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"Tropical Cyclone Track Predictions with LAMs"

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Please note: These are preliminary notes intended for internal distribution only.

THE OTCM

Type of model	: Synoptic school.
Developer (Users)	: NEPRF (JTWC)
Year of implementation	: 1979
Number of grids	: 1 (See Fig. 1)
Number of layers	: 3
Grid resolution	: 205 km.
Domain size	: Approx. 6200x4600 km.
Physics	: Analytic heating function to maintain the vortex.
Storm specification	: Vorticity bogus.
Synoptic flow specification	: Forecast of the FNOC global model.
Mass-momentum balancing	: Remove initial divergence and diagnose mass using the reverse balance equation.
Lateral boundary conditions	: One-way influence with FNOC global model.
Pre-processing	: Bias-corrector (Shewchuk and Elsberry, 1978).
Post-processing	: None.
Number of new versions since implementation	: None.
Development since implementation	: None.
Overall performance Characteristics	: Good consistency from case to case, slight speed bias (slow), good on recurvature.

THE NTCM(3.0)

Type of model	: Synoptic school.
Developer (Users)	: NEPRF (JTWC, NHC)
Year of implementation	: 1981
Number of grids	: 2 (See Figs. 1 and 2)
Number of layers	: 3
Grid resolution	: 205 km and 41 km.
Domain size	: Approx. 8000x5600 km.
Physics	: Analytic heating function to maintain the vortex.
Storm specification	: Spinup vortex from previous integration.
Synoptic flow specification	: FNOC tropical analysis.
Mass-momentum balancing	: Diagnose mass using the model divergence equation.
Lateral boundary conditions	: One-way influence with FNOC global model on the coarse grid and two-way interactive on the fine grid.
Pre-processing	: Adjust steering flow around storm to match observed motion (minus model beta drift)
Post-processing	: Blend persistence with 72 h forecast position to produce 24 and 48 h forecast (Allen, 1984).
Number of new versions since implementation	: 3 (1982, 1983, 1985)
Development since implementation	: Expansion of fine and coarse grid domains, addition of pre- and post-processing, one-way influence boundary conditions, storm spinup, more general initialization (balancing) procedure.
Overall performance Characteristics	: Significant slow speed bias, greater variability in skill than OTCM, but highly accurate when model predicts the basic track, has some skill for erratic storms.

THE MFM

Type of model	: Tropical cyclone school.
Developer (Users)	: NMC (NHC, EPHC, CPHC)
Year of implementation	: 1975
Number of grids	: 1 (see Fig. 1)
Number of layers	: 10
Grid resolution	: Approx. 60 km.
Domain size	: Approx. 3000x3000 km.
Physics	: Explicit parameterization of cumulus convection (Anthes, 1977), well-mixed PBL, large-scale precipitation.
Storm specification	: Spinup vortex from previous integration.
Synoptic flow specification	: NMC global initialized fields.
Mass-momentum balancing	: None.
Lateral boundary conditions	: One-way influence with NMC global model.
Pre-processing	: None.
Post-processing	: None.
Number of new versions since implementation	: 2 (1976, 1982)
Development since implementation	: Smaller 2-D vortex by reducing the sea surface temperature (1976), 3-D spinup vice 2-D (1982)
Overall performance Characteristics	: Slow speed bias, excellent track.

6.3

THE MNG

Type of model	: Synoptic school.
Developer (Users)	: ECC/JMA (JMA)
Year of implementation	: 1982
Number of grids	: 3 (see Fig. 3)
Number of layers	: 3
Grid resolution	: Approx. 360 , 180 and 90 km
Domain size	: Entire northern Hemisphere, 5400x5400 km and 2700x2700 km.
Physics	: Analytic heating function and surface drag in the boundary layer.
Storm specification	: Sea-level pressure and temperature profiles set by observed storm parameters. Winds geostrophically derived from the mass field.
Synoptic flow specification	: JMA global model initialized fields.
Mass-momentum balancing	: None.
Lateral boundary conditions	: Fixed on the largest grid and two-way interactive on the inner grids.
Pre-processing	: Bias corrector (Shewchuk and Elsberry, 1978).
Post-processing	: None.
Number of new versions since implementation	: 1 (1983)
Development since implementation	: Expanded coarse grid.
Overall performance Characteristics	: Slow speed bias, excellent track in midlatitudes, strong northward bias in tropics.

2.2.1 Comments on the models

Each of the above models has strengths and weakness. The OTCM is the simplest and has the best overall track record (no pun intended) in operations in the Western North Pacific, but cannot really be developed much beyond where it is today. The NTCM has the most sophisticated vortex specification of the synoptic school models (NTCM, OTCM and MNG) and explicitly incorporates current motion into the initial conditions through a modification of the steering flow around the storm. The lateral boundary conditions of the NTCM coarse grid have been shown to be the most effective in terms of assimilating the superior synoptic forecast of a global model into the NTCM environmental forcing (Fiorino, 1985). However, crude numerics and a lack of physics prevents the NTCM (and the OTCM) from simulating the tropical cyclone with much realism. The MFM is superior to the other models in this regard, but the horizontal domain is not large enough to completely predict the vortex-environment interaction. Further, the MFM does not use pre- or post-processing procedures to improve the early forecasts. The MNG is the only model that attempts to match the model storm to the real tropical cyclone, but then the NTCM is the only model that initializes (balances) the vortex and large-scale fields simultaneously.

2.2.2 An Advanced Tropical Cyclone Model

The next-generation dynamical tropical cyclone forecast systems should combine the best features of the current models and the U.S. Navy is now testing a prototype of a next-generation system we call the Advanced Tropical Cyclone Model (ATCM). The preliminary version (ATCM0.0) is based on the Navy limited-area model NORAPS (Hodur, 1982) and features:

