to be exercised when running OSSEs.

Later developments

Since the OSSE experiments, several further developments have been implemented, and others are in the pipeline

New Dynamical core

New Dynamics

- §Semi-Lagrangian
- §Semi-implicit (predictor-corrector)
- §Arakawa C-grid
- §Height based: hybrid terrain-following grid
- §Charney-Phillips
- §Full 3D Helmholtz solver

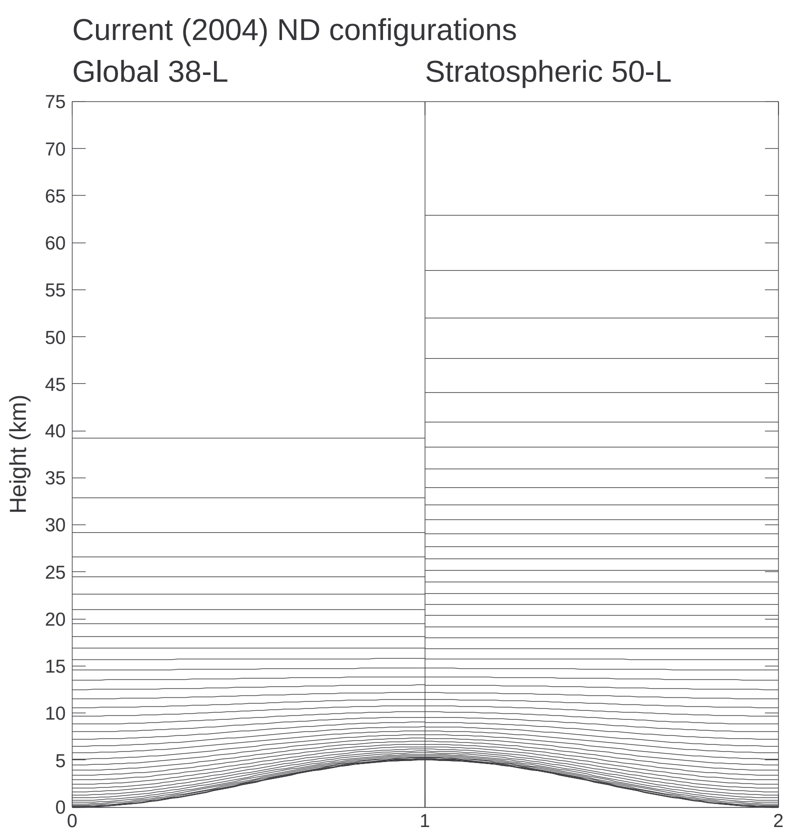
Old Dynamics

- §Explicit Heun
- §Split-explicit (2 time-level)
- §Arakawa B-grid
- §Pressure based: hybrid sigma-pressure grid
- §Lorenz
- §Reference state profile

New Dynamics model configurations

- 38-level, N216 (0.55° x 0.83°)
  - Top at 39km
  - Operational (NWP) in August 2002
- 50-level, N48 (2.5° x 3.75°)
  - Methane oxidation and spectral GWD
  - Top at 64 km
  - Operational (NWP) in October 2003

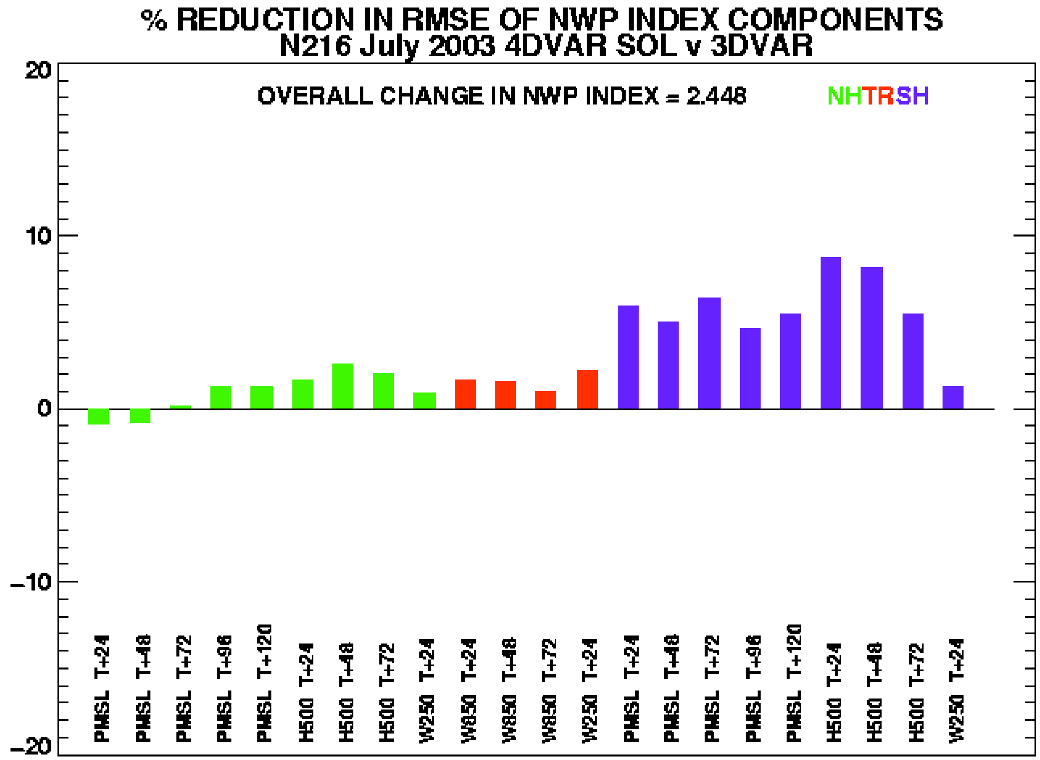
Positive benefit on forecast and analysis skill



4-D variational assimilation

§Very promising results from trials of Global forecast model

§Implemented in October 2004



Stratospheric Plans

- Ozone Assimilation
  - Used in SWIFT study
  - Envisat data being assimilated (ASSET project)
  - Further developments before operational implementation
  - Constituent Assimilation for Air Quality forecasts?
- Extend Global Assimilation to span the stratosphere
  - Improve assimilation of satellite radiances
  - Avoids need for separate operational stratospheric configuration

Questions & Answers