Overview of GSI

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History

- The Spectral Statistical Interpolation (SSI) analysis system was developed at NCEP in the late 1980's and early 1990's.
- Main advantages of this system over OI systems were:
  - All observations are used at once (much of the noise generated in OI analyses was generated by data selection)
  - Ability to use forward models to transform from analysis variable to observations
  - Analysis variables can be defined to simplify covariance matrix and are not tied to model variables (except need to be able to transform to model variable)
- The SSI system was the first operational
  - variational analysis system
  - system to directly use radiances

History

- While the SSI system was a great improvement over the prior OI system – it still had some basic short-comings
  - Since background error was defined in spectral space – not simple to use for regional systems
  - Diagonal spectral background error did not allow much spatial variation in the background error
  - Not particularly well written since developed as a prototype code and then implemented operationally

History

- The Global Statistical Interpolation (GSI) analysis system was developed as the next generation global/regional analysis system
  - Wan-Shu Wu, R. James Purser, David Parrish
    - *Three-Dimensional Variational Analysis with spatially Inhomogeneous Covariances. Mon. Wea. Rev., 130, 2905-2916.*
  - Based on SSI analysis system
  - Replace spectral definition for background errors with grid point version based on recursive filters

History

- Used in NCEP operations for
  - Regional NMMB
  - Global
  - Hurricane
  - Real-Time Mesoscale Analysis
  - Rapid Refresh and HRRR (ESRL/GSD)
- Operational at AFWA
- GMAO collaboration
- Modification to fit into FV3, WRF and NCEP infrastructure
- Evolution to JEDI

History

- Code Management
  - Instituted to allow multiple people and/or groups to work on system without chaos.
  - Svn system set up at EMC – one of the first operational systems to be under code management
  - Mirror set up at DTC + annual code releases
  - Plan is to make operational instances of the code along trunk.
  - Transition to VLAB git underway in the next few weeks
  - Requires both operational centers and collaborators to change how they do business

General Comments

- GSI analysis code is an evolving system.
  - Scientific advances
    - situation dependent background errors -- hybrid
    - new observational (satellite especially) data
    - new analysis variables
  - Improved coding
    - Bug fixes
    - Removal of unnecessary computations, arrays, etc.
    - More efficient algorithms (MPI, OpenMP)
    - Modern programming structure (GMAO, JCSDA)
    - Generalizations of code
      - Different compute platforms
      - Different analysis variables
      - Different models
    - Improved documentation
  - Fast evolution creates difficulties for slower evolving research projects

General Comments

- Code is intended to be used for Operations:
  - Must satisfy coding requirements
  - Must fit into infrastructure
  - Should be kept as simple as possible
- And Research:
  - Enhance testing
  - Reduce transition to operations work/time
  - Reduce duplication of effort
  - Since operational, realistic testing with all data types

Simplification to 3-D for presentation

- For today's introduction, I will be talking about using the GSI for standard 3-D var. analysis. Many options available or under development
  - 4d-var
  - Hybrid assimilation
  - Observation sensitivity
  - Different minimization options
  - Additional observation types
  - SST retrieval
  - Detailed options
- Options make code more complex – difficult balance between options and simplicity and understandability

