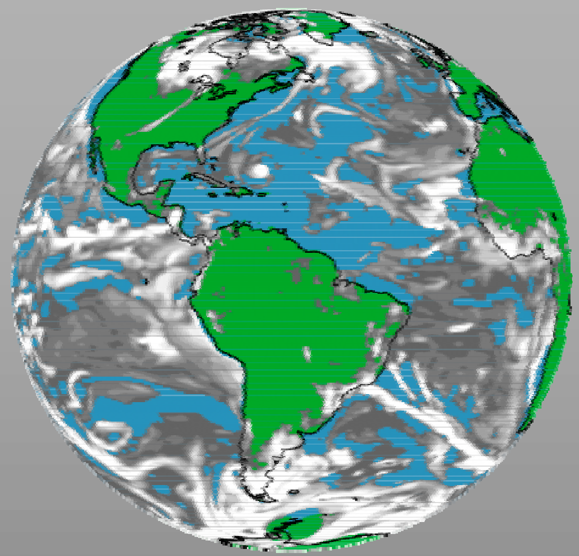


DAO’s m
mDm
Assmsm

Arlindo da Silva, SJ Lin, J. Joiner, D. Dee and

The fvDAS Development Team

Data Assimilation Office, NASA/GSFC

AIRS Workshop, 16-17 May 2001

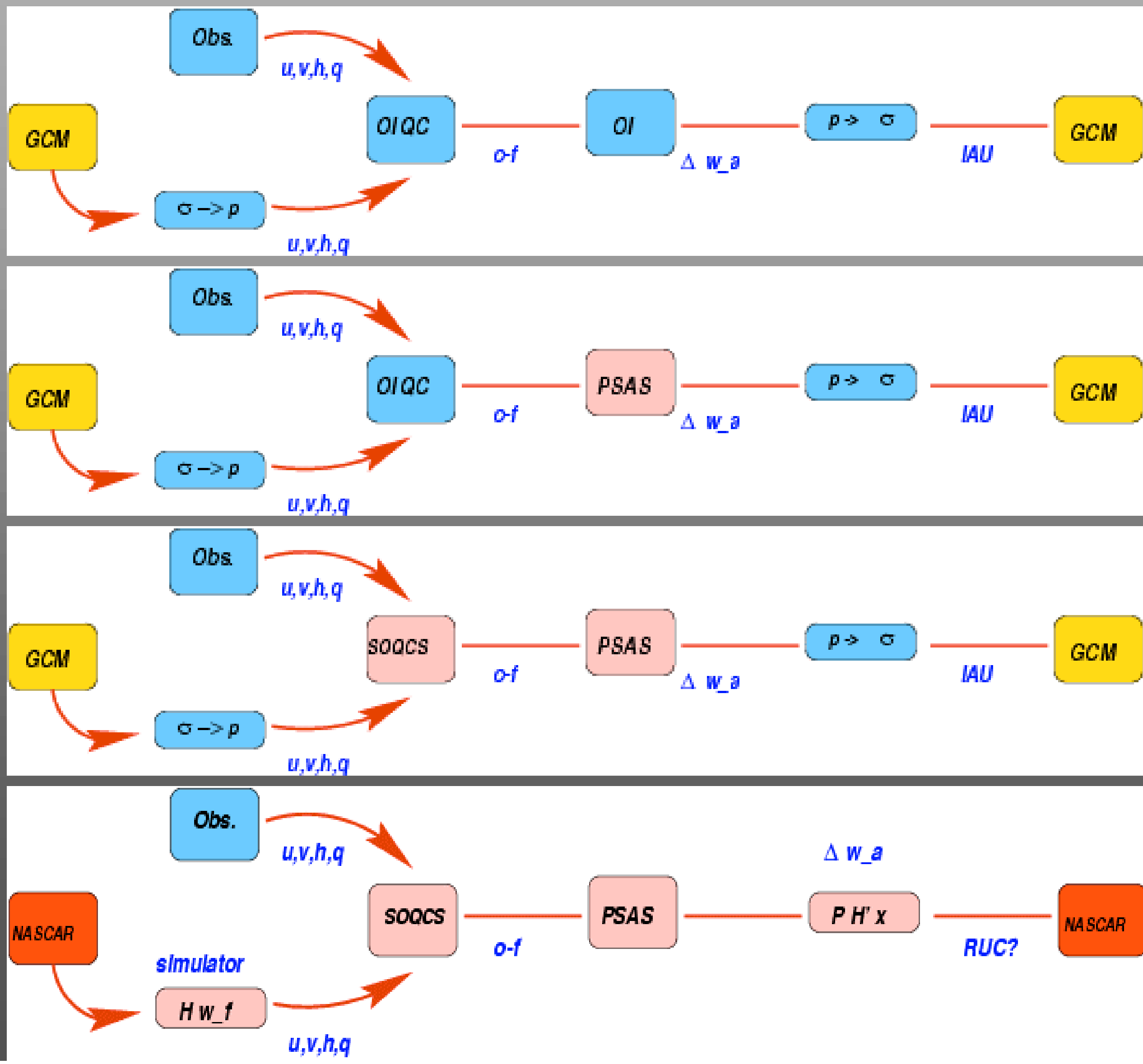
The fvDAS Development Team

- Arlindo da Silva
  - System design
  - Analyzer, observer, scripts
- S.-J. Lin
  - fvCCM, interface
- Joanna Joiner
  - iTOVS
- Jing Guo
  - PSAS library
- Dick Dee
  - QC, moisture/TPW analysis
- Genia Brin
  - SSM/I wind speed
- Meta Sienkiewicz
  - Thinner, NCEP Q/C
- Rob Lucchesi:
  - GFIO, pre-ops design
- Chris Redder
  - ODS library
- Sharon Nebuda
  - Interface, boundary conditions
- Tommy Owens:
  - Acquire
- Guang-Ping Lou
  - Digital filter, RUC

Outline

- Introduction
- System Overview
  - Finite-volume CCM
  - Quality control
  - PSAS
- Results
- AIRS related activities at DAO
- Constituent and land surface data assimilation

Data Assimilation at DAO



GEOS –1
Ca. 1992

GEOS-2
Ca. 1997

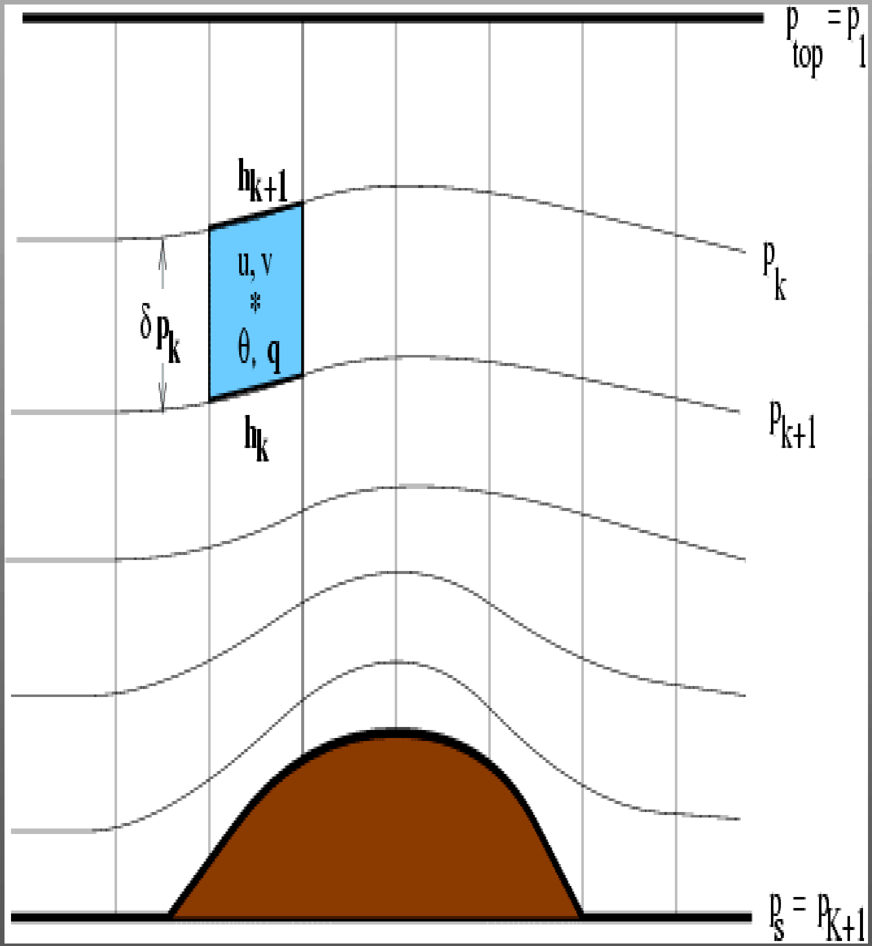
GEOS-3
Ca. 1999

GEOS-4
Ca. 2000

DAO's Finite-Volume DAS

- Finite-volume CCM (fvCCM3):
  - DAO's finite-volume dynamical core
  - NCAR's CCM 3 physics
- On-line Statistical Quality Control System (SQC):
  - Background and adaptive "buddy" check
- Physical-space Statistical Analysis System (PSAS)
- Carefully designed model-analysis interface:
  - Analysis increments produced on model levels
  - Unified surface/upper-air analysis
  - More accurate O-F computation from native fields

The fv Dynamical Core



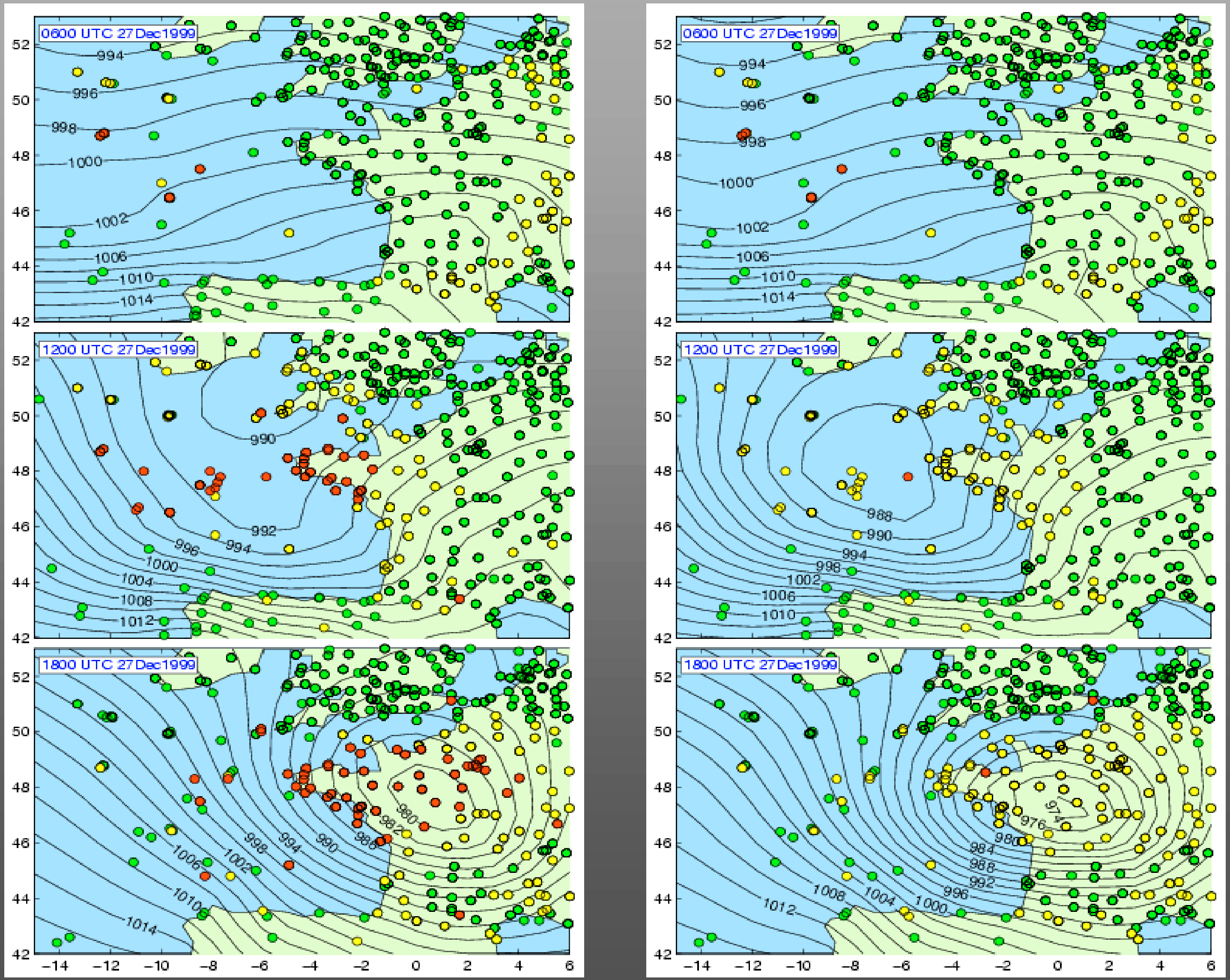
- Terrain following Lagrangian control-volume
- Basic conservation laws:
  - Mass
  - Momentum
  - Total energy
- 2D horizontal flux-form semi-Lagrangian discretization
  - Genuinely conservative
  - Gibbs oscillation free
  - Absolute vorticity consistently transported with mass dp.

