Global assimilation with Gridpoint Statistical Interpolation (GSI) and Global Observational Data Overview

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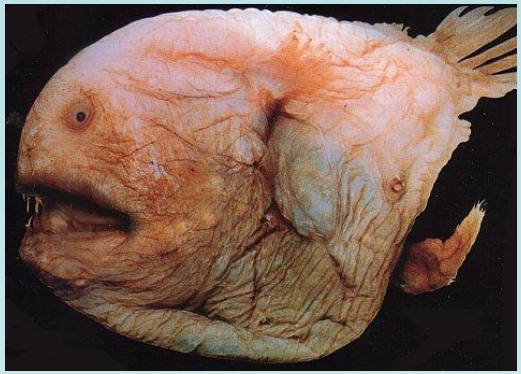
ESRL GSD

Global data assimilation is as simple as grilling a fish

FISH



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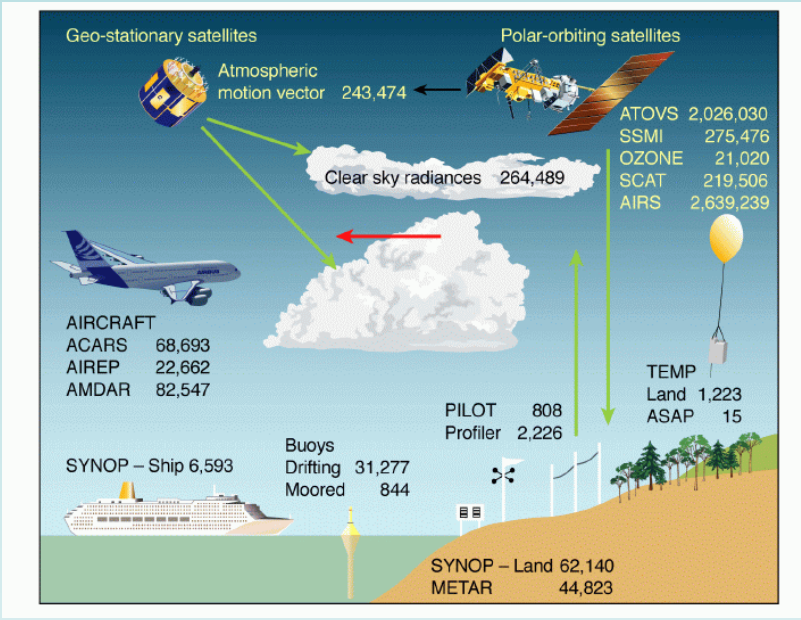
GRILL

DATA



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ASSIMILATION METHOD

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‘SMALLER INGREDIENTS’ (FIRST GUESS, BACKGROUND ERROR, OBSERVATION ERROR, ETC.

+ SMALLER INGREDIENTS (SALT, PEPPER, ETC.

Outline

- **Data assimilation context**
- **Global scale data coverage**
- **The Gridpoint Statistical Interpolation (GSI) method and its applications**

Data Assimilation Context

- Data assimilation attempts to bring together all available information to make the best possible estimate of:
  - The atmospheric state
  - The initial conditions to a model which will produce the best forecast.

Data Assimilation Context

- Information sources
  - Observations
  - Background (forecast)
  - Dynamics (e.g., balances between variables)
  - Physical constraints (e.g., $q > 0$)
  - Statistics
  - Climatology

Data Assimilation Context

- Must build data assimilation system within context of :
  - Observing system
  - Data handling system
  - Forecast model
  - Computational resources
  - Available knowledge about observations and statistics
  - Human resources
  - Verification and monitoring system

Atmospheric analysis problem (theoretical)

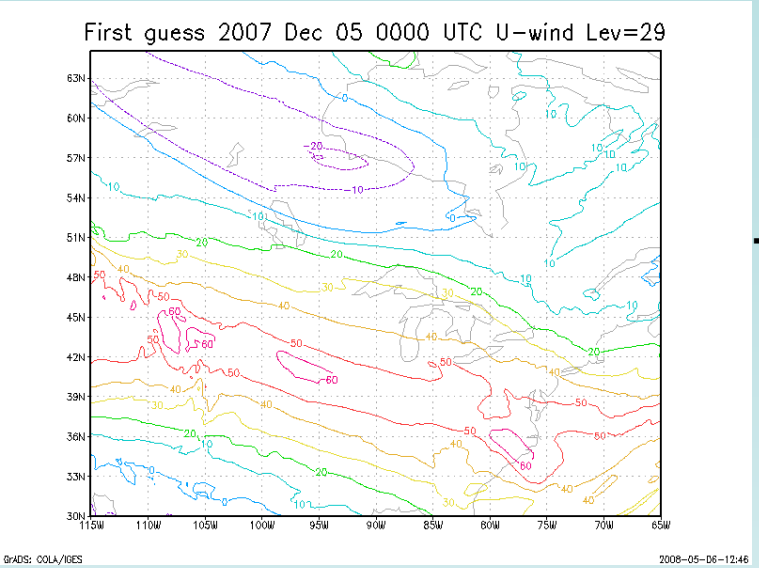
$$J = J_b + J_o + J_c$$

$$J = (x-x_b)^T B_x^{-1}(x-x_b) + (K(x)-O)^T (E+F)^{-1}(K(x)-O) + J_C$$

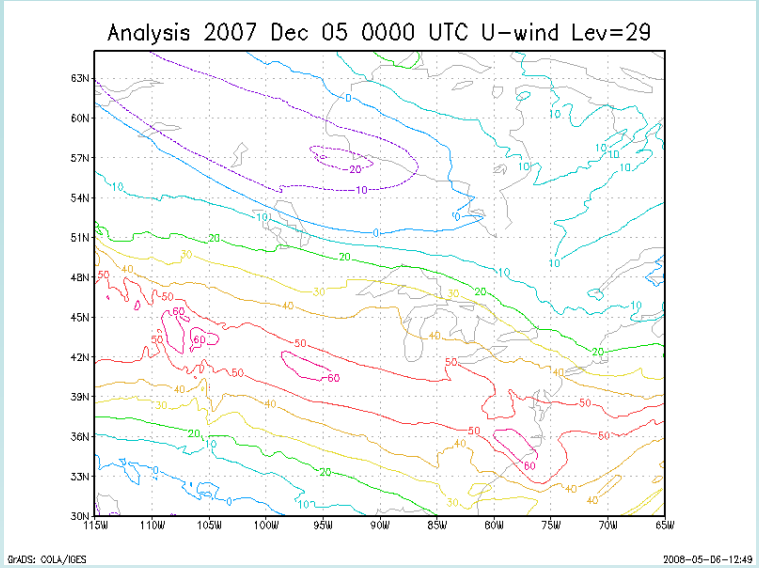
J = Fit to background + Fit to observations + constraints

x = Analysis
x_b = Background
B_x = Background error covariance
K = Forward model (nonlinear)
O = Observations
$E+F = R$ = Instrument error + Representativeness error
J_C = Constraint term