Basic analysis problem

$$J = J_b + J_o + J_c$$

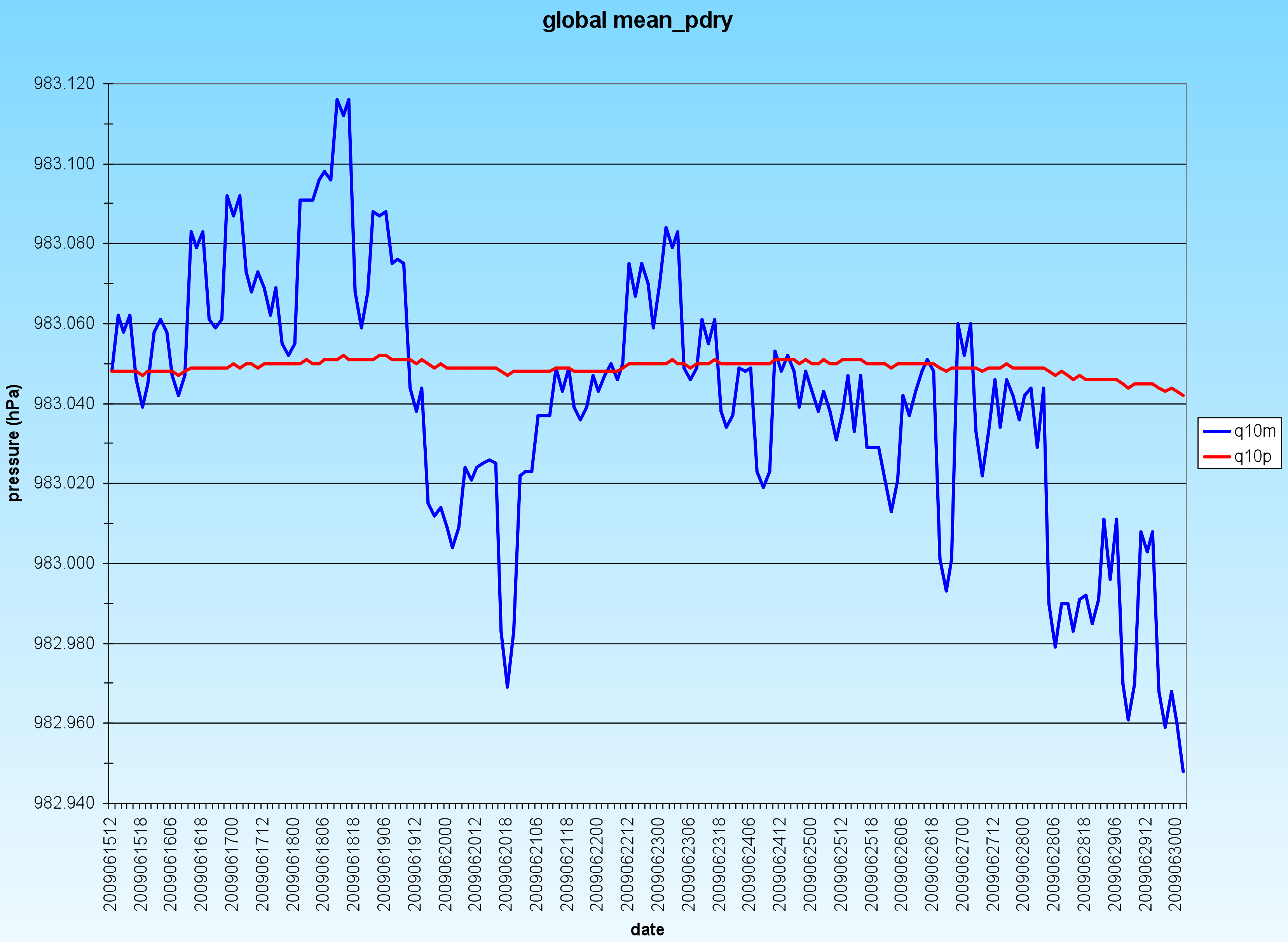
$$J = (x-x_b)^T B^{-1}(x-x_b) + (H(x)-y_0)^T(E+F)^{-1}(H(x)-y_0) + J_C$$

J = Fit to background + Fit to observations + constraints

x = Analysis
x_b = Background
B = Background error covariance
H = Forward model
y_0 = Observations
E+F = R = Instrument error + Representativeness error
J_C = Constraint terms

Jc term

- Currently Jc term includes 2 terms
  - Weak moisture constraint (q > 0, q < qsat)
    - Can substantially slow convergence if coefficient made too large.
  - Conservation of global dry mass
    - not applicable to regional problem



global mean_pdry
pressure (hPa)
983.120
983.100
983.080
983.060
983.040
983.020
983.000
982.980
982.960
982.940
2009061512
2009061518
2009061606
2009061618
2009061700
2009061712
2009061800
2009061806
2009061818
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2009062512
2009062518
2009062606
2009062618
2009062700
2009062712
2009062800
2009062806
2009062818
2009062906
2009062912
2009063000
date
q10m
q10p

Solution

At minimum, Grad J = 0, Note this is a necessary condition – it is sufficient only for a quadratic J

Grad J = $B^{-1}(x-x_b) + H^T(E+F)^{-1}(H(x)-y_0) + \text{Grad } J_C$

A minimization algorithm is used to solve for Grad J = 0.

Definition of J primarily determines the solution, not solution algorithm.

Solution Strategy

- Solve series of simpler problems with some nonlinear components eliminated
- Outer iteration, inner iteration structure
  - $x = x_{\text{outer iteration}} + x_{\text{inner iteration}} + x_b$
- Outer iteration
  - QC
  - More complete forward model
- Inner iteration
  - Several different iterative minimization options
    - Estimate search direction
    - Estimate optimal stepsize in search direction
  - Often simpler forward model
  - Variational QC
  - Solution used to start next outer iteration

Analysis variables

- Background errors must be defined in terms of analysis variable.
- Must be able to transform from analysis variables to model variables.
- Must be able to transform from analysis variables to observation variables.
- Variable transforms can include both statistical and dynamical (e.g., nnmi) relationships