Quality Control

- NCEP's Complex Quality Control
  - radiosonde temperature and moisture observations
- Background Check
  - simple check of the observations against a background field
- Adaptive Buddy Check:
  - adjusts error bounds according to the flow of the day.
  - Check suspect observations against nearby observations (buddies)

Adaptive Buddy Check

Non Adaptive Buddy Check



Adaptive Buddy Check

Analysis Equation

The analysis is obtained by minimizing the functional:

$$J(x) = \left(x - x^b\right)^T B^{-1} \left(x - x^b\right) + \left(y^o - \mathcal{H}(x)\right)^T R^{-1} \left(y^o - \mathcal{H}(x)\right)$$

where

x	(analysis) state vector	$\in \mathbb{R}^n$
x^b	background state vector	$\in \mathbb{R}^n$
y^o	observation vector	$\in \mathbb{R}^p$
$\mathcal{H}$	observation operator	$\in \mathbb{R}^{p \times n}$
B	background error covariance	$\in \mathbb{R}^{n \times n}$
R	observation error covariance	$\in \mathbb{R}^{p \times p}$
	$n \sim 10^6, \qquad p \sim 10^5$	

Main assumptions: unbiased observations and background, normaly distributed errors.

The PSAS Solver

PSAS: Physical-space Statistical Analysis System

Linearized Solution: Problem is solved in observation (dual) space in two steps:

$$\begin{aligned}(HBH^T + R)z &= y^o - Hx^b \qquad (*)\\ x^a &= x^b + BH^T z\end{aligned}$$

The linear system (*) is solved globally with an iterative pre-conditioned Conjugate Gradient algorithm.

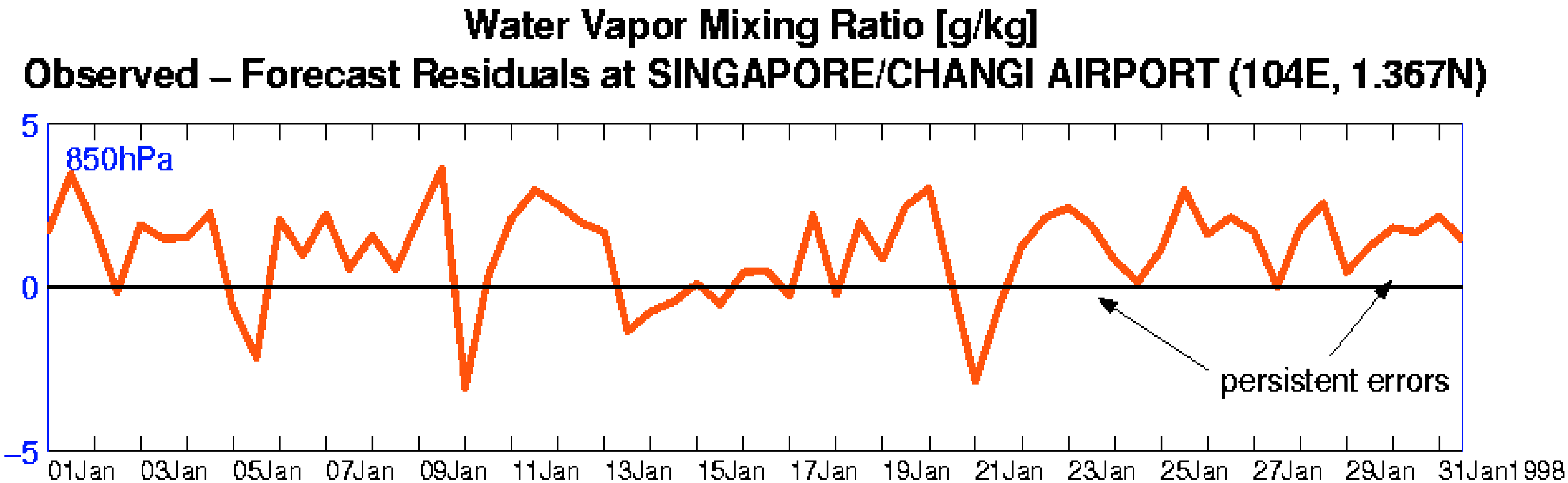
Pre-conditioner: sphere is divided in several regions and (*) is solved locally in each region.

Approximations: A compactly supported correlation function is assumed. Regions separated by more than a pre-determined distance (usually 6,000 km) are assumed not correlated.

Non-linear PSAS: involves sucessive linearizations (quasi-Newton iterations)

Forecast Model Bias

• Lots of evidence that actual errors have large systematic components



• In combination with a changing observing system, model bias will induce spurious climate signals

• Many examples of manifestations in atmospheric reanalysis data sets

Data Assimilation with Bias

The analysis equation

$$w^a = w^f + K\left(w^o - Hw^f\right)$$

has been derived under the assumption of no forecast bias. Defining,

$$e^a = w^a - w^t, \qquad e^f = w^f - w^t, etc$$

It follows that

$$e^a = e^f + K\left(e^o - He^f\right)$$

If we assume that observations are unbiased ($\overline{e^o} = 0$), but not the forecast, it follows that the analysis will be biased:

$$\overline{e^a} = (I - KH)\overline{e^f}$$

Unbiased Analysis Equation

Dee and da Silva (1998) showed how to produce unbiased analysis when the forecast is biased.

The idea is to provide a running estimate of the bias to correct the forecast accordingly. The modified two-step algorithm is:

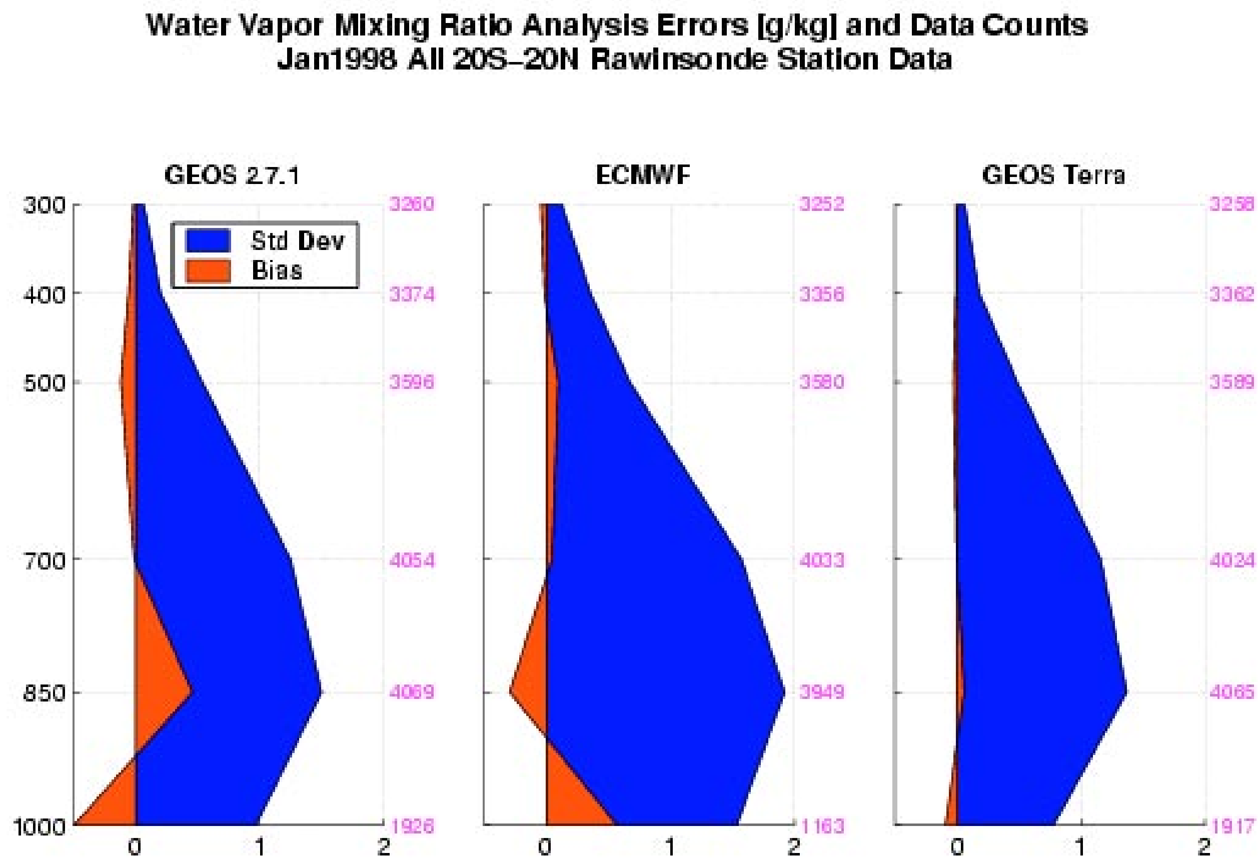
1. Forecast bias estimation:

