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SSI Analysis System 2004

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1. Introduction

The Spectral Statistical Interpolation (SSI) analysis/assimilation system of NCEP's Global Forecast System was implemented in June of 1991. The initial version of SSI was presented in Parrish and Derber and Derber et al. (1991). The direct use of radiances is described in Derber and Wu (1998) and McNally et al. (1999).

2. Documentation

The present brief documentation focuses on the current version of the SSI It contains references to the initial papers on which the SSI is based. Some relevant internet links are:

Comprehensive analysis/assimilation system information
http://wwwt.emc.ncep.noaa.gov/gmb/gdas/

SSI documentation
http://wwwt.emc.ncep.noaa.gov/gmb/gdas/documentation/ssi3.html

NWS Technical Procedures Bulletins
http://www.nws.noaa.gov/om/tpbpr.shtml

GFS forecast model documentation:
http://wwwt.emc.ncep.noaa.gov/gmb/moorthi/gam.html

History of GFS forecast model changes
http://wwwt.emc.ncep.noaa.gov/gmb/STATS/html/model_changes.html

3. Numerical/Computational Properties

3.1 Horizontal Properties

Horizontal Representation: The analysis variables are defined spectrally. For comparison to the observations, the variables are transformed to Gaussian grid and then linearly interpolated to observation locations.

Horizontal Resolution: Same as forecast model with a spectral triangular truncation of 254 (T254). The quadratic T254 Gaussian grid has 768 gridpoints in the zonal direction and 384 gridpoints in the meridional direction. Due to computation limitations the analysis uses a linear representation of the T254 Gaussian grid. This 512x256 grid contains two additional rows over that the true linear grid in order to describe the north and south pole points. This resolution is essentially equivalent to 0.7x0.7 degree latitude/longitude. The resolution of the quadratic T254 Gaussian grid is approximately 0.5x0.5 degree.

3.2 Vertical Representation and Domain

The analysis is performed directly in the model's vertical coordinate system. This sigma (pressure over surface pressure) coordinate system extends over 64 levels from the surface to about 0.27hPa. The vertical sigma levels and the approximate pressures are listed below.

Level	sigma	approximate pressure (hPa)
64	0.00027	0.27
63	0.00099	0.99
62	0.00179	1.79
61	0.00269	2.69
60	0.00372	3.72
59	0.00490	4.90
58	0.00625	6.25
57	0.00780	7.80
56	0.00956	9.56
55	0.01157	11.57
54	0.01387	13.87
53	0.01649	16.49

52	0.01948	19.48
51	0.02288	22.88
50	0.02675	26.75
49	0.03115	31.15
48	0.03615	36.15
47	0.04182	41.82
46	0.04823	48.23
45	0.05549	55.49
44	0.06367	63.67
43	0.07289	72.89
42	0.08324	83.24
41	0.09483	94.83
40	0.10778	107.78
39	0.12218	122.18
38	0.13815	138.15
37	0.15579	155.79
36	0.17517	175.17
35	0.19635	196.35
34	0.21939	219.39
33	0.24429	244.29
32	0.27102	271.02
31	0.29953	299.53
30	0.32970	329.70
29	0.36138	361.38
28	0.39437	394.37
27	0.42843	428.43

26	0.46329	463.29
25	0.49863	498.63
24	0.53415	534.15
23	0.56950	569.50
22	0.60438	604.38
21	0.63846	638.46
20	0.67148	671.48
19	0.70319	703.19
18	0.73339	733.39
17	0.76194	761.94
16	0.78872	788.72
15	0.81366	813.66
14	0.83674	836.74
13	0.85797	857.97
12	0.87739	877.39
11	0.89506	895.06
10	0.91106	911.06
9	0.92552	925.52
8	0.93849	938.49
7	0.95012	950.12
6	0.96049	960.49
5	0.96973	969.73
4	0.97793	977.93
3	0.98522	985.22
2	0.99165	991.65
1	0.99734	997.34

3.3 Computational performance

The current version is a MPP version running on IBM-SP. It has run on Cray - Y/MP, C90, and EL at various resolutions with up to 14 processors.

4. Analysis Components and basic properties

4.1 Basic Problem

The problem being solved is to minimize the equation:

$$J = J_b + J_o + J_c$$

where J_b is the weighted fit of the analysis to the six hour forecast (background or first guess), J_o is the weighted fit of the analysis to the observations and Jo is the weighted fit of the divergence tendency to the guess divergence tendency. The weights are given by the statistics described below.

4.2 Analysis variables

The analysis variables can be uniquely transformed into the model variables of vorticity, divergence, temperature, ln(surface pressure) and specific humidity. The analysis variables are normalized vorticity, unbalanced divergence, unbalanced temperature, ozone, surface skin temperature, specific humidity and coefficients for the bias correction of the satellite radiance data. Each of these variables are deviations from the background decomposed in the vertical based on the vertical error covariance and are normalized with the standard deviation of the error. The balanced part of the divergence and the temperature are implied using a linear balance equation from the vorticity.