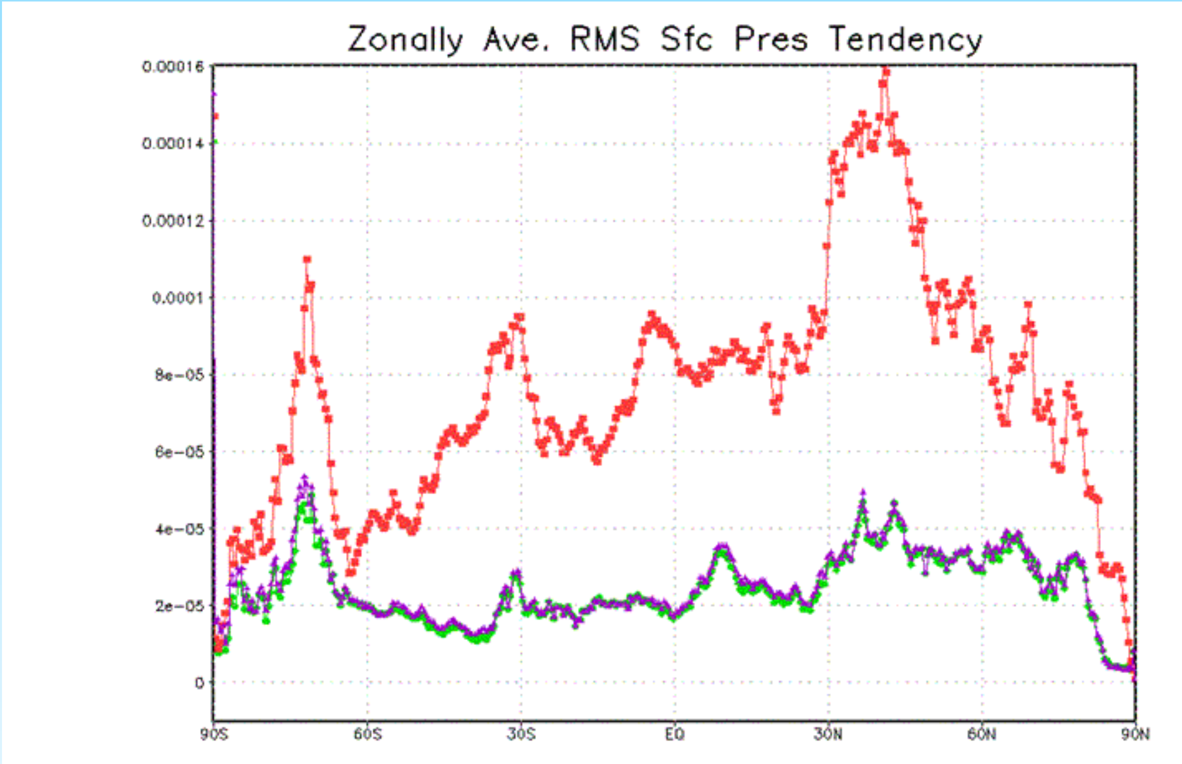
Analysis variables

- Example:
  - Streamfunction (Ψ)
  - Unbalanced Velocity Potential ($\chi_{unbalanced}$)
  - Unbalanced Temperature ($T_{unbalanced}$)
  - Unbalanced Surface Pressure ($Ps_{unbalanced}$)
  - Ozone – Clouds – etc.
  - Satellite bias correction coefficients

Analysis variables

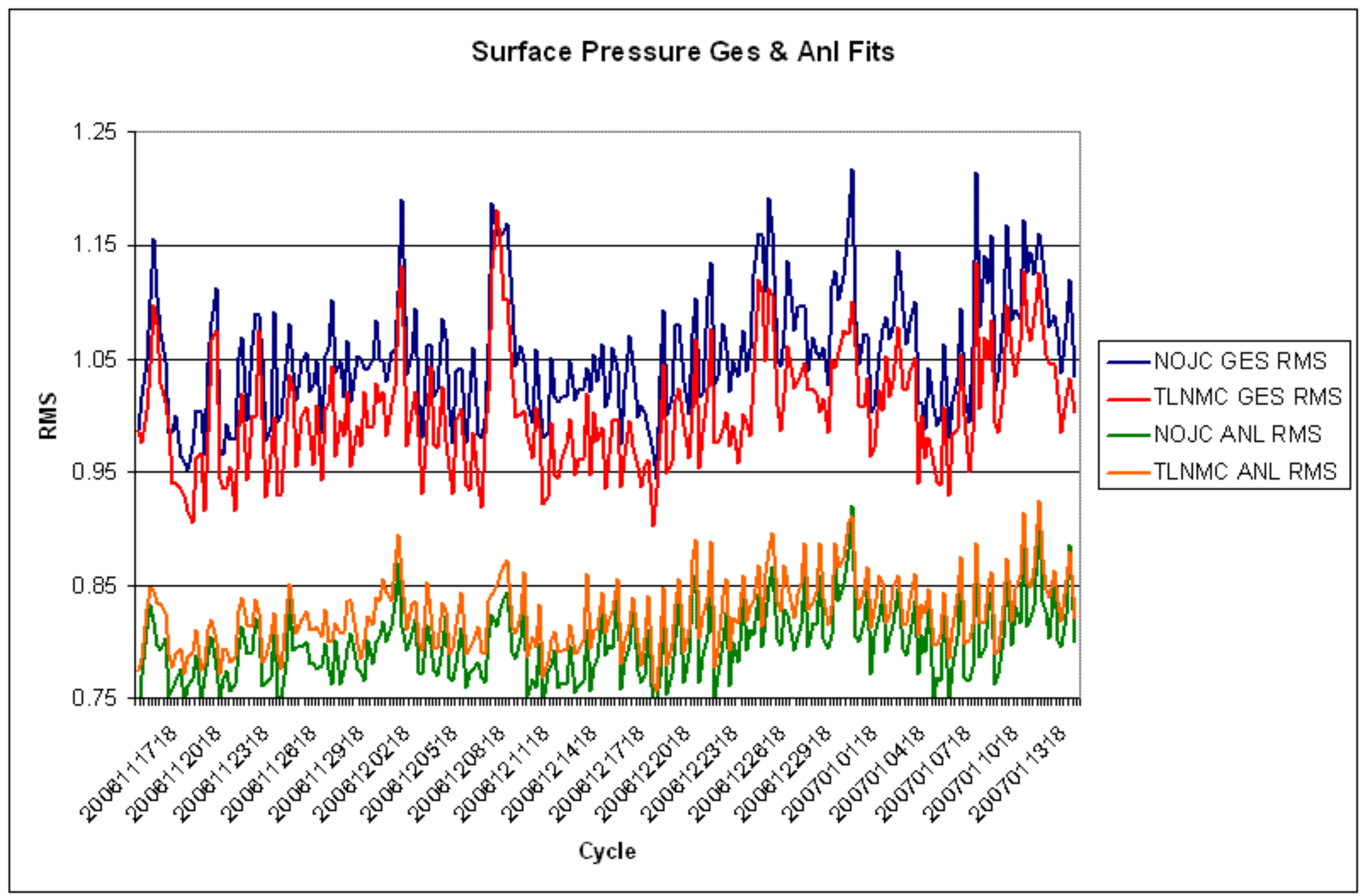
- $\chi = \chi_{unbalanced} + A\,\Psi$
- $T = T_{unbalanced} + B\,\Psi$
- $Ps = Ps_{unbalanced} + C\,\Psi$
- Streamfunction is a key variable defining a large percentage T and P_s (especially away from equator). Contribution to χ is small except near the surface and tropopause.