$$b^f = b^f - L\left[w^o - (w^f - b^f)\right]$$

2. Unbiased analysis equation:

$$w^a = (w^f - b^f) + K\left[w^o - (w^f - b^f)\right]$$

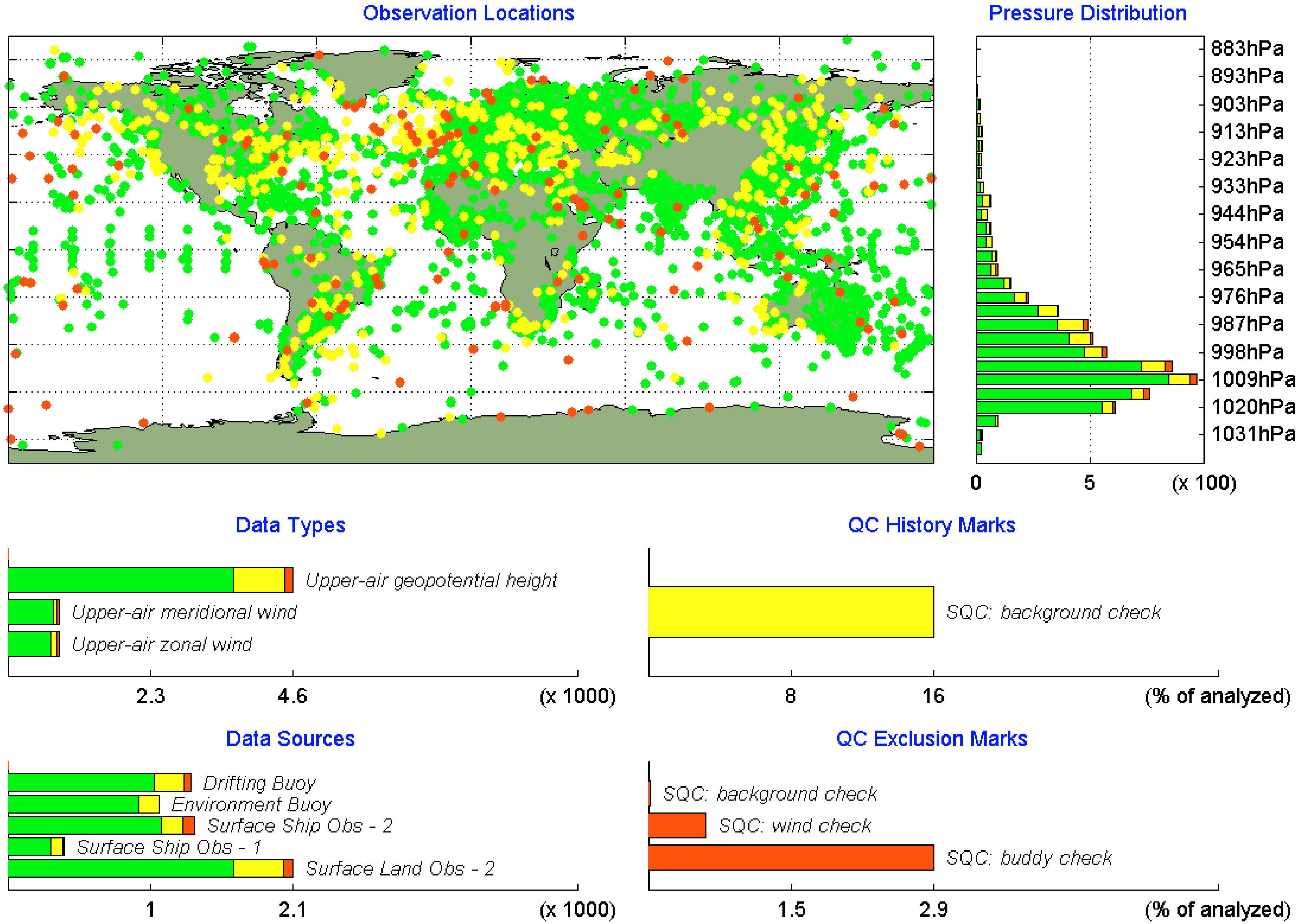
Water Vapor: Mean Obs - Analysis



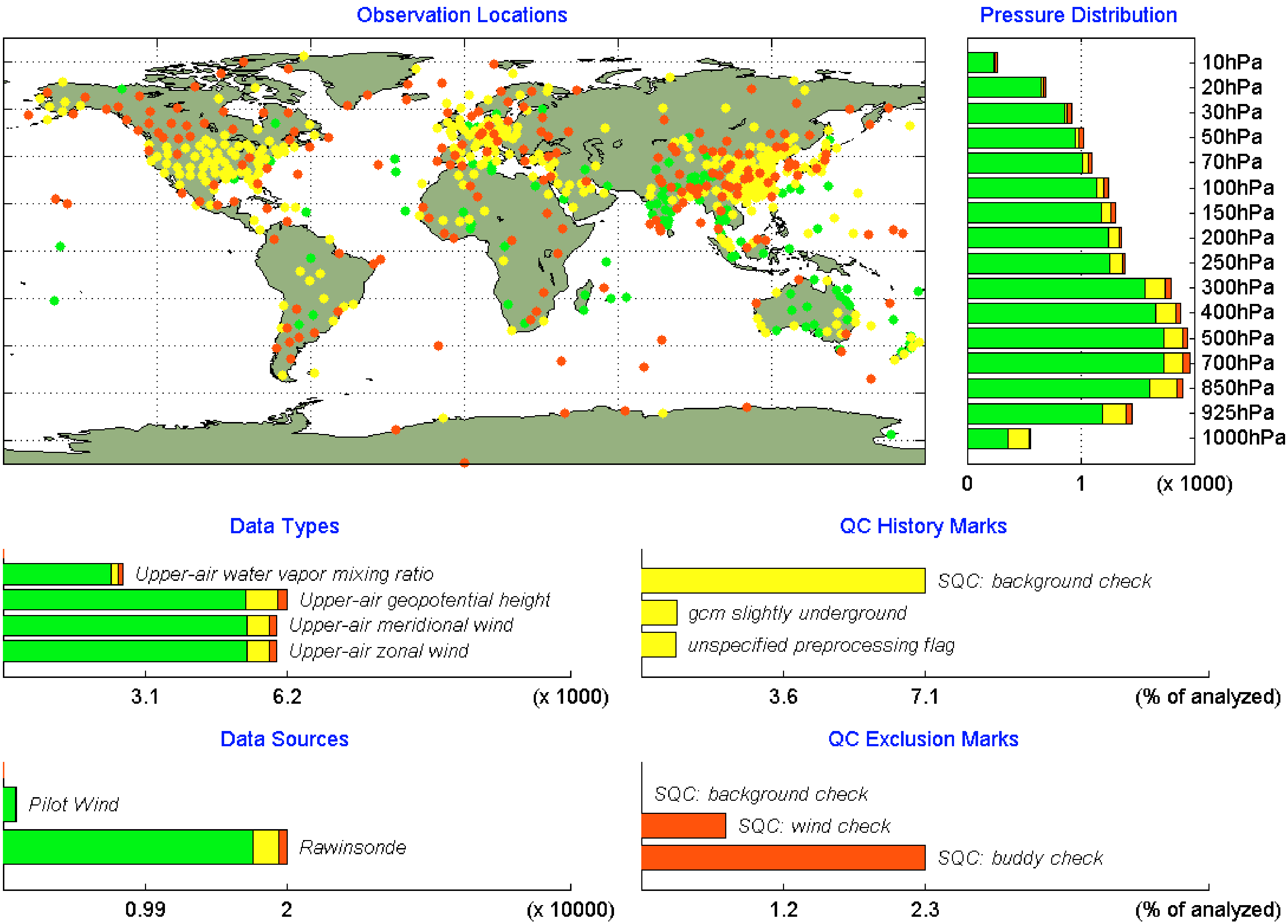
Observing System I

- Land Surface observations: slp
- Ocean surface observations: slp, u & v
- Rawinsondes: h, u, v and q at mandatory levels
- Aircraft winds: u and v, conventional & ACARS
- Cloud track winds: u and v, visible, and IR
- SSM/I: wind speed and TPW
- Scatterometers: QSCAT and ERS

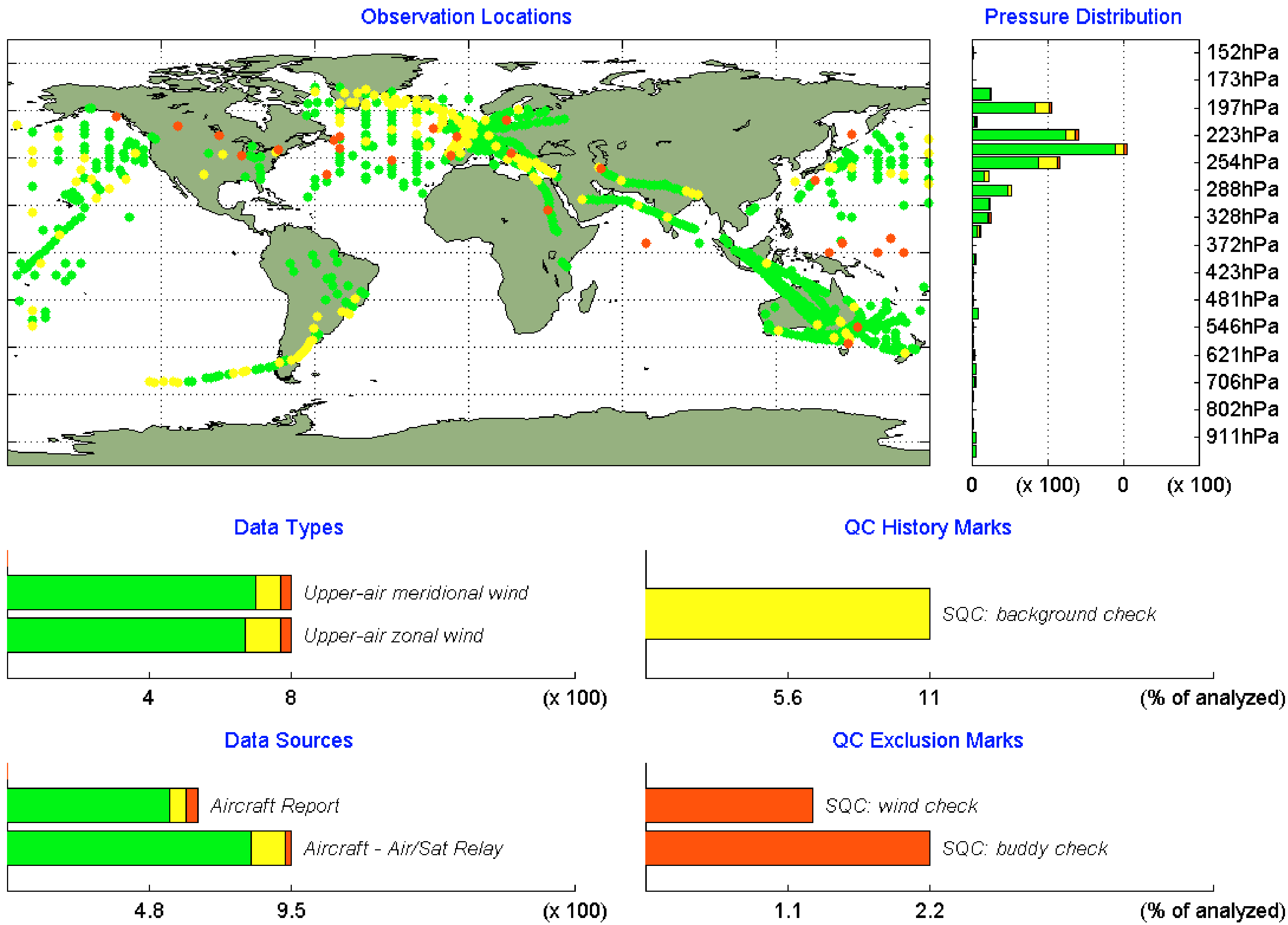
01Jan1999 12Z Surface data (6088 analyzed)

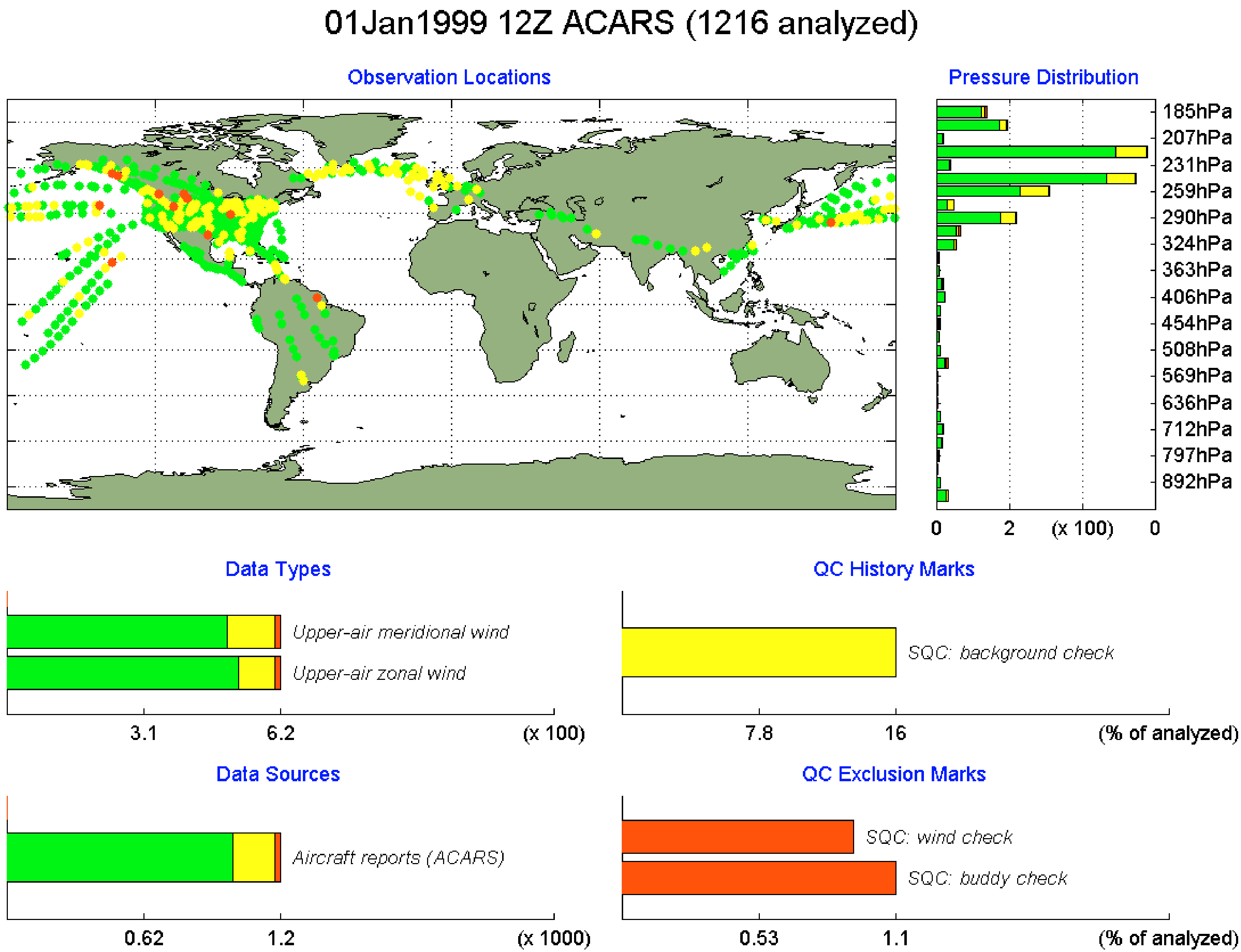


01Jan1999 12Z Radiosondes (20204 analyzed)

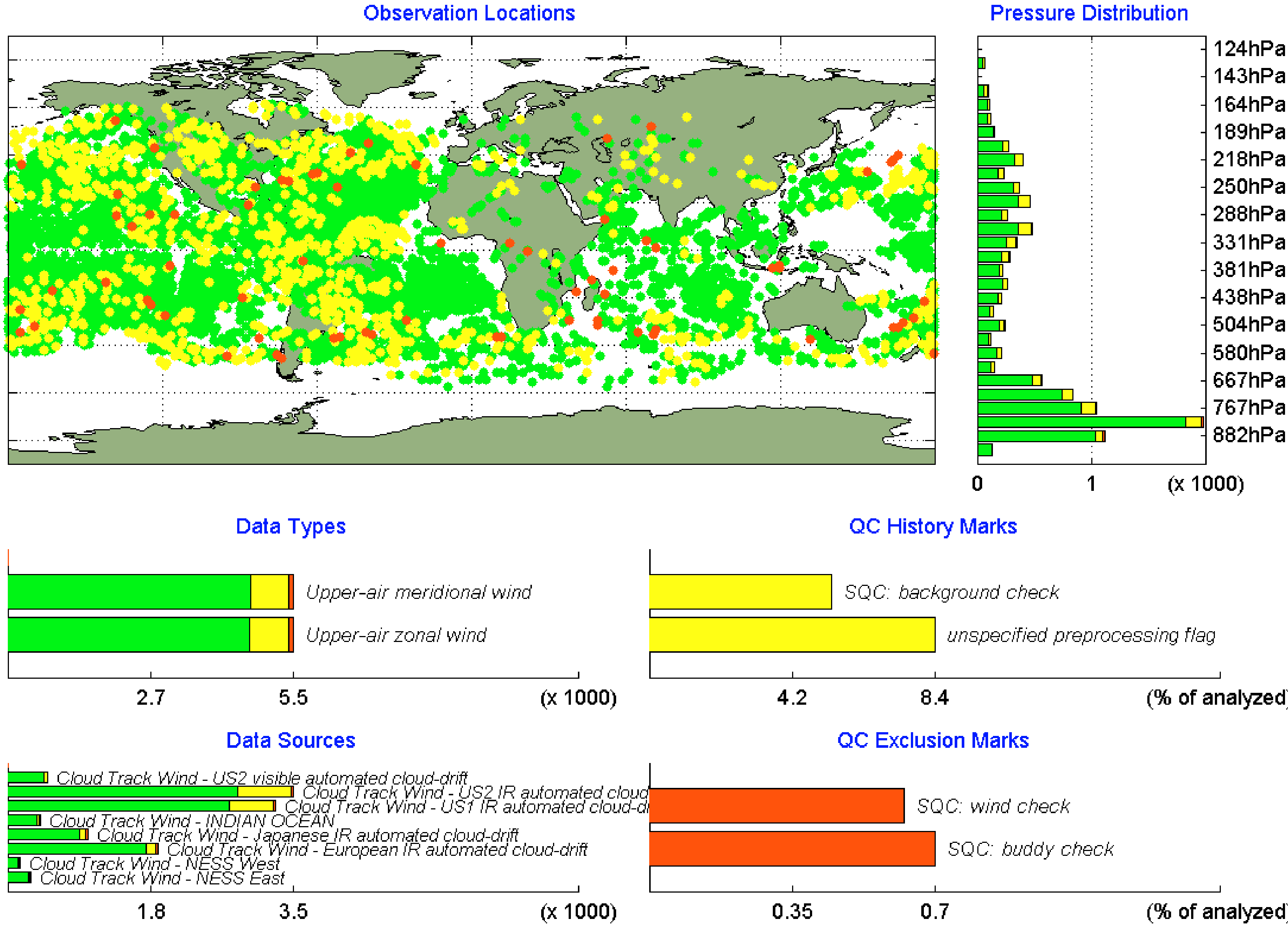


01Jan1999 12Z AIREP (1540 analyzed)

