云南大学地球科学学院实验报告

《 数值天气预报与实验 》课程实验（实习）报告

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| 年级 | 2020级 | | | 任课教师 | 曹杰 | | 成 绩 |  |
| 实验序号 | | 10 | | 实验名称 | 正压原始方程格式 | | 试验时间 | 20230613 |

**一、实验目的**

通过编程设计正压原始方程模式二次守衡平流格式，使学生深入理解数值天气预报模式的动力框架，掌握二次守恒平流格式的基本原理及计算方法。

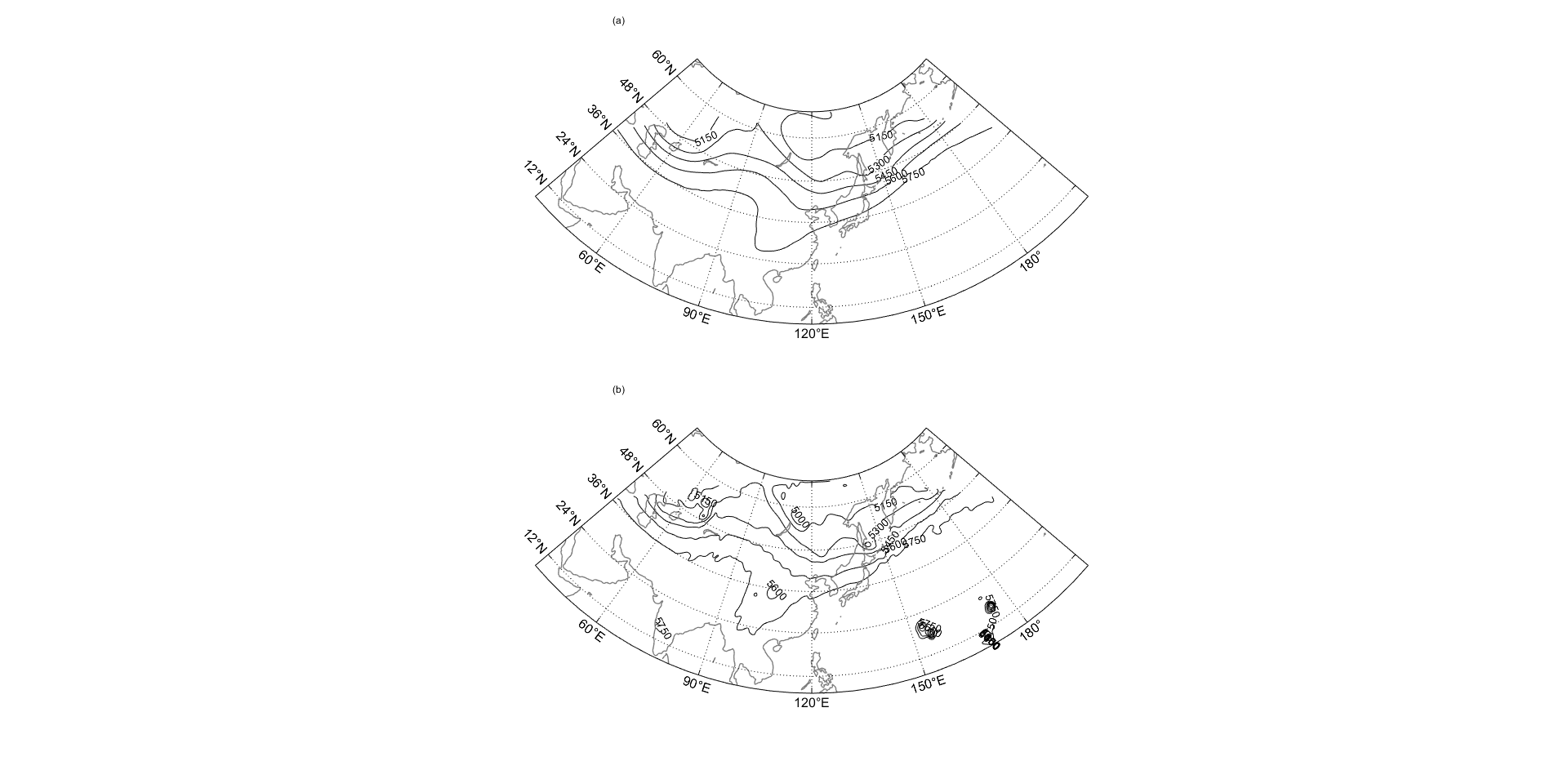
**二、实习内容、结果与分析**

题目

实验主程序[MATLAB]：

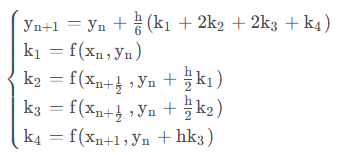
|  |  |
| --- | --- |
| clear;clc;  %参数与初始化  % m = 321;  % n = 129;  % d =300000.0/8;  % clat = 45.0;  % clon = 120.0;  % dt = 150.0/8;  m = 41;  n = 17;  d =300000.0;  clat = 45.0;  clon = 120.0;  dt = 150;  ua(m,n) = 0;va(m,n) = 0;za(m,n) = 0;  ub(m,n) = 0;vb(m,n) = 0;zb(m,n) = 0;  uc(m,n) = 0;vc(m,n) = 0;zc(m,n) = 0;  rm(m,n) = 0;f(m,n) = 0;w(m,n) = 0;  zo = 0;  s = 0.5;  nt2 = 72;  nt4 = 6;  nt5 = 36;  c1 = dt/2.0;  c2 = dt\*2.0;  % nx = (358-0)/2+1;  % ny = (90-0)/2+1;  nt = 365;  %读入初始场  z500 = ncread('era5\_uv\_geopotential\_19790109\_19790111\_00.nc','z');  z500 = z500/9.8;  u500 = ncread('era5\_uv\_geopotential\_19790109\_19790111\_00.nc','u');  v500 = ncread('era5\_uv\_geopotential\_19790109\_19790111\_00.nc','v');  lon = ncread('era5\_uv\_geopotential\_19790109\_19790111\_00.nc','longitude');  lat = ncread('era5\_uv\_geopotential\_19790109\_19790111\_00.nc','latitude');  nt\_f = 2;  u = squeeze(u500(:,:,nt\_f));v = squeeze(v500(:,:,nt\_f));z = squeeze(z500(:,:,nt\_f));  [rm,f,lmda\_degree,phai\_degree] = cmf(d,clat,clon,m,n);  [ua,va,za] = interp\_proj\_grid(u,v,z,lmda\_degree,phai\_degree,m,n,0,359.75,-90,90);  za\_ori = za;  % ni = input('Input 0(no static initilaizion) or 1(static initilaizion)');  ni = 1;  if(ni==1)  [ua,va] = cgw(za,rm,f,d,m,n);  end  %设置工作数组的边界数据并开始预报  [ub,vb,zb] = tbv(ua,va,za,m,n);  [uc,vc,zc] = tbv(ua,va,za,m,n);  disp('Forecasting 12 hours......')  % for na = 1:1  % nb = 0;  na = 1;nb = 0;  for nn = 1:6  [tmp1,tmp2,tmp3] = ti(ua,va,za,ua,va,za,rm,f,d,dt,zo,m,n);  ub(2:m-1,2:n-1) = tmp1(2:m-1,2:n-1);  vb(2:m-1,2:n-1) = tmp2(2:m-1,2:n-1);  zb(2:m-1,2:n-1) = tmp3(2:m-1,2:n-1);  [tmp1,tmp2,tmp3] = ti(ua,va,za,ub,vb,zb,rm,f,d,dt,zo,m,n);  ua(2:m-1,2:n-1) = tmp1(2:m-1,2:n-1);  va(2:m-1,2:n-1) = tmp2(2:m-1,2:n-1);  za(2:m-1,2:n-1) = tmp3(2:m-1,2:n-1);  nb = nb + 1;  end  %进行边界平滑  za = ssbp(za,s,m,n);  ua = ssbp(ua,s,m,n);  va = ssbp(va,s,m,n); | %用欧拉前差格式积分半步  [tmp1,tmp2,tmp3] = ti(ua,va,za,ua,va,za,rm,f,d,c1,zo,m,n);  ub(2:m-1,2:n-1) = tmp1(2:m-1,2:n-1);  vb(2:m-1,2:n-1) = tmp2(2:m-1,2:n-1);  zb(2:m-1,2:n-1) = tmp3(2:m-1,2:n-1);  %用中央差分积分半步  [tmp1,tmp2,tmp3] = ti(ua,va,za,ub,vb,zb,rm,f,d,c1,zo,m,n);  uc(2:m-1,2:n-1) = tmp1(2:m-1,2:n-1);  vc(2:m-1,2:n-1) = tmp2(2:m-1,2:n-1);  zc(2:m-1,2:n-1) = tmp3(2:m-1,2:n-1);  %继续中央差积分  nb = nb + 1;  [ub,vb,zb] = ta(uc,vc,zc);  for nn = 1:66  [tmp1,tmp2,tmp3] = ti(ua,va,za,ub,vb,zb,rm,f,d,dt,zo,m,n);  uc(2:m-1,2:n-1) = tmp1(2:m-1,2:n-1);  vc(2:m-1,2:n-1) = tmp2(2:m-1,2:n-1);  zc(2:m-1,2:n-1) = tmp3(2:m-1,2:n-1);  nb = nb + 1;  