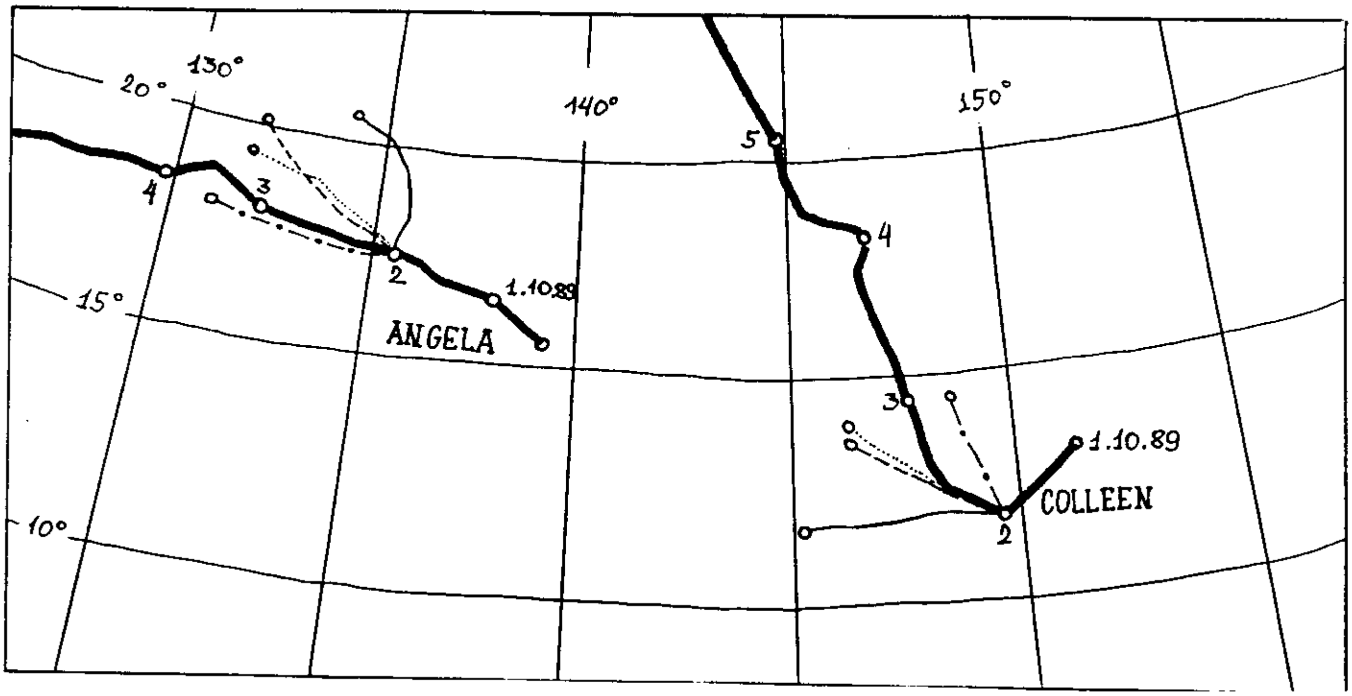
- 10 layers in the vertical.
- 81x61 points in the horizontal with a grid spacing of 80 km within a domain of approximately 6400x4800 km.

- Advanced numerics (Scheme C staggering of the variables and split-explicit time integration).
- A separate wind analysis/model assimilation cycle over the entire Western North Pacific.
- A full suite of physical parameterizations including:
  * Kuo (1974) cumulus parameterization and large-scale precipitation.
  * A stability dependent boundary layer formulation with a prediction equation for the PBL depth.
  * Short-wave and long-wave radiation.
  * Topography and a prediction of ground temperature.
- The vortex is initialized with an intensity-dependent vorticity bogus.

ATCM0.0 will be run on all storms in the Western North Pacific and the Atlantic during the 1985 season and the results will be available by the IWTC. The purpose of this test is to establish a baseline for future development, i.e. we need to know how well existing limited-area modeling technology can be applied to the tropical cyclone track (and intensity?) prediction problem.

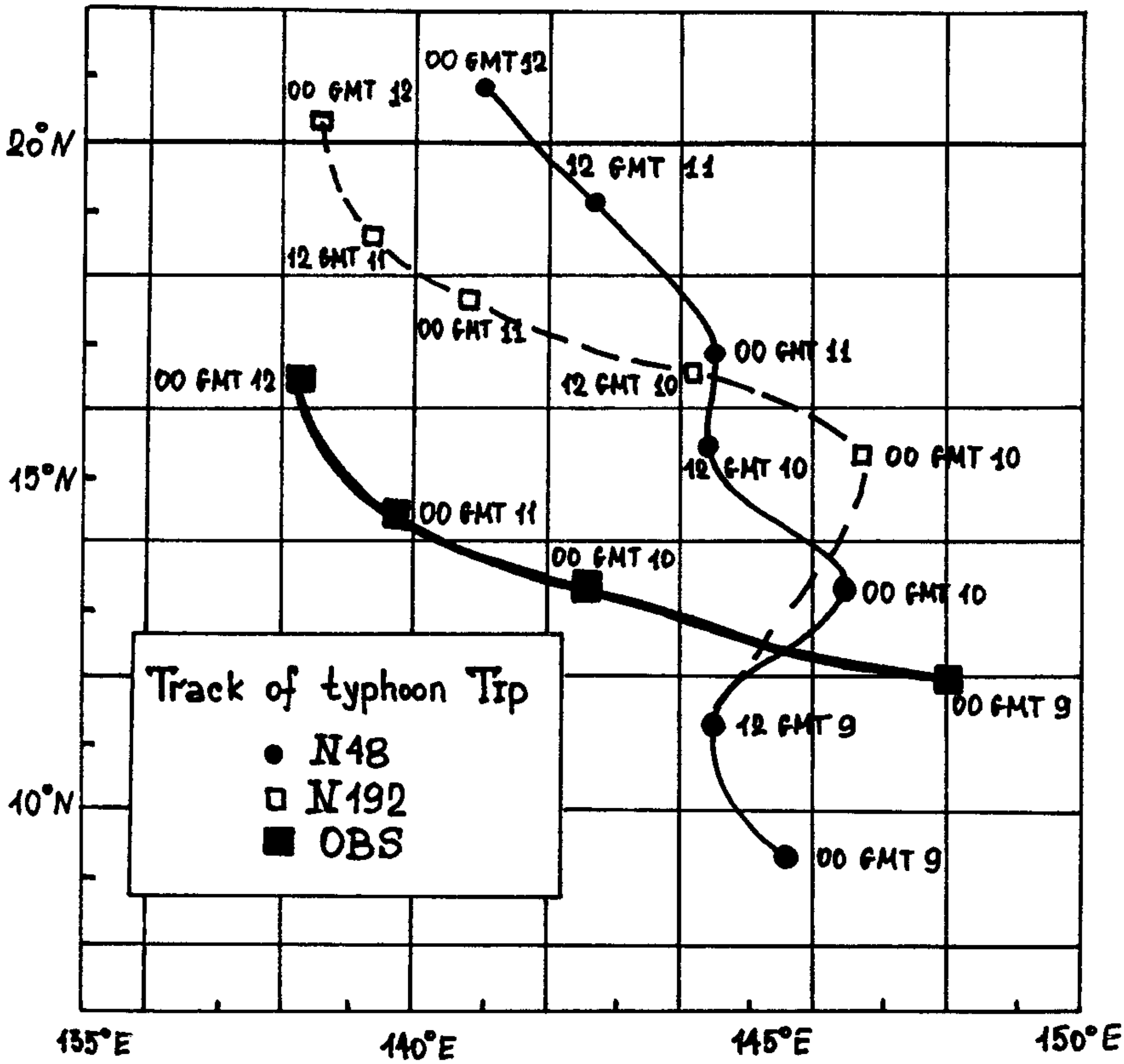
2.3 Performance Characteristics

This section will summarize the track prediction capabilities of the four operational models. We will emphasize the 72 h forecast period, mainly because the strength of the dynamical models is in the long-term forecast. We have also found that a combination of persistence and the straight-line track between the initial and the 72 h position (from a dynamical model) yields 24 h and 48 h forecast that are equally as good as



Forecasts
of
——— solitary TC motion;
interacting TC's with:
- - - - - - $V_A = 50\,m/s$, $V_C = 25\,m/s$, $R_A = R_C = 150\,km$
·········· $V_A = V_C = 30\,m/s$, $R_A = R_C = 150\,km$
—·—·—· $V_A = 50\,m/s$, $V_C = 25\,m/s$, $R_A = R_C = 500\,km$

(after Poliakova, The Hydrometerrological Centre of the USSR, Moscow)



Track of the observed and forecast typhoon Tip at resolution N48 (1.875° lat/lon) and N192 (0.47° lat/lon).

