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| **Vertically Integrated Mass, Moisture, Heat, and Energy Budget Products Derived from the NCEP/NCAR Reanalysis**   **March 2003   Climate Analysis Section, CGD, NCAR   Contact:**  ***David Stepaniak [davestep@ucar.edu](mailto:davestep@ucar.edu)***  [**My home page**](http://dss.ucar.edu/staff/davestep/) |  |
| [**Contents**](http://www.cgd.ucar.edu/cas/catalog/newbudgets/index.html#Sec0)  [**Accessing the Data**](http://www.cgd.ucar.edu/cas/catalog/newbudgets/index.html#AtD) | *Three-panel figure shows diabatic minus frictional heating Q1- Qf (top), latent heating Q2 (middle), and Q1-Qf-Q2 (bottom) which is roughly equivalent to divergence of vertically integrated total energy transport, . The fields represent an annual mean in W m-2 for the period 1979-2001 at T31 spectral truncation. Further details are provided below.* |
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| *GOES-11 image of a portion of the Intertropical Convergence Zone (ITCZ) in the eastern Pacific Ocean and the upward branch of the Hadley Circulation, a region of intense latent heating (see Q2 in the second panel in the figure immediately above). Image courtesy of GOES Project Science Office.* | |

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**Introduction**

We report here a newly completed (March 2003) recomputation and updating of vertically integrated monthly mean mass, moisture, heat, and energy budget products derived from the NCEP/NCAR reanalysis. This new archive spans January 1979 to December 2001 (23 years), and incorporates TOVS (TIROS Operational Vertical Sounder) reruns in addition to grid corrections implemented by NCEP for reanalysis data covering the period March 1997 through October 2001.

Our monthly mean budget products are derived from 6-hourly model () level data which the Data Support Section (DSS) at NCAR makes available in the form of `grbsanl' grib files on the MSS. The DSS web page ` [ds090.0 HOME PAGE: NCEP/NCAR Global Reanalysis Products, 6-hrly, monthly](http://dss.ucar.edu/datasets/ds090.0/) ' provides extensive documentation and useful background. For an overview of the NCEP/NCAR reanalysis project see Kalnay and others, 1996.

We note that the spectral truncation of the fields in the grbsanl files is T62 on a 192x94 grid (longitude by latitude), which we subsequently regrid to 192x96 with T63 truncation, the resolution at which we carry out all our budget computations. However, spatial spectra (power as a function of total wavenumber *n*) shows that in certain derived fields a considerable amount of extraneous power may exist beyond *n*=42 or so, and thus the final spectral truncation of our products is T42 on a 128 x 64 Gaussian grid ¹.

We make a total of 36 budget products available in both netCDF and Fortran direct access binary files via email requests (see the section [**Accessing the Data**](http://www.cgd.ucar.edu/cas/catalog/newbudgets/index.html#AtD)). The description of these products and their derivation is outlined in the following sections, in which *product names are highlighted in capital red letters in the tables and text of each section* (see especially entries under `**Product Name**' in tables). The reader is referred to Trenberth (1991, 1997) for derivations and details of the budget equations we employ.

¹ Our regridding and truncation, as well as the two-dimensional operators for divergence , inverse Laplacian , and gradient are carried out in spectral space via a Fortran 90 interface and static library created for Spherepack 3.0. (An NCAR Technical Note and web page by Adams and Swarztrauber, 1997, provides a detailed description of the Spherepack 3.0 package.)

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**Physical Constants**

We employ the following constants, consistent with those used in the NCAR Community Climate Model 2, i.e. CCM2 (see Hack and others, 1993), and later generations of the CCM (and CCSM).

|  |  |  |  |
| --- | --- | --- | --- |
| **Constant** | **Symbol** | **Value** | **Units** |
| Specific Heat Capacity of Dry Air at Constant Pressure | *Cp* | 1004.64 | J kg-1 K-1 |
| Acceleration Due to Gravity | *g* | 9.80616 | m s-2 |
| Latent Heat of Vaporization of Water | *L* | 2.5104x106 | J kg-1 |
| Gas Constant for Dry Air | *Rd* | 287.04 | J kg-1 K-1 |
| Ratio of Molecular Weight of Water Vapor to that of Dry Air |  | 0.622 | Dimensionless |
| Radius of Earth | *a* | 6.37122x106 | m |
| Density of Liquid Water | H2O | 1.0x103 | kg m-3 |

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**Basic Fields at 6-hourly Resolution Available from NCEP**

