Documentation for IGCM3

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1. About the Documentation

IGCM3 is the full-physics climate model version of the IGCM containing complex radiation and boundary layer schemes, a soil temperature scheme and a simple slab ocean. This document describes the changes made from IGCM2. It ought to accompany documentation for IGCM1 and IGCM2 - although without knowledge of how IGCM2 works some of this document may appear slightly confusing!

IGCM3 incorporates extensive changes to the physics of IGCM2; these changes are described in the next section. Section 3 describes the orography data set used, Section 4 describes changes to the input and output of the model and Section 5 other miscellaneous changes. Section 6 describes how to run the IGCM and Section 8 gives an example job deck.

Caution! This version of IGCM3 has only ever been tested in its T21-L22 configuration and it is by no means as final or as bug free as earlier versions. Some of the Fortran is rather messy and not properly tested - good luck!

This describes the version that PMF uses - others' versions may be quite different.

2. New Physics

2.1. Radiation -subroutine RADN

This subroutine sets up the call to the NIKOSRAD subroutine which calculates the shortwave (SW) and longwave (LW) heating rates and fluxes as a function of altitude. The heating rates are calculated from separate calls to SW and LW radiation codes from the NIKOSRAD subroutine..

As the radiation schemes are computationally expensive they are at present only called once every 'ntstep' timesteps, where 'ntstep' is normally set to the number of timesteps per day. Also, to save time, the full radiation scheme is not called every longitude of the model. The number of longitudes called at each latitude depends on the latitude and the setting of 'LNNSK' in the parameter namelist. If LNNSK is TRUE the radiation scheme is also called each side of every land/sea interface. Linear interpolation of fluxes and heating rates is performed in the longitudinal direction.

Note: in the radiation scheme level number 1 is the surface and has NL+1 levels - this is different to the rest of the model, which has NL levels, where 1 is the topmost level.

The radiation scheme takes inputs of:

- **Julian day (DOY "Day of Year"):** This is a real number telling the radiation scheme exactly how far through the year you are. It has values from 1.0, for midnight on the last day in December, to 360.999, just before midnight on the last day in December. Note the IGCM year is 360 days long

(12 equal months of 30 days).

- **Latitude and longitude:** The latitude, longitude and Julian day are needed to calculate the solar zenith angle. The longitude is only used if the radiation scheme is called more than once per day (set LDIUR=.TRUE. in the radiation scheme). In this case the time of day, position of the Sun, is given by the longitude and the decimal part of DOY. The default is LDIUR=FALSE, which produces a diurnal average of the SW heating.
- **Ozone:** Monthly mean ozone mass mixing ratios at 15 pressure levels are interpolated onto the IGCM vertical grid at each grid point where the radiation scheme is called. This scheme preserves column ozone. Monthly mean values, on the IGCM grid, are then interpolated in time to get ozone concentrations at the time the radiation is called (using DOY). The ozone climatology is from Li and Shine, 1995, it is the same as that used in the Unified Model and is based on a combination of data from the SBUV satellite instrument and ozonesonde profiles.
- **Water vapour:** This can either be prescribed from an ECMWF climatology, much like ozone, or it can be taken to be the diagnostic water vapour field from the IGCM (i.e. interactive). If the water vapour falls below a mass mixing ratio og 6.0E-6, which it does in the stratosphere, it is set to this minimum value for the call to the radiation scheme.
- **Temperature and pressure** are taken from the IGCM diagnostic temperature and pressure fields. **Surface temperature** can either be taken the interactice surface schmeme or from a climatological value, from ECMWF analyses. Either land or sea surface (or both) temperatures can be perscribed from the climatology..
- **Diagnostic clouds:** Cloud fraction and liquid water path come from the cloud diagnostic scheme, described in Section 2.5).
- **Surface albedo**: This is a diagnostic variable of the boundary layer scheme, described in Section 2.2. Where the boundary layer scheme has not formed ice or snow a climatological value of surface albedo is used from ISCCP data (Rossow and Schiffer, 1988).
- The radiation scheme also uses **carbon dioxide** and **CFC concentration**. Currently a uniform value of 336 ppmv in used for the carbon dioxide concentration and no CFCs are assumed to be present in the atmosphere.
- The **solar constant** is presently set to 1320 Wm^{-2}. This is about 4% lower that the "true" value. This was a ‘tuning’ to help obtain the observerd net SW flux at the top of the atmosphere of about 237 Wm^{-2} in the global and annual average.