disp(['na=',num2str(na),'nb=',num2str(nb)])    if(nb~=nt2)    if(mod(nb,nt4)==0)  zc = ssbp(zc,s,m,n);  uc = ssbp(uc,s,m,n);  vc = ssbp(vc,s,m,n);    else  if(nb==nt5||nb==nt5+1)    [tmp1,tmp2,tmp3] = ts(ua,ub,uc,va,vb,vc,za,zb,zc,s,m,n);  ub(2:m-1,2:n-1) = tmp1(2:m-1,2:n-1);  vb(2:m-1,2:n-1) = tmp2(2:m-1,2:n-1);  zb(2:m-1,2:n-1) = tmp3(2:m-1,2:n-1);    else    [ua,va,za] = ta(ub,vb,zb,m,n);  [ub,vb,zb] = ta(uc,vc,zc,m,n);    end  end  end    end  disp('Output results.....')  in = fopen('zc.grd','w');  fwrite(in,zc,'float32');  fclose(in);  in = fopen('uc.grd','w');  fwrite(in,uc,'float32');  fclose(in);  in = fopen('vc.grd','w');  fwrite(in,vc,'float32');  fclose(in);  zc = ssnp(zc,s,m,n);  % zc = smooth99(zc);  subplot(2,1,1)  m\_proj('lambert','lon',[min(min(lmda\_degree)),max(max(lmda\_degree))],'lat',[min(min(phai\_degree)),max(max(phai\_degree))]);  [c,h] = m\_contour(lmda\_degree,phai\_degree,za\_ori,5000:150:5750,'-k');  clabel(c,h,'LabelSpacing',1000,'fontsize',10)  m\_coast('linewidth',1,'color',[123,123,123]/255);  m\_grid('fontsize',12)  text(-1,1.,'(a)','fontsize',9)  subplot(2,1,2)  m\_proj('lambert','lon',[min(min(lmda\_degree)),max(max(lmda\_degree))],'lat',[min(min(phai\_degree)),max(max(phai\_degree))]);  [c,h] = m\_contour(lmda\_degree,phai\_degree,zc,5000:150:5750,'-k');  clabel(c,h,'LabelSpacing',1000,'fontsize',10)  m\_coast('linewidth',1,'color',[123,123,123]/255);  m\_grid('fontsize',12)  text(-1,1.,'(b)','fontsize',9) |