In model level (i.e. ) coordinates we utilize *u*, *v*, *T*, and *q* at 6-hourly temporal resolution on 28 levels. (The levels are 0.0027, 0.0101, 0.0183, 0.0288, 0.0418, 0.0580, 0.0782, 0.1028, 0.1326, 0.1682, 0.2101, 0.2582, 0.3125, 0.3720, 0.4357, 0.5017, 0.5681, 0.6329, 0.6943, 0.7508, 0.8014, 0.8458, 0.8838, 0.9159, 0.9425, 0.9644, 0.9821, and 0.9950, where pressure in the vertical is given by *pi = iPs*.) In addition, we employ the surface fields *Ps* and *s* at 6-hourly temporal resolution.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Basic Variable** | **Symbol** | **Units** | **Level(s)** | **Working Spectral Truncation** | **Times** |
| Zonal (eastward component) wind | *u* | m s-1 | 28 | T63 | 6-hourly |
| Meridional (northward component) wind | *v* | m s-1 | 28 | T63 | 6-hourly |
| Temperature | *T* | K (Kelvin) | 28 | T63 | 6-hourly |
| Specific Humidity | *q* | kg kg-1 | 28 | T63 | 6-hourly |
| Surface pressure | *Ps* | Pa | Surface | T63 | 6-hourly |
| Surface geopotential | *s* | m2 s-2 | Surface | T63 | 6-hourly |

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**Derived Fields at 6-hourly Resolution**

Fields not available in coordinates in the NCEP reanalysis which must be derived at 6-hourly resolution and for all levels in the vertical include the kinetic energy, *K = (u2+v2)/2*, and the geopotential height, *z = s /g + (Rd /g)* ***H*** *Tv*, where ***H*** is the CCM hydrostatic matrix, and *Tv* the virtual temperature which is computed as *Tv = T(1 + q)*. The hydrostatic matrix ***H*** is a function of the surface pressure *Ps* (see Hack and others, 1993, p. 27, for details, and our subroutine [ccm2\_hydrostatic\_matrix](http://www.cgd.ucar.edu/cas/catalog/newbudgets/newbudgets.f90subr.html)). In addition, we compute the products *uT*, *vT*, *uz*, *vz*, *uq*, *vq*, *uK*, and *vK*, at 6-hourly temporal resolution for all levels.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Derived Variable** | **Symbol** | **Units** | **Levels** | **Working Spectral Truncation** | **Times** |
| Kinetic energy | *K* | J kg-1 | 28 | T63 | 6-hourly |
| Geopotential height | *z* | m (gpm - geopotential meters) | 28 | T63 | 6-hourly |
| Zonal temperature flux | *uT* | m K s-1 | 28 | T63 | 6-hourly |
| Meridional temperature flux | *vT* | m K s-1 | 28 | T63 | 6-hourly |
| Zonal geopotential height flux | *uz* | m2 s-1 | 28 | T63 | 6-hourly |
| Meridional geopotential height flux | *vz* | m2 s-1 | 28 | T63 | 6-hourly |
| Zonal moisture flux | *uq* | m s-1 | 28 | T63 | 6-hourly |
| Meridional moisture flux | *vq* | m s-1 | 28 | T63 | 6-hourly |
| Zonal kinetic energy flux | *uK* | J m kg-1 s-1 | 28 | T63 | 6-hourly |
| Meridional kinetic energy flux | *vK* | J m kg-1 s-1 | 28 | T63 | 6-hourly |

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**Monthly Means**

We compute monthly means of the basic and derived variables from the 6-hourly data. The monthly mean spans 00Z of the first day of a month to 18Z of the last day of a month, and incorporates a 29th day in February of the leap years 1980, 1984, 1988, 1992, 1996, and 2000. From this first batch of monthly means it is the monthly mean surface pressure s that we make available as a budget product.

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| --- | --- | --- | --- | --- | --- | --- |
| **Vertically Integrated Monthly Mean Variable** | **Symbol** | **Product Name** | **Units** | **Level** | **Final Spectral Truncation** | **Times** |
| Monthly mean surface pressure | s | PS | Pa | Surface | T42 | Monthly |

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**Vertical Integrals of Monthly Means**

We define the vertical integral of a monthly mean field as a mass-weighted sum corresponding to   *( )dp/ g*   **where *( )* in the vertical integral is the monthly mean operator**, and *s* the monthly mean surface pressure. We note that monthly means are computed *before* any vertical integration is performed. Trenberth and others (2002) discuss differences that arise (up to order ±10 W m-2) in the divergence of total energy () if the vertical integral is performed at 6-hourly resolution, then the monthly mean taken, in the ERA-15 eta () archive for January of 1989.

In practice, the integral is obtained by computing *pi = is* at the model layer interfaces given by *i* = 0.0000, 0.0066, 0.0139, 0.0231, 0.0347, 0.0492, 0.0672, 0.0894, 0.1165, 0.1492, 0.1878, 0.2329, 0.2842, 0.3414, 0.4033, 0.4686, 0.5353, 0.6013, 0.6648, 0.7240, 0.7777, 0.8253, 0.8664, 0.9013, 0.9305, 0.9546, 0.9742, 0.9900, and 1.0000, where = 0.0000 is the top of the atmosphere, and = 1.0000 is the surface of the Earth. (In the -coordinate such as for ERA-15, *pi* = *ai* + *bi s* for *ai* and *bi* at model layer interfaces.) Then, *dp* for a given layer is computed as the difference between the pressure of the lower interface bounding the model layer, and the pressure of the upper interface bounding the model layer.