2.1.1 Shortwave - subroutine RADSW

The Morcrette (1991) scheme is used with updates to the ozone, oxygen and water vapour absorption parametrisations made by Zhong and Haigh (pers. comm.). This scheme uses the delta-Eddington approximation in two wavelength bands (0.25 -0.68 Microns and 0.68-4.0 microns) to calculate the upward and downward fluxes in the shortwave. Level number 1 is the surface. Cloud optical depth, single scattering albedo and asymmetry factors are based on a simple parametrisation (described in Morcrette, 1991) involving cloud liquid water path and effective radius. All cloud is assumed to be water cloud with an effective radius of 5 microns, somewhat lower than actual values (5-15 microns). This low value was chosen to help with the tuning of the net SW flux at the top of the atmosphere.

2.1.2 Longwave - subroutine FLUX

The Reading Wide Band Model (RWBM) is used (Christidis, 1999). This uses 6 spectral bands to calculate the thermal IR fluxes and heating rates. It includes the absorption of water vapour, ozone and carbon dioxide. It also treats the effects of the water vapour continuum has a facility for including a CFC type gas. The scheme is designed to be accurate to within 2% of irradiances from line-by-line models and is about 3 times faster than the Morcrette LW code. It is based on the method of pre-computed tables of transmittances which are stored in the computer's memory.

2.2. Boundary layer scheme - subroutine BLSURF

The original boundary layer scheme in IGCM2 calculated the fluxes of sensible heat, latent heat and momentum between the surface and the lowest model level based on the formulation of Corby, Gilchrist and Newson (QJRMS,1972). In essense, this is a modified bulk aerodynamic approach, with a constant Ce=Ch=Cd=0.001 and a modified windspeed to include "gustiness", v'=v+3m/s. In addition, a stability dependent criteria reduces the transfer by a factor of 5 in stable and neutral conditions and increases it in unstable conditions (for sensible and latent heat fluxes only). i.e.

$\tau_x=C_d\rho|v'|v_x$
$\tau_y=..........*v_y$

$H=0.2*C_e\rho|v'_{eff}|*(\theta_s-\theta_a)$
$L=0.2*C_h\rho|v'_{eff}|(q_s-q_a)$

$|v'_{eff}|=|v'|+A.sqrt((\theta_s-\theta_a)/\theta)$

A=500m/s if $(\theta_s-\theta_a)>0$, =0 otherwise. Note that A is called 'BLA' in the code.

Note that H and L are positive in the upward direction, as defined here.

This simple parameterisation of the stability dependence of the flux can actually be shown to be closely related to the more complicated Richardson number dependent schemes used in more sophisticated models, for instance the UGCM. By doing this, it is possible to derive an expression for the variable A used in the equations above.

$A=sqrt(gz_o)[k/ln(z_{ll}/z_o)]^{-2}$

where g is acceleration due to gravity, z_o is the surface roughness length, k is von Karmans constant and z_{ll} is the height of the lowest level of the model from the surface. This will allow us to calculate values of BLA appropriate to given first model level heights and roughness lengths, whereas the previous constant value of 500m/s could only be considered to be appropriate for one particular pair of values for z_o and z_{ll}.

In addition, the standard expression for the values of C_d, C_h and C_e is used, i.e.

$C_d=C_h=C_e=[k/ln(z_{ll}/z_o)]^2$

For a roughness length of 0.2m and a lowest level of 300m (typical of the model in its original, low vertical resolution, mode), the value of BLA evaluates to about 470, close to the IGCM2 value, although C_d is about 0.003, 3 times larger than previously assumed.

So, in effect, the original turbulent flux parameterisation of IGCM2 is retained but with the strength of the stability dependent term and of the drag coefficient being calculated from the local parameters rather than being assumed. The calculated parameters tend to lead to a stronger coupling between the atmosphere and surface than in the original scheme, which requires a time-splitting scheme to be used when the interactive land surface scheme is active. Using the full model timestep would lead to instability in the thin upper soil layer, whereas an implicit scheme would require substantial modifications to other portions of the model and may lead to non conservation of energy and moisture.