[after Dell'Osso and Bengtsson]

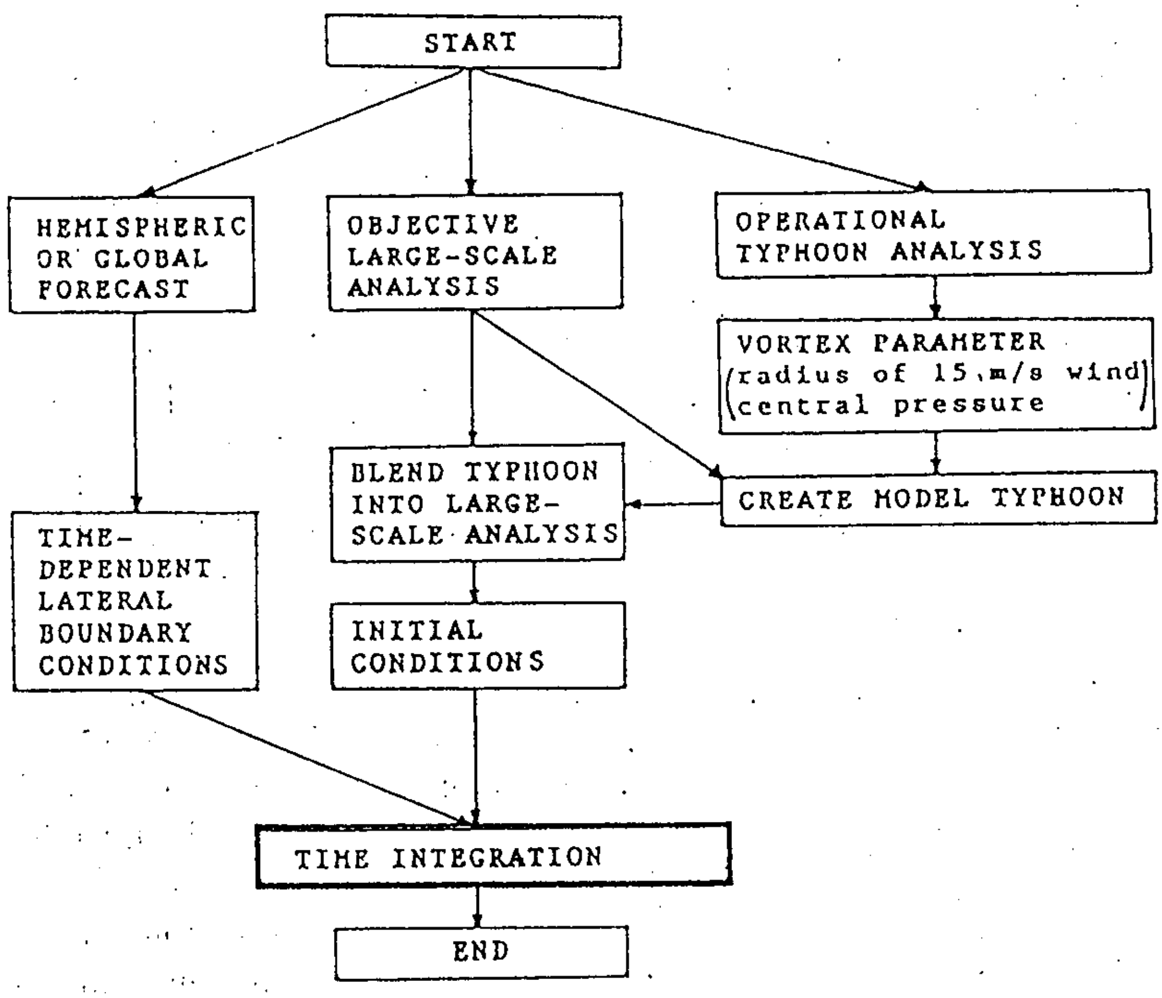


Fig. 1 Flow diagram of the experimental typhoon forecast system.

(after Iwasaki et al)

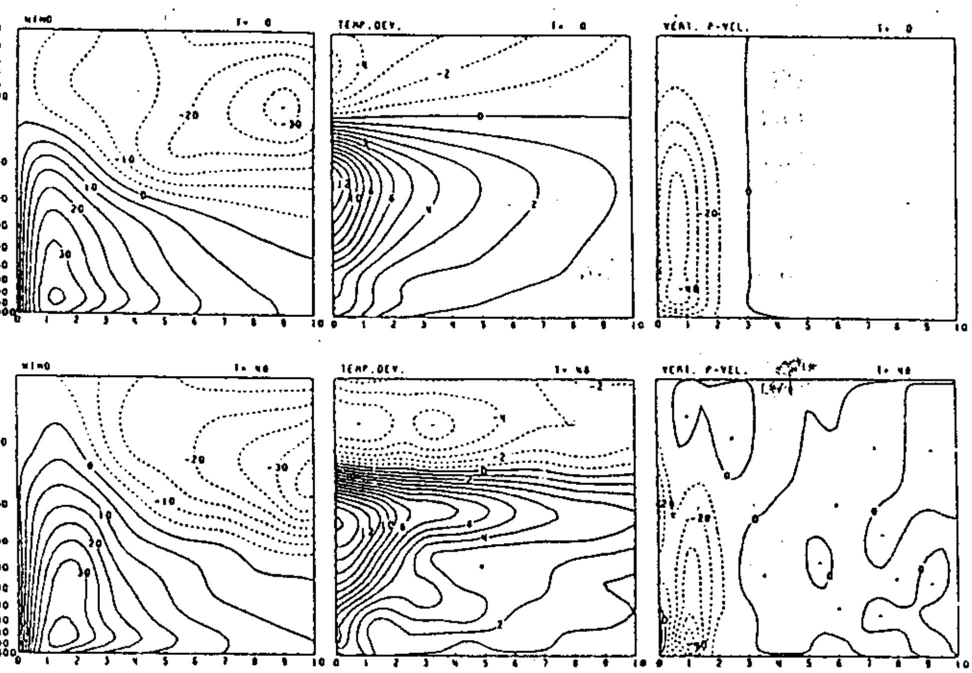


Fig. 3 Initial conditions (upper panel) and 48-h forecasts (lower panel) of tangential wind (m/sec), temperature deviation (K) from the environment and vertical p-velocity (mb/h). This experiment is performed under an ideal condition of a constant Coriolis parameter and no basic wind. (vertical unit: mb, horizontal unit: 100 km)

(after Iwasaki et al)

HOUR	MODEL	BEFORE	DURING	AFTER	ALL
		RECURVATURE			
T=12	TYM	111.3 (77)	104.2 (67)	86.2 (53)	102.1 (197)
	PER	50.8 (78)	55.4 (67)	58.1 (53)	54.3 (198)
T=24	TYM	199.4 (70)	189.2 (58)	187.3 (43)	192.9 (171)
	PER	149.5 (71)	159.9 (58)	198.6 (43)	165.3 (172)
T=36	TYM	284.1 (60)	275.7 (50)	294.8 (34)	283.7 (144)
	PER	252.9 (61)	315.7 (51)	424.7 (34)	314.8 (146)
T=48	TYM	365.5 (51)	397.2 (42)	387.8 (25)	381.5 (118)
	PER	385.3 (52)	495.4 (44)	634.2 (25)	476.8 (121)
T=60	TYM	480.1 (42)	529.5 (34)	438.8 (15)	491.8 (91)
	PER	532.7 (44)	688.6 (38)	803.6 (19)	642.3 (101)

(1) TYM : Typhoon Model

(2) PER : Persistency

(3) The number in parenthesis is the number of cases in each category.