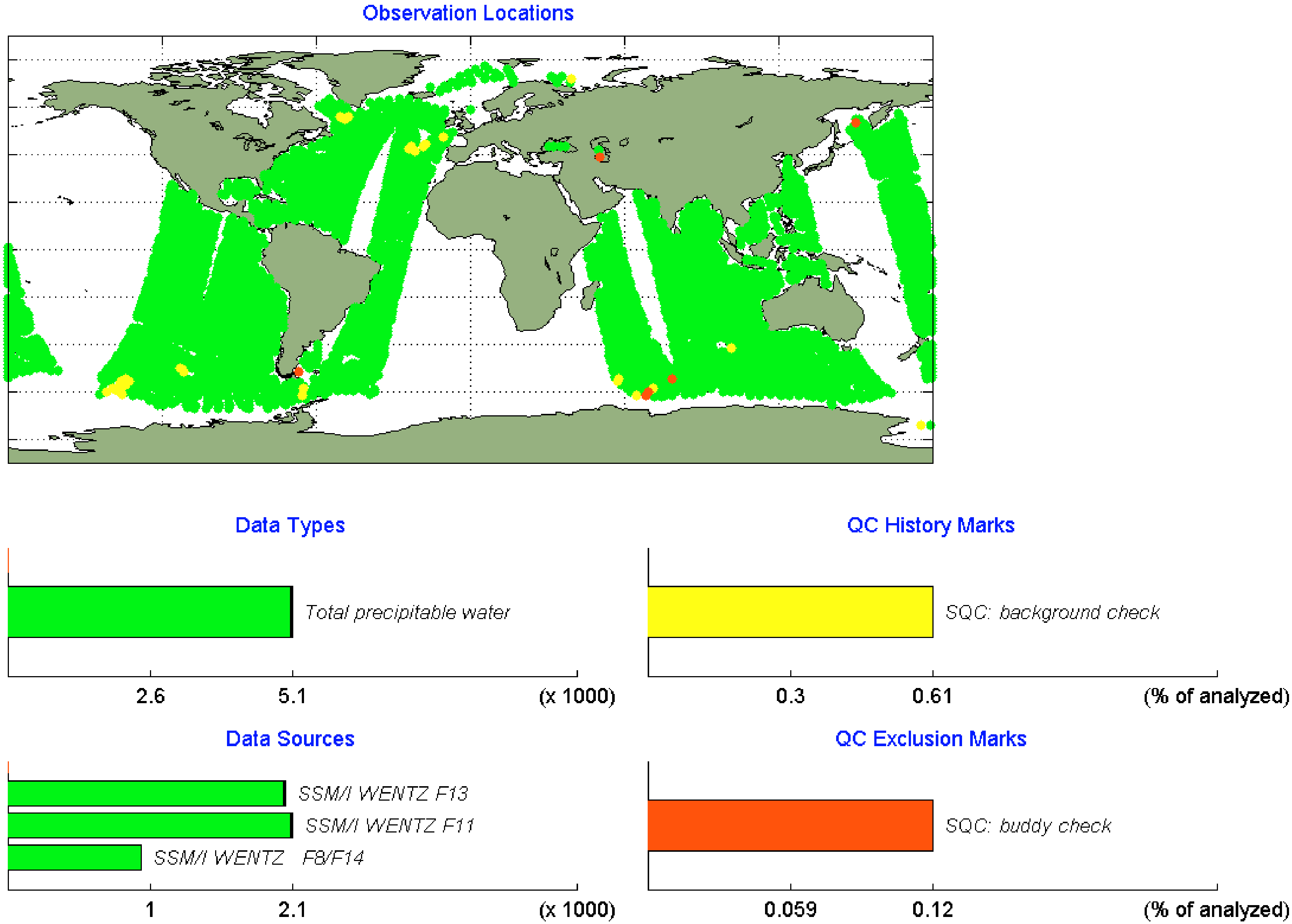



01Jan1999 12Z ACARS (1216 analyzed)
Observation Locations
Pressure Distribution
185hPa
207hPa
231hPa
259hPa
290hPa
324hPa
363hPa
406hPa
454hPa
508hPa
569hPa
636hPa
712hPa
797hPa
892hPa
0
2
(x 100)
0
Data Types
Upper-air meridional wind
Upper-air zonal wind
3.1
6.2
(x 100)
QC History Marks
SQC: background check
7.8
16
(% of analyzed)
Data Sources
Aircraft reports (ACARS)
0.62
1.2
(x 1000)
QC Exclusion Marks
SQC: wind check
SQC: buddy check
0.53
1.1
(% of analyzed)

01Jan1999 12Z Cloud track winds (10812 analyzed)

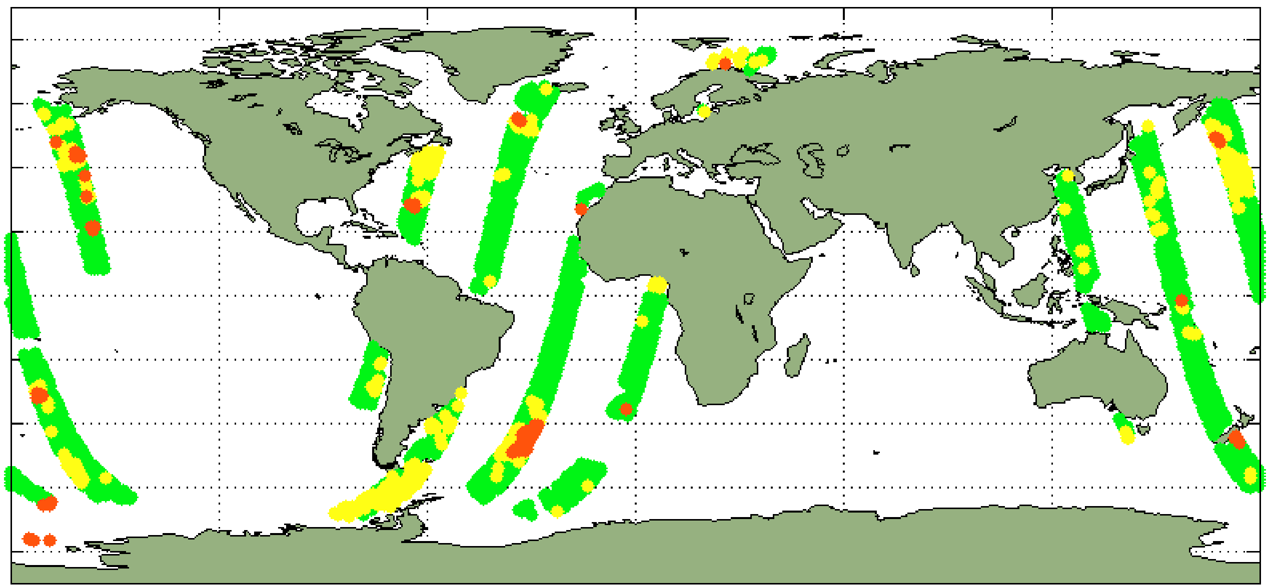


01Jan1999 12Z SSM/I TPW (5119 analyzed)

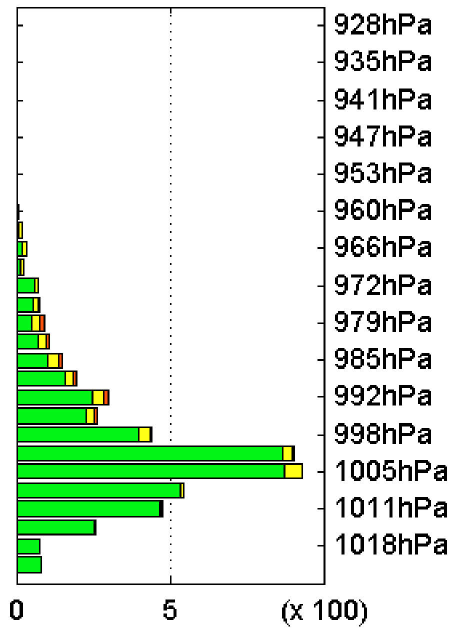


01Jan1999 12Z ERS (4948 analyzed)