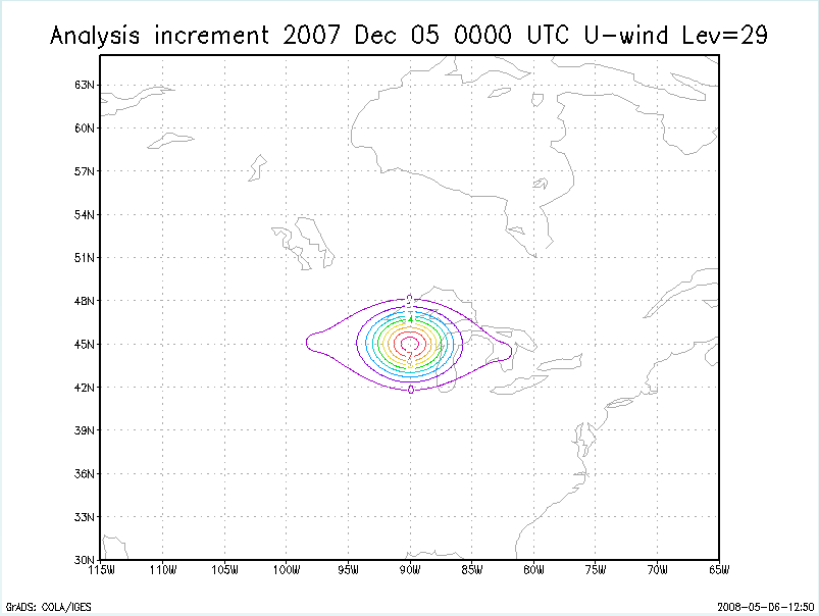
A SIMPLE EXAMPLE



+ One observation of U-wind at point 45N, 90W, 250hPa Value=+10m/s =



FIRST GUESS = FORECAST VALID AT ANALYSIS TIME **OBSERVATION** **RESULT OF ANALYSIS**



ANALYSIS INCREMENT

Satellite data context

- One of the biggest data assimilation developments in the last 15 years was allowing the observations to be different from the analysis variables
  - In variational schemes this is done through the *K* operator
  - In OI, the same thing could be done – but was only rarely done.
  - The development allows us to use the observations as they were observed AND allows the use of analysis variables with nice properties.

Observation data count (27/07/07-00UTC)

Screened

Synop	407,812	0.26%
Aircraft	487,435	0.31%
Dribu	19,494	0.01%
Temp	164,880	0.11%
Pilot	107,004	0.07%
AMVs	2,201,118	1.40%
Radiances	152,125,646	97.06%
Scat.	820,830	0.52%
GPS occult.	209,501	0.13%
Total	156,734,720	100.00%

99% of screened data is from satellites

Assimilated

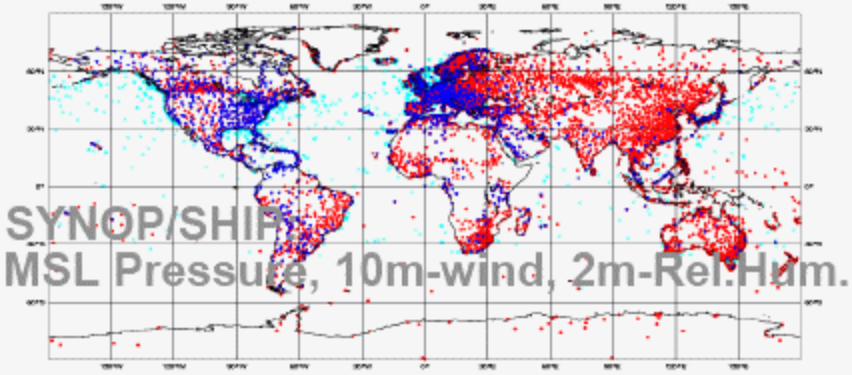
Synop	60,683	0.68%
Aircraft	235,741	2.65%
Dribu	5,901	0.07%
Temp	82,569	0.93%
Pilot	48,870	0.55%
AMVs	95,466	1.07%
Radiances	8,137,481	91.37%
Scat.	149,000	1.67%
GPS occult.	90,716	1.02%
Total	8,906,427	100.00%

95% of assimilated data is from satellites

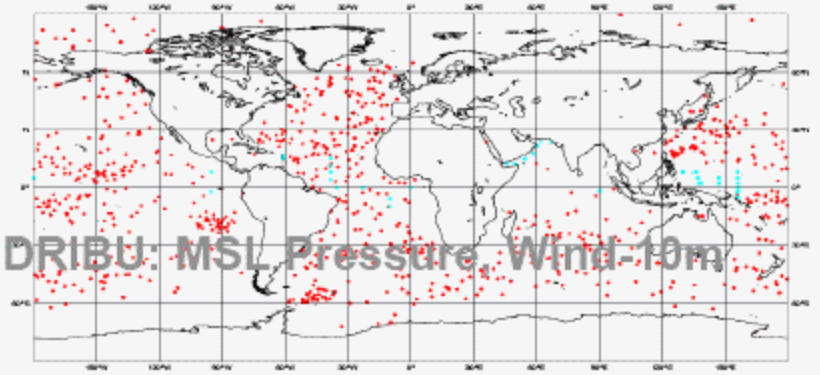
Only 5.7% of screened data is assimilated.

In John Derber's (NCEP) words: - "Over 1.43B observations received per day but over 7M observations per day used".

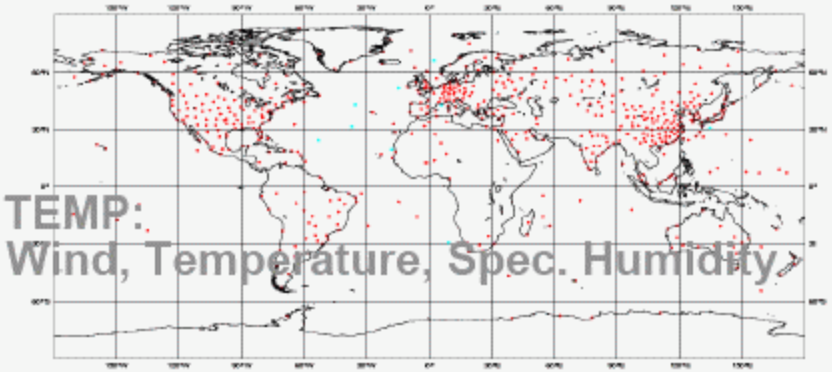
Conventional observations used



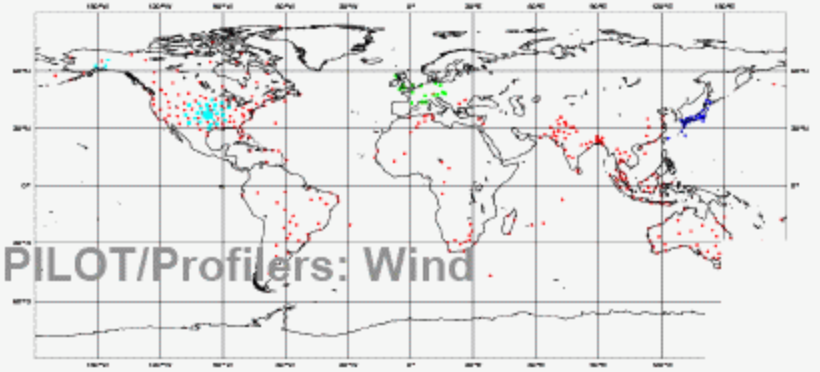
SYNOP/SHIP:
MSL Pressure, 10m-wind, 2m-Rel.Hum.