Note:The momentum, energy and moisture fluxes from the boundary layer scheme are applied only to the lowest atmospheric model level. This is only acceptable if this lowest level is very deep - at least 100mb. In other cases, the surface fluxes should be distributed amongst the levels in the lowest 1km or so of the atmosphere. This should be a simple update, but hasn't been done yet.

If the surface scheme is interactive then the boundary layer scheme timestep is reduced to keep the model stable. At present the boundary layer scheme is called six times for each model time step.

Notes for the code changes.

New array, BLCD(IGC) is introduced - contains C_d at all points for current latitude, since this is needed in convection scheme.

BLA redefined, now $(1/k^2)=5.95$

DRAG and CUT1 redefined to remove factor of C_d, which is now included explicitly from BLCD() wherever these values were used.

Sigma factor RSIGF=2.$(1-\sigma_{NL})/(1+\sigma_{NL})$ - allows the height of the first level to be calculated easily, for non-dimensional Z, T and g, Z=RSIGF.T/g

Define a roughness length (times non-dimensional g) RGZ0, which for the moment is geographically invariant.
20cm <=> 9.0904×10^{-6}.

The mean potential temperature of the lowest level (between surface and mid-level) is needed sooner than before in the calculates. This allows the calculation of $(\Delta Z/Z_o)$(RZZ0) and $(\ln(\Delta Z/Z_o))^2$ (RLZZ02) - hence CD=1/(BLA*RLZZ02)

2.3. Surface schemes - subroutines BLSURF and SURFM

Different surface schemes operate over land or ocean; they are turned on by setting LSL= TRUE and LOC= TRUE respectively. If not turned on the surface temperatures are set by their climatological values, and the surface relative humidity set to 100% over ocean and 75% over land. If you want interactive surface temperatures you have to use the new boundary layer scheme as well (i.e. have

LOLDBL= FALSE).

2.3.1 Soil/Snow scheme -in BLSURF and SURFM subroutines

Soil heat transport assumed to be diffusive only. Thermodynamics and hydrology completely decoupled. All soil thermodynamics assume 50% soil moisture. An extra heat capacity is added to that of the soil between -3C and +1C to simulated the effect of soil moisture freezing. The integrated effect of this extra heat capacity over this temperature range equals the latent heat of fusion of the soil moisture.

Two soil levels are used, the upper level is thin and provides an approximation to the skin temperature for use in the atmospheric model. The depth of the lower layer and the effective thermal conductivity of the soil are chosen so that when the soil scheme is forced by a sinusoidally varying surface flux with period of 1 year, the temperature variations of the upper soil level exactly match the amplitude and phase of the surface temperature predicted by a continuum diffusive soil model.

Any snow lying on the surface is merged into the thermal properties of the upper layer, the thermal resistance of the snow acting in series with that of the soil - to simulate the insulating properties of the snow. The heat capacity of the snow is added to that of the soil - subject to a maximum addition of 1.4m of snow.

Snow melts if the temperature of the upper layer rises above 0C, with excess energy being used to melt the snow and the temperature being reset to 0C. If there is energy left over after all snow has been melted during a timestep, a negative snow depth will be recorded and stored - thus the energy required to melt some snow the next time it falls has effectively been saved.

Surface albedo is represented by a fixed value where there is no snow cover, which is modified in the presence of snow cover towards a deep snow albedo of 80%. Scaling snow depth for this transfer is 33cm - ie 10cm liquid water.

Soil moisture is dealt with via a bucket model. Relative humidity at the surface is taken to be zero below 1/3 bucket capacity, 100% above 2/3 bucket capacity and to vary linearly between these points.

Assumed soil properties are: $\rho c_{soil,dry}=1.35x10^6$ $Jm^{-3}K^{-1}$ (Average of values for clay and sandy soil from Peixoto and Oort). Field saturation capacity for water assumed 35% by volume. Thus rc for 50% saturated soil is $2.085x10^6$ $Jm^{-3}K^{-1}$. Equivalent heat capacity for freezing of soil water is 15.312x106 Jm-3K-1 (over 4K). Density of snow taken to be 300 kgm^{-3}, rc is $627x10^3$ $Jm^{-3}K^{-1}$. Thermal conductivity is 1.1 $Wm^{-1}K^{-1}$ for soil and 0.24 $Wm^{-1}K^{-1}$ for snow. Effective soil conductivity is 1.0728. Depth of upper soil layer is 6cm and the lower is 2.3m deep. Deep snow albedo is taken to be 80%. Snow free albedos are generated from ECMWF monthly climatology. In general annual average albedos are taken for snow free values, but where the annual average is above 50% (over land) or 30% (over ocean) then minimum monthly value is used instead.