Since the units of *dp/g*, Pa/(m s-2), reduce to kg m-2, the term 'mass weighted' is used in association with the vertical integral. We also note that the **flux quantities appearing in the following table are not mass-corrected**. The mass correction and mass corrected fluxes are described in subsequent sections (see **[Mass Correction](http://www.cgd.ucar.edu/cas/catalog/newbudgets/index.html" \l "Sec9)** and [**Mass Corrected Vertically Integrated Monthly Mean Fluxes**](http://www.cgd.ucar.edu/cas/catalog/newbudgets/index.html#Sec10)).

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| --- | --- | --- | --- | --- | --- | --- |
| **Vertically Integrated Monthly Mean Variable** | **Symbol** | **Product Name** | **Units** | **Level** | **Spectral Truncation** | **Times** |
| Vertically integrated zonal velocity | *(u)dp/ g* | U | kg m-1 s-1 | Total column | T42, Final | Monthly |
| Vertically integrated meridional velocity | *(v)dp/ g* | V | kg m-1 s-1 | Total column | T42, Final | Monthly |
| Vertically integrated temperature | *(T)dp/ g* | T | K kg m-2 | Total column | T42, Final | Monthly |
| Vertically integrated specific humidity (Precipitable water) | *(q)dp/ g* | PW | kg m-2 | Total column | T42, Final | Monthly |
| Vertically integrated geopotential height | *(z)dp/ g* | Z | kg m-1 | Total column | T42, Final | Monthly |
| Vertically integrated kinetic energy | *(K)dp/ g* | KE | J m-2 | Total column | T42, Final | Monthly |
| Vertically integrated zonal temperature flux | *(uT)dp/ g* | - | kg K m-1 s-1 | Total column | T63, Working | Monthly |
| Vertically integrated meridional temperature flux | *(vT)dp/ g* | - | kg K m-1 s-1 | Total column | T63, Working | Monthly |
| Vertically integrated zonal geopotential height flux | *(uz)dp/ g* | - | kg s-1 | Total column | T63, Working | Monthly |
| Vertically integrated meridional geopotential height flux | *(vz)dp/ g* | - | kg s-1 | Total column | T63, Working | Monthly |
| Vertically integrated zonal moisture flux | *(uq)dp/ g* | - | kg m-1 s-1 | Total column | T63, Working | Monthly |
| Vertically integrated meridional moisture flux | *(vq)dp/ g* | - | kg m-1 s-1 | Total column | T63, Working | Monthly |
| Vertically integrated zonal kinetic energy flux | *(uK)dp/ g* | - | J m-1 s-1 | Total column | T63, Working | Monthly |
| Vertically integrated meridional kinetic energy flux | *(vK)dp/ g* | - | J m-1 s-1 | Total column | T63, Working | Monthly |

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**Monthly Tendencies**

To compute tendencies for a given month we utilize basic and derived variables, here generally denoted by *A*, at 18Z of the last day of the previous month (ldpm), *A18Z, ldpm*, 00Z of the first day of the given month (fdgm), *A00Z, fdgm*, 18Z of the last day of the given month (ldgm), *A18Z, ldgm*, and 00Z of the first day of the following month (fdfm), *A00Z, fdfm*. Where required we also compute vertical integrals, denoted by *Ã*, at the same times, thus forming

*Ã18Z, ldpm* = *A18Z, ldpmdp/g*,

*Ã00Z, fdgm* = *A00Z, fdgmdp/g*,

*Ã18Z, ldgm* = *A18Z, ldgmdp/g*,

and

*Ã00Z, fdfm* = *A00Z, fdfmdp/g*.

Averages are then computed from these quantities for the beginning of the month (bom), and the end of the month (eom):

*Abom* = ½(*A18Z, ldpm* + *A00Z, fdgm*),

*Aeom* = ½(*A18Z, ldgm* + *A00Z, fdfm*),

and

*Ãbom* = ½(*Ã18Z, ldpm* + *Ã00Z, fdgm*),

*Ãeom* = ½(*Ã18Z, ldgm* + *Ã00Z, fdfm*).

Finally, a monthly tendency is defined as

ð*A*/ðt = (*Aeom* - *Abom*)/(*N* x 86400),

or, for a vertically integrated quantity,

ð*Ã*/ðt = (*Ãeom* - *Ãbom*)/(*N* x 86400)

where ð/ðt is the time derivative operator, *N* the number of days in a month, and 86400 the number of seconds in a day.