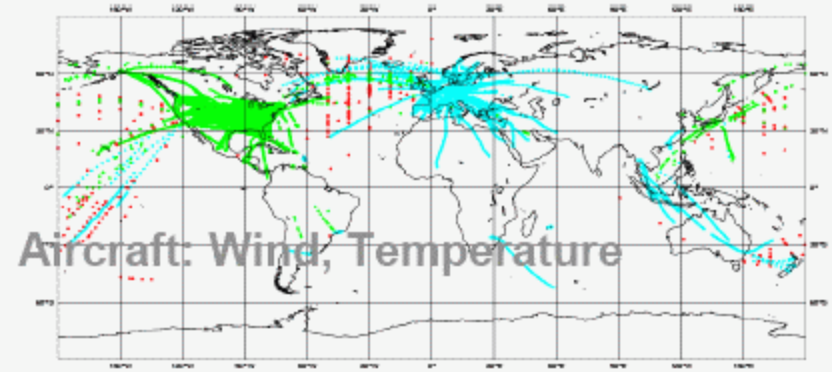
DRIBU: MSL Pressure, Wind-10m



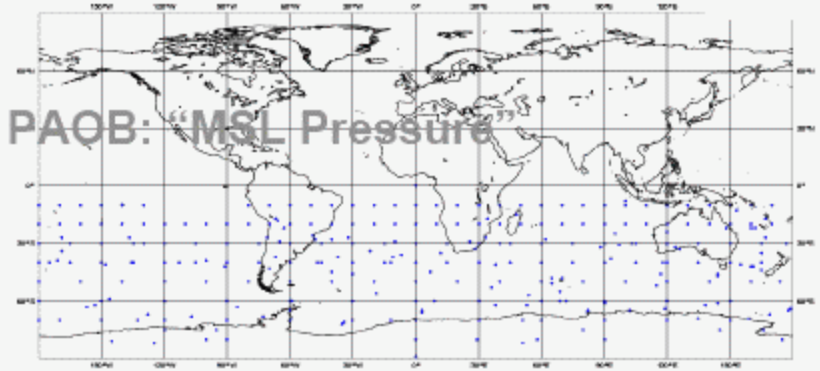
TEMP:
Wind, Temperature, Spec. Humidity



PILOT/Profilers: Wind



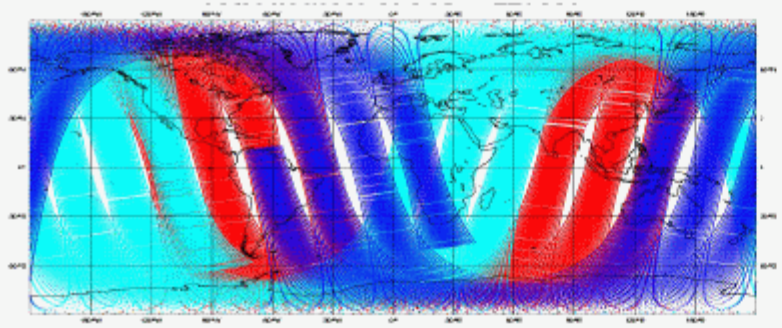
Aircraft: Wind, Temperature



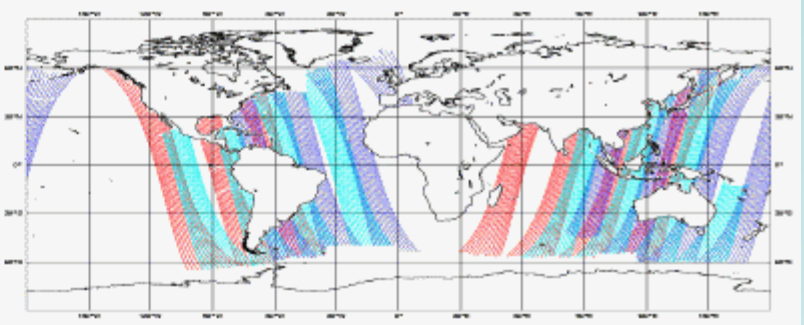
PAOB: MSL Pressure

European Centre for Medium Range Weather Forecasting