Impact of TLNM constraint



Zonal-average surface pressure tendency for background (green), unconstrained GSI analysis (red), and GSI analysis with TLNMC (purple).

Fits of Surface Pressure Data in Cycled Experiment with and without TLNM constraint



Analysis variables

- Size of problem
  - NX x NY x NZ x NVAR
  - Global = 600 million component control vector
  - Requires multi-tasking to fit on computers
  - Also, often requires analysis increment to be done at a different resolution than the model to achieve run-time requirements.
    - GSI has 3 resolutions, analysis, background and ensemble.

Grid Sub-domains

- The analysis and background fields are divided across the processors in two different ways
  - Sub-Domains – an x-y region of the analysis domain with full vertical extent – observations defined on sub-domains
  - Horizontal slabs – a single or multiple levels of full x-y fields
- Since the analysis problem is a full 3-D problem – we must transform between these decompositions repeatedly

Background fields

- Current works for following systems
  - NCEP GFS
  - NCEP NMM(B) – binary and netcdf
  - NCEP RTMA
  - NCEP Hurricane
  - NOAA FV3 (being tested)
  - GMAO FV3 global
  - ARW – binary and netcdf
- FGAT (First Guess at Appropriate Time) enabled up to 100 time levels

Background Errors

- Three options
  - Isotropic/homogeneous
    - Most common usage.
    - Function of latitude/height
    - Vertical and horizontal scales separable
    - Variances can be location dependent
  - Anisotropic/inhomogeneous
    - Function of location /state
    - Can be full 3-D covariances
    - Still relatively immature
  - Hybrid
    - Includes ensembles along with one of the two options above.

Observations

- Observational data is expected to be in BUFR format (this is the international standard)
- Each observation type (e.g., u,v,radiance from NOAA-15 AMSU-A) is read in on a particular processor or group of processors (parallel read)
- Data thinning can occur in the reading step.
- Checks to see if data is in specified data time window and within analysis domain

Data processing

- Data used in GSI controlled 2 ways
  - Presence or lack of input file
  - Control files input (info files) into analysis
    - Allows data to be monitored rather than used
    - Each ob type can be specified different
      - E.g., Specify different time windows for each ob type
    - Intelligent thinning distance specification for some obs types

Input data – Radiance currently used

- Regional , thinned to 60km or 120km hyperspectral (Global. thinned to 145km)

AMSU-A

NOAA-15	Channels 1-5,7-10, 12-13, 15
NOAA-18	Channels 1-4,6-7, 10-13, 15
NOAA-19	Channels 1-6, 9-13, 15
METOP-A	Channels 1-6, 9-13, 15
METOP-B	Channels 7-11(13)
AQUA	Channels 6, 8-13

ATMS

NPP	Channels 1-11,16-19

MHS

NOAA-19	Channels 1-2,4-5
METOP-A	Channels 1-5
METOP-B	Channels 1-5

HIRS

None

Geo Sounder

GOES-15, all 4 sensors	Channels 1-15
SEVERI M10	Channels 2-3

Hyperspectral

AIRS AQUA	148 Channels
IASI METOP-A	165 Channels
IASI METOP-B	165 Channels
NPP CrIS	84 Channels