Table 2 Mean Error in Forecast Positions (in km)

(after Puri, Manila Workshop on Tropical Cyclones, 1989)

model	forecast period (hours) 0	12	24	36	48	72
Official number of cases	12 (152)	40 (152)	72 (131)	104 (118)	143 (108)	233 (89)
BAM	58 (54)	50 (54)	99 (50)	146 (43)	187 (40)	295 (36)
CLIPER	12 (151)	46 (151)	89 (131)	126 (118)	173 (108)	276 (89)
MFM	26 (56)	79 (56)	134 (52)	190 (48)	274 (45)	406 (37)
NHC72	12 (93)	47 (93)	88 (79)	145 (63)	209 (58)	344 (48)
NHC83	12 (144)	41 (144)	68 (128)	93 (115)	128 (105)	186 (87)
QLM	12 (64)	66 (64)	115 (59)	172 (53)	229 (50)	352 (40)
SANBAR	10 (53)	36 (53)	63 (46)	101 (43)	127 (39)	240 (30)

Table 10 Track forecast errors (in nautical miles) for Atlantic region for 1988.

(after Puri, Manila Workshop on Tropical Cyclones, 1989)

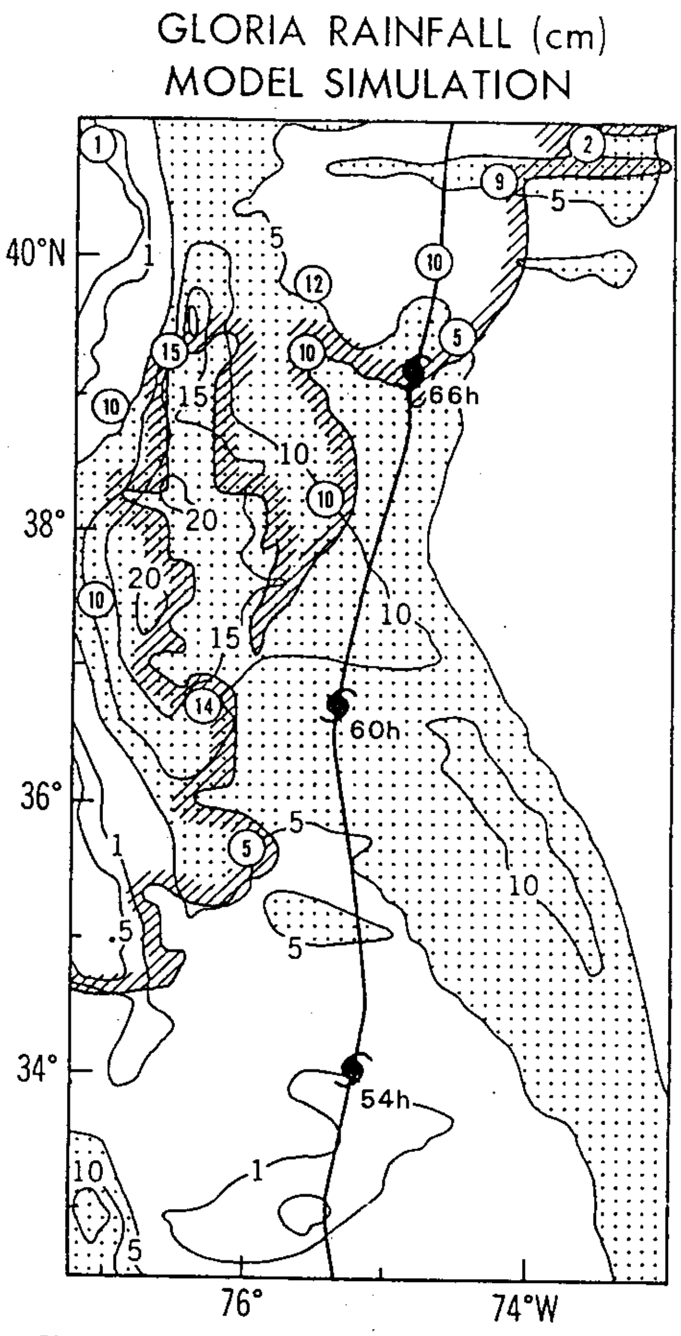


Fig. 3. The storm total rainfall distribution (cm) obtained from the GFDL simulation experiment. Also shown is the simulation storm track and some observed storm total rainfall amounts for Gloria.

(after Tuleya, Bender, Kurihara, 18th AMS Conference on Tropical Meteorology and Hurricanes, San-Diego, CA, 1989)