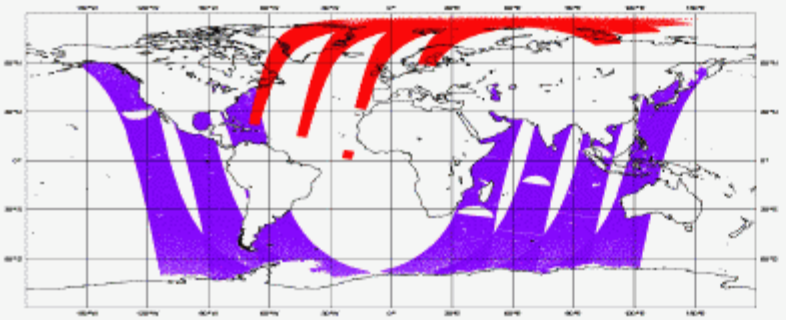
NOAA AMSUA/B HIRS, AQUA AIRS



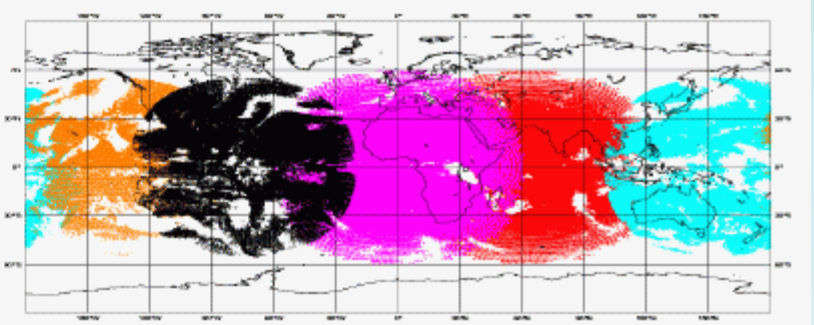
DMSP SSM/I



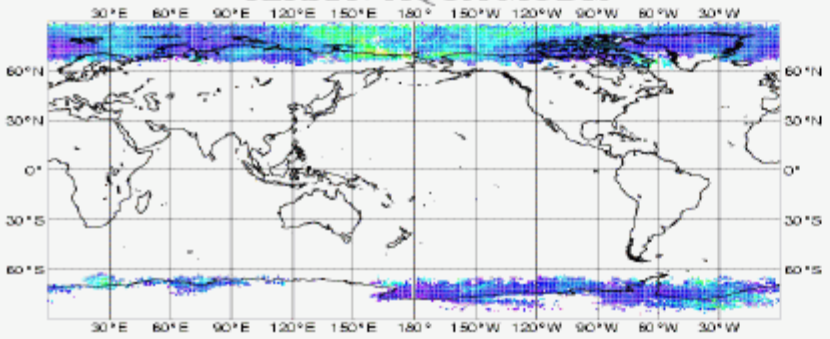
SCATTEROMETERS



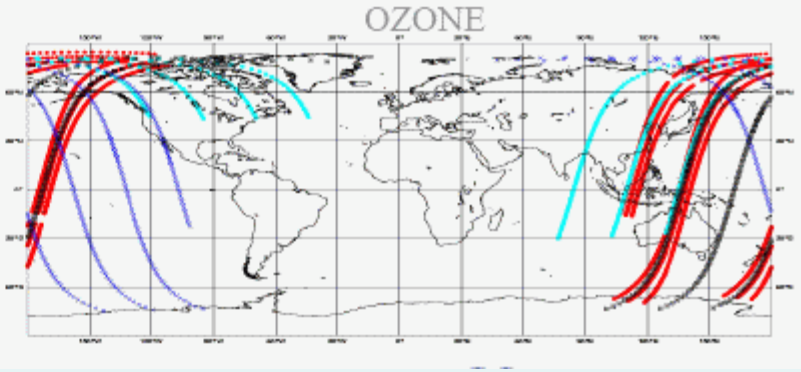
GEOS



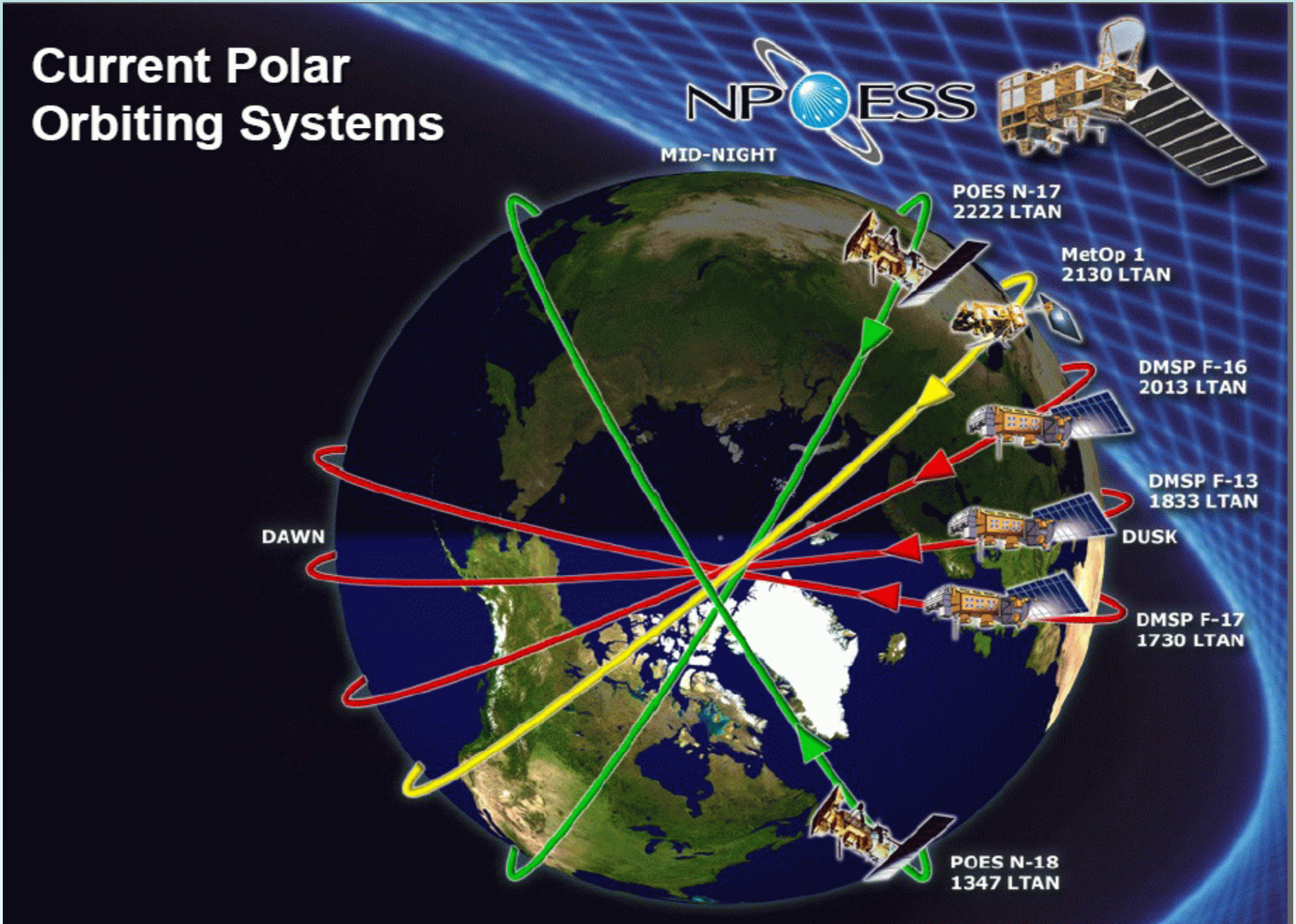
TERRA / AQUA MODIS



OZONE



National Polar-Orbiting Operational Environmental Satellite System (NPOESS)