SSMIS

F17	(Channels 1-3,5-7,24)

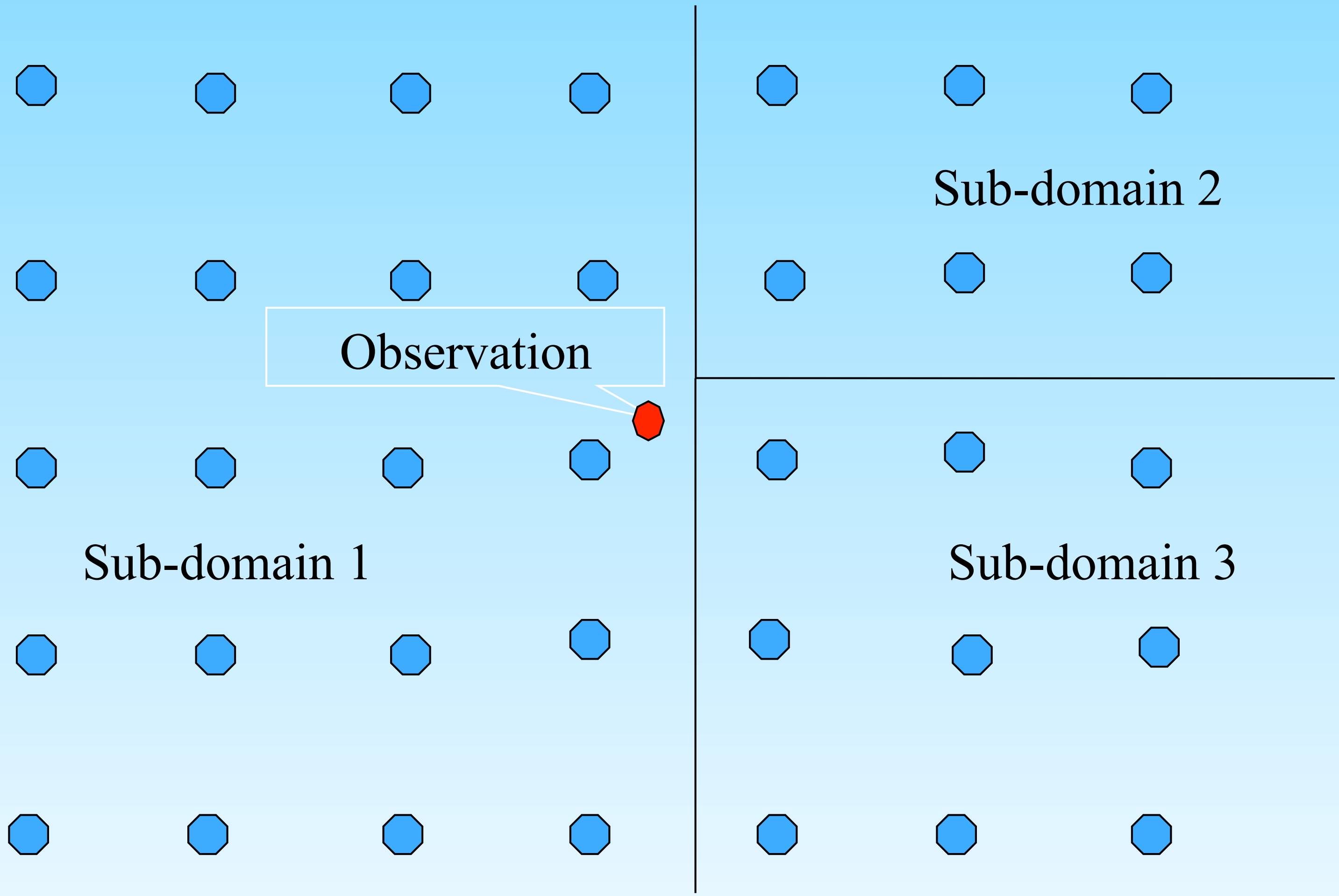
Input data – Conventional currently used

- Radiosondes
- Pibal winds
- Synthetic tropical cyclone winds
- wind profilers
- conventional aircraft reports
- ASDAR aircraft reports
- MDCARS aircraft reports
- dropsondes
- MODIS IR and water vapor winds
- GMS, JMA, METEOSAT and GOES cloud drift IR and visible winds
- GOES water vapor cloud top winds
- Surface land observations
- Surface ship and buoy observation
- SSM/I wind speeds
- QuikScat and ASCATwind speed and direction
- SSM/I and TRMM TMI precipitation estimates
- Doppler radial velocities
- VAD (NEXRAD) winds
- GPS precipitable water estimates
- GPS Radio occultation refractivity and bending angle profiles
- SBUV ozone profiles and OMI total ozone