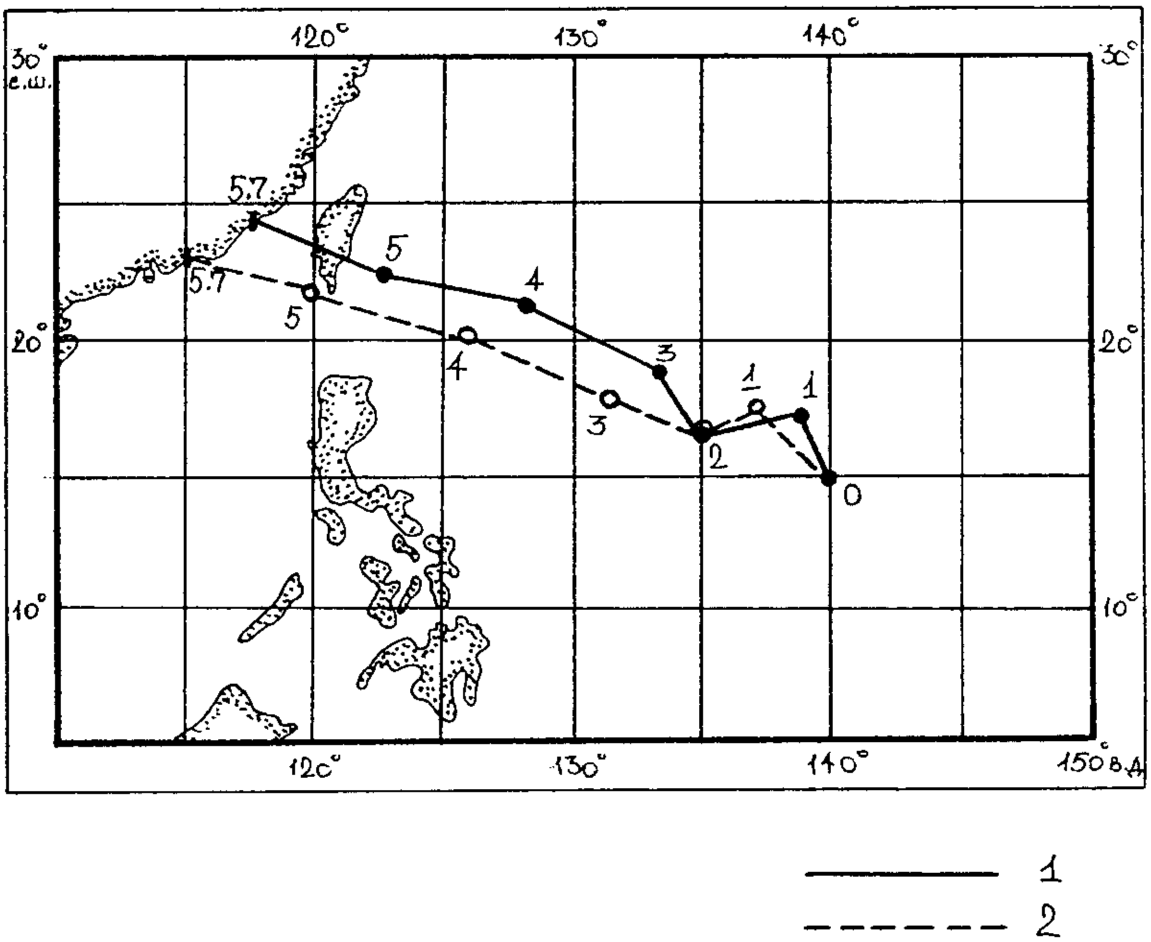


Рис. I.4. Фактическая (I) и предсказанная (2) траектории тайфуна Хоуп (начальные данные от 27 июля I979 г.) в глобальной спектральной модели высокого разрешения /2I4 /.

Числами показаны сутки, отсчитываемые от начального срока.

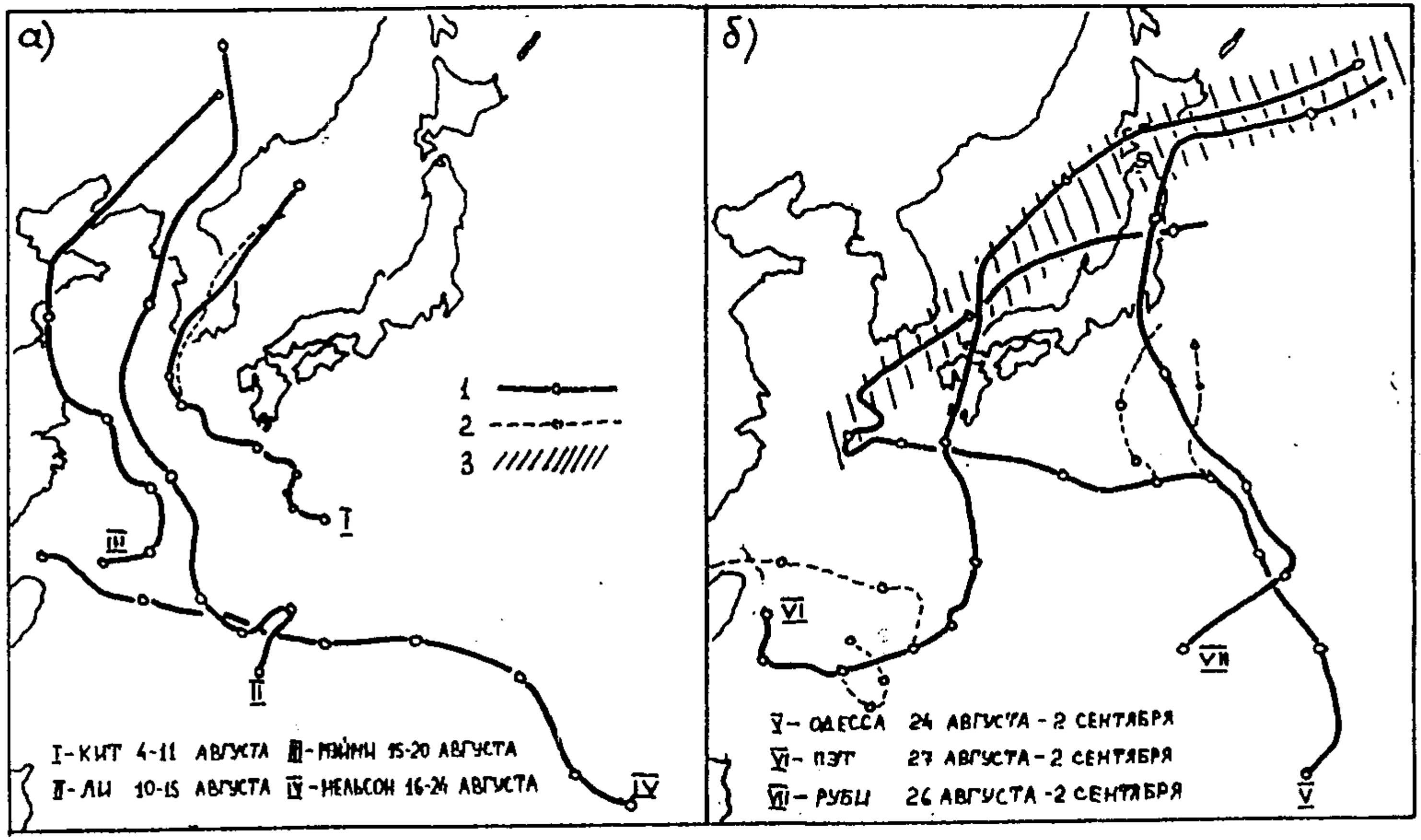


Рис. 4.6. Траектории тропических циклонов в августе-сентябре 1985 г. а - ТЦ Кит, Ли, Мейми, Нельсон (следующие друг за другом - "уединенные"); б - ТЦ Одесса, Пэт, Руби (существующие одновременно и взаимодействующие); I - фактические траектории и положения центра ТЦ; 2 - прогностические траектории; 3 - положение облачности полярного фронта на 31.08-1.09.85 г. по спутниковым данным