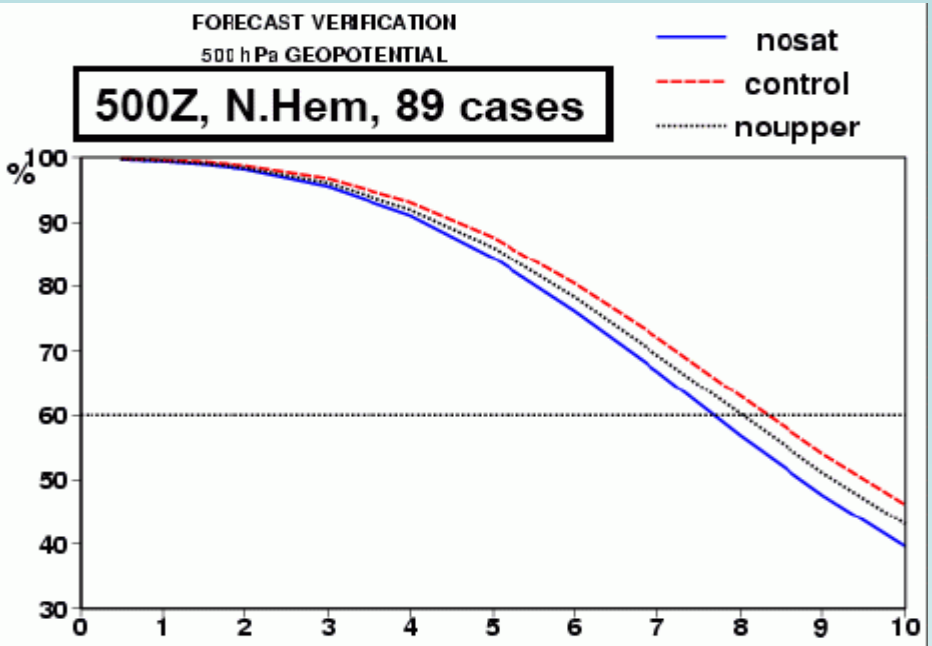


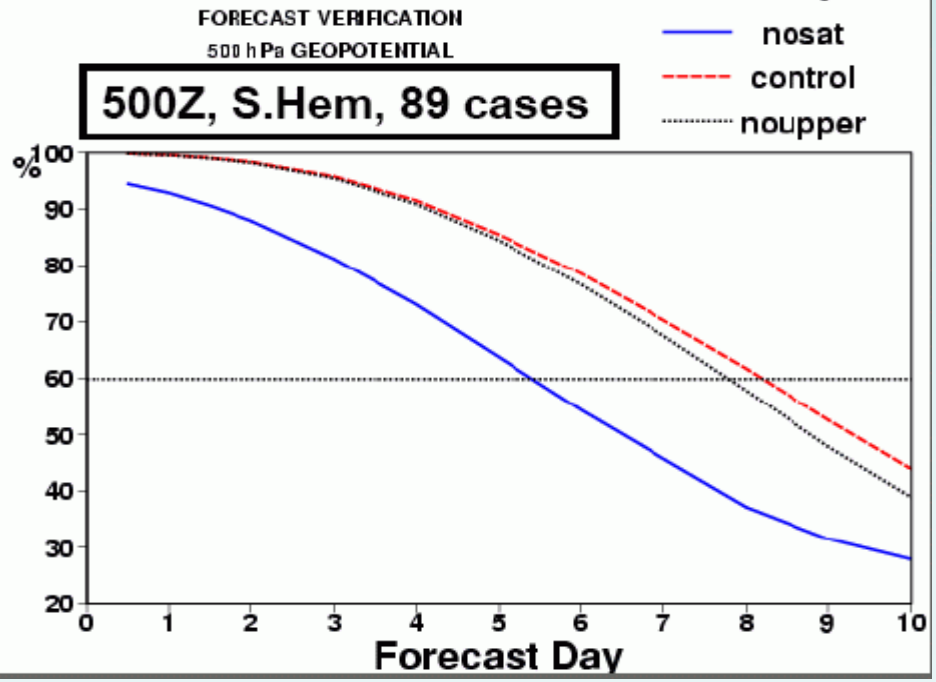
Observing System Experiments (ECMWF - G. Kelly et al.)

NoSAT= no satellite radiances or winds

Control= like operations

NoUpper=no radiosondes, no pilot winds, no wind profilers





About OSEs see ESRL Theme presentation on 7th June 2007 and present poster by Tom Schlatter

BASICS OF GSI
HISTORY OF GSI

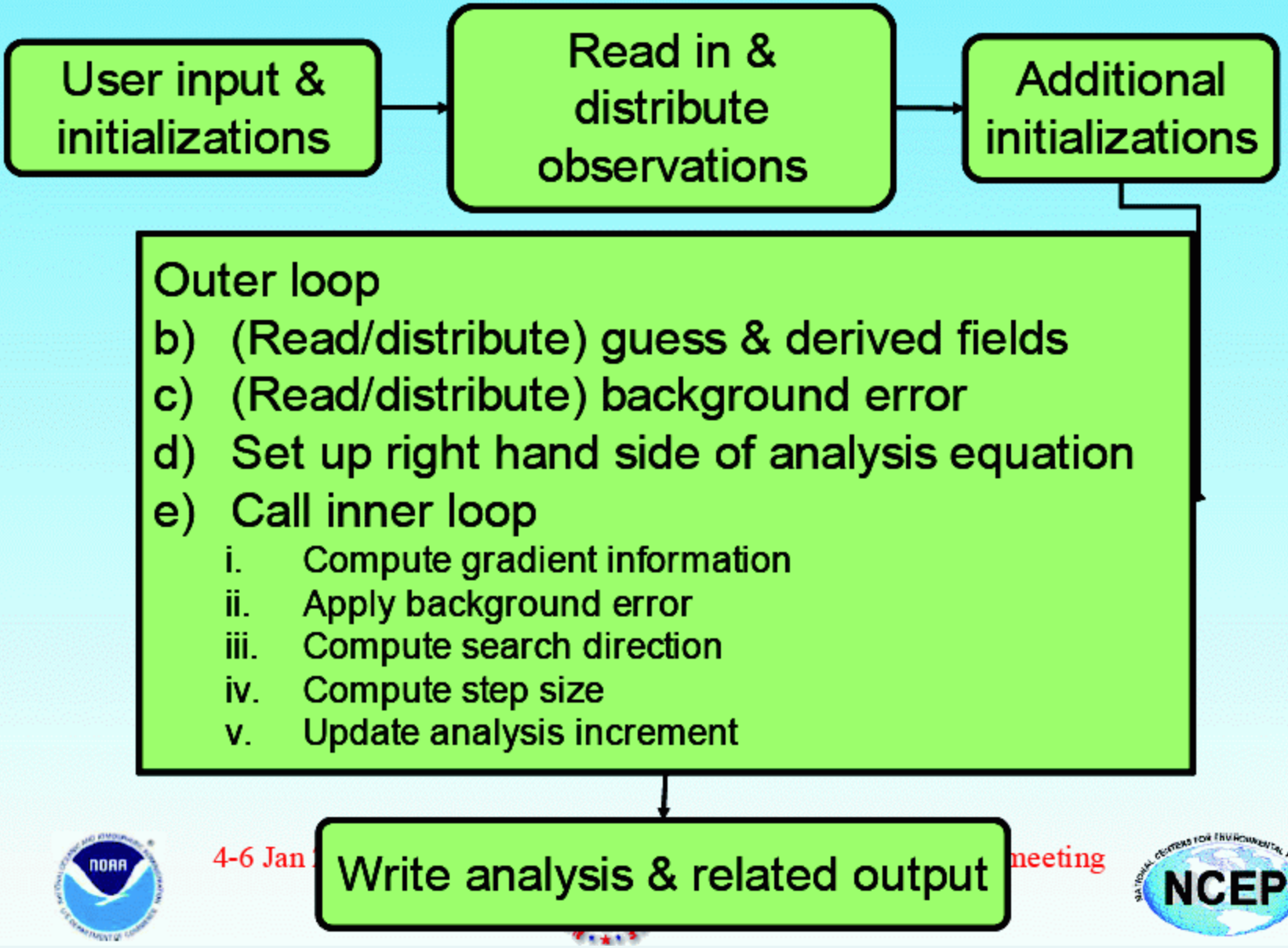
- The GSI system was initially developed as the next generation global analysis system at NCEP – standard reference:
  - Wan-Shu Wu, R. James Purser, David Parrish, 2002:

  Three-Dimensional Variational Analysis with Spatially Inhomogeneous Covariances. Mon. Wea. Rev., 130, 2905-2916.
  - Based on former Spectral Statistical Interpolation (SSI) system.
  - Replaced spectral definition for background errors with grid space defined recursive filters.
  - Horizontally, the global domain is divided into three pieces so that efficient spatial recursive filters can be used to spread out the information from the observation locations.
  - After having initial GSI available decision was made to develop it into a unified (single) global/regional analysis system.
  - Modifications were made to fit into WRF and NCEP infrastructure.
  - Evolution to ESMF.

IN ITS PRESENT FORM GSI IS A 3-DVAR.

EXTENSION TO 4-DVAR IS UNDER WAY.