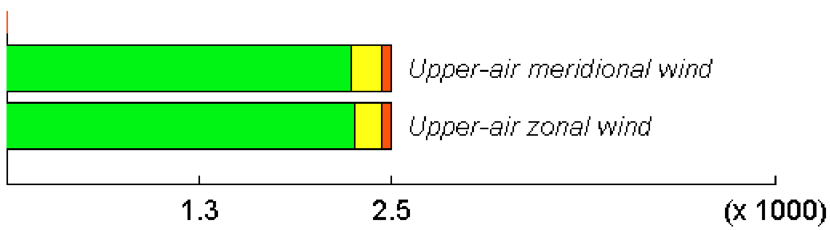
Observation Locations



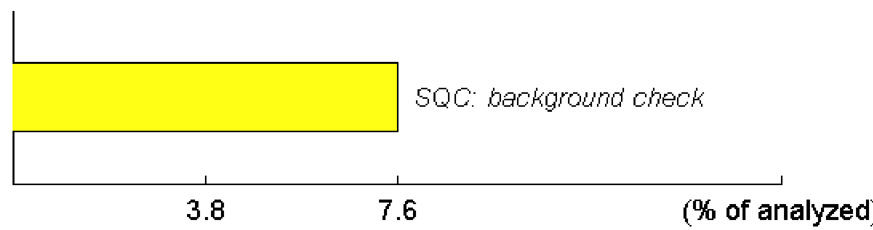
Pressure Distribution



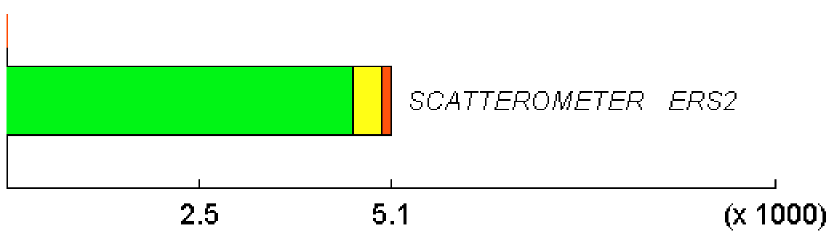
Data Types



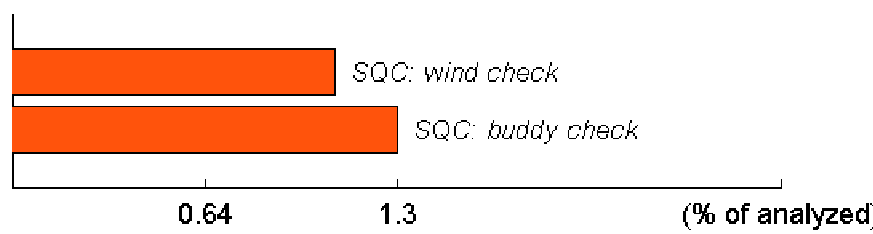
QC History Marks



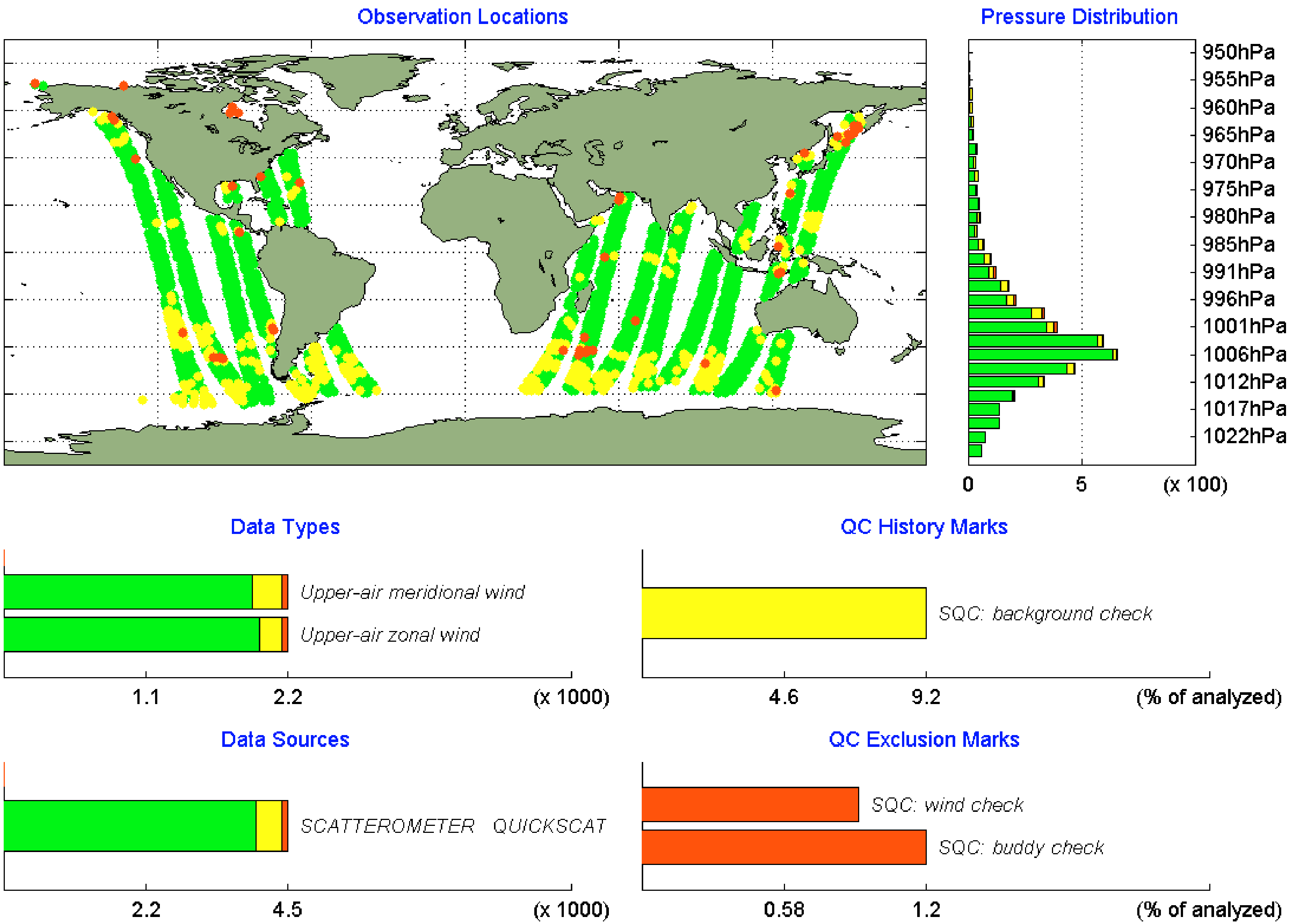
Data Sources



QC Exclusion Marks



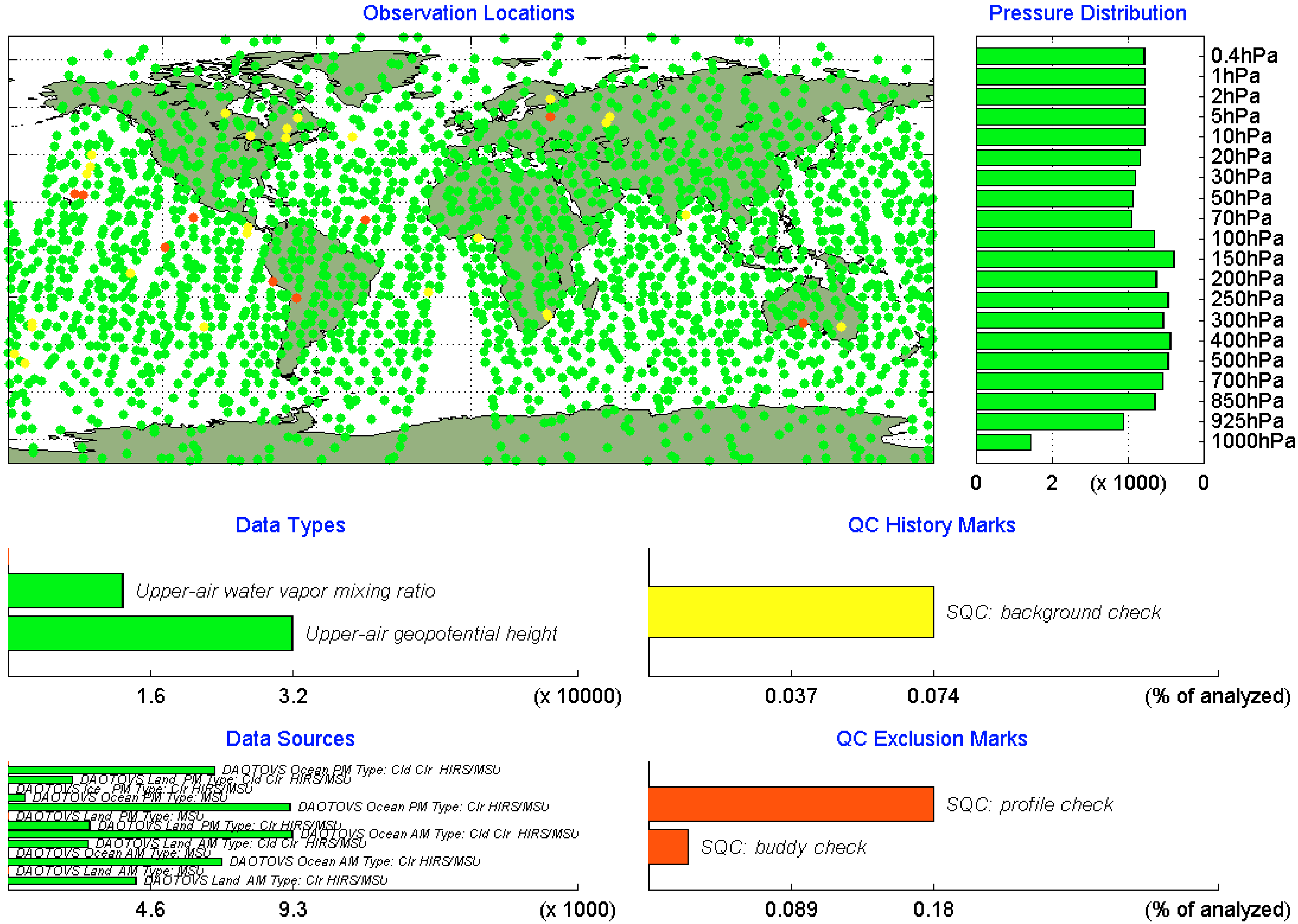
01Aug1999 12Z QSCAT (4392 analyzed)



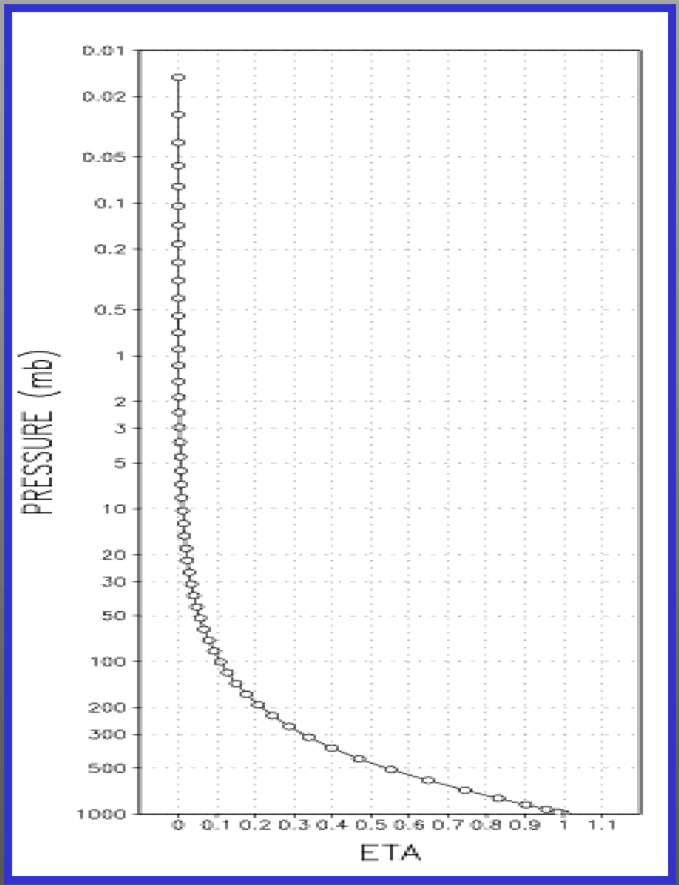
Observing System II

- DAOTOVS 1D-Var Assimilation of Radiances:
  - Uses Level 1b data
  - HIRS, SSU and AMSU radiances
  - Variational cloud-clearing (Joiner and Rokke, 2000)
  - Eigenvector FOV determination (AIRS ATBD)
  - Physically-based tuning
  - GLATOVS, MIT -> OPTRAN (NASA/NOAA collaboration)

01Jan1999 12Z iTOVS (44403 analyzed)

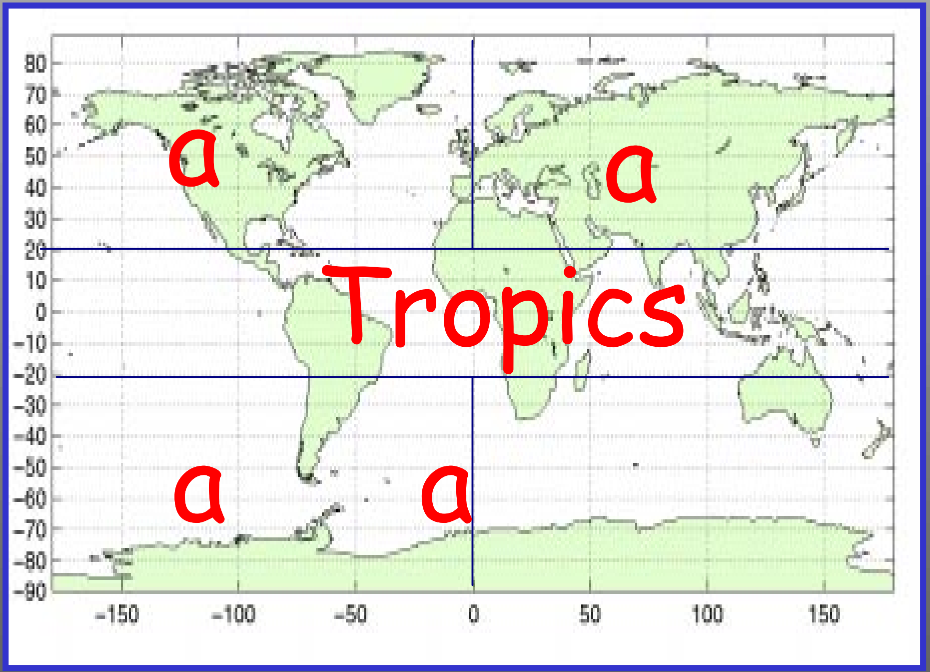


Resolution



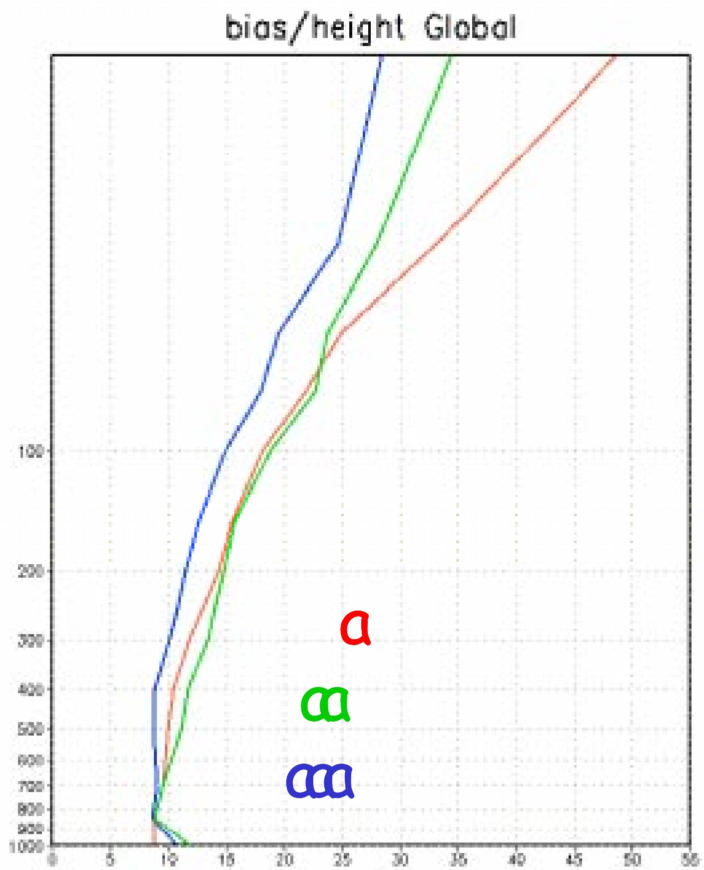
- Model Horizontal Resolution:
  - 2x2.5 degrees
  - 1x1.25 degrees
- Model Vertical Resolution:
  - 55 layers
  - Top at 0.01 hPa
- Analysis Resolution:
  - Full or half model horizontal resolution
  - 25 layers, top 0.4 hPa