Description: New global arrays are added. SMSTAR contains soil moisture. TDEEP the temperature of the lower soil level, HSNOW the snow depth (in m of snow, not liquid water in this case), SQSTAR is the *saturated* humidity at the surface, SALB is the surface albedo and SBAL is the background (snow free) albedo.Surface albedo is passed to the radiation scheme over land points. Over ocean points, the background albedo is used, except when ice is formed, see the next section.

Subroutine BLSURF is modified to prevent condensation onto warm but dry surfaces by using a QSTAR which is given by MIN(SQSTAR,MAX(QSTAR,QATMOS)).

Various parameters are set in INIPHYS and added to appropriate namelists. The switch LSL is added and used to control whether the surface scheme is invoked. When LSL is false, the climatological surface is used. LSL defaults to true.

The format of the restart record for the surface scheme is changed completely. Restart records are now unformatted, beginning with a single value of -999.999 to identify the file. Initial values are read from channel 18, periodic restart records to channel 19 and the final record to channel 17.

Subroutine INISURF reads the initial surface data from channel 18. This is recommended even for runs where the surface scheme is not used.

Subroutine LNSDURF performs the surface calculations for all land points for a given value of JL.

Problems: Deep snow albedo is probably too high. Soil scheme will not respond properly to a diurnal cycle (will lag by about 6 hours, should lag by 3 hours for a diffusive mode).

2.3.2 Ocean scheme - in BLSURF

The ocean is a very simple slab ocean of constant depth. In the standard version the depth of the ocean is set to 2m - this is very small to allow fast spin up of surface temperatures.

A 100-year control run is performed with climatological sea surface temperatures and interactive land surface temperatures to determine ocean heat transports. Monthly values of sea surface temperatures and surface heat flux are used to determine monthly mean ocean heat transports. The heat transported out of a given grid box is given by:

Ocean heat transport (+ve out of an ocean grid box) = $G_m - C(T_{m+1}-T_{m-1})/(60 \text{ days})$;

where C is the heat capacity of the ocean, $T_{m+1}-T_{m-1}$ the temperature change over a two month period and G_m the monthly mean surface heat flux. In the global and annual average these ocean heat transports add up to the net (+ve downwards) flux imbalance at the top of the atmosphere (2 Wm^{-2}) for the example job deck shown in Section 8). These climatological ocean heat transports are read in at the start of each run. The Julian day is used to interpolate between the monthly averages.

Below -2 °C sea ice forms instantly; it is assumed to have a depth of 2m and an albedo of 0.6. If ice has formed and the ocean heat transport is +ve it is set to zero. This means that ice can’t loose heat to any underlying ocean. Ocean heat transports are still allowed into the grid box. This was primarily to keep the ice edge stable, but I thought is was also vaguely physical (PMF). Different latent heats are used depending on whether a grid box is ice or water.

2.4. Rayleigh friction

The decelerating effect of breaking gravity waves on the mean flow in the stratosphere is very crudely parametrised by insertion of a drag term in the momentum equations. This operates only in the top NLEVRF levels of the model, where NLEVRF is set in the main parameter line. To date NLEVRF has usually been set to 4; since the drag effect should principally affect the mesosphere (not currently represented in the IGCM) it is recommended that NLEVRF should be kept as small as possible. At the end of subroutine DIFUSE vorticity and divergence are artificially reduced by an amount governed by RFCOEFF, which varies smoothly from 1/32 pi at the top of the model to zero at the level below the 'NLEVRF'th level down. This value for RFCOEFF has been rather arbitrarily chosen to give a reasonable model climatology and prevent the development of excessively strong winds in the stratosphere which is a common problem among middle atmosphere models. The model's sensitivity to its magnitude is currently being investigated; a better value may well result soon.