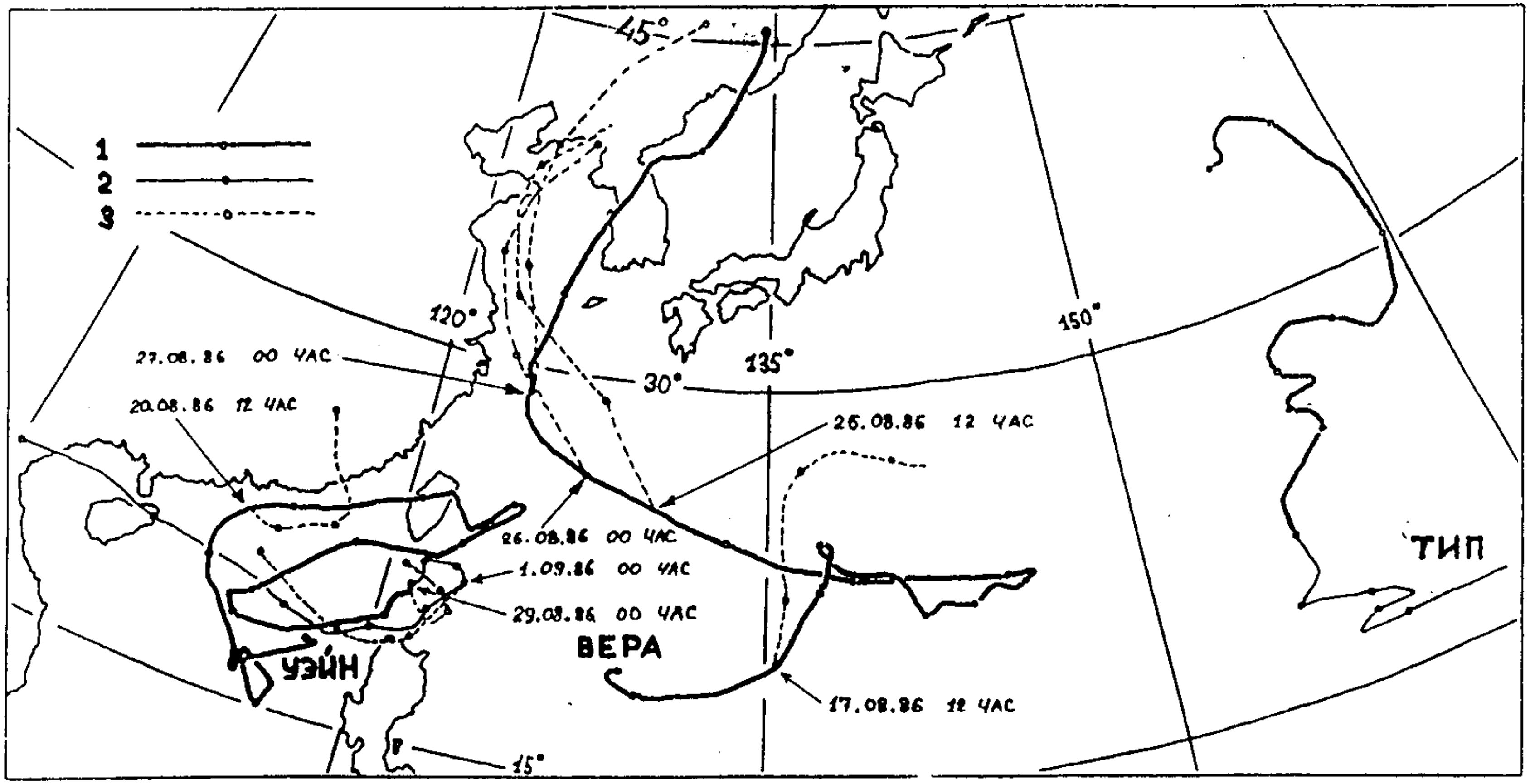


Рис. 4.II. Пример одновременного существования трех тропических циклонов (Тип, Вера, Уэйн) в западной части Тихого океана в августе 1986 г.

I – участки фактических траекторий с одновременным существованием двух или трех циклонов; 2 – прочие участки фактических траекторий; 3 – прогностические траектории; 4 – положение центра ТЦ через каждые 24 ч

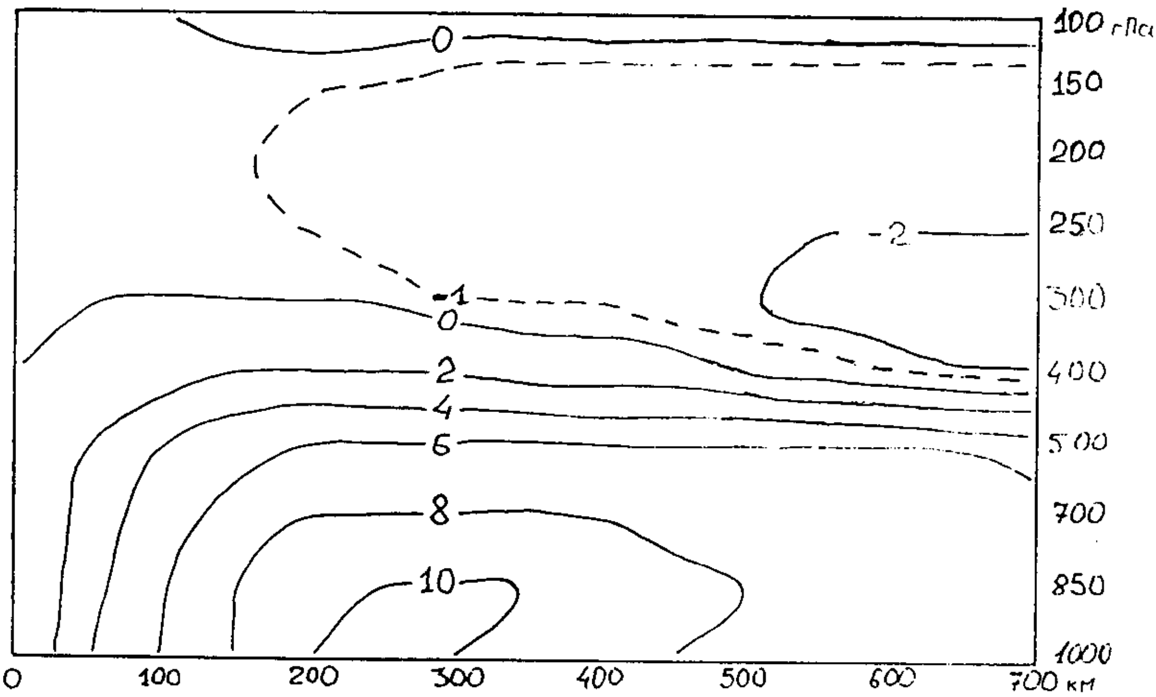


Рис. 4.27а. Осредненные по азимуту поля тангенциальной и вертикальной компонент скорости идеализированного ТЦ по завершении процедуры spin-up : а) тангенциальная скорость, м/с