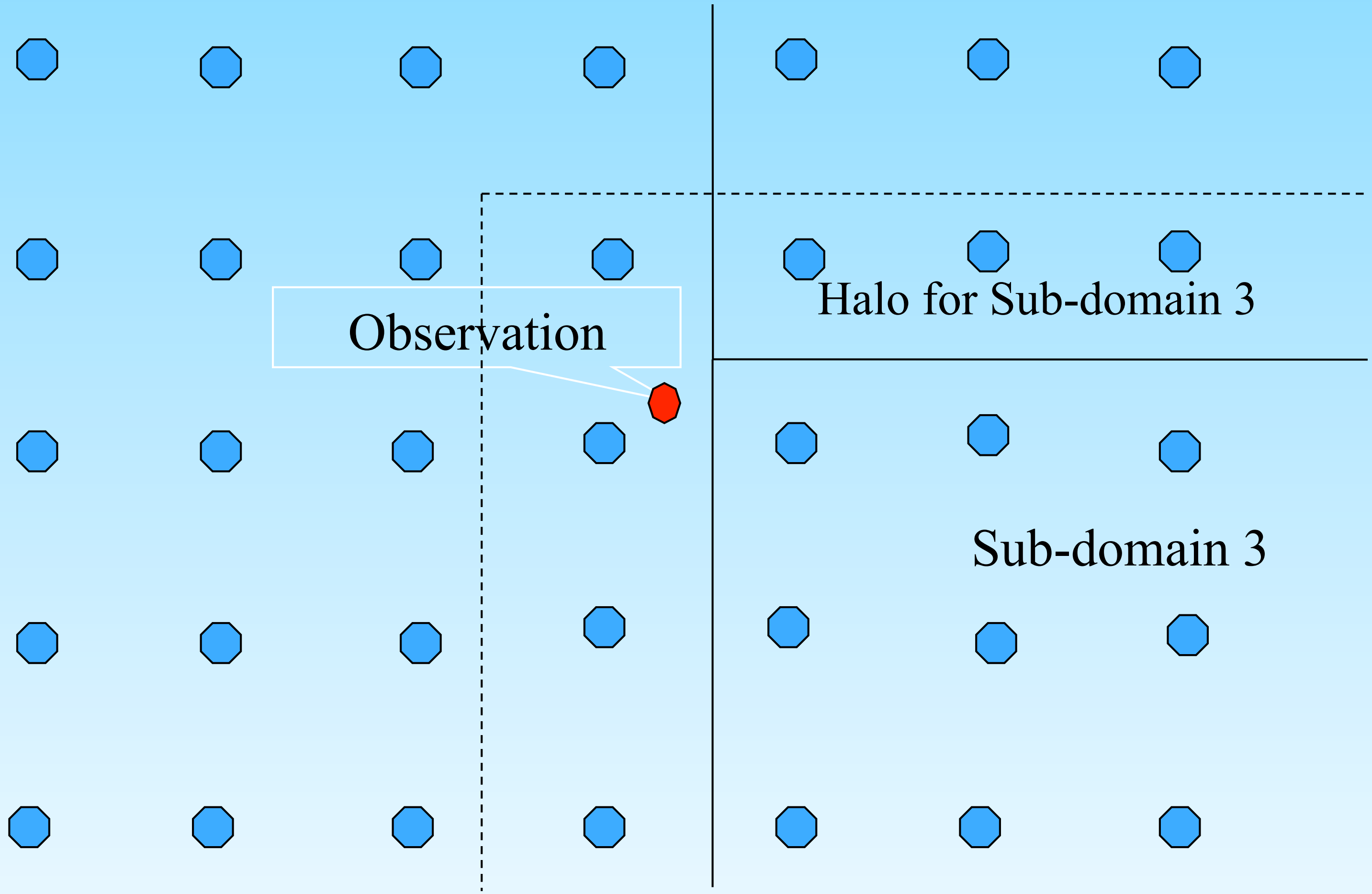
Data Sub-domains

- Observations are distributed to processors they are used on. Comparison to obs are done on sub-domains.
  - If an observation is on boundary of multiple sub-domains will be put into all relevant sub-domains for communication free adjoint calculations.
  - However, it is necessary to assign the observation only to one sub-domain for the objective function calculation
  - Interpolation of sub-domain boundary observations requires the use of halo rows around each sub-domain