GSI Code - General Flow



GSI SCIENTIFIC ADVANCEMENTS

- **Inclusion of new types of data**
  - **COSMIC GPS – radio-occultation**
  - **Radiance data**
    - **SSM/I and SSM/IS radiances**
    - **NASA instruments form AQUA, TERRA, CHEM**
    - **NPOESS and METOP (=European NPOESS, Meteorological Operational Satellite Programme)**
    - **Next generation geostationary satellite**
  - **Doppler radial velocities and reflectivities**
  - **Precipitation observations**
  - **Cloud observations**
  - **Ozone observation**
  - **Inclusion of other atmospheric chemistry related data**

GSI SCIENTIFIC ADVANCEMENTS

- **Improved specification of observational errors**
  - **situation dependent representativeness errors**
- **Advanced data assimilation techniques**
  - **situation dependent background errors**
  - **anisotropic background error correlation instead of isotropic ones**
  - **generalization to 4-dimensional variational assimilation (4-DVAR)**
  - **improved balance constraints**
- **New analysis variables**
  - **Sea Surface Temperature (SST)**
  - **Clouds**
  - **Aerosols**
  - **Precipitation**
  - **Constituents**

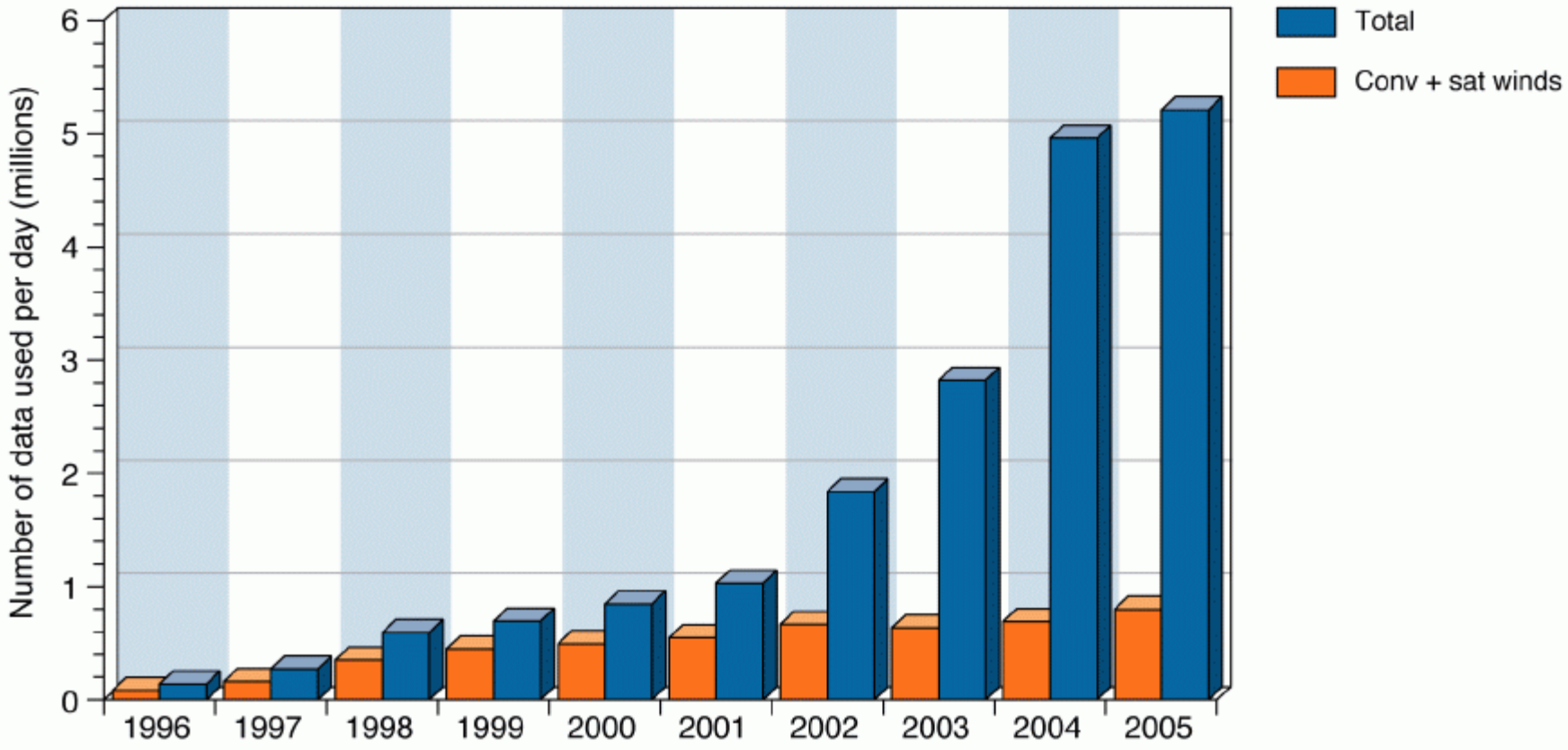
Present uses of GSI at ESRL

- **In regional forecasting including now real time Rapid Refresh (RR) system at ESRL GSD (GSI is operational in NCEP's global data assimilation system (GDAS) since 1 May 2007). See also ESRL Theme presentation on 4th October 2007.**
- **In Observing System Experiments (OSEs) and Observing System Simulation Experiments (OSSEs) including ongoing experiments with participation of ESRL. See also ESRL Theme presentation on 7th June 2007 and present poster by Tom Schlatter.**
- **In regional on-line chemical data assimilation including preliminary ozone and particle matter assimilation works at ESRL GSD.**