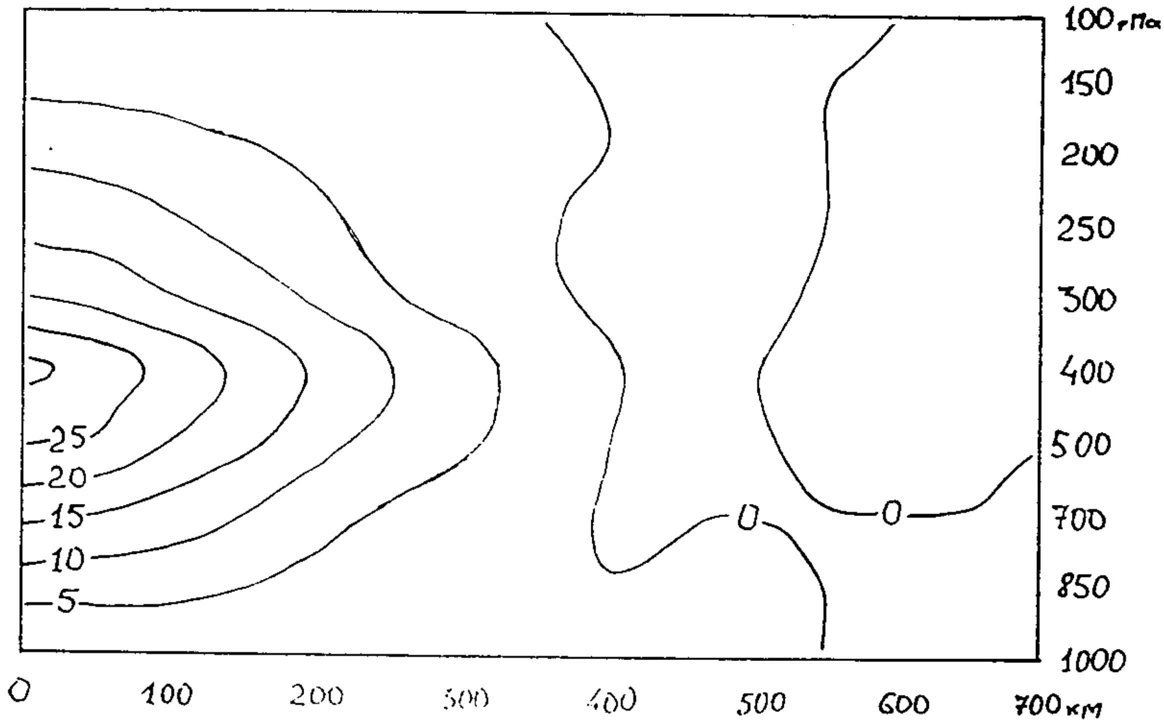


Рис. 4.27б. Осредненные по азимуту поля тангенциальной и вертикальной компонент скорости идеализированного ТЦ по завершении процедуры spin-up

б) вертикальная скорость, см/с

СХЕМА СОГЛАСОВАНИЯ НАЧАЛЬНЫХ ДАННЫХ В ОКРЕСТНОСТИ ТЦ В БАРОКЛИННОЙ МОДЕЛИ

1) Предварительная коррекция полей

$\overline{\overline{u_0}}^{x,y\;p}, \; \overline{\overline{v_0}}^{x,y\;p}$ — 2000 км

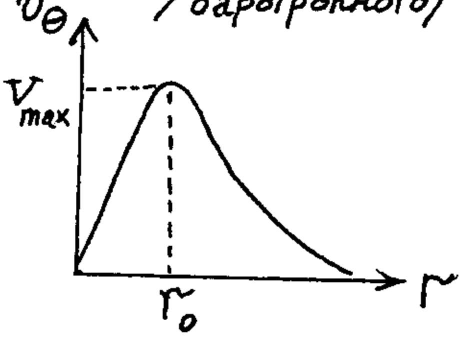
↓

$\overline{\overline{\Phi}}^{xy\;p}$ (геостроф.)

2000 км

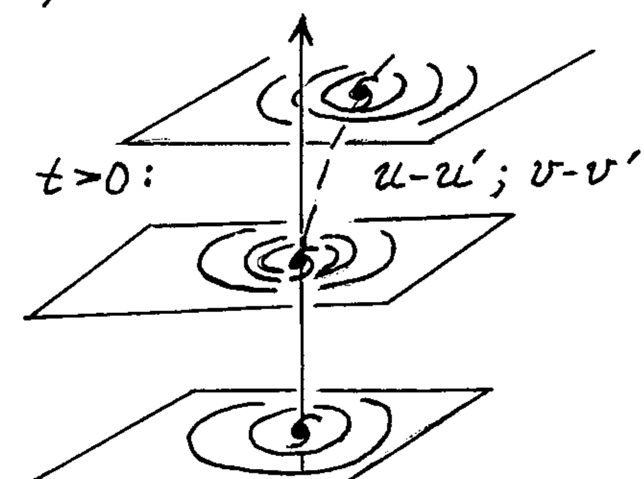
$t=0: \; u - u_0 \; ; \; v - v_0$

2) Формирование начального вихря /баротропного/



Φ — из ур-ия баланса

3) Процедура "spin-up"