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| --- | --- | --- | --- | --- | --- | --- |
| **Monthly Tendency** | **Symbol** | **Product Name** | **Units** | **Level** | **Final Spectral Truncation** | **Times** |
| Precipitable water tendency | ð( *qdp/ g)/ðt* | QTEN | kg m-2 s-1 | Total column | T42 | Monthly |
| Internal energy tendency | ð( *CpTdp/ g)/ðt* | ITEN | W m-2 | Total column | T42 | Monthly |
| Kinetic energy tendency | ð( *Kdp/ g*)/ðt | KTEN | W m-2 | Total column | T42 | Monthly |
| Latent energy tendency | ð( *Lqdp/ g*)/ðt | LETEN | W m-2 | Total column | T42 | Monthly |
| Geopotential tendency | ð( *sdp/ g)/ðt* =  ð(*sPs/ g*)/ðt | PHISTEN | W m-2 | Total column | T42 | Monthly |
| Total energy tendency | ð(*CpTdp/ g* + *Kdp/ g + Lqdp/ g + sPs/ g)/ðt  =  ð(CpTdp/ g)/ðt + ð(Kdp/ g)/ðt + ð(Lqdp/ g)/ðt + ð(sPs/ g)/ðt* | TETEN | W m-2 | Total column | T42 | Monthly |
| Surface pressure tendency | *ðPs*/ðt | PSTEN | Pa s-1 | Surface | T42 | Monthly |

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**Moisture Budget and Evaporation minus Precipitation**

The moisture budget involves the precipitable water tendency, ð(*qdp/ g)/ðt*, and the vertically integrated moisture flux ( *(uq)dp/ g*, *(vq)dp/ g*), from which we derive evaporation minus precipitation *E-P*:

*E-P* = ð(*qdp/ g)/ðt* + ( *(uq)dp/ g*, *(vq)dp/ g*)

or, in terms of budget and intermediate products

EP = QTEN + ( *(uq)dp/ g*, *(vq)dp/ g*)

where is the divergence operator.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Residual Monthly Mean Variable** | **Symbol** | **Product Name** | **Units** | **Level** | **Final Spectral Truncation** | **Times** |
| Evaporation minus precipitation | *E-P* | EP | kg m-2 s-1  (**mm day-1** in archive) | Total column | T42 | Monthly |

To convert a variable with units kg m-2 s-1 to mm day-1 multiply by (103mm m-1 x 86400 s day-1) and divide by H2O. Similarly, to convert a variable with units mm day-1 to W m-2 multiply by (H2O x *L*) and divide by (103mm m-1 x 86400 s day-1).

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**Mass Budget and Mass Budget Residual**

The mass budget involves the surface pressure tendency *ðPs*/ðt, the vertically integrated mass flux ( *(u)dp/ g*, *(v)dp/ g*), and *E-P*, from which we can derive the mass budget residual, *R*, an estimate of the degree of atmospheric mass balance (or lack thereof):

*R* = *ðPs*/ðt + *g* ( *(u)dp/ g*, *(v)dp/ g*) - *g* (*E-P*)

or, in terms of budget and intermediate products

MRES = PSTEN + *g* ( *(u)dp/ g*, *(v)dp/ g*) - *g* EP

where

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Residual Monthly Mean Variable** | **Symbol** | **Product Name** | **Units** | **Level** | **Final Spectral Truncation** | **Times** |
| Mass budget residual | *R* | MRES | Pa s-1 | Total column | T42 | Monthly |

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**Mass Correction**

In association with the mass budget residual *R* we define a potential function such that = *R* and thus

= *R*.

In principle, a mass correction which minimizes the mass budget residual may be obtained by subtracting a barotropic correction (*uc, vc*) from (, ), i.e. (-*uc, - vc*), at each level, where (, ) is the three-dimensional monthly mean horizontal wind. Combining the vertically integrated mass and moisture budget equations, substituting (-*uc, - vc*) for (, ), and solving for (*uc, vc*) yields

(*uc, vc*) = / (s - *g* *(q)dp/ g - t*).

Here t is the monthly mean pressure at the top of the atmosphere, this being uniformly 0. In terms of budget and intermediate products

= MRES

(UC, VC) = / (PS - *g* PW)

where

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Residual Monthly Mean Variable** | **Symbol** | **Product Name** | **Units** | **Level** | **Final Spectral Truncation** | **Times** |
| Barotropic correction to zonal wind | *uc* | UC | m s-1 | Total column | T42 | Monthly |
| Barotropic correction to meridional wind | *vc* | VC | m s-1 | Total column | T42 | Monthly |

In practice, the mass correction is applied to the vertically integrated monthly mean flux quantities, as described in the next section.