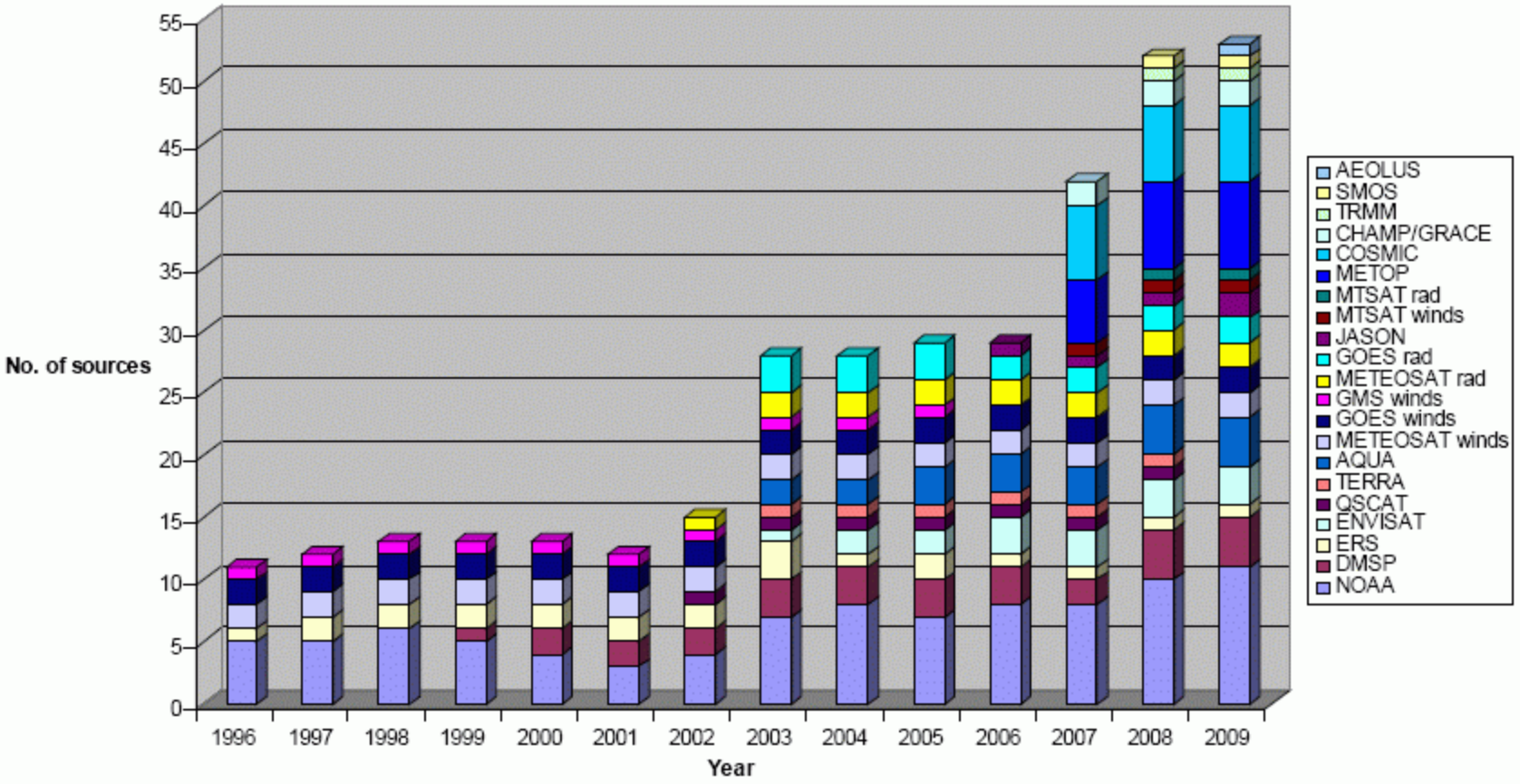
Conclusions

- **GSI has been introduced into ESRL's computer system but global scale application requires even more computing power.**
- **For any real time global scale application of GSI at ESRL global scale data coverage must be provided.**
- **Expertise in satellite data processing is crucial for global scale data assimilation.**
- **Present GSI framework is not the only possible one for global scale data assimilation. Enjoy next talk about Ensemble Kalman Filter works at ESRL.**

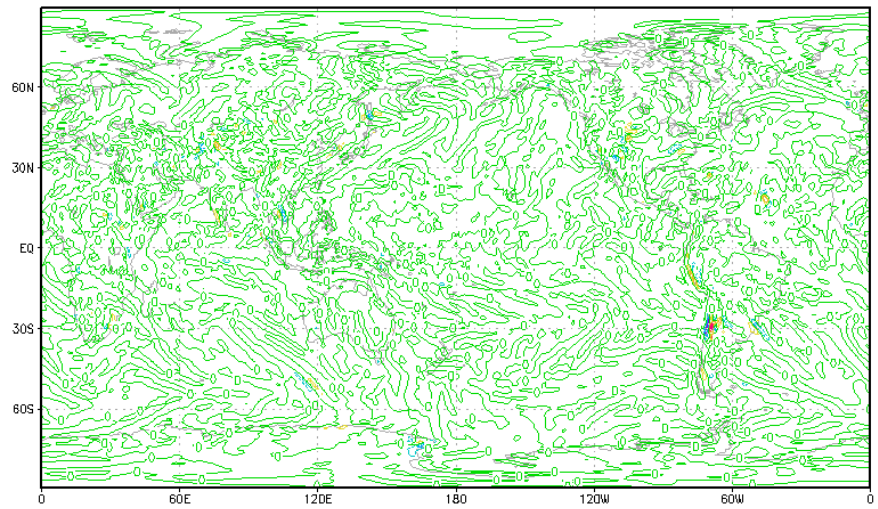
Number of Used Data per Day



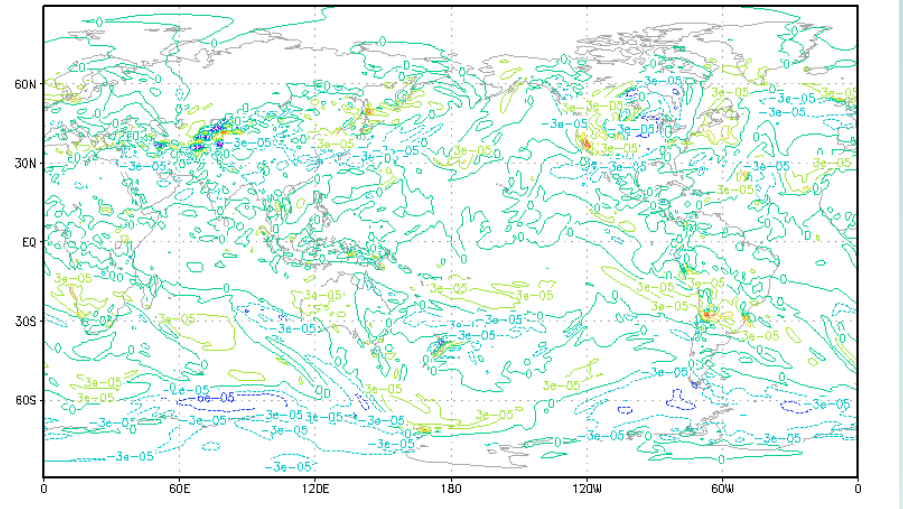
Satellite information by number of sources at ECMWF – over 50 types at present



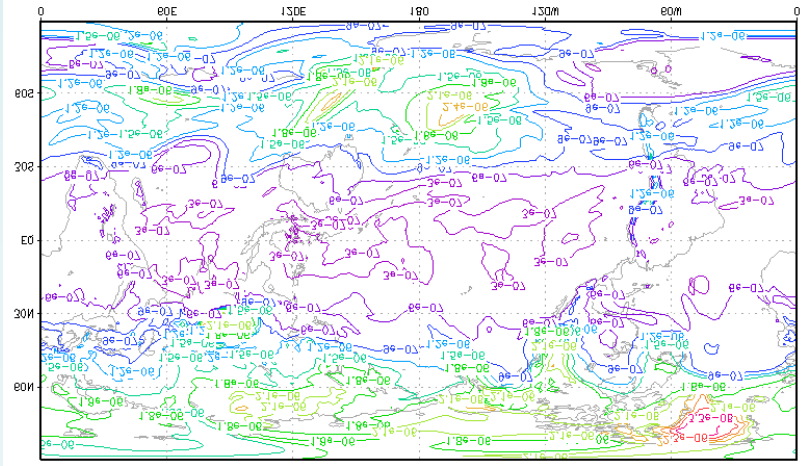
GSI global analysis results at ESRL
Example of 28 October 2005