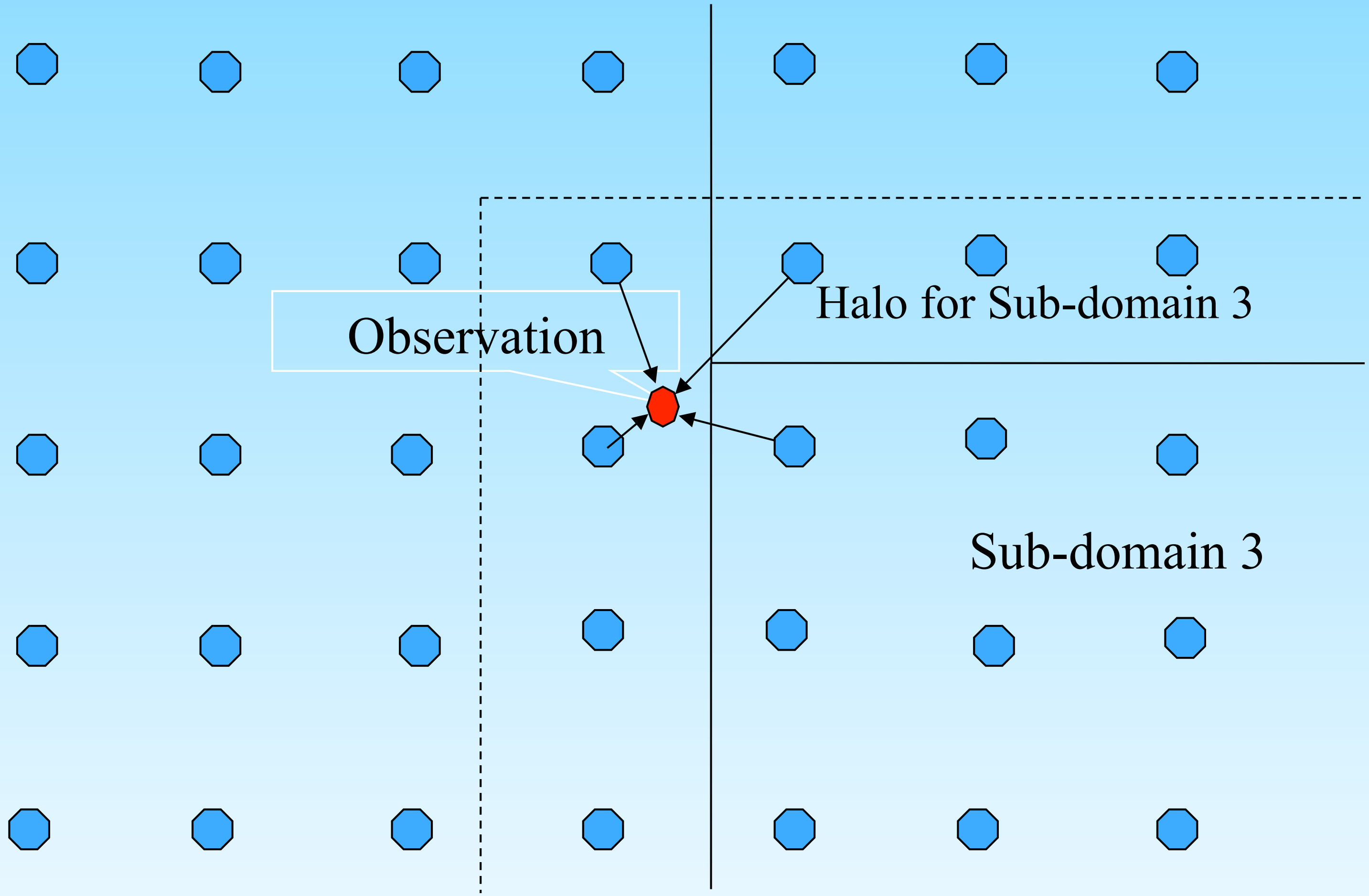
Observation/Sub-domain layout



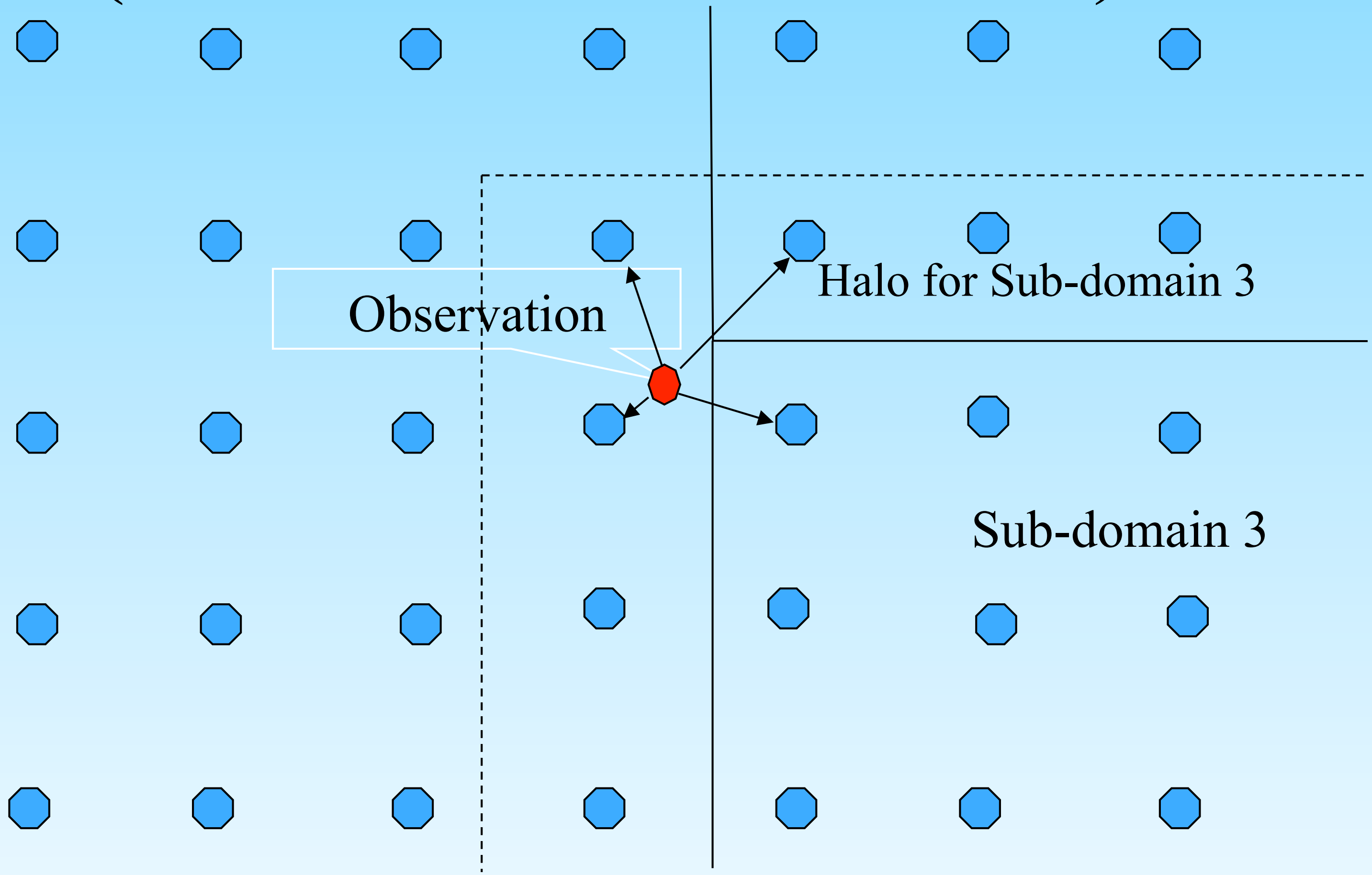
Sub-domain 3 calculation w/halo



Forward interpolation to ob.



Adjoint of interpolation to grid (values in halo not used)



Simulation of observations (forward models)

- To use observation, must be able to simulate observation
  - Can be simple interpolation to ob location/time
  - Can be more complex (e.g., radiative transfer)
- For radiances we use CRTM
  - Vertical resolution and model top important

Atmospheric analysis problem (Practical) Outer (K) and Inner (L) iteration operators

Variable	*K* operator	L operator
Temperature – surface obs. at 2m	3-D sigma interpolation adjustment to different orography	3-D sigma interpolation Below bottom sigma assumed at bottom sigma
Wind – surface obs. at 10m over land, 20m over ocean, except scatt.	3-D sigma interpolation reduction below bottom level using model factor	3-D sigma interpolation reduction below bottom level using model factor
Ozone – used as layers	Integrated layers from forecast model	Integrated layers from forecast model
Surface pressure	2-D interpolation plus orography correction	2-D interpolation
Precipitation	Full model physics	Linearized model physics
Radiances	Full radiative transfer	Linearized radiative transfer

Quality control

- External platform specific QC
- Some gross checking in PREPBUFR file creation
- Analysis QC
  - Gross checks – specified in input data files
  - Variational quality control
  - Data usage specification (info files)
  - Outer iteration structure allows data rejected (or downweighted) initially to come back in (GMAO option to turn off)
  - Ob error can be modified due to external QC marks
  - Radiance QC much more complicated. Tomorrow!