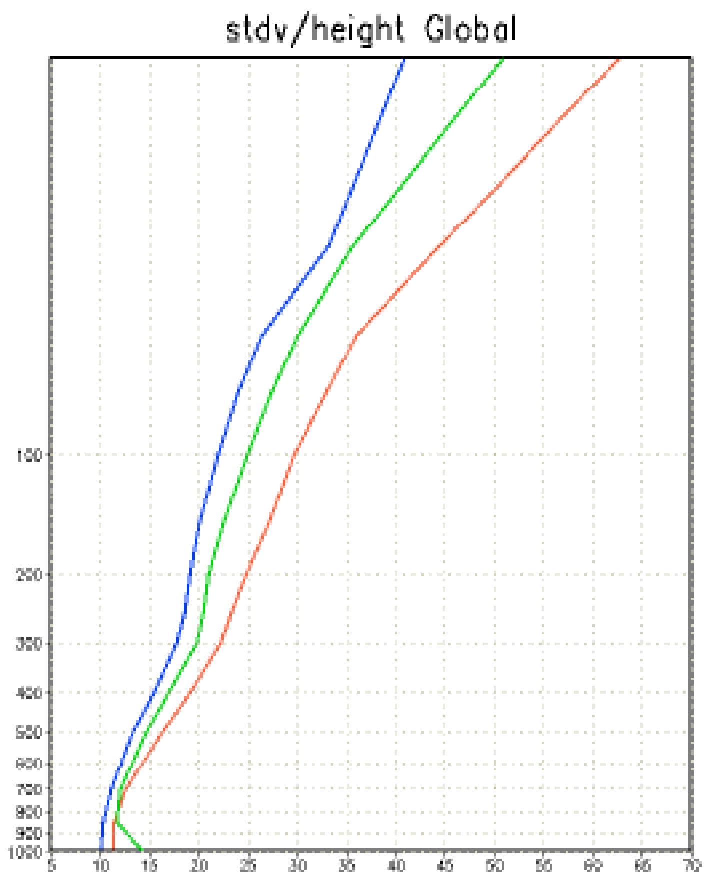
O-F Statistics



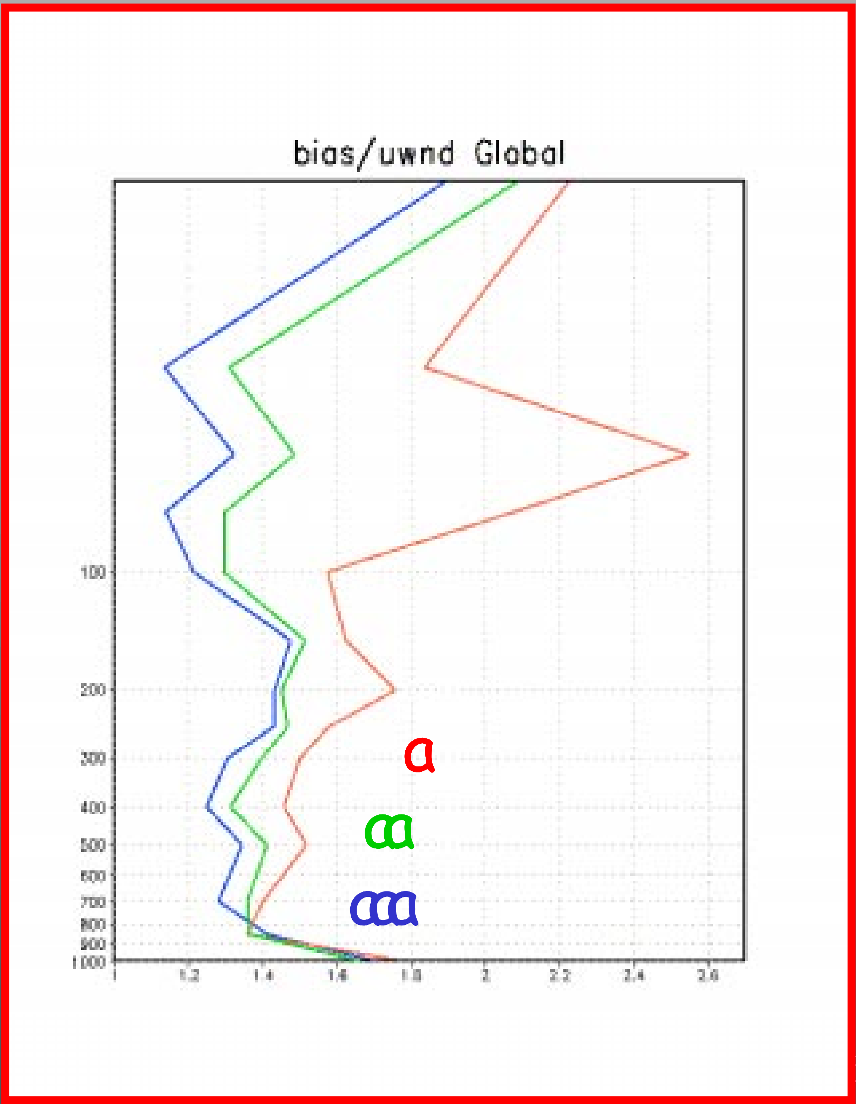
- Fit to Rawinsonde & other observations
- Obs – 6h Forecast
- Bias (time mean)
- Standard Deviations
- Globally (rms) averaged
- Regionally (rms) averaged

O-F: Height (Jan 1998)

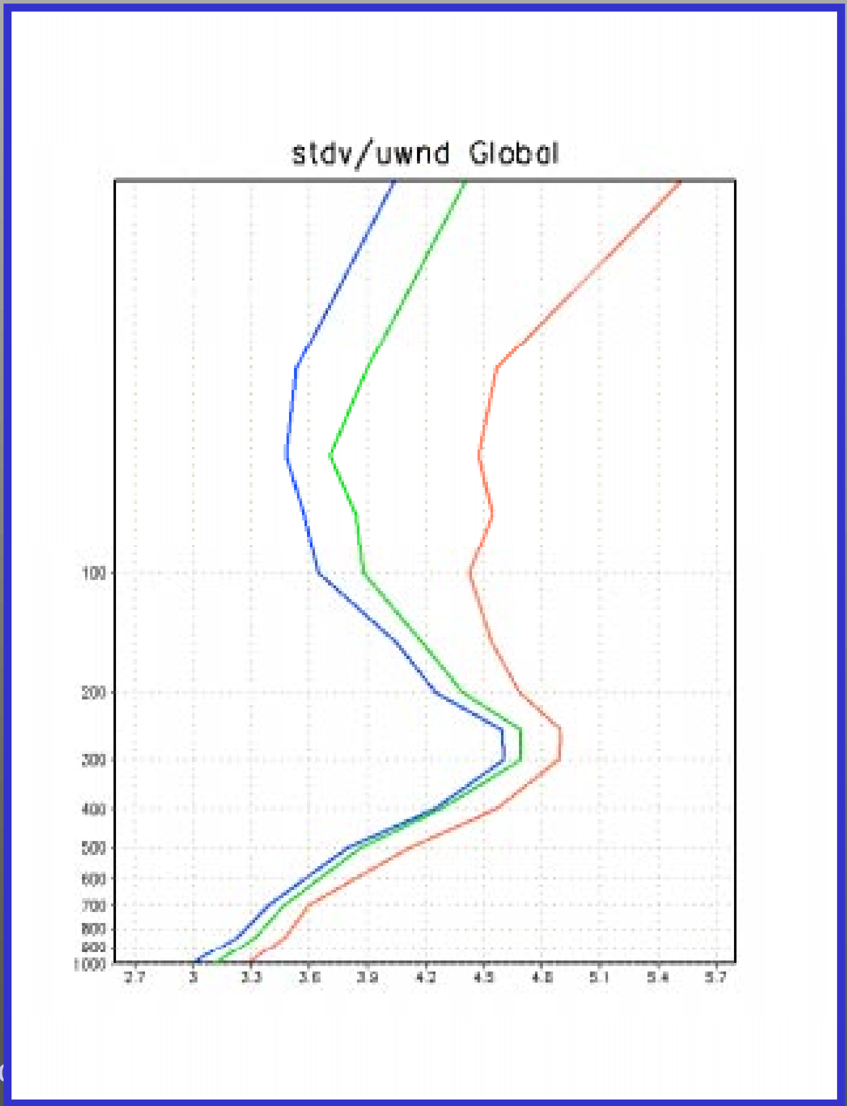




O-F: U-Wind (Jan 1998)