**实验结果**如下图：

实验中发现，dt=600时会发生溢出，故降低时间步长。同时，即使进行了9点平滑，最终结果效果仍然不好。

1979年1月10日00时500hPa重力位势高度场空间分布图

(a)原始数据;(b)1h预报结果

 **习题1：**试编程实现用Runge Kutta 4阶积分方案积分正压原始方程模式。Runge Kutta 4阶积分公式通常可表示为

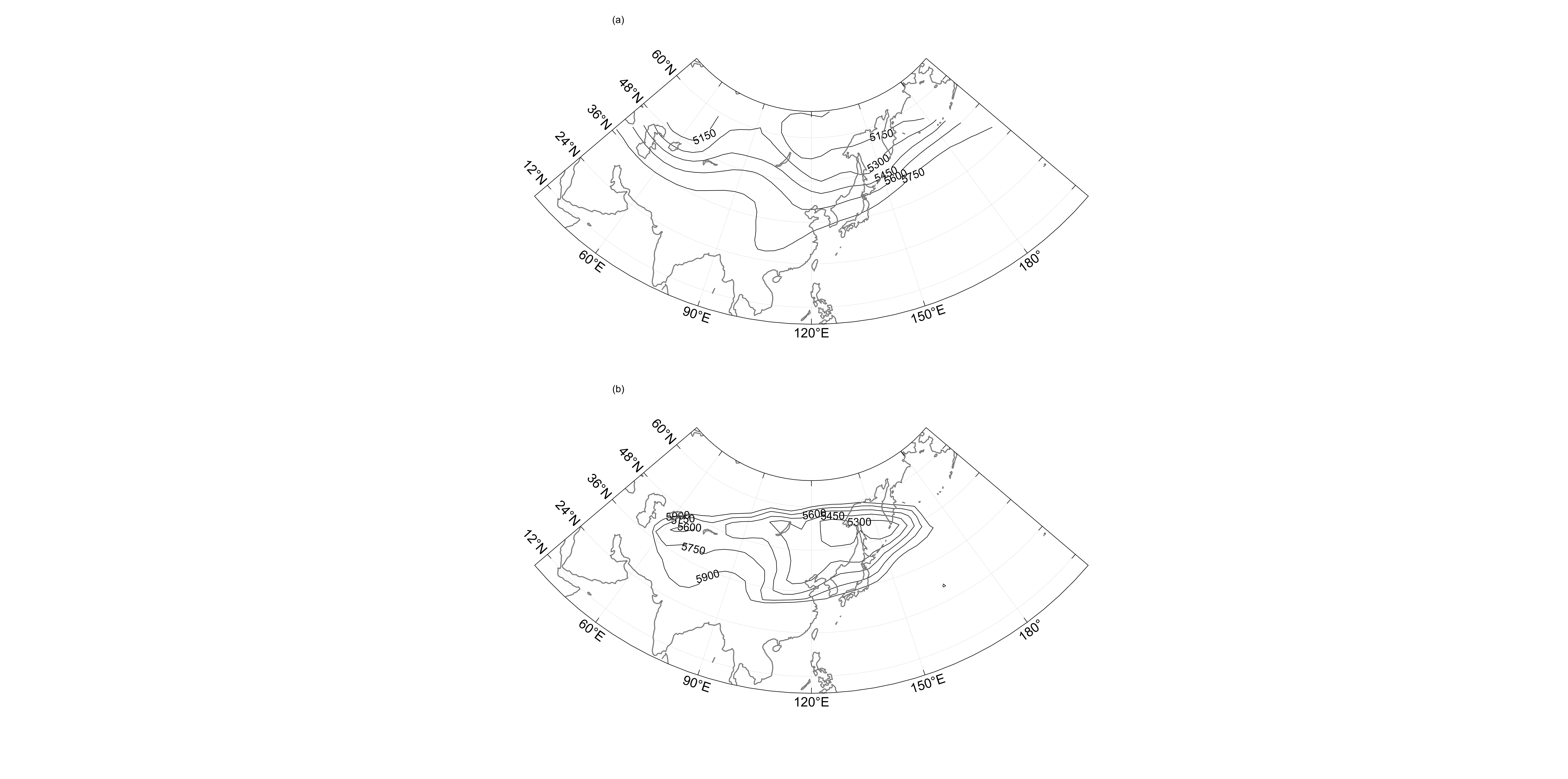
实验主程序[MATLAB]：

|  |  |
| --- | --- |
| clear;clc;  %参数与初始化  m = 41;  n = 17;  d =300000.0;  clat = 45.0;  clon = 120.0;  dt = 600.0;  ua(m,n) = 0;va(m,n) = 0;za(m,n) = 0;  ub(m,n) = 0;vb(m,n) = 0;zb(m,n) = 0;  uc(m,n) = 0;vc(m,n) = 0;zc(m,n) = 0;  rm(m,n) = 0;f(m,n) = 0;w(m,n) = 0;  zo = 0;  s = 0.5;  nt2 = 72;  nt4 = 6;  nt5 = 36;  c1 = dt/2.0;  c2 = dt\*2.0;  nt = 365;  %读入初始场  z500 = ncread('era5\_uv\_geopotential\_19790109\_19790111\_00.nc','z');  z500 = z500/9.8;  u500 = ncread('era5\_uv\_geopotential\_19790109\_19790111\_00.nc','u');  v500 = ncread('era5\_uv\_geopotential\_19790109\_19790111\_00.nc','v');  lon = ncread('era5\_uv\_geopotential\_19790109\_19790111\_00.nc','longitude');  lat = ncread('era5\_uv\_geopotential\_19790109\_19790111\_00.nc','latitude');  nt\_f = 2;  u = squeeze(u500(:,:,nt\_f));v = squeeze(v500(:,:,nt\_f));z = squeeze(z500(:,:,nt\_f));  [rm,f,lmda\_degree,phai\_degree] = cmf(d,clat,clon,m,n);  [ua,va,za] = interp\_proj\_grid(u,v,z,lmda\_degree,phai\_degree,m,n,0,359.75,-90,90);  za\_ori = za;  uc = ua;vc = va;zc = za;  for nn = 1:72  ub\_temp = uc;vb\_temp = vc;zb\_temp = zc;  [rk1u,rk1v,rk1z] = tbv(ub\_temp,vb\_temp,zb\_temp,m,n);  [tmp1,tmp2,tmp3] = ti\_xiti1(ub\_temp,vb\_temp,zb\_temp,rm,f,d,dt,zo,m,n);  rk1u(2:m-1,2:n-1) = tmp1(2:m-1,2:n-1);  rk1v(2:m-1,2:n-1) = tmp2(2:m-1,2:n-1);  rk1z(2:m-1,2:n-1) = tmp3(2:m-1,2:n-1); | ub\_temp = ua + 0.5\*rk1u;  vb\_temp = va + 0.5\*rk1v;  zb\_temp = za + 0.5\*rk1z;    [rk2u,rk2v,rk2z] = tbv(ub\_temp,vb\_temp,zb\_temp,m,n);  [tmp1,tmp2,tmp3] = ti\_xiti1(ub\_temp,vb\_temp,zb\_temp,rm,f,d,dt,zo,m,n);  rk2u(2:m-1,2:n-1) = tmp1(2:m-1,2:n-1);  rk2v(2:m-1,2:n-1) = tmp2(2:m-1,2:n-1);  rk2z(2:m-1,2:n-1) = tmp3(2:m-1,2:n-1);  ub\_temp = ua + 0.5\*rk2u;  vb\_temp = va + 0.5\*rk2v;  zb\_temp = za + 0.5\*rk2z;    [rk3u,rk3v,rk3z] = tbv(ub\_temp,vb\_temp,zb\_temp,m,n);  [tmp1,tmp2,tmp3] = ti\_xiti1(ub\_temp,vb\_temp,zb\_temp,rm,f,d,dt,zo,m,n);  rk3u(2:m-1,2:n-1) = tmp1(2:m-1,2:n-1);  rk3v(2:m-1,2:n-1) = tmp2(2:m-1,2:n-1);  rk3z(2:m-1,2:n-1) = tmp3(2:m-1,2:n-1);  ub\_temp = ua + rk3u;  vb\_temp = va + rk3v;  zb\_temp = za + rk3z;    [rk4u,rk4v,rk4z] = tbv(ub\_temp,vb\_temp,zb\_temp,m,n);  [tmp1,tmp2,tmp3] = ti\_xiti1(ub\_temp,vb\_temp,zb\_temp,rm,f,d,dt,zo,m,n);  rk4u(2:m-1,2:n-1) = tmp1(2:m-1,2:n-1);  rk4v(2:m-1,2:n-1) = tmp2(2:m-1,2:n-1);  rk4z(2:m-1,2:n-1) = tmp3(2:m-1,2:n-1);  uc = ua + 1/6\*(rk1u+2\*rk2u+2\*rk3u+rk4u);  vc = va + 1/6\*(rk1v+2\*rk2v+2\*rk3v+rk4v);  uc = za + 1/6\*(rk1z+2\*rk2z+2\*rk3z+rk4z);  end  zc = ssnp(zc,s,m,n);  subplot(2,1,1)  m\_proj('lambert','lon',[min(min(lmda\_degree)),max(max(lmda\_degree))],'lat',[min(min(phai\_degree)),max(max(phai\_degree))]);  [c,h] = m\_contour(lmda\_degree,phai\_degree,za\_ori,5000:150:5750,'-k');  clabel(c,h,'LabelSpacing',1000,'fontsize',10)  m\_coast('linewidth',1,'color',[123,123,123]/255);  m\_grid('fontsize',12)  text(-1,1.,'(a)','fontsize',9)  subplot(2,1,2)  m\_proj('lambert','lon',[min(min(lmda\_degree)),max(max(lmda\_degree))],'lat',[min(min(phai\_degree)),max(max(phai\_degree))]);  [c,h] = m\_contour(lmda\_degree,phai\_degree,zc,5000:150:5750,'-k');  clabel(c,h,'LabelSpacing',1000,'fontsize',10)  m\_coast('linewidth',1,'color',[123,123,123]/255);  m\_grid('fontsize',12)  text(-1,1.,'(b)','fontsize',9) |