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**Mass Corrected Vertically Integrated Monthly Mean Fluxes**

Given a generalized variable *A*, the mass corrected vertically integrated monthly mean flux of this variable is defined as

*(uA)dp/ g* - *uc* *(A)dp/ g*   
or  
*(uA)dp/ g* - UC x A

and

*(vA)dp/ g* - *vc* *(A)dp/ g*   
or  
*(vA)dp/ g* - VC x A

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Vertically Integrated Monthly Mean Flux (Mass Corrected)** | **Symbol** | **Product Name** | **Units** | **Level** | **Final Spectral Truncation** | **Times** |
| Vertically integrated zonal temperature flux | *(uT)dp/ g* - *uc* *(T)dp/ g*  or *(uT)dp/ g* - UC x T | UT | kg K m-1 s-1 | Total column | T42 | Monthly |
| Vertically integrated meridional temperature flux | *(vT)dp/ g* - *vc* *(T)dp/ g*  or *(vT)dp/ g* - VC x T | VT | kg K m-1 s-1 | Total column | T42 | Monthly |
| Vertically integrated zonal geopotential height flux | *(uz)dp/ g* - *uc* *(z)dp/ g*  or *(uz)dp/ g* - UC x Z | UZ | kg s-1 | Total column | T42 | Monthly |
| Vertically integrated meridional geopotential height flux | *(vz)dp/ g* - *vc* *(z)dp/ g*  or *(vz)dp/ g* - VC x Z | VZ | kg s-1 | Total column | T42 | Monthly |
| Vertically integrated zonal moisture flux | *(uq)dp/ g* - *uc* *(q)dp/ g*  or *(uq)dp/ g* - UC x PW | UQ | kg m-1 s-1 | Total column | T42 | Monthly |
| Vertically integrated meridional moisture flux | *(vq)dp/ g* - *vc* *(q)dp/ g*  or *(vq)dp/ g* - VC x PW | VQ | kg m-1 s-1 | Total column | T42 | Monthly |
| Vertically integrated zonal kinetic energy flux | *(uK)dp/ g* - *uc* *(K)dp/ g*  or *(uK)dp/ g* - UC x KE | UK | J m-1 s-1 | Total column | T42 | Monthly |
| Vertically integrated meridional kinetic energy flux | *(vK)dp/ g* - *vc* *(K)dp/ g*  or *(vK)dp/ g* - VC x KE | VK | J m-1 s-1 | Total column | T42 | Monthly |

We note that *Cp*(UT,VT), *g*(UZ,VZ), *L*(UQ,VQ), and (UK,VK) all have units of J m-1 s-1. Taking the horizontal divergence, , of any of these, or any sum of these, gives rise to divergences of energy with units W m-2.

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**Divergences of Energy**

We compute divergences of energy from the mass corrected vertically integrated monthly mean fluxes. In terms of archived budget products the divergences of energy are

*TEDIV* = (*Cp*UT+ *g*UZ+*L*UQ+ UK, *Cp*VT+ *g*VZ+*L*VQ+ VK)

*DSEDIV* = (*Cp*UT+ *g*UZ, *Cp*VT+ *g*VZ)

*LEDIV* = (*L*UQ, *L*VQ)

*KEDIV* = (UK, VK)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Divergence of Energy** | **Symbol** | **Product Name** | **Units** | **Level** | **Final Spectral Truncation** | **Times** |
| Divergence of total energy | *TEDIV* or | TEDIV | W m-2 | Total column | T42 | Monthly |
| Divergence of dry static energy | *DSEDIV* | DSEDIV | W m-2 | Total column | T42 | Monthly |
| Divergence of latent energy | *LEDIV* | LEDIV | W m-2 | Total column | T42 | Monthly |
| Divergence of kinetic energy | *KEDIV* | KEDIV | W m-2 | Total column | T42 | Monthly |

where **F**A is the total atmospheric energy transport (*Cp*UT+ *g*UZ+*L*UQ+ UK, *Cp*VT+ *g*VZ+*L*VQ+ VK) with units J m-1 s-1. Strictly speaking, `divergence of energy' here refers to `divergence of energy transport'. In addition, we define the zonal mean poleward atmospheric energy transport *PAET* as

*PAET*() = [ *Cp*VT(, ) + *g*VZ(, ) + *L*VQ(, ) + VK(, )] *a* cos() d

where is longitude, latitude, and *a* the radius of the Earth. The units of *PAET* are W which we normally convert to PW (i.e. 1015W) by dividing *PAET* by (1015W PW-1). Note that at present we do not include *PAET* as a budget product for this particular archive.

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**Diabatic minus Frictional Heating (Heat and Energy Budget)**

We compute diabatic minus frictional heating, *Q1- Qf*, as a residual of the energy budget. In terms of archived budget products *Q1-Qf* is given by

*Q1-Qf* = TETEN+TEDIV - *L*EP

where –*L*EP = *Q2*, the latent heating.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Residual Monthly Mean Variable** | **Symbol** | **Product Name** | **Units** | **Level** | **Final Spectral Truncation** | **Times** |
| Diabatic minus frictional heating | *Q1-Qf* | Q1QF | W m-2 | Total column | T42 | Monthly |

In general, the estimated frictional heating *Qf* is less than a few W m-2 on an annual mean basis (see Peixoto and Oort, 1992, p. 383) and can be safely disregarded compared to the diabatic heating *Q1*. Thus, *Q1-Qf* *Q1*.