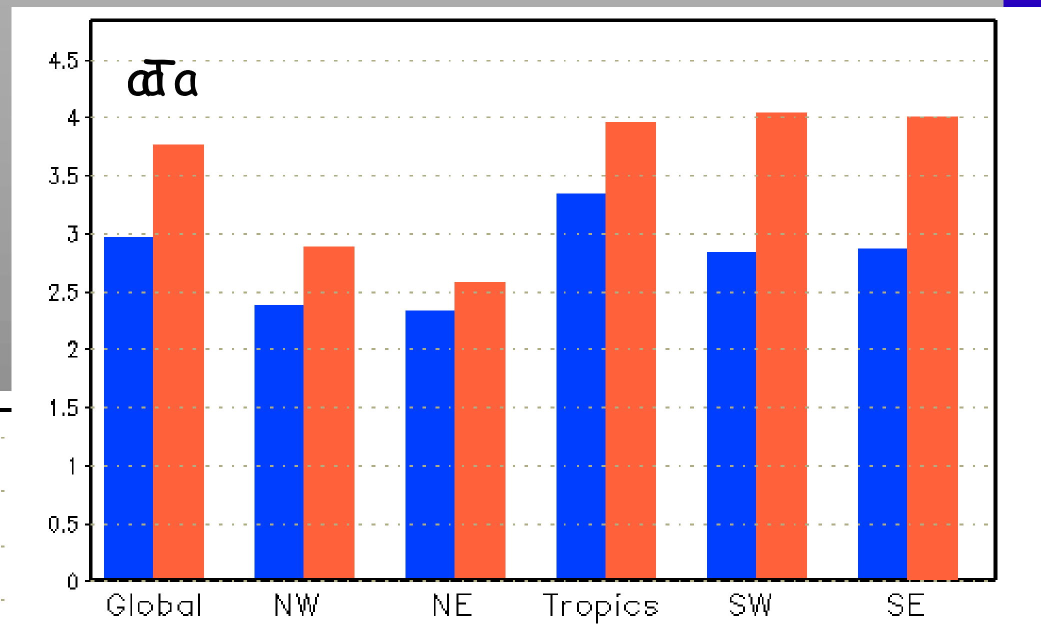


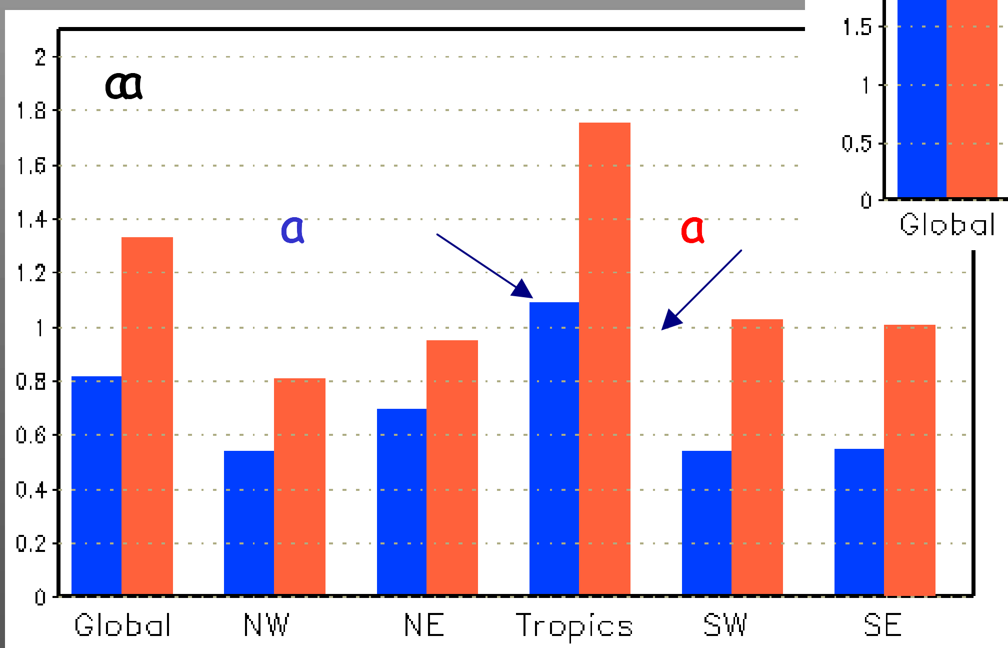
lo c



O-F: Total Precipitable H_2O

Toa
aaipia
a





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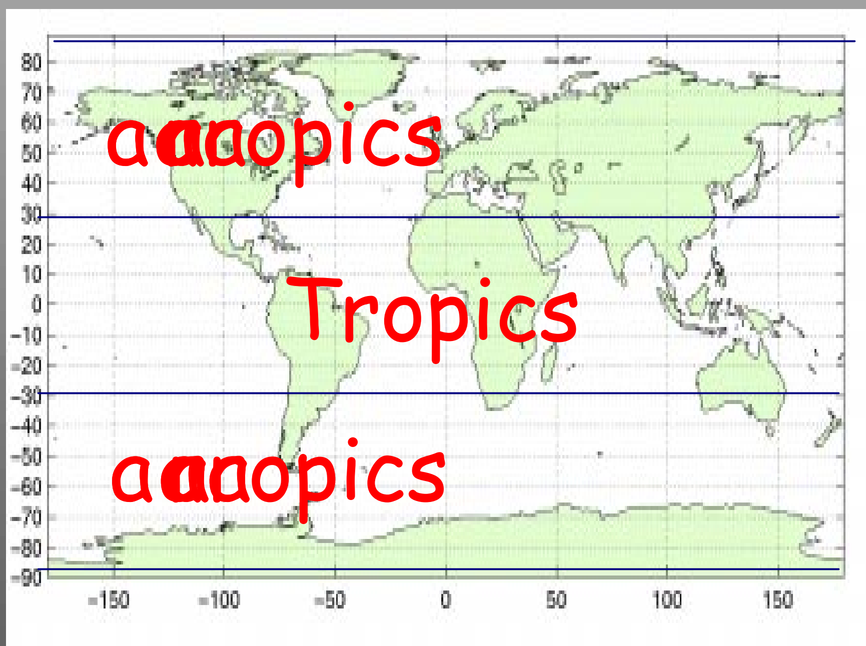
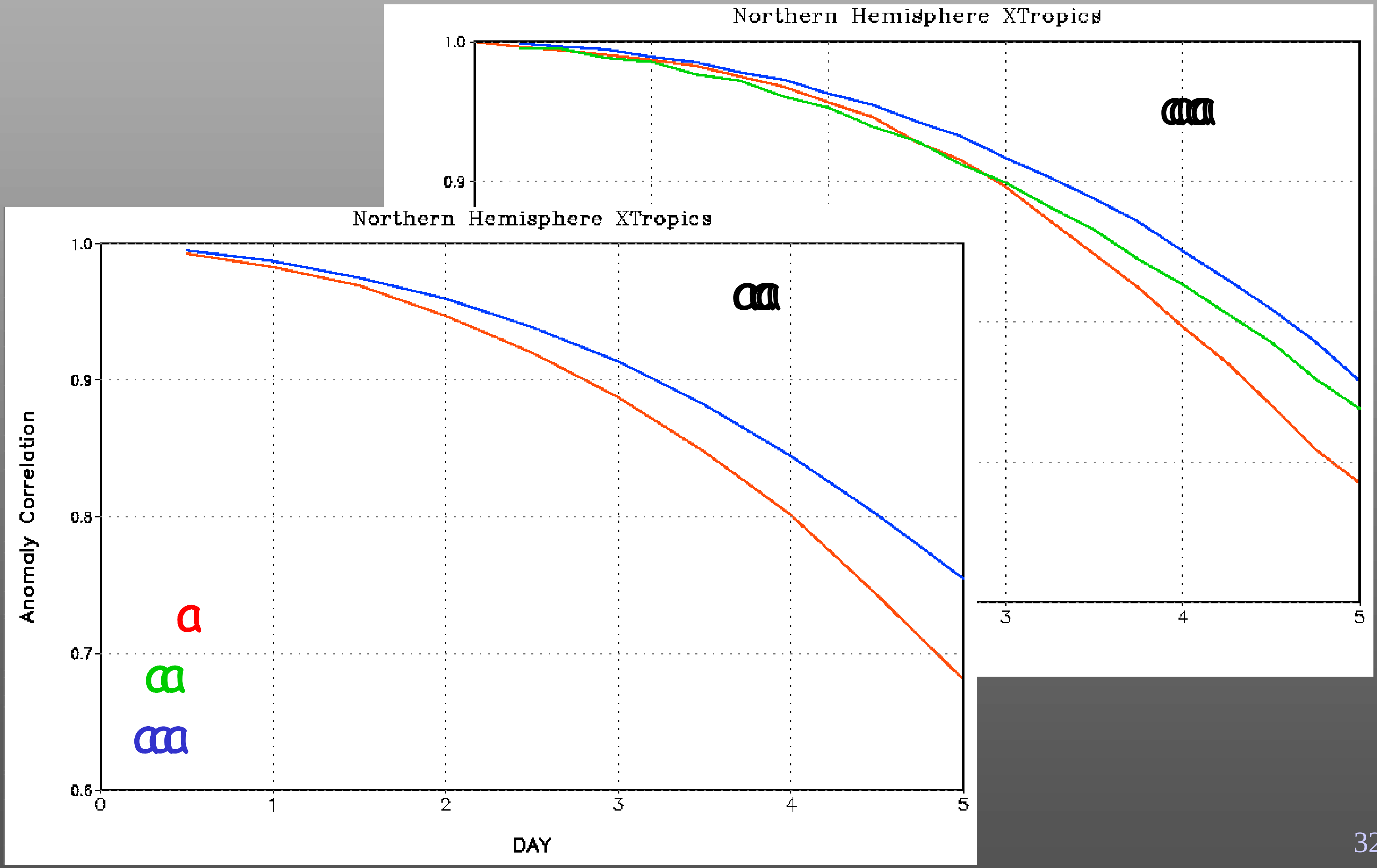
Forecast Skills

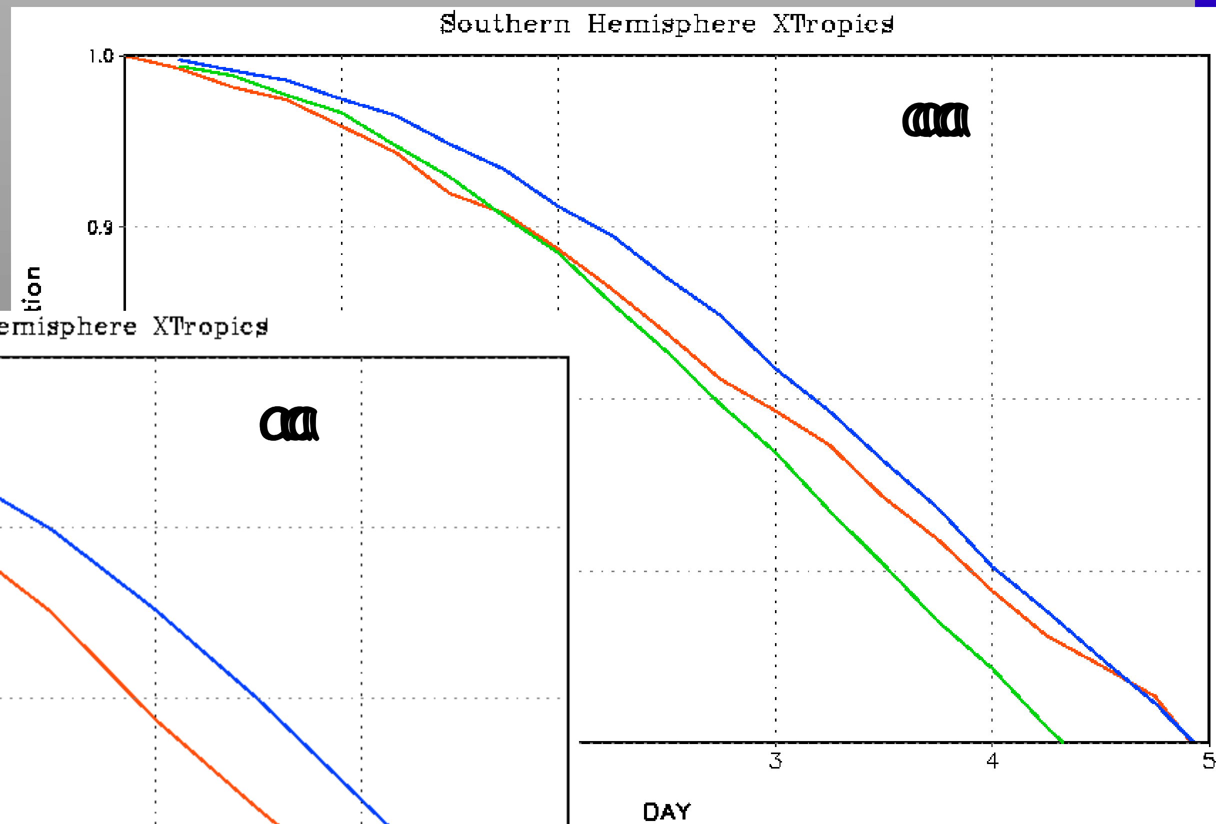


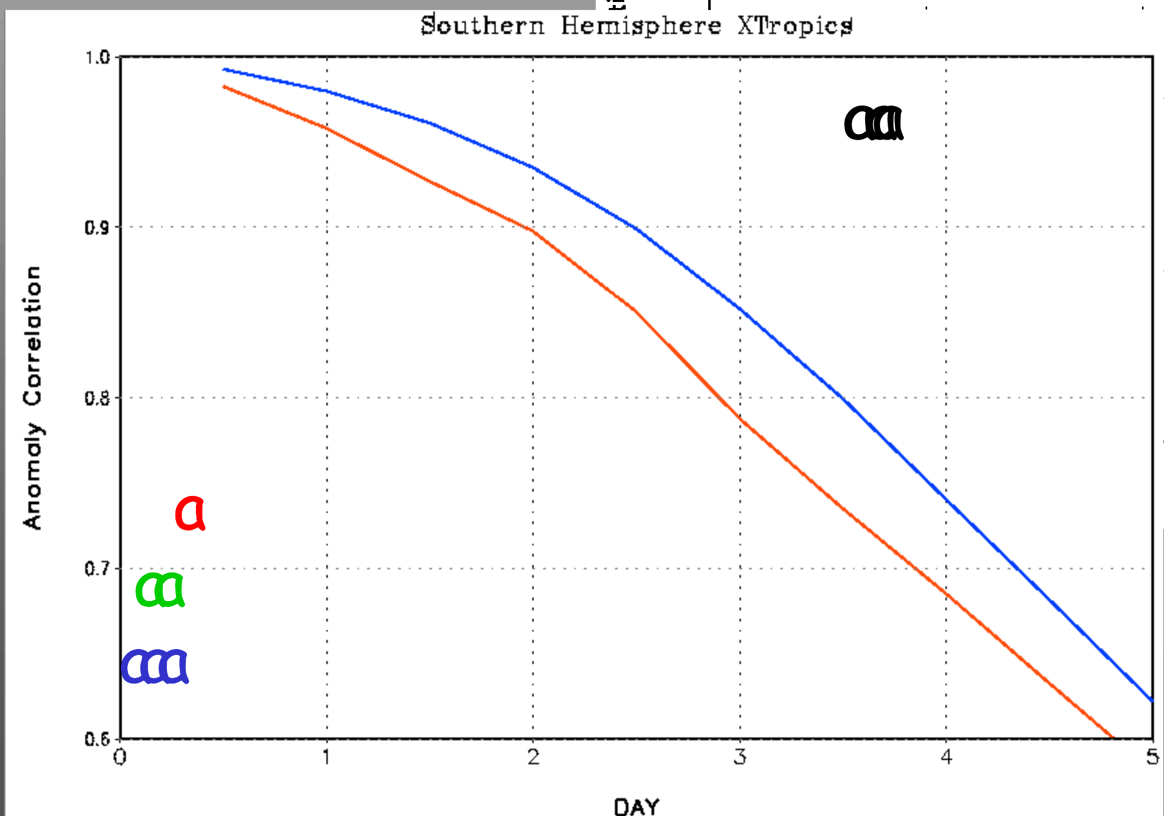
- Verification:
  - own analysis
- Climatology:
  - 1987-96 ECMWF operational analysis
  - Resolution: 2x2.5^{o}
- Area averaging:
  - RMS: YES
  - Anomaly correlation: NO
- Number of cases:
  - fvDAS: ~30 cases
  - GEOS: ~10 cases

AC: 500 hPa Heights (NH)

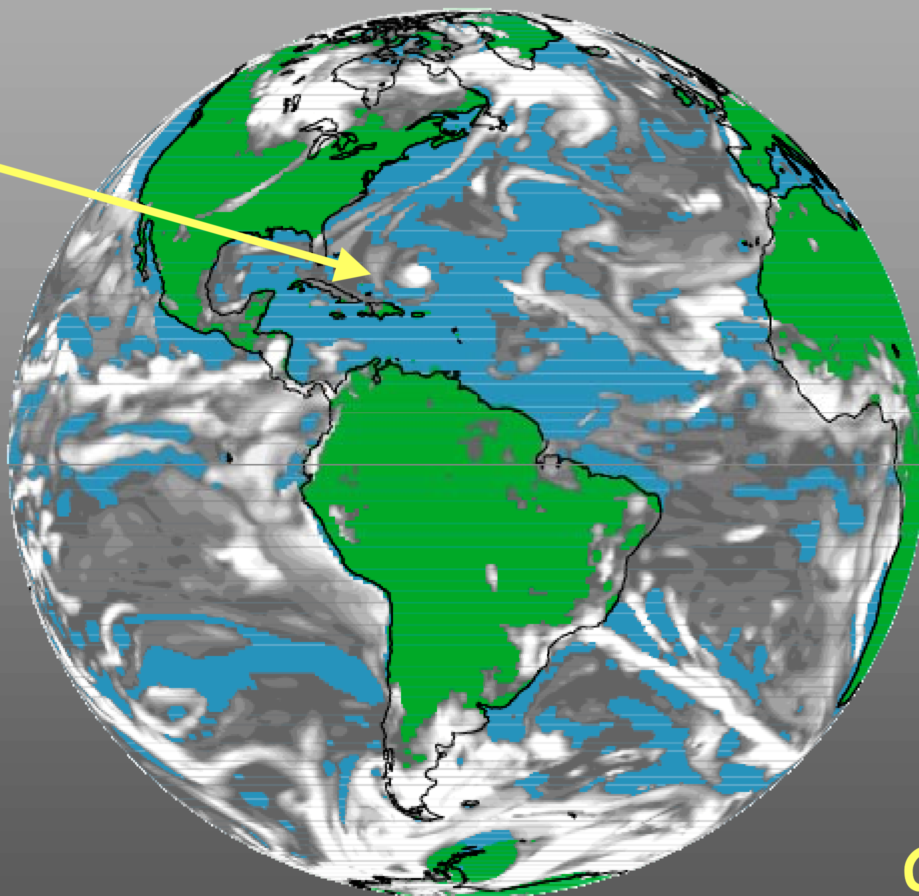


AC: 500 hPa Heights (SH)