实验子程序ti\_xiti1.m[MATLAB]：

|  |  |
| --- | --- |
| function [uc,vc,zc] = ti\_xiti1(ub,vb,zb,rm,f,d,dt,zo,m,n)  c = 0.25/d;  m1 = m - 1;  n1 = n - 1;  for i = 2:m1  for j = 2:n1  e = -c\*rm(i,j)\*((ub(i+1,j)+ub(i,j))\*(ub(i+1,j)-ub(i,j))+(ub(i,j)+ub(i-1,j))\*(ub(i,j)-ub(i-1,j))+(vb(i,j-1)+vb(i,j))\*(ub(i,j)-ub(i,j-1))+(vb(i,j)+vb(i,j+1))\*(ub(i,j+1)-ub(i,j))+19.6\*(zb(i+1,j)-zb(i-1,j)))+f(i,j)\*vb(i,j);  uc(i,j) = e\*dt; | g = -c\*rm(i,j)\*((ub(i+1,j)+ub(i,j))\*(vb(i+1,j)-vb(i,j))+(ub(i,j)+ub(i-1,j))\*(vb(i,j)-vb(i-1,j))+(vb(i,j-1)+vb(i,j))\*(vb(i,j)-vb(i,j-1))+(vb(i,j)+vb(i,j+1))\*(vb(i,j+1)-vb(i,j))+19.6\*(zb(i,j+1)-zb(i,j-1)))+f(i,j)\*ub(i,j);  vc(i,j) = g\*dt;  end  end  for i = 2:m1  for j = 2:n1  h = -c\*rm(i,j)^2\*((ub(i+1,j)+ub(i,j))\*(zb(i+1,j)/rm(i+1,j)-zb(i,j)/rm(i,j))+(ub(i,j)+ub(i-1,j))\*(zb(i,j)/rm(i,j)-zb(i-1,j)/rm(i-1,j))+(vb(i,j-1)+vb(i,j))\*(zb(i,j)/rm(i,j)-zb(i,j-1)/rm(i,j-1))+(vb(i,j)+vb(i,j+1))\*(zb(i,j+1)/rm(i,j+1)-zb(i,j)/rm(i,j))+2.0\*(zb(i,j)-zo)/rm(i,j)\*(ub(i+1,j)-ub(i-1,j)+vb(i,j+1)-vb(i,j-1)));  zc(i,j) = h\*dt;  end  end |