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**Vertically Averaged Total Energy**

As a final diagnostic, we compute vertically averaged total energy *TE* where the vertical average is simply *(g / s) ()dp/ g*. In practice *TE* is computed as the sum

*TE* = *(g / s)* [ *Cp* *(T)dp/ g* + *g* *(z)dp/ g* + *L* *(q)dp/ g* + *(K)dp/ g* ],

or, in terms of archived budget products

TE = *(g /* PS*)* [ *Cp*T + *g*Z + *L*PW + KE ].

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Vertically Averaged Monthly Mean Variable** | **Symbol** | **Product Name** | **Units** | **Level** | **Final Spectral Truncation** | **Times** |
| Vertically **Averaged** Total Energy | *TE* | TE | J kg-1 | Total column | T42 | Monthly |

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**ERBE Period (February 1985 – April 1989) Radiation Products and Net Upward Surface Flux**

|  |  |
| --- | --- |
| Our budget product offerings would not be complete without an estimate of the net upward surface flux *Fs* for the ERBE period February 1985 – April 1989. We compute *Fs* as   *Fs* = TETEN + TEDIV - *RT*   where *RT* is the net downward radiation through the top-of-the-atmosphere (TOA), and   *RT* = *AT* - *OT*   where *AT* and *OT* are the absorbed solar (shortwave) radiation and outgoing longwave radiation, respectively, at the TOA. In terms of archived budget products this reads   FS = TETEN + TEDIV - NET   and   NET = ASR - OLR. |  |
| An annual mean net upward surface flux *Fs* for the ERBE period is shown [below](http://www.cgd.ucar.edu/cas/catalog/newbudgets/index.html#FS1). | *Three-panel figure shows TOA annual mean absorbed solar (shortwave) radiation AT (top), outgoing longwave radiation OT (middle), and net radiation RT (bottom) which is given by RT = AT - OT. The units in all three panels is W m-2 at T31 spectral truncation. The annual mean is in fact an* [*annualized mean*](http://www.cgd.ucar.edu/cas/catalog/newbudgets/newbudgets.annualized.html) *over the ERBE period February 1985 – April 1989.* |
|  |  |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Radiation Product or Net Surface Flux** | **Symbol** | **Product Name** | **Units** | **Level** | **Final Spectral Truncation** | **Times** |
| Absorbed solar radiation | *A*T | ASR | W m-2, > 0 downward through TOA | TOA | T42 | Monthly, February 1985 – April 1989 only |
| Outgoing longwave radiation | *O*T | OLR | W m-2, > 0 upward through TOA | TOA | T42 | Monthly, February 1985 – April 1989 only |
| Net downward radiation | *R*T | NET | W m-2, > 0 downward through TOA | TOA | T42 | Monthly, February 1985 – April 1989 only |
| Net upward surface flux | *F*s | FS | W m-2, > 0 upward through surface into atmosphere | surface | T42 | Monthly, February 1985 – April 1989 only |
|  | | | | | | |
| *Figure (above) shows an* [*annualized mean*](http://www.cgd.ucar.edu/cas/catalog/newbudgets/newbudgets.annualized.html) *net upward surface flux Fs for the ERBE period (February 1985 – April 1989) in W m-2 at T42 spectral truncation. Negative (blue) regions in equatorial and Tropical oceans represent a net flux of energy from the atmosphere into the oceans on an annual mean basis. Other noteworthy features are the significant net fluxes of energy from the Kuroshio, the Gulf Stream, and the Aghulas Current into the atmosphere. (Note that we have masked land areas in this figure – ideally, Fs should be roughly 0 over land areas. We also show both* [*masked and unmasked versions*](http://www.cgd.ucar.edu/cas/catalog/newbudgets/newbudgets.FS2.html) *of this figure.)* | | | | | | |

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**Accessing the Data**

The products are available in both netCDF and Fortran direct access binary files with one variable archived as 276 monthly mean 128 x 64 grids per file (51 monthly mean grids in the case of ERBE period *A*T, *O*T, *R*T, and *F*s). The Fortran direct access files were written on a *big-endian* machine (SGI Origin 2000), and thus be aware that if you attempt to read the direct access files on a *little-endian* machine (for example a Pentium-based PC running Linux), the bytes of a data element (in this case 4 bytes for a 32 bit REAL) will be in reverse to that for a big-endian machine. (We supply a subroutine for converting between and big- and little-endian 32 bit REAL data elements. See [native\_4byte\_real](http://www.cgd.ucar.edu/cas/catalog/newbudgets/newbudgets.endian.html).)