Divergence



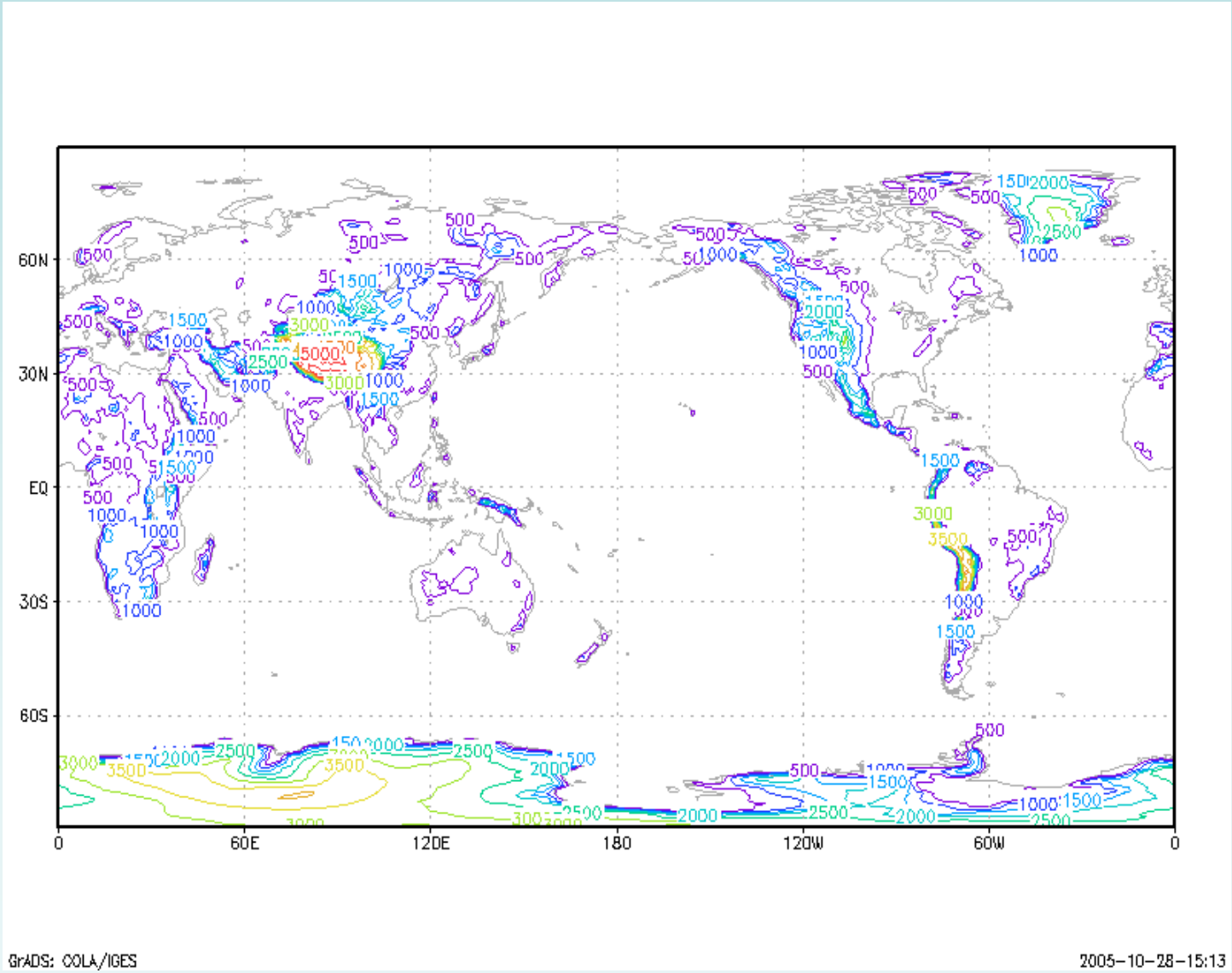
Vorticity



Tracer-2

GSI Test over Global Domain

512x256 quasi-Gaussian grid, 64 sigma levels. Topography:



GSI Test over Global Domain

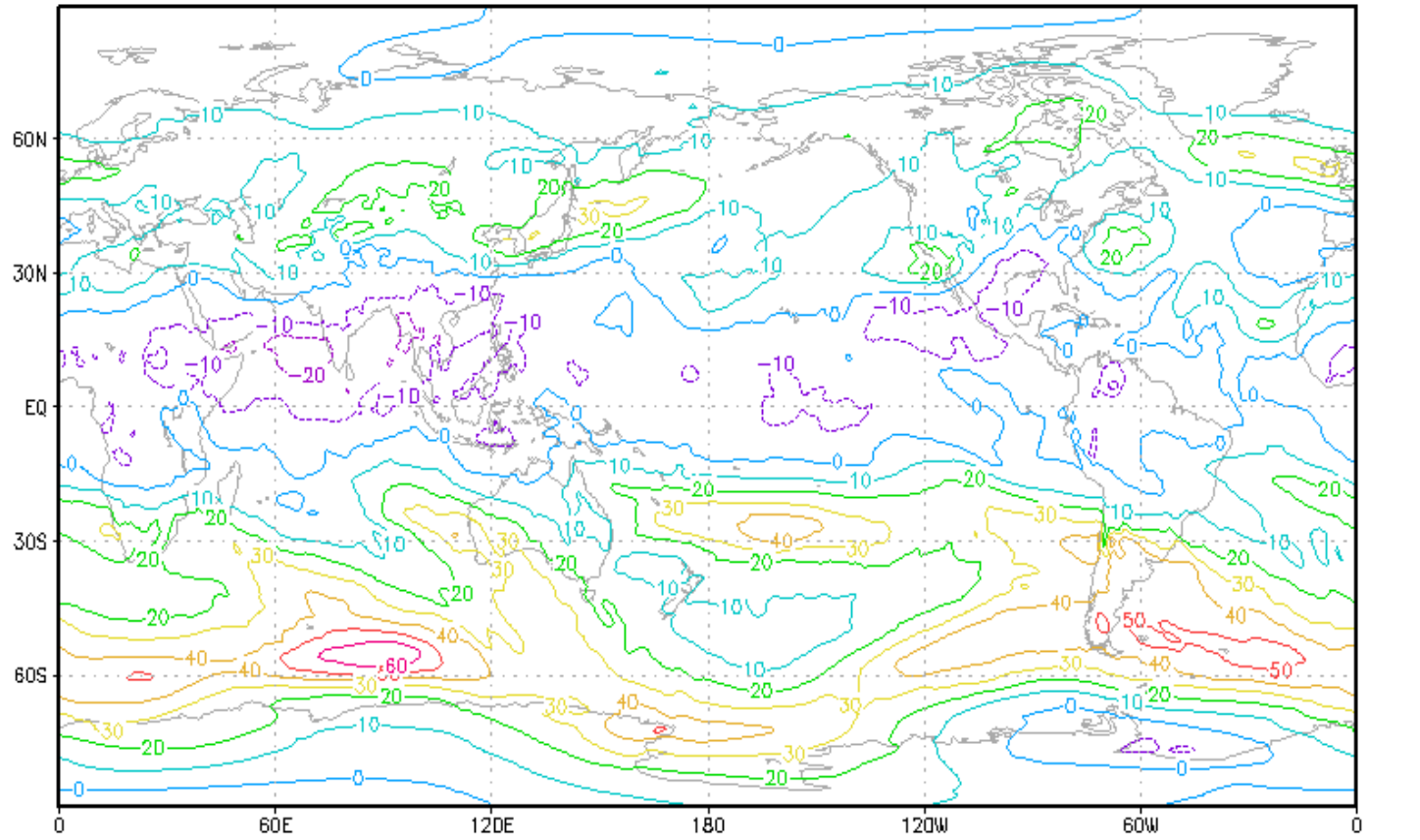
GFS forecast background. Conventional and satellite obs.

Zonal (u) component of wind on sigma level 40 sigma = 0.10777

Date:

21 Sep 2004

00UTC



Basic Assumptions (violated)

- Data (forecast and most observations) are unbiased
  - Radiosonde and others commonly biased
  - All forecast models have significant biases.
  - Satellite observations biased - but corrected.
- Observational errors normally distributed
  - Moisture errors not normally distributed because moisture cannot be < 0 or >> saturation.
- Background error uncorrelated to observational errors
  - May be true if not using retrievals
  - Representativeness error likely correlated

Anisotropic filtering in GSI