$t>0: \quad u - u' \; ; \; v - v'$

Интегрирование на 72 ч

4) Обратная коррекция

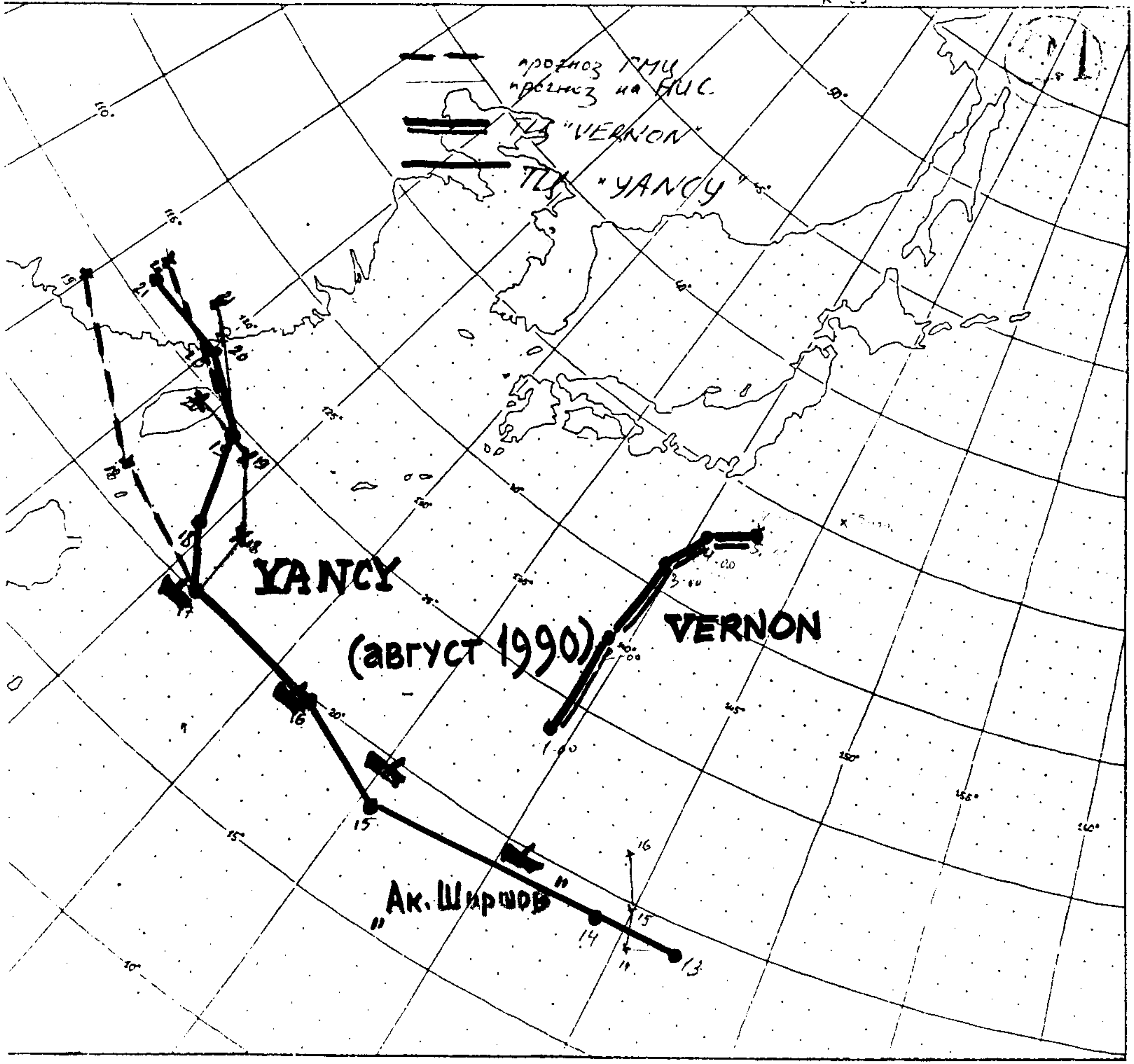
$+ u_0$
v_0

$+ \sum u'$
$\sum v'$

5) Прогноз траектории ТЦ

Интегрирование на 48 ч с учетом Q, „привязанной" к центру движущегося вихря (точки с $\frac{1}{1000}$)

К-83



прогноз ГМЦ
прогноз на НИС
ТЦ "VERNON"
ТЦ "YANCY"
YANCY
(август 1990)
VERNON
"Ак. Ширшов"

БАРОКЛИННАЯ МОДЕЛЬ

/НА БАЗЕ Л.В. БЕРКОВИЧА/

N = 10

В тропическом регионе :

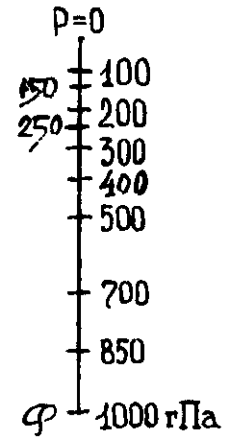
$$
\begin{cases}
\dfrac{\partial u}{\partial t} + m\left(u\dfrac{\partial u}{\partial x} + v\dfrac{\partial u}{\partial y} + \omega\dfrac{\partial u}{\partial p} + \dfrac{\partial \Phi}{\partial x}\right) - \ell v = m^2\mu\nabla^2 u - \dfrac{C_D}{h}|\vec{V}_0|\,u_0 \\[2mm]
\dfrac{\partial v}{\partial t} + m\left(u\dfrac{\partial v}{\partial x} + v\dfrac{\partial v}{\partial y} + \omega\dfrac{\partial v}{\partial p} + \dfrac{\partial \Phi}{\partial y}\right) + \ell u = m^2\mu\nabla^2 v - \dfrac{C_D}{h}|\vec{V}_0|\,v_0 \\[2mm]
\dfrac{\partial u}{\partial x} + \dfrac{\partial v}{\partial y} + \dfrac{\partial \omega}{\partial p} = 0 \\[2mm]
\dfrac{\partial \Phi}{\partial t} + m\left[\left(u\dfrac{\partial \Phi}{\partial x} + v\dfrac{\partial \Phi}{\partial y}\right) - \alpha\dfrac{R T_{\mathcal{P}}}{\mathcal{P}}\omega_{\mathcal{P}} + \displaystyle\int_p^{\mathcal{P}}\left(\dfrac{\partial u}{\partial p}\dfrac{\partial \Phi}{\partial x} + \dfrac{\partial v}{\partial p}\dfrac{\partial \Phi}{\partial y}\right)dp - \right. \\[2mm]
\left. - \displaystyle\int_p^{\mathcal{P}}\lambda\omega\,dp\right] = m^2\mu\nabla^2\Phi + R\displaystyle\int_p^{\mathcal{P}}\dfrac{Q}{p}\,dp, \quad \text{где}
\end{cases}
$$

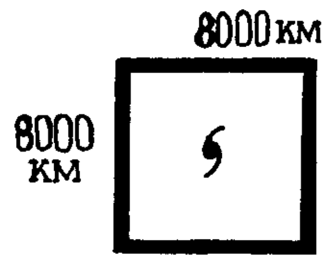
$$\lambda = \frac{R^2\bar{T}}{p^2 g}(\gamma_a - \gamma)\,\omega\,dp, \quad \bar{T} = \bar{T}(p), \quad \gamma = \gamma(p) \text{ – заданы,}$$

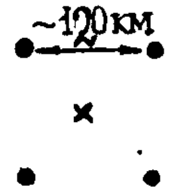
$Q = Q(r, p)$ – заданная „тепловая функция" в окрестности ТЦ

$$p = 0: \quad \omega = 0$$

$$p = \mathcal{P}: \quad \frac{\partial \Phi}{\partial t} + m\left(u\frac{\partial \Phi}{\partial x} + v\frac{\partial \Phi}{\partial y} - \alpha\frac{R T_{\mathcal{P}}}{\mathcal{P}}\omega_{\mathcal{P}}\right) = m^2\mu\nabla^2\Phi$$







На боковых границах тропического региона :

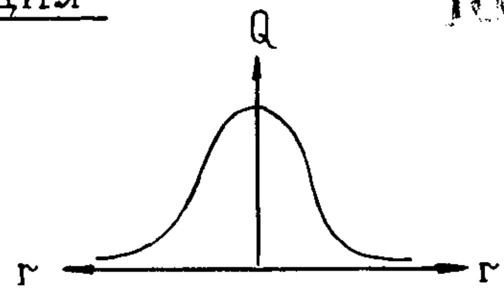
1) „склейка" переменных

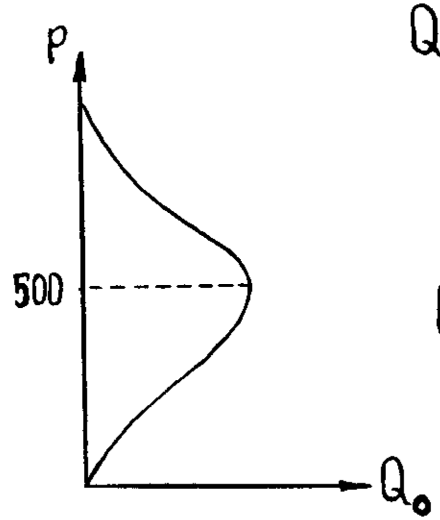
2) „склейка" производных (условия „губки") } (Perkey and Kreitzberg, 1976)

ТЕПЛОВАЯ ФУНКЦИЯ

$$Q = Q_o(p)\, e^{-r^2/\alpha}$$

$$\alpha = 1 \div 20$$





$$Q_o(p) = \begin{cases} 20^\circ C\ /\ \text{сутки}, & p = 200\ \text{гПа} \\ 60^\circ C\ /\ \text{сутки}, & p = 500\ \text{гПа} \\ 20^\circ C\ /\ \text{сутки}, & p = 850\ \text{гПа} \end{cases}$$

Q движется вслед за центром ТЦ, определенным по Φ_{1000} (сдвиг каждые 15-60 мин)

ПРОБЛЕМЫ:
- поведение ТЦ близ точки поворота
- супертайфуны
- слабые тропические штормы
- вертикальный сдвиг в процессе прогноза
- прогноз особенностей синоптического окружения при $Q=0$