2.5. Diagnostic clouds

The cloud diagnostic scheme is based on Slingo (1987), with some simplifications. The scheme is not a separate subroutine but comprises additional code added to the convective and large scale rain physics routines. The parametrisation computes cloud fractions and liquid water paths for five cloud types: Low (sigma >0.7), mid (0.7 > sigma >0.35), high (0.35 > sigma > 0.12), shallow convective and deep convective. As the radiation scheme can only take low, mid, high and convective cloud ; If both shallow and deep convective cloud occur in the same grid box the convection with the smallest cloud fraction is ignored. The maximum height of convective cloud is not set; in the model runs carried out so far few clouds are found higher than 100 mb.

The cloud fraction of low, mid and high cloud is given by: CFR=((RH-0.8)/0.2)**2, where RH is the relative humidity. Above an RH of 100% the cloud fraction is set to 1.0. If more than one level in the low, mid and high cloud ranges contain relative humidities higher than 0.8 the level with the maximum RH is chosen for the cloud placement.

Deep convective cloud fractions are parametrised by their precipitation:

CFR =0.245+0.125*ln(P), Where P is the precipitation in mm/day.

Shallow convective clouds in the IGCM do not precipitate, so we are unable to use this formula to calculate their cloud fractions. We therefore assume a cloud fraction of 0.3 at all times. This was found to be the average and roughly constant value of shallow convective cloud fraction from unified model runs (Blackburn pers. comm.).

Likewise there is no low level boundary layer cloud formed by large scale ascent, causing an underestimate of low cloud.

The cloud liquid water path is parametrized by assuming that it is equal to a 1% super-saturation of water vapour in the cloud.

Note: In the convection schemes, level NL is assumed to be the ground and cloud types are set as 1-low, 2-mid, 3-high, 4-shallow, 5-deep (numbering of CFRAC). whereas in the radiation scheme the levels are reversed and numbering of cloud type goes as 1-deep/shallow, 2-high, 3-mid, 4- low (numbering for CF).

2.6. Water vapour filler

This is a ‘fix’ to prevent negative water vapour concentrations from appearing in the model. It is a piece of code inserted at the beginning of the convection scheme. If the water vapour mass mixing ratio at any gridpoint falls below 1.0E-6, it is set to this minimum value and the water vapour deficit is taken from the level below. Water vapour tendencies are then written onto the large scale rain tendency field, which is used to increment the water vapour tendency due to convection. The scheme assumes that there is always enough water vapour to take from in the lowest model level. The employment of the scheme leads to a very slight vertical advection of water.

2.7. Other changes

Bugs?

3. Orography

Mean orography is used, from the US Naval 1/6th degree resolution dataset This has been averaged over the gridpoint spacing of the IGCM to produce the land-sea mask used in the physics; this field is then transformed to the appropriate spectral resolution and a Hoskins-type filter (Sardeshmukh and Hoskins, 1984) is used to obtain the surface geopotential, used in the primitive equation for momentum. At present files for orography both at T21 and T42 resolution have been produced.

4. Input/Output Changes

The extra physics entails the need for extra output and larger restart files. To save on disk space two namelist options (LMINIH and LSHIST) have been introduced to shorten the history file (see section 6).

Extra 2-D physics fields output are:
SURFACE DOWNWARD SHORTWAVE FLUX W/M2
,GLOBAL NET ENERGY BALANCE AT SURFACE W/M2
,SURFACE DOWNWARD LONGWAVE FLUX W/M2
,SURFACE UPWARD LONGWAVE FLUX W/M2
,TOP NET DOWNWARD SHORTWAVE FLUX W/M2
,TOP UPWARD LONGWAVE FLUX W/M2
,SURFACE ALBEDO %
,SURFACE TEMPERATURE K
,DEEP SOIL TEMPERATURE K
,SURFACE SPECIFIC HUMIDITY KG/KG
,SOIL MOISTURE M
,SNOW DEPTH M (R=0.3)
,LOW CLOUD AMOUNT%
,MID LEVEL CLOUD AMOUNT%
,HIGH CLOUD AMOUNT%
,CONVECTIVE CLOUD AMOUNT%

There is now a restart.12 file for the atmosphere and a restart.17 file for the surface. The restart.12 file is the same length and fomat as with IGCM2. The restart.17 contains information about surface temperature and humidity, deep soil temperature and moisture, surface albedo and snow depth.