4.3 Observation types

Currently, the regional and global analysis systems use the following data:

Observation type	Regional(ETA)	Global(MRF)	Comments
Radiosonde	u,v,T,q,Ps, Height	u,v,T,q,Ps	Height is redundant with T and Ps, but still slightly better results in regional
Pibal winds	u,v	u,v	
Synthetic tropical cyclone wind	not used	used	
wind profilers	u,v	u,v	
conventional aircraft reports	u,v,T	u,v,T	
ASDAR aircraft reports	u,v,T	u,v,T	
MDCARS aircraft reports	u,v,T	u,v,T	

Dropsondes	u,v,T,Ps,q	u,v,T,Ps,q	
GMS, METEOSAT, GOES cloud drift IR and visible winds	u,v	u,v	Hi density GOES cloud drift winds used. GOES hi density visible winds are not yet operational.
GOES water vapor cloud top winds	u,v	u,v	high density winds used
Surface land observations	u,v,T,Ps,q	q,Ps	
Surface ship and buoy observations	u,v,T,Ps,q	u,v,T,Ps,q	
SSM/I wind speeds	u,v	Speed	Regional system assigns direction from guess. Global uses speed directly.
ERS-2 wind speed/direction	not used	not used	
SSM/I precipitable water	used	not used	Undesirable tropical results when used in global system.
SSM/I precipitation estimates	not used	used	Precipitation included through variational scheme and model physics.
GOES precipitable water	used over land	not used	Same information contained in radiances over ocean
NOAA-14, and NOAA-15 HIRS 1b radiances	used	used	Most channels not used over land because of quality control and surface emissivity problems. Data thinned to reduce density.
NOAA-14 MSU 1b radiances	used	used	Channel 2 not used over land because of quality control and surface emissivity problems.
NOAA-15, NOAA-16 AMSU-A 1b radiances	NOAA-16 not used	Both used	Lower peaking channels (1-5) not used over land because of quality control and surface emissivity problems. Radiances thinned (every 4th point) to reduce density.
NOAA-15, NOAA-16 AMSU-B 1b radiances	NOAA-15 not used	Both used	Radiances thinned to reduce density.
GOES-8 and GOES-10 5x5 cloud cleared radiances	GOES-10 not used	used	Most channels not used over land because of quality control and surface emissivity problems. Short wave channels shut off due to increased noise on GOES-8.
SBUV ozone profiles	not used	used	NOAA-16 only
VAD (NEXRAD) winds	used	used	Reintroduced-improved QC 29 Mar 2000

In addition, the analysis systems process line-of-sight winds directly, as provided by Doppler radar or wind lidar, without the requirement to first retrieve the full wind from the measurements. However, these winds are not available operationally. The data from NWS 88-D network should be operationally available by the end of 2000. Degraded resolution and accuracy Doppler radar observations are available, but are not being used operationally.

4.4 Observational error statistics

The observational error statistics vary with each observation type and can vary with each observation location. The specified observational error statistics contain both instrument error and representativeness error.

4.5 Background error statistics

The background error statistics are used to weight the background (first guess) field. They are defined spectrally and are currently nearly homogeneous around a latitude band. The structure of these fields is very similar to that used at the ECMWF (Derber and Bouttier, 1999). The statistics are calculated by scaling the statistics from a sequence of differences between 24 and 48 hour forecasts valid at the same time.

4.6 Balance constraint

A nonlinear balance constraint is currently being used in the analysis system. The nonlinear balance constraint is a divergence tendency equation linearized around the guess in the analysis system. Vertical advection, surface friction and diabatic heating are not yet incorporated. The analysis system penalizes for differences from the guess divergence tendency. The penalty is defined in spectral space and the weights are defined as for the background error statistics.

5. Analysis Procedure

The analysis procedure is performed as series of iterative problems. There is an external iteration which partially accounts for nonlinearities in the objective function. In this external iteration, some parts of the transformation of the analysis variables into the pseudo-observations (see below) are linearized around the current solution. In the first external iteration, the current solution is the 6 hour forecast. In later iterations, the current solution is the result from the previous external iteration. Currently, the number of external iterations is limited to 2 by computation considerations.

Inside each external iteration, a series of operations are performed to create the analysis. First, The difference between the current solution and the observations is found by interpolating the 3, 6 (or the current solution after the first external iteration) and 9 hour forecasts of the model variables to the observation time. The model variables are then transformed to the pseudo-observation variables. For example, for a temperature observation no transformation is necessary. For a satellite measured radiances the profile of temperature, moisture and ozone along with various surface quantities are transformed into pseudo-radiances. The pseudo-observations are then compared to the observations and an observational increment is created. The current solution is then iteratively updated by use of a nonlinear conjugate gradient algorithm which attempts to find the solution which minimizes J. To perform the conjugate gradient algorithm, it is necessary to have the gradient of J with respect to the analysis variables.

The gradient is evaluated using the adjoint of the transformation of the analysis variables into the observation variables and the adjoint of the divergence tendency constraint.

6. Current results

Current results and further information can be found at the global data assimilation group web page (http://wwwt.emc.ncep.noaa.gov/gmb/gdas/).

7. Ongoing development

The analysis system is undergoing many enhancements as new data systems are included or new techniques developed. Many changes to the analysis system are currently under development. A few of the major development projects are listed below.

- ***Grid point version*** - The background error covariance is currently defined in spectral coefficients. A version of the analysis which defines the background error covariance in grid space using recursive filters is being developed. The major advantage of defining the covariance is that it will be much easier to define spatially varying covariance structures.
- ***Inclusion of GOES imager data*** - The GOES imager produces hemispheric data which can be used as if it were sounder data. Perhaps most useful is channel 3 which measures upper level moisture.
- ***Improved radiative transfer*** - Geostationary and Polar orbiting sounders and imagers measure the outgoing radiation in certain frequency bands. The simulation of these measurements in an accurate and computationally efficient manner is an area of intense ongoing research.
- ***Inclusion of GPS occultation measurements*** - The delay time between a low earth orbiting satellite as it sets over the horizon and a GPS satellite provides information on the density of the atmosphere between the satellites. The data has the potential to provide high vertical resolution, low horizontal resolution information. The complete use of this data may require the use of a ray tracing algorithm between the satellites. Development work is underway for incorporating this type of data in the analysis. For this type of data, the computational expense of the algorithm plays an important role. A draft office note on this subject is now available (Matsumura, 1999)

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