Observation output

- Diagnostic files are produced for each data type for each outer iteration (controllable through namelist)
- Output from individual processors (sub-domains) and concatenated together outside GSI
- External routines exist for reading diagnostic files

GSI layout (major routines) (generic names, 3dvar path)

- gsimain (main code)
  - gsimain_initialize (read in namelists and initialize variables
  - gsimain_run
    - gsisub
      - deter_subdomain (creates sub-domains)
      - *read_info (reads info files to determine data usage)
      - glbsoi
        - » observer_init (read background field)
        - » observer_set (read observations and distribute)
        - » prewgt (initializes background error)
        - » setuprhsall (calculates outer loop obs. increments
        - » Pcgsoi, sqrtmin or other minimization (solves inner iteration)
      - writeall
  - gsimain_finalize (clean up arrays and finalize mpi)

GSI layout (major routines)

- pcgsoi (other minimizations similar)
  - control2state (convert control vector to state vector)
  - intall (compare to observations and adjoint)
  - control2state_ad (transpose of convert vector to state vector
  - bkerror (multiply by background error)
  - stpcalc (estimate stepsize and update solution)
  - update_guess (updates iteration solution)

Challenges

- Negative Moisture and other tracers
- Cloud and precipitation assimilation
- Trace gas, aerosol, land, ocean, ice, etc. assimilation
- Cross-variable covariances – "balance"
- Situation dependent background and observation errors
- Use of satellite radiances in regional mode
- Use of satellite data impacted by land/ice/snow (surface emissivity issues)

Useful References

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