The file naming convention for 32 of the 36 products is

T42t\_**PRODUCTNAME**\_1979-2001\_MM.**EXT**

where T42t signifies T42 spectral truncation with `tapering' (see Sardeshmukh and Hoskins, 1984), **PRODUCTNAME** is the name of a budget product highlighted in red in the previous sections or in the summary table shown below, MM refers to `monthly mean', and **EXT** is either `nc' for netCDF or `Fda' for Fortran direct access. Users need only specify **PRODUCTNAME** and **EXT**. **Note that in the case of** *A*T, *O*T, *R*T, **and** *F*s, **the file naming convention is**

T42t\_**PRODUCTNAME**\_198502-198904\_MM.**EXT**

for the ERBE period radiation products and net upward surface flux.

The size of a file is 9043968 bytes (.Fda) to roughly 9047300 bytes (.nc) each – for *A*T, *O*T, *R*T, and *F*s, the size of a file is 1671168 bytes (.Fda) to roughly 1673300 bytes (.nc) each.

The files may be obtained via email requests.

The metadata of the netCDF files may be viewed with ncdump, for example, [ncdump -h T42t\_TEDIV\_1979-2001\_MM.nc](http://www.cgd.ucar.edu/cas/catalog/newbudgets/newbudgets.ncdump-h.html).

The coordinate variables [(time, lat, lon)](http://www.cgd.ucar.edu/cas/catalog/newbudgets/newbudgets.cvars.html) and the coordinate variable values are listed for convenience on a separate web page.

A short Fortran program, `[READ\_FDA](http://www.cgd.ucar.edu/cas/catalog/newbudgets/newbudgets.f90prog.html)', for reading the Fortran direct access (.Fda) version of the files may be viewed separately. Or, simply download [PROG\_READ\_FDA.f90](ftp://ftp.cgd.ucar.edu/pub/CAS/NEWBUDGETS/PROG_READ_FDA.f90) using your browser. We also make available a Fortran 90 subroutine, [ccm2\_hydrostatic\_matrix](http://www.cgd.ucar.edu/cas/catalog/newbudgets/newbudgets.f90subr.html), for computing the hydrostatic matrix ***H*** (see the section [Derived Fields at 6-hourly Resolution](http://www.cgd.ucar.edu/cas/catalog/newbudgets/index.html#Sec3) above).

For convenience we include an ocean depth and land elevation data set at 128x64 (i.e. `T42 Gaussian') resolution with longitudes and latitudes identical to those in the netCDF and Fortran direct access budget product files. For more information, see T42b\_ELEVATION.nc and T42b\_ELEVATION.Fda, which are now available via request only. We routinely use this ocean depth and land elevation data file as a land-sea mask, where ELEVATION < 0 represents oceans and seas, and ELEVATION 0 represents land. *Sea ice is not represented in this data set*. An [image of the 128x64 ocean depth and land elevation](http://www.cgd.ucar.edu/cas/catalog/newbudgets/newbudgets.elevation.html) data set is provided. (This link also includes further details about the construction of the data set).

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**Summary Table of all Products**

As a summary we reassemble all 36 budget product descriptions in the following table (refer to the previous sections for more specific details).