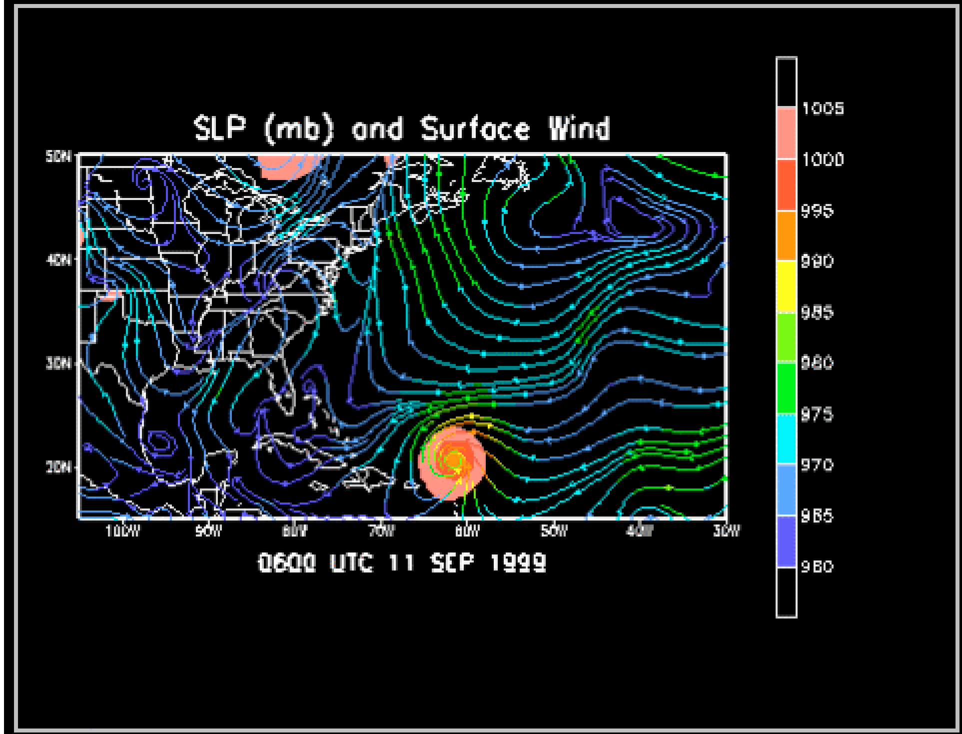


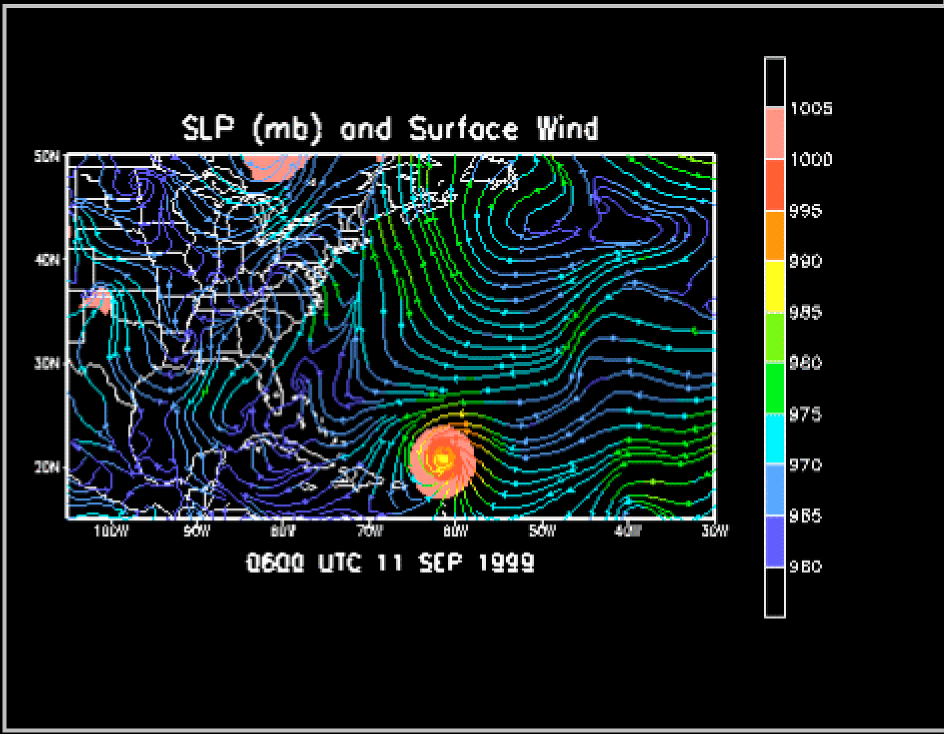


Hurricane Floyd

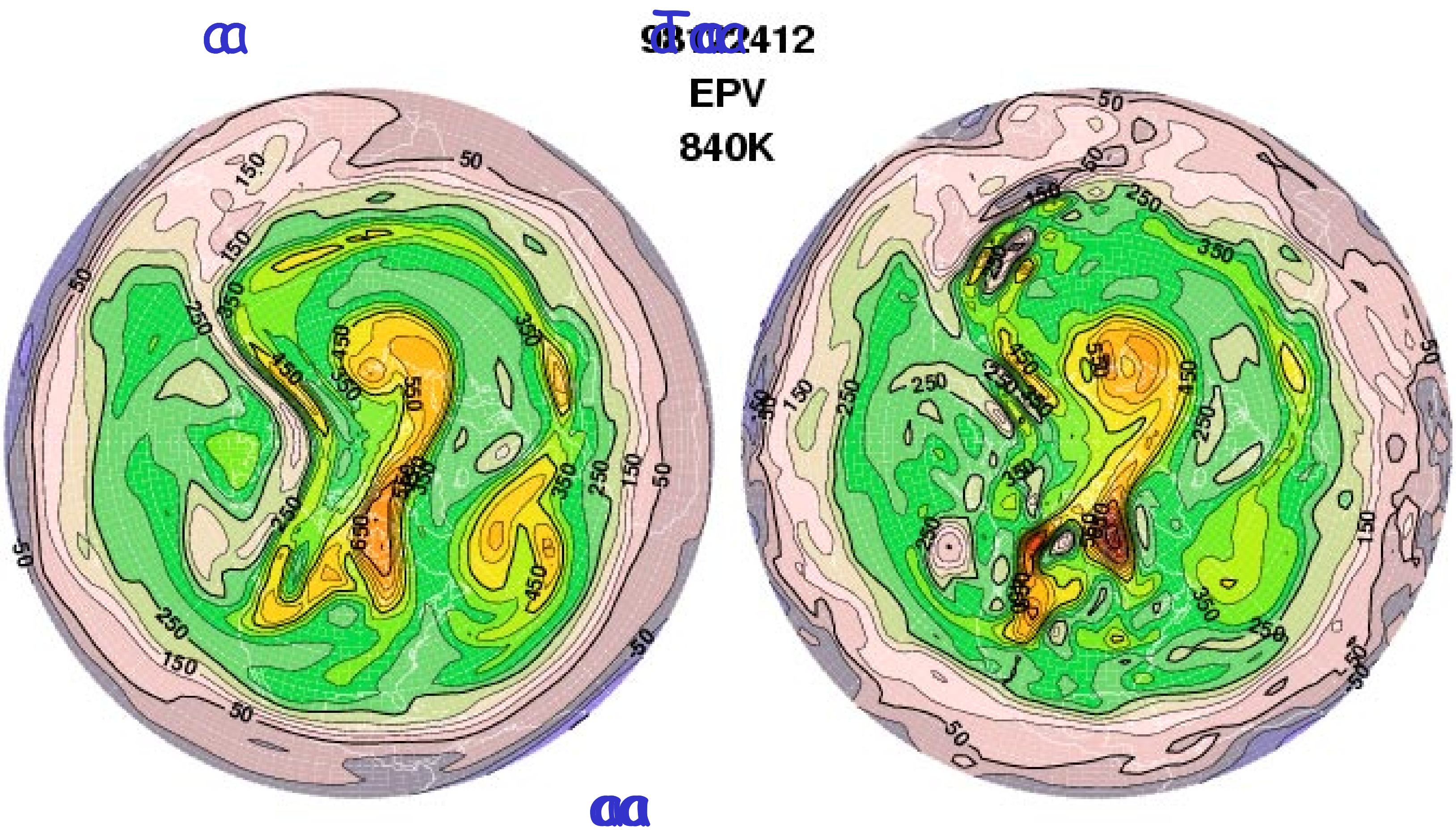


Hurricane Floyd

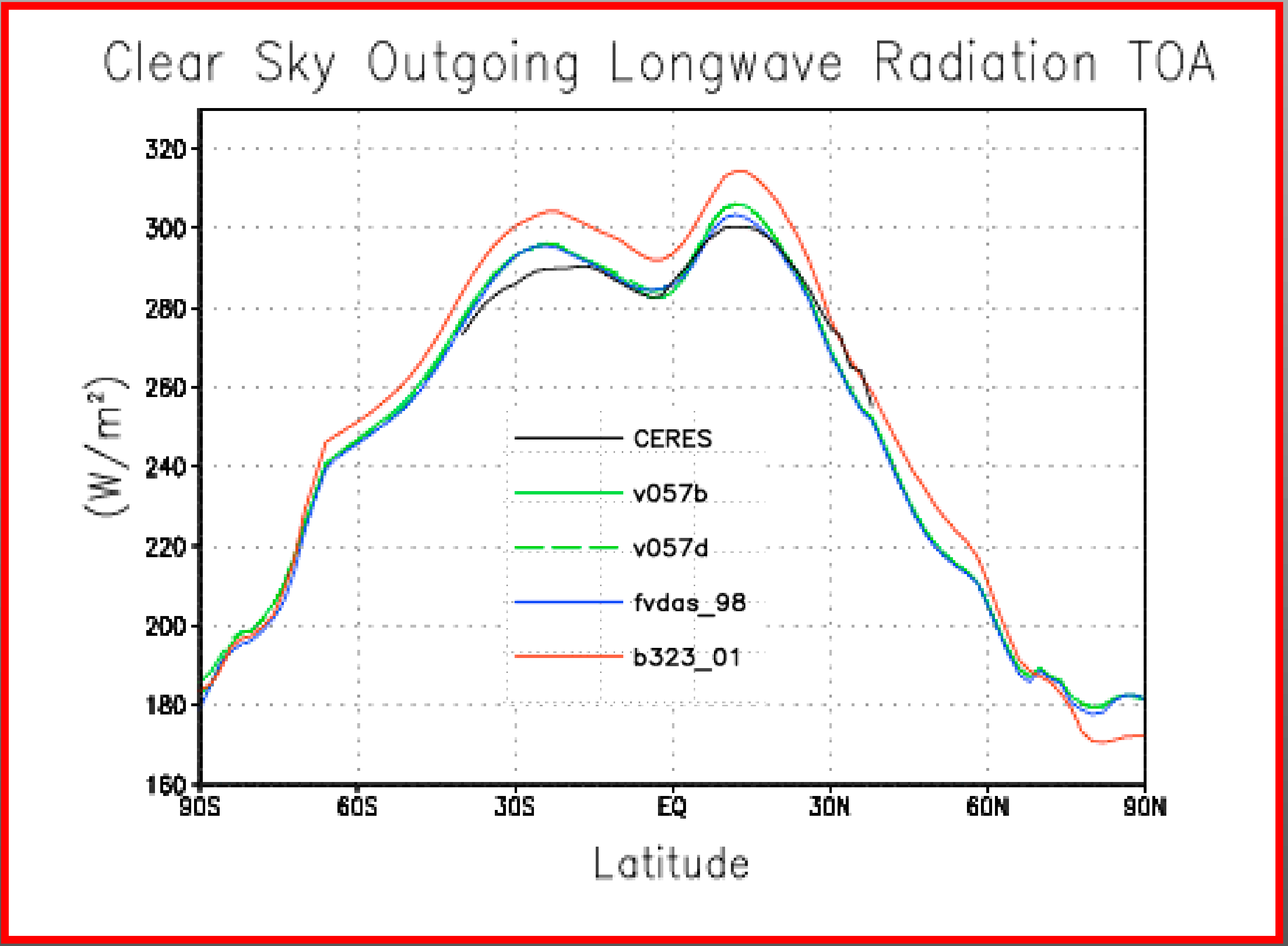




EPV @ 840K: 24 Jan 1999



TOA OLR: Clear Sky



Summary

- A fully featured fvDAS has been developed:
  - fvDAS runs much faster than current operational system
  - fvDAS has improved forecast skills and O-F statistics
  - fvDAS has a much improved stratospheric circulation
  - fvDAS has a competitive climate
- The system is under validation and is running in parallel mode (expected to become operational by Dec 2001)
- Work in progress:
  - Rapid update cycle (1 hour cycle)
  - Analysis bias estimation and correction
  - Precipitation assimilation

AIRS Activities at DAO

- DAO will be actively involved in AIRS validation:
  - Early evaluation of AIRS imagery by synoptic group
  - Radiance O-F monitoring
  - Evaluate AIRS ozone with DAO's ozone assimilation system
- Assimilation of AIRS data. DAO will be evaluating the following products:
  - Statistical retrievals by Mitch Goldberg
  - Physical retrievals by AIRS team
  - Interactive 1D-VAR scheme (DAO AIRS)
  - Assimilation of Level 1b radiances with information content-based scheme (Joiner and da Silva 1998)
- The best performing product will be selected for use in DAO's operational system.

Retrieval Error Specification

- Retrieval errors can be formally written as (e.g., Rodgers 1995):

$$\epsilon^r = (I - A)\epsilon^p + D_y\epsilon^o$$

where

A	averaging kernel ($= D_y F_z$)
$(I - A)\epsilon^p$	smoothing error (prior error)
$D_y\epsilon^o$	detector noise and forward model errors

- In PSAS, retrieval error covariances are statistically modeled as

$$R = R_c + R_u$$

where R_c/R_u are spatially correlated/uncorrelated components; background-retrieval cross-correlations are presently ignored.

- Model parameters are estimated from O-F residuals using a maximum-likelihood/bayesian approach (Dee and da Silva 1998; Purser and Parish 2000)

On-line Constituent Assimilation

- The fvCCM has a built in tracer transport capability:
  - Same Lin-Rood scheme widely used by several CTMs
  - Tracers can be transported very accurately and efficiently
- PSAS can be used to produce constituent analysis
- Candidates for on-line assimilation:
  - Ozone (TOMS, SBUV)
  - CO (MOPPITT, AIRS?)
  - Aerosols: mineral dust, sea salt, sulfates and carbonaceous (TOMS, MODIS, MISR, OMI)
- In addition to 3D assimilated constituent fields, we will also have a real-time aerosol/constituent forecasting capability.

Land Surface Assimilation

Skin Temperature Assimilation

- Mosaic LSM driven off-line with GEOS forcing forming the Off-line Global Assimilation (OLGA) System
- Mosaic tiling approach captures sub-grid scale heterogeneity
- PSAS assimilation of ISCCP skin temperature data
- Diurnal bias correction scheme applied every timestep, based on a time-dependent bias model
- Resolution: 2° x 2.5°, Timestep: 5 min, Spinup: 10+ years, Focus: July 1992

July 1992 Monthly Mean Diurnal Cycles for Experiments and ISCCP Observations