The format of the restart record for the surface scheme is changed completely. Restart records are now unformatted, beginning with a single value of -999.999 to identify the file. Initial values are read from channel 18, periodic restart records to channel 19 and the final record to channel 17.

3D fields of stream function and temperature etc. are now averaged over the last kountH timesteps rather than instantaneous values.

5. Miscellaneous

5.1. Surface pressure -subroutine MASCOR

This is set to 976 mb at the beginning of each job. It is then kept roughly constant by continually re-scaling the ln(surface pressure) to the wave number zero time-mean ln(surface pressure). **For this to work properly set KOUNTE=1.**

5.2. Saturated vapour pressure calculation.

The calculation of saturated vapour pressure was taking over 10% of the run time. This calculation has been replaced by a lookup table. Look up table contains temperatures ranging from absolute zero to 375 K, with an increment of roughly 0.00752K. Relatively crude values of SVP over water are chosen, not valid for all this temperature range. These values could be easily improved upon.

6. Practical use of IGCM3

IGCM3 has been tested on the departmental Suns, and SGI machines as well as the main SGI Onyx2 computer. The job deck shown in Section 8 is capable of splitting the source code up into component subroutines and only compiling subroutines which have been altered in any way. This option is chosen by setting FASTCOMPILE=.TRUE. at the top of the job deck. It not only has the advantage of speeding up compilation times but it also saves disk space.

DOY, the Julian day, and NLEVRF, the number of levels for Rayleigh friction, have entered the main parameter statement at the beginning of each subroutine. There are also several more namelist variables, described below:

in namelist INPRN
BEGDOY=1: Julian day at which job starts. If set to zero, Julian day continues from restart file. may be a fraction (see Section 2.1).
L22L=.TRUE.: sets up 22 sigma levels, used for the climate integrations. This is designed to resolve the stratosphere better, note with L22L=.TRUE., LSTRETCH is redundant.
LCLIM=.TRUE..: Takes water vapour profiles from climatology rather than interactively..
LPERPET=.TRUE.: Pepetual run, otherwise DOY changes with DAY.
LOROG=.TRUE.: Includes orography

in namelst INPOP
LMASCOR=.TRUE.: Do surface pressure correction
LMASPRT=.TRUE.: Print out surface pressure correction factors

LSHIST =.TRUE.: Don’t write out instantaneous physics diagnostics.
LMINIH=.TRUE.: Write out single precision history file rather than double.

in namelist INPHYS
LSL=.TRUE.: calls soil scheme to find land surface temperature changes
LOC=.TRUE.: calls slab ocean model to work out ocean temperature changes.
LNOICE=.TRUE..: makes latent heat of ICE same as that for water.
LOLDBL=.TRUE.: calls old boundary layer scheme, BLAYER, rather than new BLSURF scheme.

LNNSK=.TRUE.: calls radiation either side of land/sea interface.

LCOND=.FALSE.: In old BLAYER if set to FALSE it prevents condensation onto warm surface, which tends not to happen in reality as surface becomes quickly saturated.

7. References

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S. Manabe, R. J. Stouffer, M. J. Spelman, K. Bryan, *J. Climate.* **4**, 785 (1990).
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P. D. Sardeshmukh and B. J. Hoskins, *Month. Wea. Rev.* **112**, 2524 (1984).

8. Example Job Deck

The **igcm3.job** job deck should work on the departmental Suns, Mammoth or Genesis.

The computer you are on needs to be set in USER SWITCHES - at the beginning of the job. The job deck performs a one year integration with a 2m mixed layer ocean. The model is T21-L22 global.

It can be found in **/home/piers/alice/igcm/jobs2/igcm3.job** on the dept. machines
or **/export/genesis/sw/swsforsr/igcm/jobs/igcm3.job** on genesis.

The corresponding flux program job **flux3.job** can be found in the same directories.

Good luck!

```
#! /bin/ksh
set -xve
##########################
#                        #
#  FULL PHYSICS IGCM3    #
# 2m MIXED LAYER OCEAN   #
# Piers Forster 3-3-99   #
# standard all machine   #
# version 1.0            #
# 1 year control         #
# integration, from 1st  #
```

```
#  Jan.                    #
#                          #
############################
```