**实验结果**如下图：

习题一参考了BPEM的相关代码solve.f90和integration.f90，预报结果和原始场相比有较大的变化。

**习题2：**采用平衡初值积分正压原始方程模式，通过迭代求解由Φ场求出ψ场，再计算无辐散风场。

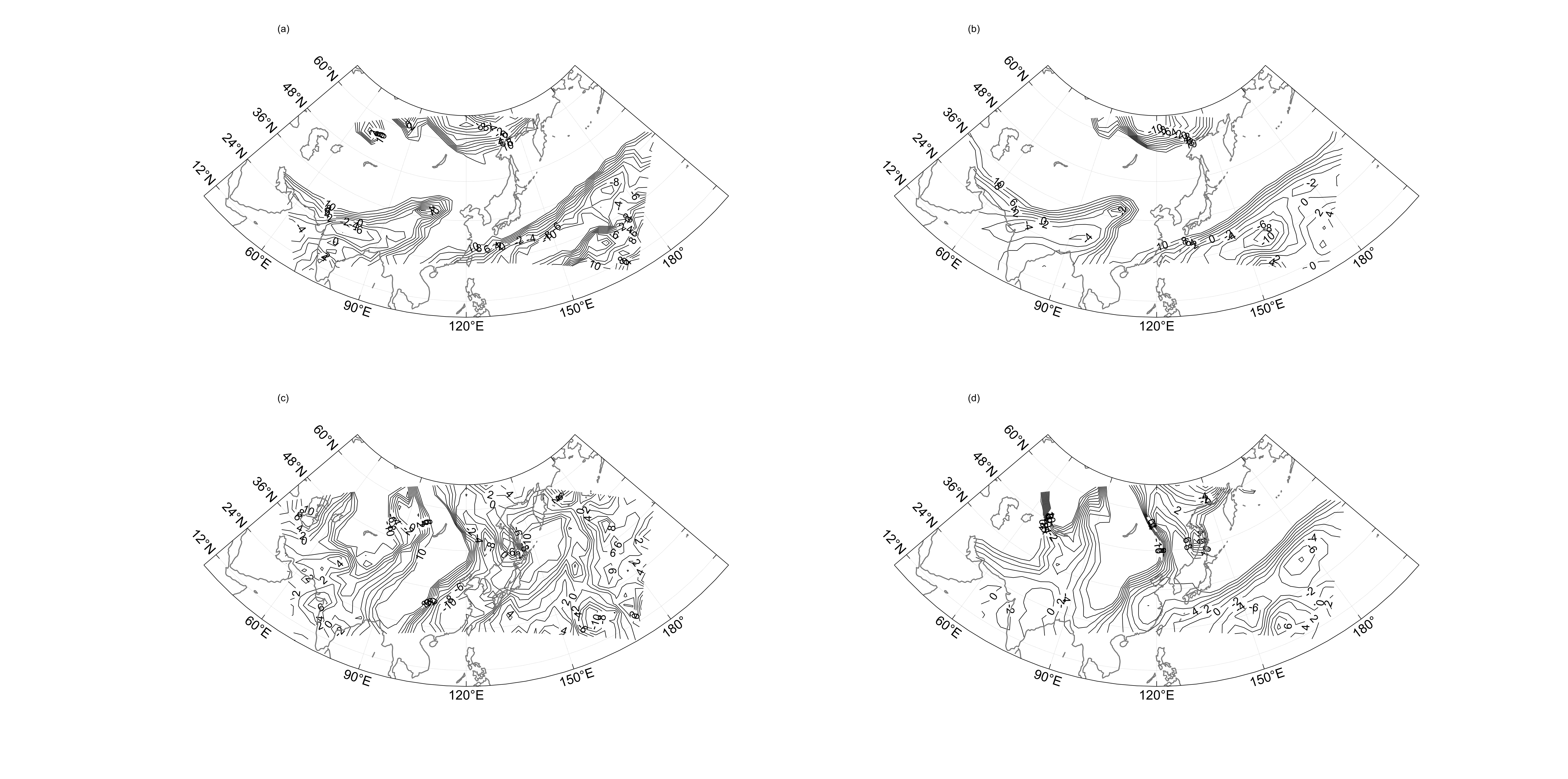
1979年1月10日00时500hPa重力位势高度场空间分布图

(a)原始数据;(b)12h预报结果

实验程序[MATLAB]：

|  |  |
| --- | --- |
| clear;clc;  %参数与初始化  m = 41;  n = 17;  d =300000.0;  clat = 45.0;  clon = 120.0;  dt = 600.0;  ua(m,n) = 0;va(m,n) = 0;za(m,n) = 0;  ub(m,n) = 0;vb(m,n) = 0;zb(m,n) = 0;  uc(m,n) = 0;vc(m,n) = 0;zc(m,n) = 0;  rm(m,n) = 0;f(m,n) = 0;w(m,n) = 0;  zo = 0;  s = 0.5;  % nx = (358-0)/2+1;  % ny = (90-0)/2+1;  nt = 365;  %读入初始场  z500 = ncread('era5\_uv\_geopotential\_19790109\_19790111\_00.nc','z');  u500 = ncread('era5\_uv\_geopotential\_19790109\_19790111\_00.nc','u');  v500 = ncread('era5\_uv\_geopotential\_19790109\_19790111\_00.nc','v');  lon = ncread('era5\_uv\_geopotential\_19790109\_19790111\_00.nc','longitude');  lat = ncread('era5\_uv\_geopotential\_19790109\_19790111\_00.nc','latitude');  nt\_f = 2;  u = squeeze(u500(:,:,nt\_f));v = squeeze(v500(:,:,nt\_f));z = squeeze(z500(:,:,nt\_f));  [rm,f,lmda\_degree,phai\_degree] = cmf(d,clat,clon,m,n);  [ua,va,za] = interp\_proj\_grid(u,v,z,lmda\_degree,phai\_degree,m,n,0,359.75,-90,90);  za\_ori = za; | uc = ua;vc = va;zc = za;  persai = zc./(2\*7.292\*10^(-5)\*cosd(36));  [up,vp] = gradient(persai,d,d);  up = -up;  subplot(2,2,1)  m\_proj('lambert','lon',[min(min(lmda\_degree)),max(max(lmda\_degree))],'lat',[min(min(phai\_degree)),max(max(phai\_degree))]);  [c,h] = m\_contour(lmda\_degree,phai\_degree,ua,-10:2:10,'-k');  clabel(c,h,'LabelSpacing',1000,'fontsize',10)  m\_coast('linewidth',1,'color',[123,123,123]/255);  m\_grid('fontsize',12)  text(-1,1.,'(a)','fontsize',9)  subplot(2,2,2)  m\_proj('lambert','lon',[min(min(lmda\_degree)),max(max(lmda\_degree))],'lat',[min(min(phai\_degree)),max(max(phai\_degree))]);  [c,h] = m\_contour(lmda\_degree,phai\_degree,up,-10:2:10,'-k');  clabel(c,h,'LabelSpacing',1000,'fontsize',10)  m\_coast('linewidth',1,'color',[123,123,123]/255);  m\_grid('fontsize',12)  text(-1,1.,'(b)','fontsize',9)  subplot(2,2,3)  m\_proj('lambert','lon',[min(min(lmda\_degree)),max(max(lmda\_degree))],'lat',[min(min(phai\_degree)),max(max(phai\_degree))]);  [c,h] = m\_contour(lmda\_degree,phai\_degree,va,-10:2:10,'-k');  clabel(c,h,'LabelSpacing',1000,'fontsize',10)  m\_coast('linewidth',1,'color',[123,123,123]/255);  m\_grid('fontsize',12)  text(-1,1.,'(c)','fontsize',9)  subplot(2,2,4)  m\_proj('lambert','lon',[min(min(lmda\_degree)),max(max(lmda\_degree))],'lat',[min(min(phai\_degree)),max(max(phai\_degree))]);  [c,h] = m\_contour(lmda\_degree,phai\_degree,vp,-10:2:10,'-k');  clabel(c,h,'LabelSpacing',1000,'fontsize',10)  m\_coast('linewidth',1,'color',[123,123,123]/255);  m\_grid('fontsize',12)  text(-1,1.,'(d)','fontsize',9) |

**实验结果**如下图：



1979年1月10日00时500hPa风速空间分布图

(a)纬向风原始数据;(b)纬向风计算结果;(c)经向风原始数据;(d)经向风计算结果

可以发现，通过重力位势计算所得的无辐散风场保留了原始风场的主要特征，但丢失了一些细节特征。

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| 教师评语： |