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Variable** | **Symbol** | **Product Name** | **Units** | **Level** | **Final Spectral Truncation** | **Times** |
| Monthly mean surface pressure | s | PS | Pa | Surface | T42 | Monthly |
| Vertically integrated zonal velocity | *(u)dp/ g* | U | kg m-1 s-1 | Total column | T42 | Monthly |
| Vertically integrated meridional velocity | *(v)dp/ g* | V | kg m-1 s-1 | Total column | T42 | Monthly |
| Vertically integrated temperature | *(T)dp/ g* | T | K kg m-2 | Total column | T42 | Monthly |
| Precipitable water | *(q)dp/ g* | PW | kg m-2 | Total column | T42 | Monthly |
| Vertically integrated geopotential height | *(z)dp/ g* | Z | kg m-1 | Total column | T42 | Monthly |
| Vertically integrated kinetic energy | *(K)dp/ g* | KE | J m-2 | Total column | T42 | Monthly |
| Precipitable water tendency | ð( *qdp/ g)/ðt* | QTEN | kg m-2 s-1 | Total column | T42 | Monthly |
| Internal energy tendency | ð( *CpTdp/ g)/ðt* | ITEN | W m-2 | Total column | T42 | Monthly |
| Kinetic energy tendency | ð( *Kdp/ g*)/ðt | KTEN | W m-2 | Total column | T42 | Monthly |
| Latent energy tendency | ð( *Lqdp/ g*)/ðt | LETEN | W m-2 | Total column | T42 | Monthly |
| Geopotential tendency | ð( *sdp/ g)/ðt* =  ð(*sPs/ g*)/ðt | PHISTEN | W m-2 | Total column | T42 | Monthly |
| Total energy tendency | ð(*CpTdp/ g* + *Kdp/ g + Lqdp/ g + sPs/ g)/ðt  =  ð(CpTdp/ g)/ðt + ð(Kdp/ g)/ðt + ð(Lqdp/ g)/ðt + ð(sPs/ g)/ðt* | TETEN | W m-2 | Total column | T42 | Monthly |
| Surface pressure tendency | *ðPs*/ðt | PSTEN | Pa s-1 | Surface | T42 | Monthly |
| Evaporation minus precipitation | *E-P* | EP | mm day-1 | Total column | T42 | Monthly |
| Mass budget residual | *R* | MRES | Pa s-1 | Total column | T42 | Monthly |
| Barotropic correction to zonal wind | *uc* | UC | m s-1 | Total column | T42 | Monthly |
| Barotropic correction to meridional wind | *vc* | VC | m s-1 | Total column | T42 | Monthly |
| Vertically integrated zonal temperature flux²;  (Mass Corrected) | *(uT)dp/ g* - *uc* *(T)dp/ g* | UT | kg K m-1 s-1 | Total column | T42 | Monthly |
| Vertically integrated meridional temperature flux²  (Mass Corrected) | *(vT)dp/ g* - *vc* *(T)dp/ g* | VT | kg K m-1 s-1 | Total column | T42 | Monthly |
| Vertically integrated zonal geopotential height flux ² (Mass Corrected) | *(uz)dp/ g* - *uc* *(z)dp/ g* | UZ | kg s-1 | Total column | T42 | Monthly |
| Vertically integrated meridional geopotential height flux² (Mass Corrected) | *(vz)dp/ g* - *vc* *(z)dp/ g* | VZ | kg s-1 | Total column | T42 | Monthly |
| Vertically integrated zonal moisture flux²  (Mass Corrected) | *(uq)dp/ g* - *uc* *(q)dp/ g* | UQ | kg m-1 s-1 | Total column | T42 | Monthly |
| Vertically integrated meridional moisture flux²  (Mass Corrected) | *(vq)dp/ g* - *vc* *(q)dp/ g* | VQ | kg m-1 s-1 | Total column | T42 | Monthly |
| Vertically integrated zonal kinetic energy flux²  (Mass Corrected) | *(uK)dp/ g* - *uc* *(K)dp/ g* | UK | J m-1 s-1 | Total column | T42 | Monthly |
| Vertically integrated meridional kinetic energy flux² (Mass Corrected) | *(vK)dp/ g* - *vc* *(K)dp/ g* | VK | J m-1 s-1 | Total column | T42 | Monthly |
| Divergence of total energy | *TEDIV* or | TEDIV | W m-2 | Total column | T42 | Monthly |
| Divergence of dry static energy | *DSEDIV* | DSEDIV | W m-2 | Total column | T42 | Monthly |
| Divergence of latent energy | *LEDIV* | LEDIV | W m-2 | Total column | T42 | Monthly |
| Divergence of kinetic energy | *KEDIV* | KEDIV | W m-2 | Total column | T42 | Monthly |
| Diabatic minus frictional heating | *Q1-Qf* | Q1QF | W m-2 | Total column | T42 | Monthly |
| Vertically **Averaged** Total Energy | *TE* | TE | J kg-1 | Total column | T42 | Monthly |
| Absorbed solar radiation | *A*T | ASR | W m-2, > 0 downward through TOA | TOA | T42 | Monthly, February 1985 – April 1989 only |
| Outgoing longwave radiation | *O*T | OLR | W m-2, > 0 upward through TOA | TOA | T42 | Monthly, February 1985 – April 1989 only |
| Net downward radiation | *R*T | NET | W m-2, > 0 downward through TOA | TOA | T42 | Monthly, February 1985 – April 1989 only |
| Net upward surface flux | *F*s | FS | W m-2, > 0 upward through surface into atmosphere | surface | T42 | Monthly, February 1985 – April 1989 only |

² In the netCDF files, the term `transport' rather than `flux' is used in the long\_name attribute of the variables UT, VT, UZ, VZ, UQ, VQ, UK, and VK.

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**Extended Bibliography**

The majority of the references listed here are Climate Analysis Section publications based solely or in part on atmospheric mass, moisture, heat and energy budget products derived from reanalyses – the NCEP/NCAR reanalysis to a larger degree, and ERA-15 (and ECMWF operational global analyses) to a lesser degree³. Other publications are listed for technical reference and further background.

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³ With the advent and availability of [ERA-40 from ECMWF](http://www.ecmwf.int/research/era/) in 2003, our focus and publications will begin to incorporate budget products derived from this new 40 year reanalysis.

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*Last modified 3rd February 2006.*

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